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Variability of Aerosol Properties Using AERONET Retrievals and Relation between Aerosol Optical Depth and PM Levels at Ioannina, Greece 2022 †

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Abstract: In this study, we try to characterize local aerosols over the city of Ioannina for the first time using continuous AERONET CIMEL Sun–Sky spectral photometer measurements. The instrument, which belongs to the Laboratory of Atmospheric Physics of the Aristotle University of Thessaloniki, was installed in 2022 at the University of Ioannina and operated for a 5-month period from 23 February to 30 June 2022. Based on its measurements and retrievals, we investigate aerosol optical properties on a monthly, daily and hourly mean basis and reveal relationships between Aerosol Optical Depth (AOD) and local particulate matter (PM). It is found that the 5-month mean AOD is 0.17, from which 0.08 is ascribed to fine-mode and 0.09 to coarse-mode aerosols, while the corresponding mean Angstrom Exponent is 0.95. The total PM, PM_{10} and $PM_{2.5}$ concentrations for the same period are equal to 32.51, 22.39 and 11.40 μg/m^3, respectively. The correlation coefficient between PM_{10} and AOD_{500nm} is equal to 0.79, and the one between the $PM_{2.5}/PM_{10}$ ratio and the Fine-Mode Fraction of AOD is equal to 0.76. Events of episodic fine and coarse aerosol conditions, which took place during the study period, are also analyzed using AERONET Volume Size Distribution (VSD) inversion products, along with back trajectories obtained with the NOAA's HYSPLIT model, to assure the origin of the particles.

Keywords: aerosols; particulate matter; aerosol optical depth; AERONET; dust episodes; Ioannina

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1. Introduction

Human activity is altering the aerosol environment through land cover change, combustion of fossil fuels and the introduction of particulate and gas species to the atmosphere [1]. Furthermore, natural aerosols, such as sea-spay, dust, sulphates, organic and volcanic can also be found in the atmosphere [2]. Aerosol particles considerably reduce visibility, influence climate and cause health problems in humans. The optical properties of atmospheric aerosol, which drive their radiative and climatic effects [3], are determined by their chemical composition, concentration, size, shape and internal structure, and significantly vary in space and time [4]. Because of this strong variability and significant role, it is important to study aerosol properties, preferably using state-of-the-art measurements, especially in unexplored areas.

In this study, local aerosols are characterized for the first time over the city of Ioannina basin using atmospheric columnar optical properties for nearly five months, derived by measurements taken with a continuously operating AERONET instrument in the University of Ioannina from 23 February to 30 June. Subsequently, the day-to-day variation of AOD and

AE was examined for each month of the period February–June, along with that of local PM levels based on data from the local Environmental station of the Region of Epirus, located about 5 km north of the AERONET site. In addition, the surface PM data were correlated with the columnar aerosol AERONET data, providing insight into the relationship between the surface and the boundary layer and free tropospheric aerosol loadings. Finally, by using the AERONET volume size distribution (VSD) and NOAA's HYSPLIT model, we investigated events of episodic fine and coarse aerosol conditions.

2. Data and Methodology

2.1. AERONET Data

In the present study, AERONET Version 3 (V3) data were used, derived by measurements taken with the CIMEL sun–sky spectral photometer which belongs to the Laboratory of Atmospheric Physics of the Aristotle University of Thessaloniki, and was installed in 2022 at the University of Ioannina (39.616° N, 20.837° E) on the roof of the Physics Department building, at an elevation of 540 m. The Version 3 (V3) algorithm provides fully automatic cloud screening and instrument anomaly quality controls measurements [5]. The data used consists of level 1.5 aerosol optical depth and aerosol inversion products. All input data are available at https://aeronet.gsfc.nasa.gov/ (accessed on 24 July 2023). Further information on the instrument and AERONET infrastructure are included in [6]. The hourly and daily mean values of AOD, AE, fine and coarse mode fractions and their standard deviations were calculated, ensuring the representativeness of the derived daily values. To this aim, a requirement for availability of at least 4 h of measurements during the interval 8:00–17:00 on each day was applied.

2.2. Environmenal Station Data

Air pollution was monitored in Ioannina on an hourly basis by an urban background station. The environmental station of the Epirus Region is located at the city center, approximately 5 km north of the University of Ioannina where the AERONET CIMEL instrument was operated. The recorded pollutants consist of PM values, specifically PM_1, $PM_{2.5}$, PM_4 and PM_{10}, as well as CO, NO, NO_2, NO_x, O_3 and SO_2 concentrations. However, only PM_{tot}, PM_{10} and $PM_{2.5}$ data were used in this study, which were derived by measurements taken with the APDA-372 Air Pollution and Dust Analyzer. This instrument uses optical light scattering as its measuring principle and can measure particle sizes between 0.18–18 μm.

2.3. Determination of Episodes of Fine-Coarse Aerosols

Due to the difference in their sources, aerosols exhibit noticeable differences in physical and optical properties with respect to their location [7]. Among other classifications, the one referring to the aerosol size is major and, to this aim, the use of the Angstrom Exponent (AE) is common for discriminating between fine and coarse particles. Typical values of AE $\leq$ 1 indicate size distributions dominated by coarse mode aerosols that are typically associated with dust and sea-salt spray, while values of AE $\geq$ 2 indicate size distributions dominated by fine mode aerosols that are usually associated with urban pollution and biomass burning [8].

We identify coarse particle episodes in days for which: (1) the daily mean AE is <0.7 and (2) the daily mean AOD for coarse aerosols is higher than the corresponding mean daily AOD value, averaged over the 5-month study period, plus one standard deviation ($AOD_{CE} > 0.24 + 0.10$). Respectively, fine particle episodes are identified in days for which: (1) the daily mean AE is >1.6 and (2) the daily mean AOD for fine aerosols is higher than the mean daily AOD, plus one standard deviation. ($AOD_{FE} > 0.12 + 0.06$).

3. Results and Discussion

In Figure 1, the temporal evolution of the daily mean values of local AERONET AOD and Angstrom Exponent (AE) are presented for the 5-month interval. In general, background AOD values are lower than 0.2, mostly ranging from 0.1 to 0.2 (the overall range is 0.03–0.49), while AE values exhibit a greater range of variability (0.07–1.88), indicating the existence of both fine and coarse particles. At the end of March, until the beginning of April (6 April), AOD rises over 0.3, up to 0.5, and AE drastically drops (to values <1 and down to near zero), revealing the presence of coarse particles, namely the occurrence of a dust episode that originated from Africa (as it is shown below). A similar dust episode also appears to have occurred on 22–25 June, while transportation of fine particles is evident, associated with AE values of ~1.65 along with AOD peak of ~0.24 in the 15 May.

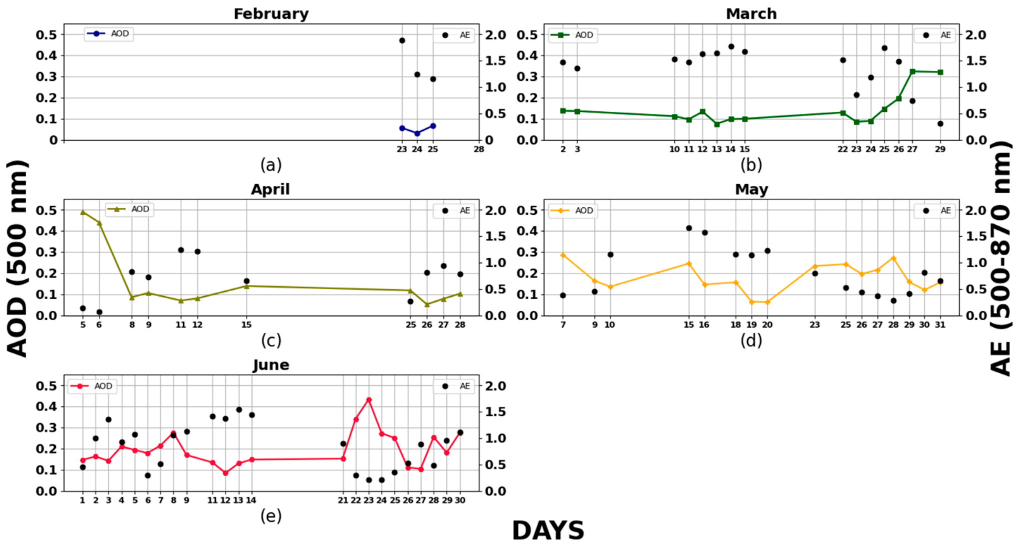


Figure 1. Day-to-day variation of AERONET AOD (colored dots and curves) and AE (black dots) daily mean values at Ioannina for the months of: (**a**) February, (**b**) March, (**c**) April, (**d**) May, (**e**) June.

Figure 2 displays the daily mean values of aerosol optical properties (AOD, AE) for the five-month period (68 days) in a scatter plot. Different color points correspond to days of a specific month. Based on this scatterplot, fine and coarse particle episodes are classified according to the methodology mentioned in Section 2.3. Coarse particles (AE < 0.7) are most often found in April, May, and June, yielding mean AOD and AE values equal to 0.25 and 0.38, respectively. On the other hand, fine particles (AE > 1.6) are more common in March with mean values AOD = 0.12 and AE = 1.72. The estimated mean AOD and AE values for the entire study period are 0.17 and 0.95, and the associated standard deviations are 0.10 and 0.49, respectively.

Figure 3 shows the temporal variation of daily mean $PM_{2.5}$ and PM_{10} concentrations whenever AERONET retrievals are available. The 5-month mean values are 22.4 μg/m^3 for PM_{10} and 11.4 μg/m^3 for $PM_{2.5}$, while the respective ranges of variability are 5.7–79.6 and 2.4–32.1 μg/m^3. The two clear peaks of PM_{10} in early April (~80 μg/m^3 on 5 April) and late June (66.3 μg/m^3 on 24 June) verify that the dust episodes detected by AERONET are also evident in coarse particulate matter concentrations recorded at the surface.

The correlation between (a) PM_{10} and AERONET AOD at 500 nm and (b) $PM_{2.5}/PM_{10}$ ratios versus the Fine-Mode Fraction (FMF) of AOD is shown in Figure 4. The data used in these figures are normalized mean daily values, with respect to the maximum daily value over the examined period in Ioannina (68 days), and linear regression is applied to the scattered points. The equation of the regression line for Figure 4a (PM_{10} = 0.75 AOD + 2.41), along with the correlation coefficient of R = 0.79 and RMSE = 0.407, indicates a relatively good match between the columnar AOD and surface PM values. A similar match is also found between the columnar Fine-Mode Fraction of AOD and the PM2.5/PM10 ratio (Figure 4b), $PM_{2.5}/PM_{10}$ = 0.57 FMF + 21.83, correlation coefficient R = 0.76 and RMSE = 0.387.

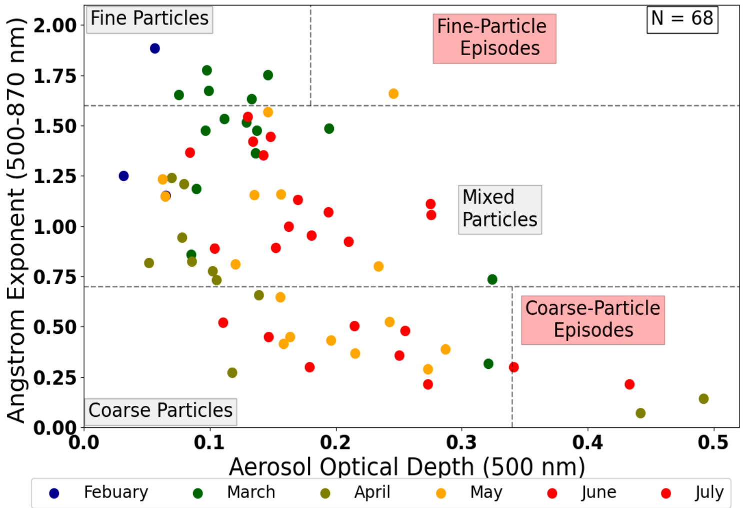


Figure 2. Aerosol classification using the scatter plot diagram of daily mean Angstrom Exponent (AE) and AOD values based on AERONET data from Ioannina. The horizontal lines correspond to the thresholds (0.7 and 1.6) set for discriminating coarse, fine and mixed particles, while the vertical lines to the thresholds (0.21 and 0.34) are used for identifying coarse and fine aerosol episodes. The thresholds for discriminating between fine and coarse aerosol episodes are calculated using the average values of fine-coarse mean AOD, plus one standard deviation.

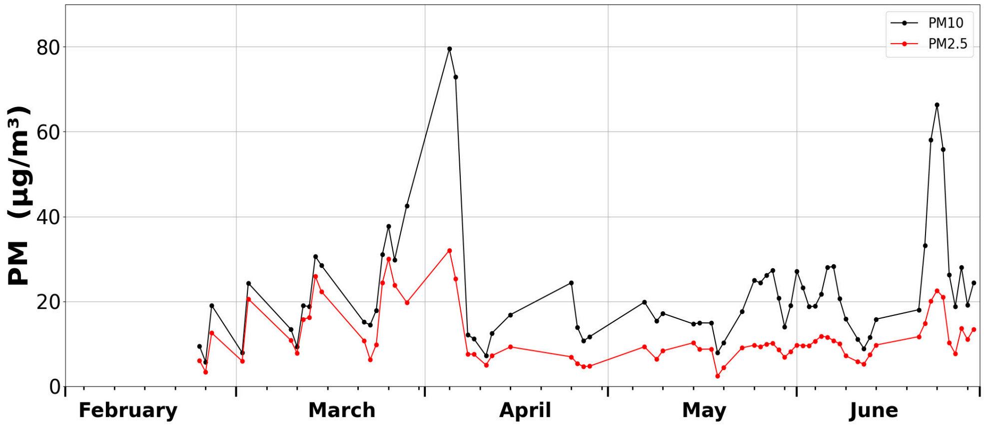
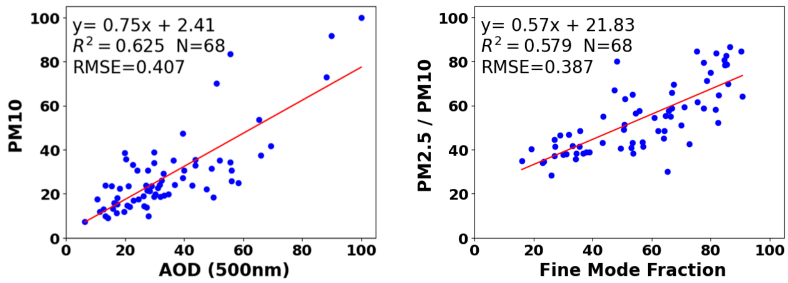


Figure 3. Timeline (day-to-day variation) of daily mean $PM_{2.5}$ and PM_{10} concentrations measured at the environmental station in Ioannina downtown throughout the study period (February–June 2022).



(**a**) (**b**)

Figure 4. Scatter plot for daily mean values of (**a**) AERONET AOD versus PM_{10} and (**b**) AERONET Fine-Mode Fraction versus $PM_{2.5}$/PM10 ratio. The red solid line represents the best fit line from linear regression, while the computed statistics are also shown.

Last, the occurrence of a fine particle episode on 15 May 2022, and a coarse particle episode on 5 April 2022, was examined by using AERONET Volume Size Distribution

(VSD) and NOAA's HYSPLIT model backward trajectories, which help to identify the particles' origin. In Figure 5a, the VSD peaks at particle radius of 0.2 µm, clearly showing the predominance of fine-mode particles that contribute more to AOD. These particles originated from Western Balkans and Northern Italy (Figure 5c) and, more specifically, are carbonaceous particles emitted by fires that took place in Northern Italy and Western Balkans. This is based on an analysis using FIRMS (https://firms.modaps.eosdis.nasa.gov/map/#d:24hrs;@0.0,0.0,3z, accessed on 24 July 2023). In Figure 5b, the VSD peaks at a radius of 2 µm, exhibiting a dominant coarse mode at 1–5 µm [9]. These coarse aerosols are associated with a dust episode which, as shown by the back-trajectory analysis (Figure 5d), originated from the Sahara Desert and subsequently moved over the Central Mediterranean through to Ioannina at high altitudes (green and blue lines).

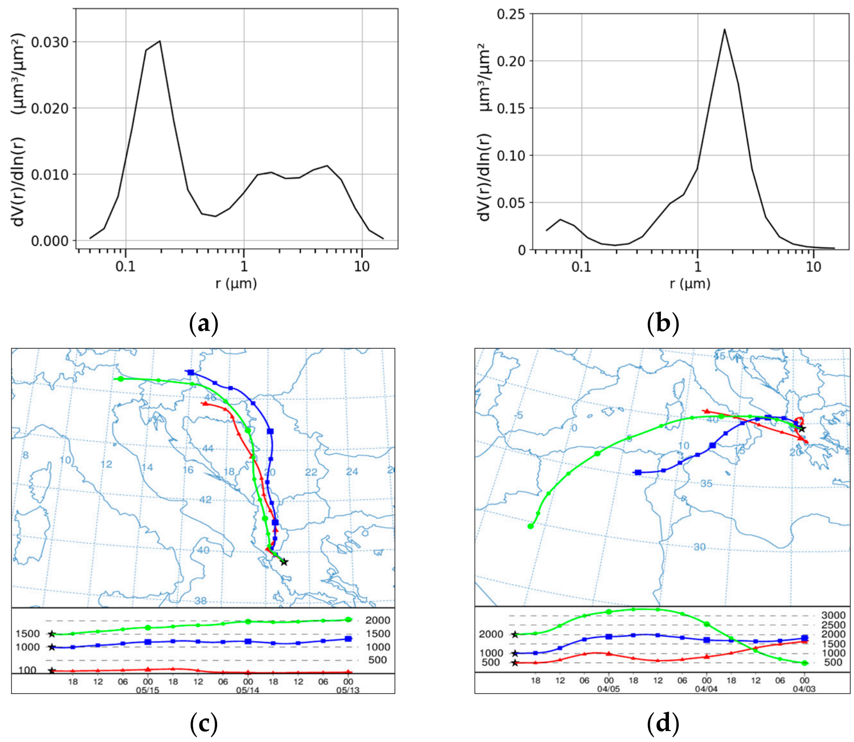


Figure 5. Volume size distribution of (**a**) a fine particle episode and (**b**) a coarse particle episode that took place in Ioannina on 15 May 2022 and 5 April 2022, respectively. The corresponding back-trajectories arriving (at the location of the star symbol) at elevations of 100 m, 1000 m, 1500 m for the fine aerosol episode (**c**), and 500 m, 1000 m and 2000 m for the coarse aerosol episode (**d**) over Ioannina are also shown.

4. Summary and Conclusions

In this study, we examined, for the first time, the optical properties of local aerosols over Ioannina using columnar AERONET products and compared them with surface PM levels for a five-month time period from February to June 2022. The estimated mean values of AOD and AE are equal to at 0.17 and 0.95, respectively, indicating relatively low aerosol loadings and mixed fine and coarse particles. It was found that, for an urban environment like the Ioannina basin, there is a relatively good correlation between the atmospheric columnar aerosol loads and surface PM concentrations (R = 0.79), as well as between the AERONET Fine-Mode Fraction of AOD and $PM_{2.5}/PM_{10}$ ratio (R = 0.76), suggesting that the columnar optical properties can be reasonably monitored at the surface. The AERONET retrievals, in particular, inversion products, along with HYSPLIT backward trajectories, enable the identification of fine and coarse aerosol episodes occurring at Ioannina, as well as their origin and pathways.

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