PLANETARY BOUNDARY LAYER INVESTIGATION FROM LIDAR MEASUREMENTS OVER BUCHAREST

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The Planetary Boundary Layer (PBL) heights have been calculated using the ratio of the two elastic channels, 1064 nm and 532 nm of a multiwavelength LIDAR system (RALI) located in Măgurele, near Bucharest, Romania, at the Romanian Atmospheric 3d Research Observatory. The measurements have been done continuouly between 09 and 12 July 2012. In this study we relied on the gradient method applied to the Range Corrected Signal (RCS). This method follows aerosols as tracers. The results from the three continuous days show the diurnal variation of the PBL above Măgurele. First day of the results shows an intrusion of long ranged transported aerosols mixed within the PBL. Also first day of measurements has the highest PBL at 2265 meters above sea level according to the highest air temperature 38^0 Celsius.

Keywords LIDAR, Planetary Boundary Layer, diurnal variation, gradient method.

1. Introduction

Atmospheric processes' studies need proper consideration of the Planetary Boundary Layer (PBL). Knowledge of its properties and structure helps a better parameterization of the phenomena from this part of troposphere. Also PBL plays a key role in atmospheric circulation [3].

Troposphere is the main layer of the atmosphere, in direct contact with the Earth's surface and concentrates the most part of air mass. High concentration of aerosols, water vapor and pollutants are present in this layer.

Bucharest is an industrialized region and is affected by the presence of particles with a diameter lower than 2.5 μm in higher concentrations as a result of emission of particles and precursor gases. These particles are dangerous to both people and environment [1].

PBL is the lowest part of the atmosphere and the first level of the troposphere directly influenced by the processes at ground level. Here are produced the most important meteorological phenomena such as rain, snow, as well as cloud formation. It has a thickness of 1 to 3 km. In this layer the vertical gradient of temperature and humidity is very high. Adding the high

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wind speed in this region result in a very turbulent air where an active exchange of heat due to evaporation from the surface and momentum due to friction between Earth surface and atmosphere occurs.

PBL is divided in three parts, one is the Mixed Layer (ML), very turbulent, another one is the Residual Layer, more calm, and the Nocturnal Layer. The ML is turbulent because of the temperature inversion and the friction forces between PBL and the layer above it and leads into a Residual Layer (RL). The layer above PBL is called Free Troposphere (FT). The ML is always present during daylight while at night it disappears fast [1].

This paper presents an improved gradient method of calculation of PBL from Range Corrected Signal (RCS), which is the mean power of the backscattered light multiplied with the squared distance. This signal considers the system function, the effective area of the receiver, the backscattered coefficient, the spatial resolution and the transmittance. For this paper were used the ratio of measurements of the two elastic channels, the 1064 nm and the 532 nm.

The gradient method assumes that the PBL contains much more aerosol particles than the free troposphere so that a strong decrease of the backscatter signal is observable at PBL top. This method follows aerosols as tracers.

2. Experiment and instruments

At RADO (Romanian Atmosphere 3D Research Observatory) a multiwavelength Raman LIDAR (LIght Detection And Ranging), RALI continuously measured between 9th and 12thof July 2012.This data set has been used for analysis of the PBL height.

Measurements took place in Măgurele (44^{0} 20' N, 26^{0} 01' E), near Bucharest, Romania (Fig. 1). Bucharest is capital of Romania and its biggest city with lots of industrial aerosol sources.

Fig. 1Location site via maps.google.ro

The LIDAR system used for these experiments has a Q-switched Nd : YAG laser which emits with short pulses (9ns), and a pulse repetition frequency of 10 Hz, on 3 main wavelengths, the fundamental, 1064 nm, the second harmonic at 532 nm and third harmonic at 355 nm. The total emitting energy is 330 mJ and the laser beam diameter is 6 mm [1] [2]. The laser beam has a divergence of 0.88 mrad. The backscattered radiation is collected with a Cassegrain telescope which has a diameter of 400 mm. The field of view of the telescope is variable, minimum range is 1 mrad. The LIDAR system is in monostatic arrangement, biaxial configuration with the overlap at 700m.

The LIDAR system has a spatial resolution of 3.75 m and a maximum range of approximately 15 km, depending on weather conditions. The LIDAR system is positioned 93 m above sea level.

3. Methodology

There are different ways to determine PBL height, based on direct measurements of the atmosphere using meteorological towers [14], radiosounding [13][15], and also based on remote sensing measurements using SODAR [8] or LIDAR [1].

The gradient method [1] has been used in this study to determine the PBL from LIDAR measurements, which follows aerosols as tracers.

Other methods to determine PBL height are the variance analysis and wavelet covariance technique. A good comparison of these three methods is well described by H. Baars, et al [16].

Whenever the signal to noise ratio is sufficiently high, the optimum results in the retrieval of layer altitude are obtained by applying the gradient method to the RCS. This method is not very sensitive to layer substructure and returns only the major peaks of the RCS derivative. Therefore, this method is the best approach for this study, a very sensitive method such as wavelet could be inappropriate. Moreover, the signal to noise ratio from the RALI system is generally higher than the threshold, therefore more sophisticated methods are not necessary for the PBL identification [15].

This method uses Range Corrected Signal (RCS) of the LIDAR output [1]:

$$RCS(\lambda_D, Z) = S(\lambda_D, Z) \cdot Z^2 \tag{1}$$

Where: Z is distance (meters), λ_D is the wavelength of the detected backscattered radiation, S (λ_D, Z) is the LIDAR mean power obtained from:

$$S(\lambda_D, Z) = S(\lambda_L, Z_0) \cdot C_S(Z) \frac{A_0}{Z^2} \delta Z \cdot \beta_{atm}(\lambda_D, \lambda_L, Z) \cdot T_{\rightarrow}(\lambda_L, Z) \cdot T_{\leftarrow}(\lambda_D, Z) \tag{2}$$

Where: S(λ_L,Z) is the medium laser power at λ_L wavelength, $C_S(Z)$ is the system function that considers the transmitters and receivers efficiencies, A_0 is the effective area of receiver, δZ is the spatial resolution, $\beta_{atm}(\lambda_D, \lambda_L, Z)$ is the backscattered coefficient, $T_{\rightarrow}(\lambda_L, Z)$and $T_{\leftarrow}(\lambda_D, Z)$ are the atmosphere transmittances from transmitter to probe and back.

For this study measurements of two elastic channels of the LIDAR system were used, the 1064 nm, representing the fundamental wavelength of the laser, and the second harmonic 532 nm channel. We analyzed the ratio of the two elastic channels for different reasons. One is that although the full overlap of the lidar system used here is generally around 750m, for the purpose of this study we applied the gradient method to the ratio of 2 channels' range corrected signals: RCS_{1064}/RCS_{532p}. This improves the retrieval, which is no longer affected by the incomplete overlap region, but keeps the information on layering [17].

Other is to highlight the micron and submicron aerosols, the 1064 nm channel is more influenced by the micron aerosol while the 532 nm channel highlight submicron aerosols. Other is to highlight the PBL height in cases where there is long range transported aerosol intrusion as it can be seen in the results chapter.

For each channel a RCS dataset was used. It contains a header with information about the starting date and time of the measurements, spatial and temporal resolutions, location site and the location of the LIDAR system according to sea level.

For three days of continuous measurements the PBL heights have been calculated. The 72 hours measurements were divided in 18 data sets, each containing 4 hours of measurements. The PBL heights were calculated for each data set and the diurnal variation of PBL was analyzed.

For the PBL analysis, RCS vertical profiles were all averaged 5 minutes. Each of these new vertical profiles was derived and a smooth function was applied, in order to reduce the noise. This smooth function uses a moving average filter with a specified span. After multiple interpolations, it was concluded that 25 is best span for this study.

Within these smoothed profiles the negative peaks are calculated. This function compares each element of the data with its neighboring values. If an element of the data is smaller than both, the element is a local peak with the specification that one peak is considered valuable if has a minimum absolute peak value.

Explanation for this minimum peak value is to avoid other small layers within PBL and to reduce noise. Each of the vertical profiles can have multiple peaks. The first negative peak means the presence of the PBL height, other negative peaks represents other aerosol layers from the free troposphere [1].

Additionally, positive peaks have been calculated. Every positive peak means the beginning of a new aerosol layer in the atmosphere. Consequently, above this positive peak, every negative peak will not be considered any more in further evaluations as it can be seen in Fig. 2. These considerations proved to be helpful when the PBL height points were calculated for the night measurements, where PBL was below the overlap threshold and the LIDAR system „saw" only some RL from the FT and when there were some long range transported aerosol intrusions.

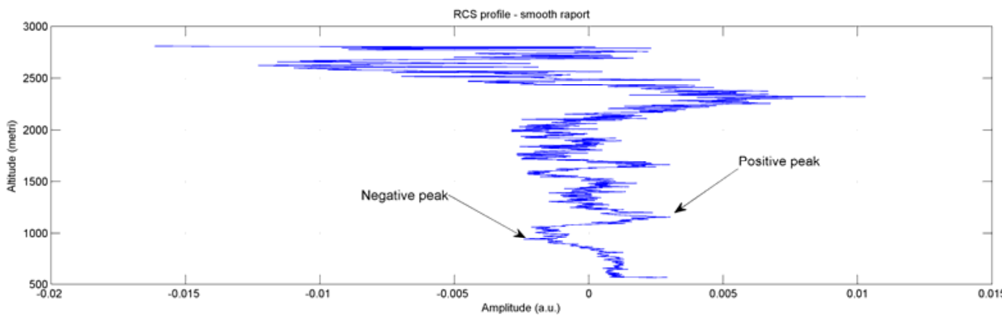


Fig. 2 RCS profile and the presence of negative and positive peaks

It can be seen that the first negative peak is around 1000 meters and it marks the top of the PBL. Other negative peaks in the vertical profile highlight the presence of different aerosol layers in the FT.

For every 4 hours of the data sets, PBL height has been determined according to the previous PBL height due to continuous considerations. Every first PBL height of a data set was considered a reference point and afterwards every negative peak was compared to the previous PBL height and the peak with the smallest difference is considered the next PBL height. After each data set of measurements there were 10 to 15 minutes breaks, due to instrument constrains.

The reference PBL height point is manually choose from one of the peaks of a vertical profile, after a careful visual examination.

For both negative and positive peaks calculations an empiric law have been considered for a better signal/noise ratio.

For a better visualization of the RCS it has been used a color graphic as:

(3)

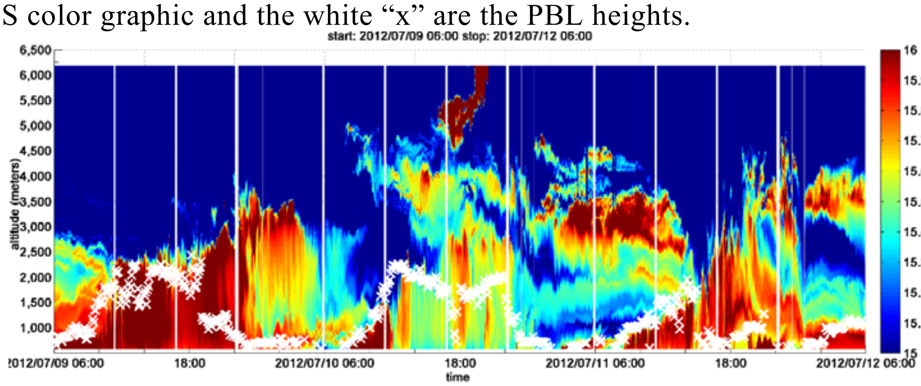
Where RCS_{1064} is the elastic RCS channel at 1064 nm,

With dark red color is represented the highest intensity and blue is the lowest intensity (arbitrary units)(Fig.3).

4. Results and discussions

In theory, each negative peak of the first derivative of RCS represents the top of an aerosol layer but the first negative peak represents the PBL height [1]. An example is shown in Fig. 2 where a smoothed vertical profile of RCS is represented.

Following the procedure described in the methodology chapter, the reference PBL height was chosen at approximately 720 m. Fig. 3 shows the RCS color graphic and the white "x" are the PBL heights.



Fi. 3 RCS time series with PBL height points calculated for the three days measurements 09-12.07.2012

The highest temperature was during the first day (38^0 Celsius) and also the PBL height had the highest level at 2265 meters above the sea level. During the next two days PBL height had a downward trend (highest points at 2261 meters and 1957 meters respectively) as also had the air temperature (www.meteoromania.ro/anm).

On the 9th of July morning an intrusion of long range transported aerosol influenced the atmosphere and later it was mixing within the PBL. Due to this event the PBL height points calculated during that time cannot be calculated precisely.

4.1. Morning measurements

During the morning it can be seen that the PBL height is increasing from full overlap height to approximately 1000 m. This is shown in Fig. 4 and Fig. 5, the time series of the RCS for July 9th and 10th respectively.

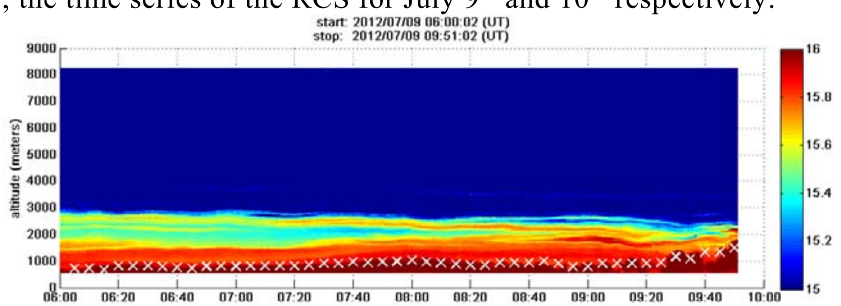


Fig. 4 PBL height evolution during morning measurements on 9th July 2012 starting at 6:00 am UTC

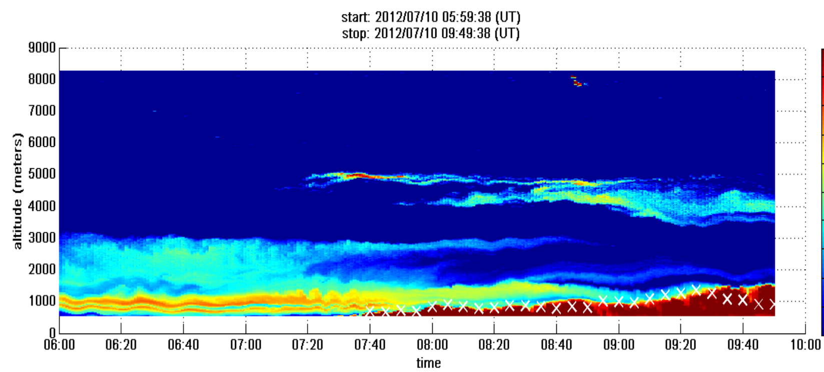


Fig. 5 PBL heights during morning measurements on 10th July 2012 starting at 5:59 am UTC

It can be seen that in the morning of 10th July for the first hour and a half the PBL height is below the overlap's system, only RL can be seen, and then it rises up to more than 1000m.

4.2. Mid-day measurements and aerosol intrusion

In the middle of the day, the PBL height it is highest. This can be seen in Fig. 6.

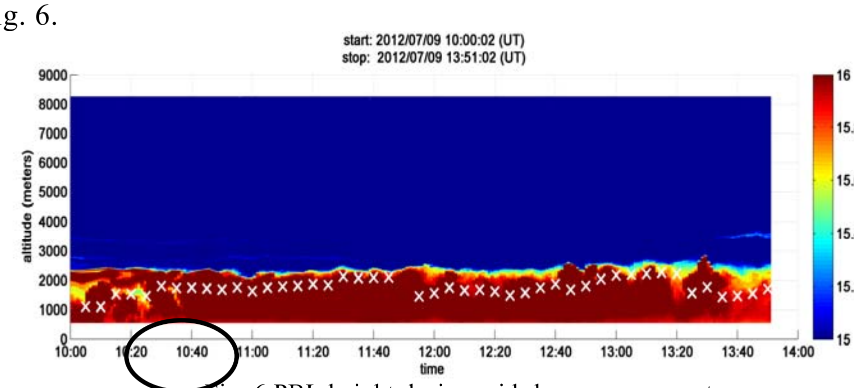


Fig 6 PBL height during mid-day measurements

During this particular measurement, it can be seen that, beside the PBL, a different aerosol layer at about 2 Km can be highlighted (marked with the black circle in Fig. 6.). The assumption that this new layer is long ranged transported aerosols layer is verified using Global Data Assimilation System backward trajectories.

The further analysis using GDAS, National Oceanic and Atmospheric Administration (NOAA), HYSPLIT model, backward trajectories shows that, at around 2000 meters above the measurement site, the air masses are coming from south Kazakhstan, a dust region source(Fig. 7).

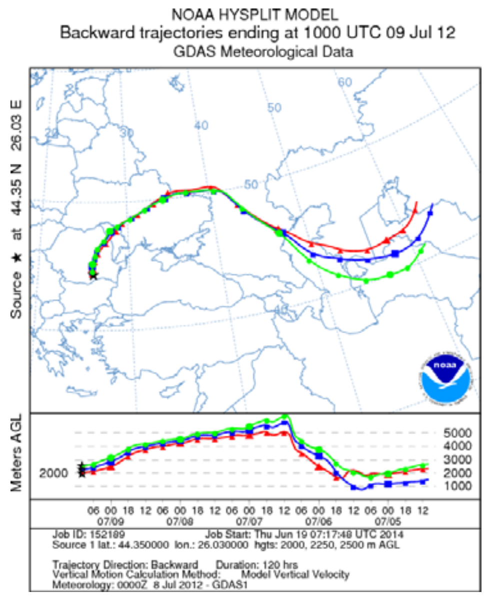


Fig. 7 NOAA HYSPLIT MODEL, Backward trajectories, GDAS

Further in time the layer mixes with the PBL and becomes indistinguishable by the LIDAR system.

4.3. Evening and night measurements

A good example of how RL emerges from PBL during evening measurements is shown in Fig. 8 and Fig. 9.

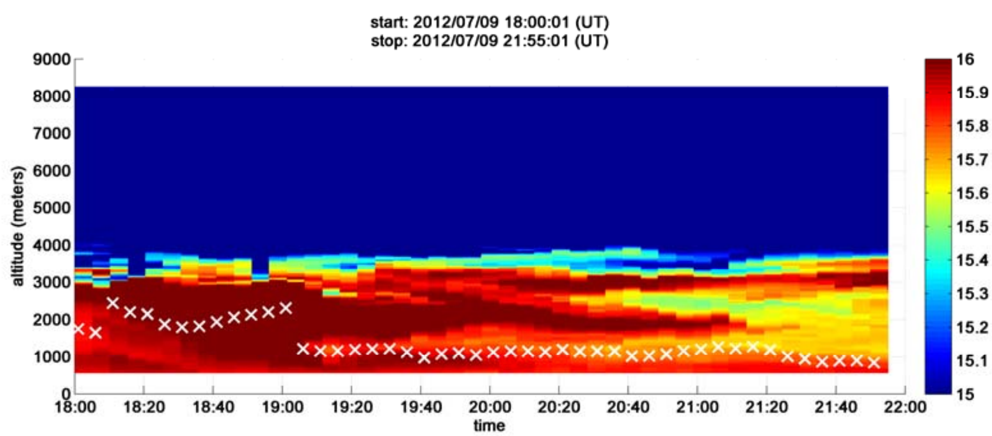


Fig. 8 RL emerges from PBL, 9th July 2012

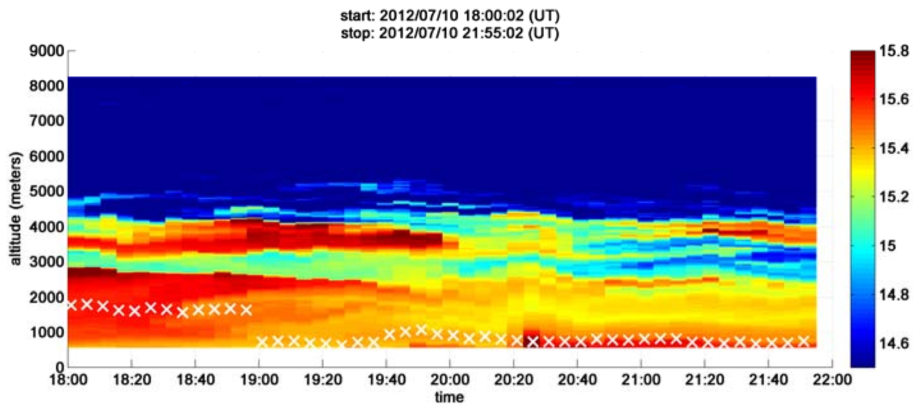


Fig. 9 RL emerges from PBL, 10th July 2012

One example, regarding night measurements where PBL height is below overlap threshold is shown in Fig. 10.

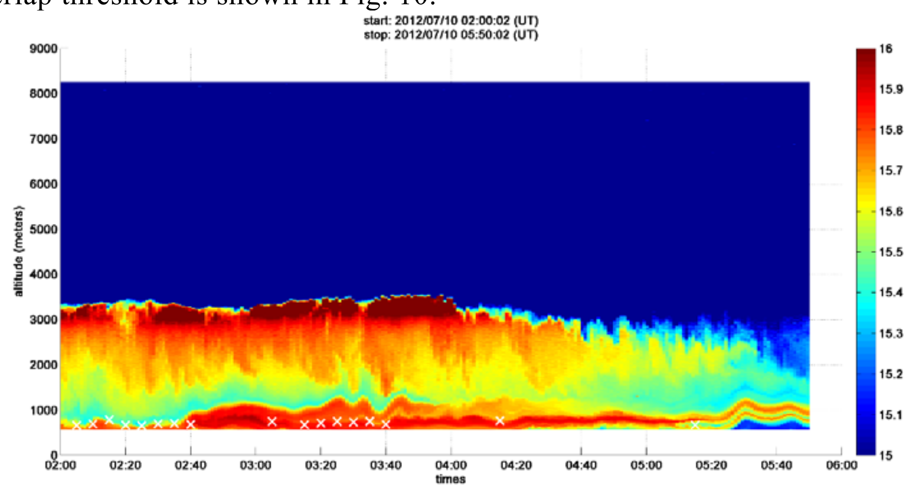


Fig. 10 Night LIDAR measurements with very low PBL height points

5. Conclusions

Vertical profiles of backscattered signal were retrieved using a multiwavelength RALI LIDAR system located in Măgurele, near Bucharest.

For each vertical RCS profile PBL height was calculated using an improved gradient method. From the three days continuous measurements it can be seen the diurnal variation of the PBL.

Morning, mid-day and evening measurements were analyzed to see the local PBL evolution.

In the afternoon of the first day a long range transported layer was detected which mixed within PBL. Backward trajectories analysis using

HYSPLIT confirmed the origin of the air masses arriving above the measuring site.

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