

TROPOSPHERIC VERTICAL PROFILES OF AEROSOL OPTICAL, MICROPHYSICAL AND CONCENTRATION PROPERTIES IN THE FRAME OF THE HYGRA-CD CAMPAIGN (ATHENS, GREECE 2014): A CASE STUDY OF LONG-RANGE TRANSPORT OF MIXED AEROSOLS

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ABSTRACT

Combined multi-wavelength aerosol Raman lidar and sun photometry measurements were performed during the HYGRA-CD campaign over Athens, Greece during May-June 2014. The retrieved aerosol optical properties (3 aerosol backscatter at 355-532-1064 nm and 2 aerosol extinction profiles at 355-532 nm) were used as input to an inversion code to retrieve the aerosol microphysical properties (effective radius r_{eff} and number concentration N) using regularization techniques. Additionally, the volume concentration profile was derived for fine particles using the LIRIC code. In this paper we selected a complex case study of long-range transport of mixed aerosols (biomass burning particles mixed with dust) arriving over Athens between 10-12 June 2014 in the 1.5-4 km height. Between 2-3 km height we measured mean lidar ratios (LR) ranging from 45 to 58 sr (at 355 and 532 nm), while the Ångström exponent (AE) aerosol extinction-related values (355nm/532nm) ranged between 0.8-1.3. The retrieved values of r_{eff} and N ranged from 0.19 ± 0.07 to 0.22 ± 0.07 μm and 460 ± 230 to 2200 ± 2800 cm^{-3} , respectively. The aerosol linear depolarization ratio (δ) at 532 nm was lower than 5-7% (except for the Saharan dust cases, where $\delta \sim 10$ -15%).

1. INTRODUCTION

The HygrA-CD campaign was an international field campaign which took place in Athens, Greece between 15 May to 22 June, 2014, in the

frame of the Initial Training on Atmospheric Remote Sensing (ITARS) project. HYGRA-CD (<http://hygracd.impworks.gr>) brought together a suite of different instruments and expertise aiming to enhance our understanding on the impact of aerosols and clouds on weather and climate. It was based on the synergy between remote sensing and in-situ instrumentation, making also use of numerical weather prediction and atmospheric modeling.

It is well established that tropospheric aerosols play a crucial role in climate change through scattering (cooling effect) and absorbing (warming effect) incoming solar and outgoing thermal radiation [1]. Despite recent progress documented in the latest Intergovernmental Panel for Climate Change (IPCC), the uncertainty about the current level of radiative forcing due to aerosols (0.5 Wm^{-2}) is still relatively large compared to that of global warming gases (0.25 Wm^{-2}). In order to clarify the mechanisms of aerosol radiative forcing and reduce the respective uncertainties, detailed knowledge of the vertical profiles of the particle optical (backscatter and extinction coefficients, AE and LR), microphysical (r_{eff} , surface-area concentration, N , single-scattering albedo (ω) and mean complex refractive index) and chemical properties (water content, dry chemical composition), as well as their mass concentrations are required [1,2].

Raman lidars have proven to be the most adapted tools in aerosol characterization experiments since

they can provide vertical profiles of the aerosol optical properties (aerosol extinction and backscatter coefficients), with high spatial and temporal resolution [3,5 and references therein]. Based on the above measurements the aerosol microphysical properties can be calculated using the regularization technique [4].

2. METHODOLOGY

In this study a synergy of instruments was used (Raman depolarization lidar and sun photometry) to derive the aerosol optical and microphysical properties aloft. The Athens Raman lidar system (EOLE) [5] was run in parallel with the AIAS depolarization lidar; both are part of the ARIADNE Greek lidar network [6] and are based in the Laser Remote Sensing Unit (LRSU) of the National Technical University of Athens (NTUA) (37.9°N, 23.6°E, 200 m a.s.l.). EOLE is able to perform independent and simultaneous measurements of the vertical profiles of the aerosol backscatter (at 355, 532 and 1064 nm) and extinction coefficient (at 355 and 532 nm) and of the water vapor to dry air mixing ratio in the troposphere (using the H₂O Raman channel at 407 nm). AIAS provides the aerosol linear depolarization ratio (δ) at 532 nm.

The EOLE Raman lidar data were also used to derive the vertical profiles of the intensive (lidar ratio, Ångström exponent) optical properties of the aerosols in the ultraviolet, visible and infrared. Due to the weak Raman signals, the complete set of aerosol products can be derived for tropospheric layers only during nighttime. The data processing was based on the Single Calculus Chain (SCC) developed within EARLINET [7].

Sun photometry data were provided by an AERONET CIMEL sun photometer located at the National Observatory of Athens (NOA) (www.aeronet.gsfc.nasa.gov).

The microphysical particle properties within specific atmospheric layers were retrieved using the inversion code provided by Müller et al. (1999 and 2011) [4 and 8, respectively]. A detailed description of the original version of the algorithm, which assumes spherical shape of the investigated particles in the retrieval procedures can be found in Müller et al. (1999) [4]. The full set of the aerosol backscatter coefficient at three

wavelengths (355, 532 and 1064 nm) and of the extinction coefficient at two wavelengths (355 and 532 nm) is required for the retrieval of the aerosol microphysical properties. The inversion model uses as input the mean values of the optical properties of the aerosols calculated within specific aerosol layers. The aerosol microphysical properties which were derived are the effective radius and the number concentration. Finally, we used LIRIC [9] to derive the volume concentration profile for fine particles.

3. RESULTS

In this paper we will focus on a case study of long-range transport of mixed aerosols arriving over Athens between 10-12 June 2014, in the height range between 1 and 5 km height a.s.l.

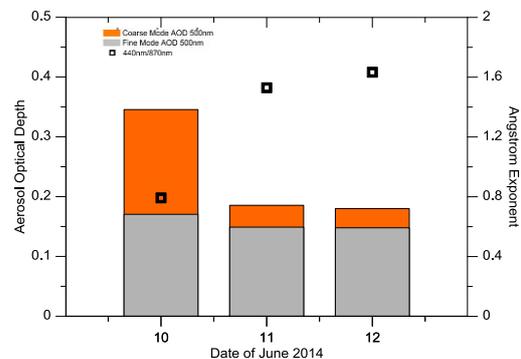


Figure 1. Evolution of the daily mean aerosol fine/coarse-mode optical depth (AOD) obtained over Athens at 500 nm as derived by the CIMEL sun photometer of NOA (left vertical axis) and the respective Ångström exponent values derived from 440 and 870 nm (right vertical axis) of the aerosol column for the period between 10 and 12 June 2014.

At first, in Figure 1 (left hand side axis) we present the evolution of the daily mean value of the aerosol optical depth (AOD) obtained over Athens at 500 nm as derived by the CIMEL sun photometer of NOA located 1.8 km from our lidar station. In the same figure (right hand side vertical axis) we present, for the same time period, the respective Ångström exponent values on 440 nm/870 nm (right vertical axis) of the aerosol column. From this figure we can see that on 10 June the AOD at 500 nm is quite high (0.35) and decreases by 30% the following 2 days, mainly due to the strong decrease of the coarse mode particles. However, for all these days, the AOD

due to the fine mode particles remains nearly constant (~ 0.15 - 0.17). On the other hand the Ångström exponent values (440nm/870nm) from CIMEL rise from 0.8 (10 June) to 1.62 (12 June) (cf. Fig. 1, right hand side vertical axis). This means that on 10 June the atmospheric column over Athens was dominated by coarse particles, while 1-2 days later the fine particles clearly dominate.

8-day air mass back trajectories calculated by HYSPLIT model showed that on 10 June (night) the air masses observed between 2-3 km height over Athens, originated from the Ukraine-S. Russia and Kazakhstan regions, where biomass burning and Asian desert dust dominated, respectively, after spending 1-2 days over the Balkans. On 11 June the situation changed and after 18:00 UTC some air masses from Sahara, mixed with continental European ones, were observed at 2-3 km height. This effect was intensified more between 22:00-24:00 UTC. The situation changed completely on 12 June, where the aerosol load dropped (similarly as on the morning hours of 11 June), as the air masses sampled over Athens originated from the Balkans-Ukraine, S. Russia and Kazakhstan regions, where biomass burning and Asian desert dust dominated.

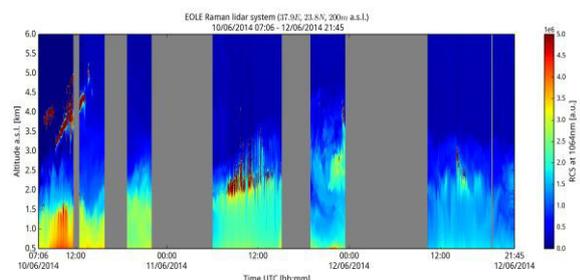


Figure 2: Spatio-temporal evolution of the range-corrected backscattered lidar signals (RCS) obtained by the EOLE lidar over Athens at 1064 nm between 10 (07:06 UTC) and 12 (21:45 UTC) June 2014.

The corresponding Raman lidar measurements, expressed in terms of the temporal evolution of the range-corrected lidar signals (RCS), between 10-12 June (Fig. 2) showed discrete aerosol layers between 2-3 km height, extending up to 3-4.5 km height on 11 June. Moreover, higher aerosol load content is observed on 10 June, compared to ones of the following 2 days.

In Figure 3 we present the aerosol optical properties (backscatter and extinction coefficients, lidar ratio and Ångström backscatter and extinction-related exponent) retrieved by EOLE lidar between 0.8 and 6 km height on 11 June 2014, between 19:00 and 20:00 UTC aerosol backscatter coefficient at 355-532-1064 nm, aerosol extinction and lidar ratio at 355-532 nm, and Ångström backscatter (355nm/532nm and 532nm/1064nm) and extinction-related (355nm/532nm) exponent.

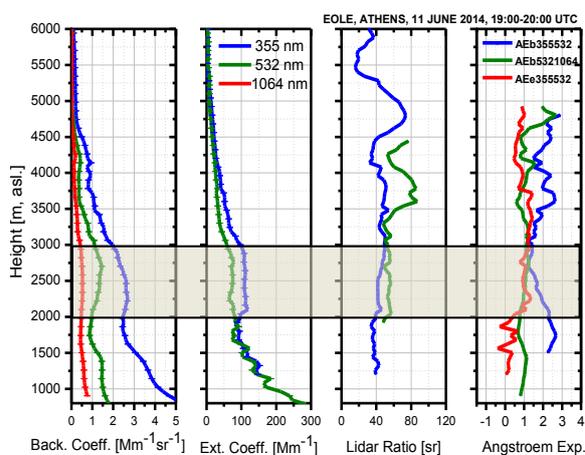


Figure 3. Vertical profiles of the aerosol optical parameters (backscatter and extinction coefficients, lidar ratio, Ångström exponent) retrieved from EOLE Raman lidar measurements on 11 June 2014 (19:00-20:00 UTC) over Athens.

In Fig. 3 we can see a strong aerosol layer between 2-3 km extending up to nearly 4.5 km height. In the 2-3 km height (shaded region) the lidar ratio values are of the order of 45-58 sr (at 355 and 532 nm), while the Ångström exponent aerosol extinction-related values (355nm/532nm) range between 0.8-1.3, close to 1.55 (440nm/870nm) measured during daytime by CIMEL in the atmospheric column. All these values compare well with those measured under similar atmospheric conditions of mixed continental aerosols with dust [10]. Using the inversion code provided by Müller et al. [8] we retrieved, within the shaded of Fig. 3, the mean r_{eff} ranging from 0.19 ± 0.07 to $0.22 \pm 0.07 \mu\text{m}$, and N from 460 ± 230 to $2200 \pm 2800 \text{ cm}^{-3}$. Our r_{eff} values compare well with those of Mamouri et al. (2012) for a mixed dust event over Athens [3].

4. CONCLUSIONS

In this paper we selected a case study of long-range transport of mixed aerosols (biomass burning particles mixed with dust) arriving over Athens between 10-12 June 2014 in the 1.5-4 km height region. In the 2-3 km height region we measured mean lidar ratios (LR) ranging from 45 to 58 sr (at 355 and 532 nm), AE aerosol extinction-related values (355nm/532nm) ranging between 0.8-1.3; the retrieved values of r_{eff} and N ranged from 0.19 ± 0.07 to 0.22 ± 0.07 μm and 460 ± 230 to 2200 ± 2800 cm^{-3} , respectively. The aerosol linear depolarization ratio δ at 532 nm was, in most cases (except for the Saharan dust ones $\delta\sim 10\text{-}15\%$), lower than 5-7%.

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