

WORLD METEOROLOGICAL ORGANIZATION

COMMISSION FOR BASIC SYSTEMS

OPAG ON INTEGRATED OBSERVING SYSTEMS

**EXPERT TEAM ON REQUIREMENTS FOR DATA
FROM AUTOMATIC WEATHER STATIONS**

Fifth Session

Geneva, Switzerland, 5 - 9 May 2008

FINAL REPORT
(May 2008)



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WMO General Regulations 42 and 43

Regulation 42

Recommendations of working groups shall have no status within the Organization until they have been approved by the responsible constituent body. In the case of joint working groups the recommendations must be concurred with by the presidents of the constituent bodies concerned before being submitted to the designated constituent body.

Regulation 43

In the case of a recommendation made by a working group between sessions of the responsible constituent body, either in a session of a working group or by correspondence, the president of the body may, as an exceptional measure, approve the recommendation on behalf of the constituent body when the matter is, in his opinion, urgent, and does not appear to imply new obligations for Members. He may then submit this recommendation for adoption by the Executive Council or to the President of the Organization for action in accordance with Regulation 9(5).

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EXECUTIVE SUMMARY

The fifth session of the CBS OPAG-IOE Expert Team on Requirements for Data from Automatic Weather Stations (ET-AWS-5) was held at WMO Headquarters, Geneva, Switzerland, from 5 to 9 May 2008.

The ET-AWS considered the issues requested by CBS-Ext. (2006) and formulated several recommendations to be submitted to CBS-XIV (2008). They were as follows:

The Functional Specifications for Automatic Weather Stations were reviewed and updated based on the proposals of other technical commissions. ET-AWS submitted [Recommendation 1](#).

The ET-AWS agreed on the principal conclusion regarding the Requirements for a robust AWS suitable particularly to remote location and adopted [Recommendation 2](#).

Preliminary draft of the Requirements for AWS sensors to contribute to the calibration and ground truth of space-based observations was developed and will be submitted to ET-SAT and ET-SUP for consideration. Further development on this issue should be subject to their recommendations. The ET-AWS adopted [Recommendation 3](#).

The ET-AWS discussed generic and sensor specific requirements for existing as well as new sensors which would improve the capability of AWS to report meteorological parameters addressing user requirements. The ET-AWS recognized that the work should continue to finalize the requirements and adopted [Recommendation 4](#).

A method was discussed that has a potential for use in the selection of observing stations for in RBSN/RBCN and for the continuous optimization of these networks. The ET-AWS agreed on the need to further investigate the suitability of this technique by its testing on the existing RBSNs/RBCNs.

Guidelines concerning the transition to specific automated observations were considered and a preliminary draft of the Guidelines and procedures to assist in the transition from manual to automatic surface observing stations was elaborated. The ET-AWS adopted [Recommendation 5](#).

The ET-AWS considered the development of four AWS metadata catalogues, agreed to continue further in their development and adopted [Recommendation 6](#).

The need for the Guidelines for the Siting classification of Surface Observing Stations (not only of AWS) was considered. The ET-AWS recommended that further work be done on the Siting Classification in close collaboration with CIMO, with the objective to be validated by CBS and then included in the Manual of the Global Observing System (WMO-No. 544) and Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8). Following approval by CBS, a joint ISO/WMO standardization should be explored. The ET-AWS adopted [Recommendation 7](#).

As requested by CBS, the list of the Basic set of variables to be reported by a standard AWS for multiple users was finalized based on the proposals received from other technical commissions. The ET-AWS adopted [Recommendation 8](#).

A preliminary review of BUFR descriptors was done. The ET-AWS expressed its opinion that the meaning of BUFR descriptors should be clear to data users and should be transparent to standard terminology of the WMO Technical Regulations. Regarding a type of measurement / observation, there should be clear reference to the Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8). The ET-AWS reviewed the BUFR descriptors related to AWS metadata transmission and identified those metadata for which BUFR descriptors do not exist. New BUFR descriptors should be developed as a part of future activities of the ET.

The ET-AWS recommended that the validation of the "merged" BUFR template for surface observations from one-hour period and for reporting SYNOP data in BUFR including proposed national station identification should be done as a matter of urgency. In this regard, the ET-AWS adopted [Recommendation 9](#).

The ET-AWS discussed in details the Vision for the GOS in 2025 and proposed additions to the draft Vision, which will be submitted to ET-EGOS for consideration and finalization.

As requested by ET-EGOS, a list of advances in AWS technology (as well as limitations) was elaborated but needs continues monitoring.

The ET-AWS reviewed the new actions in the EGOS-IP related to AWS (Action G21). Both of them were addressed by the ET. In this regard, the ET-AWS adopted [Recommendation 10](#).

The ET-AWS prepared draft future work plan for consideration by IOS-ICT and CBS-XIV.

GENERAL SUMMARY

1 ORGANIZATION OF THE SESSION

1.1 Opening of the session

1.2.1 The fifth session of the Expert Team on Requirements for Data from Automatic Weather Stations (ET-AWS), the Commission for Basic Systems (CBS) Open Programme Area Group on Integrated Observing Systems, was opened by its Chairman, Dr Igor Zahumensky, at 09:30 hours on Monday 5 May 2008 at WMO Headquarters in Geneva, Switzerland. The list of participants is given in [Annex 1](#).

1.2.2 Following the opening of the session, Dr. M. Ondráš, Chief Observing System Division, on behalf of Secretary-General, welcomed the participants to Geneva. In his statement he highlighted the most important topics the meeting was expected to address. He specifically recalled the issues related to (a) Vision for the GOS in 2025, (b) Guidelines and procedures needed for integration and standardization of AWS measurements in the context of WIGOS, and (c) Standardization of metadata for AWS.

1.2 Adoption of the agenda

1.2.1 The ET-AWS adopted the [Agenda](#) for the meeting which is reproduced at the beginning of the report.

1.3 Working arrangements

1.2.1 The ET-AWS agreed on working arrangements and adopted a tentative work plan for consideration of the various agenda items. The meeting agreed to begin every day at 09h00 and to continue until 17h00 hours with a one-and-half hour lunch break.

2 REPORT OF THE CHAIRMAN

2.1 The Chairman's report provided information on outcomes of the CBS-Ext. (2006) related to the work of the ET-AWS, changes of its membership and on activities during the last intersessional period. A proposal for future activities was suggested, taking into account the requirements and results received.

3 AWS FUNCTIONAL SPECIFICATIONS

3.1 The ET-AWS reviewed the table of the Functional Specifications for Automatic Weather Station (AWS) based on the submitted proposals. The representative of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) suggested a number of marine meteorology related variables to be inserted in the AWS Functional Specifications. Additional variables suggested by representatives of other WMO Technical Commissions (TCs) to be considered included: "freshwater salinity", "freshwater conductivity" and "(net) heat flux". However, because of the need for a clear definition and the absence of a well defined range and reporting resolution, these variables were not included in the Functional Specifications. The ET-AWS will further investigate these requests when preparing next update. It was proposed to eliminate the variable 'slant extinction coefficient' as no clear definition is still available. "Slant Path Visual Range (SVR)" could be an alternative, however, further investigations on this requirement is needed. The updated table of the Functional Specifications for AWS was approved by the ET-AWS and is reproduced in the [Annex 2](#).

3.2 The ET-AWS noted that for a number of already well-defined variables, a corresponding BUFR descriptor does not exist and should be developed.

3.3 The ET-AWS recommended that: (a) The CBS-XIV considers the approval of the revised Functional Specification for Automatic Weather Station for the inclusion in the Guide on the Global Observing System (WMO-No.488); (b) The OPAG-IOOS requests OPAG-ISS to develop BUFR descriptors of all variables, listed in the table "The Functional specifications for Automatic Weather Stations", and adopted **Recommendation 1** ([Annex 13](#)).

4 REQUIREMENTS FOR A ROBUST, LOW POWER, CONTINUOUS COMMUNICATIONS PLATFORM FOR ALL AWS, PARTICULARLY THOSE IN REMOTE LOCATIONS

4.1 The ET-AWS considered the results of the study of the Requirements for a robust AWS suitable particularly to remote locations. The ET-AWS agreed on the principle conclusions, as following:

- The robustness of power supply and communication platforms implemented on an AWS is critical to the continuous, timely, and reliable operation and retrieval of data from AWS. This is a key issue in particular for those AWS installed in remote locations.
- The constant evolution of the telecommunication technology and the increase availability of alternative means to power AWS offer new opportunities for increasing the efficiency of data collection and retrieval and the expansion of AWS in remote locations.
- The CBS should actively work towards providing guidance to Members concerning robust, low-power, and continuous communication platform for AWS, particularly those in remote locations. The cost of satellite communication, while decreasing recently, is still significant and limiting its use. Sharing of experience and methodologies through WMO could improve the access to effective communication and power techniques of all Members.
- Communication methods for an AWS consist of ground based (landline, wireless) and satellites. The most appropriate method depends on the location of the site, the availability of communication infrastructure or access, and the costs associated with the setup and operation. Satellite and mobile communications are increasingly viable options because of the extensive coverage, in particular in remote areas and are suitable for both fixed and mobile platforms (buoys).
- There is an increasing need for implementing two-way communication on an AWS (pull and push). This could significantly improve the sustainability of an AWS network, reducing its overall operating costs through remote access and troubleshooting, and improving data availability.

4.2 Various communication means are currently in use by WMO Members, taking advantage of the locally available services and conditions. Rapid changes in technology make the standardization of communication platforms and access difficult to achieve and manage.

4.3 Developing and implementing sustainable solution for supplying power to an AWS remains a challenge for an AWS situated in remote locations.

4.4 The lack of standardization, even from the same provider, hinders effective management of an AWS network.

4.5 The robustness of AWS systems could be further improved through a technology transparent design, through the use of data compression techniques to minimize the size of message transmitted and reduce the communication costs, and through creating redundancy where alternative means are available and affordable.

4.6 Critical to data availability is the ability to store data on site for extended period, in case of communication failure. This is of particular importance to the climate community.

4.7 Guideline to Members for the configuration and implementation of two-way communication on AWS and use of data compressing techniques is needed to maximize their use.

4.8 While agreeing in the principal conclusion, the ET-AWS agreed that this activity should continue to finalize the requirements, The ET-AWS recommended that the Guidelines reproduced in [Annex 3](#) should be submitted at CIMO/OPAG-SURFACE ET-ST&MT for consideration and development of surface technology and measurement techniques, and adopted **Recommendation**

2 ([Annex 13](#)). The draft version of the Requirements for a robust, low power, continuous communications platform for AWS, particularly those in remote locations is reproduced in [Annex 3](#).

5 REQUIREMENTS FOR AWS HOSTED SENSORS TO CONTRIBUTE DIRECTLY TO THE CALIBRATION AND GROUND TRUTH OF SPACE-BASED OBSERVATIONS

5.1 With the expansion of AWS networks across the globe and real time communications through the GTS, the potential has been identified by the ET-AWS to add sensors to an AWS platform which could provide reliable ground-truth observations to contribute to the calibration of remotely sensed observations. Surface stations have a long history in providing measurements traceable to SI.

5.2 An initial investigation has identified potential in observations such as total column water vapour, rainfall, (including radar rainfall estimates), sea-surface temperature, snow depth, soil moisture, surface emissivity, land surface temperature, albedo, evaporation and cloud cover.

5.3 The CCI representative recalled that the chair of the CCI Expert Team on Observing Requirements and Standards for Climate (ET-ORSC) had noted that remote sensing can provide much greater densities of observations than conventional networks. However, particularly for climate, a certain number of surface stations are required to ground-truth remotely sensed observations.

5.4 In some cases, remote sensed information can be used to supplement surface observation, such as cloud type (CB & TCU) in METAR reports.

5.5 The session recommended submitting the preliminary draft of the Requirements for AWS hosted sensors to contribute directly to the calibration and ground truth of space-based observations, reproduced in the [Annex 4](#), for consideration by CBS/OPAG ET-SAT and ET-SUP and further development on this issue should be subject to their recommendations. The ET-AWS recommended that ICT-IOIS submits the preliminary draft of the Requirements for AWS hosted sensors to contribute directly to the calibration and ground truth of space-based observations, reproduced in the [Annex 4](#), to ET-SAT and ET-SUP for their consideration. The further development on this issue should be subject to their recommendations, and adopted **Recommendation 3** ([Annex 13](#)).

6 REQUIREMENTS FOR NEW SENSORS OR THE INTEGRATION OF SENSORS TO MEET THE DEFICIENCIES OF AWS FOLLOWING THE MIGRATION FROM MANUAL OBSERVATIONS

6.1 Section 3.1.1 of the Manual on the Global Observing System (Manual on GOS) (WMO-No. 544) states the “General requirements of a meteorological station” as follows: All stations shall be equipped with properly calibrated instruments and adequate observational and measuring techniques, so that the measurements and observations of the various meteorological elements are accurate enough to meet the needs of synoptic meteorology, aeronautical meteorology, climatology and of other meteorological disciplines.”

6.2 The requirements for AWS instruments have to take into consideration all aspects related to the ability to provide relevant and representative measurements over their entire life cycle.

6.3 The requirements for sensors installed at AWS following the migration from manual to automated observations can be grouped into three basic interrelated categories, all contributing significantly to the long-term sustainability of AWS data. They are as follows:

- Requirements related to the measuring performance of instruments, covering the ability of an instrument to provide measurements with a stated uncertainty over the specified operating range and condition;
- Requirements related to maintaining the traceability of measurements over the operational cycle; and

- Requirements related to the operational reliability of AWS sensors, which include features that enable their operation for extended periods, within the expected measuring performance, with minimum human intervention over their entire operating range.

6.4 The ET-AWS discussed generic and sensor specific requirements for the existing as well as new sensors, which would improve the capability of AWS to measure and report meteorological parameters, to meet user requirements.

6.5 The ET-AWS recognized that the draft Requirements for new sensors or the integration of sensors to overcome the deficiencies of AWS following the migration from manual observations, reproduced in the [Annex 5](#), summarizes the experience of most Members and the TCs and that the work should continue to validate and finalize the draft requirements. These requirements should be submitted to the CIMO-OPAG-SURFACE Expert Team on Surface Technology and Measurement Techniques (ET-ST&MT) for comments and further development of surface technology and measurement techniques. The ET-AWS recommended that the Requirements for new sensors or the integration of sensors to overcome the deficiencies of AWS following the migration from manual observations, reproduced in [Annex 5](#), should be submitted at CIMO-OPAG-SURFACE ET-ST&MT for consideration and further development of surface technology and measurement techniques, and adopted **Recommendation 4** ([Annex 13](#)).

6.6 The ET-AWS agreed on the need to refine these requirements. See ET-AWS Work Plan in [Annex 14](#).

7 ADDRESSING THE NEED FOR INTEGRATION OF POINT MEASUREMENTS WITH AREA MEASUREMENTS

7.1 The representative of the CIMO presented a short introduction on the differences of spatial based data, obtained from remote sensing instruments, such as radars and sensors on board of satellites, and data obtained from AWS networks.

7.2 Typically, spatial based data exist mainly of equidistant speckles representing averaged values of the area covered by the speckle. AWS network delivers point based observations, while the AWSs are not equi-spatial distributed and the density varies from a region to region even on a small scale. Moreover, each AWS has its own, local-based characteristics and representativity for the surrounding area differs from station to station. This representativity depends also on the type of weather (e.g. on the wind direction at coastal stations or the measure of instability of the atmosphere).

7.3 As a result, data from AWS networks and satellite or radar data needs interpretation before further data integration. It was explained that solving this issue is not trivial or cannot follow a straightforward procedure like simple or linear interpolations.

7.4 Ideas were expressed, based on the assumption that a solution may be found based on characterization of the structure of the network. If such a structure can be characterized by one or more parameters, it should be possible to implement intelligent algorithms to make AWS network datasets comparable to spatial or uniformly spaced point datasets.

7.5 As a first approach, a rather simple technique was presented based on a statistical analysis of the mutual distances between all stations in the network, not only the neighbouring stations as it is done traditionally. From a cumulative approach of these statistics, a median value can be obtained which can be used as a characteristic parameter having length (distance) as a useful unit. Such statistical analysis will make it possible to consider local impacts (e.g. reduced representativity or morphological effects) by using weighting factors for specific stations of mutual distances.

7.6 This technique has already been applied for the selection of a fixed number of AWS for the design of a national network of synoptic AWS in the Netherlands. Based on an iterative process, a set of AWSs with the lowest distance parameter was regarded as the optimal selection.

7.7 The ET-AWS recognized the potential of this technique for the selection of observing stations for any Regional Basic Synoptic/Climatologic Network (RBSN/ RBCN) as part of a process of continuous optimization of these networks or their integration. The ET-AWS agreed on the

need to further investigate the suitability of this technique, see [Annex 6](#), by testing it on the existing RBSNs/RBCNs. See ET-AWS Work Plan in [Annex 14](#).

8 DEVELOPMENT OF GUIDELINES AND PROCEDURES TO ASSIST IN THE TRANSITION FROM MANUAL TO AUTOMATIC SURFACE OBSERVING STATIONS

8.1 The ET-AWS agreed that human observers were able to integrate and classify a wide range of information needed for full description of weather events. With the advent of AWS, particular areas such as visual observations, cloud classification and weather type identification are handled poorly or not at all, by an AWS unattended by observer. On the other hand, AWS provide benefits in frequent, regular, objective and consistent measurements and can be located in any environment, including extremely remote and harsh conditions.

8.2 The transition to AWS is often instigated by a perception that these systems are cheaper to operate and easier to manage than human observers. The ET-AWS cautioned that this was not the experience of a number of member countries. Therefore, it identified a number of responsibilities and costs that may not be immediately apparent to those that adopt automatic systems.

8.3 The ET-AWS highlighted that change for automation is a reality in all networks and the careful management of the transition process is needed to protect data user needs. The establishment of a Change Management Board (CMB), e.g. as done in Canada, was recommended. CMB provides a forum for network planners, operational managers and data stakeholders to discuss strategic issues regarding the transition process.

8.4 Before embarking on automation of their network, Members should consider i) the resource requirements, ii) potential gains and losses and iii) how to manage this transition.

8.5 The ET-AWS agreed on a preliminary list of guidelines which would assist in the process of converting to automatic systems. They include:

- Management of network change;
- Defining and assigning responsibilities;
- System costing;
- Parallel testing;
- Metadata;
- Data quality and reliability;
- User requirements;
- Access to data and metadata.

8.6 Guidelines concerning the transition to specific automated observations (such as weather, precipitation type) were considered by the ET-AWS and a preliminary draft of the Guidelines and procedures to assist in the transition from manual to automatic surface observing stations is reproduced in [Annex 7](#). The ET-AWS agreed on the need to refine these guidelines. See ET-AWS Work Plan in [Annex 14](#).

8.7 The CCI representative recalled that the chairperson of ET-ORSC had highlighted the value to the climate community of data homogeneity and continuity. He mentioned the GCOS Climate Monitoring Principles adopted by WMO Cg-XIV in May 2003. He also identified that maintenance, access to sufficient logging capacity, and sophisticated instruments were of great importance to the climate program. He recommended that a parallel observation of at least two years was strongly recommended. The indefinite co-location of AWS and manual stations was the preferred solution. The interspersing of manual and automated observations stations provides the benefit of visual observations, while also providing a means of cross checking. An AWS addressing climatological requirements should have a backup for one-hour data of at least one month.

8.8 The ET-AWS recommended that the Guidelines and procedures to assist in the transition from manual to automatic surface observing stations, reproduced in [Annex 7](#), should be submitted to CIMO-OPAG-SURFACE ET-ST&MT for consideration and further development of surface technology and measurement techniques, and adopted **Recommendation 5** ([Annex 13](#)).

9 DEVELOPMENT OF GUIDELINES FOR THE IMPLEMENTATION OF NEW DATA TYPES FROM EITHER NEW SENSORS OR FOLLOWING THE SUCCESSFUL INTEGRATION OF SENSORS

9.1 In response to increasing demands for more comprehensive meteorological information from the public and other services and with heightened awareness towards weather, climate and other environmental issues and services, requirements for new types of data from new sensors or based on integration of measurements from multiple sensors to provide new information have expanded. The need for weather, climate and other information often exceeds those provided by a traditional AWS network.

9.2 Apart from the conventional meteorological variables, new types of data are required. The requirements can be grouped into three basic categories:

- a) Automation of subjective and visual observations;
- b) New instrumentation or methods for traditional (basic) meteorological variables; and
- c) New variables (e.g. depth of snowfall measurement).

9.3 The ET-AWS agreed that the Association of Hydro-Meteorological Equipment Industry (HMEI) should play a significant role in this development by keeping the manufacturers informed of new and evolving requirements of WMO Members. The meeting further noted that flexibility and modularity of the AWS design was very important to address these changing requirements.

9.4 The ET-AWS agreed on the need to continue in developing requirements for new data types from AWS sensors; see ET-AWS Work Plan in [Annex 14](#).

10 DEVELOPMENT OF THE RECOMMENDED FOUR CATALOGUES OF AWS METADATA

10.1 Taking into account the development of WMO Core Profile of the Metadata Standards, it was noted that catalogues of standard AWS metadata should be prepared to support information sharing.

10.2 In a dynamic system such as an AWS, metadata are subject to change during the life of the station. Therefore, maintaining the station history and tracking the changes of station metadata are important for different reasons. The method to record the history of metadata was demonstrated using a number of examples.

10.3 Four metadata catalogues would comprise:

- Variables measured by a standard AWS (see Item 3 “Functional Specifications for AWS”);
- Instruments used for variables measured by standard AWS (basis for this catalogue would be the Instrument/Product catalogues by CIMO/CMA and HMEI respectively);
- Data processing procedures (algorithms) used by AWS (basis for this catalogue would be IOM Report 78);
- Data quality control procedures used for AWS data (basis for this catalogue would be relevant part of the Guide on the GOS, WMO-No. 488).

10.4 The meeting identified the requirement that terminology used in BUFR tables should be transparent to the WMO Technical Regulations. The use of traceable and unambiguous descriptors will assist in the process of correct coding and sharing of information.

10.5 The ET-AWS agreed on the need to continue in the development of metadata catalogues (see Work Plan in [Annex 14](#)). The ET-AWS recommended that the OPAG-IO requests OPAG-ISS to use existing BUFR tables in the development and implementation of metadata catalogues for WIS, and adopted **Recommendation 6** ([Annex 13](#)).

11 DEVELOPMENT OF GUIDELINES FOR THE SITING CLASSIFICATION OF AWS

11.1 WMO recommendations for the siting of instruments are well known, but sometimes it is difficult to implement them in field conditions. A poor siting can generate large errors that are much larger than the sensors' uncertainties.

11.2 M. Leroy, Météo-France, recalled the classification developed and used by Météo-France and presented at TECO-98 and TECO-2006. France has applied this classification to about 4000 surface observing stations.

11.3 The ET-AWS agreed that this classification would provide a very good starting point to develop guidelines for the Siting classification of Surface Observing Stations (not only of AWS). Therefore, the ET-AWS recommended that further work be done on the Siting Classification, reproduced in [Annex 8](#), in close collaboration with CIMO, with the objective to be validated by CBS and then included in the Manual of the Global Observing System (WMO-No. 544) and Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8). Following approval by CBS, a joint ISO/WMO standardization should be explored.

11.4 The ET-AWS agreed on the need to continue this task (see Work Plan in [Annex 14](#)) and recommended that the CBS and CIMO develop further the classification scheme presented in [Annex 8](#) for the inclusion in the Manual of the Global Observing System (WMO-No. 544) and Guide to Meteorological Instruments and Methods of Observations (WMO-No. 8). This classification scheme should subsequently be recognized as a joint WMO-ISO standard, and adopted **Recommendation 7** ([Annex 13](#)).

12 STANDARD AND OPTIONAL VARIABLES TO BE REPORTED BY AWS

12.1 As requested by CBS, the list of the Basic set of variables to be reported by a standard AWS for multiple users was finalized based on the proposals received from other TCs.

12.2 The list of standard and optional variables to be reported by AWS as recommended by ET-AWS-4 was reviewed and discussed in details. It was explained that this list is in fact extracted from the Manual on the Global Observing System (WMO-No. 544). Further review was needed because the sets of required variables presented in the Manual of the GOS may not be complete.

12.3 The representative of JCOMM provided a number of variables related to marine observations to be observed by VOS, drifting and moored buoys, rigs and platforms, tide gauges, profiling floats. However it was stated that these variables should be reviewed after consultation with the relevant JCOMM Expert Teams. The ET-AWS recommended that CBS-XIV considers the Basic set of variables to be reported by a standard AWS, presented in the [Annex 9](#), for inclusion in the Manual on the GOS (WMO-No. 544), and adopted **Recommendation 8** ([Annex 13](#)).

12.4 The ET-AWS suggested that the revised list the Basic set of variables to be reported by a standard AWS for multiple users, reproduced in [Annex 9](#), be submitted to CBS-XIV for consideration and inclusion in the Manual on the GOS (WMO-No. 544).

13 REVIEW OF BUFR DESCRIPTORS RELATED TO AWS MEASUREMENTS

13.1 A preliminary review of BUFR descriptors was done from two aspects: (a) traceability and unambiguity of terminology, and (b) requirements for metadata transmission and incorporation into WIS.

13.2 Regarding the traceability of BUFR descriptors, only International Meteorological Vocabulary (IMV) (WMO-No. 182) was taken into account at this stage. The ET-AWS expressed its opinion that the meaning of BUFR descriptors should be clear to data users and should be transparent to standard terminology accepted by scientific community, which is not the case of IMV. Regarding a type of measurement / observation, there should be clear reference to the Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8).

13.3 Another problem that causes ambiguity for data users is that in several cases more than one descriptor can be used for the same variable, e.g. air temperature, or more than one template for AWS data can be used. Therefore, more detailed regulations would be useful as to which

descriptor/template should be used for which purpose and to identify descriptors which are obsolete.

13.4 Traceability and unambiguity are important for WIGOS and WIS, especially for WIS Discovery, Access and Retrieval (DAR) services. It was agreed that a closer working arrangement between ET-AWS and relevant CBS/OPAG-ISS ETs could help to solve those problems.

13.5 The meeting noted that the requirements for the “merged” BUFR template for surface observations from one-hour period and for reporting SYNOP data in BUFR (revised, June 2006) was addressed by ET-DR&C, but it still requires validation. The meeting recommended that the validation of the template including proposed national station identification should be done as a matter of urgency. It accepted with pleasure an offer by M. Leroy, Météo-France, to take lead in this validation. The ET-AWS emphasized the need for the adoption of the relevant amendments to the Manual on Codes (WMO-No. 306) by CBS-XIV so that this “merged” template could be used instead of the B/C1 – SYNOP template for reporting SYNOP data in BUFR during and after the transition phase for the migration from traditional alphanumeric codes (TAC) to Table Driven Codes Forms (TDCF). In this regard, the ET-AWS recommended that Météo France be requested to take a lead in the validation of the BUFR Template for Surface Observations from one hour period and for reporting of SYNOP data, to implement this template and adjust it as appropriate, in collaboration with CBS and ET-DR&C and with the view of its approval by CBS-XIV, and adopted **Recommendation 9** ([Annex 13](#)).

13.6 The ET-AWS noticed the requirement from WIS community that metadata should be disseminated only when they have changed and separately from observational data. This requirement is not in line with what requested ET-AWS-4 that the standard set of metadata for the operational purposes should be transmitted in real time together with measured data. However, it was noted that the metadata transmitted in real-time together with operational data could be also minimized using BUFR Delayed replication in the same way as it was used in the AWS BUFR templates when a particular variable was not measured by AWS. This technique can be also used for metadata that do not change frequently, except BUFR descriptors classes 01-08 (coordinate descriptors).

13.7 The ET-AWS proposed that the BUFR tables/descriptors could be used as a tool in the developing of relevant WIS operational catalogues related to AWS measurements.

13.8 The ET-AWS reviewed the BUFR descriptors related to AWS metadata transmission taking into account the development of recommended AWS metadata catalogues ([Item 10](#)) and identified those metadata for which BUFR descriptors do not exist:

- Classification of roughness,
- Siting and exposure – Siting classification,
- Expected performance of the instrument,
- QC flag for each parameter,
- Method of measurement / observation OR type of detection system for each variable measured by AWS (and transmitted in AWS BUFR template now or in a future);

13.9 Referring to above, new BUFR descriptors should be developed and it was agreed that, as a part of the future Work Plan ([Annex 14](#)), the ET-AWS would prepare requirements for the ET-DR&C.

14 THE VISION FOR THE GOS

14.1 ET-AWS discussed in details the Vision for the GOS in 2025. It considered the revision of the draft Vision for the GOS in 2025 provided by Dr J. Eyre, chair of ET-EGOS in March 2008. In doing so, many different aspects were taken into account, such as development of requirements for data and observations by different WMO Programmes, various applications and users on one hand and science and technology developments on the other hand.

14.2 Ms L. Jalkanen presented the view of CAS. She recalled that, with regard to atmospheric composition observations, the GAW programme is organized under WMO CAS takes the lead in

WMO on atmospheric composition observation and analysis, as well as data discovery, access and recovery and data quality issues. In 2007, GAW published its Strategic Plan (GAW Report No. 172) for the years 2008-2015 that entered into force. The Strategic Plan has a vision for WMO's work on observing and analyzing atmospheric composition. With regard to atmospheric composition observations, these questions are channeled thus to the GAW Strategic Plan 2008-2015.

14.3 Mr W. Grabs presented a view of CHy. He underlined the need to increase capacity building efforts both technically and institutionally to enable Members to make best use of multivariate observations and to reduce the gap between rapidly evolving systems in developed countries versus the status of observational capabilities in developing countries. He also stressed the need to include hydrological observations in mainstream meteorological observations and reporting mechanisms, including access to global data and information by NHTs (which is not the case now when the GTS is accessible only through NHTs).

14.4 Mr S. Bojinski presented a view of GCOS. He expressed his satisfaction with the updated text presented in the working document.

14.5 Mr E. Charpentier presented a view of JCOMM. He informed the ET-AWS that JCOMM proposals were already incorporated in the working document and that further proposals will be provided directly to ET-EGOS session in July 2008.

14.6 The ET-AWS agreed on the revised text of the draft Vision for the GOS in 2025, reproduced in the [Annex 10](#), which will be submitted to ET-EGOS for finalization.

15 ADVANCES IN AWS TECHNOLOGY

15.1 The ET-AWS prepared a list of advances in AWS technology (as well as limitations) as reproduced in [Annex 11](#). The main advances concern telecommunications and ability of internal diagnostics to optimize the maintenance. There has been less progress in the area of sensor development.

15.2 The decreasing cost of an AWS make them more affordable and attractive, however, it has to be recognized that the cost of AWS stations remains marginal compared to the initial and running costs of a network. It is important to remember this aspect to avoid wasting investments because of a deficiency in network management, maintenance, calibration and training.

15.3 The ET-AWS agreed that there is a need for continues monitoring of advances of AWS technology for timely and comprehensive advise to Members. This task was proposed for the future Work Plan (see [Annex 14](#))

16 ANY OTHER BUSINESS

16.1 WMO Integrated Global Observing Systems (WIGOS)

16.1.1 Dr D. Hinsman, Director WMO Observing and Information Systems Department, WMO Integrated Global Observing System Branch, WMO Space Programme, briefed the session on the WMO activities related to WIGOS. In his presentation, he underlined standardization and the role the ET-AWS could play in it.

16.2 *Implementation Plan for Evolution of Space and Surface-based Sub-Systems of the GOS (EGOS-IP)*

16.2.1 The ET-AWS chairman briefed the meeting on the new actions in the EGOS-IP related to AWS (G21). A new action "Advances in AWS technology" was addressed by Item 15. The meeting agreed that a new action "The evolution of the AWS network" had been also addressed under individual Agenda Items. Developing corresponding requirements and relevant guidelines, ET-AWS formulated how this technology can be implemented in operational practices of in Member countries. When considering the role of ET-AWS, the ET-AWS recommended to expand the scope of the ET-AWS to cover surface observing network issues and to rename it to "ET on Requirements and Implementation of AWS platforms", and adopted **Recommendation 10** ([Annex 13](#)).

16.3 Input of the representative of CCL

16.3.1 The CCI representative informed that the chair of ET-ORSC had provided a paper titled "Observing the climate – challenges for the 21st century" (reproduced in [Annex 12](#)). This article briefly reviews the challenges in collecting and managing observational data suitable for the needs of national and international climate programs that are responsible for providing climate services today, and with monitoring and predicting the climate of the future. It also briefly describes the impacts of increased automation of the observing networks. It also identifies various benefits of AWS to the climate program as well as negative impacts, such as data losses, data inhomogeneities, and the loss of visual observations. It suggests:

- the use of data loggers with local data buffering capabilities for archiving raw data for at least one month, to reduce data loss,
- the need for sound management to maintain the reliable operation of the AWS, and
- the careful design of climate networks.

16.4 AWS for the Least Developed Countries

16.4.1 The Least Developed Countries (LDCs) are increasingly replacing manual observation with AWS. There has been a concern from these countries that most reliable AWS are over specified for their basic needs and therefore too expensive for the LDCs.

16.4.2 Therefore, HMEI suggested that there should be a specification for a basic AWS that would meet the needs of the LDCs addressing:

- Minimal set of requirements for local weather forecasting;
- Basic measurements for global climate monitoring;
- Ongoing maintenance and training.

16.4.3 With such recommendation established, manufacturers would have the basis for producing an AWS that can combine affordability with reliable and adequate measurements to satisfy the local and global communities.

16.4.4 It was recognized that to address this task the requirements from LDCs should be received first.

17 RECOMMENDATIONS-FOR OPAG-IOS-ICT AND CBS-XIV (2008)

16.1 During the session, the ET-AWS formulated ten recommendations for consideration by CBS/OPAG-IOS-ICT and CBS-XIV (2008). These recommendations are presented in [Annex 13](#).

18 FUTURE WORK PLAN

The ET-AWS agreed on the draft future work plan to be considered by OPAG-IOS-ICT and CBS-XIV and on the detailed work plan that proposes allocation of task to individuals willing to address those tasks. Refer to [Annex 14](#) and [Annex15](#).

19 CLOSURE OF THE SESSION

The meeting was closed at 15:00 hours on 9 May 2008.

**Expert Team on Requirements for Data from Automatic Weather Stations
(ET-AWS-5), Geneva, 5 – 9 May 2008**

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Functional Specifications for Automatic Weather Stations

VARIABLE ¹⁾	Maximum Effective Range ²⁾	Minimum Reported Resolution ³⁾	Mode of Observation ⁴⁾	BUFR / CREX ⁵⁾
ATMOSPHERIC PRESSURE				
Atmospheric Pressure	500 – 1080 hPa	10 Pa	I, V	0 10 004
TEMPERATURE ⁹⁾				
Ambient air temperature (over specified surface)	-80 °C – +60 °C	0.1 K	I, V	0 12 101
Dew-point temperature	-80 °C – +60 °C	0.1 K	I, V	0 12 103
Ground (<i>surface</i>) temperature (<i>over specified surface</i>)	-80 °C – +80 °C	0.1 K	I, V	0 12 113
Soil temperature	-50 °C – +50 °C	0.1 K	I, V	0 12 130
Snow temperature	-80 °C – 0 °C	0.1 K	I, V	N
Water temperature - river, lake, sea, well	-2 °C – +100 °C	0.1 K	I, V	0 13 082
HUMIDITY ⁹⁾				
Relative humidity	0 – 100%	1%	I, V	0 13 003
Mass mixing ratio	0 – 100%	1%	I, V	N
Soil moisture, volumetric or water potential	0 – 10 ³ g kg ⁻¹	1 g kg ⁻¹	I, V	N
Water vapour pressure	0 – 100 hPa	10 Pa	I, V	0 13 004
Evaporation / evapotranspiration	0 – 0.2 m	0.1 kg m ⁻² , 0.0001 m	T	0 13 033
Object wetness duration	0 – 86 400 s	1 s	T	N
WIND				
Direction	0 ¹³⁾ , 1° – 360°	1°	I, V	0 11 001
Speed	0 – 75 m s ⁻¹	0.1 m s ⁻¹	I, V	0 11 002
Gust Speed	0 – 150 m s ⁻¹	0.1 m s ⁻¹	I, V	0 11 041
X,Y,Z component of wind vector (horizontal and vertical profile)	0 – 150 m s ⁻¹	0.1 m s ⁻¹	I, V	N
Turbulence type (Low levels and wake vortex)	up to 15 types	BUFR Table	I, V	N
Turbulence intensity	up to 15 types	BUFR Table	I, V	N
RADIATION ⁶⁾				
Sunshine duration	0 – 86 400 s	60 s	T	0 14 031
Background luminance	1·10 ⁻⁶ – 2·10 ⁴ Cd m ⁻²	1·10 ⁻⁶ Cd m ⁻²	I, V	N
Global downward solar radiation	0 – 6·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	N
Global upward solar radiation	0 – 4·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	N
Diffuse solar radiation	0 – 4·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	0 14 023
Direct solar radiation	0 – 5·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	0 14 025
Downward long-wave radiation	0 – 3·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	0 14 002
Upward long-wave radiation	0 – 3·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	0 14 002
Net radiation	0 – 6·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	0 14 016
UV-B radiation ⁸⁾	0 – 1.2·10 ³ J m ⁻²	1 J m ⁻²	I, T, V	N
Photosynthetically active radiation	0 – 3·10 ⁶ J m ⁻²	1 J m ⁻²	I, T, V	N
Surface albedo	1 – 100%	1%	I, V	0 14 019

VARIABLE ¹⁾	Maximum Effective Range ²⁾	Minimum Reported Resolution ³⁾	Mode of Observation ⁴⁾	BUFR / CREX ⁵⁾
CLOUDS				
Cloud base height	0 – 30 km	10 m	I, V	0 20 013
Cloud top height	0 – 30 km	10 m	I, V	0 20 014
Cloud type, convective vs. other types	up to 30 classes	BUFR Table	I	0 20 012
Cloud hydrometeor concentration	1 – 700 hydrometeors dm ⁻³	1 hydrometeor dm ⁻³	I, V	N
Effective radius of cloud hydrometeors	2·10 ⁻⁵ – 32·10 ⁻⁵ m	2·10 ⁻⁵ m	I, V	N
Cloud liquid water content	1·10 ⁻⁵ –1.4·10 ⁻² kg m ⁻³	1·10 ⁻⁵ kg m ⁻³	I, V	N
Optical depth within each layer	Not specified yet	Not specified yet	I, V	N
Optical depth of fog	Not specified yet	Not specified yet	I, V	N
Height of inversion	0 – 1 000 m	10 m	I, V	N
Cloud cover	0 – 100%	1%	I, V	0 20 010
Cloud amount	0 – 8/8	1/8	I, V	0 20 011
PRECIPITATION				
Accumulation ⁷⁾	0 – 1000 mm	0.1 kg m ⁻² , 0.0001 m	T	0 13 011
Depth of fresh snowfall	0 –1000 cm	0.001 m	T	0 13 015
Duration	up to 86 400 s	60 s	T	0 26 020
Size of precipitating element	1·10 ⁻³ – 0.5 m	1·10 ⁻³ m	I, V	N
Intensity - quantitative	0 – 2000 mm h ⁻¹	0.1 kg m ⁻² s ⁻¹ , 0.1 mm h ⁻¹	I, V	0 13 055
Type	up to 30 types	BUFR Table	I, V	0 20 021
Rate of ice accretion	0 – 1 kg dm ⁻² h ⁻¹	1·10 ⁻³ kg dm ⁻² h ⁻¹	I, V	N
OBSCURATIONS				
Obscuration type	up to 30 types	BUFR Table	I, V	0 20 025
Hydrometeor type	up to 30 types	BUFR Table	I, V	0 20 025
Lithometeor type	up to 30 types	BUFR Table	I, V	0 20 025
Hydrometeor radius	2·10 ⁻⁵ – 32·10 ⁻⁵ m	2·10 ⁻⁵ m	I, V	N
Extinction coefficient	0 – 1 m ⁻¹	0.001 m ⁻¹	I, V	N
Slant extinction coefficient	0 – 1 m ⁻⁴	0.001 m ⁻⁴	I, V	N
Meteorological Optical Range ¹⁰⁾	1 – 100 000 m	1 m	I, V	N
Runway visual range	1 – 4 000 m	1 m	I, V	0 20 061
Other weather type	up to 18 types	BUFR Table	I, V	0 20 023
LIGHTNING				
Lightning rates of discharge	0 – 100 000	Number h ⁻¹	I, V	0 13 059
Lightning discharge type (cloud to cloud, cloud to surface)	up to 10 types	BUFR Table	I, V	N
Lightning discharge polarity	2 types	BUFR Table	I, V	N
Lightning discharge energy	Not specified yet	Not specified yet	I, V	N
Lightning - distance from station	0 – 3·10 ⁴ m	10 ³ m	I, V	N
Lightning - direction from station	1° – 360°	1 degree	I, V	N

VARIABLE ¹⁾	Maximum Effective Range ²⁾	Minimum Reported Resolution ³⁾	Mode of Observation ⁴⁾	BUFR / CREX ⁵⁾
HYDROLOGIC AND MARINE OBSERVATIONS				
Flow discharge – river	0 – 2.5·10 ⁵ m ³ s ⁻¹	0.1 m ³ s ⁻¹	I, V	0 23 017
Flow discharge – well	0 – 50 m ³ s ⁻¹	0.001 m ³ s ⁻¹	I, V	0 23 017
Ground water level	0 – 1 800 m	0.01 m	I, V	N
Ice surface temperature	-80 °C – +0 °C	0.5 K	I, V	N
Ice thickness - river, lake	0 – 50 m	0.01 m	I, V	N
Ice thickness - glacier, sea	0 – 4 270 m	1 m	I, V	0 20 031
Water level	0 – 100 m	0.01 m	I, V	0 13 071 0 13 072
Wave height	0 – 50 m	0.1 m	V	0 22 021
Wave period	0 – 100 s	1 s	V	0 22 011
Wave direction	0 ¹³⁾ ; 1 – 360 degrees	1 degrees	V	0 22 001
1D spectral wave energy density	0 – 5x10 ⁵ m ² Hz ⁻¹	10 ⁻³ m ² Hz ⁻¹	V, T	0 22 069
2D spectral wave energy density	0 – 5x10 ⁵ m ² Hz ⁻¹	10 ⁻³ m ² Hz ⁻¹	V, T	0 22 069
Sea salinity	0 – 40 ‰ ¹²⁾ [0 – 400 psu]	10 ⁻⁴ ‰ [10 ⁻³ psu]	I, V	0 22 059 0 22 062 0 22 064
Conductivity	0 – 600 S m ⁻¹	10 ⁻⁶ S m ⁻¹	I, V	0 22 066
Water pressure	0 – 11x10 ⁷ Pa	100 Pa	I, V	0 22 065
Ice thickness	0 – 3 m	0.015 m	T	0 20 031
Ice mass	0 – 50 kg m ⁻¹	0.5 kg m ⁻¹ (on 32 mm rod)	T	N
Snow density (liquid water content)	100 – 700 kg m ⁻³	1 kg m ⁻³	T	N
Tidal elevation with respect to local chart datum	-10 – +30 m	0.001 m	I, V	0 22 035 0 22 038
Tidal elevation with respect to national land datum	-10 – +30 m	0.001 m	I, V	0 22 037
Meteorological residual tidal elevation (surge or offset)	-10 – +16m	0.001 m	I, V	0 22 036 0 22 039 0 22 040
Ocean Current - Direction	0 ¹³⁾ ; 1° – 360°	1°	I, V	0 22 004 0 22 005
Ocean Current - Speed	0 – 10 m s ⁻¹	0.01 m s ⁻¹	I, V	0 22 031 0 22 032
OTHER SURFACE VARIABLES				
Runway conditions	up to 10 types	BUFR Table	I, V	N
Braking action/friction coefficient	up to 7 types	BUFR Table	I, V	N
State of ground	up to 30 types	BUFR Table	I, V	0 20 062
Type of surface specified	up to 15 types	BUFR Table	I, V	0 08 010
Snow depth	0 – 25 m	0.01 m	T	0 13 013
OTHER				
Gamma radiation dose	1 – 10 nSv h ⁻¹	1 nSv h ⁻¹	I, T	N
Categories of stability	9 types	BUFR Table	I, V	0 13 041

Notes:

1. Name of variable, in line with WMO Vocabulary and Technical regulations;
2. Maximum Effective Range – Maximum range of measuring capability; units traceable to SI.
3. Minimum Reported Resolution – Lower resolution of reporting is not permitted;
4. Mode of Observation – Type of data being reported:
 - I: Instantaneous – 1-minute value (instantaneous as defined in WMO-No.8, Part II, paragraph 1.3.2.4);
 - V: Variability – Average (mean), Standard Deviation, Maximum, Minimum, Range, Median, etc. of samples – those reported depend upon meteorological variable;
 - T: Total – Integrated value during defined period (over a fixed period(s)); maximum 24 hours for all parameters except radiation which requires a maximum of one hour (exception, see note 6), and precipitation accumulation (6 hours maximum).
 - A: Average (mean) value.
5. BUFR/CREX – Present ability to represent variable by BUFR Tables, N = not existing, to be defined (registered).
6. Radiation energy amounts are given over a 24-hour period.
7. Maximum interval: 6 H.
8. Definition of UV-B according to WMO-No. 8 (Vol. 1, Chapter on Radiation)
9. Humidity related variables (*i.e.* dew point) expressed as temperature are collected under temperature.
10. MOR uniquely related to "extinction coefficient", σ , by $MOR = -\ln(5\%)/\sigma$
11. Direction to indicate 0 (zero) if speed = 0.
12. Salinity of 1% (1 g of salt per 100 g of water), or 10 ‰ converts to 10.000 ppm (parts per million), which equals 10 psu (practical salinity units). Ocean water is about 3.5% salt, *i.e.* 35.000 ppm or 35 psu. Lake Asal (Ethiopia) is the most saline body of water on earth with 34.8% [348 psu] salt concentration. BUFR/CREX table references 0 22 0590, 22 0620 and 22 064, however, have only a maximum range extend of 163.830 "Part per thousand" [or psu], less than the required range maximum.
13. Calm

REQUIREMENTS AND IMPLEMENTATION PLAN FOR A ROBUST, LOW POWER, CONTINUOUS COMMUNICATION PLATFORM FOR ALL AWS, PARTICULARLY THOSE IN REMOTE LOCATIONS

A robust, low power AWS is a system for which the power and communication requirements over its life cycle are well understood, and cover all aspects related to their availability, reliability, and versatility.

AWS Data Communication parameters

The data communication parameters for AWSs are:

- Frequency of data collection and timeliness;
- Size and format of the AWS message transmitted;
- Rate and format of transmission (feasible duration of transmission);
- One or two way communication;
- Redundancy, where possible.
- Capacity to store data, when communication not available
- Consistency across systems, to ensure interoperability.

The devices used to transmit data and information from the AWS site must have the capacity to store a predetermined quantity of reportable data and information, covering, at the most, the period between two scheduled visits.

The use of one or two way communication platforms for an AWS, is a critical decision for the reliable operation of the system, especially in remote locations.

In a one-way communication platform, an AWS is equipped with transmitting capabilities (transmitter, antenna, etc). For two-way communication receiving capabilities are added. The AWS on-site transmitting terminal is generally a modem, a router, or a satellite transmitter device configured to communicate with a central collection hub. Depending on the platform, the configuration setting and equipment could vary extensively, and are seldom interchangeable.

Two-way communication (transmit and receive) improves the AWS sustainability, allowing the implementation of various housekeeping functions for the AWS (e.g. programming functions to the on-site transmitting terminal, synchronization of transmission, AWS system upgrade, downloads, troubleshooting, etc). These reduce the overall operating costs, and improve the data availability.

AWS communication methods

The AWS communication methods depend on the location of the site, the availability of communication infrastructure or access, and the costs associated with setup and operation.

The communication methods available are ground based (landlines, wireless, mobile, radio) and satellite based.

A broadband data communication service is one that requires a transfer rate greater than that afforded by a dial-up telephone line using a V.92 modem (600 bits/sec).

Ground communication

Landlines (telephone lines, high-speed):

Where landlines are already available, they are generally a robust, low cost, low power communication solution. Where landlines are not available, installing new dedicated landlines are cost prohibitive.

For telephone lines, the transmission rate is low, but manageable where the size of the data message is small. An increased rate of transmission is possible using a high-speed connection; however, the costs associated with the subscription, depending on the location, could be very high and unsustainable.

Wireless/Mobile:

The significant expansion world wide of wireless and mobile networks increases the availability of effective, low power alternatives for data transmission from an AWS, including in remote locations, as long as coverage exists. This includes radio and cellular phone networks using ground based repeaters.

Setting up wireless and mobile communication at AWS sites is similar in cost to landlines, however it could be more expensive to operate and there are issues related to the reliability of the service, the lack of consistency in communication protocols used, and the security of transmission.

Ground based communication could be easily used in two-way communication mode.

Both landlines and wireless communication are a reasonable, manageable solution in populated areas, but limited, to non-existent in remote location, where the service is poor, with frequent interruptions.

Where available, the ground communication could be used to create redundancy, where the satellite is used the primary communication mean.

Satellite communication

This is an increasingly viable option due to the extensive global coverage, in particular in remote areas, where setting up ground based communication systems is not possible or cost prohibitive. Satellite communication is suitable for both fixed and mobile platforms (buoys).

Currently data transmission rates for satellite communication (Inmarsat, GOES, Telesat) used for the collection and transmission of data from meteorological stations varies from 100 to 1200 bps, while Iridium could go up to 9600 bits/second.

When setting up satellite communication depends on the site location (latitude), satellite visibility, and the number of satellite passes over 24 h, for orbiting satellites.

The AWS communication platform characteristics to be considered are the transmitting/receiving power, the antenna gain, and the line of sight path (avoiding obstacles, which could cause fading due to shadowing and multipath)

AWS Satellite communication options:

1. *Using Geosynchronous/Geostationary Earth Orbit (GEO) satellites*, which are tied to the earth's rotation and are therefore in a fixed position in space in relation to the earth's surface (GOES, ARGOS, INMARSAT).

Advantages:

- AWS transmission antenna needs to point to only one place in space in order to transmit the signal to the GEO satellite and relay data regularly, without the need to track the satellite's motion.
- The satellite is always within the station view, increasing the reliability of communication.

Disadvantages:

- The need to capture the reception window of the satellite, which is of only several minutes; missing it leads to missing data. For this reason, the AWS clock accuracy is important for communicating with GOE satellites, in particular when equipped for transmission, only. GPS could be used for clock synchronization.

2. *Low Earth Orbit (LEO) satellite systems* (E.g. Iridium) offer complete coverage of the entire Earth, including over polar regions.

Advantages:

The Iridium satellite constellation is a promising alternative. The global coverage ensures that data reception reaches 100%, with a data rate of 1200 to 2400 bit/sec, superior to GOES and Inmarsat. Up to 9600 bits/sec is possible. However, because of the limited battery power of each satellite, only about 1100 connections can be made at a time.

An Iridium platform uses an Iridium satellite phone to connect to a network, allowing send and receive email and transfer of files. Data delivery from the site could be via Telnet, e-mail, or Internet. Every terminal (modem) has its own email address.

Disadvantages:

LEO satellites are not fixed in space in relation to the rotation of the earth. Data being transmitted via LEOs satellites must be handed off from one satellite to the next as the satellites move in and out of range of the earth-bound transmitting stations. Inter-satellite communication is critical for reliable AWS communication using LEO satellite systems. Because of the low orbit of LEO satellites, the transmitting power of the AWS station is significantly lower than those that transmit to GEO satellites.

The costs are currently very high, 10-12 cents/message, in addition to a subscription fee, and there is the possibility of interference from other devices.

Meteor Bursts

No on-going communications service fees. It can be employed effectively for both point-to-point services and multiple station networks for wide ranges (up to 1600km). It operates on a single frequency in the low VHF band (40-50 MHz), with transmission distance 100-200km.

Modem (i.e. MCC-545B) is dynamically configurable as base station, mobile transponder, or repeater. It operates independent of satellite or cellular infrastructure.

Two-way communication could improve the effectiveness of AWS satellite communication:

1. AWS could regularly receive the coordinates of the satellite constellation, to predict the occurrence and duration of next satellite passes. This will reduce the operating cycle of the transmit/receive devices by transmitting only when satellites are in view.
2. The knowledge of the next satellite pass time and duration will help better manage the transmission and hence to relay more AWS data. Quantity could increase, due to the acknowledgment of message reception by the satellite (no repetition message necessary)

Summary

The robustness of an AWS platform could be improved through:

- Using data compressing techniques, to increase the volume of data transmitted in the same window. Develop standardized coder-decoder techniques;
- Allowing for sufficient on site capacity to store the observational data for extended periods, when communication is not available. The capacity should be correlated with the frequency of scheduled site visits;
- Minimizing the dependency on specific technology, to allow the transfer from one platform to another, with a minimum incremental investment and effort and minimize the impact of the rapid changes in communication technology;
- Inventorying the communication alternatives available and taking advantage of the local services (e.g. GPRN, GSM, meteor burst, etc);
- Implementation of two-way communication to improve the robustness of the AWS operation and data transfer;
- Using adaptive communication;
- Configuring communication redundancy, using different platforms, where possible;
- Reliability and flexible power solutions, in particular in remote location.

REQUIREMENTS FOR AWS HOSTED SENSORS TO CONTRIBUTE DIRECTLY TO THE CALIBRATION AND GROUND TRUTH OF SPACE-BASED OBSERVATIONS

Introduction

The goal of this task is to prepare recommendations and guidelines how to use surface measurements instrumentation hosted by Automatic Weather Stations (AWS) to provide ground-truth measurements for remotely sensed observations in the Global Observing System.

There are a number of remotely sensed measurements made from platforms such as radars and satellites which can benefit from ground-truth measurements.

With the expansion of automated surface observing networks across the globe, the potential exists to utilize these platforms to take measurements at a scale compatible to remotely sensed variables. National AWS networks are expanding across the globe and generally self-funded. The sensor platforms report a high density of temporal measurements. They are distributed globally in a wide range of climates.

While the spatial resolution of the surface-based and remotely sensed platforms are different, this can be overcome to some extent through the use of a large number of point measurements taken over a wide range of geographical locations.

MEASUREMENTS

One of the challenges facing remote sensing is that they are unable to monitor traditional variables. Thus they can in some cases infer variables through proxies and the use of algorithms and ancillary images or variables.

The challenge in the future is to integrate remote sensing approaches with surface-based AWS measurements in such a way that the overall climate record is not compromised.

1. Total Column Water Vapour

Information on the spatial and temporal water vapour distribution is important in meteorology for both numerical weather prediction and climatological studies. Considering the high variability of water vapour in comparison to other meteorological quantities (e.g. pressure or temperature), conventional observations (e.g. radiosondes) are rather sparse and additional water vapour data from new observation techniques are desirable to improve global coverage. Using the GPS signal delay, atmospheric temperature and moisture profiles can be determined. Of particular interest to meteorologists is total column water vapour, which is the amount of water vapour contained in a column over a given area on Earth. GPS networks can estimate precipitable water to an accuracy of within 1-1.5 mm.

GPS satellite radio signals are slowed by the Earth's atmosphere, which results in a delay in the arrival time of the transmitted signal from that expected if there were no intervening media. It is possible to correct for the ionospheric delay by using dual-frequency GPS receivers. The delays due to the neutral atmosphere are not frequency dependent, but depend on the constituents of the atmosphere that are a mixture of dry gasses and water vapour.

Rawinsondes only take atmospheric measurements twice a day in select locations, whereas the GPS network is denser in most parts of the globe, with each sensor taking measurements every half hour. This allows more opportunity to compare satellite measurement of total column water vapour variations (TCWV) with GPS sensors than with rawinsondes alone.

	Remotely Sensed	Surface Based
Type	Total Column Water Vapour	Total column water vapour
Platform	ENVISAT, ERS-2, Terra, Aqua	AWS
Instrument	MODIS - Moderate Resolution Imaging Spectroradiometer	GPS Dual band L1/L2 Also requires a time clock with sub-second accuracy.
Spatial resolution	1-km	
Temporal resolution	1-2 days	1-30 minutes

2. Rainfall

Remotely sensed measurement of rainfall is performed using C or S band radar. Rainfall accumulations over periods of 10 minutes to daily are calculated using a standard Z-R relationship. Point measurement of rainfall using tipping bucket rain gauges can be used to adjust the mean field bias of the radar rain fields (Chumchean *et al.*, 2004, Sinclair and Pegram, 2004).

A rain gauge measures point rainfall continuously at the ground while radar measures areal rainfall of a radar size for a specified temporal resolution at some height above the ground. Changes in rain drop size distribution in both space and time have a different effect on the corresponding rainfall.

	Remotely Sensed	Surface Based
Type	Rainfall	Rainfall
Platform	Radar	AWS
Instrument	C or S band radar	Automatic rain gauge
Spatial resolution	1-3°	<1 m ² .
Temporal resolution	1-60 minute	One minute

3. Sea surface temperature (SST)

SST are routinely observed by satellites over the ocean. SST is measured by drifting buoys and some coastal, reef and island based fixed stations.

SSTs above 26.5 °C are generally favorable for the formation of tropical cyclones. Changes in SST primarily have important biological implications for the suitability of conditions for many organisms including species of plankton, sea grasses, shellfish, fish and mammals.

	Remotely Sensed	Surface Based
Type	SST	SST
Platform	NOAA, Terra, Aqua	Buoy, coastal fixed station
Instrument	AVHRR, MODIS (or Moderate Resolution Imaging Spectroradiometer)	Sub-surface temperature sensor
Spatial resolution	1x1 km	<1 m ² .
Temporal resolution	Daily	One minute

4. Snow depth

Snow depth information is required to identify characteristics of the snow season, impacts of storms, topography and wind.

	Remotely Sensed	Surface Based
Type	Snow depth	Snow depth
Platform	AQUA	AWS
Instrument	Advanced Microwave Scanning Radiometer (AMSR-E)	Sonic
Spatial resolution	12.5 km	<1 m ² .
Temporal resolution	5 day	1 min

5. Soil Moisture

Reliable soil moisture measurement over large areas is much needed for both hydrologic modeling and earth system applications. The soil moisture field in these models are integrated within the land surface scheme (LSS). Soil moisture has a significant influence on the latent and sensible heat fluxes between the ground and the lowest layers of the atmosphere. These fluxes contribute to the temperature and humidity structure of the atmospheric boundary layer and thus ultimately influence rainfall and other meteorological forecasts.

Satellite measurement of surface soil moisture is done using microwave sensors. There is high variability in surface soil moisture both locally and over a larger spatial scale. The Integrated Global Observing Strategy (IGOS) seeks to improve observing capacity and deliver observations in a cost-effective and timely fashion. GCOS recognizes soil moisture as an emerging climate variable.

Surface soil moisture can exhibit a high degree of variability. It may be feasible to have several sensors located at a single site (different depths or locations) to provide greater spatial representativity.

	Remotely Sensed	Surface Based
Type	[Skin] Soil moisture	Near-surface soil moisture (5 cm)
Platform	ERS, JERS, RADARSAT, Aqua AMSR-E,	AWS
Instrument	Advanced Microwave Scanning Radiometer - EOS (AMSR-E)	Volumetric soil moisture Time domain reflectometry (TDR)
Spatial resolution	25 km	<1 m ² .
Temporal resolution	Daily	>1 minute

6. *Surface emissivity*

It is important to know the emissivity of the Earth's surface if infrared satellite radiances recorded over land are to be used for weather prediction or climate studies. The emissivity defines how much of the upwelling radiance at the Earth's surface is due to thermal emission from the surface and how much is reflected radiance from the sky. Land surface emissivity is a highly variable quantity.

Terrestrial brightness temperatures measured from satellites have been used to determine the surface emissivity. The results not only depend on surface temperature and on atmospheric properties, but also on the type of surface scattering.

There is high variability in surface emissivity. This can be compensated to some extent by locating the instrument at a higher point above the station. The instrument should be located above an area of natural or representative vegetation.

	Remotely Sensed	Surface Based
Type	Surface emissivity	Surface emissivity
Platform	Aqua Terra	AWS
Instrument	ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), MODIS (or Moderate Resolution Imaging Spectroradiometer)	Radiation
Spatial resolution	1 km	<1 m ²
Temporal resolution	1 day	

7. *Land surface temperature*

Land Surface Temperature (LST) is the radiative skin temperature over land. LST plays an important role in the physics of land surface as it is involved in the processes of energy and water exchange with the atmosphere. LST is useful for the scientific community, namely for those dealing with meteorological and climate models. Accurate values of LST are also of special interest in a wide range of areas related to land surface processes, including meteorology, hydrology, agrometeorology, climatology and environmental studies.

Satellite measurement of land surface temperature is done using radiometer operating in the 8-14 μm range.

	Remotely Sensed	Surface Based
Type	Land Surface Temperature	Surface temperature
Platform	Terra, Aqua	AWS
Instrument	MODIS (or Moderate Resolution Imaging Spectroradiometer)	Infrared Thermometer
Spatial resolution	1 km	
Temporal resolution	1 day	

8. Albedo or Surface reflectivity

Albedo is the fraction of incoming solar radiation at a surface (i.e. land, cloud top) that is effectively reflected by that surface. It is a unitless measure indicative of a surface's or body's diffuse reflectivity. Most land areas have an albedo range of 0.1 to 0.4.

	Remotely Sensed	Surface Based
Type	Albedo	Albedo
Platform	Aqua, Terra	AWS
Instrument	MODIS (or Moderate Resolution Imaging Spectroradiometer)	Radiometer
Spatial resolution		<1 m ²
Temporal resolution	Once per day	10 min

9. Actual Evapotranspiration

Evapotranspiration is the combined transfer of water into the air by evaporation and transpiration. Actual evapotranspiration is the amount of water delivered to the air from these two processes.

Actual evaporation can be directly measured using a FLUXNET towers or micrometeorological instrumentation such as eddy correlation or Bowen Radio Energy Balance. Potential and actual evapotranspiration can be calculated using standard AWS sensors and the Penman-Monteith equation (FAO-56). [Note: CIMO guide has information on evaporation measurement]

	Remotely Sensed	Surface Based
Type	Evapotranspiration	Evapotranspiration
Platform	Meteosat, NOAA, Aqua, Terra	AWS
Instrument	MODIS, AVHRR	Flux tower (Flux net) Bowen ratio Eddy correlation Station footprint
Spatial resolution		
Temporal resolution	Once per day	10 min

10. Cloud cover

Cloud cover is measured routinely by many AWSs using a ceilometer. A sky condition algorithm is used to calculate cloud cover over the preceding 30 minutes. Ceilometer data is only able to estimate cloud cover based on the movement of clouds over a fixed point.

It may be possible to integrate cloud cover with [Cloud Map](#) in Europe to help identify cloud type, particularly for example CB (cumulonimbus) and TCU (towering cumulus) required for METAR reports. This would be a valuable enhancement to METAR AUTO reports.

	Remotely Sensed	Surface Based
Type	Cloud cover	Cloud cover
Platform	Terra, Aqua	AWS
Instrument	MODIS - Moderate Resolution Imaging Spectroradiometer	Ceilometer
Spatial resolution	1 km	
Temporal resolution	1 day	30 min

Conclusion

Considering the range in satellite products to enhance global data collection and the large number of national AWS networks, opportunity exists to locate specific instruments on AWS platforms to provide ground truth observations for remotely sensed data. The surface observations have a long history of preserving homogeneity. Integration between the two platforms could provide benefits for both inter-satellite calibration and surface/satellite calibration.

References

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REQUIREMENTS FOR NEW SENSORS OR THE INTEGRATION OF SENSORS TO MEET THE DEFICIENCIES OF AUTOMATIC WEATHER STATIONS FOLLOWING THE MIGRATION FROM MANUAL OBSERVATIONS

I. GENERAL REQUIREMENTS

The requirements for the AWS sensors are could be structured in three interrelated categories, all, critical contributors to the long-term sustainability of AWSs:

- Requirements related to the performance of measurement,
- Requirements related to maintaining the traceability of measurements over the operational cycle,
- Requirements related to the operational reliability.

In addition, the cost effectiveness of the AWS sensors is critical, as it could limit their use.

1. Requirements related to the performance of measurement cover the ability of a sensor to provide measurements with a stated uncertainty, over a defined operating range and conditions. These include the uncertainty of measurement, response time, long-term stability, hysteresis, operating range, start-up point, sensitivity, etc, as defined in the WMO Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8 and the ISO/IEC Guide 99:2007, International vocabulary of metrology - Basic and general concepts and associated terms (VIM)

The following requirements apply to all AWS sensors:

- Sensors should operate over the ranges and with the measuring performances stated in the Guide to the Global Observing System (WMO-No. 488) and Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8).
- Sensors and systems should integrate multiple measurements (collocated and remote) to derive and report subjective measurements. Strong science is required to support the integration of multiple parameters (e.g. drop-size distribution, snow wind transport, etc.).
- Improving the probability of detection and false alarm ratio for all measurements, subjective measurements in particular.

2. Requirements related to maintaining the traceability of measurements over the operational cycle include recommended practices and equipment for performing regular calibration and field verification over the lifecycle of a sensor.

The traceability of measurements from automatic sensors must be achieved through the implementation of national or regional calibration programs specific to each instrument or parameter. These include a set of field verifications, laboratory calibration, and preventive maintenance activities, the simplicity of which is critical to their consistency in time and space. The following requirements apply to all AWS sensors:

- Sensors should have long term stability of measurements to warrant calibration and maintenance intervals of one year or more,
- Calibration methodologies and associated traveling standards should be identified as part of the sensor package.

The installation of an AWS could be costly and an increased frequency of maintenance, in particular for stations in remote locations, could render an AWS unaffordable.

The field verification techniques should confirm the measurement performance of instruments in their operational configuration and with minimum direct intervention. Where the laboratory calibration is chosen, the sensors should be designed such that the handling (e.g. removal, transportation, etc) would not impact the sensor performance, and will ensure that the laboratory calibration remains valid, once the instrument is returned to operation.

3. Requirements regarding the operational reliability of AWS sensors focus on sensor design features that enable their operation for extended periods, within the expected measuring performance, and with minimum human intervention.

In remote locations, an AWS operates unattended and is expected to perform reliably for extended periods, sometimes of one year or more. In the absence of human intervention, the robustness of the AWS as a system is critical in the decision whether to replace the human with automatic observations.

The following requirements apply to all AWS sensors:

- Reliable auxiliary equipment to mitigate the influence of environmental factors on the sensor performance (cooling, heating, venting, decontamination, cleaning, etc.)
- Minimizing/eliminating the sensitivity of sensors to external factors (diurnal effect, wind, solar radiation, etc...)
- Sensors to withstand extreme conditions of increasing intensity and frequency (ice accretion, hurricane force winds, intense precipitation, and extensive periods with extreme temperatures).
- Sensor robustness to limit the impact of variations in the supplied power, electromagnetic discharges due to lightning and other sources.
- Sensor should operate with low power consumption;
- Sensors should offer multiple communication outputs;
- Availability of diagnostics to validate the data and troubleshoot systems, including remotely.
- The ability to interrogate and download software remotely, through the AWS.
- Interoperability of sensors.

The amount of power required by sensors and their auxiliary equipment (heating, cooling, etc), in particular in remote locations where the power is not supplied from the grid, could limit the ability of an AWS to provide data continuously with the expected quality.

Instrument developers should develop efficient power management schemes for sensors, to minimize their power needs. The entire AWS system should be designed with particular attention to the budget of power required to operate at all times, including shutting down certain sensors to conserve power, when deemed necessary (not using heating, cooling, when operating on battery).

Additionally, the AWS configuration could be designed to mitigate individual sensor limitations. For example:

- create redundancy (e.g. using three sensing elements)
- Integrate measurements from multiple sensors to develop more effective filtering algorithms and improve the data quality.

II. SENSOR SPECIFIC REQUIREMENTS

1. Air Temperature Sensors

The measurement of air temperature using sensors within an AWS configuration is at least of similar quality to human observation measurement.

Additional requirements for temperature sensors:

- Expand the operating range to reliably measure temperatures in cold climates (below -40 °C). The GOS Manual recommended range is -80 °C to +60 °C.
- Improve response time and sensitivity to measure and report extreme temperatures.

Shields/screens housing temperature sensors are direct contributors to the quality of measurement of atmospheric temperature. The shields/screens design requirements are:

- Create and maintain a measuring volume representative of the surrounding atmospheric conditions at all times;
- Minimize the effect of atmospheric and environmental factors (solar radiation, snow/ice build-up, sand, dust, dew, wind). This is primarily the case for AWSs in remote locations where the human intervention is not possible for lengthy periods.
- Shield configuration should allow the sensor field verification, with no data contamination.
- Low power consumption for ventilated shields (smart power management).

- Electrical feedback of the ventilator functioning for artificially ventilated screen.

2. Humidity Sensors

Humidity and dew-point observations made by human observer are provided using sensors with various complexities; many of those have been integrated within AWS configurations.

The humidity sensors, in general, perform well; however additional improvements are needed, relate to:

- Consistency in operation below the freezing point.
- Accuracy of measurement of humidity at the ends of the measuring range (0-10% and 90-100%)
- Maintaining the stability of measurement over 12-24 months, to minimize the frequency of required calibration.
- Immunity to environmental contamination.

The shield/screen requirements are similar to those for temperature sensors.

3. Pressure Sensors

The current sensing technology is able to measure and report atmospheric pressure and derive additional pressure related parameters with performance at least equal to that of a human observer.

The challenges facing the automatic measurement of atmospheric pressure are related to the operating environment and conditions. A manual observation of the atmospheric pressure is generally done with the barometer located inside a building, which is considered representative of the outdoor pressure (leaky building), although some limitations may apply.

AWS pressure sensors are installed outdoors, in metal or fiberglass boxes, where data could be contaminated, in particular due to solar radiation and wind.

The requirements for AWS pressure sensors, to ensure the quality of pressure observations, are:

- Provide configuration options for pressure sensors in the outdoors, to mitigate the effects of wind and solar radiation. e.g. venting, cooling, etc.
- Extend the operating temperature range below -40 °C.

4. Precipitation Sensors

The monitoring of precipitation covers a wide range of parameters and observing conditions. Broadly speaking, the quantitative parameters related to precipitation are amount and rate and the qualitative parameters are type and intensity.

While the measurement of liquid precipitation parameters using automatic rain gauges is in general acceptable, the automatic observation and measurement of frozen and mixed precipitation, still present serious challenges.

The requirements for new sensors or the integration of sensors to meet the deficiencies of AWS, are:

- Measure trace precipitation (accuracy better than 0.2 mm): trace amount of precipitation is a significant bias, particularly in the low-precipitation regions;
- Measure snowfall, snow depth, and snow on the ground, accounting for snow redistribution;
- Develop total precipitation gauges with larger capacity to allow for reliable operation for extended periods of time, while unattended;
- Eliminate diurnal effect on sensors measuring liquid and solid precipitation.
- Prevent/minimize snow and ice build up on precipitation gauges, in particular those heated, in cold climates, without compromising the measurement;
- Effective corrections for wind induced undercatch, wetting and evaporation losses;
- Eliminate/mitigate the reporting of false precipitation (e.g. blowing snow flux into the gauge or those due to the physical configuration of the gauges).
- Develop effective shields to minimize wind induced undercatch and overcatch;
- Improve the probability to correctly identify the precipitation type, in particular in mixed precipitation and around the freezing point;

- Develop capacity to reliably assess the Snow Water Equivalent. Snow depth calculations based on the optical/microwave detection of solid precipitation use the standard 10:1 SWE ratio, which is not always correct, and could lead to significant errors.
- Develop sensors for effectively detecting the state of ground: ice accretion, water/ice, wetness, rime deposition.
- Develop and make available for each sensor, reliable calibration and field verification procedures and associated equipment.
- Improve sensor auxiliaries to mitigate environmental factors (ice build-up, snow capping, insects, bird perching, etc.)
- Integrate of lightning sensors or lightning data available from other sources to identify atmospheric phenomena (e.g. a shower, thunderstorm, cloud type).
- Develop integrated sensors which will output multiple precipitation parameters (accumulation, rate, type, intensity);
- Expand the operating range of precipitation sensors, to make them suitable to a wider range of conditions. This could be achieved through the integration of measurements from multiple sensors. For example, in coastal environments, the size and velocity of water droplets in the fog bank is larger than in continental climates, which leads to significant errors (e.g. fog reported as hail or snow)

5. Visibility Sensors:

Improvements to present weather sensors, as identified above could apply to visibility sensors. Additional improvements are related to:

- The need to differentiate between fog, smoke, blowing snow, blowing sand, insects, etc.
- Availability of reliable and field usable calibration methods and equipment.

6. Sky Conditions Sensors

Cloud observations from the ground are increasingly automated, resulting in the loss of some information formerly available from trained observers, e.g. cloud type.

The requirements for new sensors and the integration of sensors to meet the deficiencies of AWS are:

- Capacity to assess and report sky coverage; eventually integrating multiple measurements or satellite data, which are ideal for observing cloud cover, although they cannot measure cloud thickness or underlying cloud layers.
- Determine and report cloud type.
- Reporting of multilayer clouds.
- Report the direction of cloud movement;
- Alternative sensors to derive and report the cloudiness (e.g. use of sunshine or solar radiation data);
- Improve the spatial representativeness of ceilometer data by combining it with data from other sources (e.g. an infrared scanner).

7. Wind Speed and Wind Direction Sensors

Human observations of wind speed and direction have been made extensively with instruments, some of which are currently integrated in AWSs. The deficiencies of AWS with respect to wind measurement are primarily related to the unattended operation, when errors could go undetected and unaddressed for extended periods.

The requirements for wind sensors integrated in AWSs include:

- Wind sensors that reliably and affordably measure and report 3-D wind data.
- Improved sensor response time: to respond to short duration, high intensity events.
- Availability of sensor specific field calibration techniques and traveling standards.
- Increase the Operating range to report extreme events (as per Guide to the GOS, WMO-no.488)
- Improve the start-up speed to consistently report calm conditions as defined in CIMO Guide (0.5 m/s)
- Minimize the effects of ice build-up, heavy snow or rainfall, bird perching, insects.
- Minimize the power consumption for the heating circuits, to make the sensors suitable for remote installations.

8. Sensors for Sunshine, Global and Net Radiation

Global Radiation sensors have been significantly improved following the CIMO definition of the expected specifications. The major issue still requiring attention, in particular for installation at unattended AWS, is the cleaning of sensors at regular intervals. Work needs to be done on the development of an automatic cleaning system for sensors that are placed on automatic stations.

On the net radiation front, Baseline Surface Reference Network has shown that component sensors provide far better observations than the typical net pyradiometers that are used in many NMHSs or agricultural programs. The use of component sensors at larger scale is limited due to their high costs. Alternative instruments, with similar performance but lower costs would greatly improve the density of net radiation measurements, beyond the climate networks.

9. Soil Temperature and Moisture Sensors

An AWS equipped to report weather and climate parameters could report, with a moderate cost increase, soil temperature and soil moisture. The primary challenge rests with the configuration of the measuring system in an AWS configuration.

The measurement of soil temperature and moisture is configured at depth of up to 100 cm of undisturbed soil. This means that the quality of measurement meets the users needs only after has been configured for a certain period, and the earth has settled to approach the density and consistency of the surrounding volume.

The sensors for soil moisture and temperature must have a long-term stability and reliability in operations. The measuring configuration should minimize the soil disturbance and permit access to the sensors for maintenance and replacement with minimum disturbance.

The measuring sensors should be installed in a protective housing/sleeve, which would tolerate both abrasive wear and extreme temperatures.

A MODERN STRATEGIC APPROACH ON THE REDESIGN OF SYNOPTIC OBSERVATIONAL NETWORKS

(Excerpt, Jitze van der Meulen, KNMI, 2005; <http://www.knmi.nl/research/biennial/03-04.html>)

Today computer simulation models describe the actual physical state of the atmosphere in all of its dynamics. The introduction of new, sophisticated observation technologies using these models has demonstrated high potential. This development is characterized by alternative technologies like active and passive remote sensing, from satellites or from the earth's surface. Moreover, the conventional instrument measurements and weather observations are fully automated using sophisticated optoelectronic sensor technologies, providing observational data in a digital format essential for input in computerized systems running dedicated applications.

Replacing human observations by automatic measurements has impact on the performance of the observing system on the whole. In fact, the advantages of a uniform, fully automated and unattended observing networks prevail over the traditional situation provided that such a network is designed appropriately. There is not only advantage of more uniform observations without any subjectivity caused by human interpretation. Also data acquisition and dissemination is performed on a continuous and real time base. As a result the forecasted timing of upcoming (severe) weather phenomena is more accurate. Also rapid trends and changes in weather are registered and reported on line providing a more efficient weather information service.

Another advantage is the flexibility in appointing suitable locations for weather stations. For more than a century, such stations were chosen at sea shore locations, harbors, airfields, nearby buildings, etc. As a consequence poor and inadequate siting often resulted in low representativeness with regard to the surrounded area and distribution of these stations over the region of interest was not very homogeneous. Defining a new set of automatic weather stations for a synoptic network has become much easier and siting criteria are better met.

New functional design of a synoptic network

Nevertheless, the question of the density requirement itself has to be solved in the first place. In fact, such density depends on the regional climate and all various meteorological variables require their own density. Typically, precipitation and wind require high density, while the density of a network of barometers may be quite low. Such density can be estimated on a simple way based on the prevailing wind or typical transport speeds of weather phenomena. A more sophisticated approach is based on statistical calculations of the covariance of the variable measured at the various locations assuming a sufficiently high correlation between these autonomous measurements. It is common experience that in practice the simple straightforward approach is sufficient. However, the latter approach, suggested in the leading WMO Guide on the Global Observing System, and its background reference The Planning of Meteorological Station Networks will result in inconsistencies, trivialities and undefined solutions and is therefore not suitable. Therefore, in the Netherlands the stated appropriate network density is based on prevailing wind speeds in combination with movement of fog and low-level clouds (about 25 km/h) and incoming fronts with showers with thunderstorms (about 50 km/h). Taking advantage of the real time functionality of the network, a spacing of about 50 km is found to be sufficient. Only for wind measurements a shorter distance is required (about 25 km) to meet the recommended correlation coefficient of 0.90 for two neighbouring stations. By placing some extra wind masts this requirement can be met in general. A network of precipitation measurements to measure daily amounts requires a small spacing of 15 km. This extreme requirement can only be met by using the additional separate, autonomous network of volunteering observers because a network with automatic gauges cannot be funded. Moreover the introduction of new precipitation radar systems will provide more redundancy. This solution has a great benefit because the high refreshment rate of radar systems provides an optimal real-time data source, extremely useful for synoptic practices.

Optimizing the meteorological station network

For an optimal network design the required level of homogeneity is the first constraint to be considered. Other relevant constraints are appropriate siting and representativity issues. A measure for the level of optimizing a network should be expressed best by a simple, well-defined single parameter. For a first order approximation such a parameter is chosen based on a statistical

analysis of the distance between every position in the Netherlands and its nearby station. This parameter represents for instance the percentage of all locations on a distance larger than a certain distance from any station. It is found that with the new network design for the stations on land the 95% cumulative level will be between 35 and 40 km. In the previous situation with 20 land stations this distance was within 40 and 45 km. For the new network design 99.9% of all positions on land are at a distance smaller than 50 km from a nearby station, fulfilling the requirement and providing sufficient redundancy. Over sea this requirement cannot be fulfilled due to the lack of suitable off shore locations (oil platforms), but a spacing of about 100 km should be acceptable for all practices.

Other statistical techniques used for network design analysis are based on the mutual distances between all stations or between neighbouring stations only (e.g. sets of triangles of three neighbors). The latter technique is common practice to demonstrate the level of representativeness or the uncertainty of a derived interpolated variable valid for a location within such a triangle. However, for an overall impression of the homogeneity of a network, a statistical analysis of all mutual distances of the stations can be carried out. Optimizing the normalized (cumulative) distribution of these sets of distances is then the first target (distribution are normalized by dividing the number by the distance).

GUIDELINES AND PROCEDURES TO ASSIST IN THE TRANSITION FROM MANUAL TO AUTOMATIC SURFACE OBSERVING STATIONS

Introduction

The aim of this document is to identify and provide observation network managers the guidelines to manage the transition from traditional manual observations to a partially or fully automated system. This guidance applies to all meteorological data users, including agricultural, aviation, climate, public, marine, and severe weather.

AWS are being increasingly used to complement and even replace manual observations as the primary mode for data collection. Thus it is essential that the transition of manual to automated observation is carefully managed in order that the existing long term climate records are not compromised, but rather enhanced by the close adherence to standards and procedures.

Recent statistics (2006) indicate that almost a quarter of all RBSN stations have already been converted to AWS. In the Netherlands manual observations are only made at large airports.

In terms of the transition from manual to automated observations, climate has special needs. Climate analysis requires observational records that are long, free from significant gaps, and free from major errors or inhomogeneities. The primary focus for climate should be on the essential climate variables such as rainfall, temperature and humidity.

In the past, Aviation weather reports were dependent on manual observations to provide an integrated assessment of present weather and issue special weather reports on occurrence. However with airports growing in number and flight movements, and with progress in automated sensors, more airports are relying on fully automated observing system.

Instigators of automation

Change is a reality in all networks, whether it be sensors replacement, site relocations or land use change around the station. Thus adjustment to changing circumstances is necessary for long-term network sustainability. Some change is planned, such as conversion to a new sensor, or unplanned when a sensor fails or site relocation is forced.

Many NMSs choose to migrate from manual observations due to external pressures such as staff reductions. Often these changes are often made initially for a few sites, but often it expands incrementally to the point when a significant part of the network may be automated. It is worth considering the overall resource requirements as an automated system requires new skills and responsibilities.

Transition to automated observing system is sometimes motivated through a perception of lower costs, greater data frequency, greater consistency and objectivity of the data. This is particularly the cases with physical or deterministic variables such as temperature, humidity and pressure. Sensors to provide more discrimination for weather and precipitation types are significantly more costly than an initial data acquisition system and with some standard sensors.

Site relocation or automation may result from urban development or retirement of remote rural observers. As demographics changes in rural communities, the traditional volunteer weather observing role is lost. In Australia for example, a large number of post offices provided rainfall and other basic observations. The postal service role has been sub-contracted resulting in a decrease on post office Observers from 150 to only 6 over a period of ten years.

Change can also result when the focus or purpose of the observation program changes. For example, a research network may be converted to a operational or climate network.

Impacts of automation

Transition from manual to automated observations can lead to a discontinuity in a climate record or a change in scope of a meteorological variable if the process is not managed carefully. For example, horizontal visibility reported by an Observer who integrates observations surrounding the station to that of a visibility sensor which extrapolates a point observation to represent the area will lead to a discontinuity.

The benefits of AWSs include their cost effectiveness, high frequency data, better ability to detect extremes, deployment in hostile locations, faster access to data, consistency and objectiveness in measurement, and ability to perform automatic quality monitoring.

On the other hand, AWSs are susceptible to the following: data losses, inadequate change management, poor maintenance procedures can lead to data contamination, inadequate training of maintenance and inspection personnel, difficulty in measuring some observations, and the loss of visual observations.

The following three questions should be assessed. i) Is it economically feasible; ii) is it technically feasible; and iii) is it operationally feasible?

Thus a national meteorological service should consider the following aspects when considering automation.

1. **Resource requirements** – Costing of automated observations systems can be simplistic when they do not include all costs such as training, expertise development, asset life cycle costs and dependence on commercial technology.
2. **Gains and Losses** – Automated observing systems are able to provide some attractive benefits include remote operation, high density in objective measurements and lowered staff costs. However, automated observations are not able to fully replace manual observations, particularly visual observations. For example, automation may result in the loss of parameters such as cloud identification, hail, frost and thunder reports.
3. **Management of system change** – The manner in which observations are managed changes when the high volume automated data becomes part of the system. Instead of local QC by the Observer, this must be programmed into computer algorithms with the ability to detect and respond to warnings. Electronic storage and archive facilities must be expanded. Fault detection and response systems need to be monitored with staff who have the appropriate competencies. Asset replacement funds need to be available to replace the equipment when necessary.

Proper planning will lead to an orderly documented change from one system to another.

Guidelines and Procedures to manage change

Thus the transition from manual to automated observations must be carefully managed and adhere to certain principles. This management must include network planning, operations and service provision staff. Canada recommend the establishment of a “Change control Board” to supervise the change management process.

The climate community in particular has been proactive in identifying ten guiding principles for long-term sustainable climate monitoring (appendix). These have been used to develop guidelines for NMSs to follow.

It is useful to distinguish between an automated system which includes physical sensors (such as pressure and temperature), a data acquisition system, processing algorithms, logging capacity, data communications, automated quality assurance and data archive and specialized or intelligent sensors which may comprise of a number of physical measurements together with algorithms and logic to provide an integrated results.

Transition to automated systems

The role of the weather Observer is more complex than the provision of objective classifications of weather, clouds and instrument readings. Observers use their experience to compare one variable with another, integrate information from multiple sources, make a quality judgment that an instrument is reading incorrectly, provide an on-site fault response, use alternative means to communicate observations when the primary mechanism is unavailable, retain an on-site archive and identify the need to send special weather observations. While an automated system can record measurements more frequently and consistently than humans, all the other roles of field Observers must be addressed during the transition from manual to automated systems. Instead of dispersed staff dealing with single station issues, the automated system will require specialized staff responsible for a component of the system across a wide range of stations.

What follows is a list of guidelines and procedures which should be followed when automating observations.

- a) **Management of Network Change:** Assess how and the extent to which a proposed change could influence the outputs of the Observations network. User requirements should be established by all network users. Ensure that the change management process includes representatives from network planning, engineering, observations, data processing and communications, data services (particularly when dealing with composite networks) and archiving.
- b) **Defining and assigning responsibilities:** In the transition from one system to another, particularly for automated systems, additional roles generally with higher skill sets are required. These responsibilities include i) meteorological data process algorithms, ii) computer programmers, iii) systems integrations, iv) communications specialists, v) data processing and archiving, vi) quality management, and vii) instrument calibration, inspection and maintenance specialist. In addition, many automated systems require regular site support on a weekly to monthly period. This may include tasks such as cleaning glass lenses, cleaning rain gauge funnels, replacing wet-bulb water reservoir and trimming vegetation. In Australia, the role of the Field Observer has transformed to a station manager who maintains and operates complex equipment together with a reduced observations role.
- c) **System costing:** Traditional manual equipment often continued to function within specification for decades with minimal maintenance. Modern instrumentation often has a significant asset value and requires regular replacement. For example, the AWS used by the Australian Bureau of Meteorology became unsupportable due to a chip which was no longer manufactured. The full life-cycle cost including support personnel and laboratory equipment must be determined. In another example, an existing solar powered site required the installation of sensor needing mains electricity. The cost to arrange mains power was double the cost of the instrumentation itself.
- d) **Parallel Testing:** Operate the old system simultaneously with the replacement system over a sufficiently long time period to observe the behavior of the two systems over the full range of variation of the meteorological variable observed. This is needed to provide understand to data users regarding the nature of the new system. For example, what happens when sensors get contaminated?
- e) **Meta Data:** Fully document each observing system and its operating procedures. This is particularly important immediately prior to and following any contemplated change. The recording should be a mandatory part of the observing routine and should be archived with the original data. Algorithms used to process observations need proper documentation. Documentation of changes and improvements in the algorithms should be carried along with the data throughout the data archiving process.
- f) **Data Quality and Reliability:** Assess data quality and reliability of the new system regularly over the first five years of operation. This assessment should focus on establishing that the user requirements have been satisfied.

- g) **User requirements:** In the development of a new system there are generally many unrealistic expectations. Design and implementation should focus on the most strategic issues. Specific network users may be particular requirements. For example, climate values stations with long historical records. Aviation requires observations at significant aviation locations.
- h) **Data and Meta Data Access:** Develop data management systems that facilitate access, use, and interpretation of data and data products by users. Easy access, low cost mechanisms that facilitate use and quality control should be an integral part of data management. This contributes to increased use of the data and feedback concerning errors and omissions.

Transition to automated sensors

Across the spectrum of observations network users there is a range of requirements. The Climate program emphasizes their focus on data continuity and homogeneity of traditional human observations. Observations which do not consist of a deterministic physical quantity provide a particular challenge to automation.

The human observation is often an integrated concept due to the ability of the human to assimilate information from various spatial and temporal scales, and various observation characteristics. For example, in the observation of visibility, the observer looks around a 360 degree spectrum and integrates information for distances up to 50km away, and includes knowledge of the immediate history of the event and the climatology of the area.

Human observations which are challenging to automate include cloud type identification, present and past weather, identification of phenomena, precipitation types, solid precipitation, obscuration, evaporation, discriminating between sand, dust and haze and the constituents of solar radiation.

When developing an automated system, the following guidelines are recommended.

- a) **Characterize the human observation:** In most cases the human observer integrates sensory cues from sight, sound, touch, and smell over a large space. The Observer has understanding of weather process and has generally monitored the development of weather system over minutes, hours and days. Therefore the human observation needs to be stratified into as many distinguishable constituents as possible.
- b) **Characterize the automated observation:** In many cases the automated observation extrapolates from a single point over time. Thus it relies on temporal averaging to represent the three dimensional space.
- c) **Compare and contrast under parallel conditions:** Automated sensors often report differently to humans under identical conditions, especially under unusual or spatially variable weather conditions.

Conclusion

Change is a normal part of observations network management. Management of the change process which includes the necessary role players and the allocation of appropriate resources can mitigate the impacts of change and provide meteorological and climate data users with the information they need to preserve standards for climate data and observations used in forecasting.

References

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Appendix

These 10 guiding principles for long-term sustainable climate monitoring have been identified and described (Karl et al. 1995).

1. **Management of Network Change:** Assess how and the extent to which a proposed change could influence the existing and future climatology obtainable from the system, particularly with respect to climate variability and change. Changes in observing times will adversely affect time series. Without adequate transfer functions, spatial changes and spatially dependent changes will adversely affect the mapping of climatic elements.
2. **Parallel Testing:** Operate the old system simultaneously with the replacement system over a sufficiently long time period to observe the behavior of the two systems over the full range of variation of the climate variable observed. This testing should allow the derivation of a transfer function to convert between climatic data taken before and after the change. When the observing system is of sufficient scope and importance, the results of parallel testing should be documented in peer-reviewed literature.
3. **Meta Data:** Fully document each observing system and its operating procedures. This is particularly important immediately prior to and following any contemplated change. Relevant information includes: instruments, instrument sampling time, calibration, validation, station location, exposure, local environmental conditions, and other platform specifics that could influence the data history. The recording should be a mandatory part of the observing routine and should be archived with the original data. Algorithms used to process observations need proper documentation. Documentation of changes and improvements in the algorithms should be carried along with the data throughout the data archiving process.
4. **Data Quality and Continuity:** Assess data quality and homogeneity as a part of routine operating procedures. This assessment should focus on the requirements for measuring climate variability and change, including routine evaluation of the long-term, high-resolution data capable of revealing and documenting important extreme weather events.
5. **Integrated Environmental Assessment:** Anticipate the use of data in the development of environmental assessments, particularly those pertaining to climate variability and change, as a part of a climate observing system's strategic plan. National climate assessments and international assessments (e.g., international ozone or IPCC) are critical to evaluating and maintaining overall consistency of climate data sets. A system's participation in an integrated environmental monitoring program can also be quite beneficial for maintaining climate relevancy. Time series of data achieve value only with regular scientific analysis.
6. **Historical Significance:** Maintain operation of observing systems that have provided homogeneous data sets over a period of many decades to a century or more. A list of protected sites within each major observing system should be developed, based on their prioritized contribution to documenting the long-term climate record.
7. **Complementary Data:** Give the highest priority in the design and implementation of new sites or instrumentation within an observing system to data-poor regions, poorly observed variables, regions sensitive to change, and key measurements with inadequate temporal

resolution. Data sets archived in non-electronic format should be converted for efficient electronic access.

8. **Climate Requirements:** Give network designers, operators, and instrument engineer's climate monitoring requirements at the outset of network design. Instruments must have adequate accuracy with biases sufficiently small to resolve climate variations and changes of primary interest. Modeling and theoretical studies must identify spatial and temporal resolution requirements.
9. **Continuity of Purpose:** Maintain a stable, long-term commitment to these observations, and develop a clear transition plan from serving research needs to serving operational purposes.
10. **Data and Meta Data Access:** Develop data management systems that facilitate access, use, and interpretation of data and data products by users. Freedom of access, low cost mechanisms that facilitate use (directories, catalogues, browse capabilities, availability of metadata on station histories, algorithm accessibility and documentation, etc.), and quality control should be an integral part of data management. International cooperation is critical for successful data management.

SITING CLASSIFICATION OF SURFACE OBSERVING STATIONS (Draft)

There are sites which do not respect the recommended WMO rules for siting. Consequently a classification has been established to help determine the given site's representativity on a small scale (impact of the surrounding environment). Class 1 hence, adheres to WMO recommendations. Class 5 indicates measurement conditions which should never exist on a measurement site. Each measurement point on a site is subject to a separate classification.

By linking measurements to their associated uncertainty levels, this classification allows us to define the levels which a station needs to adopt in order to be included in Météo-France's Radome network, or to be used for a given application.

Conventionally, for each parameter, **all sites meeting WMO criteria will be Class 1 sites.** The site as a whole is classified based on all individual classification marks given to its measurements (marks often being different).

Site classification should be reviewed periodically as environmental circumstances can change over a period of time. In the following text, the classification is (occasionally) completed with an estimated error margin calculated on the given representativity.

Temperature and humidity

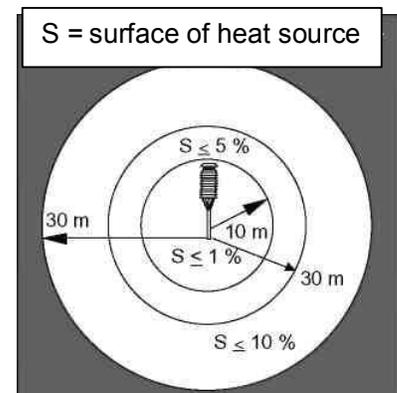
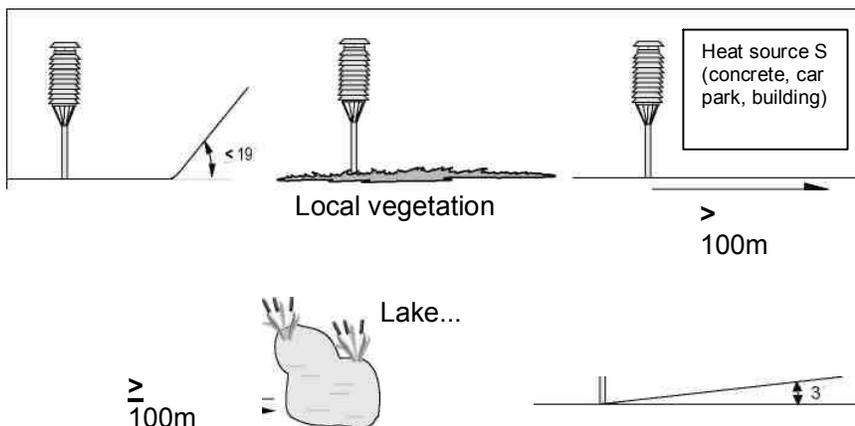
Sensors situated inside a screen should be mounted at a height of 1.5 m as standard. The height should never be less than 1.5 m. A higher level (up to 2 m) is admissible; although such a height does not have a major impact on measurement (the difference between 1.5 and 2 m placements is not higher than 0.2 °C). Projected shade from obstacles which are not part of the region's natural landscape are taken into account.

The relative significance of perturbations caused by concrete surfaces and projected shade remains to be determined. It is possible that the criteria described below could be modified, particularly where they concern projected shade. This is why it is requested that, in the beginning, a separate classification is applied to projected shade, so as to allow for readjustment of the final classification in the future.

Class 1

- **Flat, horizontal land**, surrounded by an open space, slope less than 1/3 (19°)
- **Ground covered with grass or low vegetation** (< 10 cm) representative of the region (as well as its albedo).
- **Measurement point situated:**
 - **at more than 100 m** from heat sources or reflective surfaces (buildings, concrete surfaces, car parks etc.)
 - **at more than 100 m** from an expanse of water (unless significant of the region)
 - **away from all projected shade when the Sun is higher than 3°.**

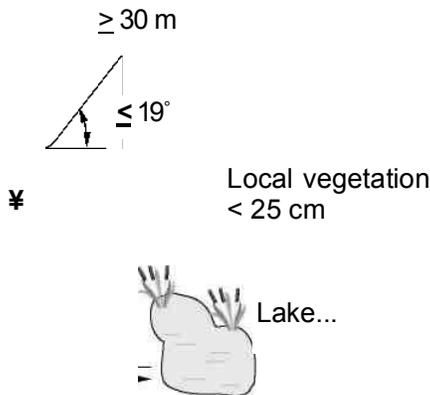
A source of heat (or expanse of water) is considered to have an impact if it occupies more than 10 % of the surface within a circular area of 100 m surrounding the station, makes up 5% of an annulus of 10m-30m, or covers 1% of a 10 m circle.



Class 2

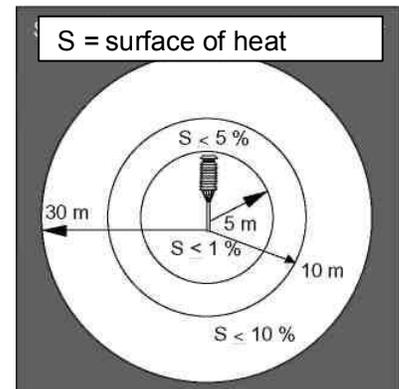
- **Flat, horizontal land**, surrounded by an open space, slope inclination less than 1/3 (19°)
- **Ground covered with grass or low vegetation** (< 10 cm) representative of the region (as well as its albedo).
- **Measurement point situated :**
 - **between 30 and 100 m** from artificial heat sources or reflective surfaces (buildings, concrete surfaces, car parks etc.)
 - **between 30 and 100 m** from an expanse of water (unless significant of the region) ;
 - **away from all projected shade when the Sun is higher than 5°.**

A source of heat (or expanse of water) is considered to have an impact if it occupies more than 10 % of the surface within a circular area of 30 m surrounding the station, makes up 5% of an annulus of 5m-10m, or covers 1% of a 5 m circle.



Heat source S (concrete, car park, building)

$\geq 30\text{ m}$

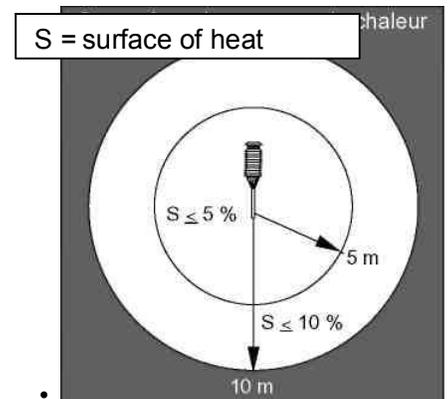
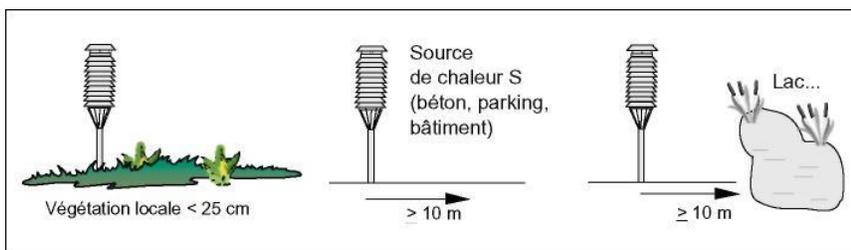


5°

Class 3 (error 1 °C ?)

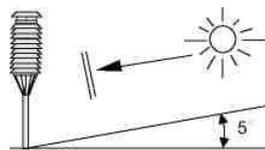
- Ground covered with grass or low vegetation (< 25 cm) representative of the region.
- **Measurement point is situated :**
 - **between 10 and 30 m** from artificial heat sources and reflective surfaces (buildings, concrete surfaces, car parks etc.)
 - **between 10 and 30 m** from an expanse of water (unless significant of the region)

A source of heat (or expanse of water) is considered to have an impact if it occupies more than 10 % of the surface within a circular area of 10 m surrounding the case or makes up 5% of an annulus of 5m.



Heat source S (concrete, car park, building)

< 10 m



Class 4 (error 2 °C or over ?)

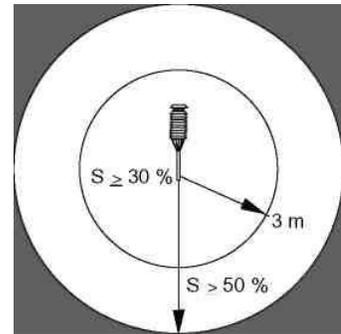
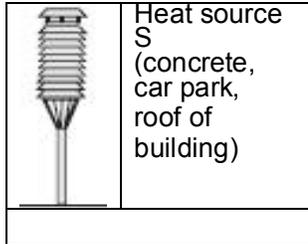
- Artificial heat sources (buildings, concrete surfaces, car parks etc.) at less than 10 m.
- Projected shade when the Sun is higher than 5°.

Class 5 (error 5 °C or over ?)

• Case situated in the middle of artificial heat sources (in a car park, on the roof of a building).

If a heat source occupies an area of over 50 % within a 10 meter radius around the station, or a 30 % part within a 3m radius, the site will be classified as 5, otherwise it will be classified as 4.

The indicated growth height represents the height of the vegetation maintained in a 'routine' manner. A distinction is made between structural vegetation height (per type of vegetation present on the site) and height resulting from poor maintenance. Classification of the given site is therefore made on the assumption of regular maintenance (unless such maintenance is not practicable). If a site is poorly maintained this aspect should be noted.



**If S check that 10 m
Then measure by class 5
otherwise use class**

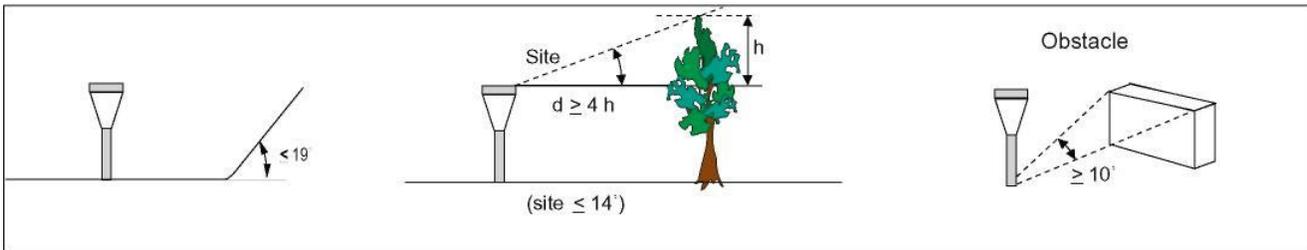
Precipitation

Wind is considered to be the greatest source of disturbance in precipitation measurement. Ideal conditions for the installation, as described by the WMO, are those where equipment is set up in an area surrounded **uniformly**, by obstacles of **uniform** height. The distance between such obstacles and the pluviometer should be equal to one to two times the height of the obstacle (angular height of obstacles 30 - 45°). Ideal conditions therefore are those where the equipment is situated in a clearing, whereby the height of surrounding trees corresponds to the criteria described above. The choice of such a site is not compatible with constraints in respect of the height of other measuring equipment. Such conditions are practically unrealistic. If obstacles are not uniform, they are prone to generate turbulence which distorts measurements. This is exactly the reason why more realistic rules of elevation impose a certain distance from any obstacles. The orientation of such obstacles, in respect of prevailing wind direction, is deliberately not taken into account. Indeed, heavy precipitation is often associated with convective factors, whereby the wind direction is not necessarily that of the prevailing wind.

Class 1

- Flat, horizontal land, surrounded by an open area, slope less than 1/3 (19°). Flat terrain interacts with the larger area in such a way that the speed of the wind is not affected by the surrounding orography.
- Potential obstacles must be situated at a distance at least four times greater than the height of the obstacles (in respect of the catchment height of the pluviometer).

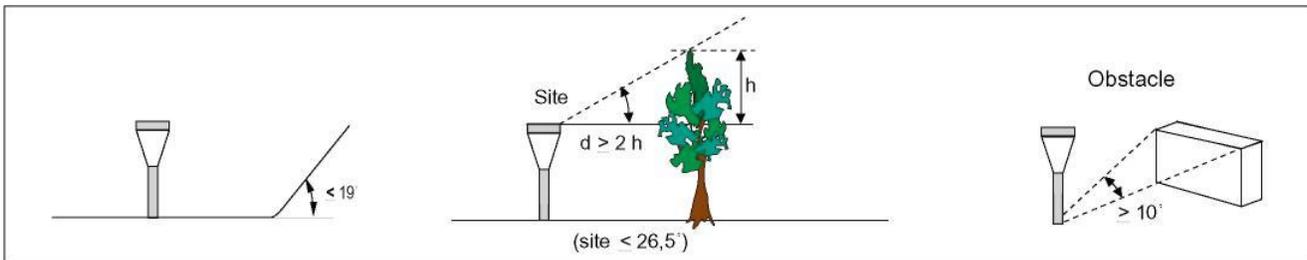
An obstacle represents an object with an angular width of 10° or over.



Class 2 (error 5 % ?)

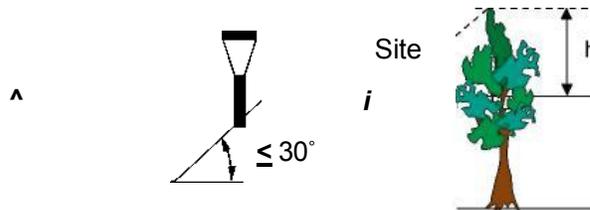
- Flat, horizontal land, surrounded by an open area, slope less than 1/3 (19°).
- **Possible obstacles must be situated at a distance at least twice the height of the obstacle** (in respect of the catchment height of the pluviometer).

An obstacle represents an object with an angular width of 10° or over.



Class 3 (error 10 to 20 % ?)

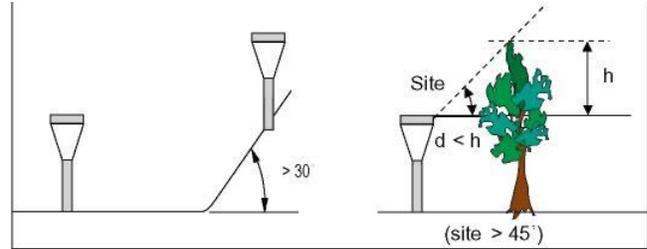
- Land is surrounded by an open area, slope less than 1/2 (≤ 30°).
- **No obstacles within a distance equal to once their height.**



(site $\leq 45^\circ$)

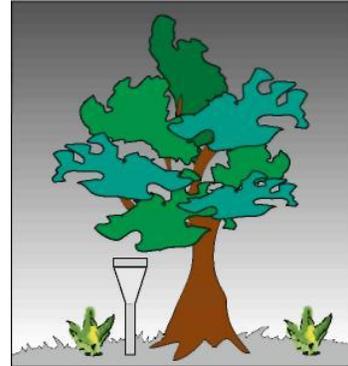
Class 4 (error > 20 % ?)

- Steeply sloping land ($> 30^\circ$).
- Adjacent obstacles (less than once their height).



Class 5 (error > 50 % ?)

Obstacles situated above the pluviometer (tree, roof etc.).



Wind

Conventional elevation rules as set by the WMO (used in most countries, including France) stipulate that sensors should be placed 10 m above ground surface level and on open ground. Open ground here represents a surface where obstacles are situated at a distance equal to at least ten times their height (see class 1 for more details).

Wind measurements are not only disturbed by surrounding obstacles; terrain roughness also plays a role here. The WMO takes wind blowing at a geometrical height of 10m and with a roughness length of 0.03 m as the surface wind.

This is regarded as a reference wind for which exact conditions are known.

The classification used for measuring the wind is therefore two-fold. The first classification takes into account the roughness of the surrounding terrain. The second concerns the immediate environment and any possible obstacles.

Roughness

Roughness length is by definition, calculated as height z_0 (above ground level) of the landscape to which the condition is applied (that is to say where the average vector wind is equal to vector zero). In respect of any wind direction, the roughness length will depend on terrain homogeneity, on the presence of obstacles as well as the distance over which these two factors intervene. Significant variations in roughness length are observed in different seasons, as a result of for instance, fallen leaves or snow cover. A characteristic of a wind measuring site is therefore expressed by its roughness length in each wind direction. As the exact calculation of roughness length is difficult to carry out, the data indicated in the table can be used for classification.

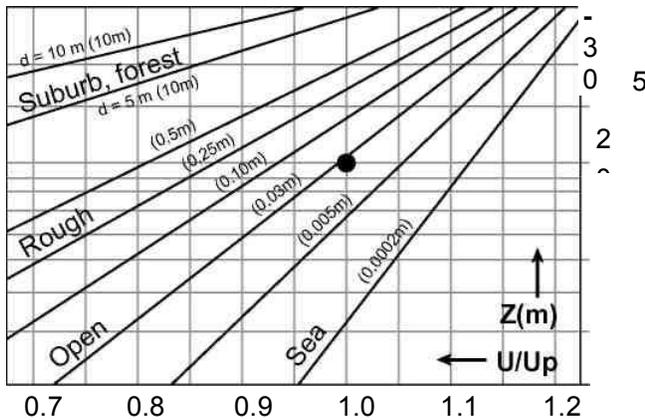
Based on a supposition that the wind measured at 60m (Wieringa, 1986) is represented on a mesoscale and using the logarithmic profile of the wind, we can set up a function, enabling us to go from a wind measured at a height z from the ground qualified by any roughness length, to a potential wind, measured at ten meters above the ground with a roughness of 0.03m (potential wind compliant with WMO recommendations).

Terrain classification by Davenport (1960), adapted by Wieringa (1980) in terms of roughness length z_o		
	Terrain description	z_o in m
1	Open sea, « fetch » at least 5 km	0,0002
2	Flat, muddy terrain, snow ; no vegetation, no obstacles	0,005
3	Open, flat terrain ; grass, infrequent and isolated obstacles	0,03
4	Low growth ; occasional, large obstacles : $x/H > 20$	0,10
5	Elevated growth; dispersed obstacles : $15 < x/H < 20$	0,25
6	Bordered terrains, shrubs ; numerous obstacles : $x/H \sim 10$	0,5
7	Regular coverage by large obstacles (suburbs, forests)	(1,0)
8	Town centre with different height buildings	??

Note : x represents the distance from the obstacle whilst H represents the height of the principal corresponding obstacle.

Table II – Roughness class, by Wieringa

Potential wind U_p (measured at 10 m above a terrain, roughness length of 0.03 m) is calculated based on wind U_s , as measured at the station (at a height z_s m above a terrain with a roughness length of z_o m).



For instance, wind measured at 10 m on a class 6 site ($z_o = 0,5$ m) will be 20 % weaker than the potential wind. By using the classification and the given function (or formula) we obtain the following figures (average where the adjacent layer stability is compliant with the logarithmic profile):
 Class 4 : 7 % less than the potential wind
 Class 5 : 12 % less than the potential wind
 Class 6 : 20 % less than the potential wind
 Class 7 : weaker than the potential wind but difficult to calculate

Figure 1 - Function (Wieringa, 1986) based on the logarithmic profile of the wind and roughness length.

Roughness classification

The roughness of a wind measuring site is usefully described by roughness class in four sectors centered in the north, east, south and west. The roughness is estimated by analyzing the terrain in these four sectors using the table provided above. The roughness is estimated taking into account objects situated at up to 250 m from the measurement point.

Environment classification

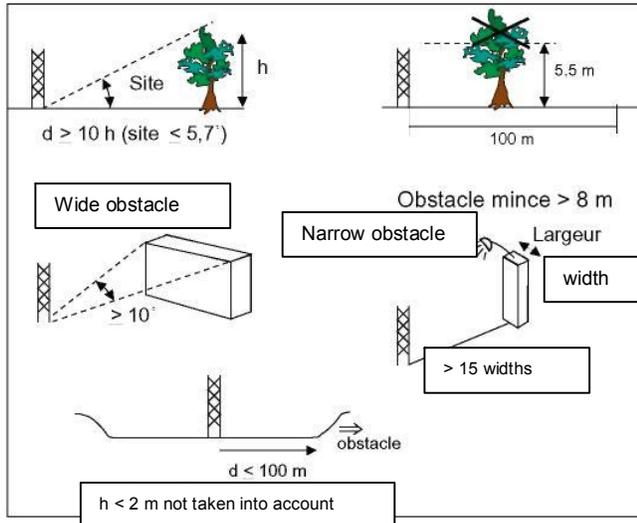
Measuring the angular height of obstacles surrounding the site enables us to characterize these obstacles. Methods and equipment used are described in a separate document.

The presence of obstacles (almost invariably) means a drop in average wind readings. Generally, wind extremes are also reduced but not always. Obstacles encourage turbulence and consequently may cause an (unpredictable) increase in instantaneous wind (from which maximum wind is derived).

The following classification assumes measurement at 10 m which is the standard elevation for meteorological measurement. Where measurement is carried out at 2 m, as is sometimes the case for agro-

climatological purposes, we can use the same classification, simply replacing 10 m by 2 m. This generally produces higher class results, which tends to favor measurements at 10 m which are more representative (these measurements may be carried out at 2 m by employing a logarithmic profile hypothesis).

Where numerous obstacles higher than 2 m are present, the WMO recommends that sensors should be placed 10 meters above the average height of the obstacles. This method allows the influence of the adjacent obstacles to be minimized. This method has so far been used little in France, although it does represent a permanent solution for partly eliminating the influence of certain obstacles. It inconveniently imposes the necessity for higher masts (consequently more expensive) which are less standard. It must be considered for certain sites and where used, the height of obstacles to be taken into account is that above the level situated 10 m below the sensors.

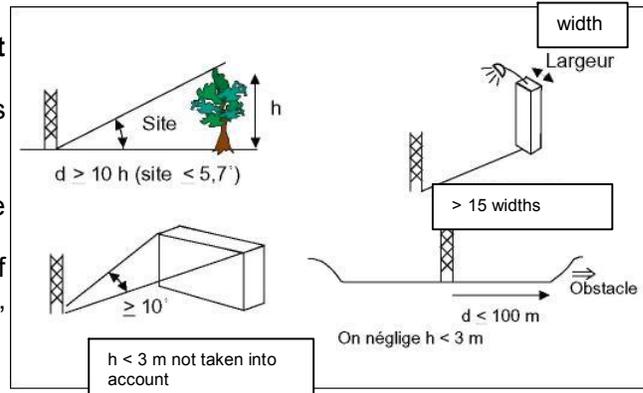


Class 1

- The pylon should be located at a distance equal to a least ten times the height of surrounding obstacles.
- An object is considered to be an obstacle if its angular width is over 10°.
- Obstacles should not exceed 5.5 m in height within 100 m of the pylon.
- Obstacles lower than 2 m can be ignored.
- Changes in the landscape within an area of 100 m are also considered as obstacles.
- Sensors should be situated at a minimum distance of fifteen times the width of narrow obstacles (mast, thin tree) over 8 m high.

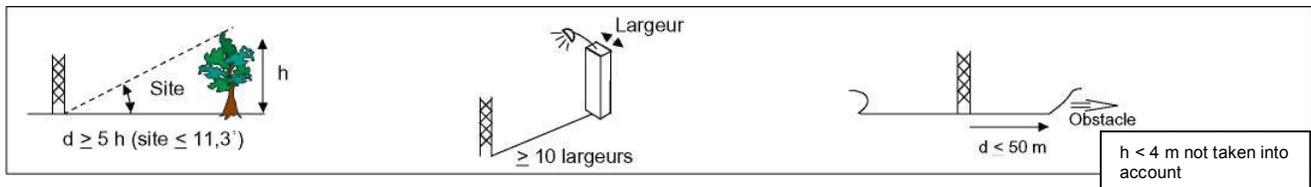
Class 2 (error 10 % ?)

- The pylon should be located at a **distance of at least ten times the height of the surrounding obstacles.**
- An object is considered as such if its angular width is over 10°.
- Obstacles lower than 3 m can be ignored.
- Changes in the landscape within an area of 100 m are also considered as obstacles.
- Sensors should be situated at a minimum distance of fifteen times the width of narrow obstacles (mast, thin tree) over 8 m high.



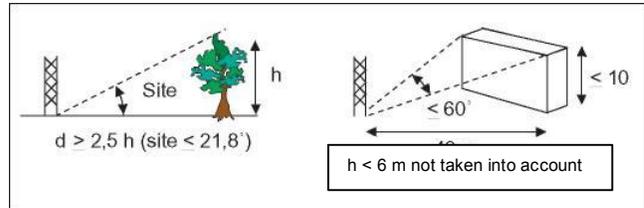
Class 3 (error 20 % ?)

- The pylon should be located at a distance of at least five times the height of the surrounding obstacles.
- Obstacles lower than 4 m can be ignored.
- Changes in the landscape within an area of 50 m are also considered as obstacles.
- Sensors should be situated at a minimum distance of ten times the width of narrow obstacles (mast, thin tree) over 8 high.



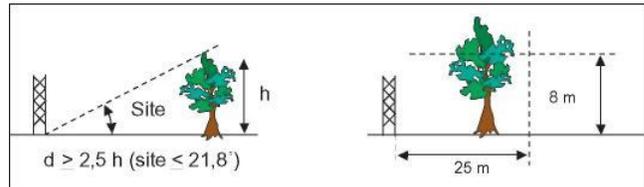
Class 4 (error 30 % ?)

- The pylon should be located at a distance of at least 2.5 times the height of surrounding obstacles.
- Obstacles lower than 6 m can be ignored.
- An object is considered to be an obstacle if its angular width is over 60° within an area of 40m.

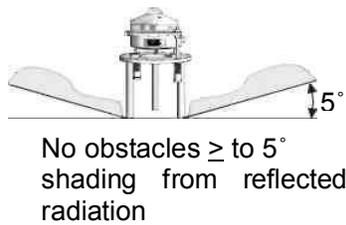
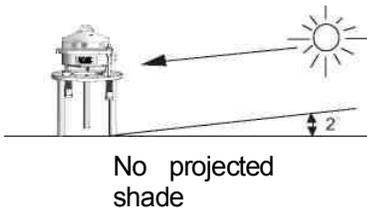


Class 5 (error > 40 % ?)

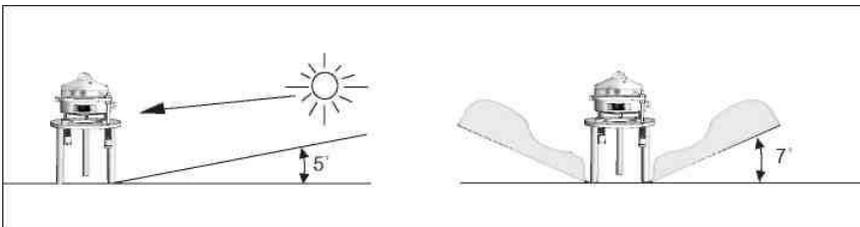
- Site not meeting the requirements of class 4.
- Obstacles over 8 m high within an area of 25 m.



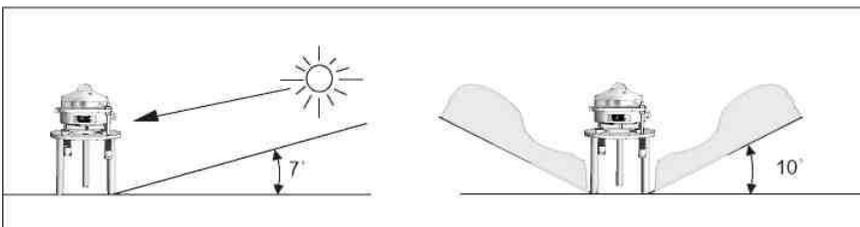
Radiation



- Class 1**
- No shade projected onto the sensor when the Sun is at an angular height of over 2° (except from the natural landscape of the region).
 - No obstacles with an angular height of over 5°.

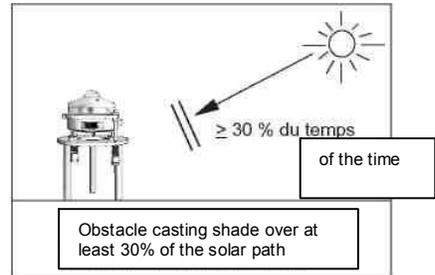


- Class 2**
- No shade projected onto the sensor when the Sun is at an angular height of over 5°.
 - No obstacles with an angular height of over 7°.



- Class 3**
- No shade projected onto the sensor when the Sun is at an angular height of over 7°.
- No obstacles with an angular height of over 10°.

Class 4



- Projected shade where obstacles are not compliant with the preceding classification, and not belonging to class 5.

Class 5

- Shade projected during at least 30% of the time (or an obstacle casting shade over at least 30% of the solar path).

**BASIC SET OF VARIABLES TO BE REPORTED BY THE STANDARD AWS
FOR MULTIPLE USERS**

Variables	<i>SYNOP Land Stations¹⁴⁾</i>	<i>[Fixed] Ocean Weather Stations¹⁴⁾</i>	<i>Ocean observing platforms⁹⁾</i>	<i>Aeronautical meteorological station¹⁴⁾</i>	<i>Principle climatological station¹⁴⁾</i>	STANDARD
Atmospheric Pressure	M A	M A	M A	X ¹⁾	X	A
Pressure tendency & characteristics	[M]	M	[M] [A]			[A]
Air temperature	M ²⁾ A	M A	M [A]	X	X ³⁾	A
Humidity⁵⁾	M A	M	[M] [A]	X ⁴⁾	X	A
Surface wind⁶⁾	M A	M A	M [A]	X	X	A
Cloud Amount and Type	M	M	[M]	X ¹¹⁾	X	A¹¹⁾
Extinction profile/Cloud-base	M [A]	M		X	X	A¹²⁾
Direction of Cloud movement	[M]					
Weather, Present & Past	M	M	M	X	X	A¹²⁾
State of the Ground	[M]	n/a	n/a		X ⁷⁾	[A]
Special Phenomena	[M] [A]	M	[M]			
Visibility	M [A]	M	M	X	X	A
Amount of Precipitation	[M] [A]	[A]	[A]		X	A
Precipitation Yes/No	A	[A]	[A]		X	A
Intensity of precipitation	[A]		[A]			
Soil temperature		n/a	n/a		X	A
Sunshine and/or Solar radiation			[A]		X	A
Waves		M [A]	[M] [A]			A⁸⁾
Sea temperature		M A	[M] A			A⁸⁾
Sea ice and/or icing	n/a	M	M			
Ship's course and speed	n/a		[M] [A]	¹³⁾		[A]⁸⁾
Sea level		¹⁰⁾	[M] [A]	n/a		[A]⁸⁾

Explanation

M = Required for manned stations
[M] = Based on a regional resolution
A = Required for automatic stations
[A] = Optional for automatic stations
X = Required

Notes:

- ¹⁾ Also QNH & QFE
- ²⁾ Optional: extreme temperatures
- ³⁾ Inclusive extreme temperatures
- ⁴⁾ Dew point temperature
- ⁵⁾ Dew point temperature and/or RH and air temperature
- ⁶⁾ wind speed and direction
- ⁷⁾ snow cover
- ⁸⁾ sea and coastal stations only
- ⁹⁾ Proposed by the representative of JCOMM, to become valid for VOS, drifting and moored buoys, rigs and platforms, tide gauges, profiling floats (for review after consultation with JCOMM Expert Teams)
- ¹⁰⁾ Coastal stations and off shore platforms only
- ¹¹⁾ Cloud amount, TCU and CB only
- ¹²⁾ Restricted to what is feasible
- ¹³⁾ Only for helidecks on ships
- ¹⁴⁾ Source: Manual on the GOS

VISION FOR THE GOS IN 2025

1. General trends and issues

1.1 Response to user needs

- a) The GOS will provide comprehensive three-dimensional observations in response to the needs of all WMO Members and Programmes.
- b) It will provide data for fundamental understanding of physical processes and variability of the atmosphere with emphasis on Planetary Boundary Layer (PBL), oceans (with emphasis on the mixed layer), inland water systems, and the upper-layers of the land surface for refining and improving all elements of the forecast process.
- c) It will provide adaptable¹ observations when and where they are needed in a reliable and sustained manner.
- d) It will respond in cost effective manner to user requirements for observations of specified spatial and temporal resolution, accuracy, timeliness and lead time.
- e) It will continue to facilitate effective global collaboration in the making and dissemination of observations, through a composite and increasingly complementary system of observing systems.
- f) Additional data integration and model calculation will also be used to response to user needs, as an alternative to network expansion.

1.2 Integration

- a) The GOS will be an essential part of the WIGOS that will build further on current GOS functionalities. Within WIGOS, further integration of various observing components will demand interoperable arrangements and common standards.
- b) Future GOS will be characterized by optimal integration of different observing platforms, especially various ground-based remote-sensing systems.
- c) Future GOS will be characterized by improved system integration of meteorological and hydrological observing systems allowing the development of innovative integrated information products based on multivariate observations in real/near-real time.

1.3 Expansion

- a) There will be an expansion in both the user applications and the variables observed.
- b) The GOS will support the production of Essential Climate Variables, adhering to GCOS climate monitoring principles.
- c) Sustainability of new components of the GOS will be secured, with Research and Development (R&D), Observing System Experiment (OSE), Observing System Simulation Experiment (OSSE) and test-bed systems integrated as operational systems when proved.
- d) Expansion in observing technologies and techniques will focus on “intelligent” (smart) integration of existing or improved systems.
- e) To optimize the cost-efficiency of the GOS, some level of targeted observations will be achieved (whereby additional observations are acquired or usual observations are not acquired) in response to the local meteorological situation.
- f) It will evolve in response to changing user and technological development based on improved scientific understanding and advances in observational and data-processing technologies.

1.4 Automation

- a) The trend to develop cost-effective fully automatic observing systems, using “intelligent” integration of existing ones and new observing and information technologies will continue.
- b) There will be improved access to real-time and unprocessed data.

¹ Easily increasing and expanding spatial and temporal data densities, and the number and type of measured elements to meet emerging user needs.

- c) Observing system test-beds will be used to intercompare and evaluate new automatic systems and develop guidelines for integration of observing platforms and their implementation.

1.5 Standardization

- a) There will be further progress in standardization of instruments and observing methods within the GOS and WIGOS.
- b) There will be significant improvements in traceability of measurements to System International (SI units; certified international standards) to ensure better data compatibility and homogeneity.
- c) There will be increased interoperability, between existing observing systems and with newly implemented systems.
- d) There will be improved standardization of data management, data archive, data and metadata formats, and their accessibility via WIS.

2. Space-based subsystem (...)

3. Surface-based subsystem

➤ **Variables of future GOS not adequately measured or observed by current systems:**

- PBL measurements, especially wind and moisture profiles;
- 3-D fields of temperature, water vapour, wind, mainly over ocean and sparsely-inhabited land areas with adequate space and temporal resolutions;
- 3-D mass, hydrometeor cloud fields, cloud microphysics;
- Surface energy balance components (soil, sensible and latent heat and moisture fluxes);
- Total column water;
- Moisture profiles, in particular in the upper troposphere and lower stratosphere.
- Measurement of subjective observations (state of the ground, present weather)
- Surface radiation components;
- UV radiation;
- Snow/ice cover and depth, snow water equivalent;
- Thermal profiling of the ocean mixed layer;

With regard to hydrology and water resources:

- Global river discharge,
- Fresh water fluxes into the world ocean,
- Discharge in mountainous regions including runoff from snow and glacier fields,
- Variables needed for Glacier Lake Outburst Flood (GLOF) Hazards,
- Variables needed for Flash-floods (rain-induced, precipitation intensity/duration, probable maximum precipitation),
- Discharge in deltas and large estuaries,
- Ice-Jams and resulting floods,
- Variables needed for Flooded areas and wetlands,
- Volume changes of large lakes and reservoirs,
- Groundwater recharge on national, river-basin and regional scales,
- Volume changes of large aquifers,
- Water quality on all scales, multitude of variables, observation adequacy dependant on use of information,
- Water use (in particular, this variable is essential to be included in national statistics and is also an essential climate variable),

- Regarding atmospheric composition measurements, reference is made to the Global Atmosphere Watch (GAW) Programme. The long-term objectives of GAW, as stated in the

WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008-2015, GAW Report No. 172 (The Plan is being updated as per changing requirements and a revision will be provided in due time for the years beyond 2015), are to:

- Develop GAW into a three-dimensional global atmospheric chemistry measurement network through the integration of observations of surface-based, balloon-borne, aircraft, satellite and other remote sensing observations.
- Make certain sectors of GAW, such as total ozone, ozone sounding and aerosol observations, compatible with near-real-time (NRT) delivery of data. Increase the usage of the WMO Global Telecommunication System/WMO Information System (GTS/WIS) for exchange of GAW data.
- Fuse observational systems, data assimilation and modeling, databases and product delivery, and quality assurance and validation into coherent data processing chains, related to a defined GAW quality management system within the WMO Quality Management Framework (QMF).
- Support research and development leading to assimilation of the essential climate variables – aerosols, ozone and greenhouse gases – in atmospheric transport and numerical weather prediction models and the production of related products and services.

4. System-specific trends and issues

4.1 Space-based (...)

4.2 Surface-based

➤ The surface-based GOS will provide:

- Improved detection of mesoscale phenomena, such as flow in complex terrain, the detailed structure of fronts and mesoscale convective systems (severe storms), the detailed evolution of the structure of the planetary boundary layer, cloud distributions and their interaction with radiation, the transport of heat, moisture and momentum,
- Integrated atmospheric profiles,
- Reference data for calibration and validation of space-based data,
- Long-term datasets for the detection and understanding of environmental trends and changes;
- Additional surface observations will come from a wide variety of surface networks (e.g.: agricultural meteorological, road, urban and other multi-application fixed and mobile networks).
- Increased data access from national meteorological networks that are not currently exchanges through GTS.
- Optimized Regional Basic Synoptic/Climatological Networks (RBSN/RBCN) will be the essential components of the integrated global observing systems.
- Radiosondes networks will be optimized, particularly in terms of horizontal resolution which will decrease in data-dense areas. They will be complemented by aircraft (AMDAR) ascent/descents profiles for most of the airports worldwide and supplemented by profilers and GPS MET in some regions.
- A GCOS Reference Upper Air Network (GRUAN) (a part of the RBCN) will serve as a reference network for climate trends. Reference radiosondes capable of measuring temperature and humidity in both troposphere and stratosphere will be developed for use within GRUAN.
- Aircraft observations will be fully integrated into the GOS with aircraft humidity measurements.
- Aircraft observations (flight-level and ascent/descent data) will be available at user-selected temporal and space resolution.
- Weather Radar observing systems will provide enhanced cloud, precipitation Quantitative Precipitation Estimation (QPE) and radial wind products with increased data coverage. There will be much improved data consistency, with defined minimum standards for quality control and accuracy. New radar technology, e.g. phased array, polarimetric and multi-channel radars for full 3-D wind fields will be available.

- Different types of radars will be integrated into national and regional radar networks. Current regional radar data exchanges will be supplemented by global exchanges for NWP centres.
- Integrated Profiling Systems will be developed and used by more applications. A wider variety of techniques and technologies will be used. Wind profilers, Raman, Elastic Backscatter and Differential Absorption Lidars, weather and cloud radars, microwave and multi-wavelength radiometers and GPS Met will mostly dominate. These systems' technologies will be integrated into "intelligent" profiling systems and integrated with other surface observing technologies.
- Ground based Global Navigation Satellite System (GNSS), which includes the Global Positioning System (GPS, USA), GALILEO and GLONASS, will be used for water vapour measurements.
- Long-range lightning detection systems will provide cost-effective, homogenized, global data with a location accuracy of about 2 km, significantly improving coverage in data sparse regions including oceanic and polar areas.
- Sustained systems will provide ocean sub-surface profiles of high vertical resolution data.
- Communications for marine observations will be improved through two-way, high data rate cost-effective satellite data telecommunication systems, which will collect the in situ observational data, and permit remote programming / control of the observing platforms.
- Marine observing technology will be improved, including cost-effective multi-purpose in situ observing platforms, profiling floats (with added sensors), ocean gliders, deep ocean time series reference stations, HF Radars, Ice Tethered Platforms & Ice Mass Balance buoys, and cost-effective *in-situ* wave observations.
- AWS will fulfill multiple functionalities. More meteorological observing platforms will be shared by instruments for different applications, and more meteorological observations will be performed on "platforms of opportunities", or using some infrastructures which have been set up for non-meteorological purposes.
- In response to economic and other pressures, observing systems will continue to exist with:
 - A broader range of station siting options including siting classifications;
 - A broader range of low-cost, low-maintenance, reliable sensors providing data critical for operational applications;
 - Increased attention to IT security. As more private sector networks join the global system of systems, issues concerning the proprietary rights of the data and the protection of the data should be addressed.
- Surface-based systems with regard to hydrological observations will see a number of developments such as:
 - Improvements of water level observations (needed to calculate discharge), such as radar-gauges, acoustic gauges, Acoustic Doppler Current Profilers, dye tracer discharge instruments in turbulent rivers, and use of isotopic observations especially in observations of glaciers, groundwater, large lakes and reservoirs.
 - Increased coupling of hydrological observations with other observing platforms including those for rainfall, evaporation, groundwater, soil moisture;
 - As a result of increasingly complex observing systems (i.e. coupling meteorological variables with hydrological variables in (near) real-time for forecasting, coupling water quantity and quality data and information etc.), integrated observing systems solutions will gain popularity in use.

ADVANCES IN AWS TECHNOLOGY

Telecommunication

- More and more telecommunication providers are available: GSM, GPRS, WIMAX, satellite communication (Inmarsat, Iridium, etc.), etc. A technical solution always exists to transmit information.
- Some telecommunication methods allow frequent transmission of data: at least hourly and sometimes every 5 or 10 minutes, or even 1 minute. The transmission period can be switched to more or less frequent transmission to optimize the cost of the transmission.
- More AWS can be seen as an IP object, thus facilitating a central management of the network. IT Security aspects must be taken into account.
- Technical diagnostics can be done remotely, thus minimizing the maintenance costs.

Data acquisition

- Due to advances in electronics, the calibration of the acquisition part of an AWS is no longer a problem, with a very high stability and integrated control procedures.
- Storage is cheap and provides security in case of transmission problems (useful mainly for climatology).
- Internal algorithms of data combination allow detection of malfunctions, to validate or invalidate a sensor output, to expand the data set with additional calculated parameters.
- AWS for marine measurements are available and operational.

Sensors

- Many sensors have internal diagnostics. There is a great interest in transmitting these diagnostics to facilitate remote diagnostics and thus to optimize the maintenance management and associated costs.
- Some sensors (such as barometers) include redundant elements.

But

- Advances in new sensors are slow. Efforts of many NMSs to develop new sensors are reduced, due to budget restrictions.
- With the rapid progress in technology, there is a reduction in the lifetime of commercial products.
- New sophisticated sensors for reporting “visual observation” or for observation in harsh conditions (cold, icing) request significant power supply, incompatible with an autonomous solar panel system. Therefore the infrastructure costs may be very high.

Quality of measurements

- Observations from modern sensors and AWS have greater consistency and repeatability, without the subjectivity which may exist with human observation.
- AWS helps in standardization.

Infrastructure and siting

- Care in the installation, electrical equipotentiality and lightning protection minimize failure and corrective maintenance.
- An AWS offers greater flexibility for the choice of its site as it does not require the infrastructure needed by a human observer.

But

- An AWS cannot be left unattended for more than one year (and sometimes less, depending on the sensors and the site).

Network

- In an area with relatively dense networks, the response to a new user need does not necessarily require the installation of a new station, but it can come from the spatialization of merged observations (i.e. precipitation radars and rain gauges).

Cost

- The cost of an AWS is small compared to the cost of a whole network. So adding an additional AWS to an existing AWS network can be cheap.
- The cost of an AWS is decreasing, but this remains marginal compared to the total initial and running costs of a network: infrastructure, maintenance and calibration, management and training costs.
- Due to the increase complexity of the data acquisition system, sensors and telecommunication system, the level of skill required for maintenance is higher than for traditional (manual) stations.

OBSERVING THE CLIMATE – CHALLENGES FOR THE 21ST CENTURY

(by Dr W Wright, CCI ET-ORSC chairperson)

Abstract: This article briefly reviews the challenges posed in collecting and managing observational data suitable for the needs of national and international climate programs, who are charged with providing climate services today, and with monitoring and predicting the climate of the future. It briefly describes the impacts of increased automation of the observational network, through to the challenges of ensuring data management activities provide climate data that is “fit for purpose”. Current activities of several WMO CCI Expert Teams in addressing these challenges are briefly outlined.

1. Introduction

One of the great challenges facing mankind in the 21st Century is how to deal with the global climate, present and future. Seasonal swings in climate, with their droughts, floods, and storms, are responsible for major natural disasters that at their worst wreak death, famine, loss of livelihood, epidemics, displacement of populations, as well as vast losses of personal and state-owned belongings. On top of that, the vast consensus of reputable scientific opinion, as represented in the fourth Assessment Report of the Intergovernmental Panel on Climate Change, states that the climate is changing, and will change significantly further. In general, these changes will be for the worse, with the most severe effects likely in developing and least-developed countries – precisely those countries with the least ability to adapt.

The good news is that scientific progress has equipped mankind with tools that can potentially reduce adverse impacts, by enabling some capacity to predict in advance what will happen so that – potentially at least - some kinds of preventive actions can be taken. Thus, an increased likelihood of drought can, in theory, lead to a range of timely mitigation activities: more careful management of water (e.g., increasing storage through tanks); agricultural responses, such as planting more drought-resistant strains of crops; government-level recognition that financial or other support may be required for affected communities. In terms of climate change, the development of increasingly powerful models and downscaling techniques can not only predict future climate patterns from known levels of atmospheric forcing, but should soon be able to estimate the likely impact on local rainfall and vegetation – provided there is sufficient data to train and verify the models. In short, mankind’s ability to manage the climate of the future should be well served by the lessons contained in the climate record of the past.

The operative phrase here is “the climate record of the past”. In order to develop effective adaptation strategies for the future, a reliable record of the climate of the present and past is absolutely indispensable. This is usually more challenging than simply collecting and recycling the observations taken to support operational weather forecasting, because climate has special needs that forecasting does not. In particular, climate scientists and service providers require observational records that are long, free from significant gaps, and free from major errors or inhomogeneities. These conditions are not necessarily met by networks designed primarily for weather forecasting, and it is one of the duties of today’s climate scientists, through advocacy and advice, to ensure that observational network designers recognize the special needs of the climate program. Other challenges connected with the effective use of data are the development of capacity to analyze and interpret what the climate record is saying; and the merging of historical observations with future climate projections.

2. A wish-list for the climate record

While it is difficult to generalize about what constitutes a sufficiently long record, one might suggest that at least 30 years of record is required, at sufficient stations to represent all the major climate zones, and vulnerable regions, within a country. Because of the need to ensure that climate extremes are properly captured, these data would be required on at least daily time-scales. Moreover, the data must be homogeneous, and accompanied by good supporting information

(metadata). A rainfall time-series with a discontinuity of 15% will make it harder to identify and attribute climate change-related trends in rainfall of similar magnitude. The task would be almost impossible if metadata recording the time and cause of the discontinuity are unavailable.

The time-series also needs to be free of significant gaps in the record, as these can play havoc with statistical relationships in particular. Finally, the wider the range of variables recorded, the better the ability to record the climate. For many purposes it is useful to know not only the average and extreme rainfalls and temperatures for an area, but the frequency of thunderstorms, hailstorms, and frosts as well.

Since climate variability and change are global phenomena this record must, as far as possible, be global in extent. While good records in some countries are valuable for those countries, the ability to understand and predict the global climate as a whole is weakened if there are few or no observations in neighbouring countries. It is highly likely that our ability to predict the global climate under conditions of future global warming would be weakened by a lack of surface and upper air observations over the Pacific Ocean region, very much the “flywheel” of the current climate system, and the home of the El Niño-Southern Oscillation phenomenon.

Unfortunately, at the very time high quality networks for climate monitoring and prediction purposes are most needed, and that there is increasing recognition of this fact, economic factors are working in the opposite direction.

3. *Impacts of AWS and remote sensing on observational quality*

It is a fact of life in nearly all countries that budgets for National Meteorological and Hydrological Services (NMHSs) are becoming increasingly constrained. In this environment, the tendency is increasingly to replace relatively resource-intensive manual observational networks with automated instrumentation and remote sensing approaches. While such networks are cost effective, and have considerable benefits for the weather forecasting community, they pose a number of problems for the climate community, and the overall integrity of the climate record.

This trend towards automating some (and in some countries, all) of the observational network has been very apparent over the last 10-15 years. It has been estimated that by late 2006, some 23% of all Regional Basic Synoptic Network (RBSN) Stations were Automatic Weather Stations (AWS), with the number increasing rapidly. To be sure, AWS have some attractive features for climate science: apart from cost effectiveness, they provide higher-frequency data (down to one minute observations in some cases); better ability to detect extremes (due to the higher-frequency data); they can be deployed in remote or climatically-hostile locations; provide generally faster access to data; and ensure consistency and objectiveness in measurement. They can also provide a useful function for some kinds of quality control: for instance, where a manual observer goes on holiday, it may be possible to use daily recordings from a nearby AWS to break down a cumulative rainfall total into its constituent daily amounts.

On the other hand, experience in several countries has shown that AWS can have an adverse effect on the climate record. Observed impacts have included:

- Data losses, due to communication failures and inadequate back-up of data, leading to significant gaps in data continuity.
- Inhomogeneities have been introduced into time-series, partly due to inadequate change management (e.g., insufficient period of overlap of conventional observations with those from AWS), and sometimes due to poor maintenance. Within Australia, two recent examples have included: (1) an apparent sudden drop in rainfall at a station comparable with the predicted long-term decline due to climate change (posing obvious problems for attribution); and a change in wind-sensor, which gave rise to discontinuities in peak wind-speeds, and attracted the ire of the national Standards authority.
- Maintenance procedures sometimes generate spurious data spikes.

- There are in some cases doubts about accuracy and precision, especially of rainfall. Again this can lead to homogeneity issues, as well as adversely influencing decisions on which significant amounts of money depend.
- Because of the complex electronics in AWS, maintenance requires more specialized skills than may be readily available within some countries;
- Unless specifically equipped with special sensors, AWS deployment usually results in a loss of visual observations (such as phenomena), making it difficult to construct some kinds of climatology, or monitor trends in, say, hail-days or cloudiness.

It must be stated that many of the impacts outlined above can be substantially reduced if the introduction of AWS is accompanied by sound implementation and change management processes, and regular maintenance. Moreover, further mitigation of the problems identified can be expected as technology continues to improve: for instance, visual sensors can record some kinds of phenomena; enhanced data loggers can minimize data losses. The catch is that sound management and technological enhancements generally mean increased costs. The challenge for climate programs everywhere will be firstly to ensure that the value of the climate record is recognized; and secondly to ensure that networks are designed in such a way that the strengths and weaknesses of conventional vs AWS are complementary. The WMO Commission for Climatology (CCI) has a leadership role to play in this regard. A current activity of the CCI Expert Team on Observing Requirements and Standards for Climate (ET-ORSC) is to identify a list of requirements for AWS data for climate purposes. These include not just sensor precision standards, but requirements for things like data back-up, extra sensors, station distribution, maintenance, etc.

Remote sensing approaches are attractive for their ability to provide much greater densities of observations than is possible with conventional networks. They have particular value over oceans or sparsely-populated areas. The drawbacks are that it is difficult to monitor, or to accurately interpret, some variables. Also, there needs to be at least a certain number of surface stations to “ground truth” the information inferred from satellites, radar, etc.

The challenge for the future will be to integrate remote sensing approaches with conventional and AWS ground-based networks, in such a way that the overall climate record is not compromised. To do this will require not only a careful change management strategy as observational systems change, but almost certainly the establishment of an optimal blend of observation systems. The latter stands as a significant research exercise.

4. *Observational data management and stewardship*

Having in place observational networks that can take and record regular climate observations is a necessary, but not sufficient, condition for ensuring the climate record can adequately support climate monitoring and service provision. The data must also be properly quality controlled, archived, and easily accessible. If large parts of the climate record exist only in hard-copy manuscript form, it is hard to use it to construct climatologies, develop statistical prediction schemes, or utilize it in climate models. Unfortunately, the question of effective management of observational data remains a major problem in many countries, particularly developing countries.

The following outlines the data management requirements to ensure that the information contained in the observations is available for optimal use. To these must be added the imperative that countries remain willing to share their data, so that the rest of the world has access to it.

4.1 *Data rescue and digitization.*

Many countries have large amounts of data locked up in largely inaccessible paper formats, such as log books or record-sheets. Worse, in such formats they are at heightened risk of permanent loss or damage due to fire, flood, rot, theft, or insect or vermin attack. For this reason WMO in recent years has been very concerned with data rescue and digitization efforts, especially in developing countries. They have been aided in such efforts by opportune funding from

Government agencies in certain countries². Activities typically involve securing vulnerable records against immediate loss or damage, digitizing/imaging these records, and/or relocating records to safer locations (including overseas), and – very importantly – providing NMHS staff with training in effective records management and archiving techniques. Various countries have supported attempts by the marine science community to rescue ships' logs, as an aid in interpreting climatic conditions over the world's oceans: The RECLAIM project (for RECOVERY of LOGBOOKS AND INTERNATIONAL MARINE DATA) is an example of such an initiative.

4.2 Database technology and archiving.

In the modern era, effective data access means having the data stored in electronic formats, and preferably in forms where it can be readily ingested into spreadsheets, analysis software, and climate models. CCI supports these activities by recommending and supporting various data management initiatives (e.g., WCDMP, 2005). One recent example of this support has been the recommendation and implementation in developing and least-developed countries (D & LDCs) of non-proprietary data management software, designed with the specific needs and limitations of those countries' NMHSs in mind. The ClimSoft software package, developed under WMO auspices, has so far been installed in countries of the Caribbean, Africa, and the Pacific, backed by training courses, tailored report formats, and an online discussion group. The Australian Bureau of Meteorology has supported the Pacific "arm" of this implementation; their experience has shown that training in the use of such software is much more effective if delivered in-country, rather than via workshops which may be attended by only one representative per country.

Where it has not been possible to digitize data, there is still a need to ensure paper records are stored securely, according to acceptable archival standards (e.g., in acid-free boxes, in air conditioned rooms, and with the data properly inventoried).

4.3 Quality Control/Assurance (QC/QA)

For data to be truly reliable, there has to be some means of diagnosing, then correcting, eliminating or at least flagging errors. In other words, the data must be subject to some kind of quality control (QC). Once, QC was very much a hands-on activity, with NMHS staff physically checking individual data recorded in log books or on sheets against a series of tests, coupled with often-subjective operator experience, a dash of local topographic knowledge, and a lot of observational knowledge. With the advent of automatic high-speed computers and larger volumes of data, QC in many locations has become more automated, with much of the testing done automatically using pre-determined checks (e.g., checks against climate extremes; internal consistency checks - e.g., does dew-point exceed temperature?; unlikely temporal fluctuations; checks against neighbouring stations). With this approach the manual operator role – if it remains at all – becomes confined to following up and deciding on cases flagged by the automated testing procedures. It is good QC practice to assign a quality flag indicating the reliance to be placed on the data, and to keep an audit trail so that original data may be regenerated if required.

Clearly, the degree and type of QC will depend on various factors, such as the number of stations; the variable type (in general Essential Climate Variables such as rainfall, temperature and humidity should receive greater attention than less critical ones); frequency of data; and – naturally - staff and computing resources within the NHMS. Some centres (e.g., the US National Climatic Data Centre, NCDC) run additional tests for homogeneity. The ET-ORSC, in collaboration with NCDC, are completing a revision of the Guidelines for QC of Surface Climate Data (Abbott, 1986).

An important part of the QC/QA process is to ensure that systematic or repeated errors are identified, and referred back to observational managers for investigation and rectification.

² In Australia, the Australian Greenhouse Office has provided funding for data rescue activities in Pacific Island Countries, where the data was deemed to be at risk of loss or damage. They have also provided funding for the implementation of data management software (ClimSoft) suitable for the needs of developing countries. The Australian Aid agency AusAID has promised funding to extend the latter activity to more countries in the Region. Such funding, and the activities it supports, has had a major impact on securing and making more accessible data from this climatically-critical region.

Recurrent errors may reflect faulty observing sensors, poor observational practices, inadequate site or instrument maintenance, or – in the case of AWS – problems with the messaging systems (e.g., in Australia recently there was a software glitch that in some circumstances caused old messages to overwrite recent data). Such end-to-end quality assurance should be a primary aim for NMHSs: it is a truism that the best form of quality assurance is to ensure that the original data is as close to perfect as possible.

The particular difficulties in developing countries

In the foregoing, reference was made to the problems faced by D & LDCs in both collecting and managing climate data. There are many such problems, which have been identified in various publications such as the First and Second GCOS Adequacy Reports (e.g., GCOS, 2003). Apart from severe resource constraints, staff turnover may be high; there is often little opportunity to train new staff; equipment and storage facilities may be poor or limited; stations are frequently remote and hard to access due to infrastructure limitations; communications may be poor; and meteorology frequently ranks low in the countries' Government priorities. Yet without observations from these countries, not only does it become difficult to provide the level of climate services required in-country to manage climate-related risk, it becomes difficult, if not impossible, to put together a truly global picture of the climate, its variations and its changes. It is essential that the global meteorological community address and help solve the observational and data management problems in D & LDCs.

The ET-ORSC is currently putting together a series of recommendations on how to support climate observational programs in D & LDCs, starting with the premise that to meet current and future needs there must be a certain minimum number of climate stations representing key centres, distinct climate zones, and particularly-vulnerable regions and sectors. The team will investigate what can be done to improve the observational standards through, e.g., improved and better-targeted training, and the role of AWS. It will attempt to provide suggestions on how to address some of the endemic problems outlined in the previous paragraph. Some suggestions for resource mobilization will also be made, including such things as drawing on aid and climate change funding bodies, utilizing where possible the assistance of private funding, and raising the profile of the NMHS in-country.

Concluding Remarks:

There is widespread recognition that climate change looms as perhaps the biggest single future threat to humanity and the environment. Major global efforts will be needed to ameliorate impacts, which the meteorological, and especially the climate community, will need to be instrumental in supporting. This support in turn will need to be underpinned by an observational system that is designed with the needs of the climate program in mind. The role of the CCI, and its partner NMHSs, in facilitating such a system, will be crucial.

References:

Abbott, P.F., 1986: Guidelines on the Quality Control of Surface Climatological Data”, *WMO/TD No 111*, World Meteorological Organisation, 56pp plus Appendices (18pp).

GCOS. 2003: Second Report on the Adequacy of the Global Observing System for Climate. GCOS Report No. 82 WMO-TD 1143. World Meteorological Organization, Geneva.

WCDMP, 2005: Report of the RA V Data Management Workshop, (Melbourne, Australia, 28 November- 3 December 2004) WCDMP – No 57; WMO - TD No 1263, World Meteorological Organization, Geneva (7 pp).

RECOMMENDATIONS

RECOMMENDATION 1 ([Items 3](#); Guide on the Global Observing System (WMO-No. 488))

Considering the further development of the Functional Specifications for Automatic Weather Station;

The expert team recommended that:

- (a) The CBS-XIV considers the approval of the revised Functional Specification for Automatic Weather Station ([Annex 2](#)) for the inclusion in the Guide on the Global Observing System (WMO-No.488);
- (b) The OPAG-IOS requests OPAG-ISS to develop BUFR descriptors of all variables, listed in the table "The Functional specifications for Automatic Weather Stations" ([Annex 2](#)).

RECOMMENDATION 2 ([Item 4](#), Requirements for a robust, low power, continuous communications platform for AWS)

Considering:

1. The ongoing transition from manual to automated observation;
2. The need for development of relevant guidelines for Members;
3. The need for standardization;

The expert team recommended that the Guidelines reproduced in [Annex 3](#) should be submitted at CIMO/OPAG-SURFACE ET-ST&MT for consideration and development of surface technology and measurement techniques.

RECOMMENDATION 3 ([Item 5](#), Ground-truth of space-based observation)

The session recommended that ICT-IOS submits the preliminary draft of the Requirements for AWS hosted sensors to contribute directly to the calibration and ground truth of space-based observations, reproduced in the [Annex 4](#), to ET-SAT and ET-SUP for their consideration. The further development on this issue should be subject to their recommendations.

RECOMMENDATION 4 ([Item 6](#), Requirements for new sensors or the integration of sensors to overcome the deficiencies of AWS following the migration from manual observations)

Considering:

1. The ongoing transition from manual to automated observation;
2. The need for the development of relevant guidelines for Members;
3. The need for standardization;

The expert team recommended that the Requirements for new sensors or the integration of sensors to overcome the deficiencies of AWS following the migration from manual observations, reproduced in [Annex 5](#), should be submitted at CIMO-OPAG-SURFACE ET-ST&MT for consideration and further development of surface technology and measurement techniques.

RECOMMENDATION 5 ([Item 8](#), Guidelines and procedures to assist in the transition from manual to automatic surface observing stations)

Considering:

1. The ongoing transition from manual to automated observation
2. The need for development of relevant guidelines for Members
3. The need for standardization

The expert team recommended that the Guidelines and procedures to assist in the transition from manual to automatic surface observing stations, reproduced in [Annex 7](#), should be submitted

to CIMO-OPAG-SURFACE ET-ST&MT for consideration and further development of surface technology and measurement techniques.

RECOMMENDATION 6 ([Items 10](#); AWS metadata catalogues)

Considering:

1. The development of WMO Core Profile of the Metadata Standards;
2. The development of metadata catalogues for AWS and their representation in TDCF;

The expert team recommended that:

The OPAG-IOS requests OPAG-ISS to use existing BUFR tables in the development and implementation of metadata catalogues for WIS.

RECOMMENDATION 7 ([Item 11](#), Siting classification)

Considering:

The impact of siting on the quality of data;

The difficulties in implementing of siting standards in operational practice;

The siting classification scheme already developed and used by Météo France;

The need to classify observing stations for GOS and WIGOS purposes;

ET recommended that:

The CBS and CIMO develop further the classification scheme presented in [Annex 8](#) for the inclusion in the Manual of the Global Observing System (WMO-No. 544) and Guide to Meteorological Instruments and Methods of Observations (WMO-No. 8). This classification scheme should subsequently be recognized as a joint WMO-ISO standard.

RECOMMENDATION 8 ([Item 12](#), Basic set of variables to be reported by the standard AWS for multiple users)

Considering that:

1. The Manual on the GOS prescribes the variables to be measured by the various types of weather observing stations;
2. Differences exist between the set of variables measured by synoptic, ocean weather stations, aeronautical, hydrological, agro-meteorological and climatological stations, which result in ambiguities when exchanged between disciplines;
3. The need for the standardization of observations;
4. A standard set of variables shall be measured for all these disciplines, whereas other variables should be measured as recommended by technical commissions or Regional Associations;

The expert team recommended that:

CBS-XIV considers the Basic set of variables to be reported by a standard AWS, presented in the [Annex 9](#), for inclusion in the Manual on the GOS (WMO-No. 544).

RECOMMENDATION 9 ([Items 13](#); Update of BUFR/CREX)

Considering:

The need for validation of the merged BUFR Template for Surface Observations from one hour period and for reporting SYNOP data;

The expert team recommended that:

Météo France be requested to take a lead in the validation of the BUFR Template for Surface Observations from one hour period and for reporting of SYNOP data, to implement this template and adjust it as appropriate, in collaboration with CBS and ET-DR&C and with the view of its approval by CBS-XIV.

RECOMMENDATION 10 ([Item 16.2](#), Name of ET-AWS)

Considering:

The need for an expert team within CBS to deal with the surface observing network issues;

The present ET AWS already deals with the observing network issues;

ET recommended to expand the scope of the ET-AWS to cover surface observing network issues and to rename it to “ET on Requirements and Implementation of AWS platforms”.

FUTURE WORK PLAN

1. Update AWS Functional Specifications (FS) for all WMO related Programmes
2. Develop the requirements (RQ) for a robust AWS, particularly those in remote locations.
3. Assess capabilities for AWS to contribute directly to the calibration and ground truth of space-based observations
4. Develop the requirements for new sensors or the integration of sensors to address the deficiencies of AWS following the migration from manual observations
5. Develop tools for network design and optimization
6. Develop guidelines and procedures to assist in the transition from manual to automatic surface observing stations
7. Develop requirements for new data types from AWS sensors
8. Develop AWS metadata catalogues for WIS
9. Develop guidelines for the siting classification of surface observing stations
10. Update the list of basic set of variables to be reported by a standard AWS for multiple users
11. Review BUFR descriptors related to AWS measurements according to requirements
12. Monitor advances in AWS technology

DETAILED WORK PLAN AND PROPOSAL FOR ALLOCATION OF TASKS

(For the period until CBS-Ext. (2010))

Task	Action	Responsible	Deadline	Deliverable
1. Update AWS Functional Specifications (FS) for all WMO related Programmes	Monitor the requirements for update of FS	J.P. van der Meulen	Feb 2010	Updated version of AWS FS for inclusion in the regulatory material
2. Develop the requirements (RQ) for a robust AWS, particularly those in remote locations.	Finalize the draft version of ET-AWS-5	R. Nitu	Feb 2010	Technical guidance to Members
3. Assess capabilities for AWS to contribute directly to the calibration and ground truth of space-based observations	Responding to the recommendations of relevant ETs.	K. Monnik	Feb 2010	Assessment of capabilities for CBS
4. Develop the requirements for new sensors or the integration of sensors to address the deficiencies of AWS following the migration from manual observations	Finalize the draft version of ET-AWS-5	R. Nitu	Feb 2010	Technical guidance to Members
5. Develop tools for network design and optimization	Testing of proposed tools on all RBSNs	J.P. van der Meulen	Feb 2010	Technical guidance to Members
6. Develop guidelines and procedures to assist in the transition from manual to automatic surface observing stations	Finalize the draft version of ET-AWS-5	K. Monnik	Feb 2010	Guidelines to be incorporated into the Guide on GOS
7. Develop requirements for new data types from AWS sensors	Finalize the draft version of ET-AWS-5	H. Zhou	Feb 2010	Technical guidance to Members

8. Develop AWS metadata catalogues for WIS	Prepare tables of AWS metadata for WIS based on BUFR descriptors	K. Monnik	Feb 2010	Relevant AWS metadata catalogues for WIS
9. Develop guidelines for the siting classification of surface observing stations	In coordination with CIMO and other relevant TCs, finalize the guidelines materials for Members	M. Leroy	Feb 2010	Guidelines for submission to CBS and inclusion into Guide to GOS and recognition as a joint ISO-WMO standard.
10. Update the list of basic set of variables to be reported by a standard AWS for multiple users	Monitor the requirements for updating the list	J.P. van der Meulen	Feb 2010	Technical guidance to Members
11. Review BUFR descriptors related to AWS measurements according to requirements	Review BUFR descriptors and propose new ones if needed Implement and validate BUFR template for SYNOP/AWS reporting (including new station identification)	I. Zahumensky	Feb 2010	List of BUFR descriptors related to AWS
		M. Leroy	Dec 2008	Validated templates for approval by CBS
12. Monitor advances in AWS technology	Review progress and advances in AWS technologies	M. Leroy	Feb 2010	Guidance material for Members and ET-EGOS