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Retrieval of Aerosol Optical Properties from Spectral Solar Irradiance Using Radiative Transfer Modelling in Mountain and Coastal Environments

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Motivation

Aerosols play a critical role on Earth's radiative balance, influencing climate, atmospheric processes and air pollution monitoring. However, large uncertainties remain in their optical properties, particularly in aerosol absorption and spectral variability. Ground-based measurements provide valuable constraints for aerosol characterization, but traditional retrievals rely mainly on sun photometer observations, which are limited in temporal resolution and measurement geometry. Spectral solar irradiance measurements offer complementary sensitivity to aerosol extinction and absorption, enabling more detailed characterization of aerosol optical properties. This study aims to develop a radiative transfer modelling and inversion framework for retrieving aerosol optical depth from spectral irradiance observations in different atmospheric environments. By applying the methodology at different sites, this work supports the improvement of ground-based aerosol monitoring and satellite product validation.

Site description and Instrumentation (Data)

The data used in this study were collected during two separate campaigns conducted in different seasons at two sites in Greece (Figure 1a), each characterized by distinct atmospheric and meteorological conditions and contrasting aerosol regimes.

- The first site, located in Kalavryta, Helmos, Western Greece (37°59'N, 22°12'E), is situated at an altitude of 1750 m (Figure 1a). This region is primarily influenced by regional aerosols and is generally characterized by relatively low aerosol levels due to its remote location. The analysis was conducted on eight representative days during November 2024.
- The second site, located in Epanomi, Thessaloniki, Northern Greece (40°22'N, 22°58'E), is a coastal area influenced by a variety of aerosol types, including urban, continental, marine, and dust particles. In this case, four representative days were selected during April 2025.

Four instruments were utilised to collect solar radiation data for both sites. Three of them were mounted on a STR-22G suntracker while an additional radiometer operated independently.

- **MS-711 DNI Spectroradiometer:** Measures spectral direct normal irradiance (DNI) in the 300–1100 nm range (UV–Visible–NIR), which provides detailed information on aerosol extinction and absorption.
- **MS-57 Pyrheliometer:** Measures broadband DNI (200–4000 nm) and serves as a reference for total direct irradiance.
- **MS-80 Pyranometer (shaded):** Measures global horizontal irradiance (GHI), capturing the diffuse component of solar radiation.
- **MS-711 Spectroradiometer (off-sun tracker):** Provides additional spectral irradiance measurements, which can be used for complementary analysis.

For validation purposes, the retrieved aerosol optical properties were compared with Level 1.5 Version 3.0 AERONET data, which include near-real-time automatic cloud screening and instrument anomaly quality control, obtained from the collocated AERONET stations (Helmos_NTUA and Thessaloniki) in campaigns sites.

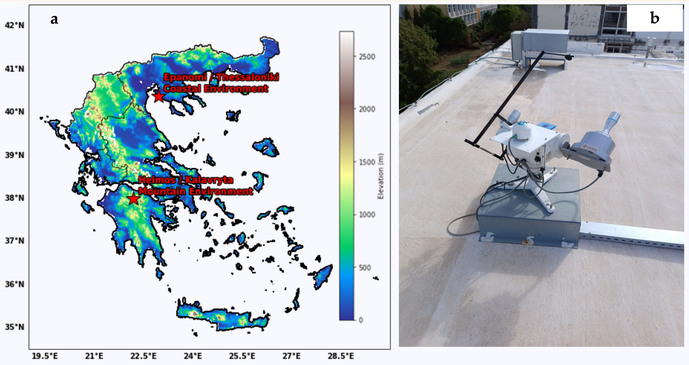
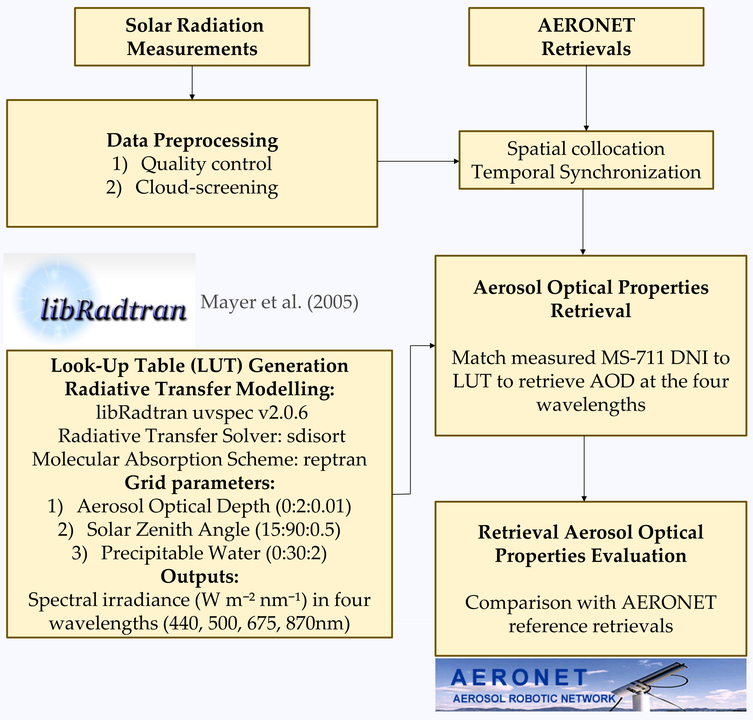


Figure 1: a) Site's location in Greece, **b)** Instrumentation for ground-based measurements, including a MS-711 DNI Spectroradiometer, a MS-80 Pyranometer (shaded) and a MS-57 Pyrheliometer, mounted on a sun tracker (STR-22G).

Methodology



Results

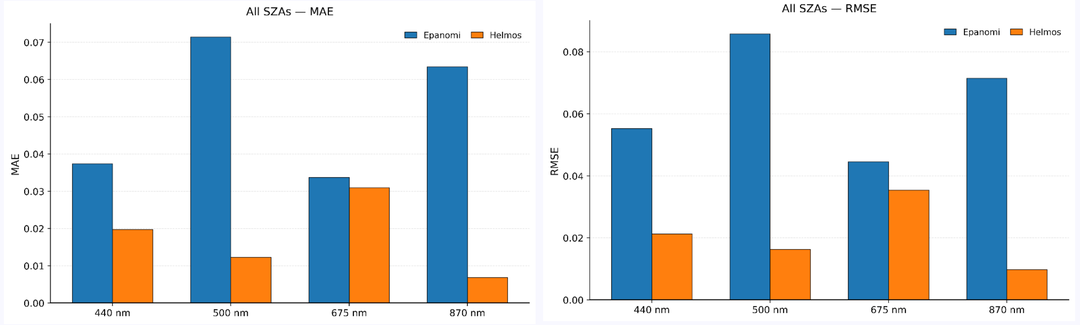


Figure 2: Comparison of AOD retrieval errors (MAE & RMSE) across wavelengths and **sites.**

The comparison between the two sites highlights clear differences in the AOD retrieval performance that are strongly linked to their distinct aerosol environments.

- Epanomi exhibits systematically higher errors (both MAE and RMSE) across all wavelengths. This behaviour can be attributed to the increased variability and also complexity of aerosol mixtures, which include maritime particles combined with anthropogenic pollution. Such conditions introduce greater uncertainty in the radiative transfer modelling, thus reducing the accuracy of the LUT-based inversion.
- In contrast, Helmos shows consistently lower errors, in some cases significantly smaller than the ones observed in Epanomi. The more stable and less polluted atmospheric conditions result in smoother spectral behaviour and better agreement between modelled and measured irradiance, leading to improved AOD retrieval performance.

Additionally, the spectral dependence of the errors suggests that shorter wavelengths (e.g., 440 nm) tend to exhibit larger discrepancies, likely due to stronger sensitivity to aerosol scattering and potential calibration uncertainties.

Conclusion

AOD can be successfully retrieved from spectral irradiance measurements using radiative transfer modelling combined with LUTs. Accuracy is site-dependent, with better performance observed under clean, stable atmospheric conditions. The methodology shows strong potential as a complementary approach to traditional AOD measurements, particularly in locations where direct aerosol observations are limited. Furthermore, it can contribute to the validation of satellite products and the improvement of ground-based aerosol monitoring.

References

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