Validation results of TROPOMI ALH product using EARLINET ground-based lidar observations during 2018 - 2022

PROGRAMME OF THE EUROPEAN UNION

Co-funded with esa

K. Michailidis[1], M-E. Koukouli[1], D. Balis[1] and M. de Graaf[3], J.P. Veefkind[2,3], V. Amiridis[4], E. Marinou[4], I. Tsikoudi[4], A. Papayannis[5] and M. Mylonaki[5]

[1]Laboratory of Atmospheric Physics, Physics Department, Aristotle University of Thessaloniki, Greece
[2]Royal Netherlands Meteorological Institute (KNMI), De Bilt, the Netherlands
[3]University of Technology Delft (TU Delft), Delft, 2628 CN, the Netherlands
[4]Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Athens, 15236, Greece
[5]Laser Remote Sensing Unit, Department of Physics, National and Technical University of Athens, Zografou, 15780, Greece

*Contact E-mail: komichai@auth.gr

Introduction

The aim of this study is to investigate the potential of the TROPOMI instrument, on board the Sentinel5-P satellite platform (Veefkind et al., 2012), to deliver accurate geometrical features of lofted aerosol layers over the Mediterranean basin. For this purpose, we use ground-based lidar data from lidar stations belonging to the European Aerosol Research Lidar Network (EARLINET; Pappalardo et al., 2014). Knowledge of the aerosol layer height (ALH) is essential for understanding the impact of aerosols on the climate system. Ground based observations are important to verify the accuracy and validity of satellite observations as well as model-based results.

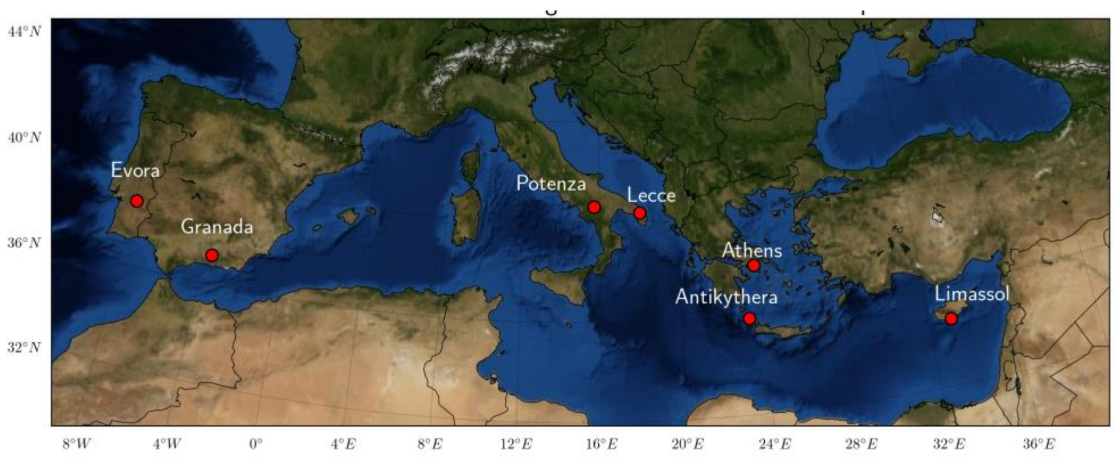
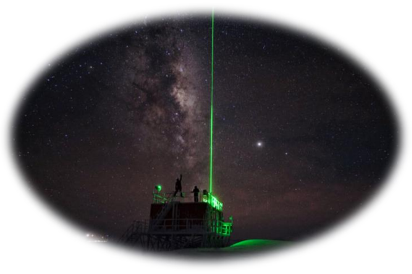


Figure 1. Location of EARLINET lidar stations used in this study

- ✓ Seven EARLINET stations across the Mediterranean were chosen (Evora, Granada, Antikythera, Athens, Limassol, Lecce and Potenza), taking into consideration their proximity to the sea, which provided 63 coincident aerosol cases for the satellite retrievals during the time period May 2018 – July 2022. Over land the TROPOMI ALH becomes unreliable (measured signal might be influenced from the surface reflectance). This is the main reason why we include only stations located close to the sea.

Why to use EARLINET Data?



- ✓ Provide quantitative and statistically significant and long-term database for the horizontal, vertical and temporal distribution of aerosols on a continental scale.
- ✓ Observations are performed to monitor special events over the continent, such as Sharan dust outbreaks, forest fires and volcanic eruptions.

Validation results

✓ **7 EARLINET stations / Time period: May 2018 - July 2022 / 63 collocated cases**

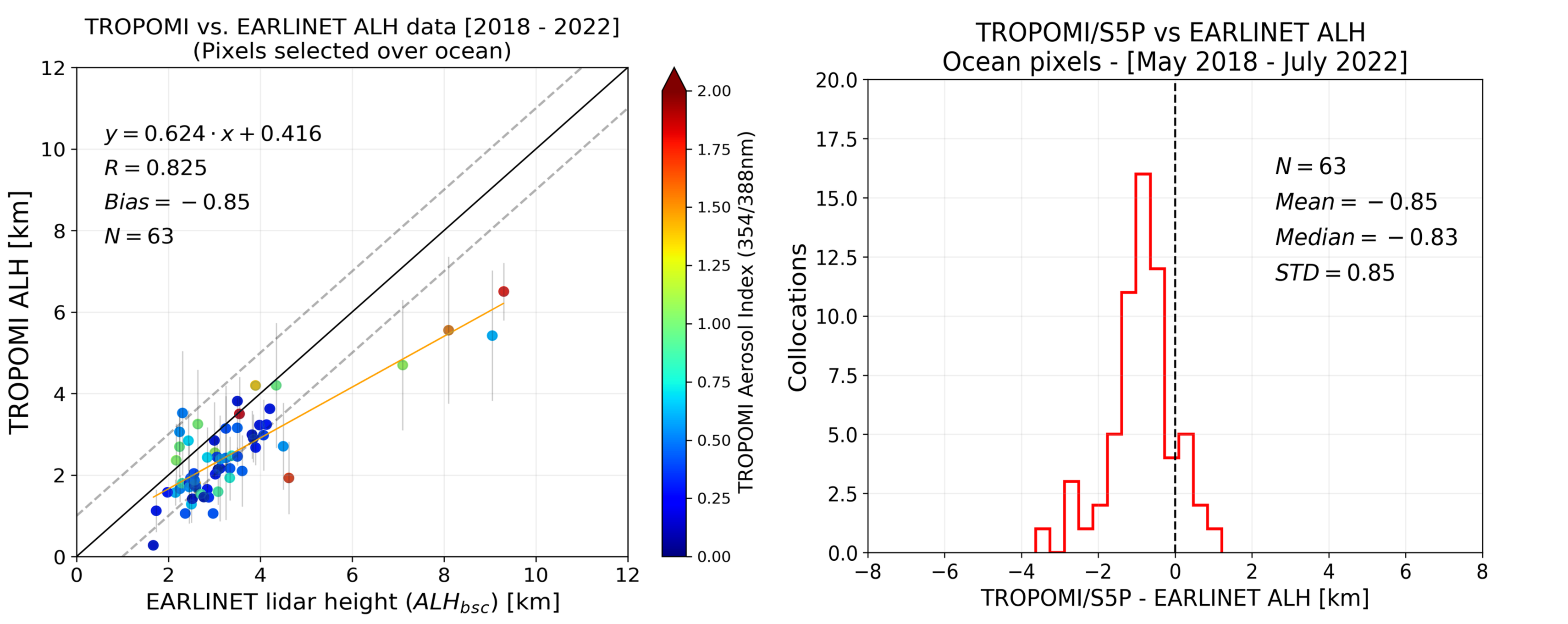


Figure 2. (Left) Scatterplot and linear regression analysis of co-located EARLINET height retrievals and averaged TROPOMI ALH. (Right) Histogram of the differences between TROPOMI & EARLINET datasets.

- Each colored point denotes a pair of averaged TROPOMI pixels against to lidar weighted backscatter altitude, as a function of the aerosol index (354/388nm).
- The comparison analysis revealed a good correlation between the two datasets, with **y-intercept=0.41, slope=0.62, correlation coefficient R=0.82**, and **mean bias -0.85±0.85km**.

Demonstration case: Dust event over Greece 22 June 2021

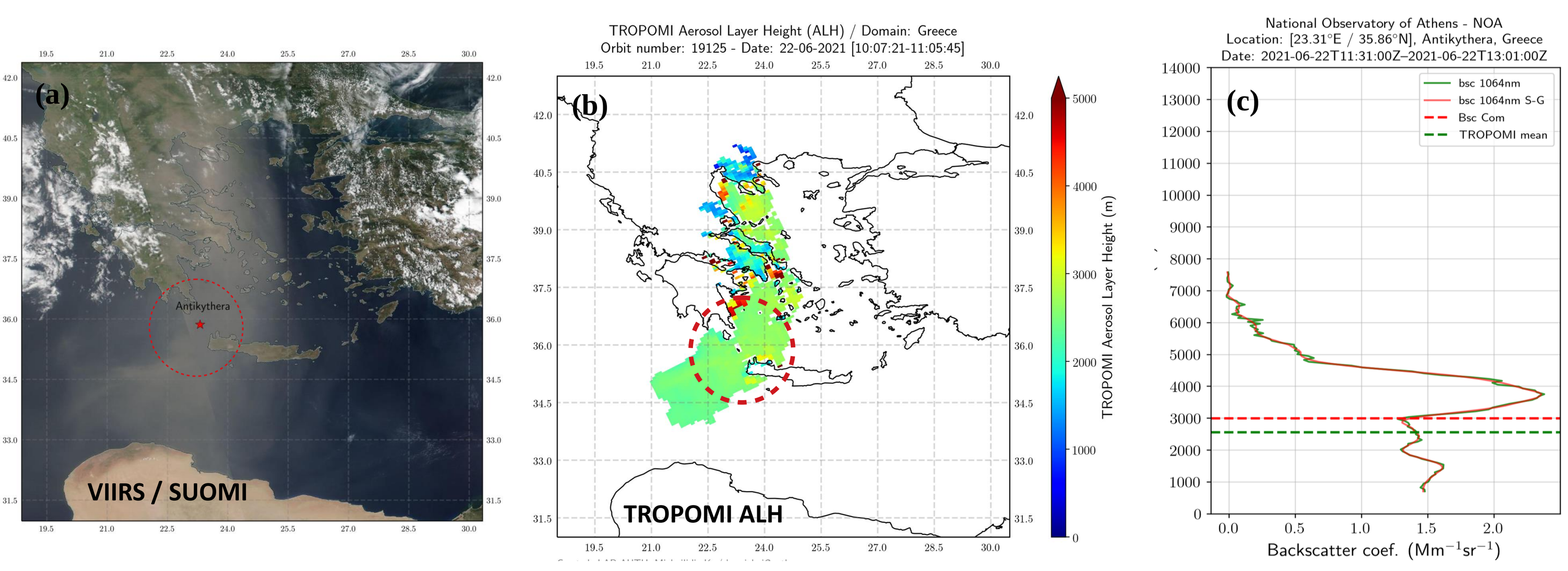


Figure 4. Dust case on 22 June 2021 at Antikythera, Greece. (a) VIIRS True color image, (b) TROPOMI ALH and (c) Backscatter vertical profile at 1064 nm attenuated from PollyXT lidar.

- ➢ An **agreement within 500m** between the satellite and ground-based lidar systems is hence found for this clear aerosol scene.
- ➢ Under cloud-free conditions where homogeneous aerosol layers are developed, the mean ALH value retrieved by the TROPOMI is in excellent agreement with the calculated ALH_{bsc} from the lidar profile.

Validation Methodology

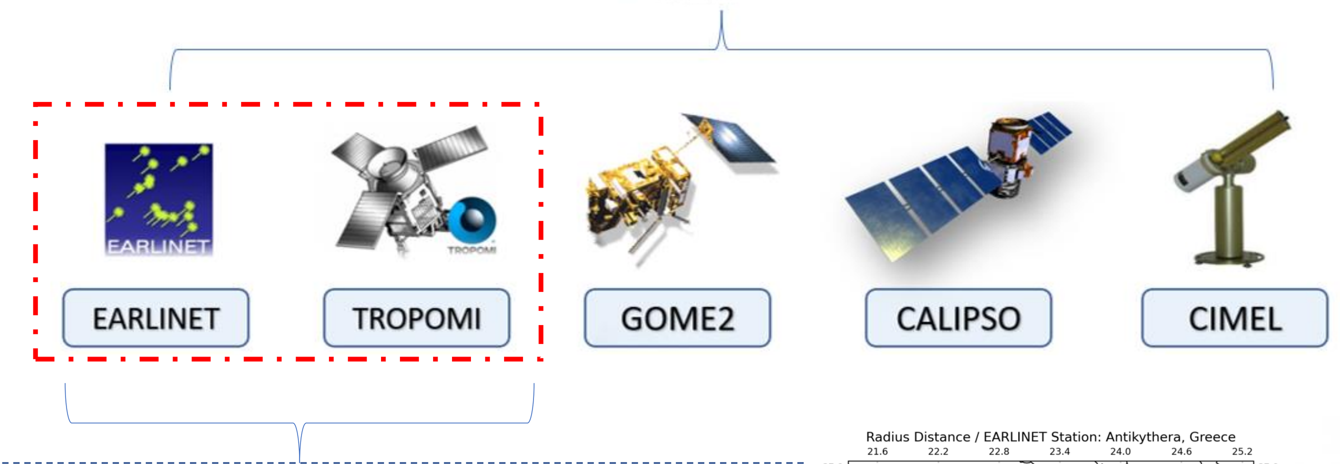
S5P AER_ALH product, focuses on retrieval of vertically localized aerosol layers in the FT, such as **desert dust**, **biomass burning** or **volcanic ash** plumes (Sanders et al., 2015).

An optimal tool has been developed for aerosol monitoring and validation of TROPOMI aerosol height product.

LAP AUTH Tool: "ATLANTIS"

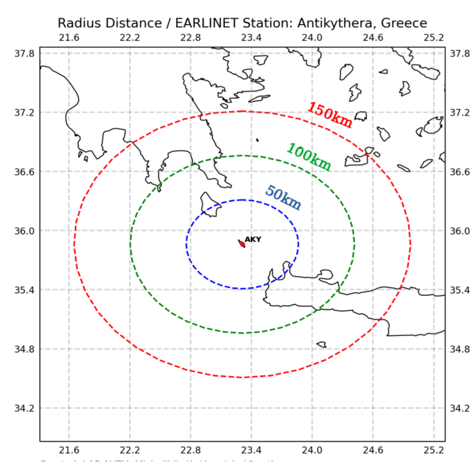
Activities performed within European Space Agency Quality Assurance for Earth Observation, QA4EO project

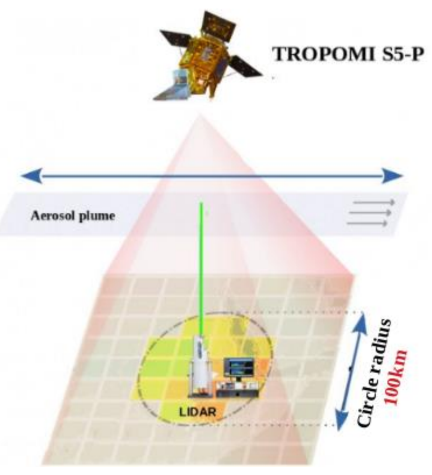
IDEAS-QA4EO



Collocation Criteria:

- ✓ The optimum search spatial radius around the EARLINET station for TROPOMI, considering the high spatial resolution of instrument but also the low availability of S5P observations is set to **150km**.
- ✓ The lidar measurements closest to the TROPOMI overpass time within a **4hours** temporal interval were selected.





Quality assured products

Lidar Dataset	TROPOMI S5P Dataset
• Lidar measurements are analyzed by the **Single Calculus Chain (SCC)** algorithm for quality-assured and uploaded on EARLINET Database. Only data labeled as Lev. 2 are included in the validation process.	• **TROPOMI pixels QA>=0.5 & Additional flags** Sunglint effect, snow/ice, cloud, surface albedo Following the Nanda et al. (2020) recommendations

- ✓ Lidar instruments retrieves the vertical backscatter coefficient, which is not directly comparable to the TROPOMI ALH product.
- ✓ The lidar aerosol heights are computed by weighting the lidar range reported in the Lev-2 EARLINET files with the backscatter profiles and then averaging them to a single value.

Weighted Lidar height (COM)

$$Z_{w-bsc} = \frac{\int_{z_{base}}^{z_{top}} z \cdot \beta_{aer}(z)\,dz}{\int_{z_{base}}^{z_{top}} \beta_{aer}(z)\,dz}$$

Additionally, following the work proposed by Michailidis et al. (2021) for automatic layer detection, we also apply the WCT (Wavelet Covariance Transform) approach in order to check whether the TROPOMI retrieved ALH is sensitive to distinct layers rather than a representative effective layer from the whole profile.

- We use the vertical backscatter profiles to retrieve aerosol layer height.
- Longer wavelengths are preferred = easier to identify aerosol layers (1064 or 532nm)
- We apply the WCT to the lidar data in order to extract aerosol geometrical boundaries (top, base, center of mass).
- Additionally, optical properties for each detected layer can be calculated (e.g. Depolarization Ratio, Angstrom etc).

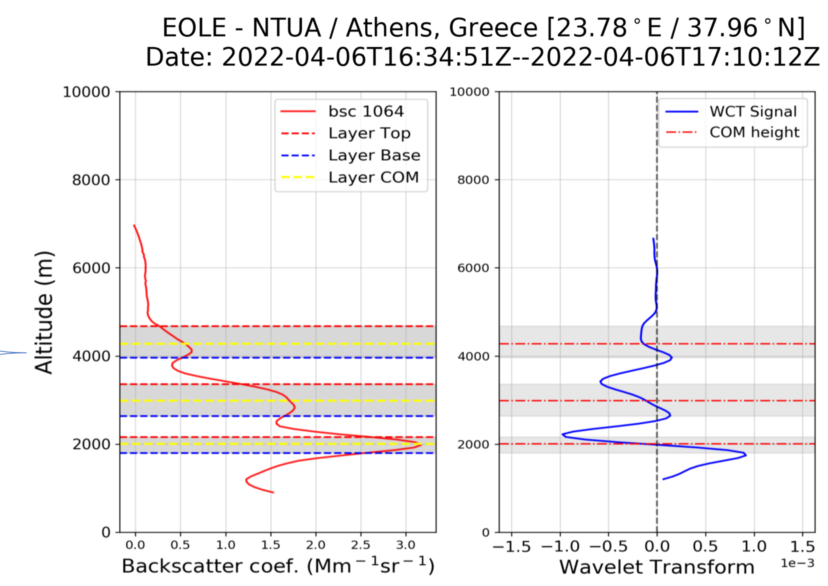
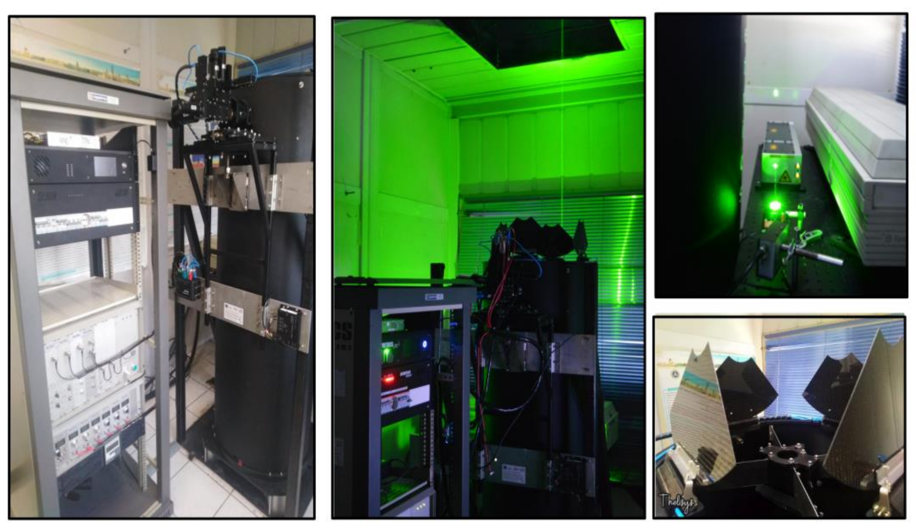


Figure 3. Lidar backscatter profile at 1064nm & resulting WCT profile on 06/04/2022

Many sensitivity tests on lidar measurements and techniques are under further development using the Thessaloniki lidar system as a reference point. This is necessary to know the accuracy and limitations of height retrievals.

Thessaloniki lidar system (THELISYS) setup: 3b+2a+1δ



THELISYS is a Raman and Depolarization lidar, member of EARLINET

- **Elastic backscattering:** 355, 532 and 1064nm
- **Inelastic Raman (N2) scattering:** 387 and 607nm
- **Depolarization Ratio:** 532nm (cross + parallel)

- Belongs to the Laboratory of Atmospheric Physics / AUTH
- The station actively participates in satellite validation activities, providing lidar measurements day and night..
- **Work in progress:** Investigation of Overlap height & Lidar Ratio impacts on weighted ALH determination on lidar backscatter profiles.

Conclusions & Future work

- **EARLINET** provides an **excellent opportunity** offering a large collection of quality assured ground-based data of the vertical distribution of the aerosol optical properties over Europe
- **TROPOMI** aerosol layer height data show **realistic dust and smoke plume heights.**
- The quantitative validation for **63 collocated cases resulted in a very promising correlation coefficient R=0.82 and low bias -0.85±0.85 km.**
- Use the presented work as a proof of concept for future satellite missions (Sentinel 4, Sentinel 5).

References

Veefkind, J. P. et al. (2012): TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications, Remote Sens. Environ, https://doi.org/10.1016/j.rse.2011.09.027

Pappalardo, G., et al. (2014): EARLINET: towards an advanced sustainable European aerosol lidar network, Atmos. Meas. Tech., 2389–2409, https://doi.org/10.5194/amt-7-2389-2014

Sanders, A. F. J. et al. (2015): Evaluation of the operational Aerosol Layer Height retrieval algorithm for Sentinel-5 Precursor: application to O2 A band observations from GOME-2A, Atmos. Meas. Tech, https://doi.org/10.5194/amt-8-4947-2015

Nanda, S., et al. (2020): A first comparison of TROPOMI aerosol layer height (ALH) to CALIOP data, Atmos. Meas. Tech https://doi.org/10.5194/amt-13-3043-2020

Michailidis, et al., (2021): First validation of GOME-2/MetOp absorbing aerosol height using EARLINET lidar observations, Atmos. Chem. Phys. https://doi.org/10.5194/acp-21-3193-202

Michailidis. et al. (2022): Validation of the TROPOMI/S5P Aerosol Layer Height using EARLINET lidars, Atmos. Chem. Phys., https://doi.org/10.5194/acp-2022-412 [in review]

SENTINEL-5P MISSION: 5 YEARS ANNIVERSARY
10-14 OCTOBER 2022 TAORMINA, ITALY

Acknowledgments: We acknowledge support of this work by the project "PANhellenic infrastructure for Atmospheric Composition and climatE change" (MIS 5021516) which is implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014-2020) and co-financed by Greece and the European Union (European Regional Development Fund). The authors also acknowledge the financial support of the European Space Agency "Preparation and Operations of the Mission Performance Centre (MPC) for the Copernicus Sentinel-5 Precursor Satellite" and the ESA IDEAS+ QA4EO project.