Assessment of ATLID Aerosol Vertical Profiles Using Synergistic Integration of the E-Profile and AERONET Networks

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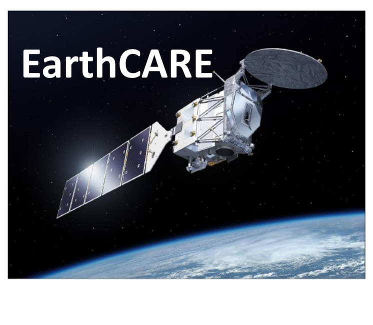
Satellite Mission

The **EarthCARE** mission (ESA/JAXA), launched on May 28, 2024, integrates four advanced instruments (ATLID, CPR, MSI, and BBR) on a single platform. This unique synergy enables detailed atmospheric profiling along its path, providing crucial data on cloud-aerosol-radiation interactions. These observations are essential for improving climate models and weather forecasting.

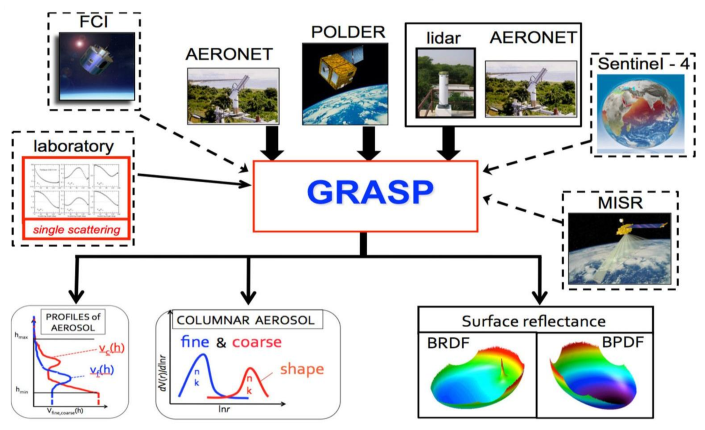


The **ATLID** high-spectral-resolution lidar aboard EarthCARE provides vertically resolved attenuated backscatter and depolarization profiles at 355 nm. Its unique capability to directly retrieve both lidar and depolarization ratios from space enables advanced aerosol and cloud typing, highlighting the need for comprehensive validation of its products.

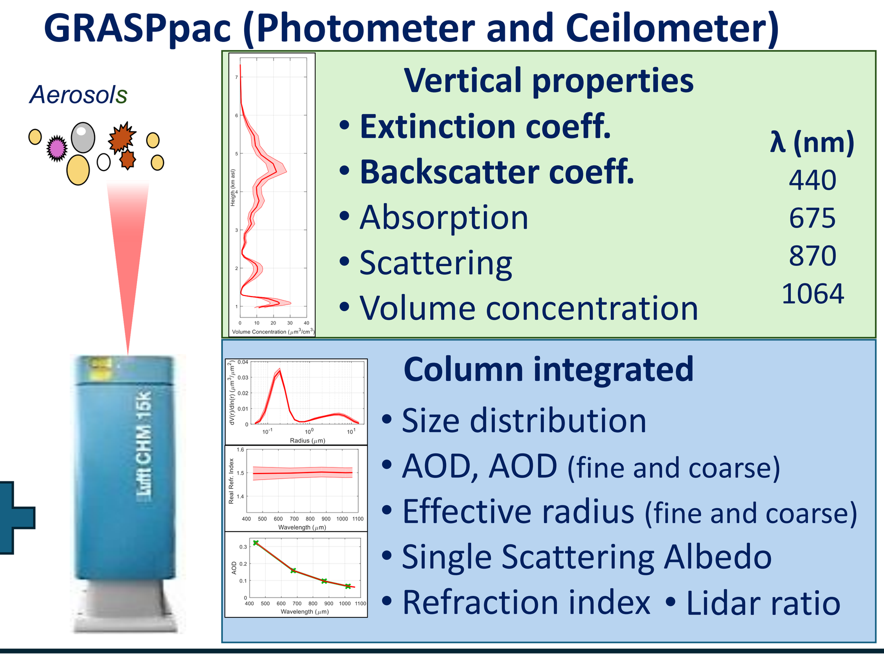
Synergy and GRASP algorithm

Generalized Retrieval of Aerosol and Surface Properties

- GRASP is a versatile and widely used open-access algorithm (*Dubovik et al., 2014*).
- Vertical and column-integrated properties based on observations from a wide variety of remote sensing instruments.



GRASPpac (Photometer and Ceilometer)



Methodology

1. Instrumentation & Station Network

- **Spaceborne Observations:** Vertically-resolved aerosol backscatter (**β**) and extinction (**α**) coefficients obtained at 355 nm from ATLID.
- **Target Product:** Data were extracted from the **ATLID Aerosol, Extinction, and Depolarization (A-EBD)** Level 2 product. The dataset corresponds to the **"BA"** version derived from the A-PRO processor algorithm chain (*Donovan et al., 2024*).
- **Temporal Coverage:** The study covers a one-year period from **August 2024 to August 2025**.
- **Ground-based Reference:** Vertically-resolved aerosol properties retrieved via the **GRASPpac** inversion algorithm (*Román et al., 2018*). Continuous measurements were collected at five stations across the Iberian Peninsula: **Valladolid, Madrid, Granada, Badajoz, and Évora**.

2. Colocation Criteria & Temporal Matching

To ensure atmospheric homogeneity during the comparisons, strict spatial and temporal constraints were applied before filtering:

- **Spatial Colocation:** Satellite tracks were considered collocated if the overpass fell within a **100 km radius** of the ground station. For each overpass event, the closest single satellite profile is selected.
- **Temporal Colocation:** The ground-based GRASPpac profile closest in time to the selected satellite overpass is chosen as the reference.

3. Quality Control & Statistical Filtering (Data Screening)

To guarantee data reliability and eliminate unphysical features, a multi-step screening protocol was applied:

I. **Cloud Screening:** Exclusion of all cases affected by clouds to avoid strong signal attenuation or multiple scattering artifacts.

II. **Signal Attenuation:** Detection and removal of attenuated profiles.

III. **Uncertainty-based Threshold**: Individual points were discarded when the uncertainty associated with the retrieved quantity was equal to or greater than the retrieved value itself ($\Delta\beta \geq \beta$ o $\Delta\alpha \geq \alpha$ i.e., **error ≥ 100%**).

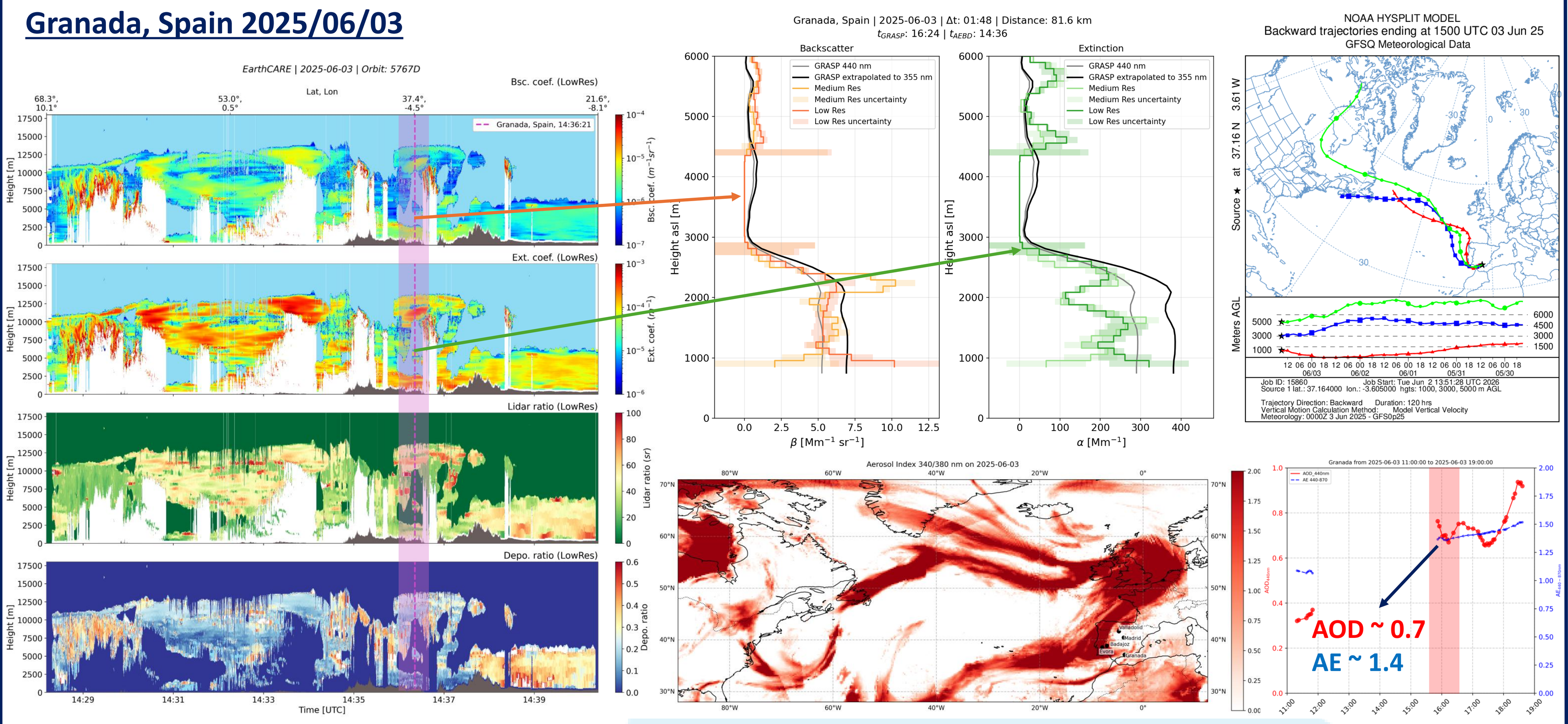
IV. **Outlier Rejection:** A $\pm$ **2σ filter** around de mean value was applied to the remaining dataset to exclude statistical anomalies and extreme outliers before the final analysis.

4. Validation Approach

- **Case Studies:** Intercomparisons of two specific events **(a Saharan dust event and a smoke event)** to evaluate ATLID's performance under different atmospheric conditions.
- **Statistical Analysis:** A multi-station statistical evaluation to assess systematic biases between the A-EBD product and GRASPpac retrievals.

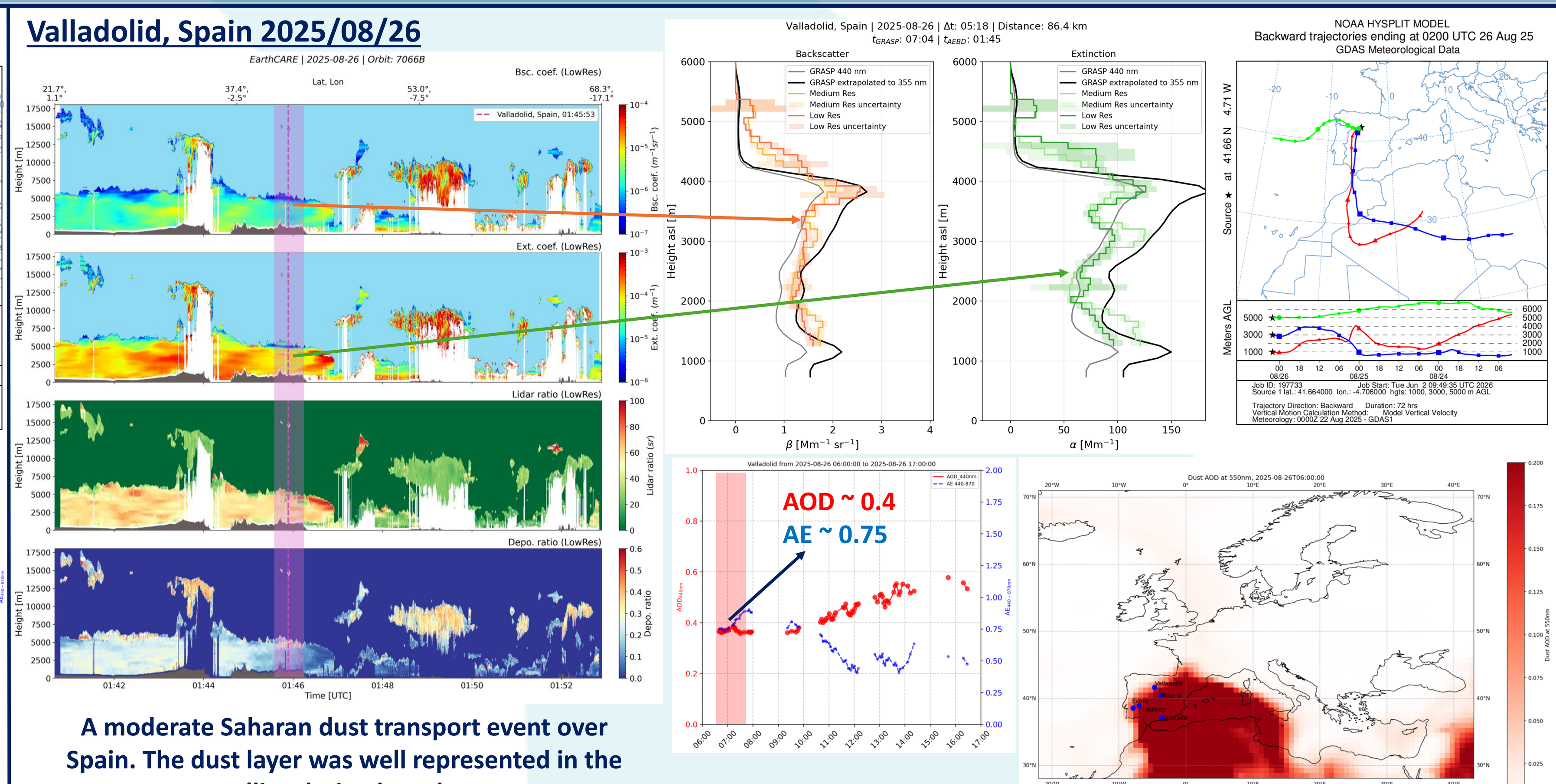
Results

Granada, Spain 2025/06/03



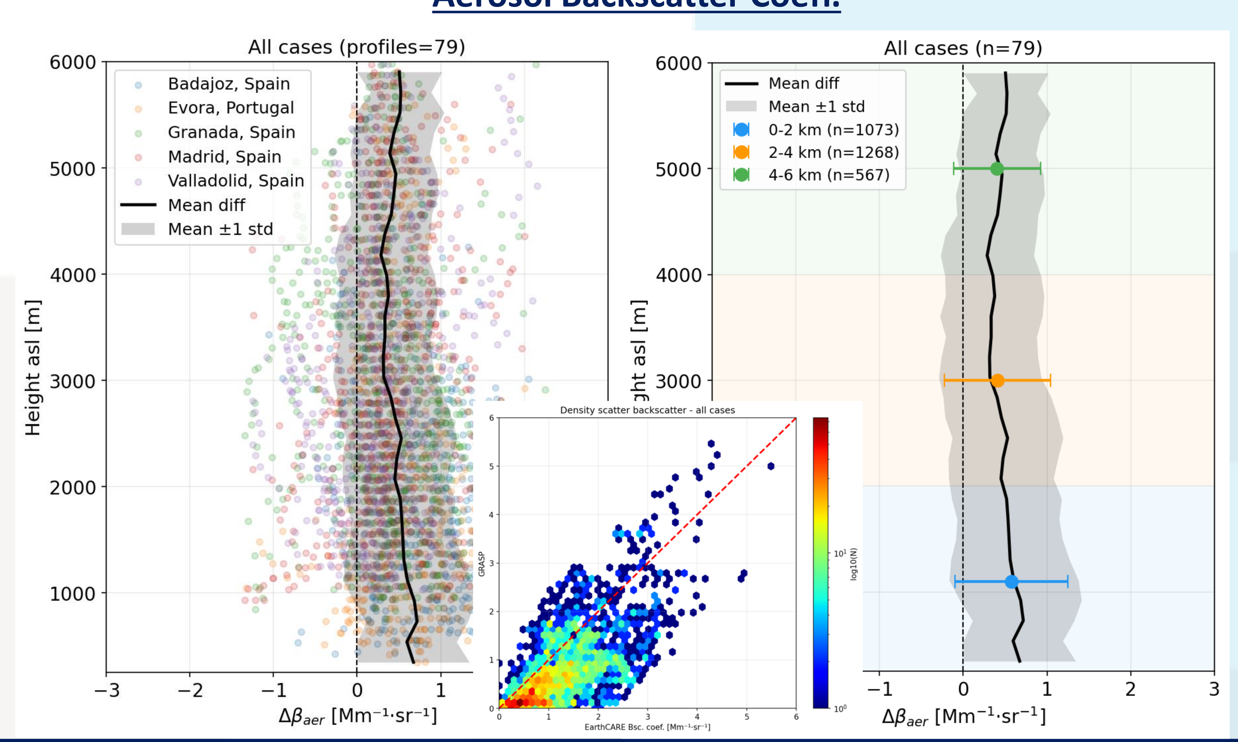
Smoke from Canadian wildfires reached Europe, with EarthCARE observations showing good agreement with collocated ground-based measurements.

Valladolid, Spain 2025/08/26

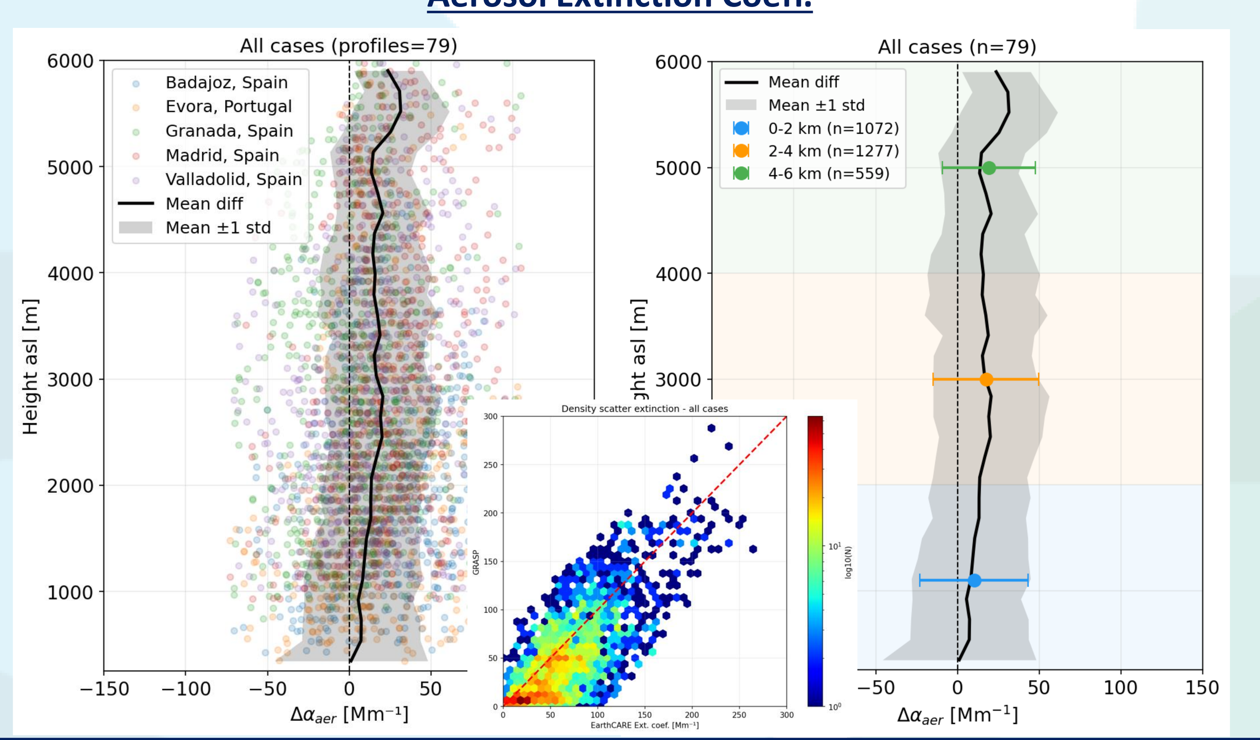


A moderate Saharan dust transport event over Spain. The dust layer was well represented in the satellite-derived products

Aerosol Backscatter Coeff.



Aerosol Extinction Coeff.



Station	Backscatter Coeff. [Mm⁻¹·sr⁻¹] (Mean $\Delta\beta \pm STD_{\Delta\beta}$)		
	0–2 km	2–4 km	4–6 km
All Cases	0.57 ± 0.68	0.41 ± 0.63	0.40 ± 0.52
Badajoz	1.04 ± 0.63	0.69 ± 0.66	0.51 ± 0.34
Évora	0.60 ± 0.59	0.53 ± 0.50	0.52 ± 0.28
Granada	0.39 ± 0.57	0.34 ± 0.64	0.25 ± 0.57
Madrid	0.29 ± 0.74	0.44 ± 0.62	0.46 ± 0.51
Valladolid	0.27 ± 0.50	0.21 ± 0.59	0.45 ± 0.56

Station	Extinction Coeff. [Mm⁻¹] (Mean $\Delta\alpha \pm STD_{\Delta\alpha}$)		
	0–2 km	2–4 km	4–6 km
All Cases	10 ± 33	17 ± 32	19 ± 28
Badajoz	25 ± 35	29 ± 34	22 ± 17
Évora	10 ± 33	22 ± 26	17 ± 16
Granada	-4 ± 28	9 ± 31	10 ± 30
Madrid	11 ± 30	27 ± 30	28 ± 30
Valladolid	6 ± 29	10 ± 34	22 ± 28

Summary

Successful characterization of case studies: ATLID effectively captured the vertical structure and magnitude of distinct aerosol events across the Iberian Peninsula, showing good agreement with ground-based GRASPpac retrievals in terms of aerosol vertical profiling.

Statistical analysis: Despite the inherent challenges associated with satellite validation, including spatial mismatches, differences in sampling volumes, and retrieval algorithm assumptions, the one-year statistical comparison (August 2024–August 2025) demonstrated an overall agreement between the A-EBD product and GRASPpac retrievals.

- **Backscatter Coeff.:** A physically consistent correlation was observed. The mean difference (Δβ) decreases progressively with altitude, from 0.57 $\pm$ 0.68 Mm⁻¹·sr⁻¹ in the lower troposphere (0–2 km) to 0.40 $\pm$ 0.52 Mm⁻¹·sr⁻¹ in the free troposphere (4–6 km).
- **Extinction Coeff.:** In contrast, the mean difference in extinction (Δα) increased with altitude, rising from 10 $\pm$ 33 Mm⁻¹ in the lower troposphere (0–2 km) to 19 $\pm$ 28 Mm⁻¹ in the free troposphere (4–6 km).

Regional Variability: Local environmental conditions influenced the validation metrics. **Granada** exhibited the lowest systematic biases in the lower troposphere (Δβ = 0.39 Mm⁻¹·sr⁻¹, Δα = -3.66 Mm⁻¹), whereas **Badajoz** showed the largest mean differences (Δβ = 1.04 Mm⁻¹·sr⁻¹, Δα = 24.56 Mm⁻¹ at 0–2 km). These results highlight the importance of multi-site regional networks for the validation of spaceborne aerosol products.

Acknowledgments

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