The E-PROFILE network for the operational measurement of wind and aerosol profiles over Europe

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Abstract

E-PROFILE is part of the EUMETNET Composite Observing System, EUCOS, operating the European networks of radar wind profilers (RWP) and automatic lidars and ceilometers (ALC) for the monitoring of vertical profiles of wind and aerosols including volcanic ash.
The RWP network consisting of 29 systems is operational and part of EUMETNET since 2005. The network is assimilated in various global and regional numerical weather prediction (NWP) models and several recent studies have shown that RWPs have a positive impact on NWP, comparable to radiosondes. We will give a short update regarding the network performance and benefits of NWP.
The second component of E-PROFILE is the ALC network, which is under development in the current program phase. It has been shown in various publications that state of the art ceilometers have the capability to do vertical profiling of aerosols including volcanic ash. Hundreds of ALCs with profiling capabilities are operated across Europe and will be integrated in the E-PROFILE ALC network. Hence, this network has the potential to significantly improve the capabilities of the current observing system to detect volcanic ash and will provide the basis for new applications in the area of air quality and fog now–casting. In a tight collaboration with the COST action TOPROF, algorithms have been developed to calibrate ALCs using the atmosphere itself as calibration target achieving a calibration uncertainty of 25 %. These algorithms are currently being implemented on the ALC data hub where all ALC data will be received, processed and redistributed. We will give a detailed description of the network architecture, the calibration algorithms and the envisaged network density and discuss the benefits of the ALC network with focus on volcanic eruption events.

1 Introduction

The integration of radar windprofilers, hereafter referred to as windprofilers, into an operational European network has been prepared by the COST (Co-Operation in Science and Technology) action 76 "Development of VHF/UHF wind profilers and vertical sounders for use in European observing systems" lasting from 1994 to 2000. In the framework of COST-76 a demonstrator network consisting of 27 windprofilers has been set up which was put under the umbrella of EUMETNET (Network of the European Meteorological Services) in 2001. Since then the network is coordinated by EUMETNET under the programmes WINPROF (2001–2005), E-WINPROF (2006–2012) and E-PROFILE (2013–2018). The data are quality checked and made available in real time. Numerous numerical weather prediction (NWP) centers assimilate wind data from the European windprofiler network operationally. With the provision of continuous wind measurements in the boundary layer, the free troposphere and lower stratosphere the network meets key requirements of the NWP community as stated in the WMO (World Meteorological Organization) statements of guidance for Global and High Resolution NWP.

The integration of automatic lidars and ceilometers (ALC) into a harmonized and operational network has been triggered, on the one hand, by the eruption of the Icelandic volcano Eyjafjallajökull in 2010 which had a major impact on aerial transport in Europe. On the other hand, it was the COST action ES0702 "European Ground-Based Observations of Essential Variables for Climate and Operational Meteorology (EG-CLIMET)" which recommended ceilometers as a mature technology for operational aerosol profiling [4]. The integration of the ALC infrastructure into the E-PROFILE network is strongly supported by the follow-up COST action ES1303 "Towards operational ground based profiling with ceilometers, Doppler lidars and microwave radiometers for improving weather forecasts (TOPROF)". While the aerosol profiling capabilities of state-of-the-art ceilometers are modest compared to research lidars, they bring two major advantages: reliability and density. The mean time between failures of ceilometers is on the order of months and the expected network density is on the order of a couple of hundreds of instruments in Europe.

The paper is organized as follows: The windprofiler network and its impact on NWP is presented in Section 2. The ALC network and its components are described in Section 3. A summary and conclusions are given in Section 4.

2 The windprofiler network and its impact on NWP

2.1 Technical description

The E-PROFILE windprofiler network comprises of windprofilers operating in frequency ranges from 50 (VHF) to 1200 MHz (L-Band) covering an altitude range from near surface up to the mid–troposphere (L–Band) or lower stratosphere (VHF). A good introduction into the working principle can be found in the final report of COST action ES0702 EG-

CLIMET [4]. It shall be highlighted that the windprofiler is the only instrument that can provide continuous upper–air wind information under all weather conditions. Most of the windprofilers work with an integration time of 30 min and submit the retrieved profile of the wind vector to the E-PROFILE RWP data hub a few minutes after the end of the integration period. From there, the data are sent on to the Global Telecommunication System (GTS) where the users can access them. The typical time lag for the data to appear on the GTS is 10 – 15 min, which is suitable for the short cut-off times of high resolution NWP systems.
Sophisticated quality checking is performed as part of the processing of the raw data in real–time. Further, an off–line quality check is performed on the level of the data hub on a daily basis. Systems which send erroneous data to the data hub can be blocked manually to avoid that their data are sent on to the the GTS. This allows to increase in general the data quality of the windprofiler network. The most common issues lowering the data quality are bird migration and radio frequency interference (RFI). The use of recently developed filter techniques combined with advanced quality checking allows to eliminate almost entirely data contaminated by bird migration [5, 6, 1]. To avoid RFI, E-PROFILE is active on the international level to protect the frequency bands used by the windprofilers. Currently, all bands in use enjoy relatively good protection through international and national regulations but there is a high pressure on the electro–magnetic spectrum which requires constant activity to maintain the protection level.

2.2 Impact on NWP

With raising pressure on the operational budgets of the National Meteorological Services (NMS), it is more and more important to know the impact of a certain component of the observing system on NWP. Forecast Sensitivity to Observations, FSO, is a new tool which allows to assess the impact of a certain observation type on the short-range forecast [7]. As for all approaches to asses the observations impact, FSO is very sensitive to the period over which it is run. Hence, FSO results must be interpreted and compared with great care. [2] finds slightly negative impact for PILOT (radiosonde and windprofiler wind observations) for a 24 h forecast for the period June–July 2016 (1 month) and positive impact for the period January–February 2007 (1 month) using ECMWF's global assimilation system. Positive impact is reported by [3] for the period April–July 2013 for a 24 h forecast using the Met Office's global NWP system. When looking at the costs per impact, the windprofilers are at fifth position. Finally, positive impact is also reported by [9] for a three day period for 3–6 h forecasts using an approximation of the FSO tool for an ensemble based forecasting system.
While more studies are needed covering longer time periods, the conclusion that windprofilers have generally a positive impact on NWP with a high impact per cost seems not premature. It has further to be noted, that the windprofiler data used in the studies are of variable quality reflecting often the variable level of expertise and technical and financial support. Concerning the E-PROFILE network, the oldest system has started operation in

No.	Requirement
1	Operational Service
2	Position of ash cloud
3	Attenuated backscatter coefficient
4	Temporal resolution: 10 min
5	Timeliness: 10 min
6	Data access in real time
7	Quick–looks available on-line
8	Data in NetCDF and BUFR

Table 1: Short list of user requirements which will be met by the E-PROFILE ALC network.

1994 and is still running as an operational system while other systems have been replaced during the past 5 years and use latest technologies.

3 The ALC network and its components

3.1 User Requirements

The user requirements for the E-PROFILE ALC network have been identified based on WMO's OSCAR (Observations System Capability and Review) tool, official statements of key stakeholders and a user survey. A summary of the key requirement which E-PROFILE will meet is presented in Table 1. The ALC network will be an operational service meeting tight requirements regarding timeliness and data availability. But it will also provide quantitative information in form of attenuated backscatter coefficient. However two important requirements cannot be met by E-PROFILE: The provision of mass concentration of volcanic ash and the provision of the aerosol extinction coefficient. For this, additional information (Lidar ratio measurements and mass extinction efficiency) is required, which is not available operationally. However, in collaboration with research Lidar networks like EARLINET this capability may be developed in the future. A further important limitation of the ceilometer network is the vertical range. Only 35% of the ALC currently implemented in Europe can measure up to the tropopause and cover the en-route flight levels. Moreover, the detectability of elevated aerosol layers including volcanic ash depends strongly on the aerosol concentration and on the presence of low clouds. A systematic assessment of the performance of the different ceilometer types in use is outstanding and hence no statement can be made yet regarding the network performance to detect aerosols and volcanic ash in the upper troposphere.

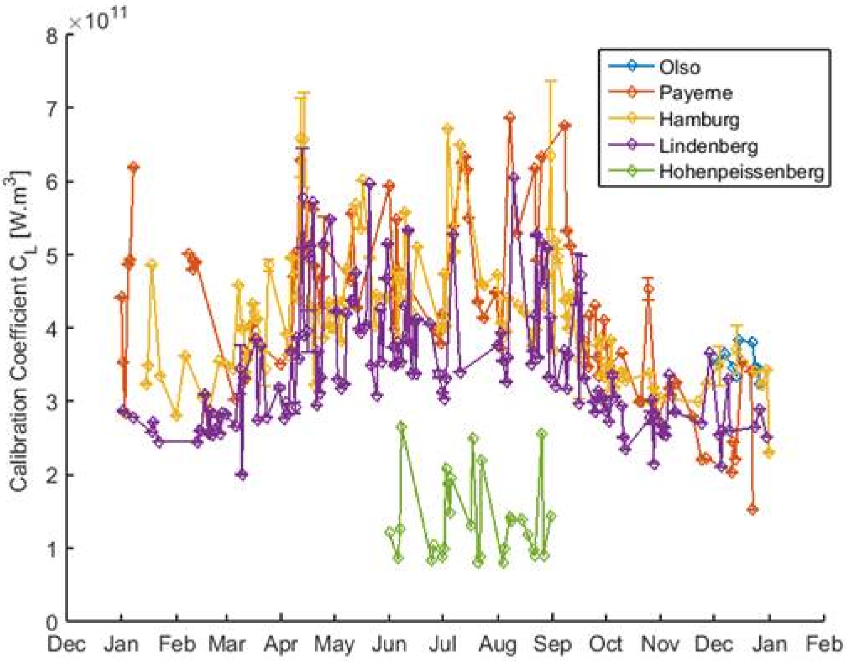

Figure 1: Time series of the calibration factor of 5 ceilometers of type CHM15k derived with the Rayleigh method (see text).

3.2 Product generation

In order to provide the attenuated backscatter coefficient, the network instruments need to be calibrated regularly. Two complementary calibration methods have been identified to be suited for network application. The first method, hereafter referred to as the Rayleigh method, is based on lidar returns from purely molecular layers and is described in detail in [11]. This method can be applied best to instruments using photon counting detection since the molecular return at wavelengths in the near infrared is very weak. The method requires the presence of a molecular layer and an atmosphere that is in good approximation constant over a few hours to allow for long integration times. Figure 1 shows the time series of the calibration factor of 5 ceilometers of type CHM15k over a time period of one year. The algorithm has been completely automated and favorable conditions are identified a few times per month throughout the year. The annual cycle visible for 4 out of the 5 stations in Fig. 1 has been found also applying external calibration using a research lidar which indicates that its origin is not methodological but rather instrumental. But further investigation is needed.
The second method, hereafter referred to as the cloud method, is based on the full attenuation of the lidar signal in a liquid cloud. This approach is described in detail in [8]. This algorithm is suited for instruments with analog detection which do not tend to saturate even for very strong returns from low clouds. Fig. 2 shows the average and the spread of

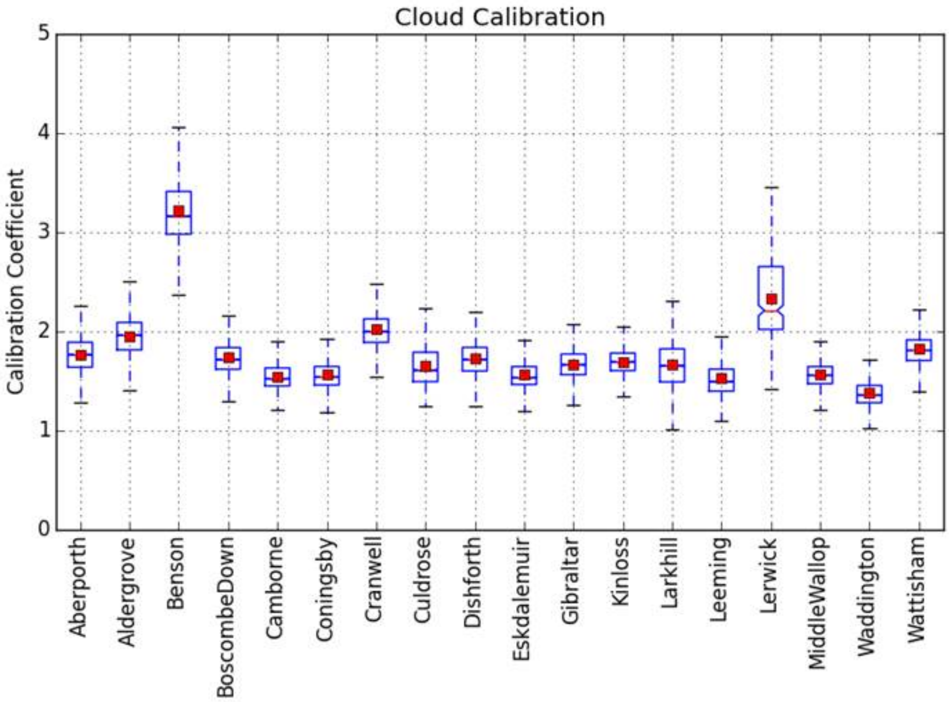

Figure 2: Average and spread of the calibration coefficient of the Vaisala/CL31 network of the Met Office derived with the cloud method calculated over 1 year (see text).

the calibration coefficients of the Vaisala/CL31 network of the Met Office calculated over one year with the E-PROFILE implementation of the cloud algorithm. Calibrations are possible several times per month and the algorithm is fully automatic. No significant drifts have been detected and the standard deviation is less than 10%. For wavelengths in the range of 910 nm absorption by water vapor according to [10] has been taken into account using water vapor profiles from a NWP model.
Both calibration algorithms have been validated in the framework of the measurement campaign CeiLinEx2015 organized by DWD in Lindenberg. Fig. 3 shows the difference in attenuated backscatter at 1064 nm between a suite of ceilometers and the research lidar Ralph (reference). Within the present aerosol layer between 1500 and 2500 m agl the difference is less than 25 %.

3.3 Data flow and dissemination

At the time of writing the operational ALC data hub is being set up according to the schematic shown in Fig. 4. The raw data are sent to the hub in instrument specific data files every 5 min. The hub converts the raw data files into L1 netCDF files every 5 min using the raw2L1 tool developed in the framework of the COST action TOPROF. This software is freely available at https://sourcesup.renater.fr/projects/sirta-raw2l1/. L1 files

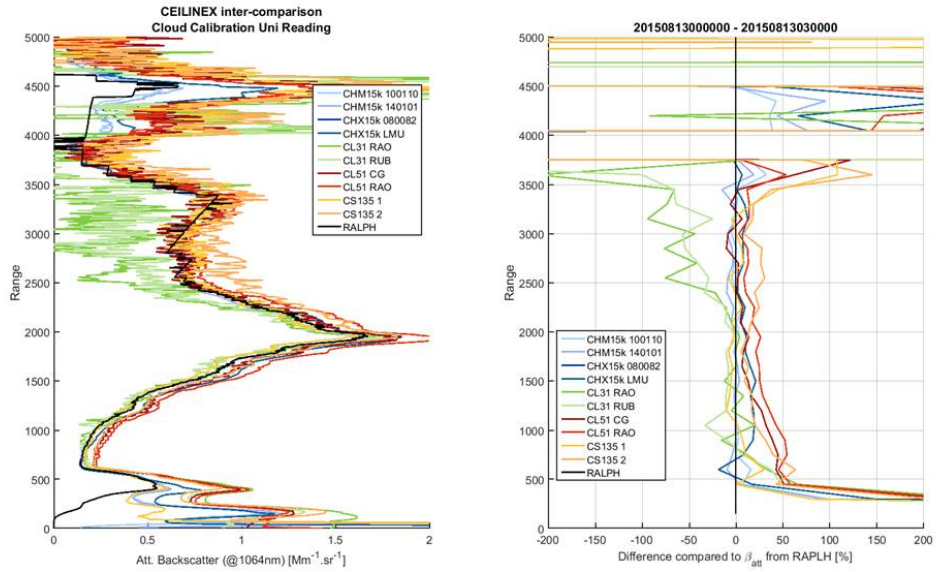

Figure 3: Left panel: profiles of attenuated backscatter coefficient at 1064 nm as measured with different ceilometers. Right panel: difference in attenuated backscatter coefficient at 1064 nm between the ceilometers and the research lidar Ralph.

conserve native time and space resolution. The calibration routines are executed once per day using L1 files as input. In case of successful calibration, the calibration coefficient is written into a dedicated file. L1 files are converted into L2 files every 5 min applying the calibration coefficient as well as user defined time and space averaging (currently none in space and 5 min in time). The L2 files are disseminated to the users in netCDF and BUFR format over ftp and GTS. Both, L1 and L2 files are archived.
Besides the dissemination of attenuated backscatter coefficient in netCDF and BUFR, quick–looks will be made available to the user at http://www.eumetnet.eu/e-profile.

4 Conclusions

E-PROFILE coordinates the European windprofiler network and is currently integrating the ceilometer infrastructure into an operation network for aerosol profiling. Based on several studies, windprofiler data have proven to be beneficial for NWP and there is a clear need to maintain the windprofiler network in Europe.
In a fruitful tandem between E-PROFILE and TOPROF a stable system has been established to process ALC backscatter data to provide attenuated backscatter coefficient profiles in real–time and on an operational basis from a dense network. The ALC network will obtain pre–operational status in 2016 and operational status in 2017. In the course of 2017 the network will be systematically expanded.
E-PROFILE meets key requirements of global and high resolutions NWP and will increase

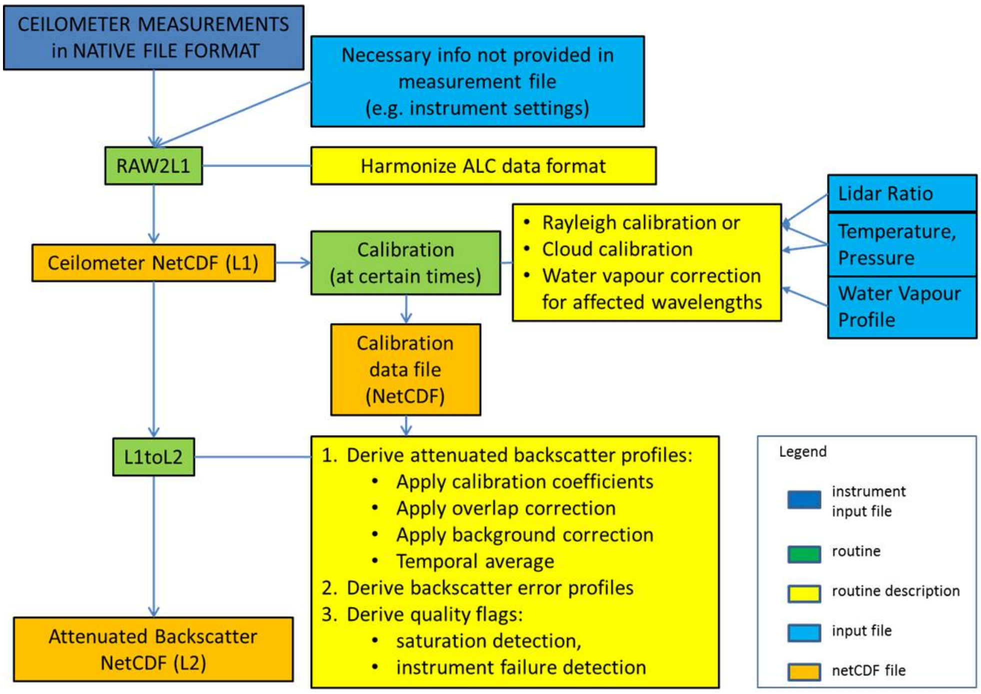

Figure 4: Schematic of the production chain of attenuated backscatter coefficient from raw data.

the capabilities of the observing system to detect volcanic ash over Europe.

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