Measurements of atmospheric parameters using aerosol lidar

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Lidar methods for measuring the aerosol content in the atmosphere are a robust means of control and analysis of the environmental state. Aerosol lidars allow for real time tracing and mapping the movement of aerosol layers above extensive territories, which represents a significant advantage in studying large-scale objects and phenomena in the atmosphere. Such is the general idea of the studies of the European Aerosol Research Lidar Network (EARLINET), consisting of 20 lidar stations spread throughout Europe. Main objectives of the project are to assure continuous observations and methodological developments, to provide multi-year continental scale database necessary to assess the impact of aerosols on the European environment and to support future satellite space-lidar missions. In this paper, an aerosol lidar with CuBr-vapor laser, created in the Institute of Electronics of the Bulgarian Academy of Sciences is presented. The results of measurements and analysis made on the atmospheric parameters are discussed. Some comparison is attempted to the satellite data obtained by CALIPSO lidar from the space.

1. Introduction

Laser remote sensing is based on extracting information about atmospheric parameters by studying the interaction of emitted laser impulses with the atmosphere. Registering the back scattered light with high-sensitive receivers, after processing the results under specific algorithms, qualitative and quantitative data about atmospheric parameters are obtained.

In 2002-2003, laboratory "Laser radars" of the Institute of Electronics of the Bulgarian Academy of Sciences (BAS) participated in the project EARLINET (Boesenberg et al., 2003) of the EC Fifth Framework Program. The project unified the researches of 22 lidar stations in 13 European countries. A profound program for quality control of the work of each lidar was carried out, as well as for unification of the applied algorithms for deriving atmospheric parameters. On March 2006 started the project EARLINET-ASOS (European Aerosol Research Lidar Network - Advanced Sustainable Observation System) of the EC Sixth Framework Program. Its main objectives are to contribute to the improvement of continuing observations and methodological developments that are needed to provide a quantitative database describing the aerosol vertical, horizontal, and temporal distribution, including its variability on a continental scale. Such a database could be used to validate and improve models that predict the future state of the atmosphere and to take actions to preserve the quality of the environment.

Bulgarian aerosol lidar with CuBr-vapor laser

Three aerosol lidar systems are developed and used in EARLINET time schedule measurements in laboratory "Laser radar" of Institute of Electronics (Grigorov et al,

2006). Two of them based on Nd:YAG lasers and another one with CuBr-vapor laser (the laser is constructed in the Institute of Solid State Physics – BAS). Detailed diagram of the lidar is presented on Fig. 1 and its parameters are 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 13.5 kHz impulses with duration of 10 ns at wavelength of 510.6 nm. Its mean power is 2.5 W and beam divergence – 2 mrad. 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 back scattered laser emission from the atmosphere. A registration in photon-counting mode is applied. Photon-pulses, produced by the photo-detector (photomultiplier EMI) 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 60s. 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 high with next one from lower high. In daytime conditions the sounding height decreases to about 4-5 km, due to intensive sky illumination, decreasing speedily Signal-to-Noise Ratio (SNR). Registered data are subsequently processed via program system in MATLAB environment, developed in the Institute of Electronics. Fernald's algorithm is used to calculate atmospheric backscatter coefficient profiles (Fernald, 1984). These final lidar measurement's products are saved on a common database created especially by EARLINET community.
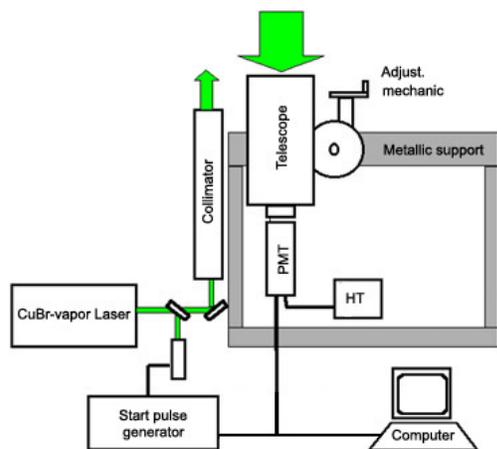

Fig. 1. Detailed block-diagram of the CuBr-vapor laser lidar

2. Regular measurements concerning EARLINET-ASOS project

The main goal of EARLINET-ASOS project is to provide a comprehensive, quantitative, and statistically significant database for the aerosol distribution on a continental scale. The network activity is based on scheduled measurements, a rigorous quality assurance program addressing both instruments and evaluation algorithms, and a standardized data exchange format.
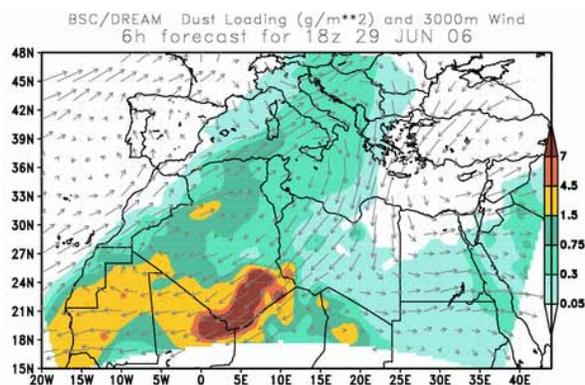

Fig. 3. Map of Saharan dust load – DREAM forecast.

In order to collect unbiased data, all the network stations perform measurements simultaneously at three fixed times a week. Lidar observations are performed on a regular schedule of one daytime measurement on Monday around noon (14:00 h LT), when the boundary layer is usually well developed, and two night time measurements per week (Monday and Thursday), with low background light, in order to perform Raman extinction measurements. Additional network measurements are performed to address specifically important processes that are localized either in space or time, like Saharan dust outbreaks, forest fires, volcanic eruptions, photochemical smog.

Each lidar measurement lasts 3-4 hours. The data-processing applies 30 min time integration interval for the data, so each lidar measurement gives 6 to 8 data files of the measured atmospheric parameter – backscatter or extinction coefficient profile. The research group using aerosol lidar with CuBr-vapor laser from "Laser radar" laboratory of the Institute of Electronics - BAS has collected data of about 120 lidar measurements, from the start of the project in April, 2006 till the end of 2006, which corresponds to about 500 data-files.

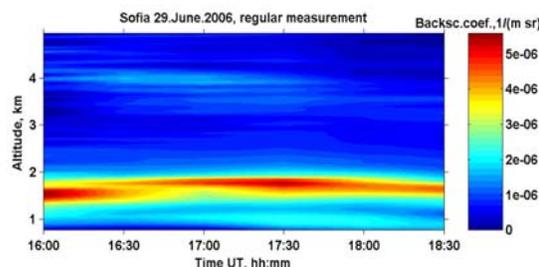### 2.1 Atmospheric backscatter coefficient profiles

Fig. 2. Lidar measurement on 29 June 2006.

In Fig.2 time series of measured atmospheric backscatter coefficient profiles on June 29th, 2007 is presented. The measurements lasts 3 hours, as can be seen on X-axis, i.e. 6 profiles of the atmospheric backscatter coefficient, each averaged for 30 min, are combined in successive plot. The color scale, next to the plot, shows the magnitude of calculated backscatter coefficient. A relatively dense aerosol layer was observed at altitude 1200-2000 m which persists during the entire measurement time interval. Such a long life aerosol layers are frequently caused by intensive dust load originating from Sahara desert. So we checked the information about Dust REgional Atmospheric Model (DREAM) forecast in Barcelona Supercomputing Center archive (http://www.bsc.es/projects/earthscience/ DREAM/). In Fig. 3 a map of the predicted dust load for the time of lidar measurement is shown. According to the forecast, dust load of 50 mg up to 300 mg per m^2 should be observed. Therefore the forecast proves our conclusion that the observed aerosol layer in the atmosphere above Sofia was due to Saharan dust transport over the sea.
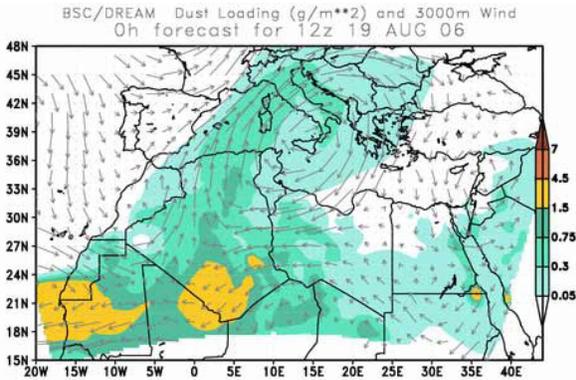
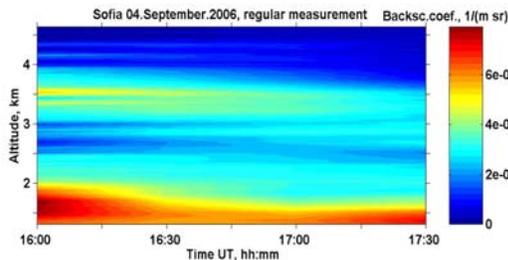*Fig. 6. Map of Saharan dust load – DREAM forecast*

Fig.4. Lidar measurement on 4 September 2006.

Another case of measured aerosol layers in the atmosphere is shown in Fig. 4. The measurement, made in the evening of September 4th, 2007, lasts 2 hours. It comprises a consequence of 4 backscatter coefficient profiles, each averaged for 30 minutes. Two aerosol layers have been observed and displayed on the graph. Lower one, spreading up to 1500-1800 m height, most probably due to the anthropogenetic smog of Sofia-town. The observation of an upper aerosol layer we explain with the existence of atmospheric inversion layer, which stops the diffusion of the smog through the atmosphere and collect at its lower limit the aerosol particles. At sunset time the inversion layer is destroyed and the upper aerosol layer becomes thinner till disappearance. The check for presence of a Saharan dust transport in the DREAM forecast archive during the time of that lidar measurement gave negative results.

3. EARLINET and CALIPSO QPQ validation plan

The EARLINET-community participates in the *Quid pro Quo* (QPQ) validation measurements of the project Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations CALIPSO (http://calipsovalidation.hamptonu.edu/ QPQ_plan062206.htm). This is a joint U.S. (NASA) and French (Centre National d'Etudes Spatiales/CNES) satellite mission with an expected 3 year lifetime. CALIPSO represents a free-flying laser radar experiment (lidar) in space and provides crucial global data on atmospheric clouds and aerosols needed for climate

studies. Ground located EARLINET stations were estimated as an optimal tool to validate CALIPSO lidar data and to provide the necessary information to fully exploit the information from that mission. In particular, aerosol extinction measurements, provided by the network, would be important for the aerosol retrievals from the CALIPSO backscatter lidar.

Lidar measurements related to CALIPSO QPQ program
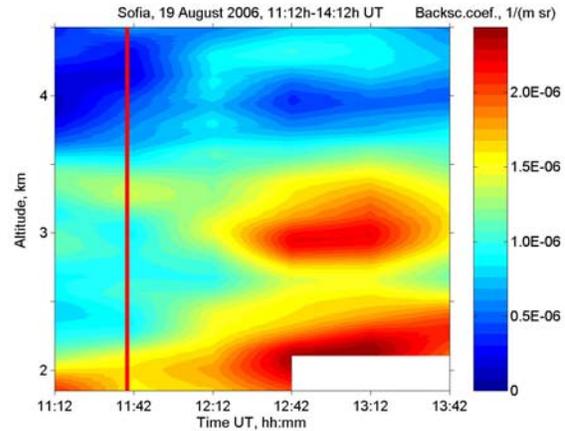

Fig.5. Lidar measurement on 19 August 2006 with significant dust load in the atmosphere at altitude 2500-3500 m.
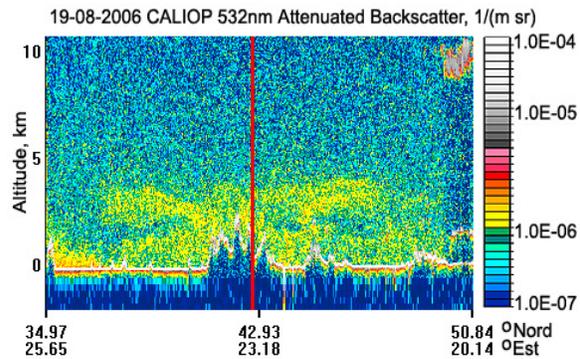

Fig. 7. Calipso lidar CALIOP measurement on 19 August 2006. The vertical red line marks the position of Sofia EARLINET lidar-station.

As a member of the EARLINET community, the research group with CuBr-laser aerosol lidar of "Laser radar" laboratory from the Institute of Electronics – BAS, started correlative measurements for CALIPSO since June 2006. These measurements were performed during CALIPSO overpasses. Each observation lasted for a minimum of 1 hour centered around the overpass time above Sofia. Actually, more than 185 profiles of the atmospheric backscatter coefficient, measured by the lidar group, were uploaded on the servers of the common EARLINET database.

In Fig.5 is presented such a measurement made on 19th August 2006. This was a daytime measurement that

lasted 3 hours and 6 profiles of the backscatter coefficient are displayed as uninterrupted time-series. Two aerosol layers are clearly distinguished on this graphic. As previously, the lower major aerosol layer we consider due to the antropogenetic smog as result of the human activity in the big city. The upper layer, at about 2500-3500 m height seems to be as thick and persistent in time as a dust layer transported from Sahara over the Mediterranean see. The map showing presence of Saharan dust transport we got from the DREAM forecast archive is presented in Fig. 6. A major dust layer covering Italy and the Balkan Peninsula had been predicted in the forecast. Fig. 7 presents a plot of the attenuated backscatter coefficient profiles measured by the Calipso lidar (CALIOP) from the space in the time when it flied over the Balkans. Calculated values of the backscatter coefficient are color-coded following the magnitude scale next to the graph. On the X-axis of the graph are presented the coordinates of Calipso groundtrack in degrees (North latitude and East longitude). On axis Y is marked the altitude. The vertical red line at X ~ 42.6^{o}N and 23.3^{o}E marks the overlap time of the Calipso lidar measurement and our ground-based aerosol lidar measurement in Sofia, at 11:39:43-11:40:05 h UT shown also with a vertical red line on Fig.5. Although both magnitude scales of the measured backscatter coefficient are not conversed to same color - same value, a coincidence of the registered aerosol layers can be observed. Flying from South-East to North-West above the Balkan Peninsula, CALIOP registered such a dust layer at about 2500-3500 m high as we registered with our CuBr-laser lidar. This is also a very good coincidence of the results of both lidar measurements, one from the ground and the other from the space with the DREAM model forecast for dust load over Europe in the same period.

4. Conclusion

In this paper an aerosol lidar with CuBr-vapor laser, created in the Institute of Electronics of the Bulgarian Academy of Sciences is presented. As part of the European Aerosol Research Lidar Network (EARLINET) this lidar performs regular measurements observing EARLINET time schedule. Some results of measurements and analysis were discussed. Also a comparison with satellite data obtained by CALIPSO lidar from the space was promoted.

Presented results give us opportunity to assume that the ground-based EARLINET lidars comply with the requirements for accurate operation and are an invaluable tool to provide multi-year continental scale data about aerosols over Europe and to support satellite space-lidar missions.

Acknowledgement

References

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