Summary of Breakout Group #2 "Going beyond HPLC: Coming to rapid consensus on science requirements for assessing phytoplankton composition from satellite imagery"
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This breakout group is a follow-up on previous activities of the international ocean colour phytoplankton composition group's discussion (IOCCG working group 2007-2014; PFT Satellite Group Meetings 2011, 2012 and 2015; breakout groups at IOCS 2013 and IOCS 2015; PFT validation IOCCG WS 2014, ESA CLEO workshop 2016; Ocean Optics Townhalls in 2016 and 2018). These activities resulted in specific reports and peer-reviewed publications summarizing the (to the time of publishing) multiple Phyto-plankton Functional Type (PFT) and Particle Size Class (PSC) algorithms (user guide), their validation and intercomparison, and recommendation (roadmap) for moving further to obtain practical use satellite PFT/PSC products with well-characterized uncertainties (see references provided in Bracher et al. 2017). To advance the objectives of the community, and following the recommendation of the latest satellite PFT roadmap (Bracher et al. 2017), the discussions in the BO were focused on moving beyond the limited uncertainty assessment of PFT algorithms via High Precision Liquid Chromatography (HPLC).

A summary was given outlining the requirements for in situ data validation as well as the pressing need for data integration, which were identified as priorities in past activities. Following a brief discussion of validation program requirements, there were a series of presentations on current regional and global satellite PFT/PSC algorithms, including an assessment of their performance and detection capabilities. This was followed by a discussion of the limitations in properly assessing model uncertainties, and challenges to meet the diverse needs of users. Then a few examples of using synthetic data sets, derived either by simple reflectance forward modelling (e.g. using GIOP) or using in water or coupled ocean-atmosphere radiative transfer, for algorithm development and sensitivity analysis were presented, and the benefit and current limitations of their modelling were discussed. In the last subsection a thorough overview was presented on U.S., Chinese, Australian, Korean, European and international activities or programs in terms of satellite PFT/PSC validation data sets and their integration beyond HPLC.

From the subsections and final discussions, the BO group formulated key gaps and recommendations, as well as short to medium term action items to close these gaps which requires support from space agencies and the IOCCG in terms of providing the funding for enabling the networking and collaboration of in situ experts with algorithm developers as well as data providers and end users. The related workshops and round-robin experiments, will help to facilitate regional and international cooperation to enable the determination of optimal user benefits of satellite PFT/PSC products.

Current gaps for satellite PFTs:
Several key gaps identified in the BO session have remained persistent topics to the community, such as the need for higher spatial and spectral resolution from satellites for nearshore bloom detection, proper characterization of the temporal/spatial/vertical resolution of PFT/PSCs, and to standardization and thorough uncertainty assessment of in situ methodologies. As one of the highest priority gaps revolves around the logistical challenges of properly validating phytoplankton groups, as the optimal ranges of any single in situ instrument does not cover the full continuum of PFTs/PSCs. The discussions identified that using multiple instruments to characterize community composition is best, however, the feasibility of obtaining a globally representative database is daunting, as the collection of an ideal data set can be expensive, time-intensive, and the merging of disparate data sets is not trivial or well understood. Unilaterally translating phytoplankton community composition into a unique optical signal can also be challenging without the use of thorough biogeographical/temporal parameterization to prevent false positives/negatives of groups that may have very similar spectral signatures. Each of the methods for assessing PFT/PSCs (see key observables below) all have distinct advantages and limitations, and face the challenge that each requires different assumptions to link observations of composition to carbon or biomass. Even so, there is no existing frame work for integrating multiple PFT data types into a common

data repository with standard formats, nomenclature, and quality control, which is requirement for robust algorithm development (note, efforts are underway to incorporate imaging data into data repositories). Discussions highlighted critical gaps in the realm of radiative transfer modeling, including the challenges faced in discriminating PFTs in waters with low algal contribution, or dominated by NAP, and that current scattering models are not accurate enough to produce real world phytoplankton-specific b_{bp}.

Key (in-situ) observables to characterize phytoplankton communities:
The following in situ observables comprise the recommended set of observations required to assess the full breadth of phytoplankton community composition and aid in algorithm development:

- Phytoplankton pigments from HPLC, phycobilins from spectrofluorometry
- Phytoplankton cell counts and ID, volume/carbon estimation and imaging (e.g. from flow cytometry, FlowCam, FlowCytobot type technologies)
- Inherent optical properties, Hyperspectral radiometry
- Particle size distribution, Size-fractionated measurements of pigments and absorption
- Genetic/-omics data for evaluation when needed

Recommendations to scientific community and space agencies:

1) To support a comprehensive and systematic analysis to fully understand PFT/PSC signal across wide ranges of water types (biomass, IOP ranges) using unambiguous in-situ measurements of phytoplankton composition and optimal AOP/IOPs, including uncertainties, complemented by an analogous RT study on the water leaving signal.
2) To promote both the standardization and integrated merging of afore mentioned key-observables to enable routine and comparable phytoplankton taxonomy resolving observations and thus the production of viable phytoplankton community metric products. Support in the form of international round-robin experiments, validation exercises, and targeted workshops will be essential.
3) To succeed at enhancing the capabilities of phytoplankton composition IOP measurements, especially improving the characterization of backscattering properties with increased spectral resolution, re-visiting chi factors, further characterizing phytoplankton-specific phase functions, and incorporating non-spherical shape/structure model assumptions).
4) While more abstract, there is a broader need for all members of the community and space agencies to be diligent in continuing to promote and quantify the novel impacts of phytoplankton composition to local/regional/global economies and ecosystems, as well as further assess the specific needs of end-users. This is necessary for the sustained funding of critical research needs.

Short to Midterm Actions:

1) Specialized group activities (require IOCCG support)
   - Novel concept IOCCG working group in a more open way: running blog, open white paper
   - IOCCG Phytoplankton taxonomy protocol
   - Hyperspectral task force
2) Broader community discussion forums (in person) for moving towards consolidation:
3) E.g. specific workshops, or breakout groups /townhalls at larger meetings
4) Agency supported actions:
   - International round-robins for in-situ PFT data integration, representative satellite PFT validation exercise, modelling translation (systematic analysis) of in situ PFT to IOP into numerical model, …
   - Workshop for User information on PFT products and fostering their contribution to in-situ PFT validation by their integrated PFT data sets from regular monitoring activities

All references provided in:

Bracher, A. H. Bouman, R. Brewin, A. Bricaud, V. Brotas, A. M. Ciotti, L. Clementson, E. Devred, A. DiCicco, S. Dutkiewicz, N. Hardman-Mountford, M. Hieronymi, T. Hirata, S. N. Losa, C. B. Mouw, E. Organelli, D. Raitsos, J. Uitz, M. Vogt, A. Wolanin (2017) Obtaining Phytoplankton Diversity from Ocean Color: A Scientific Roadmap for Future Development. Frontiers in Marine Science, 4:55, doi: 10.3389/fmars.2017.00055.