An Allometric Model to Estimate Marine Net Primary Productivity from Space

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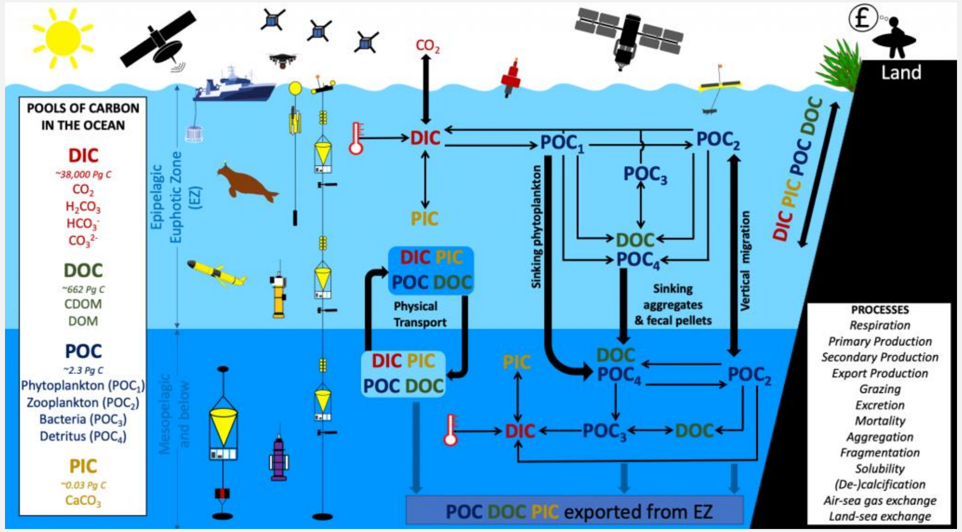
Day 4 – Session 4.1 PP-190

Phytoplankton and Primary Production (PP)

Phytoplankton size and primary production

> [P]lankton ecologists fallout into two groups: Those who delight in finding the patterns in nature that can be explained by size, and those who delight in finding exceptions to the established size-dependent rules.
>
> S. Chisholm 1992

Phytoplankton size-structure determines:
- the magnitude of net primary production in the open ocean
- trophic transfer patterns and overall productivity of marine food webs
- biological carbon pump efficiency



Brewin et al. 2021 *Earth Sci Rev*

An MTE approach to estimate NPP

Metabolic Theory of Ecology [MTE] – framework to scale biological processes from individuals to higher organization levels like populations, communities and ecosystems. [Brown et al 2014 *Ecology*]

Large tradition in marine systems [Eppley 1972, Platt & Denman 1977, Banse 1982]

Integrate effect of body size, temperature and other factors on physiological rates

Macroecological approach [seek general relationships from large data sets]

Allometric model of phytoplankton production

$$NPP = \int_0^{z_{eu}} \int_{D_{min}}^{D_{max}} \mu(D,z)\, C(z)\, p(D)\, \mathrm{d}z\, \mathrm{d}D$$

$$N(D) = N_0 \left(\frac{D}{D_0}\right)^{-\xi}, \qquad D_0 = 2.0\mu\mathrm{m}$$

Extend the Carbon-based Primary Productivity Model (CbPM) [Behrenfeld et al 2005 *GBC*; Westberry et al 2008 *GBC*]

- Unimodal size scaling of phytoplankton growth rates [Marañón et al. 2013 *Ecol Lett*]
- Size-structure and carbon biomass from [Kostadinov et al 2016 *Ocean Sci*]
- Metabolic temperature scaling from [López-Urrutia et al 2006 PNAS]
- Keeping: vertically resolved photoacclimation and nutrient stress

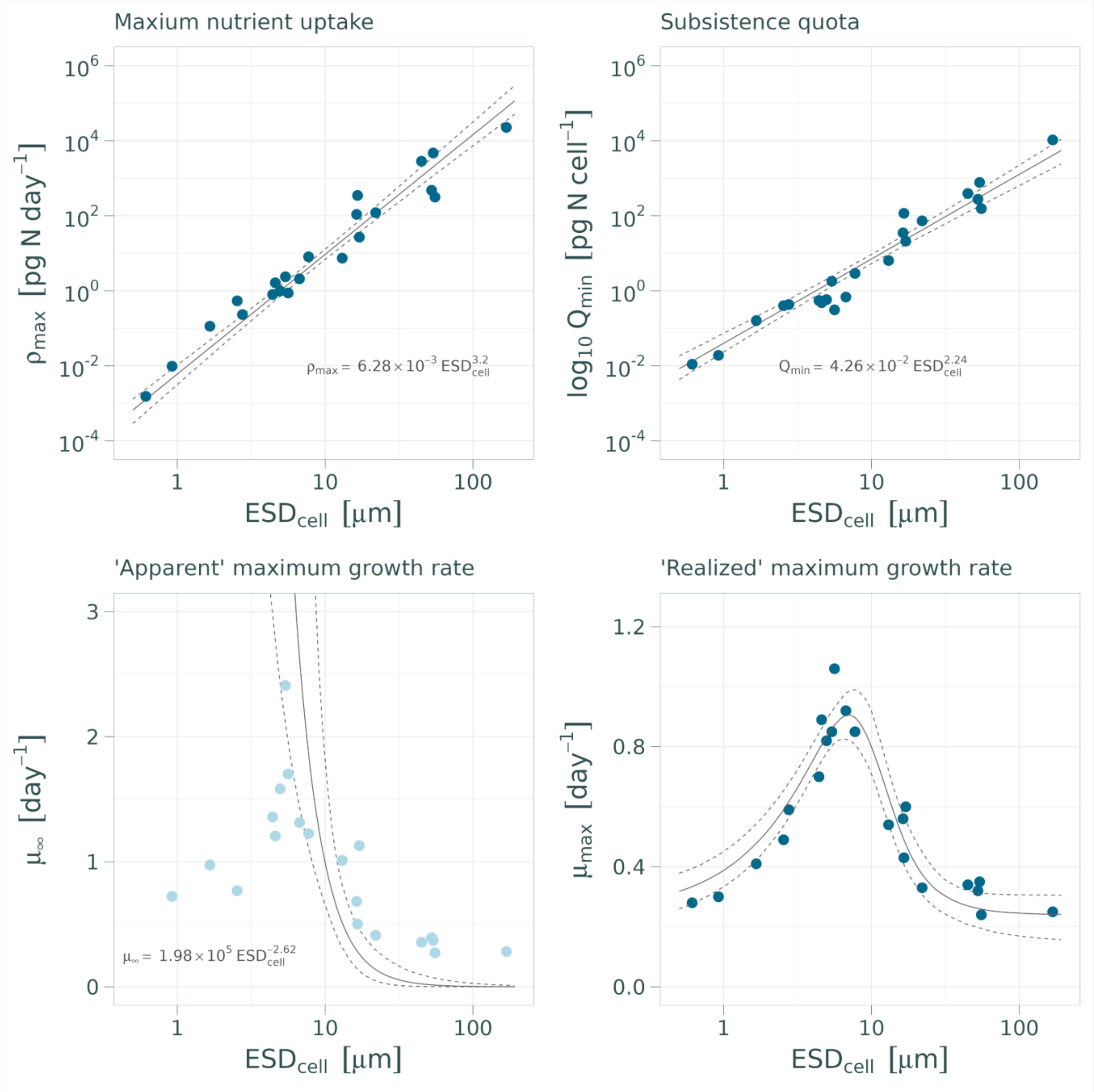
Unimodal size scaling

Consistent with the transition from prokaryotic to eukaryotic plankton [intermediate complexity]

[Ward et al 2017 Am Nat] tradeoff between nutrient acquisition and synthesis

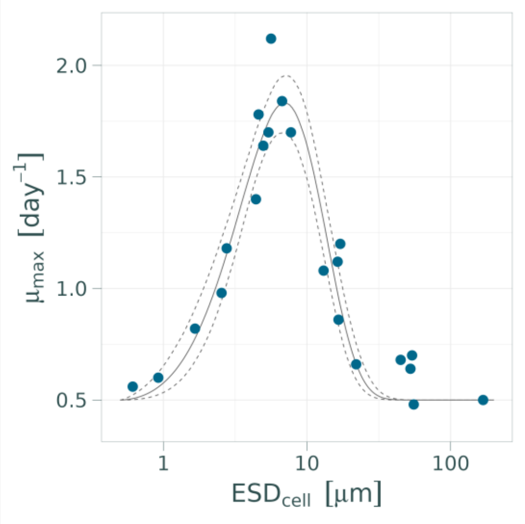
Reanalyzed here using Bayesian methods

Rescaled Beta function [posterior median]

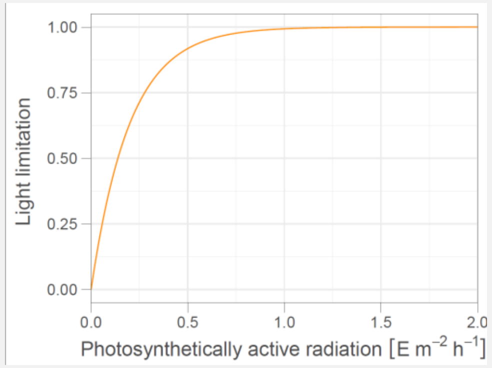


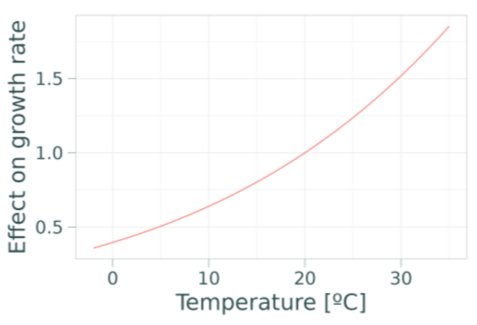
[Marañón et al. 2013 *Ecol Lett*]

Phytoplankton growth rate

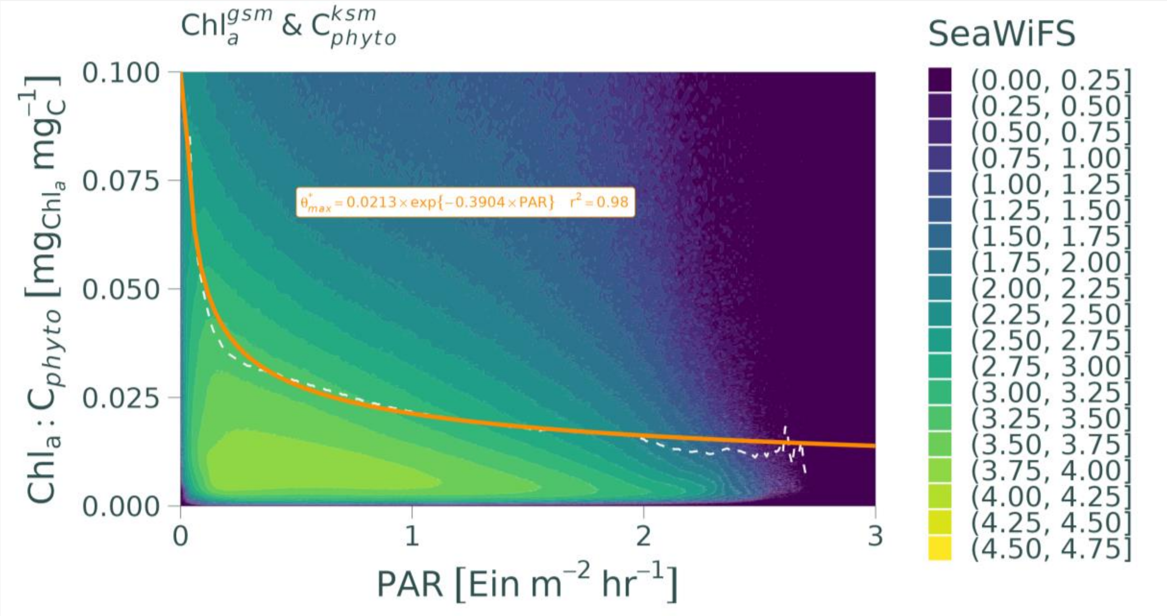


[Marañón et al. 2013 *Ecol Lett*]





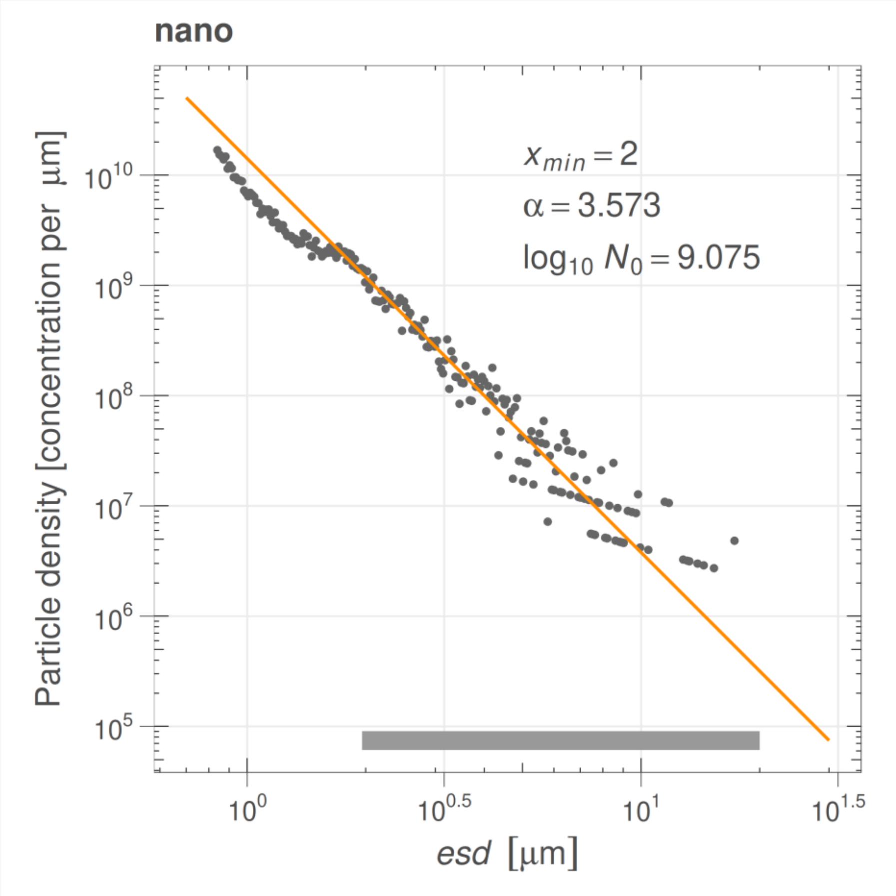
[López-Urrutia et al 2006 PNAS]

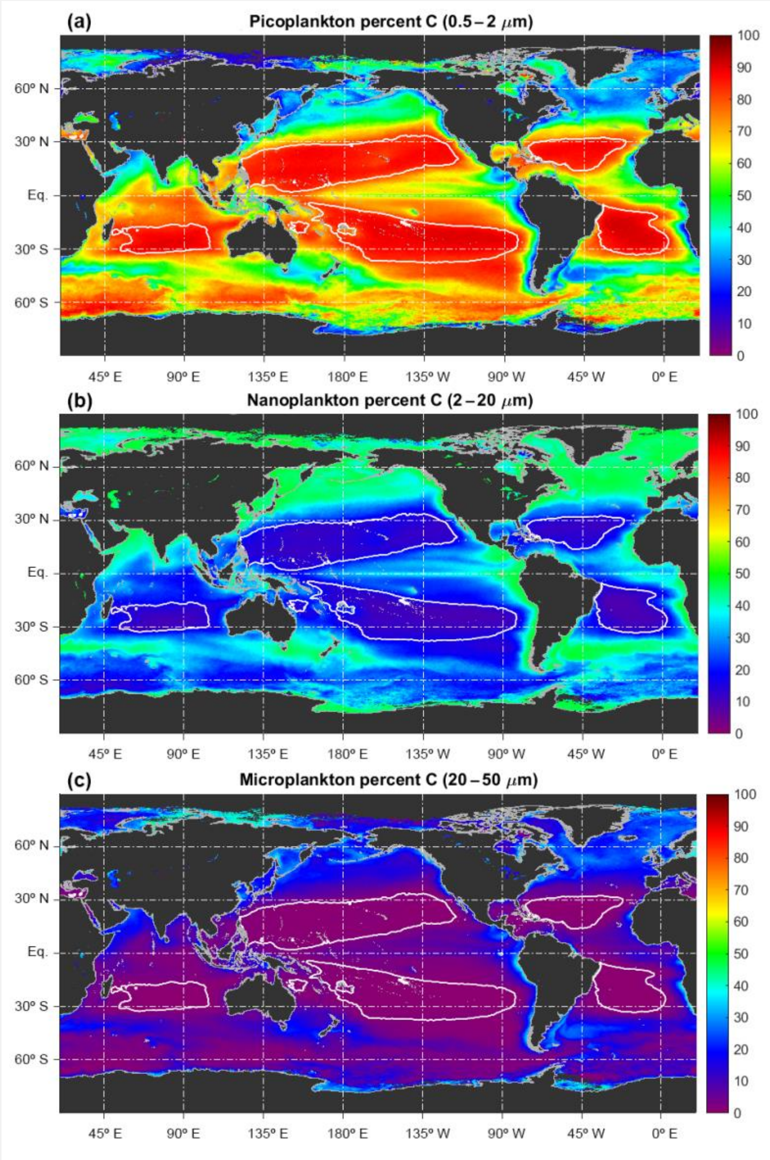


$\frac{\theta_{obs}}{\theta^*_{max}}$ to account for physiological stress

Geider et al. 1997 *MEPS* / Jackson et al. 2017 *Front Mar Sci*

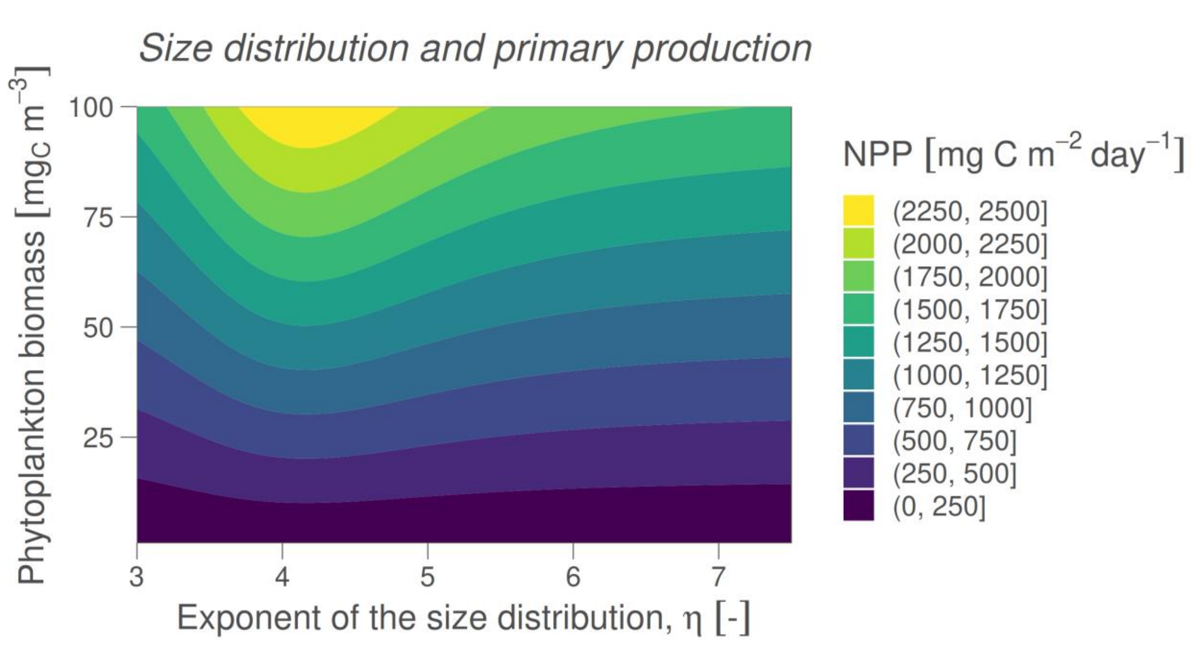
Phytoplankton size-structure

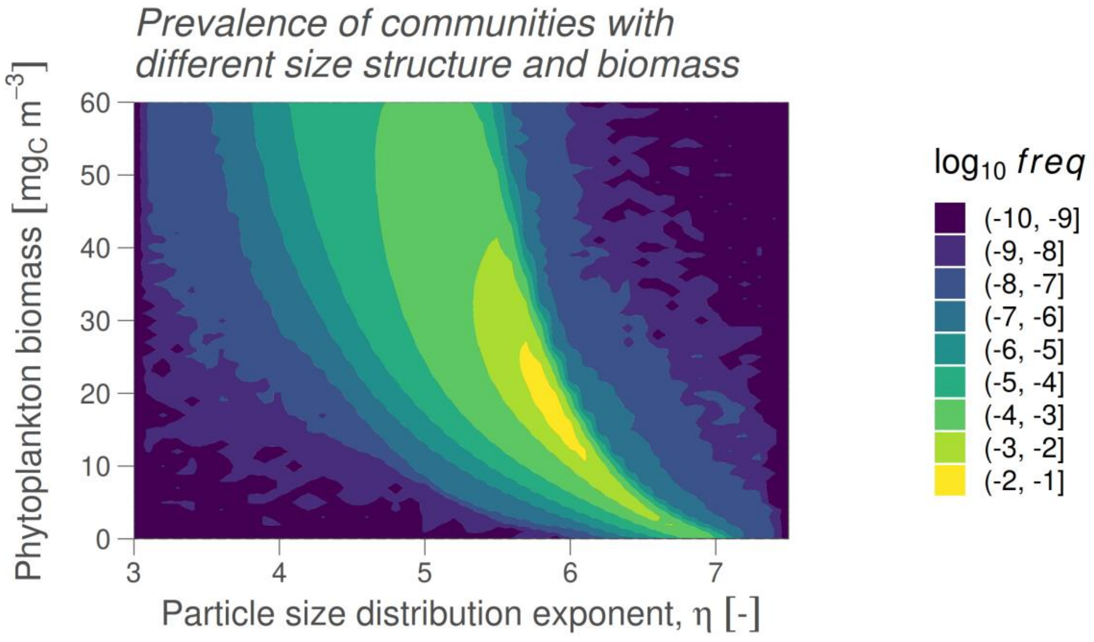




[Kostadinov et al 2016 *Ocean Sci*; Kostadinov et al 2009 JGR]

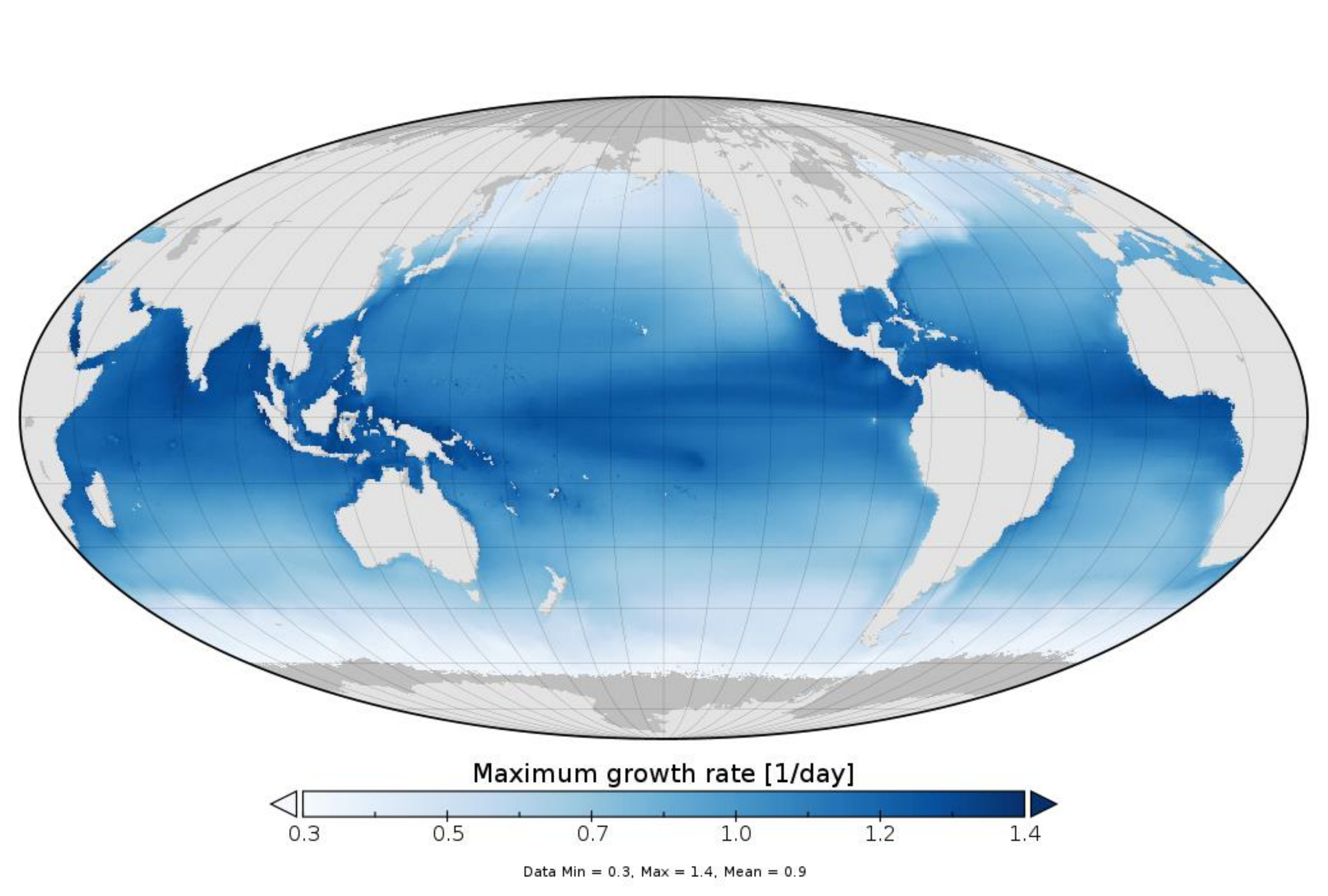
Potential impact of unimodal growth on NPP





Unimodal growth scaling introduces a nonlinearity with deviations of up to 30% in NPP for a given standing biomass

Allometric estimates of phytoplankton growth rate

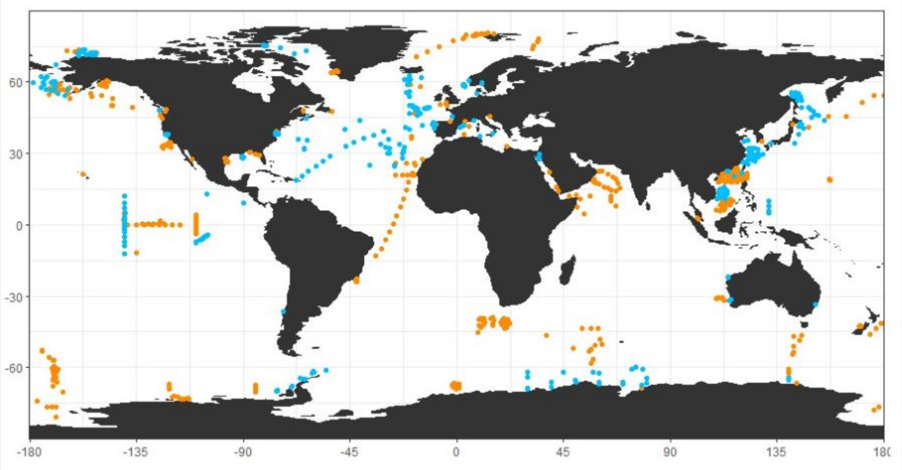


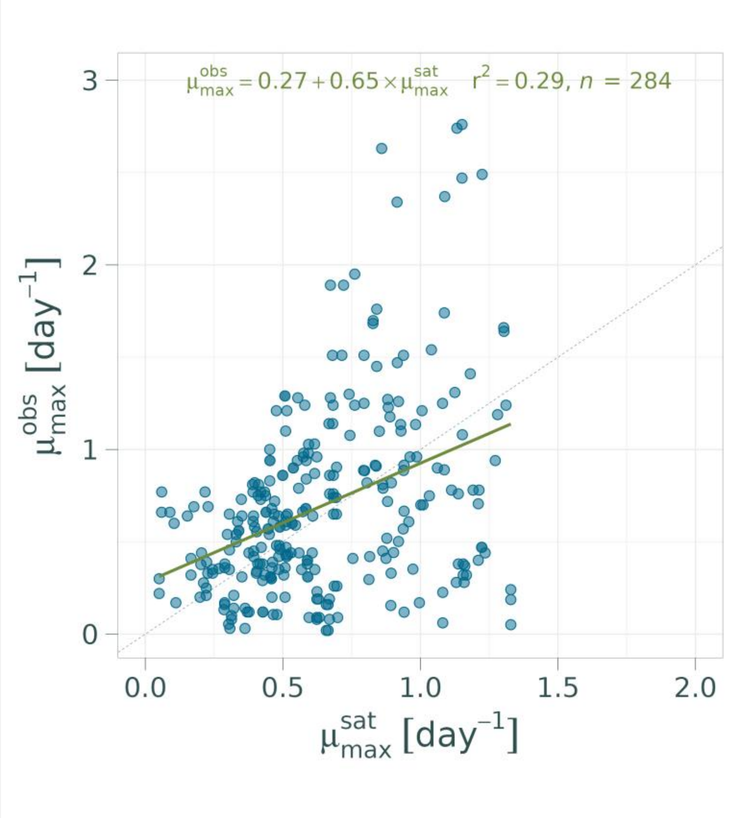
Strong latitudinal gradient, equatorial and tropical oceans show larger growth rates followed by subtropical gyres

Temperate and subpolar latitudes have lowest potential growth rates

Assessment with data from in situ experiments

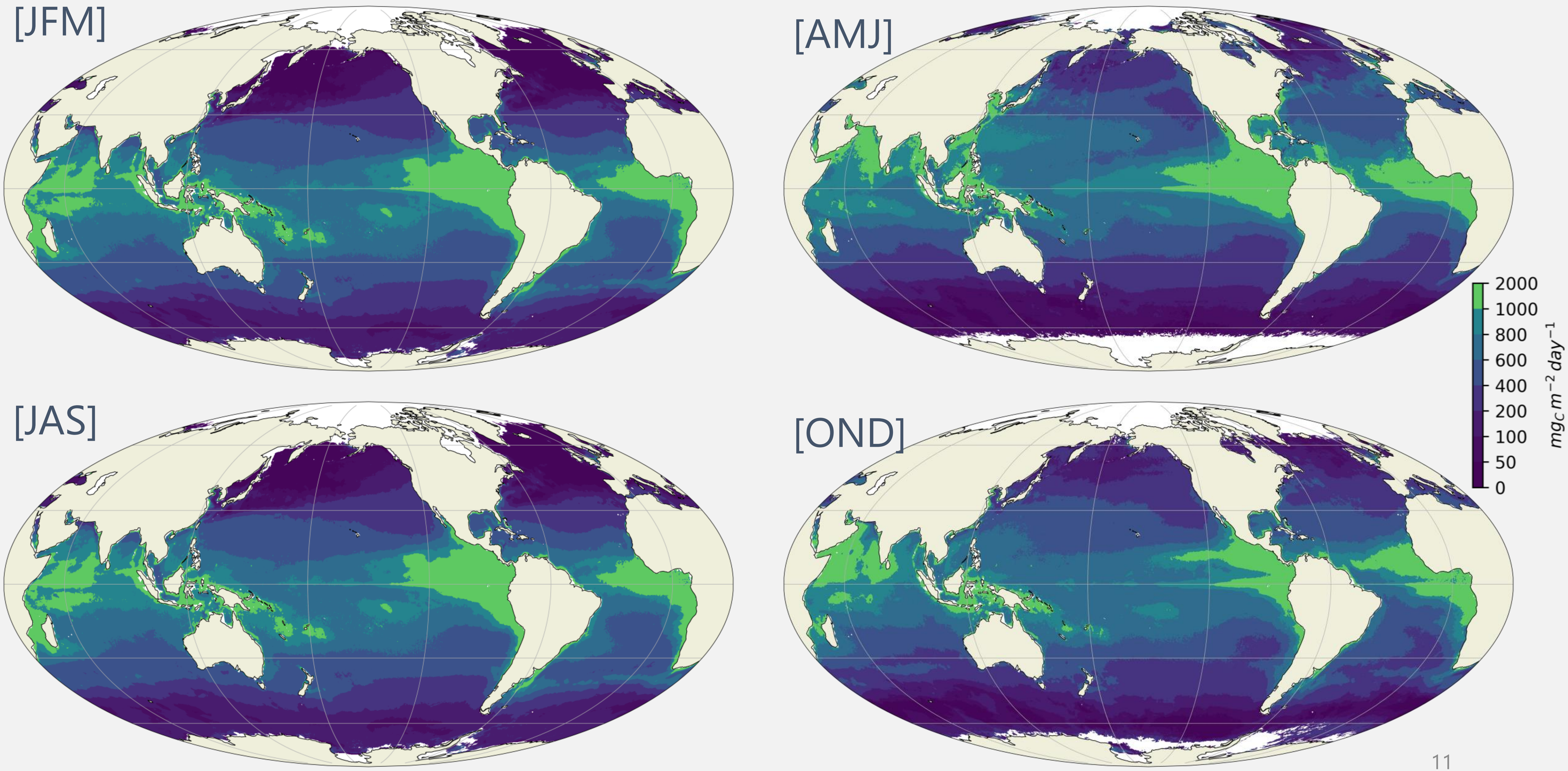
Dilution method – estimates of the maximum growth of the phytoplankton community





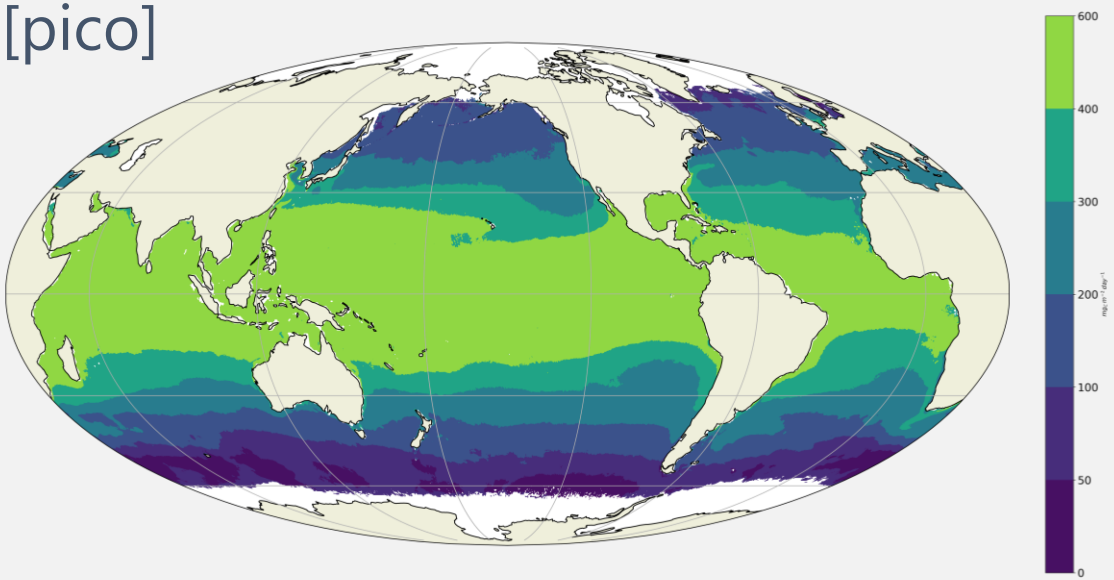
Cáceres et al *in prep*

Seasonal cycle [SeaWiFS mission]



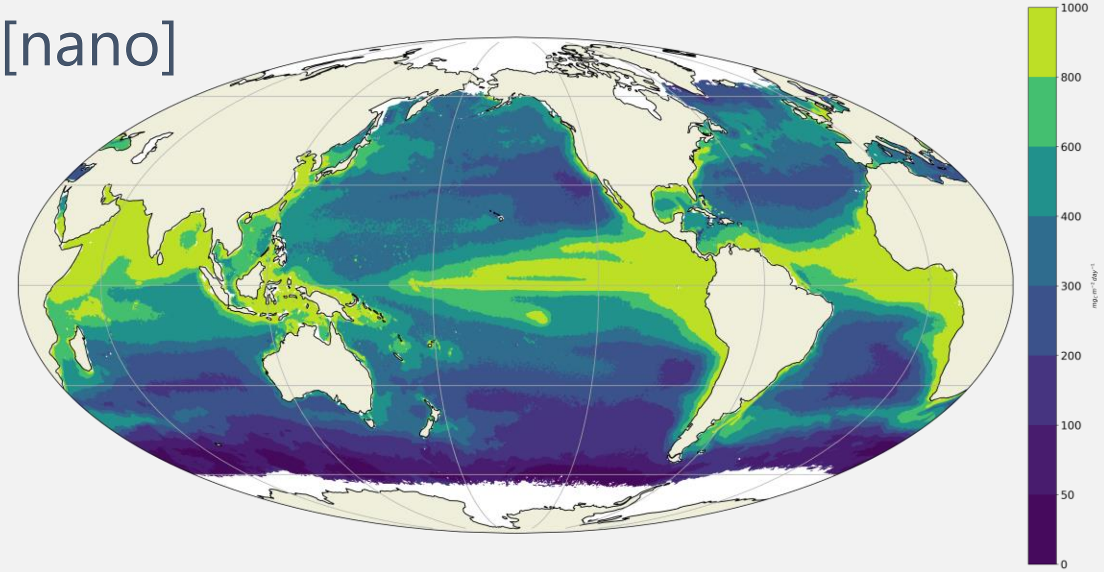
Fractionated PP [SeaWiFS mission]

[pico]

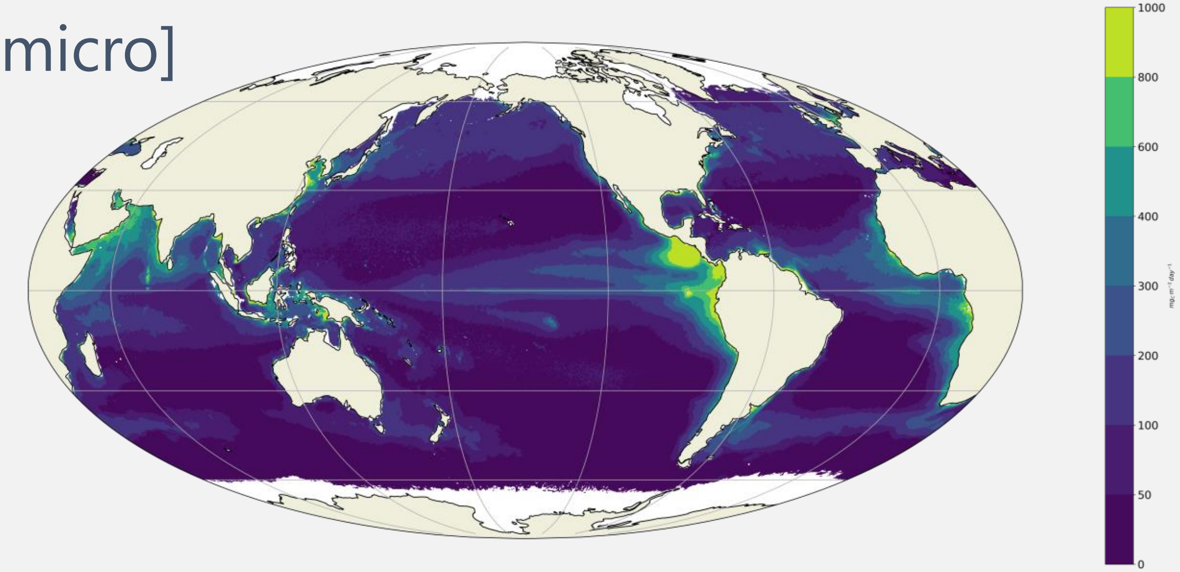


- *pico* – clear latitudinal pattern
- *nano* – major contributor including temperate blooms
- *micro* – coastal upwelling areas

[nano]



[micro]



Summary

Metabolic theory provides a framework to harness recent advances to resolve phytoplankton size distribution into mechanistic estimates of pelagic NPP

Allometric estimates of average phytoplankton growth rates seem promising and may enable NPP models to account for variability in phytoplankton size structure

The unimodal scaling of plankton growth results in a disproportionate contribution of tropical waters and nanoplankton to NPP at the global scale

Next steps – working on a manuscript, need to assess updated PSD models and improve calibration with *in situ* observations, incorporate more developments [e.g. Anderson et al 2021 *Nat Comm* – diversity of thermal responses]

Knowledge gaps

- Accuracy of chlorophyll and carbon estimates constraint NPP
- Upper ocean dynamics (winds, mixing, MLD and underwater light field)
- Coastal waters [both pelagic and benthic production]

Priorities for next steps

- 1 year – keep supporting field cruises and missions until the end of COVID19 crisis, with especial attention to vulnerable communities
- 5 year – homogenization and accessibility of data gathered by autonomous platforms, full exploitation of hyperspectral sensors
- 10 year – integration of observations, experiments and models; fulfil expectations and goals of Ocean Decade [economic, conservation and restoration objectives]

With special thanks to
Carlos Cáceres [FNCSR – Banyuls]
Ricardo Glez. Gil [U Strathclyde]

Data sources
Ocean Color Web – NASA
oiSSTv2 – NOAA NESDIS
MLD – OSU Ocean Productivity
World Ocean Atlas 2018 [NO_3]
Bathymetry – GEBCO
Natural Earth

Code
gitlab.com/fgtaboada/sopm
[request access to fgtaboada@gmail.com]
OSU Ocean Productivity Website
Ocean Data Science Software Repositories
S Prahl – miepython
V Zverovich – fmt
D Sanderson & R Curtin – armadillo

Images
NASA EOSDIS Worldview
NASA Visible Earth

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