Evaluation and Intercalibration of Various Low-Cost Sun-Photometers During the RACE-EarthCARE Validation Experimental Field Campaign in Thessaloniki, Greece

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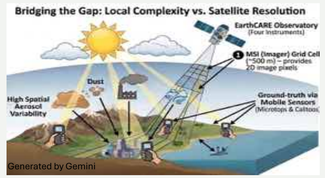
Introduction

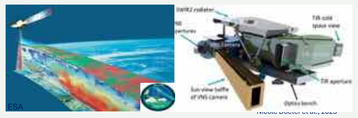
Accurate Aerosol Optical Thickness (AOT) measurements are critical for understanding climate forcing and validating satellite-derived products. While global networks provide high-accuracy data, their fixed locations create spatial gaps, particularly during satellite overpasses.

The Role of Hand-held Photometers

Low-cost, hand-held sun-photometers (**Microtops II, Calitoo**) offer a solution by providing:

- **High Monitoring Density:** Ability to deploy multiple sensors in a small area.
- **Portability:** Ideal for mobile "under-the-track" observations during satellite overpasses.
- **Near-Real Time Data:** Facilitating rapid assessment of surface solar radiation impacts.





The EarthCARE Mission & MSI

- **The Mission:** EarthCARE is a joint ESA/JAXA flagship mission designed to quantify the interaction between clouds, aerosols, and radiation.
- **The MSI Instrument:** The Multi-Spectral Imager (MSI) provides the critical horizontal context for the mission. It measures top-of-atmosphere radiances to retrieve Aerosol Optical Thickness (AOT) and cloud properties over a 150 km swath.

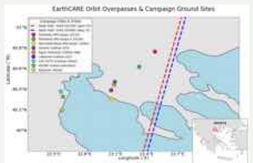
Key parameters: AOT at 670 nm over ocean and valid land pixels, **AOT at 865 nm** over ocean, **Angstrom Parameter** derived from 670/865 nm ratio (over ocean).

The RACE-ECV Campaign

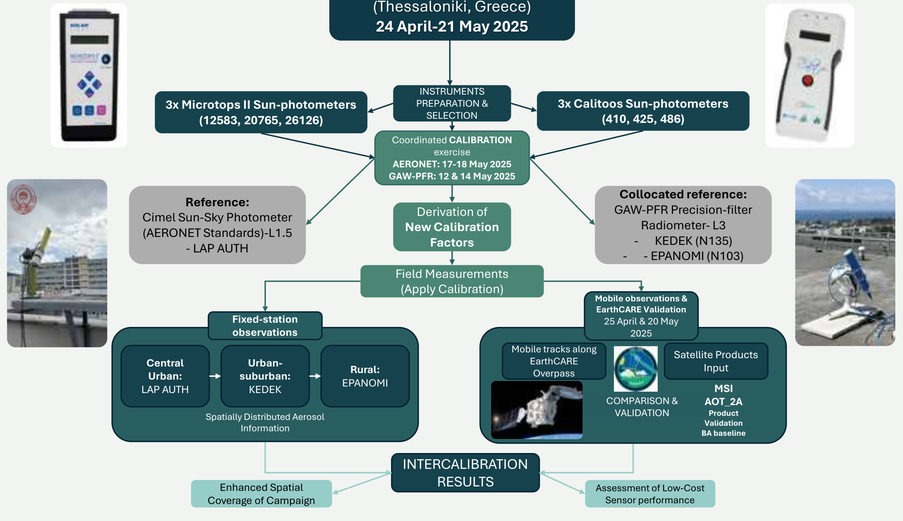
This study presents results from the **Radiation closure experiments for EarthCARE Validation (RACE-ECV)** campaign held in *Thessaloniki, Greece (April–May 2025).*

Objectives:

1. **Calibration:** Evaluate the performance of six hand-held sensors against AERONET-standard Cimel and GAW-PFR reference instruments.
2. **Validation:** Use mobile observations to validate AOT products from the EarthCARE Multi-Spectral Imager (MSI).
3. **Spatial Analysis:** Assess aerosol variability across urban, suburban, and rural sites (LAP, KEDEK, and EPANOMI).



Data & Methodology



Results

Calibration of low-cost sensors

Data Processing & Calibration

The **Aerosol Optical Depth (AOD)** was retrieved by applying the **Beer-Lambert-Bouguer Law to the raw instrument voltages** following the Core Equation

The AOD at a specific wavelength (λ) is calculated as:

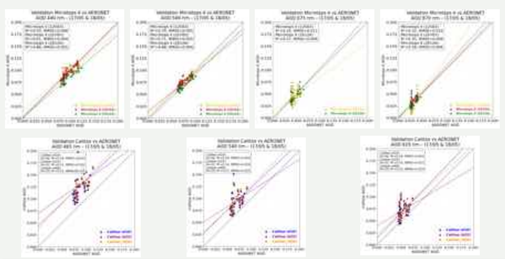
$$\mathbf{AOD} = \frac{1}{\mathbf{m_a}} * [\mathbf{lnV_0}(\lambda) - \mathbf{lnV}(\lambda) \text{-} \boldsymbol{\tau}_\mathbf{R} * \mathbf{m_R} - \boldsymbol{\tau}_{\mathbf{O3}}(\lambda) * \mathbf{m_{O3}}] \ (1)$$

$$\mathbf{AE}_{\lambda 2-\lambda 1} = \frac{\ln(\tau_a(\lambda_1))/\ln(\tau_a(\lambda_2))}{\ln(\lambda_2/\lambda_1)} \ (2)$$

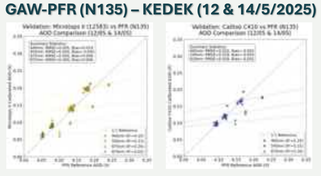
- $\mathbf{V_0}(\lambda)$: New calibration factors,
- $\mathbf{V}(\lambda)$ **:** Measured instrument voltage,
- $\boldsymbol{\tau}_\mathbf{a}, \boldsymbol{\tau}_\mathbf{R}, \boldsymbol{\tau}_{\mathbf{O3}}$ **:** Optical thickness for aerosol, Rayleigh scattering and Ozone,
- m_a , $\mathbf{m_R}, \mathbf{m_{O3}}$: Corresponding air mass factors,
- $\mathbf{AE}_{\lambda 2-\lambda 1}$ **:** Angstrom Exponent,
- λ_i **:** wavelengths, $(i = 1, 2)$.

AERONET – LAP (17-18 May 2025)

	Cimel – sun photometer AERONET								
Instrument ID	lnV_0 (340nm)	lnV_0 (440 nm)	lnV_0 (500 nm)	lnV_0 (675 nm)	lnV_0 (870 nm)	Instrument ID	lnV_0 (465 nm)	lnV_0 (540 nm)	lnV_0 (619 nm)
Microtops II (12583)	-	6.581	6.721	7.091	6.547	Calitoo (410)	8.164	8.179	7.835
Microtops II (20765)	8.257	7.494	7.425	-	7.462	Calitoo (486)	8.119	8.103	7.828
Microtops II (26126)	-	7.54	7.515	7.51	7.317	Calitoo (425)	8.124	8.101	7.83



GAW-PFR (N135) – KEDEK (12 & 14/5/2025)



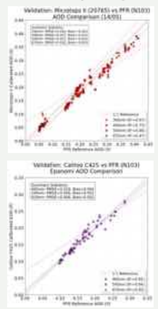
GAW-PFR (N135)				
Instrument ID	lnV_0 (340 nm)	lnV_0 (500 nm)	lnV_0 (675 nm)	lnV_0 (870 nm)
Microtops II (12583)	6.607	6.735	7.113	6.557
Instrument ID	lnV_0 (465 nm)	lnV_0 (540 nm)		lnV_0 (619 nm)
Calitoo (410)	8.1798	8.1876		7.8456

Solar/Sky camera at KEDEK station

12 May 2025, 08:21 UTC

14 May 2025, 08:13 UTC

GAW-PFR (N103) – EPANOMI (14/5/2025)



GAW-PFR (N135)				
Instrument ID	lnV_0 (340 nm)	lnV_0 (340 nm)	lnV_0 (500 nm)	lnV_0 (870 nm)
Microtops II (20765)	8.2904	7.4940	7.4275	7.4521
Instrument ID	lnV_0 (465 nm)	lnV_0 (540 nm)		lnV_0 (619 nm)
Calitoo (425)	8.1555	8.1202		7.8406

Solar/Sky camera at EPANOMI station

14 May 2025, 11:36 UTC

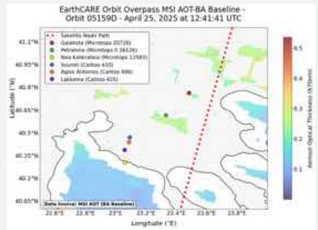
****On going/Future Work**

Low-cost Campaign Cyprus (LoCoCaCy)

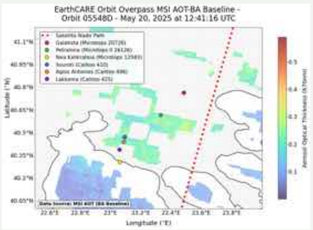
Calibration of Microtop II with reference Cimel sun-photometer
&
Validation of EarthCARE MSI and ATLID products in Cyprus with low-cost hand-held sun-photometer.

Validation EarthCARE satellite MSI-AOT

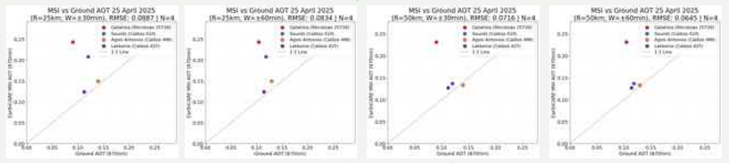
25 April 2025



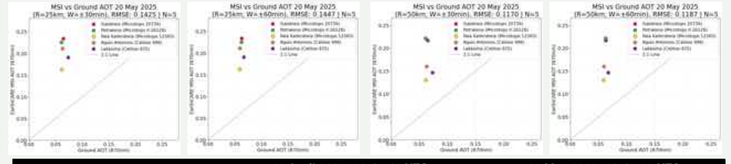
20 May 2025



25 April 2025



20 May 2025 ⚠



Overpass		25 April 2025, 12:41:41 UTC R = 25 Km, TW = ± 60 m			20 May 2025, 12:41:16 UTC R = 25 Km, TW = ± 60 m		
Instrument ID	Location	MSI AOT 670 nm BA baseline	Ground AOT 670 nm	Status	MSI AOT 670 nm BA baseline	Ground AOT 670 nm	Status
Microtops II (20726)	Galatista	0.2431	0.1041	VALID MATCH	0.2338	0.0627	VALID MATCH
Microtops II (26126)	Petralona	0.2509	N/A	Outside Time Window	0.225	0.0624	VALID MATCH
Microtops II (12583)	Nea Kalikrateia	0.1168	NaN	Data Void (NaN)	0.1627	0.0588	VALID MATCH
Calitoo (410)	Souroti	0.2077	0.1183	VALID MATCH	0.2171	NaN	Data Void (NaN)
Calitoo (486)	Agios Antonios	0.1497	0.129	VALID MATCH	0.2107	0.0594	VALID MATCH
Calitoo (425)	Lakkoma	0.1239	0.114	VALID MATCH	0.1904	0.0668	VALID MATCH

MODIS Satellite images of Thessaloniki, Greece During the days of EarthCARE overpasses

Conclusions

Calibration of low-cost sensors

- **High Precision:**

Handheld units showed **excellent agreement with AERONET/PFR** standards $R^2 > 0.95$ & $RMSE < 0.015$, proving their reliability for high-accuracy field measurements.

- **Stable Calibration:**

Consistency lnV_0 values across time, confirming calibration stability and measurement reliability.

Validation EarthCARE satellite MSI-AOT

- **High Validation Success:**

Majority of **Valid Matches (especially,** April 25th) confirms strong satellite baseline performance of MSI_AOT.

- **Identified Discrepancies:**

Higher RMSE values on May 20th due to identifiable retrieval challenges.

Acknowledgments

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