COMPACT MICRO-PULSE BACKSCATTER LIDAR AND EXAMPLES OF MEASUREMENTS IN THE PLANETARY BOUNDARY LAYER

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We present a micro-pulse depolarization-backscatter lidar for unattended measurements. The presented lidar originates from a lidar for a high-altitude aircraft, what is demonstrated in its compactness and the possibility for transportation with minimum resources. The lidar determines the aerosol backscatter coefficient in the PBL and lower troposphere, as well as the mixing layer height during the overall diurnal cycle. As examples of the lidar operation we present selected cases of the aerosol stratification above Neuchâtel, Switzerland (47.002°N, 6.955°E, 487m asl).

Key words: micro-pulse lidar, planetary boundary layer, backscatter coefficient.

1. INTRODUCTION

The aerosol in the troposphere and the Planetary Boundary Layer (PBL) plays an important role in a number of atmospheric phenomena, air quality, cloud formation, radiation balance and chemical processes [1, 2]. The aerosol is also convenient tracer in the observation of the PBL development [3].

The backscatter lidar is already an established tool for continuous aerosol profiling, where a long-term experience is accumulated in both case studies and routine network observations [4]. Anyway, when a broader and routine application of this instrument is concerned, the limiting factors are the transportation and operation resources. The motivation of this work is the demonstration of one technical solution of a micro-pulsed, compact and automatic lidar, in which these limiting factors may be overcome. Another motivation of this study is the convenience of such type of instrument both for long-term routine observations and for field campaigns in remote sites. Micro-pulsed lidars are already reported and


introduced in measurements [5, 6]. Nevertheless of their relatively early introduction, the convincing examples of its applications in the PBL are relatively few. One reason is that such operation at lower altitudes puts high requirements to the dynamic range and after-pulses probability of its detection system. The instrument solution reported here achieves high-quality measurements in the PBL and lower-troposphere studies, i.e., a closer start of the full overlap range, less influence of signal saturation and convenient means to account for the afterpulses distribution.

2. THE INSTRUMENT

The lidar is a single-wavelength, backscatter-depolarisation instrument. The block diagrams of the optical and electronic parts are presented respectively in Figs. 1 and 2. The specifications of the subsystems are given in Table 1. The lidar is assembled in a box, as shown in Fig. 3. Outside of this box are the computer for operation control and, if necessary, an air-cooling unit.

The development of the lidar and its adaptation for measurements in the PBL and lower troposphere, emerges from a similar lidar development for airborne operation [7, 8]. From its airborne predecessor, the reported instrument inherited the compact and robust design, and the stable alignment. The lidar is compact and mounted in an environmental protection box (54cm * 58cm * 58 cm), what makes it convenient for transportation to remote campaign sites. The data acquisition and the house-keeping electronic systems are controlled by a micro-processor, and an embedded PC is used to control the lidar measurements and to store the collected data.

Fig. 1 – Block-diagram of the optical part of the micro-pulse lidar.
The alignment of the lidar is performed before placing it in the environmental housing. Thanks to its small size, its alignment may be performed when it is oriented in horizontal or slant directions towards convenient hard targets. The signals used to control the alignment in our practice are, once corrected for range, the returns from local hills at approximately 2 km, 4 km and 8 km, respectively, increasing in a sequence. During the procedure, apertures with different diameters are placed in front of the receiver. The alignment is controlled by maximizing the received signal from the same target and by its proportionality to the area of the apertures. The stability of the alignment after placing the lidar in its environment box is achieved by two means: first, by the specific design of the output mirror control mechanics; second, by temperature stabilization of the overall lidar structure inside the environmental housing.

Fig. 2 – Block-diagram of the electronic part of the micro-pulse lidar.

Fig. 3 – Photo of the box where the lidar is assembled for operation and transportation. The size of the box is 54cm * 58cm * 58 cm (length *width*height), without the baffles on its top. During operation a laptop PC is attached externally as "user interface" (not shown).
Nevertheless of its compact size and low transmitted power, the presented lidar determines the values expected from backscatter depolarization instruments. Those are the *Aerosol Backscatter Coefficient* (ABC), applying signal inversion procedure, as described in [9], the mixing layer height, using the signal derivative (or gradient) method [10] and the depolarization ratio [11]. The operation of the reported lidar for ABC determination started in 2000, when it took part in EARLINET intercomparison campaigns [12]. In the next section are presented an example of a PBL diurnal cycle shown by the range-corrected signal time series and ABC examples, determined during a high-pressure period. Here we do not present examples for depolarisation ratio measurement.

### Table 1

<table>
<thead>
<tr>
<th>Specifications of the lidar subsystems</th>
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<tbody>
<tr>
<td><strong>Transmitter</strong></td>
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<tr>
<td>Laser type/Wavelength</td>
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<td>Average power</td>
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<td>Polarization</td>
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<td><strong>Receiver</strong></td>
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<td>Range resolution/single measurement duration</td>
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<tr>
<td>Interface to the local PC for operational control</td>
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3. **EXAMPLES OF MEASUREMENTS, COMMENTS AND DISCUSSION**

The examples presented here are for illustration of the capabilities of the lidar for operation both day and night time, with successful presentation of the PBL development in sufficient resolution, as well as ABC determination with inversion procedure. The examples are from measurements above Neuchâtel, Switzerland, which is one of the stations in EARLINET lidar network (http://www.earlinet.org/). During the period 10-17 March 2007 high pressure was established over Central Europe. Weak Bise wind cases were reported during its first part, which type of wind is linked to advection of aerosol [13]; an accumulation of aerosol from the beginning of the high-pressure period may be expected. Also, towards the end of
such high-pressure period, it may be expected that the local wind system is
determining the conditions for PBL development and, following from it, the
aerosol stratification.

Figure 4 presents the variation of the range-corrected signal profile during
one part of this period - from 15 till 17 March 2007. Figure 5 presents the variation
of the altitude derivative of the range-corrected signal for the same day. The dotted
curve in Fig. 5 presents the minimum of the altitude derivative of the logarithm
of the range-corrected signal, which presents the top of the PBL [10]. I.e., the lidar
signal makes it possible to determine the variation of the PBL top during the
overall duration of the daily cycle.

As the objective of this article is to present the lidar instrument capabilities
rather than analysis of specific atmospheric events, we will only briefly comment
the observations in Figs. 4 and 5, without entering specific details. Neuchâtel is
situated on the border of the lake Neuchâtel and at the rim of the Jura ridge. This
complex topography determines local flows, as katabatic and anabatic current
following the mountain slopes and breeze circulation. In this way the aerosol
stratification presented in Figs. 4 and 5 follows a typical daily cycle of PBL development, convective during daytime as expected during the high-pressure period, but superimposed with the effect of the local flows. One result is the relatively late grow of the PBL during the morning hours due to the breeze effect. The rapid grow of the PBL is during the early afternoon hours, where it is also superimposed with detached layers during evening and early night. We also observe stratified residual layer during the night (two layers may be identified, one above the other), what may be explained as a result of the katabatic flow.

Such detached layers lead to ambiguity during some periods of the daily cycle in the use of the minimum of the altitude derivative of the range-corrected lidar signal to determine the PBL top. Namely, such layers produce a second minimum. This may be seen in Figs. 4 and 5 for the periods: from approx 2:00 on 15 March till 11:00 on 16 March and in particular around 11:00, and between approx 23:00 on 16 March till 7:00 on 17 March. To present the top of PBL diurnal variation in such periods as a single line it is necessary to impose the requirement for its continuity. i.e., in time-height variation of PBL top interrupted lines presenting minimum of the signal derivative are not considered as PBL top, but as showing additional aerosol layering. We may note that the signal quality of the described compact lidar is sufficient to present such details of aerosol layering, as well as the cycle of PBL top development.

Fig. 5 – Time-height presentation of the variation of the altitude derivative of the range-corrected signal, for the period from 15 March 2007, 13h00, till 17 March 2007, 9h00 (UTC). The areas with lighter color show the low values of the derivative. They form line which is interpreted as top of the PBL (or mixing layer height, see in [10]). The fields with no color are time-altitude areas, where the SNR is below 2.3. The features as PBL grow, detached and residual layers may be compared with the range-corrected signal presentation for the same period in Fig. 4.
Figure 6 presents two ABC profiles determined respectively on 12 March, \textit{i.e.}, at the beginning of the high-pressure period and on 15 March, what is close to its end. The measurements were performed during the same afternoon hours, 15:00-16:00h. The measurements show that the ABC value at its maximum in the PBL increases from $-9.9 \cdot 10^{-7} \, [1/m^*sr]$ on 12 March 2007, to $1.0 \cdot 10^{-5} \, [1/m^*sr]$ on 15 March 2007, \textit{i.e.}, by one order of magnitude.

Figure 6 – Upper- and lower-left panels: ABC (solid lines), and molecular backscatter coefficient (dash lines) are calculated from radiosonde measurements in Payerne aerological station, at ~20km from Neuchâtel. Upper- and lower right panels: photos at direction above the Lake of Neuchâtel taken during the – respective lidar measurements (see the text).
In the same figure are shown also photos of one selected view across lake Neuchâtel and with a possibility to see the Alps. The photos are taken during the periods of the respective lidar measurements. One can note how the low value for the ABC on 12 March coincides with possibility to see the mountain peaks at \( \sim 80–90 \) km, i.e., a meteorological visibility range of \( \sim 80–90 \) km. On 15 March the ABC is an order of magnitude higher. This coincides with the much lower visibility, where it is not possible to see even the opposite shore of the lake, i.e., meteorological visibility range of less than \( \sim 8 \) km. Such significant change of the visibility correlates well with the respective ABC values determined by the lidar.

Figure 7 presents one example of ABC profile determined for mid-night 13-14 October 2007. The profile is characterized by a sharp drop from the PBL top to the free troposphere. It is also to be noted that the ABC value has its likely minimum just above the PBL top. Figure 8 presents the profiles of the temperature, relative humidity and the wind direction, determined by radiosonding at Payerne aerological station, close to the time of the presented lidar measurement.

Assessing the two sets of measurements, Neuchâtel lidar and the radiosondes profiles at Payerne station, we shall take into account that the lidar profiles are presented in altitude above ground level (agl), while the radiosondes data are presented in altitude above sea level (asl) and that Neuchâtel is located at 487m asl.
When comparing the two sets of measurements, this value shall be added to the altitude (range for lidar pointed at zenith) scale in Fig. 6.

Accounting for this difference in the altitude presentation, it can be noted the followings:

(i) The altitudes of the sharp drop of the ABC is at ~1000 m agl, i.e., at ~1480 m asl. This altitude coincides well with the altitude of the sharp drop of the relative humidity, at ~1500 m asl; (ii) The altitude of sharp drop of the ABC also coincides well with the altitude of the strong temperature inversion (~1500 m asl) and the altitude of the wind shear, also at ~1500 m asl.
Fig. 8 – Top panel: relative humidity profile; middle panel: temperature profile; bottom panel: wind direction profile. The radiosond measurements are from Payerne aerological station, at ~20km from Neuchâtel.

Following from these considerations, we may conclude that the ABC profile determined by the lidar shows correctly the PBL top and mixing layer. The wind profile contains a thin layer between 1500–2000 m asl, showing current from East direction. This layer is expected to bring air mass from above the Alps, i.e., relatively aerosol–poor. The altitude of this minimum coincides with the altitude of a sharp local minimum in the relative humidity profile. As we may see in Fig. 7, the altitude of this layer coincides with the minimum of the ABC value just above the PBL top.

4. CONCLUSION

A compact automated backscatter lidar is realised and demonstrated. The lidar is capable to present time series of its range-corrected signal with sufficient resolution for visualizing the diurnal cycle of the PBL development, as well as for determination of the aerosol backscatter coefficient. The long-term lidar operation proves to be reliable, when requiring modest infrastructure and transportation costs, and with a possibility for a remote control. With such potential, this lidar development may be a convenient complement to large-scale aerosol measurement networks, particularly at sites with not sufficient infrastructure for advanced but large-size lidars.
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