From fixed functional types to flexible models of microbial community structure in the oceans

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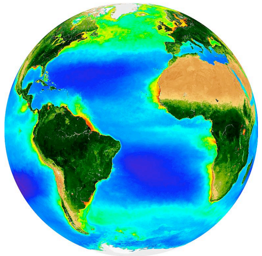
Michael J. Follows and Simon A. Levin

Outline



Classical NPZD models of microbial aquatic communities

`Emergent’ Functional Types, a new modeling approach.

Current directions and project objectives.

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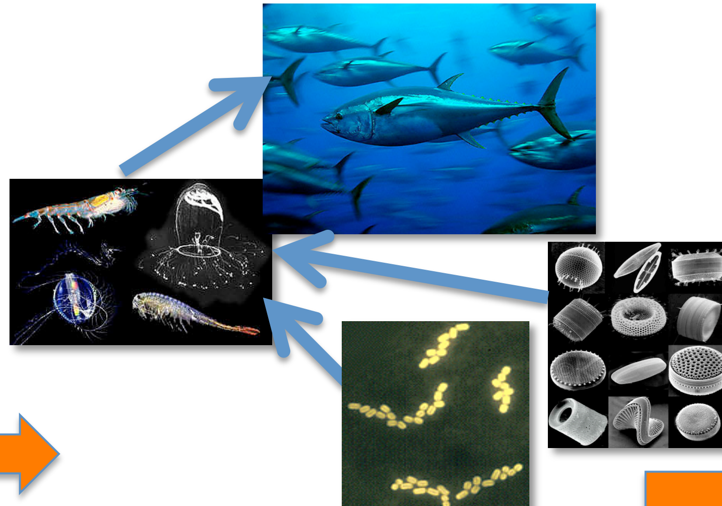
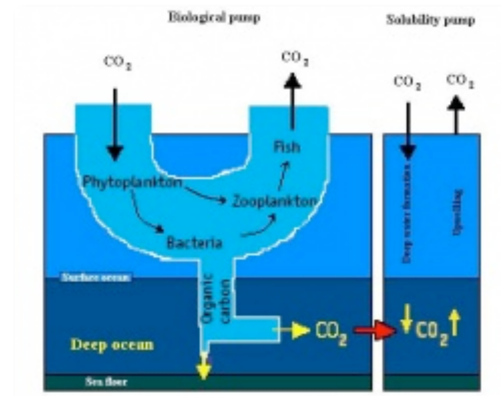
Ocean Ecosystems

Community composition and interactions



Microbial Community DNA

Ecosystem functions



Community Metabolism

Carbon fixation

Methane metabolism

Reductive carboxylate cycle

S metabolism

Oxidative phosporylation

N Metabolism

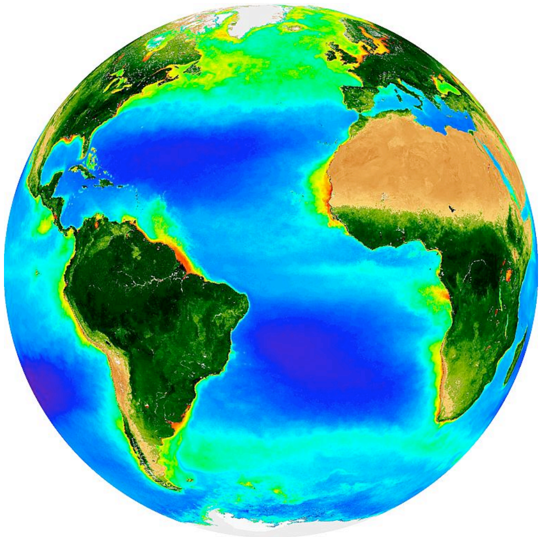
EF DeLong, *Nature* **459**, 200 (2009)

Patterns of interest

Community composition and biomass distribution along environmental gradients

Sheldon size spectra.

Redfield Ratios C:N:P.



Chl a satellite image from SeaWiFS (Boreal winter)
http://oceancolor.gsfc.nasa.gov/SeaWiFS/

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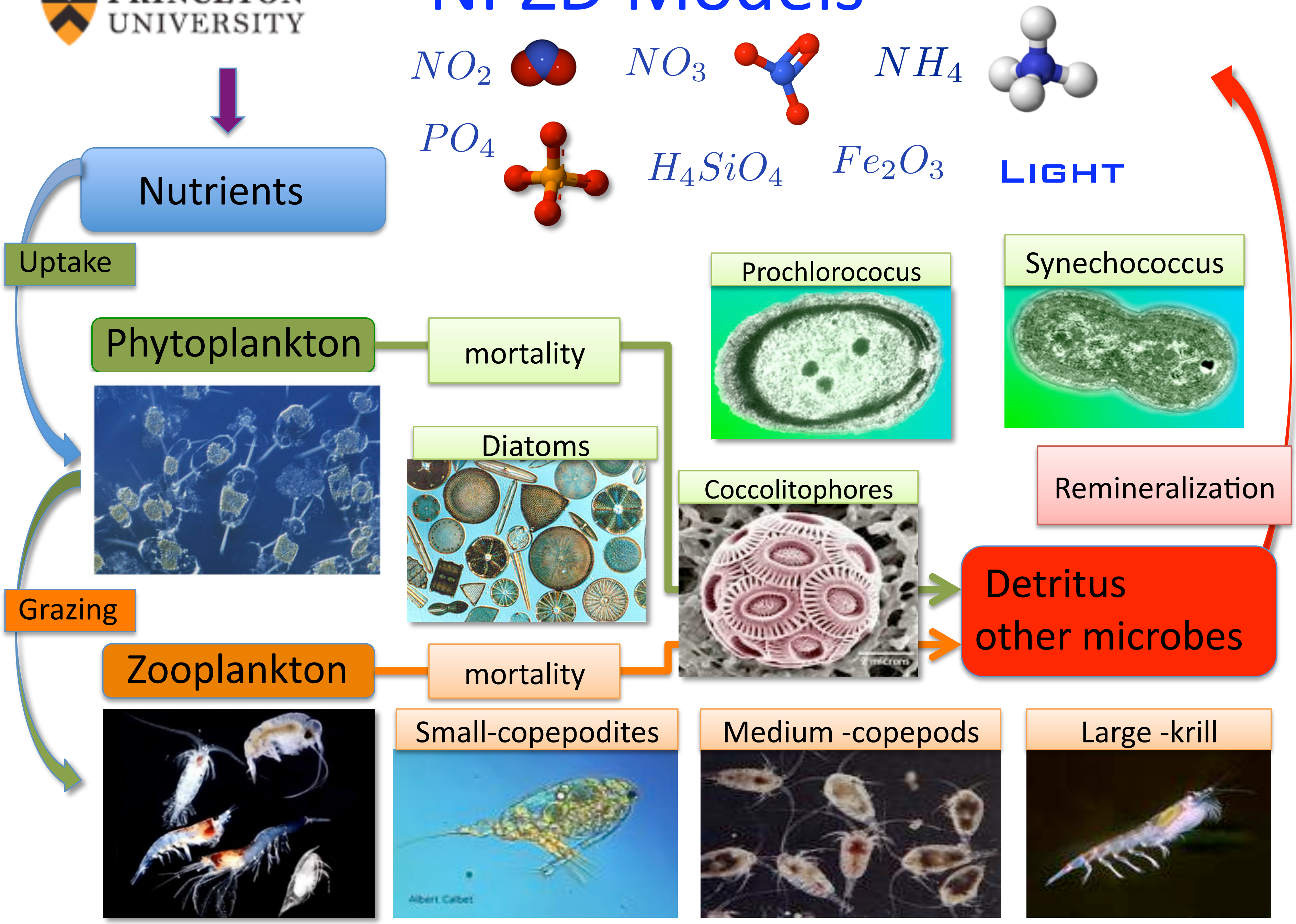
NPZD Models



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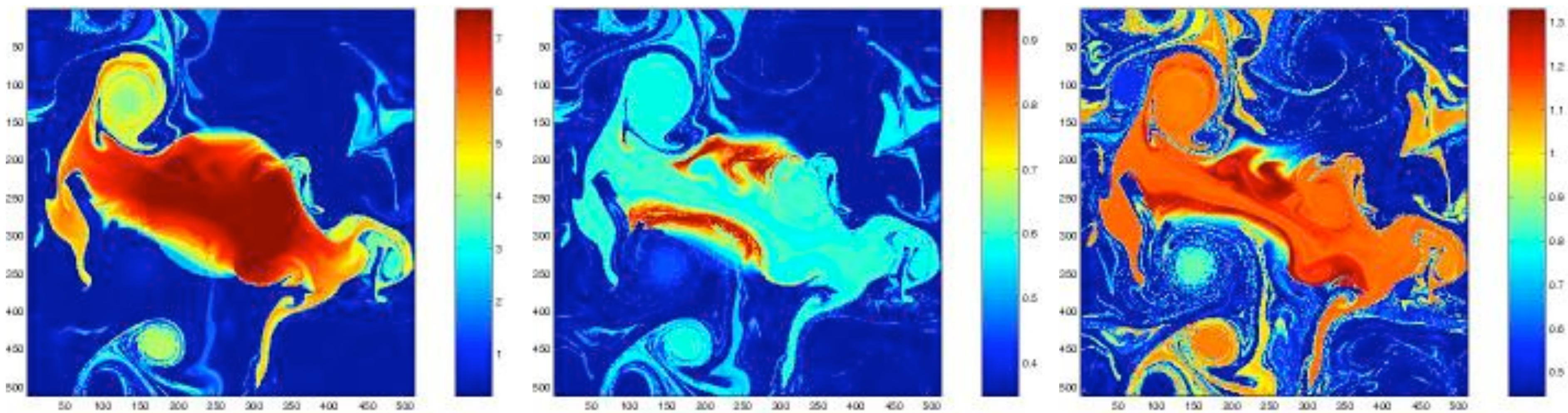
NPZ coupled with CFD

Nutrient field | Phytoplankton | Zooplankton



Pasquero, Bracco, Provenzale, *Shallow Flows, (*2004)

http://www.ess.uci.edu/~cpasquer/projects.html

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Issues with classical NPZD models

Who decides what constitutes a functional type?

How can one deal with the problem of the diversity that we don't know about, particularly when it is related to variations in metabolism?

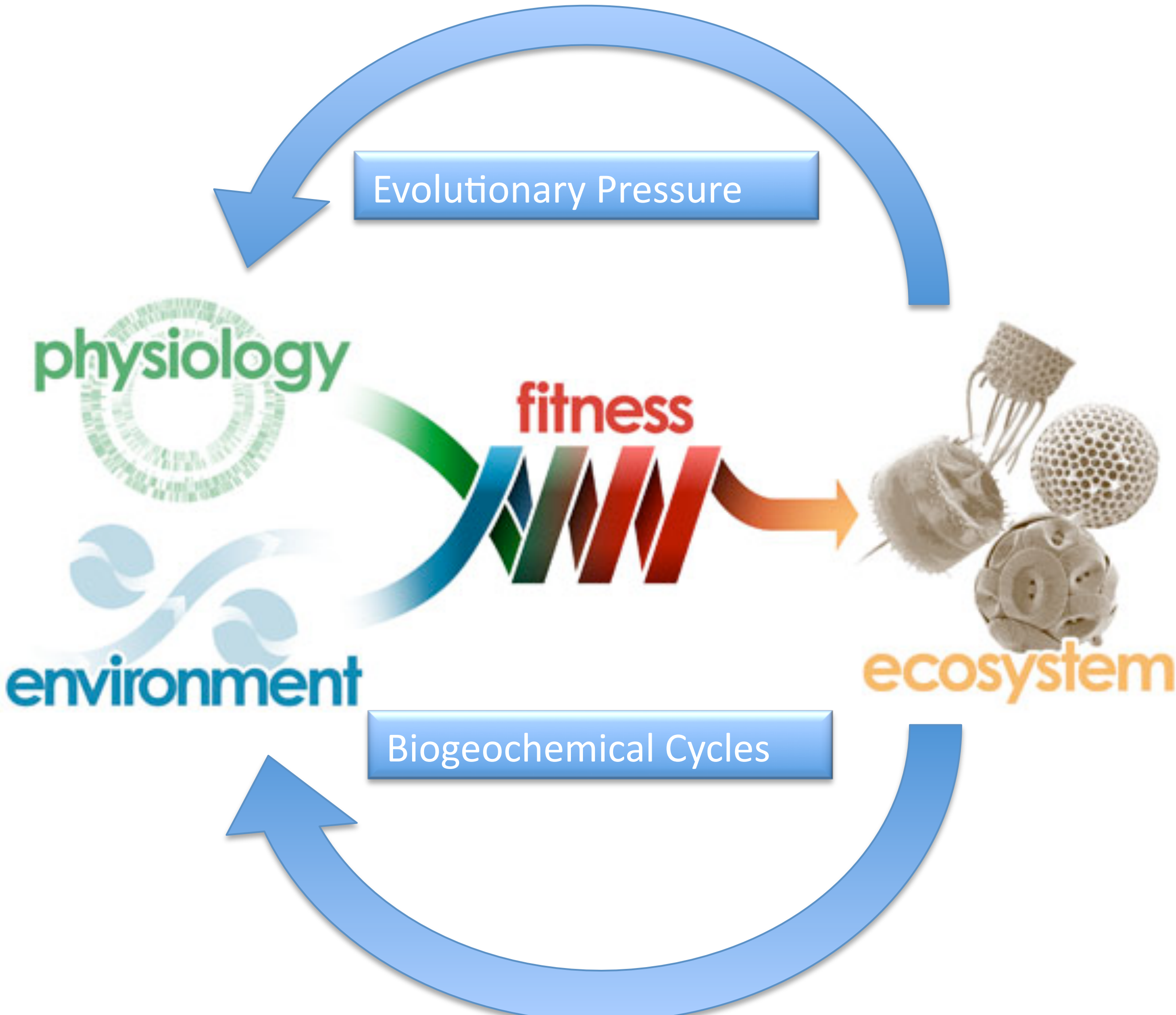
What determines the functional forms that control the rates in NPZD models?

What about macroscopic patterns that we yet don't know about (e.g. metagenomics/ new cultivation methods), can theory predict them?

Tracer transport modeling of plankton, many of these organisms actively aggregate.

`Everything is everywhere but the environment selects'

L. Baas-Becking



Slide courtesy of Stephanie Dutkiewicz

Towards a Trait-Based Ecology, the MIT-DARWIN Model

$$\frac{\partial N_i}{\partial t} = \overbrace{-\nabla \cdot (\mathbf{u}\, N_i) + \nabla \cdot (K\, \nabla N_i)}^{\textbf{u} \text{ and } \textbf{K} \text{ from ECCO2 GCM}} - \overbrace{\sum_j \mu_j P_j R_{ij}}^{\text{Phyto growth}} + \overbrace{S_{N_i}}^{\text{Remineralization \& other sources}}$$

$$\frac{\partial P_j}{\partial t} = -\nabla \cdot (\mathbf{u} P_j) + \nabla \cdot (K \nabla P_j) \overbrace{+\mu_j P_j}^{\text{Growth}} - \overbrace{m_j^P P_j}^{\text{Mortality}} - \overbrace{\sum_k g_{jk} \frac{P_j Z_{k,i=1}}{P_j + k_j^P}}^{\text{Grazing}} - \overbrace{\frac{w_j^P \partial P_j}{\partial z}}^{\text{Sinking}}$$

$$\frac{\partial Z_{ki}}{\partial t} = -\nabla \cdot (\mathbf{u}\, Z_{ki}) + \nabla \cdot (K\, \nabla Z_{ki}) - m_k^Z Z_{ki} + \sum_k g_{jk} \frac{P_j R_{ij}}{P_j + k_j^P}$$

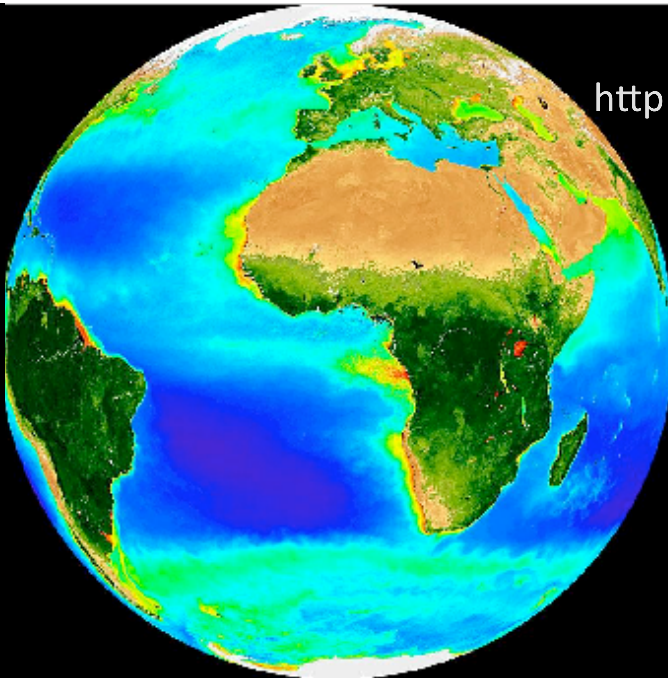
$$\frac{\partial PO_i}{\partial t} = -\nabla \cdot (\mathbf{u}\, PO_i) + \nabla \cdot (K\, \nabla PO_i) \overbrace{-r_{PO_i} PO_i}^{\text{Remineralization}} - \overbrace{w_{POM} \frac{\partial PO_i}{\partial z}}^{\text{Sinking}} + S_{PO_i}$$

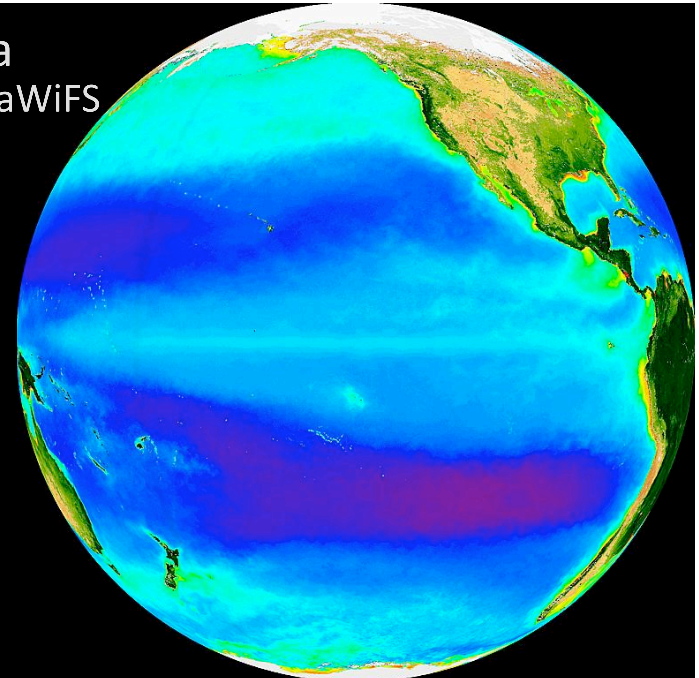
$$\frac{\partial DO_i}{\partial t} = -\nabla \cdot (\mathbf{u}\, DO_i) + \nabla \cdot (K\, \nabla DO_i) - r_{DO} DO_i + S_{DO_i}$$

C Wunsch & P Heimbach, *Physica D* **230**,197 (2007)   MJ Follows *et al*, *Science* **315**, 1843 (2007)

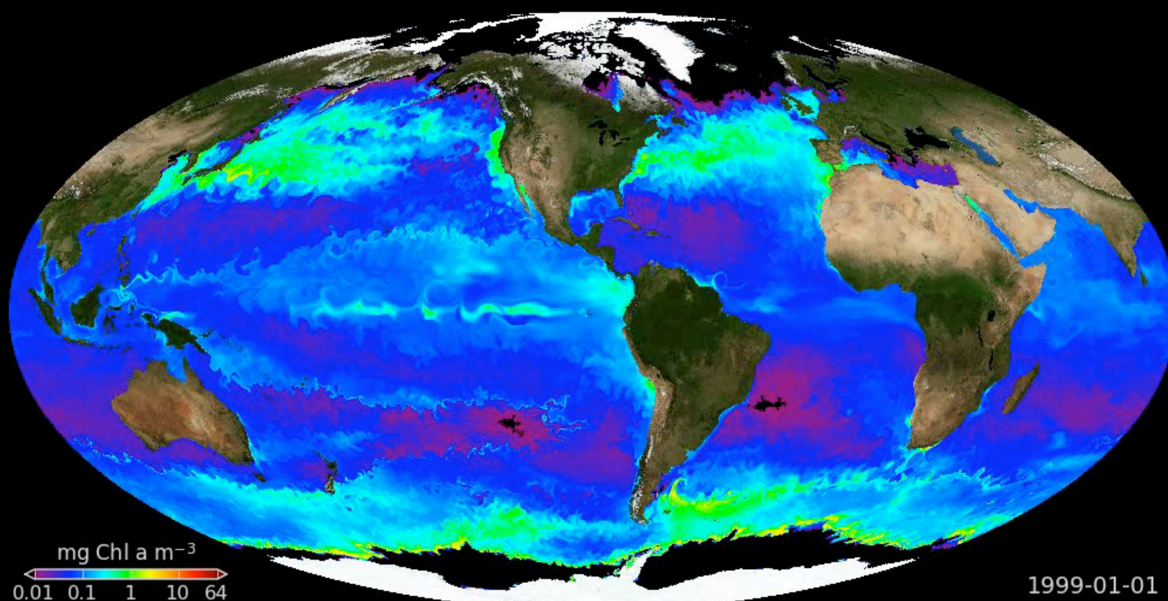
Chl a from SeaWiFS data

http://oceancolor.gsfc.nasa.gov/SeaWiFS



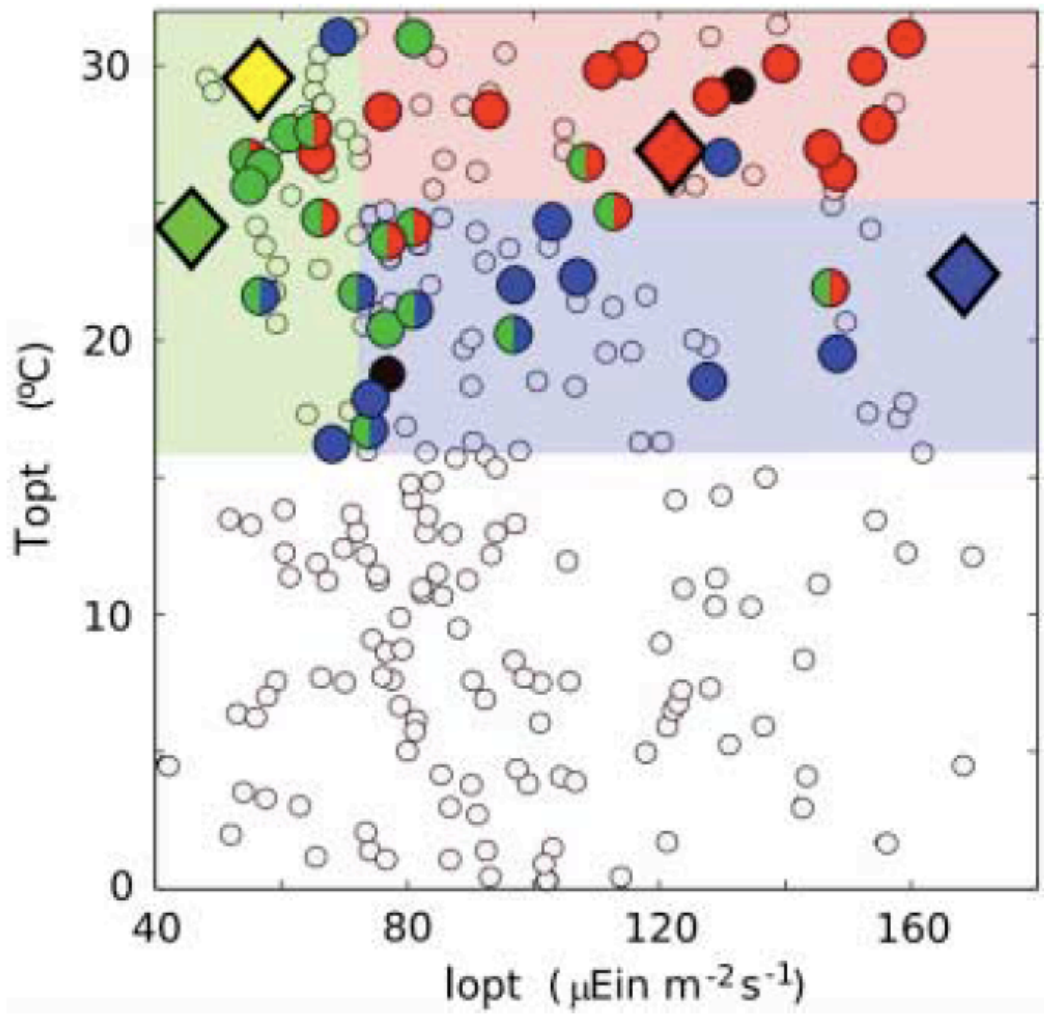


Chl a from the coupled ECCO2-Darwin Model



Images courtesy of Stephanie Dutkiewicz ,Oliver Jahn, Chris Hill and Mick Follows

DARWIN output



Winning *prochlorococcus* ecotypes in the DARWIN simulation (circles) vs observed *prochlorococcus* (diamonds) along the AMT-13 Transect.

MJ Follows *et al*, *Science* **315**, 1843 (2007)

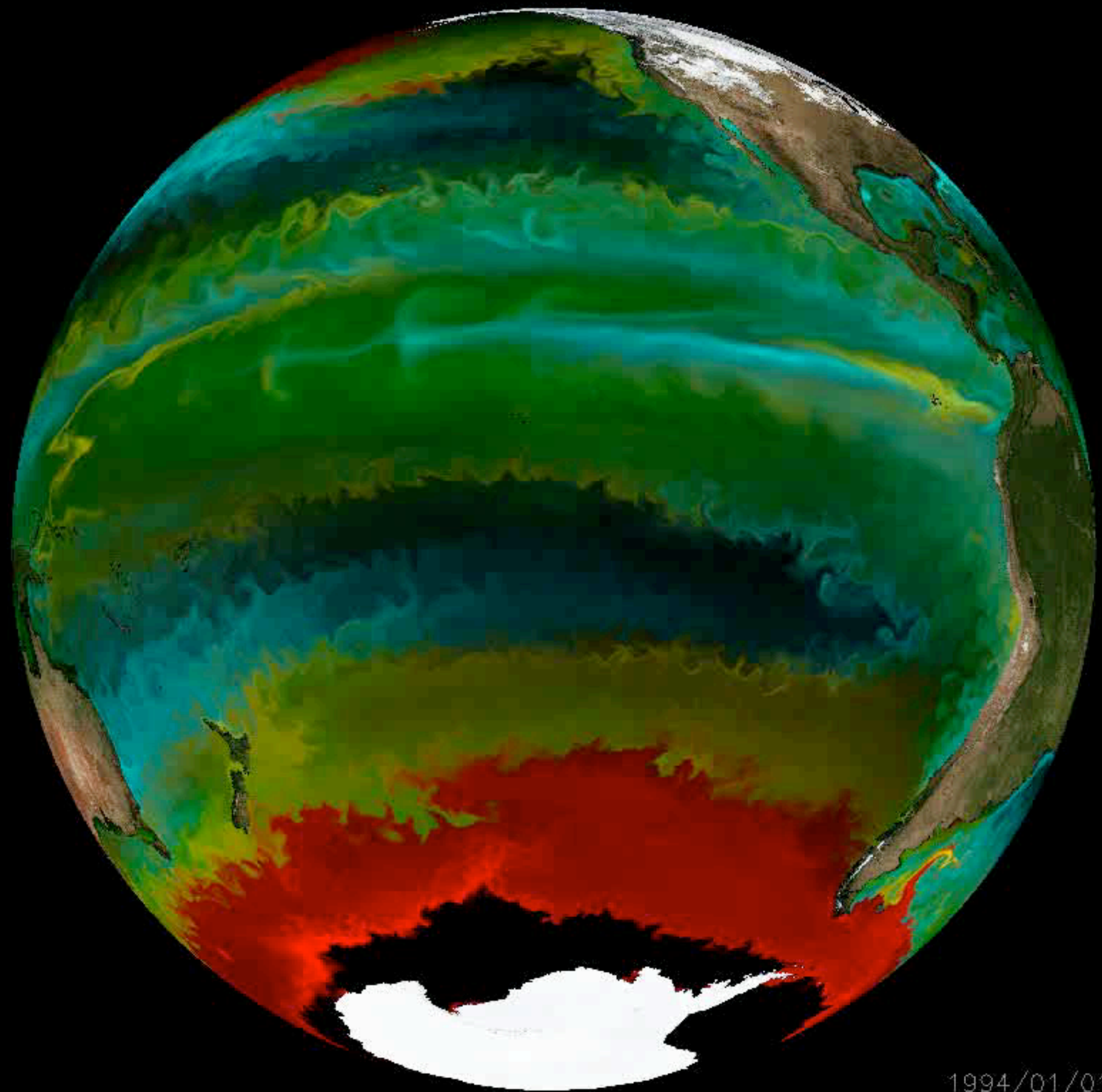
Most abundant types

Prochlorococcus

Synechococcus

Diatoms

Large eukaryote



Images courtesy of Stephanie Dutkiewicz ,Oliver Jahn, Chris Hill and Mick Follows

Project goals-> A *trait*-based representation of the community

- Derive nutrient uptake functional form from an individual-based model.
- Identify trade-off surface linking maximum growth rates with half saturation constants for N and P.
- Derive Droop model from an individual based- model.
- Use these functional forms to generate flexible stoichiometries.
- Establish the role of viruses, is an additional pool needed?
- Develop coarse-grained versions of the successful detailed models amenable to analysis.