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| **World Meteorological Organization****Commission for Instruments and Methods of Observation** **Joint Session of the Expert Team on Operational In Situ Technologies (ET-OIST) and the Expert Team on Developments in In Situ Technologies (ET-DIST)**Geneva, Switzerland, 21-23 June 2017 | **CIMO/ET-A1-A2/Doc. 5.4**  |
| Submitted by:W. Wauben9.6.2017 |

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# Automation of cloud observations: Guidance on best practices

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| **Summary and purpose of document**This document provides overview of the practices and experiences of automation of cloud observations. The focus is on the usage of ceilometers for automated cloud observations, as it is the instrument which is mostly used for this purpose. Some alternative measurement technique are also reported. |

**Action proposed**

 The Meeting is invited to take notice of the findings reported in this document and to provide feedback on the contents. Also the Meeting should decide whether the document is suitable for publication as a separate IMOP report or whether information should be included in the CIMO guide.

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**Appendix I:** powerpoint presentation with KNMI details/experiences

**AUTOMATION OF CLOUD OBSERVATIONS: GUIDANCE ON BEST PRACTICES**

***Introduction***

The observation of clouds (cloud amount, cloud base and cloud type) is traditionally done by human observers, who estimate the cloud variables considering the widest possible view of the sky. Often, for example at airports, the observer has access to the measurements of the cloud base height as determined by a ceilometer to facilitate a better estimation of the cloud base height. Generally a ceilometer is used for determination of cloud base height, but in combination with a cloud algorithm the cloud base heights in a certain time interval can be converted into cloud layers with corresponding height/amount. The availability of ceilometers and the possibility to derive cloud layers with corresponding height/amount are the reason why the ceilometer is generally used for the automation of cloud observations.

The automation of visual observation is ongoing in all regions of the world. The number of automatically generated meteorological reports including cloud information is increasing (numbers/graph?). The automation is not only used as replacement of existing manned stations, but also to increase the number of sites producing cloud information either to make the measurement network more dense or to extend it to remote locations (for example KNMI now operates more than 10 fully automated AWOS at structures in the North Sea). Also note that (in EU) the automation of visual observation at airports is ongoing. It is expected that within a couple of years only the big international airports will still be using observers.

***Ceilometers***

*Requirements*

Ceilometers are commercial and robust lidar instruments that make continuously measurements of the cloud base height directly overhead. When selecting the ceilometer one has to specify the vertical range of the ceilometer. When it is only used for aeronautical applications a range of 10,000 feet could be sufficient, but generally a higher range is required and for climatology the detection of cirrus is also important. Furthermore, users might not only require the cloud base height, but also need information on the vertical distribution of aerosol, the mixing layer height or even want to use the ceilometer for monitoring aerosol/volcanic ash clouds. Modern ceilometers are capable of measuring the above quantities, but the higher range and higher sensitivity come with an increase in costs.

*Backscatter data*

Ceilometers also make backscatter data available and manufacturers can reprocess the backscatter data. This is a useful feature to monitor the performance of the ceilometer and to analyze and optimize the cloud base detections and other derived products. The backscatter can for example be used to verify the characteristics of the overlap function of individual ceilometers.

*Overlap function*

Ceilometers with separate optical paths for transmission and reception have no or little overlap of the transmitted and received beams at low altitudes. The overlap function (as a function of altitude) should be carefully determined for each ceilometer so that the overlap function (or the correction thereof) does not introduce features in the backscatter that might be falsely interpreted as a cloud base height. During clear situations, cloud free and no precipitation, the backscatter corrected for the overlap function of ceilometer should vary smoothly with altitude and should closely correspond for collocated ceilometers.

*Precipitation*

The presence of precipitation affects the backscatter and may affect the cloud base detection or the height of the cloud base. Situations may occur when the derived cloud amount decreases during precipitation or when the reported cloud base height during precipitation is incorrect. In the first case it should be noted that some ceilometers report a so-called vertical visibility during precipitation, but no cloud base and treating this ceilometer vertical visibility (which in fact is no visibility in term of the integration of the backscatter up to a height where the extinction is reduced to 5%, but the height where the backscatter has a feature which does not meet the criteria for the cloud base) as a cloud base reduces this problem. The latter problem, a false cloud base height during precipitation, is difficult to access since the correct cloud base height is often unknown or is approximated by the cloud base height prior and after the precipitation event. Often a false cloud base height during precipitation occurs at a too low altitude and shows large variability.

*Cloud base detection*

The ceilometer reports instantaneous (updated every 15” or shorter) cloud base heights at low altitudes, but larger integration times are used for the detection of higher clouds. The detection of well-defined clouds generally poses no problems although ceilometers might disagree on the exact height due to differences in the definition of the cloud base (height where backscatter starts to increase or a slightly higher altitude partly in the cloud). The exact threshold for cloud base detection might also differ (for example whether a moist layer or cirrus should be reported as a cloud base or not may, depend on the optical depth).

*Spurious detections*

As mentioned above an incorrect correction for the overlap function and sensor noise can cause faulty cloud detection. Also airplanes passing overhead can trigger cloud base hits as can the build-up of a snow cap on the ceilometer (the cover is generally not heated). There might also be occasional faulty cloud detections when a bird sits on the ceilometer. KNMI uses an algorithm to filter out isolated cloud detections (the first 2 hits of the first layer are ignored in the METAR cloud report when the base is below 100 ft and is more than 500 ft below the third hit).

*Verification*

Each ceilometer should be verified before operational use. The verification should include the relevant part of the FAT, SAT, or verification protocol to make sure that the ceilometer and its components meet the specifications. This verification also includes a test of the ceilometer against a hard target and/or using a cloud simulator. In addition the ceilometer should be subjected to field verification which is either an inter-comparison of ceilometers (all should give the “same” results as a thrusted/good sensor) or against a reference instrument (for example research lidar) or by expert judgement of the data. The field verification might include:

* Verification of ceilometer performance during clear sky situations (FAR cloud detections below xx).
* Verification of ceilometer performance during fog or low stratus (POD cloud detections above xx)
* Verification of ceilometer performance during uniform cloud cover (focus on cloud base height using research lidar and atmospheric profiles to estimate the correct CBH)
* Verification of ceilometer performance of cloud detection during precipitation (POD cloud detection above xx)
* Verification of high (cirrus) clouds (POD cloud detections above xx using a threshold for optical depth of xx obtained from a research lidar.

*Siting*

The siting of a ceilometer has no specific requirements. Naturally the sky overhead may be obstructed, the growth of vegetation that might reach over the sensor must be taken into account, and plumes of nearby chimneys must be avoided.

The results of the ceilometer are sometimes combined/verified against the information from other sensors. Hence these sensors (for example precipitation, visibility, radiation) must be collocated when possible.

Sometimes the ceilometer is tilted in order to weaken the reflected signal of asymmetrical rain droplets relatively to that of spherical cloud droplets. However, tests did not show any improvement.

*Validation*

Spatial comparison of ceilometer results and comparison with satellite cloud information. The latter is for example used to correct the climatological total cloud cover of the old ceilometer for the poor detection of cirrus.

Statistical analysis of the cloud base heights may point out faulty detections at specific altitudes due to noise/overlap function or a reduced sensitivity for high clouds.

***Ceilometer cloud algorithm***

*Algorithms*

A ceilometer cloud algorithm is used to transform a time series of cloud base heights into cloud layers with corresponding height/amount. A ceilometer cloud algorithm is generally included in the ceilometer, but the details of the algorithm are generally not given. Using a separate or your own cloud algorithm makes “all” details available and one has generally more flexibility to do specific processing. For example, KNMI uses an algorithm with different settings for the calculation the cloud variables for synoptic and aeronautical purposes. The algorithm also handles pre-processing/corrections to take account of specific ceilometer characteristics or overcome problems, and post-processing to add information or produce specific results.

*Time window*

Several ceilometer cloud algorithms are described in literature and are in operational use. The basic parameter is the time window to be used. A large time window gives a better representation of the cloudiness whereas a shorter interval has a fast response to changes in cloudiness. A time window of 30 minutes (double weight for the latest 10 minutes) is generally used for synoptic purposes. For aeronautical purposes KNMI uses the last 10 minutes (otherwise we received complaints that the automatic cloud cover reporting was too slow or delayed; when a front moved in one had to wait first for it to reach the ceilometer and then the time window for the amount to change from 0 to 8 okta). For climate applications one might consider using a longer time window, for example one hour, and consider a time window using centered on the time of observation, for example 30 minutes before to 30 minutes after the hour. However, it should be noted that differences between the ceilometer derived cloudiness and human cloud observation will remain, regardless of the time window considered.

*Other parameters or assumptions*

Other parameters that affect functioning of the ceilometer cloud algorithm are:

* The (height) dependent minimum distances allowed between individual cloud layers (layers closer together will be combined into one layer).
* The limits for reporting 0 and 8 okta might be no cloud base hit and only cloud base hits in the entire time window or the limits might be relaxed.
* Whether the simultaneous detections of a second and third cloud base are used in the algorithm.
* The reported cloudiness should follow coding practices. For example at most three cloud layers (possibly a fourth in case of CB) are reported, the second layer has an amount of at least 3 okta and the third layer has an amount of at least 5 okta.
* Due to coding practices no cloud layer is reported over a layer of 8 okta even if the ceilometer detected a second cloud layer.
* Also a CB cloud layer over a layer of 8 okta is not allowed, but in this case KNMI reduces the 8 okta amount to 7 in order to allow reporting of the CB cloud layer.
* Total cloud cover can be reported in percentage (so not rounded to oktas)
* Criteria for reporting sky obscured/vertical visibility might be applied. KNMI uses the criteria: (i) only one cloud layer is reported with 8 okta; (ii) no simultaneous detection of a second and third cloud base occurred; (iii) the cloud base is below 500 ft; and (iv) the MOR (SYNOP) or VIS (METAR) is less than 1000 m. In these conditions the cloud base of the first and only cloud layer is reported as the vertical visibility at the same height.

Details of the KNMI ceilometer cloud algorithm are given in the appendix.

*Multiple ceilometers*

Generally one ceilometer is used in the automated cloud observations. The usage of multiple has little impact on overall scores for the total cloud amount (spatial representativeness is only slightly better). At some airports multiple ceilometers are available and used for automated cloud observations. The reason for using multiple ceilometers can be related to specific conditions or the presence of multiple runways. One might also consider using multiple ceilometers in combination with a reduce time window in order to increase the timeliness of the reported cloud information. Again, it should be noted that differences between the ceilometer derived cloudiness and human cloud observation will remain, regardless of the number of ceilometers considered.

*Interpretation*

Naturally one wants to give the users the best possible estimation of the cloudiness. However one should also take into account that the user is able to interpret the information. Using a single ceilometer and a fixed time window, it is rather straightforward to explain 8 okta (cloud base detections during the entire time window). However when multiple ceilometers or different or even varying time windows are considered depending on the location, the interpretation of the information will be rather complex, and although the results could be better (compared to that of an observer), it will still not be an instantaneous estimation of the cloudiness of the entire sky.

***Ceilometer versus observer***

*General agreement*

The ceilometer derived cloud information serves not as an 1-to-1 replacement of the human cloud observations where the entire sky is considered. However, there is a reasonable agreement between ceilometer and human cloud observations. The KNMI found that about 39±5 % of the time the total cloud cover reported by ceilometer and observer are in exact agreement whereas 75±3 % and 87±3 % of the time the differences are within ±1 and ±2 okta, respectively. Results are typical for all stations in the Netherlands, but are affected by a large fraction of overcast situations (56±2 % of the time 7 or 8 okta).

Add experiences/numbers for other climate regions?

*Cirrus*

Ceilometer reports generally less cloudiness (<nceil-nobs>=-0.2±0.3 okta), due to the lack of detection of cirrus clouds. Modern, more sensitive ceilometers are capable to detect cirrus. Here the cloudiness might be even too high. Even for the older ceilometer the KNMI cloud algorithm also provides the total cloud amount of low and middle clouds only in order to prevent situation where overcast is reported to the general public during sunny/clear situations with only cirrus clouds.

*Okta distribution*

Due to the missing spatial representativeness of the ceilometers they report more 0 and 8 okta and fewer 1 and 7 okta cases compared to human observers. The presence of even a small cloud anywhere in the sky will be reported as 1 okta by the observer whereas the ceilometer can only reported it when it passed overhead to ceilometer. Similarly a small gap in the cloud will be reported as 7 okta by observer whereas the ceilometer can only report it when it passes overhead to ceilometer.

*Shallow fog*

The ceilometer is located at the measurement field and the measurements are affected by (shallow) fog, whereas the observer is often located on top of a building and can report the cloudiness overhead. Hence ceilometers will report more cases with sky obscured/vertical visibility compared to observers. One might consider filtering the cloud base detections due to shallow fog (top below 2 m), but only when the ceilometer data can be used to detect the presence of shallow fog.

***Other techniques***

*Integration*

Cloud information from other sources can be available. It is not straightforward to combine information from different sources as the information might be different or even conflicting. For example when combining the ground-based observations of the cloud base height and the cloud top temperature obtained by satellite, one has two different quantities. When only the total cloud amount is considered, one can use for example the strong points of each system to make a situation dependent integration (low clouds determined by ceilometer and high clouds by satellite) or use a statistical approach to combine the results with fixed but possibly height dependent weighting factors. In case the height of the cloud layer is considered as well, the satellite might indicate the presence of the significant cloud layer, but when the ceilometer has no corresponding cloud base hit, the height of the layer will be unclear. In such situations it is often no option to report only the cloud amount of the layer, since users (for example aeronautical users where safety is an issue) then might have to assume the worst case.

For aeronautical applications reporting of CB/TCU is essential since it is an indicator for the presence of convective activity. The methods to determine the presence of CB/TCU use information from a lightning detection system, precipitation radar and satellite (VIS and IR channel). The method to determine CB/TCU is not generic since it has been tuned for each location using a learning set that has been created after careful evaluation of the situation by a forecaster. Some countries are also considering to use model information to enhance the CB/TCU product. An example of the way of combining CB/TCU to ceilometer cloud information in aeronautical reports, is given in the appendix (see Rules for KNMI CB-TCU encoding in METARSPECI.pdf). Note that the estimations of the amount and height of the CB layer are not obtained from ceilometer information and can be rather uncertain, particularly the height.

Another example of integration of information uses pyrgeometer cloudiness (APCADA) and ceilometer cloud information. The pyrgeometer gives not an instantaneous assessment of the cloudiness of the entire sky, but statistical analysis using measurements of the past hour and tuned for each site. MeteoSwiss uses such pyrgeometer cloudiness to adapt the ceilometer total cloud amount. (details?)

*Alternatives*

Integration of cloud detection systems that provide accurate cloud information on amount and height (and type) for the entire sky during day- and nighttime are not yet available.

An alternative that can be considered for measurement of total cloud amount for example for climatology: a scanning pyrometer or IR camera system.

An alternative that can be considered for daytime total cloud amount (and type) and for example for solar power forecasting for photovoltaic systems: visual camera system.

*Ongoing developments*

Scanning pyrometer gives accurate total cloud amount and information on cloud layers, but the estimated height is rather uncertain.

Scanning infrared camera system gives accurate total cloud amount and information on cloud layers, but the estimated height is rather uncertain. The high spatial resolution allows derivation of the cloud type.

Visual cameras (with IR option) give accurate total cloud amount and information of the cloud type during daytime. Some height information can be estimated using stereographic cloud images obtained from multiple cameras.

The height information of the pyrometer and infrared camera might be improved by using NRT temperature and humidity profiles in combination with a radiative transfer code. All three developments might improve the height information by using ceilometer information or otherwise a scanning lidar system.

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**Appendix I -**

See powerpoint presentation (MA\_AM\_WS\_2016\_KNMI\_Clouds) for details of the KNMI ceilometer cloud algorithm and examples of results/experiences and ongoing research.

Should the examples/graphs be included in the document?

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