W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N

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COMMISSION FOR BASIC SYSTEMS

OPEN PROGRAMME AREA GROUP ON
INTEGRATED OBSERVING SYSTEMS

EXPERT TEAM ON REQUIREMENTS FOR DATA FROM
AUTOMATIC WEATHER STATIONS

GENEVA

20 - 24 March 2006

FINAL REPORT

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).

EXECUTIVE SUMMARY

The worldwide AWS network was becoming more robust and mature requiring only little adjustment to improve its overall performance. This was identified in the evolution of the GOS planning document where AWS were identified as one of the observation systems, which in some circumstances is least dependant on local infrastructure. The global AWS network provides a number of benefits to its users; 1) it provides traceable measurements of fundamental physical characteristics of the near surface atmosphere with a known uncertainty; 2) In comparison with remote sensing technology, the AWS network provides a largely homogeneous continuation of the historical climate record, and 3) the worldwide AWS network is largely self-financed by member countries and requires no disproportionate investment by a small number of nations to support sustainability of the network.

The ET-AWS continues to reach out to other programs and commissions in an effort to develop standard practices for elements common to AWS. The family of AWS includes automatic complementary systems such as Upper-air, data buoys, and meteorological instruments fixed to stationary and mobile platforms such as aircraft, oil platforms and ships and ground transportation vehicles. Through sharing of information, ideas and recommendations this disparate collection platforms can and should operate with standard operational data, metadata, and code tables and descriptors for both real time and non-real time data distribution. The various attachments to this report present the group's approach toward standardization of platforms, quality control, and metadata to name a few.

During this session of the ET-AWS, both members and invited participants had the opportunity to collaborate across commission and program lines. The group addressed each of its actions from the view of achieving standardization when possible. The group was of the opinion that irrespective of the AWS platform type; whether stationary or mobile, land, sea, or air based; through mutual agreement among the disciplines, a standardization could be achieved for operational data, metadata, code tables and descriptors to name a few. Annexes to this report contain proposals for standardization developed by the ET-AWS.

The Implementation Plan for Evolution of the GOS developed and issued by the ET-EGOS (WMO/TD No. 1267) was discussed at length by the members and invited participants. Their comments have been encapsulated within item 9 listed within the agenda of the meeting. At the request of the members and participants a detailed summary of the group's concerns and recommendations will be provided to the ET-EGOS and IOC chairmen.

1 ORGANIZATION OF THE SESSION

1.1 Opening of the meeting

1.1.1 The session of the Expert Team on Requirements for Data from Automatic Weather Stations (ET-AWS), of the Commission for Basic Systems (CBS) Open Programme Area Group on Integrated Observing Systems was opened by its Chairman, Mr. Rainer Dombrowsky, at 10h00 on Monday 20 March 2006 at WMO Headquarters in Geneva, Switzerland. The list of participants is attached in Annex 1.

1.1.2 Following the opening of the session, Prof. Hong YAN, Deputy 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) Guidelines for Automatic Weather Station (AWS) quality control procedures, (b) Standardization of AWS platforms, and (c) Standardization of metadata for AWS.

1.1.3 Dr Jack Hayes, the Director of WWW, also welcomed participants to the fourth meeting of the Expert Team on Requirements from AWS and offered the assistance of the Secretariat as appropriate.

1.2 Adoption of the agenda

1.2.1 The agenda adopted by the ET as given in Annex 2.

1.3 Working arrangements

1.3.1 The Expert Team (ET) agreed on working arrangements and adopted a tentative work plan for consideration of the various agenda items. The chairman proposed working hours as early as members felt comfortable. The meeting agreed to begin each day at 09h00 and to continue until 17h00 hours with a one-hour lunch break.

2 REPORT OF THE CHAIRMAN

2.1 The chairman reported on the presentation of the ET-AWS-3 report at the CBS/ICT/IOS-4 session conducted in September 2004. The group was informed that the proposals and recommendations presented at the ICT/IOS meeting were approved and sent forward to CBS for Commission consideration and approval. The IOS chairman presented consolidated report of the ET-AWS-3, which included all proposals and recommendations. The Commission ultimately agreed with all proposals and recommendations, but requested the OPAG on IOS to keep the implementation of these proposals and recommendation under review.

3 REPORT OF THE REPRESENTATIVE TO THE ET-DR&C

3.1 The meeting considered the report on the status of collaboration between the ET DR&C and the ET-AWS during the last intersessional period presented by Mr. Igor Zahumenský. The collaboration involved the topics of reporting both instrument (Level I) and nominal (Level II) data by AWS installations, and reporting Quality Control information in the AWS BUFR template.

3.2 The team was informed about the decision of the ET DR&C (December 2005) to leave the suggested set of new descriptors 0 08 083 (Nominal value indicator), 0 07 065 (Representative height of sensor above local ground (or deck of marine platform)) and 0 07 066 (Representative height of sensor above water surface) in the validation phase until the next meeting of ET DR&C in May 2006.

3.3 The ET appreciated the activities of ET DR&C in attempting to meet the ET-AWS requirement of reporting of both instrument and nominal values of AWS; several possible solutions for the adjustment of AWS BUFR template were being considered by the team with no solution yet.

3.4 One of several possible solutions to this problem was submitted by Mr. Dragosavac, ECMWF; chairman of the ET DR&C. The ET considered the proposal and expressed the opinion that the most suitable solution should be left to the ET DR&C. The ET stressed reporting of nominal value indicator and the representative height of the sensor were required. The descriptor 0 08 083 (nominal value indicator) will indicate that the instrument value has been adjusted with respect to one or more of the defined criteria.

3.5 The ET considered information provided by ET DR&C that the new BUFR/CREX descriptor 0 33 019 “Quality control indication of the following value” proposed by ET-AWS-3 as a Flag Table was not an appropriate solution for the following reasons:

- To avoid two nearly identical tables, and
- The proposal does not follow one of the basic BUFR principles of volume efficiency. A flag table is used when there is a real possibility of combinations of most or all of the bits.

3.6 It was agreed that the solution on how to meet the requirement expressed by ET-AWS-4 should be further developed in cooperation with the ET DR&C (see Annex 9).

4 REPORT ON THE DEVELOPMENT OF GUIDELINES FOR AWS QUALITY CONTROL PROCEDURES

4.1 Mr. Zahumenský submitted a progress report on the development of the Guidelines on QC Procedures for data from AWS as well as a new version of the Guidelines.

4.2 The ET agreed on the final version of the proposed guidelines and recommended that the Guidelines on Quality Control Procedures for Data from Automatic Weather Stations (see Annex 3) be published in the next version of the Guide on the Global Observing System (GOS), (WMO-No. 488). A draft of the Guide on the GOS will be posted on the WMO website in July 2006. The WMO Secretariat will ask Members to provide comments and suggestions with the goal of submitting it to CBS-Ext. (2006) for approval.

4.3 Keeping in mind the official WMO policy of avoiding duplication, the guidelines should be published in only one WMO publication of which the Guide on the GOS is the most appropriate.

4.4 The representative of the Commission for Climatology (CCl) informed the ET that the CCl Guidelines on the Quality Control of the surface climatological data WCP-No.85, WMO/TD-No. 111, currently under revision are consistent with the guidelines proposed by the ET.

4.5 The HMEI representative from LOGOTRONIC’s made a presentation on the Integrated Quality Management System (LIQMS) which could be used as a starting point for future developments. He stressed the following aspects of the LIQMS:

- The LIQMS uses quality tags. A *quality tag* is appended to every measured value. With the help of the *quality tag*, it can be specified for each measured value whether the measured value is fundamentally correct, or whether, during its recording, there was a situation that could have falsified the measured value. The different quality tags that deviate from the *“Measured value OK”* are represented as individual bits. The *quality tags* in priority are:

    a) C … Measured value invalid; this means that no measured value is present;
    b) D … Measured value not utilizable; this means the sensor or calculation has an error;
    c) W … Maintenance;
    d) P … Plausibility error; this means that one or more *quality tests* have delivered errors;
    e) B … Auxiliary attachment not *OK*; this means that evaluation of the formula for the auxiliary attachment has an error;
    f) Z … Time error; this means that the measured value is influenced by an adjustment of the clock-time;
    g) K … Survey value; this means that the value was assigned as a survey value by the user;
    h) A … Measured value *OK*; this means no bits are set of the byte.
- The *quality tag* of result of *quality tests* always has the worst *quality tag* of the individual measured values.
- With system tests like *check the user-ID* or *check the door-open contact* and *monitoring of the station/backup battery* the LIQMS will complete.

5 REPORT ON THE DEVELOPMENT OF STANDARDS FOR THE STANDARDIZATION OF AWS PLATFORMS

5.1 All disciplines involved with meteorological observations synoptic meteorology, climatology, aeronautical meteorology, agricultural meteorology, and hydrology have formulated their own functional requirements on observations to satisfy individual functional requirements for observations to satisfying specific service needs. All disciplines, however, have stated that it is beneficial to apply universal rules or standard methods of observation to avoid unnecessary confusion and to achieve data compatibility. In line with this policy, standardization of AWS will be beneficial if designed to fulfill the requirements of the various disciplines. A standard AWS should consist of an observing system providing observational data from a standard set of variables. Apart from this standard set, a set of optional variables may be considered. A preliminary list of standard and optional variables to be measured by AWS is provided in Annex 4. This list was compiled from the Manual on the Global Observing System (WMO-No. 544). Because the sets of required variables presented in the Manual of the GOS may not be complete, it was recommended that the ET consult with relevant technical commissions to update the list of standard and optional variables. The ET adopted **Recommendation 5.1** (see Annex 10.)

5.2 The representative of CIMO informed the ET that despite the previous recommendation, no standard reference system had been endorsed by the WMO to be used as the reference for both horizontal position of a station (given as longitude and latitude) and vertical position of a station (for mean sea level, MSL). He explained that the WMO definition of MSL required such a reference. Furthermore, he informed the meeting that ICAO had endorsed a standard referencing system, the World Global System 84, (WGS 84). It was proposed that WMO should consider endorsing the *World Global System 84* (WGS 84) as its reference datum system for horizontal positioning and the *Earth Geodetic Model 96* (EGM-96) as reference for vertical positioning. The ET adopted Recommendation 5.2 (see Annex 10).

6 REPORT ON THE DEVELOPMENT OF PRACTICAL EXAMPLES FOR A STANDARD SET OF METADATA FOR AWS

6.1 Metadata, as defined by ISO 19115, are required for various purposes, e.g. for the use of data or for the discovery of data. From this aspect, the ET agreed that in addition to the development of a keyword list, a key phrase list should also be developed.

6.2 Taking into account the development of WMO Core Profile of the Metadata Standards, the ET suggested that at least four catalogues be developed:

1) Variables measured by a standard AWS (the Functional Specifications for AWS developed by the ET could be used for this purpose);
2) Instruments used for variables measured by standard AWS (information provided by manufacturers using a standardized template would be probably the most suitable approach);
3) Data processing procedures (algorithms) used by AWS;
4) Data quality control procedures used for AWS data.

The ET adopted **Recommendation 6.2** (see Annex 10.)

6.3 The standard set of metadata for AWS was considered with respect to real time, near real time, and non real time; taking into account the significance of each entry for operational use of data.

6.4 The standard set of metadata should only include those metadata that are required to be transmitted in real time together with measured data. In this regard, the ET considered the proposal prepared by Mr. Zahumenský and agreed on the final version of the standard set of AWS metadata required for operational purposes (see Annex 5), that would be submitted to CBS-Ext. (2006) consideration. The ET recommended publishing the final version of the standard set of metadata for AWS in the revised version of the Guide on the GOS (WMO-No. 488).

6.5 The ET discussed AWS metadata requirements for near and non real time data (see Annex 6). This list of metadata may not be complete and should be submitted for further collaboration with other technical commissions.

6.6 The representative of CCI recommended that the metadata should also contain information concerning the data logger storage and processing capabilities (reflecting that lost data is of great concern to the CCI), including details of how many days data can be stored, whether AWS can be interrogated remotely, and what other data back-up arrangements are in place. The ET requested Mr. Zahumenský study this request and propose a metadata standard as appropriate.

6.7 The representative of JCOMM briefly attended the meeting during discussion related to metadata. He agreed with the ET's approach to metadata and would share the prepared documents later in the week during the Third International Training Workshop for Port Meteorological Officers and the JCOMM working group meeting to establish a pilot project to collect in real time metadata from Sea Surface Temperature and subsurface temperature profile data. Comments relating to metadata and other related topics would be provided following the workshops.

6.8 Reflecting the significance of information about QC to CCI, the representative of CCI recommended that the CBS ET IPET-MI deal with the metadata issue as regards details on the QC processes carried out at the data processing centre.

6.9 For the standard set of metadata, the data transmission format should be the same as for measured data. This means that in the case of using Table-driven Code Forms (TDCF) for transmission of AWS data it would be necessary to review TDCF and develop adequate descriptors as necessary, and adjust BUFR AWS templates accordingly. The ET adopted **Recommendation 6.5** (see Annex 10.)

7 REPORT ON THE STATUS OF THE JOINT EFFORT WITH HMEI AND CIMO IN DEFINING METADATA NEEDS FOR THE FUTURE WMO INFORMATION SYSTEM

7.1 The representative of the HMEI informed the meeting that, acting on a request from the previous meeting of this ET, the HMEI Secretariat had requested their members to respond as to whether and to what extent they, the manufacturers, were willing to make algorithms used in AWS systems available to WMO.

7.2 The HMEI representative reported to the ET that only two responses had been received from their members. These responses were provided to the ET. The lack of response was probably due to the proprietary nature of such information.

7.3 The HMEI representative invited the ET chairman to further clarify this issue.

7.4 The representative of CIMO reported to the ET that the CIMO ET on Surface Technology and Measurement Techniques had been working on the issues related to the development of siting criteria and metadata standards.

8 REPORT ON THE NEED FOR UPDATING AWS CODE AND DESCRIPTOR TABLES

8.1 The representative of EUMETNET pointed out problems that would arise in the generation of BUFR messages from some NMSs, due to the existence of several WMO BUFR templates, in particular: AWS BUFR template for one hour and SYNOP BUFR template. No guidance has been provided as to which WMO BUFR template should be used. Therefore, this could lead to difficulties and/or delays in migration to TDCF.

8.2 The representative of EUMETNET presented a proposal for a single BUFR template, blending the current AWS and SYNOP BUFR templates. This approach which seems to solve the problem (see Annex 8). The ET recommended that CBS ET on DR&C address this problem and adopted **Recommendation 8.2** (see Annex 10).

8.3 The representative of EUMETNET brought to the attention of the ET an old problem related to the limitation of the range of WMO station numbers (up to 999). Unless this problem is solved many existing AWS would not be able to disseminate data over the GTS. The expert team adopted **Recommendation 8.3** (see Annex 10).

8.4 The ET discussed possible ways to meet the requirement expressed by ET-AWS-3 to overcome the shortcomings of Code Table 0 33 020 as it relates to quality information required for AWS data. It was agreed that two new BUFR/CREX descriptors should be developed for that purpose. The ET proposed that two characteristics of data, source and quality, need to be conveyed. Source indicating whether the variable is from the instrument or estimated and the quality of the variable providing some quality identifier. See Annex 9.

8.5 It was noted that there is an ambiguity in a number of BUFR descriptors and the ET proposed that the ET DR&C ensure their traceability to International Meteorological Vocabulary, WMO-No. 182 and WMO Technical Regulations, WMO-No. 49. The expert team adopted **Recommendation 8.5** (see Annex 10).

8.6 The representative of CCI recalled the problem of missing data as significant to climate program, particularly in the case of precipitation. While information on missing data is contained within the quality control section of the BUFR message, not all NMS make use of, or can decode, BUFR. From the point of view of the climate program, it is nevertheless essential that the message format from an AWS convey explicitly the presence or absence of a precipitation reading from precipitation sensors.

9 REVIEW IMPLEMENTATION PLAN FOR EVOLUTION FOR SUB-SYSTEMS OF THE GOS AND RECOMMENDATIONS TO THE ET-EGOS

9.1 The chairman asked the working group members to review the ET-ODRRGOS document detailing the implementation plan for the Evolution of Space and Ground-Based Sub-Systems of the GOS. During the session the chairman highlighted portions of the plan that might have an impact on AWS platforms. Strong concern was expressed by ET members and invited experts over the lack of references to other Commissions such as CCl, who's representative noted the need for higher resolution data and the need for the development of new instruments fulfilling the void created by the loss of some hydrometeorological parameters during the transition from manual to automated observations. In general the ET membership did not feel that the document met their expectations for the evolution of the GOS.

9.2 Concerns and Recommendations expressed by ET-AWS:

a. The plan had numerous actions but a number of actions lacked an implementation schedule or targeted dates for completion. In some cases implementation dates were left very ambiguous as to completion by using descriptors such as, "*as soon as possible*".

b. The plan lacked a defined action tracking and reporting process and one should have been presented as part of the plan;

c. The plan referenced only a small segment of the programs and Commissions who would be impacted by the implementation of the plan;

d. The plan does not mention the need and how the issue of measurement traceability to SI would be addressed, currently some measurements are not traceable;

e. The plan does not address the need to integrate operational data from different sub-systems as is required under the vision established by the GEOSS;

f. The plan does not address the need for sensor/system integration to satisfy observational requirements currently not met by AWS;

g. The plan should provide clear statements as to the importance of observations needing to be representative;

h. The document would benefit by describing the existing benefits of AWS and how they would be leveraged as part of the evolution process;

i. Considering the recommendation in section 2.3 on the evolution of the GOS concerning the surface-based sub-system of the GOS that there be more complete and timely data distribution, the ET-AWS proposes that the spaced-based sub-system actively work towards providing a robust, low-power, continuous (i.e. broadband) communications platform for all AWS, particularly those in remote locations.

j. Considering the statement under Calibration, S1, paragraph 3.1 that a major issue for the effective use of satellite data is calibration, the ET-AWS suggests that the space-based sub-system consider sensors which could be included as part of an AWS observation which could directly contribute to the calibration and ground-truth of satellite observations. Possible examples include:

   j.1. Surface temperature (using infra-red thermometers aimed at a representative natural surface);

   j.2. Near surface soil moisture;

   j.3. Albedo of the representative natural surface; and

   j.4. Surface fluxes of latent heat, sensible heat, CO_2 etc

k. The benefits of the existing AWS network needs to be emphasised. These are:

   k.1. The AWS network is robust and mature and requires only little adjustment to improve its performance.

   k.2. The AWS network provides traceable measurements of fundamental physical characteristics of the near surface atmosphere with a known uncertainty;

   k.3. In comparison with remote sensing technology, the AWS network provides a largely homogeneous continuation of the historical climate record, and

   k.4. The worldwide AWS network is largely self-financed by member countries and requires no disproportionate investment by a small number of nations to support sustainability of the network.

10 OTHER BUSINESS

10.1 Climate Requirements for AWS

10.1.1 The representative of CCI presented a report summarizing the climate program's experiences with AWS in Australia, but also encapsulates results from a qualitative CCI survey of experiences in several other developed countries, as presented at the *3 International Conference on Experiences with AWS,* Torremolinos, Spain, 2003. It also very briefly reported on experiences with, and future requirements concerning, AWS in the Southwest Pacific, which probably has wider applicability among developing countries.

10.1.2 The background against which this assessment is made stems from several fundamental requirements for climate data as they pertain to AWS implementation. These include, *inter alia*: maintaining continuity (i.e., reducing missing data); managing network change so that non-climate inhomogeneities are minimized (or at least understood); recording and managing metadata; identifying climate requirements at the outset; and ensuring changes are backed up by adequate data management systems (e.g., appropriate quality control).

10.1.3 The benefits and potential benefits of AWS to the climate program include: higher frequency data and better definition of extremes; their ability to be deployed in remote locations; general cost-effectiveness; use of AWS data in QC processes (e.g., in helping disaggregate rainfall accumulations); faster access to data; and consistency in measurement. On the other hand, past experience has indicated a number of negatives for the climate program, including: loss of visual observations; damage to continuity due to data losses; introduction of inhomogeneities in some cases (partly due to inadequate change management, partly due poor maintenance); generation of artificial data spikes; and inadequate accuracy, especially of rainfall.

10.1.4 The implications of these negatives is that, to date, the data have been generally unsuitable for climate change analysis; the ability to compile climatology of visual parameters such as cloudiness and phenomena is being reduced; and potential impacts on services provided by the climate program. In the latter case, the example was provided of how drought relief payments were allocated in Australia (which use rainfall analyses over specified periods as one of their key assessment criteria), can be adversely affected by under-representations of rainfall averaging. Limited investigations have indicated errors as much as 15% per annum, a magnitude unacceptable for climate work.

10.1.5 Many of the negative impacts are being reduced by improvements in AWS technology such as better data back-up, improved processing software, etc. A summary of the climate requirements for future AWS provided by the climate program in Australia includes: at least 99% data completeness; visual observation sensors (including cloud sensors, visibility meters, lightning detectors, etc); alert systems for failures; possibly redundant sensors (to further minimize data loss); high precision measurements (meeting the WMO requirements for uncertainty of at least 0.1 ^{0}C for instantaneous observations); regular inspections and maintenance; sound and extensive metadata processes; network planning (especially for rainfall) that includes the interspersing of manual and AWS to act as a mutual check. With regard to the planning of climate requirements from the outset, the US program of Climate Reference Stations is cited as a good example.

10.1.6 In SW Pacific countries AWS usage is not widespread, and currently problematic, for a number of reasons including: lack of funding, lack of expertise/training in maintenance, poor telecommunications infrastructure and vandalism. Overall, there is interest in pursuing AWS for climate monitoring, and a recent meeting of the RA V Working Group on climate matters (Singapore, Feb 2006) recommended with respect to AWS that: WMO (through CIMO) prepare and disseminate guidelines on technical specifications for AWS; the CCI OPAG involved with AWS keep RA V Members informed of developments; and that WMO publish as soon as possible results of AWS vs manual comparisons and its cost vs benefit analysis (refers to the presentation "AWS – costs vs benefits: A Climate viewpoint" (see: http//www.wmo.int/web/www/OSY/Expert-Teams/gos-et-aws-info.html).

10.1.7 There are areas that require improvements for meeting climate monitoring requirements. However this will require considerable expenditure per unit on higher precision sensors, and a greater array of sensors than would be the case for normal AWS, with likely higher maintenance costs. This poses challenges for cost-effective network planning.

10.2 Report on Assessment of Cost/Benefits of AWS for Climate

10.2.1 The representative of CCI presented an overview of the factors to be considered in implementing AWS from the point of view of the climate program, drawing mainly on material from two recent WMO reports (by Lynch and Allsopp; by Street, Allsopp and Durocher), (see: http//www.wmo.int/web/www/OSY/Expert-Teams/gos-et-aws-info.html). The latter mainly describes procedures for effective change management, which is an important step when changing from manual to automated observing systems, but one that has associated extra cost.

10.2.2 In general, AWS are more cost-effective in developed countries, where labor costs are higher and maintenance infrastructure is more readily accessible, than in developing countries. However even in developed countries there are significant extra costs associated with the provision of certain parameters required by the climate program, e.g., visual observations sensor, increased robustness, and change management activities.

10.2.3 One option is to provide the specific requirements needed by the climate program for just a subset of the total AWS network, but other solutions are possible, and should be considered in the context of an integrated observation program at each NMS. In developing countries, it is more a question of whether the countries, even with the assistance of external funding, can afford the implementation costs, along with the relatively high ongoing costs associated with maintenance, communications and security.

10.2.4 An important part of ensuring that serious inhomogeneities do not occur during the transition from manned to automatic systems is the establishment of an effective change management process. The example of the procedures for Change Management used by the Canadian Meteorological Service was provided. Parallel observations are an important part of the process – for at least one year, and preferably longer to ensure a full range of conditions is encountered during the overlap period, and for the development of robust transfer functions. The

Australian example of overlapping AWS-manned stations was provided, with the extra costs to run the parallel program shown to be insignificant in terms of the overall Budget for the observations program, and a very good investment, especially given the importance of the climate program.

10.3 Functional Specifications for AWS

10.3.1 The expert team corrected the table of the Functional specification for AWS installations, namely concerning the maximum effective range and respective BUFR /CREX table for the water vapour pressure. (See Annex 7).

10.4 Marine Requirements for AWS

10.4.1 The representative from JCOMM, Mr. Etienne Charpentier, was available to participate for only a short time due the upcoming the Third International Training Workshop for Port Meteorological Officers (PMOs), March 22-23 followed by a workshop establishing a pilot project to collect in real time metadata from Sea Surface Temperature and subsurface temperature profile data, March 28-29.

10.4.2 During his participation Mr. Charpentier provided an overview of JCOMM activities related to AWS and acknowledged the need for further collaboration between our working groups. He briefly spoke to the issues related to the upcoming workshop sharing JCOMM views and approaches to addressing observational network needs and the need for metadata organization. He stated the marine community is dealing with many of the similar issues, as is the land element of the AWS community. The issue of metadata for the marine community has a number of implications because of the observational systems, data telecommunication systems, and data processing systems in place are varied and not necessarily homogeneous. In addition platform operators in charge of such in situ marine observing systems often come from different communities with different perspectives and priorities. Mr. Charpentier indicated that the JCOMM working group was of the opinion that a list of metadata can easily become extensive and the collection of required metadata not practical. Therefore, the working group has developed a list of metadata for real time distribution. Based on this information the ET-AWS chairman asked that Mr Charpentier share the AWS metadata template with his working group.

10.4.3 The chairman asked Mr. Charpentier to share the proposals and recommendations from the ET-AWS-3 report and the adjustments made to these proposals accomplished early in the ET-AWS-4 session with his two workshops. The chairman also requested he provide a summary of their review, for inclusion into the final report of the ET-AWS- session 4 within one week following his two workshops. The chairman will follow up with Mr. Charpentier to capture PMO and Pilot Program Workshop on SST and subsurface temperature profile data comments.

10.5 Further development of the ET's website

10.5.1 The ET was advised about a new component on the WWW website that provides information on the Expert Teams of the OPAG on Integrated Observing Systems. This site consolidates all of the relevant information for each expert team into one easily accessible site. The site also includes various links such as the one to Core Members of the Expert Team, the Terms of Reference, links to previous reports of the team, and the action items to be worked on by the team, as well as much additional items of relevance to the team.

10.5.2 The ET was invited to provide the Secretariat with additional items that could be included on the ET-AWS section of the site. The Secretariat also advised that it would maintain the site with new information as it becomes available, thus providing a single site for members of the ET to locate all the information relevant to the work of the team.

10.5.3 The ET considered a proposal by the representative of CCI requesting that documents of interest to the members be hyperlinked via the ET's website. Dr. Wright provided the following climate documents for consideration:

- *Guidelines for managing changes in climate observation programs* (by Street, Allsopp and Durocher).
- *Automated versus manual surface meteorological observations – decision factors*. (by Lynch and Allsopp).
- WMO TD No 1186: *Guidelines on climate metadata and homogenization*, Paul Llanso (Ed).

- WMO TD No 111: *Guidelines on Quality control procedures for surface climate data*. Document under revision, to be made available when completed.

11 RECOMMENDATIONS TO BE SUBMITTED TO CBS-Ext. (2006)

During the course of this meeting, the ET-AWS formulated 7 recommendations for consideration by CBS-Ext. (2006). These recommendations are presented in Annex 10.

11.1 FUTURE WORK PLAN

Refer to Annex 11

11.2 CLOSURE OF THE SESSION

The meeting was closed at 15:00 hours on 24 March 2006.

Expert Team on Requirements for Data from Automatic Weather Stations (ET-AWS-4)
Geneva, 20-24 March 2006

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AGENDA

1. ORGANIZATION OF THE SESSION

   1.1 Opening of the session
   1.2 Adoption of the agenda
   1.3 Working arrangements for the session

2. REPORT OF THE CHAIRMAN

3. REPORT OF THE REPRESENTATIVE TO THE ET-DR&C

4. REPORT ON THE DEVELOPMENT OF GUIDELINES FOR AWS QUALITY CONTROL PROCEDURES

5. REPORT ON THE DEVELOPMENT OF STANDARDS FOR THE STANDARDIZATION OF AWS PLATFORMS

6. REPORT ON THE DEVELOPMENT OF PRACTICAL EXAMPLES FOR A STANDARD SET OF METADATA FOR AWS

7. REPORT ON THE STATUS OF THE JOINT EFFORT WITH HMEI AND CIMO IN DEFINING METADATA NEEDS FOR THE FUTURE WMO INFORMATION SYSTEM

8. REPORT ON THE NEED FOR UPDATING AWS CODE AND DESCRIPTOR TABLES

9. REVIEW IMPLEMENTATION PLAN FOR EVOLUTION FOR SUB-SYSTEMS OF THE GOS AND RECOMMENDATIONS TO THE ET-EGOS

10. OTHER BUSINESS

    10.1 Climate Requirements for AWS
    10.2 Report on Assessment of Cost/Benefits of AWS for Climate
    10.3 Functional Specification for AWS
    10.4 Marine Requirements for AWS
    10.5 Further development of the ET’s website

11. RECOMMENDATIONS TO BE SUBMITTED TO CBS-Ext. (2006)

12. FUTURE WORK PLAN

13. CLOSURE OF THE SESSION

Guidelines on Quality Control Procedures for Data from Automatic Weather Stations

INTRODUCTION

Quality control (QC) of data is the best-known component of the quality management system. It consists of the examination of data at stations and at data centres for errors. Data quality control has to be applied as real time QC performed at the Automatic Weather Station (AWS) and at Data Processing Centre (DPC). In addition, it has to be performed as near real time and non real time quality control at DPCs.

There are two levels of the ***real time*** quality control of AWS data:

- ***QC of raw data (signal measurements)***. It is basic QC, performed at an AWS site. This level of QC is relevant during acquisition of Level I data and should eliminate errors produced by technical devices, including sensors, measurement errors, systematic or random, and errors inherent in measurement procedures and methods. QC at this stage includes a gross error check, basic time checks, and basic internal consistency checks. Application of these procedures is extremely important because some errors introduced during the measuring process cannot be eliminated later.
- ***QC of processed data***: is extended QC, partially performed at an AWS site, but mainly at a Data Processing Centre. This QC level is relevant during the reduction and conversion of Level I data into Level II data and Level II data themselves. It deals with comprehensive checking of temporal and internal consistency, evaluation of biases and long-term drifts of sensors and modules, malfunction of sensors, etc.

The schema of quality control levels can be as follows:

Basic Quality Control Procedures (AWS)*:*

I. Automatic QC of raw data

a) Plausible value check (the gross error check on measured values)

b) Check on a plausible rate of change (the time consistency check on measured values)

II. Automatic QC of processed data

a) Plausible value check

b) Time consistency check:

- Check on a maximum allowed variability of an instantaneous value (a step test)
- Check on a minimum required variability of instantaneous values (a persistence test)
- Calculation of a standard deviation

c) Internal consistency check

d) Technical monitoring of all crucial parts of AWS

Extended Quality Control Procedures *(DPC)*:

a) Plausible value check

b) Time consistency check:

- Check on a maximum allowed variability of an instantaneous value (a step test)
- Check on a minimum required variability of instantaneous values (a persistence test)
- Calculation of a standard deviation

c) Internal consistency check

In the process of applying QC procedures to AWS data, the data are validated and flagged, and if necessary, estimated or corrected. If original value is changed as a result of QC practices it is strongly advised that it should be preserved with the new value. A quality control system should include procedures for returning to the source of data (original data) to verify them and to prevent recurrence of the errors, including by enabling information on errors, especially systematic errors, to be conveyed back to the managers of the observation network”

. All possibilities for automatic monitoring of error sources should be used to recognize errors in advance before they affect the measured values.

The quality of data should be known at any point of the validation process and the QC flag can be changed through the process as more information becomes available.

Comprehensive documentation on QC procedures applied, including the specification of basic data processing procedures for a calculation of instantaneous (i.e. one minute) data and sums should be a part of AWS' standard documentation.

The guidelines deal only with QC of data from a single AWS, therefore spatial QC is beyond the scope of the document. The same is also true in case of checks against analyzed or predicted fields. Furthermore, QC of formatting, transmission and decoding errors is beyond the scope of the document due to a specific character of these processes, as they are dependent on the type of a message used and a way of its transmission.

Notes:

Recommendations provided in guidelines have to be used in conjunction with the relevant WMO documentation dealing with data QC:

(1) Basic characteristics of the quality control and general principles to be followed within the framework of the GOS are very briefly described in the Manual of GOS, WMO-No. 544. QC levels, aspects, stages and methods are described in the Guide on GOS, WMO-No. 488.

(2) Basic steps of QC of AWS data are given in the Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, especially in Part II, Chapter 1.

(3) Details of QC procedures and methods that have to be applied to meteorological data intended for international exchange are described in Guide on GDPS, WMO-No. 305, Chapter 6.

(4) *GDPS minimum standards for QC of data are defined in the Manual on GDPS, WMO-No. 485, Vol. I).*

(5) "*Guidelines on the Quality Control of Surface Climatological Data*" Document in preparation, update of WMO/TD – No 111, WCP 85 (Abbott, 1986).

CHAPTER I DEFINITIONS AND ABBREVIATIONS

Quality control, quality assurance

Quality control: The operational techniques and activities that are used to fulfill requirements for quality.

The primary purpose of quality control of observational data is missing data detection, error detection and possible error corrections in order to ensure the highest possible reasonable standard of accuracy for the optimum use of these data by all possible users.

To ensure this purpose (the quality of AWS data), a well-designed quality control system is vital. Effort shall be made to correct all erroneous data and validate suspicious data detected by QC procedures. The quality of AWS data shall be known.

Quality assurance: All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfill requirements for quality. The primary objective of the quality assurance system is to ensure that data are consistent, meet the data quality objectives and are supported by comprehensive description of methodology.

Note: *Quality assurance and quality control are two terms that have many interpretations because of the multiple definitions for the words "assurance" and "control."*

There are several types of errors that can occur in case of measured data and shall to be detected by implemented quality control procedures. They are as follows:

Random errors are distributed more or less symmetrically around zero and do not depend on the measured value. Random errors sometimes result in overestimation and sometimes in underestimation of the actual value. On average, the errors cancel each other out.

Systematic errors on the other hand, are distributed asymmetrically around zero. On average these errors tend to bias the measured value either above or below the actual value. One reason of systematic errors is a long-term drift of sensors.

Large (rough) errors are caused by malfunctioning of measurement devices or by mistakes made during data processing; errors are easily detected by checks.

Micrometeorological (representativeness) errors are the result of small-scale perturbations or weather systems affecting a weather observation. These systems are not completely observable by the observing system due to the temporal or spatial resolution of the observing system. Nevertheless when such a phenomenon occurs during a routine observation, the results may look strange compared to surrounding observations taking place at the same time.

Abbreviations

AWS	Automatic Weather Station
B-QC	Basic Quality Control
BUFR	Binary Universal Form of the Representation
DPC	Data Processing Centre
E-QC	Extended Quality Control
GDPS	Global Data-Processing System
QA	Quality assurance
QC	Quality control

CHAPTER II BASIC QUALITY CONTROL PROCEDURES

Automatic data validity checking (basic quality control procedures) shall be applied at an AWS to monitor the quality of sensors' data prior to their use in computation of weather parameter values. This basic QC is designed to remove erroneous sensor information while retaining valid sensor data. In modern automatic data acquisition systems, the high sampling rate of measurements and the possible generation of noise necessitate checking of data at the level of samples as well as at the level of instantaneous data (generally one-minute data). B-QC procedures shall be applied (performed) at each stage of the conversion of raw sensor outputs into meteorological parameters. The range of B-QC strongly depends on the capacity of AWS' processing unit. The outputs of B-QC would be included inside every AWS message.

The types of B-QC procedures are as follows:

- ***Automatic QC of raw data (sensor samples)*** intended primarily to indicate any sensor malfunction, instability, interference in order to reduce potential corruption of processed data; the values that fail this QC level are not used in further data processing.
- ***Automatic QC of processed data*** intended to identify erroneous or anomalous data. The range of this control depends on the sensors used.

All AWS data should be flagged using appropriate Quality Control flags. QC flags are used as qualitative indicators representing the level of confidence in the data. At the B-QC level, a simple flagging scheme of five data QC categories is enough. The QC flags are as follows:

- good (accurate; data with errors less than or equal to a specified value);
- inconsistent (one or more parameters are inconsistent; the relationship between different elements does not satisfy defined criteria);
- doubtful (suspect);
- erroneous (wrong; data with errors exceeding a specified value);
- missing data (for any reason).

It is essential that data quality is known and demonstrable; data must pass all checks in the framework of B-QC. In case of inconsistent, doubtful and erroneous data, additional information should be transmitted; in case of missing data the reason of missing should be transmitted. In case of BUFR messages for AWS data, BUFR descriptor 0 33 005 (Quality Information AWS data) and 0 33 020 (Quality control indication of following value*)* can be used.

I. Automatic QC of raw data

a) Plausible value check (the gross error check on measured values)

The aim of the check is to verify if the values are within the acceptable range limits. Each sample shall be examined if its value lies within the measurement range of a pertinent sensor. If the value fails the check it is rejected and not used in further computation of a relevant parameter.

b) Check on a plausible rate of change (the time consistency check on measured values)

The aim of the check is to verify the rate of change (unrealistic jumps in values). The check is best applicable to data of high temporal resolution (a high sampling rate) as the correlation between the adjacent samples increases with the sampling rate.

After each signal measurement the current sample shall be compared to the preceding one. If the difference of these two samples is more than the specified limit then the current sample is identified as suspect and not used for the computation of an average. However, it is still used for checking the temporal consistency of samples. It means that the new sample is still checked with the suspect one. The result of this procedure is that in case of large noise, one or two successive samples are not used for the computation of the average. In case of sampling frequency five - ten samples per minute (the sampling intervals 6 - 12 seconds), the limits of time variance of the successive samples (the absolute value of the difference) implemented at AWS can be as follows:

- Air temperature: 2 °C;
- Dew-point temperature: 2 °C;
- Ground (surface) and soil temperature: 2 °C;
- Relative humidity: 5 %;
- Atmospheric pressure: 0.3 hPa;
- Wind speed: 20 ms^{-1};
- Solar radiation (irradiance) : 800 Wm^{-2}.

There should be at least 66% (2/3) of the samples available to compute an instantaneous (one-minute) value; in case of the wind direction and speed at least 75 % of the samples to compute a 2- or 10-minute average. If less than 66% of the samples are available in one minute, the current value fails the QC criterion and is not used in further computation of a relevant parameter; the value should be ***flagged as missing***.

II. Automatic QC of processed data

a) Plausible value check

The aim of the check is to verify if the values of instantaneous data (one-minute average or sum; in case of wind 2- and 10-minute averages) are within acceptable range limits. Limits of different meteorological parameters depend on the climatic conditions of AWS' site and on a season. At this stage of QC they can be independent of them and they can be set as broad and general. Possible fixed-limit values implemented at an AWS can be as follows:

- Air temperature: -90 °C – +70 °C;
- Dew point temperature: -80 °C – 50 °C;
- Ground (surface) temperature: -80 °C – +80 °C;
- Soil temperature: -50 °C – +50 °C;
- Relative humidity: 0 – 100 %;
- Atmospheric pressure at the station level: 500 – 1100 hPa;
- Wind direction: 0 – 360 degrees;
- Wind speed: 0 – 75 ms^{-1} (2-minute, 10-minute average);
- Wind gust: 0 – 150 ms^{-1}
- Solar radiation (irradiance): 0 – 1600 Wm^{-2};
- Precipitation amount (1 minute interval): 0 – 40 mm.

Note: *There is a possibility to adjust the fixed-limit values listed above to reflect climatic conditions of the region more precisely, if necessary.* If outside the acceptable limit it should be ***flagged as erroneous***.

b) Time consistency check

The aim of the check is to verify the rate of change of instantaneous data (detection of unrealistic spikes or jumps in values or dead band caused by blocked sensors).

- ***Check on a maximum allowed variability of an instantaneous value*** *(a step test)*: if the current instantaneous value differs from the prior one by more than a specific limit *(step)*, then the current instantaneous value fails the check and it should be ***flagged as doubtful*** (suspect). Possible limits of a maximum variability (the absolute value of the difference between the successive values) can be as follows:

Parameter	***Limit for suspect***	***Limit for erroneous***
Air temperature:	3 °C	
Dew point temperature:	2 - 3°C; 4 - 5°C [1]	4°C
Ground (surface) temperature:	5 °C	10°C
Soil temperature 5 cm:	0.5°C	1°C
Soil temperature 10 cm:	0.5°C	1°C
Soil temperature 20 cm:	0.5°C	1°C
Soil temperature 50 cm:	0.3°C	0.5°C
Soil temperature 100 cm:	0.1°C	0.2°C
Relative humidity:	10 %	15%
Atmospheric pressure:	0.5 hPa	2 hPa
Wind speed (2-minute average)	10 ms^{-1}	20 ms^{-1}
Solar radiation (irradiance):	800 Wm^{-2}	1000 Wm^{-2}

In case of extreme meteorological conditions, an unusual variability of the parameter(s) may occur. In such circumstances, data may be flagged as suspect, though being correct. They are not rejected and

[1] If dew point temperature is directly measured by a sensor, the lower limit is to be used. If dew point is calculated from measurements of air temperature and relative humidity, a larger limit is recommended (taking into account the influence of the screen protecting the thermometer and hygrometer). A screen usually has different 'system response time' for air temperature and water vapour, and the combination of these two parameters may generate fast variations of dew point temperature, which are not representative of a sensor default, but are representative of the influence of the screen during fast variations of air temperature and relative humidity.

are further validated during extended quality control implemented at Data Processing Centre whether they are good or wrong.

- ***Check on a minimum required variability of instantaneous values*** during a certain period *(a persistence test),* once the measurement of the parameter has been done for at least 60 minutes. If the one-minute values do not vary over the past at least 60 minutes by more than the specified limit *(a threshold value)* then the current one-minute value fails the check. Possible limits of minimum required variability can be as follows:
  - Air temperature: 0.1°C over the past 60 minutes;
  - Dew point temperature: 0.1°C over the past 60 minutes;
  - Ground (surface) temperature: 0.1°C over the past 60 minutes[2];
  - Soil temperature may be very stable, so there is no minimum required variability.
  - Relative humidity: 1% over the past 60 minutes[3];
  - Atmospheric pressure: 0.1 hPa over the past 60 minutes;
  - Wind direction: 10 degrees over the past 60 minutes[4];
  - Wind speed: 0.5 ms^{-1} over the past 60 minutes[5].

If the value fails the time consistency checks it should be ***flagged as doubtful*** (suspect).

A calculation of ***a standard deviation*** of basic variables such as temperature, pressure, humidity, wind at least for the last one-hour period is highly recommended. If the standard deviation of the parameter is below an acceptable minimum, all data from the period should be ***flagged as suspect***. In combination with the persistence test, the standard deviation is a very good tool for detection of a blocked sensor as well as a long-term sensor drift.

c) Internal consistency check

The basic algorithms used for checking internal consistency of data are based on the relation between two parameters (the following conditions shall be true):

- dew point temperature ≤ air temperature;
- wind speed = 00 and wind direction = 00;
- wind speed ≠ 00 and wind direction ≠ 00;
- wind gust (speed) ≥ wind speed;
- both elements are suspect***** if total cloud cover = 0 and amount of precipitation > 0[6];
- both elements are suspect***** if total cloud cover = 0 and precipitation duration > 0[7];
- both elements are suspect***** if total cloud cover = 100% and sunshine duration > 0;
- both elements are suspect***** if sunshine duration > 0 and solar radiation = 0;
- both elements are suspect***** if solar radiation > 500 Wm^{-2} and sunshine duration = 0;
- both elements are suspect***** if amount of precipitation > 0 and precipitation duration = 0;
- both elements are suspect***** if precipitation duration > 0 and weather phenomenon is different from type of precipitation;

  (*****: possibly used only for data from a period not longer than 10-15 minutes).

If the value fails the internal consistency checks it should be ***flagged as inconsistent***.

A technical monitoring of all crucial parts of AWS including all sensors is an inseparable part of the QA system. It provides information on quality of data through the technical status of the instrument and information on the internal measurement status. Corresponding information should be exchanged together with measured data; in case of BUFR messages for AWS data it can be done by using BUFR descriptor 0 33 006 – Internal measurement status (AWS).

CHAPTER III EXTENDED QUALITY CONTROL PROCEDURES

Extended Quality Control procedures should be applied at the national Data Processing Centre to check and validate the integrity of data, i.e. completeness of data, correctness of data and consistency of data.

[2] For ground temperature outside the interval [-0.2 °C +0.2 °C]. Melting snow can generate isothermy, during which the limit should be 0 °C (to take into account the measurement uncertainty).
[3] For relative humidity < 95% (to take into account the measurement uncertainty).
[4] For 10-minute average wind speed during the period > 0.1 ms^{-1}.
[5] For 10-minute average wind speed during the period > 0.1 ms^{-1}.
[6] Or greater than the minimum resolution of the rain gauge, to take into account the deposition of water by dew, etc.
[7]with the exception of snow pellets, which can occur with cloud cover = 0

The checks that had already been performed at the AWS site have to be repeated at DPC but in more elaborate sophisticated form. This should include comprehensive checks against physical and climatological limits, time consistency checks for a longer measurement period, checks on logical relations among a number of variables (internal consistency of data), statistical methods to analyze data, etc.

Suggested limit values, gross-error limit checks for surface wind speed, air temperature, dew point temperature, and station pressure are presented in the Guide on GDPS, WMO-No. 305, Chapter 6, Quality Control Procedures. The limits can be adjusted on the basis of improved climatological statistics and experience. Besides that, the Guide on GDPS also presents internal consistency checks for surface data, where different parameters in a SYNOP report are checked against each other. In case of another type of report for AWS data, such a BUFR, the relevant checking algorithms have to be redefined; in case of BUFR corresponding BUFR descriptors and code/flag tables.

Internal consistency checks of data

An internal consistency check on data can cause that corresponding values are flagged as inconsistent, doubtful or erroneous when only one of them is really suspect or wrong. Therefore further checking by other means should be performed so that only the suspect / wrong value is correspondingly flagged and the other value is flagged as good.

In comparison with B-QC performed at AWS more QC categories should be used, e.g.:

- data verified (at B-QC: data flagged as suspect, wrong or inconsistent; at E-QC validated as good using other checking procedures);
- data corrected (at B-QC: data flagged as wrong or suspect data; at E-QC corrected using appropriate procedures).

The different parameters in the AWS N-minute data report (N ≤ 10-15 minutes) are checked against each other. In the description below, the suggested checking algorithms have been divided into areas where the physical parameters are closely connected. The symbolic names of parameters with the corresponding BUFR descriptors used in the algorithms are explained in the table below.

(a) Wind direction and wind speed

The wind information is considered to be erroneous in the following cases:

- wind direction without any change and wind speed ≠ 0;
- wind direction is changing and wind speed = 0;
- wind gust (speed) ≤ wind speed;

(b) Air temperature and dew point temperature

The temperature information is considered to be erroneous in the following case:

- dew point temperature > air temperature;
- air temperature - dew point temperature > 5°C and obscuration is from {1, 2, 3} (BUFR descriptor 0 20 025);

(c) Air temperature and present weather

Both elements are considered suspect when:

- air temperature > +5°*C* and type of precipitation is from {6, …, 12};
- air temperature < -2°*C* and type of precipitation is from {2};
- air temperature > +3°*C* and type of precipitation is from {3};
- air temperature < -10°*C* and type of precipitation is from {3};
- air temperature > +3°*C* and obscuration is from {2} or (obscuration is from {1} and character of obscuration is from {4}) (BUFR descriptors 0 20 021, 0 20 025, 0 20 026);

***(d)* Visibility and present weather**

The values for visibility and weather are considered suspect when:

- obscuration is from {1, 2, 3} and visibility > 1 000 m;
- obscuration is from {7, 8, 9, 11, 12, 13} and visibility > 10 000 m;
- visibility < 1 000 m and obscuration is not from {1, 2, 3, 8, 9, 10, 11, 12, 13} and type of precipitation is not from {1, … , 14};
- obscuration = 7 and visibility < 1 000 m;
- visibility > 10 000 m and type of precipitation is missing and obscuration is missing and weather phenomenon is missing

(BUFR descriptors 0 20 021, 0 20 023, 0 20 025, 0 20 026);

***(e)* Present weather and cloud information**

Clouds and weather are considered suspect when:

- total cloud cover = 0 and type of precipitation is from {1, …, 11, 13, 14} or weather phenomenon is from {2, 5, … , 10}

(BUFR descriptors 0 20 021, 0 20 023);

(f) Present weather and duration of precipitation

Present weather and duration of precipitation are considered suspect when:

- type of precipitation is from {1, … , 10, 13, 14} and precipitation duration = 0;
- type of precipitation is not from {1, … , 10, 13, 14} and precipitation duration > 0

(BUFR descriptor 0 20 021);

(g) Cloud information and precipitation information

Clouds and precipitation are considered suspect when:

- total cloud cover = 0 and amount of precipitation > 0[8];

(h) Cloud information and duration of precipitation

Clouds and duration of precipitation are considered suspect when:

- total cloud cover = 0 and precipitation duration > 0;

(i) Duration of precipitation and other precipitation information

Precipitation data are considered suspect when:

- amount of precipitation > 0 and precipitation duration = 0;

(j) Cloud information and sunshine duration

Clouds and sunshine duration are considered suspect when:

- total cloud cover = 100% and sunshine duration > 0;

For each check, if the checked values fail the internal consistency check, they should be ***flagged as erroneous or suspect*** (depending on the type of the check) and inconsistent. Further checking by other means should be performed so that only the suspect / wrong value is correspondingly flagged and the other value is flagged as good.

The symbolic name and the corresponding BUFR descriptor (as reference) used in QC algorithms (a) – (j) are as follows:

Symbolic name	BUFR Descriptor
Wind direction	0 11 001
Wind speed	0 11 002
Wind gust (speed)	0 11 041
Air temperature	0 12 101
Dew point temperature	0 12 103
Total cloud cover	0 20 010
Visibility	0 20 001
Type of precipitation	0 20 021
Precipitation character	0 20 022
Precipitation duration	0 26 020
Weather phenomenon	0 20 023
Obscuration	0 20 025
Character of Obscuration	0 20 026

For further treatment of data it is necessary to keep the results of the E-QC data quality control together with the information on how suspect or wrong data were treated (using sophisticated system of flags).

[8] Or greater than the minimum resolution of the rain gauge, to take into account the deposition of water by dew, etc.

The output of the quality control system should include QC flags that indicate whether the measurement passed or failed, as well as a set of summary statements about the sensors.

Every effort has to be made to fill data gaps, correct all erroneous values and validate doubtful data detected by QC procedures at the Data Processing Centre choosing appropriate procedures.

As real time quality control procedures have their limitations and some errors can go undetected, such as sensor drift or bias, as well as errors in data transmission, performance monitoring at the network level is required at meteorological data processing centers and by network managers.

Effective real time QC monitoring as an integral part of a QC system has to include checks of the following items:

- ✓ Completeness of observations at the meteorological station;
- ✓ Quality of data;
- ✓ Completeness and timeliness of the collection of observational data at the centre concerned.

QC monitoring is intended to identify deficiencies and errors, monitor them and activate appropriate remedial procedures. Some assessment can be and should be performed in real time, whereas other evaluations can only be accomplished after gathering of sufficient data over a longer period.

QC monitoring requires the preparation of summaries and various statistics. Therefore, it is necessary to built up a QC Monitoring System which has to collect different statistics on observational errors of individual meteorological variables, through a series of flags indicating the results of each check, and generate hourly, daily, weekly, monthly and yearly summaries of:

- The total number of observations scheduled and available for each variable (completeness of data);
- The total number of observations which failed the QC checks for each variable (quality of data) in case of:
    - Plausible value check,
    - Time consistency check,
    - Check on a maximum allowed variability of an instantaneous value,
    - Check on a minimum required variability of instantaneous values,
    - Internal consistency check;
- The percentage of failed observations (quality of data);
- The error and threshold values for each failed observation (reason of failure);
- Root mean square (RMS) error / mean error / percentage failure for failed observations for each station (daily/weekly/monthly/yearly) (quality statistics).

Stations with large percentages of failed observations are probably experiencing hardware or software failures or inappropriate maintenance. These should be referred back to the network manager.

The QC Monitoring System must maintain station statistics on the frequency and magnitude of observation errors encountered at each station. The statistics provide information for the purpose of:

- ✓ Monitoring quality of station performance,
- ✓ Locating persistent biases or failures in observations,
- ✓ Evaluating improvement of quality of observation data, performance and maintenance of station/network.

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8 Automated Surface Observing System (ASOS) User's Guide
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Basic set of variables to be reported by the standard AWS for multiple users

Variables	SYNOP Land Stations	[Fixed] Ocean Weather Stations	Aeronautical meteorological station	Principle climatological station	**STANDARD**
Atmospheric Pressure	M A	M A	X [1]	X	**A**
Pressure tendency & characteristics	[M]	M			**[A]**
Air temperature	M[2] A	M A	X	X[3]	**A**
Humidity[5]	M A	M	X[4]	X	**A**
Surface wind[6]	M A	M A	X	X	**A**
Cloud Amount and Type	M	M	X	X	**A**
Extinction profile/Cloud-base	M [A]	M	X	X	**A**
Direction of Cloud movement	[M]				
Weather, Present & Past	M	M	X	X	**A**
State of the Ground	[M]	n/a		X[7]	**[A]**
Special Phenomena	[M] [A]				
Visibility	M [A]	M	X	X	**A**
Amount of Precipitation	[M] [A]	[A]		X	**A**
Precipitation Yes/No	A	[A]		X	**A**
Intensity of precipitation	[A]				
Soil temperature				X	**A**
Sunshine and/or Solar radiation				X	**A**
Waves		M [A]			**A[8]**
Sea temperature		M 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) Dewpoint temperature
5) Dewpoint temperature and/or RH and air temperature
6) wind speed and direction
7) snow cover
8) sea and coastal stations only

AWS Metadata Required for the Operational Purposes

2.1 Station information

Type of metadata	***Explanation***	***Examples***
Station name	Official name of the station	Bratislava-Koliba
Station index number or identifier	Number used by the National Meteorological Service to identify a station	11813, A59172,
WMO block and station numbers	BUFR descriptors 0 01 001 and 0 01 002[9]	11 and 813
Geographical co-ordinates	Latitude and longitude of the station reference point with the respect to the WGS 84[10]	18.7697 degree 18.5939 degree
Reference time	Actual time of observations in UTC	06 h 55 min.
Elevation above mean sea level	Vertical distance of a reference point of the station measured from mean sea level with the respect to the EGM 96	260.25 m
Surface qualifier	BUFR descriptor 0 08 010	Land grass cover
Classification of roughness	Davenport classification of effective terrain roughness	2
The datum level to which atmospheric pressure data of the station refer; Elevation data used for QFE/QNH	Datum levels to which the atmospheric pressure is reduced	Pressure sensor: 123.45 m MSL; Station: 125.67 m MSL. Aerodrome reference point: 124.56 m MSL;

2.2 Individual instrument information

Type of metadata	***Explanation***	***Examples***
Principle of operation:	Description of method or system used	
▪ method of measurement / observation[11]	Type of operation principle describing method of measurement/observation used BUFR Descriptors 0 02 175 – 0 02 189	constant current principal, polymer capacitance
▪ type of detection system	Complete set of measuring instruments and other equipment assembled to carry out specified measurements BUFR Descriptors 0 02 175 – 0 02 189	optical scatter system combined with precipitation occurrence sensing system
Siting and exposure:	Siting classification [12]	
▪ height above ground (or level of depth)		1.75 m, -0.1 m
▪ representative height of sensor above ground	Standard height for the measurement	1.25 m

[9] The current limitation of WMO station number to 999 (also limited by BUFR descriptor 0 01 002, which has a data width of 10 bits) is a problem for a wide exchange of observations. More than 999 stations often exist in the area covered by a given WMO block number. Not all the observations available are currently disseminated on the GTS. To disseminate the observations from all the stations potentially available, the WMO station number should be expanded (that is a new descriptor defined and used).
[10] To add a note for the relevant descriptor denoting latitude and longitude with reference to WGS 84.
[11] To add a note for the existence of shielding and type of shielding applied and whether artificially ventilated or not.
[12] To be standardized. France has defined a classification using values from 1 to 5. The NOAA/NCDC Climate Reference Stations use a similar classification system. It is recommended that CIMO develop guidelines for such classification, possibly in collaboration with ISO (TC146, SC5 meteorology).

Expected performance of the instrument	A performance classification (to be defined) should include: uncertainty of the instrument and periodicity of preventive maintenance and calibration. All these elements determine the expected performance of the instrument	Class A for an instrument following the WMO recommendations (both for instrument and maintenance). Class D for an instrument with unknown characteristics and/or unknown maintenance. Class B and C intermediate.
Adjustment procedures (for the nominal value)	Adjustment applied to the data	BUFR descriptor 0 08 083

2.3 Data processing information

Type of metadata	*Explanation*	*Example*
Measuring / observing programme:		
▪ data output	Quantity that is delivered by an instrument or system	2-min. average value
▪ processing interval	Time interval from which the samples are taken	2, 10 min. (wind)

2.4 Data handling information

Type of metadata	*Explanation*	*Example*
QC flag for each parameter	Description of QC flags	1 good, 2 inconsistent, 3 doubtful 4 erroneous, 5 not checked, 6 changed

AWS Metadata Required for Near-real Time and Non-real Time Purposes

2.1 Station information

There is a great deal of information related to a station's location, local topography and others. Basic station metadata include:

Type of metadata	***Explanation***	***Examples***
Station name	Official name of the station	Bratislava-Koliba
Station index number or identifier	Number used by the National Meteorological Service to identify a station	11813, A59172,
WMO block and station numbers	BUFR descriptors 0 01 001 and 0 01 002	11 and 813
Geographical co-ordinates	Latitude and longitude of the station reference point with the respect to the WGS 84	18.7697 degree 18.5939 degree
Reference time	Actual time of observations in UTC	06 h 55 min.
Elevation above mean sea level	Vertical distance of a reference point of the station measured from mean sea level with the respect to the EGM 96	260.25 m
Surface qualifier	BUFR descriptor 0 08 010	Land grass cover
Types of soil, physical constants and profile of soil	Description of soil type below the station, its characteristics	Clay
Types of vegetation and condition, The date of the entry	Description of the station's environment land	natural; grass, 7 Dec 2004
Local topography description	Description of the station's surroundings, with emphasis on topographic features that may influence the weather at the station	valley station
Classification of roughness	Davenport classification of effective terrain roughness	2
Type of AWS, manufacturer, HW and SW versions, model details, (model, serial number, software version)	Basic information on the AWS installed	AWS: Model Vaisala MILOS 500 Hardware v1.2, Operating system v1.2.3, Application program v1.0.2. Modem: Model ABCD, Hardware v2.3, Software v3.4.5. Power supply: Model XYZ, Hardware v4.5.
Observing programme of the station:	Information on types of observation made, variables measured	1-hour synoptic observations
▪ parameters measured	List of variables measured	Temp, Pressure, Humidity, wind speed and direction
▪ reference time	Reference time of observations	UTC
▪ message codes and reporting times (offset and interval).	Actual time of observations	METAR: Start 00:00 UTC, 1-hour intervals. SYNOP: Start 00:00 UTC, 3-hour intervals. AWS: Start 00:00, interval 1 minute.
The datum level to which atmospheric pressure data of the station refer; Elevation data used for QFE/QNH	Datum levels to which the atmospheric pressure is reduced	Pressure sensor: 123.45 m MSL; Station: 125.67 m MSL. Aerodrome reference point: 124.56 m MSL;

2.2 Individual instrument information

Relevant metadata should be:

Type of metadata	***Explanation***	***Examples***
Sensor type:	Technical information on the sensor used for the measurement of the variable	Temperature; humidity; pressure …
▪ manufacturer		Vaisala, Campbell, …
▪ model		HMP45C, PTU-2000
▪ serial number		12345…
▪ hardware version		V1.2.3
▪ software version		V2.3.4
Principle of operation:	Description of method or system used	
▪ method of measurement / observation	Type of operation principle describing method of measurement/observation used BUFR Descriptor 0 02 175 – 0 02 189	constant current principle, polymer capacitance
▪ type of detection system	Complete set of measuring instruments and other equipment assembled to carry out specified measurements BUFR Descriptors 0 02 175 – 0 02 189	optical scatter system combined with precipitation occurrence sensing system
Performance characteristics	Operating range of sensors	-50 - +60 ºC, 0 - 100 %
Unit of measurement	SI unit in which the variable is measured	K, Pa, m s^{-1}
Measuring range	Interval between upper and lower value limits for which a variable is reported	-50 - +60 ºC, 0 – 75 m s^{-1}
Resolution	The smallest change in a physical variable which will cause a variation in the response of a measurement system.	0.01 K,
Uncertainty	Variable associated with the result of a measurement that characterizes the dispersion of the values that could be reasonably attributed to the measurement; the interval in which the “the value” of the variable at the time of measurement is expected to lie.	±0.1 K
Instrument time constant	Time required for an instrument to indicate a given percentage (63.2 %) of the final reading resulting from an input signal	20 s;
Interface time constant	Time required for the interface electronics to indicate a given percentage (63.2 %) of the final reading resulting from an input signal	5 s;
Time resolution	Frequency of sampling	3 s, 10 s
Output averaging time	Time period used for the purpose of determining of reported value	1 min.; 2 min; 10 min.
Siting and exposure:	Siting classification	
▪ location		screen, mast, tower
▪ degree of interference from other instruments or objects		
▪ shielding		screen, naturally aspirated
▪ shielding time constant	Time required for the instrument exposure method (solar radiation screen, or vent etc.) to indicate a given percentage (63.2 %) of the final reading resulting from an input signal	10 s;

▪ height above ground (or level of depth)		1.75 m, -0.1 m
▪ representative height of sensor above ground	Standard height for the measurement	1.25 m
Expected performance of the instrument	A performance classification (to be defined) should include: uncertainty of the instrument and periodicity of preventive maintenance and calibration. All these elements determine the expected performance of the instrument	Class A for an instrument following the WMO recommendations (both for instrument and maintenance). Class D for an instrument with unknown characteristics and/or unknown maintenance. Class B and C intermediate
Data acquisition:		
▪ sampling interval	Time between successive observations	3 s, 10s, 30s
▪ averaging interval	Time interval from which samples are used	1, 2, 10, 30 minutes
▪ type of averaging	Method used for the calculation of the average	arithmetic; exponential; harmonic
Adjustment procedures (for the nominal value)	Adjustment applied to the data	BUFR descriptor 0 08 083
Calibration data		
▪ correction	Value to be added to or subtracted from the reading of an instrument to obtain the correct value	C = R (1+0.6R)
▪ time of calibration	Date when the last calibration was made	12 Dec 2003
Preventive and corrective maintenance:		
▪ recommended / scheduled maintenance	Frequency of preventive maintenance	one per 3 months
▪ calibration procedures	Type of method/procedure used	static/dynamic calibration
▪ calibration frequency	Recommended frequency	12 months
▪ procedure description		
Results of comparison with traveling standard	Result of the field tests of the sensor immediately after installation	98%
Results of comparison with traveling standard	Result of the field tests of the sensor immediately prior to removal	103%

2.3 Data processing information

For each individual meteorological parameter, metadata related to processing procedures should include:

Type of metadata	***Explanation***	***Example***
Measuring / observing programme:		
▪ time of observation		10^{th}, …,60^{th} min.
▪ reporting frequency		10 min.
▪ data output	Quantity that is delivered by an instrument or system	2-min. average value
▪ processing interval	Time interval from which the samples are taken	2, 10 min. (wind)
▪ reported resolution	Resolution of variable reported	0.1 ms^{-1}

Data-processing method, procedure, algorithm	Method used	A running 10-min. average
Formula to calculate the element		$VIS=N/(1/V_1+1/V_2+ \ldots +1/V_n)$
Mode of observation / measurement	Type of data being reported	An instantaneous, total, mean value, variability,
Input source (instrument, element, etc.)	Measured or derived variable	WAA 151
Constants and parameter values	Constants, parameters used in computation of derived parameter	$g=9.806\ 65 ms^{-2}$

2.4 Data handling information

Metadata elements of interest include:

Type of metadata	***Explanation***	***Example***
Quality control procedures, algorithms	Type of QC procedures	A plausible value check; time consistency check, internal consistency check
QC flag for each parameter	Description of QC flags	1 good, 2 inconsistent, 3 doubtful 4 erroneous, 5 not checked, 6 changed
Processing and storage procedures	Different procedures used in the process of data reduction and data conversion	A computation of visibility from extinction coefficient
Constants and parameter values		

2.5 Data transmission information

The transmission-related metadata of interest are:

Type of metadata	**Explanation**	**Example**
Method of transmission	Means of transmission	GSM/GPRS, OrbComm; radio
Data format	Type of message used for data transmission	BUFR; SYNOP
Transmission time	Time of regular transmission of data	11^{th} minute; 60^{th} minute
Transmission frequency	Frequency of data transmission	10 minute; 1 hour

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				
Pressure	500 – 1080 hPa	10 Pa	I, V	0 10 004
TEMPERATURE				
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 (*surface*) temperature (*over specified surface*)	-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				
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 – 0.1 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 – 360 degrees	1 degree	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	$1\cdot10^{-6}$ – $2\cdot10^{4}$ Cd m^{-2}	$1\cdot10^{-6}$ Cd m^{-2}	I, V	N
Global downward solar radiation	0 – $6\cdot10^{6}$ J m^{-2}	1 J m^{-2}	I, T, V	N
Global upward solar radiation	0 – $4\cdot10^{6}$ J m^{-2}	1 J m^{-2}	I, T, V	N
Diffuse solar radiation	0 – $4\cdot10^{6}$ J m^{-2}	1 J m^{-2}	I, T, V	0 14 023
Direct solar radiation	0 – $5\cdot10^{6}$ J m^{-2}	1 J m^{-2}	I, T, V	0 14 025
Downward long-wave radiation	0 – $3\cdot10^{6}$ J m^{-2}	1 J m^{-2}	I, T, V	0 14 002
Upward long-wave radiation	0 – $3\cdot10^{6}$ J m^{-2}	1 J m^{-2}	I, T, V	0 14 002
Net radiation	0 – $6\cdot10^{6}$ J m^{-2}	1 J m^{-2}	I, T, V	0 14 016
UV-B radiation	0 – $1.2\cdot10^{3}$ J m^{-2}	1 J m^{-2}	I, T, V	N
Photosynthetically active radiation	0 – $3\cdot10^{6}$ 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	$2 \cdot 10^{-5} – 32 \cdot 10^{-5}$ m	$2 \cdot 10^{-5}$ m	I, V	N
Cloud liquid water content	$1 \cdot 10^{-5} – 1.4 \cdot 10^{-2}$ kg m^{-3}	$1 \cdot 10^{-5}$ 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	0 – 500 mm	0.1 kg m^{-2}, 0.0001 m	T	0 13 011
Duration	up to 86 400 s	60 s	T	0 26 020
Size of precipitating element	$1 \cdot 10^{-3}$ – 0.5 m	$1 \cdot 10^{-3}$ 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}	$1 \cdot 10^{-3}$ 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	$2 \cdot 10^{-5} – 32 \cdot 10^{-5}$ m	$2 \cdot 10^{-5}$ m	I, V	N
Horizontal - extinction coefficient	0 – 1 m^{-1}	0.001 m^{-1}	I, V	N
Slant - extinction coefficient	0 – 1 m^{-1}	0.001 m^{-1}	I, V	N
Meteorological Optical Range	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 – $3 \cdot 10^4$ m	10^3 m	I, V	N
Lightning - direction from station	1 – 360 degrees	1 degree	I, V	N

“MERGED” BUFR TEMPLATE FOR SURFACE OBSERVATIONS FROM ONE-HOUR PERIOD

This template is proposed to be used for representation of surface observation data from both automatic stations and manned stations. This template is also suitable for SYNOP observation data, by including parameters covering periods longer than one hour.
Descriptors used by both templates are not marked.
Descriptors used from the SYNOP BUFR template are indicated by an asterisk *.
Descriptors used from the AWS BUFR template are indicated by an asterisk *.

3 01 090		SYNOP	AWS	**Surface station identification; time, horizontal and vertical co-ordinates**	
3 01 004				**Surface station identification**	
	0 01 001			WMO block number	Numeric
	0 01 002			WMO station number	Numeric
	0 01 015			Station or site name	CCITT IA5
	0 02 001			Type of station	Code table
3 01 011	0 04 001			Year	Year
	0 04 002			Month	Month
	0 04 003			Day	Day
3 01 012	0 04 004			Hour	Hour
	0 04 005			Minute	Minute
3 01 021	0 05 001			Latitude (high accuracy)	Degree, scale 5
	0 06 001			Longitude (high accuracy)	Degree, scale 5
0 07 030				Height of station ground above mean sea level	m, scale 1
0 07 031				Height of barometer above mean sea level	m, scale 1
0 08 010				Surface qualifier (for temperature data)	Code table
3 01 091			*	***Surface station instrumentation***	
	0 02 180		*	*Main present weather detecting system*	*Code table*
	0 02 181		*	*Supplementary present weather sensor*	*Flag table*
	0 02 182		*	*Visibility measurement system*	*Code table*
	0 02 183		*	*Cloud detection system*	*Code table*
	0 02 184		*	*Type of lightning detection sensor*	*Code table*
	0 02 179		*	*Type of sky condition algorithm*	*Code table*
	0 02 186		*	*Capability to detect precipitation phenomena*	*Flag table*
	0 02 187		*	*Capability to detect other weather phenomena*	*Flag table*
	0 02 188		*	*Capability to detect obscuration*	*Flag table*
	0 02 189		*	*Capability to discriminate lightning strikes*	*Flag table*
				Pressure data	
3 02 001	0 10 004			Pressure	Pa, scale –1
	0 10 051			Pressure reduced to mean sea level	Pa, scale –1
	0 10 061			3-hour pressure change	Pa, scale –1
	0 10 063			Characteristic of pressure tendency	Code table
0 10 062		*		*24-hour pressure change* $p_{24}p_{24}p_{24}$	*Pa, –1*
0 07 004				Pressure (standard level)	Pa, scale –1
0 10 009				Geopotential height of the standard level	gpm
3 02 072				**Temperature and humidity data**	
	0 07 032			Height of sensor above local ground	m, scale 2
	0 07 033		*	*Height of sensor above water surface*	*m, scale 1*
	0 12 101			Temperature/dry-bulb temperature (scale 2)	K, scale 2
	0 12 103			Dew-point temperature (scale 2)	K, scale 2

	0 13 003			Relative humidity	%
1 01 005			*	*Replicate one descriptor five times*	
3 07 063	*0 07 061*		*	*Depth below land surface*	*m, scale 2*
	0 12 130		*	*Soil temperature (scale 2)*	*K, scale 2*
3 02 069				**Visibility data**	
	0 07 032			Height of sensor above local ground	m, scale 2
	0 07 033		*	*Height of sensor above water surface*	*m, scale 1*
	0 33 041		*	*Attribute of following value*	*Code table*
	0 20 001			Horizontal visibility	m, scale –1
0 07 032			*	*Height of sensor above local ground (set to missing to cancel the previous value)*	*m, scale 2*
0 07 033			*	*Height of sensor above water surface (set to missing to cancel the previous value)*	*m, scale 1*
0 20 031			*	*Ice deposit (thickness)*	*m, scale 2*
0 20 032			*	*Rate of ice accretion*	*Code table*
0 02 038			*	*Method of sea surface temperature measurement*	*Code table*
0 22 043			*	*Sea/water temperature (scale 2)*	*K, scale 2*
3 02 021	*0 22 001*		*	*Direction of waves*	*Degree true*
	0 22 011		*	*Period of waves*	*s*
	0 22 021		*	*Height of waves*	*m, scale 1*
3 02 078				**State of ground and snow depth measurement**	
	0 02 176		*	*Method of state of ground measurement*	*Code table*
	0 20 062			State of ground (with or without snow)	Code table
	0 02 177		*	Method of snow depth measurement	Code table
	0 13 013			Total snow depth	m, scale 2
0 12 113		*		*Ground minimum temperature (scale2), past 12 hours* $s_nT_gT_g$	*K, 2*
				Cloud data	
	0 20 010			Cloud cover (total)	%
Useful	*0 08 002*	*		*Vertical significance*	*Code table, 0*
considering	*0 20 011*	*		*Cloud amount (of low or middle clouds)* N_h	*Code table, 0*
the	*0 20 013*	*		*Height of base of cloud* **h**	*m, –1*
following	*0 20 012*	*		*Cloud type (low clouds C_L)* C_L	*Code table, 0*
Cloud	*0 20 012*	*		*Cloud type (middle clouds C_M)* C_M	*Code table, 0*
layers ?	*0 20 012*	*		*Cloud type (high clouds C_H)* C_H	*Code table, 0*
	1 05 004		*	*Replicate 5 descriptors four times*	
	0 08 002			Vertical significance	Code table
	0 20 011			Cloud amount	Code table
	0 20 012			Cloud type	Code table
	0 33 041		*	*Attribute of following value*	*Code table*
	0 20 013			Height of base of cloud	m, scale -1
		*		***Clouds with bases below station level***	
3 02 036	*1 05 000*	*		*Delayed replication of 5 descriptors*	
	0 31 001	*		*Delayed descriptor replication factor*	*Numeric, 0*
	0 08 002	*		*Vertical significance*	*Code table, 0*
	0 20 011	*		*Cloud amount* **N’**	*Code table, 0*
	0 20 012	*		*Cloud type* **C’**	*Code table, 0*
	0 20 014	*		*Height of top of cloud* **’H’**	*m, -1*
	0 20 017	*		*Cloud top description* C_t	*Code table, 0*
		*		***Direction of cloud drift*** $6D_LD_MD_H$	
3 02 047	*1 02 003*	*		*Replicate 2 descriptors 3 times*	
	0 08 002	*		*Vertical significance 7 = low cloud, 8 = middle cloud, 9 = high cloud*	*Code table, 0*

	0 20 054	*		True direction from which clouds are moving DL, DM, DH	Degree true, 0
0 08 002		*		Vertical significance (set to missing to cancel the previous value)	Code table, 0
		*		Direction and elevation of cloud gr. 57CDaeC	
3 02 048	0 05 021	*		Bearing or azimuth Da	Degree true, 2
	0 07 021	*		Elevation angle eC	Degree, 2
	0 20 012	*		Cloud type C	Code table, 0
	0 05 021	*		Bearing or azimuth (set to missing to cancel the previous value)	Degree true, 2
	0 07 021	*		Elevation angle (set to missing to cancel the previous value)	Degree, 2
3 02 074				Present and past weather	
	0 20 003			Present weather(3)	Code table
	0 04 025			Time period (= - 60 minutes)	Minute
	0 20 004			Past weather (1) (3)	Code table
	0 20 005			Past weather (2) (3)	Code table
3 02 075			*	Intensity of precipitation, size of precipitation element	
	0 08 021		*	Time significance (= 2 (time averaged))	Code table
	0 04 025		*	Time period (= - 10 minutes)	Minute
	0 13 055		*	Intensity of precipitation	kgm-2s-1,scale 4
	0 13 058		*	Size of precipitation element	m, scale 4
	0 08 021		*	Time significance (= missing value)	Code table
0 04 025			*	Time period (= - 10 minutes)	Minute
3 02 076			*	Precipitation, obscuration and other phenomena	
	0 20 021		*	Type of precipitation	Flag table
	0 20 022		*	Character of precipitation	Code table
	0 26 020		*	Duration of precipitation (4)	Minute
	0 20 023		*	Other weather phenomena	Flag table
	0 20 024		*	Intensity of phenomena	Code table
	0 20 025		*	Obscuration	Flag table
	0 20 026		*	Character of obscuration	Code table
				Wind data	
	0 07 032			Height of sensor above local ground	m, scale 2
	0 07 033			Height of sensor above water surface	m, scale 1
	0 08 021			Time significance (= 2 (time averaged))	Code table
	0 04 025			Time period (= - 10 minutes, or number of minutes after a significant change of wind, if any)	Minute
	0 11 001			Wind direction	Degree true
	0 11 002			Wind speed	m s-1
	0 08 021			Time significance (= missing value)	Code table
	1 03 003			Replicate next 3 descriptors 3 times	
	0 04 025	*		Time period (= - 10 minutes in the first replication, = - 60 minutes in the second replication = - 60*3 or 60*6 minutes in the third replication)	Minute
	0 11 043			Maximum wind gust direction	Degree true
	0 11 041			Maximum wind gust speed	m s-1
	0 04 025		*	Time period (= - 10 minutes)	Minute

	0 11 016		*	*Extreme counterclockwise wind direction of a variable wind*	*Degree true*
	0 11 017		*	*Extreme clockwise wind direction of a variable wind*	*Degree true*
3 02 077				**Extreme temperature data**	
	0 07 032			Height of sensor above local ground	m, scale 2
	0 07 033		*	*Height of sensor above water surface*	*m, scale 1*
	1 04 002			*Replicate 4 descriptors 2 times*	
	0 04 024	*		*Time period or displacement (= - 1 hour in the first replication, = - 12 or - 24 or – x hours in the second replication)*	*Hour, 0*
	0 04 024	*		*Time period or displacement (see Notes 1 and 2)*	*Hour, 0*
	0 12 111			Maximum temperature (scale 2) at height and over period specified	K, scale 2
	0 12 112			Minimum temperature (scale 2) at height and over period specified	K, scale 2
	0 07 032		*	*Height of sensor above local ground (for ground temperature)*	*m, scale 2*
	0 04 025		*	*Time period (= - 60 minutes)*	*Minute*
	0 12 112		*	*Minimum temperature (scale 2) at height and over period specified (for ground temperature)*	*K, scale 2*
0 07 033			*	*Height of sensor above water surface (set to missing to cancel the previous value)*	*m, scale 1*
				Precipitation measurement	
	0 07 032			Height of sensor above local ground	m, scale 2
	0 02 175		*	*Method of precipitation measurement*	*Code table*
	0 02 178		*	*Method of liquid water content measurement of precipitation*	*Code table*
	1 02 005			*Replicate 2 descriptors 5 times*	
	0 04 024			*Time period in hours* ***t_R*** *(= - 1 hour in the first replication, = - 3, -6, -12, - 24 hours in the next replications)*	*Hour, 0*
	0 13 011			Total precipitation / total water equivalent of snow	kg m^{-2}, scale 1
0 07 032			*	*Height of sensor above local ground (set to missing to cancel the previous value)*	*m, scale 2*
				Evaporation measurement	
	0 02 185		*****	***Method of evaporation measurement***	*Code table*
	1 02 002			*Replicate 2 descriptors 2 times*	
	0 04 024	*		*Time period in hours (= -1 hour in the first replication, = -x hours in the second replication)*	*Hour, 0*
	0 13 033			Evaporation /evapotranspiration	kg m^{-2}
3 02 081				**Total sunshine data**	
	1 02 002	*		*Replicate 2 descriptors 2 times*	
3 02 039	*0 04 024*	*		*Time period in hours (= -1 hour in the first replication, = -x hours in the second replication)*	*Hour, 0*
	0 14 031			Total sunshine	Minute
				Radiation data	
	1 07 003	*		*Replicate 7 descriptors 3 times*	

3 02 045	*0 04 024*	*		*Time period in hours (= -1 hour in the first replication, = -x hours in the next replications)*	Hour, 0
	0 14 002			*Long-wave radiation, integrated over period specified*	J m-2, scale -3
	0 14 004			*Short-wave radiation, integrated over period specified*	J m-2, scale -3
	0 14 016			*Net radiation, integrated over period specified*	J m-2, scale -4
	0 14 028			*Global solar radiation (high accuracy), integrated over period specified*	J m-2, scale -4
	0 14 029			*Diffuse solar radiation (high accuracy), integrated over period specified*	J m-2, scale -4
	0 14 030			*Direct solar radiation (high accuracy), integrated over period specified*	J m-2, scale -4
0 04 025			*	*Time period (= - 10 minutes)*	Minute
0 13 059			*	*Number of flashes*	Numeric
3 02 046		*		*Temperature change group 54g0sndT*	
	0 04 024	*		*Time period or displacement*	Hour, 0
	0 04 024	*		*Time period or displacement (see Note 5)*	Hour, 0
	0 12 049	*		*Temperature change over period specified sndT*	K, 0
3 02 083			*	*First order statistics of P, W, T, U data*	
	0 04 025		*	*Time period (= -10 minutes)*	Minute
	0 08 023		*	*First order statistics (= 9 (best estimate of standard deviation)) (6)*	Code table
	0 10 004		*	*Pressure*	Pa, scale –1
	0 11 001		*	*Wind direction*	Degree true
	0 11 002		*	*Wind speed*	m s-1
	0 12 101		*	*Temperature/dry-bulb temperature (scale 2)*	K, scale 2
	0 13 003		*	*Relative humidity*	%
	0 08 023		*	*First order statistics (= missing value)*	Code table
0 33 005			*	*Quality information (AWS data)*	Flag table
0 33 006			*	*Internal measurement status information (AWS)*	Code table

Notes: The time identification refers to the end of the one-hour period.

For SYNOP:

1) Within RA-IV, the maximum temperature at 1200 UTC is reported for the previous calendar day (i.e. the ending time of the period is not equal to the nominal time of the report). To construct the required time range, descriptor 004024 has to be included two times. If the period ends at the nominal time of the report, value of the second 004024 shall be set to 0.

2) Within RA-III, the maximum day-time temperature and the minimum night-time temperature is reported (i.e. the ending time of the period may not be equal to the nominal time of the report). To construct the required time range, descriptor 004024 has to be included two times. If the period ends at the nominal time of the report, value of the second 004024 shall be set to 0.

3) Present weather may be represented only by 0 20 003, especially if reported from a manned non-automated station. When encoding present weather reported from an automatic weather station, the sequence of descriptors (proposed under 3 02 076) should be used, when applicable.

4) Duration of precipitation represents number of minutes in which precipitation was registered.

5) To construct the required time range, descriptor 004024 has to be included two times.

6) Best estimate of standard deviation is counted out of a set of samples (signal measurements) recorded within the period specified; it should be reported as a missing value, if the measurements of the relevant element are not available from a part of the period specified by 0 04 025.

7) Suggestion of the author, M. Leroy, Meteo France, some of the parameters are very specific to some locations with cloud bases below station level, ice deposit, sea/water temperature, waves, and temperature changes. To accommodate these parameters they could be placed at the end of the template. Additional descriptors could also be added to address specific regional needs, but caution should be used in determining the amount of information which could be included in such a template. One should ask, have all possible descriptors been included or should the message be limited to only those descriptors relevant to the station?

BUFR Quality Indicators

Table 1. Source of variable

Code figure	Description
0	Original measured value
1	Original value has been corrected
2	Original value was missing, the value has been estimated
3	The value is missing.
4	The source of the value is unknown.

Table 2. Quality control indicator

Code figure	Description
0	Not checked; The variable has not gone through any quality control checking.
1	Good; Data not exceeding a specified value.
2	Inconsistent; One or more parameters are inconsistent; the relationship with different elements does not satisfy defined criteria.
3	Doubtful
4	Erroneous; Wrong data exceeding a specified value.
5	Verified; Originally data flagged as suspects, erroneous or inconsistent; later on validated as good using other checking procedures.
6	Not applicable; The variable is missing and a quality flag is inappropriate.

RECOMMENDATIONS

(Recommendation numbers refer to the item in the agenda
under which this recommendation was formulated.)

RECOMMENDATION 1, Item 5.1 "Standard and recommended variables for AWS"

Considering that:

1. The Manual on the GOS clearly prescribes the variables to be measured at the various types of weather observing stations.
2. Differences exist between the sets of variables to be measured by manned and automatic weather stations although there are no clear reasons for such differences.
3. Differences exist between the set of variables to be measured by synoptic, aeronautical and climatological stations although observational data is mutually exchanged between the various disciplines.
4. Uniformity in observations itself and in the selection of the variables to be measured at a weather station will be beneficial for all disciplines.
5. The sets of required variables to be measured by these disciplines overlap.
6. 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:

1. CBS-Ext. (2006) considers further development of a basic set of variables to be measured by a standard AWS. This set should contain a list of standard variables to be reported, and an additional set of variables to be reported as recommended. This basic set should be developed in close collaboration with other technical commissions.
2. CBS-Ext. (2006) consider the publication of this basic set of variables in the next edition of the Manual of the GOS.

RECOMMENDATION 2, Item 5.2 “Adoption of a World Geodetic System and a Global Geoid Model as references for positioning”

Considering that:

1. The position of a weather station is given by a longitude, a latitude and an altitude with respect to Mean sea level (MSL),
2. Presented longitude and latitude both require one universal standard positioning system as reference,
3. Mean sea level requires one universal global standard datum,

4. The standard reference system the World Geodetic System 1984 [WGS 84] is applicable for the world wide use by all applications used in meteorology,
5. Most regional and national systems refer to WGS84,
6. WGS84 is endorsed by international bodies, such as ICAO,
7. MSL is defined as the average sea surface level for all stages of the tide over a 19-year period, usually determined from hourly heights observed above a fixed reference level,
8. The fixed reference level for MSL is to be appointed or defined, and
9. A well defined Earth Geodetic Model like the EGM-96 is applicable for all applications in meteorology,

The expert team recommended that:

1. CBS-Ext. (2006) consider adoption of the World Geodetic System 1984 [WGS 84] as the primary reference for horizontal positioning,
2. CBS-Ext. (2006) consider adoption of the EGM-96 as the fixed reference level for MSL determination, and
3. The WMO Technical Regulations, WMO-No. 49, and the appropriate WMO Manuals and Guides are updated accordingly.

RECOMMENDATION 3, Item 6.2 "Development of metadata catalogues"

Considering the development of WMO Core Profile of the Metadata Standards

The expert team recommended that the following catalogues should be developed:

1. Variables measured by a standard AWS (the Functional Specifications for AWS developed by the ET could be used for this purpose);
2. Instruments used for variables measured by standard AWS (information provided by manufacturers using a standardized template would be probably the most suitable approach);
3. Data processing procedures (algorithms) used by AWS;
4. Data quality control procedures used for AWS data.

RECOMMENDATION 4, Item 6.5 "Update of BUFR/CREX"

Considering the development of metadata standard for AWS and their representation in TDCF,

The expert team recommended that the review of BUFR/CREX should be done with respect to the development of new descriptors, including the adjustment of AWS BUFR templates.

RECOMMENDATION 5, Item 8.2 “Common BUFR template for any AWS”

Considering that:

1. Several BUFR templates exist for:

    a. AWS data (one-hour period),

    b. SYNOP and SYNOP MOBIL data,

    c. SHIP data,

2. The AWS data template may also be used by manned (AWS) stations,

3. The AWS are often also surface synoptic stations, which should therefore report SYNOP data,

4. The current BUFR template for AWS data (one-hour period) contains parameters representative of period of times of maximum one hour,

5. The SYNOP BUFR template contains some parameters representative of period of times of 3, 6, 12 or 24 hours,

6. According to WMO resolution 40, Surface data have to be transmitted at synoptic hours and not necessarily every hour,

7. If the current BUFR template for AWS is used for transmission only at synoptic hours, some parameters over synoptic periods will be missing (for example amount of precipitation), and

8. In such conditions a synoptic AWS could have to transmit data both with the AWS data template and the SYNOP template.

The expert team recommended that:

1. The Expert Team on DR&C follows the issue of mixing/merging the current AWS template (for one-hour period) and the SYNOP template to a single template covering both AWS data to be transmitted hourly and SYNOP data to be transmitted at standard times; or

2. The ET-DR&C adds some descriptors in the current AWS template to cover the few parameters which would be missing if a AWS BUFR is transmitted only at synoptic hours.

RECOMMENDATION 6, Item 8.3 “Definition and use of an enlarged WMO station number”

Considering that:

1. There is a recommendation of ET-ODRRGOS to distribute data from high spatial resolution networks.

2. The current BUFR templates identify a station by a WMO block number (BUFR descriptor 0 01 001) and a WMO station number (0 01 002).

3. A WMO station number is limited to 999 (alphanumeric codes) or 1022 (binary).

4. For a given WMO block number, more than 999 observing stations (mainly AWS) sometimes exist. And the number of AWS is increasing.

5. Therefore, it is not always possible to allocate a WMO station number to an AWS. Consequently, some NMSs are using national station numbers, which cannot be reported in the current WMO BUFR templates. For stations with no WMO station number, the only solution to report data using the available WMO BUFR templates is to code this WMO station number as missing. This may not be a problem for some users, considering the high accuracy localization of the station, included in a BUFR message. But any link to metadata data bases would be impossible due to this lack of reference station number.

The expert team recommended that:

This problem of limitation of the WMO station number be taken into account in the current and future BUFR template.

RECOMMENDATION 7, Item 8.5 "Variables in BUFR descriptors"

Considering that:

7. Variables stated by descriptors in the BUFR templates are not always traceable to a definition documented in any WMO document,
8. A number of variables given a descriptor cannot be uniquely explained due to lack of detail,
9. Due to this ambiguity unacceptable confusion and misunderstandings are introduced when decoding BUFR bulletins.

The expert team recommended that:

3. Variables stated as BUFR descriptor should be traceable to the International Meteorological Vocabulary (WMO No. 49), the Technical Regulations (WMO No. 49) or SI.
4. The indicated variables should be described in such a detail that any possible ambiguity is avoided.

Future Work Plan

No.	Task Description	Person(s) Tasked	Action(s)	Deadline(s)	Deliverable(s)	Deadline
1	Collaborate with CIMO in defining a list of AWS Functional Specifications	TBD	Coordinate efforts with other programs and Commissions.	TBD	Provide a complete table of functional specifications for AWS.	TBD
2	Develop the requirements and implementation plan for a robust, low power, continuous communications platform for all AWS, particularly those in remote locations.	TBD	Coordinate efforts with other programs and Commissions in identifying and documenting user needs.	TBD	A set of requirements and a viable Implementation Plan for those communication strategies which show the greatest promise.	TBD
3	Develop the requirements and subsequent implementation plan for AWS hosted sensors to contribute directly to the calibration and ground truth of space-based observations.	TBD	Coordinate with other programs and Commissions in identifying candidate sensors.	TBD	A set of requirements and a viable Implementation Plan for the suite of identified candidate sensors.	TBD
4	Develop the requirements for new sensors or the integration of sensors to meet the deficiencies of AWS following the migration from manual observations.	TBD	Coordinate efforts with other programs and Commissions in identifying and documenting user needs.	TBD	A set of requirements and a viable Implementation Plan for the future implementation of such sensors once developed.	TBD
5	As we move forward toward a global system of systems the need for integration of point measurements with area measurements will be required.	TBD	Coordinate efforts with other programs and Commissions in addressing how fixed and mobile AWS observations can be integrated.	TBD	A strategic plan for the integration of AWS data.	TBD

6	Develop network guidelines and procedures to assist in the transition from manual to automatic surface observing stations.	TBD	Coordinate efforts with other programs and Commissions in identifying and documenting user needs.	TBD	Guidelines for the transition from manual observations to automatic observations that can be incorporated into the CIMO Guide.	TBD
7	As new AWS data types are developed guidelines for their network implementation should in place.	TBD	Coordinate efforts with other programs and Commissions in preparing guidelines for the implementation of new data types from either new sensors or following the successful integration of sensors.	TBD	Guidelines for the implementation of data from new sensor types to be incorporated into the CIMO guide.	TBD
8	Develop the recommended four categories of AWS metadata.	TBD	Coordinate efforts with other programs and Commissions prior to preparing these documents.	TBD	Metadata category lists for AWS platforms.	TBD
9	Develop Guidelines for the siting classification of AWS	TBD	Coordinate efforts with other programs and Commissions prior to preparing these documents.	TBD	Approved set of guidelines for consideration by CIMO for inclusion to the CIMO Guide.	