# COMPOSITE PROFILE DERIVED FROM LIDAR AND CEILOMETER SIGNALS

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## ABSTRACT

The aim of this study was to explore the possibility to extract as much information as possible from the two systems, Ceilometer and LIDAR (LIght Detection And Ranging), by combining the best of their characteristics: continuous monitoring capabilities and low overlap of the Ceilometer and the good accuracy and calibration of the LIDAR. Measurements were performed at the Faculty of Physics and National Institute of Optoelectronics (INOE2000), Magurele (26.029E, 44.348N, ASL: 93m). Based on the LIDAR and Ceilometer signals, the composite profiles were constructed for selected days in each of the four seasons of 2009. A close correspondence between the two signals was found, emphasizing/showing the possibility to extrapolate the signals coming from the LIDAR below 700m. Consequently, combining the two backscattering-coefficient vertical distributions from LIDAR and Ceilometer, the height and mixed height of Planetary Boundary Layer (PBL) can be determined regardless the LIDAR overlap.

## 1. INTRODUCTION

The PBL (Planetary Boundary Layer) is the lower layer of the atmosphere that is sensitive to the effect of the Earth's surface, controls the flow of heat and momentum between the surface and the free atmosphere, thus playing a key role in atmospheric circulation, air composition and atmospheric processes [1]. The presence of aerosols and clouds within the PBL allows for the determination of the height of this important layer. As aerosols dominate the optical properties of the atmosphere, optical (LASER) remote sensing techniques have been in use for over a half century to study the atmospheric composition [2]. One of the earliest and important achievements of LIDAR (LASER RADAR) has been its capability to measure remotely atmospheric aerosols [3]. The knowledge of their properties and spatio-temporal distribution, as well the understanding of physical processes require the study of aerosol loading in the atmospheric boundary layer, which extends from the surface of the Earth to about 1.5-2.0 km altitude during daytime, in various geographical locations and under various meteorological conditions.

After the development of new lasers and photodetectors, various types of ground-based LIDAR systems (including Ceilometers) have been continuously used to probe the Earth's atmosphere and to measure aerosol optical properties (optical depth, spatial distribution and layering, diurnal variation etc.) [4].

A program that studies atmospheric aerosols using the LIDAR technique has been used at Magurele (a suburban area of Bucharest) in Romania, taking into account that the boundary layer has a structure that evolves with the diurnal cycle and geographical location [5].

The height of PBL was identified by using different methods applied to LIDAR [6] and to Ceilometer CL31 signals [7]. Unfortunately, PBL data retrieved by LIDAR and Ceilometer were in good agreement only in the cases when PBL height was over 700m, the height from which the LIDAR starts the measurements.

An analysis of the correlation of PBL heights obtained using the two equipments are outside the scope of this paper; the aim is to establish a correspondence between LIDAR and Ceilometer signals, to cover the LIDAR overlap. Therefore, in Section 2 the characteristics of the two equipments were discussed, and the method used to extrapolate the LIDAR signal below 700m by using Ceilometer's signal. In Section 3, the results are discussed and the conclusions end the paper.

## 2. DATA AND METHODS

The optical backscattering intensity of the air was measured with a Väïsäla CL 31 Ceilometer, on single-lens technology, 910nm wavelength. Recorded data can cover the range from 0 to 7500m altitude, with 20m vertical resolution and 2s temporal resolution. The LIDAR system is based on a short-pulse high power LASER operating at 3 elastic wavelengths (1064, 532 and 355nm) with full overlap around 700m and a signal-to-noise-ratio (SNR) <3db up to 20km altitude (depending on the atmosphere and integration time).

The measurements were performed at the Faculty of Physics with the Ceilometer), and at INOE2000 (26.029E, 44.348N, ASL: 93m, Bucharest-Magurele, Romania) with the LIDAR, in spring, summer, autumn and winter days, under clear and sunny conditions during a stable, high-pressure period. We selected LIDAR signals at 1064nm wavelength, which is the closest to the sounding wavelength of the Ceilometer (910nm). Ceilometer data (backscattering coefficients) were averaged over 60 minutes and the Ceilometer wavelength (910nm) was translated to the LIDAR wavelength (1064nm). Based on the LIDAR and ceilometer signals, composite profiles were constructed as follows. First, an altitude interval was selected, that was comprised between the last LIDAR measurement and the maximum value of the backscattering coefficient. All backscatter values within these limits were averaged. Within the same altitude limits, all Ceilometer-derived backscatter coefficients were averaged as well. Next, for each Ceilometer and LIDAR signal, a confidence function was constructed. Thus, between the ground level (20m) and the last LIDAR measurement (840m), the confidence function for ceilometer is 1; between 840m and 2000m the confidence function decreases linearly from 0 to 1, and from 2000m and the first LIDAR measurement (5000m) the confidence function is 0. Conversely, the confidence function for LIDAR signal is 0 between ground level and 840m; it increases linearly between 840m and 2000m, and is 1 from 2000m to the end.

The Ceilometer and LIDAR signals were weighted by the corresponding confidence functions, and then the two resulted profiles were added. This way, between 20m and 840m the information is given by the Ceilometer; between 840m and 2000m the information is composed from both Ceilometer and LIDAR, and above 2000m the information is assured by the LIDAR signal.

## 3. RESULTS AND DISCUSSIONS

Results obtained for the selected days show that this method is good for extrapolating the LIDAR signals below 700m. An example is depicted in Fig. 1 for the distinct case of July 8th, 2009. The upper panel is showing the initial Ceilometer backscatter, the Ceilometer's profile normalized to the LIDAR in the range 1500 - 1700m and the final LIDAR-Ceilometer composite signal for 60-minutes averaging intervals. The lower panel is showing the temporal evolution of the LIDAR range-corrected signal for an extended time interval, with the purpose of visualizing the general state of the atmosphere: presence of low and high clouds, stability and possible precipitation.

This case was characterized by almost clear sky conditions, having only few profiles corrupted by clouds, however sufficient to provide the Ceilometer a good calibration. The Ceilometer employs clouds for calibration, as described in Väïsäla CL31 User's Guide (2006).The agreement between the two instruments is quite good even quantitatively, after averaging. Nevertheless, this could be a coincidence, knowing that the average is containing the contribution of clouds for the Ceilometer, but does not contain the same contribution for the LIDAR.

The clouds increase the value of aerosol backscatter in an artificial way, which compensates the underestimated backscatter from PBL aerosols. Other cases either confirm, or contradict this situation, since the presence of clouds is very important in the analysis of coincidence of backscattering coefficients profiles.

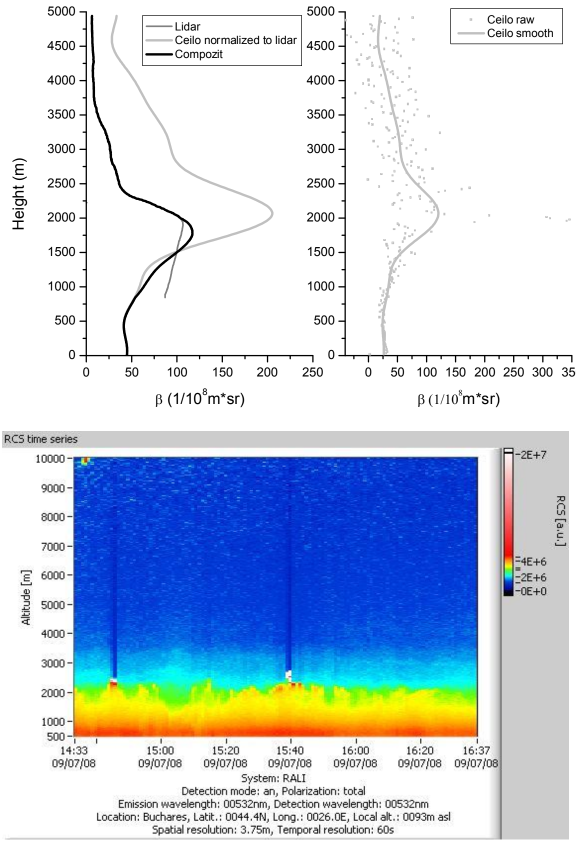

Figure 1. *Backscattering coefficient profiles obtained with LIDAR and Ceilometer systems for July 8th, 2009 within the hourly intervals of 14.33-15.33 (a) Upper panel: Ceilometer signal normalized to LIDAR is shown with a light grey line; the thin grey line is the LIDAR signal, and the thick black line is the composite signal. Right: Raw Ceilometer signal is shown with a light grey line and the smoothed signal with a solid black line. Lower panel: LIDAR RCS time series for the time period.*

## 4. CONCLUSIONS

The calibration of the two systems is very important in obtaining the coincidence of backscattering profiles. The results of this study have shown the following:

- The backscatter for Ceilometer is seriously underestimated in case of clear sky, when clouds are not available to perform the calibration; in addition, the estimation of the calibration value inside the clouds is an important source of uncertainty, providing the fact that different clouds have different optical properties.

- Calibration is not an issue for LIDAR, which uses regions free of aerosol in the high-range, as calibration interval.

- The Ceilometer also has a very low sensitivity to aerosols, which makes the retrieval uncertain in regions where the aerosol load is not significant, i.e. where the SNR is low; generally, for those regions the algorithm is not able to distinguish the presence of particles because of the noise, and therefore assumes no aerosols, thus generating an underestimation of the backscatter coefficient.

- Calibration, low sensitivity especially during daytime (due to increased background radiation), and the necessity of heavy smoothing because of the noise in the signal, all prevent the Ceilometer from accurately detecting the PBL height in most of the situations. This situation improves when clouds are present in the entrainment zone.

- Beyond all the assumptions and the large errors caused by calibration and smoothing, there is still an important information contained in the Ceilometer data, which is lacking in the case of LIDAR (e.g., how well-mixed is the PBL, PBL height during night time when is decreasing bellow the LIDAR overlap, long-term monitoring of diurnal cycle under all-weather conditions etc.).

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