Characterization of fresh and aged biomass burning aerosols during 2023 forest fires in Greece

Marilena Gidarakou[1], Panagiotis Kokkalis [2], Alexandros Papayannis[1,3], Eleni Kralli[1], Maria Mylonaki[4], Giorgios Tsaknakis[5], Kostas Eleftheratos[6,7]

[1] Laser Remote Sensing Unit, Department of Physics, National Technical University of Athens, 15780 Zografou, Greece
[2] Physics Department, Kuwait University, Safat 13060, Kuwait
[3] Laboratory of Atmospheric Processes and Their Impact, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland
[4] Meteorological Institute, Ludwig-Maximilians-Universität München, 80539 Munich, Germany
[5] Raymetrics S.A., Spartis 32 & Fil. Eterias, Metamorfosi, 14452, Greece
[6] National Kapodistrian University of Athens, Geology Department, Athens, Greece
[7] Biomedical Research Foundation, Academy of Athens, Athens, Greece
E-mail: marilenagidarakou@mail.ntua.gr

Abstract

In July and August 2023, strong wildfires occurred all over Greece producing large amount of smoke particles which were transported over Athens, Greece from ground up to ~5 km height. According to the European Forest Fire Information System (EFFIS), during the period from 17 July to 31 August, wildfires in Greece had burned an area of 76.875 ha. This study studies selected smoke aerosol layers over Athens, Greece, using multiwavelength-Raman (355-387-407-532-607 nm and depolarization (355-532 nm) lidars, as well as sun photometer data. The biomass burning sources and air mass backward trajectories were further verified by satellite observations (Aqua MODIS) and HYSPLIT air mass back-trajectory data.

Wildfires data

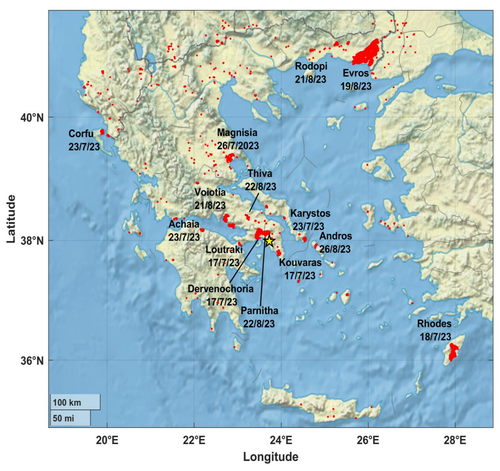

Figure 1. *Map of Greece illustrating wildfires detected by Aqua MODIS, NASA satellite imagery from 17 July to 31 August 2023.*

- Extreme wildfires broke out in several areas of Greece during summer 2023 (17 July - 31 August).
- By 31 August, the burned areas were of the order of ~174.773 ha, marking 2023 as the year with the highest recorded burned areas and the largest number of fires in Greece.
- 2023 was characterized as the warmest year ever recorded, with temperatures close to 1.5°C above pre-industrial level [1].

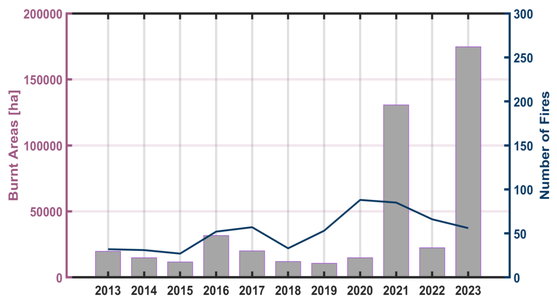

Figure 2. *Number of fires and burnt areas (ha) in Greece in the years (2013-2023), according to EFFIS (effis.jrc.ec.europa.eu).*

Instrumentation and models

- Six-wavelength EOLE Raman lidar
- Two-wavelength depolarization lidar (355 and 532 nm)
- HYSPLIT model
- MODIS satellite data.
- Single Calculus Chain (SCC) developed within EARLINET .
- CIMEL sun-sky photometer
- POLIPHON algorithm.

Case study: Transport of fresh smoke (21 July 2023)

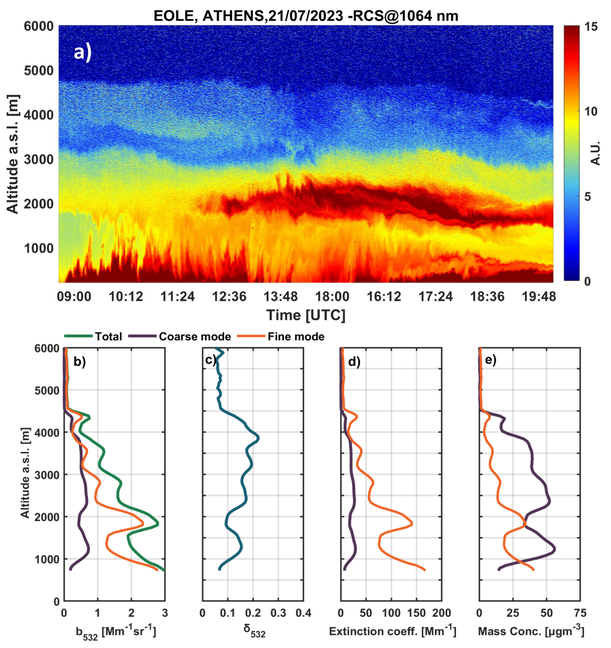

Figure 3. *(a). Spatio-temporal evolution of the range-corrected lidar signal obtained by EOLE at 1064 nm over Athens on 21 July 2023 (08:40-20:10 UTC), (b) Vertical profiles of b_{532} (c) δ_{532} (d) aerosol extinction and (e) aerosol mass concentration (coarse and fine mode particles) (18:30-19:30 UTC).*

- Thick aerosol layers between ground and 2.5 km asl. Discreet aerosol layers between 2-3 km and 3.8-4.8 km asl.
- δ_{532} ranged from 8-18%.
- Coarse mode particle mass concentrations ranged from 19±7 to 55±20 μg/m³.
- Fine mode mass concentration averaged around 8±3 μg/m³, with a peak of 34±12 μg/m³ at 1.8 km asl.
- Presence of both fine and coarse particles, with a dominance of the coarse ones [2-5].
- Strong winds carried a thick gray smoke plume southwestward as obtained by MODIS.

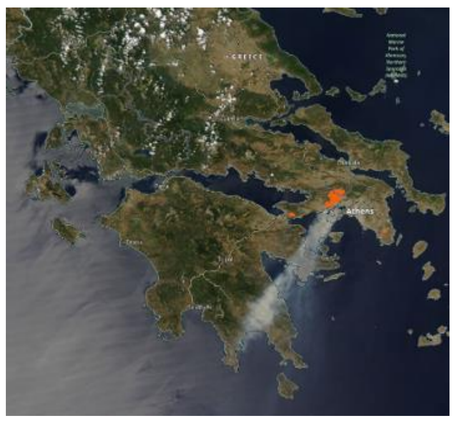

Figure 4. *Satellite image showing wildfires over Greece (afternoon of 18 July 2023 -data from Aqua MODIS, NASA) .*

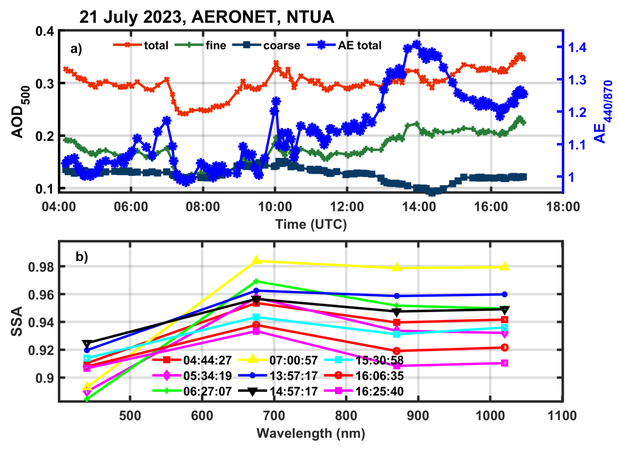

Figure 5. *(a) Fine/coarse-mode AOD (500 nm) and AE (440/870 nm), (b) SSA wavelength dependence (440, 675, 870, and 1020 nm) obtained over Athens on 21 July 2023 (04:44:27-16:25:40 UTC).*

- AOD values ranged between 0.24 and 0.35.
- AE values (440/870 *nm),* varied from 0.98 to 1.41.
- SSA values between ~ 0.88-0.93 (440 nm) and ~0.92-0.98 (675, 870, and 1020 nm).
- Presence of both fine and coarse particles.
- Indication of mixed carbonaceous particles causing strong absorption in the UV and visible spectra [6].

Case study: Transport of aged smoke (24 August 2023)

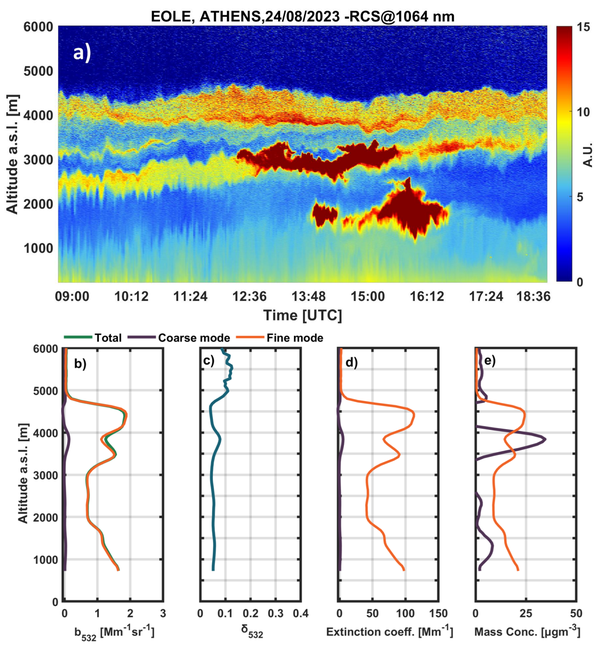

Figure 6. *Spatio-temporal evolution of the range-corrected lidar signal obtained by EOLE at 1064 nm over Athens on 24 August 2023 (08:45-18:40 UTC), (b) Vertical profiles of b_{532} (c) δ_{532} (d) aerosol extinction and (e) aerosol mass concentration (coarse and fine particles) (17:30–18:30 UTC).*

- Discrete aerosol layers are observed between 2.0-4.5 km, extending up to 3.3-4.5 km asl.
- Aerosol layers are characterized by low-to-moderate backscatter coefficients (0.7– 1.9 Mm^{-1} sr^{-1}).
- Mean value of δ_{532}~5%.
- Aerosol fine mode concentrations ranged from 15±7 to 25±10 μg m^{-3}.
- The dominance of fine and rather spherical particles is observed [7].

Figure 7. *Satellite image showing wildfires over Greece (afternoon of 22 August 2023 - data from Aqua MODIS, NASA) .*

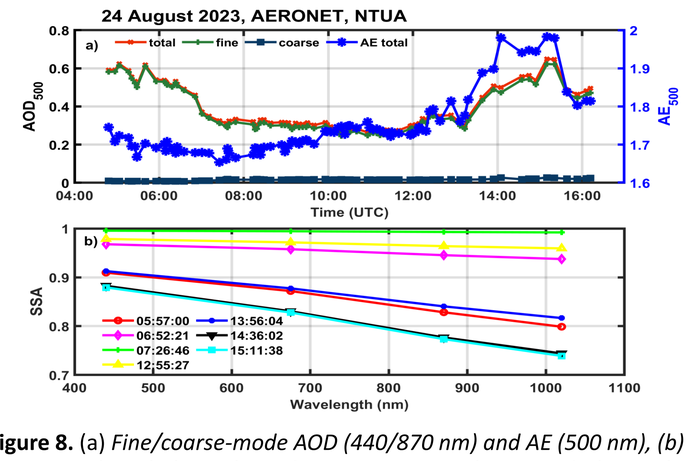

Figure 8. (a) *Fine/coarse-mode AOD (440/870 nm) and AE (500 nm), (b) SSA wavelength dependence (440, 675, 870, and 1020 nm) obtained over Athens on 24 August 2023 (05:57:00-15:11:38 UTC).*

- The fine mode coincides with the total AOD (0.25-0.65).
- AE (440/870 nm) values ranged from 1.65 to 1.98.
- SSA wavelength dependence, shows a decrease in SSA values with increasing wavelengths from ~0.93 (at 440 nm) to ~0.85 (at 1020 nm)
- Dominance of fine absorbing particles [8].

Summary

We presented 2 cases of fresh (21 July) and aged (24 August) transport of biomass burning aerosols arriving over Athens, during the 2023 wildfires in Greece. A synergy of multiwavelength-Raman lidar, depolarization lidar and sun-photometer data, the POLIPHON algorithm, as well as satellite data was used to retrieve the aerosols' optical and microphysical properties to characterize the biomass burning particles regarding their aging time. The fingerprint of the fresh smoke aerosols on 21 July showed moderate δ_{532} (8-18%), and AE (~1.2 at 500 nm) values, with negligible wavelength dependence of the SSA. Regarding, the aged particles showed lower δ_{532} (~5%) and high AE values (up to 1.8) inside the smoke layers, where the fine particles dominated with decreasing SSA values with increasing wavelengths.

References

[1] The 2023 Annual Climate Summary (*https://climate.copernicus.eu/global-climate-highlights-2023).*
[2] Ansmann, A., et al., *Atmos. Chem. Phys.*, ***12***, 9399–9415, 2012.
[3] Granados-Muñoz, M.J. et al., *Atmos. Chem. Phys.*, ***16***, 7043–7066, 2016.
[4] Wandinger, U. et al., *EPJ Web Conf.*, *119*, 01004, 2016.
[5] Ansmann, A. et al., *J. Geophys. Res. Atmos,* 116, 2011.
[6] Pokhrel, R. P. et al., *Atmos. Chem. Phys.*, **16**, 9549–9561, 2016.
[7] Müller, D. et al., *J. Geophys. Res.*, **110**, D17201, 2005.
[8] Russell, P. B. et al., *Atmos. Chem. Phys.*, **10**, 1155–1169, 2010.

Acknowledgements

M.G was supported by the Hellenic Foundation for Research and Innovation (HFRI) under the 4th Call for HFRI PhD Fellowships (Fellowship number: 9293). The project 21GRD02 BIOSPHERE has received funding from the European Partnership on Metrology, co-financed by the European Union's Horizon Europe Research and Innovation Programme and by the Participating States. Part of this work was performed in the frame of the PERICLES Campaign supported by PyroTRACH (ERC-2016-COG) funded from H2020-EU.1.1. (ERC), project ID 726165.