Uncertainty Estimates for Satellite-based Computations of Marine Primary Production

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esa
BICEP Biological Pump and Carbon Exchange Processes
cbiomes Simons Collaboration on Computational Biogeochemical Modeling of Marine Ecosystems

References
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Introduction

In the latest IPCC report, low confidence in satellite-based estimates of trends in marine primary production (PP) was expressed, citing the insufficient length of the time series as well as the lack of independent validation methods. Independent validation of basin-scale PP estimates is compromised since all available *in situ* photosynthesis-irradiance and chlorophyll-profile parameters are used with remote sensing data for the modelling of PP (Figure 1) . Direct, *in situ* PP measurements (not used in remote-sensing) would constitute an independent dataset for validation, but temporal and spatial coverage is poor.

In this study, we address the uncertainty in satellite-based PP estimates (Kulk et al. 2020, Sathyendranath et al. 2020) by assessing the errors inherent to the calculation, in which each element is considered individually, and then integrated. By doing this on a pixel-by-pixel basis, we can address the uncertainties in PP at regional scales and pinpoint regions where more *in situ* and remote-sensing data are needed to improve the confidence in satellite-based estimates of trends in marine PP.

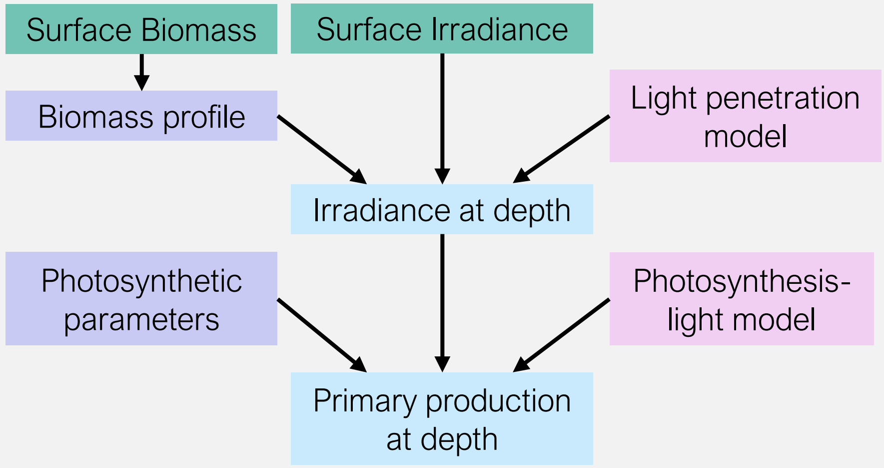

Figure 1. Schematic diagram of the spectrally resolved and fully coupled primary production model first published by Platt & Sathyendranath (1988) with input from satellite (green) and in situ (purple) observations that are used in a light penetration and light-photosynthesis models (pink) to compute irradiance and primary production at depth (blue). (Figure simplified from Sathyendranath et al. 2020)

Method

To assess uncertainty of satellite-based PP estimates, we follow the validation approach described in the Guide to the expression of Uncertainty in Measurement (GUM):

1) A model is formulated that describes the relationship between the input and output quantities (Box 1);
2) The standard error of the mean in each of the input quantities – photosynthetic parameters, phytoplankton biomass and light – is calculated;
3) The errors are propagated through the model to obtain the uncertainty in PP.

Here, we present the error in photosynthetic parameters from an *in situ* database (Bouman et al. 2018, Kulk et al. 2020) and the combined error in Chlorophyll-a (Chl) from the Ocean Colour Climate Change Initiative (OC-CCIv4.2) and the light attenuation coefficient (Sathyendranath & Platt 1988). Assuming a 10% error in the light field (Platt et al. 1995), we provide a first estimate of PP uncertainties by propagating the errors through the model for May 2010, as an example.

Model for total water-column primary production (P):

$$P = f(P_m^B, B, D, K, I) = \frac{P_m^B B D}{K} f(I_*^m),\text{ where}$$

P_m^B is the assimilation number,
B is phytoplankton biomass,
D is the day length,
K is the attenuation coefficient, and
$f(I_*^m)$ is a function of scaled dimensionless irradiance at local noon, I_m^*.

In the model, K is a function of B such that errors in B will affect K in the same direction. Since B is divided by K, some of the errors will cancel out and we will consider the combined error of K and B. We also assume there is no error in D.

Box 1. Details of the model formulated for the estimation of uncertainties of satellite-based primary production products. This represents the first three steps of the uncertainty evaluation in the Guide to the expression of Uncertainty in Measurement (GUM).

Input quantities

Error in photosynthetic parameters

Standard error of the mean in the photosynthetic parameters ranged between 0.11 and 64.3% among Longhurst's biogeographic provinces and was on average 9-10% for all seasons. Error estimates in spring illustrated the regional differences, with higher values in the central Pacific Ocean (Figure 2). Errors associated with the extrapolation of the photosynthetic parameters to larger scales was earlier estimated to be 7% (Platt et al. 1995).

Error in phytoplankton biomass

The combined standard error of the mean in Chl and the light attenuation coefficient was on average 4.3-22.5% per pixel between 1998-2019 (Figure 3). Error estimates decreased over time with the introduction of various new satellite sensors, illustrating the importance of the number of observations in reducing uncertainties in both Chl observations and satellite-based PP estimates.

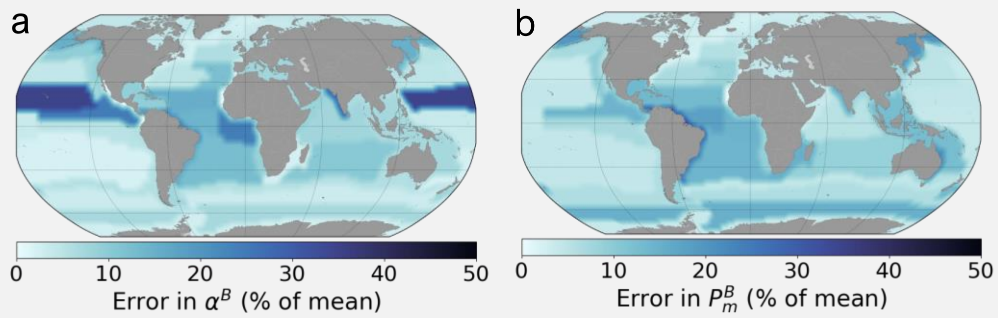

Figure 2. Maps of the standard error of the mean in a) the initial slope (α^B) and b) the assimilation number (P_m^B) of the photosynthesis-irradiance curve for spring (March-June).

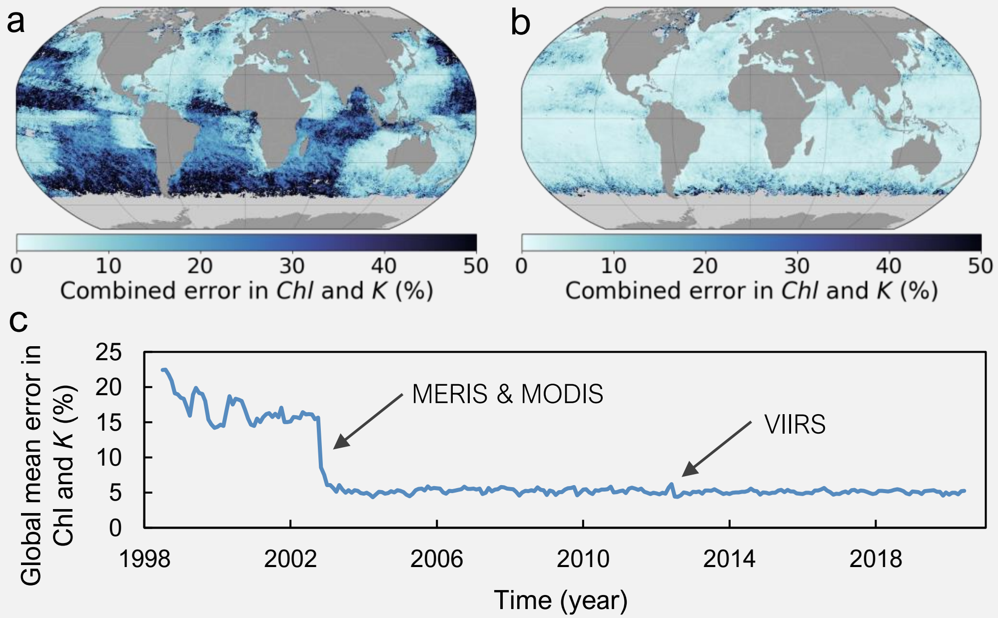

Figure 3. The combined error in Chlorophyll-a (Chl, OC-CCIv4.2) and the attenuation coefficient (K), mapped for a) May 1998 and b) May 2010; and provided as c) a global mean time series. The launch of different ocean-colour sensors are also indicated in c).

Error propagation

We propagated the errors by evaluating the combined uncertainty $u_c(P)$ of each model input quantity using $f(P)$:

$$u_c(P) = \sqrt{u_{P_m^B}^2 + u_{B/K}^2 + u_{f(I_*^m)}^2},$$

assuming a 10% error in the light field. A first $u_c(P)$ estimate for May 2010 showed that uncertainty in satellite-based PP was on average 16%, with highest uncertainty in coastal regions (Figure 4).

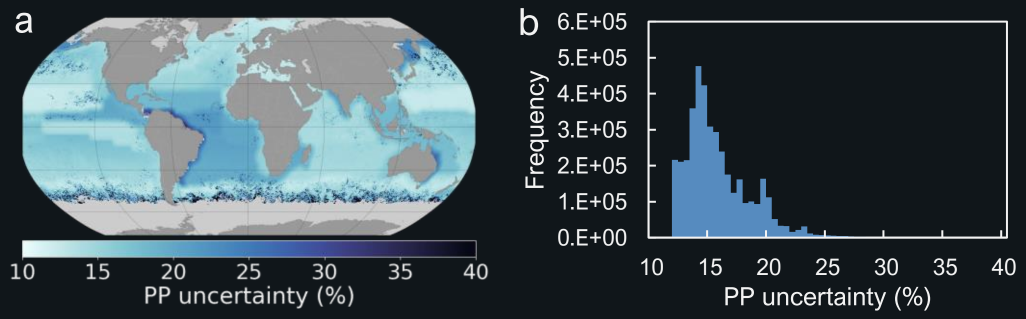

Figure 4. First results of the error propagation for $f(P)$ with a a) map and b) histogram of the combined PP uncertainty for May 2010.

Next steps

To complete our uncertainty analysis, we will:

- Determine the error in the light field,
- Propagate the errors by evaluating the combined uncertainty of each model input quantity for 1998-2021.

We also plan to numerically evaluate the uncertainty by calculating the change in PP due to changes in the input variables ± error using the full PP model (Kulk et al. 2020, Sathyendranath et al. 2020).