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BEYOND CHLOROPHYLL FLUORESCENCE

The Time is Right to Expand Biological Measurements in Ocean Observing Programs

Emmanuel Boss, Anya Waite, Frank Muller-Karger, Hidekatsu Yamazaki, Rik Wanninkhof, Julia Uitz, Sandy Thomalla, Heidi Sosik, Bernadette Sloyan, Anthony Richardson, Patricia Miloslavich, Johannes Karstensen, Gérald Grégori, Katja Fennel, Herve Claustre, Marcela Cornejo, Ilana Berman-Frank, Sonia Batten, and Silvia Acinas

A new Scientific Committee for Ocean Research (SCOR, <http://www.scor-int.org/>) working group has been formed, entitled SCOR WG-154 "Integration of Plankton-Observing Sensor Systems to Existing Global Sampling Programs (P-OBS, http://www.scor-int.org/SCOR_WGs_WG154.htm). The working group (P-OBS WG) is reviewing biological sensing technologies and measurements that are ready for integration into existing regional and global ocean observing programs. Multidisciplinary sets of measurements, whose choice is guided by research and societal benefit goals, will transform our understanding of ocean biology and its impacts on Earth systems.

The working group is currently considering measurements from two globally co-ordinated ocean observing networks: The Global Ocean Shipped-Based Hydrographic Investigations Program (GO-SHIP), <http://www.go-ship.org/> and OceanSITES, <http://www.oceansites.org/>. GO-SHIP co-ordinates trans-basin ship surveys that are repeated at least once every 10 yr per transect. OceanSITES co-ordinates full ocean depth time series observations from moorings and repeat ship visits. Both programs are represented in the P-OBS WG, along with the Continuous Plankton Recorder (CPR) program, <https://www.sahfos.ac.uk/> (the longest plankton observing system in the world), and the BGC-Argo-Biogeochemical Argo program (BGC-Argo program). BGC-Argo is implementing a global network of profiling floats equipped with bio-optical and biogeochemical sensors. Other P-OBS WG members cover areas such as remote sensing, in situ plankton measurement by imaging, genomics approaches, and biogeochemical modeling.

The P-OBS WG will help the community document the many recent advances in ocean sampling. For example, a global focus on genomic



An example of a flow-through system that could be incorporated on GO-SHIP cruises as one component to study plankton. It includes an automated microscope to capture the community of chlorophyll containing particles (McLane's IFCB), a spectro-fluorometer and fast-repetition-rate-fluorometer (WETLabs's ALFA) to study phytoplankton physiology, a particle sizer (Sequoia Scientific's LISST-100X) and a series of bio-optical instruments (WETLabs' AC-S, ECO-BB3, and CDOM fluorometer) to study the signature of upper-ocean plankton on the ocean color signals measured from space as well as constrain photosynthesis. Ocean water to this system is pumped with a diaphragm pump to minimize the impact on particles and is passed through a thermos-salinograph (SeaBird's TSG) to provide environmental information. This system has been installed around a sink of the R/V *Atlantis* as part of the NASA-funded NAAMES project (Photo credit: Lee Karp-Boss).

sampling of the oceans began with Venter's Global Ocean Sampling Expedition, which targeted surface waters of the North-West Atlantic and Eastern Tropical Pacific (2004–2006). It was followed by the *Tara* Oceans Expedition (2009–2013), which standardized sampling protocols and genomic analysis. Together with the *Malaspina* expedition (2010–2011), these programs dramatically expanded the geographical extent of genetic sampling of the ocean. They sampled temperate coastal and open oceans, the polar oceans, and both surface and deep waters, including mesopelagic and bathypelagic depths. Ocean time-series of genomic data have been expanding rapidly (e.g., Bermuda Atlantic Time Series, <http://bats.bios.edu/>; Integrated Marine Observing System, <http://imos.org.au/>; Hawaii Ocean Time series, <http://hahana.soest.hawaii.edu/hot/>; Carbon Retention In A Colored Ocean, <http://imars.marine.usf.edu/cariaco>; FRAM, <https://www.awi.de/en/expedition/observatories/ocean-fram.html>; and Marine Biodiversity Observation Network, <https://ioos.noaa.gov/project/bio-data/>). These and other programs

have accelerated the availability of genetic data for the oceans. Standardizing, managing, and interpreting these genomic data is an emerging challenge for biologists and oceanographers.

Like genomics, in situ plankton imaging holds great promise. Yet, this approach brings major data demands and a requirement for community consensus. Commercial imaging systems have matured to the point where they are deployed regularly on profiling rosettes, on moorings, and in flow-through systems. These measurements allow high-resolution mapping of organisms and particles which are transforming our understanding of their distribution in the ocean. Pigment data and particulate organic carbon samples are also measured routinely and are being collected in conjunction with validation of ocean color remote sensing and calibration of sensors on autonomous platforms, such as the floats of the BGC-Argo program (many of these floats are deployed from GO-SHIP cruises).

Bio-acoustics and bio-optical sensors are mature technologies used on both moorings and research vessels. While the collection of such

data are now standard, the quality control and interpretation of these data still require significant expertise and no global standards exist. By co-ordinating within these global sampling programs, relevant expertise can be shared to compile Best Practices for plankton observations.

Finally, flow-cytometric analysis of marine water samples is a very powerful tool to detect, discriminate, and quantify auto- and heterotrophic bacteria, eukaryotic micro-organisms, and viruses. It has expanded to include robust commercial ocean-going instruments, including some that can be deployed in situ (with remote control from the lab as-needed), including on moorings and in flow-through systems. Some flow cytometers can sort cells based on optical properties related to their size, granularity, structure (nucleic acid, proteins, lipid content) and physiological characteristics, allowing for further quantification of sub populations of particles. Imaging cells is also possible with some flow cytometers—these pictures can provide morphological characterization of the particles (cells) and enhance identification capabilities, especially for microplankton. Conversion of flow cytometry data to biovolume provides a direct pathway to quantify group-specific biomass.

The advances detailed above motivated the formation of P-OBS WG. Its main charge is to identify best practices (technologies and sampling protocols) allowing the incorporation of plankton-related measurements into global ocean observing platforms (initially GO-SHIP and subsequent expansion into the mooring array of OceanSITES).

Among the challenges that P-OBS WG has identified is the lack of standardization and protocols to perform automated quality control, data formatting, and immediate delivery of validated observations to open-use databases (e.g., OBIS). A major challenge is to prepare such global databases for a quantum jump in data volume once these protocols and data pipelines can be streamlined to deliver data.

Together, we hope to facilitate biological sampling of the oceans and promote more robust, systematic, and routine analyses. These data will establish a baseline from interoperable and comparable datasets, and facilitate the identification of spatial gradients and temporal trends in biodiversity and other key biological parameters. The data are needed to help in the calibration of autonomous platforms, contribute to the validation of remote-sensing algorithms, and constrain biogeochemical and ecosystem models of the ocean. Finally, these data are required to understand and quantify the benefits that the ocean provides to society, and how these benefits are being impacted by global change.

The P-OBS WG seeks help in identifying practical and ready-to-use plankton observation methods that use acoustics, including use of the established Acoustic Doppler Current Profiler on the GO-SHIP and OceanSITES platforms, and other programs. More generally, we invite the oceanographic community to provide information to ensure our findings represent existing and ready-to-use methodologies for plankton observations that could be readily integrated into global sampling programs. Information can be provided to any member of our WG.

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