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Standardization in instrumentation and observations

Recommendation for standard observing methods for automatic measurements of clouds, present weather and other subjective observations

(Submitted by Mrs H. Bloemink)

Summary and purpose of document

This document presents the methods used for automatic measurement of present/past weather and state of ground, as well as for automatic observations of clouds. It should serve as a base for a discussion on the recommendation of new standards.

ACTION PROPOSED

The meeting is invited to consider the methods presented and agree on recommendations for new standards that should be further developed for inclusion in the CIMO Guide and presented for approval at CIMO-XV.

Methods in use: automatic measurement of present/past weather; state of ground

Present (and past) weather is a description of the state of the atmosphere, relevant to weather for- and nowcasting. In the past, present weather was reported by trained observers, but these days, automatic measurements are used more and more. In order to determine present weather, often a combination of observations from different sources is used. The various observations are combined (using a variety of algorithms) to report phenomena such as light drizzle, thunderstorm, fog etc.

The observables used for determining present and past weather are:

- Precipitation type
- Precipitation intensity
- Lightning
- Visibility (to indicate fog/mist/haze)
- Cloud amount
- Wind speed (to indicate squalls)
- State of ground

For each of these observables, methods of observation are listed below.

1 Precipitation type

Automatic measurement methods for precipitation type detection are listed below. Each method is shortly reviewed and analyzed. The results of a large intercomparison of present weather instruments with respect to precipitation type can be found in WMO, 1998.

- Forward scatter/back scatter Present Weather sensor
- Optical disdrometer
- Doppler Radar
- Acoustic detector (hail)
- Camera’s (+observer)
- Other

1.1 Forward scatter/back scatter Present Weather sensor

Description

A variety of scatter sensors are used to report present weather, in particular precipitation type. In general, scatter of a light source by the precipitation particles is observed under a fixed angle. This gives information on the size of the particles. Additional measurements (*e.g.* water content of the particles, fall speed, temperature) help determine the nature of the particles. For example, large particles with small water content will be classified as snow. Some sensors can report unknown precipitation, in case the intensity to too low to allow for a proper determination.

Apart from precipitation type, these sensors may (depending on the sensor type) also provide precipitation intensity, precipitation duration (and can thus indicate intermittent precipitation), and visibility.

Analysis

These sensors are widely in use and generally give acceptable results for common precipitation types (rain, snow), with 70-90 % detection rates (WMO, 1998), depending on the exact test set up and the specific instrument. Other precipitation types are not so well observed, particularly mixed precipitation (rain + snow). Hail is not observed. Thresholds for light precipitation may vary.

1.2 Optical disdrometer

Description

Optical disdrometers are also used to determine precipitation type. These instruments use the extinction of a horizontal (infrared) light sheet to detect hydrometeors. When a particle falls through the light sheet, the receiver intensity is reduced. The amplitude of this reduction correlates with the particle size, and the duration correlates with the particle fall speed. Combining these two quantities results in the particle type.

Analysis

These sensors also generally give acceptable results for common precipitation types. Detection rates compared to human observers are similar to scatter sensors are found (Bloemink, 2005). Again, mixed precipitation types and hail are difficult to detect. This sensor type is relatively new in the market.

1.3 Doppler radar

Description

Doppler radar can be used to determine precipitation type. The emitted beam from the radar is backscattered by the falling hydrometeors. From the Doppler shift of the backscattered signal, the particle fall speeds can be determined. Near the ground, these are terminal fall velocities and correspond with the particle sizes. Some instruments have a measure volume above the sensor, others determine the fall speeds at different altitudes above the sensor to determine precipitation type. Additional measurements (*e.g.* surface temperature) are also used.

Analysis

Different types of Doppler radar are available for detection of precipitation type. They tend to be insensitive to small particles, like all radar-based detection techniques. Some types show similar results compared with forward scatter/back scatter sensors and disdrometers, *i.e.* decent results for rain and for snow, but not for mixtures. Hail is not observed.

1.4 Impact detector

Description

This type of sensor consists of a piezoelectric material which is capable of detecting the impact of the individual hydrometeors. The difference between the impact of hail and rain differs sufficiently to distinguish these two precipitation types. Other precipitation types are not reported. The sensor also measures other meteorological parameters.

Analysis

Since only rain and hail can be reported, this sensor is not a fully operational present weather sensor. The hail detection part may, however, be useful to some users, since this is generally a weak point of other PW sensors.

1.5 Acoustic detector

Description

The acoustic detector detects the sound of the falling hydrometeors. This is related to the precipitation type. The sensor was developed to supplement a forward/backscatter PW sensor, in particular to improve the detection of hail and ice pallets.

Analysis

Initial results of the sensor were promising (Wade, 2003). However, the NWS did not adopt it for its ASOS system. The sensor can only be used as an option on the LEDWI present weather system.

1.6 Cameras

Description.

Camera's can also be used to monitor precipitation type. An observer/operator can then monitor the various camera's from a central facility. A proper background needs to be selected in order to observe the precipitation. Since this type of measurements requires an observer/operator, it is not an automatic measurement of present/past weather.

Analysis

… (check Mike?)

1.7 Other

Freezing rain

Description.

Freezing rain detection can be improved by using the wet-bulb temperature. If liquid precipitation is detected (*e.g.* by a disdrometer, or present weather sensor), freezing rain is reported if the wet-bulb temperature less than 0 °C, even is the air temperature may be above 0 °C (Meulen, 2003).

Analysis

This method was found to be more reliable than others. However, detection of freezing rain remains difficult and testing of instruments or methods a slow process as the occurrence of freezing rain is relatively rare.

Icing

Description.

Icing detectors may be used to identify freezing precipitation. Various methods exist. For instance, the weight of ice on a pole can be measured. Another method uses a probe that vibrates ultrasonically and the frequency of this probe changes when ice is formed on it. An extensive test has recently been performed (Fikke, 2007).

Analysis

Results from PW sensors improve by including data from icing detectors, particularly freezing rain (Sheppard, 2002). AWOS systems use this technique.

2 Precipitation intensity

Present weather reports include an indication for the intensity of precipitation. For example, light drizzle or heavy rain. In many cases, this is also measured by the sensor that determines the precipitation type as well. But it is also possible to employ a different sensor for this purpose. Measuring intensity also allows for the determination of intermittent precipitation (*e.g.* snow showers).

A large intercomparison of rain gauges with respect to precipitation intensity is currently taking place (ref…) Automatic measurement methods to provide an indication of precipitation intensity are listed below. Each method is shortly reviewed and analyzed.

- Forward scatter/back scatter Present Weather sensor
- Optical disdrometer
- Doppler Radar
- Rain gauge
- Cameras (+observer)

2.1 Forward scatter/back scatter Present Weather sensor

Description

The sensor is described in section 1.1. By combining the particle size distribution, number of particles and precipitation type, the intensity of the precipitation is calculated.

Analysis

The precipitation intensity determined in this manner is usually less accurate than using conventional methods (e.g. weighing rain gauges, tipping bucket rain gauges etc…). Calibration of the precipitation intensity is also a problem. For a coarse indication of precipitation intensity (light, heavy etc..), this method is usable. Manufacturers are working on refining the precipitation intensity output.

2.2 Optical disdrometer

Description

The sensor is described in section 1.2. By combining the particle size distribution, number of particles and precipitation type, the intensity of the precipitation is calculated.

Analysis

Since the method for determining precipitation intensity is similar to the forward scatter/back scatter present weather sensor, the analysis is similar too. Work is being done to refine the precipitation intensity output (see *e.g.* Lanzinger, 2006).

2.3 Doppler Radar

Description

The sensor is described in section 1.3. By combining the particle size distribution, number of particles and precipitation type, the intensity of the precipitation is calculated.

Analysis

Precipitation intensity results have showed decent correlations (O(0.9)) with conventional rain gauges when 30 minute intervals are considered (see Peters, 2002).

2.4 Rain gauge

Description

There are many different types of "conventional" rain gauges. These are based on several different measurement methods. These are described in Part I, Chapter 6: Measurement of Precipitation. They are generally designed to measure precipitation amount, although some (smaller) instrument are also specifically designed to give (an indication of) precipitation intensity.

Analysis

Those rain gauges designed for precipitation amount, tend to be less accurate in reporting precipitation intensity. However, an *indication* of precipitation intensity, which is required for the present weather reporting, is generally satisfactory. Also, many manufacturers are improving these instrument with respect to the precipitation intensity. A large WMO intercomparison of rain gauges with respect to precipitation intensity, is currently in progress (ref...)

2.5 Cameras (+observer)

Description

The sensor is described in section 1.6. The observer/operator estimates the precipitation intensity by observing the images from the camera's.

Analysis

This is not a very accurate method to estimate precipitation intensity, and most users do not apply this method. Generally, separate instruments are used for this purpose.

3 Lightning

Part II, Chapter 7: Locating the Sources of Atmospherics, describes the automatic detection of lightning.

4 Visibility

Reporting fog, mist or haze is part of present weather reporting. These quantities can be measured automatically using visibility instrumentation. Fog is defined as a visibility less than 1 km caused by water or ice, haze and mist are defined as a visibility between 1 and 5 km, where mist occurs when the relative humidity is at least 80 %RH, and haze when the relative humidity is less than 80 R%H. These definitions may vary from user to user.

Two types of visibility instruments exist: transmissometers and forward scatter sensors. Details can be found in Part I, Chapter 9: Measurement of Visibility, particularly section 3. A short description and analysis is given here.

4.1 Transmissometer

Description

Transmissometers measure the extinction of a light source over a known distance. Usually, the light of a flash lamp is detected at a distance between 10 and 200 m. The visibility is calculated from the extinction of this light. In order to increase the range of detection, two detectors at different distances can be used (a so-called double-baseline transmissometer).

Analysis

Transmissometers are well suited for measuring visibility, and are widely in use, particularly at airports. Their accuracy decreases with visibility. They are relatively expensive in installation and also in maintenance, as they require cleaning regularly.

4.2 Forward scatter sensor

Description

The sensor is described in section 1.1. Apart from precipitation type, visibility can also be measured using this instrument. The amount of scatter is related to the optical extinction. This is determined empirically in the calibration process by comparing the output with a transmissometer.

Analysis

Forward scatter sensors are also well suited for measuring visibility and are being used increasingly. One drawback, is that its calibration is not trivial, and needs attention. The instrument is relatively inexpensive in installation and maintenance, as it does not require cleaning as often as transmissometers.

5 Cloud amount

Cloud amount is reported in Octa, with 0 octa meaning a clear sky, and 8 octa fully overcast. There are a number of methods to determine cloud amount automatically. These are reported in Part I, Chapter 15.

6 Wind speed (squall)

Squalls are sudden strong increases in wind speed which last for a couple of minutes. They are usually associated with cold fronts. Squalls are detected by measuring wind speed, and applying the appropriate thresholds according to the definition of squalls. Thus, the measurements are done with the usual wind instrumentation. These instruments are described in Part I, Chapter 5: Measurement of Surface Wind.

7 State of ground

State of ground refers to the condition of the surface resulting from recent weather events, in terms of amount of moisture or a description of solid, aqueous or non-aqueous particles covering the natural surface.
Reporting state of ground is also a part of present weather reporting which, until recently, was carried out solely by human observers. Automatic measurement of state of ground is still relatively new and not widely in use. Several problems exist. Currently, three methods are known:

- Scatter sensor
- Capacitive sensor
- Cameras (+observer)

7.1 Scatter sensor

Description

These sensors have an optical design that uses the reflecting and scattering properties of the surface. Various light sources may be used. For example, flux from a white light source reflected from a reference tile will depend on the state of this surface. Other (road-) sensors analyse reflection of an IR light source on road surface. Here the wavelength of the reflected light depends on the state of the surface.

Analysis

Not all these sensors are suited for meteorological purposes, as they may be designed for surfaces other than natural surfaces. Sensors are currently being improved.

7.2 Capacitive sensor

Description

A new, capacitive sensor is currently being developed and tested. A grid mat with conductive strips is placed on the (natural) surface. It is basically a capacitor with the natural ground as the dielectric. The dielectric constant for dry and wet earth differs considerably. The capacitance thus depends on the humidity of surface and by measuring the absolute values and phase of the emitted signals at two frequencies, the state of ground can be determined.

Analysis
The first results of the tests look promising, but this sensor is still being developed.

7.3 Cameras (+ observer)

Description

Cameras are also used to determine state of ground. They can be pointed at various surfaces and an observer/operator determines the state of the ground.

Analysis

As this method is basically a manual method of observation, it is not analyzed here.

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Methods in use: automatic observation of clouds

Traditionally, observation of clouds has been done by trained human observers. Presently, a number of these observations can be performed automatically. This chapter describes those methods that are currently in use in the automatic observation of clouds, or may be used as an aid to observers.

The classic observables for cloud detection are:

- Cloud amount
- Cloud base height
- Cloud type
- Vertical visibility

For each of these observables, automatic methods of observation are listed below.

1 Cloud amount

Several automatic measurement methods to determine cloud amount exist. Each method is shortly reviewed and analyzed.

- Ceilometer
- pyrometer
- sky cameras
- broadband radiation measurements

1.1 Ceilometer

Description

Ceilometers were developed to determine cloud base height ("ceiling"), see section 2. The instruments send out an (IR) light pulse in the vertical, and detect the scatter of this light from the clouds. The altitude of the cloud base is deduced from the time between transmission and reception of the pulse. Using the time series of these cloud base measurements, cloud amount can be deduced.

Analysis

This method has some advantages compared to manual observations. Using a ceilometer gives more consistent results. Also, output can be generated more frequently and there are no problems during night time. There are also some drawbacks. This method relies on the clouds to move over the field-of-view of the instrument. This is not always the case. Also, even if clouds do move across the field of view of the ceilometer, these clouds may not be representative of the total sky. Thus, the time series of the cloud base may not always represent the total sky, on which the reporting of cloud cover should be based. Agreements (within 2 octa) between this method and manual observation of total cloud amounts are typically 80 – 90 % (Wauben, 2006). Using multiple ceilometers results in only small improvements.

1.2 Pyrometer

Description

Pyrometers are basically IR thermometers which look to the vertical, in multiple directions and/or may scan the sky. The IR temperature which is measured, is an indication of cloud presence. When scanning, this is measured for the whole sky, and the cloud amount is determined.

Analysis

Scanning pyrometers avoid the problems of representativeness of the measurement which is present in other methods, depending on the number of points sampled. A disadvantage is that fractioned and/or transparent ‘pixels’ are difficult to classify. Also, some instruments may not be fully “weather proof”.

1.3 Sky cameras

Description

Camera’s specifically designed to measure cloud amount exist. They view the total sky using *e.g.* curved mirrors. The image from the sky is analyzed by an algorithm which determines whether a cloud is present in each pixel using the measured colour. The sum of all pixels results in cloud amount.

Analysis

This method avoids the problems of representativeness of the measurement which can be present in other methods. Some cameras use daylight, and are thus not applicable at night. Cameras measuring in the IR do not have this disadvantage, but these have a smaller field-of-view and are more expensive. Sky cameras require frequent maintenance in the form of cleaning the optical surfaces.

1.4 broadband radiation measurements

Description

“Standard” pyranometers can also be used to determine cloud amount. Knowing the amount of radiation that can be expected at a certain time, any significant reduction in this will be due to cloud presence.

Analysis

This method has similar drawbacks as the ceilometer. Although pyranometers have a field of view of 180°, the radiation that can be expected is predominantly from the direction of the sun. Thus, the cloud presence in that direction is determined and not for the total sky. Additionally, since measurements rely on the radiation from the sun, measurements cannot be done at night.

2 Cloud base height

Cloud base height is a very important part of cloud observation. Instrumental measurements of cloud base are wide spread, and are an important factor for aeronautical meteorological services (see Part II, Chapter 2: Measurements and observations at Aeronautical Meteorological Stations). Cloud base height can be measured by various instrument types, which are listed below:

- ceilometer

- search light
- balloon
- rotating beam ceilometer
- radio sounding

Each of these methods are described and analyzed shortly below.

2.1 Ceilometer

Description

The working of ceilometers is based on the LIDAR principle (LIght Detection And Ranging). The output from a laser is directed vertically upwards where, if there is a cloud present, it is scattered by the hydrometeors forming the cloud. The small fraction that is scattered downwards is focussed by the receiver onto a photo-electric detector. From the time is takes the light to travel from the transmitter to the cloud and back to the receiver, the cloud base height is determined. Many different ceilometers exist, working at different wavelengths, different frequencies, using different receiver assemblies etc…

Analysis

Ceilometers are widely used for cloud base determination. The instrument can give continuous output, which is important for aerodrome use. Calibration can be done by pointing the instrument to a solid target at a known distance (*e.g.* a tower). A WMO International Ceilometer Intercomparison (WMO, 1988) showed that laser ceilometers provided the most accurate, reliable and efficient means of measuring cloud base compared to other observation methods. Some problems remain, such as the performance during precipitation and the definition of a cloud threshold. In order to improve detection during precipitation, some users tilt ceilometers at a small angle from the vertical (O(5°)).

2.2 Search light

Description

A vertically directed search light creates a patch of light on the cloud base. This is observed at a known distance from the search light. The cloud base height is then calculated from the elevation angle of observation and the distance from the search light.

Analysis

…

2.3 Balloon ("manual")

Description

In daylight, a balloon filled with hydrogen of helium may be used to measure cloud base height. The time it takes the balloon to reach the cloud base is timed by an observer. The rate of ascent is determined by the free lift of the balloon. At night, a light may be attached to the balloon.

Analysis

This method requires an observer, and is thus not a fully automatic method. It cannot be used at aerodromes, because it is not a continuous measurement (see also part II, Chapter 2). The mean rate of ascent may differ appreciably from the assumed rate due to atmospheric disturbances, resulting in errors in the cloud base height determination.

2.4 Rotating beam ceilometer

Description

In this method, a (laser) light beam is scanned in the vertical and a receiver detects light reflected back by the cloud at a known distance. At the instance at which a proportion of the reflected light is detected, the angle of elevation of the light beam is used to calculate the cloud base height.

Analysis

Although comparisons between rotating beam ceilometer and ceilometers have shown good agreement for cloud base heights up to 500 m (WMO, 1988), the detection efficiency of the rotating beam ceilometer in precipitation was markedly inferior.

2.5 Radio sounding

Description

Cloud base height may also be determined by using operational radio soundings. The humidity measurement from this sounding will change to saturation values when the cloud is reached. The altitude of the sonde is then the cloud base height.

Analysis

This is a supplementary method. Clearly, only a few measurements a day can be taken. An advantage may be that this method can observe multiple cloud layers, provided that the unit has dried out properly, whereas the other methods can only provide the cloud base of the lowest cloud.

3 Cloud type

Cloud type determination is very difficult to automate. To date, only one method is known, which is specifically for the detection of CB/TCU (Cumulonimbus/Towering Cumulus).

3.1 Precipitation radar + lightning network

Description

Data from a precipitation radar and a lightning network is used. The radar reflectivity classes and the number of lightning discharges within a certain area are combined to give information of the presence of CB and/or TCU.

Analysis

This is a new method which is used by a few Met Services. The false alarm rate is relatively high (see Leroy, 2006).

4 Vertical visibility

Vertical visibility is defined as the maximum distance at which an observer can see and identify and object on the same vertical as him/her self. It can be calculated from the extinction profile of the atmosphere (WMO 2003).

4.1 Ceilometer

Description

Ceilometers (see section 2: cloud base height) may provide an estimate of vertical visibility, based on the integrated backscatter energy with range.

Analysis

WMO 1988 showed that this method frequently produces unreliable results. In practise, a vertical visibility report is often given by a ceilometer when the cloud base requirements are not met, but when reflected light is received from a certain altitude.

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