ABSTRACT

The Laser Remote Sensing Unit (LRSU) of the National Technical University of Athens (NTUA) belongs to ARIADNE: the Greek lidar network. LRSU is equipped with an 6-wavelength elastic-Raman lidar system (EOLE). EOLE permits vertical profiles of aerosols to be retrieved from near ground up to 10-18 km height: aerosol backscatter coefficient at 355-532-1064 nm, extinction coefficient at 355-532 nm, lidar ratio at 355-532 nm and Ångström-related exponent at 355 nm/532 nm, 532 nm/1064 nm, as well as of water vapour mixing ratio up to ~5-6 km height. The use of an advanced mathematical code permits the retrieval of the aerosol microphysical properties (mean/effective radius, mean refractive index, surface/volume density, and single scattering albedo). The data collected by EOLE in synergy with other ground-based and space-borne platforms will be used as input parameters in models, to estimate radiative transfer changes in climate models in vulnerable region of the Eastern Mediterranean.

1. INSTRUMENTATION

The Laser Remote Sensing Unit (LRSU) is based at the National Technical University of Athens (NTUA) where the EOLE multi-wavelength Raman lidar system operates [1-2]. EOLE is equipped with an advanced 6-wavelength Raman lidar system able to perform independent and simultaneous measurements of the vertical profiles of the aerosol backscatter coefficient (at 355, 532 and 1064 nm), of the aerosol extinction coefficient (at 355 and 532 nm) and of the water vapour mixing ratio in the troposphere (using the H$_2$O Raman channel at 407 nm). In addition, a new van-based depolarization lidar (AIAS system) is employed, detecting the polarized and cross polarized backscattered lidar signals at 532 nm, to further characterize the shape of the sampled particles. The calibration technique applied in this system is the ±45° calibration method, introduced by Freudenthaler et al. [3].

At a distance of about 2 km from EOLE, a fully automated sun sky radiometer (CIMEL), part of the NASA global robotic network AERONET [4], is installed in order to provide systematic measurements of the aerosol optical and microphysical properties in the atmospheric column.

2. OBSERVATIONS

During 08 and 09 September 2011, according to CIMEL data, the aerosol optical depth (AOD) over Athens reached quite high values at all wavelengths of interest (340, 500 and 1020 nm), as shown in Fig. 1. The AOD at 340 nm varied from 0.7 up to 1.0, while the Ångström exponent presented also high values of the order of 1.65, indicating the presence of rather small (anthropogenic) particles.

![Figure 1. Aerosol optical depth (AOD) and Ångström exponent retrieved by CIMEL over Athens on 08 and 09 September 2011.](attachment:image.png)

During the night of 08 to 09 September 2011, EOLE and AIAS lidars operated from 21:43 to 01:55 UTC. During this period several distinct aerosol layers were observed, extending from ground up to approximately 3 km height above mean sea level (Fig. 2), based on the spatio-temporal variation of the range-corrected lidar signal, obtained by EOLE [in arbitrary units - A.U.] at 1064 nm.
Figure 2. Spatio-temporal variation of the range-corrected lidar signal, obtained by EOLE [in arbitrary units - A.U.] at 1064 nm over Athens, Greece, on 08 and 09 September 2011.

By applying the Raman technique introduced by Ansmann et. al. [6] and the particle depolarization ratio retrieval [3] we were able to retrieve, independently, the aerosol backscatter and extinction profiles at 355, 532 and 1064 nm and thus, to calculate the aerosol optical parameters such as, the aerosol lidar ratio, the extinction-related and the backscatter-related Ångström exponents, as well as the particle depolarization ratio profiles (Fig. 3).

The aerosol layers observed in Fig. 2, from ground up to 3 km height, are also well defined in Fig. 3, by their corresponding aerosol optical parameters. More precisely, the aerosol backscatter coefficient at 355 nm is showing maximum value of the order of 4 Mm$^{-1}$sr$^{-1}$ at approximately 2 km height, while its maximum value at 532 nm (around 2 Mm$^{-1}$sr$^{-1}$) is also at the same height. The corresponding mean values of the aerosol backscatter coefficient at the height range (1.5 to 3 km) are 3.01±0.85 Mm$^{-1}$sr$^{-1}$ (355 nm) and 1.36±0.40 Mm$^{-1}$sr$^{-1}$ (532 nm), respectively. Accordingly, the mean values of the aerosol lidar ratio, at the same height range, at 355 and 532 nm, were of the order of 56±4 sr and 82±10 sr, respectively. The mean values of the backscatter-related Ångström exponents inside the aerosol layer were found to be of the order of 2, for both pairs of wavelengths (UV/VIS, VIS/IR), denoting the presence of rather fine particles. The particle linear depolarization ratio at 532 nm is showing quite constant behaviour within the whole profile. Its mean value (12±2%) denotes a well mixed aerosol layer consisting of rather non-spherical shape particles. In addition, this aerosol layer seems to be rather dry, especially at its top, since the relative humidity and the water vapour mixing ratio sharply decrease from 2 to 4 km height, to less than 7% and 0.004 g/kg, respectively (Fig. 4).

The CALIPSO lidar had an overpass at 00:31 UTC that night (approximately 140 km from Athens) with an ascending orbit. The retrieved CALISPO aerosol backscatter coefficient, lidar ratio and linear particle depolarization ratio profiles were retrieved using 25 km averaged level 2 version 3.01 profiles (Fig. 5).

The CALIPSO retrievals are in full consistency with the values retrieved by the ground-based lidar profiles, showing the presence of aerosols in the height range from near ground up to 3 km.
3. DISCUSSION

The aerosol type retrieved by CALIPSO, for the studied case, is characterized as “polluted dust” (Fig. 6). For the height range of interest (near ground up to 3 km) the number of occurrences of aerosol type resulting from CALIPSO averaged profiles (Fig. 7) shows that the dominant aerosol type is “polluted dust” (magenta line), with considerable percentages of other aerosol types such as “dust” (green line), “smoke” (dark yellow line) and “polluted continental” (red line).

The air mass stagnation (in number of days) in the 1700-2500 m atmospheric column was confirmed by FLEXPART simulations, as shown in Fig. 8. Indeed, the air masses stagnated for about 3-4 days over the Balkan area and about 2-3 days over central and South-South Western Europe. This led to an increase of the induced photochemical pollution. Additionally, in Southern Italy and the South-Western central Europe intense fire activity was observed by MODIS (not shown) during the first 10 days of September of 2011. Moreover, according to the back-trajectory analysis the air masses arriving over Greece (Fig. 9) during the studied period, originated from the Northern Saharan region 7 days before, over passed central Europe, thus advected aerosols from polluted areas towards Greece.

In Fig. 10 we present the fraction of different aerosol mixtures using the observed linear particle depolarization ratio at 532 nm, following the methodology provided by Gross et al. [7]. Since the depolarization was found to be 12%, it seems that the aerosol probed would be a mixture of about 25% dust and 75% biomass burning particles.

Figure 6. Aerosol type characterization obtained by CALIPSO satellite nearby Athens on 09 September 2011.

Figure 7. Number of occurrences of aerosol type resulting from CALIPSO averaging profiles over Athens on 09 September 2011.

Figure 8. FLEXPART simulations for aerosol stagnation days on 09 September 2011 (02:00 UTC).

Figure 9. Seven days back-trajectory analysis for air masses arriving at different heights over Athens on 09 September 2011 (00:00 UTC).
4. CONCLUSIONS

In this paper we presented a case study of an aerosol advection event which occurred over Athens, Greece on 09 September 2011. The aerosol load extended from near ground up to 3 km height and was followed by ground-based (EOLE and AIAS) and space-borne (CALIPSO) lidars, as well as by satellite observations (MODIS sensor) and sun photometry.

Along with the quantitative correlation between the space-borne and ground-based observations, en effort was given for the qualitative analysis of the aerosol optical properties and the type of particles. The measured mean values of the aerosol backscatter coefficients (at 355 and 532 nm) and the particle linear depolarization ratios (at 532 nm) inside the studied aerosol layer were approximately 3.01±0.85 Mm⁻¹sr⁻¹, 1.36±0.40 Mm⁻¹sr⁻¹ (532 nm), and 12%, respectively.

Concerning the aerosol type the CALIPSO observations characterized the probed particles as “polluted dust”. Nevertheless, inside the 25 km size window of averaged profiles by CALIPSO, a considerable amount of other aerosol types was found. Following Gross et al. [7], this aerosol mixture consisted of dust (25%) and smoke (75%). The above results were also confirmed by air mass back trajectory analysis and correlative FLEXAPRT simulations.

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5. REFERENCES