Detection of atmospheric boundary layer height from lidar measurements

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The dynamical behavior of the ABL (Atmospheric Boundary Layer) has a direct effect on the depth (or height) of the ABL and its turbulent strength changes significantly during the large-scale dust intrusion. Active remote sensing systems such as LIDARs use aerosols as tracers of the ABL dynamics. In this paper, we use backscatter LIDAR measurements from a scientific research center in Magurele, Bucharest area (44.35 N, 26.03 E) to provide information about the ABL height evolution, correlated to Saharan dust intrusions over Romania and to meteorological conditions. The Richardson number method is also used to estimate the boundary layer height. The results of this work demonstrate the importance of knowledge of LIDAR as tool for atmospheric investigation.

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1. Introduction

The Atmospheric Boundary Layer (ABL) has an important role for the whole atmosphere-Earth system because it acts as an interface where the coupling between the atmosphere and the Earth's surface occurs. The ABL contains most of the aerosol and water vapor in the atmosphere and thus has a major influence on radiative fluxes. Therefore, studies of climate sensitivity require careful consideration of the role of the ABL. Environmental applications also include long-term air-quality and climate modeling, air chemistry, and meteorological forecast modeling.

The top of the ABL has been given many names, the most popular being **inversion height**, **mixing height** and **mixed-layer depth (MLD)**. The commonality exists in that they all refer to the greatest depth to which atmospheric constituents are well mixed. The ABL is usually within 1000 meters off the surface but it is variable in space and time, ranging from hundreds of meters to a few kilometers [Stull, 1988].

Strawbridge, K. B. and B. J. Snyden [Strawbridge et al., 2004] demonstrated that LIDAR has been shown for many years to provide accurate measurements of the MLD. Several methods have been employed to extract the MLD from LIDAR data. These include critical threshold techniques, gradient techniques, wavelet analyses and techniques using idealized profiles. The LIDAR signal shows a strong backscattering within the ABL, decreasing through a transition zone and becomes weak in the free troposphere. This behavior is the base for the LIDAR estimation of the ABL height. Usually, the transition zone can be assumed proxy for the temperature inversion. Menut [Menut et al., 1999] have shown that the MLD is related to humidity effect. The height of the ABL can also be calculated using the bulk-Richardson number or Richardson number [Troen, 1986]. However, interpreting data from LIDAR must take into account possible advections of air masses that can change the vertical mixing. The aim of this paper is to provide information about the ABL height evolution, correlated to Saharan dust intrusions over Romania and to meteorological conditions, by using backscatter LIDAR measurements. The analysis was applied to individual LIDAR profiles (Section 2 –Data and Methods). The results, presented in Section 3, were compared to values of the mixed layer depth calculated by using the radio-soundings data, and the Richardson number. In addition, the results were discussed in synoptic context, using maps and air mass back-trajectories. The conclusions are presented in the final of the paper.

2. Data and methods

The LIDAR system LISA (LIght Scattering Aerosol), from the scientific research center in Magurele, is based on a Nd:YAG laser, working at the 1064 nm fundamental wavelength and at 532 nm second harmonic, delivers pulses with high repetition rate. The analyzed measurements have been made at ROMEXPO, northwestern part of Bucharest (44.25 N, 26.05 E) in April 2006. The range-squared-corrected signal (RSCS), defined as $RSCS = (S - S_0) \cdot r^2$, was used to numerically compute the profiles of backscattering coefficient and aerosol numeric concentration. The height of the ABL was obtained by three numerical methods: statistics, wavelet and the absolute minimum of the first derivative (Gauss). The top of the ABL is marked by a temperature or an equivalent potential temperature inversion, a change in air mass, a hydro-lapse, and change in wind speed and/or direction. The humidity also affects the mixed layer. All these information are shown on radio-soundings and synoptic maps used for the study. To emphasize the change in air mass kinematics backward trajectories have been invoked. The version 4 of the Hybrid Single–Particle Lagrangian Integrated Trajectory model (HYSPLIT4), developed by the National Oceanic and Atmospheric Administration (NOAA)'s Air Resources Laboratory (ARL) [web reference] was used. The height of the PBL determined from LIDAR data was also compared with the values determined using the Richardson number. The Richardson number, R_i is a function of altitude, as follows:

$$R_i = \frac{\left(\dfrac{g}{\theta}\right)\left(\dfrac{\partial\theta}{\partial z}\right)}{\left(\dfrac{\partial V}{\partial z}\right)^2}, \tag{2.1}$$

where g is the acceleration due to gravity, θ the potential temperature and V the wind speed.

3. Results and discussions

The tracer role of aerosols has been used in the RSCS profiles and backscattering coefficient dependence of altitude to determine the height of ABL.

The evolution of ABL can be observed in Figs. 1-4. During the day, the turbulence determines the mixed layer height (Figs.1-2). The MLD is about 1500 m. In the evening (19UTC), the ABL height was about 500 m, due to the decrease of energetic fluxes, and the atmosphere became stable (Figs.3-4).

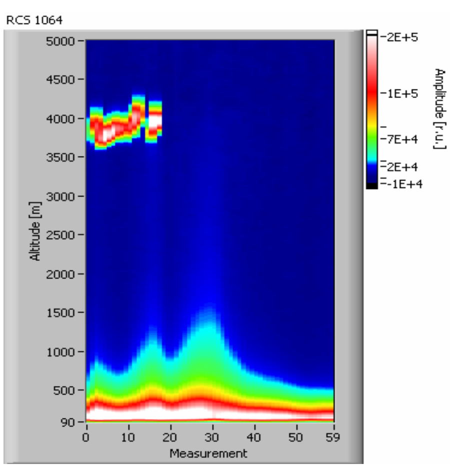


Fig. 1. Range Corrected Signal (a.u.) – temporal evolution - on April 5th 16:00 UTC, 1064 nm sounding wavelength.

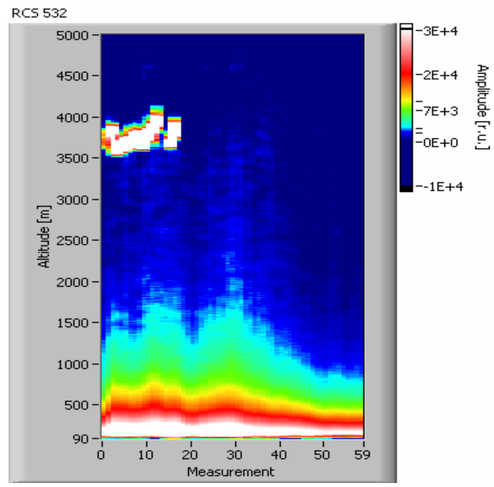


Fig. 2. Range Corrected Signal (a.u.) – temporal evolution - on April 5th 16:00 UTC, 532 nm sounding wavelength.

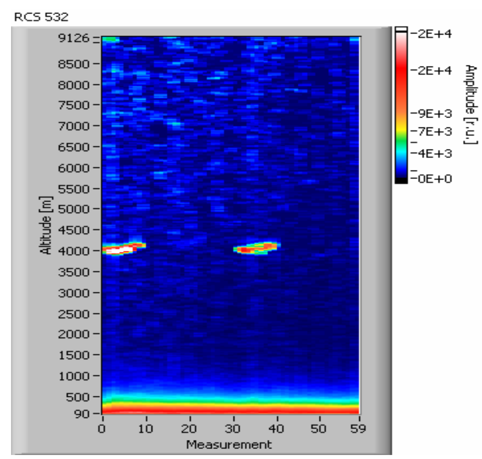


Fig. 3. Range Corrected Signal (a.u.) – temporal evolution - on April 5th 19:00 UTC, 1064nm sounding wavelength.

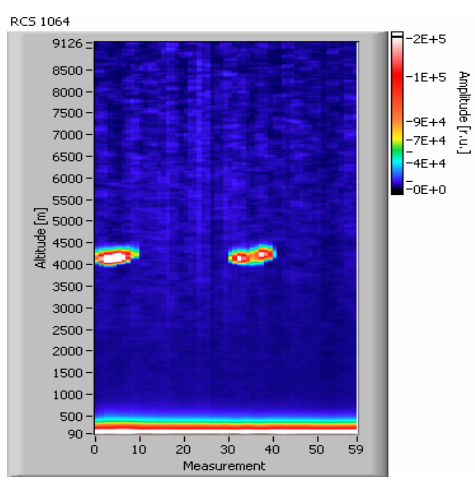
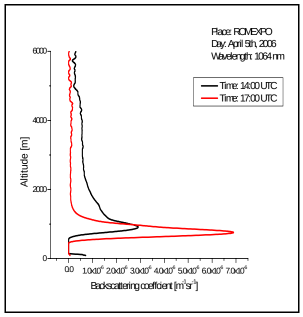
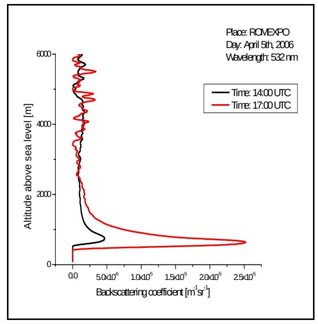


Fig. 4. Range Corrected Signal (a.u.) – temporal evolution - on April 5th 19:00 UTC, 532 nm sounding wavelength.

The LIDAR signal shows a strong backscattering within the ABL, decreasing through a transition zone and becomes weak in the free troposphere (Fig. 5). The backscattering diagrams (Figs. 5a, b) show the profile change at about 1500 m at 14 UTC. Other change can be observed at an altitude above 4000 m, at 17 UTC. The change is better observed at the 532 nm wavelength. This means that at this level there is an aerosol layer, due to Saharan dust intrusion.



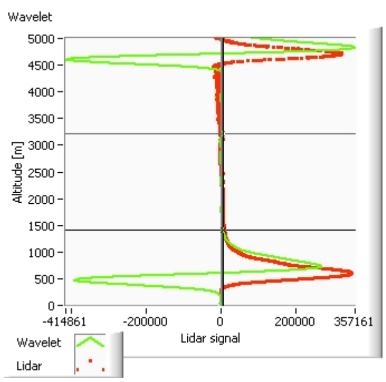
a) 14 UTC (black), 17 UTC (red), at 1064 nm



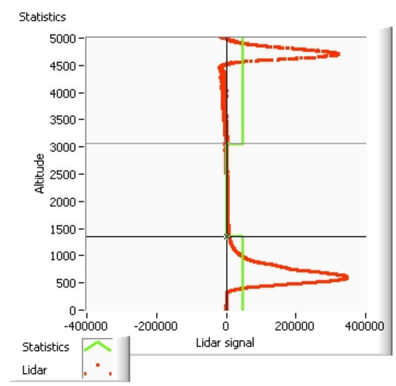
b) 14 UTC (black), 17 UTC (red), at 532 nm

Fig. 5. Backscattering coefficient profiles on April 5th 2006; the dust intrusion can be observed at altitude about 4500 m.

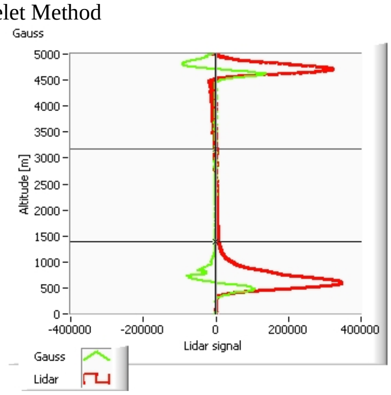
Regarding the ABL height determined by the three methods (Figs 6a, b, c), wavelet, statistics and first derivative of RCS, the height of ABL is also closed to 1500 m.



a) Wavelet Method



b) Statistical Method



c) Gauss Method

Fig 6. RSCS profile integrated over 30 minutes in April 05, at 16:00 UTC, using the wavelet (a), Statistics (b) and Gradient (c) methods.

Inversion trap air within the ABL does not allow convection to occur into the lower and middle atmosphere. Change in air mass can be observed in Figs. 7 a, b, for the days 5-6 in April 2006. The inversion above 3500 m indicates the Saharan dust intrusion; the downward of the aerosol layer can be observed during the night, at 2750 m (Fig. 7b). The air circulation is southwest and the humidity is very small, under 30 %. These confirm the Saharan dust intrusion as observed on LIDAR imagines and from backscattering coefficient dependence of altitude (Figs. 3-5). The ABL height on April 05 is at 1250 m in daytime (Fig. 7a) and at 750 m by night (Fig. 7b).

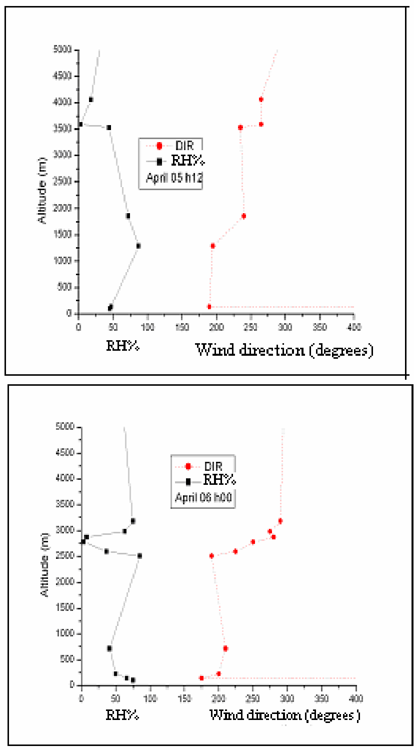


Fig. 7. The relative humidity and wind direction profiles for the April 05 and 05, 2006.

The radio-sounding data were also used to calculate the Richardson number profile. The diagram of Fig. 8 shows the sign change of Richardson number at the same height as of the change in relative humidity and wind direction, 1500m and 3500 m, respectively.

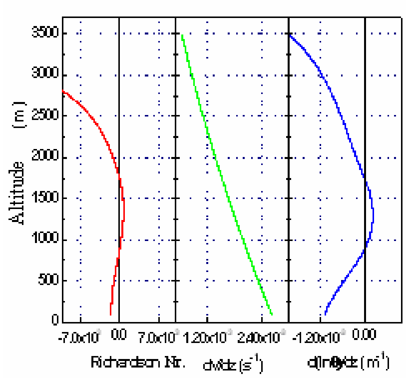


Fig. 8. The gradients of the wind speed, potential temperature logarithm and Richardson number profile for April 05,12UTC. These profiles emphasize the 1500m value for the MLD like on Figs. 6a,b,c.

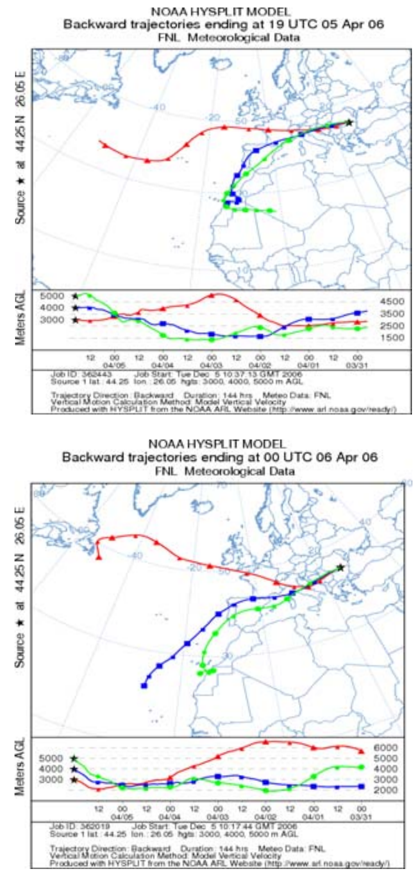


Fig. 9 a, b- back trajectories arriving at 19 UTC-April 05 and 00UTC on April 06 in 2006 year. They prove the Saharan dust intrusion at very high level in troposphere.

In addition, to demonstrate the change in air mass and consequently the intrusion of Saharan dust, kinematics backward trajectories have been invoked through HYSPLIT4 model.

The backward trajectories are shown in Fig. 9 a,b, where the altitude change in trajectory can be observed on April 05 2006. These maps clearly identify the Saharan origin of the upper air-masses. Saharan dust layers reach the southern part of Romania predominantly by cyclonic circulation due to the strong trough observed at all levels from a cyclonic system located in northwestern part of Africa (the synoptic maps are not shown).Following the previous analysis, we can therefore appreciate that the value of ABL height determined from LIDAR backscattering coefficient and RCS profiles is reasonably good.

6. Conclusions

LIDAR images (RCS signal) and backscattering profiles can be used to estimate the mixed layer depth, its time evolution and the dust intrusion by air mass advection.

The first derivative, statistics and wavelet methods can also be used to determine the ABL height as the aerosol layer in altitude (dust intrusion) influences the

ABL height after few hours by descending toward the lower troposphere. The small differences between the values of the ABL height determined from backscattering coefficient and these three methods are explained by the noise in the LIDAR signal.

The vertical profile of the Richardson number shows the unstable or stable atmospheric layers and consequently provides information on the mixed layer depth. The small differences between the values of the ABL height determined from LIDAR data and radio-soundings can be explained by the fact that the LIDAR-derived transition zone does not respond directly to the thermodynamic properties of the atmosphere.

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