

# AEROSOL AND CLOUD REMOTE SENSING OBSERVATION IN LIMASSOL, CYPRUS

*Dragoş Ene*<sup>1</sup>,  
*Maria Poutli*<sup>1,2</sup>,  
*Christodoulos Mettas*<sup>1</sup>,  
*Silas Michaelides*<sup>1</sup>

*Rodanthi-Elisavet Mamouri*<sup>1,2</sup>,  
*Argyro Nisantzi*<sup>1,2</sup>,  
*Christiana Papoutsas*<sup>1,2</sup>,  
*Diofantos Hadjimitsis*<sup>1,2</sup>

*Johannes Bühl*<sup>3</sup>,  
*Patric Seifert*<sup>3</sup>, *Holger Baars*<sup>3</sup>,  
*Albert Ansmann*<sup>3</sup>

<sup>1</sup>Eratosthenes  
Center of Excellence  
Limassol  
Cyprus

<sup>2</sup>Cyprus University of  
Technology  
Limassol  
Cyprus

<sup>3</sup>Leibniz Institute for  
Tropospheric Research  
Leipzig  
Germany

## ABSTRACT

In this paper, we present the new research infrastructure of the ERATOSTHENES CoE for aerosol and cloud remote sensing observations and its capabilities to participate in cal/val activities. The research facility is installed less than 2 km from the coastline of Limassol, Cyprus. The multiplatform for atmospheric research consists of a multiwavelength lidar, 35 GHz cloud radar, a microwave radiometer, and ancillary instruments to become a fully ACTRIS cloud and aerosol remote sensing station. Measurements performed at Limassol's station were already utilized for the validation of the aerosol products of Sentinel 5P and AEOLUS and will be used for the validation of the EarthCARE mission.

**Index Terms**— EMMENA, atmosphere, cal/val, campaigns, spaceborne.

## 1. INTRODUCTION

In the past decades, the number of facilities for clouds and aerosol observations using remote sensing increased considerably, which led to the establishment of dedicated networks, e.g. ARM in northern America [1], and ACTRIS in Europe [2]. However, these networks are not distributed uniformly across the globe, and some regions consist of more dense network stations, while others are not covered by similar research infrastructure. To improve the coverage, dedicated campaigns were organized in remote locations where mobile stations were deployed [3], even to remote locations [4] and [5].

Apart from ground-based instrumentation, during these campaigns, research aircrafts can be deployed [6], to increase the spatial representativeness of the observations. Airborne measurements can cover up to hundreds of kilometers, and can also present in situ sampling, for a more detailed characterization of the atmospheric components.

A further step towards increasing the spatial coverage is represented by the spaceborne measurements, which can offer even global scale observations in a time frame of several days. However, the precision of the spaceborne measurements is limited, and periodic validation of the measurements is a mandatory activity. These activities ensure that the accuracy of the final products is met and that the observations are reliable enough to be further used by the scientific community.

Validation of spaceborne products requires high-quality long-term ground-based measurements. These ground-based measurements can result from fixed stations observation [7], or from dedicated campaigns [8]. Locations of such campaigns are chosen based on limited observations of the region [9], their remoteness, or where local or regional sources have the strongest impact [10].

One of the regions where permanent observation is missing is the eastern part of the Mediterranean basin and the Middle East [11]. Short-term (e.g., PRE-TECT campaign, or Absorbing aerosol layers in a changing climate: aging, lifetime and dynamics A-LIFE) or long-term (e.g., Cyprus Clouds Aerosol and Rain Experiment CyCARE or BACCHUS Cyprus Campaign) campaigns were organized in this region. The observations collected during these intense observation periods provided valuable information about the properties of clouds formed in the presence of dust [12], the impact of dust outbreak on clouds [13], or the ice particle concentration in different cloud types embedded in Saharan dust [14].

The efforts to have a permanent measurement station in this region for aerosol and cloud remote sensing observation will be materialized during the H2020 EXCELSIOR project. The purpose of this paper is to present the newly built site in Limassol, Cyprus, and the preparation for the cal/val activities, including for the future ESA/JAXA joint mission EarthCARE.

## 2. CYPRUS ATMOSPHERIC REMOTE SENSING OBSERVATORY

Within the EXCELSIOR project, was established the Eratosthenes Centre of Excellence (CoE). The Centre operates three departments: Environment and Climate, Resilient Society, and Big Earth Data Analytics. Each Department is structured of additional research areas or clusters. For example, the Environment and Climate Department is divided into four research clusters: Atmosphere, Agriculture, Water, and Land [15].

The Atmosphere Department of the Eratosthenes CoE coordinates the Cyprus Atmospheric Remote Sensing Observatory (CARO). CARO is a National Facility of the Republic of Cyprus and will become an ACTRIS-ERIC Aerosol and Cloud remote sensing observational platform. CARO observations focus on the study of aerosol, clouds, atmospheric dynamic and interaction, and their effect and impact on solar radiation.

Since 2020, a permanent pollyNET [16] station started its operation in Limassol. PollyXT lidar [17] is a multi-wavelength lidar for the 24/7 monitoring of the atmospheric state. The system enables the determination of the particle backscatter coefficient at 355, 532, and 1064 nm and of the extinction coefficient at 355 and 532 nm, allowing aerosol classification and microphysical characterization. In addition, the system operates two polarization-sensitive channels at 355 and 532 nm, to determine the aerosol particle shape from the (particle) linear depolarization ratio, to separate dust and non-dust particles in mixed aerosol layers, and to investigate mixed-phase clouds. Based on the lidar observations, a study published in 2023, presents how wildfire smoke can trigger cirrus formation [18]. Furthermore, lidar measurements were used for the validation of the aerosol layer height product of the Sentinel-5P [19].

From the beginning of 2023, a Doppler wind lidar is in operation, and in the first quarter of 2024, the site will be fully operational to become an ACTRIS Cloud remote sensing station [20].

The station follows the design of the LACROS facility [21]. It is designed to operate as a mobile unit and consists of a multiwavelength polarization/Raman lidar (EARLINET lidar), a ceilometer, a wind Doppler lidar, a cloud radar, a microwave radiometer, a disdrometer, and an AERONET photometer.

Thus, CARO acts as a backbone of the Eratosthenes CoE Atmosphere Department, providing observational data to the other Departments of the CoE. For example, it can provide information about precipitation, information much needed for studies in agriculture, water resources, or landslides. Furthermore, cloud and aerosol observation can be used by the Energy sector of the Resilient Society Department to perform radiation studies.

This example demonstrates the holistic approach of the

Center in terms of Earth Observation using interdisciplinary research areas, combining ground-based with space-born observation, to produce new services and for the Center to become a reference hub in the Eastern Mediterranean basin.

## 3. CAL/VAL ACTIVITIES FOR SPACEBORNE SENSORS

The Eastern Mediterranean Basin is a region of interest in terms of aerosol and cloud observations, hence the number of past campaigns executed in this region with this purpose. The increasing number of wildfires occurring in this region, from South of Turkey or Greek islands, the strong dust intrusions from North of Africa or the Middle East, and the possibility of being associated with cyclons, are just several examples of the potential of location for the cal/val of aerosol and clouds observation.

Currently, CARO is focusing on the cal/val activities for the future ESA/JAXA EarthCARE mission, a mission designed to improve the understanding of the Earth's climate system.

More specifically, the CARO Team coordinates the project *Cyprus Observations for EarthCARE validation* (CORAL), activities and consortium consisting by ERATOSTHENES CoE and the Cyprus Institute. The proposal allows for the minimization of the gaps of the EarthCARE validation program, and among the CORAL activities can be listed the continuous monitoring of the atmosphere's vertical structure in Limassol using CARO instrumentation, collaborating with similar activities in Europe in the framework of EarthCARE cal/val activities. CARO is already involved in several pilot studies organized at the European level, pilot studies with the aim to prepare the stations for the validation of EarthCARE.

The schedule of the CORAL follows the different phases of the EarthCARE mission. The first stage of the proposed validation activities will take place in the first 6 months and will match the Preliminary Validation Results Review phase of EarthCARE. This first stage includes the setup of the instrumentations and the first intercomparison results. Once this stage is completed, the second phase of the project will start and will continue until the end of the proposal. The Long-term Validation Phase includes the following stages on an annual basis: Validation of ATLID, CPR, MSI and BBR retrievals/observations acquired from EarthCARE, and will continue with Radiative closure assessment, and validation of the EarthCARE products.

## 4. CONCLUSIONS

The East Mediterranean Basin is a region strongly affected by dust intrusion, with origins from the African or Middle East deserts. To understand better the atmospheric processes and the relationships between clouds, aerosol, and their impact on

climate change it is essential to have infrastructure that can monitor these processes.

A possibility to study these aerosol-clouds interaction is to use satellite data. However, products derived from space observations, need periodic calibration and validation, a process that requires high-quality ground-based observations.

The newly built observatory using remote sensing instrumentations from Limassol, Cyprus already provides high-quality aerosol observation, and from 2024 will also provide cloud observation. These observations will be used for the validation of the EarthCARE mission but also will be used for a better understanding of the aerosol, and cloud properties, and their dynamics and interaction.

## 5. ACKNOWLEDGEMENT

The authors acknowledge the "EXCELSIOR" project - ERATOSTHENES: EXcellence Research Centre for Earth Surveillance and Space-Based Monitoring of the Environment H2020 Widespread Teaming project ([www.excelsior2020.eu](http://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.

## 6. REFERENCES

- [1] P. Kollias, N. Bharadwaj, E. E. Clothiaux, K. Lamer, M. Oue, J. Hardin, B. Isom, I. Lindenmaier, A. Matthews, E. P. Luke, S. E. Giangrande, K. Johnson, S. Collis, J. Comstock, and J. H. Mather, "The ARM radar network: At the leading edge of cloud and precipitation observations," *Bulletin of the American Meteorological Society*, vol. 101, no. 5, pp. E588 – E607, 2020.
- [2] A. J. Illingworth, R. J. Hogan, E.J. O'Connor, D. Bouniol, M. E. Brooks, J. Delanoé, D. P. Donovan, J. D. Eastment, N. Gaussiat, J. W. F. Goddard, M. Haeffelin, H. Klein Baltink, O. A. Krasnov, J. Pelon, J.-M. Piriou, A. Protat, H. W. J. Russchenberg, A. Seifert, A. M. Tompkins, G.-J. van Zadelhoff, F. Vinit, U. Willén, D. R. Wilson, and C. L. Wrench, "Cloudnet: Continuous evaluation of cloud profiles in seven operational models using ground-based observations," *Bulletin of the American Meteorological Society*, vol. 88, no. 6, pp. 883 – 898, 2007.
- [3] Radenz M. Barja Gonzalez B. Kalesse H. Stratmann F. Bühl J. Teisseire A. Vogl T. Jimenez C. Ohneiser K. Schimmel W. Wex H. Ataei F. Gong X. Floutsi A. Engelmann R. Baars H. Witthuhn J. Ansmann A. Seifert, P. and F. Zamorano, "AEROSOL, CLOUDS, DYNAMICS and their interaction over PUNTA ARENAS, CHILE (53°s, 71°w ): A summary of two years of remote sensing and in-situ observations in the frame of DACAPOPESO," in *American Geophysical Union, Fall Meeting 2020*, 2020.
- [4] H. J. Griesche, P. Seifert, A. Ansmann, H. Baars, C. Barrientos Velasco, J. Bühl, R. Engelmann, M. Radenz, Y. Zhenping, and A. Macke, "Application of the shipborne remote sensing supersite OCEANET for profiling of arctic aerosols and clouds during *Polarstern* cruise ps106," *Atmospheric Measurement Techniques*, vol. 13, no. 10, pp. 5335–5358, 2020.
- [5] D H. Bromwich, K Werner, B Casati, J G. Powers, I V. Gorodetskaya, F Massonnet, V Vitale, V J. Heinrich, D Liggett, S Arndt, B Barja, E Bazile, S Carpentier, J F. Carrasco, T Choi, Y Choi, S R. Colwell, R R. Cordero, M Gervasi, T Haiden, N Hirasawa, J Inoue, T Jung, H Kalesse, S-J Kim, M A. Lazzara, K W. Manning, K Norris, S-J Park, P Reid, I Rigor, P M. Rowe, H Schmithüsen, P Seifert, Q Sun, Y Uttal, M Zannoni, and X Zou, "The year of polar prediction in the southern hemisphere (yopp-sh)," *Bulletin of the American Meteorological Society*, vol. 101, no. 10, pp. E1653 – E1676, 2020.
- [6] A Schäfler, G Craig, H Wernli, P Arbogast, and J D. Doyle et al, "The north atlantic waveguide and downstream impact experiment," *Bulletin of the American Meteorological Society*, vol. 99, no. 8, pp. 1607 – 1637, 2018.
- [7] J. Abril-Gago, P. Ortiz-Amezcuca, D. Bermejo-Pantaleón, J. Andújar-Maqueda, J. A. Bravo-Aranda, M. J. Granados-Muñoz, F. Navas-Guzmán, L. Alados-Arboledas, I. Foyo-Moreno, and J. L. Guerrero-Rascado, "Validation activities of aeolus wind products on the southeastern iberian peninsula," *Atmospheric Chemistry and Physics*, vol. 23, no. 14, pp. 8453–8471, 2023.
- [8] H. Baars, A. Herzog, B. Heese, K. Ohneiser, K. Hanbuch, J. Hofer, Z. Yin, R. Engelmann, and U. Wandinger, "Validation of AEOLUS wind products above the ATLANTIC OCEAN," *Atmospheric Measurement Techniques*, vol. 13, no. 11, pp. 6007–6024, 2020.
- [9] H. Baars, J. Walchester, E. Basharova, H. Gebauer, M. Radenz, J. Bühl, B. Barja, U. Wandinger, and P. Seifert, "Long-term validation of AEOLUS I2b wind products at PUNTA ARENAS, CHILE, and LEIPZIG, GERMANY," *Atmospheric Measurement Techniques*, vol. 16, no. 16, pp. 3809–3834, 2023.

- [10] H. Gebauer, A. A. Floutsi, M. Haarig, M. Radenz, R. Engelmann, D. Althausen, A. Skupin, A. Ansmann, C. Zenk, and H. Baars, “Tropospheric sulfate from CUMBRE VIEJA volcano at LAS PALMAS, transported towards CABO VERDE – lidar measurements of aerosol extinction, backscatter and depolarization at 355, 532 and 1064 nm,” *EGUsphere*, vol. 2023, pp. 1–25, 2023.
- [11] Marinos E, S Michaelides, E Evagorou, K Fotiou, K Fragkos, G Leventis, C Theocharidis, C F Panagiotou, M Mavrovouniotis, S Neophytides, C Papoutsas, K Neocleous, K Themistocleous, A Anayiotos, G Komodromos, G Schreier, C Kontoes, and D Hadjimitsis, “Earth observation in the EMMENA region: Scoping review of current applications and knowledge gaps,” *Remote Sensing*, vol. 15, no. 17, 2023.
- [12] E Marinou, KA Voudouri, I Tsikoudi, E Drakaki, A Tsekeri, M Rosoldi, D Ene, H Baars, E O’Connor, V Amiridis, and C Meleti, “Geometrical and microphysical properties of clouds formed in the presence of dust above the eastern mediterranean,” *Remote Sensing*, vol. 13, no. 24, 2021.
- [13] Radenz M. Barja Gonzalez B. Kalesse H. Stratmann F. Bühl J. Teisseire A. Vogl T. Jimenez C. Ohneiser K. Schimmel W. Wex H. Ataei F. Gong X. Floutsi A. Engelmann R. Baars H. Witthuhn J. Ansmann A. Seifert, P. and F. Zamorano, “The A-LIFE field experiment in the EASTERN MEDITERRANEAN - overview and early,” in *Proceedings from the conference 20th EGU General Assembly*, 2018.
- [14] A. Ansmann, R.-E. Mamouri, J. Bühl, P. Seifert, R. Engelmann, J. Hofer, A. Nisantzi, J. D. Atkinson, Z. A. Kanji, B. Sierau, M. Vrekoussis, and J. Sciare, “Ice-nucleating particle versus ice crystal number concentration in altocumulus and cirrus layers embedded in saharan dust: a closure study,” *Atmospheric Chemistry and Physics*, vol. 19, no. 23, pp. 15087–15115, 2019.
- [15] D Hadjimitsis, G Schreier, H Kontoes, A Ansmann, G Komodromos, K Themistocleous, K Neocleous, S Michaelides, R Mamouri, I Papoutsis, J Bühl, E Schwarz, G Melillos, S Tziortzis, C Danezis, A Nisantzi, C Mettas, C Papoutsas, M Tzouvaras, E Evagorou, A Agapiou, M Miltiadou, A Christofe, M Prodromou, E Loulli, A Yfantidou, M Alverti, V Lysandrou, T Polydorou, P Kyriakidis, N Kyriakides, E Akylas, A Anayiotos, V Ambrosia, M Maranesi, P Zeil, L Halounova, D Barok, and S Cheli, “The ER-ATOSTHENES CENTRE OF EXCELLENCE (ECO) as a digital innovation hub for earth observation,” 2020, vol. 11418.
- [16] H. Baars, T. Kanitz, R. Engelmann, D. Althausen, B. Heese, M. Komppula, J. Preißler, M. Tesche, A. Ansmann, U. Wandinger, J.-H. Lim, J. Y. Ahn, I. S. Stachlewska, V. Amiridis, E. Marinou, P. Seifert, J. Hofer, A. Skupin, F. Schneider, S. Bohlmann, A. Foth, S. Bley, A. Pfüller, E. Giannakaki, H. Lihavainen, Y. Viisanen, R. K. Hooda, S. N. Pereira, D. Bortoli, F. Wagner, I. Mattis, L. Janicka, K. M. Markowicz, P. Achtert, P. Artaxo, T. Pauliquevis, R. A. F. Souza, V. P. Sharma, P. G. van Zyl, J. P. Beukes, J. Sun, E. G. Rohwer, R. Deng, R.-E. Mamouri, and F. Zamorano, “An overview of the first decade of polly<sup>NET</sup>: an emerging network of automated raman-polarization lidars for continuous aerosol profiling,” *Atmospheric Chemistry and Physics*, vol. 16, no. 8, pp. 5111–5137, 2016.
- [17] R. Engelmann, T. Kanitz, H. Baars, B. Heese, D. Althausen, A. Skupin, U. Wandinger, M. Komppula, I. S. Stachlewska, V. Amiridis, E. Marinou, I. Mattis, H. Linné, and A. Ansmann, “The automated multiwavelength raman polarization and water-vapor lidar POLLY<sup>XT</sup>: the next generation,” *Atmospheric Measurement Techniques*, vol. 9, no. 4, pp. 1767–1784, 2016.
- [18] R.-E. Mamouri, A. Ansmann, K. Ohneiser, D. A. Knopf, A. Nisantzi, J. Bühl, R. Engelmann, A. Skupin, P. Seifert, H. Baars, D. Ene, U. Wandinger, and D. Hadjimitsis, “Wildfire smoke triggers cirrus formation: lidar observations over the eastern mediterranean,” *Atmospheric Chemistry and Physics*, vol. 23, no. 22, pp. 14097–14114, 2023.
- [19] K. Michailidis, M.-E. Koukouli, D. Balis, J. P. Veefkind, M. de Graaf, L. Mona, N. Papagianopoulos, G. Pappalardo, I. Tsikoudi, V. Amiridis, E. Marinou, A. Gialitaki, R.-E. Mamouri, A. Nisantzi, D. Bortoli, M. João Costa, V. Salgueiro, A. Papayannis, M. Mylonaki, L. Alados-Arboledas, S. Romano, M. R. Perrone, and H. Baars, “Validation of the TROPOMI/S5P aerosol layer height using EARLINET lidars,” *Atmospheric Chemistry and Physics*, vol. 23, no. 3, pp. 1919–1940, 2023.
- [20] J. Bühl, P. Seifert, A. Myagkov, and A. Ansmann, “Measuring ice- and liquid-water properties in mixed-phase cloud layers at the leipzig cloudnet station,” *Atmospheric Chemistry and Physics*, vol. 16, no. 16, pp. 10609–10620, 2016.
- [21] M. Radenz, J. Bühl, P. Seifert, H. Baars, R. Engelmann, B. Barja González, R.-E. Mamouri, F. Zamorano, and A. Ansmann, “Hemispheric contrasts in ice formation in stratiform mixed-phase clouds: disentangling the role of aerosol and dynamics with ground-based remote sensing,” *Atmospheric Chemistry and Physics*, vol. 21, no. 23, pp. 17969–17994, 2021.