WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION

INSTRUMENTS AND OBSERVING METHODS — REPORT No. 82 — WMO/TD-No. 1265

PART I - PAPERS

PART II - POSTERS

WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation

(TECO-2005)

Bucharest, Romania, 4-7 May 2005

CONFERENCE THEME

The Role of Instruments in the Earth Observation Systems

World Meteorological Organization

NOTE

INSTRUMENTS AND OBSERVING METHODS — REPORT No. 82

WMO/TD-No. 1265

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TECO-2005 IPC Members

PART II - POSTERS

- See separate file -

PART I - PAPERS

TECO-2005

OPENING KEYNOTE PAPER

Instruments and Methods of Observation Programme

Meteorological instruments and observations methods: a key component of the Global Earth Observing System of Systems (GEOSS)

Dr. R. P. Canterford
Acting President of CIMO

Instruments and Methods of Observation Programme - SUMMARY

1. **New structure** → OPAGs and ETs
2. **Future plans** → IMOP High Priority Issues
3. **GEOSS**

1. New CIMO Structure

CIMO MANAGEMENT GROUP
President
Vice-President
7 OPAG Co-cairs

OPAG
Surface Observation Technology
2 Co-chairs

- **ET on Surface Technology**
  Chair + 8 Members
  5 Representatives of other Bodies
- **ET on Surface-Based Instrument Intercoparisons and Calibration Methods**
  Chair + 5 Members
  2 Representatives of other Bodies
- **ET on Meteorological Radiation and Atnospheric Composition Measurements**
  Chair + 3 Members
  3 Representatives of other Bodies

OPAG
Upper Air Observation Technology
3 Co-chairs

- **ET on Upgrading the Global Radiosonde Network**
  Chair + 7 Members
  3 Representatives of other Bodies
- **ET on Upper-Air Systems Intercomparisons**
  Chair + 5 Members
  1 Representative of other Body
- **ET on Remote Sensing Upper-Air Technology and Techniques**
  Chair + 11 Members
  2 Representatives of other Bodies

OPAG
Capacity Building
2 Co-chairs

- **ET on Training Activities and Training Materials**
  Chair + 6 Members
- **ET on RICs, QM Systems and Commercial Instrument Initiatives**
  Chair + 7 Members
- **ET on CIMO Guide and Information Dissemination**
  Chair + 3 Members

2. Future Plans –
IMOP High Priority Issues

2. IMOP - Future Plans /GEOSS

High priority issues:

- Relation to GEOSS
- Develop performance measures to demonstrate continuous improvement in the quality of observations;
- Conduct instrument intercomparisons;
- Contribute to the review and update of WMO technical regulations, guides and other material related to quality management and standardization of observations;
- Evaluate existing RICs and review their terms of reference;
- Facilitate standardization of measurements of long-wave radiation;
- Automation of manual, visual and subjective observations;
- Strengthen links with relevant international organizations.

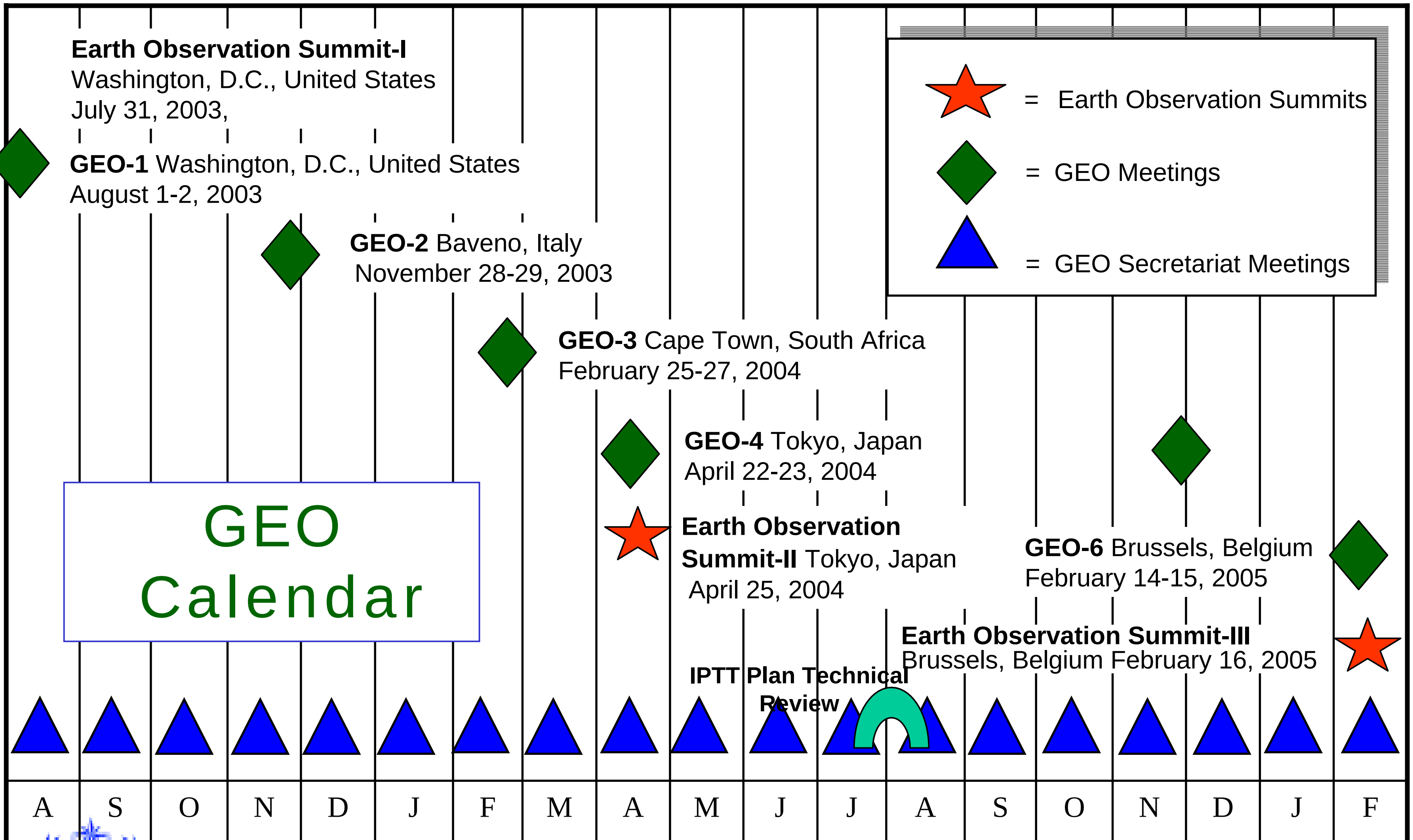
3. Global Earth Observation System of Systems (GEOSS)

3a. GEOSS Overview

- The World Summit on Sustainable Development, Johannesburg 2002 (WSSD) highlighted a need for coordinated observations relating to the state of the Earth.
- First Earth Observation Summit convened in Washington July 2003 – established *ad hoc* Group on Earth Observations (GEO).
- GEO established sub-groups which lead to a Framework Document – negotiated at GEO-3 and adopted by the second Earth Observation Summit, Tokyo 2003.
- Production of GEO 204 – 10 - year Implementation Plan

GEO 204, February 2005

3a. GEOSS Overview Contd.

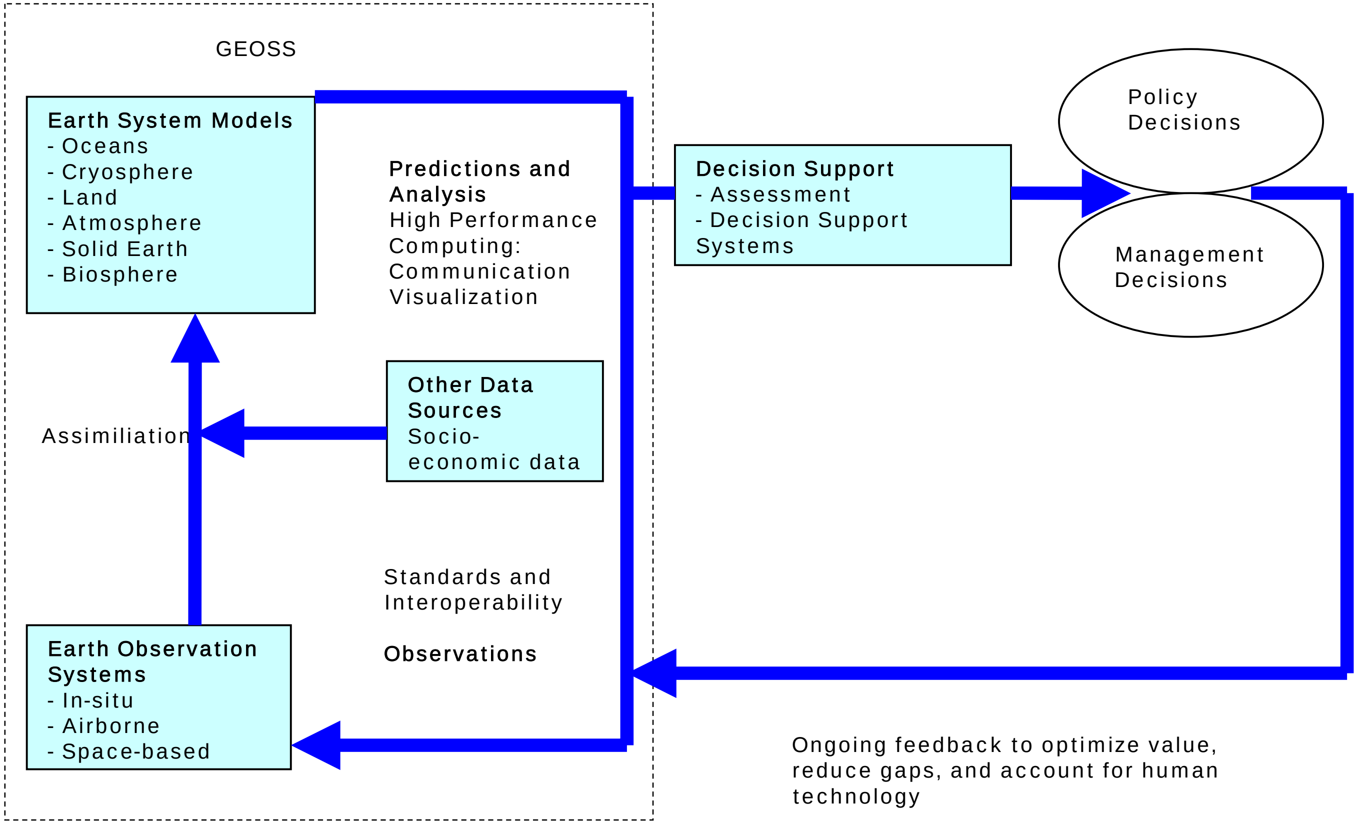


3a. GEOSS Overview Cont.

- GEOSS will be a "system of system" with components of existing and future Earth observation systems from primary observation to information production.
- GEOSS will attempt to identify gaps and unnecessary duplications, redirect or initiate activities to optimize the system, and ensure the necessary continuity in observations.
- GEOSS systems will abide by interface specifications for those portion of their data systems that they agree to share.
- This should allow linkages between systems allowing wider use of data across systems and within the wider community.

GEO 204, February 2005

3a. GEOSS Component Systems: scope and focus



The above demonstrates the end-to-end nature of data provision, the feedback loop from user requirements and the role of GEOSS in this process. The primary focus of GEOSS is on the left side of the diagram. **GEO 204, February 2005**

3a. GEOSS Components

The major components of the Earth Observation System comprise *in situ*, aircraft and space-based systems.

However, data from non-meteorological systems would able to be integrated with meteorological data.

Reliance on independent efforts has deficiencies as large parts of the globe are outside the territory of individual countries.

Deploying systems would be more feasible if undertaken as a cooperative action by many countries for the common good

GEO 204, February 2005

3a. GEOSS – meteorological perspective

- *"...GEOSS will contribute to improving weather information in three ways:*

  1. *Providing a timely, comprehensive and accurate initial state for forecast models;*

  2. *Provide comprehensive observations necessary to extend the range of useful products*

  3. *Will help GEO members and Participating Organisations to more effectively address the end-to-end weather information services needs, resulting in greater service for less cost…"*

GEO 204, February 2005

3b. GEOSS and Disaster Reduction

GEOSS will facilitate the sharing of Earth Observation data and information that are timely, of known quality, long-term and global in nature to better facilitate disaster reduction.

The global integration of data from various networks and systems will allow timely prediction, identification and verification of actual and potential disaster events

A common public warning systems with simple instructions for action would minimize the public confusion that occurs during emergencies, especially if the same system was in use for threats such as tsunamis, severe weather, fire and other threats.

3b. GEOSS and Disaster Reduction Contd.

23 June 2004

28 December 2004

As an example, the undersea earthquake of Indonesia on Dec 26, 2004 was detected by the Global Seismographic Network, one of the systems participating in GEOSS. In a potential GEOSS global warnings for earthquake and potential tsunami could then be issued to affected areas. To confirm the quake had generated a tsunami, seismic data would be further refined and combined with data from coastal tide gauges and buoys. Hazard zonation maps showing areas vulnerable to tsunami run-up, areas of safety and evacuation routes could have been prepared.

3c. GEOSS – systems overview

- WMO WWW defines and coordinates the provision of observations through national agencies. Programme requirements cover the observing component (space and surface based) and data dissemination.

- Maintenance of the programme is through a rolling review process.

3c. GEOSS – systems overview

- *In situ* observations are primarily undertaken at a national level although significant developments in cooperation/cost sharing (e.g. EUMETNET, EUCOS)
- Rapid expansion in AMDAR data and ASAP which are evolving to meet user requirements. Central management provides efficiencies for NMHSs.
- ET-ODRRGOS (Observational Data Requirements and Redesign of the GOS) developed a plan for the GOS of 2015 for *in situ* systems and data management. The plan includes a prioritized list of critical atmospheric parameters that are not adequately measured by current or planned observing systems.
- Difficulty for emerging countries because of lack of communications mechanisms to receive and act on information. Additionally, a shortfall in education and training and a lack of resources to sustain development and use of existing capabilities.

3c. Observational Gaps

- Lack of complete global coverage of the atmosphere, land and oceans (e.g. inadequate resolution and quality) inhibits development and exploitation of extended range products.

- Expansion of capacity is needed to detect precursor environmental conditions to enable improvement to all weather and climate services (as called for by WMO WWW).

- Priority to filling gaps that limit data assimilation and predictive capabilities.

- Further emphasis is needed on open global sharing of data.

3c. Observational Gaps Contd.

- Data should be exploited through better research, data assimilation and predictive models, building telecommunications infrastructure capacity and transforming predictions into formats understandable to decision makers and the public.
- Satellites have a priority need for improved calibration of all data. Additionally:
  - There is a need for improved geostationary Imagers and Sounders.
  - There is a need to improve the timeliness and temporal coverage of data delivery
  - Improvement needed for sea-surface wind, altimetry and radiation
  - Research is required in Doppler technology, precipitation observation capability and radio occulation techniques

3c. Observational Gaps Contd.

- With *in situ* observations, there is a need for improved data distribution and coding, development of AMDAR and ground-based GPS. Additionally, there is a need to:
  - improve the network of observations in the oceans, polar areas and tropical land areas;
  - develop new observing technologies;
  - address the lack of atmospheric wind profiles in polar areas;

3c. Gaps in Modelling

- Scientific modelling techniques still limit the accuracy of forecasts and warnings and data are needed to validate the models.

- NMW models still have gaps in some data categories, e.g. ozone, moisture flux, that lead to increasing uncertainty and reduce model accuracy.

3c. Gaps in Information Technology

- Telecommunication and computer processing gaps limit observation exchange, scientific collaboration and dissemination of critical information to decision-makers and the general public.
- Lack of structure to facilitate transition of research technologies to operational use in all components of the end-to-end weather information services system.

3c. Gaps in Research, Education and Training

- Improvements in producing and delivering weather information requires parallel improvements in education and training processes to ensue full exploitation of these data.

- R&D in archiving, accessing and processing these data is necessary to ensure sustained weather information for the long-term

3d. Issues

- Cooperation
  - Balanced perspective for component systems
  - Need participation by developing countries
- Data policy
  - Free & unrestricted vs charged
  - Public good vs commercial boundaries
  - Data vs products vs services boundaries
- Security/control of data
- Governance arrangements are critical to the ownership, viability, effectiveness, success and sustainability of GEOSS
- Role of research-based systems
  - Integration pathway?

3e. Positive and Negatives

- + Increased access/coverage etc to data, products
  - Interoperability
  - Data types, parameters, resolution
  - Integrated products
- + Political visibility of global/regional observing issues
- - Data policy revision → possible charging for data?
- +/- Relationship to WMO WWW
- - Lack of world-wide high-resolution terrain models (difficult to map observations)

SESSION 1

NEW DEVELOPMENTS AND OPERATIONAL EXPERIENCE WITH SURFACE OBSERVATION TECHNOLOGY

Session 1

KEYNOTE PAPER

(not available)

Session 1

PAPERS

Upgrade and new developments of the automatic weather stations network in Austria

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Abstract:
The Central Institute for Meteorology and Geodynamics of Austria (ZAMG) has launched the project for the renewal of its presently operational meteorological networks consisting of AWS's (148 stations), and classical customary stations (120 stations). As in many other places and countries AWS should not only become the primary but finally the only source of surface observations. They are in use in synoptically, climatologically, environmental and hydrological applications. The realization phase starts in this year and we are sure that the new generation will again meet the needs of all parts of meteorology to help ensure that uncertainties associated with weather and climate data are minimized.

1. Introduction and history

In our country the beginning of automation of meteorological parameters was at the end of the 1970ies with the development of algorithms for data processing and recording. 1981 the first AWS was put into operation which was working autonomously, only with local storing on data tapes. Ten years later was the beginning of the network of AWS were the data are collected nearly real time and every 10 minutes is sent via leased telephone line to regional centres [1]. The network grew continuously and it comprises today 148 stations. But at the same time this means that the oldest station in our network reaches today an operational period of more than 23 years. For various reasons such as the difficulties in guaranteeing the renewal of the spare parts, a increasing old technology (field stations and central data acquisition station), a wear of the material, the lack of flexibility, an aging system of transmission of the data, etc, but also on the undisputable advantages of using AWS'S systems instead of customary stations like

- Increasing temporary coverage
- Providing data from data sparse areas where human observations are not practical
- Providing data continuously at frequent intervals and for any observation time
- Eliminating the subjectivity in manual observations
- Reflecting the requirements of all users of near real time synoptic data
- Supporting the trends to reducing model grid scale and the need for more observations to be available in shorter timescales

- Make-believe to reduce costs

Because of the topography of the Austrian territory and supporting the trends to reduce the grid scale and increase the time resolution of meteorological models an increase of the density of AWS in Austria is required. At the other side a significant reduction of the overall costs of operation of measurement network is necessary. Therefore the following decisions were made:

- Shut down of all manually operated classical climatic stations
- Increase of the network of AWS up to 200 - 220 stations
- Substitution of the present AWS with a new generation of AWS
- Improvement of the sensor equipment of AWS

This project has to be completed within 2007.

2. Present system of AWS

The configuration of a standard AWS is shown in Fig. 1. The system consists of a Central Unit for power supply and data processing and a limited number of sensors connected directly to the Central Unit. The real time data telegrams are requested by the regional center every 10 minutes. For data transmission a special secure transfer protocol with subcarrier transmission on analog telephone lines is used. Because of the sensor specific design of the Central Unit the operation of new sensor types at this system is impossible. The hardware and software of the Central Unit are state of the early 1980ies. The source code of the system is not available, therefore also known bugs of the system can not by repaired. Even spare parts for this stations are available very difficulty.

One of the weak points of the present system is the direct connection between sensors and Central Unit via long cable lines (up to several 100m). This causes problems with electromagnetic interferences on the measurement increases the probability of faults.

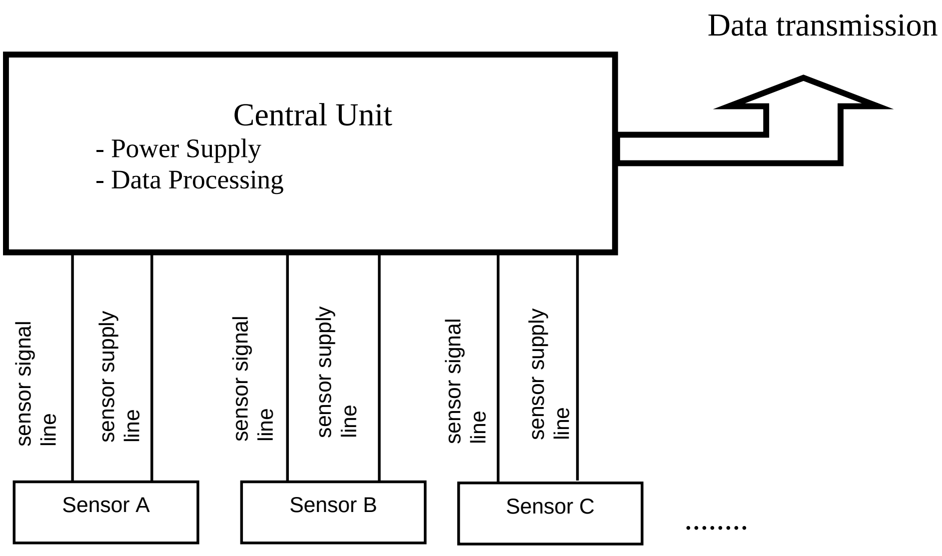

Fig. 1: Configuration of a standard AWS

3. New system of AWS

For the extended network of AWS in a new designed AWS has to be developed. In order to ensure a maximum of flexibility and reliability at one hand and reducing the cost of operation at the other hand the system has to fulfill the following requirements[2,4]:

- Installation of a bus system for power supply and data transmission
- All sensors are connected to the bus with appropriates interfaces
- Application of fiberoptic or short distant radio transmission for data transmission in the bus system.
- With universal interfaces between sensor and bus system the AWS can operate arbitrarily sensor systems with different signal output (digital, analog or digital telegram)
- The extension of the system for special sensors (present weather sensor, visibility sensors, ceilometer etc.) is possible without modifications on the basic system.
- The modular design of the AWS ensures more reliability an reduced fault rate.
- As a second way of transmission and for remote configuration of the AWS a standard GSM link is installed. In order to ensure a reliable data transmission also in case of public emergency, the same data transmission system as in the present system (secure transfer protocol with subcarrier transmission on analog telephone lines) is employed.

The supplier of system shown in Fig. 2 has to be determined in an international advertisement released in January 2005.

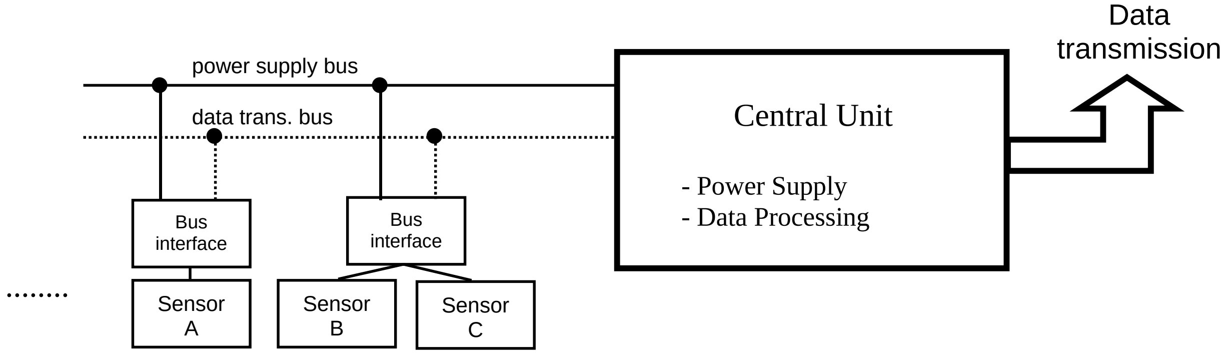

Fig. 2: Configuration of the new AWS

4. Improvement of the sensor system

In the last decade many new sensor systems for various meteorological parameters were developed and tested in national and international comparisons (e.g. WMO and EUMETNET[3,6,]). The general trend is to replace sensors with moving mechanical parts with static systems. This sensor systems ensure a noticeable reduction of cost of operation and an increase of reliability even under severe conditions. Several sensor types in operation in the present system of AWS are no longer available and need to be replaced by others, whereas several other sensors of the present system with excellent characteristics are employed also in the new system.

In Tab. 1 the sensor configuration of the present and the future AWS is shown.

Parameter	Sensor Type	
	Present AWS	Future AWS
Air temperature	NTC	NTC
Soil temperature	NTC	NTC
Relative humidity	Hair hygrometer	Hair hygrometer
Amount of precipitation	Tipping bucket or weighing gauge	Tipping bucket or weighing gauge
Precipitation detector	Resistive sensor	Optical sensor
Wind speed and direction	Cup Anemometer	Ultrasonic Anemometer
Sunshine detector	Rotating Shutter	Static detector
Global radiation	BW pyranometer	BW pyranometer
Pressure	Electronic aneroid barometer	Electronic aneroid barometer

Tab. 1: Sensor systems in AWS network

5. Conclusion

With the upgrade of the automatic weather stations network in Austria a quantitative and a qualitative improvement of the measurement of meteorological parameters in Austria is ensured. With the network of 200 AWS a station should be representative for approximately 400 km² (20x20km). The increase of the temporal resolution of the measurement data in real time is required by different users of meteorological data [5] and especially for inputs in local area numerical models (e.g. ALADIN). The standardization of the network would make it possible to optimize the operational aspects by decreasing the costs of operation.

6. References

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ACTINOMETRIC INSTRUMENTS FOR AUTOMATED SYSTEMS

Skuratovich I.M., Lutsko L.V., Klivantsova V.A., Kazeyeu Y.I.
(Belarus)

In the CIS and in some other countries there are under exploitation actinometric instruments, which were manufactured earlier, in the former USSR at the "Gidrometpribor" factory (Tbilisi).

The instrument types are as follows: the M-80 pyranometer, M-10 radiation balance gauge and M-3 actinometer.

At present these instruments production has been ceased and consequently the market is suffering from their shortage.

Replacement of the available equipment by the instruments from other manufacturers evoke some undesirable consequences, the main of them being violation of observation files and the necessity to reorganize the meteorological base on the network.

The Belarus and Russia united State, taking into account the situation, by its Program within the field of hydro meteorology and environmental monitoring foresees resumption of actinometric instruments production, similar to the enumerated ones by their characteristics, capable to operate in automated systems.

The main geophysical laboratory after A.I. Voyeikov (Russia) having large experience in the field of actinometric instrument-making and the JSC PELENG company were charged to solve this task.

The first development under this cooperation appeared to be the "Peleng СФ-06" pyranometer (hereinafter - pyranometer СФ), with its finish in 2003. This instrument is designed to measure total, scattered and reflected radiation at meteorological stations instead of the M-80 pyranometer manufactured earlier.

The СФ pyranometer is granted with the Gosstandard Certificates of Russia and Belarus and also with a Roshydromet lisence for the right to perform works within the sphere of hydrometeorology and overlapping sciences.

The instrument production started from 2004.

Figure 1. Pyranometer with unit and information board. External View.

Explanatory notes:

- *thermal battery, BW, staggered, similar to that of M-80,*
- *the body is slightly thickened and air-tight,*
- *the level, aimed to control the pyranometer horisontal position may be directed downwards during non-stop measuring of reflected radiation.*

Due to the used BW thermal battery, like the M-80 pyranometer, the CΦ pyranometer provides for storage of observation files, accumulated by the M-80 pyranometer measurements. This is confirmed by the results of comparing both the pyranometers under the natural conditions.

Meteorological equipment of the CΦ pyranometer (as well as the one of the M-80 pyranometer) is based on adjustment with the standard actinometer, and is executed as per the same schedule and with the help of the same control means (as well as for the M-80 pyranometer). The dicrepancy lies within the standard pyranometer type: the CΦ instrument is taken as the standard one and is certified like the M-80 pyranometer, that is in the result of test trial under natural conditions according to the standard actinometer.

Preparing and certifying standard pyranometers are executed by the Main geophysical observatory. Due to yearly certifying of pyranometers belonging to any type this discrepance in practice will not cause extra difficulties.

Note: In case the working pyranometers are calibrated relative to the sun, then the necessity in a standard pyranometer no longer arises.

The CΦ pyranometer head preserves external attachment dimensions of the M-80 pyranometer, due to which it may be installed on every device, used with the M-80 pyranometer.

This means no necessity to install new extra equipment for commissioning the СФ pyranometer in the countries, where the pyranometer M-80 is used on the network.

Input parameters of the СФ pyranometer head are similar to those of the M-80M instrument, that is why in principle it may be switched to the same electric measuring instrument: to the ГАС galvanometer, to the self-recording potentiometer, the X-607 electrolytic intergrator.

However, during exploitation of pyranometer СФ these instruments are not necessary, because the pyranometer СФ complete set comprises specially developed electronic measuring unit with a LED indicator information board and with their help are taken all the necessary parameters.

The unit is installed at the meteorological site, for example in a box for galvanometers. The unit has a light indicator, showing current instantaneous values and is used instead of the ГАС galvanometer during urgent observations.

The pyranometer and the unit are designed for operation under natural conditions (by temperature from minus 50 to plus 50°C and the upper value of the air relative humidity equal to 98% at 25°C). Power supply – 36 VAC. The limit of extra error by measuring the voltages ± (0,08% Umeas + 20 μV). The electronic unit is equipped with an RS 485 output interface and an V23 modem.

The information board is installed in premises, for example on the operator's table.

From the information board are taken the parameters, necessary as per programs of non-stop registration and integration: the values, averaged per each hour of the current and terminated day, average daily per each day of the current month, average monthly for the terminated month.

The information board power supply is delivered from the mains of 220V. The information board also shows current instantaneous values.

The board is equipped with an interface RS 232. Instead of the board there may be used PC capabilities with corresponding software.

On the customer's request the unit with the board may be delivered in single channel and three-channels versions, that is with three heads being connected simultaneously.

Note: The sensor output voltage is not converted into radiation values by means of the unit with the board, because the instrument has been developed for the existing on the network technology of collection and compiling monthly files with consequent processing as per the program, adopted on the network.

The executed investigations of the main СФ pyranometer errors, indicated that they are practically the same, as those of the M-80 pyranometer.

Main technical characteristics of pyranometer

Measuring range for the radiation density, kW/ m^2	from 0,01 to 1,6
Wavelength range, μm	from 0,3 to 2,4
Head conversion ratio at standard radiation drop per receiver, mV • m^2/kW, not over	8
Time interval for setting-up the head output signal, s, not over	50
Values of correction factors at the sun altitude h=20° by azimuth 90,180,270° differ from the value in azimuth direction of 0°, %, not over	10
Limit of tolerable relative error during radiation density measurement, %	11
Relative displacement of the head reference point under the influence of thermal radiation of semi sphere black surface, heated to (75±5) °C from the value of $\sigma \{(tB + 273)^4 - (t + 273)^4\}$, %, not over	6
Limit of extra error during taking measurements of radiation density, evoked by the air temperature deviation from a standard value per each 10°C, %	

In the countries, where the M-80 pyranometer is under exploitation (today the production has stopped), it is expedient to use the “Peleng СФ-06” pyranometer. This enables the following advantages:

- to memorize the observation files,
- to have a metrological base on the network without changes,
- to exploit the available extra equipment,
- to replace the obsolete electric measuring instruments (galvanomoters, self-recording analog potentiometers, electrolyte integrators) with the up-to-date electronic equipment from the СФ pyranometer complete set.

In 2004 there was developed an automated meter for the sun radiation duration (hereinafter - the IPSS), aimed for operation instead of the Kempbell-Stocks geliograph.

The IPSS sensor unit has 16 photo sensors (sections), located in such a manner which provides the angle of observation within a semi sphere equal to 180°. Sections, located along the diagonal by azimuth are connected in pairs directed to each other, due to which the signal at the IPSS output turns to be proportional to radiation intensity, coming from the sun disk, independent from azimuth direction at the sun.

Figure 2   The IPSS external view

Explanation note:
Section, illuminated by the sun, receives radiation from the sun disk and from the sky. The opposite section receives radiation only from the sky. Thus, the difference between their signals is proportional only to the sun disk radiation.

The IPSS shows the availability of the sun radiance, the direct sun radiation being not less than 120 W/m^2. The IPSS possesses an output interface RS485 and an V23 modem and may be used as with the indication board, so with the PC.

A special program enabling on the operator's choice to call on a display the current data about the sun, radiance, its duration within the chosen time intervals (5,10,30 min, hour, day and etc.), as for current, so for the terminated days. The information is memorized.

The sun radiance availability relative to time may be plotted at a display.

The body design provides the capability of fastening the IPSS to the tripod of the M-80 pyranometer.

At present the JSC PELENG company and the Main geophysical observatory have finished the radiation balance gauge of the " Peleng CΦ-08" type, designed to replace the balance gauge of the M-10 type. And also they have started the " Peleng CΦ-12" actinometer development.

The aim of development is similar to that of the pyranometer's:

- to memorize the observation files,
- to have a metrological base on the network without changes,
- to employ actinometric sensors within automated systems.

Variability of the Measurement of Temperature in the Canadian Surface Weather and Reference Climate Networks

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ABSTRACT

To assess the uncertainties of temperature and humidity measurement, the Test and Evaluation Division of the Meteorological Service of Canada organized a field evaluation of the main temperature and humidity sensor models currently used in Canadian surface weather and climate networks. The field study began in the fall of 2002 at the Centre for Atmospheric Research Experiments (CARE) in Egbert, Ontario. Twelve pairs of temperature and humidity sensors were set up in various configurations with respect to aspiration and shield type. Data was stratified by temperature. Operational comparability and functional precision values were derived to determine the differences between configurations and the variability within configurations.

INTRODUCTION

Over the past few decades, the progressive automation of the Canadian surface weather and climate networks has been undertaken by each of five national regions (Pacific and Yukon, Prairie and Northern, Ontario, Quebec, Atlantic). As a consequence, these networks are populated with a variety of different sensors installed in various configurations. Although individual manufacturers provide performance specifications for these sensors, the Meteorological Service of Canada had not undertaken nation-wide field evaluations.

To assess measurement uncertainties of temperature and humidity, the Test and Evaluation Division of the Meteorological Service of Canada initiated a field evaluation of the major temperature and humidity sensor models currently used in Canadian surface weather and climate networks. The field study began in December, 2002 and continued for a ten-month period at the Centre for Atmospheric Research Experiments (CARE) in Egbert, Ontario. Due to the large number of sensors involved, each parameter (temperature and humidity) was analysed separately While this paper addresses air temperature sensors only, a similar paper presenting the results of the humidity analysis will follow at a later date.

REFERENCE AND TEST SENSORS

Due to the impracticality of representing all sensors and configurations present in the field, this study includes only those most representative of the Canadian surface weather and climate networks. Seven different sensor models were identified as being most representative of those currently in use in the field. For each model tested, two identical sensors were evaluated to establish differences between each other as well as from a common reference.

In addition to evaluating differences in performance between different sensor models, the study also addressed the influence of different sensor configurations. Four different configurations, using different combinations of sensor screen types and aspiration, were established for the majority of sensors tested. The two types of screens most commonly used in the field are wooden Stevenson screens (Figure 1) and Gill screens (Figure 2). These screens are either aspirated (by providing a constant flow of air over the enclosed sensor) or non-aspirated (left to ventilate naturally).

Figure 1 - Test sensors in non-aspirated Stevenson screen.

Figure 2 - Test sensors in Gill 12-plate screens

All sensors in their various configurations included in this study are listed in Table 1. It should be noted that after preliminary analysis, four sensors exhibited uncharacteristically high variations from all other sensors under test (including the reference sensor). As the cause of these variations could not be easily established, the data from these sensors were not included in this analysis, but will be analysed separately at a later date. A list of the sensors removed from this analysis can be found in Appendix A. From this point forward in the paper, any reference to a particular "sensor" encompasses both the sensor model and the installation configuration.

Table 1. Sensors under test and their configurations.

	Sensor	Screen/Shield	Aspiration
CSI 44002A/WS/NA A	CSI 44002A	(WS) Wooden Screen	(NA) Non-Aspirated
CSI 44002A/WS/NA B	CSI 44002A	(WS) Wooden Screen	(NA) Non-Aspirated
CSI 44212/WS/A A	CSI 44212	(WS) Wooden Screen	(A) Aspirated
CSI 44212/WS/A B	CSI 44212	(WS) Wooden Screen	(A) Aspirated
CSI HMP35C/G12/NA A	CSI HMP35C	(G12) Gill 12-plate	(NA) Non-Aspirated
CSI HMP35C/G12/NA B	CSI HMP35C	(G12) Gill 12-plate	(NA) Non-Aspirated
CSI HMP45C/G12/NA A	CSI HMP45C	(G12) Gill 12-plate	(NA) Non-Aspirated
CSI HMP45C/G12/NA B	CSI HMP45C	(G12) Gill 12-plate	(NA) Non-Aspirated
CSI HMP45C/WS/NA A	CSI HMP45C	(WS) Wooden Screen	(NA) Non-Aspirated
CSI HMP45C/WS/NA B	CSI HMP45C	(WS) Wooden Screen	(NA) Non-Aspirated
CSI HMP45C212/G/A A	CSI HMP45C212	(G) Gill	(A) Aspirated
CSI HMP45C212/G/A B	CSI HMP45C212	(G) Gill	(A) Aspirated
CSI HMP45C212/G12/NA A	CSI HMP45C212	(G12) Gill 12-plate	(NA) Non-Aspirated
CSI HMP45C212/G12/NA B	CSI HMP45C212	(G12) Gill 12-plate	(NA) Non-Aspirated
CSI HMP45C212/WS/A A	CSI HMP45C212	(WS) Wooden Screen	(A) Aspirated
CSI HMP45C212/WS/A B	CSI HMP45C212	(WS) Wooden Screen	(A) Aspirated
CSI HMP45C212/WS/NA A	CSI HMP45C212	(WS) Wooden Screen	(NA) Non-Aspirated
CSI HMP45CF/G12/NA A	CSI HMP45CF	(G12) Gill 12-plate	(NA) Non-Aspirated
CSI HMP45CF/G12/NA B	CSI HMP45CF	(G12) Gill 12-plate	(NA) Non-Aspirated
CSI HMP45CF/WS/NA A	CSI HMP45CF	(WS) Wooden Screen	(NA) Non-Aspirated
CSI HMP45CF/WS/NA B	CSI HMP45CF	(WS) Wooden Screen	(NA) Non-Aspirated
CSI PRT1000/WS/NA A	CSI PRT1000	(WS) Wooden Screen	(NA) Non-Aspirated

Figure 3 - Field reference temperature sensor (YSI20048) in aspirated wooden screen.

The average of three reference sensors of the same model type (YSI SP20048) served as the site reference. This sensor is commonly used operationally by the Meteorological Service of Canada and has a long record of good, reliable performance. All three reference sensors were installed in aspirated wooden screens (Figure 3) in a triangle formation at the test site. The average of these three reference sensors was taken to represent the true temperature at the centre of this triangle. Test sensors were installed in a configuration which assured a distance of no more than 10 m from the centre of the reference triangle in accordance with the standard ASTM 4430. All requirements outlined in ASTM 4430 were followed and met for this experiment. The physical layout of all reference sensors and sensors under test is illustrated in Figure 4. A general view of the setup at the CARE test site is provided in Figure 5.

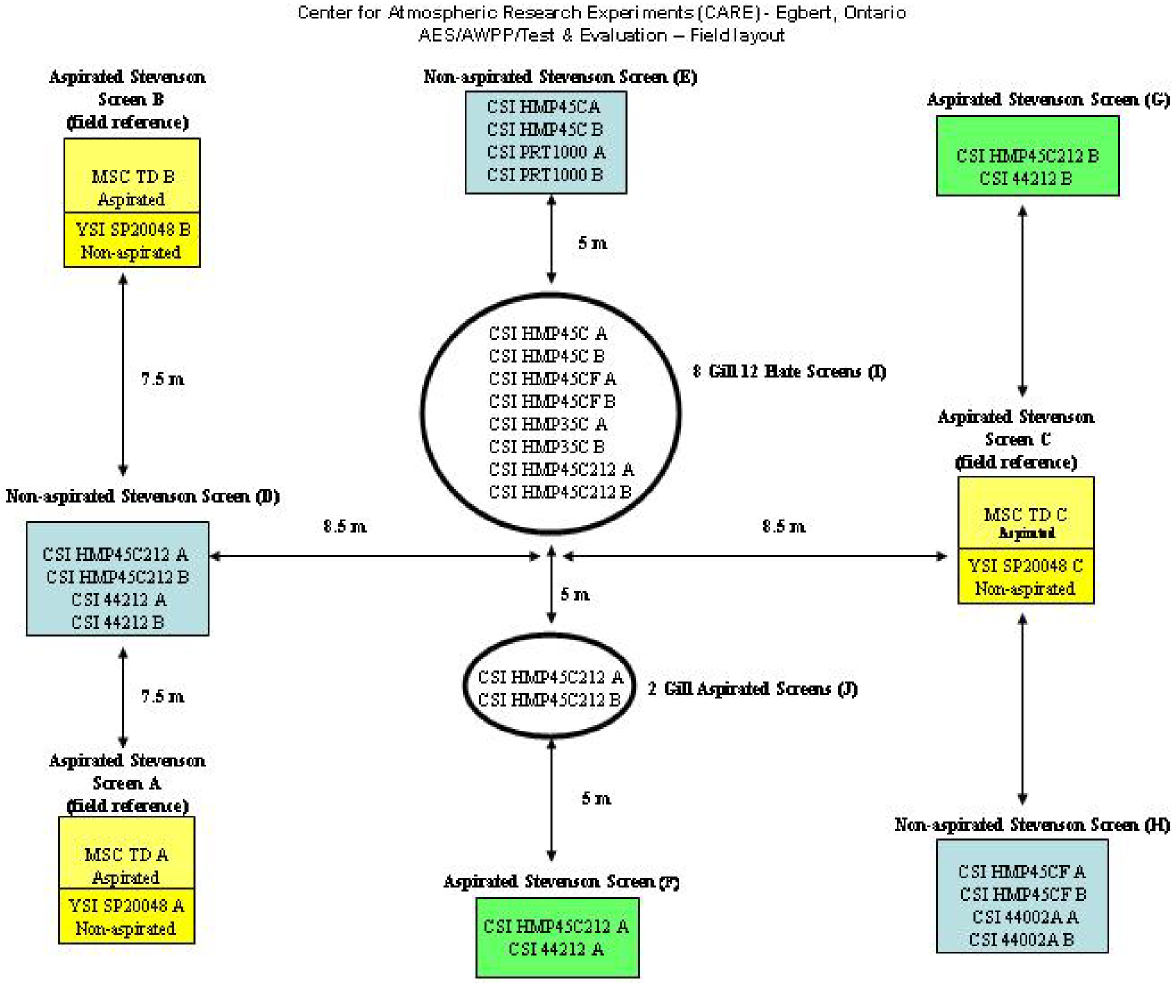

Figure 4 - Layout of all reference and test sensors at CARE test site. Reference sensors are located in the yellow boxes and are labeled (MSC TD A Aspirated).

Figure 5 - General view of temperature/humidity sensors installation in CARE test site.

All data collected for this analysis, from both reference sensors and sensors under test, were of minutely resolution. Minutely reference average values were only included in the analysis when the differences between all reference sensors was less than 0.5^{o}C. To establish a common test period, minutely values were only included in the analysis when data were present for all sensors under test and the reference. If any one sensor was missing a particular minutely value, that minutely value was removed from all other sensors under test.

DATA ANALYSIS

After filtering and the removal of missing data, the resulting dataset was separated into three categories based on reference temperature:

1) <=-5^{o}C
2) >-5^{o}C and <=5^{o}C
3) >5^{o}C

These temperature categories were established to identify temperature-dependent variability in the sensors under test. Each of these three temperature categories was analysed by applying the formulas for operational comparability and functional precision.

Operational comparability was used to quantify the degree of variability of sensors under test from the reference. Operational comparability as defined in ASTM 4430 represents the root mean square of the difference between two simultaneous readings from two systems (reference and sensor under test) measuring the same quantity in the same environment.

Functional Precision was used to quantify the degree of variability of identical sensors under test from each other. Functional precision as defined in ASTM 4430 represents the root mean square of the difference between simultaneous readings from two identical sensors.

RESULTS

Operational comparability scores for all three temperature categories are presented in Figures 6, 7 and 8 (aspirated sensors are highlighted in red). Of all configurations tested, operational comparability scores for aspirated sensors (in both Gill and wooden screens) best agreed with the reference. As the reference average sensors were aspirated, this close agreement was somewhat expected. In addition to aspiration dependence, temperature dependence was also apparent with respect to operational comparability with the lowest scores for most sensors occurring in the middle temperature range (>-5^{o}C and <=5^{o}C).

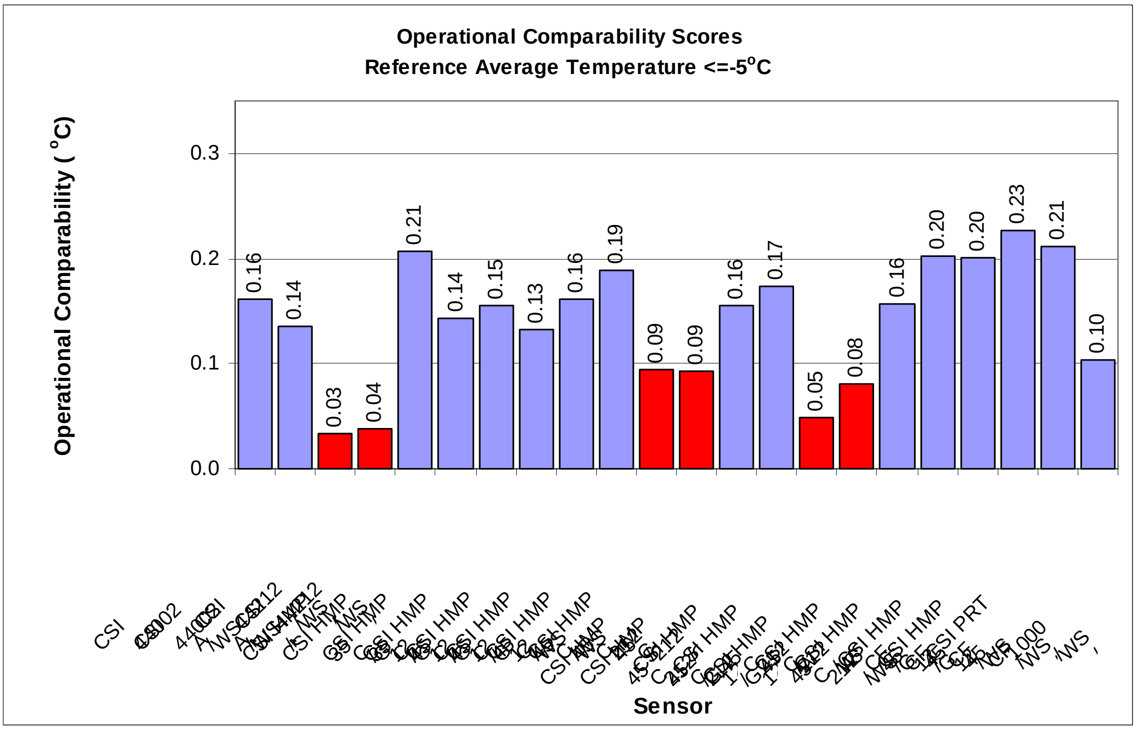

Figure 6 – Operational comparability scores for all sensors under test when reference temperature is <=-5°C. Red bars represent aspirated sensors. Blue bars represent non-aspirated sensors.

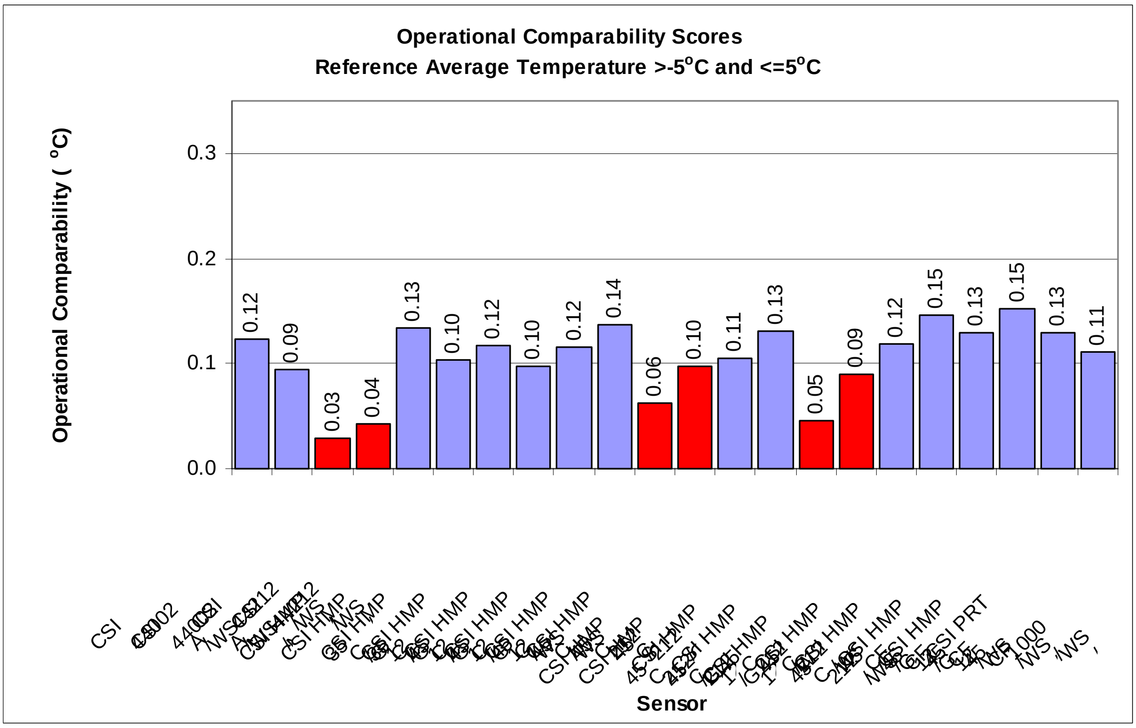

Figure 7 – Operational comparability scores for all sensors under test when reference temperature is >-5°C and <=5°C. Red bars represent aspirated sensors. Blue bars represent non-aspirated sensors.

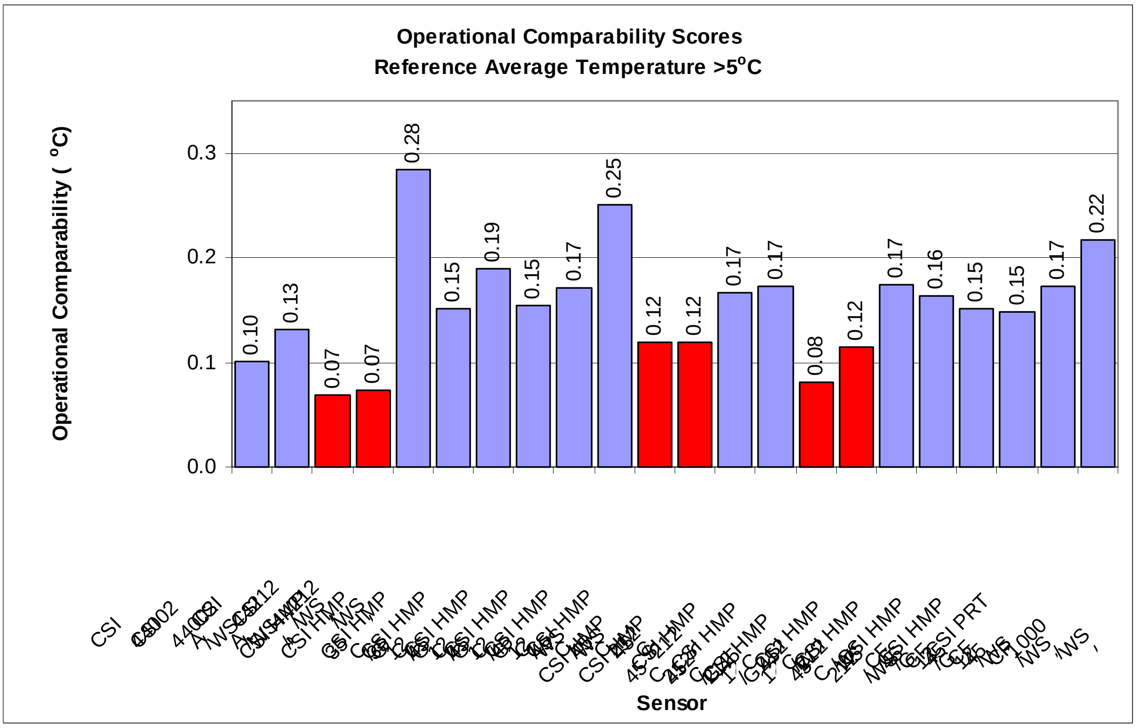

Figure 8 - Operational comparability scores for all sensors under test when reference temperature is >5°C. Red bars represent aspirated sensors. Blue bars represent non-aspirated sensors.

The distributions of the differences (between the reference and each sensor under test) were analysed and student's T-tests were done to determine whether differences between operational comparability scores were a result of higher variability or simply a higher population mean. The results of T-tests comparing the means of all sensors under test and the reference for all three temperature categories are displayed in Table 2. All sensors which have significantly different means from that of the reference are highlighted in red. The majority of sensors in all three temperature categories had significantly different means at the 95% confidence level. Some temperature dependence of T-test results was observed with 6 of 22 sensors not showing significant differences in the <=-5°C temperature category, and only 2 of 22 sensors not showing significant differences from the reference in the >-5°C and <=5°C temperature category. No consistent patterns with respect to sensor model, aspiration, or screen type were observed in the t-test results.

Table 2 – T-test results for comparison of reference and sensor under test means. All sensors highlighted in red were shown to have significantly different means at the 95% confidence leve1.

<=-5°C	>-5°C and <=5°C	>5°C
CSI 44002A/WS/NA A	CSI 44002A/WS/NA A	CSI 44002A/WS/NA A
CSI 44002A/WS/NA B	CSI 44002A/WS/NA B	CSI 44002A/WS/NA B
CSI 44212/WS/A A	CSI 44212/WS/A A	CSI 44212/WS/A A
CSI 44212/WS/A B	CSI 44212/WS/A B	CSI 44212/WS/A B
CSI HMP35C/G12/NA A	CSI HMP35C/G12/NA A	CSI HMP35C/G12/NA A
CSI HMP35C/G12/NA B	CSI HMP35C/G12/NA B	CSI HMP35C/G12/NA B
CSI HMP45C/G12/NA A	CSI HMP45C/G12/NA A	CSI HMP45C/G12/NA A
CSI HMP45C/G12/NA B	CSI HMP45C/G12/NA B	CSI HMP45C/G12/NA B
CSI HMP45C/WS/NA A	CSI HMP45C/WS/NA A	CSI HMP45C/WS/NA A
CSI HMP45C/WS/NA B	CSI HMP45C/WS/NA B	CSI HMP45C/WS/NA B
CSI HMP45C212/G/A A	CSI HMP45C212/G/A A	CSI HMP45C212/G/A A
CSI HMP45C212/G/A B	CSI HMP45C212/G/A B	CSI HMP45C212/G/A B
CSI HMP45C212/G12/NA A	CSI HMP45C212/G12/NA A	CSI HMP45C212/G12/NA A
CSI HMP45C212/G12/NA B	CSI HMP45C212/G12/NA B	CSI HMP45C212/G12/NA B
CSI HMP45C212/WS/A A	CSI HMP45C212/WS/A A	CSI HMP45C212/WS/A A
CSI HMP45C212/WS/A B	CSI HMP45C212/WS/A B	CSI HMP45C212/WS/A B
CSI HMP45C212/WS/NA A	CSI HMP45C212/WS/NA A	CSI HMP45C212/WS/NA A
CSI HMP45CF/G12/NA A	CSI HMP45CF/G12/NA A	CSI HMP45CF/G12/NA A
CSI HMP45CF/G12/NA B	CSI HMP45CF/G12/NA B	CSI HMP45CF/G12/NA B
CSI HMP45CF/WS/NA A	CSI HMP45CF/WS/NA A	CSI HMP45CF/WS/NA A
CSI HMP45CF/WS/NA B	CSI HMP45CF/WS/NA B	CSI HMP45CF/WS/NA B
CSI PRT1000/WS/NA A	CSI PRT1000/WS/NA A	CSI PRT1000/WS/NA A

The most apparent pattern observed, when comparing operational comparability scores and distributions of differences for sensors under test, involved aspirated vs. non-aspirated sensors. The distribution of the differences for the HMP 45C212 WS in aspirated and non-aspirated configurations are displayed in Figures 9 and 10. The aspirated sensor distribution appears more peaked (mesokurtic) while the non-aspirated sensor distribution appears less peaked (platykurtic), and less Gaussian with a skew toward positive differences from the reference average. These differences are common when comparing all aspirated vs. non-aspirated sensors and were exacerbated in the >5°C temperature category with differences in non-aspirated sensors becoming even more pronounced.

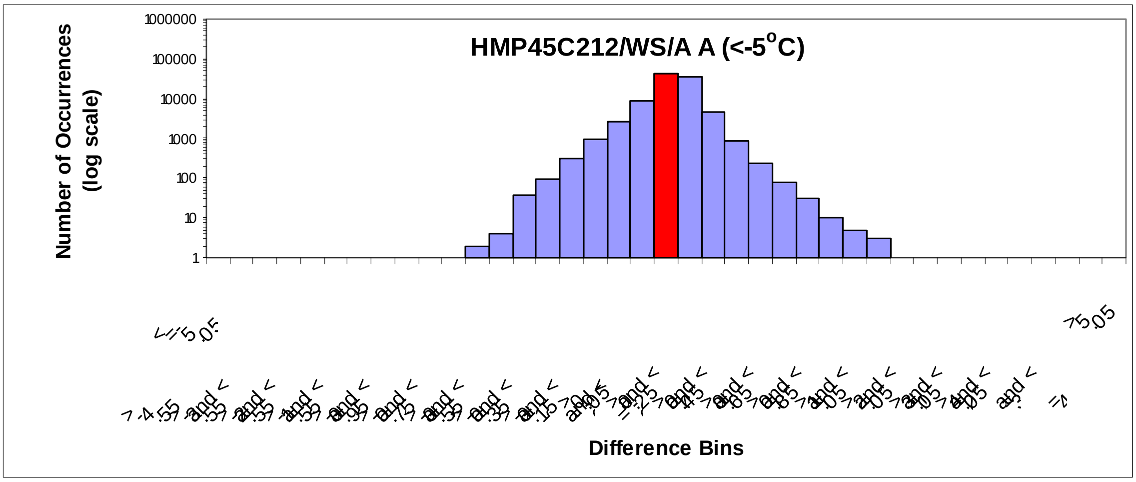

Figure 9 – Example of a frequency distribution of the differences between a sensor under test and the reference in an aspirated screen. The red bar represents the middle (optimum) difference bin.

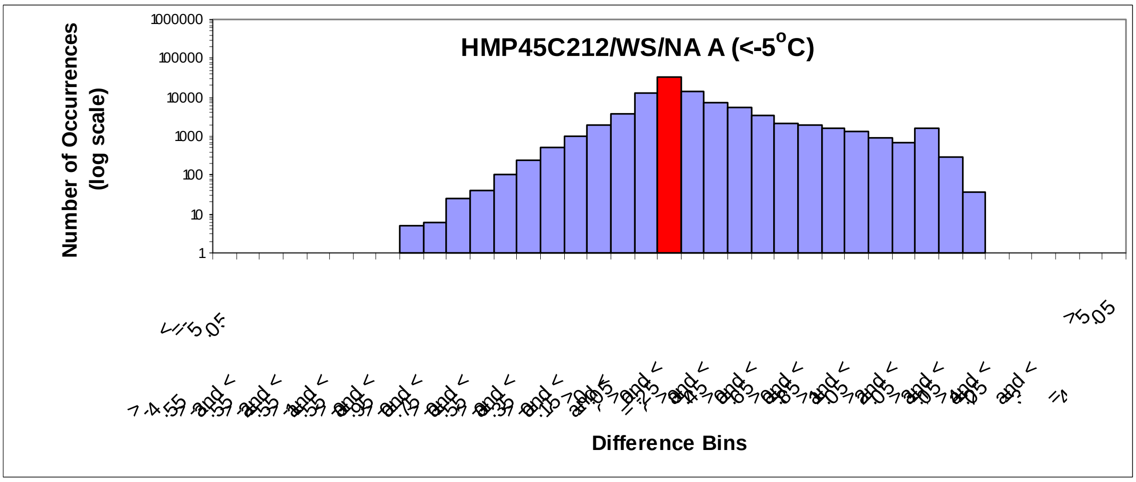

Figure 10 – Example of a frequency distribution of the differences between a sensor under test and the reference in a non-aspirated screen. The red bar represents the middle (optimum) difference bin.

Differences from the reference average for the two sensors with the best and worst operational comparability scores are illustrated in Figure 11 (Note - for graphical purposes, the minutely datasets were reduced in resolution by including only the instantaneous minutely value on the hour. As the summary statistics of mean and coefficient of variation for the minutely and hourly series are virtually identical (Appendix B), the hourly time series provided a rough graphical representation of differences from the reference). As illustrated in Figure 11, both the mean of the differences and degree of variability can differ significantly between sensors under test. Operational comparability scores for all other sensors under test lie between these two extremes.

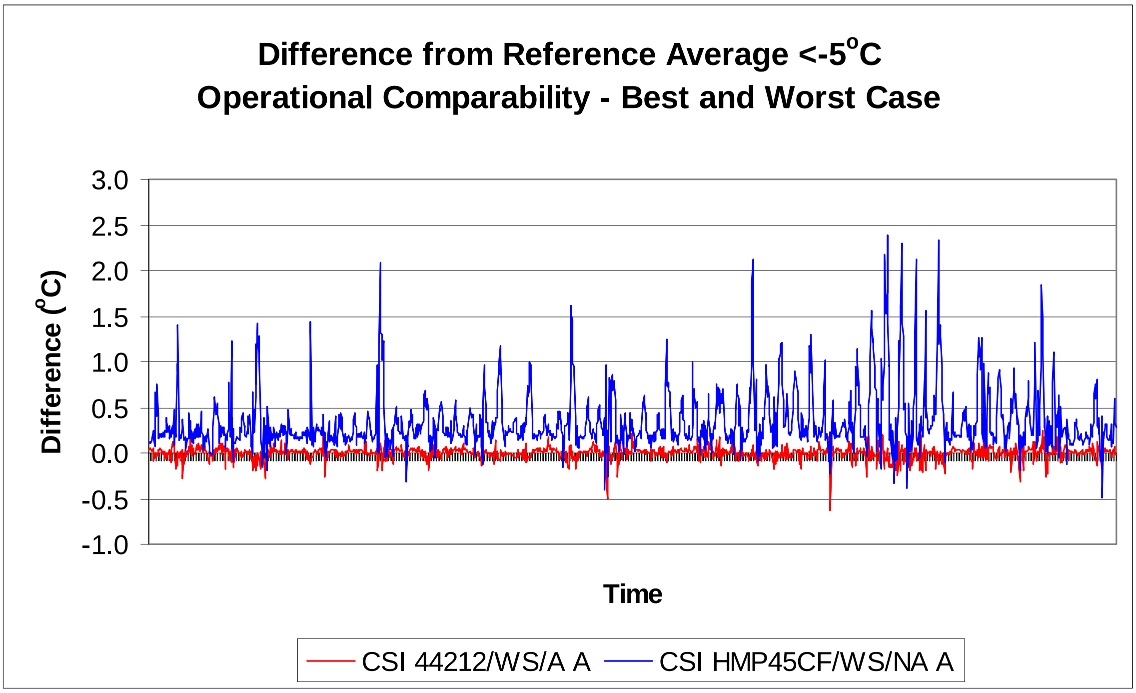

Figure 11 - The two time series represent the differences from the reference average for the sensors with the best and worst operational comparability scores.

While in the <=-5°C temperature category the CSI HMP45CF/WS/NA A sensor had the highest operational comparability score and consequently was shown to compare the worst with the reference, of all the identical pairs of sensors tested, this sensor had the lowest functional precision score. Hourly differences from the reference average for the two identical CSI HMP 45CF/WS/NA sensors (A and B) are illustrated in Figure 12. Hourly differences from the reference average for the pair of identical sensors with the worst functional precision score (CSI HMP35C/G12/NA A) are illustrated in Figure 13.

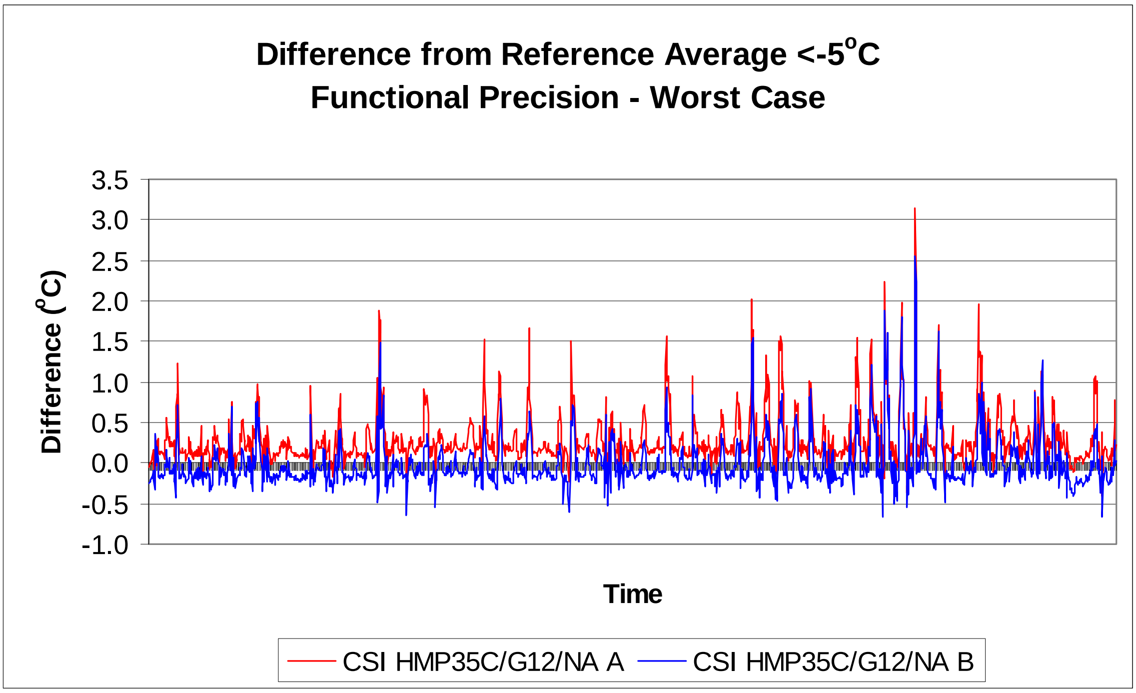

Figure 12 - The two time series represent the differences from the reference average for the pair of sensors with the best functional precision score.

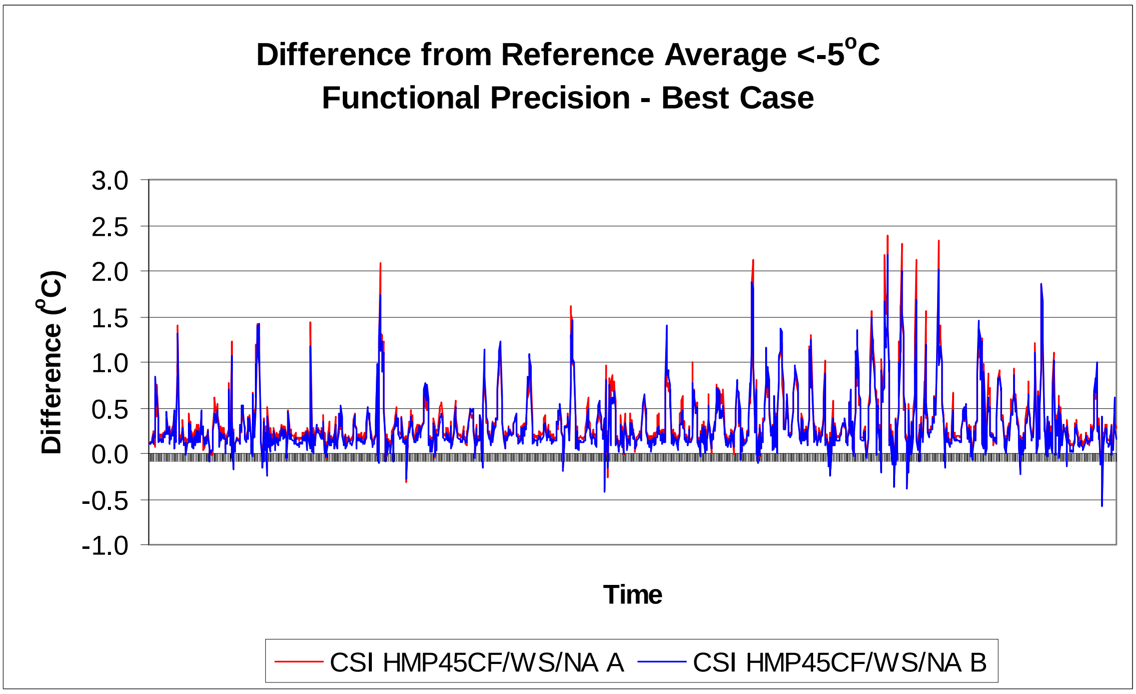

Figure 13 - The two time series represent the differences from the reference average for the pair of sensors with the worst functional precision score.

Functional precision scores for all three temperature categories are displayed in Figures 14, 15 and 16. As was observed with operational comparability, of the three temperature categories, functional precision scores were lowest in the middle category (<-5°C and >=5°C). Unlike operational comparability results, no clear pattern between aspirated and non-aspirated sensors was observed when comparing functional precision scores.

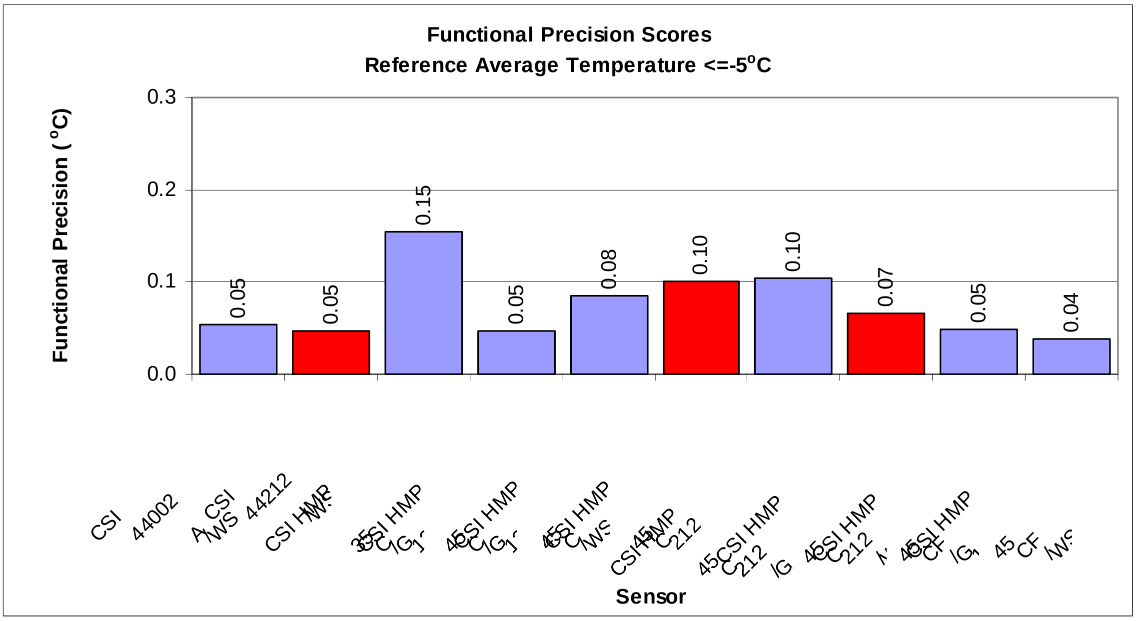

Figure 14 – Functional precision scores for all sensors under test when reference temperature is <=-5°C. Red bars represent aspirated sensors. Blue bars represent non-aspirated sensors.

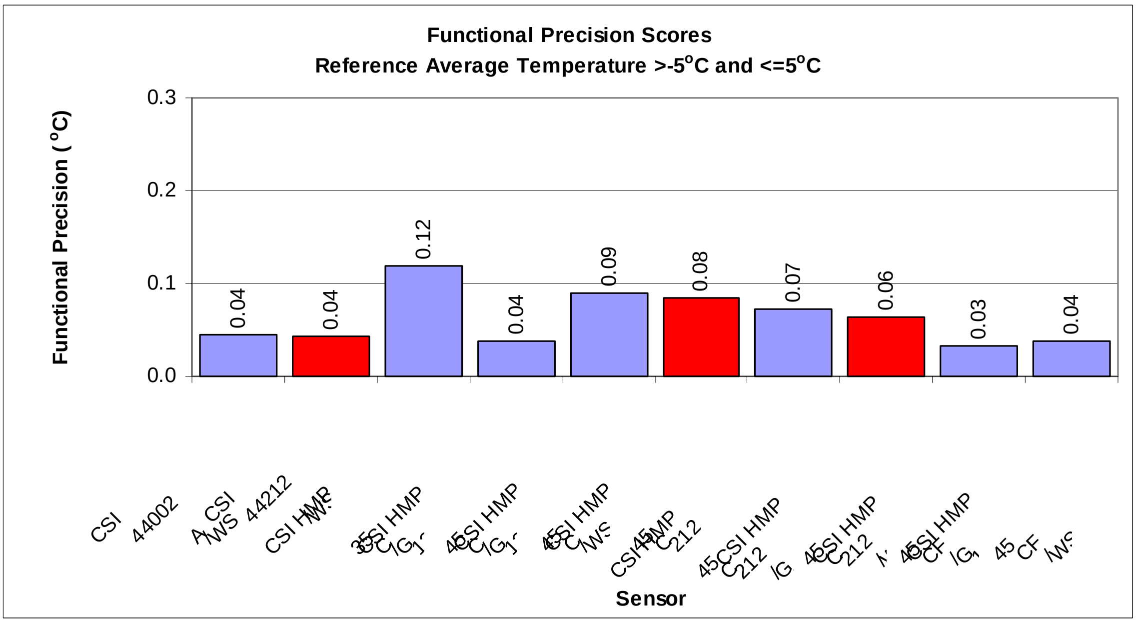

Figure 15 – Functional precision scores for all sensors under test when reference temperature is >-5°C and <=5°C. Red bars represent aspirated sensors. Blue bars represent non-aspirated sensors.

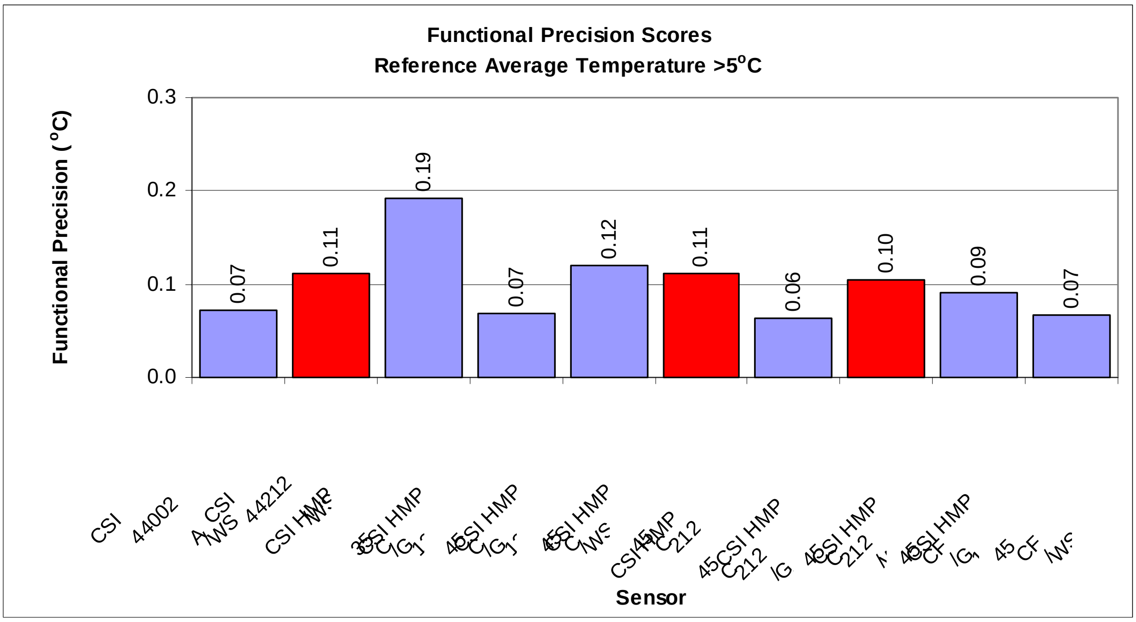

Figure 16 – Functional precision scores for all sensors under test when reference temperature is >5°C. Red bars represent aspirated sensors. Blue bars represent non-aspirated sensors.

DISCUSSION

Both operational comparability and functional precision scores from this analysis illustrate a wide range of variability among operational sensors in the Canadian surface weather and climate networks. Temperature dependence with respect to both the distributions of the differences from the reference and the differences between population means was apparent in both operational comparability and functional precision scores. Further stratification of the data by temperature may better identify the temperature ranges in which particular differences occur. The stratification of datasets by other meteorological parameters such as wind speed may also aid in further identifying the specific differences between operational sensors. The significant differences observed between aspirated and non-aspirated sensors may be less apparent during higher winds due to greater natural ventilation. It should be noted however that the results of this experiment represent a quantification of differences observed in one particular climate regime. The climatology of the test site for this study is not representative of all measurement sites throughout the country. As such, the differences observed between sensors may not be of consistent magnitude or direction in other Canadian climate regimes. To fully illustrate the differences between currently operational sensors, similar experiments would be required in different climate regimes throughout Canada.

The fact that the same sensor (CSI HMP45CF/WS/NA) had the highest operational comparability score and the lowest functional precision score in the <=-5°C temperature category illustrates the need for balance between sensor precision and sensor consistency in a climate network. Ideally, one would prefer a sensor which is shown to be both close to the "truth" and consistent in operation from sensor to sensor. If one is forced to answer the question of whether closeness to the "truth" coupled with unreliability is better or worse than reliability coupled with disparities from the "true" temperature, the answer is not straight forward. However, as systematic differences are traditionally easier to identify and remove than random differences, the latter may be the better choice; as long as the data from such sensors is suitably adjusted prior to use.

CONCLUSION

Due to the vast geographic nature of Canada, the ability to properly identify variations in climate trends depends on instrument continuity from one climate region to another. This experiment identified a wide range of variability among currently operational sensors in the Canadian surface weather and climate networks. The observed variability results from differences in sensor type, sensor configuration and air temperature. Although the Meteorological Service of Canada intends to test possible replacements for operational sensors in different climate regimes throughout Canada, the degree of variability of data residing in the Canadian climate archive from currently operational sensors will remain unknown until similar experiments have been repeated in different climate regimes.

ACKNOWLEDGEMENTS

Our thanks is given to the following colleagues who provided vital contributions to the this project: Peter Bowman, Bob Wilson and George Davis. We are grateful for the fruitful discussions with all of them.

Appendix A

	Sensor	Screen/Shield	Aspiration
CSI 44212/WS/NA A	CSI 44212	(WS) Wooden Screen	(NA) Non-Aspirated
CSI 44212/WS/NA B	CSI 44212	(WS) Wooden Screen	(NA) Non-Aspirated
CSI HMP45C212/WS/NA B	CSI HMP45C212	(WS) Wooden Screen	(NA) Non-Aspirated
CSI PRT1000/WS/NA A	CSI PRT1000	(WS) Wooden Screen	(NA) Non-Aspirated

Sensors removed from experiment prior to analysis due to uncharacteristically high differences from both the reference and all other sensors under test.

Appendix B

Sensor	Minutely (N=406299)		Hourly (N=6763)	
	Mean	Coef.Var.	Mean	Coef.Var.
Reference Average	6.019103	2.15205	6.012748	2.15510
CSI 44002A/WS/NA A	6.124509	2.08976	6.118610	2.09253
CSI 44002A/WS/NA B	6.052633	2.11524	6.046364	2.11813
CSI 44212/WS/A A	5.998492	2.15639	5.992243	2.15943
CSI 44212/WS/A B	6.065454	2.14065	6.058375	2.14394
CSI HMP35C/G12/NA A	6.304771	2.06078	6.297886	2.06402
CSI HMP35C/G12/NA B	6.051136	2.15043	6.043970	2.15381
CSI HMP45C/G12/NA A	6.033197	2.16513	6.026342	2.16854
CSI HMP45C/G12/NA B	6.026166	2.16560	6.018894	2.16920
CSI HMP45C/WS/NA A	6.076401	2.14517	6.068909	2.14861
CSI HMP45C/WS/NA B	6.237260	2.08898	6.229667	2.09226
CSI HMP45C212/G/A A	5.981902	2.16791	5.974659	2.17119
CSI HMP45C212/G/A B	6.132289	2.10982	6.126034	2.11266
CSI HMP45C212/G12/NA A	6.102319	2.13094	6.095518	2.13424
CSI HMP45C212/G12/NA B	6.167084	2.09771	6.160065	2.10098
CSI HMP45C212/WS/A A	6.040655	2.14264	6.034338	2.14561
CSI HMP45C212/WS/A B	6.146586	2.10440	6.139071	2.10767
CSI HMP45C212/WS/NA A	6.151596	2.11030	6.144211	2.11349
CSI HMP45CF/G12/NA A	6.144640	2.09118	6.136420	2.09483
CSI HMP45CF/G12/NA B	6.091604	2.10225	6.084622	2.10542
CSI HMP45CF/WS/NA A	6.118393	2.08970	6.111363	2.09296
CSI HMP45CF/WS/NA B	6.057680	2.10879	6.050991	2.11197
CSI PRT1000/WS/NA A	6.243256	2.08055	6.236481	2.08349

The Canadian Lightning Detection Network
Novel Approaches for Performance Measurement and Network Management

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ABSTRACT

The Canadian Lightning Detection Network (CLDN) was established in 1998 and now provides lightning detection coverage for over 95% of Canadians. This paper will provide some background on the CLDN, describe how the network is managed and discuss some operational issues. Some novel approaches to using the internet for real-time performance monitoring network management and data display will also be presented.

1.0 Introduction/Background

Canada is approx 10,000,000 square kilometers in size, has a population of 32M (2004) and a comparative GDP of $959B (2003 - US Dollars). To put this in context, Germany is approx 357,000 sq km in size, has a population of 82M (2004) and a comparative GDP of $2271B (2003).

The physical size of Canada coupled with the smaller population and tax base, poses unique challenges for the Meteorological Service of Canada (MSC) when designing, operating and managing monitoring networks. The Canadian Lightning Detection Network (CLDN) is one such MSC network. This paper will provide an overview of the CLDN, explain how it is managed and describe some novel approaches that have been undertaken to measure and display the performance of the CLDN in real-time.

1.1 Network Topology.

The CLDN was designed in 1997 and deployed in 1998. The primary design objective was to have Detection Efficiency of 90%+ and Accuracy of 500m or better over those areas of Canada having 5 thunderstorm days or more.

In addition to the primary objective, MSC had to ensure that all major population centres, forested areas and electricity production and transmission facilities were adequately monitored as well as all major aviation corridors and areas.

Initial capital requirements (approx $7M) were met via an internal loan to MSC. Loan repayment and operating costs are covered by a blend of MSC operational budgets and revenues from CLDN clients including Provincial Forest agencies, Public Utilities and NAV CANADA (Air Transport).

The CLDN is largely unchanged from when it was first installed in 1998. Two additional sensors were added in the Yukon in 2003 . The network consists of 51Vaisala (ex GAI) LPATS IV sensors and 32 Vaisala IMPACT ES sensors for a total complement of 83 sensors. See Fig. 1.

In order to avoid boundary conditions between Canada and the US, the CLDN operates in an integrated fashion with the National Lightning Detection Network (NLDN) owned by Vaisala and covering the continental US. Data is shared with the Alaskan Fire Service during the summer months to add an additional 5 sensors in the northwest. This amalgam of 199 integrated sensors is called the North American Lightning Detection Network (NALDN).

Raw sensor Data flows from each CLDN sensor via VSAT transmission to the ANIK-2 geostationary satellite and then to a Telesat hub station near Toronto. A landline carries the data from the Telesat hub to Vaisala's processing center in Tucson, AZ where the raw sensor data from all NALDN sensors is used to compute Flash and Stroke lightning solutions over Canada, the contiguous USA, Alaska and coastal waters. Flash solutions are then backhauled by landline to Toronto and broadcast via satellite to MSC and other clients. Typically clients have solution data on site within 60 seconds of the lightning event.

1.2 Lightning in Canada.

The CLDN and associated communications infrastructure was designed to detect, resolve and communicate to users up to 45,000 flashes per hour. We have not seen rates of this magnitude to date. A rate of 25,000 flashes per hour will occur 5-15 times a year usually in the afternoon.

Typically since 1998 the CLDN detects 5-10 Million Flashes to Ground per year with an average of 1.7-2.3 Strokes per Flash depending on the year. Intracloud and cloud to cloud lightning is also monitored on a low efficiency "survey" level but not used operationally at this time. The lightning season generally runs from April to October. Although winter lightning is detected it is infrequent and mainly confined to coastal areas. Flash densities can be described as low to moderate with densities ranging from .25 to 4 flashes/sqkm/year. There are "hot" spots. Southern and in particular southwestern Ontario has Flash Densities that consistenly range from 2 to 4 flashes/sqkm/year, large sections of central and southern Alberta consistetly exceed 1 flash/sqkm/year. Spots in southeastern BC also exceed 1 flash/sqkm/year.

We do not have accurate statistics on death and injury rates due to Lightning in Canada. However anecdotal information suggests that 3-8 Canadians die from Lightning each year in Canada with approx 80 additional injuries not causing death..

Commercial losses are also difficult to measure. Estimates of insurance losses indicate that up to 40,000 claims are filed each year with the majority of them being in the $1000-2000 range mainly in homes. Industrial claims although fewer, are considerably more expensive with some each year in the $500,000 and up range.

Losses of timber and property resulting from lightning trigged forest fires run into the $100's of Millions annually. In 2004, 6634 forest fires in Canada consumed 3.2M hectares of forest compared to ten year averages of 7631 fires and 2.8M hectares respectively. Nationally in 2002, 46% of forest fires in Canada were caused by lightning while across western and northern Canada, approximately 70% of forest fires are caused by Lightning.

As populations continue to grow, forest fires are becoming a more serious threat to lives and properties in settled areas adjacent to forested areas. During the summer of 2003, fires caused by lightning partially enveloped numerous communities in British Columbia, causing insured property damage that exceeded $150M.

In addition to direct support for Forest Fire Suppression and infrastructure managers, MSC makes use of CLDN information to support its public and aviation forecast programs. Lightning serves well as an integrated indicator of hazardous high impact weather, particularly when used in real time in conjunction with Satellite Imagery and Radar. See Fig. 2.

To enable rapid response to numerous post event lightning inquiries from police, fire officials, insurance companies, coroners and infrastructure managers, MSC has implemented a data archive and retrieval system that serves as a backend data repository and interfaces with Microsoft Mappoint. Microsoft Mappoint is a low cost (approx $400) low-mid capability shrink wrap GIS tool that can easily display lightning data plotted on maps of terrain, roads, locations and geo-political areas and includes postal code boundaries for Canada and the USA.

2.0 Network Management.

In addition to MSC using the CLDN for meteorological and high impact public safety purposes, a number of important clients use CLDN data to support their operational mandates. Keeping the CLDN healthy and producing high quality lightning solutions is important to us.

Given that the CLDN utilizes a network of sensors dispersed widely across most of Canada, management and maintenance of the network poses some unique challenges, particularly in the face of limited resources.

To assist with providing MSC personnel with access to information, most resource materials related to the CLDN are stored on line in two internal MSC web sites, one for staff to support operational use of the CLDN and a second password protected web site for managers and financial adminstrators.

Communications, Sensor Status Monitoring and Solutions Processing is contracted out to Vaisala on a fixed cost multiyear basis.

Sensor and communications (VSAT) management and maintenance is undertaken primarily by MSC personnel while Vaisala is available to MSC for service depot and specialized on site work when required. Under contract to MSC and utilizing the VSAT communications capacity, the "health"of each sensor is continuously monitored by Vaisala as data is gathered. Sensor problems that cannot be resolved remotely are reported to MSC's National Monitoring Desk and then actioned as a "Trouble Ticket" to regional service personnel for resolution.

A "tiered" approach to sensor and communications maintenance is used. Site hosts serve to fulfill tier one tasks such as processor resets, power cycling and site physical examinations. MSC technicians provide on-site tier two sensor maintenance and repair. Vaisala specialists provide tier three support for those situations that are not resolvable by tier one or tier two personnel. Tier three may entail a sensor site visit by Viasala staff but to date most tier three work has been done in house at Vaisala's location in Tucson.

As a network of sensors, the CLDN can continue to generate quality lightning solutions with a considerable number of non-contributing sensors. Although this network approach is inherently fault tolerant, beginning in 2004 with the life of the network at 5+ years, a higher emphasis was placed on ensuring that sensor outages are resolved as quickly as possible.

In 2005 we will be continuing with an upgrade plan developed with input from Vaisala that will swap out older LPATS IV sensors in favour of IMPACT LS7000 sensors in order to further improve network performance in 10 priorized areas.

As noted earlier, the CLDN is funded with a blend of MSC resources and revenues from third parties. Since 2003, the CLDN has been operationally self sufficent. Small operational surpluses are being used to fund the development of new products and services, to improve network performance through the upgrading of sensors, and most importantly to extend the life cycle of the network itself.

3.0 Performance Measurement.

To assist with efficient Network Management and as an aid to improving the performance of the CLDN, a suite of CLDN Performance Measurement (PM) tools were designed and deployed in 2004. The design premise for the PM tools was as follows:

- That whatever indicators were chosen the measurement of those indicators should be available "On Line" by staff using a simple web browser such as Microsoft Internet Explorer (IE).
- Metadata about the sensors themselves is important and although not subject to frequent change the information needs to be accurate and available immediately upon demand.
- For all but static data, the frequency of reporting should be at least daily and where possible as frequently as hourly or half-hourly.
- The presentation of the Performance Indicators should be suitable for managers, technical staff and in some case clients. As such the presentation should be simple to comprehend while offering links to more technical detail that can be mined quickly from a database when required.
- Snapshots of the state of the CLDN should be archived with a view towards satisfying possible due-diligence considerations and better understanding any recurring problems and what sensor outages mean to the network as a whole.
- That in the balance, it is the quality of CLDN solutions as measured by the Accuracy and Efficiency values that "grade" the performance of the CLDN from a users perspective. Users are more concerned about the Accuracy and Efficiency of the lightning solutions than they are about the state of any particular sensor. Hence a dynamic indicator of the Accuracy and Efficiency of the CLDN as a whole is required in addition to indicators related to sensors themselves.

The CLDN Performance Measurement tools that resulted from the design premise are as follows:

- Sensor Status and Performance Data
- Network Performance
- Dynamic Accuracy and Efficiency Maps

A secure web portal was developed to host these tools and to offer password protected access to MSC managers, maintenance personnel from MSC and Vaisala and selected clients.

3.1 Sensor Status and Performance Data.

Three indicators are used to track sensor information.
- A map of North America with color coded sensor status updated and archived every 1/2 hour. See Fig. 3. & Fig. 4.
- Diagnostic information obtained by clicking on any sensor. See Fig 5.
- Sensor metadata updated daily. See Fig. 6.

3.2 Network Performance.

Although from a maintenance perspective, sensor status and performance is extremely important, from a user perspective, the ability of the CLDN to detect lightning and correctly locate lightning is a more relevant indicator of overall performance.

A "performance measurement grid" has been developed (see Fig. 7.) that assesses one sensor and four network performance parameters for each of 112 regions in North America. Each region is then color coded and the resultant network performance map is generated and archived every 30 minutes.

Current network performance can now be examined at any time, and from anywhere via a standard web browser having access to the CLDN portal. The archive feature provides users with the ability to go back to any critical time and examine the performance of the CLDN.

3.3 Dynamic Accuracy and Efficiency Maps.

Two of the most important performance indicators for a lightning detection network are Location Accuracy and Detection Efficiency.

Location Accuracy is defined as the distance between where the network says a lightning stroke occured and where it actually occured. Accuracy is generally measured in kilometers.

Detection Efficiency is defined as the ratio of the number of lightning strokes detected by the network divided by the number of lightning strokes that actually occured. Efficiency is generally stated as a percentage %.

Vaisala has a modelling algorithm that can predict Accuracy and Efficiency of a network based on the location, density and type of lightning sensors. This algorithm has historically been used to plan and adjust networks and is run offline as a design and assessment tool on a demand basis with typical run times in the order of hours.

It is not the purpose of this paper to review the algorithm and how it works per se, but to show instead how we are using this tool in a real time mode to better monitor the performance of the CLDN.

Given that Accuracy and Efficiency are the most relevant indicators of network performance, MSC contracted Vaisala to implement a similar algorithm that could be run automatically in near real time at least once per hour. This would provide users of the CLDN with an immediate indication of Accuracy and Efficiency using the actual operational sensor suite.

Some compromises have been made to facilitate timely generation of the Location Accuracy (Fig. 8.) and Detection Efficiency (Fig. 9.) maps. The contouring is somewhat coarse and in the case of Efficiency there is an observed trend to report lower values than seen from the original algorithm run off line. Improvements are under development for deployment in 2005.

An archive of Accuracy and Efficiency Maps is also being implemented to provide the ability to determine CLDN past performance on an hour by hour basis.

4 Summary:

The Canadian Lightning Detection Network provides lightning detection coverage for over 95% of Canadians. New internet accessible Performance Measurement tools enable the Meteorological Service of Canada (MSC) to efficiently monitor and effectively display the status of the lightning detection sensors and the accuracy and efficiency of the CLDN in real time. Through use of the Performance Measurement tools, MSC managers and staff are able to see the effects of sensor outages and act quickly to minimize sensor down times.

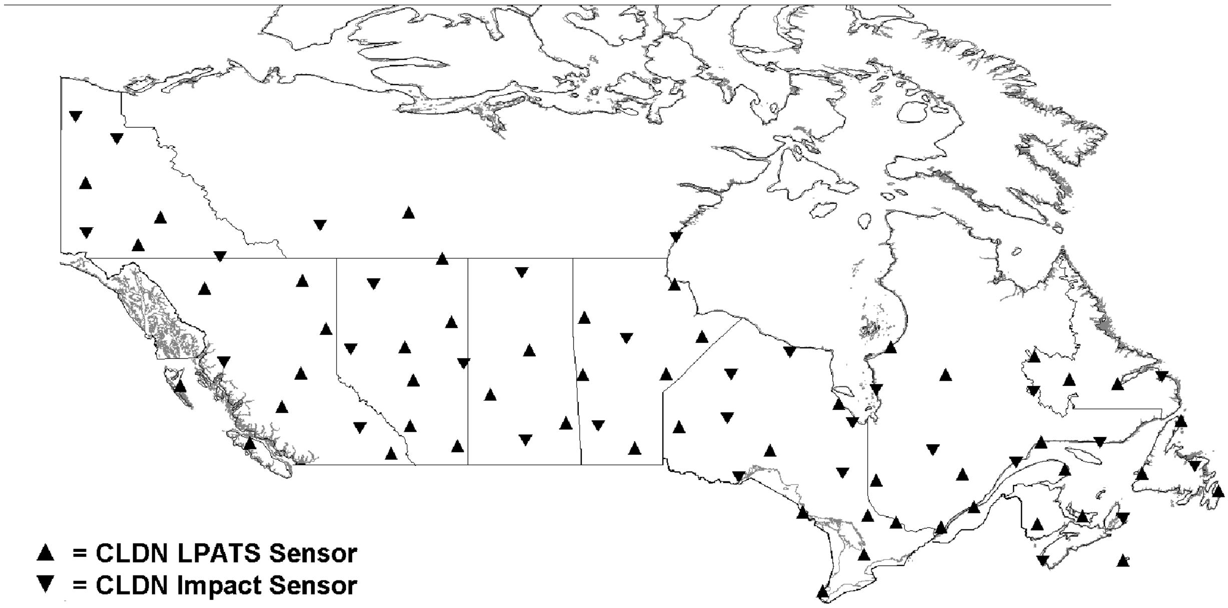

Fig. 1. CLDN Sensor Locations (Feb 2005)

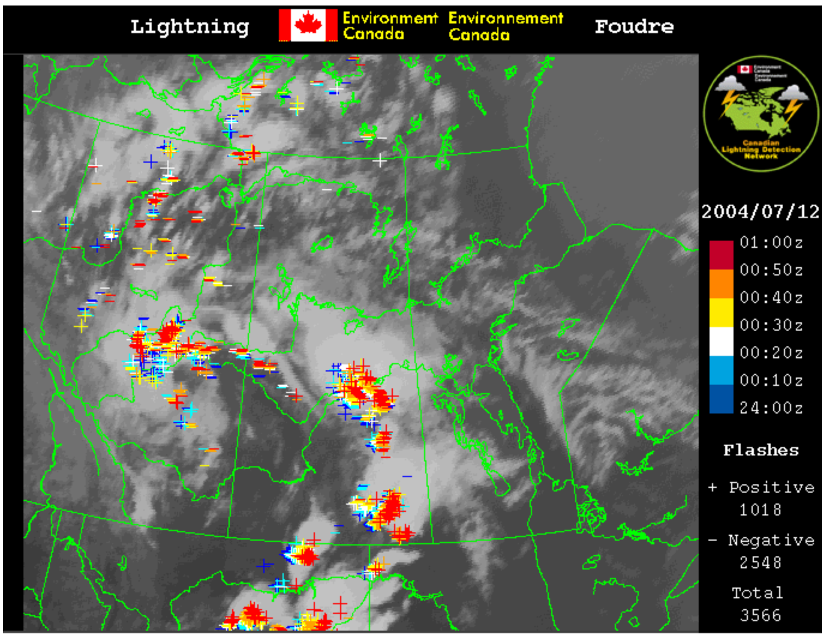

Fig. 2. Integrated CLDN and IR Satellite Image over Edmonton, Alberta (20040712 01:00 UTC)

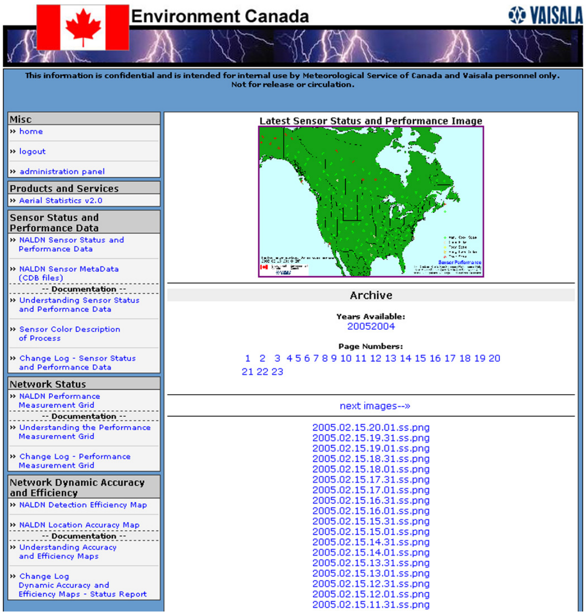

Fig. 3. Current Sensor Status & access to archive

CDB Information:

Name: "Sydney_NS"	**Type:** "IMPACT ES"	**Lim:** "TO-1"
Latitude: 46.162796020507812	**Longitude:** -60.042083740234375	**Altitude:** 61
Random Error: 10 1.5	**Threshold:** 100	

Sensor Availability:
Transitions (last 24 hours): 0
Total Time Down (last 24 hours): 24:00:03

Fig. 5. Diagnostic information

[sensor:62] Name "Fort_St._John_BC" "SJ" "" "CLDN" "SeriesIV" "TO-1" Type "SeriesIV" Transport 62 Network 0 0 Participation "yes" Location 56.248073577880859 -120.73606109619141 705 RandomError 10 1.5 AngleRandomError 0.75 0.28867501020431519 7 UsableMeasurements ".st" Cloud 10 0x0 Threshold 100 Rotation 0 SiteCorrection 0 0 0 0 0 0 0 0 SignalAttenuation 100 1 1 1000 Gain "EField6_Lpats" GainCorrection 1.3400000333786011

Fig. 6. Sensor metadata

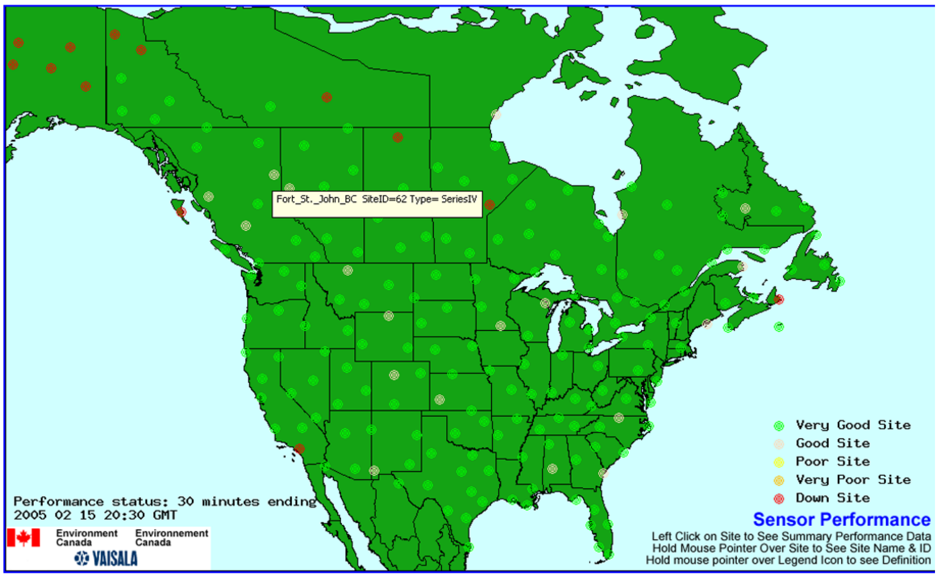

Fig. 4. Sensor Status with roll over and click-on information.

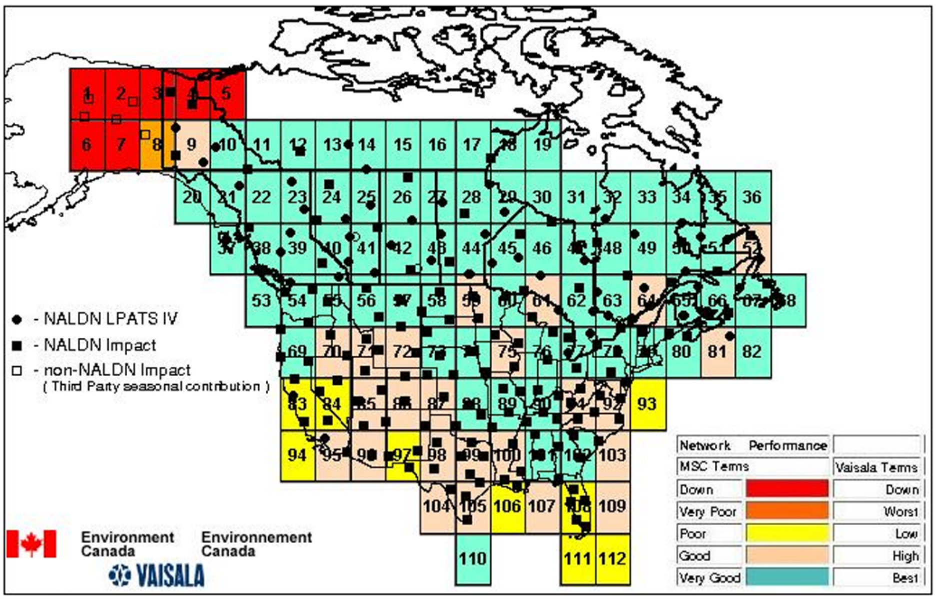

Fig. 7. Network Performance.

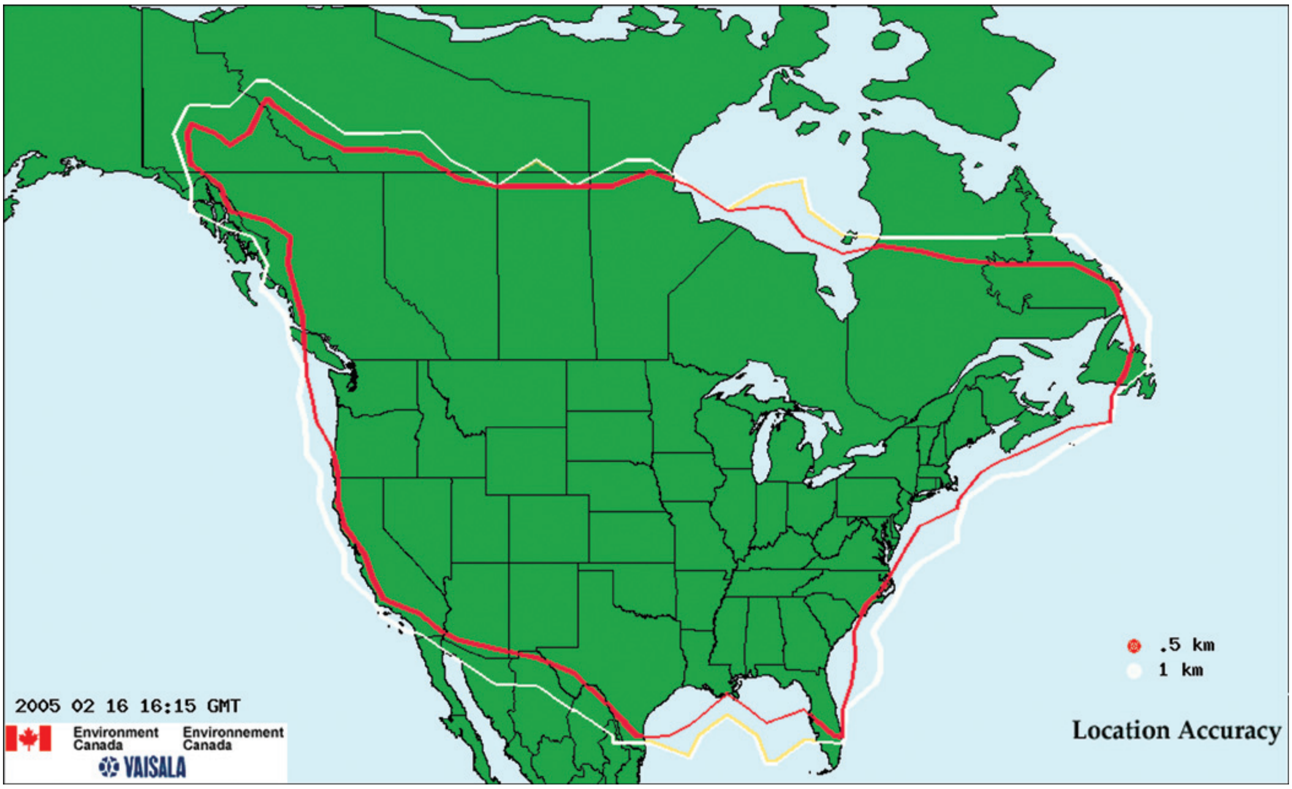

Fig. 8. Dynamic Location Accuracy Map (contours at .5 & 1 km)

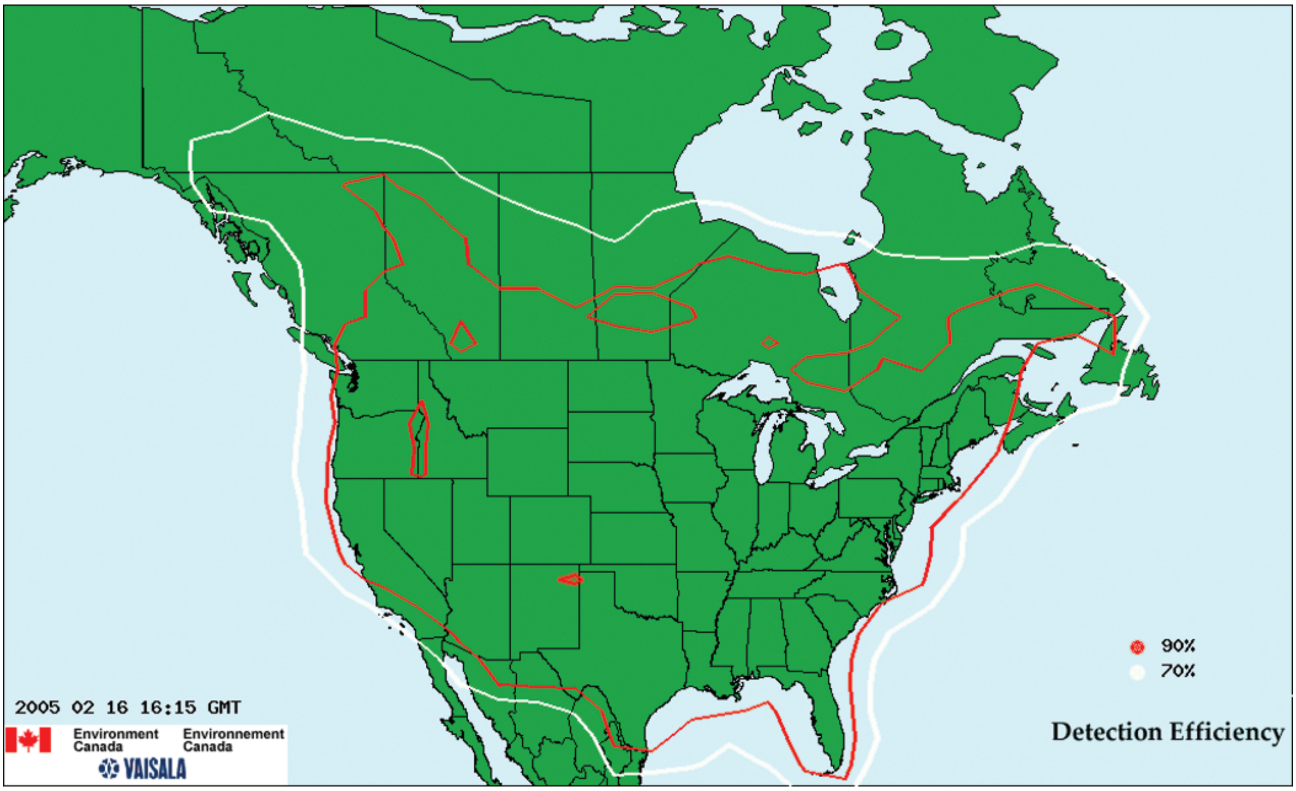

Fig. 9. Dynamic Detection Efficiency Map (contours at 70% & 90%)

Comparison between the data collected from AWOS and that collected from manual observing instruments

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Contents

1-INTRODUCTION

IT was noticed since we started in automating of our observations and, our surface observing systems in Egypt, that there were some differences between the values of weather parameters that collected from accurate and calibrated automatic observing sensors and that were collected from accurate and calibrated manual observing instruments.

Also It was noticed that with regarding to these observations, that there are limitations in the quality and quantity of data made by human observers. The main cause of this is the lack of definitions for the variables required. Although some definitions and thresholds for parameters are available at national levels, it is almost impossible for them to be applied objectively due to the limitations in, the performance of both the instruments and sensors.

The WMO alphanumeric codes currently in use also do not make provision of all measurements presently already available. This lead to the conclusion that several of the "present weather" observations could not be performed neither in a qualitative nor quantitative manner and, therefore, not be made available as reliable data sets.

It was agreed by the working group of the Egyptian meteorological authority that users' needs have to be reviewed in the light of present and future requirements and precise definitions have to be developed for the variables/parameters required.

The ultimate aim should be to define these parameters, as much as possible, in a quantitative manner, which would significantly facilitate the automation of observations.

2-Background

During the last ten years Egypt has deployed about 23 surface automatic observing stations and put them operationally in the assigned different locations to measure and determine surface observations beside the traditionally manual observing stations

-7 of these AWOS were operated for the purpose of aviation
-2 of these AWOS were operated for the purpose of agro meteorology
-14 of these AWOS were operated for the purpose of synoptic application.

During operating of these automatic observing stations some problems arises. The most important one that faced us was that reported differences between the Variables values that collected from these automatic observing stations and that values collected from traditionally manual observing instruments.

A workgroup was established from the department of instruments in our service to watch the performance of these automatic observing stations. All regarded sensors and instruments were calibrated to minimize the differences in variables values.

The workgroup started to apply a quality control system and examined the data at both of the stations and at the main data center in our service to detect errors so that data may be either corrected or approved.

The applied quality control included procedures for returning to the source of data to verify them and to prevent recurrence of errors.

We have applied this quality control at real time at both of the stations and the main data center.

Also this quality control was performed at near real time and at non real time at the main data center of our service to examine the performance of the observing system and to prescribe changes that may happened to the equipments.

Also to get the best of our study we have established two work teems of our workgroup , one for the regular maintenance and calibrations procedures and one for the monitoring of the data to get rapid response to failure reports from Monitoring system .

Our real time quality control included checks for each of the following:-

a- completeness of observations at the stations
b- completeness and timeliness of the collections of observations at data center.
c- quality of data

As a result of these above mentioned procedures we have collected different statistics on observational error of individual variables and we have generated hourly , daily, and monthly summaries for each of the following :

a- total number of observations scheduled for each variable
b- total number of observations that failed the quality control check
c- the percentage of failed observations
d- error and threshold values for each failed observation
e- check on both maximum and minimum variability of an instantaneous values

We have succeeded by applying these procedures to minimize the differences between the data of the automatic observing stations and that of manual observing instruments to the lowest values which meet with our requirements in the light of the observing regulations

3-Instrumental aspects

The working group that established in the Egyptian meteorological authority to watch the performance of these automatic sensors and equipment's presently available for measuring or determination of "present weather" and which are currently in operation in the various Services discussed their advantages and limitations compared with human observers.

It was found that single and multi-sensor solutions and the application of various combinations of sensors already meet a great range of data according to users' needs, as well as they could be determined presently.

The development of new and the improvement of existing automatic sensors and algorithms should be reconsidered to make the values of data collected from these automatic observing systems becomes as same as the values of data that collected from manual observing instruments

4-Procedures and algorithms

It was noticed that the procedures and algorithms used for the determination of "present weather" are crucial for the data generated. Several algorithms for single or multi-sensor solutions are already in application, although they still have limitations.

Some of our working group in the Egyptian meteorological authority presented details of algorithms developed in our service to correct some reports or to overcome deficiencies in the ability of instruments to report certain phenomena, mainly related to "present weather" observations.

It was generally accepted that these were valuable additions to the process of making a representative observation. However, we recognized that these procedures have been developed, in many cases, from climatological records specific to the region in which they are being applied.

They may therefore not be applicable without modification in other climatic regions. Although they may only be pertinent to specific instruments or combinations of instruments, a continued development of these algorithms could make them applicable for more general use in the future.

So it is needed that:

- The development and use of such algorithms must be encouraged;
- Members should always record details of the algorithms adopted;
- Members should make details on algorithms available to data archivists and researchers;
- Data archives should record original as well as amended (reported) data.

5-Present deficiencies

It is well known generally that an AWOS cannot report "present weather" or, more general, visual observations, in a manner as it is done by a human observer nor should an AWOS be expected to do so since an AWOS observes and reports weather differently. It was noted that AWOS provide consistent information while human observers characteristically show significant subjectivity, uncertainty, and variation especially when the parameters to be observed are not well defined.

As already stated above, it was found that in many cases no clear and agreed to definitions of "present weather", visual, or subjective observations exist so far. Even more significant, there is presently no clear statement available on the actual and future requirements of data users. In considering this unfortunate situation and noting that many of the "present be significantly reviewed in the light of present and future needs.

So individual sensors, multi-sensor systems, combination of available information or measurements, and sophisticated algorithms are already available or can be developed if there is a need for observing relevant parameters.

As already stated above, the automation of visual and subjective observations has to be reconsidered within the light that automated systems perform differently from human observers (i.e. it has to be based on a more objective and well defined basis). If this can be done, widely homogeneous observations can be achieved.

6-USED TECHNOLOGIES FOR THE AUTOMATION OF METEOROLOGICAL OBSERVATIONS

According to the common understanding of all of us, visual or subjective observations were more urgently needed in the past than nowadays (or even in future) due to the previously insufficient or generally missing measurements of various variables in the atmosphere.

That is to say, the subjective observations were in several cases used as indirect means for characterizing the status of the atmosphere, especially for forecasting purposes (such as the type, coverage, and height of clouds).

In addition, quantitative measurements were not sufficiently available or generally not yet possible at this earlier stage so that qualitative information had to be provided instead.

These mainly subjective observations were, especially if they were not well defined, very unreliable and subjective (such as the characterization of precipitation as "drizzle", "slight", "moderate", and "heavy").

7-Sensors and algorithms

It is understood that improvements of presently available automatic observing systems are ongoing and there are some individual sensors, multi-sensor systems, and sophisticated algorithms already available, in testing, or in development which may widely meet future needs. However, before further efforts will be undertaken in this regard, the future requirements have to be defined clearly.

8-Use of the composite observing systems

We have all noticed the progress made in recent times on measuring and observing meteorological variables by the application of direct and remote surface and space based techniques. It further noticed that the various types of instruments and equipment applied for these observations are already operated in automatic networks either on national or regional levels.

We have all recognized the significant work on examining approaches and benefits of composite observing methodologies which is being carried out in NAOS (North American Observing System) and within EUMETNET (Europe).

This approach enables the possibility that data obtained from different sources can be combined with the objective of achieving more complete and objective information on the status of the atmosphere.

9-APPLICATION OF WMO CODES FOR TRANSMISSION OF "PRESENT WEATHER" DATA

With reference to the assessment on the possible application of the presently available WMO codes for transmission of automatically generated visual and "present weather" observations, it can be reiterated that the operational use of alphanumeric codes SYNOP, METAR, SPECI, and 4680 "wawa" significantly restricts, or does not allow, the complete distribution of all available information to users.

Having in mind that a general amendment or supplement of these codes is a long-lasting process before it can be introduced world-wide and will, in any case, not be capable of meeting all users' needs, it is needed to develop and propose minor amendments for these codes in order to deal with the most immediate requirements.

It is possible to fulfill all present and yet to be determined future requirements, especially regarding the application of AWOS, through the application of BUFR and CREX, which allow, by nature of their flexibility, the ability to adapt to future needs.

The global introduction of BUFR / CREX will be a long process due to several issues in their application, namely:

- limitations in the capacity of telecommunication channels needed for data transmission,
- required software development, and
- due to the fact that most of various AWOS (which are in operation or are planned to be deployed in the next few years both within and outside NMHSs) cannot yet cope with these codes.

This calls for the development and introduction of an interim solution based on the currently available alphanumeric codes.

PIEZOELECTRIC PRECIPITATION SENSOR FROM VAISALA

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ABSTRACT

The new piezoelectric Vaisala RAINCAP® precipitation sensor and measurement method are presented. Unlike commonly used precipitation instruments the Vaisala RAINCAP® precipitation sensor is virtually maintenance free; without any moving parts or components needing emptying and cleaning.

Empirical results from Finnish Meteorological Institute test field in Finland and Vaisala test fields in Malaysia and Finland are presented and compared to the traditional tipping-bucket and weighing gauges. It is shown that the Vaisala RAINCAP® precipitation sensor performs especially well in moderate to heavy precipitation, and due to the measurement method is free from the typical sources of error in precipitation measurements.

1. INTRODUCTION

The Vaisala RAINCAP® precipitation sensor was developed in conjunction with a Vaisala weather multi-sensor, WXT510 Weather Transmitter. Requirements like robustness and negligible need for maintenance were mandatory. Therefore, the sensor described in this paper provides practically maintenance free precipitation measurement without any moving parts or components needing emptying and cleaning.

Precipitation instruments based on acoustic or electromechanical detection of individual raindrops have been developed in the past. However, most of them have been designed for measuring the drop size and drop size distribution (Mikhaylovskaya, 1964; Joss and Waldvogel, 1967; Kinnell, 1972; Nystuen et al., 1994).

Madden *et al*. (1998) have reported on a piezoelectric device for measuring the kinetic energy of raindrops. Also, a report on the piezoelectric rain gauge for application on buoys has been published lately by Förster *et al*. (2004).

The Vaisala RAINCAP® sensor, presented earlier by Salmi and Ikonen (2005), is based on acoustic detection of individual raindrop impacts. The signals resulting from the impacts are proportional to the volume of the drops and therefore, the signal of each drop can be directly converted to accumulated precipitation. The sensor is also capable of distinguishing hail stones from raindrops.

This paper presents the principle of the sensor and the measurement method. Field test results compared to the traditional precipitation gauges are reported from Finland and Malaysia.

2. PIEZOELECTRIC PRECIPITATION SENSOR

2.1 Construction

A schematic diagram of the sensor is shown in Fig. 1. The sensor cover made of stainless steel is attached to the sensor frame and a piezoelectric detector has been mounted on its underside.
The voltage pulses delivered by the piezoelectric element are filtered, amplified, digitized, and finally analyzed as to their selected parameters related to the raindrop size. Final computations are performed by the micro-processor system.

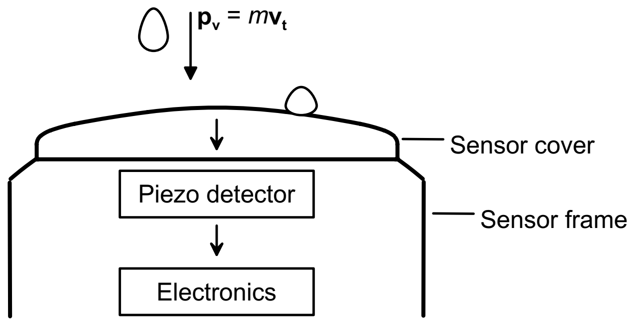

Fig. 1. A schematic drawing of the piezoelectric precipitation sensor.

The material and dimensions of the detector cover are selected such that the resonant vibration excited by the impacting raindrop is attenuated rapidly. The sensor surface area was determined by compromising between two opposite specifications:

a) The larger the sensor surface area the smaller the statistical variation in the computed value of cumulative rainfall.

b) On the other hand, the larger the sensor surface area the greater the number of simultaneous raindrop impacts, which leads to inaccuracy in the interpretation of the measured signals.

A good compromise for the diameter of the sensor surface was found to be about 90 mm.

2.2 Measurement method

A schematic diagram of the acoustic measurement method is shown in Fig. 1. The drop hitting on the sensor surface has a momentum

$$\mathbf{p} = \mathbf{p}_v + \mathbf{p}_h \ , \tag{1}$$

where $\mathbf{p}_v$ and $\mathbf{p}_h$ are vertical and horizontal momentum components. The vertical momentum can be written in the form

$$\mathbf{p}_v = m\mathbf{v}_v = m(\mathbf{v}_t + \mathbf{v}_{wv}) \ , \tag{2}$$

where m is the mass of the drop, $\mathbf{v}_t$ the terminal velocity of the drop and $\mathbf{v}_{wv}$ the vertical wind velocity. However, it has been analyzed earlier by Joss and Waldvogel (1977) that updrafts and downdrafts have negligible effect on vertical velocity and we can approximate the vertical momentum just prior to impact as

$$\mathbf{p_v} = m\mathbf{v_t} \; . \tag{3}$$

The horizontal wind velocity $\mathbf{v_{wh}}$ generates the horizontal momentum

$$\mathbf{p_h} = m\mathbf{v_{wh}} \tag{4}$$

and changes the angle of the drop impact. Due to the fact that the drop impact phenomenon is different between oblique and normal impacts, $\mathbf{v_{wh}}$ has a reducing effect on the vertical momentum component. Although this has only a small influence on the measurement, compensation has been done with the curvature of the sensor cover so that part of the horizontal momentum is also measured during oblique impacts.

The drop impact generates elastic waves to the sensor plate, which are transferred further to the piezoelectric sensor. The resulting mechanical stress in the piezoelectric material causes a voltage $U(\mathrm{t})$ to appear between the sensor electrodes and it can be written in the form

$$U(t) = c\frac{dp(t)}{dt} \; , \tag{5}$$

where *c* is a constant dependent on the properties of the piezoelectric material. Hence, the output of the sensor is a measure of the time-varying impact force $dp(t)/dt$, which is a function of the volume of the impacting drop. Since, the sensor surface area is known, the drop signals can be directly converted to accumulated precipitation.

The distinguishing of hailstones from raindrops is based on the fact that the detector signals they produce are very different from each other. The impact of a solid object, such as a hail, on the detector surface is bouncy, whereby firstly the pulse rise time is faster and, secondly, the pulse amplitude is higher than in a pulse generated by a raindrop. The third difference is found in that the hail impact also excites the resonant frequencies of the detector cover, whereupon the cover vibrates after the impact. Typical signal from a rain drop impact at sensor output is shown in Fig. 2. Typical output pulse generated by a hailstone is shown in Fig. 3.

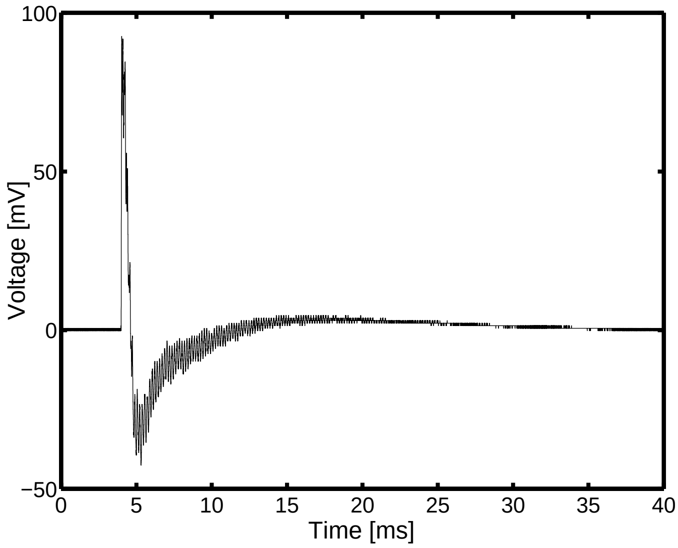

Fig. 2. Typical output signal generated by a rain drop.

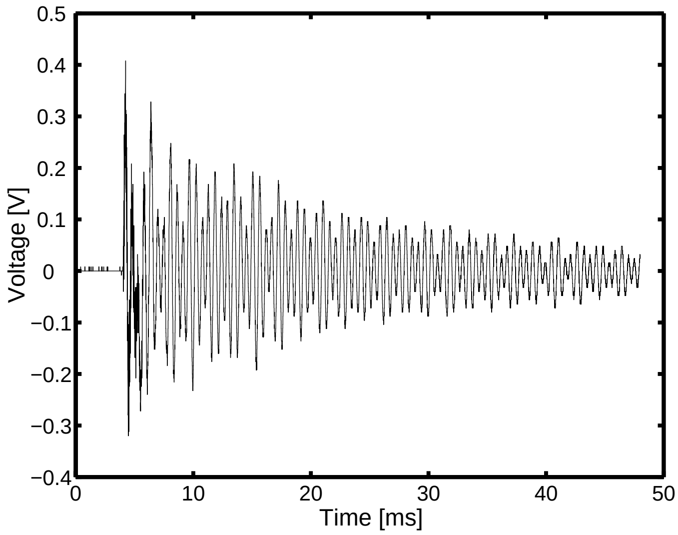

Fig. 3. Typical output signal generated by a hailstone.

2.3 Sensor calibration

The sensor calibration was done by comparing the detector voltage response with precipitation readings from accurate reference instruments under different field conditions. The data consisted large amount of measurements in light and moderate rain in Finland and moderate and heavy rain in Malaysia. The resulting calibration algorithm was verified in the laboratory by using different drop sizes and intensities. A fall distance of 14 m was achieved in the Vaisala rain laboratory. An example of such calibration data from the field is shown in Fig. 4.

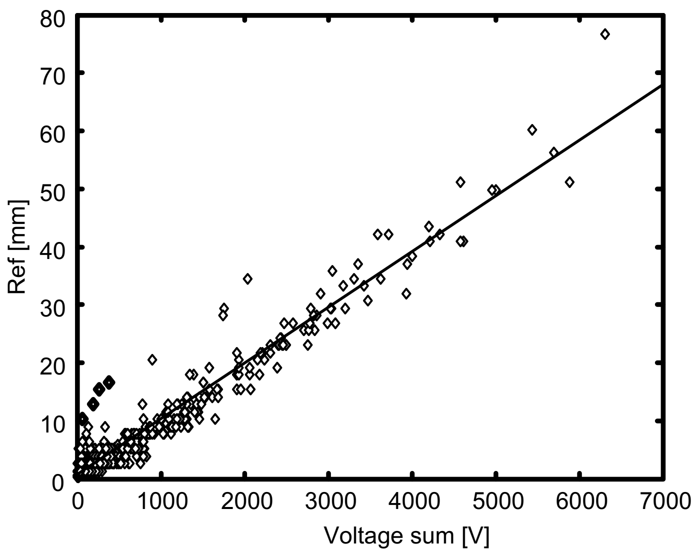

Fig. 4. An example of the field calibration data.

2.4 Errors in measurement method

Commonly used can-type raingauges are subject to significant systematic error (WMO, 1996 and 2000). The amount of liquid precipitation measured can be less than the actual amount reaching the ground by up to 30 per cent or even more. The real amount of precipitation is usually estimated by adjusting the data with a general model:

$$P_k = k(P_g + \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4) + P_r \ , \qquad (6)$$

where P_k is the adjusted amount of precipitation, P_g the recorded precipitation in the gauge, k and ΔP_1 - ΔP_4 the adjustments for different error components listed in Table 1 and P_r random observational and instrumental error.

Term	Description of error component	Magnitude
k	wind-field deformation	2 - 10 %
$\Delta P_1 + \Delta P_2$	wetting on the internal walls of the collector and the container after emptying	2 - 15 %
ΔP_3	evaporation from the container	0 - 4 %
ΔP_4	splashing of water in and out	1 - 2 %

Table 1. Error components in commonly used precipitation gauges listed in order of importance (WMO, 1996 and 2000).

Due to the measurement method, the adjustments ΔP_1 - ΔP_4 are not needed for the sensor described in this paper. Errors related to piezoelectric sensor are more stochastic than systematic. Since the measurement of rain amount is based on momentum of individual drops, variation in the shape and velocity of raindrops caused by air movements is the most important error factor. Sensitivity variations over the sensor area, due to surface wetness and construction of the sensor itself, produce stochastic error seen particularly in short exposure time. The supplementary data needed for factor k in Eq. (6) is easily achieved as the Vaisala Weather Transmitter measures the wind velocity just above the precipitation sensor.

3. FIELD TESTS

The field tests reported in this paper were performed at the Finnish Meteorological Institute observatory at Jokioinen; the Vaisala test site at Vantaa, Finland and at the test site at Kuala Lumpur, Malaysia. The data collected consists of light and moderate precipitation typical for Finland and moderate or heavy precipitation collected in Malaysia.

Also, other weather parameters from different sensors were available for data validation at all test sites.

In the following chapters, reference gauges are compared to the Vaisala Weather Transmitters. The precipitation measurement of Vaisala Weather Transmitter is based on the Vaisala RAINCAP® precipitation sensor.

3.1 Vaisala test site at Vantaa, Finland

A weighing-recording gauge (WGA) and tipping bucket gauges (TBA and TBB) from two different manufacturers were used as comparison instruments for this test. The tip size was 0.2 mm in both tipping buckets. The weighing gauge was installed with the Tretyakov wind shield, the orifice height being 1.5 meters. The both tipping buckets were at ground level and the Vaisala Weather Transmitters (WX1 and WX2) were installed at height of two meters.

3.2 Finnish Meteorological Institute observatory at Jokioinen, Finland

Three different weighing-recording gauges (WG1, WG2 and WG3) from two manufacturers were used for reference measurements at Jokioinen. The WG1 and WG2 weighing type gauges were equipped with the Tretyakov wind shield. The WG3 was surrounded by a standard double fence, consisting of two lath fences of 4 and 12 m diameter. Two Vaisala Weather Transmitters were installed at height of two meters, about 50 meters apart from the WG3. The WG1 and WG2 were mounted to the middle between the WG3 and Weather Transmitters.

3.3 Vaisala test site at Kuala Lumpur, Malaysia

Test site at Kuala Lumpur consisted of two Vaisala Weather Transmitters and two identical tipping buckets with 0.2 mm tip size as comparison instruments. The Vaisala Weather Transmitters and one of the tipping buckets (TB2) were elevated to 1.5 meters above ground. The other tipping bucket (TB1) was at ground level.

4. RESULTS AND DISCUSSION

As an example of heavy rain events, a ten-day measurement period from Malaysia is shown in Fig. 5. The average wind speed during the period was below 2 m/s and therefore has no remarkable effect on measurement, although wind shields were not used at this site.

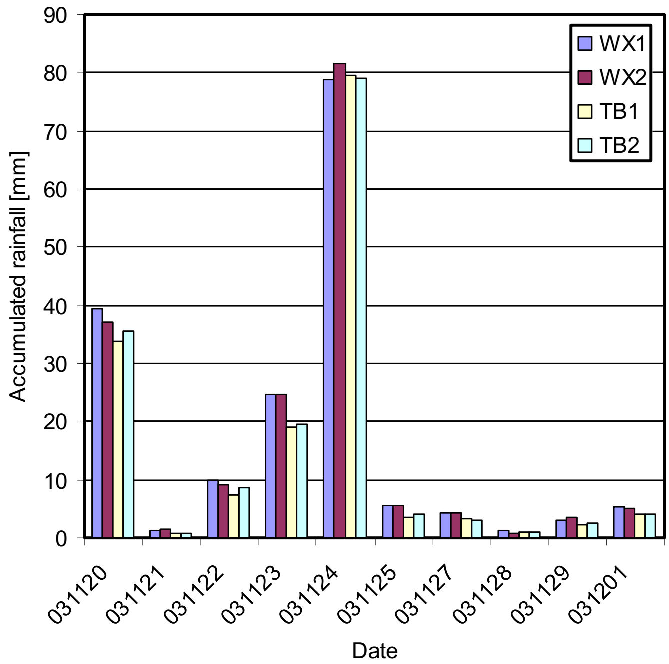

Fig. 5. Moderate and heavy rain events in Malaysia.

The tipping buckets indicated less precipitation than the Vaisala Weather Transmitters. The measurement differences between the tipping buckets and the Vaisala Weather Transmitters were 5 to 10 percent in the long term, the daily differences were occasionally somewhat higher. The readings from the two Weather Transmitters were consistent during the whole test period.

Gauge	WX1	WX2	WG1	WG2	WG3
[mm]	222.7	227.5	205.4	203.9	189.6

Table 2. Total accumulations during a three months test period at Jokioinen observatory.

The results from a three month test period at Jokioinen are shown in Fig. 6 and Table 2. The period included 42 rainy days, mainly with light rain. The collected data demonstrate comparability of the weighing-recording gauges to the Weather Transmitter.

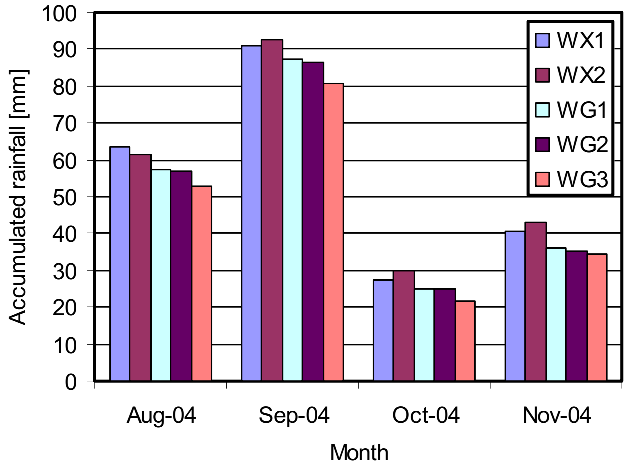

Fig. 6. Monthly accumulations at Jokioinen observatory

The Table 2 shows that there is only a slight difference between the two Weather Transmitters, (4.8 mm) as well as between the WG1 and WG2, (1.6 mm). The difference between the WG1 and WG3 is 15.8 mm and between the WG1 and Weather Transmitters 17.2 and 22.0.

Table 3 shows total accumulations of light and moderate rain measured at Vaisala test site in July-August 2004. The differences are calculated against the weighing-recording gauge (WGA). The difference between the two Weather Transmitters is negligible, but between the two tipping buckets (TBA, TBB) as large as 8.8 mm. The Weather Transmitters have reported slightly lower accumulation than the WGA.

Gauge	WX1	WX2	TBA	TBB	WGA
Total [mm]	102.2	101.2	104.4	113.2	108.0
Diff [mm]	5.74	6.74	3.57	- 5.23	-

Table 3. Total accumulations at Vaisala in July-Aug 2004.

Fig. 7 illustrates a characteristic short-interval data from three types of precipitation recorders at the Vaisala test site. It can be seen from the data that due to the measurement method, the Weather Transmitters do not suffer from evaporation error and their response time is short compared to the tipping bucket type gauges.

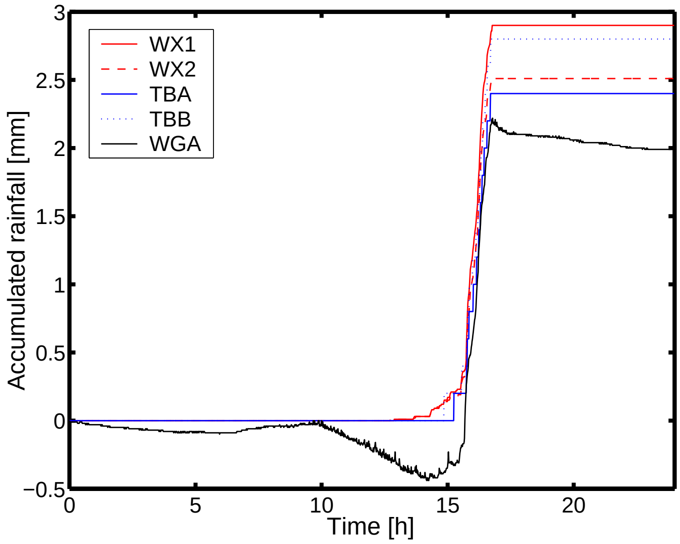

Fig. 7. Hourly data from different types of precipitation recorders.

5. CONCLUSIONS

We have demonstrated a novel piezoelectric precipitation sensor that can be used to measure liquid precipitation and characterize whether the precipitation is rain or hail. The field results show good comparability of the sensor to traditional tipping buckets and weighing-recording gauges.

Due to the measurement method and construction of the sensor, the Vaisala RAINCAP® is virtually maintenance free. The sensor does not suffer from systematic errors due to wetting, evaporation or splashing of raindrops.

When the distance between the precipitation gauges increases, deviations caused by spatial variability of precipitation have more significant effect on instrument readings than the sensor performance. That was seen at Jokioinen where the distance between the gauges were dozens of meters. Because of its robust design with no moving parts the precipitation sensor described in this paper is suitable for dense measurement networks. A network of several gauges would give better estimate of overall precipitation than a single a point measurement with a high-end instrument.

6. ACKNOWLEDGMENT

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Presentation and evolution of the Shipboard automatic weather station BATOS

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ABSTRACT

This presentation consists of a general and technical description of the weather station BATOS. The latest evolution with improved functionalities and easier set up onboard Voluntary Observing Ships (VOS) is described.

BATOS is a shipboard automatic weather station which allows for the acquisition of basic weather surface parameters (measured by sensors), manual observations, data quality control, data processing and storage, the generation and transmission of encoded messages (via satellite) and the display of parameters in real time.

The automatic station consists of the following components : weather sensors (pressure, temperature, relative humidity, wind speed and direction, water temperature), compact protective housing for sensors, satellite communication components and a central computer.

In the first version of BATOS, analog sensors are used so that it's necessary to put an interface (a sensor collector) between sensors and the data collecting computer.

The system has been improved in the second version so that the station has become more compact, easier to be set up and wired on a ship. In addition, the added flexibility of the system configuration enables the use of digital sensors.

The initial system is at present set up on 30 French VOS. As of this year, installations of the second version has been completed.

Future works will be done to start a connection with oceanographic measurements (thermosalinometer) and to reduce the transmission costs.

INTRODUCTION

The automatic weather station BATOS is intended to be set up on VOS (Volontary Observing Ships) and allows measurement of all the basic meteorological surface parameters. Manual observations may also be input, so that the station can send a complete SYNOP SHIP message.
The first version of the BATOS system, set up on VOS for several years now, proved its robustness in a marine environment.
A second version with the same functionalities has been improved : size has been reduced, the wiring is easier, new generation of digital sensors can be connected.
The next parts of this article deal with a description of the two systems and of the present network of Meteo France.

GENERAL DESCRIPTION OF THE SYSTEMS

The first version of the automatic station BATOS allows:
- acquisition of the basic weather parameters measured by analog sensors: wind speed and direction, temperature, relative humidity and sea surface temperature
- input of human observation (present weather, visibility, clouds, state of the sea, ...) with a full on-line help
- data check, proccessing and storage
- generation and transmission of normalized encoding messages by satellite
- data display on dedicated screen
- normalized data transfer (NMEA standard).

This station consists of:
- analog weather sensors
- sensor collector which collects data and converts to digital

- transmission system
- computer processing unit

(see fig. 1).

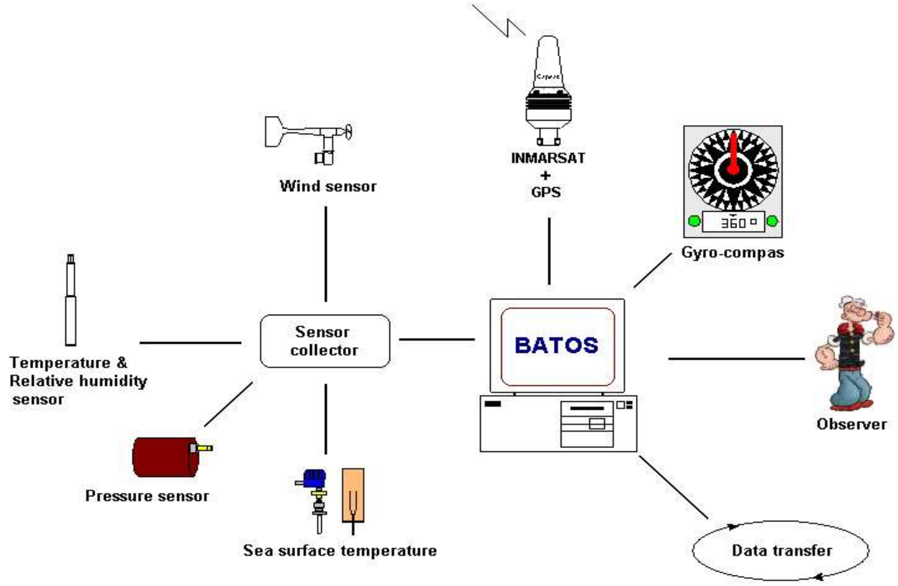

Fig. 1: BATOS first version.

In the second version of BATOS, the system allows direct acquisition of digital sensors so that the sensor collector can be removed. Wiring and installation of the station are simplified.

New sensors are used: the wind sensor, which is a new generation of ultrasonic and digital sensors, and the combined pressure, temperature and humidity digital sensor, which replaces analog ones (see next figs. 2 and 3).

Fig. 2: Components of the BATOS II system.

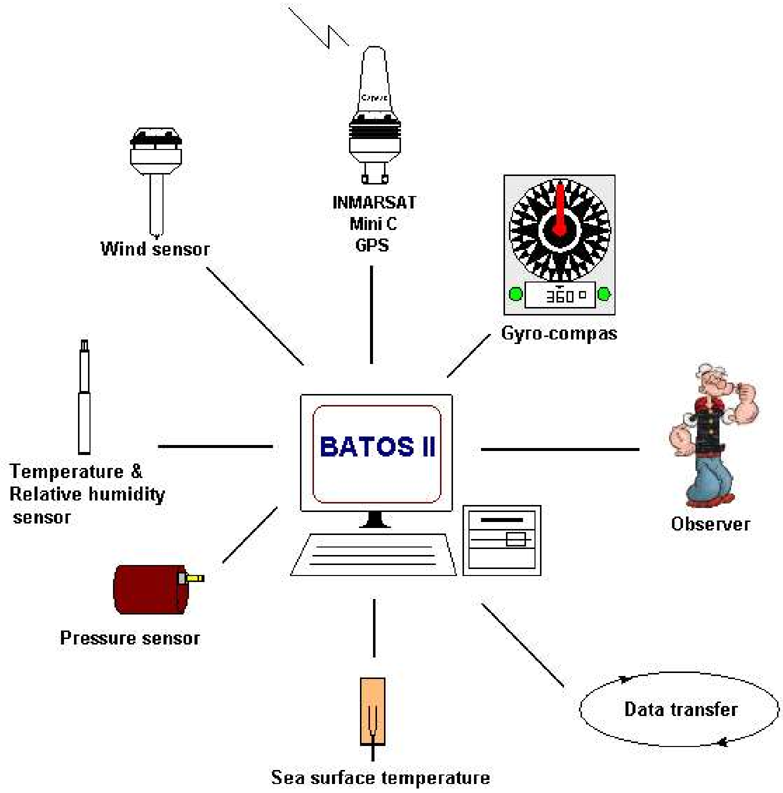

Fig. 3: BATOS Second version.

DESCRIPTION OF THE COMPONENTS

Pressure, Temperature and relative humidity

- ***BATOS:*** *PTB220* barometer (Vaisala) is used for pressure measurement, *PT100* platinium thermometer (Heraeus Sensor) for temperature, and *HMP35 DE* hygrometer (Vaisala) for relative humidity.
- ***BATOS II:*** *PTU 200* (Vaisala) is a combined sensor which consists of a pressure unit (*PTB220* equivalent) and the *HMP 45 D* sensor for temperature and relative humidity measurement.

Ranges:

- pressure: 800 hPa to 1100 hPa
- temperature: -30 to 50 °C
- humidity: 0,8 to 100 %

Wind sensor

- ***BATOS:*** *05106* (YOUNG)
  - Speed range : 0 to 60 $m.s^{-1}$
- ***BATOS II:*** *CV3F* (LCJCAPTEURS)
  - Speed range: 0 to 50 $m.s^{-1}$
  - Temperature range: 0 to 40 °C

Another ultrasonic wind sensor from GILL, suited for a larger temperature range, is currently under test and can be connected to the system.

Sea Surface Temperature

BATOS & BATOS II: a hull contact sensor PT100 (SPCK PROSENSOR) is affixed on the hull of the ship and under the waterline.

- Range: -80 to 160 °C

Screen
BATOS & BATOS II: the naturally ventilated multiplate screen *Miniature Marine* (SOCRIMA) is used to protect the *HMP 45 D* sensor.

- Enclosure: (Ø x H) 20 cm x 50 cm.

Transmission System
BATOS: Inmarsat standard C, antenna and GPS receiver, separated transceiver
BATOS II: Inmarsat standard Mini C, transceiver, omni-directional antenna and GPS receiver in one single unit.

Sensor collector
BATOS: *QLI50* sensor collector(Vaisala) acts as the interface between analog sensors and data collecting computer.

Software BATOS
BATOS: version 1, linked to the sensor collector for data acquisition, calculates the true wind (from the apparent wind and the speed and heading of the ship), allows the input of human observations, checks quality and coherence of the data, creates and sends messages every one, three or six hours (using code 41).
BATOS II: version 2, performs all functions described above by communicating directly with sensors.

CURRENT NETWORK

The first version of BATOS has been set up on thirty VOS in 2004.
The robustness of the BATOS station had been proved and the number of marine observations had been significantly increased since the beginning of the BATOS deployment. The histogram on fig. 4 shows the total number of annual French VOS observations compared to the observations done by BATOS only. According to fig. 5, the number of French VOS from 2000 to 2004 decreased, because of the progressive elimination of ineffective ships using manual sensors. In spite of this, observations have still continue to increase, due to the BATOS network expand during this 4 years (fig. 5). The quality and the punctuality of the messages had also been improved.

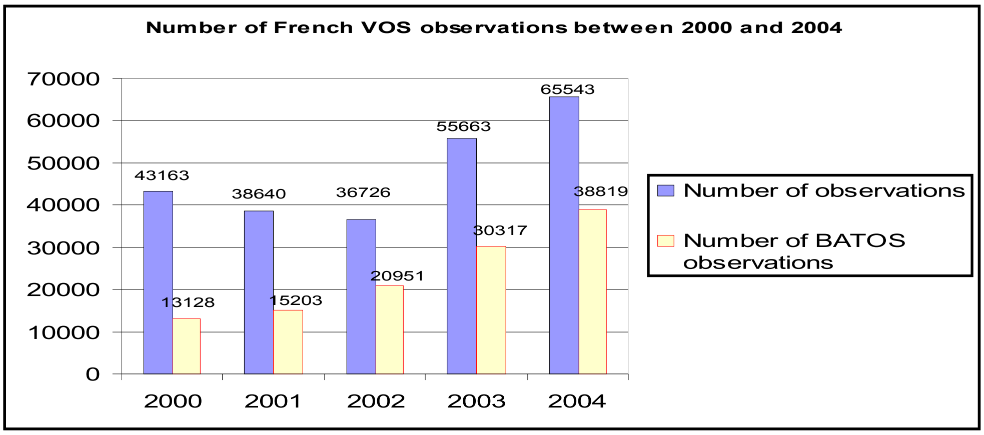

fig. 4: Number of annual French VOS observations between 2000 and 2004.

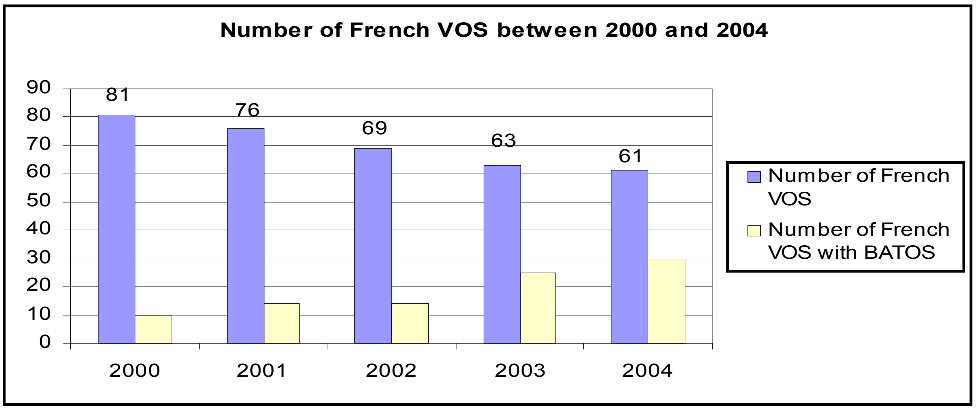

fig 5: Number of annual French VOS between 2000 and 2004.

Six of the thirty ships equipped with BATOS have been selected since two years for the VOSClim project (the ongoing project within JCOMM's Voluntary Observing Ships' Scheme which aims to provide a high-quality subset of marine meteorological data, to be available in both real-time and delayed mode to support global climate studies).

FUTURE WORK

The next generation of BATOS will include a thermosalinometer acquisition system which will send TRACKOB messages every one, three or six hours. This evolution corresponds to the intention of making a connection between oceanographic and meteorological measurements.

The station will be made available for EUMETNET members, within the context of the E-SURFMAR program.
At present, the transmission costs are not optimized. With Inmarsat C, one message costs about 0,70 euros. In the E-SURFMAR context, a study to reduce this costs will be started during this year. By using data compression and a different Inmarsat protocole, it will be possible to cut them by about a third.

A COMPARISON OF SCAPP RADIATION DATA WITH GLOBAL, DIFFUSE AND DIRECT SOLAR RADIATION

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Abstract

SCAPP is the abbreviation for SCAnning Pyrheliometer/Pyranometer. This instrument measures diffuse and direct short-wave radiation by a silicon receiver. Global radiation as well as sunshine duration are calculated within the instrument. That means one instrument is measuring all the downwelling short-wave quantities and sunshine duration. A short description of the SCAPP is given.For more than one year the measurements of the SCAPP have been measured nearby the pyranometers and pyrheliometers of the BSRN station at the Meteorological Observatory Lindenberg, Germany. The SCAPP results (time resolution is 1 minute means) were compared with the corresponding quantities of the BSRN station. Furthermore, hourly and daily totals are considered at different atmospheric conditions.

The results of these comparisons will be discussed. The daily totals of the quantities determined by the SCAPP deviate less than 10% from the direct by pyranometer and pyrheliometer measured totals.

1. Introduction

The radiation network of the German Weather Service consists of about 30 manned stations everyone of these is equipped with two ventilated and heated pyranometers CM11. One pyranometer is shaded by a shadow band measuring diffuse solar radiation while the other one is registering global radiation. Furthermore, at every station we have an electronic sunshine recorder from type SONIe.

Because of rising requests from several users for a higher spatial resolution of radiation data it was decided to increase the number of radiation stations.

The measurement of the diffuse solar radiation is only possible at a manned station because a daily check of the shadow band is demanded for high quality data. So, the realization of an extending radiation network at a stable number of manned stations is first of all an economic problem which calls for an instrument allowing the use at an automatic (unmanned) station.

In a study Bergholter and Dehne (1992) showed that it is possible to measure global, diffuse and direct solar radiation with one instrument, the **SCA**nning **P**yrheliometer/**P**yranometer (SCAPP). It fulfils the characteristics of operational pyranometers of “Moderate quality” (WMO, 1996).

In the German Weather Service the solution was found in having a basic radiation network as mentioned above consisting of about 30 manned pyranometer stations and an extending one consisting of about 130 automatic unmanned station applying the SCAPP as device measuring global, diffuse and direct solar radiation as well as sunshine duration.

In this paper the measurements of the SCAPP are compared with measurements made with pyrheliometer and pyranometer as reference instruments at the Meteorological Observatory Lindenberg (Germany) in 2004.

2. The Scanning Pyrheliometer/Pyranometer (SCAPP)

2.1. Technical description

The SCAPP was developed on the base of the SONIe sunshine recorder (Lindner, 1984). The prototype of the SCAPP was already presented at TECO-94 by Bergholter and Dehne (1994) but it was necessary to go further steps to get a stable working device.

Figure 1a shows the SCAPP as it is used for the measurements. The SCAPP consists of a head, a sensor module and an electronic board with power supply. An aluminium cylinder contains these parts.

The head with the entrance optics is protected by a glass dome against "the weather". Figure 1b depicts a schematic drawing of head and sensor module.

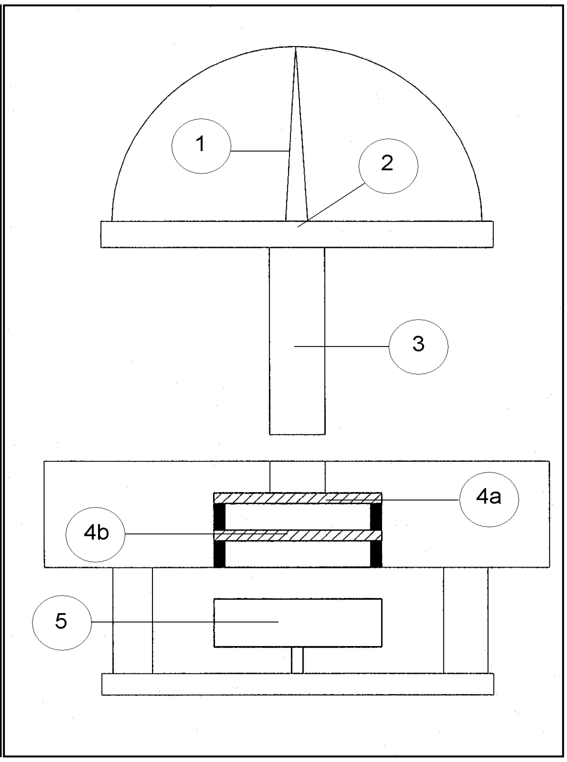


Fig. 1a: The **Sca**nning **P**yrheliometer/**P**yranometer (SCAPP) as it is used for measuring direct, diffuse and global solar radiation as well as sunshine duration.
Fig. 1b: Head and sensor module of the SCAPP consist of a spherical sector diaphragm (1), a diffuser (2), a beam-guide (3), two filter slides KG4 (4a), BG34 (4b) glass and a photodetector (5).

The head, consisting of a spherical sector diaphragm (1), a diffuser (2) and a beam-guide (3), is rotating and scans the whole sky 30 times per minute. The radiation from sky and Sun falls through the spherical diaphragm (1) and the diffuser (2) into the beam guide (3). Then the light goes via two filters slides, a white KG4 glass (4a) and a blue BG34 glass (4b), direct onto a photodetector (5). Because of the use of a photodetector as receiver only the spectral region between 0.3 to 1.1 µm is measured, which is typically for photodetectors, while shortwave radiation reaching the ground covers the region between 0.3 to 3.0 µm.

A pyranometer which is using a thermopile as detector converts, because of its spectral sensitivity, all the energy in this entire region. So, a photodetector and a thermopile never deliver the same results.

The weight of the SCAPP is about 5 kg. The height is about 260 mm and the diameter of the case is 185 mm. This device needs an electrical power of maximal 30 W.

The data transmission between SCAPP and computer happens via RS232 or RS422/485 interfaces.

2.2. The calibration of the SCAPP

The calibration of the SCAPP was made outside with the Sun as source of radiation. Measurements of direct and diffuse solar radiation by a pyrheliometer and a shaded pyranometer have to be made in parallel with the registration of the voltage of the SCAPP.
In Figure 2 schematic courses of the SCAPP signal during one rotation are shown in the case of different altitudes of the Sun, atmospheric conditions and other influences. It is visible, that the signal of the direct beam has, depending on the different factors, a more or less width. The different conditions here are generalized as signal (a) and (b). This width has to be fixed in the microprocessor and is strictly examined only valid for a special case.

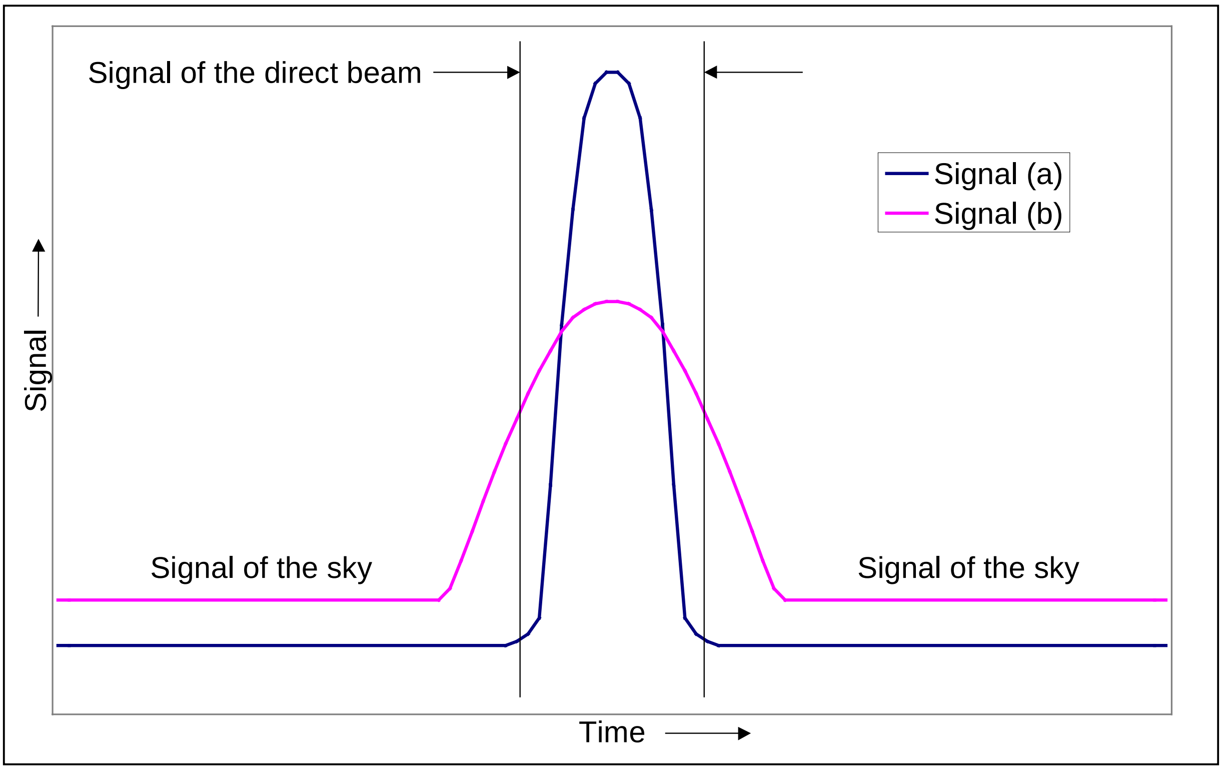


Fig. 2: Schematic courses of the SCAPP signal during one rotation of the head describing different conditions (a) and (b).

The result is, that the SCAPP needs because of the above described set up and the different pattern of the solar radiation more than one factor for the calculation of the correct radiation quantities. Therefore, at first a basic sensitivity of the diffuse solar radiation has to be determined. This is made for irradiances of the direct radiation < 2 W/m² and if the elevation of the Sun is >10°.
Because the diffuse solar radiation received within the SCAPP depends on direct radiation it is necessary to determine correction factors for the diffuse radiation. These correction factors are calculated in steps of 20 W/m² of the direct radiation. Furthermore, the sensitivity of the direct solar radiation has to be calculated depending on the solar zenith angle for every two degrees. Those factors are only calculated if the irradiance of the direct radiation is > 50 W/m² to get stable results.
This set of factors is given into the microprocessor of the SCAPP to calculate the direct and diffuse solar radiation and as sum of these the global radiation.

3. Comparisons of SCAPP, pyrheliometer and pyranometer measurements

3.1. Instruments and data

The comparisons between the SCAPP and the reference instruments were made in 2004. The data of totally 316 days were compared. In five months the data of all days were available but in May for instance only about 50% of the days could be used because of different reasons. The comparison was made at the radiation platform of Meteorological Observatory Lindenberg

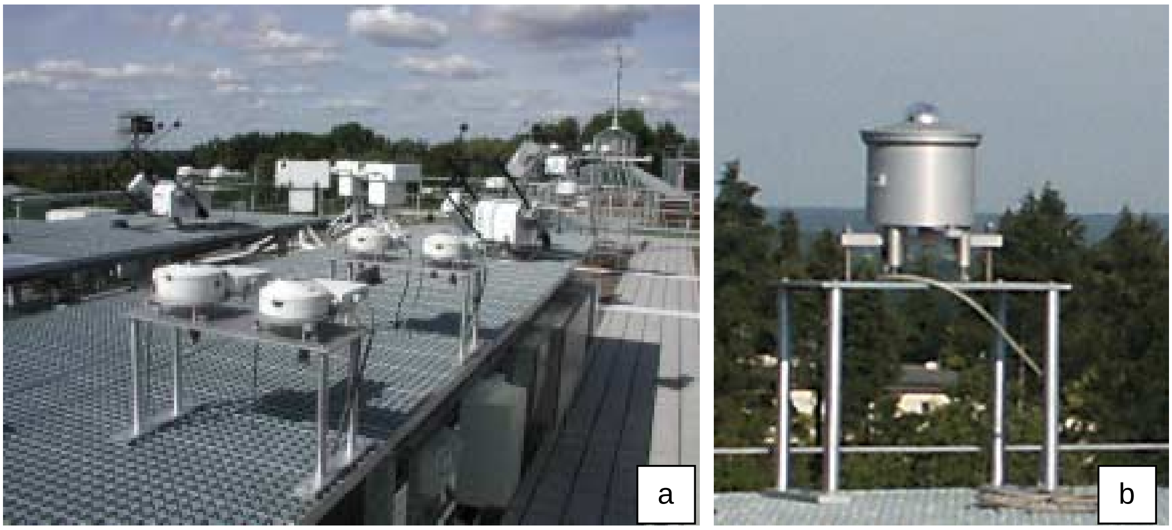
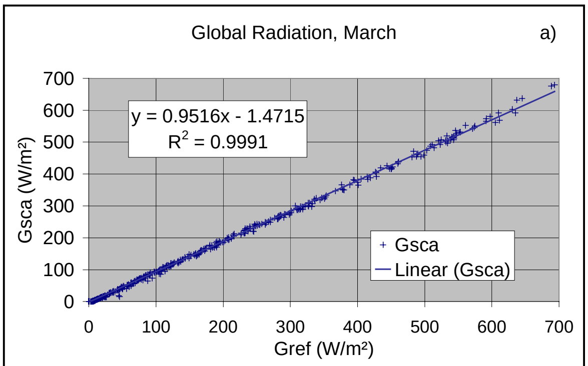


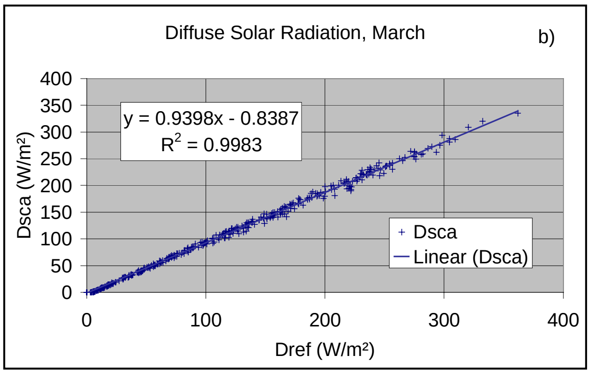
Fig. 3a: Radiation platform at the Meteorological Observatory Lindenberg with the reference instruments from the BSRN station for the comparison with the SCAPP.
Fig. 3b: The SCAPP at the radiation platform during the comparison.

(Fig. 3a and b). The instruments of the BSRN station Lindenberg were used as a reference. The pyrheliometer CH1 960129 measuring the normal direct solar radiation and the CM22 020073 for obtaining the diffuse solar radiation are mounted on a 2AP solar tracker. Global radiation was measured by the CM22 020074. All these instruments are produced by Kipp & Zonen, the Netherlands. The voltages of the pyrheliometer and pyranometers were recorded by the COMBILOG data logger (manufacturer Fa. Th. Friedrichs, Germany) and then converted into irradiances while the data of the SCAPP were already converted by its own microprocessor. All data are stored as 1 minute means. Hourly means and daily totals were calculated on this basis.

3.2. Hourly means

Mainly, user apply hourly totals. Therefore, these values of the SCAPP and the reference instruments will be compared in the following. Scatter diagrams with the hourly means from March, July and December are shown as examples for typical months at the equinox, as well as highest and lowest sun altitude.





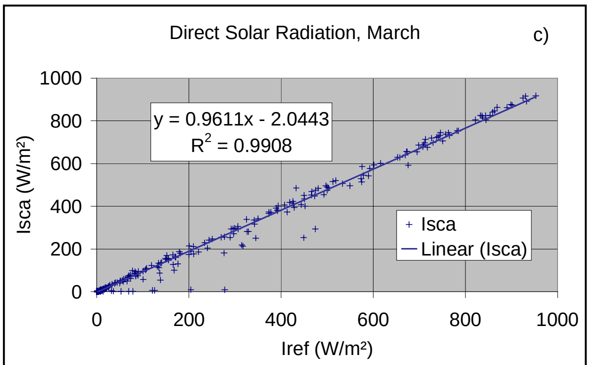
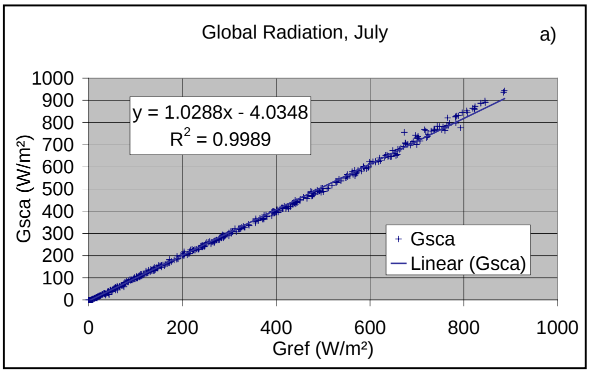
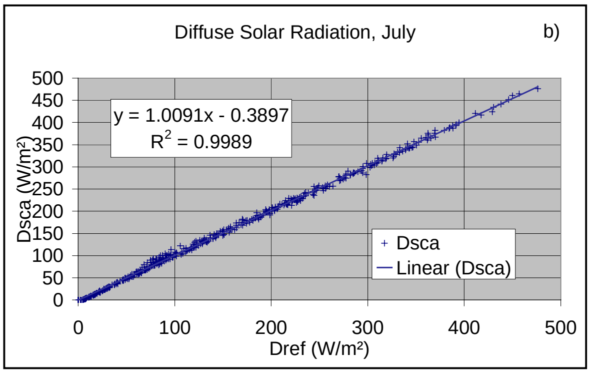


Fig. 4a-c: Scatter diagrams of hourly means of global (G), diffuse (D) and direct solar radiation (I) measured by the SCAPP (sca) and pyranometers as well as a pyrheliometer as reference instruments (ref) and the corresponding regression lines in March, respectively. Furthermore, in the text boxes the regression coefficients and the coefficient of determination (R^2) are given.

The Figures 4a-c show that there is a good correlation (R^2>0.99) between the SCAPP data and the values from the reference instruments in March. The slope of the regression line is between 0.94 (Fig. 4b) in the case of the diffuse solar radiation and 0.96 (Fig. 4c) at the direct solar radiation. This means that the SCAPP values are to low in the average.





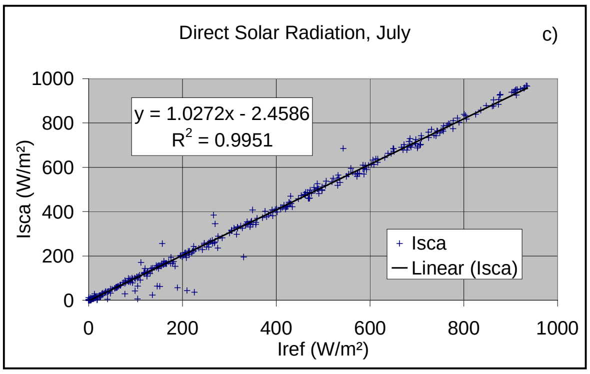
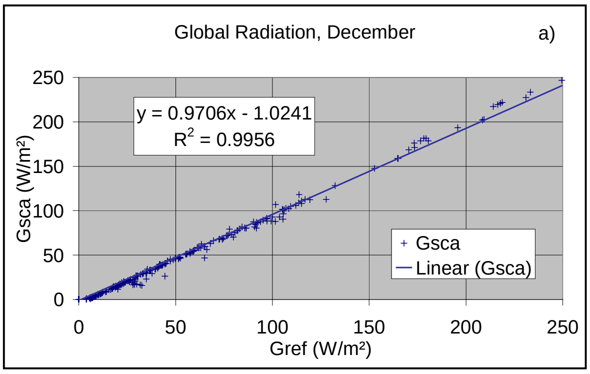
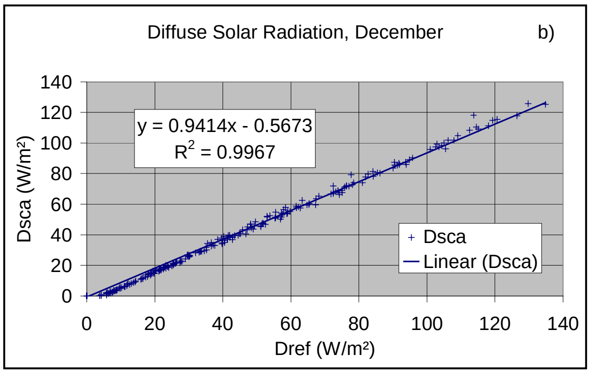


Fig. 5a-c: Scatter diagrams of hourly means of global (G), diffuse (D) and direct solar radiation (I) measured by the SCAPP (sca) and pyranometers as well as a pyrheliometer as reference instruments (ref) and the corresponding regression lines in July, respectively. Furthermore, in the text boxes the regression coefficients and the coefficient of determination (R^2) are given.

If we look at Figures 5a-c depicting the corresponding scatter diagrams for July we find only a small distinction in comparison to March. We detect the main difference in the slope of the regression lines. All three values are >1. Mainly, this is the result of a calibration which was done in June.

The Figures 6a-c show a similar picture like in the other above presented months. But especially in the Figures 6a and b it sticks out, that at a low irradiance the points are below the regression line while at the upper end the measured values above the line. This is typical for





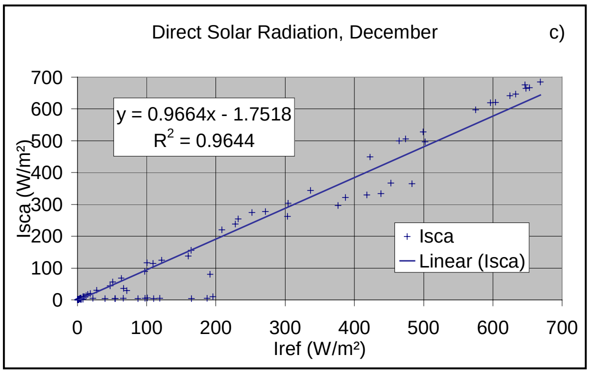


Fig. 6a-c: Scatter diagrams of hourly means of global (G), diffuse (D) and direct solar radiation (I) measured by the SCAPP (sca) and pyranometers as well as a pyrheliometer as reference instruments (ref) and the corresponding regression lines in December, respectively. Furthermore, in the text boxes the regression coefficients and the coefficient of determination (R^2) are given.

the Winter with low irradiances, while in the other seasons the points are equally distributed around the corresponding regression line.

Table 1
Regression constants (m: slope coefficient; c: point of intersection with the y-axis) and the coefficients of determination (R^2) of the hourly means of the SCAPP and the corresponding reference instruments for global, diffuse and direct solar radiation

Month	global			diffus			direct		
	m	c	R²	m	c	R²	m	c	R²
Jan	0.931	-0.812	0.997	0.920	-0.584	0.998	0.932	-2.189	0.960
Feb	0.945	-1.043	0.999	0.933	-0.679	0.999	0.956	-1.629	0.983
Mar	0.952	-1.472	0.999	0.940	-0.839	0.998	0.961	-2.044	0.991
Apr	0.974	-2.658	0.998	0.951	-0.700	0.998	0.989	-4.542	0.992
May	0.995	-2.388	0.998	0.984	-1.347	0.999	1.028	-0.382	0.977
Jun	1.011	-2.364	0.999	1.012	-1.807	0.999	1.032	-2.108	0.994
Jul	1.029	-4.035	0.999	1.009	-0.390	0.999	1.027	-2.459	0.995
Aug	1.021	-3.344	0.999	1.002	-0.548	0.999	1.026	-3.923	0.996
Sep	1.013	-2.450	0.999	0.995	-0.331	0.998	1.006	-5.241	0.992
Oct	0.989	-1.355	0.999	0.979	-0.615	0.999	0.986	-2.929	0.982
Nov	0.976	-1.002	0.998	0.979	-0.735	0.998	0.985	-1.051	0.970
Dec	0.971	-1.024	0.996	0.941	-0.567	0.997	0.966	-1.752	0.964

Table 1 gives an overview about the regression constants and the coefficient of determination. In the case of the global and diffuse solar radiation the correlation between the SCAPP and the reference values is very strong in all months as visible in the corresponding R^2 column, while at the direct radiation the R^2 especially in Winter has lower values.

The slope coefficients m show at all radiation quantities a clear annual course with low values in Winter and high in Summer time.
As above mentioned in June a calibration of the SCAPP was made and the new coefficients were used from the beginning of June. The new and improved calibration constants led to a higher level of the slope coefficients at all radiation quantities showing a better agreement between the SCAPP and the reference values of the pyrheliometer and the pyranometers.

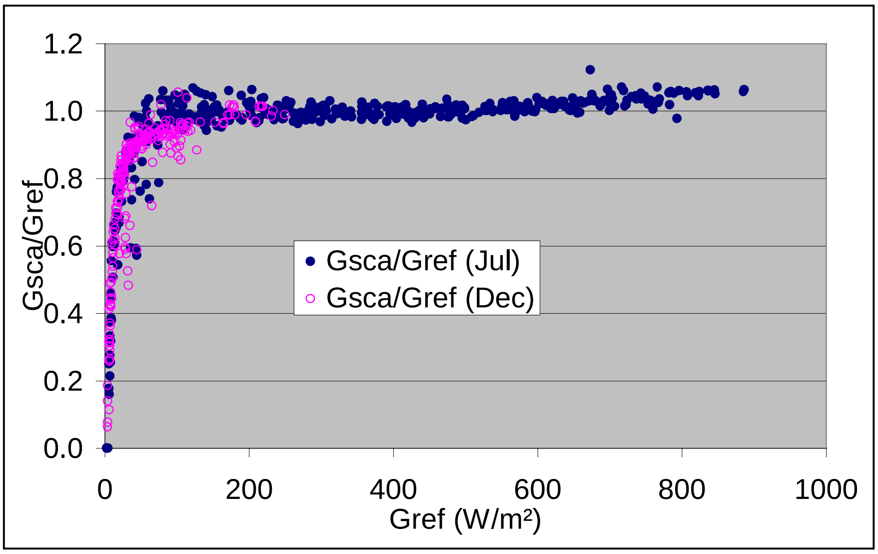


Fig. 7: Hourly ratios Gsca/Gref in dependence on Gref for July and December.

Figure 7 shows the hourly ratios Gsca/Gref in dependence on the corresponding global radiation Gref. The ratio Gsca/Gref is about 1.0 at values Gref > 75 W/m². In July these cases occur in about 78 % of the hours, while in December only 29 % exceed this bound. Therefore, the mean ratio Gsca/Gref in December is less then in July. This means that at a lower global radiation, this bound is about 75 W/m², the SCAPP values systematically to low. This is also the reason for the annual course of the slope coefficients of all quantities given in Table 1.

3.3. Daily totals

In Figure 8 the annual courses for the daily ratios of Gsca/Gref and Dsca/Dref are shown.

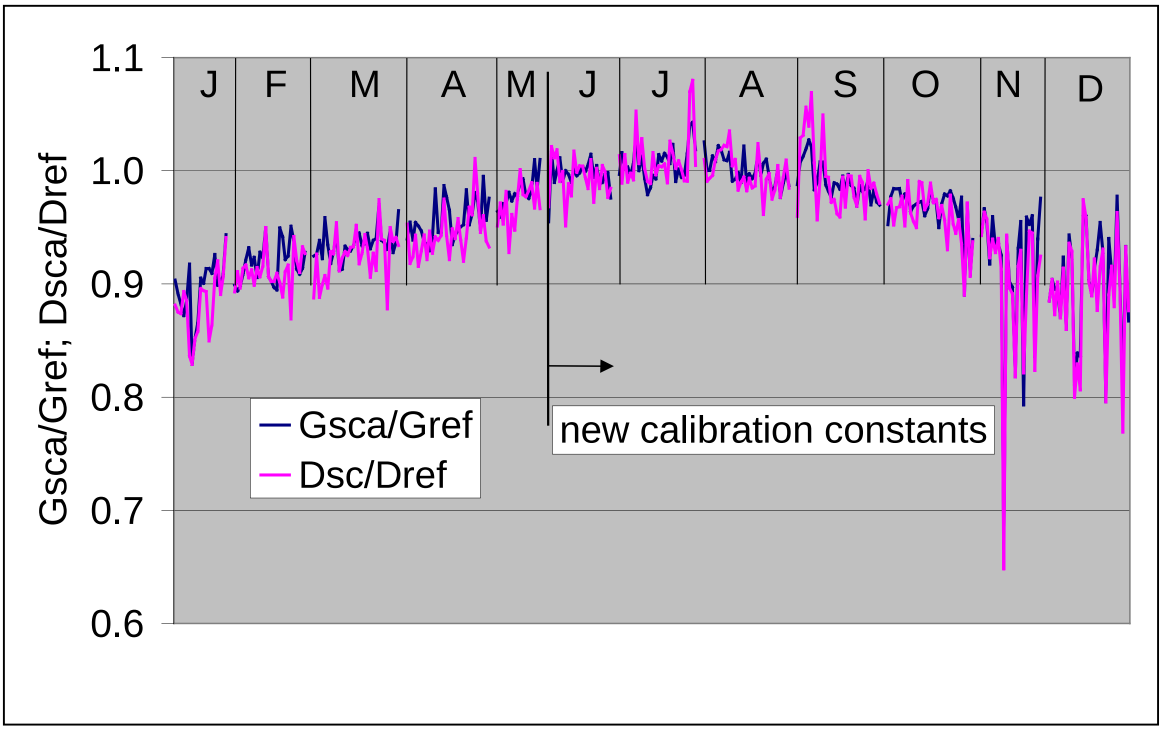


Fig. 8: Annual courses for the daily ratios Gsca/Gref and Dsca/Dref.

A look at Figure 8 shows a clear annual course of the investigated ratios with a very good agreement of the SCAPP and the reference values in Summer time, where the ratios of the daily totals within ± 5 %. Outside this time most of the values >0.9. Very small daily totals in November and December are the reason for the ratios <0.9. Especially, the daily total of only 36 J/cm² at the 9th of November led to the remarkable outlier.
The new calibration constants used with begin of June improved the results. This is visible, if we compare the level of the blue and pink line in months the a comparable altitude of the Sun, e.g. March and October or April and September, for instance. The ratios are closer to 1 in autumn then in the corresponding months in spring.

4. Conclusions

- The comparison showed that the measurements of the SCAPP in most cases are in good agreement with the results of the reference instruments.
- At lower global radiation (about <75 W/m²) the SCAPP results are frequently to low in comparison with the reference. In future this should be improved.
- The SCAPP is a multisensor of "Moderate quality", which is suitable for radiation measurement where highest quality is not demanded.

5. Literature

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DIGITAL VIDEO TECHNIQUE AS A NEW PART OF THE DWD OBSERVING NETWORK

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Abstract

The project "Messnetz 2000" for the renewal of the systems in the observing network of the German Meteorological Service (DWD) includes techniques for the automation of visual observations. One part of this attempt are digital pictures and movies from video cameras for the remote determination of clouds, visibility etc.

The DWD today operates a network of 10 camera systems, mainly for evaluation purposes. Each system consists of one camera in a fixed housing and another camera on a Pan-Tilt (PT) device. The fixed camera is oriented westward and takes one picture every 15 seconds. Pictures from one hour are merged to movies in mpeg-code. For every PT-camera there is a site-dependent schedule for taking pictures of the upper half sphere and of some targets at different distances. The systems are Linux based, run fully automatic and all products are accessible via browser.

Some of the systems are situated at manned stations. For a one year period observers from a neighboring station coded clouds, visibility etc. based on pictures and movies. The results of local and remote coding were compared. Forecasters reported usefulness especially for aviation and made suggestions for improved siting.

1. Introduction

In the mid 90s the German Meteorological Service (DWD) started to replace old measuring systems of the observing network. This was accompanied by a significant reduction of observing personnel. So a main goal of the project "Messnetz 2000" was to introduce new sensors for replacing eye observations. New sensors like "Present-Weather-Sensor" are tested and will be introduced. Data from existing sensors like ceilometers will be processed by more complex algorithms to get e.g. cloud coverage.

Also in the last ten years the number and quality of web cams increased substantially. Therefore DWD started a small camera network (Weather-Observing-Camera-Network - WeBoKaN). The aims were to find out how this technique could supplement the new sensors and to get experience with such systems. Starting in 2000 a small network of 10 systems was set up with prospect of more systems.

2. System overview

The main requirement for the system was to provide pictures and movies as memomotion. Since there was no complete system available on the market and the schedule was quite terse, standard components (commercial-off-the-shelf) were integrated by DWD. Fig. 1 shows the main components.

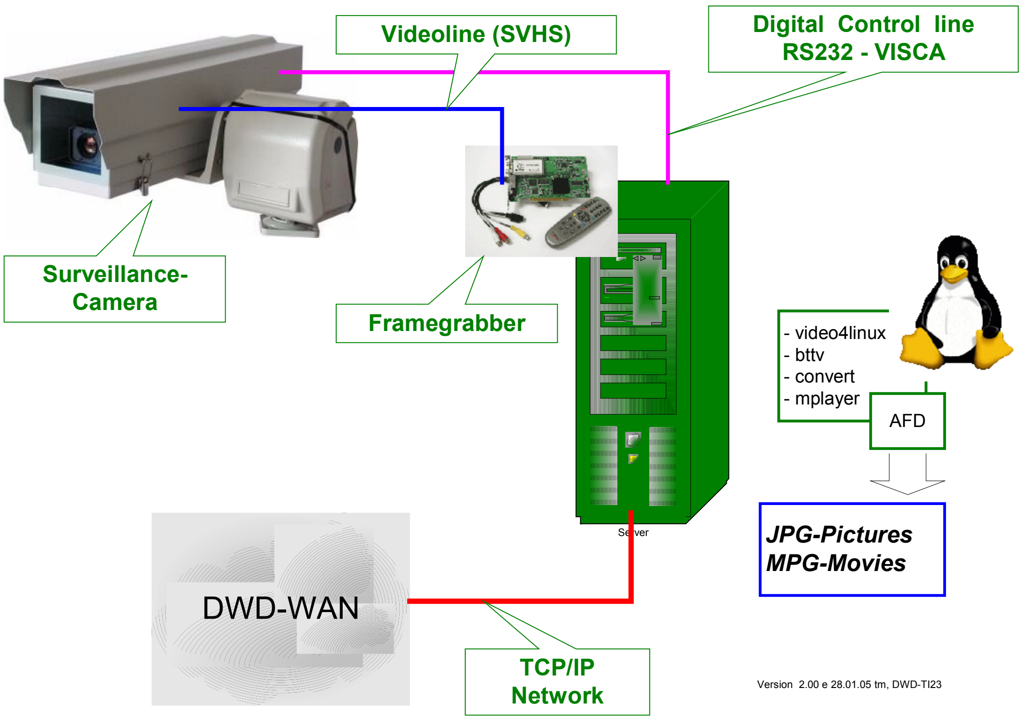


Fig.1: Main Hardware components of WeBoKaN.

The video signal (SVHS) from a Sony block camera is digitized in a Linux computer by a standard framegrabber and Open Source Software. Functions of the camera and the Pan-Tilt-Device are controlled over serial line busing the VISCA-Protocol. Since the movies need an update rate of the pictures of about 15 seconds, there is also a fixed camera. Here only parameters of the camera like focus can be adjusted, see Fig. 2.

The fixed camera points westward and about 20% of the image is below horizon as an optical reference for the users. The movable camera scans the upper hemisphere and zooms in some targets.

The digital pictures are processed, e.g. tagged with metadata or a DWD logo and MPEG-Movies are encoded.

Fig. 2: Outside installation.

Then the products are sent to the WeBoKaN operation center in Hamburg by the Automatic-File-Distribution (AFD) software. Here a webserver application provides access to all products. A nationwide overview (Fig. 5) gives a synopsis and through links on the thumbnails a display of all products of one site comes up (as thumbs too).

Fig. 4 shows a zoom-series of a target. Using distinct targets at different distances it is possible to evaluate the visual range.

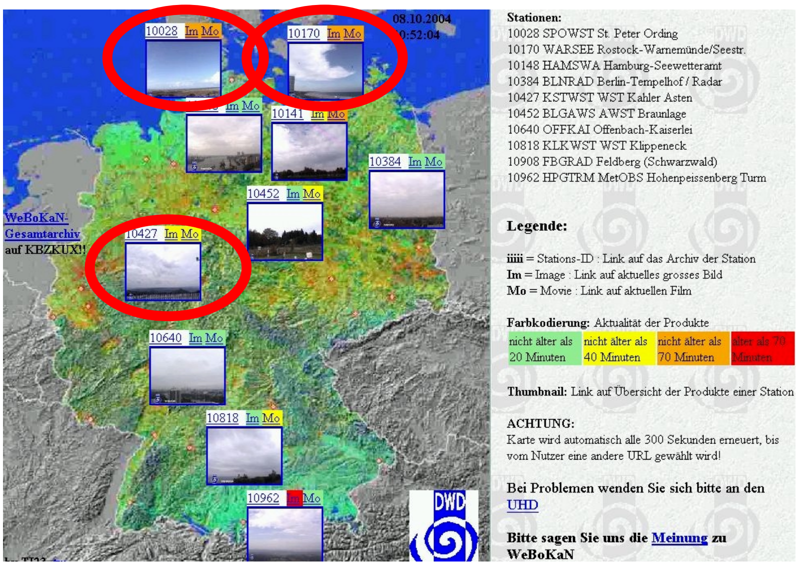
Meta information of each picture is encoded in the JPG-Header, to assure that the meta information can directly be used.

Fig. 3: Single picture with decoded header-information.

Fig. 4: Zoom-series of a target.

Parameters like temperature or precipitation yes/no are gathered by the Built-In-Test-Equipment (BITE), making it possible to control the wiper automatically and to do an automatic self check of the system.

3. Comparison of local and remote observations



As soon as the first system was installed the whole staff of DWD could access the products and check them for usability. Additionally comparisons between on site and remote observations of cloud amount, visual range, type and intensity of precipitation as well as state of ground were conducted.

The results were statistically evaluated.

Fig. 5: Nationwide overview with stations marked for comparison.

Evaluation of total cloud coverage
Time period: 01.09.2003 to 31.08.2004

WEBOKAN-Station: Rostock-Warnemünde   Remote Station: Kap-Arkona

WN Total cloud amount from WeBoKaN (columns); N Total Cloud amount SYNOP (rows)

	0/8	1/8	2/8	3/8	4/8	5/8	6/8	7/8	8/8	9/8	Sum
0/8	198	20	3	0	0	0	0	0	0	0	221
1/8	52	186	21	2	1	0	0	0	0	1	263
2/8	5	105	81	26	4	0	0	0	0	0	221
3/8	0	51	130	69	23	7	1	2	0	0	283
4/8	0	13	25	57	76	35	7	2	0	0	215
5/8	0	6	20	39	107	105	61	11	0	0	349
6/8	0	4	11	22	40	128	257	153	8	0	623
7/8	0	0	0	7	6	28	111	648	100	3	903
8/8	0	0	0	0	0	2	8	165	1157	12	1344
9/8	0	0	0	0	0	0	0	3	8	31	42
Sum	255	385	291	222	257	305	445	984	1273	47	4464
Dif. > 1/8	5	74	59	70	51	37	16	18	8	4	
Dif. in %	1,96%	19,22%	20,27%	31,53%	19,84%	12,13%	3,60%	1,83%	0,63%	8,51%	

Sum (all Hits): **4464**   *ideal Hits* 2808 or 62,9%

Non-Hits: 342 or 7,7%   *incl. +/- 1/8:* 4122 or 92,3%

Fig. 6: Comparison of local / remote cloud coverage determination.

In Fig. 6 an example of the comparison is given. The observers in Warnemünde created their SYNOP message as usual. In Arkona they used the pictures and movies of WeBoKaN to determine cloud coverage etc. Assuming a typical uncertainty of 1 octa, more than 90% of the values are in agreement. This is consistent with results from the other stations.

Generally it can be asserted, that the results are very good for cloud coverage and good for visibility, if there are good targets. They are not good for state of ground, as well as type and intensity of precipitation. All comparisons were done during daylight.

4. Noise reduction

At low brightness, e.g. at night, the noise in the pictures increases. This effect reduces the perceptibility of details and increases the file sizes, because the compression algorithms work worse. This can be overcome widely if a few pictures are averaged, see Fig. 7 and 8. Since the pictures and movies are available as files under Linux, they can be modified on site (before transmission).

Fig. 7: Night-picture single shot (80kB).

Fig. 8: Night-picture averaged (8 contributions, 45kB).

5. Outlook

The evaluation will be continued especially at low brightness and for state of ground observations. With the experience from 3 years of operation Hard- and Software will be tuned to complete the automatic observations of the other (new) sensors in the observing network of DWD.

ORGANISATION POUR L’ASSISTANCE METEOROLOGIQUE AUX ACTIVITES MARITIMES – TRANSPORTS ET PECHE; AGRICULTURE – PRECIPITATION

Antoninho Ocundo Ca (Guinée-Bissau)

INTRODUCTION

Comme est de la connaissance de la majorité de Votre Excellence que la Guinée-Bissau est un pays dont les informations météorologiques ont toujours joué un rôle essentiel dans le déroulement sûr et efficace des activités maritimes et + l’agriculture ! Malheureusement, la Direction Général de la Météorologie National a beaucoup eu un retarde pour le développement des activités dans ces domaines :

I - Référence Géographique

Voyons d’abord que, la Guinée-Bissau, est un Pays situé la côte occidentale de l’Afrique, dans l’hémisphère Nord, entre les parallèles 1059’ et 1220’ N et les méridiens de 1340’ et 1643’ W. Elle a une frontière commune avec le Sénégal au Nord, et avec la Guinée Conakry l’Est et au Sud. La surface totale du territoire est de 36.125 Km2. Elle est composée d’une partie continentale, la plus important, et l’archipel BIJAGOS constitué de 40 îles dont 20 sont habitué.

Les plaines côtières sont entrecoupées par des nombreux estuaires formant un système complexe de canaux. Les plateaux de l’intérieur sont drainés par les fleuves CACHEU, GEBA et CURUBAL.

Tous les estuaires de la Guinée-Bissau sont des lieux de pêches artisanales et semi industrielles.

Les statistiques concernant la pêche fluviale sont mal connues. Une contribution importante de l’hydrologie à cette activité économique serait suivie de la qualité chimique de l’eau et notamment de la salinité.

I.1.– NOTAMMENT POUR CE QUI CONCERNE LES ACTIVITES MARITIMES – TRANSPORT ET LA PECHE.

I.1.1. Structures de ports (seiches portuaires) (voir photo)

Les états des ondes stationnaires engendrées par une force dont la période est identique à – ou en résonance avec – la période naturelle d’oscillation d’un plan d’eau fermé ou presque fermé. En général, alors que les seiches observées dans le lacs ou les baies sont dues à des variations de la pression atmosphérique ou du vent.

I.1.2. Petites bateaux que naviguent en haut mer (voir photo)

Ces bateaux sont vulnérables en cas de forte dégradation du temps ou l’état de la

mer. Il arrive souvent qu’ils ne disposent pas du temps nécessaire pour se réfugier dans un port protégé ou pour se mettre à l’abri du vent le long de la côte.

Dans ces états aura toujours la nécessite du pays d'appliquer et développer la météorologie ل fin de meilleur assurer la vie et l'économie du Pays. Pour cela, le Pays envisage des installations des stations maritimes pour les assistances météorologiques aux activités maritimes sur la base des objets suivants :

II – PRECIPITATION ET L'AGRICULTURE

(voir Image du Parque de la station météorologique a Bissau (siège)

Pour l'histoire savons que l'agriculture est le pivot économique de la Guinée-Bissau.

Avant l'indépendance la politique agricole était axée sur les cultures d'exportations, de plusieurs produits agricoles. L'ensemble du territoire est caractérise par un climat chaud et humide avec une saison de la pluies. Cette saison dure environs 7 mois. Elle débute en Mai et fini en Novembre.

Les données pour la majorité des stations débutent dans l'année 1950 avec une lacune entre 1967 et 1977 excepte par les stations synoptiques et, une interruption dans l'année 1998 jusqu à la date présente.

Il a été impossible d'avoir une période commune de 30 années sûr et suffisamment de stations pour établir la carte des isohyètes interannuelles.

L'ensemble du territoire est compris entre pluviométries annuelles 1250 mm et 2750 mm.

Il est possible d'avoir une estimation grosserie de la pluviométrie interannuelle en (mm) en tout point du territoire de la Guinée-Bissau en utilisant une régression linéaire à partir de la latitude de ce point exprimé en minutes d'angle.

Les ressources pluviométriques par bassin, ont été étudié en 1991 et qui ont été distinguées trois zones :

- 1ère – La zone continentale avec les bassins de CUUBAL, du GEBA et du CACHEU.

- 2ème– La zone pluvio-marine avec les bassins et sous bassins maritimes.

- 3ème – Les îles, ou' l'ensemble est représentée par un polygone de 4752

Km2 et actuellement aucune poste s'opère.

Est évident que pour les études des précipitations sur les îles la méthode est très incomplète. La pluviométrie dans les îles d'atlantique Nord st très influencé par l'exposition au vent en altitude. Cette valeur observée, donne cependant une idée, vu le peu de relief dans les îles BIJAGOS.

En Général, le Pays continue cependant avoir une balance déficitaire en agriculture et mesure total des quantités de précipitation. Sur tout la mauvaise dite « Conflit Politique Militaire 07 Juin 1998» Qui a détruit les réseaux des observations et télécommunication météorologiques avec les respectifs équipements installés et en stocks. A partir de ce date, jusqu à la présente, la Direction Général de la Météorologie National n'arrive pas avoir un financement pour la choix et demandes des équipements plus précieux pour les intérêt. Certains projets obtiennent certains équipements (pluviomètres) que par fois installent personnellement sans consulter la Direction de la Météorologie ou leurs technicien. Par conséquents, avait constaté mal installations et exploitations de ces équipements par projet en charge.

RECOMMANDATION POUR L'ASSISTANCE METEOROLOGIQUE AUX ACTIVITES MARITME

- Il est nécessaire faire connaître bien divers équipements pour éventuelles installations technique ;

- Prendre en considération les divers sorts d'activité maritimes sensibles aux conditions météorologiques (pêche, la navigation de plaisance, pollution, forage et prospection pétrolier, etc…).

- Prendre les contactes avec les usager et, d'un commun accord, faire l'inventaire de leurs besoins au nombres d'usagers figurent habituel ment (Administrations des pêches, l'organisations des pêches, les autorités responsables de la sauvegarde de la vie humain en mer et notamment dans les côtiers, les autorités chargés de lutte contre la pollution marine, les opérateurs de transports analogues, les entreprise de forage pétroliers et les compagnies des navigations, les autorités chargés de protéger les population des zones côtiers des ondes de tempête, des hautes vagues, les autorités portuaires) ;

- Définir un programme d'assistance pour la fourniture des produits élabore en vue de reproduire à ces besoins ;

- Déterminer dans quelle mesure il est nécessaire de disposer des données et des moyens de traitements supplémentaires pour élaborer le produit d'assistances ;

- Organiser fa fourniture des produits des assistances;

- Mettre sur pied un système de surveillance pour vérifier si les produits fournissent correspondant bien aux besoins;

- Prendre des dispositions appropries pour recueillir et vérifier les registres météorologiques;

- Définir les besoins en ce que concernent les recherches supplémentaires se rapportant (aux méthodes de prévision, aux capteurs et au matériel connexe);

- Assurer une représentation appropriе du service météorologique national dans les organisations nationales et internationales qui se consacrent à l'amélioration de l'assistance aux activités maritimes;

- Faire en sorte que la météorologie et certains éléments de l'océanographie physique fassent l'objet d'une attention particulier dans les écoles de navigation maritimes et que ces ma tiers figurent aux programmes des examens d'officiers de marine.

- des stations maritimes ;

Développer et mettre en œuvre des programmes destinés a former des spécialistes pour la météorologie maritime et du personnel de soutien

RECOMMANDATION

Les gestions et les contrôles des réseaux d'observation doivent être bien assuré par la Direction Général de la Météorologie National Qui aura comme tâche :

- connaître les différents des équipements, leurs exploitations et interpolations de leurs mesures.

- Les installations, contrôle des installations et exploitations des équipements doivent rigoureusement faites suivant la recommandation de l'OMM.

- Les méthodes et heures des observations par différents équipements doivent être à l'attention des professionnelles de la météorologie.

- Les usines qui fabriquent les équipements doivent être à la reconnaissance de l'OMM dont ces reconnaissances doivent être informé aux différents Services Météorologiques les qualités du fabricant.

- Les équipements acquis dans le cadre des projets et gérés par les autres Ministères doivent être homologués, installés et contrôlés par la Direction de la Météorologie Nationale. De chaque Pays.

- L'OMM doit aider les Pays en crise ou moins développer aides financier pour les récupérations des stations ou postes pluviométriques. Et aider améliorer et restructurer les stations existantes et créer nouvelles stations.

New developments and operational experience with surface observation technology TECO ET METEOREX – 2005 (Bucharest, Romania, 4 to 7 May 2005)

ORGANISATION POUR L'ASSISTANCE METEOROLOGIQUE AUX ACTIVITES MARITIMES (TRANSPORTS ET PECHE) ET L'AGRICULTURE EN GUINÉE-BISSAU

Par: Antoninho Ocundo Cá
Technicien Supérieur en Instruments Hydrométéorologiques et Electroniques

PLAN D'EXPOSÉ

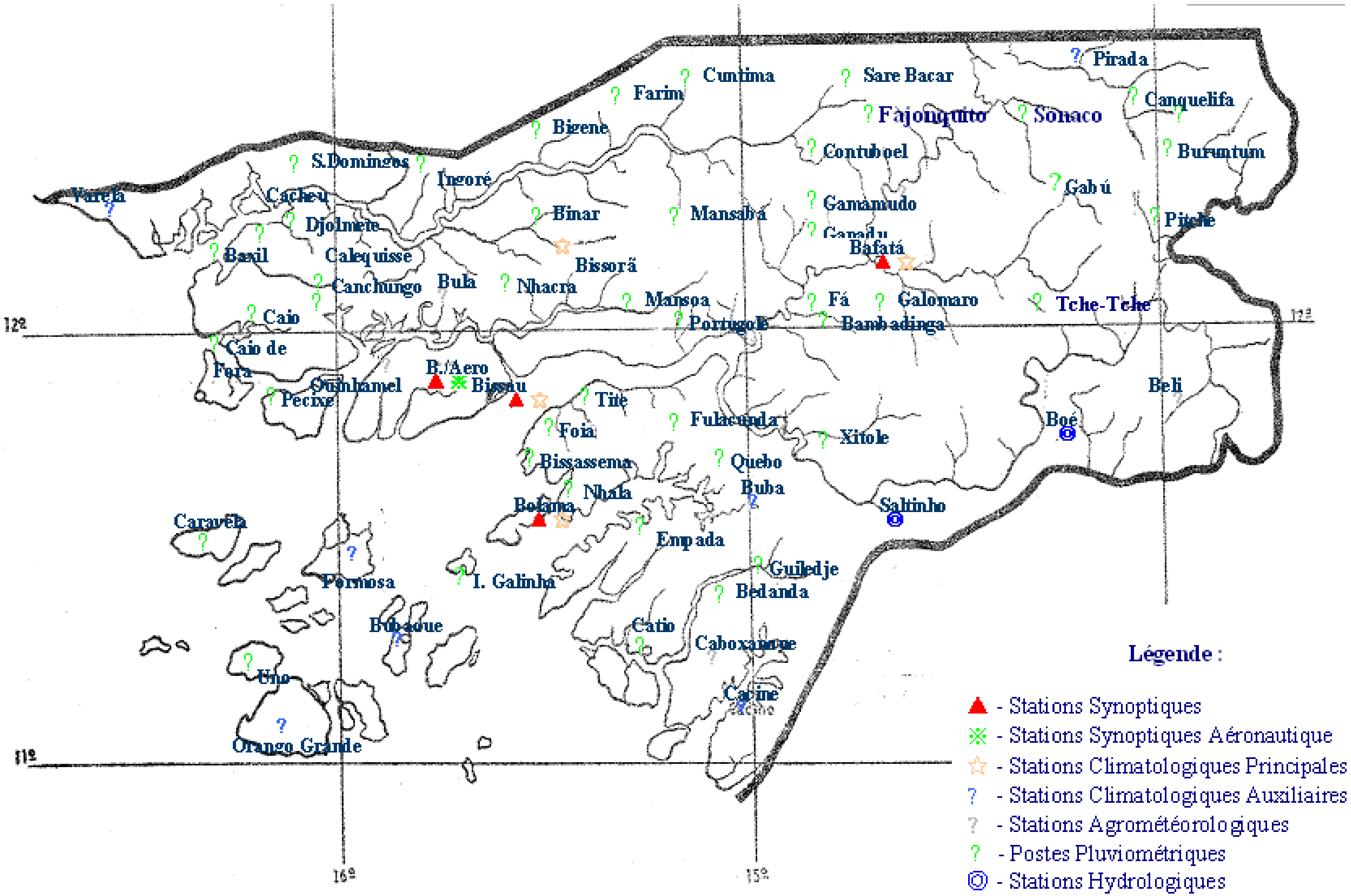
INTRODUCTION

En Guinée-Bissau le secteur AGRICOLE dans le sens le plus large (l'agriculture, l'élevage et la pêche) représente plus de deux-tiers de la production nationale.

L'assistance météorologique aux activités maritime (la pêche et la navigation) et à l'agriculture joué un rôle essentiel dans le bon déroulement et l'efficacités de ces activités socio-économiques.

Le but essentiel de ces assistances et de contribuer pour la sauvegarde des vies et des biens, la réduction des effets des catastrophes naturels, la sécurité alimentaire et au développement durable de la Guinée-Bissau.

Carte n° 2 : RESEAUX AGRO-CLIMATOLOGIQUE DE LA REPUBLIQUE DE LA GUINE-BISSAU



Anemogirouette à 10 mètres de hauteur

2. ASSISTANCES MÉTÉOROLOGIQUES

2.1. AUX ACTIVITÉS MARITIMES (Transports et Pêche)

Situation des bateaux dans le ports: **Les états des ondes stationnaires engendrées par une force dont la période est identique à – ou en résonance avec – la période naturelle d'oscillation d'un plan d'eau fermé ou presque fermé. En général, alors que les seiches observées dans le lacs ou les baies sont dues à des variations de la pression atmosphérique ou du vent**

2. ASSISTANCES MÉTÉOROLOGIQUES (Suite)

2.1. AUX ACTIVITÉS MARITIMES (Transports et Pêche)

Petites bateaux que naviguent en haut mer

Ces bateaux sont vulnérables en cas de forte dégradation du temps ou l'état de la mer. Il arrive souvent qu'ils ne disposent pas du temps nécessaire pour se réfugier dans un port protégé ou pour se mettre à l'abri du vent le long de la côte.

Dans ces états aura toujours la nécessite du pays d'appliquer et développer la météorologie á fin de meilleur assurer la vie et l'économie du Pays. Pour cela, le Pays envisage des installations des stations maritimes pour les assistances météorologiques aux activités maritimes sur la base des objets suivants

2. ASSISTANCES MÉTÉOROLOGIQUES

2.2. A L'AGRICULTURE (Situation pluviometrique)

Les données pour la majorité des stations débutent dans l'année 1950 avec une lacune entre 1967 et 1977 excepte par les stations synoptiques et, une interruption dans l'année 1998 jusqu à la date présente.
Il a été impossible d'avoir une période commune de 30 années sûr et suffisamment de stations pour établir la carte des isohyètes interannuelles.
L'ensemble du territoire est compris entre pluviométries annuelles 1250 mm et 2750 mm.
Il est possible d'avoir une estimation grosserie de la pluviométrie interannuelle en (mm) en tout point du territoire de la Guinée-Bissau en utilisant une régression linéaire à partir de la latitude de ce point exprimé en minutes d'angle.
Les ressources pluviométriques par bassin, ont été étudié en 1991 et qui ont été distinguées trois zones :
1ère – La zone continentale avec les bassins de CUUBAL, du GEBA et du CACHEU.
- 2ème– La zone pluvio-marine avec les bassins et sous bassins maritimes.
- 3ème – Les îles, ou' l'ensemble est représentée par un polygone de 4752
Km2 et actuellement aucune poste s'opère.
Est évident que pour les études des précipitations sur les îles la méthode est très incomplète. La pluviométrie dans les îles d'atlantique Nord st très influencé par l'exposition au vent en altitude. Cette valeur observée, donne cependant une idée, vu le peu de relief dans les îles BIJAGOS.

Pluviographe

3. CONCLUSIONS ET RECOMMANDATIONS

Les gestions et les contrôles des réseaux d'observation doivent être bien assuré par la Direction Général de la Météorologie National Qui aura comme tâche :

- connaître les différents des équipements, leurs exploitations et interpolations de leurs mesures.
- Les installations, contrôle des installations et exploitations des équipements doivent rigoureusement faites suivant la recommandation de l'OMM.
- Les méthodes et heures des observations par différents équipements doivent être à l'attention des professionnelles de la météorologie.
- Les usines qui fabriquent les équipements doivent être à la reconnaissance de l'OMM dont ces reconnaissances doivent être informé aux différents Services Météorologiques les qualités du fabricant.
- Les équipements acquis dans le cadre des projets et gérés par les autres Ministères doivent être homologués, installés et contrôlés par la Direction de la Météorologie Nationale. De chaque Pays.
- L'OMM doit aider les Pays en crise ou moins développer aides financier pour les récupérations des stations ou postes pluviométriques. Et aider améliorer et restructurer les stations existantes et créer nouvelles stations.

3. CONCLUSIONS ET RECOMMANDATIONS (Suite)

- Il est nécessaire faire connaître bien divers équipements pour éventuelles installations des stations maritimes ;
- Développer et mettre en œuvre des programmes destinés a former des spécialistes pour la météorologie maritime et du personnel de soutien technique ;
- Prendre en considération les divers sorts d'activité maritimes sensibles aux conditions météorologiques (pêche, la navigation de plaisance, pollution, forage et prospection pétrolier, etc…).
- Prendre les contactes avec les usager et, d'un commun accord, faire l'inventaire de leurs besoins au nombres d'usagers figurent habituel ment (Administrations des pêches, l'organisations des pêches, les autorités responsables de la sauvegarde de la vie humain en mer et notamment dans les côtiers, les autorités chargés de lutte contre la pollution marine, les opérateurs de transports analogues, les entreprise de forage pétroliers et les compagnies des navigations, les autorités chargés de protéger les population des zones côtiers des ondes de tempête, des hautes vagues, les autorités portuaires) ;
- Définir un programme d'assistance pour la fourniture des produits élabore en vue de reproduire à ces besoins ;
- Déterminer dans quelle mesure il est nécessaire de disposer des données et des moyens de traitements supplémentaires pour élaborer le produit d'assistances ;
- Organiser fa fourniture des produits des assistances ;
- Mettre sur pied un système de surveillance pour vérifier si les produits fournissent correspondant bien aux besoins ;
- Prendre des dispositions appropries pour recueillir et vérifier les registres météorologiques ;
- Définir les besoins en ce que concernent les recherches supplémentaires se rapportant (aux méthodes de prévision, aux capteurs et au matériel connexe) ;
- Assurer une représentation approprie du service météorologique national dans les organisations nationales et internationales qui se consacrent à l'amélioration de l'assistance aux activités maritimes ;

Faire en sorte que la météorologie et certains éléments de l'océanographie physique fassent l'objet d'une attention particulier dans les écoles de navigation maritimes et que ces ma tiers figurent aux programmes des examens d'officiers de marine.

New Automatic Weather Station System in Hong Kong
Featuring One-stop Quality Assurance, Internet Technology and Renewable Energy

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Abstract

The Hong Kong Observatory (HKO) has developed a new Automatic Weather Station (AWS) System with a capability to carry out one-stop data quality assurance. Data from AWSs are collected by the system's central station and go through quality assurance processes there in real time, resulting in reduced manpower required for subsequent data processing. An added advantage of this feature is that it enables early detection and diagnosis of faults. The fault message is conveyed to the maintenance staff via email to enable early remedial action, enhancing data availability.

Selected AWSs are equipped with a network camera, and pictures taken are uploaded to HKO's website in real time via a mobile telephone network. The pictures would enable the public and tourists to assess the weather conditions at their travel locations in a direct and intuitive manner. As a contribution to conservation, the AWSs are designed to run on solar and wind power. The experience in remote locations in Hong Kong has demonstrated very satisfactory results in terms of data availability and reduced maintenance effort. This paper presents the overall design concepts, quality assurance algorithms, as well as a plan to further expand the capability of the system.

1. Introduction

Since 2000, the Hong Kong Observatory (HKO) started to modernize its Automatic Weather Station (AWS) System with a view to enhancing its public weather service. The modernization process involves the following aspects:

(i) expanding the capability of the AWS network in making observations;
(ii) extending the coverage of the AWS network in Hong Kong, China; and
(iii) enhancing the quality assurance of meteorological data gathered from the AWSs.

For conservation purpose, the AWSs are designed to run on solar and wind power. This paper describes the overall design concept of the new system, its quality assurance algorithms, as well as a plan to further expand its capability.

2. Major components of the new AWS system

The new AWS system consists of the following components:

(i) AWSs;
(ii) Network cameras;
(iii) AWS central data acquisition system; and
(iv) Integrated data quality assurance system.

Figure 1 shows the technical set-up of the AWS system.

3. AWS network

In expanding the capability of the AWS network, new types of meteorological instruments have been installed at selected AWSs. These include a total sky imager, a device for taking snapshot of the sky to assess the cloudiness during daytime (Figure 2), and a broadband UV sensor for measuring ultraviolet radiation to alert people about the need to adopt protective measures when exposed to the sun (Figure 3). Recently, network cameras have been installed at selected tourist spots to provide high quality weather photographs in real time to the public. Details of the network cameras are described in section 4.

In extending the coverage of the AWS network in Hong Kong, HKO has setup new AWSs and installed additional weather observing instruments at popular tourist spots to provide detailed weather information to the public and tourists (Figure 4).

4. Network cameras

Network cameras have been installed at several places in Hong Kong to provide real-time weather photographs to the public. These network cameras can transmit, without the use of a PC, high quality weather photographs or video clips to the HKO website via broadband network or GPRS in real time. Operational parameters such as picture frequency, mode (photo or video clip) and picture resolution, can be remotely controlled via the Internet (Figure 5).

4.1 New weather service to the public and tourists

The aim of installing network cameras at popular tourist spots is to provide real-time weather photographs via HKO's Internet website (Figure 6), so that tourists and members of the public can plan their travel in a direct and intuitive manner. On the website, they can also view animation of weather photographs for the past three hours as well as some notable weather events of the past.

4.2 Weather monitoring and forecasting

The real-time weather photographs also assist forecasters in monitoring more closely changes in weather conditions such as deterioration in visibility (Figure 7) as well as the development of strong convective weather.

The snapshots shown in Figure 8 are an example of how real-time weather photographs can be used to monitor the development of strong convective weather. The weather on 4 August 2004 was characterized by a broad trough of low pressure lying over South China, which brought showers and thunderstorms to Hong Kong. In the afternoon that day, thunderstorms started to develop over the northeastern part of Hong Kong due to very rapid upward motion of moist air (Figure 8.1(a) and 8.1(b)). Following the northeasterly winds aloft, the cumulonimbus clouds spread to the south-west and obscured the sky (Figure 8.2(a)). As satellite pictures are normally only available once every hour, the use of real-time weather photographs together with radar pictures can help forecasters monitor closely the development of convective weather and if necessary issue weather warnings in good time.

4.3 Promoting public education on weather

Because of its continuous operation, the network cameras have captured valuable snapshots of weather events. Figure 9 shows a picture sequence of cumulonimbus clouds captured in the afternoon of 14 July 2004. The weather that day was generally fine at first with light to moderate southerly winds blowing over the coast of south China. On the radar (not shown), strong convection was observed to develop over inland areas in the afternoon, about 50 to 100 km north of Hong Kong. The photograph sequence shows strong vertical motion of very moist air developing to a great height. An anvil, with its characteristic fibrous texture, gradually formed and spread out from left to right, a result of westerly winds aloft.

5. AWS central data acquisition system

At present, the AWS central data acquisition system is still running on a DOS platform. It is responsible for acquiring meteorological data from over 70 AWSs once every minute via the public telephone network. HKO is now working on migrating the system to a high-speed and stable platform running on the UNIX operating system so that multi-tasking operation and faster data transfer can be supported.

6. Integrated data quality assurance system

The AWS data received by the central data acquisition system are passed to the integrated data quality assurance system for quality control. The latter system has been developed by HKO to provide one-stop data quality assurance. The data flow and processing are shown in Figure 10. The system is highly automatic. It serves to enhance data quality and at the same time reduce manual labour. Through various real-time and non-real-time automatic data quality control processes, the system carries out quality assurance for each data received from the AWS by assigning a quality assurance flag to the data, filtering out erroneous data from the AWS, and alerting maintenance staff to action via automatic email. Operation of the AWSs can also be monitored via a webpage which displays the status of the AWS network in real-time (Figure 11). The advantage of this automatic alerting feature is that it enables early detection and diagnosis of faults, enhancing data availability. Apart from monitoring the operation of the AWS, the quality assurance flags also serve as an indication of quality, facilitating reference by users in future case studies and climatological research.

6.1 Quality Assurance Algorithms

The following automatic QA algorithms have been implemented in the system:

(i) Range test: The range test (WMO (1996) and Shafer (2000)) is an algorithm that determines if an observation lies within a pre-determined range. The allowable ranges are based on sensor specifications, sensor location, monthly and annual climate extremes in Hong Kong. Every meteorological element at each site has a unique set of limits. If a datum is observed to lie outside the allowable range, it is assigned with a specific flag.

(ii) Trend test: The trend test (Shafer (2000)), also known as the step test, uses sequential observations to determine, for each of the elements measured, which abrupt change in the data represents unrealistic “jump” during the observation time interval. Observations that exceed the maximum allowed value will receive a specific flag (different from the one for (i) above).

(iii) Inter-sensor consistency test: This test (WMO (1996) and Shafer (2000)) makes use of the internal consistency of an element against other element(s) measured at the same site with the use of established physical and meteorological principles (e.g. dew point and wet-bulb temperature cannot exceed the ambient temperature).

Other automatic QA tests (Shafer (2000)) are being developed and tested to further enhance the effectiveness of the system. These include spatial test for rainfall (with reference to radar echoes) and persistence test for wind speed and direction.

For each data, a set of QA flags corresponding to the automatic QA tests will be generated by the system. Following the guidelines of WMO (1996), a composite QA flag, also known as final quality control flag, is assigned by the system to each weather data element based on the QA flags of the various QA tests. The composite QA flag will be assigned a value of “1” if the data passes all QA tests; it will be assigned a value of “3” if the data fails in any of the QA tests; it will be assigned a value of “2” if the data is treated as suspicious by any of the QA tests. The meaning of the QA flags is explained in Table 1 and 2. A typical error log generated by the system is shown in Figure 12.

Assigning different values to the QA flag allows the data user to decide on the level of QA they prefer for their applications and exercise caution when interpreting the data. The “suspicious” QA flag may sometimes help to identify a real but unusual meteorological event, e.g. an extreme value breaking previous records. The system also allows manual editing of the QA flag by a meteorologist. The raw AWS data together with the final QA flag thus serve as a complete record of the data as well as a key for reference by users.

7. Use of Renewable Energy

HKO has been using renewable energy for about 20 years. Since the 1980s, solar panels have been used to power some AWSs in Hong Kong, particularly for AWSs in remote areas and on outlying islands with no city power supply. However, insufficient sunshine due to prolonged periods of overcast or rainy weather has occasionally resulted in inadequate power to keep a station running. Since early 2000, HKO started deploying a hybrid of solar panel and wind-powered generator at some remote stations. Experience indicates that the windy conditions that normally come with overcast weather complement the sunshine shortage quite well in terms of providing a continuous supply of renewable energy. Moreover, as AWSs with renewable energy do not run on city power, they do not suffer from power interruptions. As of today, there are altogether 22 AWSs utilising solely solar and wind energy in Hong Kong (Figure 13). Results so far have demonstrated very satisfactory performance in terms of higher data availability and reduced maintenance effort. The plan is to deploy more AWSs on renewable energy in future.

8. Discussion

The introduction of new weather services giving the public more weather information, in quantity, in type and in detail, has been received very positively. Feedback of the public has enabled HKO to make further improvements to the services.

The plan for the intermediate future is to add network cameras to more strategically located AWSs in Hong Kong. Plan is also in hand to integrate additional sensors into the AWSs, e.g. sensors for measuring radioactivity and solar radiation.

References

Shafer, M.A., C.A. Fiebrich, D.S. Arndt, S.E. Fredrickson, and T.W. Hughes, 2000: Quality assurance procedures in the Oklahoma Mesonet, J. Atmos. Oceanic Technol., 17, 474-494.

World Meteorological Organization, 1996: Guide to Meteorological Instruments and Methods of Observation, WMO-No.8, Geneva, pp II.1-10 to pp II 1-12.

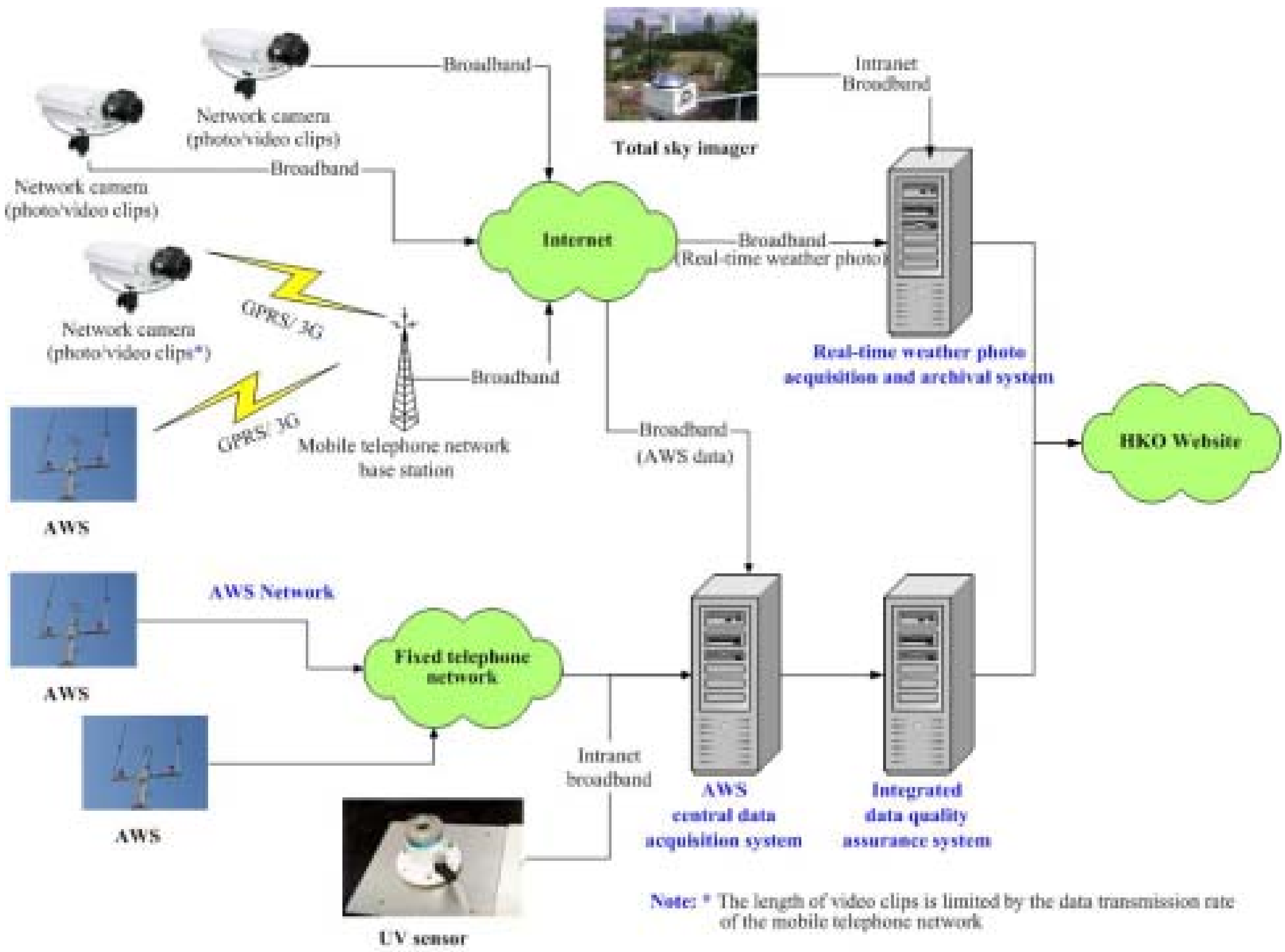


Figure 1: The technical set-up of the new Automatic Weather Station (AWS) System in Hong Kong

Figure 2(a): The total sky imager takes snapshot of the reflected sky from a convex mirror every 10 minutes. The snapshot is useful for observing clouds and assessing cloudiness during daytime.

Figure 2(b): Halo captured by the total sky imager on 7 May 2002.

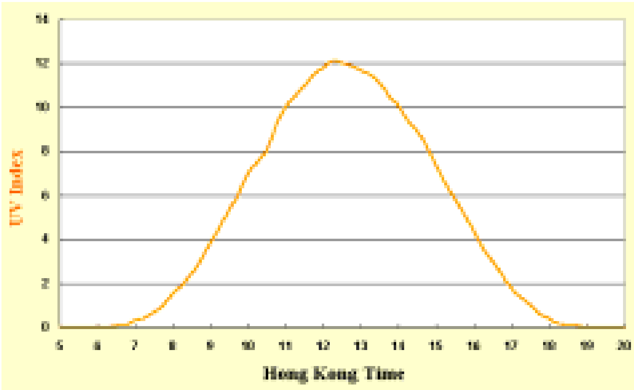
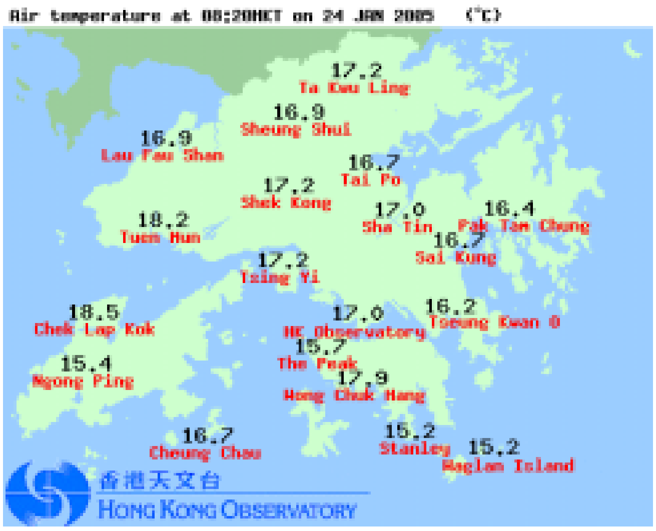


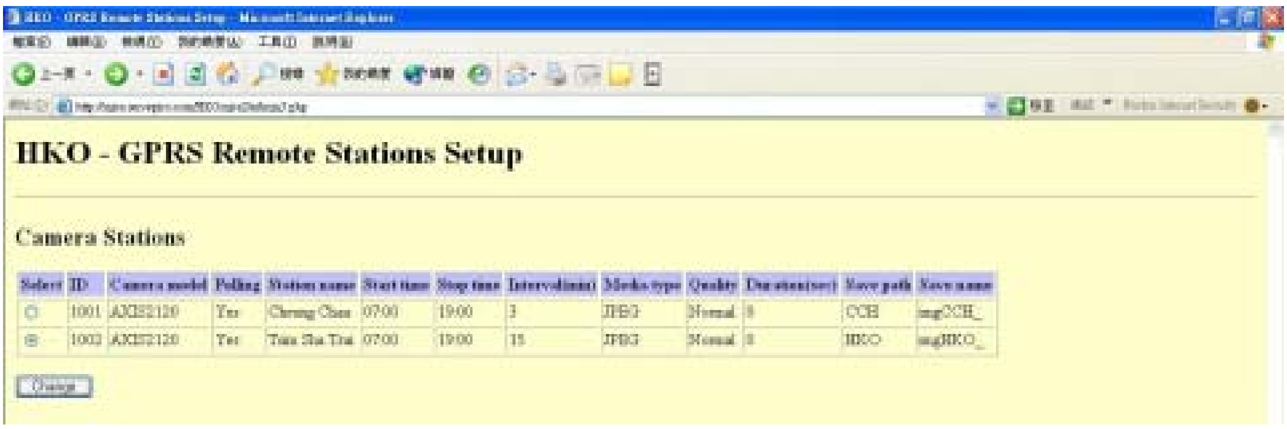
Figure 3(a): Broadband UV sensor

Figure 3(b): Time series of UV index on a hot summer day.



(a) (b)

Figure 4: HKO's regional weather webpage showing distribution of (a) temperature, and (b) wind in Hong Kong



Select	ID	Camera model	Polling	Station name	Start time	Stop time	Interval(min)	Media type	Quality	Duration(sec)	Save path	Save name
○	1001	AXIS2120	Yes	Cheung Chau	07:00	19:00	3	JPEG	Normal	8	CCH	imgCCH_
◉	1002	AXIS2120	Yes	Tsim Sha Tsui	07:00	19:00	15	JPEG	Normal	8	HKO	imgHKO_

Figure 5: Network camera operation is remotely controlled via the Internet

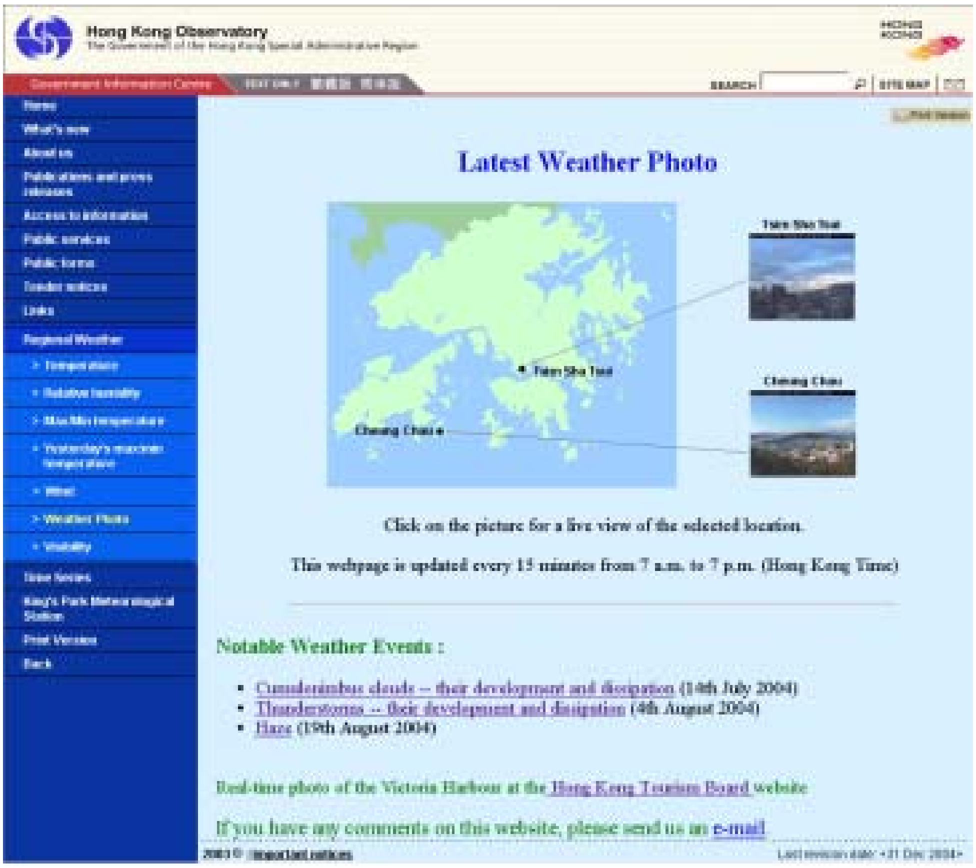


Figure 6(a): The “weather photo” webpage on the Hong Kong Observatory website

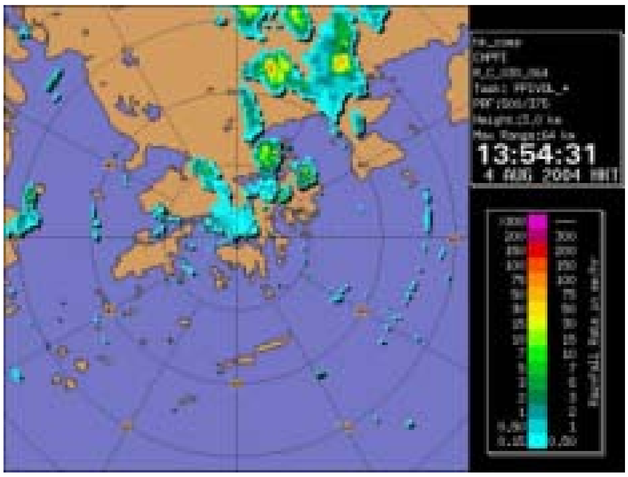
Figure 6(b): A downward link to the webpage in Figure 6(a), showing the latest weather photo at Cheung Chau, an outlying island in the south-western part of Hong Kong.

Figure 7: **Haze captured by the network camera at Cheung Chau (left) and at the HKO Headquarters (right) on the morning of 19 August 2004. The visibility at Cheung Chau at the time was only about 1 km.**

8.1(a)

8.1(b)

8.2(a)



8.2(b)

Figure 8: **Simultaneous use of real-time weather photographs and radar pictures helps forecasters to closely monitor the development of strong convective weather and the movement of the convective clouds.**

9.1

9.2

9.3

9.4

Figure 9: Development of cumulonimbus clouds over inland areas on the afternoon of 14 July 2004. The picture sequence helps the public understand such natural phenomenon in a direct manner.

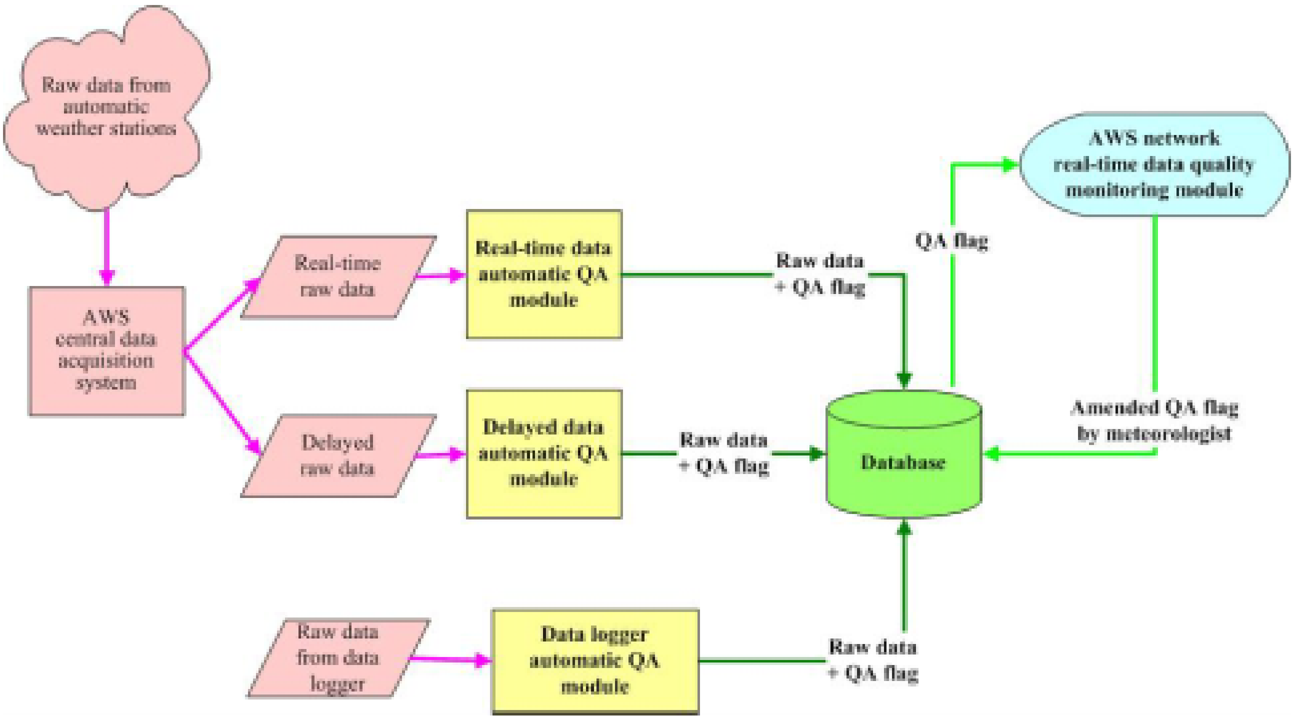


Figure 10: Data flow and processing by the integrated data quality assurance system

Figure 11: A typical display of real-time data quality monitoring of the AWS network

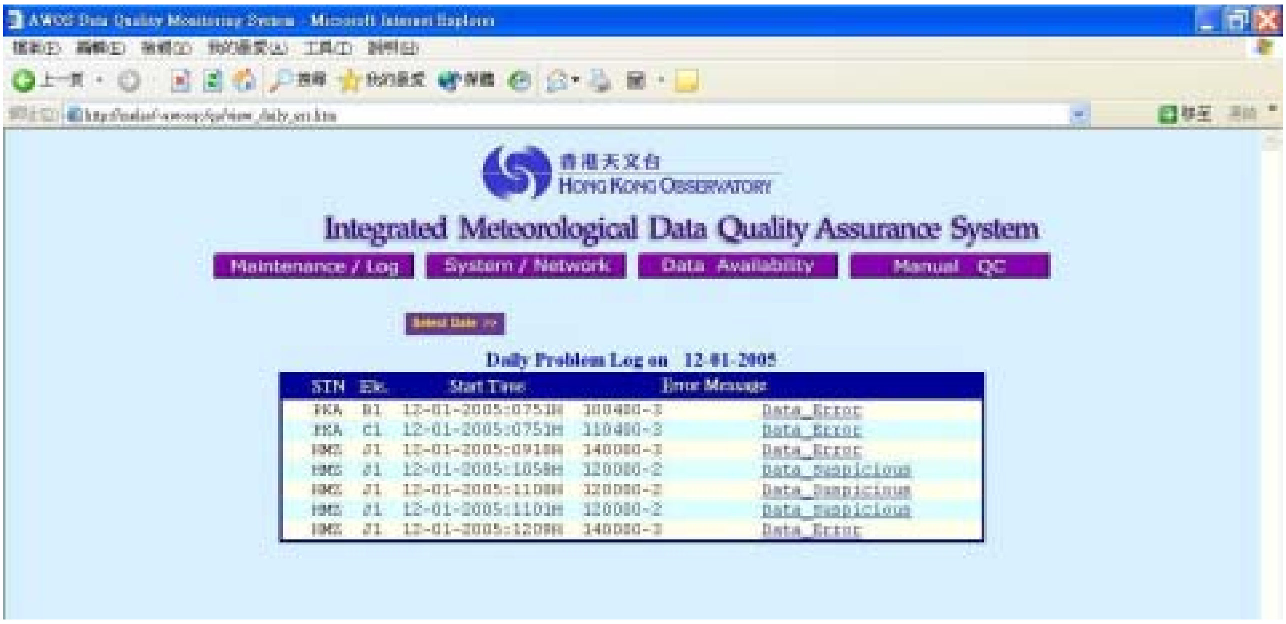


Figure 12: **A typical error log generated by the integrated data quality assurance system. The fourth column shows the QA flags for the individual tests and the last digit is the composite QA flag for the data concerned. This webpage is updated once every 10 minutes.**

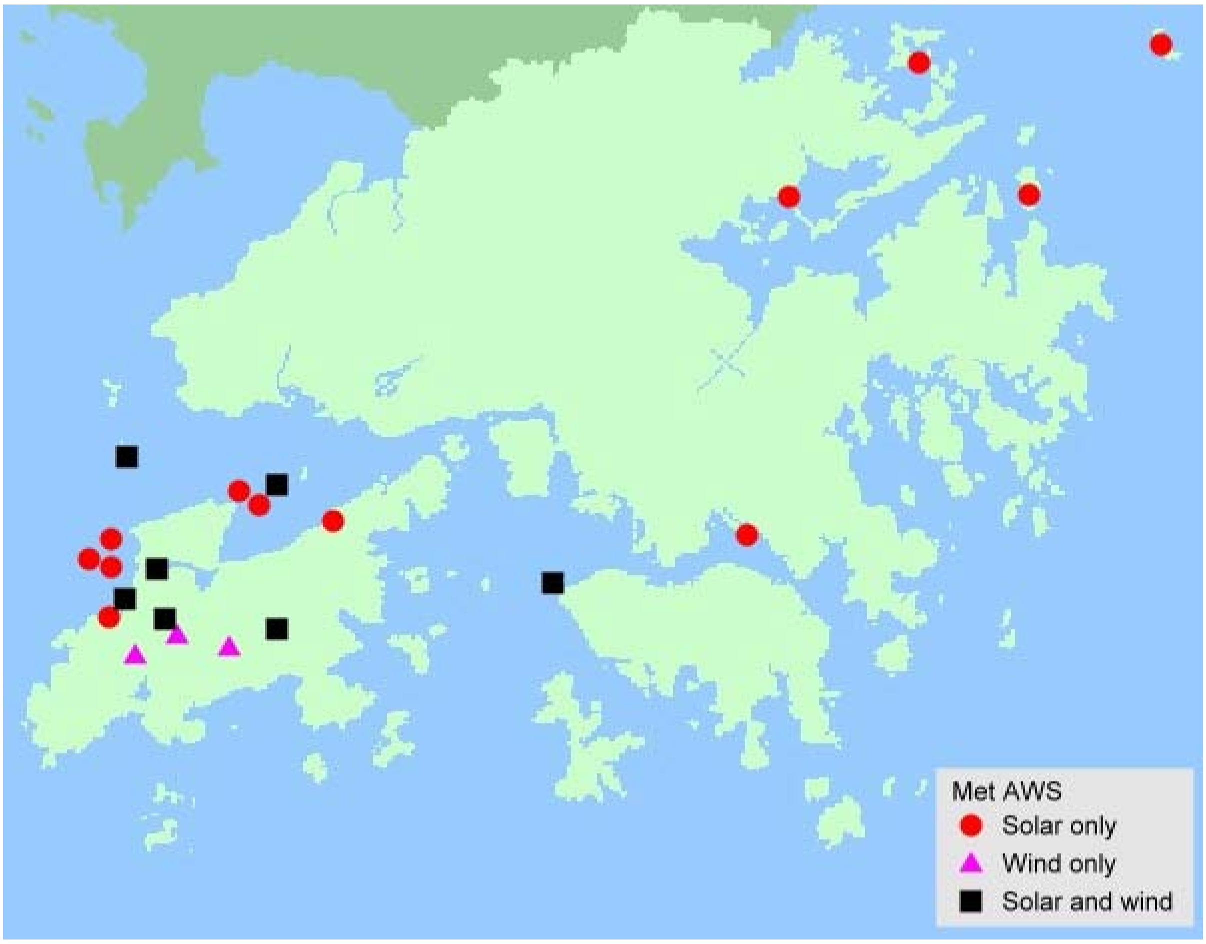


Figure 13: **A map showing automatic weather stations utilising renewable energy in Hong Kong.**

Character	Descriptions
E_nE_n	Weather element identifier (2 characters)
Q_1	QA flag value for range test (1 character)
Q_2	QA flag value for trend test (1 character)
Q_3	QA flag value reserved for persistence test (1 character)
Q_4	QA flag value for inter-senor consistency test (1 character)
Q_5	QA flag value reserved for spatial test (1 character)
Q_6	Reserved QA flag (1 character)
Q_7	Composite QA flag value based on the result of the various QA tests (1 character)
Q_8	Final QA flag assessed manually by meteorologist, if required (1 character)
vv	Auto-QC algorithm version number (2 characters).

Table 1: Format of QA flag - $E_nE_nQ_1Q_2Q_3Q_4Q_5Q_6Q_7Q_8vv$ (12 characters)

QA Flag	Values and Meaning	
$Q_1, Q_2, Q_3, Q_4, Q_5, Q_6$	0 – test not implemented 1 – passed auto-QC 2 – suspicious	3 – warning (highly suspicious) 4 – erroneous
Q_7	0 – auto-QC not implemented 1 – passed auto-QC 2 – suspicious	3 – erroneous 8 – instrument under maintenance 9 – data unavailable
Q_8	0 – QA flag not assessed by meteorologist (default); 1 – data confirmed correct by meteorologist; 3 – data confirmed erroneous by meteorologist.	
vv	Version number, ranging from 01 to 99, refers to the particular set of QA algorithms implemented	

Table 2: Meaning of QA Flags

MONITORING OF HIGH WIND SPEED BY NEW STATE-OF-THE-ART HIGH WIND SPEED RECORDING SYSTEM DURING RECENT DECEMBER 2003 MACHILIPATNAM CYCLONE

By

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A B S T R A C T

The accurate measurement of wind speed and direction will provide a greater help to the weather man, particularly during cyclone time. It will also help in tracking the cyclone accurately and to estimate its devastating potential.

India Meteorological Department has recently installed 20 High Wind Speed Recorders (HWSR) along the East and West Coasts of India. HWSR is having a solid-state sensor with no moving parts. It is capable of providing uninterrupted data in cyclone prone coastal areas in severe weather conditions including high winds and heavy rains. The system is capable of measuring wind speeds up to 0-65 mps with an accuracy of 1.5 per cent rms and a resolution of 0.01 mps.

The system has monitored high wind speed during December 2003 Machilipatnam cyclone. A complete description of HWSR system and the wind data as observed during the cyclone is presented in this paper.

1. INTRODUCTION

Tropical cyclone is an atmospheric system in which very strong winds prevail over a large part. It also consists of a huge mass of revolving moist air. Within this system there is an annular zone close to the earth's surface, sea or land where wind speeds of 25 to 50 mps are encountered. On rare occasions wind speed can be as high as 65 mps with gust superposed. The winds are weaker towards the centre as well as towards the periphery of the system. The sense of rotation of this large mass of air is anticlockwise in the northern hemisphere. This large revolving mass of moist air has a deficiency of atmospheric air pressure throughout the system. The deficiency of pressure at the centre is often about 2% below the normal. The amount of pressure deficiency at the centre determines the severity of the cyclone. The horizontal pressure gradient from the periphery to the centre is small almost half the way and thereafter it becomes steep. This rapid decrease of pressure with horizontal distance coupled with forces brought into play by the rotation of earth around polar axis gives rise to the very strong winds of 25 to 50 mps or even more. The revolving system moves as a whole and the direction of displacement in the Indian latitudes is between West-North-West and East-North-East.

Besides strong winds and large deficiency of atmospheric pressure, a tropical cyclone is characterized by heavy cloudiness and heavy to very heavy rainfall over wide areas.

In many cyclones, particularly the severe ones, there is a cloud-free, almost circular area, at the centre called the 'eye'. Here, the atmospheric pressure is the lowest. The winds are very weak; often it is calm.

The number of Cyclonic Storms/Severe Cyclonic Storms which have crossed different states of Indian coasts, (for the period 1891 –2000) is presented below:

State	Total Nos.
West Bengal	69
Orissa	98
Andhra Pradesh	79
Tamil Nadu	62
Karnataka	02
Maharashtra	18
Gujarat	28
Kerala	03

2. THE NET WORK OF HWSR STATIONS

IMD has recently installed state-of-the-art instruments for monitoring the high winds associated with cyclonic storms on the East and West Coasts of India, at 20 stations (Fig. 1).

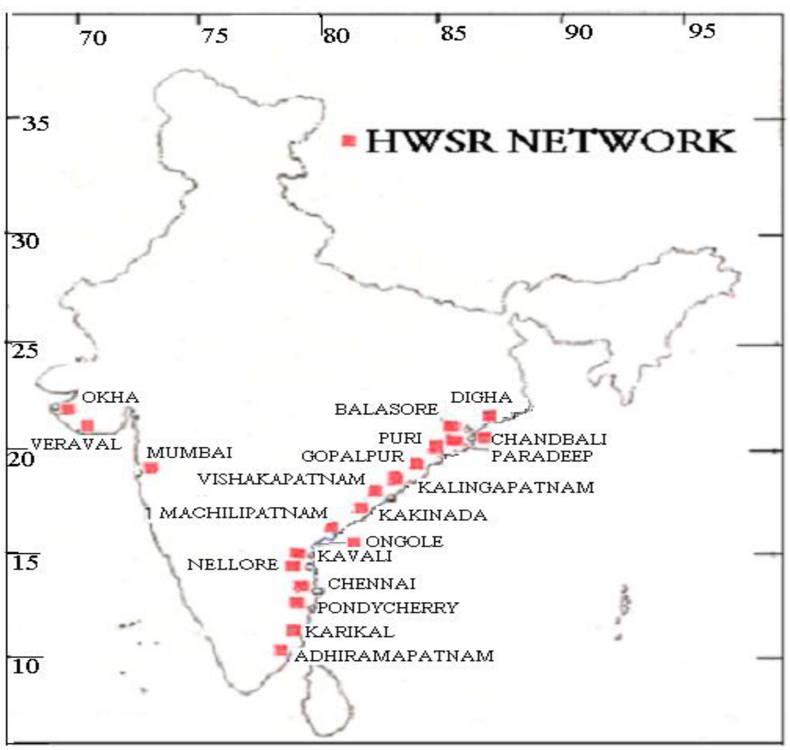


Fig.1: HWSR Network.

3. SYSTEM DESCRIPTION

The High Wind Speed Recorder System mainly consists of an Ultrasonic wind sensor, which has no moving parts; it consists of display unit with an easy read-out of wind information, a data logger with 22-bit A/D converter, a strip chart recorder with selectable recording speed and a PC for downloading the data from data logger. The system is also provided with 48 h back-up power supply (UPS). It has a lightning protection for the sensor. A block diagram of the system is given in Fig. 2.

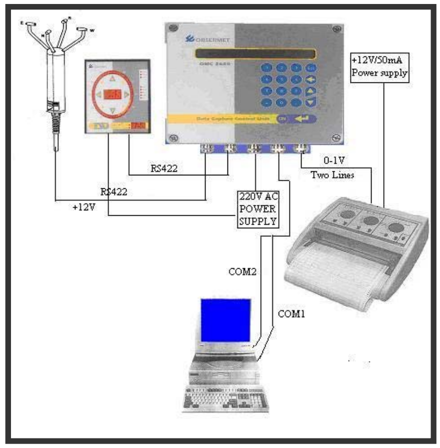


Fig.2: Signal flow diagram of High Wind Speed Recorder

COM1→ Live wind data to the computer COM1 port every 1s either from the display unit or the ADAM card (RS422 to RS232 converter) of the data logger Unit decided by the mechanical switch at back of the data logger.

COM2 → Logged data from the data logger to the PC COM2 port in the interactive mode.

3.1 Wind sensor & its Calibration:

The two-axis (x, y) wind sensor uses the ultrasonic technology with no moving parts. The system does not need any expensive calibration tools. IMD carried out calibration of ultrasonic wind recording sensors in its wind tunnel.

The tunnel is of the open circuit type having a square test section of 60cm x 60cm. It has a contraction ratio of 9 and honeycomb and screens at inlet. The maximum speed in the test section with a 15 HP electric motor drive is about 45 mps smooth and continuous variation of speed is provided over a wide range (4.5 to 45mps) by means of an aerodynamic speed control (flap) mechanism combined with variable speed drive of electric motor.

The true wind speed is calculated using a projection manometer reading using the formula $3.8245\sqrt{diff}$, mps, where *diff* is manometer readings (original – actual after attaining the desired speed).

The wind sensor works on 9 to 30V dc with a current consumption of 60 mA max. It has a wind speed reporting range from zero to 65 mps and possess uniform rate for the entire range. The accuracy for 0 to 5 mps is better than ±3% and for >5 mps it is better than 2%. The response time is better than 1s and threshold is 0.5 mps or better. It has a very high resolution i.e. ±0.01mps.

In case of wind direction, it is reporting in the range from 0 to 359 degrees, with an accuracy better than ±2% for <25 mps and better than 1% for >=25 mps. The output of sensor is in serial mode with RS-422 full duplex with selectable baud rate from 300, 1200, 2400, 4800, 9600, 19200 and 38400 bauds.

3.2 Working principle:

The two-axis ultrasonic sensor works on the principle of travel time taken by the 40 kHz ultrasonic sound pulse between the trans-receivers located in E-W and N-S direction separated by a distance of 115 mm. The travel time is detected & measured by the processor circuit in the sensor. From the travel times TE-W (sound pulse travel time between east transreceiver to west transreceiver) and TW-E (sound pulse travel time between west transreceiver to east transreceiver) are sampled from E-W. Similar measurements of the travel time done by the N-S transreceiver and TN-S, TS-N are measured. The processor in the sensor takes 40 samples of these travel times per second.

40 Samples are averaged for 1 s interval both north and east component of the wind is computed by the processor inside the sensor. The processor further calculates the wind direction and actual wind speed in the polar co-ordinates. Finally sends wind speed and direction for 1 s average in the form of a telegram in RS 422 format.

There are two modes of operation for the system (1) measurement mode – which is normal mode of operation (by default) from power up onwards. The other mode is (2) Interactive mode – which allows the anemometer to be set up and interrogated.

3.3 Sensor Installation:

Ultrasonic sensor was set to point North, using North alignment indicator on the base of the instrument. Separate earthing was provided for the sensor in order to protect it from the lightning. A typical photograph where sensor is installed with lightning protection is given in Fig. 3.

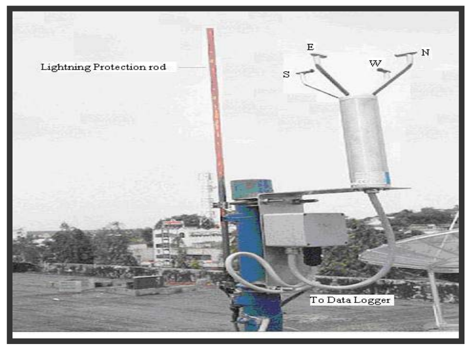


Fig. 3 →

3.4 Wind Display:

Incoming RS 422 serial data (9600 baud, 8 data bits, 1 stop bit, parity-none), from the wind sensor via a surge protector enters the display unit through Data Logger unit. The processor PCB in the display unit converts this incoming serial data into parallel mode, which is given to the display driver unit for the display of both wind direction and wind speed.

Wind speed is displayed in 3 digits, seven segment LED display of 14.3 mm height. The gust display is three digit 7-segment display 10.1mm height. The direction is indicated by 36 LEDs circularly placed having amber colour. The scale selection option in knots, mph, mps and kmph is available on a press of the button.

3.5 Data Logger:

It basically consists of four analogue input channels, with 22-bit analogue to digital converter. It has 1 MB cyclic memory and averaging interval programmable from 1 minute onwards.

The D/A converter in the unit converts incoming wind speed data to analogue voltage in the range from 0-1V for 0-65 mps. The converter also converts the wind direction signal for 0-400° to analogue voltage in the range 0-1V and feeds to the memory module of data logger. These outputs can also be connected to an analogue recorder for continuous recording of wind speed and direction.

It has a provision for telephone modem housed inside the logger casing for down loading the data remotely. It has RS 232 connectivity for computer and also for satellite transmitter.

3.6 <u>Strip Chart Recorder:</u>

The strip chart recorder works on the principle of comparing the input voltage against the derived variable voltage. In a comparator, the output of the comparator drives the DC motor till the variable voltage is equal to the input voltage. The recording pen is connected to the motor by mechanical means. The pen records continuously for the varying input voltage. The magnification/scaling can be adjusted by magnification of the variable voltage source.

4. SEVERE CYCLONIC STORM THAT CROSSED MACHILIPATNAM

A trough in the easterlies over the Andaman Seas and the adjoining southeast Bay became a low pressure area by 11 Dec. Its subsequent developments are given in the following Table 2:

TABLE –2

DEVELOPMENTAL STAGES OF THE SYSTEM

Date	Time (IST)	Location		State of the pressure system
		Lat. (°N)	Long. (°E)	
11.12.2003	-	-	-	Low pressure
11.12.2003	1730	4.5	90.5	Depression
12.12.2003	0830	6.0	89.0	Depression
12.12.2003	1730	7.5	88.0	Depression
13.12.2003	0830	9.0	87.5	Deep depression
13.12.2003	1730	9.5	87.0	Cyclone
14.12.2003	0830	11.0	85.0	Cyclone
14.12.2003	1730	12.0	83.5	Severe cyclonic storm
15.12.2003	0830	14.0	81.5	Severe cyclonic storm
15.12.2003	1730	15.5	81.0	Severe cyclonic storm 80km south of Machilipatnam.
16.12.2003	0230	-	-	Cyclonic storm
16.12.2003	0830	-	-	Deep depression

Maximum intensity of the system as given by Satellite Kalpana-1 was T3.5 between 1730 h of 14 and 2030 h of 15 December, 2003. The track of this cyclone is presented in Fig. 4. Satellite pictures about the movement of this cyclone are given in Figs. 5-7 and the radar pictures as observed by Cyclone Detection Radar installed at the station in Fig. 8.

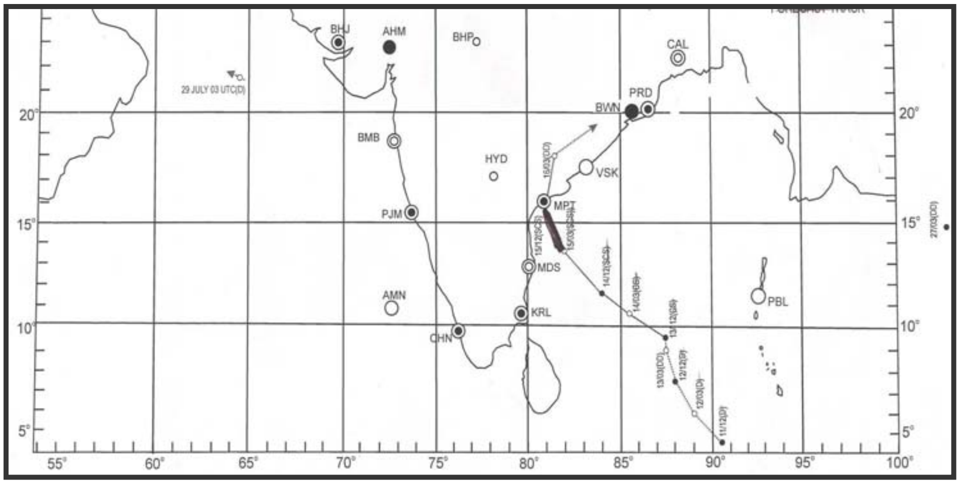


Fig. 4: Track of the cyclone crossed Machilipatnam during December 2003.

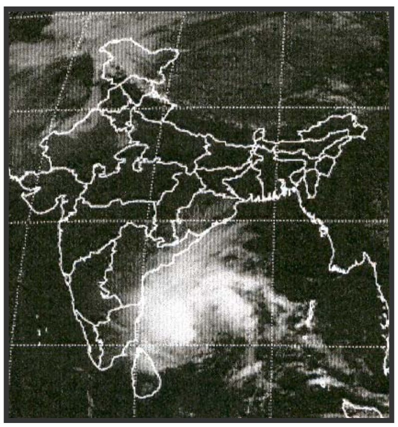


Fig. 5: Satellite image (2030h. IST – 14 Dec.) before the cyclone crossed the Coast

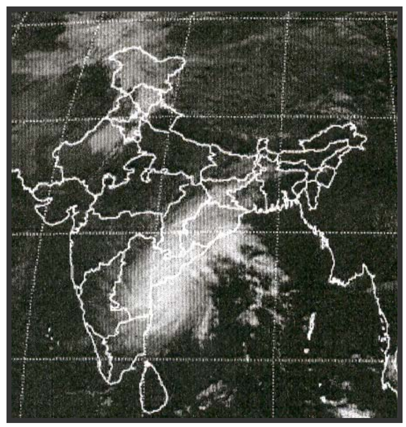


Fig. 6: Satellite image (1730h. IST – 15 Dec.) during the cyclone crossing the Coast

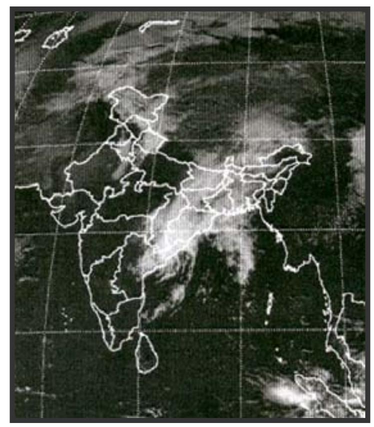
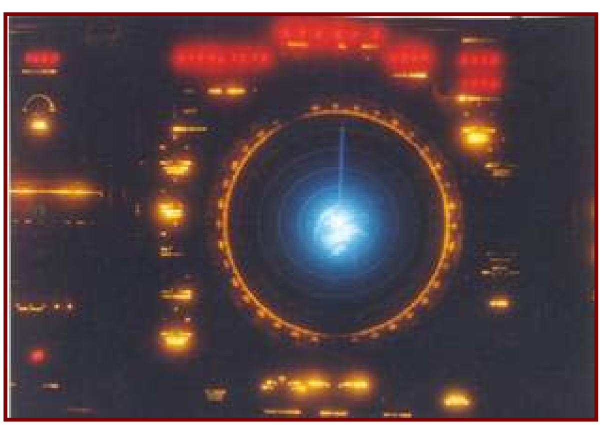
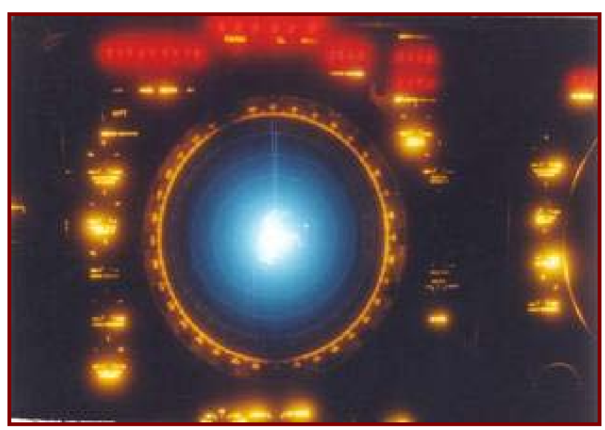


Fig. 7: Satellite image (0830h. IST – 16 Dec.) after the cyclone crossed the Coast



11:30 h. (IST) – 15 Dec., 2003.



15:30 h. (IST) – 15 Dec., 2003.

Fig. 8: Radar pictures as obtained by the Cyclone Detection Radar of Machilipatnam.

4.2 Damages caused by the cyclone:

- Eight people died due to heavy wind and rainfall.
- About 2000 buildings were destroyed completely and more than 7000 were partially damaged.
- Overhead telecom lines were disrupted.
- About 2 lakh hectares of agricultural land was submerged in the associated heavy rainfall.
- Total cost of all damages was estimated to be about Rs.240 crores.
- Ship M.V. Nandak was severely disabled and it sank near Machilipatnam. All the crew members were, however, rescued by Coast Guards.

4.3 Chief amount of rainfall in cm (16 Dec.):

Repalle	-	19
Bhemodele & Kodia	-	17
Nuzvid & Tenali	-	15
Machilipatnam & Kakinada	-	15
Gannavaram	-	13

5. DISCUSSION

The variations in wind direction and wind speed are presented in the following graphs while the cyclone was crossing the coast. 1-hour average wind speed (in mps) as recorded by the system from 1600 h. of 15 Dec. to 1700 h. of 16 Dec. are shown in Graph-2.

The peak wind speed was observed between 1800 h. and 1900 h. Hence 10-minute average wind speeds (in mps) as recorded by the system between 1830 h. and 1930 h. are given in Graph-3.

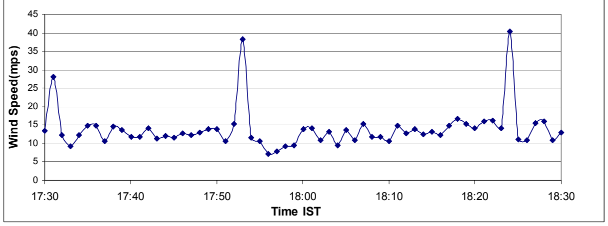
1-minute average wind speeds (in mps), as recorded by the system, between 1830 and 1930 h. is presented in Graph-4.

1-minute average wind speeds (in mps), as recorded by the system, when cyclone was 80km south of Machilipatnam are presented in Graph-1.

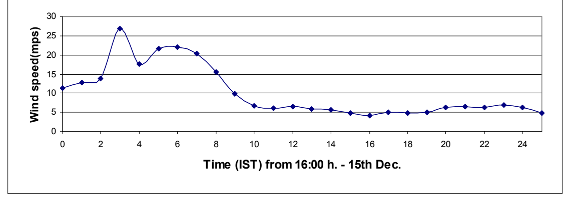
1-minute average wind speeds (in mps), as recorded by the system, after the cyclone crossing the coast is presented in Graph-6.

Similarly, changes in wind direction (in degree), as observed before during and after the cyclone crossed the coast, are shown in Graphs 7-9.

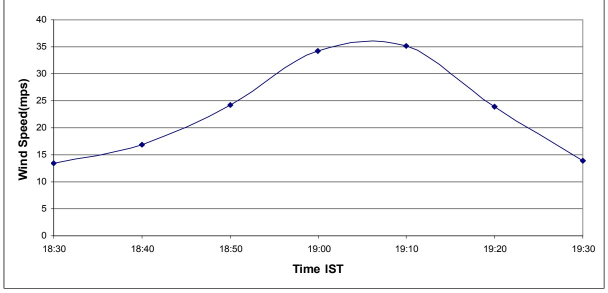
Changes in wind direction and wind speed with reference to critical time when cyclone was crossing the coast are presented in Graph-5.



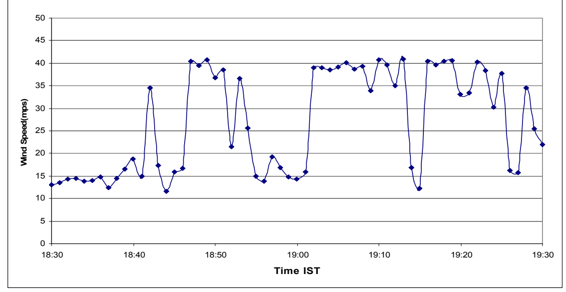
Graph 1: One-minute mean wind speed when cyclone was 80 km south of Machilipatnam



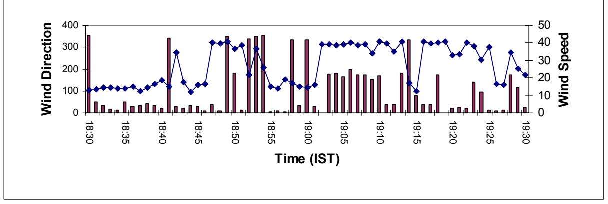
Graph 2: Wind speed (1-hour average) experienced during cyclone was crossing the Coast.



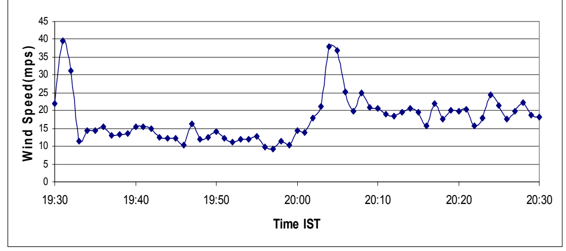
Graph 3: 10-minute mean wind speed at the time of the cyclone crossing the coast.



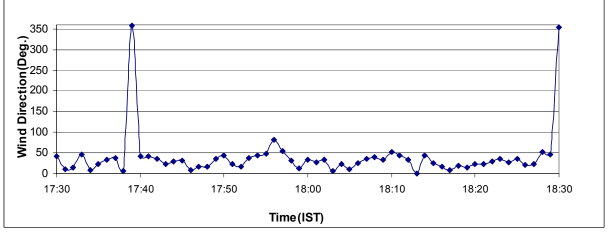
Graph 4: One-minute mean wind speed at the time of the cyclone crossing the coast.



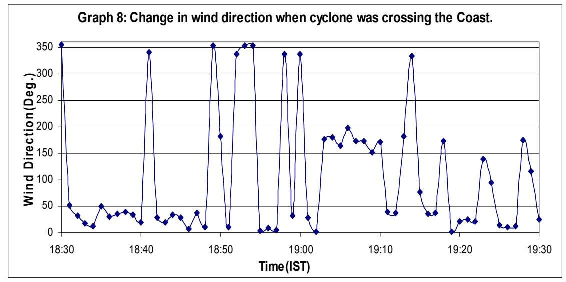
Graph 5: Wind direction and speed while cyclone crossed Machilipatnam Coast.



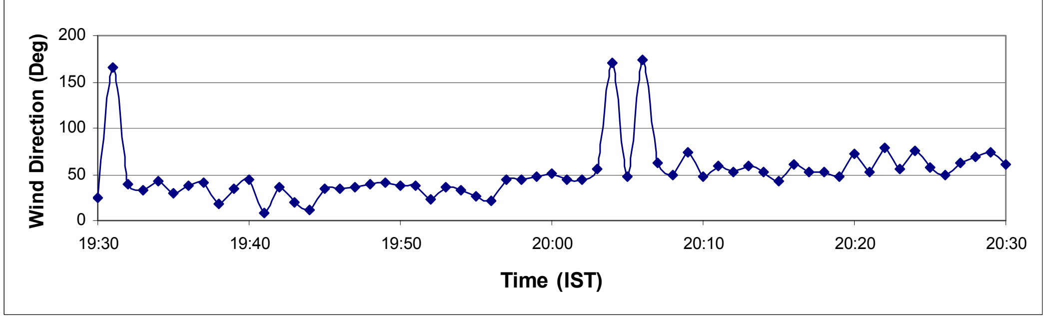
Graph 6: One-minute mean wind speed after cyclone crossed the Coast.



Graph 7: Change in wind direction observed before cyclone crossed the Coast.



Graph 8: Change in wind direction when cyclone was crossing the Coast.



Graph 9: Change in wind direction experienced after cyclone crossed the Coast

The wind speed/wind direction with time when cyclone was about 80 km south of the station shows no significant variation. However, when cyclone was crossing the coast, following variations in wind speed and wind direction are observed:

- A sharp increase in wind speed from 14 mps to 27 mps between 1800 h. and 1900 h. and from 2000 h. and 2100 h.
- A sharp decrease in wind speed in between these two peaks, i.e. between 1900 h. and 2000 h.
- The peak hourly average wind speed recorded is of the order of 27 mps between 1800 h. and 1900 h.
- The peak 10-minute average wind speed recorded is of the order of 36 mps during 1900 h. and 1910 h.
- The peak 1-minute average wind speed recorded is of the order of 40 mps from 1847 h. and 1853 h. and again between 1902 h. and 1925 h.
- The change of wind direction from 'NNE' to 'southerly' is experienced between 1902 h. and 1930 h.
- The significant changes both in wind direction and wind speed is recorded between 1830 h. and 1930 h. of 15 Dec., 2003. The cyclonic wind experienced is seen to be for a very short duration and weakened immediately after crossing the coast.

6. CONCLUSION

A large number of environmental factors influence the formation, development, movement, areal extent and structural features of a cyclone. However, due to non linear nature of the atmosphere the assessment of these environmental factors in an operational mode remains practically difficult causing uncertainty in landfall forecast. The accurate and continuous wind information is possible with the help of high wind speed recorder system installed at the station. With the help of radar system available for cyclone tracking, exact position of the cyclone in the sea is known well in advance.

The performance of the HWSR system was satisfactory during the cyclone and it has provided vital information of wind when the cyclone was crossing the coast.

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THE NEW METEOROLOGICAL OBSERVATION NETWORK IN THE NETHERLANDS; STATUS AND OPERATIONAL EXPERIENCE

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ABSTRACT

At the TECO 2002 the new meteorological observation network of the Netherlands was introduced. The synoptic part of the network became operational as planned in November 2002. Since then all synoptical and climatological reports of KNMI are produced fully automated, including 15 stations that include visibility, cloud and weather information. The airport systems became operational in February 2003. The slight delay was caused by the adaptations required for the systems of the air traffic services provider. The most difficult part of the introduction of the new observation network was the embedding of the maintenance in the various departments within KNMI. In 2003 and 2004 the flexibility of the MetNet system was used extensively for making configuration changes. These changes include e.g. the introduction of the new fifth runway at Amsterdam Airport Schiphol in combination with the renumbering of nearly all runways, and the connection of 9 airbases of the Royal Netherlands Air Force to the network. The network acquires data from all stations centrally every 10 minutes and makes it available to users. This proved to be a major advantage compared to hourly reports. Internal as well as external users now use the 10-minute data extensively. KNMI developed several applications for presenting the data that is available in the network. Furthermore, functionality has been added to the MetNet system e.g. a fully automated METAR including algorithms for cloud and weather and the AUTO TREND. Apart from 3 major incidents the entire network proved to be very stable.

1. INTRODUCTION

At the end of the 90's, the Royal Netherlands Meteorological Institute (KNMI) realised that it had to replace its network of automated weather stations and the meteorological systems that were used at the Dutch civil airports. The system was getting too old so spare part were hardly available, the maintenance was cumbersome and expensive, and it could not be extended for future needs such as the automation of visual observation (Wauben, 2002) and the addition of the new runway at Amsterdam Schiphol Airport. Another reason was the separation of the air traffic services and the meteorological systems that resulted from new governmental regulations. Furthermore, the new network should use available new techniques like network TCP/IP connections and remote maintenance. The new system should be modular and flexible, and should replace the different systems that were used at automated stations, manned stations, airports and airbases. The boundaries of the redesign project were that the sensors and KNMI sensor interfaces should be kept, and on the other hand that the meteorological and hydrological reports should be continued, but in addition a 10-minute database should be made centrally available containing the data of the entire network. The architecture of the new meteorological observation network has been described in Kuik and Haig (2002) and Wauben et al. (2002). In 2000 KNMI and Almos Systems started the project to implement the new meteorological network. In total there are 23 fully automated observation stations, 5 civil airports, 2 navy airbases and a central site at De Bilt. Furthermore data is acquired from a lightning detection system and from another database providing 10-minute data from about 75 stations in the North Sea and the Dutch coastal waters. At the central site all data is collected, processed and stored. All meteorological reports are generated at De Bilt, except for the aeronautical reports that are generated locally at the airport systems, since airports should be able to operate stand-alone.

2. UPGRADE PROJECT

In January 2000 Almos was granted the contract after an EU tender procedure. The rest of 2000 was taken by making more detailed specifications and system designs. The functional specifications were described in a document of about 100 pages, but further details were given in 75 KNMI documents. The hardware and software requirements, interfaces, design and tests were documented within the project by another 100 documents. In order to check the specifications test data was provided for all algorithms and reports. It was agreed that when inconsistencies or omissions in the specifications turned up that the following priority should be applied: (i) the source code of algorithms provided by KNMI, (ii) the project documentation and minutes of meetings, (iii) the supplied KNMI documents, (iv) official WMO and ICAO documents, (v) and finally the Almos solution. In order to obtain more flexibility the KNMI algorithms were added to a DLL library that interfaces with the MetConsole Almos software. In order to get a feeling of the user interface several sessions were organised using demo versions of the systems. These sessions resulted in a design of the Human Machine Interface that was documented and later used as a starting point of the manuals. End 2000 the design phase was completed and Almos started building the prototypes that took most of 2001 and was completed with the Factory Acceptance Tests (FAT). Separate FATs were conducted for the automated observations stations and the central system in De Bilt in September 2001, and the airport systems in February 2002. After the FAT the central system in De Bilt and the automated observation station, and later the system at Schiphol airport, were installed by Almos and Site Acceptance Tests (SAT) were performed in November 2001 for the De Bilt system and July 2002 for the Schiphol system. The other automated observation stations and airports and airbases were installed after the FAT by KNMI staff. The new system was built up next to the old system. That way there was sufficient time to get experience with the new system. During this parallel period it also turned out that the automated observation stations were not stable enough and required a design change. Near the end of the project there was a planned opportunity for upgrading the new system. During this upgrade all relevant changes, which were made in the meantime to the old system, could be implemented in the new system, so that there was no deterioration of the quality of the data and reports. This upgrade mainly consisted of changes in the coding of the meteorological reports and to the relatively new algorithms for to the automation of visual observations that required some fine-tuning after operational experience with the old system. Finally, a Final Site Acceptance Test was conducted for the entire network under full load. At the end of the project a switch was made from the old to the new observation network systems. This mainly meant that the users switched to the new system for viewing and extracting the meteorological data, a similar switch was made for monitoring and maintaining the network and observers had to make the meteorological reports on their new systems. The only configuration required for the introduction of the new network was that the meteorological reports of the new system had to be processed by the message switch instead of the reports of the old systems. This change was made on the message where the appropriate connections were started and closed. The synoptical part of the system, including the automated observation stations, the central site in De Bilt and the 2 nave airbases became operational on November 20, 2002 one day before the day planned at the start of the project. The civil airports required at the last minute a new format for the dissemination of the local MET reports and were delayed. The civil airports became operational in February 5, 2003.

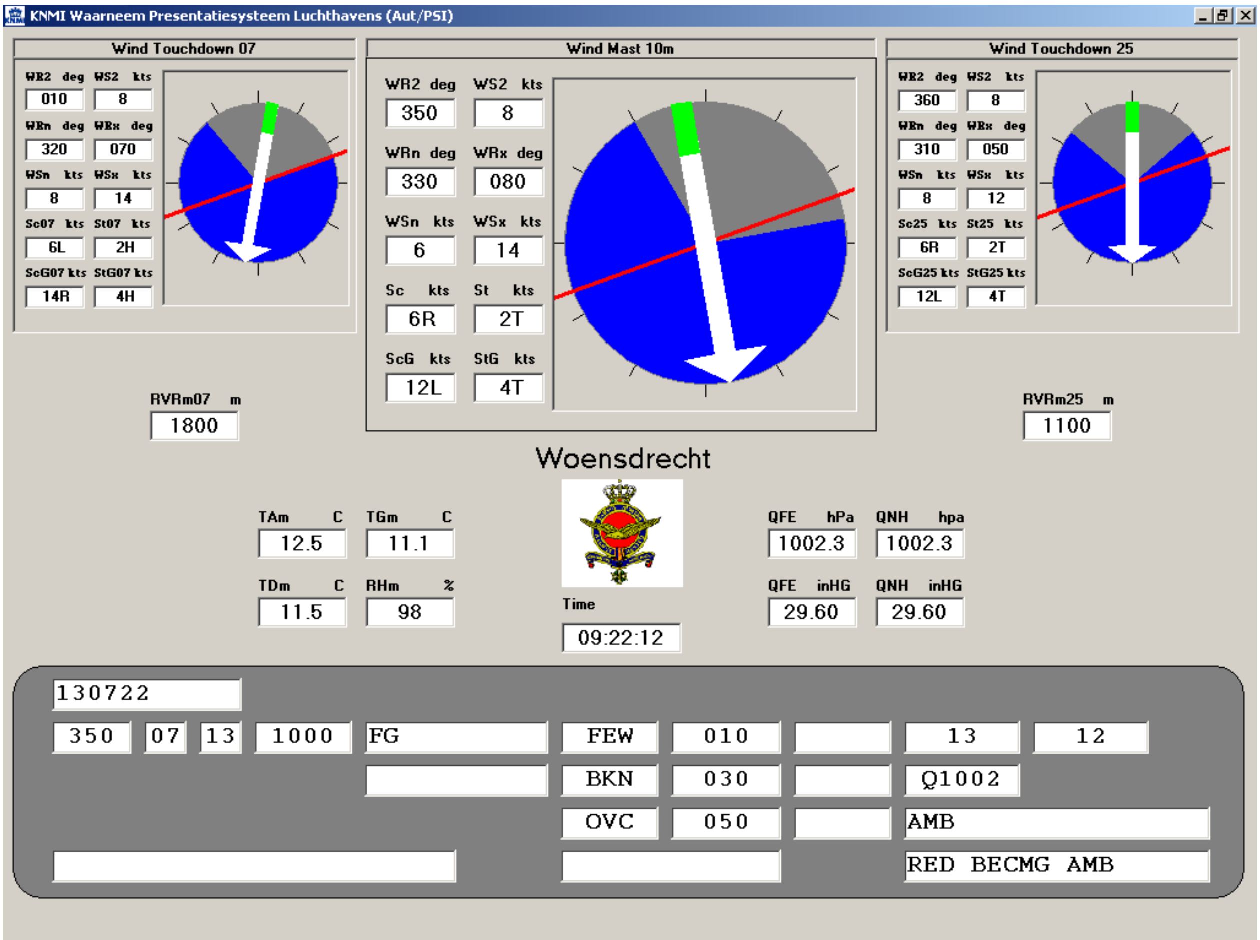

Figure 1: Screen shot of the KNMI WPL application that is used to present real time sensor information and current reports available in the MetNet server systems to local users.

The project was conducted almost exactly as scheduled. The delay was only small considering the requested 20 changes that were made during the project. Most changes had little impact on the project, but the new format of the local MET reports (aeronautical), the inclusion of Valkenburg airbase of the Royal Navy and the new civil airport Lelystad at a later stage of the project could only be handled after rescheduling the tasks. Also the problems with the automated observation stations which lead to a redesign of the system and therefore required an exchange of all systems by a combined effort of Almos and KNMI staff did not lead to a delay. Even the largest delay encountered in the project, i.e. the Site Acceptance Test of Schiphol airport that occurred with a delay of 8 months, had almost no impact on the overall progress of the project. The reason for this is the KNMI could continue with the installation of the automated observation stations and also started with the installation of the other airports. When the SAT of Schiphol was finally accepted, a software upgrade could be applied to all other airports remotely from De Bilt. KNMI also developed the WPL application in order to facilitate the presentation of real time data to local users. A screen dump of the WPL application is shown in Figure 1. When the new observation network became operational KNMI already had a lot of experience with the new system. The required functionality was available and the network had already proved to be very stable.

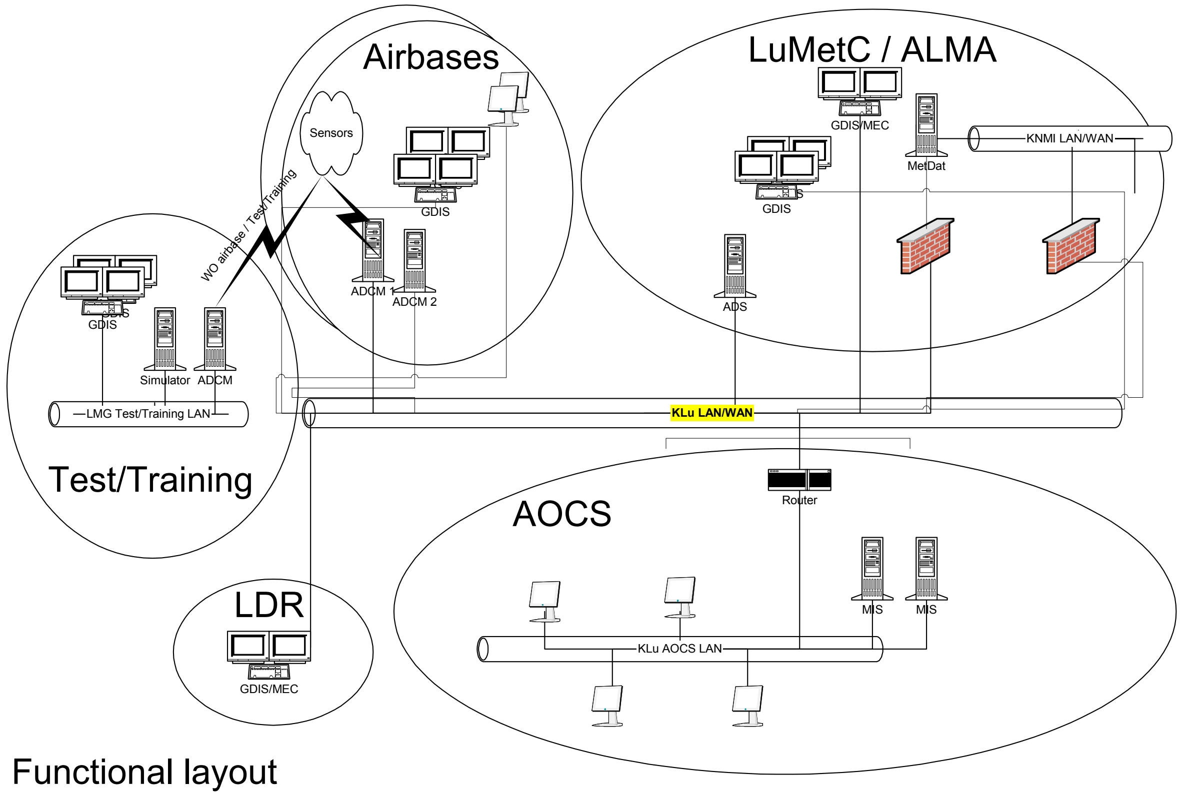

Figure 2: Functional layout of MetNet systems of the Royal Netherlands Air Force indicating the airbase systems, the Test and training system, the maintenance systems at LDR and LuMetC, the central database and the uplink to KNMI at Woensdrecht and the central data server system at AOCS.

3. METNET OVERVIEW

The layout and architecture of the new meteorological observation network has already been described in Kuik and Haig (2002) and Wauben et al. (2002). The system layout today is more or less the same, although some automated observation stations have been rearranged. However, in 2004 the locations of the Royal Netherlands Air Force (RNLAF) were connected to MetNet. Within this project KNMI was contracted by RNLAF to upgrade the network, whereas Almos was contracted by KNMI to assist in the upgrade. Almos purchased all hardware and made some changes to the software in order to handle the specific local aeronautical report of the RNLAF. Furthermore, the central systems in De Bilt were upgraded in order to be able to handle the additional data efficiently. Within this project the RNLAF locations have been upgraded and connected to the MetNet system one by one and separate acceptance tests were executed per location. While Almos assisted in the installation of the central RNLAF sites of Woensdrecht and Nieuw Milligen, all other sites have been installed by a joint effort of RNLAF and KNMI staff. At present all locations have been installed except 1 and the project is running on schedule. Figure 2 gives a scheme of the functional layout of the RNLAF network. All 9 airbases will be equipped with single or dual server systems processing the sensor data and providing data and digesting manual input from observer systems. Real time data is also presented at several locations, e.g. in the tower and at the fire brigade, using the KNMI WPL application. All airbases are connected to the RNLAF central site Woensdrecht where a central database is located to store all airbase data for a period of 100 days. The CIBIL system of KNMI can connect to each airbase via Woensdrecht in order to acquire all sensor data for generation synoptical reports. Woensdrecht also contains the Test and Training system of the RNLAF that is used for education and testing new software and configuration releases. The Test and Training systems of RNLAF and KNMI in De Bilt can be connected for performing integrations tests of the entire network. At the meteorology group of LuMetC in Woensdrecht the software configuration and maintenance is performed while the technical and sensor maintenance is performed from by LDR. In both cases RNLAF and KNMI cooperate closely together. Finally the RNLAF operates a dual system for providing data to users at the centralised Military Air Traffic Services Unit (AOCS) in Nieuw Milligen. These systems acquire sensor and derived data and reports from each airbase and make it available to the RNLAF air traffic staff at centralised approach. Again the KNMI WPL application is used for presenting the data of each airbase to the users. The user can select which airbase is presented.

All systems of MetNet run identical software, i.e. MetConsole, and by configuration the system is told whether it should operate as the central CIBIL system or a specific airport. A separate configuration is available for each server system in the network, although e.g. the 4 server systems that make up the Schiphol MetNet system (a dual server system for the data acquisition and processing of the data and a dual server system for providing the data to the users) use the same configuration. The usage of identical software ensures that the products of all systems are the same and requires less effort in keeping the software up to data. The MetNet systems also use the same hardware, although the server and client systems are different and by now also the recently installed systems of the Royal Netherlands Air Force use different hardware, but these systems can also be used within the KNMI network. Identical hardware has of course the benefit that less spares are required. The MetNet system can optionally be configured as a single or dual system and can furthermore be separated in a data acquisition/processing unit and a unit providing data. The above mentioned Schiphol system uses a full set of 4 servers consisting of a dual system for acquisition/processing and a dual system for providing data, whereas e.g. the Deelen Military Aviation Terrain system consists of a single data acquisition/processing/providing system. It should be noted that the automated observation stations use a tailor made hardware that is designed for outdoors usage and require no configuration. It simply stores all incoming sensor data as provided by the sensor interface in a fixed format and makes this data, upon request, available to the central system. At the central site the data is processed according to the rules contained in the configuration.

Figure 3 gives an overview of the data flow and the data processing in the MetNet system. Sensor data is acquired by an AWS or an airport or airbase systems or enters MetNet via the RMI system, a central system that contains North Sea and coastal area data. Data is also obtained from a lightning detection system and a precipitation radar and METEOSAT, although the latter 2 are not operationally used in the production of meteorological reports. Synoptical data is processed at the central site, whereas aeronautical data is generated at location and provided to the users. For that purpose the servers can be configured to perform calculations. The airports and airbases run algorithms that derive the cloud layer heights and amounts from ceilometer data and check for vertical visibility in cases of low visibility when the ceilometer data shows no details. The aviation systems also determine the weather based on the measurements of several sensors such as a present weather sensor that reports precipitation type and uses the lightning discharges detected by the SAFIR system. The SAFIR data is provided to the airport and airbase systems via CIBIL. In case the connection to the central site is lost, the airport systems can still generate the automated reports although it will remark in the reports that lighting data is not available. Similarly the central site also uses algorithms to provide e.g. cloud and weather data but the processing of synoptical data differs from that of aeronautical data as a result of different requirements.

4. SOME METNET NUMBERS

The MetNet system of Amsterdam Airport Schiphol acquires the data of about 60 sensor interfaces. This sensor interface reports the sample, 1-minute average, 10-minute average and extreme values of meteorological parameters and their status. All sensor information, including the running averages are updated every 12 seconds. The sensor data at Schiphol is stored in 66 sub-stations. These stations include the 23 physical locations that are used for the 23 visibility sensors situated along the runways of Schiphol as well as other physical locations for providing selected sensor information of other airports throughout the Netherlands as well as data from other stations that are used in the generation of the so-called Regional QNH and the Transition Level report. Furthermore so-called pseudo stations are used that do not correspond to a physical location, but are used to generate the data for e.g. the 12 available runways and the up to 4 runways in use for take-off and landing. Note that Schiphol has in fact only ‘6’ runways, but since some runways can be operated from both sides and since regulations regarding backup of sensors and cross and tail winds differ between landing and take-off operation a further distinction had to be made. In total the Schiphol system contains about 2100 variables, 1300 of which are updated every 12 sec. A example of a screen of the Schiphol MetNet system is shown in Figure 4.

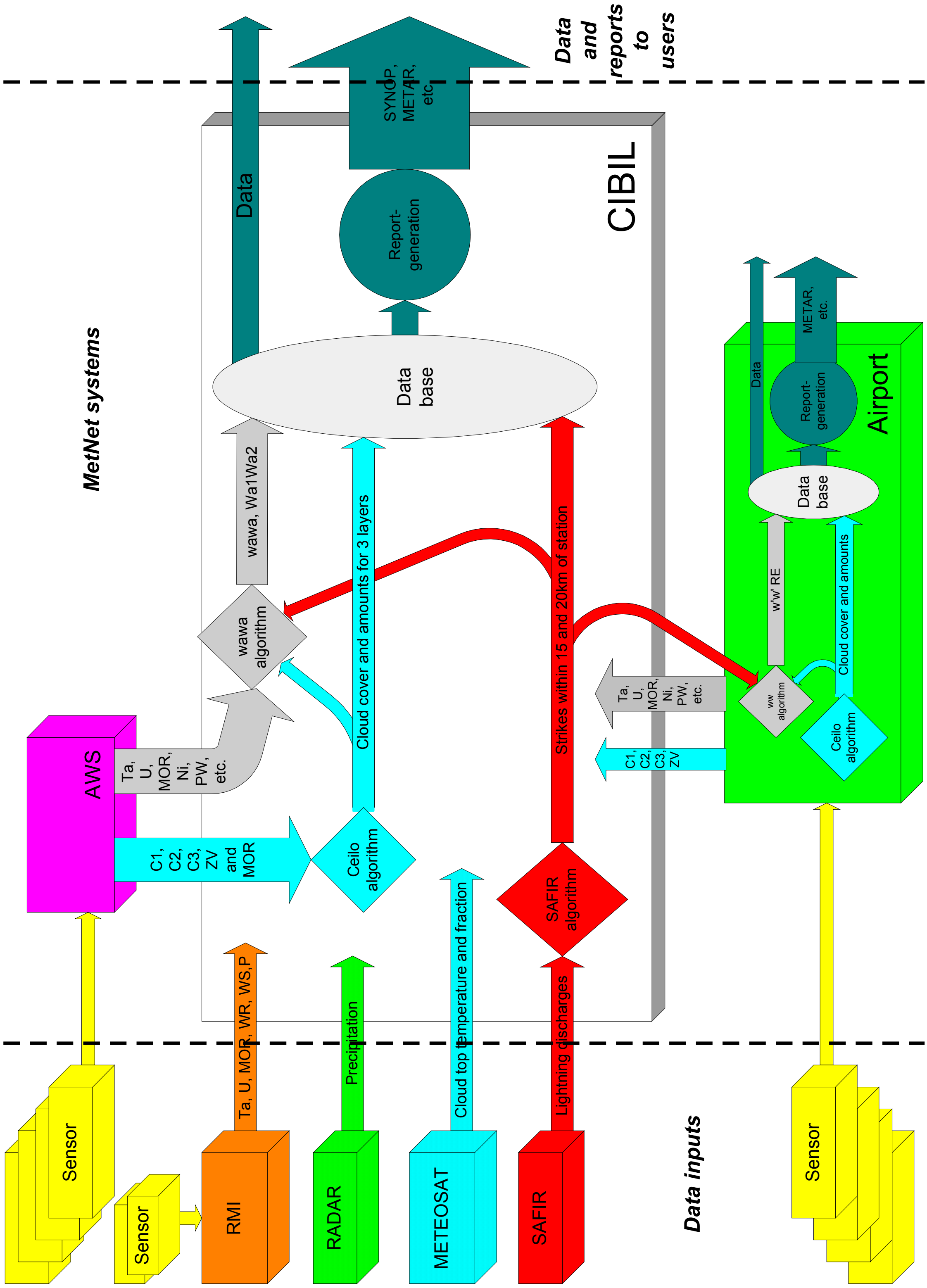

Figure 3: Schematic view of the data flow and processing in the MetNet system.

In the beginning of 2003, after the new airport systems were already operational, the fifth (new) runway of Schiphol became operational and was added to the system. This meant that a total of 16-substations had to be added. The new runway required 4 visibility sensors since the length did not allow the regular usage of 3 sensors along the runway. Furthermore, the touchdown position of the runway was equipped with 2 visibility sensors because it was agreed that the observer, situated at a distance of about 8km, would not always be able to detect incoming fog banks. In order to accurately detect such events using visibility sensors, sensors were posted at both sides of the touchdown position. Since the systems of the air traffic services require only 3 positions per runway, the data had to be reduced. The minimum visibility of the 2 sensors near the middle of the runway of the mid position is reported as the visibility at the mid position. The same holds for the visibility at touchdown, but here the visibility is only reported when valid data is obtained from both sensors at either side of the runway. Hence in addition to the 4 physical stations, 2 pseudo stations were required and this times 2 for operation as take-off and landing. Since the runway may only be used from one side, only one set of take-of and landing pseudo stations needed to be included. The introduction of the new runway coincided with a new runway designation scheme. Runways 19R, 19L, 01L and 01R were renamed as 18C, 18L, 36C and 36R, respectively, and the new runway was named 18R/36L. This renumbering changed the names of nearly 30 sub-stations and affected the other airports and the central system in De Bilt as well, since they used data of (some) of these stations.

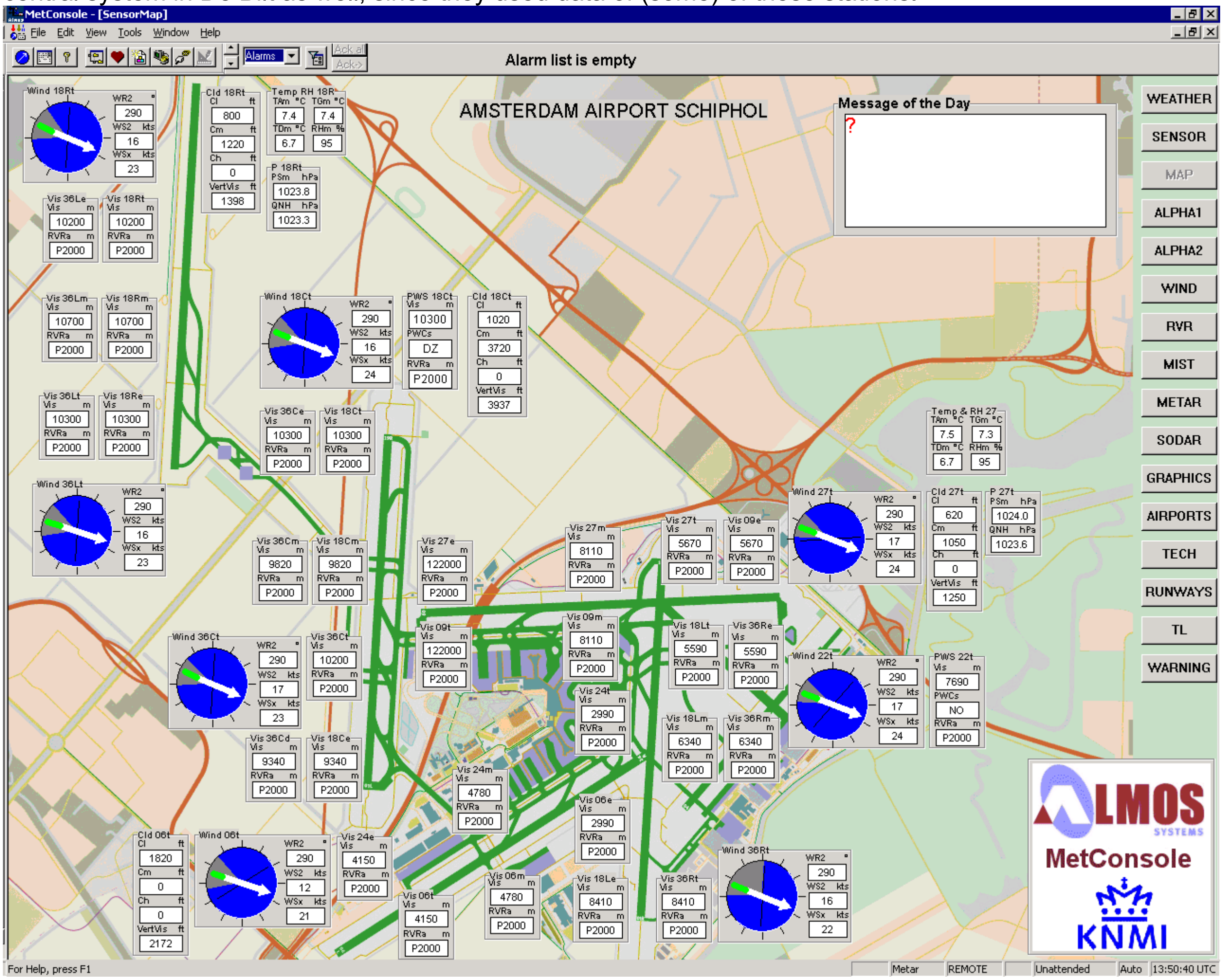

Figure 4: The sensor map overview screen of the MetNet system for Schiphol airport.

The central system in De Bilt currently acquires data from 21 fully automated observation stations. These stations range from basic stations measuring P/T/U/W/R/Q to the 200m research tower in Cabauw containing, apart from a basic station, wind and temperature/humidity measurements at several levels. In total Cabauw consists of 20 sub-stations and 35 sensors. The central system also acquires data from 5 airports, 2 navy airbases and currently 8 air force airbases. Furthermore, 10-minute data is obtained from 27 locations in the North Sea and 46 locations near the coast. In total the central system contains 350 sub-stations and has 9600 variables, of which about 2500 variables are updated every minute, and 4900 variables that update every 10 minutes. All this information is stored for a period of 7 days, during which the data is provided to user systems including the climatological department.

5. METNET EXPERIENCE

The flexibility of the MetNet systems was already illustrated above when the addition of the airbases of the Royal Netherlands Air Force to the MetNet system and the addition of the fifth runway and renumbering of the runways at Schiphol was discussed. Apart from these large changes, many smaller changes on a sensor or station level were performed. The total number of functional configuration changes of the central system now largely exceeds 100. Apart from the configuration changes other changes were made that often required additional functionality to be implemented by Almos. These changes are upgrades of the Windows 2000 operating system and MSSQL server, which were required for security purposes, as was the implementation of anti-virus software to all MetNet server and client systems. The MetNet systems were also equipped with a maintenance tool that is used to monitor the correct functioning of the system and given automatic alerts when certain threshold are exceeded, e.g. CPU and disk usage. Furthermore software was installed in order to be able to perform remote maintenance on the system, besides the remote maintenance available within the Almos MetConsole software. Changes also had to be made to the software so that the central system could process the lightning data in the new HDF5 format after an upgrade of the lightning system. Apart from these changes new functionality was added to the MetNet system on request of KNMI. One of these changes is the AUTO METAR that now also includes algorithms for cloud and weather and is used operationally by KNMI during closing hours of some airports. Another extension was AUTO TREND, which reads the so-called pseudo TREND that are produced by KNMI using centrally available 10-minute MetNet data in combination with precipitation radar and model output. The airport system acquires the pseudo TREND for a specific location and performs a validation and correction step on the airport system so that there are no conflicts in the observation reported in the METAR and the forecasted TREND. Furthermore, KNMI is currently changing the costly ISDN dialup connections to the automated observation stations into GPRS connections. Future changes to the MetNet system include the introduction of the new WMO BUFR format for exchanging synoptical and climatological information; a sensor upgrade of the RNLAF stations that facilitates the generation of fully automated synoptical and aeronautical reports including the visual parameters; a new data input for platforms in the North Sea that will provide detailed sensor data and allow fully automated synoptical and aeronautical reports including visual parameters.

During the extensive Almos projects for the implementation of the new KNMI observation network and the equipment of the locations of the RNLAF the cooperation between Almos and KNMI was very good. Both projects finished nearly on time and the result was satisfactory for both KNMI and Almos. KNMI obtained a system that met the requirements and was very stable, whereas Almos was able to make a product that was in demand in the meteorological community. The smaller projects related to the changes mentioned above were generally not so successful, because the limited amount of man power assigned to them made it hard to get a good and efficient feedback. Almos and KNMI made appropriate changes to the service level agreement and expect that this situation will improve in the near future. The availability of the MetNet system is very good. The synoptical part had an overall availability of 99.64% in 2003 for the automated observation systems, whereas the overall availability of the airport systems was 99.72%. The maintenance staff of the MetNet system had a difficult start when the system became operational. This was partly caused by the fact that although the old and the new system ran parallel for about a year the maintenance staff was not able to make time free to get acquainted with the new system. It was also difficult to get the various aspects of a KNMI wide system settled in the appropriate maintenance groups within the organization. This proved also difficult because the new system changed the distribution of workload within the organization. There was a decrease of workload related to the automated observation systems because those systems did not require any configuration. However, more time had to be spent on the airport systems that were formerly the responsibility of the civil aviation community. This was particularly felt in functional maintenance where one central database was exchanged by another central system with more flexibility and hence more changes were requested requiring additional time. Furthermore the functional maintenance of the hitherto unknown airports systems was added to their responsibilities. During the first year of operation a significant support from the project team was still required. As experience grew and a staff member was added to functional maintenance for the airport systems, the maintenance staff was able to cope with the new network. During the first 2 years of operation there have been some major incidents. During one incident an old configuration of Schiphol was introduced by mistake followed by subsequent coincidences and uncoordinated actions. Since the old configuration contained the old Schiphol names the users did not get the requested information for most of the sub-stations. After remote activation of the correct configuration the problem was solved. Two other incidents involved virus attacks at regional airports. As a result of these attacks several security measures were implemented and the entire network is separated from the outside world by Fire Walls. The last incident involved a leap year bug that showed up on some server systems when the time difference became too large. During this incident Almos provided support and advised KNMI to switch the time synchronization of in the configuration. The following day the bug was traced and new software was made available. However, by that time some damage had already been done.

Another point that needs attention is related to the fact that the introduction of the new observation network at KNMI coincided with the full automation of the entire synoptical network. With the introduction of MetNet the manned stations ceased to exist, except for the airports, but even there the observers only made the aeronautical reports. This automation put much stress on the project and many user complaints that were obtained during the project were not related to the incorrect functioning of the MetNet system, but were the result of the automation of the visual observations and the expected differences. The automation of the visual observations also required that more extensive use should be made of the available 10-minute data. In another project a tool was developed for presenting the available 10-minute data in time series and geographically. The user can easily select the parameter and can show loops or go to a specific time. Furthermore the users can set alarms for any combination of parameters. An example of a screen of the KNMI AVW-Tools application is shown in Figure 5. Please note that KNMI decided that the MetNet system should only acquire, process and make data available to users. The MetNet systems provide information to the maintenance staff and allow monitoring and change of the configuration. The airport systems have a more detailed user interface that is required by the observers for viewing the data en generating the reports. The subsequent visualization of the available data was part of another system, i.e. the meteorological workstation, and the AVW-Tools application has been made as a first step in order to learn by experience how the 10-minute data can be best made available to forecasters.

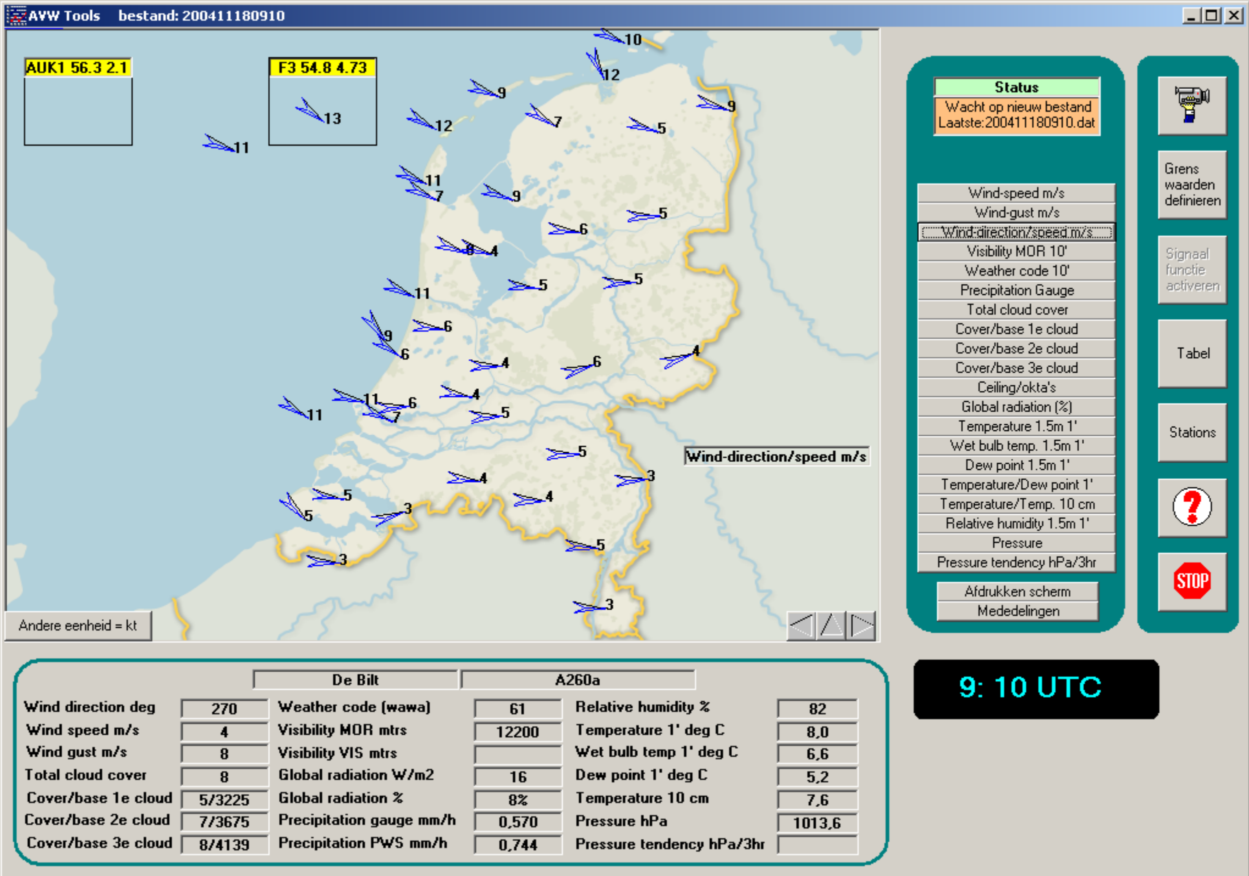

Figure 5: Screen shot of the KNMI AVW-Tools application that is used to present 10-minute data, which is acquired and generated by the central MetNet server systems, to users.

6. CONCLUDING REMARKS

At the TECO 2002 the new meteorological observation network of the Netherlands was introduced. The synoptic part of the network became operational as planned in November 2002. The airport systems followed in February 2003. The most difficult part of the introduction of the new observation network was the embedding of the maintenance within the various departments within KNMI. The entire network proved to be very stable. The availability for synoptic and airport systems in 2003 is 99.66% and 99.72%, respectively. The flexibility of the system was used extensively for making configuration changes. These changes include e.g. the introduction of the new fifth runway at Amsterdam Airport Schiphol. In 2004 9 Royal Netherlands Air Force airbases were equipped and connected to the network. The network acquires data from all stations every 10 minutes and makes it available to users. This proved to be a major advantage compared to hourly reports. There have been made some changes to the MetConsole software in order to correct or change functionality. Furthermore, the automated METAR was extended with algorithms for cloud and weather and an automated TREND was added. A test is performed for GPRS connections to automated weather stations in order to reduce communication costs. Upcoming changes include the introduction of the WMO BUFR format for exchanging synoptical and climatological information.

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REMOTE MONITORING OF WEATHER AT NORWEGIAN AIRPORTS

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ABSTRACT

The paper presents a meteorological parameter display and storing system that is developed to reduce workload in connection with meteorological observations at Norwegian airports. Based on use of license free software (LINUX and PostGre SQL database) all instrument-measured meteorological variables at the airports are displayed in near real-time at forecasting centrals. The parameters are displayed both as time-series and as digital actuals. Sensors are connected to LAN, thus allowing for data processing both locally at the airport and at any chosen forecasting central. All data that are stored and displayed comes from already exsisting sensors at the various airports without any restraint on type of sensor in use at a specific airport. By use of video-technique, the weather around the airport can also be monitored at any chosen forecasting site. Video cameras allows for 360 degree survey of the weather by transmitting JPG-images every 1 minute form each camera. The developed system is very flexibel both with regard to setup of the displaying function, storing of data and inclusions of new sensors as well as to enable users at any site connected to the network to view data from any sensor at any airport they might wish to monitor. At the moment the main use of the system is to add TREND to METARs by meteorologists serving different airports from their workplace at forecasting centrals.

Background.

It was decided that Meteorological personal working at Norwegian airports should be removed from the airports. Meteorological observations, i.e. METAR, should be made by CAA personal at the airport while the TREND addition to METAR should be added by well trained and skilled meteorological personal working at forecasting centrals. To be able to do this it was necessary to present airport meteorological instrument information as near true time time-series at the forecasting centrals. In addition to the measurements from the traditional batch of sensors, video images presenting the sky conditions around the airport had to be included in the information necessary to perform TREND forecasting.

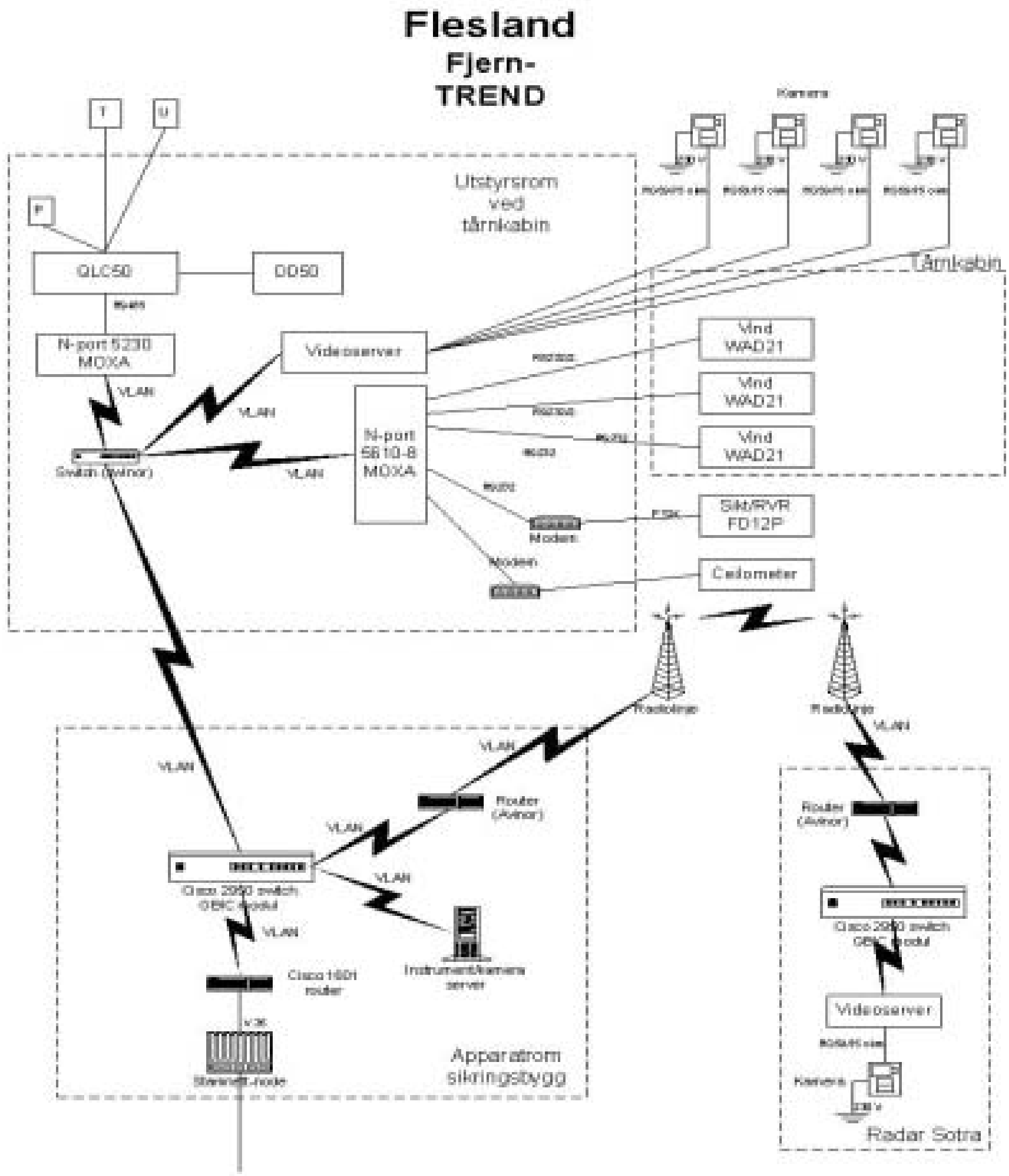
Instrumentation.

In addition to sensors for measurement of air temperature, humidity, air pressure, cloud base and vertical visibility, wind speed and wind direction, the airports were also equipped with forward scatter instrumentation to give information on RVR and present weather. Some of the airports have, in addition to wind measurement along the runway, wind information from nearby mountain sites to help estimation on wind shear in the airport area. All relevant parameters from all meteorological sensors are stored in a database.

System design at the airports.

Serial output from existing sensors at the airport are converted to LAN by means of terminal servers (MOXA). Serial lines from wind sensors are directly connected to the terminal servers. Information from ceilometers and visibility instrumentation goes into the terminal server via modems. Temperature, humidity and pressure measurements are taken from a local logger. Video images are created by a video server. That means that all data are available on net communication. A net connected LINUX server is installed locally at each airport. Figure 1 below shows the design at one of the airports, Flesland outside Bergen. From the airport there is a net connection to the forecasting central that have the responsibility to do the TREND forecasting for that particular airport. Altogether 3 forecasting centrals are included in the net, i.e. Oslo, Bergen and Tromsoe.

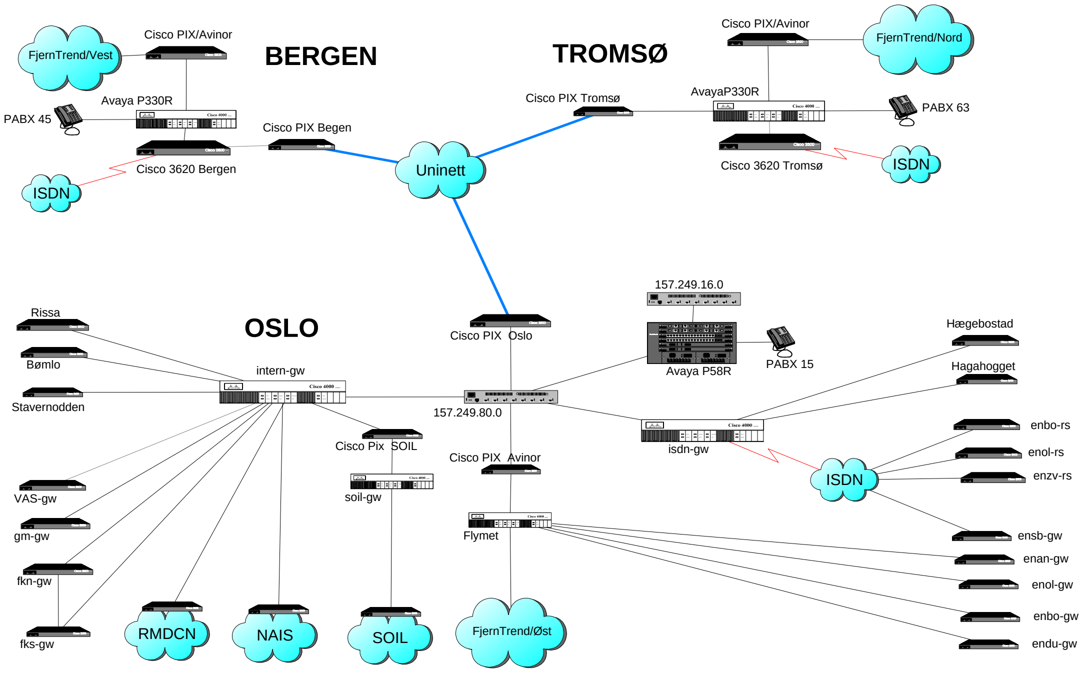
Figure 1. System design at Flesland airport.



At each forecasting central a LINUX server is directly connected to all sensors at all airports that are served by that central. Storing of data in the database is done independently and simultaneously at the central server and at the local server at the airport.

The centrals themselves is further connected via uninet, see figure 2 below.

Figure 2. Net connection



Maintenance of the system is provided by the Observation division which is located in Oslo.

Software development.

All software is developed to run on licence free platforms, i.e. LINUX and PostGreSQL.
As developing tools are used Kylix and Java.

Following software modules are developed:

- Sensor data collector
- Video image collector
- Database
- Sensor data presentation
- Video image presentation

The **Sensor data collector** reads digital parameters from the sensors and store new readings in the database every minute.
The **Video image collector** store new pictures from all video cameras attached once every minute.
The **Database** structure is developed based on **PostGre SQL** database. The structure includes different tables for configuration used to tailor the database to each individual airport, to tailor the data presentation to end users wishes and tables containing meteorological parameter names to enable flexible input of different parameters into the database.
The **Sensor data presentation** is software developed to create the machine/man interface. Since the presentation setup is determined by a configuration table included in the database, it is very simple to change the visual presentation.

The **Video image presentation** is software developed to present the pictures from all cameras to the user. The presentation of video images is available to the user as last picture from each camera as well as an animation showing a sequence of pictures.

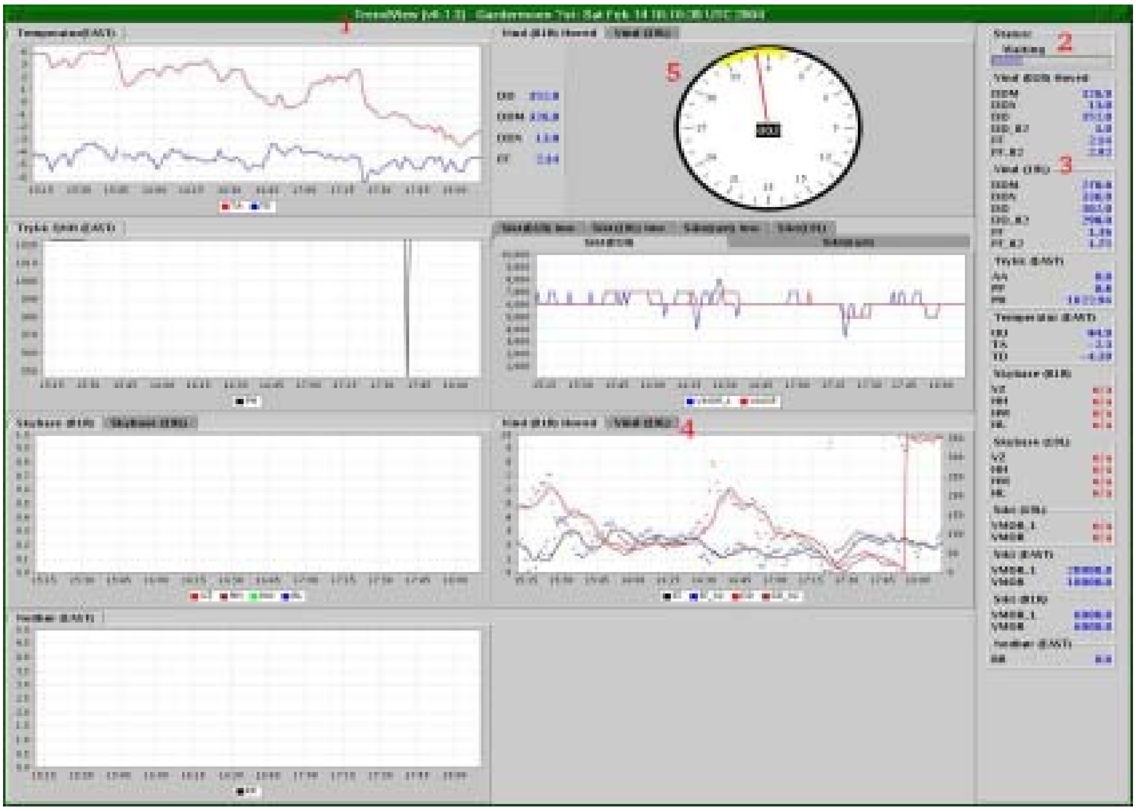
User interface/Data presentation.

All information is shown to the user on two screens, one for information from standard meteorological sensors and one separate screen for video images. For presentation both of sensor measurements and video images we have used 19” flat screens.

Information from standard meteorological sensors

The screen image consists of 7 graphical fields, a field presenting the last measured data as numerical values, a field giving information on the program status and a top field where location and time is given. An example of the screen picture is shown in Figure 4 below.

Figure 4: Data presentation screen.



The Status field (2) consists of a text field and a program progress indicator. The text field tells what goes on at the moment, i.e. Sleeping/Reading/Distributing data. The program progress indicator shows how far the program has come on the ongoing task.

The numerical values field (3) on the right hand side of the screen contains all last values for all wind sensors at the airport, the air pressure values, temperature and humidity values, cloud information from ceilometers and visibility information from forward scatter instruments or transmissometers whichever are mounted at the actual site. When using the mouse to point on an actual value the user will get information about exact time for that measurement. The colour of the numbers also give information regarding the updating of the measurements. A dark blue colour indicates that a valid value, i.e. new value received last minute, a light blue number indicates that the value was not updated last minute and a red number tells the user that the value shown no longer is valid. In some cases n/a is shown in red instead of a numerical value. This is the case if the sensor providing the information is not available for instance due to servicing or sensor breakdown.

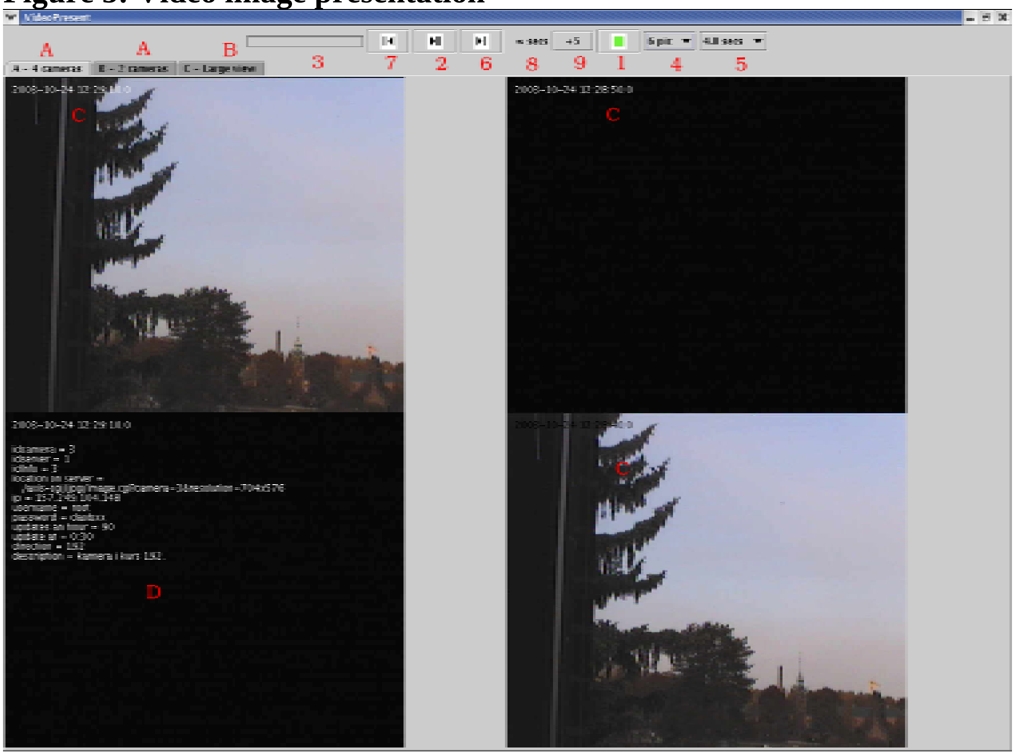
The graphical fields (4 and 5) as developed for TREND forecast users can show altogether 15 different graphs but only 7 visible in a chosen display at the same time. Each shown graph has a tabulator enabling the user to select what information he wants in the graph. By pointing the mouse at a specific graph the user will get information about the content of that graph. For other applications it is possible by database configuration to make many more graphs available on the screen. The restricting factor will be the size of each graphical field in relation to the size of the screen.

Video image presentation.
Normally images from 4 cameras covering a 360 degree horizon is shown on the screen. An example of the user interface for video images is shown in Figure 5 below.

Normally new images will arrive on the screen once a minute.

By pointing on a particular image the chosen image will cover will be enlarged to cover the screen. The upper left corner of each image will give a time stamp for the image. The user can choose to view a sequence of images instead of last image from each camera.

Figure 5: Video image presentation



The user can select the number of images in a sequence. The user also have a possibility to look at selected images by using a pause button in the top field on the screen. To avoid unintended display of old images the status of the video display will automatically go to default showing last image from all cameras after a selected time.

Configuration.

All information and set up tables are stored in the database as configuration tables. Tools to create or change configuration has been developed. As a result of this structure we are left with a very flexible system for different applications for collecting meteorological information via net technology. To add new sensors it is only necessary to write a “driver” for the wanted sensor and put it in the data base by means of existing parameter configuration tables.

Maintenance and operational experience.

The system was operational at the beginning of 2004. Although we have experienced breakdown of some servers, mostly due to power supply failure on the server, the end user has up to now not been left without a valid set of data at his working place. This good experience is due to the design with independent data collection at least two servers for each airport and that the presentation software automatically looks for another server if it is not able to contact the defined main server.

Using the terminal server technology (MOXA) to connect measuring instruments to net communication allows service personal to monitor raw data from each individual sensor system from their working site in Oslo. Such monitoring of raw data will not disturb the normal use of the system, i.e. end users will receive all information undisturbed also when service personal are monitoring sensor data. This functionality is very helpful in relation to troubleshooting.

EVALUATION OF THE RADAR PRECIPITATION MEASUREMENT ACCURACY USING RAIN GAUGE DATA

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Abstract

A weather radar system can provide spatial and temporal information on the clouds and precipitation over several hundreds square kilometres. Using raw data and specific processing algorithms, radar products are obtained. Among these products, a special attention is paid to rain rate product and precipitation accumulation products over predefined time intervals.

The facts that the rain rate is not a directly measured parameter by the radar and there are several limitations of the radar equipment that induce some times big errors in measuring the quantity of precipitation, opened a large opportunity for researches and studies, all these with the goal of obtaining, from radar measured data, the best estimates of the precipitation accumulation. The conventional algorithms for precipitation accumulation actually integrate the rain rate over a user selectable time interval.

Another source of information for the ground level precipitation is the rain gauges network. But, even these sensors cannot be considered "truth" for precipitation accumulation measurements, being affected by several limitations. It was demonstrated, both scientifically and experimentally, the best results are obtained when both data sources (radar and rain gauges) are used together.

This paper presents the results of a statistic analysis of the precipitation data measured during 2001 – 2003 period for the Muntenia region (southern Romania). The two data rows (measured with the Bucharest weather radar and with rain gauges) were processed using statistic – mathematic techniques in order to determine the correlation intensity and type. Two techniques for radar data adjustment using rain gauge data were applied and the results were studied and commented.

Key words: correlation, quantity of precipitation, radar, rain gauge

1. Introduction

The weather radar is, among other sensing instruments, one of the most modern and precise methods for atmosphere investigation.

The estimation of the precipitation quantity that will reach the ground, the estimation of the precipitation distribution inside hydrological basins and supplying the necessary data for hydrological forecast numerical models initialisation in order to prevent the effects of the flash floods, these are just few of the most important application fields for the weather radar.

Comparing to a rain gauge network, the weather radar as a precipitation sensor has couple of major advantages:

- the spatial continuity of the measurements (generally, the density of the weather stations provided with rain gauge is small comparing to the scale of the developed convective cells producing heavy rain, so that the convective cells could be "missed" by the rain gauge network or errors related to the maximum intensities caught by rain gauges could appear);
- possibility for real-time surveillance, from a single spot, over a large surface (for example, a radar with 10 centimetres wavelength and one degree beam width can perform precipitation measurements over 100 km range);
- digital acquisition, processing and storage for the radar data.

Typical radar "deficiencies" are ground clutter, beam blocking, vertical profile of reflectivity, different Z–R relations, etc.

The oldest instrument delivering a point measurement value of precipitation amount is the in-situ can-type precipitation gauge. The rain gauge measures the average precipitation quantity during a rain event, the highest error being induced by the airflow around the sensor (the drift of precipitation particles due to wind field deformation around the gauge). These instruments are also subject to a few another systematic errors, the most important sources of which are:

- lost water by wetting of the inner walls of the gauge;

- evaporation of water accumulated in the gauge "vessel";
- splashing of raindrops or blowing of snow flakes out or into the gauge.

Nevertheless, data from precipitation gauges are still required for calibration of remote sensing techniques (radar, even satellite).

The relative error in measuring at the ground level the spatial and temporal distribution of a rain event using a rain gauge network depends on the observed precipitation structure and the network characteristics:

- increases with the distance between measuring points

and

- decreases when precipitation intensifies.

The rain gauge network used for radar measurements testing should have an average density of one measurement point at each 10 – 20 square kilometres. In such conditions (and if local scale storms are not present and air flow speeds are not high), the error for measuring precipitation quantities with a rain gauge network is less than 5%. A high-density rain gauge network is a satisfactory way to measure the precipitation at the ground level, but this is not enough. Radar information can be considered either supplementary data to be used for interpolation between measuring point on the ground or a way to extend the measurements over the terrestrial network.

2. Data and methods

The authors performed in this paper a first evaluation of the radar liquid precipitation measurement accuracy. The data used were provided by the Doppler weather radar system in Bucharest (EEC DWSR-2500C type, commissioned in October 2000). The precipitation data were collected for the 2001 – 2003 period in the Muntenia region, without being categorized by the season and precipitation type.

The authors used radar accumulation products (ACC) to be compared to the rain gauge data. ACC data was generated from:

a) maximum column reflectivity (CMAX)
   and
b) first elevation (0.5 degrees) radar reflectivity (PPIZ).

The two data rows are not simultaneous because the EDGE software (the software designed by manufacturer used for radar control, data acquisition, product generation and display) does not allow the simultaneous generation of the ACC products from two different reflectivity products. The ACC products are raster format with 1 km resolution.

The relationship used for converting reflectivity data (dBZ) into rain rate (mm/h) is Marshall – Palmer standard:

$$Z = 200\ R^{1.6}$$

The obtained rain rate is then integrated over specific time intervals (like one, three, six, 24 hours or any user selected time interval) resulting the ACC products for these intervals.

The correction factor automatically entered for all ACC products was F=1.

The raw radar data was acquired in a 24/7 manner, with one volume scan every 10 minutes, for a range of 240 km (figure 1). Beam blockage correction, rainfall attenuation, range correction and smoothing were applied.

For the analysis presented in this paper, 24 hours ACC products were used (the start moment for the ACC was 00:00 hours). The radar data were compared to the rain gauge measured precipitation accumulation, for the same 24 hours interval, from 35 meteorological stations located in the Bucharest radar surveillance area. Most of these weather stations are placed in the plain, in the range of 120 – 150 km relative to the radar location, and only few of them are placed in hilly and mountain areas.

In order to eliminate, as much as possible, the errors caused by the localization precision of each station and those caused by air movement near the rain gauge, the radar data were read in two different ways:

- the precipitation accumulation value exactly on the station spot (for all 35 stations);
- maximum value in a 5 km range relative to each station, or the average accumulation value when the maximum value was exactly on the station spot.

In this way, two rows of radar data (accumulation) were obtained for each type of radar ACC product (CMAX and PPIZ).

In this way, two rows of radar data (accumulation) were obtained for each type of radar ACC product.

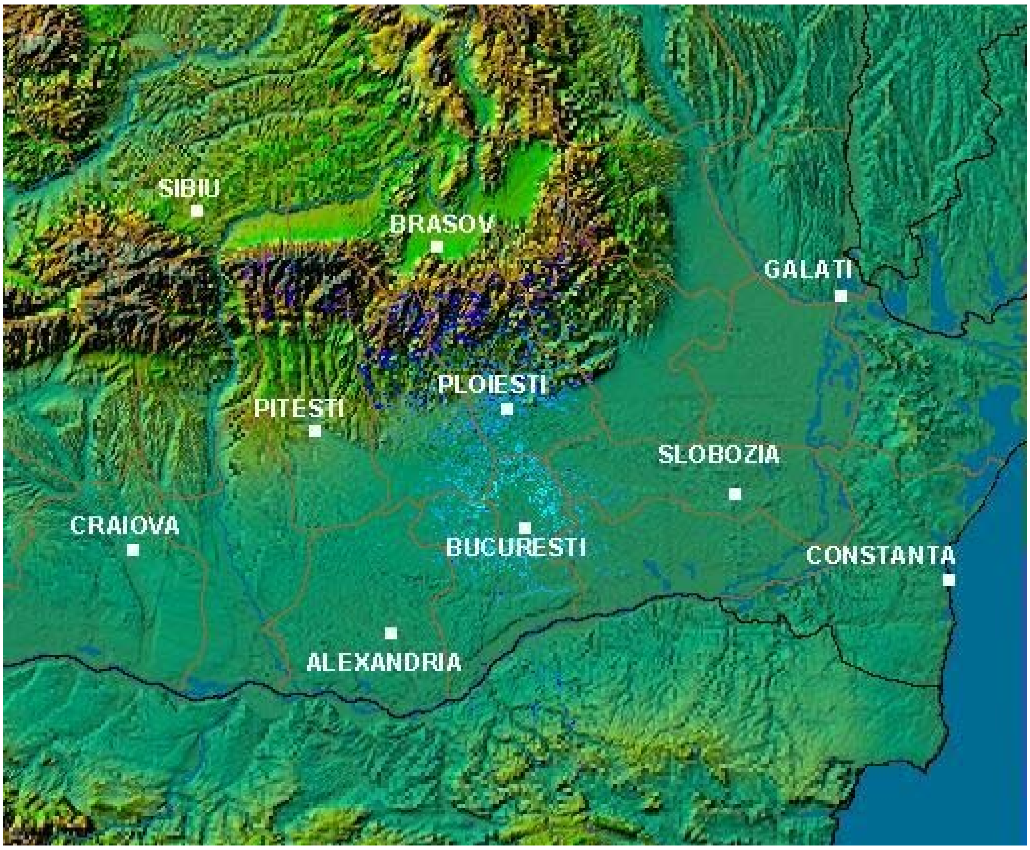


Figure 1

These four pairs of random variables, associated to the evaluation of the precipitation accumulation using the radar and, respectively, the rain gauge, were introduced in a statistical study based on co-relational theory. Considering the large drawn samples size (2934 for ACC generated from PPIZ and 2500 for ACC generated from CMAX) the normality assumptions necessary for parametric correlation are no longer a matter of concern, due to the Central limit theorem. However, they were tested with normal probability plots. For the correlation coefficients, Pearson's r formula was used since numerical variables, with no significant departures from normality are involved. Then three significance tests were applied to the obtained values (T test, classic Z test using Fisher transformation and ANOVA analysis). Using Fisher transformation, confidence intervals for the populations' correlation coefficients (ρ) were computed.

3. Results

The numerical values obtained for **r** indicates a good correlation between variables (table 1). The best correlation was obtained for the radar product generated from PPIZ and read on the station spot, while the worse correlation was for radar products obtained from CMAX in a 5 km range.

Table 1

r (PPIZ)	r_5 (PPIZ)	r (CMAX)	r_5 (CMAX)
0.68	0.668	0.625	0.595

According to the values obtained for the significance tests statistics, (much bigger than the critical values at the significance level α=0.01) the null hypothesis is rejected. There is indeed a good correlation between the variables.
Moreover, the performed statistical tests gave as well information about the regression slope; this parameter is significantly different from zero and therefore the regression lines were computed.

$R_{PPIZ} = 0.337*P + 0.852$; (1) $P = 1.375*R_{PPIZ} + 1.417$; (2)   equation (2) - figure 2 a

$R_{PPIZ5} = 0.457*P + 1.874$; (3) $P = 0.977*R_{PPIZ5} + 0.839$; (4) equation (4) - figure 2 b
$R_{CMAX} = 0.44*P + 1.329$; (5) $P = 0.888*R_{CMAX} + 0.902$; (6) equation (6) - figure 2 c
$R_{CMAX5} = 0.482*P + 1.634$;(7) $P = 0.736*R_{CMAX5} + 1.003$.(8) equation (8) - figure 2 d

Figure 2a

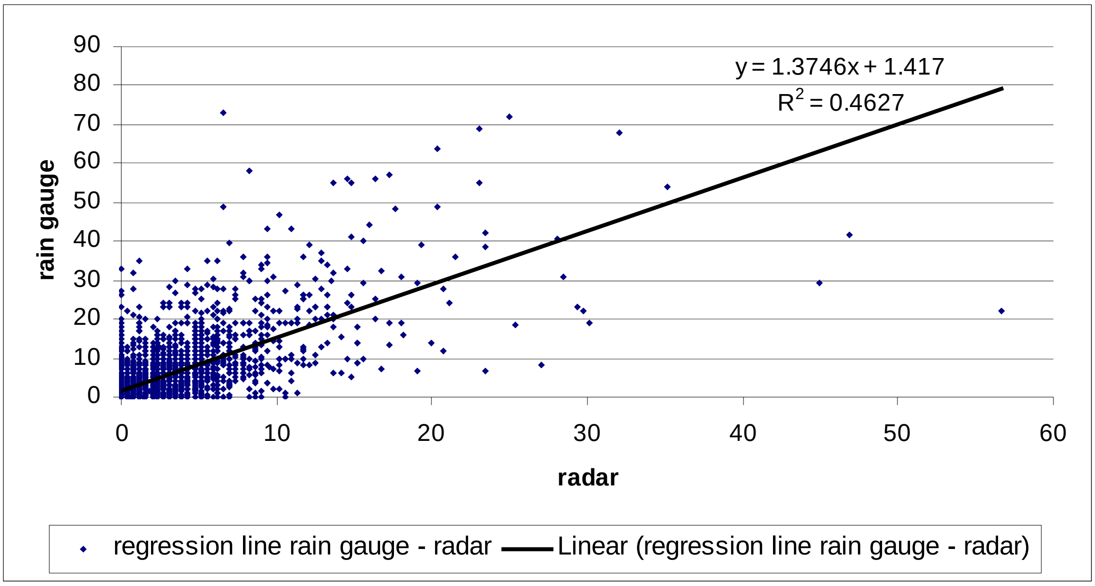
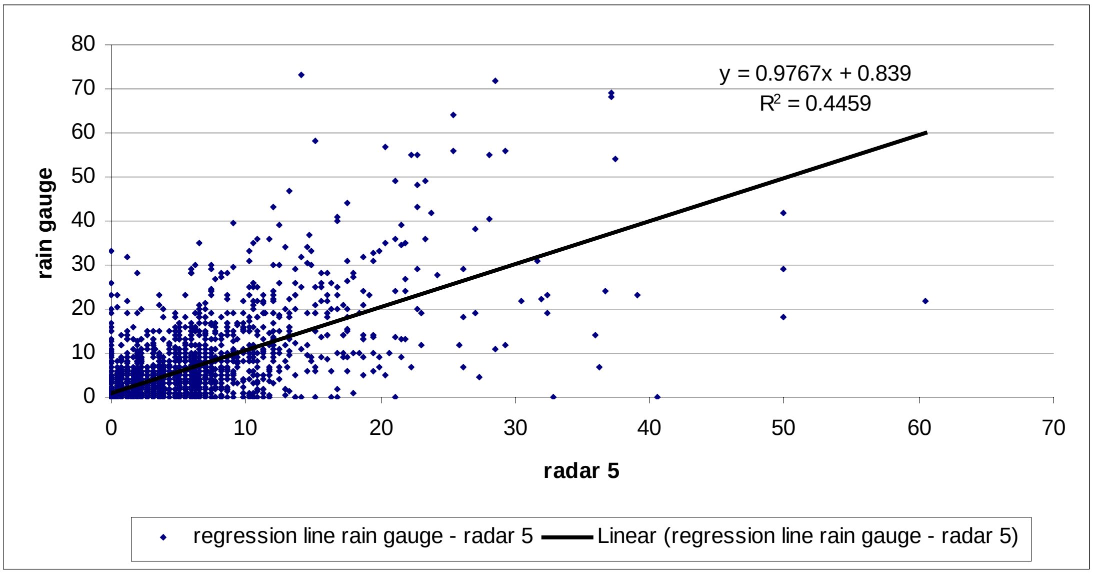


Figure 2b



In the next step, the samples were divided into 35 repeated selections for each random variable, the selection being done using the geographical criterion (for each rain gauge in the network). The presented co-relational analysis was repeated in order to determine a weight for each rain gauge in the network. Figures 3, 4, 5 and 6 are graphic representations for the 4 types of correlation coefficients.

Considering that, from statistical point of view, a coefficient between 0 and 0.4 means no correlation between variables, values between 0.4 and 0.7 are equivalent to a good correlation and values between 0.7 and 1.0 suggests a strong correlation, the cases with a correlation coefficient less than 0.4 were carefully considered.

For Braila station, located at a distance over 160 km from the radar site, the correlation is weak for PPIZ (radar beam, even at the first elevation, is approximately 3 km high), but it gets a lot better for CMAX. About Penteleu, Voinesti and Intorsura Buzaului stations (all being mountain stations), the correlation can be considered satisfactory, even good for at least two pairs of data rows. It can be noted the fact that, for all these stations, the best correlation is obtained for ACC products generated using PPIZ in 5 km range, while for ACC from CMAX the correlation is weak or even absent.

Figure 2c

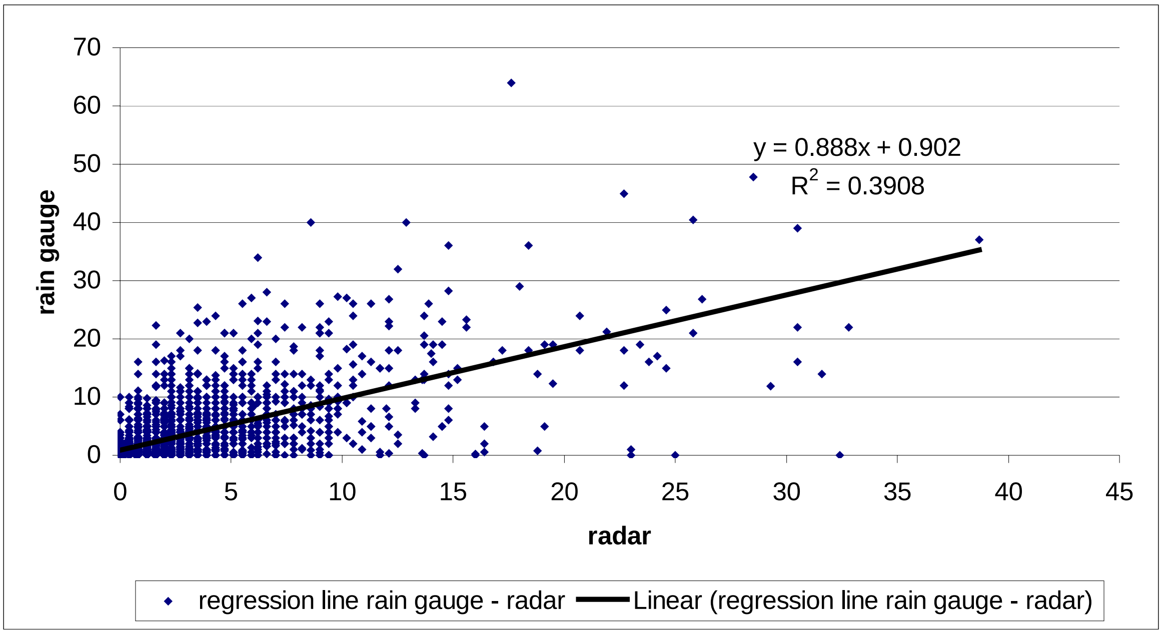


Figure 2d

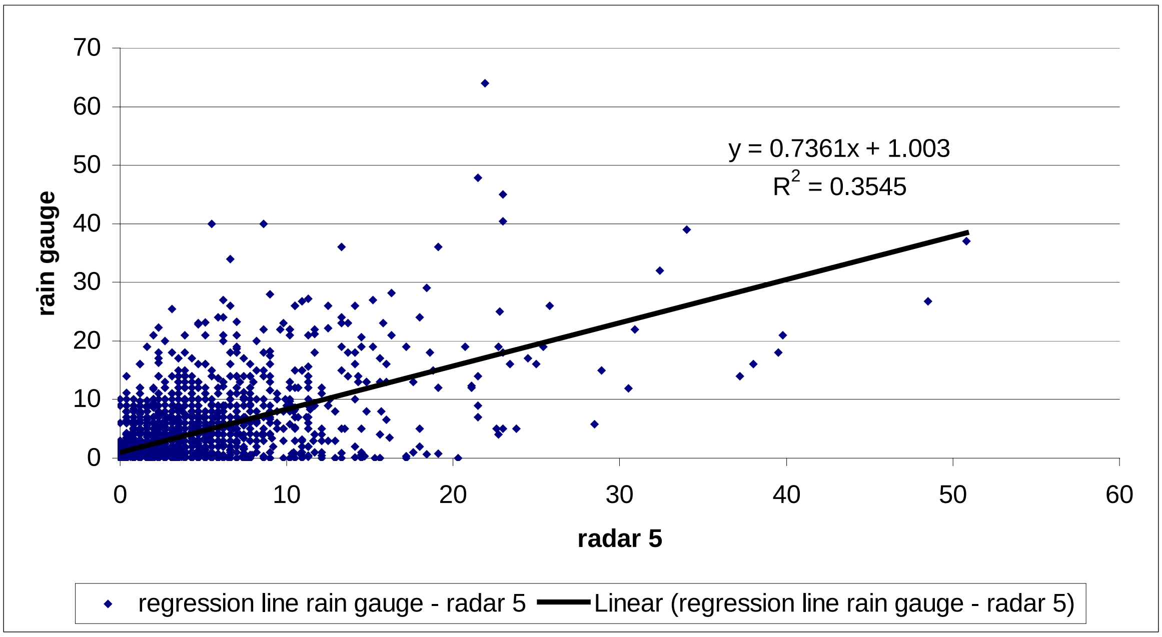


Figure 3

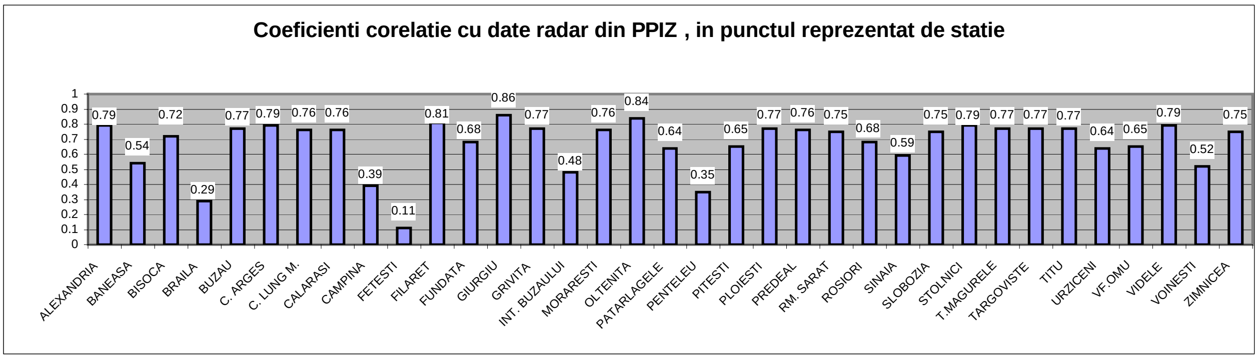


Figure 4

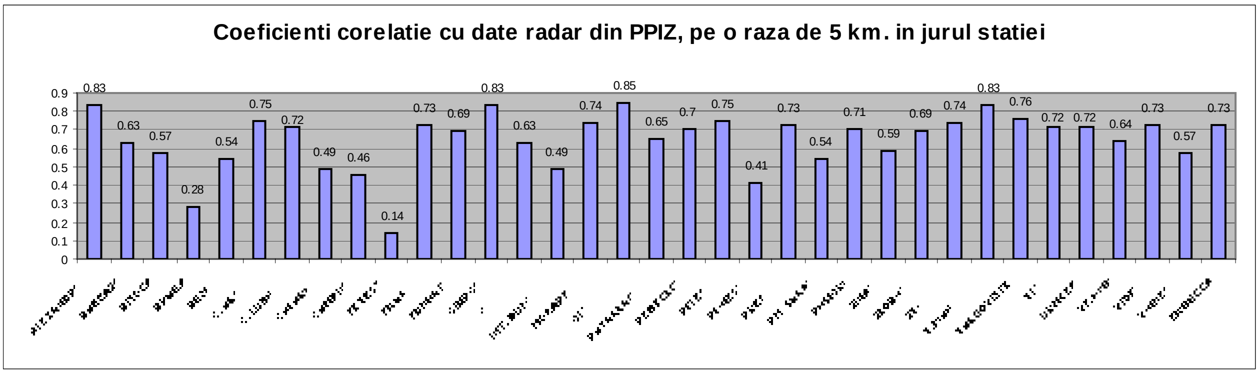


Figure 5

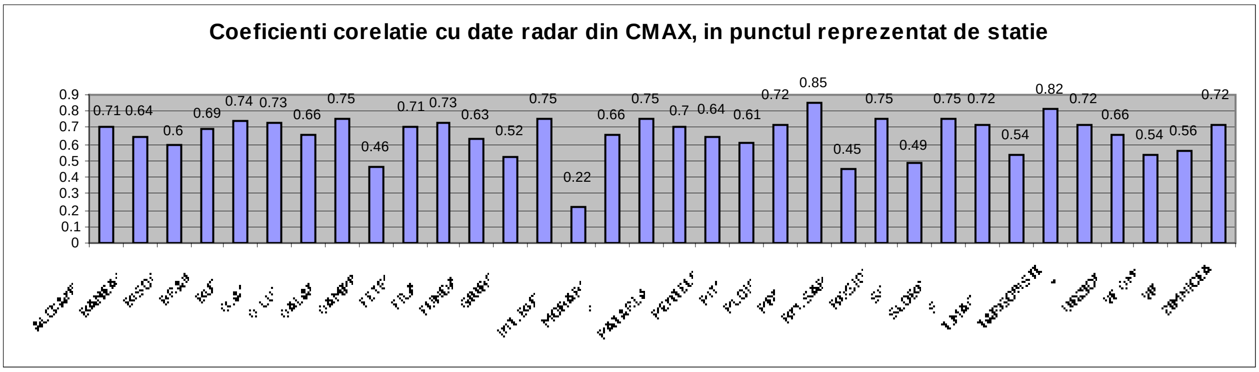
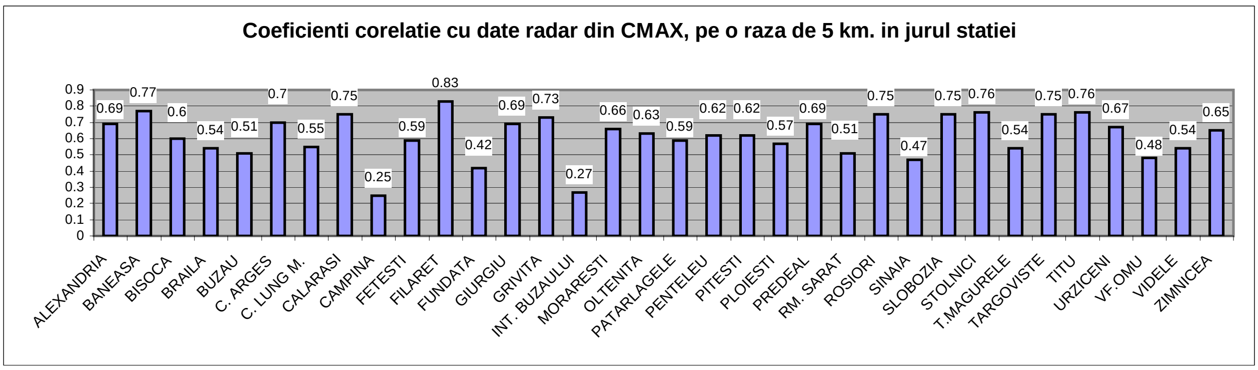
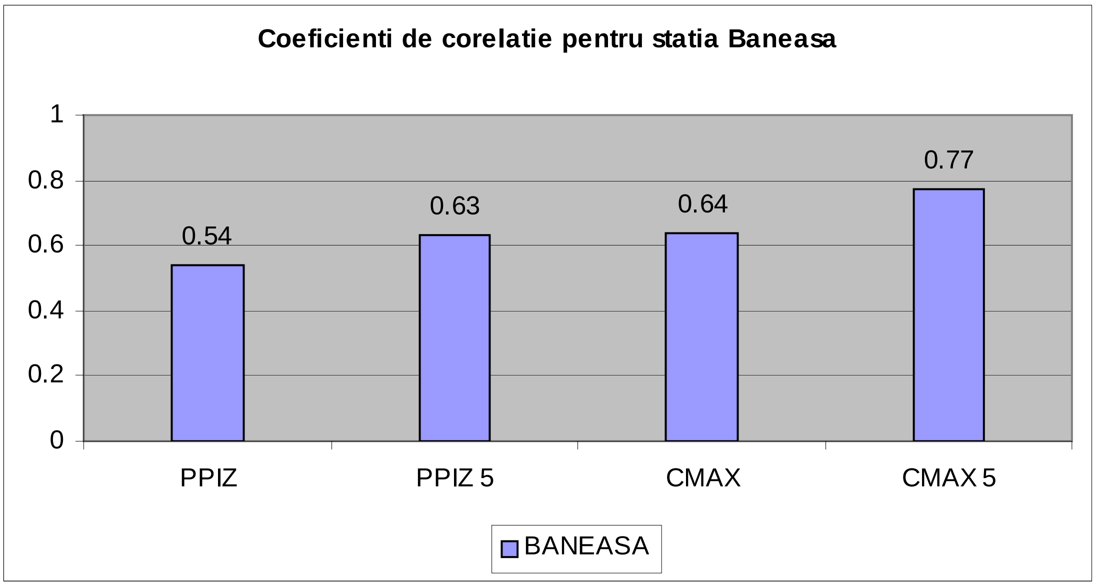


Figure 6



For Baneasa station (Figure 7), where the radar site is, the correlation for the CMAX 5 km (0.77) is the best from all 4 types of data, fact explainable by the "cone of silence" specific to all radar sites. The value of the correlation coefficients increasing with the distance from the radar site and with the elevation of the antenna, demonstrates this fact:

Figure 7



Another reason for comparing radar data with rain gauge data is to find a way to improve the accuracy and quality of the radar data. This can be achieved either

- modifying the coefficients of the Z-R relationship

or

- uniformly applying to the radar data of a correction factor obtained using the rain gauge data.

In order to adjust the radar data using the second method presented above, two multiplicative adjusting factors were applied. These factors were obtained using the following formulas:

$$F_1 = \sum_{i=1}^{n} P_i \Big/ \sum_{i=1}^{n} R_i \; ; \qquad\qquad F_2 = (1/n) * \sum P_i / R_i \; .$$

When F1 is used, the data is weighted by the rain quantity, while when applying F2 all radar – rain gauge data pairs have equal weights. The corrections refer also to the errors due to the radar calibration and Z-R relationship. The following values were obtained for the factors F1 and F2:

$F_{1\,PPIZ} = 1,95$; $F_{1\,PPIZ\,5} = 1,18$; $F_{2\,PPIZ} = 2.18$; $F_{2\,PPIZ\,5} = 1.24$;
$F_{1\,CMAX} = 1,21$; $F_{1\,CMAX\,5} = 1.04$; $F_{2\,CMAX} = 1.41$; $F_{2\,CMAX\,5} = 1.33$.

As we are dealing, in both situations, with multiplicative factors, meaning linear transformations of radar data, the linear model performance remains the same (mean square error over sample variance).
Only the parameters of the regression lines (slope and intercept) are changing as can be seen from the equations.
However, another aspect ignored by the linear regression (but important) was analysed. It is about the basic question of whether the two methods of measurement agree sufficiently closely. The quantities that best answer this question are the differences between the pairs of data. If the measurements are comparable, the differences should be small, cantered around 0, and show no systematic variation with the mean of the measurement pairs. In terms of distribution parameters, the matter is best summarized by the standard deviation of the differences. If this number is small enough from a practical standpoint, then it can be said that the measurements are comparable.

From the analysis on this paper, it can be noticed that the radar data underestimate the precipitation values (the underestimation is bigger when the reading is taken right on the station spot). This can be corrected using the first adjusting factor: the average of the difference variable becomes zero and the standard deviation remains approximately the same.

Figure 8a

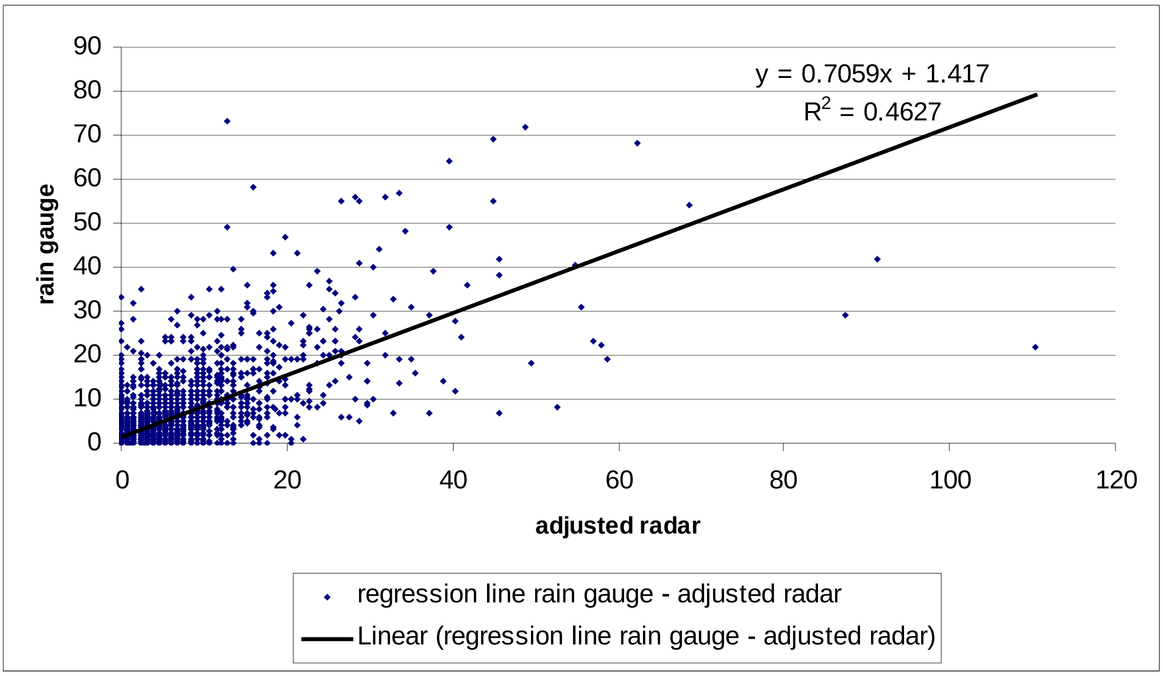
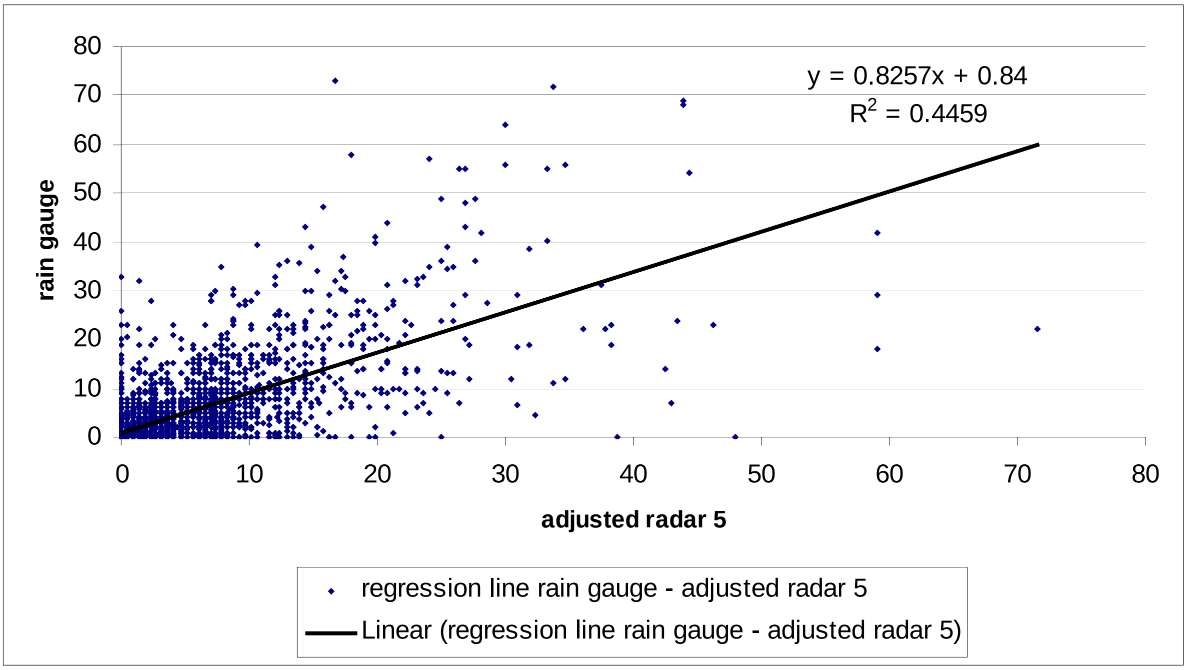


Figure 8b



In the case of the second adjusting factor, the values of the radar data increase too much and an overestimation of the precipitation is obtained; moreover, the standard deviation increases as well.
Consequently, the first adjustment factor (F_1) was preferred and the new coefficients for the regression lines were computed:

$R_{PPIZ} = 0.655*P + 1.66$; (1) $P = 0.706*R_{PPIZ} + 1.417$; (2) equation (2) - figure 8 a
$R_{PPIZ5} = 0.54*P + 2.216$; (3) $P = 0.826*R_{PPIZ5} + 0.839$. (4) equation (4) - figure 8 b
$R_{CMAX} = 0.531*P + 1.603$; (5) $P = 0.736*R_{CMAX} + 0.902$; (6) equation (6) - figure 8 c

$R_{CMAX5}= 0.502*P + 1.703$; (7) $P = 0.706*R_{CMAX5}+ 1.003$; (8) equation (8) - figure 8 d

Figure 8c

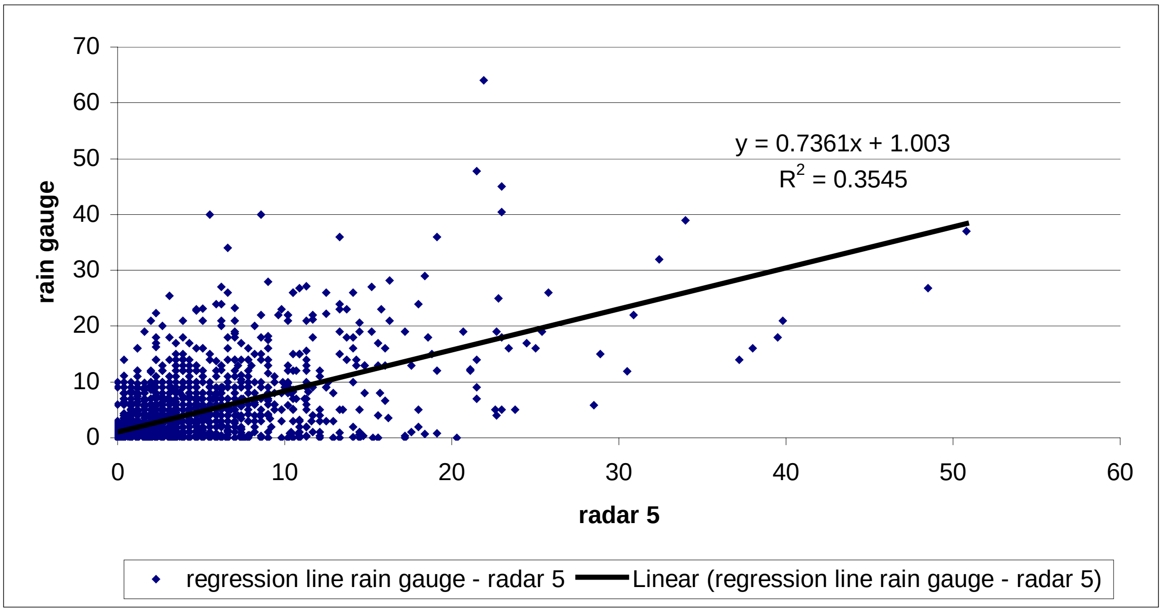
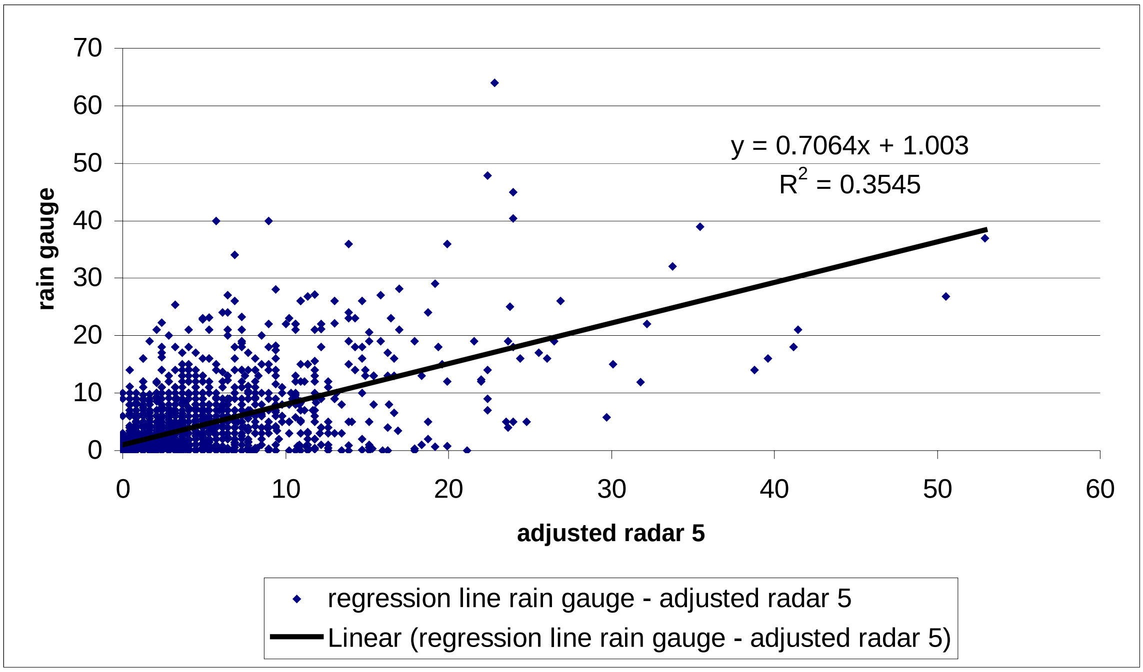


Figure 8d



Results of testing the factor F1

As a result of the above analysis, starting with 01 November 2004, the ACC product was generated using PPIZ and an automatic correction factor F1 = 1.95 was applied.

The consequences of adjusting the radar data by F1 were analysed using a sample of 497 data collected from the moment of its application. As shown above, the purpose of this correction concerns only the differences between the rain gauge precipitation values and the radar values taken exactly on the station spot. Therefore, the best way to verify the consequences is to compare the distribution parameters of the differences before and after adjustment. These are as can be seen below:

Before: $m_1 = -2.34$; $\sigma_1 = 6$

After: $m_2 = -0.7$ $\sigma_2 = 5.43$.

It can be noted that the average value had significantly decreased, which proves the applied correction to be a useful way of getting the two measured values much closer than they were. The standard deviation had also decreased even though not as significantly as the mean.

As a new sample is always a good opportunity of testing estimates homogeneity, Pearson's **r** has been computed again. The obtained values are:

r(PPIZ)	**r_5(PPIZ)**
0.76	0.738

It can easily be noticed the difference between the values; these coefficients do not even belong to the computed confidence intervals. Considering that very large samples estimates results are highly reliable, a sampling error may have occurred in this case. It was found testing the homogeneity of means and variances across the two samples for each variable, that the rain gauge precipitation data had a greater average in the smaller sample.

This study we may say, emphasized again the importance of the sample size in parametric analysis; very large samples are required especially when a variable phenomenon like precipitation is involved.

4. Conclusions

1. It was noticed a good correlation between precipitation data measured with DWSR-2500 C weather radar and precipitation data measured with rain gauge; the radar measured quantities are, in general, underestimated; the underestimation is more evident when the reading is taken in the station spot. However, there are cases when the radar quantities are higher than those measured with the rain gauge at the weather stations.
2. For the majority of the weather stations, the correlation between radar data and rain gauge data is better when the radar ACC products are generated using PPIZ first elevation products.
   For the mountain stations, the correlation is satisfactory for PPIZ 5 km and is missing for ACC products generated using CMAX.
   For the stations located at a great distance from the radar site (120 – 150 km), the correlation is better for the accumulations generated using CMAX.
3. The multiplicative factor that best adjusts the 24 hours radar accumulation data for Muntenia region (using DWSR-2500C equipment) is F1 (that weights proportional with the rain quantity) applied to radar accumulation using PPIZ products. From the data analysed and processed in this study, for the F1 factor was found the value of 1.95.
4. For other "reference" stations (like Baneasa), where the correlation is better when radar accumulation is generated using other product than for the majority of the weather stations, a specific adjustment factor will be computed and tested. This factor will be applied in a non-automatic manner.
5. In parametric analysis, when a variable phenomenon like precipitation is involved, very large samples are required.

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Mobile system for atmospheric temperature profile monitoring: mobile MTP-5

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***Abstract**: Mobile system MMT -5 for investigating a spatial variability of atmospheric boundary layer temperature stratification and distribution of contaminants concentration on the territory of a big city and its suburb has been developed. The results of the measurements carried out by this system in the territory of Nijny Novgorod and its suburb during August–October 2004 are presented in this paper. The temperature profile measurements made by stationary profiler MTP-5 are used in the analysis also as a reference point. The results showed that within the city were observed 3-5 zones with different temperature stratification. The vertical and horizontal sizes of these zones depended on orography and weather conditions.*

1. Introduction

The numbers of researches dedicated to the urban heat island study were considerably increased in recent years. These investigations show anthropogenic interactions in the form of the powerful sources of pollution and water vapor and supplemental heat sources can exert a substantial influence on the intensity and form of the environment response in the large industrial cities and megalopolises. These factors lead to special climate formation in a megalopolis *(Oke 1973; Oke 1977)*. The sufficient number of the research contains information about the quantitative parameters of this phenomenon. These studies are based most frequently on near the ground surface measurements of temperature and humidity *(Duckworth and Sandberg 1954).*

Studies of ground temperature heterogeneity show that the heat island inside of the city can have heterogeneous structure so-called "multicupolas" *(Golitsyn at al 2002, Khaikine at al, 2003).* But this assumes, in turn, the three-dimensional heterogeneity of temperature profile. Thus, in the city can be observed different conditions for forming and destroying the inversions and, therefore, can be formed different prerequisites for pollution concentration increase in the atmospheric boundary layer (ABL). It is known that the successful solution of the problem of air pollution forecast is based as on the physical features of the propagation of admixtures in atmosphere and meteorological factors. Temperature atmospheric stratification is one of the most important meteorological parameters for air pollution level forecasting. For measuring the profiles of the temperature of ABL traditionally the contact temperature sensors were used, raised on the radiosondes and tethering balloons, and installed on the meteorological masts *(Garratt, 1992).* More lately appeared the remote methods, namely: lidars and radioacoustic (*Westwater, e.a., 1999*). All these methods, as a rule, are used in the stationary version.

The method of ABL temperature profiles remote measuring was developed in the Central Aerological Observatory (Roshydromet) about 15 years ago. It was created remote meteorological temperature profiler MTP–5 *(Ivanov, Kadygrov, 1994)*. The comparative tests of MTP-5 with the traditional methods of atmospheric temperature measuring showed that MTP-5 is fully acceptable for routine measurements on any National observational network *(Kadygrov and Pick 1998; Westwater et al 1999; Viazankin at al 2001, Cadeddu at al 2002)*.

Since 2000 MTP-5 is used on the network of Roshydromet. MTP-5 has a comparatively low weight (10 kg), small overall dimensions and small required power (60 W). These parameters made it possible to develop the mobile system MMTP-5 on the base of MTP-5. The investigations of space heterogeneity of atmospheric temperature stratification were carried out by this mobile system in large city Nijny Novgorod and in its suburb in August-October 2004. The measurements of temperature profiles were conducted simultaneously by MMTP-5 and by stationary MTP-5 installed on the roof of hotel “Oka” at the altitude 235 m. The special equipment installed on the mobile system MMTP-5 allowed measuring air pollution concentration. The results of temperature profile measurements and air pollution concentration in 12 points of Nijny Novgorod and its suburb (5 points) are discussed in this article.

2. The technique and equipment used in the measurements.

Two temperature profilers MTP–5 were used for investigation of ABL temperature profiles space variability in Nijniy Novgorod and its suburb. The first MTP-5 was installed on the roof of the hotel of "Oka" and the second was a mobile system MMTP-5. Common view of these devices is shown in Figure 1.

Mobile system MMTP-5

Stationary MTP-5

Fig. 1. Common view of temperature profilers.

The following equipment was installed in the mobile system MMTP-5:

- Profiler MTP-5.
- GPS system.
- Equipment for measuring the concentration of following contaminants: carbon monoxide, nitrogen dioxide, phenol, benzene, toluene, xylene, ethylbenzene, cyclohexanone, cyclohexanol**.**

Nijny Novgorod is placed on the confluence of two largest rivers of the Eastern European plain: Oka River and Volga River. Nijny Novgorod is the large industrial center occupying the area of approximately 350 km^2. The city is divided on two parts depending on the relief, namely: beyond the river part and upland part.

The upland part of the city is the watershed plateau, rugged by numerous ravines of different depth and valleys of small rivers. The altitude of plateau varies from 100 to 200 m.

Another part of the city (beyond the river) is placed between the right bank of Volga River and the left bank of Oka River. It has the altitude 70-80 m. Oka River is the boundary between the elevated and lowland city. The slopes of right bank of Oka River they are rugged by a number of large ravines. Of about ten small creeks and channels are located in the beyond the river part of the city. Swamps occupy in entire 25% of this part of the city territory.

Two meteorological stations regularly carrying out measurements of meteorological parameters are located on the territory of Nijny Novgorod. The first meteostation (M1) is located in the upland part of the city at a distance of approximately 3 km north-north-east apart from the stationary MTP-5. The second meteostation (M2) is placed in the beyond the river part of the city at a distance of approximately 2 km westward from point No 15(see fig. 2).

The places of measurements (points) were determined before beginning the measurements on the territory of Nijniy Novgorod and its suburb. The points were determined in such a way that the measurements would be carried out in the regions having characteristic landscape, orography or placed near the pollution sources. 17 points (12 in the territory of city and 5 in the suburb) were choosen taking into account these requirements. The measuring point locations in the territory of Nijny Novgorod are shown in the Figure 2a, while the measurement point locations in the suburb are shown in the Figure 2b. The point N0 is the stationary profiler MTP-5.

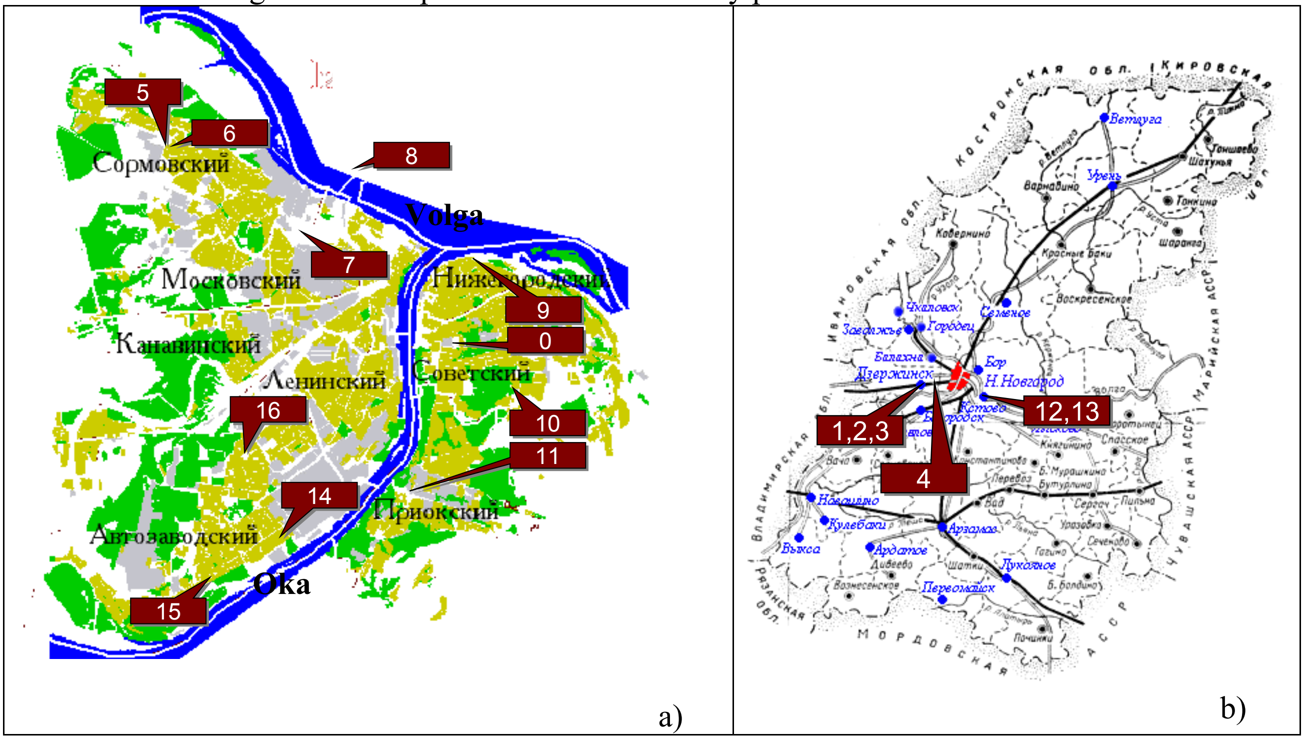

Fig. 2. Measuring point locations. a)- in Nijny Novgorod; b)- in subuarb

The altitudes of metostations M1, M2, measuring points and its distance to the stationary MTP-5 are shown in Table 1

Table 1

The measuring point's number	Altitude [m]	Distance from stationary MTP-5 [km]
0	235	0
1	98	48.1
2	102	56.2
3	105	49.3
4	89	26.2
5	92	14.2
6	92	14.2
7	80	8.0
8	75	8.6
9	155	4.5
10	160	3.5
11	184	5.5
12	80	21.7
13	130	21.2
14	86	9.5
15	85	11.7
16	86	8.7
Metostation M1	157	3.0
Metostation M2	77	13.1

The measurements were carried out on August 6, 7, September 1, and October 16, 17, 18 under weather conditions, favorable for formation and development of temperature inversions, i.e., under the stationary weather conditions at night and in the morning.

3. Results of the measurements

The changes of ground temperature measured by meteorological stations in standard terms and by MMTП-5 are shown in the Figure 3. It can bee seen that at August, 6-7 and October, 16-17 the heat island is shown brightly. Spatial heterogeneity of ground temperature is well visible. Temperature difference exceeds 2 degrees in points N1 and N3 located in center of Dzerzhinsk city and in its suburb correspondingly. The difference city-suburb exceeded 6 degrees at the distance from the city about 25 km (point N4). In same time the temperature measured by meteorological stations changed less than 1^{O}C. The significant changes of ground temperature (more than 3 degrees) are also observed during the motion through Nijny Novgorod.

For instance, at August 7 the temperature difference in points N 7 and N 9 was greater than 2.5 degree and temperature difference between points N9 and N10 was greater than 3 degree.

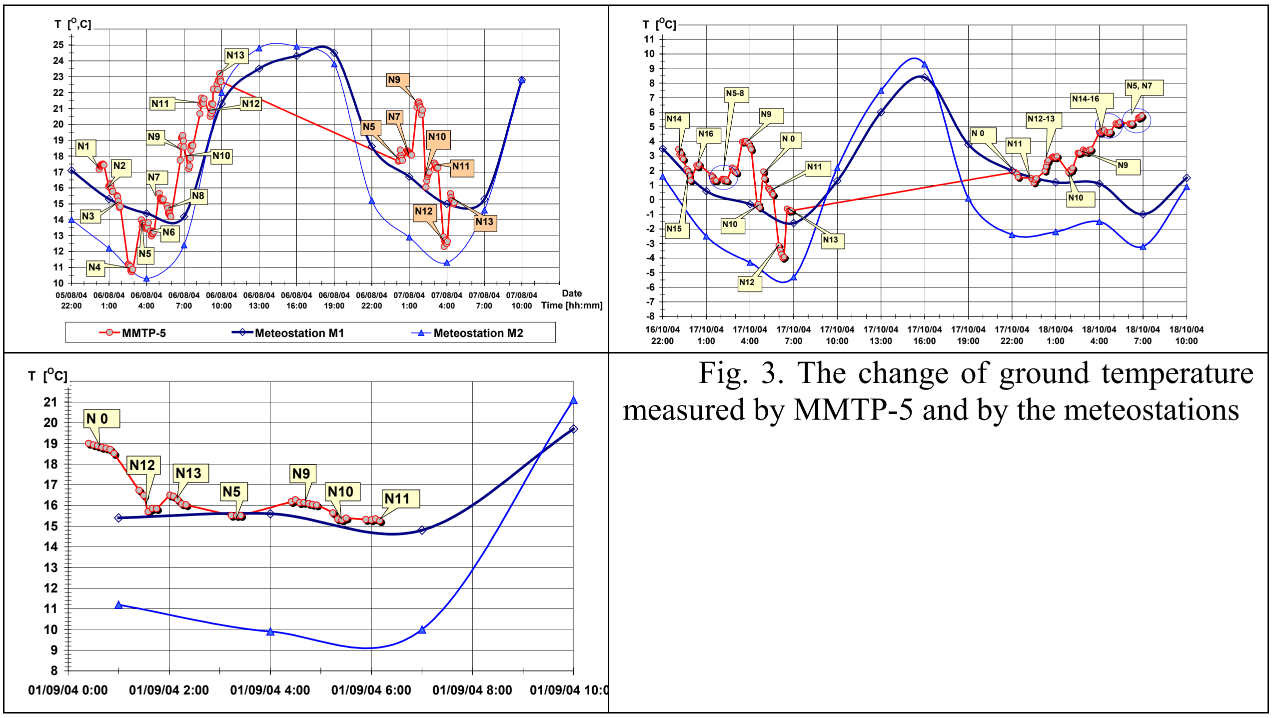

Fig. 3. The change of ground temperature measured by MMTP-5 and by the meteostations

On September 1 the ground temperature difference between the upland and beyond the river parts of the city exceeded 5 degrees as indicated by the meteostations at night and in the morning. In the same time on data MMTP-5 the ground temperature differences between the beyond the river part of the city (point 5), the suburb (point N12 and N13) and upland part (points 9-11) did not exceed 2 degrees. Approximately the same picture was observed on October 18. It is necessary to pay attention on an increase of ground temperature measured by MMTP-5 in contrast to ground temperature change on meteostations data after 3 hours in points 14-16 and points 5 and 7.

The spatial structure of temperature stratification on the city territory and its suburb was also heterogeneous. Figure 4 shows the thermograms and color field of temperatures obtained by mobile (MMTP-5) and stationary (MTP-5) profilers. It can be seen the color field obtained by stationary MTP-5 has relatively homogenous structure. Consequently the change of temperature profiles during the night and morning occurs gradually. And the color field of temperature measured by MMTP-5 differs sharply from that, obtained by stationary profiler.

As an example figure 5 shows the temperature profiles measured by mobile (in points N7 and N8) and stationary (N0) profilers. The time of the profiles obtaining in points N7 and N8 differed at less than 15 minutes. It can be seen in the figure the temperature differences for the points placed at the same height above sea level and spacing at the distance not more than 4 km exceed 1 degree at the heights more than 200 m.

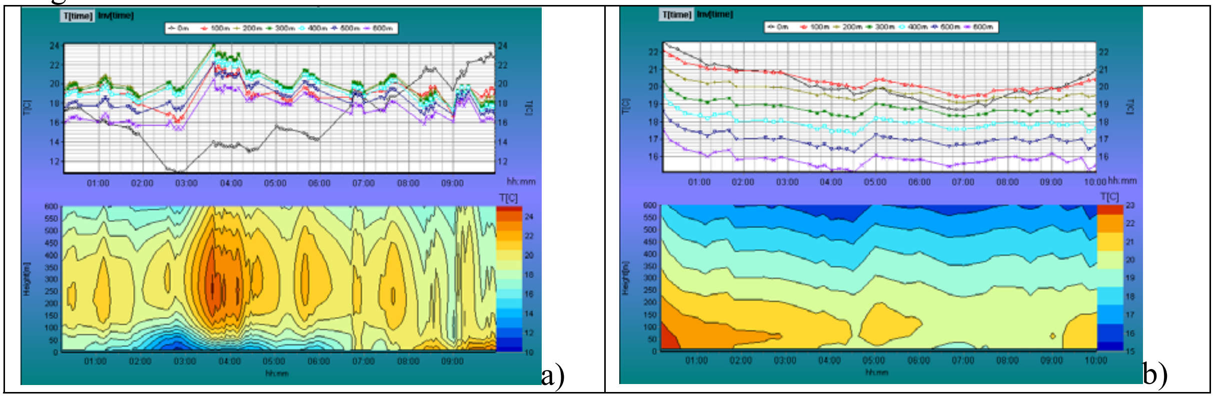

Fig. 4. Thermograms and color field of temperature, obtained by MMTP-5 (a) and MTP-5 (b). August 6, 2004 .

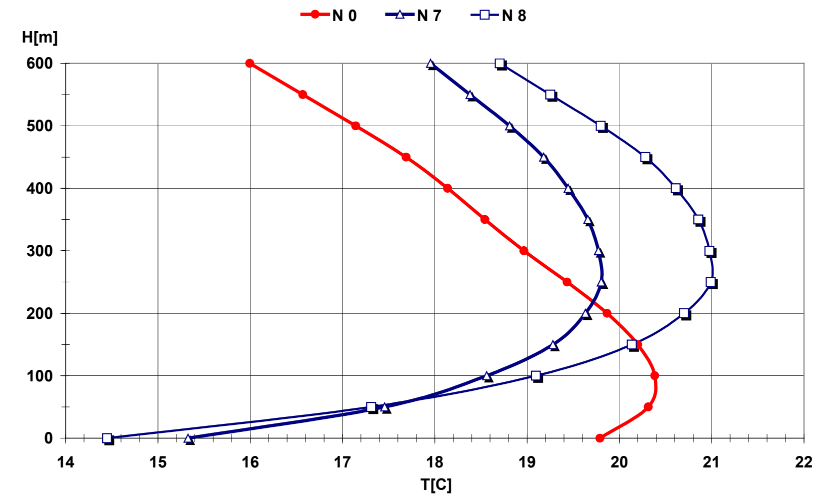

Fig. 5. Temperature profiles, obtained by MTP-5 (point N0) and MMTP-5 (points N7 and N8). August 6, 2004.

The coefficients of correlation (K_{correl}) were calculated for estimating the relations of profiles measured synchronously by mobile and stationary profilers. This parameter makes it possible to evaluate the possibility of using data obtained by stationary MTP-5 to the territory of city and its suburb. Figure 6 shows the summary dependence of K_{correl} on the distance from stationary MTP-5 for all observation days.

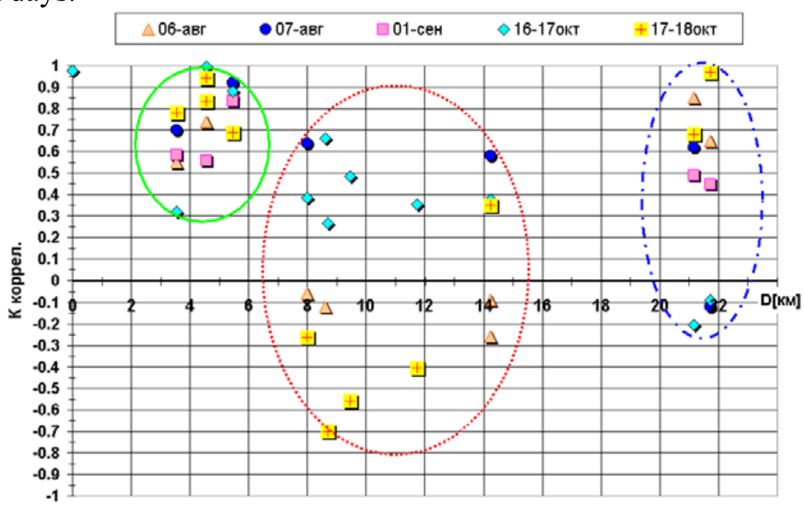

Fig. 6. Dependence of correlation coefficient from distance between stationary and mobile profilers.

On our opinion, it is possible to resolve three zones (they are shown by ovals in the figure), for which it is possible to observe a certain regularity. The steadiest correlation is observed in the first zone (D<6 km). In the second zone (7km<D<16km) K_{correl} can vary from –0.7 to +0.7 with the approximately the same probability. In the third zone (region of town Kstovo) K_{correl} was above 0,4 approximately in 70% cases. In this zone, very week relations of the profiles (K_{correl}<0) were observed also.

The calculation of K_{correl} makes it possible to estimate the zone of the representative of the data obtained by the stationary profiler MTP-5. But, as it has been mentioned above, Nijny Novgorod has clearly expressed heterogeneity of the orography and underlying surface. These factors had to have an effect on the Urban Heat Island (UHI) formation and on its spatial structure. From the data obtained, it was possible to observe the "multicupolas" of UHI under specific conditions in the city. For the evaluation this effect we calculated the synchronous temperature differences obtained at different points at the same heights relative to sea level. I.e., it was calculated temperature difference between stationary MTP-5 and mobile system at any definite point. In figures 7 and 8 are shown the color fields of temperature difference obtained at August 6 and 7, 2004 accordingly.

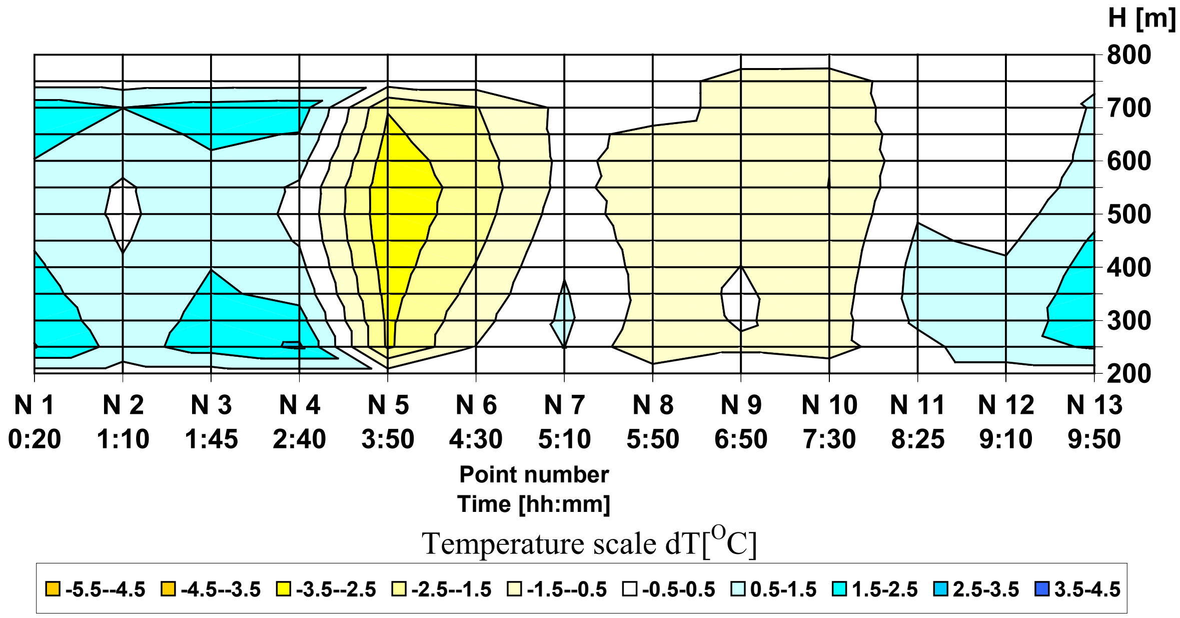

Fig. 7. Color field of temperature difference measured by MTP-5 and MMTP-5. August 6, 2004.

The measuring point's numbers and the time of the measurement are indicated on the X-axis of the figures. The altitude in meters is shown on the Y-axis. The correspondence of the temperatures difference to a color is given in the bottom of the figures. The warm color scale (nuances of yellow and brown) corresponds to the situation when the temperature in the point is greater than that measured by MTP-5. The reverse situation (temperature in the point is colder) corresponds to cold colors scale (nuances of blue and dark-blue).

Weather conditions in Nijny Novgorod were formed under the influence of an anticyclone as showed by synoptic-meteorological analysis on August 6 and 7. According to the data of radiosonde (00 UTS) at night on August 6 the week wind (< 2 m/s) was observed in entire lower 800 m layer. The wind was less than 1 m/s in the lower 500 m layer. At night on August 7 weather conditions in the lower 500 m layer were close to those observing on August 6. But in the layer 600-800 m according to radiosounding data was observed the jet stream with wind speed greater than 6 m/s. In figures 6 and 7 can be see "multicupolas", i.e. the several local zones with identical temperature difference. These zones have the form of the columns with the altitude 500-750 m and the size 3-6 km. The bars of equal temperature were observed at the altitude higher than 500 m on August 7. The jet stream observed in the layer 600-880 m could lead to such effect.

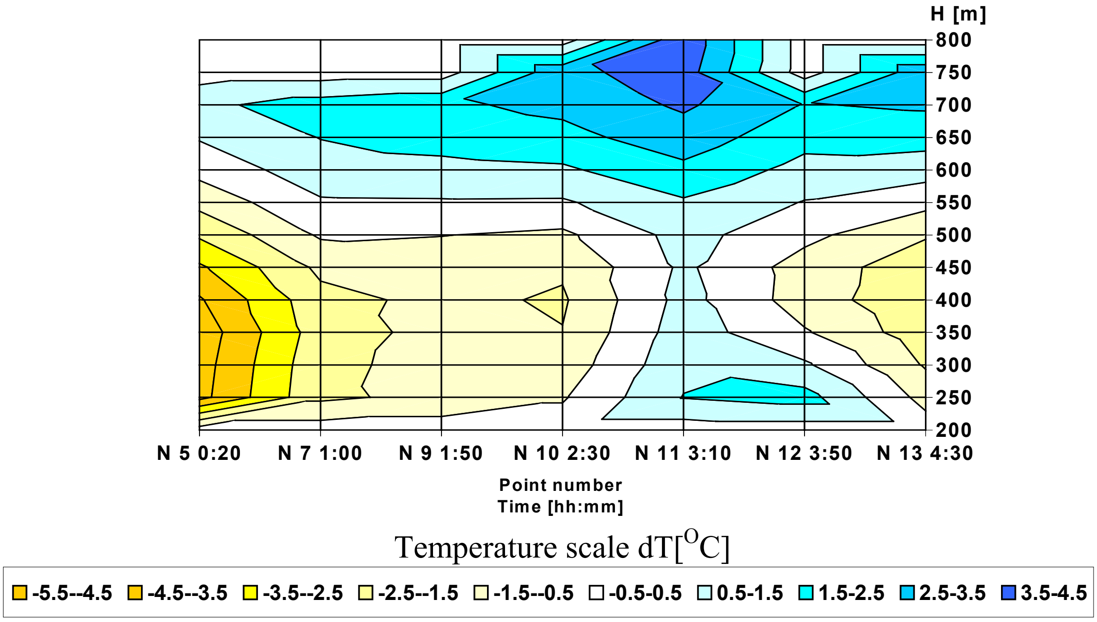

Fig. 8. Color field of temperature difference measured by MTP-5 and MMTP-5. August 7, 2004.

Weather condition on September 1 (Fig. 9) was formed under the crest of anticyclone. Wind speed from 0.5 to 2.3 m/s was observed northeastern in entire 800 m layer at night. In all observed points the temperature was colder than in the locality of the hotel "Oka". Coldest locality was near the point N 10.

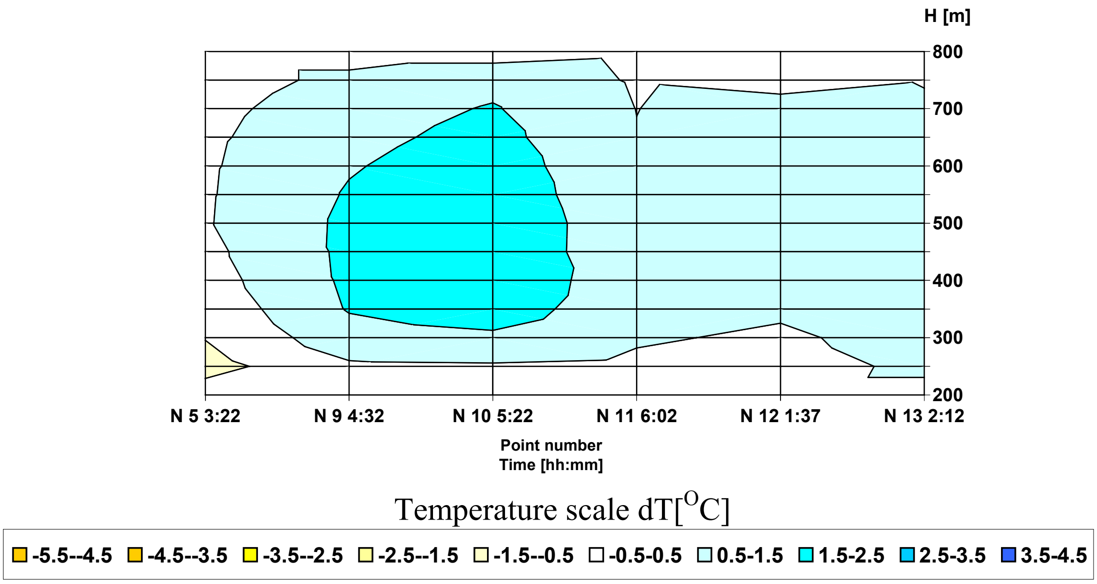

Fig. 9. Color field of temperature difference measured MTP-5 and MMTP-5. September 1, 2004.

A calm was observed near the earth surface during the night October 16-17. Weather conditions were close to those observing on August 6 and the color fields of temperature difference obtained for these days were also similar (Figure 10).

Coming cyclone caused air masses change observed at night October 17-18. A cold front passed the city in the afternoon on October 18. The significant intensification of wind with the height was observed on radiosonde data (00 UTS). Wind speed changed from 3.0 to 11.5 m/s in the height range 150 to 322 m. As it can be seen in Figure 11, these processes changed strongly the structure of color field. The warm zones were observed only up to the height 400-450 m and the cold zones were observed above.

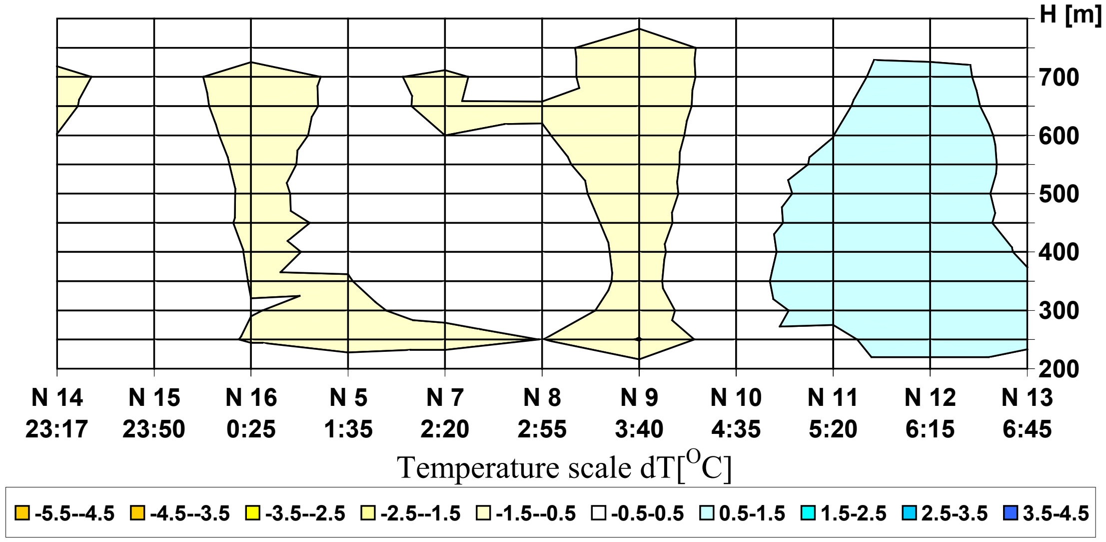

Fig. 10. Color field of temperature difference measured MTP-5 and MMTP-5. October 16-17, 2004.

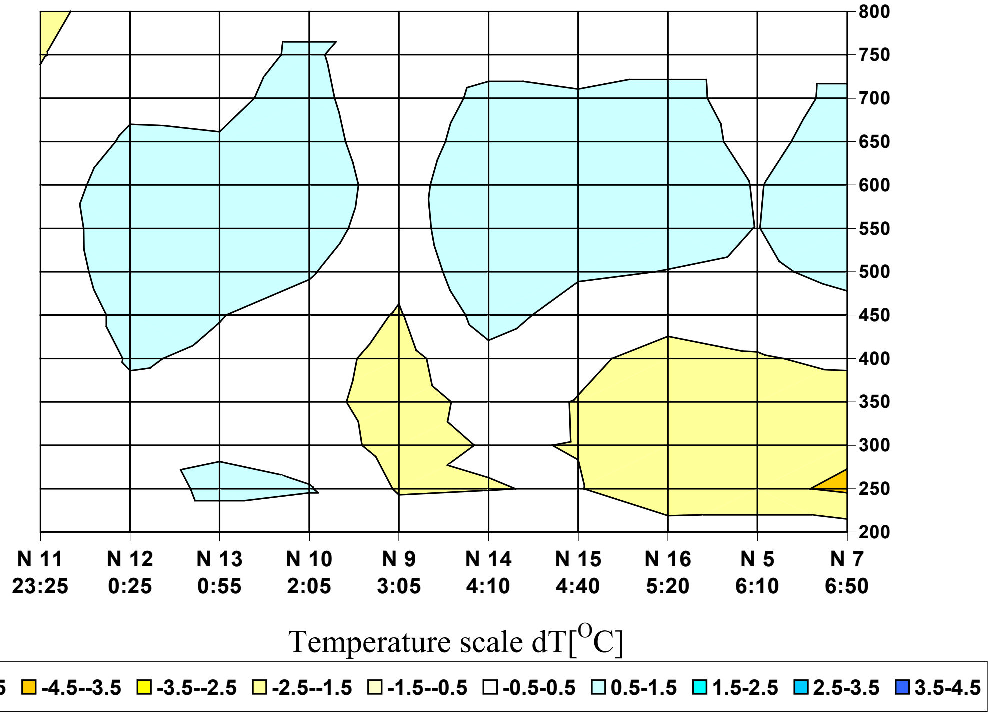

Fig. 11. Color field of temperature difference measured MTP-5 and MMTP-5. October 16-17, 2004.

As it has been marked above, the measurements of the temperature profiles at different points were accompanied by measuring of following contaminants concentration, namely: carbon monoxide, nitrogen dioxide, phenol, benzene, toluene, xylene, ethylbenzene, cyclohexanone, cyclohexanol. These measurements supplemented the standard measurements of contaminants concentration conducted by air pollution monitoring stations of Upper Volga Regional Department of Hydro Meteo Service Russia in Nijny Novgogrod. The average and maximum levels of excess of the maximal-one time limited ultimate concentration (LUC) obtained during these measurements are given in Table 1.

Table 1.

	Carbon monoxide	Nitrogen dioxide	Phenol	Benzene	Toluene	Xylene	Ethyl benzene	Cyclo-hexanone	Cyclo-hexanol
Mean	0.17	0.48	0.48	0.46	0.19	0.57	0.50	0.17	0.15
Maximum	0.52	**3.18**	**2.00**	**2.13**	0.40	**1.00**	**2.58**	0.50	0.67

The analysis of obtained data showed that although weather conditions during conducting of the measurements favored the accumulation of contaminators in the atmosphere, it was not observed systematic exceeding LUC in the entire territory of city. It was not revealed regions with the regular excess of LUC levels. At the same time the excesses of LUC level by some contaminators (with exception of nitrogen dioxide) obtained during these measurements were not measured by the air pollution monitoring stations. This result is additional confirmation of high time-spatial variability of contaminants distribution on the city area.

4. Conclusion

The measurements of temperature stratification in the Nizhny-Novgorod industrial agglomeration carried out by means of mobile and stationary temperature profilers MTP-5 showed that

- In the inspected territory it was observed 3-5 sufficiently well resolved and steady zones distinguishing by the thermal structure of ABL. These zones are coupled with the orographical features of the city. The sizes and internal structure of these zones depended on the synoptic situation.
- The zone of representative using of stationary MTP-5 data for the forecast of bad weather conditions (BWC) was determined on the basis of data obtained during these measurements. As consequent from the analysis, the data of stationary MTP-5 can be used regularly in the forecast of BWC within the radius 6-8 km. The extending of forecast to entire territory on the city and its suburb is possibly only under the specified synoptic conditions.

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SwissMetNet: Renewal of the Swiss Meteorological Networks

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Abstract

The Swiss Federal Office for Meteorology and Climatology (MeteoSwiss) has launched the SwissMetNet-project for the renewal of its presently operational meteorological networks (subproject SDM) consisting of ANETZ (72 stations), ENET (44 stations) and KLIMA (25 stations). The main goals may be summarized as following:

1) *to better fulfil the requirements of the clients,*
2) *to standardize the different networks and their operation and*
3) *to lower the maintenance and operating costs.*

Furthermore, a new camera network (subproject CAM) is presently being installed consisting of 25 stations distributed around Switzerland to provide on-line information for now-casting information as well as for increasing the information potential concerning the aeronautical flight corridors over the Alps. Independently, an upgrade of the visual observation network (subproject OBS: 70 stations) is presently being performed by making use of modern computer techniques in order to increase the user-friendliness and therefore the quality of the observations. Finally, the EUMETNET/SWS project is now concluded and the results have been presented during TECO-2003 in Bratislava.

1. History

The first automatic station of the ANETZ network was installed in Switzerland in 1975 and the last one in 1989. This means that the oldest station reaches today an operational period of about 30 years.

For various reasons such as the difficulties in guaranteeing the renewal of the spare parts, a increasingly old technology (field stations and central data acquisition station), a wear of the material, the lack of flexibility, an aging system of transmission of the data on the technical level, etc., it was decided in 1998 to carry out an inquiry on the future requirements of the data users on one side and of the operators responsible for maintenance and correct operation of these networks on the other side. The need for a general concept became progressively obvious to work out a global strategy for MeteoSwiss concerning all the ground-based measurements for terrestrial and atmospheric meteorological information. This analysis was called “Messkonzept 2010” and was performed in parallel to the project dealing with the renewal of the meteorological networks. Very quickly, it was recognized that:

- in the long term, all the networks of MeteoSwiss were to be renewed together with a total cleansing of the sites;
- only an integral and standardized renewal of the networks would make it possible to optimize the operational aspects, and to decrease the operational costs;

- MeteoSwiss could build-up its capacity in this field and offer its competences to other institutions in charge of meteorological networks.

The direct consequence of these findings was an extension of the preliminary project (which took then the name of SwissMetNet) to all the existing meteorological networks operated by MeteoSwiss. Therefore, the following decisions were made concerning the specifications of the SwissMetNet project:

- Task 1: Renewal of the automatic and conventional meteorological networks in Switzerland that are run by MeteoSwiss (automatic backbone network ANETZ: 72 stations, automatic extended network ENET: 44 stations, “manual” climatic network KLIMA: 25 stations). In the future, and when suitable, take in charge other meteorological networks of the Confederation, Cantons, Communes and other partners to ensure their maintenance and operation (“Service provider”).
- Task 2: Develop a new network of 25 cameras (either fixed or mobile) for monitoring the atmospheric state and increase the competences of the forecasters (sub-project CAM).
- Task 3: Separate physically the visual observations from the weather stations and develop a new stand alone network for visual observations (sub-project OBS: 70 stations) making use of the most modern technologies.
- Task 4: Participate together with Finland and France to the EUMETNET/SWS "Severe Weather Sensors" project to gather the necessary bases to proceed to the choice of the weather instruments installed on sites under very harsh conditions (sub-project SWS).

2. Initial conditions

2.1 General

The initial requirements for the project SwissMetNet were defined as following:

- Take into account the requirements of all the existing and potential users such as they were defined within the framework of Concept MK2010 ("Messkonzept 2010").
- Take into account the needs for modernization of the infrastructures and the operational processes according to requirements of the operators while carrying out the following objectives:
  - eliminate the recognized problems;
  - adapt the networks to modern technologies of the XXI century;
  - reduce the operational costs.

2.2 Configuration of the network

Considering the recommendations contained in the Concept MK2010, the following configuration of SwissMetNet was defined:

Stations

- 45 stations of type WEeather STAtion WESTA B (basic climate stations, high quality standards),

- 45 stations complementary stations of type WESTA S1 (identical WESTA B with reduced instruments' configuration),
- 40 complementary stations of type WESTA S2 (simplified stations, reduced instrumentation),
- 70 visual observation stations of type WESTA O,
- 25 camera stations of type WESTA K.

Instruments

According to the Concept MK2010, the following criteria have to be applied:

- Preserve the instruments that give satisfaction.
- Replace the problematic instruments while preserving the quality of the existing long series of measurements by performing parallel measurements as far as possible.
- Prepare as far as possible the extension to new types of sensors in the future.

With regards to these requirements, the decision was made to partially renew the weather sensors outfitting the automatic weather stations.

Data Acquisition Systems

Concerning the data acquisition systems, the following requirements of performances were selected, such as:

- Record and digitalize the signals produced by the instruments.
- Format and transmit the data to the Central station.
- Perform the needed computation to deliver physical values for local use.
- Store locally the measurements (in the event of breakdown of transmission).
- Perform measurements concerning the state of the sensors and the station .
- Provide an electrical backup system for 7 days "low mode" operation (battery and solar panels)
- Initialize and transmit meteorological or technical alarms.
- Guarantee the flexibility of the system and its user friendliness

With regards to these requirements, the decision was made to completely renew the data acquisition systems of the automatic weather stations. In view of the volume of the task, the immediate consequence was that an international Call for Tenders following the rules of the World Trade Organization WTO became mandatory.

Measurement fields

Concerning the stations' field facilities, the following recommendations were defined:

- The local data acquisition systems have to be installed on the field (unlike the setup of the old ANETZ where the loggers were installed in a nearby building).
- The infrastructure for the installation of the instruments has to be renewed (masts, towers, measurement bridges, etc.).
- A complete renewal of the cables and wirings is mandatory.
- An enhancement of the maintenance procedures is to be planed.

With regards to these requirements, the decision was made to proceed to the general cleansing of all the measurement fields of the automatic weather stations.

Transmission of the data

From the 1.1.2001, the Federal Office for Informatic and Telecommunications (FOITT) is responsible for all the transmissions within the Swiss Confederation. This new situation makes it possible to make use of the advanced technologies established and operationally used by the FOITT. For SwissMetNet, the following conditions were defined:

- Use of the BVnet (“BundesVerwaltungs Netz”) network of the Confederation (FOITT).
- Installation of Cisco "routers” located in appropriate buildings as near as possible from the field facility.
- TCP/IP Sessions between the measuring site and the Central station
- Availability and reliability of about 100%.

Central Server

The basic requirements for a standardization of the meteorological networks lead to the conclusion that the WTO Call for Tenders should include the delivery of the central server, which would fulfill the existing requirements and make full use of the major improvements in the field of software and telecommunications.

Data must be logged from each weather station every 10 minutes and undergo a first set of quality tests within the Central Server (quasi on-line plausibility tests). Bulletins are then edited and automatically transmitted through a Message Handling System MHS to the new Data Warehouse DWH of MeteoSwiss and to other potential clients.

Technical Quality Assurance

A restricted set of data (e.g. all the surface networks’ data for the last 3 months) is automatically updated every night (Data Mart). In this way, off-line quality assurance tests (or diagnostics) can be performed on a daily basis, based on the set of data of the last 3 months. Procedures adapted to single instruments, single stations or to the complete network are applied to monitor the overall technical state of the network, allowing for preventive maintenance (early recognition of erroneous data or system degradation) avoiding time consuming and expensive breakdown repairs and data corrections.

Data Warehouse and meteorological Quality Assurance

In 2001 MeteoSwiss has started a project to consolidate its various databases, data processing and quality control systems in a unified conceptual architecture. As far as quality control is concerned a new generation of tools was implemented which has been developed over the last few years. The checking logic follows the recommendations of WMO. Additional tests were added to take into account the particularities of Alpine weather (e.g. Föhn, strong cold air pools). Station specific percentiles for each month are used as threshold values for limit checks which were recalculated from long time series of high temporal resolved data (usually 10 minute data).

The quality control tools are distributed in several modules in order to check data as close as possible to the data source and to provide checked data to the users as quickly as possible. Some of the modules in the chain are performed without user interaction, flagging suspicious data and attempting to correct obvious errors automatically. Others allow interactive checking and correction of actual as well as historical data. This concept allows different levels of quality according to the customers needs. All modules use a unified flagging procedure consisting of the 'plausibility information' (a bitmap indicating the test violations), a 'treatment information' (indicating the correction if one was applied) and the 'time series state' (indicating the quality level of the data) to guarantee transparency about a value’s status.

3. Current State of the SwissMetNet project

3.1 New automatic meteorological network (SDM)

A preliminary analysis phase was first launched in order to analyze the prevailing situation and to submit the different possibilities for the future network. A tentative budget and human resources planning was performed. This preliminary phase ended in December 2000.

This action was followed by a Concept phase where the specifications and requirements for the new network were defined. An international WTO Call for Tenders (4.2.2002) for the selection of the basis infrastructure of the network was then launched and its results evaluated: the final decision was made on the 27.5.2002 with the selection of Almos Systems as supplier for the SwissMetNet.

The Realization phase was then initialized to test the selected hardware and software. This was achieved by proceeding to the installation of two pilot stations in the plain (types WESTA B & S2 at Payerne) and in the mountains (Guetsch, altitude 2300 m a.s.l.). This test period gave enough positive information to launch the Introduction phase in July 2003.

Fig. 1 displays the installation of the Guetsch pilot station. As this site has to be used in the future as a MeteoSwiss test station for harsh environment, the design has been extended in comparison with a “standard” B station. This may be seen with the installation of up to 4 potential measurement bridges to allow for the testing of numerous instruments and their references. The new SwissMetNet type of mast, which can be kipped for the anemometer installation, can be spotted at the back of the picture. Furthermore, a new model of enclosure has been selected, which contains in separate compartments the power supplies and the data acquisition system (double units for the test station). A dedicated heating and ventilation system has also been designed to protect the latter sensitive elements. Finally, a full set of “house-keeping” measurement has been integrated in the system, allowing for an advanced remote diagnostic capacity.

Fig. 1: Pilot station on the Guetsch, 2300 m a.s.l.

As the effective construction of the network has to be performed by the "owner" of the network (Federal Office for Constructions and Logistics), two companies for the civil engineering and electrical tasks were selected again through a public publication procedure. In order to train this new manpower and tune the numerous project interfaces, it was then decided to proceed with the construction of two model stations in the plain (station Aigle) and in the mountains (station Guetsch). At the same time, the former pilot stations at Payerne and on the Guetsch (see Fig. 1) were upgraded to the newest level and refurbished as test stations, while a laboratory test stations was installed in Payerne.

In parallel, the new Central Server was installed at Zurich (standard version), so that the final Acceptance Test procedures for the pilot network (2 pilot/test and 2 model stations with a complete set of measurements connected through the BVnet to the central server) could be performed in 2003 and 2004 with full success.

3.2 New network of camera (CAM)

A preliminary analysis was concluded in January 2002, based on the evaluation by the clients (MeteoSwiss forecasters) of the pictures yielded by a test station installed at the International airport of Geneva and equipped with 3 types of cameras (fix, mobile and a "Total Sky Imager"). It was followed by a Concept phase where the definitive layout of the future network was defined as well as the procedures to be applied for the installation of totally new techniques for the MeteoSwiss staff. It was then decided that the Realization (pilot) phase had to deal with the following tasks:

- Installation of a reduced set of pilot stations.
- Tests of the use of mobile cameras for the reconstruction of panoramic sights.
- Tests of the quality of transmission of multiple pictures through the BVnet.
- Dissemination / Storing of the pictures (Internet, Data Base).

The installation of 3 and later 8 pilot sites has been performed in 2004 with good results. From the available test sites, the following preliminary conclusions could be drawn:

- The use of mobile cameras is possible even under harsh conditions. The problem concerning the degradation of the pictures' quality due to rain or snow can be avoided by integrating the cameras in a dedicated heated enclosure which can be positioned towards the ground between each panorama picture acquisition. This preventive measure gave very good results.
- The use of mobile cameras for reconstructing panorama views gives good results.
- The use of the BVnet for the data transmission has proved very reliable.

However, for different reasons, it was decided mid-2004 to out-source (through a new WTO Call for Tenders) the installation as well as the operation/maintenance of the complete network which will be operational in summer 2005.

3.3 Visual observations (OBS)

A Preliminary Phase was conducted in November 2001 based on the evaluation by the clients and the experiences with the current system, followed by a Concept phase ending in July 2002 which emphasized the physical separation of the visual observations from the automatic weather stations together with the development of a user friendly tool for the observers.

Based on these requirements the following tasks have been achieved during the ongoing Realization phase:

- The OBS-Clients are developed based on the browser technology without a local intelligence. All the intelligence is on the central system (which is part of the Data Warehouse system: measuring program, plausibility checks, context-data, etc.). Locally there is only some information like pictures of clouds stored.
- The GUIs for the observers are set up dynamically, based on information provided by the central system.
- Data transmission is based on a Remote Access Server (via modem and ISDN-terminal) to perform a high security standard.
- The observations are collected on-line. Tests on limits are done immediately while tests on consistency and variability are performed at the end of each session.
- The Software development is done in-house.
- The Realization phase is split into a "Proof of Concept" (detail-specification, performance, user guidance, security aspects, availability, etc.) and a pilot phase to implement the new tool at several pilot-sites.

The pilot phase ended at the end of 2004 and the upgrade of the whole network will start in March 2005.

3.4 EUMETNET/Severe Weather Sensors (SWS)

The EUMETNET[1] project "Specification of Severe Weather Sensors 1997-1998" summarized the icing effects on different types of meteorological sensors. Following the first SWS project, the SWS II project was started by the EUMETNET in July 2000 in order to test a number of ice-free sensors, as well as other measurement arrangements designed for cold climate conditions. Three different sites in Finland, France, and Switzerland were selected for this purpose. The final full report was published in 2002 and a reduced version in 2003. For more details see proceeding of the TECO-2003 Conference.

Fig. 2: Test platforms with different sensors at Mont Aigoual (left) and Säntis (right)

[1] EUMETNET is a network of 18 National Meteorological Services: those of the EU plus Iceland, Norway and Switzerland; www.eumetnet.eu.or

4. Perspectives

The intensive installation phase of the single stations of the new meteorological network is due to start on April 1st 2005. From that moment onward, the station will be upgraded following a very tight schedule so that the first 70 stations should be operational at the end of 2007.

In parallel to those activities, there are two other projects which are worth mentioning in relation with SwissMetNet.

4.1 CN-MET

The meteorological components linked to the security of the nuclear power plants (NPP) in Switzerland are integrated within SwissMetNet. Among others, 100 meter towers are operational at each NPP and should be also upgraded at the installation time. However, new concepts are today emerging, with the combination of remote sensing measurements and high spatial resolution models. This is why a new project named CN-MET has been launched to analyse the solution best fitted to the Swiss topography (more details are presented by B. Calpini: “Meteorology and Security around the Nuclear Power Plants in Switzerland”, Paper 2(7)).

4.2 Airports

One of the basic philosophical arguments sustaining the SwissMetNet project is the attempt to standardize all the measurement activities operated by MeteoSwiss. This includes also the 2 international airports located at Geneva and Kloten near Zurich, where SwissMetNet stations are anyhow planed. As the organization of the maintenance of the airports installations is also being presently reviewed, it is obvious that the SwissMetNet project will have to be extended to the complete infrastructure of the 2 airports. Discussions are presently underway to define a general maintenance concept for these 2 sites and the consequences on the installations’ configuration.

SESSION 2

NEW DEVELOPMENTS AND OPERATIONAL EXPERIENCE WITH UPPER-AIR OBSERVATION TECHNOLOGY

Session 2

KEYNOTE PAPER

Review of progress in the development of operational upper air technology.

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This paper provides a brief review of progress with operational Upper Air Technology, considering radiosonde systems, wind profilers, microwave radiometers and GPS water vapour.

1. Introduction

The main aim of many operational meteorological services at the present time appears to be reducing expenditure on ground based upper air measurements. Radiosonde consumable prices are generally considered as too high, although in real terms they may not have increased very much, given the very large improvement in measurement, processing and transmission technology applied in the latest systems.

The latest radiosonde designs produce measurements of much better quality than earlier designs, so it becomes more important to follow the manufacturer's guidance on preparation in order to ensure the best quality measurements. Modern hydrogen generators appear more reliable in operation than predecessors and can readily generate enough hydrogen to fill even large balloons (1200g) so that it should be practical to fly large balloons at a reasonable number of sites in the tropics without excessive expenditure.

Ground based remote sensing offers the chance of measurements at very high temporal resolution at a given site, for instance modern wind profilers and microwave radiometers can produce observations at 10 minute intervals compatible with the traditional sampling periods of surface measurements. Thus, in terms of number of observations per day the systems appear good value for money, if the operational meteorological services have a use for this number of measurements.

However, are these systems largely developed with research interests in mind and not operational applications? Is current development taking the systems towards improved usefulness for research or improved suitability for operations?

Are operational meteorologists hindering progress by failing to agree on suitable specifications for future observing systems? or by failing to provide the long-term investment in terms of skilled staff with expert meteorological insight who can work with the manufacturers developing equipment?

With a system like GPS water vapour measurements, large amounts of research have been taking place, but the system is not yet really used operationally by many meteorological services. This is probably because ingesting the measurements into existing numerical weather prediction models has produced results with varying success. In some countries the magnitude of benefits achieved has not yet justified the considerable costs that can be associated with accessing GPS data in near real time.

Currently most operational upper air wind and temperature measurements from large commercial aircraft are close to radiosondes measurements in quality. In the US relative humidity measurements are starting to become available in real time operations. On the other hand aircraft measurements are not available and will not be available from a large number of sites where upper air observations with high vertical resolution are required.

Thus, radiosondes and ground-based vertical sounding still have a viable future. On the other hand, network planners should take into account that the ground-based systems could lose commercial viability or face even more price increases in the future if the market size for the systems remains relatively small (wind profilers?) or the current market size is drastically reduced (radiosondes).

2. Progress with radiosondes

Modern radiosonde systems are much more sophisticated systems than the best radiosondes in use 20 years ago.

The best systems now have small temperature sensors that have rapid time constants of response so solar heating in the daytime is less than about 1 K at 10 hPa, and a simple correction scheme can be expected to produce temperatures with final errors less than 0.5 K in all circumstances. The use of aluminised sensors eliminates strong coupling to the infrared radiation fields allowing relatively uniform sensor performance around the world, independent of temperature structure. The temperatures at night from the better radiosondes should agree at all levels to within about 0.3 K.

Errors in height/ pressure used to be the limiting factor in stratospheric temperature in the tropics , but this can now be overcome by using GPS height measurements, see the results from the WMO Radiosonde Comparison in Mauritius. Thus, GPS radiosondes should no longer need to use a pressure sensor and this should lead to a reduction in the cost of GPS radiosondes.

Up to ten years ago the better quality radiosondes would only give consistent comparison results in dry conditions and very few worked reliably at temperatures lower than -40 deg C. In wet conditions very large persistent errors of greater than 20 per cent relative humidity were often found above cloud. Now, nearly all modern radiosondes are using capacitative relative humidity sensors. These can give reproducible relative humidity measurements down to temperatures of -70 deg C [height 14 km in the tropics]. Some of these modern radiosondes can now produce reliable relative humidity measurements in both wet and dry conditions.

Wind measurements with the new generation of code correlating GPS wind systems are much more accurate than any of the earlier operational wind systems. The capability of GPS radiosondes has been improved so that systems are now available that synchronise rapidly during radiosonde preparation with minimal requirement for exposure outside before launch.

The new generation radiosonde transmitters are much more stable in frequency and as such cannot be criticised by the ITU for wasting radiofrequency spectrum. This also leads to very good data reception in the ground system with relatively low power radiosonde transmissions.

Ground systems associated with GPS radiosondes have become so small that it is easy to transport them around with minimal time necessary for installing an upper air station.

At this time a large scale changeover to the new generation radiosondes is starting to occur in the global network. This has caused problems since although the radiosondes are much superior to the earlier radiosondes; many customers are reluctant to pay the cost associated with upgrading. In this situation it is clear that the main manufacturers need to upgrade to modern components and manufacturing technology to minimise the cost of production. On the other hand, the customer cannot be expected to endlessly pay out for upgrades in equipment, particularly when the equipment was purchased as perfectly adequate only a few years ago. Thus, it is to be hoped that suitable arrangements can be made which minimise the costs involved to both manufacturer and customer.

A second problem involves those countries that do not wish to buy from the main commercial manufacturers, but wish to use national resources to produce radiosondes. Monitoring results for the global radiosonde network readily demonstrate that these countries lag behind in radiosonde measurement performance, particularly with respect to relative humidity measurements and in some case even with temperature. The continued existence of this very large gap in observing system performance is a major obstacle to progress in upgrading the global radiosonde network. Unfortunately, any actions to remedy the problem have not yet been effective. There remains a challenge to CIMO to devise better methods of encouraging progress, since this is not a problem caused by insufficient technical capability in the nations concerned.

2. Wind profilers and Doppler weather radars

The use of operational wind profilers has been expanding most rapidly in Asia where since 2001 Japan has installed a network of 31 profilers observing from near the surface to about 5 km in dry conditions and 8 km in precipitation [Ishihara, 2005], see Fig. 1(a) and (b) This network operates well and delivers the measurements required, i.e. wind in the lower and middle troposphere, for numerical weather prediction in Japan. The frequency used is in the range 1300-1375 MHz. Fig.1 (c) shows an example of wind measurements on a day when the centre of a typhoon passed close to one of the small island wind profiler sites, with winds as high as 60 ms^{-1} reported at a height of 1.5 km. Given that wind profilers can operate well in these conditions as long as the power supply and communications can be maintained, it is surprising that more systems are not deployed for observing conditions in these types of storms in other parts of the world.

In contrast to Japan, the main new wind profiler developments in Europe have been in operational systems designed to observe from near the surface to heights above the tropopause. In Germany 2 new generation profilers, operating at around 482 MHz

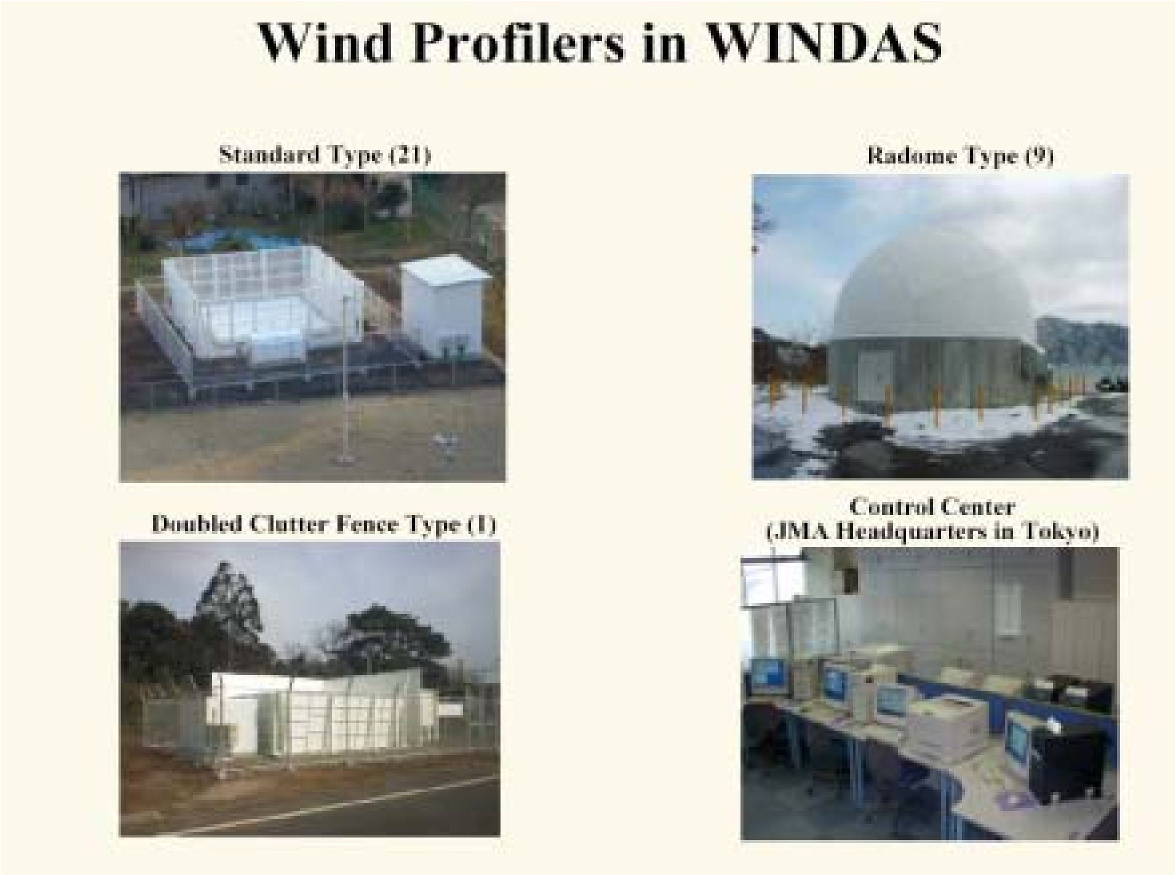


Fig.1(a). Different types of wind profiler installation in the JMA wind profiler network plus the control centre in Tokyo, extracted from Ishihara [2005]

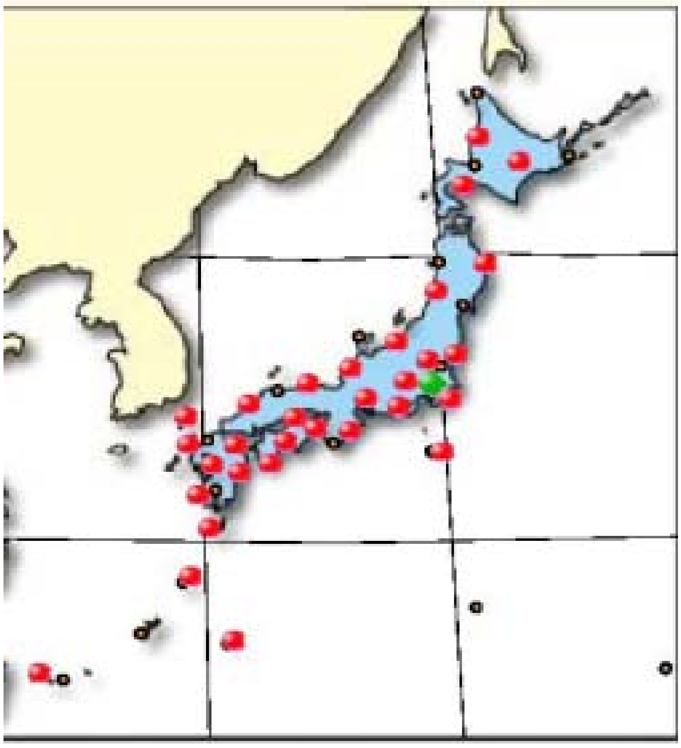


Fig.1(b) Map of wind profiler sites in the WINDAS network , extracted from Ishihara[2005]

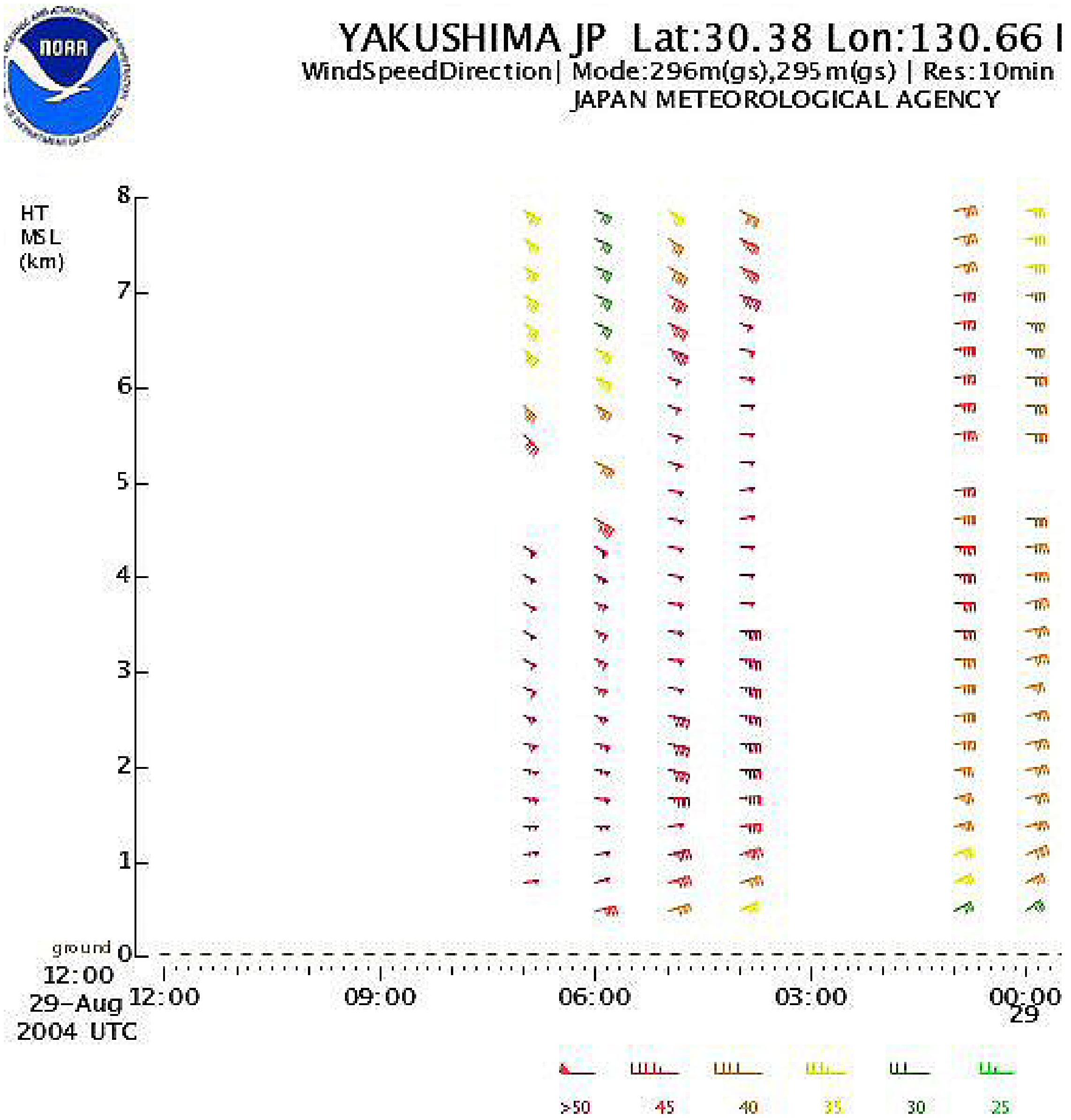


Fig.1 (c) Wind profiles measured by JMA wind profiler as typhoon approaches mainland Japan on 29 August 2004, extracted from NOAA-NPN archive.

have been installed and are in satisfactory operation, see Fig.2 (a) for a picture of the system at Nordholz. The measurement coverage in the vertical in the upper mode of this system can be seen in Fig.2 (b). The winds at 12 km show plenty of variation during the day, and these variations will become more important as numerical weather prediction attempts to represent smaller scales of atmospheric motion. Of course, if there are plenty of aircraft flying over the area day and night then expenditure on a profiler with this capability may not be justified. The profilers in Germany have excellent signal to noise characteristics and probably represent close to optimum in the measurement quality that can be obtained from an operational wind profiler, see Fig.3.

Fig.2(a) Deutsche Wetterdienst 482 MHz wind profile +RASS installed at Nordholz.

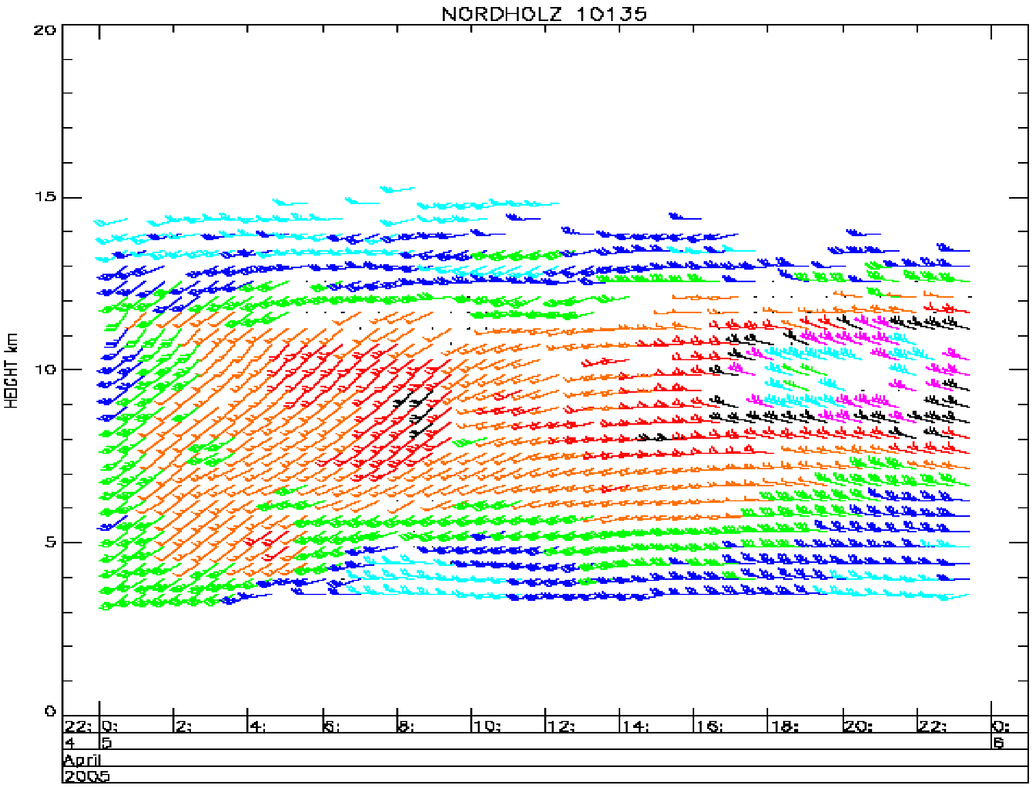
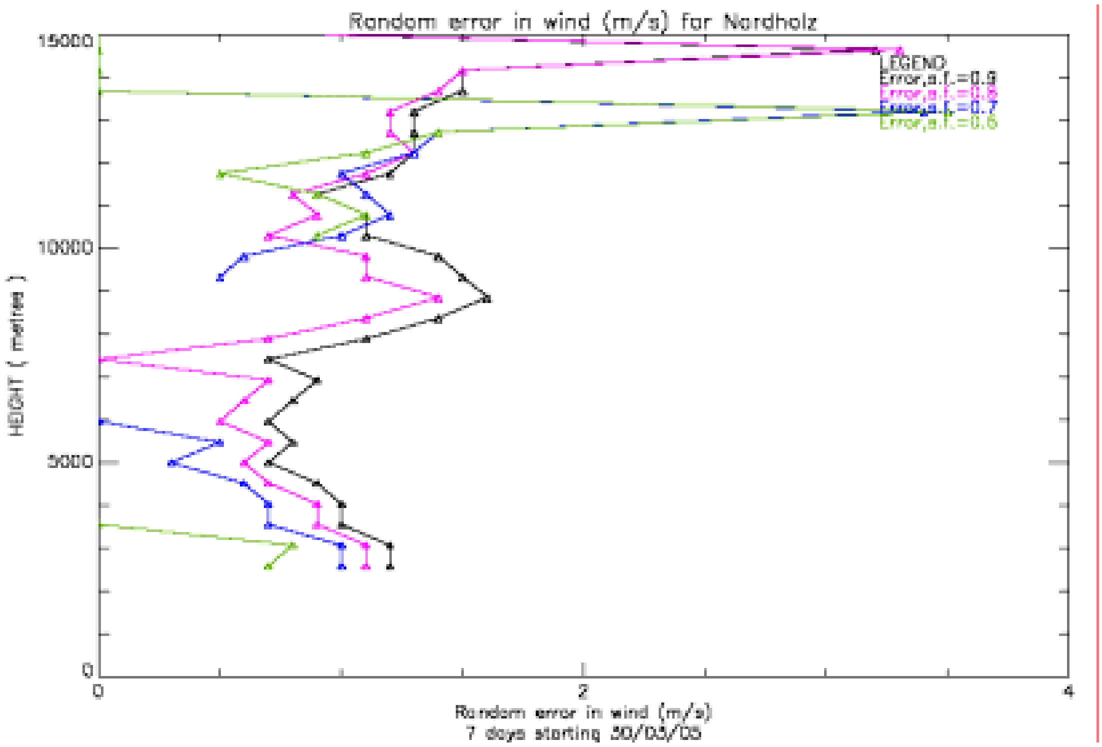


Fig.2(b) WINPROF[CWINDE] hub monitoring display of time-height display for winds from 5 April2005



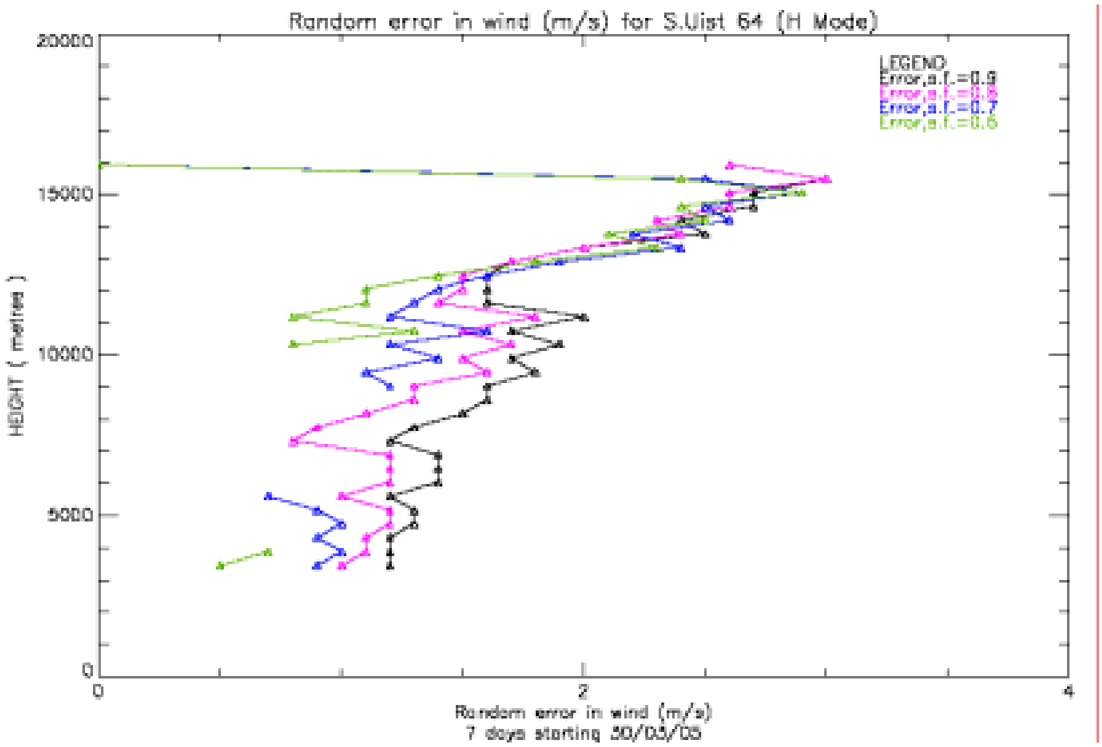


Fig.3 Comparison of random error estimates from the Nordholz [Germany] and South Uist [UK] wind profilers produce by the WINPROF [CWINDE] monitoring hub.

Fig.4 Operational wind profiler observing at 64 MHz on the island of South Uist.

Fig.4 shows a profiler installed with a similar purpose to the systems in Germany, but with a more tolerant specification on acceptable wind error. This is on an island to the west of the Scottish mainland, where in wintertime there can be extremely violent storms. Although much of the internal electronics and software is similar to the systems in Germany, a different antenna design was chosen because of the need of the antenna system to be very resilient against corrosion from driven rain, with the system very close to the sea. Although the concrete foundation for the Yagi antenna was expensive, the overall cost of this system was much less than the systems in Germany. Even so, it is still very expensive and will require a very strong business case to justify expenditure on many more systems. At 64 MHz, it has been found essential to use multipeak identification software in processing the results from the Doppler spectra, whilst this type of software is not required with the Germany systems. Thus, although the UK and Germany tried to keep to a similar specification for these wind profilers, in practice the systems have diverged because of the different operating conditions. The UK system has less ongoing problems with radiofrequency sharing, but the German systems having fewer problems with ground clutter.

Fig 5(a) shows an alternative solution to the more expensive wind profilers , where a 1290 MHz system is deployed at Zurich airport by MeteoSuisse for a development project. This system has been assembled from spares available to MeteoSuisse and Deutsche Wetterdienst, with a clutter screen devised by Meteo Suisse, avoiding the expensive option of purchasing the manufacturers clutter screen.

Fig.5(a) Temporary installation of Meteo Suisse-DWD wind profiler at Zurich airport.

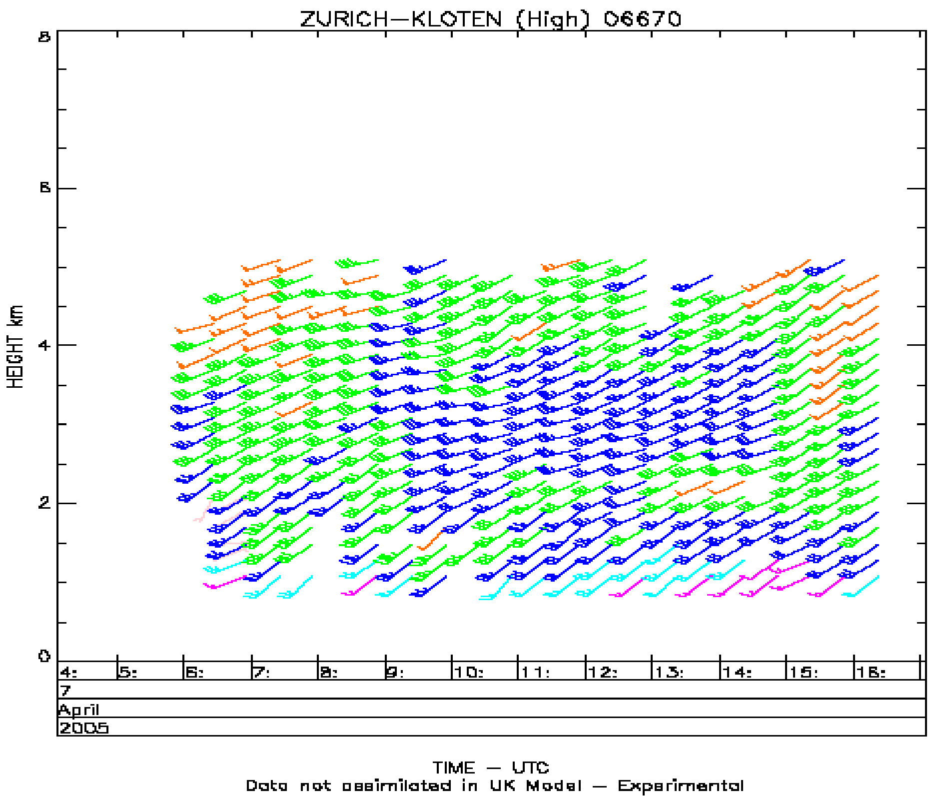


Fig.5(b) WINPROF[CWINDE] hub monitoring display of time-height display for Zurich winds from 7 April2005

The wind measurements at Zurich are again of acceptable quality, random errors of 2 ms^{-1}.

In the US, the conversion of wind profilers in the NOAA-NPN from 400 to 449 MHZ continues. It is unfortunate that some countries are still trying to design new wind profilers operating in the 400 to 406 MHz band. This design of new systems was specifically forbidden by the ITU when granting the current allocations for wind profilers.

NOAA is making efforts also to assimilate winds from at least 80 cooperating sites (with different types of profilers, as in Europe). A new 449 MHz profiler intended to be cheaper than the full scale NPN profilers and only observing at heights up to 8 km has already been supplied to a limited number of sites.

Are wind profilers only to be used for measuring at heights below aircraft cruise levels in future, or are there sufficient locations where observations will be required to heights above 12 km to justify economic production of the larger systems? What is the necessary accuracy requirement for acceptable observations?

The costs of some of these large profiler systems are coming close to the cost of modern Doppler weather radar. Fig.6 shows VAD wind outputs from weather radar in Finland

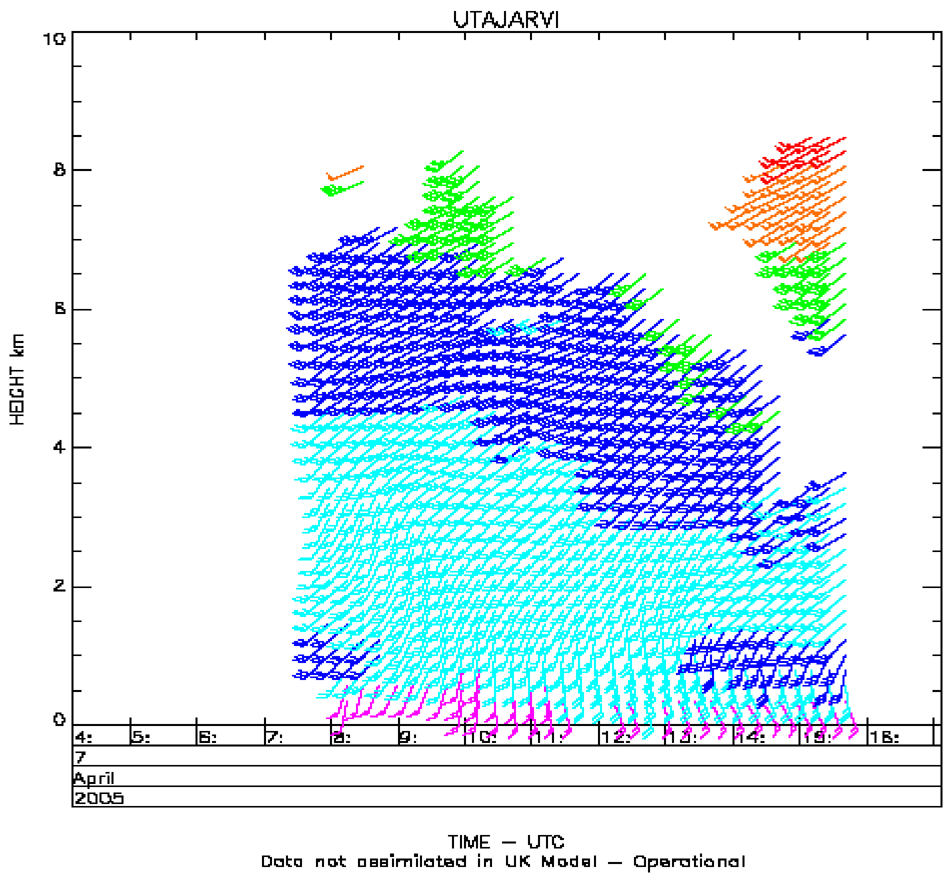


Fig.6 WINPROF[CWINDE] hub monitoring display of time-height display for Utajarvi winds on 7 April 2005. Here the failure to assimilate the data in the UK model is not related to poor measurement quality on this day.

Network planning for the future also needs to take into account the availability of winds from Doppler weather radar systems. These radar winds are now being used in numerical weather prediction.

3. Microwave radiometers

RASS systems provide a method of measuring profiles of virtual temperature in the atmosphere, but in many countries it is difficult to find sites where the noise from the systems is not accepted by the local population or the noise attracts attention to the position of the ground based remote sensing installation and then vandalism occurs.

Multichannel microwave radiometers have been available for ground based remote sensing of temperature and water vapour for many years. They offer the option to measure temperature in the lower troposphere, integrated water vapour plus an indication of the vertical structure of relative humidity in the lower troposphere, liquid water in cloud and some indication of cloud base height if an upward pointing infrared radiometer is incorporated with the system. As with wind profilers, the cost of radiometers was not cheap. However, in recent years efforts have been made to design the systems so they can be manufactured in a more cost-effective manner, and the prices have fallen significantly.

In late 2004 two systems were compared in Camborne, both being able to observe the atmosphere sufficiently quickly to resolve the effects of cloud moving rapidly over the observing site. Fig.7 shows how the scan rates of the Radiometrics MP3000 have increased since January 2002. Radiometers with this observing capability were not available commercially five years ago.

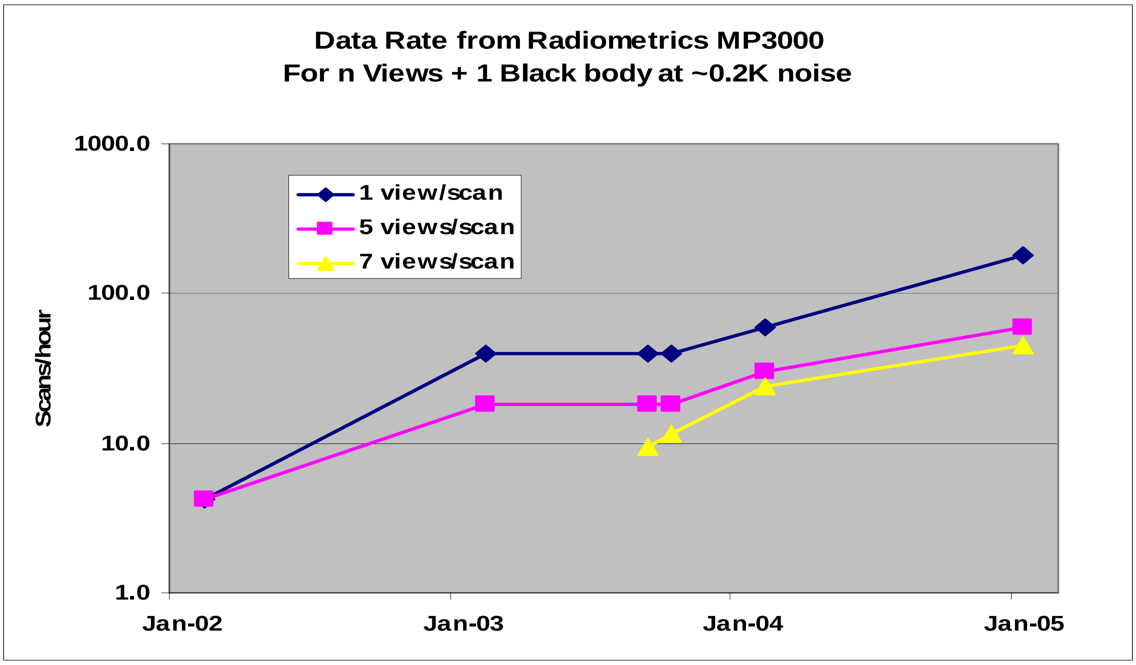


Fig.7 Increase in the scan rates available with the Radiometrics MP3000 microwave radiometer.

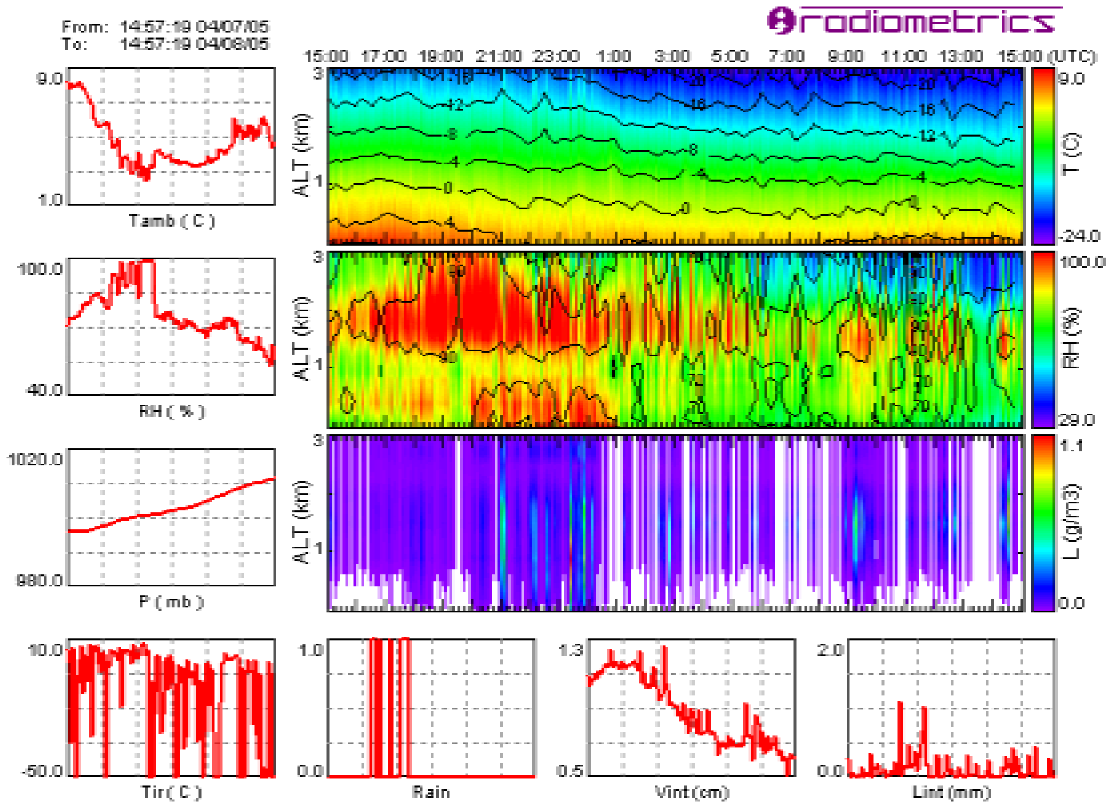


Fig. 8 Time height displays of high resolution temperature , relative humidity and cloud measurements observed at Camborne during a 24 hour period from 14.57 on 07 April 2005 [long displays, upper right side]. Displays against time in[other boxes working anticlockwise from top left hand side are surface temperature, surface relative humidity, pressure, infrared temperature, presence of rain, integrated water vapour, and total liquid water in cloud..

The comparison at Camborne identified problems in calibration and noise with the two radiometers, but it is expected that these will be rectified before further tests this year. Both systems seem to be able to make measurements in situations with drizzle and light rain where earlier radiometers could not produce reliable measurements.

4. GPS measurements of integrated water vapour

Whilst there are several Internet sites where real time measurements of integrated water vapour can be accessed there are relatively few countries where the system has been handed over from the scientists to be run as a standard part of operational observing. The COST 716 project in Europe looked at the use of the data and produced estimates of the true costs of setting up an operational system, see Elgered et al [2004]. Costs of installing the sensors are not negligible for a closely spaced network, and even where large number of sensors have been installed for other purposes it may be difficult to get cheap real time access to the sensors for operational purposes. In the UK there was a relatively small network of GPS sensors during the COST 716 demonstration, but in the last year this has increased as a consequence of a memorandum of understanding between the Met Office and the Ordnance Survey, the UK government mapping agency. The Ordnance Survey are installing sensors on some Met Office automatic weather station sites and in return are getting access to real time data from the whole of the mapping agency network . Fig.9 shows an example of the coverage of IWV that is now being processed in real time for the Met Office.

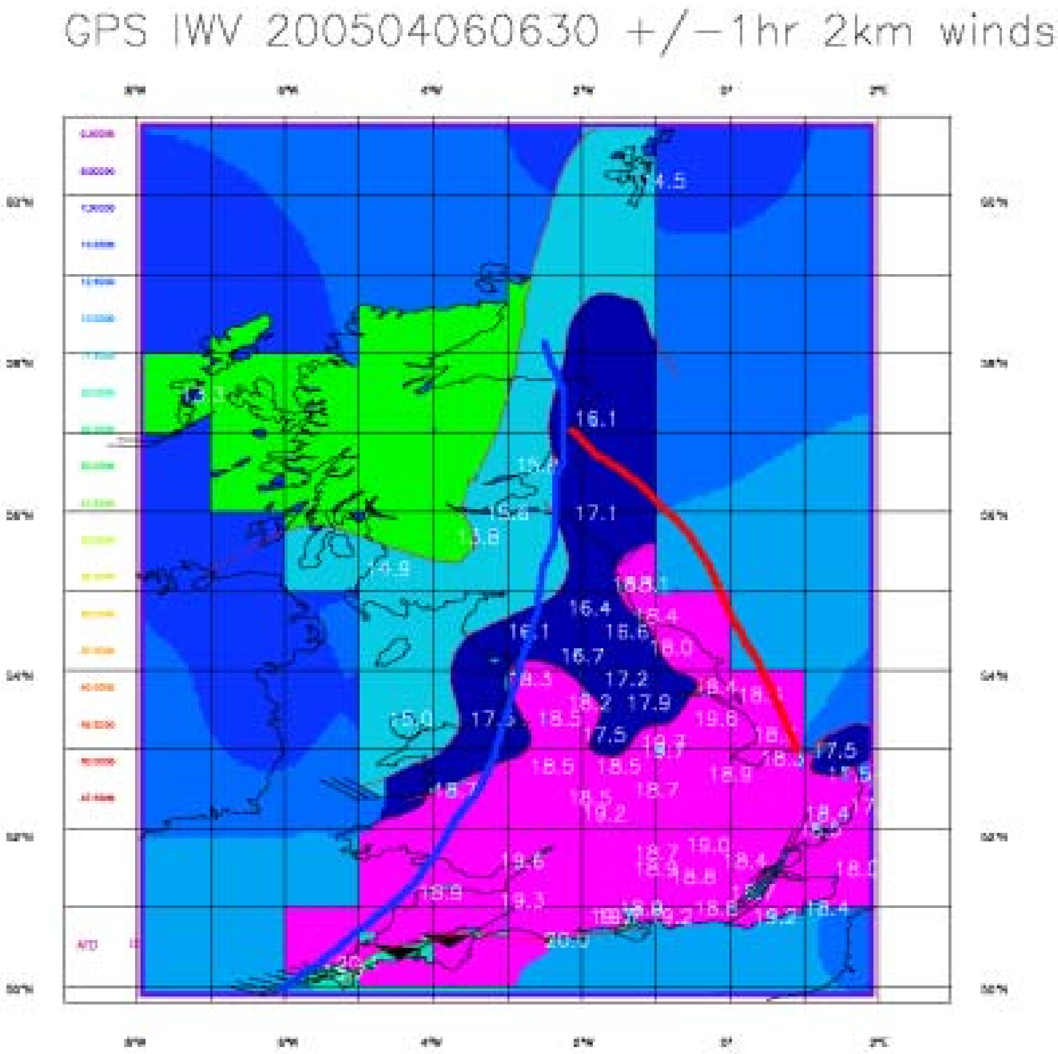


Fig. 8 IWV field averaged over one hour derived from about 70 sites across the UK, mostly owned by the Ordnance Survey, processed in collaboration with IESSG, Nottingham University. This plot was derived in real time, with a delay of about 30 minutes after the end of the sample period. IWV values are contoured at 2 kg. m^{-2} intervals wind, with the winds taken from the UK wind profilers at 2 km.

It is probable that to obtain most benefit from the water vapour measurements it is necessary to ensure that the atmospheric motions on the scales observed with the GPS system are accurately represented in the model. Thus, it will be essential that upper winds are available on the necessary scales and assimilated correctly.

In summary GPS water vapour measurements are not as cheap as was originally claimed. However, it does seem apparent that useful information for meteorology can be obtained at suitable cost by negotiating sharing arrangements with other government agencies. If these systems are to be used in the tropics it may be necessary to organise centralised regional processing and distribution of the data in future.

References:

Elgered, G., H.-P. Plag, H. van der Marel, S. Barlag, and J. Nash, COST 716[2004]: Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications, Final Report, to be published by the European Community, available from: http://www.oso.chalmers.se/~kge/cost716.html.

Ishihara, M.(2005) Wind Profiler network of Japan Meteorological Agency: document 4.3.2, CIMO Expert team on Remote Sensing Upper-Air Technology and Techniques, 16-17 March, Geneva, available on WMO web site: http://www.wmo.int/web/www/IMOP/IMOP-home.html

Session 2

PAPERS

OBSERVATIONS FROM THE GLOBAL AMDAR PROGRAMME

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ABSTRACT

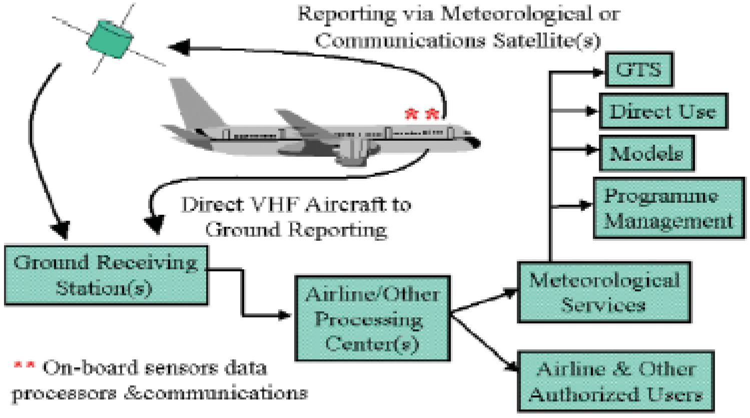
The global AMDAR programme provides a relatively new upper air observing system that has expanded rapidly over the past 10 years. It is a very cost effective system that is automatically producing daily more than 170,000 high quality observations of wind and temperature from the surface to 40,000 ft from regular passenger and freight aircraft. The programme is coordinated by the WMO AMDAR Panel that comprises a group of 21 Members and other interested organizations. The programme has 2 main goals - firstly, to provide timely, low cost observations in data sparse areas of the world in support of the WMO World Weather Watch Programme through integration in the Global Observing System. Secondly, to provide such observations to supplement data from existing conventional observing systems as part of a more complete integrated upper air programme. The AMDAR Panel has undertaken a priority project to meet the fundamental requirement for high quality observations of humidity/water vapour for operational use. There are also requirements for observations of turbulence and icing to support the aviation industry. This paper presents an outline of the status of the programme and presents information on data quality and progress in developing and implementing new types of observations.

Introduction

Since the beginning of flight, weather observations taken from aircraft have made an important contribution towards understanding the current state of the atmosphere so that better weather forecasts can be made. The value of automated reporting of meteorological observations from aircraft was established in the 1970s during the First Global Atmosphere Research Program Global Experiment (FGGE). A number of long-haul wide-bodied passenger jet aircraft were fitted with specially built **A**ircraft to **S**atellite **Da**ta **R**elay (ASDAR) systems that provided valuable observations of temperature, wind and pressure over data sparse land and oceanic areas of the world. High quality data were transmitted via geostationary meteorological satellites to national meteorological services and exchanged globally on the WMO GTS. Today, the Aircraft Meteorological Data Relay (AMDAR) system facilitates the fully automated collection and transmission of weather observations on commercial aircraft around the world. AMDAR has been adopted as the generic name for automated meteorological reporting systems from aircraft. The first operational AMDAR program commenced in 1986 with 5 aircraft producing less than 1000 observations per day, but the program has grown rapidly since then with more than 2300 aircraft worldwide contributing approximately 180,000 observations per day. Further more, various AMDAR programs undertaking operational trials are producing more than 20,000 observations per day. AMDAR data are used operationally to support a wide range of meteorological applications and are considered by WMO to be an essential source of basic upper air information.

The AMDAR System

AMDAR takes advantage of existing systems and infrastructure onboard aircraft as well as those established by airlines for routine operations. Onboard sensors, computers and communications systems obtain, process, format and transmit data to ground via the aviation industry standard Aircraft Communication Addressing and Reporting System (ACARS) that consists of Very High Frequency (VHF) and satellite elements to provide communications coverage for much of the world. Once on the ground, the data are relayed to the global network of national meteorological services (NMS) and other authorised users as shown in the figure. Data are received at the data acquisition system of the NMS where they undergo basic quality checks and control before being reformatted to the relevant Text FM42 or BUFR FM94 AMDAR code for distribution for internal use and via the GTS to other NMSs.



Data Flow through an AMDAR System

An essential element of the AMDAR system is the routine data quality monitoring undertaken by global and regional centres. Reports are provided on a daily basis by some centres to assist program managers make decisions on maintaining high quality data. Other centres provide monthly reports that also assist with careful program management. Of equal importance is the 2-way feedback path between the NMS and airlines to ensure relevant remedial actions are taken to remove the source of poor quality data. This is one of the main reasons for the proportion of poor quality AMDAR data being less than 1%.

Other essential elements include the ability to target observations in time and space to help fill data sparse regions of the world and to optimise local operations to maintain tight control over data coverage to meet operational and financial constraints.

AMDAR Data

National meteorological services have shown these cost-effective high quality AMDAR observations contribute to improved short to medium term numerical weather forecasts and provide a valuable tool to real-time forecasters for a wide range of operational services including severe weather, aviation, defence, marine, public weather and environmental monitoring. Since AMDAR observations are used for a wide variety of operational functions, they are considered to be basic data and can provide valuable asynoptic in-situ information in data sparse areas that otherwise would not be available. AMDAR has shown that it can form an important component of national, regional and global composite observing systems.

Evaluation of AMDAR data over many years has shown the observations to be of high quality comparable to operational radiosonde data. Requirements for the desirable horizontal spatial and temporal density of vertical profiles of wind, temperature and humidity have become more stringent over recent years. Currently, the requirements for Europe and the US respectively are one profile on a 250 km grid at 3-hourly intervals and a 100 km grid at 30 min. intervals.

The primary (basic) data set from each aircraft participating in the AMDAR program includes position in time and space, wind speed and direction and ambient temperature that are available directly from the aircraft avionics system. A secondary additional data set contains derived observations that require further onboard processing of other basic observations form the aircraft data bus. Details are given in the following tables.

BASIC Data

Element	Unit	Range	Output resolution	Desired accuracy
Pressure Altitude	Foot (ft)	-1000 to 50000	10	100[1]
Static Air Temperature	°C	-99 to 99	0.1	0.5[2]
Wind Direction	° from true N	1 to 360	1	Note (2,3)
Wind Speed	Knot (kt)	0 to 800	1	Note (2,3)
Latitude	Degree:minute	90:00S to 90:00N	1.0min	Note (4)
Longitude	Degree:minute	180:00E to 180:00W	1.0min	Note (4)
Time (UTC)	Hour:Minute:Second	00:00:00 to 23:59:59	1 min	1s

Notes:

(1) required to preserve temperature accuracy
(2) WMO requirement for NWP in troposphere
(3) $2ms^{-1}$ (4kt) vector error
(4) 5Nm equivalent (specified for ASDAR)

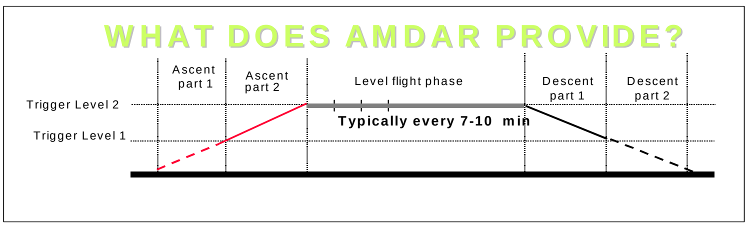
ADDITIONAL DATA

Element	Unit		Output resolution	Desired accuracy
Maximum wind	kt	0 to 800	1	4
Turbulence (g)	g [4]	-3 to 6	0.1	0.15[1]
Turbulence(DEVG)	$m s^{-1}$	0 to 20	0.25	0.5[1]
Turbulence(EDR)	$m^{2/3}s^{-1}$	0 to 1	0.05	0.1[1]
Humidity(RH)	%	0 to 100	1	5[2]
Humidity (dew pt)	°C	-99 to +49	0.1	Note 5
Humidity(mixing ratio)	gram/kg	0 to 100	0.001	$1:10^3$ (measurement)[3]

Notes:
(1) Determined by output categories required
(2) WMO requirement for NWP in troposphere
(3) To meet stratospheric humidity requirement
(4) Acceleration due to gravity. 'Zero' reference on aircraft is usually +1.
(5) Equivalent to 5% RH error.

Profiles and Cruise Level Data

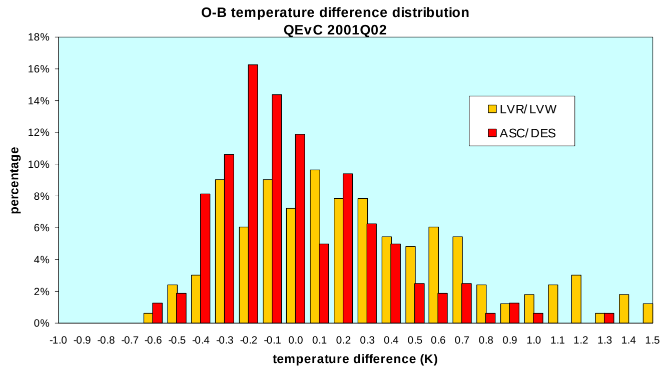
AMDAR provides data profiles during ascent and descent phases of flight and routine observations at given time intervals at cruise level as shown in the diagram. Profiles are divided into 2 stages and may be triggered according to preset pressure levels (preferred) or time intervals. Sampling rates can be varied as required to meet operational requirements and budgetary constraints.

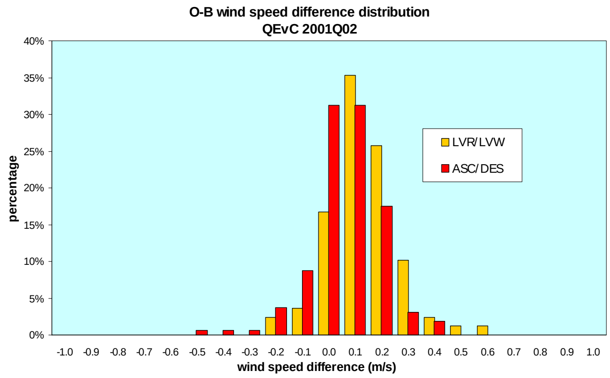


	Pressure Based Triggering	Time Based Triggering
Ascent Part 1:	5 or 10 hPa intervals for first 100 hPa	3 to 20 second intervals (default 6) for 30 to 200 seconds (default 90)
Ascent Part 2:	25 or 50 hPa intervals above first 100 hPa	20 to 60 second intervals (default 20) for 490 to 1050 seconds (default 510)
Enroute:		1 to 60 minute intervals (default 7)
Descent Part 1:	25 or 50 hPa intervals from TOD to last 100 hPa	20 to 300 second intervals (default 40) from top of descent to surface.
Descent Part 2:	5 or 10 hPa intervals for last 100 hPa	

Data Quality

The general quality of automated aircraft observations is consistently high across the 2300 participating aircraft around the world. Mean temperature bias and uncertainty respectively are typically less than 0.5 and 1.3 deg. C . The equivalent numbers for wind observations are 0.6 and 4.0 m/s. The figures below provided by the E-AMDAR monitoring centre at KNMI show the results of monitoring about 300 aircraft over a 3-month period and are typical of all fleets.





Centres monitoring AMDAR data include the National Centers for Environmental Prediction, ECMWF, UK Met Office, KNMI, Canadian Met. Centre, Meteo France, Deutscher Wetterdienst, Bur. of Met. and JMA most of whom make the data available ether on a daily basis for local and regional use or monthly for global use. A number of other centres including those from Saudi Arabia and China also monitor their own data. The results are generally quite consistent across the centres and poor performing aircraft are readily identified. WMO has produced a standard set of monitoring criteria that are being implemented across all centres. Monitoring is achieved by comparing observations with the model first guess field, however in at least one case, 2 additional techniques are employed. AMDAR data are routinely compared with radiosonde data as well as as against other aircraft. This latter technique is very sensitive and removes contributions from the reference monitoring systems. Some 94% of data are available on the GTS within 60 minutes and more than 99% are available within 120 minutes.

As previously stated, critical elements of the AMDAR system are the free exchange of data-quality information between monitoring centres and the respective participating NMSs together with the excellent collaborative relationship most AMDAR operators have with their participating airlines. Apart from providing the airlines with a very sensitive and accurate calibration service of the temperature and wind sensors onboard their aircraft, the various national and regional AMDAR focal points alert the airlines when sensor biases approach 2 deg.C. As soon as the bias consistently goes beyond this value, data from the aircraft are withdrawn from distribution and local operational use and the airline is requested to take remedial action. Initially airlines were reluctant to consider such drastic steps until the bias reached 5 deg. or more but they now recognise the importance that accurate temperature observations have on aircraft engine performance. This of course converts to money saved on fuel burned and engine wear. Similarly, the airlines appreciate the improved wind forecasts, particularly for long-haul routes.

To the left is a picture of an insect taken from an aircraft temperature probe. Errors were first noticed when a large jump in temperature bias was detected by the national AMDAR monitoring centre. This coincided exactly with the airline detecting an increase in fuel burn on the same aircraft. Engine performance returned to normal after the probe was replaced.

Participating Countries and the AMDAR Panel

AMDAR programs are now operated by 14 countries including Australia, New Zealand, Japan, China, Hong Kong China, Saudi Arabia, South Africa, US, Canada, The Netherlands, UK, France, Sweden and Germany (the latter group of 5 operating as a European regional program under EUMETNET). Programs are under development in Finland, Chile, Argentina, The Republic of Korea and the United Arab Emirates. A number of other countries are either planning or exploring the feasibility of developing programs including the Russian Federation, Romania, Poland, Hungary, the Ukraine, Austria, Spain, Iceland, Ireland, Morocco, Brazil, India and Pakistan.

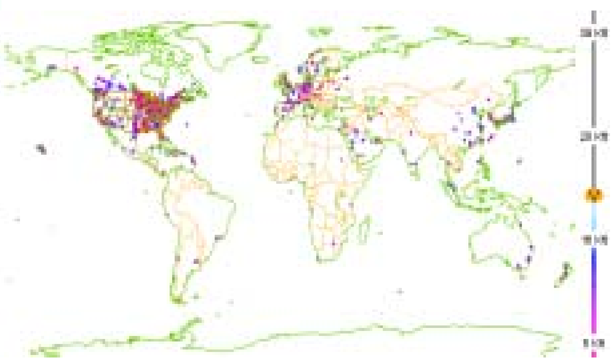
AMDAR is an internationally coordinated program with the core aim of collecting and globally distributing high quality meteorological/environmental data obtained automatically from appropriately equipped aircraft. Stakeholders include aircraft operators, national meteorological services, research institutions and other national and international agencies. In recognition of its importance and value as a reliable source of high quality upper air data, AMDAR is being integrated into the World Weather Watch Global Observing System under the World Meteorological Organization. AMDAR will also form an important component of the Global Earth Observing System of Systems that will be supported by WMO and countries committed to providing and using AMDAR data.

The AMDAR Panel was formed in 1998 and consists of representatives from WMO Member countries that participate directly in the AMDAR program and who provide the funding for its activities. Panel meetings and workshops are coordinated by the AMDAR Panel with organizations and groups actively involved in the development, collection and use of observations from aircraft. Observers currently include international agencies representing airline operators and providers of air traffic safety. Other bodies with direct interest include providers of airline communications, aircraft avionics and sensors and research institutes. The AMDAR Panel is the executive manager for the International AMDAR program.

Data Coverage and Growth

The following two figures show the global enroute AMDAR coverage and the locations where AMDAR profiles were generated on 15 February 2005. The second figure in particular clearly reveals the data sparse areas where no profiles are available. At the moment these sites tend to correlate with the sparsity of upper data from conventional observing systems. The CBS Expert Team on Data Requirements and Redesign of the Global Observing System has identified a number of regions that urgently in need of upper air data that generally match the second figure. One of the main aims of the AMDAR Panel is to increase AMDAR coverage using a variety of techniques to help reduce these data sparse areas. The principle means of achieving this is through the provision of targeted data by existing AMDAR providers through collaborative programs with countries in the data sparse regions. This system is further explained below.

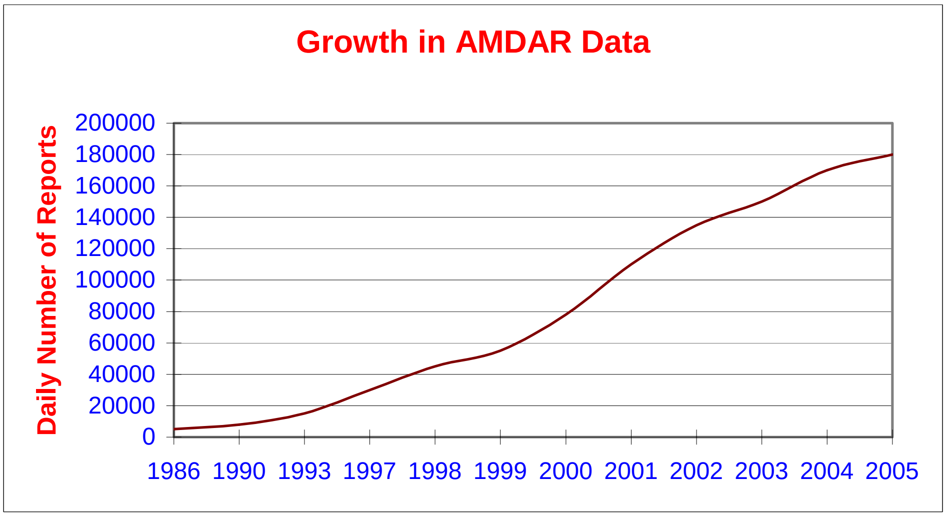
Global AMDAR Coverage 15/2/05



AMDAR Profile sites

Figures provided Courtesy of NOAA Forecast Systems Laboratory

The number of AMDAR observations exchanged daily on the GTS has grown from less than a thousand in 1986 to over 180,000 currently as shown in the accompanying figure. It is anticipated that the number will nearly double over the coming 5 years as existing programs expand, new observation types are introduced and new national and regional programs come on line.



Data Constraints

The production of AMDAR observations is subject to a number of constraints:

- Data profiles are confined to airports where AMDAR configured aircraft operate;
- Cruise-level data are confined to normally well defined aircraft routes;
- Maximum altitude reports are limited to aircraft cruise levels, typically between 20,000 and 40,000 feet;
- The time of observations are constrained to scheduled flight time tables;
- The number of reporting aircraft, area coverage and sampling frequency including vertical profile density are governed by budgetary constraints of the responsible national weather service;
- Observed elements have been limited to pressure, temperature and wind with a small number of turbulence observations. Moisture content, icing and more extensive coverage of turbulence will be gradually phased in over the next few years;

New Types of Observations

One of the major limitations of automated observations from aircraft has been the lack of a reliable humidity/water vapour sensor. Although trials of a prototype sensor occurred several years ago, no aircraft are routinely reporting water vapour content. Work on a new water vapour sensor (WVSSII) in the US has been completed and a 6-month evaluation trial using 30 sensors mounted on B757 freighter aircraft will take place later in 2005. A number of countries including the E-AMDAR group, Australia, South Africa and New Zealand are planning operational evaluation trials in 2006 on the Airbus A320 family of aircraft using a small number of sensors. Once proven, the number of sensors will grow slowly because all purchase, installation and operational costs are paid by the participating weather service. However, additional countries have indicated their intension to install and operate a limited number of sensors to help supplement radiosonde soundings in carefully planned integrated upper air observing systems.

Although an aircraft independent observation of turbulence in the form of Derived Equivalent Vertical Gust Velocity (DEVG), has been reported automatically by some aircraft since 1986, there has not been a strong demand for this type of observation. Data were used mostly for forecast verification and the location of jet streams and gust fronts. More recently however, as awareness has grown of the potential operational use of this observed element particularly in the aviation industry where the safety of passengers and aircraft has become a major issue, new implementation programs have commenced reporting turbulence in the form of Eddy Dissipation Rate. The US FAA has a number of programs to develop services based on these data.

Another type of observation that is not of great interest or value for routine forecasting but is of special interest to the aviation industry is the detection of icing conditions. In flight icing potential and the rate of ice accretion on aircraft flight control surfaces is of value to the industry for a number of operational and safety reasons. Tests are being undertaken to determine the most appropriate way to report and use the on/off signal of automated de-icing systems found on many modern aircraft. A number of icing sensors are being developed to report icing conditions. Information relating to the existence of super cooled water droplets is currently considered to be the preferred type of data needed.

Data Targeting and Optimisation

It is now technically feasible to control the time and location of observations on appropriately configured AMDAR aircraft operating anywhere in the world. This can be achieved by a number of techniques including manually initiated commands from a control centre eg. NWS, or automatically either by onboard software controls or via uplinking commands from a ground-based control system via the aircraft communications system. This gives national weather services 2 very valuable tools:

(i) The ability to optimise its operational AMDAR program to meet requirements for data while still meeting financial constraints; and

(ii) The ability to target the generation of data in data sparse regions of the world in collaboration with NMSs in these regions with a basic very cost effective upper air program. This same tool can be used to target the collection of upper-air data in locations and at times of special meteorological interest.

The European E-AMDAR program has developed a range of optimisation systems that provide very effective cost control on a daily basis while attempting to meet the basic operational need for a profile at 3-hourly intervals at most airports. In some cases, vertical sampling density is increased together with more frequent profiles to meet specific operational needs of very busy airports. Data are used to better control approach and landing times of aircraft either to improve airport efficiency while still maintaining safety standards or to conduct research for example on aircraft wake vortices. Australia and New Zealand also operate limited optimisation systems through onboard software to help control expenditure on data.

A number of data targeting programs have been implemented by NMSs to data sparse regions. E-AMDAR is providing targeted data for Eastern Europe, the Middle East, Africa, the Central Atlantic Ocean, Caribbean countries and South America. The group is developing an ambitious program in collaboration with the ASECNA organisation to provide profiles for 14 countries in Central and West Africa and Madagascar. In the latter case the agency will meet the operational costs to operate the program. South Africa provides data over Africa up to the equator. Australia provides profile data for New Zealand, Hong Kong and South Africa and enroute data over many countries in Asia, Pacific Islands, the Middle East and Eastern Europe. The US is providing data over Asia, Canada and South America. Development of further collaborative programs with countries that can contribute to their operational cost, are also envisaged.

Benefits and Impacts

AMDAR observation profiles and enroute data provide benefits to operational forecasters, numerical weather prediction products, climatology and atmospheric quality monitoring. More detailed knowledge of vertical profile temperature and wind structure provides significant improvements to:

(i) Short to medium term Public Weather and Marine Weather forecasts:

- Surface wind and temperature;
- Detection of height and strength of inversion;
- Cloud development;

- Onset and dissipation of fog and sea breeze;
- Timing and strength of warm and cold fronts; and
- Eddy circulation systems and other local meteorological phenomena.

(ii) Severe Weather forecasts
- Improved timing of weather fronts, strong winds, dust sqalls etc.;
- Improved in-situ information, particularly upper winds near tropical cyclones;
- Validating satellite-based cloud drift and water vapour winds;
- Vertical stability, helicity (convection, wind shear, thunderstorms, hail, turbulence, wind squalls, etc.);
- Fire-weather (high temperatures, low humidity, strong winds, wind changes);
- Better understanding of the impacts of topgography.

(iii) Now-Casting
- The close-to-real-time nature of AMDAR data provides a very useful data source in most now-casting situations, eg. monitoring current situations and updating NWP forecast information.

(iv) Climatology
- AMDAR provides the ability to develop vertical wind and temperature climatologies for general application throughout the year, eg. to provide basic meteorological information for air quality and other numerous applications.

(v) Impact Studies
- Impact studies show benefits to NWP regional analyses and forecasts;
  - Improved accuracy of jet stream location and depth;
  - Improved analysis and forecasts of wind in the mid to upper troposphere;
  - Improved accuracy in short and medium range analyses and forecasts out to 6 days;
  - Improved forecasts of rainfall accumulation, particularly at the higher rainfall thresholds (even without the availability of AMDAR humidity observations);

(vi) Aviation
- AMDAR data provide a number of important direct meteorological forecast benefits to airlines, air traffic control service providers and airport operators:
  - Improved surface and low level temperature and wind data (for ARFOR and TAF);
  - Cloud development, type, bases, tops;
  - Observed freezing level;
  - Boundary layer stability, severe weather (strong winds, dust, rain, freezing rain, hail, convection etc.
  - Vertical wind shear, turbulence, mountain wave activity and winds for middle level steering mechanisms;
  - Onset and dissipation of fog, sea breeze and other relevant phenomena governing the safety and control of airport operations;
  - Enroute winds, turbulence, jet stream location, structure and intensity, severe weather, icing conditions, etc.;
  - Support for balloonists and glider pilots;
  - Investigations into air-safety incidents;
  - Routine quality monitoring of AMDAR data provides a very effective quality check on aircraft sensing and data management systems.

The Results of Some Impact Studies

A number of studies have been undertaken by NWP centres including ECMWF, UK Met Office, DWD, NCEP CMC, Hong China, JMA,, CMA and SAWS. A sample of the results of studies reported by ECMWF and NCEP together show strong positive impact of AMDAR from hours to more than 6 days. Two examples of the many available are given below.

Example of Short-Term Impact (Courtesy of Dr. Ralph Petersen, University of Wisconsin)

The most extreme test of the impact of the aircraft data was conducted by the Forecast Systems Laboratory (personal communication, 2004) in which aircraft observations were excluded from the RUC analyses at all levels and all times during a multi-week wintertime test period in 2002. The results in figure 3 show very clearly that, when averaged over the entire contiguous United States area, the inclusion of aircraft data adds more than 1.5 knots to the accuracy of the 3 hr forecasts. At specific locations, the improvements can be much greater, reaching as high as 10-15 knots in some instances – much larger than the two kt threshold for 'significant' differences designated by aviation users. Stated in another way, the net effect of including aircraft observations at all levels and times in the hourly RUC analysis and forecast updates consistently reduces the error in standard 12 hr forecasts by as much as 20 %, even though other 'off-time' data sets are available over the U.S.

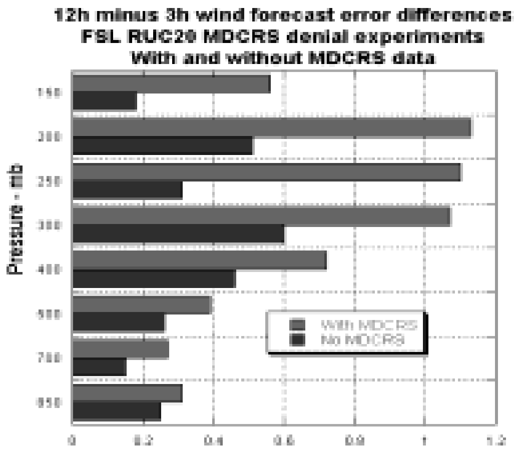


Figure 1a: Differences between 12hr and 3 hr forecasts with and without aircraft (labeled MDCRS) data. Difference in RMSV Error shown in m s^{-1}, where 1 m s^{-1} equals approximately 2 knots.

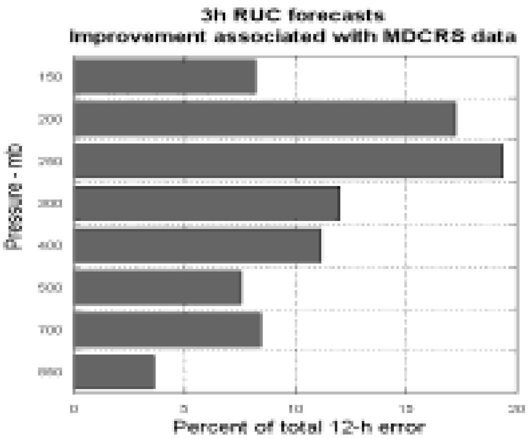
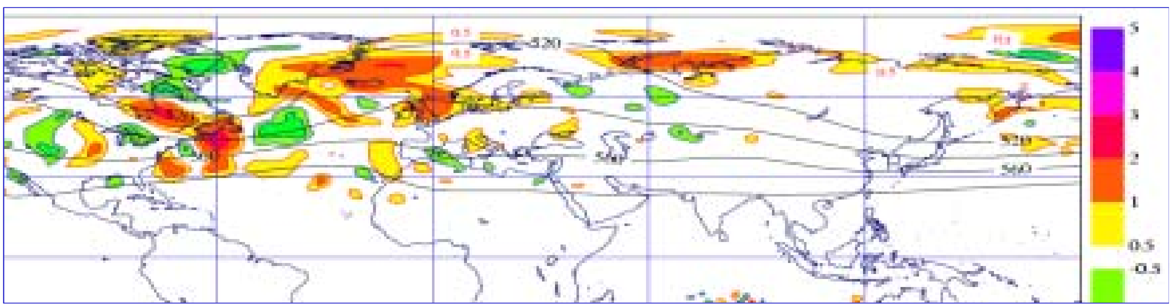


Figure 3b: Percentage of 3hr forecast improvement due to aircraft (MDCRS) data.

Examples of Medium Term Impact (Courtesy Erik Andersson, ECMWF)

Diff in RMS of 120 Hr Forecast Error: Exp-Control
500 hPa, 20010102-0131, Valid 12 UTC

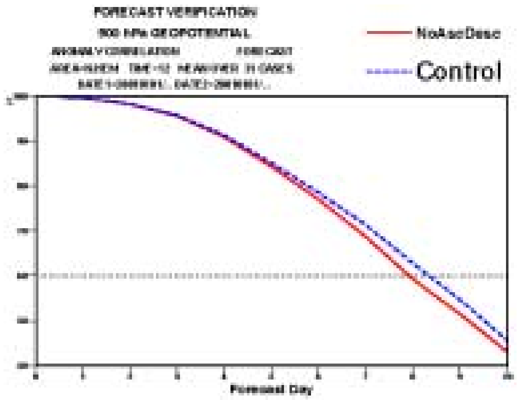
- Exp: Denied ascending and descending aircraft, p>350 hPa
- Positive Values indicate ascent/descent data added value



Eur: 3.02m, N.Atl: 2.90m, N.Amer: 0.31m N.Hem: 1.35m

Exp: Forecast impact

- **Exp: Denied ascending and descending aircraft, p>350 hPa**
- **Higher Values** *(Dashed)* **indicate ascent/descent data added value**



The Ascent/Descent data add ~0.4 days of forecast skill at day 8 –
a 5% improvement in forecast skill - - this is significant

Observations From the Global AMDAR Program

Presentation to

WMO TECO-2005
4-7 May 2005

by

Jeff Stickland
Technical Coordinator, WMO AMDAR Panel

System Description

AMDAR = Aircraft Meteorological Data Relay

AMDAR is:

- A fully automated upper air observing system;
- Collects high quality upper air observations of wind speed and direction, temperature, and sometimes turbulence and humidity;
- From many existing commercial aircraft;
- In collaboration with national domestic and international airlines;
- Uses **existing aircraft and airline infrastructure** including:
  - **standard installed** high quality sensors for wind, temperature and turbulence plus height (pressure), time and position;
  - onboard **avionics and communications** hardware and software;
  - Airlines normally use the **international communications system** called Aircraft Communications and Reporting System **(ACARS).** Global services are provided by 2 companies – ARINC and SITA.

System Description (cont.)

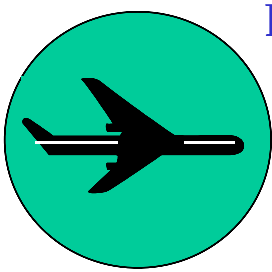
– airline ground-based **data processing systems;**

• **No new hardware** is required on the aircraft;

• The **only additional requirement** to make AMDAR work is **special AMDAR software** installed in the aircraft avionics or communications hardware;

• Humidity sensors are being developed and will be added in the future to SOME aircraft;

TYPICAL AMDAR INSTALLATION

= 

FITTED WITH EXISTING SENSORS

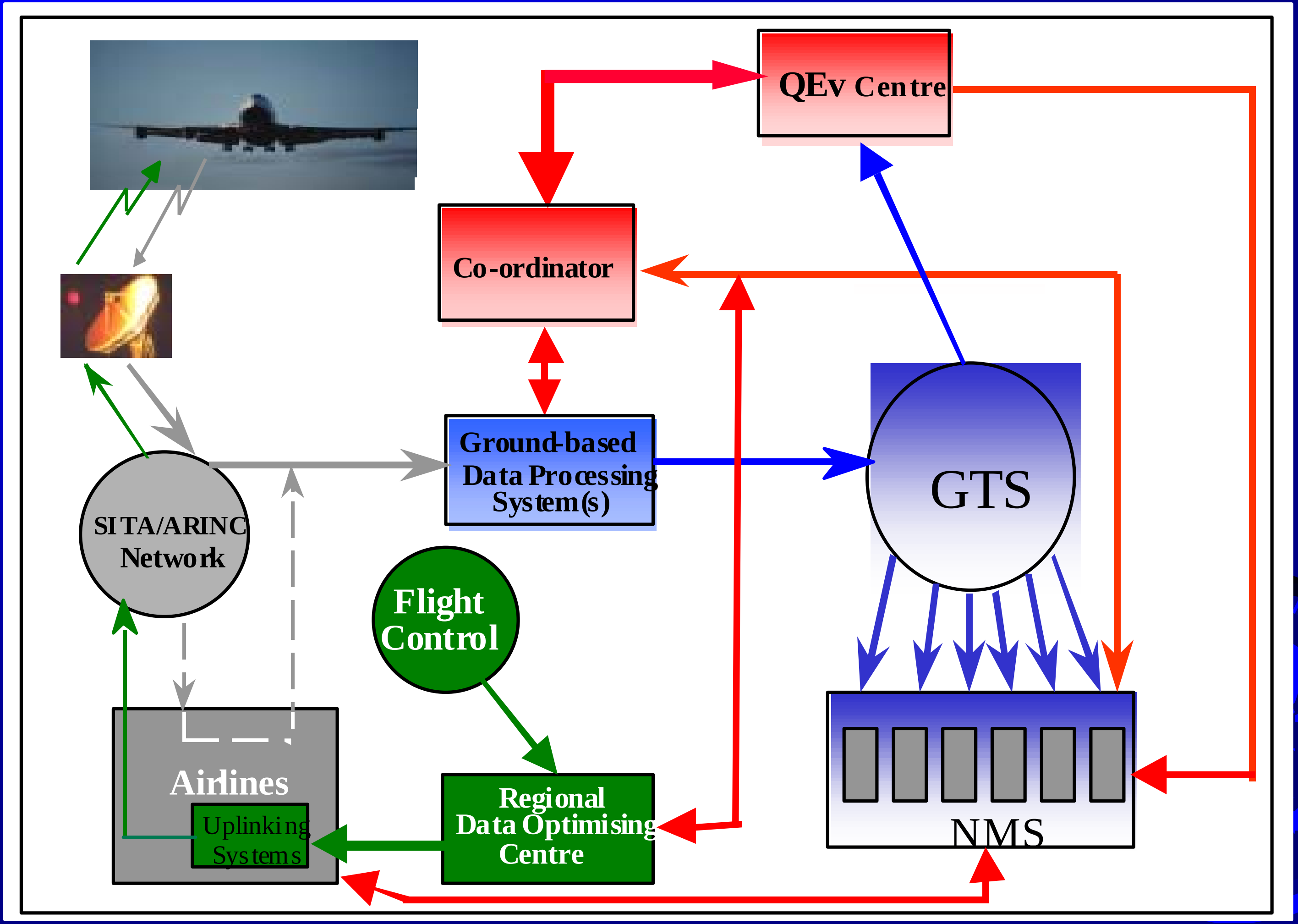
\+ AVIONICS HARDWARE

\+ AVIONICS SOFTWARE

\+ COMMUNICATIONS

\+ **AMDAR SOFTWARE**

AMDAR System Structure
Operational, Reporting, Monitoring & Feedback



Why is AMDAR Data Needed?

- To provide a cost effective source of upper air observations to support national, regional and global basic meteorological operations and research;

- AMDAR data can be used in most meteorological applications that use upper air data obtained from conventional observing systems. Vertical profiles of temperature and wind are often the most valuable:

- Examples in operational bench forecasting for the short to medium term include-

  Severe weather forecast and warning services;
  Public weather forecast and warning services;
  Aviation weather services (enroute and terminal area forecasts supporting airlines, air traffic control and airport operations;
  Marine and industrial applications;
  Environmental monitoring and warning applications;
  Climate studies, etc.

- To meet the NWP community's requirement for greater quantities and improved coverage of relevant upper air data;
- For forecast verification;
- To help provide a more comprehensive assessment of the atmosphere for local modelling research, local forecasting, etc;
- To provide data from data sparse areas around the world to improve local forecasts and to contribute to the WMO World Weather Watch Global Observing System
- Operational Cost compared to radiosonde is 1%

Data Requirements

Desirable Horizontal Spatial and Temporal Density:

1 profile on 250 km grid at 3 hourly intervals

BASIC Data

Element	Unit	Range	Output resolution	Desired accuracy
Pressure Altitude	Foot (ft)	-1000 to 50000	10	100[1]
Static Air Temperature	^{o}C	-99 to 99	0.1	0.5[2]
Wind Direction	^{O} from true N	1 to 360	1	Note (2,3)
Wind Speed	Knot (kt)	0 to 800	1	Note (2,3)
Latitude	Degree:minute	90:00S to 90:00N	1.0min	Note (4)
Longitude	Degree:minute	180:00E to 180:00W	1.0min	Note (4)
Time (UTC)	Hour:Minute:Second	00:00:00 to 23:59:59	1 min	1s

Notes:

(1) required to preserve temperature accuracy
(2) WMO requirement for NWP in troposphere
(3) 2ms^{-1} (4kt) vector error
(4) 5Nm equivalent (specified for ASDAR)

Data Requirements (cont.)

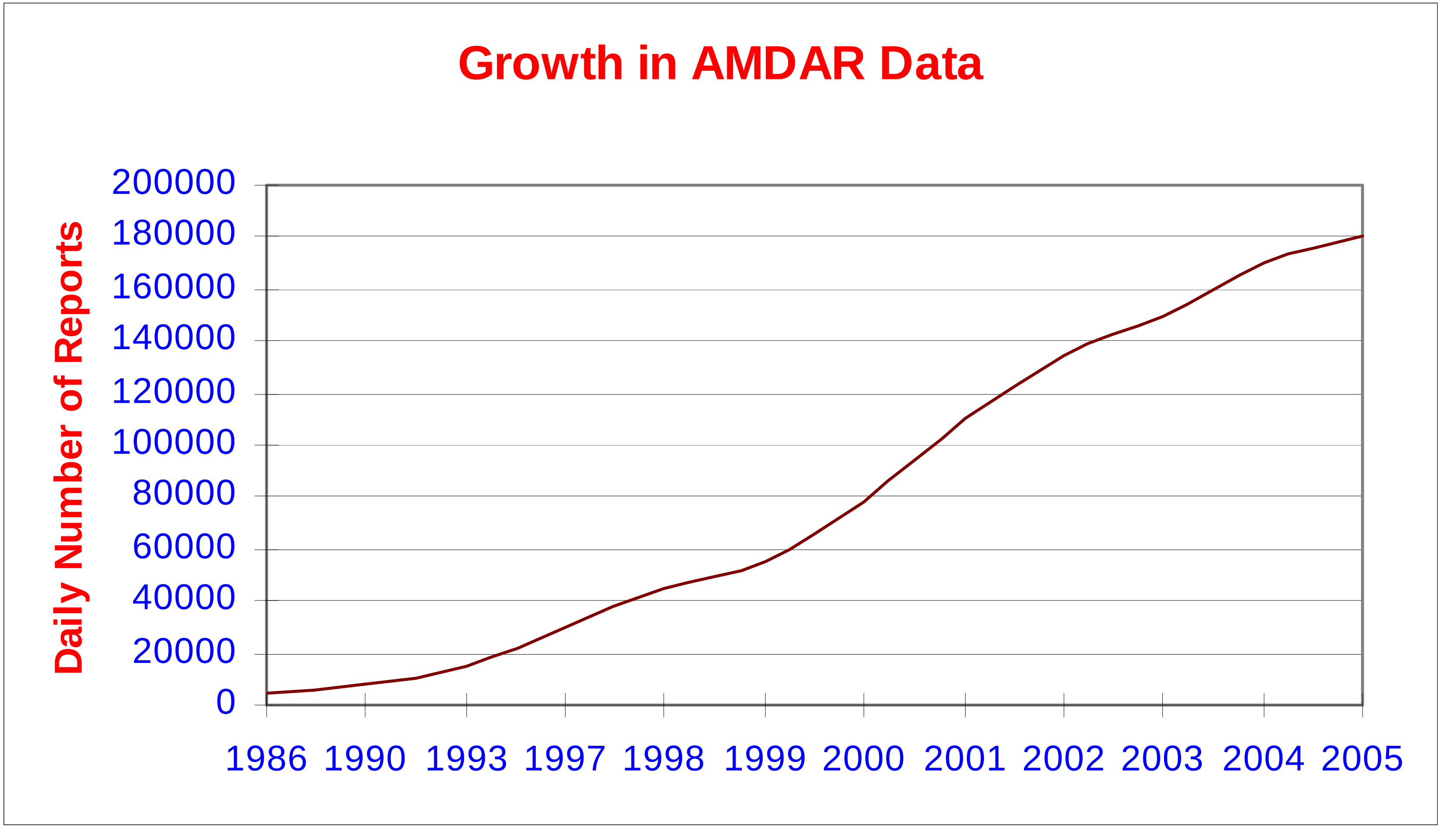
Additional Data

Element	Unit		Output resolution	Desired accuracy
Maximum wind	kt	0 to 800	1	4
Turbulence (g)	g [4]	-3 to 6	0.1	0.15[1]
Turbulence(DEVG)	ms^{-1}	0 to 20	0.25	0.5[1]
Turbulence(EDR)	$m^{2/3}s^{-1}$	0 to 1	0.05	0.1[1]
Humidity(RH)	%	0 to 100	1	5[2]
Humidity (dew pt)	^{o}C	-99 to +49	0.1	Note 5
Humidity(mixing ratio)	gram/kg	0 to 100	0.001	$1:10^3$ (measurement)[3]

Notes:
(1) Determined by output categories required
(2) WMO requirement for NWP in troposphere
(3) To meet stratospheric humidity requirement
(4) Acceleration due to gravity. ‘Zero’ reference on aircraft is usually +1.
(5) Equivalent to 5% RH error.

Mandatory and Optional Reported Elements

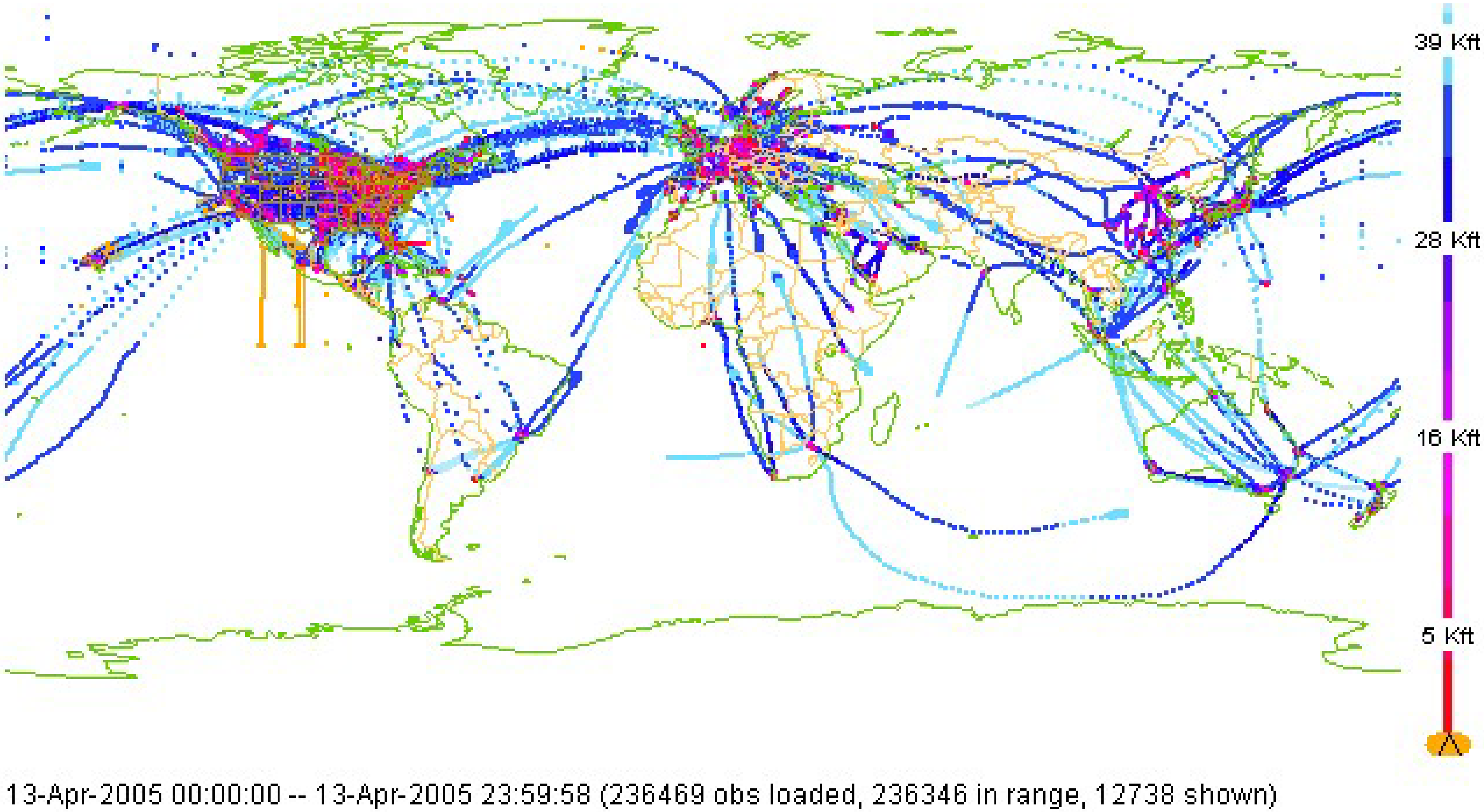
Element	Mandatory/Optional	Requires Additional Onboard Processing
Aircraft identifier	M	
Phase of flight	M	
Latitude	M	
Longitude	M	
Day & time of observation	M	
Pressure altitude	M	
Static air temperature	M	
Wind direction	M	
Wind speed	M	
Maximum wind	M	
Roll & pitch angle flag	M	*
Humidity	O	*
Turbulence	O	*
Icing	O	*



Growth in AMDAR Data
Daily Number of Reports
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
1986 1990 1993 1997 1998 1999 2000 2001 2002 2003 2004 2005

24 Hour Global Coverage

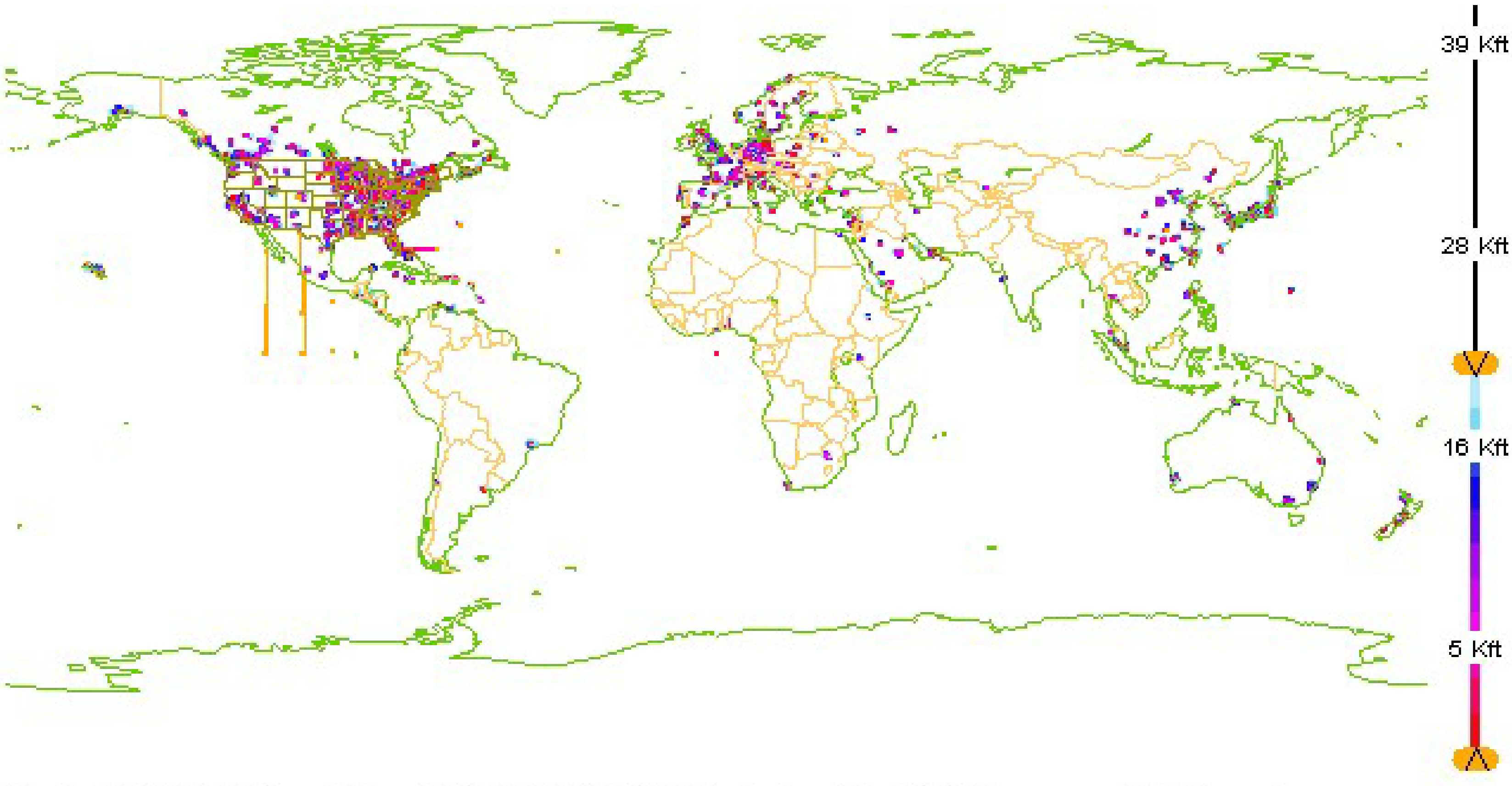
13 April 2005



Courtesy NOAA FSL

24 Hour AMDAR Profiles

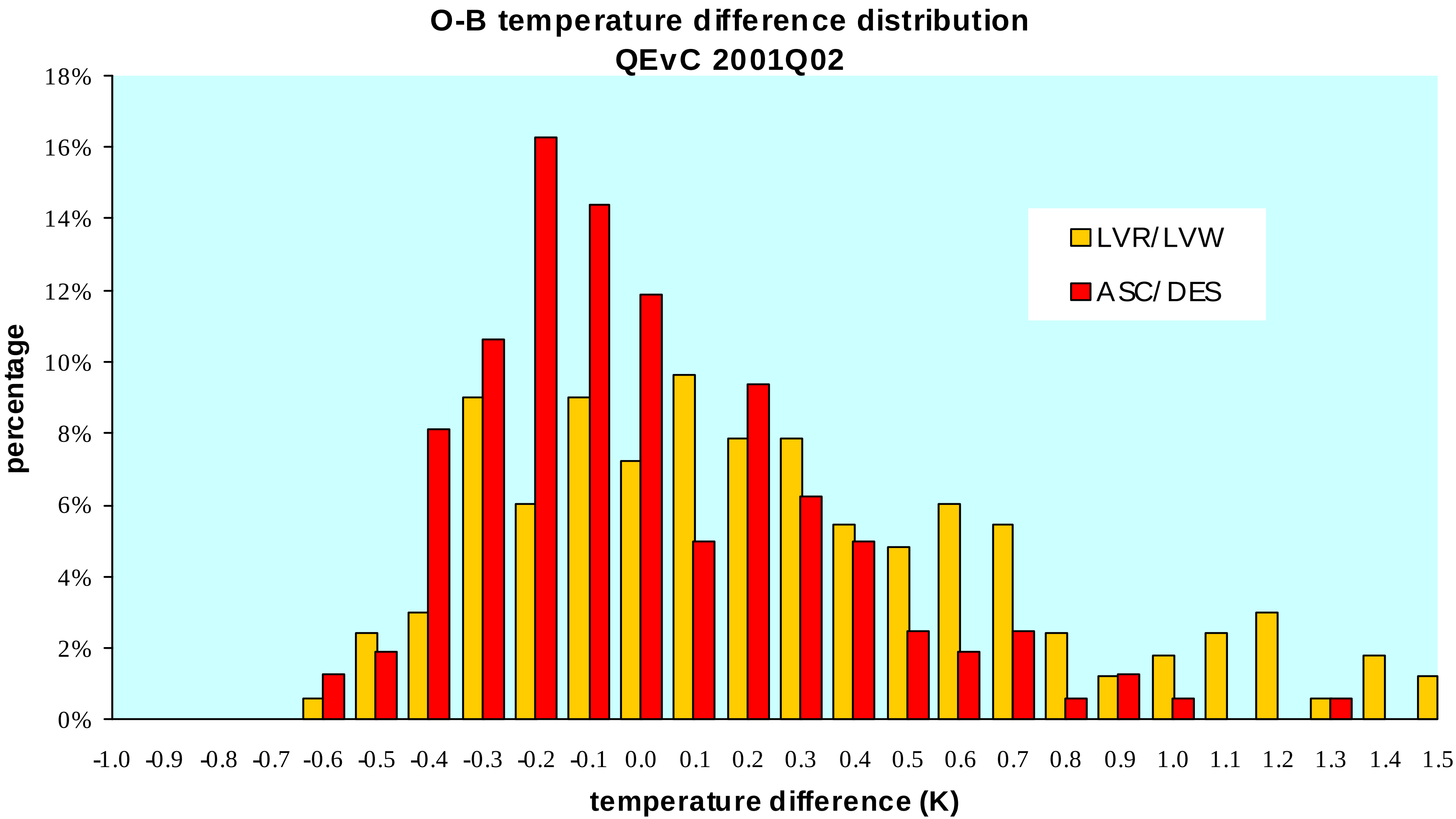
13 April 2005



13-Apr-2005 00:00:00 -- 13-Apr-2005 23:59:58 (236469 obs loaded, 126403 in range, 2427 shown)

Courtesy NOAA FSL

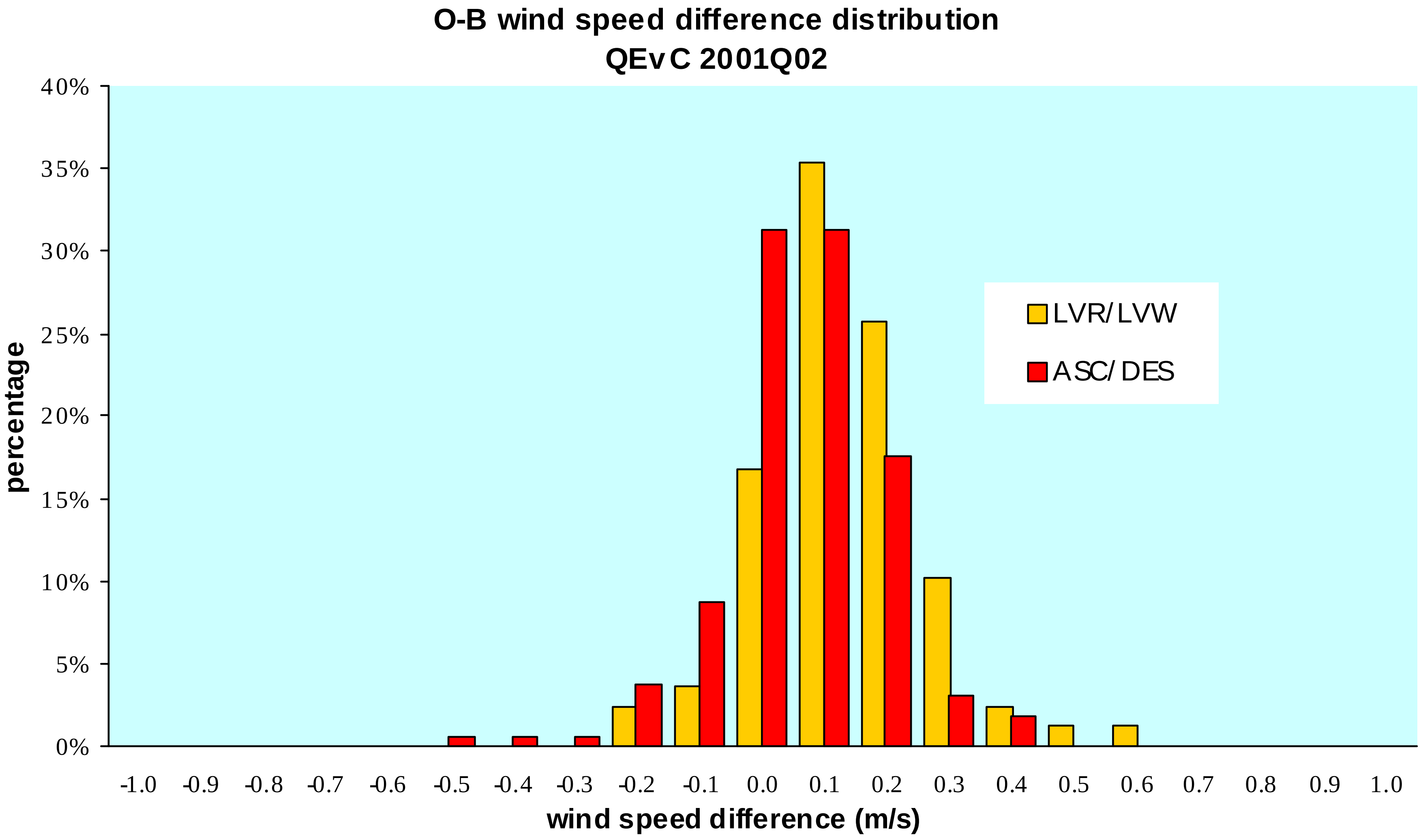
E-AMDAR Temperature Quality



Frequency distribution of the mean temperature difference (OBS–Background)

KNMI QEV Report - April - June 2001

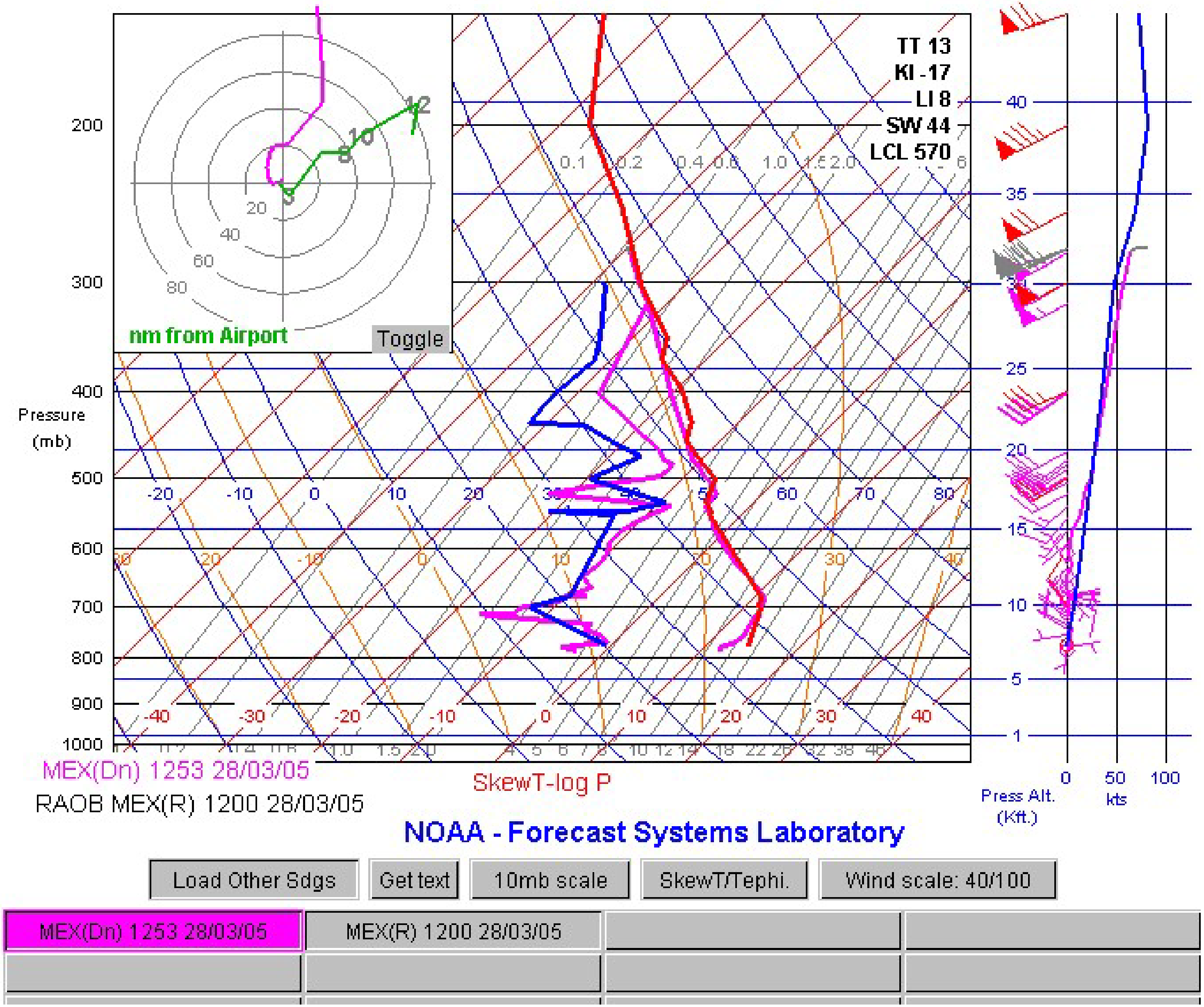
E-AMDAR Wind Speed Quality



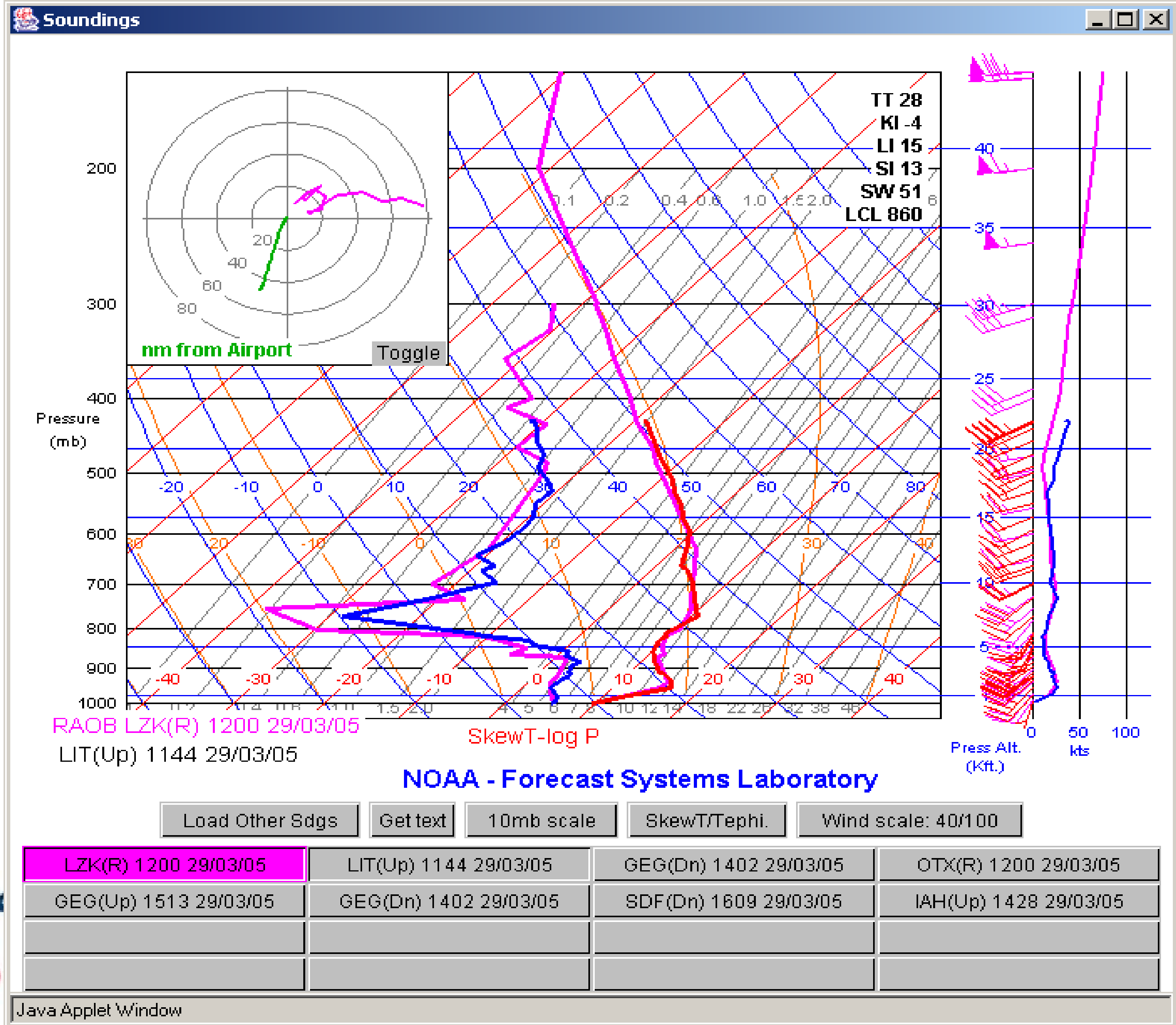
Frequency distribution of the mean wind speed difference (OBS–Background)

KNMI QEV Report - April - June 2001

WVSSII on N407 Versus Sonde at Mexico City, 12:53, 28 March 2005

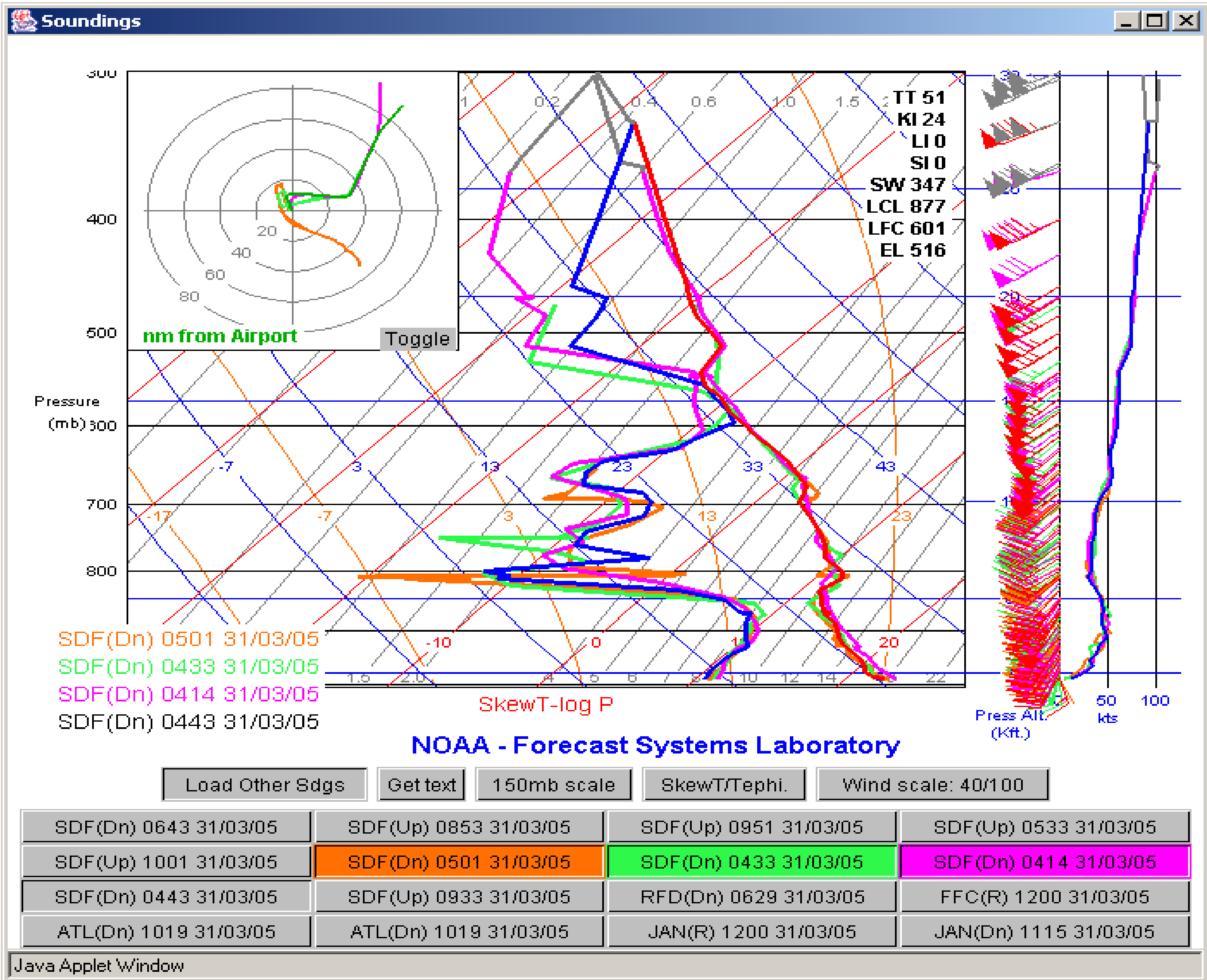


LIT WVSS-2 vs. Raob Comparison



SDF WVSS-2 Comparisons 31 MAR 05

Comparisons of 4 WVSS-2 aircraft on descent into SDF. Between 06z and 08z the profiles changed markedly as a line of thunderstorms approached and moved through, along with cold front passage. 2 Ascents are also included. Things stabilized by around 10z.



Mixing ratio (g/kg) for 3 aircraft on ascent with 62 minutes of each other 3/11/05)

Criteria (1000's ft)	Range of Height (feet)	N453 (0941Z)	N411 (1006Z)	N402 (1043Z)	{range of mixing ratio}
h < 1	760 – 960	4.3	4.8	4.4 – 4.3	[0.5]
1 < h < 2	1010 – 1940	4.3 – 4.1	4.7 – 4.3	4.2 – 3.8	[0.9]
2 < h < 3	2120 – 2950	3.8 – 3.2	4.1 – 3.8	3.7 – 3.6	[0.9]
3 < h < 3.7	3120 – 3630	3.0	3.6 – 3.2	3.5 – 3.4	[0.5]
4.5 < h < 5.1	4530 – 5070	2.8	3.0	3.3	[0.5]
6.0 < h < 7.0	6070 – 6490	2.8	2.6	2.5	[0.3]
7.1 < h < 8.3	7170 – 8230	2.6 – 2.3	2.4	2.4 – 2.1	[0.5]
9.4 < h < 10.8	9400 – 10740	1.6	1.4	1.6 – 1.4	[0.2]
11.2 < h < 12	11220 – 11930	1.4	1.3	1.3	[0.1]
12.1 < h < 13	12140 – 12930	1.1	.84 – .75	1.3 – 1.2	[0.55]
14 < h < 18	14110 – 17970	.88 - .49	.61 - .38	.82 - .41	[0.5]
22.0 < h < 26	22440 – 26000	.30 - .28	.04 - .03	.22 - .20	[0.27]

Relative Humidity (RH) for 3 aircraft on ascent with 62 minutes of each other 3/11/05)

Criteria (1000's ft)	Range of Height (feet)	N453 (0941Z)	N411 (1006Z)	N402 (1043Z)	{range of RH} (%)
h < 1	760 – 960	85.2 - 84.1	95.1	84.9 – 81.2	[13.9]
1 < h < 2	1010 – 1940	83.2 – 81.9	89.1 – 79.1	80.3 – 79.8	[9.3]
2 < h < 3	2120 – 2950	77.1 – 70.7	76.8 – 73.4	87.5 - 78.4	[16.8]
3 < h < 3.7	3120 – 3630	71.0 – 67.9	77.8 – 71.3	91.9 - 88.1	[24.0]
4.5 < h < 5.1	4530 – 5070	83.9	83.6 – 78.4	101.6	[23.2]
6.0 < h < 7.0	6070 – 6490	91.9	82.8	88.0	[9.1]
7.1 < h < 8.3	7170 – 8230	100.5 – 97.7	88.6	97.7 – 95.7	[11.9]
9.4 < h < 10.8	9400 – 10740	87.9 – 76.7	67.4	87.1 – 80.2	[20.5]
11.2 < h < 12	11220 – 11930	107.8 – 95.7	89.4 – 82.8	82.6 – 74.0	[33.8]
12.1 < h < 13	12140 – 12930	77.2	47.8 – 45.5	88.3 – 84.7	[40.5]
14 < h < 18	14110 – 17970	76.8 – 61.5	48.4 – 39.8	83.0 – 64.7	[34.6]
22.0 < h < 26	22440 – 26000	98.2 – 82.3	7.1 – 6.0	67.2 – 52.0	[92.2]

Dew point for 3 aircraft on ascent with 62 minutes of each other 3/11/05)

Criteria (1000's ft)	Range of Height (feet)	N453 (0941Z)	N411 (1006Z)	N402 (1043Z)	{range of mixing ratio}
h < 1	760 – 960	1.5 to 1.4	3.0	1.8 to 1.4	[1.6]
1 < h < 2	1010 – 1940	1.2 to 0.2	2.6 to 0.9	0.8 to -0.8	[3.4]
2 < h < 3	2120 – 2950	-0.9 to -3.6	0.1 to -1.2	-1.6 to -2.0	[3.7]
3 < h < 3.7	3120 – 3630	-4.6 to -4.8	-2.1 to -3.9	-2.5 to -3.1	[2.7]
4.5 < h < 5.1	4530 – 5070	-6.4	-5.2 to -5.5	-4.0	[2.4]
6.0 < h < 7.0	6070 – 6490	-6.4	-8.0	-8.4	[2.4]
7.1 < h < 8.3	7170 – 8230	-8.4 to -10.4	-9.6	-9.4 to -11.5	[3.1]
9.4 < h < 10.8	9400 – 10740	-15.4 to -15.9	-17.3	-15.6 to -17.6	[2.2]
11.2 < h < 12	11220 – 11930	-17.9 to -18.1	-18.7 to -18.9	-18.8 to -19.0	[1.1]
12.1 < h < 13	12140 – 12930	-21.3	-24.1 to -25.7	-19.1 to -20.4	[5.0]
14 < h < 18	14110 – 17970	-24.5 to -32.3	-28.6 to -34.7	-25.2 to -34.1	[10.2]
22.0 < h < 26	22440 – 26000	-39.4 to -40.5	-56.6 to -58.2	-42.1 to -44.3	[18.8]

VAISALA RS92 RADIOSONDES OFFER A HIGH LEVEL OF GPS PERFORMANCE WITH A RELIABLE TELEMETRY LINK

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ABSTRACT

Upper-air observational data gathered with radiosondes benefits from continuous instrument development. Accurate and reliable measurement of GPS winds as well as robust telemetry link performance is needed to meet the requirements of the meteorological community and the applications it works with.

Vaisala's code correlating GPS windfinding technology was developed specifically for upper-air weather observation and has proven to be highly reliable in operational use. It is implemented in custom ASIC (Application Specific Integrated Circuit) electronics that provide advanced levels of performance. In addition to conventional autonomous GPS positioning technology, it utilizes differential measurements to further improve measurement accuracy.

The digital RS92 radiosondes utilize a narrowband downlink which meets the requirements of the ETSI EN 302 054-1 European standard. Meeting the requirements of this standard is a basic operational requirement for all digital radiosondes used in the European community area. The best data transmission performance of the RS92 radiosonde is achieved by using the new Vaisala "Software Defined Radio" receiver that is built into the DigiCORA MW31 ground equipment. This receiver utilizes modern digital signal processing technology to replace the signal path sections conventionally utilized in analog electronic components. As a result, more robust performance is achieved which is also consistent from unit to unit.

The RS92 radiosonde is designed to be fast and easy to launch manually and also automatically from Vaisala AUTOSONDE unmanned sounding stations. The RS92 radiosonde along with the latest DigiCORA® MW31 sounding system represents the most modern solution for upper-air weather observation.

1. INTRODUCTION

The RS92 radiosonde has received operational testing in many different geographical locations around the world. Its performance has proved to be reliable. Several reports have been published on the PTU, GPS and telemetry performance and more information will soon be available along with the WMO's analysis of the Mauritius 2005 WMO Radiosonde Intercomparison. This article concentrates on presenting an up-to-date report on the RS92's telemetry link and GPS windfinding performance.

2. VAISALA RS92-SGP RADIOSONDE DATA LINK UTILIZING THE NEW SOFTWARE DEFINED RADIO-BASED DigiCORA SOUNDING SYSTEM

There is a fully digital telemetry link between the Vaisala Radiosonde RS92-SGP and the Vaisala Sounding Subsystem SPS311 (component of the DigiCORA MW31 Sounding System), which incorporates Vaisala's new Software Defined Radio technology. This telemetry link enables the use of modern digital modulation methods, error correction algorithms and telemetry diagnostics. The result is improved bandwidth efficiency, reliable data transmission, improved diagnostic cababilities and more consistent unit-to-unit operation. Furthermore, future receiver upgrades can be accomplished by updating the software only.

2.1. Software Defined Radio technology

Vaisala's Software Defined Radio technology consists of a low-noise antenna amplifier which resides in the antenna, a 400 MHz receiver unit and a receiver processor unit.

In the 400 MHz RF unit, the entire 400...406 MHz meteorological frequency band is first translated to an intermediate frequency (IF) band of 16...22 MHz. The IF signal is then sampled by a high-performance analog-to-digital converter using a sampling rate of 64 Msamples/second. All further processing of the signal – filtering, downconversion to baseband, demodulation, error detection/correction and telemetry analysis – is done in the receiver processor unit by digital down converters (DDCs) and a powerful digital signal processor (DSP).

When compared to conventional analog RF receiver technology, the new technology offers significant advantages including accurate and flexible digital signal processing, software-configurable digital filters, modern digital modulation techniques and efficient error detection and correction methods.

RB31 400 MHz telemetry antenna with low noise antenna amplifier

SPS311 Sounding Processor Subsystem

SPS311 Sounding Processor Units

Figure 1. The Vaisala Sounding Processing Subsystem SPS311 with Software Defined Radio

2.2. Vaisala RS92-SGP telemetry link and error coding

The RS92-SGP's telemetry link performance is a sum of the performance of its subcomponents: GFSK-modulation, Reed-Solomon error correction coding, data validation and the performance characteristics of the software defined radio receiver.

The RS92-SGP radiosonde transmits a narrowband GFSK (Gaussian Frequency Shift Keying) modulated signal which carries 2400-bit data frames at a data rate of 2400 bits / second. The radiosonde data frame is divided into several sub-blocks, each followed by a check sum. In addition, each data frame is protected with Reed-Solomon check bytes that are used for error correction. Data is scrambled to achieve a uniform distribution of ones and zeros and to avoid long sequences of the same value.

In the receiver end, the demodulated baseband data is descrambled and the Reed-Solomon error correction algorithm is applied. The data is then validated using the checksums. With the selected error correction coding, 4.7% of the symbols can be erroneous without causing the system to lose data. The relative coding gain is approximately 5 dB. A more detailed description of the Vaisala Software Defined Radio technology is presented in a separate document (Åkerberg 2004).

2.3. Telemetry link performance

The RS92-SGP telemetry link using the Software Defined Radio was tested in Tenerife in November 2004 at the Izana Observatory of the Spanish National Institute of Meteorology. The observatory has many characteristics that make it interesting for testing meteorological devices. In addition to this, it is suitable for testing telemetry link performance because it offers the possibility of exposing the test system to controllable levels of TV and other telemetry link interference.

The telemetry noise circumstances in which the soundings were made are presented in Figure 2. The spectrum snapshot on the left shows the situation when the receiving antenna was placed in a location that was shielded from telemetry noise. The spectrum snapshot on the right shows the type of severe link interference that was experienced when the receiving antenna was placed in a location that was not shielded from telemetry noise. The base noise level is some 10-20 dB higher in the section of the band the radiosondes were tuned to. Test soundings were performed as single-flight soundings and multiple-flight rig soundings.

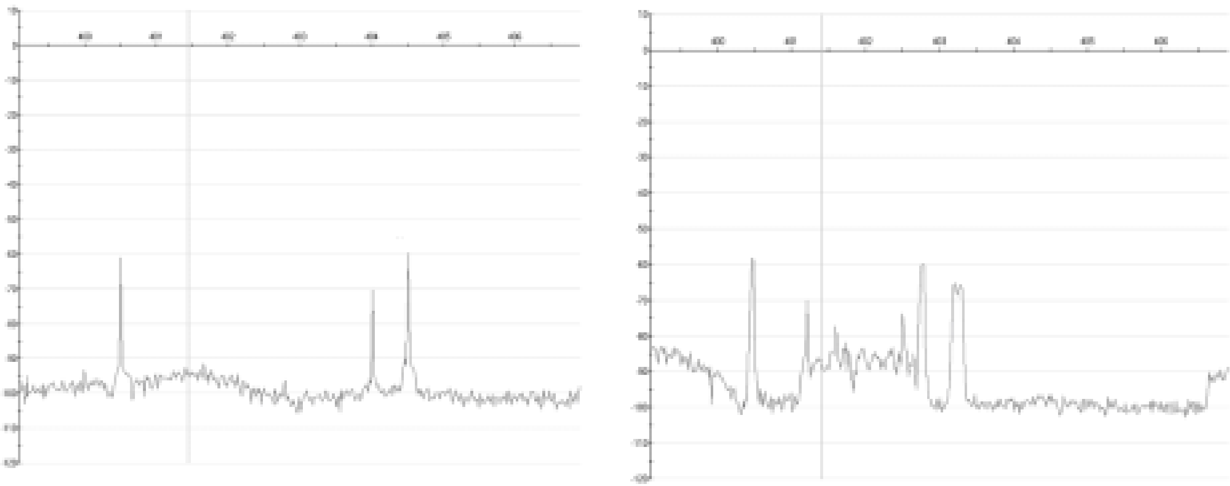

Figure 2. Frequency spectrum snapshot examples: at left - shielded; at right - unshielded

2.3.1. Comparison of performance: SPS311 with Software Defined Radio vs. SPS220 with analog receiver

In the test, there were two configurations of the receiving ground equipment: one configuration comprised the new SPS311 with software defined radio, the other configuration comprised the SPS220 and its analog receiver. The results of the soundings made with the RS92-SGP in the presence of severe telemetry link disturbance are presented in Table 1. The Channeling Ratio [%] is a measure of the PTU data availability as reported by the Vaisala DigiCORA MW31 Sounding System. The Valid Raw Wind [%] was reported by the DigiCORA MW31 Sounding System. The Frame Error Ratio (FER) is the ratio of erroneous data frames to all data frames. The erroneous data frames were data frames that could not be repaired by the Reed-Solomon error correction.

The reason for the termination of each test sounding was increasing pressure: a normal type of termination. The results were good for both systems but the combination of the RS92-SGP and SPS311 gave a better result. This can be seen in the Channeling Ratio [%] and Valid Raw Wind [%]. The wind conditions caused the RS92-SGP/SPS311 soundings to be the longest ones.

	Type	**Channeling Ratio [%]**	**Valid Raw Wind [%]**	**FER [%]**	**Range [km]**	**Height [km]**
1	**RS92-SGP / SPS311 SW-radio**	**100**	**100**	0.1	127	31
2	**RS92-SGP / SPS311 SW-radio**	**100**	**99**	0.4	55	30
3	**RS92-SGP / SPS311 SW-radio**	**100**	**100**	0	109	28
4	**RS92-SGP / SPS311 SW-radio**	**100**	**100**	0	89	30
5	**RS92-SGP / SPS220 radio**	**94**	**89**	NA	61	33
6	**RS92-SGP / SPS220 radio**	**98**	**96**	NA	70	32

Table 1. The soundings made with the RS92-SGP in the presence of severe telemetry disturbance. Tested with the SPS311 equipped with software defined radio and SPS220 with analog radio receiver.

2.3.2. Performance comparison: Vaisala RS92-SGP and SPS311 with software defined radio VS. Vaisala RS80-15G and SPS220 with analog radio receiver

In order to compare the performance of the RS80-15G radiosonde vs. that of the RS92-SGP radiosonde in conditions of severe telemetry link disturbance, the direction of the Vaisala UHF Antenna RB31 was turned upwards manually. Thus in addition to the telemetry link disturbance experienced, the telemetry range was also manually restricted by limiting the antenna radiation pattern. Table 2 shows the difference in telemetry performance of the Vaisala Radiosonde RS92-SGP with the Vaisala Sounding Processing Subsystem SPS311 vs. that of the Vaisala Radiosonde RS80-15G with the Vaisala Sounding Processing Subsystem SPS220. The test was made with the two radiosondes attached to one rig. The reason for termination of the soundings was a "No PTU" signal, which indicated that the limiting factor was telemetry.

The results show that in sounding conditions featuring telemetry link disturbance, the telemetry performance of the combination of the RS92-SGP radiosonde and SPS311 with software defined radio was clearly better than that of the RS80-15G and SPS220 combination. This can be seen in Table 2 from the longer sounding range and altitude achieved. As a conclusion, it can be stated that the RS92-SGP and SPS311 combination offers good immunity to telemetry noise and an increased margin for telemetry errors in long-range soundings with little telemetry disturbance.

	Type	**Range [km]**	**Height [km]**
1	**RS92-SGP / SPS311 SW-radio**	**56**	**15**
	RS80-15G / SPS220	**13**	**8**
2	**RS92-SGP / SPS311 SW-radio**	**44**	**12**
	RS80-15G / SPS220	**12**	**6**
3	**RS92-SGP / SPS311 SW-radio**	**31**	**9**
	RS80-15G + SPS220	**8**	**7**

Table 2. The comparison of RS92-SGP + SPS311 and RS80-15G + SPS220 in conditions of severe RF disturbance. A limited antenna radiation pattern was also introduced to restrict the telemetry range artifically.

2.3.3. Vaisala RS92-SGP / DigiCORA MW31 telemetry link performance in Mauritius WMO Radiosonde Intercomparison

The combination of the RS92-SGP radiosonde and DigiCORA MW31 / SPS311 with software defined radio was used in the Mauritius WMO Radiosonde Intercomparison that was conducted in February 2005. Figure 3 plots the percentage of received frames from the Mauritius soundings. The reliability of the data transmission was very high; on average it was 99.2% while median was 99.9%.

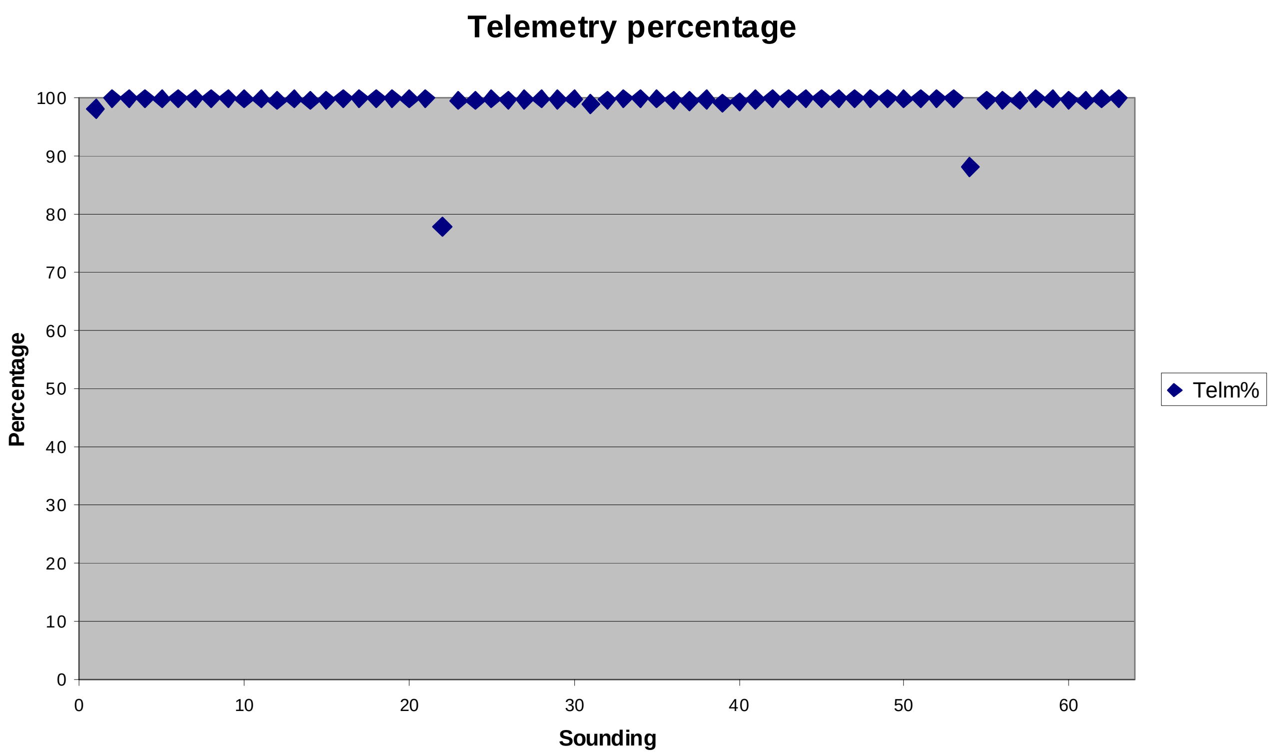

Figure 3. Telemetry performance of RS92-SGP / SPS311 with software defined radio in the Mauritius WMO Radiosonde Intecomparison of February 2005. Percentage of received frames, average 99.2% and median 99.9%

3. VAISALA RS92 GPS WINDFINDING PERFORMANCE

The GPS windfinding of RS92 GPS radiosondes is based on code correlating GPS (ccGPS) technology (Währn, 2004). This technology offers excellent accuracy and better immunity to external interference compared to previous codeless GPS windfinding solutions.

3.1. Wind measurement accuracy

Due to the lack of a good reference, the absolute accuracy of wind measurement in the test soundings cannot be determined. However, it is possible to compare the wind measurement performance of the radiosondes flown on the same sounding rig. The windfinding repeatability of the RS92 radiosonde was presented at the CIMO UASI-1/IOC-1 meeting on March 3, 2004. It was reported that the wind direction measurement repeatability (1-σ stdev) was generally better than 2 degrees and, in fast changing layers over a shorter period, better than 6 degrees. The repeatability for wind speed measurement was better than 0.2 m/s. More recent test data show a similar level of windfinding performance.

A multiple radiosonde sounding test was performed in Tenerife in November 2004 at the Izana Observatory. Figures 4 and 5 show the typical wind direction and wind speed measurement performance with three RS92 radiosondes flown on the same rig.

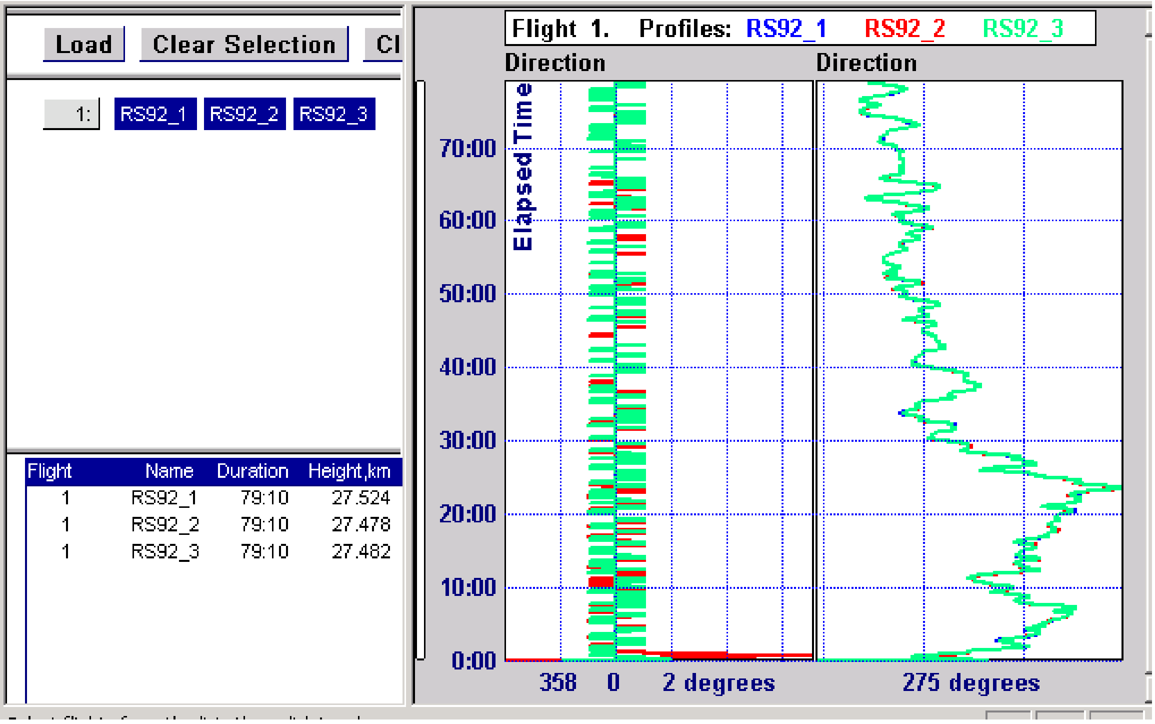

Figure 4. Triple sounding test result: wind direction

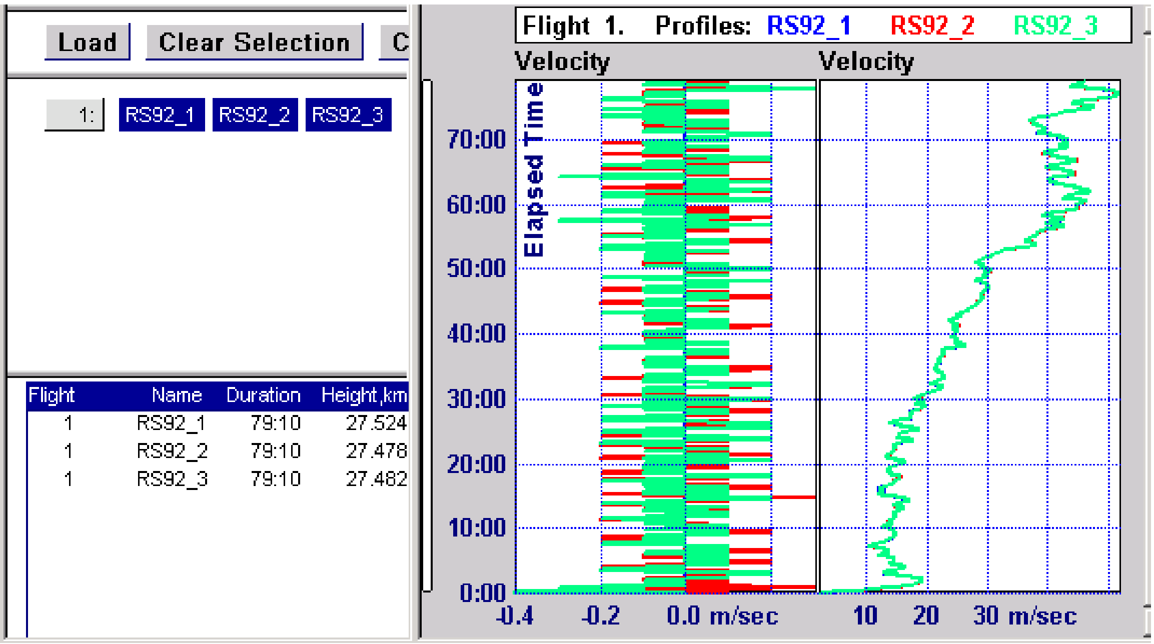

Figure 5. Triple sounding test result: wind speed

3.2. Wind data availability in operational use

Table 3 summarizes the GPS wind data availability of RS92 radiosondes flown in Europe's Region VI as extracted from European Region VI TEMP messages. The category "Missing winds to PTU top (%)" was calculated by dividing the total sum of reported missing wind meters by the total sum of reported wind meters to PTU Top. The result was scaled to a percentage by multiplying the division result by 100. The analysis covers all the observations made in 2004 with RS92 GPS radiosondes in the WMO Region VI Europe. The results show an excellent (almost 100%) success rate for windfinding reliability. Considerable improvement is seen when compared to the results achieved with older, codeless GPS technology.

TEMP messages, Region VI Europe, Year 2004 **Vaisala RS92 GPS sondes**			
Month	**Missing winds to PTU top (%)**	**Month**	**Missing winds to PTU top (%)**
Jan	1.8	July	0.6
Feb	0.1	August	0.3
March	0.3	September	0.7
April	0.1	October	0.4
May	0.2	November	0.2
June	0.1	December	0.1

Table 3. RS92 GPS wind data availabilty shown as a % of missing wind data

3.3 RS92-SGP wind data availability in the WMO Mauritius Radiosonde Intercomparison

The GPS wind data availability of the RS92-SGP radiosonde has been evaluated based on the large data set generated in the WMO Mauritius Radiosonde Intercomparison. Figure 6 plots the average number of GPS satellites that was tracked by the RS92 GPS radiosondes: on average, 11 satellites were tracked. Not all of the tracked satellites were used in the GPS wind calculations, however. For example, the weather station and radiosonde GPS receivers may have tracked different satellites during the course of a particular sounding, and satellites below a certain angle of elevation were not used. GPS wind calculation requires at least four satellites to be tracked and this was the case in 99.95% of the received GPS frames. When this figure is combined with excellent figures for telemetry performance, it can be seen that the RS92-SGP offered excellent wind data availability performance in the WMO Mauritius Radiosonde Intercomparison.

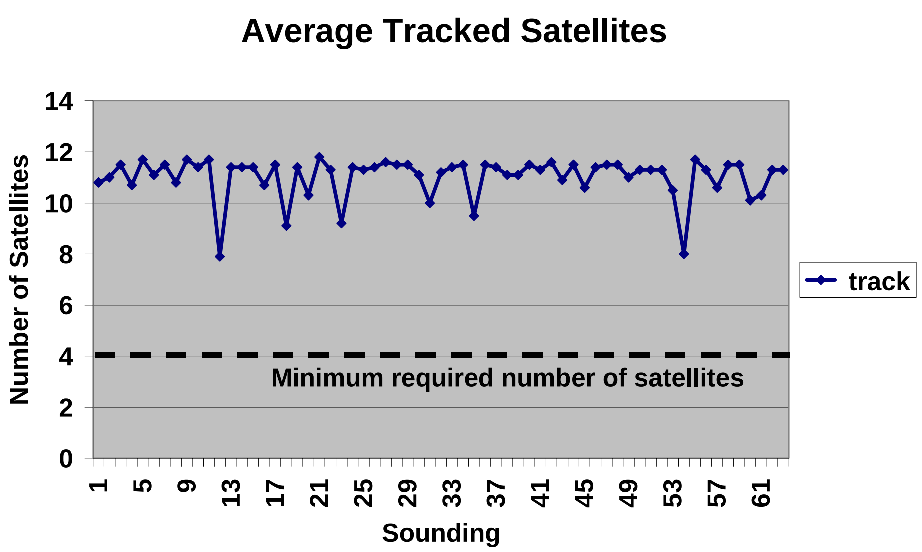

Figure 6. Average tracked satellites

3.4 Vaisala DigiCORA MW31 GPS height calculation

GPS velocity and location computations are made by the Vaisala DigiCORA MW31 ground equipment. The Vaisala DigiCORA sounding software provides autonomous radiosonde GPS navigation but is also capable of using the local GPS receiver as a differential base station.

Differential GPS calculation provides better accuracy when GPS positioning is used to calculate the GPS geopotential height. Future releases of the DigiCORA MW31 sounding software will provide a GPS height calculation with accuracy comparable to the accuracy of height computed from PTU. The algorithm, utilizing WGS84 specifications, was used in the Mauritius WMO Radiosonde Intercomparison.

The GPS height algorithm was also tested in the Tenerife sounding test. Figure 7 shows an example of the differences in GPS and PTU height measurements that were seen in Tenerife. Typically the difference will be a few meters up to 100 hPa. The larger difference that starts to be seen below the 100 hPa level is estimated to be due to measurement inaccuracies in the pressure sensor: even a small bias in pressure measurement can give rise to differences in the height calculation. This is seen in Figure 8, which shows the results of the same sounding used for Figure 7 but with a simulated -0.1 hPa constant pressure offset. In the Tenerife tests, the typical difference between the PTU and GPS heights was seen to be about 100 meters at 10 hPa, which reveals the very good accuracy of the pressure sensor.

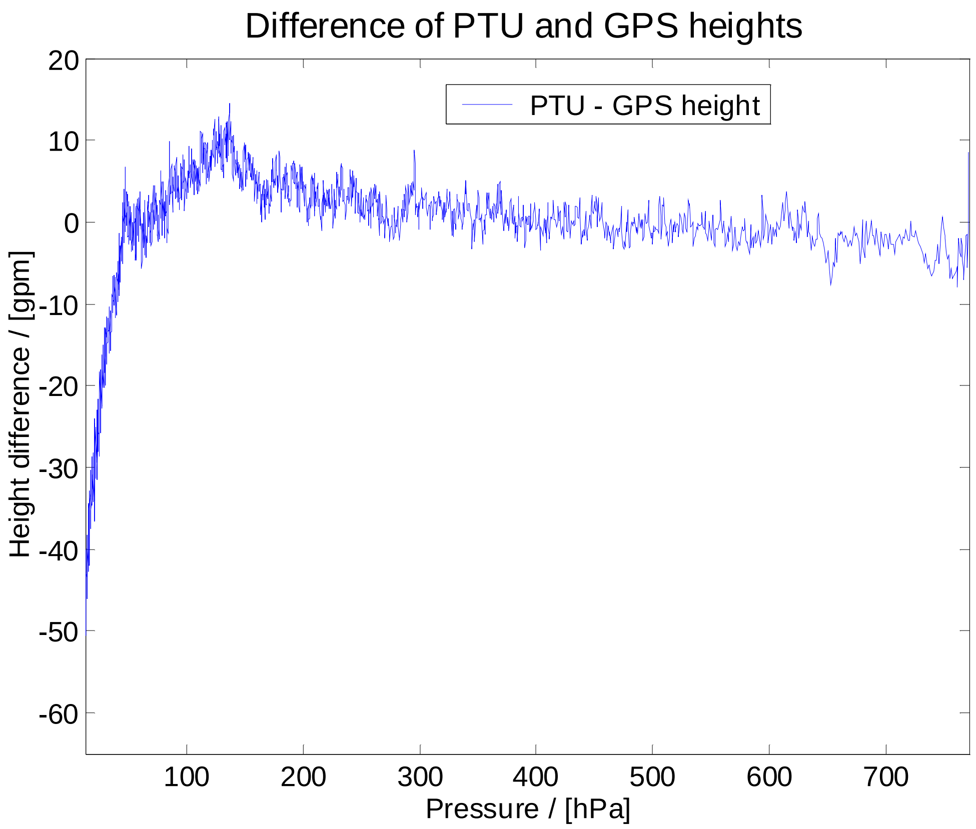

Figure 7. Difference between PTU and GPS heights

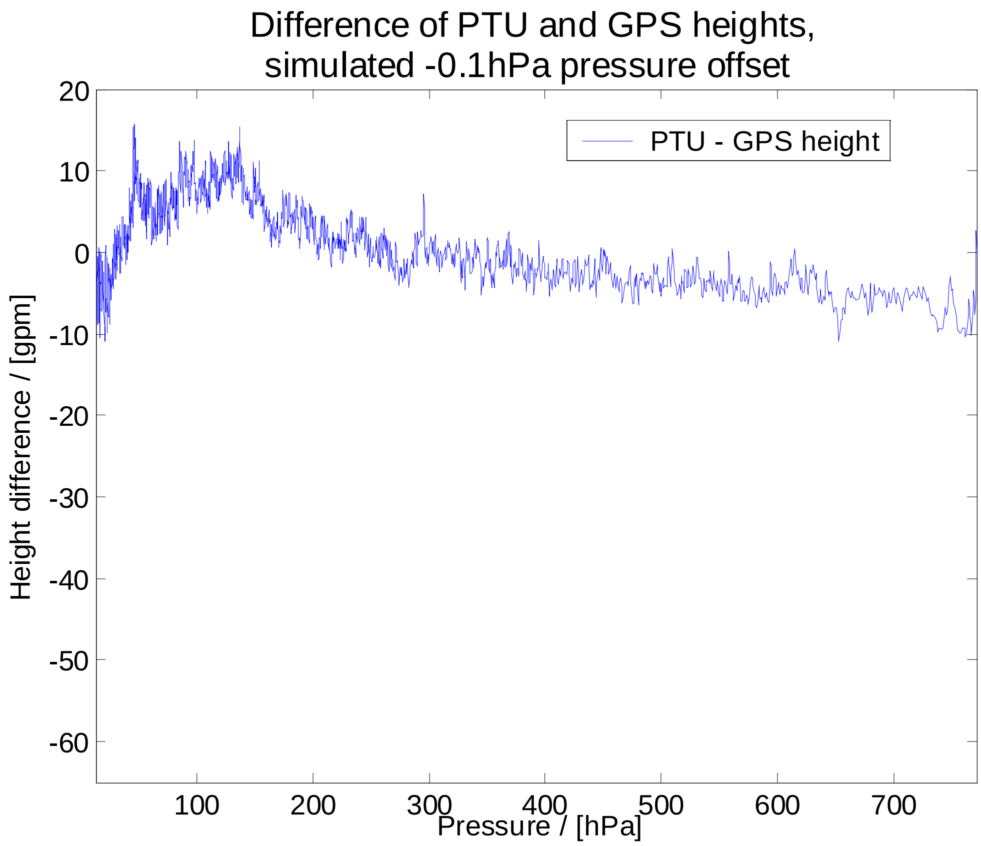

Figure 8. Differences between PTU and GPS heights, simulated with –0.1 hPa pressure offset

To test the repeatability of the GPS height calculation, multiple radiosondes were tested in a rig attached to a balloon. Figure 10 shows an example of the typical performance of three radiosondes measuring the same altitude. Figure 11 provides a close-up showing noise level in more detailed time scale. The excellent result for repeatability is due to the DigiCORA ground equipment's use of differential GPS-height calculation algorithms.

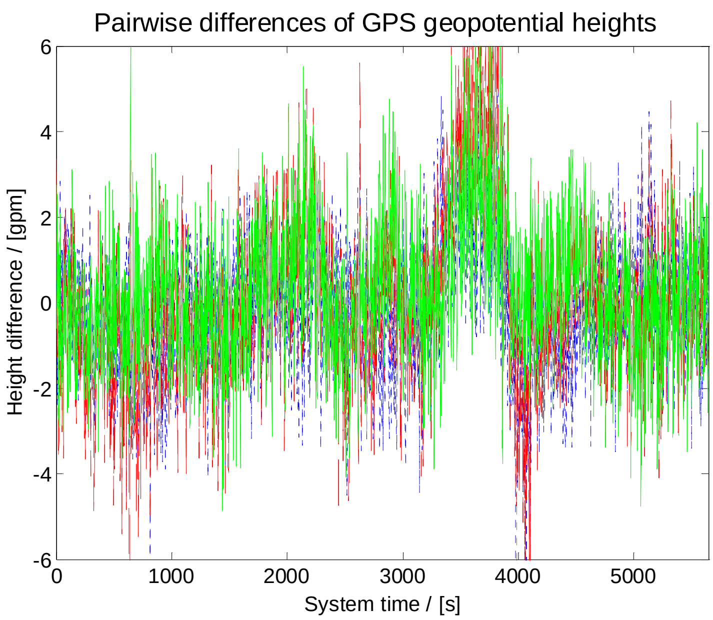

Figure 10. Radiosonde-pair differences of GPS geopotential height from a triple sounding

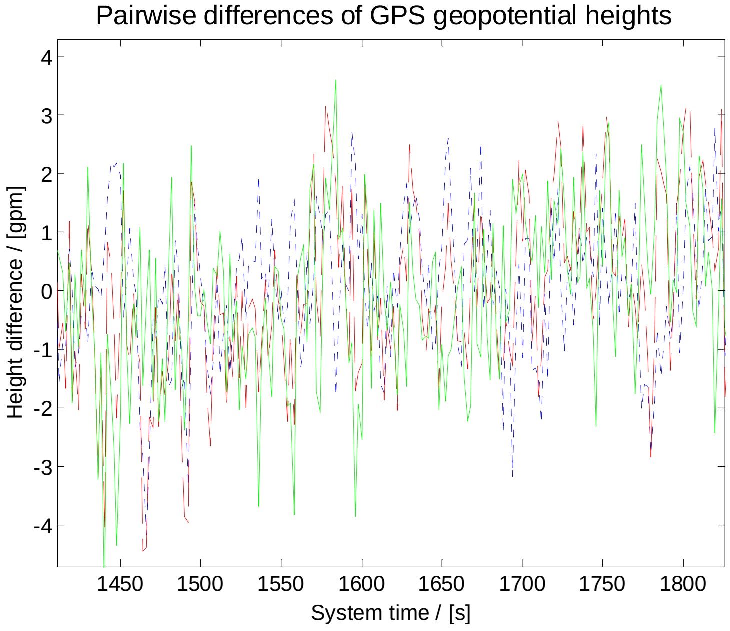

Figure 11. Radiosonde-pair differences of GPS geopotential height from a triple sounding, close-up

4. SUMMARY

Recent tests of the Vaisala RS92-SGP radiosonde and DigiCORA MW31 Sounding System equipped with the SPS311 (featuring software defined radio technology) have revealed very good results for telemetry performance and GPS windfinding performance. This system offers a digital telemetry link and receiving equipment featuring modern software defined radio technology that increases the reliability of the telemetry link by making it more immune to external disturbances experienced in the transmission band. The GPS technology of the system was designed specifically for radiosonde applications. The same is true of the differential algorithms used by the DigiCORA MW31 ground equipment. Taken together, these two facts ensure highly accurate wind speed/direction calculation in soundings made with RS92 GPS radiosondes.

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MODEM UPPER-AIR GPS RADIOSOUNDING SYSTEM

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Modem's new-generation upper-air sounding system consists in SR2K2 ground station associated with the M2K2 GPSonde. Last developments have brought some technical innovations to reinforce reliability , performances and easy operation and maintenance.

Ground station:

Beside the basic desktop station, Modem has developed a portable version. SR2K2-P is specially designed for temporary field operations on different sites. The receiving system is integrated in a very compact and robust suitcase including a laptop. During transport, antennas and cables are protected into their own smart foam bag.
Both desktop and portable systems have the same functionalities and performance level.

A built-in barometer board provides automatically launch area ground pressure to the software. There is no risk to forget updating the value just before the launch. Nevertheless, the software will accept manual entry from the operator.

New generation ground check looks like a plastics box with a transparent door and it can be set on a table or wall-mounted. The ground check system allows two simultaneous functions.
One is the calibration of temperature and humidity sensors prior launch. Sensor calibration is preformed in ambient atmosphere without using any desiccant salt. Placing the sonde into the box doesn't need direct handling of sensor boom, reducing risk of damage and contamination of sensitive elements.
The second function consists in GPS initialization of the radiosonde. Thanks to the built-in GPS repeater antenna, indoor sonde initialization is performed while the sensor calibration is in progress. It is no longer necessary to place the sonde outdoor.

According to customers request, MODEM developed as an option, a dual antenna system particularly designed for shipboard station when deck superstructure doesn't allow ideal installation of a unique antenna. There is also another application for tropics areas where wind flow often brings back the sonde overhead the ground station at the end of the flight. In this case, we offer to combine a basic antenna and a turnstile antenna with a predominant vertical diagram. Both manual or automatic reception modes are available. Running the latest mode, the software will shift automatically to the antenna receiving the best signal.

Software

ICAR (Interface of Calculation and Analysis of Radiosounding) is the new software module developed by Modem's engineers for edition of WMO messages (Pilot, Temp, Climat Temp…) aerological reports (significant points, standard levels….) and sounding analysis

Radiosonde

M2K2 GPSonde is registered under WMO code 56. M2K2 conception refers to the highest technology in this matter and is fully compliant with the recent ETSI standard for radiosonde transmitter.

The full coded GPS receiver board provides the position along Latitude, longitude and Altitude with a constant accuracy (10m) during the whole flight

Modem's GPS antenna is an original design for optimization of satellite signal reception in spite of unusual move due to strong pendulum.

M2K2 GPSonde offers three connectors for additional sensors. It is fully compatible with ozone sounding without using the costly interface board traditionally necessary

GPS wind finding is based on differential calculation providing position and speed components (Vx, Vy, Vz) as well. Therefore, we have two radically different methods to determine wind speed:

- Speed is derived from GPS positions (Geometric calculation)
- Doppler measurement is performed on instant speed

Our system combines both possibilities choosing for each data frame the more appropriate method to get the best quality.

Pressure is calculated from GPS altitude and temperature and humidity parameters accordingly to Laplace law. No pressure sensor is implemented in the radiosonde.
This operating mode ensure the same accuracy all along the flight and the benefit is clearly shown below:

At ground level

A sonde with a pressure sensor provides an accuracy around 1.5 hPa which is equivalent to 10 to 15m altitude.
M2K2 GPS accuracy is 10 m on altitude which is equivalent to 1.5 hPa.

At high altitude - 20 hPa level

Pressure sensor accuracy is now around 0.6 hPa which is equivalent to more than 250 m error on altitude.
Conversely, M2K2 GPS accuracy is still 10 m which is equivalent to 0.1 hPa error.

At ground level, both operating modes are similar, but progressively during the ascent, the error introduced by the pressure sensor can reach considerable values on altitude.

M2K2 radiosonde is powered by alkaline dry cells instead of traditional water activated battery:

- Simple and easy operation – Handling without any hazard for the operator
- Autonomy more than 3 hours
- Excellent resistance to extreme conditions up to –90°C outdoor temperature. (batteries and electronics are protected inside polystyrene box)
- No excessive heating production comparatively to water activated batteries. This issue is specially tricky for tiny sonde without any thermic protection, where temperature measurement may be contaminated by the heating of the batteries quite close to the sensor. Artificial software corrections should be applied on raw data
- 3 year shelf life
- On environmental point of view, dispersion of water activated batteries (electrolytic liquid) is finally worse than unleaded dry cells

A new generation dereeler with field-proven efficiency is delivered along M2K2 GPSondes

ADVANCES IN WIND PROFILER RADAR

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ABSTRACT

Wind profiler radars are being deployed increasingly world-wide, furnishing critical information on changing wind fields. These instruments continuously monitor wind fields above with a high temporal / spatial resolution. The measurements do not depend on the presence of precipitation.
The quality of available data has improved significantly over the past few years. Because of advances in hardware / software, measurements below 100 m are common. In addition to mean wind profiles, wind profiler radars also furnish in real time wind variability, atmospheric turbulence, wind shear information, rainfall rates, boundary layer height. We present examples of various information available from wind profiler radar data.

INTRODUCTION

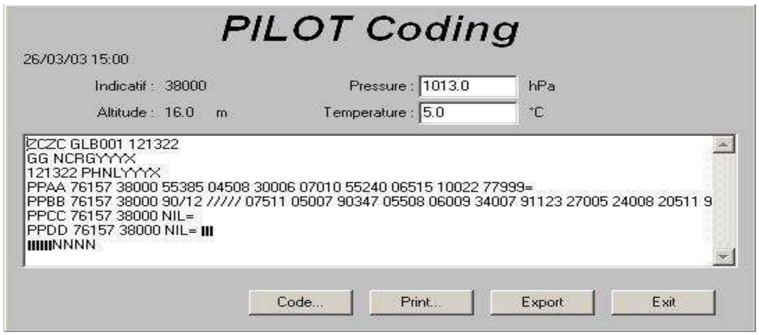
Initialy, wind profiler radar outputs were limited to mean wind information and signal to noise from the vertical beam. Output products were produced for a single end user. The quality control was limited to a rudimentary comparison with neighboring wind estimates.
Today, the radar's output include detailed system parameters in order to determine precise reflectivity information which can be related directly to atmospheric reflectivity or rainfall rate. A multitude of products can be generated simultaneously and independently for a variety of end users (for local applications: pollution or airport applications and synoptic applications). The statictics (mean, standard deviation, skewness) for each beam of all velocity, spectral width and Signal to Noise estimates are available for each product. This additional information is invaluable for statistical quality control and for the elaboration of end user products complementing simple wind profiles.

Wind Profilers today

Wind profilers are being used increasingly by people that are not always specialists in meteorology. Consequently new ways of displaying the information are being developed. Quality control of the products is becoming increasingly sophisticated.

These instruments are providing valuable data for a wide variety of applications.

<u>Airport Applications:</u>
In most airport applications wind shear and turbulence is of primary interest. The wind field itself is of secondary importance. The final end user requires simple/efficient displays. In such cases simple "pop up" windows indicating in real time wind shear warnings are used along with simple tabular displays of current wind condition at specific altitudes / headings. The information is available in real time via simple ASCII text files, or coded into the METAR or PILOT messages.



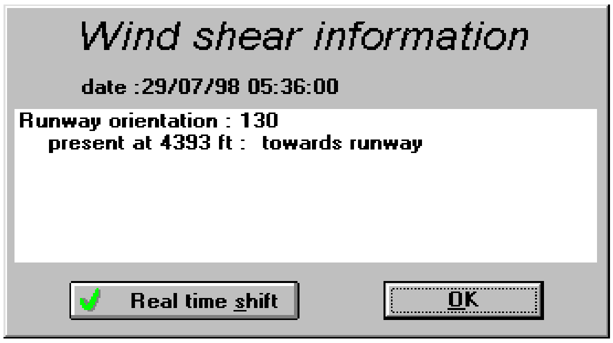


Figure 1 Pilot message

Figure 2 Wind shear message

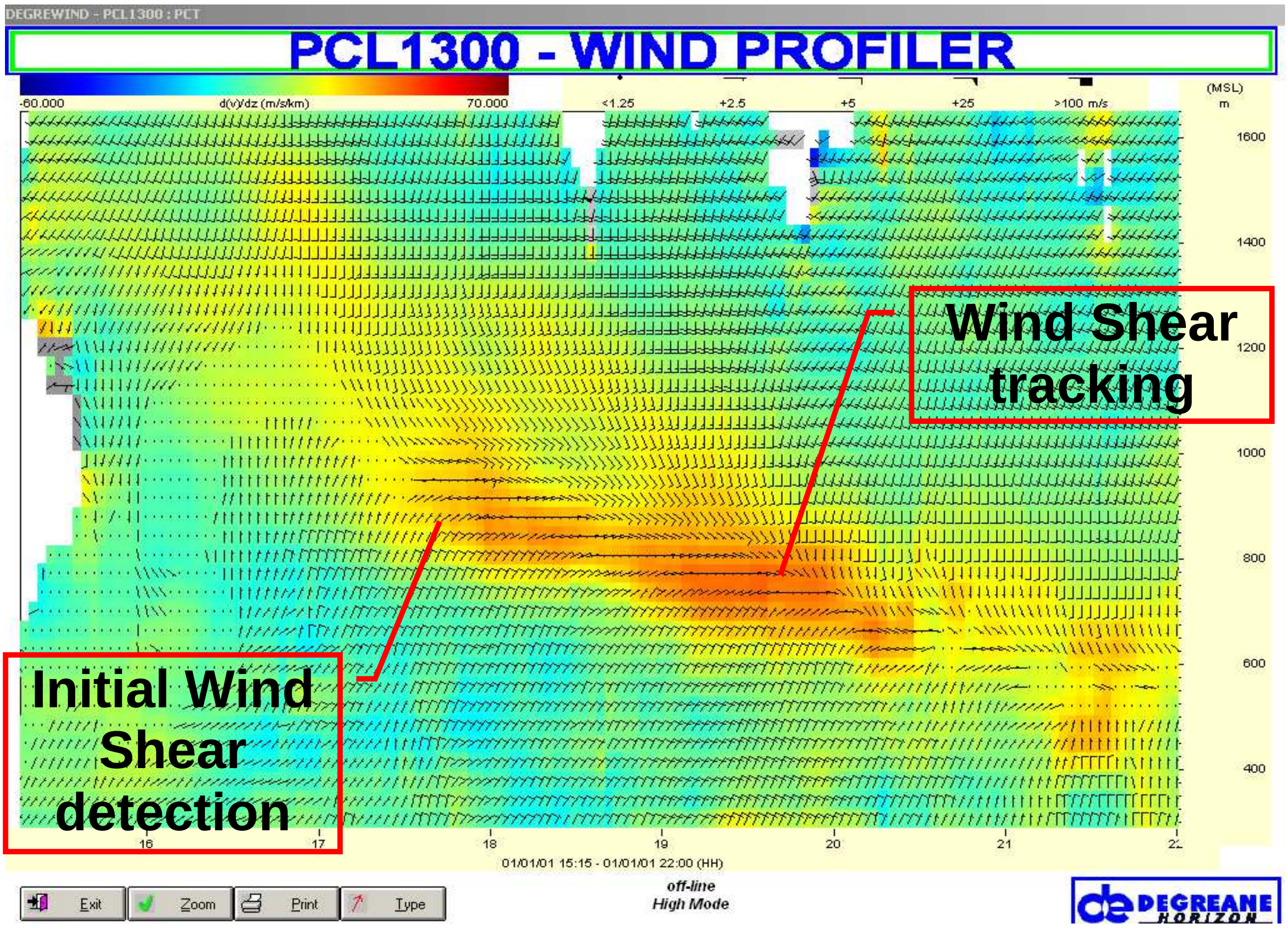


Figure 3 Example of a horizontal wind + wind shear display

<u>Air Monitoring Applications:</u>
The wind profiler, in addition to the wind fields, provides estimates of the boundary layer height, turbulent kenetic energy dissipation rate. The information is available in real time via simple ASCII text files.

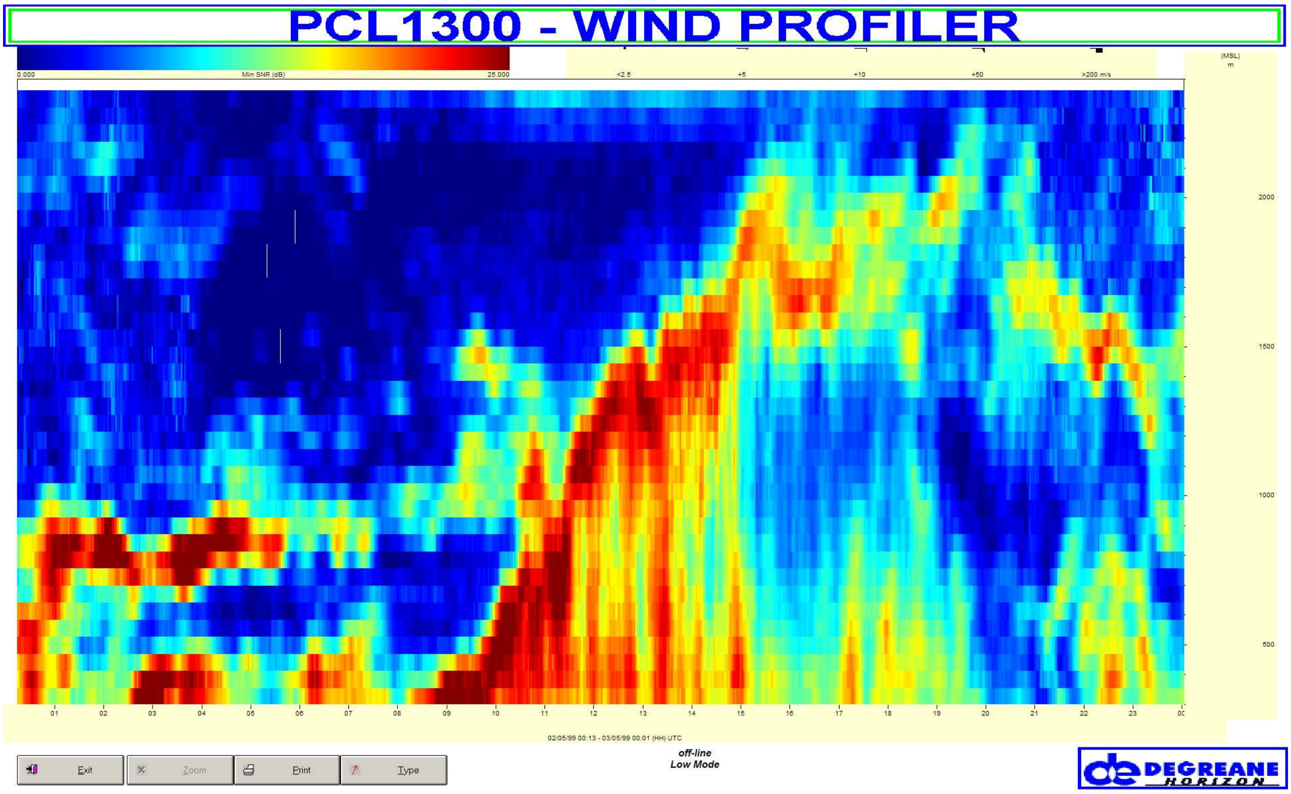


Figure 4 Example of a Convective boundary layer development (SNR)

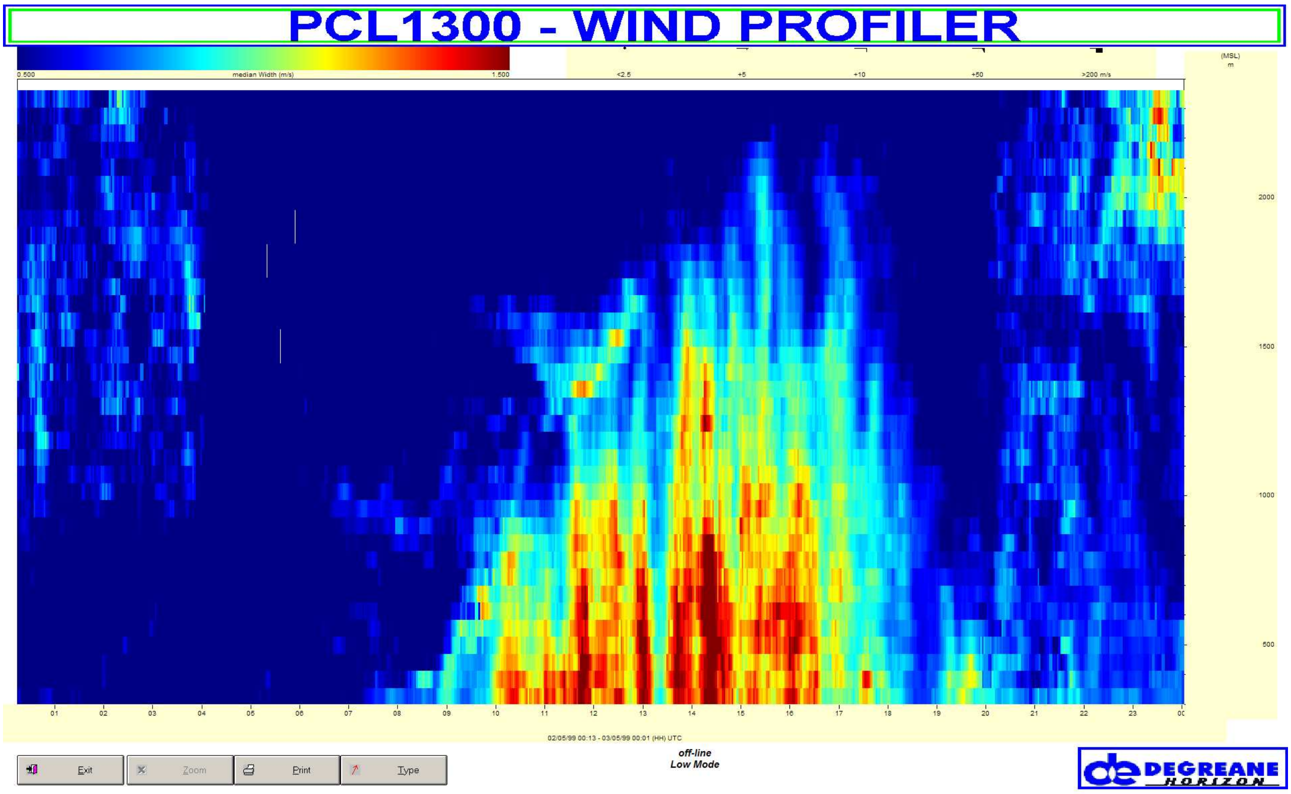


Figure 5 Boundary layer development using median spectral width

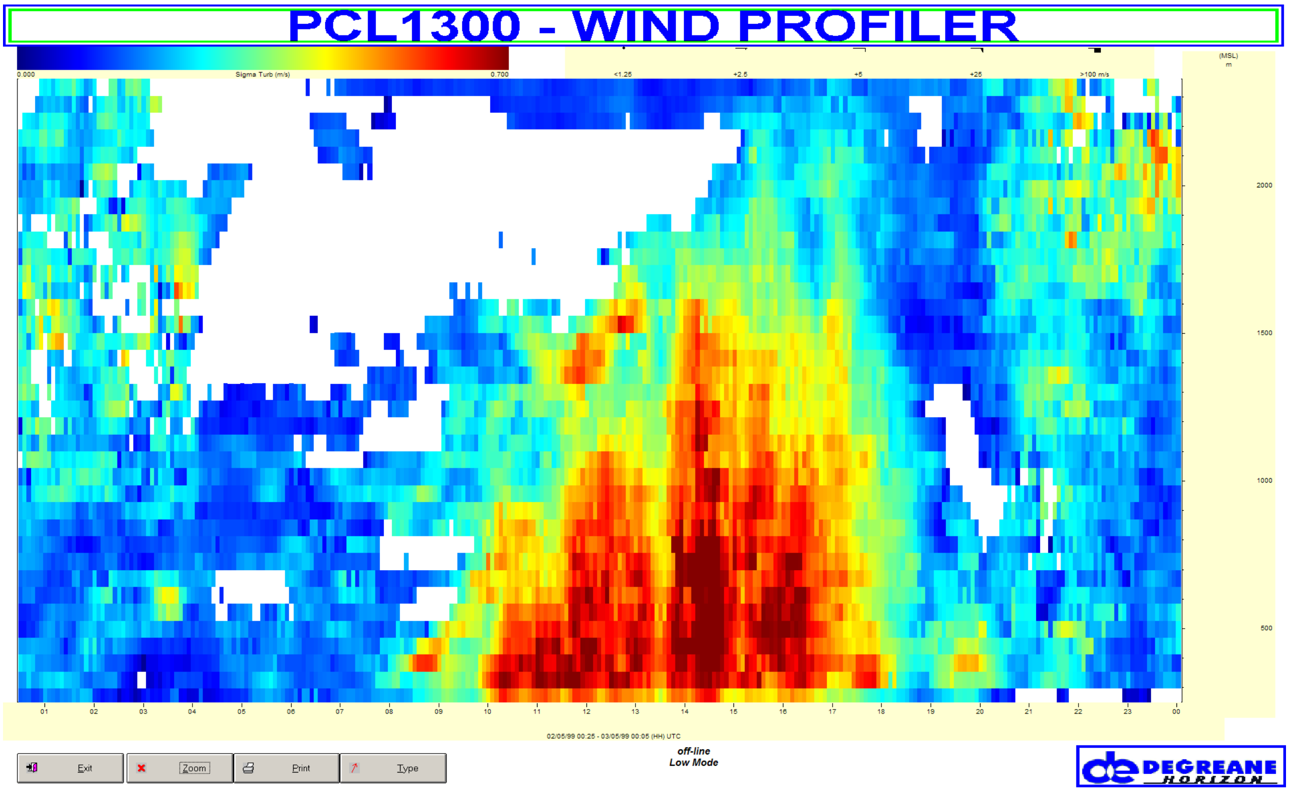


Figure 6 Boundary layer development identified by turbulenced induced beam broadening

<u>Synoptic applications:</u>

In synoptic applications, the wind profile is available in real time via BUFR coded messages. Secondary products such as rainfall rate or atmospheric reflectivity, turbulence, shear, turbulent kenetic energy dissipation rate, virtual temperature profiles are also available in real time. Often, in such applications, wind profilers are networked together: US (33, 400 MHz), Japan (25, 1 GHz), Korea (10, 1 GHz), UK (2, 50MHz; 3, 1 GHz), Germany (4, 400 MHz).

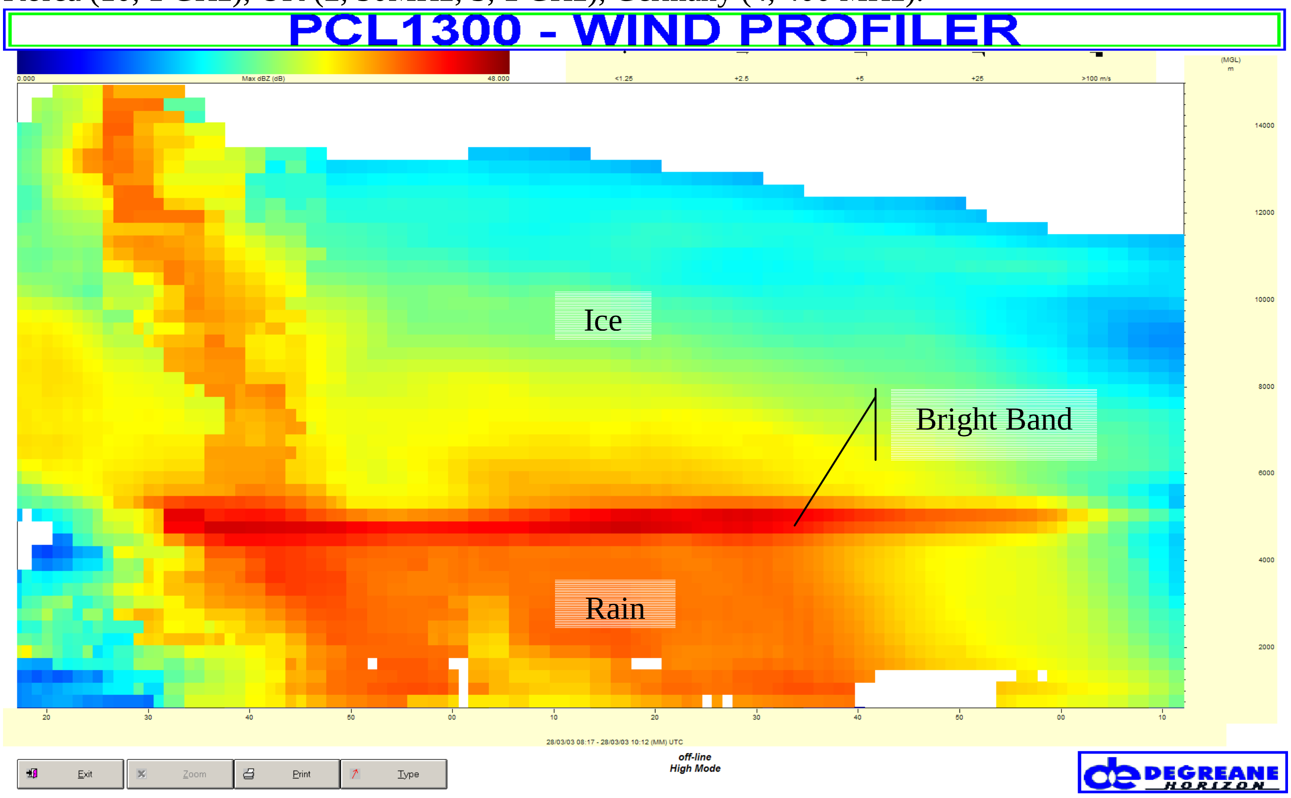


Figure 7 dBZe display

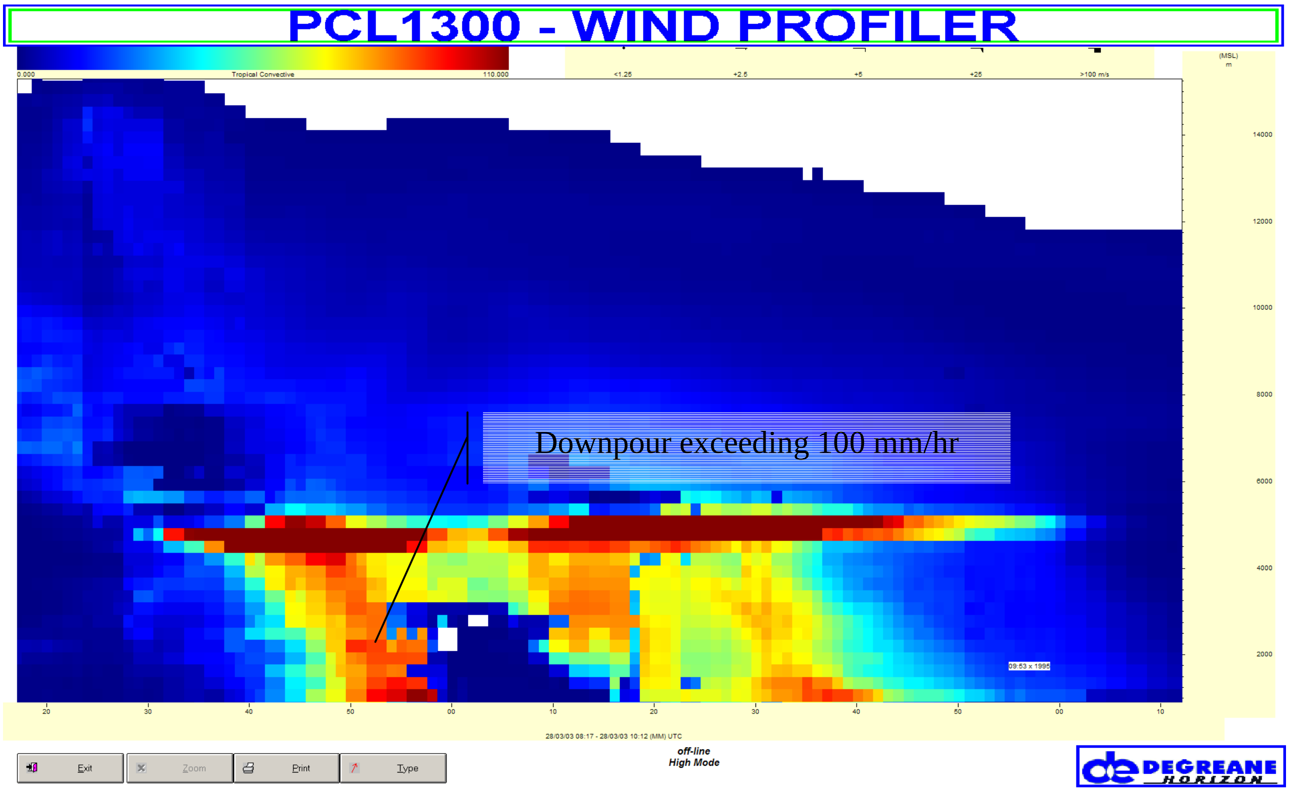


Figure 8 Rainfall Rate display

Current developments:

The integration of 2 wind profilers (1 GHz), airport sensors, and automatic weather stations with a microscale urban climate model is currently underway.

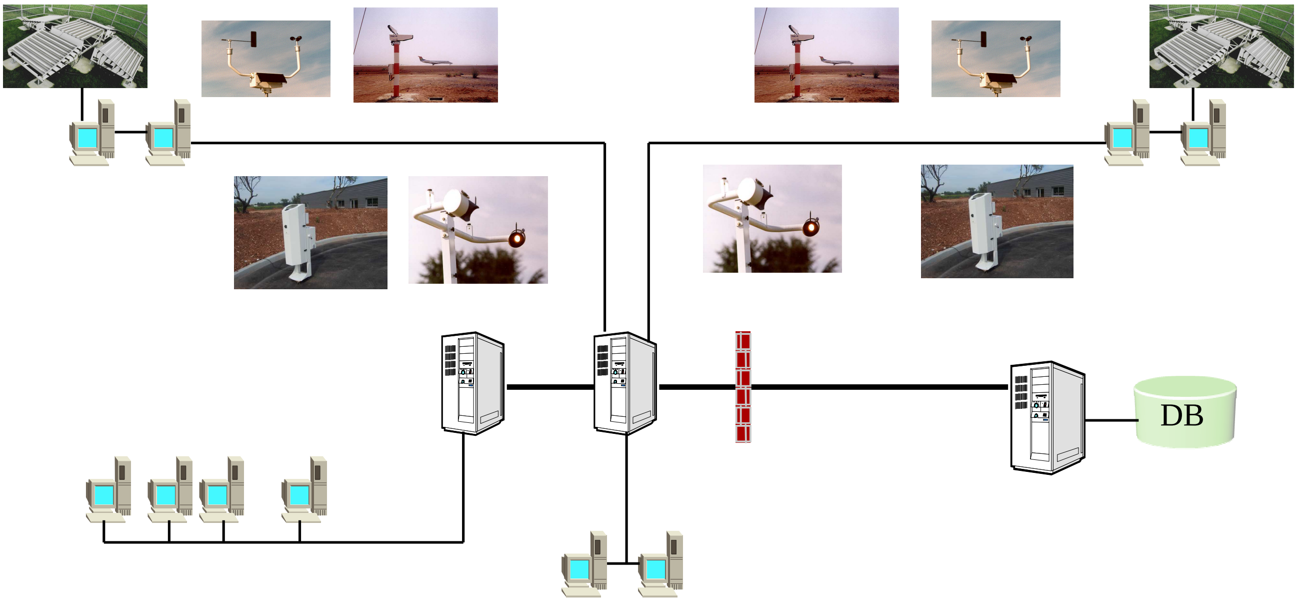


Figure 9 Wind profiler, AWOS, model integration

The development of a mechanically tilting profiler antenna is currently underway (1 GHz) . This will allow to increase significantly system sensitivity. For research application, the radar will also be able to scan in two orthogonal vertical planes. One such application is the study of land/sea breeze interaction within the boundary layer.

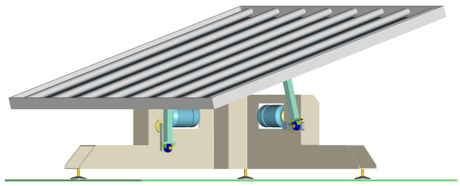


Figure 10 Mechanical tilting antenna

Conclusions

Wind profilers are being used increasingly world wide. However, in many applications new types of displays are being developed and others still need to be found. The new generation of wind profilers allow the instrument to be used simultaneously for several different applications / end users. This dissemination of information is an opportunity to create links between different end users which can lead to an exchange of expertise/knowledge increasing the quality of the end products being generated.

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Upper Air Wind Measurements by Weather Radar

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Abstract

Doppler weather radars can be employed to determine wind profiles at a high temporal resolution. Several algorithms and quality ensuring procedures for the extraction of wind profiles from radar volume data have been published. A comparison and verification of the extracted wind profiles has been performed at KNMI. The observation minus background statistics of the weather radar wind profiles against the Hirlam NWP model are at least as good as those of the radiosonde profiles. This result clearly demonstrates the high quality of weather radar wind profiles.

1 Introduction

Weather radars are well known for their ability to detect precipitation at a high spatial and temporal resolution. Precipitation data deduced from reflectivity measurements by weather radars are extensively used for monitoring of (severe) weather and are increasingly used for hydrological applications. The majority of the operational weather radars in Europe is capable of performing Doppler measurements. Using the Doppler technique, the environmental wind can be extracted from the motion of the precipitation. The wavelength of weather radars is optimized for detection of precipitation and is typically 5 or 10 cm. In clear air, therefore, no return signal and thus no wind information is expected, but often (weak) signal is received from the boundary layer, moisture gradients, or large cloud particles. KNMI operates two C-band Doppler weather radars from Gematronik GmbH which are amongst others used for obtaining wind profiles.

A Doppler radar only measures the component of the velocity vector in the line of sight, the so-called radial velocity. Radial velocity data is not straightforward to interpret, some further processing is required before it can be presented to users or assimilated into numerical weather prediction (NWP) models. Under the assumption of a linear wind field within the analyzed volume, profiles of the wind speed and direction, vertical velocity, and divergence can be extracted from radial velocity data. Several algorithms for the extraction of wind profiles have been developed, most notably Velocity Azimuth Display (VAD) (Lhermitte and Atlas, 1961; Browning and Wexler, 1968) and Volume Velocity Processing (VVP) (Waldteufel and Corbin, 1979).

Here we present an extensive verification of VVP wind profiles against radiosonde and Hirlam model profiles. Nine months of wind profile data have been used for this verification. Different implementations of modules to retrieve wind profiles from Doppler volume scan data

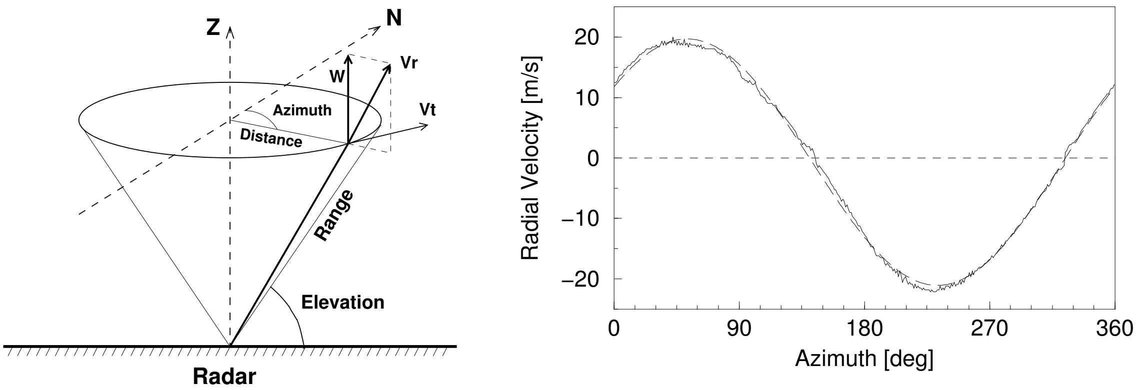

Figure 1: Schematic overview of the radar geometry used to measure Doppler wind profiles is given in left part of the figure. An example of a VAD extracted from radial velocity data is shown together with a fitted sine on the right.

using the VAD and VVP techniques have been considered as well. It is found that the most simple implementation of the VVP technique, i.e., with the fewest wind field parameters, provides the best horizontal wind data. The verification results indicate that the biases of the VVP wind profiles satisfy the accuracy requirements for upper-air wind measurements as provided by WMO (1996). The observation minus background statistics of the VVP wind profiles against the Hirlam NWP model demonstrate the high quality of weather radar wind profiles.

2 Wind Profile Retrieval: VAD and VVP

A Doppler weather radar measures the radial component of the velocity of scattering hydrometeors. The Doppler weather radar performs a three-dimensional scan and thus provides the mean radial velocity as a function of range, azimuth, and elevation. In the case of single-Doppler radar wind profile retrieval, information on the local wind field has to be deduced from these radial velocity volume data only. A schematic overview of the typical Doppler radar geometry and the relevant local wind field vectors is presented in figure 1. The figure shows clearly the three scanning directions of a (Doppler) weather radar and the three components of the local wind field: the radial velocity V_r, the tangential velocity V_t, and the vertical velocity w. Because only one of these components V_r can be observed by the Doppler radar, the other two components of the wind field have to be estimated using a local wind model.

Wind profiles can be obtained from single-site radial velocity data under the assumption of a linear wind model. In this model, the wind field in the vicinity of the radar is approximated by:

$$U(x,y,z) = u_0 + x\frac{\partial u}{\partial x} + y\frac{\partial u}{\partial y} + (z - z_0)\frac{\partial u}{\partial z} \quad (1)$$

$$V(x,y,z) = v_0 + x\frac{\partial v}{\partial x} + y\frac{\partial v}{\partial y} + (z - z_0)\frac{\partial v}{\partial z} \quad (2)$$

$$W(x, y, z) = w_0 + (z - z_0)\frac{\partial w}{\partial z} \quad (3)$$

The derivatives of the vertical velocity W in x- and y-directions can be neglected with respect to the derivatives of U and V in z-direction (Waldteufel and Corbin, 1979). In addition to the movement due to the wind, the hydrometeors have a fall velocity ($W_f < 0$). Using a uniform wind field and a constant fall velocity, the radial velocity V_r can be calculated as a function of azimuth (ϕ) and elevation (θ):

$$V_r = (w_0 + W_f)\sin\theta + u_0\cos\theta\sin\phi + v_0\cos\theta\cos\phi \quad (4)$$

When Doppler radar data is displayed at constant range and elevation, the radial velocity as a function of azimuth will have the form of a sine, see figure 1. The wind speed and direction can be determined from the amplitude and the phase of the sine, respectively. This technique is called Velocity-Azimuth Display (VAD) (Lhermitte and Atlas, 1961; Browning and Wexler, 1968).

Instead of processing multiple VADs and averaging the results, one can also process all available velocity volume data within a certain height layer at once. The parameters of the linear wind field can then be extracted using a multi-dimensional and multi-parameter linear fit. This so-called Volume Velocity Processing technique (VVP) has been introduced by Waldteufel and Corbin (1979). It has been a matter of debate whether or not the VVP method for retrieval of wind profiles is as robust as the VAD method, because the VVP basis functions are not inherently orthogonal. It has already been mentioned, however, that the orthogonality of the VAD basis functions is reduced by the presence of gaps in the collected data (Matejka and Srivastava, 1991). Boccippio (1995) presents a robust and stable implementation of the VVP method.

3 Error sources and Quality Control

The retrieval methods for wind profiles approximate the local wind field by a uniform or a linear wind model. Inevitably deviations of the local wind field from the wind model will cause errors in the retrieved wind parameters. Caya and Zawadzki (1992) have investigated the effect of nonlinearity of the local wind field on the quality of the VAD retrieval. Errors due to nonlinearities of the wind field are controlled by application of a maximum range (e.g. 25 km) on the analyzed volume data.

Sidelobe clutter and other ground clutter in the received Doppler signal is suppressed using a digital time domain filter before the mean radial velocity is calculated. Strong clutter is not suppressed completely, however, and it will cause a bias of the mean radial velocity towards zero. Application of a minimum range (e.g. 5 km) on the analyzed volume data and rejection of data from low elevations reduces the impact of clutter on the quality of the wind profiles. In addition, the error can effectively be controlled by rejection of all radial velocities close to zero before the wind profile retrieval method is applied.

The absence of hydrometeors or other scatterers leads to gaps in the radial velocity data. Wind profile retrieval algorithms have problems with large gaps, because the basis functions loose orthogonality and the linear fit becomes unstable. To avoid gross errors, no wind field retrieval should be performed on volume data with large gaps.

The unambiguous interval of the radial velocity data is extended by a factor of 3 using the dual-PRF technique (Sirmans et al., 1976). Analysis of dual-PRF velocity data has revealed that a small fraction of the range bins will be dealiased incorrectly (Holleman and Beekhuis, 2003). These velocity outliers constitute typically 1 percent of the range bins, and the velocity error will be twice the unambiguous velocity of the primary observations. The velocity outliers can efficiently be flagged by a comparison with the modeled radial velocity obtained from a first fit. After removal of the outliers the final wind field parameters are again determined by a second wind model fit.

Migrating birds and actively flying insects are a major source of error for wind profile retrieval methods (Koistinen, 2000; Collins, 2001). Bird migration can easily be recognized by inconsistency of the wind vectors or by deviation of the Doppler wind profiles from reference profiles. Koistinen (2000) has noted that the standard deviation of the radial velocity determined from the wind profile retrieval is larger in bird migration than in rain. The retrieved wind vectors are quality controlled by rejection of the vectors with a standard deviation larger than a certain threshold.

4 Verification of Radar Wind Profiles

The intercomparison of different implementations of the VAD and VVP wind profile retrieval methods using radiosonde profiles as a reference revealed that the VVP method performs slightly better than the VAD method (Holleman, 2003). Furthermore it was found that the most simple implementation of the VVP retrieval method, i.e., using a uniform wind field, provides the best horizontal wind data. Figure 2 shows a timeseries of weather radar (VVP) and Hirlam NWP wind profiles for 8 January 2005 between 06 and 12 UTC in black and blue, respectively. On this day a low pressure area with strong winds moved over the Netherlands. In figure 2 wind speeds up to 50 m/s are observed between 4 and 6 km altitude. Evidently the agreement between the radar and model wind vectors is good, but the update frequency and availability are different.

Histograms of the wind speeds observed by Doppler radar have been constructed for three different height ranges. The constructed histograms for the 0-2 km, 2-4 km, and 4-6 km height ranges are shown in figure 3. The vertical axis represents the wind vector count per 1 m/s-wide bin using all available radar wind profiles between 1 October 2001 and 30 June 2002. Comparing the histograms for the three height ranges, it is evident that the total number of available wind vectors and the mean wind speed are decreasing and increasing, respectively, with increasing height. The fraction of the number of available wind vectors to the maximum number of vectors decreases from 0.39 at ground level to 0.16 at 6 km altitude.

The observation minus background statistics for the weather radar (upper frames) and ra-

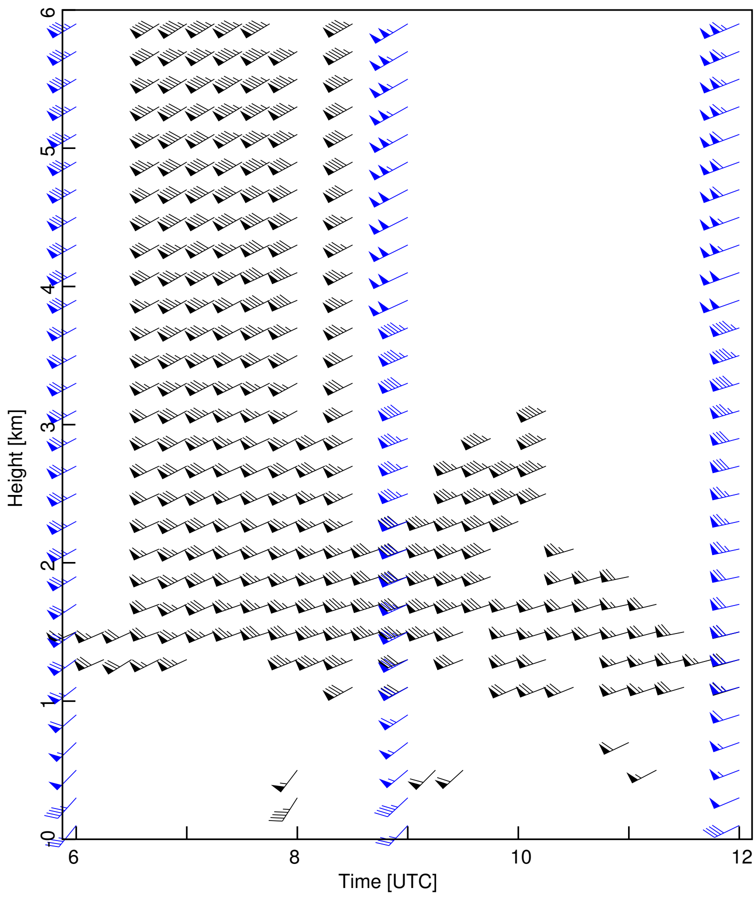

Figure 2: A time-height plot with the weather radar wind vectors (VVP) for 8 January 2005 between 06 and 12 UTC. The wind profiles from the Hirlam NWP model are overlayed in blue. Wind speed and direction are indicated by wind vanes. Each full barb represents a wind speed of 5 m/s and each triangle a wind speed of 25 m/s.

diosonde (lower frames) wind profiles against the Hirlam NWP model are shown in figure 4. The figure shows the bias and standard deviation of the Cartesian u- and v-components of the wind vectors calculated for the 9 months verification period (1 October 2001 and 30 June 2002). In this comparison the radiosonde has a clear advantage over the weather radar because the radiosonde profiles are assimilated by the Hirlam model. It is therefore not a surprise that the observed biases of the wind vector components from the radiosonde are only a few tenths m s^{-1} and thus negligible. The standard deviation of the radiosonde wind vector components against the Hirlam background is between 1.5 and 2.0 m s^{-1} at ground level and gradually increases to almost 3.0 m s^{-1} aloft. This increase is probably due to the increase of the wind speeds with height and to the drifting of the radiosonde. For the radar wind data, a small positive bias for both Cartesian components is found. The standard deviation of the VVP wind vector components against the Hirlam background is around 2.0 m s^{-1} at ground level and about

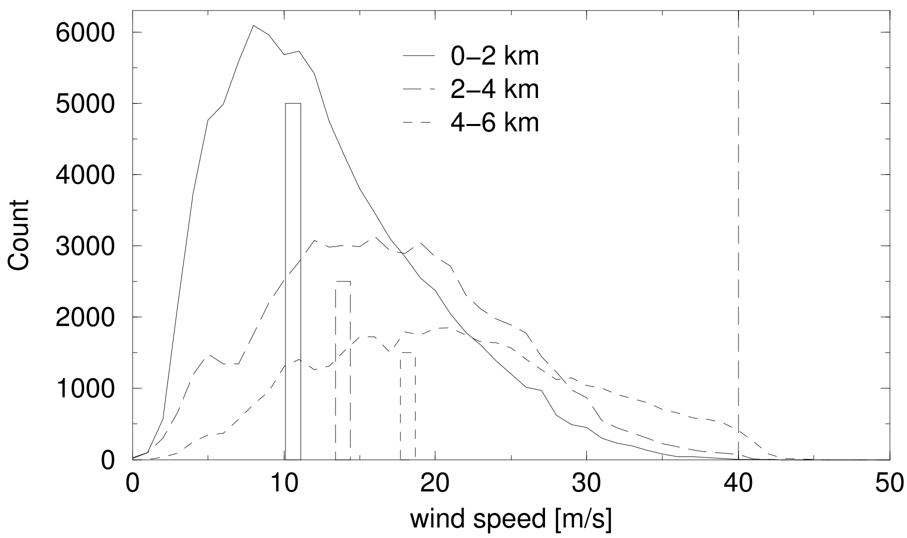

Figure 3: This figure shows histograms of the observed wind speeds for three different height layers and using wind speed bins of 1 m/s. The wind speeds are obtained from the radar using the VVP retrieval method. The vertical bars represent the mean wind speeds as obtained from the radiosonde observations over the same period.

2.5 m s^{-1} aloft. Figure 4 shows that observation minus background statistics of the weather radar wind profiles are at least as good as those of the radiosonde profiles. This result evidently demonstrates the high quality of the weather radar wind profiles.

5 Conclusions

In many meteorological circumstances, a Doppler weather radar can provide wind profiles at a high temporal resolution. It was found that the most simple implementation of the VVP retrieval method provides the best horizontal wind data. An availability fraction of weather radar wind vectors of about 0.39 is found in the lowest 1 km of the troposphere, and this availability drops below 0.16 at 6 km altitude.

A comparison of the observation minus background statistics for the radar and radiosonde wind profiles against the Hirlam NWP model has been performed. The observed biases of the wind vector components are negligible for the radiosonde data and slightly positive for the radar data. The observed standard deviation of the radiosonde and radar wind vector components is comparable at ground level and it is slightly lower for the radar data at higher altitudes. Thus the observation minus background statistics of the weather radar wind profiles are at least as good as those of the radiosonde profiles. This result demonstrates the high quality of (quality controlled) weather radar wind profiles.

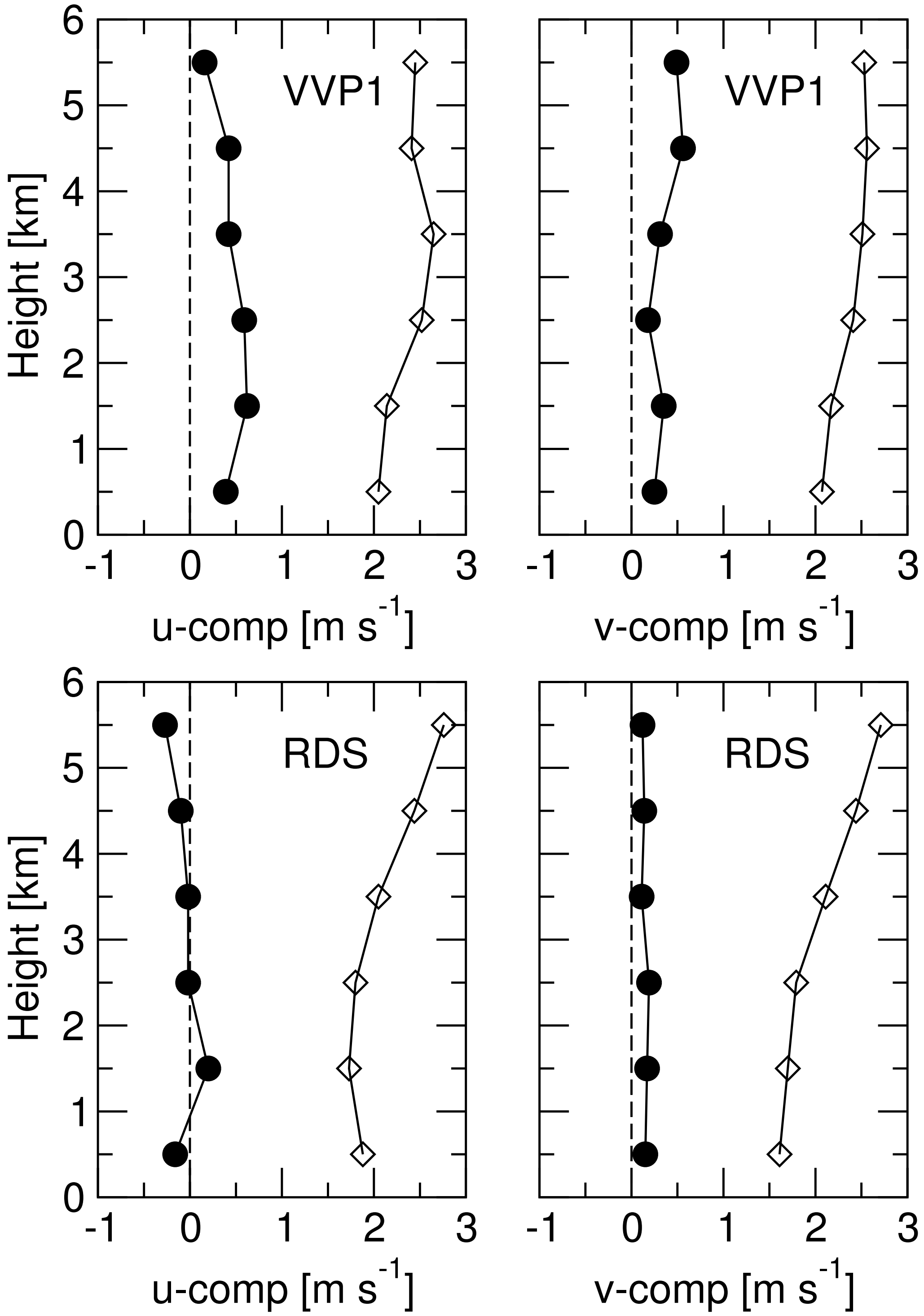

Figure 4: Profiles of the bias (•) and standard deviation (◇) of the Cartesian u- and v-components from the verification of the radar (upper) and radiosonde (lower) wind data against the Hirlam model.

Acknowledgments

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STUDYING THE ACCURACY OF AFAR-BASED RADAR SOUNDING SYSTEM

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1. Introduction

The Russian upper-air network comprises 125 stations with 107 of them included in the 2005 operational plan. Most stations are equipped with upper-air radar systems AVK-1 that are highly radiative and power-consuming. Their microwave transceivers are very costly, their computers obsolete, and mechanics sophisticated. Service-life period of some of the “Meteorite” radars expired long ago. Therefore, the network updating has been undertaken in two directions: AVK-1 systems updating and installation of new upper-air radars MARL-A.

MARL-A is a radar system with active phased antenna array (AFAR) composed of 64 elements (Fig. 1), 100 W pulse power, and consumed power less than 500 W.

The beam is controlled by electronics in both planes, with automated slewing provided.

Some features of electronic scanning (no transit-time effects, high rate, stepwise mode) may cause additional errors in radiosonde target tracking whose accuracy needs to be specially investigated.

2. To evaluate the characteristics of AFAR and the radar in general in terms of both its adjustment and control in the course of operation, each radars set to be delivered includes a radiosonde mock-up. The latter is to be stationary installed at a 50-100 m distance at maximum possible height and is remotely controlled from an operator's workplace. The mock-up serves to check the operability of each AFAR module and the performance of antenna in general. Electronic angular scanning within ± 15 deg. azimuth and elevation with a 1 deg. step is performed in an automated mode resulting in a spatial display of the antenna pattern and bearing characteristic (Figs. 2 and 3).

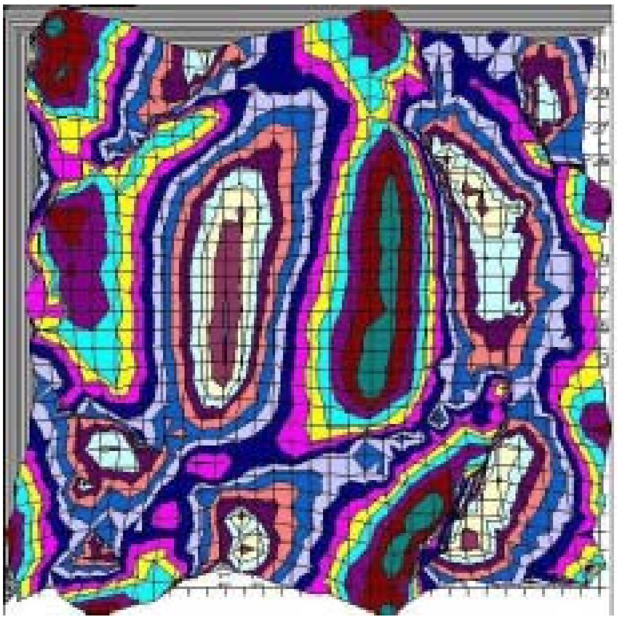

Fig.2 Azimuth pattern

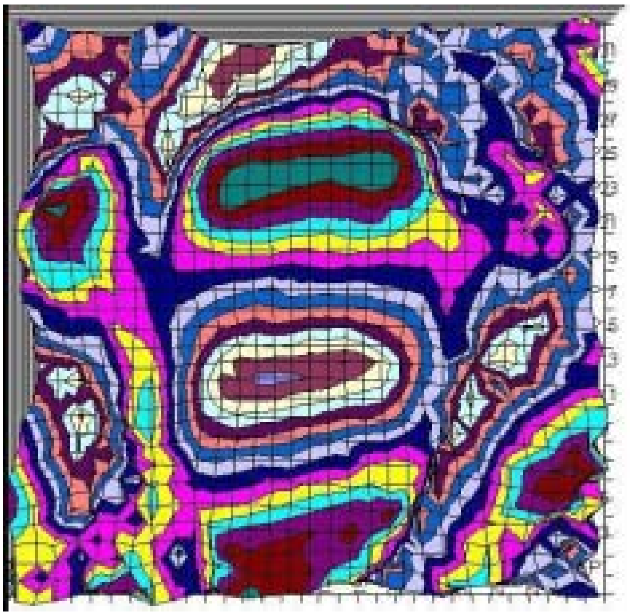

Fig. 3 Elevation pattern

Linearity, symmetry, and sufficient sloping of the bearing curve in both planes are critical for radiosonde angular tracking with high accuracy. The mock-up is also used to check the parameters of automatic lock-on to a target and mechanical antenna slewing.

Errors in the angular tracking of a moving target are readily revealed and both antenna orientation and leveling checked against the solar disk whose radio emission is sufficient for angular tracking to be performed in the working frequency range.

The r.m.s. sun-based elevation error for an well-adjusted MARL-A was found to be less than 0.1 deg. (Fig. 4), while systematic errors could be eliminated using either mechanical or software means.

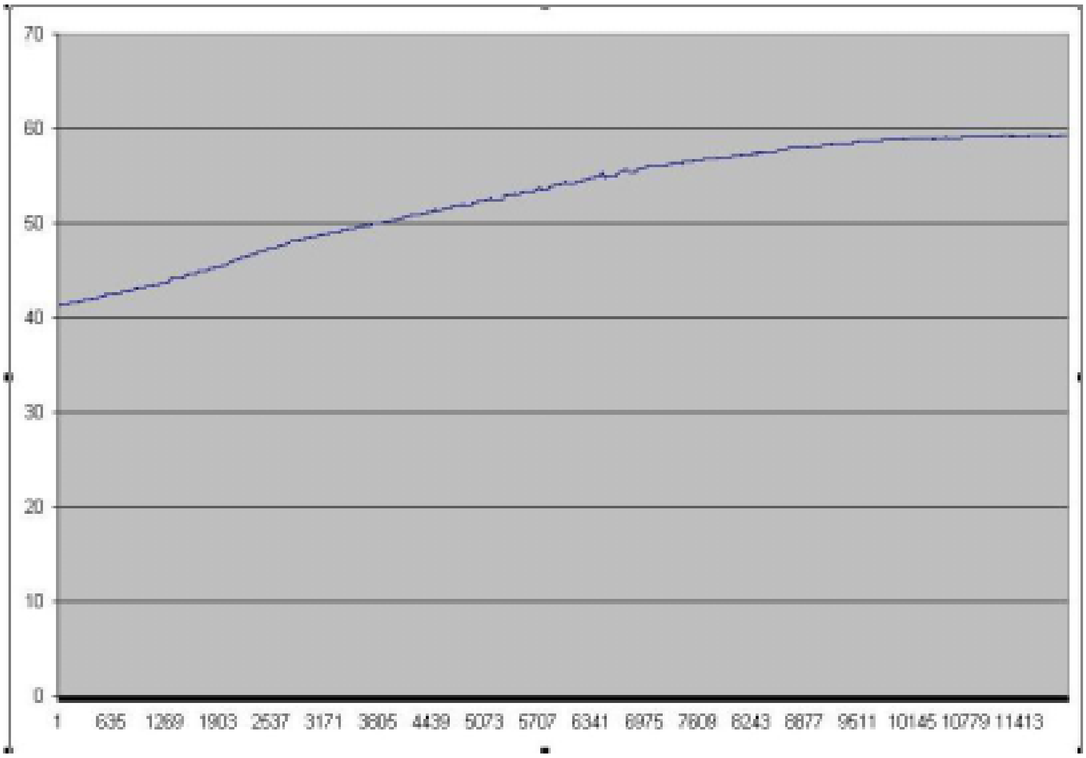

Fig. 4 Sun tracking in elevation

Under favorable conditions it was even possible to evaluate antenna pattern in the main lobe by solar radiation (Fig. 5 and 6).

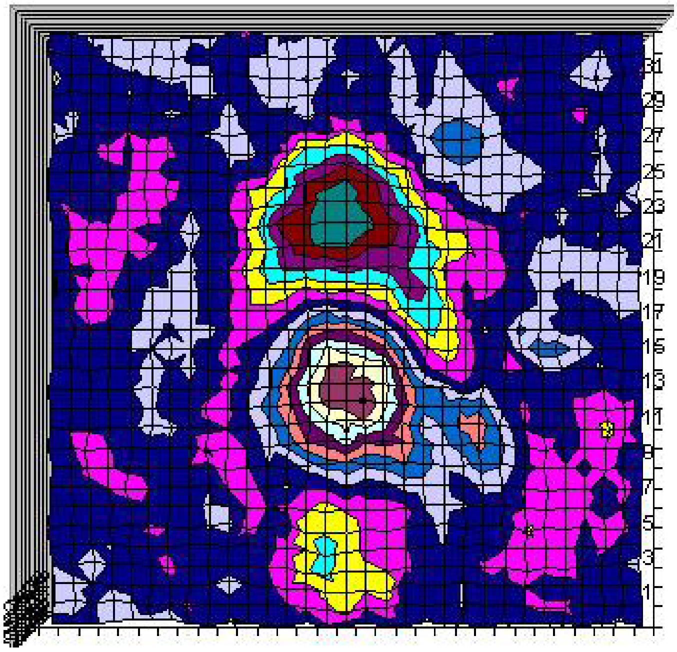

Fig.5 Sun pattern diagram

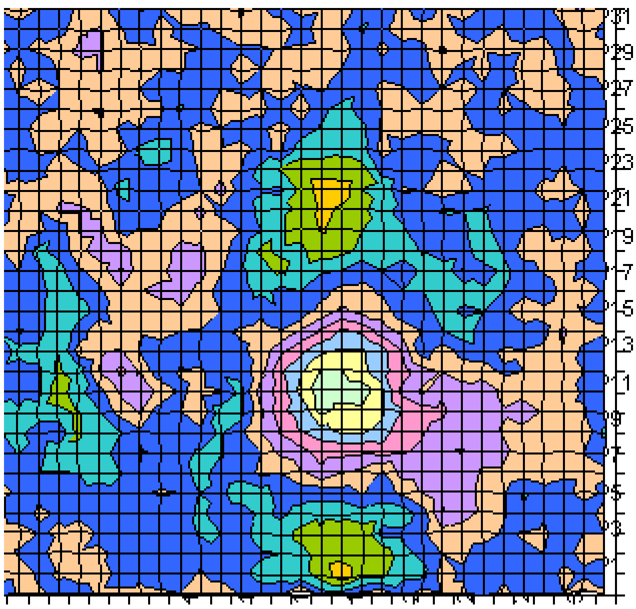

Fig.6 Sun main lobe

3. The final evaluation of the radio sounding accuracy of the new system MARL-A was performed by way of direct comparison of the coordinates and upper-air telegrams in paired radiosonde launches and their tracking independently with MARL-A and AVK-1 radar systems. The radars were mounted on top of the same building, 25 m apart, with a 4-m difference in height.

Figure 7 shows a fragment of synchronous records of elevation angle from the two radars with a 0.5-deg. offset. The r.m.s. angular difference in the distance range from 1 to 140 km was 0.16 deg, somewhat increasing at larger distances due different influences of the underlying surface on the two antenna types – paraboloid and AFAR. The contribution of the Earth’s reflections to elevation error was investigated when radiosonde was falling down. A noticeable departure from a continuous reduction of elevation angle was only observed below 6 degrees.

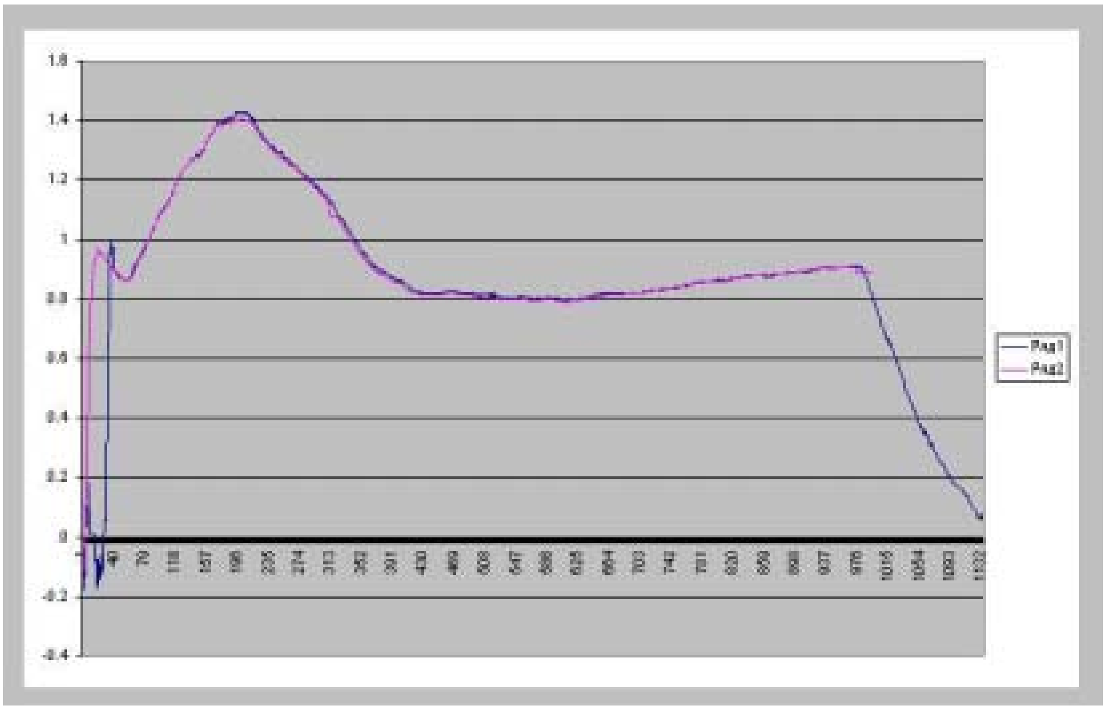

Fig.7 Tracking radiosondes with AVK and MARL

On the whole, 25 paired radiosonde launches were fulfilled. When compared, the telegrams revealed the difference between geopotential heights at standard levels less than 25 m up to a 50 hPa height.

4. Experiments were performed to track a single radiosonde simultaneously with two MARL-A radars that were 42 km apart and AVK-1 (Fig.8).

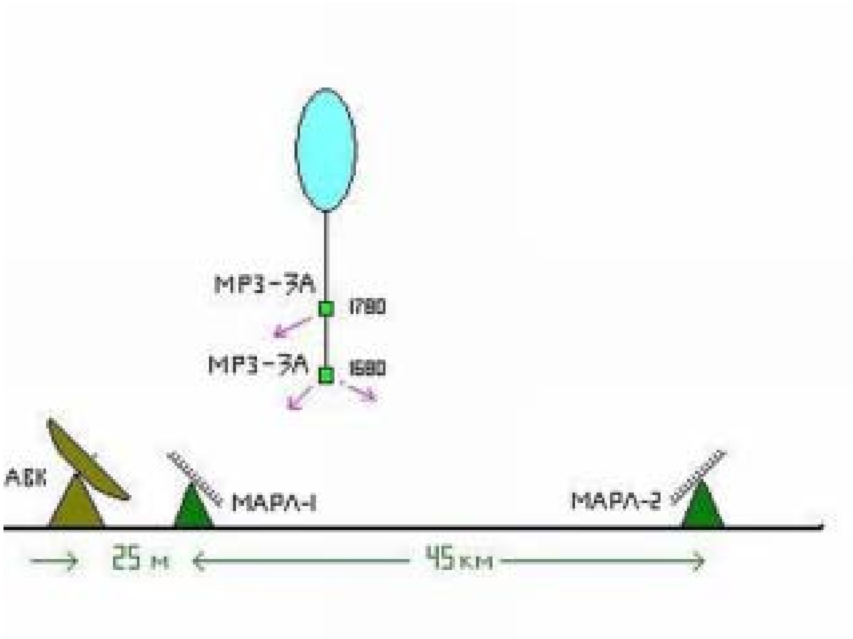

Fig.8 The sceme of experiment

The radiosonde was launched near the first radar. The second radar could start tracking beginning from 1-km height (1-deg. elevation). Figure 9 shows the zone of signal failure at angles of 3-4 deg. due to the influence of the earth surface. Further tracking with the second radar was stable and permitted evaluating errors in height measurements with an AFAR radar at small tracking angles.

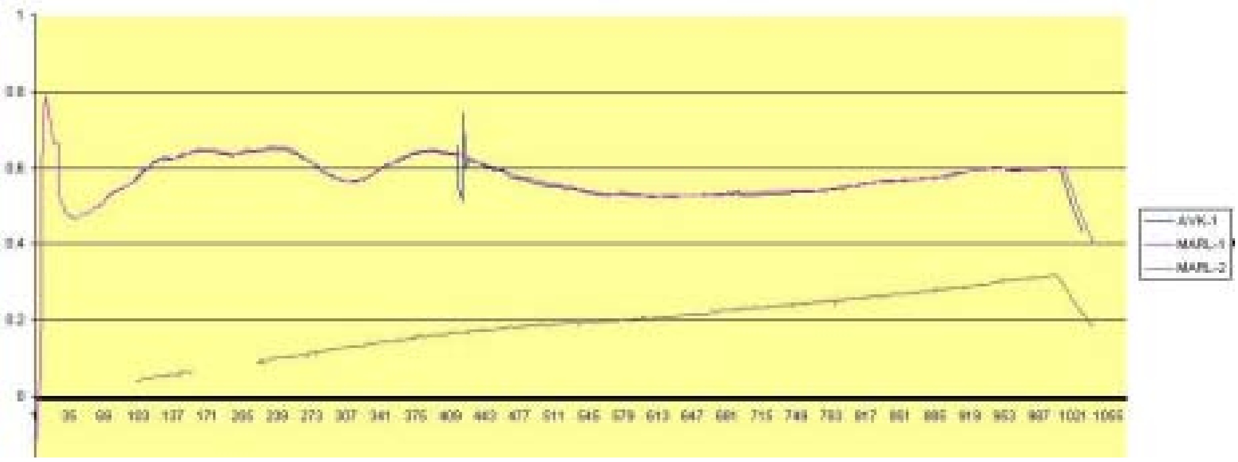

Fig.9 Elevation angle tracking with 3 radars

A thorough experimental study is to be performed to reveal the peculiarities of measuring wind by radar technique for different radiosonde distances. The wind profiles provided by the two radars at height over 5 km were found to agree fairly well.

5. Due to the paired launches of radiosondes with single-type temperature and humidity sensors it became possible to check once again the performance of these sensors, which are still in used for operational sounding on Russia's upper-air network. The dispersion of temperature differences (data reproducibility) was found to be 0.3^0C.

6. The new upper-air radar MARL-A with a phased antenna array, whose introduction on the Russia's network is under way, ensures the required accuracy of radiosonde angular tracking, with the leveling of error in geopotential height being no less correct than for the radar system AVK-1.

The authors wish to thank D. Ganzhenko, M. Azarov, and R Leskov for the development of software for MARL-A and also a team of researchers from the Central Aerological Observatory who participated in the experiments.

Meteorology and Security around the nuclear power plants in Switzerland

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The Nuclear power plants in Switzerland are currently equipped with meteorological towers (up to 110m height) and ground-based instruments which yield the basic data input to a gaussian-dispersion model. The latter is used as the meteorological security tool in case of a nuclear power plant accident.

MeteoSwiss is in charge of upgrading this security tool linked to the nuclear power plants for the next two decades. It is intended to take advantage / peculiarity of the fact that the four nuclear power plants are all located on the Swiss Plateau, where wind fields are channeled towards the NE and SW directions due to the presence of the Jura mountains on the NW and the Swiss Alps on the SE.

The project CN MET "Centrales Nucléaires et Météorologie" is directly addressing this issue: it is based on the development of a high resolution forecast model linked to a meteorological network of ground-based and remote sensing instruments. With CN MET, the description of the dynamics of the atmosphere will be covered for the entire planetary boundary layer (e.g. up to 2km above ground level) over the Swiss Plateau. It will be achieved by using remote sensing instruments such as wind profilers, passive microwave temperature instruments, as well as a sodar for low altitude wind measurements. These data will be used as input and boundary conditions for a new developed fine grid model. Two major goals are foreseen:

- *The meteorological security tool that includes the measurement network and the fine grid model will at any time (e.g. the time of a power plant accident) give the best picture of the evolution of the air masses for the next 24 hours over the entire Swiss Plateau.*
- *Furthermore the met security tool will generate the necessary data input for the local dispersion model, the latter being specifically set for each of the four nuclear power plants location respectively.*

This idea of combining a meteorological network with a fine grid forecast model for security purposes may represent the future for a number of similar issues worldwide.

1. Introduction:

Four nuclear power plants generate ca. 40% of the total electricity in Switzerland. They are operated 24 hours a day. The Swiss Federal law defines the guidelines for their secured operation. In particular the Swiss Federal Nuclear Safety Inspectorate (SFNSI) is the public office in charge of the systematic control of the nuclear security and radioprotection in the nuclear power plants, as well as of the related equipment and nuclear waste storage. Among others, one of the SFNSI tasks is to provide an operational tool that allows at any time (eg. the time of a nuclear power plant accident) to forecast in the next few hours where and how the radioactive plume will evolve.

The results of the SFNSI models are directly transmitted to the National Emergency Operations Centre (NEOC) whose mission is to inform and alert the Swiss population (see Figure 1). The NEOC is responsible for all events involving assumed or increased radioactivity.

For the nuclear security, MeteoSwiss the Swiss Federal institute of meteorology and climatology is in charge of operating the mesoscale Eulerian forecast model (aLMo) in order to define the general meteorological situation over central Europe and the Alpine regions. MeteoSwiss acts also as the advisory center of expertise for meteorological model used for the SFNSI.

On the other hand MeteoSwiss is the meteorological data provider: it is in charge of the radioactivity measurement network, and also of the local meteorological equipment located on each nuclear power plant site, the latter being equipped with a meteorological mast with wind measurements and temperature at three given heights (typ. up to 110m above ground level).

These data are distributed in real time to the SFNSI which uses them as initial conditions for their own gaussian and atmospheric dispersion models. Each of these model is centered respectively on the nuclear power plant's location. It represent a valuable tool for forecasting the evolution of a radioactive plume on the local scale, say over a radius of ca. 20km. The SFNSI's atmospheric dispersion model is based on the Random Displacement Method, designed as an operational tool directly linked to each of the four nuclear power plants with its site specific topography, and with output results used in real time.

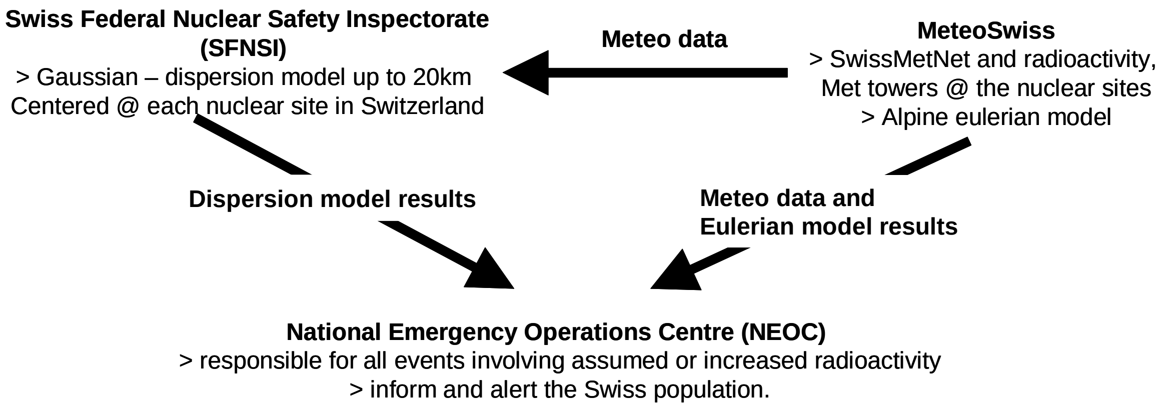

Figure 1: Information flow diagram between MeteoSwiss, the Swiss Federal Nuclear Safety Inspectorate (SFNSI), and the National Emergency Operations Centre (NEOC)

A number of parameterized meteorological conditions are used as input conditions for the SFNSI's atmospheric dispersion model such as the atmospheric stability, the boundary and the mixing layer height, and the turbulence parameters.

Basically the current nuclear security tools in Switzerland can be rated as satisfactory for the short range/short term prediction scales (eg. the development of a plume over the next 3-6 hours, and over ca. 20km radius), and also satisfactory for a general description of the synoptic conditions (eg. the meteorological conditions in central Europe over the next 3 -5 days).

"In between" or at a range of some hundreds of km and over a period of time of ca. 24 hours, the development of a radioactive plume is not ideally described. This point was already stated in the 80's at the end of the consolidation phase of the current security tool (Schneiter 89, 0). In particular the following remarks were highlighted:

- "…in case of a major radioactive emergency, there could be leaks at high temperature, with rising speed and upward motion that would develop into the planetary boundary layer and free troposphere.."
- "…the trajectories that are predicted at higher altitude do not necessarily match with the one measured and calculated at 110m above ground level…"
- "…the use of remote sensing method for wind field measurements at higher altitude would be useful information…"
- "…there is a need for additional predictive results based on a fine grid atmospheric model output…"

Even though the current security tool was designed in the 70-80's with well known intrinsic limitation, there was essentially no existing and robust solution at that time either for remote sensing measurements or for an operational use of a fine grid and real time atmospheric model. This is the background of the currently available meteorological security tool for the nuclear power plants in Switzerland.

Finally in the last years, a new fact triggered the start-up of CN MET: the SwissMetNet project, the renewal of the automatic and conventional meteorological networks operated in Switzerland (see the paper by Heimo et al.). This renewal directly impacts on the actual meteorological equipment around the nuclear power plants.

2. CN MET, a new project for "the meteorology and nuclear security" in Switzerland

The four nuclear power plants in operation in Switzertland are all located on the Swiss Plateau at a distance of ca. 100km or less one from the other: this essentially means that they undergo similar weather conditions, the Swiss Plateau consisting of a basin surrounded by mountains in the N-NW (Jura mountains) and by the Alps in the S-SE (Figure 2).

As a consequence, this peculiar situation allows to design a meteorological security tool based on the idea of a network of ground based and remote sensing stations that are measuring the instantaneous inflow / outflow conditions over the Swiss Plateau (and not anymore a meteorological mast located at each of the four nuclear sites), and brings the adequate database to a fine grid numerical weather prediction model (typ. 2km horizontal grid cell resolution) directly designed to provide the right tool for decision makers in case of a nuclear accident over the Swiss Plateau. In addition most of the Swiss population is living on the Swiss Plateau with six of the nine major cities located within a 50km radius of a nuclear power plant.

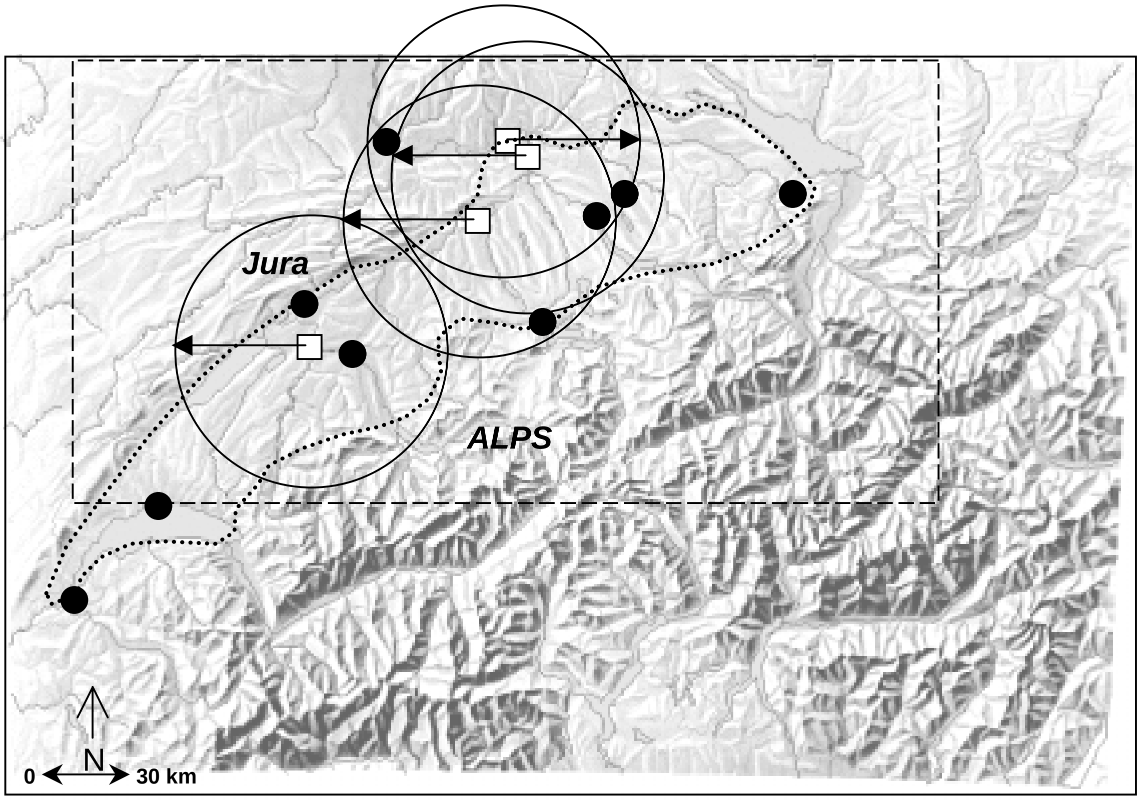

Figure 2. Topographical view of Switzerland with the Swiss Plateau (dotted line) surrounded by the Jura mountains to the north-west and the Alps to the south south-east. The solid dots represent the 9 major cities of the country, the white squares, the four Swiss nuclear power plants and their respective 50km (black arrows) radius circle. The dashed rectangle defines the domain used in Figure 3.

3. The CN MET measurement network

A combination of near-surface measurements and ground-based remote sensing techniques will constitute the CN-MET observation network. Three main types of instrumentation are planned.

1) Three low-tropospheric wind profilers 0 combined with three microwave radiometers provide a continuous observation of the vertical structure of the PBL over the Swiss Plateau. These wind-temperature profiles (e.g. Figure 3) will be located at three important spots in the domain: at the two main boundary conditions of the domain (in- respectively out-flow conditions) and one in the center of the domain for test comparison with model results. This center station will also give a realtime observation of the weather conditions close “in the middle” of the power plants. A fourth system (SODAR), will cover the area influenced by the local topography at one of the specific nuclear power plant location (Leibstadt).
2) The aerological radiosonde station in Payerne will provide the state of the atmosphere four times a day: twice with pressure, temperature, humidity and wind and twice with wind only.
3) At each nuclear power plant site (Mühleberg, Gösgen, Beznau, and Leibstadt), a SwissMetNet surface station will bring the needed meteorological observations for a correct description of the local weather conditions. It will also include turbulence

measurements at 10 m height by using sonic anemometers, the turbulence measurement being of vital need for the short scale dispersion model input. Four high towers in the surroundings of the nuclear sites (Stockeren, Bantiger, St.Chrischona, and Uetliberg) will remain equipped with wind and temperature sensors, and bring an additional set of data for the control of the model results.

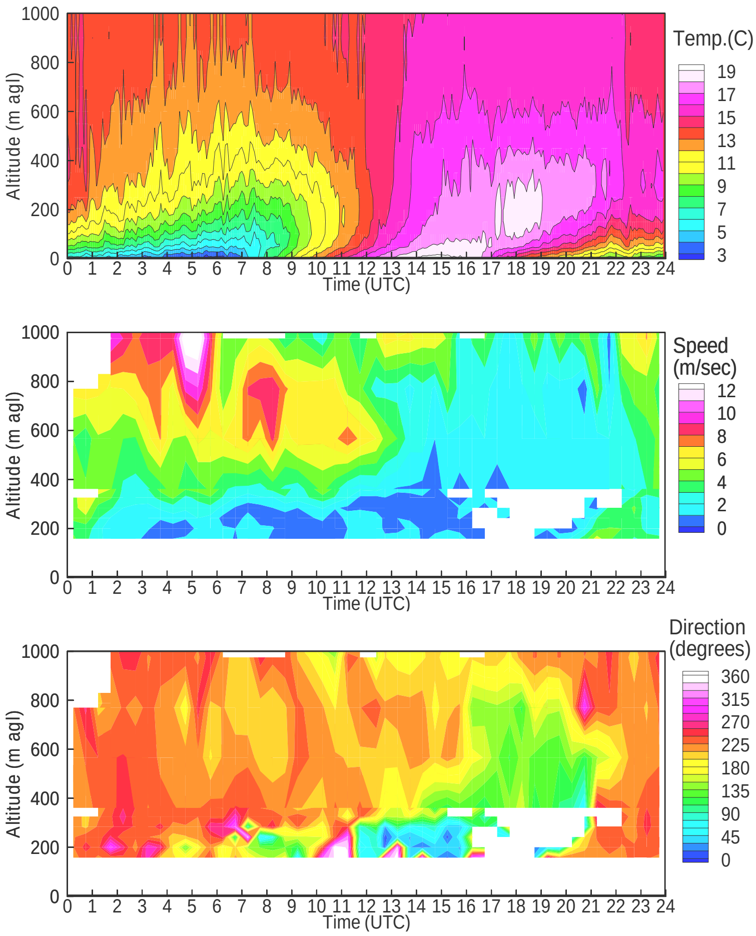

Figure 3. Typical set of vertical profiles time series within the planetary boundary layer as expected in CN MET: this example was measured in Payerne on March 17th 2004 during the TUC campaign. Temperature is measured by passive microwave radiometer, wind speed an direction by low tropospheric wind profiler.

4 The CN MET fine grid NWP model

Within the COSMO consortium [3], there is a strong impulse to improve the current horizontal resolution of the European Local Model (LM). The move from a grid of 7 km to a finer of ca. 2 km mesh is under way in Europe. The new Swiss NWP aLMo/2 (aLpine Model) will be a nested grid of the 7 km LM **Error! Reference source not found.**, centered over Switzerland, and encompassing the main alpine region (Figure 4). A rapid update cycle with quasi-real time data assimilation from the CN-MET network will be designed, and short term forecasts of up to 18 hours, renewed every 3 hours, will be provided.

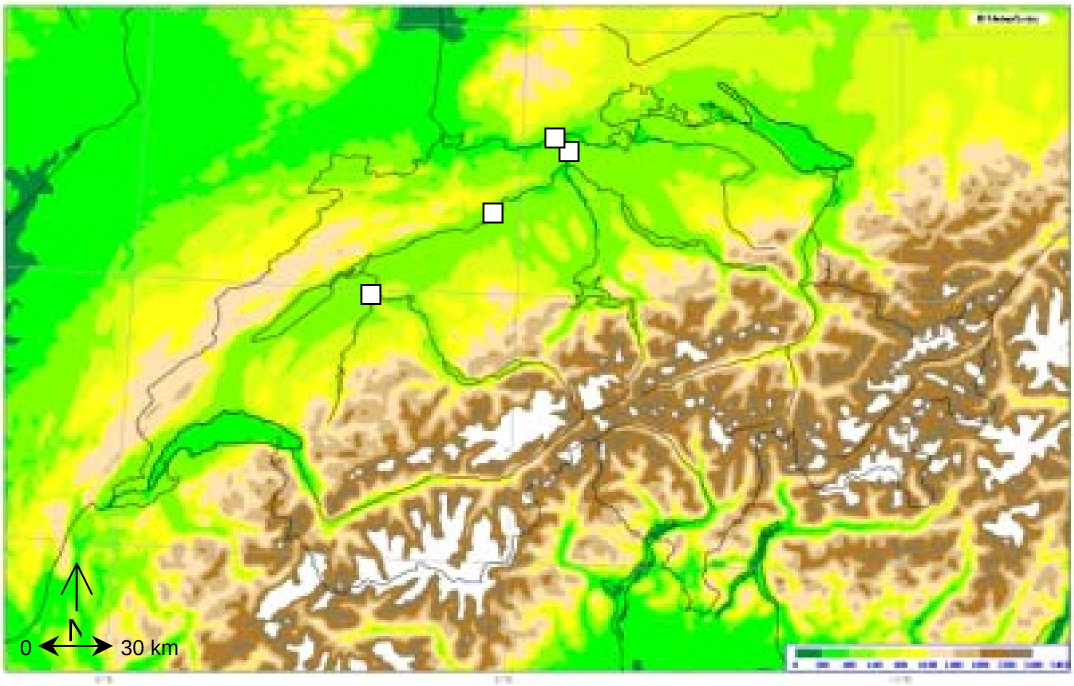

Figure 4. aLMo topography with a horizontal resolution of 2.2 km. White squares represent the four Swiss nuclear power plants.

The numerical results (e.g. Figure 5) from aLMo/2 will be used as a “now casting” tool over the Swiss Plateau and for the next few hours up to one day after a nuclear event, but they will also be used as initial input data for the atmospheric dispersion model in operation at the Swiss Federal Nuclear Safety Inspectorate (SFNSI): in particular, a three-dimensional snapshot of wind field and turbulence will greatly enhance the quality of the SFNSI’s model output.

5 Conclusion

CN-MET is the combination of the aLMo/2 fine grid NWP model with the ideal network of meteorological observations, namely a network with observations at similar time and space resolution as the model resolution, designed as input and boundary conditions for the model.

Instead of having meteorological towers located at each individual nuclear power plant, CN-MET is based on a “global network” of in-situ and ground-based remote sensing systems covering the three dimensions of the entire region. By combining the measurements with a high resolution non-hydrostatic NWP model, the meteorological information will be available at each point of the grid cell, including the nuclear power plants’ locations. Data from the observation network will be assimilated in real-time. Therefore, the model will provide a coherent image of the state of the atmosphere at and around the nuclear power plants and of its evolution in time and in space. A new 18 hours forecast will be issued every 3 hours, with a temporal resolution of 30 minutes, over the entire Swiss Plateau.

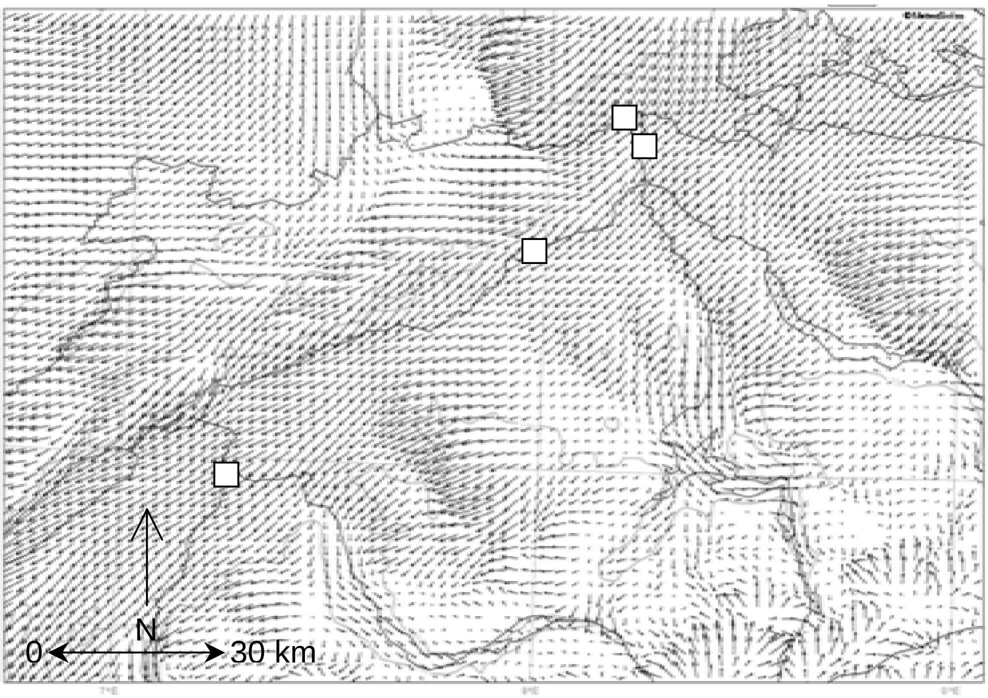

Figure 5. Example of wind field at 30 m agl, 27 March, 2004, 06UTC, calculated with the aLMo/2.2. White squares=nuclear power plants.

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Development of a UK National Water Vapour Processing System

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Since 1998 the Met Office has worked to investigate the potential of a network of dual frequency GPS receivers for the near real time (NRT) measurement of Integrated Water Vapour (IWV) as a component of the UK upper-air network. This presentation will describe the history of the project, the challenges encountered, associated costs and the future system requirements for handover to operations.

Introduction and Requirement for a National Near Real Time GPS Network

The path delay between a GPS satellite and a ground based GPS receiver depends, after elimination of ionospheric effects, on the integral effect of the densities of dry air and water vapour along the signal path. The total delay in the signal from each satellite is known as the slant delay as the path is most likely to be non-azimuthal. The slant paths are then transferred into the vertical (or zenith) by an elevation mapping function, and this parameter is called the Zenith Total Delay or ZTD. With further calculation, taking into account surface temperature and pressure, we can then convert the ZTD into IWV. From previous work it has been shown that it is possible to estimate the IWV reproducibility of 1 kg/m^2, equivalent to about 3% relative humidity.

In 2002 the Met Office established a project to develop the near real time processing capability for a network of GPS receivers with the main objectives being to increase the number of GPS sites being processed and to process data with the minimum time delay. Since this time the Met Office has placed annual contracts with the Institute of Engineering, Surveying and Space Geodesy (IESSG) at Nottingham University to develop an automated processing system. IESSG are leaders in the field of GPS processing and also maintain the British Isles GPS archive Facility (BIGF) which is funded by NERC (National Environmental Research Council). The decision to develop the project further was made by the customer groups (Numerical Weather Forecasting and nowcasting) on the basis of information gathered from non-real time GPS water vapour plots for the UK. High IWV conditions are often are associated with extreme weather events such as thunderstorms or heavy rainfall which are of obvious interest to the Met Office.

Network - Progress and History

The first Met Office GPS installations specifically for the measurement of IWV were completed in early 1998. Since this time the Met Office has increased the network to a total of 10 GPS receivers installed at meteorological significant locations around the UK.

Figure 1 – GPS Antenna at Lerwick, Shetland Isles

Figure 2 – Ashtech Z-FX GPS Receiver

In order to enable the Met Office to increase network density in the most cost effective manner, it was decided to seek out further sources of GPS stations such as national mapping agencies, the UK Tide Gauge Authority and Universities etc. By 2003 the UK real time ground-based GPS water vapour network consisted of 18 sites operating remotely with automated contribution of hourly data to BIGF and to the COST-716 user community. The network at this time consisted of 9 sites operated by the Met Office, 6 sites operated by the UK Tide Gauge Authority, 2 sites at Morpeth and Herstmonceux (which are operated as part of the IGS EUREF network) and also 1 site at IESSG. All sites have been installed to a standard suitable for reference geodetic work as well as for meteorological studies.

COST is an intergovernmental framework for European CO-operation in the field of Scientific and Technical research, allowing the co-ordination of nationally funded research on a European level. The COST716 Action was concerned with the 'Exploitation of ground-based GPS for climate and numerical weather prediction applications' of which the Met Office was a member nation ran from 1998 to 2003 and helped cooperation and advancement of GPS meteorology in Europe. For more details see www.oso.chalmers.se/~kge/cost716.html/.

Costs of an Individual Sensor Site

Table 1 provides estimated costs for the purchase, installation and maintenance of a GPS site. When installing a GPS site it is recommended that the equipment is co-located on an existing instrument site, with an enclosure/building. The figures in Table 1 are estimates taken from the COST716 Final Report and based on an installation on an existing site, with no special requirements for antenna mounting and/or cable ducting/length. Therefore the estimated cost for installing a single NRT GPS is in the order of 25k – 30k Euros.

Equipment	Maximum Costs (Euro)
GPS Equipment (Receiver, Antenna, cables etc)	20,000
Installation (work services)	5,000
PC and UPS	2,500
Communication connection	500

Table 1. – Estimated GPS site installation costs

From the COST716 Action it was estimated that a NRT GPS network with approximately a 50km average network resolution would be required to realise the full benefits of NRT GPS water vapour. In the UK the only method by which such a network could be realised is by resource sharing with the national mapping agency in the UK, Ordnance Survey GB (OSGB). Ordnance Survey are in the process of transitioning their existing ‘Active’ network of receivers providing positioning updates for differential GPS to a Real Time Kinematic (RTK) network which can provide real time positioning updates to allow almost instant coordinates accurate to a centimetric level. One of the main criteria for this new network would be that all RINEX data would have to be at OSGB’s server in real time. Thus the Met Office has negotiated a resource sharing agreement with OSGB. The Met Office will permit and facilitate installation of OSGB GPS sensors at various Met Office sites throughout the UK (where practicable) in return for access to NRT data from their national network. As a result, by the end of 2004 OSGB equipment had been installed at 5 Met Office surface sites and in return the Met Office has access to data from around 50 OSGB sites. Figure 3 shows the location of the total UK NRT GPS network as of January 2005.

It is only now with the sort of spatial resolution obtained in the mid-UK (see Figure 3) we can begin to see IWV fields with a resolution high enough to be useful for nowcasting applications, and as such begin to realise the full potential of NRT GPS IWV. Through the continuing effort with Ordnance Survey we estimate that the network should grow to a similar resolution over the entire UK and by the end of 2005 we estimate to have access to data from about 150 stations in NRT. Furthermore the Met Office is still looking for other sources of GPS data such as accessing data from the Northern Lighthouse Board and from offshore platforms which have a combined total of ~30 stations around the UK and in the North Sea respectively.

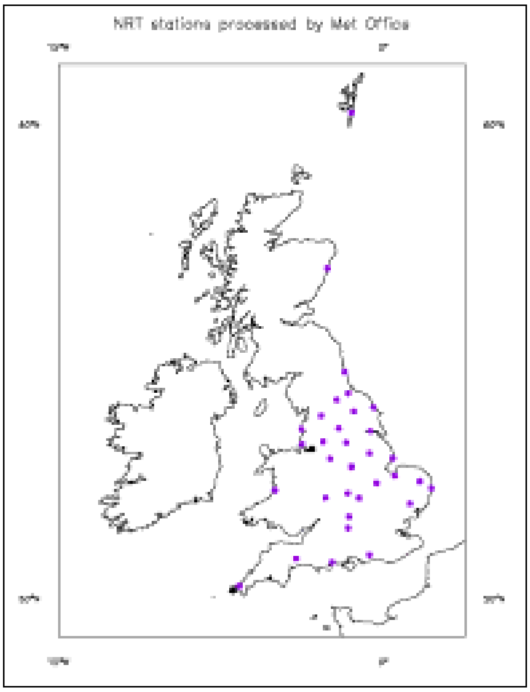

Figure 3 – UK NRT GPS Network – Aug 2004

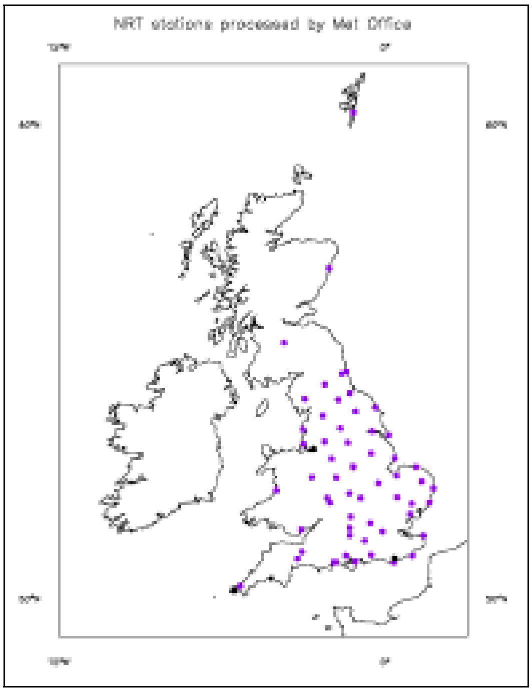

Figure 4 - UK NRT GPS Network - Jan 2005

Processing System - History and Works

Until mid-2004 UK GPS RINEX signals were being processed on behalf of the Met Office by GOPE, Czech Republic. GOPE kindly processed all UK scientific GPS data using Bernese v4.2, on a best effort basis. This arrangement came out of the COST716 Action. Using a single network approach GOPE process data from approx. 50 European stations and as such the time delay between raw data capture and delivery to COST716 takes approx 1:45 hours. The main aims of the Met Office GPS Project was to process GPS data ‘in-house’ to reduce the time delay associated with processing as far as possible. This was required by the customers. To accomplish the tasks required the Met Office purchased 2, dual-processor Linux PC’s to run Bernese GPS processing software, under a Red Hat software environment. Bernese was chosen as the processing software choice due to the significant knowledge and experience held by staff at Nottingham University and also due to the fact that it is the processing software utilised by GOPE. This consistency of processing methods should allow for more accurate comparison and result validation.

For quality control of the NRT solution the decision was taken to produce five different estimates of ZTD, obtained from four different solutions. In this method the NRT solution takes the predicted orbit and uses steps 2 – 5 as quality checks. Some results of comparison between steps 1 and 2 can be seen in the Results section later in this document. Steps 3, 4 and 5 are further quality checks using the more accurate IGS final orbits and thus the most accurate estimate of ZTD may be calculated from this data.

Solution	Orbit Used	Latency	Purpose
NRT	Predicted part of IGU	1 Hour	NRT Solution
IGU12	Observed part of IGU	13 Hours	1st Quality Check
IGU24	Observed part of IGU	25 Hours	2nd QC
DD	IGR	48 Hours	3rd C
PPP	IGR	48 Hours	Independent processing method as 4th QC
Daily_igsPPP	IGS Final	20 Days	Calculates an a-priori coordinate

Table 2 - Initial Processing Solutions

During 2004 UK NRT network size increased greatly and this overloaded the processing power of the PCs. To resolve this issue 3 out of the 6 quality check solutions were removed form the processing cycle only leaving the NRT solution using the predicted part of the IGU orbit, a quality solution using Double Difference processing and the IGR48 orbit and the Daily_igsPPP solution using the IGS final orbit to provide a-priori coordinates for processing.

The initial processing platform (from May ’04 to Dec ’04) employed a single network approach whereby all available sites were processed in a single national network solution which took approximately 20minutes to be processed. For operational use this time delay was deemed unacceptable and other processing strategies needed to be looked at to find the optimum strategy. IESSG looked at the effect of using smaller network sizes and revealed that processing time may be greatly reduced when a sub-network approach was utilised. The downside of this approach though is that the smaller number of stations used in a sub-network lower the relative data quality. After extensive research on the subject IESSG came to the conclusion that a compromise could be reached where quality was maintained to an acceptable level whilst reducing processing times as far as possible. This was achieved by splitting the network into sub-networks of 7 stations. As such the new processing system currently processes the UK network in approximately 10 sub-networks of 7 stations. This move has significantly reduced processing time from 20 minutes to about 4 minutes for a ~50 station network.

One of the main issues problems encountered during initial trials were software conflicts between the Bernese processing software and the Red Hat 8 environment and Perl scripts used to call the solutions. The conflicts caused the Bernese processing to crash at seemingly unpredictable instances thus preventing reliable stable processing. This software conflict was something which was predicted by IESSG from previous work but with the advent of Bernese v5.0 (written entirely in Perl) these conflicts were predicted to cease. With the implementation of Bernese v5 in December 2004 these conflicts have been resolved.

With the advent of the Met Office system and the resolution of the issues above it has been possible to reduce all times associated with processing as far as is practicable at this point in time. In the future it may be possible to reduce processing time further by the use of sub-hour GPS files, but this is something which is only beginning to be investigated. Under the current system the processing times are as follows:

00:00 – End of hour of GPS data file
00:05 – 00:15 - Raw GPS data sent from GPS sites to BIGF Archive at IESSG, Nottingham
00:16 - Surface Met Data acquired
00:18 – Processing begins using Bernese v5 software in sub-networks of 7
00:23 – ZTD and IWV produced

The outputs are then copied to the Satellite Applications Group at the Met Office for dissemination to the user community and in the near future for assimilation into the mesoscale model.

The main function of the processing software is to provide the user with the highest quality GPS sensor coordinates. In production of the coordinates the ZTD is accurately calculated and used to adjust the coordinates accordingly. As such the user must have a good understanding of global positioning systems and geodetic principles in order to understand the methodology of GPS processing. The principles behind the processing are taught at higher degree level and as such a manager trained to a high level is required to manage the processing system. To maintain the operational software suite, support staff knowledgeable in Bernese, Perl, mysql and Linux must be available.

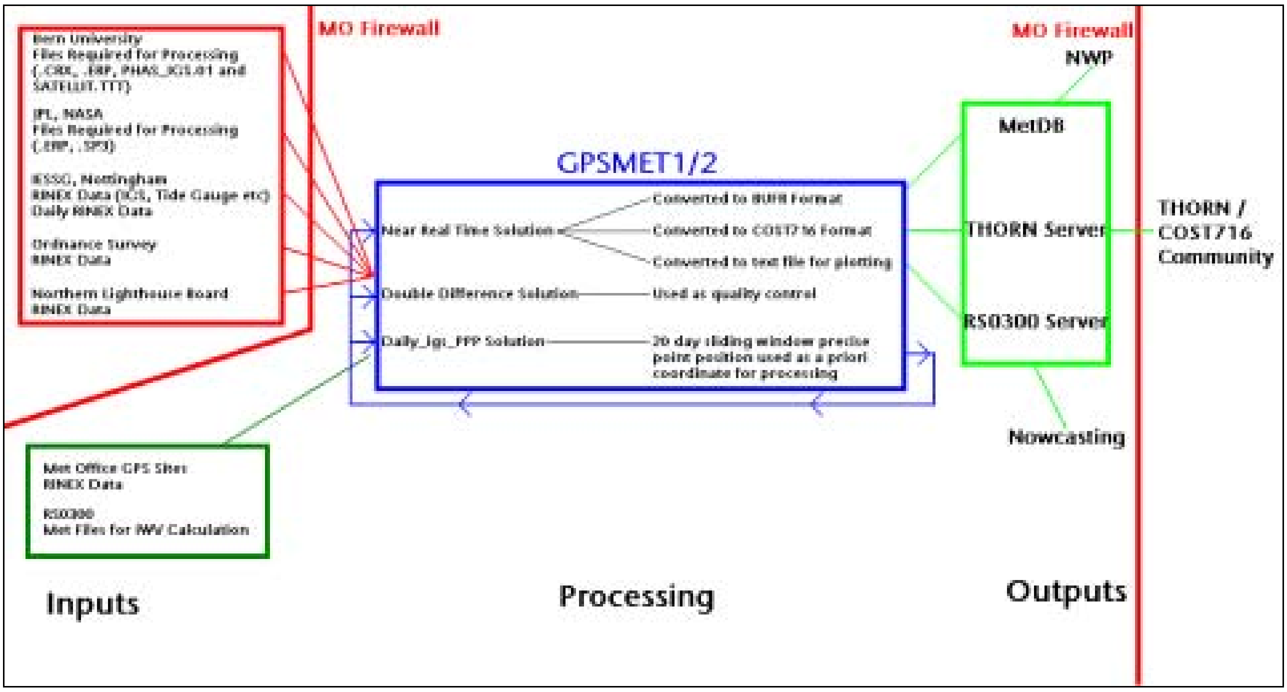

Figure 5 – Met Office Processing System

The costs associated with setting up and running a processing centre is very much dependent on the national costs for both manpower and equipment. In the UK the 2 processing platforms cost in the region of 7k EURO each. Table 2 provides an estimate of the current equipment and staff costs taken from COST716 findings for each of the main European processing centres. These figures should be used as a guideline for what it would cost to set-up and operate a processing centre and are accurate as of 2002. However the UK Met Office believes that the figures estimated are overestimated in most cases and more accurate assessment will be obtained through the development project

Processing Centre	GFZ (Germany)	GOPE (Czech Republic)	IEEC (Spain)	ASI (Italy)	LPT (Switzer-land)	NKG (Norway)	NKGS (Sweden)
Personnel Costs (per year)	1.0 person (split between 3 staff)	1.0 person (split between 2/3 staff)	1.0 person	1.0 person	1.0 person (split between 3 staff)	0.3 person	0.5 person
Hardware Costs (per 3 – 5 years) Processing Backup Archive	6,000 6,000 30,000 (RAID array)	4,500 3,000 estimate below	6,000	6,000 3,000 10,000	30,000 (2 Linux PC plus RAID)	2,000	5,000 3,000 3,000
Comms. pa 1 - Internal 2 - Primary	0 (central Intranet)	0 (academic) 4,800 (primary)	0	0 (ASI) 5,000 (fixed, no limit)	0 (central facility) 100,000 (fixed line)	0	0
Data Archiving (per year)	n/a (central resource)	3,500 (estimate)	n/a	n/a (central resource)	n/a (central resource)	n/a (central resource)	3,000

Table 2. Estimated GPS Processing Costs

In the future more work needs to be carried out to optimise assimilation of GPS ZTD to NWP models. The majority of this work is being carried out as part of the TOUGH Project (Targeting Optimal Use of GPS Humidity Measurements in Meteorology) which is due to continue until 2006 (See http://web.dmi.dk/pub/tough/ for more details). TOUGH is a shared-cost project co-funded by the EU (5^{th} framework programme).

Development of NRT GPS networks for meteorology in Europe will be taken forward by way of a 3 year EUMETNET (E-GVAP) project proposed for initiation in 2005. The main objective of E-GVAP would be to enable and coordinate collection and distribution of European near real time ground based GPS water vapour measurements to EUMETNET members for operational meteorology. As such E-GVAP would facilitate cohesion between European national scale GPS networks and allow for inter-European data transfer and hence bring about standardisation. Also E-GVAP will work to gradually increase quality, amount, and geographical coverage of GPS water vapour data and assist members in utilising GPS water vapour data.

Validation of Results

The first comparisons made were designed to prove the quality of the NRT solution by comparison against the more accurate Double Difference (DD) solution. The DD solution uses the more accurate IGS Rapid orbits (IGR), which are available with a 48 hour delay – see Tables 2 for more details. As can be seen in Figure 5, there is excellent correlation between the two solutions indicating that the NRT solution does not suffer greatly by using the less precise predicted orbits and is satisfactory for meteorological applications.

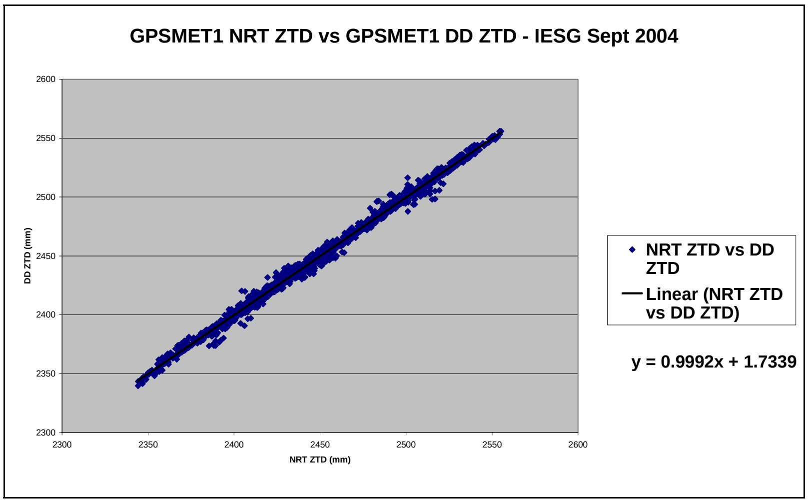

Figure 5 – GPSMET1 NRT vs. DD solutions, Sept 2004

Since 2001 comparisons have been carried out of NRT IWV against operational radiosonde ascents (Vaisala RS80H) at specific sites in the UK where co-located with GPS. At these sites a time series may be produced of GPS against other measurements available. In the case of a recent plot from Lerwick, Shetland Isles (Figure 6) Met Office processing is compared against GOPE GPS, NKG ( ) GPS, radiosonde ascents (x) and against the HiRLAM-22 NWP model data.

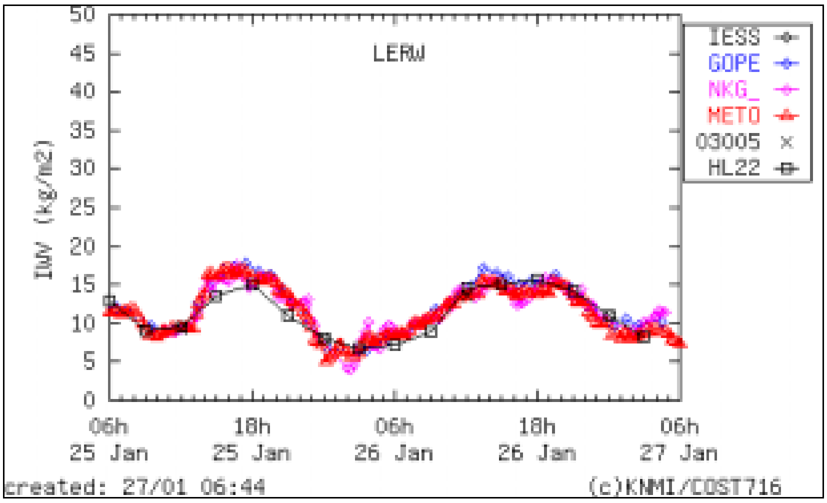

Figure 6 – NRT validation plot of GPS against radiosonde and model IWV

Quality control and quality evaluation procedures require development to check both the short and long term stability of the solutions now that Bernese v5 software has been implemented.

Animated display

In the past there had been relatively poor spatial resolution of NRT GPS sensors in the UK, and as such plotting IWV values in NRT would have had limited impact due to the high amount of interpolation necessary. However, as a result of the resource sharing agreement between the Met Office and OSGB, in the very near future the Met Office should have access to data from a NRT GPS network of 150+ sensors with an average spatial resolution of <50km and as such developing visualisation techniques become a useful tool to very short term forecasting. Since mid-2003 a suite of programs has been developed to plot IWV onto a 2D map, advect +1 and -1 hour IWV values up and downwind according to wind speed and direction and also add secondary relevant information to the plot in an effort to assist forecasting such as wind barbs and ATD info. Wind information is taken from wind profilers, radiosonde ascents as well as from AMDAR sensors. The vast majority of water vapour is located in the lower troposphere, as such winds at 2km are typically chosen which enables the best approximation of IWV advection.

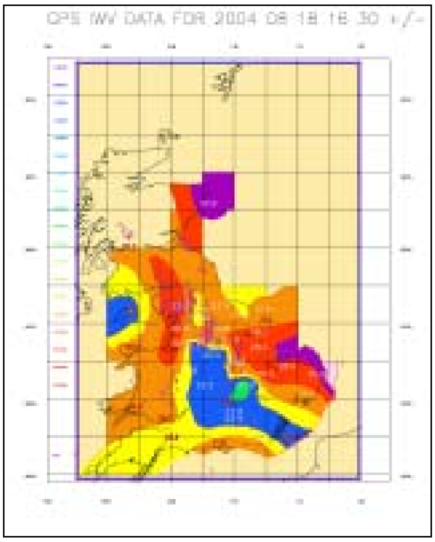

Figure 10 – IWV plot 2004081816

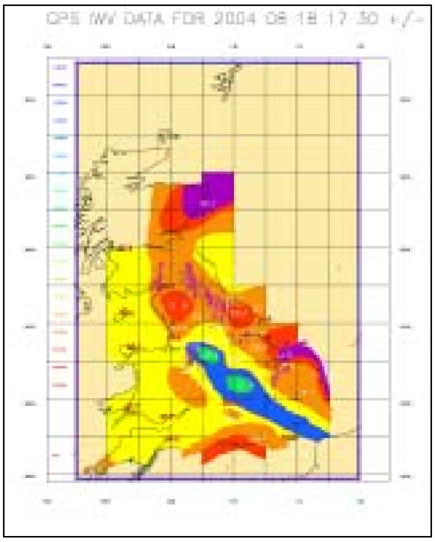

Figure 11 – IWV plot 2004081817

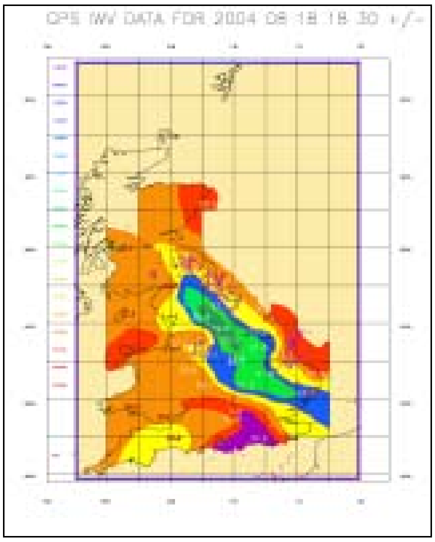

Figure 12 – IWV plot 2004081818

Contouring at 2kgm2, intervals: Green 20 – 22, blue 22 – 24, yellow 24 – 26, orange 26 – 28, red 28 – 30 and purple 30 – 32.

The contoured plots in Figures 10 to 12 demonstrate the current NRT processing and plotting capabilities. From Figures 10 – 12 it can be observed that IWV is a very dynamic quantity which may change rapidly under certain conditions. As such, 1 hour temporal resolution does not appear to be great enough to identify such short term fluctuations of IWV in the horizontal. The current maximum resolution is limited by the hourly RINEX GPS files, however in the near future it may be possible to increase resolution to 30 or even 15 minute files.

Conclusions

The Met Office has successfully demonstrated the capability of a ground based GPS network for the near real time measurement of integrated water vapour. The network has increased in size in a cost effective manner primarily due to collaboration with the UK national mapping agency, Ordnance Survey. Upgrade of the processing software now makes it possible to maintain stable processing but there have been periods using Bernese when processing did crash and further monitoring is necessary before final conclusions are made.

Progress in introducing new technology sensor sites for the Met Office long-range lightning detection system.

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1. Introduction

The UK Met Office has run a long-range lightning detection system since 1986, designated ATD (Arrival Time Difference) system. This uses rubidium oscillators at each detector station to provide accurate time stamps of received Sferic waveforms. Thunderstorm locations are issued on the GTS as SFLOC messages, but the data in these messages do not provide the accurate locations that are available to Met Office and commercial users of the system.

A new control computer was introduced during a project lasting from 1996 to 2000. However, the operational detection efficiency of the existing ATD system across Europe has continued to be very variable in recent years. On some occasions detection efficiency around the British Isles is towards 90 per cent, but on other occasions the current detection efficiency in this area is barely 10 per cent.

Figs. 1(a) to (d) show the number of locations reported in an area covering the British Isles and surrounding seas. The ATD locations are compared to those reported by EA Technology (a system originally built for the UK electricity supply industry, claiming 99 per cent detection efficiency over the British Isles, with detection efficiencies lower over the sea.). The numbers of flashes plotted are average values for three months, derived for the years between 2002 and 2004.

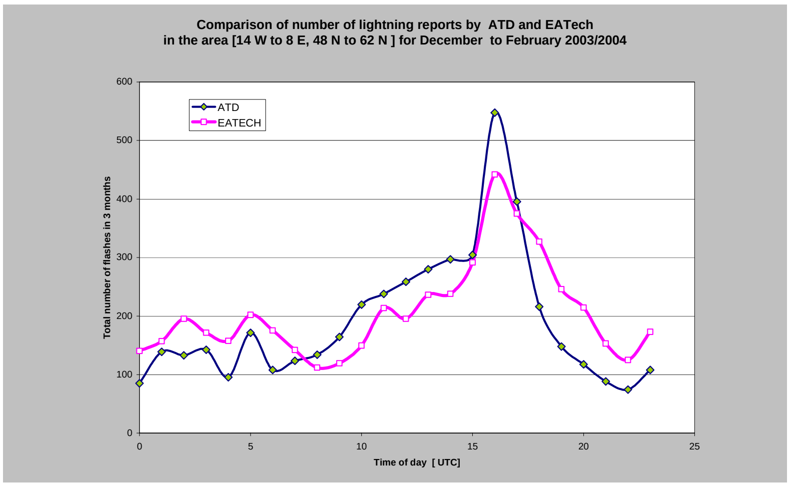

Fig. 1(a) In December to January, ATD was more sensitive than EA Technology from 08 to 17 UTC, but much less sensitive at night when long range activity was highest.

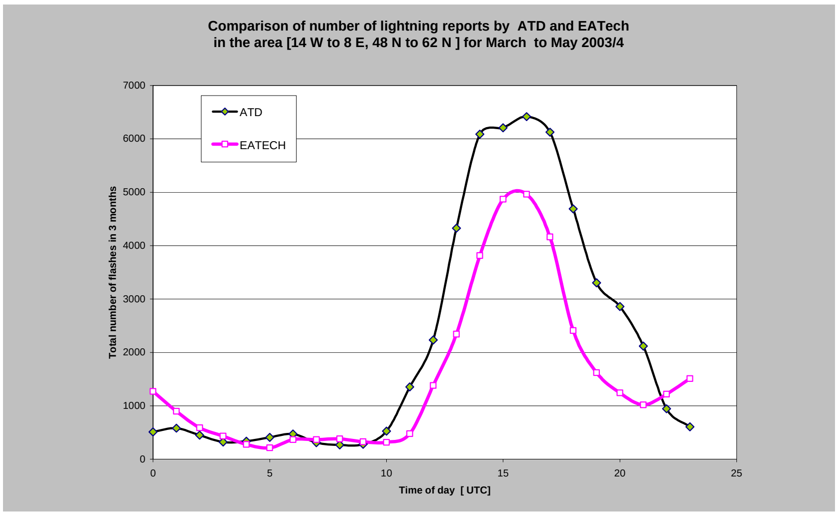

Fig 1(b) ATD performance was good relative to EA Technology from March to April.

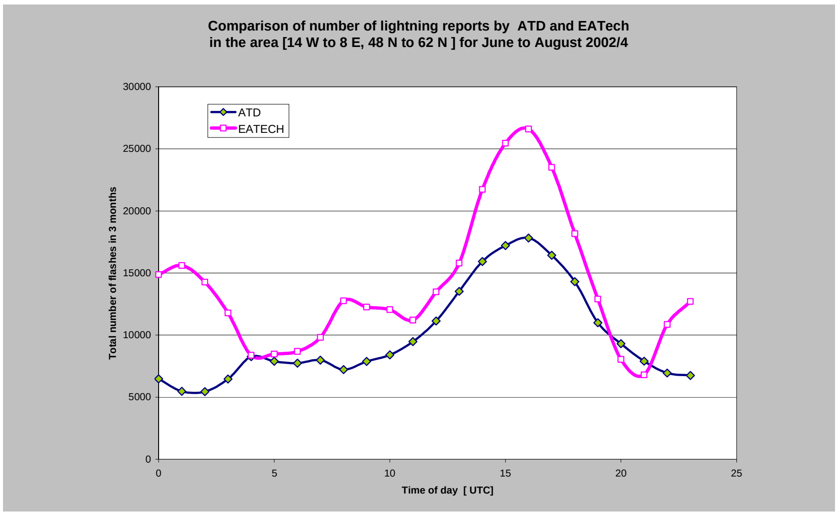

Fig.1(c) ATD was much less sensitive than EA technology for most of June to August lacking the throughput to deal with thunderstorm activity in summer afternoons.

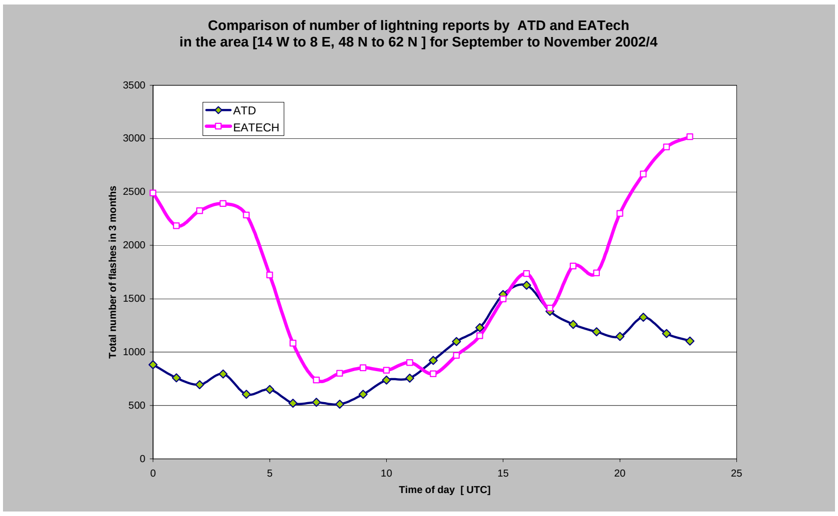

Fig.1 (d) ATD was insensitive around the British Isles during the night from September to November, when very large numbers of strong Sferics were originating in South America.

The number of thunderstorms in the vicinity of the British Isles is relatively small compared to the total number of locations being reported by ATD. In three months the total numbers of flashes reported by ATD will often be 9 million or more in UK summer and around 5 million in UK winter see Fig.2.

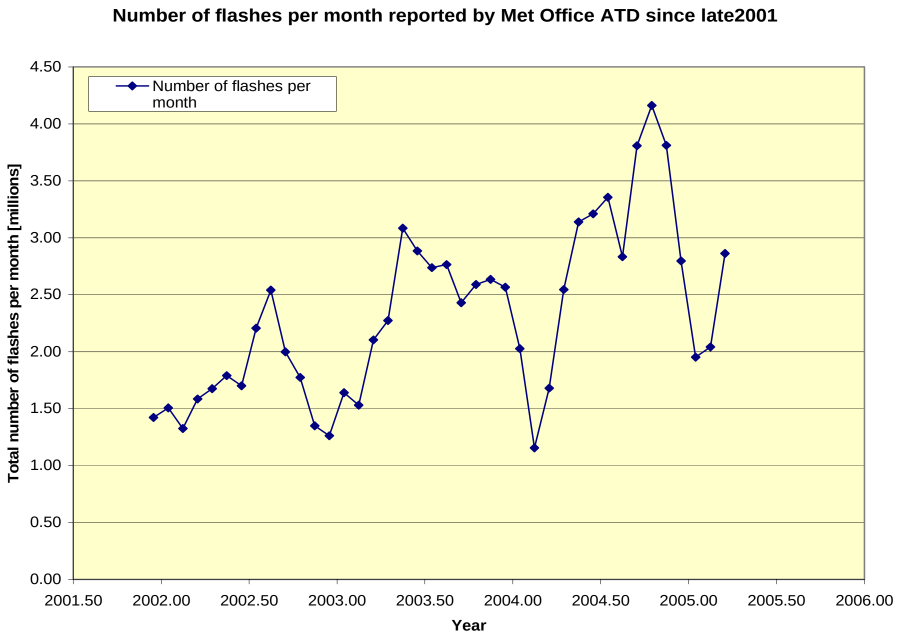

Fig. 2 Number of flashes reported by ATD per month since late 2001

By 2003, it was clear that the current ATD out-stations did not report Sferic waveforms at a sufficiently high rate to allow the ATD system to meet detection efficiency requirements around the UK. Thus, a design for a new out-station (NOS) was required.

2. New out-station

This new out-station was designed by Nigel Atkinson (N.C. Atkinson, personal communication- internal Met Office Document,-ATD101 (2002)]. It is based around a standard PC containing two National Instruments cards for signal processing [PCI-4451] and timing [PCI-6602]. The control and processing software is implemented through the National Instruments graphical programming system LABVIEW. The signal inputs are obtained via a conventional ATD sensor.

Both of the input channels to the PCI-4451 are connected to the same ATD sensor. One channel is operated with a higher gain than the other in order to maximise the dynamic range of the system. The software normally selects data from the high gain channel, but switches to the low gain channel if the high gain is overloaded. The expected effective dynamic range of the Analogue to Digital converters with this arrangement is in the range 80dB. The sampling rate of the 4451 card is set to every 12.8μs, similar to the existing ATD out-stations.

The reference signal for the counting card is provided by the Starloc II GPS system, incorporating a rubidium oscillator, that allows a timing reference to be maintained even if there is a temporary problem with GPS reception.

Processing software is set up to be similar to the existing ATD out-stations in most respects. One significant difference from the existing out-stations is in the Sferic event detection software. Here only "clean waveforms" are now accepted, i.e. those with a well defined threshold peak substantially above noise level. In the existing stations the threshold gain can rise to such an extent that the out-station reports pure noise.

The NOSs do not support the feedback loop that allowed the central computer to request data from out-stations for selected events. All events detected will be forwarded automatically to the Flash Location Processor (FLP).

After several iterations, the configuration for operational New Out-stations (NOS) was finalised in late 2004, see Fig.3.

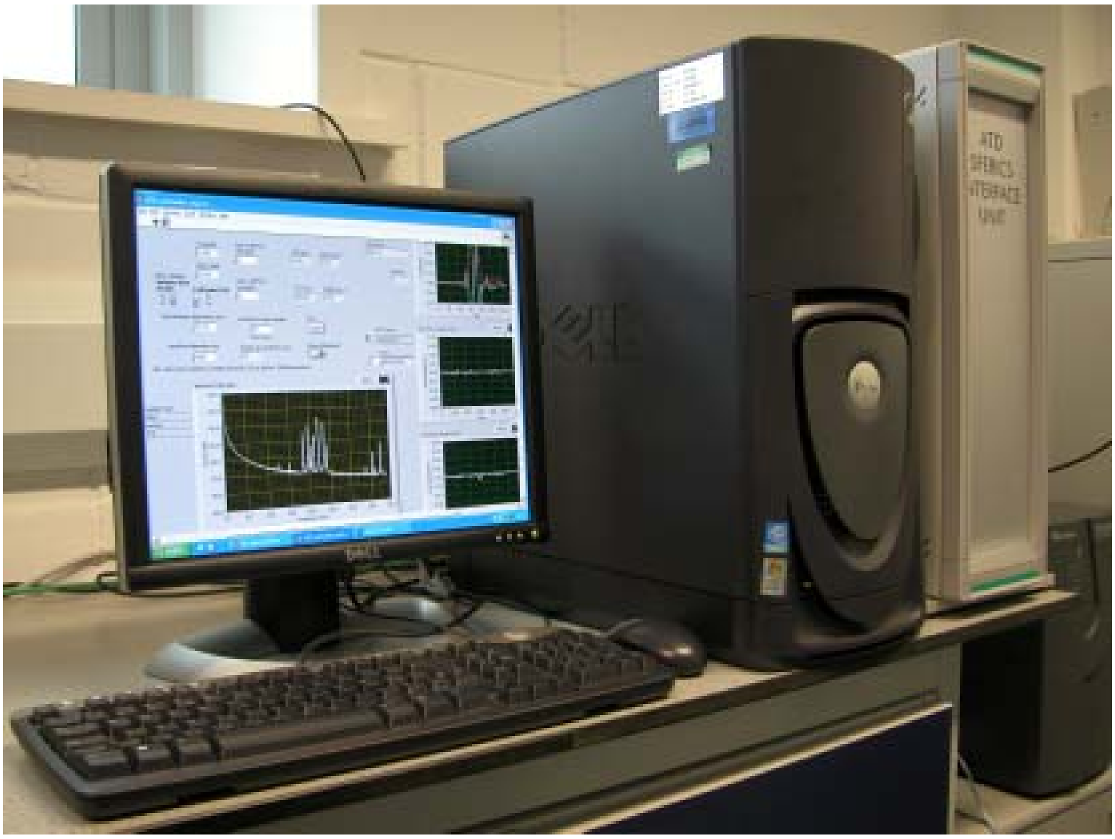

Fig.3 New out-station PC with Sferics display and Interface Unit at Exeter.

2.1 Evaluating the response of the NOS

A prototype new out-station (NOS) was completed and began testing in 2003. By 2004 two improved NOS prototypes were available and could be connected to the existing central computer. This was achieved through an interface computer that selected the information from the NOS requested by the central computer. One NOS was retained in Exeter near the central computer and the other sent to Camborne for evaluation at a site with less than optimum communications availability to the central computer.

The out-stations were evaluated against the following requirements:-

- No large gaps in the supply of waveforms to the central computer.

- A 95 per cent return on Sferic events requested by the central computer.

- An increase in the number of lightning locations reported when using NOS data, especially when operating with only 5 existing out-stations.

- Time differences to be within 2μs of collocated existing out-stations

- Noisiness of reported Sferics should not be high

- The number of Sferic events per hour detected in the UK summertime should be in excess of 60,000

The pre-operational testing of the NOS commenced in June 2004. This showed that gaps in reported data were occurring regularly. Consequently the NOS software was modified in August 2004. At this time the two NOS were incorporated into the operational processing.

Thus, from August onwards:-

- The NOS reported Sferic waveforms without significant gaps, apart from a limited number of gaps caused by problems in communications from Camborne..
- The waveform contribution rate for data requested from the central computer was 97 per cent on average for both Exeter and Camborne NOS
- When the NOS were incorporated in operational processing in August at a time when several existing out-stations were faulty the number of flashes reported doubled. The number of flashes reported per month from September to November were more than a million higher than in 2002 and 2003
- About 90 per cent of the NOS arrival times were within 1μs of the existing out-station at Camborne, and were rarely larger than 1.5μs.
- Noisiness of reported NOS waveforms was of similar quality to the existing out-station.
- During the summer the Exeter NOS often reported more than 60,000 Sferics per hour and on some days as high as 80,000 Sferics per hour. The Camborne antenna unit was found to be less sensitive than the antenna at Exeter, so the total numbers of Sferics reported from Camborne NOS was about two thirds of the numbers from Exeter.
- In winter the rates of reporting at Exeter were rarely larger than 10,000 Sferics per hour.

The results were taken as satisfactory and a decision made to build 5 operational NOS to facilitate testing of a new central computer [Flash Location Processor]. In addition a further 10 out-stations were to be manufactured to complete a new operational long range lightning detection system by 2006.

3. Deployment of NOS systems

When thunderstorm activity in Europe is high in summer and autumn many of the out-stations are rendered insensitive by local thunderstorm activity from time to time. Thus at the time when most throughput is required the number of out-stations able to function at full detection sensitivity is quite limited and may be only 4 out of 7. Thus, a wider spread of ATD out-stations around Europe is required to sustain high detection efficiencies in summer.

In designing the replacement out-stations (NOS) it was decided that maintenance of the out-station would be by module replacement. Replacement of modules (PC or National Instruments processing card) should take place with a possible time delay of several weeks to minimise maintenance costs. Duplication of facilities within the existing out-stations was considered inefficient, because this duplication was not pertinent to the most common operational problem encountered. This was the failure of communications to an out-station site for extended periods.

Thus, processing functionality within the NOS has not been duplicated. Problems with communications failure/insensitivity near thunderstorm activity should be addressed by increasing the number of core NOS sites slightly to provide the necessary improved redundancy in detecting sites. The aim of the redundancy recommended is to allow ATD to continue without serious loss of functionality even if two or three core sites are not contributing to flashes. With the current system, the loss of one or two sites usually has a serious impact on throughput, especially if some of the remaining out-stations are functioning poorly.

Operating costs of ATD are primarily associated with communication costs. However, it is intended that the new system will benefit from much reduced telecommunication costs and this will allow the deployment of more out-stations than in the current system. The cost of building NOS is an order of magnitude cheaper than current ATD out-stations .Thus, the existing ATD out-stations would probably cost £1.4 million pounds to replace with equivalent technology whereas 15 NOS out-stations for ATDNET is costed at £225k.

Thus, a minimum network of 13 stations is proposed for the new ATDNET system with 10 within Europe, see Fig 4. Thus the proposed NOS locations in Europe are:-

1. Exeter which should always contribute and have no communication costs..
2. A site in Ireland [to be negotiated Belmullet, Castor Bay , Valentia, Shannon??]]
3 Lerwick
4. Nordeney, Germany
5. Korpoo, Finland or another site in Finland if earthing continues to prove a problem at Korppoo.
6 Iceland
7. Cyprus, with location chosen to ensure improved communications
8 Gibraltar
9 Payerne, Swizterland or a site in southern France (Toulouse) [for improved short range redundancy] - to be negotiated
10 Azores [for improved redundancy at times of highest thunderstorm activity in Europe and near the British Isles.] – to be negotiated

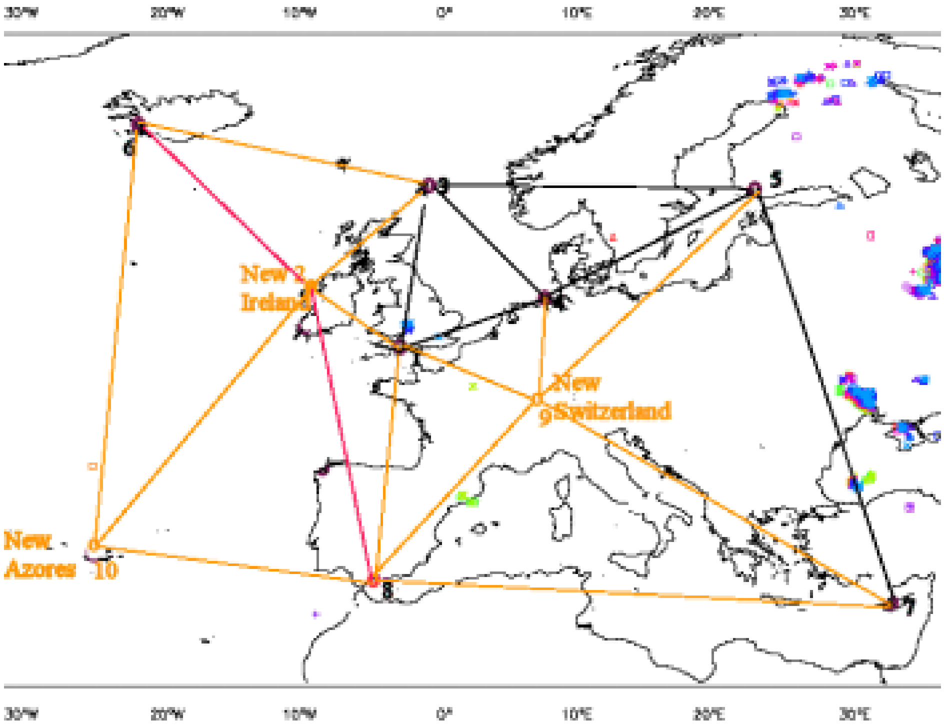

Fig.4. Proposed ATD NOS locations to sustain high detection efficiency for British Isles and European Service areas.

4. Long rang coverage

4.1 Service area

Currently, ATD can provide a 24 hour thunderstorm detection service over the areas shown in Fg.5. The area of coverage is governed by the properties of Sferic propagation, with least loss of sensitivity with distance travelled occurring along sea tracks. Thus, in autumn and winter most of the locations reported by ATD are in South America., Central America, the Caribbean and Africa. In summer when the numbers of storms in Europe is very much higher, then the area of long range coverage shrinks since the ATD out-stations are operating at lower sensitivity. ATD's sensitivity to storms in central, southern and eastern Africa only becomes useful for relatively short time in the middle of the day, when the number of thunderstorms in the Americas drops to a level that the storms in Africa can be sensed. In North and West Africa the system provides useful thunderstorm detection throughout the day.

South Africa is well outside of the Service Area covered throughout the day, but wishes to collaborate in extending the ATD service area to cover the whole of Africa. Meteo France also wishes to cooperate in extending the coverage towards La Reunion.

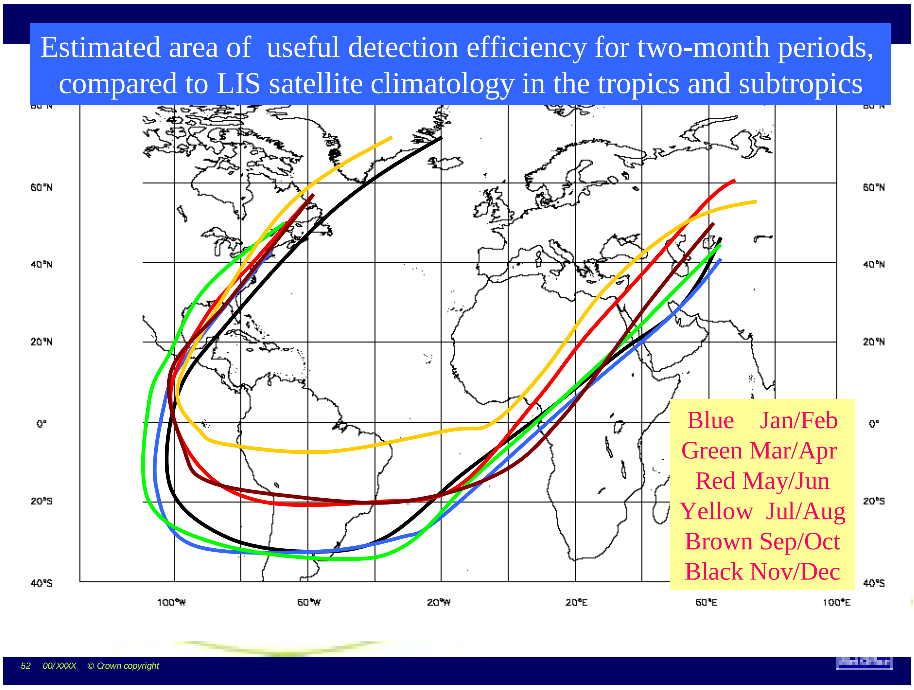

Fig.5. Estimates of the range off current ATD service area where most large thunderstorms are detected 24 hours a day.

4.2 Long range NOSs

To minimise the radial errors in long-range locations and to support the quality control in Europe by improving location accuracy in the long range areas, 3 more NOS sites will definitely be added to the new system. These will be numbers 11, 13 and 15, see below. Number 12 would be necessary to ensure good redundancy and location accuracy in central and east Africa.

11 South Africa [test ability to keep long range communications cheap]- essential, collaboration with South Africa started

12 Kenya/Tanzania- choose Mombassa or Dar-es-Salaam – essential to be negotiated

13 Ascension Island or St Helena- essential

14 Oman [Muscat] or Bombay or Karachi to improve coverage in the direction of India – funding to be negotiated

15 La Reunion or Mauritius together with Meteo France –essential, negotiation in progress

On this basis it is proposed that the ATDNET flash location processor be capable of receiving data from up to 20 sites without significant modification.

Note: The feasibility of adding out-stations in addition to the 13 recommended will depend on the cost of the communication link, or the willingness of another Met service/Agency to pay for the annual cost of the link. The cost of long-range communications for the future is to be identified by the pilot deployment of out-station 11. Once these communication costs have been identified, it will be possible to finalise the out-station deployment plans, given a target annual communication costs for ATDNET of £50k.

5. Examples of current performance

The Met Office ATD is a fully operational system, with worldwide output accessible hourly to users of the Met Office HORACE workstation.

The old out-stations are becoming difficult to maintain and Figs 6(a) to (c) show operational output in March 2005, with the ATD system functioning in an interim state with 5 old out-stations and 2 new out-stations in the UK.

Output from a renewed system dependent entirely on new out-stations and a new central processor should be available operationally before 2007.

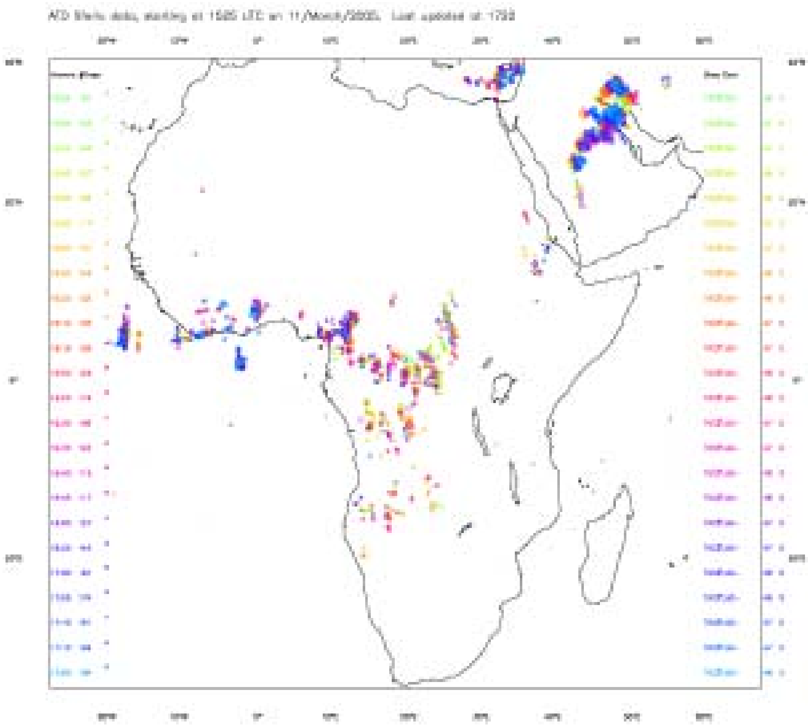

Fig. 6(a) Long-range lightning detection over Africa, 17.00, 11 March 2005.

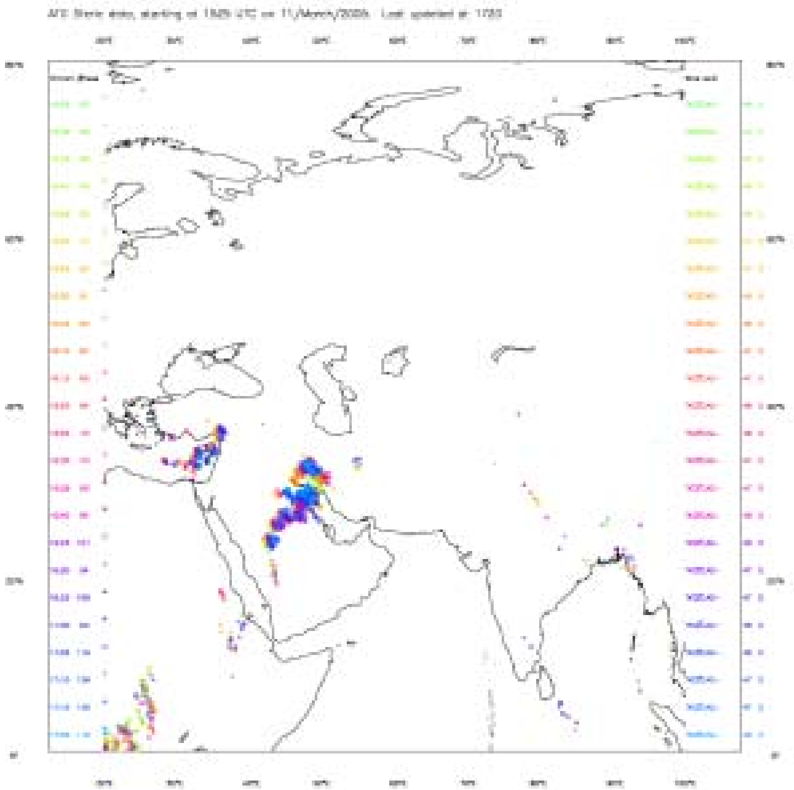

Fig. 6(b) Long -range lightning detection over Asia 17.00, 11 March2005

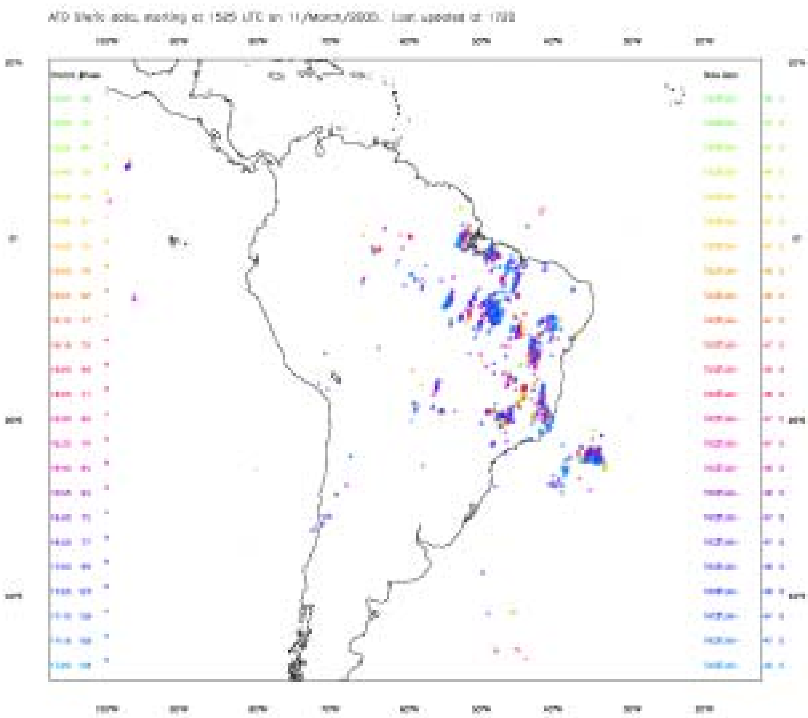

Fig. 6(c) Long-range lightning detection over South America, 17.00, 11 March 2005

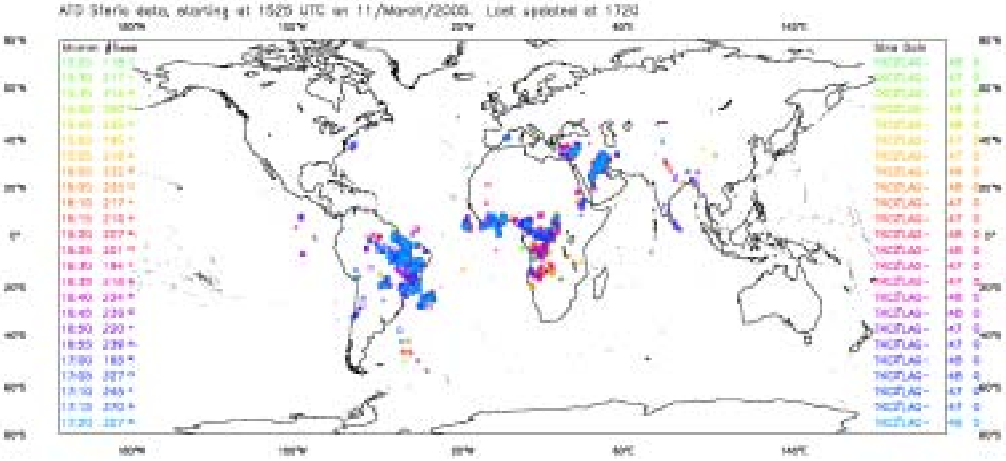

Fig. 6(d) All flashes reported at 17.00, 11 March 2005

The challenges for an operational wind profiler – remote and unattended.

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The Met Office has recently installed a Tropospheric 64MHz wind profiler on South Uist, an island off the west coast of Scotland. After many years in developing the use of wind profiler observations as a component of the UK upper-air network, this was the first system procured directly for operations and was linked to the closure of a radiosonde sounding station. This presentation will describe the challenges encountered, from the original specification, the installation/testing process and ultimately the hand over to operations, in delivering an unattended, remote managed observing system.

The Requirement/Specification for a Wind Profiler Radar.

At the beginning of 2000 the Met Office Upper-Air observing network consisted of 8 Radiosonde stations providing 4 ascents per day and a number of supplementary stations providing irregular ascents based on local forecasting requirements. Figure 1 shows the location of these sites.

A strategic review of the network in 2000 provided plans to reduce the number of manned upper-air stations in the network with the use of Autosondes and some site closures. In addition it recommended a greater integration of other upper-air measurements (i.e. Amdar, profilers) within the operational network.

With the closure of the radiosonde station at Stornoway (NE Scotland) the upper-air development team were tasked with the procurement and installation of a wind profiler (WPR). The decision to install a WPR as a direct replacement for the operational wind measurements was based on extensive experience of operating boundary layer WPR's in Southern UK. However this procurement would be unique, in providing a system suitable for operations, with a maintenance and spares policy for a 10 year life time.

Figure 1 – UK Upper Air Network (Jan 2000)

A summary of the specification of the wind profiler radar is as follows:

- An operating frequency either in the band 440-450MHz or 50 - 65 MHz.
- Winds reported in the range 1 - 12km, at a minimum of 90% availability.
- Height Resolution 150m – 500m
- Temporal Res. 30min → 10min
- Random Error ≤ 2ms-1 (Absolute error tested against Radiosondes)
- Lifetime 10 years, harsh environment. 1 visit per 6 months.
- System to run unattended, with complete remote access capability.

As a result of a competitive tendering exercise the contract to supply the WPR system was awarded to Vaisala (Finland), who was using ATRAD (Australia) as a sub-contractor to provide the antenna and amplifiers. The agreed specification for the system was as follows:

- An operating frequency in band 50 - 65 MHz. The final frequency of 64MHz was agreed at a later stage.
- 90% availability of winds reported in the range 1.5 - 12km, however on occasions it is expected that winds up to 16km would be reported.
- Height Resolution 150m (1.5-6km) and 450m (3-16km)
- A recommended temporal resolution of either 1 hour or 30minutes. However 10 minute resolution is possible to configure for research use.
- Random Error will meet those detailed in the tender document.
- A detailed maintenance document and level of spares for a 10 year operational lifetime. Once operational a maintenance visit is only required every 6 months.
- System will run unattended and has remote access capability.

Site Selection.

A site needed to be identified which was still in the western Isles of Scotland but had the necessary land and services for the wind profiler. Careful consideration was needed to ensure that a licence to operate at the chosen frequency would be granted and that the likelihood of external interference was small. Criteria used to assess the suitability of the site were as follows:

- Possible to transmit in the band 50-65 MHz and have adequate protection from other non-licensed users.
- A flat area of land suitable for the installation of an antenna array of $160m^2$.
- A nearby shelter with power and communications.
- A secure site, as for most of the time the system will be unattended.
- Local contact with technicians/caretaker able to provide on-site support.
- Located near other Met Office equipment (sharing of resources).

The site selected was on a military range on the Hebridean island of South Uist. The range already hosted surface observing equipment and had an onsite forecast office capability for trials work. On-site technical, work services & security support was available and a communication link between the Met Office HQ at Exeter and the range already existed. Figure 2 shows a picture of the selected site.

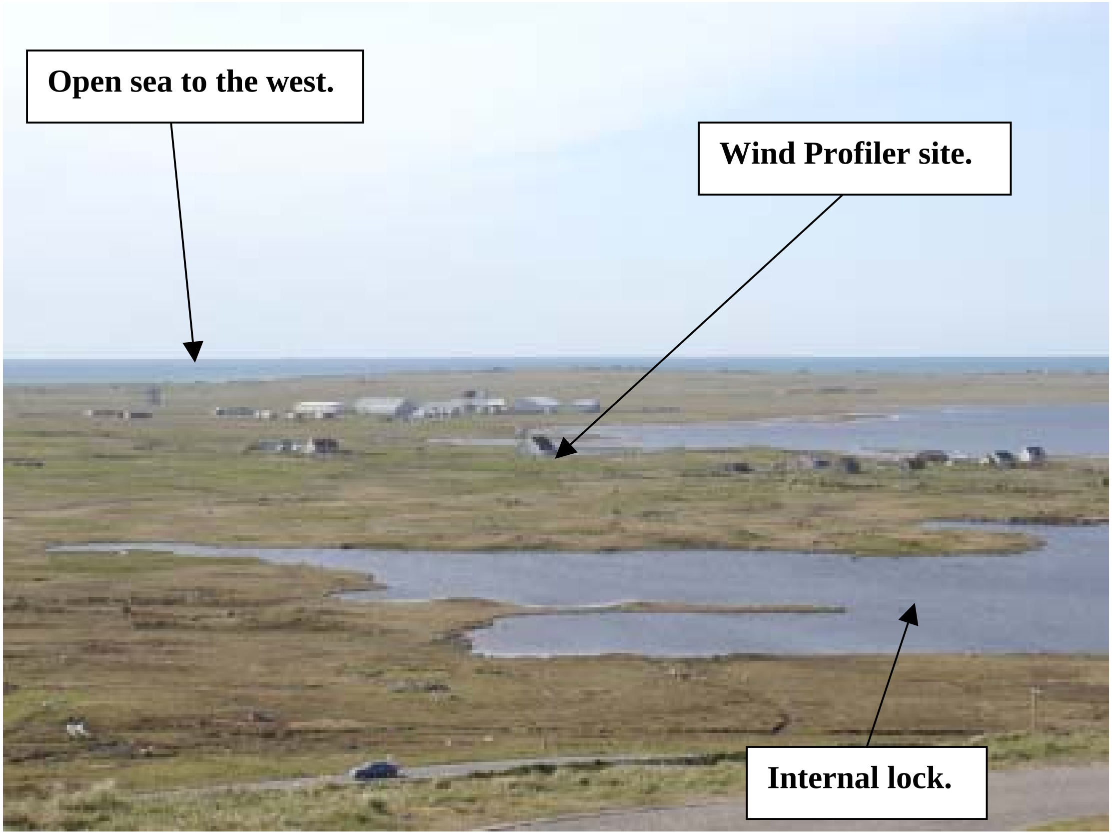

Figure 2 - The wind profiler site on South Uist

System Installation.

Work services for the antenna and internal electronics began in November 2002. Not only did the installation need to be fully compliant with the regulations for the Met Office but also needed to be accepted by the range authorities to ensure that the profiler didn't interfere with other equipment on the range. Extensive work was necessary to prepare the site and install a concrete base for the antenna. A solid concrete base was chosen for the antenna, as this would make the YAGI antenna installation, earthing and tuning a simpler process. The antenna would be easier to maintain over the lifetime of the system. Figures 3-6 show the progress of the antenna installation, which was completed at the end of March 2003. Approximately ⅓ of the total cost of the project was for work services.

Figure 3 – Start of site preparation.

Levelling of site and concrete capping of existing communication duct.

Figure 4 – Concrete base.

Concrete base being constructed in strips, to allow the concrete to fully harden and for access to create a polished surface. Requirements stipulated a level of ± 10cm over the whole base.

Figure 5 – YAGI Mountings.

Installation of mounting plates. Positioning required an accuracy of ± 2cm between each plate. Security fence being installed.

Figure 6 – Completed antenna.

Completed installation of YAGI antennas, cables and earthing straps.

Work was also required to prepare the shelter for the wind profiler electronics. A 3 phase-supply was necessary to power the 6 transmitter modules and air-conditioning was needed to maintain the room at a constant temperature. Security constraints meant that a communication link to the Met Office forecast office had to be a fibre-optic link over a distance of 4km. Figure 7 shows the internal electronics for the wind profiler system. Installation was completed in early May 2003, with the first transmission on 9th May 2003.

Figure 7 – Internal Electronics. (1) Communications cabinet. (2) Transmitters and power supply. (3) Beam Steering unit and digital processing.

System Acceptance.

Once the wind profiler started working at the beginning of May 2003, a number of issues needed to be resolved before the system could be regarded as ready for the 4 week acceptance test by the Met Office. This acceptance test would require the system to run unattended for a period of 4 weeks, with the wind measurements meeting the specification documented in the tender documents. The major initial problems with the system were as follows:

1. ‘Bleed through’ of the transmit signal on the receive (Problem in T-R Switch).
   This was a serious problem causing an interfering signal around zero Doppler frequency which dominated the atmospheric signal above 5km. Attempts on-site and later in Australia were unable to modify the T-R Switch to remove the problem. A software fix was necessary by Vaisala to eliminate all the signals around zero and thus allow the atmospheric signal to be selected by the software.
2. Polar Mesosphere Summer Echo’s (PMSE).
   Signals from 80-90km were being aliased into the Doppler spectrum and causing significant problems with the wind measurements from 10 – 14km (See Figure 8). A change in the configuration was necessary to ensure that these signals were ignored.
3. Internal & External interference.
   Significant problems were encountered with interfering signals from either an internal or external source. Attempts were made internally to limit the effects of the likely culprits (i.e. 32MHz oscillators) but these problems persisted on an ad hoc basis for a period well after installation. Figure 9 provides wind measurements from the system for 24/12/03, with an example spectrum plot in Figure 10. Clearly the winds are unusable above 9km. At a later stage it was possible to demonstrate that much of the interference originated internally within the system, notably after switching off and working on the system. This highlighted that particular care was required in replacing components and earthing links after working on the system.
4. Ground clutter and Precipitation.
   On occasions both ground clutter and precipitation signal returns caused errors with the measured winds, especially when the signals were in one beam but not the other. When validating the system against the specification (random error) for these periods the measurements were clearly outside the limits.
5. Remote monitoring and diagnostics.
   Once the system was delivered and left running unattended, it was clearly evident that the remote monitoring capability, especially fault diagnostics, was not suitable for operations. Unfortunately this was a weakness in the procurement specification with a lack of detail in defining the monitoring capability required for a remote, stand alone operational system.

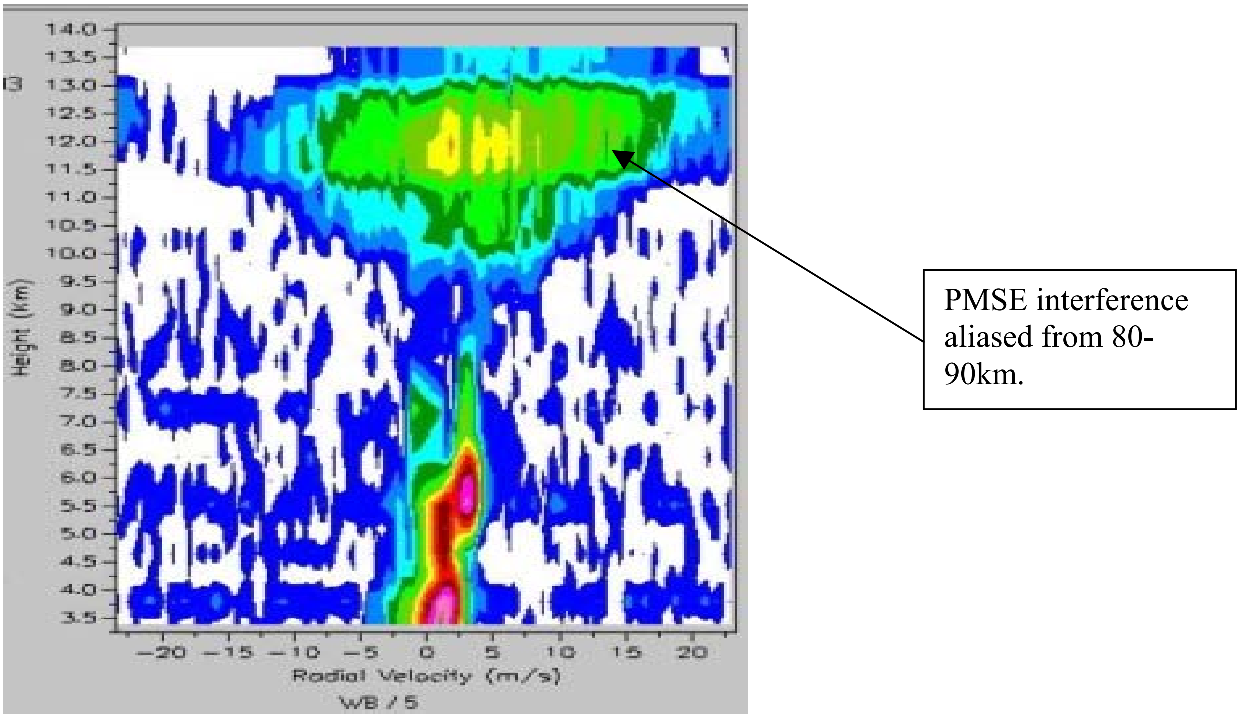

Figure 8 – Non normalised log contour plot of the Doppler spectrum (PMSE interference).

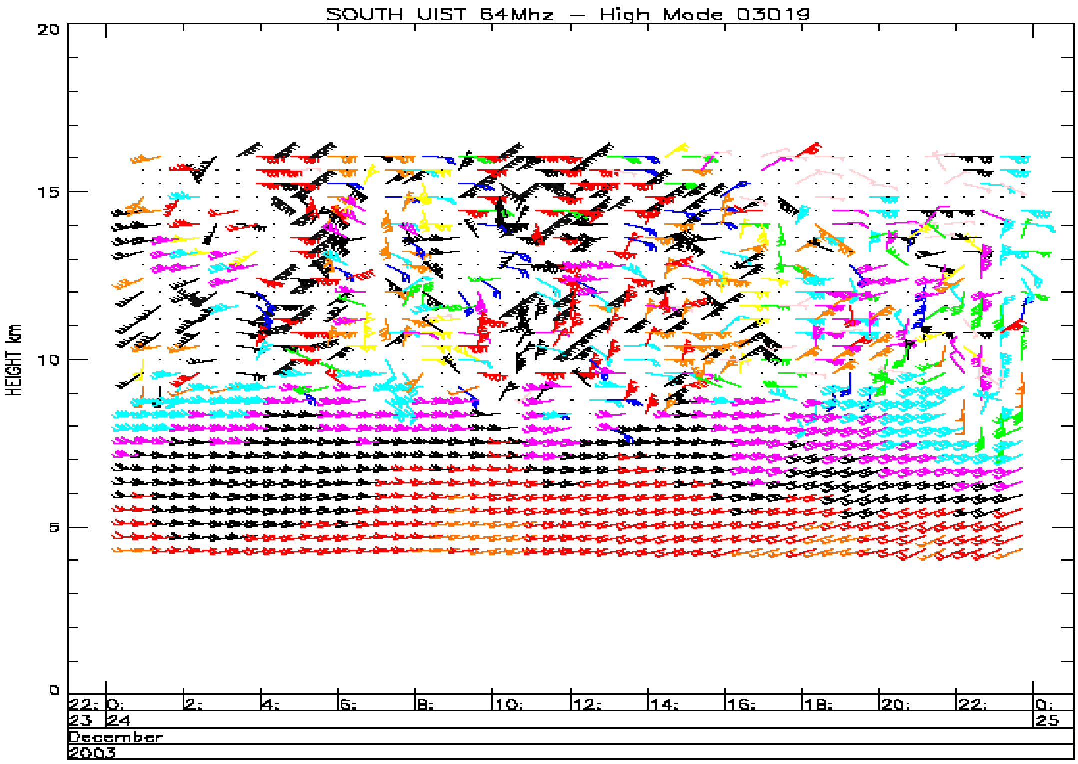

Figure 9 – 24 hour wind barb plot, showing measurement problems above 9km

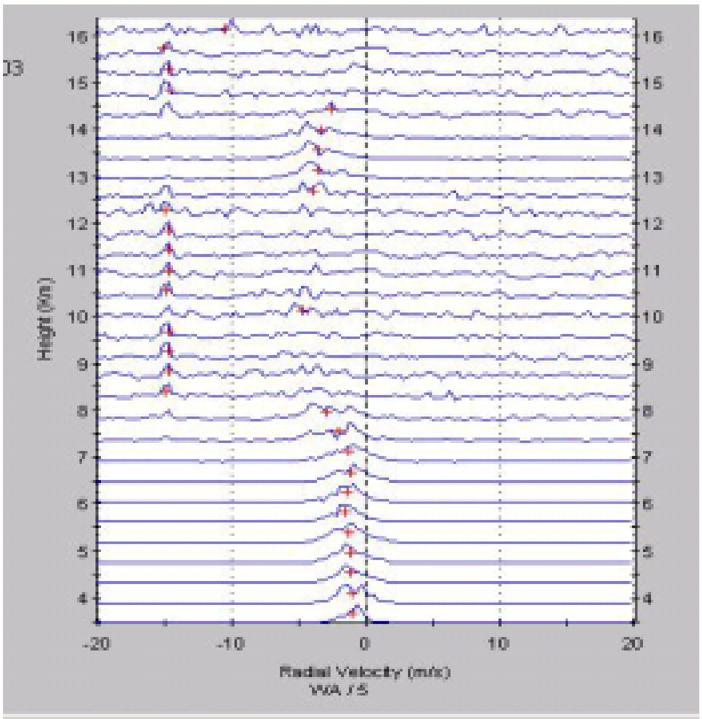

Figure 10 – Stacked Doppler power spectra plot showing interfering signal.

At this stage it was evident that additional signal processing was required to fully optimise the system for operations. The low mode data (1 – 5km) had been accepted for operational use by the Met Office (NWP assimilation from Nov 03) but during precipitation there were some errors in the reported winds. The high mode was still clearly outside the acceptance limits detailed in the tender documents and thus was not accepted for data assimilation. It should be stressed that this is a unique system which required a significant learning commitment for all parties involved in the installation and acceptance process.

At the beginning of 2004 it was decided to use a 'Multi-Peak' solution in processing the spectral data. Work on the archived spectral data by Vaisala and further testing by the Met Office demonstrated a significant improvement in the high mode wind data. Figure 11 provides an example of the improvement on 24th Dec using the same spectral data as shown in Figure 10.

These new algorithms were introduced operationally on the system from February 2004. With additional Quality Control on the reported winds the high mode data was accepted for NWP data assimilation by the end of March 2004. A 2nd Radiosonde acceptance test was conducted in July 2004 to document the comparison statistics between the radiosonde wind measurements, a 915MHz boundary layer profiler and the 64MHz profiler. Figure 13 shows an example of the wind measurements from the 3 systems. Figure 14 summarises the standard deviation of the differences of the wind profiler measurements with the radiosonde (26 comparison flights).

The wind profiler system was fully handed over to operations in October 2004. This process not only required the acceptance of the system against the tender documents but required detailed documentation and training so that the daily support and the long-term maintenance of the wind profiler could be maintained by the network managers.

Figure 12 shows a 24-hour wind barb plot for the South Uist wind profiler as reported in real-time. The overall measurement quality and vertical coverage can easily be assessed from this plot, which is produced on a daily basis.

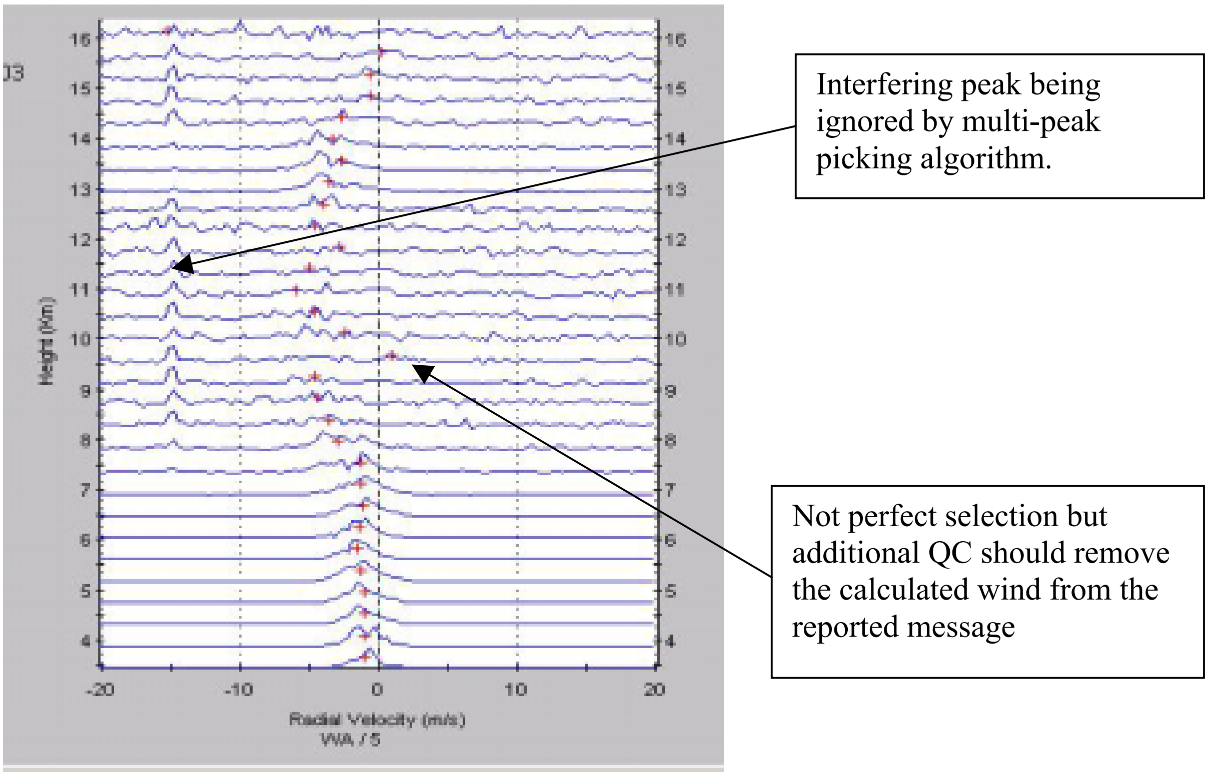

Figure 11 – Stacked power spectra and peak identification using the multi-peak algorithm

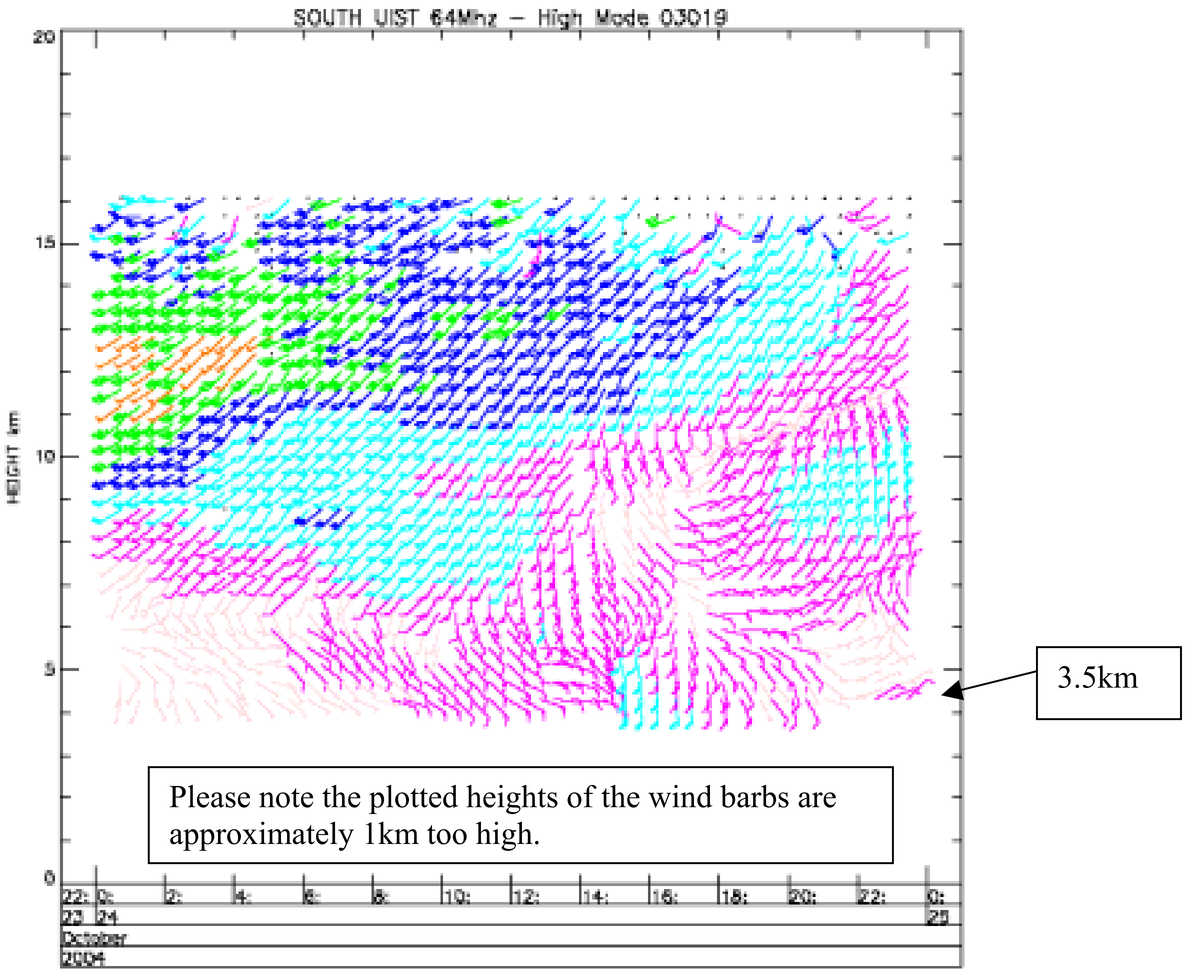

Figure 12 – Example of 24-hour wind barb plot (South Uist 64MHz wind profiler)

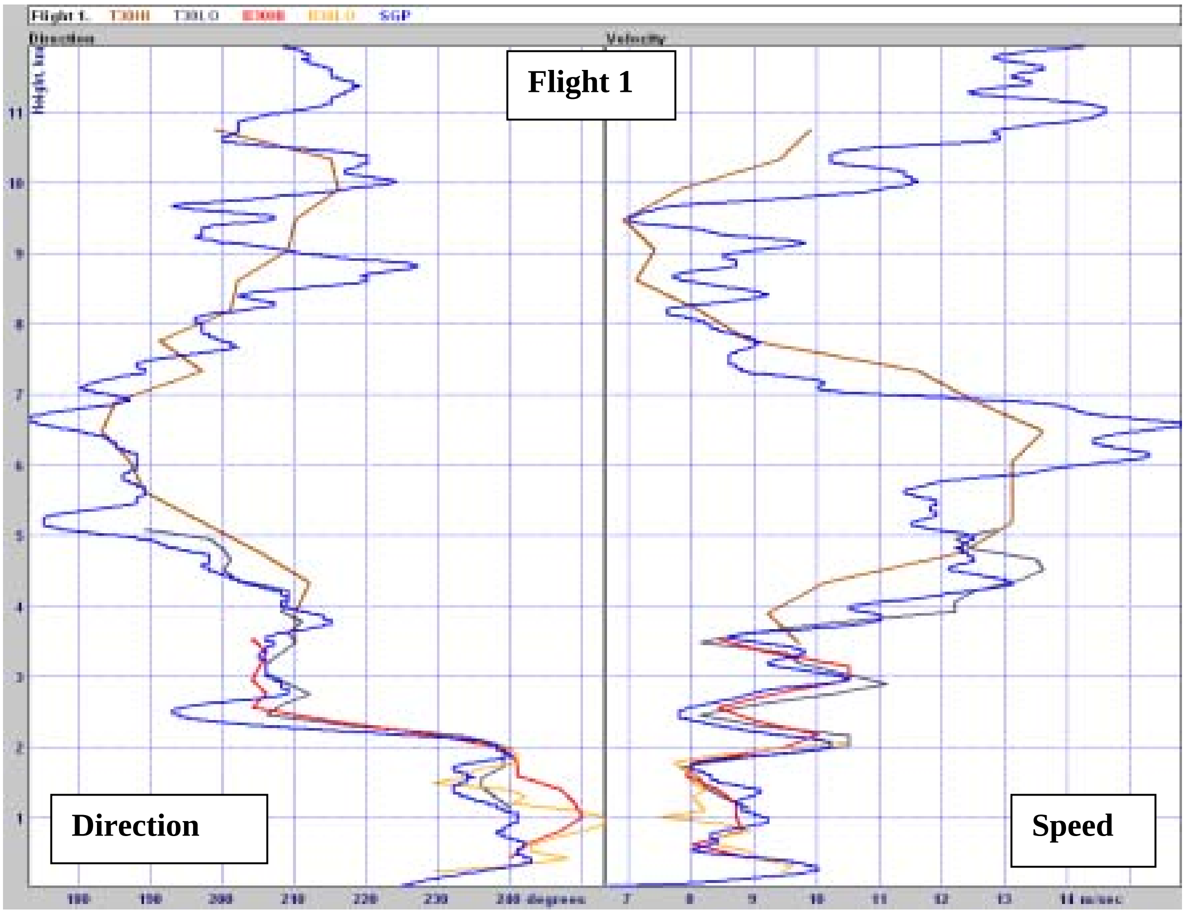

Figure 13 – Radiosonde & Wind Profiler (64MHz and 915MHz) comparison.
[Blue– Radiosonde, Brown– 64MHz(high), Red– 64MHz(low), Grey– 915MHz(high), Yellow– 915MHz(low)]

Height Band	64MHz (High) u,v components Standard Deviation	64MHz (Low) u,v components Standard Deviation	915MHz (High) u,v components Standard Deviation	915MHz (Low) u,v components Standard Deviation
0-1km			0.7 , 0.8	0.7 , 0.8
1-2km		0.7 , 0.6	0.8 , 0.7	0.8 , 0.7
2-3km		0.8 , 0.9	1.0 , 1.0	1.0 , 1.0
3-4km	1.3 , 1.1	0.9 , 1.0	1.0 , 1.0	
4-5km	1.1 , 1.2	0.8 , 1.0		
5-6km	1.5 , 1.2	1.2 , 1.1		
6-7km	1.4 , 1.1			
7-8km	1.7 , 1.3			
8-9km	1.9 , 1.5			
9-10km	1.9 , 1.8			
10-11km	1.2 , 1.4			
11-12km	1.5 , 1.5			
12-13km	2.1 , 1.7			

Figure 14 – Acceptance test (26 Flights). Standard Deviation of the differences (m/s)

Conclusion and future work.

- The wind profiler system has now been running unattended for a period of greater than 6 months.
- The remote access has proven capable of allowing updates of the software & system configuration and maintaining the IT security of the processor whilst operating on the Met Office network.
- Data from both modes are being operationally assimilated in the NMP models and real time displays are used by forecasters.
- The manufacturers have been requested to address the hardware issues for the system, notably on the T-R switch problem and with remote monitoring/diagnostics.
- Additional analysis was done to assess the quality of the lowest wind measurement (1.5km) and to compare the reported winds where the 2 modes overlap. Comparison statistics for the lowest range gate showed a good agreement between the profile winds and that of the GPS radiosonde & the 915MHz wind profiler. In general the low and high modes show a good agreement but on occasions where there are marked variations in the signal power in the vertical there are inconsistencies in the measurements. Further information on these studies can be provided by contacting the author.
- With the introduction of the multi-peak picking (MPP) algorithm there was a significant improvement in the reported winds. On most occasions the algorithm is able to ignore any ground clutter or interference peaks. Also when precipitation is present below the melting layer the winds are normally resolved correctly. However above the melting layer the ice-crystals present more of a problem as their fall speeds are closer to the atmospheric signal. Figure 15 shows a plot of vertical velocity from the wind profiler low mode, with clear examples of the processing locking onto the ice-crystal signals. The wind measurements are satisfactory as long as all beams lock onto the ice-crystal signal but this is not always the case.

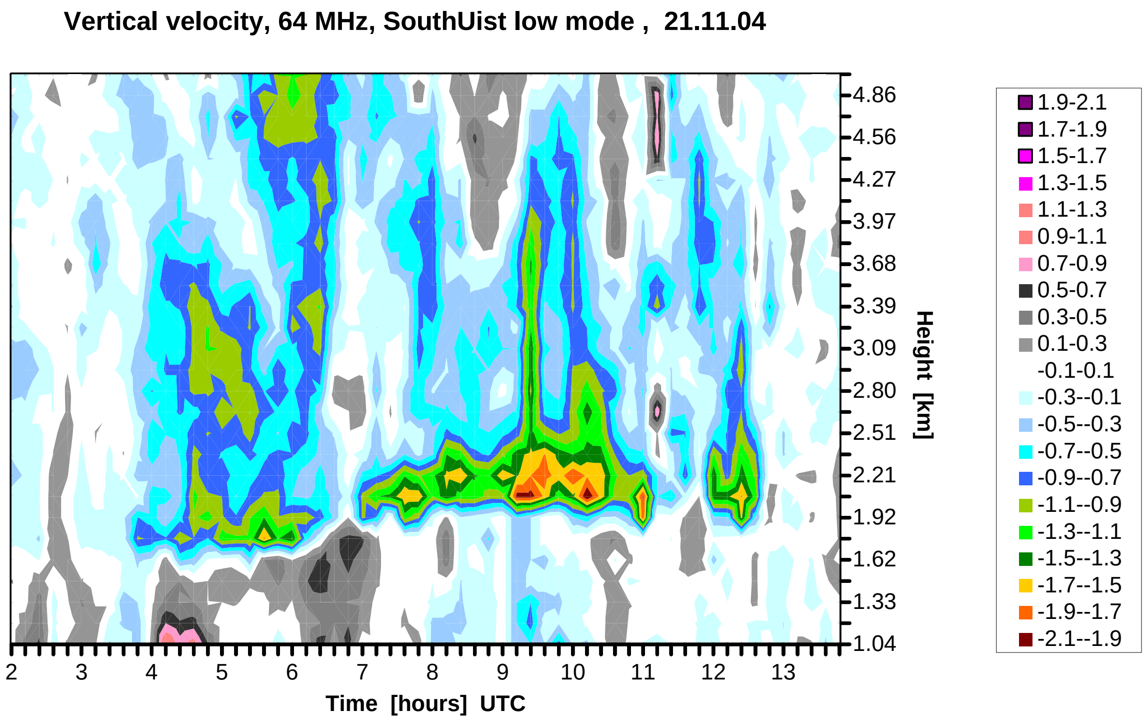

Figure 15 – High resolution vertical velocity measurements from the 64MHz profiler.

- Operational monitoring of the reported winds shows that on 1 or 2 days a month, notably in winter conditions, the current MPP algorithm is not identifying the peaks correctly in one beam. Thus further work is necessary in an attempt to ‘fine-tune’ or even update the algorithm to improve the wind data on these occasions. The Met Office has an ongoing collaboration with Vaisala to investigate these cases.

Case Study

This winter (04/05) has proven a good test of the resilience of the wind profiler system. One of the key requirements was for the system to maintain full operations during severe weather. Thus the system included a back-up generator which would automatically provide power in the event of a cut in the main supply. On 11th January 2005 a severe storm battered the west coast of Scotland, causing some loss of life, significant structural damage and periods in excess of 24 hours without power on South Uist. Figure 16 shows the 18utc analysis chart for 11th January. Throughout the storm the wind profiler continued to provide measurements, for long period in excess of 100 knots (110 mph). Figure 17 shows the wind speeds measured by the system from 09 -21utc.

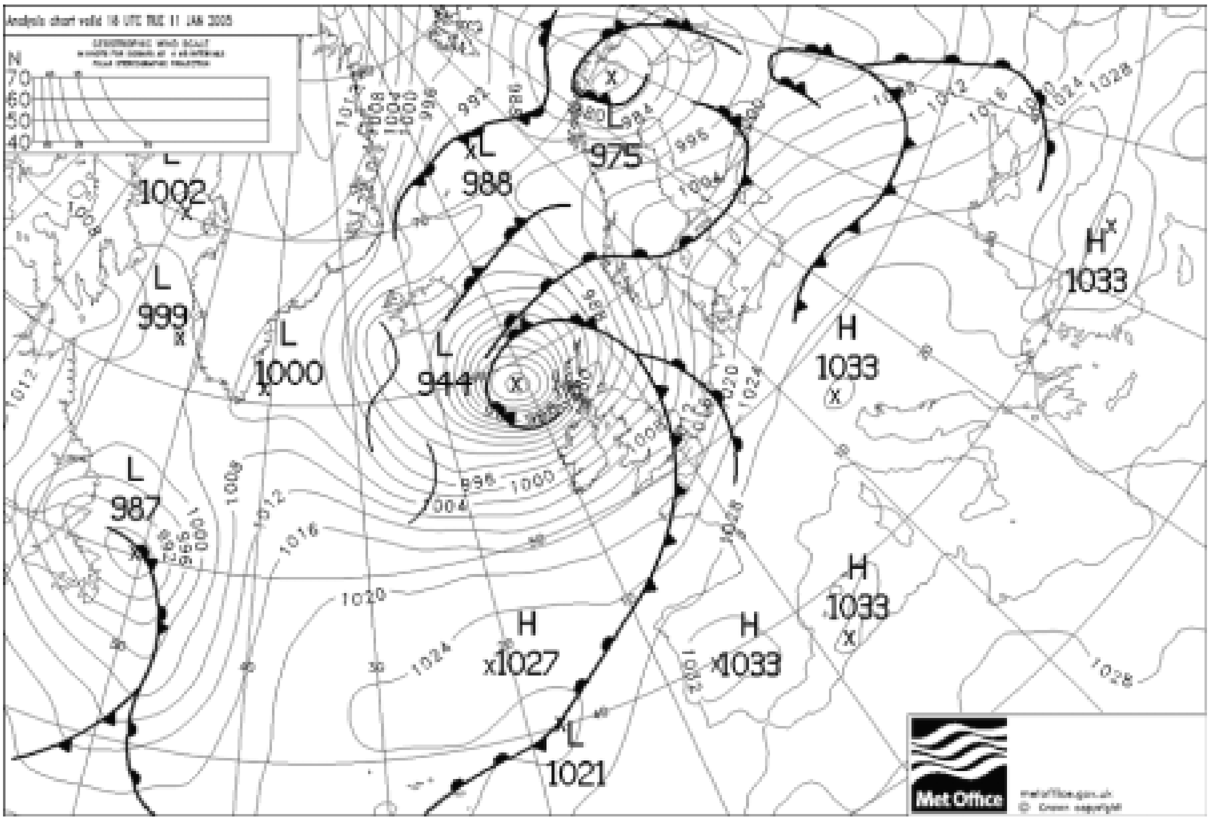

Figure 16 – Met Office analysis chart for 18utc on 11th January 2005.

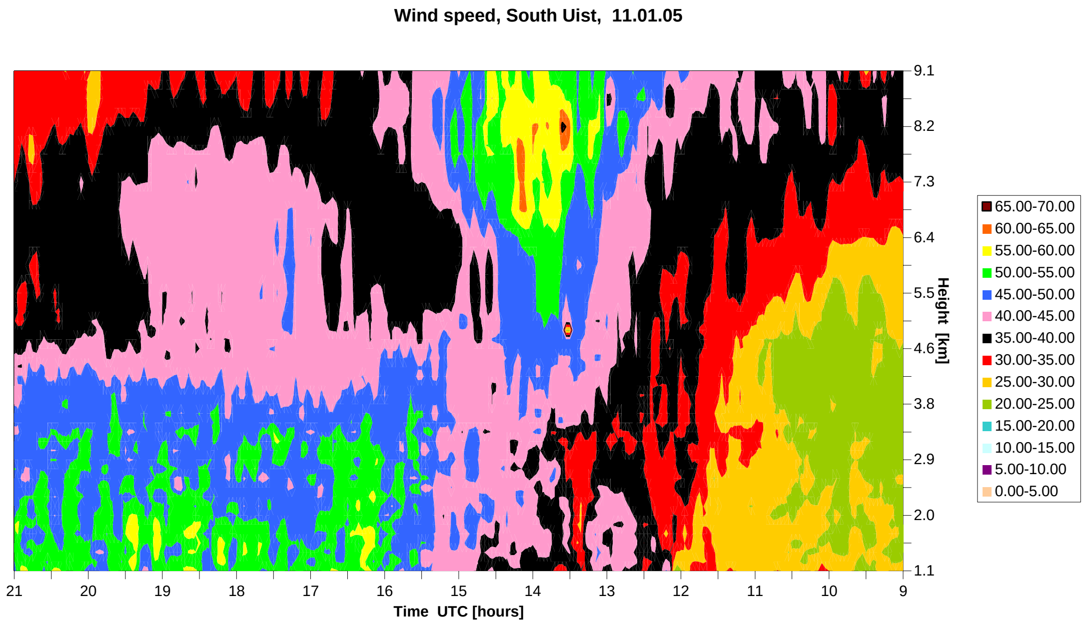

Figure 17 – South Uist Wind Speed (m/s) 11th January 2005 [contoured at 5m/s] Integrated from both high and low mode measurements.

Results of the RS92 Acceptance Test performed by the Met Office (UK)

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Abstract

During summer 2004 the Met Office conducted an extended acceptance test of the Vaisala RS92 GPS radiosonde. This test was the culmination of three year collaboration with Vaisala in improving the relative humidity measurements of Vaisala radiosondes. The acceptance test was conducted in three distinct sections; Relative humidity tested against the Meteolabor Snow White sensor, Temperature tested against Sippican 3 thermistor Radiosonde, and with geopotential height and winds checked against measurements from the Graw DFM97 radiosonde. The results of this test are presented here.

Introduction

The Met Office has considered upgrading from the RS80 radiosonde since 2001, when the DigiCORA III ground system was introduced into use in the UK upper air network. However, the RS90 radiosonde did not meet the UK specification for relative humidity measurements when it was tested in 2000. Subsequently, Vaisala agreed to co-operate with the Met Office in developing solutions to the problems encountered. This has led to a series of tests at regular intervals of various possible solutions to the problems in the last three years.

In the case of the relative humidity sensor a variety of changes have been introduced since the test in 2000, for instance:-

- Relative humidity sensors were regenerated to eliminate contamination. Both in the factory, before calibration, and also before the radiosonde was used in flight.
- The pulse heating cycle was speeded up to provide more regular heating to minimise errors in clouds with high liquid water content in the early parts of the measurement.
- The pulse heating has also now been continued to temperatures as low as -60°C to minimise contamination in upper cloud.
- Production problems with the manufacturing of the pulse heating drives have been rectified.
- The thickness of the relative humidity sensor was adjusted to improve the stability of the sensors during flight.
- Revised calibrations were introduced to improve accuracy at lower temperatures.

With the announcement from Vaisala that the production of the RS80 will stop in 2005, the time came to perform a detailed acceptance test on the Vaisala RS92.

Test facilities

For this test, Vaisala loaned the Met Office a SPS311 processing board, a PC running DigiCORA III version 3.12 and a pre-amp to upgrade the RB21 antenna at Camborne. The radiosondes to be tested were a mixture of Vaisala RS92- SGP and Vaisala RS92-AGP, supplied by Vaisala.

High quality relative humidity measurements were to be provided by Snow White chilled mirror hygrometers (see Fig 1) flown with the Meteolabor SRS C34 radiosonde and Argus37 ground station. One of the main benefits of the Argus ground station was the provision of additional ‘house keeping channels' allowing performance of the Snow White systems to be monitored. The upgrade with additional channels required the Snow White hygrometers to be returned to Meteolabor. Problems were encountered with damage during the shipping of the Snow Whites from Switzerland, and this led to considerable delay in the completion of the test. This had the advantage that test flights were performed in a variety of conditions over several months, so that the results are more likely to be generally applicable than if the test was completed in two weeks.

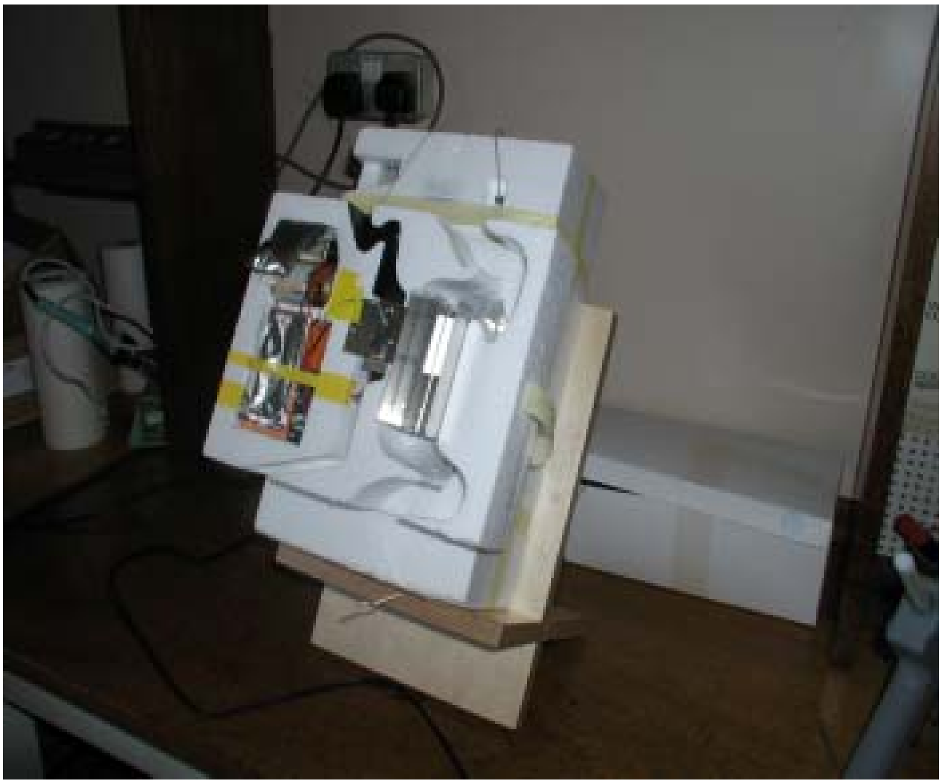


Figure 1- Snow White undergoing flight preparation at Camborne.

The Graw GK90C ground station has been used at Camborne since 2001 as a height reference for testing other radiosondes but within a short time of starting the test the ground system developed a fault. On repair by the manufacturer the interface between the ground station and radiosonde was upgraded to take into account advances in GPS technology that had recently been introduced by Graw. The DFM97 GPS radiosondes stored at Camborne since 2002 were replaced by the manufacturer with radiosondes incorporating the GPS upgrade.

A Sippican ground station is also used at Camborne for referencing height measurements. This required a software upgrade to allow processing measurements for the 3 thermistor radiosonde. The software allowed processing of 4 additional temperature channels plus the standard channel.

Relative Humidity Results

Fig 2 shows an example of a comparison between simultaneous measurements of dewpoint measured by the Snow White and values derived from temperature and relative humidity measurements from the Vaisala RS92. The correct value of dewpoint in the stratosphere [after minute 40] for the time of year in the UK was probably between -75 and -80°C [relative humidity between 8 and 3 per cent.)

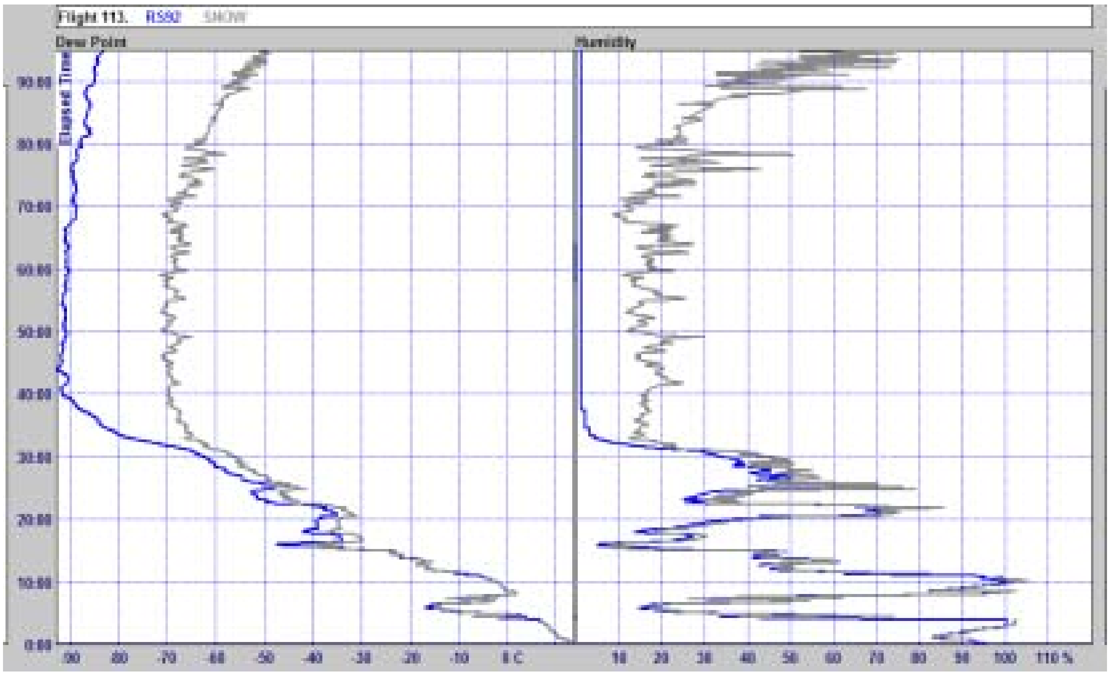


Figure 2- Simultaneous comparison between Snow White and Vaisala RS92 dewpoint, left hand pane and relative humidity right hand pane.

The increase in dewpoint with height after minute 70 was related to the build up of water vapour contamination around the cold mirror in the Snow White [P.Ruppert[1], personal communication] and would mostly disappear once the balloon burst and ventilation of the Snow White improved. On many flights the Snow White dewpoint did not fall lower than -60°C in the stratosphere because of contamination in the ducts. Thus, in order to minimise the build up of this contamination, an open-ended metal cylinder was inserted immediately above the Snow White sampling chamber, and the entry to the ducts at the top of the radiosonde was blocked off, see Fig. 3. The measurement in Fig.2 is made with this arrangement, and although it did not solve the contamination problem entirely, the speed of response of Snow White and the level of contamination after passing through several layers of high relative humidity was better than in some of the early test flights.

Figure3 - Snow White showing the ventilation modification. With a normal Snow White, ice crystals can enter through the top vent and accumulate in the ventilation duct and around the sensor housing. Side ventilation should limit this ingress by extending the duct well away from the body of the radiosonde.

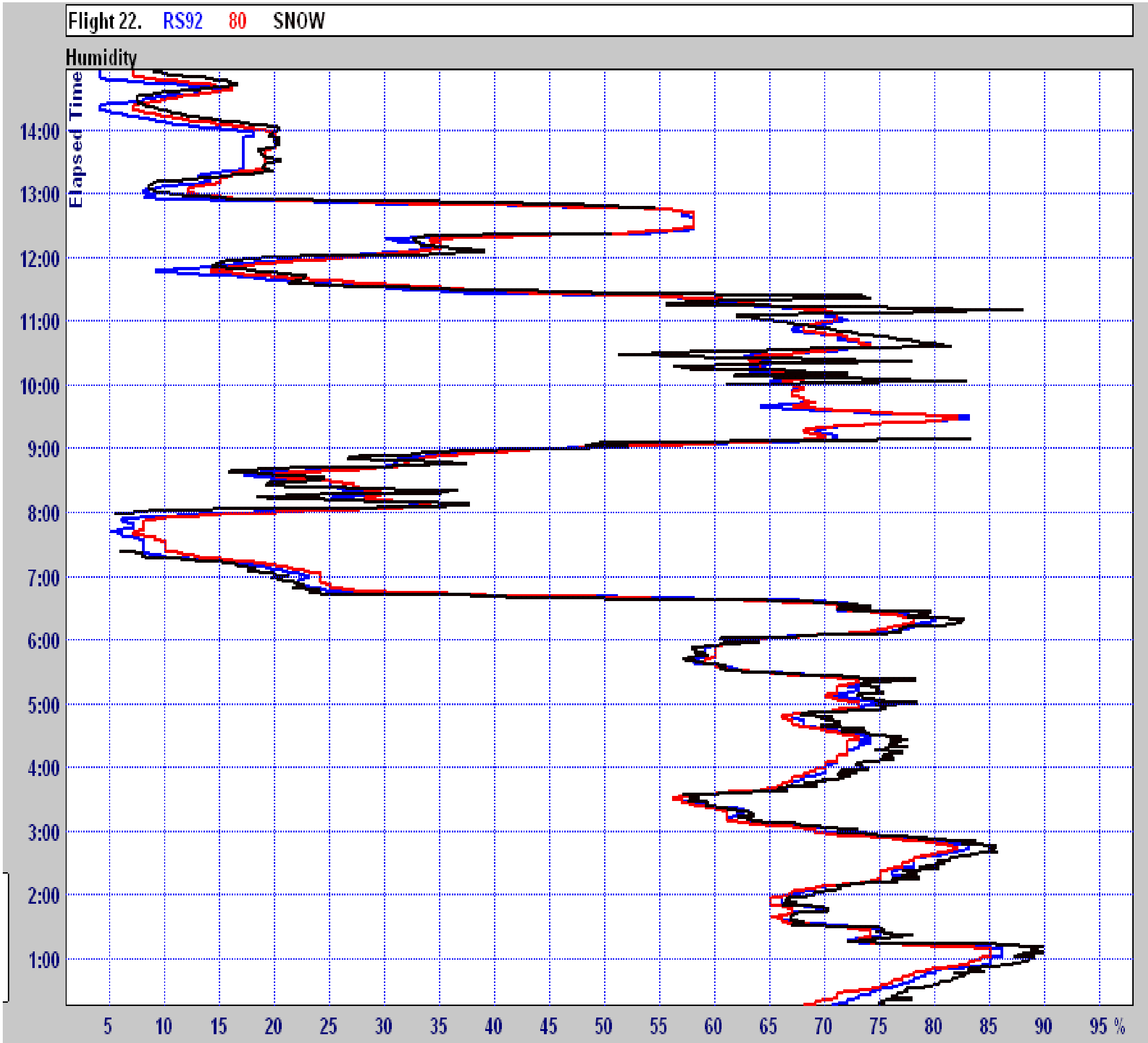


Figure 4(a), Simultaneous relative humidity measurements of RS92 (blue), RS80 (red) and Snow White (black). The Y axis is time from 0 to 15 minutes and the X axis is relative humidity (%)

Figure 4 shows a detailed comparison between Snow White and Vaisala in the lower troposphere. It takes about 20s into flight before the RS80 and Snow White sensors begin to ventilate correctly. Snow White data have been edited out for about 40s before minute 8, because the air was so dry that the film of water on the mirror disappeared and dewpoints were invalid. Snow White data were also edited out between minute 9 and 10 because it tended to be unstable, with the dewpoint temperature oscillating after the rapid increase in relative humidity [dewpoint] at minute 9.

The full extent of the instability in dewpoint control of this particular sensor is seen later in the flight after minute 23, see Fig.4b. In some flights, the dewpoint oscillations were much larger in upper cloud and all the Snow White data were edited out. Data from at least one comparison in rain were excluded from the data set, since all the sensors were heavily contaminated and iced, with the results not representative of normal measurement conditions.

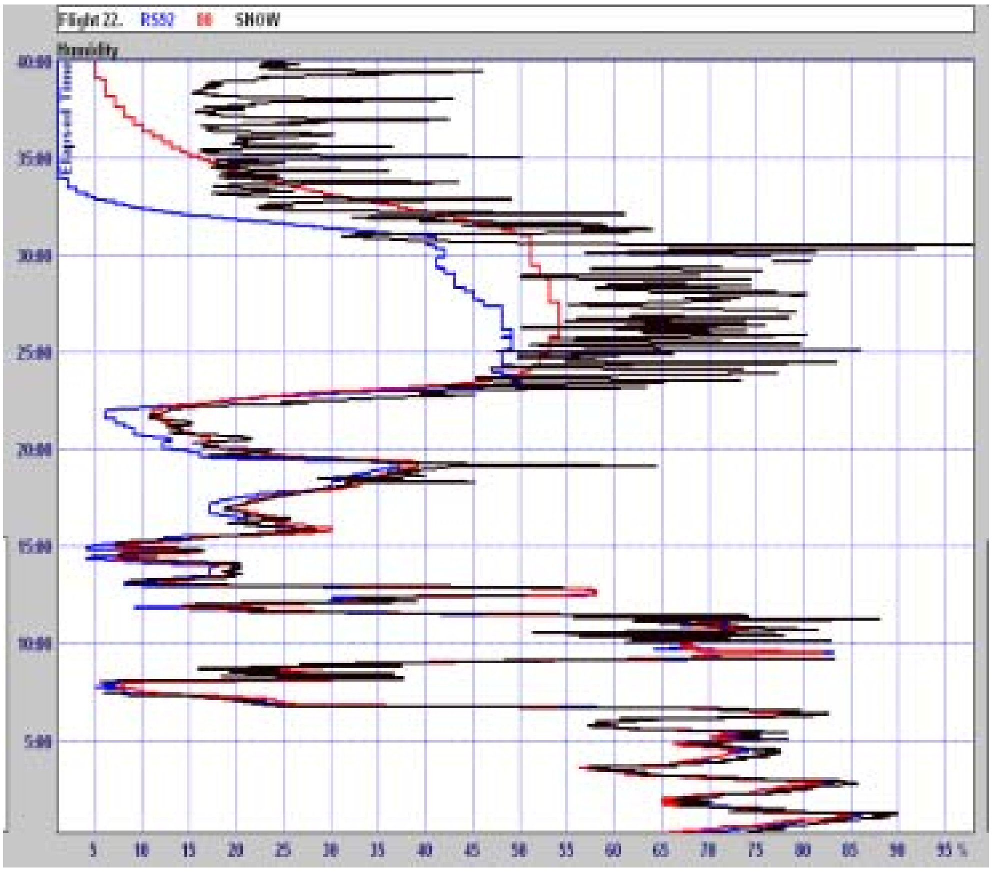


Figure 4. (b), Simultaneous relative humidity measurements of RS92 (blue), RS80 (red) and Snow White (black). The Y axis is time from 0 to 40 minutes and the X axis is humidity (%)

By the end of the test, the number of successful Snow White, Vaisala RS92 comparisons was 18 in the day and 15 at night. Here, the results have been processed using RSKOMP software [S. Kurnosenko[2], personal communication] for 3 temperature bands, greater than 0, 0 to -30, and -30 to -60. The systematic difference in Relative Humidity between RS92 and Snow White, and the standard deviation of the comparison are presented for day and night in Figs 5 to 7.

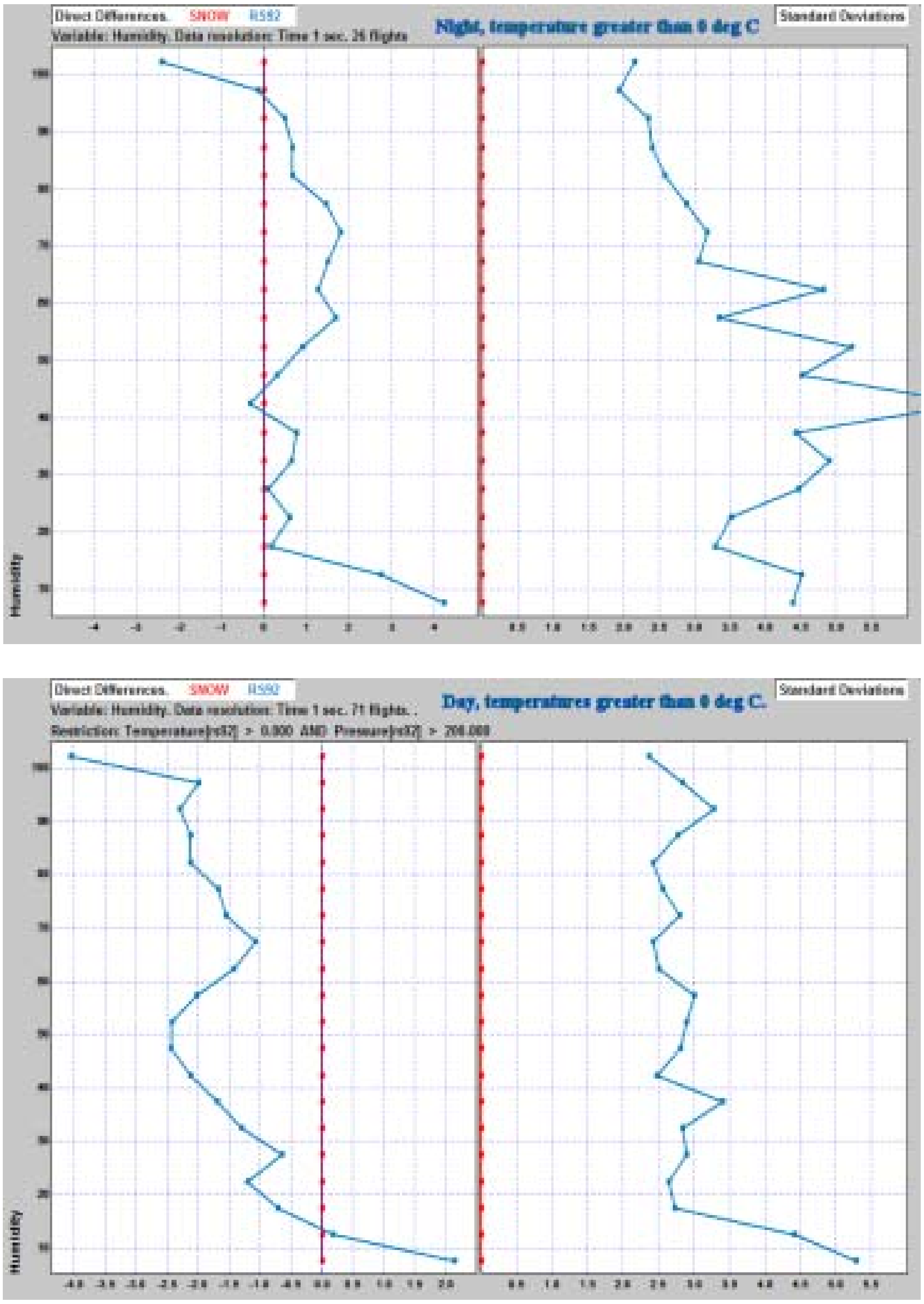


Figure 5- Left hand pane is direct differences in relative humidity [Snow White-RS92] as a function of relative humidity for temperatures greater than 0°C. RS92 trace is blue, and Snow White (red, reference). The standard deviations of the differences are shown in the right hand pane. Upper plots are for night time measurements, lower plots for daytime.

In Fig.5, the typical day-night difference between Vaisala and the reference was -3 per cent at high relative humidity. On average at night the two sensors agreed to better than 2 per cent. The standard deviations between the measurements are consistent with the random error in each of the two sensors in the range 2 to 4 per cent.

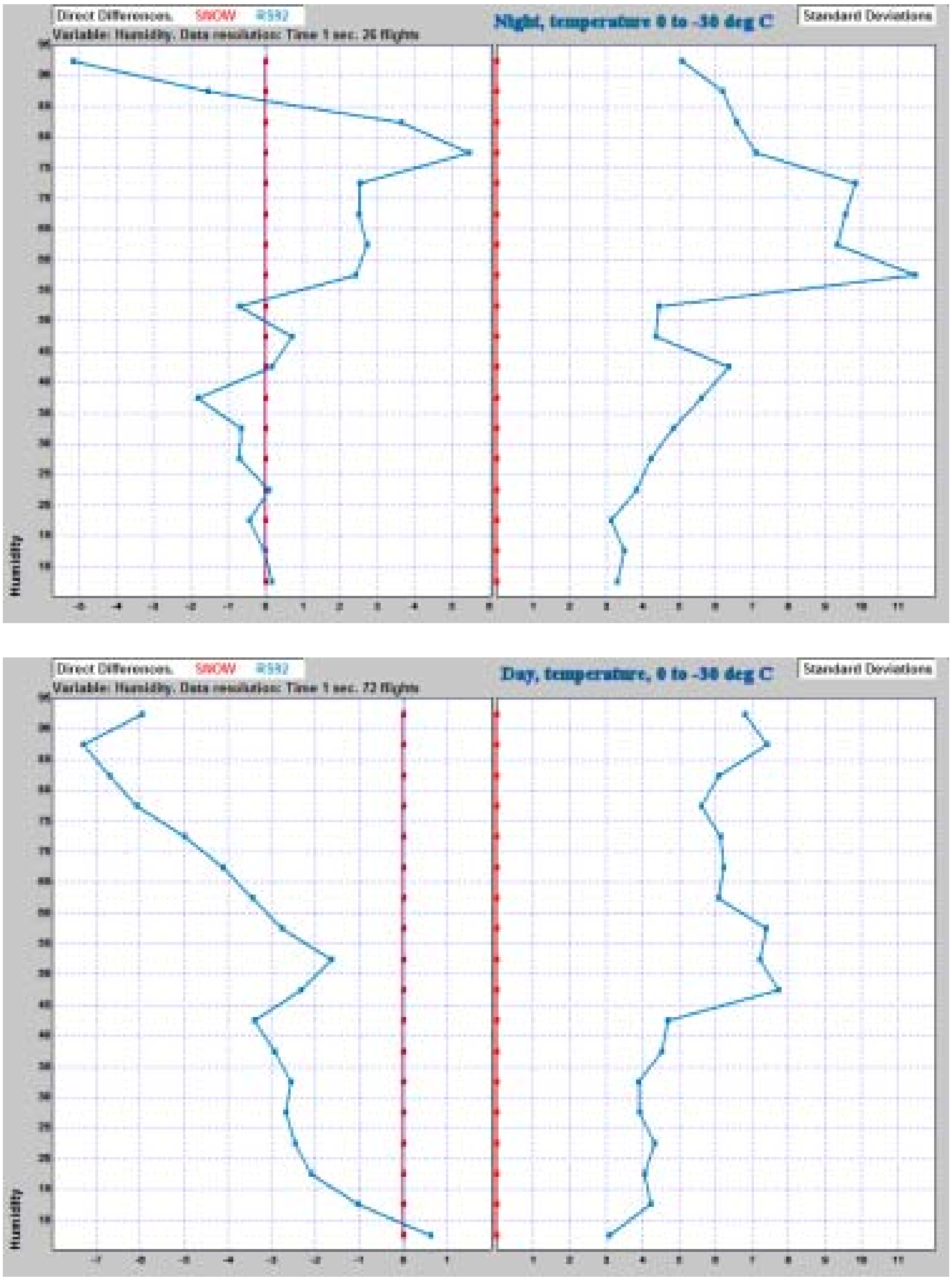


Figure 6- Similar plots to Fig.5 but for the temperature range 0 to -30 °C

In Fig.6 the typical day–night difference for this temperature range, centred at about 70 per cent was about -6 per cent relative humidity. At night both sensors agreed on average to better than 2 per cent. The standard deviations between the measurements were consistent with random errors in individual sensor of between 3 and 7 per cent. Some of this may have been due to oscillations in Snow White dewpoint, but some of the variation will be induced by the response to changes from wet to dry layers [contamination in the Snow white ducts, hysteresis in the capacitative sensors].

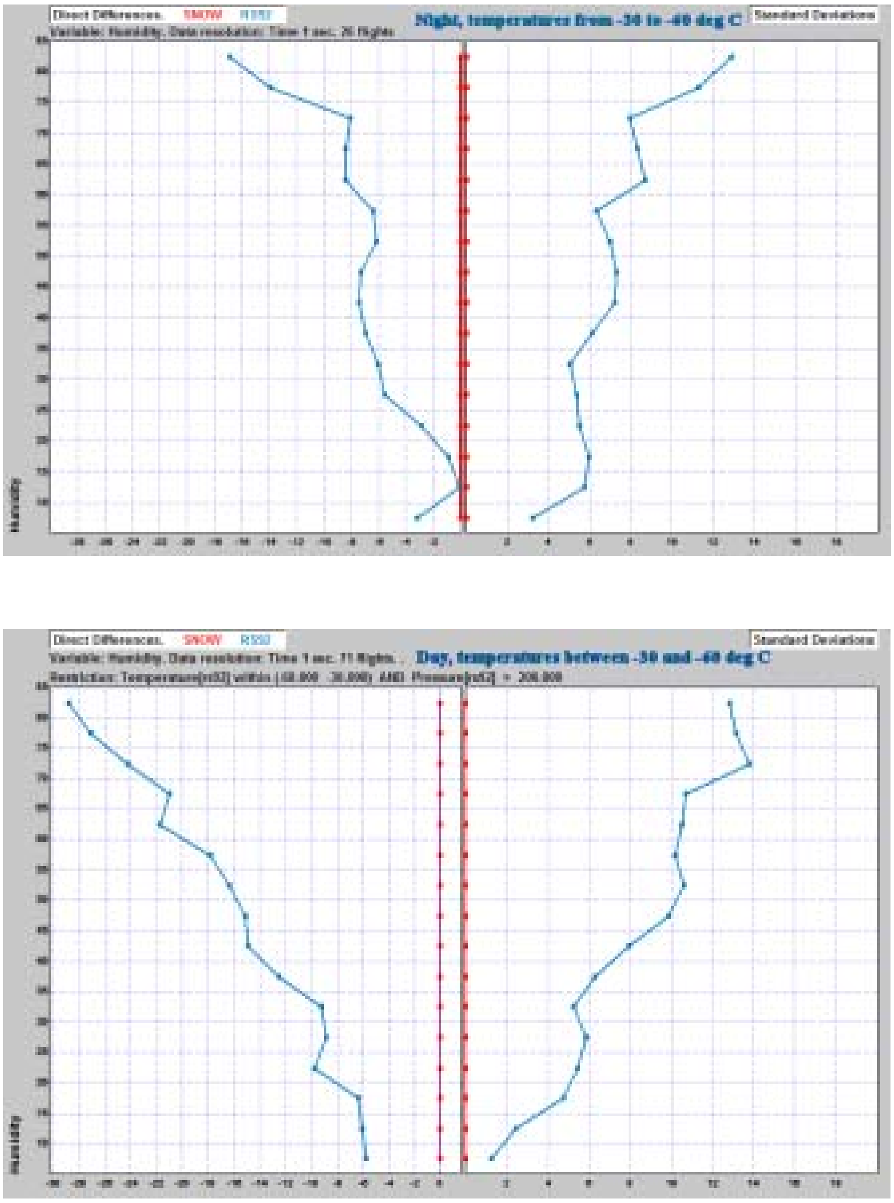


Figure 7- Similar plots to Fig.5 but for the temperature range -30 to -60 °C

In Fig.7 the typical day–night difference for this temperature range, centred at about 60 per cent was about -12 per cent relative humidity. At night both sensors agreed on average to better than 2 per cent at low relative humidity, but differed by about 7 per cent at 70 per cent relative humidity. In the daytime the differences at 70 per cent had increased to about 20 per cent. The standard deviations between the measurements at all but the highest relative humidity were consistent with random errors in individual sensor of between 3 per cent at low relative humidity to up to 8 per cent at high relative humidity. Some of the higher random errors may have been due to oscillations in Snow White dewpoint, but not all.

Throughout the test GPS water vapour measurements and microwave radiometer measurements of integrated water vapour were available both at night see Fig. 8 and during the day see Fig.9

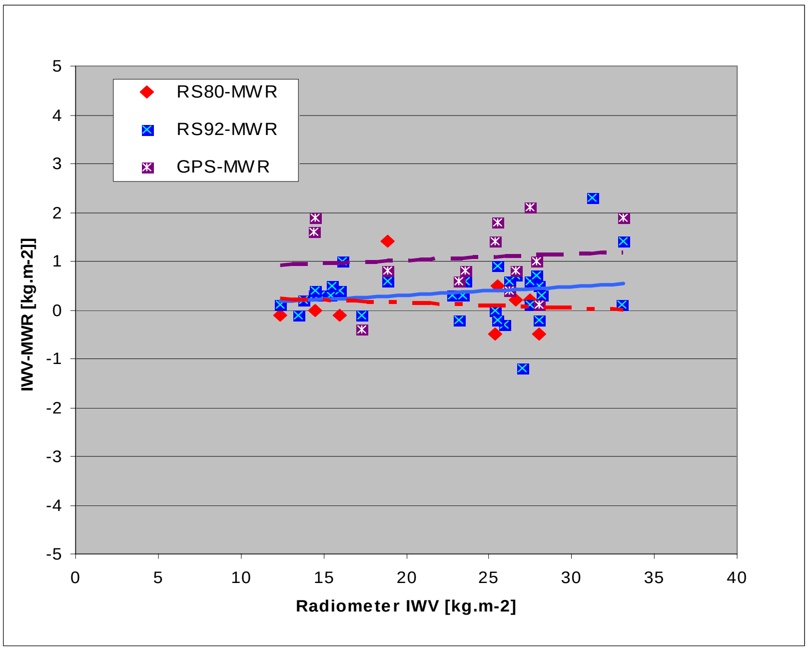


Figure 8- Night time differences between radiosonde and GPS integrated water vapour measurements from simultaneous Radiometrics microwave radiometer measurements when it was not raining, RS92 Acceptance Test, Camborne.

In Fig 8 the night time radiosonde measurements were in close agreement with the microwave radiometer measurements, whereas the GPS water vapour measurements had a positive bias of about 1 kg.m^{-2}.

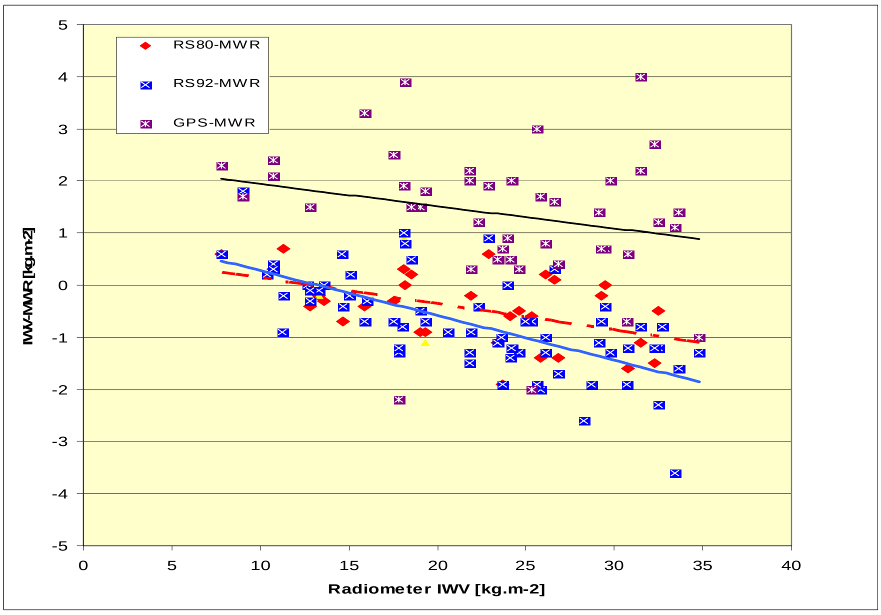


Figure 9- Daytime differences between radiosonde and GPS integrated water vapour measurements from simultaneous Radiometrics microwave radiometer measurements when it was not raining, RS92 Acceptance Test, Camborne.

In the daytime, Fig.9, the RS92 radiosonde measurements show a negative bias of about -1.3 kg.m^{-2} for IWV of 30 kg.m^{-2}. This would be equivalent to a negative bias of about 4 per cent relative humidity on average through the lowest 4 km of the troposphere. The temperature at 4 km during the test was normally in the range 0 to -10 °C. This value appears consistent with the day-night biases in RS92-Snow White comparisons, if nearly all the day-night difference in Fig. 5 and 6 were originating in a change in the RS92 humidity sensor performance.

A 78GHz cloud radar was operated during the test flights for most of the test. This allowed the presence of upper cloud to be monitored.

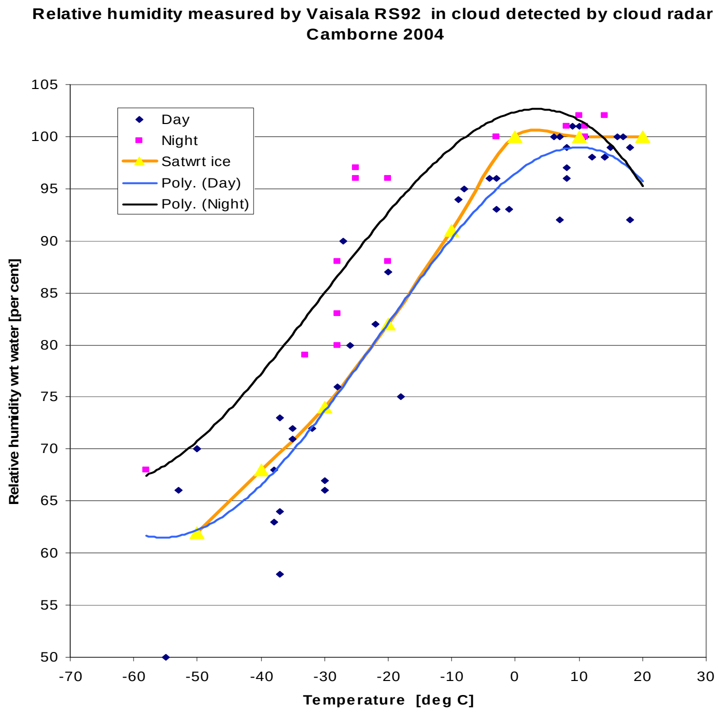


Figure 10- Maximum relative humidity observed at level of cloud detected by cloud radar, RS92 Acceptance Test, Camborne

Fig 10 shows the maximum values observed in layers of cloud or fog identified by the cloud radar. The results above 0°C are again consistent with a day-night difference of about 3 per cent in Vaisala measurements. Most of the mid-level cloud was observed at temperatures around -30°C. Fig.10 shows a clear day-night difference in the relative humidity measurements of about 10 per cent. This was again consistent with most of the day-night difference in Figs 6 and 7 originating from a day-night difference in the Vaisala measurements. Fig.10 shows that at -35°C the daytime relative humidity measurements were about 5 per cent lower than saturation with respect to ice. The night time relative humidity in cloud centred at -20°C was about 10 per cent higher than saturation with respect to ice, but this may be correct because of supercooling in some of the clouds.

<u>Height and wind analysis</u>.

Figure 11 shows the direct differences and standard deviation for simultaneous comparisons of geopotential height including the Graw DFM97 GPS (reference, blue), the RS92 GPS (green) and the RS80 (black). The GPS height reported by the Graw radiosonde was converted from geometric to geopotential height before comparing against the two Vaisala radiosondes. As can be seen from the left hand plot the RS92 geopotential height is within 5 meters of the Graw GPS height from the surface to burst.

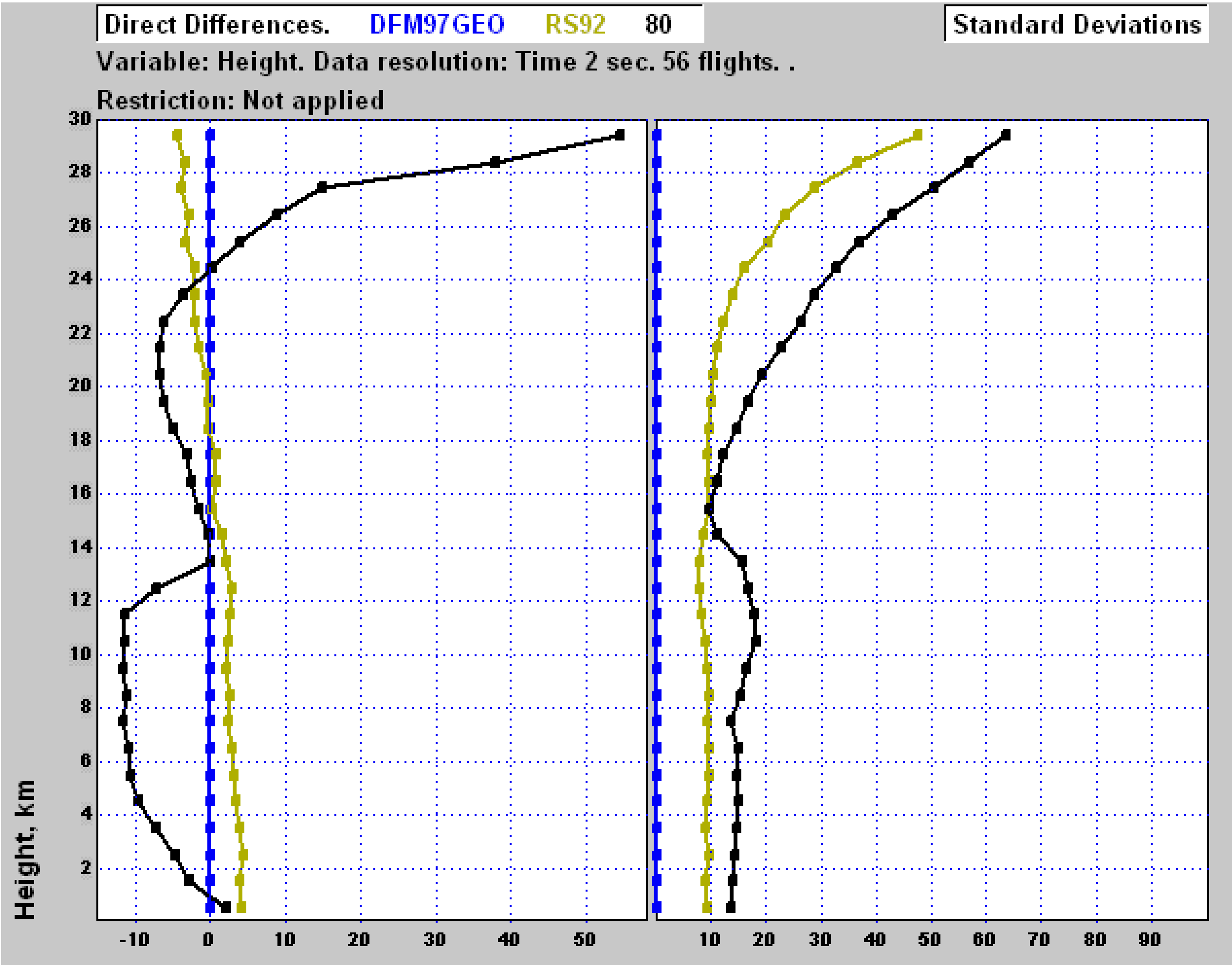
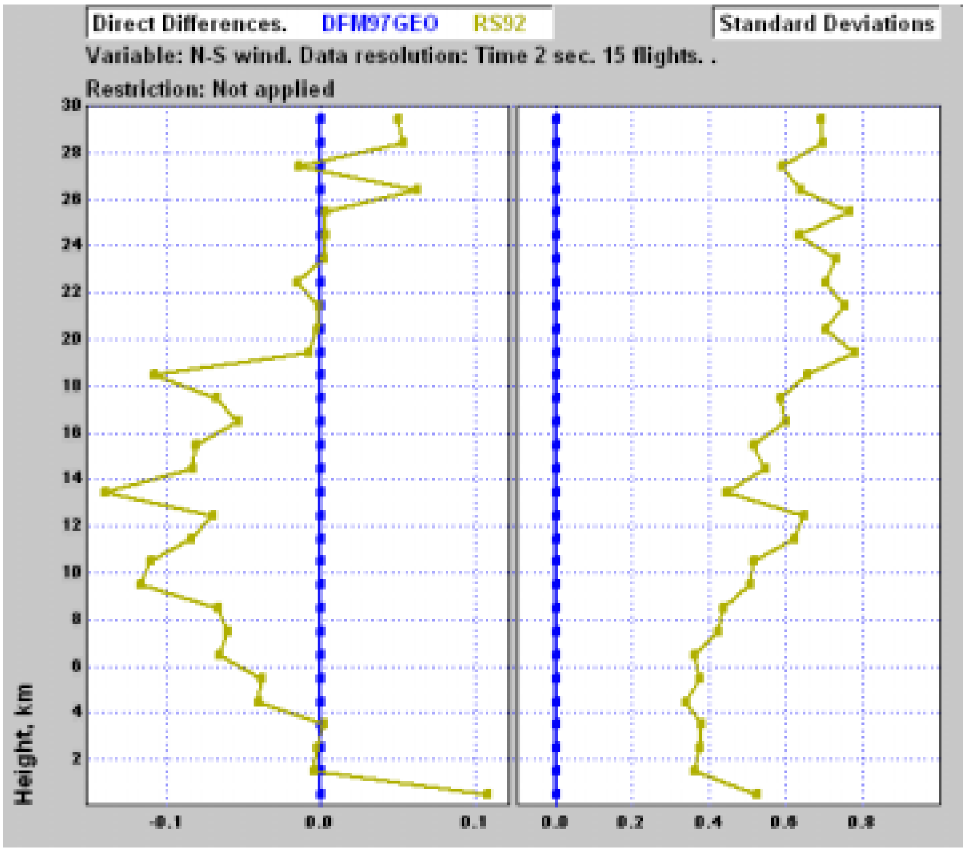


Figure11- Simultaneous comparison of geopotential height, RS92 acceptance test, Camborne, Left hand pane direct differences, right hand pane standard deviations

The accuracy of the GPS heights is not expected to vary significantly with height, so the rapid increase in the standard deviations at heights above 24 km for the RS92 was caused by the random errors in the RS92 pressure sensor. This suggests that the random errors in Vaisala RS92 pressures near 10 hPa were less than 0.1 hPa.

Figure 12, shows the direct differences in the North- South and East-West wind components between the Graw DFM97 (reference, blue) and the RS92 GPS (green).
These results show larger standard deviations than in previous trials. It is probable that the basic smooting of the Graw winds has changed, since if the winds are averaged in the vertical the standard deviations in the comparison have values around 0.1 ms^{-1}.



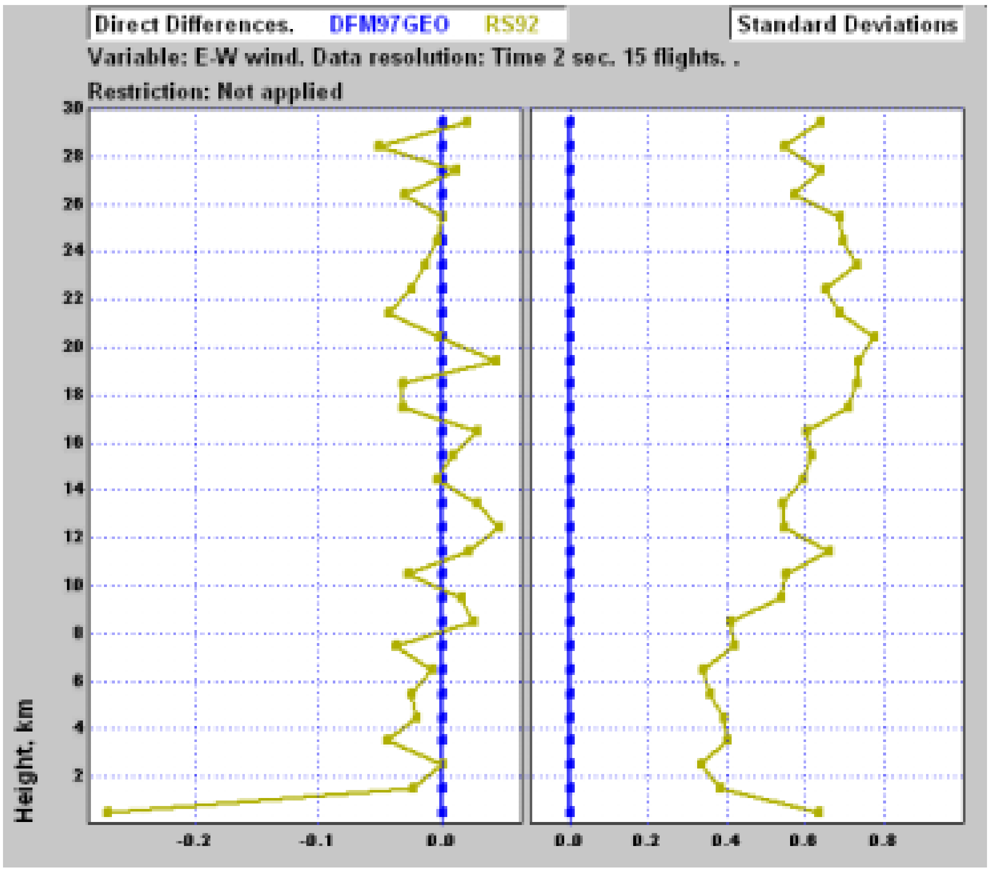


Figure12- Simultaneous comparison between wind components as a function of height, presented as systematic difference, left hand pane and standard deviations, right hand pane.

Temperature measurement

The main purpose of the temperature comparisons was to check the correction of Vaisala RS92 daytime measurements against a reference provided by Sippican 3 thermistor measurements. The thermistors used were Sippican chip thermistors, much smaller than the rod thermistors, so that errors to be corrected were smaller than with the rod thermistor.

Although the five thermistors supplied would usually agree well before launch, once in flight significant discrepancies occurred that were clearly not related to differences in the thermistor coatings. The origin of these differences could have been faulty calibration or variations in radiofrequency pickup between the signal channels on the radiosonde. Thus, in order to produce consistent results the thermistor readings of some sensors were adjusted to values that gave consistent results in the stratosphere. The aluminium sensors required adjustment most often and were most often in error by 0.5 and sometimes 1°C. The adjustment procedure employed relied on knowing the uncorrected temperatures of the Vaisala RS92 and was estimated to limit the reliability of the final multi-thermistor output to an optimum accuracy of 0.2°C at best.

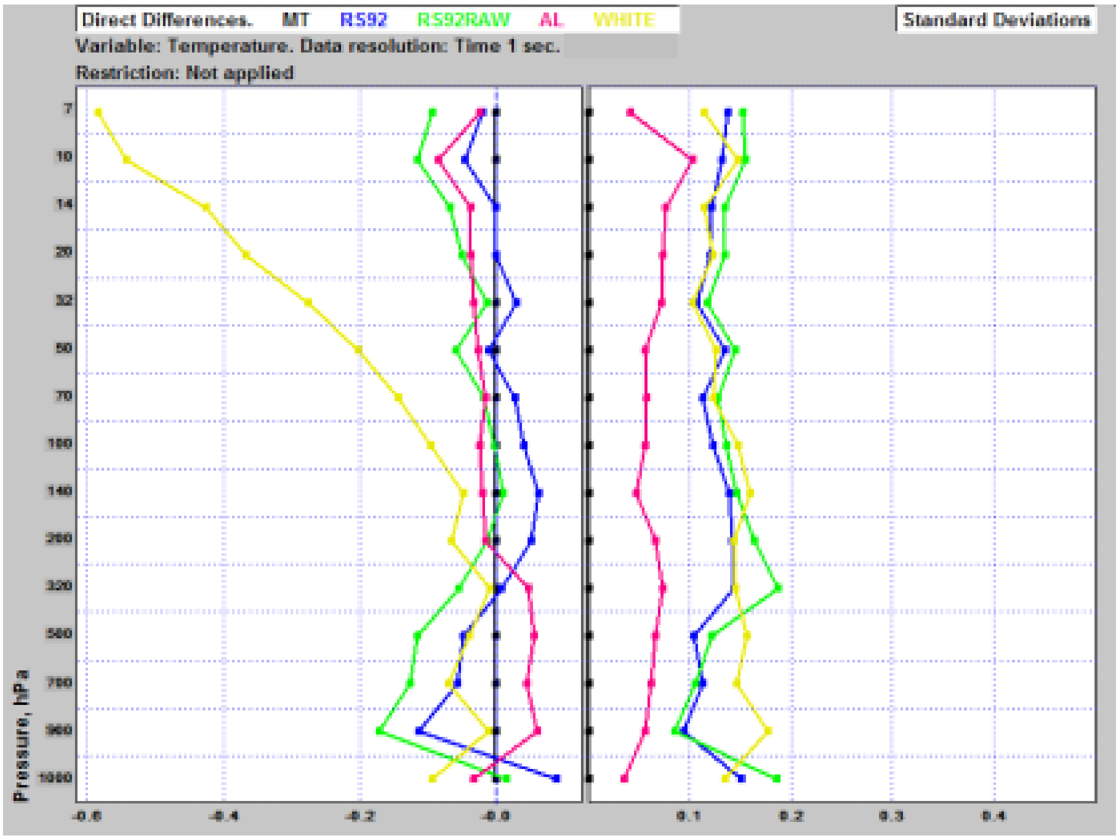


Figure13- Result of simultaneous night time comparisons between multi-thermistor output [black, reference], Vaisala RS92 [blue], Vaisala RS92 raw [green], multi-thermistor aluminium sensor [red] and multi-thermistor white sensor [yellow]. 5 comparison flights. Direct differences as a function of pressure, left hand pane, standard deviations, right hand pane.

The 5 night time comparison flights confirmed close agreement between the multi-thermistor and Vaisala RS92 measurements. The white paint used was relatively black at night so infrared cooling lowered the temperature of this thermistor by about 0.5 °C at night.

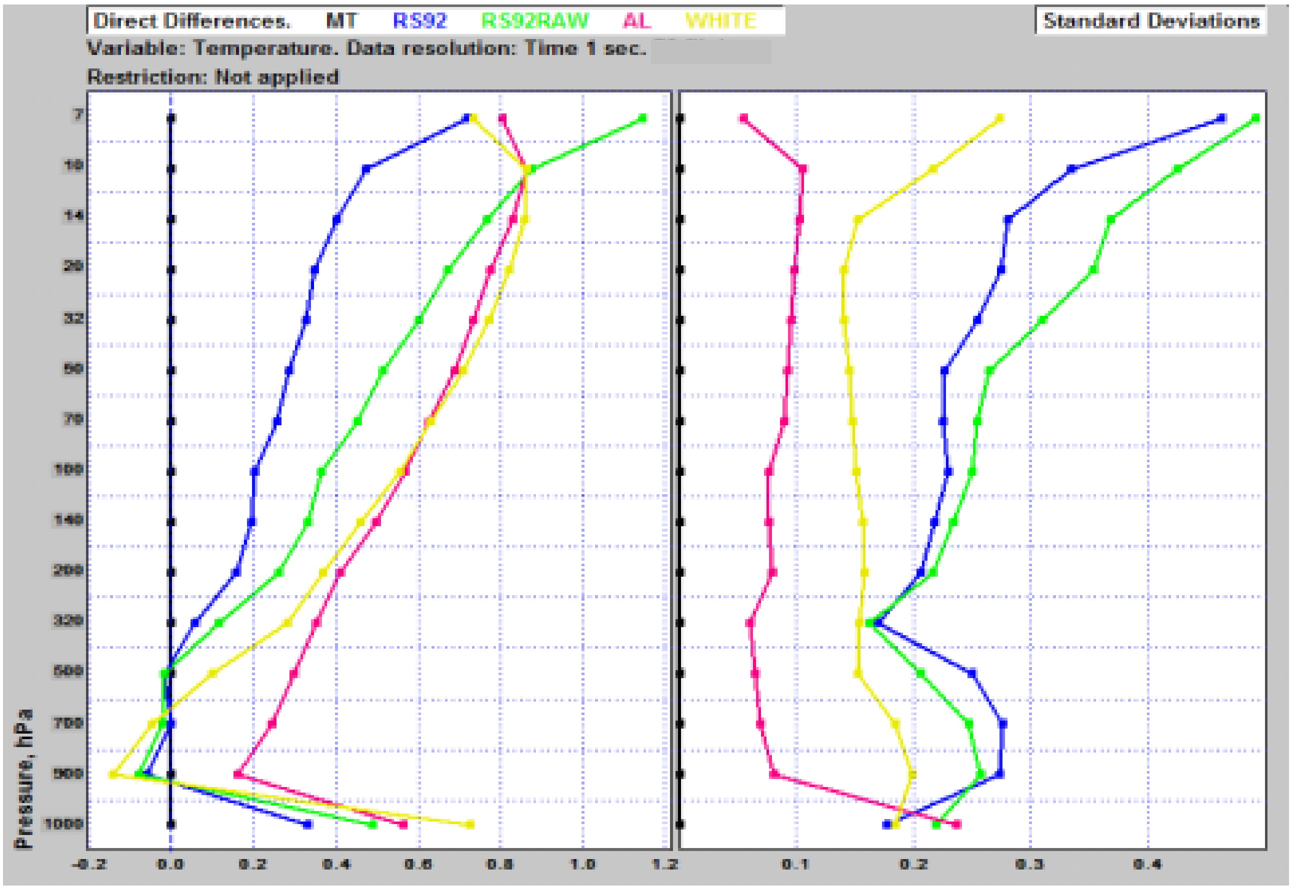


Figure14- Result of simultaneous daytime comparison between multi-thermistor output [black, reference], Vaisala RS92 [blue], Vaisala RS92 raw [green], multi-thermistor aluminium sensor [red] and multi-thermistor white sensor [yellow]. 14 comparison flights. Direct differences as a function of pressure, left hand pane: standard deviations, right hand pane.

In the daytime, the uncorrected 3 thermistor measurements were close to the Vaisala RS92 uncorrected measurements. In the stratosphere, the Vaisala measurements showed heating spikes of up to 1 °C [probably air heated by the sensor support frame passing onto the sensor] as the radiosondes rotated. The Sippican chip thermistors, deployed pointing upwards above the supports, did not show temperature variations correlated with radiosonde rotation. The Vaisala editing process removed most of the heating spikes, and this is probably the main reason why the standard deviations associated with the Vaisala RS92 in Fig.14 are lower than for the Vaisala raw in the stratosphere. If the Sippican 3 thermistor computation is correct then the Vaisala RS92 needs larger temperature corrections than are currently applied, with the correction twice that currently applied at 10 hPa.

Frequency Drift

One of the factors influencing the version of the Vaisala RS92 radiosonde in the long term is the radiofrequency characteristics of the transmitter.

	RS80	RS92-SGP	RS92-AGP
Number of Flights :	46	77	45
Total drift (MHz) :	5.911	0.291	0.020
Maximum drift (MHz) :	0.700	0.270	0.003
Mean drift (MHz) :	0.1285	0.0038	0.0004
Flights with drifting :	40	13	11
Flights with no drifting :	6	64	34

Table 1- Summary of the stability of radiosonde transmissions, RS92 Acceptance test

Conclusions

During the UK RS92 radiosonde acceptance test, not only was the new Vaisala radiosonde exercised but also new versions of systems from Graw, Meteolabor and Sippican. It is hoped that this will lead to improved performance of all these systems.

In particular, a diurnal heating problem with the relative humidity sensor of the Vaisala RS92 was quantified. It has subsequently been identified that the heating of the humidity sensors in daytime was exacerbated by the coatings on some of the surfaces close to the sensors. Vaisala will change these coatings for the WMO Radiosonde Comparison in Mauritius and for future operational versions of the RS92 radiosonde.

Similarly, the Vaisala day time temperature correction software will be modified for the Mauritius test.

References

[1]Paul Ruppert, Manager, Meteolabor AG , Hofstrasse 92, CH-8620 Wetzikon, Switzerland; email: paul.ruppert@meteolabor.ch
[2]Sergey Kurnosenko, Scientific software consultant; email: skurnosenko@cox.net

THE EVOLUTION AND DEVELOPMENT OF THE UNITED STATES NATIONAL WEATHER SERVICE UNIVERSAL RADIOSONDE REPLACEMENT SYSTEM

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ABSTRACT

The National Weather Service has been using a radiosonde "Universal Ground System" for close to 20 years. The development of the new 1680 MHz Global Positioning System ground receiver evolved through the interfacing of different vendor's radiosondes with the Radio-direction finding systems in use for the past 45 years. The basis of a universal system is that a given radiosonde signal can be received by a generic ground receiver, the engineering units for thermodynamic variables changed to meteorological units in a signal processor, and the output interfaced with a system computer to generate WMO coded messages. It is possible to use different radiosondes with a generic ground receiver and processing software without end-to-end specification. However, the use of pre-defined interface standards between a vendor's radiosonde and a generic ground receiver, the ground receiver and a specification compliant vendor provided signal processing system, and the interface between the signal processor and generic workstation data processing software ensure successful integration. This paper will detail the operational use of the early universal system by the National Weather Service, prototype development of a dual frequency navigation aided system (Omega and Loran-C) in the early 1990s, and the subsequent universal Global Positioning System radiosonde system the National Weather Service is deploying.

1. INTRODUCTION

The NOAA National Weather Service (NWS) is developing a Radiosonde Replacement System (RRS) to replace its old Microcomputer Automatic Radio-theodolite (Micro-ART) system. The RRS is comprised of a new Global Positioning System (GPS) tracking antenna referred to as the telemetry receiving system (TRS), 1680 MHz GPS radiosondes, a new workstation, and software. The requirement to use GPS with the 1680 MHz frequency was a technological challenge in combining of the GPS L1 frequency with the 1680 MHz Meteorological Aids frequency.

The RRS is required to:

Comply with Government direction to reduce radio frequency use.

Maintain or increase system availability and data accuracy.

Provide high resolution data to users.

Increase amount of data provided to users.

2. BACKGROUND

The earliest automated upper-air sounding systems used radio direction finding (RDF) of the radiosonde signal's emanating position in azimuth and elevation to acquire thermodynamic data as well as determine wind speed and direction of the radiosonde. The NWS has been using using the 1680 MHz band with its RDF system almost exclusively for 50 years with minimal interference from other users. Until 1986, the NWS relied on radiosondes from one vendor to supply the network. With the upgrade of the old Automatic Radiotheodolite (ART) wind finding minicomputer-based system to the Microcomputer Automatic Radio-theodolite (MicroART) was the introduction of the microcomputer interface card (ARTIC). The ARTIC card converts received signals from the radiosonde ground receiver into meteorological units. These meteorological units were subsequently input to the microcomputer for data processing into WMO coded messages. The introduction of the upgraded system with the microcomputer and ARTIC card enabled the participation of more than one radiosonde provider to satisfy the NWS radiosonde requirements. In 1987, VIZ and Space Data became qualified providers of radiosondes to the NWS. In the early 1990s, Vaisala also became a qualified provider. Their radiosonde required modification to interface with the NWS ground receivers and was not compatible with the ARTIC card interface. Vaisala provided the interface between the ground receiver and the microcomputer with the Vaisala Signal Processing Unit (SPU-11). This adaptation has been in use since the mid-1990s and has proven reasonably successful although it did much more than just change engineering units to meteorological units through the use of transfer equations. The use of ARTIC interface card and the Vaisala SPU-11 interface with the ART ground receivers and MicroART software enabled flying radiosondes from multiple manufacturers. This has been beneficial in that it provided two sources of radiosondes by two procurements, encouraged manufacturers to offer the best prices, and stimulated product improvements. Figure 1. is an example of the

ART-1, a Military GMD-1 that is over 45 years old and a key component in the aging network.

Figure 1. NWS ART-1 Ground Receiver

2. NETWORK REPLACEMENT CONSIDERATIONS AND REALITIES

In response to the end of system-life, parts obsolescence, increasing repair costs, and the limitations of the RDF technology to accurately determine winds without transponder capability over much of the mid-latitude part of the network where jet streams are prevalent during the winter season, the NWS set out to replace the existing radiosonde network. A key requirement was the ability to fly multiple radiosonde types from competing manufacturers. This would allow the NWS to continue purchasing expendable radiosondes through contract awards at competitive pricing.

The requirement to fly competing vendor radiosondes marked reversal from the trend that has been in place since the early 1990s when radiotheodolites were largely displaced internationally by NAVAID systems. With the introduction of the first OMEGA systems, ground stations became integrated end-to-end by the same vendor. Multi-sonde compatibility disappeared and operators were faced with single-source radiosonde suppliers without competitive pressures after initial system investment.

The variety of NAVAID systems increased (OMEGA, Loran-C, coded/uncoded GPS) and the expendable navaid radiosondes became increasingly linked to the accompanying ground stations and vendor source code and processing systems.

Operators were also exposed to situations where manufacturers discontinued the only compatible radiosondes, making high cost ground stations instantly obsolete (the demise of OMEGA and the demise of the AIR IS-4A are two examples). This forced operators to make untimely, costly, and unproven technology changes ahead of schedule. Very Low Frequency windfinding systems that were deemed as adequate replacements for the OMEGA radiosondes and early GPS radiosondes were problematic. The data using community was the recipient of low quality data to no data for many of the radiosonde flights.

Commercial off-the-shelf Radiosonde system versus new system development

An assessment of readily available commercial off the shelf (COTS) radiosonde systems versus a development effort established the direction the NWS would follow with network replacement. Technology Management Corporation (TMC) was awarded a contract in 1991 to:

> Determine core requirements of the NWS upper air system of the future.
>
> Assess alternative commercially available upper air systems.

TMC evaluated five vendor's systems and determined that:

> No COTS approach supported multiple radiosonde vendors with one vendor's ground receiver and software.
>
> A reception range of 250km between the radiosonde and ground receiver was not possible with COTS systems

National Center for Atmospheric Research (NCAR) Next Generation Upper-Air Sounding System (NEXUS) Prototype Development

NEXUS was a prototype development effort between the National Weather Service and the NCAR. The purpose of the development for a navigation aided radiosonde sounding system was to determine the feasibility of a flexible, modular system design for radiosonde support, launch operations, wind-finding, and systems software. The developed prototype supported radiosondes from three manufacturers in both the 400 and 1680 MHz frequency bands. The wind-finding implementation was supported by Loran-C and OMEGA navigation aided (NAVAID) techniques. The system electronics were modular and adaptable to the emerging GPS wind-finding technique.

The requirements for the prototype follow:

> Support radiosondes from multiple vendors.
>
> Support both 403 and 1680 MHz frequency bands.

Support Loran-C and OMEGA navaid wind-finding and GPS as technology became available.

Employ automatic radiosonde tracking in both 400 and 1680 MHZ frequency bands.

Demonstrate semi automated balloon launcher.

One-person operation.

The NAVAID radiosondes used with the NEXUS were available in both 400 and 1680 MHz. An antenna and telemetry receiver switch allowed for easy selection and control of the hardware for either frequency type. For 400 MHz radiosondes, a 70 degree beam-width vertically polarized Yagi antenna was mounted on an antenna rotor mast on the system antenna tower. The antenna was pointed upward approximately 25 degrees from horizontal. The wide beam width provided signal reception from low to high elevation angles. The 400 MHz telemetry receiver had wide-bandwidth, and was digitally synthesized.

The 1680 MHz radiosondes were tracked using an electronically steerable, phased array patch antenna. Two identical antennas were mounted on the same tower as the 400 MHz Yagi antenna. Each antenna, through a phasing technique could be electronically steered in azimuth but not elevation. The first of the two antennas was mounted at an elevation angle of 75 degrees to track radiosondes at high elevation angles. The other was 15 degrees off horizontal for tracking low elevation angle portions of flights.

Automatic tracking of the 1680 MHz method as with the 400 MHz frequency used the telemetry receiver to measure the receiver signal strength from the radiosonde. The 1680 MHz antenna was accomplished differently however for elevation. Periodic signal strength measurements were determine for both antennas to determine which of the two antennas, the high angle or the low angle antenna were receiving the stronger signal. The antenna with the stronger signal electronically steered the beam steered the antenna plus or minus four degrees azimuth from the current pointing angle.

The NEXUS modular design was not an open architecture system. It used the stand-alone PTU processors built by the individual radiosonde manufacturers and relied on COTS OMEGA and Loran-C receivers. These decoders acquired and converted the raw engineering data from the sensor suites into meteorological units. The standalone PTU processor concept permitted the NEXUS system to interface with virtually any radiosonde supported by a matching PTU processor. Minimal impact on the system hardware and software would be incurred if a new type of radiosonde was added to the system. Figure 2 is an example of the balloon inflation launcher, and antenna systems for the 403 MHz and 1680 MHz navaid Loran-C and OMEGA systems.

Wind information was input through an RS232 port into the receiver from either the Loran-C or OMEGA navigation signal processor for the navaid wind-finding capability.

The demise of the OMEGA navigation system and the uncertainties of a possible phas eout of Loran-C in the United States in the 1990s turned attention to GPS. The modular architecture of the NEXUS prototype could accept the GPS solution

Figure 2. NEXUS Prototype Navaid System

NEXUS assessment

The NWS carried out a broad assessment of NEXUS over a one-year period from 1993 to 1994 at 17 sites. The sites encompassed a wide variety of weather conditions and differing Loran-C and OMEGA geometries. The prototype system functioned in Loran-C and OMEGA in the 403 MHz and 1680MHz bands. VIZ, Vaisala, and AIR provided radiosondes and signal processing units for the modular integration effort.

The broad band telemetry characteristics of the receiver enabled use of multiple brand radiosondes but also increased vulnerability to interference. There were concerns over the long-term robustness of the prototype electronics and the hand-built 1680 MHz antenna required redesign for manufacturing. The Navaid receivers were obsolete and Loran-C and OMEGA were being replaced by GPS. The thermodynamic processors were essentially black-box configurations but proved the modular concept of decoder cards to isolate proprietary signals from main software. The NEXUS software while rich in functionality was developed as a research and prototype tool and was not of operational quality.

3. POST NEXUS REQUIREMENTS VALIDATION

Industry Request for Information

The NWS placed a Request for Information with industry to assess the state of development of radiosonde systems and to determine the best value approach. The basic information received was primarily vendor's proposals to sell existing closed architecture systems that would not facilitate the ability to fly multiple vendor's radiosondes with one generic ground system.

A reevaluation of the advantages of a COTS turn-key option was performed during 1995-1996. A turn-key approach would incur lower integration, schedule, and cost risks, but also had significant disadvantages. The COTS systems would not support anticipated radio spectrum limitations and other NWS requirements, and did not allow for follow-on competition for radiosonde purchases. The turn-key option was dropped.

Radiosonde Frequency Study

The Joint Spectrum Center surveyed both the 401-406 MHz band and the 1675-1700 MHz band for the NWS. After reviewing the density of the NWS sites and the heavy use of the 403 MHz band by the military and other civilian operations, the Joint Spectrum Center recommended use of the 1675-1683 MHz band for radiosonde operations.

Radio Direction Finding Versus GPS for Radiosondes

While a dual mode system (RDF/GPS) would provide lower operating costs, the advantages of GPS for mid-latitude operations were greater than potential cost savings from a dual mode system. The system specifications contained performance parameters only supported by GPS. The decision however to operate the radiosonde in the 1680 MHz band required a parabolic reflector to achieve the 250km range. The parabolic antenna was not optimized for good RDF performance.

4. RADIOSONDE REPLACEMENT SYSTEM ACQUISITION APPROACH

The acquisition approach was to develop a Radiosonde Replacement System comprised of a Telemetry Receiver System, Radiosondes and Signal Processing Systems, Software development support, Surface Observing Instrumentation, and a Balloon Inflation and launch shelters. Figure 3 depicts Radiosonde Replacement System and the sub-systems.

A contract was awarded to International Met Systems to build the Telemetry Receiver Systems (TRS). Some of the characteristics are that it has a 2 meter diameter parabolic dish, is lightweight in construction, and has a 19 inch environmentally controlled rack pedestal that contains the Signal Processing System. The unit is known as the IMS 2000. Figure 4 illustrates components of the basic telemetry receiver system.

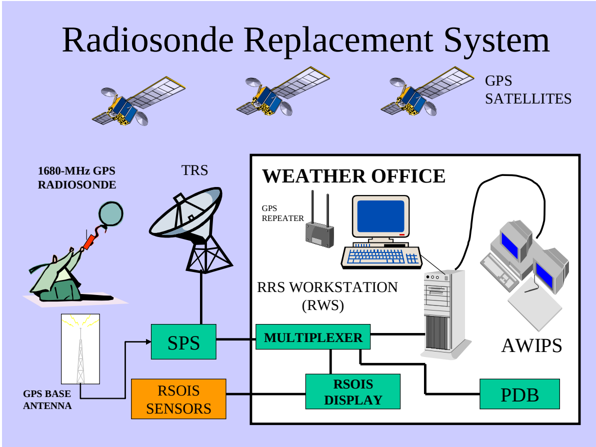

Figure 3. Radiosonde Replacement System

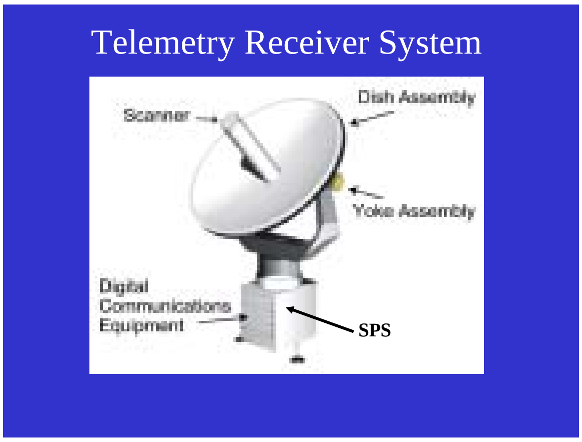

Figure 4. IMS Telemetry Receiver System

Figure 5 shows the IMS 2000 with the added wide angle antenna affixed to the top of the large parabolic antenna. The wide angle antenna is used for close-in automatic lock-on to the radiosonde signal at release.

Other efforts directly related to RRS are the software and workstation, and the radiosonde and signal processing system (SPS). The purpose of the SPS is to acquire radiosonde PTU telemetry data and the radiosonde GPS position data from the telemetry receiver. The SPS processes Global Positioning Data for use in wind finding and any necessary processing for position accuracy and error correction. The SPS generates raw data from the data transmitted by the radiosonde. The SPS in turn interfaces with the Government developed and operated computer system using specified communication protocol to transmit data, report subsystem status and process control commands.

One of the major features of the RRS is the use of state-of-the-art GPS radiosondes operating in the 1680 MHz radiosondes frequency band. Until recently, commercial systems/radiosondes sold worldwide were operated in the 403 MHz frequency band. The interfacing of the GPS technology with 1680 MHz radiosonde transmitters created technological challenges for the commercial vendors. Two vendors,

Figure 5. IMS 2000 Radiosonde Ground Receiver

Intermet and Sippican have produced functional radiosondes and Vaisala is in the process of qualifying a radiosonde and Signal Processing System for the TRS. Vaisala has demonstrated that their developmental SPS functions with the TRS and the Vaisala 1680 MHz GPS radiosonde prototype. radiosonde. The combining of the GPS with the 1680 MHz was not as difficult as envisioned. However, different sensor technologies have required extensive testing and evaluation.

The software development for the workstation will allow for continuous monitoring of a flight. The RRS design maximizes data acquisition capabilities for all angles of radiosonde position with respect to the ground system to include very low elevation angles associated with high winds aloft or at zenith.

5. STATUS AND CONCLUSIONS

Operational Acceptance Testing of the RRS will commence this summer. As testing commences, prior to full-commissioning, the flights will become official synoptic flights of record.

A contract has been awarded to Sippican to provide the early GPS radiosondes for the operational network.

New procurement activities are underway to establish the next Qualified Products List for the next radiosonde procurement. The next procurement will include the radiosondes and their respective signal processing systems.

The combined GPS radiosonde receiver and the 1680 MHz transmitter do not interfere with each other. With the GPS capability, it is routine to get accurate winds during the most extreme wind conditions.

The open architecture approach to radiosonde systems is already in operation. The NWS contracted with Intermet to provide ten IMS 1500 ground receivers for the Caribbean Hurricane Upper Air Stations. Intermet assembled a system using Sipican B-2 radiosondes, the Sippican SPS for RDF radiosondes, and Intermet software to process data and produce WMO coded messages. This system configuration works well in the tropical and sub-tropical areas where high wind speeds are not encountered.

UNIVERSAL UPPER AIR SOUNDING SYSTEM

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1. INTRODUCTION

The earliest automated upper-air sounding systems used RDF wind finding and were able to track qualified radiosondes from multiple manufacturers. Examples include the ART-1 and ART-2 systems employed by the U.S. National Weather Service (NWS). By being able to fly sondes from multiple manufacturers, the NWS has been able to purchase disposables using competitive auctions. Competition has encouraged manufacturers to offer the best prices and has stimulated product innovation.

When the NWS decided to replace the ART ground systems, a key design specification was the ability to fly multiple sondes from competing manufacturers. This would allow the NWS to continue purchasing disposables through competitive auctions.

The requirement to fly multiple sondes marks a reversal from the trend that has been in place since the early 1990s when radiotheodolites were largely displaced by NAVAID systems. With the introduction of the first OMEGA systems, ground stations became integrated with radiosondes made by the same vendor. Multi-sonde compatibility disappeared and operators were faced with single-source suppliers without competitive pressures.

As the variety of NAVAID systems increased (OMEGA, Loran-C, coded/uncoded GPS) disposables became even more linked to the accompanying ground stations. After the initial ground station competition, there was little motivation for manufacturers to offer low prices for disposables - or to improve product performance. This led to conditions where operators were paying high prices for products with high failure rates.

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Operators were also exposed to situations where manufacturers discontinued the only compatible radiosondes, making high cost ground stations instantly obsolete (the AIR IS-4A being one example). This forced operators to make costly ground equipment upgrades ahead of schedule.

2. THE UNIVERSAL SYSTEM

In 1999, International Met Systems (InterMet) was awarded a contract to design and build the Telemetry Receiving System (TRS) to replace the ART systems. The resulting IMS-2000 fulfilled all NWS specifications including the requirement for multi-sonde compatibility. The ground station is currently being used with the Sippican Mark IIA and the InterMet model 3010 radiosondes. A new round of qualifications is underway which is expected to see a new InterMet sonde (the iMet 1) and a version of the Vaisala RS92 qualified for use along with the Mark IIA.

After completion of the IMS-2000, InterMet adapted the multi-sonde capability to its existing IMS-1500 radiotheodolite. The 1500 is currently being used at 20 synoptic sites with Sippican Mark II and B2 radiosondes, as well as the IMD-Mk IV manufactured by the India Meteorological Department. The 1500 is also capable of flying the Sippican Mark IIA and the InterMet 3010. Figure 1 shows the IMS-2000 and the IMS-1500 systems. The 2000 is a 2-meter, high gain system designed for fixed installations within a radome. The 1500 is a smaller, lower gain system with a 1.2-meter dish and is designed for portable or fixed installations.

In 2003, InterMet introduced the multi-mode IMS-1600, which integrates 403 MHz GPS capabilities with 1680 MHz RDF. This system was initially developed for military use with the objective of providing complete flexibility for changing field conditions. In 2004, an IMS-1600 was installed for synoptic use in Dar es Salaam, Tanzania under the auspices of the WMO. This system will be a component of the Global Upper Air Network (GUAN).

Figure 1: IMS-2000 and 1500

For purposes of discussion, an upper air sounding system consists of a radiosonde for making PTU and wind measurement, a ground based antenna for receiving data from the radiosonde, and a system computer for controlling the antenna and providing reports and data outputs in various formats. As defined by InterMet, a *universal system* is an upper air sounding system that can use radiosondes from multiple manufacturers. Two other terms also need to be defined to avoid confusion. A dual-mode system is one that can operate in both RDF and GPS wind finding modes. The IMS-1500 and 2000 both have this capability. A multi-mode system is one that operates in both 1680 MHz RDF and 403 MHz GPS modes. The IMS 1600 falls into this category. In this paper, we will be restricting discussion to the universal system, with references to the other modes where appropriate.

The purpose of this paper is to describe the technical challenges of implementing the universal system concept and to discuss the benefits and drawbacks of this approach. The central question is whether universal RDF systems can provide high quality met data at a meaningfully lower life-cycle cost than the GPS systems widely in use.

3. TECHNICAL ISSUES

An upper air sounding system performs four distinct functions:

- Sonde tracking
- Telemetry reception and decoding
- PTU/Wind data processing
- Report generation

Each of these will be discussed below.

Sonde Tracking

The InterMet radiotheodolites use solid state scanners to track radiosondes transmitting in the 1680 MHz meteorological band. The 1500 scanner is vertically polarized while the 2000 uses left-hand circular polarization. Gain and range depend on dish size, with the 2000 achieving 26 dB and a range of up to 300-Km (22dB and 250 Km for the 1500).

Radiosonde transmitters vary widely in the stability of the carrier signal tracked by the antenna. Older designs such as the IMD MK-IV have free running oscillators with relatively poor control over signal stability and relatively high bandwidth requirements. More modern sondes have crystal controlled oscillators that are very efficient and require much less tracking bandwidth.

In order to track sondes with widely different transmitter characteristics, InterMet developed a software controlled digital receiver. When tracking the IMD-Mk IV, the receiver is set to its maximum bandwidth of 1,000 kHz. When used with a more efficient transmitter, the bandwidth is narrowed to as little as 50 kHz to increase performance and gain. This allows the InterMet theodolites to track virtually every 1680 MHz sonde currently being built.

Telemetry Reception & Decoding

Every sonde uses a unique methodology for encoding PTU data before transmission. This coded data stream is passed from the antenna's receiver to a decoder, or signal processing system (SPS). The SPS is a proprietary device that decodes the PTU data on the ground. Most modern decoders consist of single board computers with onboard power supplies and flash memories. They can be free standing or rack mounted.

For a radiosonde to be compatible with the universal systems, the inputs and outputs of the decoder must conform to the requirements of the tracking antenna. As long as these requirements are met, the only hardware required to introduce a new radiosonde is the appropriate decoder.

Portability of the SPS is a critical requirement for the universal concept since it allows the manufacturer to retain control over proprietary methodologies and ensures that the sonde will produce the specified PTU output regardless of the system used to receive the telemetry. The sonde coding and decoding remains a closed system under control of the manufacturer that is indifferent to the antenna used to receive the data and calculate winds.

In a competitive market, manufacturers could provide decoders in a variety of ways including leases, outright sales or loans with the cost included in the sonde price. For example, if an operator purchased sondes for a 12-month period, the manufacturer would lend or lease the decoder for the same interval. If a new sonde was purchased for the next annual period, the decoder would be returned to the manufacturer.

PTU/Wind Data Processing

Each sonde has its own requirements for data corrections and smoothing in order to produce PTU data that meets the accuracy requirements specified by the manufacturer. The most common correction is for solar heating of the temperature sensor during daylight flights. Infrared corrections for day and night flights may also be required. Every sensor has unique solar and infrared correction algorithms that must be applied in either the SPS or the operating system. Although it would be desirable to have this happen within the proprietary confines of the SPS, this has not been done up till now because today's SPSs do not have the information needed to determine if the corrections are needed (e.g., the date, time of day, station coordinates). Since today's SPS are "dumb" and have no ability to communicate interactively with the system computer, there is no way to pass the necessary data or commands.

Similarly, a sonde's PTU sensors may have proprietary functions to smooth the data or make other corrections. This information must be included in the system computer so it can be called up when the sonde is flown.

To protect proprietary information, the SPS could include the solar/infrared corrections as well as any other corrections and smoothing (e.g., wind) if the system computer is designed to provide the required information to the SPS. There is no technical reason why data smoothing and correction cannot be accomplished in the system computer or the SPS. The question relates more to proprietary concerns where manufacturers may hesitate to disclose techniques used to process raw data.

Report Generation

The creation of standard met messages, graphic outputs, etc., is well defined and relatively simple. Once the PTU data is decoded and processed, there are no longer any sonde-specific aspects and the information can be consistently reported. Data editing can also be performed on the output of any sonde.

4. OPERATIONAL ISSUES

There are a number of operational issues that need to be considered to be sure a universal system can be used effectively:

- Calibration coefficient input
- Transmitter frequency control
- Sonde initialization and baselining
- Data quality assessment and adjustments
- Ease of use

Calibration Coefficient Input

Every radiosonde has its own method for transferring calibration coefficients to the SPS. These methodologies have varied widely and are not a trivial issue.

The Sippican Mark II passes coefficients in the transmitted data stream with no operator input required. The B2 uses 5 1/4" floppy disks, which are obsolete and require hard-to-find disk drives in the system computer. The IMD MK-IV uses 3 ½" floppies or manual input of up to 350 pressure coefficients. The Vaisala RS80 uses a proprietary paper tape that is also difficult to obtain.

InterMet has successfully adapted to three of the methods described above and we see no reason why this will present problems in the future. Ideally, sonde manufacturers would adopt a standard method using the transmitted data stream to eliminate the need for special hardware. Cooperation between sonde manufacturers and InterMet has prevented problems in the past.

Transmitter Frequency Control

In order to cope with interference within the meteorological frequency band, radiosondes need to be able to tune their frequencies within the band. This can be accomplished mechanically or through software control.

InterMet and Sippican sondes use mechanical methods for setting frequencies. These vary from a potentiometer in the Mark II to dip switches in the InterMet 3010 and cut wires in the Mark IIA. These methods require no involvement of the ground station and are ideal for the universal system.

Most GPS sondes currently in use (Modem M2K2, Vaisala RS92, Graw DFM97) employ "umbilical cords" to program their transmitter frequencies, to calibrate the sensors, and to enter pre-flight sensor coefficients. This methodology is not currently in use for 1680 RDF sondes. This method is not optimal for the universal approach but could be accommodated using a USB port on the system computer and sonde-specific software. Again, the essential factor would be cooperation between the manufacturers.

Sonde Initialization and Baselining

Every sonde has different requirements for initialization before flight. This is both a training issue and a technical one. The key distinction is whether the PTU sensors need to be calibrated prior to flight.

NWS specifications for sondes to be flown as part of the Radiosonde Replacement System (IMS-2000) require that temperature and humidity sensors be stable enough not to require calibration before flight (Sippican Mark IIA, InterMet 3010 and iMet 1). Other sondes (Modem M2K2 and Vaisala models) require single point calibration of temperature and humidity using calibrated ground sensors.

All sondes with discreet pressure sensors require calibration with a reference at the release point. This has not presented any problems in the past since all upper air stations have calibrated barometric pressure sensors that can be used for reference. No special device is required and the adjustment is made through software in the system computer.

Temperature and humidity sensors are more problematic since accurate calibration requires a controlled environment with a stable airflow. Vaisala and Modem both offer such calibration boxes as options (Modem) or requirements (Vaisala). Failure to accurately calibrate pre-launch will compromise the flight data.

Data Quality Assessment and Adjustments

At the operational level, data quality assessments are no different for RDF systems than GPS and will depend on the experience and training of local observers. A bigger question concerns the impact on time series databases of what could potentially be annual changes in radiosondes.

Climatologists will always prefer the use of single sonde models for extend periods of time to eliminate bias errors in their models. If one of the reasons for adopting the universal system is to encourage competition in sonde selection, continuity will necessarily suffer. The question is whether sonde biases are adequately understood to make the necessary corrections when models are changed at a particular site. The sonde designation is included in the standard met messages so there should not be any confusion about which correction needs to be made. Further discussion of this important topic is beyond the scope of this paper.

Ease of Use

With the widespread acceptance of NAVAID systems, operators have grown accustomed to the ease of release and forget flight operations. Although InterMet's radiotheodolites are highly automated, they require adequate operator training to capture the sonde at release. Radiotheodolite systems have more parts than comparable NAVAID installations and require slightly more detailed maintenance.

InterMet's experience with ten synoptic sites in the Caribbean has shown that operators quickly grasp the technical aspects of flight operations. Since we began installing systems in 1997, we have encountered no ongoing flight operations problems and are confident this is not a significant issue.

The IMS-1500 is a mature system that requires very little maintenance. The C release includes extensive built-in-test functions that allow operators to quickly isolate faults to the individual LRU. When necessary, spares are dispatched from either Cape Town, South Africa or Grand Rapids, U.S. to replace failed components. Field experience has shown that the 1500 will operate for extended periods with no electronic or mechanical failures. InterMet also offers fixed-price extended maintenance contracts to eliminate unexpected costs.

5. RDF WIND FINDING

For the universal system concept to be valid, the RDF antennas must consistently deliver high quality measurements of wind speed and wind direction. Accurate winds are one of the selling points of GPS systems. The question here is how do RDF winds compare, and if there is a degree of diminished performance, what is an acceptable tradeoff for the economic benefits of reduced operating costs?

The most noted weakness of RDF systems is the difficulty of generating accurate winds at low tracking angles. Although this is a genuine concern, the potential benefits of the universal approach will be most realized on days when light upper air winds are expected and low angle tracking is unnecessary.

Measuring wind accuracy presents numerous challenges due to the difficulty of obtaining reliable references. The most commonly used test is to track a sonde with high accuracy radar. Dual flights of GPS and RDF sondes are another option that is simpler and less costly to execute. The ability of InterMet radiotheodolites to simultaneously track the same radiosonde in both GPS and RDF modes offers a third option that eliminates many of the measurement errors found in the other two methodologies.

For the purposes of this paper, we will use IMS-2000 (TRS) dual-mode GPS/RDF data. Comparison flights executed in Dar es Salaam during October 2004 by the UK Met Office working under contract for the WMO will be used when the data becomes available.

6. DUAL-MODE COMPARISON

For accurate wind calculations, the accuracy requirement for the azimuth and elevation angles is 0.2 degrees RMS. Figures 3 and 4 show typical TRS measured azimuth and elevation angles on a flight overlaid on the calculated angles from the GPS data. The slightly noisy curves are the IMS-2000 (TRS) measured angles. Because of the high accuracy of the GPS (5 m), it can be used as “truth” when calculating pointing angles. The azimuth mean error is -0.1 deg and the standard deviation is 0.1 deg. The elevation mean error is 0.0 deg and the standard deviation is 0.1 deg. The GPS measurements were used for boresighting the TRS, resulting in the small mean errors.

The major contributor to the wind error is an error in the measurement of the elevation angle, especially at low elevation angles. At elevation angles below 18-20 degrees the wind accuracy begins to degrade below that shown in the plots. Good accuracy is provided down to 10 degrees of elevation.

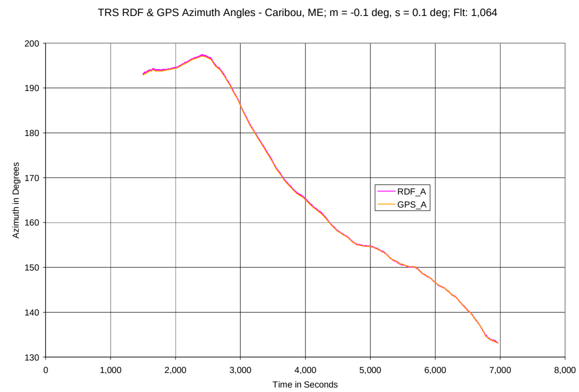

Figure 2 TRS Azimuth Pointing Error

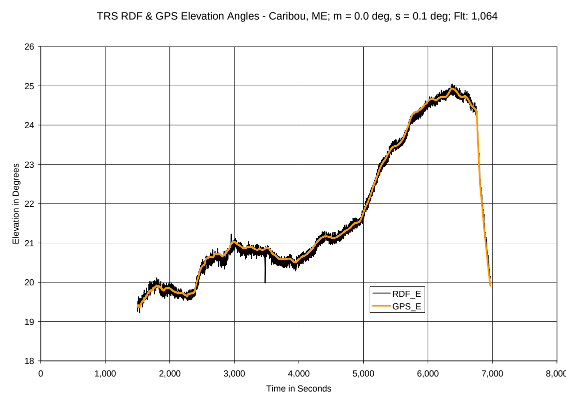

Figure 3 TRS Elevation Pointing Error

7. OPERATING COST COMPARISON

In the sections above we described the technical challenges of applying the universal system concept at synoptic sites. To determine whether the additional effort of using RDF systems is justified, we must estimate the potential cost savings over dedicated GPS systems.

The basic cost model is shown in Table 1. This looks at factors that differentiate RDF (1680) from GPS (403) systems and do not include costs that are the same regardless of which system is used (balloons, lifting gas, personnel). The model looks at fixed costs calculated on an annual basis and variable costs depending on the number of sondes flown each year.

Table 1: Cost Model

Description	Range
10 yr. Straight line depreciation of initial capital cost	$5K (GPS) $10K (RDF)
Maintenance at 2.5% of orig. cost per year	$875 (GPS) $2,500 (RDF)
Sonde cost differential (premium of GPS over RDF)	$50 to $100
Flights per year	365 or 730

From this starting point, fixed and variable costs are calculated as shown in Tables 2 and 3.

Table 2: Fixed Costs

Description	RDF	GPS
Original Cost	$ 100K	$ 50K
Years Deprec.	10	10
Annual Maint.	2.5%	2.5%
Total	**$ 12,500**	**$ 6,250**

Table 3: Variable Costs

Description	RDF	GPS
Sonde Cost	$ 90	$ 160
$/yr – 365 flts/yr	32,850	58,400
$/yr – 730 flts/yr	65,700	116,800

Adding the fixed and variable costs gives the total costs for RDF vs. GPS systems on an annual and per-flight basis (see Table 4).

Table 5 calculates the RDF cost savings in annual, per-flight and life cycle terms. The net benefit is 30% for daily flights, 37% for twice daily.

Based on these simple calculations, the RDF approach appears to offer a significant cost saving on both annual and life cycle bases.

Table 4: Total Cost

Description	RDF		GPS	
	Total $	$/Flt	Total $	$/Flt
$/yr – 365 flts/yr	$ 45,350	$ 124	$ 64,650	$ 177
$/yr – 730 flts/yr	78,200	107	123,050	169

Table 5: Annual Savings, RDF vs. GPS

Description	Total $	$/Flt	%	10 Yr Life
$/yr – 365 flts/yr	$ 19,300	$ 53	30%	$ 193,000
$/yr – 730 flts/yr	44,850	62	37%	448,500

8. CONCLUSIONS

We have shown that there are significant cost savings available from the use of universal RDF systems in synoptic locations. The critical performance element of wind finding accuracy is within acceptable bounds. Operational support requirements are slightly greater than for comparable NAVAID systems but have not proven to be a problem in existing locations.

Technical issues arising from the use of multiple sondes and the lack of consistent methods for calibration and data transfers are an important consideration but do not present any significant obstacles to successful installations. Cooperation between manufacturers can act to minimize these issues in the future.

In summary, we believe that universal RDF systems can deliver high quality synoptic data. There are a number of trade-offs with NAVAID designs but they are adequately compensated for by lower operating costs.

SESSION 3

QUALITY MANAGEMENT, CALIBRATION, TESTING AND COMPARISON OF INSTRUMENTS AND OBSERVING SYSTEMS

Session 3

KEYNOTE PAPER

(not available)

Session 3

PAPERS

Canadian Program and Facilities for the Functional Testing of Surface Weather Instruments and Systems

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ABSTRACT

High quality meteorological data are essential to the needs of forecasters and climatologists. Selecting instruments to provide those data requires thorough testing to ensure data quality and system reliability. To meet that need, the Meteorological Service of Canada (MSC) has developed and implemented an extensive program for evaluating meteorological instruments and systems. This program combines the activities of calibration, laboratory and environmental testing, and functional testing. Prior to making changes to hardware or software used in its networks, MSC conducts a vigorous change management process. This process reviews test results and examines such factors as data quality, life cycle costs, and maintainability.

MSC conducts functional testing of meteorological instruments at a set of test sites configured specifically for this purpose and selected to provide a range of conditions representative of the various Canadian climate conditions. These sites have a complex infrastructure which allows evaluators to assess the functional performance of sensors and instruments in an outdoor, natural environment where instruments are expected to operate over a wide variety of meteorological conditions and climatic regimes.

MSC operates six major test sites for evaluating surface weather monitoring systems. Two of sites – St. John’s (Newfoundland) and Iqaluit (Nunavut Territory) - merit particular attention. St. John’s has a maritime climate and is frequently subject to extreme weather events such as heavy snowfall, freezing rain, and fog. Iqaluit, MSC’s newest site, has an arctic climate and is prone to cold temperature extremes and severe winter storms.

In addition to meeting MSC’s operational testing requirements, Iqaluit has significant potential to meet the needs of the international scientific community. Several initiatives are currently under discussion to carry out field tests in support of such initiatives as SEARCH and the International Polar Year.

INTRODUCTION

High quality meteorological data have long been essential to meeting the needs of weather forecasters and climatologists. With increasing emphasis on the need to detect signals of climate change, national meteorological services need to pay particular attention to ensuring that measurement uncertainty neither masks nor misrepresents those signals.

When selecting and integrating new meteorological sensors and measurement systems, it is particularly important to carry out thorough testing to ensure that uncertainly lies within acceptable limits. It is equally important to fully understand and document the more subtle biases that instrument changes may introduce into the data set. Such an understanding is critical to ensuring that current and future researchers are fully able to distinguish differences caused by environmental factors from those simply due to instrument change.

Canada's vast size along with its diverse and variable climate combine to present major challenges when selecting meteorological sensors and measurement systems. The selection process requires answers to such questions as:

a) What is the sensor or system accuracy?
b) What is the variability of measurements in a network containing such systems or sensors?
c) What change, or bias, will there be in the data provided by the sensor or system when its siting or location is changed?
d) What change or bias will there be in the data when a new instrument or method of observation replaces an existing one measuring the same weather element(s)?

To answer those questions and to assure the validity and relevance of the meteorological data provided to users, the Meteorological Service of Canada (MSC) has developed and implemented an extensive program for evaluating meteorological instruments and systems. This program combines the activities of calibration, laboratory and environmental testing, and functional testing.

MSC operates meteorological sensors and systems in a set of observing networks that are generally organized according to the primary purpose of the data collected e.g. public weather, aviation, climate reference, marine, and upper air. Prior to making changes to hardware or software used in these networks, MSC conducts a vigorous change management process. This process reviews the results of testing and examines such factors as data quality, life cycle costs, and maintainability. The quality of a measuring system is assessed by comparing the stated and implied user requirements and the ability of the systems to fulfill them, with optimal cost/benefit and cost/performance ratios. This involves a shared responsibility among users, technical experts, and network managers to best balance user requirements with technical, operational, and financial considerations.

A recent driving force behind the strengthening of the program for the testing of meteorological instruments for surface weather has been the need to qualify meteorological sensors through a competitive process. Examples include:

- wind, pressure, temperature, and humidity sensors for use in the reference climate and surface weather networks

- wind and pressure sensors for the marine weather network

- automated weather systems and sensors for the aviation weather network (in support of NAV CANADA, the operator of the Canadian air navigation system).

A related initiative has been the development of an algorithm for deriving snowfall amount data from snow depth measurements at sites equipped with snow-depth sensors. The algorithm uses simultaneous data from the snow-depth sensors, total precipitation gauge, and potentially wind, and/or temperature data. It is expected to improve both the quality of the reporting of snowfall amount and of depth of snow on the ground.

MSC TEST SITES

MSC conducts functional testing of meteorological instruments at a set of test sites configured specifically for this purpose and selected to provide a range of conditions representative of the various Canadian climate conditions. These sites have a complex infrastructure which allows evaluators to assess the functional performance of sensors and instruments in an outdoor, natural environment where instruments are expected to operate over a wide variety of meteorological conditions and climatic regimes.

The location of these sites is as follows:

a) St. John's, Newfoundland: situated in Eastern Canada near the Atlantic shore; subject to conditions such as heavy snow and rainfall, high wind speeds, fog, and freezing rain.

b) Iqaluit, Nunavut: situated in the eastern Arctic, on the south end of Baffin Island; subject to arctic conditions such as extreme cold, ice crystals, and permafrost.

c) Egbert, Ontario: approximately 50 km north of Toronto; situated in a temperate, continental climate regime.

d) Wiarton, Ontario: located approximately 100 km north of Toronto near the Lake Huron shoreline; subject to heavy snowfall conditions.

e) Bratt's Lake, Saskatchewan: located in rural central Saskatchewan on the Canadian prairies; situated in a continental climate regime.

f) Terrace, British Columbia: located on the west coast of Canada with a maritime climate strongly influenced by the Pacific Ocean.

MSC also operates a facility to carry out operational testing of upper air systems and radiosondes at Stony Plain, Alberta. It has also recently added a site for testing marine weather instruments in Burlington, Ontario (approximately 50 km west of Toronto on the shore of Lake Ontario).

The map in Figure 1 indicates the approximate locations of the above sites.

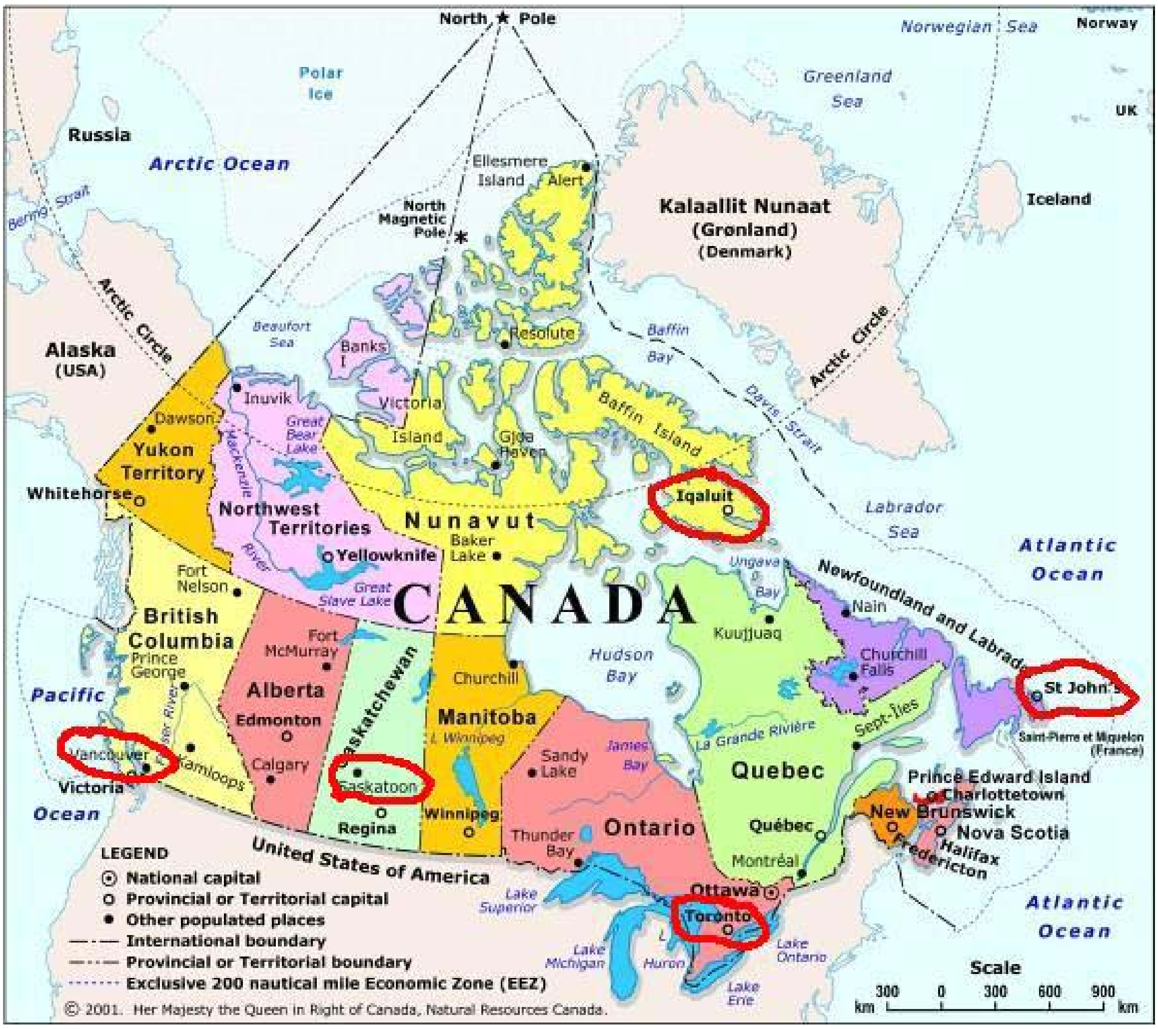


Figure 1 - MSC test sites

The charts in Appendix A summarize the climatology of the areas where the test sites are located and illustrate how they compare with the Canadian extremes for each of the parameters evaluated. The analysis uses meteorological data collected between the early fifties and 2001.

Two of the test sites - St. John's and Iqaluit - merit particular attention because of their local conditions and location.

St. John's Newfoundland

St. John's Newfoundland is situated in eastern Canada on the shore of the Atlantic Ocean. The site is noted for its very active weather, offering ideal conditions for testing the performance and the performance limits of any meteorological instrument.

Of all the major Canadian cities, St. John's is the foggiest (124 days), snowiest (359 cm), wettest (1514 mm), windiest (24.3 km/h average speed), and cloudiest (1497 hours of sunshine). It also has more days with freezing rain and precipitation than any other city. While the city does have relatively mild winters (the third mildest among major Canadian cities), it's location along principle storm tracks has provided it with a well earned reputation as one of North America's stormiest cities. The day-to-day variability of the winter temperature in the St. John's area is characteristic of a storm-prone maritime climate, with frequent incursions of moist, mild Atlantic air.

Freezing rainstorms are a major hazard in many parts of Canada, but they are nowhere more frequent than in the province of Newfoundland where they are known as silver thaws. The St. John's area is prone to prolonged periods of freezing precipitation that last for several hours or intermittently for two days or more. One of the worst ever freezing rainstorms struck St. John's on the evening of April 11, 1984, and continued intermittently until the 14th. Jackets of ice as much as 15 cm thick formed on over-head wires. Freezing rain or freezing drizzle occur an average of 150 hours each winter, with March being the worst month.

Another characteristic of the St. John’s weather is the fog, sometimes known as "sea smoke”. The fog develops when warm, humid air from the south strikes the cold, sometimes ice-infested, waters of the Labrador Current, and is often accompanied by strong winds. Normally, winds can be expected to disperse fog, but there the fog is frequently so dense and widespread that the winds have little clearing effect.

All these conditions create the ideal environment for the functional testing of meteorological instruments intended for use in the diverse Canadian climate. The site has also been used for the WMO intercomparison of present weather sensors in 1994, and for the field evaluation of ice-resistant wind sensors for the U.S. National Weather Service.

Iqaluit, Nunavut

Given increasing scientific interest in arctic weather and climate, MSC recognized the need to establish a permanent test facility in the arctic. Iqaluit is the newest MSC test site, established in 2004. It is located at 63°45’N, 68°31’W on Baffin Island in the south-eastern arctic.

Situated approximately 200 km south of the Arctic Circle, Iqaluit is the capital of the territory of Nunavut and is its largest community. Daily flights to southern Canada facilitate easy access and direct, year-round communications with the site. The test facility is located next to the airport where there is a human observing program. This offers the opportunity to use the METAR observation as a reference for various test programs. MSC also has a permanent office collocated with the test site which provides a local source of skilled maintenance and site supervision.

Meteorological hazards and storms in the Arctic are common and some of the most intense storms occur in the eastern Arctic. This is due to the natural progression of low-pressure systems that form to the west and south that intensify as they track east and north. In fact, Baffin Bay is considered the “burial ground” for intense storms where open water can exist even in mid-winter, acting as a supply of heat and moisture that can re-intensify storms. See Appendix B for additional details about weather conditions in the Iqaluit area.

The primary objective of the test site is to evaluate the performance of the surface weather instruments and systems and related processing algorithms in arctic conditions. Given that about 25% of Canadian territory is situated above the Arctic Circle, the site is critical to effectively managing the operation of all surface-based weather observing networks. In addition, the site provides an infrastructure suitable for other environmental research initiatives. It has the potential to become a base for major research projects organized to provide a better understanding of the physical features of arctic storms and their hazards.

The Test and Evaluation group of MSC is currently negotiating its participation in the STAR project (Storm Studies in the Arctic) initiated by a network of Canadian university and federal/provincial government researchers in 2004. The stated goal of the project is to better understand severe Arctic storms and the hazards associated with them, to contribute to their better prediction, and to assess how conditions may change in the future.

The proposed project will focus, although not exclusively, on storms occurring in the southern Baffin Island region. This region has the best developed environmental monitoring infrastructure in the area and has the highest population density. Iqaluit itself is a thriving community that is increasing in population through industry, tourism and recreation.

The project will also examine atmospheric-related extremes in the Arctic and assess the likely impact of climate change on their occurrence, frequency, severity and location. Examples include harsh temperatures, strong winds, heavy precipitation, blowing snow, low visibility, freezing rain, and lightning. Such extremes may also significantly affect sea-ice behavior and generate storm surges. They also produce human hardship on a daily scale and there is concern that they may become more frequent in the future.

The proposed project has numerous international linkages. It will be carried out in a complementary manner with the U.S. based SEARCH program and the International Arctic Research Center (IARC) weather research initiative (J. Walsh, D. Atkinson). It is expected that joint activities will be carried out with the Alfred Wegener Institute in Germany with researchers at the University of Bergen. Discussions are also under way for Japanese involvement and the project will contribute to the objectives of the International Polar Year (IPY). The major activity of the initiative will be the acquisition of enhanced detailed data collection in the vicinity of Iqaluit over the period from the spring of 2007 through to the winter of 2007/08.

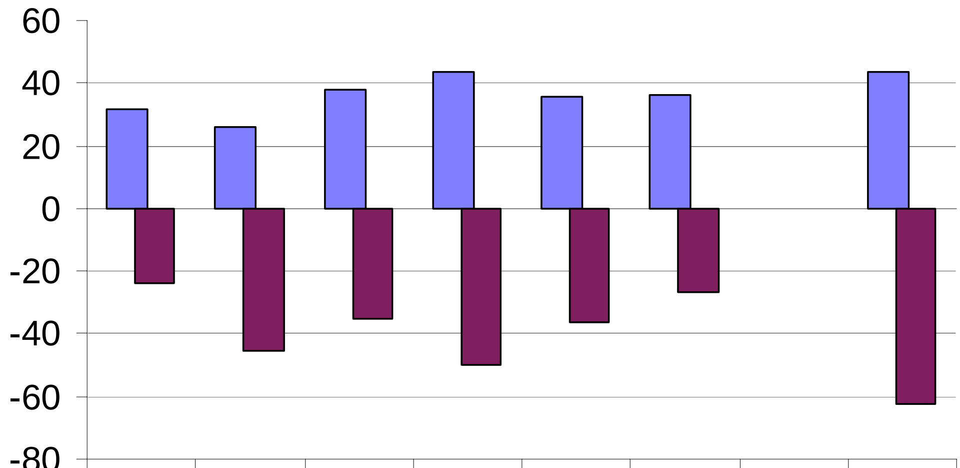
There are also other indications that the international meteorological community can benefit from the access to the Iqaluit test site. The U.S. National Weather Service (NWS) and the National Center for Climate Data (NCDC) have expressed a strong interest in using the facility to test their monitoring technologies. The first cooperative project at Iqaluit will begin in January 2005, when NWS will begin testing their ice-resistant wind sensors in an arctic environment.

The work proposed at Iqaluit will improve understanding of the performance of meteorological sensors and systems before their network-wide deployment. This in turn can be expected to improve data quality and availability and enable MSC to better manage the life cycle costs of its networks in the harsh arctic environment. Overall, it will create the conditions for effective use of monitoring technologies in support of MSC's programs to deliver its services in the North, contributing to better service to northern communities, and increasing the capacity to accurately predict climate variability and climate change.

Appendix A

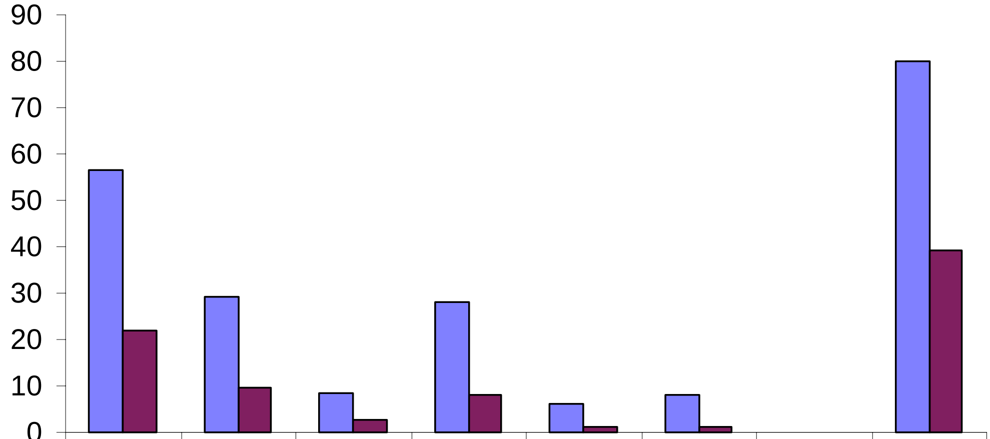
Summary of the climate conditions of the MSC test sites

Extreme maximum and minimum daily temperature (deg C)



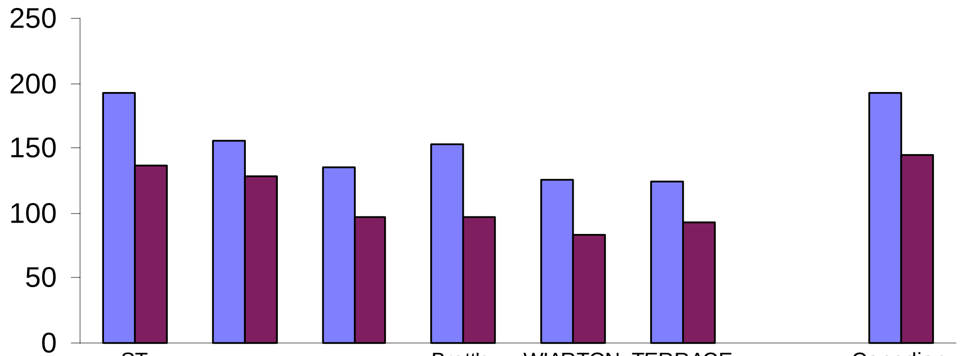
	ST JOHN'S A	IQALUIT A	Egbert	Bratt's Lake	WIARTON A	TERRACE A		Canadian extreme
Extreme maximum daily max temp (C)	31.5	25.8	37.8	43.3	35.6	36.2		43.3
Extreme minimum daily min temp (C)	-23.8	-45.6	-35.2	-50	-36.4	-26.7		-62.2

Wind speed distribution chart (days/year)



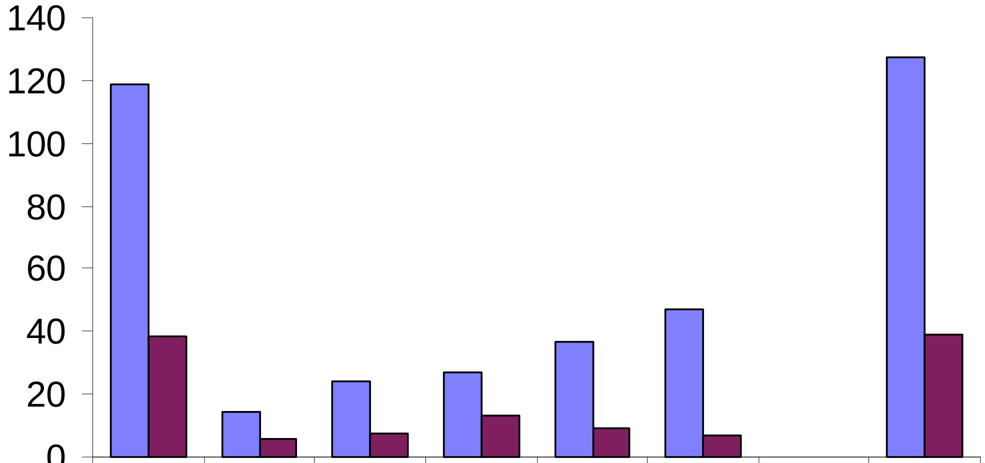
	ST JOHN'S A	IQALUIT A	Egbert	Bratt's Lake	WIARTON A	TERRACE A		Canadian extreme
Days with Wind>=28 knots	56.65	29.09	8.51	27.96	6.04	8.19		80.02
Days with wind>=34knots	22.11	9.51	2.85	8.14	1.33	1.1		39.17

Extreme wind gust and hourly wind speed (km/h)

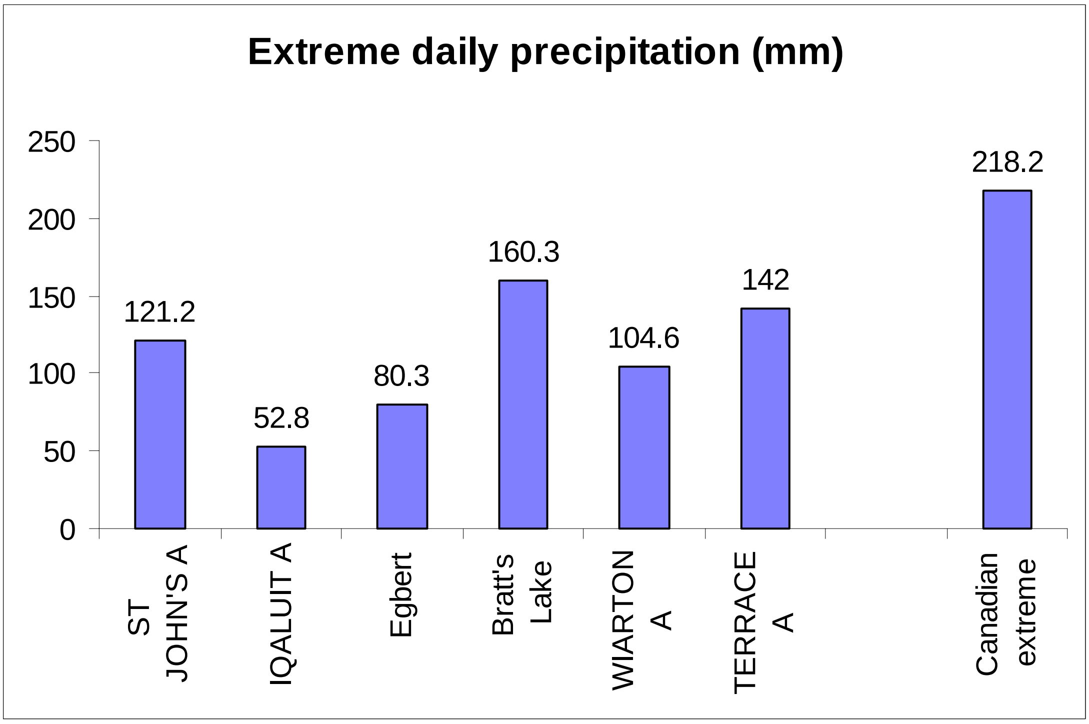


	ST JOHN'S A	IQALUIT A	Egbert	Bratt's Lake	WIARTON A	TERRACE A	Canadian extreme
Extreme dayly max gust (km/h)	193	156	135	153	126	124	193
Hourly max 10 min wind speed(km/h)	137	129	97	97	84	93	145

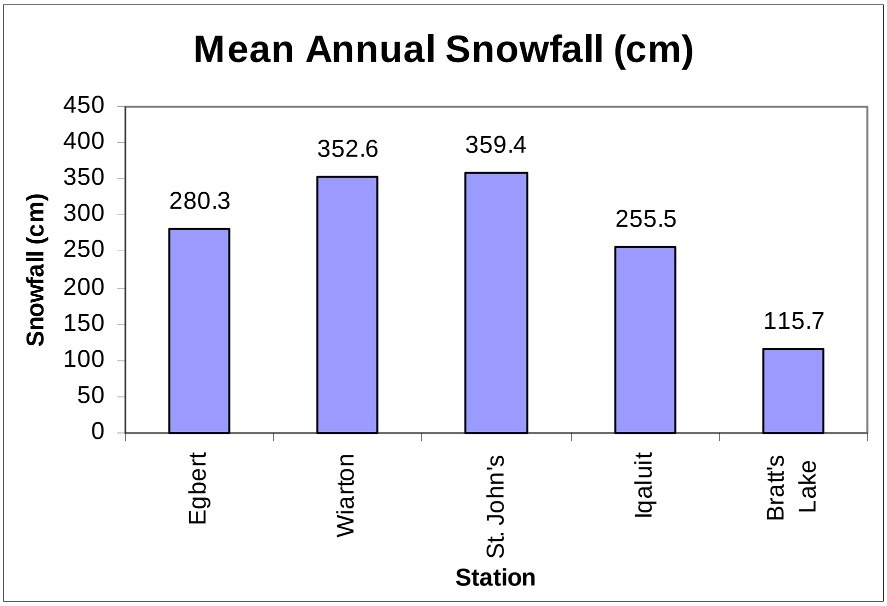
Precipitation chart (days/year)



	ST JOHN'S A	IQALUIT A	Egbert	Bratt's Lake	WIARTON A	TERRACE A		Canadian extreme
Days with fog, ice fog, or freezing fog	118.96	14.44	24.03	27.2	36.63	47		127.32
Days with freezing rain, rain, or freezing drizzle	38.62	5.6	7.51	12.99	9.16	6.94		39.07



Extreme daily precipitation (mm)
250
200
150
100
50
0
121.2
52.8
80.3
160.3
104.6
142
218.2
ST JOHN'S A
IQALUIT A
Egbert
Bratt's Lake
WIARTON A
TERRACE A
Canadian extreme



Mean Annual Snowfall (cm)
Snowfall (cm)
450
400
350
300
250
200
150
100
50
0
280.3
352.6
359.4
255.5
115.7
Egbert
Wiarton
St. John's
Iqaluit
Bratt's Lake
Station

Appendix B

The climatology of Iqaluit and area

January and February are characterised by a mean temperature of about -27°C and relatively little precipitation (about 20 cm of snow per month). Although mean monthly wind speeds on the order of 4.3 m/s are relatively low, this period can have very strong gusts and it has the highest occurrence of blowing snow.

The periods of March through May and from October through December are defined as the two storm seasons. They are characterised by monthly snow amounts in excess of 30 cm, very little rain, and mean monthly wind speeds greater than 5 m/s. The fall season (October to December) is the stormiest with southern latitude air clashing with invading cold air from the north over a relatively warm ocean surface. This of course represents an ideal environment for extreme storms to form and evolve.

From June to September the dominant precipitation is rain. With a dominant wind direction from the southeast over the fjord, fog is common. During the rest of the year, the prevailing wind direction is from the northwest.

From October to May there are preferential areas of open water (Frobisher Bay and Cumberland Sound polynyas[1]). Open water areas are a moisture source and are prone to low cloud and fog. In addition, during fall and winter, the cloud and fog are often composed of supercooled water and are capable of producing both freezing drizzle and significant aircraft icing.

The highest temperatures at Iqaluit may approach 30°C. Usually, however, maximum annual temperatures are in the low 20s. During winter, temperatures routinely fall to below -30°C, and occasionally to below -40°C. While such low temperatures are potentially dangerous, the most hazardous conditions related to temperature may occur due to unseasonable temperatures or extreme warming and cooling events.

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[1] source: Canadian Ice Service

Meteorological Standardization in China

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ABSTRACT

In order to implement the meteorological standardization, China Meteorological Administration (CMA) has set up a division to carry out related duties. From 1998 to now, CMA has made a lot of achievement in this area. this article introduces the standardization system in China and the related work of CMA has finished as well as a brief introduction of the task that ISO/TC146/SC5 performed.

1. Standardization system in China

China standardization is a kind of centralized administrative system combined with respective responsibility of any official departments and civil association. Standardization Administration of the People's Republic of china (SAC) is authorized by the State Council to exercise the administrative functions and carry out centralized administration for standardization in China. While relevant competent administrative departments of the State Council shall be assigned the responsibility of managing the work of standardization within their respective professional sectors. The competent administrative departments for standardization in the provinces autonomous regions and municipalities shall execute unified administration of the work of standardization in their respective administrative regions. The competent administrative departments of the governments of provinces, autonomous regions and municipalities shall administrate the work of standardization within their respective sectors in their respective administrative regions.

The competent administrative agencies on standardization of the city and county governments shall, in accordance with their respective responsibilities specified by relevant governments of provinces, autonomous regions and municipalities, administrate the work of standardization in their respective administrative regions.

There are three subordinate units of SAC. China Association for Standardization (CAS), founded in 1978, is a public society of standardization enjoying a legal status approved by the Ministry of Civil Affairs, which consisting of organizations and individuals engaged in standardization in national wide based on the voluntary participating. The Standards Press of China (SPC), founded in 1963, is the only publication center in China for publishing national standards, professional standards, standard compilation books, scientific and technical books, and other books concerned with standardization, quality control and quality supervision. In order to promote standardization in the relevant research development and management of standards so as to meet the demands of socialist market economic construction, China National Institute of Standardization (CNS) was established on July 13, 1999.

In the P.R.China, there are four levels of standardization system, which are national standard, professional standard, local standard and enterprise standard. National Standards shall be developed for technical requirements need to be unified national wide. Professional Standards may be developed for which no

National Standards are available but unified technical requirements are needed in a certain professional field throughout country. Local Standards may be developed for which neither National Standards nor Professional Standards are available, but unified requirements for safety and hygiene of industrial products are needed within a local area. Enterprise Standards may be developed within an enterprise when National Standards, Professional Standards and Local Standards aren't available. However, an enterprise is encouraged to adopt National Standards, Professional Standards and Local Standards if they are available.

Moreover, national advisory technical documents may be developed for some developing projects, which are required relevant guiding standard documents or have standardization value but can't be developed formal standards or adopt ISO/IEC and other international standards at present.

Chinese Standards are divided into mandatory standards and voluntary standards. Standards concerning protection of human health, personal property and safety and those enforced by laws and administrative regulations are mandatory standards, others are voluntary standards.

SAC is responsible for the standardization of the whole country, and each professional technical committee is responsible for the standardization work of related area. Only in that area, which still has no technical committee organization, government subsidiary Ministry or Administration will do the standardization work. China Meteorological Administration (CMA) is entitled to compose the national standards on behalf of the SAC, to issue meteorological professional with code of Chinese Standards as “QX” and to give guidance to the procedure of local standards.

Usually, each related technical committee carries out the activities of standardization. Now in China there are 263 technical committees. CMA is preparing to set up two technical committees, which specified in meteorological observations and meteorological instruments. CMA has its own standardization organization in the whole business, and will focus its point to lightning protection.

2. Meteorological standardization in CMA

CMA began to carry out the standardization plan in year 1998. As an ordinary duty, it was clarified in the department of observation and telecommunication, division of quality control and technical support. In year 2004, a division related to standardization was set up in the department of policy and regulation.

- **Standardization in meteorological instrument**

In order to implementation this work, CMA tried to focus its point connected with the observation work closely. As CMA is putting most of its effort in building the ground-base observation system, especially in promoting the AWS to local observation stations, in order to meet the needs of operational work, CMA produced the first meteorological professional standard of 《Type Ⅱ Automatic Weather Station》which is composed by one of major instrument suppliers in China. This standard was issued in 2000, and it has played a very important role in the production of AWS. Every meteorological instrument manufacture that wants his product to be qualified for the requirement of CAM, must obey the specifications listed in the standard. This helps us to improve the quality of the instrument as well as the observation data accuracy. After that CMA issued another six professional standards for meteorological instrument, such as 《HM4 Electric aspirated psychrometer》,《TB1-1 Apparatus for measuring frozen ground deep》,《SL2-1 Precipitation sensor》,《DJM10 Calibration equipment for humidity instrument》,《EY 3-2A and EY 3-2B thermocouple anemometer》, 《YE1-1 Calibration equipment for pressure instrument》.

- **Standardization in lightning protection**

Lightning disaster is one of the most serious meteorological hazards not only to the human life but also affect real time observation greatly. The observation field is often attack by the lightning and the instrument in the observation field maybe destroyed by the lightning, which result in the loss of data information collection and the damage of the equipment itself. Even some large equipment also encounters this kind of situation and will bring a lot of economic loss to the CMA, such as the next weather radar. CMA installed its first set of next weather radar in Shanghai city, but the radar was destroyed by a lightning accident. Because CMA is planning to building 126 weather radar stations, so it becomes a quite important question confront the regular operational business, how to protection meteorological equipment from lightning disasters. CMA has set up a research program to do the scientific experiment to find most effective way to avoid lightning.

After two years hard work, three professional standards (QX2,QX3,QX4) related to the lightning protection was issued: 《Technical specifications for lightning protection at China new generation weather radar station》,《Technical specifications for protecting the meteorological information system from lightning electromagnetic impulse》,《Technical specifications for lightning protection at the meteorological offices(stations)》, which lead to regulate designing of the lightning protection system. Two lightning equipment testing laboratory was build in Beijing and Shanghai separately, and a professional standard 《Surge protective devices-Part 1: Performance requirements and testing methods》 was finished correspondingly. In the meantime, a professional standard of 《Technical specifications for lightning protection at the automatic weather stations》 is going put into power recently.

Except those two area, CMA also noticed that standardization is very important in unify the data format, observation station environment protection.

3. Meteorological standardization in international organization

The purpose of international standardization is to facilitate the exchange of goods and services through the elimination of technical barriers to trade. There are three bodies are responsible for the planning, development and adoption of International Standards: ISO (International Organization for Standardization), IEC (International Electrotechnical Committee), ITU (International Telecommunication Union).

ISO is a legal association, the members of which are the National Standards Bodies of some 140 countries (organizations representing social and economic interests at the international level), supported by a Central Secretariat based in Geneva, Switzerland.

ISOTC146 air quality technical committee has 6 subcommittees (SC), which are SC1/Stationary Source emissions, SC2/Work Place Atmospheres, SC3/Ambient Atmospheres, SC4/General Aspects, SC5 /meteorology and SC6/ Indoor Air.

SC5 is responsible for the elaboration of standards in the field of meteorological measurements and analyses that are focused on air quality programs. The meteorological standards may include identifying: the initial standards being developed are focused on basic surface-based and remote sensing instrument system descriptions and test methods. Further work is planned in standardizing observation systems and analytical methods and models that have general meteorological applications. Other planned work includes promoting standardization of new measurement and analysis techniques.

The Secretary of SC5 is Mr. Paul M. Fransioli and the chairperson is Mr. John S. Irwin, both of them are from the US. Till now, SC5 has published one ISO standards: ISO 16622:2002 Meteorology -- Sonic anemometers / thermometers -- Acceptance test methods for mean wind measurements

There are 9 countries (including Australia, Austria, Canada, France, Germany , Poland, Sweden, United Kingdom) working in the SC5 as participating countries and 11 countries(such as Belgium, China, Finland, India, Ireland, Republic of Korea, Netherlands, Slovakia, South Africa, Turkey, Uganda) as observers.

SC5 has five working groups listed as follow:

TC 146/SC 5/WG 1	Wind vanes and rotating anemometers
TC 146/SC 5/WG 2	Sonic anemometers/thermometers
TC 146/SC 5/WG 3	Test methods for comparing the performance of radiation shields and definitions of important characteristics
TC 146/SC 5/WG 4	Evaluation methods for atmospheric dispersion models
TC 146/SC 5/WG 5	Remote atmospheric boundary layer profiling - Test methods for ground based equipment.

Hope WMO could pay more attention to the meteorological standardization, and make this work going further and further.

Field comparison of different raingauges and present weather sensor at MHS of Croatia

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ABSTRACT

The Meteorological and Hydrological Service (MHS) of Croatia started in May 2004 field comparison of three different tipping-bucket raingauges with heating, an ordinary raingauge, a float raingauge and the present weather sensor. All detectors were mounted at the test field at Meteorological Observatory Zagreb Maksimir. The tipping bucket raingauges were equipped with the data loggers and the GSM interfaces that enabled full remote control. Stored data as the one-minute amounts were transferred to the remote center at MHS every hour when there was a rain. The main objectives of the comparison were to test a response of different raingauges, to control the measured amounts of precipitation during rain showers and light rain, and to find an influence of a high wind speed on the measured amounts. The comparison was very helpful for a selection a reliable instrument for desired geographical region, an interpretation of present weather sensor data and for involving these instruments in the network of automated weather stations in Croatia.

Introduction

In early nineties of 20th century MHS started to develop automatic weather stations (AWSs) and a telemetric system (network) for remote transfer of data in close co-operation with domestic manufacturer *Tritonel multimedia*. Number of AWSs was constantly growing and AWSs have been used for MHSs purposes as well as to meet special needs of different users for different measurements, like temperature measurement on special ships, wind measurement on bridges and towers, etc.

Nowadays MHSs network of AWSs consists of 65 stations that are reachable 24 hours per day via fixed telephone, GSM or internal network. Measured data as the 10-min records are transferred to the main database at central building of MHS in Zagreb at different time interval from 30 min to 1 day. Most of the AWSs are also equipped with different raingauges. Due to difficulties experienced in precipitation measurement, MHS decided to test few of the available raingauges with the aim of finding the most suitable raingauge for our geographical regions.

Test field and measuring systems

Meteorological and aerological Observatory Zagreb Maksimir is located in the east part of Zagreb. Meteorological measurements and observations were started early after second world war and have continued till nowadays. The crew of 10 people performs standard meteorological measurements and observations 24 hours per day with pilot balloon and rawinsonde observations twice per day. In front of the building there is a large, newly built, meteorological examination field with electricity and other infrastructure that enables a testing of different meteorological instruments or automatic weather stations.

This field is used for the testing of different tipping bucket raingauges (Figure 1.) that are aimed to be added to automatic weather stations. According to the possibilities, three different manufacturers were chosen (Table 1.).

Figure 1. Tested rain gauges at meteorological observatory Zagreb – Maksimir

The tipping bucket raingauges were equipped with the processor module and data logger (Figure 2.), type a-ombro (*Tritonel Multimedia, Croatia*) that enables storage of one-minute amounts in real time during the rainfall. The storage capacity can accumulate six months of the one-minute data samples. GSM interface assures full remote control and data transfer. Automatically, the data were transferred to the main database at central building of MHS in Zagreb every hour, during rainfall. The available power supply is 220 V or 12 V according to the demand of the manufacturer.

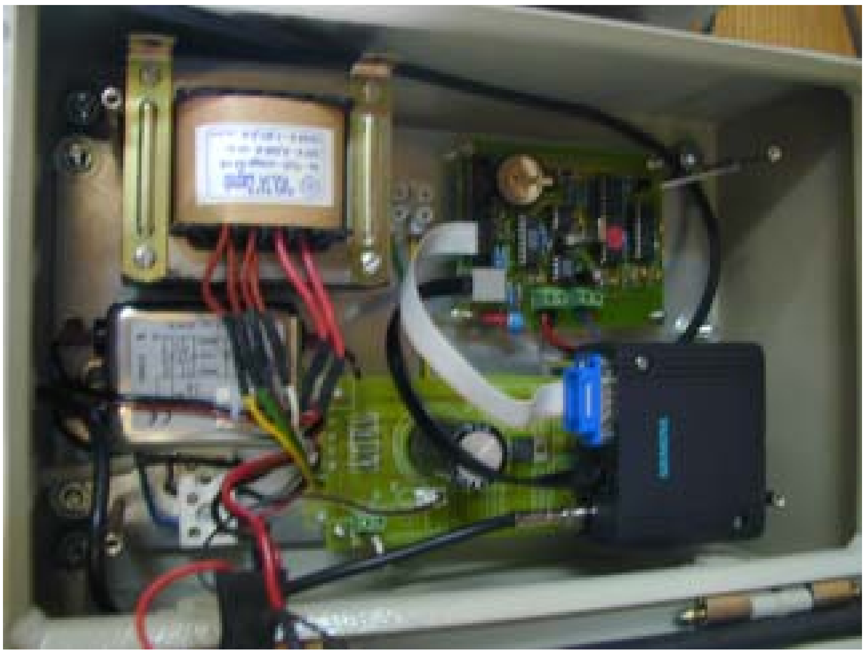

Figure 2. Processor module and data logger, type a-ombro (*Tritonel Multimedia, Croatia*)

All raingauges were calibrated by the manufacturer and checked before start of their operation. Routine maintaining procedures were performed regularly as it was suggested by user manuals.

Table 1. Technical characteristics of tested raingauges

producer	type	measuring system	orifice			resolution (mm)	heating (W)
			area (cm^2)	type of material	h (m)		
Lambrecht, Germany	1518 H3	tipping bucket	200	aluminium	1,5	0,1 ± 2%	235
Meteoservis, Czech Rep.	MR3H-F	tipping bucket	500	aluminium	1,5	0,1 ± 2%	57
Young, USA	M52202	tipping bucket	200	plastic	1,5	0,1 ± 2%	18
Lambrecht, Germany	1507A	float	200	zinc	1,5	0,1	160

Observational period

Operational mode of the raingauges started in April 2004. In these papers data from May till October are analysed. This period was chosen because no heating of instruments was required. All instruments have worked continuously without any data loss. All data were officially verified and are available as minute, hourly or daily sum.

Data analysis

Lambrecht float raingauge data was corrected and verified in comparison with ordinary gauge. These data are referred to as ordinary gauge data. All comparisons and deviations were calculated relatively to the ordinary gauge data. The data were analysed on monthly and daily basis. Amounts of precipitation recorded by tested instruments were compared during days with higher or lower amounts of precipitation. Finally, comparison with PWD sensor and analysis of the influence of higher wind speed was done.

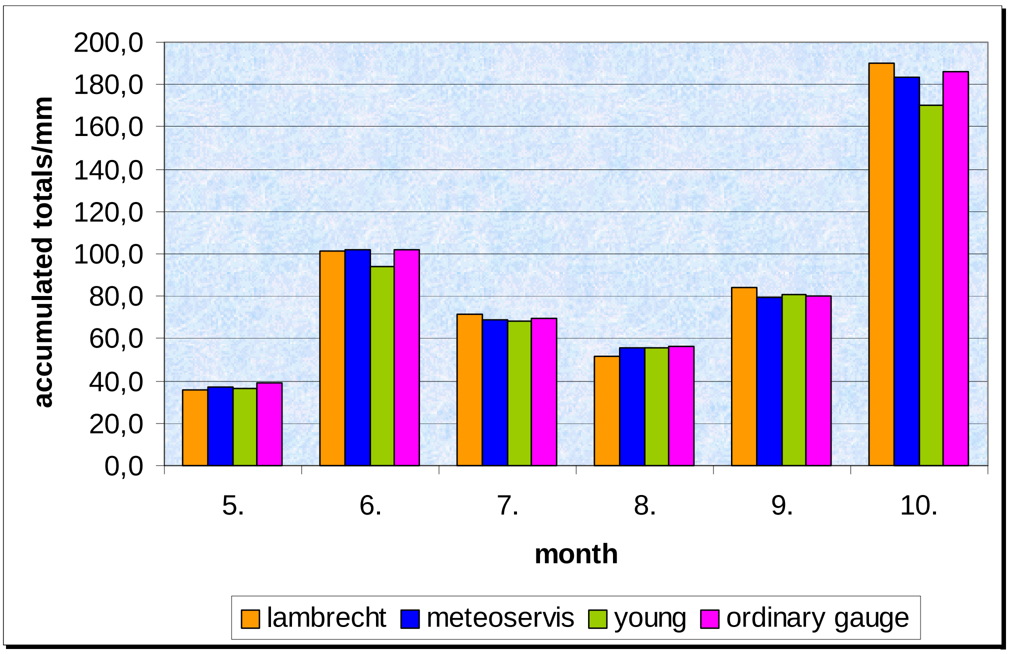

Figure 3. Accumulated totals of different raingauges for whole observed period

Monthly total amounts

Monthly total amounts (Figure 3.) show that during drier months, like in May, ordinary gauge has the largest value and Lambrecht raingauge the lowest one. In October when there was over 180 mm precipitation the highest amount was registered by Lambrecht raingauge and the lowest by Young raingauge. Meteoservis raingauge always recorded values somewhere in the average.

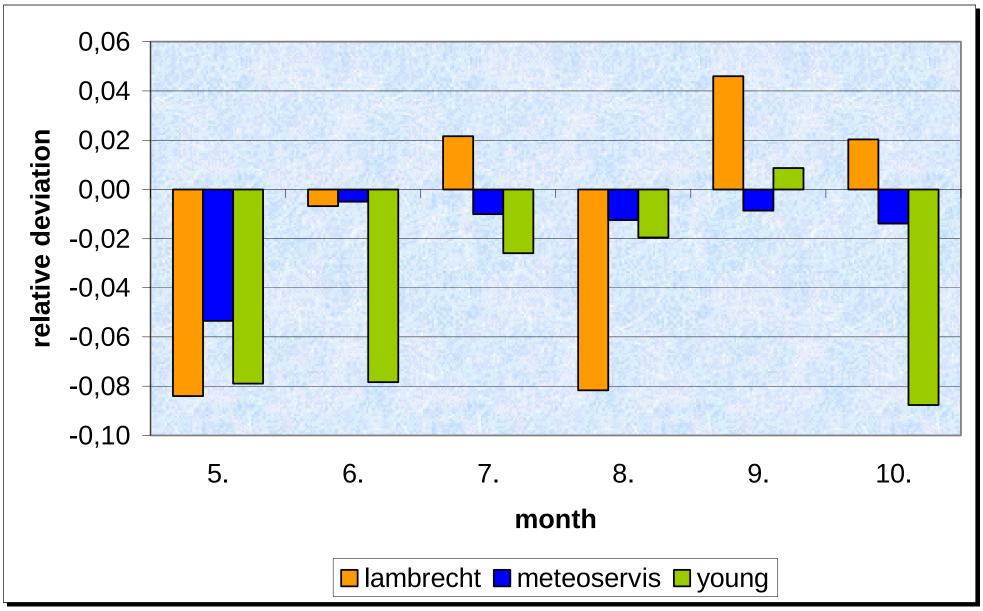

Figure 4. Relative deviations of different raingauges to the ordinary gauge for whole observed period

Relative deviation of tipping bucket raingauges is in most cases negative, which implies that tipping bucket raingauges underestimate precipitation. It is fully consistent with Young and Meteoservis raingauge relative deviations that have always negative values (Figure 4). Relative deviations of Young raingauge show the highest underestimation of measured precipitation, even up to 8 %. Meteoservis raingauge deviations are very uniform and below 2% with only one exception in May (the lowest monthly amount). It is found that Lambrecht raingauge deviations are as much positive as negative but absolute value of negative deviations is even two times greater than the value of positive deviations.

Daily deviations

Clear overview of daily relative deviations is seen on Figures 5. and 6. Mostly negative deviations support the fact seen from monthly totals that tipping bucket raingauges underestimate precipitation. The deviations are very often below 0.2, looking absolute values. There are few exceptions. One exception happened on 30th of May (Figure 5). The relative deviation for Meteoservis raingauge is 2.0 and for the others –1.0. Explanation is seen from the real data. There was very light rain and Meteoservis raingauge registered amount 0.3 mm, ordinary gauge 0.1 and other raingauges nothing. On 15th July only ordinary gauge registered precipitation with amount 0.6 mm. At the end of July there were two days with very light rain. The first is 27th; when Meteoservis raingauge registered 0.2 mm and others half of this, and on 29th all tipping bucket raingauges registered twice of ordinary raingauge amount that was 0.1mm. It could be said that Meteoservis raingauge has the best sensitivity among selected raingauges.

In October when it was very rainy, situation with daily relative deviations is different (Figure 6.). There are as much positive deviations as negative but looking absolutely positive are higher, even higher then 0.4.

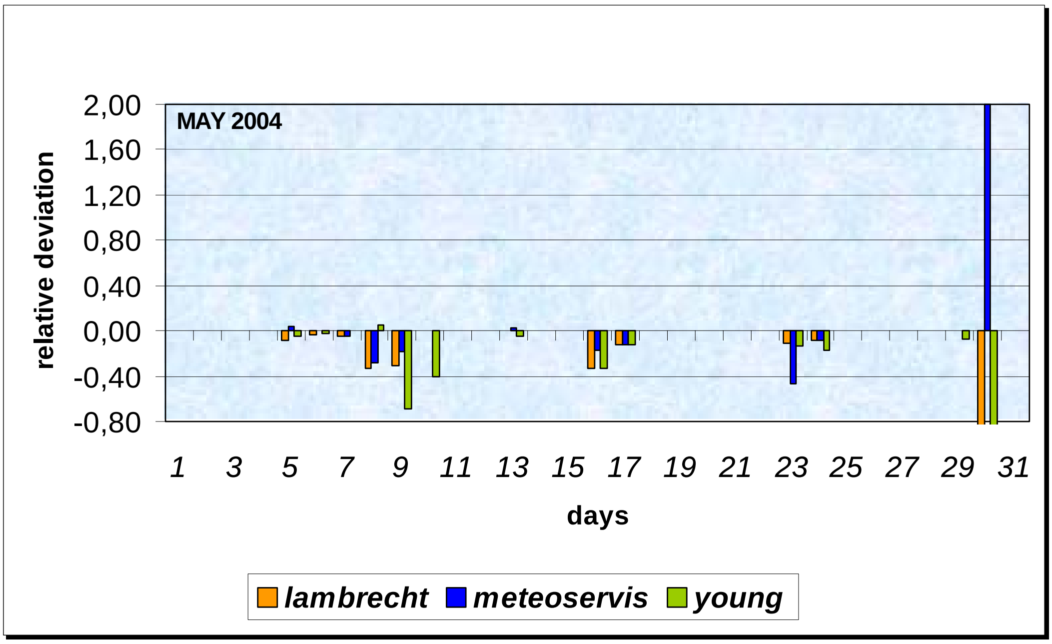

Figure 5. Relative deviations of different raingauges to the ordinary gauge for May

According to this it can be concluded that during light rain tipping bucket raingauges underestimate precipitation, but during very rainy conditions they overestimate it.

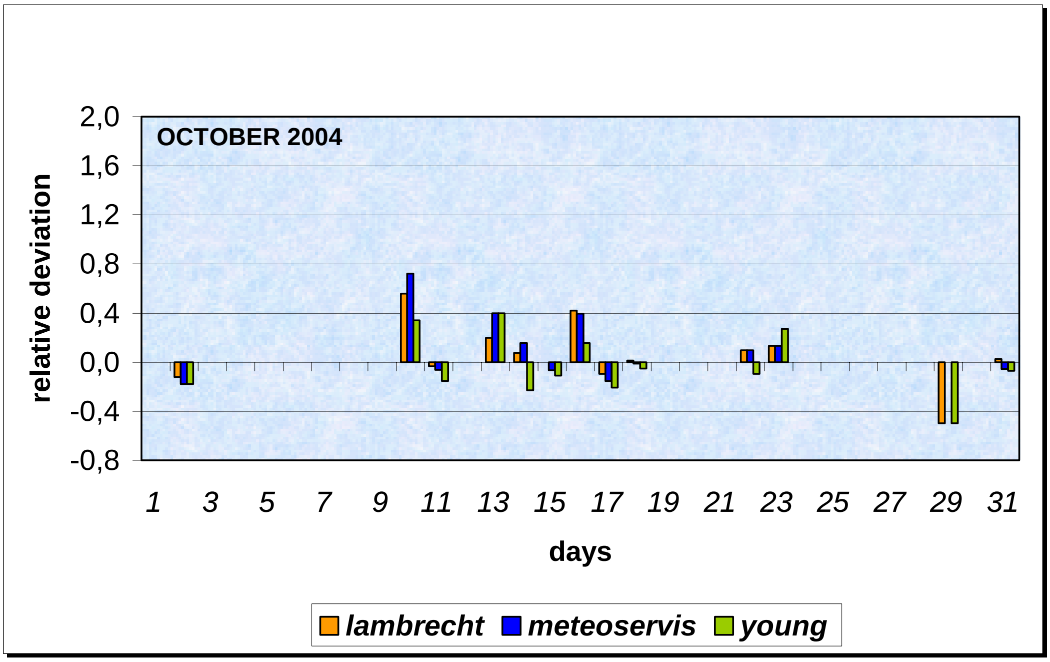

Figure 6. Relative deviations of different raingauges to the ordinary gauge for October

The analysis of the range of the relative deviations is shows on Figure 7. Ends of the bar represent values mean ±1 standard deviation, respectively. Higher dispersion of the relative deviations is seen for all raingauges in May and July and this is probably due to lower amounts of precipitation In these months the highest dispersions and the positive averages of relative deviations are found for Meteoservis raingauge which support the fact that it showed the best sensitivity. In other months dispersion of Meteoservis raingauge is the lowest and Lambrecht raingauge the highest. Average relative deviations of Lambrecht and Meteoservis raingauges have positive and negative values while Young raingauge is significantly negative but generally with the lowest dispersion.

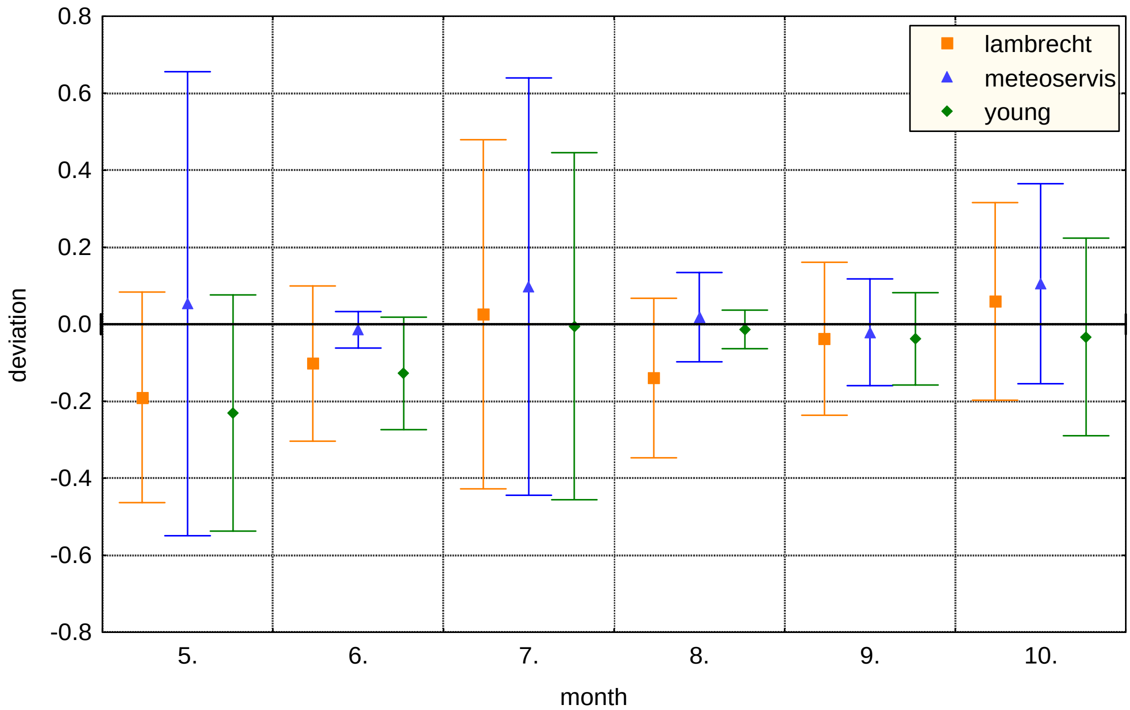

Figure 7. Dispersion (mean +/- 1 stdev) of relative deviations of different raingauges

Comparison during showers and light rain

Only the days with precipitation lower than one mm and higher than twenty mm were taken in consideration as light rain or shower days, respectively. During light rain days (Figure 8.) the deviations were also mostly negative. Only in 25% of the selected days deviations were positive, among which Meteoservis and Lambrecht raingauges overestimated precipitation three times and Young only two times.

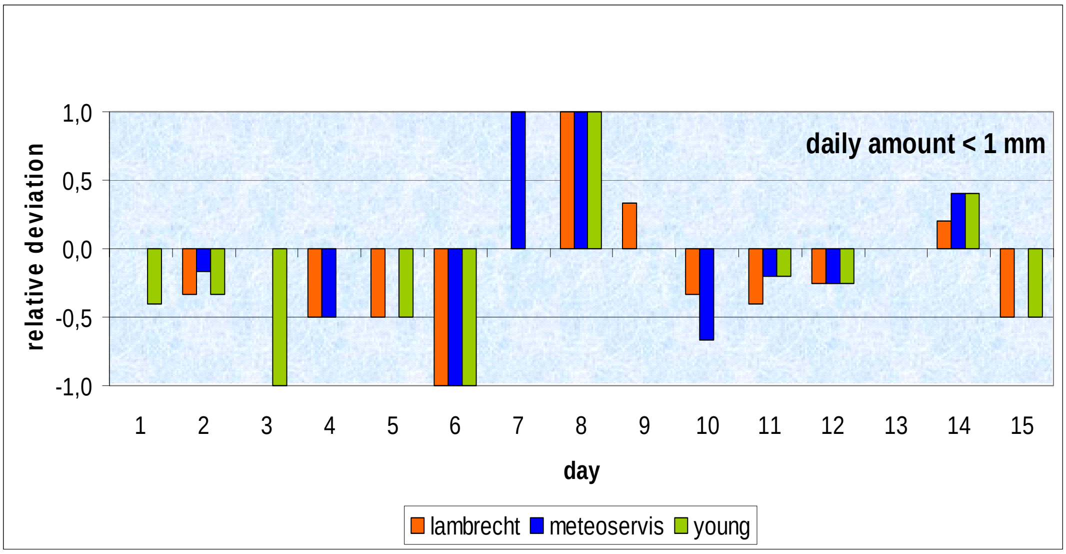

Figure 8. Relative deviation for measured precipitation (daily amount < 1 l)

Only once, tipping bucket raingauges registered precipitation and ordinary raingauge didn't, and vice versa. There was one day when only Meteoservis raingauge registered precipitation.

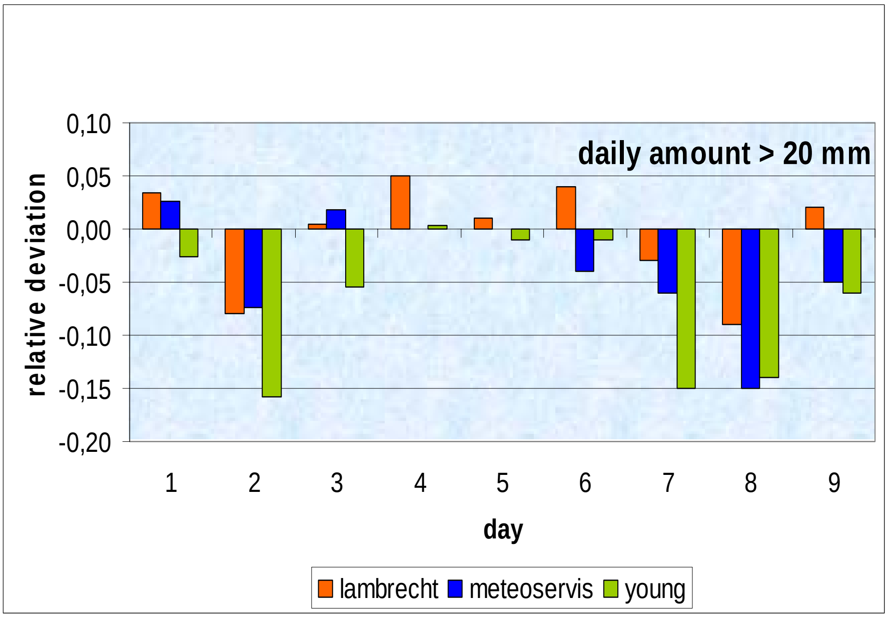

Figure 9. Relative deviation for measured precipitation (daily amount > 20 l)

During shower days there were as much positive as negative deviations (Figure 9). Negative deviations were higher values on absolute scale. Young raingauge consistently underestimated precipitation. Lambrecht raingauge on the other hand doesn't show any regularity in deviations. Comparing intensities in mm/h it was found that the most frequent intensity was 6 mm/h what corresponded to very often registered amount of 0.1 mm. The highest intensities were registered most frequently by Lambrecht, then Meteoservis and then Young raingauge.

Comparison with PWD at higher wind speed

Earlier practice showed that at very high wind speeds Young raingauge registered precipitation even when there wasn't any precipitation.

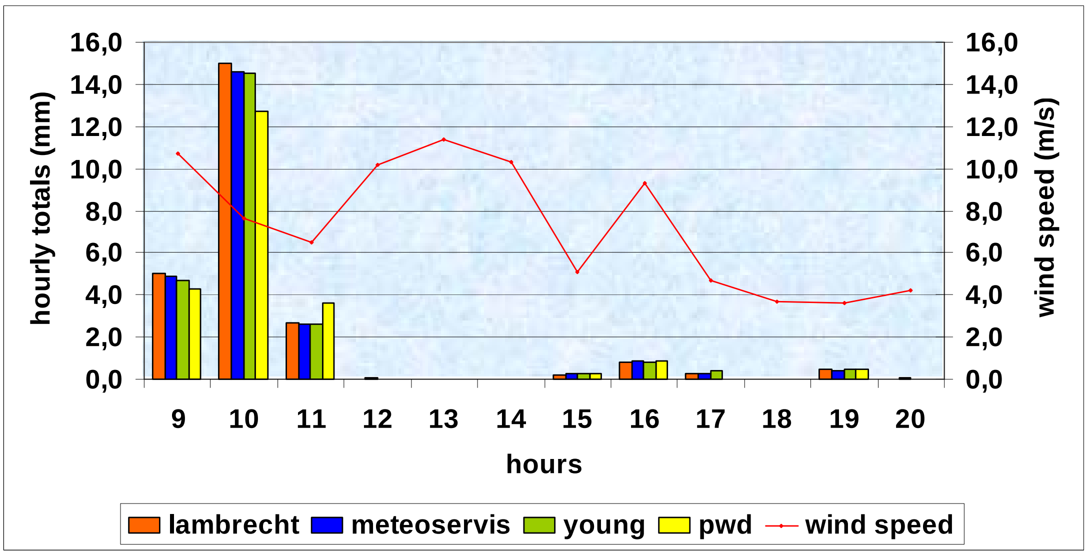

Figure 10. Hourly totals and associated wind speed for selected day, 26th August 2004.

Additional observations and analyses of other meteorological parameters led to conclusion that the main reason for the “precipitation” were vibrations of light plastic raingauge due to high wind speed. Fixing of the raingauge body eliminated the problem. That was the reason why the days with higher wind speed are taken in consideration (Figure 10.). As it was already seen at higher intensities Lambrecht raingauge registered the highest amounts, then Meteoservis and then Young. At lower intensities Lambrecht registered less than Meteoservis and Young. Any clear influence of wind speed on registered amounts couldn’t be directly found due to the lack of very windy days with precipitation.

Although there were some technical problems in transformation of the data of PWD21 (*Vaisala, Finland*) sensor, an initial comparison was done. PWD sensor in most cases registered the lowest amounts especially during higher intensities. There were just very single cases when the situation was different, but generally it could be said that PWD sensor underestimates precipitation.

Conclusions

In analysed period it was found that generally tipping bucket raingauges underestimate precipitation. Due to relative deviations comparison it could be said that Young raingauge showed the highest underestimation of measured precipitation but also the lowest dispersion of the deviations. Very high uniformity and the highest sensitivity in registration were found for Meteoservis raingauge and its registration was the closest to the ordinary gauge. Although Lambrecht raingauge registered the highest amounts, its registration deviations showed the least regularities. Daily analysis helped in finding that during light rain tipping bucket raingauges underestimate precipitation, but during very rainy conditions they overestimate it.

Comparison with PWD sensor showed that in most cases PWD sensor registered the lowest amounts, especially during higher intensities and higher wind speed.

Further comparisons and investigations especially with main emphasis on the influence of the heating will be done.

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1. Lambrecht: Operation instructions Recording Rain Gauge (1507).
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WMO LABORATORY INTERCOMPARISON OF RAIN INTENSITY GAUGES

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In response to the request of CIMO-XIII, the first session at Trappes in November 2003 of the joint **E**xpert **T**eam on Instruments Intercomparisons and Calibrations methods on surface–based instruments and **I**nternational **O**rganizing **C**ommittee on surface–based instruments defined, among many others objectives, a standardized procedure for laboratory calibration of catchment type rain gauge, including uncertainty of laboratory testing devices within the range from 2 to 2000mm/h. Three laboratories (France, Netherlands, Italy) involved in the WMO Intercomparison of Rain Intensity Gauges will be evaluating the performances of 19 rain gauges, with usually 2 instruments of the same type.

First tests were carried out from the 2nd of September 2004 to the 10th of December 2004 in the Laboratory of Trappes (France) on 7 different rain gauges and 3 types of measuring techniques: weighing, tipping buckets, and conductivity. Five calibrations were carried out for each device at different intensities, with an uncertainty on calibration bench intensity less than 1%.

1) CALIBRATION BENCH AND ASSOCIATED UNCERTAINTY ON GENERATED CONSTANT INTENSITY

To establish an error curve, a calibration bench is used by the laboratory of Météo-France, at Trappes. An error exists with high intensities with tipping buckets gauges because the bucket tip is not instantaneous. Water falling during the tip may be lost. For example, for a rainfall rate of 120 mm/h, we have a tip every 6 s (with a 0.2 mm resolution). If the tip has a duration of 300 ms, the loss will be 5% (0.3/6). The duration of the tip depends on the inertia of the system (the inertia momentum related to the swing axe) and the momentum generated by water inside the bucket. All this is design dependent. The smaller is the inertia; the faster is the tip. The measurement resolution is also a factor. A bucket adjusted for 0.1 mm will tip 2 times more than for 0.2 mm and the loss of water may be doubled. The loss increases with intensity as the period between 2 tips decreases. The loss should be proportional to the intensity; but at high intensity, the dynamic of water falling into the bucket helps the tip. Therefore, the loss is reduced.

That leads to the need of a bench calibration to plot the error curve with intensity. Note, for weighing rain gauge and conductivity measurement, that relative error do not increases with intensity

1-1) Calibration bench

We use a bench composed of an electronic weighing machine, a peristaltic pump, both connected to a standard PC with dedicated software. The electronic weighing machine has a 0.01 g resolution, a 5 kg range and outputs the measurements on an RS232 line to the PC, 7 times per second. A water container is weighed. A tube injects water into the buckets through a peristaltic pump. This pump is also controlled by the PC, both for its speed and start and stop. With (8 g, 0.2mm) buckets, this bench allows the generation of 3 mm/h to 250 mm/h intensity range with one tube. The range may be adjusted by increasing the number of tubes. The tip detector such as a contact closure for tipping bucket, the measure of mass for weighing gauge or the conductivity converted in rain accumulation for SEROSI rain gauge, is connected to a junction signal of an RS232 line of the PC. The dedicated software controls the pump, sets a given intensity, counts a selected number of tips, or mass, or conductivity, and gets the mass variation of the water container. It outputs the rain gauge measured precipitation quantity, compared to the decrease in mass on the balance, and calculates the difference expressed in %. A succession of tests at various intensities may be programmed, leading to an automatic establishment of an error curve with intensity.

1-2) Uncertainty about constant intensity generated by bench calibration

The uncertainty calculation of intensity is mainly dependent on the duration of the test and on total mass of water used.

1) Duration of test
   Electronic weighing machine outputs a message each 0.17s: we get a new weight each 0.17s. A maximal error on mass is choosen as 0.1%, therefore the duration of test must be at least 170 s. An uncertainty $\mathbf{U_1}$ about this error on mass is calculated.

2) Total mass of water to use
   Errors of calibration with reference weights, repeatability, drift depending on temperature and resolution according to specifications of the manufacturer, allows to calculate an uncertainty on mass $\mathbf{U_2}$. Total uncertainty **U** is square-law addition of U_1 and U_2 and we applied a enlargement factor **c =2** :

$$\mathbf{U = c\sqrt{U_1^2 + U_2^2}}$$

   Finally, the mass of water **M** is chosen for one intensity so that $\mathbf{U/M \leq 1\%}$.

2) STANDARDIZED PROCEDURE FOR CALIBRATION

Each calibration has been performed at least at seven reference flow rates. However, since the higher rainfall intensities are of outmost importance for the intercomparison, the whole range of operation declared by the manufacturer has also been investigated. In particular, seven fixed reference intensities have been set at 2, 20, 50, 90, 130, 170, 200 mm/h.

Further reference intensities are set at 300 mm/h and 500mm/h, if the maximum declared intensity is 500mm/h. Otherwise, three further reference intensities are determined within the remaining range of operation of the instruments by dividing it logarithmically from 200 mm/h up to the maximum declared intensity. (*For this presentation, the calibration points for plotting error curve have been choosen each 200mm/h, from 200mm/h to 2000mm/h, for Indian TBRG).*

For weighing principle, in addition to measurements based on constant flow rates, the step response of instrument has been checked, based on the devices developed by each laboratory.

An average error curve is obtained by discarding the minimum and maximum error value obtained per each reference flow rate, then evaluating the arithmetic mean of the three remaining error values and the reference values, and finally fitting these average values with a second order polynomial as below, over the whole range of operation of the instrument:

$$e(I_r) = a \cdot I_r^2 + b \cdot I_r + c$$

with *a, b* and *c* suitable numeric coefficients;

3) ENVIRONMENTAL MEASUREMENTS AND CAUTIONS FOR CALIBRATIONS

Water used for the experiments was tap water, with a limited change of temperature. However, the SEROSI rain gauge requires pure water, close to rain.

Minimum time for one tip measurement without "bounce" effect in signal acquisition was adapted according to the specifications of the transducer of each rain gauge.

We took into account the time needed to stabilise the pump flow rate before data acquisition.
At each beginning of test, at least two tips used for wetting the buckets were discarded.

Tests were carried out with a maximum water flow rate of 8000 g/h for each tube, according to the specifications of the pump manufacturer. A variable number of tubes were used to cover the needed range of intensity (1 to 10 tubes).

In the rain gauge, tubes were put as close as possible to the nozzle of the funnel.

For some rain gauges data, scattering occurs, depending on performance characteristics of the sensor itself.

With our calibration bench, at low intensity with uncertainty of 1%, only 2 tips can be used for calibrate some device: it’s not adequate. So, standard deviation of mass buckets is calculated according to number of tips, until it becomes more or less stable: it happens for a fit minimum number tips for calibration (4 to 10 tips, depending on device).

Water temperature, air temperature, relative humidity, atmospheric pressure were recorded during the calibrations.

4) ERROR CURVES AND COMMENTS ON DEVICES UNDER CALIBRATION

4-1) CONDUCTIVITY MEASUREMENT

SEROSI RAIN GAUGE

Measurement principle: rainfall water flows in a tube where water level is measured by conductivity. When the water level is equivalent to 6 mm of rain, an electromagnetic sluice gate stops water and a peristaltic pump drains water off from the tube. This rain gauge is not heated.

Aperture	400 cm^2
Resolution	0.1 mm for the OMM test
Funnel mean wetting loss	9.8 g
Maximum intensity (according to manufacturer)	360 mm/h
Outer geometry	Cylindrical

A software supplied by Serosi specially for the OMM tests enable to acquire every round minute both the measure of the water weighted and the rain gauge measure.

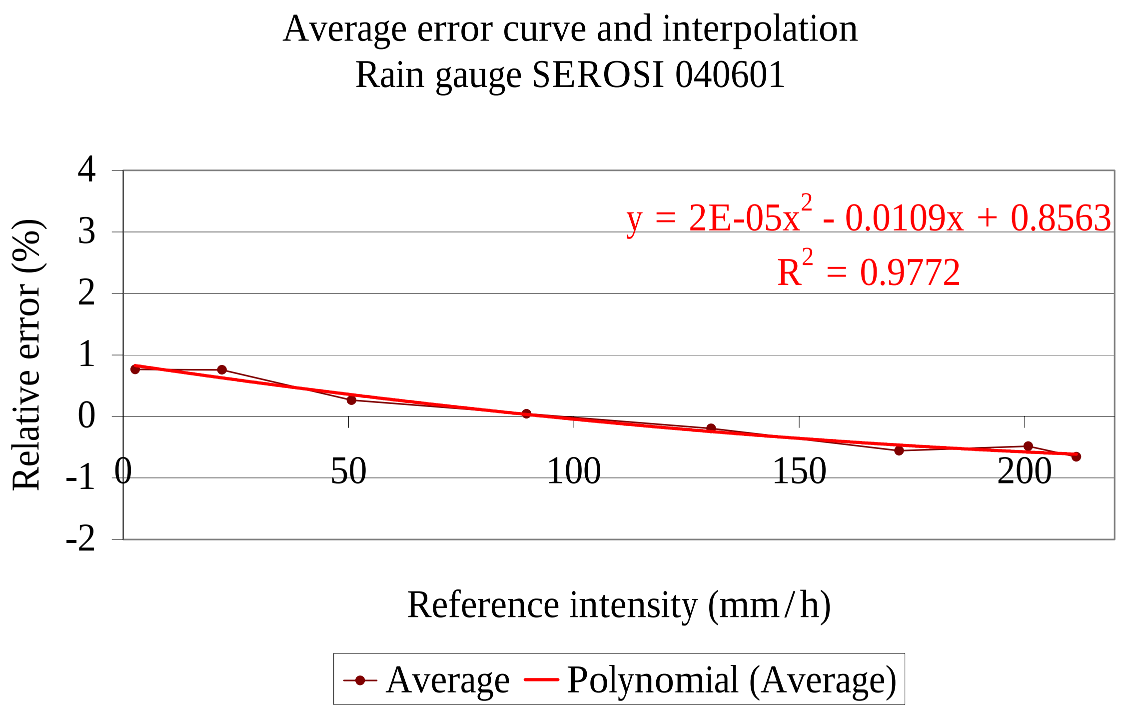
Laboratory tests are carried out with demineralized water, mixed with 5 % of tap water. The nominal resolution of this rain gauge is 0.01 mm but a resolution of 0.1 mm is enough for the test. It was possible to measured intensities up to 210 mm/h with the standard secondary funnel. For greater intensities, water overflows, because the electromagnetic sluice gate is closed during 30 s. This rain gauge can measure intensities up to 360 mm/h with a larger secondary funnel.

The error calculation for this rain gauge is done using 15 minutes of measurement for the intensity of 2 mm/h and using 10 minutes for other intensities. With each duration, we remove 1 minute at the beginning (time for pump stabilisation and because the beginning of the test is not exactly at round minute), or even 2 minutes if water empties out at the first minute. Indeed, if the tube is currently drained at the round minute, the water level measured by the rain gauge is the same as the water level at the previous minute. Because of that, the last minute of the test must not have the same water level than the previous minute. In this case, we decide that the end of the test is the last minute we measure. If the last minute of the test has the same water level than the previous minute, we decide that the end of the test is the penultimate minute.

For low intensities, the Serosi rain gauge gives a great error, comparable to tipping buckets rain gauges because:

1. The constant resolution of 0.1 mm is important for low water levels with low intensities. It gives a larger percentage of error than for the one for a high intensity (in this case, the test duration to decrease uncertainty on intensity makes large water level variations).
2. The tube that brings water from the pump to the rain gauge was put as close as possible of the nozzle, but it did not take into account the retention of the circuit where water flows until the measurement tube.

Repeatability is not good at low same intensity for two same devices: with SEROSI n°2 under calibration at 2 mm/h, we have got a maximum relative error of 33% for first serie and a minimum relative error of –19.7% for fifth serie.



4-2) WEIGHING MEASUREMENT

OTT RAIN GAUGE

A software from manufacturer inputs primary data from weighing and rules out effects of the wind (vibration and surpression-depression).

Due to the filtering software, this rain gauge provides intensity and rain accumulation some minutes later and not instanteanously. This rain gauge is more useful for rain accumulation than intensity. This device my be heated.

Aperture	200 cm^2
Outer geometry	cylindrical
Maximum intensity (according to manufacturer)	1200 mm/h

As one of the main objective of the intercomparison is to compare instruments capable of measuring rainfall intensity at a time resolution of 1 minute, we have :

1) To verify if rain accumulation is right at constant given flow rate (step response, rain intensity provided by the device).

   We have to wait 2 minutes after given flow rate stops for obtaining right results: before, rain accumulation is undervalued.

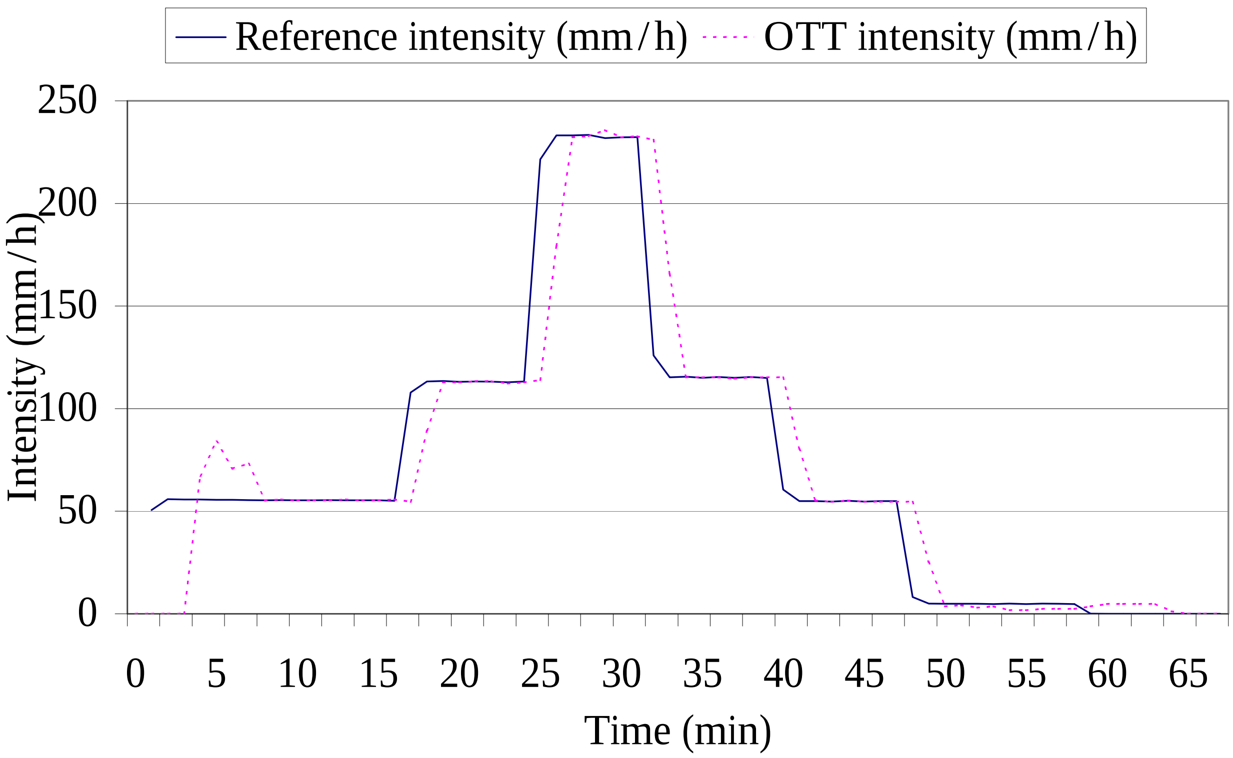
   Intensity is right but after 8 to 9 minutes for stabilisation: it needs 4 minutes after the beginning of rain fall for having minute intensity which is false (about +40%) and 4 at 5 minutes more for stabilization, that is to say 8 to 9 minutes for obtaining right intensity after the test starts.

   It means that a short and strong shower which begins with high intensity will not be recorded correctly, rules considering intensity (water accumulation will be correct).

2) To verify if rain accumulation is right at non-constant given flow rate (step response, rain intensity provided by the device). For tests, if flow rate changed during the test, it was at each beginning of minute.

   Provided by this rain gauge, rain accumulation is right, intensity delayed of 2 minutes except for the first intensity given 4 minutes after the start of given flow rate: it is overvalued for having a valid rain accumulation.

   Stop record of rain accumulation finishes 2 minutes after given flow rate stops and it's only at this time than rain accumulation is perfectly right. Relative error is close to 1%. Just at the time rain fall stops, rain accumulation provided by the software of this rain gauge is false.



Comments on the tests

Vibrations generated by impacts far and close to the rain gauge and light shocks on this rain gauge don't disturb intensity provided.

A specific software made by our laboratory staff:

1) sets a given flow rate synchronised with recording start of rain gauge

2) inputs in a PC both synchronised

- RS485 of this rain gauge transformed into RS232 signal
- mass variation of the weighing machine.

4-3) TIPPING BUCKET MEASUREMENT

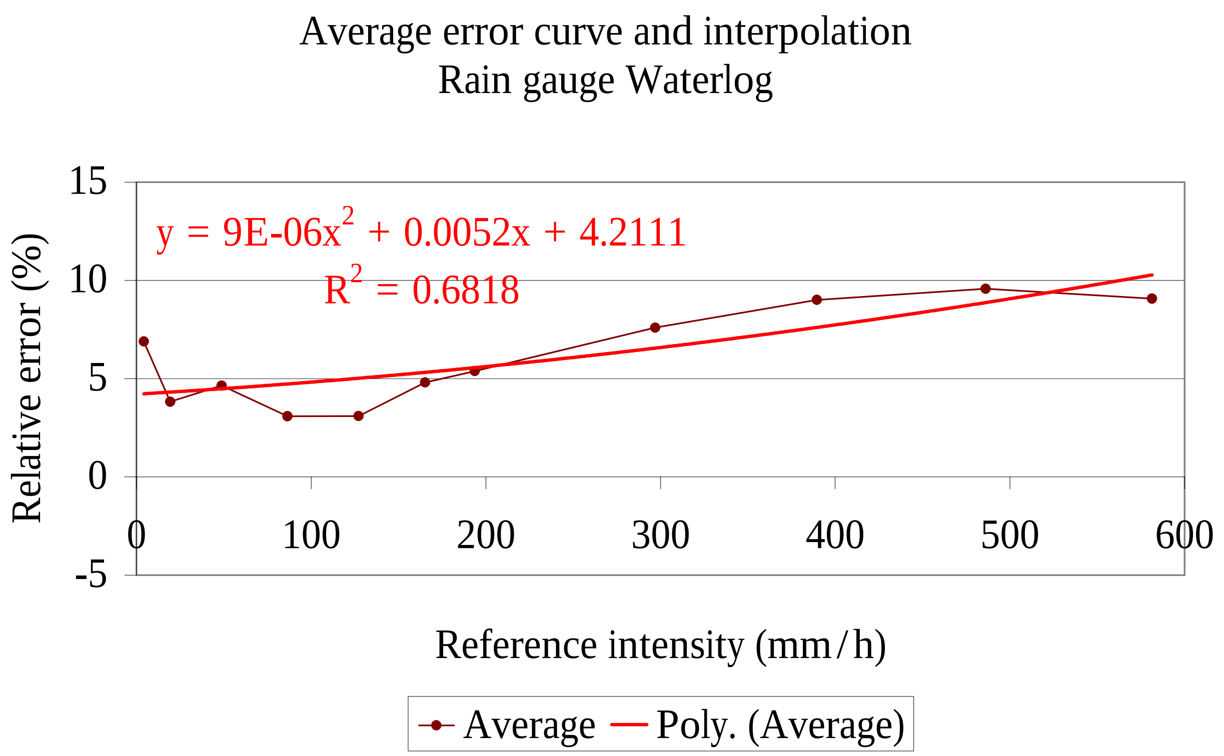
4-3-1) H340-SDI

Measurement principle : a magnet on the bucket closes a reed switch at each tip.

A software from manufacturer included in the sensor inputs primary data from tips and provides mathematical correction for bucket volume errors due to varying rainfall rate. Bucket pivot pins are mounted on bearings.

This rain gauge is not heated.

Aperture	324.3 cm^2
Mass per tip	8 gr
Outer geometry	Cylindrical
Maximum intensity (according to manufacturer)	635 mm/h
Only one device was provided by the manufacturer.	



The correction about tips is calculated as a function of the frequency of tips. This correction is overestimated. It remains an error after this correction, due to software correction, adjusting and repeatability (friction).

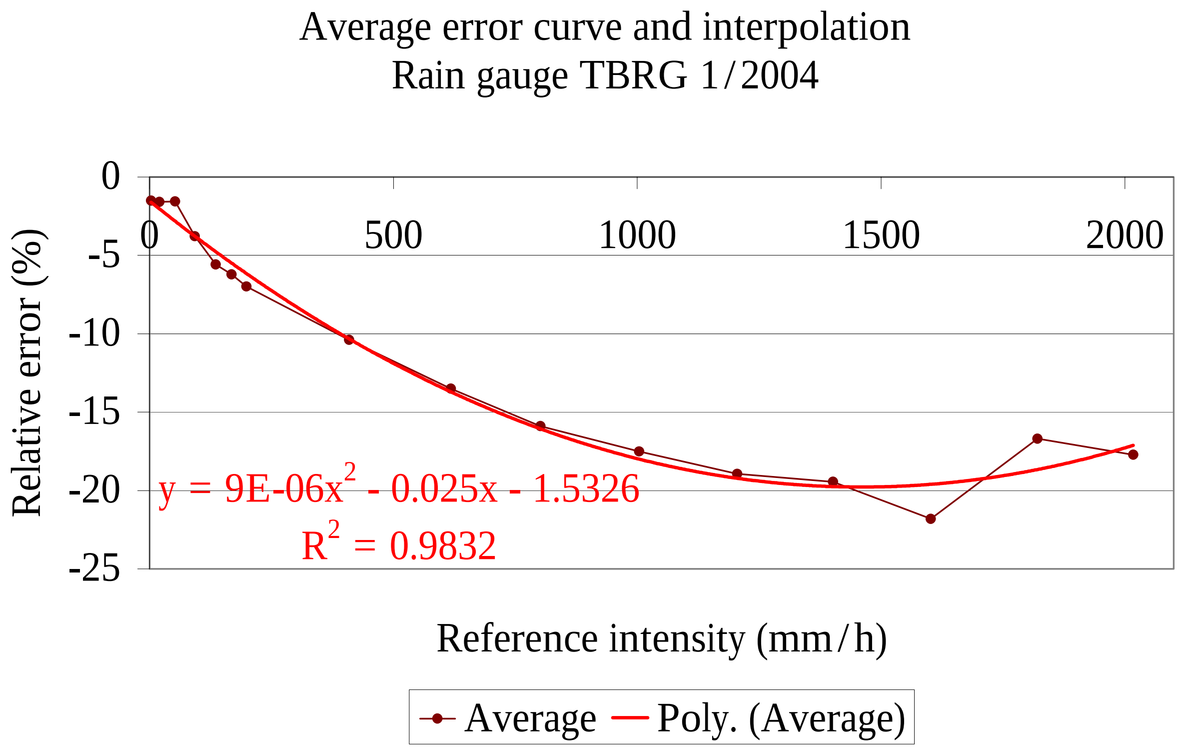
4-3-2) Indian rain gauge (TBRG)

Measurement principle : a magnet on the bucket closes a reed switch at each tip.

This rain gauge is not heated.

Aperture	324.3 cm^2
Mass per tip	16.21 gr
Outer geometry	cone put on cylinder
Maximum intensity (according to manufacturer)	/////

Monsoon in India involves rain gauges can measure high intensities and rain accumulation.



An intensity up to 1700 mm/h can be measured correctly and maximum error is got for 1700mm/h. Between 1700 mm/h and 3000 mm/h, error value varies to –15% to –23%. It's probably due to the secondary funnel above buckets which loads up to an intensity which is maybe 1700mm/h.

Conclusion:

Three types of measurement for rain gauges have been under tests :

1) Weighing
2) A right rain accumulation is got by the OTT weighing system but with an shifted intensity on time.
3) Tipping buckets, tipping buckets with mathematical correction provided by software
4) A software correction according to variable intensity is an amelioration for high intensities.
5) Conductivity
6) At low intensity with a low rain accumulation:
7) for the same intensity generated by calibration bench, the second device provides a larger difference of relative error (errors from -20% to +33%) than the first (errors from –2% to 4%).
8) with a resolution of 01.mm, relative error on intensity recorded by conductivity system is identical to tipping buckets
9) High intensities recorded by this device are very close to reference intensity, with a low relative error.

Tests in the field on these same rain gauges in 2005-2006 will be a very interesting additional information

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FIELD ACCEPTANCE TEST PROCEDURE OF 40 VAISALA PRESENT WEATHER PWD22 SENSORS AND USE OF A THIES SPECTRO-RAIN GAUGE.

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ABSTRACT

Méteo-France has just purchased in 2004 40 PWD22 present weather sensors from Vaisala company . These equipment must be commissioned with a field acceptance test procedure sensors. It is a good opportunity to get a general idea of the capability of the sensor PWD22. They are checked under real weather conditions, by series of 8 sensors. One proceeds to a comparison inter-sensors and also compared to reference sensors. Detection of precipitations, visibility measurement are tested to check that the delivered sensors are in conformity with the schedules of conditions. The results show good correspondence compared to reference sensors :

Visibility : 50% of measurements at ± 20% of the reference

Rain detection : better 90%

Drizzle detection : better 70% (in drizzle or rain)

False alarms : less than 2%

Inter-sensors good coherence : around 80% for precipitations.

At the same time a precipitation reference sensor (Thies spectro-pluviometer) is tested. A simple experience was done : Glass balls from several diameters were dropped from different heights to evaluate diameter and velocity given by the sensor. It is noted that the measurements provided by this sensor are not rigorously exact (diameter size and vertical velocity). They account generally for more or less 25% of the good value.

These advanced sensors gradually appear on the sale. The difficulty will be to be able to evaluate them with realism and rigour.

TEXT

1. INTRODUCTION

Dans le cadre de l'automatisation de l'observation du temps présent, Météo-France vient d'acquérir en mai 2004, 40 systèmes de détection et d'identification des précipitations. Ces 40 capteurs de temps présent PWD22 (VAISALA) ont fait l'objet d'une recette technique. Un spectro-pluviomètre Thies est essayé et comparé à cette occasion.

Les objectifs sont multiples :

1) Tester si les capteurs *recettés* sont en conformité avec les objectifs du CCTP en vue de prononcer la recette technique.

2) Obtenir des informations sur les réponses de ces nouveaux capteurs aux divers épisodes météorologiques rencontrés (pluies continues, averses de pluie, réduction de la visibilité, …).
3) En accord avec les spécifications du CCTP, avoir une idée de la dispersion des mesures pour un ensemble de capteurs de temps présent théoriquement identiques.

2. METHODE

Les capteurs envoient un message par minute qui décrit les données classiques de : Status de fonctionnement, Visibilité moyennée sur une minute, moyennée sur 10 minutes, Temps présent code NWS, code synoptique 0…99, Intensité de précipitation, Cumul de pluie, de neige. Les capteurs sont mis en service par groupes de 8 sur le parc instrumental de la DSO (Trappes). Les capteurs PWD22 sont disposés en deux rangées de 4 et espacés de 5 mètres environ. Un des capteurs (N° Z11309) de la première série sera gardé comme témoin pendant toute la durée de la recette. Une période de recette dure au moins une semaine et doit comporter au moins un épisode de précipitations. Le capteur spectro-pluviomètre Thies est en fonctionnement permanent. Il est distant de 30 m du champ des PWd22.

Photo 1 : Vue de 5 capteurs PWD22 (sur 8) en recette dans le parc DSO

2.1. <u>ETUDE DU TEMPS PRESENT</u>

2.1.1. Calcul d'une référence temps présent sur les codes Synop

La difficulté réside dans la détermination du temps présent réel ou plausible en absence d'observateur clinique. A partir des codes Synop des 8 capteurs on définit une référence de la façon suivante : Pour chaque minute on prend le code majoritaire, celui qui est indiqué le plus souvent par les capteurs valides. En cas d'égalité on retient le code le plus élevé.
Chaque minute d'observation comporte donc une observation de référence déduite de l'ensemble des 8 capteurs en fonctionnement. Cette méthode permet de vérifier si tous les capteurs PWD22 en essai ont un comportement identique. Les capteurs fonctionnent sans interruption, il n'y a pas de minute manquante.

2.1.2. Traitements des données

Cette méthode permet d'obtenir un tableau de contingence pour chaque capteur. Les documents associés à chaque capteur (40 imprimés) sont disponibles dans un document de travail général. Les principaux types de temps présent rencontrés sont : « 0 » : pas de phénomène, pas de précipitation., « 4 » : brume sèche ou fumée ou poussières en suspension mais visibilité supérieure à 1 km, « 10 » : brume, « 30 »: brouillard, « 51 » : bruine faible ne se congelant pas, « 61 » : pluie faible, « 62 » : pluie modérée, « 63 » : pluie forte, « 67 » : pluie (ou bruine) et neige faible, « 99 » : code artificiel créé par la base de données pour indiquer que la donnée du capteur est absente.
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Compte tenu de la période d'évaluation on ne devrait pas trouver de précipitation congelante (codes 54, 55, 56, 64, 65, 66), ni de neige (67, 68, 70, 71, …75).

2.2. COMPARAISON AVEC UN SPECTRO PLUVIOMETRE

Pour palier à l'absence d'observateur humain pendant les campagnes de comparaison, on a comparé les PWD22 à un instrument de nature différente qui peut être considéré comme un capteur de référence : le spectro-pluviomètre Thies.

2.3. ETUDE DE L'INTENSITE DES PRECIPITATIONS

Il n'y a pas de capteur de référence. On procède par inter comparaison des capteurs en recette. Pour chaque minute, la référence sera la médiane des mesures d'intensités de précipitations mesurées par les 8 capteurs de la série. On fixe à 6 le nombre minimum de capteurs fournissant des données situées dans leur gamme de mesure pour valider cette référence. Les résultats sont donnés graphiquement sous forme de « boites à moustaches ». Les intensités de précipitations sont exprimées en mm/h et moyennées sur une minute. Des classes d'intensité de précipitations sont définies.

2.4. ETUDE DE LA VISIBILITE

La Portée Optique Météorologique POM est moyennée sur une minute. La gamme de mesure du PWD22 est limitée à 20 km. On a défini un certain nombre de classes de visibilité. Pour chaque capteur, on disposera : d'un graphique présentant une inter comparaison entre les huit capteurs en essais en prenant comme référence la médiane des 8 POMs des PWD22 et d'un graphique où on le compare à la médiane des POMs de 3 diffusomètres de référence du site de Trappes : FD12 visibilimètre de Vaisala, Belfort type 6210, Degréane DF20 témoin n°1

Symboles utilisés dans les graphiques « boites è moustaches » :

Pour chaque classe qui a été définie, une boite rectangulaire est tracée, prolongée par 2 traits horizontaux et 3 autres symboles :

la croix (X) représente la médiane de la classe
la boite rectangulaire contient 50% des valeurs
entre les pointes des moustaches (lignes horizontales) il y a 90% des valeurs
entre les tirets verticaux il y a 99% des valeurs
les signes < indiquent les valeurs extrêmes (quand elles sont à l'intérieur de limites de l'échelle horizontale des graphiques)
le nombre d'éléments dans la classe est écrit en gras à droite

3. RESULTATS

La période de recette comporte 6 sessions. Elles sont décrites dans un document général. Les codes les plus souvent rencontrés sont :le code WW = 10 pour la brume, le code WW = 30 pour le brouillard. les codes WW 51, 52, 61, 62, 63 pour les bruines faibles à modérées et les pluies faibles à fortes.

3.1. COMPARAISON D'UN PWD22 AVEC UN SPECTROPLUVIOMETRE THIES

3.1.1. Temps présent

L'étude est faite sur la plus longue session de recette avec le PWD22 qui reste fixe (n° Z11309) pendant toute la campagne (la n°6 du 14/06 au 14/07/2004). Le capteur Thies fournit des informations de temps présent et d'intensité de précipitation. Le tableau ci-dessous indique les pourcentage de distribution par rapport aux indications du capteur de référence Thies. Les résultats montrent une bonne correspondance en détection des précipitations liquides.

PWD22 / Thies	Absence de précipitation	Précipitation de bruine	Précipitation de pluie	
Absence de précipitation	97%	0%	2%	Sur 41514 cas
Précipitation de bruine	12%	12%	72%	Sur 416 cas
Précipitation de pluie	3%	1%	96%	Sur 1742 cas

Tableau 1 : Comparaison du PWD22 (n° Z11309) avec le spectro-pluviomètre Thies (période du 14/06 au 16/07/2004)

La somme des valeurs des lignes n'atteint pas toujours 100%. Ces cas sont ceux où le capteur PWD22 identifie de la brume

Le taux de fausses alarmes est correct. En matière de détection, les taux de concordance sont corrects. Le spectro pluviomètre est un appareil de référence très sensible détectant des précipitations dont l'intensité est inférieure à 0,01 mm par heure. L'identification de la pluie en « pluie » est bonne. L'identification de la bruine en « bruine » est moins en accord avec les données du spectro pluviomètre. Le PWD22 privilégie l'identification de la pluie par rapport à la bruine lorsqu'il y a une faible précipitation liquide.

3.1.2. Intensité et cumuls de précipitations

Le graphique figure 8 représente les variations des cumuls de précipitations mesurés par le Thies et le PWD22 pendant la période du 14/06/2004 au 16/07/2004. On constate que malgré une certaine différence qui s'accentue au fil du temps entre les deux cumuls. Les sauts représentant les épisodes précipitants sont simultanément marqués par les deux capteurs. On verra que les intensités de précipitation mesurées par l'ensemble des capteurs se situent dans une fourchette d'un rapport 2.

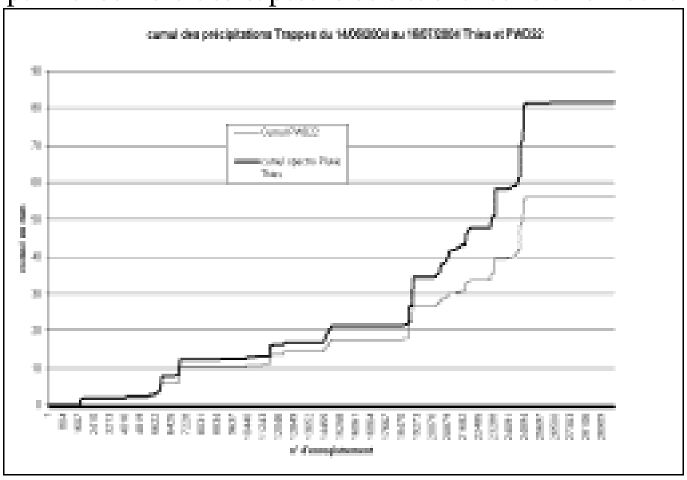


Figure 8 : Cumul des précipitations entre le 14/06 et le 16/07/2004 mesuré par le capteur Thies et le PWD22 Z11309 témoin.

3.2. COMPARAISON INTER-CAPTEURS, DISPERSION DES DIAGNOSTICS

Sur le tableau 3 de contingence qui résume le comportement des 40 capteurs dans les situations rencontrées, on constate une assez bonne correspondance entre les observations de « *référence inter capteurs* » et les observations des capteurs pris séparément. Ce tableau de contingences global est établi à partir des 40 tableaux de contingence de chaque capteur. Chaque case de ce tableau est la somme des cases correspondantes des tableaux individuels. La référence est indiquée dans la première colonne. Les données des capteurs sont réparties par rapport à la première ligne du tableau. Les précipitations liquides sont correctement observées. La brume met en évidence la dispersion des mesures de visibilité inter capteurs autour du seuil de 5000 m. Pour les précipitations, il y a similitude entre ce tableau et celui obtenu précédemment par comparaison du capteur témoin avec le spectro-pluvio Thies. Accord sur :

- absence de précipitation : 98% contre 97%
- détection de la bruine faible : 84% (74% bruine faible + 10% pluie faible) contre 84% pour le Thies
- détection de la bruine modérée : 99% (14% bruine faible+71% bruine modérée+12% pluie faible+2%pluie modérée) contre 84% pour le Thies
- détection et identification de la pluie : 93% (91%pluie+2%pluie modérée) contre 96%. pour le Thies

Les deux méthodes **($ 3.1.1 et $ 3.2**) de comparaison des codes synoptiques sont différentes. La première compare directement un capteur à un autre de type différent. La seconde compare le même capteur à l'ensemble du groupe de même type dont il est issu. Ces résultats valident le calcul de la référence majoritaire inter capteurs pour le choix de la référence de temps présent.

	0	**4**	**10**	**30**	**51**	**52**	**61**	**62**	**63**	**67**	**99**	**somme**
0	**98%**	1%	1%	0%	0%	0%	0%	0%	0%	0%	1%	**645097**
4	16%	**80%**	4%	0%	0%	0%	0%	0%	0%	0%	0%	**2907**
10	13%	0%	**85%**	0%	0%	0%	0%	0%	0%	0%	1%	**59985**
30	0%	0%	2%	**98%**	0%	0%	0%	0%	0%	0%	0%	**4327**
51	14%	0%	2%	0%	**74%**	0%	10%	0%	0%	0%	0%	**3896**
52	0%	0%	0%	0%	14%	**71%**	12%	2%	0%	0%	0%	**84**
61	6%	0%	0%	0%	1%	0%	**91%**	2%	0%	0%	2%	**45301**
62	0%	0%	0%	0%	0%	0%	9%	**87%**	3%	0%	0%	**4910**
63	2%	0%	0%	0%	0%	0%	0%	0%	**93%**	0%	0%	**990**
67	71%	0%	0%	0%	0%	0%	7%	7%	0%	**14%**	0%	**14**

Tableau 3 : Tableau de contingence représentant les correspondances entre l'observation de référence (majorité des 8 capteurs en service au moment de l'observation) et les observations des capteurs pris individuellement.

Remarque : la somme des % représentent les mesures valides et ne concernent pas les mesures manquantes de la dernière colonne.

3.3. DISPERSION DES INTENSITES DE PRECIPITATIONS

Le facteur multiplicatif est la valeur par laquelle il faut multiplier l'intensité de précipitation donnée par un capteur pour obtenir la valeur d'intensité de pluie de la *référence*. La grande majorité des intensités de précipitations mesurées est inférieure à 5 mm/heure. Pour les intensités inférieures à 2 mm/h, 99% des mesures se situent dans un facteur multiplicatif allant de 0,6 à 1,5. de la valeur de référence (médiane entre les 8 capteurs en essais à chaque session. Pour chaque capteur, on ne remarque pas de relation particulière entre la sous évaluation ou la sur évaluation et l'intensité de la précipitation. Un capteur conserve sa tendance indépendamment de l'intensité de la précipitation.

Dispersion du facteur multiplicatif des PWD22	Intensité < 2mm/h largeur de la plage du coefficient	Intensité > 2mm/h largeur de la plage du coefficient
Pour 50% des données	0,3	0,25
Pour 90% des données	0,8	0,65

Tableau 4 : Tableau donnant la largeur de plage du coefficient en fonction du pourcentage de données en accord.

Ce tableau signifie qu'un capteur possédant un coefficient de comparaison de 1 (capteur parfait) peut donner parfois, lorsque l'intensité est inférieure à 2 mm/h, une intensité inférieure ou supérieure de 40% (0,8/2) à la réalité ou d'un capteur à l'autre, alors que ceux-ci sont identiques et placés au même endroit dans les mêmes conditions.

3.4. <u>MESURES DE VISIBILITE</u>

Le graphique (figure 9) suivant représente pour le capteur témoin Z11309 l'ensemble des six périodes de tests.

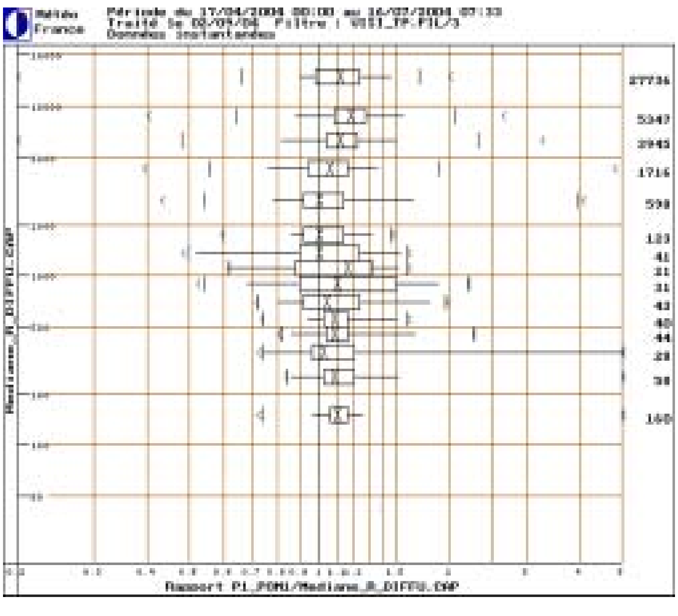


Figure 9 : Comparaison de la visibilité donnée par le PWD22 Z11309 avec la référence (médiane des capteurs de Trappes) sur la somme ses six sessions.

Le nombre de valeurs de visibilités inférieures à 2000 m est assez restreint (2% des données de la période). On ne peut donc tirer des conclusions définitives. Il apparaît tout de même que le capteur conserve un comportement régulier et acceptable dans toutes les gammes de visibilité (90% des mesures (extrémités des lignes horizontales) à ± 20%). Ici, ce capteur à tendance à surestimer la visibilité.

3.5. DISPERSION DES VISIBILITES

Dans le premier tableau (tableau 5), la dispersion est calculée par rapport à la référence inter capteurs, dans le second (tableau 6) par rapport aux capteurs fiables (BELFORT 6210, FD12, DF20 témoin) du site. Les dispersions importantes apparaissent lorsqu'il y a peu de mesures. Les coefficients sont donnés dans une fourchette car les sessions ont donné des résultats différents.

Visibilité du capteur PWD Z11309 en comparaison inter-capteurs PWD22	Position de la Médiane coefficient	Position du coefficient pour obtenir 50% des mesures en accord	Position du coefficient pour obtenir 90% des mesures en accord
Inférieure à 1000 m	entre 0,95 et 1,1 (peu de cas)	entre 0,95 et 1,2	entre 0,8 et 1,25
Entre 1000 et 5000 m	entre 0,9 et 1,2	entre 0,8 et 1,2	entre 0,7 et 1,3
Supérieure à 5000 m	entre 1 et 1,15	entre 0,95 et 1,15	entre 0,8 et 1,25

Tableau 5 : Comparaison avec la référence inter capteurs donnant la largeur de plage du coefficient en fonction de la visibilité et du pourcentage choisi de données en accord.

.

Visibilité du capteur PWD22 Z11309 en comparaison avec les références du site	Position de la médiane coefficient	Position du coefficient pour obtenir 50% des mesures en accord	Position du coefficient pour obtenir 90% des mesures en accord
Inférieure à 1000 m	entre 1 et 1,2	entre 0,9 et 2	entre 0,5 et 5
Entre 1000 et 5000 m	1,1	entre 0,85 et 1,4	entre 0,5 et 3
Supérieure à 5000 m	1,1	entre 0,95 et 1,3	entre 0,75 et 1,7

Tableau 6 : Comparaison avec les capteurs de référence du site donnant la largeur de plage du coefficient en fonction de la visibilité et du pourcentage choisi de données en accord pendant toute la campagne (6 sessions).

Un capteur parfait devrait montrer un coefficient égal à 1 et des largeurs faibles pour 50% et 90% des mesures. On remarque pour ce capteur témoin un coefficient légèrement supérieur à 1, ce qui indique une mesure des POM légèrement optimiste.

4. CONFORMITE AVEC LE CCTP

4.1. DETECTION ET IDENTIFICATION DES PRECIPITATIONS

	CCTP	PWD22 Z11309 (tableau 1)
Fausses alarmes	moins de 3%	2%
Détection de la bruine	Au moins 60%	84% (12%+72%)
Détection de la pluie	Au moins 60%	97% (1%+96%)
Identification de la bruine	Au moins 65%	12%
Identification de la pluie	Au moins 65%	96%

Tableau 2 : comparatif entre les exigences du CCTP et les résultats comparatifs (en utilisant le capteur Thies comme référence).

4.2. CONFORMITE, CONCLUSION

On a vu qu'en matière de détection le PWD22 est acceptable voir bien supérieur aux demandes du CCTP. Pour l'homogénéité des mesures de précipitations (tableau 3), les résultats sur la bruine sont légèrement inférieurs (de 6%) à ce qui était demandé (80% des identifications d'un même phénomène devaient être identiques). La pluie est toujours bien vue par un ensemble des capteurs. Rappelons que nous n'avons pas effectué de tests en situation de neige. Pour les mesures de visibilité, le capteur est conforme dans la gamme de mesure. Si on fait une comparaison avec les capteurs de référence du site, il n'y a pas 90% des mesures de visibilité à ± 20**%** de la valeur de la visibilité de référence. Les traits horizontaux des boites à moustaches dépassent largement les valeurs de 0,8 et 1,2 des coefficients. Ce phénomène apparaît encore plus sur les basses visibilités à cause de leur faible nombre par sessions. En revanche on peut dire que 50% des valeurs tiennent correctement à ± 20% de la bonne visibilité. La dispersion inter capteurs est correcte

5. CAPTEUR SPECTROPLUVIOMETRE THIES

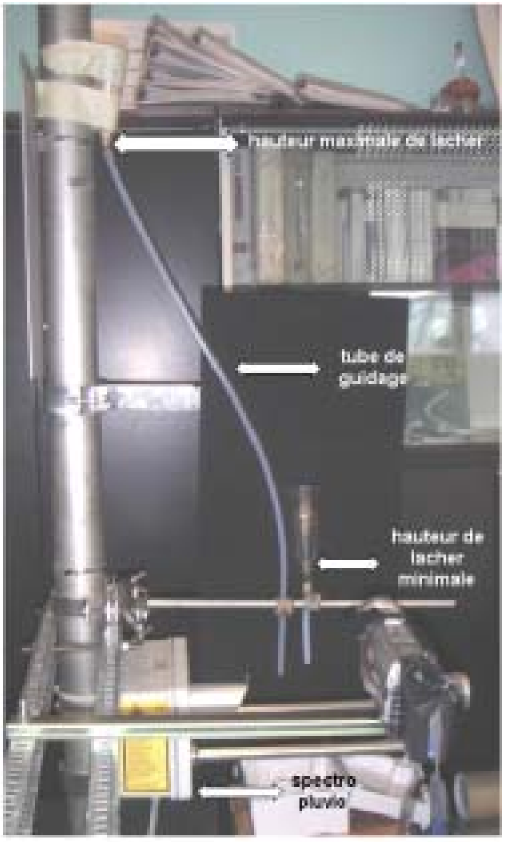


Photo 2 : Montage expérimental permettant de lâcher des billes calibrées de différents diamètres et hauteurs dans le volume d'analyse du spectro pluviomètre Thies

5.1. <u>DESCRIPTION DE L'APPAREIL ET DES ESSAIS</u>

Les essais qui suivent se déroulent en laboratoire. Le spectro pluviomètre Thies est prévu pour donner des informations sur la taille et la vitesse de chute des particules qui traversent un certain volume d'analyse situé entre ses optiques. Les détails de fonctionnement sont donnés dans la notice de l'appareil. Un grand nombre de messages différents peut être délivré. Nous retenons principalement les spectres en vitesse et en diamètre qui sont renvoyés par le capteur. Chaque minute le système comptabilise par classe de diamètre (20 classes) et par classe de vitesse (20 classes) le nombre de particules détectées. Un tableau minute comportant 400 totaux (20 X 20) est transmis. Pour effectuer l'essai de validation, on lâche devant l'appareil un grand nombre de particules dont on connaît précisément le diamètre et la vitesse de chute. Ces particules sont des billes de verre calibrées (opaques ou translucides). Pour être certain que ces particules traversent bien le domaine d'analyse, on canalise les billes dans ses tubes fins. La photo 2 montre le principe de l'expérience. Pour obtenir des vitesses verticales de chute, on lâche les billes à des hauteurs différentes. Une caméra de vidéo numérique est installée pour tenter d'effectuer des vérifications sur la vitesse.

Tableau de classes de diamètre en mm

Classe	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
diamètre	0,12	0,25	0,37	0,5	0,75	1	1,25	1,5	1,75	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7

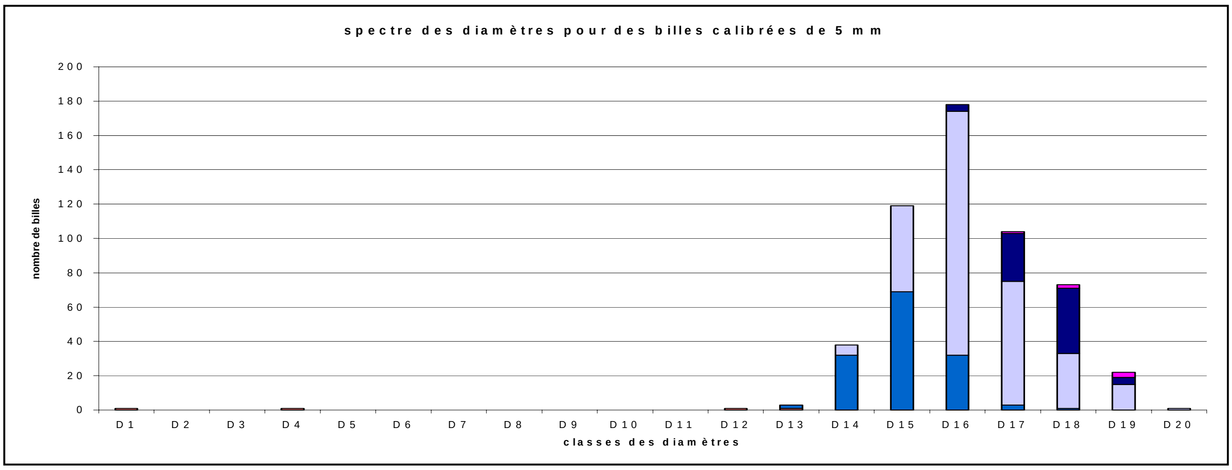
Tableau de classes de vitesses en m/s

Classe	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Vitesse	0	0,2	0,4	0,6	0,8	1	1,4	1,8	2,2	2,6	3	3,4	4,2	5	5,8	6,6	7,4	8,2	9	10

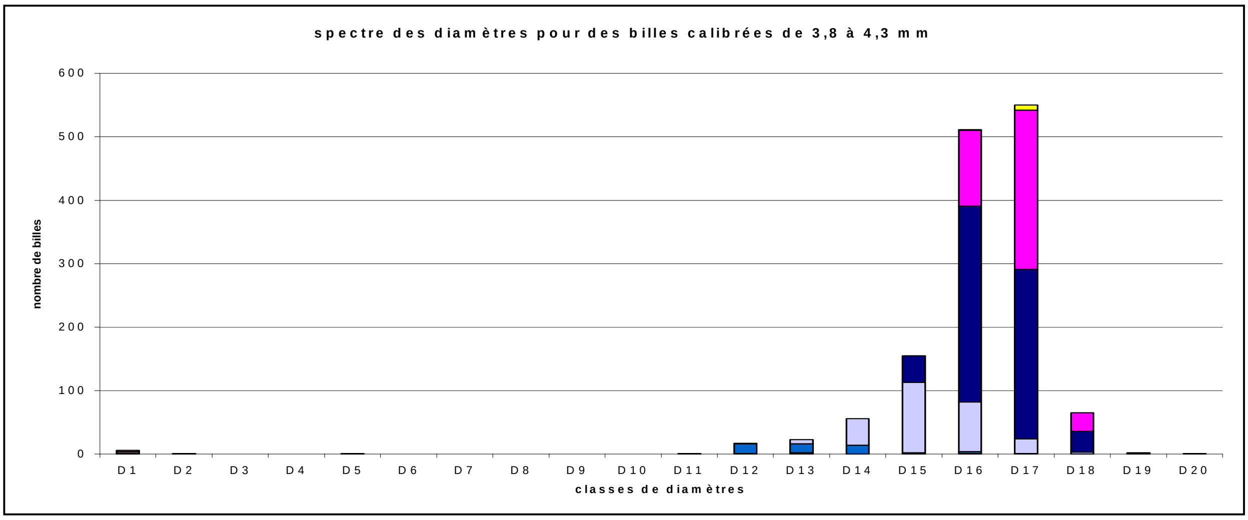
5.2. RESULTATS ET CONCLUSIONS

Les billes sont lâchées progressivement. Il est peu probable que des billes de diamètre supérieur à 2 mm passent en même temps devant le capteur. En revanche pour les petits diamètres cette possibilité est permanente. Les échantillons d'essais de billes vont de 500 billes pour les plus grosses (5 mm) à 80000 pour les plus petites (0,5 mm).

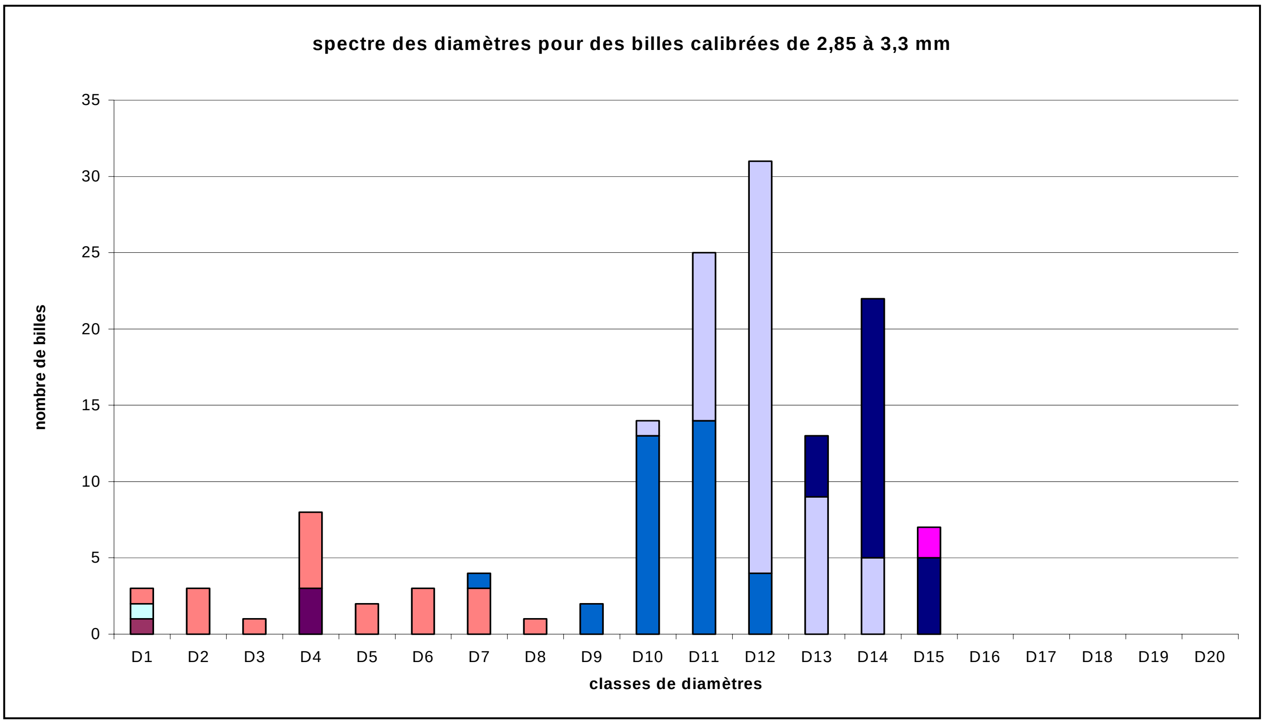
5.2.1. étude des diamètres



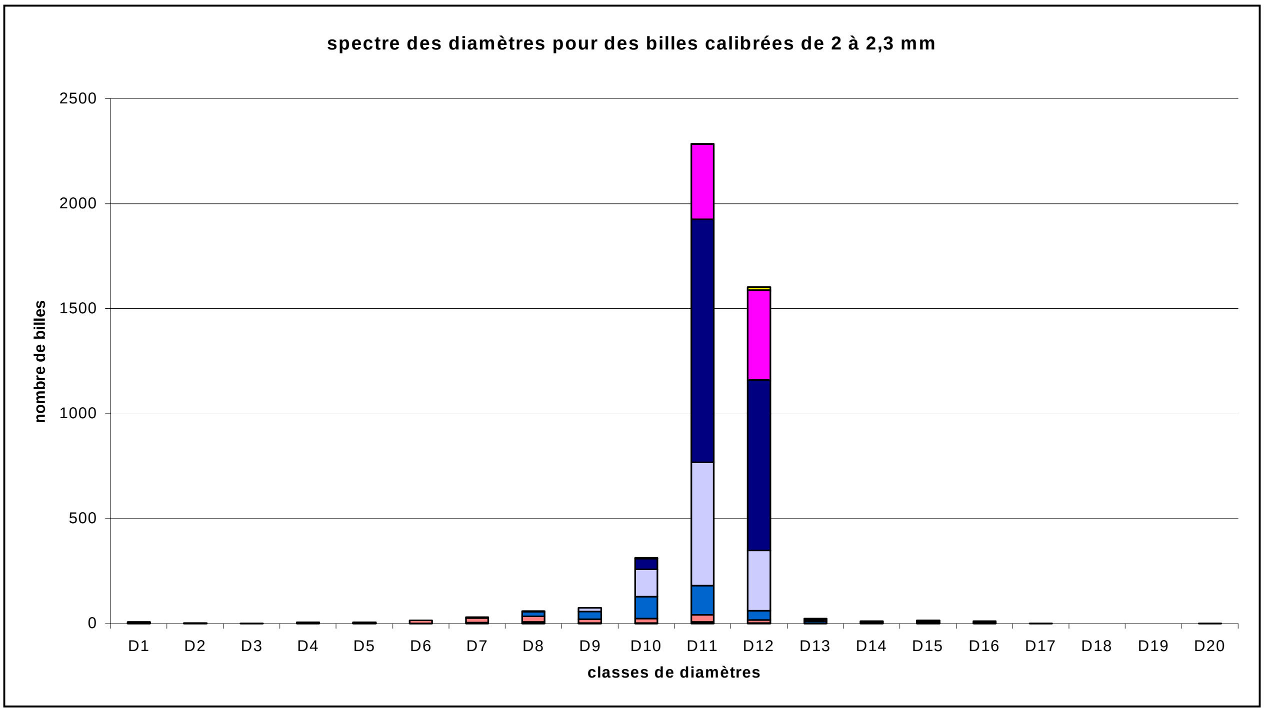
Graphique 1 : Billes de 5 mm. Les diamètres sont évalués entre 4 et 6,5 mm avec un maximum autour de 5 mm



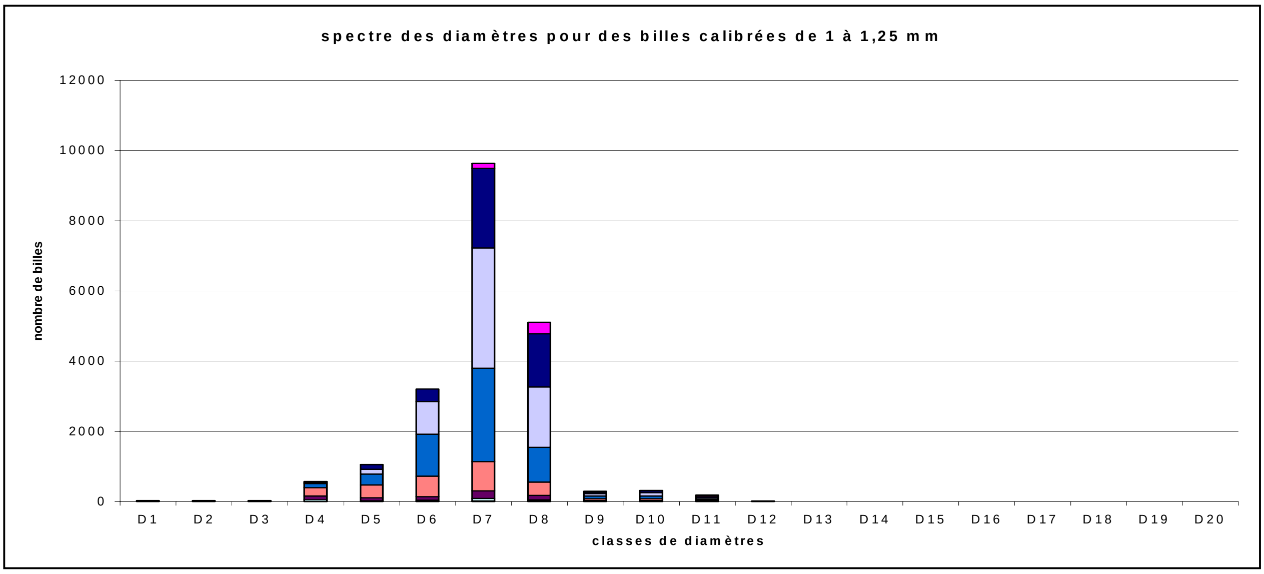
Graphique 2 : Billes de 3,8 mm à 4,3 mm. Les diamètres sont évalués entre 3,5 et 6 mm avec un maximum autour de 5,5 mm



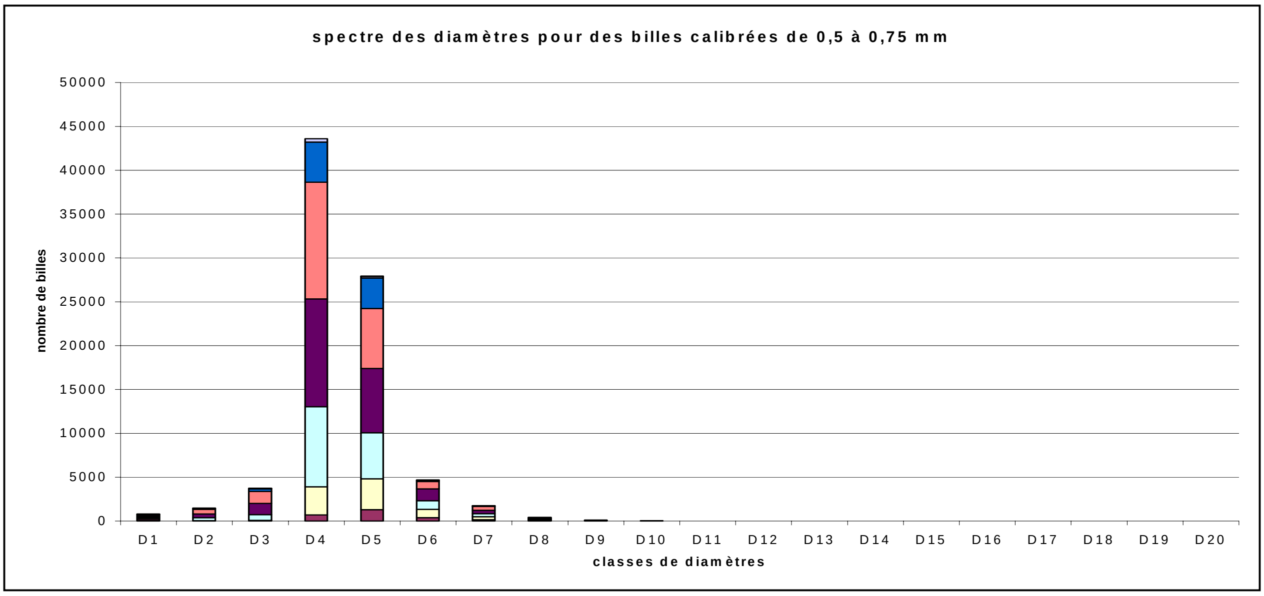
Graphique 3 : Billes de 2,85 mm à 3,3 mm. Les diamètres sont évalués entre 0,5 et 4,5 mm avec un maximum autour de 3 mm. Le nombre faible d'expérience explique la dispersion.



Graphique 4 : Billes de 2 mm à 2,3 mm. Les diamètres sont évalués entre 2 et 3 mm avec un maximum autour de 2,5 mm



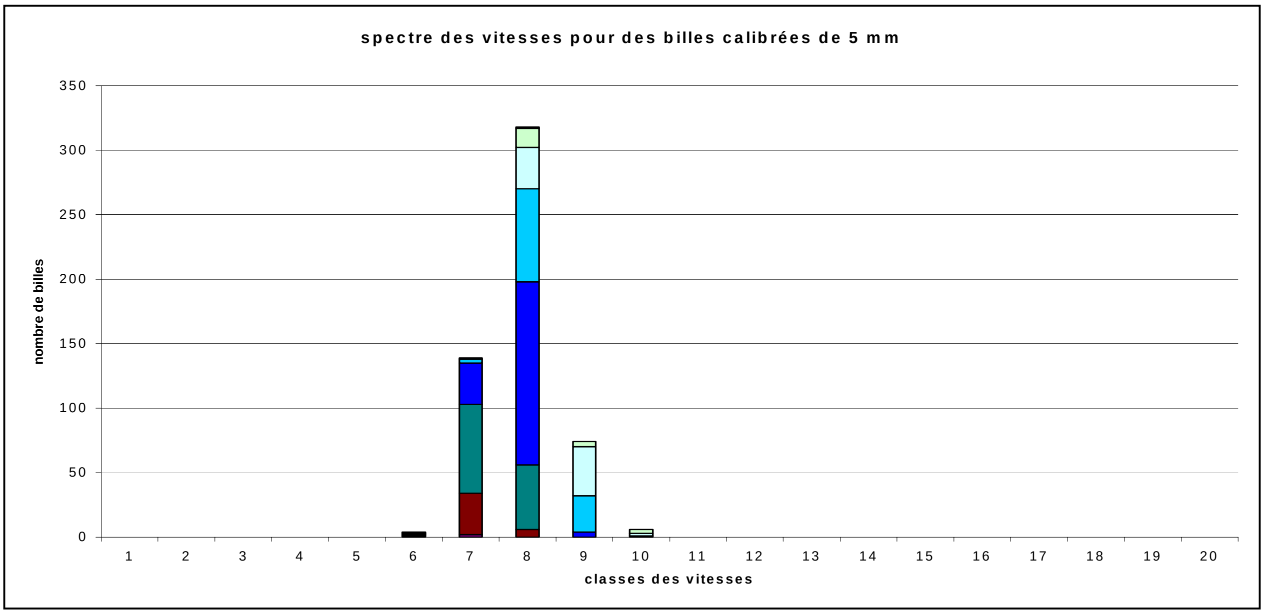
Graphique 5 : Billes de 1 mm à 1,25 mm. Les diamètres sont évalués entre 0,75 et 1,5 mm avec un maximum autour de 1,25 mm



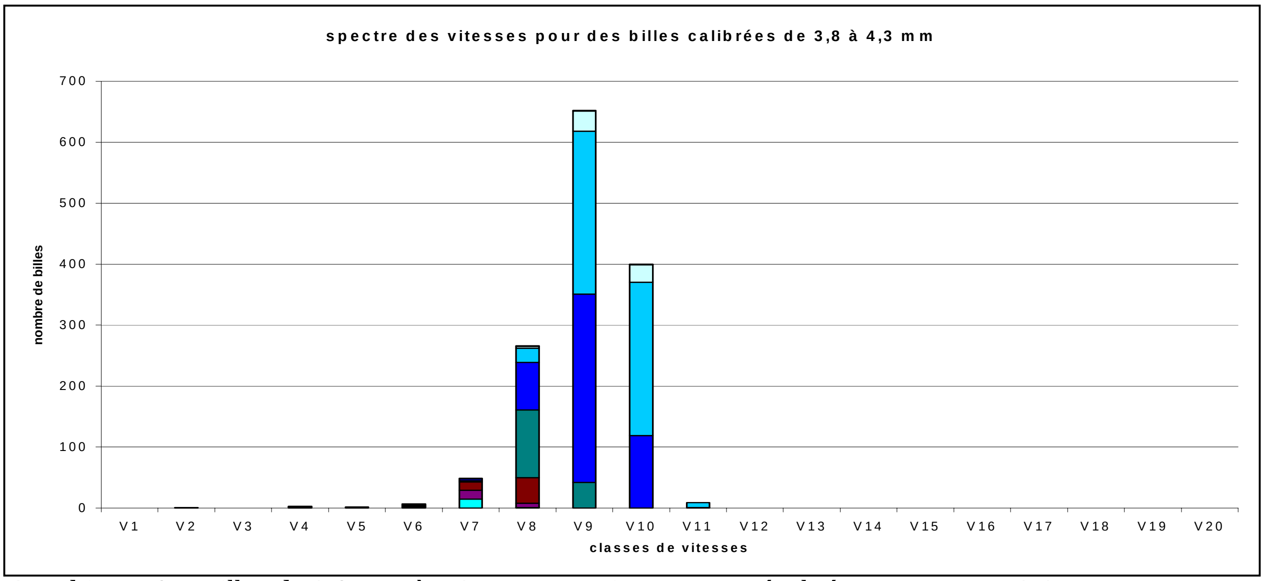
Graphique 6 : Billes de 0,5 mm à 0,75 mm. Les diamètres sont évalués entre 0,25 et 1 mm avec un maximum autour de 0,5 mm

Un document plus détaillé est disponible à la DSO. L'ensemble des essais à montré une dispersion des mesures autour de la valeur moyenne de l'ordre de la moitié de la valeur moyenne du diamètre mesuré. Pour les billes de taille supérieure ou égale à 2 mm, la position de passage dans le volume d'analyse est importante. Une bille qui est détectée sur un bord sera vue comme une particule au diamètre plus petit que la réalité. Ces erreurs ou incertitudes de mesures influent obligatoirement sur les calculs d'intensité de précipitation. On note aussi qu'en laboratoire, en absence de particules, le capteur ne détecte rien (ce qui semble normal). Ce n'est pas le cas en extérieur en absence avérée de précipitation, où le système peut comptabiliser jusqu'à 200 particules de diamètre 0,1 mm, notamment par vent modéré. Ce défaut conduit parfois à de fausses détections de précipitations.

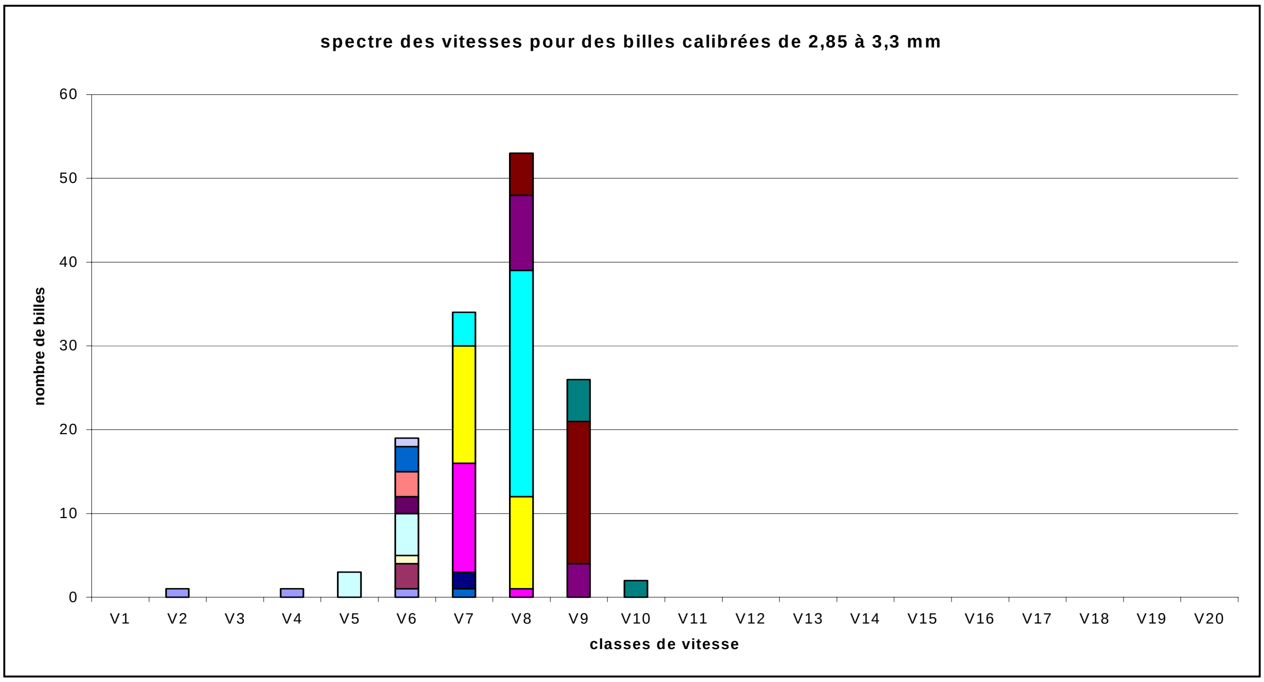
5.2.2. Etude des vitesses



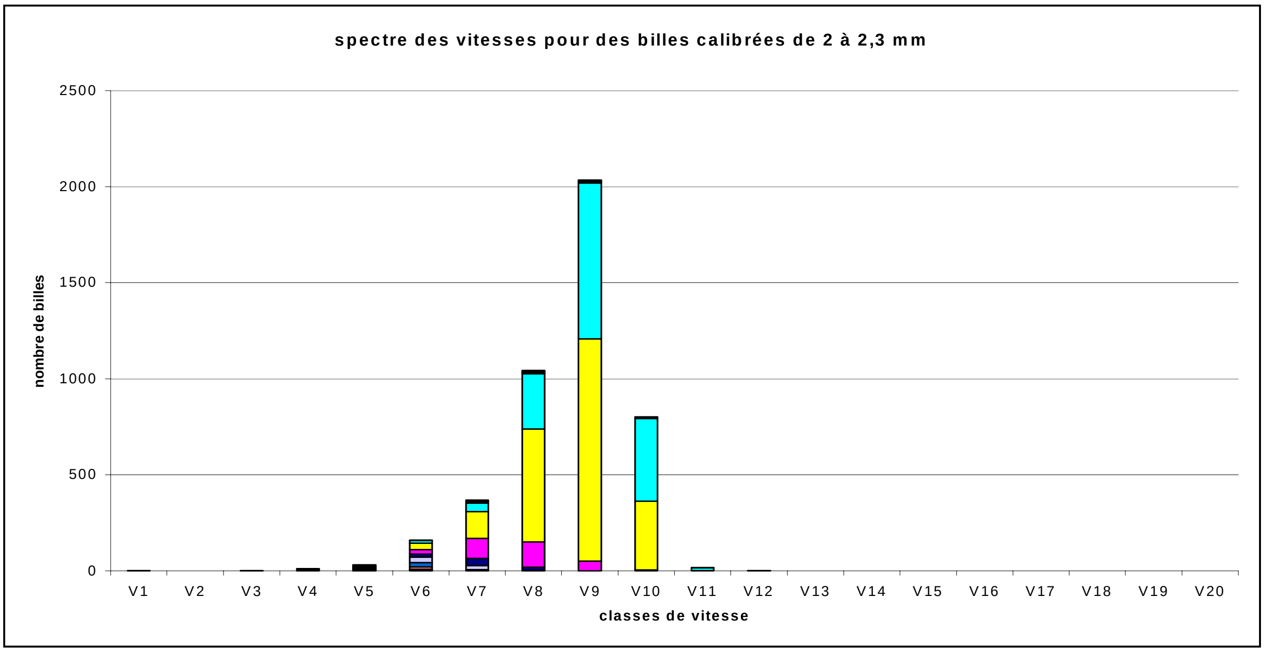
Graphique 7 : Billes de 5 mm. Les vitesses sont évaluées entre 1,4 et 2,2 m/s avec un maximum autour de 1,8 m/s



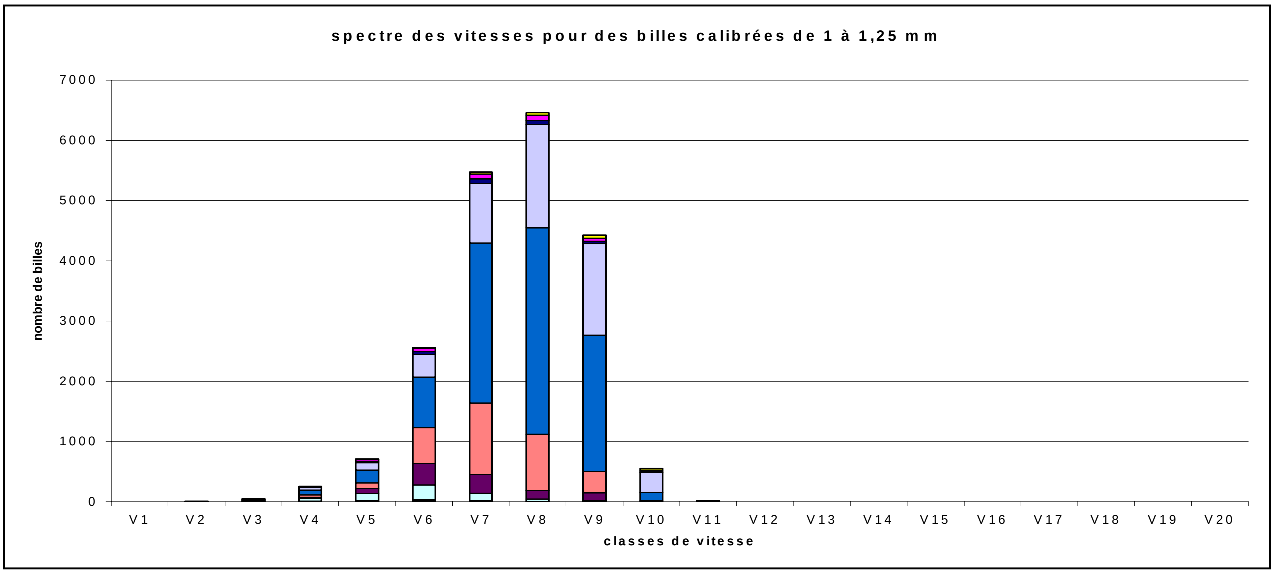
Graphique 8 : Billes de 3,8 mm à 4,3 mm. Les vitesses sont évaluées entre 1,4 et 2,6 m/s avec un maximum autour de 2,2 m/s



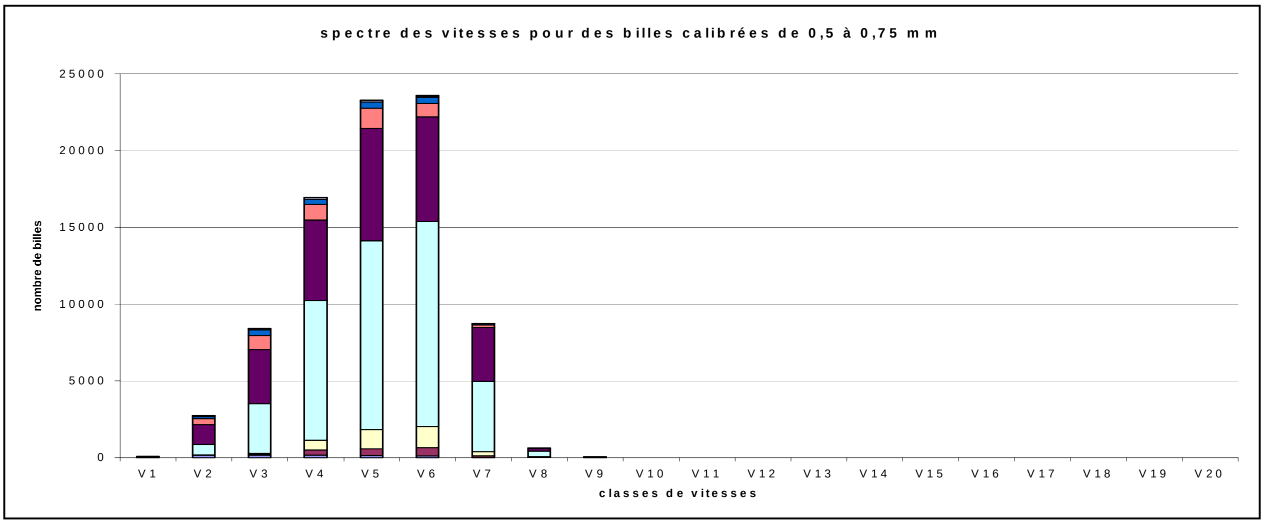
Graphique 9 : Billes de 2,25 mm à 3,2 mm. Les vitesses sont évaluées entre 1 et 2,2 m/s avec un maximum autour de 1,8 m/s



Graphique 10 : Billes de 2 mm à 2,3 mm. Les vitesses sont évaluées entre 1 et 2,6 m/s avec un maximum autour de 2,2 m/s



Graphique 11 : Billes de 1 mm à 1,25 mm. Les vitesses sont évaluées entre 0,8 et 2,2 m/s avec un maximum autour de 1,8 m/s



Graphique 12 : Billes de 0,5 mm à 0,75 mm. Les vitesses sont évaluées entre 0,2 et 1,4 m/s avec un maximum autour de 1 m/s

La hauteur de chute est de l'ordre de 0,8 m. En absence de frottement le capteur devrait indiquer une vitesse de chute d'environ $\sqrt{2gh}$ soit 4m/s. Les billes calibrées sont guidées dans leur chute dans un tube légèrement incliné. Il est normal d'enregistrer des vitesses inférieures à la valeur théorique sans frottement. Toutes les billes ont donné une vitesse de passage devant les optiques centrée autour de 1,8 à 2,2 m/s. Seules les billes de diamètre inférieur au mm ont des vitesses de passage inférieure. Une étude comparative plus poussée mesurant les vitesses réelles de passage avec une caméra fixe est en cours.

6. CONCLUSION

La recette technique de 40 capteurs de temps présent PWD22 a montré que si ces capteurs se comportent assez correctement pour l'ensemble des mesures qu'ils sont destinés à produire, ils présentent tout de même des différences de comportement avec des valeurs dispersées dans des conditions météorologiques rigoureusement identiques. Parallèlement, un spectro pluviomètre, capteur pris comme référence, possède lui aussi des incertitudes de mesures en particulier pour l'évaluation des diamètres des particules de bruine, de pluie ou de neige.. Ces écarts peuvent conduire à des différences dans l'identification des phénomènes. Dans l'avenir, d'autres appareils vont se développer et apparaître sur le marché des équipements (systèmes permettant de caractériser la couverture nuageuse, l'état du sol, le givrage, …). Ils équiperont progressivement les centres météorologiques. Il sera nécessaire de tester et de *recetter* ces systèmes. La difficulté dans l'évaluation de ces types d'appareils sera d'estimer avec justesse et réalisme les écarts en détection, en intensité, en identification, .. qui seront acceptables ou qui ne le seront pas.

7. BIBLIOGRAPHIE

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LAUTLOS upper-air humidity comparison – the first results

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[8] NOAA Climate Monitoring and Diagnostic Laboratory, Boulder, USA

1. Introduction

The LAUTLOS field campaign was hosted by FMI Arctic Research Center, Sodankylä assisted by Vaisala and was conducted successfully in January-February 2004. The idea of LAUTLOS-WAVVAP (**LA**PBIAT **U**pper **T**roposphere **Lo**wer **S**tratosphere **Wa**ter **V**apor **Va**lidation **P**roject: LAUTLOS-WAVVAP) is the comparison/validation of the world's best hygrometer types which are usable as research-type radiosondes for precise water vapor measurements in the troposphere and stratosphere region up to 10 hPa. One of the focal points of the scientific aims is to improve and validate research-type hygrometers/radiosondes like the Meteolabor Snow White hygrometer **[SW]**, NOAA frostpoint hygrometer **[NO]** and improved CFH version, CAO Flash Lyman alpha hygrometer **[FL]**, Lindenberg FN-sonde **[FN]**, Vaisala's latest RS92 GPS-version **[92]**. The aim is to define an optimal working range (related to temperature, water vapor mixing ratio, relative humidity and pressure) for each of the participating hygrometers/radiosondes. In addition to the balloon borne instruments the University of Bern used it's ground based 22 GHz microwave instrument MIAWARA at Sodankylä to obtain water vapor profiles from approx. 25 to 70 km. In addition a further microwave radiometer has been operated from a Learjet of the Swiss air force to obtain water vapor profiles close to the balloon locations. Besides the advanced hygrometers, SW, NO, FL, FN, 92 also older routine radiosondes participated, e.g. RS80-A-Humicap, RS80-H-Humicap, RS90 (manufacturer Vaisala Oyj).
In this paper the authors concentrate on the comparison of the radiosondes/hygrometers 92/FN/SW/NO in the troposphere of the Arctic atmosphere between 0.18 (height of Sodankylä upper air station) and 12 km. For the lower and middle stratosphere a separate contribution is planned including the systems FL, NO/CFH and the microwave techniques.
The RS80-A humidity profiles were corrected by the Sodankylä scientific team using different correction methods [2], [3]. Also this results will be published in a separate paper.

2. The comparison

The experiment started with a precampaign (November 27, 2003 – December 06, 2003) to check the FN-sondes [1] (special prepared modified RS90 sondes using the FN-method of *standardized frequencies*) together with the routine Sodankylä RS90 sounding system.
The main campaign (January 29, 2004 – February 26, 2004) was subdivided in two parts. During the first part (January 29, 2004 – February 06, 2004) five flights were carried out with a full payload including the expensive hygrometers NO, FL carried by an approx. 600 m^3 plastic balloon up to 27 km height.
During the second part of the main campaign (February 11 – February 26, 2004) all 29 flights were carried out by two flights per day (11:30 and 17:00 UT), 20 with smaller rubber balloons (e.g. TOTEX TX 2000g) and a smaller payload configuration) and 9 with the larger plastic balloons for heavy payload configuration, used mostly for the evening flights (17:00 UT) and the large payloads.
The construction for the payload rack was a square cross made from plastic rods of approx. 2 m length. The smaller payload was assembled as follows:

- in the center 1. Snow White and central battery package,
- at the four ends of the cross the four sondes: 2. FN; 3. RS90; 4. RS80-A; 5. RS92.

The larger heavy payload had following configuration:

- in the center 1. NOAA and 2. RS80-H (connected to one package),
- at the four ends 3. FN; 4. FLASH and 5. RS80-A (connected to one package), 6. RS92, 7. Snow White.

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During all flights both the ascent and descent (using a parachute) data were recorded.

3. Results

Figure 1 shows one example of the 29 comparison flights of the second part of the main campaign on February 15, 2004. All relative humidities RH derived from saturation water vapor partial pressure related to water [4], also for temperatures below 0°C.

In the following figures 2-7 some height regions which are particularly interesting when comparing the different sonde types, are marked with thick lines and Roman numerals **I, II, III, IV** and discussed in detail.

Figure 2 shows the RH of FN, 92 (both polymer sensors); SW_w, NO_a (both frostpoint mirrors, NO_a means ascent data) in height range 0.18-2 km; the ambient air temperature T_{ai} (absolute accuracy ±0.15°K) and the mirror surface temperature T_{sw} of the SW.
In the region **II** (1.05 to 1.2 km, T_{ai} ~ -11°C) the polymer systems FN and 92 have nearly the same RH of approx. 100 % RH. FN shows 99-100 % with two maxima between 1.05 and 1.2 km. This humidity layer is connected with undercooled ice supersaturated liquid Sc clouds (100 % RH and 10 % RH supersaturation related to ice saturation [SAT_i]). This result of FN and 92 is correct, i.e. confirmed by a priori.
Both frostpoint hygrometers (the NO_a more and the SW_w lesser) demonstrate also water supersaturation between 102 and 105 % RH. This assumed sublimation effect by sublimation heat is characterized by T_{sw} > T_{ai}. Additional water vapor causes this effect either by evaporating of water/ice droplets in the air channels of SW and NO and/or by water vapor sublimation (warming effect) directly on the mirror surfaces of SW and NO.
Some 100 m lower, (after the takeoff) in region **I** (0.4-0.6 km) all hygrometers, also NO and SW agree, within small limits of 3 % RH.
In region **III** (1.4-1.6 km) and region **IV** (1.8-2.0 km) the polymer hygrometers (FN, 92) and the mirror hygrometers (NO, SW) agree each other. Please notice there are systematic deviations between polymer and mirror devices. The mirror hygrometers show approx. 5 % lower RH. The SW mirror has had problems to find stabil conditions (see T_{sw}). For the ambiguous NO_a RH further investigations are necessary.

Figure 3 illustrates the regions **I** (2-2.2 km), **II** (2.4-2.6 km), **III** (2.95-3.05 km) and **IV** (3.6-4.0 km) which are valuable for the discussion. All systems (FN, 92, NO_a; SW_i) agree well in region **III**. FN and 92 are identical in that region! The mirror hygrometers SW and NO_a are also nearly identical, but show 2-4 % RH lesser values than the polymer hygrometers FN and 92. More critical are the RH values in region **I** and **II**. T_{ai} is varied between –17 to –21°C and the air is 5-15 % RH ice supersaturated. The polymer hygrometer 92 and FN show similar results as the mirror hygrometer but with a difference in the assessment of the RH maxima near 2.1 and 2.5 km. Here in the ice supersaturated ice As cloud the 92 (factory calibration) shows 2-4 % RH higher values than the FN (FN-method). The mirror hygrometer SW_w and NO_a provide contradictory RH. NO_a agrees good with FN and has similar values like 92. SW_w has problems with the equilibrium state on the mirror surface. After cooling-heating operations (see the variations of T_{sw} in the limits –30 to –20°C) between 2.7 and 2.8 km the SW-mirror surface state changed finally from water to ice.
Then SW_i follows excellent the RH of the other hygrometers NO_a, 92, FN (see region **III**), but we needed additional information, e.g. from FN or NO or 92, to define the aggregate state of the SW mirror surface.
Finally, in the dry region **IV** near 15 % RH and –24°C each hygrometer shows different values. The 92 RH is 3 % lower than FN. The SW_i RH is between 92 and FN and NO_a RH crosses the values of FN, SW_i, 92.

Figure 4 illustrates the RH accuracy of the sensors in a colder (-25 to –38°C) and dryer section of the atmosphere. The ice saturation SAT_i was not reached. A good (±2 % RH) agreement of all hygrometers we find in region **I** (4.2-4.4 km) and in region **IV** (5.6-5.8 km) where the vertical RH-gradient is low. For fast increasing RH in region **III** (5-5.2 km) FN, 92, SW_i nearly agree, NO_a produces some to lower values. In the sharp structured region **II** (4.6-4.8 km) the 92 and the FN agree. The SW has problems with the equilibrium (see T_{sw} in region **II**) and the NO_a is to inert to follow the RH changes. NO_d means descent data using a parachute.

Figure 5 represents cold ice supersaturated wet **I** (6.2-6.4 km) and dry **II** (7.0-7.2 km) and **III** (7.5-7.7 km) regions between T_{ai} = -40 to -48°C. In region **I** only the mirror devices NO_a and SW_i have good agreement. The polymer devices FN and 92 show lower RH values and they seem more “inert” than the mirror devices. It is evident that SW_i and NO_a may be correct measured, but to high RH (see T_{sw} > T_{ai}). The higher mirror temperatures, could be caused by sublimation of water vapor at the mirror surface (the same as discussed for Figure 2, region **II**). For region **I** the FN claims to have the correct RH because using the reference FN-method (this method uses the raw data measured frequencies when the polymer is in a heated stage ([1], [2]) as independent reference. The 92 trusts that coefficients of the factory calibration (that means the sensitivity of the

polymer) has not changed within some weeks/months and the polymer sensitivity will not be influenced by extreme weather circumstances (e.g. ice supersaturated undercooled water clouds, see Figure 2, region **II**). Therefore the FN RH could be the most correct RH in that region **I**.
In region **II**, **III** the FN is identical with the SW_i and similar to the NO_d for the range 7.1-7.2 km and 7.5-7.7 km. The 92 gives 2 % lower and the NO_a 2 % higher RH. The descent data NO_d with a time delay of about 1.5 hours between ascent and descent (on a parachute) come closer to the assumed true values represented by SW_i and FN for region **III** and **II**. The NO_a RH may be contaminated by ice particles from the deeper supersaturated regions **I** (Figure 5) and **II** (Figure 3).

Figure 6 shows dryer regions with 10-20 % RH below the tropopause with T_{ai} = –56°C at 9.7 km. In this case for the regions **I** (7.4-7.6 km) and **II** (9.4-9.6 km) the polymer sensor data FN and the frostpoint sensor data SW agree. The 92 provides 2 % lower RH than FN and SW_i. The NO_d data with ~1.5 hours time delay are near to the 92 RH. The water vapor contamination problem of NO_a ascent data (to large RH) are obvious.

Figure 7 illustrate the RH situation in lower stratosphere above the tropopause (9.7 km). The RH dropped to 2.0 % 1 km above the tropopause. This RH in region **I** (10.8-11.6 km) is confirmed as it is measured by two polymer hygrometers (92, FN) and one mirror hygrometer NO_d. For the stratosphere and descent (on a parachute) the NO_d hygrometer is worldwide recognized as reference. The ascent data of the mirror hygrometers SW_i and NO_a are likely falsified by evaporating ice particles accumulated during the flight through deeper water and ice supersaturated regions with undercooled water or ice clouds.

4. Conclusions

Both advanced hygrometers FN and 92 using the same polymer sensors. The different calibration and evaluation methods mostly agree within ±3 % RH (Figure 2, 3, 4, 6, 7). Only for the temperature range -40 to -46°C, height range 6,2 – 6,7 km (Figure 5), the FN-sonde gives 5 to 8 % lower RH than 92. It is in the moment difficult to decide "What is the correct RH in a supersaturated Cirrus cloud".
We suppose that the NO_a and SW_i RH could be falsified by evaporating ice particles and/or by sublimation of water vapor directly at the mirror surface. Further research is needed.

The comparison shows:

- polymer hygrometers (e.g. 92, FN) are cheep devices working under all meteorological circumstances,
- the mirror hygrometers (e.g. SW, NO) should be used always together with hygrometers working by an another physical principle (e.g. polymer hygrometers) to decide the aggregate state on the mirror.
- The polymer hygrometers can be used for relative humidity (RH) measurements under all atmospheric temperature and humidity circumstances from the ground up to the lower stratosphere.
- The mirror hygrometers (in the actual state of development) are working with some restrictions for relative humidity (RH) determination esp. for saturated and supersaturated atmospheric circumstances. They are sensitive for "water vapor contamination" caused by water and ice clouds. They should be used mainly during descents flights with parachutes.

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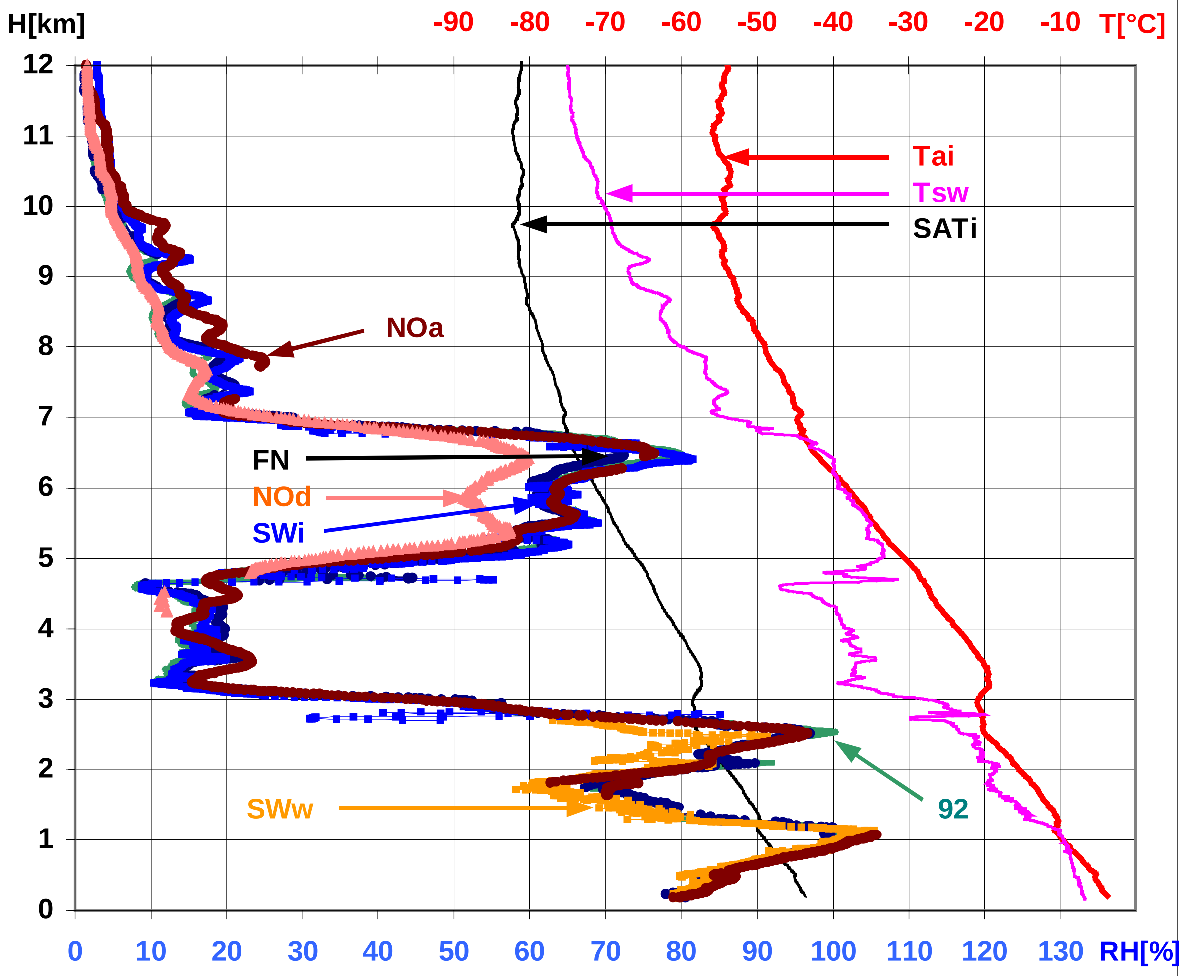

Fig.1: Comparison of nighttime FN-SW-92-NO relative humidity profiles in the Arctic troposphere in the height range 0.18 - 12 km, Sodankylä, 15.02.04, 17:25 ascent. Details are presented in Fig.2 (0 - 2 km), Fig.3 (2 - 4 km), Fig.4 (4 - 6 km), Fig.5 (6 - 8 km),

Notes to the abbrevations:

FN - Lindenberg reference sonde using polymer and FN method

92 - Vaisala RS92 advanced sonde using polymer and factory calibration

SWw - Meteolabor Snow White dew/frostpoint mirror sonde with condensated water at the mirror

SWi - Meteolabor Snow White dew/frostpoint mirror sonde with sublimated/frozen ice at the mirror

NOa - NOAA/CFH frostpoint mirror sonde with sublimated/frozen ice at the mirror, ascent data

NOd - NOAA/CFH frostpoint mirror sonde with sublimated/frozen ice at the mirror, descent data

SATi - RH related to water for ice saturation (only dependent of Tai)

Tai - air temperatur measured with F-Thermocap at the FN-sonde (modified RS90 sensor) and Vaisala factory calibration

Tsw - Snow White mirror surface temperature

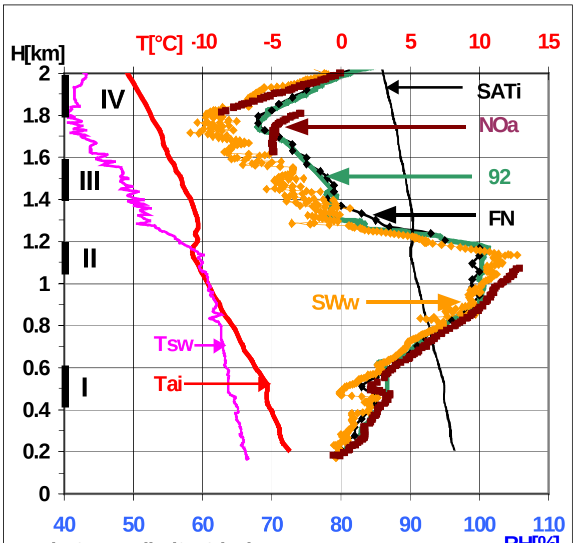

Fig.2 : Details (0 - 2 km)

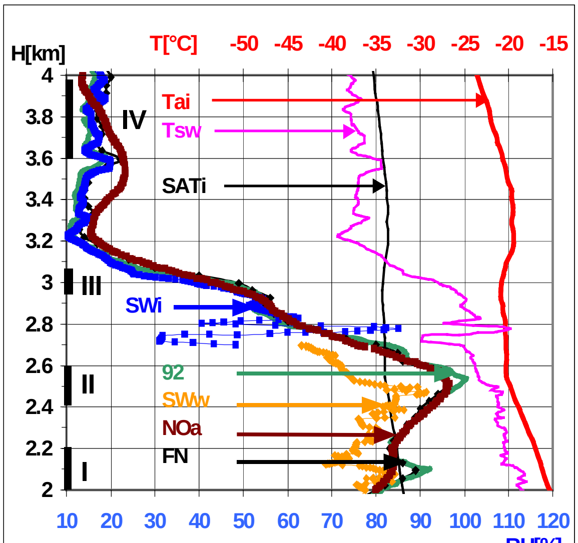

Fig.3 : Details (2 - 4 km)

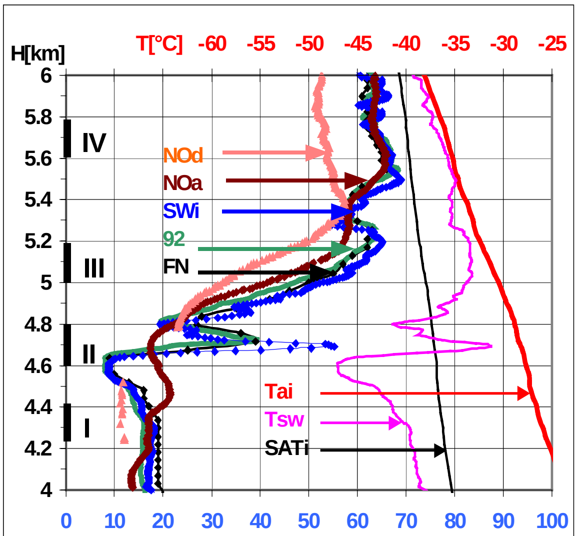

Fig.4 : Details (4 - 6 km)

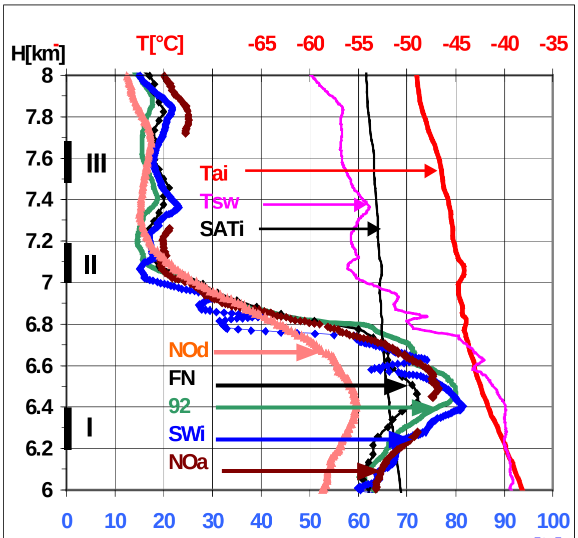

Fig.5 : Details (6 - 8 km)

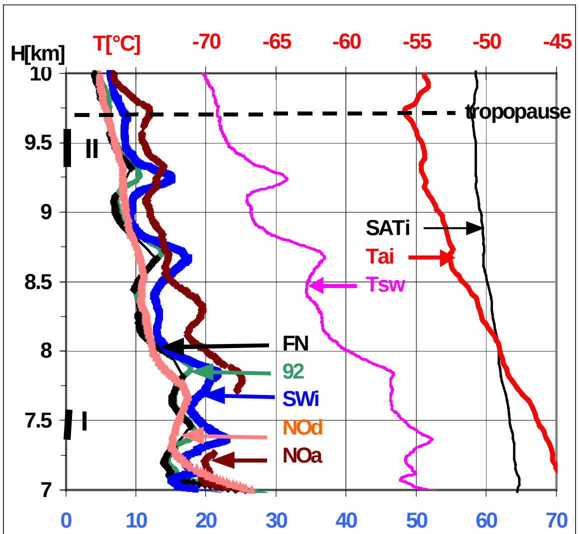

Fig.6 : Details (7 - 10 km)

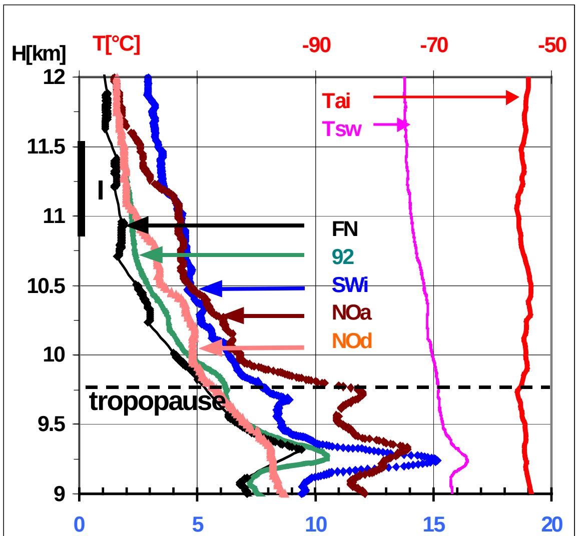

Fig.7 : Details (9 - 12 km)

A QUALITY MANAGEMENT SYSTEM FOR THE PROCESS OF COLLECTING METEOROLOGICAL DATA

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Abstract

Quality Management has been discussed widely within WMO Commissions meetings and it has been understood that the certification of NMHSs and its processes will become a future necessary activitiy. The German Meteorological Service (Deutscher Wetterdienst) implemented a quality management system and received its certificate following the ISO 9001 standards in July 2004.

It will be presented how the implementation of a quality management systems has been practically solved in the German NHMS. The presentation will introduce the main elements of a quality management system especially for meteological data generation and data management, that is, the documentation of the individual processes which are responsible for collecting meteorological data, performance indicators and mechanisms to integrate user requirements.

Quality Management System (QMS) and ISO Standards

A Quality Management System (QMS) is a business management system to direct and control an organization with regard to quality, i.e., to achieve its objectives. It is not a simple set of documents but a dynamic process, based usually upon ISO Standards that bring resources, activities and behaviours together and focus on the achievement of objectives. A QMS embraces all business processes of a NMS and is build on Technical Standards. The ISO 9001:2000 is nothing else than the international standard that specifies the fundamental concepts and vocabulary with quality management systems.

The up-dated standard ISO 9001:2000 is based on a model of a process-based QMS. This new standard is focussing on four major processes of which interactions establish a comprehensive QMS. The major processes are:

- I Management Responsibility,
- II Resource Management,
- III Measurement, Analysis and Improvement,
- IV Product Realisation.

These four major processes can be broken down into several sub-processes. Each of those sub-processes needs to be described and documented with regard to the specific framework of laws, guidelines and organisational peculiarities.

The ISO 9001 standard defines a "process" as a set of interrelated or interacting activities which transforms inputs into outputs. Processes are generally carried out under controlled conditions to add value. A process of a NMS can be, e.g., forecasting, warning, consultancy or collecting meteorological data.

The introduction of a QMS can be divided into five phases. The model of introducing the QMS in phases has been practised more or less in the same manner in most of the private and public sectors and is described in the respective literature. The phases are as follows:

Phase 1 Definition of the quality policy and the quality objectives.
Phase 2 Education and Training of the staff.
Phase 3 Analysis of the Processes Analysis.
Phase 4 Realisation and Implementation of the Processes.
Phase 5 Evaluation and Process Control.

Every 3 years the certificate expires and the process of registration has to be repeated.

The QMS of Deutscher Wetterdienst (DWD) obtained a certificate following the standard ISO 9001:2000 in July 2004.

The Processes of DWD

One major QM principle is the “process approach”. This principle expresses the following:

“**A desired result is achieved more efficiently when activities and related resources are managed in process.**”

For product realization you need a defined purpose and goal or objective. The process will need inputs in the form of product, people, information, equipment, materials and money. There should be a pool of resources available in the form of tools, equipment, machinery, money, people and knowledge to support the process development. The activities of a process have a sequence from start to finish.

The output of a process, which is in the form of a product, information, people or decision, needs to be controlled by standards, measurements and feedback loops. The process is characterized by results as a measure of achievement, efficiency and effectiveness.

Figure 1 shows the main processes (vertical columns) of the DWD and its supporting processes (horizontal columns).

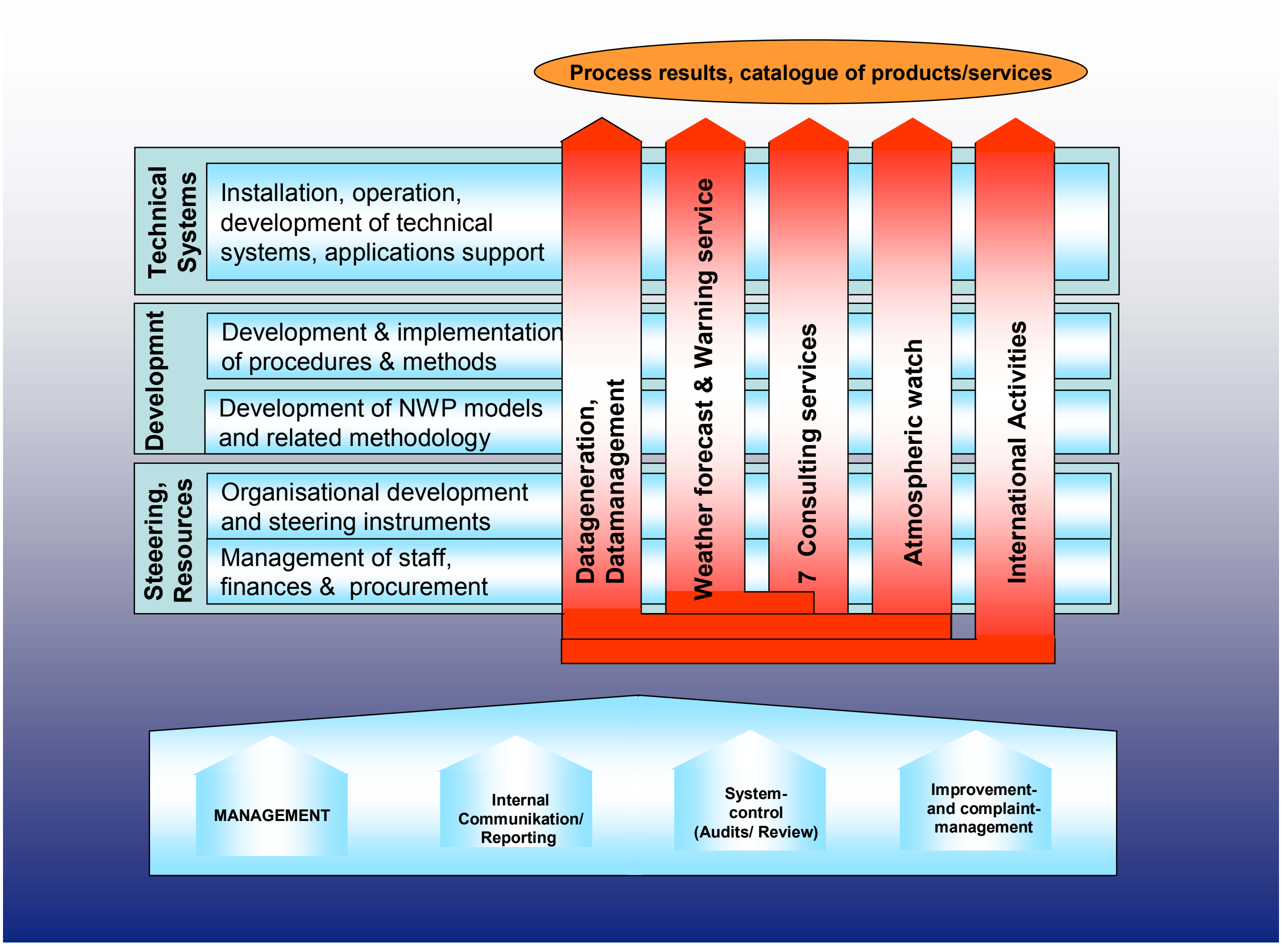


Figure 1: Major DWD processes and its supporting processes.

The major process of data generation and data management underwent again a process analyses and is divided again into main (vertical columns) and supporting processes (horizontal columns)(Figure 2).

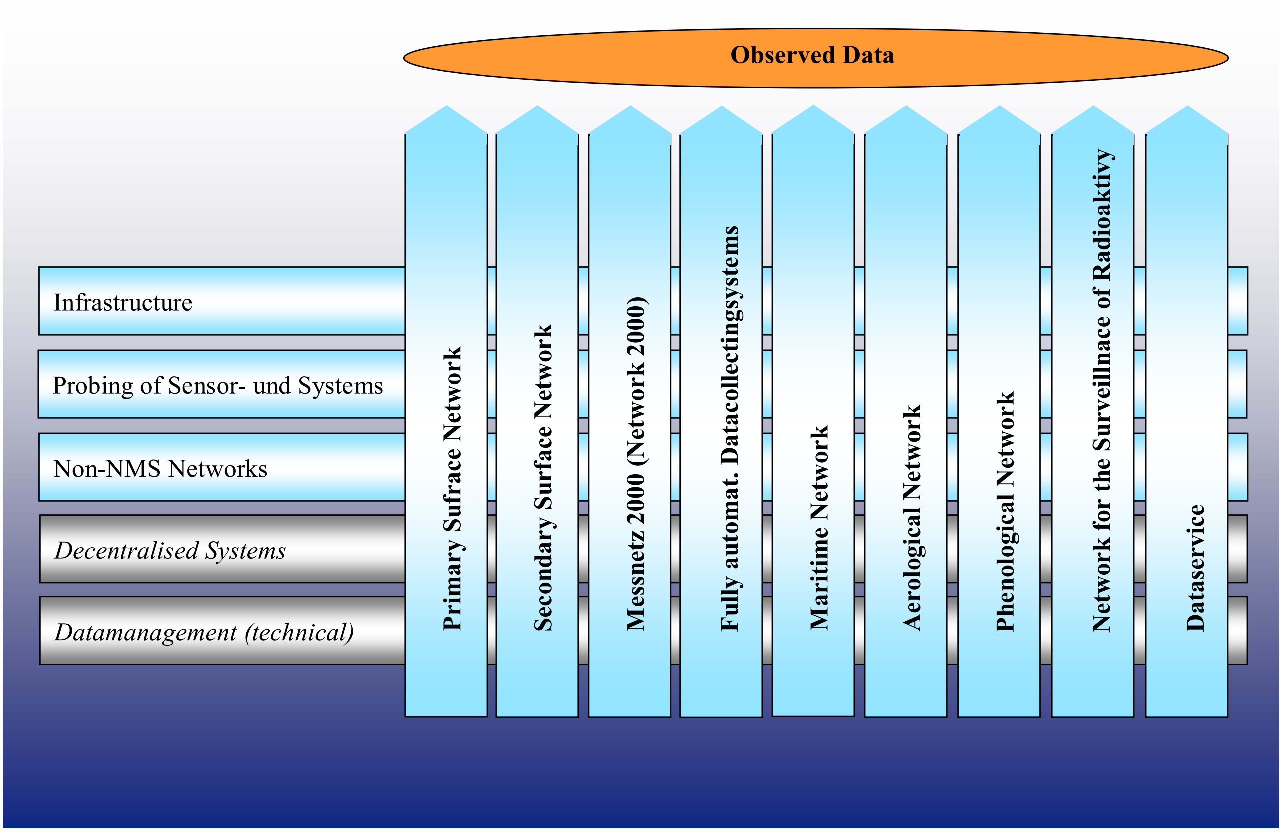


Figure 2: Process of Data Generation and Data Management as defined by DWD.

Documentation

The documentation of a QMS is a hierarchy of documents as demonstrated in Figure 3. At the top level there is a QM manual which contains the specifics of a QMS of an organisation. It contains the policies and objectives of the organisation. It is a means of showing how the systems has been designed, who carries the responsibilities for which process and how to improve the systems. The documentation of processes is at Level 2.

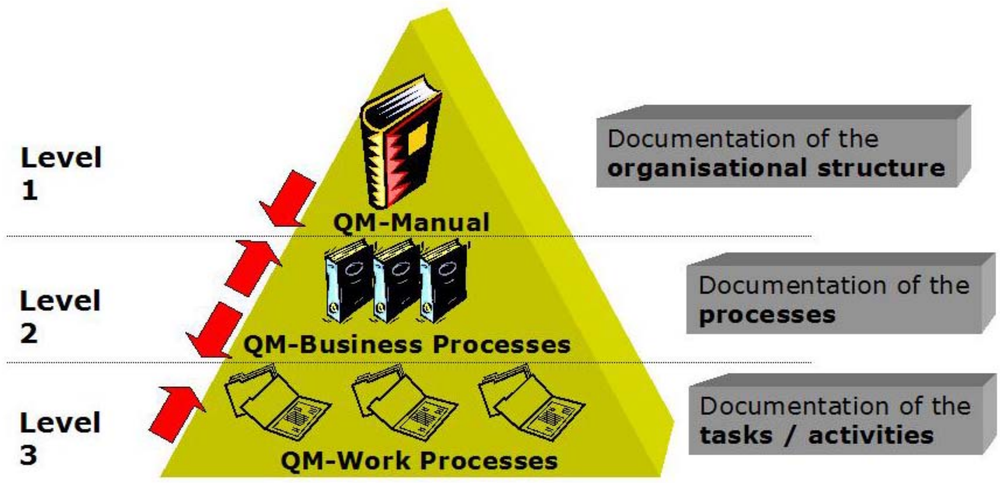


Figure 3: The three levels of Quality Management Documentation.

Performance Indicators of the Data Generation and Data Management Process

Performance indicators are an important tool to control processes. The process will only work successfully if the staff is appropriately qualified and performs satisfactorily, if hardware and software are reliable and if in particularly the cooperation with the major DWD process "Technical Infrastructure" works smoothly.

DWD determined the following indicators to monitor its Data Generation and Data Management Process:

- Completeness of data (E.g., Did all the stations reported in time ?).
- Timeliness of data (E.g., Did all data arrived in time ?).
- Percentage of corrected or complemented data.
- Number of user-help-desk tickets.
- Downtime of individual meteorological sensors.

The following examples show indicators from the secondary ground based observing network of DWD. Figure 4 gives the completeness of data during 2004. Figure 5 indicates in percentage how many of the data have been flagged in the quality control run and Figure 6 gives the result of the man-machine interactive quality control procedure. The results are shown for the different Regional Network Group of DWD which are responsible for the data control.

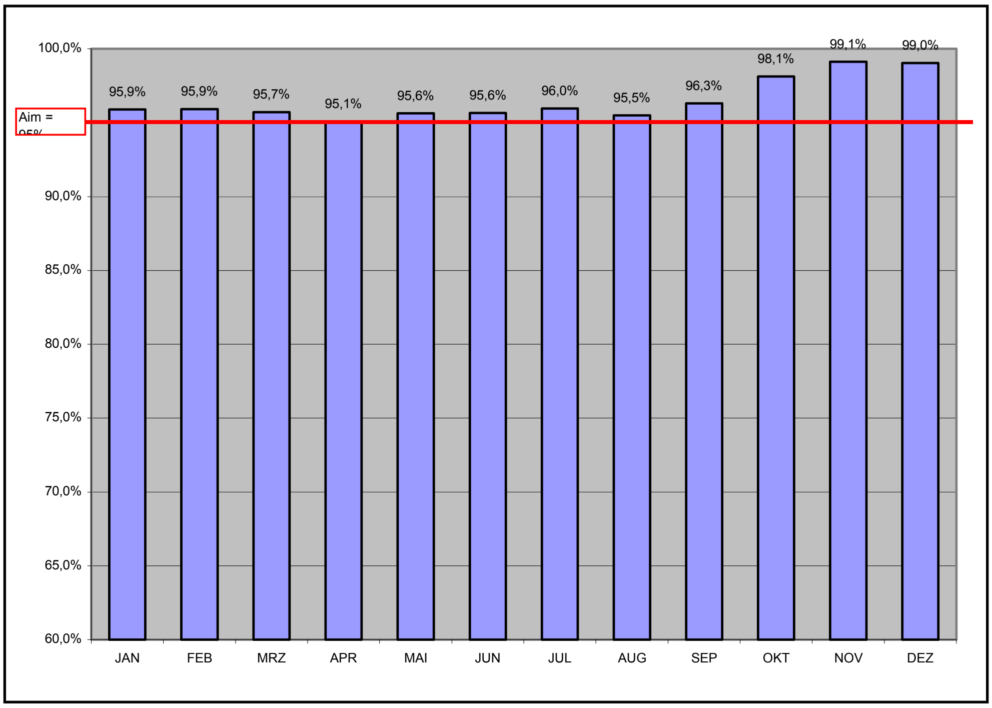


Figure 4: Data completeness for the secondary ground based observing network of DWD during 2004.

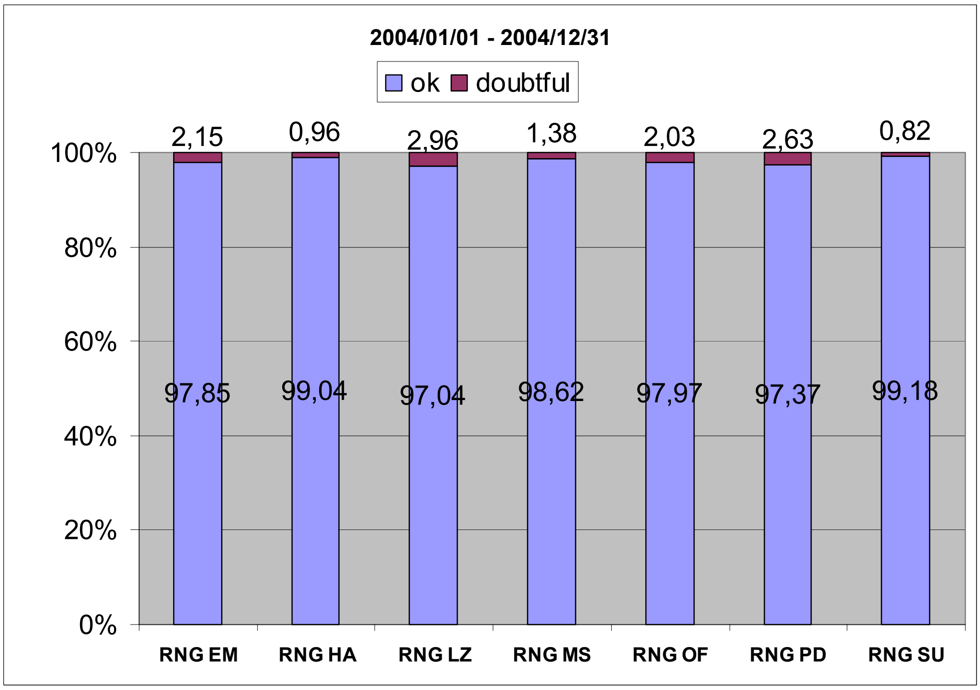
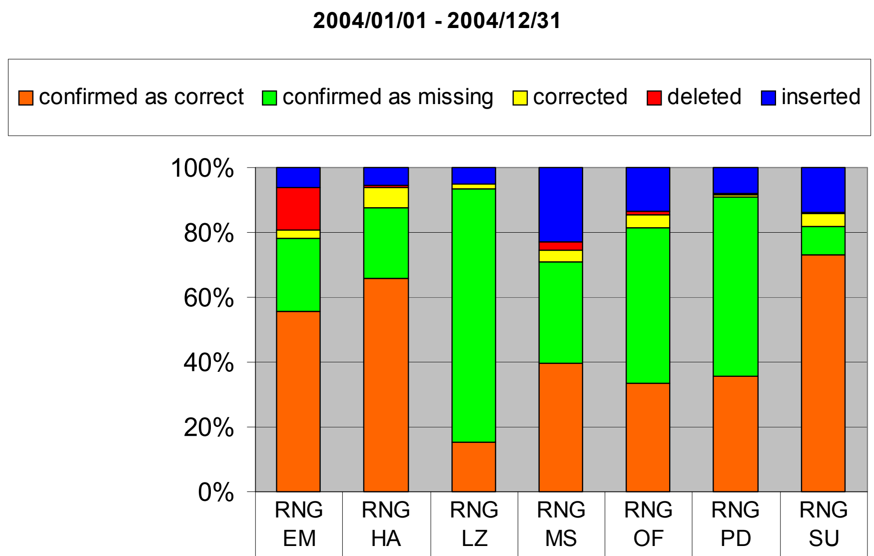


Figure 5: Percentage of data which have been flagged during the control run; results for the different Regional Network Groups of DWD.



	RNG EM	RNG HA	RNG LZ	RNG MS	RNG OF	RNG PD	RNG SU
inserted	6,19	5,52	5,06	23,02	13,32	8,11	13,97
deleted	13,22	0,64	0,16	2,31	1,21	0,17	0,04
corrected	2,35	6,07	1,41	3,77	4,01	0,78	4,17
confirmed as missing	22,73	21,97	78,19	31,33	47,96	55,18	8,63
confirmed as correct	55,51	65,80	15,18	39,57	33,50	35,76	73,20

Figure 6: Results of the man-machine interactive quality control procedure. The number of flagged data have been set to 100%. The results are shown for the different Regional Network Group of DWD which are responsible for the data control.

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Comparaison entre une Station météo Automatique et une Station météo classique.

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Résumé

L'élargissement des applications de la Météorologie au service du bien être de l'homme nécessite des besoins accrus concernant la précision des données, la fréquence rapprochée des observations et une plus grande densité des réseaux de stations d'observations.

Il est évident que les moyens traditionnels ne sont plus suffisants pour faire face aux tâches opérationnelles actuelles de la météorologie, surtout en aéronautique où les données instantanées sont fréquemment sollicitées.

La substitution d'une station classique par une station automatique nécessite un calibrage afin d'évaluer l'homogénéité des séries de données d'observations.

Depuis Juin 2004 une station automatique de type VAISSALA MIDAS IV a été installée par la FIR (Flight Information Région) à l'Aéroport de Conakry dans le cadre de l'amélioration de la protection aéronautique.

Au cours de la période d'essai, les données examinées dans ce document sont : le vent (ddd et ff), la température, le point de rosée et la pression (QNH).

Les deux Stations ont fonctionnées sans discontinuité et les valeurs relevées ont été analysées et comparées pour évaluer l'homogénéité des deux séries.

La comparaison des deux séries de près de 500 données l'une s'est faite sans tenir compte des heures d' observations à trois niveaux. :

- Mesures Comparatives ;
- Contrôle Graphique ;
- Test Statistique ;

L'expérience conduite ici, témoigne que si pour certaines mesures il est possible de mettre en évidence un rapport satisfaisant entre les séries de données d'une station classique et celle de la station automatique, dans d'autres, les différences peuvent être importantes. Cette situation nous interpelle à des recherches plus détaillées.

I - Introduction:

L'élargissement des applications de la Météorologie au service du bien être de l'homme, nécessite des besoins accrus concernant la précision des données, la fréquence rapprochée des observations et une plus grande densité des réseaux d'observations.

Il est évident que les moyens traditionnels ne sont plus suffisants pour faire face aux tâches opérationnelles actuelles de la météorologie, surtout en aéronautique où les données instantanées sont fréquemment sollicitées.

La substitution d'une station classique par une station automatique nécessite un calibrage afin d'évaluer l'homogénéité des séries de données d'observations.

La République de Guinée, avec une superficie de 245.857km^2 a un Réseau Météorologique National de 45 Stations classiques dont 12 Synoptiques, 24 stations climatologiques, 7 stations agrométéorologiques, une station aérologique et une station maritime.

Ce réseau national est renforcé par 4 stations automatiques installées pour les besoins spécifiques dont 2 dans la zone du barrage hydroélectrique de GARAFIRI, une dans la zone minière de SANGAREDI et une le long du fleuve Milo dans le bassin du Niger, ce dernier est d'ailleurs en panne depuis longtemps.

Ces stations automatiques opérationnelles permettent de collecter les données sur la température, le rayonnement, le vent, la pluviométrie, l'humidité etc.…

Ces données sont destinées à mener des études d'impacts sur l'environnement du barrage de Garafiri et de future Fonderie d'Alumine prévue à Sangaredi.

Les observations météorologiques recueillies dans ce réseau renforcé en qualité, fréquence et en volume de données permettent de surveiller les évènements météorologiques marquants et les anomalies climatiques sur le plan national et régional.

En Guinée, les premières observations météorologiques ont débutées en 1897 à Beyla. C'est en 1922 que les observations météorologiques ont commencé à l'Aéroport de Conakry-Gbèssia.

Depuis Juin 2004 une station automatique de type VAISSALA MIDAS IV a été installée par la Région d'Information de Vol de Roberts, FIR (Flight Information Région) à l'Aéroport de Conakry dans le cadre de l'amélioration de la protection aéronautique.

Les capteurs de cette station automatique sont installés à 200m du parc à instruments de la station classique et à 75m de la piste.

II - Caractéristiques Techniques des deux Stations.

1) - Station Classique.

Instruments	**Caractéristiques**	**Unité de mesure**	**Etendue de l'Echelle**	**Précision**	**Sensibilité**
Abri météo	Bois	/	/	/	/
Thermographe	JR- à lame bimétallique.	°c	-35 à 45	/	/
Hygrographe	JR -à cheveux	%	0 à 100	/	/
Thermo mini	A alcool	°c	-25 à 60	/	/
Thermo maxi	A mercure	°c	-30 à 50	/	/
Psychromètre	A ventilation artificielle	%	-10 à 70	/	/
Pluviographe	PM à augets basc.	mm	0 à 20	/	/
Baromètre	PM à mercure	mb	790 à 1090	/	/
Barographe					
Anémomètre	Moulinet à coupes Girouette	M/s degré	 0 à 360	/ /	/ /

2) - Station Automatique.

Instruments	Caractéristiques	Unité de mesure	Etendue de l'Echelle	Précision	Sensibilité
Températures T/ Td Humidité	Humicap 180 R HMP45D plymer sensor	°c %	-40 à 60 0,8 à 100	+/- 0,4 +/- 1	
précipitations	RG13/RG13H	mm			0,2mm
Pression	PTB220/PMT16A	hpa	500 à 1100	0,15	0,1
Direction Vent	Optoelectronic	degré	0 à 360	+/- 3	5,6
Vitesse du vent	Optoelectronic	M/s	0,4 à75		0,1

III - Instruments et Méthodes.

Au cours de la période d'essai, les données examinées dans ce document sont : le vent (ddd et ff), la température, le point de rosée et la pression (QNH).

Les deux Stations ont fonctionné sans discontinuité et les valeurs relevées ont été analysées et comparées pour évaluer l'homogénéité des deux séries.

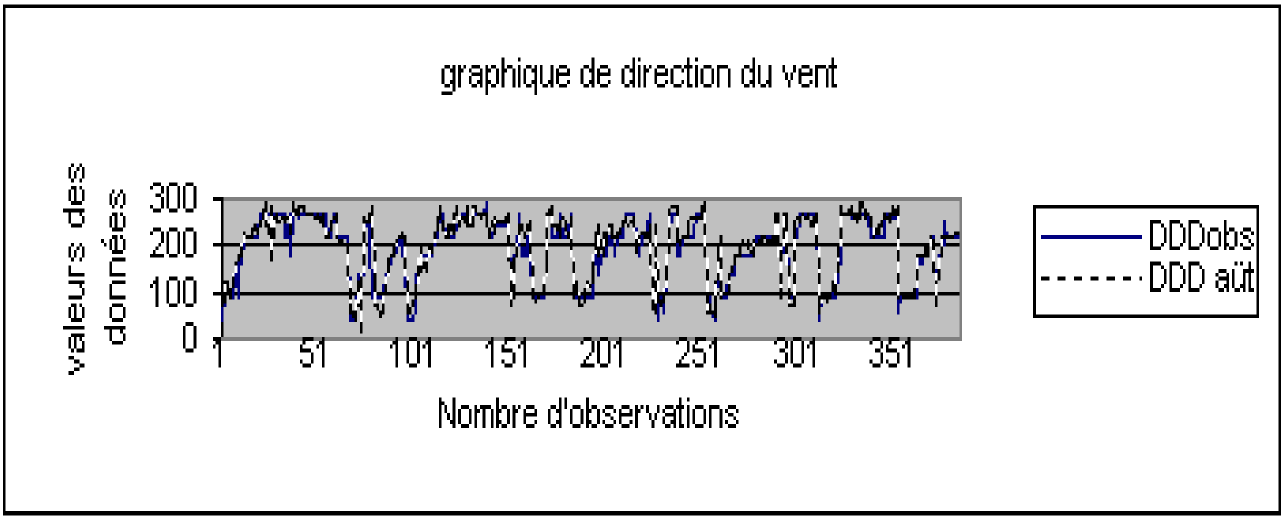
La comparaison des deux séries de près de 500 données l'une s'est faite sans tenir compte des heures d' observations à trois niveaux. :

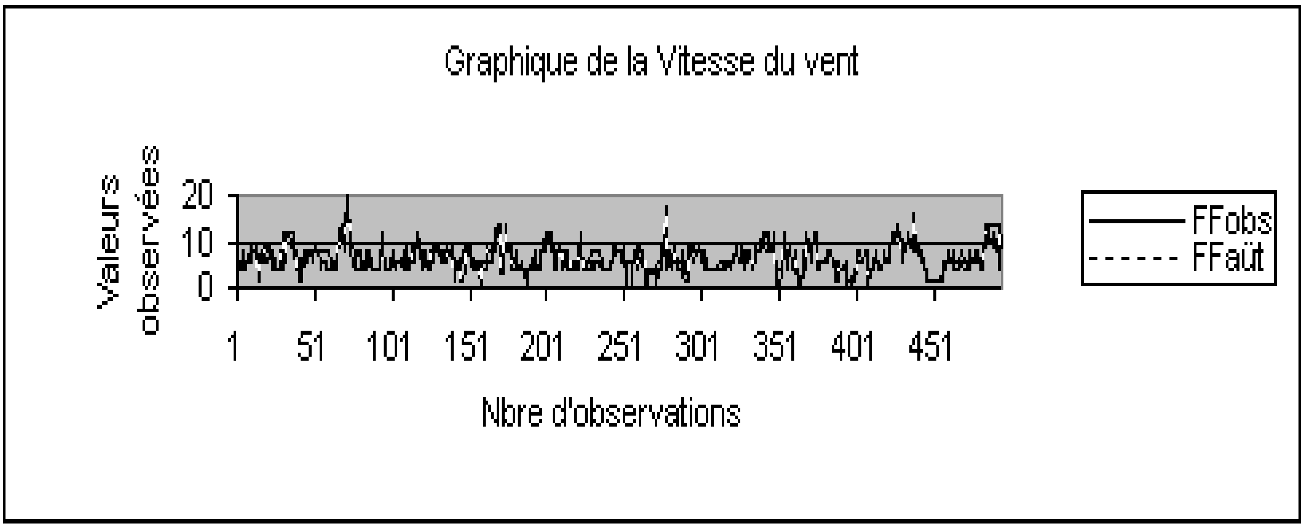
1) **- Mesures comparatives**

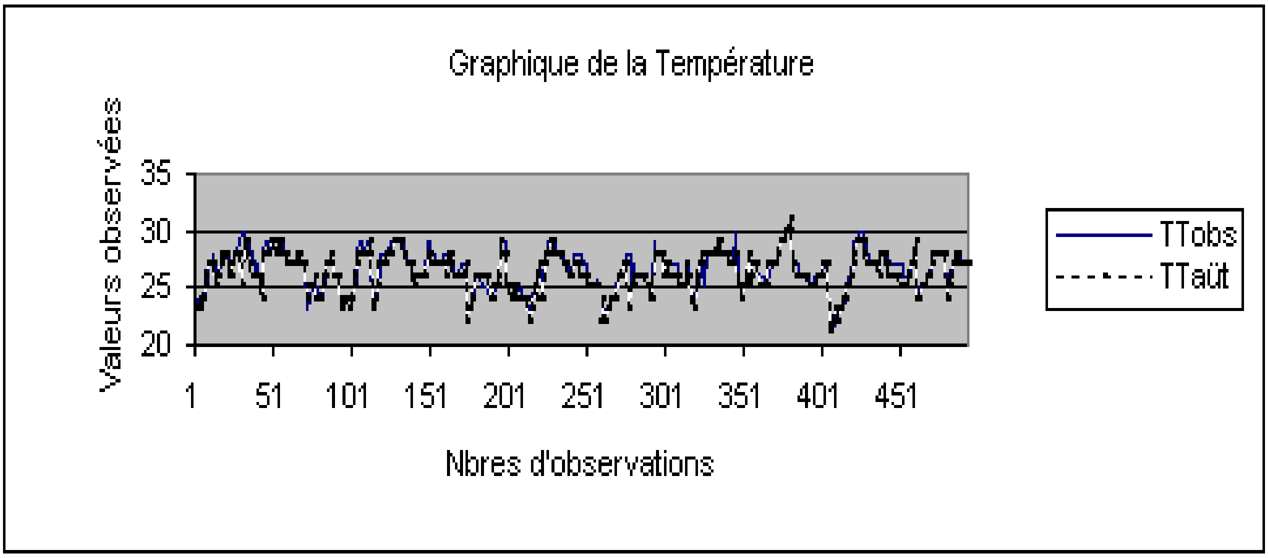
Les mesures de la pression et du vent provenant des deux stations et celles obtenues des aéronefs ont été comparées et analysées.

Les mesures comparatives des données de la pression (QNH), de la direction et de la vitesse du vent des aéronefs et des deux stations sont en général d'une homogénéité satisfaisante avec quelques décalages des données de la direction du vent observées à celles des aéronefs et de la station automatique.

2) **- Contrôle Graphique**






Graphique de la Température
Valeurs observées
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20
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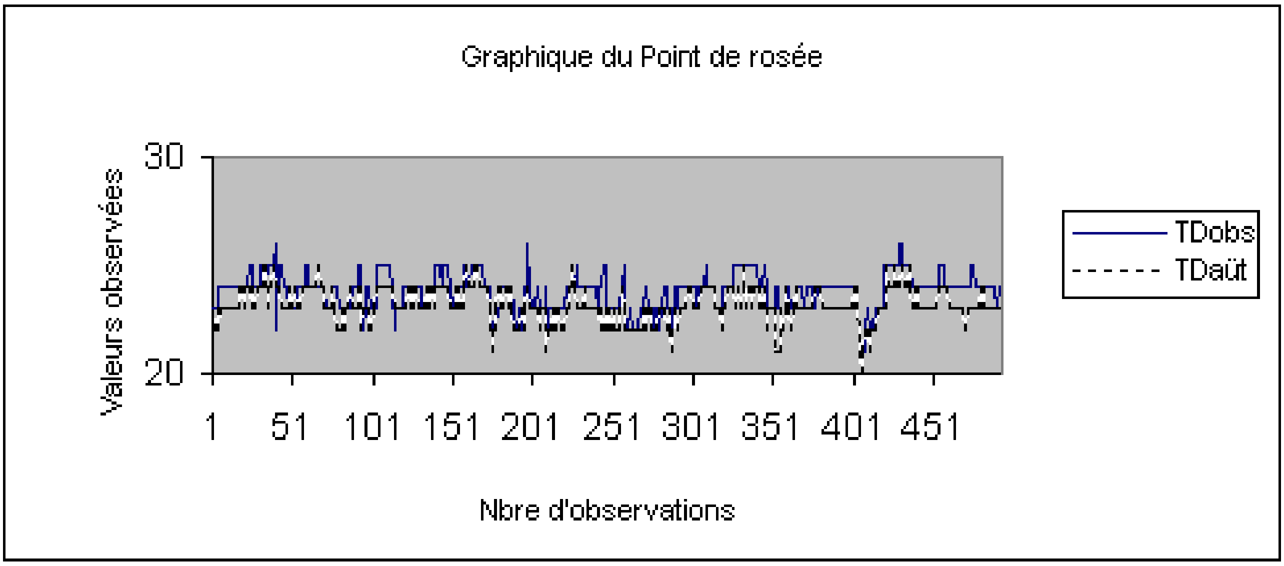
Nbres d'observations
TTobs
TTaüt


Graphique du Point de rosée
Valeurs observées
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Nbre d'observations
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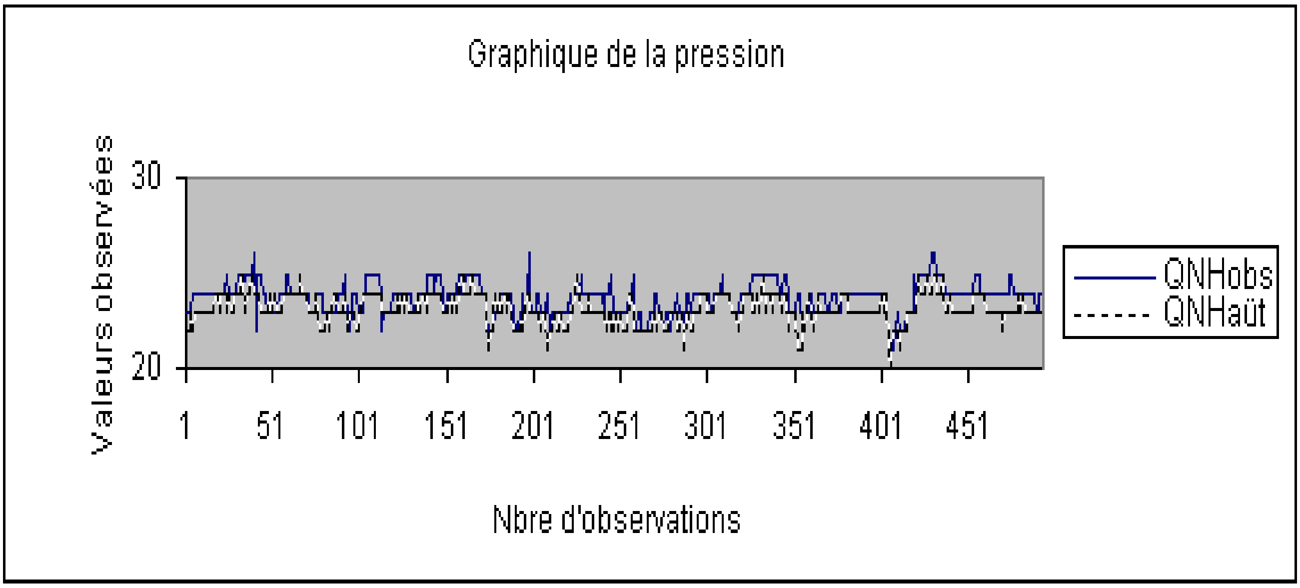
Graphique de la pression
Valeurs observées
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Nbre d'observations
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QNHaüt

Ce test montre le cours des deux séries et leur éventuelle superposition.

Pour la température, la pression, le point de rosée et la force du vent, les graphiques confirment une homogénéité satisfaisante des relevés de deux stations.

3) **- Test Statistique**

Pour les deux séries de données, nous avons procédé au calcul des statistiques descriptives. Ceci nous a permis de mettre en évidence :

- une constante sur-estimation de la station automatique pour la pression, la force et de la direction du vent.
- une sous-estimation de la station automatique de la température et du point de rosée.

Eléments	Ecart type	Moyenne arithmétique
Direction du vent	20,89	+4,4
Force du vent	4,32	+0,5
Température	1,16	-0,3
Point de rosée	0,87	-0,6
Pression	18,35	+0,6

IV - Conclusion:

La substitution d'une station classique par une station automatique pose une série de problèmes liés certainement à la nature de la station ou à la méthode d'observation.
L'expérience conduite ici, témoigne que si pour certaines mesures et paramètres il est possible de mettre en évidence un rapport satisfaisant entre les séries de données provenant d'une station classique et d'une station automatique, comme la pression, la température, le point de rosée et la force du vent; pour d'autres paramètres comme la direction du vent, les différences peuvent être importantes qu'il est impossible de considérer les deux séries comme homogènes et continues. Sans doute, les causes de ces différences sont soit dans les positions différentes des senseurs soit dans les caractéristiques techniques des instruments. Dans tous les cas, cette situation nous interpelle à des recherches plus détaillées.

THE WMO LABORATORY INTERCOMPARISON OF RAINFALL INTENSITY (RI) GAUGES

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Abstract

The Joint Expert Team on Surface-Based Instrument Intercomparison and Calibration Methods (ET on SBII&CM) and International Organizing Committee (IOC) on Surface-Based Instrument Intercomparison, according to the CIMO Plan of WMO intercomparisons, started in September 2004 the WMO Laboratory Intercomparison of Rainfall Intensity (RI) Gauges. The Intercomparison was held at the recognized laboratories of the Royal Netherlands Meteorological Institute (KNMI), the Netherlands, Météo France, France, and the University of Genoa, Italy.

The main objective of the laboratory intercomparison was to test the performances of catchment type rainfall intensity gauges of different measuring principles under documented conditions. Further objectives can be summarized as follows:

- To define a standardized procedure for laboratory calibration of catchment type rain gauges, including uncertainty of laboratory testing devices within the range from 2 to 2000 mm/h;
- To evaluate the performance of the instruments under test;
- To comment on the need to proceed with a field intercomparison of catchment type of rainfall intensity gauges;
- To identify and recommend the most suitable method and equipment for reference purposes within the field intercomparison of catching and non-catching types of gauges;
- To provide information on different measurement systems relevant to improving the homogeneity of rainfall time series with special consideration given to high rainfall intensities.

Only catchment type of instruments that are currently being used in national observing networks or are being considered for use in national networks and are capable of measuring rainfall intensity of at least 200 mm/h at a time resolution of 1 minute were tested.

Nineteen (19) types of instruments had been selected, with usually 2 instruments of the same type, produced by 18 different manufacturers. Fifteen countries were represented; out of them 10 from Europe and five non-European countries. All instruments were tested in each laboratory.

This paper describes the main objectives of the Intercomparison, the adopted methods, and expected/obtained results, also with a view of the foreseen Field Intercomparison of Rainfall Intensity Gauges in Various Climatic Regions.

Introduction

The need for a WMO Intercomparison of RI gauges goes back to the Expert Meeting on Rainfall Intensity Measurements (EM), held in Bratislava, Slovak Republic, 23-25 April 2001. The meeting, giving a high priority especially to RI, agreed that the calibration of rain gauges was a high priority task. Calibration techniques for catchment type gauges have been described in the literature (e.g. Calder and Kidd, 1978; Marsalek, 1981; Niemczynowicz, 1986; La Barbera *et al.*, 2002), however at the present there is no standardized calibration equipment or procedure suitable for general application. Therefore the development and testing of a standardized calibration technique has to be developed first in well-certified laboratories.

The EM discussed in depth the advantages and disadvantages of the various performance characteristics of various measuring techniques used for RI observations. The *in situ* non-catchment type of sensors were not considered further because, at the time, the primary use of these sensor was generally not for RI measurements but rather for present weather observations and research applications. In addition, laboratory calibration / intercomparison of these sensors were not considered to be feasible or at best, very difficult to design for the full range of rainfall intensities at the available laboratories.

With a reference to the proposals developed for present and future requirements related to RI measurements, it was considered that there had been a particular need to compare gauges for high RI rates, since their performance related to low intensities was tested at various national and global WMO intercomparisons. The general performance characteristics of various types of rain gauges had been sufficiently documented for low RI range. Taking into account the difficulties related to organization and conducting of a field intercomparison in a climatic region with the required high RI during a comparison period, the unavailability of suitable and well recognized reference instruments, it was agreed to start first with a laboratory RI Intercomparison, before other, more comprehensive, field RI intercomparison would be considered. A decision towards a field intercomparison should then be made based on the results of the initial laboratory comparison.

The EM proposed to test the same types of rain gauges in at least two independent certified laboratories. It was the opinion of the experts that there is no need to check the performance at a measuring range less than 0.2 $mm \cdot h^{-1}$ at all while preference should be given to the full range above 2 $mm \cdot h^{-1}$. The Expert Meeting also proposed that a standardized procedure for generating consistent and repeatable laboratory flow rates be developed and designated for use as the laboratory standard for RI calibration of catchment type gauges (e.g. Lanza and Stagi, 2003). This should include definitions on accuracy and range requirements; the recommended calibration equipment and its proper configuration; and the expected performance as well as standard method(s) of testing, taking into account the variability of conditions of the test facilities.

Taking into consideration the results of the laboratory test and expectations that any new correction and calibration factors of gauges might be derived which have not been considered earlier, the Expert Meeting recommended that appropriate correction procedures and instrument specific factors should be developed by the user community for the application on long-term data series to maintain temporal homogeneity. Special consideration should be given to extreme values (see e.g. La Barbera *et al.*, 2002; Molini *et al.*, 2001).

The proposal of the EM was included in the CIMO Plan of WMO Intercomparisons and the International Organizing Committee on Surface-Based Instrument Intercomparison (IOC) have been established by the President of CIMO for the organization and conduct of the intercomparison. The first session of the Joint meeting of the Expert Team on Surface-based Instrument

Intercomparisons and Calibration Methods (ET) and the IOC was held in Trappes, France, 24-28 November 2003. The ET/IOC, in addition to the general rules and procedures for WMO Intercomparisons as defined in the Guide to Instruments and Methods of Observation, WMO - No.8, Part III, Chapter 5, Annex 5.A and 5.B, agreed upon specific rules and procedures, which are described in the final report of that meeting and can be found on the CIMO/IMOP website: http://www.wmo.int/web/www/IMOP/reports.html

Selection of Instruments

Due to limited resources, the number of participating instruments was initially limited to a maximum of twelve pairs of gauges. However, given the higher demand and based on the proposal of the project leader, the ET/IOC had selected nineteen instruments, based on the following criteria:

a) Instruments are to be selected in a way to cover a variety of measurement techniques;
b) Preference should be given to new promising measuring techniques;
c) Preference should be given to instruments that are widely in use in member countries.

The list of selected instruments is recalled in Table 1.

The three laboratories involved in the WMO Laboratory Intercomparison of RI Gauges therefore tested the performances of 19 rain gauges, with usually 2 instruments of the same type. All instruments have been calibrated in each laboratory. That means that about 6 models have been calibrated in each laboratory during a period of about 2 months and then the instruments were shifted from one laboratory to another one, for a new period of 2 months and so forth until all instruments have been calibrated in all laboratories.

COUNTRY & MANUFACTURER	MODEL TYPE	MEAS. PRINCIPLE	Number of instruments
ITALY - SIAP	UM7525	TIPPING BUCKET	2
ITALY – CAE	PMB2	TIPPING BUCKET	2
ITALY – ETG	R102	TIPPING BUCKET	2
CZECH REPUBLIC – METEOSERVIS	MR3H	TIPPING BUCKET	2
SWITZERLAND – LAMBRECHT	1518 H3	TIPPING BUCKET	2
UNITED KINGDOM – CASELLA	100000E	TIPPING BUCKET	2
INDIA – INDIA MET DEPT	TBRG	TIPPING BUCKET	2
AUSTRIA – PAAR	AP23	TIPPING BUCKET	1
USA – DESIGN ANALYSIS ASSOC	H340 – SDI	TIPPING BUCKET	1
JAPAN – YOKOGAWA DENSHI KIKI	WMB01	TIPPING BUCKET	2
AUSTRALIA – MC VAN Instr.	RIMCO 7499	TIPPING BUCKET	2
AUSTRALIA – Hydrol. Serv.	TB-3	TIPPING BUCKET	2
CZECH REPUBLIC – METEOSERVIS	MRW500	WEIGHTING	2
SLOVAKIA – MPS SYSTEM	TRWS	WEIGHTING	2
GERMANY – OTT HYDROMETRY	OTT	WEIGHTING	2
FINLAND - VAISALA	VRG101	WEIGHTING	1
NORWAY - GEONOR	T-200B	WEIGHTING	2
FRANCE – SEROSI	SEROSI	CONDUCTIVITY	2
CANADA – AXYS Env. Syst	ALLUVION 100	WATER LEVEL	2

Table 1: List of instruments selected for the WMO Laboratory Intercomparison of RI Gauges.

Methods and procedures

The Intercomparison of RI gauges were conducted at the recognized laboratories under the supervision of the Site Managers appointed by the host laboratories.. Per each of the instruments involved in the intercomparison, each laboratory performed five calibration tests according to the different calibration/testing instruments used and to the experience of the Site Managers. The number of tests performed per each of the instruments, their description and duration (in terms of time units and/or number of tippings, etc.) was noted and reported.

For each calibration test the following environmental parameters were noted and recorded:

- date and hour (start/end);
- air temperature [°C];
- water temperature [°C];
- atmospheric pressure [hPa];
- ambient humidity [%];
- any special condition that may be relevant for the single calibration (e.g. vibrations)

The calibration was different according to the type of instrument analyzed, namely its measuring principle. In the following a description is given per categories.

Tipping Bucket

The calibration test consists of providing the gauge with a constant water flow, generated by a suitable device, by calculating the average intensity from the measurement of the total amount of water actually provided within a given period of time and by comparing this amount with the average intensity measured by the instrument in the same period (see Fig. 1).

The duration of the test and the mass measurement are controlling factors for determining the accuracy of the calibration. A mass and a duration used for each test must be chosen so that the uncertainty of the reference intensity is less than 1%, taking also into account the resolution of the instrument. These masses and durations have been noted and reported, together with the number of tips involved in each test.

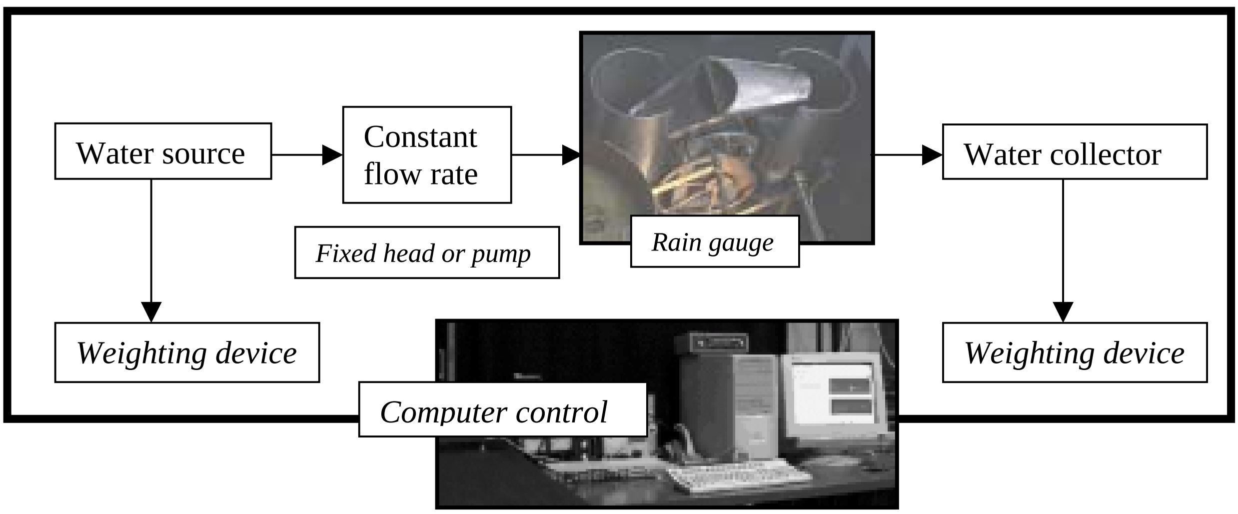

Figure 1: Rationale of the testing device for calibration purposes within the Intercomparison.

Each calibration was performed at least at seven reference flow rates. However, since the higher rainfall intensities are of utmost importance for the intercomparison, the whole range of operation declared by the manufacturer was also investigated. In particular the following rules have been agreed upon:

- Seven reference intensities are fixed at 2, 20, 50, 90, 130, 170, 200 mm/h;
- If the maximum declared intensity is less or equal to 500 mm·h^{-1}, further reference intensities are determined at 300 and 500 mm·h^{-1}.
- Otherwise, three further reference intensities are determined within the remaining range of operation of the instruments by dividing it logarithmically from 200 mm·h^{-1} up to the maximum declared intensity.

In case of water storage (in the funnel above the bucket) for an intensity below the maximum declared intensity, the intensity at which water storage begins was reported and intensities above this limit were taken into account.

The reference intensity has been obtained within the following limits:

- 1.5 – 4 mm·h^{-1} at 2 mm·h^{-1}
- 15 – 25 mm·h^{-1} at 20 mm·h^{-1}

and within a limit of ± 10% at higher intensities.

Weighting gauges

In addition to measurements based on constant flow rates, the step response of each instrument was checked based on the devices developed by each laboratory.

The step response of the weighing gauges was measured by switching between two different constant flows, namely from 0 mm·h^{-1} to 200 mm·h^{-1} and back to 0 mm·h^{-1}. The constant flow was applied until the output signal of the weighing rain gauge was stabilized. The time resolution of the measurement was higher than 1 minute, e.g. 10 seconds, and the possible delay was evaluated by determining the first time interval when the measure is stabilized, within a maximum period of 10 minutes. Attention was paid in particular to assess the effects of vibrations and to reduce them in order that their impact on the measurement was less than 1%.

Other measuring principles

In addition to measurements based on constant flow rates, the step response of each instrument was tested based on the devices developed by each laboratory. Full description of the method and instruments adopted in each specific case was provided by every Site Manager.

Attention was paid in particular to assess the effects of the following potential error sources:

- conductivity measure
- time between the water falls in the gauge and the level is adapted
- water level not stabilized
- water retention in the funnel and in the pipes
- etc.

Presentation of the results

The results are presented in the form of an average error curve that is derived as follows:

– The error is evaluated per each reference flow rate as:

$$e = \frac{I_m - I_r}{I_r} \cdot 100\%$$

where I_m is the intensity measured by the instrument and I_r the actual reference intensity provided to the instrument;

– Five calibration tests are performed per each set of reference intensities, so that five error curves are associated with each instrument;

– An average error curve is obtained by discarding the minimum and maximum error value obtained per each reference flow rate, then evaluating the arithmetic mean of the three remaining error and reference values, and finally fitting these average values within the range of reference intensities with a second order polynomial as below, over the whole range of operation of the instrument:

$$e(I_r) = a \cdot I_r^2 + b \cdot I_r + c$$

with *a, b* and *c* suitable numeric coefficients;

– In this curve the reference flow rates used for fitting the average curve are the average values of the three reference intensity values.

Preliminary results

At the time of writing only the first phase of the Intercomparison was completed, with all rain gauges being tested in at least one of the three involved laboratory. Preliminary results are therefore available and are synthesized here. The second phase is in course and the first indications confirm that the results obtained in different laboratories are consistent with each other, although different calibration devices are used (see e.g. the Qualification Module for RI Measurement developed at the DIAM laboratory in Figure 2).

As an example of the results obtained hitherto, two average error curves are presented in Figure 3 and 4 from two different tipping-bucket rain gauges respectively tested in the laboratories of Météo France and DIAM. Although the absolute value of the involved errors at corresponding reference intensities differs by a factor of ten and the two ranges investigated are quite different, an analogous behavior is observed. Note that the second graph refers to a rain gauges that is automatically corrected by software before an output intensity is provided, and this is the reason of the very good performances shown during the test (absolute error $\leq$ 1%). This result confirms that dynamic calibration allows increasing the performances of tipping-bucket rain gauges up to the limits requested by WMO.

In Figure 5 the average error curve obtained for a tipping-bucket rain gauge tested in the laboratory of KNMI is also presented. For this instrument the error at the lowest intensities is much higher than in the above cases due to the presence of irregular tips. Also at intensities higher than 200 $mm \cdot h^{-1}$, water accumulates in the funnel.

Figure 2*:* A tipping-bucket rain gage under test at the laboratory of DIAM (University of Genoa).

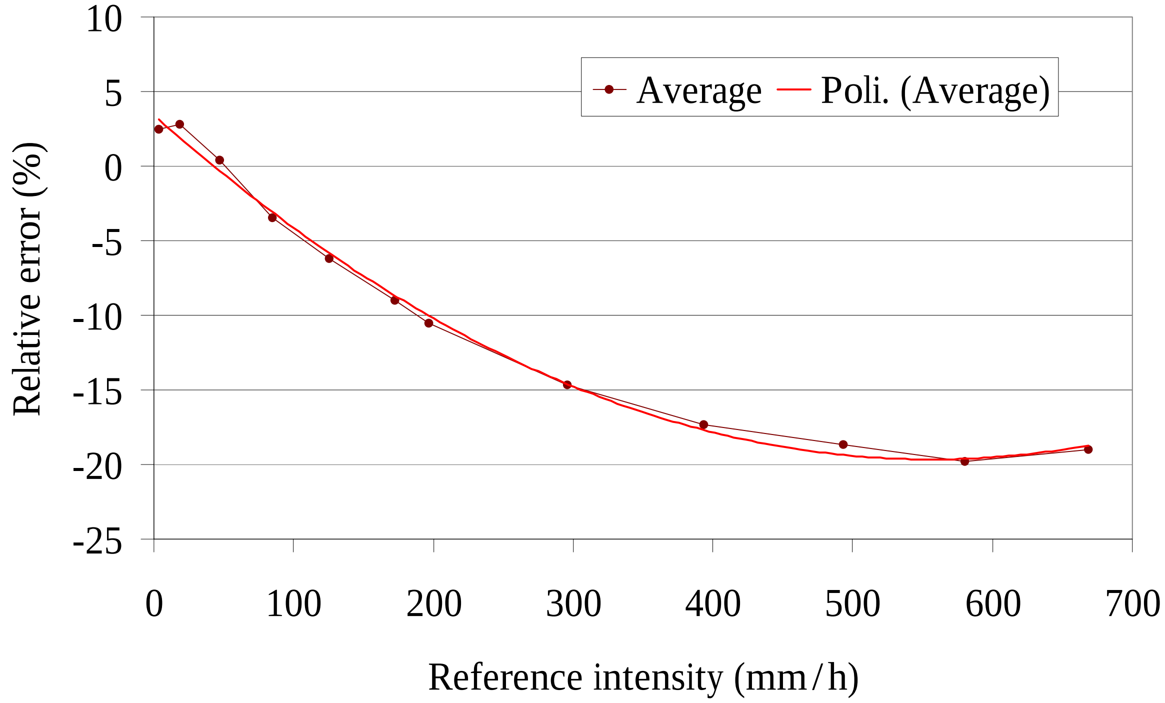

Figure 3: Example of an average and interpolated error curve obtained at the laboratory of Météo France for a tipping bucket rain gauge.

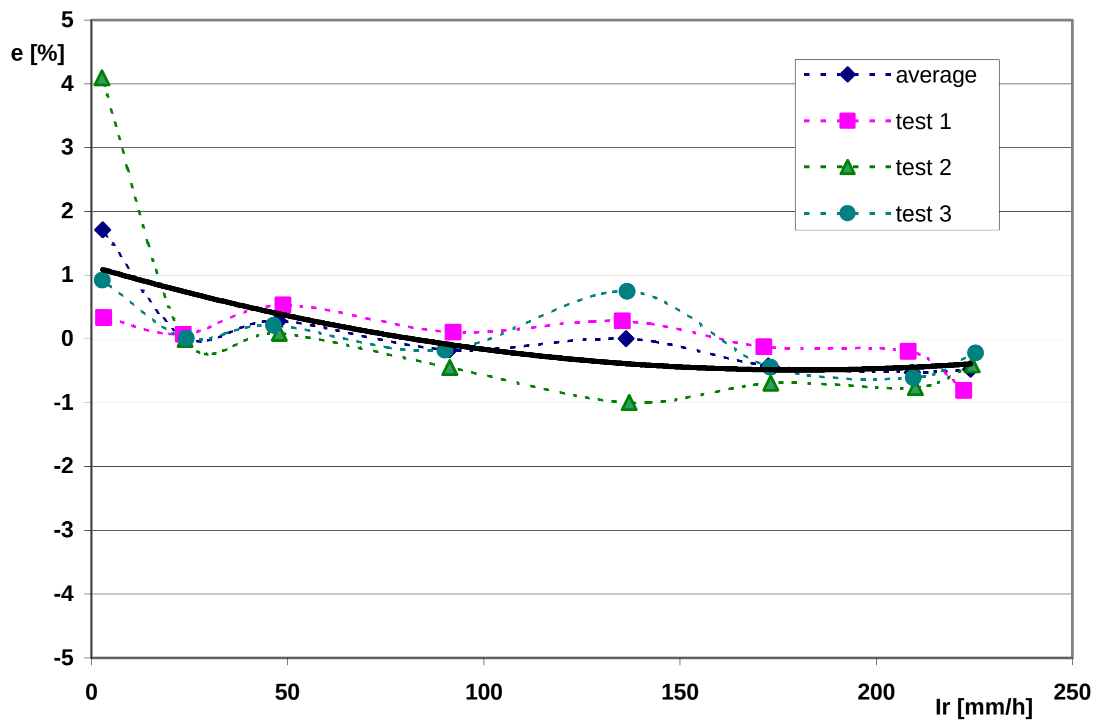

Figure 4: Example of single test and average error curves obtained at the laboratory of DIAM for a tipping bucket rain gauge.

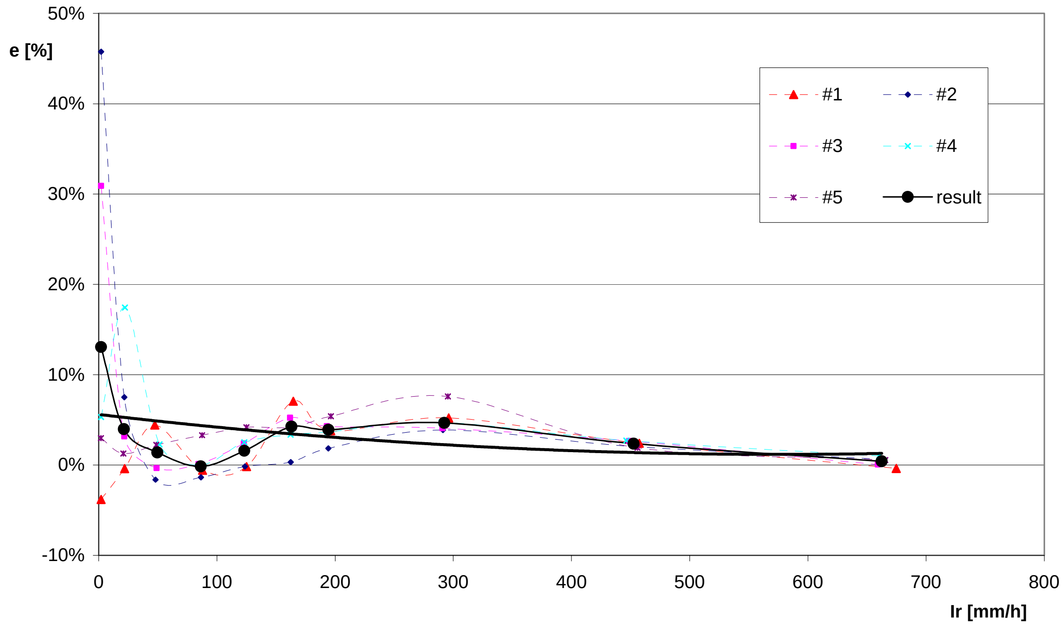

Figure 5: Example of single test and average error curves obtained at the laboratory of KNMI for a tipping bucket rain gauge.

				ERROR (%)				
Reference intensity	**2.75 (1.5-4)**	**20 (15-25)**	**50 (45-55)**	**90 (81-99)**	**130 (117-143)**	**170 (153-187)**	**200 (180-220)**	**max**
TBR 1	*+1.45*	*+0.93*	*-0.85*	*-1.93*	*-2.93*	*-3.37*	*-5.28*	*-5.61*
TBR 2	*+0.11*	*-1.20*	*-2.27*	*-0.67*	*-1.21*	*-1.13*	*+0.57*	*+3.63*
TBR 3	*-1.72*	*-1.75*	*-0.08*	*+0.63*	*-0.59*	*-1.24*	*-0.76*	*-2.52*
WG 1	*-0.46*	*-0.09*	*-0.26*	*-0.17*	*-0.21*	*+0.16*	*+0.10*	*+0.06*
WG 2	*-0.93*	*-0.87*	*-4.21*	*-3.37*	*-4.40*	*-3.41*	*-2.89*	*- **
TBR 4	*+1.71*	*+0.03*	*+0.28*	*-0.18*	*+0.01*	*-0.42*	*-0.52*	*-0.48*

TBR = Tipping Bucket, WG = Weighting Gauge ** = storage observed in the funnel*
max = max. declared intensity

Table 2: Average error figures for a sample set of rain gauges at various reference intensities.

	a	***b***	***c***	R^2
TBR 1	*4·10-5*	*- 0.04*	*1.5059*	*0.98*
TBR 2	*1·10-4*	*- 0.019*	*- 0.4295*	*0.89*
TBR 3	*5·10-5*	*- 0.018*	*1.14*	*0.70*
TBR 4	*7·10-5*	*-0.097*	*2.62*	*0.99*
TBR 5	*-1·10-5*	*-0.019*	*-5.37*	*0.99*
TBR 6	*7·10-5*	*-0.083*	*3.40*	*0.99*

Table 3: Set of parameters of the polynomial error curve for a sample group of tipping-bucket rain gauges tested in two of the involved laboratories.

Conclusions

The WMO Laboratory Intercomparison of Rain Intensity (RI) Gauges is in progress at the time of writing, with the laboratory tests on the 19 instruments involved to be completed within Summer 2005. A glance on the methodologies used at all three laboratories in charge of the intercomparison at Météo France, KNMI (The Netherlands) and the University of Genoa (Italy) has been provided in this paper, together with some preliminary results on the tests already performed.

The wide response obtained in the launching phase of the intercomparison, the large number of instruments proposed and the spreading of such instruments among various measurement principles and techniques is very promising and the final results of the intercomparison will be certainly of interest for both the meteorological and the hydrological communities.

From the initial data obtained in all three laboratories, we can say that – as expected – tipping bucket rain gauges that do apply correction for systematic mechanical errors by means of some post-processing technique dramatically reduce the errors and seems to accommodate for the [-5%, 5%] relative error requirements, while non-corrected gauges show much larger errors while progressively increasing the reference rain rates (up to 20% at the highest intensities). As for the weighting gauges, the main problem seems to be the step response though this will need additional data before conclusions can be drawn.

References

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Documentation on Quality Assurance and Representativity of Meteorological Observations

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Abstract

Keywords: meteorology, observations, guide, metadata

Appropriate quality management and assurance of the representativity of meteorological observations require an up to date view on the functional specifications of the variabels to be observed. The Royal Netherlands Meteorological Institute KNMI has published a guide-document on in situ measurements, data reduction, quality control and data presentation. The content of the guide and the chapters of the guide is in accordance with the style and contents of the WMO Guide to Meteorological Instruments and Methods of Observation and gives details on:

- definitions, units, coding, derived variabels;
- requirements on range, resolution, accuracy, frequency of measurements, etc.
- instruments and technical specifications, calibration procedures;
- procedures in case of missing data, methods on datavalidation, procedures on site inspection;
- calculating derived parameters: used formula to transform data;
- siting conditions and –requirements.

The guide is as a loose leave booklet, so it remains up-to-date with new revisions. The book consists of 20 chapters. The first chapter gives a general overview of the conditions, rules, etc. with respect to observation sites in general. Like the CIMO Guide, the other chapters describe the special rules per variable. An important element of the quality system is document management. A number of tasks are highlighted: mangement issues, maintenance, procedures and know-how. An electronic version will published on the world wide web in 2005.

Royal Netherlands Meteorological Institute KNMI, De Bilt, January 2005

1. Introduction

For the departments in the Royal Netherlands Meteorological Institute (KNMI), which frequently use data of meteorological measurements, it is of high importance to have a good view on the specifications of the measurements. Interested departments are in the fields of weather forecasting, climate research, development of high resolution models and other applications, statistical research, inspection of observation sites, validation of data, etc. However, most of the above mentioned information is spread out over a lot of special documents or is even only in the heads of the specialists. In the framework of quality assurance, to provide better view on those specifications and to realize a central information source, a couple of years ago the KNMI has started the project Guide on Observations. This project mainly focuses on the publication of a guide containing descriptions of all relevant matters concerning the operational meteorological and climate variables, especially with respect to the situation in The Netherlands:

- definitions, units, coding, derived variables;
- requirements on range, resolution, accuracy, frequency of measurements, etc.
- instruments and technical specifications, calibration procedures;
- procedures in case of missing data, methods for data validation, procedures on site inspection;
- calculating other parameters: used formulae to transform data;
- site conditions and requirements with respect to the surroundings.

The guide is provided as a booklet consisting of removable pages. A system like this makes it relatively simple to delete , change or add parts of the document and to quickly generate up-to-date versions of the guide. The book has been divided in 20 chapters, for the main part in accordance with the content of the WMO-guide to Meteorological Instruments and Methods of Observation, Part I (ref.1).

The first chapter gives a general overview of the conditions, rules, etc. with respect to observation sites in general. The next 19 chapters describe the special rules per weather variable. One variable per chapter and every chapter in a standard format. Part of the guide has been published: the chapters concerning the observation stations and the variables temperature, atmospheric pressure, humidity, wind and precipitation have been finished. The chapters about radiation, sunshine duration, visibility, evaporation, soil temperature, present weather, clouds, sea waves and lightning are in preparation.

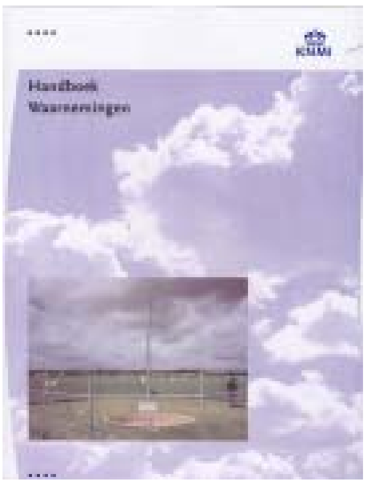

Fig. 1. Front page of the guide

A draft version of those chapters is available on the KNMI- intranet site. It is foreseen that the whole document will be completed before the end of 2005. It is also the intention to publish the document on Internet. A translation of the chapters 1 -6 into has been produced under the supervision of Dr. Günter Olbrück of EUMETNET. The word-document of the English version is available on http://www.dwd.de/EUMETNET/ see "NEW!! Meteorological Handbook".

A main functional element of the system is the document management. The following tasks have been distinguished:

a) the management of the maintenance, for instance being alert to changes in methods, requirements or procedures, and realizing up-date versions;
b) management with respect to administrative procedures, up-dating distribution lists, taking care of sending new paragraphs, etc.
c) the appointment in the institute of experts per variable.

These important functions and tasks have been given a fixed place in the organisation, especially in the KNMI-department for Observations and Models.

The distribution list of the guide includes about 200 persons and departments in the institute and about 80 extern relations in the Netherlands.

2. Content of the guide

The guide contains 20 chapters. The first 17 concern subjects and variables that are in line with the contents of the WMO-guide to Meteorological Instruments and Methods of Observation, Part I (ref.1). Three subjects have been added as extra chapters, i.e. sea water temperature, sea waves and lightning. Chapter 11 in the KNMI-guide concerns the measurements of soil temperature. This differs from the philosophy of the WMO regarding this variable. In the WMO-guide soil temperature has been described in the framework of chapter 2, temperature. The KNMI considers soil temperature a parameter requiring specific attention and procedures, so it has been given a special chapter. The corresponding chapter number 11 in the WMO-guide concerns soil moisture. However, the variable soil moisture is (still) not measured operationally by KNMI, therefore this parameter is not included in the KNMI-guide.

The content of the KNMI-guide is as follows:

1.General
2.Temperature
3.Atmospheric pressure
4.Humiity
5.Wind
6.Precipitation
7.Radiation
8. Sunshine duration
9. Visibility
10. Evaporation
11. Soil temperature
12. Upper air pressure, temperature, humidity
13. Upper air wind
14. Present weather, past weather, state of the ground
15. Observation of clouds
16. Ozone measurements
17. Atmospheric composition
18. Seawater temperature
19. Ocean waves
20. Lightning

Chapter 1, “observation station general” gives an overview of the different types of observation stations in The Netherlands, the composition of an (automatic) weather station, the repartitioning of the various weather stations around the country, the scales, general rules and procedures with respect to inspection, control and management with respect to weather stations, general information about the site conditions, etcetera.

Added to this chapter are appendices with a scheme of the site of an automatic station, a map of The Netherlands with the locations of all kind of stations (automatic stations, wind palls, specific precipitation stations, etc.), tables with the names of the stations, the positions of the stations, the measured variables, etcetera.

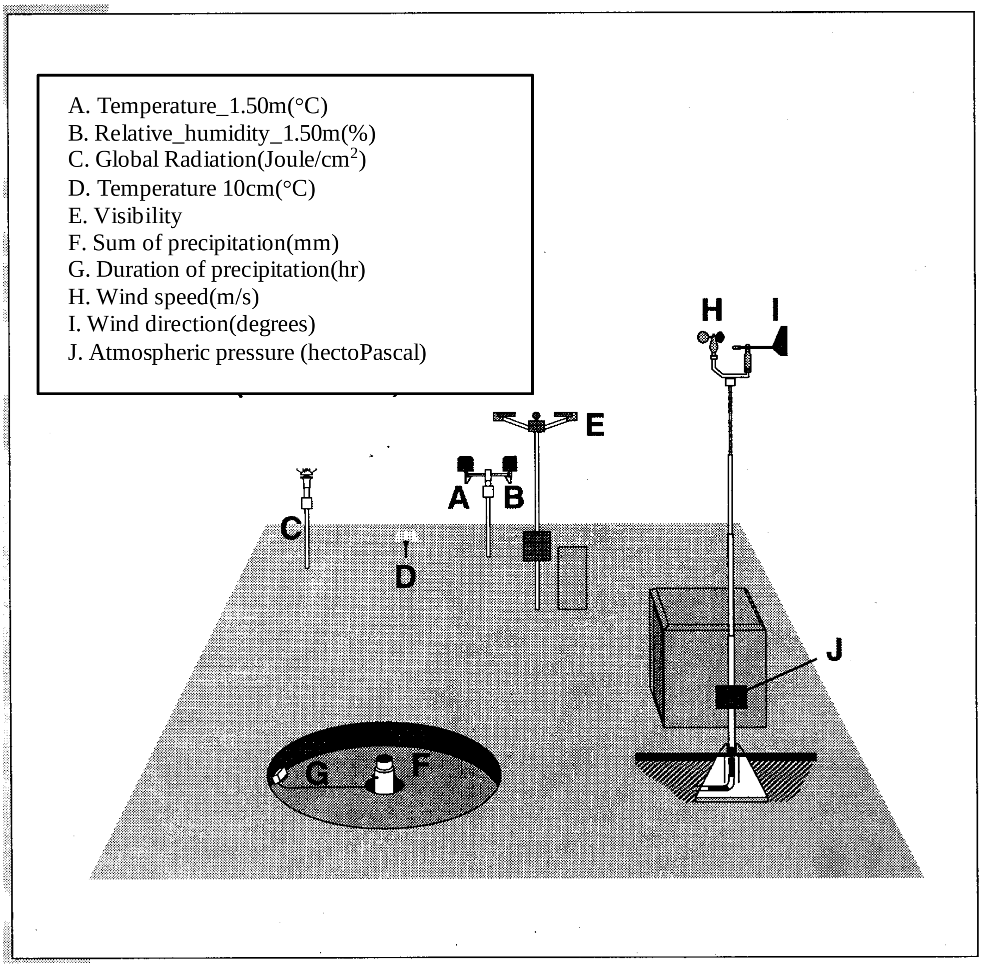

Fig.2 Automatic weather station

Fig.3. Meteorological observation network

In the chapters 2 – 20, a standard lay out of the paragraphs has been, c.q. will be followed:

1.Description
- 1.1 name of variable (e.g.. wind, precipitation)
- 1.2 definitions
- 1.3 units: standard cf. SI (e.g. m/s), or non-standard (e.g kts.)
- 1.4 derived variables (e.g. wind speed, -direction) + definition
- 1.5 codes and explanations (synop, metar)

2. Operational requirements
- 2.1 range, e.g. 0 - 50 m/s
- 2.2 resolution, e.g. 0.1 ° C
- 2.3 required accuracy, e.g. ± 0.5 hPa
- 2.4 required frequency of observations, e.g. every 12 seconds
- 2.5 required availability per specific period, e.g. 50 % per hour

3. Instruments and techniques
- 3.1 technical specifications of the instruments
- 3.2 management- and calibration procedures

4.Procedures
- 4.1 procedures in case of missing data
- 4.2 procedures for data validation
- 4.3 procedures for inspection and control of observation sites

5. Calculation of other parameters

e.g. formula for calculating atmospheric pressure from measured value of pressure, or formula for calculating relative humidity out of dew point temperature and air temperature

6. Site conditions, requirements with respect to surroundings
- 6.1 Specific conditions per instrument
- 6.2 Conditions with respect to the surroundings of the site

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Precipitation type from the Thies disdrometer

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Abstract

This paper describes research done to determine the capabilities and limitations of the disdrometer manufactured by Thies with respect to Present Weather determination. The results show that the disdrometer compares about equally well to an observer as the Vaisala FD12P Present Weather Sensor. The agreement with the observer is about 91% for precipitation phase.

Introduction

Detecting Present Weather, and in particular precipitation type, is done at KNMI with the Vaisala FD12P Present Weather Sensor. Although this sensor generally works quite well, there are some weak points and there is room for improvement. For this reason, new developments in the market in this area are closely monitored. A relatively new instrument is this field is the Laser Precipitation Monitor manufactured by Thies. This instrument is a disdrometer, which can measure size and fall speed of precipitation particles. Also because of an interesting price tag (about €3000, compared to about €15000 for the FD12P) it is worth investigating the performance of this sensor. Unlike the FD12P, the disdrometer does not report visibility.

Experiment

The data used in this investigation were provided by the Deutscher Wetter Dienst. The observations were made at the test site Wasserkuppe, in central Germany (Hessen). This site is situated near the summit of a mountain (hill) at 950 m above sea level. Because of this, the precipitation in summer is mainly rain, and in winter mainly snow, resulting in a good range of precipitation types for Present Weather research. At the site, a variety of Present Weather systems were present. These can be seen in the photo of Figure 1.

Figure 1. The PW sensors at Wasserkuppe, 25 February 2004. 1: Vaisala FD12P, 2: 2 Thies laser precipitation monitors (disdrometers), 3: Parsivel disdrometer (in front), 4: Metek micro rain radar. Also visible 5: Thies precipitation detector.

This work focuses on the Thies Laser Precipitation Monitor (disdrometer) and the Vaisala FD12P Present Weather Sensor. Another important data source at this test site is the reference data which includes observations made by a human observer and data from the Thies precipitation detector. Details of these 3 data sources are given below.

Thies disdrometer

A disdrometer measures the size and fall speed of precipitation. A laser diode and some optics produce a parallel infrared light sheet of 0.75 mm thickness with a detection area of 20 x 228 mm^2. When the precipitation particles fall through this beam, the receiving signal is reduced. The amplitude of the reduction is related to the size of the particles, and the duration of the reduction is related to the fall speed. Precipitation type is then determined from known statistics of particle size and velocity for the different precipitation types. A rough temperature constraint is also used; all precipitation above 9 °C is considered liquid (except hail) and all precipitation below −4 °C is solid. The output consists of many parameters, including 1- minute SYNOP, METAR codes, precipitation intensity and amount, and full particle size and velocity distributions. Theoretically one could even write an own classification algorithm based upon the raw data (velocity – size spectra). However, in the current investigation only the 1-minute PW SYNOP codes produced by the instrument are used. More details on the instrument and its output can be found in the 'Instructions for Use' of the instrument[1].

Figure 2 shows the two Thies disdrometers at Wasserkuppe. The one on the left is an older version, and the one in front is the latest version. This one has lower arms, to prevent spray from the arms into the

[1] Thies Laser Precipitation Monitor, Instructions for Use: 5.4110.X0.X00, Software version 1.04, 07/2003.

measuring volume. Also, spray from the heads is reduced by means of two small plates. This latter disdrometer is the one that is investigated. Adjustments to the instrument have been made based upon tests at this site, so its performance may be somewhat tuned to the meteorological conditions there. The data used in this investigation is the first data from this improved sensor. Since then, further fine-tuning has been (and is being) done.

Figure 2. The two Thies disdrometers at Wasserkuppe.

Vaisala FD12P

This type of sensor measures the scattering of light of a small volume of the atmosphere. If there are precipitation particles present in this volume, they will lead to peaks in the scattered light. These peaks are related to (the size of) the particles. Separately, the FD12P has a capacitive sensor (DRD 12) that measures the water content of the precipitation. Combining these two quantities leads to a discrimination between large particles with low water content (*i.e.* snow) and small particles with high water content (rain). Fine tuning is done by choosing appropriate limits for, for instance, mixed precipitation, hail and freezing rain. Also, temperature constraints, maximum particle size and a selection algorithm to determine the most significant precipitation type are used. Every minute, an "instant" precipitation type is given (amongst other parameters). This is normally the most popular of the last 5-minute types[2]. More details can be found in the FD12P User's Guide[2]. Figure 3 shows the instrument in use at Wasserkuppe.

[2] Vaisala, Weather Sensor FD12P, User's Guide, M210296en-A, May 2002.

Figure 3. The Vaisala FD12P Present Weather Sensor at Wasserkuppe.

Reference

The reference at Wasserkuppe contains data from various sources. First of all an observer, located about 100 m from the instruments, reports Present Weather 24 hrs/day with a time resolution of 1 minute. In addition, a number of instruments report precipitation intensity, 2m temperature, 2m relative humidity, 2m wind speed and dew point temperature. Also, two Thies precipitation detectors are logically combined to give a precipitation flag: y/n. All data are given in 1-minute intervals.

Data processing

In order to compare the various quantities, some data processing is necessary. All data are given in synchronously recorded 1-minute intervals, leading to a maximum of 1440 measurements per day. The following processing has been done:

- Because the combined Thies precipitation detectors have a 25 second delay, data are only accepted if the previous minute has the same precipitation indication (y or n).
- If the Thies precipitation detector indicates no precipitation, the PW code of the observer is changed to 00 (clear). This is because it is expected that the detector is quicker in detecting a change (from dry to precipitation, or vice versa) than the observer.
- The (human) observed precipitation type is reported in WMO code 4677 (manual observations). This is changed into code 4680 (automatic observation) to match with the output of the two PW instruments. Next, all PW codes are condensed into the precipitation type possibilities shown in Appendix A.

Averaging. When 10-minute averages are considered, the precipitation type is averaged by taking the maximum PW code in the interval considered. Averaging the FD12P data to 10-minute data is done by taking 10 instant precipitation types, even though these are 5 minute averages. This is because these 5-minute averages are updated every minute and so this way of averaging leads to the best possible (but not perfect) 10-minute average.

Results

All results were obtained using data from12-10-2003 to 31-11-2003, with the exception of 31-10-2003. In this time interval, there was a fair amount of both liquid precipitation (7 % of the time) and solid precipitation (5 % of the time), allowing for a good evaluation of the systems' capabilities.

Precipitation phase

The 10-minute comparison of the PW output of the three sources (observer, Thies disdrometer and FD12P) is shown in the following tables. 10-minute data is used because observers may not note a change in precipitation on a 1-minute time scale. Also, the FD12P "instant" precipitation type is really from the latest 5 minutes. And in normal use, 10-minute averages are used. Shown are the results for the precipitation phase (with freezing rain classified as liquid, and unknown precipitation disregarded).

observer →

Thies ↓

	no precip	liquid	mixed	solid	total	%
no precip	5077	0	0	0	5077	100.0
liquid	398	339	33	14	784	43.2
mixed	0	0	12	3	15	80.0
solid	89	2	3	230	324	71.0
total	5564	341	48	247	6200	
%	91.2	99.4	25.0	93.1		
total %		91.4				

observer →

FD12P ↓

	no precip	liquid	mixed	solid	total	%
no precip	5027	13	0	5	5045	99.6
liquid	51	356	29	2	438	81.3
mixed	0	1	8	3	12	66.7
solid	439	21	11	299	770	38.8
total	5517	391	48	309	6265	
%	91.1	91.0	16.7	96.8		
total %		88.6				

FD12P →

Thies ↓

	no precip	liquid	mixed	solid	total	%
no precip	4722	32	0	329	5083	92.9
liquid	439	514	7	213	1173	43.8
mixed	0	6	4	8	18	22.2
solid	85	2	2	380	469	81.0
total	5246	554	13	930	6743	
%	90.0	92.8	30.8	40.9		
total %		60.0				

Table 1. Comparison of the precipitation phase detected by the Thies disdrometer (Thies), the observer (Obs) and the Vaisala FD12P PWS (FD12P). The numbers are based on 10-minute data. % means the correct identification divided by the total for the column or row in question.

It is clear that the Thies performs quite well, especially in the case when the observer reports liquid precipitation (99 %). In case of solid precipitation, the FD12P performs somewhat better (97 %) than Thies (93 %). For all precipitation phases, the performance of the Thies is 91 % and the FD12P 89 %. When the Thies reports liquid precipitation, quite often the observer reports no precipitation. This may indicate that the Thies is not very good as a precipitation detector and should really be used as a precipitation *type* detector only, or that the Thies is more sensitive than the combined observer/Thies precipitation detector. This will be investigated further. Also, the same seems to hold for the FD12P in case of solid precipitation. Mixed-phase precipitation remains a weak point for both sensors. Interestingly, the Thies and the FD12P each agree better with the observer individually, than with each other (lower table of Table 1).

Verification scores

From the above tables, the verification scores can be derived. These are defined using the following results for a particular precipitation phase (e.g. liquid):
a: the observer and the instrument both report the precipitation phase
b: the observer reports the phase, and the instrument reports another phase or no precipitation
c: the instrument reports the phase, and the observer reports another phase or no precipitation
d: both the observer and the instrument do not report the phase

The verification scores are then defined as:

Probability Of Detection (POD): a/(a+b)
False Alarm Rate (FAR): c/(a+c)
Heidke Score Skill (HSS): (ad-bc)/((ad-bc)+ ½n(b+c)), with n the total number of events
* indicates that only the precipitation type is considered when the observer reports precipitation[3]

The range of the POD is between 0 and 1, with 1 the perfect score. The FAR range is also between 0 and 1, and here of course 0 is the perfect score, meaning no false alarms have occurred. HSS has a range between –1 and 1. 1 is the perfect score and 0 means random guessing.

This leads to the following results for the disdrometer (Table 2) and the FD12P (Table 3).

phase	POD	FAR	FAR*	HSS	HSS*
liquid	0.99	0.57	0.12	0.57	0.84
mixed	0.25	0.2	0.2	0.38	0.36
solid	0.93	0.29	0.02	0.80	0.93

Table 2. Verification scores for the Thies disdrometer. For the definition of the scores, see text.

phase	POD	FAR	FAR*	HSS	HSS*
liquid	0.91	0.18	0.08	0.84	0.82
mixed	0.17	0.33	0.33	0.26	0.24
solid	0.97	0.61	0.10	0.52	0.89

Table 3. The verification scores for the FD12P. For the definition of the scores, see text.

Again, there is a clear indication that the sensors report too much precipitation and/or that the observer reports too little. But aside from that, the HSS* for the FD12P and the Thies disdrometer are very similar.
Previous research on the FD12P done at KNMI[4] resulted for liquid precipitation in a POD of 0.71 with a FAR of 0.24. Solid precipitation had a POD of 0.63 and a FAR of 0.14 (mixed precipitation was not considered). The different manual observing methods (1 minute vs. 10 minutes, the use of the precipitation detector) and/or the different climatology may be responsible for the difference with the current results.

[3] This is equivalent to regarding the instruments as a precipitation *TYPE* detectors only. Cases where the observer reports no precipitation are disregarded.
[4] Wauben, W.M.F., Automation of visual observations at KNMI; (I) comparison of present weather, paper no. J3.1, AMS annual conference, 2002.

Conclusions

In conclusion, the Thies Laser Precipitation Monitor (or disdrometer) performs quite well in distinguishing precipitation type. The results of the available data show that this instrument compares about equally to the current Present Weather Sensor in use at KNMI, the Vaisala FD12P. The agreement with the observations is 91 % if precipitation phase is considered (and 89 % for the FD12P for the same data set).
Based on these results, and the favourable price tag of the disdrometer compared to the FD12P, KNMI has purchased a Thies disdrometer for testing so that we can gain experience with the instrument and see how it performs in Dutch weather conditions. If these tests are successful, this instrument may be used on the smaller automatic weather stations to better inform the meteorologists regarding precipitation type.

Acknowledgements

The authors wish to thank Manfred Theel from the DWD for assisting this research and for a pleasant cooperation. Hans de Jongh and Wiel Wauben are acknowledged for careful reading of this document.

Appendix A: Present Weather codes

All the weather codes in this paper are used according to the table below.

PW code	NWS code	Precipitation type
00	'C'	no precipitation
40	'P'	precipitation (unknown)
50	'L'	drizzle
55	'ZL'	freezing drizzle
57	'RD'	drizzle and rain
60	'R'	rain
65	'ZR'	freezing rain
67	'RS'	rain and snow
70	'S'	snow
75	'IP'	ice pellets
77	'SG'	snow grains
78	'IC'	ice crystals
87	'SP'	snow pellets
89	'A'	hail

An Assessment of the UV Broad Band Filter Radiometer Measurement Accuracy

Alexander Los*and Julian Gröbner†

Abstract

The lack of a standard calibration procedure for UV broad band filter radiometers introduces potentially large uncertainties in their measurement products. Although most UV calibration facilities take critical instrument properties that affect the measurement quality of UV filter radiometers into account, several properties need special consideration to keep the measurement uncertainty within acceptable limits.

At the European Reference Centre for UV Radiation measurements (ECUV) of the Joint Research Centre (JRC) of the European Commission, a UV filter radiometer calibration facility was established. UV filter radiometers are calibrated in the laboratory for their spectral sensitivity. Then, the absolute calibration is obtained by collocated solar measurements with the reference spectroradiometer of the ECUV.

From July 2003 until the end of 2004, various broad band UV filter radiometers were evaluated at the ECUV with the intension to estblish a reference group composed of instruments from institutions which may benefit from the uniform and well maintained UV irradiance scale realised at the ECUV. We present results obtained from collocated measurements performed with the broad band UV filter radiometers and the reference UV spectroradiometer. Besides the spectral characteristics of UV filter radiometers, their angular response and stability must also be considered in order to make a comprehensive uncertainty estimate. The measurements show that the selected group of radiometers agree within 10% to the reference spectroradiometer.

1 Introduction

One of the most widely used instruments to measure atmospheric UV radiation is the broad band UV filter radiometer. Since the introduction of the Robertson-Berger radiometer in 1976 [1] a number of commercial broad band UV radiometers have been developed. Although the broad band UV filter radiometer is an accepted monitoring instrument it must be used carefully in order to make accurate and valuable measurements. There are a number of critical instrument properties that have to be considered during calibrations and measurements: (i) the spectral response function of broad band UV filter radiometers deviates considerably from the theoretical response curve, (ii) the cosine response function of the entrance optics is not perfect, (iii) the long term stability of broad band UV filter radiometers can be poor, and (iv) the optical components can be sensitive to temperature and humidity variations.

The measurements performed at the ECUV with a number of different broad band UV radiometers are used to investigate the measurement quality and long term stability of this instrument type. In this study we present results obtained with two YES Inc. and three Kipp & Zonen instruments. The measurement period used for the investigation started in July 2003 and ended in December 2004. The Brewer MKIII spectroradiometer of the ECUV was used as the reference instrument, i.e. all broad band UV radiometer calibrations are traceable to this spectroradiometer.

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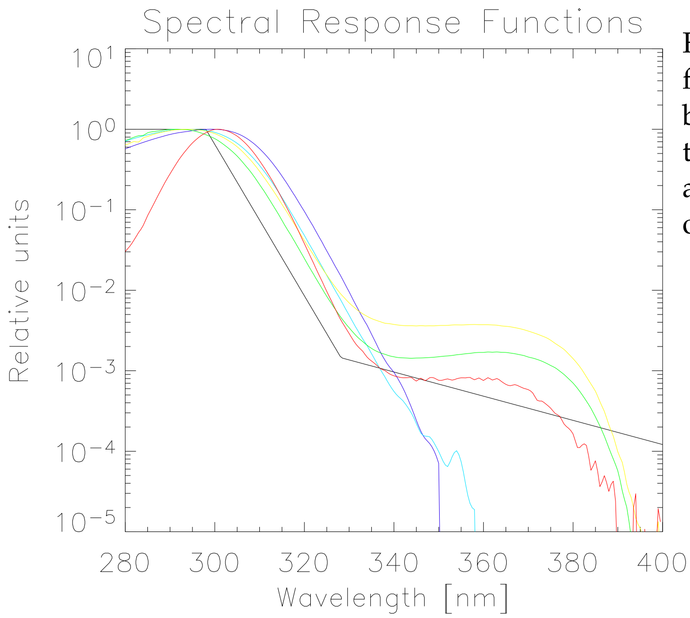

Figure 1: Relative spectral response functions, S_{uvs}, of the five broad band UV filter radiometers used in this study. S_{uvs} is shown on a logarithmic scale (y-axis) as a function of wavelength in nm (x-axis).

2 Instrumentation and Measurements

Figure 1 shows the relative spectral response functions, S_{uvs}, of the two YES Inc. and three Kipp & Zonen instruments on a logarithmic scale (y-axis) as a function of wavelength in nm (x-axis). As one can see, deviations between the response functions of the individual instruments are large and substantially different from the theoretical curve, given with the black line (CIE-1987). The quality of the spectral response function measurements has been verified recently in an intercomparison of several laboratory facilities [3]. Figure 2 shows the measurement platform of the ECUV located at the Joint Research Centre (Italy) with the UV spectrophotometer (Brewer, MKIII) at the right hand side and some broad band UV radiometers in the back.

2.1 Calibration

The purpose of the first step in the calibration process is to allocate a sensitivity to the broad band UV radiometer in Volts per W/m^2, referred to as the "radiometric calibration factor", ρ_{uvs}. The index "uvs" stands for "UV Sensor" which represents one of the five broad band UV radiometer used in this study. To determine ρ_{uvs} the broad band UV radiometer has to measure atmospheric UV radiation under (ideally) cloud-free measurement conditions, side-by-side to the reference spectrophotometer. Only synchronised spectral and broad band measurements are used to determine ρ_{uvs} according to

$$\rho_{uvs} = \frac{U_{uvs}}{\int E_{Bre}(\lambda)\, S_{uvs}(\lambda)\, d\lambda}. \tag{1}$$

U_{uvs} denotes the radiometer readings (in Volts) and $E_{Bre}(\lambda)$ represents the spectrophotometric measurements. The calibration formula given in equation 1 yields a classic sensitivity, i.e. the ratio between the reading of the radiometer (enumerator) and the UV radiative flux which is physically detected by the radiometer (denominator). Note, that the denominator does not account for the deviation between physical and theoretical response functions. The radiometric calibration factor ρ_{uvs} therefore yields the UV irradiance, I_{uvs}, as it is physically detected by the broad band UV radiometer, according to

$$I_{uvs} = \frac{U_{uvs}}{\rho_{uvs}}. \tag{2}$$

As broad band UV radiometers usually have spectral response functions which do not match the theoretical function (see Fig. 1) the UV irradiance, obtained according to equation 2, is physically unsatisfactory. Therefore, a measurement correction is required to minimise the so-called "spectral mismatch error", i.e. the error between the UV irradiance obtained according to equation 2 and the true, Erythema weighted (CIE-1987) irradiance.

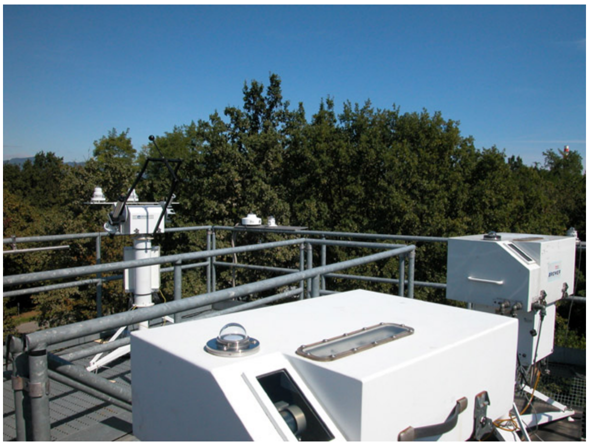

Figure 2: Measurement platform of the ECUV located at the Joint Research Centre (Italy) with the UV spectrophotometer (Brewer, MKIII) at the right hand side and some broad band UV radiometers in the back.

2.2 Measurement Correction Methods

Without any measurement correction, the broad band UV radiometer can provide results that deviate by a factor of 2 or more from the true values. The magnitude of the deviation depends mainly on the extent of the spectral mismatch and the measurement condition. In addition to the spectral mismatch error, other factors as mentioned in Section 1 potentially reduce the measurement quality of broad band UV radiometers.

The variable measurement conditions taken into account in this study include the solar zenith angle, Θ_0, and the total Ozone column density, $[O_3]$. Other atmospheric factors affecting UV irradiances, such as extinction of UV radiation due to aerosols, are not explicitly accounted for as they are assumed to be small compared to the effects that varying solar zenith angles and the Ozone column densities have on the spectral distribution of the UV radiation. In this second step of the calibration process we use two correction methods which both can significantly reduce the spectral mismatch induced measurement error of broad band UV radiometers.

2.2.1 Model-based correction method

The model-based correction method improves the broad band UV radiometer measurements for atmospheric conditions typically encountered during field applications. The variable model parameters used to determine the various correction factors are the solar zenith angle, Θ_0, and the Ozone column density, $[O_3]$. Other fixed model parameters were chosen in order to represent the measurement conditions at the ECUV as close as possible. Table 1 summarises the most important TUV model parameters as they were used to calculate the correction factors for this study. The modelled spectra are used to determine the conversion factors, $\gamma(O_3, \Theta_0)$, defined as

$$\gamma(O_3, \Theta_0) = \frac{\int E_{TUV}(O_3, \Theta_0, \lambda)\, S_{uvs}(\lambda)\, d\lambda}{\int E_{TUV}(O_3, \Theta_0, \lambda)\, S_{cie}(\lambda)\, d\lambda} \tag{3}$$

The solar zenith angles, Θ_0, are varied between $0°$ and $85°$ (using steps of $5°$) and the Ozone column densities, $[O_3]$, are varied between $200DU$ and $500DU$ (using steps of $10DU$), yielding 18 times 31 conversion factors. Hence, the variable effects of other atmospheric compounds on the UV radiation, e.g. extinction due to aerosols, are not explicitly included in the model-based correction method. However, the dedicated model parameters as listed in table 1 account for many local measurement conditions. If broad band UV irradiances under exceptional conditions have to be measured with broad band UV radiometers, it is recommended to calculate new conversion factors using model parameters that are representative for the exceptional condition (e.g. snow covered land surface at a location which is normally snow free).

2.2.2 Observation-based correction method

The observation-based correction method uses spectroradiometric measurements to infer the final calibration factors, which include the correction of the spectral mismatch error. In Bodhaine et al. [2] a detailed description of the observation-based correction method can be found. The observation-corrected Erythema weighted irradiance, I_{uvs}, is determined according to

$$I_{uvs} = \frac{U_{uvs}}{\delta_{uvs}(O_3, \Theta_0)}. \tag{4}$$

Table 1: TUV radiative transfer model parameters representing typical measurement conditions at the ECUV. (BL: Boundary Layer; FT: Free Troposphere; ST: STratosphere)

Layer	Aerosol				Other parameters						
	α	β	g	$\widetilde{\omega_0}$	Albedo	SO_2 [DU]	NO_2 [DU]	Lat North	Lon East	Profile	P_{Surf} [hPa]
BL		0.08	0.7	0.95							
FT	1.6	0.008	0.6	1.0	0.1	0.16	0.29	45.8	8.6	mls	1015
ST		0.0013	0.6	1.0							

where $\delta_{uvs}(O_3, \Theta_0)$ denotes the spectral mismatch corrected calibration factor of the broad band UV radiometer. As the observation-based correction method uses measured spectra to determine the corrected calibration factors, all atmospheric parameters affecting the spectral UV irradiance will be included in the calibration factor. Therefore, the observation-based correction method is – strictly spoken – only valid for the location at which the calibration has taken place. However, a large number of measurements under many measurement conditions (covering a large number of solar zenith angles and Ozone column densities) should improve the statistics of the corrections sufficiently to provide an universal corrected calibration factor table as a function of Θ_0 and $[O_3]$.

3 Results and Conclusion

From July 2003 until the end of 2004 a total of 12864 useful broad band UV radiometer measurements could be collected with the five radiometers at the ECUV. To get the best results out of the measurements the YES instruments had to be corrected according to the observation-based method while for the Kipp & Zonen instruments the model-based correction method had to be used. It is likely that the observation-based correction method removes certain instrument-specific measurement errors more efficiently than the model-based correction method. This, however, does not legitimate to draw conclusions about the quality of the instruments. As will be shown later, both correction methods can reduce measurement errors equally well, despite the significant differences in optical properties that exist among all five instruments.

For the assessment of the measurement accuracy all corrected broad band UV radiometer measurements where subtracted from the integrals of the spectrally measured Erythema weighted irradiances. With the differences, which represent the best possible estimate of the Erythema weighted irradiance measured by broad band UV radiometers, a probability distribution function ("PDF") is determined. Figure 3 shows the individual PDFs, which are normalised for better comparability in the figure only. The statistical moments of the broad band UV radiometer measurements are determined with the enveloping function, i.e. the sum of all PDFs. The mean value, i.e. the mean difference between the spectrally derived and the broad band radiometer based irradiances, is as small as $5.6 \cdot 10^{-4}\, W/m^2$. This difference corresponds to a UV Index of only 0.02. However, the standard deviation at a 2σ-level is as large a 10%, meaning that although dedicated measurement corrections were applied large deviations are still possible.

To measure Erythema weighted UV irradiances with broad band UV filter radiometers, careful calibrations and measurement corrections must be applied. Under ideal measurement conditions the differences between spectrally derived and properly corrected broad band radiometer measurements of the Erythema weighted irradiance can be arbitrarily low. However, it is far more difficult to determine the accurate UV irradiance under variable atmospheric measurement conditions. Nevertheless, it can be concluded that the broad band UV radiometer is a suitable instrument for UV monitoring, especially under fair weather conditions, provided that it is regularly calibrated and corrected properly.

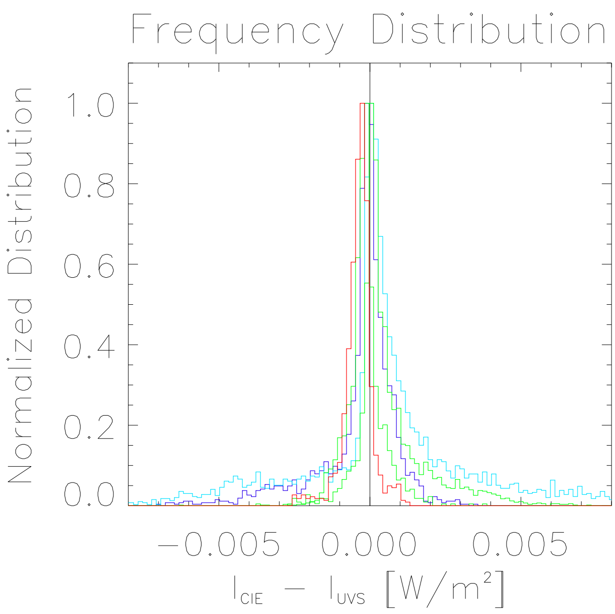

Figure 3: Probability distribution functions of the difference between spectral and corrected broad band radiometer measurement of the Erythema weighted irradiances for all five broad band UV radiometers (normalisation is for better comparability only).

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KVALOBS

Presentation at the WMO Technical Conference, Bucuresti 7 May 2005

Gabriel Kielland, met.no

Kvalobs is the quality assurance system for observations at The Norwegian Meteorological Institute (met.no). See overview figure 1. The first runtime version was set in operation on 4 January 2005 after a five year specification and development process. The system will be updated and improved upon in the years to come.

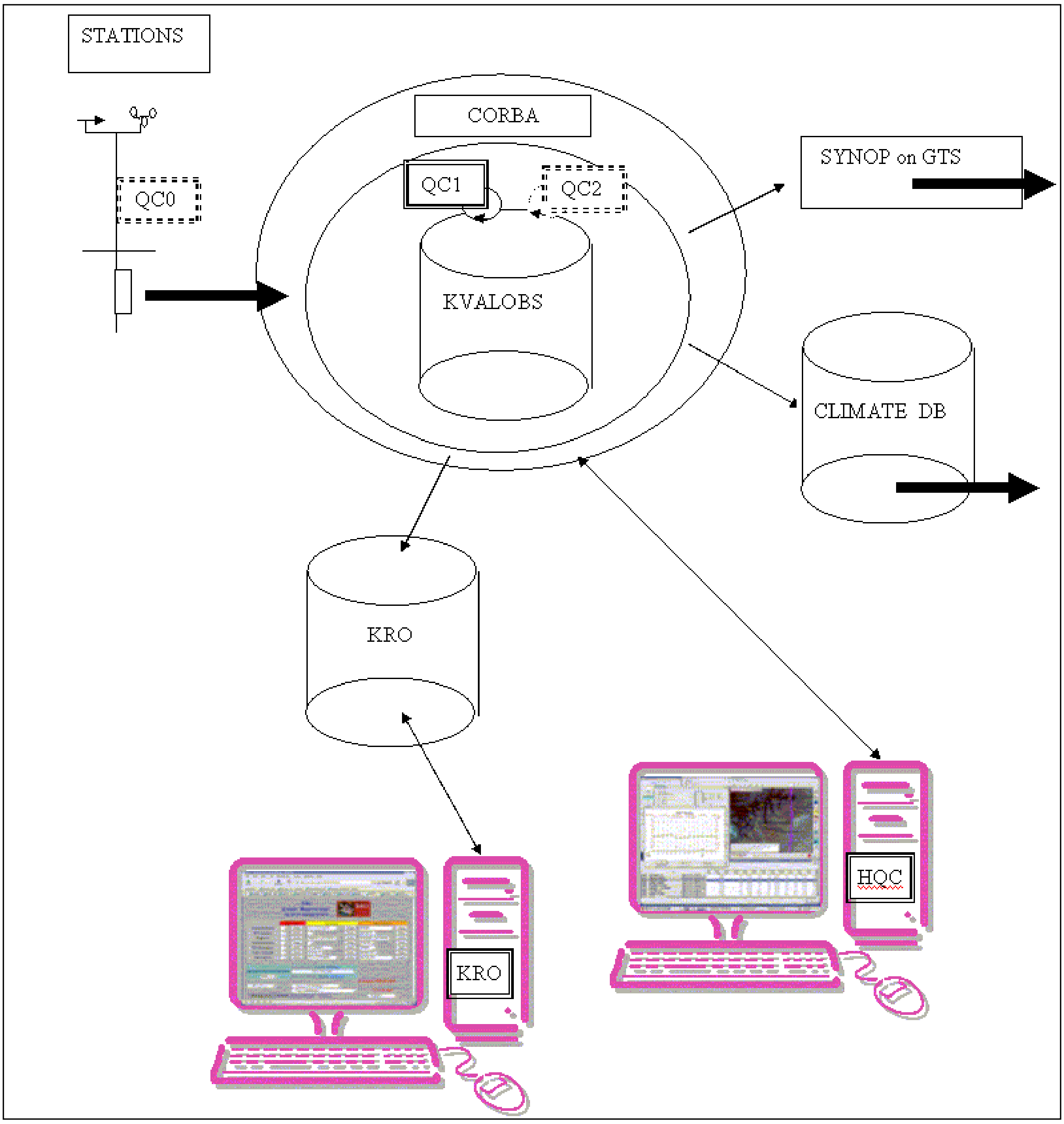

Figure 1. Kvalobs design overview. The arrows represent the data flow. The main input and output of observations in bold.

The institute is in the process of modernising the observation network. Development of an automated quality control system was necessary to enable rapid delivery of high quality data to users. The system was also designed to minimise human intervention and ensure mitigating activities taking effect as early as possible in the data flow process.

Central to the system is the automatic control system using the Kvalobs database. Messages from the stations are routed directly to the Kvalobs decoders. The message is parsed and controlled. Each observation or weather element contained within the message is separately stored in the database. While the observations is controlled, deficiencies as well as apparent or suspected errors are flagged accordingly. The expected messages that fail to arrive are detected 30 minutes past observation time. Before the first time use of the observation, only unphysical values are removed. When an expected message fails to arrive, the observation is marked as blank in the database for further substitution later, every entry pertinently flagged. All results are signalled to the subsequent user systems of which there are three: The SYNOP generator for direct distribution onto the GTS; The Climate Database for permanent storage; And the quality assurance message system KRO. The observations are subject to further control when additional reference material is available. After six months the data are automatically deleted from the Kvalobs database.

In parallel with the Kvalobs development new standard message formats have been introduced mainly to fit with the public GSM format restrictions [See TECO poster P1(17)].

Decoding

The formats decoded during the first version of Kvalobs are SYNOP/SHIP; Internal formats on messages from dial-up modems; Internal formats on the GSM net; Internal format on manual registrations or on batch file registrations. Other formats considered but not yet implemented are METAR messages, BUFR, and the DF22 file format in use by the offshore industry. Messages with syntactic errors are rejected for manual inspection and eventual correction by reentry in a corrected version.

Quality control

In the Nordic cooperation a nomenclature on quality control aspects has been discussed [1]. The term QC0 is applied to quality control at the station. QC1 is quality control at a central location before the first use of the observations. QC2 is quality control after the first use of the observations. HQC is human quality control which in Kvalobs is restricted to the period subsequent to the first use of the observations.

QC0 is the fixed set of procedures applied at each station. A feature of automatic feedback to the observers on errors received were discussed within the Kvalobs project, but was found undesirable. The errors will often be beyond the observer's control and feedback on these will only be demotivating. Rather than the automatic and direct feedback, routines on regular reports output from the automatic QC1 system manually edited will be developed.

All observations received are in Kvalobs subject to the automatic QC1. The result from the control is fed into the feedback system KRO.

The quality control system design

The quality control is fully database oriented. The control algorithms and their various attributes are parameterized in database tables. The framework software is compiled from C++ code and runs on Linux servers. The database engine is PostgreSQL [2]. PostgreSQL has shown high reliability, is an open source product and as such free of charge. A perl script interpreter is integrated in the system with the possibility to include other interpreters later. The four programs kvDataInputd, kvManagerd, kvQabased and kvServiced are run. The interface between these programs is arranged in CORBA. Also the systems outside are interfaced with CORBA allowing different priorities to different clients.

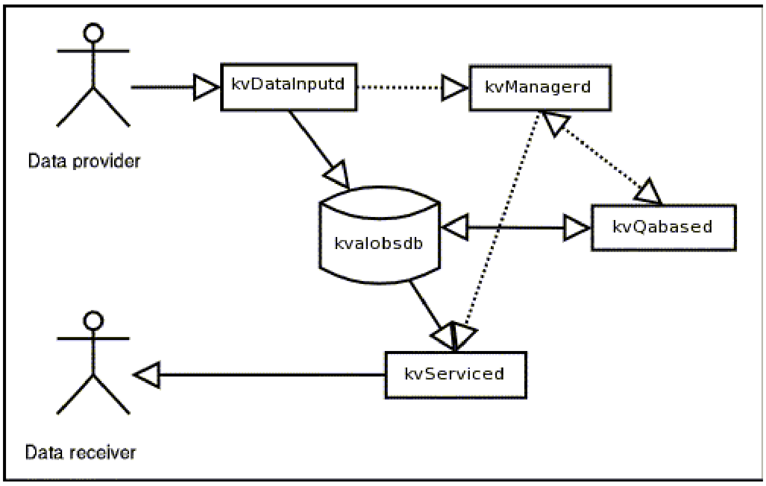

Figure 2. Schematic overview of control and data flow in Kvalobs. Fully drawn arrows show the data flow. Dotted arrows show control intervention.

Sequence of the quality control

Once the parameter identification is clear all checks relevant to the actual time and station are retrieved from the database. For every check firstly the basic script algorithm is retrieved from the database, then the specified observation data and model data are retrieved including reference observations, then all the check, station and parameter specific metadata are retrieved. From the different information elements a script is constructed and run. When the script terminates, flags and values are updated for one or more parameter and/or station.

In the first version of Kvalobs only QC1 is operational with

- range check on 94 parameters;
- step/freeze/drift check on 44 parameters;
- 181 formal consistency checks on 36 parameters;
- 97 climatological consistency checks on 19 parameters;
- comparison with numerical prognosis on 7 parameters;
- 2 checks on ship's position.

Details on the checks are available in a separate report [3].

Planned QC2 extensions will include

- dip check with automatic correction;
- statistical control, i.e. significant deviation from monthly frequency distribution relative to neighbouring stations';
- automated distribution of collected measurements, for example distribution of 72 hours precipitation measurements onto three 24 hours equivalents.

Additional checks are easily implemented. A testing environment was developed as an integral part of the system to enable easy verification of new checks.

Interpolation

There are always two observation values available for the end user: The observation as received from the station ("original") and an observation value considered best measuring the actual condition ("corrected"). In most instances the two values are identical. Otherwise the corrected values may be one of

- A short term HIRLAM prediction value;
- An interpolated value using the Akima algorithm [4];
- A missing value when the original is missing or rejected, and interpolation is inappropriate;
- A value manually entered using the HQC application.

During QC1 the HIRLAM values are available. Later when sufficient time has elapsed to enable interpolation the Akima algorithm is applied. Lastly during the HQC phase manual intervention may overrule the automatic substitution. Whenever a check or a manual operation has changed either values or flags the new information is transferred to the Climate Database for permanent storage. The end users will normally obtain their observation data from the Climate Database.

Human quality control (HQC)

An application with graphical user interface to the observations under scrutiny was developed. Data are displayed in a table and the interactive dialogue helps to filter out non essential information. From the table the observation data can be further displayed on a map using the GIS application module DIANA[5] in combination with model generated fields, satellite images, radar images and the subjective analysis. Independently from Kvalobs, DIANA is also the main tool used by the met.no forecasters to display all synoptic information available. A time series display is also available.

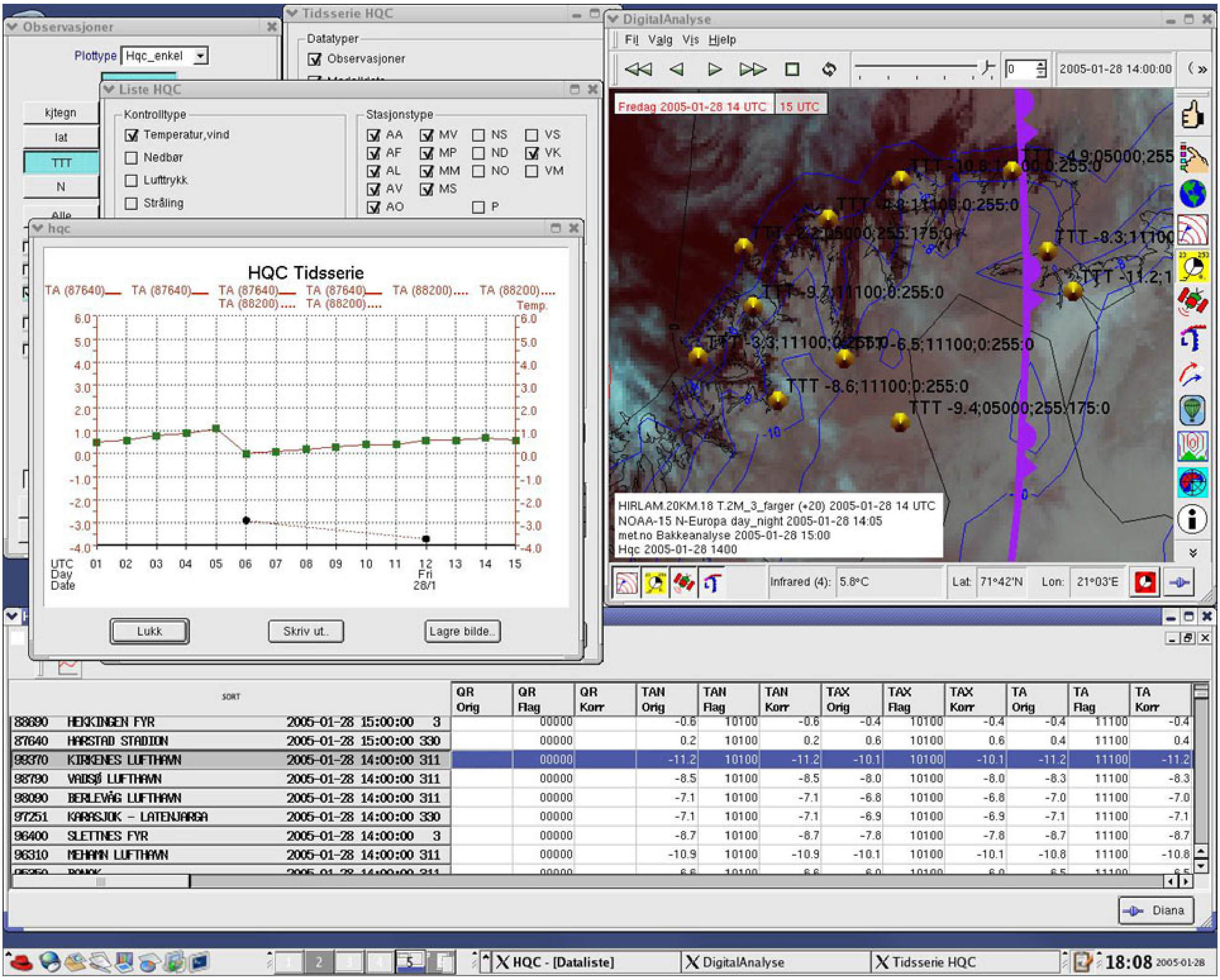

Figure 3. Sample screen capture of the HQC application with data table at the bottom. Map with observations and their flags displayed with HIRLAM isolines, NOAA satellite image and a front from the subjective analysis on upper right. Time series presentation is on the left. Part of the dialogue is also visible in the upper left.

Flags

Each control within the automatic control application has available a set of detailed control flags to indicate further action on suspected errors. Some of these are summarised to flags pertinent to end users' needs. The useflags implemented are in agreement with the NORKLIM recommendations [6].

Surveillance and service information

The feedback system KRO was developed in the Kvalobs project as a separate application. KRO has a separate database and a web interface as main features (figure 4). Firstly KRO is available to everybody connected to the internal net of met.no. The users can manually enter a message to the database on suspected errors with stations. Secondly the observers can send messages into KRO by using the GSM connection. Thirdly the automatic quality control system provides information that is aggregated into KRO messages on specific events of concern. In the first version of Kvalobs three events are dealt with:

- Messages failing to arrive; A text summarising the situation is generated when three or more subsequent messages fail to arrive;
- The precipitation gauge in need of being emptied; Repeated exceedance of a fixed alarm level;
- Sensor malfunction; Repeated errors in a number of connected parameters.

When a new KRO message is entered the station shows status "red" in the web interface. The station net service staff has authority on KRO to acknowledge the error and describe the action taken. When an action on error is described the status changes from "red" to "yellow". Another two options are available to the service staff. If the operator decides that no action is required the error message can be dismissed and the station status turned to "green". If the message is considered by the operator as information only it will remain visible additional to and separate from the error messages (figure 5).

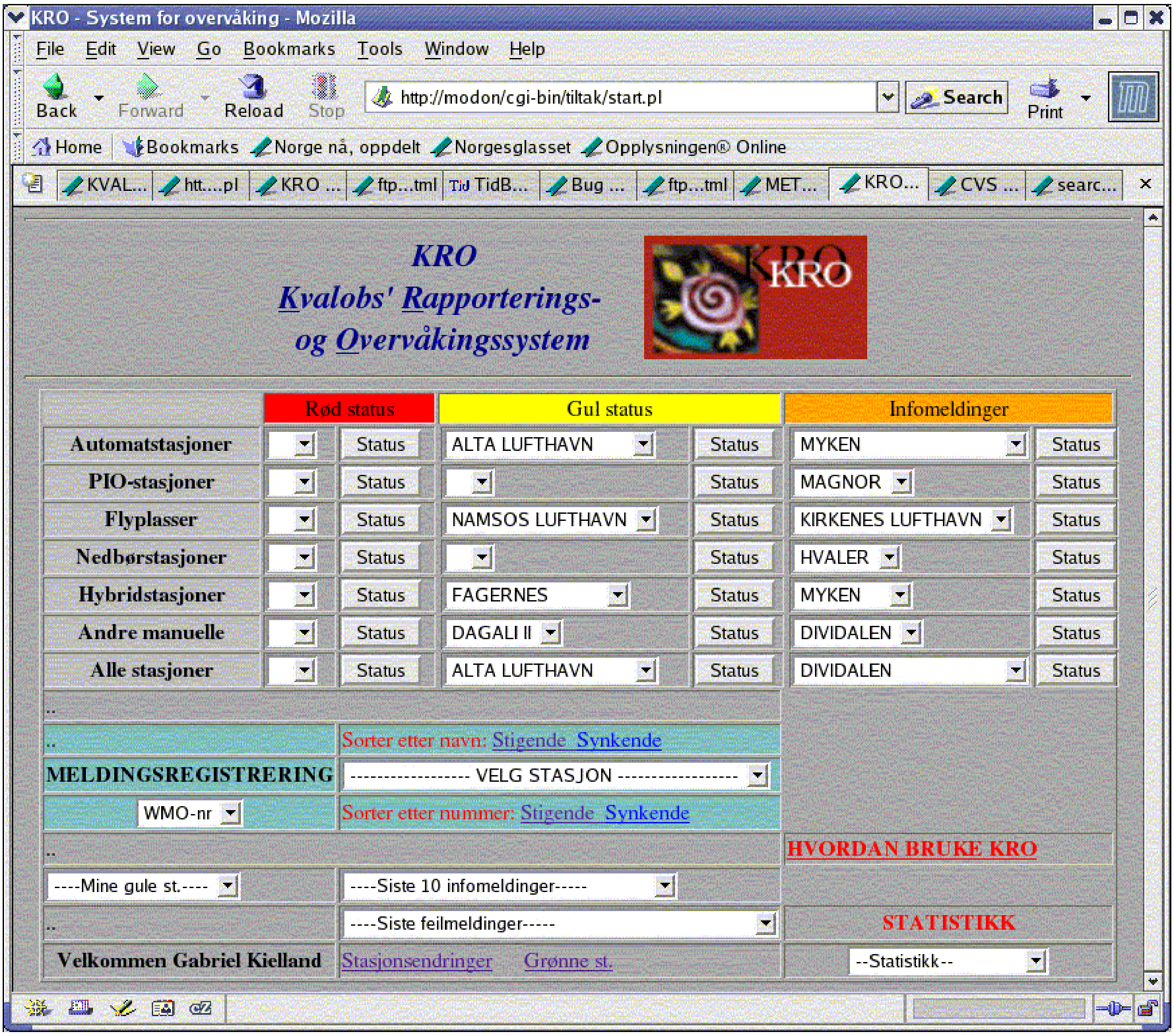

Figure 4. The KRO web interface available to all met.no staff.

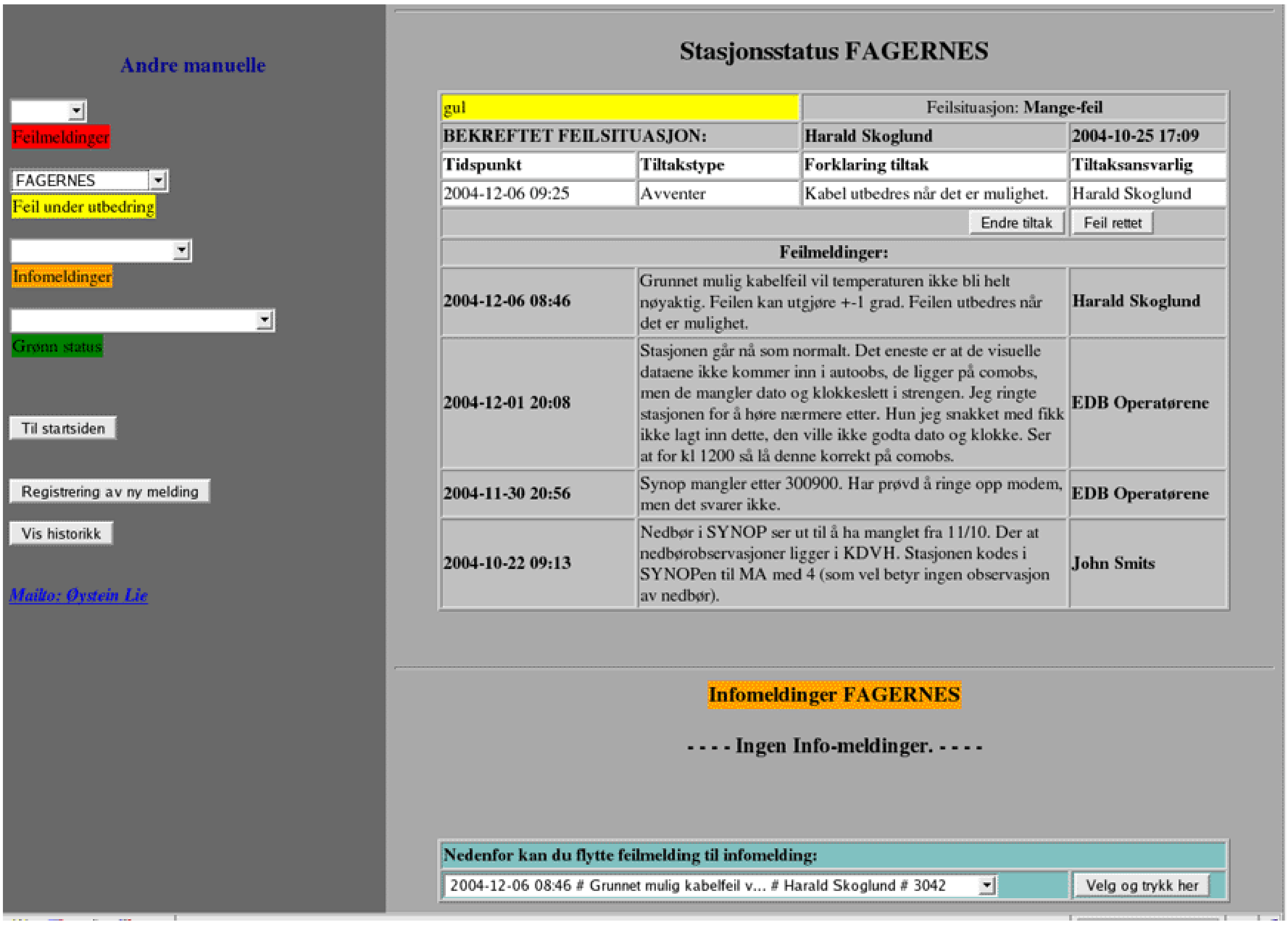

Figure 5. Example of KRO station status screen with options available to the station net service staff. In the example there are four error messages. Three buttons are available: "Edit action description", "Error corrected" and "Move error message to information message".

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http://www.ecmwf.int/newsevents/meetings/workshops/2003/9th_Meteorological_Operational_Systems/presentations/Christoffersen.pdf

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Guidelines on Quality Control Procedures for Data from Automatic Weather Stations

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Abstract

There are different quality control procedures for the various phases of the data collection process but there is an absence of comprehensive QC at all levels. The proposed Guidelines try to overcome this deficiency and presents a comprehensive system of the check procedures and algorithms and quality control flags that should be implemented at all levels of data quality control.

The proposal addresses only real time QC of data from a single AWS platform, while spatial QC is beyond a scope of the proposal. The same is also true for checks against analysed or predicted fields as well as for QC of formatting, transmission and decoding of errors, due to a specific character of these processes.

At the CBS and CIMO expert meetings it was agreed that ET AWS, jointly with CCI, JCOMM, GCOS, and CIMO, would continue with this work in the development of the guidelines for AWS quality control procedures for future publication in WMO Guide on Global Data Processing System (WMO-No. 305), the CIMO Guide, and WMO/TD-No.111.

INTRODUCTION

Quality control (QC) of data is the best known component of quality management systems. It consists of examination of data with the aim to detect errors. Data quality control has to be applied as real time QC performed at the Automatic Weather Station (AWS) and at Data Processing Centre (DPC). In addition, it has to be performed as near real time and non real time quality control at DPC.

There are two levels of the ***real time*** quality control of AWS data:

- ***QC of raw data (signal measurements)***. It is basic QC, performed at an AWS site. This QC level is relevant during acquisition of Level I data and should eliminate errors of technical devices, including sensors, measurement errors (systematic or random), errors inherent in measurement procedures and methods. QC at this stage includes a gross error check, basic time checks, and basic internal consistency checks. Application of these procedures is extremely important because some errors introduced during the measuring process cannot be eliminated later.

- ***QC of processed data***: It is extended QC, partly performed at an AWS site, but mainly at a Data Processing Centre. This QC level is relevant during the reduction and conversion of Level I data into Level II data and Level II data themselves. It deals with comprehensive checking of temporal and internal consistency, evaluation of biases and long-term drifts of sensors and modules, malfunction of sensors, etc.

The schema of quality control levels is as follows:

Basic Quality Control Procedures *(AWS)*:

I. Automatic QC of raw data
a) Plausible value check (the gross error check on measured values)
b) Check on a plausible rate of change (the time consistency check on measured values)

II. Automatic QC of processed data
a) Plausible value check
b) Time consistency check:
- Check on a maximum allowed variability of an instantaneous value (a step test)
- Check on a minimum required variability of instantaneous values (a persistence test)
- Calculation of a standard deviation

c) Internal consistency check
d) Technical monitoring of all crucial parts of AWS

Extended Quality Control Procedures *(DPC)*:

a) Plausible value check
b) Time consistency check:
- Check on a maximum allowed variability of an instantaneous value (a step test)
- Check on a minimum required variability of instantaneous values (a persistence test)
- Calculation of a standard deviation

c) Internal consistency check

In the process of applying QC procedures to AWS data, the data are validated and, if necessary, deleted or corrected. A quality control system should include procedures for returning to the source of data to verify them and to prevent recurrence of the errors.

Comprehensive documentation on QC procedures applied, including the specification of basic data processing procedures for a calculation of instantaneous (i.e. one minute) data and sums should be a part of AWS' standard documentation.

The guidelines deal only with QC of data from a single AWS, therefore spatial QC is beyond the scope of the document. The same is also true in case of checks against analyzed or predicted fields. Furthermore, QC of formatting, transmission and decoding errors is beyond the scope of the document due to a specific character of these processes, as they are dependent on the type of a message used and a way of its transmission.

Notes:

Recommendations provided in guidelines have to be used in conjunction with the relevant WMO documentation dealing with data QC:

(1) Basic characteristics of the quality control and general principles to be followed within the framework of the GOS are very briefly described in the Manual of GOS, WMO-No. 544. QC levels, aspects, stages and methods are described in the Guide on GOS, WMO-No. 488.

(2) Basic steps of QC of AWS data are given in the Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, especially in Part II, Chapter 1.

(3) Details of QC procedures and methods that have to be applied to meteorological data intended for international exchange are described in Guide on GDPS, WMO-No. 305, Chapter 6.

(4) GDPS minimum standards for QC of data are defined in the Manual on GDPS, WMO-No. 485, Vol. I).

CHAPTER I DEFINITIONS AND ABBREVIATIONS

Quality control, quality assurance

Quality control: The operational techniques and activities that are used to fulfil requirements for quality.

The primary purpose of quality control of observational data is missing data detection, error detection and possible error corrections in order to ensure the highest possible reasonable standard of accuracy for the optimum use of these data by all possible users.

To ensure this purpose (the quality of AWS data), a well-designed quality control system is vital. Effort shall be made to correct all erroneous data and validate suspicious data detected by QC procedures. The quality of AWS data shall be known.

Quality assurance: All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality.

The primary objective of the quality assurance system is to ensure that data are consistent, meet the data quality objectives and are supported by comprehensive description of methodology.

Note: Quality assurance and quality control are two terms that have many interpretations because of the multiple definitions for the words "assurance" and "control."

Types of error

There are several types of errors that can occur in case of measured data and shall to be detected by implemented quality control procedures. They are as follows:

Random errors are distributed more or less symmetrically around zero and do not depend on the measured value. Random errors sometimes result in overestimation and sometimes in underestimation of the actual value. On average, the errors cancel each other out.

Systematic errors on the other hand, are distributed asymmetrically around zero. On average these errors tend to bias the measured value either above or below the actual value. One reason of random errors is a long-term drift of sensors.

Large (rough) errors are caused by malfunctioning of measurement devices or by mistakes made during data processing; errors are easily detected by checks.

Micrometeorological (representativeness) errors are the result of small-scale perturbations or weather systems affecting a weather observation. These systems are not completely observable by the observing system due to the temporal or spatial resolution of the observing system. Nevertheless when such a phenomenon occurs during a routine observation, the results may look strange compared to surrounding observations taking place at the same time.

Abbreviations

AWS	Automatic Weather Station
B-QC	Basic Quality Control
BUFR	Binary Universal Form of the Representation
DPC	Data Processing Centre
E-QC	Extended Quality Control
GDPS	Global Data-Processing System
QA	Quality assurance
QC	Quality control

CHAPTER II BASIC QUALITY CONTROL PROCEDURES

Automatic data validity checking (basic quality control procedures) shall be applied at an AWS to monitor the quality of sensors' data prior to their use in computation of weather parameter values. This basic QC is designed to remove erroneous sensor information while retaining valid sensor data. In modern automatic data acquisition systems, the high sampling rate of measurements and the possible generation of noise necessitate checking of data at the level of samples as well as at the level of instantaneous data (generally one-minute data). B-QC procedures shall be applied (performed) at each stage of the conversion of raw sensor outputs into meteorological parameters. The range of B-QC strongly depends on the capacity of AWS' processing unit. The outputs of B-QC would be included inside every AWS message.

The types of B-QC procedures are as follows:

- ***Automatic QC of raw data (sensor samples)*** intended primarily to indicate any sensor malfunction, instability, interference in order to reduce potential corruption of processed data; the values that fail this QC level are not used in further data processing.
- ***Automatic QC of processed data*** intended to identify erroneous or anomalous data. The range of this control depends on the sensors used.

All AWS data should be flagged using appropriate QC flags. At B-QC five data QC categories are enough:

- good (accurate; data with errors less than or equal to a specified value);
- inconsistent (one or more parameters are inconsistent);
- doubtful (suspect);
- erroneous (wrong; data with errors exceeding a specified value);
- missing data.

It is essential that data quality is known and demonstrable; data must pass all checks in the framework of B-QC. In case of inconsistent, doubtful and erroneous data, additional information should be transmitted; in case of missing data the reason of missing should be transmitted. In case of BUFR messages for AWS data, BUFR descriptor 0 33 005 (Quality Information AWS data) and 0 33 020 (Quality control indication of following value*)* can be used.

I. Automatic QC of raw data

a) Plausible value check (the gross error check on measured values)

The aim of the check is to verify if the values are within the acceptable range limits. Each sample shall be examined if its value lies within the measurement range of a pertinent sensor. If the value fails the check it is rejected and not used in further computation of a relevant parameter.

b) Check on a plausible rate of change (the time consistency check on measured values)

The aim of the check is to verify the rate of change (unrealistic jumps in values). The check is best applicable to data of high temporal resolution (a high sampling rate) as the correlation between the adjacent samples increases with the sampling rate.

After each signal measurement the current sample shall be compared to the preceding one. If the difference of these two samples is more than the specified limit then the current sample is identified as suspect and not used for the computation of an average. However, it is still used for checking the temporal consistency of samples. It means that the new sample is still checked with the suspect one. The result of this procedure is that in case of large noise, one or two successive samples are not used for the computation of the average. In case of sampling frequency five - ten samples per minute (the sampling intervals 6 - 12 seconds), the limits of time variance of the samples implemented at AWS can be as follows:

- Air temperature: 2 °C;
- Dew-point temperature: 2 °C;
- Ground and soil temperature: 2 °C;
- Relative humidity: 5 %;
- Atmospheric pressure: 0.3 hPa;
- Wind speed: 20 ms^{-1};
- Solar radiation (irradiance) : 800 Wm^{-2}.

There should be at least 66% (2/3) of the samples available to compute an instantaneous (one-minute) value; in case of the wind direction and speed at least 75 % of the samples to compute a 2- or 10-minute average. If less than 66% of the samples are available in one minute, the current value fails the QC criterion and is not used in further computation of a relevant parameter; the value should be flagged as missing.

II. Automatic QC of processed data

a) Plausible value check

The aim of the check is to verify if the values of instantaneous data (one-minute average or sum; in case of wind 2- and 10-minute averages) are within acceptable range limits. Limits of different meteorological parameters depend on the climatic conditions of AWS' site and on a season. At this stage of QC they can be independent of them and they can be set as broad and general. Possible fixed-limit values implemented at an AWS can be as follows:

- Air temperature: -80 °C – +60 °C;
- Dew point temperature: -80 °C – 35 °C;
- Ground temperature: -80 °C – +80 °C;
- Soil temperature: -50 °C – +50 °C;
- Relative humidity: 0 – 100 %;
- Atmospheric pressure at the station level: 500 – 1100 hPa;
- Wind direction: 0 – 360 degrees;
- Wind speed: 0 – 75 ms^{-1} (2-minute, 10-minute average);
- Solar radiation (irradiance): 0 – 1600 Wm^{-2};
- Precipitation amount (1 minute interval): 0 – 40 mm.
-

Note: Of course there is a possibility to adjust the fixed-limit values listed above to reflect climatic conditions of the region more preciously, if necessary.

If the value is outside the acceptable range limit it should be flagged as erroneous.

b) Time consistency check

The aim of the check is to verify the rate of change of instantaneous data (detection of unrealistic jumps in values or dead band caused by blocked sensors).

- ***Check on a maximum allowed variability of an instantaneous value*** *(a step test)*: if the current instantaneous value differs from the prior one by more than a specific limit *(step)*, then the current instantaneous value fails the check and it should be flagged as doubtful (suspect). Possible limits of a maximum variability can be as follows:

Parameter	***Limit for suspect***	***Limit for erroneous***
Air temperature:	3 °C	
Dew point temperature:	2 - 3°C; 4 - 5°C [1]	4°C
Ground temperature:	5 °C	10°C
Soil temperature 5 cm:	0.5°C	1°C
Soil temperature 10 cm:	0.5°C	1°C
Soil temperature 20 cm:	0.5°C	1°C
Soil temperature 50 cm:	0.3°C	0.5°C
Soil temperature 100 cm:	0.1°C	0.2°C
Relative humidity:	10 %	15%
Atmospheric pressure:	0.5 hPa	2 hPa
Wind speed (2-minute average)	10 ms^{-1}	20 ms^{-1}
Solar radiation (irradiance):	800 Wm^{-2}	1000 Wm^{-2}

In case of extreme meteorological conditions, an unusual variability of the parameter(s) may occur. In such circumstances, data may be flagged as suspect, though being correct. They are not rejected and are further validated during extended quality control implemented at Data Processing Centre whether they are good or wrong.

- ***Check on a minimum required variability of instantaneous values*** during a certain period *(a persistence test),* once the measurement of the parameter has been done for at least 60 minutes. If the one-minute values do not vary over the past at least 60 minutes by more than the specified limit *(a threshold value)* then the current one-minute value fails the check. Possible limits of minimum required variability can be as follows:

  - Air temperature: 0.1°C over the past 60 minutes;
  - Dew point temperature: 0.1°C over the past 60 minutes;
  - Ground temperature: 0.1°C over the past 60 minutes[2];

[1] If dew point temperature is directly measured by a sensor, the lower limit is to be used. If dew point is calculated from measurements of air temperature and relative humidity, a larger limit is recommended (taking into account the influence of the screen protecting the thermometer and hygrometer). A screen usually has different 'system response time' for air temperature and water vapour, and the combination of these two parameters may generate fast variations of dew point temperature, which are not representative of a sensor default, but are representative of the influence of the screen during fast variations of air temperature and relative humidity.

[2] For ground temperature outside the interval [-0.2 °C +0.2 °C]. Melting snow can generate isothermy, during which the limit should be 0 °C (to take into account the measurement uncertainty).

- Soil temperature may be very stable, so there is no minimum required variability.
- Relative humidity: 1% over the past 60 minutes[3];
- Atmospheric pressure: 0.1 hPa over the past 60 minutes;
- Wind direction: 10 degrees over the past 60 minutes[4];
- Wind speed: 0.5 ms^{-1} over the past 60 minutes[5].

If the value fails the time consistency checks it should be flagged as doubtful (suspect).

A calculation of ***a standard deviation*** of basic variables such as temperature, pressure, humidity, wind at least for the last one-hour period is highly recommended. If the standard deviation of the parameter is below an acceptable minimum, all data from the period should be flagged as suspect. In combination with the persistence test, the standard deviation is a very good tool for detection of a blocked sensor as well as a long-term sensor drift.

c) Internal consistency check

The basic algorithms used for checking internal consistency of data are based on the relation between two parameters (the following conditions shall be true):

- dew point temperature ≤ air temperature;
- wind speed = 00 and wind direction = 00;
- wind speed ≠ 00 and wind direction ≠ 00;
- wind gust (speed) ≥ wind speed;
- both elements are suspect***** if total cloud cover = 0 and amount of precipitation > 0[6];
- both elements are suspect***** if total cloud cover = 0 and precipitation duration > 0[7];
- both elements are suspect***** if total cloud cover = 8 and sunshine duration > 0;
- both elements are suspect***** if sunshine duration > 0 and solar radiation = 0;
- both elements are suspect***** if solar radiation > 500 Wm^{-2} and sunshine duration = 0;
- both elements are suspect***** if amount of precipitation > 0 and precipitation duration = 0;
- both elements are suspect***** if precipitation duration > 0 and weather phenomenon is different from precipitation type;

  (*****: possible used only for data from a period not longer than 10-15 minutes).

If the value fails the internal consistency checks it should be flagged as inconsistent.

A technical monitoring of all crucial parts of AWS including all sensors is an inseparable part of the QA system. It provides information on quality of data through the technical status of the instrument and information on the internal measurement status. Corresponding information should be exchanged together with measured data; in case of BUFR messages for AWS data it can be done by using BUFR descriptor 0 33 006 – Internal measurement status (AWS).

[3] For relative humidity < 95% (to take into account the measurement uncertainty).
[4] For 10-minute average wind speed during the period > 0.1 ms^{-1}.
[5] For 10-minute average wind speed during the period > 0.1 ms^{-1}.
[6] Or greater than the minimum resolution of the rain gauge, to take into account the deposition of water by dew, etc.
[7] with the exception of snow pellets, which can occur with cloud cover = 0

CHAPTER III EXTENDED QUALITY CONTROL PROCEDURES

Extended Quality Control procedures should be applied at the national Data Processing Centre. The checks that had already been performed at the AWS site have to be repeated at DPC but in more elaborate form. This should include comprehensive checks against physical and climatological limits, time consistency checks for a longer measurement period, checks on logical relations among a number of variables (internal consistency of data), statistical methods to analyze data, etc.

Suggested limit values (gross-error limit checks) for surface wind speed, air temperature, dew point temperature, and station pressure are presented in the Guide on GDPS, WMO-No. 305. The limits can be adjusted on the basis of improved climatological statistics and experience. Besides that, the Guide on GDPS also presents internal consistency checks for surface data, where different parameters in a SYNOP report are checked against each other. In case of another type of report for AWS data, such a BUFR, the relevant checking algorithms have to be redefined; in case of BUFR corresponding BUFR descriptors and code/flag tables.

Internal consistency checks of data

[0]An internal consistency check of data can cause that both corresponding values are flagged as inconsistent, doubtful or erroneous when only one of them is really suspect or wrong. Therefore further checking by other means should be performed so that only the suspect / wrong value is correspondingly flagged and the other value is flagged as good.

In comparison with B-QC performed at AWS more QC categories should be used, e.g.:

- data verified (at B-QC: data flagged as suspect, wrong or inconsistent; at E-QC validated as good using other checking procedures);
- data corrected (at B-QC: data flagged as wrong or suspect data; at E-QC corrected using appropriate procedures).

The different parameters in the AWS N-minute data report (N $\leq$ 10-15 minutes) are checked against each other. In the description below, the suggested checking algorithms have been divided into areas where the physical parameters are closely connected. The symbolic names of parameters with the corresponding BUFR descriptors used in the algorithms are explained in the table below.

(a) Wind direction and wind speed

The wind information is considered to be erroneous in the following cases:

- wind direction = 00 and wind speed $\neq$ 00;
- wind direction $\neq$ 00 and wind speed = 00;
- wind gust (speed) $\leq$ wind speed;

(b) Air temperature and dew point temperature

The temperature information is considered to be erroneous in the following case:

- dew point temperature > air temperature;
- air temperature - dew point temperature > 5°C and obscuration is from {1, 2, 3};

(c) Air temperature and present weather

Both elements are considered suspect when:

- air temperature > +5°*C* and precipitation type is from {6, …, 12};
- air temperature < -2°*C* and precipitation type is from {2};

- air temperature > +3°*C* and precipitation type is from {3};
- air temperature < -10°*C* and precipitation type is from {3};
- air temperature > +3°*C* and obscuration is from {2} or
  (obscuration is from {1} and character of obscuration is from {4});

(d) **Visibility and present weather**

The values for visibility and weather are considered suspect when:

- obscuration is from {1, 2, 3} and visibility > 1 000 m;
- obscuration is from {7, 8, 9, 11, 12, 13} and visibility > 10 000 m;
- visibility < 1 000 m and obscuration is not from {1, 2, 3, 8, 9, 10, 11, 12, 13}
  and precipitation type is not from {1, … , 14};
- obscuration = 7 and visibility < 1 000 m;
- visibility > 10 000 m and precipitation type is missing and obscuration is missing
  and weather phenomenon is missing;

(e) **Present weather and cloud information**

Clouds and weather are considered suspect when:

- total cloud cover = 0 and precipitation type is from {1, …, 11, 13, 14}
  or weather phenomenon is from {2, 5, … , 10};

(f) Present weather and duration of precipitation

Present weather and duration of precipitation are considered suspect when:

- precipitation type is from {1, … , 10, 13, 14} and precipitation duration = 0;
- precipitation type is not from {1, … , 10, 13, 14} and precipitation duration > 0;
-

(g) Cloud information and precipitation information

Clouds and precipitation are considered suspect when:

- total cloud cover = 0 and amount of precipitation > 0[8];
-

(h) Cloud information and duration of precipitation

Clouds and duration of precipitation are considered suspect when:

- total cloud cover = 0 and precipitation duration > 0;

(i) Duration of precipitation and other precipitation information

Precipitation data are considered suspect when:

- amount of precipitation > 0 and precipitation duration = 0;

(j) Cloud information and sunshine duration

Clouds and sunshine duration are considered suspect when:

- total cloud cover = 100% and sunshine duration > 0;

For each check, if the checked values fail the internal consistency check, they should be flagged as erroneous or suspect (depending on the type of the check) and inconsistent. Further checking

[8] Or greater than the minimum resolution of the rain gauge, to take into account the deposition of water by dew, etc.

by other means should be performed so that only the suspect / wrong value is correspondingly flagged and the other value is flagged as good.

The symbolic name and the corresponding BUFR descriptor (as reference) used in QC algorithms (a) – (j) are as follows:

Symbolic name	**BUFR Descriptor**
Wind direction	0 11 001
Wind speed	0 11 002
Wind gust (speed)	0 11 041
Air temperature	0 12 101
Dew point temperature	0 12 103
Total cloud cover	0 20 010
Visibility	0 20 001
Precipitation type	0 20 021
Precipitation character	0 20 022
Precipitation duration	0 26 020
Weather phenomenon	0 20 023

For further treatment of data it is necessary to keep the results of the E-QC data quality control together with the information on how suspect or wrong data were treated (using sophisticated system of flags). The output of the quality control system should include QC flags that indicate whether the measurement passed or failed, as well as a set of summary statements about the sensors.

Every effort has to be made to fill data gaps, correct all erroneous values and validate doubtful data detected by QC procedures at the Data Processing Centre choosing appropriate procedures.

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The World Radiometric Reference and its Quality System

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Abstract: The World Radiometric Reference (WRR) has been the basis for meteorological radiation measurements for the last 25 years. It is realized by a group of instruments, the World Standard Group (WSG), which is maintained at the World Radiation Center (WRC) in Davos. In these times of concerns about global warming, it is extremely important to accurately monitor the solar radiation impinging on Earth. Consequently, the proper maintenance of the WRR is crucial.
In order to guarantee the highest accuracy of the WRR and its international recognition, WRC implemented a quality management system satisfying the standard ISO/IEC 17025 and presented it to the EUROMET QS-Forum in February 2005.
The WRC is also in the process of carrying out comparisons between the WRR and cryogenic radiometers to ensure the stability of the WRR and to have a direct link to the SI system of units maintained by metrological institutes.
In this paper, we report on the state of the WRR and on the implementation of the quality management system.

1. Introduction

In these times of concerns about global warming, it is more than ever important to accurately characterize and monitor the radiation budget of the Earth. The solar radiation reaching the Earth and its surface is obviously a major issue in this context.

The World Radiometric Reference (WRR) is maintained and operated by the World Radiation Center (WRC) at Physikalisch-Meteorologisches Observatorium Davos (PMOD), Switzerland. The WRR serves as the reference standard used by WMO and other communities for measurements of the direct solar irradiance. Indeed, some ISO standards require traceability to the WRR.

The aim of the WRC is to ensure the best-possible maintenance of the WRR in order to make possible the detection of subtle changes in radiation climates.

In this paper, we present the way chosen by the WRC to ensure the quality of its standard and its international recognition by both the meteorological and metrological communities[1].

First we will give a brief history of the WRR. Then we will focus on the technical challenges of solar irradiance measurements and explain why there is a need for a dedicated primary standard for this purpose. Finally we will present our efforts to become a recognized metrology laboratory based on the international standard ISO/IEC 17025.

2. The WRR and its maintenance

Radiation measurements in meteorology have to be very homogeneous in space and time in order to yield useful information about the subtle differences of the different radiation climates and their evolution. The achievement of homogeneity in radiation measurements had been of concern since radiation network started to be implemented. At that time the measurement capabilities of metrology institutes were restricted to low intensity levels and consequently, not adapted to solar irradiance. This was the main reason for the development of an independent radiation standard in meteorology. Over the years, several steps were needed to finally define the WRR [1, 2], which has now been in use since January 1, 1981 within the meteorological community [3].

The WRR is basically the result of the intercomparison of 15 absolutely characterized cavity radiometers originating from different manufacturers, each of them being a realization of the unit W/m^2.

The WRR is realized by a group of absolute cavity pyrheliometers - the World Standard Group (WSG) – and is maintained by the WRC at Davos. Some of the original instruments used to define the WRR are still members of the WSG.

The WSG is made up of different types of instruments in order to enable detection of any

[1] Throughout this paper, the reader should pay attention to carefully distinguish between the different realms of “meteorology” and “metrology”.

aging process or malfunction of an instrument (or an instrument type). All the WSG members had to prove long-term stability in order to be considered as members.

At present all the WSG radiometers are more than 25 years old. Therefore, there is a strong concern, that some of these instruments may fail sooner or later. In order to ensure the future of the WSG, PMOD/WRC currently operates instruments of newer generations on the WSG platform in order to test their long-term stability. After successful performance testing, such instruments could possibly be integrated into the WSG if they are of different types than the WSG instruments or replace faulty instruments.

Another point of concern is that there are presently only two manufacturers of commercial absolute cavity radiometers. In the future, it may consequently become impossible to keep having enough instruments of different types in the WSG. Therefore PMOD/WRC tried to obtain instruments from other manufacturers. Though positive feedback was initially received from various laboratories, only one Chinese laboratory provided instruments on loan.

The stability of the WRR is secured by regular intercomparisons of the WSG instruments. Every 5 years, an International Pyrheliometer Comparison (IPC) is organized and held by PMOD/WRC in Davos. The main goal of the IPC is the dissemination of the WRR to ensure worldwide homogeneity of meteorological irradiance measurements. Since many instruments are regular participants in the IPC, their measurements can be used as an independent check to confirm the stability of the WRR. Should the situation arise that most participating instruments experienced a significant drift relative to the WRR since the last IPC, correcting steps necessitating a deeper analysis would need to be taken, but this has never happened yet.

3. Intercomparisons between the WRR and cryogenic radiometers

Direct intercomparison between the WRR and cryogenic radiometers is not possible since there are presently no cryogenic radiometers, which can measure irradiance and most are restricted to much lower power levels than those used for solar measurements.

Indirect intercomparisons between the WRR and the UK National Physical laboratory's (NPL) primary standard radiometer (PSR) were carried out in 1990 [4] and 1994 [5], using a laser beam and a trap detector as transfer standard. The results lie well within the absolute uncertainties of the two scales. Such comparisons are primordial in order to independently confirm the stability of the WRR and its consistency with SI units.

It should be noted that, for technical reasons mentioned above, these comparisons were based on power measurements rather than irradiance measurements, i.e. the diameter of the laser beam was smaller than the precision aperture of the WSG radiometer. The radiometer is consequently not exactly in the same environment as during solar measurements. It cannot be excluded that the estimated uncertainties of the comparisons to the cryogenic radiometer were underestimated. Possible causes of uncertainty which were not taken into account are for example due to the use of the instrument in power-mode instead of irradiance mode, non-complete illumination of the cavity, diffraction correction, stray-light correction, etc.

A new comparison has taken place this year and it is planned to carry out such comparisons on a regular basis to independently check the stability of the WRR.

4. The need for a quality system

As stated above, the WRR was originally designed to meet the needs of the meteorological community. However, since various ISO standards require traceability to the WRR, it is actually used by a much wider community.

Nowadays, the need for certification and traceability is being more and more asked for. This requires a complete traceability chain, where each step from the definition of the unit to the end user is associated with a stated uncertainty.

PMOD/WRC wants to ensure that solar radiation measurements are based on a stable reference and wants to provide this service to the communities relying on the WRR. To achieve these goals, PMOD/WRC decided to implement a quality management system according to ISO/IEC 17025 (General Requirements for the Competence of Calibration and Testing Laboratories).

5. BIPM and its relation to WMO

WMO and the Bureau International des Poids et Mesures (BIPM) decided to co-operate as to ensure that meteorological data are properly traceable to SI units.

Figure 1 shows schematically the structure of the BIPM. It was the Metre Convention, signed in 1875 in order to promote the use of the metric system, which originally led to the foundation of the BIPM. The Comité International des Poids et Mesures (CIPM) supervises the BIPM and Consultative Committees (CC) and co-operates with other international metrological organizations.

In 1999 CIPM issued the so-called Mutual Recognition Arrangement (MRA) based on which National Metrology Laboratories (NMI) mutually recognize each other's standards and calibration certificates. For these purposes metrology laboratories are required to comply with the following regulations:

- Credible participation in key comparisons

- Credible participation in other comparisons
- Declaration of each participant’s calibration and measurement capabilities (CMC)
- Quality system for calibration services recognized to be on the level of international best practices.

All quantities (measurables) are subject to approval by the Consultative Committee. In this respect, it should be noted that the quantity “Solar Irradiance” has been proposed to the Consultative Committee on Photometry and Radiometry (CCPR), but the approval process of this quantity is not yet completed. Upon approval of this quantity by CCPR it will be possible for PMOD/WRC (and other metrology laboratories) to announce CMC’s on Solar Irradiance to BIPM.

Since the WRR is a conventional primary standard it needs to be included in the international system of standards. To further accentuate this need it should be mentioned that several ISO standards require traceability to the WRR. The WMO Guide to Meteorological Instruments and Methods of Observation also refers to some of these ISO standards.

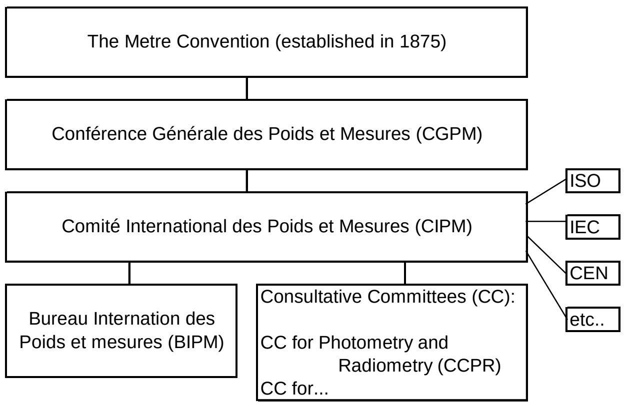

Figure 1: Structure of the BIPM and related bodies.

6. National Metrological Institutes and the EUROMET QS-Forum

The formal recognition of the National NMI takes place on a regional basis. The European regional metrology organization is the EUROMET.

The Quality System Forum (QS-Forum) is the EUROMET operational instrument used to share knowledge on ISO/IEC 17025 and its implementation by NMIs. It is a collaborative forum on measurement standards and is the way used by EUROMET to do QS review by peers.

NMIs can also devolve the maintenance of certain measurement standards to external laboratories. Of course, these also have to comply with the same rules.

7. The case of the World Radiation Center

The WRR can be considered as a primary standard since it was based on absolutely calibrated radiometers and it is accepted as such throughout the meteorological community (WMO). This situation of a primary standard not being owned by an NMI is rather unique. Therefore the Swiss NMI (METAS) designated it as the institute responsible for Solar Irradiance within CIPM-MRA.

PMOD/WRC consequently opted for self-declaration by implementing a quality system according to ISO/IEC 17025 for parts of its activities – the maintenance of the WRR and the calibrations of pyrheliometers and pyranometers. In these fields PMOD/WRC acts as a metrology laboratory. In the future other activities at PMOD/WRC are planned to be included into the quality system.

ISO/IEC 17025 incorporates all requirements of ISO 9001 and ISO 9002 that are relevant to the scope of testing and calibration services[2].

The quality system at PMOD/WRC has a two-stage structure. Stage one consists of the *quality management*, which includes the quality policy statement and defines the general rules and range of application for all departments and activities. In each department subject to the quality system a set of documents was compiled to describe all processes and infrastructure within that department (stage two of the quality system). All work procedures, diagrams, schematics of hardware, as well as documents on uncertainty and traceability etc. are part of the stage two quality documentation.

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[2] Note that certification against ISO 9001 and ISO 9002 does not of itself demonstrate the competence of the laboratory to produce technically valid data and results.

Preliminary Results of WMO Intercomparison of high quality radiosonde systems, Mauritius, February 2005

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This paper provides a brief survey of the initial results from the WMO Intercomparison of High Quality Radiosonde Systems, Mauritius. All radiosondes that took part in the test proved to be of good quality, although problems were identified with some systems which will need to be addressed in the long term. The most suitable contenders for climate temperature monitoring work were the Vaisala and Sippican radiosondes. Both specialised reference systems (Meteolabor Snow-White and Sippican 3-Thermistor) needed further development to be fully reliable as working references.

1. Introduction

The WMO Intercomparison of High Quality Radiosonde Systems consisted of 62 successful radiosonde comparison flights, performed between 7 and 25 February 2005 at the headquarters of the Mauritius Meteorological Services, Vacoas.

This test was organised by the Expert Team on Upper- Air Systems Intercomparisons, chaired by Dr. J. Nash. Mauritius Meteorological Services volunteered to host this test at CIMO-XIII. February 2005 was chosen for the test by the Expert Team to allow the radiosonde relative humidity sensors to be tested in both wet and dry conditions.

B. Pathack performed a variety of tasks as Project Manager. Organising import and export of equipment proved a major effort, but all equipment was delivered on time. Provision of facilities for the test included the installation of a hydrogen generator to facilitate filling 2000g balloons, stabilised power supply for the ground system computers and Internet connections for the participants. The number of international participants present in Mauritius at any time during the test was about 15. The typical number of people from Meteorological Services Mauritius involved in the test during one week was more than 20. 4 teams of 3 persons were trained to prepare balloons, provide surface observations and manage the launch of the balloons. Radiosonde support rigs were assembled in advance from green bamboo canes obtained locally. Training in balloon handling and comparison launch procedures were provided by J. Nash and R. Smout.

Mauritius Meteorological Services provided technical support to participants throughout the test. Repair work was performed on the power supplies of the cloud radar brought from the UK, without which measurements would not have been obtained.

2. Radiosondes tested

Six main radiosonde types were tested [method of height determination indicated]:

Vaisala RS92	(Finland)	[pressure sensor and GPS height]
Graw DFM-97	(Germany)	[pressure sensor and GPS height]
MODEM M2K2	(France)	[GPS height only]
Sippican MKIIA	(USA)	[GPS height only]
Meisei RS-01G	(Japan)	[GPS height only]
Meteolabor, SRSD-C34	(Switzerland)	[Hypsometer pressure sensor]

InterMet Systems withdrew from the test in autumn 2004.

Vaisala, Modem and Meisei radiosondes and Vaisala, Graw and Sippican radiosondes were flown together as two groups with either Meteolabor or three thermistor radiosondes included as a working reference. This arrangement had been agreed at the International Organizing Committee by the HMEI representatives, since all manufacturers wished to have the opportunity to compare with Vaisala. Fig.1 shows preparation for launching the Vaisala-Sippican-Graw radiosonde group with a 3 thermistor radiosonde.

Fig.1 Graw and Sippican 3 thermistor radiosondes ready for a night time comparison of the Vaisala-Sippican-Graw radiosonde group on the bamboo cross support rig.

All radiosondes tested were operating in the band 400.5 to 405.5 MHz. It would have been possible to fly all the radiosondes supported by one balloon if the frequency stability and bandwidth of the Sippican transmitters had been similar to the other radiosondes. Only one set of measurements was lost from poor radiofrequency reception /interference, when the first SRS was flown at too low a frequency.

Vaisala radiosondes were flown on all test flights, with 59 out of 62 successful. Thus, it is convenient to use the Vaisala measurements to link the performance of the radiosondes in the two groups. Launch times were separated by about 5 hours to allow enough time to generate hydrogen for the 2000g balloons, but this separation was shortened at night in the second and third weeks. Thus, the two daytime flights were launched at 09.00 and 14.00 local time, so that solar elevation was similar in the stratosphere for both groups. Night time launches were at 19.00 and between 22.00 to 23.30 local time.

24 Sippican MKII, 3 thermistor radiosondes were flown, [5 at night, 19 in the day] to provide a "working reference" for temperature. The Snow- white chilled mirror hygrometer was successfully deployed as a "working reference" for dew point/ relative humidity measurements on 34 flights.

During the second half of the test MODEM flights were operated by staff from Mauritius, see Fig.2, and the Graw system was operated by staff from the UK at the request of the respective manufacturers.

Fig.2 Staff from the teams of Mauritius Meteorological Services working with the MODEM system during the second half of the test.

50 flights reached higher than 30 km and sufficient flights ascended to heights above 34 km to provide useful comparisons up to this level. The balloon performance was judged as good given the rainy conditions and the presence of thick upper cloud at night for part of the test. Local staff only received a short period of training before starting the test, but coped well with unpredictable launch conditions with low level winds varying significantly between launches.

3. Data processing

The processing software used for this test was provided by S. Kurnosenko. This was an updated version of the RSKOMP software used to analyse results from Phases III and IV of earlier WMO Radiosonde Comparisons.

Sergey Kurnosenko managed the data input from the files provided by the manufacturers. The workload associated with data entry was increased by the large number of last moment modifications made to proposed file formats by most manufacturers in the test. The comparison data base consists of samples extracted at 1s intervals from the files provided by the manufacturers, after modification of the extraction software on site in Mauritius.

The attempt to use GPS timing as a method of synchronising samples did not work because of a lack of consistency in the use of GPS time between the systems. In practice, data samples were synchronised by matching temperature and relative humidity profiles near the ground using the WVIEW software. The adjustment procedure works well with temperature and humidity data sampled at 1 s intervals. The timing adjustment procedure may not work so well for pressure, especially near the ground where sensed values may have been adjusted by software to a different value to be consistent with a different launch time.

Input data were checked by the WMO supervisory team as soon as possible following the flight. Problems with systems were discussed with the specific teams, e.g. the filtering of the Japanese GPS measurements and a solution agreed. The aim was to ensure that data represented correct functioning of the systems deployed in Mauritius. For some of the systems, this entailed ensuring that algorithms for converting GPS geometric height to geopotential height used the correct value of g for Mauritius.

In some cases, launch procedures were modified to try and prevent damage to the more fragile radiosondes and to ensure that other systems did not lose GPS lock during the launch procedure.

Test procedures and early results were reviewed towards the end of the first week by all the participants. The team leaders agreed that test procedures were satisfactory.

Some data problems became more obvious towards the end of the trial and this required some rework of the observations after the final flight.

- Vaisala reprocessed daytime temperature measurements using a different editing filter.
- Meisei recomputed temperatures because incorrect corrections had been applied to night time measurements during the test.
- Meteolabor reprocessed geopotential heights because of errors in the height computation software.
- MODEM reprocessed geopotential height computations since an incorrect value of local g had been used for the geometric height to geopotential conversion.

Statistical processing was based on the WSTAT program supplied by S. Kurnosenko. The data were edited by the Chairman of the IOC, before the statistics were processed. Editing was required mostly by the two specialised sensing systems, where elimination of the various occasional Snow white failure modes [excessive instability in dewpoint measurement at upper levels, contamination in the Snow white duct leading to dewpoints that were higher than air temperature in upper layers in daytime, loss of the water film on the chilled mirror in very dry layers], and thermistor calibration errors/ inter-channel radiofrequency offset problems for the 3 Thermistor radiosondes.

When a temperature sensor becomes wet in passing through cloud, the sensor is cooled on emerging into a drier layer above the cloud, as the water evaporates. The Vaisala sensor was least sensitive to this problem. The other manufacturers ought to consider using a hydrophobic coating on the temperature sensor to minimise the significant errors that follow sensor wetting. The measurements in the layers where this wetting error happened were hidden and not used in the following statistics.

4. Simultaneous temperature comparisons

Figures 3(a) and (b) show the results of temperature comparisons at night. Meisei, Sippican and Vaisala measurements agreed to within ± 0.3 K from the surface to 31 km. At the lowest temperatures [-80 deg C] in the upper troposphere, Graw and SRS temperatures had calibration discrepancies of about +0.5 K. In the case of Graw the discrepancies were much smaller than the night time errors in the previous WMO GPS Radiosonde test in Brazil, where errors had been larger than 1K. Only, the MODEM radiosonde had a temperature sensor coated with white paint. This sensor was in error by more than 2 K at 30 km, with at least 1K the result of cooling by infrared radiation.

At night the standard deviations of the differences between each radiosonde and Vaisala were consistent with a reproducibility of temperatures from sensors with aluminized coatings of better than 0.2 K from the surface up to 30 km.

Figures 4(a) and (b) show the results for day time temperature comparisons. The absolute values of the three thermistor measurements may be offset by up to ± 0.2 K from truth. Significant numbers of errors in individual thermistor measurements had to be offset by comparison with the results from the other radiosondes. However, the 3 thermistor measurements provide an accurate representation of the variation in the vertical of the correct temperature in the stratosphere.

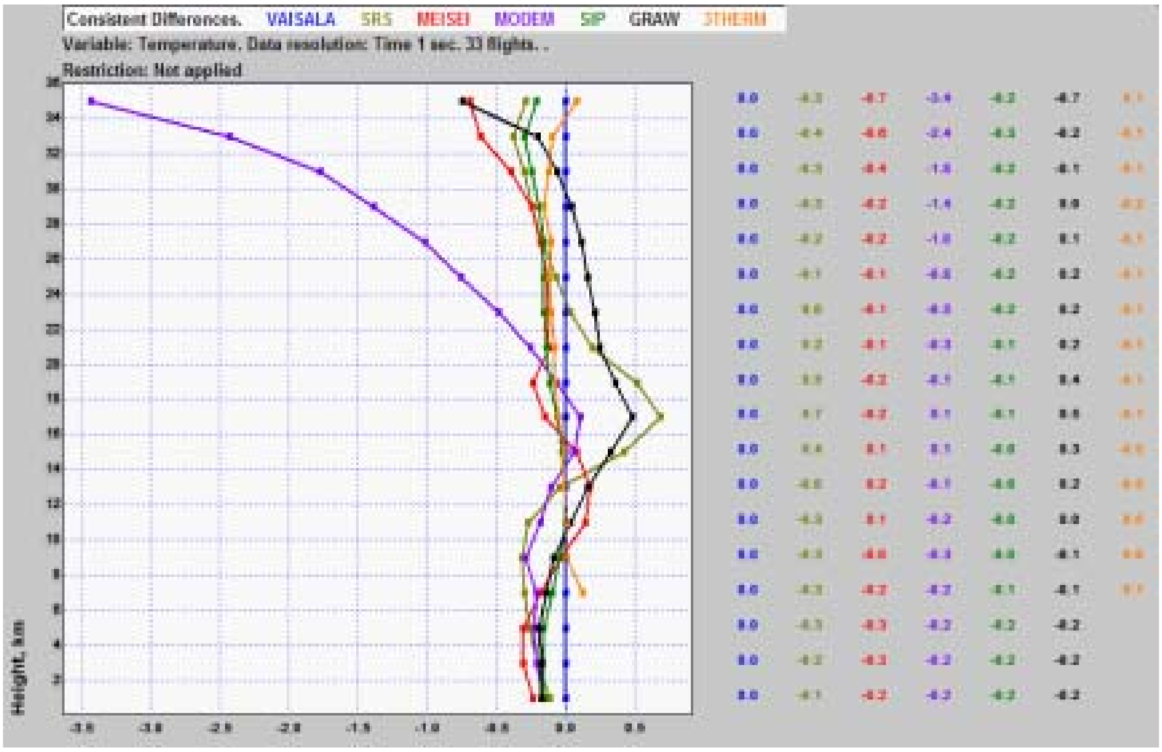


Fig.3 (a) Systematic bias between simultaneous temperatures [K] at night using Vaisala as a working reference

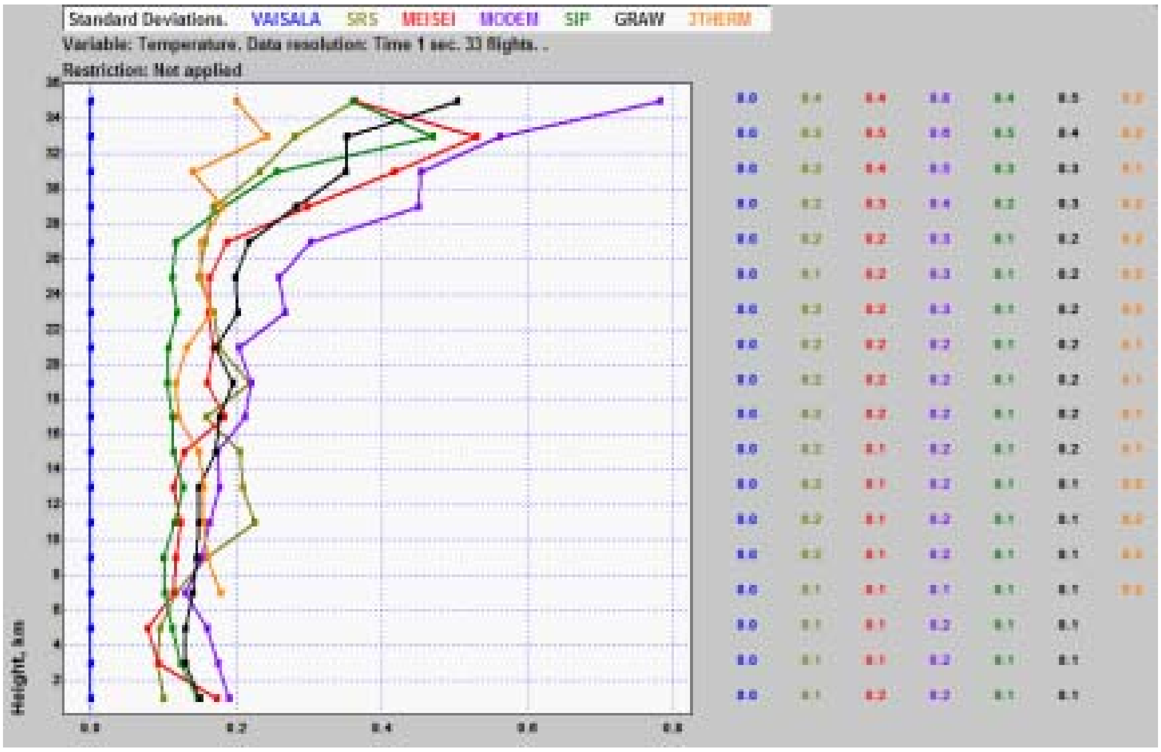


Fig. 3(b) Standard deviations between simultaneous temperatures [K] at night using Vaisala as a working reference.

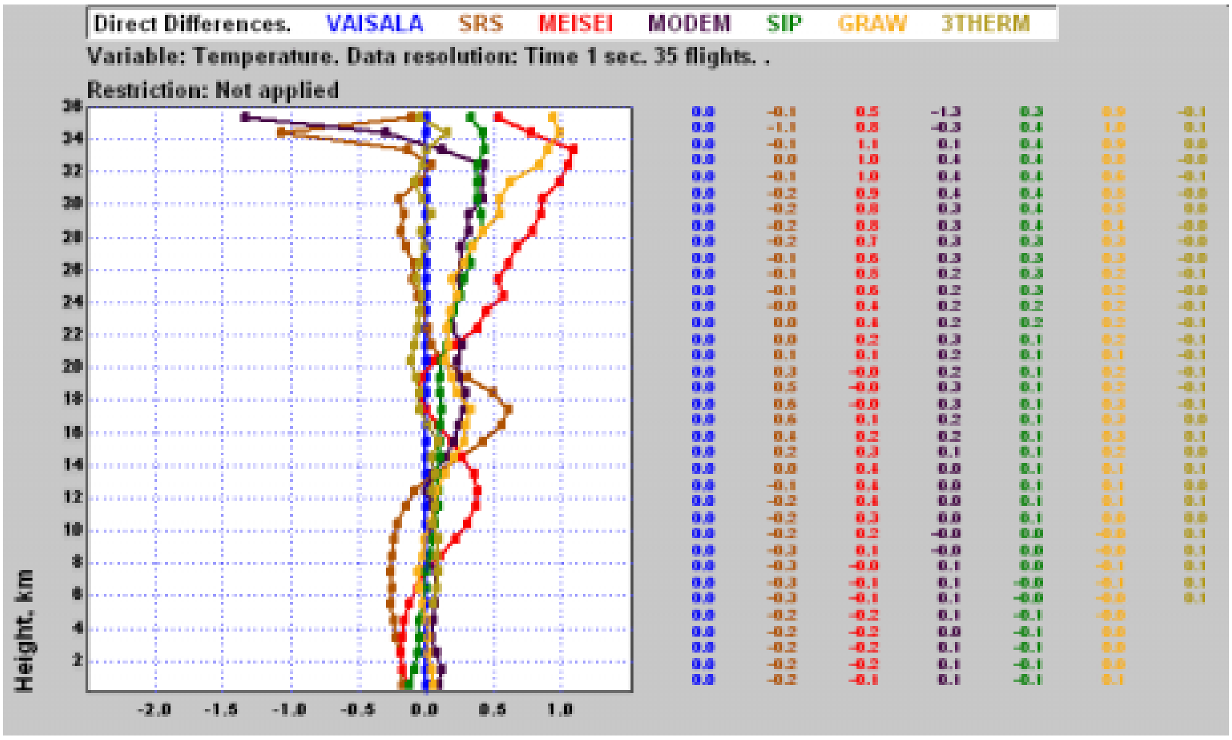


Fig.4 (a) Systematic bias between simultaneous daytime temperatures [K] using Vaisala as a working reference

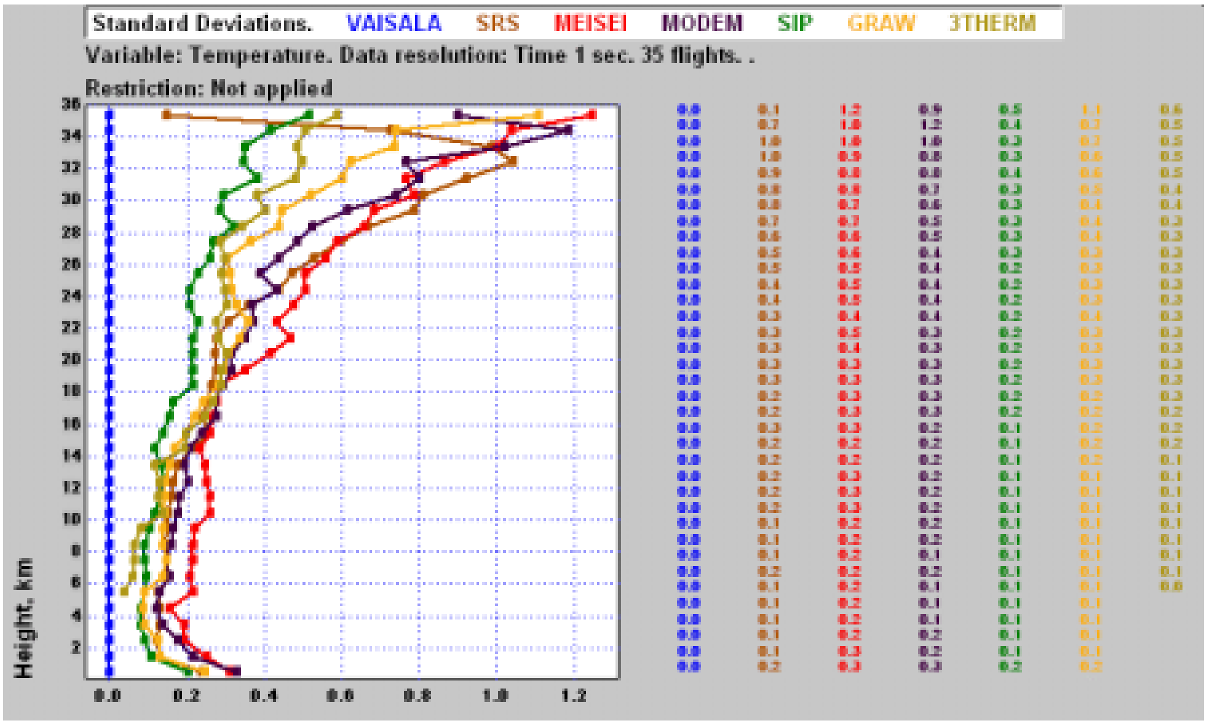


Fig. 4(b) Standard deviations between simultaneous daytime temperatures [K] using Vaisala as a working reference.

Vaisala make the smallest daytime temperature correction (about 0.6 K at 10 hPa). SRS and Sippican make corrections of just over 1 K at about 30 km. From Fig 4 (a), Vaisala and SRS corrections produce results very close to the three thermistors at upper levels. The Sippican measurements diverge from the three thermistors at 30 km so the Sippican corrections should probably be larger by about 0.3 K at 30 km. Modem temperature corrections are about 2 K at upper levels. Meisei daytime temperature corrections, about 2.5 K at 30 km, were larger than most of the other radiosondes. With the upper cloud conditions experienced in Mauritius, Meisei temperature corrections needed to be larger by at least 0.7 K at 10 hPa.

Temperature errors in daytime measurements fluctuate in the short term as the radiosondes rotate in flight, with the period of the predominant rotation between 10 and 15 s. These fluctuations increase with height and affect all the radiosondes to some extent, including Vaisala. Raw daytime Vaisala measurements have significant error fluctuations at upper levels. Air passing over the Vaisala sensor support is warmed and if this air then passes over the temperature sensor, positive temperature error pulses result. In Mauritius, the magnitude of the temperature pulses was about 1 K at 30 km if the radiosonde was rotating smoothly under the support rig. These pulses are larger than occur in individual Vaisala flights where the radiosonde motion is more random. In the reported Vaisala data, the temperature pulses are largely filtered out by Vaisala processing software. The new filter used in processing the final Vaisala data in Mauritius is not yet in operational use. The original Vaisala data in Mauritius used the existing operational Vaisala filter. At heights above 28 km these original Vaisala temperatures showed larger standard deviations in the differences with Sippican and three thermistor than are now found in Fig. 4(b). The standard deviations in Fig. 4(b) are consistent with the reproducibility of Sippican and Vaisala daytime temperature measurements being better than 0.2 K at heights up to 28 km. The random errors in the other radiosonde daytime temperature measurements became larger than 0.2 K above 18 km. At 32 km, the random errors in daytime temperatures had increased to between 0.3 and 1 K depending on the radiosonde design.

Overall, the two most suitable radiosonde temperature measurements for climate monitoring both day and night were Vaisala and Sippican. Three thermistor radiosonde measurements can also give very high quality measurements if the system is implemented carefully, but the Sippican system used in Mauritius needs further development to be reliable as an absolute reference.

A combination of Vaisala GPS with a suitable operational version of the Sippican GPS radiosonde would be recommended for best measurement quality for high performance climate/satellite monitoring.

5. <u>Simultaneous geopotential height comparisons</u>

The simultaneous height comparisons from this test demonstrate that GPS height measurements give geopotential heights that are more accurate than the best pressure sensors at all heights above 16 km and are of similar accuracy to pressure sensor measurements at heights below 16 km. The systematic bias of all the geopotential heights relative to the Vaisala GPS height measurements are shown in Fig. 5 (a).

All the GPS height measurements agreed on average to within ± 20 m from the surface to 34 km. At 30 km pressure sensors were in error by values between -70m (Vaisala) up to +120m (SRS). Both Graw GPS and Sippican geopotential had standard deviations relative to Vaisala of less than 10m. Thus, GPS heights are suitable to replace geopotential from pressure sensors at all heights, i.e. a pressure sensor is no longer a necessity for a best quality radiosonde.

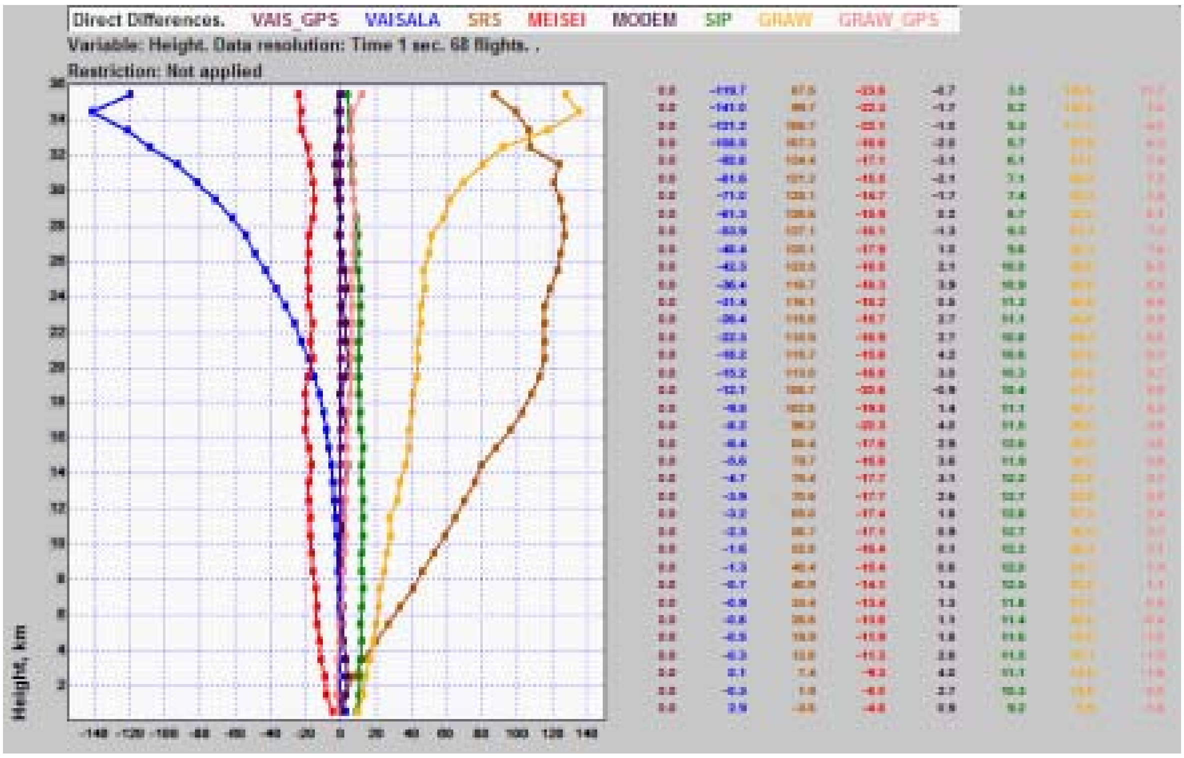


Fig. 5 (a) Systematic bias between simultaneous geopotential height measurements [gpm], using Vaisala GPS measurements as a working reference. Vaisala, SRS and Graw are heights derived from high quality pressure sensors

The reproducibility of the GPS geopotential heights at 32 km is an order of magnitude better than the reproducibility of the heights from the best pressure sensors, see Fig. 5(b) . Thus, temperature errors caused by height errors in radiosonde output will become negligible with the new GPS height measurements, even at pressures lower than 5 hPa.

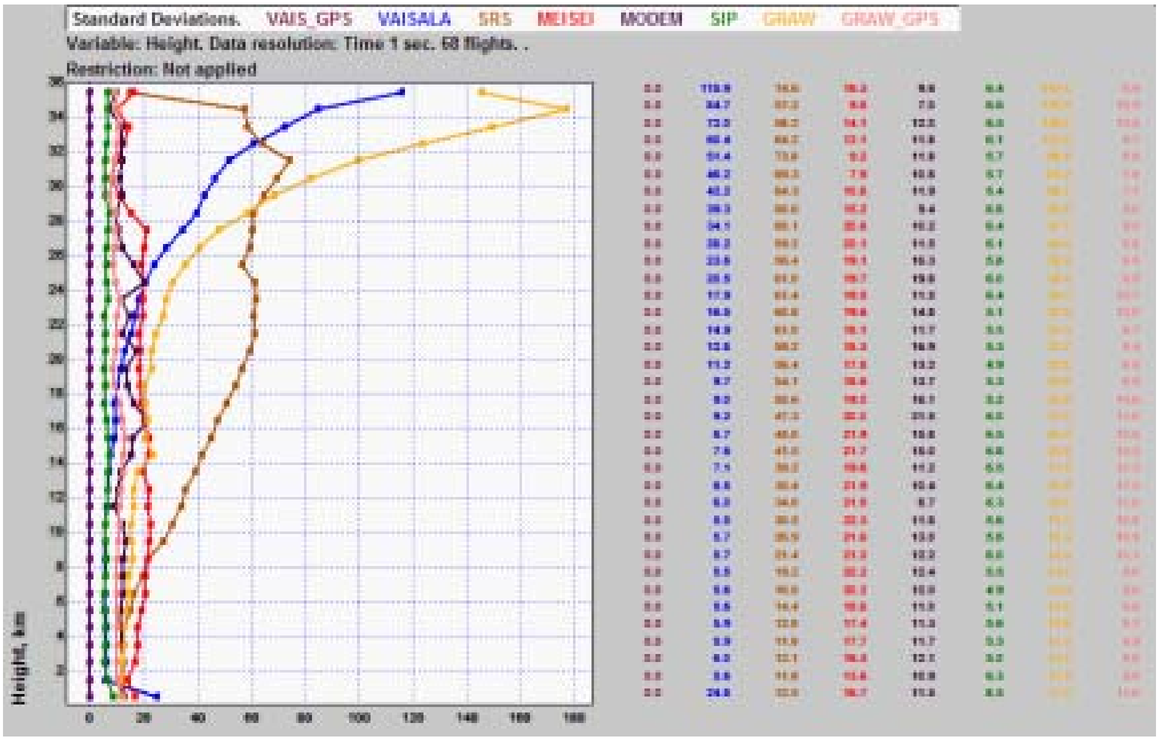


Fig. 5 (b) Standard deviations between simultaneous geopotential height measurements [gpm] using Vaisala GPS measurements as a working reference. Vaisala, SRS and Graw are heights derived from high quality pressure sensors

6. Simultaneous pressure comparisons

Fig. 6 shows the results of the simultaneous pressure comparisons from the data base. Two Modem flights where water/ice apparently shunted the temperature sensor for part of the flight giving very large negative temperature anomalies were excluded Four out of 34 SRS pressures were also judged atypical and excluded.

The spread of systematic differences in pressure close to the ground may have partly been the results of the time adjustment procedure used to synchronise temperature and relative humidity and winds, since all systems were using a similar surface pressure, but the launch times used were not always coincident

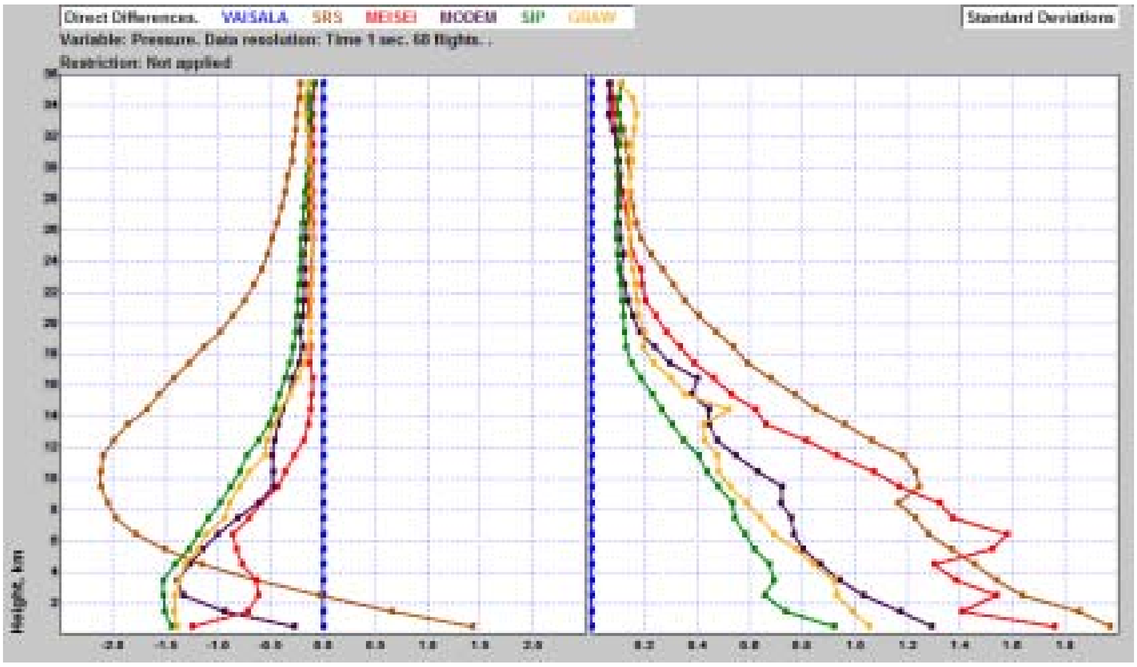


Fig.6 Systematic bias and standard deviations of simultaneous comparisons between pressure measurements [hPa].

7. Simultaneous relative humidity comparisons

The systematic differences between the relative humidity sensors is presented as a function of height for 5 relative humidity bands, with daytime and night time results presented separately. The bands were 75 to 95 per cent in Figs. 7(a) and (b), 55 to 75 per cent in Figs. 7(c) and (d)) and 35 to 55 per cent in Figs 7(e) and (f), 15 to 35 per cent in Figs 7(g) and (h) and 0 to 15 per cent in Figs 7 (i) and (j)

In Fig 7(a) it can be seen that most of the relative humidity measurements at high humidity were within ± 4 per cent of the average used. Meisei measurements below 2 km were an exception with a large negative bias of greater than 8 per cent shortly after launch. Fig.7 (b) contains an estimate of the daytime relative humidity measurements referenced to the same reference as at night. It has been assumed that there is little day-night difference in Snow-white measurements in this height range. This assumption gives a day-night difference in the other radiosonde measurements consistent with the day-night differences indicated by initial comparisons of radiosonde integrated water vapour amount (IWV) with GPS water vapour measurements

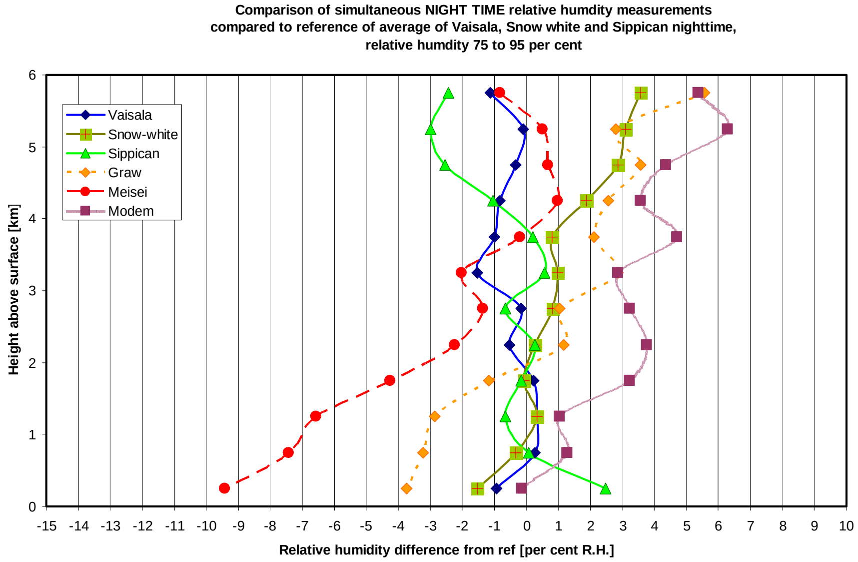


Fig. 7(a) Systematic bias for night time relative humidity , range 75 to 95 per cent, referenced to the average of Vaisala, Snow white and Sippican.

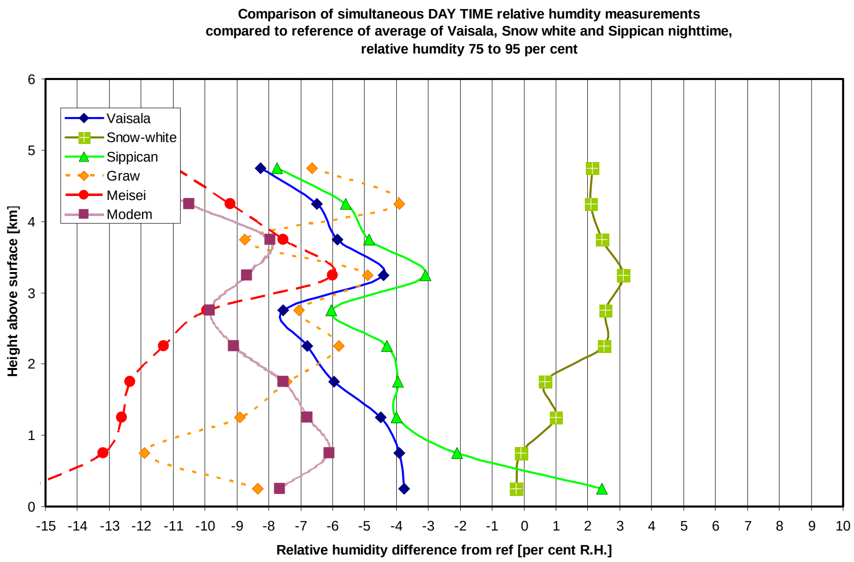


Fig. 7(b) Systematic bias for daytime relative humidity, range 75 to 95 per cent , referenced to the night time average of Vaisala, Snow white and Sippican,

Fig.7 (b) shows Sippican relative humidity had the smallest day-night difference with daytime measurements low by between 0 and 4 per cent relative to night. The largest day-night differences were present in Modem measurements with daytime low by between 8 and 16 per cent compared to night.

Day-night differences in Vaisala measurements varied from about -3 per cent near the surface to about -7 per cent at about 5 km. The Vaisala RS92 radiosondes used in Mauritius had improved protection against solar heating with the white glue and the bare copper near the sensors both aluminized, in contrast to current production models.

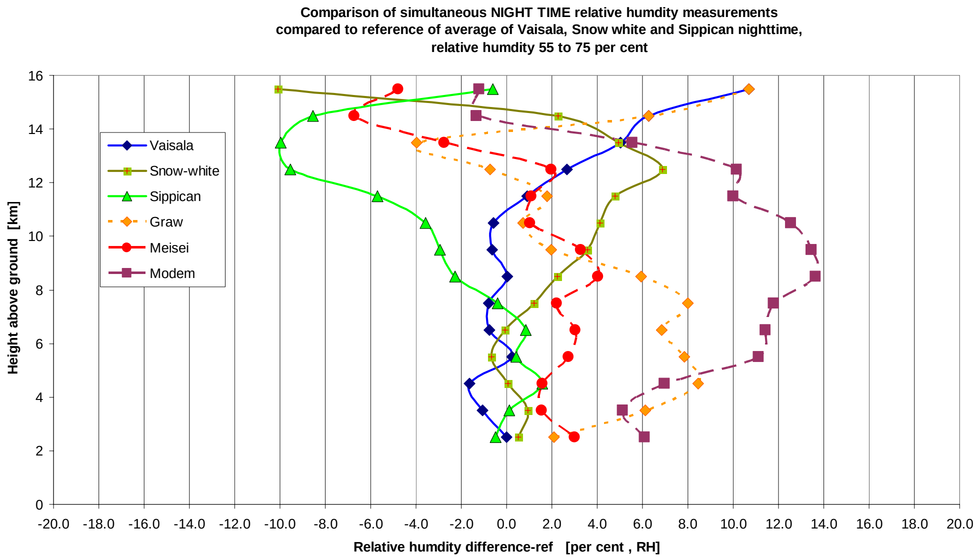


Fig. 7(c) Systematic bias for night time relative humidity , range 55 to 75 per cent, referenced to the average of Vaisala, Snow white and Sippican.

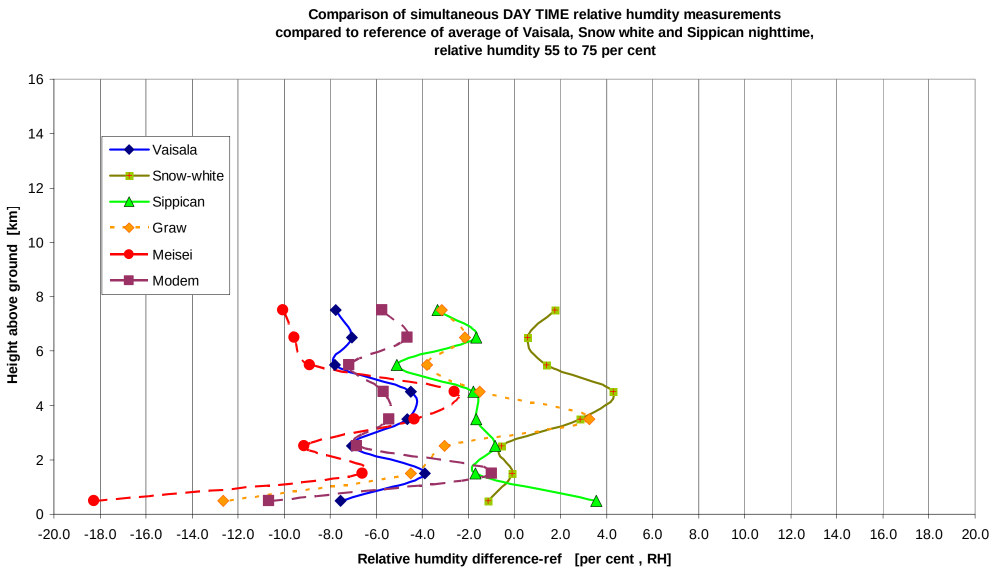


Fig. 7(d) Systematic bias for daytime relative humidity, range 55 to 75 per cent referenced to the night time average of Vaisala, Snow white and Sippican.

Comparison data from the relative humidity range 55 to 75 per cent, see Figs 7(c) and (d), were available over a much greater height range than for the highest relative humidity. This humidity range includes observations in middle and upper cloud.

Fig.7(c) shows that Meisei, Sippican, Snow white and Vaisala measurements agreed with the average to within ± 4 per cent from 2 to 11 km, i.e. for all temperatures down to -40 deg C. Exceptions were the positive bias of Modem measurements at night, more than 10 per cent for much of the height range, and to a lesser extent positive bias in Graw measurements. Above 11 km Vaisala and Snow white measurements agreed to 4 per cent down to temperatures of about -70 deg C. but Snow white measurements were much lower (20 per cent) than Vaisala at the lowest temperature. The reasons for the negative bias in Snow White relative to Vaisala can be seen in a typical individual comparison plot from the test.

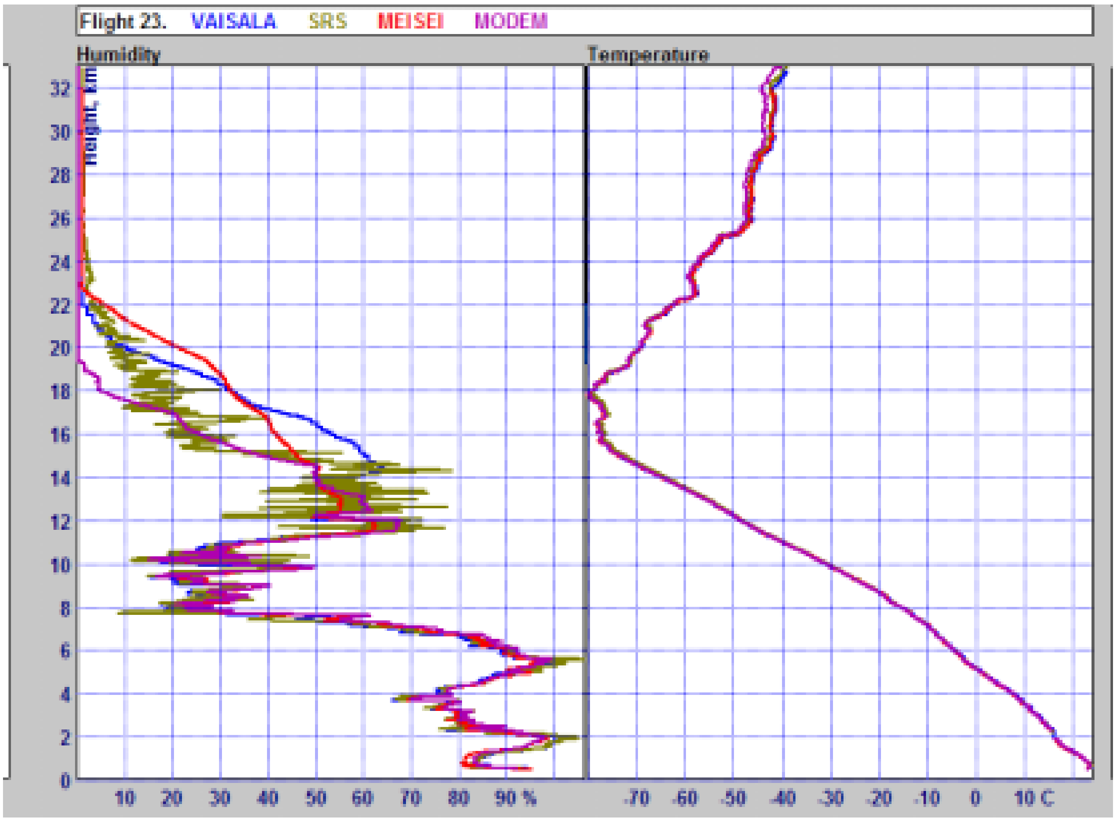
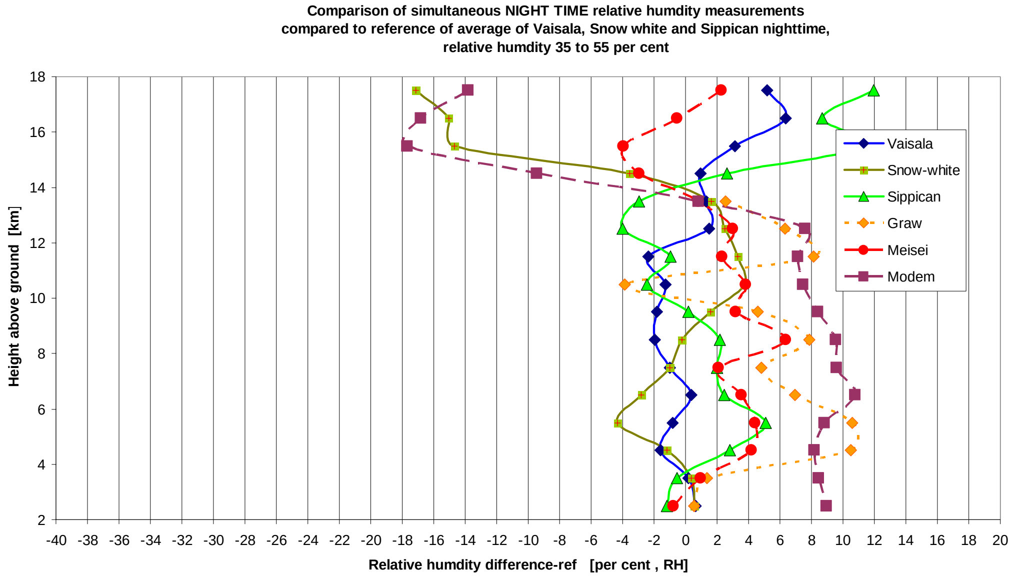


Fig.8 Night time relative humidity and temperature comparison between the Vaisala, Meisei –Modem group and SRS Snow White

In Fig. 8, the Vaisala relative humidity does not seem to fall fast enough after emerging from an upper cloud, possibly because of contamination from the cloud. Pulse heating of the Vaisala humidity sensors was limited to temperatures greater than -40 deg C on this flight.

Daytime relative humidity measurements shown in Fig.7(d) were again offset low relative to night time measurements , with Sippican showing the smallest day-night difference, 0 to -2 per cent, and Modem the largest of -12 to -17 per cent. In the case of Modem the night time measurements were very different from the other radiosondes, but the daytime measurements were similar to most of the other radiosondes. Vaisala day-night difference increased from about -4 per cent at 2 km to -6 per cent at 6 km.



.Fig. 7(e) Systematic bias for night time relative humidity, range 35 to 55 per cent, referenced to the average of Vaisala, Snow white and Sippican

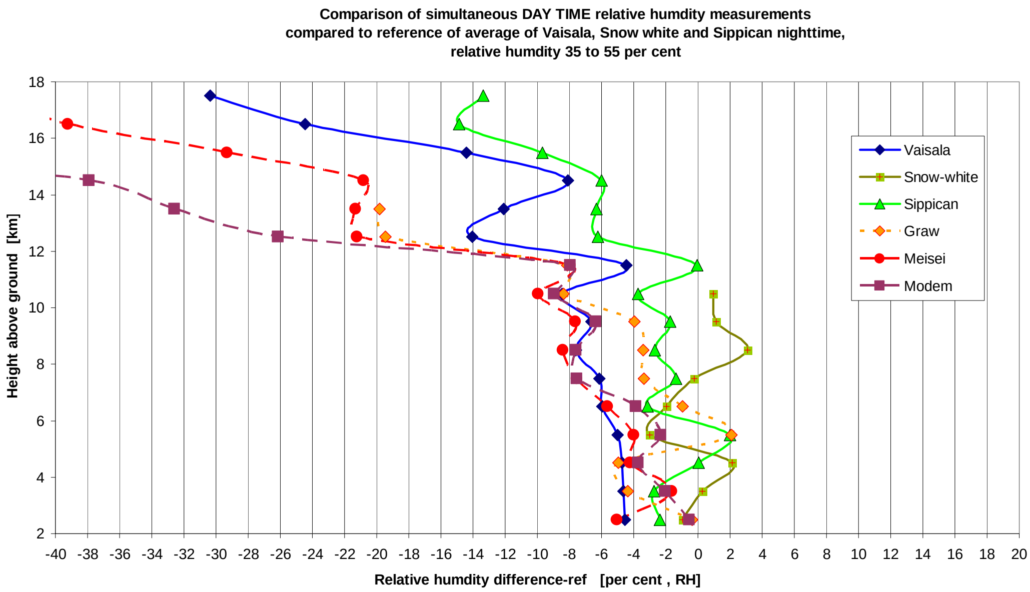


Fig. 7(f) Systematic bias for daytime relative humidity band 35 to 55 per cent referenced to the night time average of Vaisala, Snow white and Sippican.

The humidity range 35 to 55 per cent allowed measurements to be compared both day and night from 2 to 18 km; see Figs. 7(e) and 7(f). This range contains a significant number of samples from daytime upper cloud. Fig. 7(e) shows that Meisei, Sippican, Snow-white and Vaisala mostly agree to within ±5 per cent of the average at all heights up to 14 km. Modem and Graw again had a positive bias at night relative to the others. At heights above 14 km, Modem agrees most closely with Snow white. These two radiosondes had a negative bias of around 20 per cent relative to the other radiosondes. The magnitude of day-night differences deduced from Fig. 7(e) appear to range from Sippican, near zero up to 14 km, to Modem in the range from -11 to -16 per cent up to 14 km. Vaisala day- night differences were about -4 at 2 km, -6 at 10 km , and higher than 10 per cent at 14 km.

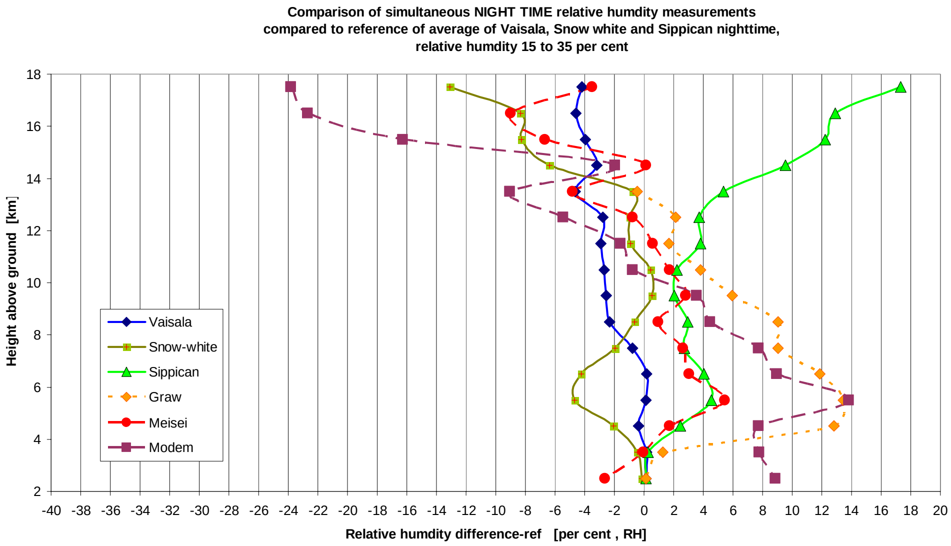


Fig. 7(g) Systematic bias for night time relative humidity, range 15 to 35 per cent, referenced to the average of Vaisala, Snow white and Sippican

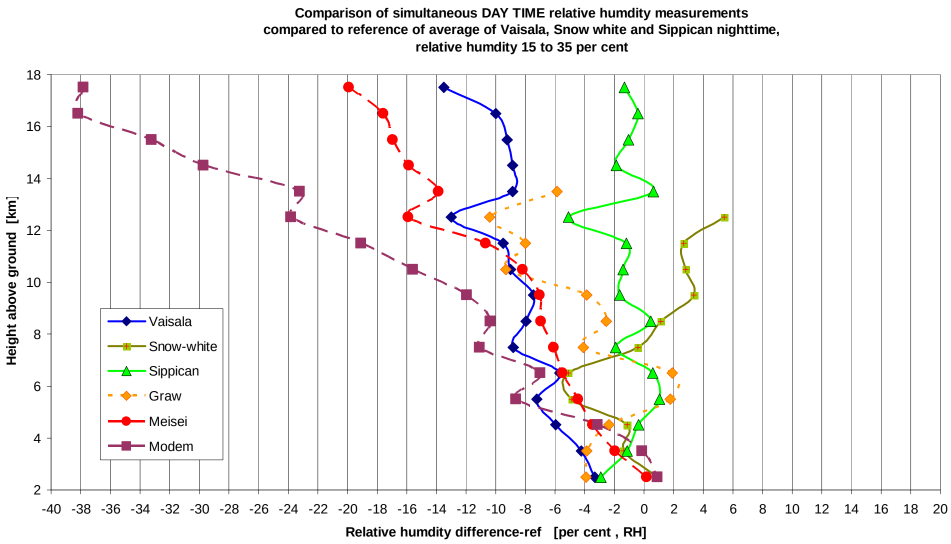


Fig. 7(h) Systematic bias for daytime relative humidity, range 15 to 35 per cent referenced to the night time average of Vaisala, Snow white and Sippican.

Figs. 7(f) and (g) show the night and day comparisons for the relative humidity range 15 to 35 per cent. At night all the radiosondes apart from Graw and Modem agree within ± 5 per cent from 2 to 14 km. At heights above 14 km, the differences between Vaisala and as Snow white were smaller than at higher humidity. However, Sippican shows a more pronounced positive bias than in higher humidity categories. Day-night differences for Vaisala in this low humidity range were about -3 at 2 km increasing to about -6 at 14 km.

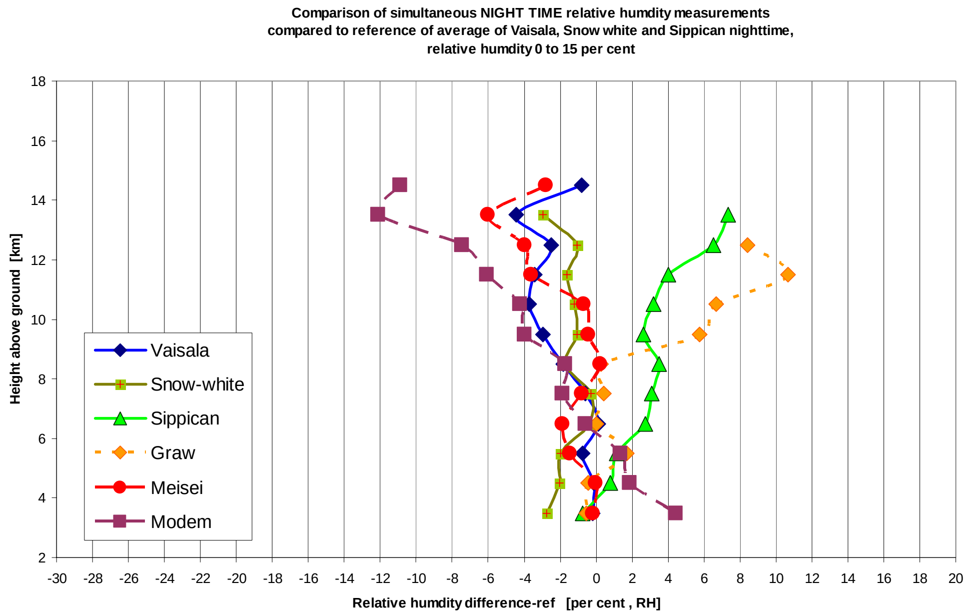


Fig. 7(i) Systematic bias for night time relative humidity, range 0 to 15 per cent, referenced to the average of Vaisala, Snow white and Sippican

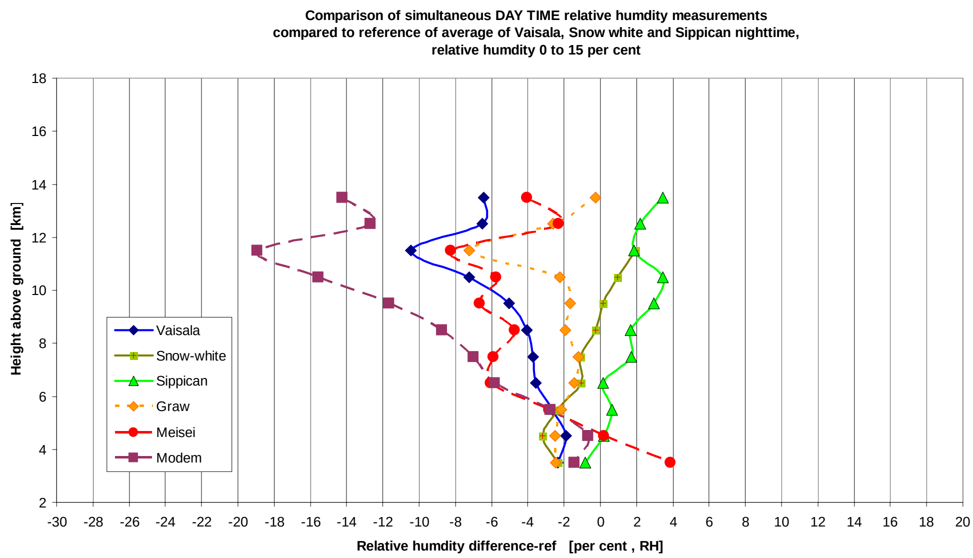


Fig. 7(j) Systematic bias for daytime relative humidity, range 0 to 15 per cent referenced to the night time average of Vaisala, Snow white and Sippican.

In this lowest humidity range, Meisei, Sippican, Snow-white and Vaisala again agree within ± 4 per cent between 3 and 12 km. Day-night differences were generally small.

The Sippican calibration for very low temperatures needed some improvement since there was a low bias at high humidity, see Fig. 7(c) and high bias at low humidity, see Figs. 7(g). Also, at heights between 18 and 20 km, Sippican had a positive bias of about 27 per cent relative to Vaisala at night for the relative humidity range 0 to 15 per cent.

Fig.9 (a) shows the standard deviations of the relative humidity differences with respect to Vaisala in the layer 0 to 4 km . Apart from Graw the magnitude of the standard deviations are consistent with random errors in relative humidity in the range 1 to 4 per cent, with lowest random errors found at night.

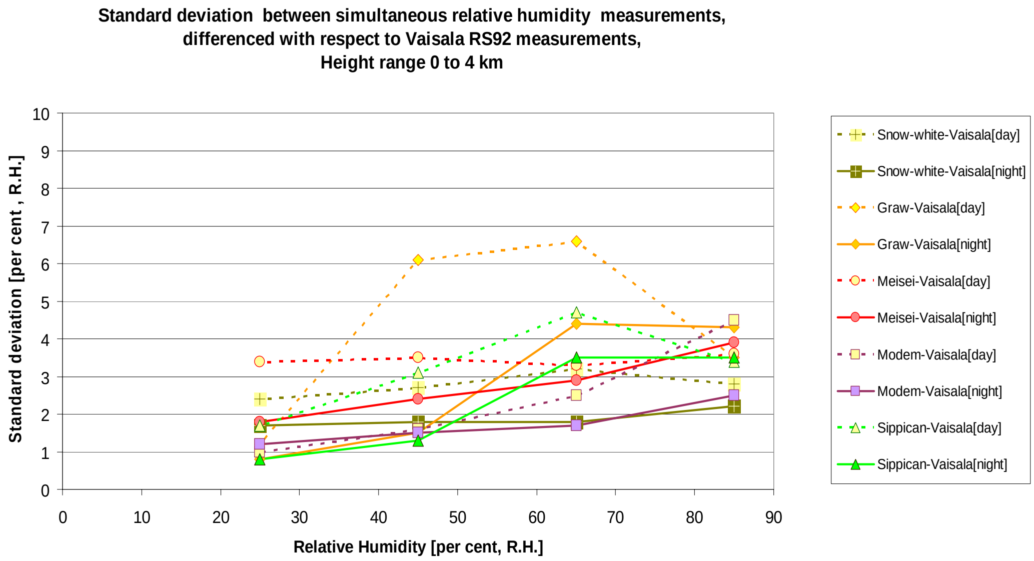


Fig 9(a) Standard deviations of differences with respect to Vaisala, 0 to 4 km

Fig. 9(b) and (c) show that the random errors of the relative humidity sensors increased slightly for the height range 8 to 12 km to values between 2 and 6 per cent, but only Meisei shows low standard deviations relative to Vaisala in the height range 12 to 16 km. This probably means that the random errors in Meisei measurements were similar in nature to those of Vaisala. The larger standard deviations with respect to Snow white measurements were caused by errors in Vaisala as well as random errors in Snow white, see Fig.8. Thus , it is probable that random errors in Vaisala measurements at temperatures lower than -70 deg C were in the range 5 to 10 per cent.

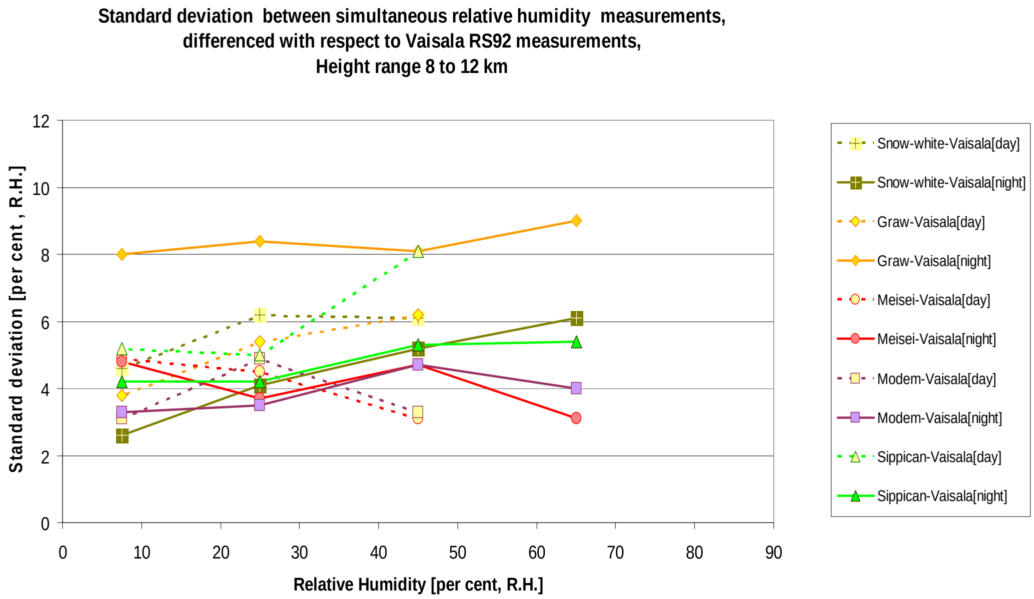


Fig 9(b) Standard deviations of differences with respect to Vaisala, 8 to 12 km

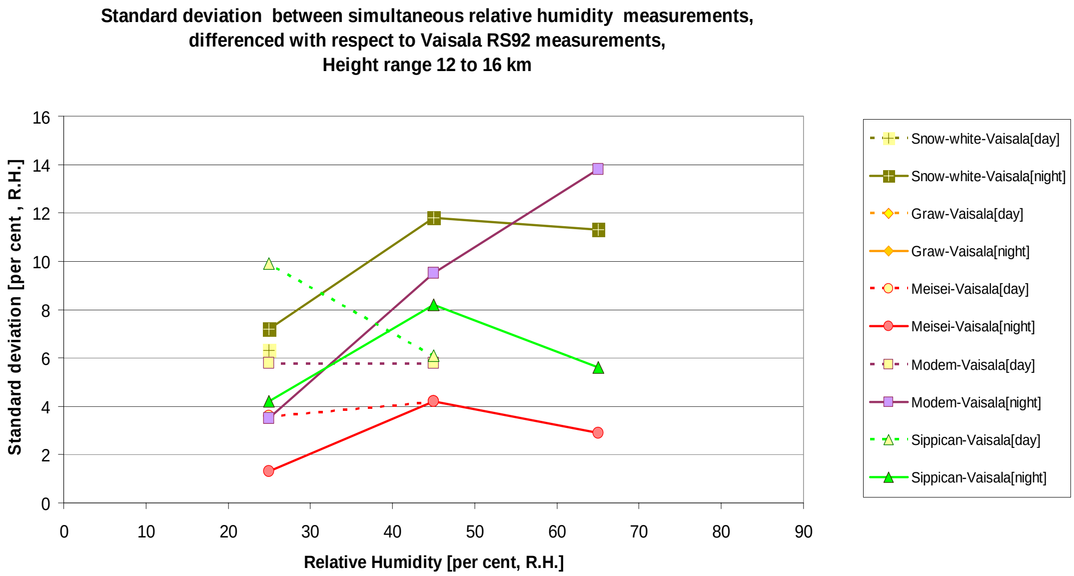


Fig 9(c) Standard deviations of differences with respect to Vaisala, 12 to 16 km

8. Simultaneous wind comparisons

There were no significant problems with this generation of GPS wind measurements. The main differences between the systems see Figs.10 (a) and (b) for comparisons between U and V wind components, arose from the different types of filtering used to remove the pendulum motion of the radiosonde under the balloon. The filtering of the Meisei measurements averaged over too long a period to give optimum performance in the stratosphere, and some of the test flights were too long for the battery design, so some Meisei measurements deteriorated in quality at the uppermost heights.

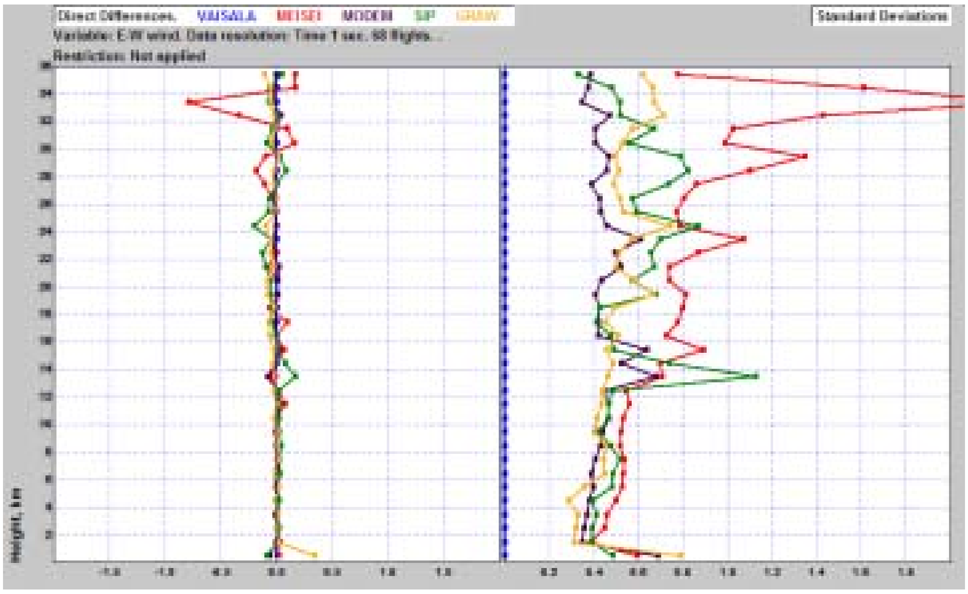


Fig. 10(a) Systematic bias and standard deviations of simultaneous comparisons between U components [ms^{-1}].

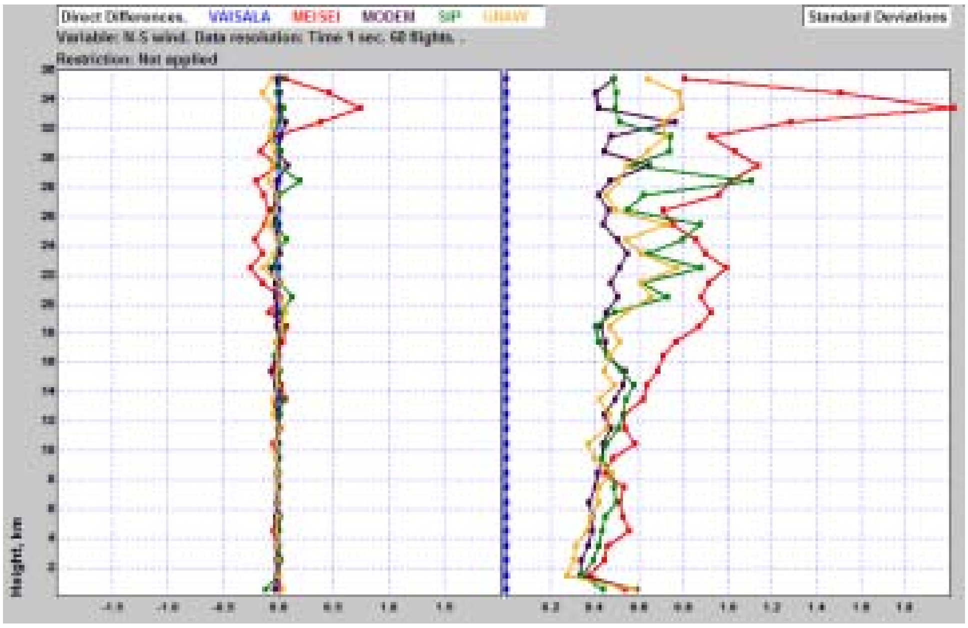


Fig. 10(b) Systematic bias and standard deviations of simultaneous comparisons between V components [ms^{-1}].

Typical random errors in wind component [u, v] measurements must have been less than or equal to 0.3 ms^{-1} for all systems at all heights apart from Meisei in the stratosphere. Systematic bias between measurements from different systems was negligible. These results were obtained with minimal editing of the wind profiles by the WMO Supervisors.

Thus, it is concluded that the new generation of GPS radiosondes should be capable of very accurate wind measurements in tropical locations, with minimal missing data. This will be true even when there are strong upper winds as in Mauritius with wind speed higher than 40 ms^{-1} at heights around 30 km.

Acknowledgements
This test could not have been successfully implemented without a very large amount of work from many people, often at unsocial hours, including

- Many staff from the Meteorological Services, Mauritius,
- the six manufacturers,
- colleagues representing the COST meteorological projects in Europe [H. Richner, Switzerland: T. Oakley, M. Oldfield and D. Lyth (UK)]
- support from the WMO secretariat through M. Ondras.

QUALITY MANAGEMENT OF A EUROPEAN WIND PROFILER NETWORK (CWINDE)

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Currently a network of 20 wind profiler systems in Europe (CWINDE) is providing continuous, real-time wind observations for operational use. This network is being supported under a programme sponsored by the National Met Services (EUMETNET) and the UK Met Office has been tasked in maintaining the hub and providing a quality management service. The network comprises of wind profiler systems of differing technical specification & measurement capabilities, which are operated for a variety of reasons ranging from research to aviation forecasting. In addition to the wind profilers the hub services have been extended to include wind observations from a number of the weather radar networks in Europe.

The Met Office has developed a suite of quality management software to enable the performance of the systems to be monitored in real-time and to allow feedback to the system operators and data users. This presentation will provide details on the quality management techniques being used to monitor the systems, the successes of CWINDE network and the challenges for the future.

Background

Operational networking of wind profilers in Europe started within the COST-76[1] Project and was successfully tested during two campaigns, CWINDE-97[2] and CWINDE-99. It was able to demonstrate that real-time networking of existing profiler installations was possible, even though these systems differed significantly in design & purpose and were operated by various research and operational institutions. After the COST-76 Action ended in March 2000 a proposal was made to continue the networking activities under the umbrella of EUMETNET[3], with a programme called WINPROF.

The main focus of WINPROF was to maintain the existing CWINDE network and to develop it further towards operations. Currently, there are 24 wind profiler systems able to provide wind data to CWINDE and countries like the United Kingdom and Germany are continuing to install further wind profiler radar systems as part of their operational upper air network. In addition, CWINDE is able to receive and process wind profile data from other systems, like the conventional Doppler weather radars using the VAD/VPP technique (60 sites) and sodars (2 sites). The wind profile data provided by CWINDE are nowadays mainly used by NWP. Major
NWP centres in Europe, for example ECMWF, UK Met Office, Meteo France, Deutscher
Wetterdienst and the HIRLAM group, are now using these data in their operational data assimilation.

Figure 1 provides a map of the current wind profiler systems contributing to CWINDE.

Annex A contains tables of the wind profiler & weather radar sites configured in CWINDE.

[1]COST - Cooperation On Science and Technology
[2]CWINDE - COST Wind Initiative for a Network Demonstration in Europe
Co-ordinated WIND profiler network in Europe (later definition)
[3]EUMETNET - Network of European Meteorological Services.

Other wind profiler networks are operated in the USA by NOAA-FSL (35 systems operating at 404 and 449~MHz, plus about 50 systems of so-called co-operative agencies) and in Japan by JMA (31 systems operating at 1357~MHz).

Figure 1: CWINDE Profiler Network (January 2005)

WINPROF & the CWINDE Network

On taking over the responsibility for the CWINDE network hub, the WINPROF program was tasked with 7 key objectives:

- To harmonise and improve the existing exchange of all wind profiler (National Met Services and Research institutions) and Weather radar wind data in Europe.
- To run and further develop a network hub for data processing and quality evaluation.
- To integrate new wind profiler and weather radar systems.
- To establish appropriate quality control procedures
- To define general quality standards and user requirements for operational use.
- To work on new/updated processing algorithms to improve data quality/availability.
- To provide expert support to members for wind profiler installations and operations.

Under COST76 the responsibility of managing and updating the CWINDE hub was tasked to the UK Met Office and this remained the case for the WINPROF project. A key objective for the hub is to provide a real-time processing and data-display service (the later via the Internet) for wind profiler and weather radar system in Europe. Providing a quality management service and feedback to the system operators is also an important task as this not only developed a better understanding of the relative quality of the wind data but also made operators aware when there were quality and/or data availability issues with their systems.

The hub processing and data displays are run on a dedicated workstation within the Met Office. Although the system is not classed as operational, it is housed within the main computer room of the Met Office and thus benefits from a number of services supported 24/7. Automated communication with the hub, from the observing site, is possible via the GTS (Global Telecommunication Service) or FTP. All products and archives are generated on the workstation automatically and currently the complete system requires approximately 0.3 of a person per year to support.

Figure 2 provides a schematic of the CWINDE processing hub.

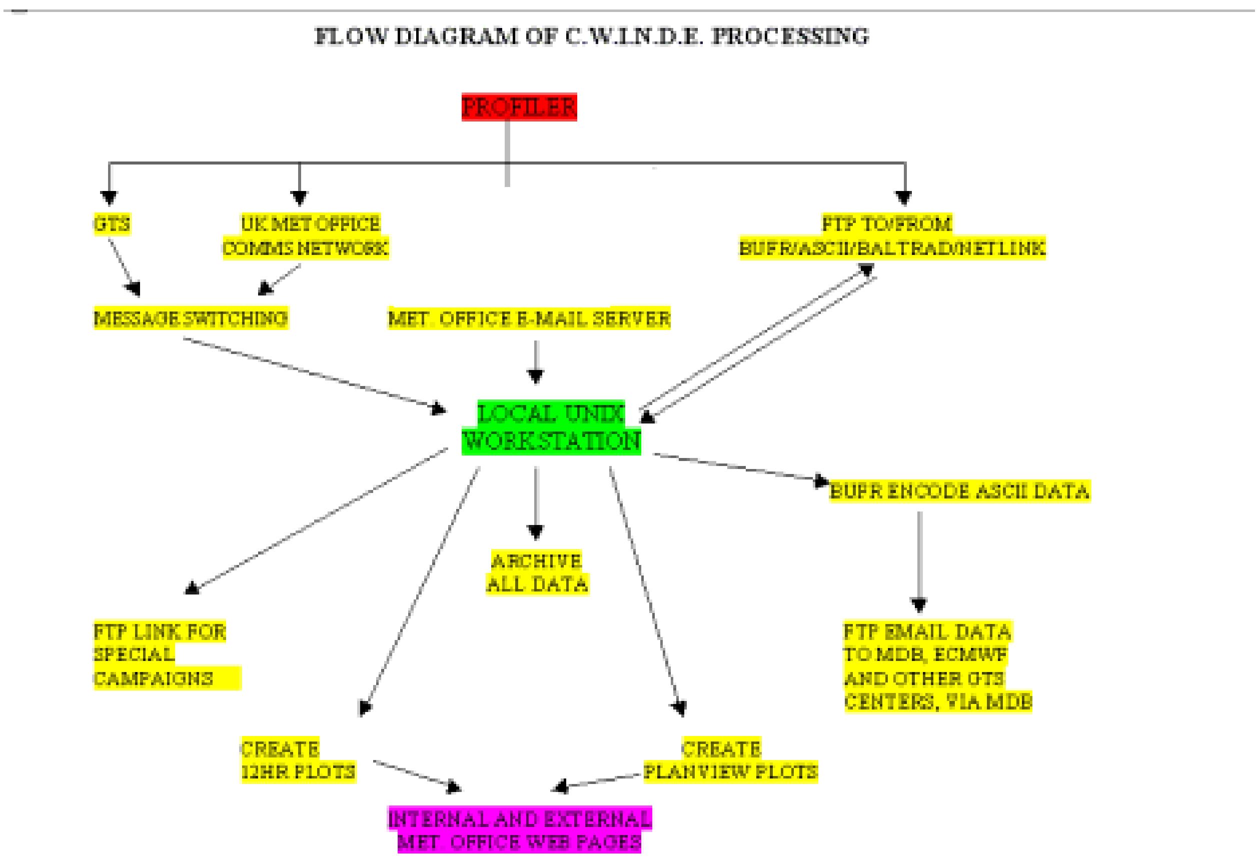

Figure 2: CWINDE Processing schematic (Jan 2005)

Since the automated processing was initiated in 1997, it has continued to run until the present day, with only a few outages due to hardware problems and the relocation of the Met Office from Bracknell to Exeter. The system is currently processing in excess of 7,500 messages each day. Figure 3 provides details of the percentage of data received in real-time for the wind profiler systems connected to CWINDE (2004). These statistics are produced regularly for the WINPROF program and are useful in classifying operational/non-operational systems on the basis of delivery of data.

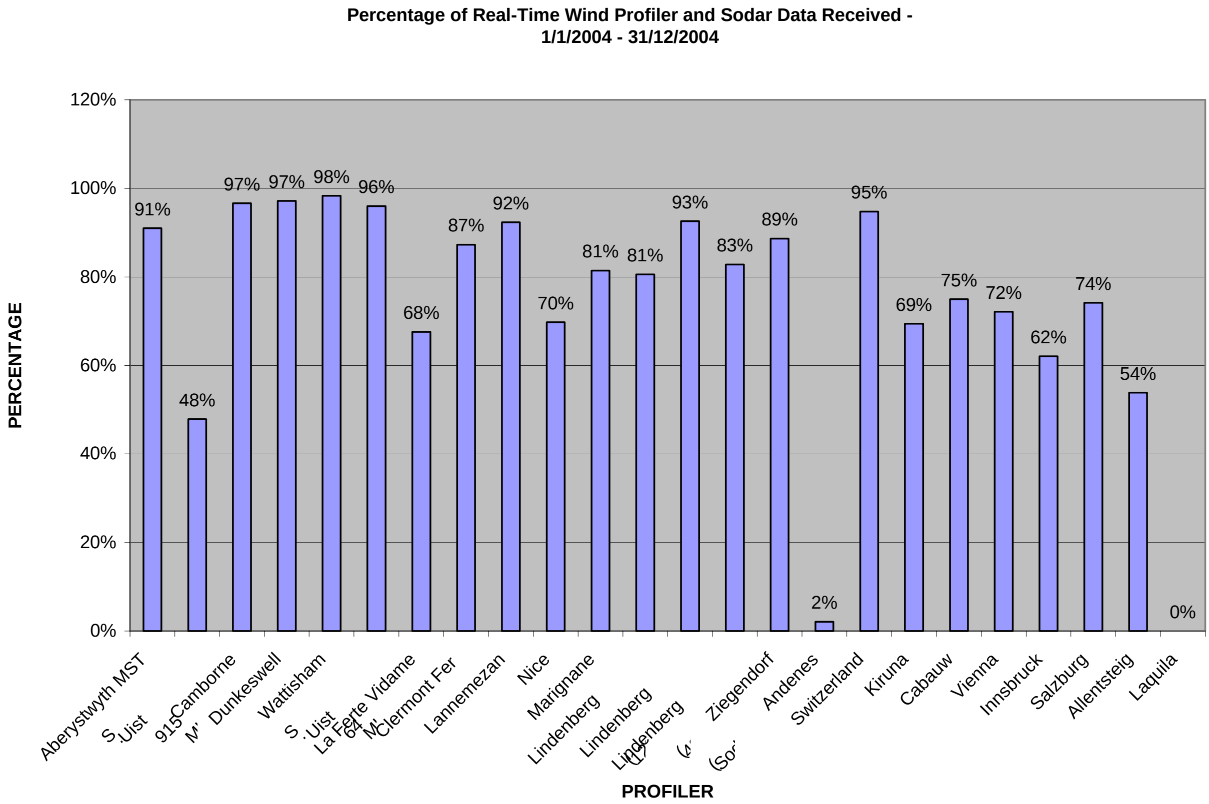

Figure 3: Data Availability from European wind profilers 2004.

Quality Management

CWINDE provides a comprehensive package of quality management products for the systems connected to the hub. These products vary for short term 'real-time' information (updated each hour), to longer term 'off-line' information (produced monthly or on request). The website address of CWINDE is:
http://www.metoffice.gov.uk/research/interproj/cwinde/index.html

A summary of the products available is as follows:

1. ***Real time data plots (See Figure 4)***

These plots are updated every 30 minutes and are made available on the CWINDE website. They provide an instant method of checking on the performance of the individual system both for data availability and quality. For forecasting they also provide access to the latest measurements of not only the wind data (wind barbs) but also the vertical velocity & signal to noise values. Many of the wind profiler and weather radar systems are completely automated and run unattended, thus these displays are a vital component on checking the current status. Figure 4 provides an example of the wind barb plot from Torino, Italy, the latest wind profiler to be added to CWINDE.

2. ***Plan view plots (See Figure 5)***

A composite data plot is generated every 3 hours showing data at selected height levels for all wind profiler and weather radar systems. The time frame for the plot is ±1.5 hours from the nominal time and wind data is displaced according to time and wind speed/direction. Radiosonde and aircraft data (if available) are included in these plots and these are also displaced according to the time and wind values. These displays provide a direct comparison of wind measurements with other sites and observing systems. They are also useful to observe the horizontal wind fields over Europe and the distribution/density of the measurements

3. Weekly random variability/error plots (See Figure 6)

These plots are a quality evaluation product used to access the overall performance of the wind profiler systems. They calculate the random variability of the wind measurements and use these values combined with known structure functions to produce a random error estimate. Not only is this useful in accessing the current performance of a system but because the hardware from these radars tend to degrade over time, rather than completely fail, these plots from week to week (or longer) can detect changes in the systems performance. The example given in figure 5 is for the 64MHz wind profiler on South Uist. This system is working operationally and generally meets the 2ms^{-1} random error specification. In this case we observed some interference (clutter) from a wind-turbine 9-10km from the site which has slightly increased the random error estimate.

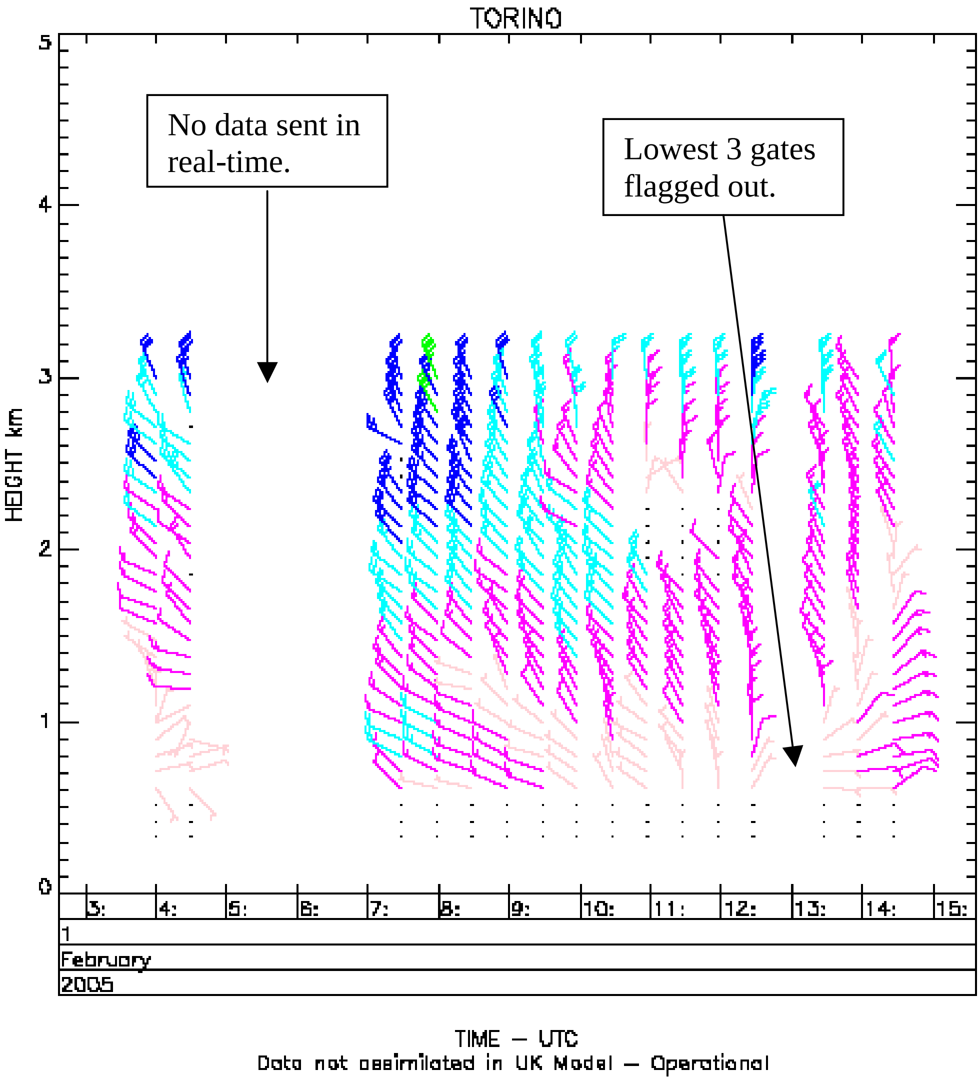

Figure 4: Real-time wind barb plot for Torino, Italy.

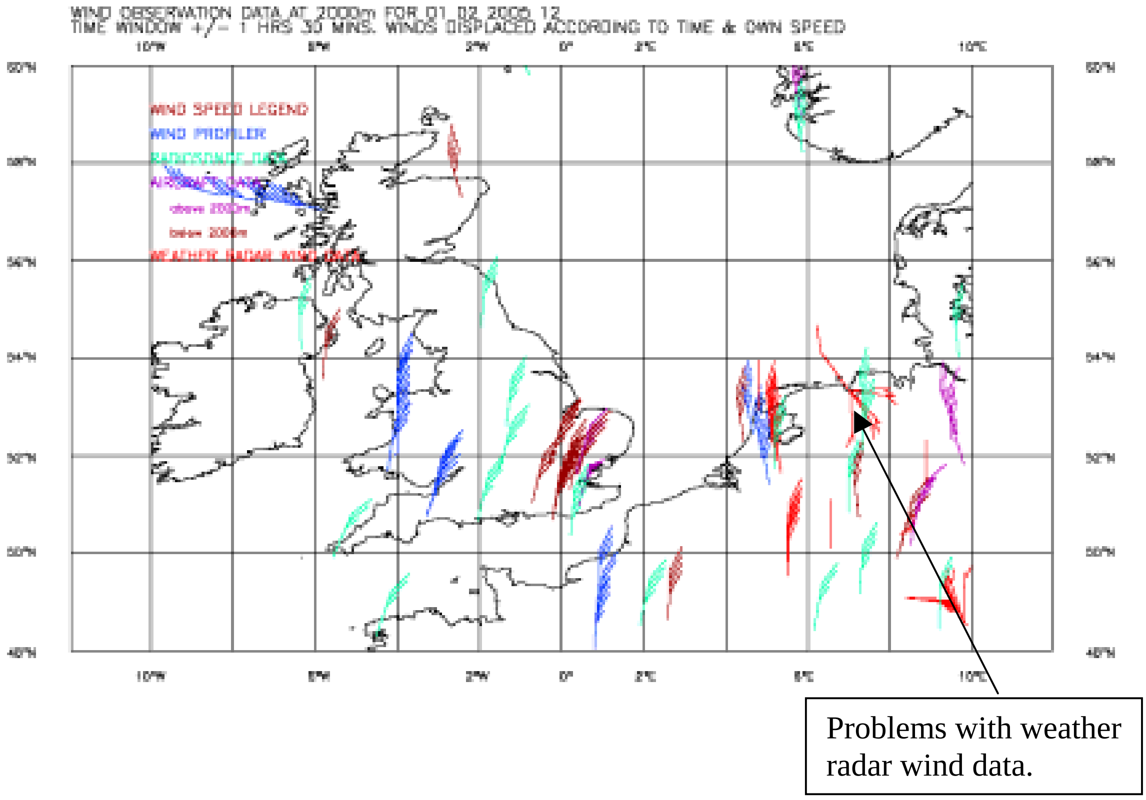

Figure 5: Example of plan view plot, UK area at 2km.

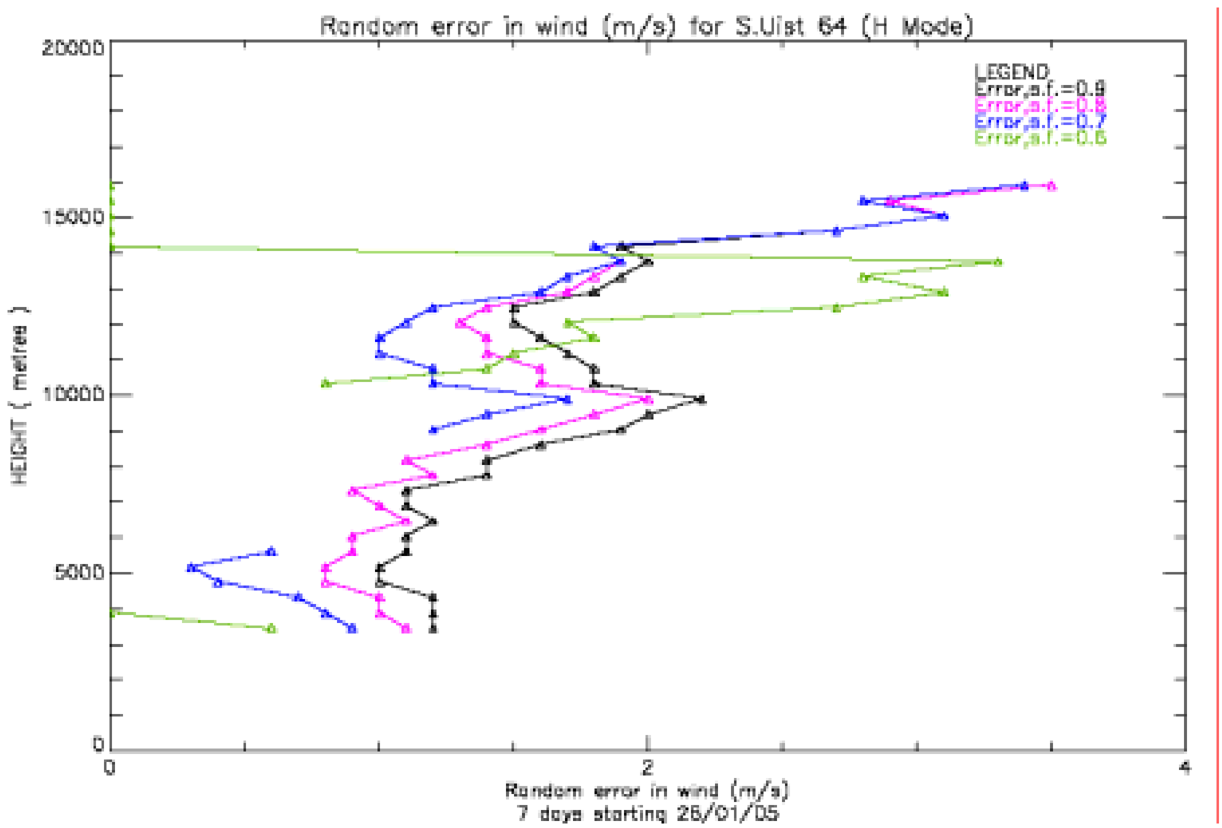

Figure 6: Random error plot for South Uist (26/01/05 – 02/02/05).

4. Monthly quality evaluation information.

The hub is responsible for producing and distributing a number of monthly quality evaluation products. These are either related to the real-time availability of wind data or the quality. Currently the wind data for the wind profiler systems are compared with the NWP background field of the Met Office, Meteo France and ECMWF, for the weather radar only a comparison with the Met Office models is available. Figure 7 provides an example of the monitoring statistics provided by Meteo France.

5. Archive data and Reprocessing.

A complete archive of the BUFR messages received by CWINDE is maintained by the hub. This allows data to be provided ‘off-line’ for case studies or impact assessments, it also allows a check of any data processed by the hub should there be any questions at a later date. It is also possible to reprocess the data to produce any of the real-time plots.

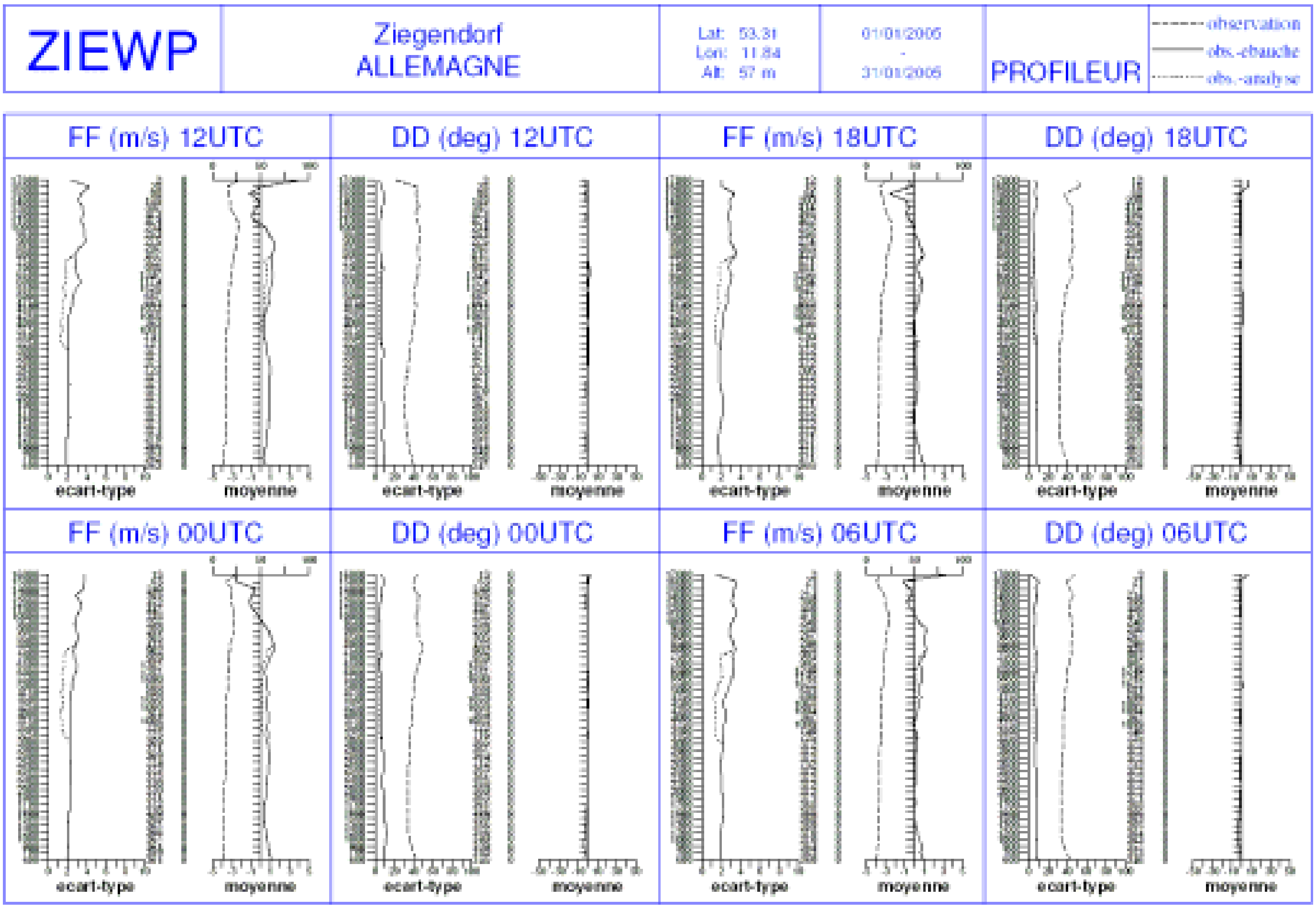

Figure 7: Monthly NMP statistics plot generated by Meteo France.

Conclusion and Future Plans

- CWINDE has been successful in providing a European wind profiler network hub for more than 5 years. It has been extended to include new wind profiler systems and wind data from the European weather radar network. It now has more than 80 sites providing routine data, with completely automated processing and requiring about a third of a man year to maintain.

- A number of the wind profiler and weather radar (UK only) sites are now being used operationally for NWP data assimilation. In February 13 of the 23 wind profiler sites and 20 of the 52 weather radar sites were being assimilated by the UK modellers.
- The 2 year WINPROF programme ended on 30th June 2004. A WINPROF-II programme has recently been approved and is expected to commence in the spring 2005. In the mean time the Met Office is continuing to maintain the hub under an extension contract with WINPROF. A key objective for WINPROF-II is the 'hand over' of the network to EUCOS (another EUMETNET program) which will take on the operational and quality management.

ANNEX A - WIND PROFILER & WEATHER RADAR LOCATIONS

PROFILER (Providing Data)	WMO NO.	LAT	LONG	HEIGHT
KIRUNA, SWEDEN	02043	67.88N	21.10E	295m
SOUTH UIST, UK	03023	57.21N	07.22W	4m
ABERYSTWYTH,UK	03501	52.42N	04.00W	50m
WATTISHAM,UK	03591	52.09N	00.96E	87m
CAMBORNE,UK	03807	50.13N	05.10W	88m
DUNKESWELL,UK	03840	50.90N	03.20W	253m
CABAUW,NETHERLANDS	06348	51.95N	04.88E	0m
PAYERNE,SWITZERLAND	06610	46.81N	06.95E	491m
ZURICH, SWITZERLAND	06670	47.48N	08.53E	425m
LA FERTE VIDAME, FRANCE	07112	48.61N	00.87E	245m
TOULOUSE, FRANCE	07115	43.37N	01.26E	158m
CLEMONT FERRAND, FRANCE	07453	45.71N	03.09E	660m
LANNEMEZAN, FRANCE	07626	43.13N	00.36E	600m
MARIGNANE, FRANCE	07650	43.43N	05.23E	7m
NICE, FRANCE	07690	43.66N	07.19E	4m
LINDENBERG, GERMANY	10394	52.17N	14.12E	70m
ZIEGENDORF, GERMANY	10266	53.30N	11.80E	57m
NORDHOLZ, GERMANY	10135	53.47N	08.40E	18m
VIENNA, AUSTRIA	11036	48.10N	16.60E	227m
INNSBRUCK, AUSTRIA	11120	47.16N	11.23E	614m
SALZBURG, AUSTRIA	11150	47.47N	13.00E	430m
BUDAPEST, HUNGARY	12843	47.43N	19.18E	139m
SZEGED, HUNGARY	12982	46.30N	20.10E	83m
TORINO, ITALY	16300	45.40N	07.40E	277m
LINDENBERG, GERMANY (SODAR)	10391	52.17N	14.12E	70m

PROFILER (Not Providing Data)	WMO NO.	LAT	LONG	HEIGHT
KARLSRUHE,GERMANY	10722	49.05N	08.26E	109m
ROME, ITALY	16239	41.83N	12.64E	121m
ALLENTSTEIG, AUSTRIA	11019	48.68N	15.37E	596m
L'AQUILA, ITALY	16228	42.40N	14.40E	980m
ANDENES,NORWAY	01012	69.28N	16.03E	0m

WEATHER RADAR	WMO NO.	LAT	LONG	HEIGHT
KIRUNA, SWEDEN	02032	67.70N	20.62E	646m
LULEA, SWEDEN	02092	65.55N	22.12E	35m
OSTERSUND, SWEDEN	02200	63.18N	14.44 E	465m
ORNSKOLDSVIK,SWEDEN	02262	63.63N	18.39E	522m
LEKSAND, SWEDEN	02430	60.72N	14.88E	458m
ARLANDA, SWEDEN	02451	59.65N	17.95E	75m
NORRKOPING, SWEDEN	02570	58.61N	16.12E	57m
HEMSE, SWEDEN	02588	57.24N	18.38E	56m
VARA, SWEDEN	02600	58.25N	12.81E	170m
ANGELHOLM, SWEDEN	02607	56.36N	12.85E	10m
KARLSKRONA, SWEDEN	02666	56.29N	15.60E	122m
LUOSTO, FINLAND	02836	67.13N	26.89E	534m
UTAJARVI, FINLAND	02870	64.76N	26.31E	118m
KUOPIO, FINLAND	02918	62.86N	27.38E	268m
KORPO, FINLAND	02933	60.13N	21.64E	61m
IKAALINEN, FINLAND	02941	61.77N	23.07E	154m
ANJALANKOSKI, FINLAND	02954	60.90N	27.11E	139m
VANTAA, FINLAND	02975	60.27N	24.87E	83m
SHANNON, IRELAND	03962	52.70N	08.93W	26m
DUBLIN, IRELAND	03969	53.43N	06.24W	100m
DEN HELDER, NETHERLANDS	06234	52.96N	04.79E	51m
DE BILT, NETHERLANDS	06260	52.10N	05.18E	44m
ZAVENTEM, BELGIUM	06451	50.90N	04.47E	73m
WIDEUMONT, BELGIUM	06477	49.92N	05.51E	592m
LA CORUNA , SPAIN	08007	43.17N	08.52W	621m
ASTURIAS, SPAIN	08019	43.46N	06.30W	933m
PALENCIA, SPAIN	08072	42.00N	04.60W	870m
VIZCAYA, SPAIN	08081	43.4N	02.84W	625m
BARCELONA, SPAIN	08179	41.41N	01.88E	664m
ZARAGOZA, SPAIN	08162	41.73N	00.56W	829m
MADRID, SPAIN	08228	40.18N	03.71W	717m
CECERES, SPAIN	08262	39.00N	06.00W	676m
VALENCIA, SPAIN	08289	39.00N	00.00W	234m
MURCIA, SPAIN	08364	38.00N	01.00W	1274m
SEVILLA, SPAIN	08386	37.00N	06.00W	530m
ALMERIA, SPAIN	08489	37.00N	03.00W	1173m
MALAGA, SPAIN	08475	37.00N	04.00W	495m

WEATHER RADAR	WMO NO.	LAT	LONG	HEIGHT
GRAN CANARIA, SPAIN	60028	26.00N	15.00W	1781m
LA CORUNA , SPAIN	08007	43.17N	08.52W	621m
HAMBURG, GERMANY	10147	53.62N	09.99E	46m
ROSTOCK, GERMANY	10169	54.17N	12.05E	36m
EMDEN, GERMANY	10204	53.34N	02.40E	58m
HANNOVER, GERMANY	10338	52.45N	09.69E	81m
UMMENDORF, GERMANY	10356	52.15N	11.17E	185m
BERLIN, GERMANY	10384	52.47N	13.38E	80m
ESSEN, GERMANY	10410	51.41N	06.97E	180m
FLETCHDORF, GERMANY	10434	51.33N	08.85E	550m
DRESDEN, GERMANY	10488	51.12N	13.77E	262m
NEUHAUS, GERMANY	10557	50.50N	11.14E	873m
NEUHEILENBACH, GERMANY	10605	50.11N	06.50E	585m
FRANKFURT, GERMANY	10637	50.05N	08.57E	146m
EISBERG, GERMANY	10780	49.54N	12.40E	799m
TUERKHEIM, GERMANY	10832	48.58N	09.78E	765m
MUNICH, GERMANY	10871	48.34N	11.61E	511m
FELDBERG, GERMANY	10908	47.87N	08.00E	1517m
VIENNA, AUSTRIA	11038	48.12N	16.57E	183m
SALZBURG, AUSTRIA	11052	48.06N	13.06E	581m
PATSCHERKOFEL, AUSTRIA	11126	47.21N	11.46E	2254m
ZIRBITZKOGEL, AUSTRIA	11164	47.07N	14.56E	2372m
BRIC DELLA CROCE, ITALY	16061	45.03N	07.73E	736m

SESSION 4

TECHNOLOGY TRANSFER, CAPACITY BUILDING, TRAINING AND DEVELOPMENT OF RICs

Session 4

KEYNOTE PAPER

(not available)

Session 4

PAPERS

WIND PROTECTION DESIGNS FROM MEASUREMENTS WITH SIMPLE WIND EQUIPMENT IN FOUR AFRICAN COUNTRIES IN RESEARCH EDUCATION CAPACITY BUILDING PROJECTS

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Abstract

Low external input farmers in Africa suffer from various wind problems. In the research education capacity building project "Traditional Techniques of Microclimate Improvement (TTMI)" carried out at Universities in Kenya, Nigeria, Sudan and Tanzania between 1985 and 2002, several such problems were tackled using simple wind equipment to quantify wind speeds in the agricultural environment concerned.

The research of the authors and their teams proved that appropriate design rules for wind protection could be derived from such simple wind observations, if a sufficient instrument density was chosen, if the instruments were appropriately calibrated in situ and if agrometeorological wind disaster literature was properly reviewed for the design of wind protection.

In Kenya, design rules were derived for a hedged agroforestry system in semi-arid Laikipia. In Central Sudan, design rules were derived for protecting crops from drifting sand by shelterbelts and scattered trees/grasses. In northern Nigeria, the design of multiple shelterbelt systems had to be considerably improved for efficient protection of crops grown between the belts. In northern Tanzania, diminishing soil and crop protection were quantified for decreasing savanna woodland tree densities.

Measurement strategies to represent simultaneous observations of wind reduction with a sufficient instrument density were developed in each country. Ancillary wind information equipment was generated and tested to support such strategies.

Introduction

The TTMI-Project in four African countries (Kenya, Sudan, Nigeria and Tanzania) had between 1985 and 2002 various sub-projects on selected farmer defined priority problems of low external input farmers suffering from disasters caused by wind. Relief measures had to be designed for bringing such problems under control. These sub-projects were research education capacity building projects at Universities and Institutes in Africa that had policies, or were planning such policies, of getting its staff trained in problem solving research with the simple means that could be afforded in the context of the TTMI-Project or otherwise. The need for such work was discussed at TECIMO ten years ago on invitation (Stigter, 1994).

This paper deals with measurements to quantify airflow in the agricultural environment with simple wind equipment, from which wind protection could be designed in these cases. Such problems included mechanical damage, damage caused by drifting sand and hot air related damage. All these examples have been well-documented in peer reviewed journals from 1994 onwards till the present (Kainkwa and Stigter, 1994; 2000; Mohammed et al., 1996; 1999; Stigter et al., 1997; 1998; 2000; 2001; 2002; 2003; 2004a; 2004b; 2005; Oteng'i et al., 2000; Onyewotu et al., 2003; 2004; 2005; Al-Amin et al., 2005), also reviewing wind disaster literature.

Even more importantly, farmers' problems were solved. In all four countries, serious wind protection problems were preventing farming systems to get or remain (re) established. The issue here is the use of basically simple field equipment, in the present case studies to quantify potentially damaging air flow and flow mitigated by protective elements, under remote agricultural field conditions. The focus of this paper is the interpretation of wind measurements for the drawing of design rules for wind protection measures. Can simple wind observations give the right information to take decisions on how to protect crops and soil? The answer for our cases is: yes.

Equipment

In all four countries, a solar powered battery operated data logging system, with wind tunnel calibrated electrical cup anemometers from Wageningen, was applied as basic equipment. The cup anemometer is suitable for this kind of work because it measures all wind components in the damaging and modified flows with an angle of attack lower than 45 degrees. It can be dynamically (re) calibrated outdoors over flat land, if obstacles can be prevented, using an unexposed standard instrument.

The main puzzling issue is a strategy to obtain sufficient observation density to capture particular conditions and details of the flow fields within and around vegetation in space (quasi) simultaneously. What makes these strategies possible is that one is always interested in wind reduction due to protective vegetation. Such relative wind speeds may be obtained on different days as long as the approach wind differs not much in flow direction, flow speed and other flow characteristics.

We will now give four case studies that each delivered design rules from simple wind reduction quantification. In all cases, wind equipment was regularly field calibrated by intercomparisons and data quality was retained in all possible manners. Research education is served this way.

Case studies

Kenya

The first case is about protective hedged agro-forestry in demonstration projects in Laikipia, semi-arid central Kenya. Problems were due to mechanically damaging winds, also redistributing mulch of dry maize stalks used in water conservation. Intercropped trees with hedges all around protected mulched maize/bean intercrops. Root pruning appeared necessary to limit competition.

Wind in the open was compared with an array of measuring points in a hedged area, in which mulch was used on some parts, and that had pruned and unpruned trees for timber production, with maize biomass higher than the hedges. In this experiment wind was always measured 20 cm above the highest maize, the height increasing with time. Main wind directions were varying, from year to year and within seasons, giving different gradients of wind protection from the trees and hedges. The measuring results also revealed the danger of deliberate or natural gaps in the hedges, leading to visibly damaging tunneling effects near gaps (Oteng'i et al, 2000).

An error in the design appeared to be a gap between the highest biomass of hedges and the lowest biomass of trees, endangering maize when high. Another unexpected problem was damage by turbulence generated outside the demonstration plot, which could not be detected by the cups.

The conclusion on these agroforestry experiments, as to the role of simple wind measurements in the redesign of the most suitable protective system, must be considered positive. Although some aspects could have been visibly observed, the quantification with varying wind direction revealed sound details otherwise not detectable (Oteng'i, 2000; Stigter et al., 2002; 2003).

Because of the size of the demonstration plot, instrument density was not a serious problem. Piches as ancillary wind equipment, as earlier reported on at TECIMO (Stigter et al., 1998), were successfully tested under these conditions with small errors remaining due to differences in time constants between cups and Piches (Stigter et al., 2000). Using a reference anemometer from within the agroforestry system improved accuracies considerably.

Sudan

The second case is about drifting sand damage in desertifying Central Sudan endangering the Gezira irrigation scheme. Wind was blowing sand towards canals and crops, which had to be protected by a shelterbelt. Design rules for such shelterbelts were derived from early observations and measurements already reported more than 15 years ago (Stigter et al., 1989). In a follow-up investigation, suitability of selected trees was studied for establishment under simple trickle irrigation, for wind reduction near to the ground and for sand capture and settlement.

In these earlier unique experiments on sand establishment/catching due to wind reduction with an irrigated protective Eucalyptus shelterbelt, that we carried out at Sihaimab between 1985 and 1990, it was shown that in the long run such protective belts had themselves to be protected from sand accumulation (Mohammed et al., 1995). Simple wind equipment had been very useful in these early experiments, including Woelfle anemographs (Mohammed et al., 1999). If multiple shelterbelts are not feasible, only corridors of scattered trees and grasses, that are able to reduce wind sufficiently to catch and settle sand, can bring a solution. Wind reduction and sand settlement by trees and grasses, as a function of their biomass distribution, have then to be quantified in situ (Al-amin et al., 2005).

Measurements of wind reduction were done with arrays of cup anemometers at various heights in front of, behind and at the sides of various tree species and one grass, that had been shown to be sufficiently suitable for establishment under limited irrigation in this desertified environment. The results obtained revealed that medium to high, but not the highest, biomass density closest to the ground, over the largest distance from the tree stem or grass turf center (perpendicular to the wind), and for the largest height, was most efficient for wind reduction and the related sand settlement. The conclusion on these experiments, as to the value of quantification of simple wind profiles for selection of trees & grasses, is moderately positive. Visual observations of patterns of settled sand already revealed a lot on the efficiency of wind reduction. Quantifying wind revealed more on the influence of the biomass distribution.

Nigeria

The third case is about inefficiently established multiple shelterbelts in a desertified part of northern Nigeria. The Kano state Forestry Department planted more than 20 km of multiple Eucalyptus shelterbelts, to combat desertification by settling drifting sand & undulations and this way encouraging the return of soil protecting grasses. Farmers returned to their soils between the belts after the oil boom was over. Shelterbelts were combating desertification well but insufficiently protected crops grown between the belts from hot air. Design rules of better protection and implications for farmers have been discussed (Onyewotu et al., 2003, 2005).

Shelterbelts have been extensively studied with respect to protection of soil and crops from mechanical damage by wind but have nowhere been studied for damage of crops due to hot dry air. It is generally accepted that wind reduction measurements at one height are representative for at least half the height H of such a protective structure. Because the shelterbelts were not equidistant, we chose the narrowest two belts and the nearest large distance belts for belt to belt wind reduction measurements, 20 cm above the highest millet to be expected. This appeared a golden choice, because wind speed returned to close to original values between all belts beyond 5-6 H (Onyewotu et al., 2004).

It was concluded from the wind data, obtained under strong advection, in an unstable atmosphere with low speeds, that actual distances between the belts were too low in all cases and much too low in most cases, even when wind direction had been perpendicular to the belts (Onyewotu et al., 2004). Scattered trees in an increased density parkland would likely have done better (Onyewotu et al., 2005).

Interpretation of simple wind reduction confirmed what yields already showed. In particular the combination of wind data with soil moisture data was very revealing on the dangers of hot dry air movement from before sowing till harvesting. Also homogeneity of permeability could be well quantified by simple wind observations. Increased turbulence due to the belts could not be detected by the cups and it spoiled ancillary wind quantification (Stigter et al., 2000).

Tanzania

The fourth case was on consequences of diminishing tree densities in northern Tanzania for soil/crop protection. Wind reduction in Savanna woodland appeared endangered by felling of trees. Earlier tree densities provided sufficient protection. Simultaneously with the early research on catching sand by wind reduction in front of and inside shelterbelts in Central Sudan, in northern Tanzania this work was done on wind reduction downwind a savanna woodland edge (Kainkwa and Stigter, 1994). These early TTMI wind research undertakings are now appearing in review literature and textbooks as unique examples.

Because of the felling of trees, tree density diminished over three seasons of wind reduction measurements. Data were taken at two heights, 1 m and 2.5 m, both possible crop heights for intercropping between the trees, in long parallel rows of wind instruments that we brought deeper into the woodland each measuring day. There was higher biomass density at 2.5 m and some tunneling at 1 m.

These were also the first experiments were ancillary wind equipment was tried out, that later played an important role in the second generation of wind problems research dealt with earlier in this presentation: Woelfle anemographs and shaded Piche evaporimeters (developed in Tanzania and Sudan) as isothermal air movement indicators. Accuracies were determined. Particularly wind reduction ratios of different instruments were well correlated. Results were widely published (Spaan and Stigter, 1991; Stigter, 1994; Kainkwa and Stigter, 2000; Stigter et al., 2000; 2002).

These results revealed that thinning of savanna woodland had diminished tree densities so much that the soil was finally no longer protected from wind erosion, because wind reduction had lowered appreciably. Other issues were: wind reduction saturation at 50% for still sufficient tree densities, and keeping equal reduction over large gaps, comparable to close enough multiple belts.

As in the other work, important design rules of wind protection by scattered trees could be derived from these simple wind reduction quantifications in the field. Rules on an approximation of necessary tree densities and biomass distributions and on felling strategies, to keep wind reduction sufficiently high, could be derived.

Final remarks

The four case studies illustrate that the use of simple wind equipment can indeed support the appropriate development of design rules for the use of trees in shelterbelts, parkland agroforestry, woodlands and other non-forest situations. It appears possible to develop policies for wind protection, including protection from drifting sand, based on quantitative results locally obtained with relatively simple means, using appropriate quantification densities and strategies.

In capacity building of research education, this demonstrated to African scientists and students what is possible under their research conditions to support policies that may be recommended to authorities for the development of agrometeorological services.

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TECHNOLOGY TRANSFER, CAPACITY BUILDING, TRAINING AND DEVELOPMENT OF RICS (THE NIGERIAN EXPERIENCE)

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1.0 INTRODUCTION:

Meteorological services globally under the auspices of World Meteorological Organisation (WMO), relies on the use of various instruments and sensors of different forms (digital or analogue) for terrestrial monitoring of different and dynamic weather parameters: precipitation, temperature, winds, humidity, pressure, evaporation etc. The instruments or sensors for monitoring these parameters in developing countries especially Africa come from the western and advanced WMO member nations as donations or purchase. Similarly, training on sustainability of these instruments and other meteorological equipment come from the same source. It is evident that weak economies of most countries and under funding of meteorological institutions in developing countries especially in Africa has forced most National Meteorological and Hydrological Services (NMHSs) to operate with obsolete equipment. Nigerian Meteorological Agency, in pursuance of the WMO standard for weather monitoring coverage has over 50 synoptic/ airport stations, over 150 rainfall/climate and agro-meteorological stations. The capability (conventional instruments/automatic weather stations) to sustain production of regular and reliable meteorological data, from these stations budget wise is a burden on the institution like in other countries in RA 1.Technical support in form of equipment donation from WMO and other advanced member nations can not support these.

The road to relevant in self reliant on meteorological instruments and capacity building should hence forth go beyond basic equipment donation , seminars on technology transfer and capacity building for the developing nations

The activities of WMO-CIMO related to capacity building in developing countries will be attended especially by increasingly supporting intensive technical empowerment to sustain local content development of conventional instruments, automatic weather station (AWS) assemble, calibration, repairs and maintenance of instruments.

Involving and equipping the established Regional Instrument Centres RIC's and establishing new ones in the regions where there is none for obvious regional development and support activities. It is however important to note that the available base workshops and human resources in some countries, if properly harnessed can support production of the basic conventional instruments requirement, calibration and assemble automatic weather stations for use in the region.

2.0 DEVELOPMENT OF REGIONAL INSTRUMENT CENTRES (RICs)

Most of the existing NMHSs workshops or regional instrument centers in RA I such as South Africa, Kenya, Nigeria, Ethiopia, Egypt and a host of others have shown serious interest and commitment in achieving technological growth. The workshops can support local fabrication of conventional instruments like: evaporation tank, hook gauge and still well, rain gauge, wind vane, digital instruments and assemble AWS. They can also calibrate some meteorological and industrial weather instruments. Presently these workshops or regional instrument centers operate with obsolete equipment and cannot sustain the self-reliant bid. The NMHSs workshops and RICs need to be upgraded with modern calibration and fabrication equipment, specialized engineering/technical and craftsman training.

2.1 PURPOSE:

The purpose of establishment of Regional Instrument Centres (RICs) could be viewed from two main standpoint of technological divide.

- First for the technologically advanced countries; to ensure constant testing and comparison of instrument operational efficiency, methods and maintenance of regional and international standards.

- In the developing countries of RA I (Nigeria); the drive for the status of WMO regional instrument center is primarily to create enabling environment, attract WMO assistance for capacity building through specialised training to sustain efforts in instrument fabrication, repairs, calibration, AWS assembly and more. To hasten sustainable development through fabrication of local instruments, reduce cost and dependence on imported instruments.

2.2 FUNCTIONS OF RICS:

The regional instrument centers are designated to carry all functions as contained in the WMO instrument and method of observation programme, in addition to the following especially for the developing countries.

- Facilitate high level WMO sponsored train the trainer programme with organized/specialized WMO equipment/instrument manufacturers and institutions.
- Harness the regional local instrument development/calibration capabilities and make them functional for revenue generation.
- Hasten local development, self/collaborative fabrication of conventional and electronic instrument and AWS assembly (the current and future instrument).

- Provide grass root capacity building (training) for countries within the region on instrument/ equipment repairs and calibration.
- Regional instrument repair and calibration center for maintenance of regional and international standards .
- Offer sustainable assistance and recommendation to national workshops on the adoption and implementation of appropriate technology.
- Should embrace information and communication technology (ICT) as an opportunity for facilitating sustainable technological development in the region.

3.0 NIGERIAN MET. AGENCY WORKSHOP:

The Nigerian Meteorological Agency's Instrument Workshop in the drive for self-sufficiency in production, maintenance and calibration of meteorological instruments has in place

- **Fabrication workshop:** measuring 14.5 X 12.5 meters, housing the existing lathe machines, milling, drilling, cutting, bending, rolling, grinding, spraying machines etc.
- **Calibration and Repair workshop:** measuring 9 X 7 meters, housing the existing Pressure calibration chamber, Humidity chamber, Temperature chamber/ bath etc though obsolete
- **Human Resources:** the units has Engineers, Technologists, technicians and craftsmen in the fields Electrical/Electronics, Computer, Mechanical Engineering for full take of RIC.
- **Internet Access:** Vsat based internet connectivity for information and research base activities

4.0 Development Proposal

- Expansion of the fabrication/production capability to include the production of anemometers, tipping bucket rain gauge among other conventional instruments; by equipping the workshop with modern machine for boring, shaping, power press etc.
- Expansion and full commercialization of the calibration capability by replacing the obsolete equipment with modern ones.
- Capacity building; specialized training for all cadres in instrument design, fabrication, assembling, repairs and calibration.
- Offer quality and sustainable services in the areas of calibration, maintenance assembly of instruments and training to the member West African sub-region
- Collaborative arrangement (MoU) for instrument component production with local specialized scientific agencies or industries.

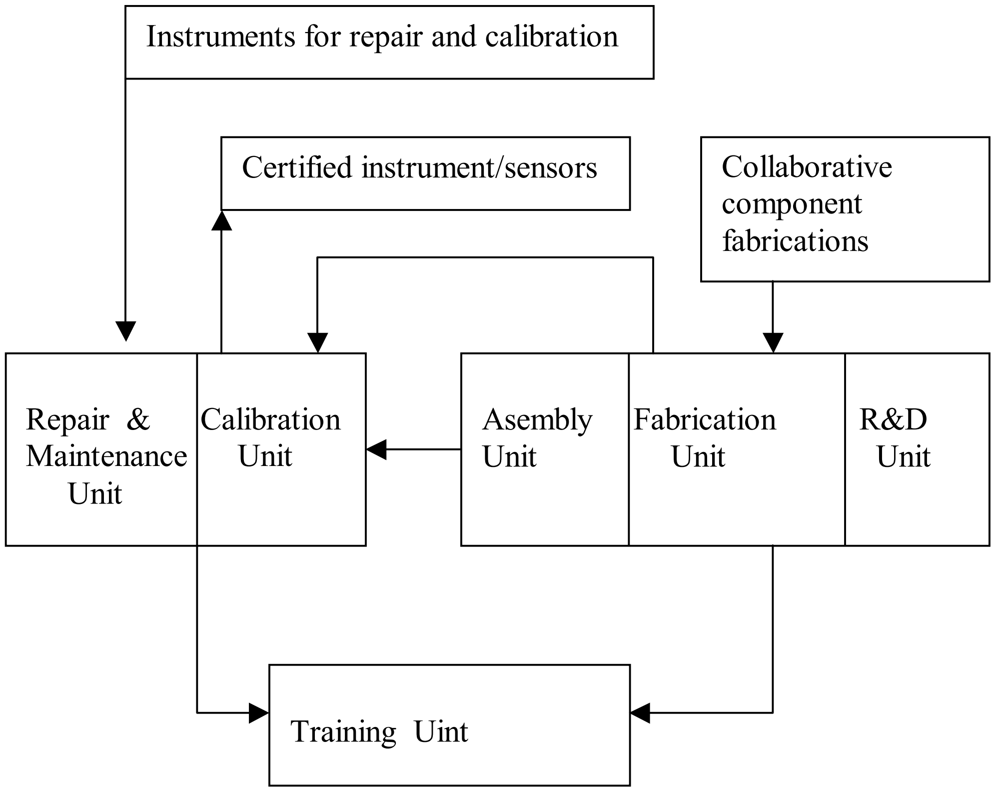

Fig. 1: Proposed expansion of Nigerian Met. Workshop

4.0 CONCLUSION:

The call for technology transfer or technological growth, capacity building and development of RICs in R A I is a call for help to harness technical capabilities to increase local development, production and maintenance of weather monitoring instruments/ equipment at reduced cost .

The situation can be linked to the man inside a deep pit, desiring to come out. He has to raise alarm for attention. He has to make effort, jump up or raise his hands to grab the lifeline lowered for him. These efforts have been made by existing RICs and NMHSs workshops.

The aim of this presentation is to emphasis that the purpose of this call can be realized faster through meaningful counterpart contribution of WMO-CIMO, WMO technologically advanced member countries, Established RICs and NMHSs. This is through training and provision of facilities for instrument fabrication, calibration, assembling of AWS and sensors etc.

The Nigerian Meteorological Agency (NIMET) have in pursuance of it's workshop expansion activity program wish to make it the WMO-RIC for the West African sub-region. This is in line with the WMO 2002 sponsored consultant mission for the establishment of manufacturing and calibration facilities for meteorological instrument in Nigeria.
The Nigerian MET. Agency needs your support and contribution to realize this for the sub-region, R A I and WMO.

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DESIGN AND CONSTRUCTION OF METEOROLOGICAL INSTRUMENTS -THE NIGERIA EXPERIENCE

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ABSTRACT

The Nigerian Meteorological Agency is at the midpoint of an unprecedented effort to engage in the design and fabrication of some conventional and automatic weather monitoring instruments that are also suitable for installation where power supply is an issue.

The goal of this undertaking, which include challenges, is to promote technology transfer and subsequently conserve foreign exchange, which the Agency normally spend on conventional Instruments Procurement.

The paper will address the agency's local manufacturing capability and the efforts being made in the design and development of semi-automatic weather monitoring instruments. Detailed design and construction of electronic wind speed and wind direction indicators is covered in this work.

INTRODUCTION

The Nigerian Meteorological Agency has its fabrication workshop in Lagos, where the operational headquarters is located. The workshop was originally established to maintain conventional meteorological instruments.

Shortly after the then Department of Meteorological Services under the ministry of Aviation became autonomous and transited to an agency (Nigerian meteorological Agency) in year 2002, the Director-General of the Agency,Mr.L.E. Akeh, introduced an awareness program by organizing lectures on service delivery and this led to an aggressive drive by members of staff to contribute their quota to the progress of the newly established Agency.

The Oshodi Workshop in Lagos, Nigeria manufactures basic meteorological equipment such as Rain Gauges, Class 'A' Pan Evaporimeter, Stillwell, Hook Gauges, Telecommunication masts, Automatic Weather Station couplers, anemometer masts, thermometer brackets, Stevenson screens for thermometers and thermo hygrographs, Wind vane called weather vanes, and other mechanical parts needed for maintenance of existing equipment.

The raw materials required to produce the above listed instruments are available in the local market. In the case of self recording raingauge, more than 70% of the materials used are sourced locally, for accuracy of measurement and conformity to the World meteorological Organization standards, mechanical clock and the siphon chamber are being sourced from abroad to produce a complete tilting siphon rain gauges.

Work is in progress on the design and fabrication electronic weather observing instruments such as digital thermometer, Tipping bucket raingauge, cup counter anemometer, humidity sensor and the wind monitor.

Effort to produce basic meteorological instruments locally by the Nigerian meteorological Agency is borne out of a desire to make available these instruments for use at

cheap and affordable price to all users of environmental monitoring equipment in the country.

LOCAL MANUFACTURING CAPABILITY

The pictures below show some areas in which we have capabilities

Fig. 1.0 Technicians working in the workshop

Fig.2.0 A section of NIMET fabrication workshop at Oshodi

Fig. 3.0 some of the fabrication equipment in the workshop

WIND VANE

This instrument is designed for the indication of wind direction. For a given change in the direction of wind, it will rotate with minimum friction since it is balanced to avoid being tilted towards any particular direction.

The instrument consists of a horizontal arm with a rectangular flat aluminium plate at one end and a brass counterweight at the other end, mounted on a vertical spindle, which rotates freely on a frictionless ball bearing. The support for the bearing incorporates a ring carrying the four direction arms (N-W-S-E) and this is securely locked in position once oriented correctly with compass.

Fig. 4.0 Wind vane produced at the workshop

2.0 ORDINARY RAIN GAUGE

This instrument is made from galvanized sheet with soldered seams and its circular base provides extra stability. It has a brass rim of diameter 127mm and an inner can with a pouring lip and handle. The measuring jars or glass-collecting bottles are normally purchased to measure the amount of rain over a particular period of time.

Fig. 5.0 Production process of a simple rain gauge

In Nigeria, the use of this instrument is in high demand in rainfall stations, schools and research institutes for precipitation measurements. The cost of each imported rain gauge is roughly $412 whereas a locally made one is $200.Therefore, the low cost of local rain gauge has assisted the Agency to conserve foreign currency for procurement of modern technological equipment from hydro-meteorological equipment manufacturers from the developed countries.

Fig. 6.0 Component parts of a simple rain gauge

Fig.7.0 Finished products wrapped ready for installation.

3.0 STEVENSON SCREEN

The workshop also constructs large Stevenson Screen with suitable wood for use in our synoptic stations all over the country. The screen produced is a rectangular wooden box provided with doors at the back and front; the sides, back and front are double louvered. The base of the floor consists of overlapping boards; the roof is also double and is separated vertically by an air space. The front door is suspended and is securely mounted at the bottom with two hinges. When open, it is suspended in the horizontal position by two chains. The extra space available is normally used to house a bimetallic thermograph and air hygrograph, resting on the centre board, one on each side of the thermometers. The top of the screen is covered with galvanized sheet, which is turned at the edges; the wooden screen is painted with white gloss that reflects from light, keeping the thermometer from heating above the air temperature. The model's double louvers features and a separated top minimizes the effect o direct solar radiation and yet allow airflow to ensure accurate temperature and humidity readings by the enclosed instruments.

Dimensions: 49cm(H) x99cm (W) x30cm (D).

Fig. 8.0 Stevenson Screen

6.0 CLASS A PAN EVAPORIMETER

We construct Class 'A' pan with gage 14 galvanized iron plate. The instrument is painted with silver coated gloss paint.

SPECIFICATIONS:

Material: Galvanized Iron

Construction: Heliarc welded

Size: 25cm(H) x 120cm Dia.

Material: Galvanized Iron

A complete evaporimeter consists of Class A Pan, Hook gauge and Stillwell.

Fig.9.0 Complete Evaporimeter

Fig.10.0 Class A Pan Evaporimeter under construction

7.0 HOOK GAUGE EVAPORIMETER

The hook gauge is made from brass and it consists of cast brass tripod frame and engraved brass component. It is graduated from 0 to 10mm and subdivided to 0.02mm by means of an engraved micrometer dial. The instrument is used to measure evaporation rate from a free water surface. Hook gauge rests on top of still well. The gauge is supported by its three arms and has a micrometer head for very accurate adjustment.

Fig. 11.0 The Hook gauge

The gauge is normally placed in a still well and adjusted so that the point of the hook just breaks the water surface. The change in the water level is then read on the adjusted micrometer.

8.0 STILL WELL

This is a cylindrically shaped instrument that rests on a cast brass tripod. It is normally installed in conjunction with the hook gauge at the center of Class A pan and provides a small area of water surface that is free from ripples thus permitting measurement of evaporation rate from a free water surface.

Fig. 12.0 Stillwell and the hook gauge

DIGITAL THERMOMETER

The effort being made in this direction is to start doing something that will give us the competence to come up with the design of low cost digital meteorological instruments in the no distant future. This is of course a work in progress that will still accommodate many design improvements as time goes on. The thermometer below is designed to display with no logging device.

Fig.13.0 Digital Thermometer

13.0 WIND DIRECTION AND WIND SPEED ANEMOMETER:

We are working on speed and direction sensor from base the parts. There is a pre-programmed microprocessor to decode the sensor input and display readings on a neat LED display. There is also an RS-232 interface to communicate with the PC.

This design only needs two wires from the interface to the sensors thus reducing cable costs. And this can be adapted to use optical fibre giving a total lightning safe unit.

The direction sensor uses the four inner reflective rings to get a 4-bit binary code; a latching buffer is added to only read position when the disc is in the center of a binary digit. The outer ring is used to enable the buffer, and also to give tachometer pulses for the wind speed instrument.

Reflective IR (Infra-Red) units are used with the PCB (Printed Circuit Board) mounted in the base of the housing.

WIND DIRECTION SENSOR

We were able to determine the direction of the wind by connecting 50Hz Astable multivibrator generates a triangular wave at 50Hz to the non-inverting input of the operational amplifier. The sensor converts the angular displacement into voltage value, which is fed into the inverting input of the Op-amp. The output of the Op-amp. is 50Hz pulse width modulated square wave whose width varies with angular displacement of the sensor. Another high frequency astable multivibrator is designed to generate frequency in multiples of 359Hz i.e. 359.9x50x10 =179.5kHZ. This also takes care of one place of decimal counting. The output of this astable multivibrator and that of the Op-amp is fed to the AND gate whose output is a pulse train, the number of pulses per train depends on the width of the output of the operational amplifier which corresponds to the angular degree of the direction of the wind.

The pulse train is now fed into BCD (Binary Coded-Decimal) counter that counts the number of pulses per train for each width of the operational amplifier output. As the width collapses, the counter resets and the process is repeated 50 times in one second (50Hz), which allows the display to appear as being stable. The output of the BCD Counter is fed from the BCD to seven-segment decoder, which decodes the readings and displays it on the seven-segment display.

Acknowledgements

The author wishes to place on record the immense contribution of the Director-General of the Agency for providing the funding for the on-going work in the Workshop. Equally we would like to appreciate the various input and suggestions of the Director of Engineering Services whose encouragement and pioneering efforts in this direction has brought meaning to the whole of our experience in this work.

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ROMANIAN NATIONAL METEOROLOGICAL INTEGRATED OBSERVATIONAL SYSTEM – ACHIEVEMENTS AND CURRENT STATUS

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Abstract

The paper briefly describes the architecture of the national meteorological infrastructure, the progresses Romanian National Meteorological Administration did over last few years and provides the current status and modernization perspectives.
Each subsystem (the national radar network, surface observation system, upper-air sounding stations, lightning detection sensors, communication network etc.) is further detailed, presenting data collection philosophy, dissemination and available products.

Key words: SIMIN, modernization, up-grade, weather radar system, ASOS, upper-air sounding, meteorological satellites, lightning detection network, WAN

1. Introduction

Romanian National Meteorological Administration (RNMA) is the national authority in the meteorology field, except aeronautical meteorology (another organization, ROMATSA, being responsible for this activity). Under these circumstances, RNMA plays an important role in almost all activities carried out over Romanian territory, its primary mission being protection of life and goods. RNMA serves all Romanian citizens through Government authorities, but also performs specialized meteorological services for any kind of end-user (like public organizations, private companies etc.). In order to be successful in its missions, RNMA has to develop, up-grade and maintain the national meteorological system (observational infrastructure, communication, processing, displaying and dissemination systems, qualification of the personnel etc.) at high standards. It is important to note that Romania is an Eastern Europe country and the whole process of transition to European Union over the last 15 years highly impacted the meteorological activity. This paper will describe the RNMA achievements in the meteorological infrastructure (sensor networks and communication) domain. The modernization process started in 1998 with the acquisition of an automated message switching system (AMMS), continued in 2000 with the installation of the first two Doppler radar systems, but the biggest contribution was brought by the SIMIN project (implemented during 2000 – 2003 period). The total value of the project was 55 million USD with the primary objective of modernizing and integrating the nations various resources and real-time detection capabilities, and also facilitates the exchange of data at the Local, Regional, and Global levels.
Figure 1 illustrates the geographic distribution of the sensor network and communication and includes all the sensor sites and national and regional meteorological centres.

2. National weather radar network

History:

- Before October 2000, Romanian national radar network included only conventional analogic radar systems (mainly MRL-5 and MRL-2 Russian equipment); the exploitation regime was exclusively manual and consisted in one radar map every hour and one national mosaic map every three hours;
- Modernization – step 1: in October 2000 two new Doppler radar systems are commissioned in Bucharest and Craiova (manufacturer DRS-WS – former EEC, equipment type – DWSR-2500C);
- Modernization – step 2: in 2001 one new Doppler radar system is commissioned in Oradea (manufacturer Gematronik, equipment type – METEOR 500C);

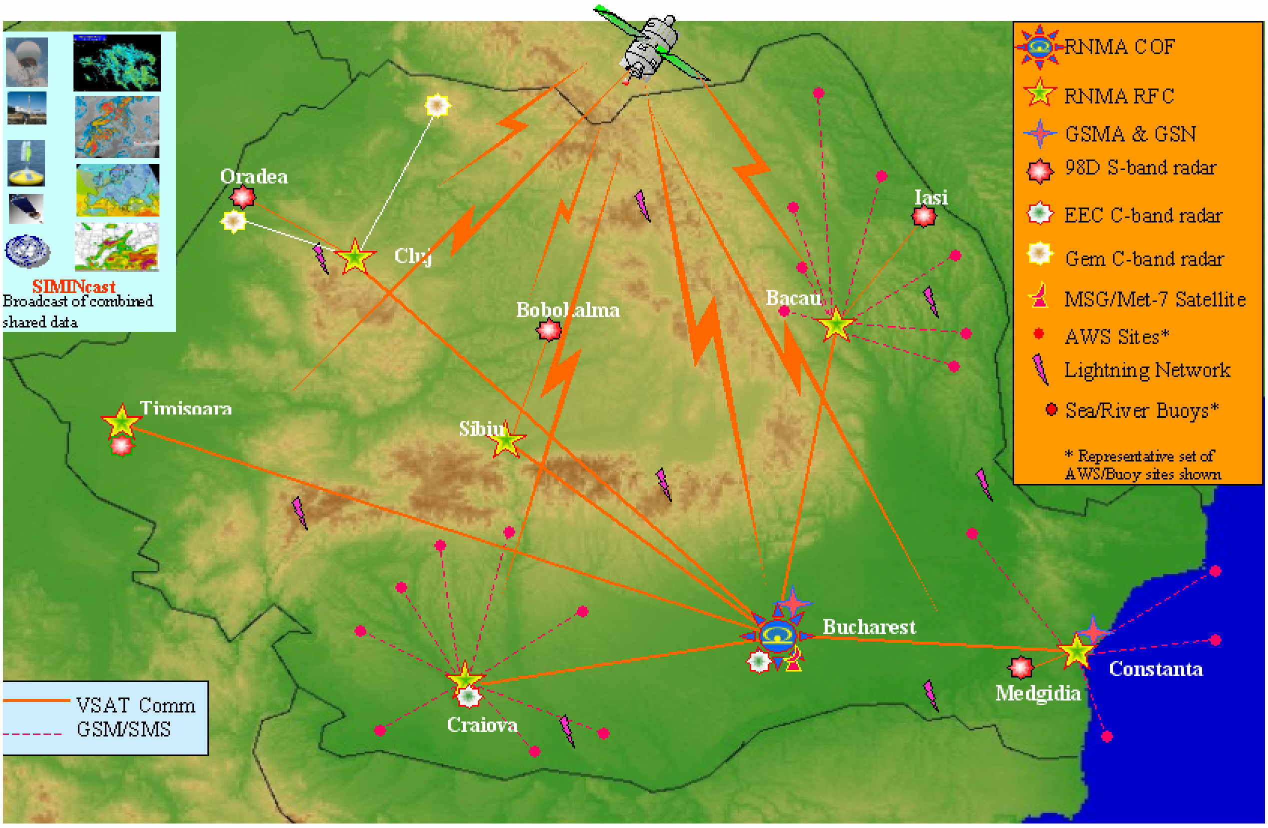

Figure 1 – RNMA sensor networks and communication

- Modernization – step 3: SIMIN project completes the national radar network; during 2002-2003 period, 5 (five) new Doppler S-band radar systems are installed in Barnova, Medgidia, Bobohalma, Timisoara and Oradea (manufacturer Lockheed Martin/Metstar, equipment type – WSR-98D, an upgraded version of the WSR-88D NEXRAD system used by the National Weather Service in US);
- October 2003 – National Integrated Meteorological System (SIMIN) is commissioned by Romanian Meteorological Service; Romanian national radar network consisting in 8 (eight) Doppler radar systems is declared operational;
- First half of 2004 – Romanian Water Authority installed the second Gematronik METEOR 500C in northwestern part of Romania; this system will become soon part of the RNMA weather radar network.

Before October 2000, the Romanian weather radar network consisted of ageing manually operated radar systems. Specifically the Russian MRL-2 and MRL-5 equipment was used. The disadvantages of such equipment were the obsolete technologies, the manual exploitation of the system, and the large amount of time necessary for processing and distribution. The MRL-2 was designed in 1967 and the MRL-5 in 1972, thus repair and maintenance was always an issue. Manual operation forced the radar operator to sit in front of the radar display and draw the radar echoes on paper by hand. The manual collection also required a large amount of time necessary for acquiring the radar information, putting it on a paper map and disseminating to the end-users. Therefore, radar data was not available in real-time. Every three hours, on the basis of the local information received from the component systems of the network, the National Radar Center at the RNMA headquarters created a national radar mosaic, also in analog paper map format. Figure 2 represents an example of national radar mosaic product used till recently by RNMA.

The first step of the national network modernization was achieved in October 2000 when two modern systems manufactured by Enterprise Electronics Corporation (EEC) were commissioned in the Southern part of Romania. These two systems met the criteria imposed by the EUMETNET GORN and OPERA programs for harmonizing and improving the exchange of the data from operational weather radars in Europe. For the first time, in 2000 Romania had its first regional radar mosaic, with only two systems, and updated every 20 minutes. Figure 3 represents an example of the first stage radar mosaic covering the southern portion of the country.

The second step was early 2001 when Romanian Water Authority (RWA) installed and commissioned another radar system. This equipment is manufactured by Gematronik (METEOR 500C type) and currently is operated also by RNMA.

SIMIN has concluded the transition of the Romanian weather radar network from exclusively manually operated and obsolete systems, to one of the most modern and unique radar networks in the world. SIMIN has installed five (5) new and modern WSR-98D S-band radar systems, to complete the national network. The WSR-98D system, from the Beijing Metstar Radar Co., is based on the technology and meteorological algorithms developed over more than 30 years in the US NEXRAD network. It generates an impressive suite of more than 70 products, including both base and derived products.

The SIMIN added value consists not only in installing the new WSR-98D radar systems, but also in bringing the power of a reliable radar network and integration of the existing digital systems (EEC and Gematronik) into this network. In this respect, Romania is one of very few countries that have fully integrated three types of radar equipment into one integrated network.

Currently, RNMA produces individual site radar products every 6 minutes, depending on the radar and mode of operation. Three types of national radar mosaics are produced every 10 minutes. The available national radar mosaic products include first tilt base reflectivity, echo top and composite reflectivity. The fact that Romania has three radar products at a nationwide scale is another unique feature of the Romanian radar network. Figure 4 illustrates an example of the three current Romanian National Mosaic products.

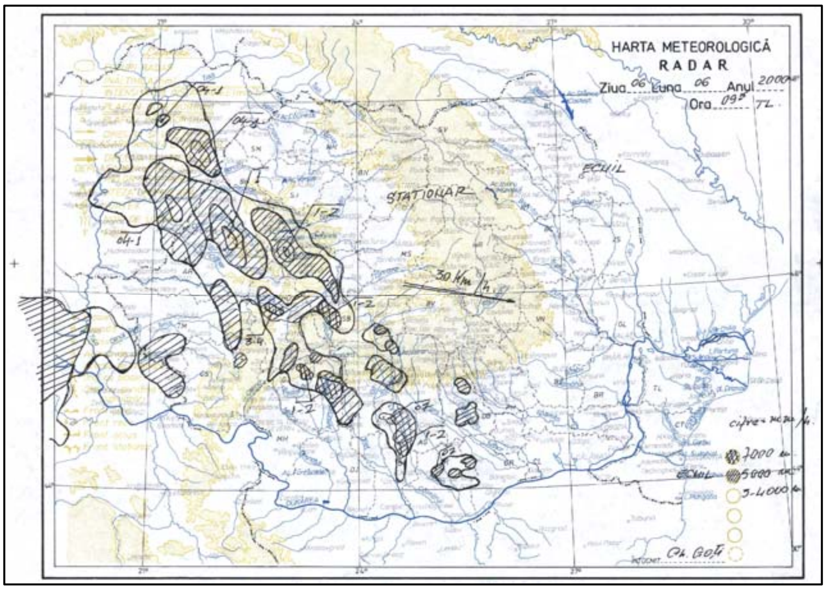

Figure 2 - Manual National Radar Mosaic

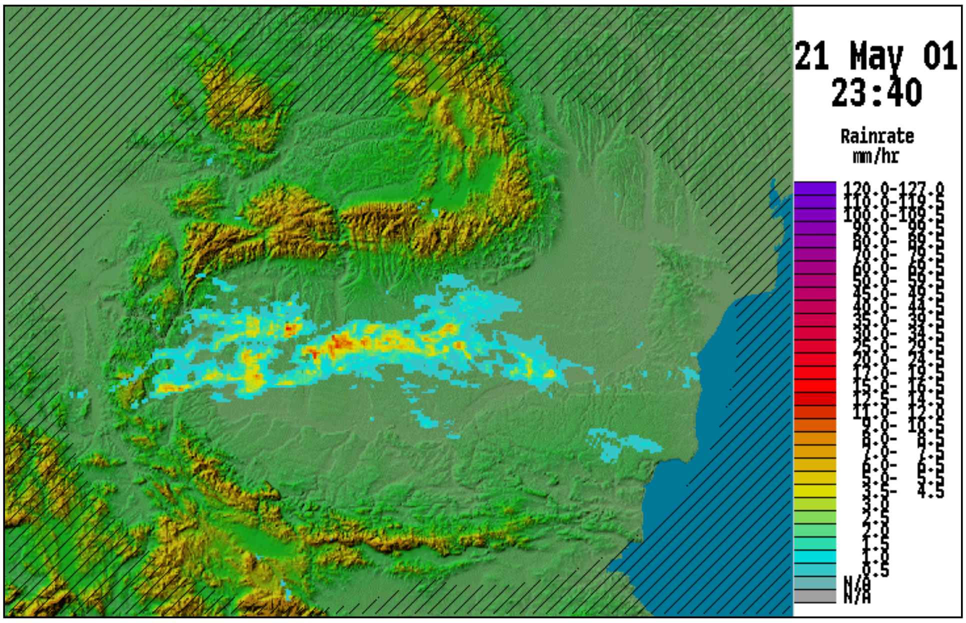

Figure 3 - Initial Regional Mosaic with 2 Radars

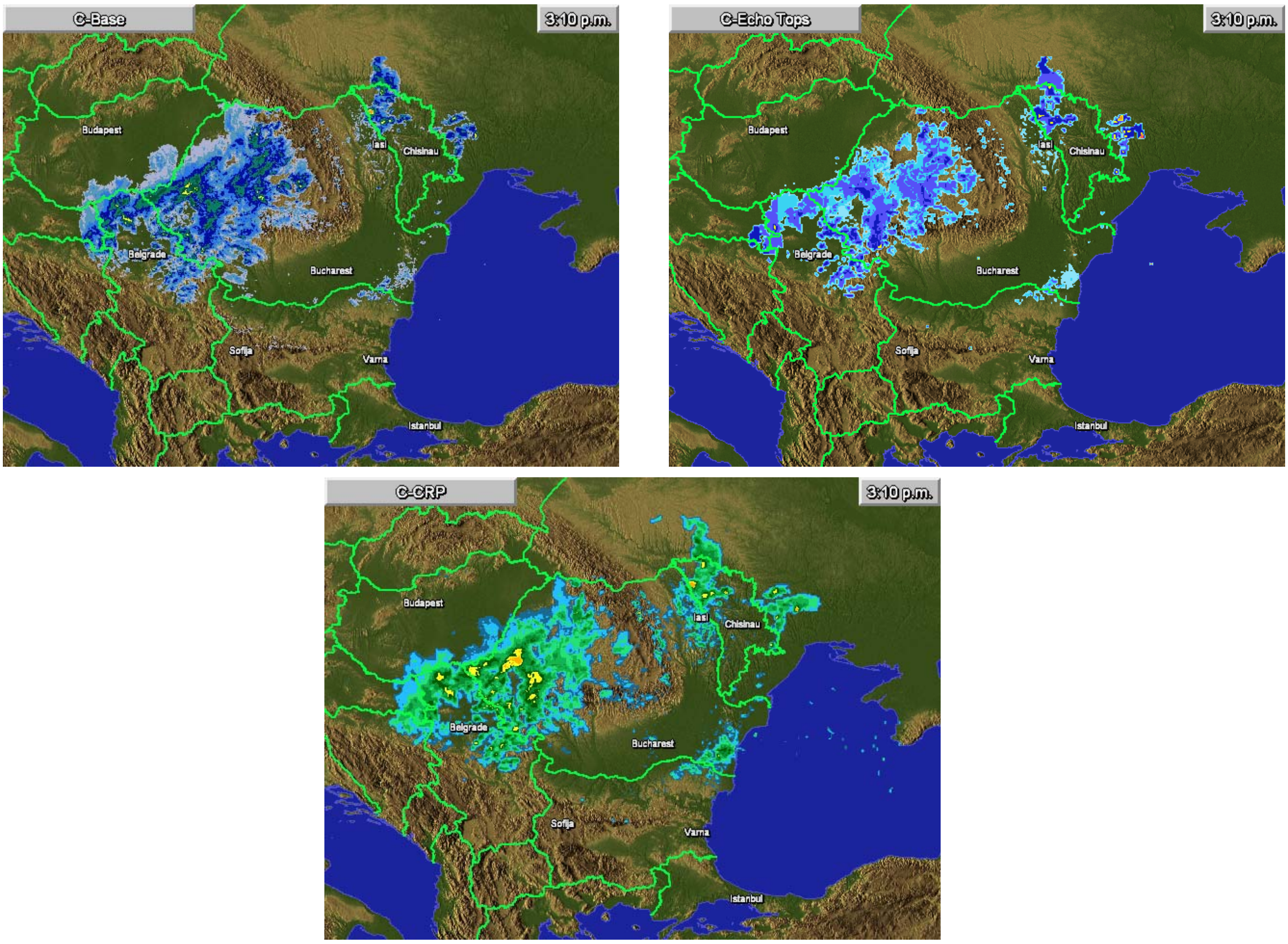

Figure 4 – The three types of National Radar Mosaic with 8 contributing radars

3. Romanian surface observation network

The surface observation network (the meteorological stations) is a very important component of the RNMA observational system. The data provided by this network is used directly by the forecasters (they receive hourly reports from all meteorological stations), is used in climatological studies, serves as input for NWP and part of this data is introduced in the international meteorological data flow (GTS).

The network consists in approximately 135 meteorological stations that perform various types of observations (synoptic, climatologic, agro meteorological etc.). Data coming from 23 out of these 135 stations is representing the RNMA contribution to the international data flow.

Figure 5 illustrates the geographical distribution of the RNMA surface observation network. It is important to note the fact that the number and the locations for the meteorological stations are slightly varying from one year to another depending on various conditions (new needs for meteorological information in a specific area, degradation, from meteorological standpoints, of some locations, administrative problems -like RNMA is not the owner of the station land / building, budget cuttings etc.

At the beginning of 90s, all the meteorological stations were using classic instruments for measuring the various parameters. Starting with 1995, RNMA acquired the first automatic surface observation stations (ASOS), but, due to the fact that these ASOS were very few, it can not be considered the start for the modernization of the network. This modernization happened only in 2000 when a number of 10 ASOS were installed in 10 important locations (mostly county capitals locations). The modernization continued with the SIMIN project – 60 new ASOS were installed all over Romania. In the present, the national network contains a number of 73 fixed location ASOS and another 2 mobile ASOS. In the first half of 2005 another 15 ASOS will be installed, and other infrastructure modernization projects are in progress (like agro meteorological projects, INTEROPERATE project etc.).

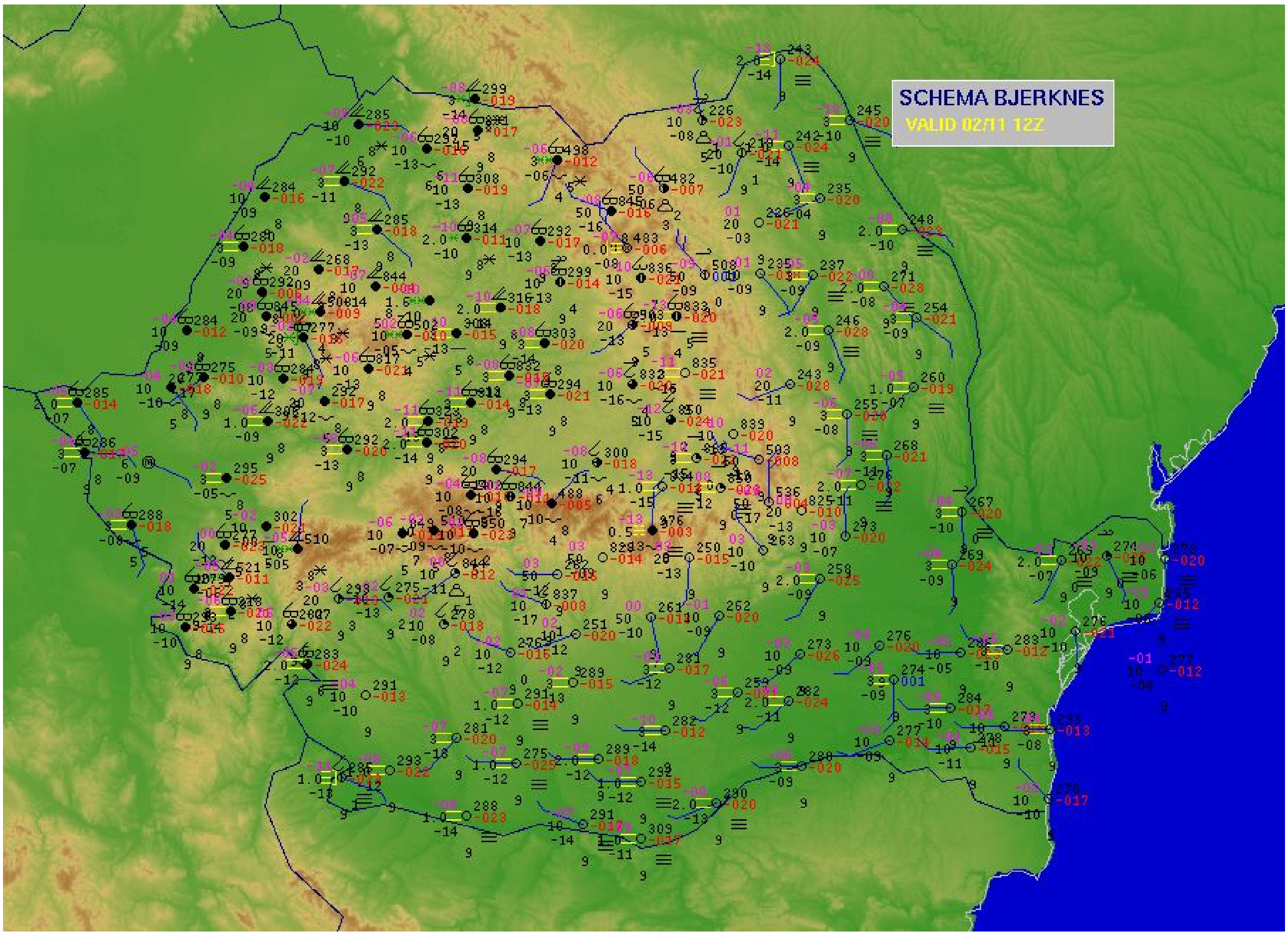

Figure 5 – RNMA surface observation network

The table below summarizes the type, locations, manufacturers and the year of acquisition for all the automatic surface observation stations included in the RNMA network. When the ASOS locations were selected, several criteria were considered: county capitals are important from synoptic and climatological standpoint, other representative locations are important for their geographical areas, special needs (like mountain and marine meteorology, special projects for different areas etc.).

Number / Location	Manufacturer	Type	Year of installation	Acquisition procedure
10 / county capitals	Vaisala/Finlanda	MAWS301	**2000**	RNMA funds, international bidding
1 / Mangalia (mobile)	Vaisala/Finlanda	MAWS201	**1998**	RNMA funds
1 / RNMA HQ (mobile)	Vaisala/Finlanda	MAWS201	**1998**	RNMA funds; special measurements (like 1999 eclipse, Baia Mare project)
1 / Bucuresti – Afumati	Thies/Germania	AWS7800	**1997**	PHARE funds
1 / Constanta	Vitel/SUA	VX1004	**1996**	Offered free of charge, in the frame of a WMO programme
1 / Bucuresti – Banesa	Thies/Germania	DL15	**1995**	RNMA funds
60 / county capitals and other representative locations	Vaisala/Finlanda	MAWS301	**2001 - 2003**	SIMIN project

Another aspect of the network modernization is the data collection method. Before 1998 the collection and validation of the data was done manually, using phones and radio communication devices. In 1998 another communication concept was introduced: GSM SMS (short message system). All the stations were provided with cell phones and all the observers were reporting to the collecting centre using SMS service. Later on, in the frame of SIMIN project, a complex application for data collection, transmission and validation was implemented. This application has three components, one for each level of collection and validation: local (station site), regional and national.

4. Upper-air observations

Romanian upper-air network consists of three operational upper-air sounding stations located in Bucharest, Cluj and Constanta. All three stations are equipped with Vaisala DigiCORA systems upgraded to Loran C in 2004 in order to use RS-92 KL sondes and, alternatively, Vaisala GPS sondes RS-92 SGP.
The upper-air measurements program consists of two soundings per day at the synoptic hours of 00 and 12 GMT in Bucharest and Cluj stations. The Loran C wind finding system and RS-92 KL radiosondes are used. Currently the measurements program in Constanta is temporary interrupted for the hydrogen building reconstruction and it is estimated that during 2005 the activity will be resumed.
Meteorological variables measured in upper-air programs include pressure, temperature, humidity, and wind direction and wind speed. The obtained data are examined using quality control procedures, coded in TEMP bulletins and disseminated in national and international data flow at the a.m. synoptic hours.
Upper-air meteorological measurements used daily as input for numerical weather forecast models are therewith the main support for nowcasting activity, especially to analyse and predict severe weather and the evolution of the local meteorological phenomena. For this purpose the upper-air data are daily processed to derive the thermodynamic parameters and other atmospheric variables such as: potential and equipotential temperatures, main isotherm levels, height and strength of inversions, onset and dissipation of fog, convective condensation level, precipitable water content, vertical stability (convective instability indices, thunderstorms, hail, turbulence), mixing level, etc. Two types of aerological diagrams are automatically performed for visualization and graphical analyze of physical processes: thermodynamic diagram and daily variations of the main upper-air parameters for the last seven days.
The upper-air data are recorded on temporary files in order to perform CLIMAT-TEMP bulletins and update database at every end of month. At the same time the main upper-air climatological parameters are computed assuring hereby the input data for climatological studies of the atmosphere.

5. Satellite data acquisition and processing

Since 1970, in the frame of Satellite Meteorology Department there are sustained preoccupation concerning the use of digital information provided by the geostationary and polar-orbital meteorological satellites for specific activities.
The main purpose of the RNMA Satellite Department is to provide satellite images, derived products for operational meteorology purposes, and integration of the satellite derived parameters in NWP models.
Meteorological products and geophysical parameters are derived and made available to the operational services like the National and Regional Forecasting Centres. Taking into account all these aspects, a NOAA AVHRR / HRPT system was installed in 1998 – 1999 by SMARTECH company. The software for the acquisition and pre-processing (SMARTrack and SMARTVue) was also delivered by SMARTECH. The development of new algorithms is done using ERDAS IMAGINE and ENVI software. Also the RNMA - Satellite Department benefits by the direct reception of digital High Resolution Imagery Transmissions data from METEOSAT and High Rate Information Transmission and Low Rate Information Transmission data from MSG (Meteosat Second Generation). These two receiving stations have been manufactured by VCS-Engineering and were provided in the frame of SIMIN project. The systems actually receive, store and process all the HRI data dissemination formats (A-format, B-format and X-formats for foreign satellites) and HRIT and LRIT data from MSG.
The products derived from MSG data are listed below and are used to support the nowcasting and very short range forecast:

Cloud Mask (CMa)

This product shall provide information on the possible occurrence of clouds within each pixel. The central aim is to delineate all absolutely cloud-free pixels in a satellite scene with a high degree of confidence.

Cloud Type (CT)

The main objective of this product is to support detailed cloud analysis. It may be used as input to an objective meso-scale analysis or as an image product for display at the forecaster’s bench.

Cloud Top Temperature and Height (CTTH)

The CTTH product shall contain information on the cloud top temperature and height for all pixels identified as cloudy in the satellite scene with the highest possible spatial and temporal resolution. The main use of this product is in the analysis and early warning of thunderstorm development.

Precipitating Clouds (PC)

The Precipitating Clouds product provides information on the probability of weak, moderate and strong precipitation.

Convective Rainfall Rate (CRR)

The CRR product provides the maximum level of information on convective rainfall from the SEVIRI channels. The main use of this product is the monitoring of convective systems and their rain intensity.

Total Precipitable Water (TPW)

The TPW gives information on the total atmospheric water vapour contained in a vertical column of unit cross-sectional area extending from the Earth's surface to the "top" of the atmosphere. This product can be used for objective quantitative studies giving a diagnosis of the total water vapour content in pre-convective areas and therefore helps to classify the air mass in terms of severe weather air masses. Also it gives some information on the intensity of the phenomena to be expected and localisation where severe convection is likely to occur.

Layer Precipitable Water (LPW)

The LPW product provides, in absence of clouds, information on the atmospheric water vapour contained in a vertical column of unit cross-sectional area in three layers in the troposphere. The special interest of this product is the detection of dry-over-moist configurations and of horizontal moisture gradients, as these factors contribute to severe storm formation.

Stability Analysis Imagery (SAI)

The SAI product gives an index summarising the information content in the SEVIRI channels on the vertical thermodynamic structure of the cloud-free atmosphere. In particular, information on the stability of the troposphere is given by SAI with the scope of delineating unstable and stable areas.

High Resolution Wind Vectors on HRV (HRW)

The HRW provides information on mesoscale wind vectors at two different horizontal resolutions: a basic wind product at a scale of approximately 20-25 km, a fine-scale product with a resolution of 10 km. Both products use data from the HRVIS channel and are thus solely extracted during daytime.

Automated Satellite Interpretation Imagery (ASII)

This product provides an automatic interpretation of features seen on satellite images. Hence, the product identifies fronts, wave structures, areas of intensification at fronts by jet streak crossing, position of the jet axis, comma clouds, enhanced convection areas, etc. The result of the automatic interpretation will be given in the form of text and object attributes, which can be overlaid on the satellite IR image.

Rapid Development Thunderstorms (RDT)

The RDT provides information about significant convective systems from meso-alpha scale down to smaller scales, and possible isolated storms (meso-gamma scale). The objectives are twofold: identification, monitoring and tracking of intense convective systems and detection of rapidly developing convective cells.

Air Mass Analysis (AMA)

The goal of the AMA product is to evaluate basic quantities that describe air masses (upper and middle level humidity, mean temperature, atmospheric stability, cloud pattern, etc) and to combine them into one integrated classification of the air mass. The main use is to monitor air masses and air mass boundaries for an early recognition of unstable weather situations.

6. Lightning detection network (LDN)

This type of network represents something new for Romania, therefore we can not speak about modernization but about a new type of information. The network was installed in 2002 in the frame of SIMIN project. The purpose was gathering precise information on the electric activity of the atmosphere. The manufacturer of the network is Vaisala company. The system provides information on its own display, but the data is also integrated into RNMA data flow and can be displayed on other integrated platforms / applications. Below is a brief description of the system, with main specifications and few considerations on localization accuracy.

The LDN consists of:

1. Detection Network of 8 SAFIR 3000 Total Lightning Automatic Detection Stations, located on RNMA sites;
2. Spare parts set;
3. Transmissions from the detection stations to the Network Centre, using the RNMA communication means (leased lines, wireless 64 kbps);

4. A network centre situated at RNMA HQ comprising:
    - Central Processing System (CPS) performing the acquisition and processing of detection network data (SCM), the technical control of the detection network (DCM) and data storage into Oracle database.
    - Main User Terminal performing the real-time mapping of Total Lightning localizations and thunderstorm nowcasting processing & display (PDM or BPDM), and post processing on archived data (DAM & EPM).

The Detection Stations are made of a VHF Interferometric sensor designed to perform the accurate angular localization of total thunderstorm electrical activity (intra-cloud and cloud to ground lightning), complemented by a wide band LF electric field sensor for the characterization of lightning strikes to ground. Detection stations are connected via telecommunication means to the central processing system.
The Central Processing System (CPS) acquires the data transmitted by the detection stations and computes the locations of lightning discharges by triangulation technique. The CPS processes and displays the technical status of the detection stations and communication links, and can be remotely accessed from VAISALA technical centre for diagnostics and maintenance. The CPS stores the processed data to the Oracle data base.
The Main User Terminal receives the data from the CPS and depending on the selected processing modules perform the advanced real-time processing and display of lightning and storm nowcasting information, as well as post processing of archived data, such as:

- Localization of Total lightning activity;
- Discrimination of lightning type;
- Total lightning activity density mapping;
- Automatic thunderstorm cells identification and tracking (direction and velocity);
- Automatic thunderstorm cells nowcasting;
- Automatic storm warning functions.

Detection performance

- Type of lightning discharges: Total lightning activity, (intra-cloud + cloud to ground lightning);
- Detection efficiency: 90 % (see simulation map hereafter);
- Localization accuracy: minimum < 1 km (mean error, see simulation map hereafter);
- Coverage: (see simulation maps)

Processed data provided by the CPS

- Localization of total lightning activity (date, time, lat., long, intensity);
- Discrimination of lightning type, and characterisation of CG return stroke parameters:
    - Polarity
    - Peak current
    - Rise time
    - Decay time

Processing on display terminal

- Total lightning activity density mapping;
- Automatic thunderstorm cells identification and tracking;
- Automatic thunderstorm cells nowcasting;
- Automatic warning functions for user defined sites and areas.

The simulation of localization accuracy for 8 stations are presented hereafter using the final station locations selected and agreed by RNMA:

- Station 1: Tarcu Peak
- Station 2: Rosia Montana
- Station 3: Grivita
- Station 4: Pauleni
- Station 5: Poiana Nord
- Station 6: Furculesti
- Station 7: Rociu

- Station 8: Movileni

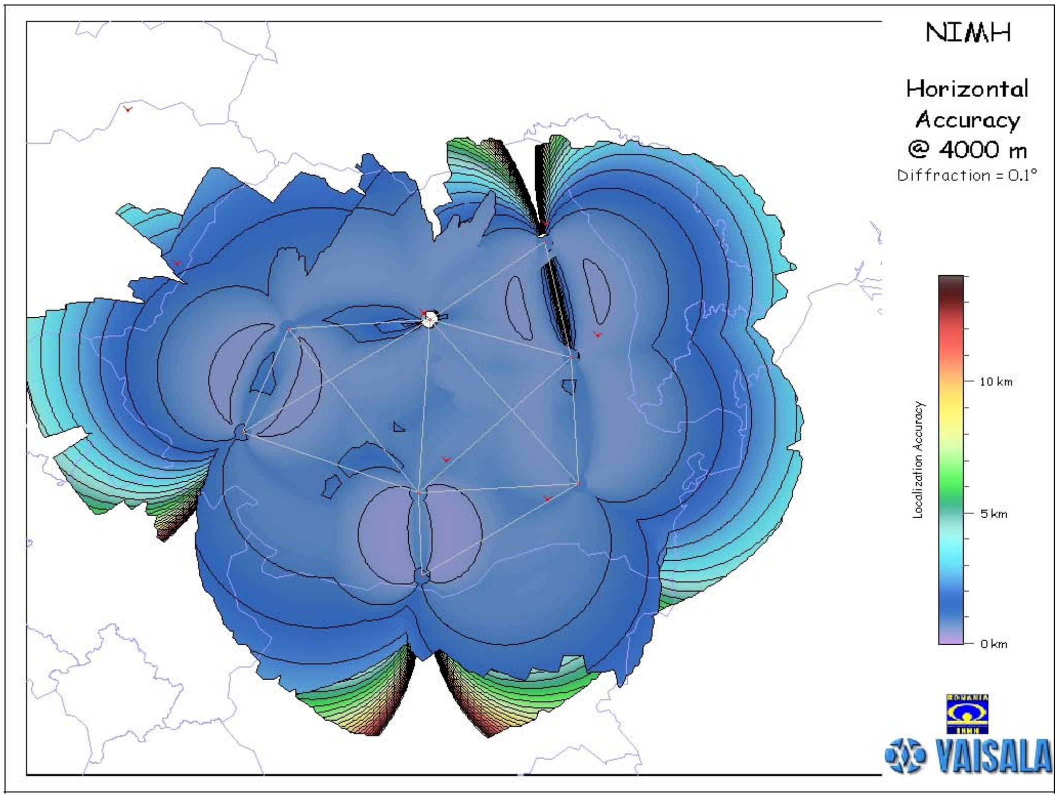

Figure 6 - Simulation of coverage and accuracy at an altitude of 4000m, with 8 HR SAFIR 3000 stations

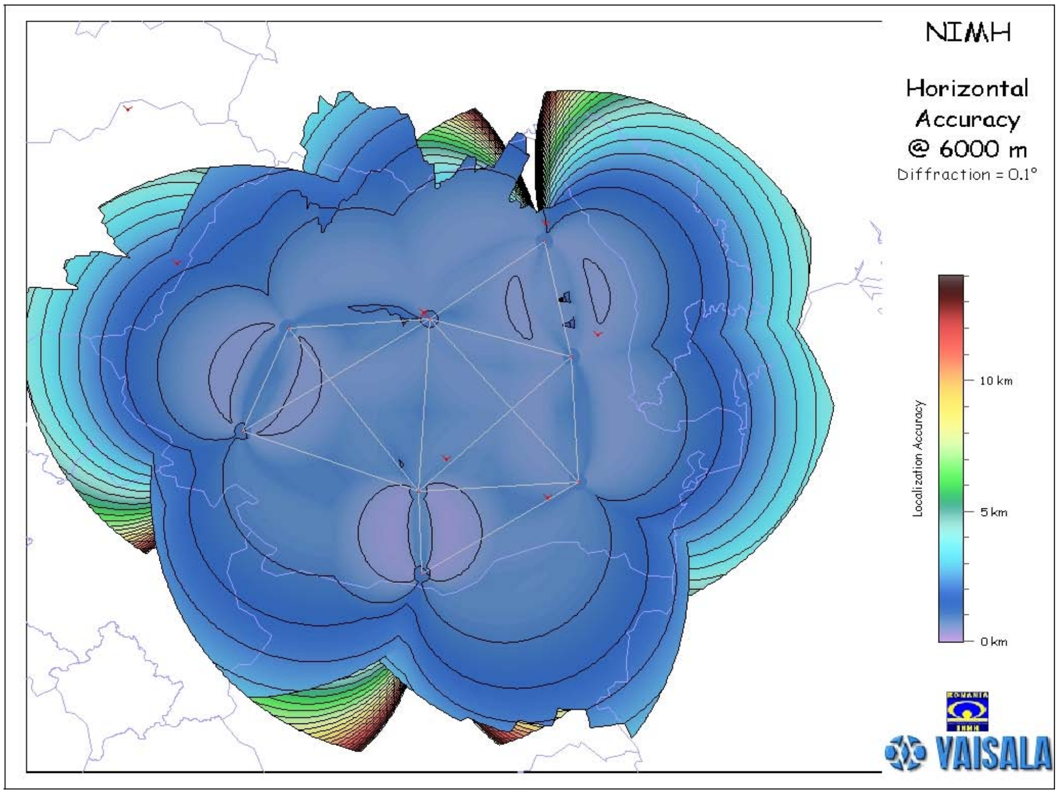

Figure 7 - Simulation of coverage and accuracy at an altitude of 6000m, with 8 HR SAFIR 3000 stations

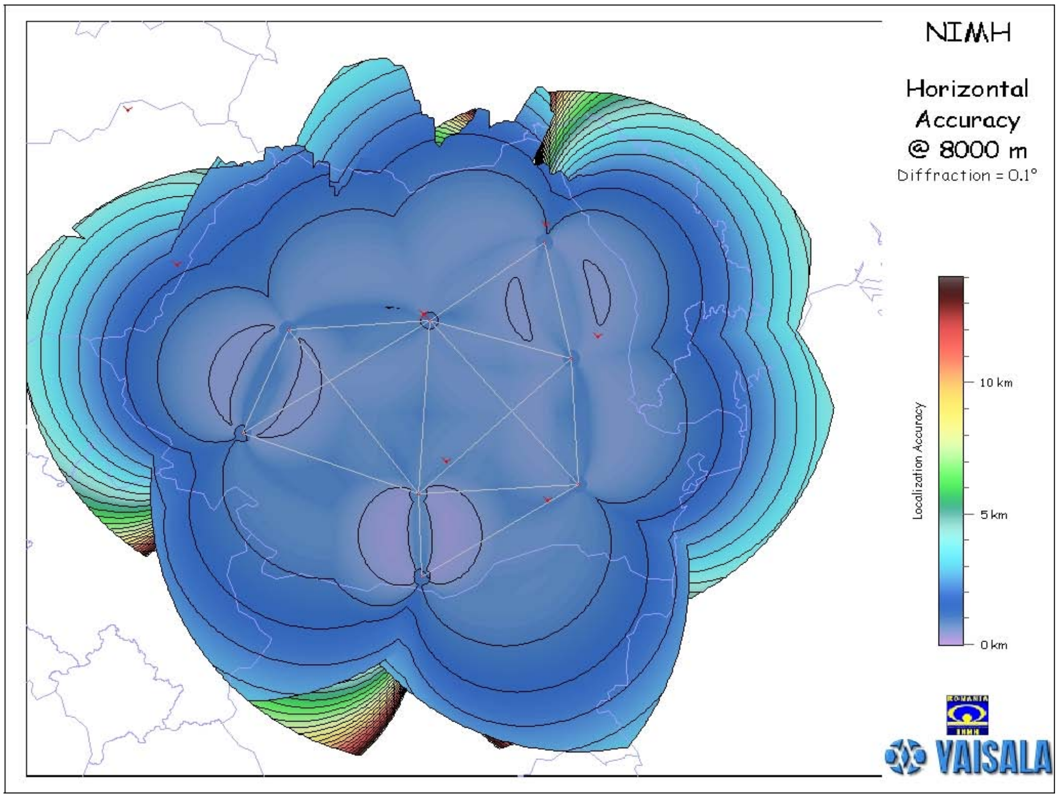

Figure 8 - Simulation of coverage and accuracy at an altitude of 8000m, with 8 HR SAFIR 3000 stations

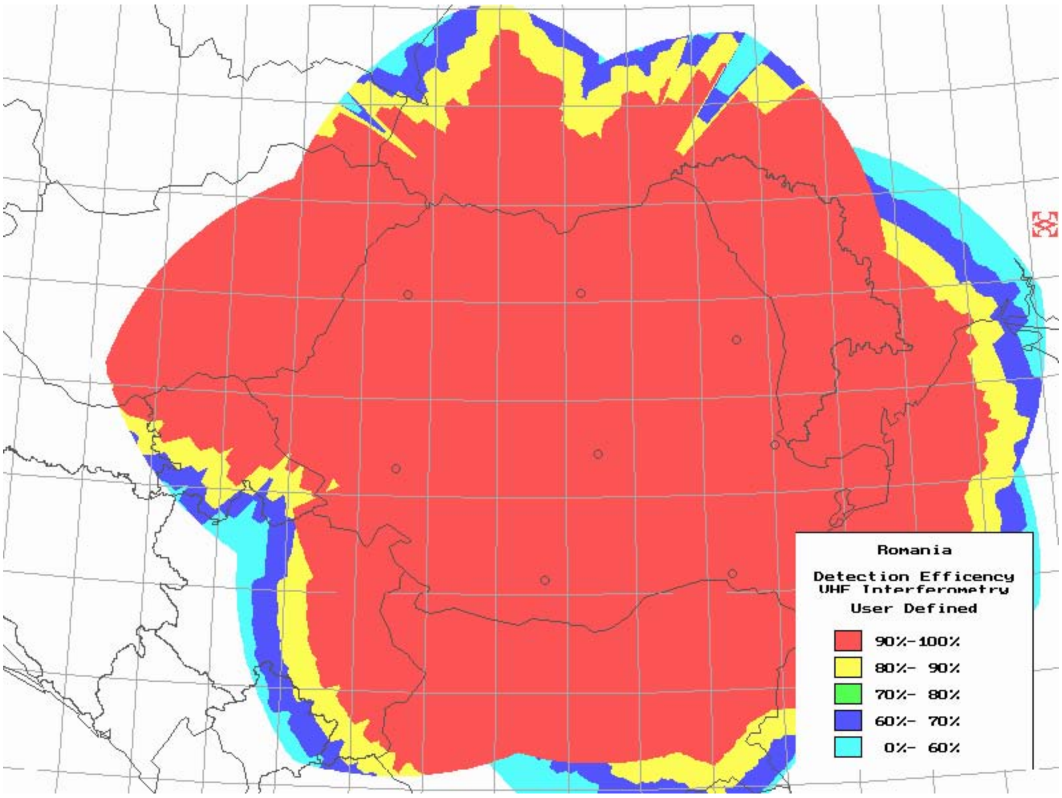

Figure 9 - Simulation of Total Lightning Detection Efficiency (Cloud to Ground and Intra Cloud lightning) with 8 SAFIR detection stations over Romania

7. Communication network

In order to be able to perform data collection and transmission and to preserve the timeliness of the data, any meteorological system needs a communication network specially designed in accord to the volume of the data transported, number of sites, other types of traffic involved in the network (like voice / IP, e-mail, internet, administration etc.).
In the frame of SIMIN project a WAN was designed and implemented taking into account the above mentioned criteria. The support of the WAN is a mesh VSAT network, with 12 terminals: 2 at RNMA HQ (for redundancy reason), 6 at the RFCs and 4 at the S-band radar sites. This network sustains both operational data traffic and voice traffic necessary for administration. The routing and switching equipment is provided by CISCO. The figures below provide the topologies of the WAN and LAN at the RNMA HQ.

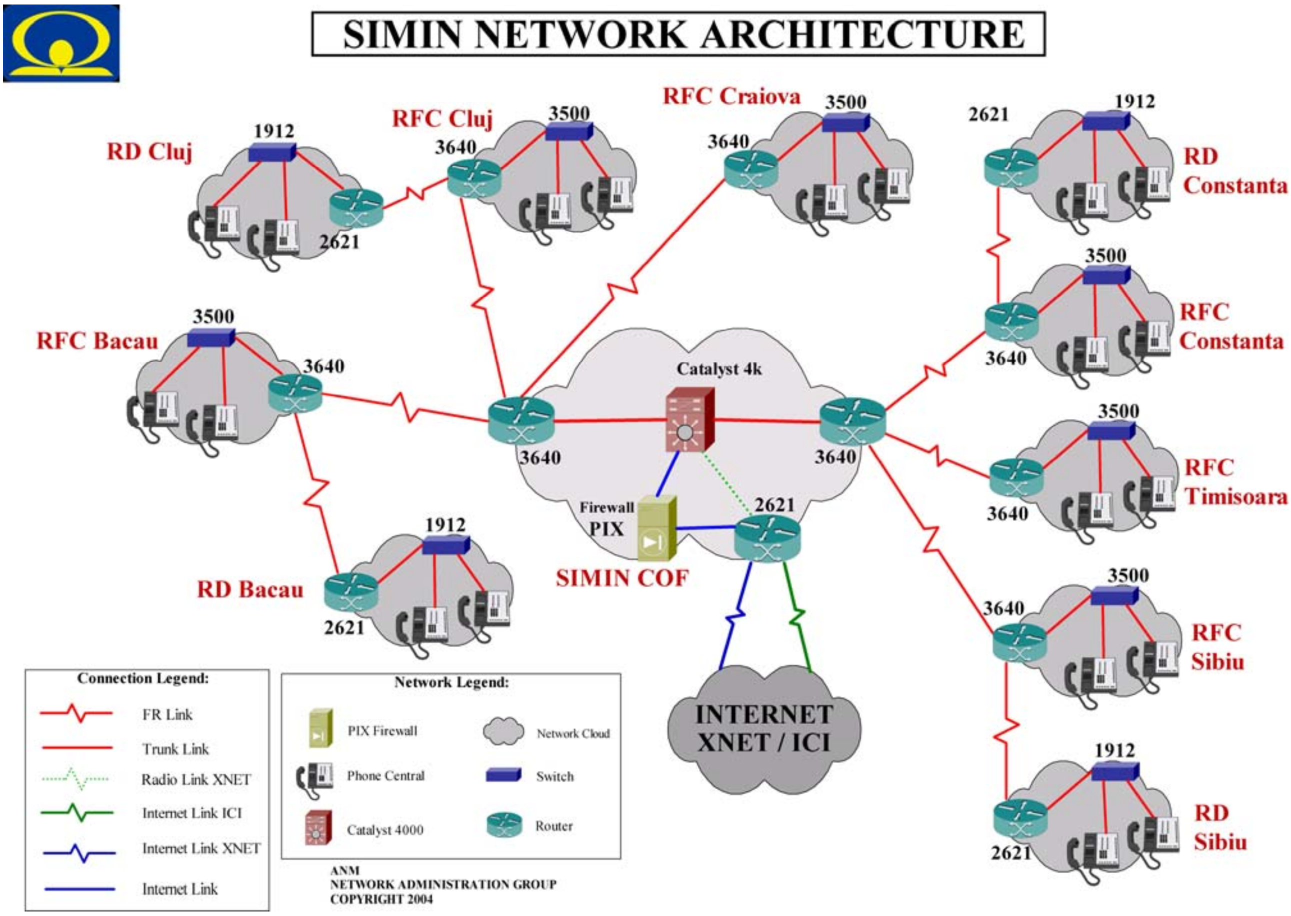

Figure 10 – RNMA WAN topology

Considering the importance of the communication network for a meteorological system, during 2004 RNMA implemented a back-up solution for the VSAT network. The back-up is in fact a VPN that includes all site locations and few others. When the VSAT network is functioning normal, the VPN is used for off-line and administrative traffic (like e-mail, Internet etc.), but in case a PVC is going down, the back-up correspondent connection comes up automatically and drops all non-operational traffic.

During the last couple of years, a special attention was paid in developing the IT&C domain: acquisition of new switching equipment (CISCO), renewing the computer fleet, performing security audits in order to better protect the WAN/LAN against inside and outside threats, etc.

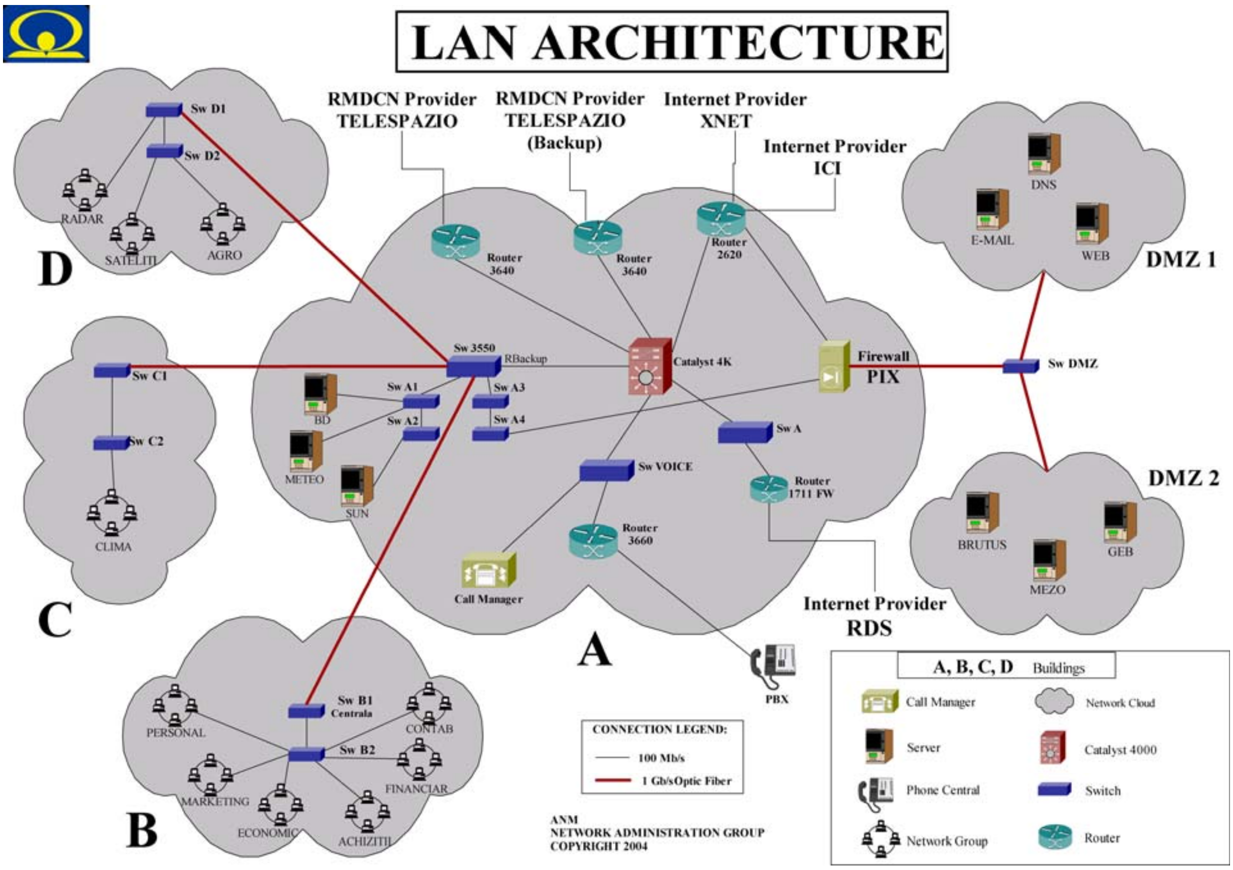

Figure 11 – RNMA HQ LAN topology

8. Conclusion and up-grade perspectives

As presented in this paper, RNMA made a lot of efforts since 1998 to continuously develop and modernize its observational system. In some domains (like radar and lightning detection) the progresses are spectacular and in others (like upper-air or ASOS) the progress is visible but it takes more time to be completed.
Below is synthesized the RNMA strategy for each domain included in this paper:

- Radar network. Some of the radar equipments are becoming obsolete (due to the analog receiver used and because dual-polarization feature is absent). The plan for the oldest systems (those installed in 2000) is to be up-graded to dual-polarization and digital receivers. Eventually, in the next 5 years, dual-polarization will become a standard for any operational radar equipment. Another directions that RNMA will pursuit in the future are integration of the radar data in NWP models and increasing the accuracy of the precipitation data measured by the weather radar;
- For the surface observation network, it is obvious that, over the next couple of years, the automatization of the surface observations will become a priority for all meteorological services. This is the case also for RNMA, but this process takes time and money. Another direction of modernization is to up-grade the existing ASOS with new sensors or to up-date the existing sensors;
- The upper-air sounding domain is evolving a little bit slower. The priorities in this domain would be increasing the number of sounding stations and soundings performed at each station, keeping the sounding equipment up to date and evaluation and implementation of the new techniques (for example using the upper-air data provided by the commercial aircrafts);
- In the meteorological satellites domain, RNMA plans include implementation of all MSG products in the operational activity, using data supplied by other satellites for meteorological applications, integration of the data into NWP models;
- About lightning detection network, RNMA plans to keep the hardware up to date and to obtain more products from the LDN data, both for internal use and for other customers;
- For the IT&C domain, RNMA will try to keep as close as possible to the international evolution of this domain.

SIMIN - THE INTEGRATED SYSTEM FOR METEOROLOGICAL SURVEILLANCE, FORECAST AND ALERT IN ROMANIA

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Abstract

The Project Team led by The National Administration of Meteorology (ANM) and Lockheed Martin, has integrated current technologies in weather radars, automated weather observation stations, lightning detection networks, weather satellite reception, numerical weather prediction models, hydrological buoys, forecaster decision/display systems, and various forms of telecommunication. The Project Team has successfully integrated state-of-the-art, commercial-off-the-shelf (COTS) technologies and products with the resources of Romania's existing legacy meteorological infrastructure.

SIMIN provides a turn-key integrated national system that modernizes ANM's capability to detect, monitor and forecast meteorological phenomena and the resulting hydrological impacts, and elevates Romania to a regional leadership position in weather prediction for the 21st Century. SIMIN has upgraded the ANM sensor network and fully integrated with the existing sensors to provide comprehensive national coverage of all observation types. SIMIN has upgraded the ANM meteorological processing capabilities including fully integrated and highly automated Forecasting and Nowcasting workstations for national, regional, and defense forecasting operations. Enhanced NWP platforms support ALADIN and MM5 mesoscale modeling. Observational processing supports real-time surface observation validation and climatology database archiving for the nation.

SIMIN has upgraded the ANM communication infrastructure to support real-time collection and distribution of meteorological data and products throughout Romania. This includes LAN/WAN upgrades for ANM sites, as well as message processing upgrades for internal and external data exchange. SIMIN has supplied over 75 local and remote Briefing Terminals to End-Users throughout the Romanian Government, to ensure all information promptly reaches critical decision makers.

1 Introduction*

Romania, despite its relatively small area, has a substantial variation in its terrain and other factors influencing the airflow dynamics. The hilly and mountainous areas are strongly affected by flash flooding, and all areas are subject to diverse conditions ranging from severe thunderstorm with hail in summer, to heavy snowstorms in winter. Upgrading and integrating the various environmental and meteorological sensor data to provide a comprehensive understanding of the rapidly evolving environment and its impacts on human activities, is a necessity for achieving the modernization plan of the Romanian Authorities for Waters and Environmental Protection.

In November 2000, the Romanian National Institute of Meteorology and Hydrology (INMH) began the first stage of the plan to modernize Romania's capabilities for detecting, monitoring and predicting meteorological and hydrological phenomena affecting Romania, by implementing the *National Integrated Meteorological System - SIMIN* project. SIMIN addresses Romania's primary objective of modernizing and integrating the nations various resources and real-time detection capabilities, and also facilitates the exchange of data at the Local, Regional, and Global levels.

2 Program Overview

The Project Team led by INMH and Lockheed Martin, has integrated current technologies in weather radars, automated weather observation stations, lightning detection networks, weather satellite reception, numerical weather prediction models, hydrological buoys, forecaster decision/display systems, and various forms of telecommunication. The Project Team has successfully integrated state-of-the-art, commercial-off-the-shelf (COTS) technologies and products with the resources of Romania's existing legacy meteorological infrastructure. SIMIN provides a turn-key integrated national system that modernizes INMH's capability to detect, monitor and forecast meteorological phenomena and the resulting hydrological impacts, and elevates Romania to a regional leadership position in weather prediction for the 21st Century.

SIMIN has upgraded the INMH sensor network and fully integrated with the existing sensors to provide comprehensive national coverage of all observation types. SIMIN adds 5 WSR-98D S-band radars, 60 AWOS stations, Meteosat 7 and MSG satellite receiving stations, an 8 sensor Lightning Detection Network, 4 Aviation Weather observation stations, and 11 meteo/hydro observations buoys.

SIMIN has upgraded the INMH meteorological processing capabilities including fully integrated and highly automated Forecasting and Nowcasting workstations for national, regional, and defense forecasting operations. Enhanced NWP platforms support ALADIN and MM5 mesoscale modeling. Observational processing supports real-time surface observation validation and climatology database archiving for the nation.

SIMIN has upgraded the INMH communication infrastructure to support real-time collection and distribution of meteorological data and products throughout Romania. This includes LAN/WAN upgrades for INMH sites, as well as message processing upgrades for internal and external data exchange.

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SIMIN has supplied over 75 local and remote Briefing Terminals to End-Users throughout the Romanian Government, to ensure all information promptly reaches critical decision makers.

3 SIMIN System Architecture

The SIMIN system is a distributed architecture with one national center, connected to multiple regional sites. It supports all types of users, with a suite of tools dependent on the operational need of each user. Figure 3-1 illustrates the top level SIMIN architecture, showing the primary forecasting sites and sensor locations.

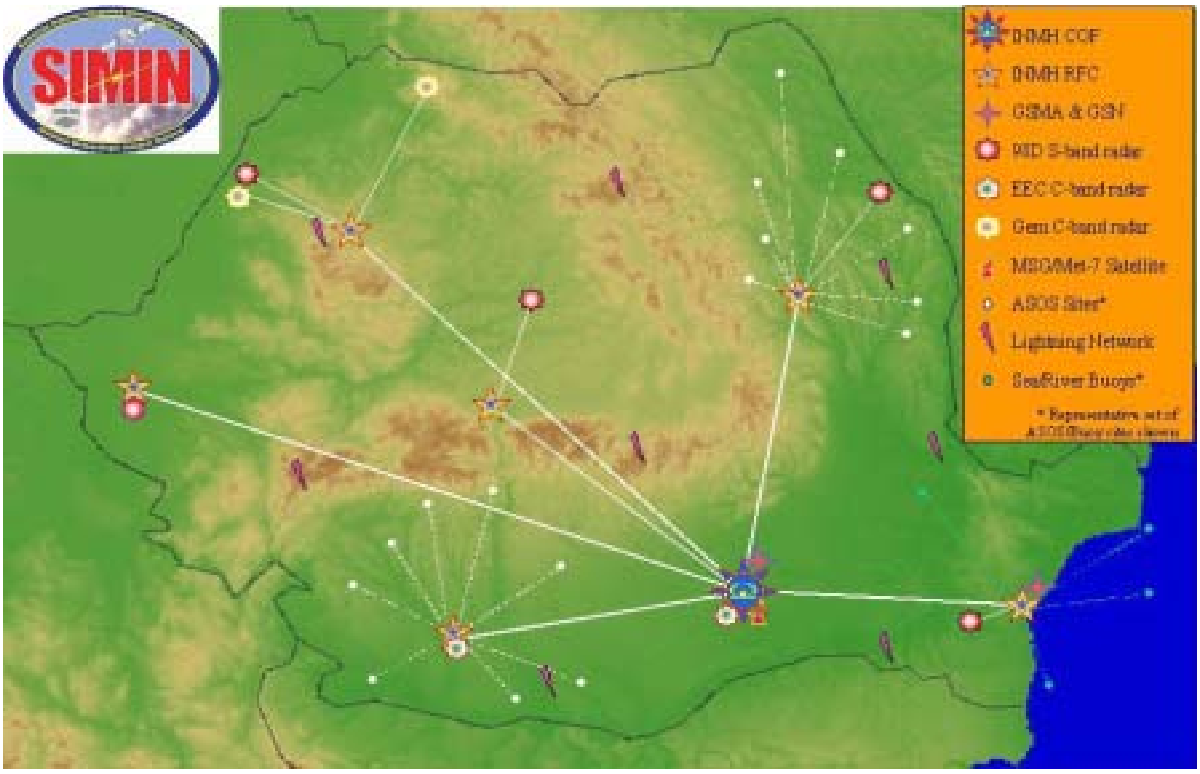

Figure 3-1 SIMIN National Architecture

3.1 Sites and Users

SIMIN sites are categorized as one of five types. The types are the Central Operations Facilities (COF), Regional Forecast Centers (RFC), Forecast Product Centers (FPC), Sensor Sites, and Associated Subscribers (AS). INMH maintains the responsibility for Fundamental Forecasting supporting the nation. The SIMIN COF is located at the INMH national headquarters in Bucharest. The COF has responsibility for national forecasts, system wide coordination, international cooperation and agency policy control for INMH. There are six (6) RFCs located throughout the country, with regional data collection and forecast responsibility.

Other forecasting users of SIMIN include Forecast Product Centers (FPC) that support specific Tailored forecast operations. This includes forecast operations at the General Staff of Military Aviation (GSMA) and General Staff of Navy (GSN). These agencies coordinate the specific needs of their organization, utilizing the national resources available from the SIMIN sensor network and integrated applications.

Non-forecaster end users of SIMIN include many users throughout the country providing various Operations Support functions. This includes users at the Ministry of Agriculture (MOA), Ministry of Transportation (MOT), Ministry of Interior (MOI), Civil Protection, Ministry of Defense (MOD) and various other agencies reporting to these organizations. These users utilize the products and information provided by INMH in conducting their daily operations, through the use of Briefing Terminals, receiving product from the appropriate forecasting site.

Operations and Maintenance users at all locations support the continued administration of all system equipment including sensors, computers, networks, and software applications. This allows SIMIN to remain in continuous operation, supporting all national needs.

3.2 SIMIN Sensor Network

SIMIN has upgraded the INMH sensor network and integrated with the existing legacy components to provide comprehensive sensor coverage.

The classical Surface Observation network has been upgraded to integrate sixty (60) Automated Weather Observation Stations (AWOS) from Vaisala, in addition to twelve (12) existing automated stations, at strategic locations throughout the country. Another 88 surface observation stations remain in operation as manual stations. All automated and manual stations are integrated to comprise the Romanian Surface Observation Network.

The previously existing 1960s era weather radars used throughout the country, have been replaced with WSR Doppler radars. SIMIN integrates five (5) WSR-98D S-band radars with four (4) existing C-band* radars, to form a 9 radar network. The WSR-98D is an upgraded version of the WSR-88D systems used in the US NWS network. The existing C-band radars (2 from EEC and 2 from Gematronik*) have been integrated into the SIMIN national radar network. Data from the C-band radars is converted to 88D/98D formats, to facilitate integration with all applications in the system. National radar mosaic products are also produced to provide a national scale view of phenomenon detected by radar. This allows full national coverage to be provided by the radar network, plus nearly 150Km across the boarders of all neighboring countries, with accessibility to all products by all appropriate users.

SIMIN provides new satellite receiving systems to support real-time collection of METEOSAT 7 satellite imagery, as well as a receiving system for the new MSG satellite. These receiving systems are provided by VCS Engineering, Germany. This dual system supports continued operation during the transition from METEOSAT 7 to MSG. Imagery from both satellites is collected, formatted, and distributed to all forecasting sites as appropriate. Products from an existing NOAA receiving system are also collected and distributed throughout the system for use in forecast operations.

SIMIN provides an eight (8) sensor Lightning Detection Network (LDN), using the SAFIR sensor technologies supplied by Vaisala. The network provides national coverage at approximately 1Km accuracy, for both cloud-to-cloud and cloud-to-ground lightning. The information received from the LDN is distributed throughout the system in near real-time to support integrated forecast operations.

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* From two commercial suppliers of C-band radars.

* At the time of this writing, only one Gematronik radar has been installed by the previously existing contract.

SIMIN provides eleven meteorological/hydrological buoys in two configurations, provided by AANDERAA. Three (3) are in a sea configuration for use on the Black Sea. Eight (8) are in a river configuration for use along the Danube River. The river sites also include a water level sensor nearby the buoy location.

3.3 Communications

SIMIN uses a three-level data collection and distribution architecture, interconnecting all INMH sites and end user locations. Sensor data is collected from the sensor sites to an RFC. The COF then collects all relevant data from each RFC in the nation. Data collected from regional sites, is combined with data collected or generated at the COF, for distribution to all forecasting operations sites. This combined data stream of common shared data is called SIMINcast*.

Various communications technologies are used for the collection and distribution of data, dependent on the bandwidth needs, cost of operation, and end user requirements.

3.3.1 VSAT WAN Communications

The primary high bandwidth site-to-site WAN communication used between INMH sites in SIMIN is a Very Small Aperture Terminal (VSAT) satellite system, interconnecting the COF to all RFCs and 98D radar sites. The VSAT supports multiple channels or Permanent Virtual Circuits (PVC). This configuration allows the establishment of a private network with channels independently configured for the needs of each data link. Each link supports TCP/IP protocols, to allow standard applications to communicate over the distributed system WAN.

The SIMINcast PVC uses the Multicast Dissemination Protocol (MDP) for the distribution of high bandwidth data to the remote RFCs. MDP provides guaranteed delivery of all data to all sites, while minimizing overhead. The SIMINcast MDP is set to distribute data at rates up to 312Kbps. This architecture provides excellent distribution performance for the SIMIN network. For example, measurements of the distribution times for radar data distributed from the COF indicate all radar products reach the remote RFCs in an average of 37 seconds.

3.3.2 International Data Communications

The existing INMH interface to GTS and other international data circuits was provided by a Messir-Comm from COROBOR, France. SIMIN provided hardware and software upgrades, in order to improve overall performance and throughput. SIMIN uses Messir-Comm as the external data source, and integrates this data into the data communications environment.

3.3.3 Internal Data Communications

Data communications internal to SIMIN is controlled by the Communications Gateway (CG), provided by Harris Corp. The CG controls all internal data collection from SIMIN sources and external data from Messir-Comm. It then controls routing of all data to all applications internal to the INMH COF and RFC sites, and the FPCs. The COF CG controls the SIMINcast distribution of data throughout SIMIN.

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* For illustration purposes, users in the US may think of SIMINcast as being similar to NWS NOAAPORT.

3.3.4 Surface Observation Communications

The collection of surface observations from the new AWOS as well as manual stations, to the RFC is performed using GSM mobile phone SMS text messaging technologies. This provides a convenient and cost effective means to collect the very low bandwidth surface observations, without the need for developing an independent network. The GSM mobile phone market in Romania currently provides adequate coverage of all sites in the observation network, with excellent reliability.

3.3.5 Lightning Network Communications

The collection network for unprocessed lightning data in the LDN uses a low bandwidth VPN, over the GSM mobile phone network. The LDN requires continuous TCP/IP connectivity from each sensor to the central server in Bucharest, at data rates of 32Kbps to 64Kbps for each sensor. The GSM network selected for this application has proven to be reliable and cost effective.

3.3.6 End User Product Communications

The distribution of end user products from the INMH forecast product site to remote AS end user Briefing Terminals is conducted via various VPN and dial-up connections, depending on the end user needs. This connection is a low bandwidth connection, requiring approximately 28.8Kbps for the average site. Special point-to-point applications ensure products are delivered to all online users as quickly as the available bandwidth will allow.

4 Surface Observation Processing

Within the SIMIN project a Surface Observation Processing (SOP) application has been developed to support the collection, validation, and distribution of all surface observations in the country. The SOP was developed by a local Romanian company, in cooperation with INMH, ensuring the data processing for all Romanian surface observation stations, either automated or manual.
Generally the SOP is quite similar with the old procedure available in INMH, involving three levels of processing sites: local, regional and central.

4.1 SOP Local site

When there is an automated station the Local Site SOP application (SOP-LS) retrieves raw measured data and derived data calculated in the station, for further processing, decoding, local display, and archiving. Messages are generated from the measured parameters and supplemented with human observations, then automatically sent to the Regional Collecting Center using GSM/SMS text messaging technology. The SOP-LS supports all automated stations within SIMIN, including the new Vaisala MAWS 301 and 201 stations, and previously existing automated stations from various suppliers including Vaisala MILOS 500, Vitel 1040, Thies AWS 7800, and Thies DL 15. From the manual stations, messages are entered by the observer into a mobile phone, and sent as GMS/SMS text messages to the Regional Center.

4.2 SOP Regional Collection

The Regional Collection SOP application (SOP-RC) collects hydro-meteorological messages sent from all automated and manual observation stations assigned to the Regional Center. It supports manual data editing and validation of the received data and generates collective messages of multiple stations in standard formats, according to WMO regulations and national practices. All data are decoded and stored in the local database, allowing the display in alphanumeric and graphic format. Messages are automatically sent to the National Center via the SIMIN Communications WAN.

4.3 SOP National Collection

The National Collection center SOP application (SOP-NC) supports all required capabilities of the SOP-LS and SOP-RC applications, with additional features to support national operational responsibilities.

4.4 SOP features

While the SOP application set follows the same logic as the old INMH procedures, they involve a higher level of sophistication and capabilities characterized by the following features:

- High flexibility in defining new message types (alert, rain, agricultural, climatological, free text, etc.) and templates, new variables, etc.

- Calculation of a large amount of derived parameters from the measured data;

- Pre-configured time schedule for collection, generation, sending, and receiving of messages;

- Parallel use of raw data formats for data exchange between SOP applications, ensuring higher level of data precision and compression, and standard formats for data exchange with other applications;

- The possibility of local configuration and control of all applicable parameters and features of the sensor stations associated with command, control, status, and calibration;

- A real-time display to allow the operator at local sites to continuously monitor the measured meteorological parameters, including alphanumeric and graphic display capabilities;

- The collection center SOP-RC/NC can automatically interrogate certain automated stations that do not have a local PC and SOP-LS application;

- The collection center SOP-RC/NC can interrogate a missing station to request data, and accept the raw data returned, in case messages are not reported by user pre-configured time schedule;

- The collection center SOP-RC/NC can activate a higher frequency of data collection and message transmission for any selected site, in special situations;

- All SOP levels provide a more elaborate data validation process, depending on the application level including features such as;

    - Verification of message formats from manual stations;

    - Multiple correlations between measured and observed parameters

    - Temporal validation by graphical visualization of the parameter evolution for each station, for a user specified time interval and time step, with the possibility to correct any value;

- Spatial validation by visualization in one or more geographically plotted forms: i) one or more parameters via the Bjerknes scheme, ii) time differences for a given parameter at two selected times, iii) variance from climatological values, for a given parameter; iv) the sum of a selected parameter for a given interval;

- The SOP-NC also provides comparison with INMH forecast model outputs.

5 Radar Operations Transition

Before October 2000, the Romanian weather radar network consisted of ageing manually operated radar systems. Specifically the Russian MRL-2 and MRL-5 equipment was used. The disadvantages of such equipment were the obsolete technologies, the manual exploitation of the system, and the large amount of time necessary for processing and distribution. The MRL-2 was designed in 1967 and the MRL-5 in 1972, thus repair and maintenance was always an issue. Manual operation forced the radar operator to sit in front of the radar display and draw the radar echoes on paper by hand. The manual collection also required a large amount of time necessary for acquiring the radar information, putting it on a paper map and disseminating to the end-users. Therefore, radar data was not available in real-time. Every three hours, on the basis of the local information received from the component systems of the network, the National Radar Center at the INMH headquarters created a national radar mosaic, also in analog paper map format. Figure 5-1 represents an example of national radar mosaic product used till recently by INMH.

The first step of the national network modernization was achieved in October 2000 when two modern systems manufactured by Enterprise Electronics Corporation (EEC) were commissioned in the Southern part of Romania. These two systems met the criteria imposed by the EUMETNET GORN and OPERA programs for harmonizing and improving the exchange of the data from operational weather radars in Europe. For the first time, in 2000 Romania had its first regional radar mosaic, with only two systems, and updated every 20 minutes. Figure 5-2 represents an example of the first stage radar mosaic covering the southern portion of the country.

The second step was early 2001 when Romanian Water Authority (RWA) installed and commissioned another radar system. This equipment is manufactured by Gematronik (METEOR 500C type) and currently is operated also by INMH. It is anticipated that in late 2003 or early 2004, RWA will install a second Gematronik METEOR 500C in the Northwestern part of Romania. Before the SIMIN integration, these radars were not included in the national network.

SIMIN has concluded the transition of the Romanian weather radar network from exclusively manually operated and obsolete systems, to one of the most modern and unique radar networks in the world. SIMIN has installed five (5) new and modern WSR-98D S-band radar systems, to complete the national network. The WSR-98D system, from the Beijing Metstar Radar Co., is based on the technology and meteorological algorithms developed over more than 30 years in the US NEXRAD network. It generates an impressive suite of more than 70 products, including both base and derived products.

The SIMIN added value consists not only in installing the new WSR-98D radar systems, but also in bringing the power of a reliable radar network and integration of the existing digital systems (EEC and Gematronik) into this network. In this respect, Romania is one of very few countries that has fully integrated three types of radar equipment into one integrated network.

Currently, SIMIN produces individual site radar products every 6 minutes, depending on the radar and mode of operation. Three types of national radar mosaics are produced every 10 minutes. The available national radar mosaic products include first tilt base reflectivity, echo top and composite reflectivity. The fact that Romania has three radar products at a nationwide scale is another unique feature of the SIMIN radar network. Figure 5-3 illustrates an example of a current Romanian National Radar Base Reflectivity Mosaic product.

Using the communications infrastructure, all radar products may be made available anywhere in the system in near real-time. This includes the COF, RFC, FPC, and AS sites, culminating with a variety of special integrated displays developed for real-time interpretation of radar data in Nowcasting and Forecasting environments. These applications range from the versatile 98D Principal User Processor (PUP), the OmniWeatherTrac and VIPIR advanced radar visualization, the Integrated neX-REAP workstations, and End User Briefing Terminals. As users of the system become more familiar with the available radar products, this real-time access to national radar information by all users will dramatically increase the early warning benefits to the nation.

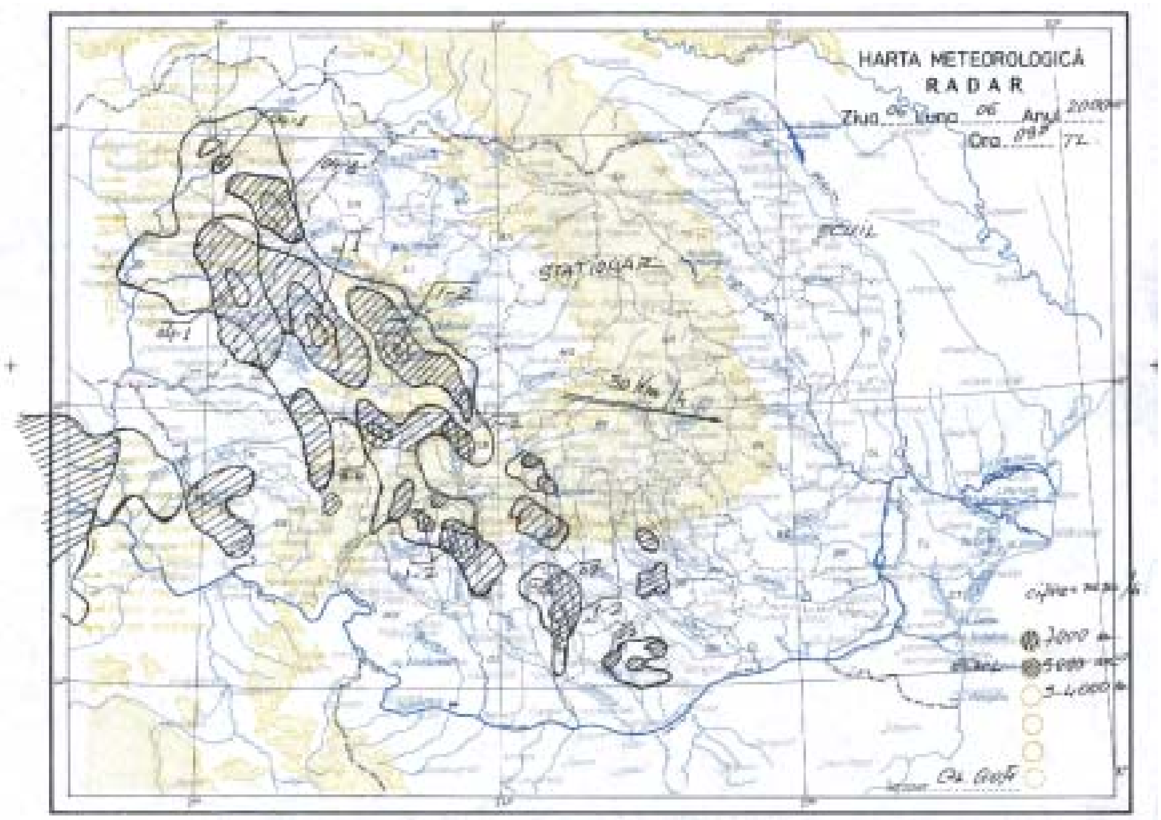

Figure 5-1 Manual National Radar Mosaic

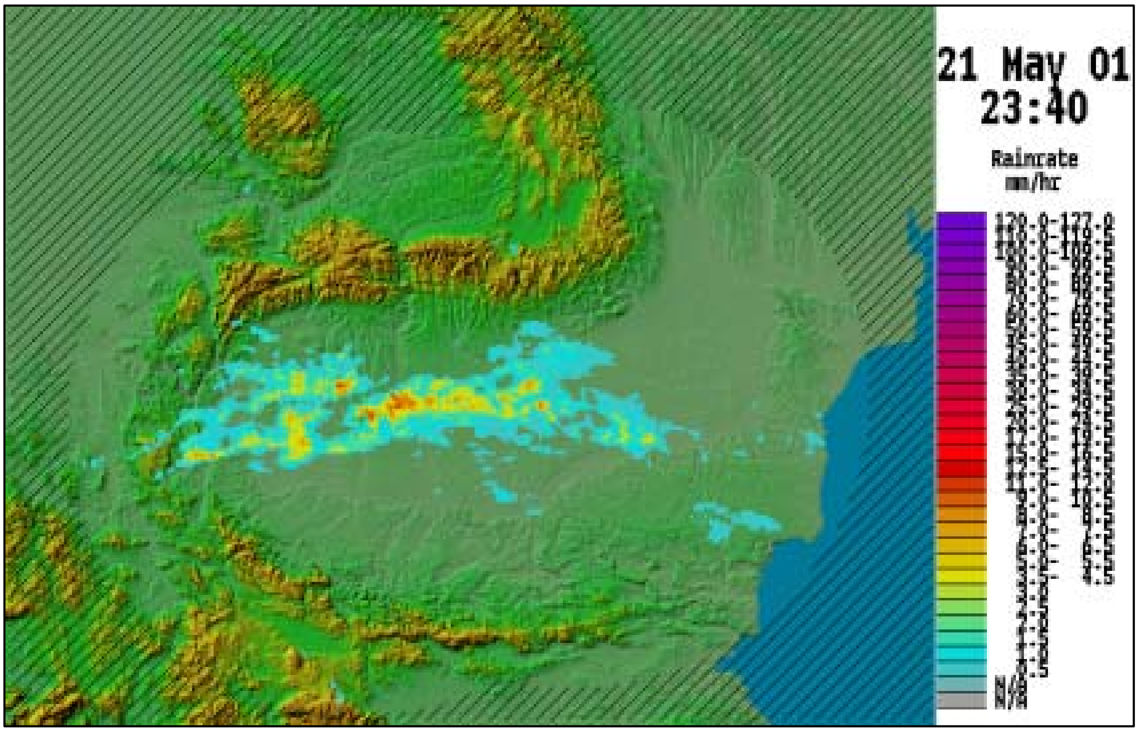

Figure 5-2 Initial Regional Mosaic with 2 Radars

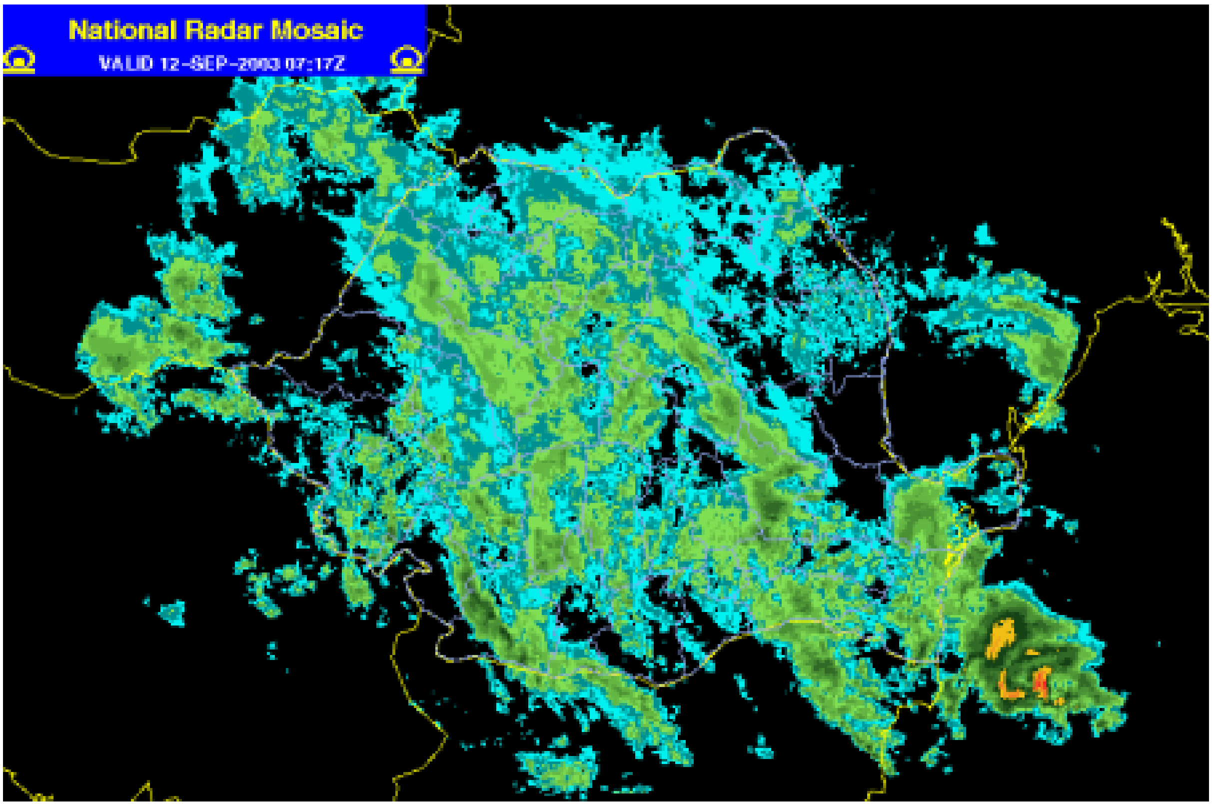

Figure 5-3 – One form of the National Radar Base Reflectivity Mosaic, from 07:17 UTC Sept 12th, 2003

6 Forecasting/Nowcasting Operations

SIMIN provides a variety of tools to support improvements to the existing INMH Forecasting and Nowcasting environments. This includes applications for numerical weather prediction, applications for advanced radar processing, and applications for integrated product generation, display and distribution of all meteorological data types. A key requirement for the Forecasting and Nowcasting upgrades was the need to support various types of forecasting operations, define products to user specifications, and distribute them to a wide variety of end users in different operating environments throughout the country. SIMIN also provides site-to-site voice communications via Voice-over-IP technologies on the VSAT WAN, which allows the INMH COF to hold daily teleconferences will all RFC forecast operations. This capability is essential to harmonizing the forecasts throughout the nation.

6.1 Numerical Weather Prediction

The basis of the national Numerical Weather Prediction (NWP) System of INMH is the ALADIN model, which has been developed within an international cooperation. The initial and boundary conditions are supplied by the ARPEGE global model from MeteoFrance. SIMIN provides an enhanced computing platform for the development and run time environment of ALADIN. While the new 8-CPU server environment is a modest platform by NWP standards, the enhancement allows significant improvements over the existing ALADIN environment. Thus the decrease of integration time has led to the transition from the model integration in lagged mode to a synchronous one. The improvements allow further upgrades to ALADIN to support a wider area of coverage, a greater resolution, and an increase in the number of vertical levels. In addition to ALADIN, SIMIN provides an implementation of the MM5 model for a domain large enough to fit the area covered by the radar network, with a lower resolution. The SIMIN MM5 implementation is coupled with the AVN model from the US NWS.

6.2 Forecasting Environment

The integrated forecasting environment of SIMIN centers on the Forecaster Workstation using the neX-REAP application, from Harris Corp., and is used in the forecast operations of the INMH COF, INMH RFCs and the FPCs at GSMA and GSN. NeX-REAP provides a wide variety of interactive tools to support forecast operations. This includes integrated processing of data from various sensor platforms and processing equipment including:

- Surface and Upper Air station data
- Alphanumeric products from WMO sources
- Various NWP Forecast models
- METEOSAT, MSG and NOAA satellite imagery
- Individual and Mosaic Radar products
- Lightning Strike information
- Manual vector graphic products
- Thermodynamic analysis products

Key features of the neX-REAP system are the ability to define the content of all products used in operations, and fully automate the product generation. This includes products used for forecast operations, as well as those for distribution to Associated Subscribers using Briefing Terminals.

These features provide the ability to highly automate the generation of a large majority of the routine products, leaving more time for detailed analysis and monitoring of developing conditions. The automated distribution of products allows a diverse set of end users to continuously receive real-time information in support of their specific operations. This includes users such as Civil Defense, Water Management, Transportation authorities, and many other governmental agencies.

6.3 Nowcasting Environment

The nowcasting environment of SIMIN centers on the display and advanced processing of radar information available in the Romanian National Radar Network. The WSR-98D PUP provides the initial display of radar information. C-band radar products are converted to 88D/98D formats allow the PUP to display of products from all radars in the network. The Radar Product Integrator* application set from Baron Services Inc., BSI, provides the foundation of the nowcasting environment at the INMH COF and RFCs. The RPI provides a unique combination of real-time radar processing, enhanced 2D and 3D visualization, and automated product distribution and alert messaging.

The RPI provides real-time processing and display of radar information with capabilities designed to enhance early warning to the public. This includes display of street level mapping for all cities in Romania, allowing warnings to occur at the local level.

The RPI includes an integrated implementation of a hydro-static NWP model*, to provide current and forecasted value-added radar products, such as precipitation types and accumulation amounts. These advanced products provide situational awareness to Nowcasting operations, greater than what is possible with radar information alone.

The Nowcasting environment also includes a Forecaster Workstation with the neX-REAP application to provide a full set of integrated information to this environment. Generation of a standard product set is also possible using the Forecaster Workstation.

The RPI integrates the Open RPG environment for the C-band radars, to allow production of standard 88D/98D product set.

6.4 Transition Issues

As might be expected, the largest issues faced by the INMH team during the transition to the new SIMIN environment, was the large influx of new technologies that must be learned concurrently with continued support of routine operations. To help alleviate these difficulties, the transition was planned to take place in three phases; Initial Products, Enhanced Products, and Final Products. The entire transition spanned a 12 to 15 month period, depending on the order of site installation. During this transition, on-site support from Lockheed Martin and appropriate subcontractors was provided to ease the transition into operations. This support included standard workshop activities, hands-on application guidance, and real-time trouble shooting assistance. Additional remote support was provided from all SIMIN team members. These actions helped to ease the difficulties that are always expected from the operational transition of a new system. Even with this assistance,

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* The RPI consists of various products from BSI, integrated specifically for the SIMIN environment.

* The MetModel is provided by BSI and Harris Corp.

it is only through the extensive dedicated support and commitment exhibited by the INMH team that the transition has been possible.

7 Benefits to Romania Resulting from SIMIN

The benefits brought by SIMIN to the Romanian meteorology are unquestionable.

Under the aspect of the meteorological infrastructure modernization, SIMIN complies with the intended purpose of achieving a National Integrated Meteorological System, comprising all the functional components of a National Meteorological Service, as illustrated in Figure 7-1.

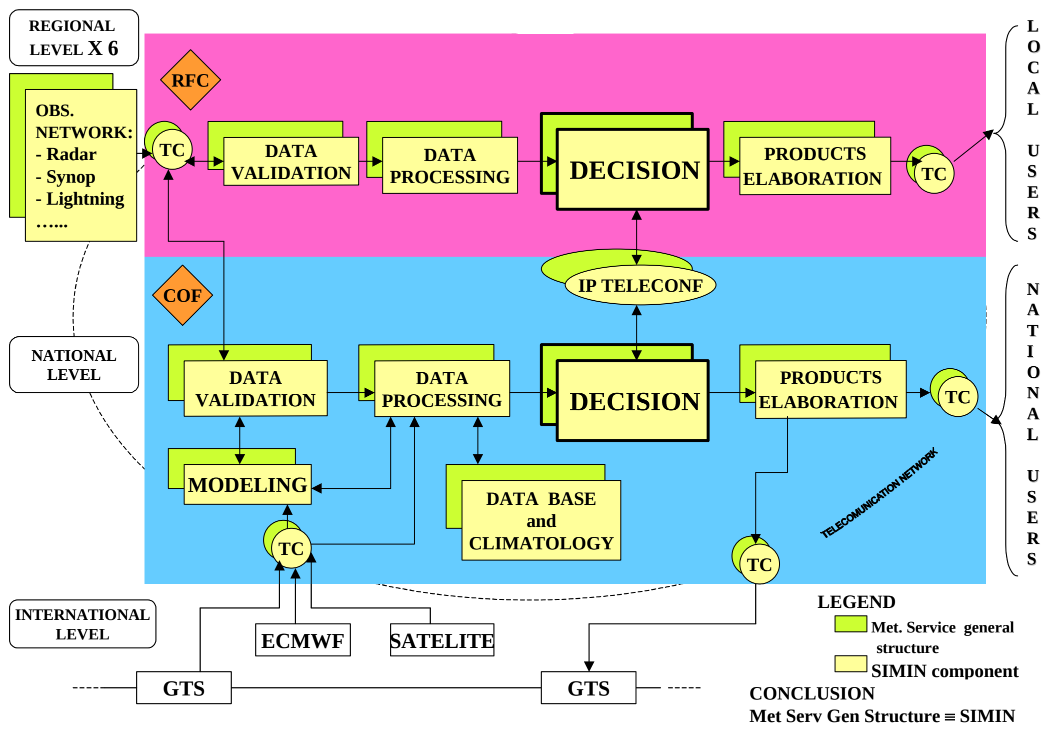

Figure 7-1 National Meteorological Service Components

The main benefit brought by SIMIN is materialized through increasing the capacity of response, the credibility and visibility of INMH – Romania, as the National Meteorological Service, acknowledged by the World Meteorological Organization (WMO) and the Romanian Law of Meteorology.

Any National Meteorological Service has two compulsory tasks:

- Ensuring the protection of life and goods in case of severe meteorological events; and
- Providing reliable, comparable long-term meteorological data series for substantiation and climatological studies for the present, and for the future generations.

In order to accomplish these compulsory tasks, the elaboration of meteorological warnings cannot be separated from the elaboration of weather forecasts, the product dissemination, and the interface with the users. Each of these activities is absolutely necessary within any functioning meteorological system. Figure 7-2 illustrates this principle.

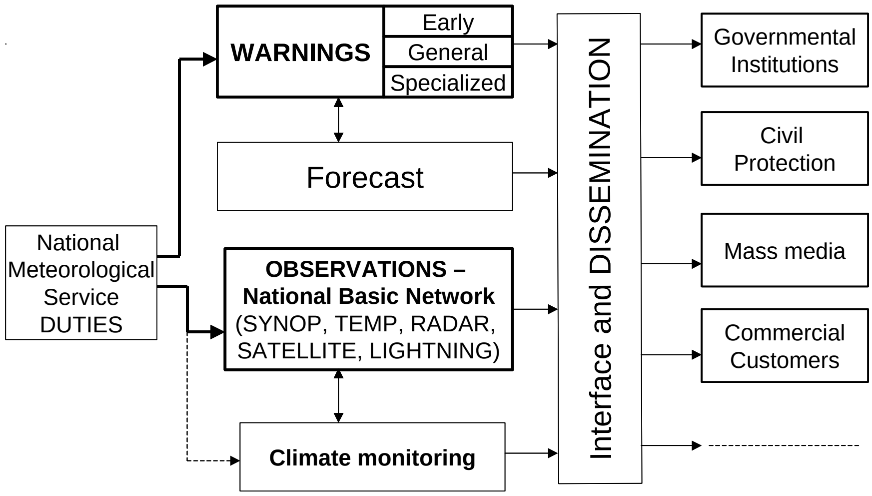

Figure 7-2 Mission Tasks of National Meteorological Services

These general requirements are entirely available for Romania that, on the one hand, always faces a large range of severe meteorological events, and on the other hand, has had a long-standing meteorological network, providing a very long series of observational data. But the historical database is an old-fashioned one, technologically speaking, and does not easily support significant advances in early warning.

Romania faces a wide variation in extremes of severe weather conditions. It receives heavy rains which generate floods over large surfaces, and also extremely dangerous flash floods, which are hard to predict / localize. There are also strong wind events, sometimes with a tornado-like aspect, generating damages in the forest-related sector and destroying / deteriorating buildings. The electric discharges also cause loss of life every summer. During the winter the snowfalls and associated strong winds generate transportation damages and other severe impacts.

The WMO statistics for 2002, World Meteorological Organization, Bulletin Vol. 52, No. 3, July 2003, situate Romania on a mean position both regarding the human life losses of 0.68 / mil. This positions Romania immediately after France and just ahead of Turkey, Belgium, Poland, and others, in terms of human casualties. (Reference Table 7-1) The same WMO report provides national economic losses due to abnormal weather, with Romania recording 0.16% of GNI. This positions Romania after Austria, Germany, but ahead of Hungary, Italy, UK, etc., in terms of economic impacts. (Reference Table 7-2.)

The new S-band DOPPLER weather radars, the lightning detection network, the modern procedures of data processing and numerical modeling, and the telecommunication network of SIMIN provide a significant improvement in weather surveillance and meteorological forecasts to INMH. While many components have been available for some time, the operational transition of the fully functioning system has resulted in noticeable improvements in INMH ability to issue early warnings over the interval June 1st to September 30th 2003. Continued improvement is expected as the transition continues.

With respect to the national surface observation network, INMH – Romania has a network of 160 surface weather stations using a synoptic program. Most of these stations are able to provide observation series older than 25 years, and 44 weather stations recording observations older than 100 years (Table 7-3). In this domain, the 60 automatic weather stations included in SIMIN, the new data collection and validation system and the database server constitute components generating benefits.

Table 7-1 Weather Fatalities by Country

WMO Member	2002 Fatalities*	Population* (Millions)	Fatalities/ Million
Mongolia*	43	2	21.50
Costa Rica	30	4	7.50
Jamaica*	13	3	4.33
Peru*	76	26	2.92
Morocco*	79	29	2.72
Ecuador*	34	13	2.62
Cyprus	2	0.766	2.61
South Africa*	94	43	2.19
Hong Kong*	14	7	2.00
Chile	28	15	1.87
Russia	264	146	1.81
Czech Republic	18	10	1.80
Indonesia*	275	210	1.31
Brazil*	193	170	1.13
Uruguay	3	3	1.00
Saudi Arabia	19	21	0.90
Canada*	25	31	0.81
Papua New Guinea	4	5	0.80
France*	42	59	0.71
ROMANIA	**15**	**22**	**0.68**
Egypt*	33	64	0.52
Colombia	21	42	0.50
Turkey	28	65	0.43
Switzerland	3	7	0.43
Belgium	4	10	0.40
Madagascar*	5	16	0.31
Poland	11	39	0.28
Australia*	5	19	0.26
Lithuania	1	4	0.25
Denmark	1	5	0.20

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* Fatalities include those reported killed and missing.

* Populations from World Development Report 2002.

* Members marked with an asterisk gave numbers of fatalities associated with all reported events.

WMO Member	2002 Fatalities*	Population* (Millions)	Fatalities/ Million
Italy*	5	58	0.09
Bahamas*	0	0.302	0.00
Dominican Rep*	0	9	0.00
Kazakhstan*	0	15	0.00
Macao, China*	0	0.422	0.00
Norway*	0	4	0.00
Trinidad & Tobago	0	1.301	0.00
Venezuela	0	24	0.00
TOTALS:	**1238**	**1033**	**1.2**

Table 7-2 Economic Losses from Weather

Member	Loss (Mil US$)	GNI[1]	Loss (% of GNI)
Mongolia	137.8	0.9	15.31
Lithuania*	261.886	10.7	2.45
Jamaica	67.415	6.4	1.05
Australia	4078.225	394.1	1.03
Mauritius*	45.12	4.512	1.00
Chile	650	69.9	0.93
Guyana	5.3	0.667	0.79
Georgia*	20	3.2	0.63
Nicaragua	11.95411	2.1	0.57
Austria	1095	204.2	0.54
Germany	10 000	2 057.6	0.49
Canada	2 000.5	647.1	0.31
Trinidad & Tobago	10.62	6.477	0.16
ROMANIA	**61.268**	**37.4**	**0.16**
Uruguay	25	20.3	0.12
Hungary	37	47.5	0.08
Costa Rica	8.024	14.4	0.06
New Zealand	12.610837	50.1	0.03
Latvia	1.6	6.9	0.02
Italy	200.35	1 154.3	0.02
South Africa	15.055	129.2	0.01
Turkey	17	201.5	0.01
Congo	0.15	1.8	0.01
UK	78.125	1 463.5	0.01
USA	300.00000	9645.6	0.00
Sweeden	4.372	237.5	0.00
Marocco*	0.286	33.8	0.00
Bahamas*	0	4.533	0.00

[1] Gross National Income, GNI, in thousands of millions of US dollars. Formerly Gross National Product, GNP, GNI is the broadest measure of national income.

* Members marked with an asterisk evaluated losses in money terms for all reported events.

Member	Loss (Mil US$)	GNI[1]	Loss (% of GNI)	
Dominican Rep*	0	18.0	0.00	
Kazakhstan*	0	17.6	0.00	
Norway*	0	151.2	0.00	
Venezuela*	0	104.1	0.00	
2002 Totals	19 145	16 747	Mean	0.11%
2001 Totals	13 230	19 770	Mean	0.067%

Table 7-3 Observation Station History

Data series duration (years)	Number of stations	Of which:	
		Existing automatic stations	SIMIN automatic stations
≤ 25	19	-	6
26 – 50	32	-	6
51 – 75	49	5	14
76 – 100	16	2	8
101 – 124	40	2	25
≥ 125	4	1	1
TOTAL	**160**	**10**	**60**

8 A Black Sea Storm as seen by the SIMIN System

Since its installation, many meteorological events have been observed in the integrated SIMIN environment. A storm occurring 12th September 2003 has been chosen as an example of SIMIN capabilities. This storm was selected not only for its unusual characteristics, but also for its grave consequences. The remote monitoring of the meteorological phenomena over the Black Sea, a region with very poor classical observation data, was possible using the facilities offered by the SIMIN system. This Case Study provides a brief reconstruction of the events, and several sample products from SIMIN.

8.1 The Forecasts

On September 10th, after a long period of dryness, the forecast models and other information available within the SIMIN environment indicated that atmospheric instability and a probability of high precipitation would occur over the next three days. The Weather Forecasting National Center therefore released a Warning (nr. 67/2003) concerning the anticipated phenomena.

On September 11th, a large low-pressure area formed covering Central Europe, as well as the Central and Eastern basin of the Mediterranean Sea. All of the global atmospheric model results available at INMH (ARPEGE, GSM, ECMWF, UK-MET) showed the tendency of the extension of the cyclonic area over the Black Sea. The ALADIN model, which is a meso-scale model running at 10Km horizontal resolution, showed the same tendency but with more details.

The 30-hour ALADIN meso-scale forecast of the surface pressure and wind fields, valid September 12th at 06 UTC, agreed quite well with the large-scale models, Ref Figure 8-1. However the ALADIN model forecasted the Low in the Western Black Sea to be deeper and positioned not so far out into the sea. The strong wind and high ageostrophic flow over South-Eastern Romania and the

North-Western Black Sea, forecasted precipitation (Ref. Figure 8-2) and high positive vorticity nuclei (Ref. Figure 8-3) allowed the INMH forecasters to predict the deterioration of weather condition over the western Black Sea basin during the day of September 12th. Additionally the INMH wave forecast model indicated wave heights to be heights around 3-4 meters (Ref. Figure 8-4). This information provided INMH justification to continue the Warning condition.

Another Warning (nr. 68/2003) was issued on the morning of Sept 12th, 2003, specifying the intensification of the phenomena over the South-East Romania and Western Black Sea

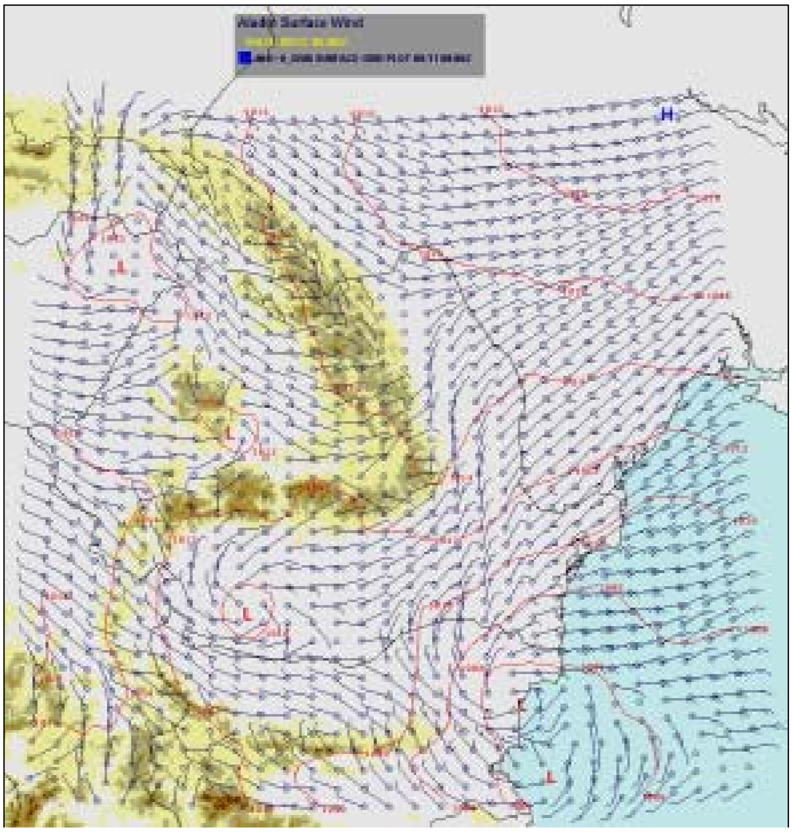

Figure 8-1 ALADIN 30-Hr Forecast of Sfc Pressure and Winds, Valid Sept 12th, 06 UTC

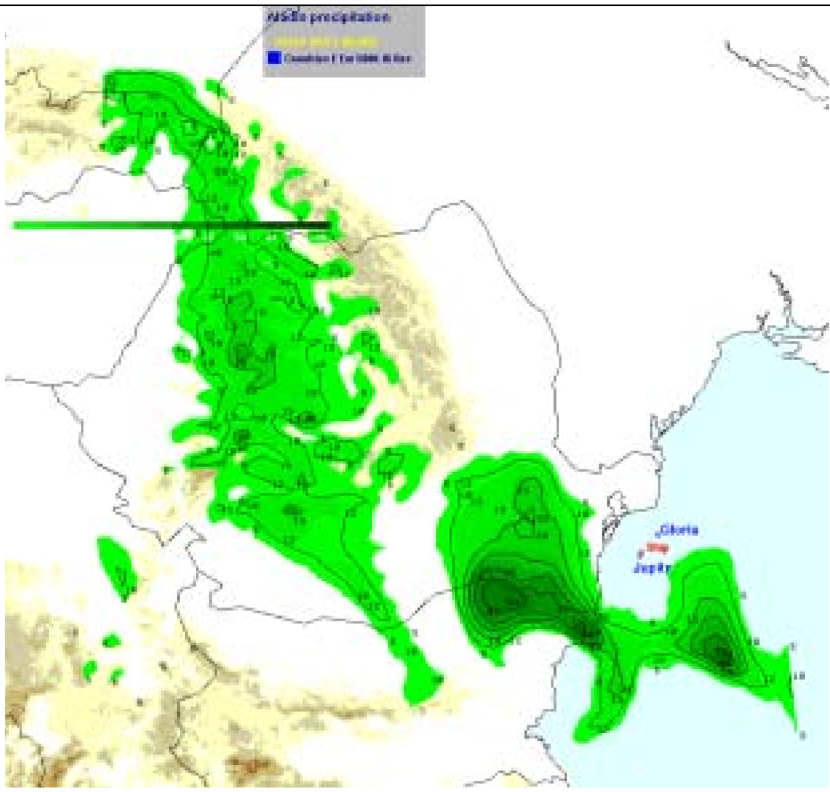

Figure 8-2 ALADIN 30-Hr Forecast of Precipitation, Valid Sept 12th, 06 UTC

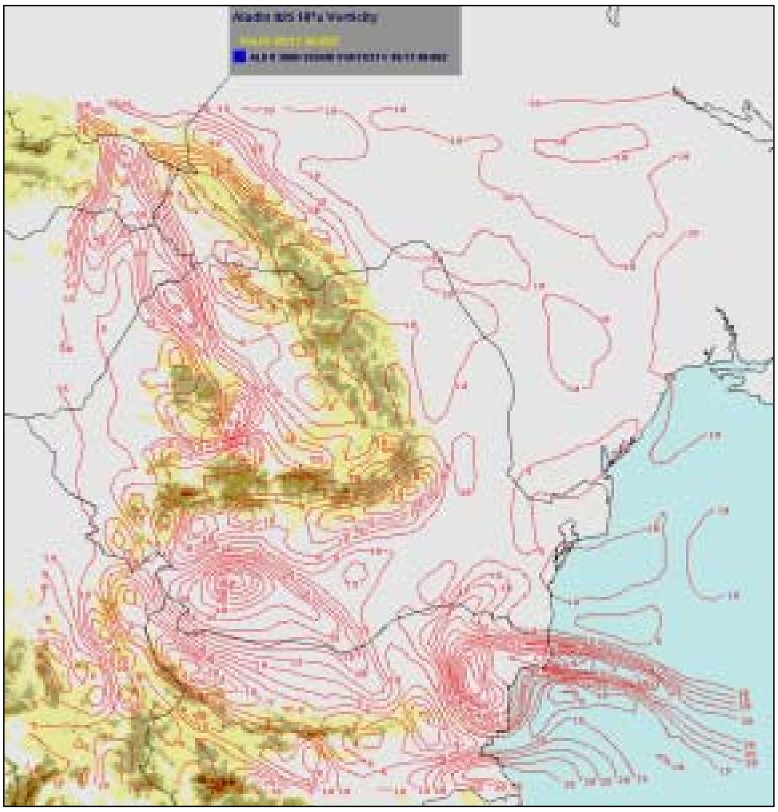

Figure 8-3 ALADIN 30-Hr Forecast of Vorticity, Valid Sept 12th, 06 UTC

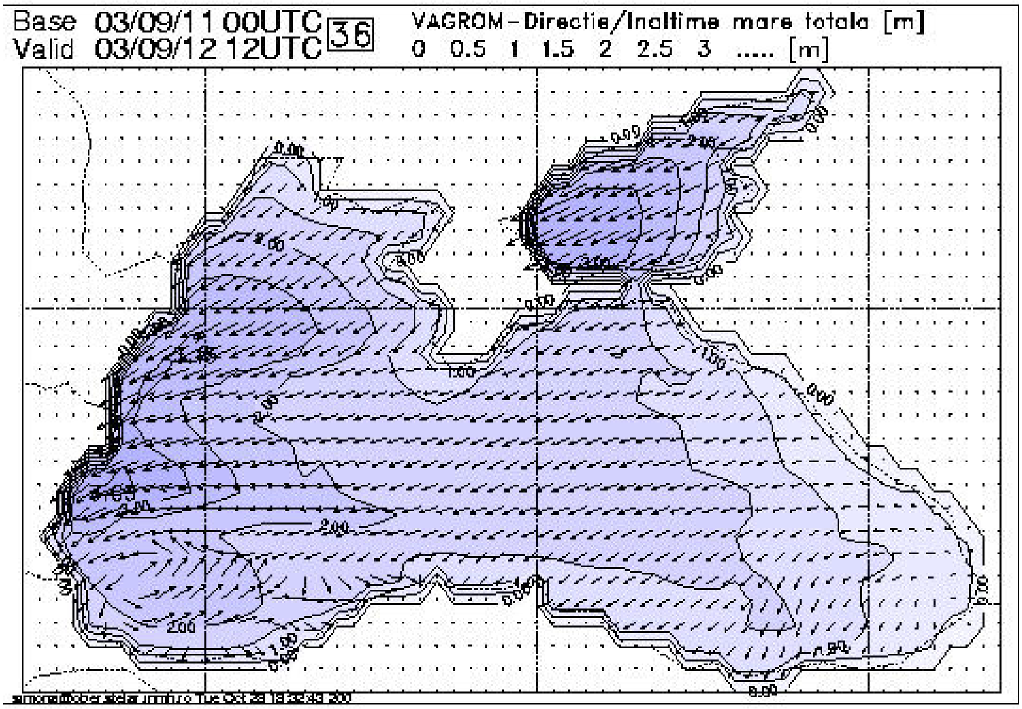

Figure 8-4 VAGROM Wave Model, Valid Sept 12th, 12 UTC

8.2 Forecast Verification and Nowcasting Response

Indeed, the GSM analysis of the surface pressure field and 500-hPa Geopotential field on September 12th, 06 UTC confirmed the foreseen evolution, Ref. Figure 8-5 and Figure 8-6. These analysis fields agree quite well with the large-scale features forecasted by INMH.

Moreover, the remote sensing capabilities provided by SIMIN provide a real-time integrated view of the phenomenon to National and Regional forecasters. In the absence of remote sensing, observation of the phenomena over the sea would not have been possible. Under the situation, the progress of the storm could not have been monitored by the INMH forecasting team. The NOAA Polar Orbiter image, Ref Figure 8-7, shows the event from the satellite perspective. The WSR-98D Radar in Medgidia, Ref Figure 8-8, provides the most detailed observation of the development of the storm over the western basin of the Black Sea, during the morning of Sept 12th, 2003.

After seven hours, the storm moved slowly to the North, affecting Romanian territorial Black Sea waters, as seen in the METEOSAT image of Figure 8-9 and the National Radar Mosaic in Figure 8-10.

Additionally, at 12 UTC, the surface observation station on the oil platform Gloria (~50km offshore, as marked in Figures 8-2 and 8-11) reported 16-17 m/s wind speeds, with 22-23 m/s wind gust, and 6-7 m wave heights. The Gloria station did not record significant amounts of precipitation until Sept 12th, 06 UTC. At that time it reported 13.5 l/m2, accumulated during the previous 24 hours. Conversely, other land stations on and close to the Romanian boarders recorded precipitation up to 130.5 l/m2 accumulated during the previous 24 hours, Ref. Figure 8-11, from the SOP application. This corresponds well with the forecasted amount by the ALADIN model.

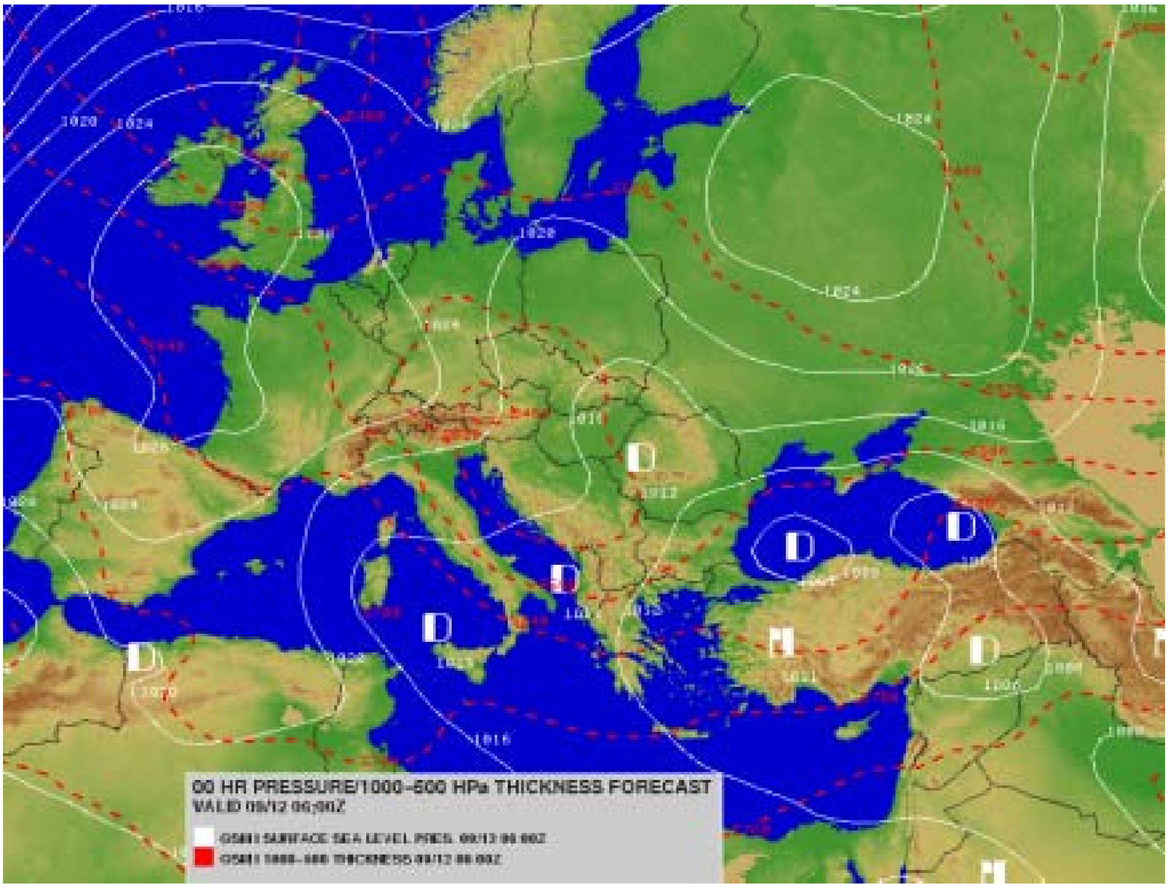

Figure 8-5 GSM Analysis of Surface Pressure and 1000-500 hPa Thickness, valid at Sept 12, 06 UTC

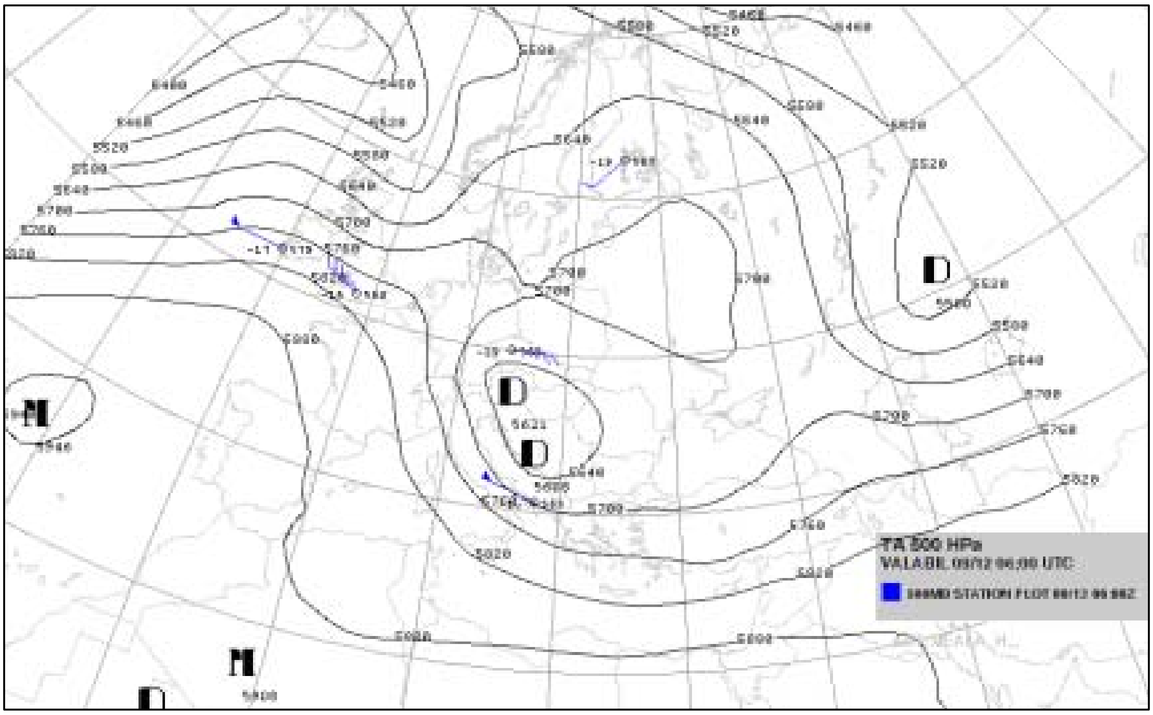

Figure 8-6 GSM Analysis of 500 hPa Geopotential, valid at 06 UTC Sept 12th, 2003

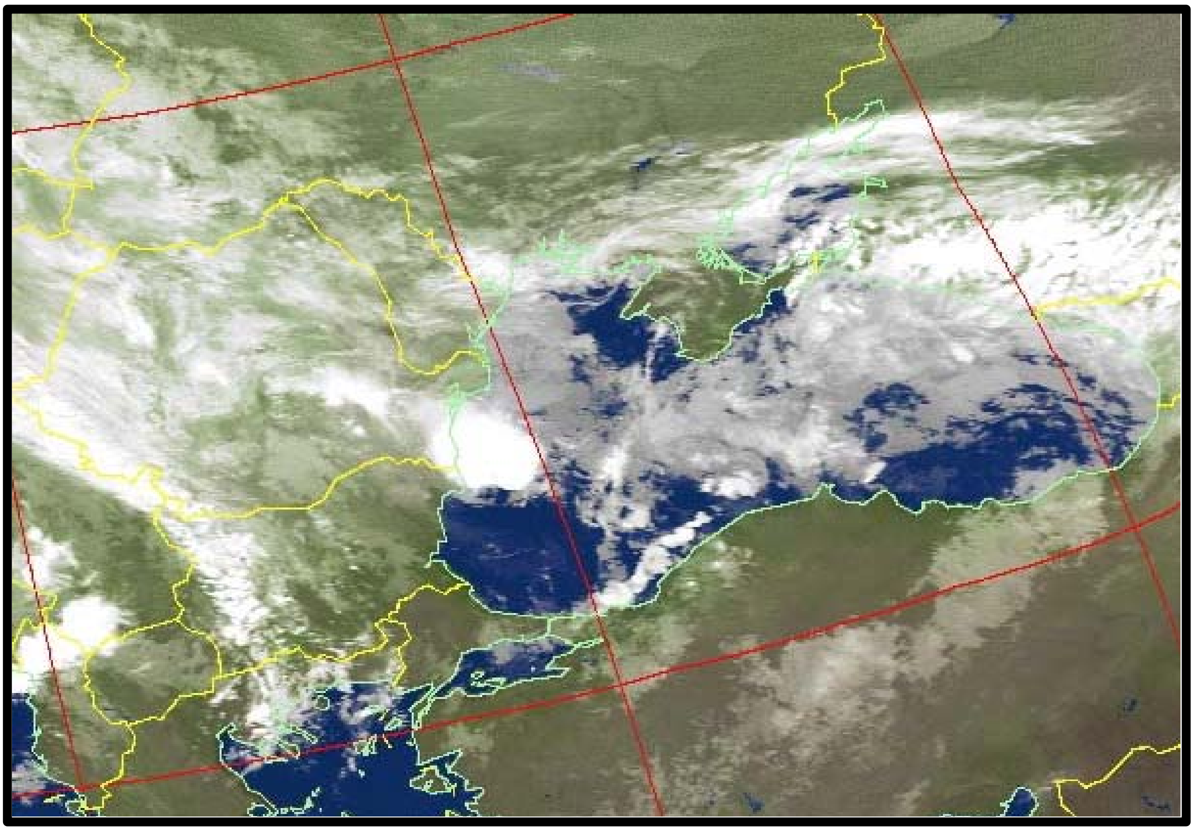

Figure 8-7 NOAA Polar Orbiter Satellite Image Sept 12th , 2003

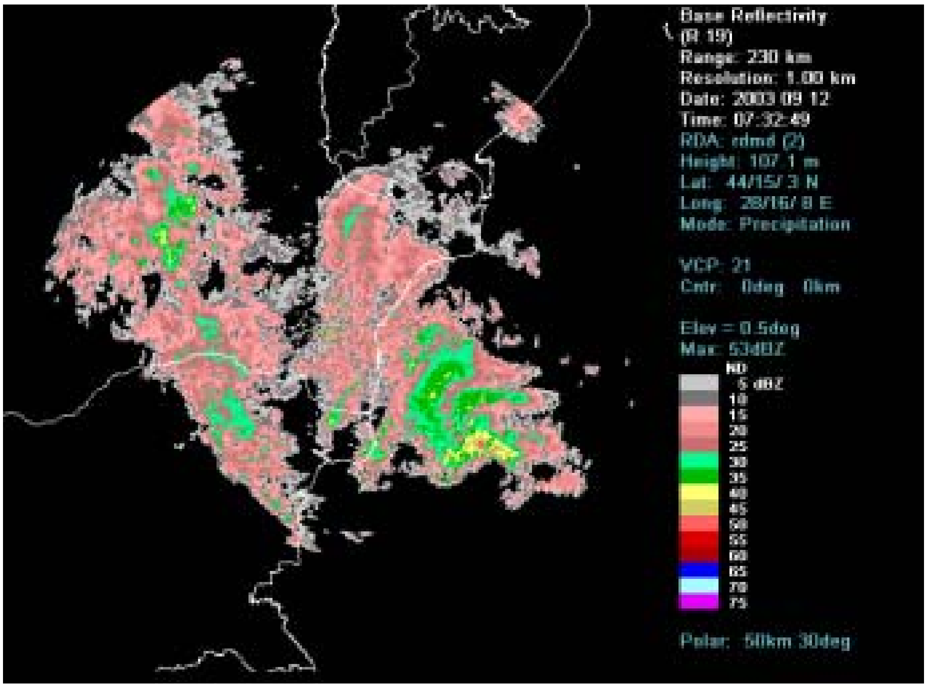

Figure 8-8 Reflectivity Product from the WSR-98D Radar at 07:32 UTC Sept 12th, 2003

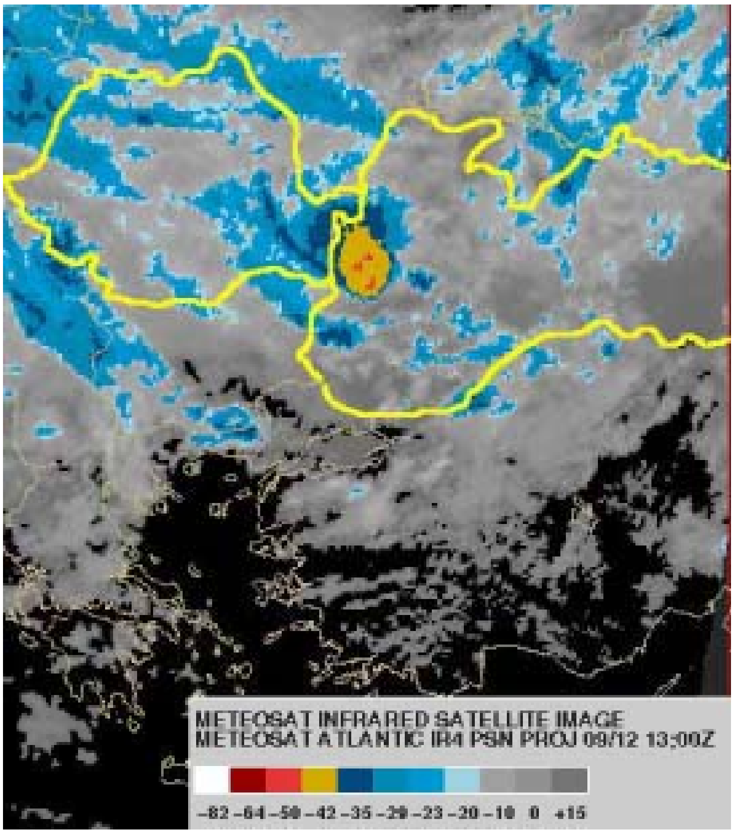

Figure 8-9 METEOSAT 7 InfraRed Satellite Image at 13:00 UTC Sept 12th, 2003

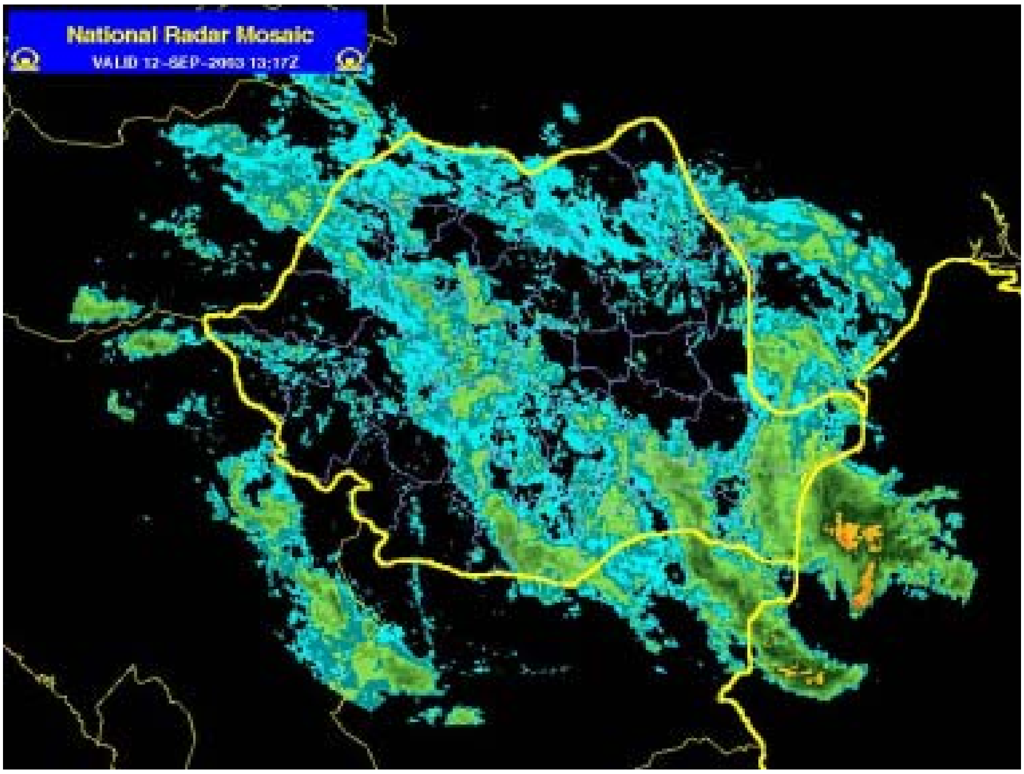

Figure 8-10 The National Radar Mosaic at 13:17 UTC, Sept 12th 2003

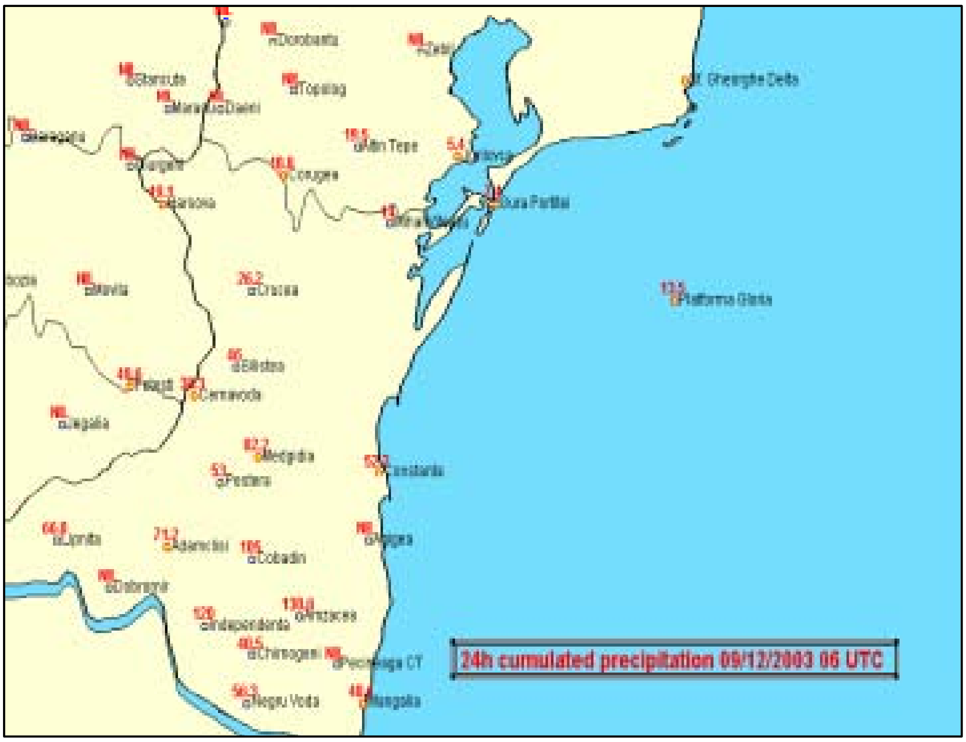

Figure 8-11 24-hour Precipitation Accumulation, Sept 12th ,06 UTC

8.3 The Unfortunate Results

Another signature of the storm intensity concerns the tragic accident of the Ukrainian ship "Slavutich 7" belonging to the "Ukrichflot" company. On Sept 12th, the ship suffered engine damage and drifted near the Jupiter Oil Platform, Lat 44°31'96" N, Lon: 29°28'03" E, Ref Figure 8-2. Unfortunately, the damaged engines did not allow the vessel to heed the warnings from INMH in time to avoid the storm. An SOS was sent at 12:07 UTC, near the time of the severe conditions observed by the Gloria platform, to the NE of Jupiter, as described in 8.2. Being battered by the storm the ship broke apart, as seen in Figure 8-12, and subsequently sank. The photo is taken from a movie captured from the Jupiter Platform. (Used with permission of videographer N. Barliva, engineer, Petromar Company.) This accident clearly shows the severity of this Black Sea storm, and demonstrates the need for early warning in Romania.

Figure 8-12
The Breakup of a Vessel Caught in the Black Sea Storm of Sept 12th, 2003

9 Summary

Consequently, SIMIN means:

- Modernizing the technical infrastructure of INMH – Romania in all its components (Radar data, synoptic data, satellite data, lightning detection, national and international communication, data validation, data processing and visualization, modeling, elaboration of warning and forecast products, climatological database, dissemination of products to the users, etc.);

- Improving the capacity building of the human resources, both by performing trainings for each component and directly through using the new equipment. It is very important to take into account the ever-growing motivation level of the young specialists using a high technology.

As a result of these points, there is an improved capacity of response in the Romanian meteorology community for the surveillance of atmospheric-related phenomena, elaboration of forecasts and warnings, climatological support, as well as increased visibility through public awareness and capacity building at national and European level.

The main benefits of SIMIN consist in fulfilling the essential goals and tasks of the National Meteorological Services, by providing the technical infrastructure and Human Resources for effective response to dangerous phenomenon, to ensure protection of life and goods and provide direct economic benefits which is ready to be realized in the rapidly developing Romanian "meteorological market", (Ref Figure 9-1).

SIMIN provides the meteorological infrastructure upgrade, which forms the first stage of the Romanian Governments' multi-stage plan for modernization of various environmental monitoring and control systems throughout the country.

Further details of the SIMIN system may be found at the website http://www.lmco.com/syracuse/IWS.

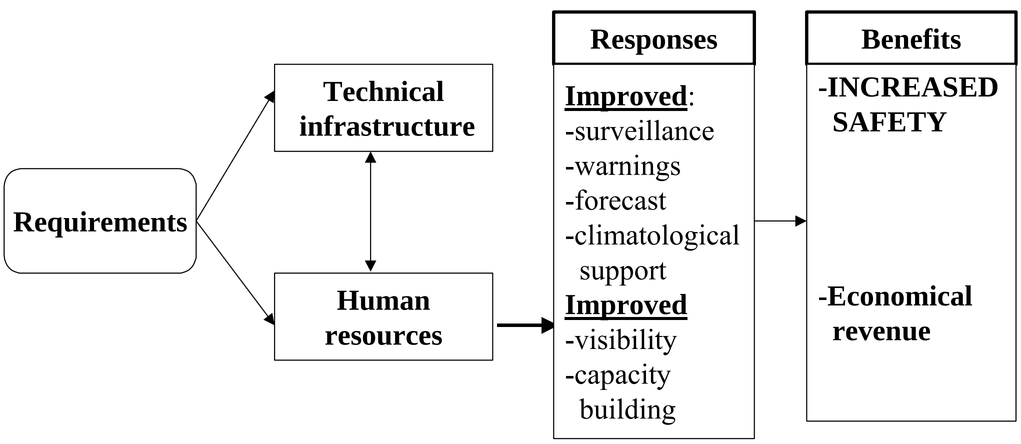

Figure 9-1 The Building Blocks to Effective Meteorological Service

ANNEX

Conference Work Plan

Conference Programme

TECO-2005 - IPC Members

TECO-2005 - WORK PLAN

Wednesday, 4 May	Thursday, 5 May	Friday, 6 May	Saturday, 7 May
10:00 - 10:55	9:00 – 10:20	9:00 - 10:30	9:00 - 10:20
Opening of TECO-2005 Introductory Keynote Paper	**SESSION 1 (cont'd)** *Papers 1(12) to 1(15)*	**SESSION 2 (cont'd)** *Papers 2(11) to 2(13)* **SESSION 3** **Quality Management, Calibration, Testing and Comparison of Instruments and Observing Systems** *Keynote Paper*	**SESSION 3 (cont.)** *Papers 3(14) to 3(17)*
11:00 - 12:10	10:40 – 12:10	10:50 - 12:10	10:40 - 12:50
SESSION 1 **New Developments and Operational Experience with Surface observation technology** *Keynote Paper* *Papers 1(1) to 1(2)*	**SESSION 1 (cont'd)** *Papers 1(16) to 1(17)* **SESSION 2** **New Developments and Operational Experience with Upper-air observation technology** *Keynote Paper* *Paper 2(1)*	**SESSION 3 (cont'd)** *Papers 3(1) to 3(4)*	**SESSION 4** **Technology Transfer, Capacity Building, Training and development of RICs** *Keynote Paper* *Papers 4(1) to 4(5)*
14:00 - 15:40	14:00 - 15:40	14:00 – 15:40	14:00 – 16:00
SESSION 1 (cont'd) *Papers 1(3) to 1(7)*	**SESSION 2 (cont'd)** *Papers 2(2) to 2(6)*	**SESSION 3 (cont'd)** *Papers 3(5) to 3(9)*	**Summary and round table discussion**
16:00 - 17:20	16:00 - 17:20	16:00 - 17:20	16:00 – 16:20
SESSION 1 (cont'd) *Papers 1(8) to 1(11)*	**SESSION 2 (cont'd)** *Papers 2(7) to 2(10)*	**SESSION 3 (cont'd)** *Papers 3(10) to 3(13)*	***Closure of TECO-2005***
17:20 - 17:45	17:20 - 17:45	17:20 - 17:45	
SESSION 1 (cont'd) *Available Posters*	**SESSION 2 (cont'd)** *Available Posters*	**SESSIONS 3 & 4** *Available Posters*	
Exhibition METEOREX - 2005 Official opening on 4 May 2004 at 12h30			

WORLD METEOROLOGICAL ORGANIZATION
COMMISSION FOR INSTRUMENTS AND METHODS OF OBSERVATION

INSTRUMENTS AND OBSERVING METHODS — REPORT No. 82 — WMO/TD-No. 1265

WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2005)

Bucharest, Romania, 4-7 May 2005

CONFERENCE THEME

The Role of Instruments in the Earth Observation Systems

CONFERENCE PROGRAMME

Opening Keynote Paper

Session 1
New Developments and Operational Experience with Surface Observation Technology

Session 2
New Developments and Operational Experience with Upper-Air Observation Technology

Session 3
Quality Management, Calibration, Testing and Comparison of Instruments and Observing Systems

Session 4
Technology Transfer, Capacity Building, Training and Development of RICs

Session 5
Summary and round table discussion

Wednesday	Thurdsay	Friday	Saturday
4 May 2005	5 May 2005	6 May 2005	7 May 2005

TECO-2005
CONFERENCE PROGRAMME

Wednesday, 4 May 2005

Opening Keynote Paper

Meteorological instruments and observation methods:
a key component of the Global Earth Observing System of Systems (GEOSS)
by Canterford, R.P. (Australia), acting president of CIMO

Session 1

NEW DEVELOPMENTS AND OPERATIONAL EXPERIENCE WITH SURFACE OBSERVATION TECHNOLOGY

Co-chairs: *R. Dombrowsky (USA) and J.P. van der Meulen (Netherlands)*

Session 1 - Keynote Paper:

New developments and operational experience with surface observation technology
by *Dombrowsky, R. (USA), co-chair of OPAG-UPPER-AIR, chair of CBS ET on AWS*

Session 1 - Papers:

1(1) Upgrade and new developments of the automatic weather stations network in Austria
by Rudel, E. (Austria), et al.

1(2) Actinometric Instruments for automated systems
by Skuratovich, I. (Belarus), et al.

1(3) Variability of the measurement of temperature and humidity in the Canadian surface weather and reference climate networks
by Beaney, G. (Canada)

1(4) The Canadian lightning detection network - Novel approaches for performance measurement and network management
by Dockendorff, D. (Canada), et al.

1(5) Comparison between the data collected from the automatic weather observing systems and that collected from manual observing systems
by Elsayed, M. (Egypt)

1(6) Piezoelectric precipitation sensor from VAISALA
by Salmi, A. (Finland), et al.

1(7) Presentation and evolution of the Shipboard automatic weather station BATOS
by Unger, V. (France).

1(8) A comparison of SCAPP radiation data with global, diffuse and direct solar radiation
by Behrens, K. (Germany), et al.

1(9) Digital video technique as a new part of the DWD observing network
by Mammen, T. (Germany), et al.

1(10) Organization of the weather assistance to maritime activities and agriculture
by Ocundo Ca, A. (Guinea Bissau)

1(11) New automatic weather station system in Hong Kong featuring one-stop quality assurance, Internet technology and renewable energy
by Tam, K. (Hong Kong, China), et al.

Session 1 - Poster Presentations:

P1(1) Meteorological monitoring system for NPP-Kozloduy
by Branzov, H. (Bulgaria)

P1(2) Research on Lightning warning with SAFIR lightning observation and meteorological detection data in Beijing-Hebei areas
by Meng, Q. (China), et al.

P1(3) Observations of stormy zone hourly study in Kinshasa
by Tagisabo, A. (Dem. Rep. of Congo), et al.

P1(4) New developments and operational experience with surface observation technology
by Refaie, E. (Egypt)

P1(5) Next generation all weather precipitation gauge
by Räisänen, E. (Finland), et al.

P1(6) Météo France Network Supervision
by Vogt, V. (France).

P1(7) The new synoptic-climatological station AMDA in the DWD primary network
by Klapheck, K. (Germany), et al.

P1(8) Visibility measurement technique and its application in aviation services at international airports in India
by Mali, R. (India), et al.

P1(9) Present status of surface meteorological measurements in India
by Vashistha, R. (India), et al.

P1(10) Modernization of radiation network
by Vashistha, R. (India), et al.

P1(11) Rain intensity gauge with no moving parts
by Yassky, D. (Israel), et al.

P1(12) Chemical analysis of meteoric wet atmospheric deposition. Comparison between daily and weekly precipitation samples
by Casu, G. (Italy), et al.

P1(13) Automatic cloud-coverage evaluation by a ground-based Total-Sky Camera
by Rafanelli, C. (Italy), et al.

P1(14) Surface energy balance investigations using scintillation measurements
by Sciortino, M. (Italy), et al.

P1(15) A method to estimate sunshine duration from global irradiance measurements
by Benschop, H. (Netherlands)

P1(16) Cost effective 1-minute network data collection: A new paradigm
by Hartley, B. (New Zealand)

P1(17) Cost efficient data transport with GSM from weather stations in Norway
by van Nes, A. (Norway)

P1(18) Surface meteorological measurements and meteorological services in Pakistan
by Mir, H. (Pakistan), et al.

P1(19) Technical and operational aspects of setting-up an AWS network in Romania
by Lucaschi, B. (Romania), et al.

P1(20) The low cost radio frequency rain meter
by Koldaev, A. (Russian Federation), et al.

P1(21) The new capillary surface microlayer sampler for monitoring of the transboundary source of coastal ecosystems' pollution
by Syroeskhin, A. (Russian Federation), et al.

P1(22) Design and development of a low cost and reliable automatic weather station.
by Kumarasinghe, E. (Sri Lanka)

P1(23) The flood forecasting and precipitation measurement by using radar system
by Eroglu, H. (Turkey)

P1(24) The man-made satellite; an instrument of opportunity
by Mudenda, O. (Zambia), et al.

P1(25) A comparison of Beaufort, Vaisala and radiosonde wind measuring systems in the course of migration
by Ngenda, Ch. (Zambia)

P1(26) Mass and energy fluxes monitoring using eddy covariance techniques
By Mendicino, G. (Italy), et al.

P1(27) TOA - Advanced Lightning Positioning System (ALPS)
by *Geitz, W. (USA)*

P1(28) The ozone influence risk assessment on population health: Optical instrument of ozone concentration measurement
by *Naumenko, T. (Belarus), et al.*

P1(29) OTT Parsivel® - Enhanced precipitation identifier and new generation of present weather sensor by OTT Messtechnik, Germany
by Nemeth, K. (Germany), et al.

Thursday, 5 May 2005

Session 1 *(continued)*

NEW DEVELOPMENTS AND OPERATIONAL EXPERIENCE WITH SURFACE OBSERVATION TECHNOLOGY

1(12) Monitoring of high wind speed by new state-of-the-art high wind speed recording system during recent December 2003 Machilipatnam cyclone
by Mali, R. (India), et al.

1(13) The new meteorological observation network in the Netherlands; status and operational experience
by Wauben, W. (Netherlands), et al.

1(14) Remote monitoring of the weather at Norwegian airports
by Hegg, K. (Norway), et al.

1(15) Evaluation of the radar precipitation measurement accuracy using rain gauge data
by Apostu, L. (Romania), et al.

1(16) Mobile system for atmospheric temperature profile monitoring: mobile MTP-5
by Khaikine, M. (Russian Federation), et al.

1(17) SwissMetNet: Renewal of the Swiss automatic meteorological network
by Heimo, A. (Switzerland), et al.

Session 2

NEW DEVELOPMENTS AND OPERATIONAL EXPERIENCE WITH UPPER-AIR OBSERVATION TECHNOLOGY

***Co-chairs**: A. Ivanov (Russian Federation) and J. Nash (UK)*

Session 2 - Keynote Paper:

Review of a progress in the development of the operational upper-air technology
by Dr John Nash, UK, vice-president of CIMO,
co-chair of OPAG-UPPER-AIR, chair CIMO ET on UASI

Session 2 - Papers:

2(1) Observations from the global AMDAR programme
by Stickland, J. (Australia), et al.

2(2) VAISALA RS92 radiosondes offer high level of GPS performance with a reliable telemetry link
by Jauhiainen, H. (Finland), et al.

2(3) MODEM upper-air GPS Radiosounding system
by Charpentier, J. (France), et al.

2(4) Advances in wind profiler radar
by Currier, F. (France).

2(5) Upper air wind measurements by weather radar
by Holleman, I. (Netherlands), et al.

2(6) Studying the accuracy of Afar-based radar sounding system
by Ivanov, A. (Russian Federation), et al.

2(7) Meteorology and security around the nuclear power plants in Switzerland
by Calpini, B. (Switzerland), et al.

2(8) Development of a UK national GPS water vapour processing system
by Jones, J. (UK), et al.

2(9) Progress in introducing new technology sensor sites for the Met Office long-range lightning detection system
by Nash, J. (UK), et al.

2(10) The challenges for an operational wind profiler - remote and unattended
by Oakley, T. (UK), et al.

Session 2 - Poster Presentations:

P2(1) Some results from atmospheric sounding in cases with foehn in Sofia valley
by Videnov, P.(Bulgaria), et al.

P2(2) Applying working knowledge for well managing the upper air stations network in order to preserve its historical achievements and work on continuing its development and prosperity
by Amer, M.(Egypt)

P2(3) A round the clock observation technology to measure vertical profiles of visibility and spectral transmission of the mixing layer
by Weller, M.(Germany), et al.

P2(4) Radiosounding: Impact on aerological measurements due to instrumentation transition
by Casu, G.(Italy), et al.

P2(5) Use of doppler radar in Romania for nowcasting and warning
by Stan-Sion, A.(Romania), et al.

P2(6) Time-lag correction of operational RS80-A radiosonde humidity
by Kats, A.(Russian Federation), et al.

P2(7) The impact of new RF95 radiosonde introduction on upper-air data quality in the North-West region of Russia
by Kats, A.(Russian Federation), et al.

P2(8) The field and laboratory intercomparison test between two different types of the sondes and the ground systems
by Borštnik, A.(Slovenia), et al.

P2(9) On board processing capability for radiosonde platforms using low-cost processors mixed signal ICs and semi-conductor sensors
by Kumarasinghe, N.(Sri Lanka)

P2(10) Upper air observations in Turkey
by Erdem, M.(Turkey), et al.

P2(11) Observing fog and low cloud with a combination of 78 GHz cloud radar and laser ceilometer
by Nash, J.(UK, et al.)

P2(12) Demonstration of the new InterMet radiosondes system installed at the Tanzania Meteorological Agency, Dar es Salaam
by Smout, R.(UK), et al.

P2(13) Maturation and application of operational doppler lidar for meteorological applications
by Hannon, S.(USA), et al.

P2(14) Recent application of the accurate temperature measuring radiosonde
by Schmidlin, F.(USA).

P2(15) Improved forecast skill with ground-based radiometric profiling
by Ware, R.(USA), et al.

P2(16) InterMet 403 MHz radiosonde system
by Wierenga, R.(USA), et al.

P2(17) Quantitative assessment of improved spectral moments selection algorithms on an operational 64 MHz clear-air doppler wind profiler
by Winston, H.(USA), et al.

P2(18) Polarization diversity for the National Weather Service, WSR-88D radars
by Zrnic, D.(USA)

P2(19) Radar technique for the study of structure and dynamics of the hail-storm process
by Imamdjanov, K.(Uzbekistan)

P2(20) Radar techniques of meteorological events detection by polarization characteristics of signal
by Imamdjanov, K.(Uzbekistan), et al.

P2(21) Development of a mean intensity radiometer for GRAW radiosondes
By Schmidmer, F. (Germany)

Friday, 6 May 2005

Session 2 *(continued)*

NEW DEVELOPMENTS AND OPERATIONAL EXPERIENCE WITH UPPER-AIR OBSERVATION TECHNOLOGY

2(11) Results of the RS92 acceptance test performed by the Met Office (UK)
by Smout, R. (UK), et al.

2(12) The evolution and development of the United States National Weather Service universal radiosonde replacement system
by Bower, C. (USA).

2(13) Universal upper air sounding system
by Wierenga, R.(USA), et al.

Session 3

QUALITY MANAGEMENT, CALIBRATION, TESTING AND COMPARISON OF INSTRUMENTS AND OBSERVING SYSTEMS

Co-chairs: *B. Baker (USA) and C. Richter (Germany)*

Session 3 - Keynote Paper:

Quality management, calibration, testing and comparison of instruments and observing systems
by Dr Bruce Baker, USA, Chairman of the AMS's Committee on Instrumentation and Observations

Session 3 - Papers:

3(1) Canadian program and facilities for the functional testing of surface weather instruments and systems
by Nitu, R. (Canada)

3(2) Meteorological standardization in China
by Ding, H. (China)

3(3) Field comparison of different raingauges and present weather sensor at MHS of Croatia
by Premec, K (Croatia), et al.

3(4) WMO laboratory intercomparison of rainfall intensity gauges (France - Italy - Netherlands) . First results from France
by Alexandropoulos, Ch. (France), et al.

3(5) Field Acceptance Test Procedure of 40 Vaisala Present Weather PWD 22 Sensors and Use of a Thies Spectro-Rain Gauge
by Zanghi, F, (France)

3(6) LAUTLOS upper-air humidity comparison – the first results
by Leiterer, U. (Germany), et al.

3(7) A quality management system for the process of collecting meteorological data
by Richter, C. (Germany), et al.

3(8) Comparison between an automatic weather station and a traditional station
by Soumah, F. (Guinea)

3(9) The WMO laboratory intercomparison of rainfall intensity gauges
by Lanza, L. (Italy), et al.

3(10) Documentation on quality assurance and representativity of meteorological observations
by Benschop, H. (Netherlands)

3(11) Precipitation type from the THIES disdrometer
by Bloemink, H. (Netherlands), et al.

3(12) An assessment of the UV broad band filter radiometer measurement accuracy
by Los, A. (Netherlands), et al.

3(13) KVALOBS - the quality assurance system of Norwegian Meteorological Institute observations
by Kielland, G. (Norway)

Session 3 and Session 4 - Poster Presentations

Session 3 - Poster Presentations

P3(1) Intercomparison of ground-based water vapour radiometer measurements and radiosonde measurements with the integrated water vapour from numerical models
by Vukovic, Z. (Canada)

P3(2) The experiment and analysis on available data rate of wind profiler radar
by He, P. (China), et al.

P3(3) Performance evaluation for net pyrradiometers
by Lu, W. (China), et al.

P3(4) Some step of quality control of upper-air network data in China
by Zhao, Z. (China), et al.

P3(5) The in Situ Pressure Calibration System in Météo-France
by Duvernoy, J. (France), et al.

P3(6) ISO 9001 Quality Certification in the Area of Surface Observing Systems
by Leroy, M. (France)

P3(7) Uncertainties of Measurements in Météo France's Monitoring of the Chemical Composition of Precipitation
by Mezdour, A, (France), et all.

P3(8) A Quality Control Program for Radiation Data
by Behrens, K. (Germany), et al.

P3(9) Measuring air temperature by using an ultrasonic anemometer
by Lanzinger, E. (Germany), et al.

P3(10) Automatic technical self check system for the DWD weather radar network
by Mammen, T. (Germany), et al.

P3(11) Fast-response, open path optical hygrometer for long-term measurements - experiences, results, future requirements
by Weisensee, U. (Germany), et al.

P3(12) Quality management and quality control of the long-term observing system “ZUZI“ a provider of the WMO World Data Centre for Aerosols (WDCA)
by Weller, M. (Germany), et al.

P3(13) Temperature measurement
by Traore, F. (Guinea)

P3(14) Intensity of precipitation and comparison among different measuring instruments
by Casu, G. (Italy), et al.

P3(15) Influence of rain gauge calibration on data series at Re. S.M.A. station in Vigna di Valle (Italy)
by Lanza, L. (Italy), et al.

P3(16) Dealing with uncertainty in rainfall gauges calibration: The QM-RIM metrological validation
by Molini, A. (Italy), et al.

P3(17) The new automatic weather system
by Zahari, A. (Malaysia)

P3(18) Quality and representativity of wind measurements
by Benschop, H. (Netherlands)

P3(19) A test of the precipitation amount and intensity measurements with the OTT Pluvio
by Wauben, W. (Netherlands)

P3(20) Wind tunnel and field test of three 2d sonic anemometers
by Wauben, W. (Netherlands)

P3(21) Testing of wind sensors and the usefulness of video technology at marine stations
by Larre, M. (Norway)

P3(22) Comparison of manual precipitation observations with automatic observations in Oslo and Utsira
by Mathisen, T. (Norway), et al.

P3(23) Variation in precipitation measurement through different instrumentation
by Awan, S. (Pakistan)

P3(24) Preliminary results obtained following the intercomparison of the meteorological parameters provided by automatic and classical stations in Romania
by Baciu, M. (Romania), et al.

P3(25) Review of the Dobson 121 spectrophotometer accuracy as a result of the international intercomparison sessions
by Manea, L. (Romania) , et al.

P3(26) The meteorological data quality management of Romanian national surface observation network
by Ralita, I. (Romania) , et al.

P3(27) Advanced atmospheric boundary layer temperature profiling with MTP-5HE microwave system.
by Kadygrov, E. (Russian Federation) , et al.

P3(28) The operational web-based presentation of the Russian Federation upper-air network performance monitoring
by Kats, A. (Russian Federation) , et al.

P3(29) Intercomparison measurements of recording precipitation gauges in Slovakia
by Chvila, B. (Slovakia), et al.

P3(30) Calibration of relative humidity measuring instruments at EARS
by Groselj, D. (Slovenia), et al.

P3(31) Accredited calibration laboratory service as a subject of an integral QA system at EARS
by Groselj, D. (Slovenia), et al.

P3(32) The effect of the relative humidity on sunshine duration measurements during the last eclipse in Turkey
by Aksoy, B. (Turkey)

P3(33) Data quality management
by Karatas, S. (Turkey), et al.

P3(34) Detection of Zdr abnormalities on operational polarimetric radar in Turkish weather radar network
by Sireci, O. (Turkey), et al.

P3(35) The United States National Weather Service in-situ radiation temperature correction for radiosonde replacement system GPS radiosondes
by Bower, C. (USA)

P3(36) Wind tunnel tests of some low-cost sonic anemometers
by Sturgeon, B. (USA)

Session 4 - Poster Presentations:

P4(1) Technology, training, development, testing and calibration at the ReSMA
by Casu, G. (Italy), et al.

P4(2) Modernization of Observation Network in Turkey
by Büyükbas, E. (Turkey), et al.

P4(3) U.S. support for the global climate observing system (GCOS) and associated support for international, regional, and bi-lateral GCOS activities
by Diamond, H. (USA)

P4(4) Revitalization of the GCOS surface and upper-air network stations
by Thigpen, R. (USA)

Saturday, 7 May 2005

Session 3 *(continued)*

QUALITY MANAGEMENT, CALIBRATION, TESTING AND COMPARISON OF INSTRUMENTS AND OBSERVING SYSTEMS

3(14) Guidelines on quality control procedures for data from automatic weather stations
by Zahumenský, I. (Slovakia)

3(15) The world radiometric reference and its quality system
by Rüedi, I. (Switzerland)

3(16) Preliminary results of WMO intercomparison of high quality radiosonde systems, Mauritius, February 2005
by Nash, J. (UK), et al.

3(17) Quality management of a European wind profiler network (CWINDE)
by Oakley, T. (UK), et al.

Session 4

TECHNOLOGY TRANSFER, CAPACITY BUILDING, TRAINING AND DEVELOPMENT OF RICs

Co-chairs: *E. Bazira (Uganda) and H. Zhou (China)*

Session 4 - Keynote Paper

Technology Transfer, Capacity Building, Training And Development of RICs
by Dr. Joseph R. Mukabana, Permanent Representative of Kenya with WMO

Session 4 - Papers:

4(1) Wind protection designs from measurements with simple wind equipment in four African countries, in research education capacity building projects
by Stigter, K. (Netherlands), et al.

4(2) Technology transfer, capacity building, training and development of RICs (the Nigerian experience)
by Adeniji E. O. (Nigeria), et al.

4(3) Design and construction of meteorological instruments, the Nigeria experience
by Aderinto, S. (Nigeria)

4(4) Romanian national meteorological integrated observational system - achievements and current status
by Apostu, A. (Romania), et al.

4(5) SIMIN - the integrated system for meteorological surveillance, forecast and alert in Romania
by Allen, G. (USA), et al.

Note: *Session 4 - Poster Presentations scheduled immediately following Posters of Session 3.*

Session 5

SUMMARY AND ROUND TABLE DISCUSSION

Chaired by: *R.P. Canterford (Australia), acting president of CIMO*

* * * * * * * * * *

INTERNATIONAL PROGRAMME COMMITTEE

List of Members

Ray Canterford (Australia)	Scientific Director
Carolin Richter (Germany)	Member
Jitze van der Meulen (The Netherlands)	Member
Rainer Dombrowsky (USA)	Member
John Nash (UK)	Member
Alexei Ivanov (Russian Federation)	Member
Eliphaz Bazira (Uganda)	Member
Heng Zhou (China)	Member
Vladimir Ivanovici (Romania)	Coordination with the host country
Bruce Baker (USA)	Coordination with the AMS's Committee on Instrumentation and Observations
Miroslav Ondráš (WMO Secretariat)	WMO Coordinator