# Synergistic use of ground-based multi-instrument platforms and satellite recordings to investigate the aerosol-cloud-dynamic interaction in Cyprus

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**Keywords:** Aerosol-cloud-dynamic interaction, Multi-instrument platforms, Satellite recordings, Eastern Mediterranean and Middle East and North Africa region (EMMENA).

## 1. Manuscript

### 1.1 Introduction

The exact impacts of aerosol particles on the evolution of the different types of clouds, precipitation, and radiation budget are still the source of the highest uncertainty in assessing climate change with many processes yet to be fully understood. Remote-sensing instruments currently provide the most advanced observations of aerosols and clouds. Passive and active remote sensing instruments on ground-based, airborne, and spaceborne platforms provide different pieces of information on atmospheric aerosols. Each technique alone is subject to indeterminacies that make it difficult to separate the effect of different aerosol parameters such as particle shape, composition, absorption, size distribution, and vertical distribution. So, the synergistic multi-instrument platforms must be utilized to investigate the aerosol and cloud interaction and its impact on cloud evolution. The Atmospheric Cluster of the Department of Climate and Environment of the ERATOSTHENES Centre of Excellence (ECoE) coordinates the Cyprus Atmospheric Remote Sensing Observatory (CARO). In the context of the EXCELSIOR project, the ERATOSTHENES CoE has acquired the aerosol and cloud observational platforms including modern multi-instruments lidar/radar facilities to investigate the complex impact of different aerosol mixtures on cloud formation, in addition to studying the direct and indirect effects of aerosols on radiative transfer and dynamic precipitation generation. This multi-instrument platform is unique with the latest modern standard that is only available in few regions globally. These facilities are used to quantify the different impacts of wildfire smoke, pure and aged in addition to coated mineral dust and urban haze on cloud evolution. Furthermore, CARO actively participates in the EarthCARE satellite validation through the project CORAL (Cyprus Observation for EarthCARE validation), providing ground- truthing observation of the atmosphere's vertical structure. The CARO ground-based high-quality infrastructures with the addition of the new knowledge on modelling related and satellite based atmospheric research through the ATARRI project (ATmospheric and solAR Research and Innovation in the Eastern Mediterranean), will allow a measurement–modelling synergistic approach dealing with major environmental and atmospheric research and innovation aspects.

### 1.2 Measurement site

The CARO is located at Limassol, a coastal city of Cyprus (34.677°N, 33.0375°E, 2.8 m above sea level). Cyprus, located in the most Eastern Mediterranean corner, already exhibits Middle Eastern type of atmospheric and climate conditions. The Mediterranean Basin is well recognized by the IPCC as a hot spot for climate change, the impacts of which are expected to amplify further in the years to come. Cyprus climate conditions, as well as air quality, are strongly affected by a mixture of aerosols (Fig.1a), such as urban haze, originating mainly from urban and industrial activities in the south east Europe, but also from the Middle East and North Africa, by biomass-burning smoke from North (e.g., Black Sea countries), by mineral dust originating from arid regions in Turkey and Middle East deserts (often mixed with anthropogenic pollution), and by Saharan dust from North Africa [1-3]. In addition to the dust aerosols, some studies already have been done to show the long-range transport of wildfire smoke from the strong fire in the United state and Canada toward the Cyprus atmosphere [4-5]. Since Cyprus is an island, marine aerosols play an important role, too. There are very few locations on Earth that experience such complex aerosol structures, vertical layering and mixtures which can dramatically influence cloud evolution, cloud lifetime, and precipitation processes.

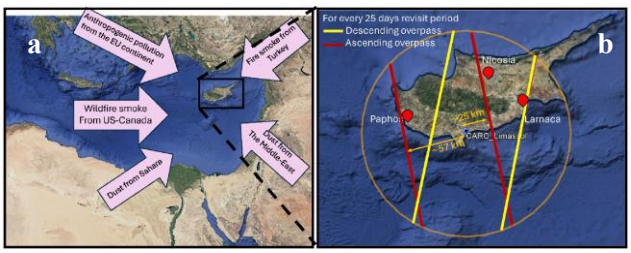


Figure 1. a) Geographical location of Cyprus and most dominant sources which have an impact on its atmospheric pollution, b) The location of the CARO station and EarthCARE descending (yellow) and ascending (red) ground track passing through a 100km around it for each 25 days revisit period of the satellite.

### 1.3 CARO National Facility

The Cyprus Atmospheric Remote Sensing Observatory (CARO) is a National Facility (NF) for remote sensing of aerosol and clouds under labelling procedures to become an ACTRIS National Research Infrastructure facility for Cyprus consisting of the aerosol remote sensing (ARS) observational platform and the cloud remote sensing (CRS) observational platform. CARO is equipped with a state-of-the-art PollyXT Raman lidar (from October 2020) part of PollyNET [7], a Doppler wind lidar (from February 2023), a ceilometer and a disdrometer - Parsivel2 model (since January 2024), a 35-GHz cloud radar of type Mira-35 and a microwave radiometer of type HATPRO since July 2024. The 24/7 CARO will provide a complete high-quality dataset of atmospheric parameters over Cyprus.

| Active sensors in the CARO observatory includes: |
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| A) A multi-wavelength dual field of view Raman polarization Lidar |
| B)A scanning polarimetric cloud Doppler radar (Mira-35) |
| C)A Streamline-XR Doppler lidar (Halo Lidar Snoopy) |
| D)A 1064-nm ceilometer (CHM 15kx) |
| Passive sensors in the CARO observatory includes: |
| E) A 14-channel microwave radiometer (HATPRO G5) |
| F) An optical 1-d precipitation disdrometer (PARSIVEL) |
| G) A CUT-TEPAK AERONET Sun-photometer |
| H) A Radiation station (Sun-traker STR22G, Pyrgeometer) |

Table 1- List of instrumentation operating continuously at CARO

### 1.4 Conclusion

This abstract presents the importance of CARO as a multi-instrument platform, used from combined active remote-sensing measurements of Raman Polarization Polly lidar, cloud radar and doppler wind lidar. This comprehensiveness gives the advantages of performing Closure studies using multiplatform observations and synergies [8-9].

### 1.5 Acknowledgment

The authors acknowledge the 'EXCELSIOR': ERATOSTHENES: EXcellence Research Centre for Earth Surveillance and Space-Based Monitoring of the Environment H2020 Widespread Teaming project (www.excelsior2020.eu). The 'EXCELSIOR' project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 857510, from the Government of the Republic of Cyprus through the Directorate General for the European Programmes, Coordination and Development and the Cyprus University of Technology. The authors acknowledge the ATARRI project funded by the European Union's Horizon Europe Twinning Call (HORIZON-WIDERA-2023-ACCESS-02) under the grant agreement No 101160258.

### 1.6 References

[1]- Mamouri, R.-E. and Ansmann, A.: Potential of polarization lidar to provide profiles of CCN- and INP-relevant aerosol parameters, Atmos. Chem. Phys., 16, 5905–5931, https://doi.org/10.5194/acp-16-5905-2016, 2016.

[2]- Mamouri, R.-E. and Ansmann, A.: Potential of polarization/Raman lidar to separate fine dust, coarse dust, maritime, and anthropogenic aerosol profiles, Atmos. Meas. Tech., 10, 3403–3427, https://doi.org/10.5194/amt-10-3403-2017, 2017.

[3]- Nisantzi, A., Mamouri, R. E., Ansmann, A., Schuster, G. L., and Hadjimitsis, D. G.: Middle East versus Saharan dust extinction-to-backscatter ratios, Atmos. Chem. Phys., 15, 7071–7084, https://doi.org/10.5194/acp-15-7071-2015, 2015.

[4]- Mamouri, R.-E., Ansmann, A., Ohneiser, K., Knopf, D. A., Nisantzi, A., Bühl, J., Engelmann, R., Skupin, A., Seifert, P., Baars, H., Ene, D., Wandinger, U., and Hadjimitsis, D.: Wildfire smoke triggers cirrus formation: lidar observations over the eastern Mediterranean, Atmos. Chem. Phys., 23, 14097–14114, https://doi.org/10.5194/acp-23-14097-2023, 2023.

[5]- Ansmann, A., Ohneiser, K., Mamouri, R.-E., Knopf, D. A., Veselovskii, I., Baars, H., Engelmann, R., Foth, A., Jimenez, C., Seifert, P., and Barja, B.: Tropospheric and stratospheric wildfire smoke profiling with lidar: mass, surface area, CCN, and INP retrieval, Atmos. Chem. Phys., 21, 9779–9807, https://doi.org/10.5194/acp-21-9779-2021, 2021.

[6]- Baars, H., P et. al., An overview of the first decade of PollyNET: an emerging network of automated Raman-polarization lidars for continuous aerosol profiling, Atmos. Chem. Phys., 16, 5111–5137, https://doi.org/10.5194/acp-16-5111-2016, 2016.

[7] Baars, H. et al. (2016): An overview of the first decade of PollyNET: An emerging network of automated Raman-polarization lidars for continuous aerosol profiling. ACP, 16, 5111-5137, doi:10.5194/acp-16-5111-2016, 2016.

[8]- Ansmann, A., Mamouri, R.-E., Bühl, J., Seifert, P., Engelmann, R., Hofer, J., Nisantzi, A., Atkinson, J. D., Kanji, Z. A., Sierau, B., Vrekoussis, M., and Sciare, J.: Ice-nucleating particle versus ice crystal number concentrationin altocumulus and cirrus layers embedded in Saharan dust:a closure study, Atmos. Chem. Phys., 19, 15087–15115, https://doi.org/10.5194/acp-19-15087-2019, 2019.

[9]- Ansmann, A., Ohneiser, K., Mamouri, R.-E., Knopf, D. A., Veselovskii, I., Baars, H., Engelmann, R., Foth, A., Jimenez, C., Seifert, P., and Barja, B.: Tropospheric and stratospheric wildfire smoke profiling with lidar: mass, surface area, CCN, and INP retrieval, Atmos. Chem. Phys., 21, 9779–9807, https://doi.org/10.5194/acp-21-9779-2021, 2021.