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Report on the OPAG-CB

(Submitted by the Mr A. Ivanov, OPAG-UPPER-AIR Co-chair)

Summary and purpose of document

This document summarizes activities of the OPAG-UPPER-AIR and the Expert Team on Remote Sensing Upper-air Technology and Techniques.

Action proposed

The management group is invited to review the activities of the OPAG and the Expert Team on Remote Sensing Upper-air Technology and Techniques.

Report of the OPAG-UPPER-AIR Co-chair and Chairman of the Expert Team on Remote Sensing Upper-Air Technology and Techniques

A. OPAG Upper-Air was established in 2002 by XIII session of CIMO in Bratislava. The main common purposes of OPAG are:

1. Facilitate upgrading the global radiosonde network:
–Prepare and perform comparison tests to detect error characteristics of various types of aerological measurement systems, establish links to previous designs and systematic differences between new radiosonde designs (over four years);
–Develop techniques and report annually on the performance of radiosonde types in the GOS;
–Solicit agreement on BUFR-code table and descriptors for international use (1–2 years).

2. Investigate error characteristics of water vapour measurements and explore compatibility between the different types of measurement:
–Prepare guidance material on developing national GPS water vapour network;
–Monitor and assist in the introduction of humidity measurements by AMDAR.

3. Investigate the suitability of modern conventional and Doppler radars for deployment in NMHSs:
–Improve quality and availability of remotely sensed upper wind measurements;
–Report on the suitability of modern radar's and wind profilers for deployment in NMHSs;
–Report and advise manufacturers on the operational performance of weather radars in developing countries.

4. Monitor and report on new development of other upper-air measurement techniques:
– The techniques are expected to include lidar, microwave radiometer, sodar, RASS.

5. Monitor and report on calibration of satellite remote sensing instrumentation.

6. Investigate the standardisation of data-processing algorithms for radiosondes.

7. Report on progress of lightning detection:
– Monitor and report on national and regional lightning detection projects and networks;
– Propose evaluation methods for operational lightning detection systems;
– Review the progress in the compatibility of lightning detection remote sensing and conventional in situ observations.

8. Promote, facilitate and assist with developments in integrated observing systems.

9. Continue radiofrequency allocation studies for ground-based observing systems:
– Improve co-ordination of radiosonde operating frequencies between neighbouring countries.

Expert team on Remote Sensing Upper-Air Technology and Techniques was created in 2003 in LosAngeles by CIMO MG, which also has confirmed Work Plan 2003-2006. Main issues of the Plan:

- Investigate complementary use of modern Doppler radar's and profilers in the U/A network;
- Investigate error characteristics of water vapour measurements and explore compatibility between the different types of measurement;
- Promote, facilitate and assist with developments in integrated profiling systems and report on other upper-air measurement techniques;
- In consultation with HMEI, determine the operational use of lightning detection methods;
- Development of technical information for support of radio frequency sharing policy for WRC.

In all areas high experience experts was nominated. Usual outputs of expert activities are the reports on the status and operational aspects of different remote sensing technique. So, the next reports was prepared by experts:

- Summary of experience with the ground-based GPS at KMNI;
- GPS meteorology;
- Wind profiler radar, data availability and quality;
- NOAA Wind Profiler Network;
- Operational aspects of wind profiler radar's;
- Report on the operational use of lightning detection method in Brazil;
- Operational aspects of different ground-based remote sensing techniques for vertical profiling, and others.

B. The first session of the Expert Team on Remote Sensing Upper-Air Technology and Techniques (ET-RSUT&T) was held in Geneva, Switzerland, 14-17 March 2005. The main results in various areas of Remote Sensing were presented and discussed.

1. GPS WATER VAPOR MEASUREMENTS

1.1 Presentations by the various members in attendance validated the fact that they had several systems or had established a full network to assess the operational potential of these systems for both Numerical Weather Prediction and Climate application. Each reporting member briefly discussed their experiences in developing their network, techniques used in validating the performance of their systems and how they were applying these measurements to various aspects of their operations. All members provided favorable responses when asked how they were using the high temporal frequency signals from GPS to assess various aspects of the atmosphere.

Members of the ET who are also associated with COST716 provided information on an upcoming investigation of GPS and its uses. Several members reported that GPS derived Integrated Water Vapor (GPS-IWV) in near-real time and applications vary from being used to compliment their operational radiosonde network to using the measurements as a proxy for moisture soundings in Numerical Weather Prediction. These measurements have found application in operational weather forecasting, climate monitoring, atmospheric research, as well as satellite calibration and validation. The members were in agreement that these measurements could be made with high reliability under all weather conditions. Retrieval accuracies have been shown to be comparable to radiosonde measurements, and GPS-IWV appears to provide a cost-effective approach to measuring atmospheric water vapor.

1.2 The members were in general agreement that the quality of IWV derived from GPS MET is thought to be compatible to that obtained from radiosonde observations. GPS MET data have proven to provide high temporal resolution when compared with conventional measurements.
However, IWV from GPS MET only provides an integrated value of the profile. The vertical information of water vapor can be retrieved from GPS-derived slant water vapor (SWV) and tomography techniques. Work plan element 1a calls for the review of national and regional GPS procedures with the goal of developing international operational procedures for GPS water vapor networks.

2. COMPLEMENTARY USE OF MODERN DOPPLER RADARS AND PROFILERS IN THE UPPER-AIR NETWORK

2.1 Wind Profilers (WPR)

2.1.1 Active ground-based remote sensing systems such as profilers are used by Member countries to provide wind speed and direction, profiles of vertical motions, position of the melting layer and other related information. These systems are operated to monitor atmospheric conditions. Member reports proved the quality of data being collected by these systems and their value to the meteorological community. Some national meteorological and hydrological agencies assimilate these data into the NWP model, use these data in weather now-casting, or used in an integrated fashion to complement their radiosonde network providing improvements to atmospheric profiling, and used in support of airport safety.
2.1.2 Regional experiments and thorough investigations have been conducted with various tropospheric WPRs to determine their operational suitability. These experiments have shown that WPR direction and speed detected by these systems compare favorably with radiosonde profiles.
Many of these experiments have led to or will lead to future WPR deployments and network expansions. These results have led to high space- and time-resolution wind measurements suitable for weather warnings, watches, and numerical forecasts. These data have produced improvements in forecast and warning accuracy as well as statistical improvements in model output.
2.1.3 Special emphasis is still being placed on improving the standard signal processing for WPRs, which will improve the system performance characteristics such as data accuracy and availability under all kind of meteorological conditions. At present many of these networks show a technical reliability of about 98% or more and provide data up to 12 km in height (dependent on frequency) with the data availability greater than 70 percent. Depending on the type of profiler (frequency used, pulse length, vertical resolution, etc.), the maximum measuring height may be as high as 16 km, however, with the data availability progressively reduced.
2.1.4 Due to external problems strict quality control measures must be applied to maintain high quality data. Presenters expressed concern over the need for better algorithms and techniques to remove unrealistic data due to migrating birds, aircraft's, wind turbines, electromagnetic field, ground-clutters and other contamination. A multi peak processing algorithms may improve data availability by 10 to 20 % in some systems as it eliminates and replaces suspicious and unrealistic wind data due to all kind of contamination.
2.1.5 Another concern expressed by some team members was the concern over discrete characteristics of WPR data. There is the variation in height coverage due to seasonal variation. For example in the summer the JMA network provides height coverage between 6 and 7 km and during the winter season only between 3 and 4 km. This seasonal variation of the height coverage results from the seasonal difference in water vapor in the lower troposphere.

2.1.6 During the last decade WPR systems have proven their technical and operational suitability and usefulness for improving numerical weather forecasts and for short-term forecasting and now-casting purposes. The usefulness of WPRs for NHMS has been well illustrated through the operational experience of profilers in Europe, the United States and Japan, the EUMETNET-WINPROF experiment and its focus on assimilation of WPR data into NWP models, and finally COST720 with its focus on integration of systems with the goal of improving temperature and humidity profiling. WPRs and other ground-based remote sensing systems such as microwave radiometers and LIDARs were identified as being current or future elements of any integrated upper-air network.

2.2 Modern Doppler Radars

2.2.1 All members reported that they have either completed the upgrading of their radar network or will be upgrading their radar network with Doppler radar systems. Some representatives reported that their networks were operating S-band, C-band or X-band radars and some networks were operating a mix of systems depending on function and cost. Several representatives with established networks reported ongoing efforts to upgrade systems to dual polarization. Software requirements for Doppler radar and other ground-based systems require constant review and must evolve to meet the ever-increasing user requirements. Many of the presenters made reference to the extensive use of the Doppler radars for nowcasting and the use of Velocity Azimuth Display (VAD) wind profiles as one element in identifying severe weather environments. Operational procedures have been developed by Doppler radar operators in such a way that the operational forecaster is able to maintain situational awareness while having the ability to investigate in greater detail individual thunderstorms in an efficient way and timely fashion.

2.2.2 The advances in Doppler radar technology and algorithms have proven the value of the system not only in localized severe weather situations, but on a larger scale when investigating synoptic systems such as tropical cyclones and their application to the investigation of the lower atmosphere for lower and middle level wind shear. For this reason alone some national agencies have positioned Doppler radars at or near airports. Independent investigations have documented the accuracy of wind speed measurements to be accurate within about 1m/s, and wind direction to an accuracy of about 10 degrees. Doppler radars are used not only for wind calibrations but for calibration of rainfall mapping as well as a complementing technology to surface rain gauge networks and satellite rainfall estimates. Considerable processing is required to produce rainfall mapping and this is still evolving. These techniques allow the forecaster to provide accurate precipitation now-casts up to 1 hour and short-term precipitation forecasts up to 6 hours by combining with NWP.

2.2.3 Assimilation experiments of Doppler velocity data to the next generation non-hydrostatic model have proceeded. One such experiment has shown that use of data of 3D Doppler velocity as well as GPS integrated vertical water vapor data provide quality information and perform well in forecasting the development of severe thunderstorms associated with low-level convergence of moist air preceding the development.

2.2.4 Real-time operational use of Doppler radars requires a strict data quality control regiment to maintain the system's high performance scan strategy. The quality and accuracy of Doppler radar data is very important to post-processing and data analysis to the climate and hydrologic sectors.

2.2.5 The various presentations highlighted that data quality is higher today, thanks to improvements in digital technology and that polarization has become more affordable. Doppler radar systems have proven their potential as an additional tool for nowcasting purposes. The technical advances and operational advances make this system suitable for deployment in national or regional networks. NWP data assimilation systems emphasize the need for estimates of uncertainty of the radar data that are consistent within and across national boundaries. This requires the development of the science and algorithms for the estimation of these measurements and their uncertainties. These measurements included reflectivity, precipitation rate, radial wind and VAD wind. Science, algorithm and Intercomparison workshops should be developed.

3. OPERATIONAL USE OF LIGHTNING DETECTION METHODS

3.1 The various aspects of Lightning Detection Systems (LDS) of UKMO, Brazil, Vaisala, TOA Inc., Canada, Korea and Japan were presented, such as system networks, the various techniques being used, network sensor types and quality of network measurements.

3.2 Lightning detection networks were becoming more affordable and would be easily extended to other national or regional areas. Performance of LDS may vary from 70 to 90 percent at an accuracy of around 2 km depending on range, location, season (during the winter, 30 to 60 percent, than summer, 80 to 90 percent) and the sensor frequency being used (LF systems used for long-range applications do not provide accurate results at longer distances).

3.3.The meeting concluded the following:

- LDS have well defined applications and should play a larger role in operations.
- Despite the number of regional networks much of Asia, Africa, India and South America are still poorly covered. The UK representative indicated that that addition of a few additional sensors in the southern hemisphere would extend their coverage towards African and India.
- Today's technologies are capable of very accurate measurements of time and location, but more can be done.
- Total lightning has value for some applications but is currently available only from VHF systems.
- Coverage is possible with VLF in data sparse areas, but will likely require linkage through satellite applications.
- Verification of lightning detection systems should be done by network owners at a level commensurate with other meteorological observation instruments.
- Most of the existing networks are heterogeneous (either LF or VLF, or both). Few manufacturers have combined LF/VHF networks to detect both cloud-to-cloud and cloud-to-ground lightning within one network.
- Technical difficulties diminished, but the effects of propagation and topography still remain.
- The technology to identify both cloud-to-cloud and cloud-to-ground lightning currently exists, but the majority of systems measure cloud-to-ground lightning only. This will likely remain the situation until the need for Intra-cloud data increases.
- Reporting of flashes or individual strokes remains an issue and will be addressed by the various needs of the different user groups.
- LDS network performance needs to be verified this includes detection efficiency, peak current estimates and location accuracy. Methods including independent measurements should be applied as much as possible as well as conducting inter-system comparisons should also be encouraged at both national and regional levels.

3.4. The meeting was presented with a description of a number of commonly used methods to evaluate LDS performance. It was noted by that any of the following methods independently or in combination could be used to verify performance. The different methods include instrumented towers, rocket triggered lightning, video camera studies and network inter-comparisons. Each method has its strengths and weaknesses and papers on each of these methods are available from a number of sources such as the American Meteorological Society.

4.INTEGRATED PROFILING SYSTEMS AND OTHER UPPER-AIR MEASUREMENT TECHNIQUES

4.1. The integration of profiling systems can be accomplished on either of two levels; the first approach is the combination of systems to improve one single meteorological parameter such as wind, temperature, humidity or cloud parameter. This is achieved through improved vertical resolution, vertical coverage and/or data quality. An example for this type of integration objective would be the combining of WPR and microwave radiometer and achieving enhanced vertical resolution of WPR measurements or the combination of Sodar and WPR of different systems to achieve enhancements in vertical data coverage compared to the using a single system. The second approach to integration is through the identification of new parameters using the synergy derived between two or more systems. This is achieved through simultaneous evaluation of multiple remotes-sensing techniques. An Example of this form of integration is the combination of WPR with acoustic sources (RASS) to derive temperature profiles as well as wind profiles. A second example of this form of integration is the simultaneous use and evaluation of cloud radar, microwave radiometer and lidar in order to receive microphysical cloud property profiles, which cannot be derived reasonably using one single profiling system.

4.2 Projects for integration of different ground-based observing techniques

4.2.1 Experiments such as Operational Wind Profiler Program (WINPROF) and the Coordinated Wind Profiler Network in Europe (CWINDE) have proven the value of integrating complimentary data from different systems that can provide a positive impact to the quality of forecast products. During the period between 2002 and 2004 the first phase of the EUMETNET WINPROF was successfully implemented. The outcome resulted in the operational assimilation of CWINDE network data by several NHMSs into their NWP models. The comparison between NWP analysis data (model background) and WPR measurements from the 482 MHz system at Lindenberg Observatory, Germany showed that the WPR data, which are available every 30min, provide equal or higher quality data than the radiosonde wind measurements.

4.2.2 With the improvements in data quality and availability of WPR networks, the continuation of the EUMETNET activity, WINPROF-II, is under way. The goal of this effort is to integrate European WPR network into the EUCOS (European Composite Observing System) Program.

4.2.3 Following the WPR-related experiments under COST-74 and COST-76 a new European research activity has been defined. This activity known as COST-720 will focus on the development of “integrated ground-based remote-sensing stations for atmospheric profiling”. This five-year activity began in 2001 and is organized on two levels. The first addressing basic operational techniques and algorithms and the second addressing the feasibility of integrating of different ground based remote sensing upper-air platforms. This effort is addressing the development of complex algorithms taking into account measurements of more than one basic technology, (WPR, cloud radar, microwave profiler, ceilometers or others) in order to derive standard parameters of higher quality and vertical resolution with the goal of deriving new parameters through the combination of several different remote-sensing instruments.

4.2.4 Within COST-720 an experiment, TUC-2003, was conducted in the aerological station Payerne, Switzerland. The objective of this experiment was to use several technologies in combination to detect the upper boundary of fog and its change with time.

4.2.5 A second and final major campaign of COST-720 is being organized to assess the effectiveness of new techniques derived for the use in the integration of different water-vapor lidar systems, FTIR spectrometer, doppler wind lidar, and Ka-band cloud radars. First results of this campaign are envisaged to be available with the end of

COST-720 in 2006. One of the special issues to be investigated will be the question of whether ground-based microwave or water-vapor lidar systems will have any impact on NWP model forecasts.
4.2.6 In Canada, the development of an integrated approach to measurements is being led by collaboration between McGill University and the Meteorological Service of Canada as well as various efforts within the Cloud Physics and Severe Weather Research Division of the MSC. Each system is focused on a particular meteorological problem. McGill/MSC has developed the Canadian Mesoscale Observational Testbed (CMOST) for mesoscale applications including hydrological studies. The Alliance Icing Research Study, AIRS-II, project has an extensive set of cloud radars, profilers, surface observations, etc that is focused on the study and forecast of icing conditions and precipitation type. A special workstation (AVISA) is developed to integrate the various data sets. Integrated observation systems will focus on precipitation, particularly snowfall. Canada is working towards a prototype disdrometer network for the calibration of weather radar, high-resolution estimation of precipitation type and measurement. Validation of the Cloudsat will involve integrated measurements to both validate the precipitation retrievals but also their physical foundation.
4.2.7 The Russian effort in system integration is in its early stages. The Russian remote sensing community will prepare a draft review for operation aspects of different ground-based remote sensing observing techniques for vertical profiling of temperature, wind, humidity and cloud structure using various systems. The Russian presenters were of the opinion that it would be useful to combine microwave tropospheric profilers data with doppler radar data for acquiring water vapor profiles and liquid water profiles in clouds. For determining narrow elevated temperature inversions it will be useful to integrate microwave temperature profiler data with SODAR and weather radar data.
4.2.8 The future "system of systems" is NOAA's Integrated Observing system (IOS) consisting of three elements; the Integrated Upper-Air Observing System (IOUS) – a network with a Climate, Aviation, and NWP focus; the Integrated Surface Observing System (ISOS) – a network with a Climate, Public, and Surface Transportation focus; and the Integrated Ocean Observation System (IOOS) – a network with a Climate and Marine Transportation focus.
4.2.9 The mission of the IUOS will be to support NOAA's ocean and surface integrated observing systems. A successful integration will improve time and space resolution as well as accuracy. The vision for IUOS is to develop a system capable of improving short term warnings and forecasts by observing precursor conditions related to high-impact weather events, detect changes in regional and hemispheric conditions impacting transportation, and provide climate quality information for monitoring climate change.

5. OPERATIONAL ASPECTS OF DIFFERENT GROUND-BASED REMOTE SENSING TECHNIQUES FOR VERTICAL PROFILING

5.1 The current state of remote sensing in some countries (Brazil, Canada, China, Germany, Japan, India, Korea, Netherlands, Russian Federation, Switzerland and USA) was presented.

5.2 Mr Engelbart (Germany) presented results of the IOM Report No.79 on the Operational Aspects of WPRs. Further details could be found on CIMO/IMOP website: http://www.wmo.int/web/www/IMOP/publications-IOM-series.html.

5.3 Mr Kadygrov (Russian Federation) presented first draft IOM Report on Operational Aspects of Different Ground-Based Remote Sensing Observing Techniques for Vertical Profiling of Temperature, Humidity, Wind and Clouds. ET members, and interested experts, are invited to provide further comments and addition to this draft report, which could be downloaded from: http:// www.wmo.int/web/www/IMOP/meetings/UpperAir/RemoteSensing/DocPlan.html.

6. RADIOFREQUENCY ISSUES

6.1. Due to the increasing demand for radiofrequency spectrum, there is more or less constant pressure on the frequency bands presently assigned for meteorological purposes. They are particularly attractive for other users such as satellite operators because they are almost always allocated on a worldwide basis and not regional.

6.2. As concerned study the problems related to Frequency allocation for wind profiler and weather radars all designs and resolutions are adopted by WARC-2003, and other problems are related with national radio-frequency administrations. The next step is to get more full information about possibility in using frequencies for radars in NMS.

6.3. The threat to meteorological frequency bands comes from passive sensing devices. At present the most prominent threat is from problems related to ultra wide band (UWB) systems that plan to operate near 24 GHz, this frequency is used to observe the emissions from water molecules. This data serves to calibrate many different space-based systems yielding, among other parameters, temperature and humidity.

6.4 In order to solve the problems, the meteorological community should find means to demonstrate what value the different frequency bands have for their activities. It has been show, that the loss of satellite-based radiometer data due to interference from active systems would result in a significant reduction of the forecasting capability: The ability to forecast the height of the 500 hPa level with a given skill factor would, e.g., be reduced by about 10 hours on the northern, and by about 48 hours on the southern hemisphere.

6.5 Active radiofrequency systems must be licensed and they are registered. Since a number of years, WMO keeps also a database covering satellite-based passive systems, i.e., radiometers. However, at present there is no inventory of surface-based radiometers, making it difficult to argue for protecting certain bands for passive observations. The WMO Steering Group for Radiofrequency Coordination will deal with this issue at its next meeting.

6.6 The awareness of the national meteorological services in relation to radiofrequency allocations must be increased. Decisions at the different International Telecommunication Union (ITU) levels are ultimately made by the members of ITU, and these members are the national telecom authorities. Consequently, national meteorological services should seek the dialogue with their national telecom administration and make them aware of the value of radiofrequency spectrum for their operations. This should not be restricted to the frequencies actually used in a certain country (e.g. for radiosondes or wind profilers), but should also cover satellite-based systems operated by international (e.g. ESA) or other national (e.g. NOAA) organizations from which all WMO members profit.

7. CALIBRATION OF SATELLITE INSTRUMENTS

Much not idle time question calibrations satellite remote instruments. The consultations with Active President of CBS and expert OPAG on IOS has shown that this question remains important and under investigation. In ditto time, CBS does not lead direct work on calibration instrument, sparing main attention to validation of data. In this connection best of interest is the report of the chair of the OPAG on IOS (Integrated Observing Systems), presented on CBS-XIII (2005). After investigation of this report, as also the report of CGMS-XXXII (2004), the understanding of current state of resolution and accuracy may be presented to CIMO. There are other important documents like CURRENT STATEMENTS OF GUIDANCE REGARDING HOW WELL SATELLITE AND *IN SITU* SENSOR CAPABILITIES MEET WMO USER REQUIREMENTS IN TEN APPLICATION AREAS (2004). The report by Tony Reale (NOAA/NESDIS, 2004) proposes a network of about 40 upper-air sites (and available ships) that would routinely launch reference radiosondes coincident with polar satellite overpass, referred to as the Satellite Upper Air Network (SUAN).

8. WORK PLAN

The outcome of the discussion on the above agenda items were recast into a detailed Work Plan that specifies actions and deliverables for all tasks that were put forward to the team by CIMO-XIII and CIMO-MG.