A budget for biological pools and fluxes of carbon in the oceanic mixed layer

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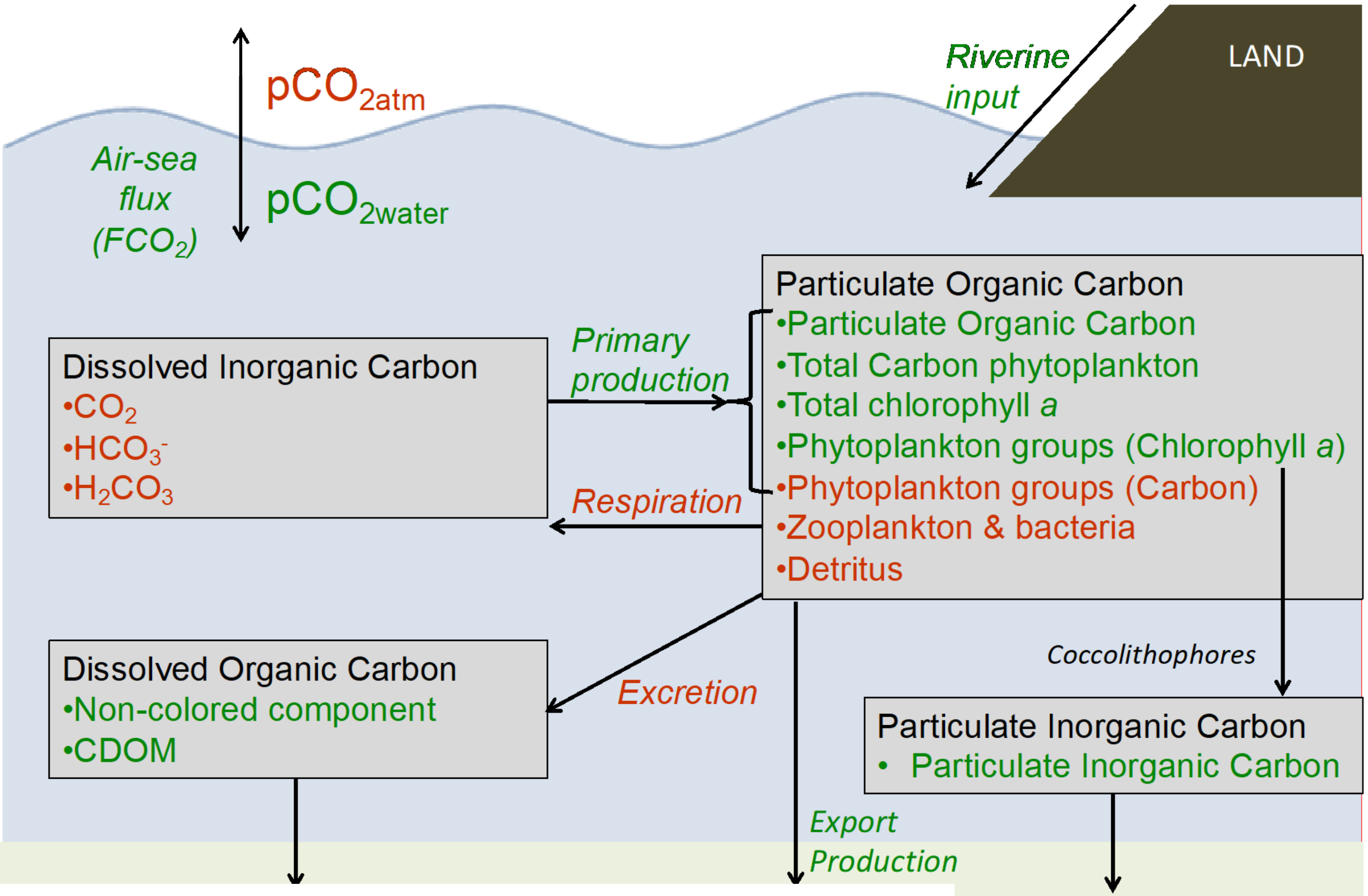
Simons Collaboration on Computational Biogeochemical Modeling of Marine Ecosystems

BICEP
Biological Pump and Carbon Exchange Processes

Ocean Pools and Fluxes of Carbon



- Green components: amenable to remote sensing
- Components not yet accessible to remote sensing

Figure courtesy of C.S. Rousseaux & W.W. Gregg

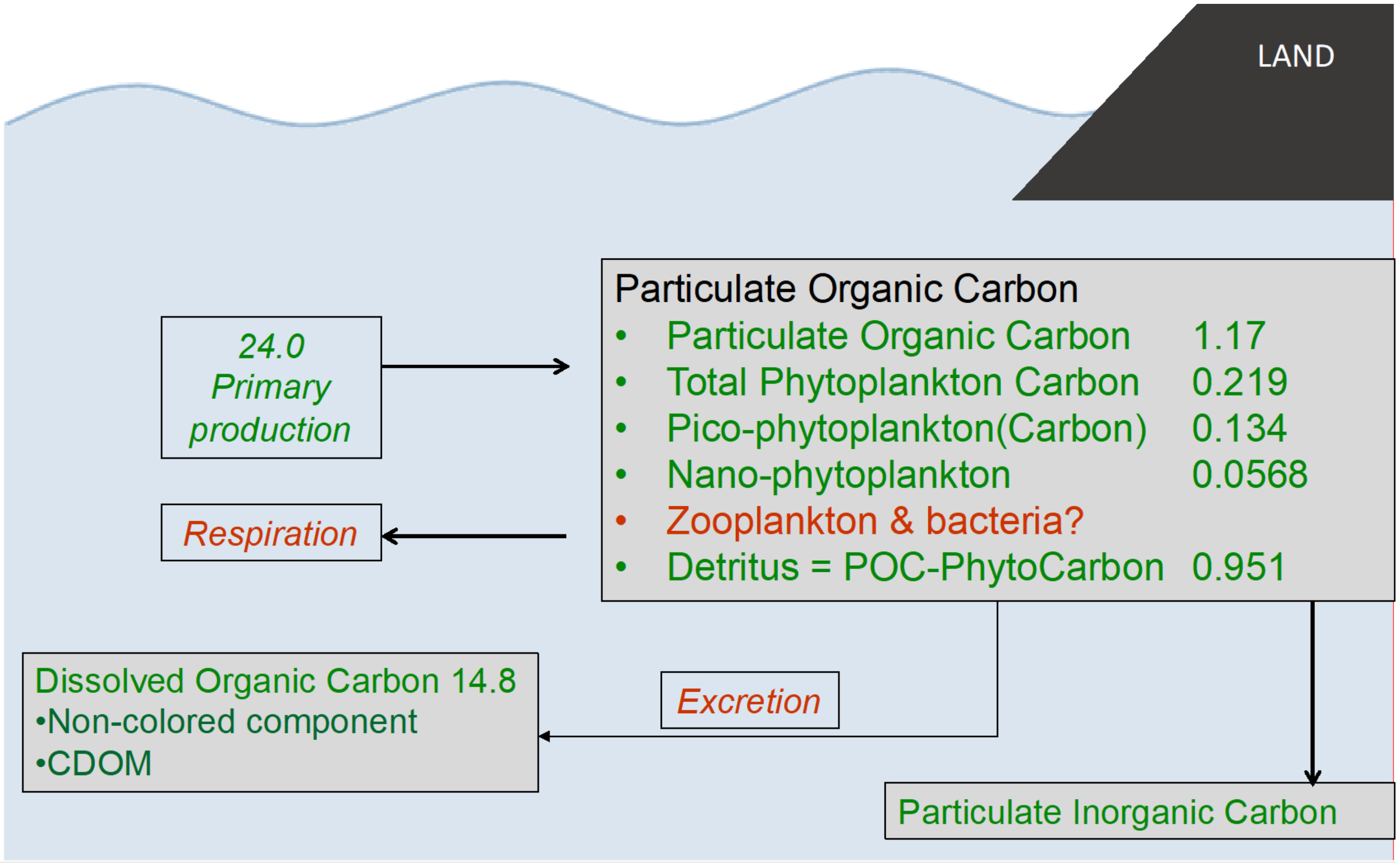
CEOS Carbon Strategy Report (2014) has identified many pools and fluxes of carbon in the ocean that are accessible to remote sensing.

But there are gaps as well.

What can be done to fill the gaps?

Can we arrive at a satellite-based carbon budget for the oceans?

Organic Pools and Fluxes of Carbon



- Green components: amenable to remote sensing
- Components not yet accessible to remote sensing

Eight years later:

We are in a position to discuss a satellite-based budget of the biological pools and fluxes in the mixed layer.

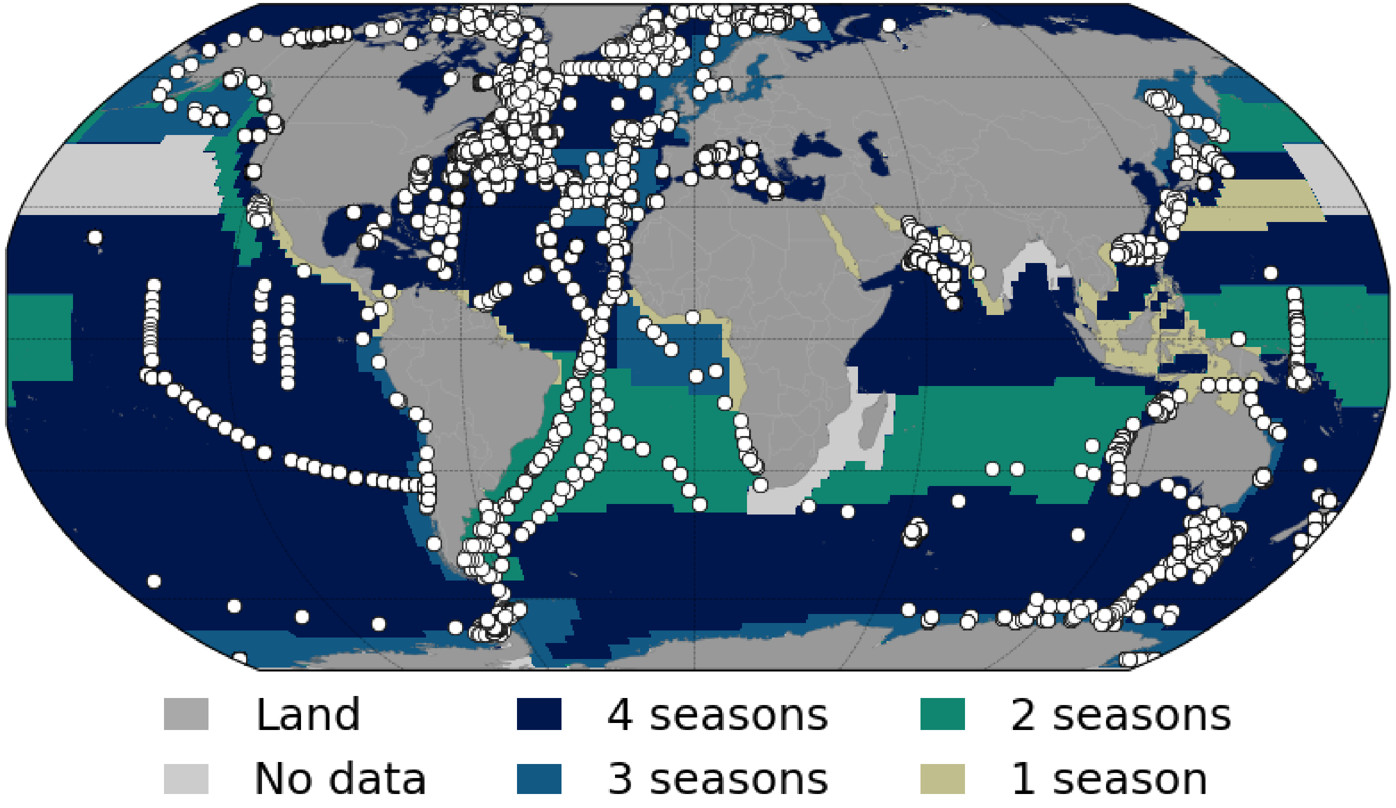
Some additional pools have become amenable to remote sensing:

- Phytoplankton groups
- Detritus (a first approximation)

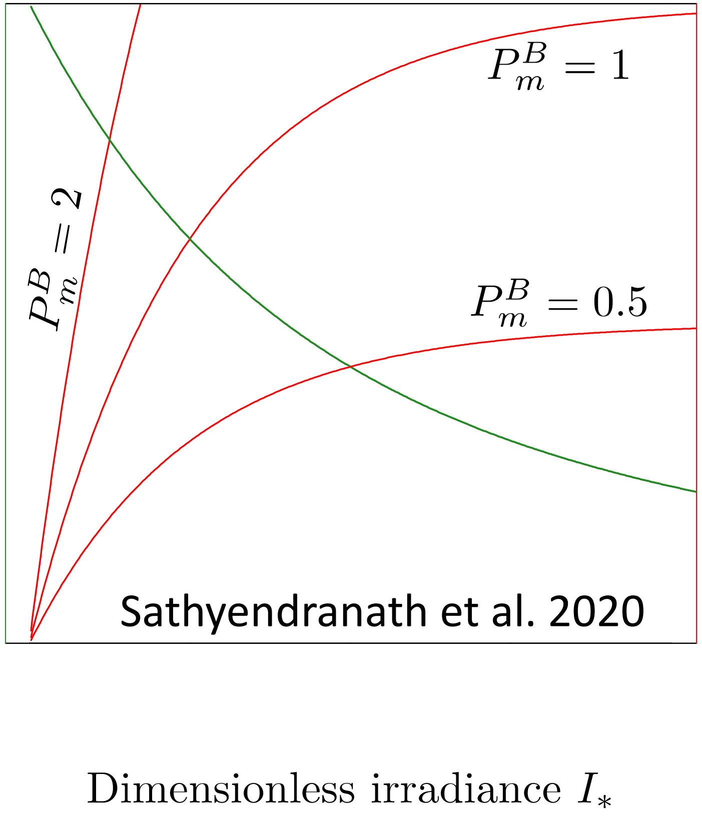
We have a budget for most of the pools and fluxes of carbon in the mixed layer.

Implementation

In situ database of photosynthesis-irradiance parameters P_m^B and α^B combined with the unified model of photo-acclimation and primary production (Geider et al. 19997; Jackson et al. 2017; Sathyendranath et al. 2020)…

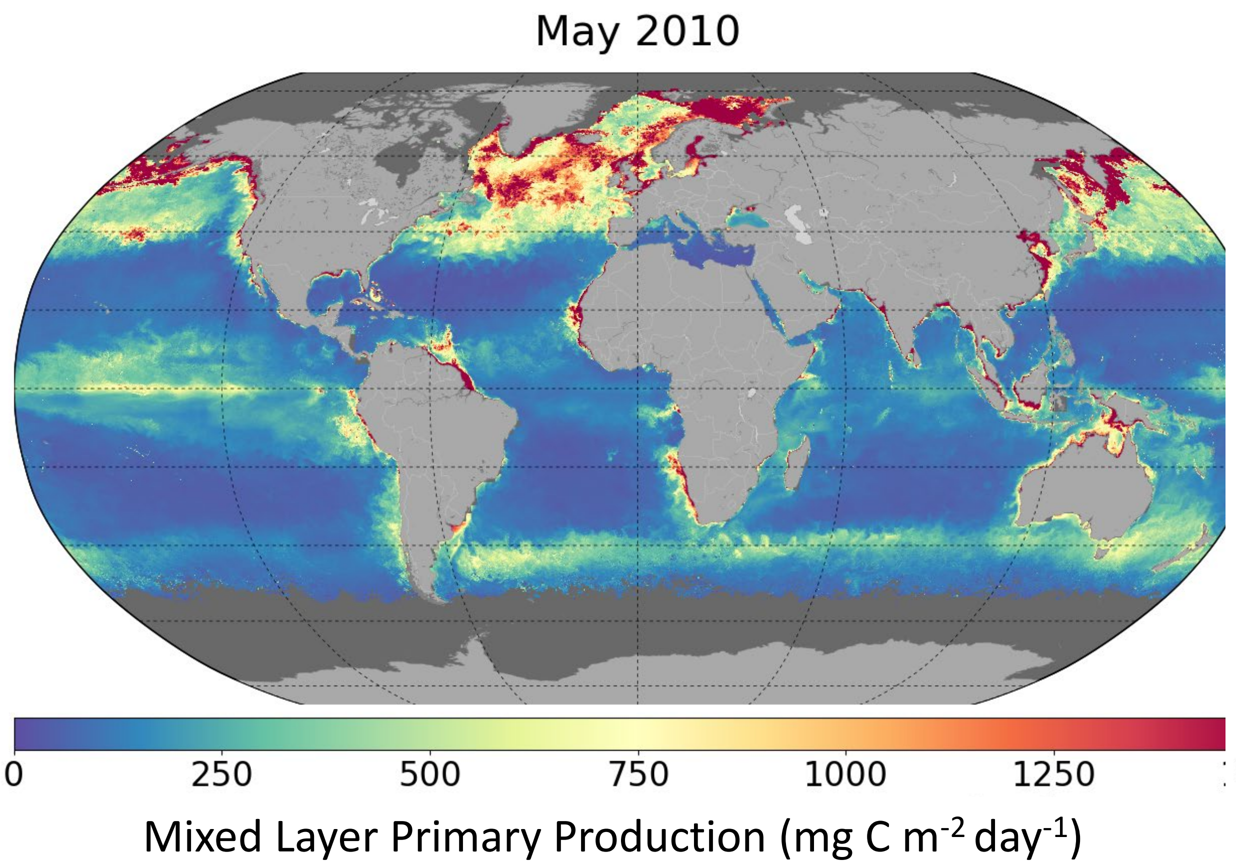


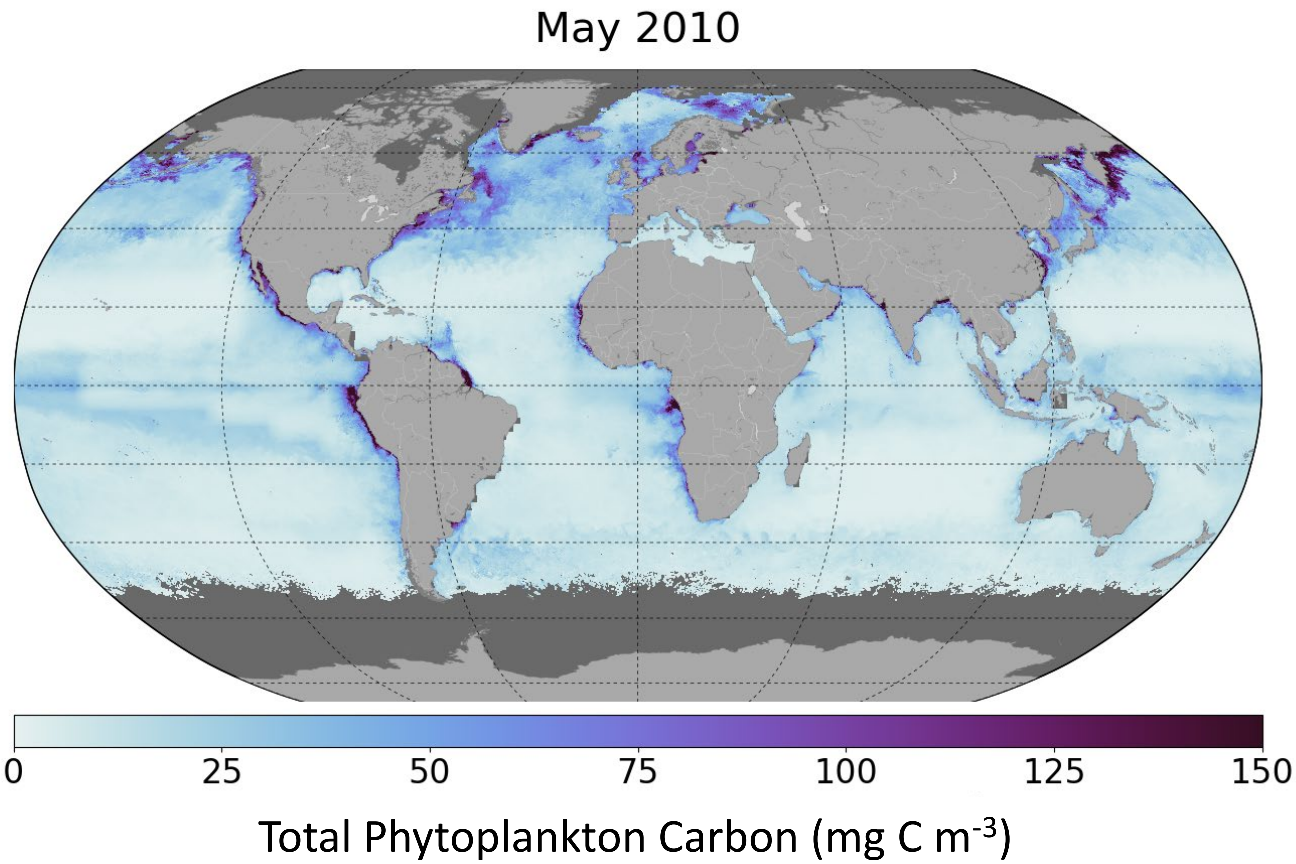
Bouman et al. 2018; Kulk at al. 2021



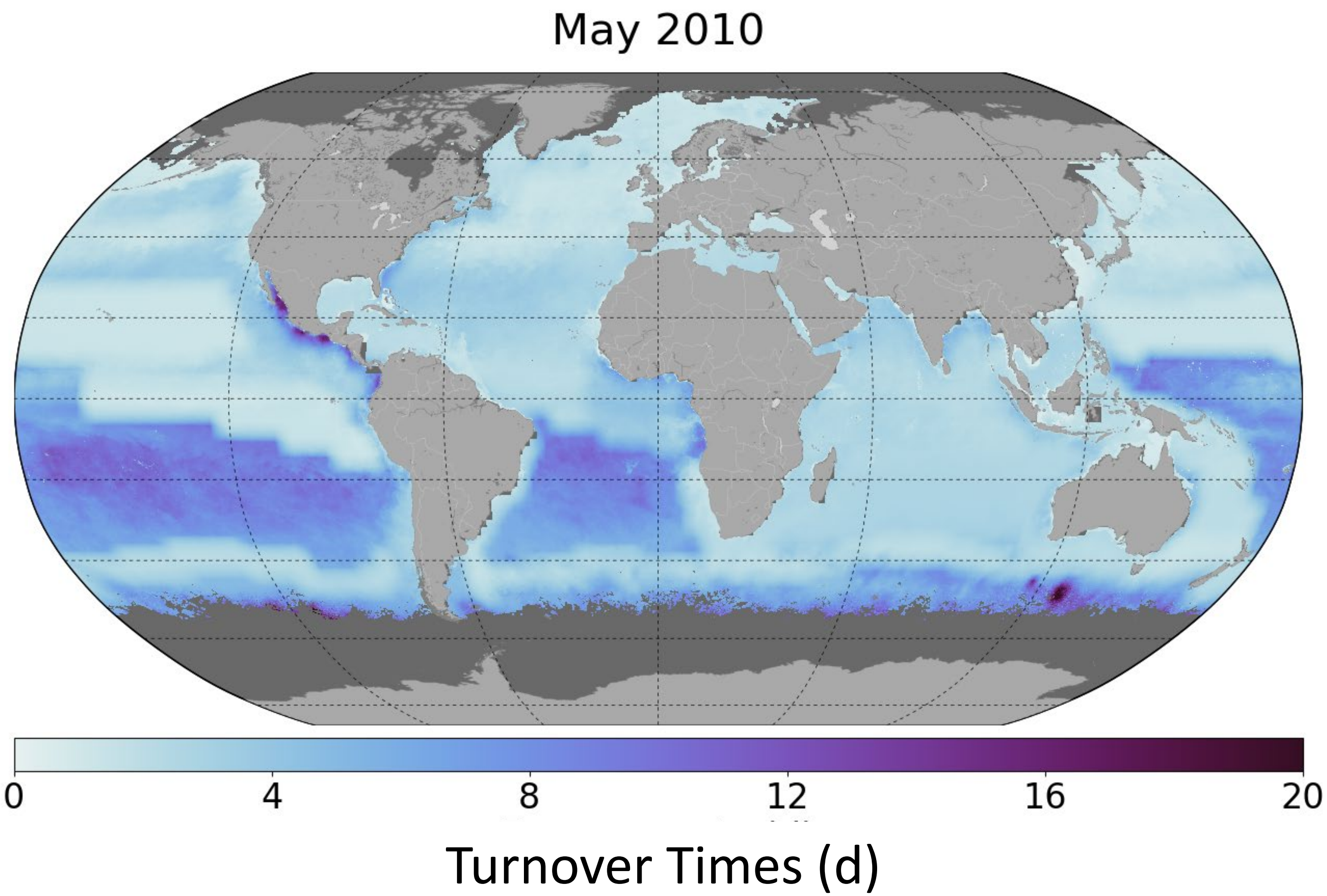
… allows the computation of primary production and phytoplankton carbon in the mixed layer, in a mutually consistent manner. Here, θ is the chlorophyll-to-carbon ratio, θ_m is its maximum value. Principles of resource allocation embedded in the Geider et al. (1997) model are respected.

Primary Production & Phytoplankton Carbon





Phytoplankton Turnover Times



The approach works seamlessly between carbon and chlorophyll fields and fluxes.

We no longer have to sit on one side of the debate about whether carbon-based or chlorophyll-based methods are better for primary production.

We can show the equivalence (or otherwise) between the two types of models, and we can focus the discussion where it matters the most:

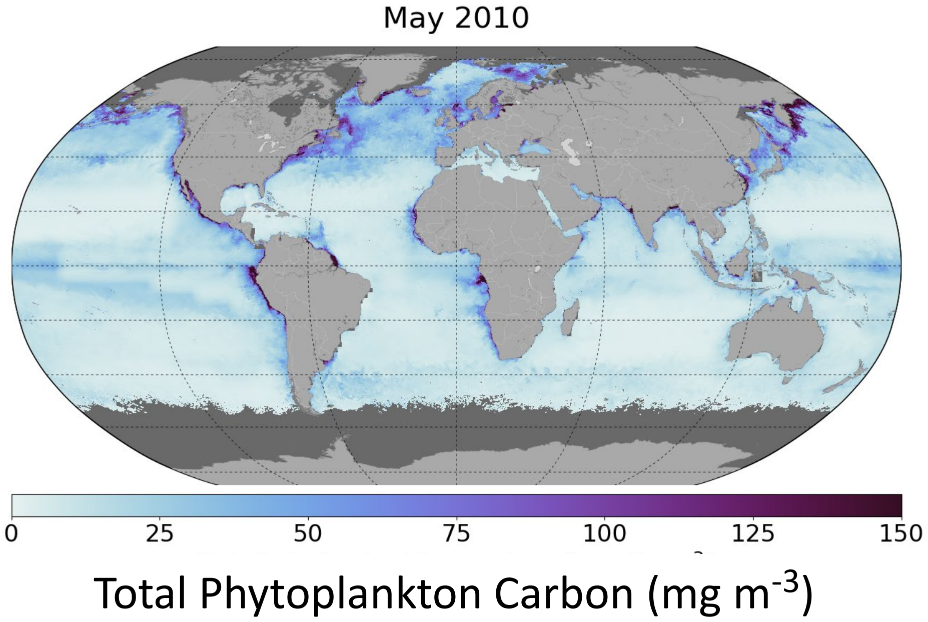
- How different or similar are the model parameters, across different implementations of primary production models?
- Are we approaching the problem at the right time and space scales?

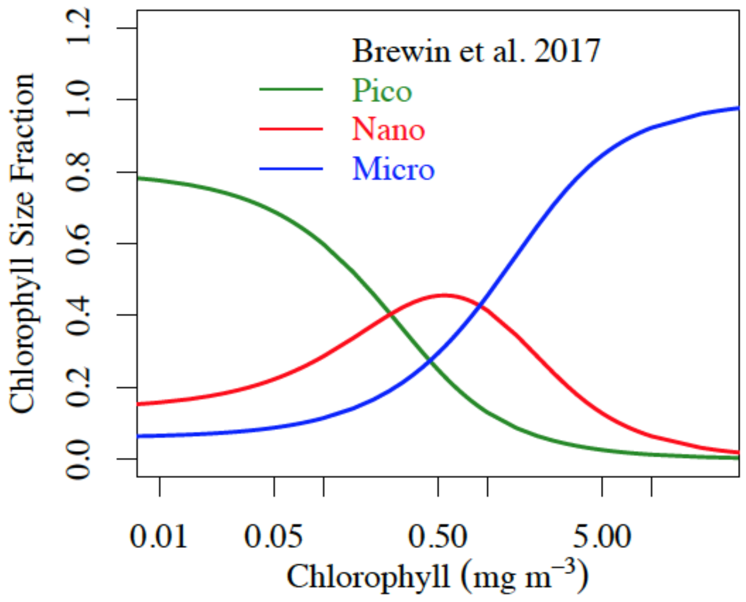
We can explore implications, for example, for turnover times.

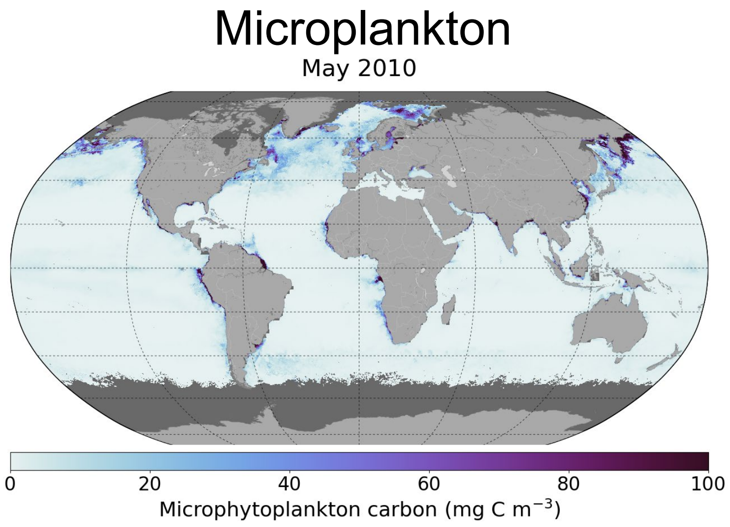
We are now in a better position to compare the methods as well as the results, with ecosystem models.

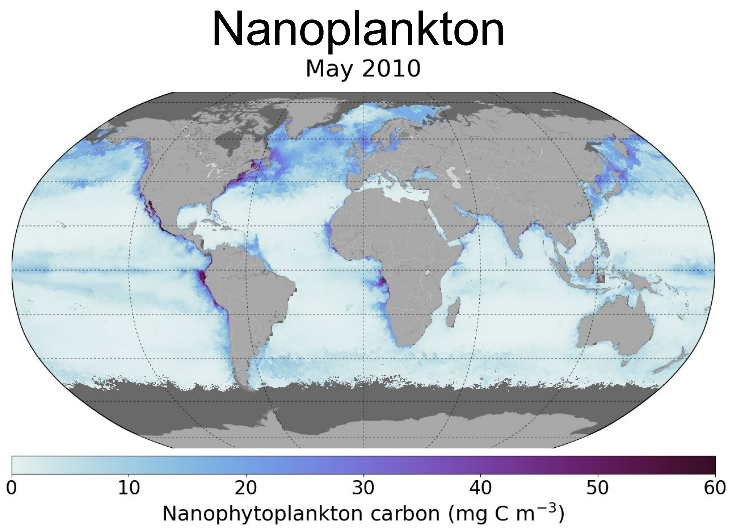
Fields of phytoplankton carbon (an example)

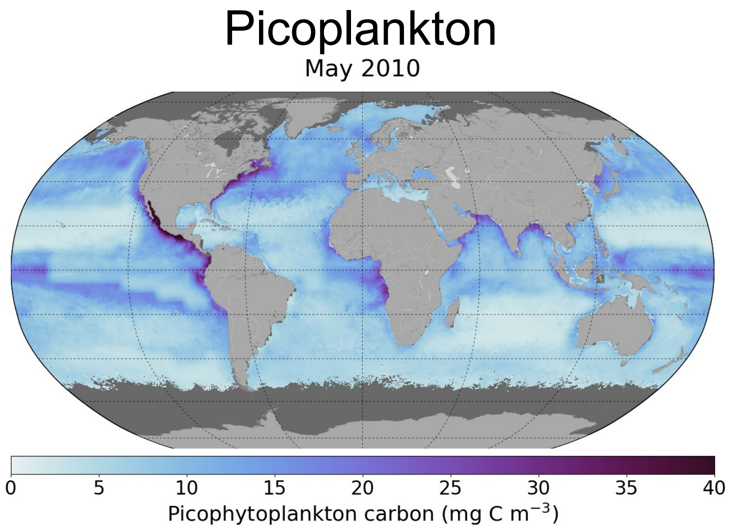
Total phytoplankton carbon combined with a size class model (Brewin et al. 2015) in carbon units (Sathyendranath et al. 2020) allows partition of total phytoplankton carbon into three size classes.



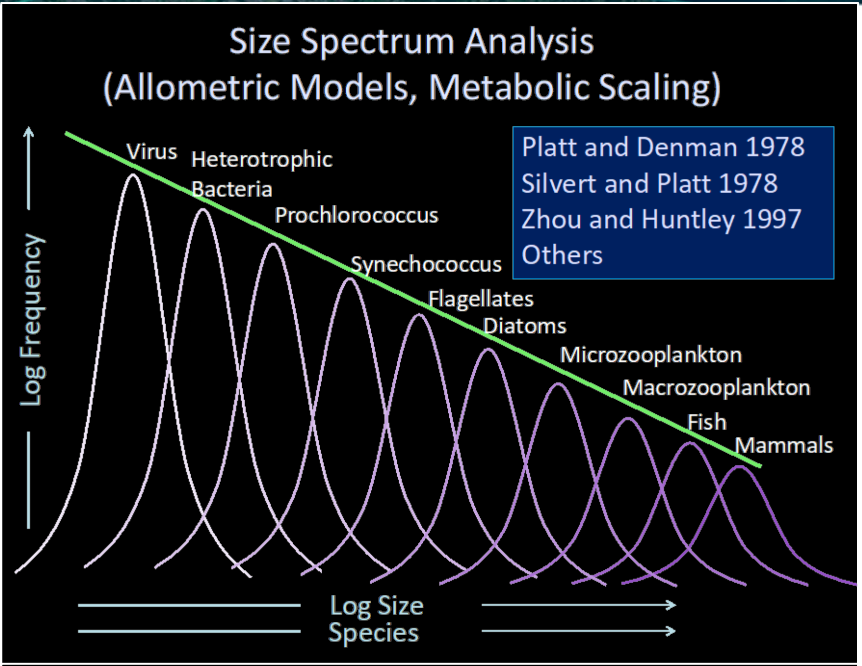


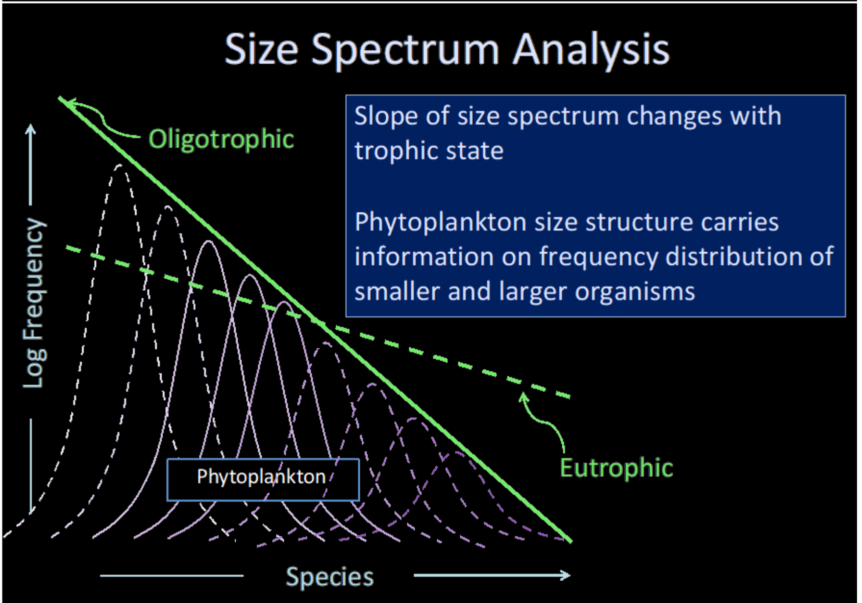


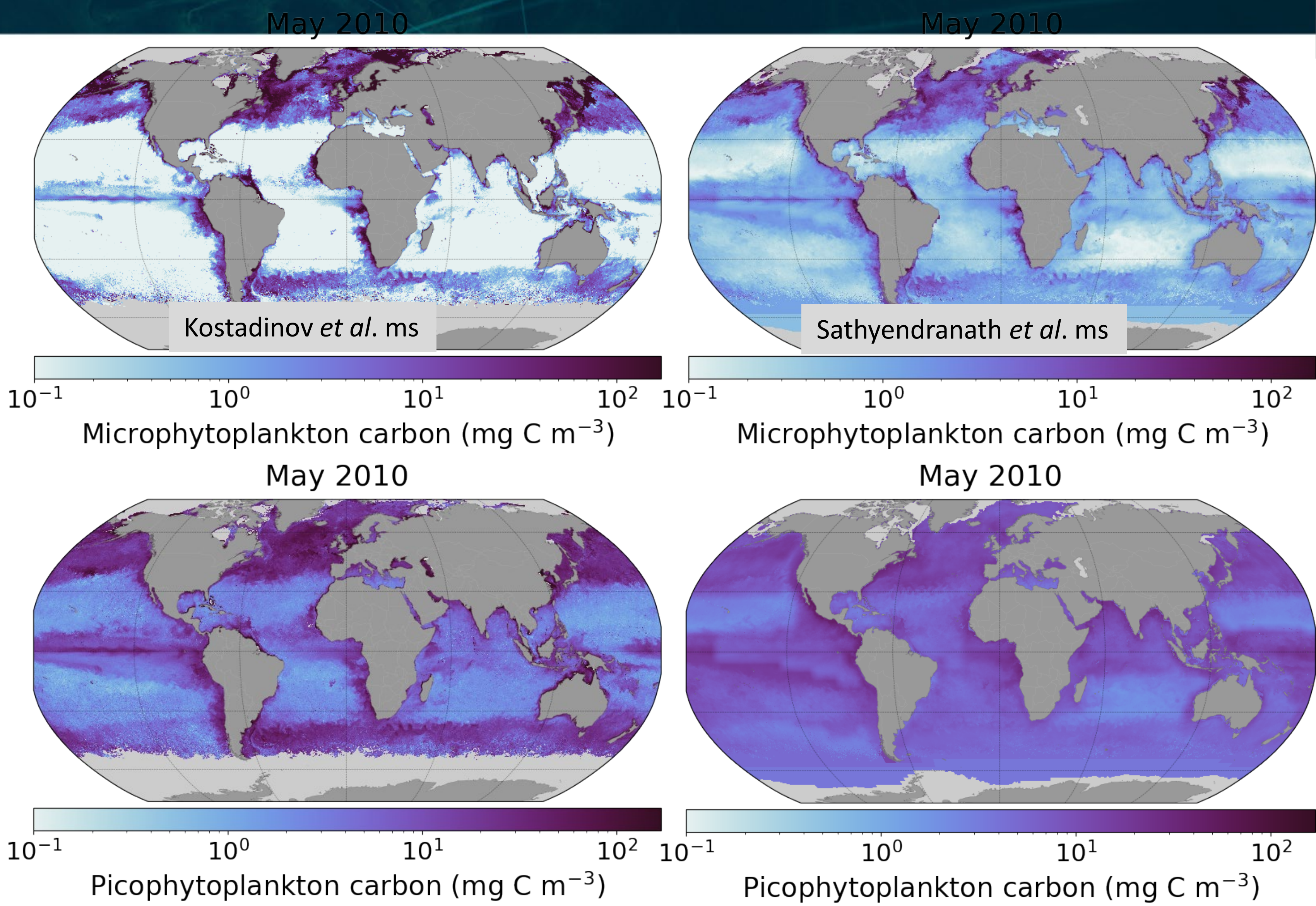




The phytoplankton size classes

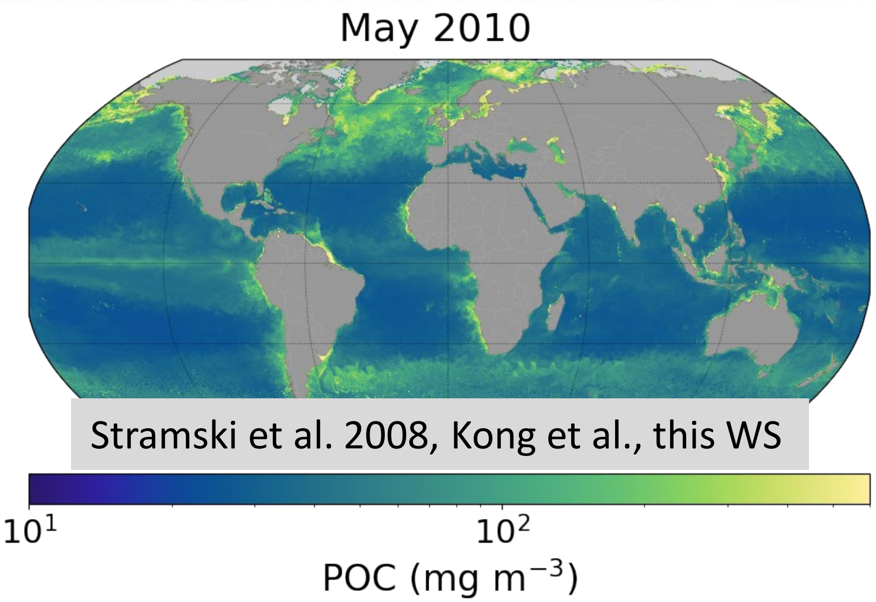


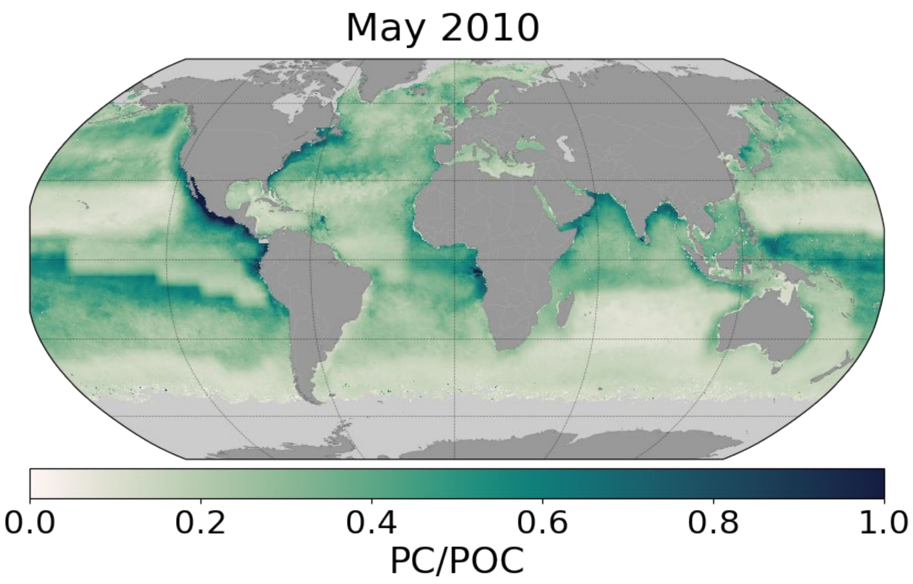


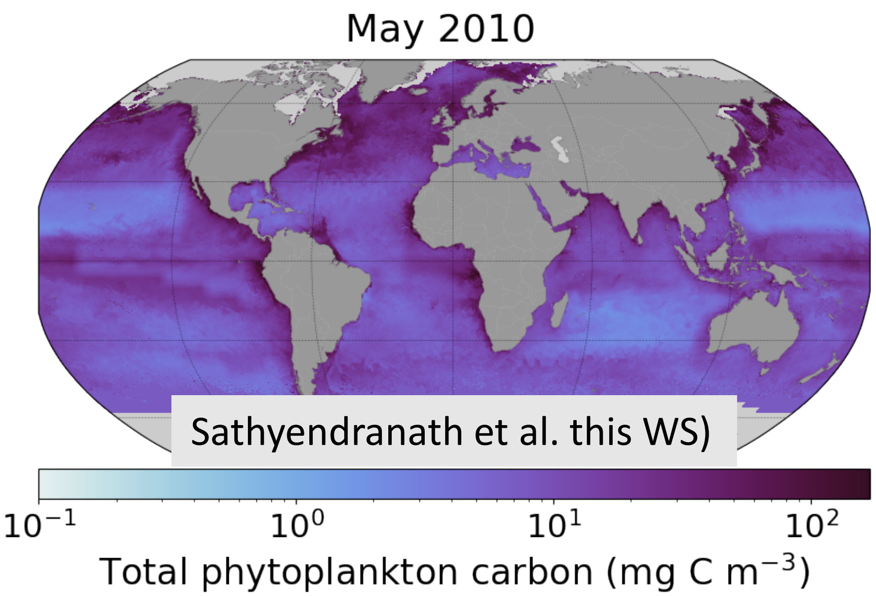


Can we reconcile differences between back-scattering-based and photo-acclimation-based methods for estimating carbon pools in phytoplankton size classes?

Particulate Organic Carbon (POC)







Phyto-carbon: POC Ratio		
Back-scattering method	POC from Ocean-colour R_{rs}, phyto-carbon using photo-acclimation model	
Kostadinov et al. (2016) OC-CCI V5.0	OC-CCI V4.2	OC-CCI V5.0
0.33	0.19	0.23

Unresolved Questions:

In our approach, PC/POC is a variable quantity. Average, value is close to 0.2. Is it right?

What underlies the difference between the outputs for OC-CCI V4.2 and V5?

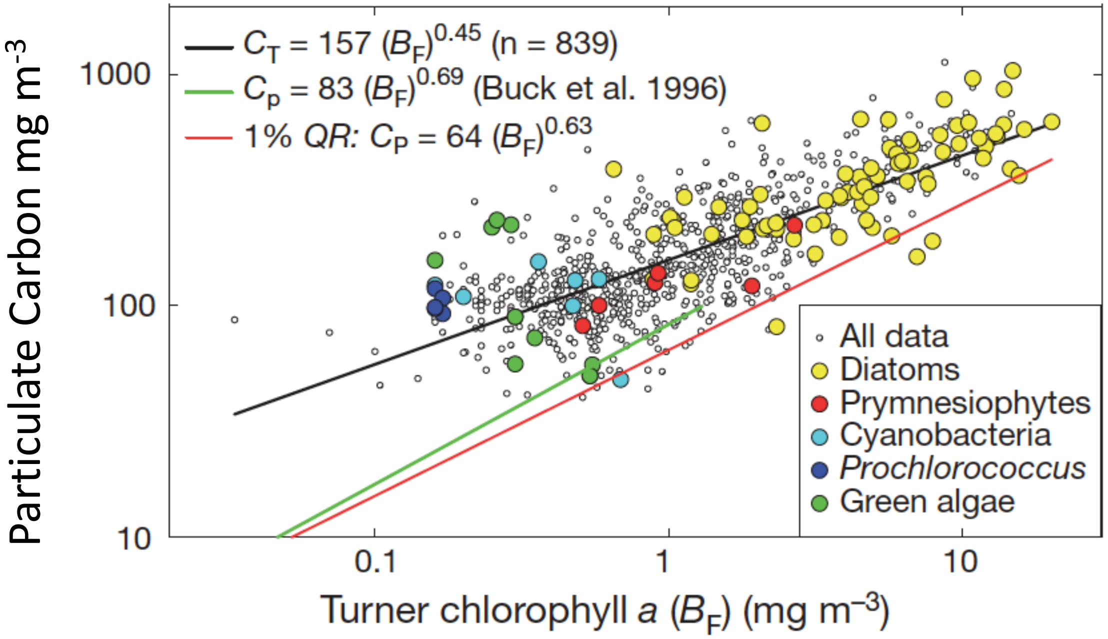
Candidates:

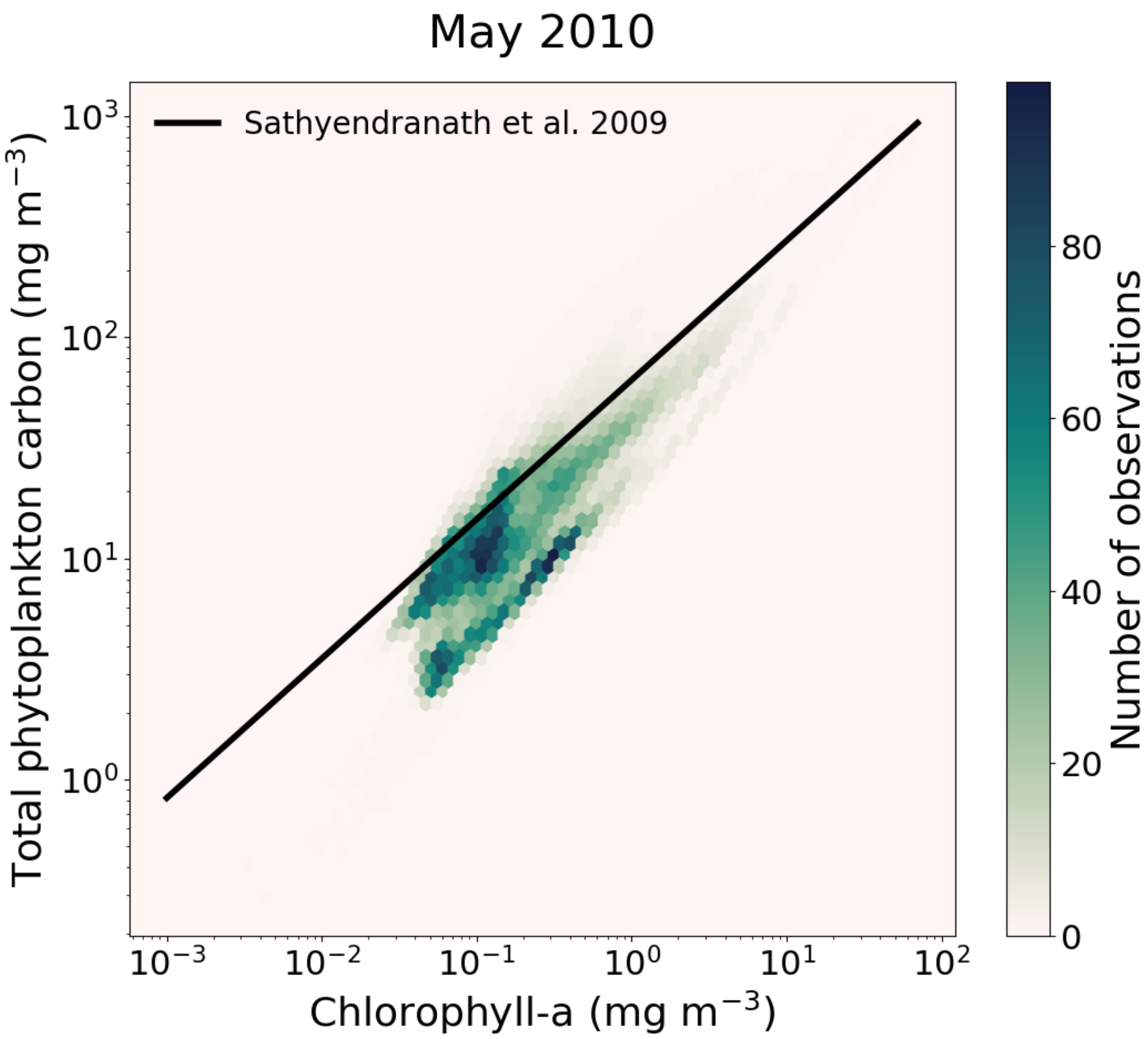
- Gaps in data
- Differences in atmospheric correction
- Differences in chl algorithm
- Changes in bias in chl?

The absorption-based model (Roy et al. 2016, Kochetkova et al. this WS) a third piece of the puzzle to be explored.

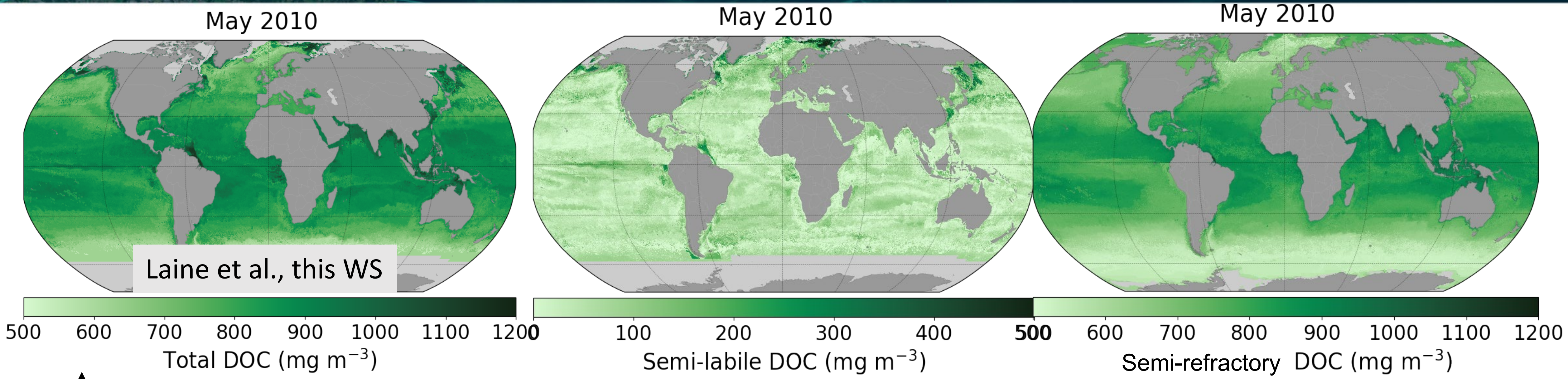
Effect of uncertainties in photo-acclimation model parameters?

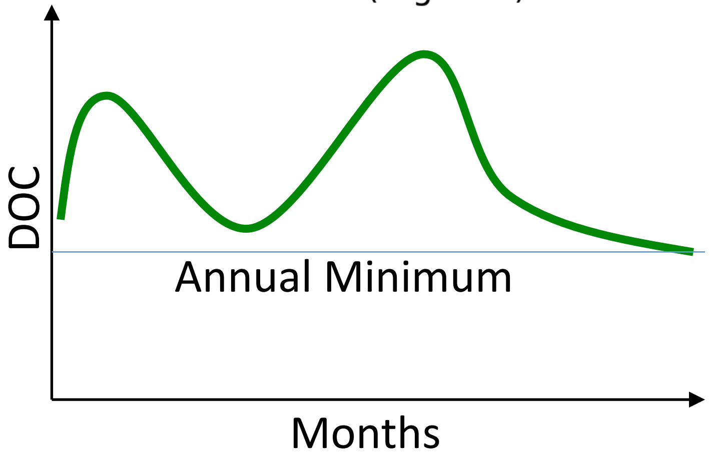
Particulate Organic Carbon and Phytoplankton Carbon





Dissolved Organic Carbon





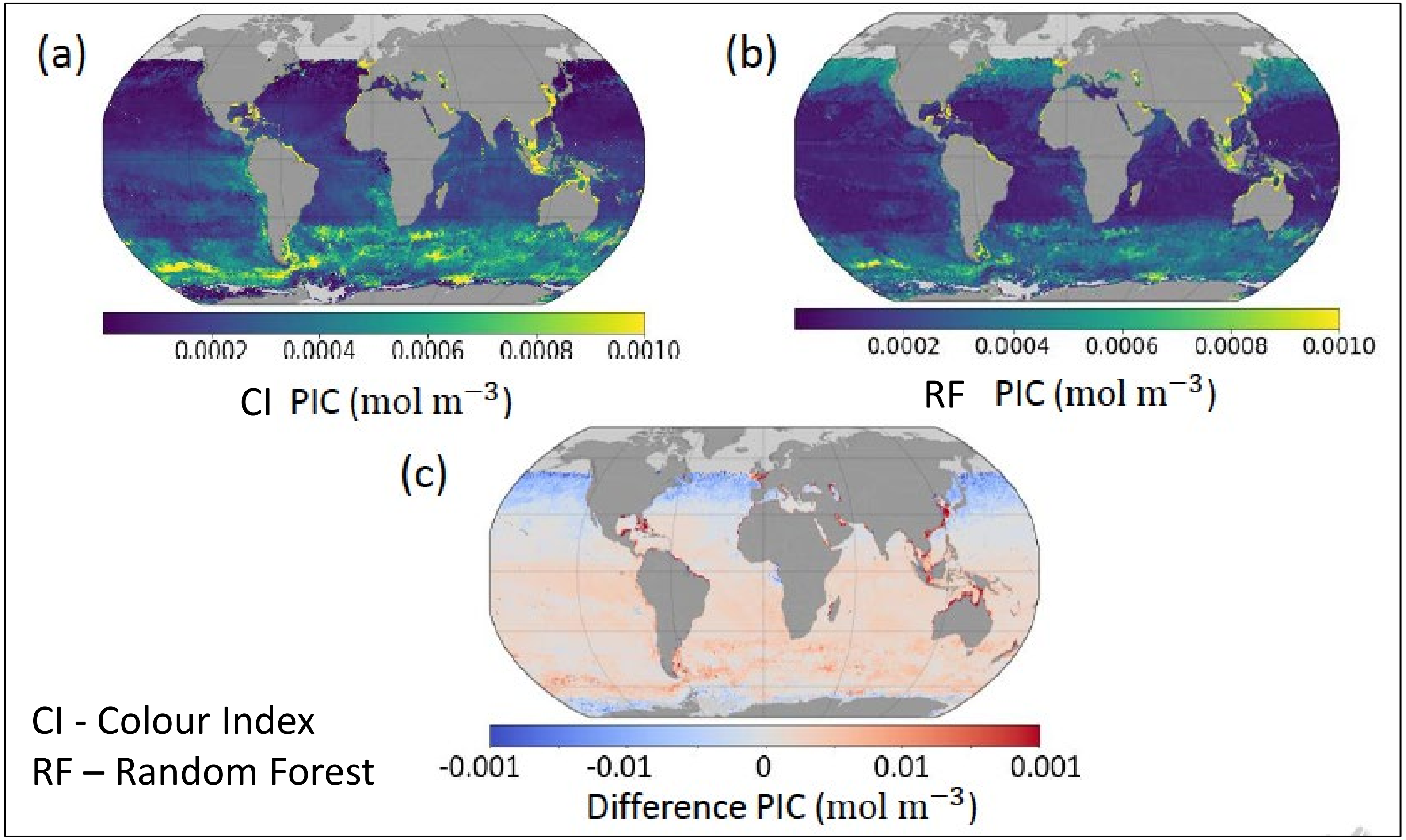
DOC	Satellite-based estimate [Pg C]	Hansell (2013) [Pg C]
Total	14.8	20±3
Semi-labile?	0.71	6±2
Semi-refractory?	14.1	14±2

Simple assumption: At every pixel, seasonally-varying component is the semi-labile component. Rest is semi-refractory.

If our simple assumption is acceptable, then the results indicate that the satellite-based method is underestimating the semi-labile component.

Link to excretion and primary production?

Particulate Inorganic Carbon

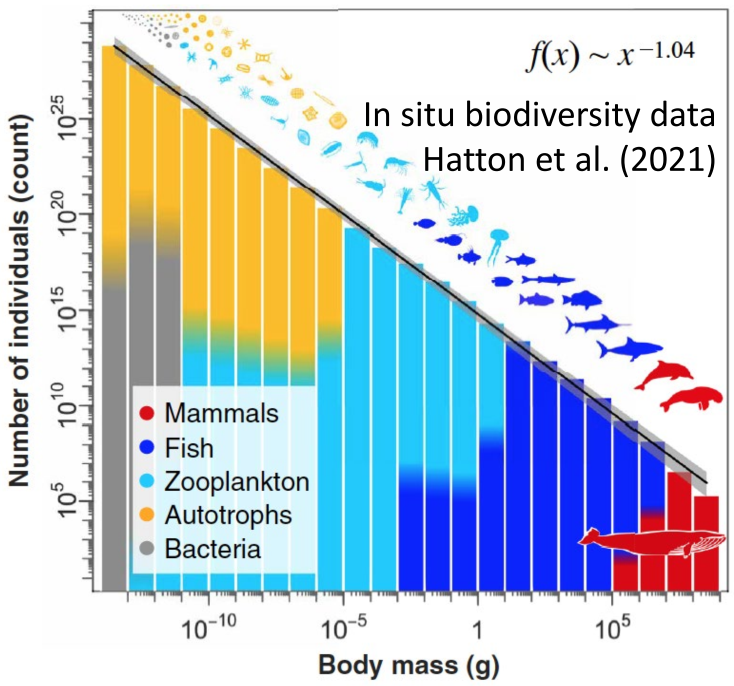


Kong et al. work in progress

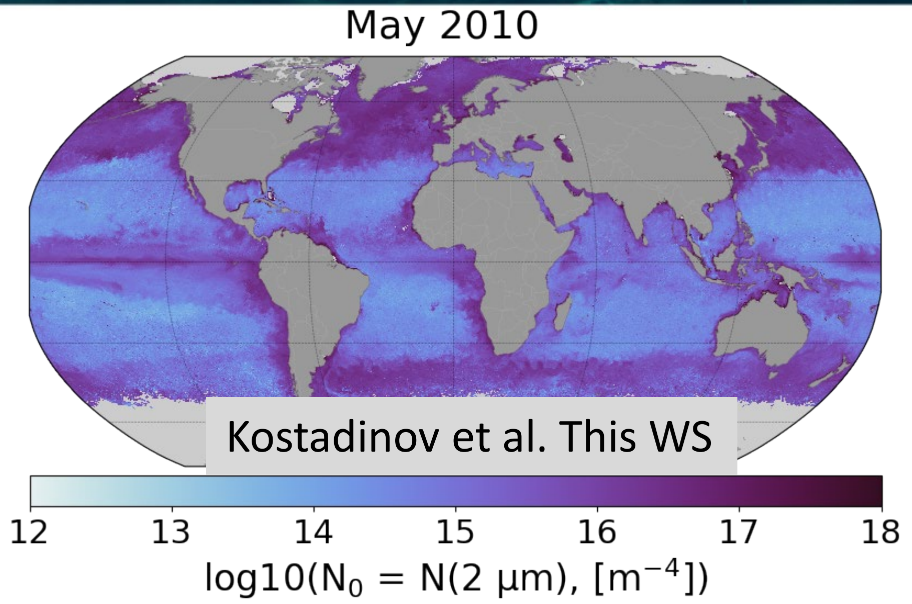
Methods are being Compared.

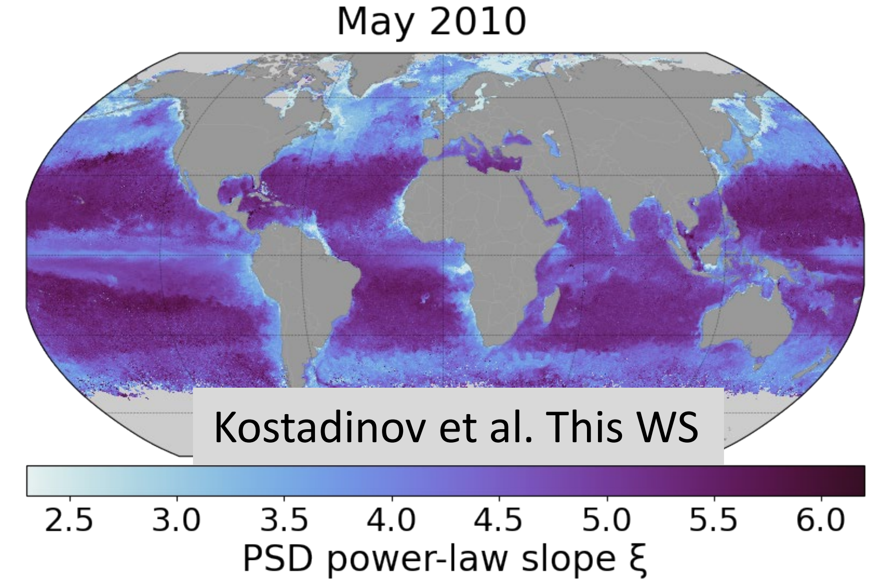
Collaboration with Catherine Mitchell.

Bacteria and Zooplankton? Exploit ecosystem structure



Ecosystem size structure typically follows a power function (Platt and Denman, 1977; Silvert and Platt 1978… Hatton et al. 2021, González Taboada et al. this WS). The two parameters N_o, the abundance at a reference size and ξ, the slope, are available from ocean colour. See Kostadinov et al. this workshop.





Approaches:

Kostadinov et al. (2016; 2022) assume 1/3 of POC resides in living organisms.

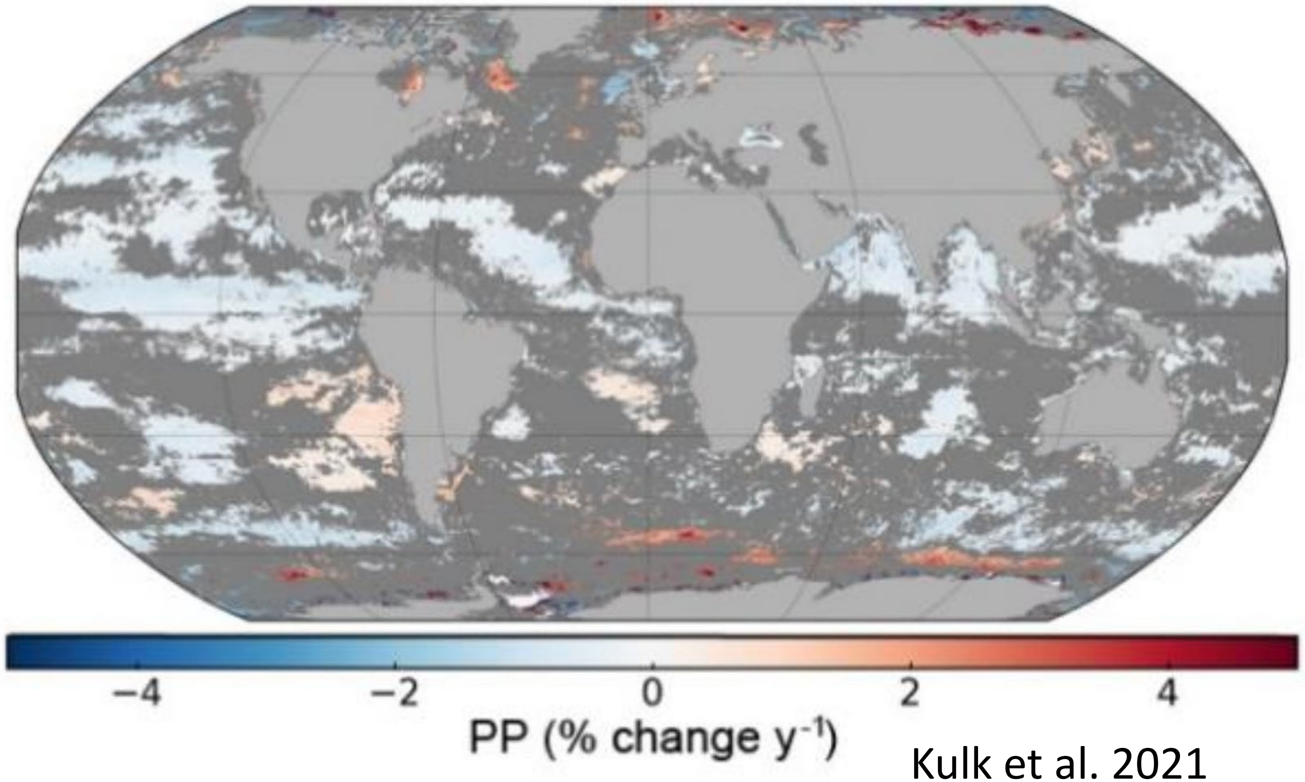
Roy et al. (2016) have proposed another method, based on phytoplankton absorption and chlorophyll-a concentration. (see also Kochetkova et al. presentation, this WS).

Strömberg et al. (2009) used trophic transfer of energy from phytoplankton to zooplankton to map zooplankton from satellite data.

Ecosystem structure can be exploited to infer patterns in other size classes or trophic levels, given the right information on phytoplankton.

Note: Brewin et al. (2014) have shown how we can go from size classes to size spectrum.

Trends in Primary Production



Kulk et al. 2021

Excerpt from an earlier IPCC report chapter on "The Carbon Cycle and Atmospheric Carbon Dioxide", coordinating lead author Colin Prentice (2018?):

Falkowski et al. (1998) listed three major classes of biologically linked factors that can in principle alter the air-sea partitioning of CO_2:

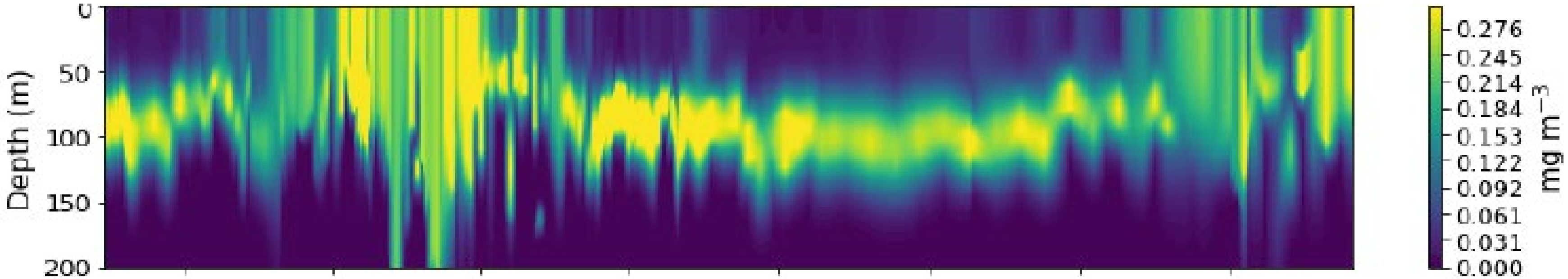
1) changes in surface nutrient utilisation (e.g., in HNLC areas);
2) changes in total ocean content of major nutrients;
3) changes in the elemental composition of biogenic material (including the rain ratio).

Our incomplete understanding of present day nutrient controls on productivity limits our ability to predict future changes in ocean biology and their effect on CO_2 levels.

It is time to address this gap!

Key Messages

- **Gaps:**
- Lack of photosynthesis-irradiance parameters in some provinces and seasons. High uncertainty in the photo-acclimilation parameter θ_m for the three size classes, but especially for the picoplankton size class.
- **Priorities:**
- Improving estimates of, and uncertainties in, model parameters: better seasonal and geographic coverage.
- Dynamic assignment of parameters
- Closer links to physical oceanography: for example to define phytoplankton profiles (e.g., Brewin et al. 2022).
- An ocean carbon budget for ocean stewardship



Brewin et al. 2022

Acknowledgements:

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