One Year of EarthCARE ATLID Level 2 Validation at CARO, a Coastal Ground-Based Observatory in Cyprus

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ERATOSTHENES CENTRE OF EXCELLENCE

CARO Observatory and Instrumentation

- **Cyprus Atmospheric Remote Sensing Observatory (CARO)** is a National Facility of the **ERATOSTHENES Centre of Excellence (ECoE)** located at Limassol, Cyprus (34.67° N, 33.04°E). The CARO actively contributes to EarthCARE validation within the **CORAL project** (EVID-39, site: **CARO_Limassol**).
- CARO operates as a **multi-instrument atmospheric observatory** (Table 1 and Fig 2).

Table 1: Instruments running continuously at CARO_Limassol for monitoring aerosols, clouds, and radiative properties
Active Remote-sensing (1-4 Fig. 2): PollyXT Dual-FOV, Cloud Doppler Radar 35GHz, Wind Doppler lidar, CHM15k ceilometer
Passive remote-sensing (5-8 Fig.2): MWR HATPRO RPG, AERONET photometers, Disdrometer Parsivel
Radiation station: Sun-traker STR22G, Pyrgeometer, Erythemal UV irradiance measurement, All sky camera, Pyrgeometer

- Benefiting from its unique geographical position, CARO is influenced by diverse air masses and aerosol types (Fig. 1), making it a strategic reference site for remote-sensing activities in the Eastern Mediterranean and the wider **MENA region**.

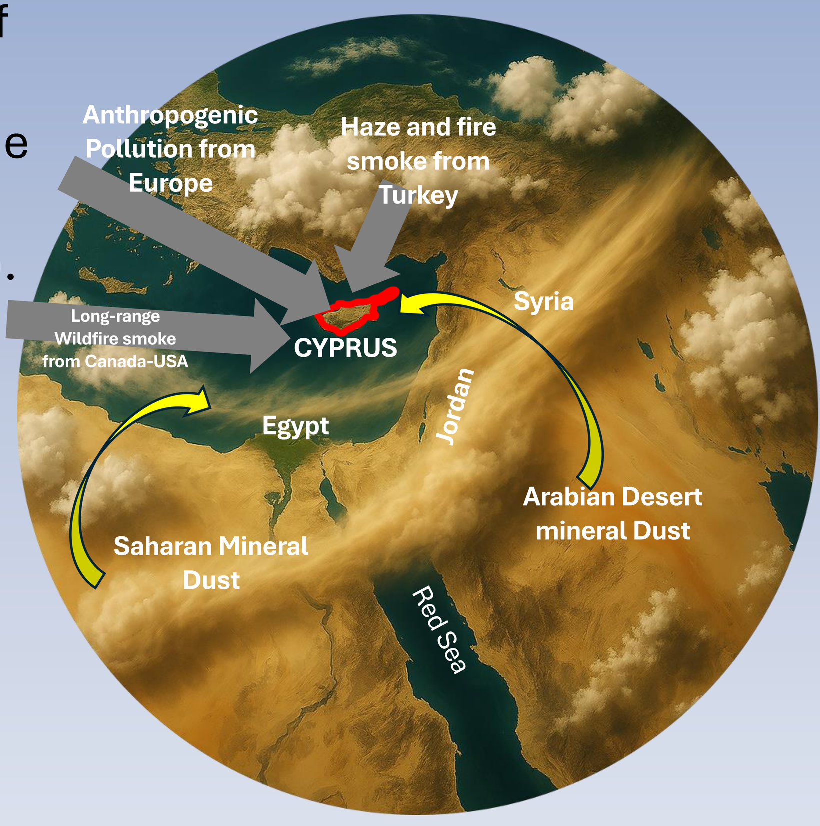

Fig 1- Unique location of CARO-Limassol station

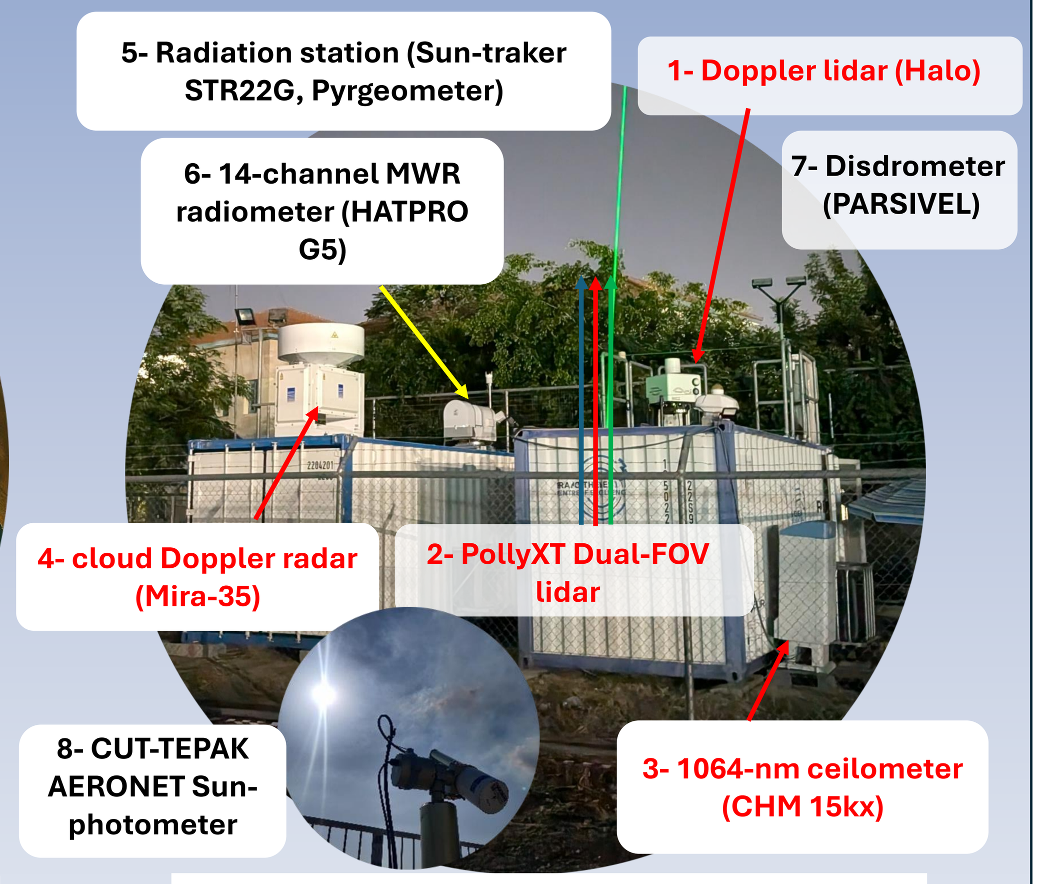

Fig 2- CARO Limassol instrumentation

Dataset and Methodology

- **Study Period: 1 Oct 2024 – 1 Oct 2025** (PollyXT resumed continuous operation on 26 Sept 2024).
- **EARLINET 355 nm** ground-based profiles (Level 01, SCC-processed, 1-h averages) used for backscatter (b0355) and extinction (e0355).
- **ATLID L2A** (**ECA_EXBA / 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.
- 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.

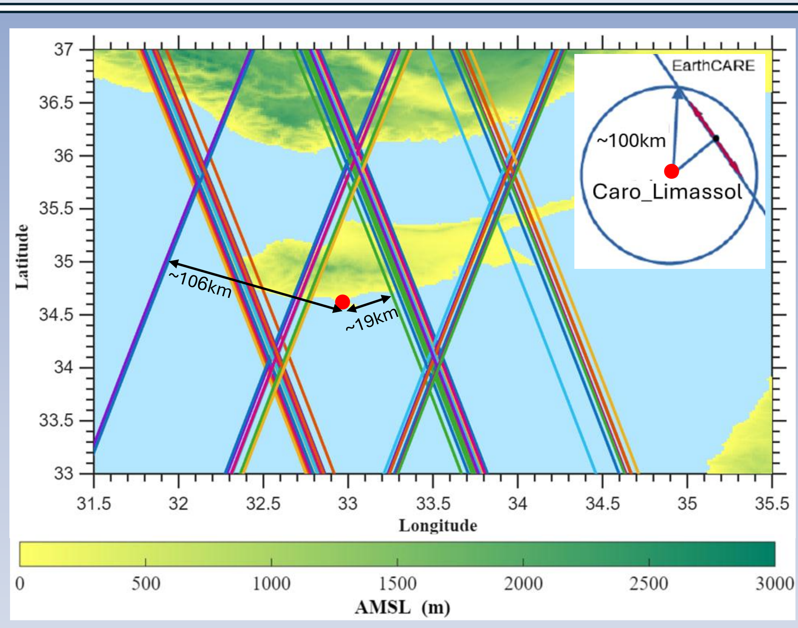

Fig 3- The closest/farthest distance between the satellite ground track and CARO-Limassol is approximately **19 km** and **106 km**.

Table 2- Dataset Filtering Summary

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

Result 1: Height-Resolved Relative Differences Between ATLID and EARLINET Polly

- The **relative difference** was computed at each altitude using the EARLINET profile as the reference for all cases. Then the **mean ± standard deviation** profiles are retrieved for high (blue line) and low resolution (red line) and shown in Figs. 4.

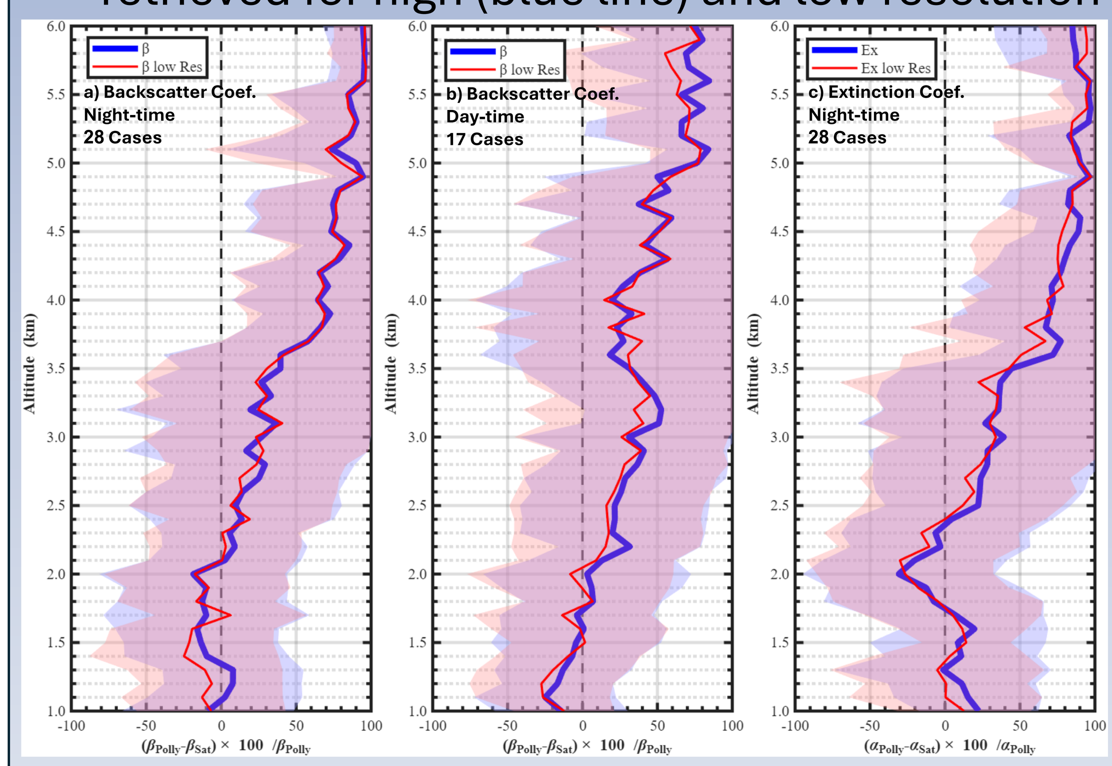

Fig 4- Height-resolved relative differences between ATLID and EARLINET Polly products. **Below 1 km**: There is not data for these heights at EARLINET.

Fig 4a and 4b, Backscatter Coef.

- **Below 3km**: Relative differences generally remain within **±30%.**
- **Night-time (left panel)**: Slightly **less noisy** compared to daytime, especially above 3–4 km.

Fig 4c, Extinction Coef.

- **Below 3km**: Relative differences generally remain within **±30%.**
- High- and low-resolution ATLID profiles show **very similar behavior.**

Result 2: Backscatter and Extinction Scatter Density Analysis

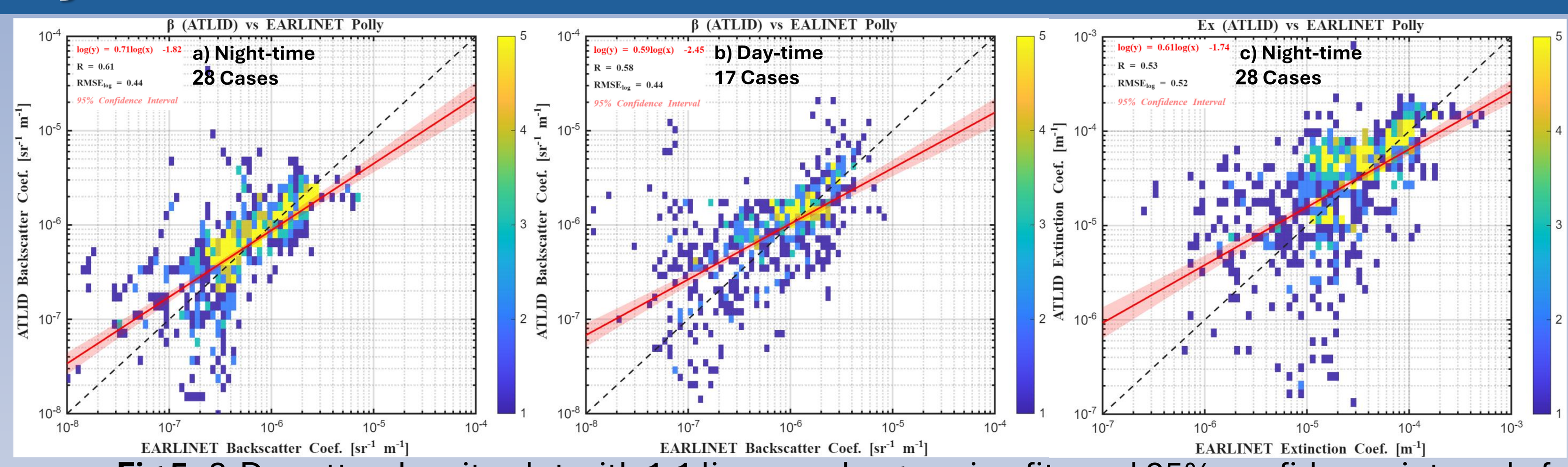

Fig 5- 2-D scatter density plot with 1:1 lines, and regression fits and 95% confidence intervals for backscatter and extinction coefficient.

Fig. 5a

- Main density cluster is located around **10^{-7}–10^{-6} sr^{-1} m^{-1}**, slightly **above the 1:1 line**, indicating a mild **ATLID overestimation** in this central backscatter range.
- Higher backscatter values (≥2 × 10^{-6} sr^{-1} m^{-1}): The regression line falls **below the 1:1 line**, indicating **ATLID underestimation** Earlinet Polly.

Fig. 5b

- At **low backscatter** (<10^{-7} sr^{-1} m^{-1}) ATLID shows more **scatter** and occasionally **stronger overestimation**, a typical effect of increased **solar background noise**.

Fig. 5c

- The main density cluster is located around **10^{-5}–10^{-4} m^{-1}** extinction, where **ATLID and Polly show generally good agreement**.

Result 3: Layer-Resolved Comparison of Optical Properties

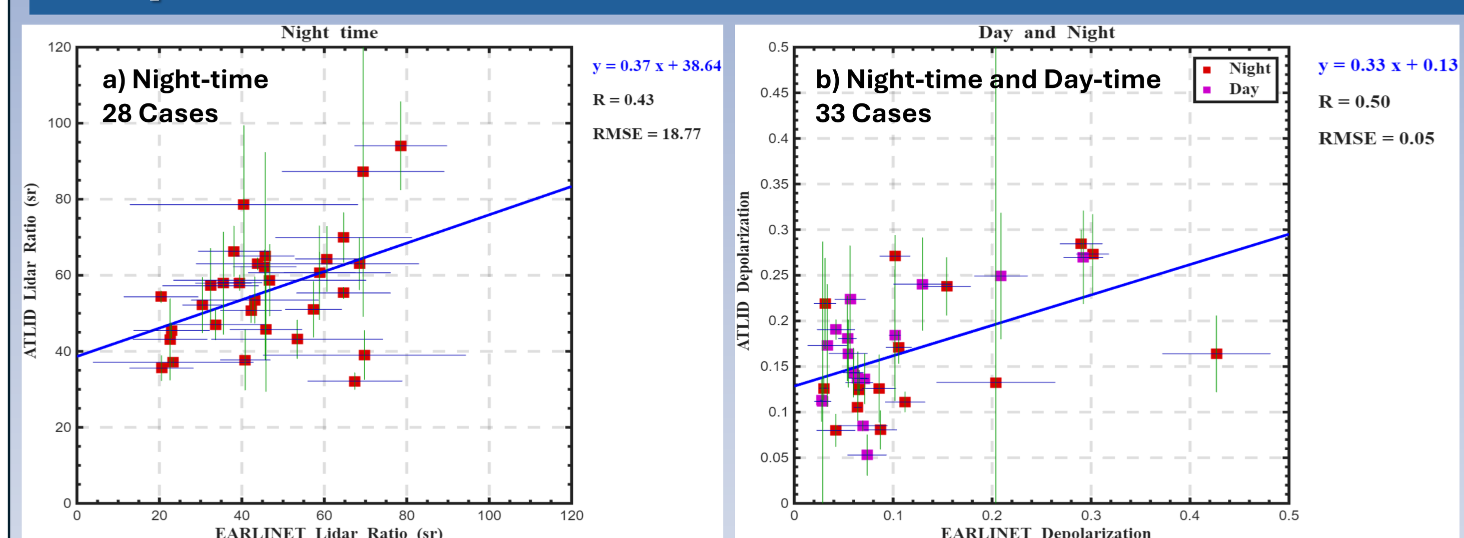

Fig 6- Layer-resolved comparison retrieved from ATLID and EARLINET Polly for
a) Lidar ratio night-time cases,
b) Depolarization ratio For night-time and Day-time cases.

- **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.

Summary

- Relative differences for both **backscatter** and **extinction** show good agreement **below ~3 km**, with mean values typically within **±30%** for both high-resolution (blue) and low-resolution (red) ATLID datasets.
- ATLID aerosol backscatter coefficients and extinction coefficients are close to the EARLINET products and have good linear correlation.
- ATLID lidar ratios exhibit weak correlation with EARLINET (R = 0.43) and tend to be biased toward higher values, especially for layers with EARLINET lidar ratios below ~50 sr.
- The ATLID aerosol linear depolarization ratio is generally higher than the EARLINET particle linear depolarization ratio for low-to-moderate depolarization (<0.20).
- For layers with stronger depolarization (>0.25), ATLID values remain comparable.
- For Depolarization ratio, biases appear in weakly depolarizing layers and mixed aerosol conditions common over the Eastern Mediterranean and need more refinement.

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