EarthCARE dry-run demonstration with EMORAL lidar

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Abstract: The Opto-Electronics section (TEC-MME) at the European Space Research and Technology (ESTEC) of the European Space Agency (ESA) invested into the ESA Mobile Raman Lidar (EMORAL) to serve for Cal/Val missions. The lidar has been co-developed in a collaborative R&D effort of three research performing organizations (University of Warsaw, National Observatory of Athens, and Ludwig Maximilian University of Munich), and private sector companies (Raymetrics, Licel, Innolas). The current configuration places the EMORAL lidar operated by RS-Lab Team at University of Warsaw in the forefront of ground-based systems for Cal/Val missions and beyond. A set of new functionalities, such as broadband fluorescence and water vapor measurements, together with wavelength-dependent polarization, backscattering and extinction coefficients observations present highly desirable, state-of-art ensemble for near-real-time profiling. During campaigns conducted in different environments (urban, industrial, peatland, rural, mountainous) we collected exclusive sets of quality-assured high-level data products. Therefore, the EMORAL lidar is foreseen to serve as one of the core ESA assets for the upcoming EarthCARE Cal/Val activities.

1. Introduction

The first development of the EMORAL mobile lidar commenced in 2007, driven by a primary purpose to actively participate in campaigns across Europe, contributing to the advancement of European expertise in the domain of Calibration and Validation (Cal/Val) for Earth Observation Program (EOP) missions of European Space Agency (ESA). The EMORAL has been developed to serve as a platform to test and refine atmospheric lidar concepts and technologies, ensuring their effectiveness and reliability in real-world scenarios. Furthermore, the provision of comprehensive datasheets was a key aspect, enabling scientific research and supporting various ESA activities.

Over the years, the EMORAL lidar has undergone several upgrades to enhance its capabilities. In the last (~5) years the lidar was intensely upgraded within the ESA-funded Polish Radar and Lidar Mobile Observation System (POLIMOS) activity coordinated by University of Warsaw. The latest advancements and improvements made to the system were achieved through collaboration between different partners and staff at ESA-ESTEC, UW, LMU, NOA, and Raymetrics. They upgrades of the lidar allow to operate it at even higher level of performance, thus enhancing capabilities for comprehensive atmospheric observations.

The lidar has been extensively utilized in various field campaigns addressing a range of research topics, such as smog, trans-boundary pollution, and biomass burning, which demonstrate the system’s versatility. Notably, EMORAL was deployed within POLIMOS in April-September 2018 and June-August 2019 at the PolWET site of Poznan University of Life Sciences (PULS) located over unique vast peatland environment in Rzecin, Poland and provided long-term observations resulting in several publications of interest to satellite research (e.g. methodology for synergic lidar, cloud radar and microwave radiometer retrieval

[1], atmosphere-ecosystem model with full set of data assimilation at peatland site [2], comparative study of mineral dust properties of long-range transported mineral dust form Sahara [3]). In 2018, a pilot campaign was conducted on the short-term schedule for observations in large Polish city – Kraków, at the premises of Jagiellonian University in collaboration with AGH University of Science and Technology. These observations revealed high usefulness of the use of EMORAL for a dry-ran type short-notice operation in challenging smog conditions influenced by long-range transport of biomass burning from North America and mineral dust intrusions from Northern Africa [4].

The ESA's and JAXA's Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) satellite mission is planned to be launched in May 2024. The atmospheric Earth's observations using satellite-based missions have intense validation needs over a limited time. Validation of the datasets from the satellite missions requires a large network of high-quality ground-based and airborne observations with desired instruments. The EMORAL lidar, as a reference instrument, will have a major input to the successful validation of the satellite data during this mission due to its robustness and mobility, and in connection to this, possibility of reaching different satellite overpasses being a clear advantage in comparison to the non-mobile ground-based lidar research infrastructures.

2. Lidar design

The lidar is currently incorporating a new more powerful Nd-YAG laser, (SpitLight 400, InnoLas, Germany) operating at 1064 nm (nominal 112 mJ), 532 nm (nominal 103 mJ) and 355 nm (nominal 128 mJ), with a repetition rate of 10 Hz and pulse length 5-7 ns, a smaller size Cassegrain-type telescope with primary mirror of 300 mm, and an adjustable FOV within 2-3.6 mrad. We upgraded the detection unit with 16-bits transient recorders (TR40-160, Licel, Germany) used for recording signals by PMTs simultaneously in photon-counting and analog mode, except 1064 nm (analogue detection with APD).

This core modifications (exerted in 2018-2020) to the lidar design allowed us to derive successfully at the main objectives, namely, we improved the minimal range of the overlap down to ~250 to 350 m, we increased spatial (height) resolution to 3.75 m, and thus improved the data quality, while maintaining the overall high lidar performance. The upgraded wavelength separation unit (WSU) enabled detection of signals at eight channels: three elastic Mie channels at 1064 nm, 532 nm, and 355 nm, two depolarization Mie channels at 532 nm and 355 nm, three vibrational Raman channels for nitrogen detected at 387 nm and 607 nm, and water vapor at 407 nm.

In September 2022 we introduced broadband fluorescence channel at 470±50 nm, that is, together with water vapor channel, marking a major advancement in the overall capabilities of EMORAL lidar (see Figure 1, with the wavelength separation unit redesigned).

Additionally, to enhance the safety during the lidar operation, a radar system for detecting the aircrafts/helicopters was installed. Furthermore, there were several improvements made to the van, e.g. additional insolation of the van doors, mounting a more powerful air-conditioning to empower efficient temperature control. EMORAL is fully prepared for an unattended automated remote operation.

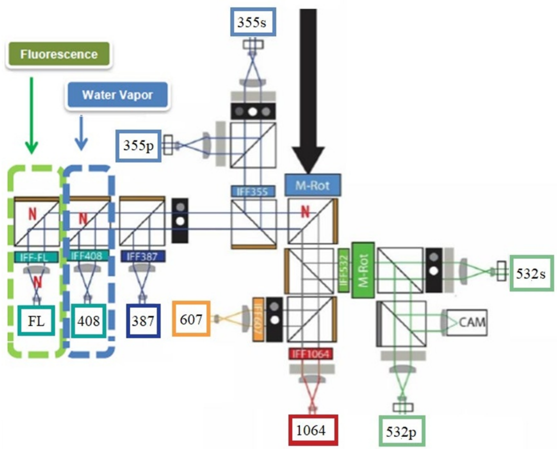

Figure 1 *Schematic design of the current Wavelength Separation Unit (WSU) of the EMORAL lidar.*

Within the last years, the EMORAL has undergone several direct intercomparisons with the reference lidars to ensure the stability of operating performance and the high-quality of observational data. The system was compared on the basis of the dedicated ACTRIS Quality Assurance (QA) tests, at the level of the lidar performance and at the level of the obtained data products. This QA work has been possible thanks to inevitable help of the CARS-ACTRIS at the MARS facility of INOE, Romania.

3. Cal/Val dry-runs

The EMORAL dry-run operation was done in connection to the ESA&JAXA EarthCARE Rehearsal Part 2 activity. The dry-runs took place in February-March 2024. The lidar was transported to five different locations within the territory of Poland, communicated to the RS-Lab UW team at a short notice (3days prior to overpass). Each location was collocated with the predicted EarthCARE orbits; observations were performed within ±3 hours window from the predicted overpass time (see Table 1). Measured data had been uploaded in a fast time (within 24h form measurement) first to the EARLINET Single Calculus Chain (SCC), then after obtaining sets of optical properties profiles of interest, they were submitted to the dedicated repository provided by the ESA Validation Data Center (EVDC). The tests related to the Quality Assurance and Quality Control (QA/QC) had been processed using the ATLAS software provided and recommended by ACTRIS.

Table 1 *EMORAL's dry-runs during Rehearsal Part 2.*

Locations	Overpass (UTC)	Measurement performed
Łowicz (120 m) 41.8261N; 12.6752E	2/24/2024 12:03:47 AM	No (rain)
Ojrzanów (153 m) 52.0113N; 20.7354E	2/27/2024 1:12:54 PM	Yes (low clouds)
Racibórz (212 m) 50.0835N; 18.1909E	3/5/2024 1:19:21 PM	Yes (low clouds)
Tarnów (191m) 49.9747N; 20.9021	3/7/2024 1:08:19 PM	Yes (low clouds)
Złoty Stok (360m) 50.4459N; 16.8861E	3/9/2024 12:17:41 AM	Yes (low clouds)

**altitude in meter above the sea level (a.s.l)*

Measurement data were submitted to the SCC to obtain the low/high-resolution attenuated backscatter (ELIC) for 355, 387, 407, 532, 607, and 1064 nm and the low-resolution optical products (ELDA) for backscatter coefficient (β) at 355, 532, and 1064 nm; extinction coefficients (α) at 355 and 532 nm, as well as depolarization ratio (δ) at 355 and 532nm. The NRT data provision to the SCC are realized within 25 hours from the measurement time of the dry-run. Not all of the data pushed to the SCC were leading to availability of product. Special software (Python scripts) was created for completing the work, namely: script for rapid data conversion and submission for data provision to SCC, script to generate uploading command for data provision to the EVDC repository, and script to assist with ATLAS software, and code for visualization and evaluation of products.

4. Field Campaigns

Apart from Cal/Val activities, the EMORAL lidar took part in the vast range of the filed campaigns aiming at different research topics.

The Ecosystem-Atmosphere campaigns in the peatland environment in Rzecin, Poland (2018, 2019) assessed influence of aerosol abundance and properties on ecosystem functioning and growth production [2].

The Agriculture Dust campaigns conducted in Chwałki (2021) and Głowno (2022), Poland, aimed at capturing local agriculture dust events and examining the properties of aerosols found to significantly differ from Saharan mineral dust particles [3].

The Smog campaigns focused on investigation of the wintertime smog aerosol optical and microphysical properties in highly-polluted Polish cites, Zabrze (2021), Kraków (2018, 2022), and Wrocław (2022) [4], while summertime observations allowed for estimation of properties of photosmog (Warsaw 2019).

The Trans-Pollution campaigns focused on examination of local versus long-range trans-border pollution, combination of in situ and remote sensing data, and assessment of the warm vs cold season in background urban environment of Vilnius, Lithuania (2022, 2023). Results revealed an increase in aerosol optical depth attributed to pollution transfer, and differences in surface/layers/column properties. Moreover, significant insights were gained into the optical and microphysical properties of the observed aerosols [4].

The most recent campaigns, after September 2022, aimed at derivation of new data products: fluorescence backscatter coefficients (β_F) and fluorescence capacity (G_F). Thus, special efforts of the RS-Lab Team at UW were focused on developing novel algorithms that facilitate synergistic evaluation of unique set of signals.

Currently, the EMORAL stand as the only mobile system in the world capable of providing such data. The campaigns that were conducted in Bucharest, Romania (September 2022), Orašac, Croatia (October 2022), Wrocław, Poland (November 2022), and Vilnius, Lithuania (January-March 2023) yield promising first results, shown below.

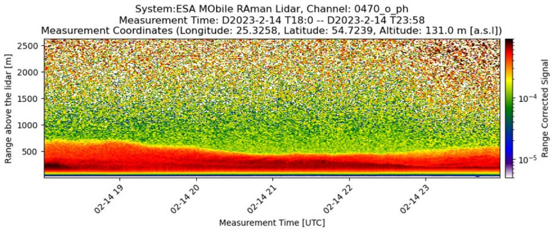

Figure 2 *Temporal distribution of range-corrected-signal from fluorescence channel at 470 nm (pc mode)*

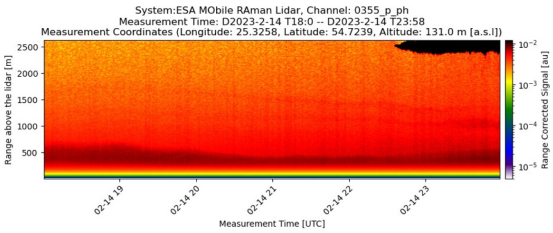

Figure 3 *Temporal distribution of range-corrected-signal from fluorescence channel at 355p nm (pc mode)*

Figures 2 and 3 highlight the differences: the cloud-layer at 2.5 km is not visible in broadband fluorescence channel, while it is observed in the 355p nm (parallel polarized) channel. The layers observed in fluorescence channel are strictly confined to lower altitudes (< 1km), within the boundary layer.

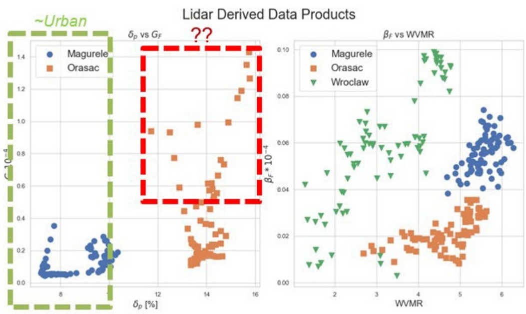

Figure 4 *Fluorescence capacity (G_F) vs particle depolarization ratio (δ_p) on the left and fluorescence backscattering coefficient (β_F) vs water vapor mixing ratio (WVMR) on the righ, obtained from different campaigns: periurban Magurele (RO), urban Wrocław (PL), costal-rural Orasac (CR).*

Figure 4 reveals results for use of the new parameters β_F and G_F for a) aerosol typing (left-hand plot) and b) the water vapor content analyses (right-hand plot). The reference values of δ_p and G_F used as typing parameters in [5] and [6] indicate that Magurele data can be categorized as urbans aerosol. For Orasac data, the G_F values in the range of 0.1-1.4 can be interpreted as sort of mixture of mineral dessert dust, pollen grains, and urban aerosols (however the latter diverging to δ_p criteria).

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5. References

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