<u>Splinter Session 10:</u> Phytoplankton Community Structure from Ocean Colour: Methods, Validation, Intercomparisons and Applications

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The remote identification of phytoplankton functional types (PFTs) is of interest to Earth system modeling due to the specific impacts of these groups on marine biogeochemistry and food web dynamics. Increasing efforts have been invested internationally to develop ocean colour algorithms to retrieve PFTs using satellite data, providing an opportunity to yield a new operational satellite product. The aim of the PFT splinter session was to bring relevant sciences and scientists together to develop and foster a larger community effort in PFT research, in order for the PFT community to contribute to interdisciplinary science using ocean colour. The session was well attended with lively discussions after each of the five overview talks, and also a final discussion at the end.

The session commenced with Shubha Sathyendranath (PML) reporting on the activities of the IOCCG working group (WG) on "Phytoplankton Functional Types" (http://www.ioccg.org/groups/PFT.html) which was established in 2006 with Cyril Moulin as Chair. Since he had other obligations the chair passed on to Shubha Sathyendranath in 2008. The publication of the WG's report has been delayed because of this and also because the WG wanted to incorporate more recent satellite PFT algorithms. The report will consider the relevance, definition and current understanding of PFTs and will review existing techniques, compare algorithms and show applications including primary production and biogeochemical modelling. It will also conclude with a series of recommendations.

After that Astrid Bracher (AWI/UB) and Nick Hardman-Mountford (CSIRO) gave an overview of most currently available satellite algorithms to retrieve multiple phytoplankton types, based on the response of a call to the satellite PFT algorithm developers to contribute to this talk. Products either show dominance, chl-a concentration or fraction of total chl-a concentration of several PFTs or size classes (PSC). The variety of algorithms ranged from an abundance-based (using satellite chl-a only or empirical relationships via marker pigments) to spectral approaches. The latter are exploiting either reflectance anomalies to determine dominant PFTs, or use size-class specific phytoplankton absorption characteristics (based on their magnitude and slope) or particle backscattering to infer PSC or the particle size classes distribution, respectively. An analytical approach was shown which retrieves the imprints of PFT's characteristic phytoplankton absorption among all other atmospheric and oceanic absorbers from top of atmosphere data of the hyperspectral satellite sensor SCIAMACHY. All other PFT algorithms have been applied to SeaWiFS (sometimes also to MERIS and MODIS).

The lively discussion after this talk clarified that further development of PFT algorithm is currently undertaken and that the techniques vary from fast and simple versus more complex algorithms that provide a direct physiological interpretation of spectral variations, and from purely empirical to (semi-)analytical (by accounting for imprints of PSC or PFTs on radiative transfer, RT). Most techniques shown are global or have the potential for global processing. Several issues were raised during the discussion regarding the basics of satellite PFT methods, in particular in respect to spectral deconvolution and HPLC pigments: Since statistical methods like CHEMTAX apply their decomposition to PFT fractions based on an attribute matrix, the outcome will vary tremendously depending on that matrix. Also, since each species will have a wide range of phenotypic plasticity depending on acclimation status as regulated by light, temperature and nutrients, there simply is not a monolithic matrix that actually can be fully robust at global scale. In parallel, spectral absorption deconvolution can be fraught with challenges since the spectral shape also depends considerably on light, temperature and nutrient acclimation, due both to changes in relative proportions of pigments to each other and also due to pigment packaging effects. Finally, pigment or spectral based methods are a few steps removed from cellular carbon, which is the key basic state variable we would really like to know with respect to its distribution across the PFT classes. Not much has been done to allocate relative biomass of PFT into carbon. Another separate but very important issue is the wisdom of applying a single method globally. For example, the Southern Ocean south of the Polar Front does not have *Prochlorococcus* or *Synechococcus* so applying methods that will allocate part of the community to those classes would not make sense.

The discussion showed that satellite PFT products, since these are inferred properties, need justifying if they are to be considered as an independent observation. The latter comment probably only holds for the part of the approaches, which have other limitations (assume fixed phytoplankton absorption spectra, large footprints of hyperspectral data, application to case-2 waters). Sensitivity tests with RT modeling should clarify the spectral resolution for the top-of-atmosphere radiance or water-leaving radiance data that is needed and how retrievals could be improved by accounting for other variables (e.g. photoacclimation) to detect different PFTs in case-1 and case-2 waters (so far satellite PFTs have been shown to cover case-2 only marginally). Sensitivity tests with RT code has recently been extended to coupled atmospheric and oceanic processes (e.g. COART, SCIATRAN), which should help to quantify errors and validate the algorithms. Several of the algorithms' PFT products have been used in wider applications; mostly for evaluation of biogeochemical / ecosystem models, but also beyond (e.g. inferring oceanic emissions, harmful algal blooms). In order to become operational, these algorithms have to be validated, intercompared and adapted to new sensors in a consistent way. An intercomparison of the first PFT algorithms has been performed (Brewin et al. 2011). Now, a new effort has been started to intercompare and validate most of the more recent algorithms in a consistent way. The next two talks showed the first steps and discussion points for this new initiative.

Lesley Clementson (CSIRO) gave a talk on the task of "In situ/laboratory classification of phytoplankton types – data base: efforts/goals". Within this task group an *in situ* database for the development and validation of robust regional and global PFT algorithms is being built in order to enhance standard global algorithms in the future. Global HPLC data, gathered by an international effort, will be the main base for PFT validation because HPLC is the most commonly used data source in the parameterisation of algorithms and a relatively large number of data points are available in all ocean environments. However, challenges are that the uncertainties involved in the PFT-HPLC data (e.g. different photoacclimation, ambiguous marker pigments), so the HPLC PFT data set needs verification by other *in situ* data. The goal is to produce a database similar to the one currently established by the Australian PFT data base (IOCS Poster by Clementson et al.). This is an interrogative database of bio-optical parameters for Australian waters established by the AEsOP project, funded by the EOI-TCP. The current establishment of the PFT data base is funded, but the long term maintenance is open and it was suggested may be provided by space agency support / hosting.

Taka Hirata (HU) showed intermediate results of the 2nd satellite PFT intercomparisons (still other new satellite PFT algorithms are welcome to participate) and a road map for the later PFT satellite validation. So far, the intercomparison has been done for micro- and picoplankton (PSCs rather than PFTs), which were the only common products among the nine algorithms. The intercomparison is still open to new global algorithms. Generally, optics-based and abundance-based algorithms showed some differences in spatial distribution of PSCs, but our (= satellite algorithm developers) understanding is that the spatial distribution is generally consistent except for higher latitudes (as expected since retrieval of chl-a does not meet minimum standards at these latitudes). Discrepancies between SeaWiFS-based PFTs and SCIAMACHY-based algorithms in mission means were larger than within the SeaWiFS based ones, but generally SCIAMACHY products were showing similar behavior as other spectral based PFT algorithms. Different representations of phytoplankton groups within algorithms (e.g. "Micro" defined by physical size but represented by HPLC (DPA, CHEMTAX), a_{ph}, etc.) may largely explain differences/consistencies within the results. The PFT validation exercise is being planned against in situ PFT from HPLC (as soon as the data base is ready), globally and for time series stations' data.

Cecile Rousseaux (NASA) introduced the MARine Ecosystem Model Intercomparison Project (MAREMIP) which is very interested in satellite-derived PFT products for evaluating model performances. Many activities are currently on-going. She showed results of an exercise of the comparison of satellite (Hirata et al. 2011) and NOBM model phytoplankton groups which will help NOBM model parameterizations (Rousseaux et al. 2013 BGD). The future plan is to assimilate the satellite PFT data as is already done now in NOBM for total chl-a from SeaWiFS.

Finally, the discussion raised the following **important issues** which resulted in recommendations of actions that require funding on a broad international level:

Efforts need to be made to establish the robustness and limitations of these algorithms. In order to do so the limits on detection of PFTs and the errors in the products have to be determined. Areas for future activity include checking how many PFTs can be separated with optical methods using improved RT models and what spectral resolution for atmospheric corrected or not corrected spectra is necessary for the satellite input data. In that respect, the signal-to-noise ratio at which remotely-sensed radiative properties can be retrieved which will be a crucial issue if we aim at detected subtle changes in their spectral signature to identify PFTs. There should be at the least be some consideration of IOP budgets e.g. better understanding of the relative contribution of phytoplankton to the absorption and backscattering budgets across water types, biomass ranges, dominant assemblages etc.; this being a critical first step in understanding reflectance causality with respect to assemblage variability. It is important to also take into account the sensitivity studies of other aspects influencing the optical characteristics of PFTs, e.g. a change of signal due to physiology (photoacclimation). Further effort is required to intercompare the products and validate them in a consistent way (requiring more in situ data acquisition). The 2nd international intercomparison task group has been formed but with no direct funding and so progressing slowly.

Efforts have to be made to have PFT/PSC products ready for applications. For global large-scale biogeochemical and ecological research many current algorithms have shown potential to be used to study changes, variability and trends of phytoplankton types, but for coastal applications (coastal management, fisheries,…) algorithms still require development. This is very challenging as, in addition to much more complex optics in those waters, the time scale of changing PFTs composition is much shorter than in the open ocean. So far the PFT satellite data sets start in 1997 (with SeaWiFS) providing a 10-15 year data set that needs extending to investigate longer-term changes, i.e., through the incorporation of upcoming missions. New missions may also be able to extend the range of PFT products due to improved spectral, temporal and spatial resolutions. The above mentioned sensitivity studies will further clarify the requirements for new sensors in respect to the retrieval of PFTs. It was also discussed that the earth system modelers prefer other units than chl-a (e.g. carbon concentration, productivity, nitrogen), but that modelers would rather make their own conversions was also proposed.

<u>Recommendations to the Agencies</u>:

1. Agencies should support PFT algorithm development, validation and intercomparisons as well as activities to merge different techniques and multi-mission data sets, in order to develop a new “standard product” of ocean colour.
2. The development of PFT methods (including radiative transfer modelling to hyperspectral data sets) should be supported with relevant *in situ* measurements from ships, gliders and buoys.
3. Simultaneous collection of *in situ* HPLC pigments, other PFT parameters which identify size, groups and functions (e.g. size-fractionated Chla, particle size distribution etc.) and optical data are essential for validating PFTs from current and upcoming satellite missions.
4. The validation of HPLC-PFT data sets should be supported by all agencies: a single method may not be globally applicable.
5. Optical and pigment methods used to discriminate PFTs should be linked for a better understanding of actual community structure using imaging flow cytometry and

genetics. Better methods to allocate cellular carbon across the PFT categories should be defined.

References:

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