Proposed by

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Working group title

Lidar for ocean applications

Scientific and programmatic background and rationale

Remote sensing of ocean color from space has been operational since the late 1970s with the proof-of-concept space-borne Coastal Zone Color Sensor on-board the Nimbus-7 satellite (Hovis, 1981). This space mission provided the first estimates of the chlorophyll-a concentration from space (Gordon et al., 1983) and enabled a new era in the study of the interaction of light with optically-active marine constituents (McClain, 2009). Continuous records of ocean color radiometry from space exists since 1997. These long-term space observations were used to study the spatial and temporal distribution of the particulate back-scattering, b_{bp}, (Lee et al., 2002; Loisel et al., 2018; Werdell et al., 2018; Jorge et al., 2021), chlorophyll-a (Matthews et al., 2011, Loisel et al., 2017), suspended particulate matter (Odermatt et al., 2012; Loisel et al., 2014b), colored dissolved organic carbon (Nelson and Siegel, 2013, Loisel et al., 2014a), particulate organic carbon (Tran et al., 2019, Stramski et al., 2022), phytoplankton carbon (Behrenfeld et al., 2005; Bellacicco et al., 2020) and phytoplankton groups in the open ocean and coastal waters (IOCCG, 2014; Cetinic et al., 2024).

However, these measurements are limited to clear sky, daytime, high sun elevation angles, ice-free oceans and are exponentially weighted toward the first few meters of the ocean surface. Moreover, the processing of the ocean color images requires the knowledge (or assumed relationships) of the atmospheric components (gases, air molecules and aerosols), which contributes to around ninety percent of the total signal measured by the remote sensor in the open ocean (IOCCG, 2010; Frouin et al., 2019). Finally, passive ocean color measurements are unable to resolve phytoplankton vertical structure, and this can be a primary source of error in global phytoplankton biomass and net primary production estimates. This means that it becomes highly necessary to use complementary remote sensing techniques for getting a 3-D view of the ocean color.

Among existing remote sensing techniques, lidar (Light Detection And Ranging, an active remote sensing, as it produces its own signal) is particularly promising for ocean applications as it can overcome some limitations of passive remote-sensed observations (Hostetler et al., 2018; Jamet et al., 2019; Behrenfeld et al., 2023). It has the capability to provide vertical profiles of the particulate backscattering and seawater attenuation coefficients. A substantial additional advantage of lidar is that it operates during night-time, thus allowing for a proper exploitation of measurements carried out by polar orbiting missions during the night portion of their orbits, and monitoring latitudes up to 88° North-South. These measurement capabilities are not available from passive sensors and their availability enables profound scientific discoveries including detection of diel vertically migrating zooplankton and polar phytoplankton phenology (Behrenfeld et al., 2017, 2019). Lidar has also been used to identify atmospheric correction errors in ocean color (Bisson et al., 2021a,b) and has been used in tandem with ocean color to retrieve new inherent optical properties (Bisson et al., 2023). Thus, lidar systems have the potential to strongly enhance our observational capabilities for diverse atmospheric and oceanic conditions and climate scenarios and ultimately allow one to obtain a much more complete picture of a number of ocean-related scientific questions.

The application of lidar to ocean studies date back to mid-1970s (Kim, 1973) and early 80s (Gordon, 1983; Hoge and Swift, 1981; Bufton et al., 1983) and has been used for a wide range of oceanic-related studies from airplanes or ships of opportunity, such as fisheries (Churnside and McGillivary, 1991; Gauldie et al., 1996; Churnside and Donaghay., 2009), detection of scattering layers (Churnside, 2014) or vertical structure of the particulate back-scattering and diffuse attenuation coefficients (Hoge et al., 1988, Vasilkov et al., 2001; Yang et al., 2022; Zhou et al., 2022; Zhang and Chen, 2022; Zhang et al., 2023a and references in this article). Pioneered work from Behrenfeld et al. (2013) showed that it was possible to study the particulate backscattering coefficient, b_{bp}, and the particulate organic carbon from the CALIOP space-borne lidar which was designed to study aerosols and clouds.

However, despite those oceanic applications, lidar has not received significant attention from the ocean color community. Several reasons can explain this: cost and size of the instrument, no commercially-available shipborne oceanic profiling lidar, lack of sampling swath and low revisit time frequency for space-borne lidar, few available wavelengths (typically 355, 486 and/or 532 nm), lack of a dedicated space-borne oceanic profiling lidar, lack of training, lack of fully understanding for lidar multiple scattering effect, lack of software and tools to process the data and lack of deep links between lidar observations and ocean color parameters.

The Working Group will provide an overview of the capabilities of lidar technique to study and monitor the upper ocean layer from ships, airplanes and satellites and will discuss its advantages and limitations. An emphasis will be on recommendations and actions needed to be taken in term of training, instrumentations and algorithms development. The IOCCG report series is the perfect venue to reach the ocean color community and to advocate for the use of lidar. There is an urgent need for the ocean color to use lidar as a lidar space mission, CALIGOLA, is in preparation by the Italian Space Agency and NASA for a launch in 2032. This space-borne lidar will have oceanic profiling capabilities and it is urgent to train the ocean color community.

Terms of reference

- To showcase the use of active remote sensing technique, Lidar, for studying the ocean
- To explain and to train ocean color community to the basics of lidar instrumentation and data processing
- To provide sample data and codes for visualizing and processing lidar data
- To provide examples of applications of lidar for oceanic studies
- To discuss the advantages and limitations of lidar to monitor the upper ocean layer
- To provide recommendations and actions for increasing the use of lidar in the ocean color community in term of training, instrumentation, algorithms and good practices
- To prepare a report on lidar for ocean applications with the IOCCG series

Proposed membership

Here the potential participants. Most of them already agreed to participate to the WG.

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Draft timeline

ACTIVITY	0-3m	3m-6m	6m-9m	9m-12m	12m-15m	15m-18m	18m-21m	21m-24m
Refinement of the term of references								
Literature review on lidar applications for the ocean								
Evaluation of the advantages and limitations of lidar								
State-of-the-art of the algorithms for resolving the lidar multiple scattering effects								
State-of-the-art of the algorithms for processing lidar techniques								
Roadmap for training courses on lidar								
Future recommendations and actions								
Prepare-publish a report								

Chapter 1: Fundamentals of lidar

Chapter 2: Glossary

Chapter 3: Instrumentation appendix linked to fourth paper

Chapter 4: Lidar multiple scattering and RTE

Chapter 5: Lidar data processing (how it links, how to find the data, how to process, XXXX)

Chapter 6: Lidar Applications (optical profiling; phytoplankton profiling; bathymetry; fishes; Internal waves; diel observation; polar observation)

Chapter 7: Lidar and ocean color fusion remote sensing (spatial fusion method; spectral fusion method: lidar-based QAA and so on; AI-based fusion method)

Chapter 8: Recommendations