e-COST Virtual Mobility report

Title: Dust Optical Properties over the Mediterranean Basin

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1. Introduction

1.1. Background – rationale

Variations in aerosol type and concentration are critical drivers of climate change, as they modulate atmospheric processes and regional weather patterns (Nabat et al., 2015). The Mediterranean Basin frequently experiences dust events. Dust is transported over the Mediterranean from the Sahara Desert as well as from the deserts of the Middle East. Dust aerosols play a key role in many physical, chemical, and biological processes over the area (e.g., enrichment of the soil with nutrients, photochemical processes in the troposphere, meteorology). Furthermore, dust aerosols play a key role in the formulation of the regional climate by scattering and absorbing solar radiation, thereby reducing the amount of solar irradiance that reaches the surface.

Previous studies in the area showed that the radiative forcing of aerosols in the Mediterranean Basin is among the highest in the world (Zittis et al., 2022). The complexity of aerosols such as dust, sea salt and continental aerosols makes the area particularly interesting for radiative closure studies.

The "AErosol RObotic NETwork" (AERONET) global network of photometers (Holben et al., 1998; Giles et al., 2019) consists of a collaborative network of ground-based sun photometers along with a comprehensive system for data inversion and associated records. This network is instrumental in understanding how the optical properties of aerosols are modified during transport events, such as dust storms, and how various stations can be influenced by multiple aerosol source

1.2. Aims of the VM

The main goals of this study are to:

1) Investigate the differences between dust optical properties for different dust sources.
2) Investigate the evolution of dust optical properties during transport
3) Discuss how local pollutants affect dust optical properties over different sites

2. Methodology

Level 1.5 (v3) AERONET Version 3.0 () retrievals were employed to identify significant dust episodes impacting various stations across the Mediterranean Basin

The identification of cases was based on observations where Aerosol Optical Depth (AOD) at 500 nm > 0.2 and Ångström Exponent (AE) -0.1 < AE (380 – 500 nm) < 0.3 (Floutsi et al. 2023). Then we created maps to find 20-day periods when a large number of AERONET stations (more than 10) were affected by dust (not necessarily by a single event). An example is seen in Figure 1, where between 20th April and 10th of May 2022 dust affected more than 10 stations from East to West Mediterranean.

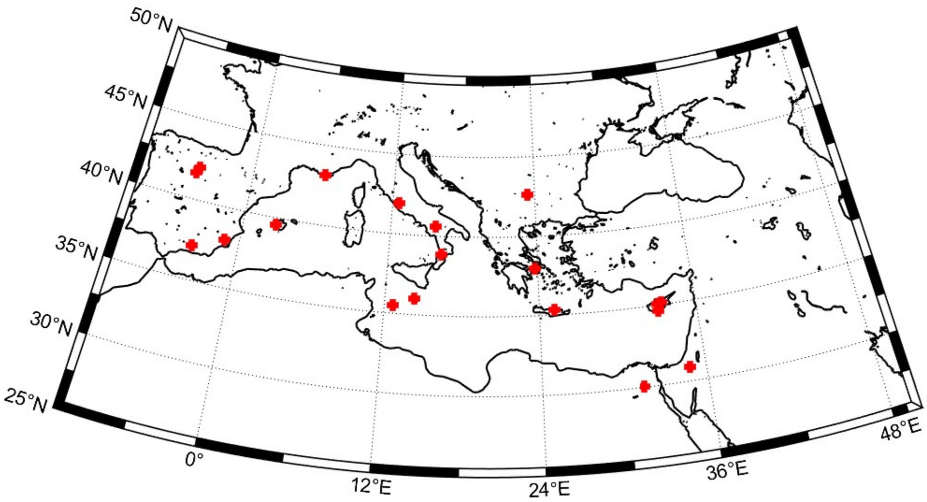
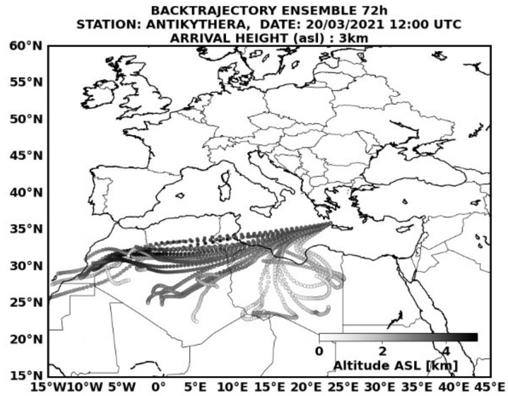


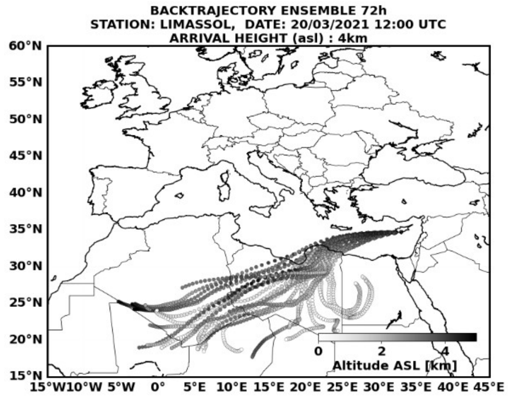
Figure 1. Map of stations that were affected by dust between 20th April and 10th May 2022.

Further analysis was conducted to identify the exact timing of the events and the origin of dust. Visual inspection of AERONET products initially allowed us to identify the dates of dust events more accurately. Then, we conducted trajectory analysis using HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory; Stein et al., 2015) to determine the origin of each event and the corresponding dust transport paths. The back trajectories illustrated in Figure 2 depict the pathways at two stations affected during each event. The arrival height of the dust plume was estimated utilizing co-located vertical profile observations, when available, obtained from ACTRIS/EARLINET (Pappalardo et al., 2014) lidar instruments.

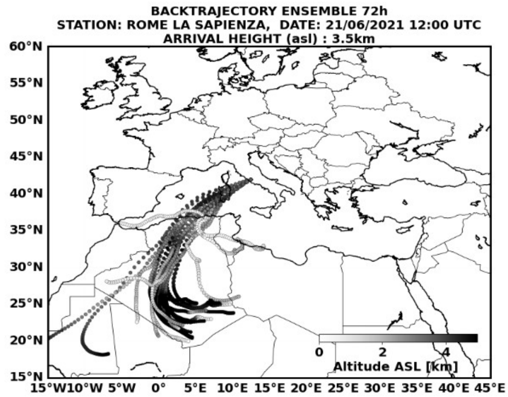
a)


BACKTRAJECTORY ENSEMBLE 72h
STATION: ANTIKYTHERA, DATE: 20/03/2021 12:00 UTC
ARRIVAL HEIGHT (asl) : 3km
Altitude ASL [km]

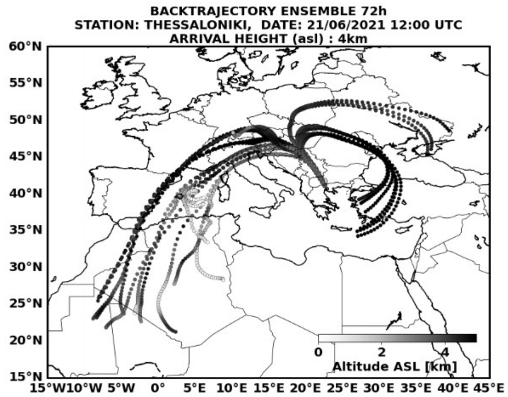
b)


BACKTRAJECTORY ENSEMBLE 72h
STATION: LIMASSOL, DATE: 20/03/2021 12:00 UTC
ARRIVAL HEIGHT (asl) : 4km
Altitude ASL [km]

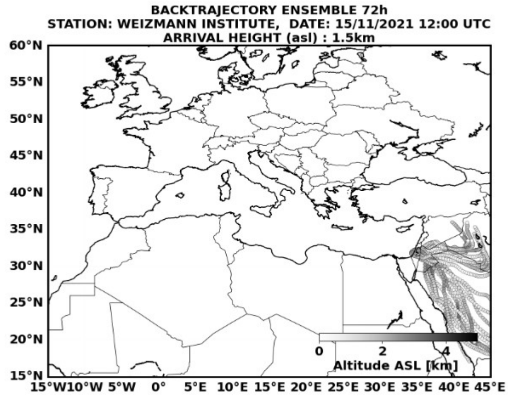
c)


BACKTRAJECTORY ENSEMBLE 72h
STATION: ROME LA SAPIENZA, DATE: 21/06/2021 12:00 UTC
ARRIVAL HEIGHT (asl) : 3.5km
Altitude ASL [km]

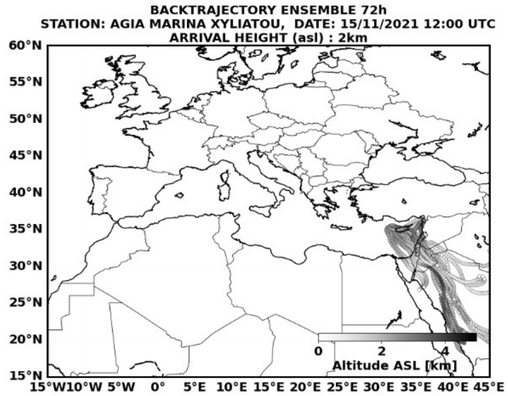
d)


BACKTRAJECTORY ENSEMBLE 72h
STATION: THESSALONIKI, DATE: 21/06/2021 12:00 UTC
ARRIVAL HEIGHT (asl) : 4km
Altitude ASL [km]

e)


BACKTRAJECTORY ENSEMBLE 72h
STATION: WEIZMANN INSTITUTE, DATE: 15/11/2021 12:00 UTC
ARRIVAL HEIGHT (asl) : 1.5km
Altitude ASL [km]

f)


BACKTRAJECTORY ENSEMBLE 72h
STATION: AGIA MARINA XYLIATOU, DATE: 15/11/2021 12:00 UTC
ARRIVAL HEIGHT (asl) : 2km
Altitude ASL [km]

g)

h)

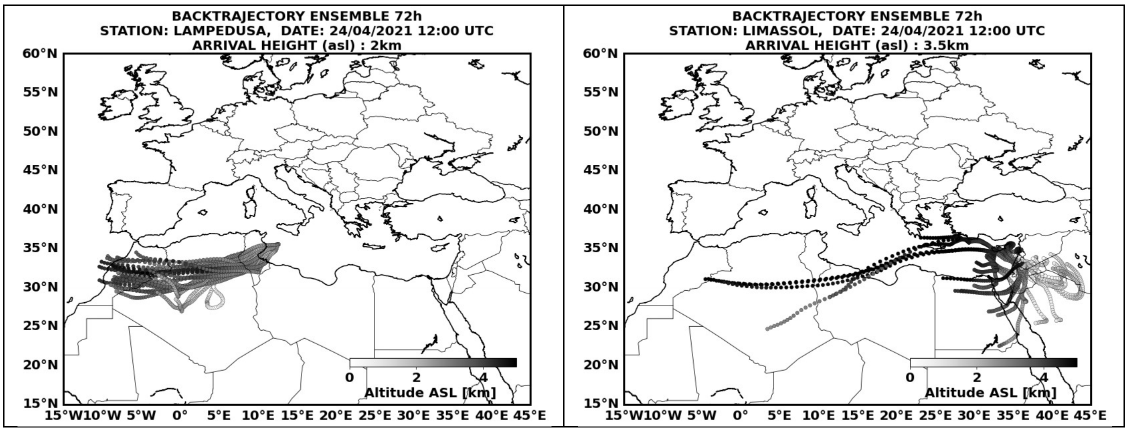


Figure 2. 72-hour HYSPLIT Ensemble backtrajectories for four events: Event 1 (a, b), Event 2 (c, d), Event 3 (e, f), and Event 4 (g, h). Each ensemble member is generated by applying a fixed grid offset to the meteorological data, highlighting the variability in transport pathways. Arrival heights are calculated based on vertical profiles from collocated lidar observations.

Figure 3 shows the quicklooks used to identify the altitude of the dust layer over the Antikythera and Limassol stations during Event 1 (Fig. 2a-b).

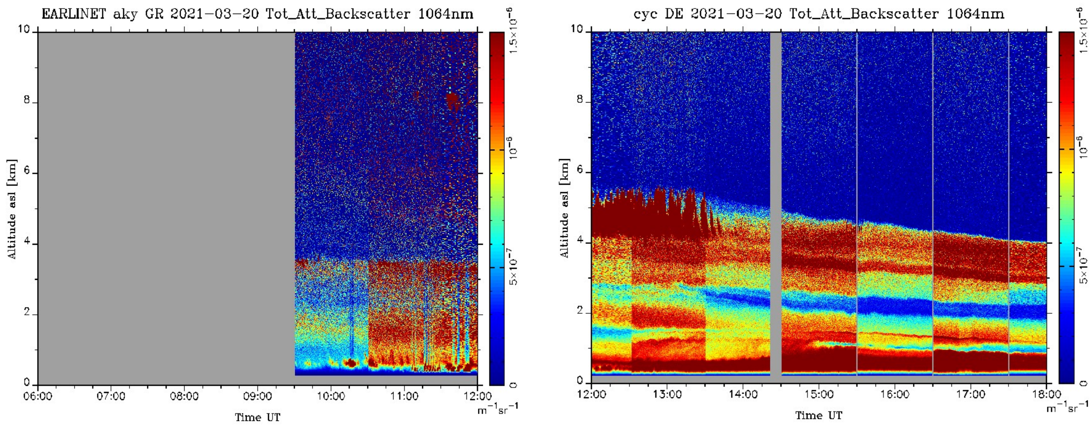


Figure 3. Lidar measurements of total attenuated backscatter at 1064 nm taken at the EARLNET stations of Antikythera (top) and Limassol (bottom) on 20th March 2021.

Based on the trajectories, we chose four strong episodes where the origin of dust was different and a large number of stations were affected. The four dust episodes are summarized in Table 1. For each episode we choose six sites at relative long distances to each other to study the aerosol optical properties.

Table 1. Stations that were used for each event.

Dates	18 – 29 March 2021	17 – 28 June 2021	10 – 21 Nov. 2021	21 April – 1 May 2022
Origin	**East and Central Sahara**	**Western Sahara**	**Middle East**	**Central Sahara**
Station 1	Antikythera (35.9N, 23.3E)	Antikythera (35.9N, 23.3E)	Sede Boker (30.9N, 34.8E)	Lampedusa (35.5N, 12.6E)
Station 2	Cairo (30.1N, 31.3E)	Athens (38.0N, 23.7E)	Weizmann Institute (31.9N, 34.8E)	Mallorca (39.6N, 2.6E)
Station 3	Finokalia (35.3N, 25.7E)	Ben Salem (35.6N, 9.9E)	Cairo (30.1N, 31.3E)	Rome (41.9N, 12.5E)
Station 4	Nicosia (35.1N, 33.4E)	Rome (41.9N, 12.5E)	Agia Marina Xyliatou (35.0N, 33.1E)	Valladolid (41.7N, 4.7W)
Station 5	Sede Boker (30.9N, 34.8E)	Magurele-Inoe (44.3N, 26.0E)	IMS-METU-ERDEMLI (36.6N, 34.3E)	Athens (38.0N, 23.7E)
Station 6	CUT-TEPAK (34.7N, 33.0E)	Thessaloniki (40.6N, 23.0E)	Finokalia (35.3N, 25.7E)	CUT-TEPAK (34.7N, 33.0E)

For further identification of the events, we exploited MIDAS (ModIs Dust AeroSol; Gkikas et al., 2021) data regarding the Dust Optical Depth (DOD) values at 550 nm (Figure 4).

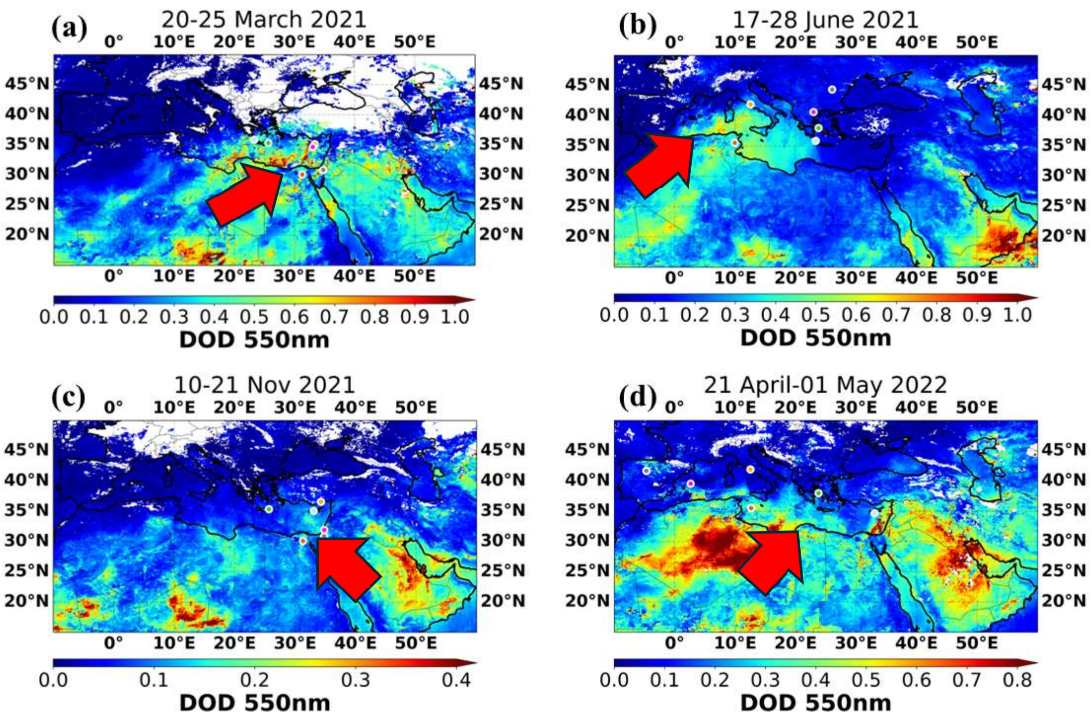


Figure 4. Average DOD (at 550 nm) over the Mediterranean Basin from MIDAS for the four dust events. Averaging has been performed for the days with very high DOD levels.

3. Results and discussion

Figures 5–7 present the AOD at 500 nm, the Angstrom Exponent (AE) at 440–675 nm from direct sun AERONET measurements, and the coarse-to-total AOD ratio at 500 nm. Additionally, Figures 8–10 show the Size Distribution, Single Scattering Albedo (SSA), and Asymmetry Factor (ASY) from the inversion AERONET products for each station during the study period.

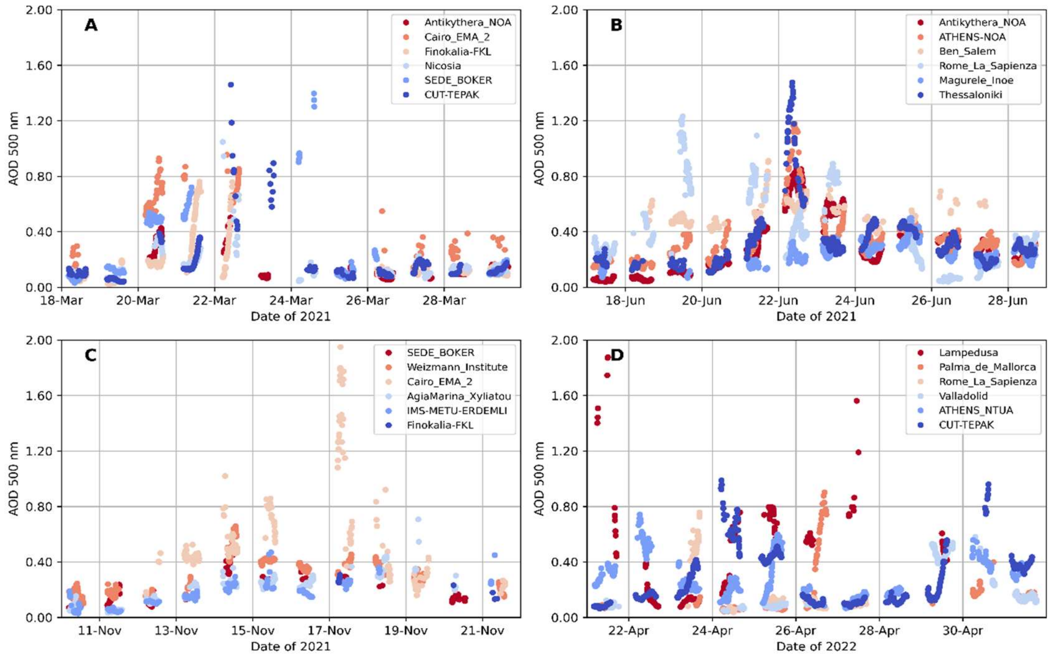


Figure 5. AOD at 500 nm from direct sun AERONET measurements.

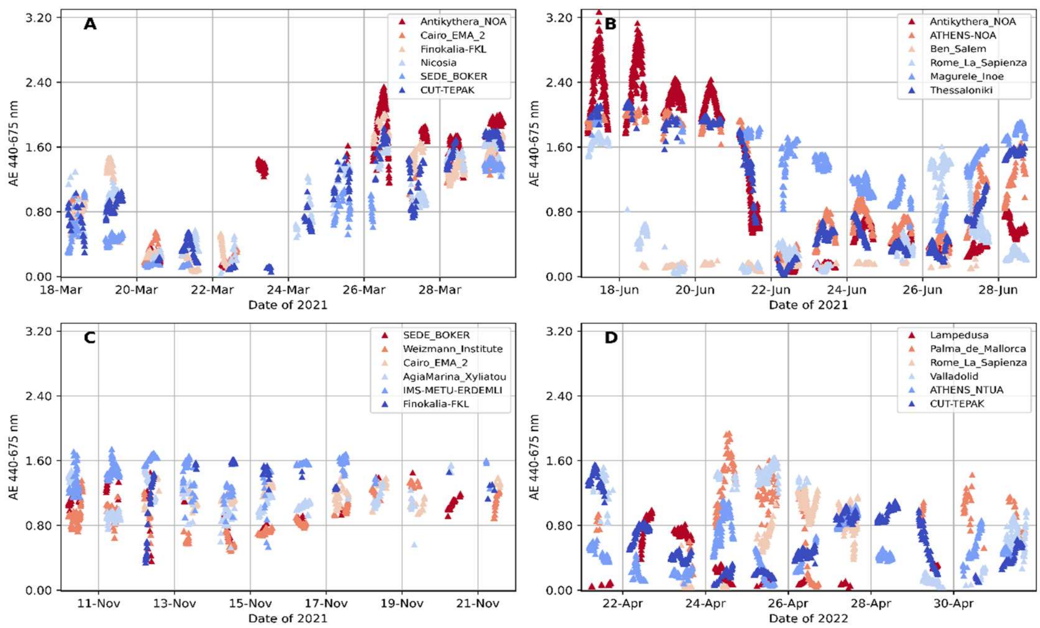


Figure 6. AE at 440-675 nm from direct sun AERONET measurements.

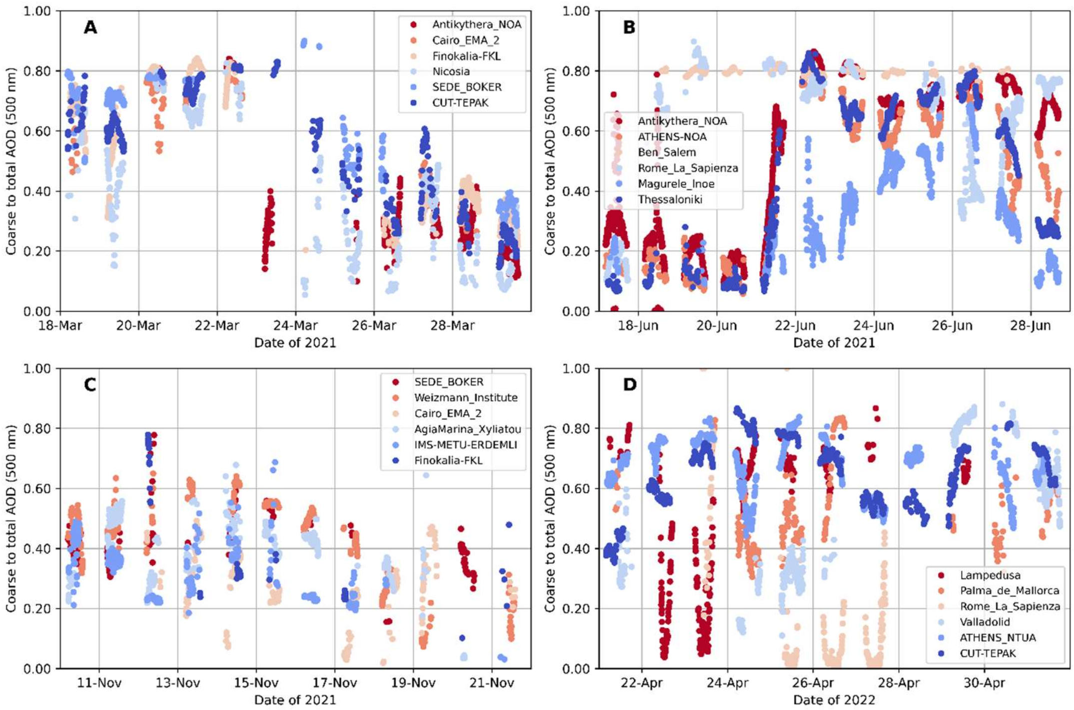


Figure 7. Coarse to total AOD at 500 nm

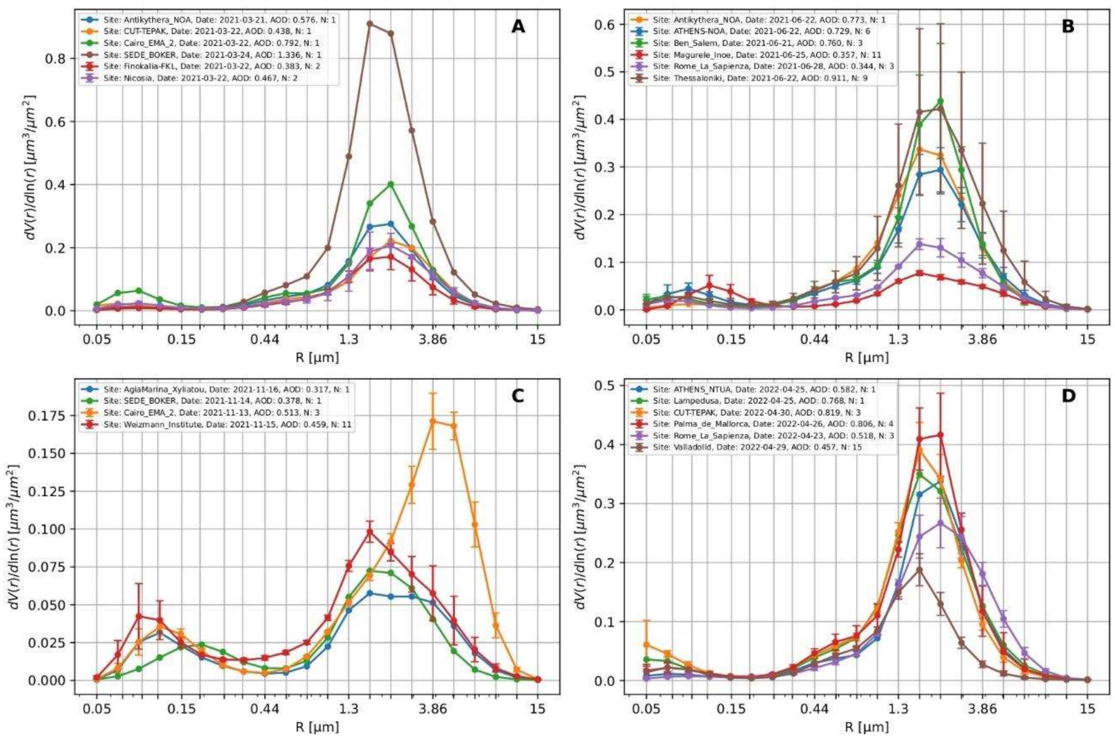


Figure 8. Size distribution inversion AERONET product.

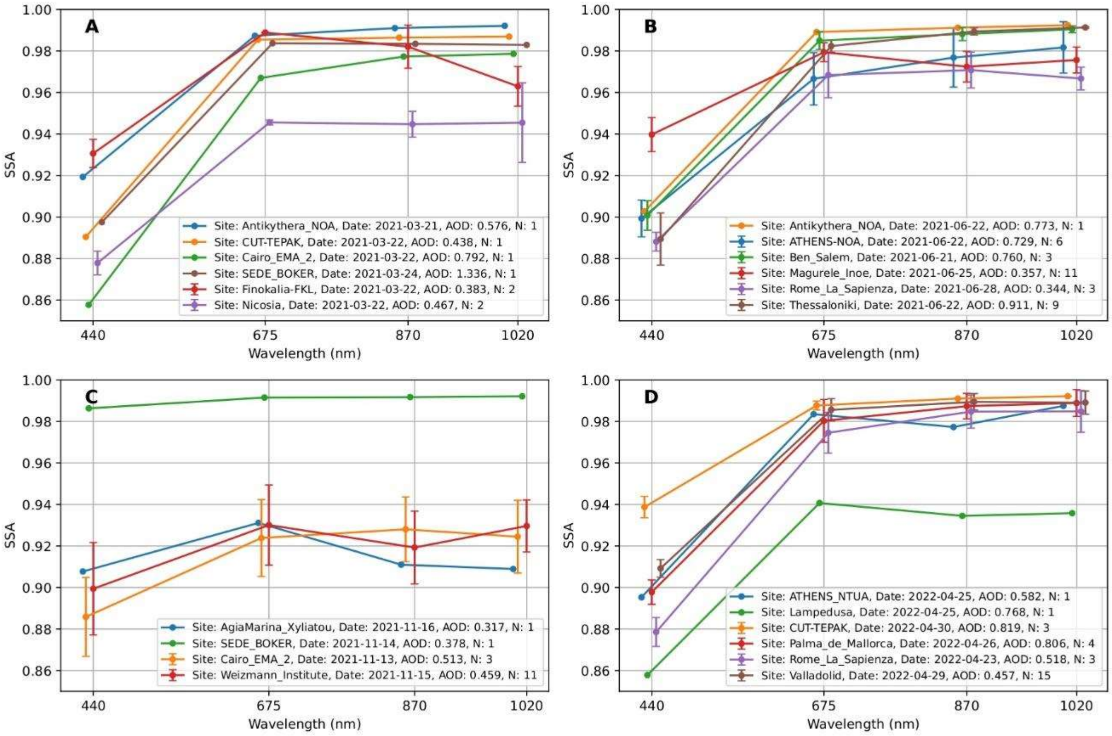


Figure 9. SSA inversion AERONET product.

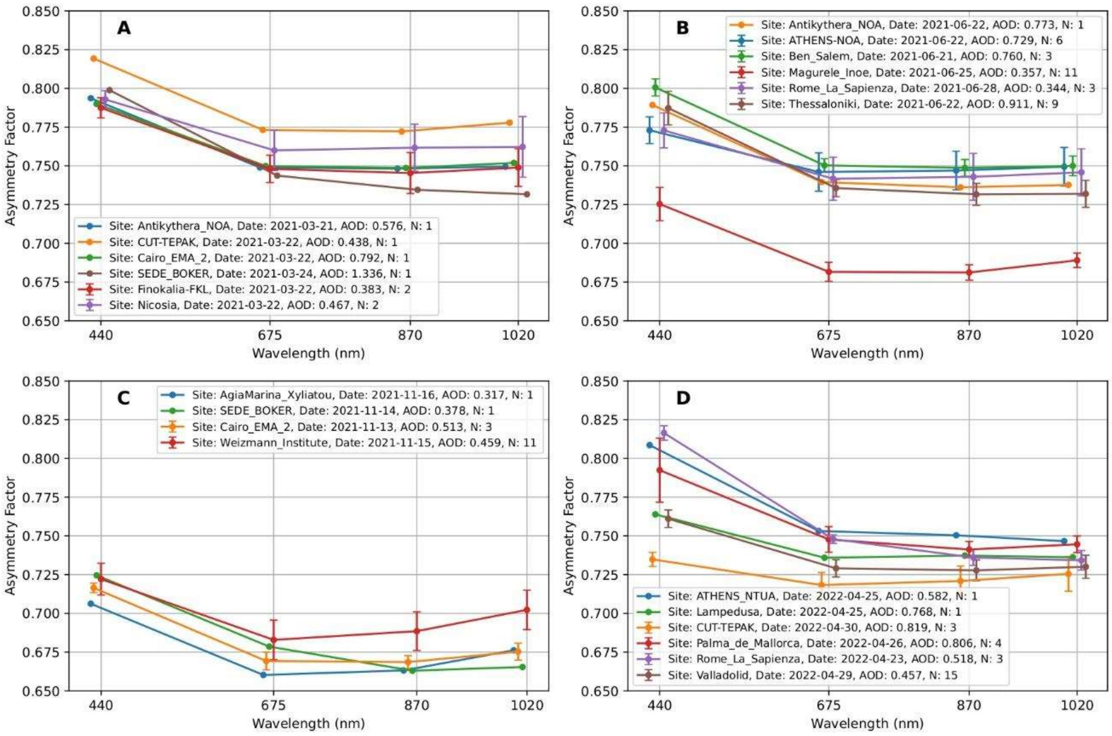


Figure 10. Asymmetry factor inversion AERONET product.

There is no obvious dependence of the dust optical properties from the distance from the source for none of the events. Nevertheless, there are differences between the optical properties over different sites that are possibly due to the effect of local pollutants.

In almost all cases, the spectral behavior of the SSA and the ASY for dust are clearly shown, although the exact spectral pattern and the absolute levels may differ.

Event 1 (origin: East-Central Sahara):

For this particular event, the mixture is dominated by coarse particles at all stations, and the SD is practically monomodal, with the exception of Cairo_EMA where the SD is bimodal, i.e., there is a second peak at ~0.08 μm (and maybe a third one at ~0.5 μm).

The SSA over Nicosia is generally smaller with respect to other stations, in some cases by up to 0.04 - 0.06. It is interesting that the mixture over Nicosia is composed mostly of large particles, i.e., this behavior does not seem to be due to external mixing with local polluted particles. The ASY at the same station is at similar levels to the ASY at all other stations.

The SSA at 440 nm (0.86 – 0.93) is lower than the SSA at 675 – 1020 nm (0.94 – 0.99) by 0.06 – 0.1. The ASY at 440 nm (0.78 – 0.82) is higher relative to the ASY at 675 – 1020 nm (0.73 – 0.78) by ~ 0.05.

Event 2 (origin: Western Sahara):

In general, the results are very similar to the results for event #1. The differences between the different sites are however less pronounced, which could be due to the fact that the sources of dust in western Sahara are more homogeneous in terms of dust composition.

Another difference with event#1 is that a secondary maximum is present for all sites at ~ 0.08 – 0.12 μm. The amount of smaller particles is larger at Magurele, possibly due to the increased concentration of continental aerosols, and the smaller amount of dust that reaches the site. The presence of local non-dust particles is possibly the reason for the less pronounced wavelength dependence of the SSA and the significantly lower ASY.

Event 3 (origin: Middle East):

There are many interesting aspects of this event. In addition to other events, there is significant contribution of fine mode aerosols in the mixture over all sites, even near the sources (e.g., Weizmann Institute). This might be an indication that dust that originates from the Middle East arrives over the Eastern Mediterranean sites with a significant amount of fine mode particles.

While the spectral behavior of the ASY is similar to that for other events, its levels are on average lower by ~ 0.05 – 0.1 with respect to other events. The wavelength dependence of the SSA is also much weaker, and in general the SSA at wavelengths 675 – 1020 nm is lower by 0.05 – 0.08 with respect to other events.

The SSA for Sede Boker is very high, ~0.99, and practically independent from wavelength. We will further investigate this case to clarify if this is due to the mixing with other pollutants.

Event 4 (origin: Central Sahara):

The findings for this event are again very similar to those for events 1 and 2. The main difference is that the spread within the SSA and the ASY values is larger, which however can be related to the fact that dust originates from a very wide area, and thus different sites can be affected by dust with different properties. For example, the SSA over Lampedusa is lower by 0.02 – 0.06 with respect to the SSA for other stations. This is interesting since the low SSA values over Lampedusa could possibly be due to the presence of very large particles rather than due to local pollutants. There is however no evidence for the presence of such particles (i.e., with R>15 μm) in the retrieved size distribution.

4. Future plans

The optical properties from AERONET that have been analyzed in this study will be further exploited to perform radiative transfer simulations with the radiative transfer model libRadtran to quantify the attenuation of the GHI and DNI solar irradiance during the dust events.

The optical properties from AERONET will be compared with the corresponding optical properties that have been estimated from the new version of the METAL-WRF model. The GHI simulated by the METAL-WRF radiative transfer scheme will be also compared with the GHI that has been simulated with libRadtran.

The impact of differences in SSA and ASY on the GHI and DNI, and subsequently on energy production for different events will be further investigated.

The losses in solar energy production during the events will also be discussed.

5. Linkage to Harmonia deliverables

This study contributes to the objectives of WG3 (end user engagement towards maximizing aerosol measurement use) by using radiometric measurements of aerosol optical and physical properties to improve our understanding on how dust affects surface solar radiation and solar energy production. It must be kept in mind that this study will be extended to identify how dust from different sources (i.e., Saharan Desert, Middle East) impacts solar energy production.

The study addresses mainly the action deliverable: “T3.3: Investigate and report on the role of aerosol uncertainty on user requirements” since it will provide information that will contribute to assessing the role of dust optical properties in the modeling of solar radiation and solar energy.

6. Conclusions

The main conclusions of this study can be summarized as follows:

- There are significant differences between the optical properties of dust from the Middle East and dust from the Sahara. These differences are, at least partially, due to differences in SD. Further investigation is needed to determine the role of different chemical composition.
- As dust is transferred over different sites, wash out, dilution, and/or dry deposition result in differences in its optical depth. Optical properties such as SSA and ASY also differ. One of the interesting findings of this study is that differences in SSA and ASY can not be attributed solely to the mixing with local pollutants.
- During the four events discussed in this study, very high AOD levels have been measured over many Mediterranean sites, that are expected to result in significant attenuation in GHI and DNI.

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