EPJ Web of Conferences **362**, 05007 (2026) https://doi.org/10.1051/epjconf/202636205007
ILRC31/CLRC22-2024

Assessing the Ocean Color observation capability of the CALIGOLA mission: the PROTEO project

Dionisi, D.[(a)], Di Paolantonio, M.[(b)], D'Acunzo, E.[(a)], Giuliano, G.[(a)], Liberti, G. L.[(a)], Volpe, G.[(a)], N. Franco[(b)], Andrisani, A.[(c)], Venafra, S.[(c)], Zoffoli, S.[(c)] and Di Girolamo, P.[(b)]

[(a)] *Institute of Marine Sciences, Italian National Research Council (ISMAR-CNR), 00133 Rome, Italy*
[(b)] *School of Engineering, University of Basilicata, 85100 Potenza, Italy*
[(c)] *Italian Space Agency (ASI), 00133 Rome, Italy*

Lead Author e-mail address: davide.dionisi@cnr.it

Abstract: Recently, the use of space-borne atmospheric lidar measurements for the study of ocean color has provided insight into the relevance of the information provided by the lidar technique in this field. The Cloud and Aerosol Lidar for Global Scale Observations of the Ocean-Land-Atmosphere System (CALIGOLA) space mission, conceived by the Italian Space Agency (ASI), will be the first space lidar mission with a focus also on oceanic observation. Within this frame, the PeRfOrmance simulaTor for ocEan Observations (PROTEO) project aims at supporting the CALIGOLA mission by consolidating and extending the scientific and application aspects of the mission, quantitatively assessing its ocean observation capabilities. The core activity of the project is the development of an end-to-end Lidar Performance Simulator (E2E-LPS) for OC measurements with the objective of assessing the specifics of CALIGOLA lidar system and estimating the expected OC performances. An overview of PROTEO is here presented.

1. Introduction

During the last decade, several studies using spaceborne lidar measurement from satellite mission focused on atmospheric observations have unveiled the significant potential of spaceborne lidar measurements in Ocean Color (OC) applications [1-6]. Unlike traditional passive OC satellite sensors, lidar systems can directly estimate the vertical distribution of water optical properties and constituents (e.g., chlorophyll-a concentration, suspended sediments, and phytoplankton biomass) and operate in conditions of low/absent solar illumination. Thus, lidar OC measurements integrate the information obtained from measurements acquired by passive sensors and more important fill the observational gap of describing the depth distribution of these variables and associated bio-geophysical products. This capability allows to better understand and monitor complex oceanic processes, including primary productivity, carbon cycling, and ecosystem dynamics.

The Cloud and Aerosol Lidar for Global Scale Observations of the Ocean-Land-Atmosphere System (CALIGOLA) represents an advanced multi-purpose space lidar mission designed to focus on atmospheric and oceanic observations [7]. Conceived by the Italian Space Agency (ASI), the primary objective of CALIGOLA is to characterize the Ocean-Land-Atmosphere system and explore the interactions within it. Hence, this mission represents a groundbreaking leap in space lidar capabilities, uniquely designed to observe also the ocean subsurface and its characteristics through dedicated receiving channels [7]. This innovation promises to deliver unparalleled data for OC studies, marking a significant advancement in the field [8].

Studies to support the definition of observation, mission and instrument requirements for space lidars have been traditionally carried out based on the support of end-to-end performance simulators [9-11]. The PeRfOrmance simulaTor for ocEan Observations (PROTEO) project has the objective to support the CALIGOLA mission by consolidating and extending the scientific and application aspects of the mission, quantitatively assessing its ocean observation capabilities. For this purpose, two specific numerical simulation tools will be developed:

1) In-water forward model to simulate the lidar signal from the sea surface and below.
2) In-water inversion algorithms to estimate the marine geophysical products from the lidar signal from satellite.

An overview of these components is here presented.

2. In-water forward model

The identified preliminary strategy planned to fully model CALIGOLA in-water signal consists in the development of a modular, portable, integrable and easily updatable set of simulation modules. As the atmospheric components of the simulator have been already developed [7], within PROTEO we will focus on the marine part with the following modules:

- Sea-surface radiative transfer simulation. It includes the representation of: 1) the geometry of the signal and its change when passing from a medium to another one; 2) the geometry and composition of the air-sea interface (sea surface roughness, foam characteristics); 3) all relevant radiative processes.

- In water radiative transfer simulation. It includes the representation of the geometry of the signal, as well as all relevant spectrally dependent radiative processes: absorption, elastic and inelastic scattering, polarization and components' fluorescence.

- Sea-bottom radiative transfer simulation. It includes the representation of the geometry of the signal, as well as all relevant spectrally dependent radiative processes due to the interaction of the signal with the surface.

- Signal background simulation. For this purpose, SCIATRAN [12] radiative transfer model has been identified as possible candidate to simulate radiative processes with natural radiation sources.

3. In-water inversion algorithms

The planned configuration of CALIGOLA, in terms of receiving acquisition channels, consists of:

- 6 elastic co and cross polarized channels at 355, 532 and 1064 nm;

- 2 pure rotational Raman channels at 354 and 356 nm;

- 1 water Raman channel at 405 nm;

- 1 fluorescence channel at 450 nm;

- *1 water Raman channel at 650 nm (optional);*

- *1 fluorescence channel at 685 nm (optional).*

Considering this configuration, the lidar retrieval techniques that potentially could be applied to the in-water sub-surface signals are:

- 1) Elastic Backscatter Lidar (EBL);

- 2) Elastic and Raman Lidar (ERL);

- 3) Depolarization Lidar (DPL);

- 4) Fluorescence Raman Lidar (FRL).

4. Oceanic geophysical variables retrieved

The OC variables retrieved through the mentioned instrumental configuration using these algorithm inversion techniques are:

- the particle back scattering coefficient, b_{bp}, at 355 and 532 nm;

- the diffuse attenuation coefficient, K_d, at 355 and 532 nm;

- the depolarization ratio, δ, at 355 and 532 nm;

- the fluorescence backscatter coefficient, β_{FL}, at 450 and *685* nm, which provides information on the coloured dissolved organic matter, CDOM, and the chlorophyll-a pigment concentrations, respectively.

The observational requirements for the listed CALIGOLA's OC variables will be defined, reviewed and updated based on the results of the described simulation tools developed within PROTEO. This will allow assessing CALIGOLA's actual OC capabilities according to the final instrumental configuration.

5. References

[1] Hostetler, C.A., Behrenfeld, M.J., Hu, Y., Hair, J.W., Schulien, J.A., "Spaceborne Lidar in

the Study of Marine Systems", Annu. Rev. Mar. Sci. 10, 121–147 (2018).

[2] Jamet, C., and Coauthors, "Going Beyond Standard Ocean Color Observations: Lidar and Polarimetry", Front. Mar. Sci. 6, 251 (2019).

[3] Behrenfeld, M.J., and Coauthors, "Global satellite-observed daily vertical migrations of ocean animals", Nature 576, 257–261 (2019).

[4] Lu, X., Hu, Y., Omar, A., Yang, Y., Vaughan, M., Lee, Z., Neumann, T., Trepte, C., Getzewich, B., "Lidar attenuation coefficient in the global oceans: insights from ICESat-2 mission", Opt. Express, OE 31, 29107–29118 (2023).

[5] Dionisi, D., Brando, V.E., Volpe, G., Colella, S., Santoleri, R., "Seasonal distributions of ocean particulate optical properties from spaceborne lidar measurements in Mediterranean and Black sea", Remote Sensing of Environment 247, 111889 (2020).

[6] D. Dionisi, and Coauthors, "Exploring the potential of Aeolus wind mission for ocean color applications", submitted to Remote Sensing of Environment (2024).

[7] P. Girolamo, and Coauthors, "Introducing the Cloud Aerosol Lidar for Global Scale Observations of the Ocean-Land-Atmosphere System: CALIGOLA," in Proceedings of the 30th International Laser Radar Conference, pp. 625–630 (2023).

[8] Behrenfeld, M.J., Lorenzoni, L., Hu, Y., Bisson, K.M., Hostetler, C.A., Di Girolamo, P., Dionisi, D., Longo, F., Zoffoli, S., "Satellite Lidar Measurements as a Critical New Global Ocean Climate Record", Remote Sensing 15, 5567 (2023).

[9] Di Girolamo, P., Behrendt, A., and Wulfmeyer, V., "Spaceborne profiling of atmospheric temperature and particle extinction with pure rotational Raman Lidar and of relative humidity in combination with differential absorption Lidar: performance simulations, App. Opt., 45, 2474-2494 (2006).

[10] Di Girolamo, P., Behrendt, A., Kiemle, C., Wulfmeyer, V., Bauer, H., Summa, D., Dörnbrack, A., Ehret, G., "Simulation of satellite water vapour lidar measurements: performance assessment under real atmospheric conditions, Remote Sensing of Environment, 112, 1552-1568 (2008).

[11] Di Girolamo, P., Behrendt, A., Wulfmeyer, V., "Space-borne profiling of atmospheric thermodynamic variables with Raman lidar: Performance simulations, Optics Express, 26(7), 8125-8161 (2018).

[12] Blum, M., Rozanov, V.V., Burrows, J.P., Bracher, A, "Coupled ocean-atmosphere radiative transfer model in the framework of software package SCIATRAN: Selected comparisons to model and satellite data", Advances in Space Research 49, 1728–1742 (2012).