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LIDAR Sensing of Aerosol Processes over Sofia Region in the Frame of the European Aerosol Research Lidar Network (EARLINET)*

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Abstract. An overview is given of the remote sensing of the atmospheric processes over Sofia region by using lidars. Results obtained in the Institute of Electronics in the frame of the European Aerosol Research Lidar Network are presented and discussed.

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1 Introduction

LIDARs (LIght Detection And Ranging) are powerful tools for remote sensing of the atmospheric aerosol processes with high spatial and temporal resolution, high sensitivity and accuracy, covering large observation areas [1,2]. Lidar data, provided by a big variety of ground-based, air-borne, and space-borne lidar systems spread all over the world, are in wide use in developing and improving atmospheric models, following climate changes, and helping monitor air quality in global and regional scale. The investigations on developing experimental systems for laser remote sensing and monitoring of the atmosphere started in the Institute of Electronics of the Bulgarian Academy of Sciences (IE-BAS) more than 35 years ago.

EARLINET, the European Aerosol Research Lidar Network, is the first aerosol lidar network, established in 2000, with the main goal to provide a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on a continental scale [3]. At present, 27 stations distributed over Europe are part of the network (http://www.earlinet.org). The Bulgarian Lidar station is positioned in Sofia, in the Laser Radar Laboratory of the Institute of Electronics

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(LRL-IE). The scientists from the LRL-IE actively participate in the joint lidar research over the European continent within projects from the Fifth, Sixth and Seventh Framework Programmes of the European Union.

In this paper we present some basic results achieved in LRL-IE during the last 10-years systematic lidar monitoring of the atmospheric processes, such as unusually high concentrations of aerosols in the troposphere (transportation of mineral dust from Sahara desert over the Mediterranean Sea to Europe, volcanic eruptions, formation of smoke layers resulting from forest or industrial fires, *etc.*), originated from 3 continents - Europe, North Africa and North America.

2 Laser Remote Sensing of Atmospheric Aerosol at Sofia Lidar Station

LIDAR remote sensing of the atmosphere represents a complex activity joining together a variety of experimental equipments, measurement techniques, analytical methods, theoretical approaches, *etc*. Basic aerosol parameters derived from lidar data are the aerosol backscattering and extinction coefficients. Theoretical models for retrieving their range profiles from raw lidar data are based on solving the so-called lidar equation describing the relation between the received range-resolved backscattered optical radiation power and atmospheric and system parameters [4–6].

The Sofia lidar station is equipped with two lidars, certified for measurements in the European Lidar Network: two-wavelength aerosol Lidar using CuBr vapour laser (510.6 nm and 572.8 nm) and three-wavelength aerosol-Raman Nd:YAG Lidar (532 nm, 1064 nm, and 607 nm) [7] (see Figure 1).

Figure 1: Photos of the CuBr-vapor laser (left) and Nd:YAG laser (right) aerosol lidars at Earlinet Sofia Station.

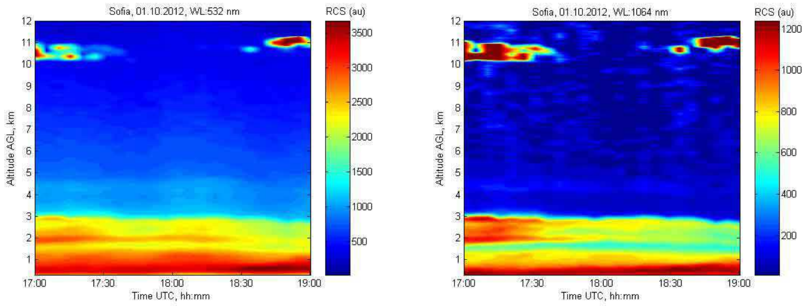

Figure 2: Time evolution of RCS measured at 532 nm (left) and 1064 nm (right) by the Nd:YAG lidar on 01.10.2012 - a Saharan dust layer seen at 1.5-3 km AGL.

Monitoring and characterization of the intercontinental atmospheric transport of mineral aerosols (dust particles) from Sahara desert over Europe is one of the principal goals of the lidar observations in the frame of the EARLINET program because of the strong impact of these aerosols on the atmospheric processes and the climate on regional and global scale. Systematic measurements of Saharan dust layers are carried out by the two lidars of the Sofia lidar station during events of intrusions [8]. Along with characterization of the presence, distribution, and spatial-temporal dynamics of the dust layers, assessments on the aerosol particle composition (in terms of type and size) are also performed *via* lidar measurements at more than one wavelength. Information concerning the particle size distribution and dominating size modes derived from two- or multi-wavelength lidar measurements is important for helping monitor air quality, as well as for estimating radiative and thermal properties of the atmosphere, having direct impact on the climatic changes. Based on multi-wavelength measurement particle size analysis, assumptions can be made about the type and origin of the aerosols. In Figure 2 evolutional colormap diagrams are presented of the atmospheric aerosol distribution in terms of range-corrected lidar signals (RCS) at altitudes of up to 12 km above ground level (AGL), for two hours of measurement on 01.10.2012 in a period of considerable transfer of Saharan dust over Sofia region. Results are obtained by simultaneous two-wavelength measurements, by using the two aerosol channels of the Nd:YAG lidar. Saharan dust layer of thickness of about 1.5 km can be seen in the altitude range 1.5-3 km AGL, as partially mixed with and overlaying the planetary boundary layer ($\leq$ 1.5-2 km AGL). The aerosol fields emerging in the altitude range 10-11 km AGL are cirrus clouds. Due to the different wavelength-to-size sensitivity, the left panel (at 532 nm) shows predominantly the distribution and evolution of the molecular atmospheric component and the fine-aerosol fractions ($\leq$ 0.5-0.6 μm), whereas the right one (at 1064 nm) visualizes mainly the ones of coarse aerosol fractions (≥ 1 μm). The different patterns of the dust layer at the two wavelengths are clearly seen in Figure 2, mapping the layer parts dominated by fine or coarse particle modes. Further processing of the signals and analysis of the results at the two wavelengths by calculating the backscattering coefficient (BC) profiles and, subsequently, the backscatter-related Angstrom exponents (BAE) and the corresponding BAE frequency-distribution analysis [9], can provide more details about the size distributions of the dust and general aerosol particles.

A long-range transportation of the forest fire originated aerosol masses is demonstrated in Figure 3. During the period of measurements the sky above the lidar station remained totally covered with clouds at altitude ~ 4 km AGL. For a short time interval between 18:20-18:40 UTC, a window opened in the thick cloud cover and an additional aerosol layer at ~ 10 km was detected by the lidar. The analysis of the backward HYSPLIT trajectories ending at the lidar measurement place (see Figure 3, green trajectory) demonstrates that air masses from a big Canadian forest fire reached Sofia at that time and are the likely source of the measured aerosol layer.

The lidar data presented in Figure 4 (left panel) demonstrates the observation of the volcanic dust over Sofia after the end of the Eyjafjallajokull volcanic eruption in Iceland. Some days later the volcanic plume continued to hover over Europe, going down (because of sedimentation) as shown by the vertical behaviour of the backward air mass trajectories (Figure 4, right panel). We registered two aerosol layers at ~ 2 km and 3 km AGL with air mass originating over Iceland, during the volcanic eruption.

Results of two-wavelengths lidar observations of atmospheric aerosol dynamics over a complex terrain, representing adjoining city, plain, and mountain zones in Sofia region, are shown in Figure 5. Lidar measurements are carried out simulta-

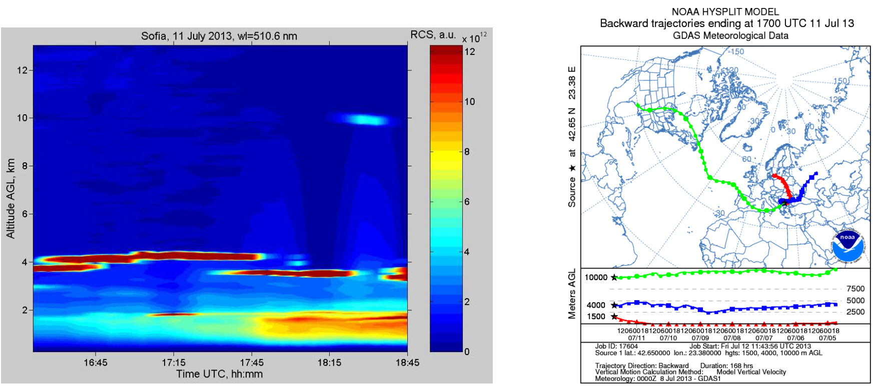

Figure 3: Time evolution of RCS at 510.6 nm (left) as measured by the CuBr lidar on 11.07.2013 and the corresponding backward HYSPLIT air mass trajectories (right).

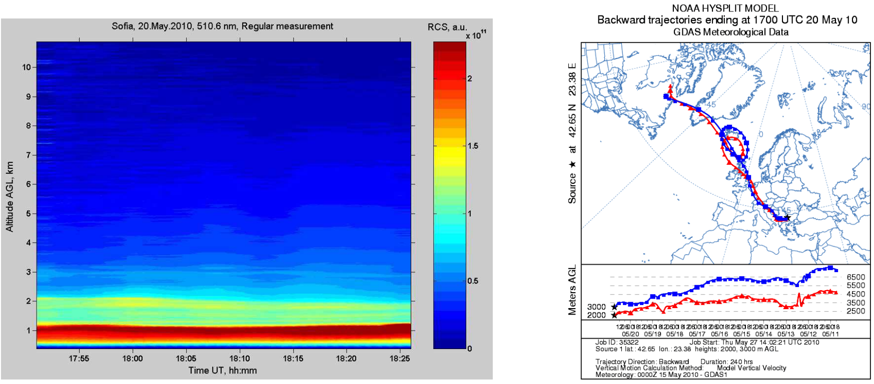

Figure 4: Time evolution of RCS at 510.6 nm (left) as measured by the CuBr lidar on 20.05.2010 and the corresponding backward HYSPLIT air mass trajectories (right).

neously at wavelengths 1064 nm and 532 nm [10]. Range profiles of the normalized standard deviation (NSD) of the range-corrected lidar signals, characterizing the aerosol dynamics, are shown on the right panel. Mean values of NSD over the three orographic zones are presented in the inset. The NSD of range-corrected lidar signals at 532 nm (corresponding to the fine-mode aerosols) is higher than the one at 1064 nm (corresponding to the coarse-mode aerosols) over the most part of the measurement range. Over the city zone ($\leq$ 2 km distance from the lidar station), the NSD values for 1064 nm and 532 nm have close low values alternatively varying near 0.1, indicating low aerosol dynamics. Over the plain zone (2.5-6 km distance) the NSD values increase gradually up to about 0.3 at 1064 nm and up to 0.4 at 532 nm. Over the mountain zone (6–9.5 km distance), the increase of NSD values tends to saturation. In the immediate vicinity of the mountain surface, the dynamics is more intense. The strongest internal

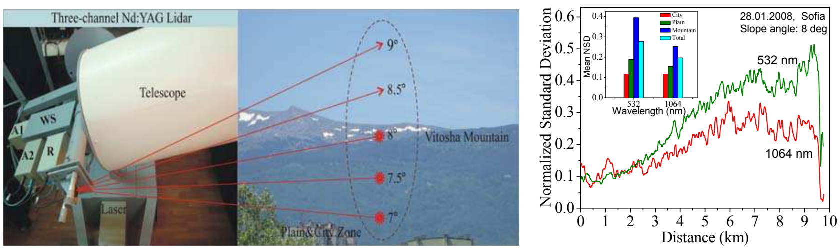

Figure 5: Schematic view of the lidar experiment over complex terrain (left) and the time-averaged range profiles of NSD and space-time averaged values of NSD over the three orographic zones (inset) for the two wavelengths of measurement (right).

dynamics for the coarse-mode aerosol fractions is observed over the plain-to-mountain interface zone (about 6 km), whereas those of the fine-mode aerosol fractions appear close to the mountain surface. The observed behavior of the NSD at the two wavelengths is in good correlation with meteorological data at the time of measurement.

3 Conclusions

In this work we briefly presented some of our results in the area of lidar sensing of the atmosphere within the European Aerosol Research Lidar Network. As it is seen, the lidar research in the LRL-IE covers all the basic areas of application of lidars in the atmospheric research on the European continent. The further improvement of the available lidar technologies is one of the most important tasks for the Lidar community and for the LRL of IE-BAS as well. One of the ways to improve the quality of the lidar output information and its significance for the global and regional atmospheric monitoring is the creation of complex multispectral lidar systems in a synergy with other existing instruments and networks such as the sun-photometer network, ground-level in-situ aerosol monitoring networks, satellite measurements (lidar and multispectral radiometers), radars, etc. Such is the main purpose of the European project ACTRIS (Aerosols, Clouds, and Trace gases Research InfraStructure Network). It integrates the existing research infrastructures EARLINET, EUSSAR, CLOUDNET, and a new trace gas network component into a single coordinated framework, with impact on the climate changes, air quality, and long-term transport of pollutants. The future development of LRL of IE-BAS is seen just in a close cooperation with the Lidar Laboratories all over the European continent.

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