AOD Retrievals from Ground-Based EM27/SUN FTIR Measurements in Thessaloniki, Greece



T. Panou[1], D. Karagiozidis[1], C. Biskas[1], C. Topaloglou[1], D. Balis[1], C. Alberti[2], D. Dubravica[2], and F. Hase[2]

[1]Laboratory of Atmospheric Physics, Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[2]Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research (IMK-ASF), Karlsruhe, Germany

* Contact e-mail: tpanou@physics.auth.gr

Introduction

Aerosol Optical Depth (AOD) is a key parameter used to quantify aerosol loading in the atmosphere. Traditional ground-based measurements are typically performed using dedicated instruments such as sun photometers (e.g., AERONET). The EM27/SUN FTIR spectrometer, although primarily designed for greenhouse gas observations, provides high-quality solar spectra that can also be exploited for aerosol studies. By applying the Langley technique to selected spectral regions with minimal gas absorption, it is possible to retrieve reliable AOD estimates. In this study, we explore the capability of EM27/SUN measurements in an urban environment (Thessaloniki, Greece) to derive AOD and assess their performance through comparison with co-located AERONET observations.

Methodology

The retrieval of AOD is based on the Beer–Lambert law, which describes the extinction of direct solar radiation as a function of the total atmospheric optical depth and air mass (Eq.1). By applying a logarithmic transformation to the measured signal, the equation is linearized, allowing it to be expressed as a function of air mass (Eq.2).

$$V_\lambda = V_{0,\lambda} \cdot d^{-2} e^{-m \cdot \tau_\lambda} \quad (1)$$

$$ln(V_\lambda \cdot d^2) = ln(V_{0,\lambda}) - \boldsymbol{m_R} \cdot \tau_{R,\lambda} - \boldsymbol{m_a} \cdot \tau_{a,\lambda} - m_g \cdot \boldsymbol{\tau_{g,\lambda}}$$

$\boldsymbol{m_{aerosol} = m_{Rayleigh}}$ Assuming that the method is applied between 0–75 degrees

$$ln(V_\lambda \cdot d^2) = ln(V_{0,\lambda}) - m_R \cdot (\tau_{R,\lambda} + \tau_{a,\lambda}) \quad (2)$$

The term $\boldsymbol{\tau_{gases} = 0}$, for unaffected by gas absorption wavelengths

This transformation enables the use of the Langley plot, where the natural logarithm of the measured irradiance is plotted against the optical air mass. A linear regression is applied, with the slope corresponding to the total optical depth and the intercept represents the extraterrestrial signal ln(V0,λ) (calibration factor). After subtracting the Rayleigh optical depth, the remaining contribution yields the AOD.

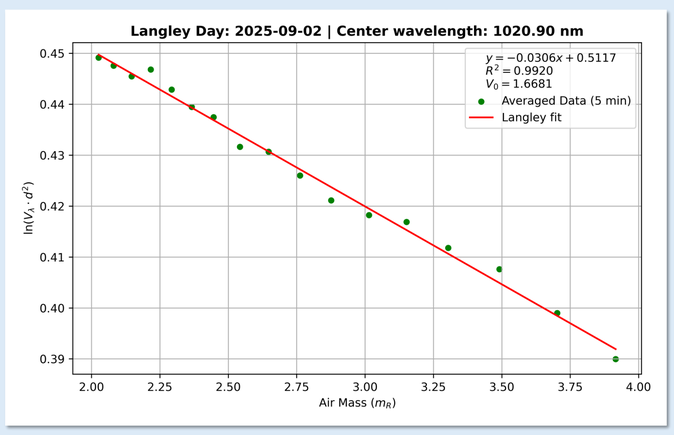

Figure 1. *Example of a Langley day at 1020.90 nm, based on 5-minute averaged observations to minimize noise effects. Reliable Langley calibration requires stable atmospheric, typically characterized by clear skies and low aerosol loading. conditions*

Comparison of EM27/SUN FTIR and CIMEL/AERONET AOD measurements in Thessaloniki, Greece

The comparison between the CIMEL-318T sun photometer and the EM27/SUN FTIR spectrometer shows a strong consistency at both 870 nm and 1020 nm channels. High correlation coefficients (R ≈ 0.96–0.98) and slopes close to unity indicate very good agreement between the two instruments. The low mean differences and RMSE values suggest minimal bias and limited dispersion, confirming the reliability of EM27/SUN FTIR AOD retrievals when compared to AERONET observations.

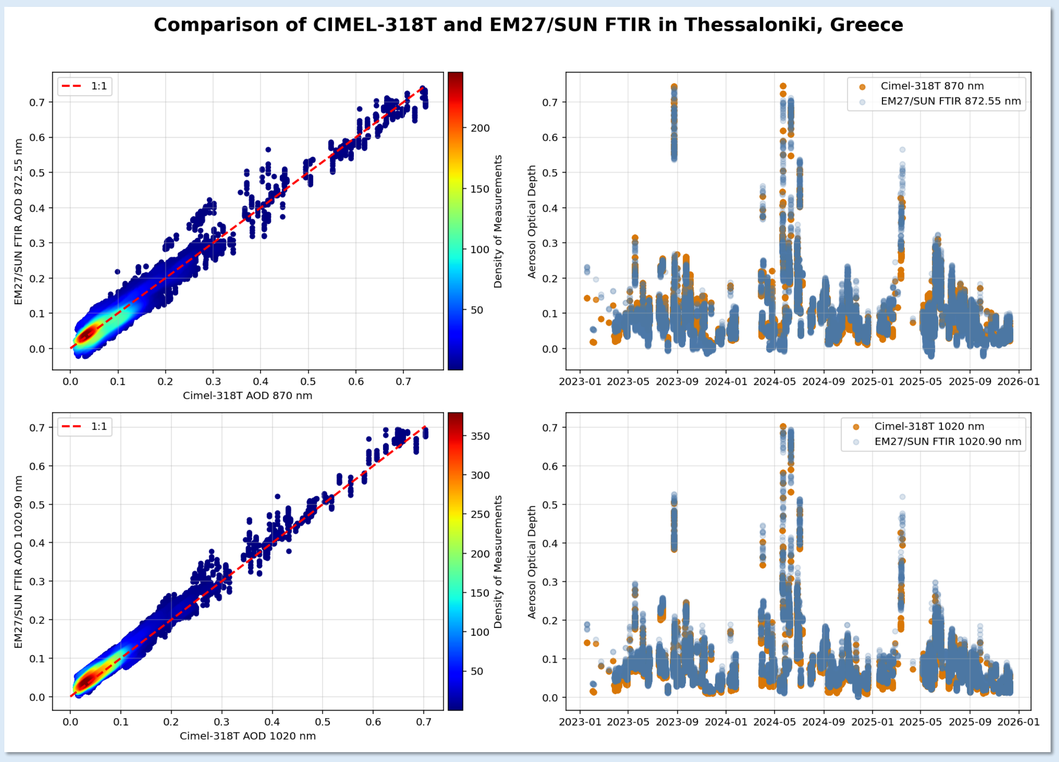

Figure 6. *Comparison of Aerosol Optical Depth (AOD) measurements between the CIMEL-318T sun photometer (AERONET) and the EM27/SUN FTIR spectrometer in Thessaloniki, Greece. Scatter plots (left) for the 870/872.55 nm (top) and 1020/1020.90 nm (bottom), while the right panels show the corresponding AOD time series for both instruments over the period 2023–2025.*

Bands	MD	σ	RMSE	R	Slope	Intercept
870/872.55 nm	0.002	0.024	0.024	0.96	0.978	0.001
1020/1020.90 nm	-0.008	0.015	0.017	0.98	1.02	0.006

Table 1. *Statistical metrics of Aerosol Optical Depth (AOD) comparison between the CIMEL-318T sun photometer and the EM27/SUN FTIR spectrometer at 870 nm and 1020 nm, including mean difference (MD), standard deviation (σ), root mean square error (RMSE), Pearson correlation coefficient (R), and linear regression parameters (slope and intercept).*

EM27/SUN FTIR AOD

During the period 2023–2025, a total of 25 Langley days were identified, during which the calibration factor was calculated for each of the eight selected wavelengths. The time series of calibration factors reveals a gradual degradation over time, primarily attributed to dust accumulation on the optical components of the instrument. In contrast, the observed step-like increases correspond to instrument maintenance and cleaning events, which restore the optical throughput.

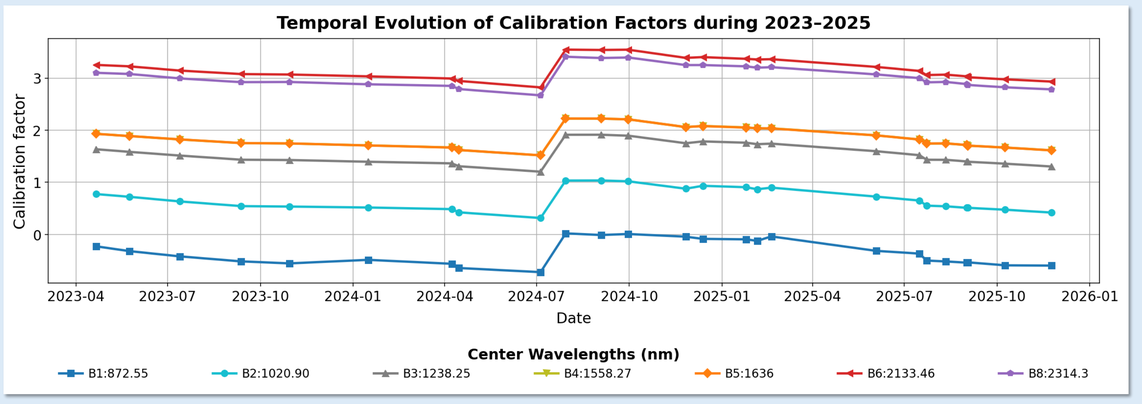

Figure 2. *Temporal evolution of Langley-derived calibration factors for eight spectral channels (872.55–2314.3 nm) over the 2023–2025 period. Each point corresponds to a selected Langley day under clear-sky conditions.*

Based on the temporal evolution of the calibration factors, interpolation was applied to derive continuous values for all measurement days, enabling consistent AOD retrievals. The AOD time series corresponds to near-infrared wavelengths (872.55–2314.3 nm), where the aerosol signal is weaker than at shorter wavelengths. Nevertheless, significant events are clearly detected.

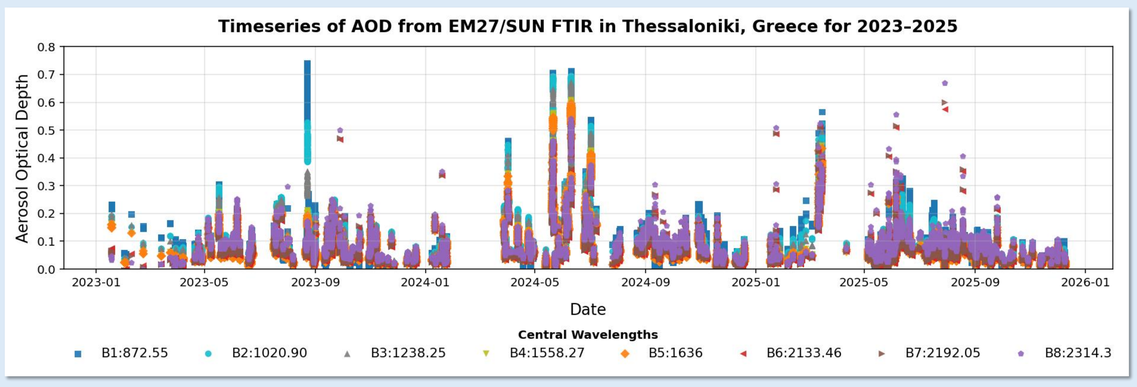

Figure 3. *Time series of aerosol optical depth (AOD) derived from EM27/SUN FTIR measurements in Thessaloniki for the period 2023–2025.*

Smoke and Dust Events Examples

The Alexandroupoli wildfire smoke episode (23 August 2023) demonstrates the capability of the EM27/SUN FTIR to simultaneously monitor aerosol loading and trace-gas enhancements. Both AOD and XCO decreased as the smoke plume dispersed, while their strong correlation (R = 0.987) confirms a common biomass-burning origin.

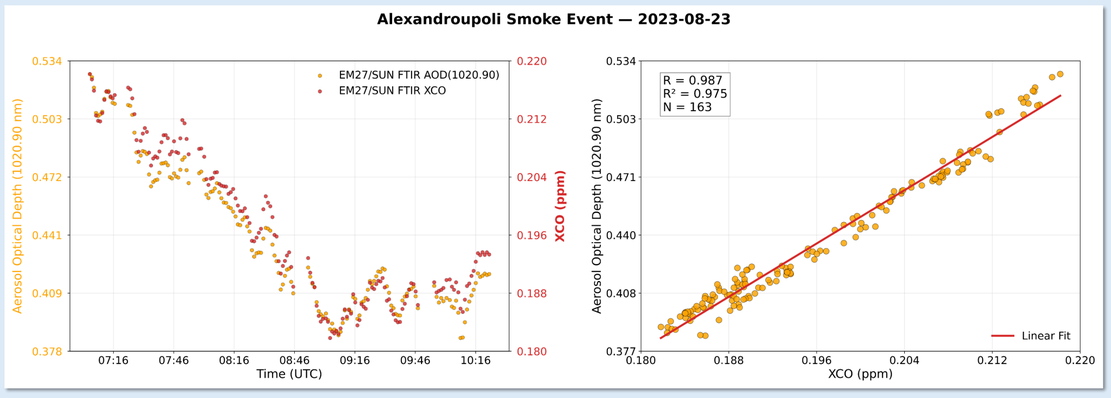

Figure 4. *Temporal evolution of aerosol optical depth (AOD) at 1020.90 nm and column-averaged carbon monoxide (XCO) measured by the EM27/SUN FTIR during the Alexandroupoli smoke event on 23 August 2023 (left), together with the corresponding AOD–XCO correlation and linear regression analysis (right).*

A strong Saharan dust intrusion was observed over Thessaloniki in March 2024 and was clearly captured by the EM27/SUN FTIR measurements. Elevated AOD values were recorded throughout most of the day, indicating a substantial increase in atmospheric aerosol loading associated with the dust outbreak. At the same time, the Ångström exponent exhibited consistently low values, providing strong evidence for the dominance of coarse-mode particles.

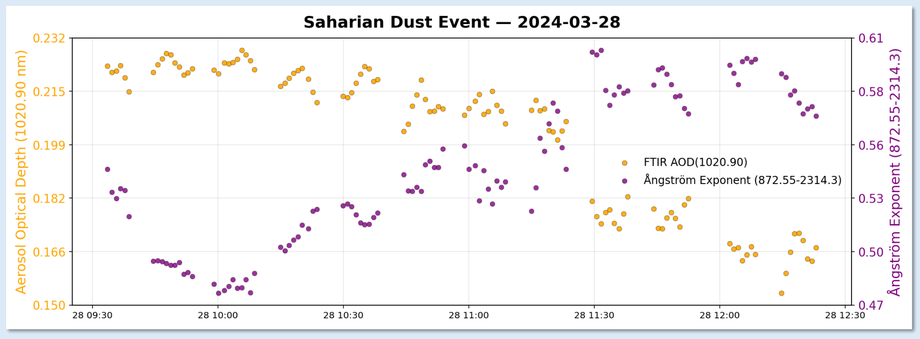

Figure 5. *Temporal evolution of aerosol optical depth (AOD) at 1020.90 nm and Ångström exponent derived from EM27/SUN FTIR measurements during a dust intrusion event over Thessaloniki, Greece.*

Conclusions

i. Langley calibration using EM27/SUN FTIR was successfully applied at eight near-infrared wavelengths, enabling consistent AOD retrievals for the period 2023–2025.
ii. The temporal evolution of calibration factors reveals gradual degradation due to optical contamination, with clear recovery after instrument maintenance.
iii. EM27/SUN FTIR captures aerosol variability and detects significant events (e.g., smoke and dust), despite reduced sensitivity in the near-infrared spectral region.
iv. A strong agreement is observed with CIMEL-318T AERONET measurements at 870 and 1020 nm (R > 0.96, slopes ≈ 1).
v. Low bias and RMSE confirm the reliability of EM27/SUN FTIR for AOD retrievals and its suitability for long-term aerosol monitoring.

References:

Alvárez, Ó., Barreto, Á., García, O. E., Hase, F., García, R. D., Gröbner, J., León-Luis, S. F., Sepúlveda, E., Carreño, V., Alcántara, A., Ramos, R., Almansa, A. F., Kazadzis, S., Taquet, N., Toledano, C., and Cuevas, E.: Aerosol properties derived from ground-based Fourier transform spectra within the COllaborative Carbon Column Observing Network, Atmos. Meas. Tech., 16, 4861–4884, https://doi.org/10.5194/amt-16-4861-2023, 2023.

Barreto, África, Omaira Elena García, Matthias Schneider, Rosa Delia García, Frank Hase, Eliezer Sepúlveda, Antonio Fernando Almansa, Emilio Cuevas, and Thomas Blumenstock. 2020. "Spectral Aerosol Optical Depth Retrievals by Ground-Based Fourier Transform Infrared Spectrometry" *Remote Sensing* 12, no. 19: 3148. https://doi.org/10.3390/rs12193148.

Frey, M., Sha, M. K., Hase, F., Kiel, M., Blumenstock, T., Harig, R., Surawicz, G., Deutscher, N. M., Shiomi, K., Franklin, J. E., Bösch, H., Chen, J., Grutter, M., Ohyama, H., Sun, Y., Butz, A., Mengistu Tsidu, G., Ene, D., Wunch, D., Cao, Z., Garcia, O., Ramonet, M., Vogel, F., and Orphal, J.: Building the COllaborative Carbon Column Observing Network (COCCON): long-term stability and ensemble performance of the EM27/SUN Fourier transform spectrometer, Atmos. Meas. Tech., 12, 1513–1530, https://doi.org/10.5194/amt-12-1513-2019, 2019.

Acknowledgements:
We acknowledge support of this work by the Karlsruhe Institute of Technology (KIT – "The Research University in the Helmholtz Association").

Follow me on LinkedIn for more information and contact details