INNOVATIONS IN OBSERVING SYSTEMS AND PRACTICES TO MEET THE EVOLVING NEEDS OF MEMBERS

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ABSTRACT

There is increasing pressure on NMHSs to provide high quality data (and metadata) at a high temporal resolution for a range of purposes including (but not limited to) climate monitoring, fire weather, aviation, transportation, agriculture, public weather, and research. Data users are becoming more sophisticated and their data requirements are ever expanding. Issues such as disaster mitigation and climate change now have greater focus. NMHSs have to carefully monitor their networks to ensure that observing systems are in place that produce outputs that meet the needs and expectations of clients as well as ensure that data homogeneity is maintained. As well as integrating new technology, members are required to maintain existing technology to ensure that climatological aspects of their meteorological and hydrological data networks are preserved. WMO's Commission of Instruments and Methods of Observation (CIMO) works cooperatively with instrument manufacturers to ensure that high quality instruments are available at a cost that ensures their take-up by NMHSs and ensures that instrument manufacturers (through the Association of Hydro-Meteorological Equipment Industry (HMEI)) have a facility to further develop their instruments and systems. CIMO's endeavours in capacity building ensure that all members are able to integrate systems that suit their particular needs. CIMO through the cooperation of Regional Instrument Centres (RICs) and Regional Radiation Centres (RRCs), and in conjunction with WMO No. 8 Guide to Instruments and Methods of Methods of Observation[1], well known to instrument experts as the "CIMO Guide", ensure that standards and traceability of data are consistent. Technology transfer of innovations and capacity building ensure that experience and capability are shared between member countries.

1. INTRODUCTION

The purpose of this paper is to highlight the work being undertaken by CIMO experts to harness new innovations in observing instruments and incorporate acceptable instruments into NHMS operational networks.

All NMHSs face increased national and international pressures to provide greater amounts of high-resolution data of high certainty or quality, with more immediacy, at no (or little) cost to a more sophisticated client base. In most cases, these demands are required to be met from a static, or decreasing, resource pool. This compels CIMO, NMHSs and HMEI to be more innovative in the design and use of instruments and systems.

CIMO's goal is to insure required quality of data, traceable to System International (SI) standards, from a spatially distributed network performing surface and upper air observations for the global monitoring of meteorological data. These data are observed and/or derived by a number of NMHSs using a variety of instrumentation of varying sophistication. CIMO's role is to facilitate the standardization and compatibility of instruments and methods of observations to achieve this goal. CIMO produces technical documentation and training modules on practices and procedures and regularly reviews these to ensure that they provide up-to-date guidance on the most effective practices for taking meteorological observations and measurements. CIMO also has an important role in the calibration and comparison of instruments to ensure instrument compatibility, data homogeneity and traceability of measurements to SI standards. CIMO encourages standardization even where innovation has a high priority. Collaborative technology transfer between NMHSs and HMEI assist in the standardization of instruments and methods of observation.[2]

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2. INNOVATION

2.1 Automation

In relation to the automation of surface-based observing systems, there has been a rapid increase in the number of Automated Weather Observing Systems (AWOS) integrated into the networks of NMHSs. In a large part, this is due to the lower cost of systems/technology as they mature as well as the increase in reliability of these systems. Advances continue in the development of systems that measure the “visual elements” of present weather and discrimination of cloud amounts and types. For example, many NMHSs are developing the practice of using video cameras to automate the visual observation of cloud and visibility[3].

In relation to the automation of upper air systems, many NMHSs are actively investigating methodologies for reducing their expenditure on ground-based upper air observations. Remote sensing is being integrated into NMHSs networks and research continues into the better assimilation of satellite data into numerical weather predictions (NWP).

Although research continues in the development of instruments and systems, cooperation between NMHSs and instrument manufacturers (represented by HMEI) has seen an increase in the availability of turn-key or end-to-end systems. An example of this cooperation assisting both NMHSs and HMEI can be found in the experience of integrating 13 Autosonde systems into the Australian upper air network presented at TECO 2000[4] and TECO 2002 [5]

2.2 Interoperability

Development is continuing on systems that use various radiosonde types and are able to determine upper level wind data using different wind resolution technology. A recent IOM report[6] describes a test of one such system at Dars-es-Salaam in 2004. Congratulations to Messrs Nash, Smout, Smees and Bower for their excellent paper for which they have been awarded the Professor Dr Vilho Väisälà Award for the Development and Implementation of the Instruments and Methods of Observations.

Another example of interoperability is the USA NWS radiosonde system. Since the mid-1990’s their recently replaced ground system was able to receive data from radiosondes supplied by two different manufacturers. This functionality has been expanded in their Radiosonde Replacement System[7].

Standardization of algorithms enhances the prospect of interoperability of electronic sensors that are interfaced into Automatic Weather Observing Systems (AWOS). To this end, CIMO works cooperatively with other WMO Programmes, in particular with the WMO Commission for Basic Systems (CBS) “Expert Team on Requirements for data from Automatic Weather Stations” to facilitate standardization.

2.3 Composite Networks

NMHSs are continually integrating newer technology into existing networks. An example of this can be seen in the global upper air network with the integration of wind profilers into existing radiosonde networks. This has been successfully developed by a number of NMHSs including EUMETNET, Japan[8], USA, UK [9]and Australia. Another example is the EUMETNET composite observing system (EUCOS) that integrates surface, upper-air and aircraft observations. A further example is the development of GPS water vapour and precipitable water detection such as the EUMETNET E-GVAP project. There are a number of NMHS and HMEI developing GPS precipitable water systems, e.g. UK Met Office[10].

AMDAR[11] has developed into a valuable upper air network which will benefit from the further development of an acceptable water vapour sensor.

Through the continuing efforts of Open Programme Area Groups (OPAGs) and Expert Teams (ETs), CIMO makes continued efforts to encourage NMHSs and HMEI to develop research system so that they can mature into operational systems.

2.4 Tiered Networks

The concept of tiered networks has been implemented by a number of NMHSs as a methodology for operating a nationally sustainable observation network. This concept incorporates a network of observing sites of varying complexity, instrumentation and support enabling the NMHSs to meet core objectives and client expectations such as climate monitoring.

An innovation developed by various NMHSs is the use of redundant sensors at their higher tiered networks to facilitate less uncertainty for data quality and greater stability for operations. This concept has become sustainable as costs of reliable accurate instruments decrease to a level wherein it is less expensive to have multiple sensors than it is to maintain one sensor. Redundant sensors also allow NMHSs greater flexibility in their maintenance regimes, which can also lead to efficiencies.

2.5 Adaptive Observations

This concept allows the NMHS to perform observations according to key national imperatives – usually for national forecast and warnings. Although these observations may not align with global and/or national climatological data users' expectation, these data are used nationally and internationally by NWPs. An example of adaptive Observations is adaptive radiosonde soundings in Australia after a reduction to their 12 UTC upper air network[12].

The adaptive observations concept is also used by many NMHSs within their surface network through the use of limited manual input at times of national or international significance to supplement *in situ* AWOS, although the development of advanced sensors is making this less of a requirement for some NMHSs.

2.6 Rebalancing of NMHSs Networks

Although, reviewing their networks to ensure that goals, objectives and outcomes are met is a continuing function of all NMHSs, developments in remote sensing and GEOSS as well as maturing new technology have seen many traditionally conservative NMHSs rebalance their networks to ensure that outputs can be met as efficiently as possible. For example, major work has been done recently in several countries[13] on an efficient rebalancing of networks[14].

2.7 Data Assimilation

Over the past few years, the greater assimilation of satellite and surface-based data into more sophisticated numerical models has improved forecasting for weather, climate and hydrology. NMHSs are developing methodologies to ingest more satellite data as they become available. In some case, this results in redundancies for existing networks and NMHSs need to carefully balance national and international outputs from their networks.

NMHSs also need to carefully balance real-time data requirements with that of long-term climatological requirements. Allowing for biases introduced by new technology complicates the detection of climate change and as such metadata becomes increasingly important. CIMO recommends detailed metadata information be part of the overall NMHS quality management system[15].

As client requirements and data availability becomes more sophisticated NMHSs are required to place more focus on applications development software. Many NMHSs are cooperatively developing high-end systems in conjunction with their meteorological field editing.

When examining innovation in observations technology, it is clear that remote sensing has become increasingly important to NMHSs. For many applications, increased data volume (even at a reduced quality) may become more valuable to NMHSs than high quality data at a lower temporal resolution. New generations sensors and satellites have seen an increasing appreciation across the meteorological and hydrological communities for the data that these systems make available for users. GEOSS and WMO are liaising to ensure that the requirements of all members are taken into consideration.

A key component of data assimilation is the use by NMHSs of comparative data as a quality management and assurance tool for various systems. Therefore CIMO has a key role in determining key user requirements and standards for satellite calibration as this will have a critical impact on the Global Observing System.

3 Collaboration/Integration and GEOSS

Social-economic drivers have seen greater cooperation and collaboration nationally at an inter-agency level. Collaboration may result in enhanced respect and authority for NMHSs which with the inclusion of additional funding may provide a building block for better NMHS services[16]. WMO has pioneered the international cooperation on exchange, standards and metadata for meteorological and related data from instrument networks. The World Weather Watch Programme, amongst others, is of fundamental importance to NMHSs and CIMO has played a crucial role in the development of observing networks and their ongoing maintenance. Innovation in instrumentation is continually incorporated into this collaboration.

This inter-agency collaboration has enhanced the amount of data from meteorological, aviation, climate, agricultural, environmental and transportation networks that are being assimilated to provide outputs that compliment the networks of other agencies.

There has been increasing cooperation between NMHSs with a number of jointly operated networks and cooperative research projects taking place. These include: EUMETNET; CWINDE; EUCOS; PRISM; THORPEX to name a few.

One of the core activities of CIMO is the liaison and cooperation between NMHSs and HMEI. The cooperative organisation of WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2002) and the conjointly organized Exhibition of Meteorological Instruments, Related Equipment, and Services (METEOREX-2002) in Bratislava, Slovakia, in September 2002 allowed greater appreciation of each community's requirements and expectations.

CIMO provides cooperation, encouragement and assistance to HMEI to develop instruments that better suit NMHSs. Collaboration between CIMO and HMEI, and the generous support of the Chinese Meteorological Agency, has seen the production of the World Meteorological Instrument Catalogue.

It should be recognized again[17] that CIMO and NMHSs operating observation networks provide valuable input to the recently broad reaching goals of GEOSS (Global Earth Observation System of Systems). CIMO's role remains one of promoting the standardization of meteorological observations. With this in mind CIMO validates meteorological practices and procedures to be followed by Members. CIMO periodically reviews documents containing practices and procedures to ascertain whether updates or changes are required. An element of this process is preparing documents and training materials reflecting recent innovations with the sole purpose of providing up-to-date guidance on the most effective practices for taking meteorological observations and measurements. In addition CIMO plays an important role in instrument calibration and comparisons conducted in both the laboratory and the field. Any societal benefit realized from instruments is based on the production of high quality data. Therefore, the activities undertaken by CIMO as listed below support the improvement of instrument performances, instrument compatibility, data homogeneity and traceability of measurements to SI standards. CIMO will specifically be contributing to GEOSS activities through the following:

- determining whether additional siting standards are required for different programs requiring support from observation networks, such as climate, marine, agro-meteorology, highway, hydrology as well as urban and roadway networks;
- providing GEOSS support through its interaction with instrument manufacturers in establishing performance specifications for systems operating in extreme weather conditions;
- assisting GEOSS in developing guidelines and procedures for the transition from manual to automatic surface observation stations;
- provide expertise that will assist in producing high quality instrument measurements across all relevant disciplines in the GEOSS framework;
- reviewing AMDAR water vapor comparisons, and once the next generation sensor is deemed operationally ready an Intercomparison of AMDAR and remote sensing upper-air systems will be initiated;
- providing expertise on standardizing procedures for instrument siting, calibration, and operation;
- examining possibilities of developing standards and protocols for data exchange from networks of ground-based GPS receivers;
- instrument intercomparisons to guarantee instrument compatibility and data homogeneity seen as one of the preconditions to integration of different observing systems into a system of systems;
- coordination of the RICs and RRCs to ensure traceability of measurements to SI standards to allow integration of different observing systems on data level.

As can be seen, these activities and accommodation of innovations in observing systems mesh particularly well with the implementation plans of GEOSS[18].

4 Technology Transfer related to Innovation

A key component for addressing innovations for Members is the requirement for training and capacity building. There has been significant progress in this area, with several Training Workshops on Upper-air Observations in many Regions. The aim of the training is to improve the knowledge and skills of operational personnel in making upper air observations in particular. Training is provided through CIMO in collaboration with manufacturers and on a variety of instrument platforms, and is an essential part of the introduction of new innovations in instrumentation.

Another aspect of technology transfer that takes place through NMHSs and HMEI is via documentation published and reviewed by CIMO, and guidelines that are routinely updates to account for new innovations as they become part of operational measurements. Specifically the:

- WMO No 8: The Guide to Instruments and Methods of Observation (the “CIMO Guide”), 7th Edition. This provides guidelines for conducting meteorological measurements, understanding variables and performing quality assurance of data and instruments;

- IOM Reports – each of these reports address a unique topic relating to instruments, research, or guidance on instruments and systems and/or procedures;

- The Instrument Development Inquiry Reports, which have now reached the 7th edition are an important way of transferring technology to all NHMS and are published regularly as IMOP reports on the WMO IMOP web site;

- Instrument Catalogue – provides a list of instruments and manufacturers, which allows users to make informed choices on whether to take up recent innovations.

5 Intercomparisons of Innovations in Measurement

The intercomparison of instruments, sensors and methods of observation is a cornerstone for any innovation or introduction of a new system into operational measurement networks. CIMO, through its Expert Teams and International Intercomparison Organising Committees, with well established Terms of Reference and procedures provides this essential work. It is often undertaken by experts from countries well versed in relevant technology and supported by scientists in countries where the tests, trials or experiments are undertaken. A recent and watershed intercomparison, with large implications for all Members, was the WMO Intercomparison of High Quality Radiosonde Systems, Vacoas, Mauritius, 7-27 February 2005. It determined that, while some problems remain in most systems tested, the results of the controlled trials will further improve radiosonde measurement quality (including long term stability of measurement quality). This should produce a stability in radiosonde measurements that has not been present in earlier generations of radiosondes[19].

Another example was the Tenth International Pyrheliometer Comparison (IPC-X) and the conjoint Regional Pyrheliometer Comparisons (RPCs), held at the World Radiation Centre (WRC), Davos, Switzerland, 26 September to 14 October 2005[20]. Seventy-two participants from 16 Regional and 23 National Radiation Centers and 11 institutions took part in the comparison and their 89 pyrheliometers were made compatible.

At the last CIMO XIII, Members requested intercomparison of rainfall intensity measurements. A great deal of innovation has entered this field over a long period of time, and NMHSs have long been concerned at the capabilities of the various instruments. After a great deal of planning and careful trialling at three recognized calibration laboratories, a final report was published on the "WMO Laboratory Intercomparisons of Rainfall Intensity (RI) Gauges" held in the laboratories of the Royal Netherlands Meteorological Institute, Météo France and University of Genova, September 2004 - March 2005[21].

6 Quality Management- Essential for Innovation

Much work has been done on the update of the Guide to Instruments and Methods of Observation ("CIMO Guide") with forty-two experts from seventeen countries working on the update since 2000. The preliminary issue of the Seventh Edition has been made available for comment in an electronic version on the IMOP/CIMO web site in preparation for CIMO-XIV. CIMO is taking a lead role in the WMO Quality Management Framework work and integration into Technical Regulations and Guides, such as the CIMO Guide.

A first session of the Expert Team (ET) on Regional Instrument Centers, Quality Management Systems and Commercial Instrument Initiatives was held in Geneva, Switzerland in April this year. The main objective of the ET meeting was to discuss options for improving the functionality of Regional Instrument Centers, and ultimately preparing a strategy for strengthening their services and their role in overall Quality Management. The ET proposed recommendations to be submitted for consideration by CIMO-XIV Session, Geneva, December 2006.

7 Instrument Innovation for Disaster Preparedness and Mitigation

With increased populations and their associated infrastructure, there is an escalating need for Members to monitor and develop procedures for disaster detection, mitigation and prevention. CIMO participates through the activities of the CIMO Coordinator for the Disaster Preparedness and Mitigation Programme.

These have been innovations in the development of instruments for extreme conditions. These innovations have included instrumentation and sensors such as anemometers and humidity probes for alpine environments, AWOS electronics and sensors for extreme tropical cyclone, hurricane or typhoon wind and pressure measurements and rainfall intensity instruments for measuring major rainfall events for flood predictions and drought environments at the other end of the scale.

Innovation has also been demonstrated recently by the integration of enhanced tsunami warning/monitoring networks following the tragic tsunami off the coast of Aceh, Indonesia in December 2004. Several countries are purchasing and installing tsunami sea level instruments and deep ocean tsunami monitoring buoys to put in place detection and warning networks for this hazard. Many NHMS are becoming involved with this type of instruments and the sharing of data. Significant effort has been directed into both the design of coastal and deep ocean networks that will provide the maximum possible warning time for affected countries. At the same time there has been investigation of the sampling protocols needed for rapid and accurate detection of tsunami. This includes sampling frequencies, reporting frequencies and metrology.

Since the devastating tsunami of December 2004 a great deal has come to light about the science of tsunami and it has become apparent that there is a lot more to learn in terms of appropriate instruments and methods of sharing data for which CIMO, in collaboration with the Joint Commission for Oceanography and Marine Meteorology (JCOMM), will be able to provide assistance. Most of the existing networks have been designed for monitoring of long period phenomenon, such as tides and climate change. These networks and instruments in general cannot accurately characterize the tsunami events and are often located in harbours that complicate the detection and wave characteristics. Significant effort is going into development of siting procedures with a specific focus on medium period phenomenon such as tsunami. There are also significant developments in measurement technologies for detection of tsunami. Australia is planning to carryout an initial intercomparison of some of the viable coastal sea-level technologies to determine their suitability for use for tsunami detection[22]. This will include assessment of calibration methods and traceability.

Overall, CIMO has a critical role in innovation of measurements and observation techniques for disaster preparedness and mitigation, and assists WMO in the Disaster Preparedness and Mitigation (DPM) Programme through the provision of:

a. Instrument specifications and observing systems to meet requirements for the accurate and traceable measurement of meteorological, related geophysical and environmental variables, taking into account both experience and new developments for hazard monitoring and detection;
b. Encouragement to the instrument manufacturers to develop more robust instruments with greater resilience to extreme weather conditions and with increased measuring ranges;
c. Guidance on the use of instruments in harsh atmospheric conditions[23].

8 Conclusion

This paper has explored the procedures, operations and regulations developed by experts working within the WMO CIMO framework over a long history. These allow the uptake of innovations in instruments and meteorological observation techniques from research into operations in an efficient and effective way. The following papers in this conference will provide technical details on an exciting range of these innovations.

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