# WP5 – NA5: Clouds and aerosol quality controlled-observations
# Deliverable D5.2: Minutes of aerosols algorithm workshop

**Clouds and aerosol quality controlled-observations Workshop**

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| Time : | 12-13 Sep 2011 |
| Place : | Snijderszaal, Dept. of Elec. Eng., Math. and Computer Science, Delft University of Technology, Delft, The Netherlands. |
| Chair: | Ulla Wandinger |
| Minutes: | Ulla Wandinger, Anthony Illingworth and Ewan O'Connor |
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Aim of the workshop was to review the current status of the aerosol measurement capabilities and existing aerosol retrieval algorithms at the different Cloudnet stations, to identify instrumental and algorithm gaps, and to discuss a strategy for extending the set of Cloudnet observables towards aerosol products.

## 1. Aerosol measurement capability of the existing and candidate Cloudnet stations

The Table below shows (potential) aerosol measurement equipment at 13 stations.

| | Ceilometer | Aerosol lidar | Doppler lidar | Sunphotometer | Surface aerosol |
|---|---|---|---|---|---|
| **Cabauw** | CT75K | 3b+2a+d | Y (1.5 μm) | Y | |
| **Chilbolton** | CT75K | b (355) | Y (1.5 μm) | Y | |
| **Juelich** | CT25K<br>CHM15k* | | Y (1.5 μm)* | Y* | |
| **Leipzig** | CHM15kx | 3b+2a+d | Y (2 μm) | Y | Y |
| **Lindenberg** | CHM15k+kx | b+a+d (355) | | Y | |
| **Mace Head** | CHM15k | b+d (355)* | | | Y |
| **Marburg** | CL31 | | | | Y |
| **Munich** | CHM15kx | 3b+2a+d | | Y | |
| **Palaiseau** | CL31 | b (355, 532)<br>3b+2a+d * | Y (1.5 μm) | Y | Y |
| **Potenza** | CT25K | 3b+2a+d | | Y | |
| **Sodankylä** | CT25K | | Y (1.5 μm) | Y | Y |
| **Zugspitze** | CT25K | | | | |
| **Warsaw** | CHM15k | 3b+2a+d * | | Y | Y |

* planned to be installed by end of 2012

**Ceilometer** – uncalibrated backscatter profile at 905 (CTxx, CLxx) or 1064 nm (CHMxx) sensitive enough for identifying optically thick aerosol layers.

**Aerosol lidar:** '3b+2a+d', backscatter at 355, 532, 1064 nm, extinction from nitrogen Raman at 355, 532 nm, depolarization at one or more frequencies. b+a backscatter and extinction at a single wavelength (in parentheses),

**Doppler lidar** – aerosol returns at 1.5 or 2 μm, usually uncalibrated in terms of signal-to-noise ratio**.**

**Sunphotometer** – spectral aerosol optical depth, sky brightness, and derived information on aerosol microphysics in the atmospheric column (AERONET).

**Surface aerosol** – particle size distribution and other parameters measured with in situ instrumentation at ground level.

The aerosol measurement capabilities of the Cloudnet stations are quite disparate. Combined Cloudnet-EARLINET stations (Cabauw, Leipzig, Munich, Palaiseau, Potenza) are best suited to implement sophisticated aerosol and aerosol-cloud algorithms. Most stations are equipped at least with a ceilometer and a sunphotometer, which is considered to be the minimum set of instruments for the application of less-sophisticated aerosol retrievals.

## 2. Instrumental and observational issues

**Ideal aerosol instrument fit:** Consists of a three-wavelength Raman lidar with depolarization measurement capability (3b+2a+d) and an AERONET sunphotometer, running continuously every day of the year, together with the other Cloudnet instruments (cloud radar, microwave radiometer, ceilometer). It provides spectrally resolved aerosol extinction and backscatter profiles together with the particle depolarization ratio. Aerosol typing and the retrieval of microphysical particle properties are possible.

**EARLINET lidars**: High-sophisticated aerosol lidars are applied in EARLINET to establish an aerosol climatology for Europe. Measurements are performed on a fixed schedule (three times per week). The instruments are usually not continuously operated.

**Backscatter lidars**. Lidars which cannot measure a pure molecular return signal (Raman or Rayleigh) need an assumption on the extinction-to-backscatter ratio (lidar ratio) in the aerosol retrieval. Accurate extinction profiling is not possible with such instruments. When operated in the UV or visible spectral range, calibration is possible in aerosol-free regions of the atmosphere. Reliable backscatter profiles are obtained when these lidars are combined with a sunphotometer to constrain the aerosol optical depth of the atmosphere.

**Ceilometers.** Ceilometers can be regarded as low-power backscatter lidars. Usually, they are continuously operated. Because of the low signal-to-noise ratio, only layers with high aerosol load (PBL, pollution or dust plumes) can be observed. The instruments are operated at 905 or 1064 nm. Because of the low power and the long wavelength a direct calibration in aerosol-free regions is not possible.

**ACTION:** All stations to improve aerosol observation capabilities wrt to continuous operation and the retrieval of quantitative, quality-assured products (see below).

## 3. Calibration of ceilometers and Doppler lidars

Alternative calibration methods are needed when the conventional method of calibrating lidar signals in aerosol-free regions of the atmosphere fails, as it is the case for ceilometers and Doppler lidars at 1.5 and 2 µm. Three methods were discussed in more detail: the cloud lidar autocalibration technique (O'Connor et al., 2004), an external calibration by using the aerosol optical depth from a sunphotometer as a retrieval constraint (Heese et al., 2010), and the calibration through simultaneous measurements with Raman lidar (Binietoglou et al., 2011). The first two methods can be seen as complementary since the first works in the presence and the second in the absence of clouds. Further activities are required.

**ACTION:** Cloudnet community to implement and compare different calibration methods for ceilometers/Doppler lidars at Cloudnet sites; study the applicability for different instruments (0.9, 1.06, 1.5, 2 µm); validate results (comparison of aerosol products with those from other lidars, sunphotometers etc); investigate calibration stability for the different instruments.

**ACTION:** Illingworth to contact organisers of COST SWG meeting on ceilometer calibration which should also include the calibration technique to be used by DWD using sun photometers.

## 4. Aerosol products, algorithms and data formats

***Hierarchy of potential aerosol products for Cloudnet:***

1. attenuated backscatter profile: range-corrected and calibrated atmospheric backscatter profile
2. aerosol mask: atmospheric regions with enhanced aerosol load (to be added to Cloudnet target mask)
3. PBL height, aerosol layer boundaries: upper boundary of the aerosol layer that is in touch with the surface and of top and bottom heights of lofted aerosol layers
4. particle backscatter-coefficient profile (at one or several wavelengths): quantitative, i.e. calibrated and attenuation-corrected, description of 180° volume backscattering caused by aerosol particles (in $m^{-1}sr^{-1}$)
5. particle linear depolarization-ratio profile (at one or several wavelengths): quantitative, i.e. calibrated, description of the depolarization of linear-polarized laser light caused by (non-spherical) aerosol particles
6. particle extinction-coefficient profile (at one or several wavelengths): quantitative description of atmospheric extinction caused by aerosol particles (in $m^{-1}$, derived from a pure molecular return signal, i.e. with a self-calibrating method)
7. aerosol type/target classification: discrimination of major aerosol types (such as dust, maritime aerosol, smoke, pollution, volcanic ash) from depolarization ratio, lidar ratio, and/or Angström exponent (color ratio)
8. particle microphysical properties (e.g., effective radius, volume size distribution, refractive index) derived from spectral extinction and backscatter coefficients

The hierarchy of products is coupled to the instrument capabilities (from simple ceilometer to advanced multiwavelength Raman lidars).
Products 1) – 4) are recommended to become mandatory for all Cloudnet stations in the course of the ACTRIS activities.
Products 5) – 8) are of interest for combined Cloudnet-EARLINET stations and should be implemented depending on the instrument capabilities (see above) and the available resources.

***Aerosol algorithms for Cloudnet:***

In principle, algorithms for the aerosol products listed above are available. Most of them have been widely discussed in the literature. Nevertheless, specific adaptions for Cloudnet purposes will be necessary.
Within its quality-assurance program EARLINET has tested standard algorithms for the retrieval of backscatter and extinction coefficients (Böckmann et al. 2004, Pappalardo et al. 2004). These algorithms have been implemented in the EARLINET Single Calculus Chain (SCC), a central software tool to be used to evaluate data from all EARLINET stations. New algorithms to determine depolarization ratio, PBL height, layer boundaries, and layer-mean optical properties will be implemented in the SCC within the frame of ACTRIS (see WP2, Task 2.3).
Microphysical retrieval schemes have been developed in EARLINET as well and will be implemented in the SCC during ACTRIS. The development of combined lidar-sunphotometer retrieval algorithms is part of ACTRIS Joint Research Activity 1 (see WP20, Task 20.3).

It is recommended that Cloudnet and EARLINET coordinate aerosol algorithm developments in WP2, WP5, and WP20. The goal of Cloudnet is to develop operational algorithms. The EARLINET SCC is currently used as an off-line data evaluation tool, but should become operational in the future. The EARLINET SCC is essential to implement sophisticated aerosol products (4 – 8) in Cloudnet.

**ACTION:** O'Connor to implement 1) and 2) after instrument calibration by the community (see Sec. 3).

**ACTION:** For sites with Doppler lidars, O'Connor to implement within Cloudnet processing.

**ACTION:** Community to determine appropriate PBL-height algorithm for backscatter lidar/ceilometer following results of COST SWG intercomparison.

**ACTION:** Wandinger and EARLINET/Cloudnet community to select appropriate algorithms 4) – 8).

**ACTION:** Cloudnet and EARLINET community to define and implement appropriate depolarization calibration schemes.

**ACTION:** Cloudnet community to apply algorithms 3) – 8) to sites with appropriate instrumentation.

***Data formats:***
The basic data format in Cloudnet and EARLINET is NetCDF. Standard EARLINET products (available via the EARLINET database) are so-called e-files and b-files containing extinction and backscatter profiles, respectively (for details see the EARLINET website, http://www.earlinet.org/). Furthermore, EARLINET has defined an nc file format for lidar raw signals in order to handle the data in the SCC (internal documentation, available on request). The same format is used in the combined lidar-sunphotometer algorithms.

It is recommended to follow EARLINET format definitions for lidar raw data and aerosol products in Cloudnet as far as possible in order to use the data in common algorithms and to avoid conflicts in the databases.

## 5. Incorporation of aerosol variables into Cloudnet scheme

The final goal of Cloudnet is to provide variables that can be directly compared to NWP model results. Stage one is to consider the lidar backscatter profile and then compare it with the forward modelled value from the aerosol properties held in the NWP model. This is the approach adopted when comparing CALIPSO spaceborne lidar profiles with the ECMWF MACC model. Some progress is being made compiling O-B statistics with this approach using the Met Office model.

**ACTION:** Discuss this implementation at the users consultation workshop in spring 2012.

**ACTION:** Wandinger to supply documentation of present technique for deriving the error bars in the lidar/ceilometer backscatter observed profile.

**ACTION:** O'Connor to document technique for deriving uncertainty in Doppler lidar backscatter measurements.

Stage two is to consider more advanced lidars with a Raman channel which provides direct observations of optical extinction profiles without need for calibration. This can also be compared with the sun-photometer optical depth.
Stage three is to consider the information in the color ratio, including the use of 1.5-2 µm lidars, and how this might be used to evaluate aerosol size held in NWP models.
Stage four is to consider the information from lidar ratio and depolarization ratio and color ratio and how this could be used. Because aerosols are usually present as mixtures it is probably difficult to retrieve the precise nature of the aerosols; instead a forward modeling approach using the NWP output which does carry a mixture of aerosols might be more productive.

**ACTION:** Discuss these various retrieval philosophies at the SWG meeting with NWP users in spring 2012. Need to consider the trade off between continuous ceilometer observations and the more intermittent observations from advanced lidars under EARLINET.

## References

Binietoglou, I., Amodeo, A., D'Amico, G., Giunta, A., Madonna, F., Mona, L., Pappalardo, G. (2011) Examination of possible synergy between lidar and ceilometer for the monitoring of atmospheric aerosols, SPIE Europe Remote Sensing, Proc. SPIE 8182, 818209.

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Heese, B. Flentje, H., Althausen, D., Ansmann, A., Frey, S. (2010) Ceilometer lidar comparison: backscatter coefficient retrieval and signal-to-noise ratio determination, *Atmos. Meas. Tech.*, **3,** 1763–1770.

O'Connor, E. J., Illingworth, A. J., Hogan, R. J. (2004) A technique for autocalibration of cloud lidar, *J. Atmos. Oceanic Technol.,* **21,** 777-786.

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## APPENDIX-1 Participant list

1. Henk Klein Baltink, Cabauw, KNMI, Netherlands
2. Adolfo Comeron, UPC, Barcelona, Spain
3. Kerstin Ebell, U of Cologne, Germany
4. Ulrich Goersdorf, DWD, Met Obs Lindenberg, Germany
5. Martin Hagen, DLR Oberpfaffenhofen, Germany
6. Anne Hirsikko, FMI, Finland
7. Anthony Illingworth, University of Reading
8. Holger Linne, MPI, Hamburg, Germany
9. Ulrich Loehnert, U of Cologne, Germany
10. Ewan O'Connor, U Reading UK and FMI, Finland
11. Christophe Pietras, IPSL, LMD, Palaiseau, France
12. Fabio Madonna, CNR-IMAA, Potenza, Italy
13. Giovanni Martucci, NUIG, Galway, Ireland
14. Kersten Schmidt, DLR, Oberpfaffenhofen, Germany
15. Boris Thies, University of Marburg, Germany
16. Herman Russchenberg, TU-Delft
17. Ulla Wandinger, Leibniz Institute for Tropospheric Research
18. Matthias Wiegner, LMU-MIM, Munich, Germany

## APPENDIX-2 AGENDA

**Monday 11.9.11**

11.00 Welcome and opening of the meeting.

11.10 Description of the 12 existing and candidate cloudnet stations.

12.30 Lunch

13.30 Continuation of description of the stations.

14.15 Overview of the cloudnet observations and processing scheme (Illingworth)

15.00 Coffee

15.30 Calibration, data format, target classifications, retrieval algorithms (O'Connor)

16.30 Incorporation of aerosol observations (Wandinger)

17.30 Close

19.30 Dinner

**Tuesday 12.9.11**

09.00 General discussion and conclusions.

12.00 Close the meeting.