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

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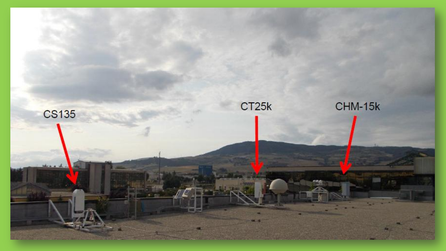
Motivation and scientific objectives

Ceilometers are inexpensive instruments (typically in the 12k-20k Euro range, but also up to 50k for higher-end models) that are already deployed widely at meteorological observatories stations and airports. These instruments are based on the lidar principle and measure elastically-backscatter returns, usually at 905-910 nm or 1064 nm, and have traditionally been used only to report cloud base and vertical visibility, rather than the vertical profiles of the aerosol backscattering coefficient on which their retrievals is based.

These instruments show great potential for aerosol applications such as volcanic ash tracking [4], boundary layer monitoring [5], as well as cloud parameterization. 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 simultaneous and co-located advanced multi-wavelength Raman lidar measurements.



Ceilometers located on the roof of the CNR-IMAA Atmospheric Observatory (CIAO) in Potenza [6].

Instrument	Wavelength (nm)	Pulse Energy (μJ)	Repetition Rate (kHz)	Configuration	Laser Divergence (mrad)	RFOV (mrad)	Approx. Full Overlap Height (m)
MUSA	1064	5.5 10^5	0.02	Biaxial (0.3° tilt angle between the two axis)	0.10	0.10	405
Jenoptik CHM15k	1064	8	5.0-7.0	Biaxial	0.15 (CHM15k Manual)	0.23 (Wiegner et al. 2014)	1500 (Heese et al. 2010)
Vaisala CT25k	905±5nm	1.6	5.6	Coaxial common optics	0.75 (CT25k Manual)	0.66 (CT25k Manual)	450-1000*
Campbell Sci CS135s	905±5nm	3	10.0	Split-lens biaxial	0.35	0.75	300-350 (Vande Hey, 2013)

Table: Specification of the MUSA lidar at 1064 nm and of the three intercompared ceilometers. RFOV indicates the half-angle rectangular field of view of the instruments. *Due to the fact that its laser divergence is smaller than its FOV, the CT25k never reaches 100% overlap. By the convolution calculation method described in Vande Hey et al (2011), the instrument's optical overlap was calculated for this study from specifications in the CT25k user manual to be: 45% at 100 m, 78% at 300m, 85% at 500m, and reaching maximum of 90% at approximately 1000 m, though unspecified internal corrections which determine the instrument's effective overlap could not be factored into this analysis. Markowicz et al (2008) reported observing overlap effects of the CT25k directly from its signal to up to 450-550m.

Approach

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

It has been compared:

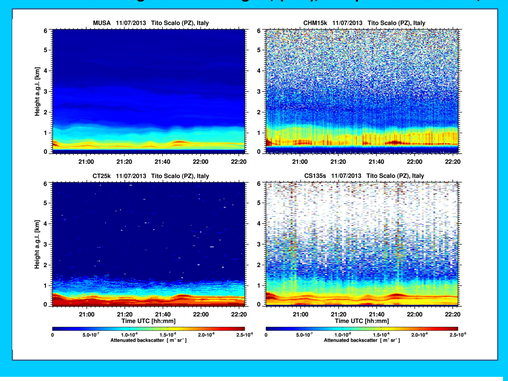
► the attenuated backscatter calculated using the Raman lidar retrieval of extinction for the MUSA lidar;

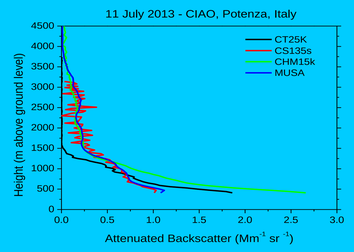
► the attenuated backscatter calculated using the Cloudnet calibration scheme (O'Connor et al., 2005) for the 905-910 nm ceilometers by Vaisala (CT25k) and Campbell (CS135s prototype);

► the attenuated backscatter for the 1064 nm Jenoptik ceilometer (CHM15k) obtained by calibrating the ceilometers signals on the MUSA signals over a time window larger than 1 hour, and using a fixed lidar ratio of 55 sr.

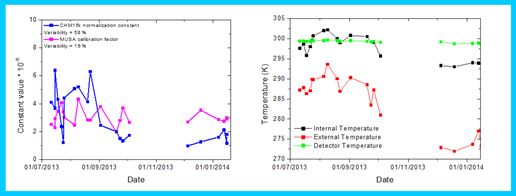
Ceilometer attenuated backscatter profiles have been interpolated at the MUSA altitude levels. Only data above 1200 m above the sea level have been considered. No overlap corrections have been applied because of the large variability of the overlap correction, that needs further investigations. To compare 905 nm and 1064 nm attenuated backscatter coefficient profiles, the spectral dependency of the attenuated backscatter coefficient has been considered using the backscatter-related Angstrom exponent at 1064-532 nm retrieved from the MUSA measurements, assumed as the best approximation of the 1064-905 backscatter-related Angstrom exponent

Comparison of MUSA Range-Corrected Signal, (RCS), Jenoptik CHM15k RCS, Vaisala CT25k





Comparison between the attenuated backscatter coefficient profiles provided by the four instruments (MUSA, CHM15k, CT25K, CS135s) on 11 July 2013 in the time interval between 20:50 UTC and 22:22 UTC (upper panel), and on 19 December 2013 in the time interval between 16:49 UTC and 18:10 UTC (lower panel). CHM15k is not corrected for the overlap function.



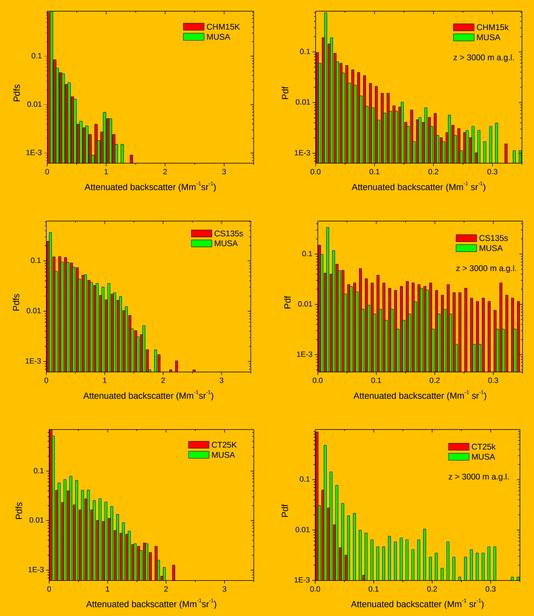
Analysis of CL variability allows the stability of the lidar system to be tracked. The comparison shows that the variability of CC is quite high, 58 %, while the variability of CL is 19 %. The internal temperature is also well correlated with the ambient temperature. Indeed the correlation coefficient derived from a linear fitting between the ambient temperature and CC is 0.6. This could indicate that there is a not negligible influence of the internal temperature on the instrument stability over short and mid-periods (~6 months) likely driven by changes in the external temperature (i.e. change of season). This indicates that thermal insulation or, more generally, the capability to have stable thermal working conditions for the ceilometer experimental setup is critical.

Results

Left panels 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 different selection criteria

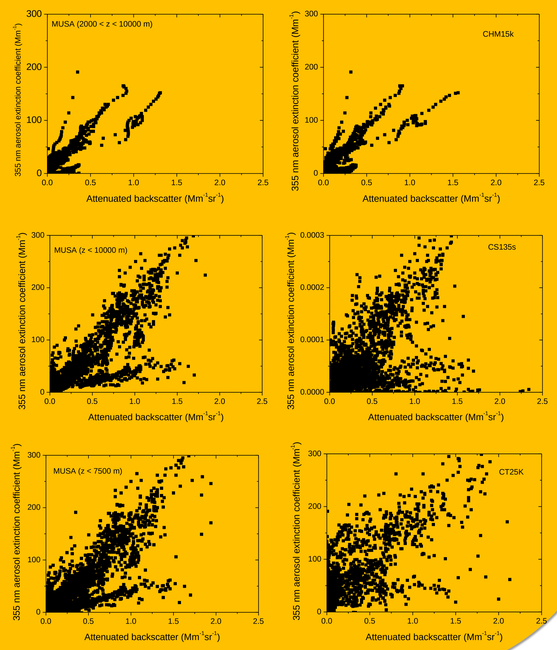
The comparison of the pdfs shows that CHM15k agrees closely with MUSA; CT25K underestimates in a more significant way the values of ß' measured by MUSA. CS135s is in very good agreement with MUSA for values lower than 1.7 10-6 m-1 sr-1, but few larger values of ß' are measured by CS135s probably because 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 right panels show the same as the left panels but only for the altitude levels above 3000 m. MUSA and CHM15k pdfs show good agreement, though CHM15k overestimates the values of ß' below 1.5 10-7 m-1 sr-1. On the contrary, CS135s tracks MUSA to some extent for the values ranging from 0.5 10-7 m-1 sr-1 to 2.4 10-7 m-1 sr-1 but the signal distortion compromises the comparison, and CT25K looks mostly insensitive to aerosol layers above 3000 m a.g.l. This indicates that the CHM15k setup permits better performance over a larger vertical range with respect to CS135s and CT25K which show perform better performance in the boundary layer.



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.

Differences among MUSA and the ceilometers look proportional to the value of ß' and , i.e. larger value of ß' and are associated with larger discrepancies between MUSA and each ceilometer. Larger value of ß' and can be associated with summer and with the increase of surface temperature that affect the stability of ceilometer over short term periods inducing larger discrepancies when the temperature becomes warmer. Moreover, differences at large values of both of ß' and α 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 of aerosol plumes in synergy with lidars and/or transport/chemical models (Emeis et al., 2011). Though differences among MUSA and the ceilometers are expected by the large difference in the SNR due to the different laser sources used by an advanced lidar and a ceilometer, further technological improvements of ceilometers towards their operational use in the monitoring of the atmospheric aerosol are needed. An extension of the current analysis to daytime is foreseen. Moreover, it has been planned to check historical data from CT25K and CHM15k to confirm or improve the outcome of the INTERACT campaign.

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Acknowledgements

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