Validation of automatic ceilometer calibration with lidar system and its application for layer detection

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Abstract.

Active remote sensing has been consolidated as a very useful tool to study the atmosphere. Particularly, the use of lidar systems has been mainly extended for determining aerosol optical and microphysical properties, whereas ceilometers has been used mainly for detecting cloud base height due to their lower signal-to-noise ratio compared to lidar systems. However, the potential spatial distribution of ceilometers is considerably higher than lidars and as well as their temporal resolution. Thus, the calibration of ceilometers for determining aerosol optical properties would help to improve the spatial and temporal resolution already reached using lidar systems. This work shows a methodology for the calibration of a ceilometer Jenoptik CHM 15k that consists on applying a Rayleigh fit in an automatic and non-supervised way. Results show the calibration factors retrieved with a 1.5-year measurement database performed at the Granada EARLINET station (Granada, Spain). In addition, a statistic calibration factor and standard deviation for the calibration factor value of $(4.6 \pm 0.9) \cdot 10^2\ km^3 sr$ is validated with lidar system. Finally, as practical application of the ceilometer calibration, layer detection algorithm is developed and evaluated.

Keywords: ceilometer, lidar, aerosol, calibration, atmospheric classification, EARLINET.

Introduction

Atmospheric aerosols influence to Earth climate in many different ways, being the main forcing agents of the climate system. Several in-situ or remote sensing networks provide atmospheric properties. In this sense, lidars have since become popular active remote sensing tools for aerosol studies, providing vertical profiles of atmospheric particles properties. Lidar networks as EARLINET (European Aerosol Research Lidar Nework) (Pappalardo et al., 2014) monitors aerosol transport over Europe and future plans are aimed at continuous measurements. Lidars are enough sophisticated and require qualified staff, making difficult the establishment of lidars thick networks. Ceilometers have the same principle that lidars with modest performance, but new generation of ceilometers seem to be a promising tool as lidar complement to obtain three-dimensional aerosol information. To this aim, calibration of ceilometers is needed to retrieval quantitative aerosol information. This study intend to validate Jenoptik CHM 15k ceilometer Rayleigh calibration by co-collocated lidar measurements in the framework of the TOPROF[1] COST Action.

Experimental site and instrumentation

The measurements used in this work were performed at Granada in South-Eastern Spain (Granada, 37.16ºN, 3.61ºW, 680 m asl[2]) in the Andalusian Institute for Earth System Research (IISTA-CEAMA). The station is member of EARLINET and AERONET (Aerosol Robotic Network). Ceilometer measurements were performed by a Jenoptik CHM 15k that include a pulsed Nd:YAG laser, emitting in 1064 nm of wavelength. Lidar measurements were performed by a multiwavelength Raman lidar system (Raymetrics Inc, model LR331-D400), emitting in 355, 532 and 1064 nm of wavelength. Finally, ground-based passive microwave radiometer RPG-HATPRO retrieves atmospheric temperature profiles.

Methodology

A. Pre-processing

In order to increase the SNR of ceilometer measurements, we perform a temporal and spatial average. After testing, profiles are packed and averaged for one hour for all the measurements. Moving average is used for the height average with windows sizes of 330 and 990 meters for calibration and lidar comparison, respectively.

B. Calibration algorithm

Rayleigh calibration method proposed by Wiegner et al. (2014) compares the range corrected signal retrieved by the ceilometer at free particles region respect to the

[1] TOPROF COST Action: Towards operational ground based profiling with ceilometers, doppler lidars and microwave radiometers for improving weather forecasts
[2] Above sea level

attenuated molecular backscatter at the same region (known by Rayleigh theory). The principal advantage of this method is that it does not need any additional data from others instruments.

The calibration algorithm searches a region where the slopes of both profiles are similar, assuming this region free of particles. Particles transmittance is unknown, so it is necessary to consider the following calibration factor:

$$C_L' = \frac{RCS(z_{ref})}{\beta_m(z_{ref}) \cdot T_m^2} \quad \text{Eq. 1}$$

Then, calibration process was automatized by the Atmospheric Physics Group.

Results

A. Sensitivity studies: height average and temperature and pressure profiles

In order to increase the SNR is necessary to establish the window size for the vertical profile average. The calibration method searches for molecular regions, thus as, a large average is necessary due to the weak molecular signal. Larger window sizes introduce an uncertainty in transition points that is not introduced in the molecular region where the changes are only due to noise. Therefore, in this work for the calibration we use a window of 990 meters, and a window of 330 meters for the comparison between lidar and ceilometer.

Rayleigh calibration requires molecular attenuated backscatter profile retrieval. This profiles can be derived from temperature (T) and pressure (P) profiles. Different methods to attenuated molecular backscatter retrieved can be performed. After testing, differences between methods are negligible therefore, we use the Scaled-SA[3] for the sake of simplicity.

B. Algorithm validation

The calibration process automatized by the Atmospheric Physics Group needs to be validated. An automatic algorithm is applied for the whole ceilometer dataset, obtaining a large number of calibration factors. These values show a high variability being necessary filter the calibration factor values obtained. Out of the filtered calibration

[3]SA: Standard Atmosphere (defined in 1976 by the American Meteorological Society). Scaled-SA uses the surface temperature and pressure measured at the meteorological station located at IISTA-CEAMA to model T and P atmospheric profiles.

factors, there are six coincident cases with lidar measurements that we can use to validate ceilometer calibration factor. Comparing each coincident case the relative error between ceilometer and lidar attenuated backscatter profile goes from 1% to 13% in the calibration region, being $6 \pm 4\%$ the mean relative error.

C. Statistic calibration factor

After restrictions, a mean value of the calibration factor is obtained, with a value of $C_L' = (4.6 \pm 0.9) \cdot 10^2\ km^3 sr$. Separating day- and night-time cases is possible to obtain a calibration factor for each period. Same values are obtained for separated time, therefore it is possible to find a calibration during day- and night-time with this algorithm and restrictions. Then, the validation of the calibration factor values is done by comparison with lidar cases. First case for validation shows comparison between lidar and ceilometer, using ceilometer attenuated backscatter profile retrieved with coincident calibration factor and statistic calibration factor. Second case shows ceilometer and lidar comparison for a case when it is not possible to calibrate, therefore using statistic calibration factor value.

Application: layer-detection algorithm

A. Layer-detection algorithm

Once the ceilometer is calibrated, it is possible provide a vertical structure of the atmosphere distinguishing between aerosol, cloud or molecular (near free particles) regions. The $\beta_{att}(r)$ depends on the atmospheric components, being larger values for clouds than for aerosol or molecules. Furthermore, with different thresholds is possible to identify the different atmospheric components. Thresholds used are based on others algorithms for vertical structure classification of the atmosphere such as STRAT (Morille et al., 2007). For this identification, ceilometer data average of 15-min temporal average and 30-meters height moving average are used

B. Algorithm evaluation

After description, we evaluated the layer-detection algorithm during July and August 2013. For this purpose, we show 2 analyzed cases with different atmospheric conditions. For each case we show the detection for the complete day and the β^{att} profile for one period of each day. Finally, we present a statistical analysis of aerosol maximum height during the same period (Jul-Aug 2013). For this research period, percentage of time where the maximum height of aerosol is above to 1, 2, 3, 4 and 5 km is of 98%, 74%, 22%, 5% and 2% respectively.

Conclusions and perspectives

The calibration factor for the ceilometer was validated with lidar system. This comparison was in good agreement with a relative error mean value of $6 \pm 4\%$ between lidar and ceilometer. Finally, for the ceilometer used in this work the calibration factor value retrieved was: $C_L' = (4.6 \pm 0.9) \cdot 10^2\ km^3 sr$.

Once calibrated, and as practical application of the ceilometer calibration, we developed and evaluated a layer-detection algorithm. Two cases with different atmospheric conditions was analyzed. In these cases, attenuated backscatter profiles comparisons with algorithm detections showed that layers transition are in disagreement. Also, aerosol detection above 5 km seems difficult as Wiegner et al. (2014) showed.

As future research will be advisable extend this studies to other EARLINET stations where Jenoptik CHM 15k ceilometers are available. Aerosol Optical Depth (AOD) retrieval with ceilometers is a challenge, in particular automatic retrieval. In regard to layers detection algorithm, include wavelet transform or derivative methods can improve layers transition detection. Finally, possible correlation between height of Planetary Boundary Layer (PBL) and aerosol maximum height can be evaluated.

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