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CEILOMETER AEROSOL PROFILING VERSUS RAMAN LIDAR IN THE FRAME OF INTERACT CAMPAIGN OF ACTRIS

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ABSTRACT

In this paper, multi-wavelength Raman lidar measurements are used to investigate the capability of ceilometers to provide reliable information about atmospheric aerosol properties through the INTERACT (INTERcomparison of Aerosol and Cloud Tracking) campaign carried out at the CNR-IMAA Atmospheric Observatory (760 m a.s.l., 40.60 N, 15.72 E), in the framework of ACTRIS (Aerosol Clouds Trace gases Research InfraStructure) FP7 project. This work is the first time that three different commercial ceilometers with an advanced Raman lidar are compared over a period of six month. The comparison of the attenuated backscatter coefficient profiles from a multi-wavelength Raman lidar and three ceilometers (CHM15k, CS135s, CT25K) reveals differences due to the expected discrepancy in the SNR but also due to effect of changes in the ambient temperature on the stability of ceilometer calibration over short and mid-term. Technological improvements of ceilometers towards their operational use in the monitoring of the atmospheric aerosol in the low and free troposphere are likely needed.

1. INTRODUCTION

For the study of both climate, air pollution and its influence on health, knowledge of vertical distributions of aerosols is a key factor. This scenario has pushed the demand for continuous aerosol measurements provided by high resolution networks of ground-based instruments also to validate and improve aerosol and pollution forecasting. In order to achieve broad, high resolution coverage, low-cost and low-maintenance instruments are needed. Despite of their differences from more advanced and more powerful lidars, low construction and operation cost of ceilometer, originally designed for cloud base height monitoring, have fostered their use for the quantitative study of aerosol properties. The large number of ceilometers available worldwide represent a strong motivation to investigate to which extent they can be used to fill the geographical gaps between advanced lidar stations and how their continuous data flow can be linked to existing networks of the advanced lidars, like EARLINET (European Aerosol research LIdar NETwork – Pappalardo et al., 2014).

In order to make the best use of existing and future ceilometer deployments, ceilometer must be better characterized. This is the purpose of the INTERACT campaign (Madonna et al., 2014) carried out at the CNR-IMAA Atmospheric Observatory (760 m a.s.l., 40.60N, 15.72E), named CIAO (Madonna et al., 2011), in the framework of ACTRIS (Aerosol Clouds Trace gases Research InfraStructure) FP7 project.

This work is the first time that three different commercial ceilometers with an advanced Raman lidar, MUSA (Multi-wavelength System for Aerosol) are compared over a period of six months. An overview of the results achieved during the campaign is provided.

2. METHODOLOGY

The INTERACT campaign, was held at CIAO in Potenza, Italy from 1 July 2013 to 12 January 2014, with the main scientific objective to evaluate the stability, sensitivity, and uncertainties of ceilometer aerosol backscatter profiles. Here, three commercial ceilometers (CHM15k, CT25K, CS135s) from different manufactures are compared with an advanced multi-wavelength Raman lidar (MUSA), and their aerosol detection sensitivity and stability are assessed using a dataset collected over a period of more than six months.

MUSA data (aerosol extinction and backscatter coefficients) are processed using the automatic Single Calculus Chain (SCC) of EARLINET (Pappalardo et al., 2014). The SCC is able to pre-processing lidar signals to provide aerosol optical and geometrical properties (e.g. layering) using Raman and elastic algorithms.
CHM15k data are collected using the JO-Dataclient software provided by the manufacturer, while the attenuated backscatter coefficient profiles are obtained by normalizing the ceilometer range-corrected signals to the corresponding MUSA attenuated backscatter coefficient profiles. Normalization was first attempted using a region 1-2 km wide, located at 6-7 km a.g.l. and identified as an aerosol free region identified from the quicklooks of the lidar measurements time series. This choice, however, tended to underestimate the normalization factor because of the very poor SNR of the ceilometer at those altitude levels. Throughout the campaign the ceilometer proved to be able to detect values of the attenuated backscatter coefficient larger than 1.0 10^{-7} m-1 sr-1 at altitude levels lower than 4 km a.g.l. with a vertical resolution of 30 m and a time resolution ranging from 45 to 120 minutes. Therefore, the normalization has been performed over a vertical range of 1 km, below the altitude level where this threshold value is detected. This typically occurs around 4 km and a detailed visual inspection has been also performed.
CS135's raw signals have been collected using a terminal emulator: attenuated backscatter coefficient profiles are obtained upon normalization on the corresponding MUSA attenuated backscatter coefficient profiles, using the same procedure followed for the CHM15k. Since signals in the upper troposphere were affected by electronic distortion, the normalization region has been selected typically immediately below 2.0-2.5 km in order to have a sufficient SNR to obtain a stable normalization over the lidar profiles.
The CT25K does not provide any raw signal but the so-called normalized sensitivity backscatter coefficient (that is proportional to the range corrected signal) through the manufacturer's software; therefore, attenuated backscatter coefficient profiles can only be obtained using the stratocumulus calibration typically performed within Cloudnet (www.cloud-net.org).

The time and vertical resolutions have been selected in order to keep the ceilometer SNR to sufficient levels to allow them to be compared to and calibrated by MUSA. In addition, for the CHM15k (to avoid problems with the sudden change of the internal gain automatically selected by the ceilometer itself) only signals corresponding to a value of the "base" (daylight correction factor) parameter less than 0.0015 (low background light level) are considered.
A comparison between the attenuated backscatter coefficient profiles provided by the four instruments (MUSA, CHM15k, CT25K, CS135S) is reported in Figure 1 and it is related to the observations collected on 15 July 2013 from in the time interval between 01:18 and 02:54. CHM15k profile is not corrected for the overlap function.

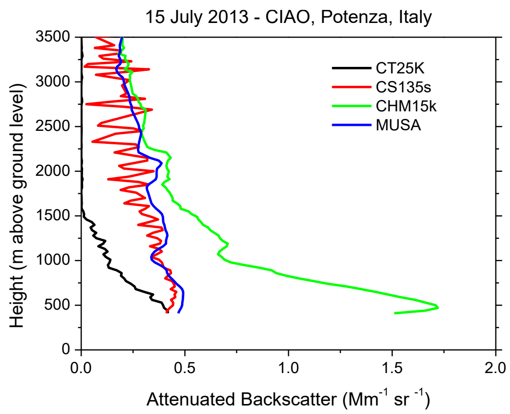

Figure 1: comparison between the attenuated backscatter coefficient profiles provided by the four instruments (MUSA, CHM15k, CT25K, CS135S) on 15 July 2013 from in the time interval between 01:18 and 02:54. CHM15k is not corrected for the overlap function.

3. RESULTS

In this section, a statistical comparison of the MUSA and the ceilometer attenuated backscatter coefficient is discussed. This is performed by comparing the probability density functions (pdfs) of the ß' retrieved for the simultaneous observations performed by the four instruments. Results of this comparison are summarized in Figure 2 that show the probability density functions (pdfs) of ß' measured by MUSA and each of the ceilometers calculated for the whole INTERACT campaign from 405 m a.g.l. to 10000 m a.g.l. MUSA 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 the selection criteria mainly affecting the CHM15k selected data. Moreover, for the CHM15k only data above 1.3 km above the ground have been considered to remove the region of incomplete overlap. This data selection is the reason for the difference among the MUSA pdf reported in the different panels of Figure 2. Under ideal conditions, the pdf's of the ceilometers and MUSA should be the same. Calibration error and a low SNR can largely affect the comparison. In the case of a calibration error, the pdf could show much higher or much lower values for the ceilometer with respect to the MUSA pdf, though the effect might compensate over the whole dataset. A low SNR, however, can show very high positive and very low negative values affecting, respectively, the values of the pdf higher than the maximum value observed by MUSA and values lower than 1.0 10^{-10} m^{-1} sr^{-1}.

The comparison of the pdfs shows that CHM15k agrees closely with MUSA; CT25K underestimates in a more significant way the values of ß' measured by MUSA. CS135s is in very good agreement with MUSA for values lower than 1.7 10^{-6} m^{-1} sr^{-1}, but few larger values of ß' are measured by CS135s probably because of the distortion affecting the signal. This indicates that the suppression of the electronic distortion might strongly improve the CS135s performance. Moreover, CT25K shows several very low values of ß' (<1.0-10 m^{-1} sr^{-1}) corresponding to much larger values of ß' for MUSA and CHM15k. The other deviations for both the CT25K and CS135s are mainly due their lower SNR than MUSA.

The relationship between the 355 nm aerosol extinction coefficient (α) provided by MUSA and the attenuated backscatter coefficient ß' obtained at 1064 nm by MUSA and by the three ceilometers, respectively, have been compared to further investigate the ceilometers' performance and their sensitivity to different aerosol types, i.e. different extinction coefficients. The parameter is calculated over the same time window as ß' but using a lower effective vertical resolution (typically within 480 m) in order to reduce the uncertainty and the related oscillation affecting the extinction profile calculated using the Raman lidar signal. The profile is output at 30 m vertical resolution to match the backscatter coefficient vertical resolution.

CHM15k shows a very good agreement with MUSA (the regression coefficient of the two attenuated backscatter coefficient is R=0.95), though a bit larger dispersion than MUSA in the relationship between and the ß' is observed. With an increasing value of the difference becomes larger and the value of the ß' is overestimated. This is particularly evident for values of α larger than 0.5 10^{-4} m^{-1}. Values of α larger than 0.5 10^{-4} m^{-1} are mainly located in the atmospheric region below 3 km above the ground.

In the case of the CS135s, three clusters of data are observed: the first corresponds to values of ß' higher than 5.0 10^{-7} m^{-1} sr^{-1} and values of lower than 0.5 10^{-4} m^{-1} where the values of ß' are largely overestimated by the CS135s because of the signal distortion; a second cluster corresponds to values of ß' lower than 5.0 10^{-7} m^{-1} sr^{-1} and values of lower than 0.5 10^{-4} m^{-1}, where the relationship looks well estimated but the noise affecting the CS135s is much larger than MUSA; finally, a third cluster corresponding to values of higher than 5.0 10^{-4} m^{-1}, where a small systematic effect seems to increase the values of ß' with respect to those measured by MUSA, which is probably related to the effect of environmental temperature, described above, on the CS135s hardware.

Finally, the CT25k show values in fair agreement with MUSA for the values of lower than 0.5 10^{-4} m^{-1}. Above this value, in agreement with the analysis reported in section 4.2, a systematic effect appears to increase the values of ß' with respect to those measured by MUSA. Values of above 0.5 10^{-4} m^{-1} the values are also strongly affected by the decrease of the SNR.

Differences between MUSA and the ceilometers are expected due to the large difference in the SNR due to their different laser sources. Nevertheless, all the plots show a difference between MUSA and ceilometers that looks proportional to the value of ß' and α. At CIAO, higher values of aerosol optical thickness are typically observed in summer than in fall and winter (Mona et al., 2006; Boselli et al., 2012). Therefore, the sensitivity issues ceilometers face in higher aerosol optical thicknesses are compounded by the larger discrepancies between ceilometers and MUSA at higher temperatures and, for the 905 nm instruments, by the higher water vapor content in the summer. In particular, warmer temperatures can decrease the efficiency of the ceilometer hardware and increase the bias of ceilometer attenuated backscatter coefficient profiles if calibration is not performed frequently. At large values of both of ß' and α also the insufficient dynamic ranges of the systems significantly affects the comparison.

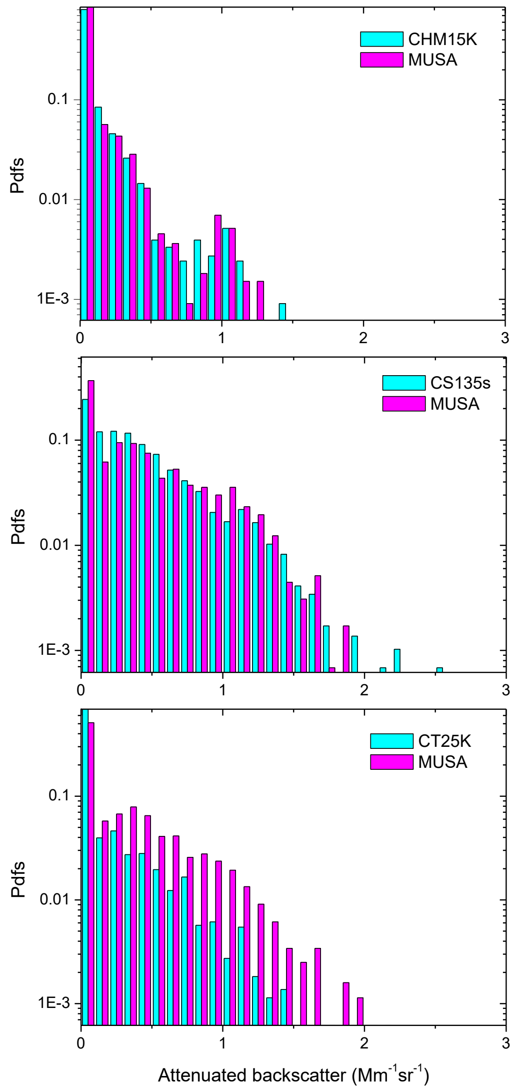

Figure 2: Probability density function of attenuated backscatter coefficient values retrieved from simultaneous observations performed by CHM15k and MUSA (upper panels), CS135s and MUSA (middle panels), CT25K and MUSA (lower panels).

4. CONCLUSIONS

The outcome of INTERACT campaign how ceilometers, though rugged instruments, are quite sensitive to the large changes in external temperature and collected background levels that occur on daily or seasonal bases; this generates adjustments of system parameters that affect the stability of the instrument response over the short and mid-term time period. Therefore, the use of a forward approach to calibrate a ceilometer using lidar observations or the use of a different calibration method should be frequently re-evaluated. Differences in the value of aerosol attenuated backscatter (ß') among the MUSA Raman lidar and the ceilometers look proportional to the aerosol extinction coefficient (α). Changes in the values of α can be associated to seasonal changes affecting the ambient temperatures and, therefore, the ceilometer stability.

In conclusion, further technological improvements of ceilometers towards their operational use in the monitoring of the atmospheric aerosol are likely needed. It is planned to study historical data available at CIAO to confirm or improve the outcome of the INTERACT campaign.

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