# EarthCARE satellite mission: Validation of L2a aerosol products using CARO ground-based measurements in the eastern Mediterranean


**Contributors - Work Group**

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Activities conducted under:

EVID39 CORAL and ATARRI-EU


EarthCARE validation meeting

TROPOS, Leipzig

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CONSORTIUM

AFFILIATED ENTITIES

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# CARO – CORAL project EVID39

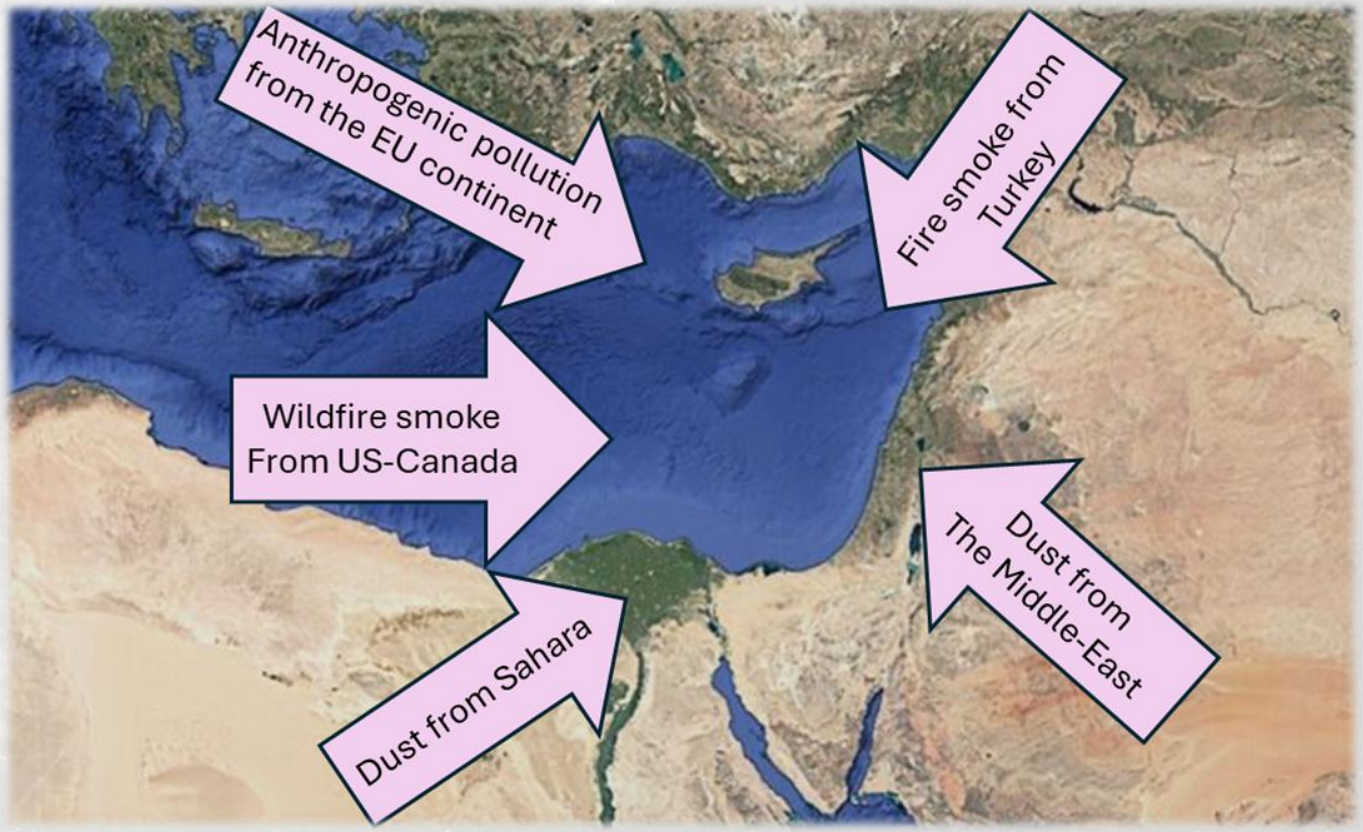


Various calibration/validation (cal/val) activities take place for the EarthCARE mission to be successfully operated

Many scientific communities are involved worldwide

**Cyprus**: key area for the cal/val activities because of its unique geographical position

→ participation the **CORAL project**
(Cyprus Observations for EarthCARE vALidation)



# CARO station

ACTRIS | Cyprus

Limassol, Cyprus (34.7°N, 33°E)

- less than 2 km from the coastline; conditions representative of typical Mediterranean and Middle East region



**ACTRIS AEROSOL REMOTE SENSING OBSERVATIONAL PLATFORM**

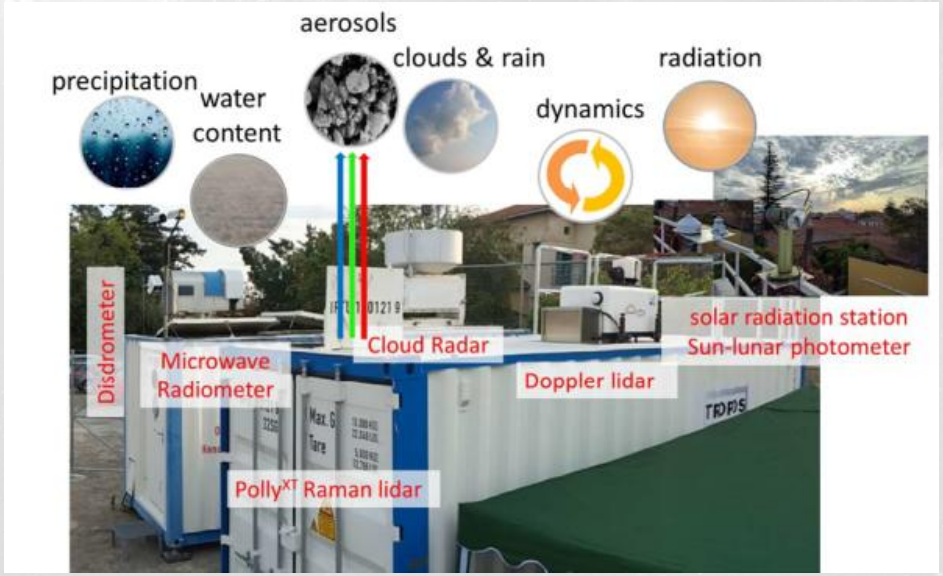
- AERONET Sunphotometer
- PollyXT multiwavelength polarization Raman lidar

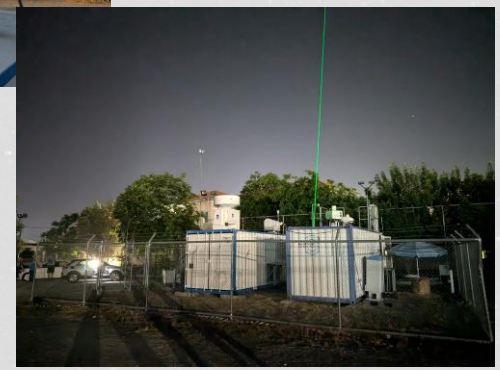
**ACTRIS CLOUD REMOTE SENSING OBSERVATIONAL PLATFORM**

- microwave radiometer
- ceilometer
- optical precipitation disdrometer
- 35 GHz MiRA cloud radar
- Wind Doppler lidar (Streamline-XR)

**SOLAR STATION**

- Sky Camera
- Brewer
- Pyranometer



# CORAL project



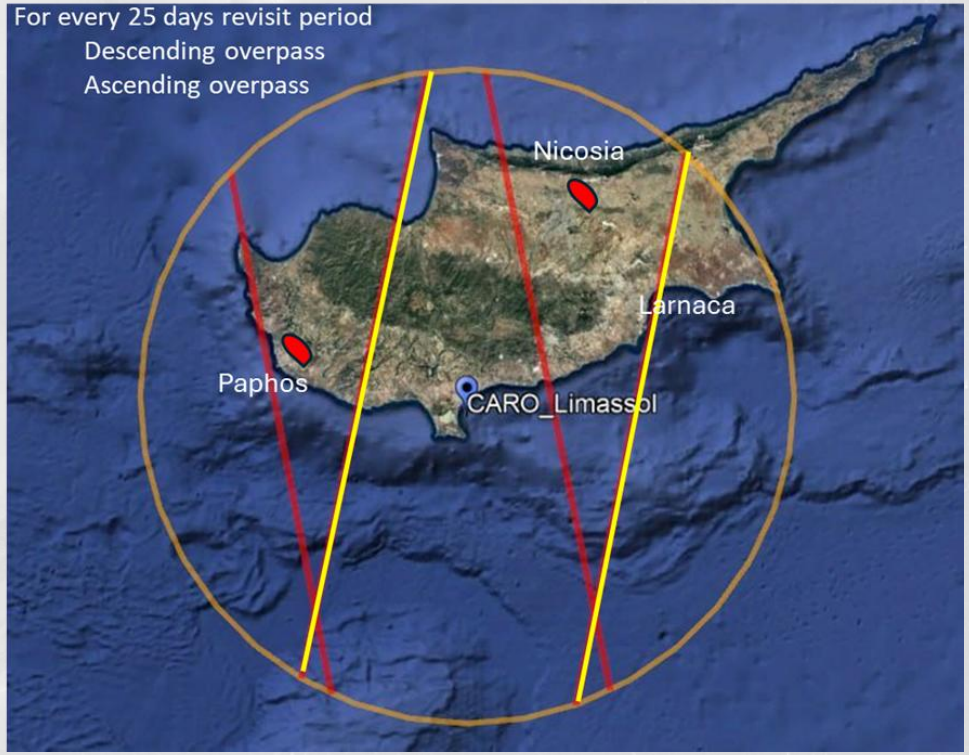
→ **CORAL** focuses on an overall approach for validating EC observations using standardized Aerosol Remote Sensing *(ARS),* Cloud Remote Sensing *(CRS)* and *solar radiation* measurements in Cyprus

→ 4 stations taking part:

- Limassol (ARS-CRS-Solar)
- Nicosia (ARS)
- Agia Marina (Solar)
- Orounda (UAV, in-situ aerosol observations)

*Coordination: Cyprus Atmospheric Remote Sensing Observatory (CARO) of ERATOSTHENES CoE*

→ **CARO station participation** with the operating **PollyXT 24/7 LIDAR, MIRA35 cloud radar** providing real time aerosol profiles**,** and **solar radiation instruments**



# CORAL project – CARO station

| | | | | | INSTRUMENT AVAILABILITY | | |
|---|---|---|---|---|---|---|---|
| | | | | | Aerosol | | Cloud |
| PASS | UTC_TIME_START | STANCE_TO_MID_SW | NDING/DESCEND | ABS_ORBIT_STA | PollyXT | Ceilometer | MIRA 35 |
| 1 | 2026-03-08T12:01:04.745845 | 53.551217 | DESC | 10091 | ☑ | ☑ | ☐ |
| 2 | 2026-03-05T23:23:27.506817 | 22.721507 | ASC | 10052 | ☑ | ☑ | ☐ |
| 3 | 2026-02-27T12:04:41.955615 | 29.493678 | DESC | 9951 | ☑ | ☑ | ☐ |
| 4 | 2026-02-24T23:27:08.657683 | 60.332934 | ASC | 9912 | ☑ | ☑ | ☐ |
| 5 | 2026-02-11T12:01:01.745862 | 53.551054 | DESC | 9702 | ☑ | ☑ | ☐ |
| 6 | 2026-02-08T23:23:24.506830 | 22.72166 | ASC | 9663 | ☑ | ☑ | ☐ |
| 7 | 2026-02-02T12:04:38.955650 | 29.493842 | DESC | 9562 | ☑ | ☑ | ☐ |
| 8 | 2026-01-30T23:27:05.657678 | 60.332781 | ASC | 9523 | ☑ | ☑ | ☐ |
| 9 | 2026-01-17T12:00:58.745883 | 53.550943 | DESC | 9313 | ☑ | ☑ | ☐ |
| 10 | 2026-01-14T23:23:21.506845 | 22.721788 | ASC | 9274 | ☑ | ☑ | ☐ |
| 11 | 2026-01-08T12:04:35.955685 | 29.493954 | DESC | 9173 | ☑ | ☑ | ☐ |
| 12 | 2026-01-05T23:27:02.657671 | 60.332654 | ASC | 9134 | ☑ | ☑ | ☐ |
| 13 | 2025-12-23T12:00:51.214456 | 53.322865 | DESC | 8924 | ☑ | ☑ | ☐ |
| 14 | 2025-12-20T23:23:14.312112 | 22.950573 | ASC | 8885 | ☑ | ☑ | ☐ |
| 15 | 2025-12-14T12:04:29.535638 | 29.722865 | DESC | 8784 | ☑ | ☑ | ☐ |
| 16 | 2025-12-11T23:26:56.512572 | 60.104713 | ASC | 8745 | ☑ | ☑ | ☐ |
| 17 | 2025-11-28T12:00:51.214445 | 53.322982 | DESC | 8535 | ☑ | ☑ | ☑ |
| 18 | 2025-11-25T23:23:14.312103 | 22.950461 | ASC | 8496 | ☑ | ☑ | ☑ |
| 19 | 2025-11-19T12:04:29.535611 | 29.722748 | DESC | 8395 | ☑ | ☑ | ☑ |
| 20 | 2025-11-16T23:26:56.512573 | 60.104824 | ASC | 8356 | ☑ | ☑ | ☑ |
| 21 | 2025-11-09T2:31:633 | | | 8247 | ☑ | ☑ | ☑ |
| 22 | 2025-11-03T12:00:48.863809 | 52.943095 | DESC | 8146 | ☑ | ☑ | ☑ |
| 23 | 2025-10-31T23:23:12.521151 | 23.331679 | ASC | 8107 | ☑ | ☑ | ☑ |
| 24 | 2025-10-25T12:04:29.035748 | 30.104047 | DESC | 8006 | ☑ | ☑ | ☑ |
| 25 | 2025-10-22T23:26:56.471035 | 59.725012 | ASC | 7967 | ☑ | ☑ | ☑ |
| 26 | 2025-10-09T12:00:43.194333 | 52.639162 | DESC | 7757 | ☑ | ☑ | ☑ |
| 27 | 2025-10-06T23:23:07.293072 | 23.636699 | ASC | 7718 | ☑ | ☑ | ☑ |
| 28 | 2025-09-30T12:04:24.840529 | 30.409121 | DESC | 7617 | ☑ | ☑ | ☑ |
| 29 | 2025-09-27T23:26:52.642483 | 59.421119 | ASC | 7578 | ☑ | ☑ | ☑ |

## Overpasses

Total overpasses (since August 2024): more than 108

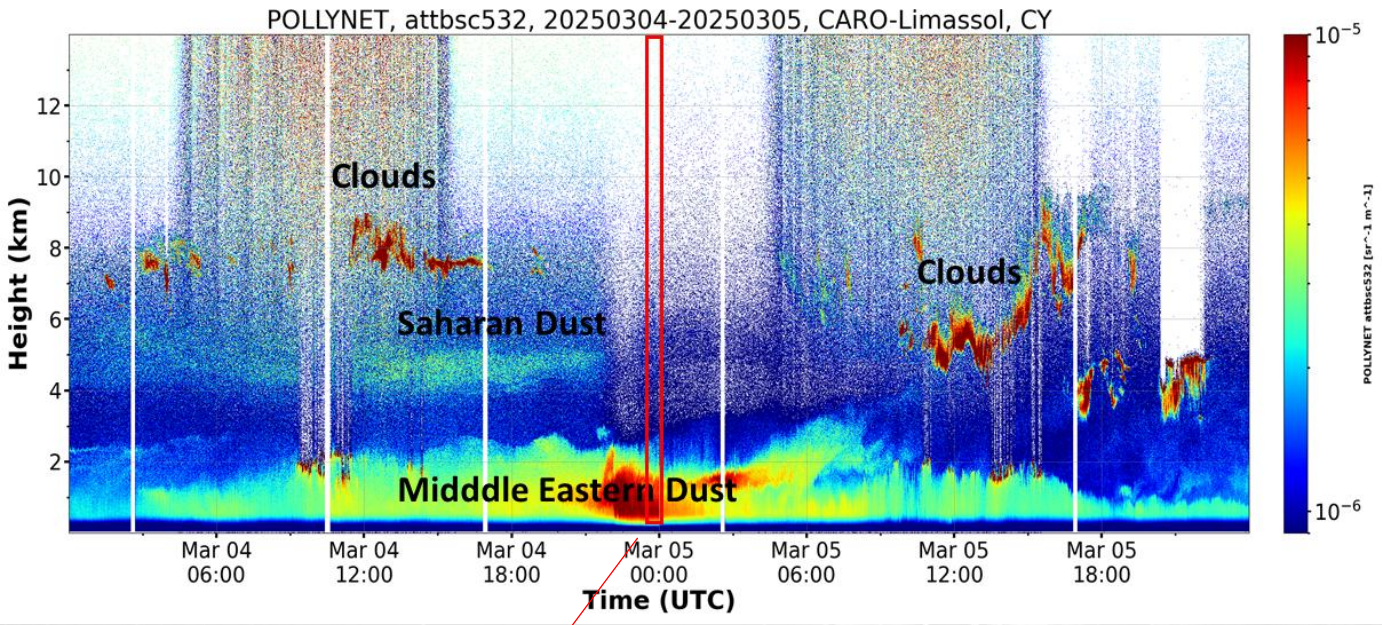
PollyXT operation: **90**
Cloud radar operation: **72**
Ceilometer operation: **108**

→ Submission of **7 ATLID reports** under EVID39 CORAL project (EVID39_PR)

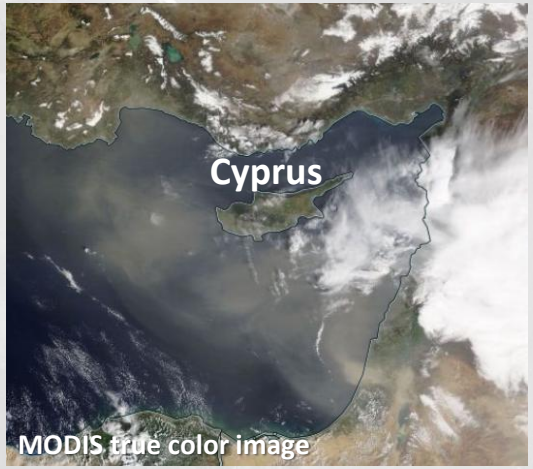
# GOLDEN CASES

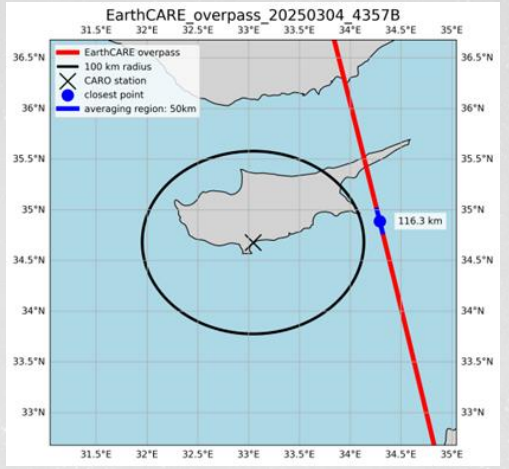
1. Dust – *Middle Eastern, Saharan*
2. Wildfire Smoke – *Local fire*

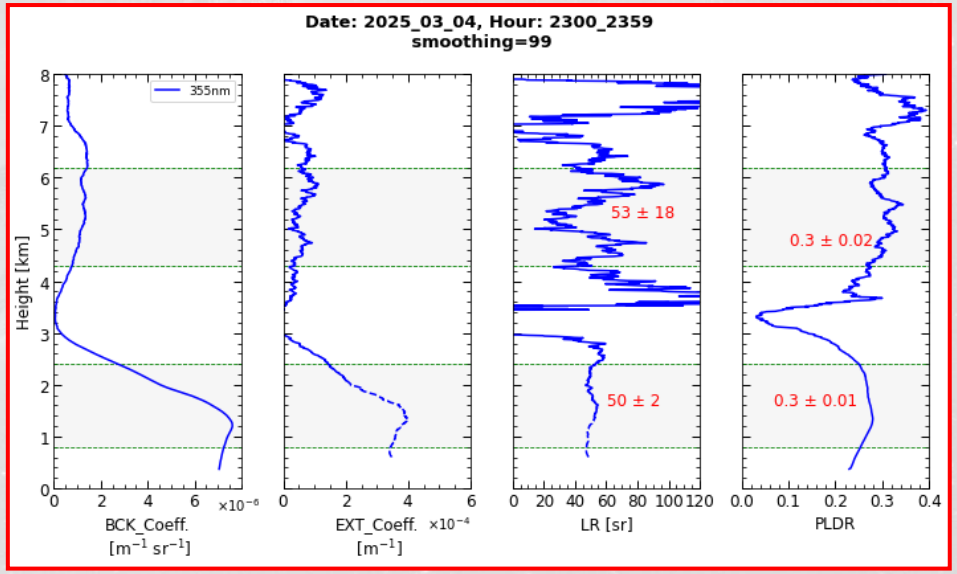
# Dust Case 04.03.2025




EarthCARE overpass

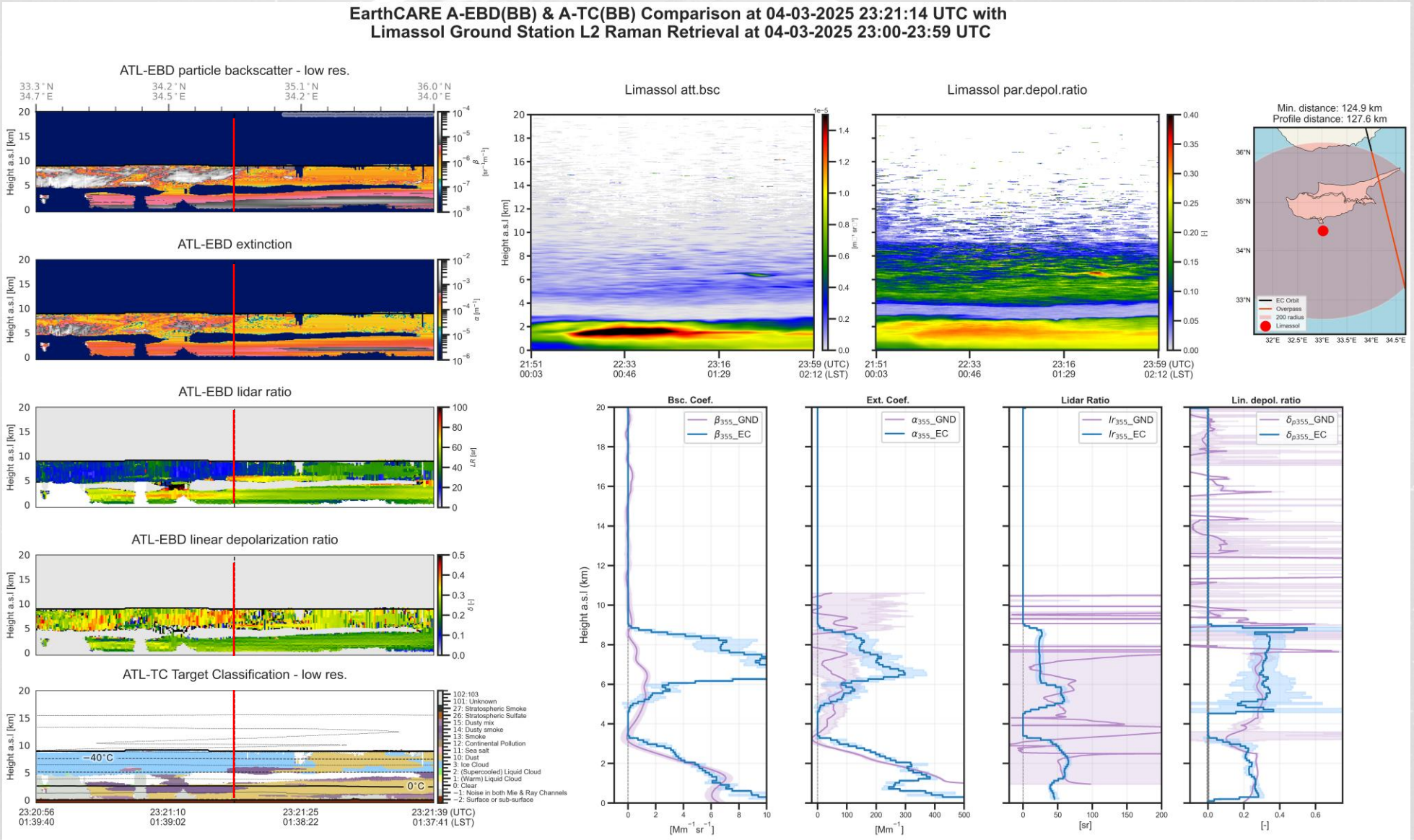


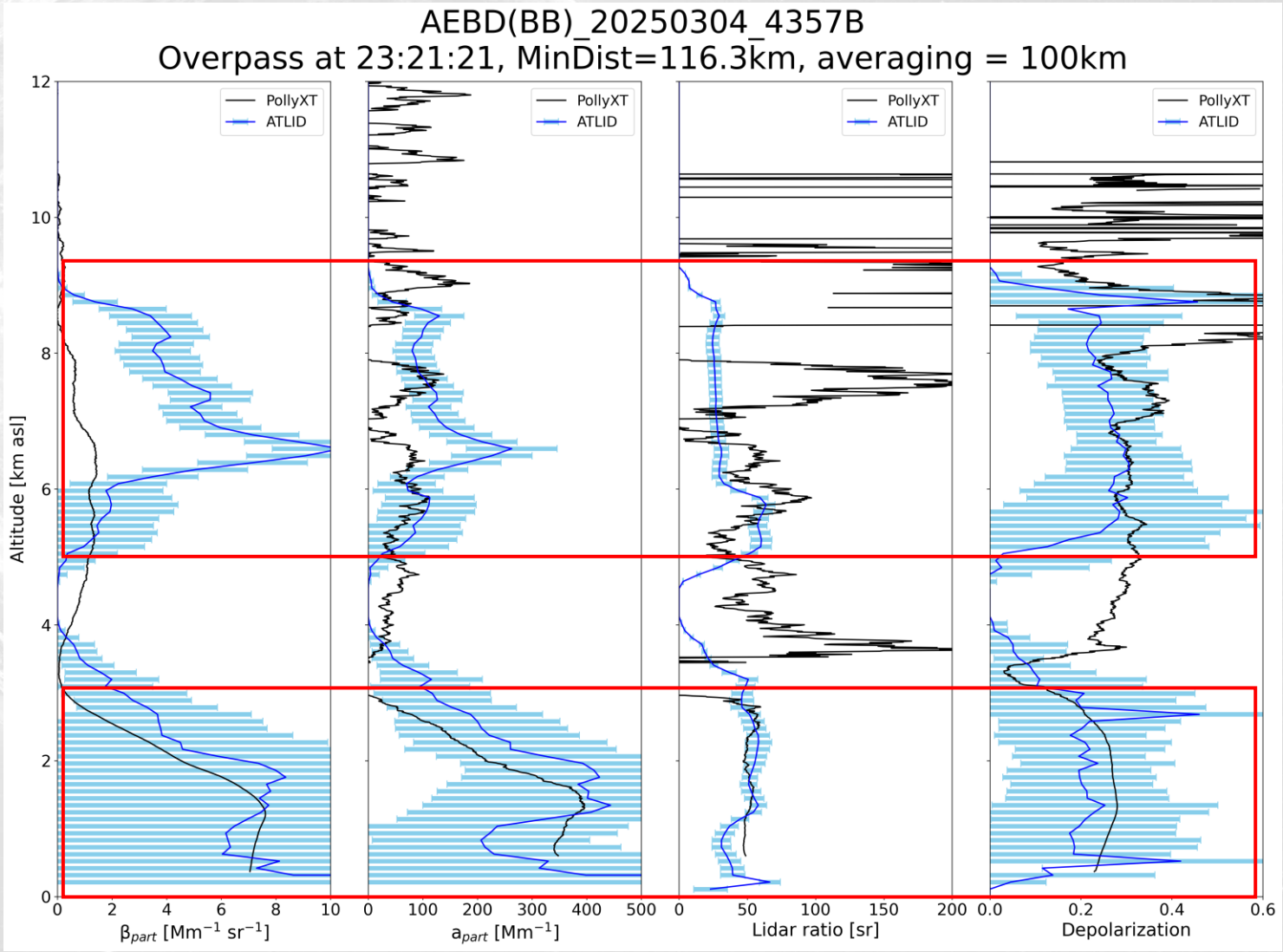
**A-EBD**
Low-resolution

**A-TC:**
Upper layer→
ice cloud

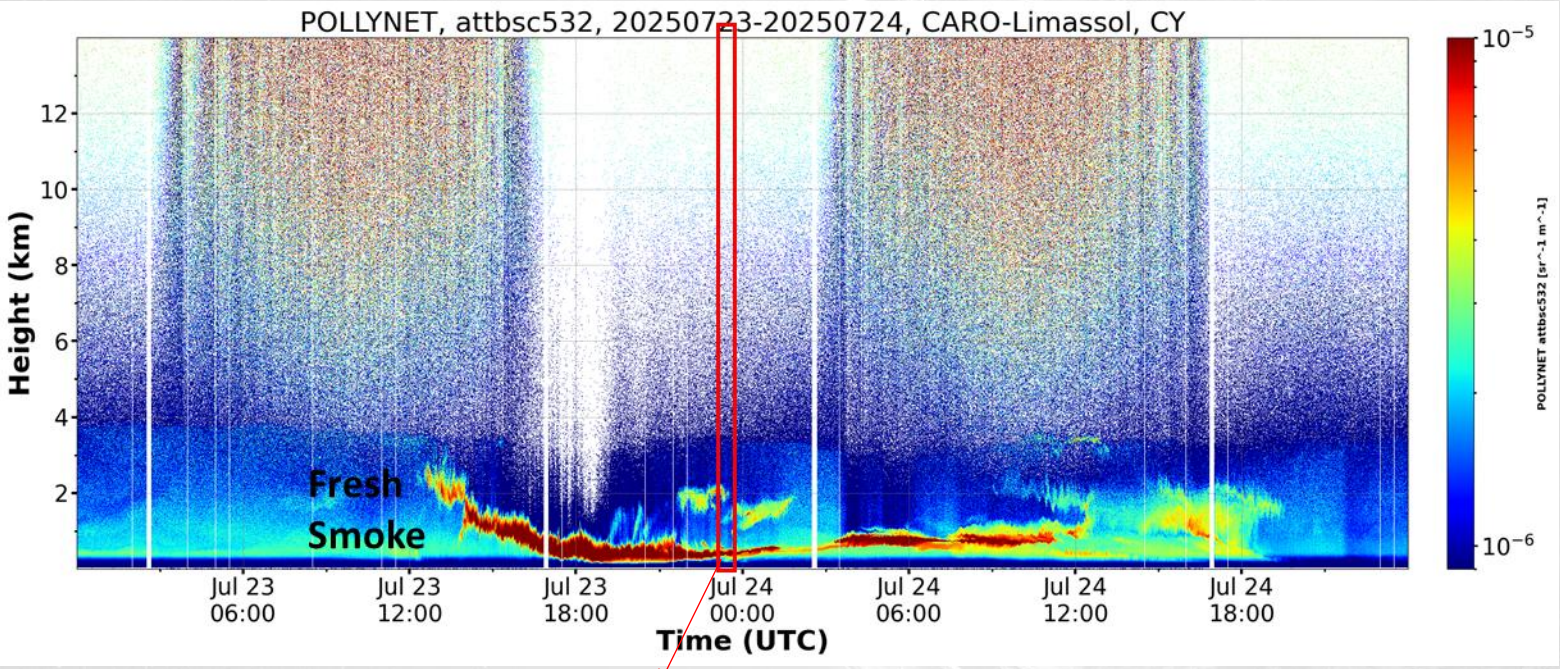


→ **PollyXT**: manual analysis
(2300-2359 UTC, smoothing = 99)

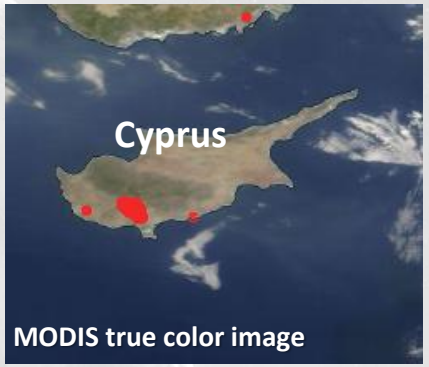
→ **ATLID**: 23:21:21 UTC, averaging = 50km,
*high-resolution profiles*

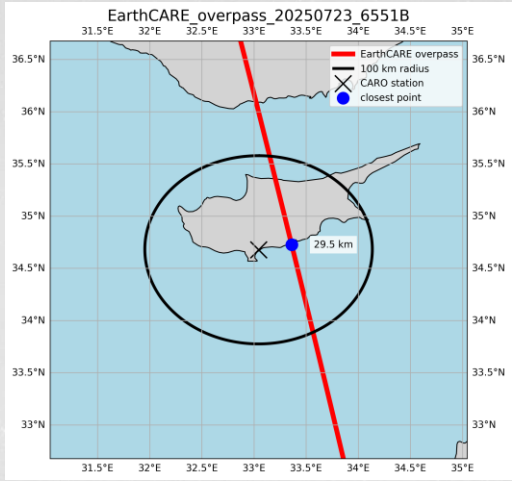


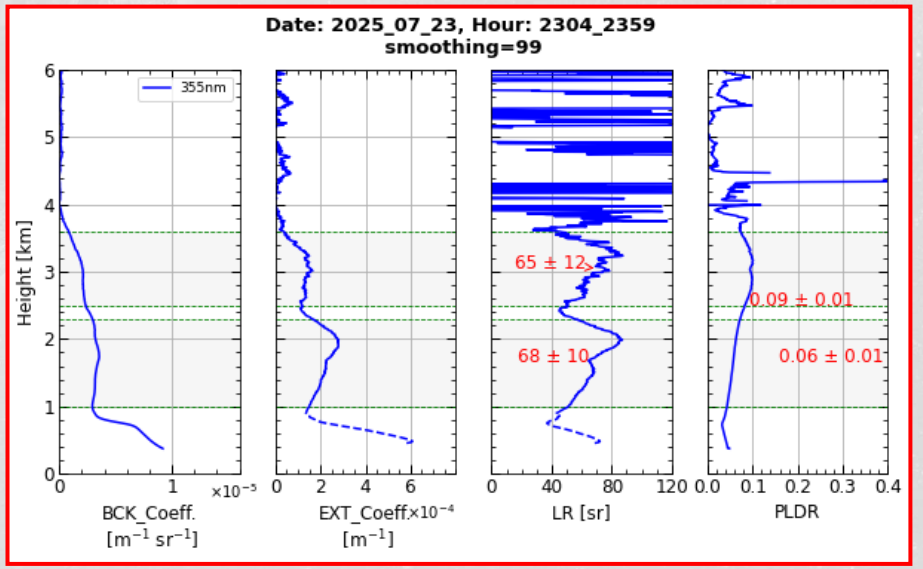
# Wildfire Smoke Case 23.07.2025




EarthCARE overpass

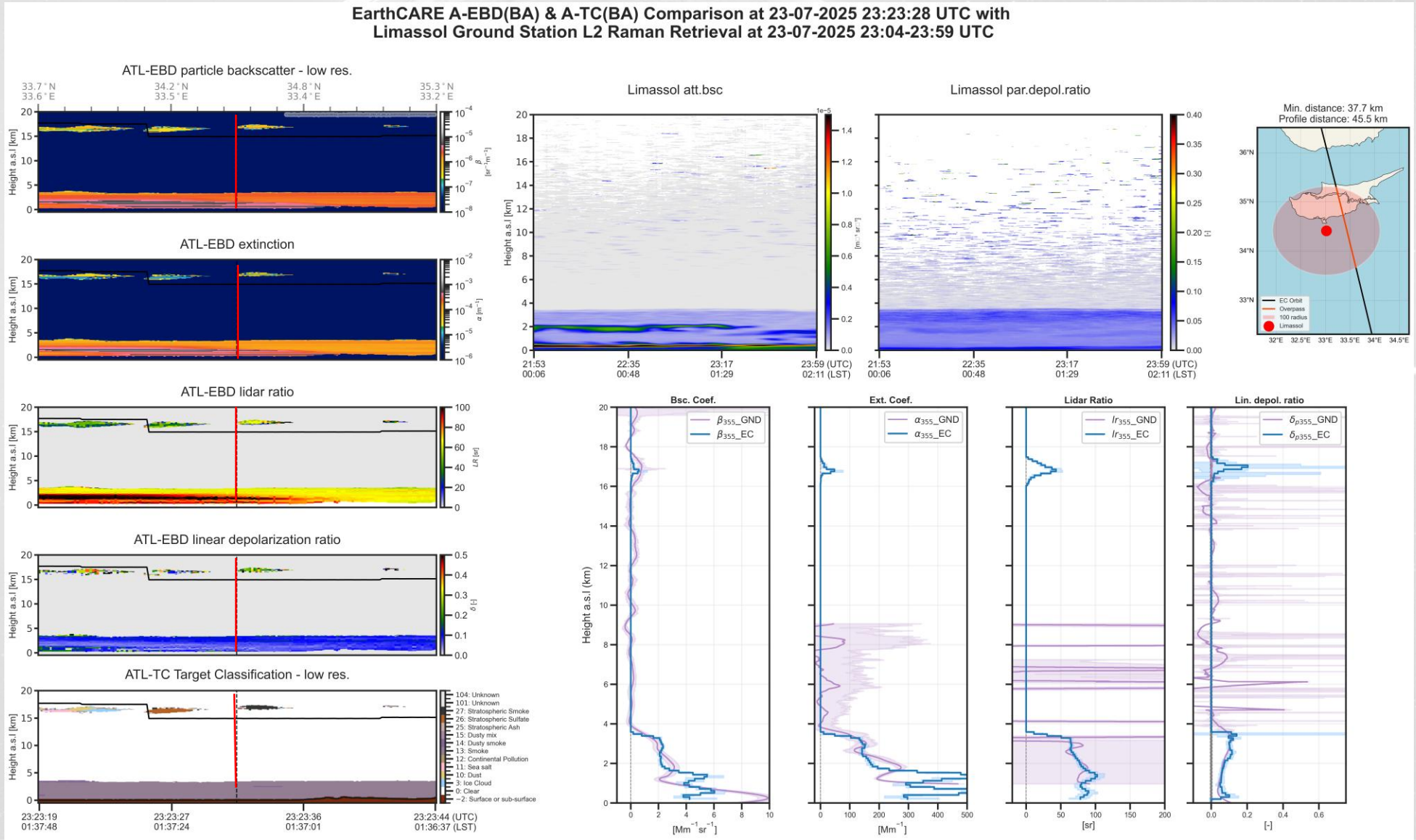


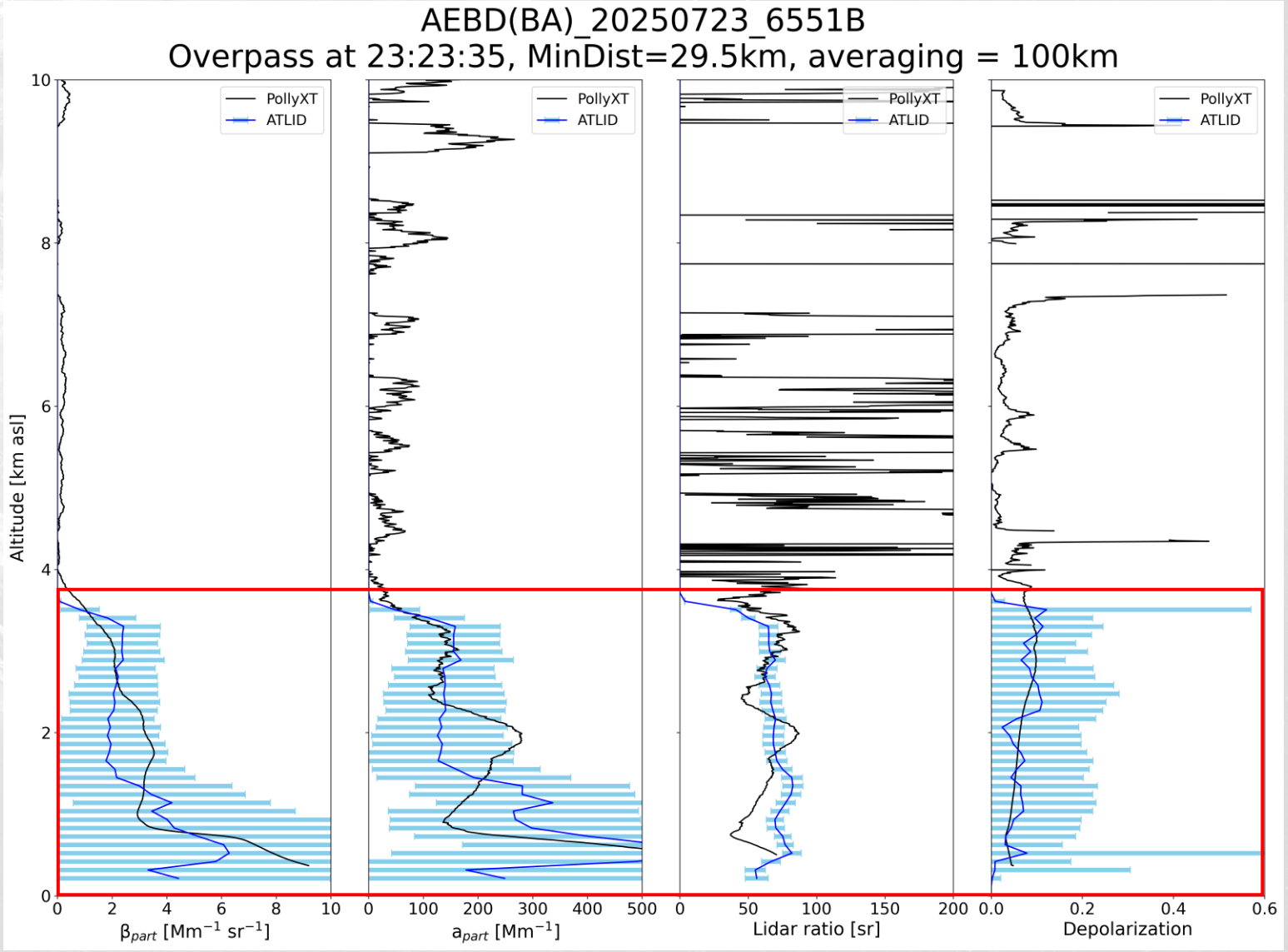
**A-EBD**
Low-resolution

**A-TC:**
Identifies the smoke layer



→ **PollyXT**: <u>manual</u> analysis
(2304-2359 UTC, smoothing = 99)

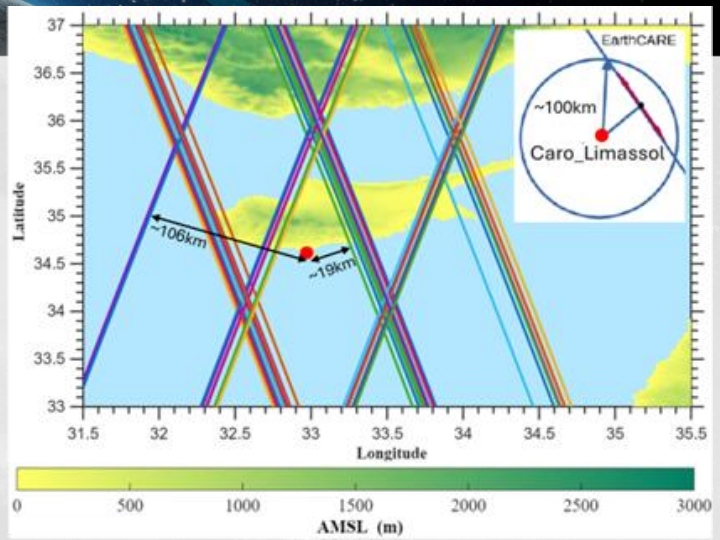
→ **ATLID**: 23:23:35 UTC, averaging = 100 km,
*high-resolution profiles*



# Statistical Analysis
# Oct. 2024 – Oct. 2025

# Statistical analysis: 1 Oct. 2024 – 1 Oct. 2025





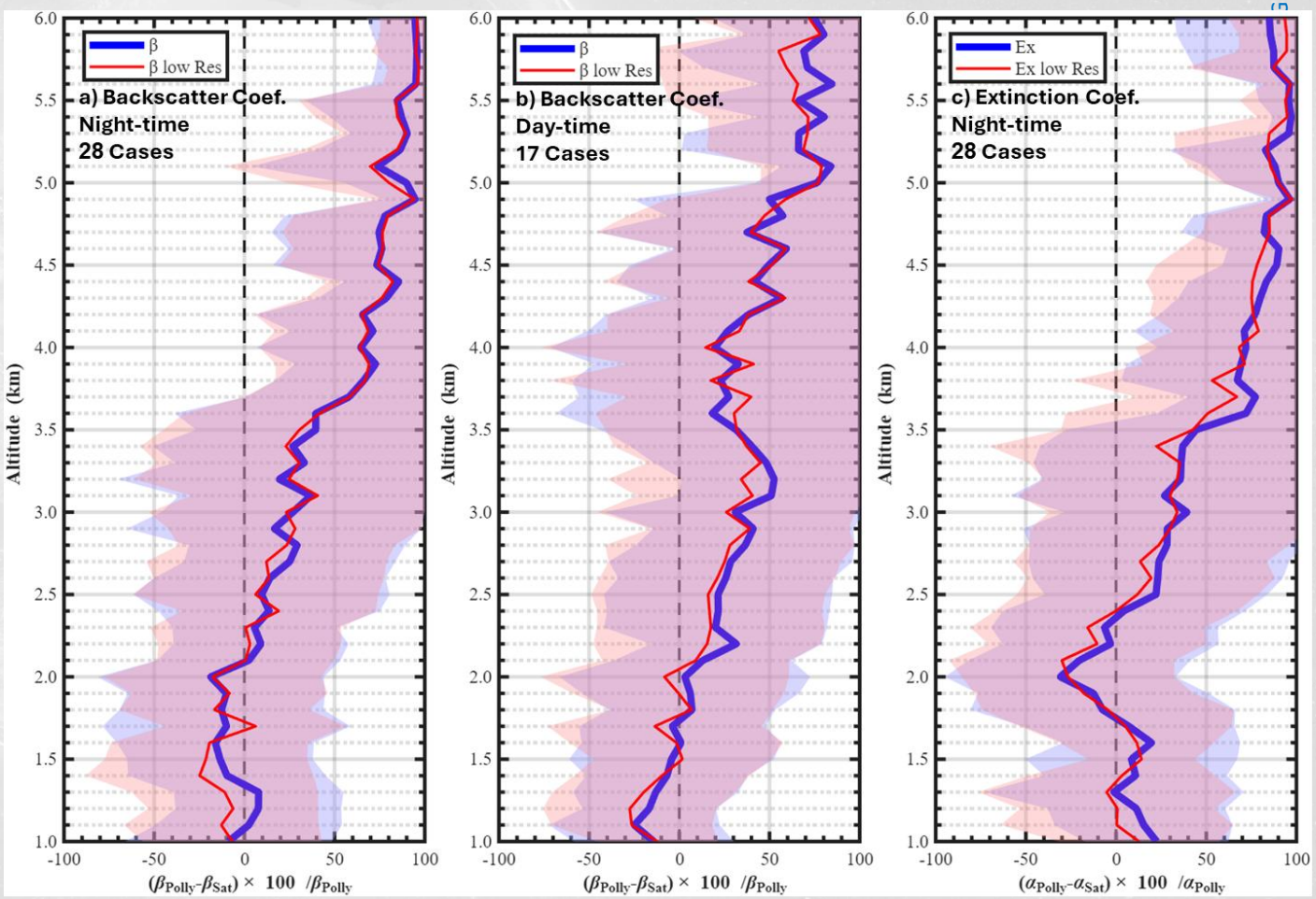

- **Study Period:** 1 Oct 2024 – 1 Oct 2025 (HP)
- **EARLINET 355 nm** ground-based profiles (Level 01, SCC-processed, 1-h averages) used for backscatter (b0355) and extinction (e0355).
- **ATLID L2A (**ECA_EX**BA /** ATL_EBD_2A**)** products used: backscatter, extinction, lidar ratio, depolarization.
- **±25 ATLID pixels** around the closest overpass point to CARO–Limassol has been used from high-resolution and low-resolution to retrieve ATLID signals.

| Category | | Counts | Percentage(%) |
|---|---|---|---|
| Total ATLID overpasses with distance ~100km | | 65 | - |
| Missing dates- No data at EARLINET data center | Daytime | 7 | 10.8 |
| | Nighttime | 9 | 13.8 |
| Missed data due cloud | | 4 | 6.2 |
| Total usable overpass | | 45 | 69.2 |
| Daytime available | | 17 | 26.2 |
| Nighttime available | | 28 | 43.1 |

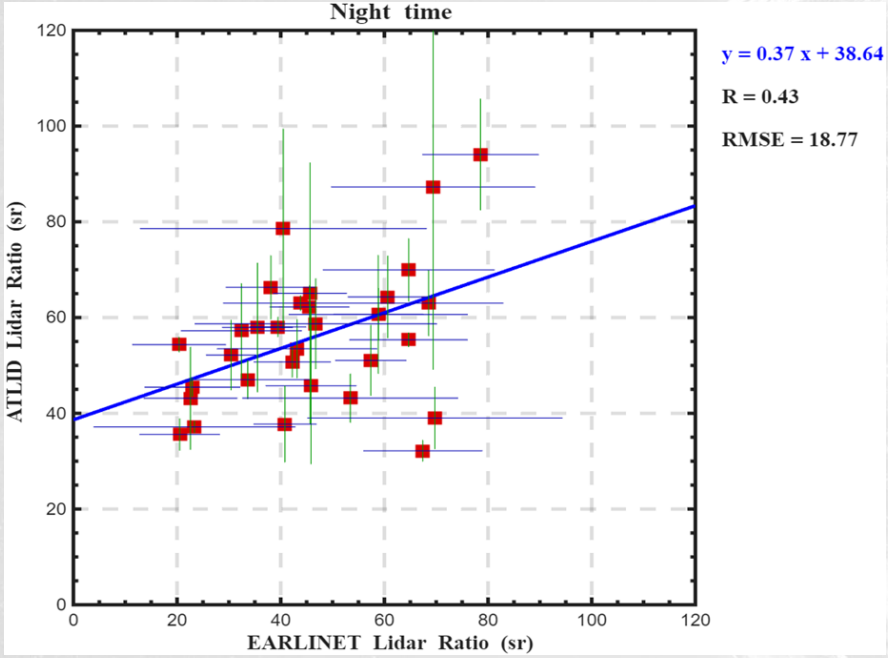
# Height-Resolved Relative Differences Between ATLID and EARLINET Polly

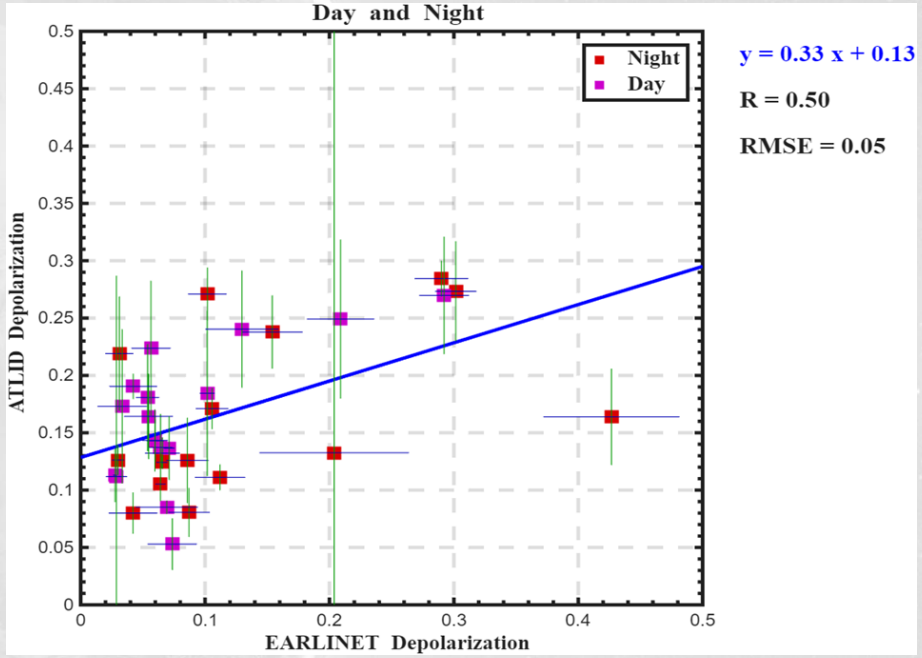


- The original EARLINET Polly (~60 m) and ATLID (~102 m) vertical resolutions were harmonized to a **common 100 m grid** for a consistent level-by-level comparison
- **Relative difference** at each altitude
  →reference data: EARLINET profiles
- High (blue line) and Low resolution (red line)
- **Below 3km**: Relative differences generally remain within **±30%** for both extensive parameters
- High- and low-resolution ATLID profiles show **very similar behavior**



# Layer-Resolved Comparison of Optical Properties




- **ATLID overestimates lidar ratio**. The regression line has a positive intercept (~38 sr) and a low slope (0.37)
- Most Earlinet lidar ratio falls between 30-60 sr, while ATLID cluster lies between 45-70 sr

- ATLID **depolarization** values are generally **higher than EARLINET** for low-to-moderate depolarization (<0.20), indicating a **systematic overestimation** by ATLID in mixed or weakly depolarizing layers
- Depolarization slightly greater scatter during daytime due to higher noise levels

# EarthCARE Aerosol Products (MSI, ATLID-AOT)

# Assessment of EarthCARE's aerosol products (MSI, ATLID) – ATARRI project

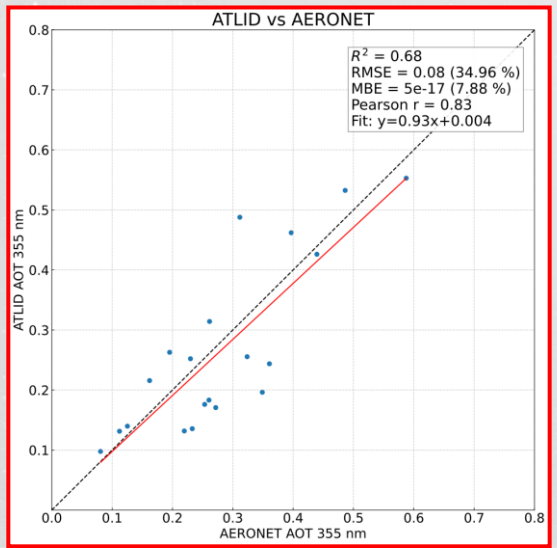


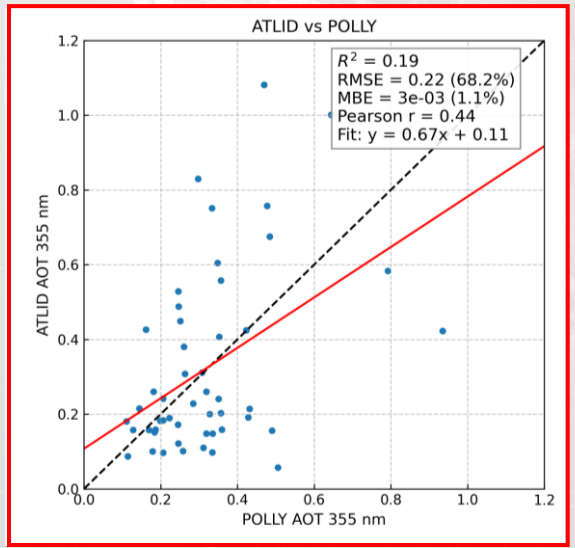
- CARO members GK and AP evaluated the accuracy of aerosol measurements retrieved by EarthCARE's Multi-Spectral Imager (**MSI**) and ATmospheric LIDar (**ATLID**) instruments

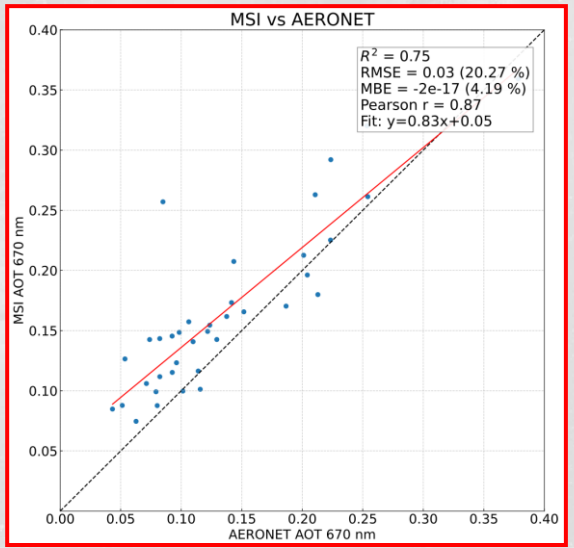
- **Cross-comparisons**: MSI, ATLID, PollyXT-CYP, and AERONET (total aerosol load, vertical distribution) – Limassol area *(future work: analysis for other AERONET stations)*

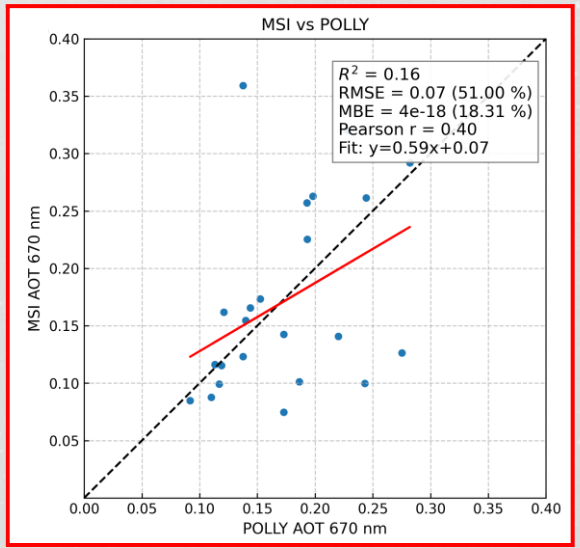
- Overall **good agreement** between **ATLID-AERONET** (closest overpass point + 1-hour temporal averaging of AERONET data) & **MSI AERONET** data (60 km spatial averaging of the MSI swath around the station + 1-hour data averaging for AERONET data)

- Not so strong agreement for ATLID vs POLLY & MSI vs POLLY



# EarthCARE Campaigns

# EarthCARE Campaign Thessaloniki (RACE-ECV) -Overview

- Dates: 22 April - 21 May 2025, focus on EarthCARE overpasses
- 3 PhD students and members of the CARO team participated in this campaign from ECoE (AS, GC, and MP).
- Instruments: 6 handheld sun-photometers (3 Microtops II, 3 Calitoo), sun/sky photometer
- Purpose: **measure Aerosol Optical Depth (AOD)** and **compare** with **MSI outputs**, **calibrate instruments**

Participant institutes:

i. Observatorium Davos **PMOD/WRC** (Switzerland)
ii. Laboratory of Atmospheric Physics – **AUTH**
iii. **University of Zurich** (Switzerland)
iv. National Observatory of Athens (**NOA – ReACT**)
v. **University of Patras**
vi. Eratosthenes Centre of Excellence (**ECoE**)



**Microtops II** and **Calitoo** instruments

**Sun/sky photometer, LAP station at Aristotle University of Thessaloniki**

**Start** of Campaign — **End** of Campaign

**EarthCARE overpass 1** — **Calibration measurements** — **EarthCARE overpass 2**

22 April 2025 — **25 April 2025** — 17-18 May 2025 — **20 May 2025** — 21 May 2025

# EarthCARE Campaign with Microtops II, Cyprus - LoCoCaCy



- EarthCARE validation campaign LoCoCaCy (Low-Cost Campaign Cyprus)
- PhD students AS and GC performs the measurements using the *low-cost handheld sun-photometer Microtops II*
- Dates: started in December 2025 in Cyprus
- Ground-based measurements are conducted during **daytime** EarthCARE satellite overpasses (cloud-free conditions)
- **Primary Objective**: Evaluation the Aerosol Optical Thickness (AOT) products retrieved from the EarthCARE Multi-Spectral Imager (MSI) through comparison with ground-based observations

# Conclusions

- **CARO station** provides strong potential for EarthCARE validation activities

- **Golden case studies:**
  - Good agreement between ATLID and PollyXT (LR & PLDR)
  - Slight ATLID overestimation of backscatter in dust conditions
  - A-TC product:
    -Misclassifies upper dust layer as ice cloud
    -Correctly identifies smoke

- **Statistical analysis (Oct 2024 – Oct 2025, A-EBD product, baseline BA):**
  - Good agreement below ~3 km (relative differences within ±30% for backscatter and extinction)
  - Consistent results across high- and low-resolution ATLID datasets
  - LR: ATLID *lidar ratios* exhibit weak correlation with EARLINET (R = 0.43)
  - PLDR:
    -ATLID *aerosol linear depolarization ratio* is generally higher than the EARLINET particle linear depolarization ratio for low-to-moderate depolarization (<0.20)
    -Layers with stronger depolarization (>0.25) → ATLID values remain comparable
    -Biases appear in weakly depolarizing layers and mixed aerosol conditions common over the Eastern Mediterranean and need more refinement

# Conclusions



- **AOT comparisons**:
  Good agreement:
    - **MSI vs. sun-photometer AOT**
    - **ATLID-derived vs. sun-photometer AOT**

  Low correlation:
    - **Polly vs. ATLID AOT**
    - **Polly vs. MSI AOT**

- **Supporting campaigns:**
    - Results confirmed during **EarthCARE campaigns** (Thessaloniki, Cyprus) → ongoing work

# Thank you!!

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