# Analysis of aerosol optical properties and implications to radiative forcing over the Mediterranean Basin

*Ibtissam MARSLI*, Abdelilah Makaoui, Mohammed Amine Moussaoui, Ahmed Mezrhab and Mohammed Diouri*

Mechanics and Energy Laboratory, University Mohammed 1st, Oujda, Morocco

**Abstract.** The Mediterranean atmosphere is impacted by a mixture of natural and anthropogenic aerosols, which generate complex and regionally variable impacts on climate and air quality. In this study, aerosol optical properties were examined at six sites: Burjassot, OHP Observatoire, Napoli_CeSMA,Thessaloniki, CUT-TEPAK and Medenine-IRA over the Mediterranean basin using ground-based measurements. The analysis focuses on key parameters, aerosol optical depth and its spectral dependence Angström exponent, Volume Size Distributions and aerosol radiative forcing. The annual mean aerosol optical depth at 500 nm was found high at the Southern Mediterranean site Medenine-IRA reaching 0.20 and coincide with relatively lower Angström exponent (440–870 nm) value,this opposite patterns indicates the dominance of coarse particles. The aerosol volume size distribution revealed that the coarse-mode aerosols showed a significant contribution to the total volume particle concentration at all Mediterranean sites. The aerosol radiative forcing of the vertical columnar atmospheric balance showed a heating effect, with high radiative forcing ATM value of +25 W/m², reflecting the absorption of solar radiation by larger dust aerosols at the Southern Mediterranean site, this increased atmospheric column warming is accompanied by a marked cooling at the surface reaching –30 W/m².

**Keywords**: Aerosol optical depth, Aerosol radiative forcing, Volume size distribution, Angstrom exponent, AERONET, Climate

## 1 Introduction

Atmospheric aerosols are one of the key constituents of the Earth-atmosphere system, they originate from natural sources such as desert dust transport, sea spray and volcanic eruptions, and from anthropogenic activities including industrial emissions and biomass burning. Aerosols affect climate directly by scattering and absorbing solar radiation, and indirectly by altering microphysical properties and cloud formation processes [1]. The increase of both

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natural and anthropogenic particles has a significant impact on climate and human health and may significantly affect hydrologic cycles, air quality and reducing visibility [2-3].
The Mediterranean Basin is a complex environment where aerosols from different sources are mixed, with significant implications for regional climate and air quality. Due to the variety of the regions around the basin, a wide range of sources with different classes of particles can be found in the Mediterranean atmosphere. These aerosols include, desert dust, originated from North Africa and other desert regions, marine aerosol, continuously formed over the Mediterranean itself or transported from the Atlantic Ocean, fine anthropogenic aerosols from urban and industrial areas of Continental and Eastern Europe and biomass burning particles produced by wildfires mostly in summer [4-5].
Given this wide variety of aerosol, it is important to precisely characterize their optical, microphysical and radiative properties. Ground-based measurements, provides effective tools for monitoring and characterizing column-integrated aerosol optical properties over diverse environments with relatively high temporal resolution. A number of studies have been published in various parts of the world [6,7,8,9] and selected regions in Mediterranean Basin [10-11]. Advancing knowledge of aerosol–climate interactions in the Mediterranean and to improve the accuracy of radiation budget, more extensive, reliable and higher-quality data on aerosol properties and loads are essential.
In this study, aerosol measurements were taken using several AERONET (V3) solar photometers located at various stations across the Mediterranean basin. The aerosol data include Aerosol Optical Depth (AOD), Angström exponent (AE), volume size distribution (VSD) and aerosol radiative forcing (ARF)

## 2 Data and study area

The remotely sensed ground-based aerosol data from the global network AERONET, represent one of the most accurate and standardized methods for monitoring aerosol optical properties. The measurements were made with the CIMEL sunphotometer (CE-318) an automatic sun-sky scanning spectral radiometer was established in the early 1990s and is growing rapidly in the number of stations worldwide. The instruments provide high temporal resolution data. The CIMEL was programmed to make measurements of the direct sun at eight spectral direct intensities for visible and IR wavelengths (340, 380, 440, 500, 670, 870, 940 and 1020 nm) and diffuse sky radiances, called almucantar at 440, 675, 870 and 1020 nm. The data obtained from these measurements enable the calculation of aerosol columnar properties including aerosol optical depth, single scattering albedo, Ångström exponent, and detailed inversion products such as particle size distribution, aerosol radiative forcing, complex refractive index, precipitable water and vapor content. In version 3 of AERONET, the database was provided in three levels. Level 1.0 was defined as cloud-contaminated; level 1.5 corresponded to cloud-screened and level 2.0 indicated an automatically cloud-screened and quality-assured [12]. The sites studied in this work are distributed in the Mediterranean area (Fig.1). Tab.1 presents the description of the different sites, according to the Koppen classification.

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**Table 1.** Sites characteristics

| **Sites** | **Lat.** | **Long.** | **Alt.(m)** | **Climate** |
|---|---|---|---|---|
| Burjassot,Spain (2024) | 39.5° N | 0.4° W | 104 | Csa (Mediterranean climate) |
| OHP Observatoire, France (2024) | 43.9° N | 5.7° E | 680 | Csa |
| Napoli_CeSMA, Italy (2024) | 40.8° N | 14.3° E | 50 | Csa |
| Thessaloniki, Greece (2024) | 40.6° N | 22.9° E | 60 | Csa |
| CUT-TEPAK, Cyprus (2024) | 34.6° N | 33.0° E | 22 | Csa |
| Medenine-IRA,Tunisia (2023) | 33.4°N | 10.6° E | 33 | BWh (Hot desert climates) |

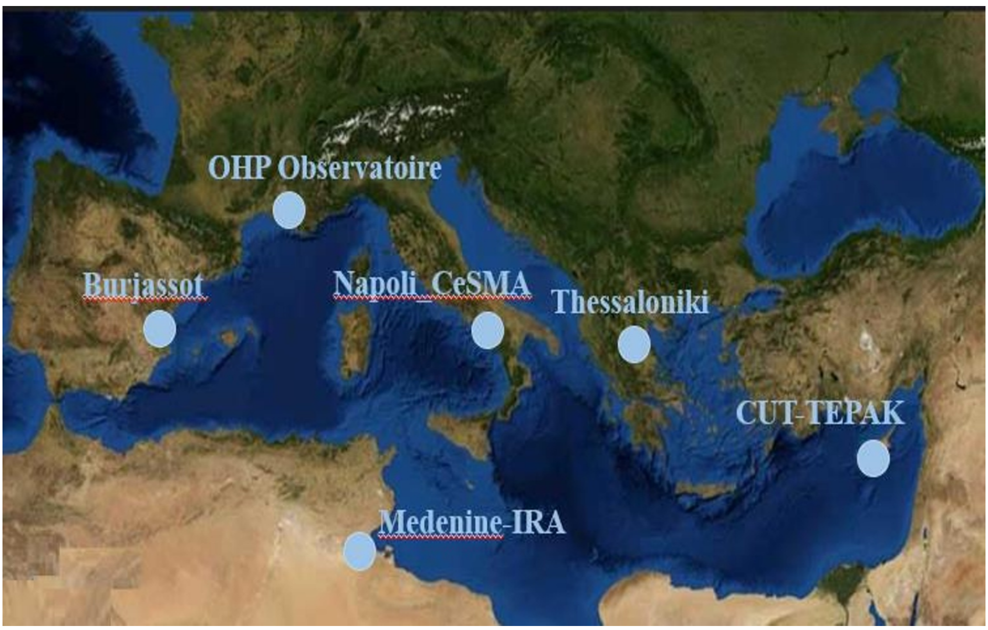


**Fig.1:** Selected Mediterranean AERONET sites

## 3 Results and discussion

### 3.1 Aerosol optical depth and AE

The box plots of the AOD at 500 nm (Fig. 2) and AE at 440–870 nm (Fig.3), illustrates the spatial variability of the aerosol load over the Mediterranean basin and reveals distinct aerosol regimes driven by regional sources and long-range transport. In Western Northen Mediterranean sites, AOD shows relatively low values and coincide with relatively higher AE values with an annual average of AOD (AE) around 0,09 (0.97) in OHP-Observatoire and 0,14 (1.18) in Burjassot. This indicates generally clean to moderately turbid conditions with the influence of marine aerosols and limited influence from long-range transport.

Progressing towards the Central and Eastern Mediterranean sites both AOD(AE) progressively increase and reaching 0,17 (1.20) in Napoli, 0,19 (1.41) in Thessaloniki and 0,18 (1.17) in CUT-TEPAK, indicating which can be attributed to a mix of local urban-industrial emissions, episodic Saharan dust transport and regional transport of anthropogenic pollutants. [1-13]. In contrast at the Southern Mediterranean site, AOD exhibit a different pattern and reaches its highest levels in the Tunisian site Medenine-IRA around 0.20 while AE decreases, This inverse behavior indicates the growing contribution of desert dust due to their proximity to Saharan source areas and Middle Eastern deserts. These dust outbreaks occur frequently in the North Africa and eastern Mediterranean, particularly in spring and summer [14].

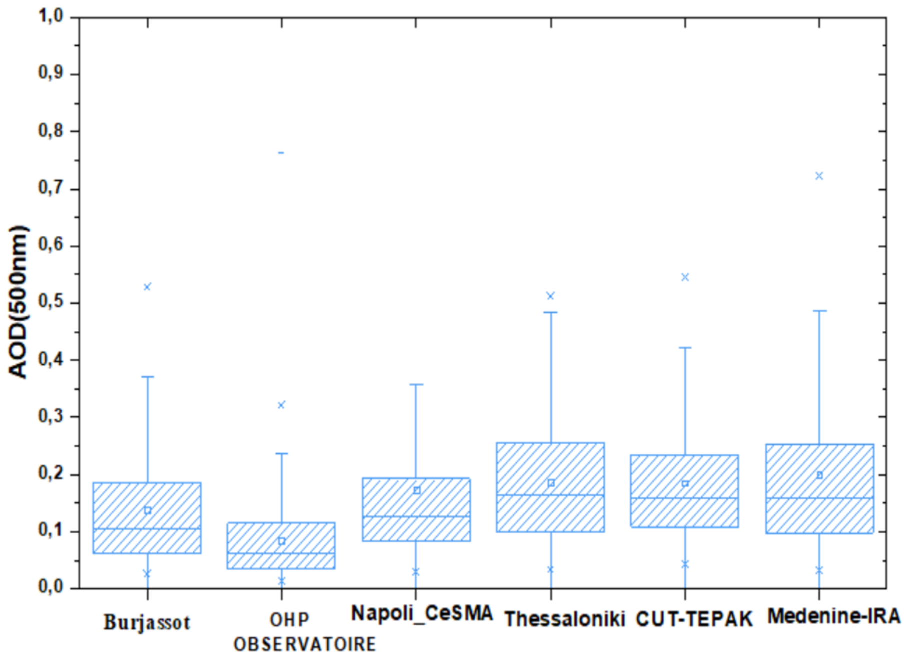


**Fig. 2.** Annual average of AOD (500nm)

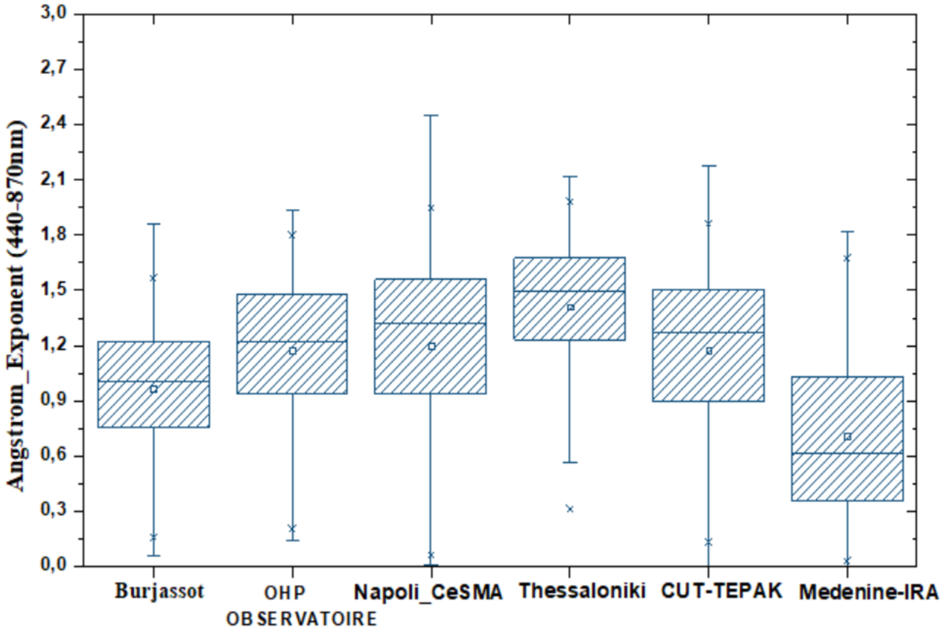


**Fig. 3.** Annual average of AE (440-870 nm)

### 3.2 Volume size distribution

The volume size distribution across the Mediterranean Basin (Fig.4), reveals clear spatial differences between fine and coarse mode particles. The volume concentrations of coarse mode VSD-C, shows a significant contribution at all studied sites, confirming the strong contribution of marine and mineral dust transported from the Sahara and surrounding arid regions, with the exception of the French site OHP Observatoire, where the VSD-C is markedly reduced, this can be attributed to its geographical location and higher altitude, which limits the direct impact of Saharan dust storms. The highest concentrations are observed at Southern site Medenine-IRA with VSD-C peaks reaching 0,081 $\mu m^3/\mu m^2$ followed by 0,058 $\mu m^3/\mu m^2$ at Napoli_CeSMA, and 0,055 $\mu m^3/\mu m^2$ at CUT-TEPAK. At the Medenine-IRA site, the seasonal cycle is particularly pronounced, with markedly elevated coarse-mode values during the summer months peaking in July and centered around radius of ~2 µm (Fig.5), consistent with the strong influence of Saharan dust outbreaks, which are more frequent and intense in summer due to stronger surface winds and persistent dry conditions that facilitate dust mobilization and long-distance transport to the southern Mediterranean[15]. These results reflect the influence of mineral dust, which decreases towards the northern Mediterranean but intensifies in the eastern and southern basins.

The volume concentrations of fine mode VSD-F remain present across all sites, but their relative contribution is more significant in Central and Eastern Mediterranean sites, compared to the strong coarse-mode dominance observed. The VSD-F reaches 0,023 $\mu m^3/\mu m^2$ in Thessaloniki, 0,020 $\mu m^3/\mu m^2$ in CUT-TEPAK and 0,019 $\mu m^3/\mu m^2$ in Napoli. This can be associated the influence of urban/industrial emissions and local and regional anthropogenic activities, such as domestic heating, biomass burning.

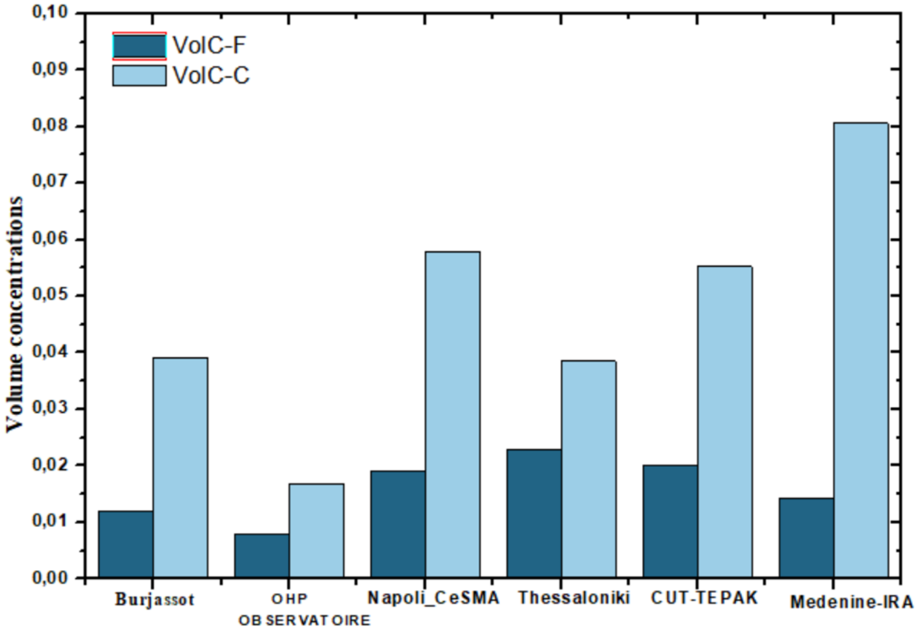


**Fig. 4.** Volume concentrations (µm3/µm2) histograms

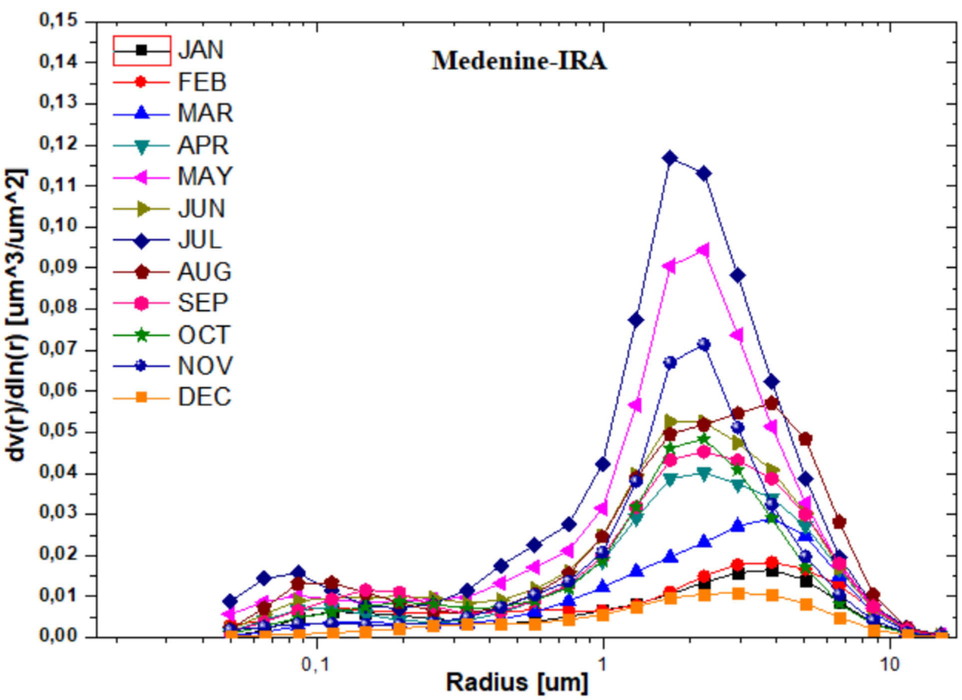


**Fig. 5.** Monthly mean of PSD over Medenine-IRA

### 3.3 Aerosol radiative forcing

The ARF was examined at three levels, at the top of the atmosphere (TOA), at the land surface (BOA) and within the atmospheric (ATM) (Fig.6). Across all sites, ARF are negative for BOA, TOA and ranging from –10 to –30 and –4 to –15 W/m² respectively. The Southern site Medenine-IRA, is a dust-dominated site with high coarse mode particle, marked by strong surface cooling over the Mediterranean basin around –30 W/m² and weakly radiative forcing at TOA –4 W/m², this reflects the regionally significant mineral aerosol load which reduce incoming solar radiation at the surface. This surface cooling leads to a warming of the corresponding atmospheric column, reflected by a positive atmospheric forcing ATM with high value +25 W/m², reflecting the absorption of solar radiation by larger dust aerosols. The Central and Eastern Mediterranean sites register also significant BOA cooling around –25 W/m² in Thessaloniki, –24 W/m² in CUT-TEPAK, and from –23 W/m² in Napoli_CeSMA with relatively high TOA forcing varying between –10 and –15W/m, reflecting the scattering of incoming solar radiation outside the atmospheric column. This is associated with a moderate atmospheric heating reaching +15W/m² indicating the presence of a mixture of dust and anthropogenic aerosols.

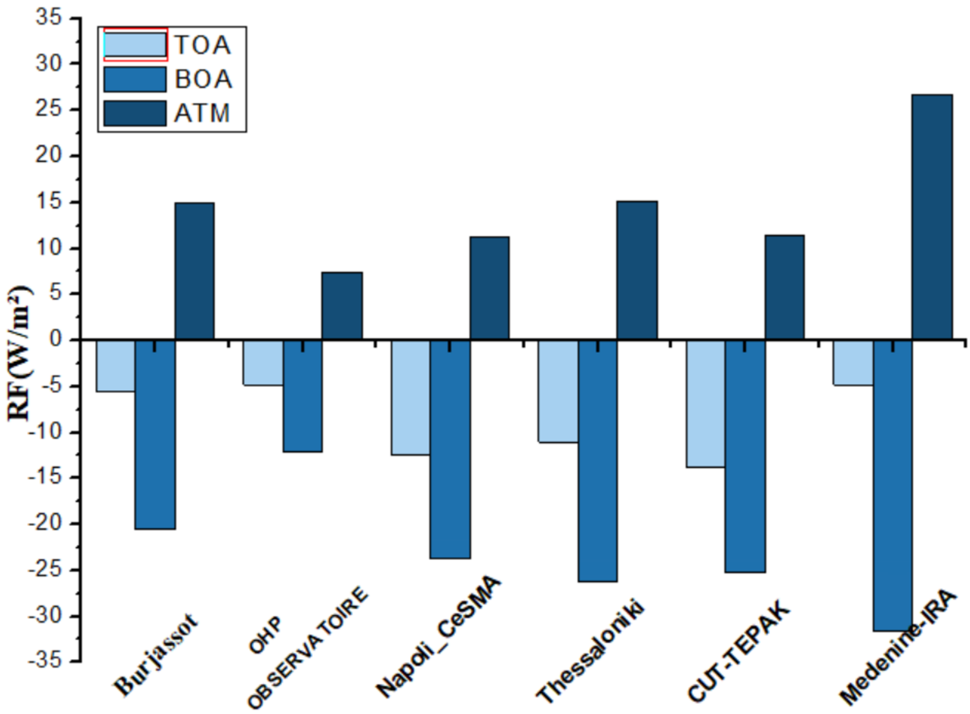


**Fig. 6.** Annual average of ARF

## 4 Conclusion

This study illustrates the high spatial and temporal variability of Mediterranean aerosols, which reflects the combined impact of natural sources, such as desert dust, and anthropogenic emissions concentrated in urban areas. The analysis of optical and radiative parameters and composition in the atmosphere at six Mediterranean sites: Burjassot, OHP Observatoire, Napoli_CeSMA, Thessaloniki, CUT-TEPAK and Medenine-IRA show distinct aerosol loading patterns influenced by local and regional aerosol characteristics. The general spatial patterns of annual mean AOD and AE showed increased variations from the Central to Eastern Mediterranean sites over the study period whereas they exhibit opposite patterns at Southern site Medenine-IRA, linked to the influence of mineral dust emitted from the Sahara and Sahel regions. The annual averages of the VSD show a clear dominance of the coarse mode across all Mediterranean sites, this dominance is particularly pronounced at Southern sites which records the highest VSD confirming the direct impact of Saharan dust transport and marine particles in the region. The Fine-mode remain important at urban and coastal sites such Thessaloniki, underlining the role of anthropogenic emissions and regional transport. The Analysis of RF results reveal that sites characterized by high AOD and VSD registers the strongest radiative perturbation. This confirms the direct correlation between aerosol load and radiative impacts in the Mediterranean region. The elevated RF values observed at Southern and Eastern sites Medenine-IRA and Thessaloniki that record the highest AOD and AE values, is accompanied by a strong cooling at the surface and a net atmospheric warming of the atmospheric column reflected by strong positive ATM.

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