Modelling phytoplankton distributions in the ocean: a novel multi-species approach

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Outline

Motivation:

- Why are multi-species models important for export?
- What's new with the stochastic approach?

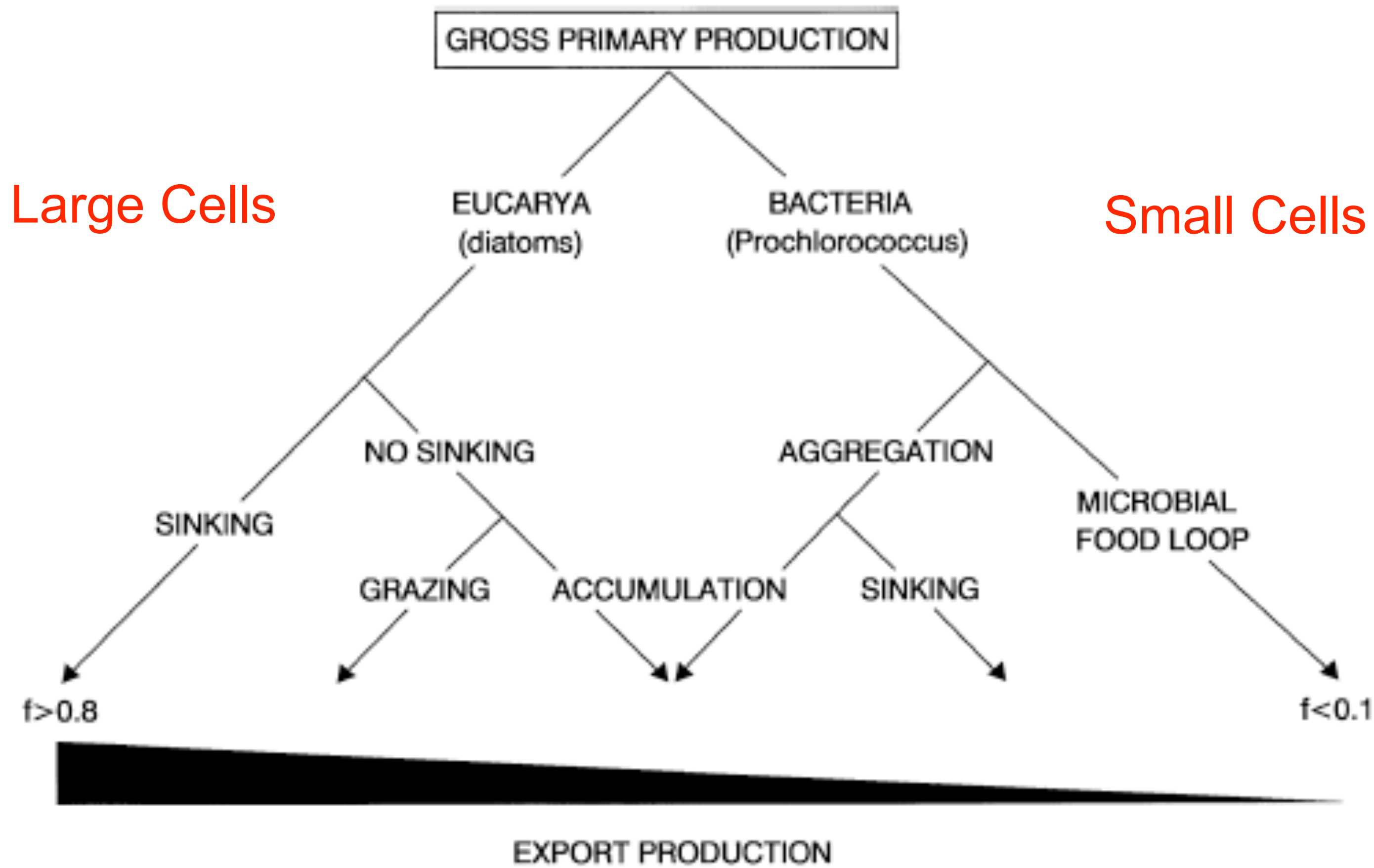
Illustrating the model:

- Hypothesis
- Model framework and outcomes
- How do the phytoplankton interact?

Global Application

Summary

Motivation



- Diatoms
- Coccolithophores
- Biogeochemical cycles

from Karl *et al.*, 2001

Motivation

Stochastic approach

- Avoid preconceived combinations of parameter values
- Initialise many potentially viable ecotypes
- Let the ecosystem do the work

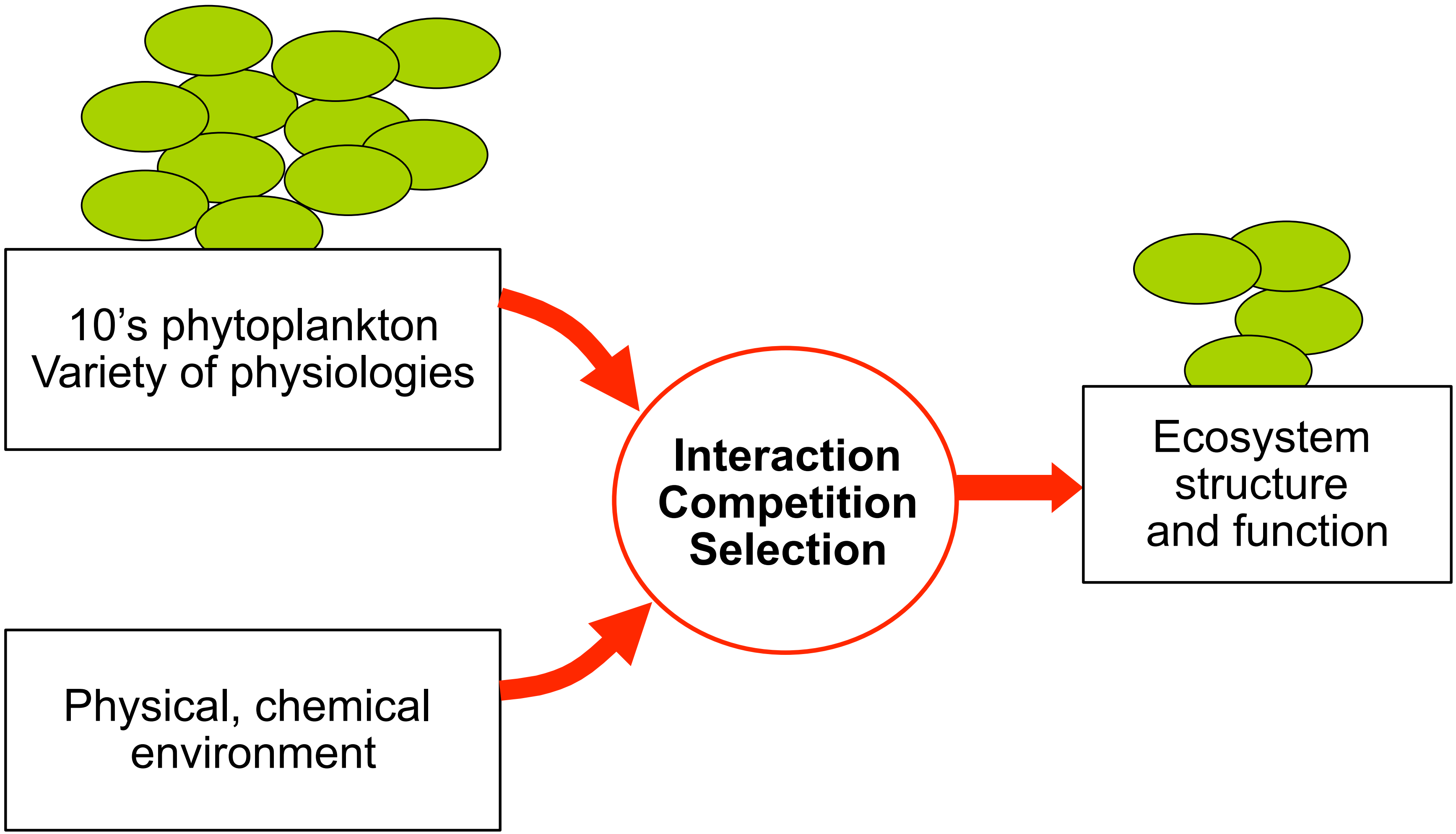
Emergent Biogeography of Microbial Communities in a Model Ocean

Michael J. Follows,[1*] Stephanie Dutkiewicz,[1] Scott Grant,[1,2] Sallie W. Chisholm[3]

A marine ecosystem model seeded with many phytoplankton types, whose physiological traits were randomly assigned from ranges defined by field and laboratory data, generated an emergent community structure and biogeography consistent with observed global phytoplankton distributions. The modeled organisms included types analogous to the marine cyanobacterium *Prochlorococcus*. Their emergent global distributions and physiological properties simultaneously correspond to observations. This flexible representation of community structure can be used to explore relations between ecosystems, biogeochemical cycles, and climate change.

(Follows et al. 2007, Science)

Darwin Ecosystem Model

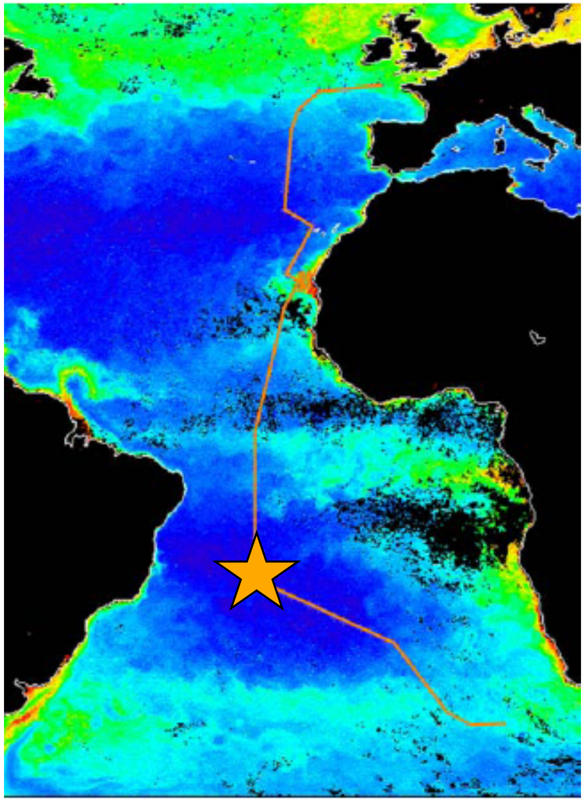


(Follows et al. 2007, Science)

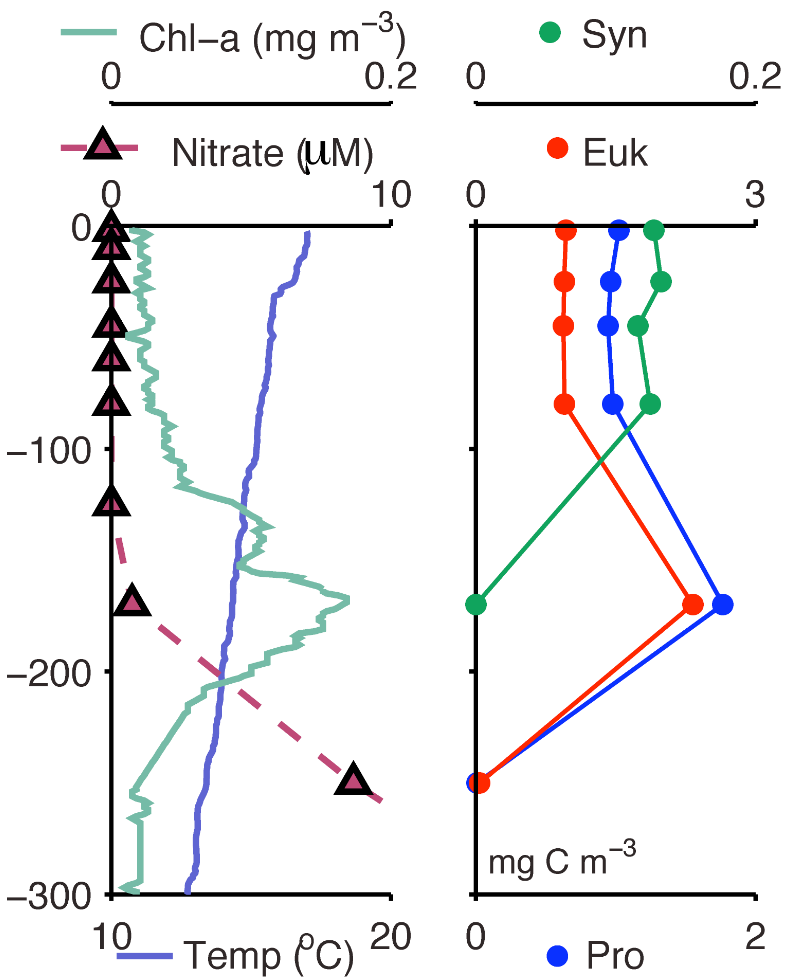
Hypothesis

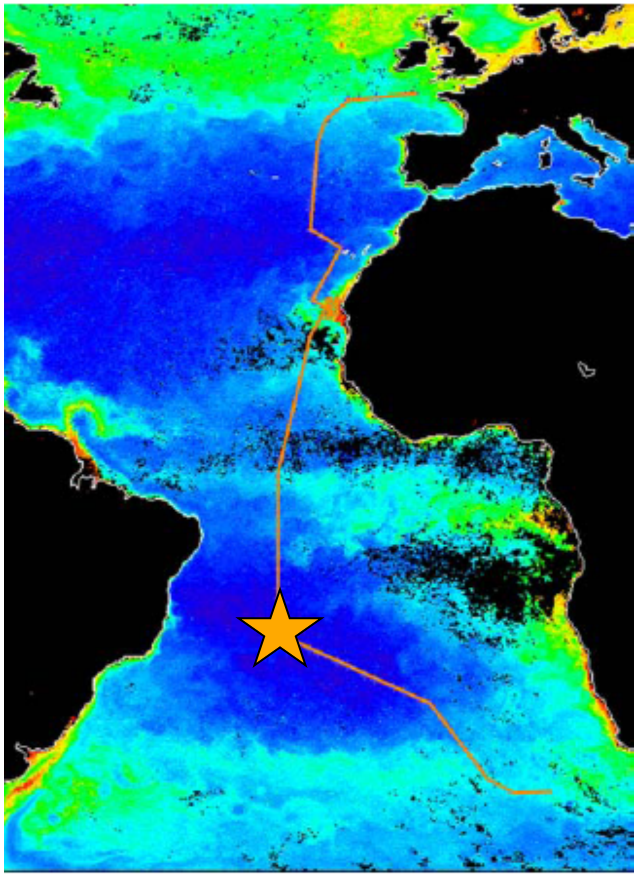
Are pigments important for phytoplankton distributions?

- 1-D profile
- Data AMT-15



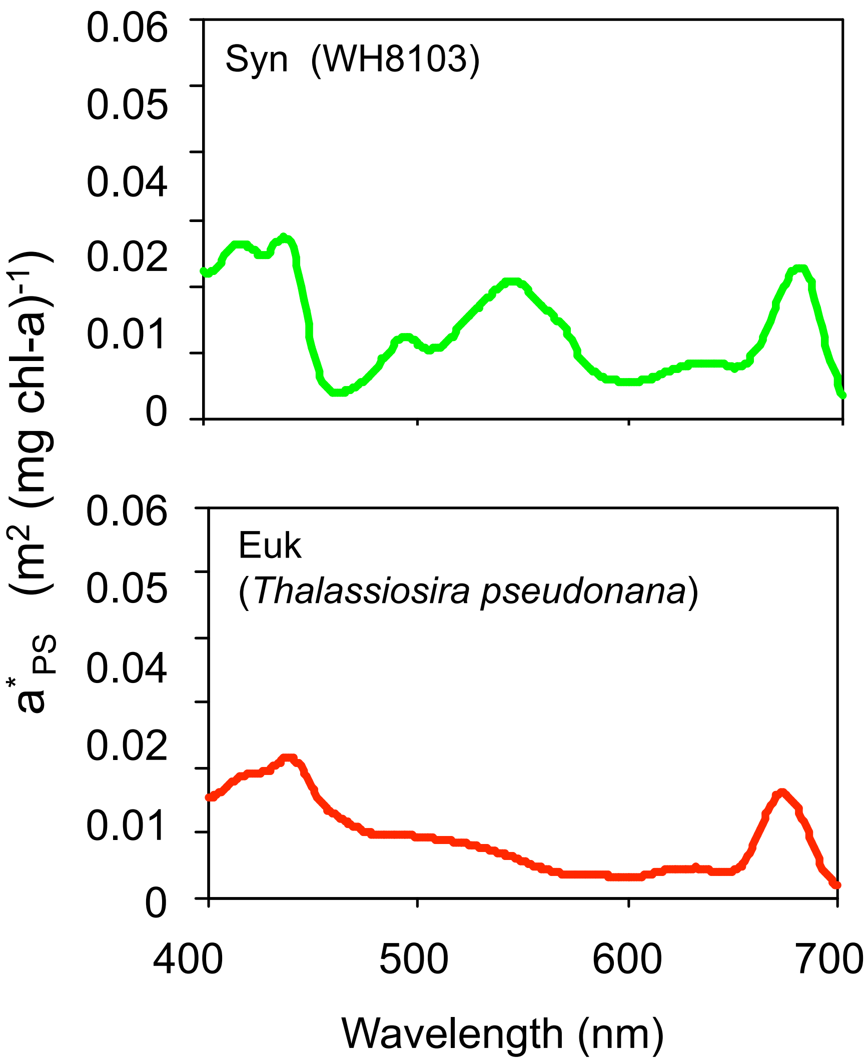
Phytoplankton distributions





(Data courtesy: M. Zubkov, J. Heywood)

Phytoplankton pigments

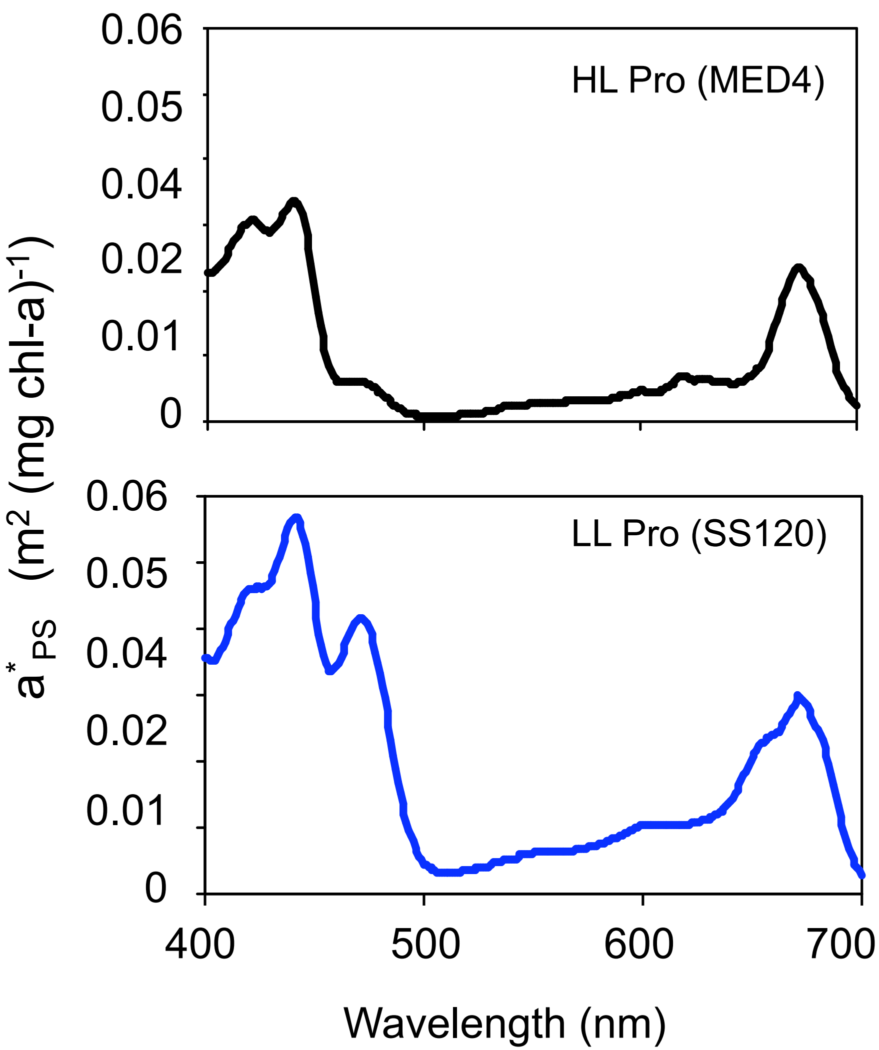


Synechococcus
- Phycobillins
- Zeaxanthin
- β – carotene

Eukaryotes
- 19'-Hex
- 19'-But
- Fucoxanthin
- Peridinin
- Alloxanthin

(Data courtesy: D. Suggett, L. Moore)

Phytoplankton pigments

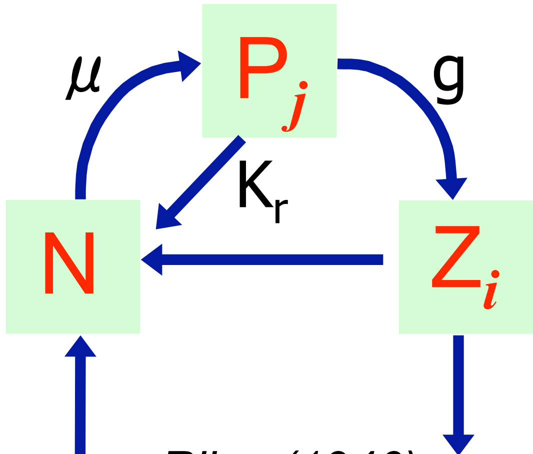


Prochlorococcus

- Div. chl-a
- Div. chl-b
- Zeaxanthin
- α, β -carotenes

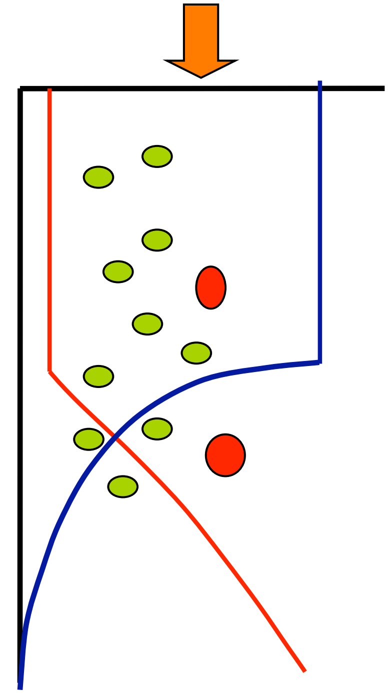
(Data courtesy: L. Moore)

Model Framework



Riley (1946)

- MITgcm (1-D)
- 13 wavebands
  400–700 nm



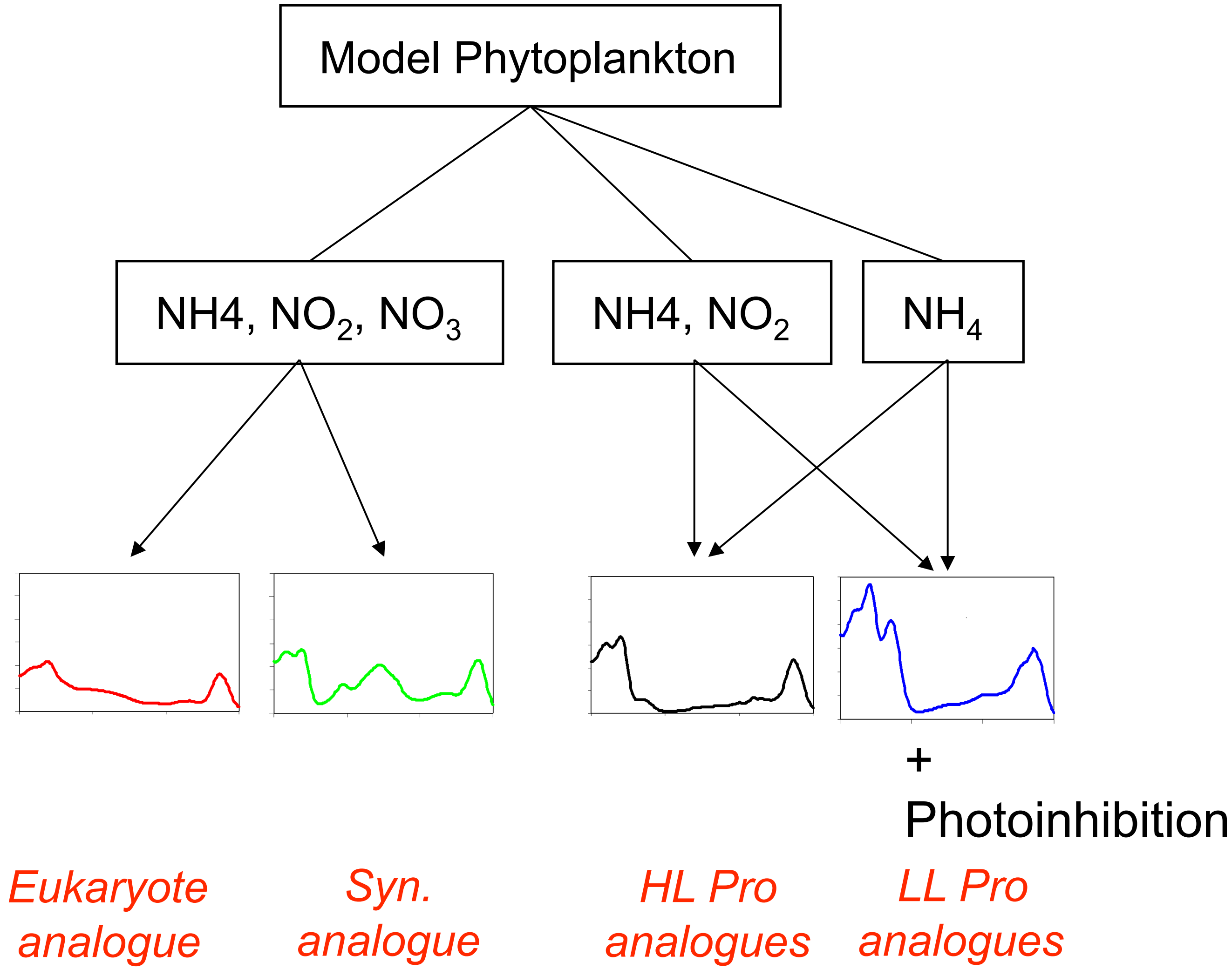
- 1000 phytoplankton ‘phenotypes’
- Temperature
- Nutrients
- Light

vs. Growth

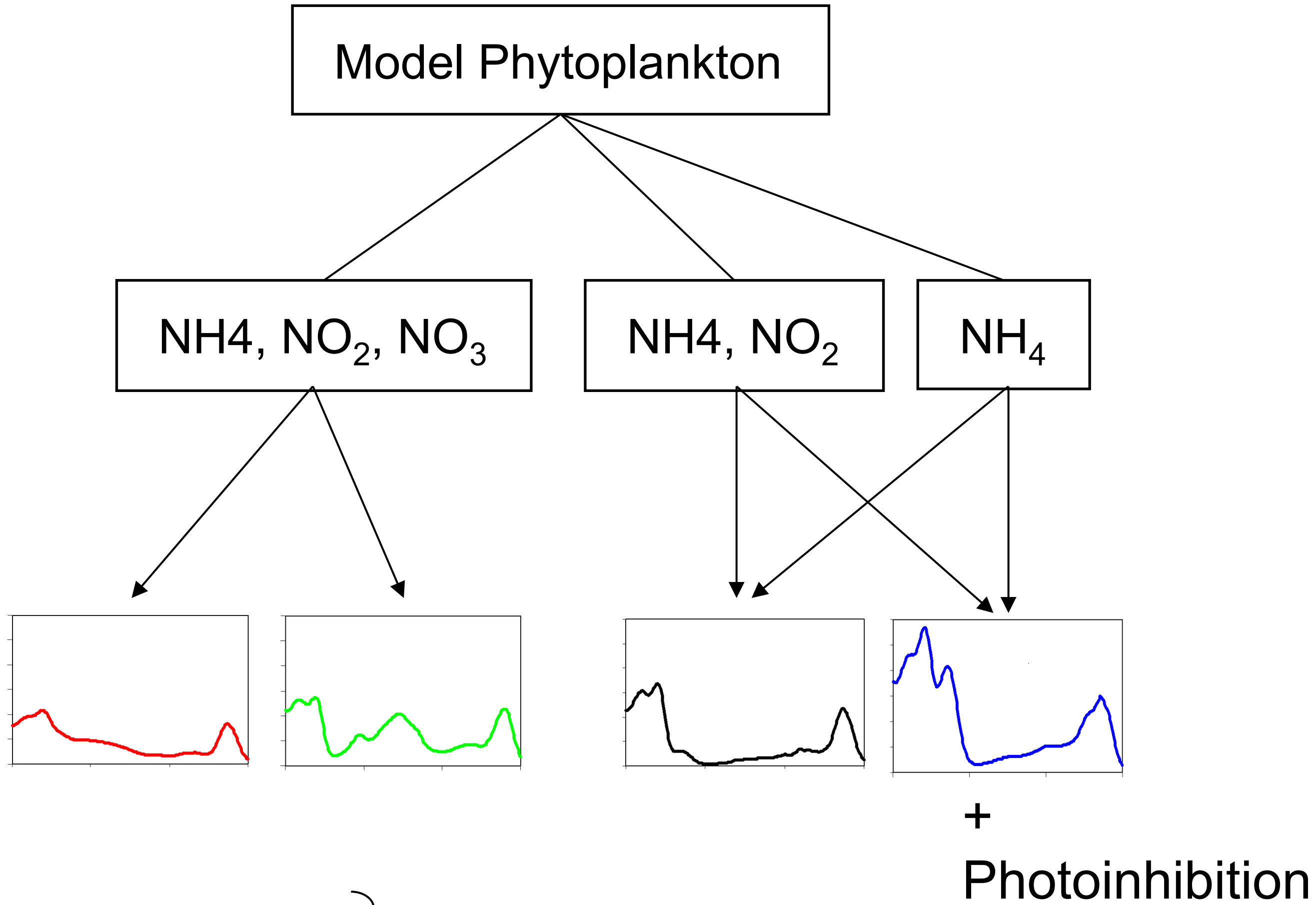
Variable Chl-a:C
(Geider et al. 1997)

Coin Flips
Random selection

Model Framework



Model Framework

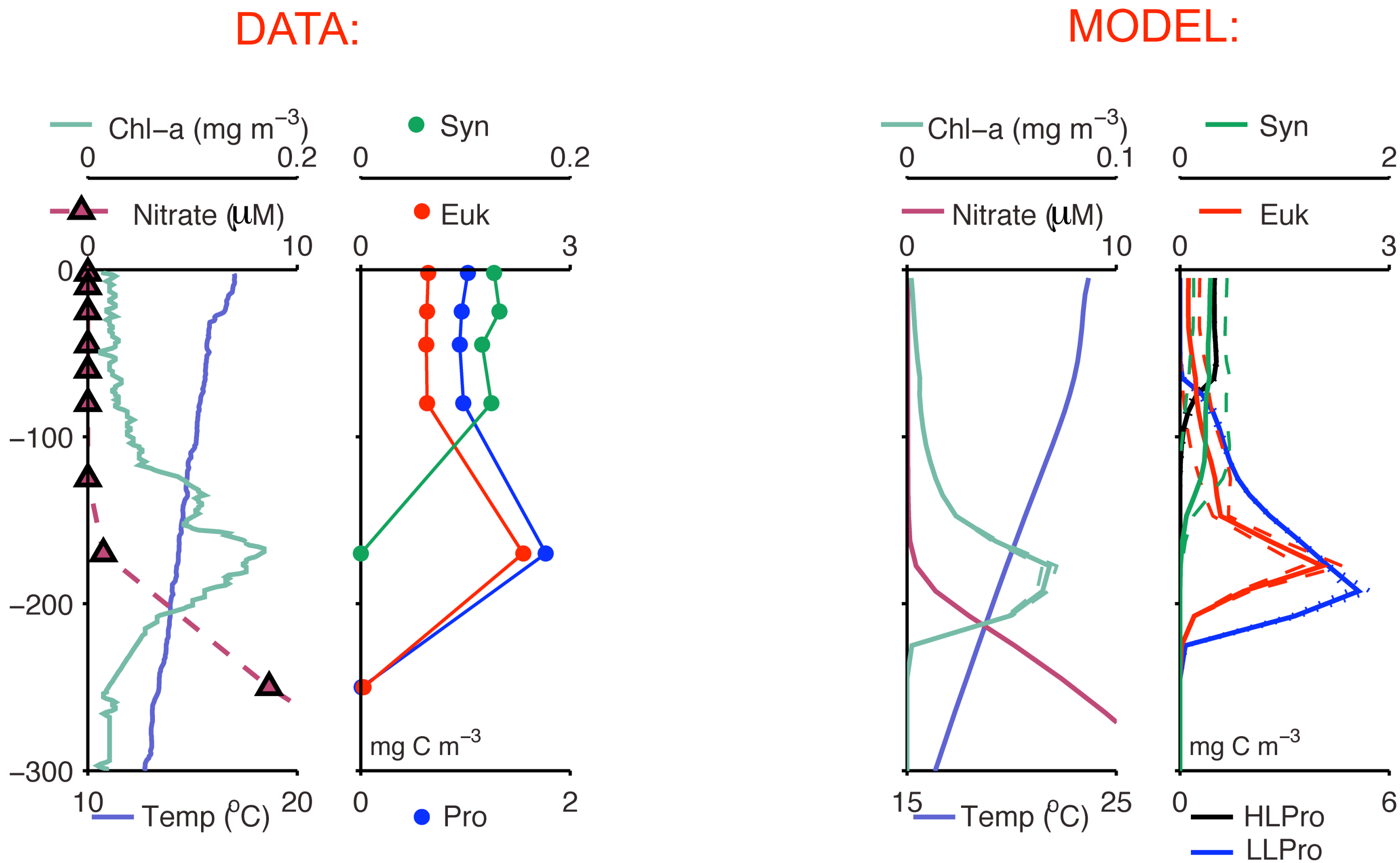


Temperature Optima

Nutrient Half Saturation

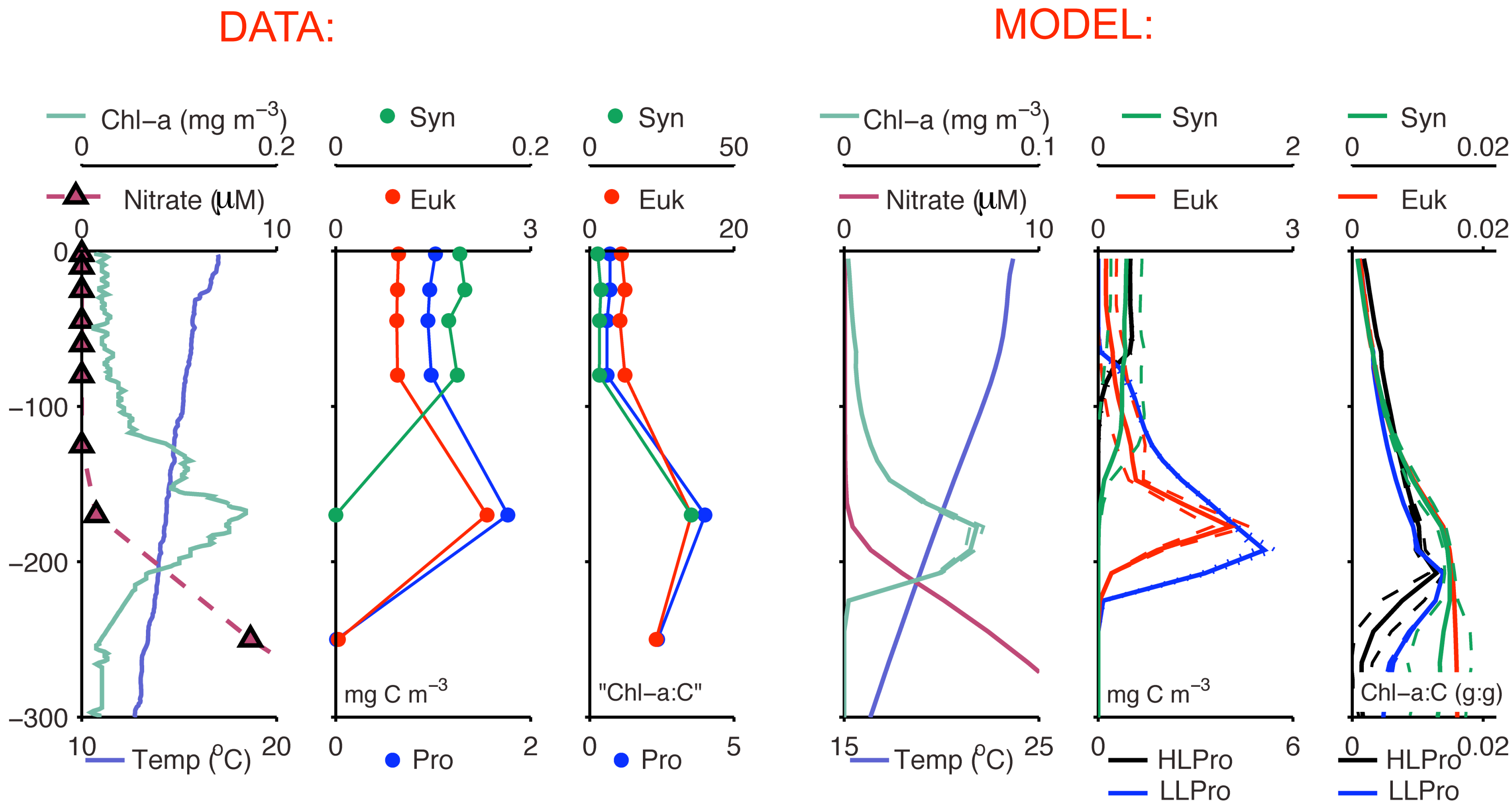
random from ranges

Model vs. Data



(Data courtesy: J. Heywood, M. Zubkov)

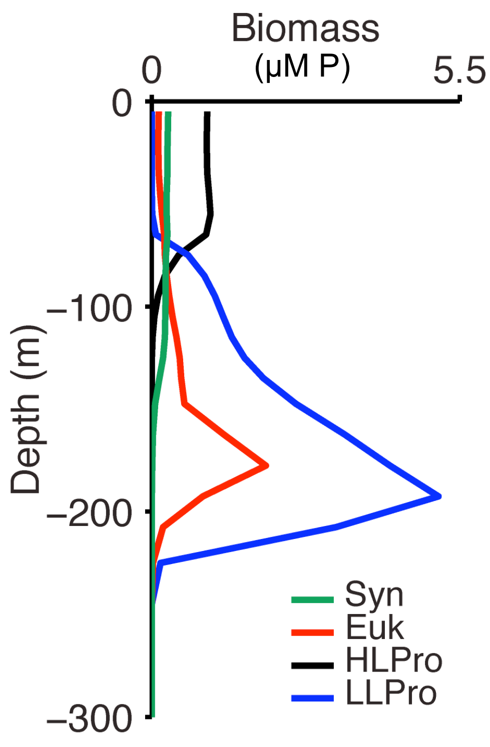
Model vs. Data



(Data courtesy: J. Heywood, M. Zubkov)

Ecotype Selection

MODEL



Pro and non-Pro coexist

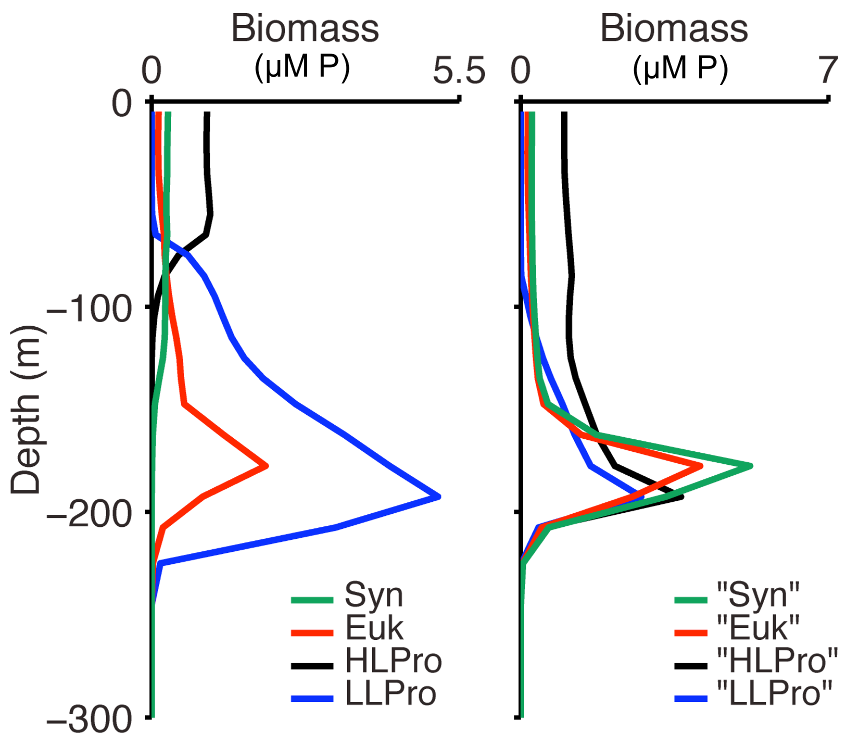
Vertical gradient Syn vs. Euk

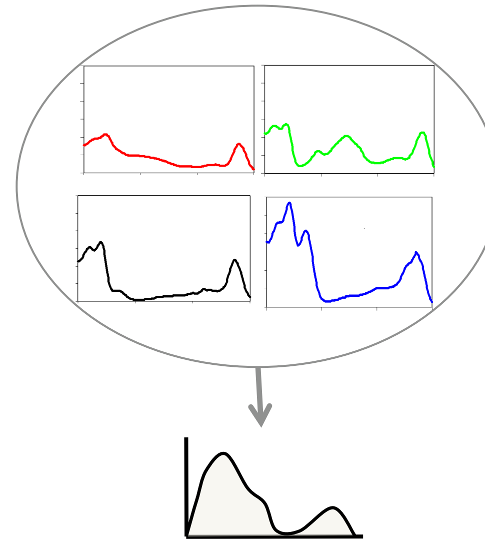
Vertical gradient HL vs. LL Pro

Ecotype Selection

MODEL SAME ABSORPTION SPECRTA

Thought experiment:





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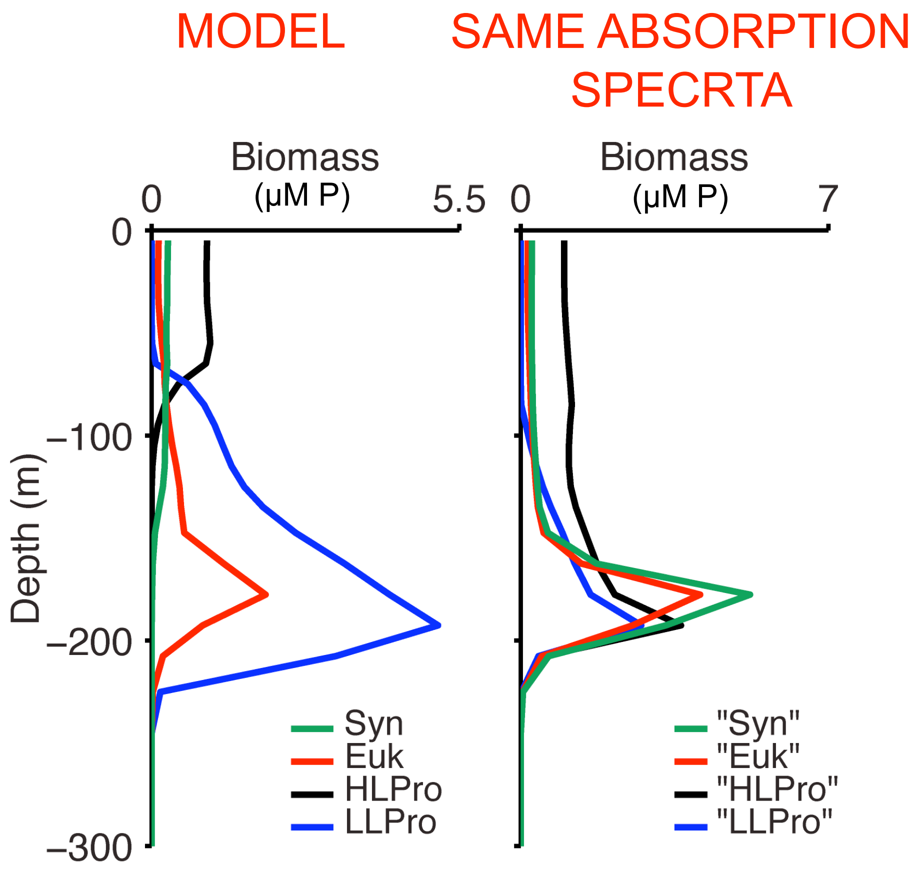
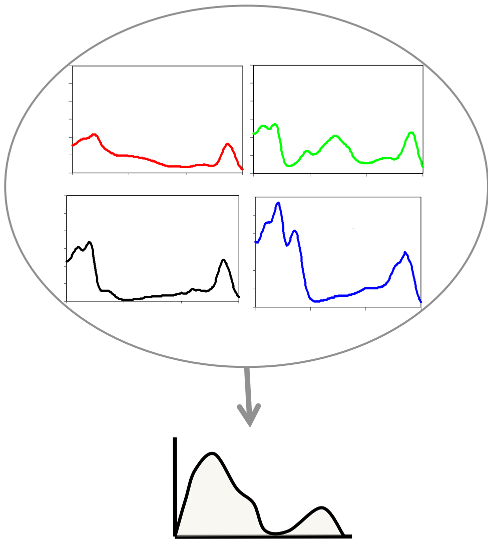
Ecotype Selection

Thought experiment:





Pro and non-Pro coexist

Nutrients

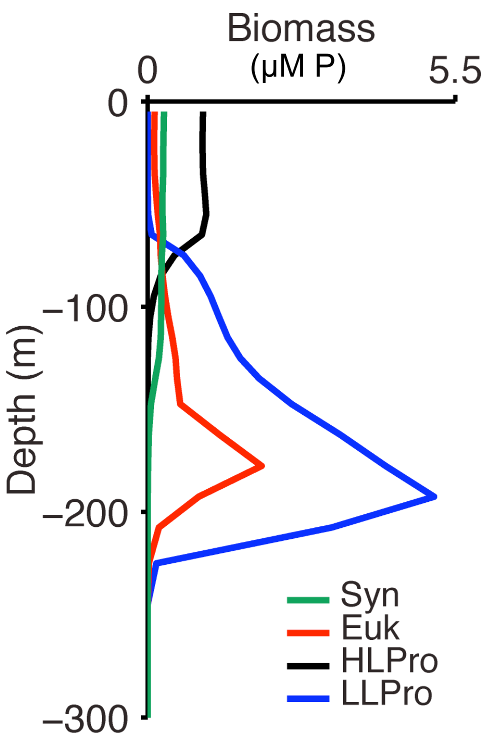
Vertical gradient Syn vs. Euk

Vertical gradient HL vs. LL Pro

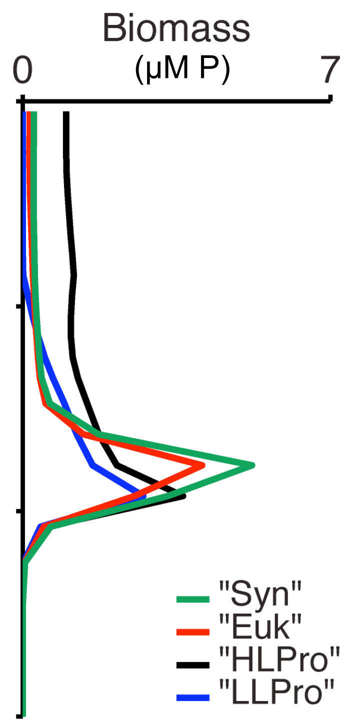
Ecotype Selection

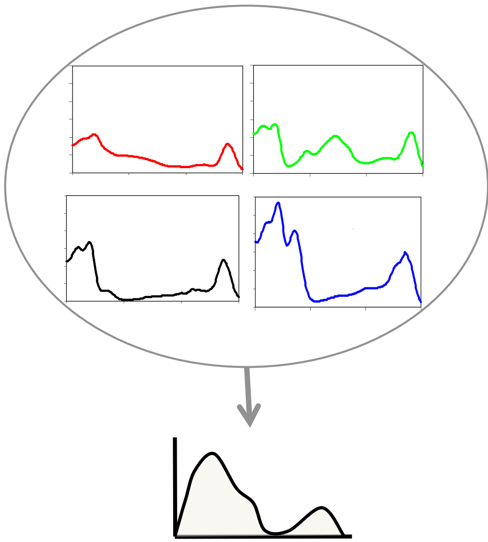
Thought experiment:

MODEL



SAME ABSORPTION SPECRTA





Pro and non-Pro coexist ← Nutrients

Vertical gradient Syn vs. Euk ← Spectral Light Absorption

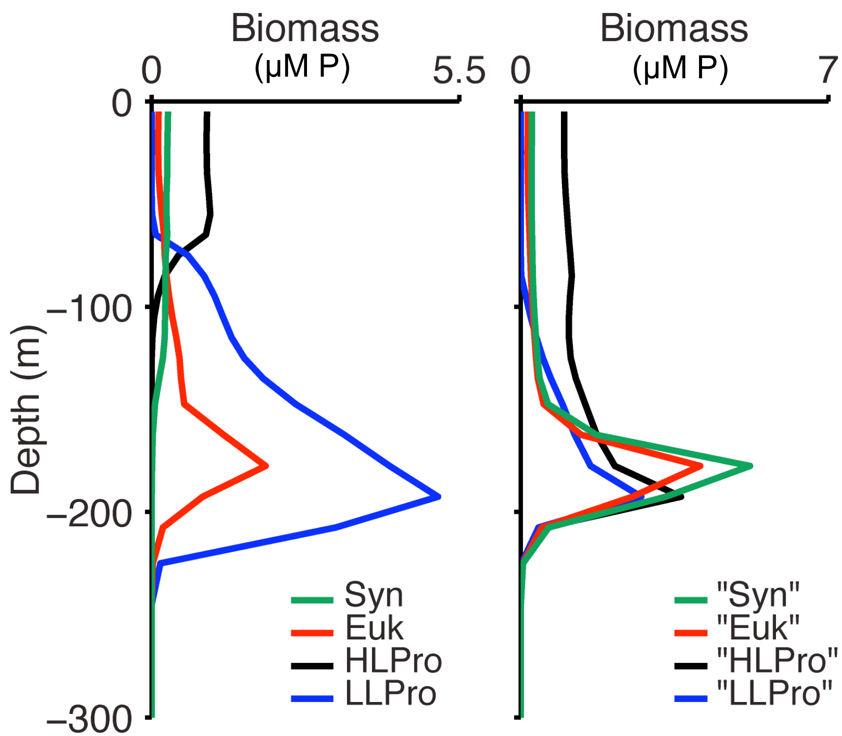
Vertical gradient HL vs. LL Pro

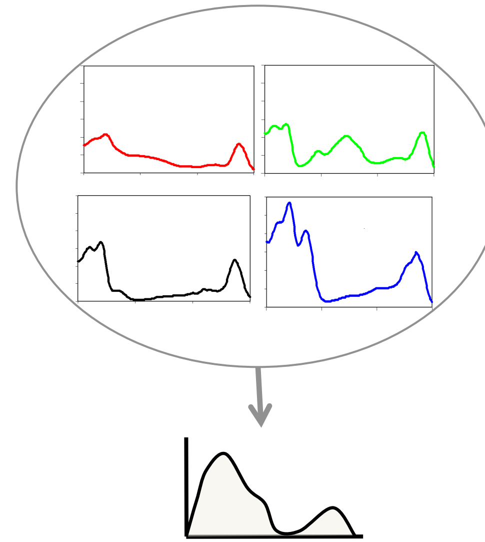
Ecotype Selection

Thought experiment:

MODEL

SAME ABSORPTION SPECRTA



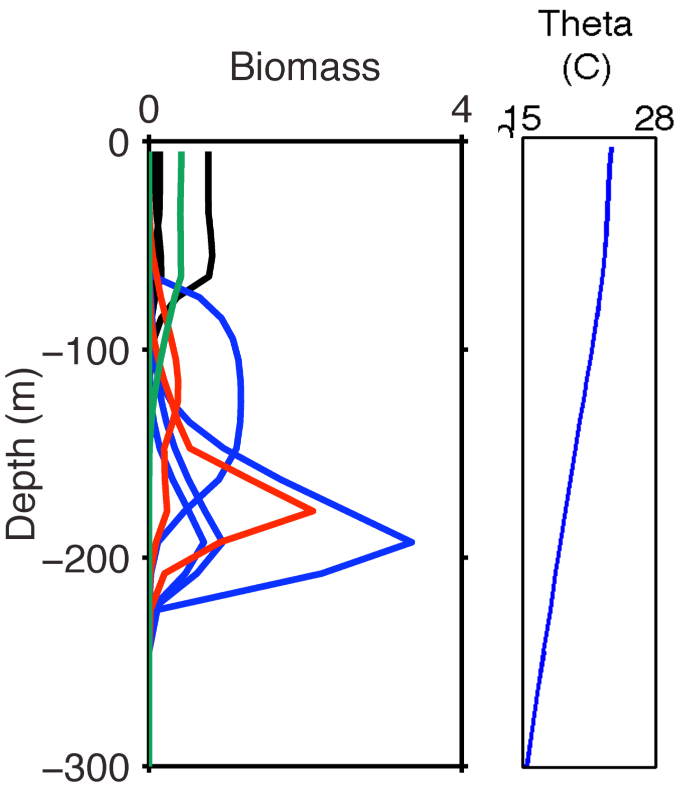


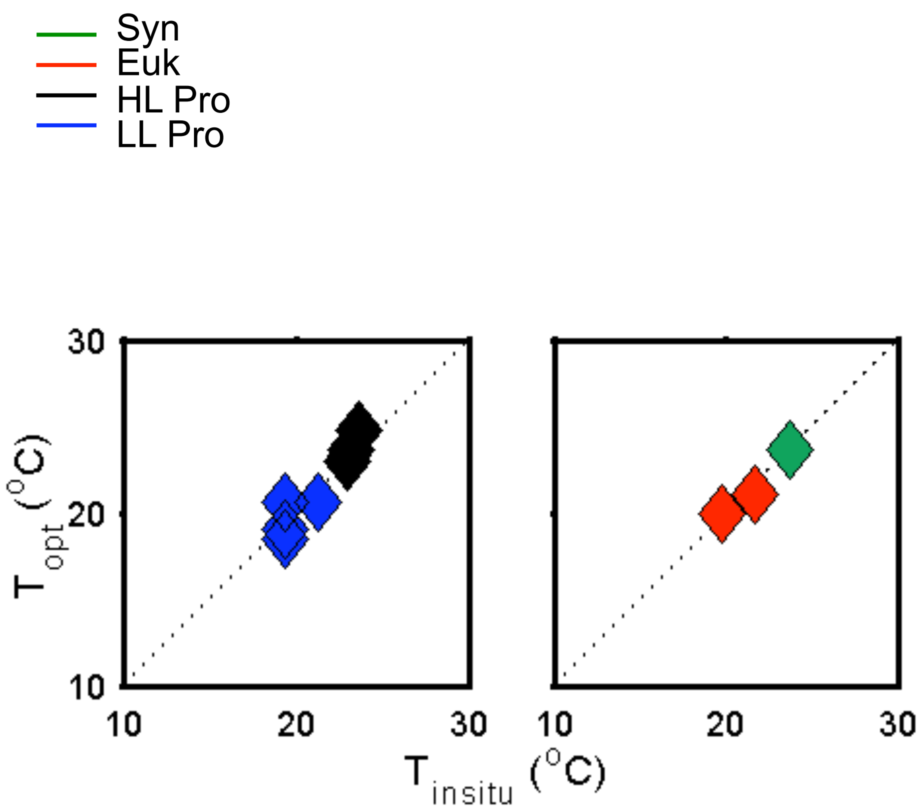
Pro and non-Pro coexist ← Nutrients

Vertical gradient Syn vs. Euk ← Spectral Light Absorption

Vertical gradient HL vs. LL Pro ← Photoinhibition

Ecotype Selection





Selection for lowest K_{sat}

Competition on Temp gradient

Hypothesis Summary

Are pigments important for phytoplankton distributions?

- Pigments are important for

  Syn vs. Euk

- Photoinhibition important for

  LLPro vs. HLPro *(Six et al. 2007)*

- Combination of traits is important

  nutrients, temperature, light "optimised"

Global Application

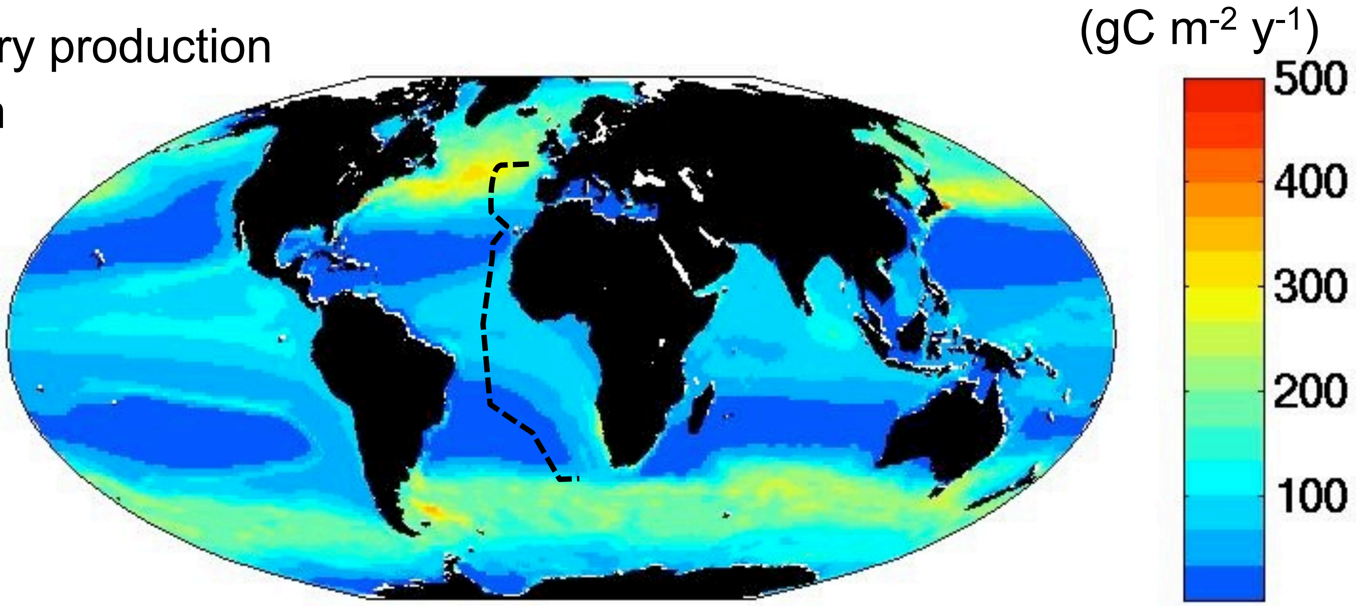
What about global distributions?

3-D application (MITgcm) 8 phytoplankton types:

Includes Large (size trade-offs)

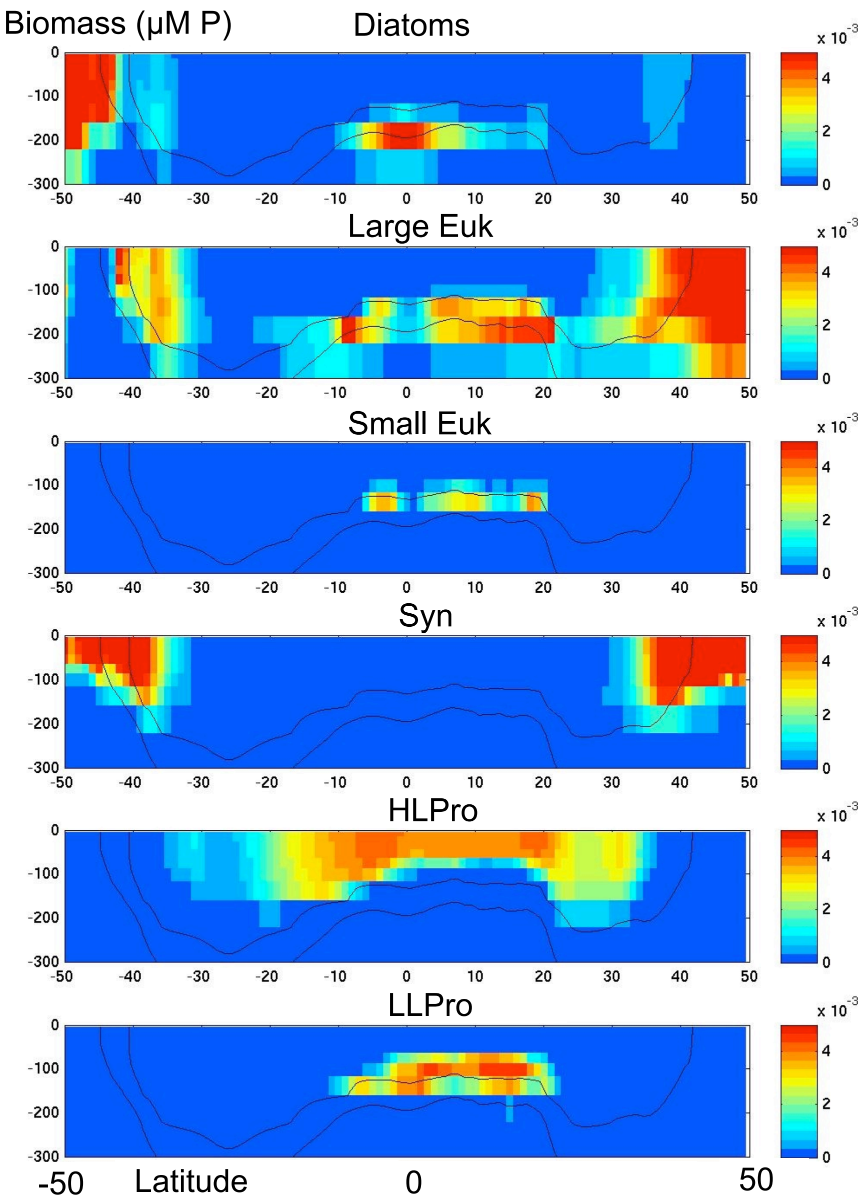
Includes Large Si -using

Primary production 0-55m

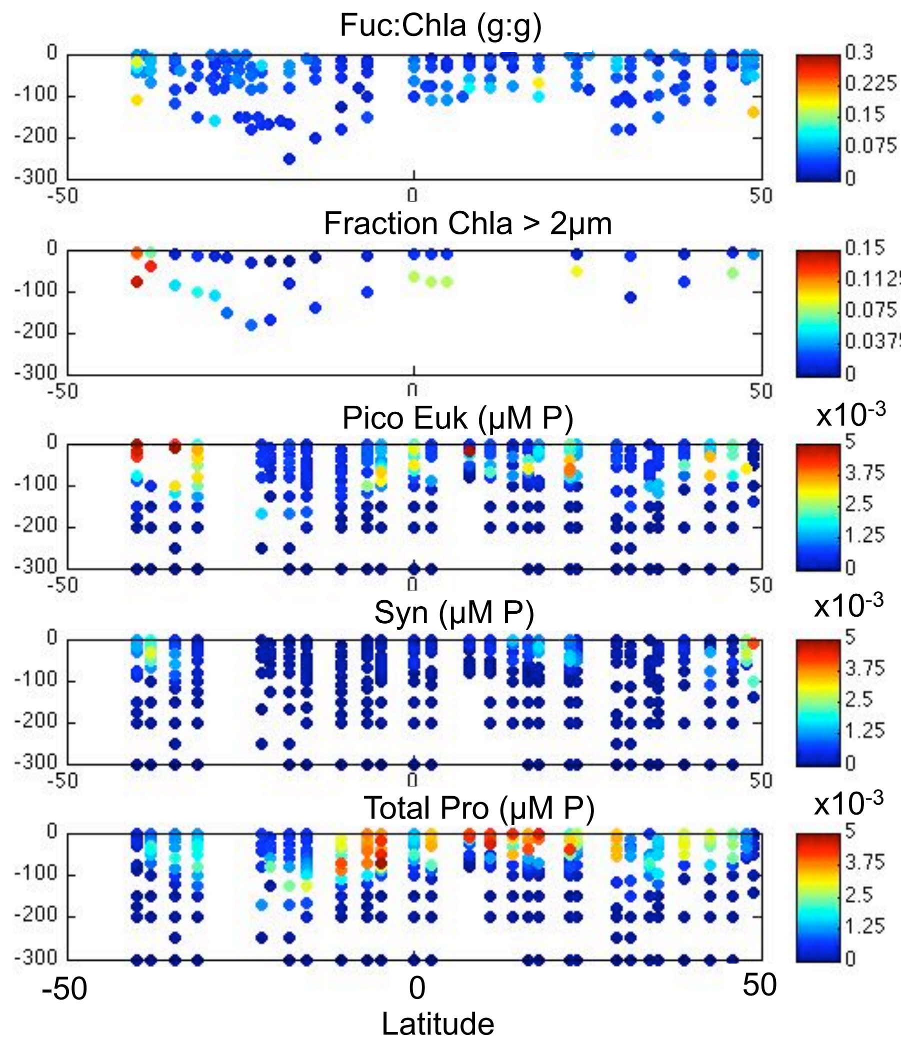


Global Model

MODEL:



DATA:

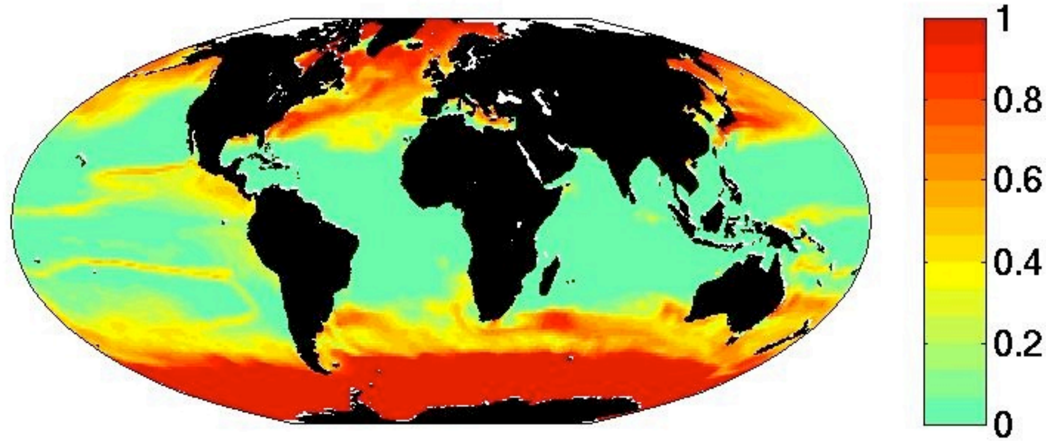


(Data courtesy: AMT community)

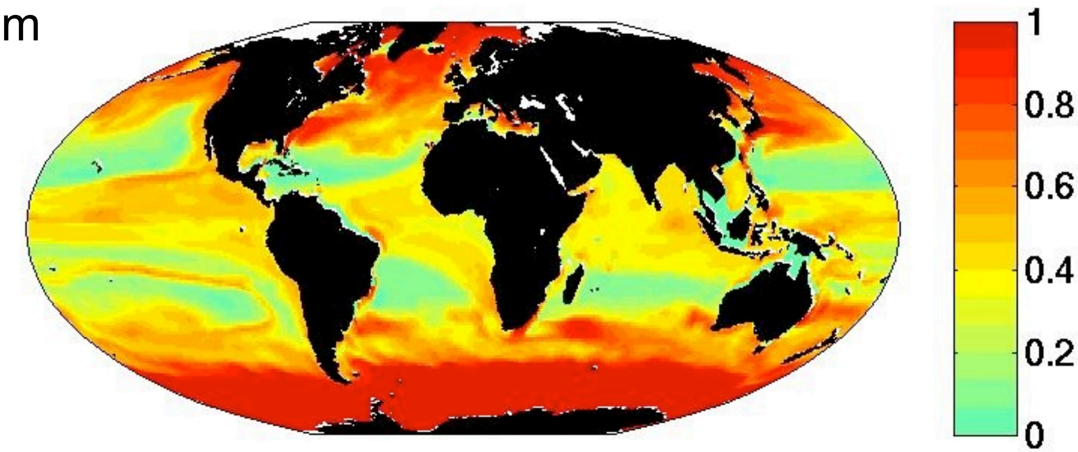
Global Model

Large Phyto :Total Phyto Biomass

0-55m



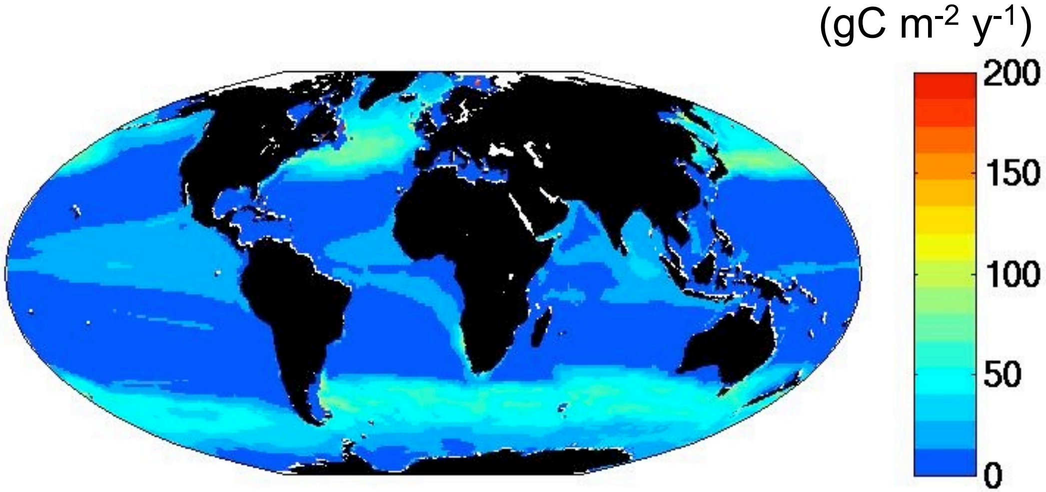
0-175m



Global Model

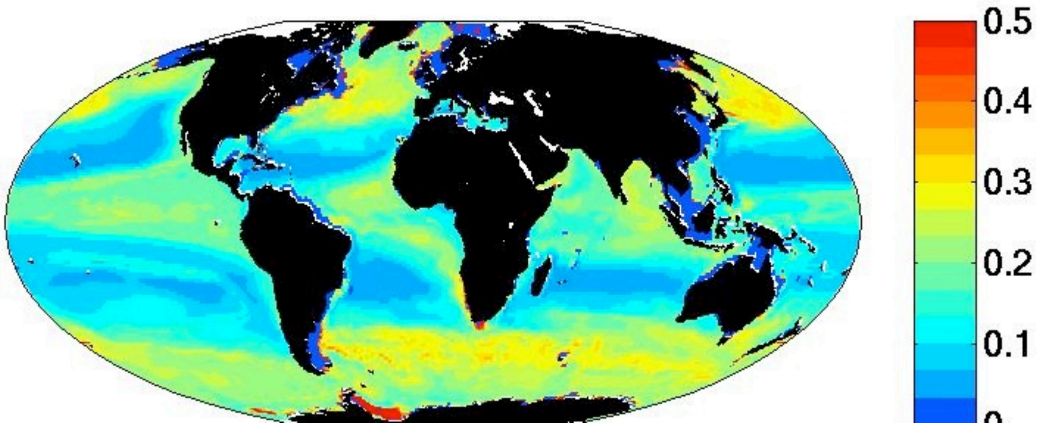
Export:

POC flux
through 0.1%
light level



POC flux
through 0.1%
light level
: Primary Production

("ez-ratio"
of Buesseler & Boyd, 2009)



Overall Summary

The stochastic approach:

- is flexible new tool
- brings to the fore the fundamentals of physiology and ecosystem processes

Open Questions: physiological principles, trade-offs.

Overall Summary

Potential for modelling export:

- resolving size structure
- explicit carbon
- resolving optics (radiative transfer)
  - Coccolithophore scattering
- trophic interactions

Acknowledgements:

Mick Follows, Stephanie Dutkiewicz, Ric Williams, Oliver Jahn, Dave Suggett, Lisa Moore, Jane Heywood, Mike Zubkov, Gerrald Moore, AMT community.