

# Intense dust transport event over Athens, Greece during the BIOSPHERE campaign Summer 2023: Aerosol profiling in relation to the near-ground UVB levels

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**Abstract:** We present an intense dust transport event occurred over Athens, Greece during the BIOSPHERE campaign in summer 2023. Three multi-wavelength lidar systems have been used to provide the vertical profiles of the aerosol optical properties, and relevant mass concentration, together with temperature profiles, for the case of 13 July 2023. The dust load presence was responsible for the reduction of the UVB radiation at ground of the order of 5-10%.

## 1. Introduction

One of the most ecological challenges facing EU citizens is the impact on human and ecological health of the increasing atmospheric ionisation caused by extra-terrestrial radiation (cosmic rays and solar UV radiation) boosted by anthropogenic emissions [1]. Cosmic rays entering the top of the Earth's atmosphere, commonly referred to as primary cosmic rays (PCR), interact with atmospheric constituents (aerosols, molecules) to produce secondary cosmic rays (SCR) [2]. Therefore, quantification of ionisation and production rates of charged molecular fragments and other reactive species is needed beyond present-day models that are limited to ionisation and the nonspecific energy loss values required to produce an ion pair.

The 3-year (2022-2025) EURAMET European Partnership on Metrology (EPM) project BIOSPHERE (<https://euramet-biosphere.eu/>) aims to develop the necessary tools, methodologies and measurement infrastructure needed to evaluate the mutual impact of cosmic rays and biologically active UV radiation on the Earth's biosphere, and to support EU policy makers with scientific assessments and information that have the potential to

substantially improve policies on climate, health, and anthropogenic activities.

Since the generation and decay of SCR depends on air density, knowledge of atmospheric profile parameters such as temperature, density, and aerosols is needed to establish an accurate relationship between SCR and PCR fluxes. To this end, the first BIOSPHERE's measurement campaign was carried out in Athens, Greece, during summer 2023, at the premises of the National Scientific Research Center Demokritos (NCSR-DEM) and the National Technical University of Athens (NTUA).

## 2. Experimental instrumentation

The instrumentation utilized at the Athens Campaign involved, between others, the NTUA advanced elastic-Raman lidar system aErosol and Ozone Lidar systEm (EOLE) of the Laser Remote Sensing Unit (LRSU) based on a pulsed Nd:YAG laser system which emits, simultaneously, at 354.93-532-1064.2 nm, with energies of 240-310-260 mJ, respectively, at 10 Hz pulse repetition frequency. A Cassegrainian telescope of 300 mm diameter (f=600 mm) collected all elastically backscattered lidar signals (354.93-532-1064.2 nm), as well as those generated by the spontaneous vibrational-rotational Raman effect (by atmospheric N<sub>2</sub> at

386.6 and 607.4 nm, as well as by H<sub>2</sub>O at 407.5 nm), within a field of view of 1.5 mrad.

Thus, EOLE can provide independent and simultaneous measurements of the vertical profiles of the aerosol backscatter  $\beta_{\text{aer}}$  (at 355, 532, and 1064 nm) and extinction  $\alpha_{\text{aer}}$  (at 355 and 532 nm) coefficients, as well as the water vapor mixing ratio in the troposphere, typically up to 10 km height. Furthermore, EOLE provides the vertical profiles of the aerosol intensive parameters, namely the backscatter- and extinction-related Ångström exponents ( $AE_{\alpha 355/532}$ ,  $AE_{\beta 355/532}$ ,  $AE_{\beta 532/1064}$ ), as well as the lidar ratio (LR) at 355 and 532 nm. Additionally, the vertical profile of the atmospheric density can be easily calculated (in an aerosol-free atmospheric region) based on a standard atmospheric model or radiosonde data, the received lidar signal and the vertical profile of  $a_{\text{mol}}$ .

A second lidar system is synergistically used to provide the depolarization of the laser light by the atmospheric aerosols. The NTUA DEPOL- arization lidar systEm (DEPOLE) is based on the second and the third harmonic frequency of a pulsed Nd:YAG laser emitting vertically a linearly polarized beam at 532 and 355 nm, respectively (polarization purity >99.5% reached using a polarizing filter). It is equipped with a 200 mm diameter telescope (Dall-Kirkham Cassegrainian), with focal length  $f=1000$  mm, which collects the elastically backscattered lidar signals at 355 and 532 nm (at two polarization planes: parallel and perpendicular), which are optically separated by a polarizing beam splitter cube. The vertical profiles of coarse and fine particle mass concentrations can be calculated using the aerosol depolarization data and the particle mass profiling polarization lidar photometer networking (POLIPHON) method [3].

The Raymetrics temperature lidar system is designed to have a monoaxial configuration. Thus, the laser beam propagation axis and the receiving telescope optical axis coincide. The lidar is equipped with a commercial Single Longitudinal Mode (SLM) Nd:YAG laser, emitting 200 mJ/pulse at 354.7 nm, with 10 Hz repetition rate and 6-8 ns laser pulse duration. The receiving telescope is of the classical

Cassegrain type, with a diameter of 400 mm and  $f$  number=10. Its field of view (FOV) can be adjusted from 0.25 to 1 mrad depending on the field stop diameter. The telescope is shielded by a 410 mm diameter, 10 mm thick fused silica window, with anti-reflection (AR) coating to obtain a maximum optical transmittance at 355 nm ( $T>99.5\%$ ). It has a central hole of 80 mm diameter permitting the laser pass-through, as sent to the atmosphere.

The Raymetrics lidar system detects 5-spectral channels: 354.78 nm (aerosol elastic backscattered signal), 387 nm N<sub>2</sub> Raman channel (only nighttime measurements) in order to independently measure the molecular extinction coefficient and retrieve the aerosol backscatter and extinction coefficient profiles, 407 nm H<sub>2</sub>O Raman channel (nighttime measurements) to retrieve the water vapor mixing ratio profiles, and finally, two pure rotational Raman (PRR) channels at 355.4 and 356.3 nm, to retrieve atmospheric temperature profiles.

Measurements of the global solar-spectral UV-B irradiance (integrated at 290–315 nm) from the Brewer spectral photometer were available with a temporal resolution of about 30 min, at a nearby site, run by the Center for Environmental Effects on Health, Biomedical Research Foundation, Academy of Athens, Athens (BRFAA), Greece. The uncertainty in the Brewer measurements is estimated to 5% for wavelengths above 305 nm and solar zenith angles (SZAs) lower than 70° [4].

### 3. Dust event of 13 July 2023- Results and discussion

In this paper we focus on an intense dust event occurred over Athens, Greece, on 13 July 2023 around 18:00 UTC. On that day an extended high (H) was established over the eastern Mediterranean region, moving eastwards, while an occluded front system was developed over central Europe moving south-eastward. These two systems in conjunction with a conjunction with an intense high system over the western Saharan region, resulted in an extraction of high desert dust loads which overpassed south-eastern Spain, central Italy, and the central Balkans before arriving over Athens.

Figure 1 shows the relevant aerosol optical depth (AOD) at 550 nm on 13 July 2023, at 21:00 UTC, provided by the Multiscale Online Nonhydrostatic Atmosphere Chemistry model (MONARCH) weather forecast model developed and run at the Barcelona Supercomputing Center. Over Athens (marked by asterisk) the AOD reached high values of the order 0.2-0.4.

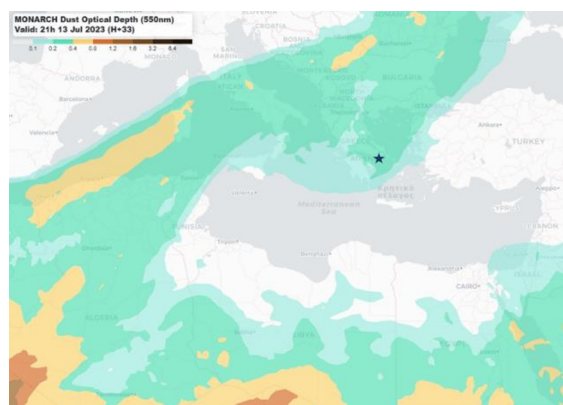


Figure 1. Aerosol optical depth (AOD) at 550 nm as provided by the Multiscale Online Nonhydrostatic Atmosphere Chemistry model (MONARCH) weather forecast model for 13 July 2023, at 21:00 UTC.

At the same period the daytime evolution of the Planetary Boundary Layer (PBL) is clearly observed in Figure 2, with a PBL height reaching its highest value (up to 2 km height asl.) around 13:00 UTC. Later the same day (19:40-23:00 UTC) the upper dust layer is expanded between 3-4.5 km height asl.

The use of the POLIPHON algorithm [3] provided the vertical profiles of the aerosol backscatter coefficient  $b_{\text{aer}}$ , and the aerosol mass concentration, discriminating between the dust and the non-dust components at 08:00 and 19:30 UTC, up to 6 km height asl. (Figure 3). Based on that figure, the dust layers are again clearly visible between 2 and 4.5 km height asl. The high linear particle depolarization ratios  $\delta_{532}$  ratios, ranging between 15-32% (daytime) and up to 25% (between 2-5 km height asl.) indicated the presence of dust aerosols. The corresponding aerosol mass concentrations for daytime and nighttime measurements are also shown (cf. Figure 3, last column).

Figure 4 presents the daytime evolution of AOD at 340, 500 and 1640 nm, derived from the NTUA CIMEL sun photometer of AERONET.

The AOD reached quite high values (up to 0.5 at 500 nm) throughout the whole day of 13 July

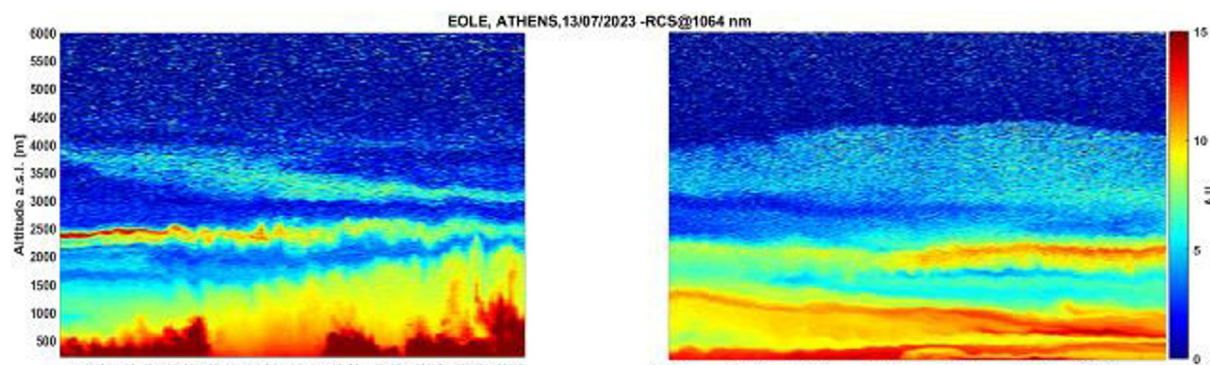


Figure 2. Spatio-temporal evolution of the range-corrected lidar signal obtained by EOLE at 1064 nm (in arbitrary units-AU) over Athens on 13 July 2023 (10:00-23:00 UTC).

In Figure 2 we present the range-corrected lidar signal (RCS) obtained by EOLE at 1064 nm, on 13 July 2023, between 10:00 and 23:00 UTC. In this figure a very intense dust layer is visible around 2-2.5 km asl., throughout the day, while a less intense is observed descending from 4 to 3 km height, between 10:00-13:00 UTC.

2023. The relevant values of the Ångström exponent of the atmospheric column over Athens showed values around 1.5 (up to 14:30 UTC) and down to 1.0 earlier than 17:00 UTC. These high values are indicative of the presence of mixed coarse aerosols, which is corroborated by the depolarization ratios ranging between 6-15%, very close to the values derived from the lidar measurements.

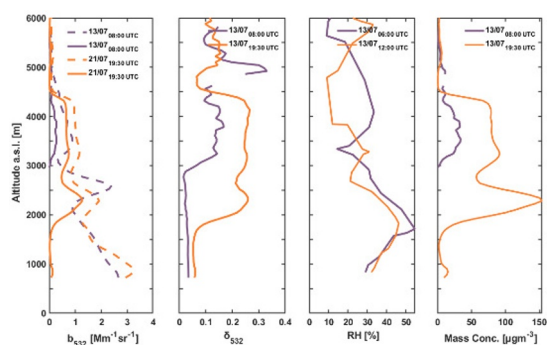


Figure 3 (left to right). Vertical profiles of the aerosol backscatter coefficient  $b_{aer}$  ( $Mn^{-1}sr^{-1}$ ) discriminating between the dust and the non-dust components, linear particle depolarization ratio at 532 nm ( $\delta_{532}$ ), relative humidity RH (%) and aerosol mass concentration, obtained by the NTUA lidars on 13 July 2023 (08:00 and 19:30 UTC).

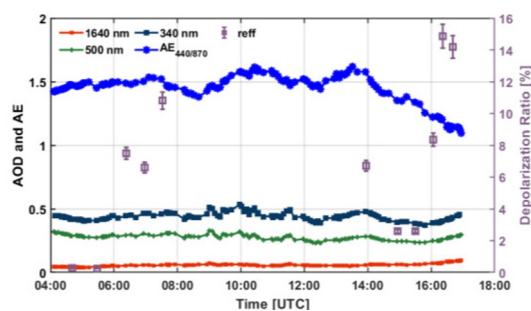


Figure 4. Daytime evolution of the aerosol optical depth (AOD) at 340, 500 and 1640 nm, Ångström exponent (440nm/870nm) and columnar depolarization ratio (%) obtained over Athens by the NTUA sun-sky AERONET photometer on 13 July 2023 .

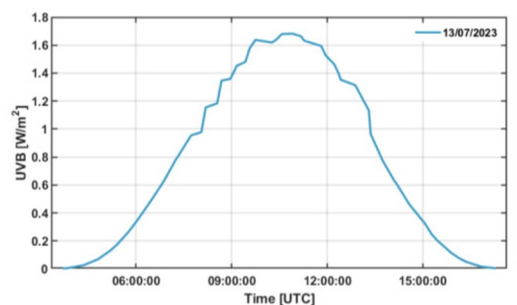


Figure 5. Daytime evolution of the total UVB radiation ( $W/m^2$ ) reaching ground, as measured by the Brewer spectrophotometer of BRFAA on 13 July 2023 over Athens.

In Figure 5 we present the daytime evolution of the total UVB radiation ( $W/m^2$ ) reaching the

ground, as measured by the Brewer instrument of the BRFAA on 13 July 2023. The highest UVB values were observed at the local noon hours (11:00 UTC) and are responsible for producing erythema to the population exposed depending on the total exposure time. When these values are compared to the mean UVB values measured at the same period over Athens under clear sky conditions and aerosol-free conditions they are about 5-10% lower [5], due to the scattering of the UVB radiation by the desert dust aerosols.

As a conclusion we can argue that AODs at 500 nm of the order of 0.5 contribute to a 5-10% reduction of the UVB radiation levels reaching ground.

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