Report on the outcomes of a Short-Term Scientific Mission[1]

Action number:

Grantee name: Athina Savva

Details of the STSM

Title: Evaluation and intercalibration of various low-cost sun photometers in an experimental field campaign

Start and end date: 05/05/2025 to 24/05/2025

Description of the work carried out during the STSM

During the EarthCARE campaign in Thessaloniki measurements with six low-cost hand-held sun-photometers (three Microtops II and three Calitoo instruments), were used to measure the Aerosol Optical Depth and to calibrate the instruments. These measurements were conducted also on the days of the EarthCARE satellite overpasses and throughout the campaign period at multiple locations across the city of Thessaloniki, Greece.

Cloud-free measurements were conducted on 17–18 May 2025 using six handheld sun photometers (three Microtops II and three Calitoo instruments) as part of the calibration of the instruments with a reference instrument. The measurements were performed at the Laboratory of Atmospheric Physics (LAP) station of Aristotle University of Thessaloniki in Greece (40.38° N, 22.57° E, 60 m a.s.l.). The handheld instruments were calibrated against a reference Cimel sun–sky photometer, which is part of the AERONET network of NASA and regularly maintained and calibrated. Among the Microtops II instruments, the unit from NOA (National Observatory of Athens) – instrument number [20765], the unit from ERATOSTHENES CoE – instrument number [12583], the unit from University of Patras – instrument number [26156] and 3 Calitoo instruments with instrument numbers [410, 486, 425] – was included in the intercomparison.

The Cimel sun photometer (reference instrument) does not provide measurements at all wavelengths that the six hand-held instruments provide. The aerosol optical depths (AODs) of the missing wavelengths 465 nm, 540 nm, and 619 nm were estimated using the Ångström exponent (AE). The AE was derived from Cimel data within a wavelength range that includes the target wavelength. The AOD at a desired wavelength (λ_1) was calculated using the Ångström power-law relationship:

$$AOD_{\lambda 1} = AOD_{\lambda 2} \times \left(\frac{\lambda 2}{\lambda 1}\right)^{-AE}$$

where:

[1] This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the GH for payment of the Grant.

AODλ_1: aerosol optical depth at the desired wavelength, **AODλ_2:** known AOD at a nearby reference wavelength, **λ_1** and **λ_2** : target and reference wavelengths, respectively, **AE:** Ångström exponent calculated over a relevant spectral range.

The retrieval of the AOD calibration factors and aerosol optical depth (AOD) of each instrument per wavelength is based on the **Beer-Lambert Law**, which describes the attenuation of light through a medium:

$$\mathbf{I = I0 \cdot e^{-\tau M}}$$

where:

I0: initial intensity (top-of-atmosphere signal), **I**: measured signal at the surface, **τ**: optical depth, **M:** air mass factor.

In this study, the following form derived from the Beer-Lambert Law was used to retrieve the aerosol optical depth

$$AOD_\lambda = \frac{\ln(V_{0\lambda}) - \ln(V_\lambda * SDCOR)}{M} - \tau_{R\lambda} - \tau_{O3}$$

where:

V0λ: Extraterrestrial voltage at wavelength λ, **Vλ** : Measured voltage at wavelength λ, **SDCOR**: Sensor degradation correction factor, **M**: Air mass, **τRλ:** Rayleigh scattering optical depth, **τO3**: Ozone optical depth.

The new AOD calibration factors per instrument and wavelength are presented in the following table.

Table 1. New AOD calculated Calibration factors of six hand-held sun-photometers per wavelength.

Wavelength	Previous calibration factors	New calibration factors	Difference
Microtops II (ECoE-12583)			
440	6.596	6.5547	0.0413
500	6.77	6.6955	0.0745
675	7.115	6.5589	0.5561
870	6.558	6.4995	0.0585
Microtops II (NOA-20765)			
340	8.339	8.2275	0.1115
440	7.484	7.4674	0.0166
500	7.436	7.3987	0.0373
870	7.436	7.4370	-0.001
Microtops II (Patras-26126)			
440	7.533	7.5272	0.0058
500	7.567	7.4971	0.0699
675	7.53	7.4870	0.043
870	7.322	7.2922	0.0298

Calitoo (410)			
465	-	8.1732	-
540	-	8.1883	-
619	-	7.8412	-
Calitoo (486)			
465	-	8.1295	-
540	-	8.1101	-
619	-	7.838	-
Calitoo (425)			
465	-	8.1362	-
540	-	8.1138	-
619	-	7.8466	-

The ozone optical depth (τO_3) was not considered for the calculation of the calibration factor calculations for Microtops II at 500 nm and Calitoo at 465 nm, as the corresponding ozone absorption coefficients (Ozabs).

Ground-based measurements using the six hand-held instruments conducted on two days of the EarthCARE satellite overpasses over Thessaloniki, on 25 of April 2025 and 20 of May 2025 between 10:00 and 15:00 UTC. The instruments were deployed at six different locations near the satellite overpass path.

The calibrated AODs at 440 nm for Microtops II and 540 nm for Calitoo measurements, recorded over each measurement area during the overpass time, are presented in the Table 2 and Figure 1.

Table 2. Locations, mean calibrated AOD values at 440 nm for Microtops II and at 540 nm for Calitoos, along with the number of ground-based handheld measurements corresponding to the two EarthCARE satellite overpasses on 25 April 2025 and 20 May 2025.

Instruments	**Location of measurements (Long, Lat, elevation** (a.s.l)**)**	**Mean AOD440nm 1st overpass (25 April 2025)**	**Number of measurements 1st overpass (25 April 2025)**	**Mean AOD440nm 2nd overpass (20 May 2025)**	**Number of Measurements 2nd overpass (20 May 2025)**
Microtops II (ECoE-12583)	**Nea kalikrateia** 1st [40.18'N, 23.03'E, 0] 2nd [40.18'N, 23.03'E, 5]	0.063	14	0.154	31
Microtops II (NOA-20765)	**Galatista** 1st [40.26'N, 23.29'E, 390] 2nd [40.28'N, 22.16'E, 423]	0.176	19	0.108	20

Microtops II (Patras-26126)	**Petralona** 1st [40.62'N, 23.33'E, 75] 2nd [40.22'N, 23.09'E, 60]	0.186	12	0.138	17
Instruments	**Location of measurements (Long, Lat, elevation** (a.s.l)**)**	**Mean AOD540nm 1st overpass (25 April 2025)**	**Number of measurements** **1st overpass** **(25 April 2025)**	**Mean AOD540nm 2nd overpass (20 May 2025)**	**Number of** **Measurements** **2nd overpass** **(20 May 2025)**
Calitoo (410)	**Souroti** 1st [40.28'N, 23.05'E, 25-63] 2nd [40.28'N, 23.05'E, 100-116]	0.188	15	NaN – no AM	19
Calitoo (486)	**Ag. Antonios** 1st [40.26'N, 23.05'E, 25-63] 2nd [40.26'N, 23.05'E, 30-70]	0.172	18	0.112	14
Calitoo (425)	**Lakkoma** 1st [40.23'N, 23.03'E, 30-70] 2nd [40.23'N, 23.03'E, 30-70]	0.177	16	0.117	18

Figure 1. *EarthCARE overpass path and locations of handheld sun-photometer measurements (indicated with pins), along with the mean calibrated AOD values per instrument at 440 nm for Microtops II and 540 nm for Calitoo instruments.*

The calibrated AODs from Microtops II and Calitoos measurements, recorded over each measurement area during the overpass time, are presented in the Figure 2. The missing data for the time-period 10:00-15:00 UTC which measurements were implemented is due to cloud conditions.

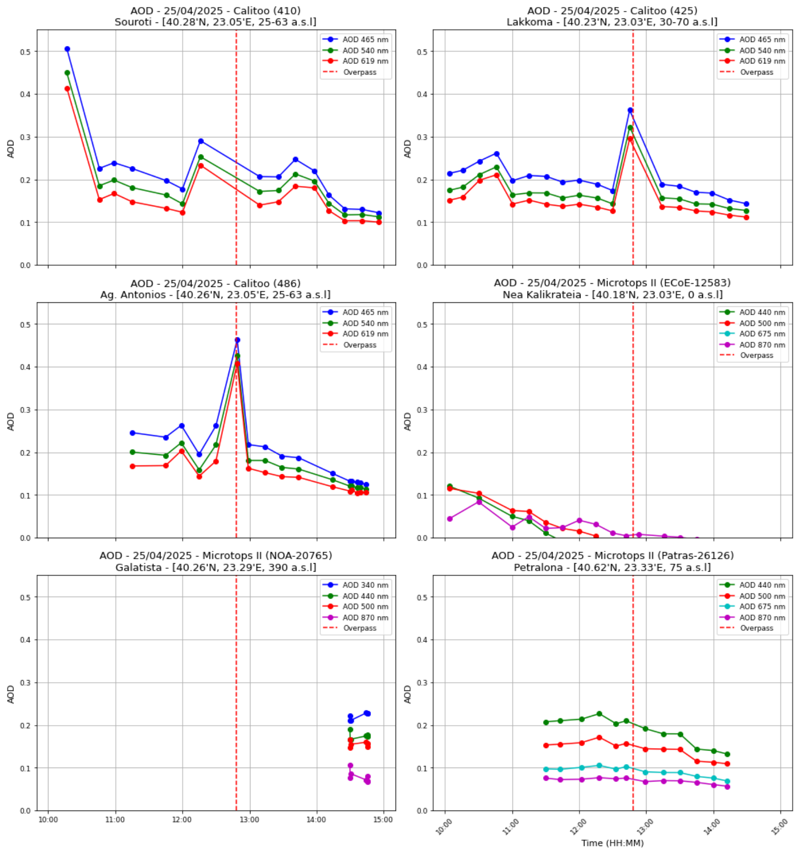

Figure 2. *Calibrated Aerosol Optical Depth (AOD) measurements at various wavelengths from different instruments, collected on the day of the EarthCARE satellite overpass.*

Furthermore, additional measurements were performed at three locations at the Laboratory of Atmospheric Physics (LAP) station of Aristotle University of Thessaloniki [40.38'N, 22.57'E, 60 a.s.l.], at the Center for

Interdisciplinary Research and Innovation (KEDEK) of Aristotle University of Thessaloniki (AUTH) in Greece [40.33'N, 22.59'E, 63 a.s.l.] and in Epanomi [40.20'N, 22.58'E, 17 a.s.l.] (EPANOMI).

Figure 3. Location of the three stations LAP, KEDEK, EPANOMI.

<u>Description of the STSM main achievements and planned follow-up activities</u>

The goals of the experiment were

- To calibrate two microtops and two Calitoo handheld low cost AOD measuring instruments using the CIMEL with 2 days of parallel measurements

- To expand the measurements to other locations (two days each) to compare the AOD measurements

- and to assess if they can be used for homogenization/intercalibration activities.

In the EarthCARE validation campaign in Thessaloniki, three Microtops II and three Calitoo hand-held sun-photometers were calibrated using reference instrument Cimel (sun-photometer) measuring for two days in a raw with clear sky. Measurements also performed at three locations (city (LAP station), airport (KEDEK station), rural (EPANOMI station)). In addition, each instrument gathered data from six different locations near the EarthCARE satellite's overpass paths on April 25 and May 20, 2025. The calibration of the instruments can provide trustworthy measurements of the AOD that can be used for homogenization and intercalibration activities.

This STSM accomplished directly some of the objectives of the HARMONIA Action particularly for evaluation of low-cost sensor technologies and improving aerosol measurements.

The key challenge that is addressing in the MoU of the cost **"How can scientists improve aerosol measurement quality and future measurement capabilities, including low-cost sensors?"**— accomplished by testing and deploying low-cost aerosol sensors at different locations which assessed their spatial consistency and technical reliability.

By comparing the hand-held instruments with reference instrument (Cimel of AERONET network) for calibration needs and identify strengths and limitations which supports the objective **"Assess the performance and the accuracy versus different applications of low-cost sensors".**

"Encourage the use of low-cost systems and fill geographical gaps" goal of HARMONIA is in line with the practical deployment of such systems in underrepresented areas and promotes their broader adoption.

This STSM also supports the Objective 4 of the HARMONIA's cost action **"Report on new instrument development capabilities according to different user needs"** by providing feedback by the users on sensor performance and operational efficacy.

In conclusion, this STSM contributes to multiple HARMONIA's deliverables by assessing performance, technical knowledge and recommendations for future studies. The outputs will support the action members and may potentially lead to future synergistic publications.