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The potential of the ERATOSTHENES CARO National Facility in the EMMENA region: An Holistic Approach for aerosol and cloud profiling over Limassol, Cyprus

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Introduction

Cyprus is strategically located in the region of the Eastern Mediterranean, the Middle East and North Africa (EMMENA). As a crossroad between Europe, Asia and Africa, it is representative of meteorological conditions and coastal areas in the EMMENA region. Therefore, Cyprus, and especially Limassol as a coastal city, can be considered an ideal natural laboratory for advanced and comprehensive field studies on climate change, aerosol-cloud-dynamics-precipitation interaction, and the weather-precipitation-dryness complex [1].

A major challenge in the global understanding of atmospheric processes is the incomplete coverage of ground monitoring stations. Although satellite missions provide continuous regional-to-global observations, their data must be validated with high-resolution ground-based measurements. The lack of a modern supersite in the Eastern Mediterranean, one of the world's hotspots for climate change, limits the ability to monitor pollution, dust storms, and changing precipitation patterns in the region.

To address this gap, a state-of-the-art observational supersite—the Cyprus Atmospheric Remote Sensing Observatory (CARO)—has been established in Limassol. The CARO National Facility (NF) is designed to provide long-term, high-resolution profiling of atmospheric parameters including aerosol, cloud, wind, humidity, and precipitation. Its strategic role is amplified through participation in international satellite validation activities, including the CORAL project, part of the EarthCARE CAL/VAL program.

In addition, to apply a measurement–modelling synergistic approach to address key environmental and atmospheric challenges, CARO's advanced ground-based infrastructure is also leading the ATARRI project (ATmospheric and solAR Research and Innovation in the Eastern Mediterranean). ATARRI aims to strengthen scientific knowledge and innovation and increase the readiness of CARO NF towards supporting cal/val for future satellite missions, as well as supporting, dust modelling and forecasting [2], relationship between aerosol, clouds and solar radiation and modelling in urban areas and Solar energy assessment in different spatiotemporal scales [3]. Selected cases that demonstrate the complex aerosol conditions over Eastern Mediterranean will be presented as well as an intercomparison between EarthCARE products and CARO NF observations.

Methodology

CARO NF allows a holistic approach to atmospheric monitoring through the synergy of multiple remote sensing techniques. By combining lidars, radars, radiometers, and in situ sensors, the facility is able to capture a comprehensive four-dimensional representation of the atmosphere. This integrated strategy is critical for studying aerosol-cloud interactions, understanding the vertical distribution of atmospheric constituents, and validating data retrieved from spaceborne sensors. The inclusion of Doppler lidar data allows for the examination of wind fields and dynamic processes, while the cloud radar and radiometer contribute valuable information on cloud microphysics and vertical humidity structure.

The value of this holistic approach is particularly evident in the context of satellite validation. EarthCARE's instruments, especially ATLID and CPR, rely on ground-based observations for calibration and performance assessment. CARO's instruments provide high temporal and vertical resolution data that fill observational

gaps and offer independent datasets for comparison, thereby enhancing the accuracy and reliability of satellite products.

Results and Discussion

Several atmospheric events recorded during EarthCARE overpasses in 2024, as well as March 2025, illustrate the importance of CARO NF in complex event analysis. During these events, intense dust outbreaks and multilayer cloud structures were observed over Cyprus. Coordinated measurements between EarthCARE's ATLID lidar and the CARO PollyXT lidar enabled the detailed profiling of aerosol layers, including parameters such as backscatter and extinction coefficients, lidar ratios, and depolarization ratios. In the March 2025 event, a particularly dynamic dust transport episode was captured during a cross-path overpass. With wind speeds reaching up to 40 kilometers per hour, dust was transported from the Middle East across Cyprus. The data acquired by PollyXT and the Doppler lidar were instrumental in tracking the evolution and vertical movement of aerosol layers.

The dust layer was identified by elevated particle linear depolarization ratios (PLDRs), ranging between 0.25 and 0.35 at 532 nm, and lidar ratios between 40 and 55 sr, values typical of non-spherical mineral dust particles. The ATLID instrument onboard EarthCARE captured backscatter and depolarization profiles at 355 nm that were highly consistent with the PollyXT measurements.

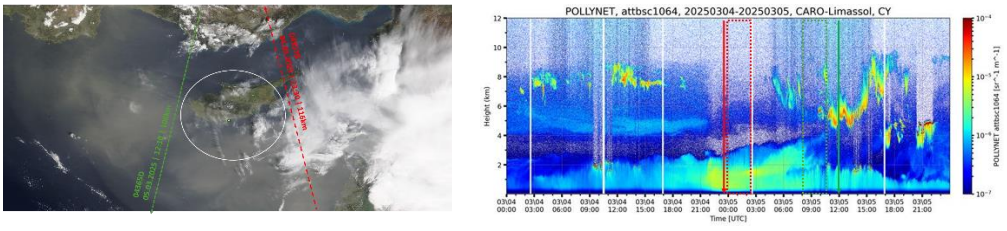

Figure 1. Time–height cross-section of attenuated backscatter at 1064 nm from the PollyXT lidar (left). The red box indicates the period 2–3 hours after the EarthCARE overpass, while the green box shows the period 2–3 hours before the overpass. The map on the left illustrates the EarthCARE overpass ground tracks relative to the CARO location.

Conclusions

The CARO's NF strategic location, advanced instrumentation, and continuous measurement capabilities make it valuable for the validation of satellite missions and the study of complex atmospheric phenomena. By integrating aerosol and cloud measurements with wind and radiometric profiling, CARO offers a holistic approach to atmospheric monitoring. The synergy between its ground-based observations and satellite data enhances the reliability of EarthCARE products, especially in challenging scenes involving high aerosol loading or mixed-phase clouds. Future efforts will focus on expanding CARO's role in international observation campaigns, continuing long-term monitoring, and contributing to satellite product validation.

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