RAMAN LIDAR CHARACTERIZATION OF PBL HEIGHT AND STRUCTURE DURING COPS: COMPARISON BETWEEN DIFFERENT APPROACHES

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ABSTRACT

The planetary boundary layer includes the portion of the atmosphere which is directly influenced by the presence of the Earth's surface. Aerosol particles trapped within the PBL can be used as tracers to study boundary-layer vertical structure and time variability. The PBL height and structure can be estimated based on the use of Raman lidar data. The method is based on the first order derivative of the range-corrected elastic signal (RCS), which is a modified version of the method defined by Seibert et al. [1] and Sicard et al. [2]. Estimates of the PBL height and structure are obtained from the above mentioned approach are compared with simultaneous estimates obtained from potential temperature profiles determined from the radiosondes launched simultaneously to lidar operation. Additional estimates of the boundary layer height are obtained from rotational Raman lidar signals, used for temperature measurements signals. Preliminary results and correlation are illustrated and discussed.

INTRODUCTION

The planetary boundary layer (PBL), the lower region of the atmosphere in direct contact with the Earth's surface and is directly influenced by this surface. In this layer physical quantities such as flow velocity, temperature, moisture etc., display rapid fluctuations (turbulence) and vertical mixing is strong. The characterization of planetary boundary layer is of primary importance in a variety of fields as weather forecasting, climate change modelling and air quality prediction [1]. Aerosol particles are trapped within the PBL and can be used as tracers to study boundary-layer vertical structure and time variability. Aerosols can also be dispersed out of the PBL during strong convection or temporary breaks of the capping temperature inversion. Therefore aerosol backscattered signals collected by lidar systems can be used to determine the height and the internal structure of the PBL [1,2]. Several methods have been applied to estimate PBL height from lidar signals in the presence of mixed, stable and residual boundary [4,5,6,7,8]. However, the complexity of the phenomena occurring within the PBL and the influence of advection and local accumulation processes in many cases prevent unambiguous determination of PBL height from lidar signals, especially when aerosol stratifications are present within the PBL. The present works aims to compare different approaches to characterize the PBL height and structure based on the data provided by a Raman lidar system with aerosol, water vapour and temperature measurement capability. A method based on the first order derivative of the range-corrected elastic signal, which is a modified version of the method defined by Seibert and Sicard is considered and compared with simultaneous estimates obtained from potential temperature profiles determined from radiosonde data and with estimates obtained from rotational Raman lidar signals.

BASIL

The University of BASILicata Raman Lidar system (BASIL) was deployed in Achern (Black Forest, Germany, Lat: 48.64 °N, Long: 8.06 °E, Elev.: 140 m) in the frame of the Convective and Orographically-induced Precipitation Study [9,10]. The COPS experiment was held in Southern Germany and Eastern France in the period 01 June - 31 August 2007, as part of the German Research Foundation (DFG) Priority Program 1167 “Quantitative Precipitation Forecast, with the overarching goal of advancing the quality of forecasts of orographically induced convective precipitation by four-dimensional observations and modelling of its life cycle [11,12,13]. During COPS, BASIL operated between 25 May and 30 August 2007 and collected more than 500 hours of measurements, distributed over 58 measurement days and 34 intensive observation periods (IOPs). Quick-looks of the data are available on the COPS Website (http://www.cops2007.de/), under Operational Products, while data for the most important IOPs can be downloaded from the World Data Center for Climate (http://cera-www.dkrz.de/WDCC/ui/BrowseExperiments.jsp?proj=COPS). All other data can be requested directly to the authors of this paper.

The major feature of BASIL is represented by its capability to perform high-resolution and accurate measurements of atmospheric temperature and water vapour, both in daytime and night-time, based on the application of the rotational and vibrational Raman lidar techniques in the UV [14,15,16,17]. Besides temperature and water vapour, BASIL provides...
measurements of the particle backscattering coefficient at 355, 532 and 1064 nm, of the particle extinction coefficient at 355 and 532 nm and of particle depolarization at 355 and 532 nm [18,19,20].

RESULTS

The algorithm used in this work consider the quantity:

\[ D(z) = \frac{d}{dz} \left( \ln \left( P_1 \left( \frac{z}{h} \right) \right) \right) \quad (1) \]

where \( P_1(z) \) is the elastic lidar signal and the quantity \( P_1 \left( \frac{z}{h} \right) \) represents the range correct signal.

The minima of the quantity \( D(z) \) identify the transitions between different layers. The first minimum usually identifies the boundary layer height. This approach is identified as “approach 1” in what follows. For the purpose of this study, expression (1) was applied to the elastic lidar signals at 1064 nm, because of the larger sensitivity of this wavelength to aerosols and their variability. Potential temperature profiles, \( T_{pot}(z) \), obtained from the radiosonde data, can also be used to get additional estimates of the boundary layer height.

In this regard, we need to recall that temperature measurements are performed by \textit{BASIL} through the application of the rotational Raman lidar technique in the UV, which is based on the detection of pure rotational Raman scattering from oxygen and nitrogen molecules in the proximity of the laser wavelength (\( P_{1_{rot}}(z) \) and \( P_{2_{rot}}(z) \)). Atmospheric temperature can be obtained from the power ratio of high-to-low quantum number rotational Raman signals. Both \( P_{1_{rot}}(z) \) and \( P_{2_{rot}}(z) \) are characterized by a strong sensitivity to temperature variations, the variability being anyhow larger for the signal \( P_{1_{rot}}(z) \) than for the signal \( P_{2_{rot}}(z) \). In the approach 2 considered in the present paper expression (1) is applied to the rotational Raman signal \( P_{1_{rot}}(z) \).

Figure 1 illustrates the lidar measurements of the particle backscattering ratio at 1064 nm on 15 July 2007. The black line in this figure represents the PBL height as determined through the application of approach 1. Figure 2 illustrates the evolution of the boundary layer height as obtained from approach 1 and 2 and the radiosonde data for 15, 25 and 30 July 2007. The figure covers the complete cycle of the PBL evolution with both night-time and daytime and the transitions between the two. For all cases the PBL height is found to grow during the day, reaching a maximum value in the early afternoon and then decaying later in the afternoon and evening. In the figure the continuous lines identify the estimates obtained from approach 1, while the yellow stars represent the estimates obtained from the potential temperature profiles of the radiosondes and the blue squares represent the estimates obtained from approach 2.

For the purpose of the application of approaches 1 and 2, for the signals \( P_d(z) \) and \( P_{1_{rot}}(z) \) we used an integration time of 30 min and a vertical resolution is
300 m, which allowed to reduce signal statistical fluctuations which could affect their applicability. It is to be noticed the good agreement between the different approaches, with deviations between the different estimates never exceeding 200 m. These results support us on the applicability of the present techniques and the possibility to apply them to different case study characterized by different meteorological conditions.

In figure 3 we have compared the outcome of the different algorithm based on the application of a least-square fit analysis. Specifically, figure 3a illustrated a liner fit of the PBL estimates from approach 1 versus those obtained from the radiosonde data, while figure 3b illustrated a liner fit of the PBL estimates from approach 2 versus those obtained from the radiosonde data, with the correlation coefficients being $R=0.978$ and $R=0.961$, respectively.

![Figure 3](image)

**Figure 3**: Panel a): PBL estimates from approach 1 versus those obtained from the radiosonde data, panel b) PBL estimates from approach 2 versus those obtained from the radiosonde data. The figure also illustrates the best fit lines for these datasets.

**CONCLUSION**

The present work compares estimates of the PBL height for specific case studies as obtained from three distinct methods. The first approach (approach 1) considers a method based on the first order derivative of the range-corrected elastic signal, which is a modified version of the method defined by Seibert et al. [1] and Sicard et al. [2]. Potential temperature profiles, $T_{pot}(z)$, obtained from the radiosondes launched simultaneously to lidar operation are also used to get additional estimates of the boundary layer height. Additional estimates of the boundary layer height and structure are obtained from rotational Raman lidar signals (approach 2). These good agreement between the different approaches support us on the applicability of the present techniques and the possibility to apply them to different case study characterized by different meteorological conditions. In this respect, the dataset collected by BASIL during COPS provides a unique source of information for the study of the boundary layer structure and evolution.

**REFERENCES**


