Lidar Remote Monitoring of Aerosol Dust Layers over Sofia

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Abstract– **Results of lidar remote sensing of aerosol layers in the atmosphere beyond Sofia are presented in this work. Considering the lidar observations together with meteorological forecasts and calculated backward air mass trajectories, a conclusion about the aerosol's origin is made that it is due to transportation of a dust from Sahara over the Mediterranean Sea to Europe.**

Keywords– **Lidar remote sensing, monitoring of the atmosphere, aerosol transportation, European Aerosol Research Lidar Network**

I. Introduction

EARLINET-ASOS (European Aerosol Research Lidar Network - Advanced Sustainable Observation System) [1] is an integrated activity implemented as coordination action within the EC Sixth Framework Programme. It started on the base of the EARLINET [2], and actually covers 20 lidar stations distributed over Europe. The main objective of the project is to improve the EARLINET infrastructure resulting in a better spatial and temporal coverage of the observations, continuous quality control for the complete observation system, and fast availability of standardized data products.

We reported in our previous paper [3] some lidar measurements made in the Institute of Electronics of the Bulgarian Academy of Sciences within the frame of the project EARLINET. We discussed there all obligatory tests our lidar system passed for assessment of its accuracy of operation [4]. The type of lidar measurements within the network was enlarged and now we perform lidar observations as follow:

- Regular lidar measurements within the objective to establish a common database from measurements of profiles of the atmospheric aerosol backscatter coefficient. Measurements are conducted twice weekly, every Monday at noon when the sun is in zenith, and in the evening during sunset, and every Thursday at sunset.
- Observation of special phenomena, such as unusually high concentrations of aerosols in the troposphere. Their appearance may be due to transportation of a dust from Sahara over the Mediterranean Sea to Europe, volcanic eruptions, formation of smoke layers as a result of forest or industrial fires, intense photochemical smog, etc. In some cases such aerosol layers are detected at significant altitudes – 4-6 km above the ground surface.
- Measurements in the frame of cooperation with a satellite missions within the objective of detailed comparison of ground-based and spaceborne lidar data sets over Europe.

The lidar measurements concerning the second type of measurements are carried out upon notification by the program coordinator for upcoming dust events above the territory of Europe. The notification is based on satellite observations and weather forecasts, provided by the Forecast system of Barcelona Supercomputing Center (BSC) (http:// www.bsc.es/projects/earthscience/DREAM). EARLINET's system for notifications that works currently helped our team to make lidar measurements and registration of Saharan dust transportation events presented in this paper.

II. Aerosol lidar with CuBr-vapor laser

The Aerosol lidar with CuBr-vapor laser was presented in details in our previous works[3]. Its parameters are briefly listed in Table 1.

TABLE 1.
PARAMETERS OF THE LIDAR

Laser	CuBr-vapor
Wavelength	510.6 nm
Pulse energy	0.5 mJ
Pulse repetition rate	13 500 Hz
Telescope	Cassegrain type D = 20 cm F = 100 cm
Photo-detector	PMT EMI 9863 QB100 in photon counting mode

The CuBr-laser generates high-repetition pulses with duration of 10 ns at wavelength of 510.6 nm Laser beam is directed vertically upward, parallel to the axis of the receiving telescope, forming a lidar base of 24 cm between the axes. Cassagrain type telescope with 20-cm aperture and 1 m focal length receives the backscattered laser emission from the atmosphere. A registration in photon-counting mode is applied. Photon-pulses are memorized in Photon Counting Board LD-P 03-01 in a computer. This board allows registration of the backscattered lidar signal in altitude with spatial resolution of 30 m, in 1024 samples and averaging time of 60 s. The sounding height is from 900 m to 10-12 km at nighttime. The maximum height is limited by the laser pulse frequency generation because of an overlap of the laser pulse diffused from great hight with next one from lower hight. In daytime conditions the sounding height decreases to

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about 4-5 km, due to intensive sky illumination, decreasing speedily Signal-to-Noise Ratio (SNR).

Each lidar measurement lasts about 3-4 hours. The lidar profiles integrated for accumulation time of 1 min were additionally averaged by summation of the data of 30 profiles. Thus the effective measurement time for each profile amounts to 30 min. Registered data were subsequently processed via program system in MATLAB environment, developed in the Institute of Electronics. Fernald's algorithm [5] was used to calculate atmospheric backscatter coefficient profiles.

III. Mineral dust forecast maps and backward air mass trajectories calculations

The aerosol lidar detects aerosol layers in the atmosphere, determines their relative density, temporal evolution and motion. But the type of the aerosols could not be determined without additional information or observations, using other conventional measurement systems. In our practice, we obtain such information exploring the weather-forecast maps for the Euro-Mediterranean zone, elaborated by BSC and accessible via Internet. These maps give an image of the wind direction and speed, position of cloud fields and magnitude of dust load in the atmosphere above North Africa and Europe. They visualize the prediction concerning the dispersion of Saharan dust storm outbreaks over the Mediterranean Sea to Europe.

Another source of information about the origin of the detected by the lidar aerosol layers, offers the HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory)[6] model. It represents a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The model can be run interactively on the Web through the READY system [7] on the site of the Air Resource Laboratory of NOAA (National Oceanic and Atmospheric Administration), USA. The calculations of the backward air mass trajectories prove that the observed aerosol layers are due to transportation from Sahara.

III. Measurements and discussions

On Fig.1.a. and 2.a. some results of our lidar measurement of the profiles of atmospheric backscatter coefficient are shown. Since the magnitude of the backscatter coefficient value is proportional to the aerosol density, the time evolution of the profiles show the changes of the aerosol load in the atmosphere over the lidar. The data-processing procedure applies 30 min time integration interval for the accumulated lidar data. Thus each lidar map of the aerosol stratification is builded on the base of 6 to 8 profiles of the atmospheric backscatter coefficient. The measurements are made in daytime and their altitude does not overpass 6 km. Next to the plots of the backscatter profiles, vertical scales of the backscatter magnitude are presented, with a degree of the gray color.

On Fig.1.b. and 2.b. are shown forecast maps of the dust load for the two measurement days, respectively 29 May and 06 November 2008. In the maps published on the BSC's Internet site, the different magnitudes of dust load are color-

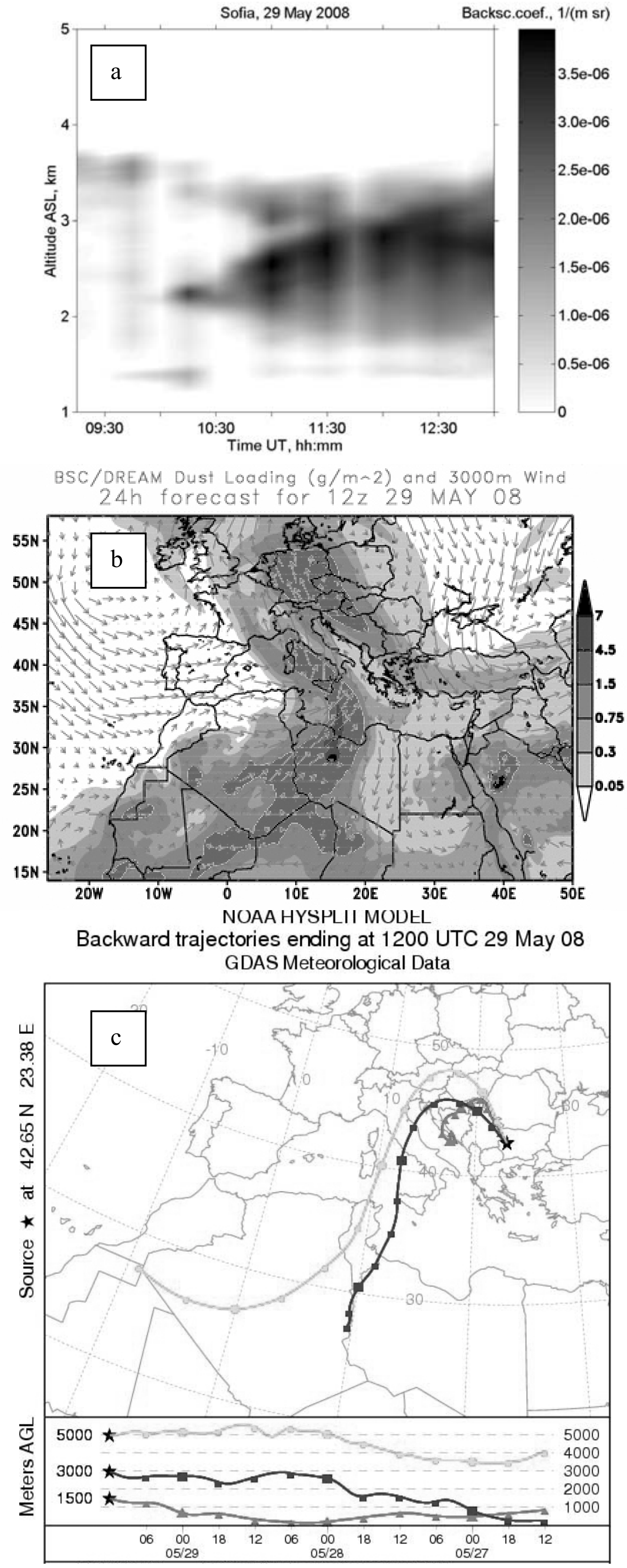

Fig.1. Lidar measurement on 29 May 2008 (a), corresponding weather forecast map given by BSC (b) and air mass backward trajectories (c), calculated using HYSPLIT model.

coded and well distinct. The labels of X- and Y-axis on Fig.1.b. and 2.b. show the geographical coordinates of the countries of the Euro-Mediterranean region. The lidar station, where the observations were made, is positioned in the Institute of Electronics of BAS, in Sofia, at $42^{o}41'$ N and $23^{o}21'$ E and at about 500 m altitude above sea level (ASL). The time interval for the forecasts is 24 hours and the dust load is given in g/m^2, i.e. column of atmospheric air with base of 1 m^2.

On Fig.1.c. and 2.c. are presented the calculated backward air mass trajectories, using HYSPLYT model. 72-hours period, preceding the time of lidar measurements was applied in the calculations. The motion of air parcels observed over Sofia at three characteristic altitudes (1500 m, 3000 m and 5000 m) is displayed. We found that beyond 1500 m high the overlap function between the laser beam and the field of view of the telescope is close to 1. At altitude 3000 m habitually the dust aerosol reach maximal density and the atmosphere over 5000 m altitude we consider free of aerosols. The plots of the calculated backward trajectories show that the air mass arriving in Sofia in the time of lidar measurements stem from North Africa region, from Sahara.

The plots in Fig.1.a. and 2.a. present a multi-layers structure of the observed aerosol. This is typical structure of dust loaded air masses. Depending on the dimensions of the aerosol particles, the deposition process has started for the heavier fraction of them, while the lighter is moving away and higher at the line of the atmospheric front, between hot and cold air masses. For the measurement on 29 May 2008 (Fig.1.a) the backscatter coefficient reach magnitude of 3.0-$3.5x10^{-6}$ $m^{-1}sr^{-1}$. The estimated values of the optical depth of all the layers, from Earth surface to the upper limit of the observed height at 5 km ASL, are in the range of 0.06-0.25. The measured values of the atmospheric backscatter on 6 November 2008 (Fig.2.a) are lower $1.0\text{-}1.5x10^{-6}$ $m^{-1}sr^{-1}$, and the estimated optical depth is 0.08-0.16. The aerosol upper limit varies respectively at 3.5 km ASL and 4.0 km ASL for the two cases.

Referring the weather forecast maps of BSC in Fig.1.b. and 2.b., we find a good coincidence between the prediction and the lidar observations plotted on Fig.1.a. and 2.a. Because of the movement of the front between the hot air masses coming from North Africa to Europe and these in opposite direction, the hot air goes up, taking also the Saharan dust aerosol up. In the same time, the sedimentation for heavier fraction of dust particles is already active, so the depth of the Saharan dust layer grows in height and becomes multi-layered. The higher values of the lidar measured backscatter coefficient and optical density on 29 May, comparing to the values, measured on 06 November, could be explained with the different degrees of dust contamination, as predicted by the weather forecasts. In both cases the Saharan dust formation in North Africa was enough intensive that the dust transportation, following the calculated backward trajectories maps (Fig.1.c. and 2.c.), overpass the Mediterranean Sea and was observed over Sofia lidar station, far from the sea cost.

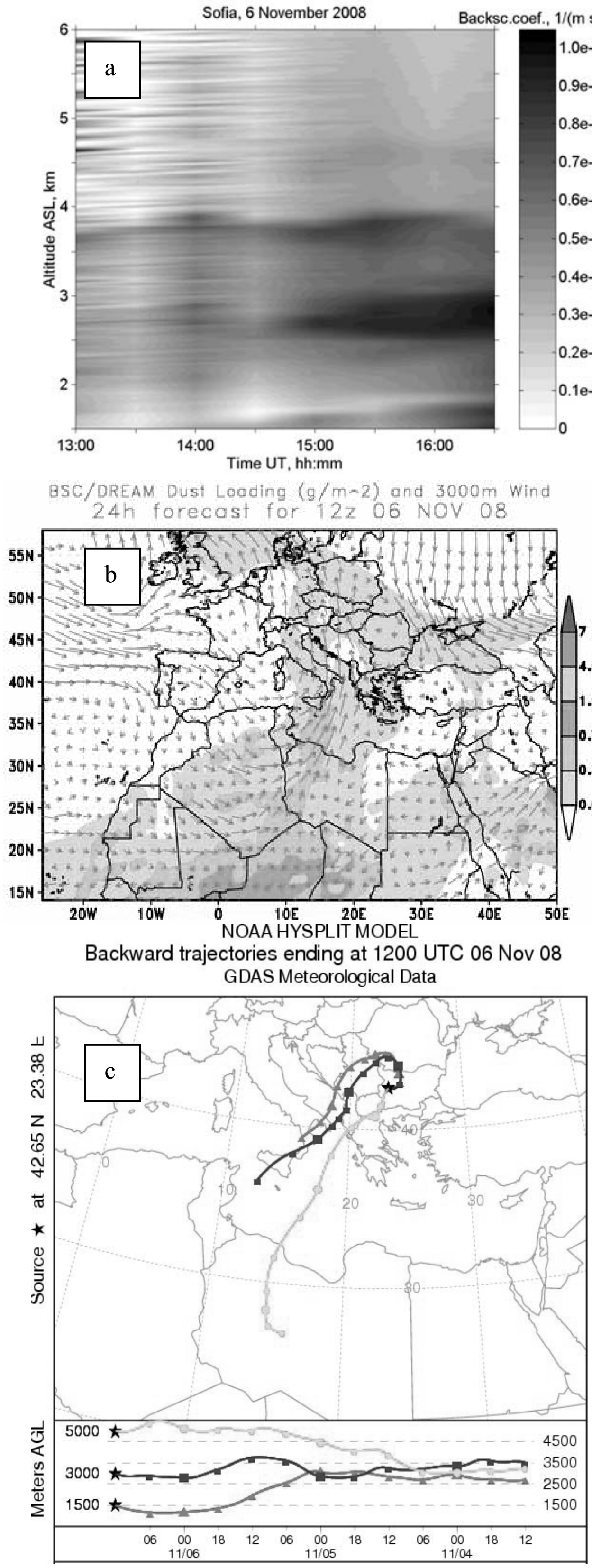

Fig.2. Lidar measurement on 6 November 2008 (a), corresponding weather forecast map given by BSC (b) and air mass backward trajectories (c), calculated using HYSPLIT model.

IV. Conclusion

Previous systematic dust observations over Europe in the frame of EARLINET [8] showed that multiple aerosol dust layers of variable thickness were observed. Upon the analyses of the information about the weather condition, we conclude that the observed by the lidar aerosol layers, reported in this paper, are due to transportation of Saharan dust over the Mediterranean Sea to Europe. In both cases the dust layers thickness reached values of about 1300-2500 m. The center of mass of these layers was located in altitudes between 2500-3000 m. Mean aerosol optical depths (AOD) ranged from 0.1 to 0.25. The data of presented measurements is stored in the database that has been established by the EARLINET project. This database is now growing continuously and is of very high scientific interest, because it is by far the most comprehensive quantitative data set on the vertical distribution of aerosols on a continental scale.

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