ATS 421/521

Climate Modeling

Spring 2015

Lecture 17

- Ocean Biogeochemistry

May 27, 2015

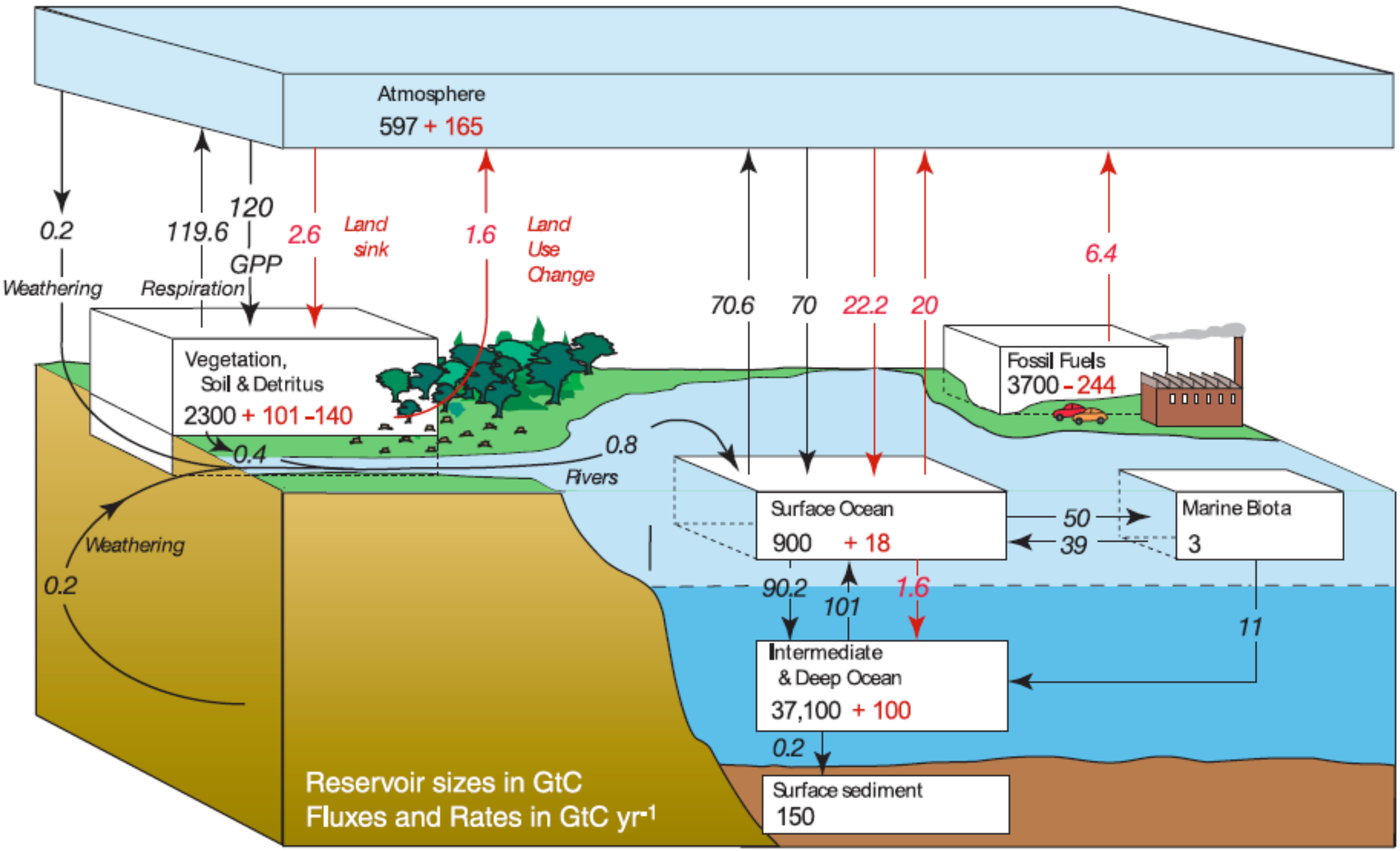
Reading

- Wednesday: textbook chapter 3.3.5 (Marine Biogeochemistry)
- Friday: Friedlingstein et al. (2006)

Paper Outline

- due Friday

The Global Carbon Cycle



2 GtC = 1 ppmv

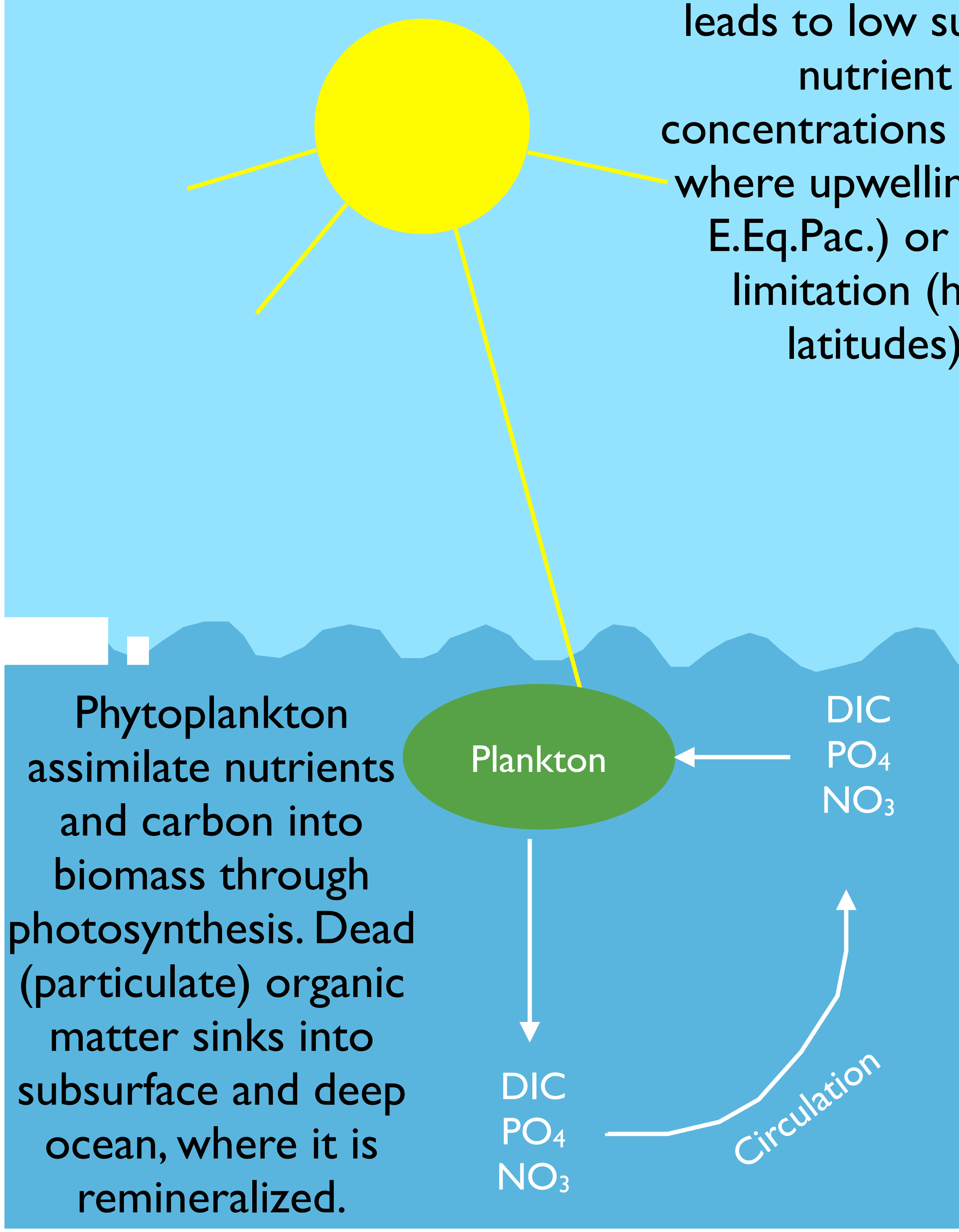
IPCC (2007)

The Biological Pump

1. The Soft Tissue (Organic Matter) Pump

The Biological Pump

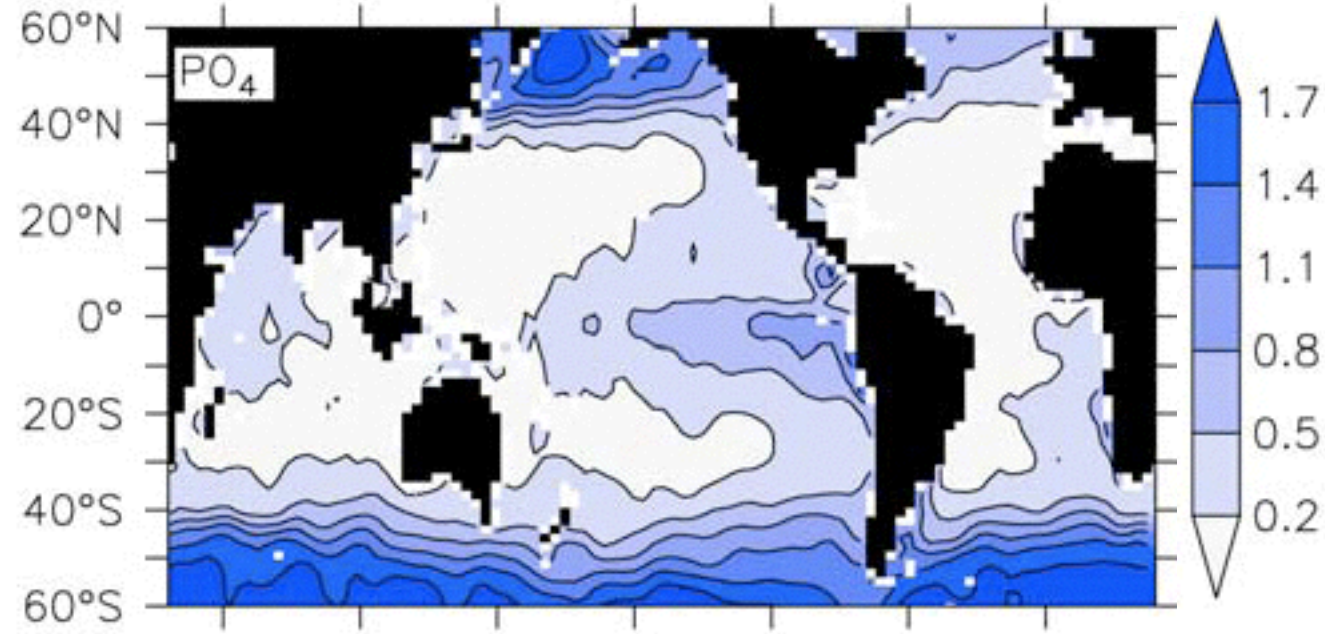
leads to low surface nutrient concentrations except where upwelling (e.g. E.Eq.Pac.) or light limitation (high latitudes)

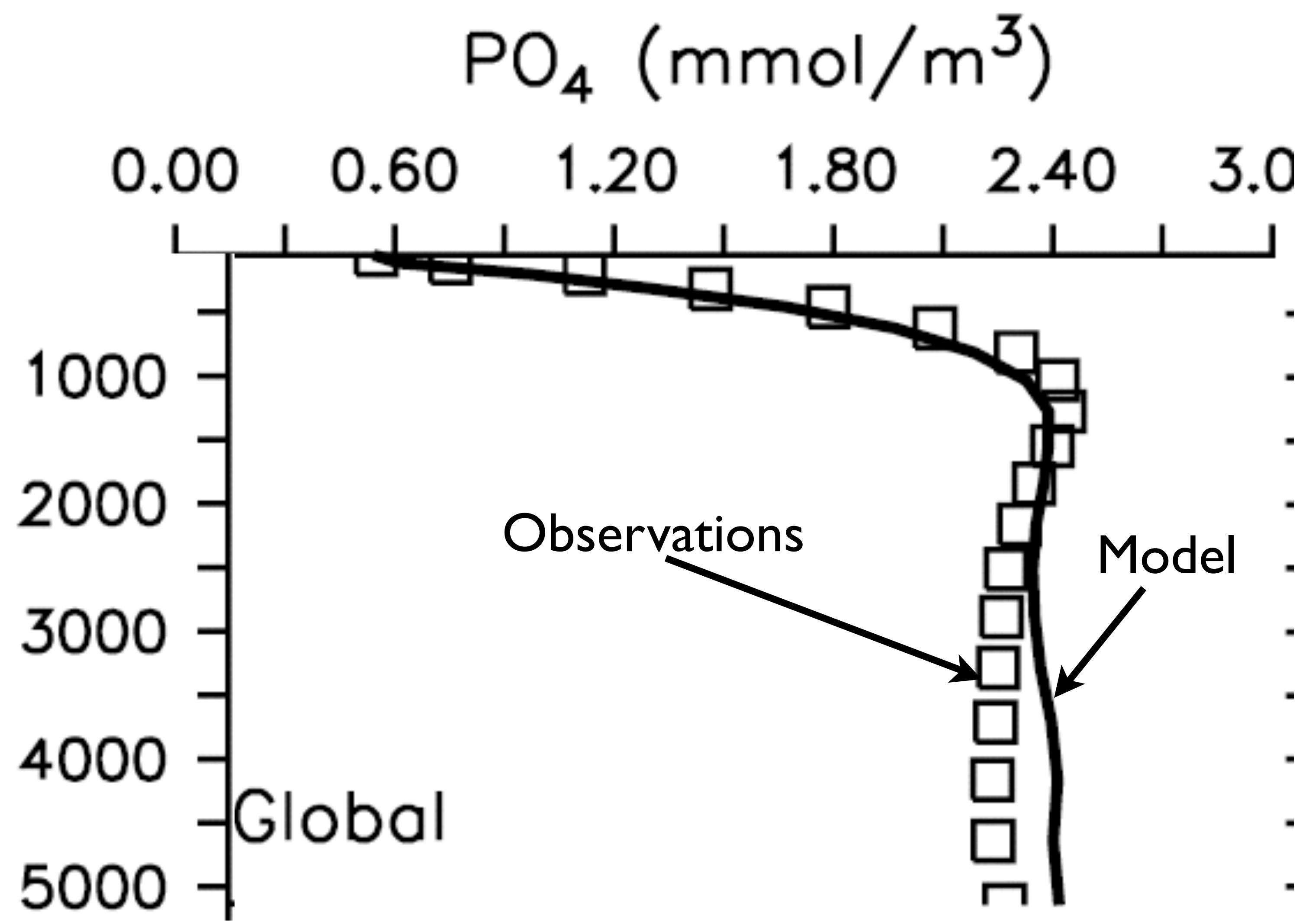


Phytoplankton assimilate nutrients and carbon into biomass through photosynthesis. Dead (particulate) organic matter sinks into subsurface and deep ocean, where it is remineralized.

Physical processes (circulation, mixing, upwelling) re-supply nutrients and inorganic carbon to the surface.

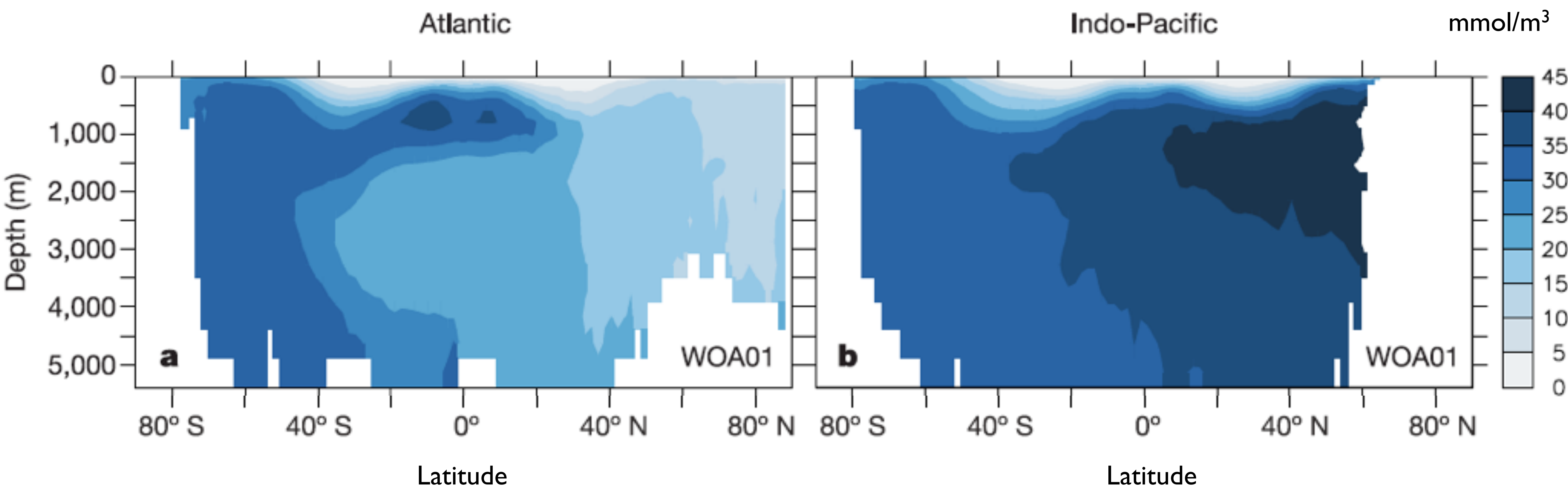
Surface Nutrients





Globally horizontally averaged phosphate

NO_3 in the deep ocean

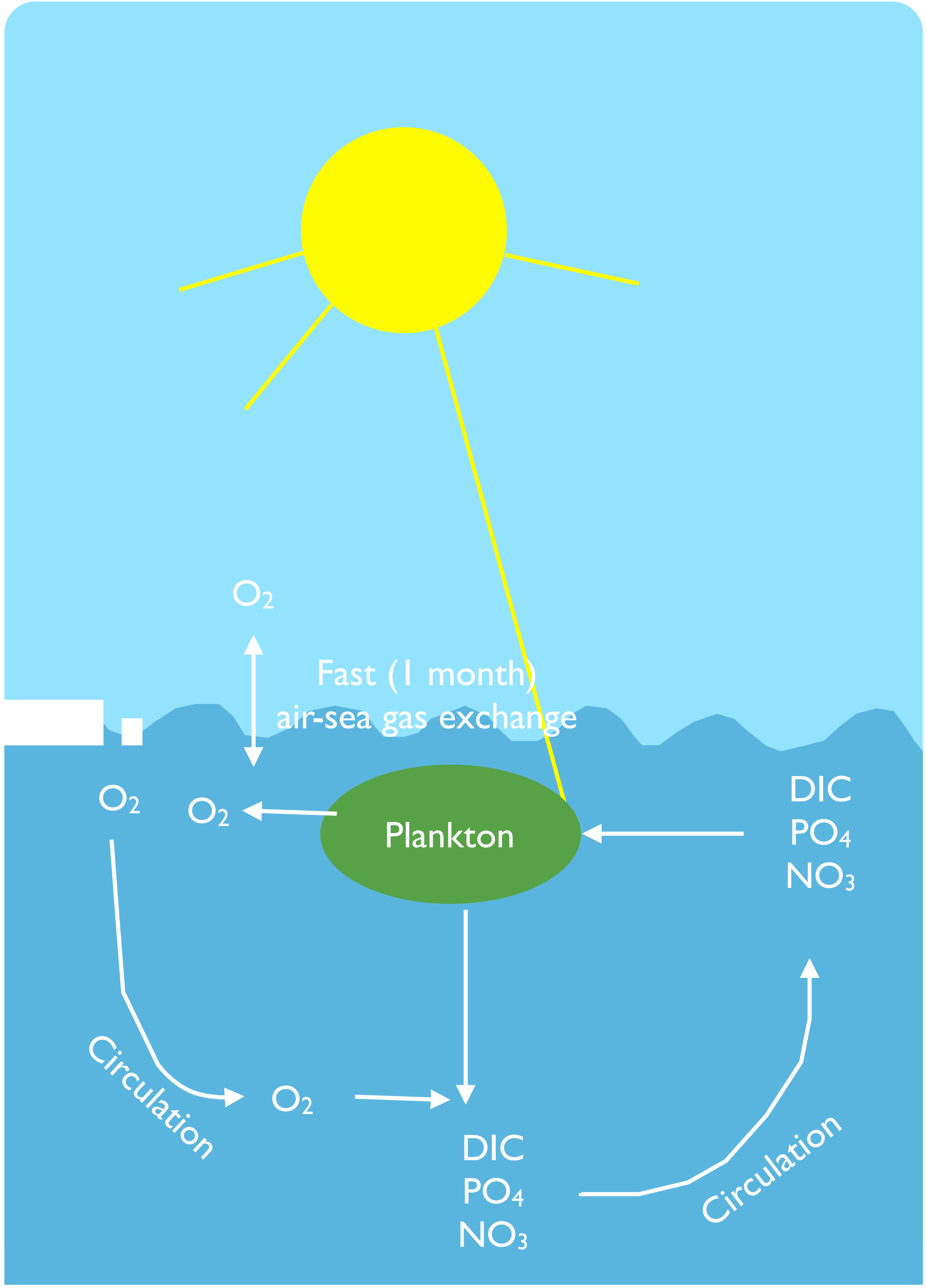


North Atlantic Deep Water is "young", has little accumulated remineralized organic matter and **low** in nutrients.

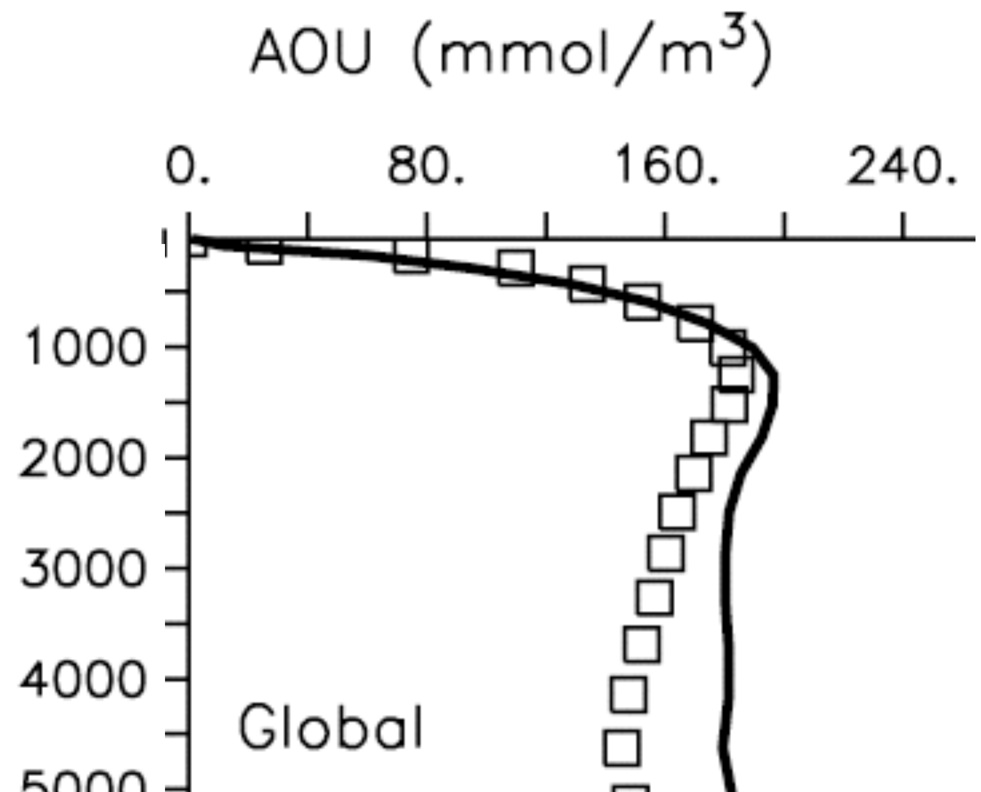
North Pacific Deep Water is "old", has accumulated lots of reminderalized organic matter and is **high** in nutrients.

Oxygen and Apparent Oxygen Utilization (AOU)

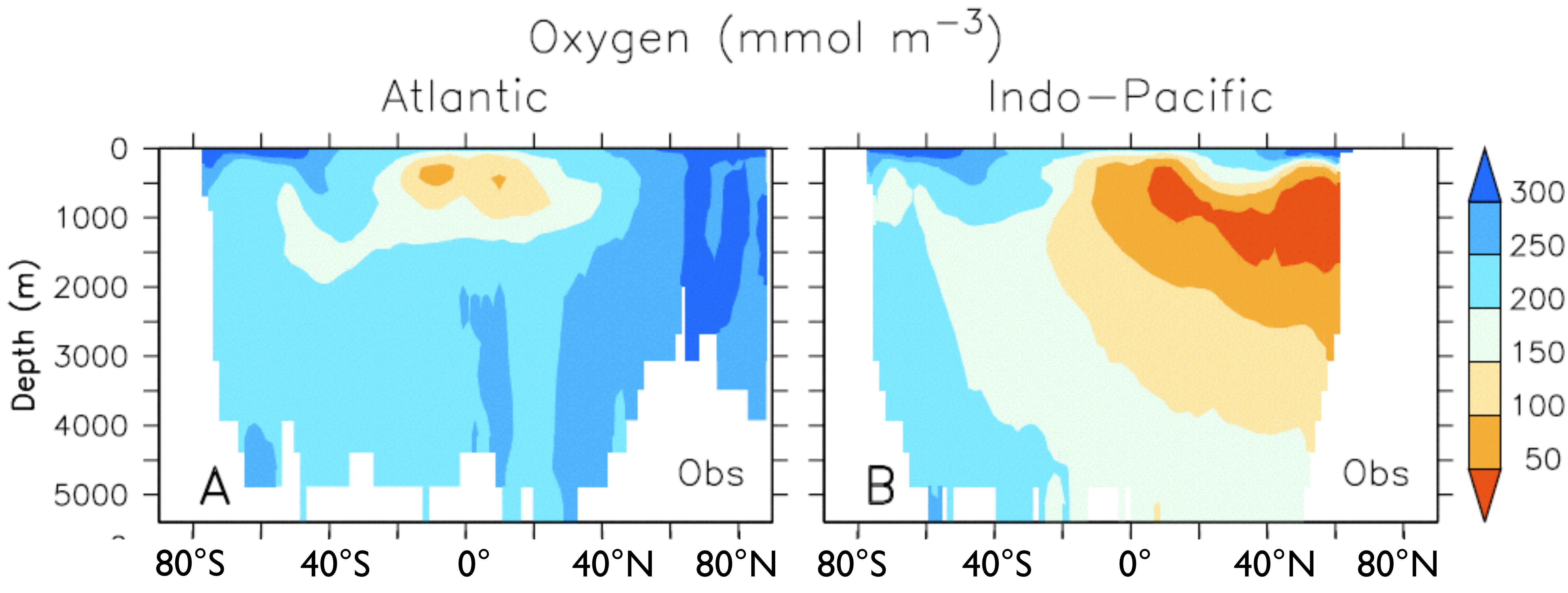
$$AOU = {}^{sat}O_2(T) - O_2$$



Remineralization (oxidation) of organic matter consumes dissolved oxygen, photosynthesis produces it.



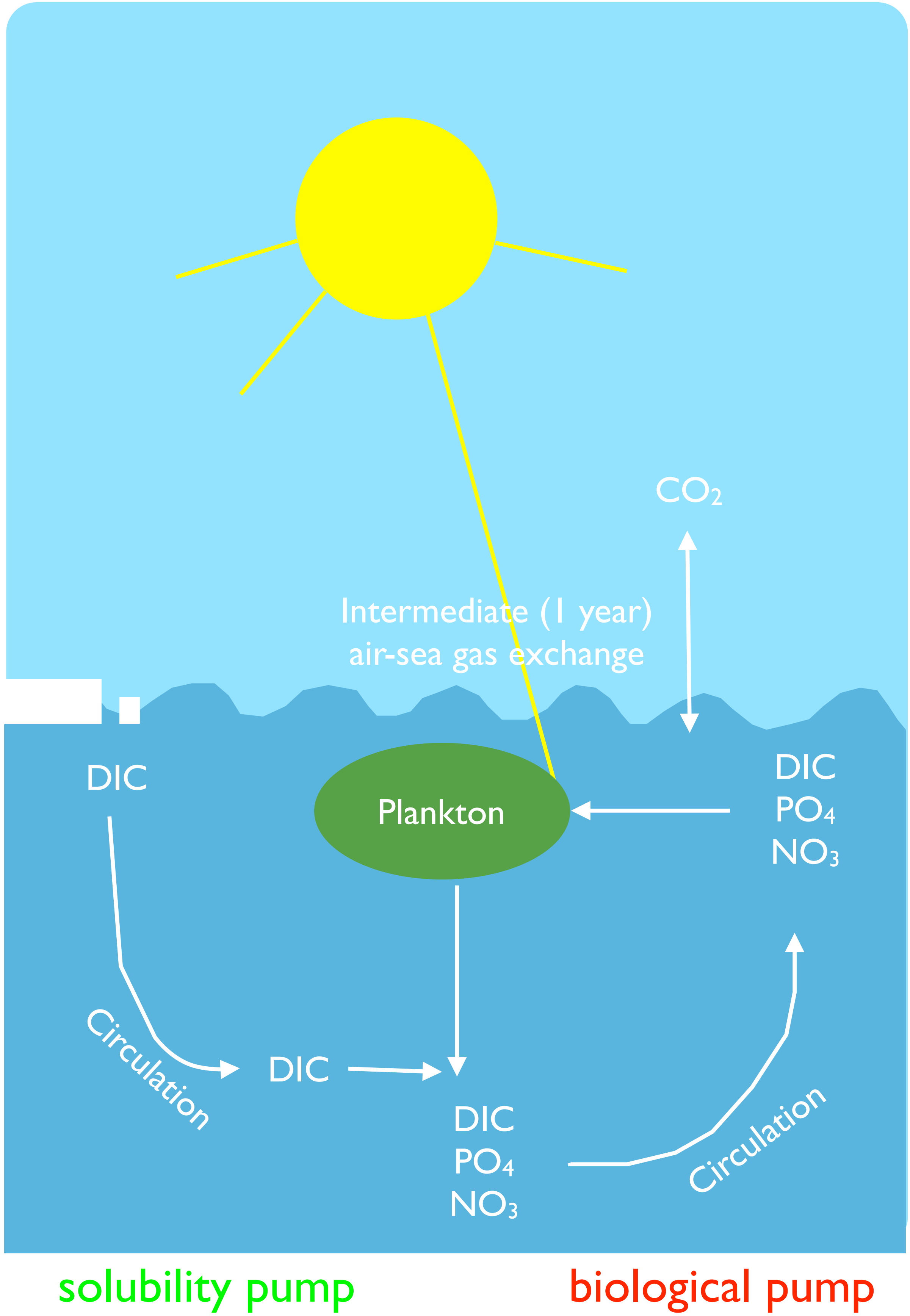
Oxygen is more soluble in cold water than in warm water. To to efficient air-sea gas exchange surface oxygen is close to thermodynamic equilibrium (saturation concentration)



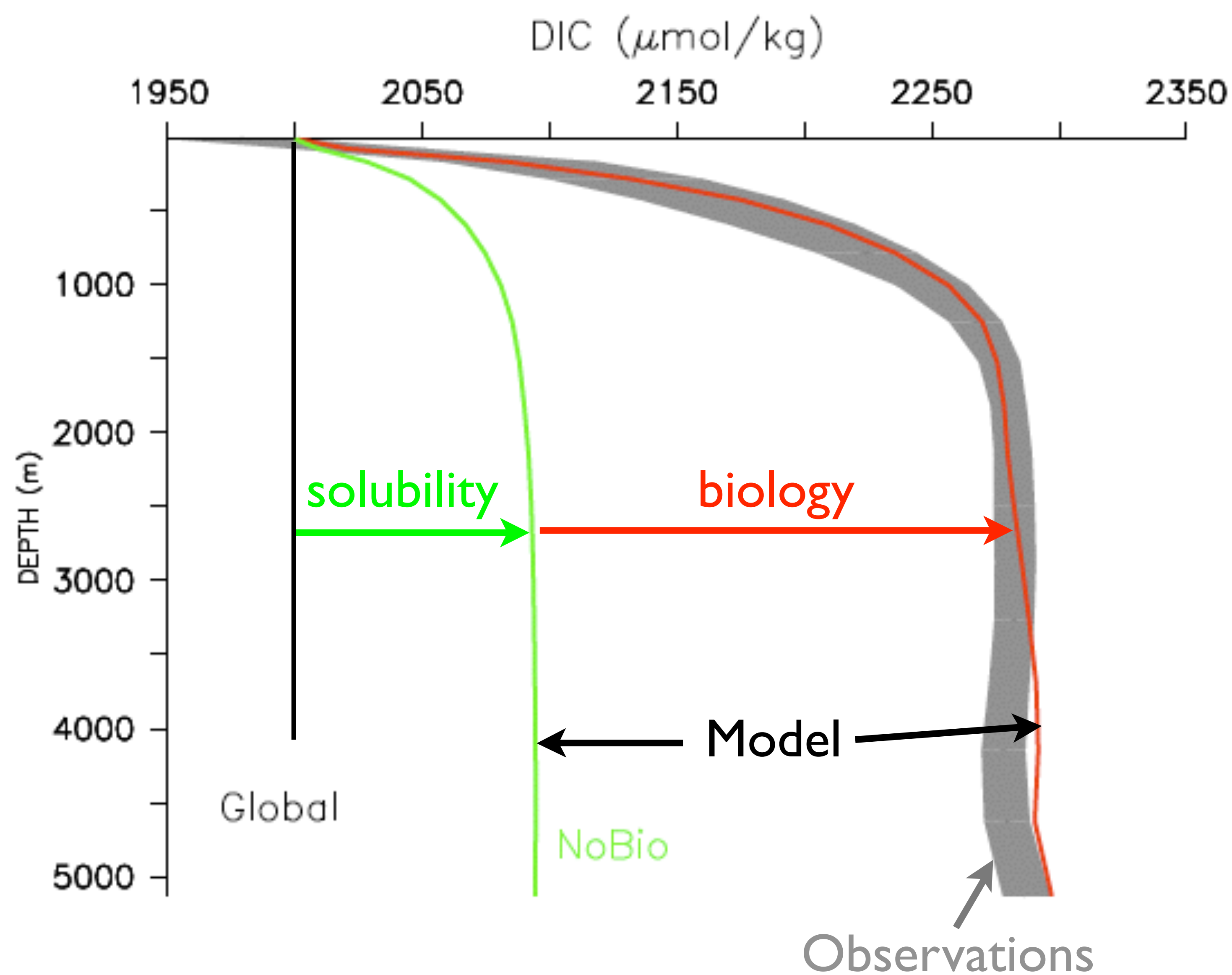
North Atlantic Deep Water is **high** in oxygen.

North Pacific Deep Water is **low** in oxygen.

Dissolved Inorganic Carbon (DIC)



CO_2 is also more soluble in cold water than in warm water. Air-sea gas exchange is slower than for oxygen. Both solubility and biological pump contribute to surface-to-deep gradients.



Air sea gas exchange:

$$q=-K(|v|,T,S)(pCO_2^{atm} - pCO_2^{ml})$$

$$pCO_2^{ml}=[CO_2]^{ml}/\alpha(T,S)$$

Solubility

Chemistry

$$CO_2 + H_2O \Leftrightarrow HCO_3^- + H^+$$

$$HCO_3^- \Leftrightarrow CO_3^{2-} + H^+$$

Total Carbon

Dissolved Inorganic Carbon

$$DIC = \sum CO_2 = [HCO_3^-]+[CO_3^{2-}]+[CO_2]$$

bicarbonate carbonate 1%

The Biological Pump

2. The Hard Tissue (Inorganic Matter/Alkalinity) Pump

$$[H^+][HCO_3^-]=K_1[CO_2]^{ml}$$
$$[H^+][CO_3^{2-}]=K_2[HCO_3^-]$$

$$\Rightarrow [CO_2]^{ml}=K_2[HCO_3^-]^2/(K_1[CO_3^{2-}])$$

$CaCO_3$ production increases $[CO_2]$ because $[CO_3^{2-}]$ is taken up by organisms:

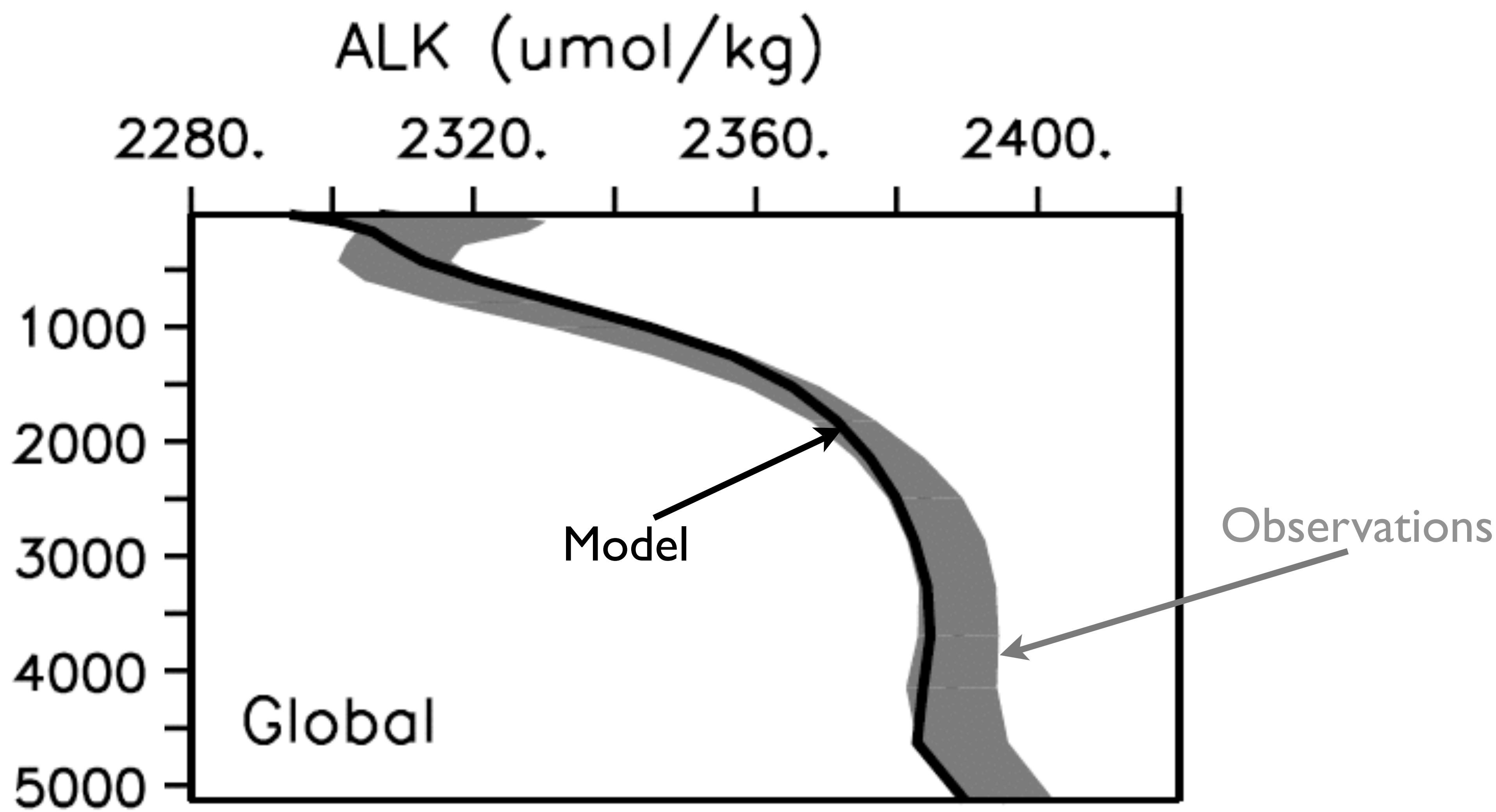
- Coccolithophorids (phytoplankton)
- Foraminifera (zooplankton)
- Pteropods (zooplankton)

$\left.\begin{array}{l}\text{Coccolithophorids}\\ \text{Foraminifera}\end{array}\right\}$ Calcite

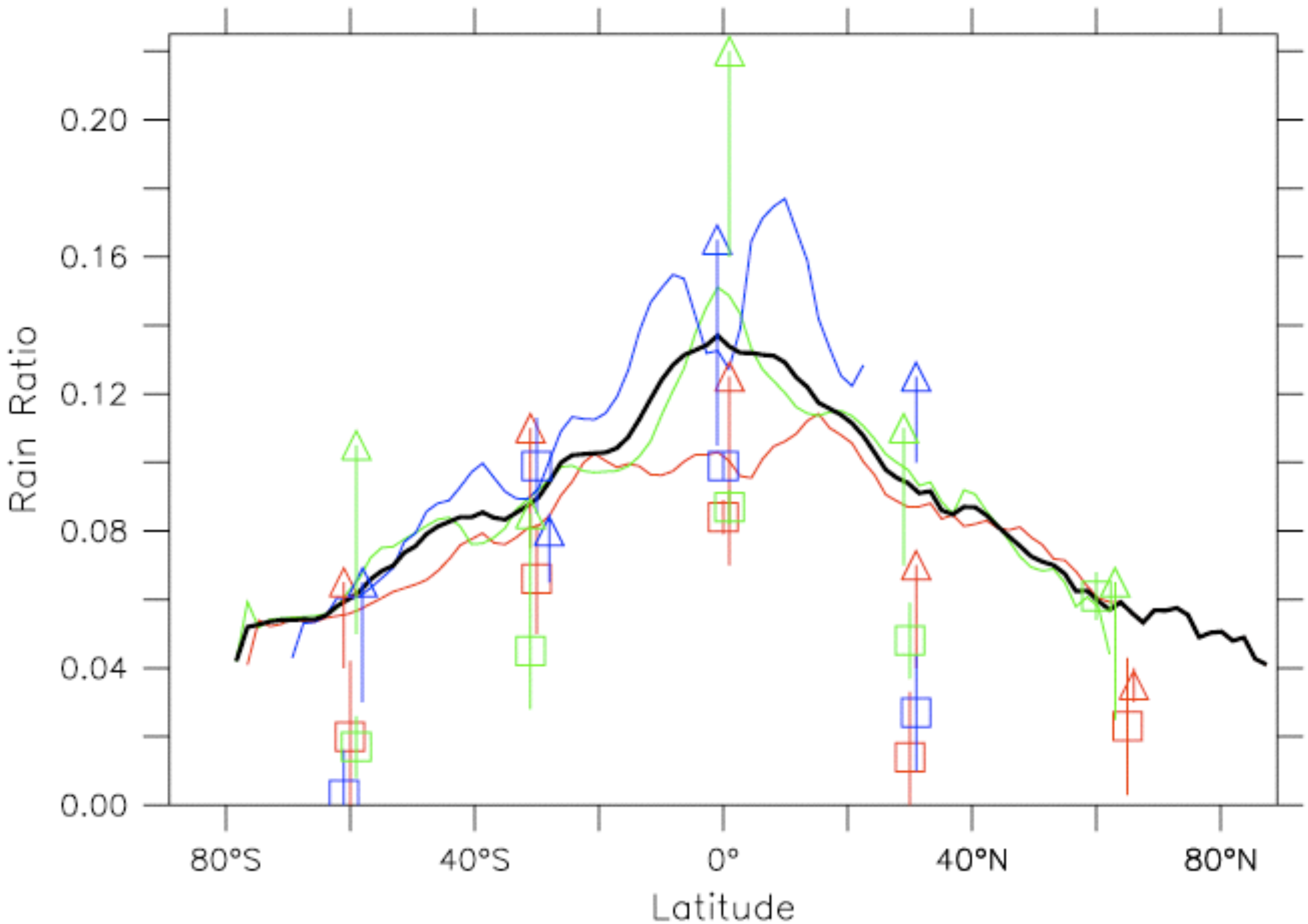
Pteropods: Aragonite

Carbonate Alkalinity

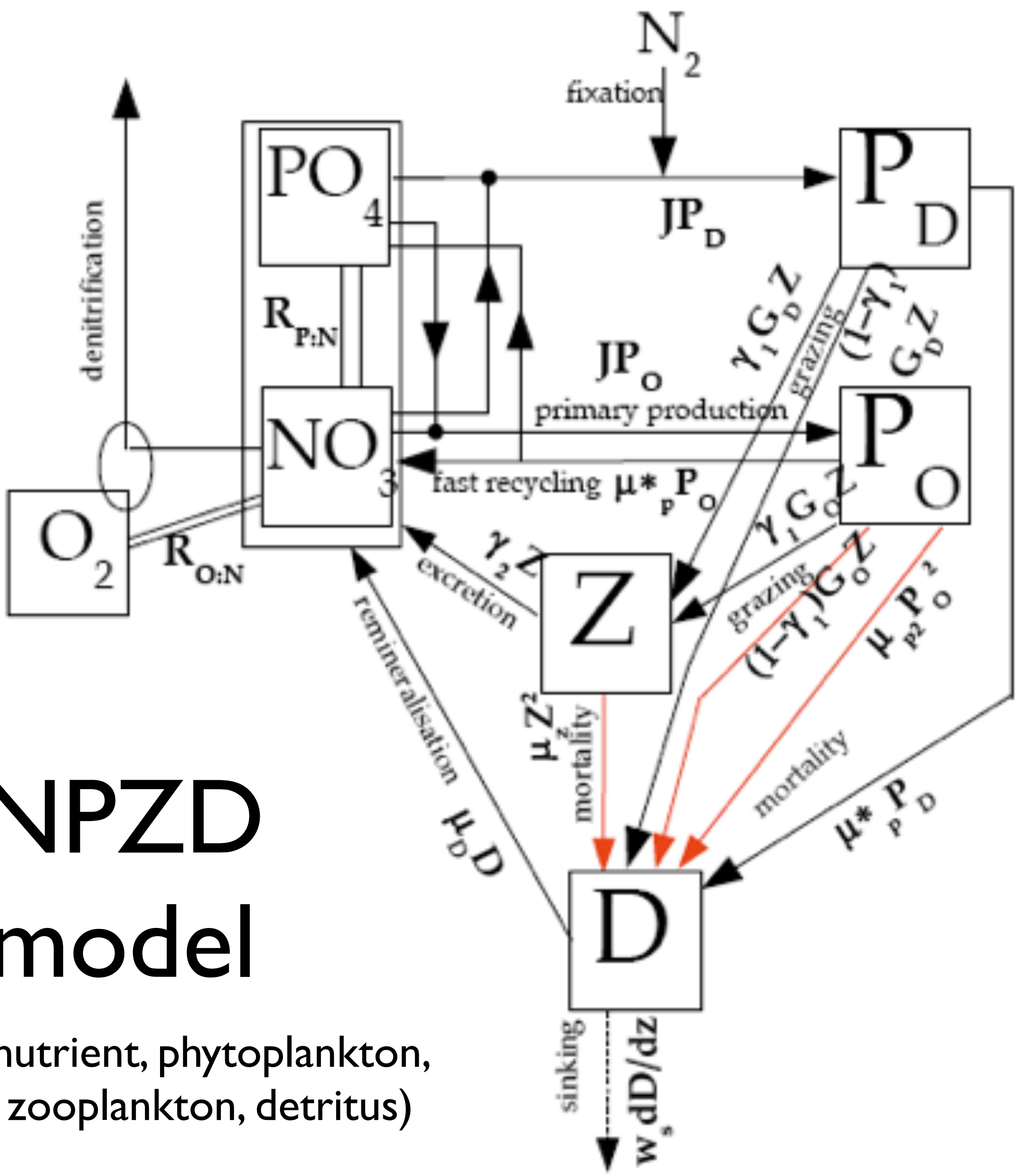
$$ALK=[HCO_3^-]+2[CO_3^{2-}]=2DIC-[HCO_3^-]$$



Rain Ratio = Export of $CaCO_3$ / Export of POC



Details of Ecosystem and Carbon Cycle Model



NPZD model

(nutrient, phytoplankton, zooplankton, detritus)

$$\frac{\partial C}{\partial t} = \underbrace{T}_{\text{Transport}} + \underbrace{S}_{\text{Biological Sources/Sinks}},$$

$$S(\mathrm{DIC}) = S(\mathrm{PO_4}) R_{C:P} - S(\mathrm{CaCO_3})$$

$$S(\mathrm{ALK}) = -S(\mathrm{NO_3}) \times 10^{-3} - 2S(\mathrm{CaCO_3}).$$

$$S(\mathrm{PO_4}) = (\mu_D \mathrm{D} + \mu_P^* \mathrm{P}_O + \gamma_2 \mathrm{Z} - J_O \mathrm{P}_O - J_D \mathrm{P}_D) R_{P:N}$$

$$S(\mathrm{NO_3}) = (\mu_D \mathrm{D} + \mu_P^* \mathrm{P}_O + \gamma_2 \mathrm{Z} - J_O \mathrm{P}_O - u_\mathrm{N} J_D \mathrm{P}_D) \cdot (1 - 0.8 R_{O:N}\ r_{sox}^{NO3})$$

$$S(\mathrm{P}_O) = J_O \mathrm{P}_O - \mu_P^* \mathrm{P}_O - G(\mathrm{P}_O)\mathrm{Z} - \mu_{P2} \mathrm{P}_O^2$$

$$S(\mathrm{P}_D) = J_D \mathrm{P}_D - G(\mathrm{P}_D)\mathrm{Z} - \mu_P \mathrm{P}_D$$

$$S(\mathrm{Z}) = \gamma_1 [G(\mathrm{P}_O) + G(\mathrm{P}_D)]\mathrm{Z} - \gamma_2 \mathrm{Z} - \mu_Z \mathrm{Z}^2$$

$$S(\mathrm{D}) = (1-\gamma_1)[G(\mathrm{P}_O) + G(\mathrm{P}_D)]\mathrm{Z} + \mu_P \mathrm{P}_D + \mu_{P2} \mathrm{P}_O^2 + \mu_Z \mathrm{Z}^2 - \mu_D \mathrm{D} - w_\mathrm{D}\, \partial \mathrm{D} \partial z$$

$$S(\mathrm{O_2}) = F_{sfc} - S(\mathrm{PO_4}) R_{O:P}\ r_{sox}^{O2}$$

$$\Pr(\mathrm{CaCO_3}) = ((1-\gamma_1) G(\mathrm{P}_O)\mathrm{Z} + \mu_{P2} \mathrm{P}_O^2 + \mu_Z \mathrm{Z}^2) R_{\mathrm{CaCO3/POC}} R_{C:P},$$

$$Di(\mathrm{CaCO_3}) = \int Pr(\mathrm{CaCO_3}) dz \cdot \frac{d}{dz}\left(e^{-z/D_{\mathrm{CaCO_3}}}\right)$$

$$J(I, \mathrm{NO_3}, \mathrm{PO_4}) = \min(J_{OI}, J_{O\max} u_N, J_{O\max} u_P), \qquad u_\mathrm{P} = \mathrm{PO_4}/(k_\mathrm{P} + \mathrm{PO_4}).$$

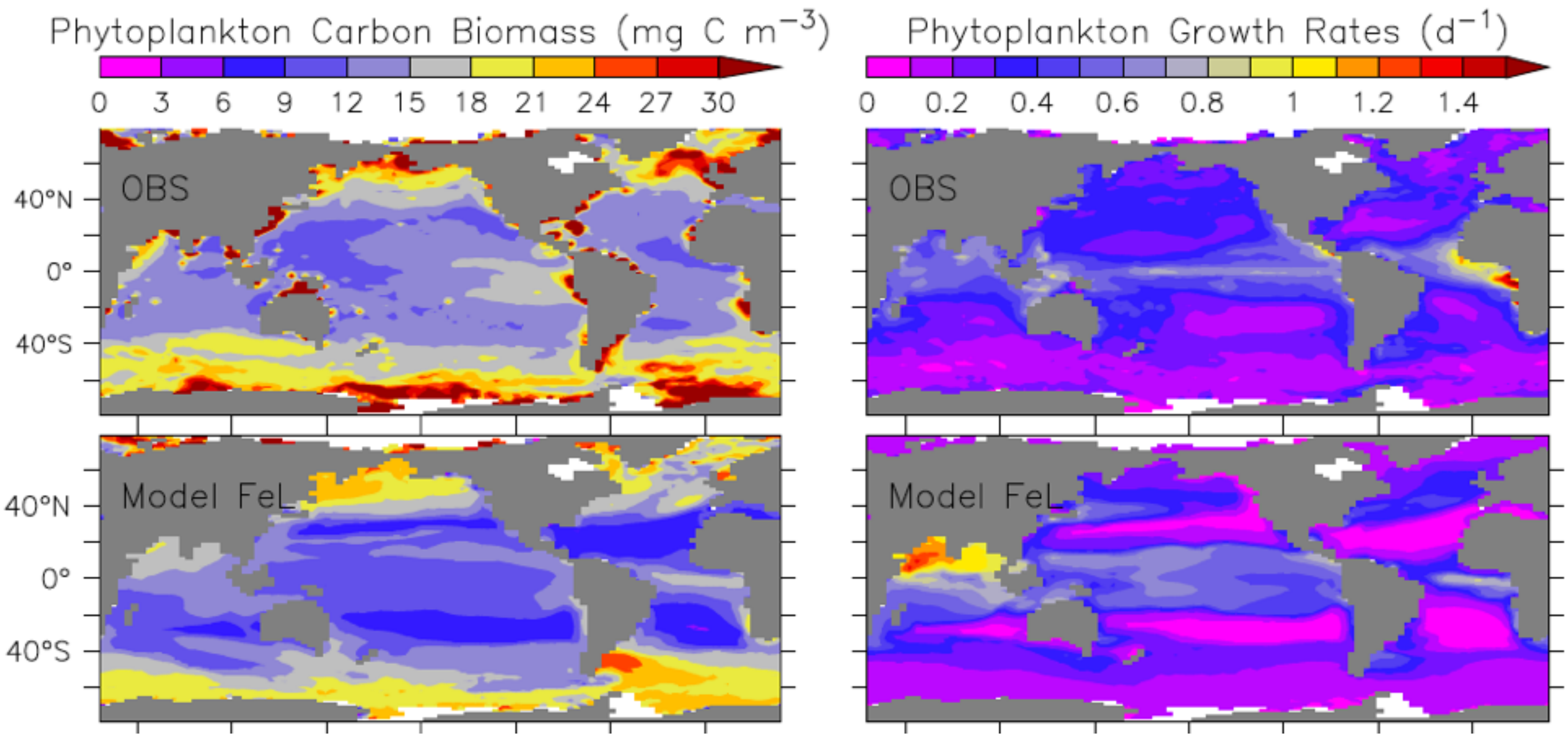
growth rate

$$J_{OI} = \frac{J_{O\max} \alpha I}{\left[J_{O\max}^2 + (\alpha I)^2\right]^{1/2}} \qquad J_{O\max} = a \times \exp(T/T_b)$$

$$w_D = \left\{ \begin{array}{c} w_{D0} + m_w z, z \le 1000m \\ w_{D0} + m_w 1000m, z > 1000m \end{array} \right\},$$ sinking speed

$$\mu_D = \mu_{D0} \exp(T/T_b)[0.65 + 0.35 \tanh(O_2 - 6)]$$ remineralization rate

Schmittner et al. 2008 GBC



Schmittner et al. 2013 Biogeosciences

- More advanced models include more plankton functional types (e.g. diatoms, coccolithophores)
- DARWIN model (Follows et al. 2007 Science) uses randomly assigned traits (parameter values) to create artificial species some of which survive and others get extinct
- Some models also include higher trophic levels (meso-zooplankton, fish)

Summary

- Ocean biogeochemical models describe cycling of nutrients, oxygen, carbon and alkalinity
- Ecosystem components (NPZD type) include phytoplankton, zooplankton, detritus