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Guidelines on Quality Control Procedures for Data from Automatic Weather Stations

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Summary and purpose of document

The document contains a proposal for the Guidelines on Quality Control Procedures for data from Automatic Weather Stations.

Action proposed

The meeting is invited to consider the proposal for the Guidelines on Quality Control Procedures for AWS data submitted by ET AWS for approval by CBS-XIII and recommended for publishing the Guidelines in both the Guide to Meteorological Instruments and Methods of Observation (WMO-No.8), and in the WMO Guide on Global Data Processing System (WMO-No. 305).

References:

1 CBS-Ext.(02), Abridged Final Report with Resolutions and Recommendations, WMO-No. 955
2 Final Report, ET AWS, Geneva, 28 June - 2 July 2004.

I. Background

The ET AWS (Geneva, 28 June - 2 July 2004), considered the proposal for the Guidelines on Quality Control Procedures for Data from Automatic Weather Station developed by I. Zahumensky. The proposal was reviewed and updated during the session, including a number of relevant inputs from the representative of EUMETNET.

It was noted that there are different quality control procedures for the various phases of the data collection process, but there is an absence of comprehensive quality control at all levels where sophisticated methods should be applied. It is evident that data quality flagging is of utmost importance when using data and should be implemented on all levels of data quality control.

The document presents the proposal for recommendations for different quality control procedures to be used at an AWS site and at a Data Processing Centre. The proposal addresses only QC of data from a single AWS platform, while spatial QC is beyond a scope of the proposal. The same is also true for checks against analysed or predicted fields as well as for QC of formatting, transmission and decoding of errors, due to a specific character of these processes.

Every AWS BUFR message has to include outputs of Basic QC, using BUFR descriptor 0 33 005 (Quality Information AWS data) and 0 33 020 (Quality control indication of following value) or preferably a new flag table (needed to be defined). Shortcoming of the descriptor 0 33 020 is that it is the code table, which is capable to express only one quality control indication but it should be capable to indicate more than one. Therefore ET proposed the new Flag Table, 0 33 019 (Quality control indication of following value) as follows:

Flag Table 0 33 019 “Quality control indication of the following value”, data width 9 bits:

Bit N°	
1	Good
2	Inconsistent
3	Doubtful
4	Erroneous
5	Not checked
6	Changed
7 - 8	Reserved
All 9	Missing value

The meeting agreed on the final proposal to CBS-XIII for approval and recommended the Guidelines on Quality Control Procedures for Data from Automatic Weather Stations be published in both the WMO Guide on Global Data Processing System (WMO-No. 305) and in the Guide to Meteorological Instruments and Methods of Observation, WMO-No.8.

It was also agreed that ET AWS, jointly with CCI, JCOMM, GCOS, and CIMO, will continue with this work in the development of the guidelines for AWS quality control procedures for future publication in WMO Guide on Global Data Processing System (WMO-No. 305), the CIMO Guide, and WMO/TD-No.111.

Proposal for Guidelines on Quality Control Procedures for Data from Automatic Weather Stations

INTRODUCTION

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

- ***QC of raw data (signal measurements)***. It is basic QC, performed at an AWS site. This QC level is relevant during acquisition of Level I data and should eliminate errors of technical devices, including sensors, measurement errors (systematic or random), errors inherent in measurement procedures and methods. QC at this stage includes a gross error check, basic time checks, and internal consistency checks.
- ***QC of processed data***: It is extended QC, partly performed at an AWS site, but mainly at a Data Processing Centre. This QC level is relevant during the reduction and conversion of Level I data into Level II data and Level II data themselves. It deals with comprehensive checking of temporal and internal consistency, evaluation of biases and long-term drifts of sensors and modules, malfunction of sensors, etc.

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.

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

Notes:

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

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

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

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

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

CHAPTER I DEFINITIONS AND ABBREVIATIONS

Quality control, quality assurance

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

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

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

Quality assurance: All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality.

The primary objective of the quality assurance system is to ensure that data are consistent, meet the data quality objectives and are supported by comprehensive description of methodology.

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

(For a detailed discussion on the multiple definitions, see ANSI/ISO/ASQ A3534-2, Statistics-Vocabulary and Symbols - Statistical Quality Control, www.asq.org)

Types of errors

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

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

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

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

Abbreviations

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

CHAPTER II BASIC QUALITY CONTROL PROCEDURES

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

The types of B-QC procedures are as follows:

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

All AWS data should be flagged using appropriate QC flags. At B-QC five data QC categories are enough:

- good (accurate; data with errors less than or equal to a specified value);

- inconsistent (one or more parameters are inconsistent);
- doubtful (suspect);
- erroneous (wrong; data with errors exceeding a specified value);
- missing data.

It is essential that data quality is known and demonstrable; data must pass all checks in the framework of B-QC. In case of inconsistent, doubtful and erroneous data, additional information should be transmitted; in case of missing data the reason of missing should be transmitted. In case of BUFR messages, 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 six samples per minute (a sampling interval 10 seconds), the limits of time variance of the samples implemented at AWS can be as follows:

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

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

II. Automatic QC of processed data

a) Plausible value check

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

- Air temperature: -80 °C – +60 °C;
- Dew point temperature: -80 °C – 35 °C;
- Ground temperature: -80 °C – +80 °C;

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

If the value is outside the acceptable range limit it should be flagged as erroneous.

b) Time consistency check

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

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

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

Another possibility is to compare the difference between the current instantaneous value with the previous and the following (next) ones. If the following condition is not fulfilled then the current instantaneous value fails the check.

The algorithm used is as follows: $|V_i - V_{i-1}| + |V_i - V_{i+1}| \leq 4 \cdot \sigma_V$,

where:

V_i is the current value of the parameter,

[1] In extreme meteorological circumstances, unusual variability may occur. In such circumstances, data may be flagged as suspect, though being correct.

[2] If dew point temperature is directly measured by a sensor, a 2°C limit is to be used. If dew point is calculated from measurements of air temperature and relative humidity, a larger limit of 4°C is recommended, to take 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.

V_{i-1} is the previous value of the parameter,

V_{i+1} is the next value of the parameter,

σ_V is the standard deviation of the parameter calculated at least from the last 10-minute period.

If the previous value or the next one is missing, the corresponding part of the formula is omitted and the comparison term is $2 \cdot \sigma_V$.

- ***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 60/120/240 minutes by more than the specified limit *(a threshold value)* then the current one-minute value fails the check. Possible limits of minimum required variability can be as follows:
  - Air temperature: 0.1°C over the past 60 minutes;
  - Dew point temperature: 0.1°C over the past 60 minutes;
  - Ground temperature: 0.1°C over the past 60 minutes[3];
  - Soil temperature may be very stable, so there is no minimum required variability.
  - Relative humidity: 1% over the past 60 minutes[4];
  - Atmospheric pressure: 0.1 hPa over the past 60 minutes;
  - Wind direction: 10 degrees over the past 60 minutes[5];
  - Wind speed: 0.5 ms^{-1} over the past 60 minutes[6].

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 $\leq$ air temperature;
- wind speed = 00 and wind direction = 00;
- wind speed $\neq$ 00 and wind direction $\neq$ 00;
- wind gust (speed) $\geq$ wind speed;
- both elements are suspect[1] if total cloud cover = 0 and amount of precipitation > 0[7];
- both elements are suspect[1] if total cloud cover = 0 and precipitation duration > 0[8];
- both elements are suspect[1] if total cloud cover = 8 and sunshine duration > 0;
- both elements are suspect[1] if sunshine duration > 0 and solar radiation = 0;
- both elements are suspect[1] if solar radiation > 500 Wm^{-2} and sunshine duration = 0;
- both elements are suspect[1] if amount of precipitation > 0 and precipitation duration = 0;

[3] Only if ground temperature is not in the interval [-0.1°C +0.1°C] (This interval rather than O°C, to take into account the measurement uncertainty). Melting snow can generate isothermy, during which the limit should be 0°C.

[4] Only if the measurement relative humidity is less than 95%, to take into account the measurement uncertainty.

[5] Only if 10-minute average wind speed during the period is larger than 0.1 $m.s^{-1}$.

[6] Only if 10-minute average wind speed during the period is larger than 0.1 $m.s^{-1}$.

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

[8] But snow pellets can occur with cloud cover = 0

- both elements are suspect[1] if precipitation duration > 0 and weather phenomenon is different from precipitation type;

  (1: possible used only for data from a period not longer than 10 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 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. The checks that had already been performed at the AWS site should be repeated at DPC but in more elaborate form. This should include comprehensive checks against physical and climatological limits, time consistency checks for a longer measurement period, checks on logical relations among a number of variables (internal consistency of data), statistical methods to analyze data, etc.

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

Internal consistency checks of data

The different parameters in the AWS BUFR N-minute data report ($N \leq 10$ 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 bellow.

(a) Wind direction and wind speed

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

- wind direction = 00 and wind speed ≠ 00;
- wind direction ≠ 00 and wind speed = 00;
- 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};

(c) Air temperature and present weather

Both elements are considered suspect when:

- air temperature > +5°*C* and precipitation type is from {6, …, 12};
- air temperature < -2°*C* and precipitation type is from {2};
- air temperature > +3°*C* and precipitation type is from {3};
- air temperature < -10°*C* and precipitation type is from {3};
- air temperature > +3°*C* and obscuration is from {2} or

  (obscuration is from {1} and character of obscuration is from {4});

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

The values for visibility and weather are considered suspect when:

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

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

Clouds and weather are considered suspect when:

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

(f) Present weather and duration of precipitation

Present weather and duration of precipitation are considered suspect when:

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

(g) Cloud information and precipitation information

Clouds and precipitation are considered suspect when:

- total cloud cover = 0 and amount of precipitation > 0[9];

(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 checks, they should be flagged as suspect or erroneous (depending on the check) and inconsistent.

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

Symbolic name	BUFR Descriptor
Wind direction	0 11 001
Wind speed	0 11 002
Wind gust (speed)	0 11 041
Air temperature	0 12 101
Dew point temperature	0 12 103
Total cloud cover	0 20 010
Visibility	0 20 001
Precipitation type	0 20 021
Precipitation character	0 20 022

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

Precipitation duration	0 26 020
Weather phenomenon	0 20 023
Obscuration	0 20 025
Character of obscuration	0 20 026
Amount of precipitation	0 13 011
Sunshine duration	0 14 031

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 had been treated. Therefore data, passing through QC, should be flagged. 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.

References

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