Handbook for the

Meteorological Observation

Koninklijk Nederlands

Meteorologisch Instituut

KNMI

September 2000

Contents

Chapter 1. Measuring stations – General

1. MEASURING STATIONS - GENERAL

1.1 Introduction

The mission statement of the KNMI1 (from their brochure "KNMI, more than just weather" of August 1999) reads:

"The KNMI is an agency with approximately five hundred employees that is part of the Ministry of Transport, Public Works and Water Management. From its position as the national knowledge centre for weather, climate and seismology, the institute is targeted entirely at fulfilling public tasks:

weather forecasts and warnings
monitoring the climate
acquisition and supply of meteorological data and infrastructure
model development
aviation meteorology
scientific research
public information services"

The tasks mentioned above are split across a number of sectors within the KNMI. One of the sectors is WM (Waarnemingen en Modellen = Observations and Models). This particular sector's mission has been formulated as follows:

"The Observations and Models sector (WM) is responsible for making the basic meteorological data available and for provision of climatological information to both internal and external users.

The basic meteorological data, both current and historical, contains:

- observations made by measurement, visual observation, using remote sensing or acquired from external sources
- output from atmospheric and oceanographic models, acquired by processing the sector's own models of acquired from institutes abroad.

Additionally, the sector develops user-specific applications and models for processing the basic data.

Considerable research and development (R&D) work is done in the WM sector to ensure that the quality of the products measures up to international yardsticks and in order to be able to keep up to date with new developments and implement them. This lets the WM sector maintain the necessary knowledge and expertise concerning the basic data and its applications.

The WM sector makes this knowledge and expertise available to both internal and external users."

As a consequence of the mission statements and task definitions given above, the KNMI must perform meteorological observations. These are needed if we want to know anything about the weather and the climate. In this context, the following can be mentioned:

- synoptic meteorology;

Important specifically Dutch terms and abbreviations without a standard translation will generally be explained and/or translated when they are first introduced in the text, but left unchanged thereafter:
e.g. *KNMI : Royal Netherlands Meteorological Institute*
VenW : Verkeer en Waterstaat = Transport, Public Works and Water Management
A list of all such terms is provided as an appendix

- warnings for dangerous weather conditions, e.g. gales, strong gusts, heavy precipitation, thunder, hail, snow, black ice, extremely high or low temperatures (ad hoc);
- warnings of health risks for certain weather situations, e.g. air pollution, high UV irradiation and similar (ad hoc);
- maritime reporting;
- aviation meteorology and aviation climatology;
- acquisition of data for climatology and past weather analyses (e.g. for weather reconstructions in cases of damage or disasters);
- acquisition of data for use in analysis and verification models (HIRLAM, wave models, statistical models and so forth).

The measurement network in the Netherlands comprises equipment belonging to the KNMI, the Royal Netherlands Air Force (RNLAF), the Royal Netherlands Navy (RNLN) and Rijkswaterstaat (Department of Public Works, hereinafter RWS). The measurement network consists of approx. 55 weather stations on land and in the North Sea. Observations and (automatic) measurements of meteorological variables are carried out at these stations. Furthermore, the KNMI has a separate measurement network of over 320 stations where volunteer observers measure the precipitation on a daily basis. The KNMI also has the use of a 220-metre high mast in Cabauw for making meteorological observations in the boundary layer of the atmosphere. Radio sondes for making measurements in the upper air layers are attached to weather balloons and released from the KNMI location at De Bilt. The observing stations and the instrumentation used meet the requirements set by the World Meteorological Organization (WMO), the coordinating body (refs. 3, 4, 5). The Measurement Systems Management department of the KNMI (Meetsystemenbeheer, hereinafter MSB) and a team of station inspectors monitor the quality of the observations by regularly checking the measuring equipment and the environment at the measurement site. The observational data is carefully verified, validated, stored and processed for a large number of applications.

1.2 Variables

The KNMI performs observations with which the values or codes for the following meteorological variables can be determined:

- temperature (at various heights above the ground or sea surface)
- atmospheric pressure or air pressure
- humidity or relative humidity, dew point temperature
- wind speed and direction
- precipitation (amount and duration), snow cover
- solar radiation (short wavelength, UV-a, UV-b, sunshine duration)
- horizontal visibility
- evaporation
- soil moisture content, soil temperature (various depths)
- upper air pressure, temperature, humidity
- upper air wind
- weather state (present weather, past weather)
- clouds (type, sort and height) and degree of coverage
- ozone
- composition of the atmosphere
- sea water temperature
- waves and swell (height, direction, period)
- lightning

The observations are generally “ground based”, i.e. that they are measured on or at the surface level of the ground or sea. A number of meteorological variables (temperature, relative humidity, wind, pressure, etc.) are also measured at greater altitudes:

- by releasing balloons with radio sondes (up to altitudes of more than 15 km);
- at various levels on the Cabauw measuring mast (up to a height of 200 m).

Meteorological observations are carried out in principle as a continuous process, in which the frequency of observation can vary from a fraction of a second up to periods of 24 hours. Observations are made using instruments, manually, visually or by ear. A value is not directly determined for a number of meteorological variables, but is rather derived from other variables that have been directly observed or measured. Examples are evaporation (calculated from temperature and global solar radiation), dew point temperature (calculated from temperature and relative humidity) and sunshine duration (calculated from global shortwave radiation).

Important weather information is acquired using remote sensing techniques (e.g. radar systems for detecting showers), satellite observations, observations made on board ships (about 200 VOS ships for the Netherlands), measuring buoys at sea and observations made from aircraft (AMDARs). Although the observations concerned are in all cases either performed under the responsibility of the KNMI or where the KNMI is (partly) involved or makes used of the data, a description of the various details falls outside the scope of this manual.

1.3 Type of observing station

The observational network of the KNMI (the Netherlands, the North Sea) comprises the following types of meteorological stations:

a) Manned weather station: visual and instrumental observations;
b) Automatic weather station (AWS): exclusively instrumental observations;
c) Wind measuring mast: instrumental observations of wind direction and speed only;
d) Cabauw measuring mast: instrumental observations at heights from 20 m to 200 m;
e) precipitation stations: (manual) observations of precipitation amount and snow cover;
f) lightning detection masts: observations of lightning discharges.

The distinguishing feature of a meteorological station is that the variables concerned are measured or are observed there regularly in order to provide a (real-time) picture of the actual weather situation in that region. The observational data from a weather station is collected at the KNMI in De Bilt, validated (using pre-determined objective procedures) and systematically archived for later analysis of specific events and for climatological purposes. A selection of the data is also used for the analysis and verification of operational weather models.

The KNMI network also contains a number of stations when (continuous) measurements of meteorological variables are also being made, but then only for specific local purposes:

- automatic weather stations at airfields for measuring visibility, cloud base height, wind, temperature, humidity, pressure and so forth;
- automatic weather stations several kilometres away from Schiphol airport, known as the mist watch stations, for measuring visibility, wind speed and direction, temperature and relative humidity.

1.4 Conditions relating to the layout of the measurement site of a weather station

The following conditions relating to the layout of the measurement site of a weather station have been laid down:

a) If the station is “manned”, in other words where both visual and instrumental observations are being performed, then all these observations should in principle be made at the same geographic location and at the same observation height. The distance between any separate observation locations that there may be at a single station should in principle be a maximum of 500 metres (with exceptions for infrastructural reasons on airfields, etc.). This condition is required in order to guarantee a synoptic weather picture (in which all the variables in principle comprise a coherent whole).

b) The measuring instruments at a “manned station” or in an “automatic observation station” are installed within a limited area, as a consequence of the above-mentioned criterion that “observations are in principle made at the same geographic location and at the same observation height”. Given the required infrastructural facilities and the costs of the plot, a measurement site has a surface area of 225 to 300 m2. The separation between the individual measuring instruments and their distribution around the measurement site is arranged in such a way that the measurements of all meteorological variables can be performed coherently, appropriately and according to the specific requirements. This condition also applies to the 10-metre wind mast that is placed on the measurement site or immediately adjacent to it. At a number of KNMI measuring stations, the wind mast has been placed some distance from the measurement site, due to the (excessively) irregular wind in the immediate surroundings of the measurement site. This separation from the measurement site is however in principle not greater than 500 metres.

c) The interior part of the measurement site is completely flat, apart from the bank around the pit for the precipitation measurements. The site is covered with short grass (height ≥ 4cm and ≤ 10cm). This requirement applies in particular to the immediate surroundings of the sensor for observation of the temperature at 10cm. The area will need to be mown at least once a week in the period from April to September, meaning it will be mown about 28 times in the grass growing season.

d) A measurement site is surrounded by a fence to prevent unauthorized access. The surroundings will be made of non-opaque fencing, depending on the location. The mesh will be (at least) 20 cm2 and the height of the fence is at most 2 m. These dimensions are required to ensure that the measurements are affected as little as possible by the fencing.

e) The measuring instruments are positioned on the site in such a way as not to interfere with each other. Examples:

  - The radiation meter must always be free of shadows; the arrangement of the other instruments will therefore have to take this into account.
  - The precipitation measurement is sensitive to obstacles in its immediate surroundings (see relevant chapter). It is therefore preferable to keep the measuring equipment for the precipitation measurements place as far away from the fencing and other measuring instruments as is possible, particularly from the wind mast.

The neighbourhood of the measurement site must be free of objects that could affect the measurements. This also applies to mobile obstacles such as parked or passing cars, cranes, planes taxiing or landing or taking off, and similar.

The KNMI has adopted the following guidelines:

- no crops or plants exceeding 0.5 m in height may be grown or placed within a radius of 25 metres around the observation site;

- no crops or plants exceeding 1.5 m in height may be grown or placed within a radius of 50 metres around the observation site;
- no obstacles such as trees and shrubs may be placed within a radius of 100 metres around the observation site;
- no obstacles such as sheds or other buildings and woodland may be placed within a radius of 400 metres around the observation site.

The conditions relating to the types of observing station with wind masts, stations specifically measuring precipitation and stations with lightning detection masts are described in the corresponding chapters of the Manual.

1.5 Spatial distribution of the measuring stations and the representativeness of the observations

The objective of “acquiring sufficient information about the weather and climate (large scale and local)” is the factor determining the level of representativeness needed for the observations. Examples:

a) The purposes of the synoptic observations include mapping large-scale weather systems (in real time and for climatology). They also provide the basis needed for proper analysis and verification of the operational weather models. These criteria determine the spatial distribution of the observation locations across the Netherlands and the continental shelf to a large extent, including the selection of the elements to be measured in the measurement network.

b) The international regulations state that the wind observations (speed, direction) at an airfield must be representative for the touchdown zone of a runway (ref. 6). In practice, this means that the wind measurements must be made at as short a distance as possible away from this point on the runway (100 to 200 metres).

The distribution and the separations between the measurement points for wind speed and direction in the Netherlands are based on statistical investigations by Wieringa (ref. 1). This study demonstrated that a wind speed gradient of 5% is exceeded in a homogenous landscape over a distance of 30km in just 10% of cases. This accuracy is regarded as sufficient for creating a spatial description of wind behaviour and climate in the Netherlands by means of interpolation. This comes down to implying that a grid with a diagonal of 2 x 30 km = 60 km is required for the wind measurement network. A finer mesh of grid is required at the coast (North Sea, Wadden Sea and the IJsselmeer) and in more heterogeneous landscapes (the waters around Zeeland, Limburg).

In the end, the current measurement network was made concrete with the following aspects underlying it:

a) Buishand’s proposal concerning the selection of the variables to be measured in the observational network (ref. 2);

b) the “Wieringa standard” for wind measurements described above;

c) the KNMI’s policy of trying to standardize the measuring stations;

d) specific local requirements.

When a station does have to be moved, the new site is situated in such a way as to take the aspects stated above into account. This will not disrupt the spatial distribution. What this requirement means in practice is that the new location should preferably not be more than approx. 5 km from the old location as the crow flies, depending among other things on the type of landscape.

In order to guarantee the representativeness of the measurements for use at the larger scales (synoptic meteorology, climatology), the observations in the immediate neighbourhood (a radius of 500 metres around the measurement site) should not be perturbed by specific local objects. Within this radius, the type of environment and the coarse structure of the terrain are homogenous and consistent in all directions for every measuring station (as judged by the inspector).

The stations on the coast are an exception. For these stations, two environment sectors can be considered: “water surface” and “land surface”. The requirements of homogeneity and consistency indicated above apply to each of the sectors individually.

The amount and intensity of precipitation can be highly localized in unstable atmospheric conditions. The measurement network for this element therefore requires a much higher density: roughly 1 precipitation station per 100 km2. The representativeness of a national distribution of specific precipitation stations will be discussed in the chapter on precipitation.

1.6 Procedures relating to the inspection, maintenance and management of a weather station

1.6.1 Inspection

A weather station is visited at least twice a year by an inspector from the KNMI's OD division (Operationele Data =Operational Data), or once a year in the case of fields belonging to the Royal Netherlands Air Force and the measuring stations in the North Sea. He carries out the inspection according to procedures that have been defined by and are kept by WM/OD. In particular, checks are made on whether the measuring conditions meet the conditions described above and specific to each element. The following items are examined, among others:

- Are the measurement equipment, the sensors and the measurement site being looked after (inter alia the upkeep of the grass and the removal of any weeds or similar)?
- How do the surroundings of the observation site look (and how have they changed): plant growth, buildings, other obstacles?
- How are the operational sensors functioning: is there any deviation of the values measured from the values registered at the same time by a (calibrated) test sensor?

If required, an ad hoc interim inspection can be done, if indicated by those making use of the observations.

As the results of the inspection visit require, Insa/MSB (Insa: Instrumentele Afdeling = Instrumentation Division) will be asked to perform any actions that may be necessary. The OD inspector will also draw up an inspection report that will be sent for informational purposes to those involved (particularly WM/KD, WM/OD, WA, MI/Insa).

1.6.2 Technical maintenance

The department Insa/MSB is responsible for the technical management and maintenance of the SIAM (ref. 7) and the instruments in a weather station. Important aspects in this context are:

- replacement of the sensors before their calibration lifetime expires;
- replacement or repair of sensors and other apparatus if the status check in the SIAM suggests this is needed;
- replacement or repair of sensors and other apparatus as indicated by a WM/OD Station Management inspector, or by the users (particularly WM/KD, WA) through WM/OD Station Management;
- the status of the weather station according to the standards of the CCM working group "Synoptic Observation Network in the Netherlands": primary, secondary, supplementary (ref. 8);

After carrying out the said activities, Insa/MSB will report back to WM/OD Station Management (which will then apprise the users of this).

1.6.3 Supervision

Supervision of a weather station is carried out (in principle daily) by the observation site's owner (civil airfield, farmer, Royal Netherlands Air Force, Royal Netherlands Navy, etc.). The owner could also delegate this supervision to a company or a private individual residing in the area.

Important aspects in this context are:

- maintenance of the site (mowing the grass, weeding and so forth);
- keeping the instruments clean (removing any dirt or frost that may have formed on the radiation meter, removing dirt or stones from the precipitation meter's inlet, keeping the precipitation recorder clean, brushing off the dishes on the temperature meters and the humidity meter, etc.);

- monitoring for any unauthorized visits or vandalism;
- keeping an eye out for any changes in the surroundings (new buildings, planted areas, etc.) and reporting these immediately to WM/OD Station Management.

Agreements will be made with the appointed officials (laid down contractually) concerning the actions required.

References

J. Wieringa, Inrichting van het KNMI-windmeetnet [Layout of the KNMI wind measurement network], KNMI memo 75-652 (unpublished manuscript), November 1975 (particularly para. 5, pp. 15 and 16);

T. A. Buishand, Keuze van te meten elementen in het voorgestelde netwerk van synoptische en klimatologische landstations [Choice of elements to be measured in the proposed network of synoptic and climatological stations on land], KNMI document (unpublished manuscript), November 1987 (para. 2);

World Meteorological Organization, 1996: WMO No. 8, Guide to meteorological instruments and methods of observations, 6th edition, 1996 (particularly Chapter 3); WMO, Geneva, 1996.

World Meteorological Organization, 1973, International Meteorological Tables, WMO No. 188 in particular table 3.9 on the ICAO standard atmosphere); WMO, Geneva, 1973.

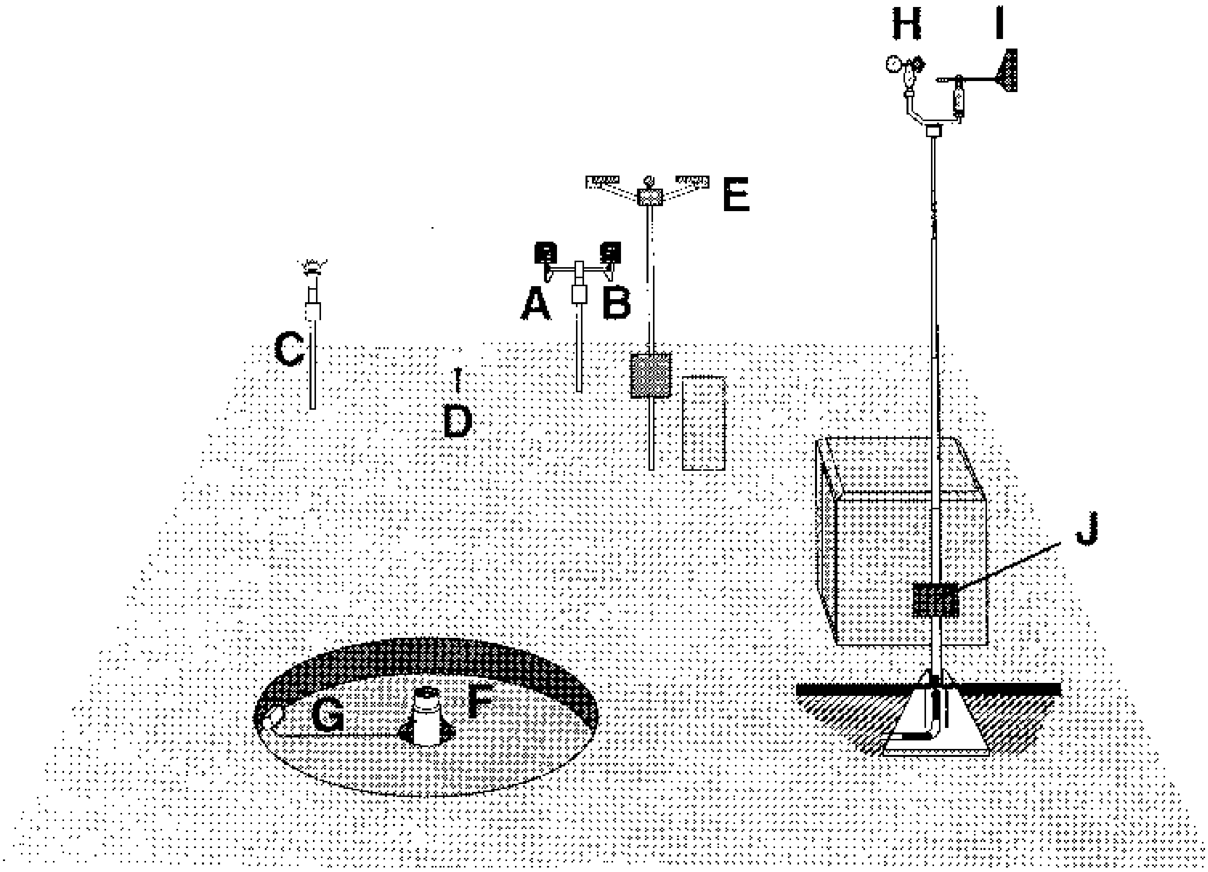
Statement of operational accuracy requirements of level II data, according to WMO codes SYNOP, SHIP, METAR and SPECI; Annex X of WMO No. 807 (CIMO XI)

International Civil Aviation Organization 1998: Meteorological Service for International Air Navigation, International Standards and Recommended Practices, Annex 3 to the Convention on International Civil Aviation, 13th edition; ICAO, Montreal, Canada, 1998.

KNMI 1997: X-SIAM specification [X-SIAM specificatie], J. R. Bijma, KNMI/Insa, KNMI document, Insa document number ID-30-015; KNMI, De Bilt, 1997.

Final report of the CCM working group "Synoptisch Waarneemnetwerk Nederland" [Synoptic Observation Network in the Netherlands], De Bilt, November 1996.

Diagram of an automatic weather station (example: Stavoren AWS)



A	**temperature (°C)**	**F**	**precipitation (mm)**
B	**humidity (%)**	**G**	**precipitation period (min)**
C	**global radiation (Joule/cm^2)**	**H**	**wind speed (m/s)**
D	**gras minimum temperature (°C)**	**I**	**wind direction (degree)**
E	**visibility**	**J**	**air pressure (hPa)**

National meteorological measurement network

2001

Weather Stations in the Netherlands

2nd D R A F T

WMO No.	*Station name*	Temperature (1.5 m)	Temperature (0.1 m)	Atmospheric pressure	Humidity	Wind (speed)	Wind (direction)	Precipitation (amount)	Precipitation (duration)	Radiation (global)	Visibility	Soil temperature	Weather (present, past), ground state	Clouds and degree of coverage
06210	Valkenburg	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta		green	green
06225	IJmuiden			magenta		magenta	magenta				green		green	green
06229	Texelhors					magenta	magenta							
06235	De Kooy	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	green		green	green
06239	F-3	magenta		magenta	magenta	magenta	magenta	magenta			magenta			magenta
06240	Schiphol	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta		green	green
06242	Vlieland	magenta	magenta	magenta	magenta	magenta	magenta				magenta		green	green
06247	Bloemendaal	magenta	magenta		magenta					magenta				
06248	Wijdenes					magenta	magenta							
06249	Berkhout	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta	magenta			
06250	Terschelling										green		green	green
06251	Hoorn Terschelling	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta				
06252	K13/A	magenta		magenta	magenta	magenta	magenta							
06254	Noordwijk measuring station	magenta		magenta	magenta	magenta	magenta							
06260	De Bilt	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red	magenta	green	green
06265	Soesterberg	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06267	Stavoren	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta	magenta			
06268	Houtribsluizen												green	green
06269	Lelystad	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red X		green x	green X
06270	Leeuwarden	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06271	Stavoren Harbour					magenta	magenta							
06273	Marknesse	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta		
06275	Deelen	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06277	Lauwersoog	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta				
06278	Heino	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta				
06279	Hoogeveen	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta		magenta	magenta
06280	Eelde	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06283	Hupsel	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta				
06285	Huibertsgat					magenta	magenta							
06286	Nieuw Beerta	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta		magenta		
06290	Twenthe	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06308	Cadzand					magenta	magenta							
06310	Vlissingen	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	green		green	green
06311	Hoofdplaat					magenta	magenta							
06312	Oosterschelde					magenta	magenta							
06313	Vlakte van de Raan					magenta	magenta							
06315	Hansweert					magenta	magenta							
06316	Schaar					magenta	magenta							
06319	Westdorpe	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta				
06320	LE Goeree	magenta		magenta	magenta	magenta	magenta				magenta			
06321	Euro platform	magenta		magenta	magenta	magenta	magenta				magenta			
06323	Wilhelminadorp	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta		magenta		
06324	Stavenisse					magenta	magenta							

WMO No.	Name	Temperature (1.5m)	Temperature (0.1m)	Atmospheric pressure	Humidity	Wind (speed)	Wind (direction)	Precipitation (amount)	Precipitation (duration)	Radiation (global)	Visibility	Soil temperature	Weather (present, past), ground state	Clouds and degree of coverage
06330	Hook of Holland	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	green		green	green
06331	Tholen					magenta	magenta							
06340	Woensdrecht	magenta	magenta	magenta	magenta	magenta	magenta				red		green	green
06343	Geulhaven					magenta	magenta							
06344	Zestienhoven	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06348	Cabauw measuring mast	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta				
06350	Gilze Rijen	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06356	Herwijnen	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta				
06370	Eindhoven	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06375	Volkel	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06377	Ell	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta				
06380	Zuid Limburg	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	magenta	red		green	green
06391	Arcen	magenta	magenta		magenta	magenta	magenta	magenta	magenta	magenta				

automatic	magenta	*automatic: not in bulletin, but read by sensor*	magenta
visual	green	*visual and automatic (when unmanned)*	red

X *Lelystad (06269) also visual as of 1/2/2001*

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Weather stations of the Netherlands – March 2001 (Exel-File)

WMO No.	***Name***	Temperature (1.5m)	Temperature (0.1m)	Atmospheric pressure	Humidity	Wind (speed)	Wind (direction)	Precipitation (amount)	Precipitation (duration)	Radiation (global)	Visibility	Soil temperature	Weather (present, past), ground state	Clouds and degree of coverage
06209	IJmond					magenta	magenta							

06210	Valkenburg													
06225	IJmuiden													
06229	Texelhors													
06235	De Kooy													
06239	F-3													
06240	Schiphol													
06242	Vlieland													
06248	Wijdenes													
06249	Berkhout													
06250	Terschelling													
06251	Hoorn Terschelling													
06252	K13/A													
06254	Noordwijk measuring station													
06257	Wijk aan Zee													
06260	De Bilt													
06262	De Bilt radiation													
06263	De Bilt PWS													
06265	Soesterberg													
06267	Stavoren													
06268	Houtribsluizen										C			
06269	Lelystad													
06270	Leeuwarden													
06271	Stavoren Harbour													
06273	Marknesse													
06275	Deelen													
06277	Lauwersoog													
06278	Heino													
06279	Hoogeveen													
06280	Eelde													
06283	Hupsel													
06285	Huibertsgat													
06286	Nieuw Beerta													
06290	Twenthe													
06308	Cadzand													
06310	Vlissingen													
06311	Hoofdplaat													
06312	Oosterschelde													
06313	Vlakte van de Raan													
06315	Hansweert													
06316	Schaar													
06319	Westdorpe													
06320	LE Goeree													
06321	Euro platform													
06323	Wilhelminadorp													
06324	Stavenisse													
06330	Hook of Holland													
06331	Tholen													
06340	Woensdrecht													
06343	Geulhaven													
06344	Zestienhoven													
06348	Cabauw measuring mast		C											
06350	Gilze Rijen													
06356	Herwijnen													

06370	Eindhoven													
06375	Volkel													
06377	Ell													
06380	Zuid Limburg													
06391	Arcen													

	Automatic		automatic: not in SYNOP but read by sensor
	Visual		visual and automatic (when unmanned)

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1-20 Observations Manual; 1. Measuring Stations - General; November 2001 release

C	*correction w.r.t. March 2001 release*
	additional station w.r.t. March 2001 release

Weather stations of the Netherlands – November 2001 (Exel-File)

		Chapter no. in Manual	2		3	4	5		6		7		8	9	11	14	15	18	19
		Variable	Temperature (1.5m)	Temperature (0.1m)	Atmospheric pressure	Humidity	Wind (speed)	Wind (direction)	Precipitation amount	Precipitation duration	Radiation (global)	Radiation components	Sunshine duration (CS)	Visibility	Soil temperature	Weather (present, past), ground state	Clouds and degree of coverage	Sea water temperature	Waves, swell
Station name	***Station number***																		
IJmond	06209																		

Valkenburg	06210
IJmuiden	06225
Texelhors	06229
De Kooy	06235
F-3	06239
Schiphol	06240
Vlieland	06242
Wijdenes	06248
Berkhout	06249
Terschelling	06250
Hoorn Terschelling	06251
K13/A	06252
AUK-Alfa	06253
Noordwijk measuring station	06254
Noordelijke Zeeraaf	06255
Wijk aan Zee	06257
De Bilt	06260
De Bilt radiation	06262
De Bilt PWS	06263
Soesterberg	06265
Stavoren	06267
Houtribsluizen	06268
Lelystad	06269
Leeuwarden	06270
Stavoren Harbour	06271
Marknesse	06273
Deelen	06275
Lauwersoog	06277
Heino	06278
Hoogeveen	06279
Eelde	06280
Hupsel	06283
Huibertsgat	06285
Nieuw Beerta	06286
Twenthe	06290
Cadzand	06308
Vlissingen	06310
Hoofdplaat	06311
Oosterschelde	06312
Vlakte van de Raan	06313
Hansweert	06315
Schaar	06316
Westdorpe	06319
LE Goeree	06320
Euro platform	06321
Wilhelminadorp	06323
Stavenisse	06324
Hook of Holland	06330
Tholen	06331
Woensdrecht	06340
Geulhaven	06343
Zestienhoven	06344
Cabauw measuring mast	06348

Gilze Rijen	06350																		
Herwijnen	06356																		
Eindhoven	06370																		
Volkel	06375																		
Ell	06377																		
Zuid Limburg	06380																		
Arcen	06391																		

automatic | automatic: not in SYNOP but read by sensor
visual | visual and automatic (when unmanned)

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Weather stations of the Netherlands – November 2001 (Exel-File)

Chapter number	Variable
2	Measurements of temperature (1.5m)
	Measurements of temperature (0.1m)
3	Measurements of atmospheric pressure
4	Measurements of relative humidity
5	Measurements of wind speed
	Measurements of wind direction
6	Measurements of sum of precipitation
	Measurements of duration of precipitation
7	Measurements of global radiation
	Measurements of radiation components
8	Measurements of sunshine duration
9	Measurements or observations of visibility
10	Calculation of evaporation from temperature and global radiation
11	Measurements of soil temperature
12	Measurement of upper air pressure, temperature, humidity
13	Measurement of upper air wind
14	Measurements or observations of Present weather
15	Observations of clouds
18	Measurements of sea water temperature
19	Measurements of waves at sea
20	Detection of lightning

Name	*WMO No.*
IJmond	06209
Valkenburg	06210
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Wijdenes	06248
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Terschelling	06250
Hoorn Terschelling	06251
K13/A	06252
AUK-Alfa	06253
Noordwijk Measuring station	06254
Noordelijke Zeeraaf	06255
Wijk aan Zee	06257
De Bilt	06260
De Bilt (radiation)	06262
De Bilt PWS	06263
Soesterberg	06265
Stavoren	06267
Houtribsluizen	06268
Lelystad	06269
Leeuwarden	06270
Stavoren Harbour	06271
Marknesse	06273
Deelen	06275
Lauwersoog	06277
Heino	06278
Hoogeveen	06279
Eelde	06280
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Huibertsgat	06285
Nieuw Beerta	06286
Twenthe	06290
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Vlakte van de Raan	06313
Hansweert	06315
Schaar	06316
Westdorpe	06319
LE Goeree	06320
Euro platform	06321
Wilhelminadorp	06323
Stavenisse	06324
Hook of Holland	06330
Tholen	06331
Woensdrecht	06340

Geulhaven	06343
Zestienhoven	06344
Cabauw measurment mast	06348
Gilze Rijen	06350
Herwijnen	06356
Eindhoven	06370
Volkel	06375
Ell	06377
Zuid Limburg	06380
Arcen	06391

instrumental measurements
visual observations

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Weather stations of the Netherlands – November 2001 (Exel-File)

Contents

Chapter 2. Temperature

2. Temperature

1. Description

1.1 Nomenclature of the variable

General name: Temperature
Temperature is also the international nomenclature (as required by the WMO, see WMO No.8, ref. 0)

1.2 definition; description of the concept

The thermodynamic temperature (in short: the temperature) is a measure of the heat energy in a given material or body. The distinguishing feature of temperature is that a flow of heat will arise when there is a difference in temperature between two adjacent materials or bodies, the direction of flow being from the material or body with the lower temperature, until the temperature of the two bodies becomes equal (for a definition, see WMO no. 8, par. 2.1.1, ref. 0).

Temperature describes a state and is thereby a rather unusual variable, in that it cannot be directly derived from primary tangible variables such as mass or length. In general, the temperature of a gas is directly proportional to the average kinetic energy of the molecules. For further background information about the physical variable *temperature*, the reader is referred for example to ref. 0. Because temperature indicates a state, the associated scale is based upon an agreed definition. The internationally defined temperature scale is determined among other things by the triple points and freezing points of elementary substances. This scale is regularly revised due to the increasingly accurate technology for determining phase transitions and the use of increasingly purified materials. A further definition of this scale can be found under 1.3, *units*.

1.3 Units

According to SI (ref. 0), the permanently recognized unit of thermodynamic temperature *T* is Kelvin (K). This unit is defined as the fraction 1/273.16 of the temperature of the triple point of water.

Alongside the thermodynamic temperature *T* (also known as the Kelvin temperature), the Celsius temperature *t* is also used. The recognized SI unit for this is the degree Celsius, symbol °C, which is the same as the Kelvin. The Celsius temperature is defined as the difference $t = T - T_o$ where T_o = 273.15K (see ref. 0 and ref. 0, par. 2.1.2.). Therefore:

$$t/°C = T/K - 273.15.$$

The unit "degree Fahrenheit", symbol °F (given by t_F/°F = 9/5 *t*/°C + 32) is not used as a recognized variable in the Netherlands.

The current international temperature scale for which *T* and *t* have been defined since 1990 is given by ITS-90 (see ref. 0 and ref. 0, chap. 2, Annex). This scale becomes, when expressed as a Celsius temperature:

t_{90} [freezing point H_2O] = 0.000°C

t_{90} [triple point H_2O] = 0.010°C

t_{90} [boiling point H_2O] = 99.974°C

The variable 'temperature' is used in meteorology for direct measurements of air, soil and water, and as a derived variable with respect to the air humidity.

The treatment of (sea) water temperature is given in the chapter on maritime observations and ref. 0, and soil temperature is described in the corresponding chapter. This chapter refers hereafter only to the air temperature, as measured above the surface of the ground.

1.4 Description of the variables

Meteorology uses a number of variables based on the variable quantity 'temperature'. These can be subdivided into a primary measured temperature and a secondary or derived temperature. The primary measured temperature refers exclusively to the instantaneous air temperature, measured at a fixed height. The other variables are determined using a time series, affected by the air or based on a derivation in which other (measured) quantities are included. The variables involving temperature are:

1. primary measured
   a) air temperature
2. derived from a temperature time series:
   a) minimum air temperature
   b) maximum air temperature
3. other derived temperatures
   a) dew point temperature and frost point
   b) saturation temperature
   c) virtual temperature

- **dry bulb temperature, air temperature**

Indicator: *T* or *t* (T_{air} or t_{air} also permissible) in codes: TTT, BUFR table ref. 0 12 001.

Air temperature is determined at a height of 150 cm above the ground surface. This variable is also called the “temperature” in practice.

- **maximum temperature**

Indicator: T_{max} or t_{max} in codes: T_x T_x T_x, BUFR table ref. 0 12 011.
The maximum temperature is the highest air temperature (at a height of 150 cm) reached in a time period, for example 6 hours or 12 hours (for the KNMI: between 06 and 18 UTC).

- **minimum temperature**

Indicator: T_{min} or t_{min}, in codes: T_n T_n T_n, BUFR table ref. 0 12 012.
The minimum temperature is the lowest air temperature (at a height of 150 cm) reached in a time period, for example 6 hours or 12 hours (for the KNMI: between 06 and 18 UTC).

- **10 cm temperature, or air temperature at a height of 10 cm**

Indicator: T_{10}.or $t_{10;}$ The 10 cm temperature is the actual air temperature at a height of 10 cm above the ground surface. This variable is often confused with the undefined variable “grass temperature” (see below also)

- **minimum 10 cm temperature**

Indicator: $T_{10, min}$, in (exclusively national) codes: T_g T_g T_g
The minimum 10 cm temperature is the lowest air temperature measured at a height of 10 cm reached in a time period, for example 6 hours (for the KNMI: between 18 and 08 UTC). This minimum temperature can be related to the so-called “grass minimum temperature” as formulated in WMO No. 8, Vol. I, par. 2.2.2.2 (see ref. 0).

However, the grass minimum temperature is defined based on the measured air temperature at the height of the tops of short mown grass, which is very awkward for automatic measurement.

The table WMO FM 94 BUFR, Class 12 – Temperature, also incidentally refers to a "ground minimum temperature, past 12 hours", table ref. 0 12 013.

- **dew point temperature**

Indicator: T_{dew}, in codes: T_d T_d T_d, BUFR table ref. 0 12 006.
The dew point temperature is the temperature (at a height of 150 cm) to which the air must be cooled (with other conditions remaining unchanged) in order to achieve complete saturation of the water vapour present in the air and at which condensation will occur. The dew point temperature is of the air temperature itself and is determined by the density of water vapour in the air. Dew point temperature can have a wide range extending a long way below 0°C, always with $t_{dew} \leq t$.

Chapter 4 of this manual describes the parameter humidity and the interrelationship between dew point temperature, temperature and relative humidity.

- **frost point**

Indicator: T_{ice} or t_{ice}
The frost point is the analogue of the dew point temperature, but referring to solid deposition and only defined for values below 0°C. Frost will form below this temperature.

- **other saturation temperatures, including the wet bulb temperature**

As well as the dew point temperature, in which the composition of the air itself is unchanged other than cooling, it is also possible to determine other saturation temperatures in which the air itself is affected and a thermodynamic equilibrium is reached. The most well known technique is psychrometry, which is used for humidity measurements (also known as wet and dry bulb measurements). In this method, the air comes into contact with a moist body, resulting in a mixture of saturated air / moisture at a saturation temperature. The adiabatic saturation temperature is the most obvious one to use for thermodynamic applications, due to the simple calculation that can then be used to determine the humidity.

It is however virtually impossible to meet the adiabatic requirement in practice and psychrometers are developed with their own individual calibration diagrams (see ref. 0). A psychrometer consists of a sensor that measures the air temperature (also referred to as the dry bulb temperature) and a sensor that measures the temperature of a moistened sleeve that is open to the air (thereby measuring the saturation temperature of the air adjacent to the sleeve). This is why that temperature is also referred to as the wet bulb temperature, indicated in codes for maritime observations as $T_bT_bT_b$, BUFR table ref. 0 12 005 (for measurements at a height of 2m). Because there is no useful fundamental relationship between moistening, evaporation, airing, radiation and heat conduction (meaning that this wet bulb temperature cannot be calculated), the humidity can only be determined after calibration.

Only the wet bulb temperature as measured by an Assmann psychrometer has been defined for international use (see ref. 0, WMO No. 8, Vol. 1, Annex 4.B). The Assmann psychrometer is not used at the KNMI.

NB: the so-called dry bulb temperature should only be used in combination with the wet bulb temperature (i.e. in psychrometry).

- **virtual temperature**

The virtual temperature is a derived quantity, used primarily in the simplification of formulae in which moisture is involved. The virtual temperature is defined as the temperature that a hypothetical system of dry air would have, in relation to the actual condition of (moist) air at the same density and pressure. This virtual temperature T_v is derived from the ideal gas law and is given by:

$$T_v = T\,(1 + r/\varepsilon)/(1 + r),$$

where r is the mixing ratio of moist/dry air and ε is the ratio of the molecular weight of water vapour to that of dry air, namely $\varepsilon = 0.62198$. The virtual temperature is used *inter alia* for reduction of the air pressure to see level (see chapter 1 of this manual). For additional details concerning virtual temperature, the reader is referred to ref. 0, chapter 4.

- **potential temperature**

The potential temperature θ (of unsaturated moist air) is defined as the temperature that a quantity of air at pressure p and temperature T would attain if it were subjected to an adiabatic change to standard pressure (p_o = 1000 hPa) and constant mixing ratio r. See ref. 0, chap. 4 for more details.

1.5 Element code

The coding used for temperature values in the SYNOP, KLIM and METAR messages is defined in the KNMI manual of meteorological codes (ref. 0). A good guideline for this is module B1 ("Observing") of the Elementary Professional Training in Meteorology (see ref. 0, chapter 7).

The codes below are used for the various temperature variables mentioned earlier, at the frequency intervals given.

- **FM 12-X SYNOP / FM 13-X SHIP**

section 1 (international groups)

- air temperature T: 1s_nTTT every hour;
- dew point temperature T_{dew}: 2$s_nT_dT_dT_d$ every hour;
-

section 3 (regional groups) and section 5 (national groups)

- maximum temperature T_x: 1$s_nT_xT_xT_x$ 18 UTC: maximum for the past 12 hours
- minimum temperature T_n: 2$s_nT_nT_nT_n$ 06 UTC: minimum for the past 12 hours; 08 UTC: minimum for the past 14 hours;
- minimum 10cm temperature $T_{10,\,min}$: 4$s_nT_gT_gT_g$ 08 UTC: minimum for the past 14 hours;

The following are applicable for these symbols:

1. All temperature variables in the SYNOP are given in multiples of 0.1°C.
2.
3. The sign is given by s_n, i.e.:
   s_n = 0 if temperature value ≥ 0.0°C and s_n = 1 for temperature values < 0.0°C

Examples:
t_n = –6.2°C → 2$s_nT_nT_nT_n$ = 21062
t = +27.4°C → 1s_nTTT = 10274

- **NF 01 KLIM** (national code agreement)

section 2 (regional groups)

- maximum temperature t_x: 1$s_nT_{x6}T_{x6}T_{x6}$ 00, 06, 12, 18 UTC: maximum for the past 6 hours
- minimum temperature t_n: 2$s_nT_{n6}T_{n6}T_{n6}$ 00, 06, 12, 18 UTC: minimum for the past 6 hours;
- minimum 10cm temperature $t_{10,min}$: 4$s_nT_{g6}T_{g6}T_{g6}$ 00, 06, 12, 18 UTC: minimum for the past 6 hours;

NB: the hourly periods in which both TX and TN occurred are also stated in the KLIM.

The following apply to the symbols:

1. All temperature variables in the KLIM are given in multiples of 0.1°C.
2. The sign is given by s_n (see SYNOP).

Examples:
t_n = –6.2°C → 2$s_nT_{n6}T_{n6}T_{n6}$ = 21062
t = +27.4°C → 1$s_nT_{x6}T_{x6}T_{x6}$ = 10274

- **FM 15-IX Ext. METAR / FM 16-IX Ext. SPECI**

  – air temperature t, together with
  – dew point temperature t_{dew} T’T’/T’$_d$T’$_d$ every half hour;

The following are applicable for these symbols:

1. both the air temperature and the dew point temperature are given in whole degrees Celsius (i.e. $\{t\} = \{t_{dew}\}$ = °C).
2. Where the air temperature or dew point temperature are negative (t, t_{dew} < 0°C), T'T' and T'$_d$T'$_d$ respectively are preceded by a letter M (=minus).

Examples:
T = +27°C, TD = +19°C → T’T’/T’$_d$T’$_d$ = 27/19
T = +14°C, TD = –6°C → T’T’/T’$_d$T’$_d$ = 14/M06

2. Operational requirements

This section covers the operational requirements concerning observation of the air temperature at 150 cm and 10 cm above ground level at the observation site. The operational requirements concerning the dew point temperature are described in Chapter 4, Humidity.

2.1 Range

The operational range for the observations of (air) temperature at 150 cm and 10 cm above the ground is –30 to +40°C.This applies to momentary values, averages and to the extremes.
The WMO standard is actually –60 to +60°C (WMO No. 8, ref. 0). Since the likelihood of a temperature below -30°C or above +40°C is negligible in the Netherlands, the above-mentioned range is sufficient for national use.

2.2 Relationship between the observational resolution and the messages

The resolution required in synoptic meteorology and climatology for observations of (air) temperature at 150 cm and 10 cm height is 0.1°C.This is in accordance with WMO regulations (WMO No. 8, ref. 0).
In the messages for aviation, i.e. the METAR, the resolution for temperature is however whole degrees Celsius, i.e. 1°C. (as per WMO/ICAO, see ref. 0).

2.3 Operationally required accuracy

- The required accuracy (margin of error) in the measured (air) temperature at 150 cm and 10 cm height is 0.1°C. This requirement is in accordance with WMO regulations (WMO No. 8, chap. 1, Annex 1, see ref. 0). The extremes (t_x, t_n) must fulfil the same condition: required accuracy (margin of error) of 0.1°C, although WMO regulations permit an uncertainty of 0.5°C (see ref. 0).

- The maximum acceptable operational uncertainty in the (air) temperature at 150 cm and 10 cm height (including maximum and minimum values) in the synoptic reports (SYNOP) and for climatological purposes (KLIM) is 0.2°C. This is in line with WMO regulations ("achievable operational accuracy", see WMO No. 8, ref. 0).

- The desired operational accuracy for the (air) temperature at 150 cm height for reporting in aviation meteorology (METAR) is 1°C (as per WMO/ICAO, ref. 0).

2.4 Required frequency of observation

1’ averages
In accordance with the WMO guidelines (refs. 0 and 0), the reporting should be done based on 1' average values. These averages always refer to the arithmetic mean of the continuous observations in the last completed period, in this case one minute. This method is sufficiently accurate for data acquisition via digital systems such as the SIAM, which uses five successive 12" samples for the purpose. This means that the natural fluctuations in temperature as measured, which can sometimes be large (very localized), are damped out and the measurement becomes more representative.

In systems that store data over a 10-minute period, such as an AWS or in RIS, the most recent 1-minute average is recorded every 10 minutes. Example: the 1’ value at time 14:10:00 is the average of the momentary values at the times 14:09:12, 14:09:24, 14:09:36, 14:09:48 and 14:10:00.

10’ values
Although hourly (SYNOP) and half-hourly (METAR) reporting is still the norm, there is a clear international development under way towards presentation of the data at a resolution of 10 minutes. In order to comply with this, generation of 10’ averages and the associated standard deviations is desirable. These parameters are incidentally a useful tool for validation of the actual measurements. The sampling frequency should be sufficiently high for the standard deviation to be determined when digital instruments are used. In the case of temperatures, 12” samples are suitable.

- extremes: maximum and minimum values

A temperature SIAM calculates the 10’ maximum and the 10’ minimum temperatures at 150 cm or 10 cm height over the last 10 minutes every 12 seconds. These extremes are based on an average from a 1-minute period, i.e. a sequence of five successive observations when the observation interval is 12 seconds. For a 1o’ extreme, this will be one of the 50 overlapping 1’ averages (see also ref. 0).
In systems that store data over a 10 minute period, such as an AWS or in RIS, the 10’ maximum and the 10’ minimum calculated in this manner are registered every whole ten minutes for the ten minute period just completed, according to the sequence HH:05, HH:15, HH:25, HH:35, HH:45, HH:55.

- average and standard deviation

The 10’ average temperature (measured at a height of 10 cm or 150 cm) and the associated standard deviation refer to the previous 10-minute period. This is the arithmetic mean of a sufficiently large number of measurements, for example based on fifty 12-second values, including the instantaneous temperature at the end of the 10-minute period.
In systems that store data over a 10 minute period, such as an AWS or in RIS, the average over the ten minute period just completed is presented every whole ten minutes , according to the sequence HH:05, HH:15, HH:25, HH:35, HH:45, HH:55.
Example: the 10’ average temperature value for the time 13:15:00 is the average of 50 instantaneous values: 13:05:12, 13:05:24, 13:05:36 and so forth up to 13:15:00.

hourly value (SYNOP)
The temperature value at a height of 150 cm averaged out over the last minute and determined at exactly 10 minutes before the hour (i.e. the 1-minute average value over the period form 11 minutes to the hour up to exactly 10 minutes to the hour) is used for determining the temperature value *t* in °C (code $1s_nTTT$) for the hourly SYNOP. This observation moment is within the period that has been set (internationally) for performing the SYNOP observation (approx. 15 minutes before the hour up to no later than 2 minutes before the hour, see also ref. 0).

half-hourly temperature value in the METAR
The timestamp for the METAR report is precisely 5 minutes before the whole hour or precisely 5 minutes before the half hour. The temperature value *t* in the METAR (code T'T') is the 1' average temperature value at 150 cm height at exactly 5 minutes before the time of the METAR message, i.e. exactly 10 minutes before the whole hour or 10 minutes before the half hour. Example: T'T' at 10:25 UTC is the 1-minute average temperature over the period 10:19:00 to 10:20:00.

maximum and minimum values in SYNOP and KLIM
At the times that SYNOP and/or KLIM require the maximum or the minimum temperature values at 150 cm or 10 cm height to be reported over a given useful period (6, 12 or 14 hours), these will be determined at exactly 10 minutes before that whole hour. The maximum value for the SYNOP or KLIM is the highest of all the 10' maximum values and the minimum value for the SYNOP or KLIM is the lowest of all the 10' minimum values.
Example: $1s_nT_xT_xT_x$ at 18 UTC: the highest 10' maximum value of the temperature at 150 cm over the period from 05:50 to 17:50 (the period lasts 12 hours, i.e. the highest of seventy-two 1o' maximum values; this is actually the highest single 1' average temperature value recorded of the 12 x 60 x 5 = 3600 twelve-second values over the period from 05:50:12 up to 17:50:00).

2.5 Data required to be present for each specific period

1' average and 10' average
An average over 1 minute or 10 minutes can be based on the 12" instantaneous values that are available ("available" implies not reporting "////"). Given the nature of the parameter, a 100% availability of the 12" measured values during the time period in question is not required for (operationally) determining a 1-minute or 10-minute average. The percentage of missing 12" instantaneous values should however be stated in the SIAM message (ref. 0). If no measure values are available at all, then a 1' average or 10' average will be deemed to be "missing".

10' maximum and 10' minimum
All 50 of the overlapping 1-minute averages involved do not have to be available for determination of a 10-minute maximum or minimum. What is required is at least that a 1' average has been recorded for each successive one-minute period within this 10-minute period. If this requirement is not met, then the said 10-minute maximum or minimum is deemed to be "missing".

maximum and minimum over a 6-hour period (KLIM) or 12-hour or 14-hour period (SYNOP)
The following criteria apply to the determination of a maximum or minimum temperature at 1.5m or 0.1m height over a given period for inclusion in SYNOP or KLIM reports:

– 6-hour period:

Of the 36 successive 10-minute blocks involved, no more than 5 (non-successive) blocks or one successive block may be missing.

– 12-hour period:
Of the 72 successive 10-minute blocks involved, no more than 11 (non-successive) blocks or one successive block may be missing.

– 14-hour period:
Of the 84 successive 10-minute blocks involved, no more than 12 (non-successive) blocks or one successive block may be missing.

3. Instrumentation and technology used

3.1 Technology used and specifications

The standard sensor used by the KNMI for operational measurements at 150 cm or 10 cm above the surface (ground level) is a platinum resistor element (Pt500) that is positioned in the tip of what is known as a "temperature measurement needle" made of stainless steel (see fig. 1a). A relatively high resistance of 500Ω is used, since the heat dissipation is low enough to be able to make measurements to the required margin of error of <0.1°C (this is not possible with a 100 Ω Pt element). To ensure that the leakage of heat from the sensor to the measuring wires is kept to a minimum, the sensor is connected to the rest of the cabling using wires made of manganese, which is a poor conductor of heat. A four-wire measurement method is employed, preventing significant systematic errors that can occur die to thermoelectric effects, current leakage or excessive additional resistance due to the length of the wiring. The Pt500 element is of a good enough quality that the systematic error in the given range, expressed in °C, is no greater than 0.05°C. The temperature measurement needle is then placed in a screen shaped like an inverted dish, which is there to protect it from radiation (see para. e)). This instrument (sensor, including SIAM transmitter) can be calibrated to a margin of error of <0.1°C. The resolution (of the SIAM output) is 0.1°C. The range is –30 to +4o°C. (Reference: ref. 0). The specifications of the instrumentation are therefore compliant with the operational requirements laid down.
.

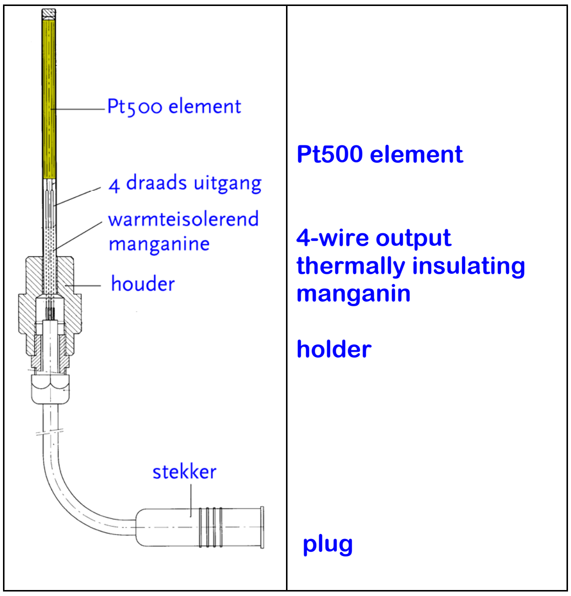

figure 1a: measuring needle with sensor


figure 1b: placement of the measuring needle in a cut-away dish screen

3.2 maintenance and calibration procedures

The measuring instruments must meet the accuracy requirements. This means that they require periodic maintenance during which the instruments are checked at intervals determined through experience and are calibrated and adjusted to ensure that they meet the requirements laid down. A calibration certificate is registered for each interval, in which the reference measurement values can be entirely reduced to a standard recognized by the RvA/NKO (*Accreditation Council / Dutch Calibration Organization*). The Insa (the KNMI's instrumentation department) is responsible for the procedures, which are embodied in the KNMI calibration laboratory's procedures for calibration. These procedures do comply with the Insa quality manual, which is recognized according to ISO 9001 (ref. 0). They do not (as yet) comply with the EN 45001 European standard for calibration and testing laboratories, or with any NKO certification requirements.

4. Procedures

4.1 procedures on failure of automatic observations

The SYNOP and METAR reports are not filled in when the automatic generation of data fails. At manned stations where backup equipment is present, the observations from these devices may be used as an alterative (only for local use, not for the SYNOP and METAR). Deviations from this rule are only possible in exceptional circumstances.

4.2 procedures for subsequent validation of temperature values

The KNMI's Climatological Information System (KIS) contains archived observations, namely:

- hourly temperature values *t* from the SYNOP, with the indicator: T
- 6-hourly maximum temperature values t_{max} from the KLIM: TX6
- hour in which this maximum temperature occurred (from the KLIM): HTX6
- 6-hourly minimum temperature values t_{min} from the KLIM: TN6
- hour in which this minimum temperature occurred (from the KLIM): HTN6
- 6-hourly minimum 10 cm temperature values $t_{g,\,min}$ from the KLIM: TG6

The datasets used are the archived SYNOP and KLIM observations from the inland and coastal stations, as well as the stations from the North Sea measurement network. Data input into the KIS system is done daily and uses the hourly and six-hourly values from the previous day (hourly periods HH = 00 to 23). All values that are entered into KIS are subjected to automated checking procedures that are programmed into the system. The following procedures are carried out for each station:

- **T**

  If the requirements below are not met, then the observation is highlighted as being 'suspect':

  a) TX6 ≥ T ≥ TN6
  b) if WW = 56, 57, 66, 67, 70,…, 79, 83, …87 of 88 then: T ≤ 5.0°C
  c) T[H] – ((T[H+2]+ T[H–2])/6 + (T[H+1]+ T[H–1])/3) ≤ 2.0°C
  d) –30.0 °C ≤ T ≤ 40.0°C

- **TX6**

  If the requirements below are not met, then the observation is highlighted as being 'suspect':

  a) TX6[H] ≥ T[H] and the same for (H–1) to (H–6)
  b) TX6 > TG6
  c) TX6 > TN6
  d) –30.0°C < TX6 < 40.0°C

- **HTX6**

  If the requirements below are not met, then the observation is highlighted as being 'suspect':

  a) If observation time = 06 then HTX6 = 1, 2 … 6
  b) If observation time = 12 then HTX6 = 7, 8 … 12
  c) If observation time = 18 then HTX6 = 13, 14 … 18
  d) If observation time = 24 then HTX6 = 19, 20 … 24
  e) If T[H–n] ≥ TX6 then $HTX6_h$ ≤ H–n (where n=1, 2, 3, 4, 5, 6)
  Comment: if H-n = 0, then T[H=24 UTC from the previous day] is validated.

- **TN6**

  If the requirements below are not met, then the observation is highlighted as being 'suspect':

  a) TN6 ≤ T[H] (for H through to H–6)
  b) TN6 < TX6
  c) –30.0°C < TN6 < 40.0°C

- **HTN6**

  If the requirements below are not met, then the observation is highlighted as being 'suspect':

  a) If observation time = 06 UTC then HTN6 = 1, 2 … 6
  b) If observation time = 12 UTC then HTN6 = 7, 8 … 12
  c) If observation time = 18 UTC then HTN6 = 13, 14 … 18
  d) If observation time = 24 then HTN6 = 19, 20 … 24
  e) If T[H-n] ≤ TN6 then HTN6[H] ≤ H-n (where n=1, 2, 3, 4, 5, 6)
  Comment: if H-n = 0, then T[H=24 UTC from the previous day] is validated

- **TG6**

  If the requirements below are not met, then the observation is highlighted as being 'suspect':
  a) TG6 > TX6
  b) -35.0°C < TG6 < 40.0°C
  c) -2.0°C < (TN6 - TG6) < 7.0°C

See ref. 9 for further details.
The KNMI's Climatological Services Division (KD) is responsible for the validity of the temperature values finally stored in KIS. This means that the KD in principle assesses every new value, assisted by the output of the test procedures described above. A missing value or a value that is evidently incorrect will be replaced by the KD if possible, based on procedures defined by the KD. The alternative value can be based among other things on:
- linear interpolation of adjacent (correct) values in the time series;
- spatial interpolation based on synchronous values from two or more nearby stations;
- estimation of the hourly value based on the time series of 10-minute data.

Replacement is done by hand, during which every case is individually assessed.

4.3 inspection procedures

Every thermometer that has an operational function within the KNMI observation network is inspected on average twice annually by a station inspector from WM/OD. This procedure covers both the sensors at 1.50 m height and the sensors at 10 cm height. Extra interim inspections can also be carried out if the validation of the data gives cause for this. Any backup sensors used at the manned stations are also subjected to this inspection process. The observers at the stations concerned are expected to keep an eye on the margin of error in these auxiliary devices at all times.

Inspections should preferably be done:
a) when a sensor is being placed at a new measuring station;
b) when a sensor on site has been replaced.

In both cases, WM/OD will be informed of the forthcoming placement or replacement by Insa/MSB. Within one week of the placement or replacement, Insa/MSB will inform WM/OD about it, including sending them proof of calibration, so that an inspection can take place.

The inspection covers the following checks:

a) Comparison of the instantaneous 12" values given by the operational sensor with the corresponding and synchronous values read at that moment by a reference thermometer (which is a Pt500 thermometer calibrated for the purpose according to the KNMI's calibration procedures, see ref. 0). A report is drawn up for all inspection visits by the station inspector. This report is distributed throughout the KNMI, according to a list of staff members concerned that has been drawn up by WM/OD/station management. The inspector will inform Insa/MSB if deviations are noted (absolute deviation ≥ 0.2°C) and will start discussions or make agreements for any corrective actions needed. These agreements are recorded and the inspector monitors the progress of the said agreements.

b) Checking that the calibration period of the measuring instrument has not expired. If this is the case, then Insa/MSB will be notified so that a replacement can be made.

c) A visual assessment of whether the circumstances under which the measurements are made and the surroundings meet the conditions laid down (see para. 0). This is also covered in the inspection report. Depending on the situation, the station inspector will evaluate which corrective actions need to be taken to bring the various items back into line with the operational requirements. The actions may vary from an order or request that the manager of the observation site concerned should alter the site conditions, through to starting up a procedure to look for a new observation site. If there are defects in the measuring apparatus, a repair order will be sent to Insa/MSB.

5. Derivation of parameters

Temperature values are used for the determination or derivation of a number of parameters:

a) reference to evaporation from crops according to Makkink, *inter alia* from the average diurnal temperature. See chapter 9 for a derivation
b) maximum vapour pressure (uses among other things the temperature at a height of 1.50 m) for calculation of the dew point temperature (from relative humidity and temperature). See the derivation in chapter 4
c) reduction of air pressure to another level, e.g. MSL. See the derivation in chapter 3
d) determining the stability of the atmosphere from t, t_{10} and if possible the 1o' standard deviation as well
e) 'wet bulb' temperature (from humidity and air temperature) for use in an algorithm for determining the presence of super-cooled precipitation (*present weather*)

6 Setup requirements and conditions for the surroundings

6.1 Setup requirements and facilities

air temperature at 1.50 m height

The sensors for measuring temperature should according to the WMO be situated at a height of between 1.25 and 2.00 metres above flat ground (see ref. 0). The KNMI has adopted 150 cm as the standard height. The terrain above which the measurements are being made should be covered with short mown grass; any snow that may be present need not be removed. The measuring element may not be significantly affected by sunlight, radiation and meteorological phenomena such as precipitation, dew, frost and wind. For this reason, the measuring element is placed in a so-called “dish screen” (shaped like an inverted dish) that protects it against radiation. This casing is white on the outside and black on the inside, to minimize the influence of radiation. The space between the dishes is chosen so that sunlight and radiant heat have no effect on the measuring element and also so that the space inside the screen is suitably naturally ventilated. See ref. 0 for more detailed information about thermometer screens.

figure 2a: setup showing a dish screen at an inland station (De Bilt)

figure 2b: setup showing a dish screen at a sea station (Noordwijk measuring station)

air temperature at 10 cm height

The sensors for measuring air temperature at 10 cm height should be positioned according to the same principles as for measurement at 150 cm. The sensor is positioned in a special radiation protector, among other things due to the fact that it measurements are made close to the ground surface.

The area around the measuring equipment should be covered with very short mown grass, no more than 3 cm in height. If the site is covered in snow, then the terrain should be cleared of snow to a radius of 50 cm around the device.

figure 3: dish screen with radiation protection for 10 cm temperature

6.2 conditions relating to the surrounding and the measurement location/

representativeness of the observations

There may not be any obstacles nearby such as buildings and trees that could affect the variable being measured. These can influence the temperature by emission of radiation and so can affect the representativeness of the observation. Furthermore, the presence of such objects can lead to a kind of valley structure in which warm or cold air can be “trapped”. The temperature of the air in this “valley” can then deviate (greatly) from the air temperature in the surrounding area.
In concrete terms, this means that the surrounding terrain must be sufficiently clear of building, crops and other plants being grown in the area around the observation site, in particular within a radius of:

a) 25 m: there may be no crops and/or other plants being grown that exceed a height of 50 cm
b) between 25 m and 50 m: there may be no crops and/or other plants being grown that exceed a height of 1.50 m
c) 100 m: no obstacles such as trees and shrubs
d) 400 m: no obstacles such as barns or other buildings, or woods

Any objects that are at a radius of more than 100 m must not be taller than $1/10^{th}$ the distance from that object to the measurement site

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Contents

ATMOSPHERIC PRESSURE

1. *description*

1.1 nomenclature of the variable

General name: atmospheric pressure or air pressure.
"Atmospheric pressure" is also the international nomenclature (WMO No. 8, ref. 1).

1.2 definition; description of the concept

The atmospheric pressure is the force exerted per unit area as a result of the weight of the atmosphere above the point of measurement. This pressure is thus equal to the weight of the total vertical column of air above the unit surface area.
(as per WMO No. 8, para. 3.1.1, ref.1 and WMO No. 182, A2930, ref. 16)

1.3 units

a) recognized SI unit (ref. 13)
The recognized SI unit (ref. 13) The SI unit for pressure is the Pa (pascal).
In meteorology both the air pressure and the pressure tendency (trend) are expressed in hectopascals (hPa).
1 hPa = 100 Pa; 1 Pa = 1 Nm^{-2} = 1 $kg.m^{-1}s^{-2}$ (where N is in newtons; 1N = 1 $kgms^{-2}$)

b) Non-recognized SI unit (ref. 13).
A unit that is still commonly used, but not recognized by SI, is the bar.
1 bar = 105 Pa; 1 mbar = 1 millibar = 10^{-3} bar = 100 Pa = 1 hPa.

1.4 variables

The following variables may be distinguished:

a) **The measured air pressure**
Indicator: p
The air pressure as measured is the value of the air pressure at the sensor location (and sensor height).

b) **The station air pressure**
Indicator: Po
This variable is the air pressure derived from the measured air pressure, reduced to the official altitude of the observing station. This altitude is known as the station height or station level and is determined relative to MSL (Mean Sea Level). In the Netherlands, NAP ("Nieuw Amsterdams Peil" ~= sea level) may be used. The reduced value is determined using the weight per unit area of a column of air between sensor level and station level. The height of this column is traditionally approx. 1.50 metres. On aviation sites (aerodromes and heliports), the height above MSL of the operational runway or the actual airfield site itself is relevant. In the case where the absolute difference between this height and the official station height is more than 2m, the station air pressure P_0 is determined by reducing the measured air pressure p to this height rather than to the official station height (in compliance with annex III of the convention on International Civil Aviation (ICAO), para. 4.11.3, ref. 4). It is also possible for the height above MSL described above to be higher than the sensor height above MSL, so that the reduction is actually negative: $P_0 < p$.
QFE

In synoptic reporting (SYNOP) and the reporting for aviation purposes (METAR), the station air pressure is indicated using the code QFE. QFE is the same as P_0, in accordance with aviation regulations 3012, art. 1 (ref. 17).

c) **Air pressure, reduced to sea level**
Indicator: P: This variable is the air pressure derived from the station air pressure P_0, reduced to MSL using a fixed factor. This factor can be obtained by adding the weight per unit area (or subtracting it in cases where the station lies below sea level) of the (virtual) column of air between station level (or airfield level or runway level as the case may be) and sea level to P_0.

The (virtual) column of air is taken to be affected by the actual atmospheric circumstances at the locality of the station (that is, the current air temperature at 1.50 m height and the current air pressure P_0). At MSL (applicable to Dutch stations and to the stations on the North Sea), the reduction is based on approx. 0.125 hPa/m. The basis for the calculation for this reduction is given in para. 5.

Remarks:
where the stations belonging to the North Sea measurement network are concerned, the reduction is based on the height of the landing platform relative to MSL and therefore to the actual air column between the platform and the sea surface.

The acronym QFF is also used in the Netherlands for the air pressure *P* reduced to MSL. This term is however not registered as such in the national and international regulations. This is just ICAO jargon.

The term “correction factor” may not be used for derivation factors. Correction factors may only be used for correcting/validating measured values.

QNH
According to the international regulations (ICAO), the term *QNH* is used for adjusting the sub-scale of an altimeter in an aircraft. In this scale, the relationship between altitude and air pressure is used according to a defined formula, the ICA standard atmosphere, namely:
QNH = A +B x QFE. (Refs. 2, 22)

The factors A and B are only dependent on the station geopotential height. Because of the simple basis for calculation and since the reduction factor is small in the Netherlands (<1.04), it has become customary to take QNH to be “QFE reduced to MSL in the ICAO standard atmosphere” (aviation regulations 3012, art 1; ref. 17), as an alternative for *P.* Since the difference between QNH and *P* is smaller than the permissible margin of error in the measurements, they can be used interchangeably.

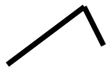
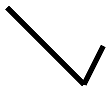
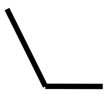
d) **Air pressure change** (tendency)
Indicator: a and p.

This variable is reported in the SNYOP (see para. 1.5).

A distinction is made between:
p: the size of the change in a particular time period (3 hours). This is actually based on the absolute difference between the value of P_0 three hours ago and the current value of P: $P_0(t) - P_0(t\text{-}3H)$.
a: the characteristic of the change during this period (for example, continually rising or first rising then dropping, etc.), represented with a code digit from 0 to 8. The definition of this characteristic assumes a continuous registration of pressure values.

The definition of the code digit is given in the table below and has been taken from the Handbook of Meteorological Codes (ref. 14). In accordance with the WMO “Manual on Codes” (ref. 18), the pressure tendency should be determined using pressure measurements that are made at fixed times with equal intervals between them of no more than one hour. Although the WMO “Manual on Codes” (ref. 18) refers to the “CIMO Guide” (ref. 1) for the algorithms, there is as yet no mention of them there. The algorithm published in WMO documents that does seem to be the most suitable comes from L. Bergman (SMHI, see ref. 19). The method for determining a from equal time intervals of one hour is given in the table below. This uses pressure measurements p_0, p_1, p_2 and p_3, i.e. the current pressure and the pressure values from one, two and three hours ago respectively.

Definition and method for determining the pressure tendency

Code digit	Descriptions		Graphical representation	$p_0 - p_3$	$p_0 + p_3 - p_1 - p_2$	$p_0 - p_1$
0	air pressure is the same as or higher than three hours earlier	rising, then falling		+	–	–
				0	–	+, 0, –
1	air pressure is higher than three hours earlier	rising, then steady		+	–	+, 0
2	air pressure is higher than three hours earlier	rising (steadily or irregularly)		+	0	+, 0, –
3	air pressure is higher than three hours earlier	falling or steady, then rising; or rising, then rising more rapidly		+	+	+, 0, –
4	air pressure is the same as three hours earlier	steady		0	0	+, 0, –
5	air pressure is the same as or lower than three hours earlier	falling, then rising		0	+	+, 0, –
				–	+	+
6	air pressure is lower than three hours earlier	falling, then steady; or falling, then falling more slowly		–	+	0, –
7	air pressure is lower than three hours earlier	falling (steadily or irregularly)		–	0	+, 0, –
8	air pressure is lower than three hours earlier	rising or steady, then falling		–	–	+, 0, –

+: result > 0, -: result < 0.

1.5 element codes

The coding used for pressure values in the SYNOP and METAR reports is defined in the KNMI manual of meteorological codes (ref. 14). A good guideline for this is module A4/B1 (“Observing”) of the Elementary Professional Training in Meteorology (see ref. 6, chapter 8).

Relevant groups in the synoptic weather report from a fixed land-based station, FM 12-X SYNOP:

- Station air pressure: $3P_0P_0P_0P_0$, pseudo code: QFE
  The value of $P_0P_0P_0P_0$ is given in 0.1 hPa, reduced by 1000.0 hPa if $P_0P_0P_0P_0 > 1000$.
  Examples: 39822: P_0 = 982.2 hPa, 30201: P_0 = 1020.1 hPa.

- Air pressure, reduced to MSL: coding 4PPPP, pseudo code: QFF
  The value of PPPP is given in 0.1 hPa, reduced by 1000.0 hPa if PPPP > 1000, i.e. analogous to $3P_0P_0P_0P_0$.

- Air pressure change: coding 5appp
  a: characteristic of the air pressure change: nine types are distinguished, indicated by the digits a = 0 through 8 (see section 1.4).
  ppp: value of the absolute air pressure change in the previous three hours. The value is in 0.1 hPa.

Some examples:
appp = 2008: air pressure rising (steadily or irregularly) over the last 3 hours. The rise is 0.8 hPa
appp = 5002: pressure falling, then rising, but lower than 3 hours ago. The fall is 0.2 hPa
appp = 8013: pressure rising or steady, then falling; or falling, then falling more rapidly; pressure lower than 3 hours ago. The fall: 1.3 hPa.

Relevant group in the weather report for aviation purposes, FM 15-IX Ext. METAR:

- air pressure, reduced to MSL, calculated according to the ICAO standard atmosphere: coding $QP_HP_HP_HP_H$, pseudo code: QNH
  The value is in whole hPa.
  Examples: Q1022: QNH =1022 hPa
  Q0987: QNH = 987 hPa
  NB: pressure values in the METAR are not rounded off to whole hPa, but truncated; so P_H = 987.8 hPa becomes Q0987.

2 *Operational requirements*

2.1 range

The operational range for observations of the pressure reduced to MSL are given by the WMO as *P* = 920 to 1080 hPa (references 1 and 3). Because of the relatively small difference in altitude between station height and MSL in the Netherlands (or in the North Sea), the chance of the measured air pressure P or P_0 being less than 940 hPa or greater than 1060 hPa is zero, judging by observations in the past. The operational range for observations of air pressure is therefore 940.0 to 1060.0 hPa.

2.2 relationship between observational resolution and reporting

The resolution required in the observation of air pressure is based on the resolution required in the reporting of synoptic meteorology and in the local messages for airports and heliports. This is 0.1 hPa (in accordance with WMO, refs. 14, 18). This resolution is consistent with the defined margin of uncertainty in the observations (ref. 1).

The resolution of the air pressure presented in the METAR reports is in whole hPa (as per ICAO, ref. 4).

2.3 required accuracy

International regulations concerning the use of words and concepts such as accuracy, uncertainty and hysteresis are set down in the "International Vocabulary of Basic and General Terms in Metrology" (publ. ISO; see ref. 20).

- The uncertainty (margin of error) in the air pressure as measured should not be greater than 0.1 hPa (as per WMO, ref. 1).

- The required operational accuracy in the air pressure for P and P_0 in the synoptic reporting (SYNOP) is 0.3 hPa (as per WMO, ref. 1).

- The required operational accuracy for the air pressure change in the synoptic reporting (SYNOP) is 0.2 hPa (as per WMO, ref. 1).

- The required accuracy for the air pressure for use in internal reporting at an airport or heliport is 0.1 hPa.

- The required operational accuracy for the air pressure in reporting for aviation meteorology (METAR) is 0.5 hPa (as per ICAO, ref. 4).

2.4 required observation frequency and times

1' average
In accordance with the WMO guidelines (refs. 1 and 18), the reporting should be done based on 1-minute average values.
These averages always refer to the arithmetic mean of the continuous observations in the previous period, in this case one minute. Given the slow rate of change in pressure measurement, a 1' average based on five previous 12-second measurements is sufficiently accurate, which is a suitable method for data acquisition using digital systems (such as the SIAM).

Example: the 1' value at time 14:08:00 is the average of the instantaneous values at the times 14:07:12, 14:07:24, 14:07:36, 14:07:48 and 14:08:00.

10' average

Although hourly (SYNOP) and half-hourly (METAR) reporting is as yet still the norm, there is a clear international development under way towards presentation of the data at a resolution of 10 minutes. In order to comply with this, generation of 10' averages and the associated standard deviations is desirable. These parameters are incidentally a useful tool for validation of the actual measurements. The sampling frequency should be sufficiently high for the standard deviation to be determined when digital instruments are used. In the case of pressure, 12-second samples are suitable.

Example: the 10' value at time 13:20:00 is the average of the 50 instantaneous values at the times 13:10:12, 13:10:24, 13:10:36 and so forth through to 13:20:00.

hourly value for air pressure (SYNOP)
The pressure value at 10 minutes before the whole hour, averaged over the previous minute, is used for determining or deriving the pressure values $P_0P_0P_0P_0$ and PPPP in the hourly SYNOP. This observation moment is within the period that has been set (internationally) for performing the SYNOP observation (approx. 15 minutes before the hour up to no later than 2 minutes before the hour, see also ref. 6).

hourly value for pressure change (SYNOP)
This is the absolute difference between the current hourly SYNOP air pressure value $P_0P_0P_0P_0$ and that of 3 hours ago.

half-hourly air pressure value in the METAR
The timestamp for the METAR report is precisely 5 minutes before the whole hour or precisely 5 minutes before the half hour. The air pressure value in the METAR (QNH) $P_HP_HP_HP_H$ is derived from the 1' average pressure value at exactly 5 minutes before the time of the METAR message, i.e. exactly 10 minutes before the whole hour or 10 minutes before the half hour.
Example: QNH at 10:25 UTC is the 1-minute average reduced to MSL calculated over the period 10:19:00 to 10:20:00 (in accordance with derivation using the ICAO standard atmosphere).

2.5 data required to be present for each specific period

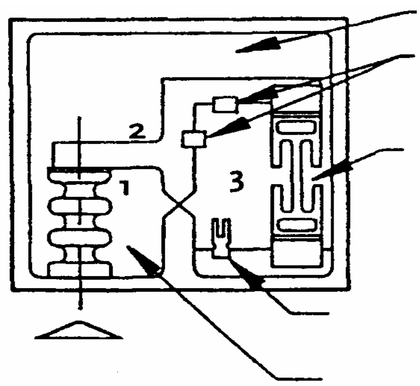
An average over a given period of time can be based on the 12" measured values that are available (not "////"). Given the nature of air pressure as a parameter and its relatively gradual rate of change per unit time, a 100% availability of the 12" measured values during the time period in question is not required for (operationally) determining a 1-minute or 10-minute average. Minimum requirement: a single 12" value in the time period concerned. Presentation of a quality factor is desirable, in which the number of available measured values is given. See e.g. ref. 10.

3. Instrumentation and technology used

3.1 technology used and specifications

- **standard measuring instrument**

The digital barometer Paroscientific (model 1015A) is used by the KNMI as the operational measuring instrument in observation stations. The uncertainty in the measurement using this instrument under laboratory conditions is 0.03 hPa, i.e. better than the operationally required margin of error of 0.1 hPa. The measuring range of the measurement system (instrument, including SIAM) is 940.0 to 1060.0 hPa, in accordance with the range chosen by the KNMI for operational pressure observations. (References ref. 5 and ref. 8)



digital barometer (Paroscientific 1015A)

Description and operation of the Paroscientific 1015A:
The barometers uses a “Digiquartz Pressure Transducer”, based on a resonator made of thin quartz crystal (3). This piezo-electric material is brought into an excited state using an alternating current and made to resonate.
The resonant frequency is the determined. This is actually a function of the mechanical pressure that is applied using a balance (2) and the device for transferring the atmospheric pressure to the crystal (1). The harmonics are also measured in addition to the basic resonant frequency; this allows calculations to be made to eliminate the effect of temperature (references: ref. 12 and ref. 15).

- **backup measuring device**

At manned stations where there is only one operational standard measuring instrument, there is also a backup instrument (model: Negretti & Zambra type MK2) for moments when the former is not available. This is operated manually to determine *p.* P_o and P are then derived using the derivation instructions given later in this document (see also 4.1). The margin of error for this instrument is 0.3 hPa.

3.2 maintenance and calibration procedures

The measuring instruments must meet the accuracy requirements. This means that they require periodic maintenance during which the instruments are checked and adjusted at intervals determined through experience and are calibrated to ensure that they meet the requirements that have been laid down. A calibration certificate is registered, in which the reference measurement values can be entirely reduced to a standard recognized by the RvA (*Accreditation Council*). (ref. 15) The KNMI department Insa is responsible for the procedures, which are embodied in the KNMI calibration laboratory’s ISO 9001 procedures for calibration. (ref. 7)

4. Procedures

4.1 procedures on failure of automatic observations

The SYNOP and METAR reports are not filled in when the automatically generated values are absent. At manned stations where backup equipment is present, the observations from these devices may be used as an alterative (only for local use). Deviations from this rule are only possible in exceptional circumstances.

4.2 procedures for subsequent validation of pressure values

The KNMI's Climatological Information System (KIS) contains archived observations of air pressure reduced to sea level (P) and air pressure change at sea level (a, p; see code appp) for stations on land and at sea. Data input into this system is done daily and uses the hourly values from the previous day (hourly periods h = 00 to 23 UTC). All values that are entered into KIS are subjected daily to automated checking procedures that are programmed into the system. The following procedures are carried out for each station:

- test for the presence of P_h = P and AP_h = ap (KIS encoding), where
  P_h : value of *P* at hour h
  AP_h : a_h and p_h : code a and value p at hour h, one after the other

- for each value P_h:
  a) if abs[$P_h - P_{h-1}$] > 4.0 hPa then treat as “suspect”;
  b) if P_h > 1060.0 hPa then treat as “suspect”;
  c) if P_h < 940.0 hPa then treat as “suspect”.

- for each value of P_h in AP_h, represented as p_h:
- if $|p_h - | P_h – P_{h-3} || > 0.3$ hPa then treat as “suspect”.

The WM/OD department will be informed if suspicious observations are noted. Based on this, steps can be taken such as maintenance (by Insa/MSB).

The KNMI’s Climatological Service division (WM/KD) is responsible for the validity of the pressure values finally stored in KIS.
This means that the KD in principle assesses every value, assisted by the output of the test procedures described above. A missing value or a value that is evidently incorrect will be replaced by the KD if possible, based on procedures defined by the KD.

The alternative value can be based among other things on:
a) linear interpolation of adjacent (correct) values in the time series;
b) spatial interpolation based on synchronous values from two or more nearby stations;
c) estimation of the hourly value based on the time series of 10-minute measurement data (10’ averages).

Replacement is done by hand, during which every case is individually assessed

4.3 inspection procedures

Every barometer that has an operational function within the KNMI observation network is inspected on average twice annually by a station inspector from WM/OD. Extra interim inspections can also be carried out on request by WM/KD if the validation of the data gives cause for this. The backup sensors used at the manned stations are also subjected to this inspection process. The observers at the stations concerned are expected to keep an eye on the margin of error in these auxiliary devices at all times.

Inspections should preferably be done:
a) when a barometer is being placed at a new measuring station;
b) when a barometer on site has been replaced.
In both cases, WM/OD will be informed in advance using a timing plan of the forthcoming placement or replacement by Insa/MSB. Within one week of the placement or replacement, Insa/MSB will inform WM/OD about it, including sending them proof of calibration, so that an inspection can take place.

The inspection covers the following checks:

a) Comparison of the instantaneous 12” pressure values given by the sensor with the corresponding and synchronous pressure value read at that moment by a reference barometer (which is a Paroscientific type 760 digital barometer, calibrated for the purpose according to the KNMI’s calibration procedures, see ref. 7). A report is drawn up for all inspection visits by the station inspector. This report is distributed throughout the KNMI, according to a list of staff members concerned that has been drawn up by HOD. The inspector will inform Insa/MSB if deviations are noted (absolute deviation greater than 0.2 hPa) and will start discussions or make agreements for any corrective actions needed. These agreements are recorded and the inspector monitors the progress of the said agreements.

b) Checking that the calibration period of the measuring instrument has not expired. If this is seen to be the case, then Insa/MSB will be notified so that a replacement can be made.

c) A visual assessment of whether the circumstances under which the measurements are made and the surroundings meet the conditions laid down (see para. 6). This is also covered in the inspection report. Depending on the situation, the station inspector will evaluate which corrective actions need to be taken to bring the various items back into line with the operational requirements. The actions may vary from an order or request that the manager of the observation site concerned should alter the site conditions, through to starting up a procedure to look for a new observation site. If there are defects in the measuring apparatus, a repair order will be sent to Insa/MSB.

5. Derivation of parameters reduction of pressure to another level

5.1 General

The WMO recommends a derivation formula for reducing the *p*-value measured by the sensor to the pressure at sea level, P_o (see ref. 21). A simpler formula may be used for stations that are virtually at sea level, as long as the result does not mean that the uncertainty exceeds 0.2 hPa. This applies to virtually the whole of the Netherlands as well as the North Sea, and this simplified method is used nationwide.

In accordance with the WMO guidelines (ref. 1, para. 3.11.2), the reduction of the air pressure at level 1 in a vertical direction to level 2 can be done for the stations in the Netherlands both on land and at sea using the following derivation formula:

$$\Delta p = p(h_2) - p(h_1) = -\left(\frac{p(h_1)}{29.27} * \frac{\Delta h}{T_v}\right);\ \Delta h = h_2 - h_1 \qquad (1)$$

- p_1 is the value of the air pressure at level 1 (hPa)
- p_2 is the synchronous value of the air pressure at level 2 (hPa)
- Δh is the vertical distance between the two levels, h_2–h_1 (m)
- T_v is the “virtual” temperature at the location concerned (level 1) (K)
- 29.27 is a constant that is determined by the density of air, according to the ideal gas law for dry air. (m/K)

NB: the so-called “virtual temperature” of air (as measured, including water vapour) is equal to the temperature of dry air (i.e. without water vapour) at the same pressure and the same density as the air with the water vapour (ref. 1, para. 3.11.2) at the current temperature T.

5.2 Calculation of the station air pressure: P_0

The calculation of P_0 (= QFE) is based on the formula described above (1).

$$P_0 = p + \left(\frac{P}{29.27} * \frac{\Delta h}{T^*}\right) \qquad (2)$$

- *p* is the air pressure measure by the sensor (point value or average value) (hPa)
- Δh is the height of the sensor minus the station altitude (or platform height or touchdown altitude, see 1.4) (m)
  NB: Δh is not necessarily the same as the height of the sensor above ground level! Δh can also have a negative value.
- T* is the average of the current 1.5 m air temperature and the 1.5 m air temperature 12 hours ago (K)
  (see comments about the determination of T under 5.5)

5.3 Calculation of the pressure at MSL: P

The calculation of P is based upon formula (1), working from the current actual atmospheric conditions.

$$P = P_0 + \left(\frac{P_0}{29.27} * \frac{H}{T^*}\right) \qquad (4)$$

- P_0 is the calculated air pressure at station altitude (or platform height or touchdown altitude)
- H is the station altitude relative to MSL (or platform height above MSL, or touchdown altitude above MSL) (m)
- T is the average of the current 1.5 m air temperature and the 1.5 m air temperature 12 hours ago (Kelvin)
  (see comments about the determination of T under 5.5)

5.4 Calculation of QNH

The calculation of QNH is different from the calculation of P, since the ICAO standard atmosphere is used (ref. 2). As previously, a simplified derivation formula has been chosen for use in the Netherlands, because H is small:

$$QNH = P_0 + \left(\frac{1013.25}{29.27} * \frac{H}{288.15} \right) = P_0 + 0.12014 * H \qquad (3)$$

- 1013.25 is the assumed air pressure at MSL (standard) (hPa)
- H is the station altitude relative to MSL (m)
  (or platform height above MSL, or touchdown altitude above MSL)
- 288.15 is the assumed temperature of dry air at MSL (= 15°C) (Kelvin)
- 29.27 is a constant that is determined by the density of air, according to the ideal gas law for dry air

5.5 Determination of virtual temperature

The average temperature over the last 12 hours is a good approximation for the virtual temperature as required by the derivation formulae. For this purpose, the average of the current air temperature and the air temperature 12 hours ago is taken in principle. The following procedure has been adopted:

a) the current value of the (1.5 m) air temperature is used for the “current air temperature”; this value is in principle no older than 1 hour;

b) The value of the (1.5 m) air temperature that is 12 hours older than the current value is used for the “air temperature 12 hours ago”; if this value is not available, then the oldest value present for the (1.5 m) temperature is used;

c) it may be the case that there is only one value for the (1.5 m) temperature available in the period concerned (as per criteria a) and b). In that case, no averaging is done and that value is used directly in the derivation formulae;

d) if there are no air temperature values at all (as per criteria a and b) available in the period concerned, then the average temperature for the month will be used as a standardized value, with a distinction being made between the stations on land and at sea (see table)

e)

Month	A	B
01	2.2	5

02	2.5	5
03	4.9	5
04	7.9	7
05	12.1	10
06	15.0	13
07	16.6	15
08	16.7	16
09	14.1	14
10	10.6	12
11	6.1	9
12	3.3	6

- column A:
  monthly values (1.5 m) for air temperature for all inland and coastal stations in °C (ref. 11)

- column B:
  monthly air temperature values for stations on the North Sea in °C (standard data based on the period from 1961 to 1980, information from the Climatological Service, Maritime Affairs).
  NB:
  On stations in the North Sea, the temperature and the atmospheric pressure are not measured at approx. 1.5 m above MSL, but at the height of the platform. The air temperature and air pressure as measured are taken to be equal to those at station altitude.

6. Setup requirements and conditions for the surroundings

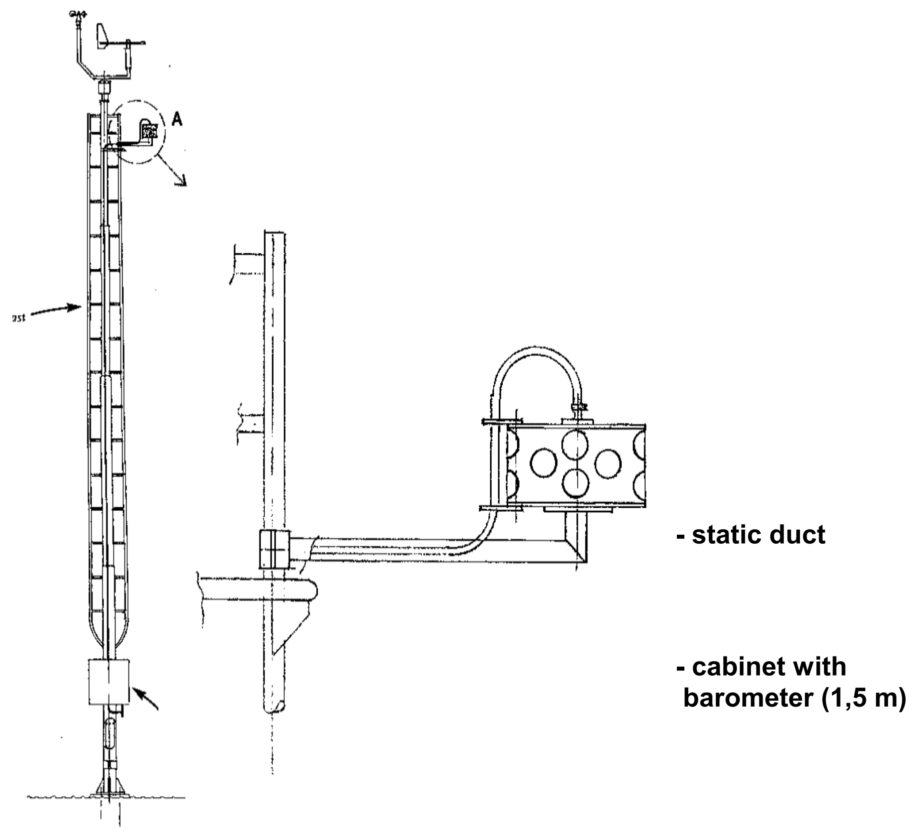
6.1 General

Wind can affect pressure measurements significantly. Not only are measurement errors of more than 1 hPa then possible, but large fluctuations in pressure can also occur (see ref. 23). Measurements made inside buildings in particular suffer from this (pressure accumulation or suction effect). Measurements are therefore made in an environment in which this effect is kept as small as possible by using what is known as a “static tube”.

6.2 Setup requirements and facilities:

Qualitative requirements concerning the setup of the measuring equipment in an operational observing station are:

a) the air must be undisturbed, i.e. the pressure measurement may not be affected either by air turbulence as a result of the wind or as a result of objects passing nearby;



mast erection (10 m)

b) there may not be any effect on the pressure observation due to wind or turbulence as a consequence of the “roughness” of the surrounding area or free-standing objects;(sudden) effects on the air temperature and thereby on the pressure observation must be avoided, for example due to sunlight, artificial lighting, heating equipment, etc.
c) the equipment setup must be free of vibrations.

The setup requirements relate to both the operational instrument and any backup barometer. (Ref. 5)

This is achieved by placing the pressure sensor in a special housing that is connected to a so-called “static tube”. The entrance to this tube should be positioned in such a way that the chance of the effects mentioned above occurring is minimal.
Any disruptive effects that may occur can be damped as much as possible by choosing a suitable length for the tube.

One suitable method is to attach the pressure sensor and static tube to the wind mast, so that the sensor is positioned about 1.5 metres above the ground with the entrance to the static tube at a height of around 8 metres above ground level (the influence of the wind mast on the pressure field and thereby on the representativeness of the observation is zero).

If such an arrangement is not possible – for example because there is no wind mast present or in the case of the backup measurement equipment – then measurement conditions should still be created that meet the above requirements.
A more detailed discussion is given in ref. 24 (KNMI equipment setup conditions for air pressure measurement).

6.3 Conditions relating to the surrounding and the measurement location and representativeness of the observations

In order to ensure the representativeness of the observations, no permanent or mobile obstacles may be present in the direct vicinity of the measurement location:

a) the distance from the measurement equipment to the nearest permanent large objects such as buildings, trees, edges of woodland, etc. should be at least five times the height of the object concerned, for example: the distance to a 15-metre high building should be at least 75 metres;

b) the distance to moving objects (whether regularly occurring or *ad hoc*) should be at least 200 metres (cf. vehicular traffic or aircraft taking off or landing on a runway).

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Contents

4 HUMIDITY

1. Description

1.1 nomenclature of the base variables

Nomenclature (also the international indicator):

- relative humidity
- dew point temperature

(WMO No.8, ref. 1)

1.2 definition; description of the concepts

Relative humidity (RH) is calculated from the vapour pressure (e) and the saturation vapour pressure (e_S) at the prevailing temperature (T).
The vapour pressure is the pressure exerted by the water vapour molecules present in the atmosphere. This pressure is a component of the total air pressure.
The saturation vapour pressure is the vapour pressure at which the air is in equilibrium with a water or ice surface. A higher vapour pressure is not possible under the given conditions because the water vapour will condense, i.e. there will be a transition from the gaseous phase (or vapour phase) to a liquid phase.
The saturation vapour pressure depends among other things on the temperature.

For air at temperature T and vapour pressure e:
$RH = e / e_S(T) * 100\%$

The dew point temperature (T_d) is the temperature to which the air must be cooled - with other conditions remaining unchanged - in order to achieve complete saturation of the water vapour present in the air.

Reference: WMO No.8, par.4.1.1, ref 1

1.3 variables and units

The units used are in accordance with the internationally accepted SI system of units (ref. 12).

a) vapour pressure and saturation vapour pressure: hPa
1 hPa = 100 Pa; 1 Pa = 1 N/m^1 (N is newton: 1 N = 1 $kg.m/s^2$)

b) relative humidity: %

c) dew point temperature: K (derived unit: °C)
According to SI (ref. 12), the recognized unit of temperature is the kelvin (K).
1 Kelvin (1K) is the fraction 1/273.16 of the temperature of the triple point of water (measure in K).
As well as this Kelvin temperature, the Celsius temperature is also used. According to SI (ref. 12), the recognized unit for this temperature is the degree Celsius (°C).
The relationship between the Celsius temperature (t) and the Kelvin temperature (T) is: $t = T - 273.15$
An interval of 1 degree Celsius (1°C) is equal to 1K.

Reference: WMO No.8, par. 4.1.2, ref 1.

1.4 element codes

The following symbols are used:
- relative humidity: RH (WMO and WM/KD use U as the symbol)
- dew point temperature: T_d
- vapour pressure: e (WM/KD uses EE as the symbol)
- saturation vapour pressure: e_S

The coding used for hourly values of the dew point temperature in the SYNOP and METAR reports is in accordance with the KNMI manual of meteorological codes (ref. 14). Reference can also be made here to module A4/B1, Waarnemen *(Observing)* of the Elementary Professional Training in Meteorology (ref. 4).

The code for dew point temperature in the SYNOP: $2s_n\ T_dT_dT_d$

$s_n = 0$: value $\geq 0°C$
$s_n = 1$: value $< 0°C$
Examples: 20117: dew point temperature T_d = +11.7°C
21042: dew point temperature T_d = -4.2°C

The code for dew point temperature in the METAR is $T'_dT'_d$. The dew point temperature in the METAR is given in whole degrees Celsius. A negative dew point temperature is preceded by the letter M (=minus).
Examples:
dew point temperature T_d = 19°C becomes: $T'_dT'_d$ = 19
dew point temperature T_d = -6°C becomes: $T'_dT'_d$ = M06

2. Operational requirements

2.1 range

The respective operational ranges for observations of relative humidity and dew point temperature are:

- relative humidity: 5 - 100%
- dew point temperature: < -60 to +35°C

This is in accordance with the WMO standard: ref. 1 and ref. 2.

2.2 relationship between observational resolution and reporting

Synoptic meteorology and climatology require a resolution of 1% in the observation of relative humidity and a resolution of 0.1K (or 0.1°C) in the observation of dew point temperature.
These items are in accordance with the WMO standard: ref. 1 and ref. 2.

The resolution of the dew point temperature in the METAR report is1K or 1°C.
This is in accordance with the ICAO guidelines: ref. 15.

2.3 required accuracy

International regulations concerning the use of words and concepts such as accuracy, uncertainty and hysteresis are set down in the "International Vocabulary of Basic and General Terms in Metrology" (publ. ISO; see ref. 16).

- The uncertainty (margin of error) in the dew point temperature as measured or calculated should not be greater than 0.5K (as per WMO, ref. 1).

- The uncertainty (margin of error) in the relative humidity as measured or calculated should not be greater than 3% (as per WMO, ref. 1).

- The required operational accuracy for the dew point temperature in synoptic reporting (SYNOP) is 0.5K (as per WMO, ref. 1).

- The required operational accuracy for the relative humidity in synoptic reporting (SYNOP) is:

  5% (if RH $\leq$ 50%) and 3% (if RH >50%)
  (as per WMO, ref. 1 and ref. 2).

- The required operational accuracy for the dew point temperature in reporting for aviation meteorology (METAR) is 1K
(as per WMO, ref. 1 and ICAO, ref. 15).

2.4 required observation frequency and times

1-minute average
Registration of the 1-minute values of relative humidity and dew point temperature respectively provides the basis for all the necessary derivations and for all the reports in the messages (as per WMO, ref. 1).

In order to achieve this, the SIAM registers the instantaneous value of the relative humidity and dew point temperature respectively every 12 seconds. Furthermore, the SIAM calculates the average value over the last minute every 12 seconds, as the arithmetic mean of five 12-second registrations (this includes the most recently recorded instantaneous value).

In systems that store data over a 10-minute period, such as the local data storage in an AWS, the 1-minute average is recorded every 10 minutes, calculated using this method with the data from the last minute.
Example: the 1-minute value at time 14:10:00 is the arithmetic mean of the momentary values at the times 14:09:12, 14:09:24, 14:09:36, 14:09:48 and 14:10:00.
(NB in practice there will always be a processing time, varying from about 5 to 17 seconds; the “instantaneous” value is in fact “instantaneous plus the processing time”)

hourly value for dew point temperature (SYNOP)
The 1-minute average value for the dew point temperature as recorded at precisely 10 minutes to the whole hour (i.e. the 1-minute average over the period from 11 minutes before the whole hour through to exactly 10 minutes before the whole hour) is used as the dew point temperature T_d (code $2s_nT_dT_dT_d$) in the hourly SYNOP. This observation moment is within the period that has been set (internationally) for performing the SYNOP observation (approx. 15 minutes before the hour up to no later than 2 minutes before the hour, see also ref. 4).

half-hourly dew point temperature value in the METAR
The timestamp for the METAR report is precisely 5 minutes before the whole hour or precisely 5 minutes before the half hour. The dew point temperature value in the METAR (code $T'_dT'_d$) is derived from the 1-minute average value at exactly 5 minutes before the time of the METAR message, i.e. exactly 10 minutes before the whole hour or 10 minutes before the half hour. Example: $T'_dT'_d$ at 10:25 UTC is the 1-minute average temperature over the period 10:19 to 10:20.

2.5 data required to be present for each specific period

As for 2.5 in Chapter 2, “Temperature”. For more details, see section 4.1 “procedures when data is missing”.

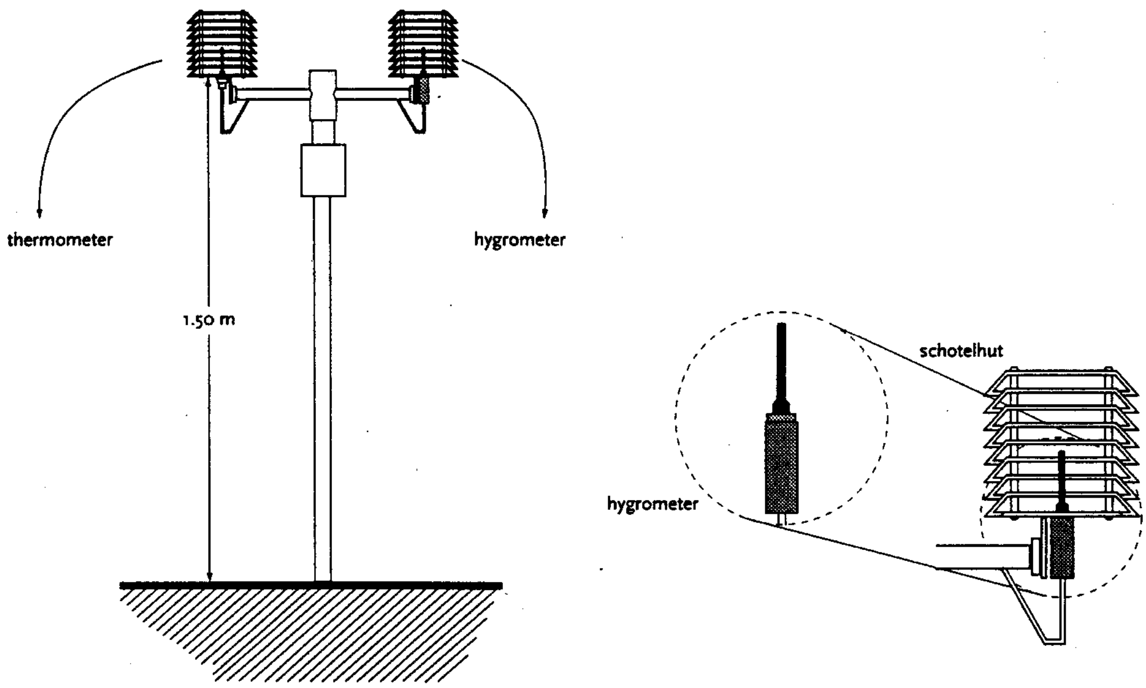
3. Instrumentation and technology used

3.1 technology used and specifications

The KNMI used a capacitative humidity meter (Vaisala) as the standard instrument for measuring relative humidity.
The dew point temperature is derived from the temperature and the relative humidity.
Determination of the dew point temperature therefore requires two sensors:
- a sensor for measuring the temperature (see chapter on temperature);
- a sensor for measuring the relative humidity.

The technical specifications of the humidity meter used with the SIAM are as follows:

Measurement range:	2 to 100% RH;
Resolution:	1% RH;
Accuracy:	±3.5% RH;
Measurement frequency:	1/12 Hz.



3.2 maintenance and calibration procedures

The calibration procedures are determined in Insa's ISO-9001 quality system, as part of procedure 2.2.3 (control procedure for preventive maintenance).

The calibrations and checks are carried out in a climate chamber where the relative humidity sensor is compared with a Michell S4000 dew point meter. This reference instrument is in turn calibrated in the NPL (UK) and has – according to the calibration – an uncertainty in the measurement of the dew point of ± 0.13°C.

4. Procedures

4.1 procedures on failure of automatic observations

The guidelines when data is absent are as follows:
a) *non-aviation stations*:
If the humidity reading from surrounding stations is available, repairs will be carried out on the next working day.
If there is insufficient humidity measurement data from surrounding stations (at least two within a distance of 50 km) then repairs will be started within twelve hours of the problem starting.
b) *aviation stations*:
If the humidity reading from another humidity sensor at the airfield can be used as a fallback, repairs will be carried out on the next working day.
If there is no local backup available, repairs will be carried out immediately after the problem arises.

4.2 procedures for subsequent validation of humidity values

The SYNOP values for dew point temperature are read into the Climatological Information System (KIS) on a daily basis and archived. The corresponding values for the relative humidity are derived from the temperature and the dew point temperature (para. 5). The following checking procedure is applied automatically to each hourly value RV_h from each station:

$RV_h - \{2/3\ (RV_{h-1} + RV_{h+1}) - 1/6\ (RV_{h-2} + RV_{h+2})\}$ must be $\leq 15\%$, otherwise “suspect”.

A suspicious or missing value will be replaced if possible.
The alternative value is based on:
- linear interpolation of adjacent (correct) values in the time series;
- spatial interpolation based on synchronous values from two or more nearby stations;
- estimation of the hourly value based on the time series of 10-minute values.

Replacement is done manually.

4.3 inspection procedures

Every humidity meter that has an operational function within the KNMI observation network is inspected on average twice annually by a station inspector from WM/OD. Extra interim inspections can also be carried out on request by WM/KD if the validation of the data gives cause for this.
Inspections will also be performed:
- when a humidity meter is being placed at a new measuring station;
- when a humidity meter on site has been replaced.

In both cases, WM/OD will be informed in advance using a timing plan of the forthcoming placement or replacement by Insa/MSB. Within one week of the placement or replacement, Insa/MSB will inform WM/OD about it, including sending them proof of calibration, so that an inspection can take place.

The inspection covers the following checks:

a) A comparison of the relative humidity value registered by the sensor with the relative humidity value as measured by a reference sensor. This sensor is a capacitative humidity meter (Vaisala) that has been calibrated according to the KNMI's calibration procedures. If their respective values for the dew point temperature as calculated from the relative humidity values have an absolute difference of 0.2K or more, then the inspector will with immediate effect mark down the site concerned as being unsatisfactory for operational observations of relative humidity. The inspector will inform the Insa/MSB department where deviations are noted and will start discussions or make agreements for any corrective actions needed. These agreements are recorded and the inspector monitors the progress of the said agreements.
b) Checking that the calibration period of the measuring instrument has not expired. If this is seen to be the case, then the Insa/MSB department will be notified so that a replacement can be made.
c) A visual assessment of whether the circumstances under which the measurements are made and the surroundings meet the conditions laid down (see para. 6). If this is not the case, then the inspector will with immediate effect mark down the site concerned as being unsatisfactory for operational observations of relative humidity. Depending on the situation, the station inspector will evaluate which corrective actions need to be taken to bring the various items back into line with the operational requirements. The actions may vary from an order or request that the manager of the observation site concerned should alter the site conditions, through to starting up a procedure to look for a new observation site. If there are defects in the measuring apparatus, a repair order will be sent to the department Insa/MSB.

A report of all inspection visits is drawn up by the station inspector. This report is distributed throughout the KNMI, according to a list of staff members concerned that has been drawn up by HOD.

5. Derivation of other parameters: calculation of the dew point temperature T_d

5.1 General

The following parameters are used in the derivation of the dew point temperature T_d:

- the temperature T, which is measured directly;
- the relative humidity RH, which is also measured directly;
- the saturation vapour pressure $e_S(t)$, which is a function of the temperature T (K): t (°C) = T (K) - 273.15;
- the vapour pressure e under the given conditions, which is a consequence of the relative humidity and the saturation vapour pressure.

5.2 Calculation of the saturation vapour pressure

The most accurate calculation of the saturation vapour pressure $e_S(t)$ is done using what is known as the Goff-Gratch polynomial (ref. 5). The WMO has adopted this polynomial as the standard formula. Because of the complexity of this formula and the highly intensive calculation it requires, the WMO advises using the following approximations:
For water vapour in equilibrium with (or possibly supercooled) a flat water surface:

$e_S(t) = 6.112 * e^{\{17.62\ t/(t+243.12)\}}$ (1)

Above ice:

$e_S(t) = 6.112 * e^{\{22.46\ t/(t+272.62)\}}$ (2)

(ref. 1)

The above formulae are applicable to pure water vapour. If the situation involves humid air, i.e. both air and water vapour, then a small correction should be applied. However, given the required accuracy, this deviation is negligible. The conclusion is then that using formulae 1 and 2 achieves a very good approximation in the range -40 to +35°C for the parameter to be derived. These items meet the accuracy requirements.

Alternative approximation formulae (Magnus, Tetens, Bolton, Sprung) also provide the required accuracy. These are described in KNMI-TR 153 (ref. 5) and KNMI-TR 140 (ref. 11).

The KNMI has adopted its own formula for derivation of the dew point temperature in the SYNOP and the METAR:

$e_S(t) = 6.11 * e^{\{17.504\ t/(t+241.2)\}}$ (3)

This formula is used both for the water and the ice conditions, since the relative humidity sensor provides a measurement relative to the water saturation. This formula has been implemented in the software of the SIAM (ref. 13). The Insa calibration laboratory uses the following formula, providing close agreement with (3):

$e_S(t) = 6.11213 * e^{\{17.5043\ t/(t+241.3)\}}$ (4)

Using formulae (3) and (4) for the calculation also produces a derived parameter that meets the accuracy requirements.

When the SYNOP data is archived in the Climatological Information System (KIS), the dew point temperature is treated as a basic parameter from which the synchronous value of the relative humidity is derived. This process is the inverse of the process described above. The derivation is based on Sprung's formulae.
Above water:

$e_S(t) = 6.107 * e^{\{17.27\ t/(t+237.3)\}}$ (5)

Above ice:
$e_S(t) = 6.107 * e^{\{21.87\ t/(t+265.5)\}}$ (6)
(ref. 6)

Summary:
Standard formula:
$e_S(t) = A * \exp\{B\ t/(t+C)\}$ (7)

Water surface

	A	B	C
WMO	6.112	17.62	243.12
KNMI (SYNOP, METAR, SIAM)	6.11	17.504	241.2
KNMI (Insa Calib.Lab.)	6.11213	17.5043	241.3
KNMI (KIS)	6.107	17.27	237.3

ice surface

	A	B	C
WMO	6.112	22.46	272.62
KNMI (SYNOP, METAR, SIAM)	not applicable		
KNMI (Insa Calib.Lab.)	not applicable		
KNMI (KIS)	6.107	21.87	265.5

5.3 Calculation of the vapour pressure: e

Given that RH = $\{e / e_S(t)\} * 100\%$,

it follows that $e = \{RH * e_S(t)\} / 100\%$ (8)

5.4 Calculation of the dew point temperature T_d

Given that $e_S(T_d) = e$ and using the standard formula (7), we obtain:

$A * \exp\{B\ T_d /(T_d + C)\} = e$ (9)

Conversion of this formula produces:
$T_d = C * \{\ln e - \ln A\} / \{B - \ln e + \ln A\}$ (10) or
$T_d = C / [\{B / (\ln e - \ln A)\} - 1]$ (11)

5.5 Calculation of RH from t and T_d

- $e_S(t)$ is calculated using (7)
- e is then obtained by filling in $t = T_d$ in (7): $e = e_S(T_d)$
- RH is calculated using RH = $\{e / e_S(t)\} * 100\%$.

6. Setup requirements and conditions for the surroundings

6.1 Setup requirements and facilities

The advice from the WMO is that the sensors for the measurement of relative humidity (and the dew point temperature) should be placed at a height of between 1.25 and 200 metres above flat ground. The KNMI uses a standard height of 1.5 metres.

6.2 Conditions relating to the surrounding and the measurement location and representativeness of the observations

There may not be any obstacles such as buildings and trees nearby. Radiative heat from these can affect the temperature and thereby the relative humidity. These objects can also retain heat or cold for longer and thus affect the air flowing past them. These phenomena affect the representativeness of the observation. Warm or cold air can also be “trapped” between such objects. The temperature of such air can then deviate from the air temperature in the wider surroundings.
In concrete terms, the following conditions apply:

- there may not be any obstacles within a radius of 100 metres around the location of the sensor; the ground surface within this radius must also be sufficiently flat; any objects that are at a radius of more than 100 m must not be taller than 1/10th the distance from that object to the measurement site.

The humidity sensor must be at least 5 metres away from open water (ditches, canals, ponds, rivers, etc.).

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Contents

Chapter 5. Wind

1 Description –

- 1.1 nomenclature of the variable
- 1.2 definition; description of the concept
- 1.3 units
- 1.4 variables
- 1.5 element codes

2 Operational requirements

- 2.1 range
- 2.2 relationship between observational resolution and reporting
- 2.3 relationship between required accuracy and the reporting
- 2.4 required frequency of observation
- 2.5 data required to be present for each specific period

3 Instrumentation and technology used

- 3.1 technology used and its specifications
- 3.2 maintenance and calibration procedures

4 Procedures

- 4.1 procedures on failure of automatic observations
- 4.2 procedures for subsequent validation
- 4.3 inspection procedures

5 Derivation of parameters

- 5.1 derivation of potential wind speed from measured wind speed

6 Setup requirements and conditions for the surroundings

- 6.1 setup requirements and facilities
- 6.2 conditions relating to the surrounding and the measurement ocation/representativeness of the observations

7 References

5. Wind

1. Description

1.1 nomenclature of the variable
General name: wind.
International indicator: surface wind (WMO No. 8, ref. 1)

1.2 definition; description of the concept
Wind is the horizontal displacement of air. The most important cause of this displacement of air is a difference in air pressure. The difference in air pressure per unit distance is the air pressure gradient. The greater this gradient is, the larger and more powerful the displacement of air will be. The placement of areas of higher air pressure relative to those of lower pressure is to a large extent the factor determining the direction of the air displacement.

The wind parameters that play a part in meteorology and climatology are:
- wind speed
- wind direction
- wind gusts

1.3 units
a) recognized SI unit (ref. 13)
The recognized SI units (ref. 13) are:
- wind speed: m/s
- wind direction: degrees (degrees of arc)
- wind gust: m/s

b) non-recognized SI unit (ref. 13)
In operational meteorology and in particular in aviation meteorology, the usual unit for wind speed and gust speed is still knots (abbreviated to kts).
1 knot = 1 nautical mile per hour = 1852 m / 3600 s = 0.514444 m/s.

1.4 variables
The following variables may be distinguished:

a) *wind speed:*
The wind speed is the horizontal speed of (a packet of) the air in m/s.

b) *average wind speed:*
The average wind speed refers to the average of the horizontal speed of the packets of air passing a given geographic point during a previously defined period, e.g. 10 minutes. In operational terms, this comes down to the arithmetic mean of all the 3”-averages recorded during the period concerned.

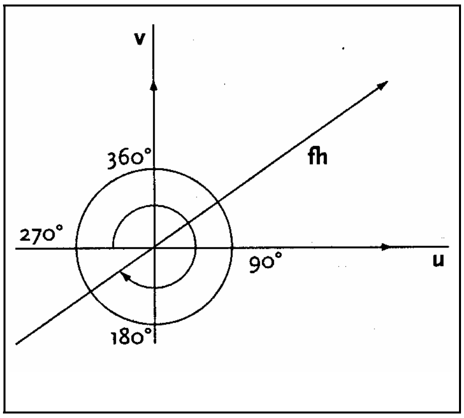
c) *instantaneous wind speed:*
The instantaneous wind speed is the current wind speed at the time in m/s. In reality this refers to the average wind speed over the previous 3 seconds.

d) *maximum wind gust speed:*
This refers to the maximum wind speed in a given time period. In operational terms, this refers to the highest 3”-average value recorded in a particular time period, e.g. 10 minutes.

e) *wind direction:*

The wind direction at a given geographic point is the direction of horizontal displacement of (a packet of) the air. Meteorological convention defines the wind direction as being the direction that the wind is coming from (i.e. the direction you are looking in if you have the wind in your face). The direction is determined as the angle relative to the positive axis (y-axis). In this coordinate system, the y-axis is oriented towards true geographic north (in aviation meteorology this axis is oriented towards geomagnetic north). The positive section of the x-axis (running perpendicular to the y-axis) is oriented towards the east. The angle varies from 0 through to 360 degrees of arc, counting from the positive y-axis and moving clockwise.
Example:
Meteorological convention makes a south-westerly wind one that is blowing from the south-west, which is equivalent to a wind direction of 225 degrees (225°).

f) *wind vector and vector components:*



The wind vector gives the direction towards which the wind is blowing and is thus the exact opposite of the meteorological wind direction. The wind vector is determined by the magnitude of the horizontal wind speed and the complement of the meteorological wind direction. The vector components are the projections of the wind vector on the x-axis and y-axis, the u-component and v-component respectively; see diagram.

g) *average wind direction:*
It has been internationally agreed that the average wind direction is based upon an averaging of the wind directions involved, in which all the corresponding vectors are treated as unit vectors. That is to say, when the average wind direction is determined, the wind speeds associated with the corresponding vectors are not taken into account. In practice, the averages of the u-components and v-components of the unit vectors are calculated for all the wind registrations in the time period concerned. The average vector is then put together from the average u-component and the average v-component. The average (meteorological) wind direction is then the complement of this vector.

1.5 element codes
The coding for the wind is SYNOP, KLIM and METAR reports is set out in the KNMI manual of meteorological codes (ref. 14). A good guideline is module A4/B1 ("Observing") of the Elementary Professional Training in Meteorology (see ref. 6, chapter 6).

SYNOP:

section 1:

- **code dd (KIS: DD)**: the average (vector) wind direction in tens of degrees of arc in the 10 minutes preceding the moment of observation {i.e. exactly 5 minutes before every whole hour (UTC)}.
- **code ff (KIS: FF)**: the average wind speed in m/s in the 10 minutes preceding the moment of observation {i.e. exactly 5 minutes before every whole hour (UTC)}.

Remark 1:
Where there is little wind (wind speed < 2 m/s) or in the case of a strongly variable wind (standard deviation of wind direction ≥ 30 degrees), then the wind direction is referred to as changeable or variable. In these cases the code number dd = 99 is used.

Remark 2:
If a significant change in wind behaviour occurs during a 10-minute observation period, then the average is determined over the period between the moment of change and the observation time. This applies both to the calculation of the average wind direction and to the calculation of the average wind speed. A significant change is regarded as having taken place if any one of the following situations arises:

a) there is an abrupt and persistent change in the wind direction during the observation period of 30 degrees or more, with the wind speed being 5 m/s or more either before or after the change;
b) there is a change in the wind speed of 5 m/s or more, lasting for at least two minutes.

For a detailed description: see document “Wind SIAM”, para. 2.3.3, ref. 16.
The average wind (speed and direction) is therefore determined for the period AFTER the change and is therefore an average over a period of less than 10 minutes.
This is incidentally NOT something that can be seen in the reports!

- **code f_xf_x**:
  group 910ff: the maximum wind gust in m/s in the 10 minutes preceding the moment of observation {i.e. exactly 5 minutes before every whole hour (UTC)} where this is 5 m/s or more greater than the synchronous value of ff in section 1.
  group 911ff: the maximum wind gust in m/s in the hour preceding the moment of observation {i.e. exactly 5 minutes before every whole hour (UTC)} where this is ≥ 13 m/s.

- **code f_mf_m**:
  group 912ff: the maximum 10-minute average wind speed in m/s in the hour preceding the moment of observation {i.e. exactly 5 minutes before every whole hour (UTC)} where this is ≥ 13 m/s.

section 5:

- **code f_xf_x**:
  group 511ff: only at the main or intermediate hours: the maximum wind gust in m/s in the observation period (i.e. period of 6 hours in the case of the main hours, or 3 hours for the intermediate hours) preceding the moment of observation {i.e. exactly 5 minutes before every whole hour (UTC)} where this is ≥ 13 m/s.

- **code f_mf_m**:
  group 512ff: only at the main or intermediate hours: the maximum 10-minute average wind speed in m/s in the observation period (i.e. period of 6 hours in the case of the main hours, or 3 hours for the intermediate hours) preceding the moment of observation {i.e. exactly 5 minutes before every whole hour (UTC)} where this is ≥ 13 m/s.

- main hours: 00, 06, 12, 18 UTC
- intermediate hours: 03, 09, 15, 21 UTC

KLIM:

- **code f_hf_h or fh (KIS: FH)**:
  This relates to the average wind speed in the last hour; in principle this is the hourly period between two successive whole hours on the hour; for practical reasons the time period actually used is from precisely 5 minutes before the hour to exactly 60 minutes later.

- **code f_xf_x or fx (KIS: FX)**:
  This relates to the maximum gust in the hour just passed; this is the maximum 3"-average wind speed recorded during that hour; the hourly period is defined the same was as for average hourly wind (see above).

METAR:

- **code: dddffGf_mf_m {KMH** or **KT** or **MPS}**
  ddd: true direction in degrees, rounded off to the nearest multiple of 10 degrees, from which the wind is blowing;
  ff : wind speed in km/h, knots or m/s;
  G: letter indicator for maximum gust speed;
  f_mf_m: maximum wind speed in km/h, knots or m/s;
  KMH: km/h;
  KT or left blank: knots;
  MPS: m/s;

- **code: $d_nd_nd_nVd_xd_xd_x$**
  $d_nd_nd_n$: extreme wind direction *measured anti-clockwise* of a variable wind, given relative to true north and rounded off to the nearest multiple of 10 degrees;
  V: letter indicator to separate the elements of the extreme values, which otherwise have no spaces between them;
  $d_xd_xd_x$: extreme wind direction *measured clockwise* of a variable wind, given relative to true north and rounded off to the nearest multiple of 10 degrees;

The average true direction in degrees of the direction from which the wind is blowing, rounded off to the nearest multiple of ten degrees, and the average wind speed over the 10-minute period directly preceding the moment of observation are given with dddff, which is followed without any intervening white space by one of the abbreviations KMH, KT or MPS to indicate the units that have been used for the wind speed. Values of less than 100 degrees for the wind direction are given with a leading zero and a wind coming from true north is given as 360 degrees. Values for the wind speed that are less than 10 of the unit being used are stated with a leading zero. However, if there has been a distinct alteration in the wind characteristics during the 10-minute period, then only the data after the alteration is used for determining the average wind speed and the value of the maximum gust; the average wind direction and changes in the wind direction are also determined over the truncated period in such circumstances.

A distinct alteration is deemed to occur when:

a. there is an abrupt and persistent change in the wind direction of 30 degrees or more, with the wind speed being 20 km/h (10 kt) or more either before or after the change; or

b. there is a change in the wind speed of 20 m/s (10 kt) or more lasting for at least two minutes.

When the wind direction is variable, ddd is coded as VRB if the average wind speed is 3 kt (2 m/s or 6 km/h) or less. A variable wind with higher speeds, with a variability in wind direction of 180 degrees or more, is only given if it is impossible to determine a single wind direction, for example when a thunderstorm is passing over the airfield.

If the total variation in the wind direction during the 10-minute period preceding the moment of observation is 60 degrees of arc or more and the average wind speed is more than 3 kt (2 m/s or 6 km/h), then the two extremes of direction between which the wind has varied are stated, counting clockwise, using $d_nd_nd_n\mathbf{V}d_xd_xd_x$. This group is otherwise not included.

Dead calm (wind still) is coded as 00000 followed immediately (with no white space between) by one of the abbreviations KMH, KT or MPS showing the units which are usually used for indicating the wind speed.

If the maximum gust speed exceeds the average wind speed by 10 knots (5 m/s or 20 km/h) or more during the 10-minute period preceding the moment of observation, then this maximum speed is given as $\mathbf{G}f_mf_m$ immediately after dddff and is followed without any intervening white space by one of the abbreviations KMH, KT or MPS showing the units which are used for indicating the wind speed The $\mathbf{G}f_mf_m$ element is otherwise not included.

Where wind speeds are 100 units or more, the exact value of the wind speed units is given, rather than the two-digit code ff or f_mf_m.

2. *Operational requirements*

2.1 range

The operational range for observations of wind speed and direction is given by the WMO (refs. 1 and 3) as:

- average wind speed: 0 - 70 m/s; wind gusts: 5 -75 m/s;
- wind direction: >0 and ≤360 degrees.

The KNMI uses the range 0 – 50 m/s for measurement of the wind speed (actually a 3” average, from which the average values and the extremes are derived). This deviation from the WMO standard is a result of instrumental limitations and the fact that wind speeds (including gusts) of >50 m/s are can be virtually excluded in and around the Netherlands on climatological grounds.
The KNMI standard for measuring the wind direction is compliant with the WMO.

2.2 relationship between observational resolution and reporting

The resolution required in the observation of the wind is based on the resolution required in the reporting of synoptic meteorology and in the (local) messages for airports and heliports (refs. 1 and 4). This resolution is consistent with the defined margin of uncertainty in the observations (ref. 1).
SYNOP

- wind direction: 10 degrees (as per WMO)
- average wind speed: 1 m/s (WMO: 0.5 m/s)
- gusts: 1 m/s (WMO: 0.5 m/s)

Comment: the KNMI deviates from the WMO as far as wind speed is concerned. This is due to the limited space in the code (2 positions).

KLIM

- average wind speed: 1 m/s (WMO: 0.5 m/s)
- gusts: 1 m/s (WMO: 0.5 m/s)

Comment: the KNMI deviates from the WMO as far as wind speed is concerned. This is due to the limited space in the code (2 positions).

METAR

- wind direction: 10 degrees (as per WMO/ICAO)
- average wind speed: 1 kt (as per WMO/ICAO)
- gusts: 1 kt (as per WMO/ICAO)

2.3 relationship between required accuracy and the reporting

In accordance with the regulations of the WMO and the ICAO (refs. 1 and 4), reporting in a SNYOP or KLIM or METAR is done to the following accuracy:

- wind direction: ±5 degree (only applies if wind speed ≥ 2m/s);
- average wind speed: ±0.5 m/s where ≤ 5 m/s , ±10% where > 5m/s;
- gusts: ±10%.

2.4 required frequency of observation

3” average wind speed value
The SIAM registers the average value of the wind speed over the last three seconds every quarter of a second A 3” average is the basis for all derivations relating to the wind speed.

12” wind speed value

The running average over the last 3” is determined 48 times by the SIAM every 12 seconds (i.e. every 0.25 sec). The maximum and minimum of these 48 values are determined (the largest and smallest 3” averages respectively). These extreme values are stored in the SIAM’s 12” database.

1’ average wind speed
For generating reports for operational aviation meteorology, the SIAM calculates the 1’ average wind speed. This is the arithmetic mean of the 240 mutually overlapping 3” samples in the 1’ period, including the 3” average as determined at the end of the 1-minute period. The SIAM performs this calculation every 12 seconds and stores the resultant values in the 12” database.

10’ wind speed values
The SIAM calculates the 10’ values for average, maximum and minimum wind speed and the standard deviation for use in various systems, including AWS and RIS.

- the average: This is the arithmetic mean of the 2400 mutually overlapping 3” averages in the 10’ period, including the 3” average as determined at the end of the 10-minute period. NB: if there is a sudden and persistent change during the said 10-minute period, then the average is determined over the period between the change and the observation time.
- the maximum: This is the maximum of the 50 successive 12” maximum values, including the 12” maximum as determined at the end of the 10-minute period concerned.
- the minimum: This is the minimum of the 50 successive 12” minimum values, including the 12” minimum as determined at the end of the 10-minute period concerned.
- the standard deviation: This is calculated from the 2400 mutually overlapping 3” averages in the 10’ period, including the 3” average as determined at the end of the 10-minute period concerned.

The SIAM performs the above 10’ calculations every 12 seconds and stores the resultant values in the 12” database.

The average, maximum, minimum and standard deviation for the 10-minute period running from 5 minutes before up to exactly five minutes after the period are presented in the said systems, after being extracted from the SIAM database for each 10-minute period (i.e. the moments hh:10, hh:20, hh:30, hh:40 and hh:50 for every hour hh).

Hourly wind speed values in SYNOP/KLIM

The hourly values are determined according to the code definitions described in §1.5 and are based on the underlying 10’ values (average or maximum) for the 10’ periods during the hourly period concerned. So for hour {hh+1}, the 10’ values used are those for the moments hh:00, hh:10, hh:20, hh:30, hh:40 and hh:50.

Example: the value of ff (section 1) for 14:00 UTC uses the 10’ average value at the time 13:50:00 and is the arithmetic mean of the 2400 mutually overlapping 3” averages in the period from 13:45:00 through to 13:55:00 (i.e. the 3” values at 13:45:03.25, 13:45:03.50, 13:45:03.75 and so on through to 13:54:59.75 and 13:55:00.0o).

Comment:
KIS only stores FF, FH and FX. The rest is discarded.

12” average wind direction values
The wind direction is determined in the SIAM every 12 seconds.
These values are stored in the SIAM’s 12” database.

1' average wind direction
For generating reports for operational aviation meteorology, the SIAM calculates the 1' average wind direction. This is the vector mean of the five 12" samples in the 1' period just past, including the 12" average as determined at the end of the 1-minute period. (NB: the vector mean is based on the unit vectors – see earlier). The SIAM performs this calculation every 12 seconds and stores the resultant values in the 12" database.

10' wind direction values
The SIAM calculates the 10' values for the average wind direction, the maximum and minimum amount it has veered at any given moment and the standard deviation for use in various systems, including AWS and RIS.

- the average wind direction: This is the vector mean of the fifty 12" averages in the 10' period, including the 12" average as determined at the end of the 10-minute period. (NB: the vector mean is based on the unit vectors – see earlier). NB: if there is a sudden and persistent change during the said 10-minute period, then the mean vector is determined over the period between the change and the observation time.
- the maximum wind veer at any given moment: This is the maximum of the 50 successive 12" average wind direction values, including the 12" value determined at the end of the 10-minute period concerned. The "maximum" refers to the largest amount (≤ 180°) by which it has veered relative to the vector mean in the 10' period concerned ("veering" is a clockwise change).
- the minimum wind backing at any given moment: This is the minimum of the 50 successive 12" average wind direction values, including the 12" value determined at the end of the 10-minute period concerned. The "minimum" refers to the largest amount (≤ 180°) by which it has backed relative to the vector mean in the 10' period concerned ("backing" is an anti-clockwise change).
- the standard deviation: this is calculated as a vector using the 50 successive 12" average wind direction values, including the 12" value determined at the end of the 10-minute period concerned. (NB: vector calculations using the unit vectors, see earlier).

The SIAM performs the above 10'-calculations every 12 seconds and stores the resultant values in the 12" database.

The average, maximum, minimum and standard deviation for the 10-minute period running from 5 minutes before up to exactly five minutes after the period are presented in the said systems, after being extracted from the SIAM database for each 10-minute period (i.e. the moments hh:10, hh:20, hh:30, hh:40 and hh:50 for every hour hh).

Hourly wind direction value in the SYNOP

The hourly values are determined in accordance with the code definitions described in §1.5 and are based on the 10' period concerned.

Example: the value of dd (section 1) for 14:00 UTC uses the 10' average value at the time 13:50:00 and is the vector mean of the 50 non-overlapping 12" averages in the period from 13:45:00 through to 13:55:00. (NB: the vector mean is based on the unit vectors – see earlier)

Comment: KIS only stores DD. The rest is discarded.
half-hourly wind speed (average, maximum) and wind direction values for the METAR
The timestamp for the METAR report is precisely 5 minutes before the whole hour or precisely 5 minutes before the half hour. The wind speed (average, maximum) and wind direction values for the METAR are determined at that point in time, based on the average or maximum for the previous 10-minute period.

Example: ff at 10:25 UTC is the 10-minute average wind speed over the period 10:15:00 to 10:25:00.

2.5 data required to be present for each specific period

An average wind speed or average (vector) wind direction over a given period (12”, 1’, 10’ or 1 hour) is based on the available 3” or 12” values in the period concerned (NB: “available” means data present with no fatal errors). It is not a prerequisite for the determination of an average that the data is 100% available in the time period concerned. The percentage of missing data should be stated. This is given in the SIAM message.

- A 1-hourly wind speed value (average or maximum) is not determined and coded if 1 or more of the 10-minute values required is absent.
- A 3-hourly wind speed value (average or maximum) is not determined and coded if 3 or more of the 10-minute values required are absent.
- A 6-hourly wind speed value (average or maximum) is not determined and coded if 6 or more of the 10-minute values required are absent.

These items are in encoded in the software (AWS, RIS).

3. Instrumentation and technology used

3.1 technology used and specifications

Standard instruments
The KNMI has been using wind speed meters of the cup anemometer type since about 1960 for virtually all its weather stations.
The instrument looks like three hollow half balls on a vertical axis. The wind blows into the hollows of these balls, making the axis rotate.

A sensor is built into the mechanism the reacts to a signal from the rotating spindle every revolution. Registration of the rotation rate, which is near enough proportional to the prevailing wind speed, is done using a pulse counter. The number of pulses per unit time (e.g. per second) is counted and the speed of rotation is derived from this.

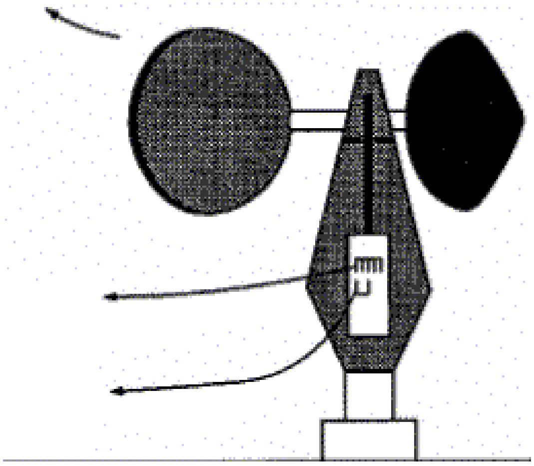


diagram of a cup anemometer

Registration of the wind direction is done using a weather vane. This is actually a fairly inflexible metal sheet mounted on a rotating spindle. The force of the wind moves the vane in the same direction as the wind.

The orientation of the spindle can be registered inside the apparatus. If north has been calibrated at zero (0 degrees) then the angle of the wind direction can be derived from the spindle position.

Detailed information can be found in Meteorological Instruments by J. G. van der Vliet (ref. 5, para. 5).

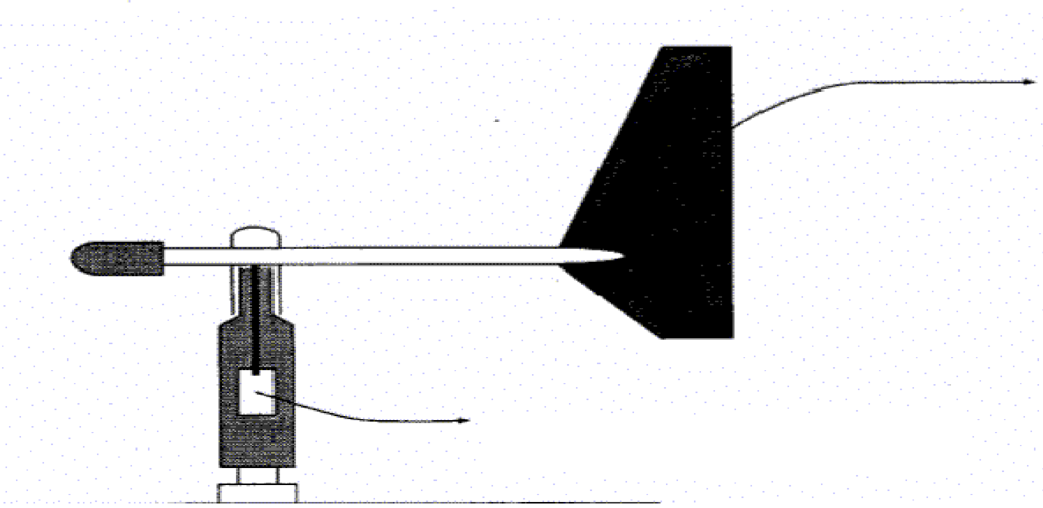


diagram of the weather vane

The technical specifications of the cup anemometer and weather van used are as follows:

Anemometer with SIAM:

Measurement range:	0.5 -50 m/s
Resolution:	0.1 m/s
Accuracy:	±0.5 m/s
Measurement frequency:	1 Hz

Dynamic response of the cup: response length λ =2,9 m

Weather vane with SIAM:

Measurement range:	360 degrees of arc (where wind speed ≥ 2m/s)*
Resolution:	1 degree
Accuracy:	±3 degrees (where wind speed ≥ 2m/s)*
Measurement frequency:	1 Hz

- the lower limit mentioned for wind speed is the minimum speed required to move the weather vane

Backup instrument for wind speed
At manned stations where there is just a single operational stand measuring instrument for the wind speed, there is also a backup instrument available (a hand-held anemometer) for occasions when the former is not operational. It may only be used for local purposes.

3.2 maintenance and calibration procedures

The measuring instruments must meet the accuracy requirements. This means that they require periodic maintenance during which the instruments are checked and adjusted at intervals determined through experience and are calibrated to ensure that they meet the requirements that have been laid down. A calibration certificate is registered, in which the reference measurement values can be entirely reduced to the internationally recognized standard. The KNMI department Insa is responsible for the calibration procedures, which are laid down in Insa's (ISO-9001) quality system, as part of procedure 2.2.3 "control procedure for preventive maintenance".

4. Procedures

4.1 procedures on failure of automatic observations

The SYNOP, KLIM and METAR reports are not filled in when the automatically generated values are absent. At manned stations where backup equipment is present, the observations from these devices may be used as an alterative (exclusively for local use). Deviations from this rule are only possible in exceptional circumstances.

4.2 procedures for subsequent validation

The KNMI's Climatological Information system (KIS) contains archived data about wind speed and direction for the stations on land and at sea. Data input into this system is done daily and uses the hourly values of FX, FH, FF and DD for the previous day (hourly periods h = 01 through 24 UTC*). All values that are entered into KIS are subjected daily to automated checking procedures.
* KIS uses hourly period 24 UTC; this actually refers to 00 UTC in the next daily period

The following procedures are carried out for each station:

<u>FX</u>

- FX must be ≥ FH, otherwise suspect;
- FX must be ≥ FF, otherwise suspect;
- $abs[FX_h - (-1/6\ (FX_{h-2}+FX_{h+2}) + 2/3\ (FX_{h-1}+FX_{h+1}))]$ must be ≤ 8 knots, otherwise FX is suspect;
- FX must be ≤ 80 knots, otherwise suspect;

<u>FH</u>

- FH must be ≤ FX, otherwise suspect;
- $abs[FH_h - (-1/6\ (FH_{h-2}+FH_{h+2}) + 2/3\ (FH_{h-1}+FH_{h+1}))]$ must be ≤ 4 knots, otherwise FH is suspect;
- H must be ≤ 60 knots, otherwise suspect;

<u>DD</u>

- If FF <> 0 then DD must be = 1 or 2..36 (unit: tens of degrees) or 99, otherwise suspect;
- If FF = 0 then DD must be = 0, otherwise suspect;
- If FH_h ≥ 10 knots and FH_{h-1} ≥ 10 knots, then the difference between DD_h and DD_{h-1} must be ≤ 50 degrees, otherwise suspect;
- DD must be = 0 or 1..36 (unit: tens of degrees) or 99, otherwise suspect;

<u>FF</u>

- If DD = 0 then FF must be = 0, otherwise suspect;
- If DD <> 0 then FF must be <> 0, otherwise suspect;
- FF must be ≤ FX, otherwise "suspect";
- If DD = 99, then FF must be < 4 knots, otherwise suspect;
- $abs[FF_h - \{-1/6\ (FF_{h-2}+FF_{h+2}) + 2/3\ (FF_{h-1}+FF_{h+1})\}]$ must be ≤ 4 knots, otherwise suspect;
- FF must be ≤ 80 knots, otherwise "suspect";

The WM/OD division will be informed if suspicious observations are noted. Based on this, steps can be taken such as maintenance (by Insa/MSB).

The KNMI's Climatological Service division (WM/KD) is responsible for the validity of wind speed and direction values finally stored in KIS.
This means that WM/KD in principle assesses every value, assisted by the output of the test procedures described above. A missing value or a value that is evidently incorrect will be replaced by the KD if possible, based on procedures defined by WM/KD.

The alternative value can be based among other things on:

- linear interpolation of adjacent (correct) values in the time series;
- spatial interpolation based on synchronous values from two or more nearby stations;
- estimation of the hourly value based on the time series of 10-minute data that can be retrieved from AWS or RIS.

Replacement is done by hand, during which every case is individually assessed.

4.3 inspection procedures

Every wind measurement site that has an operational function within the KNMI observation network is inspected on average twice annually by an official from WM/OD/station management. Extra interim inspections can also be carried out on request by WA or WM/KD if (validation of) the data gives cause for this.

Inspections should preferably be done:

a) when a measurement mast (in principle a 10-metre mast) with a cup anemometer and weather vane is being placed at a new measuring station, or when the measurement mast at an existing measuring station is being moved;
b) *ad hoc* when a cup anemometer or weather vane is being replaced.

In these situations, the procedural agreement is that WM/OD will be informed in advance using a timing plan of the forthcoming placement or replacement by Insa/MSB. Within one week of the placement or replacement, WM/OD will be informed of this, including receiving proof of calibration, so that an inspection can take place.

The inspection can cover the following checks:

d) Comparison of the instantaneous (12") wind speed value measured by the sensor with the instantaneous wind speed value as read off from a reference hand-held anemometer calibrated according to the KNMI calibration procedures (inspection only on request by WA or WM/KD). Should there be an absolute deviation of ≥ 1 m/s, then this fact will be reported by the inspector (also in writing) to WM/KD and Insa/MSB. After receiving this report, the latter body will determine what corrective actions are required, if any. The subsequent procedure (e.g. replacement and recalibration of the operational anemometer and/or recalibration of the control anemometer) will be done according to ISO-9001.
e) Checking that the calibration period of the measuring instrument has not expired. If this is seen to be the case, then Insa/MSB will be notified so that a replacement can be made.
f) The positioning of the weather vane will be tested on average once every two years. To do this, the weather vane will be fixed in place and the wind direction being recorded is compared with the value read off from a reference theodolite. This check will be performed for three different orientations (in sector of approximately 120 degrees of arc). The three deviations will be averaged out. {where the masts are more fragile, the check will only be performed for a single position due to the much more time-consuming procedure for fixing the weather vane in place} Should there be an absolute deviation of ≥ 5 degrees, then this fact will be reported by the inspector (also in writing) to WM/KD and Insa/MSB. After receiving this report, the latter body will determine what corrective actions are required, if any.
g) A visual assessment of whether the circumstances under which the measurements are made and the surroundings meet the conditions laid down. Should this not be the case, then it will be reported by the inspector (also in writing) to WM/KD and Insa/MSB.

Depending on the situation, OD or Insa/MSB will evaluate what corrective actions need to be taken to bring the various items back into line with the operational requirements. The actions may vary from a request that the manager of the observation site concerned should alter the site conditions, through to starting up a procedure to look for a new observation site.

A report of all inspection visits is drawn up by the station inspector. This report is distributed throughout the KNMI, according to a list of staff members concerned that has been drawn up by HOD.

5. Derivation of parameters

5.1 derivation of potential wind speed from measured wind speed

The potential wind speed is the average wind speed (averaged out over a period ≥ 1 minute) that would prevail at the site of the wind mast if the immediate surroundings were flat, as per the WMO standard. In practice, completely flat surroundings for all points of the compass are rarely achievable. In order to derive a potential wind from the measured average wind speed, the average wind speed is multiplied by a factor known as the "sheltering factor", which varies for each 20 degree sector of the compass.

The sheltering factor (SF) is calculated for all average wind speed data archived in KIS. This comes down to a SF for every 20-degree sector of wind directions per station**. Two SFs are stored per wind direction sector for stations in a more leafy environment (i.e. where the "roughness" of the terrain varies depending on whether there are leaves on the trees), namely one SF for the summer period (1-May through 1-Oct) and one SF for the winter period (1-Oct through 1-May).

** Comment:

The 18 sectors used are 20, 40, 60… 360. The sector 20.n is the group of directions dd = (20.n - 10) ± 5 and dd = (20.n) ± 5.
Example: sector = 60 actually means the range of wind directions between 45 and 65 degrees.

To allow for possible changes in the "roughness" of the surroundings, the shelter factors are recalculated regularly (i.e. once every three years) and whenever the mast is moved.

The calculation of the shelter factor is based on the relationship between the gustiness of the wind and the roughness of the terrain, z_0. The gustiness is represented by the median value of a set of gust factors: <G>.
In any random period of time τ, e .g. 10 minutes or 1 hour, G = {maximum wind speed during τ} / {average wind speed throughout τ}.

The relationship between <G> and z_0 has been formulated by Wieringa as follows:
(ref. 8, pp. 56 ff.)

- f_T = 1.0 for 10-minute data and 1.1 for hourly data;
- $u_x * t$ = wavelength of the gusts: ˜ 50 m, assuming a wind gust u_x of 15 to 20 m/s lasting for a time *t* of approx. 3 sec.;
- z: (measurement) height (m)

Remarks:

a) since G is a function of the average wind speed u, <G> must be determined using u within a limited interval: 8 m/s < u < 12 m/s.
b) Using wind speeds above 15 m/s means that "overspeeding" effects can start to happen. This effect is a consequence of the inertia of the anemometer, which is less able to follow a (sharp) drop in wind speed rapidly than a sudden increase in wind speed.

When using 10' data (with f_T = 1.0) and $u_x * t$ □ 50, the formula becomes:
$\langle G\rangle = 1 + \{ 2.25 / \ln (z/z_0)\}$.
This gives: $z_0 (\langle G\rangle) = z \cdot \exp\{2.25 / (1-\langle G\rangle)\}$

A modified version of the Beljaars / Wieringa gust model has been described by Verkaik (ref. 21):

$$< G >= 1 + \frac{0,88}{\ln \frac{z}{z_0}} * \tilde{u}_p$$

- u_p = 2.41 for 10-minute data and 2.99 for hourly data;
- z: (measurement) height (m).

Comment:
The formula assumes an average wind speed of approximately 6 m/s.
In the case of 10'data, the formula becomes:
$<G> = 1 + \{ 2.12 / \ln (z/z_0) \}$.
This gives: $z_0 (<G>) = z \cdot \exp\{2.12 / (1-<G>)\}$

In the following calculation of the SF, the assumption is made that the vertical wind profile is logarithmic so that the following applies for the reduction of the average wind speed at height z_1 to height z_2:

$ff_{z1} / ff_{z2} = \{ \ln (z_1/z_0) / \ln (z_2/z_0) \}$

The said assumption is correct up to 60 or 100m altitude and where atmospheric conditions are neutral (applicable where ff > 5 m/s). (Wieringa and Rijkoort, ref. 8, para. 3.5)

The above hypothesis is used when the average wind speed at the measurement site is converted to a "fictitious" average wind speed at z_0 = 0.03 m, as is the assumption that the wind speed at 60 m (meso-altitude) is roughly the same throughout a large surrounding area (radius = 4 km). The reduction to 60 m altitude is actually done first and then the "fictitious" situation. So, we obtain:

$SF = ff_{pot} / ff_{met} = \{ \ln (10/z_{0p}) / \ln (60/z_{0p}) \} / \{ \ln (z/z_{0s}) / \ln (60/z_{0s}) \}$

z_{0p} = roughness for flat surroundings;
z_{0s} = actual roughness at the location of the wind mast; this is calculated for every wind direction sector of 20 degrees;
z = sensor height.

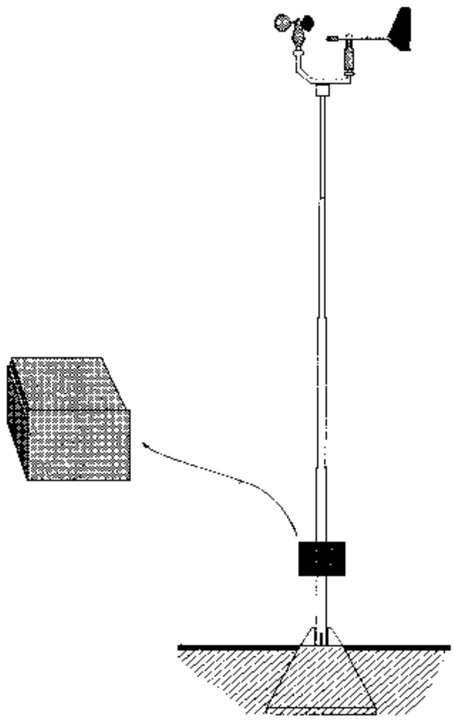
Filling in z_{0p} = 0.o3 m and z = 10 m gives:

$$BF = \frac{1 + (\frac{1,79}{2,3 - \ln z_{0s}})}{1,308}$$

6. Setup requirements and conditions for the surroundings

6.1 Setup requirements and facilities

The sensors for measurement of wind speed and direction are mounted on a stable metal or plastic mast. The sensor height is 10 metres above terrain that should in principle be flat.



wind mast

6.2 conditions relating to the surrounding and the measurement location/representativeness of the observations

a) Conditions relating to the surroundings and the measurement location

The roughness z_0 should be < 0.5 m in all directions. This condition implies a shelter factor SF of < 1.2 (less than 20% reduction of the average wind speed).

The distance from the wind mast to any obstacles in the vicinity must be at least ten times and preferably twenty times the height of the obstacle (applies to all obstacles).

The terrain in the immediate vicinity of the wind mast (radius ≥ 100 metres around the measurement site) is flat grassland or a water surface.

b) Conditions relating to the surrounding and the measurement location and representativeness of the observations

The location of the wind mast is such that an observation of the wind can be performed (including any reduction using a shelter factor) that is representative for an area with a radius of 30 km around the measurement site. (NB: for wind measurements on the coast, the degree of representativeness is obviously partly dependent on the wind direction) This condition is based on statistical studies performed by J. Wieringa: *“For a separation of 30km between two observation points in a homogeneous landscape, the difference in wind speed is less than 5% for 90% of the time.”* The density of the wind measurement network required then follows from the level of representativeness to be achieved.

c) specific conditions relating to the surroundings and the measurement site on an airfield
The wind observation at an airport must be representative for the wind conditions on the (adjacent) runways for take-off or landing, and in particular for the touchdown zone. In order to realize these objectives as well as possible, the following measure are taken:

- A 10-metre metal wind mast is placed 190 metres away from the centre of the runway. Closer than this to the runway is not possible, since a metal mast may not protrude through what is known as the “obstacle surface”. {the obstacle surface is a plane running parallel to the centre of the runway120 metres from it and then rising at a 1 in 7 angle}

- In the case of a so-called “frangible” plastic mast with a sensor at a height of 10 metres, the mast can be placed 115 metres from the centre-line of the runway. Closer than this is not possible, given the wingspan of NLA craft and the disruption of the wind behaviour caused by passing aircraft.

- The measurement height for wind speed and direction should preferably be 10 metres and at least 6 metres, placed above flat ground.

- The wind mast is positioned at least 120 metres from the centre of a runway for taxiing, due to the *ad hoc* effects on wind behaviour due to stationary or moving aircraft.

- The wind mast should be placed at a distance of at least 50 metres and preferably at least 100 metres behind the nearby ILS-GP antenna mast [NB: the ILS mast is an open construction approximately 1 metre in width and 9 metres in height]. When placed behind the ILS mast, disturbance of the wind measurement will only occur for wind directions that are inappropriate for use of the runway. Turbulence effects in the airflow as a result of passing a narrow, porous obstacle such as an ILS mast at a distance of 30 times the width of the obstruction will be virtually damped out anyway, and the wind profile at this distance is once again near enough identical to the profile in front of the obstacle. At a distance of 50 metres from an ILS mast, the wind as measured is in principle no longer perturbed.

- Positioning of the wind mast in front of the ILS mast is only possible if the distance is at least 100 metres, due to the possibility of the wind mast interfering with the ILS signal. Furthermore in this case, maintenance or inspection activities on the wind mast can only be carried out when the runway (and therefore the GP antenna too) is not in use.

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Contents

Chapter 6. Precipitation

6. Precipitation

1. Description

1.1 nomenclature of the variable
General name: precipitation.
This is also the international nomenclature (WMO No. 8, ref. 1).

1.2 definition; description of the concept
Precipitation is defined as the liquid or solid product of condensation or sublimation of water vapour that falls down out of clouds or groups of clouds and reaches the earth's surface. The concept covers rain, drizzle, super cooled rain, snow, hail, ice rain, ice needles, precipitation from mist, dew, etc.
(WMO No. 8, ref. 1)

1.3 units
The recognized SI units (ref. 14) are:

• precipitation amount:	mm (= litre/m^2)
• precipitation duration:	hour
• precipitation intensity:	mm/s (not standard SI: mm/hour)
• occurrence of precipitation:	dimensionless: 1 (yes) / 0 (no)
• snow thickness:	m or cm
• snow coverage:	dimensionless: code (various classes; this is actually height/thickness)
• occurrence of hail:	dimensionless: 1 (yes) / 0 (no)

1.4 variables
The following variables may be distinguished:

- **precipitation amount**

The precipitation amount refers to the volume of water per unit area (1 m^2) that reaches the earth's surface during the observation period (hour, day, etc.) in solid and/or liquid form.

- **precipitation duration**

The precipitation duration refers to the total time (not necessarily a continuous period) during the observation period (hour, day, etc.) during which precipitation is occurring (=water reaches the earth's surface in solid and/or liquid form).

- **precipitation intensity**

The precipitation intensity is the amount of precipitation [i.e. the volume of liquid, expressed in m^3 or litres (=0.001 m^3)] per m^2 per s.
Also: the amount of precipitation (as the thickness of a layer of liquid in m or mm) per second.
Meteorological standard unit: mm/s

- **occurrence of precipitation**

The occurrence of precipitation is given either as "yes" or "no" for each specific period (operational use: 12 seconds), indicating whether precipitation was occurring at any moment during the period concerned. If:
yes: value = 1
no: value = 0

- **snow thickness**

The snow thickness is the vertical thickness of the snow layer at the measurement location at the moment of observation.

- **snow coverage**

Characteristics of the snow present in the immediate vicinity of the measurement site.

- **occurrence of hail**

The occurrence of hail is given either as “yes” or “no” for each 24-hour period (from 08:00 to 08:00 UTC), indicating whether hail (in any form whatsoever) occurred at any moment during the last 24 hours.

1.5 element codes

The coding of precipitation in the SYNOP and KLIM is set out in the KNMI Manual of Meteorological Codes (ref. 15). A good guideline is module A4/B1 (“Observing”) of the Elementary Professional Training in Meteorology (ref. 4).

• reporting precipitation amount in the SYNOP

The relevant group in the synoptic weather report (section 1) is: 6RRR t_r

The amount of precipitation is stated at the main hours only: 00, 06, 12, 18 UTC.
Indicators: i_r , t_r , RRR:

i_r : code = 1: there was precipitation: amount is stated in code RRR
code = 3: there was no precipitation (precipitation = 0)
code = 4: precipitation not being reported

t_r : code = 1: precipitation during the last 6 hours, reported at 00 and 12 UTC
code = 2: precipitation during the last 12 hours, reported at 06 and 18 UTC

RRR : code = 000 - 989: precipitation amount in whole mm
(example: RRR =037: precipitation amount ≥ 37 and < 38 mm)
code = 990 - 999 : precipitation amount in tenths of a mm
(example: RRR = 992: precipitation amount ≥ 0.2 and < 0.3 mm,
NB: RRR = 990: precipitation amount > 0.0 and < 0.1 mm)

• reporting precipitation amount and duration in the KLIM

The amount and duration of precipitation is stated hourly:
Indicators: i_{rh} , D_r , $R_hR_hR_h$:

i_{rh} : code = 1: there was precipitation: details in D_r and $R_hR_hR_h$
code = 0: there was no precipitation (precipitation = 0)

D_r : code = 0 - 9: precipitation duration in tenths of an hour
(example: D_r = 3: precipitation duration ≥ 0.3 hours and < 0.4 hours,
NB: D_r = 0: precipitation duration > 0.0 hours and < 0.1 hours)
code = - (dash): precipitation duration: the entire hour

$R_hR_hR_h$: code = 000 - 999: precipitation amount in tenths of a mm
(example: RRR = 134: precipitation amount ≥ 13.4 and < 13.5 mm,

NB: RRR = 000: precipitation amount > 0.0 and < 0.1 mm)
code = 00- : a few drops

• coding of precipitation amount, precipitation duration and snow cover in KIS

When precipitation data is stored in the Climatological Information System (KIS), the following codes are used:

- RH: precipitation amount (same as $R_hR_hR_h$)
- R6: precipitation amount that has fallen in the last 6-hour period
- DR: precipitation duration in the last hour (same as D_r)
- RD: precipitation amount over the last 24 hours, measured at 08 UTC

The *ad hoc* 6-hourly data on the thickness of lying snow is also stored in KIS (measurement points: 00, 06, 12 and 18 UTC) under the code SS.

code number	mm	code number	mm	code number	mm
00	0	34	340	68	1800

01	10	35	350	69	1900
02	20	36	360	70	2000
03	30	37	370	71	2100
04	40	38	380	72	2200
05	50	39	390	73	2300
06	60	40	400	74	2400
07	70	41	410	75	2500
08	80	42	420	76	2600
09	90	43	430	77	2700
10	100	44	440	78	2800
11	110	45	450	79	2900
12	120	46	460	80	3000
13	130	47	470	81	3100
14	140	48	480	82	3200
15	150	49	490	83	3300
16	160	50	500	84	3400
17	170	51	510	85	3500
18	180	52	520	86	3600
19	190	53	530	87	3700
20	200	54	540	88	3800
21	210	55	550	89	3900
22	220	56	560	90	4000
23	230	57	570	91	1
24	240	58	580	92	2
25	250	59	900	93	3
26	260	60	1000	94	4
27	270	61	1100	95	5
28	280	62	1200	96	6
29	290	63	1300	97	<1 mm
30	300	64	1400	98	>4000 mm
31	310	65	1500	99	Measurement impossible or inaccurate
32	320	66	1600		
33	330	67	1700		

The *ad hoc* 24-hourly data on the snow cover is also stored in KIS (measurement point: 08 UTC) under the code S: code digits 0 through 9.

Specific precipitation phenomena such as drizzle, showers, snow, hail, black ice, etc. are coded separately and are given in chapter 14 (present weather, past weather, ground conditions).

2. Operational requirements

2.1 range

The requirements for the operational range of the measurements are:

- total amount of liquid water: 0 to >400 mm
- snow thickness: 0 to 10 m

(as per WMO, ref. 1).

2.2 relationship between observational resolution and reporting

The resolution required in the automated observation of precipitation is based on the resolution required in the reporting for synoptic meteorology (refs. 1 and 4). This resolution is consistent with the defined margin of uncertainty in the observations (ref. 1).

- amount of liquid water: 0.1 mm
  (as per WMO, ref. 1)
- snow depth: 0.01 m
  (as per WMO, ref. 1)
- precipitation duration: 0.1 hour

2.3 required accuracy

International regulations concerning the use of words and concepts such as accuracy, uncertainty and hysteresis are set down in the "International Vocabulary of Basic and General Terms in Metrology" (publ. ISO; see ref. 19).

- The uncertainty (margin of error) in the amount of liquid water as measured should not be greater than:
  0.1 mm where the registered amount is ≤ 5 mm;
  2% where the registered amount is > 5 mm
  (as per WMO, ref. 1).

- The required operational accuracy for the precipitation amount in the KLIM report is:
  ±0.05 mm where the registered amount is ≤ 5 mm
  (example: value 3.4 is registered: precipitation amount > 3.35 and ≤ 3.45 mm);
  ±1% where the registered amount is > 5 mm
  (example: value 41.3 is registered: precipitation amount > 40.9 and ≤ 41.7 mm);

- The required operational accuracy for the precipitation amount in the SYNOP report is:
  ±0.05 mm where the registered amount is ≤ 1 mm
  (example: value 0.4 is registered: precipitation amount > 0.35 and ≤ 0.45 mm);
  ±0.5 mm where the registered amount is > 1 mm and ≤ 50 mm
  (example: value 34 is registered: precipitation amount > 33.5 and ≤ 34.5 mm);
  ±1% where the registered amount is > 50 mm
  (example: value 81 is registered: precipitation amount > 80.2 and ≤ 81.8 mm);

- The required operational accuracy for the precipitation duration in the KLIM report is:
  ±0.05 hours (=3 minutes)

(example: value 3.4 is registered: precipitation duration > 3.35 hours and ≤ 3.45 hours)

- The required accuracy when reading off a conventional manual rain gauge is:
  ±0.1 mm
  (example: value 3.4 is read: precipitation amount > 3.3 and ≤ 3.5 mm);

- The uncertainty (margin of error) in the measured snow thickness should not be greater than:
  0.01 m where the registered amount is ≤ 0.2 m
  5% where the registered amount is > 0.2 m
  (as per WMO, ref. 1)

2.4 required observation frequency and times

Electronic rain gauge
The average value of the precipitation intensity over the last 12 seconds is registered every 12”. Where the precipitation intensity is registered in units of mm/s, this value is actually just the amount of precipitation during this period divided by 12 seconds. Since the precipitation intensity values are stored in the SIAM in units of 0.001 mm/hour, the figure given for the amount measured in the 12” period (in mm) is multiplied by 0.3 (since 1 mm/12 sec = 0.3 m/hour).

The SIAM also registers and records the following every 12”:
- the average precipitation intensity over the last 1 minute: this is the arithmetic mean of the precipitation intensity values of the last five 12” samples;
- the maximum precipitation intensity over the last 1 minute: this is the highest precipitation intensity value from the last five 12” samples;
- the minimum precipitation intensity over the last 1 minute: this is the lowest precipitation intensity value from the last five 12” samples;
- the average precipitation intensity over the last 10 minutes: this is the arithmetic mean of the precipitation intensity values of the last fifty 12” samples;
- the standard deviation of precipitation intensity over the last 10 minutes: this is the standard deviation in the series of precipitation intensity values over the last fifty 12” samples.

Unit of storage for all variables: 0.001 mm/h.

Multiplication of the average precipitation intensity during the last ten minutes gives the amount of precipitation during that ten-minute period. Summation of six successive 1o-minute values for the precipitation amount gives an hourly value for the precipitation amount. Summation of 36 successive 1o-minute values for the precipitation amount gives an six-hourly value for the precipitation amount, and so forth.

In the 1o-minute data storage systems (cf. AWS), the 10-minute values for the precipitation amount are stored after being extracted in the above manner from the SIAM database for each ten-minute period (i.e. at times hh:00, hh:10, hh:20, hh:30, hh:40 and hh:50 for each hour hh).

The hourly precipitation amount for the KLIM or the 6-hourly or 12-hourly precipitation amounts for the SYNOP at a particular hour (observation time 18 UTC for example) are determined at exactly 10 minutes before that hour (in the example, 17:50) and is the amount of precipitation that was measured at the location concerned over the hourly period (or six or twelve hours) preceding the moment of measurement (in the example: KLIM – period 16:50 to 17:50, SYNOP – period 05:50 to 17:50).

Precipitation detector
The precipitation detector determines every second whether or not there has been any precipitation during the last second. Answer: “yes” or “no”. The SIAM registers every 12” how many 1-second periods there have been with any precipitation during the last 12 seconds. This value is recorded as the number of seconds’ precipitation during the last 12 seconds.

The SIAM also registers and records the following every 12”:

- the number of seconds’ precipitation during the last 1 minute: this is a summation of the precipitation duration values (in seconds) from the last five 12” samples;
- the number of seconds’ precipitation during the last 10 minutes: this is a summation of the precipitation duration values (in seconds) from the last fifty 12” samples.

Unit: s.

In the 1o-minute data storage systems (cf. AWS), the 10-minute values for the precipitation duration (=number of seconds’ precipitation in the last ten minutes) are stored after being extracted in the above manner from the SIAM database for each ten-minute period (i.e. at times hh:00, hh:10, hh:20, hh:30, hh:40 and hh:50 for each hour hh).

Summation of six successive 1o-minute values for the precipitation duration gives an hourly value for the precipitation duration.

The hourly precipitation duration for the KLIM at a particular hour (observation time 18 UTC for example) is determined at exactly 10 minutes before that hour (in the example, 17:50) and is the precipitation duration that was measured at the location concerned over the hourly period preceding the moment of measurement (in the example: period 16:50 to 17:50).

Snow thickness
If applicable, the current thickness of the snow layer will be determined manually every six hours. The observation times are 00, 06, 12 and 18 UTC. The measurement times are exactly 10 minutes before the hours concerned.

Conventional manual rain gauge
At the specific precipitation stations (approx. 325 of them), the precipitation amount over the previous 24 hours is determined once a day. This determination is performed by manually releasing and measuring the precipitation trapped in the instrument at 5 minutes to 8 UTC.

At these precipitation stations, if applicable, the situation as regards the snow cover at that moment is determined once daily (at 8 UTC). The observation is reported using a code digit.

The observers at these precipitation stations can also, if applicable, optionally indicate once a day (at 8 UTC) whether or not any hail has fallen at any moment during the preceding 24 hours.

2.5 data required to be present for each specific period

Determination of the acceptable length of time that precipitation observations are unavailable is *ad hoc*, based on the operational and prognostic relevance and the relationship with other observations (SYNOP network, radar images and so forth) that are available.

In the SYNOP/KLIM:

- A 1-hourly precipitation value (amount and duration) is not determined and coded if 1 or more of the 10-minute values required are absent;
- A 6-hourly precipitation value (amount and duration) is not determined and coded if 1 or more of the hourly values required are absent;
- A 12-hourly precipitation value (amount and duration) is not determined and coded if 1 or more of the hourly values required are absent;

3. Instrumentation and technology used

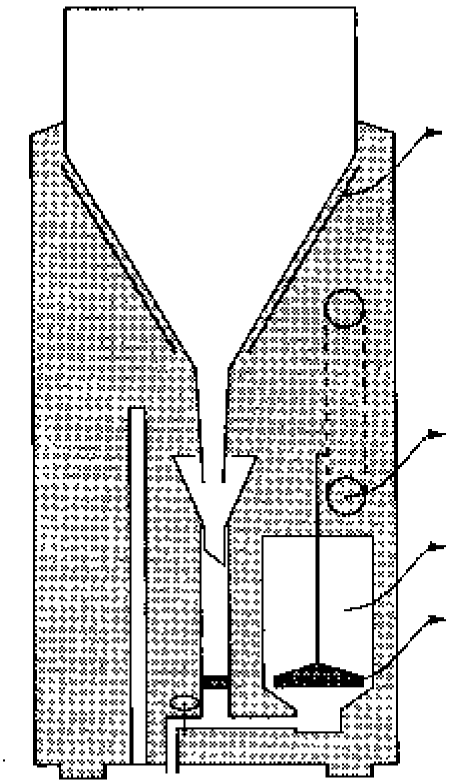
3.1 technology used and specifications

The KNMI uses the following as the standard instruments for measuring precipitation:

- the electronic rain gauge at approx. 30 stations in the Netherlands;
- the electronic precipitation detector at approx. 30 stations in the Netherlands;
- the conventional manual rain gauge at approx. 325 sites in the Netherlands.

Electronic rain gauge

The amount of precipitation that has fallen is determined in the electronic rain gauge by measuring the position of a float that has been placed in the measuring cell where the precipitation is collected. The float is linked to a potentiometer. Solid precipitation (hail, snow) is melted by heating the funnel and then measured as liquid precipitation.



- heating

The measurement frequency is 1/12 Hz. That is, the cell is emptied every 12 seconds and the actual flow of liquid out of it is measured. During this process, allowance is made among other things for precipitation that falls during the emptying process but which has not yet been measured. Allowance is also made for hysteresis effects when the float rises again after the cell is emptied.

- potentiometer

- measuring container

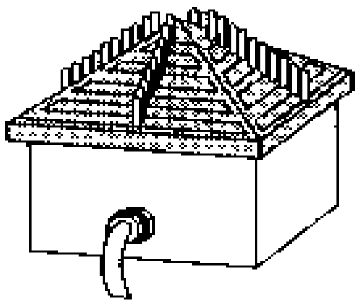
- floater

The precipitation intensity is determined from the difference in the float positions between the moments that the averaging period starts and ends. This ensures that noise is eliminated.

electronic precipitation sensor

The technical specifications of the precipitation meter used with the SIAM are as follows:

Measurement range:	0 to 0.7 mm per 12 seconds
Resolution:	0.1 mm
Accuracy:	±0.2 mm
Measurement frequency:	1/12 Hz.



The precipitation duration is determined using a precipitation detector. This instrument gives the current situation: is precipitation falling or not? The device is fitted with a heating element that has to ensure that the electrodes are dry again within 1 second after the precipitation has run off. Any more new precipitation can then be detected.

Electronic precipitation detector

The technical specifications of the precipitation detector used with the SIAM are as follows:

Activation threshold:	0.02 mm/h
Measurement frequency:	1/12 Hz.

Conventional manual rain gauge

The conventional manual rain gauge consists of two parts: a funnel with a horizontal entry surface of 2 dm^2, a narrow passage through to the bottom and a collection reservoir. The narrow opening is required in order to prevent the water that has been collected from disappearing due to evaporation.
Measurement of the amount of precipitation in the collection reservoir is done manually, using a plastic measuring cylinder. The resolution of the scale on the measuring cylinder is 0.1 mm.

The representativeness of the measurement can be (seriously) affected by a large number of source of potential errors, such as droplets or snowflakes being blown by the wind, evaporation (particularly of the first drops), losses on pouring it into the measuring beaker, and so on. The actual observational accuracy of the conventional manual rain gauge is therefore more than 0.1 mm in practice. By carefully choosing the environment, the magnitude of the error can be limited (see also para. 6).

Other methods

The KNMI uses radar systems operationally to measure precipitation. However, this methodology falls more in the field of remote sensing and such techniques are as yet beyond the scope of this manual. Furthermore, radar detection always involves observation of precipitation at altitude. This precipitation does not necessarily have to reach the ground.

Snow cover and thickness

The six-hourly observation of the snow thickness for use in the SYNOP is done using a ruler with a millimetre scale. This is pushed into the snow layer.
The snow cover observation at the 325 stations specifically for precipitation observations (once every 24 hours at 08 UTC) is done partly using a ruler and partly by visual

interpretation of the current snow cover situation (complete or broken) in the area around the observation station. The observation is recorded using a code (code digits 0 through 9). (ref. 7)

3.2 maintenance and calibration procedures

The sensors for the precipitation measurement and detection must meet the accuracy requirements. This means that they require maintenance, during which the instruments are checked and adjusted at intervals determined through experience and are calibrated to ensure that they meet the requirements that have been laid down. A calibration certificate is registered, in which the reference measurement values can be entirely reduced to the internationally recognized standard. The KNMI department Insa is responsible for the calibration procedures, which are laid down in Insa's (ISO-9001) quality system, as part of procedure 2.2.3 "control procedure for preventive maintenance" (ref. 10).

4. Procedures

4.1 procedures on failure of automatic observations

The SYNOP and KLIM reports are not filled in when the automatically generated values are absent. Estimation of the precipitation conditions in the region concerned is done using the observations from neighbouring synoptic stations and radar imagery.

4.2 procedures for subsequent validation

The KNMI's Climatological Information system (KIS) contains archived precipitation data for the stations on land and at sea. Data input of the precipitation values RH, R6, DR and RD (plus the snow cover data SS and S as appropriate) into KIS is done daily, using the hourly, six-hourly and 24-hourly values from the previous day (hourly periods h = 00 to 23 UTC).

28 Automated checking procedures

The new RH, R6, DR and SS values that have just been entered are subjected to automated checking procedures. The following procedures are carried out for each station:

RH

a. if WW = 20 or 21 .. 27 or 50 .. 97 or 99, then RH must be <> o, otherwise suspect,
b. if WW < 20 and WW <> 17, then RH must be = 0, otherwise suspect,
c. if W2 = 0 and W3 =0 and W4 = 0, then RH must be = 0, otherwise suspect,
d. if W2 = 1 or W3 = 1 or W4 = 1, then RH must be <> 0, otherwise suspect,
e. RH must be ≤ 90, otherwise suspect,
f. RH must be ≥ 0, otherwise suspect.

R6

a. if any one of the elements W2, W3 or W4 = 1 in any hour h, h-1, h-2 .. h-5, then R6 for hour h must be <>0, otherwise suspect,
b. if the elements W2, W3 and W4 = 0 in all the hours h, h-1, h-2 .. h-5, then R6 for hour h must be = 0, otherwise suspect,
c. R6 must be ≤ 160, otherwise suspect.

Comment: the checks for R6 are only applicable to stations that do not generate RH hourly values.

DR

a. if RH = 0 then DR must be = 0, otherwise suspect,
b. if RH > 2 then DR must be > 0, otherwise suspect,
c. DR must be ≤ 10, otherwise suspect,
d. DR must be ≥ 0, otherwise suspect,
e. if DR <> 0 then WW must be = 20 or 21 .. 27 or 50 .. 97 or 99, otherwise suspect,
f. if W2 = 0 and W3 = 0 and W4 = 0, then DR must be = 0, otherwise suspect,
g. if DR <>0 then W2 or W3 or W4 must be = 1, otherwise suspect,
h. if DR <> 0 then RH must be ≥ 1, otherwise suspect.

SS

a. if E ≤ 4 then SS must be = 0, otherwise suspect,

b. if E > 4 then SS must be > 0, otherwise suspect,
c. SS must be = 0 or 1 .. 50 or 97 .. 99, otherwise suspect,
d. if W3 for hour h through to hour h-5 are all = 0, then $SS_h <= SS_{h-6}$ (except where SS = 97 or 98 or 99), otherwise suspect.

The meaning of the codes WW, Wi (i = 2, 3, 4) and E is described in ref. 4 and will be introduced at the appropriate time in chapter 14 of the Manual.

Validation

The KNMI's Climatological Service division (WM/KD) is responsible for the validity of precipitation and snow cover data finally stored in KIS. This applies both to the values that are automatically checked for validity according to the above procedures, and to the 24-hourly values RD and S.

This means that WM/KD in principle assesses every value daily (on working days only), assisted by the output of the test procedures described above. A missing value or a value that is evidently incorrect will be replaced by the KD if possible, based on procedures defined by WM/KD (described in an internal document, the KD Procedures Manual).

The alternative value can be based among other things on:

- linear interpolation of adjacent (correct) values in the time series;
- spatial interpolation based on synchronous values from two or more nearby stations;
- estimation of the hourly value based on the time series of 10-minute data that can be retrieved from AWS.

Replacement is done by hand, during which every case is individually assessed.
The precipitation measurement values from a (automatic) meteorological station are missing or are suspect, then the 24-hourly values from neighbouring precipitation stations (08 – 08 UTC measurement) and the radar images are used to provide an (estimated) distribution of the 24-hourly total over the individual hours. (ref. 9)

The KNMI's Operational Data division (WM/OD) will be informed if missing or suspect observations are noted. Based on this, steps can be taken such as maintenance (by the Insa/MSB division).

4.3 inspection procedures

Electronic precipitation measurement (approx. 30 stations)
Every site within the KNMI observation network where electronic precipitation measurements are made (amount, detection) is inspected on average once annually by an official from WM/OD/station management.

Extra interim inspections can also be carried out on request by WA or WM/KD if (validation of) the data gives cause for this. Inspections should preferably be done:

a) when a new observing station is being established (including precipitation measurement and detection) or when the (precipitation) measurement location for an existing observing station is being moved;
b) *ad hoc* when the instruments for precipitation measurement and detection are being replaced.

In these situations, the procedural agreement is that WM/OD will be informed in advance using a timing plan of the forthcoming placement or replacement by Insa/MSB. Within one week of the placement or replacement, WM/OD will be informed of this, including receiving proof of calibration, so that an inspection can take place.

The inspection can cover the following checks:

h) Checking that the calibration period of the measuring instrument has not expired. If this is seen to be the case, then Insa/MSB will be notified so that a replacement can be made.

i) A visual assessment of whether the circumstances under which the measurements are made and the surroundings meet the conditions laid down. Should this not be the case, then it will be reported by the inspector (also in writing) to WM/KD and Insa/MSB. Depending on the situation, OD or Insa/MSB will evaluate what corrective actions need to be taken to bring the various items back into line with the operational requirements. The actions may vary from a request that the manager of the observation site concerned should alter the site conditions, through to starting up a procedure to look for a new observation site.

A report of all inspection visits is drawn up by the station inspector. This report is distributed throughout the KNMI, according to a list of staff members concerned that has been drawn up by HOD.

Manual precipitation measurement (approx. 325 stations)

Every site within the KNMI observation network where manual precipitation measurements are made is inspected on average once every two years by an official from WM/OD/station management.
Extra interim inspections can also be carried out on request from WM/KD if (validation of) the data gives cause for this.
Inspection also takes place when a new observing station is being established or when the measurement location for an existing observing station is being moved.

The inspection can cover the following checks:

- checking the condition of the instrument and cleaning as required;
- checking that the surroundings (still) meet the conditions laid down; relocation if needed, in discussion with the observer;
- checking everything is correctly set up (properly levelled etc.); correction if needed;
- contact with the observer: keeping each other up to date;
- dealing with various items in the dossier of the station concerned.

5. Derived data

5.1 Precipitation amount or sum for specific periods

In the case of a period of a single second, the sum precipitation over the period is numerically the same as the precipitation intensity during the one-second period (unit: mm).

In the case of a period of more than one second, say n seconds (where $n > 1$), the amount of precipitation over the period is the integrated precipitation sum over the n seconds involved (unit: mm).

5.2 Precipitation duration for specific periods

In the case of any random period, say n seconds, the total precipitation duration within this period is the sum total of seconds within this period during which precipitation occurred.

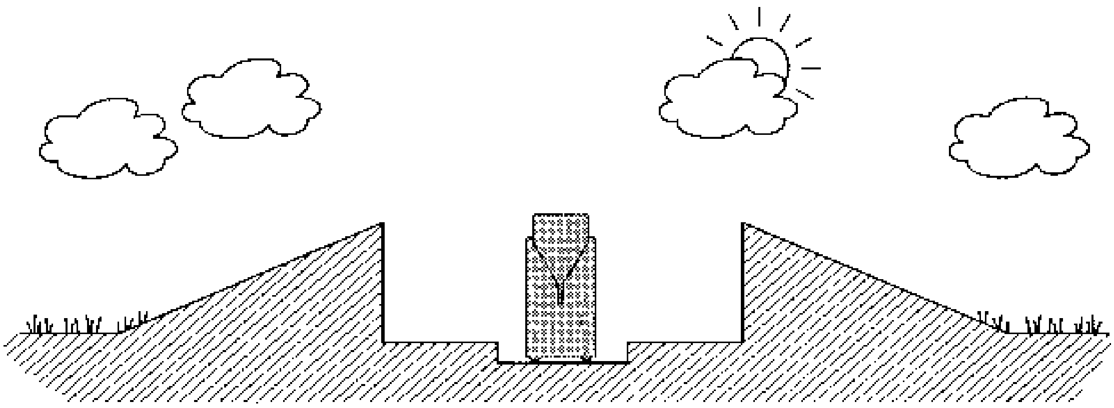
6. Setup requirements and conditions for the surroundings

6.1 Setup requirements and facilities

The positioning of the precipitation meter and the precipitation detector must be done in such a way that precipitation from all directions can fall unrestricted on the collection aperture or the sensor surface. The immediate vicinity of the instruments must be horizontal and can be covered with grass, short ground-covering plants, soil or gravel. Hard, flat surfaces are undesirable due to the risk of water spattering up from the ground and falling into/onto the instrument. A certain amount of protection at a small distance is desirable, to prevent rain or snow from being blown in by the wind.

The upper rim of the precipitation meter must be horizontal. The standard height of the rim is 40 cm above ground level. (ref. 3)

The standard arrangement for the electronic rain gauge is the “English” setup. The rain sensor is surrounded by a wall of earth with a diameter of 3 metres and a height of 40 cm (i.e. this is the height of the upper edge). On the other side of the wall there is a slope to ground level. This arrangement minimizes the effect of blowing and drifting in the wind. This is the arrangement recommended by Braak (1945), particularly for unprotected places (ref. 8).



protected installation

6.2 Conditions relating to the measurement location and the surroundings; representativeness of the observations

The distance from the precipitation measurement location to nearby obstacles (trees, hedgerows, walls, houses, etc.) should be at least two times and preferably four times the height of the obstacle above the plane of the top edge of the precipitation meter.
Example: the height of an obstacle such as a 3-metre hedge is 3.0 - 0.4 = 2.6 m. The distance from the measurement site to this hedge should be at least (2 x 2.6 =) 5.2 m and preferably (4 x 2.6 =) 10.4 m.
(as per WMO, ref. 1).

When a (new) station is being established, this condition often turns out to be unrealistic for the conventional manual rain gauge. For practical reasons, the KNMI has adopted the condition for these stations that the distance from the precipitation measurement location to nearby obstacles (trees, hedgerows, walls, houses, etc.) should be at least equal to the height of the obstacle above the plane of the top edge of the precipitation meter. The station management inspector who is responsible for the positioning of the station should of course always attempt to choose the location in such a way that the influence of any obstacles there may be is negligible.

The chosen arrangement and the measures taken relating to the surroundings will limit systematic errors in the measurement of precipitation as a result of evaporation or drifting/blowing (of droplets or of snow). This is one reason why no corrections are made. The development of a correction algorithm using *inter alia* input information relating to current meteorological parameters such as wind, radiation and temperature is optional (these various items being based on WMO studies, ref. 6).

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Appendix:

1. Protocol for Measurement Infrastructure Changes

1.1 Problem

Long-term meteorological data (both satellite and conventional) is increasingly being used for detecting and determining the causes of climate change and for measuring low-frequency climate variability. In the past, inhomogeneities[2] have been introduced into the sequences, which now mean that the usefulness of those series for that sort of climate research is limited. If no action is taken, new inhomogeneities will also arise in the climate sequences in the future. An attempt is therefore being made within GCOS (Global Climate Observing System) to set up a proportion of the existing observation systems in such a way that good quality climate series are guaranteed (e.g. GCOS Surface Network, GSN). The KNMI can go along with this by drawing up a "Protocol for Measurement Infrastructure Changes".

Although the KNMI does its best to prevent inhomogeneities, performing parallel measurements where necessary, the observations (even from the main stations) do not always appear to be suitable for climate research. One of the reasons for this is that there are no adequate guidelines about how to deal with planned changes in the measurement infrastructure. The WMO goes no further in the *Guide to Climatological Practices* than the following recommendation: "When a major relocation of a station is necessary, or when one stations is to replaced by another one nearby, it is desirable to operate both observing stations for a period of one year to find out what the effect the move has on the observational data" (WMO No. 100, 1983). A recommendation such as this is also insufficient to guarantee series of measurements that are homogeneous over the required time frame. A second reason is financial in nature. Parallel measurements, for example, mean that the costs of a change in the measurement infrastructure are significantly increased. The priority of such an action is therefore low.

1.2 Proposal

It is proposed that a protocol should be developed by HISKLIM. This "Protocol for Measurement Infrastructure Changes" will be drawn up for a number of as yet undetermined KNMI observation stations (measurements)[3] that are important in detecting and determining the causes of climate change. International recommendations for climate monitoring[4] (see Karl *et al*, 1995 and NRC, 1999) will be made concrete in the protocol. The protocol can be part of the Observations Manual, but should then have a status that is more than just that of a recommendation. The protocol will be presented to both the cgNAWA and the HISKLIM programme council for evaluation. Upon approval, the protocol will be presented to the MT by HISKLIM. Financial resources will have to be reserved for the implementation of the protocol.

The estimated capacity needed for this activity is approx. one man-month.

Karl *et al*, 1995: Critical issues for long-term climate monitoring, *Climatic Change* **31**: 185–221.
NRC (National Research Council), 1999: *Adequacy of Climate Observing Systems*, National Academy Press, 51 pp.

[2] Inhomogeneities in climate sequences are caused by repositioning of the station or of the instrument (both horizontally and vertically), changes in the instrumentation or measurement method or the surroundings, etc.
[3] For example: measurements of temperature, air humidity, precipitation, etc. at the five main stations, radio-sonde measurements, radar measurements, ozone measurements.
[4] Examples of this are: management of changes in the measurement network, performing parallel measurements, determining the correct metadata and making it accessible, monitoring the homogeneity of the series.

Appendix:

Dutch Terms and Abbreviations

	Dutch term		English translation or near equivalent	
	AWS	automatische weerstation	AWS	automatic weather station
	CCM	Coördinatiecommissie Meteorologie		Meteorological Coordination Commission
KNMI div.	Insa	Instrumentele Afdeling		Instrumentation Division
KNMI div.	KD	Klimatologische Dienst		Climatological Services
	KLu	Koninklijke Luchtmacht	RNLAF	Royal Netherlands Air Force
	KM	Koninklijke Marine	RNLN	Royal Netherlands Navy
	KNMI	Koninklijk Nederlands Meteorologisch Instituut		Royal Netherlands Meteorological Institute
KNMI dept.	MI	Meestsystemen en Infrastructuur		Measurement and Information Systems
KNMI div.	MSB	Meetsystemenbeheer		Measurement Systems Management
	NKO			Dutch Calibration Organization
KNMI div.	OD	Operationele Data		Operational Data
	RvA			Accreditation Council
	RWS	Rijkswaterstaat		Department of Public Works
KNMI h/w	SIAM	sensor intelligent aanpassingsmodule		intelligent adaptive sensor module
	VenW	Verkeer en Waterstaat		(Ministry of) Transport, Public Works and Water Management.
KNMI dept.	WA	Weersverwachtingen en Adviezen		Forecasting Services
KNMI dept.	WM	Waarnemingen en Modellen		Observations and Models

Names of KNMI departments/divisions/hardware are the translations they use internally