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# Review of current and emerging technologies and update of the CIMO guide: Clouds, Visibility and PWD measurement technologies

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| **Summary and purpose of document**This document provides a review of current and emerging measurement technologies related to clouds, visibility and Present Weather. |

**Action proposed**

 The Meeting is invited to take notice of the findings reported in this document and to decide whether the recommendations are appropriate.

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**Appendix:** I References

**REVIEW OF CURRENT AND EMERGING TECHNOLOGIES AND UPDATE OF THE CIMO GUIDE: Clouds, Visibility and PWD measurement technologies**

***Approach***

1. Review current and emerging in-situ surface measurement techniques related to clouds, visibility and weather.
2. The review of various sources of information (literature, internet, conference proceedings, manufacturers, private communication from colleagues) for the period 2010 to present resulted in the findings listed below.
3. Note that manufacturers were not asked to report any new/significant developments.

***Visibility***

*Transmissometers*

Transmissometers generally serve as reference for the evaluation of forward scatter visibility sensors. Some institutes/manufacturers use such a setup, but the reference is generally limited to low visibility values and visibility reductions are generally caused by fog. There is no visibility reference for moderate to high visibility values, nor is there experience with other causes of visibility reduction (sand, precipitation types such as drizzle and snow).

*Contamination*

There were some upgrades to existing visibility sensors, notably the way window contamination is measured and taken into account. This results in better visibility measurements, an extended visibility range and/or a reduction of maintenance. There are, however, no reports showing the advantages of the window contamination compensation or its impact on maintenance in operational conditions!?

*Flying insects*

Flying insects can reduce the visibility reported by forward scatter visibility sensors. Vaisala introduced a filtering algorithm in the FD12P that eliminates the spikes resulting from these insects prior to calculation of the visibility. Other manufacturers haven’t implemented a filter to eliminate the signal caused by flying insects, and also in the newer range of forward scatter visibility sensors of Vaisala such a filter is not available as standard functionality. However, some manufacturers indicated that filtering is applied within the forward scatter sensor. Is the visibility reduction caused by flying insects, when using forward scatter visibility sensors, a recognized problem?

*Spider webs*

Spider webs on optical sensors can also lead to faulty visibility readings and may require regular service visits to the site to remove webs. Measures to prevent spider webs have so far not been successful. One manufacturer provides forward scatter sensor with vibrating parts to discourage spiders from the instrument.

*Cameras*

The determination of the presence of fog and the estimation of visibility from camera images has received attention lately. This is not surprising given that the availability and quality of (web)cameras has increased whereas the costs of these systems decreased and the data can easily be made available on internet. Furthermore, image processing techniques have evolved over the last years and are readily available. Since the visibility information derived from cameras may provide useful additional source of information, it got a lot of attention. Various techniques have been considered such as determining whether objects at known distances are visible by evaluating the presence of edges or by contrast reduction. Other techniques relate statistical parameters of an image such as gradients or Fourier analysis to visibility or use the results of image enhancement methods such as dehazing techniques. These techniques can be applied to either each image individually, 2 images of the same scene obtained with 2 cameras at different distances, or one image relatively to a (set of) reference image(s) under different atmospheric conditions. Often the cameras are limited to daytime and techniques need to be tuned to the images/scenes. Note also that often visibility is not quantitatively determined. Camera systems and software are sometimes also used as an aid for a (remote) observer.

*Recommendations*

Investigate possible candidates for WMO lead centre for visibility measurements (not related to new technique).

Consider inclusion of experiences with flying insects and spider webs and typical maintenance intervals for contamination (with/without window contamination compensation) in chapter 9 of the CIMO guide (not related to new technique).

Consider inclusion of section on camera derived visibility in chapter 9 of the CIMO guide.

***Weather***

There have been some improvements or new versions of existing present weather sensors (PWSs). Available techniques are: forward scatter (in combination with precipitation detector); forward and back-scatter; scintillation; disdrometer; combination of forward scatter and disdrometer (multi sheet); static Doppler radar; impact disdrometer. Generally the PWSs use a multi-sensor approach and can be enhanced/complemented with information obtained by other sensors. For the latter a new lightning sensor and an acoustical hail sensor have become available. Independent evaluations of these sensors are not yet available.

Some PWSs have been included in the SPICE solid precipitation intercomparison of WMO, but as the focus was on catchment techniques for measuring solid precipitation, the usage of PWSs during SPICE was limited and different PWSs were considered per location. KNMI selected and evaluated several PWSs for the upcoming replacement of the Vaisala FD12P PWS.

A new development for PWS is the introduction of a 2D video disdrometer. This sensor will have advantages over the well-known disdrometers as the location of the detected particle can be used to eliminate particles occurring at the boundaries of the sample area. Also the contribution of individual particles and their shape can be used in the determination of the precipitation amount and the discrimination of the precipitation type. However, this sensor is not yet commercially available and the advantages have not yet been demonstrated in field evaluations.

*Recommendations*

Consider a WMO evaluation of PWSs in the near future (not related to new technique).

Consider mentioning of new 2D video disdrometers in chapter 14 of the CIMO Guide.

***Clouds***

*Ceilometers*

A new generation of ceilometers have become available that have a higher sensitivity and a vertical range up to 15 km. These ceilometers are capable of detecting cirrus clouds, which up to now was inadequately detected by commercially available ceilometers. Due to the higher sensitivity the new generation ceilometers are also able to derive the mixing layer height from the decrease in the aerosol backscatter at the top of the mixing layer. These modern ceilometers also make the “raw” backscatter data available, that can be used to verify and optimize the output of the ceilometer. For example, archived backscatter data have recently been used by the manufacturer to optimize the performance of the cloud base direction during precipitation events.

Some evaluations and comparisons of ceilometers are in progress. Systematic differences in the cloud base height of about 100-150 ft have been observed between ceilometers from different manufacturers. This is probably related to differences in the interpretation of the definition of the cloud base height, although the differences seem not to depend on the type of cloud. Independent verifications have been performed or are under consideration using, for example, visibility sensors in a meteorological tower, cameras observing a local tower, observations from a helicopter and the usage of tethered balloons.

Several papers have been published on the differences between cloudiness reported by human observers and by automatically generated cloud observations using ceilometers.

*Visual cameras*

In the past, specifically designed sky imagers were used during daytime only to estimate the cloud amount. Nowadays DSP (Digital Signal Processing) IP camera or webcams can be used for that purpose, whereas cameras with infrared night vision also give useful images in low lighting conditions. An important application for the daytime cloudiness extracted from cameras is the solar power forecasting for photovoltaic systems.

Extensive developments have been achieved in the software that is used to analyse sky images in order to determine not only cloud amount but also cloud type. The cloud type is determined by considering several statistical spectral and textural features of the image that are related to cloud type using a reference data set. The success rate is quite good for homogenous cases (75-88 %), but lower in case of mixed scenes.

A new sky imager was introduced that reports cloud amount and height. The height is obtained stereographically by using overlapping scenes obtained by 2 imagers. A study into the number of times that cloud base height can be estimated using stereographic cloud images and the accuracy of the obtained heights is not yet available.

Note that cloud motion vectors can also be extracted from these sky images with high spatial and temporal resolution.

*Infrared detectors*

There have also been developments regarding the use of infrared sensors for estimation of the cloudiness. Naturally infrared detector has the advantage that it produces results during day time as well as night time. Infrared measurements used to estimate cloudiness include:

* Pyrgeometer measurements of long wave radiation of the sky. Here the level of long wave radiation and its variability is used to estimate the cloud cover. This method is used operationally by MeteoSwiss, the pyrgeometer derived cloudiness is used to change the ceilometer derived cloud cover.
* Pyrometer measurements of the thermal infrared radiation of the sky in one or more fixed orientations or with a scanning pyrometer. Pyrometers with a field of view of several degrees measure the thermal infrared radiation (8-14 μm) obtained from a small part of the sky. During clear sky the pyrometer reports a low temperature, but higher temperatures denote the presence of a cloud. The cloud detection threshold is about -60 °C, but depends on calibration of the pyrometer, the contamination on the lens and the optical depth of the cloud. A scanning pyrometer can be used to obtain the cloud amount of the entire sky. For example a scanning pyrometer, the so-called NubiScope, is operated continuously by KNMI at the Cabauw research site for routine measurements of the cloud cover. Every 10 minutes a scan of the sky is obtained with a resolution of 36 by 30 pixels. The pyrometer is located at the end of the tube making it quite insensitive to contamination. The calibration and contamination of the pyrometer is verified every 6 months. Note that the cloud base temperature can be used to estimate the cloud base height. However, the signal of the pyrometer is affected by the presence of aerosol and water vapor, and should be corrected using temperature and relative humidity profiles in combination with a radiative transfer model.
* Infrared sky camera system using uncooled micro-bolometers detector arrays measuring the downwelling atmospheric radiation in the 8-14 μm wavelength band. Here several infrared images of the sky are combined to get a whole sky image every 15 minutes with a resolution of 650 by 650 pixels. The processing of the infrared images for cloudiness is as that of a scanning pyrometer. In addition, the high spatial resolution allows derivation of the cloud type as for a visual camera. The University of Science and Technology in Nanjing, China, developed and operates the so-called WSIRCMS (Whole-Sky InfraRed Cloud Measuring System). The system uses real-time temperature and relative humidity profiles and horizontal visibility data to optimize the threshold for cloud base detection.

*CB/TCU*

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 have been extended and now 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.

*General*

It should be noted that the above developments are often not operational yet, but are used by research institutes or universities.

*Recommendations*

The CIMO Guide chapter 15 would benefit from references with recent work on pyrgeometer, pyrometer and infrared sky camera systems and visual cameras used for measurement of cloudiness (not related to new technique).

Consider updating of section on visual and infrared camera derived cloudiness and instrumental measurement of cloud type in chapter 15 of the CIMO guide.

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**Appendix I References**

This appendix lists references related to the findings reported in the document.

References need to be extended/updated and grouped by topic.

*Clouds*

Lead Centre Lindenberg performs test of ceilometer/LIDAR.

APCADA pyrgeometer cloud cover information is combined with height resolved ceilometer cloud information (MeteoSwiss).

Submitted paper on new NubiScope with cloud (free) detection and cloud base height are obtained using T and RH profiles (paper rejected, not yet been resubmitted).

Various contributions on cloud cover (and type) derivation from sky/web cams in EU-COST workshop.

Several papers concerning cloud type determination from sky images

1-s2.0-S0169809512001342-main-Cloud detection and classification with the use of whole-sky ground-based images.pdf

amt-3-557-2010-Automatic cloud classification of whole sky images.pdf, art%3A10.1007%2Fs13143-015-0083-4-Cloud Cover Retrieved from Skyviewer A Validation with Human Observations.pdf

amt-8-2001-2015-Comparing satellite- to ground-based automated and manual cloud coverage observations – a case study.pdf

jgrd51942-Cloud observations in Switzerland using hemispherical sky cameras.pdf.

Continued developments on CB/TCU derivation from TS/weather radar and satellite. See WR2010-04-Probability of Cb and Tcu occurrence based upon radar and satellite observations.pdf and WR2015-01-Cb-Tcu classification based on radar and satellite observations.pdf.

Other (EU) countries do similar developments and some even consider using a convection module as well (information from MET Alliance AUTO METAR workshop).

New sky imager for cloud amount and height (stereographic) Schreder-TSIMG-15.pdf.

Visibility

Biral enhances MOR range of SWS sensor (and in future also of VPF sensors) by using better correction for window contamination (firmware update).

Visibility from camera images (several older papers on internet, presentation by Austro Control) whether objects at known distances can be distinguished. Exploration has been performed by KNMI, see for example

Feasibility study of fog detection and visibility estimation using camera images 20151221-final2.pdf,

Visibility-monitoring-using-conventional-roadside-cameras-Emerging-applications\_2012\_Transportation-Research-Part-C-Emerging-Technologies.pdf

A-model-driven-approach-to-estimate-atmospheric-visibility-with-ordinary-cameras\_2011\_Atmospheric-Environment.pdf

CVPR2009-Single Image Haze Removal Using Dark Channel Prior.pdf.

“New” OFS backscatter visibility sensor from Catec (representative of ..)

Weather

Thies introduced a new 2D video disdrometer. Not yet commercially available. Test version at KNMI test field. First only gathering data (gif images), since 7/2015 precipitation intensity output and by end of 2016 also PW. MTI-2014Thies video disdrometer.pdf

Also a Chinese 2D version (VPS) amt-7-2037-2014-A video precipitation sensor for imaging and velocimetry.pdf.

CS new correction for flattening in the shape of larger raindrops for PWS100.

Evaluation new Ott Parsivel2 JTECH-D-13-00174-Evaluation of the New Version of the Laser-Optical Disdrometer, OTT Parsivel2.pdf

Acoustic hail sensors Löffler-Mang hail sensor Atmospheric Research 100 (2011) 439–446.pdf and DWD ?

New Biral lightning sensor: MetTech2015-BiralLightning.pdf

New IDS-100 icing detection sensor form Sommer

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