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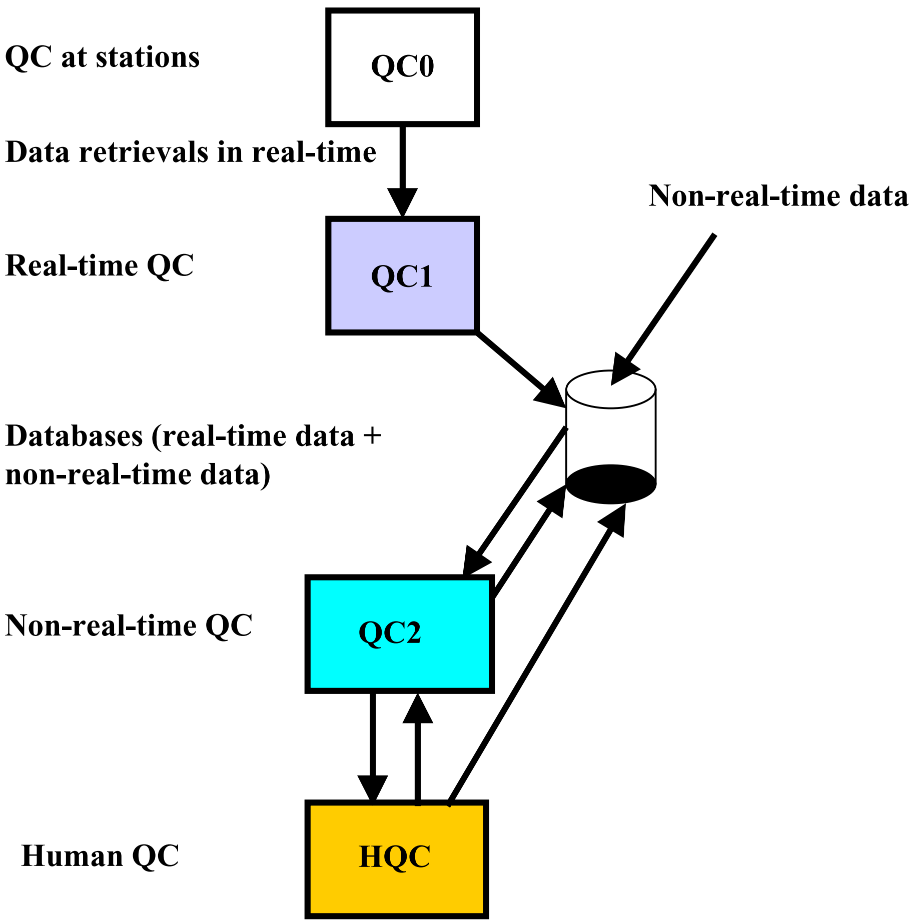
Quality Control of Meteorological Observations

Automatic Methods Used in the Nordic Countries

Flemming Vejen (ed), Caje Jacobsson, Ulf Fredriksson, Margareth Moe, Lars Andresen, Eino Hellsten, Pauli Rissanen, Þóranna Pálsdóttir, Þordur Arason



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TITLE

Quality Control of Meteorological Observations.
Automatic Methods used in the Nordic Countries.

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ABSTRACT

This report is prepared under Task 1 in the Nordic NORDKLIM project: Nordic Co-Operation Within Climate Activities. The NORDKLIM project is a part of the formalised collaboration between the NORDic METeorological institutes, NORDMET.

The report focuses on the best automatic quality control methods of meteorological observations practiced in the Nordic countries. Two groups of methods are presented: single station methods, where data from one station at a time are analysed, and spatial methods that use data from several stations. Single station methods are suitable for real-time quality control (QC1). Spatial methods are used mainly in non-real-time (QC2) as data from a sufficient number of stations are required, but also in real-time when data from numerical weather prognosis are used (QC1).

Basic flagging principles for quality control results have been outlined. A flag value, an informative label, should be assigned to all data values to indicate their status. Detailed flagging information and related statistics should be estimated for internal use to enable a diagnosis of each step in the QC scheme, and to evaluate observation problems in order to detect erroneous stations and parameters. The flags will also inform end-users whether the observation is an original corrected/interpolated value.

KEYWORDS

Quality control, Meteorological observations, NORDKLIM

SIGNATURES

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Summary

The Task 1.2 activity on quality control methods for meteorological observations is a part of the NORDKLIM co-operation under the NMD/NORDMET umbrella. It is a new opportunity to gather experience, knowledge and methods used in the Nordic countries for quality control of meteorological observations in order to improve operational quality control methods. This document focuses on best practices in the Nordic countries on automatic methods for quality control. The main focus is on checking of temperature, pressure, precipitation, wind and humidity parameters.

Two fundamentally different groups of methods are presented; (i) single station methods where data from one station at the time are analysed, e.g. range, step and consistency checks, and (ii) spatial methods where data from several stations are analysed.

Single station methods are suitable for internal real-time quality control (QC1). For spatial checking to be carried out, it is necessary to wait until data from a sufficient number of stations have been received (QC2) or to compare with data from NWP (QC1). In QC2 more exact statistics can be applied and different kinds of data be combined, e.g. Kriging interpolation, HIRLAM analyses, mesoscale analyses, radar and satellite data.

Step checks test the change of parameter values against certain limits during a limit time period. A comprehensive step-checking scheme that has been established at DMI on the basis of a large data set, is used in order to query and subsequently check unusual, extreme and physical impossible values. For checking of temperature, wind speed and relative humidity, a dip test (step check) has been developed at DNMI to find outlier values in data series.

Consistency checks comprise a large group of simple or complex algorithms for testing of related parameters, which enables flagging for certain and possible errors. For example, DNMI has developed an efficient consistency algorithm for tracking of several kinds of errors on precipitation, snow depth, snow cover and weather type.

At SMHI a special single station algorithm using input from present weather sensors, is used to check for various error conditions on Geonor rain gauge recordings, especially for identification of false precipitation signals.

An integrated QC system for real-time checking is in operation at SMHI. Before entering HIRLAM, observations are checked by single station methods and other tests in order to give an initial decision on the data quality. The most important check is the comparison between the observed value and a short-range forecast (e.g. 6 hours). This process detects about 90% of the errors, but increases the risk of eliminating correct observations e.g. in explosive cyclogenesis. Consistency checks (OI, 3D-VAR) are performed. This means that observations that deviate significantly from the analysis may be eliminated. This is an implicit check using neighbouring observations and HIRLAM analysis. An observation may be flagged as suspect when values regularly depart significantly from the short-range forecasts. In this case, a sometimes automatic, but more often manual decision to blacklist, semi-permanently remove, the station can be taken. At DNMI, short time prognostic values are used to check observations.

A non-parametric spatial checking method, the Madsen-Allerup method developed at DMI, tests for outliers in precipitation data, and is a fast method for easy comparison of neighbour stations. It works well in rather homogeneous areas, but may not work well in mountainous regions.

At SMHI manually observed precipitation sums is checked and corrected on the basis of "micro statistics" comparing observations from neighbouring stations. Logical errors can be corrected automatically, while errors without logic explanation are subject to manual inspection.

At DNMI is used a double exponential correlation weighted interpolation method, by which observations exceeding certain range values are highlighted and listed for manual control. The method is less accurate for precipitation, but otherwise experiments have shown good results.

At FMI Kriging interpolation is used to compare measured and expected values of specific parameters. Various physical effects are dealt with by the interpolation, e.g. the height and the effect of the sea and lakes on each station. Stations with continuously big differences are manually checked.

At SMHI mesoscale analyses are used for spatial checking. The program is called QC MESAN and is controlling observations close to real time. MESAN is a mesoscale analysis of surface parameters and clouds. Optimal interpolation is used for the analysis. MESAN is also taking care of the normal divergence from the reference value for an observation depending on the weather situation and the position of the observation site. HIRLAM data are normally used as first guess fields, and observations are taken from synop, metar, climate stations, automatic weather stations, satellite and radar.

In QC MESAN the original observation will be flagged, if the difference between the observation and a reference value is bigger than a decided value. The reference value is taken from MESAN as an interpolated value for the decided observation site. The reference value can also be used as a corrected value. This program has been in use since August 2001 as a tool and a control program in the HQC work.

The results of the quality control have to be communicated to advanced users as well as end-users. Basic principles for flagging of erroneous and suspicious values have been outlined. Detailed flagging information and related statistics should be estimated for internal use to enable diagnoses of each step in the QC scheme, and to evaluate observation problems in order to detect erroneous stations and parameters.

Flags should at least indicate the quality level (e.g. four different values, 0-3), the method that detected data problems and the reason of error. Flagging codes should in an easy way tell the end-users if the observation is the original value or a corrected/interpolated value.

Flagging information can be extensive. To get a more effective HQC system the flagging information needs to be presented in an easy and clear way to handle the suspected wrong observations correct and to avoid exclusion of extreme weather phenomena. How to improve HQC systems will be the main task for further co-operation in Nordklim.

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Abbreviations

3D-VAR	three dimensional variables (volume)
4D-VAR	four dimensional variables (volume and time)
ACOR	Automatic correction (DNMI)
ADP	automatic data processing methods
AMDARs	Aircraft Meteorological DAta Relay (SMHI)
AWS	automatic weather station
BUFR	Binary Universal Form for the Representation of meteorological data
CHE_SYNOP	a SMHI observation checking program
CLIMATE	monthly tests at FMI
CREX	the ASCII version of the binary BUFR representation
DECWIM	spatial checking by double exponential correlation weighted interpolation
DMI	Danish Meteorological Institute
DNMI	The Norwegian Meteorological Institute (new abbreviation is met.no)
ECMWF	European Centre for Medium Range Weather Forecasts
FMI	Finnish Meteorological Institute
GIS	Geographical Information System
GTS	Global Telecommunication System
HIRLAM	HIgh Resolution Limited Area Model
HQ1	manual inspection of QC1 level data
HQ2	manual inspection of QC2 level data
HQC	human quality control on all levels
HYB	semi-automatic weather station
KLIBAS	Report series at DNMI (Climatology Division) concerning data flow and control items
KVALOBS	a quality control project at DNMI
Linewise/Mogul telephone	automatic observation collection system from MAN stations using a common
MAN	manual weather station
Mandat	a SMHI system for automatic collection of observations from MAN stations
MESAN	a SMHI system for mesoscale analysis using a first guess from Hirlam
Metadata	meteorological station information
METCOM	meteorological communication system, SMHI, today MSS=Messir system
MIOPDB	operational data base at DNMI
NCEP	National Centre for European Prognosis
NMD	Nordic Meteorological Directors meeting
NMS	National Meteorological Services
NORDKLIM	Nordic co-operations within climate activities
NORDMET	the formalised collaboration between the NORDic METeorological institutes
NWP	short range (3-9 hr) Numerical Weather Prediction forecast (first guess)
PWS	Present Weather Sensor
OI	Optimum Interpolation
QC0	quality control at station site
QC1	real-time on-line quality control
QC2	non real-time quality control
QC	quality control of meteorological observations

RMS	Root Mean Square
SATOBs	SATellite OBservations
SMHI	Swedish Meteorological and Hydrological Institute
SYNCHE	a SMHI program for real-time synoptic observations checking
SYNO_KONTR	Quality control programmes routinely used at DNMI
SYNOP	a synoptic observation from an AWS, MAN or HYB station
SYTAB	a program developed at SMHI for checking of temperature parameters stations
TELE	Temporary database table at DNMI containing real-time synoptic observations
TEMP	METEO radiosonde station data
TEMPCHE	a SMHI program for checking other kinds of observations
Tis	a SMHI program for temperature interpolation and checking
Tisnoll	a SMHI program for temperature interpolation and checking
TTSI	Topographical Thiessen Statistical Interpolation
VI	The Icelandic Meteorological Office
WMO	World Meteorological Organisation
VViS	a SMHI system for spatial/temporal quality control of road stations

1. Introduction and background

This document focuses on practices and recommended quality control methods of meteorological observations including: step checking, consistency checking, and spatial checking methods. Range and limit checks will not be presented because range values depend on local climate conditions and can not generally be used. Flagging principles and methods will be presented and discussed. The report focuses mainly on automatic quality control.

The presentations and discussions concentrate on the most important meteorological parameters in the following priority order;

- temperature, pressure and precipitation (1^{st} important parameters),
- wind parameters (2^{nd} important),
- humidity parameters (3^{rd} important).

The Task 1.2 activity on quality control methods for meteorological observations is a part of the NORDKLIM co-operation under the NMD/NORDMET umbrella. It is a new opportunity to gather experience, knowledge and methods used in the Nordic countries for quality control of observation data.

The main purpose is to develop more effective data checking methods, to create recommendations for different phases of quality control, and to formulate general guidelines for flagging data. Within this co-operation, quality control systems at the Nordic meteorological institutes have been reported by Rissanen et al. (2000).

During recent years, station automation and increased data transmission speeds are steadily progressing. Due to increased observation frequency, huge amounts of data are received and delivered from NWS's. Fast and effective quality control for identification and flagging of errors or suspicious observations is needed to provide fast access to information, and dissemination of as reliable observations as possible to the users. Generally, the goals for quality control systems development are as follows:

- to make quality control more effective and closer to real time
- to identify calibration, measurement and communication errors as close to the observation source as possible
- to focus on automatic quality control algorithms development
- to develop a comprehensive flagging system to indicate data quality level
- to make it easier for data users to identify suspicious and erroneous data, and to highlight corrected values

Generally, the quality control can be done by numerous methods, which can be classified according to the basic methodology and requirements to organisation of data:

- analysing data by using self diagnostic methods in the equipment to monitor actual conditions
- analysing data from one station, either instantly or temporally
- analysing data from several stations (spatially), either instantly or temporally

There are different demands for time of data delivery to the end-users; some want data in real time while others can accept some delay. Consequently, there will be a different need for the level of the preceding quality control and inspection of suspicious data, and it can be split up into two phases:

- real-time quality control (QC1): All checking is done continuously for one station at a time, e.g. step and consistency checks, or comparing with numerical models
- non real-time quality control (QC2): Ann expansion of QC1 including spatial and temporal checks with multiple stations

During quality control, suspicious values or certain errors may have been identified. Flagging information should be assigned to each data element in order to indicate the level of data quality. Some erroneous and suspicious values must be inspected manually to avoid exclusion of extreme weather phenomena. Data corrections are mostly done manually, but some automatic methods or model output can sometimes be used. Improving HQC methods will be the main task for further co-operation in Nordklim.

2. Definitions

2.1 General overview

Various symbols and names are used to indicate the quality control level (QC0, QC1, QC2, HQC, where HQC can be divided up into HQ0, HQ1 and HQ2) and the checking types (e.g. range/limit, step, consistency, spatial and homogeneity checks). Naming guidelines of meteorological parameters and checking algorithms are defined in order to make it possible to specify any checking algorithm and parameter name.

2.2 Definitions of data types

2.2.1 Real-time data

Real-time data are observations retrieved by automatic data processing (ADP) methods from the site in real time, or almost in real time, and transmitted to a collecting centre instantaneously and delivered to users. For instance, synoptic messages and AWS data are considered real-time data. It is difficult to define an exact time limit for an acceptable delay in the receipt of data from the stations. A straightforward definition could be that real-time data are observations that may have been subjected to automatic quality control, but are received early enough to be used by real-time data users, e.g. forecasters. Warning systems data should be received as quickly as possible while other end-users do not need data as fast.

2.2.2 Non real-time data

According to the previous definition of real-time data, non real-time data are observations that are received later than for example 10 minutes after the observation time. Typically, this is data from automatic or hybrid stations delayed due to interruptions in data transmission, or data from manual stations, for example manual precipitation stations that send the observations by mail.

2.2.3 Metadata

Metadata are various kinds of information about meteorological stations such as: general station information (e.g. geographical co-ordinates, addresses, personnel), station history, sensor history (e.g. calibration, repairs), description of station environment (vegetation, terrain, exposure, etc.), kind of equipment, state of station, service information and plans, sensor statistics (e.g. frequency and kind of error), station statistics, station climate, software versions, and references to documentation.

2.3 Definitions of quality control levels

2.3.1 QC0 - quality control at station site

QC0 is performed at the station site by correction programs that are developed by the met office or the manufacturer. On-site quality control procedures include:

- site evaluation
- installation of instruments
- installation of data collection and transmission systems (hardware and software)
- quality control methods
- self-diagnostic systems

- instrument service
- personnel training

QC0 may include quality flagging. Some automatic stations produce error reports attached to the messages they send. QC0 may be fully automatic or involve human resources, i.e. the observer. A fundamental statement is that "data quality starts at the site".

Types of quality control methods that can be implemented on-site are range, step and consistency checking.

2.3.2 QC1 - Real-time on-line quality control

QC1 is automatic checking of real-time data performed on-line on a station-by-station basis. Because observations from neighbouring sites are not necessarily available in real-time it is not possible to use interpolation methods. Furthermore, observations arrive at the NMS's in random order, which makes the use of data from neighbouring sites impractical in the real-time window.

Methods for checking data values at the QC1 level are mainly based on the following methods:

- range and limit checks based on statistical limits
- step checks for control of parameter value changes
- internal consistency checking
- checking missing values and syntax control
- checking methods comparing observed and expected values, the latter derived from numerical forecast models, e.g. HIRLAM

At this quality control level, preliminary flagging for values, that are suspicious or certainly in error, can be included in order to prevent the use of totally erroneous data and warn the users.

2.3.3 QC2 – non-real-time quality control

QC2 is automatic data checking after real time. This definition implies that observations from neighbouring sites are normally available during quality control. This enables spatial analyses of data through a variety of checking methods, for example interpolation methods. Tests from QC1 can be applied at the QC2 level. More exact statistics can be applied in this part of the quality control, for example by using interpolation methods such as Kriging or HIRLAM analyses, special products, mesoscale analyses that may use parameter fields of prognosis models, radar and satellite data.

Comprehensive quality data flagging should be included in this phase as much as possible. Correction methods could be included in QC2. Missing data will be detected, and it is possible to calculate or interpolate values to compensate for missing data.

2.3.4 HQC - human quality control

Manual quality control can be done on all levels. HQ0 is done at station level. HQ1 includes manual inspection of errors and suspicious values that have been identified at the QC1 level, while HQ2 includes inspection of values found at the QC2 level. HQC can include inspection at any level.

After quality control at a certain level, databases may include some unresolved errors in observation data. HQC is the final phase in quality the control procedure. The purpose of manual inspection is to examine only erroneous or suspicious values, and a comprehensive flagging will allow the map representation of erroneous, suspicious and modified values. A manual control system can be used to modify and accept values and these modifications in turn will affect the flagging.

HQC can be done in many different ways; for instance, it could be based on various paper formats, error lists and possibly graphical fields, and on the other hand it could be based on a GIS system for interpretation of flagging and data values by maps and tables. Visualisation of data is very important, e.g. sums, graphical presentations of data, observations of neighbouring stations etc. Currently, GIS tools are only slightly used.

From the HQC phase it should be possible to return to the previous quality control phase in order to check and trace modifications.

2.4 Definition of checking types

Figure 2.1 presents a general overview of data flow from the station site through quality control procedures to human inspection and possible correction, resulting in data storage in a database. Quality control is simply a matter of comparing measured and expected values, i.e. what is acceptable before a value is assumed suspicious or in error. The definition of quality control could be clarified by classifying control methods into three general groups:

- self-diagnostic techniques to identify instrument related errors in automatic equipment
- 'traditional' methods such as single parameter checking, interpolation and test statistics
- methods used on long time series of data, for example homogeneity tests

Some parameter types may contain systematic errors of significant magnitude, and corrections must be applied before using the data quantitatively. A good example of this is measured precipitation that is affected by several sources of error such as wind speed, wetting and evaporation. The magnitude of these errors can be significant at high wind speeds, especially for solid precipitation, but fortunately, corrections can be calculated by well established correction methods (e.g. Allerup and Madsen, 1980, Förland et al., 1996, Allerup, Madsen and Vejen, 1997, WMO, 1998).

2.4.1 Requirements for data organisation

A general overview of the data flow in quality control is shown in figure 2.1, starting at collection sites, continuing with automatic quality control and resulting in database storage. Three main groups of quality control methods are shown: checking of equipment and observations at the station site by self diagnostic methods in order to monitor the actual conditions, classical QC methods, e.g. spatial, limit, step and consistency tests, and QC of time series by homogeneity testing. It may be necessary to apply corrections for systematic errors before performing quality control, for example on precipitation data.

The quality control methods discussed in this report will focus on techniques for QC0, QC1 and QC2, i.e. classical QC, but not on instrument error detection, homogeneity tests of time series and correction of systematic errors.

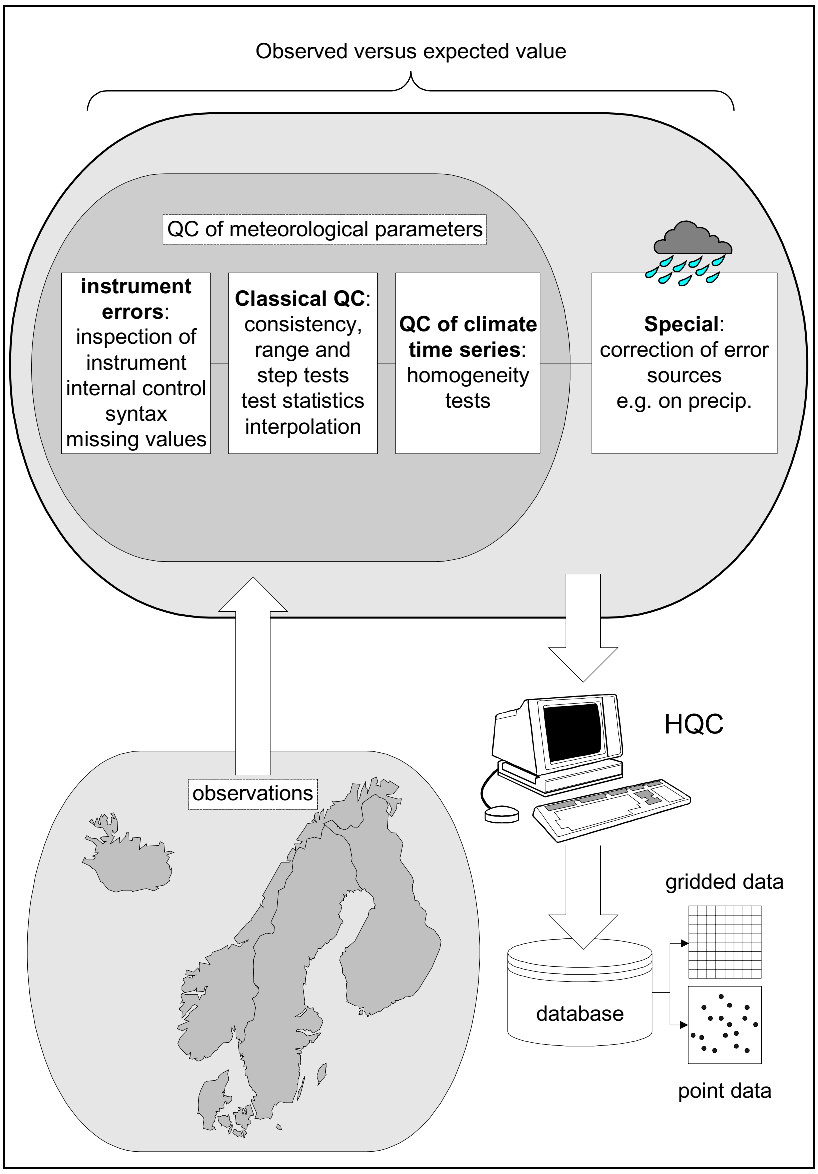


Figure 2.1. Visualisation of the flow of data is shown starting at the collection sites and ending with storage in databases either as point or grid data. Different levels of quality control include: automatic checks at station sites, other automatic checks, human quality control and correction of wrong values.

The methods in figure 2.1 can be classified according to their requirements for data organisation. Before entering a control method, data can be organised into two fundamentally different forms:

- *Type (A) data*: $\{X_{t1},...,X_{tN}\}$, where t1 to tN are time steps in the X-series of a single station, i.e. instant observations or time series for N time steps at one station, only.
- *Type (B) data*: $\{X_{t1,k1},...,X_{tN,kK}\}$ where X is a matrix of data containing N time steps of K stations.

Methods using data of type (A) cannot be used in spatial analyses, but can be used in temporal analyses and checking instant values, while methods using data of type (B) can be used for temporal as well as spatial analyses. Type (B) data allows more complex quality control analyses.

According to the two forms of data organisation, there are two main classes of methods:

A: *single station methods* using data from *one station*, instant observations (1) or one time series (2)
B: *spatial methods* using data from *more than one station*, instant observations (1) or time series (2)

Each of the (1) and (2) subgroups can be divided into:

a: only one parameter is involved in the control method,
b: two or more parameters are involved.

Table 2.1 shows the exact definition of data type classes, and table 2.2 is shows examples of temperature checking algorithms.

Table 2.1. Classification methods according to the requirements for organisation of data: the abbreviations for data classes are explained in the text. For naming guidelines for checks: see appendix A.

data class	number of stations	temporal resolution	number of parameters	classes of methods
A1a		instant observations	1	range checks
A1b	one		≥2	consistency checks
A2a	station	time series	1	step checks
A2b			≥2	step consistency checks
B1a		instant observations	1	spatial checks
B1b	two or more		≥2	spatial consistency checks
B2a	stations	time series	1	spatial/temporal checks
B2b			≥2	spatial/temporal consistency checks

Table 2.2. Examples of methods related to temperature checking at DNMI where k_1-k_{10} are test values, mostly climatological or based on experience. Ta=air temperature, Tan=minimum air temperature, Tax=maximum air temperature, and particularly: Tax_12h=maximum air temperature over a 12-hour period, Ta_12h_{max}=highest observed air temperature within the period. The indices mean: j=current observation, j-1=previous observation, ipol=interpolated value, obs=observed value, stati=statistical value, num=value from a numerical model. These kinds of checks are explained in more detail in appendix A.

method group	test algorithm		kind of check
A1a	Ta, Tan, Tax < k_1	Ta, Tan, Tax > k_2	range
A1b	Tax < Ta	Tan > Ta	certain consistency
A1b	Tax – Ta > k_3	Ta – Tan > k_4	probable consistency
A2a	$\lvert Ta_j - Ta_{j-1} \rvert > k_5$		step
A2b	$Tax\_12h < Ta\_12h_{max}$		certain step consistency
A2b	$\lvert Tax_j - Ta_{j-1} \rvert > k_6$		probable step consistency
B1a	$\lvert Ta_{ipol} - Ta_{obs} \rvert < k_7$		spatial interpolation
B1a	$\lvert Ta_{stati} - Ta_{obs} \rvert < k_8$		spatial statistics
B1a	$\lvert Ta_{num} - Ta_{obs} \rvert < k_7$		spatial numerical prognosis
B1b	$\lvert (Tax - Ta)_{num} - (Tax - Ta)_{obs} \rvert < k_8$		probable spatial consistency
B2a	$\lvert [Ta_j - Ta_{j-1}]_{num} - [Ta_j - Ta_{j-1}]_{obs} \rvert < k_9$		spatial step using prognosis
B2b	$\lvert [Tax_j - Taj_{-1}]_{num} - [Tax_j - Ta_{j-1}]_{obs} \rvert < k_{10}$		probable spatial consistency

Widely used QC methods are climatological limit checking, physical limit checking, homogeneity, run, trend, difference sign test and double mass test, as well as Kriging interpolation, statistical optimal weights, fixed weights, median, simple average, Thiessen weighted average, HIRLAM and TTSI, some of which are described in chapter 3 and 4.

If data are organised as type (B), the statistical procedures can be verified. Furthermore, complexity can be introduced into the statistical methods. Unlike type (A) data, type (B) data make it possible to calculate statistical characteristics such as covariance and correlation, and then accuracy and confidence limits of the statistical procedure can be estimated. The statement 'spatial/temporal' checks in table 2.1 (data of type B2) should be understood in the general sense. On one hand it covers checking methods based on interpolation, and on the other it covers methods that use checking of the consistency of parameter changes by comparing neighbouring stations. If both the temporal and spatial data structure is considered for type (B) data as in special interpolation methods, spatial correlation functions can be estimated. If interpolation is done on the basis of spatial analyses only, such functions must be assumed or even ignored. For data of type (A) none of such kinds of analyses can be done. Quality control accuracy requirements suggest which control procedure should be used.

Figure 2.2 shows classes of methods that can be used for analysing data of type (A) and (B), either methods analysing data from one station (instantly or temporally) or methods analysing data from more than one station (instantly or time series, i.e. spatial and temporal analyses). Some methods are based on type (A) data, e.g. self diagnostic methods in the equipment that monitor the actual conditions, climatological limit tests, step checks and consistency checking, while type (B) data are used by interpolation methods such as Kriging, numerical model interpolation and test statistics algorithms.

2.4.2 Definition of limit and step check

In a limit or range check an observation is always compared to previously defined limit values. In a step check temporal changes are compared to step limit values. If the check implies control of one parameter only, it is a pure step check. If the check implies control of two or more parameters, it is a consistency check (of time series or instant values). Limit and range checks can be divided into a check for physically impossible values (certain errors) and a check for very unusual values (probable errors) that may be wrong, e.g. values with a return period of years.

2.4.3 Definition of consistency checking

In a consistency check an observation is compared with other parameter values to see if they are physically or climatologically consistent, either instantly or for time series according to adopted observation procedures. A check for illegal parameter value combinations is called certain error detection. A check for unusual parameter value combinations, e.g. caused by an unusual weather situation, is called probable error detection, and returns a warning.

The check always includes two or more different parameters from a single station. For example, if a step check is supplied with other parameter types, it becomes a consistency check. Following this definition, a step check comparing present and previous measurements of a parameter, e.g. air pressure, is still a step check, but if present and previous air pressure is compared with pressure tendency it becomes a consistency check.

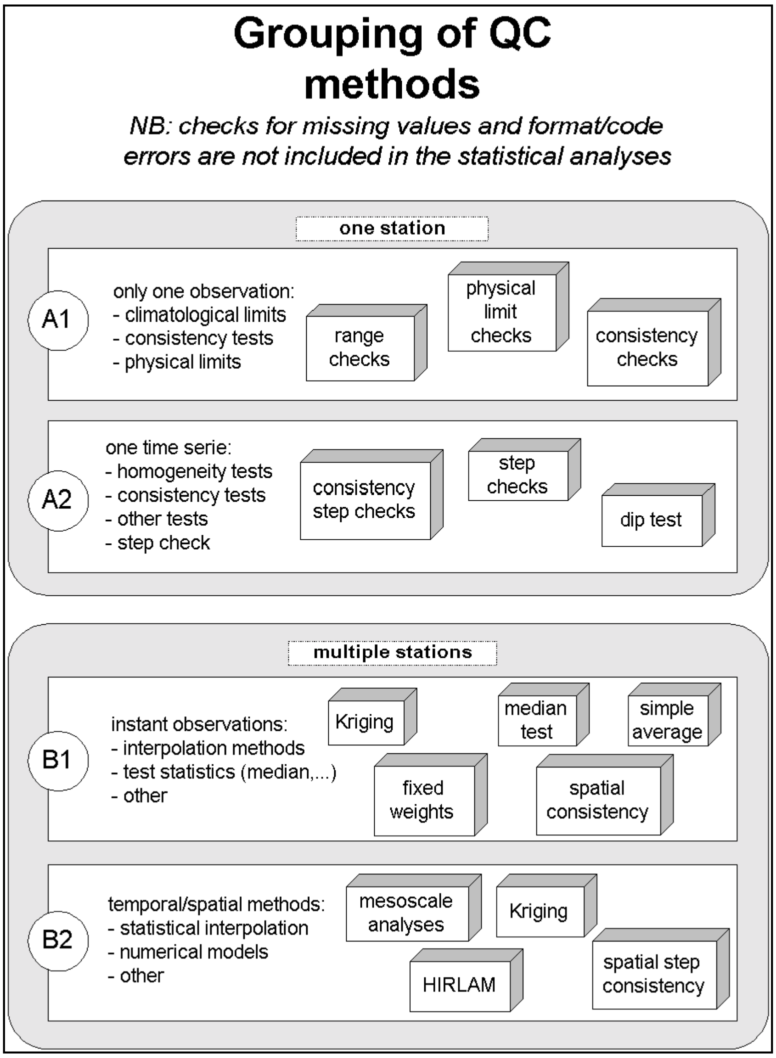


Figure 2.2. Classification of quality control methods is shown according to the way of organising data, among which typically methods are mentioned.

2.4.4 Definition of spatial checking

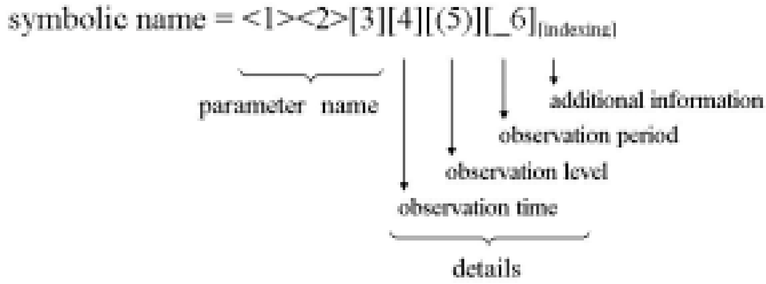
In spatial checking the observation is compared with the expected value at the station which can be estimated by various methods. Spatial checks involve parameter values of neighbouring stations, either by interpolation between observations by checking against numeric prognostic values (on the basis of values from many different stations), or by comparing statistics. The checks can involve more than one parameter at one point in time, or single or multi-parameter analyses of time series.

2.4.5 Definition of homogeneity checking

Homogeneity checks consist of a variety of control methods to unveil if data series are homogeneous or not during a long period of time. Such control methods are based on statistics of different kinds (e.g. internal consistency checks, Nordli, 1997), tests for detecting change points (e.g. Pettitt test, Sneyers, 1995), comparison of statistics from neighbouring stations (e.g. Standard Normal Homogeneity Test, Alexandersson, 1986) and historical metadata checking (e.g. inspection reports from weather station).

2.5 *Symbolic parameter names*

Below is a description of the definition system for symbolic parameter names:



where <1><2>[3] comprise the main parameter name (see table 8.2 in appendix A), while [4][(5)][[_6] represent various details about the parameter (see table 8.3 and 8.4 in appendix A). A detailed explanation of the definition of symbolic names is found in appendix A.

The brackets [ ] mean that the letter is required, while < > means optional. The first letter in the symbolic name, <1>, is always in uppercase. The indexing is used to indicate special characteristics about a parameter, e.g. Ta_{i-t}=the previous air temperature, and Ta_{max}=the highest value of Ta having been measured within a certain period of time.

Symbolic names for all parameters in the report are defined in appendix A in table 8.2, 8.3 and 8.4.

2.6 *Symbolic names of checks*

Any check is given a symbolic name according to the following definition (details are given in appendix A):

<QCL><t><inst>[(ver)]–<*par1>[,[*]par2][,...]

<>	=	parameter is required
[]	=	parameter is optional
QCL	=	QC level (QC0, HQ0, QC1, HQ1, QC2, HQ2, HQC)
t	=	type of quality control method (details below)
inst	=	abbreviation of institution, e.g. DNMI, VI, SMHI, FMI, DMI
(ver)	=	version number of checking algorithm if more than one version exists
*	=	indicates the parameter (or parameters) being checked (further details in text)
par1	=	one parameter used in the checking
par2	=	another parameter also supporting the checking

Several parameters can be specified in the symbolic name for a check. The parameter or parameters being checked and subsequently flagged are indicated by an asterisk. Parameters without asterisks are supporting parameters.

The type of QC method, t, comprises one or more letters of which only the first is required:

t = <M>[m_1][m_2][(d)]

M	=	main method group
m_1 and m_2	=	details about the method
d	=	indicate whether a check is a certain (c) or probable (p) error detection

The following letters are used to indicate the QC methods reported in this document:

Single station methods:	r	=	range/limit checks
	c	=	consistency checks
	s	=	step checks
Spatial methods:	i	=	spatial checking based on interpolation of observations
	n	=	spatial checking based on numerical models
	t	=	spatial methods based on test statistics
	p	=	other spatial checking methods

3. Selected single station checking methods

This chapter discusses automatic quality checking methods. Data checked with single station methods are type (A), i.e. time series parameters from one station only. Methods using type (A) data cannot perform spatial analyses, but can accomplish temporal analyses and various kinds of checking of instant values. Simple temporal analyses are for example step checks, and checking of instant values, limit/range checks and consistency checks. Except for limit/range checks various single station checks will be presented as follows.

Single station tests can be applied immediately after data is received from a station, which makes these tests useful for real-time data checking.

Some instrument manufacturers include internal checks (test algorithms) of sensors with error reports in their products. These results can be used in on-site quality control (QC0) and also later in QC1. In some cases, suspicious observations are deleted automatically by these test algorithms. Corrections are not usually made automatically at the site.

Calibration, on-site self-diagnostic checking by equipment software and metadata maintenance of metadata is not discussed. Range and limit checks are not discussed, because the limit values depend on the local climate conditions. Missing value and format checking are not addressed because they depend on local data formats. Code checking, for example checking of synoptic code format, is not discussed either. The coding rules are defined by WMO (Manual on Codes, WMO-No. 306 (1995)), and checking is related to this standard format.

In appendix A and B tables are shown that summarise the various checks used for quality control of data from single stations in the Nordic countries.

3.1 Step checks

A step check is a temporal check that in some way can be called a limit check that uses a climatological record of how much various parameters can change within a certain period of time, e.g. limits for temperature changes during 3 hours. For some parameters such as temperature, the limits depend on climate conditions. For other parameters such as changes in pressure, the changes may be less sensitive to local climate.

Step checks can distinguish between a pure check for physical impossible values (certain error) and a check for climatological very unusual values (probable error). In the following, various step checks from the Nordic countries are presented.

3.1.1 General step checking at DMI

Generally, two sets of limit values are used for step checking: (i) limits for very unusual values with a return period of up to several years (u, U), and (ii) limits for physical impossible values (i, I).

Probability distributions have been established on the basis of a large data set in order to estimate limits for unusual and impossible values. The philosophy has been to estimate what the magnitude of the limit value should be to fulfil the criterion that only a small quota $z^0/_{00}$ of all data are allowed to exceed the limit value (in the lower and upper part of the data distribution). The reason to use limits of type (i) is that, very often, erroneous data values do not exceed the physical limits even though they are in error. In this way more errors can be flagged as suspicious before dissemination. This does not prevent true values from being flagged, and the correct term for it is “flagging for an unusual or erroneous value”.

It seems reasonable to check whether a parameter is close to record values, i.e. the extreme $z^0/_{00}$ part of all data, so that the extremely unusual value can be queried and checked shortly after it occurs. Since there is usually seasonal variation in most of the parameters, separate limits for step and range checks have been established for each month of the year.

The limit values, i, for physical impossible values, have been established based on analyses of distributions, examination of climatological statistics and extreme weather events, as well as using general meteorological theory and experience. The difficult part of it has been to identify reasonable values Δ in order to define limits i and I for physically impossible values given by $i_m=r_m-\Delta$ and $I_m=R_m+\Delta$, where r/R_m are the record values for a parameter during a specific month m. Necessarily, Δ must be large enough that the limit value cannot be surpassed, even in exceptional cases.

Figure 3.1 shows a histogram of all maximum temperatures in May 1979-2000 (while not the step distribution, it is shown for illustration). The vertical lines mark the limits for unusual values, record values and impossible values. Figure 3.2 shows the probability distribution.

The range limits are given by: $i_m=r_m-\Delta<r_m<u_m<U_m<R_m<R_m+\Delta=I_m$, where i,r,u are the lower and I,R,U are the upper limit values. For step checks there are only positive limit values and no minimum records, i.e. $0<U_m<R_m<I_m$.

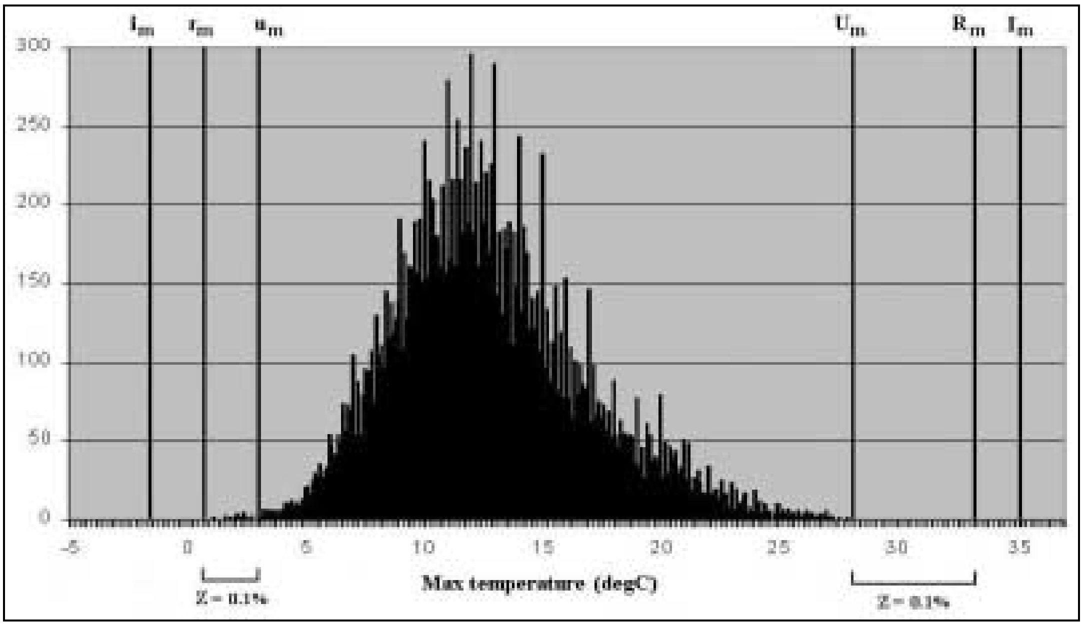


Figure 3.1. Histogram for maximum temperatures in May, Denmark, i,I=impossible values, r,R=record values and u,U=unusual values for a specific month m, in this case in May.

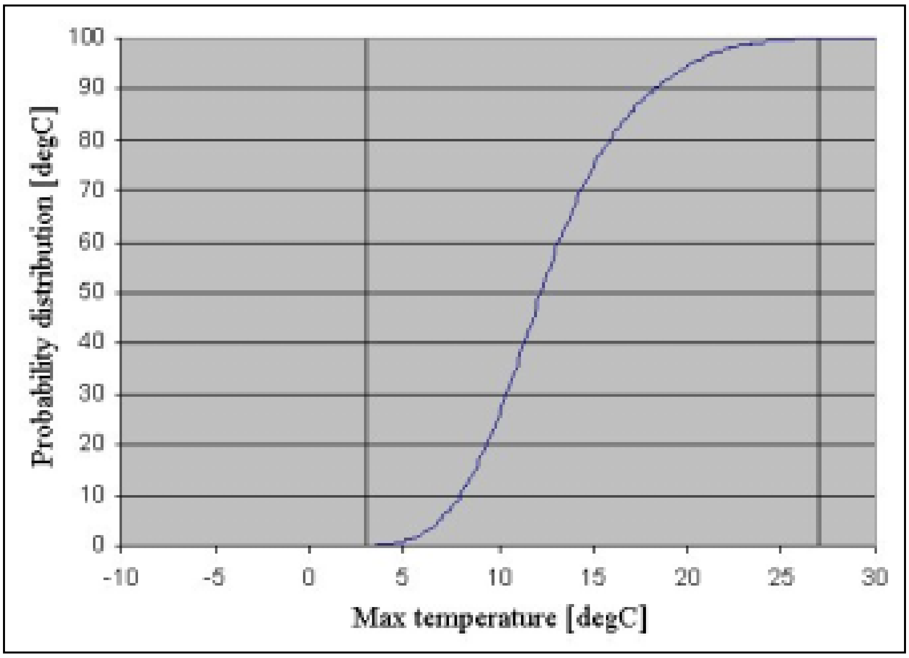


Figure 3.2. Probability distribution for maximum temperatures in May, Denmark.

Limit values for step checks have been established for temperature, humidity, wind speed and pressure for changes over 10-minute and 1-, 3- and 6-hour periods. Examples of step limits for Denmark are shown in table 3.1.

Table 3.1. Examples of limit values for step checks in Denmark. The step limits are valid for 1- and 3-hour periods. The flagging values are: 3=certain error, 2=probable error or unusual value.

Step check limit values

Parameter	period	flag	J	F	M	A	M	J	J	A	S	O	N	D
	1 hr	3	> 8	> 8	> 8	> 7	> 5	> 5	> 5	> 5	> 7	> 8	> 8	> 8
Ph [hPa]	3 hrs	3	> 25	> 25	> 25	> 20	> 15	> 15	> 15	> 15	> 20	> 25	> 25	> 25
	1 hr	2	> 4	> 3	> 3	> 2	> 2	> 2	> 2	> 2	> 2	> 3	> 3	> 4
	3 hrs	2	> 10	> 10	> 8	> 6	> 5	> 5	> 5	> 5	> 6	> 8	> 9	> 10
	1 hr	3	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15	> 15
Ff [m/s]	3 hrs	3	> 20	> 20	> 20	> 15	> 15	> 15	> 15	> 15	> 15	> 20	> 20	> 20
	1 hr	2	> 7	> 7	> 6	> 6	> 6	> 6	> 6	> 6	> 6	> 7	> 7	> 7
	3 hrs	2	> 10	> 10	> 10	> 10	> 10	> 10	> 10	> 10	> 10	> 10	> 10	> 10
	1 hr	3	> 6	> 6	> 6	> 7	> 8	> 8	> 8	> 8	> 8	> 7	> 6	> 6
Ta [°C]	3 hrs	3	> 11	> 11	> 12	> 13	> 14	> 14	> 14	> 14	> 13	> 13	> 12	> 11
	1 hr	2	> 3	> 3	> 3	> 4	> 4	> 4	> 4	> 4	> 4	> 4	> 3	> 3
	3 hrs	2	> 6	> 6	> 7	> 8	> 8	> 8	> 8	> 8	> 8	> 7	> 6	> 5

3.1.2 Temperature checking

3.1.2.1 The dip test of temperature, wind speed and relative humidity (QC2sDNMI1-Ta,Ff,Uu)

At DNMI the following method has been used on temperature, wind speed and relative humidity data from automatic stations on hourly basis.

This is a dip-test used to find outlier values in series of any geophysical parameter with a continuous distribution. The sampling rate must be constant.

Given a positive real number δ depending on the physical parameter *x(t)* in question, an observation $x_i = x(t_i)$ which satisfies the condition

$$(x_{i-1} - x_i)(x_{i+1} - x_i) > \delta^2 \tag{3.1}$$

is regarded as suspicious and may be rejected.

The dip-test is associated with the implicit curve $xy=\delta^2$ that is the hyperbole scaled with a factor δ^2.

For a test T of the type where an observation x_i is rejected due to $\mathrm{T}(x_i - x_{i-1}, x_{i+1} - x_i)$ being greater than some constant δ independent of x_i. The area:

$$\Omega = \{(x, y) : T(x, y) > \delta\} \tag{3.2}$$

is defined as the rejection area of the test.

<u>The dip-test is modified to handle non-uniform sampling:</u>

Given a positive real number δ, an observation $x_i = x(t_i)$ should be marked suspicious if

$$\left(\frac{x_{i-1} - x_i}{t_i - t_{i-1}}\right)\left(\frac{x_{i+1} - x_i}{t_{i+1} - t_i}\right) > \delta^2 \tag{3.3}$$

<u>Uniform sampling with missing values:</u>
If samples of a continuous parameter are taken uniformly in time, that is $t_{i+k} = t_i + k$, this formula is reduced to:

$$\frac{(x_{j-m} - x_j)(x_{j+n} - x_j)}{mn} > \delta^2 \tag{3.3}$$

where $x_{j-k}, k = 1,2,...,m-1$ and $x_{j+r}, r = 1,2,...,n-1$ corresponds to missing values.

The dip test should only be applied in series of observations with good data coverage.

As practical values at DNMI, empirically selected values are δ = 30% for relative humidity (Uu), δ = 7.46 m/s for wind speed (Ff) and δ =5.0 °C for temperature (Ta).

This method is used for statistical purposes only as instrument maintenance information. Suspicious data is neither flagged nor corrected.

This method is recommended for checking at the QC2 level. The method is not currently in operation, and it is difficult to determine the optimal frequency.

The drawback to this method is that test (A) depends on complete data series, that is, observations must arrive uniformly in time and without missing values or values may have to be interpolated.

If one of the leaps is sufficiently small, the value will not be considered suspicious, no matter how great the other leap is. This might be avoided by further development of the dip-test:

$$\left|\frac{x_i - x_{i-1}}{t_i - t_{i-1}}\right| + \left|\frac{x_{i+1} - x_i}{t_{i+1} - t_i}\right| > 2\delta \qquad \text{and} \qquad \min\left(\left|\frac{x_i - x_{i-1}}{t_i - t_{i-1}}\right|, \left|\frac{x_{i+1} - x_i}{t_{i+1} - t_i}\right|\right) > \delta \tag{3.4}$$

With regard to practical experience and performance, the dip method efficiently detects outliers in series with good data coverage. When applying the test in a data set containing missing values, the greater the size of the gaps in the data set, the less is the chance of finding errors.

The dip-test is not currently in use because a similar test was planned for all AWS stations. At the moment this is not implemented.

Further documentation can be found in Report no. 24/93 KLIMA (Øgland, 1993).

3.1.3 Pressure checking

3.1.3.1 Step checking of pressure parameters at DNMI

At DNMI the station pressure values are checked by using time series in connection with other parameters (see section 3.2. Consistency checks) and in connection with other stations (see 3.3. Spatial checks).

3.1.3.2 Checking of pressure at FMI (QC2sFMI-Ph)

At FMI a commonly used step check of pressure (QC2sFMI-Ph) is implemented by setting a threshold for the maximum acceptable change in air pressure over for example 3 hours (se also appendix 11.1.1):

$$Ph_i - Ph_{i-3h} > 5.0 \quad [\text{HPa}] \tag{3.5}$$

Other tests within this family take a similar form with different warning limits:

$$Ph_i - \left[Ph_{i-3h} + Ph_{i+3h}\right]/2 > 2.0 \quad [hPa] \tag{3.6}$$

$$Ph_i - \left[Ph_{i-3h} + Ph_{i+3h} \right] / 2 > 4.0 \quad [hPa] \tag{3.7}$$

3.1.4 Checking of precipitation parameters

None of the Nordic countries use step tests for checking precipitation. Precipitation is not a continuous parameter, and hence it is difficult to find a relevant step test.

3.1.5 Step checking of wind parameters

See section 3.1.1.

3.1.6 Step checking of humidity parameters

See section 3.1.1.

3.2 Consistency checks

A consistency check may identify certain errors as well as possible errors. For example, if the air temperature is more than +10°C and it is snowing, the temperature or the weather type is certainly wrong. Also, a consistency check may check the relationship between dry bulb and maximum temperature.

In the following, various consistency checks from the Nordic countries will be presented by type of parameter.

3.2.1 Consistency checking of temperature parameters

The most obvious consistency checking of temperature with certain error detection is:

Ta > Tax	(3.8)
Ta < Tan	(3.9)
Tax < Tan	(3.10)

Such tests are used in all Nordic countries.

Commonly used tests with probable error detection:

Tax – Ta > k	(DNMI)	(3.11)
Tax_12h – Ta_12h$_{max}$ > k	(DNMI)	(3.12)
Ta – Tan > k	(DNMI)	(3.13)
Ta_12h$_{min}$ – Tan_12 > k	(DNMI)	(3.14)

Until now k has been one or a few fixed values determined by experience. In the future k should be statistically determined on a monthly basis.

Other tests are used to check ground temperature. Knowledge of micro meteorological vertical temperature changes are used in such tests. The following identifies certain inconsistencies:

$Tg > Ta + 2$	(FMI)	(3.15)
$Tgn - Tan = \{ j \mid 0.1 \le j \le 1.9 \}$	(FMI)	(3.16)

$(\mathrm{Tgn} - \mathrm{Tan06}) = \{ j \mid 0.1 \le j \le 1.9 \}$	(FMI)	(3.17)
$\mathrm{Tgn} > \mathrm{Tan06} + 2.0$	(FMI)	(3.18)

A physical relationship exists between dry bulb and wet bulb temperatures Ta and Tw and humidity. Small inaccuracies in the measurements can be accepted, and at low temperatures these are more likely to occur than at higher temperatures. This is one method for splitting up the test for wet and dry temperature:

$\mathrm{Ta} > -2.0$ and $(\mathrm{Tw} - \mathrm{Ta}) > 0.0$	(FMI)	(3.19)
$\mathrm{Ta} < 0.0$ and $(\mathrm{Tw} - \mathrm{Ta}) > 0.2$	(FMI)	(3.20)
$(Ta - Tw) > L_i$ where L_i = various limit values	(FMI)	(3.21)

When the total record of observations from a single station is available, more tests can be done by comparing daily values with extreme values of the corresponding month.

Tests of dew point temperature are dictated by physical laws, for example:

$\mathrm{Td} - \gamma > \mathrm{Ta}$	(DMI)	(3.22)

where γ=a tolerance threshold (0.2°C is recommended). Other tests recognise an upper limit for the difference between Td and Ta:

$\mathrm{Td} > 20$ & $\mathrm{Ta} - 15 > \mathrm{Td}$	(DMI)	(3.23)
$\mathrm{Ta} - 26 > \mathrm{Td}$	(DMI)	(3.24)

Many tests check whether the maximum or minimum temperature in a period is extreme compared to Ta:

$\mathrm{Tax} > \mathrm{Ta}_{max} + \delta$	(DMI)	(3.25)
$\mathrm{Tan} < \mathrm{Ta}_{min} - \delta$	(DMI)	(3.26)

where Ta(max) and Ta(min) are the maximum and minimum of Ta measured during the period, and the threshold value $\delta=3$ if Ta is measured hourly, $\delta=5$ if Ta is measured every 3rd hour.

Within this checking family, Ta can be tested against the average temperature Ta_{avr} of the last eight temperature observations (Ta at 2m level), where $\delta=12.9$:

$\lvert \mathrm{Ta}_{avr} - \mathrm{Ta} \rvert > \delta$	(FMI)	(3.27)

The comparison of temperature observations in a period depends on the frequency of observations. In order to make the examination of temperature independent of frequency, the threshold value can be estimated from the number, i, of previous temperature observations from the last 12 hours, as shown in the test below that checks whether Tax and Tan are extreme when compared to Ta:

$\mathrm{Tax} - \mathrm{Ta}_{max} > 30/(i+1.3)$	(SMHI)	(3.28)

$Ta_{min}–Tan > 30/(i+1.3)$ (SMHI) (3.29)

The threshold values δ in the general tests above can be modified according to climatological surveys. At DNMI other threshold values k_1 and k_2 are used in the tests $Tax–Ta>k_1$ and $Ta–Tan>k_2$, and in other cases the algorithms depend on the time of the day due to the fact that the temperature variations are different in the day and at night. Between 18z the previous day and 06z, some tests include:

$Tan06<Ta06_{min}–9$			(DNMI)	(3.30)
$Tax06>Ta06+5$			(DNMI)	(3.31)

Between 06z and 18z in the same day other tests include:

$Tan18<Ta06–5$			(DNMI)	(3.32)
$Tan18<5$	&	$Tan18<Ta18_{min}–4$	(DNMI)	(3.33)
$Tan18\geq5$	&	$Tan18<Ta18_{min}–2$	(DNMI)	(3.34)
$Tax18>Ta18+5$			(DNMI)	(3.35)
$Tax18>Ta12+5$			(DNMI)	(3.36)
$Tax18<12$	&	$Tax18>Ta18_{max}+3$	(DNMI)	(3.37)
$Tax18\geq12$	&	$Tax18>Ta18_{max}+5$	(DNMI)	(3.38)

Finally, a test for inconsistency between weather codes Ww for fog and mist and low dew point temperature has been suggested by Abbot (1986) (note that Ww is observed manually):

$Ta–Td>0.5$	&	$Ww=\{42,43,44,45,46,47,48 \text{ or } 49\}$	(Abbot)	(3.39)
$Ta–Td>1.0$	&	$Ww=\{10,11,12,40 \text{ or } 41\}$	(Abbot)	(3.40)

3.2.2 Checking of pressure

Below is a list of basic checks of air pressure, tendency and pressure change that also includes inconsistencies in the synoptic code between Pp and Pa:

$Po–Pp\neq Po_{-3h}$			(DMI)	(3.41)
$Pp<0$	&	$Pa=\{0,1,2,3,4\}$	(DMI)	(3.42)
$Pp=0$	&	$Pa=\{1,2,3,6,7,8\}$	(DMI)	(3.43)
$Pp>0$	&	$Pa=\{4,5,6,7,8\}$	(DMI)	(3.44)

According to Abbot (1986), a simple check of pressure tendency against actual and previous pressure t hours previously can be performed by:

$|Pp–(Po–Po_t)|>1$ [hPa] (Abbot) (3.45)

3.2.2.1 Checking of pressure at DNMI (QC2cDNMI2-Po,Pa,Pp)

Observers at meteorological stations in Norway use tables to find sea level pressure from station pressure and air temperature. It is then suitable to check sea level pressure from a standard reduction formula. The station pressure parameters are checked in the following way:

$\mid (Po_{t-6} + Pp\_3h_{t-6}) - (Po_t - Pp\_3h_t) \mid < 2.0$	$\Rightarrow$	No suspicious values, check is ended
If not:		
$\mid (Po_{t-6} + 2Pp\_3h_t$ (or $2Pp\_3h_{t-6}) - Po_t \mid < 2.0$	$\Rightarrow$	No suspicious values, check is ended
If not:		
$\mid (Po_{t-6} + Pp\_3h_{t-6}) - (Po_t + Pp\_3h_t) \mid < 2.0$	$\Rightarrow$	Pa suspicious and listed, check is ended
If not:		
$\mid (Po_{t-6} + Pp\_3h_{t-6}) - (Po_t - Pp\_3h_t) \mid < 2.0 \mid$	$\Rightarrow$	Pp suspicious and listed, check is ended

3.2.3 Checking of precipitation

Basic consistency checks of precipitation parameters in the synoptic code are:

Ra_3h>Ra_6h	(DMI)	(3.46)
Ra00_6h>Ra06_12h	(DMI)	(3.47)
Ra12_6h>Ra18_12h	(DMI)	(3.48)

Suspicious values in precipitation parameters can easily be identified by comparing them with weather observations in the following consistency checks. By these checks the precipitation or the weather observation is wrong:

Ww>19 & Ra=0.0	(FMI)	(3.49)
Ww<20 & Ra>0.0	(FMI)	(3.50)

For checking Ra against the present weather type Ww, the following checks result in a warning where tracer means tracer precipitation:

Ra=0 & Ww={20-27 or Ww≥50}	(DMI)	(3.51)
Ra>0 (incl. tracer) & Ww={00-19 or 28-40}	(DMI)	(3.52)
Ra={010-989} & Ww≠{59,64,65,67,69,74,75,81,82,84,86,90,92,94,97,99}	(Abbot)	(3.53)
Ra={001-989} & Ww≠{53-55,57,59,62-65,67,69,72-75,81,82,84,86,88,90,92,94-97,99}	(Abbot)	(3.54)
Ra>0 & Ww<20 (incl. tracer)	(FMI)	(3.55)
Ra>0.3 mm & no precipitation phenomena	(FMI)	(3.56)
0<Ra≤0.3 mm & no precipitation or no moist weather phenomena	(FMI)	(3.57)
Ra≤trace & Ww={63,65,73,75}	(DMI)	(3.58)
Ra>δ & Ra has come out of hoar frost, soft rime or dew, i.e. Ww={40,49}	(FMI)	(3.59)

In the last check the threshold δ is0.3 at FMI, but other NWS's use δ=0.5. If Ww=5 is reported together with high moisture and precipitation, something is wrong:

Rr_6h>0 & Wx=5 & Uu>60%	(FMI)	(3.60)

Finally, the past weather codes W1 and W2 can be checked:

W1,W2={5,6,7,8}	&	Ra=0	(or Rir=3)	(DMI)	(3.61)
W1,W2={0,1,2,3,4}	&	Ra>0	(& Rir=1 or 2)	(DMI)	(3.62)
W1,W2=9	&	Ra>0	(& Rir=1 or 2)	(DMI)	(3.63)

3.2.3.1 Precipitation checking algorithm at DNMI (QC2cDNMI1-Rr_24h,Sa,Sd,Wsp)

At DNMI the following method compares precipitation (Rr_24h), snow depth (Sa), snow cover (Sd, code 0-4 (0-100% snow covering)) and weather symbols (Ws represents present weather symbols, Wsp represents past weather symbols) to check for different errors and to give an indication of the problem.

Daily characteristics (Dkar) are computed from the weather symbols in Table 3.2, column 2-9, the change in snow depth (Sad_24h in cm) in column 10, and the precipitation grouped into "Rain", "Snow" and "Dew/Hoar Frost". Some consistency tests dependent on the daily characteristic are shown in Table 3.4. The consistency between the daily characteristics and observed precipitation amount, snow depth, snow cover and change in snow depth is tested. Suspicious observations according to inconsistencies are logged to file and the errors are described by the text in Table 3.5. Precipitation amount test limits (seasonal range) in Table 3.4 vary according to Table 3.3.

Table 3.2. Daily characteristic is based on columns 2-10.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Daily characteristics (Dkar)	**None**	**Rain**	**Sleet**	**Snow**	**Dew**	**Hoar-Frost**	**Hail**	**Thunder**	**Sad_24h**
Rain		x							
		x	x						≤ 0
		x	x	x					≤ 0
		x		x					≤ 0
			x						≤ 0
			x	x					≤ 0
					x	x	x		≤ 0
						x	x		≤ 0
					x		x		≤ 0
							x		≤ 0
Snow				x					
			x	x					> 0
		x	x	x					> 0
		x		x					> 0
			x						> 0
			x	x					> 0
					x	x	x		> 0
						x	x		> 0
					x		x		> 0
							x		> 0
Dew/Hoar frost					x	x			
					x				
						x			
None	x							x	

Table 3.3. Seasonal ranges for Rr used in Table 3.4.

Month	Seasonal Range (Rr_24h in mm)
1, 2, 3, 10, 11, 12	10.0
4	5.0
5, 9	3.0
6	1.0
7, 8	0.0

Table 3.4. 13 checks between daily characteristics, precipitation amount, snow depth, change in snow depth and snow cover.

Error no.	Daily characteristics (Dkar)	Precipitation (Rr_24h)	Snow depth (Sa)	Change in snow depth (Sad_24h)	Snow cover (Sd)
1	None	≥ 0.0			
2	≠ None	missing			
3	Dew / Hoar Frost	> 0.5			
4	(No precipitation)		> 0		< 1
5	(No precipitation)		≥ 15		= 1
6	(No precipitation)				> 4
7	Snow	> Seasonal range	≤ 0		
8	Snow	≥ 10.0	> 0	≤ 0	
9	≠ Snow			> 0	
10	Snow	$(Sad)^2 > 10*Rr\_24h + 25.0$		> 4	
11	Snow	> 1.0		< -15	
12	Rain	$(Sad)^2 > 10*Rr\_24h + 225.0$		< 0	
13	≠ Snow		≤ 0	< -15	

Table 3.5. Proposed reasons for suspicious values or errors are shown in accordance with Table 3.4.

Error no.	Text
1	Weather symbol is missing
2	Precipitation (Rr_24h) is missing
3	Not only dew / hoar frost
4	Snow cover code too low
5	Snow cover code too low
6	Snow cover code too high
7	Snow symbol without snow depth
8	Snow depth not increasing
9	Snow depth increasing without weather symbol
10	Snow depth increasing too much
11	Snow depth decreasing too much
12	Snow depth decreasing too much
13	Snow depth decreasing to 0

Some comments to the method:

- Daily observations of precipitation, snow depth, snow cover and weather symbols are required.

- Empirical values of test limits are selected.

- There is no automatic flagging. The corrections are manually flagged during the HQC-process.

- The recommended quality control level is QC2 of daily values.

- The tests are currently performed weekly or monthly, but should be performed daily.

- Negative aspects of this method are that snow depth changes due to snowdrift are not taken into account. Snowdrift should be included in the weather symbols at precipitation stations. This would make it possible to take into account in the algorithm wind effects during the winter.

- For weather stations, the temperature could be used to refine the algorithm.

- This method is an efficient algorithm to track several kinds of errors, particularly errors caused by a mismatch between the parameters; i.e. reported weather symbols and reported precipitation/snow depth. The main source of these errors is the manual delivery (observations denoted on cards sent once a week by post) of the observations once a week. The manual correction of traced errors makes it possible to correct the data series.

- This method is an efficient tool with regard to practical experience and performance. The error log tracks only real errors.

Further documentation can be found in Report no. 01/95 KLIBAS (Kjensli, Moe and Øgland, 1995).

3.2.4 Checking of wind

If the weather is calm and no wind direction has been reported, a consistency error occurs when the wind speed is above 0 m/sec, or the opposite:

Dd = 0 and Ff > 0 (DMI) (3.64)
Dd > 0 and Ff = 0 (DMI) (3.65)

Another check in this category is a comparison of 3-hour changes in wind speed and direction:

$$\left|Dd_i - Dd_{i-3h}\right| > 40^\circ \quad \text{and} \quad \left|Ff_i + Ff_{i-3h}\right| / 2 > 9 \quad [\text{m/sec}] \qquad \text{(FMI)} \qquad (3.66)$$

where index i refers to the observation time.

Slight and variable wind can also be checked with the following method, where the threshold value δ=4:

Dd=99 & Ff≥δ m/s & (Fiw=0 or Fiw=1) (DMI) (3.67)

Low wind speed reported together with drifting snow or sand can be checked by:

Ff<5m/sek & (Fiw=0 or Fiw=1) & (Ww=7 or 30≤Ww≤39) (DMI) (3.68)

It is very unlikely that the maximum wind speed value in a 3-hour period is more than 15 m/s larger than the wind speed at the beginning of the period, or that the wind speed is 8 m/s larger than the value in the beginning and the end of the period:

$Ff_{max}>Ff_{-3h}+15$	(SMHI)	(3.69)
$Ff_{max}>Ff+8$ & $Ff_{max}>Ff_{-3h}+8$	(SMHI)	(3.70)

According to the definition in the synoptic code, gusts only exist if the wind speed exceeds 5 m/s, resulting in the check:

$Fg<Ff+5$ [m/s]	(DNMI)	(3.71)

At DNMI the wind parameters Ff and Fx are checked with regard to certain error detection and with regard to correspondence between 6 hours - and previous 3 hours -, Ff and Fx, observations. Suspicious values are listed.

3.2.5 Checking of humidity

A consistency error will occur if certain relationship between dry bulb temperature Ta, relative humidity Uu, wet bulb temperature Tw and dew point temperature Td is violated.

The measured relative humidity Uu can be checked against present weather Ww, and also against the humidity Uu_c calculated from dew point temperature Td:

$(Uu_c - Uu) \leq -7$ % or $(Uu_c - Uu) \geq 12\%$	(FMI)	(3.72)
$Uu > 60\%$ & Ww=5 (dry haze)	(FMI)	(3.73)
$Uu < 90\%$ & $41 \leq Ww \leq 48$ (fog)	(FMI)	(3.74)

3.3 Other checking methods

3.3.1 SMHI algorithm for checking of Geonor gauge measured precipitation

The OBS2000 observation stations have a precipitation measurement unit consisting of a bucket, where the precipitation is collected. The weight of the bucket and the precipitation is registered.

The algorithms in use to calculate the precipitation are not returning satisfactory values. Therefore a program calculates the precipitation during the latest six and twelve hours by using the original bucket values. The most important algorithms in this program are;

1. If the actual bucket value is higher than both the values measured before and after the actual observation time, the value will be dismissed. If the present weather instrument is measuring precipitation, the highest of the latest approved values and the next measured value will be accepted. If there is no present weather instrument the latest approved value will be used.
2. A value must not be lower than an earlier measured value.
3. If a value is higher than an earlier measured value and the PWS is not registering any precipitation and the hourly measured values are continuous, the bucket value will be dismissed.
4. If the increase in the accumulated precipitation after the most recent measurement is more than 1 mm, it will be accepted even if the PWS is recording no precipitation. This case is separated from ex 1 provided that this is not a single high value.

Sometimes frozen snow on the inside of the gauge suddenly can fall down into the bucket. These cases are registered and must be manually corrected.

The date when the bucket is emptied is registered.

The values measured by Geonor are noisy. If the variation is more than 1 mm, hourly measurements are graphically compared with accepted precipitation values and finally manually corrected.

The quality control program goal is to deliver acceptable observations to customers. The most important future goal is to find a solution for the drifting snow sticking to the inside of the bucket. The previously mentioned programs can then be used to control and correct the observations instead of the current situation.

3.4 Integrated QC systems for real-time checking

3.4.1 Real time quality control using HIRLAM at SMHI

Further details about real time quality control using HIRLAM can be found in Jacobsson (2001).

3.4.1.1 Database level

Observations are checked internally when they are decoded from GTS and inserted into the observations database (or observation files) as input for Hirlam. This is done through;

- various checks on the telegram format
- checks on climatological limits on parameters
- internal consistency checks between parameters
- a hydrostatic check

No attempt is made to correct the offending value, although it is possible in some cases using elaborate algorithms (done at NCEP).

Flags of values 0-3 are assigned at the database stage:

- 3 indicate that the observation is certainly wrong and it will not be used.
- 2 are probably incorrect.
- 1 is probably correct
- 0 is unsuspicious

A final decision on the use of the observation is made later in combination with other tests.

3.4.1.2 Comparison with a background field

The observed parameters are compared with the best prior estimate available at the observation point. Usually this is a short-range (3-9 h) numerical weather prediction (NWP) forecast, often called the first guess or background for a numerical analysis. Differences between observations and background fields are small and typically similar in magnitude to the perceived observation error (instrument plus so called representativeness error of the NWP model). Quality control is based on accumulated statistics of such anomalies. Most parameters have anomalies that are nearly normally distributed and some outliers.

In Hirlam those outliers are defined in terms of observation minus background difference being greater than x number of standard deviations of the expected background error at the observation point. These x values are fixed for long periods, but occasionally the limits are tuned when the system is revised. Examples of such numbers can be found in the Data Assimilation Scientific Documentation of the ECMWF.

The background check (or first guess check) is a powerful check since the quality of the short-range forecasts is high. Some caution may be taken in sparse data areas or during rapid weather developments where statistical assumptions are not representative. The risk of rejecting good observations increases in such cases.

Background check flags of 0-3 are assigned just as for the data base check. All flag sets are archived for later use. Observations with the flag value 3 are rejected and, for some types of data, also observation values flagged 2 (e.g. significant levels but not mandatory).

3.4.1.3 Combined background check

In some cases it is advantageous to make a combined decision based on a number of background flags.

3.4.1.4 Wind direction check

A check of the wind direction departure above a certain wind speed is performed to detect large errors in direction although the wind components may not be sufficiently in error to be rejected. This method is rather ad-hoc to overcome certain types of observational errors.

3.4.1.5 Asymmetric wind check

For biased observations it is possible to apply different limits when the wind departure is positive than when it is negative. This method is also rather ad-hoc and was developed for SATOBs.

3.4.1.6 Comparison with other observations

Spatial checks are done but not directly as some sort of interpolation procedure. In the Hirlam analysis this is done inside the analysis computations. In a special mode of the analysis each observation is analysed with the use of all neighbouring observations (but not the observation itself). Based on statistics of departures between observations and analysed values, decisions are taken based on y number of standard deviations.

Flags in the range 0-3 from this check are stored and the data with flag values of 2 and 3 are rejected.

In 3D-VAR or 4D-VAR it is difficult to repeat the method used in the Hirlam optimum interpolation (OI) above. Instead the observational cost function is minimised with modified statistics to account for gross errors. It makes the minimisation (or analysis) devalue outliers which do not agree with nearby observations. The algorithm is different than the one used in OI, but results are similar.

These kinds of checks are less important than the background check. The majority of the checking is done by the background check. The comparison with nearby observations is a refinement that can be more important in areas where the background is poor.

3.4.1.7 Blacklisting

Based on previous records of either departures or flags, blacklisting decisions may be taken on stations that are consistently or often wrong. The blacklist is updated once or twice a month or as often as necessary.

3.4.1.8 Other automatic control programs at SMHI

After collecting all observations from the METCOM system some automatic controls are done in real time. SYNCHE is a program written by Lars Meuller, SMHI. This program checks Synop from automatic weather stations and manual observation stations by flagging but not correcting the values.

Parameter	Code check	Int. cons. Check	Limit Check	Time cons. Check	Compl. check
Visibility	Yes	Yes	-	-	Yes
Total cloud cover	Yes	Yes	-	-	Yes
Wind	Yes	Yes	Yes	Yes	Yes
Temperature	-	Yes	Yes	Yes	Yes
Dew point	-	Yes	Yes	Yes	Yes
Parameter	Code check	Int. cons. Check	Limit Check	Time cons. Check	Compl. check
Pressure at sea level	-	-	Yes	Yes	Yes
Pressure at station	-	-	Yes	Yes	Yes
Pressure tendency	Yes	Yes	Yes	Yes	Yes
Parameter	Code Check	Int. cons. Check	Limit check	Time cons. check	Compl. check
Precipitation	-	-	Yes	Yes	Yes
Present weather	Yes	Yes	-	-	Yes
Past weather	Yes	Yes	-	-	-
Cloud group	Yes	Yes	-	-	Yes
Temp.-max	-	Yes	Yes	Yes	Yes
Temp.-min	-	Yes	Yes	Yes	Yes
Temp. Ground	-	Yes	Yes	-	Yes
Snow	-	-	Yes	Yes	Yes
Significant clouds	Yes	Yes	-	-	Yes
Temp. Sea	-	-	Yes	-	-
Ship movement	Yes	Yes	-	-	-
Ship position	-	-	-	Yes	-

The quality flags	= 0	No check has been made
	= 1	Checked and not found suspect or erroneous
	= 2	Checked and found suspect
	= 3	Checked and found erroneous
	= 4	Corrected during check (only pressure tendency)

Other real time observations such as temperature soundings are checked by a similar program called TEMPCHE.

The automatic control program SYNCHE controls observations in real time and flags the suspected values. No corrections are made. After the observations have been checked, they are stored in a work file to be checked and corrected later.

A future suggestion is to attempt to use a first guess from Hirlam as a comparison and correction method.

4. Selected spatial checking methods

This chapter concentrates on spatial quality control methods using data organised as so-called type (B) data, i.e. data from *more than one station*, either instant observations or time series.

Methods using data organised in this way can perform temporal as well as spatial analyses, and it is possible to apply complex procedures for quality control, e.g. it is possible to verify the statistical procedures used and to calculate statistical characteristics such as covariance and correlation as well as accuracy and confidence limits of the statistical procedures. Spatial correlation functions can be estimated if the temporal and spatial structure is considered, but if only spatial analyses are performed, such functions must be assumed or even ignored.

4.1 Simple spatial checks

At DNMI spatial checks are performed manually by looking at lists of parameter values or time differences of parameter values from comparable stations. Such tests are performed for air temperature and sea level pressure on a 6 hourly basis, for minimum and maximum air temperature and grass minimum temperature (only 06 UTC) on a 12 hourly basis, and 12 and 24 hours for precipitation.

Humidity is checked manually by looking at a list where frequency distributions of monthly data from comparable stations are presented. If the humidity distribution from a station is suspicious, the instrument will be replaced.

*4.2 Spatial checking by median analyses: the Madsen-Allerup method (QC2tDMI-*Rr_24h)*

The "Madsen-Allerup" method developed at DMI by Madsen and Allerup (Madsen, 1992, 1993) is a non-parameter spatial checking method. The method is based on analyses of median values and upper and lower quartiles of data from stations in the surrounding area. The basic idea, that median and quartiles are the turning point of the algorithm, prevents outliers from disturbing the results. Initially, the method was designed for QC of precipitation data, but it could possibly be used for control of other meteorological parameters. This requires further investigation beyond the scope of the research project.

The method is a non-parametric checking for identification of suspected precipitation sum values. The method is designed for identification of outliers among neighbouring stations. Test statistics are calculated by the algorithm from precipitation sums from neighbouring stations:

$$T_{it} = \frac{x_{it} - M_t}{q_{t,75} - q_{t,25}} \qquad \text{(DMI)} \qquad (4.1)$$

where

T_{it} = the median test statistic value

x_{it} = the observation at station i for day t

M_t = the median value of the observations from N stations

$q_{t,25}$ = 25% quartile value of the N observations

$q_{t,75}$ = 75% quartile value of the N observations

Data from neighbouring stations are required and the recommended number of stations is 12, but this method performs well even by entering a smaller or a larger number of stations. Data from one or more stations may be missing. Neighbour stations should be carefully selected: terrain variations may result in local variations in precipitation amount, for example due to orographic growth, and the distance between the stations must then be relatively small. In homogeneous terrain, the distance can be larger without problems, but there is no general rule for an optimal distance.

Stations must be selected through experience, i.e. the spatial resolution of stations entering the check may vary depending on local conditions.

The algorithm has been tested on a significant amount of precipitation data known to have a skew distribution, i.e. a log-normal distribution. A check involves only about 12 stations, and then it is sufficient to do the analyses on non-transformed observations.

Testing limits and flagging values have been established as a result of empirical studies. Various observation errors may occur in daily precipitation sums. The kind of error depends on whether the observation is done manually or automatically:

- Type 1: accumulated sums (occurs most often on manual observations)
- Type 2: wrong days (manual observations)
- Type 3: incorrect time of observation (manual observation)
- Type 4: wrong value, it is too large or small (manual and automatic observation)

If precipitation measurements are checked, the following checking limits for flagging of suspicious data are recommended:

Test limits 1:
$|T_{it}|>2.00$ and $x_{it}>4$ e.g. for flagging of too large values

Test limits 2:
if $q_{t,75}-q_{t,25}=0$: especially occurs in dry weather situations

then complete the test with:

$x_{it}/\sum x_{it}>0.60$ and $x_{it}>4$ e.g. for flagging of rainfall on a wrong day

This method is a statistical (non-parameter) spatial test and the recommended quality control level is QC2. Table 4.1 shows examples of the three types of errors and missed error flagging.

With regard to the frequency of control, this method has been designed for checking 24-hour precipitation sums. If other parameters are checked, for example hourly precipitation sum, the testing limits have to be changed according to the normal spatial variations in hourly precipitation.

This method may be able to check other kinds of parameters such as temperature and wind speed, but tests of spatial variations must be done.

One drawback of this method is that it is insensitive to systematic differences in precipitation between stations, and the same station may pop-up as an error all the time. Also, dry weather conditions with very scattered precipitation faces the algorithm with another problem.

An important advantage is that it is a fast method to compare neighbouring stations. This method works well in homogeneous areas, but may not work well in mountainous regions. It may also not work well for scattered precipitation, such as isolated showers. The advantage of using test limits (1) is that erroneous data will often be extreme and therefore leave the median value as probably "true". In that way (1) will not depend on a single or a few outliers.

This method is not currently in operation, but studies have developed confidence in the results.

*Table 4.1. Example of flagged errors and missed flagging in the Madsen-Allerup method. - = 0.0mm, " = <0.1mm, *=no observation, **=accumulation (indicated in station report). The result of the automatic quality control of daily precipitation sums, Ra_24h, was as follow: Station 31290 (˜ ˜ ˜): wrong days the whole month, station 31522 (· ˜ · ˜ ·): accumulated value (indicated in station report), station 31460 (˜ ˜ ˜): accumulated value (not indicated in station report), station 31530 (· · · ·): incorrect time of observation.*

Date	Station number							
	31540	31290	31480	31485	31510	31522	31530	31460
1	21.8	0.7	19.9	24.8	21.0	17.1	16.3	23.5
2	-	-	-	0.3	-	0.2	0.6	*
3	-	0.8	-	-	-	-	-	*
4	0.4	6.3	0.3	-	2.7	-	2.1	*
5	1.4	-	2.3	2.7	4.0	4.3	2.1	*
6	-	12.0	-	-	-	-	-	*
7	12.8	-	8.4	9.0	15.0	9.9	16.6	*
8	-	1.4	-	-	-	-	-	14.5
9	2.9	2.3	3.3	5.7	1.9	2.0	2.3	1.8
10	1.5	6.1	1.3	2.1	1.8	**	5.3	0.5
11	5.1	2.0	0.8	1.1	1.5	*	1.4	1.4
12	2.9	-	2.3	1.6	2.5	*	2.1	0.9
13	-	3.9	-	-	-	10.2	-	0.1
14	0.6	-	1.1	5.2	-	1.2	1.0	0.2
15	-	0.2	-	-	-	-	-	-
16	0.3	16.4	-	-	-	0.1	-	0.1
17	17.2	-	14.1	17.9	13.0	10.2	7.1	7.4
18	-	1.4	-	-	-	-	-	-
19	1.0	3.7	1.3	0.8	1.1	1.0	4.5	1.4
20	3.3	-	3.0	3.9	3.4	3.7	-	3.2
21	-	-	-	-	-	-	-	-

The *Madsen-Allerup* method has been tested on a large amount of data that showed a reasonable performance in finding errors in manual 24-hour precipitation sums. The automatic flagging has been verified by manual inspection of the total data set. The verification showed that about 50% of the total number of error flagged data were marked correctly by both methods, and in most of these cases large-scale precipitation systems occurred (table 4.2).

In nearly all cases in test limits 2 the precipitation was caused by convective cells or other small-scale systems and explains the failure of the automatic control. In this case, manual checking is necessary.

Table 4.2. Comparison between manual control and the automatic Madsen-Allerup method. Numbers of flagged and not flagged data of daily precipitation from 12 stations over a 5-year period in relation are shown. The automatic flagging has been verified by manual control of the data set. In the brackets are shown the percentage of type 1, 2 and 3 errors, respectively. Type 1=accumulations, type 2=wrong days, Type 3=incorrect time of observation.

Verification		manual control (verification)	
12 stations over a 5 year period		not flagged	flagged
	not flagged	no error	No.3
automatic		18868	290 (82%, 5%, 13%)
control	flagged	No.2	No.4
		477 (50%, 15%, 35%)	796 (49%, 42%, 9%)

The percentage of flags where the manual control succeeded but the automatic method was failed, is 18% of the total number of flagged cases. Most of these cases (82%) comprise accumulations where the amount does not differ significantly from neighbour stations, and they cannot be identified by the automatic method, only by the trained eye.

4.3 The double exponential correlation weighted interpolation method (DECWIM)

This method and the HIRLAM method described in 4.3 are performed in a cooperative way. Petter Øgland has developed the method for interpolation of meteorological data at DNMI, described in Report no. 25/97 KLIMA (Øgland, 1997b).

Symbolic name of method: QC2iDNMI2-Ta,Tan_12h,Tax_12h,Po,Pr,Nn,Uu,Rr_12h

Interpolating values for 06, 12, 18 hrs UTC for MAN, HYB, AWS stations – data on SYNOP-format.

Only missing observations are interpolated. Existing observations are neither checked nor interpolated.

The linear estimator $\tilde{x}$ is calculated:

$$\tilde{x}_i = \alpha \sum_{j=1}^{10} w_j y_{i,j} + \beta \qquad \text{(DNMI)} \qquad (4.2)$$

where $y_{i,j}$ is the observed value at reference station *j* relative to the test station, recorded at time step *i*. The set $w_j, j = 1,2,......,10$ is a set of empirically constructed values called the *weights* for the estimator.

The weights associated with the meteorological DECWIM method are defined as

$$w_j = \frac{\exp(\exp(\lambda corr(x, y_j))) - \mu}{\sum_{k=1}^{10}[\exp(\exp(\lambda corr(x, y_k))) - \mu} \qquad \text{(DNMI)} \qquad (4.3)$$

where $\lambda = \log(\log(100 + e), \mu = e$

Log is the natural logarithm and *e* is Euler's number (2.71828...). The weights share the following property:

$$\sum_{j=1}^{10} w_j = 1 \qquad \text{(DNMI)} \qquad (4.3)$$

The coefficients α and β are empirically decided values. They are referred to as *correlation coefficients* as they are introduced in order to reduce the bias of the estimator, and are constructed by a least squares method using $w_j y_{i,j}$ as predictor variables and $\tilde{x}_i$ as response variables.

Correlation coefficients α and β are only computed if there are more than 3 pairs of observations. If no correlation is computed, the correlation coefficient is set to 0.0 by default.

If no data are available for the test station in the chosen interval, α and β must be constructed in some other manner. Presently α is set to 1 and β to 0 reintroducing whatever bias that might be inherit within the weighted estimation method.

The required data are observations on SYNOP format for 06, 12, 18 hours UTC. The 10 closest stations to the test station are used as reference stations.

Concerning testing limits the following statements can be made:

Only missing values are interpolated. When interpolated values exceed defined range values, they are listed for manual control (HQC), see below. If the temperature difference between interpolated value and previous or preceding observation exceeds 5 °C, or the difference between interpolated value and the next 12 hours minimum and maximum temperature exceeds 5 °C, the interpolated value is listed for HQC. The programme will skip clearly wrong values. Such values, defined as null values, are flagged and will later be replaced by a HIRLAM value (see 4.4).

Range values are: -35.0°C≤Ta,Tan,Tax≤30.0°C, Rr_12h≤35.0 mm, Uu≥20%. Nn has no limit value. The test limits of Pr are unknown or do not exist.

According to this method, observations are flagged indicating that the value is automatically interpolated. If an observation is corrected manually, it is flagged. The recommended QC level is QC2 because of data requirements.

This programme runs twice a day: 06:45 and 18:45 by SYNO_KONTR (INTERPOL2).

Experience has shown this method is less accurate, at least for precipitation, than a spatial interpolation method based on fixed reference stations. Stations should be selected by people familiar with the station network, HQC and the topography. Verification of DECWIM by experiments and manual interpretation has given favourable results.

There is no physical understanding of the weather elements programmed into the estimator. Each set of values, include code estimates for cloud cover and percentage estimates for relative humidity are treated as floating numbers with no restrictions to allowable values.

As the initial choice of ten reference stations is independent of meteorological to be estimated, there may be cases where a reference station is chosen that does not support measurements of this particular element. In such cases the correlation is by default assigned the value of zero.

In the present system, the DECWIM method is used when enough data for generating correlation values is available. If not, the radial method, described in Report no. 23/97 KLIMA (Øgland, 1997a)) is used without correctional coefficients.

Experiments carried out for all the actual parameters showed no indication that the radial method is better than the DECWIM method for any of the parameters and that the DECWIM method works well. In some cases however, severe estimation errors are detected.

Both radial and DECWIM methods are performed on missing data. If neither of these manage to generate computed data; that is if too few neighbouring stations have data or if data for the test-station is missing for some time period (36 hr), values are inserted from HIRLAM. If interpolations by HIRLAM have proceeded for 90 days, the interpolation is stopped.

Statistical values such as mean error, mean absolute error, standard deviation of error, root mean square error, min and max absolute errors, covariance and correlation coefficients are computed for the methods in use. Test results are presented in Report no. 25/97 KLIMA (Øgland, 1997b). Further documentation can be found in Report no. 23/97 KLIMA (Øgland, 1997a) and Report no. 25/97 KLIMA (Øgland, 1997b).

4.4 Spatial checking using HIRLAM short time prognostic values

If there are rejected values (null values) from the DECWIM method (see 4.2) or if more than two consecutive values are missing, the DECWIM method is replaced by the HIRLAM method.

Symbolic name of method: QC2nDNMI1-*Ta,*Tan_12h,*Tax_12h,*Td,*Uu,*Pr,*Po,*Nn,*Rr

After inserting HIRLAM values from MIOPDB (operational data base), prognostic values are calculated for every station position for the +06 hour period. Interpolated values for 00, 06, 12, 18 hrs UTC for MAN, HYB, AWS stations – data on SYNOP-format. Only missing observations are interpolated. Existing observations are not checked. The method requires HIRLAM values. Testing limits are the same as described in Ch.4.3. Suspicious and clearly wrong values are listed and checked manually. Observations flagged according to this method are automatically interpolated by the HIRLAM method. If an observation is corrected manually it is flagged. The recommended QC-level is QC1 and QC2. The program runs twice a day: 06:45 and 18:45 by SYNO_KONTR (INTERPOL2).

A disadvantage is that there is a confidence number connected to the actual prognostic values. This application does not take into account such confidence estimations. An important advantage is that prognostic values dependent on the weather situation are available at observation time. This method is not fully tested, but is used to provide complete observations of chosen parameters in near real time. Statistics on such data are favourable. Interpolated values are not stored permanently.

Further documentation can be found in Report no. 65/99 KLIBAS (Øgland, 1999a).

4.5 Spatial checking based on Kriging statistical interpolation

One way of performing spatial checks is by comparing measured values with the expected value that was estimated by statistical interpolation from neighbouring stations. The Kriging interpolation method is used by FMI in the following way.

In spatial testing of weather parameters Kriging method can be used. Non real time quality control of meteorological data is done more or less on a test mode once a day after 06 UTC (Eino Hellsten, internal paper). It is performed as a spatial test for the following parameters:

- 2 m temperature
- minimum temperature
- maximum temperature
- relative humidity
- dew point
- air pressure
- wind speed
- wind direction

These parameters are gathered from the previous day starting at 09 UTC until the current day at 06 UTC. Each parameter at each synoptic time (every 3 hours) at each station is tested using Kriging method. Kriging is a spatial interpolation method (Ripley 1981, Henttonen 1991) which gives the best linear unbiased predictors of the unobserved values and provides an estimate of the prediction error variance. This method is closely related to Gandin's optimum interpolation method.

The interpolation distributions are presented in a 10 km×10 km grid. Opposite to traditional subjective analysis that depends on the skill of the analyser, Kriging can utilise physically reasonable explainers. The principles are illustrated in figure 4.1, and the various physical effects are considered in the interpolation:

$Z(x)=M(x)+e(x)$, M = trend, e="random fluctuation" (FMI) (4.4)

$M(x,y,h,l,s) = a_0 + a_1x + a_2y + a_3x^2 + a_4y^2 + a_5xy + a_6h + a_7s + a_8l$ (FMI) (4.5)

where:

x,y = location
h = elevation above sea level
l = lake effect
s = sea effect

The advantage of the Kriging method is that it can easily take into account of different kind of effects in interpolation. Co-ordinates in x- and y-directions (m), height (m) and percentage shares (%) of lakes and sea on each station are included. Values of these effects are stored and calculated from land use and forest interpretation satellite data into the grid of 10 km×10 km covering Finland.

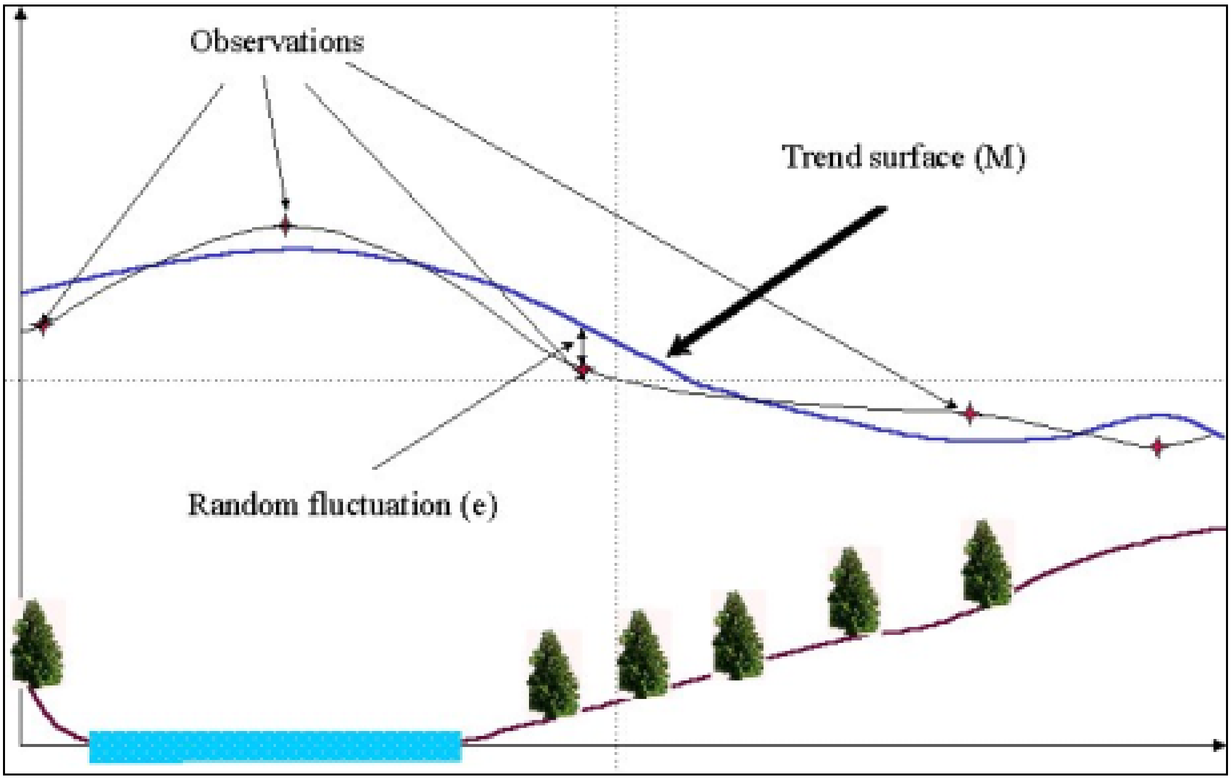


Figure 4.1. Outline of the principles of Kriging.

The effects for each station are interpolated from this 10 km grid with the help of the four nearest grid points so that the values are inversely related to the distance from the station. Next a surface is calculated with the Kriging method from the values of the observations within the given radius (400 km) from the station with the effects included. The station itself is not included in the calculation. The interpolation results in a surface that goes through the observed weather parameter values of the stations. From this surface, estimated value of the weather parameter can be calculated at the station and compared to the observed one. This is repeated for each station for each parameter.

If the differences exceed certain limits, a warning results as seen in table 4.3. It shows suspiciously large differences between observed and interpolated (estimated) values. If there are often large differences, the cause will be manually checked and if necessary, values are deleted. There are about 150 stations covering Finland of which usually more than 3/4 is included in Kriging interpolation (i.e. stations within 400 km from the station in question).

The height, lake and sea effects are not necessarily needed in calculations, but improve the interpolation results.

Figure 4.2 presents the RMS (Root Mean Square) of the estimated/observed values of dew point temperature, relative humidity, wind speed and sea level pressure from about 150 Finnish stations calculated by Kriging interpolation method as explained above. The test period is 21.11.1998 - 18.12.1998 in three-hour intervals. The sea level pressure can be estimated within 1 hPa precision, dew point temperature with about 1.5 degree precision, wind speed with about 2 m/s precision and relative humidity with about 5-6% precision. Figure 4.3 presents corresponding RMS values of maximum and minimum temperatures at 06 and 18 UTC for the same period and also about1.5 degree precision. The bigger RMS values between 3.12.1998 - 10.12.1998 can be explained by a cold period that causes great local temperature variations.

Table 4.3. Comparison of the difference between Kriging interpolated values, observed values and a threshold value. Suspiciously large differences exist between observed and interpolated values. Finland is divided into squares of equal size. In this system, lpnn is the internal FMI station number in a square (Lp=square number, nn=station number in the square). Obs=observed value, interp=interpolated value, differ=difference between observed and interpolated value, and limit=limits for suspicious values.

lpnn	year	mm	dd	hr	Parameter	Obs.	Interp	Differ.Limit
2401	1999	12	22	9	TEMPERATURE	–1.1	–6.7	5.6>4.0
3020	1999	12	22	9	TEMPERATURE	1.6	–3.2	4.8>4.0
3314	1999	12	22	9	TEMPERATURE	–1.7	–8.0	6.3>4.0
4108	1999	12	22	9	TEMPERATURE	–0.1	–5.4	5.3>4.0
4109	1999	12	22	9	TEMPERATURE	–0.5	–5.1	4.6>4.0
4201	1999	12	22	9	TEMPERATURE	–2.0	–7.3	5.3>4.0
4212	1999	12	22	9	TEMPERATURE	–0.8	–6.1	5.3>4.0
4314	1999	12	22	9	TEMPERATURE	–2.2	–8.7	6.5>4.0
4402	1999	12	22	9	TEMPERATURE	–5.2	–10.0	4.8>4.0
5201	1999	12	22	9	TEMPERATURE	–2.4	–6.8	4.4>4.0
5507	1999	12	22	9	TEMPERATURE	–20.8	–13.4	–7.4>4.0
6301	1999	12	22	9	TEMPERATURE	–18.8	–11.0	–7.8>4.0
6307	1999	12	22	9	TEMPERATURE	–17.1	–10.4	–6.7>4.0
6812	1999	12	22	9	TEMPERATURE	–12.8	–19.2	6.4>4.0
6816	1999	12	22	9	TEMPERATURE	–23.9	–17.1	–6.8>4.0
7401	1999	12	22	9	TEMPERATURE	–21.9	–14.9	–7.0>4.0
7409	1999	12	22	9	TEMPERATURE	–22.3	–13.9	–8.4>4.0
7411	1999	12	22	9	TEMPERATURE	–19.9	–13.5	–6.4>4.0
7708	1999	12	22	9	TEMPERATURE	–10.7	–19.3	8.6>4.0
7709	1999	12	22	9	TEMPERATURE	–27.8	–18.5	–9.3>4.0
7804	1999	12	22	9	TEMPERATURE	–27.7	–19.6	–8.1>4.0
8208	1999	12	22	9	TEMPERATURE	–28.2	–15.8	–12.4>4.0
8306	1999	12	22	9	TEMPERATURE	–10.5	–15.9	5.4>4.0
8307	1999	12	22	9	TEMPERATURE	–12.3	–19.5	7.2>4.0
8308	1999	12	22	9	TEMPERATURE	–10.1	–17.8	7.7>4.0
8309	1999	12	22	9	TEMPERATURE	–20.6	–16.0	–4.6>4.0
7502	1999	12	22	9	PRESSURE	1019.8	1017.5	2.3>2.0
7709	1999	12	22	9	PRESSURE	1020.0	1017.8	2.2>2.0
8309	1999	12	22	9	PRESSURE	1020.0	1017.2	2.8>2.0
9614	1999	12	22	9	PRESSURE	1014.3	1018.1	–3.8>2.0
9706	1999	12	22	9	PRESSURE	1014.1	1018.1	–4.0>2.0
0103	1999	12	22	9	WIND DIRECTION	ION200.0	265.0	–65.0>40.0
1101	1999	12	22	9	WIND DIRECTION	ION210.0	263.2	–53.2>40.0
6812	1999	12	22	9	WINDSPEED	9.0	1.9	7.1>7.0
0333	1999	12	22	9	DEWPOINT	–4.8	–0.7	–4.1>4.0
0401	1999	12	22	9	DEWPOINT	–5.2	–1.1	–4.1>4.0
2401	1999	12	22	9	DEWPOINT	–1.4	–7.4	6.0>4.0
3003	1999	12	22	9	DEWPOINT	–1.1	–5.3	4.2>4.0
3018	1999	12	22	9	DEWPOINT	–0.5	–4.9	4.4>4.0
3020	1999	12	22	9	DEWPOINT	0.3	–4.8	5.1>4.0
3314	1999	12	22	9	DEWPOINT	–2.0	–8.7	6.7>4.0
4108	1999	12	22	9	DEWPOINT	–0.8	–7.0	6.2>4.0
4109	1999	12	22	9	DEWPOINT	–0.9	–6.9	6.0>4.0
4212	1999	12	22	9	DEWPOINT	–1.6	–7.9	6.3>4.0

4314	1999	12	22	9	DEWPOINT	–2.4	–9.7	7.3>4.0

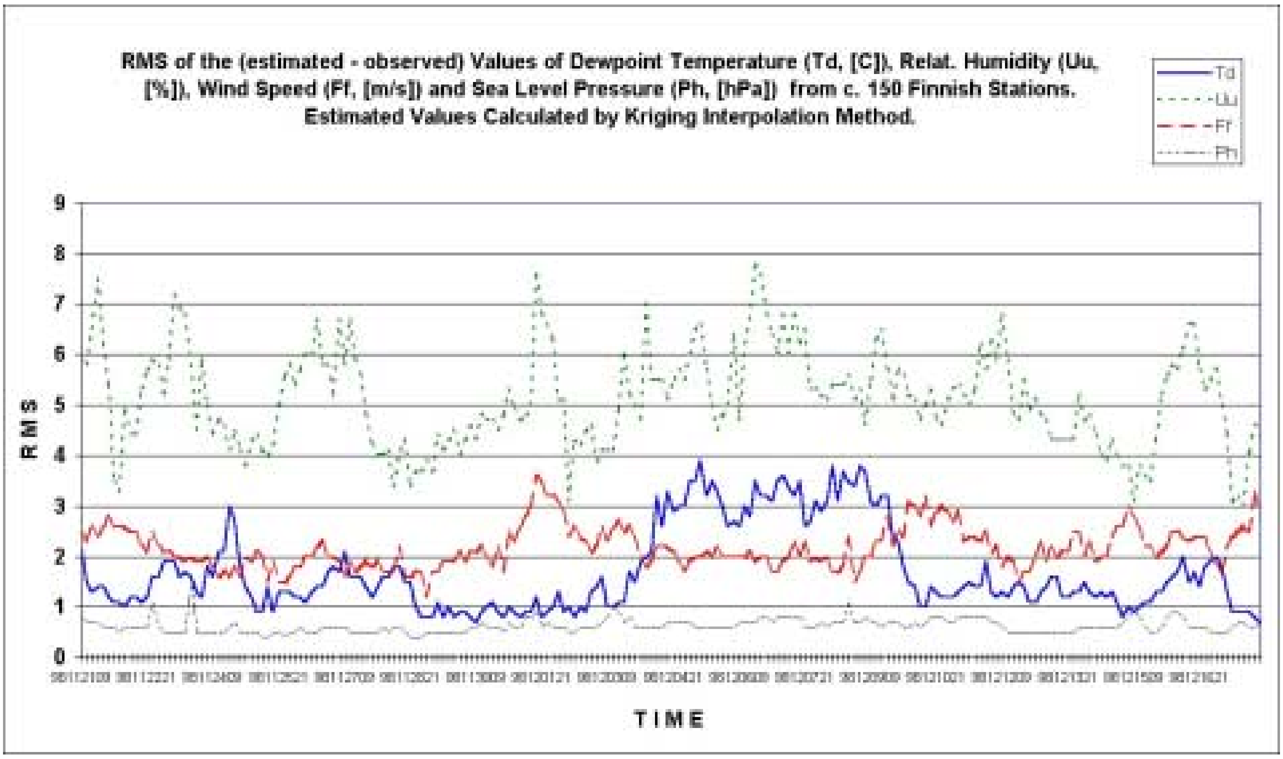


Figure 4.2. RMS of estimated – observed values of dew point temperature, relative humidity, wind speed and sea level air pressure (period 21.11.1998 – 18.12.1998).

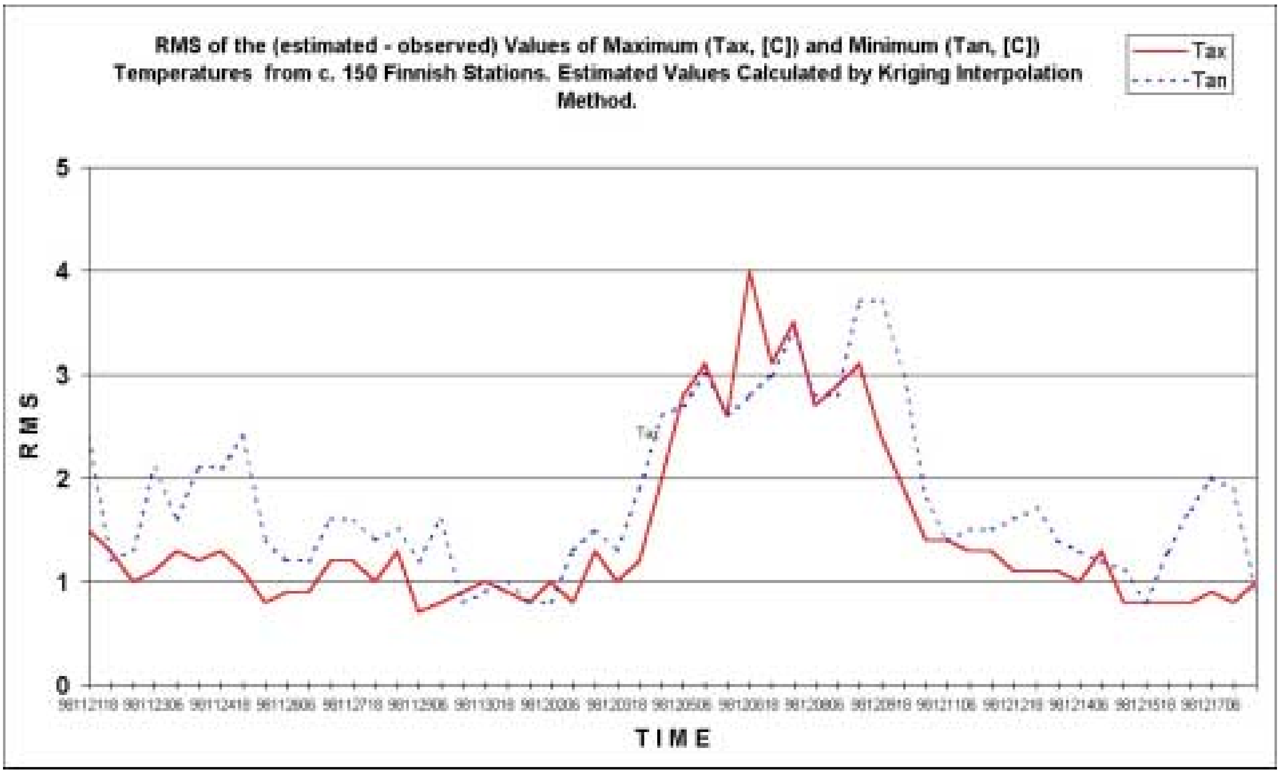


Figure 4.3. RMS of estimated – observed values of maximum temperature and minimum temperatures (period 21.11.1998 – 18.12.1998).

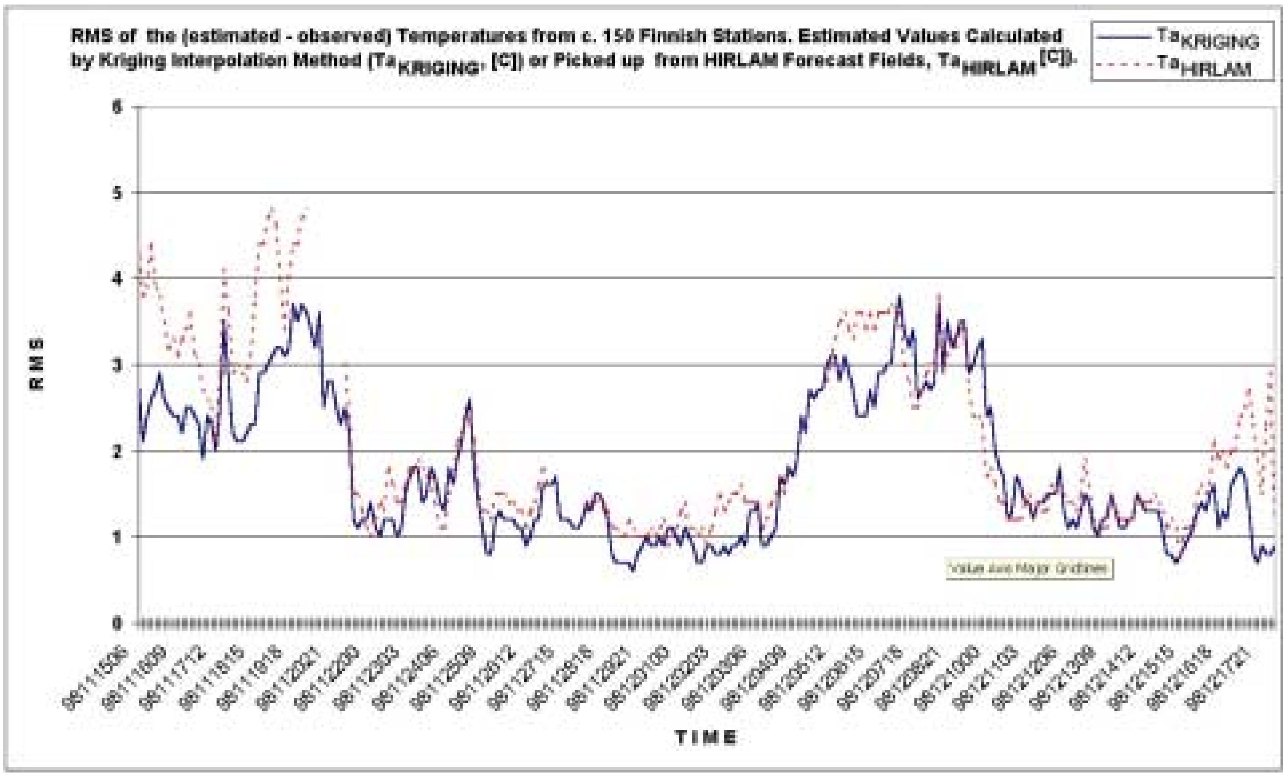


Figure 4.4. RMS of estimated – observed temperature values. Estimated values by Kriging method and by HIRLAM forecast fields (period 15.11.1998 – 18.12.1998).

The 2-meter HIRLAM model forecast temperatures were tested by comparing them with corresponding observed temperatures by 3 hour intervals. As HIRLAM is run 4 times per day based on 00, 06, 12 and 18 UTC analysis and the forecast fields are available about 5 hours from analysis time, the HIRLAM temperature fields will be 6 or 9 hours forecast values. Figure 4.4 presents the RMS of the (forecast (by HIRLAM) - observed) temperatures from about 150 Finnish stations. For comparison, the corresponding RMS values by Kriging method are also in figure 4.4. The period is 15.11.1998 - 18.12.1998 in 3-hour intervals. During the cold period precision has been 2.5 to 3.0°C, otherwise about 1.5°C, and the HIRLAM and Kriging values are of similar magnitude, Kriging is slightly better.

Although the test period is relatively short, both methods (Kriging, HIRLAM) are worth trying in spatial weather parameter testing.

4.6 Spatial checking by using mesoscale analyses

4.6.1 MESAN

MESAN is a mesoscale analysis of surface parameters and clouds.

HIRLAM data are normally used as first guess fields. Observations are taken from synop, metar, Swedish climate stations, automatic weather stations, satellite and radar. Much work has been devoted to minimise systematic observation errors and investigation structure functions of first guess errors.

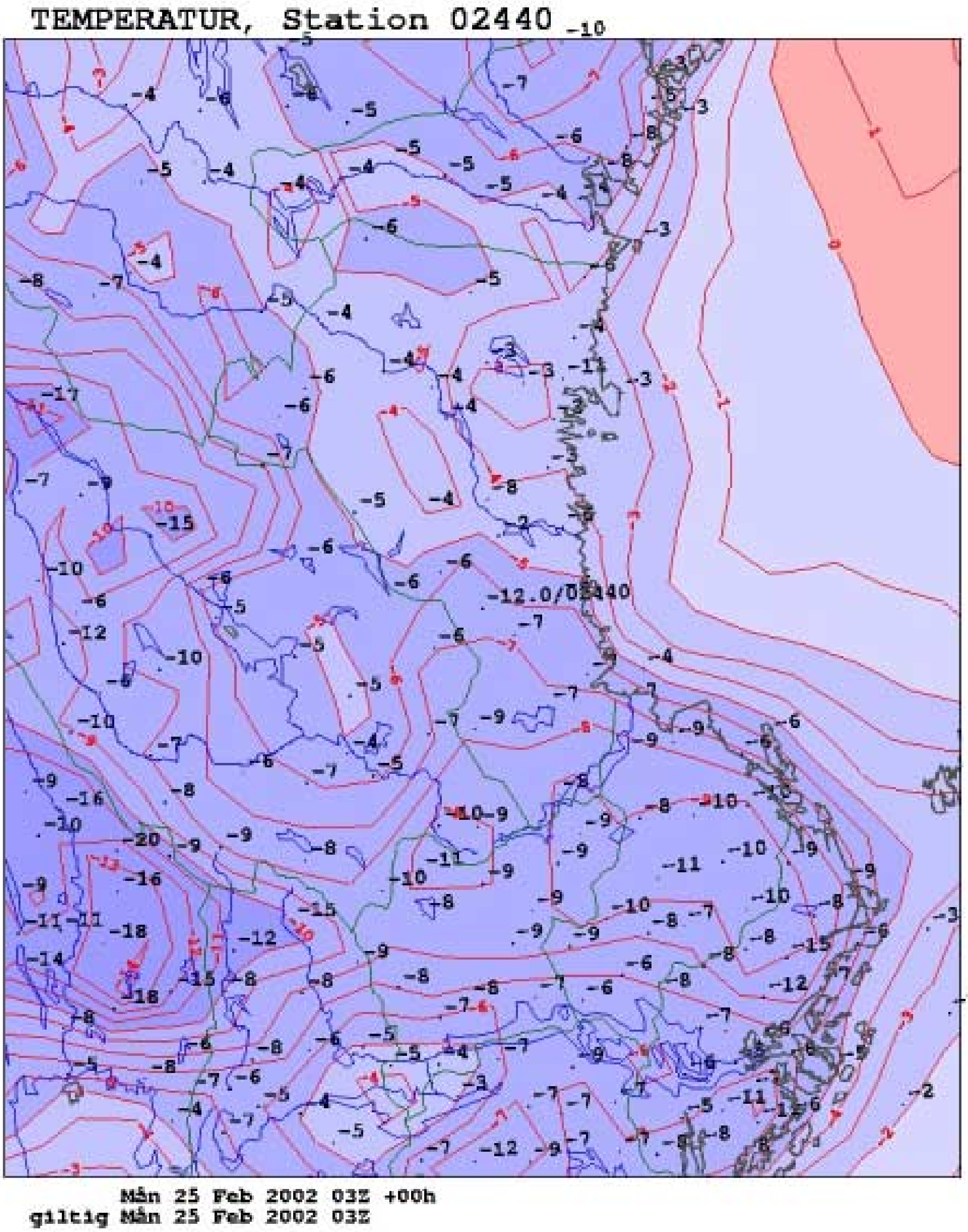


Figure 4.5. The observed temperatures are compared with reference values, calculated from MESAN. 25 February 2002 at 03 UTC.

The used analysis method is optimal interpolation.

Quality control of the observations is first used as a reliability control. The observations are compared to the HIRLAM values. If the difference between the observation and the value from HIRLAM exceeds a limit, the observation is dismissed.

A confidence interval of the difference between the observation and the analysis is calculated. If the difference between the observation and the analysis exceeds the confidence interval, the observation is rejected. This is a standard procedure in optimal interpolation.

Further documentation of the system can be found in Häggmark, Ivarsson and Olofsson (1997).

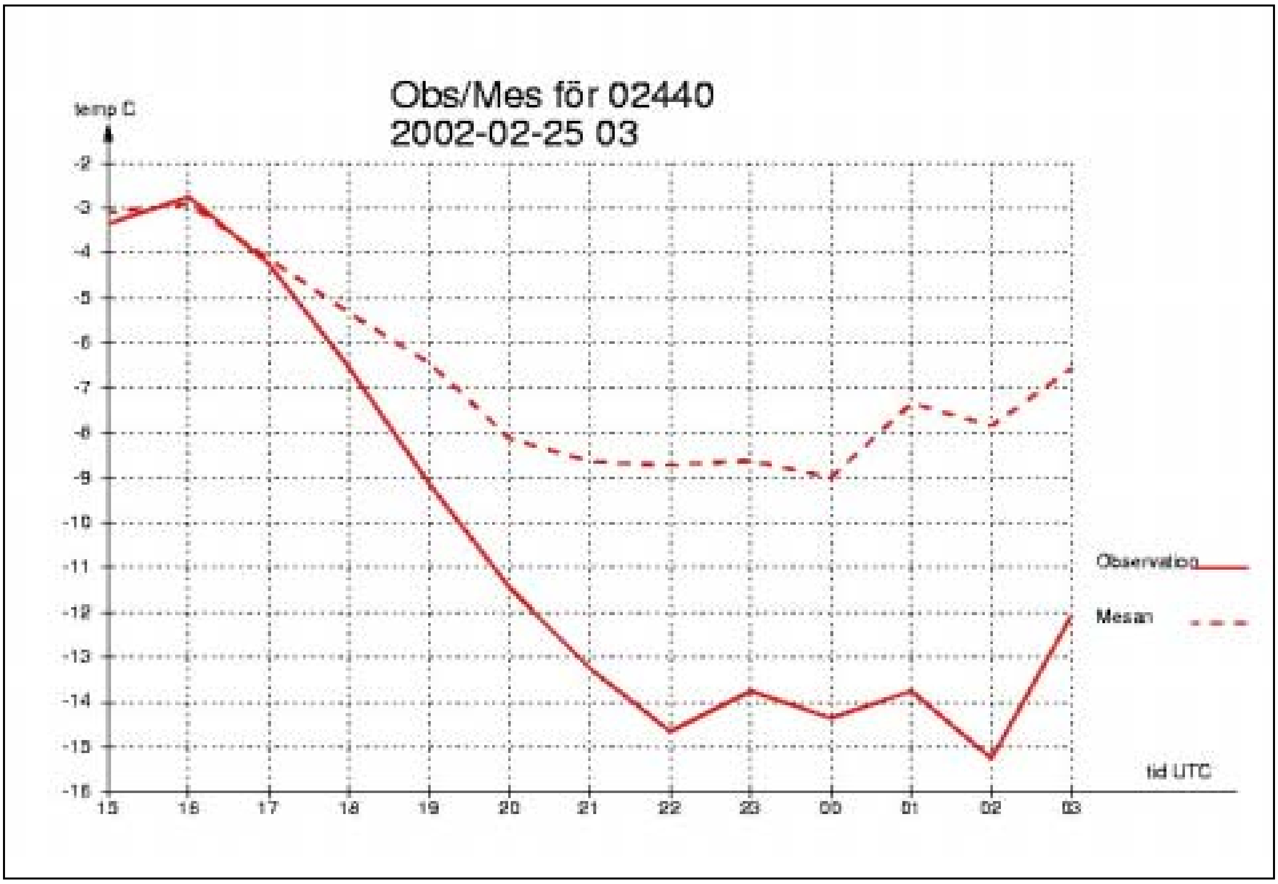


Figure 4.6. The observed temperatures from one station 02440, Åmot, during a 12 hour period compared to the suggested values from MESAN.

4.6.2 The VViS control program

The VViS program is used to control observations from automatic weather stations belonging to the Swedish Road Company.

IThe program flags the observation as uncertain if the parameter deviates substantially from a reference value. This reference value is an interpolated value estimated from MESAN. Depending on the weather situation, an observation can differ from the expected value for a small area without being wrong (the grid area is 22km×22km). The weather related expected deviations are estimated by the quality control system. This control program tests temperature, relative humidity and precipitation.

4.6.3 QC MESAN

MESAN is used to control the meteorological parameters collected in real time at SMHI.

Since August 2001, an improved version of the VViS program has been used to test real time observations at SMHI. The reference value is estimated by MESAN. The parameters that are controlled are temperature, maximum and minimum temperatures, air pressure, relative humidity and precipitation. About half an hour after the observation time, all the observations collected in real time are checked. A correction value is also calculated by the model. The maximum and minimum temperatures and the precipitation are calculated about half an hour after 06 UTC and 18 UTC.

The results are presented in tables, maps or as a graphic time sequence. Statistical values are presented as a frequency table for the most recent 30 days.

4.7 Automatic Quality Control not in real time at SMHI (QC2)

4.7.1 Spatial control methods

4.7.1.1 Roy Berggren's method

Roy Berggren's (1989) interpolation method replaces a missing temperature value. An interpolated value is a mean of observations from up to ten neighbouring stations within a distance of 100 km, weighted inversely by the square of the distance.

A statistical list is created monthly to investigate whether the temperate at a station is comparable to the surrounding stations. This list consists of the deviation between the observed value and the integrated value for the station. This deviation is then used as a “zero point correction”.

4.7.1.2 Checking and correcting precipitation data

The program described below was written by Bengt Dahlström and Nils-Åke Andersson (SMHI, internal document, 1979. See Biometrics volume 9, 1953, p. 74-89).

The system for checking and correcting the precipitation data is both automatic and manual. An automatic program can correct logic errors. Errors without any direct logical explanation are referred for manual inspection. The main steps in the automatic system are as follows:

- The nearest neighbours to the studied precipitation station are chosen. Generally the six closest stations are considered.
- The system investigates trivial errors. A special decision table is within the system to handle special situations connected with the case when the studied station reports dry weather. This part of the system is constructed to minimise manual inspection.
- The station is tested by a formula based on micro-statistics.

The formula reads as follows:

$$r_c = \frac{\left|Ra - Ra_{nearest}\right|}{Ra_{\max} - Ra_{\min} + \varepsilon} \qquad \text{(SMHI)} \qquad (4.6)$$

where:

Ra	=	the checked precipitation value
$Ra_{nearest}$	=	the value among the neighbouring values that is closest to the checked value (Ra)
Ra_{max} and Ra_{min}	=	the highest and the lowest values among the neighbours
ε	=	a small quantity to avoid zero in the denominator
r_c	=	critical ratio

The value r_c is then compared to tabulated values for a selected confidence level.

- If the test value above is classified as suspect (the ratio r_c is larger than the tabulated value), then further testing is performed. The value is checked for time consistency. For instance, if the following days had significantly higher or lower precipitation when compared to neighbour station values, then a new value is computed based on the previous quantities with consideration to the spatial pattern as revealed by the neighbours. If no reasonable explanation can be found to explain a deviation, then the value is recommended for manual inspection. This can be the case when isolated showers do not affect all the neighbouring precipitation stations.
- Manual inspection is achieved in a PC-environment, where a GIS is used. The suspect values are specially highlighted. The corrected values are indicated though it is possible to change these values.

A new value is calculated as a mean value based on the neighbouring station values. If there are more than three neighbouring stations, the highest and the lowest are excluded. For days where no measurements are made and the precipitation is accumulated, a mean value is calculated.

If no observations are made during a period of days, the accumulated precipitation on the following day is distributed when compared to the mean of the neighbours. If observations during a period of days are marked suspect or wrong, the accumulated precipitation is redistributed using the mean of the neighbours.

Figure 4.7 shows observations controlled by the program written by B. Dahlström et al. The figure shows the whole of Sweden and a zoomed part of Sweden including the suspected observations.

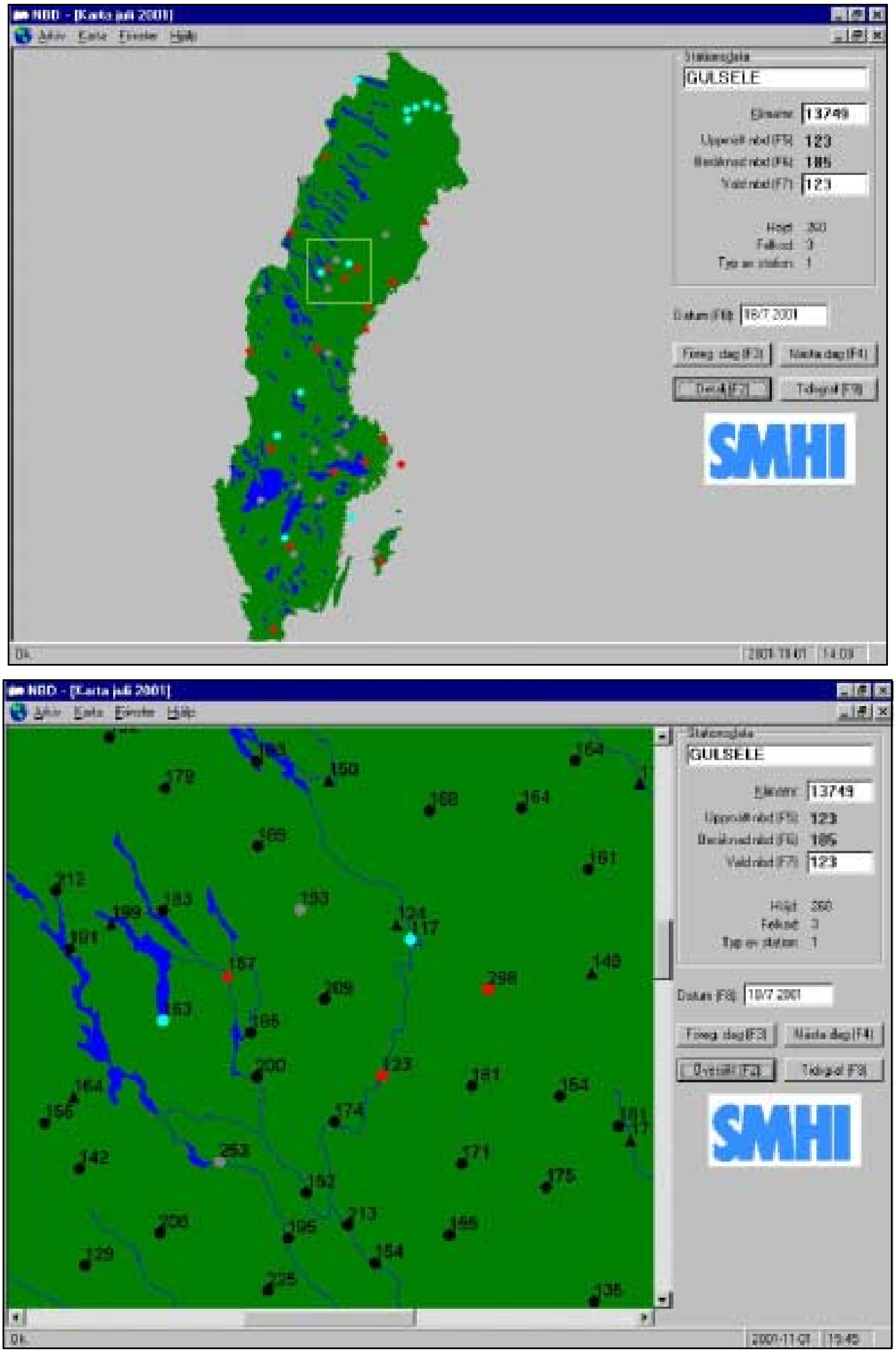


Figure 4.7. Example of checking of daily precipitation sums at SMHI. The program marks a suspected wrong observation, which the program has not been able to correct in red. The program marks a suspected wrong observation, which has been automatically corrected in grey. A suspected wrong observation, which is manually approved or corrected, is marked in cyan. Values marked in black are approved by the program.

5. Flagging principles

5.1 General

Through quality control algorithms, suspicious or certainly wrong data values may be identified. Information about detected problems can be passed on together with data elements as an information label, or flag, in order to:

- indicate the quality level
- inform which control methods and control levels data have passed
- inform about the error type if an error or suspicious value was found

Such flagging information is useful both in quality control phases and for users of meteorological information. Flagging should enable an understanding of what kinds of data problems may have been identified. A common definition for the quality level can be made, but the flagging of error types will be different for various parameters because they are subject to different kinds of errors.

Flags in each quality control level, QC0, QC1, QC2 and HQC, may vary. Detailed information should be estimated for internal use to enable evaluation of observation problems and diagnoses of each step in the QC scheme. Flagging codes for end-users should be simple and clear.

5.2 QC0-flagging information

QC0 is important so errors can be fixed immediately at the station. Then the observation should be correct and QC-flags are unnecessary when data are received centrally. Instrument errors at the stations may be detected in QC0. Such information should be communicated to the weather service, eventually by flags.

If it is possible to detect errors in QC0 which are impossible to detect at a later stage, e.g. because of aggregation algorithms applied at the stations (logging-values), such information should be made available from the AWS station.

5.3 Flagging on QC1 and QC2 levels

5.3.1 Flagging for internal purposes

Traditionally the purpose of flagging is to provide an overview of the quality of an observation and to identify whether the observation has been corrected. Ideally the only flagging necessary should be “QC-controlled” or “not QC-controlled”. QC-controlled is reliable and the observation is correct or corrected/interpolated. Observations that are not QC-controlled may be in error.

In practice it is impossible to distinguish absolutely the quality of the observations, therefore more flags are necessary. It is reasonable to distinguish between two modes of quality-control information; a detailed mode that is actively used during the QC-phase, and a general mode for the end-user.

For example, at DNMI it is proposed that during the quality control process, all data are to be flagged. The flagging will be used during the execution of the different controls in order to decide what other controls or handling of the observations should be performed. When the observations are collected at SMHI, all parameters are checked during QC1 and QC2, and receive different flags depending on the status of the observation, i.e. if they are correct, suspected wrong or certainly wrong. Similarly, all observations are checked and flagged at DMI. More details about the flagging system at some NMS's can be found in appendix E.

5.3.2 Types of flags

The control flags must be designed in a way that makes it possible to make statistics concerning:

1. station
2. date and observation hour
3. parameter
4. control level
5. control method (identification of performed check / algorithm)
6. result of control (flag – OK/not OK, eventually scaled)

All of these flags will lead to a huge amount of information, which should not necessarily be attached to the observation when the control procedure is performed, but this is debatable. At DMI, for example, all flagging information is attached to the observation. When the observations have reached this stage, the control flags will be compressed to relatively few end-user flags.

Advanced users often require detailed flagging information, while other users, for example external, only need it in more simple terms. Below is a discussion of the flagging designed for advanced users, while flagging for end-users is described in a separate section.

The user flags (or quality information codes) must be designed in a way that satisfies advanced user needs and should provide information about the result of the control procedure. It should be possible to determine whether:

1. an observation is missing
2. a missing observation is interpolated manually or automatically
3. an observation is controlled or not
4. an observation is found OK
5. an observation is corrected manually or automatically, and why
6. an observation is suspicious, but <u>not</u> corrected
7. collected precipitation during a period is distributed
8. absolute maximum or minimum temperatures during a period are distributed

It might be suitable to distinguish between automatic and manual corrections, if someone in the future finds a suspicious value and wants to correct the observation. Manual correction or interpolation does not exclude that eventual model values might have been used in the controls; experts might have evaluated the proposed values.

Since data are often used on the parameter level, parameter values decided controllable should be flagged. Details about the controls in the different control levels should also be flagged, e.g. in order to evaluate the performance of algorithms and QC schemes. This implies that detailed flagging information should be attached to each parameter at all QC levels to indicate:

- quality level of an observation
- the method that identified something suspicious
- reason of error

Four values are used to indicate the quality level of an observation, while a dummy value is used to specify whether an observation has not been subject to quality control:

0=the value is certainly correct
1=the value is probably correct
2=the value is probably in error, but in unusual cases it may be correct
3=the value is certainly in error, but in exceptional cases, it may be correct

Between single station and spatial checking methods, there is a fundamental difference in how the quality level should be understood (see table 5.1). For example, range, step and consistency checks cannot assign the flag value 0 (certainly correct), because they do not take neighbour stations into account. Even if there are no consistency problems, and even if the observed value is within the limits of step and range checks, big errors in the observation can still be possible. A value with flag=2 (probably in error) detected by single station methods can still be correct, or erroneous observations may be flagged as probably correct. Spatial checks are much more reliable in detecting errors because they can estimate the probability of error detection. Spatial checks are necessary for subsequent and more accurate flagging of the observations (see also appendix E, Ch.12).

Table 5.1. Description of quality level flags for observations checked by single station and spatial checking methods.

flag	description of flag in single station methods (probability of error detection cannot be estimated)	description of flag in spatial methods (probability of error detection can be estimated)
0	not possible to assign this flagging value	certainly correct
1	probably correct, but can be a very big error	probably correct
2	probably in error, but correct in unusual cases	probably in error
3	certainly in error, but correct in exceptional cases	certainly in error

It is complicated to develop common guidelines for flag definitions, methods, and algorithms that identify suspicious or erroneous observations. Many different methods can be used at each QC level, and observations may sometimes be flagged by several methods. An extreme and erroneous value may be flagged by more than one method, e.g. both by range-, step-, consistency- and spatial checks. Should the observation run through all checks in a specific QC level until a certain error eventually is found, or should the checking stop the first time the observation is flagged, or should the observation always run through all checks? Should flagging information from all checking routines be saved, or is it sufficient to save those flags that were set by the “winning” routine? Flagging information is needed to describe the problem, i.e. a diagnosis of the error type, as well as how the quality level was estimated.

The flagging information can be disseminated internally in separate files or attached to each observation element in the data bulletin, e.g. in BUFR format as is done at DMI.

The purpose of quality flagging is to give information about quality of observations. Metadata, such as information about observational methodology, equipment and sensors at the weather stations, could be linked to the observations and the QC flags to support HQC.

The aim of flagging should be to ensure correct and reliable use of observations and products. Because observations are used in variable areas with different needs for accuracy, the need for QC-information is varying.

When all defined QC's (incl. HQC) for the observations are performed, all detailed QC-information is summed up in one status information code for each parameter of an observation. For ordinary use, this code should give indications for correct use of the observation.

At DNMI the implementation of the QC-information (codes) is under consideration (e.g., in the same table as the observations, in own flag tables, as a column for each parameter, as strings). The idea is that it should be possible to give adequate quality information both to the advanced user and the end-user.

5.3.3 Storage of QC information

All controls are flagged, and the flagging history should be stored during the control process. The system for storage of QC information, and the amount of information stored can be different. Details can be found in appendix E.

5.3.4 Flagging for end-users

When all defined QC's (incl. HQC) for the observations are performed, all detailed QC-information is summed up in one status information code for each parameter of an observation. For ordinary use, this code should give indications for correct use of the observation, for example:

- The observation is correct
- An error was detected, thus the value has been corrected by interpolation
- The observation is in error
- The observation has not been subject to quality control

Before delivering data to end-users, it should be decided whether the observations are correct. The content of end-user flags is open for discussion, and, for example, further information could be valuable for the end-users such as the level of accuracy of corrected values. It may also be important to distinguish between manual and automatic observation corrections, and raw data must be kept without changes.

Adequate quality information should be available according to the needs of the end-user. Internal and external end-users may not need the same kind and amount of information. Detailed suggestions for end-user flagging are unique to the practice and plans of different NMS's.

Several coding systems are available, but one proposal, perhaps mainly suitable for internal use, is described below as an example (further details in appendix E, Cp.12). The quality level of data and the control levels that the observations have passed are specified by a single flag value.

The quality of data (error severity level) is described by a one digit code, and the control level is described by a code where the numbers of digits indicate the number of QC levels the observation has passed, as shown below.

Error severity level E:		Control level L:	
0	*no check*	1	*observation has passed QC0*
1	*observation OK*	10	*observation has passed QC1*
2	*suspected small difference*	100	*observation has passed QC2*
3	*suspected big difference*	1000	*observation has passed HQC*
4	*calculated value*		
5	*interpolated value*		
6	*...*	The end-user code C is given by:	
7	*...*		
8	*missing value*	$C = E_{QC0}L_{QC0} + E_{QC1}L_{QC1} + E_{QC2}L_{QC2} + E_{HQC}L_{HQC}$	
9	*deleted value*		

If for example the following results were found by quality control of a temperature observation:

QC0	the value was found correct	$E_{QC0}=1$	and	$L_{QC0}=1$
QC1	the value was found erroneous (big difference)	$E_{QC1}=3$	and	$L_{QC1}=10$
QC2	a new value has been estimated by interpolation	$E_{QC2}=5$	and	$L_{QC2}=100$
HQC	the interpolated value has been accepted	$E_{HQC}=1$	and	$L_{HQC}=1000$

By this definition the end-user flagging code becomes $C = 1\cdot 1+3\cdot 10+5\cdot 100+1\cdot 1000 = 1531$. If no check was done by HQC, the flagging code is simply given by $C = 1\cdot 1+3\cdot 10+5\cdot 100+0\cdot 1000 = 531$. This flagging code can easily be simplified for end-users who need less information.

5.4 Closing remarks

Some end-users need data immediately after it arrives at NMS's. Quality control must be quick and it should provide information about reliability of data. To ensure that only reliable data reaches users:

- Use automatic controls before delivering data to users
- Flagging should concern all parameters if possible
- Keep flagging simple to end-users
- identify which quality control levels parameters have passed

Flag information must follow data, e.g. flags may be added to the data bulletin as some kind of appendix or trailer, or they may be written in separate files. Furthermore, the flags should be stored permanently in a database, either all details or at least the end-user flags.

Automatic quality control at QC1 and QC2 levels are based on different methods, e.g. prognosis model data from HIRLAM, various statistical methods such as Kriging interpolation, consistency tests and step checks. As much flag information as possible should be assigned during the quality control process in order to make it easy to evaluate what has been detected as well as how and why specific observation problems may have been found. For the same reasons, and to make it possible to evaluate the QC process itself, flag values assigned during each of the quality control levels QC1, QC2 and HQC should be kept unchanged and not be overwritten.

A flag value, an informative label, must be assigned to all data values to indicate their status. It is up to subsequent data processing to inspect data and, eventually, correct erroneous values before transmission to end-users. The need for corrections may be different at the various checking levels. Some end-users need data immediately after observation time while other can wait until a more extensive checking procedure has been applied. It may be practical to distinguish between detailed control flags connected to the data during the control process, either stored temporarily or permanently for special use (e.g. research purposes), and simplified user flags connected to historical data and stored permanently for general use.

During the quality control process, errors and suspicious values may be flagged, and it may be necessary to inspect data in HQC in order to; (i) carefully analyse whether the parameter is in error, (ii) correct the parameter when it is in error, either by manual or automatic methods. Accordingly, changes should be indicated by new flag settings.

When HQC or some other automatic verification has been performed, the final status of the observation must be indicated by flags that are stored in a database. This includes at least one kind of flagging code that specifies the quality level and what has happened with the observations during the quality control process. It may be desirable to have access to the detailed flagging information from each QC step.

Flagging information can be extensive. A system to present and inspect flag values and observations is desirable to assist manual checks and possibly correct data, or to evaluate the quality control scheme. Various statistics should be estimated, either by a HQC system or by frequently run programs. For example, it could be of great value if detailed summary statistics were frequently provided to identify stations or parameters that are often in error.

6. Conclusions

A main objective of this report has been to describe automatic methods used in Nordic countries for quality control of meteorological observations.

Automatic methods are computer programs, which are able to identify erroneous or suspicious observation values. All observations are collected centrally and controlled automatically at meteorological institutes. The suspected wrong values are flagged depending on the likelihood that the error is suspect. At this stage of the control phase, only a few corrections may be applied such as pressure tendency and minor corrections of the maximum and minimum temperature. The suspected wrong observations should not be used in real time work, as for example in weather analysis or as input in numerical models. In time, many erroneous observations are corrected manually for climatological purposes. A suggestion for the future is to use models for correcting some of the observation values, but extreme values must always be checked manually. The present control systems are regarded as only semi-automatic systems even though automatic control methods are used.

When presenting control methods in this report, it has been appropriate to use a common inter-Nordic nomenclature for naming the methods and the parameters involved. The symbolic names for quality checks contain QC level, type of QC, institution, version number, an indicator for which parameter to be checked (if more than one parameter) and the parameter(s) used in the check. The symbolic parameter names contain a first letter, indicating a main group of weather elements, then a second, some times a third letter, which describes the actual parameter, and finally (optionally) observation hour, observation level and observation period (se appendix A).

6.1 Quality control methods

6.1.1 Methods using single station observations

At present, timely dissemination of meteorological observations that have been subject to quality control is a basic requirement for many purposes. Because observations from neighbouring stations are not available in real-time, which would make spatial checking possible, quality control is only possible on a station-by-station basis. Single station methods include range, consistency and step (temporal) checks (Ch.3).

Single station checks can be applied on the observations already at the station site or in connection with real-time data reception. The automatic observations are controlled at delivery. The human observer can use an automatic control programme for self-diagnostic checking. Consistency checks can reveal certain errors in at least one of the parameters involved. Spatial checking methods identify parameters in error and suggest probable corrections. Correspondingly observations from neighbouring stations are necessary to correct erroneous data revealed by step checking methods.

Concerning manual observations there is not much more to gain in quality with the consistency control methods using algorithms that reveal certain errors. Most of the possible algorithms are already in use. Maybe new algorithms should be developed concerning other data types like aerodrome data or when combining different data types. Otherwise it is possible to fine-tune the limits for physically impossible and very unusual values by using monthly climatological statistics from individual stations, both in step tests and consistency control methods with probable error detection.

Selected methods for spatial checking are mostly used in non-real-time, when information from neighbouring stations is available. If a parameter field is prepared in advance, as short-term prognostic values for all station site positions, it is possible to check single stations observations by a spatial checking method in real-time. However, when using model values, the model should be evaluated to determine whether it is describing the weather situation.

6.1.2 Methods using observations from more than one station

Spatial control methods have more potential than single station methods. They can be used for checking existing observations as well as for interpolating missing observations. The performance of the different methods is untested with respect to different geographical regions (climatic classification), weather situation, station density, topography, each stations representation of its area, different parameters.

Suspicious values discovered by use of simpler single station methods such as range checks, can often be clarified by use of spatial methods.

Non-real-time spatial checking is performed in many different ways (Ch.4). These methods are vital to quality control work. Currently, these control programmes mainly use observations from weather stations, but would achieve more effective control by using additional information from other sources, as is the case in the Swedish MESAN control programme. This system relies on a reference value and can be used near real time. In MESAN it is possible to utilise radar and satellite information together with a first guess from HIRLAM. In this way a mesoscale analysis contributes a reference value for a parameter for a small grid area, which is then compared to the observed value. This reference value is based on statistical values. It can be difficult to identify extreme values on-site. An advantage of this method is that it can check nearly all meteorological parameters in close to real-time and suggest corrections.

Other interpolation methods utilise meteorological information from the near past, as is the case with the Kriging statistical interpolation method. Statistical relations between neighbouring stations are used by this interpolation technique. An advantage of this method is that it is possible to take into account different effects that influence the parameters, e.g. station co-ordinates (always included), height above sea level, influence from lakes and sea etc. within an area of 10 km x 10 km as in Finland. The method is mainly used to check air temperature, humidity, sea level pressure and wind parameters. When comparing Kriging with HIRLAM, Kriging shows a somewhat better result.

Statistical interpolation methods without geophysical information can be useful if there is a relatively short distance between the meteorological stations or when the terrain is homogeneous. Otherwise only larger errors may be found. These methods are especially vulnerable in some weather situations when the parameter fields are strongly inhomogeneous.

Non-parametric methods are tests involving ranked data, i.e. data that can be put in order. They are most convenient in relatively flat areas and high station density. In Denmark, a method using the median and quartiles of 24-hour precipitation values from a number of neighbouring stations has shown good results. With this method, outliers are prevented from disturbing the result. A similar technique is used in Sweden where the precipitation from the six nearest neighbours is compared with the value to be checked. A weather situation with a continuous rain area usually results in fewer suspicious values than in a rain shower situation. Also with this method it is possible to leave out the highest and the lowest values to prevent outliers to influence. Both methods are developed to discover errors mainly at manual stations like accumulated precipitation sums, precipitation recorded on wrong days or at incorrect observation time, and otherwise unknown reasons for wrong observation values.

6.2 Flagging

A variety of control flags are needed throughout a quality control process with many methods in use as the process starts at the observation site and continues through different phases in real-time and non-real-time at the NMS's. Flagging principles have been presented and discussed in order to come up with general guidelines for a comprehensive and flexible flagging (Ch.5).

A flag has to be assigned to each data element in order to indicate the data quality. Flag information should contain quality level, quality method, type of error and kind of correction. It may be practical to distinguish between control flags connected to data during the control process, either stored temporarily or permanently for special use (e.g. research purposes), and quality code values (simplified user flags) connected to historical data and stored permanently for general use.

Flagging at different QC levels is discussed in this report. Flagging at the QC0 level should be performed at automatic or semi-automatic stations. Moreover, most of the flagging should occur at the QC1 and QC2 level. Flags or control information can be organised in many different ways and views vary on to the best methods to differentiate or grade the flagging information.

Automatic quality control is mainly based on automatic flagging. But the quality control procedure either involves manual control and flagging that may contradict the automatic ones, or involves a manual inspection of the quality control routine, which may or may not lead to manual flagging. Any manual control, by which the quality level is identified, has the decisive influence on the quality code that is assigned to the observation before storing it permanently.

6.3 Recommendations

Some end-users need data immediately after reception at the NMS. The quality control must be quick and should give information on what quality control levels data has passed and reliability of data. Suspicious data should not reach users. Real time end-users should be informed that more extensive quality control will continue some days after observation day leading to improved quality.

To achieve reliable real-time or near-real-time data, *improved automatic controls are recommended*. Implementation of more comprehensive checking systems should be done to avoid inconsistencies between different parameters, and to locate other erroneous observation values. Single station control methods should be performed as soon as possible, preferably at the observation station, e.g. to avoid observation inconsistencies. Otherwise the quality control system should be designed to make it possible to choose between different control methods, especially different spatial controls.

Flagging should concern all parameters. User flags, or the resulting quality code information, should be formulated in a simple and uniform way. This information should contain passed control levels and error warnings. Suspicious values should have different flags at the end of the control process depending on whether the observations are approved or not. It should be possible to go back to the original data at any time. *When the automatic procedures have been completed it should still be possible to add flags while manually checking suspicious data in HQC level, e.g. to specify that suspicious observations were found correct during HQC. In principle, flags set in HQC overrule flags set at previous QC levels, because it is in HQC that a definitive decision is made whether suspicious observations are wrong. Flag information must be kept unchanged at all QC levels, e.g. to make it possible to evaluate the control steps. For verification of automatic procedures, it is inevitable to use some kind of HQC system, for example to estimate performance statistics.*

6.4 Further work within the quality control group

As shown by this report, the participants in the Nordklim Task 1.2 Quality Control project have learned a lot from each other by *discussing and exchanging experience and algorithms*. Each participating country has special knowledge and experience within specific fields that contributes to the common improvement of the QC systems. Until now, this project has concentrated on QC1 and QC2 automatic methods and associated flagging aspects.

Further work should focus on the manual part of the total quality control system, HQC in order to see if it is possible to automate some of the present HQC procedures, or at least make HQC procedures more efficient. Although automatic quality control methods in most instances can identify erroneous and suspicious observations correctly, there is still a grey area left where the existing procedures cannot identify problems or where the control system suspects too many values. For this reason, there is an inevitable need for manual evaluation of flagged observations, e.g. before corrections are applied to data elements. Also, manual procedures are obviously needed for evaluation of automatic checking methods whether they perform well and have a high hit efficiency. Currently the manual procedure is a time-consuming task, and it should be possible to improve the routines in order to spare time and do the work more effectively.

Most of all, the NMS's need effective meteorological information and a *comprehensive tool for decision making* concerning correction of data, adapted to the different quality control levels. The Nordic countries would benefit from co-operation on such matters because it would be waste of resources and time-consuming if small staffs at the NMS's should try to do the work independently.

The first step will be to agree on a common description of the operational functionality of the HQC, and design guidelines for future control routines. Based on these descriptions and guidelines, a pilot study should be performed to find a common software platform for development of a comprehensive decision support system (DSS). The NMS's can then contribute to an inter-Nordic modular software package.

Continuing co-operation under the Nordklim umbrella will expand the opportunity to exchange knowledge, design training courses on QC programmes, and improve methods and algorithms particularly spatial checking.

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8. Appendix A - definitions

8.1 Types of station sites

It has been difficult simply to categorise stations with different observation times, transmission techniques, instruments, observation methods etc., into named categories such as synoptic, climate, precipitation, AWS-stations. The naming of the station types vary from country to country, and even inside one country the observation repertoire, for instance on "climate stations", can be different. It will be very confusing if national station naming were used. Furthermore, observations can be retrieved in real time as well as being delivered by mail.

In this document the national definitions of station types will be simplified into only three categories.

8.1.1 MAN - manual weather station

A ‘MAN’ station is simply a manual weather station where all observations are done manually by the station staff. It is stations such as manual rain gauge stations, manual climate stations, manual synoptic stations, etc.

8.1.2 HYB - semi-automatic weather station

A ‘HYB’ station is a hybrid station where some of the observations are done manually while other observations are done automatically by necessary equipment. For example, many synoptic stations in the Nordic countries are still semi-automatic; precipitation may be recorded manually while other parameters may be measured automatically.

8.1.3 AWS - automatic weather station

An ‘AWS’ station is a totally automatic weather station. More and more stations are equipped with sensors and communication systems for real-time automatic measurements and transmission of data. Automatic stations are such like automatic climate stations, road stations, synoptic stations, etc.

8.2 Naming guidelines for indication of quality control methods and parameter names

The purpose of having naming guidelines for indication of parameters is to standardise the very different parameter names that are used in the countries participating the Nordklim co-operation. At the same time, there is a need for a common naming of control methods.

8.2.1 Symbolic names for checks

Any check is given a symbolic name according to the following definition:

<QCL><t><inst>[(ver)]–<*par1>[,[*]par2][,...]

<>	=	means that parameter is required
[]	=	means that parameter is optional
QCL	=	QC level (QC0, HQ0, QC1, HQ1, QC2, HQ2, HQC)
t	=	type of quality control method (details below)
inst	=	abbreviation of institution, e.g. DNMI, VI, SMHI, FMI, DMI

(ver) = version number of checking algorithm if more than one version exists
* = indicates the parameter (or parameters) being checked (further details in text)
par1 = one parameter used in the checking
par2 = another parameter also supporting the checking

Several parameters can be specified in the symbolic name. The parameter being checked and subsequently flagged must be indicated by an asterisk. If two or more parameters are specified, only the parameter or parameters that are going to be flagged have to be indicated by an asterisk. The parameters without an asterisk are helping parameters.

The type of QC method is indicated by t that comprises one or more letters of which only the first one is required:

t = <M>[m_1][m_2][(d)]

The *first letter*, M, indicates the main method group, while *letter two and three* (m_1 and m_2) are used to specify details about the method. The *fourth letter* given in brackets () can be used to indicate whether a check is a certain or probable error detection (c and p). For example, r(p) means probable error detection by range checking and c(c) means certain error detection by consistency checking. It is only in single station checking that is it possible to discriminate between probable and certain errors.

The following letters are used to indicate the QC methods reported in the document:

Single station methods:	r	=	range/limit checks
	c	=	consistency checks
	s	=	step checks
Spatial methods:	i	=	spatial checking based on interpolation of observations
	n	=	spatial checking based on numerical models
	t	=	spatial methods based on test statistics
	p	=	other kinds of spatial checking methods

There are four main groups of spatial control methods. The letters i, n and t is used for spatial checking of the value of one parameter at one observation time, only. The letter p is used for other spatial methods such as manual inspection of station data, i.e. no objective calculations have been done. Examples of 'p' methods are such like manual inspection of either suitable organised station lists or meteorological information that have been visualised by graphic representation.

It is allowed to combine the method letters in order to specify details about a method. Table 8.1 shows all combinations.

Methods analysing the temporal variation of one parameter value at a single station, i.e. pure step checking methods, are overall called 's'. If the step is analysed by test statistics, the abbreviation becomes 'ts', while 'ns' are step checks based on numerical models.

Methods analysing the temporal change in two or more parameters at a single station, i.e. pure step consistency methods, are overall called 'sc'. If the step consistency is analysed by interpolation the abbreviation becomes ‘isc’ and in case of numerical methods it is ‘nsc’, etc. If the consistency, only, between neighbour stations is checked by interpolation, it is designated by ‘ic’.

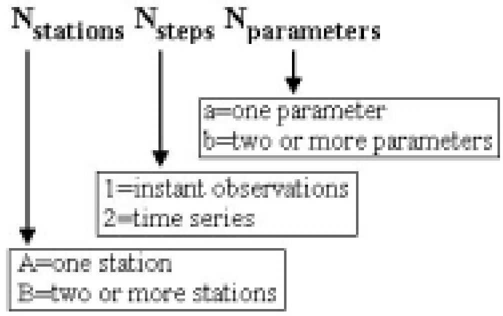
In general, if two or more parameters are involved in spatial checking, i.e. spatial consistency checking, a ‘c’ is added which gives: pc, ic, nc and tc. In this case the consistency concerns probable errors and not formal errors as in single station consistency checking.

If the temporal change in one parameter value is checked against the changes at neighbour stations, i.e. spatial step checking a ‘s’ is added which gives: ps, is, ns, ts.

If two or more parameters are involved in spatial checking of variations in parameter values, i.e. spatial step consistency checking both ‘s’ and ‘t’ are used: psc, isc, nsc and tsc.

Table 8.1. Symbolic names for indication of the type of QC methods. Dataorg=a letter code indicating details about the method grou/p and how data are organised (further details i Chapter 2 and on next page), abbr=symbolic name for the specific group of methods.

Main	method group	dataorg.	abbr	explanation of method group
A single station methods	r = range	A1a	r	range check in general
			r(c)	range check (certain error detection)
			r(p)	range check (probable error detection)
	c = consistency	A1b	c	consistency check in general
			c(c)	consistency check (certain error detection)
			c(p)	consistency check (probable error detection)
	s = step	A2a	s	step check of a time series
			sc	step consistency check of a time series
		A2b	sc(c)	consistency check of a time series (certain error detection)
			sc(p)	consistency check of a time series (probable error detection)
B spatial methods	i = interpolation	B1a	i	spatial check of a single value
		B1b	ic	spatial check involving two or more parameters
		B2a	is	spatial check of the development in time of a single parameter value
		B2b	isc	spatial check of the development in time of a parameter value involving two or more parameters
	n = num models	B1a	n	spatial check by comparing observation versus numerical prognostic value
		B1b	nc	spatial check based on values from numerical prognosis involving two or more parameters
		B2a	ns	spatial check based on values from numerical prognosis of the development in time of a value from a single parameter
		B2b	nsc	spatial check based on values from numerical prognosis of the development in time of a value involving two or more parameters
	t = test statistics	B1a	t	spatial check by estimation of test statistics
		B1b	tc	spatial check based on test statistics involving two or more parameters
		B2a	ts	spatial check based on test statistics of the development in time of a value from a single parameter
		B2b	tsc	spatial check based on test statistics of the development in time of an algorithmic value involving two or more parameters
	p = other spatial	B1a	p	spatial check by other methods
		B1b	pc	spatial check by other methods involving two or more parameters
		B2a	ps	spatial check of the development in time of a single parameter value
		B2b	psc	spatial check of the development in time of a parameter value involving two or more parameters



A code is used to indicate details about the method group and the organisation of data. First of all, it is important to discriminate between single station methods and spatial methods.

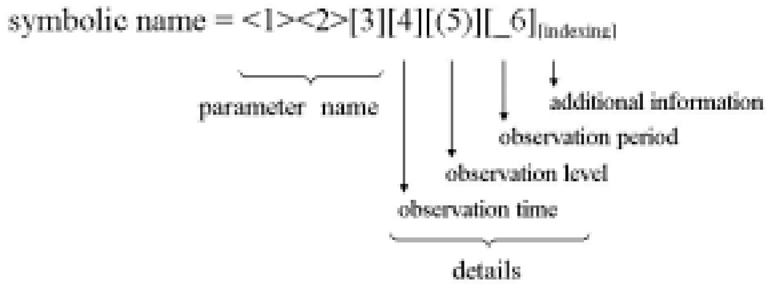
In each of these two main groups of methods, data can be organised according to the number of parameters and time steps, i.e. whether a single station or a spatial method is a consistency check, a step check, or a step consistency check.

8.2.2 Definition of symbolic parameter names

For indication of type of parameter a general definition of the symbolic names is used. It is partly based on WMO specifications of symbolic first letters (WMO-No. 306 (1995), with some exceptions) and on tables in the document 'dnmiparameter_standard.doc' (DNMI), concerning the second letters.

The symbolic name always comprises at least two letters (1 and 2). The first letter indicates the main group of the parameter and is always in uppercase. The second letter tells which parameter it is and is normally in lowercase, but it can be in uppercase. A third letter may be added as an indicator giving details of the parameter (3). Eventually, observation hour (4), observation level (5) and observation period (6) can be added. Examples of symbolic names are shown in table 8.2, 8.3 and 8.4.

The nomenclature of symbolic names can be written in the general form:



where:

<1> = letter, indicating main group of parameter (always uppercase) (required).
<2> = parameter indicator, given as a letter or number (normally lowercase) (required).
[3] = parameter indicator, giving details (always lowercase) (optional).
[4] = observation time (optional), always Z time, given by at least two digits HH.
Two more digits can be added to indicate hours, i.e. HHmm.
[(5)] = observation level (optional) given by the level value L and the level unit u.
[_6] = observation period (optional) given by the period value P and the time unit u.
[indexing] = specification of additional information.

Item 1 rules - main group of parameters:
The following main groups of parameters (first letter) have been defined (in alphabetical order):

C = cloud type	N = cloud amount	S = snow
D = wind direction	O = sunshine	T = temperature
E = state of ground	P = air pressure	U = humidity
F = wind speed	Q = radiation	V = visibility
H = cloud height	R = precipitation	W = weather

There are also other important parameters involved in quality control, as for instance wave parameters. These are not mentioned in this report and are therefore not included in the above list.

Item 2 rules - parameter indication:
The second letter tells which parameter it is, but letters for all kinds of parameters within each main group has not yet been thoroughly defined. For example, for temperature T the definition of second letter is like this: Ts=soil temperature, Tg=grass temperature, Ta=air temperature, Td=dew point temperature, Tw=wet bulb temperature, and TW=sea water temperature.

Item 3 rules - parameter indication:
The third indicator describes details about the parameters. The convention has not yet been thoroughly defined, but at least, the following is in effect:

x = maximum value
n = minimum value
m = average value

By this convention, the symbolic name for maximum dry bulb temperature becomes Tax.

Item 4 rules - observation time:
If it is necessary to separate maximum temperatures measured at different times, the observation time can be specified by two digits, for example Tax06 or Tax18. If the observation time is not the hour, it may be necessary to insert the full observation time by four digits, i.e. as hour HH and minutes mm. For example, Ta0615 means air temperature at 06:15z. Then there is no doubt whether the time is in hour or hour/minute. Item 4 is optional, and it becomes necessary only for clarification reasons. In many instances it is not necessary to add the observation time.

The observation time must always be given as Z time.

Item 5 rules - observation level:
The fifth indicator marks the observation level above or below the ground surface. It it is given in meter ‘m’ above ground and in centimetre ‘c’ below ground. Decimal numbers are not allowed. The unit is required for clarification reasons, which are especially helpful when reading very long symbolic names. For example, Tax18(4m) is the maximum air temperature at four meter level while Ra(2m) is the precipitation amount at approximately measure height (for instance 1.5 meter). If a parameter is measured at WMO standard level, for example two meter for temperature, the level option can be omitted, but in any other cases it must be given. The symbol for soil temperature one meter below ground then becomes Ts(100c).

Item 6 rules - observation period:
Finally, the observation period can be added to the symbolic name and comprises a number giving the length of the period and a letter giving the time unit. The time unit goes by the following rules, all in lower case except month:

s = seconds
m = minutes
h = hours
d = days
M = months

By this definition, the symbolic name for 12-hour precipitation amount becomes Rr_12h, and the name for maximum dry temperature for a 24-hour period becomes Tax_24h. The symbolic name for the 10 minute dry temperature at 1m level becomes Ta(1m)_10m.

8.2.3 Examples of symbolic names for checks

Following the above definitions, the symbolic name for consistency checking of dry bulb temperature and dew point temperature becomes QC2cDNMI–*Ta,Td where Ta is checked using Td. The observations are made instantly at 2-meter standard level. The observation time is not important in this case. The name for spatial checking of wind speed by interpolation becomes QC2iFMI–*Ff. The observation is made instantly at 10-meter standard level. In some cases names can be very long. What about this: QC2cDMI-*Tax18(3m)_12h,Tan18(3m)_12h, which means consistency checking of maximum and minimum air temperature measured at 3 meter at 18z with a 12-hour observation period. If a consistency check includes several parameters, a line in this document may be too short! But in many cases observation level and observation period is unnecessary because of standard values.

8.2.4 Observation frequencies

The observation frequency, i.e. the number of observations per time unit is indicated in the QC tables in this way:

<type>/<n><u>

where type=station type, n=number of observations and u=per d (24 hours), w (week), m (month)

Following this definition, u=d when n≥1 per 24 hours, u=w when n=1-6 per week and u=m when n=1-3 per month. For example AWS/24d indicates hourly observations at automatic weather stations. At manual precipitation stations emptied every 24 hours, observations frequency is indicated by MAN/1d. At some stations observation frequency may be less than one day. For example, if observations are made only once a week the indication will become MAN/1w.

Table 8.2. Symbolic names of main parameters that are used in the report. Other kinds of parameters, such as wave parameters, are not included in the list.

main parameter group	details	Explanation
Temperature parameters T	Ta	air temperature (dry bulb) (°C)
	Tan	minimum air temperature (°C)
	Tax	maximum air temperature (°C)
	Td	dew point temperature (°C)
	Tw	wet bulb temperature (°C)
	Tg	grass temperature (°C)
	Tgn	minimum grass temperature (°C)
	Tgx	maximum grass temperature (°C)
	Ts	soil temperature (°C)
	TW	sea water temperature (°C)
Precipitation R	Ra	precipitation amount, total container content (in mm)
	Rr	precipitation, increase during last hour by default (in mm)
	Rt	precipitation, number of tips (0.2mm/tip) in a tipping bucket raingauge
	Rd	duration of precipitation (minutes), e.g. measured by on-off sensor
	Rir	indicator of precipitation data
wind speed F	Ff	wind speed, 10m, 10 minutes now value (m/s)
	Fx	maximum 10-minutes average wind speed since previous observation
	Fb	wind speed in Beaufort, now value
	Fg	wind speed, 10m, max. 3 sec. gust pr. hour (m/s)
	Fiw	indicator of unit and method of measurement
wind direction D	Dd	10m wind direction, vectorial (degrees), belongs to Ff
air pressure P	Ph	air pressure, reduced to sea level according to ICAO standard (hPa)
	Po	air pressure at station level (hPa)
	Pr	air pressure, reduced to sea level by using air temperature (hPa)
	Pp	air pressure tendency, 3-hour difference by default
	Pa	air pressure change
weather W	Ww	present weather type
	W1	past weather type
	W2	past weather type
	Wx	past weather (W1 and W2)
snow S	Sd	snow cover
	Sa	snow depth (cm)
	Sad	change in snow depth (cm)
Humidity U	Uu	relative humidity (%)
cloud amount N	Nn	total cloud cover
	Nh	the amount of all Cl cloud present or, if no Cl cloud is present, the amount of all the Cm clouds present
	Ns	amount of individual cloud layer or mass whose genus is indicated by C
cloud type C	Cl	the type of low clouds
	Cm	the type of medium clouds
	Ch	the type of upper clouds
Cloud height H	Hh	height above surface of the base of the lowest cloud seen
Visibility V	Vv	Visibility
state of ground E	Em	state of ground

Table 8.3. Details on parameters mentioned in the main text and appendix.

main parameter	detailed name	Explanation
Ta	*Ta06* *Ta0615* *Ta12* *Ta18* *Ta(1m)_10m*	*air temperature measured at 06z* *air temperature measured at 06:15z* *air temperature measured at 12z* *air temperature measured at 18z* *air temperature at 1m level measured every 10 minutes*
Tan	*Tan06* *Tan18* *Tan_12h* *Tan06_12h* *Tan18_12h* *Tan18(3m)_12h*	*minimum air temperature measured at 06z* *minimum air temperature measured at 18z* *minimum air temperature for a 12-hour period* *minimum air temperature at 06z valid for a 12-hour period* *minimum air temperature at 18z valid for a 12-hour period* *minimum air temp (3m level at 18z, 12-hour observation period)*
Tax	*Tax06* *Tax18* *Tax_12h* *Tax06_12h* *Tax18_12h* *Tax_24h* *Tax18(4m)* *Tax18(3m)_12h*	*maximum temperatures measured at 06z* *maximum temperatures measured at 18z* *maximum air temperature for a 12-hour period* *maximum air temperature at 06z valid for a 12-hour period* *maximum air temperature at 18z valid for a 12-hour period* *maximum air temperature for a 24-hour period* *maximum air temp at 18z at four meter level* *maximum air temp (3m level, 18z, 12-hour observation period)*
Tg	*Tg06*	*grass temperature at 06z*
Ts	*Ts(100c)*	*soil temperature one meter below ground*
Ra	*Ra(1.5m)* *Ra_3h* *Ra_6h* *Ra00_6h* *Ra06_12h* *Ra12_6h* *Ra18_12h*	*precipitation amount at 1.5m level* *precipitation amount for the last 3 hours* *precipitation amount for the last 6 hours* *precipitation amount for a 6-hour period measured at 00z* *precipitation amount for a 12-hour period measured at 06z* *precipitation amount for a 6-hour period measured at 12z* *precipitation amount for a 12-hour period measured at 18z*
Rr	*Rr00_6h* *Rr06_12h* *Rr12_6h* *Rr18_12h* *Rr_6h* *Rr_12h* *Rr_24h*	*increase during last 6 hours measured at 00z* *increase during last 12 hours measured at 06z* *increase during last 6 hours measured at 12z* *increase during last 12 hours measured at 18z* *increase during last 6 hours* *increase during last 12 hours* *increase during last 24 hours*
Pp	*Pp_3h*	*air pressure tendency, 3-hour difference*
Sa	*Sa06* *Sa18*	*snow depth measured at 06z* *snow depth measured at 18z*
Sad	*Sad_24h*	*change in snow depth during last 24 hours (in cm)*

Table 8.4. Indexing on parameter names used in the main text and appendix.

main parameter	detailed name	Explanation
Ta	Ta_{-3h},Ta_{-6h},Ta_{-12h} Ta_j , Ta_{j-1} Ta_{avr} Ta_{max} $Ta18_{max}$ Ta_12h_{max} Ta_{min} Ta_12h_{min} $Ta_{interpolated}$ Ta_{obs} $Ta_{statistical}$ Ta_{num} $Ta06_{min}$, $Ta18_{min}$	*air temperature 3, 6 or 12 hours before present observation* *air temperature at time j and previous time j-1, respectively* *average of Ta of the last number of temperature observations* *highest value of Ta measured within a certain period of time* *highest value of Ta measured at 18z* *highest measured air temperature Ta over a 12-hour period* *lowest value of Ta measured within a certain period of time* *lowest measured air temperature Ta over a 12-hour period* *air temperature estimated by interpolation* *observed air temperature* *air temperature estimated by statistical methods* *air temperature estimated by a numerical model* *lowest value of Ta measured within a period before 06z or 18z*
Tan	Tan_{abs} Tan_{record}	*absolute value of minimum air temperature* *lowest minimum temperature ever recorded*
Tax	Tax_{abs} Tax_j Tax_{record}	*absolute value of maximum air temperature* *maximum air temperature at time j* *highest maximum temperature ever recorded*
Td	Td_{-3h}, Td_{-6h}, Td_{-12h} Td_{+3h}	*dew point temperature measured 3, 6 or 12 hours before now* *dew point temperature measured 3 hours later*
Tw	Tw_d Tw_{d-1}	*present wet bulb temperature* *previous wet bulb temperature*
Tg	Tg_{abs} Tg_{record}	*absolute value of grass temperature* *lowest and highest grass temperature ever recorded*
Rr	Rr_i Rr_{close}	*precipitation increase during last hour measured at time i* *precipitation increase measured at nearby station(s)*
Ff	Ff_{-3h} Ff_{max}	*10m wind speed measured 3 hours before* *highest value of Ff within a certain period of time*
Dd	Dd_i Dd_{-3h} , Dd_{i-3h}	*present wind direction* *wind direction measured 3 hours before*
Ph	Ph_{-j} Ph_{-3h} , Ph_{i-3h} Ph_{i+3h}	*previous air pressure, reduced to sea level according to ICAO* *air pressure 3 hours before present time i* *air pressure 3 hours later*
Po	Po_{-3h} Po_t Po_{t-1} , Po_{t-6}	*air pressure at station level 3 hours before* *air pressure, present value* *air pressure, 1 or 6 hours before present value at time t*
Pp	Pp_t , Pp_{t-6} Pp_3h_t , Pp_3h_{t-6}	*air pressure tendency, 3-hour difference by default* *air pressure tendency, 3-hour difference*
Pr	Pr_{-3h}, Pr_{-6h}, Pr_{-12h} $Pr_{estimated}$	*air pressure, reduced to sea level 3, 6 or 12 hours before* *Pr estimated by other means*
Sa	Sa_{abs} $Sa06_i$, $Sa06_{i-1}$, $Sa06_{i+1}$ $Sa18_i$, $Sa18_{i-1}$ $Sa06_{-24h}$, $Sa06_{+24h}$ $Sa18_{-24h}$, $Sa18_{+24h}$ Sa_{record}	*absolute value of snow depth* *present, previous or next snow depth measured at 06z* *present or previous snow depth measured at 18z* *snow depth at 06z, 24 hours before or after present time* *snow depth at 18z, 24 hours before or after present time* *highest snow depth ever recorded*
Ww W1/W2	Ww_i , Ww_{i-1} Ww_{man} , Wx_{man} Ww_{aut} , Wx_{aut} $W1_i$, $W1_{i-1}$, $W2_i$, $W2_{i-1}$	*now value and previous value of present weather code* *weather codes by manual observation* *weather codes by automatic measurements* *now value and previous value of past weather codes*
Uu	Uu_c	*humidity calculated from dew point temperature Td*

9. Appendix B - Errors and suspicious values

9.1 Common types of error at DNMI

Various kinds of error and suspicious values can be found in data, for example sign errors, wrong date errors in precipitation data, decimal errors often found in manual observations, absurd and very odd values, observation made ad wrong time, wrong use of the value 0.0 typically found in manual precipitation data, etc.

From the DNMI experience of error handling the most important or common types of errors are listed below:

Manual stations:

1. Inconsistency in an observation (e.g. observed fog and visibility above 1 km).
2. Missing information (e.g. observed rain as a weather phenomena, but no precipitation height – or opposite).
3. Misunderstanding of length of observation period (e.g. max wind speed period).
4. Forgetting to include weather (or temperature or wind speed) at the previous observation hour within the observation of past weather (or minimum/maximum temperature or maximum wind speed) at the actual observation hour.
5. Observation performed too early or too late, more than acceptable.
6. Missing sign when temperature is below zero.
7. Observation entered on wrong place in the journal (mix up Tan and Tax).
8. Observation entered on a wrong day in the journal (especially at precipitation stations).
9. Complete wrong values or missing values because of defect instrument.
10. Accumulated information (e.g. precipitation, minimum and maximum temperature).

Automatic stations

1. Signal disturbances, leading to inconsistencies (Fx > Fg) or wrong values of different kinds.
2. Frozen values (e.g. wind velocity, due to icing or "slow" ball bearings).
3. Software/calculation errors (bad filters in calculation process).
4. "Old" stations have not the possibility of observing maximum 10 minute mean value and maximum gust value belonging to the same period of time, if this occurs first minutes of a new hour.
5. Systematic errors, due to deviation from original calibration value.
6. Complete wrong values or missing values because of defect instrument or faults on the communication lines.

Errors might also occur as a result of changes of the surroundings of the station (e.g. vegetation, buildings, etc). Such errors might be discovered in homogeneity controls or by systematic inspections of the stations.

9.1 Common error at SMHI

By Caje Jacobsson, Sigvard Andersson, Anders Dagsten and Ulf Fredriksson, SMHI

9.2.1 Errors due to manual or automatic treatments at the observation sites

Kind of error	**Kind of observations**	**Checking program**	**Flagging method**	**Correction method**	**Suggestion how to avoid and correct the errors**
Sign error +/–	Manual observation real time	Che Synop and Meullers program, SYTAB	Depends on the magnitude of the error. See the programs	HQC	Be more careful at QC0
	not in real time	Max and min temperature check program, SYTAB			
Wrong date	Manual observation of precipitation not in real time	Precipitation program (BD)	Flags	HQC	At delivery using an automatic method (Linewise/Mogul)
Decimal error	Manual observation	Che Synop / Meuller and Precipitation program (BD)	Flags	HQC	Be more careful at QC0
Errors when summing up the monthly precipitation	Manual observation not in real time	Addition program	Flags at scanning and typing	HQC	Be more careful. At QC0
Write the value at the wrong place in the telegram	Manual synop	Che Synop/ Meuller	Flags	HQC	Automatic test at delivery, QC0
Absurd values	Automatic observation	Che Synop / Meuller	Depends on the size of the error	HQC	To be more careful at service of the AWS
Errors when copied by hand	Manual observation not in real time	Max and min temperature check and precipitation program (BD)	Depends on the size of the error	HQC	Automatic delivery
Obs at wrong time: Temperature	Automatic observation	Che synop / Meuller	Depends on the size of the error	HQC	Check the AWS routine program
Precipitation	Manual obs not in real time	Precipitation program (BD)		QC2/HQC	Be more careful at QC0
Missing “day 32”	Lists with values of measured precipitation	Day 32 – program	Flags for missing data	HQC	Automatic delivery
No journals	Manual climate obs journals (not in real time)	Special programs for missing journals	Missing journals are flagged	HQC	Be more careful
Wrong code	Manual obs	Che Synop / Meuller		HQC	Education, new control algorithms in QC0
Wrong use of the value 0,0	Manual obs of precipitation	Che Synop / Meuller		HQC	Education of the observers

Missing day32: “day32” has been invented because the value measured at day one the next month is used to calculate the total monthly precipitation. The value from day 32 and from day1 the next month must agree.
Linewise/Mogul: a system for automatic collection of observations from MAN stations using a common telephone.

9.2.2 Missing observations

Kind of error	**Kind of observation**	**Checking program**	**Flagging method**	**Correction method**	**Suggestion to avoid the error**
Broken contact	AWS	Program for missing observations	Missing observations are flagged	Automatic inter-polation using the observations done before and after, if they exist.	A data collecting system, which can collect old undelivered data from AWS sites
	Manual synop and climate observations in real time	Program for missing observations	Missing observations are flagged	Manually typed from journal (HQC)	Use automatic delivery system. Update Mandat to save undelivered observations. (Linewise/Mogul is OK today.)
Missing observations of other reasons than above	Manual and automatic observations in real time.	Che_synop	Missing parameter, which are expected to be interpolated, are flagged	HQC	Check at the observation site, QC0, and quick service of the AWS
	Temperature not in real time	Visual check of monthly tables		Automatic interpolation program	Use the result from the project "Few parameter station"
	Manual precipitation not in real time	Precipitation program (BD)	Flags due to size of error	HQC Precipitation program (BD)	Be more careful at QC0.

Mandat: a system for automatic collection of observations from MAN stations.

9.2.3 No consistency between the parameters

In some observations there is no consistence between the observed parameters. Two examples:

Kind of error	**Kind of observation**	**Checking program**	**Flagging method**	**Correction method**	**Suggestion to avoid the error**
$Ta_{max}<Ta$	Manual obs in real time	Che-Synop	Depending on the size of the error	Automatic correction program if temperature difference < 0,5° Otherwise HQC	Education of observers. Update the programs in QC0
	AWS				Update the programs at AWS stations
Fog and visibility>1 km	Manual obs in real time	Che synop	Depending on the size of the error	HQC	Education, update Mandat
	AWS				A new QC0 correction algorithm is already developed but not yet in use

9.2.4 Summary

The suggestions to avoid some of the most common errors are:

- An improved automatic check at the automatic observation stations and at delivery from manual observation stations. See activity 1.
- Continual education of the observers and update equipment.
- Missing values can be avoided by:
  - More frequent services at the AWS.
  - Deliver the observations every day by using automatic collection, e.g. Linewise/Mogul.
- To avoid inconsistencies between the different parameters by using control programs with different algorithms.
- To use automatic correction programs for suggesting correct values, which will be checked manually. These values can be a first guess from HIRLAM. However it is most important not to loose extreme values.

9.2.5 Control programs

The list of control programs are:

- Meullers automatic control program. No corrections are done.
- Che_synop written by Ulf Fredriksson is an improved version of Meullers program
- Different kinds of spatial checking programs. E.g. B. Dahlströms precipitation program (BD), which also gives a correction of the value.
- SYTAB is a temperature checking program
- Addition program: an additional program for monthly amount of precipitation, Meuller (1989) and Fredriksson (1997).
- Maximum and minimum temperature check program
- Program for missing observations and journals
- Day 32–program: The value measured at day one should be used to calculate the total precipitation for the previous month. Therefore, the “day32” has been invented. The value from day 32 and from day1 the next month should agree.
- See also QC programs described in chapter 3 and 4.

10. Appendix C - QC single station methods

10.1 Appendix C1 - step checks

10.1.1 Step checks from FMI

Check no	**Parameter**	**Type of stn / obs freq**	**Check freq.**	**Automatic checking method / algorithm**	**Flagging method**	**Correcting methods**	**Comments**
QC2sFMI-*Ph	Ph	MAN, HYB AWS	3 h 3 h	CLIMATE $\lvert Ph-Ph_{-3h}\rvert >5.0$	? printed	Manual	HQC will take control
QC2sFMI-*Sa	Sa	MAN,HYB	12 h	$Sa06-(Sa18_{-24h}+Sa18_{+24h})/2 > 5$	< > printed	Manual	HQC will take control
QC2sFMI-*Sa	Sa	MAN,HYB	12 h	$Sa18-(Sa06_{-24h}+Sa06_{+24h})/2 > 5$	< > printed	Manual	HQC will take control
QC2sFMI-*Sa	Sa	MAN,HYB	24 h	$Sa06-(Sa06_{-24h}+Sa06_{+24h})/2 > 5$	< > printed	Manual	HQC will take control
QC2sFMI-*Dd,Ff	Dd	MAN, HYB AWS	3 h 3 h	CLIMATE $\lvert Dd-Dd_{-3h}\rvert > 40$ and $\lvert Ff-Ff_{-3h}\rvert > 9$	? printed	Manual	HQC will take control

These tests are run on monthly routine (CLIMATE). Most of the tests are included also to Synop-routine (3h, QC1). Format checks (synop code) are done earlier. See Hellsten (1999a and 1999b).

10.1.2 Step checks at DMI

Check no	**t**	**Parameter**	**Check freq**	**Automatic checking method/algorithm**	**Flagging method**	**Evaluation method**
QC1s(c)DMI-*Ph QC1s(p)DMI-*Ph	c p	Ph	10min, 1h, 3h	$\lvert Ph-Ph_{-z}\rvert > I_{m(t)}$ $U_m < \lvert Ph-Ph_{-z}\rvert < I_{m(t)}$	BUFR	HQC
QC1s(c)DMI-*Ff QC1s(p)DMI-*Ff	c p	Ff	10min, 1h, 3h	$\lvert Ff-Ff_{-z}\rvert > I_{m(t)}$ $U_m < Ff-Ff_{-z}\rvert < I_{m(t)}$	BUFR	HQC
QC1s(c)DMI-*Ta QC1s(p)DMI-*Ta	c p	Ta	10min, 1h, 3h	$\lvert Ta-Ta_{-z}\rvert > I_{m(t)}$ $U_m < \lvert Ta-Ta_{-z}\rvert < I_{m(t)}$	BUFR	HQC
QC1s(c)DMI-*Td QC1s(p)DMI-*Td	c p	Td	10min, 1h, 3h	$\lvert Td-Td_{-z}\rvert > I_{m(t)}$ $U_m < \lvert Td-Td_{-z}\rvert < I_{m(t)}$	BUFR	HQC
QC1s(c)DMI-*Rt QC1s(p)DMI-*Rt	c p	Rt	10min, 1h, 3h	$\lvert Rt-Rt_{-z}\rvert > I_{m(t)}$ $U_m < \lvert Rt-Rt_{-z}\rvert < I_{m(t)}$	BUFR	HQC

I_m = limit value for impossible observation values (exceeding weather record by a magnitude Δ) valid in month m for time step t, where t=10 minutes, 1 or 3 hours.
U_m = limit value unusual observation values valid in month m for time step t.
c = certain error detection
p = probable error detection

For further details, see Ch. 3 and Ch. 5.

10.1.3 Step checks from SMHI

10.1.3.1 Step checks of temperature

Check no	**Parameter**	**Type of stn**	**Check Freq**	**Automatic checking method / algorithm**	**Flagging method**	**Correcting methods**	**Comments**
QC2s(p)SMHI-*Ta	Ta	MAN, AWS	3 h	**Che_synop** • If $\lvert Ta - Ta_{-3h}\rvert > 13$ & $\lvert Ta - Ta_{+3h}\rvert \geq 10$ • If $\lvert Ta - Ta_{-6h}\rvert > 19$ & $\lvert Ta - Ta_{+6h}\rvert \geq 10$ • If $\lvert Ta - Ta_{-12h}\rvert > 25$ & $\lvert Ta - Ta_{+12h}\rvert \geq 10$ - and the change before and after Ta have the opposite sign	Stored on file during three month	Manual	HQC will take control
QC2sSMHI-*$Ta_{interpolated}$	Ta	AWS	3 h	**Komp_all** Interpolation method using observation one hour before and after the checking time		Automatic	Interpolation only.
QC2sSMHI-*$Tax_{interpolated}$,Ta	Ta, Tax	AWS	3 h	**Komp_all** Missing Tax are maid from the highest 1h-observations		Automatic	Completing only
QC2sSMHI-*$Tan_{interpolated}$,Ta	Ta, Tan	AWS	3 h	**Komp_all** Missing Tan are maid from the lowest 1h-observations		Automatic	Completing only

Documentation of the check QC2s(p)SMHI-*Ta can be found in Meuller (1989) and Fredriksson (1997).

10.1.3.2 Step check of winds

Check no	**Parameter**	**Type of stn**	**Check Freq**	**Automatic checking method / algorithm**	**Flagging method**	**Correcting methods**	**Comments**
QC2s(p)SMHI-*Ff	Ff	MAN, AWS	3 h	**Che_synop** $\lvert Ff - Ff_{-3h}\rvert > 10$	Stored on file during three month	Manual	HQC will take control
QC2s(p)SMHI-*Fx	Fx	MAN, AWS	3 h	**Che_synop** $\lvert Fx - Fx_{-3h}\rvert >10$	Stored on file during three month	Manual	HQC will take control

Documentation can be found in Meuller (1989) and Fredriksson (1997).

10.1.3.3 Step checks of pressure

Check no	Parameter	Type of stn	Check Freq	Automatic checking method / algorithm	Flagging method	Correcting methods	Comments
QC2s(p)SMHI-*Pr	Pr	MAN, AWS	3 h	**Che_synop** $\lvert Pr - Pr_{-3h} \rvert > 9$ $\lvert Pr - Pr_{-6h} \rvert > 18$ $\lvert Pr - Pr_{-12h} \rvert > 36$	Stored on file during three month	Manual	HQC will take control
QC2s(p)SMHI-*Pr,*Pp QC2s(c)SMHI-*Pr,*Pp QC2s(p)SMHI-*Pr,*Pp QC2s(c)SMHI-*Pr,*Pp	Pr , pp	MAN, AWS	3 h	**Che_synop** $Pr_{-3h} \pm Pp - Pr < -2$ $Pr_{-3h} \pm Pp - Pr > 2$ $Pr_{-3h} \pm Pp - Pr < -3$ $Pr_{-3h} \pm Pp - Pr > 3$ $Pr_{-6h} \pm Pp_{-6h}*0.5$ $\pm Pp*1.5 - Pr < -6$ $Pr_{-6h} \pm Pp_{-6h}*0.5$ $\pm Pp*1.5 - Pr > 6$ $Pr_{-6h} \pm Pp_{-6h}*0.5$ $\pm Pp*1.5 - Pr < -8$ $Pr_{-6h} \pm Pp_{-6h}*0.5$ $\pm Pp*1.5 - Pr > 8$	Stored on file during three month	Manual	Before checking Pr against Pp, Pr is counted back to station level

Documentation can be found in Meuller (1989) and Fredriksson (1997).

10.1.3.4 Step check of humidity

Check no	Parameter	Type of stn	Check Freq	Automatic checking method / algorithm	Flagging method	Correcting methods	Comments
QC2s(p)SMHI-*Td	Td	MAN, AWS	3 h	Che_synop $Td - Td_{-3h} > 11$ & $Td - Td_{+3h} \geq 9$ $Td - Td_{-6h} > 15$ & $Td - Td_{+3h} \geq 9$ $Td - Td_{-12h} > 20$ & $Td - Td_{+3h} \geq 9$	Stored on file during three month	Manual	HQC will take control

Documentation can be found in Meuller (1989) and Fredriksson (1997).

10.1.4 Step checks from DNMI

	<t>	<*par>	<par>	Check freq	Automatic checking method / algorithm	Corr. method	Comments
QC2sDNMI(1)-*Tw	s	Tw			$\lvert Tw_d - Tw_{d-1} \rvert > 1.5$		

10.2 Appendix C2 - Consistency checks

10.2.1 Consistency checks from FMI

Check no	**Parameter**	**Type of stn / obs freq**	**Check freq.**	**Automatic checking method / algorithm**	**Flagging method**	**Correcting methods**	**Comments**
QC2cFMI- *Ta, Tax	Ta and Tax	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE Ta > Tax during 12 h period 06/18	X printed	Manual	HQC will take control
QC2cFMI- *Ta, Tan	Ta and Tan	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE Ta < Tan during 12 h period 06z/18z	N printed	Manual	HQC will take control
QC2cFMI- *Tax, Tan	Tax and Tan	MAN, HYB AWS MAN	12 h 12 h 12 h	CLIMATE Tax < Tan	< > printed	Manual	HQC will take control
QC2cFMI- *Tax,Tax_{record}	Tax and Tax_{record}	MAN, HYB AWS MAN	12 h 12 h 12 h	CLIMATE $Tax>Tax_{record}$	) printed	Manual	HQC will take control
QC2cFMI- *Tan,Tan_{record}	Tan	MAN, HYB AWS MAN	12 h 12 h 12 h	CLIMATE $Tan<Tan_{record}$	(printed	Manual	HQC will take control
QC2cFMI- *Ta,Tax_{record}	Ta and Tax_{record}	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE $Ta > Tax_{record}$	) printed	Manual	HQC will take control
QC2cFMI- *Ta,Tan_{record}	Ta and Tan_{record}	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE $Ta < Tan_{record}$	(printed	Manual	HQC will take control
QC2cFMI- *Tax,Tan_{record}	Tax and Tan_{record}	MAN, HYB AWS MAN	12 h 12 h 12 h	CLIMATE $Tax < Tan_{record} + 3$	(printed	Manual	HQC will take control
QC2cFMI- *Tan,Tax_{record}	Tan and Tax_{record}	MAN, HYB AWS MAN	12 h 12 h 12 h	CLIMATE $Tan > Tax_{record} – 3$	) printed	Manual	HQC will take control
QC2cFMI- *Tg,Tg_{record}	Tg and Tg_{record}	MAN, HYB AWS MAN	12 h 12 h 12 h	CLIMATE $Tg < Tg_{record}$	(printed	Manual	HQC will take control
QC2cFMI- *Tg, Tan	Tg and Tan	MAN, HYB AWS MAN	24 h 24 h 24 h	CLIMATE Tg – Tan = 0.1, …, 1.9 C	? printed	Manual	HQC will take control
QC2cFMI- *Tg06, Tan06	Tg06 and Tan06	MAN, HYB AWS MAN	24 h 24 h 24 h	CLIMATE Tg06 > Tan06 + 2	) printed	Manual	HQC will take control

These tests are run on monthly routine (CLIMATE). Most of the tests are included also to Synop-routine (3 h, QC 1). Format checks (synop code) are done earlier. Record=highest or lowest monthly value ever observed. See also Hellsten (1999a and 1999b).

Check no	Parameter	Type of stn / obs freq	Check freq.	Automatic checking method / algorithm	Flagging method	Correcting methods	Comments
QC2cFMI-*Ta, Tw	Ta and Tw	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE Tw – Ta > 0.0 and Ta > –2.0	< > printed	Manual	HQC will take control
QC2cFMI-*Ta, Tw	Ta and Tw	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE Tw–Ta > 0.2 and Ta < 0.0	< > printed	Manual	HQC will take control
QC2cFMI-*Ta, Tw	Ta and Tw	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE Ta–Tw> DTTW(array) depending on temperature	< > printed	Manual	HQC will take control
QC2cFMI-*Ta, *Tw, *Td, *Uu	Ta, Tw, Td and Uu	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE Td is calculated in different ways and compared to each other	< printed to denote error in Ta, Tw,Td or Uu	Manual	HQC will take control, but in same cases Td will be recalculated automatically
QC2cFMI-*Rr, W, weather symbols	Rr, W Present weather, weather symbols	MAN, HYB MAN, HYB	12h 24 h	CLIMATE Rr is checked against observed weather	< printed	Manual	HQC will take control
QC2cFMI-*Sa, *Em	Sa, Em	MAN, HYB	12h 24h	CLIMATE Correspondence between Sa and Em are tested [*1)]	< printed	Manual	HQC will take control
QC2cFMI-$*Sa,Sa_{record}$	Sa, Sa_{record}	MAN, HYB	12 h 24 h	CLIMATE $Sa > Sa_{record}$	< printed	Manual	HQC will take control
QC2cFMI-*Vv, Ww	Vv, Ww-codes	MAN, HYB AWS MAN	3 h 3 h 6 h	CLIMATE Vv is checked against fogs and vica versa	<> printed	Manual	HQC will take control
QC2cFMI-*Nn, *Nh, *Cl, *Cm, *Ch, *Hh	Nn, Nh, Cl, Cm, Ch	MAN, HYB AWS MAN	3 h 3 h 3 h	CLIMATE Clouds are tested	<> printed	Manual	HQC will take control

These tests are run on monthly routine (CLIMATE). Most of the tests are included also to Synop-routine (3 h, QC 1). Format checks (synop code) are done earlier. Record=highest monthly value ever observed. See also Hellsten (1999a and 1999b).

[*1)] Flagging: (1) if E>5 in June, July or August, (2) if E=0 in January or February, (3) if Sa>0 and E<5, (4) if Sa=0 and (E=7 or E=9), (5) if no snow depth and E<4.

10.2.1.1 QC2 – non real Time Quality Control at FMI of synoptic stations on a monthly basis

Currently, about 30 stations write down their observations on a notebook 3 times a day at 06, 12 and 18 UTC. At around 55 stations the observers write down their observations to the laptop computer, which calculates the synoptic message, which is retrieved to FMI by the collection program. Most of these stations also write down the weather symbols to the notebook, which is posted to FMI once a month. The 3 times observing stations also post their monthly thermographs and the notebook.

At FMI the 00 UTC temperatures from each day of the month are read from the thermographs into digitised form by computer to the diskettes and these data are transferred to the database. The weather symbols from the notebooks are written to the same data base area. After this the raw synoptic data are ready to go through different kind of quality control tests made by computer. The quality control program results in the listing of the monthly data day by day with suspecting values flagged. These are manually studied, checked and corrected to the database, and then a new quality control program runs etc. as long as errors are encountered.

After the quality control of synoptic stations has been run in the monthly tests on QC2 level, an output list is printed with all weather parameters of all days of the month. Suspicious values are flagged. In the tests, (record) refers to the extreme value of the parameter ever observed at the station or at the neighbouring station.

Weather Symbols and Precipitation

we = Weather symbol (weather symbols have been converted to special codes).

If we>19 and no rain	Ł	<	is printed
If Ra≥0 and we<20	Ł	+	is printed
If Ra>0.3 mm and has come out of hoar frost, soft rime or dew	Ł	+	is printed

Winds

If Dd=0 and Ff>0 or Dd>0 and Ff=0	Ł	<,>	is printed

Snow Depth

If $Sa06_i – (Sa06_{i-1} + Sa06_{i+1}) / 2 > 5$	Ł	<,>	is printed (4 obs./day)
If $Sa06_i – (Sa18_{i-1} + Sa18_i) / 2 > 5$	Ł	<,>	is printed (8 obs./day)
If $Sa18_i – (Sa06_i + Sa06_{i+1}) / 2 > 5$	Ł	<,>	is printed (8 obs./day)
If $Sa06 > Sa_{record}$ or $Sa18 > Sa_{record}$	Ł	<	is printed

Cloudiness

Nn = Total cloudiness
Nh = The amount of the lowest clouds
Cl,Cm,Ch = the type of low, medium, upper clouds
Hh = The height of the lowest clouds (in dekameters)

If Nn < 0 or Nn > 9	Ł	P	is printed
If Nn ≠ Nh and Cl = 0 and Cm > 0 and Ch = 0 or Ch = 10	Ł	<,>	is printed
If Cl = 10 and Cm = 10 and Ch < 10	Ł	<	is printed
If Nn = 8 and Nh = 8 and Ch < 10	Ł	<	is printed

If Nh = 9 and Cl = 10 and Cm = 10 and Ch = 10 and Hh < 999	Ł <,>	is printed
If Cl between 1 and 9 and Hh > 300	Ł <,>	is printed
If Ch between 1 and 9 and Cl = 0 and Cm = 0 and Hh < 250	Ł <,>	is printed
If Nh = 0 and Cl = 0 and Cm = 0 and Ch = 0 and Hh > 0	Ł <,>	is printed

Pressure

Pa = sea level pressure

$Pa_j - (Pa_{j-3h} + Pa_{j+3h}) / 2 > 2.0$ [hPa]	Ł ?	is printed (8 obs./day)
$Pa_j - (Pa_{j-3h} + Pa_{j+3h}) / 2 > 4.0$ [hPa]	Ł ?	is printed (<8 obs./day)

Visibility

Vv = visibility (dekameters), Ww = present weather code.

If Vv < 0 or Vv > 9999	Ł P	is printed
If 30 < Ww < 36 and Vv > 100	Ł <,>	is printed
If 40 < Ww < 50 and Vv > 100	Ł <,>	is printed
If 0 ≤ Ww < 4 and Vv < 500	Ł <,>	is printed
If Ww = 15 and Vv < 500	Ł <,>	is printed
If W2>W1	Ł p	is printed

In addition almost all (max. no. 100) Ww codes are tested against the observed weather symbols.

Checking of precipitation stations

Journals from precipitation stations (which observe 24 hour precipitation, ground quality and snow depth at 06 UTC) posted once a month to FMI are written to the database and after that checked by computer (see the tests below). The remarks are then checked manually using also journal or corresponding data from nearby stations.

The following parameters from precipitation stations are tested on a monthly basis (QC2): Rr_24h=24 hour precipitation amount at 06 UTC, Sa=snow depth at 06 UTC, Em=ground quality at 06 UTC.

Remarks are produced if the following tests are true:

- Rr_24h > 260 mm
- Sa > the maximum Sa of the month
- Rr_24h > the average precipitation amount of the month
- snow depth change from the previous day > 25 cm
- the station should not measure snow depth
- the station should not observe Em
- Em < 5 (= no snow) and Sa ≥ 0
- Em > 4 (=snow exists) and no Sa
- Em missing
- no precipitation or no moist weather phenomena but 0 ≤ Rr_6h ≤ 0.3 mm
- no precipitation phenomena and Rr_6h > 0.3 mm
- precipitation phenomena but no Rr_6h
- the manually calculated monthly precipitation differs from the one calculated by computer
- station has not been operational according to the station register

10.2.2 Consistency checks from SMHI

10.2.2.1 Consistency checks of temperature

Check no	**Parameter**	**Type of stn**	**Check Freq**	**Automatic checking method / algorithm**	**Flagging method**	**Correcting methods**	**Comments**
QC2c(c)SMHI-*Ta,*Tax	Ta and Tax	MAN, AWS	3 h	**Che_synop** Tax> Ta-0.5	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-Ta,*Tax	Ta and Tax	MAN, AWS	12 h	**Che_synop** Tax < Ta < Tax+0.5		Automatic	
QC2c(c)SMHI-Ta,*Tan	Ta and Tan	MAN, AWS	3 h	**Che_synop** Ta < Tan – 0.5	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-Ta,*Tan	Ta and Tan	MAN, AWS	12 h	**Che_synop** Tan > Ta > Tan–0.5		Automatic	
QC2c(p)SMHI-Ta,*Tax	Ta and Tax	MAN, AWS	12 h	**Che_synop** Tax – Ta_{max} > 30/(i + 1.3) where i is the number of earlier measured temps during the last 12h	Stored on file during three month	Manual	HQC will take control
QC2c(p)SMHI-Ta,*Tan	Ta and Tan	MAN, AWS	12 h	**Che_synop** Ta_{min} – Tan > 30/(i + 1.3) where i is the number of earlier measured temps during the last 12 h	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta, *Ww	Ta and Ww	MAN AWS	3 h	**Che_synop** Ta > 5 and 67 < Ww < 80	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta, *Ww	Ta and Ww	MQN AWS	3 h	**Che_synop** Ta > 5 and 82 < Ww < 89	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta, *Ww	Ta and Ww	MAN AWS	3 h	**Che_synop** Ta < –2 and 49 < Ww < 56	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta, *Ww	Ta and Ww	MAN AWS	3 h	**Che_synop** Ta < –2 and 57 < Ww < 66	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta, *Ww	Ta and Ww	MAN AWS	3 h	**Che_synop** Ta > –2 and 67 < Ww < 70	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta, *Ww	Ta and Ww	MAN AWS	3 h	**Che_synop** Ta > –2 and 79 < Ww < 83	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta, *Ww	Ta and Ww	MAN AWS	3 h	**Che_synop** Ta < –7 and Ww = 56/57/66/67	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta, *Ww	Ta and Ww	MAN AWS	3 h	**Che_synop** Ta > 0 and Ww = 56/57/66/67	Stored on file for 3 months	Manual	HQC will take control
QC2c(c)SMHI-*Ta,*Tax	Ta and Tax	Climate stations	24 h	**'Temp-Nbd-table'** Tax < Ta – 0.5	Flagged on month paper table	Manual	HQC will take control
QC2c(c)SMHI-*Ta,*Tan	Ta and Tax	Climate stations	24 h	**'Temp-Nbd-table'** Ta < Tan – 0.5	Flagged on m paper table	Manual	HQC will take control

Temp-Nbd-table = Temperature–precipitation table: Every month a special table is written with observed values of temperature, maximum and minimum temperature and precipitation. A special program checks that the maximum and minimum temperature values do not exceed respectively be lower than the air temperature with more than half a degree. No document is available.

Documentation can be found in Meuller (1989) and Fredriksson (1997).

10.2.2.2 Consistency checks of pressure

Check no	**Parameter**	**Type of stn**	**Check Freq**	**Automatic checking method / algorithm**	**Flagging method**	**Correcting methods**	**Comments**
QC2c(p)SMHI-*Pa,*Pp	Pa, Pp	MAN, AWS	 3 h 3 h 3 h 3 h	**Che_synop** Pa missing Pp exist Pp missing Pa exist Pa = 4 and Pp > 0.5 Pp = 0 and Pa = 1/2/3/6/7/8	 Stored on file during three month	 Manual	HQC will take control

Documentation can be found in Meuller (1989) and Fredriksson (1997).

10.2.2.3 Consistency checks of precipitation from SMHI

Check no	**Parameter**	**Type of stn**	**Check Freq**	**Automatic checking method / algorithm**	**Flagging method**	**Correcting methods**	**Comments**
QC2c(c)SMHI-*Rr,*Wx	Rr, Wx [1) 1)]	MAN	12 h	**Che_synop** Wx reports precipitation and Rr=0	Stored on file during three month	Manual	HQC will take control
QC2c(c)SMHI-*Rr,Ww	Rr, Ww	MAN	12 h	**Che_synop** Rr = 0 and 49 < Ww < 99	Stored on file during three month	Manual	Ww 0 – 12 h earlier
QC2c(c)SMHI-*Rr,W1,W2	Rr, W1, W2	MAN	12 h	**Che_synop** Rr = 0 and 4 < W1/W2 < 9	Stored on file during three month	Manual	W1,W2 0 – 6 h earlier

Documentation can be found in Meuller (1989) and Fredriksson (1997).

[1)] Wx = national climate groups that reports the weather during the day from 10 UTC to 18 UTC.

10.2.2.4 Consistency checks of winds from SMHI

Check no	Parameter	Type of stn	Check Freq	Automatic checking method / algorithm	Flagging method	Correcting methods	Comments
QC2c(c)SMHI-*Dd,*Ff	Dd, Ff	MAN, AWS	3 h	**Che_synop** Dd = 0 and Ff > 0 Dd > 0 and Ff = 0 Dd missing ff exist Ff missing dd exist Dd = variable and Ff > 3	Stored on file during three month	Manual	HQC will take control
QC2c(c)SMHI-*Ff,*Fx	Ff, Fx	MAN, AWS	3 h	**Che_synop** Ff > Fx+1 Ff_{-3h} > Fx + 1	Stored on file during three month	Manual	
QC2c(p)SMHI-*Fx,*Ff	Fx,Ff	MAN, AWS	3 h	**Che_synop** Fx > Ff_{-3h} + 15	Stored on file during three month	Manual	HQC will take control
QC2c(p)SMHI-*Fx,*Ff	Fx,Ff	MAN, AWS	3 h	**Che_synop** Fx > Ff + 8 and Fx > Ff_{-3h} + 8	Stored on file during three month	Manual	HQC will take control

Documentation can be found in Meuller (1989) and Fredriksson (1997).

10.2.2.5 Consistency checks of humidity from SMHI

Check no	Parameter	Type of stn	Check Freq	Automatic checking method / algorithm	Flagging method	Correcting methods	Comments
QC2c(p)SMHI-Ta,*Td	Ta, Td	MAN, AWS	3 h	**Che_synop** Td > Ta - 20	Stored on file during three month	Manual	HQC will take control
QC2c(c)SMHI-Ta,*Td	Ta, Td	MAN, AWS	3 h	**Che_synop** Td > Ta + 0.5	Stored on file during three month	Manual	HQC will take control

Documentation can be found in Meuller (1989) and Fredriksson (1997).

10.2.3 Consistency checks from DNMI

QC1 controls are not considered here. They are very much alike the QC0 and QC2 controls, and end up with a type of flag (confidence number for the total observation) which follows the observation further on.

QC2 controls are performed on daily (once or twice a day) and/or monthly basis.

Hourly AWS observations are checked for missing values and range checks, step checks, consistence checks and repeated values checks for most parameters are performed. Errors found are reported to file and inspected by the AWS service group, who initiate action when problems are detected with the AWS. The stored observations are not automatically corrected (and neither manually at the time).

Documentation:
QC2:
Report no. 62/94 KLIBAS (Håland and Øgland, 1994)
Report no. 10/96 KLIBAS (Øgland, 1996)
Report no. 62/97 KLIBAS (Øgland, 1997c)
Report no. 40/98 KLIBAS (Øgland, 1998)
Report no. 91/99 KLIBAS (Øgland, 1999b)

Programs and algorithms are documented in a number of KLIBAS and KLIMA reports 1993-2000. Monthly system quality evaluation reports and monthly statistics reports are available from 1995.

QC0:
"Inntastingsprogram for synopstasjoner. Brukerveiledning for PIO, versjon 5" (Moe, 1999). PIO means Pc In the Observation service.

10.2.3.1 Consistency checks of cloud amount, cloud type, cloud height parameters – N, C, H

c = certain error detection
p = probable error detection

	<t>	<*par>	<par>	Ch. fr.	Automatic checking method / algorithm	Corr. method
QC0c(c)DNMI(1)-*Nh,*Cl,*Cm	c	Nh,Cl,Cm			Cl=0, Cm=0, Nh≠0	HQC
QC0c(c)DNMI(1)-	c	Nh,Cl,Cm,Ch	Cl,Cm		Nh=9, ClCmCh≠xxx	
Nh,*Cl,*Cm,*Ch	c	Nh	Cl,Cm,Hh		Nh=0, Cl≠0 or Cm≠0	
QC2c(c)DNMI(1)-*Nh,Cl,Cm	c	Nh	Cl		Nh≠9, Cl=0,Cm=0,Hh≠9	
QC2c(c)DNMI(1)-	c	Nh	Ch		Nh≠9,Cl=missing	
*Nh,Cl,Cm,Hh	c	Nh			Nh=8, Ch≠x	
QC2c(c)DNMI(1)-*Nh,Cl						
QC0c(c)DNMI(1)-*Nh,Ch						
QC2c(c)DNMI(1)-*Nn,*Nh,*Ns	c	Nn,Nh,Ns			Nn<9, Nh<9, Ns<9, (Nh>Nn or Ns>Nn)	
QC2c(c)DNMI(1)-*Nn,*Nh	c	Nn,Nh			Nn<Nh	
QC0c(c)DNMI(1)-*Nn,*Nh	c	Nn,Nh			Nh>Nn, Nh≠9	
QC2c(c)DNMI(1)-*Nn,*Ns	c	Nn,Ns			Nn<Ns	
QC0c(c)DNMI(1)-*Nn,*Ns	c	Nn,Ns			Ns>Nn, Ns≠9	
QC0c(c)DNMI(1)-*Nn,*Ww	c	Nn,Ww			Nn<8, 50<Ww<79	
QC2c(c)DNMI(1)-*Nn,Ch	c	Nn	Ch		Nn=0,Ch≠0	
QC2c(c)DNMI(1)-	c	Nn	Cl,Cm,Ch		Nn≠0, Cl=0, Cm=0, Ch=0	
*Nn,Cl,Cm,Ch	c	Nn	Vv		Nn missing, i.e Nn=9	ACOR
QC2c(c)DNMI(1)-*Nn,Vv					If Vv<10 or (Hh missing, Vv≠missing)	
QC0c(c)DNMI(1)-*Hh,*Cl,*Cm	c	Hh,Cl,Cm			Cl=0, Cm=0, Hh≠9	HQC

10.2.3.2 Consistency checks of temperature

Types of stations are AWS (observation every hour) and MAN (observation every third or sixth hour, with the exception of 12 hour at 06 UTC for some stations). The AWS- and some MAN observations are checked and flagged every day, but not corrected permanently. All MAN observations are checked and corrected manually every month and simple flags are stored.

c = certain error detection
p = probable error detection

	<t>	<*par>	<par>	Ch. fr.	Automatic checking method/algorithm	Corr. method
QC2c(c)DNMI(1)-*Ta,*Tan_12h	c	Ta, Tan			Tan>T, i.e. Tan=Ta+a If a<0.4 If a≥0.4	ACOR HQC
QC2c(p)DNMI(2)-*Ta,*Tan_12h QC2c(p)DNMI(1)-*Ta,*Tan06_12h QC2c(p)DNMI(2)-*Ta06,*Tan06_12h QC2c(p)DNMI(3)-*Ta06,*Tan06_12h QC2c(p)DNMI(1)-*Ta06,*Tan18_12h QC2c(p)DNMI(1)-*Ta,*Tan18_12h QC2c(p)DNMI(2)-*Ta,*Tan18_12h	p	Ta, Tan			Tan<Ta_12h$_{min}$ -15 Tan06<Ta06_12h$_{min}$ -9 Tan06<Ta06 -10 Tan06<Ta06 -20 Tan18<Ta06 -5 If Tan18 <5, Tan18<Ta18_12h$_{min}$ -4 If Tan18 ≥5, Tan18<Ta18_12h$_{min}$ -2	HQC
QC2c(c)DNMI(1)-*Ta,*Tax_12h QC2c(c)DNMI(1)-*Ta,*Tax06_12h QC2c(c)DNMI(1)-*Ta,*Tax18_12h	c	Ta, Tax			Tax<Ta, i.e. Tax=Ta-a If a<0.4 If a≥0.4 Tax06<Ta06_12h$_{max}$ Tax18<Ta18_12h$_{max}$	ACOR HQC
QC2c(p)DNMI(2)-*Ta,*Tax_12h QC2c(p)DNMI(2)-*Ta06,*Tax06_12h QC2c(p)DNMI(3)-*Ta06,*Tax06_12h QC2c(p)DNMI(1)-*Ta18,*Tax18_12h QC2c(p)DNMI(1)-*Ta12,*Tax18_12h QC2c(p)DNMI(2)-*Ta12,*Tax18_12h QC2c(p)DNMI(4)-*Ta,*Tax06_12h QC2c(p)DNMI(2)-*Ta,*Tax18_12h QC2c(p)DNMI(3)-*Ta,*Tax18_12h	p	Ta, Tax			Tax>Ta_12h$_{max}$ +15 Tax06>Ta06 +5 Tax06>Ta06 +10 Tax18>Ta18 +5 Tax18>Ta12 +5 Tax18>Ta12 +10 Tax06>Ta06_12h$_{max}$ +3 If Tax18 <12, Tax18>Ta18_12h$_{max}$ +3 If Tax18 ≥12, Tax18>Ta18_12h$_{max}$ +5	
QC2c(c)DNMI(1)- *Tan_12h,*Tax_12h	c	Tan, Tax			Tan>Tax	HQC
QC2c(p)DNMI(1)-*Ta,Ws QC2c(p)DNMI(2)-*Ta,Ws QC2c(p)DNMI(3)-*Ta,Ws QC2c(p)DNMI(4)-*Ta,Ws	p	Ta	Ws		Ta<0 & rain Ta<-1 & sleet Ta>5 & sleet Ta>3 & snow	HQC
QC2c(p)DNMI(1)-*Tan_12h,Wsp	p	Tan	Wsp		Tan>2 & snow	
QC2c(p)DNMI(1)- *Tan_12h,*Tax_12,Wsp	p	Tan,Tax	Wsp		Tan>5, Tax<-2 & sleet	
QC2c(p)DNMI(1)-*Tax_12h,Wsp	p	Tax	Wsp		Tax<0.5 & rain, drizzle	
QC2c(p)DNMI(1)-*Tg,Tan06_12	p	Tg	Tan		Tg>Tan06	
QC2c(p)DNMI(1)-*Tg,Ta,Nn QC2c(p)DNMI(2)-*Tg,Ta,Nn	p	Tg	Ta, Nn		If Nn<7, Tg<Ta06 -10 If Nn≥7, Tg<Ta06 -5	

ACOR means automatic correction
HQC means human quality control
Ws means weather symbols at observation hour
Wsp means weather symbols during past hours

10.2.3.3 Consistency checks of wind direction, wind speed parameters – D, F

	<t>	<*par>	<par>	Ch. fr.	Automatic checking method / algorithm	Corr. method
QC2c(p)DNMI(1)-	p	Dd, Ff, Fb			(Dd=0, Ff≠0) OR (Dd≠0, Ff=0)	HQC
Dd,*Ff,*Fb	c	Dd, Ff			(Dd=0 OR Dd missing), Ff>0	
QC0c(c)DNMI(1)-*Dd,*Ff	c	Dd, Ff			(Ff=0 OR Ff missing), Dd>0	
QC0c(c)DNMI(1)-*Dd,Ff	c	Ff, Fb			Mismatch Ff and Fb	
QC2c(c)DNMI(1)-*Ff,*Fb	c	Ff, Fx			Fx<Ff	
QC0c(c)DNMI(1)-*Ff,*Fx	c	Ff, Fx			Fx<Ff, i.e. Fx=Ff	ACOR
QC2c(c)DNMI(2)-*Ff,*Fx	c	Ff, Fx			Fx<Ff_{max} OR Fx>(Ff_{max} +20)	HQC
QC2c(c)DNMI(3)-*Ff,*Fx	c/p	Fx	Ff		Ff_{max}>Fx OR (Fx – Ff_{max})>10	
QC2c(c)DNMI(4)-*Fx,Ff	c	Fg	Fx		Fg<Fx,	
QC2c(c)DNMI(1)-*Fg,Fx	c/p	Fg	Fx		Fg<Fx OR Fg>2Fx	
QC2c(c)DNMI(2)-*Fg,Fx	c	Fg, Fx			Fg<Fx OR Fg>13 OR Fg>3Fx	
QC2c(c)DNMI(1)-*Fg,*Fx	c	Fg, Fx			Fx>Fg OR Fx=Fg, Fx>9	
QC2c(c)DNMI(2)-*Fg,*Fx						

10.2.3.4 Consistency checks of air pressure parameter – P

	<*par>	<par>	Ch. fr.	Automatic checking method / algorithm	Corr. method
QC2c(c)DNMI(1)-*Pa,Pp_3h QC2c(c)DNMI(2)-*Pa,Pp_3h QC2c(c)DNMI(3)-*Pa,Pp_3h QC2c(p)DNMI(1)-Po,*Pp_3h	Pa Pa Pa Po, Pp_3h	Pp_3h Pp_3h Pp_3h		Pa missing, Pp_{-3h}<0, i.e. Pa=7 Pa missing, Pp_{-3h}>0, i.e. Pa=2 Pa missing, Pp_{-3h}=0, i.e. Pa=4 $\|(Po_{t-6}+Pp\_3h_{t-6}-(Po_t+Pp_{t-3}))\| < 2$	ACOR ACOR ACOR HQC

QC2c(p)DNMI(2)-
*Pa,*Pp_3h,Po
	Po, Pp_3h	Po		If $\|(Po_{t-6} + pp_{t-6}) – (Po_t + Pp_t)\| \geq 2.0$ then
				If $\|(Po_{t-6} + 2\ Pp\_3h_t$ (or $2Pp\_3h_{t-6}$) $–(Po_t)\| \geq 2.0$ then
				If $\|(Po_{t-6} + Pp\_3h_{t-6}) – (Po_t + Pp\_3h_t)\| < 2.0$ then warning Pa
				Else if $\|Po_{t-6} - Po_t\| < 2.0$ then warning Pp
					HQC

QC2cDNMI(1)-*Po,Ph,Pr	Po	Pr		Po missing, i.e. Po=Pr*(1.0-(0.0065*Phref)/288.16)5.2561 Phref = reference height of the barometer	ACOR
QC2cDNMI(1)-*Pp,Po	Pp	Po		Pp missing, i.e. Pp=Po_{t-1}-Po_t, 3h obs. period	ACOR
QC2cDNMI(1)-*Pr,Po,Ta	Pr	Po, Ta		Phref<600masl, $\|Pr_{table}-Pr_{calculated}\| \geq 0.5$ Phref≥600masl, $\|Pr_{table}-Pr_{calculated}\| \geq 0.8$ Pr_{table} = observed and reduced to sea level at station $Pr_{calculated}$ = calculated at DNMI Phref = reference height of the barometer	HQC
QC2cDNMI(2)-*Pr,Po,Ta	Pr	Po, Ta		If $\| Pr-Pr_{estimated} \| \geq 0.5$, Phref < 600 If $\| Pr-Pr_{estimated} \| \geq 0.8$, Phref ≥ 600 where: K= Ta + 273.16 (no inversion) K= 0.315*Ta + 274.16 (inversion) a=0.5 a=1.0 (for 0.0 < Ta ≤ 10.0) a=1.7 (for 10.0 < Ta ≤ 20.0) a= 3.0 (for 20.0 < Ta) $Pr_{estimated}$ = exp(2.3026*[ln(Po) + 0.0148275*Phref / (K + 0.00325*Phref + a)])	
QC2cDNMI(3)-*Pr,Po,Ta	Pr	Po, Ta		$\| Pr-Pr_{estimated} \| > 0.5$	

10.2.3.5 Consistency checks of precipitation parameters – R

	<t>	<*par>	<par>	Ch. fr.	Automatic checking method / algorithm	Corr. method
QC0c(c)DNMI(1)-*Rr,*Ir QC0c(c)DNMI(2)-*Rr,*Ir QC0c(c)DNMI(3)-*Rr,*Ir	c c c	Rr,Ir Rr,Ir Rr,Ir			Rr missing, Ir=1 Rr NOT missing, Ir=3 Rr NOT missing, Ir=4	HQC
QC2c(c)DNMI(1)-*Rr,W1,W2	c	Rr	W1,W2		If Rr < 0.0 and W1 ≥ 5 and W1 ≤ 8 If Rr < 0.0 and W2 ≥ 5 and W2 ≤ 8	
QC0c(c)DNMI(1)-*Rr,Ws,Wsp	c	Rr	Ws,Wsp		No precipitation, Ws OR Wsp = precipitation symbol	
QC2c(c)DNMI(1)-*Rr,Ww	c	Rr	Ww		If Rr < 0.0 and (Ww ≥ 20 and Ww ≤ 27) or (Ww ≥ 50 and Ww ≤ 99)	
QC2c(c)DNMI(2)- *Rr_6h,*Rr_12h	c	Rr_6h,Rr_12h			Rr00_6h > Rr06_12h |Rr00_6h-Rr06_12h| < 0.4, i.e. Rr00_6h = Rr06_12h Rr12_6h > Rr18_12h, |Rr12_6h-Rr18_12h| < 0.4, i.e. Rr12_6h = Rr18_12h	ACOR
QC2c(c)DNMI(3)- *Rr_6h,*Rr_12h	c	Rr_6h,Rr_12h			Rr12_6h > Rr18_12, Rr12_6h + Rr18_12h does not increase the absolute difference between area estimations, i.e. Rr18_12h = Rr12_6h+Rr18_12h	
QC2c(p)DNMI(1)- *Sa,Rr_24h,Em	c	Sa	Rr_24h,Em		For programming, see Kjensli et al (1995)	

10.2.3.6 Consistency checks of visibility, weather parameters – V, W

	<t>	<*par>	<par>	Ch. fr.	Automatic checking method / algorithm	Corr. method
QC0c(c)DNMI(1)-*Vv,*Ww,Ws	c	Vv, Ww	Ws		(Vv<60 (10 km) OR Vv missing), Ws ≠ precipitation, mist, haze, drifting snow, fog OR Ww≠15,16,17,40,41	HQC
QC0c(c)DNMI(2)-*Vv,*Ww,Ws	c	Vv, Ww	Ws		Vv<10 (1000m), Ws ≠ fog, snow, sleet, drizzle, rain, snow shower, shower of sleet, rain shower, hail, snow grains, snow pellets, ice pellets	
QC0c(c)DNMI(1)-*Vv,*Ww QC0c(c)DNMI(2)-*Vv,*Ww QC0c(c)DNMI(3)-*Vv,*Ww QC0c(c)DNMI(1)-*Vv,Ws QC2c(c)DNMI(2)-*Vv,*Ww QC0c(c)DNMI(1)-*W1,*W2 QC0c(c)DNMI(1)-*W1,Wsp	c c c c c c c	Vv, Ww Vv, Ww Vv, Ww Vv Vv, Ww W1, W2 W1	 Ws Wsp 		Ww=42-49, Vv≥10 (1000m) Ww=00-04, Vv<60 (10 km) Ww<38, Ww≠16, 17 Vv≥10 (1000m), Ws=fog Ww=10, Vv>60 W1<W2 5≤W1<9, Wsp = missing	
QC2c(p)DNMI(1)-*Ws,Ta	c	Ws	Ta		(Ws=sleet OR Ws=shower of sleet), (Ta<-1.0 OR Ta>5.0)	
QC2c(p)DNMI(2)-*Ws,Ta	p	Ws	Ta		(Ws=snow OR Ws=snow shower OR Ws=snow grains), Ta>3.0	
QC2c(p)DNMI(3)-*Ws,Ta	p	Ws	Ta		(Ws=rain OR Ws=rain shower OR Ws=drizzle), Ta<0.0	
QC2c(c)DNMI(1)-*Wsp,W1,W2	c	Wsp	W1, W2		(W2>W1 OR (W1=4 OR W2=4)), Wsp≠fog	
QC2c(c)DNMI(1)Ww,Vv QC0c(c)DNMI(1)-*Ww,Ws QC0c(c)DNMI(2)-*Ww,Ws	c c c	Ww Ww Ww	Vv Ws Ws		Ww=10, Vv>60 Ww<50, Ws=precipitation Ww>49, Ws is missing	

10.2.4 Consistency checks from DMI

10.2.4.1 Consistency checks of air pressure parameter – P

Check no	**t**	**Parameter**	**Check freq**	**Automatic checking method/algorithm**	**Flagging method**	**Evaluation method**
QC1c(c)DMI-*Po,*Ph	c	Po, Ph	10min, 1h, 3h	Po<Ph	BUFR	HQC
QC1c(c)DMI-*Ph,*Pp QC1c(c)DMI-*Po,*Pp	c c	Ph, Pp Po, Pp	10min, 1h, 3h	$Ph-Pp \neq Ph_{-3h}$ $Po-Pp \neq Po_{-3h}$	BUFR	HQC
QC1c(c)DMI-*Pp,*Pa	c	Pp, Pa	10min, 1h, 3h	Pp<0 and Pa={0, 1, 2, 3 or 4} Pp=0 and Pa={1, 2, 3, 6, 7 or 8} Pp>0 and Pa={4, 5, 6, 7 or 8}	BUFR	HQC
QC1c(c)DMI-*Pp,*Pa	c	Pp, Pa	10min, 1h, 3h	Pp=missing & Pa=exists or Pp=exists & P=missing	BUFR	HQC

10.2.4.2 Consistency checks of precipitation parameters – R

Check no	**t**	**Parameter**	**Check freq**	**Automatic checking method/algorithm**	**Flagging method**	**Evaluation method**
QC1c(c)DMI-*Ra_3h,*Ra_6h	c	Ra_3h, Ra_6h	6h	Ra_3h>Ra_6h	BUFR	HQC
QC1c(c)DMI-*Ra00_6h,*Ra06_12h	c	Ra00_6h, Ra06_12h	12h	Ra00_6h>Ra06_12h	BUFR	HQC
QC1c(c)DMI-*Ra12_6h,*Ra18_12h	c	Ra12_6h, Ra18_12h	12h	Ra12_6h>Ra18_12h	BUFR	HQC
QC1c(c)DMI-*Ra_1h,*Rd_1h	c	Ra_1h, Rd_1h	1h	Ra_1h>0 & Rd_1h=0 or Ra_1h=0 & Rd_1h>0	BUFR	HQC
QC1c(c)DMI-*Ra,*Ww	c	Ra, Ww	3h	Ra=0 & precip according to Ww, i.e. Ww_{man}={20-27 or ≥50} or Ww_{aut}={11,21-25,40-87, 89,92,93,95,96}	BUFR	HQC
QC1c(c)DMI-*Ra,*Wx,*Rir	c	Ra, Wx, Rir	3h	Ra=0 & {Rir=3 or precipitation according to Wx}, i.e. Ww_{man}={5,6,7,8} or Ww_{aut}={4,5,6,7,8}	BUFR	HQC
QC1c(c)DMI-*Ra,*Ww	c	Ra, Ww	3h	Ra>0 (incl. tracer) but no precipitation according to Ww, i.e. Ww_{man}={00-19 or 28-40} or Ww_{aut}={00-10,12-19,27-29,91,94,99}	BUFR	HQC
QC1c(c)DMI-*Ra,*Wx,*Rir	c	Ra, Wx, Rir	3h	Ra>0 (incl. tracer) but no precipitation according to Wx or Rir={1 or 2}, i.e. Wx_{man}={0,1,2,3,4} or Wx_{aut}={0,1,2,3,9}	BUFR	HQC
QC1c(c)DMI-*Ra,*Ww	c	Ra, Ww	3h	Ra≤trace & Ww={63,65,73,75}	BUFR	HQC
QC1c(p)DMI-*Ra,*Wx	p	Ra, Ww	3h	Ra>0.5 & Ww={40,49}	BUFR	HQC
QC1c(p)DMI-*Ra,*Wx,*Uu	p	Ra, Ww, Uu	3h	Ra>0 & Ww=5 & Uu>60	BUFR	HQC

10.2.4.3 Consistency checks of weather parameters – V, W

Check no	t	Parameter	Check freq	Automatic checking method/algorithm	Flagging method	Evaluation method
QC1c(p)DMI-*Wx,Ta	p	Wx, Ta	3h	Wx={5 or 6}& $Ta<\delta_{snow}$ & $Ta_{-3h}<\delta_{snow}$	BUFR	HQC
QC1c(p)DMI-*Wx,Ta	p	Wx, Ta	3h	Wx=7 & $Ta>\delta_{RAIN}$ & $Ta_{-3h}>\delta_{RAIN}$	BUFR	HQC
QC1c(p)DMI-*Ww,Ta	p	Ww, Ta	3h	$Ta>\delta_{RAIN}$ and [Ww_{aut}={89,93,96} or Ww_{man}={23,26,27,87-90,93,94,96,97}]	BUFR	HQC
QC1c(p)DMI-*Ww,Ta	p	Ww, Ta	3h	$Ta>\delta_{rain}$ and [Ww_{man}={22,70-75,85,86} or Ww_{aut}={24,45,46,70-73,85-87}]	BUFR	HQC
QC1c(p)DMI-*Ww,Ta	p	Ww, Ta	3h	$Ta>\delta_{snow}$ and [Ww_{man}={76,77,79} or Ww_{aut}={11,74-78}]	BUFR	HQC
QC1c(p)DMI-*Ww,Ta	p	Ww, Ta	3h	$Ta<\delta_{snow}$ and [Ww_{man}={21,25,50-55,58-65,80-82,91,92} or Ww_{aut}={23,25,43,44,47,48,50-58,60-66,81-84}]	BUFR	HQC
QC1c(p)DMI-*Ww,Ta	p	Ww, Ta	3h	[$Ta<\delta_{SNOW}$ or $Ta>\delta_{RAIN}$] and [Ww_{man}={68,69,83,84} or Ww_{aut}={67,68}]	BUFR	HQC
QC1c(p)DMI-*Ww,Ta	p	Ww, Ta	3h	$Ta>\delta_{freezing}$ and Ww_{man}={24,56,57,66,67}	BUFR	HQC
QC1c(p)DMI-*Ww,Ta	p	Ww, Ta	3h	$Ta>\delta_{SNOW}$ and Ww_{man}=78	BUFR	HQC
QC1c(c)DMI-*W1,*W2	c	W1, W2	3h	W1<W2	BUFR	HQC
QC1c(c)DMI-*Ww,*Nn	c	Ww, Nn	3h	Ww={precipitation phenomena} & Ww≠76 & Nn=0	BUFR	HQC
QC1c(p)DMI-*Ta,*Ww	p	Ta, Ww	3h	Ta≥5 & Ww={36-39, 48 or 49}	BUFR	HQC
QC1c(p)DMI-*Ww,Td,Ta	p	Ww, Ta, Td	3h	Ta–Td>0.5 & Ww={42-49}	BUFR	HQC
QC1c(p)DMI-*Ww,Ta,Td	p	Ww, Ta, Td	3h	Ta–Td>1.0 & Ww={10-12,40,41}	BUFR	HQC
QC1c(p)DMI-*Ww,*Uu	p	Ww,Uu	3h	Uu>60% and Ww=5	BUFR	HQC
QC1c(p)DMI-*Ww,*Uu	p	Ww,Uu	3h	Rh<90% and Ww={41-48}	BUFR	HQC

The threshold values δ can be configured according to experience, and for the moment they are: $\delta_{RAIN}=5$, $\delta_{rain}=2$, $\delta_{snow}=0$, $\delta_{SNOW}=-2$ and $\delta_{freezing}=2$. Of course, it must always be valid that $\delta_{SNOW}<\delta_{snow}<\delta_{rain}<\delta_{RAIN}$. If nothing else is mentioned, Ww is always the code for manual observation.

10.2.4.4 Consistency checks of temperature

Check no	t	Parameter	Check freq	Automatic checking method/algorithm	Flagging method	Evaluation method
QC1c(c)DMI-*Tax,*Tan	c	Tax, Tan	12h	Tax<Tan	BUFR	HQC
QC1c(c)DMI-*Tax,*Ta	c	Tax, Ta		$Tax<Ta_i$ for i={0,–10,.., –720 minutes}	BUFR	HQC
QC1c(c)DMI-*Tan,*Ta	c	Tan, Ta		$Tan>Ta_i$ for i={0,–10,.., –720 minutes}	BUFR	HQC
QC1c(c)DMI-*Ta,*Td	c	Ta, Td	10min, 1h, 3h	Td–0.2 > Ta	BUFR	HQC
QC1c(p)DMI-*Ta,*Td	p	Ta, Td		Td>20 & Ta–15 > Td	BUFR	HQC
QC1c(p)DMI-*Ta,*Td	p	Ta, Td		Ta–26 > Td	BUFR	HQC
QC1c(p)DMI-*Ta,*Tax	p	Ta, Tax	1h, 3h	$Tax>Ta_{max}+3$, Ta measured hourly $Tax>Ta_{max}+5$, Ta measured 3-hourly	BUFR	HQC
QC1c(p)DMI-*Ta,*Tan	p	Ta, Tan		$Tan>Ta_{min}-3$, Ta measured hourly $Tax>Ta_{max}-5$, Ta measured 3-hourly	BUFR	HQC

10.2.4.5 Consistency checks of wind direction, wind speed parameters – D, F

Check no	t	Parameter	Check freq	Automatic checking method/algorithm	Flagging method	Evaluation method
QC1c(c)DMI-*Ff,*Dd	c	Ff, Dd	10min, 1h, 3h	Ff=0 & Dd≠0 or Ff≠0 & Dd=0	BUFR	HQC
QC1c(p)DMI-*Ff,*Dd	p	Ff, Dd	10min, 1h, 3h	Dd=99 & Ff≥4	BUFR	HQC
QC1c(p)DMI-*Ff,*Ww	p	Ff, Ww	10min, 1h, 3h	Ff<5 & {Ww=7 or 30≤Ww≤39}	BUFR	HQC
QC1c(c)DMI-*Ff,*Fg	c	Ff, Fg	10min, 1h, 3h	Fg < Ff+5	BUFR	HQC

10.2.4.6 Consistency checks of cloud amount, cloud type, cloud height parameters – N, C, H

Check no	t	Parameter	Check freq	Automatic checking method/algorithm	Flagging method	Evaluation method
QC1c(c)DMI-*Nn,*Ww	c	Nn, Ww	3h	Nn=0 and Ww={14-17,19,50-75 or 77-99}	BUFR	HQC
QC1c(c)DMI-*Nn, *Nh	c	Nn, Nh	3h	Nn=0 and {Nh≠0 or Nh=missing}	BUFR	HQC
QC1c(c)DMI-*Nn,*Nh	c	Nn, Nh	3h	N=9 and Nh≠9	BUFR	HQC
QC1c(c)DMI-*Nn,*Nh	c	Nn, Nh	3h	Nn<Nh	BUFR	HQC
QC1c(c)DMI-*Nn,*Hh	c	Nn, Hh	3h	Nn=9 and Hh={0-9}	BUFR	HQC
QC1c(c)DMI-*Nn,*Ch	c	Nn, Ch	3h	Nn=9 and Ch≠0	BUFR	HQC
QC1c(c)DMI-*Nn,*Ch	c	Nn, Ch	3h	Nn<8 and Ch=7	BUFR	HQC
QC1c(c)DMI-*Nn,*Vv	c	Nn, Vv	3h	N=9 and Vv≥1000m	BUFR	HQC
QC1c(c)DMI-*Nn,*Cl,*Cm,*Ch	c	Nn,Cl,Cm,Ch	3h	Nn=0 and {Cl≠0, Cm≠0 and/or Ch≠0}	BUFR	HQC
QC1c(c)DMI-*Nn,*Cl,*Cm,*Ch	c	Nn,Cl,Cm,Ch	3h	Nn=9 and {Cl≠0, Cm≠0 and/or Ch≠0}	BUFR	HQC
QC1c(c)DMI-*Nn,*Cl,*Cm,*Ch	c	Nn, Cl, Cm, Ch	3h	Nn=8 and Cl=Cm=0 and Ch={0,1,4,5,6,8,9}	BUFR	HQC
QC1c(c)DMI-*Nn*Nh,*Ns	c	Nn, Nh, Ns	3h	Nn<9 & Nh<9 & Ns<9 & {Nh>Nn or Ns>Nn}	BUFR	HQC
QC1c(c)DMI-*Nh,*Nn	c	Nn, Nh	3h	Nh>Nn & Nh≠9	BUFR	HQC
QC1c(c)DMI-*Nn,*Ns	c	Nn, Ns	3h	Nn<Ns	BUFR	HQC
QC1c(c)DMI-*Nn,*Ns	c	Nn, Ns	3h	Ns>Nn & Ns≠9	BUFR	HQC
QC1c(c)DMI-*Nn,*Cl,*Cm,*Ch	c	Nn, Cl, Cm, Ch	3h	Nn≠0 & Cl=Cm=Ch=0	BUFR	HQC
QC1c(c)DMI-*Nn,*Nh,*Cl,*Cm,*Ch	c	Nn, Nh, Cl, Cm, Ch	3h	Nn=0 & {Nh>0 or Cl>0 or Cm>0 or Ch>0}	BUFR	HQC
QC1c(c)DMI-*Nn,*Nh,*Cl,*Cm,*Ch	c	Nn, Nh, Cl, Cm, Ch	3h	Nn≠Nh & Cl=0 & Cm=0 & {Ch=0 or Ch=10}	BUFR	HQC
QC1c(c)DMI-*Nn,*Nh,*Cl,*Cm,*Ch	c	Nn, Nh, Cl, Cm, Ch	3h	Nn=9 & Nh≠9 and {Cl or Cm or Ch reported}	BUFR	HQC
QC1c(c)DMI-*Nn,*Nh,*Ch	c	Nn, Nh, Ch	3h	Nn=8 & Nh=8 & Ch<10	BUFR	HQC
QC1c(c)DMI-*Nn,*Hh	c	Nn, Hh	3h	0<Nn<9 & Hh=missing	BUFR	HQC
QC1c(c)DMI-*Nn,*Hh	c	Nn, Hh	3h	Nn=9 & Hh≠0 & Hh≠999	BUFR	HQC

11. Appendix D - Spatial checks

11.1 Spatial checks of temperature from SMHI

Check no	Parameter	Type of stn	Check Freq	Automatic checking Method / algorithm	Flagging method	Correcting methods	Comments
QC2iSMHI-*Ta	Ta	All temp stations	24 h	**SYTAB** Ta12 – Ta18	No flagging	Manual	Temperature difference are listed where the stations are arranged together with their neighbours.
QC2icSMHI-*Ta,*Tax	Ta, Tax	All temp stations	24 h 24 h	**SYTAB** Tax – Ta12 Tax – Ta18	No flagging	Manual	
QC2icSMHI-*Ta,*Tan	Ta, Tan	All temp stations	24 h	**SYTAB** Ta06 – Tan	No flagging	Manual	
QC2iSMHI-*$Ta_{interpolated}$	Ta06, Ta12, Ta18	Climate stations	24 h	**TIS , TISNOLL** Closest neighbours are used max 10 and max distance 100 km. The inverted value of the distance in square are used	The values are automatically written in a file but also a list of the new values is produced	Automatic	*Berggrens interpolation program* In TISNOLL a correction is done for normal diff. between the station an the neighbours
QC2iSMHI-*$Tax_{interpolated}$ QC2iSMHI-*$Tan_{interpolated}$	Tax Tan						

TISNOLL: gives the deviation from average value in an area for a month, TIS: estimated value according to measurements at surrounding stations (see Berggren, 1989).

11.1.1 Spatial checks of precipitation from SMHI

Check no	Parameter	Type of stn	Check Freq	Automatic checking method / algorithm	Flagging method	Correcting methods	Comments
QC2tSMHI-*Rr	Rr	All stations	24 h	**B. Dalström** r= (Rr– Rr_{close})/ (Rr_{max} – Rr_{min} +ε) r > 1 % conf r > 5 % conf	Some values are automatically corrected other have to be corrected by man	Automatic and manual	Rr = checked value. Rr_{close} = closest value among 6 neighbours. Rr_{rmax} = greatest value among 6 neighbours Rr_{min} = lowest value among 6 neighbours

11.2 Spatial checks from FMI

Check no	Parameter	Type of stn / obs freq	Check freq.	Automatic checking method / algorithm	Flagging method	Correcting methods	Comments
QC2iFMI-*Ta	Ta	MAN, HYB AWS MAN	3 h 3 h 6 h	Kriging	List of Suspects	Manual	HQC will take control
QC2iFMI-*Uu	Uu	MAN, HYB AWS MAN	3 h 3 h 6 h	Kriging	List of Suspects	Manual	HQC will take control
QC2iFMI-*Ff,Dd	Ff	MAN, HYB AWS MAN	3 h 3 h 6 h	Kriging	List of Suspects	Manual	HQC will take control
QC2iFMI-*Dd	Dd	MAN, HYB AWS MAN	3 h 3 h 6 h	Kriging	List of Suspects	Manual	HQC will take control
QC2iFMI-*Ph	Ph	MAN, HYB AWS	3 h	Kriging	List of Suspects	Manual	
QC2tFMI-*Rr_24h	Rr	MAN, HYB	12 24	Madsen-Allerup method	List of Suspects	Interpolated values	

For further documentation, see Hellsten (1999c).

12. Appendix E - Flagging

12.1 Flagging system at DNMI

12.1.1 General

In the first report from the quality control project at DNMI (KVALOBS), it is proposed that during the quality control process, all data are to be flagged. Traditionally the purpose of flagging is to get an overview of the quality of an observation and to get knowledge of whether the observation is corrected or not. In KVALOBS flagging will be used during the execution of the different controls in order to decide what other controls or handling of the observations should be performed. All controls end up with a control flag, and the flagging historic is stored during the control process, e.g. like this for the parameter, p1, of station, STNR:

STNR_date_obs.hour_p1_QC1_r1fr1, c(c)1fc(c)1, c(c)2fc(c)2, c(p)1fc(p)1, n1fn1,QC2d_s1fs1, n2fn2,QC2m_i1fi1,

where <t><ft> = type of QC and flag value as a result of this QC. In the example above there are one range check (r1), three consistency checks (c(c)1, c(c)2, c(p)1) and one prognostic spatial check (n1) at QC1 level, and three checks at QC2 level (s1, n2, i1). The QC2 level is divided in a daily control (d) and a monthly control (m). See also Appendix A, Table 9.1.

Ideally the only flagging necessary should be "QC-controlled" or "not QC-controlled", implicit meaning: QC-controlled and reliable (observation correct or corrected/interpolated) or observations not QC-controlled (error might exist), which means uncertain reliability.

In practice it is impossible to distinguish that sharp in quality of the observations, therefore more flags are needed. It seems reasonable to distinguish between two modes of quality-control information; one detailed mode actively used during the QC-phase, and one general mode for use when the QC's of the observations are finished.

12.1.2 Types of flag

<u>Control flags</u>

The control flags must be designed in a way that makes it possible to make statistics concerning:

1. station
2. date and observation hour
3. parameter
4. control level
5. control method (identification of performed check / algorithm)
6. result of control (flag – OK/not OK, eventually scaled)

All these flags will lead to a huge amount of information, which should not follow the observation when the control procedure is carried through. When the observations have reached this stage, the control flags will be comprised to a relatively few user flags.

User flags

The user flags (or code of quality information) must be designed in a way that satisfies relatively advanced users needs. The flags should give information about the end result of the control procedure, not details about the controls of the different control level. It should be possible to find out:

1. if observation is missing
2. if missing observation is interpolated manually or automatically
3. if observation is controlled or not
4. if observation is found OK
5. if observation is corrected manually or automatically, and why
6. if observation is suspicious, but not corrected
7. if collected precipitation during a period is distributed
8. if absolute maximum or minimum temperature during a period is distributed

It might be suitable to distinguish between automatic and manual corrections, if someone in the future finds a suspicious value and wants to correct the observation. Manual correction / interpolation do not exclude that eventual model values might have been used in the controls; experts might have evaluated the proposed values.

Since data very often are used on the parameter level, parameter values, decided controllable, should be flagged.

The purpose of quality flagging is to give information about quality of observations. Some other information might be related to the observations as e.g. special procedures used in the QC, interpolation methods, flag indicating observational methodology, equipment / sensors used and so on. Some of this information might also be regarded as metadata information.

The aim of flagging should be to ensure correct and reliable use of the observations and products. Because the observations are used in variable areas with different needs for accuracy, the need for QC-information is varying.

12.1.3 Example of possible storing of QC-information

Storing of detailed QC-information start as early as possible after the observation is received and it will be updated as long as QC of the actual observations is performed (for some stations may be more than a month after the observation was taken). The performance and sequence of different checks depend on checks already performed and the outcome of these. At this stage full trace ability of the QC-procedure (checks performed) is required.

When all defined QC's (incl. HQC) for the observations are performed, all detailed QC-information is summed up in one status information code for each parameter of an observation (advanced users needs are listed in 12.1.2). For ordinary use this code should not tell anything about what might be the reason for eventually wrong values, but give indications for correct use of the observation.

This information might be:

1. QC OK.
2. QC Error detected (error or missing value), and corrected / interpolated (auto. / man.)
3. QC Error detected (error or missing value), but not corrected / interpolated
4. QC Not performed

Table 12.1. Example of QC log file (non operational). IOK means "Not OK". NA means "Not available".

QC-log (detailed, all QC-checks for selected period and stations. Sorted: date, stnr., parameter, QC-check)									
Log no.	QC-check no.	Stnr.	Date	Parameter	Status	Interpolated / Corrected value	Interpolation / Correction method	Observed value	Comments
1	QC-134	40500	05.12.2000.06:00	Ta	IOK	5.3	HIRLAM	10.2	see Ch. 4.3
2	QC-134	40500	05.12.2000.06:00	Tax	OK			9.7	
3	QC-134	40500	05.12.2000.06:00	Rr	OK			15.6	
4	QC-677	40500	05.12.2000.06:00	Tax	OK			9.7	
5	QC-677	40500	05.12.2000.06:00	Rr	IOK	0	DECWIM	15.6	see Ch. 4.2
6	QC-127	55000	05.12.2000.06:00	Ta	OK			10.8	
7	QC-134	55000	05.12.2000.06:00	Ta	OK			10.8	
8	QC-677	55000	05.12.2000.06:00	Ta	NA			10.8	Too many interpolated reference stations
9	QC-677	55000	05.12.2000.06:00	Rr	OK			0	
10	QC-134	40500	05.12.2000.09.00	Ta	OK			17.6	
11	QC-677	40500	05.12.2000.09.00	Ta	IOK	9.8	DECWIM	17.6	see Ch. 4.2
12	QC-134	40500	05.12.2000.12:00	Ta	OK			23.6	
13	QC-677	40500	05.12.2000.12:00	Ta	IOK	13.1	DECWIM	23.6	see Ch. 4.2
14	QC-134	55000	05.12.2000.12:00	Ta	OK			20.5	
15	QC-677	55000	05.12.2000.12:00	Ta	IOK	15.9	DECWIM	20.5	see Ch. 4.2
16	QC-127	60100	05.12.2000.12:00	Ta	OK			16.3	
17	QC-127	60100	05.12.2000.12:00	Ff	IOK	4.6	HIRLAM	46	see Ch. 4.3
18	QC-677	60100	05.12.2000.12:00	Ta	OK			16.3	
19									
20									

As shown in the previous chapter there are suggestions of detailing information 2 into corrected value, interpolated missing value, distributed precipitation during a period, etc. Another question is whether it is important to distinguish between manual corrected / interpolated values and automatic corrections / interpolations.

At DNMI the implementation of the QC-information (codes) is under considerations (in the same table as the observations, in own flag tables, as a column for each parameter, as strings or whatever). The idea is that it should be possible to give adequate quality information both to the advanced user and the ordinary user (see also Moe, 2001).

12.2 Flagging system at DMI

At DMI is implemented a new format of data bulletins, the BUFR format (Binary Universal Form for the Representation of meteorological data), including reservation of bytes for national additions of extended flagging of data errors and warnings. Comparable with this format is the CREX format, which is the ASCII version of the binary BUFR representation. The BUFR coding is purely binary, and in the data string any number of bits can be added to a parameter. In figure 12.1 is shown the fundamental structure of that part of the BUFR code that is used for quality control information.

12.2.1 Organisation of flagging in internal BUFR bulletin

The BUFR bulletin is disseminated to internal users at DMI and consists of a number of data entries. An entry is the internal binary address in the BUFR string of the starting position of a parameter data block, e.g. an observation value or QC information of a parameter. There are three QC levels:

1. Basic QC, i.e. initial checking at DMI of data from the Danish network together with QC of GTS data done by ECMWF.
2. QC1: on-line automatic checking of single station data.
3. QC2: various automatic checking where spatial methods are the most important.

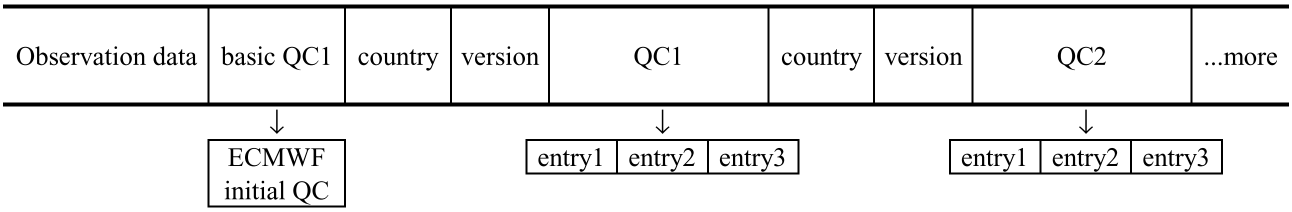


Figure 12.1. Basic principles of how the QC information is structered in the BUFR data string.

In each of the QC levels there are tree entries for indication of the results of the quality control of an observation:

- Entry 1: 3 bits (values 0-7) for indication of the quality level of the observation
- Entry 2: 3 bits (values 0-7) for indication of which main group of method that found the error
- Entry 3: 6 bits (values 0-63) for flagging of the reason of error

If entry1=entry2=entry3=0 the parameter has been controlled and was not in error. If entry1=entry2=entry3=7 the parameter has not been subject to quality control.

The following flagging values are used in entry1 to indicate the quality level:

0=the value is certainly correct
1=the value is probably correct
2=the value is probably in error, but in unusual cases it may be correct
3=the value is certainly in error, but in exceptionally cases it may be correct
7=the value has not been subject to quality control

The following main groups of methods are indicated by entry2:

0=the parameter has been subject to quality control and was found correct
1=an error was found by limit check
2=an error was found by step check
3=an error was found by consistency check
...etc
7=no control

Detailed information about which one of the algorithms in a method group that detected something suspicious or wrong, are written in a logfile as an ‘algorithm identification number’. The error type is indicated in entry3 using the following flagging principle, where the number refers to a detailed error text, which is also written to the logfile:

0	:	data was found correct
1-62	:	a diagnosis of the error type
63	:	no control

12.2.2 Basic principles for allocation of flags

When an observation enters the QC system the quality level is by default set to 7 (i.e. no control has been done). All observations come out of the single station checking methods in QC1 with the flagging value 1 corresponding to “the value is probably correct”, unless a probable error (flag=2) or a certain error (flag=3) has been found. This makes sense if it is kept in mind that QC1 consists of pure single station tests without spatial comparisons, of which reason it is not possible to assign the flag “certainly correct” (flag=0) to the observations. Spatial comparisons are required to assign the flag “certainly correct” (flag=0) to the observations, because only such methods have the potential for proving the statement “certainly correct”. Without data from neighbour stations it is not possible to decide whether an observation is in error or not, unless it is physically impossible.

Some kinds of checks, such as range, step and consistency checks, cannot assign the flagging value 0 (probably correct) because they are pure single station checking methods, and the best quality level coming out of these methods can only be the flag “probably correct” (flag=1). Even if there are no consistency problems, and even if the observed value is within certain limits of what is believed to be possible in step and range checks, big errors in the observation can still be possible. The idea is illustrated in figure 12.2. An observation can attain any value in the distribution, and any of these values can be correct or in error, unless it is certain that the value is physical impossible. The flagging value 3 (certain in error) is assigned to physically impossible values, but in exceptionally cases a value with this flag can still be correct (see Ch.3 for further explanation).

Single station checks have big difficulties in finding certain errors. A consistency check always implies at least two parameters, and if the check has detected an impossible value it cannot specify which of the two parameters are in error. In fact, both of the parameters can be in error, and more checks may be needed, perhaps also a manual inspection, to find out the quality level.

A value with flag=2 (probably in error) detected by single station methods can still be correct, while spatial checks are much more reliable in detecting errors. Thus values in error that are coming out of range, step and consistency checks as probably correct, can still be detected by spatial checks later on when enough data have been received from other stations. A summary of the meaning of the quality level flags is given in table 12.2.

Most parameters have known climatological limits. Then it is reasonable to check whether a parameter is close to those weather records, i.e. the extreme $z^0/_{00}$ part of all data in figure 12.2, so that an extreme (an unusual) value can be queried and checked fairly soon after it occurs.

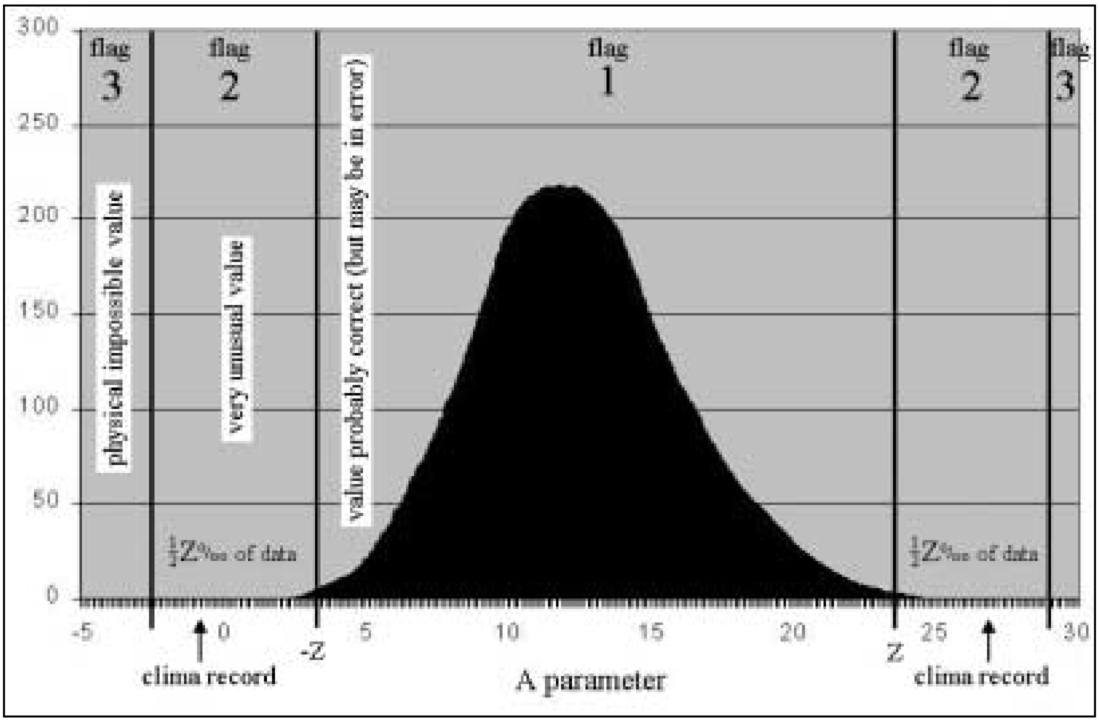


Figure 12.2. The principle of flagging in single station checking in QC1.

By single station methods in QC1 the following quality level flags can be assigned to an observation:

0 not allowed
1 probably correct (observation went through all checks without problems)
2 probably in error, but in unusual cases data may be OK (something suspicious was found)
3 certainly in error (a consistency error or a physical impossible value was found)

Without data from neighbour stations it is not possible to decide whether a value is wrong or unusual. A value with flag=2 can still be correct, and undetected errors passing the range and step check filters with the flag=1 can still be caught, at first by consistency checks and later on by spatial checks in QC2. When enough data have been received from the stations, spatial checking is possible and the flagging value 0 (certainly correct) can be assigned to the observations. Flags set in QC1 and QC2 are kept unchanged in individual buffers.

In QC2 the following quality level flags can be assigned to an observation:

0 certainly correct
1 probably correct
2 probably in error, but in unusual cases the observation may be correct
3 certainly in error, but in exceptionally cases the observation may be correct

12.2.3 Discussion of the quality level of observations

Between single station and spatial checking methods there is a fundamental difference in how the quality level should be understood. Some kinds of checks, such as range, step and consistency checks, cannot assign the flagging value 0 (certainly correct) because they are pure single station checking methods, and the best quality level coming out of these methods can only be the flag "probably correct" (flag=1). Spatial comparisons are required to assigned the flag "certainly correct" (flag=0) to the observations, because only such methods have the potential for proving the statement "certainly correct".

In the principle, apart from consistency checks no single station methods can find true observation errors. Even if there are no consistency problems, and even if the observed value is within the limits of step and range checks, big errors in the observation can still be possible. On the other hand, even if the flagging value 3 (certain in error) has been assigned to a physically impossible value, the value can still be correct in exceptionally cases. A consistency check always implies at least two parameters, and if the check has detected an impossible value it cannot specify which of the two parameters are in error. In fact, both of the parameters can be in error, and more checks may be needed, perhaps also a manual inspection, to find out the quality level.

Without data from neighbour stations it is not possible to decide whether an observation is in error or not, unless it is physically impossible. A value with flag=2 (probably in error) detected by single station methods can still be correct, while spatial checks are much more reliable in detecting errors. Thus values in error that are coming out of range, step and consistency checks as probably correct, can still be detected by spatial checks later on when enough data have been received from other stations.

In general, the probability of detection can be estimated by spatial methods, while this is not possible by single station methods. A summary of the meaning of the quality level flags is given in table 12.2.

Table 12.2. Summary of how the quality level flags should be understood if the observation has been checked by single station and spatial checking methods, respectively.

flag	meaning of flag in single station methods (probability of error detection cannot be estimated)	meaning of flag in spatial methods (probability of error detection can be estimated)
0	not possible to assign this flagging value	certainly correct
1	probably correct, but can be a very big error	probably correct
2	probably in error, but correct in unusual cases	probably in error
3	certainly in error, but correct in exceptional cases	certainly in error

12.2.4 Error logfile

If an error or suspicious value was found, a detailed log is written to a logfile for information and evaluation purposes. Among other things, the logfile gives information about the quality level of the observation and about the specific algorithm that identified the suspicious or wrong observation, and, moreover, a detailed text string is written to the logfile to outline the reason of the flag setting.

12.3 Flagging system at SMHI

When the observations are collecting at SMHI, they are controlled and flagged at the QC1 process. All the parameters are checked and will get different flags depending on the status of the observation, i.e. if they are correct, suspected wrong or truly wrong and will not be accepted. These different flag signs are written at the end of the observations and saved together with the observations in the real time database. These flags are not used any more in the quality control work.

In the QC2 process a similar program is testing the parameters and flagging them in the same way as in QC1. The flags are saved in data files for three months. The controllers in the manual correction work, HQC, will lately use these flags.

Before the observations are saved in the final archive (BÅK) all the flagged observations should be controlled and corrected, except some flagged cloud parameters, which will not be checked.

Before the observations are saved in BÅK, they will be marked (flagged) just to tell if the observations are interpolated or corrected.

In the future the flags from QC1 should be saved in the final archive (BÅK). All the corrected observations should then get new flags to describe what kinds of corrections have been done.

12.4 A proposal for end-user flagging from FMI

Certainly there are several coding systems available, but one proposal will be introduced here.

Quality of data (error severity level):

No check	OK	Suspected, small difference	Suspected, big difference	Calculated	Interpolated	…	Missing	Deleted
0	1	2	3	4	5	…	8	9

Control level:

HQC	QC2	QC1	QC0
1000	100	10	1

Examples:

1) By combining as a sum different control levels and quality of data one can get for instance the code for temperature value:

1531 = 1000 + 500 + 30 + 1 =>

1 = QC0 level at the site found the value correct.
30 = QC1 found the value erroneous (big difference), for instance monthly ranges for temperature were exceeded.
500 = QC2 level interpolated the value by using neighbouring stations.
1000 = HQC level accepted the interpolated value.

2) As above, but HQC level has not yet checked the value, the code is following:

531 = 0 + 500 + 30 + 1 =>

1 = QC0 level at the site found the value correct.
30 = QC1 found the value erroneous (big difference), for instance monthly ranges for temperature were exceeded.
500 = QC2 level interpolated the value by using neighbouring stations.
0 or null = no HQC level controls

3) Temperature value is missing:

1588 = 1000 + 500 + 80 + 8 =>

8 = QC0 level at the site reported missing value.
80 = QC1 found the value missing though it should have been observed
500 = QC2 level interpolated the value by using neighbouring stations.
1000 = HQC level accepted the interpolated value.