Ceilometer for aerosol profiling: comparison with the multiwavelength in the frame of INTERACT (INTERComparison of Aerosol and Cloud Tracking)

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EGU2015-13353

Motivation and scientific objectives

Ceilometers are inexpensive instruments (typically in the 12-20k Euro range, but also up to 50k for high-end models) that are already deployed widely at meteorological observation stations and airports. These instruments are based on the lidar principle and measure backscatter returns, usually at 350-380 nm or 1644 nm, and have traditionaly been used only to report cloud base and vertical visibility, rather than the vertical profiles of the aerosol backscattering coefficient on which their retrievals are based.

These instruments show great potential for aerosol applications such as volcanic ash tracking [6], boundary layer monitoring [5], as well as cloud parameterisation. In order to make the best use of existing and future ceilometer deployments, they must be fully characterized.

The scientific objectives of INTERACT are to evaluate the stability, sensitivity, and uncertainties of ceilometer aerosol backscatter profiles, to evaluate the sensitivity, uncertainties, and idiosyncrasies of ceilometer automated cloud base detection, and to compare them with similar and co-located advanced multiwavelength lidar systems.

Approach

Comparison has been carried out among NASA lidar operational at CAH, and the three ceilometers described above.

It has been compared:

- the attenuated backscatter calculated using the Venus lidar retrieval of extinction for the NASA lidar;
- the attenuated backscatter calculated using the Clouds and Aerosols Lidar (CML) and Campbell (CS15) prototype;
- the attenuated backscatter for the 355 nm Jennifer ceilometer (CHM15Kt) obtained by calibrating the ceilometers signals on the MUSA data over a time window larger than 1 hour, and using a fixed lidar ratio of 3.5 sr/

Ceilometer attenuated backscatter profiles have been interpolated at the MUSA altitude. Only data above 1200 m above the sea level have been considered. No overpass corrections have been applied because of the large variability of the overpass correction, that needs further investigations. To compare 355-nm and 1644-nm attenuated backscatter coefficient profiles, the spectral dependencies of the attenuated backscatter coefficient have been calculated using the backscatter-related Angstrom exponent at 1044-522 nm retrieved from the NASA measurements, assumed as the best approximation of the lidar backscatter properties at both wavelengths.

Analysis of CL variability allows the stability of the lidar system to be tracked. The comparison shows that the variability of CL is quite high. The annual mean is around 20%. This means that the CL is not very well correlated with the ambient temperature. Indeed the correlation coefficient derived from a linear fitting between the ambient temperature and CL is 0.3. This could indicate that between a not negligible influence of the atmosphere on the CL system. This results in a large variability between years that is not related to seasonal cycles. A seasonal cycle of CL variability might exist but it is not evident on a mean seasonal scale. The relationship between the 355 nm aerosol extinction coefficient is provided by MUSA and the attenuated backscatter coefficient of CL calculated at 1044 nm by MUSA and by the three ceilometers, respectively, have been compared.

Differences among NASA and the ceilometers look proportional to the value of B and s, i.e. larger value of B and s are associated with larger differences between MUSA and each ceilometer. Larger value of B and s can be associated with summer and with the increase of surface temperature that affect the stability of ceilometer over short term period, inducing larger discrepancies when the temperature becomes warmer. Moreover, differences at large values of B and s are also probably related to limitations in dynamic range of the systems.

Conclusions

In conclusion, ceilometers show a good potential for aerosol profiling, but they are limited. They have shown promising capabilities in the detection and quantification of volcanic ash plumes, for example, during the volcanic eruptions in Indonesia of 2006-2009 and in the Eyjafjallajökull volcano of 2010. However, they have shown some limitations in terms of accuracy and in the detection of volcanic ash layers, and have been used mainly for monitoring the atmospheric ash are neutral. An extension of the current analysis to day to day is a future step. MUSA has been planned to check historical data from CT25K and CHM15K to confirm or improve the outcome of the INTERACT campaign.

Table 1: Specification of the MUSA lidar at 1044 nm and of the three co-located ceilometers. BRF indicates the half-angle rectangular field of view of the instruments. Due to the fact that laser divergence is smaller that 5mrad, the CT25K power inserects 100%. By the collimation calculation method described in Vande Hey et al. (2011), the instrument’s field of view was calculated for the study from specifications in the CT25 manual to be 45 degrees at 100 m, 78 degrees at 300 m, 85 degrees at 500 m, and reaching maximal value for the approach of 45°. The CT25K correction, which determine the instrument’s effective overlap, cannot be factored in this analysis. Martinec et al. (2008) reported observing overlap effects of the CT25K directly from its signature up to 450-500 m.

Results

Left panels show the probability density functions (pdfs) of B measured by MUSA and each of the ceilometers calculated for the whole INTERACT campaign (from 405 to 4500 m in g.p. to 10500 m in g.p.). MUSA’s pdf’s are considered as the truth/ reference. The number of cases available for each ceilometer and MUSA simultaneously is not the same due to the use of different selection criteria.

The comparison of the pdfs that CHM15K agrees closely with MUSA. CT25K underestimate in a more significant way the values of B measured by MUSA. CS15K is in very poor agreement with MUSA for values lower than 1.7 and mostly m-1. However, there were larger values of B are measured by CS15K probably because of the location affecting the signal. This indicates that the suppression of the electronic distortion might strongly improve the CS15K performance. Moreover, CT25K shows several very low values of B (<1.0-1.0 m-1) corresponding to much larger values of B for MUSA and CHM15K. The other deviations for both the CT25K and CS15K are mainly due their lower SNR than MUSA.

The right panels show the same as the left panels but only for the altitude levels above 3500 m. MUSA and CHM15K pdfs show good agreement, though CHM15K overestimates the values of B below 1.5-0.7 m-1. On the contrary, CT25K tracks (to some extent for the values ranging from 0.5-1.0 m-1 to 2.4-1.0 m-1) but the signal distortion compromises the comparison, and CT25K looks mostly independent of the other two instruments. The CHM15K setup permits better performance over a larger vertical range with respect to CS15K and CT25K which show perform better performance in the boundary layer.