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Working group title:

Ocean primary production from space

Scientific and programmatic background and rationale

Increasing CO_2 and other greenhouse gases (GHGs) emissions are causing significant changes to our planet's climate with cascading impacts on both natural and human systems. During 2008–2017, global anthropogenic carbon emissions increased every decade from an average of 3.1 Gt C/yr in the 1960s to an average of 9.4 Gt C/yr today. The consequent increase in extreme events (e.g., floods, heat waves, forest fires and storms) caused by the build-up of CO_2 and other GHGs in our planet's atmosphere, have prompted national, state, local governments, and international agencies, to accelerate plans and policies to reduce GHG emissions drastically and attain net neutral carbon emissions by 2100.

The oceans are huge sink for anthropogenic CO_2, and an important means by which CO_2 is stored in the oceans is via marine phytoplankton photosynthesis. Although a significant fraction of this newly produced organic carbon is remineralized as it sinks, the portion of organic matter that survives grazing and bacterial metabolism and is exported to the ocean floor, becomes a long term sink for anthropogenic CO_2. In the absence of primary production and carbon export to the ocean floor, atmospheric CO_2 would have been ~200 ppm higher than at present raising average global temperatures by ~2^{o}C.

However, despite the ocean's critical role in balancing C between the ocean and atmosphere, the economic significance of the ecosystem service provided by phytoplankton photosynthesis is poorly represented in carbon policy and management narratives. While stocks and flows of carbon in the ocean have been identified and described in broad terms, there is large uncertainty in current estimates of primary production (PP) as shown in Figure 1. This has led to a great deal of uncertainty in future projections of atmospheric CO_2. The IPCC report (2019) indicates that the oceans capacity to sequester atmospheric CO_2 and the strength of the biological pump will diminish due to density stratification of the upper ocean, but this projection is also fraught with uncertainties. None of the IPCC projections address accuracy of current estimates of global PP, and there is no effort to understand and assess the scientific value of reducing their uncertainties, or to understand the socio-economic costs associated with a potential reduction in the global ocean's carbon sequestration service. It may be noted that most monitoring, reporting and verification (MRV) activities by Paris Climate Agreement signatories are focused on land or shoreline systems, and the oceans carbon cycle has received very little attention within the carbon accounting framework. Here, we contend that policy responses that do not account for uncertainties in oceanic PP estimates, could muddle efforts to reduce carbon emissions to achieve carbon neutrality by 2050 and minimize CO_2 abatement impacts. We argue that reducing uncertainties in PP, and better predictions of the long-term consequences of climate change on PP and carbon export would aid governments and institutions in crafting policies and frameworks for adaption and CO_2 abatement required to constrain planetary temperature increases.

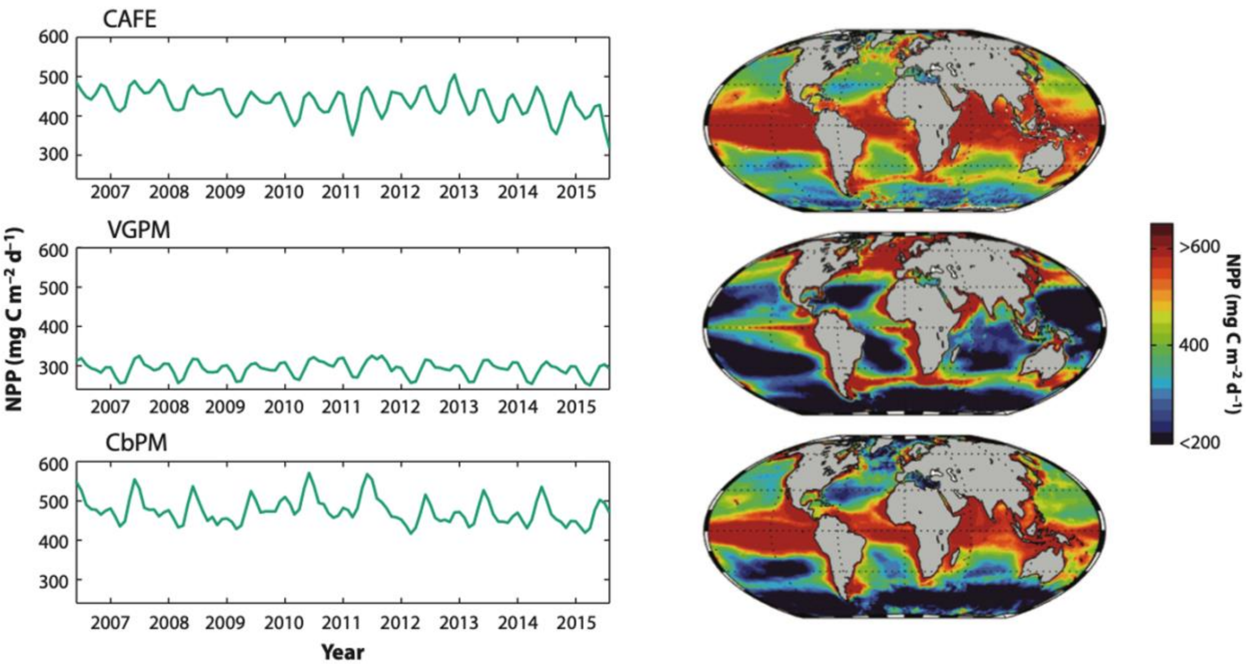

Figure 1 (taken from Siegel et al. 2023 https://doi.org/10.1146/annurev-marine-040722-115226). Comparison of satellite data products for PP (in this case net primary production, NPP). CAFE represents the Carbon, Absorption, and Fluorescence Euphotic-resolving model; VGPM the Vertical General Production Model; and CbPM the Carbon-Based Productivity Model. All models were driven by MODIS-Aqua ocean colour observations.

In addition to its key role in the ocean carbon cycle, PP plays a fundamental role in channeling energy from the sun into the marine ecosystem, where it propagates to higher trophic levels and to humans through seafood consumption. In fact, PP is thought to be a good proxy for seafood production and its associated economic performance (see Marshak & Link, 2021, https://doi.org/10.1038/s41598-021-91599-0). Reducing uncertainties in PP has implications for global seafood sustainability and food security.

Given the vast size of the global oceans, the only viable means of monitoring the spatial and temporal variations of oceanic PP is via remote sensing by satellites. Over the past few decades, based on over two decades of ocean-color satellite data and other measurements, various estimates have been achieved on the drawdown of CO_2 via this biological pump, with annual global PP estimates in the range of ~35-70 GT/year. There is also significant disagreement among models on the direction of change in the global ocean's PP in response to increasing CO_2 levels and warming, casting doubt on its use for assessing the response and feedback of ocean's primary producers and the biological pump to climate change. To address some of these critical issues, with an overarching objective to get the other carbon-related communities to recognize and appreciate the importance of estimating global PP and the biological pump via ocean color measurements, we propose to form a Working Group under IOCCG focusing on the remote sensing of PP.

With carbon MRV becoming central to global carbon accounting and carbon reduction efforts by national, regional, and international agencies, the establishment of this Working Group, with its goals to improve the accuracies of, and reducing uncertainties in, oceanic PP estimates from space, assumes special significance. Among the central requirements for improving the accuracy of existing PP algorithms, or for developing a new generation of algorithms, are: 1) large-field PP estimates from a diverse range of oceanic water types and ecosystem states, and 2) improvements in satellite estimates of PP algorithm inputs. Traditional approaches to measurements of PP at sea such as those based of ^{14}C-, ^{13}C and oxygen, continue to fall short in fulfilling the first requirement.

The Working Group will discuss and evaluate new methods and novel manned and unmanned technologies for measuring PP at sea and approaches designed to harness multi-spectral and hyperspectral ocean color datasets anticipated from new missions such as PACE, GLIMR , Sentinels, EnMap, CHIME, EarthCARE etc. Although addressing these shortcomings will benefit from inputs from primary productivity researchers scattered world-wide, currently there is no international agency available or an international mechanism to support this effort. Given its central role in coordinating various facets of ocean color research and fostering collaborations worldwide, the IOCCG is an ideal platform for connecting disparate international projects/work and bringing scientists together to advance the discipline. It may be noted that although estimating PP is a big theme within IOCCG, and featured as a subthemes to some IOCCG reports (e.g., in Synergy between Ocean Colour and Biogeochemical/ Ecosystem Models), there has not yet been an IOCCG report dedicated to the theme. Our proposal is also timely, considering the recent release of an IOCCG Protocol Series *Volume 7.0: Aquatic Primary Productivity Field Protocols for Satellite Validation and Model Synthesis* (September 2022). There is an urgent need for consensus on harnessing lessons learned from recent large multi-institutional and multi-disciplinary programs such as EXPORTS, NAAMES, BICEP, MAPPS, POCO etc., long-term observational programs such as HOT, BATs, AMT, CARIACO, LTER etc., and the standardized protocols for developing field datasets, to improve the accuracy of satellite PP estimates.

Terms of Reference

- Compile a match-up database of concurrent and co-located in-situ PP data and satellite ocean-color measurements and identify data gaps.
- Summarize the advantages and limitations of the various PP algorithms and identify pathways for improving PP estimates from satellites.
- Obtain ensemble estimates of global PP of the past two decades with the latest-revised/updated PP algorithms and satellite products.
- Provide a thorough/in-depth account on the sources/magnitude of uncertainties (building on IOCCG report 18 *Uncertainties in Ocean Colour Remote Sensing*) in satellite PP estimates and their economic value.
- Discuss potential new technologies for in-situ PP estimates (e.g., IOCCG report 11 *Bio-Optical Sensors on Argo Floats*), associated uncertainties as well as approaches for overcoming challenges.
- Provide recommendations and action for improving PP/biological pump remote sensing.
- Discuss and assess the socio-economic costs associated with inaccuracies of PP estimates.
- Prepare/publish a report on ocean PP from space within the IOCCG series.

Working Group Members

To be successful, it is important to have international participation and collaboration. Tentatively we have identified several international experts, and they will be invited immediately (some were already contacted) should this working group be approved.

Timeline

A tentative timeline for activities is provided below

Activity	Month							
	1-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24
Matchup in-situ PP data and satellite ocean-color measurements								
Document advantages and limitations of the various PP algorithms								
Ensemble estimates of global PP for the past two decades								
Quantify uncertainties in satellite PP estimates and their economic value								
Review potential new technologies and approaches for overcoming challenges								
Future recommendations and socio-economic costs								
Prepare/publish a report								