ATS 421/521

Climate Modeling

Spring 2013

Discussion/Lecture 18

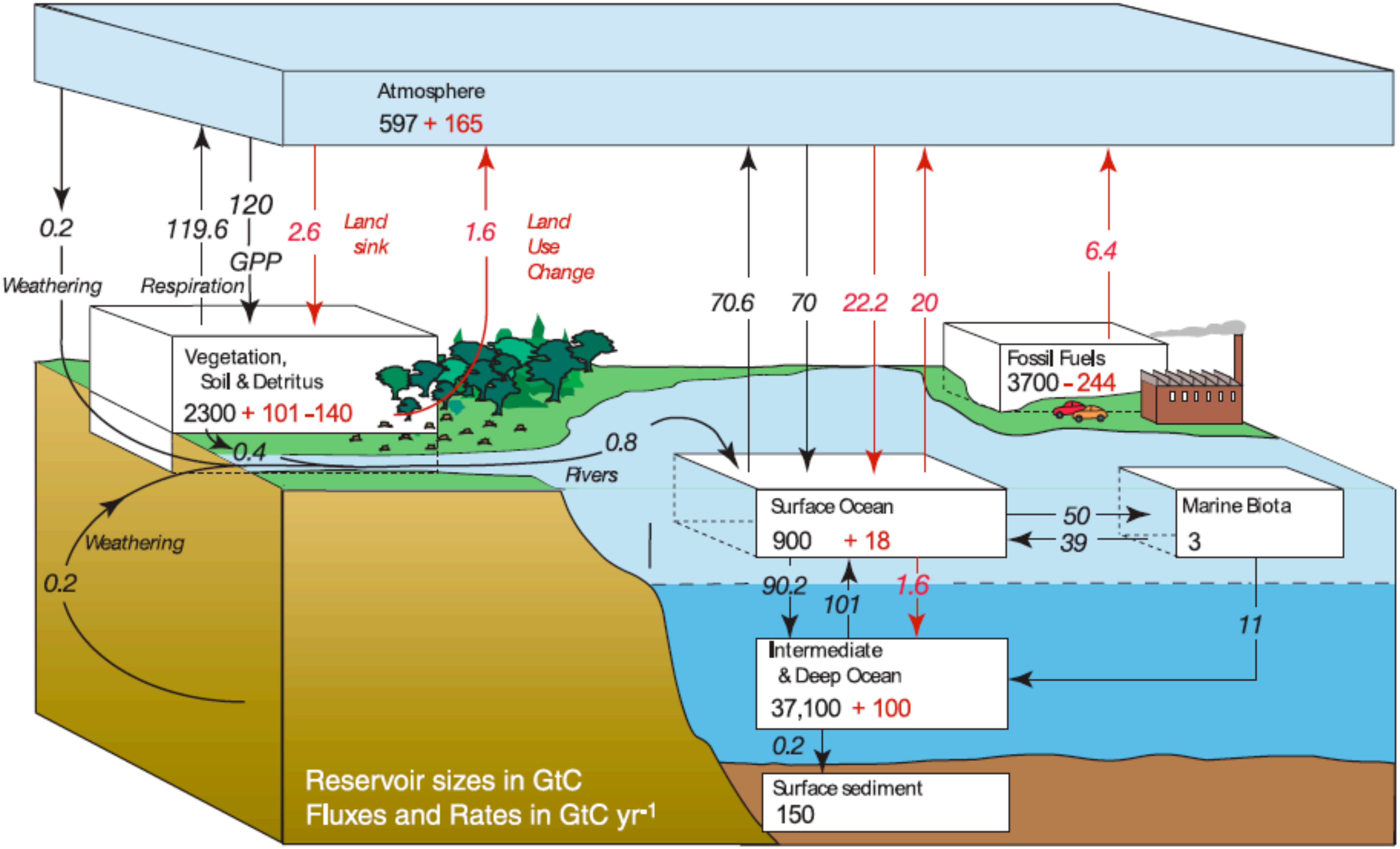
- Carbon Cycle Feedbacks (Friedlingstein et al., 2006)
- Ocean Biogeochemistry

May 24, 2013

Homework Projects

- Student presentations on June 6th (15 min), paper (~5 pages)
- Send me draft until May 31

The Global Carbon Cycle



2 GtC = 1 ppmv

IPCC (2007)

Friedlingstein et al. (2006)

Climate - Carbon Cycle Feedback

Two simulations with coupled climate - carbon cycle models. One with (coupled) and one without (uncoupled) climate change.

Forcing: A2 CO_2 emission scenario.

Grain g: $\Delta C_A^c = 1/(1-g)\,\Delta C_A^u,$ (1)

$g = -\alpha(\gamma_L + \gamma_O)/(1 + \beta_L + \beta_O).$ (7)

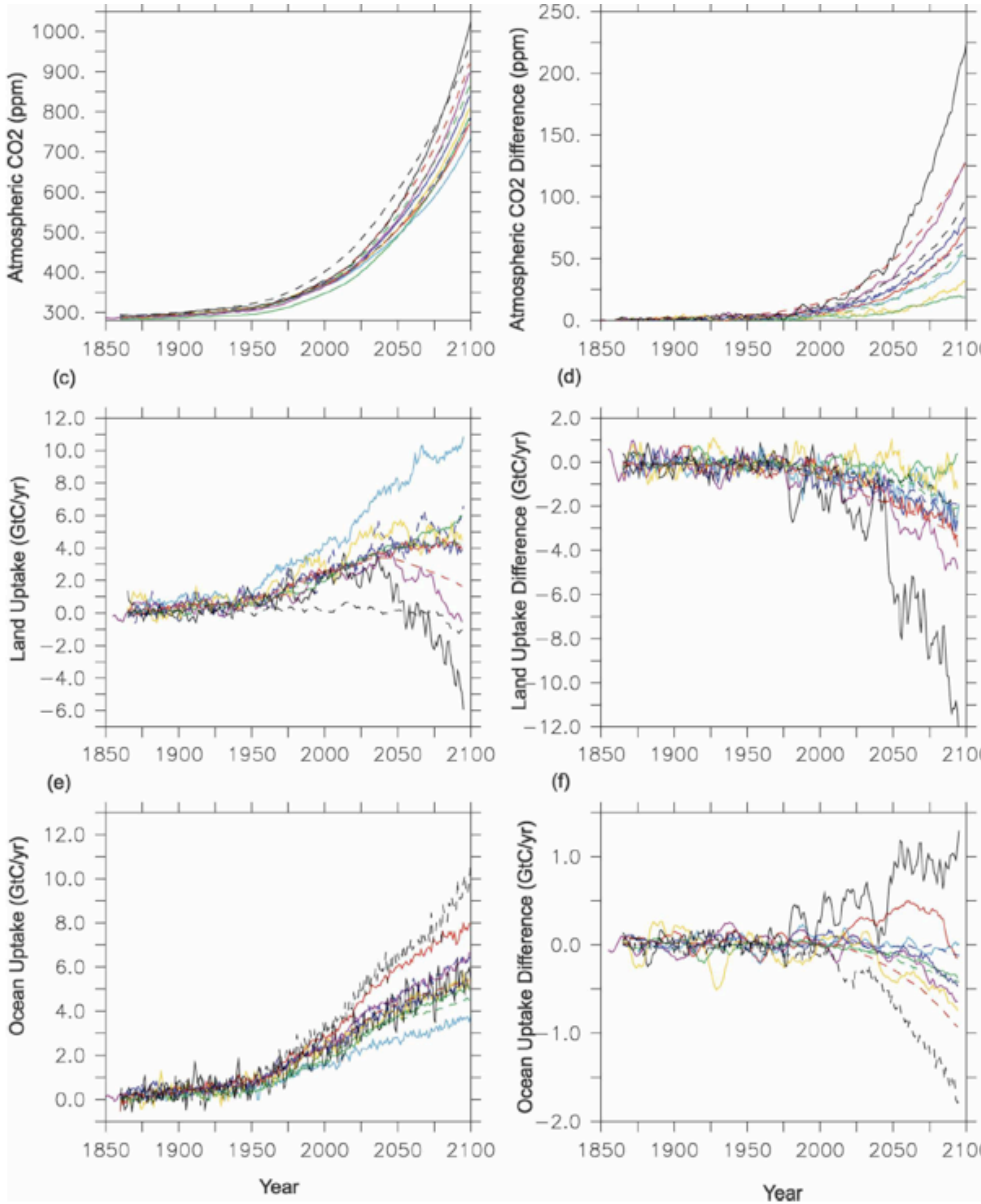
	Coupled		Uncoupled	
Land:	$\Delta C_L^c = \beta_L \Delta C_A^c + \gamma_L \Delta T^c,$	(2)	$\Delta C_L^u = \beta_L \Delta C_A^u,$	(4)
Ocean:	$\Delta C_O^c = \beta_O \Delta C_A^c + \gamma_O \Delta T^c,$	(3)	$\Delta C_O^u = \beta_O \Delta C_A^u.$	(5)

Transient Climate Sensitivity: $\Delta T^c = \alpha \Delta C_A^c,$ (6)

ΔC_A^c $\quad\quad$ $\Delta C_A^c - \Delta C_A^u$

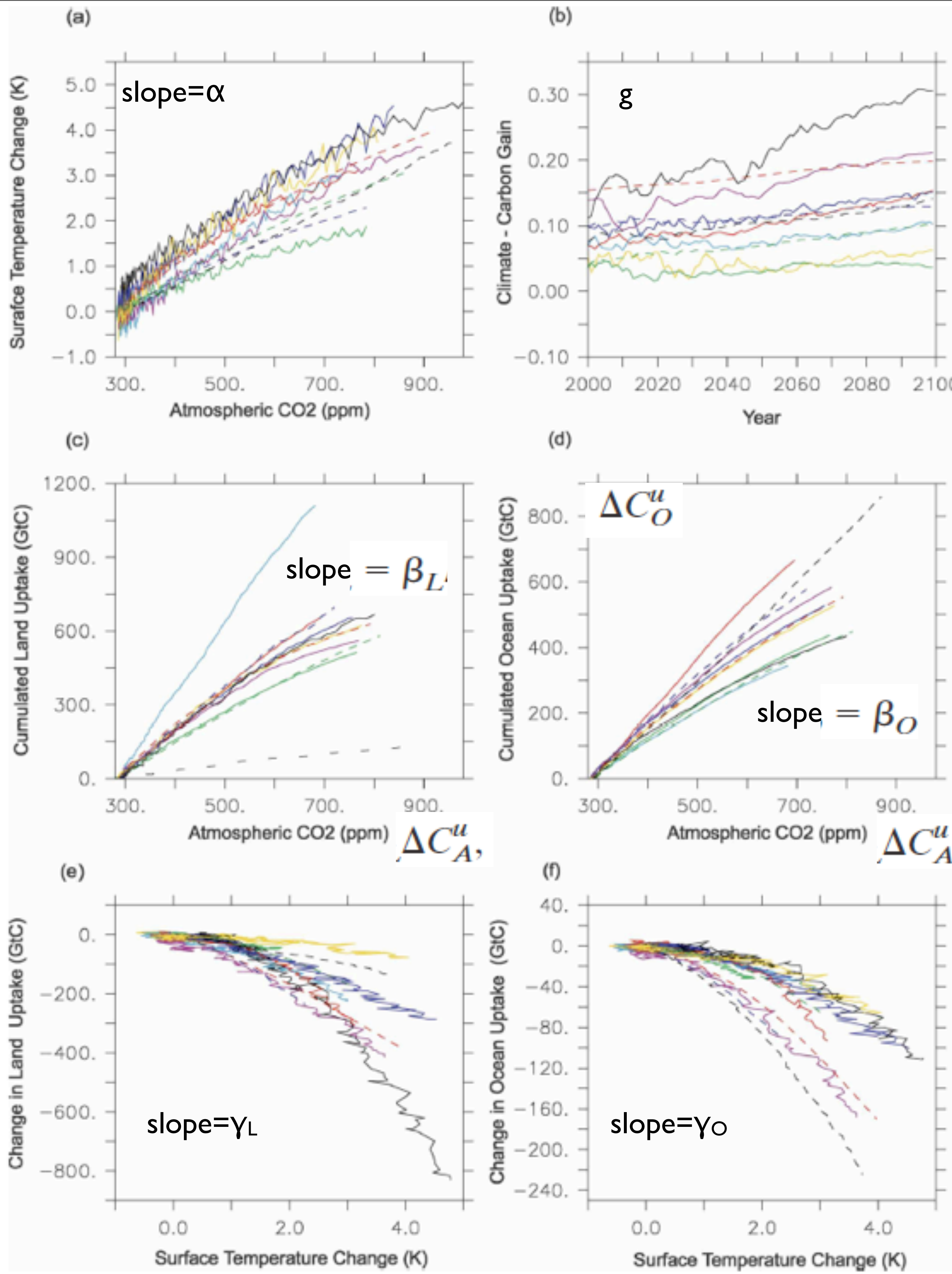
ΔC_L^c $\quad\quad$ $\Delta C_L^c - \Delta C_L^u$

ΔC_O^c $\quad\quad$ $\Delta C_O^c - \Delta C_O^u$



$$\Delta T^c = \alpha \Delta C_A^c$$

$$\Delta C_L^u$$



$$\Delta C_L^c - \Delta C_L^u =$$
$$= \gamma_L \Delta T^c$$

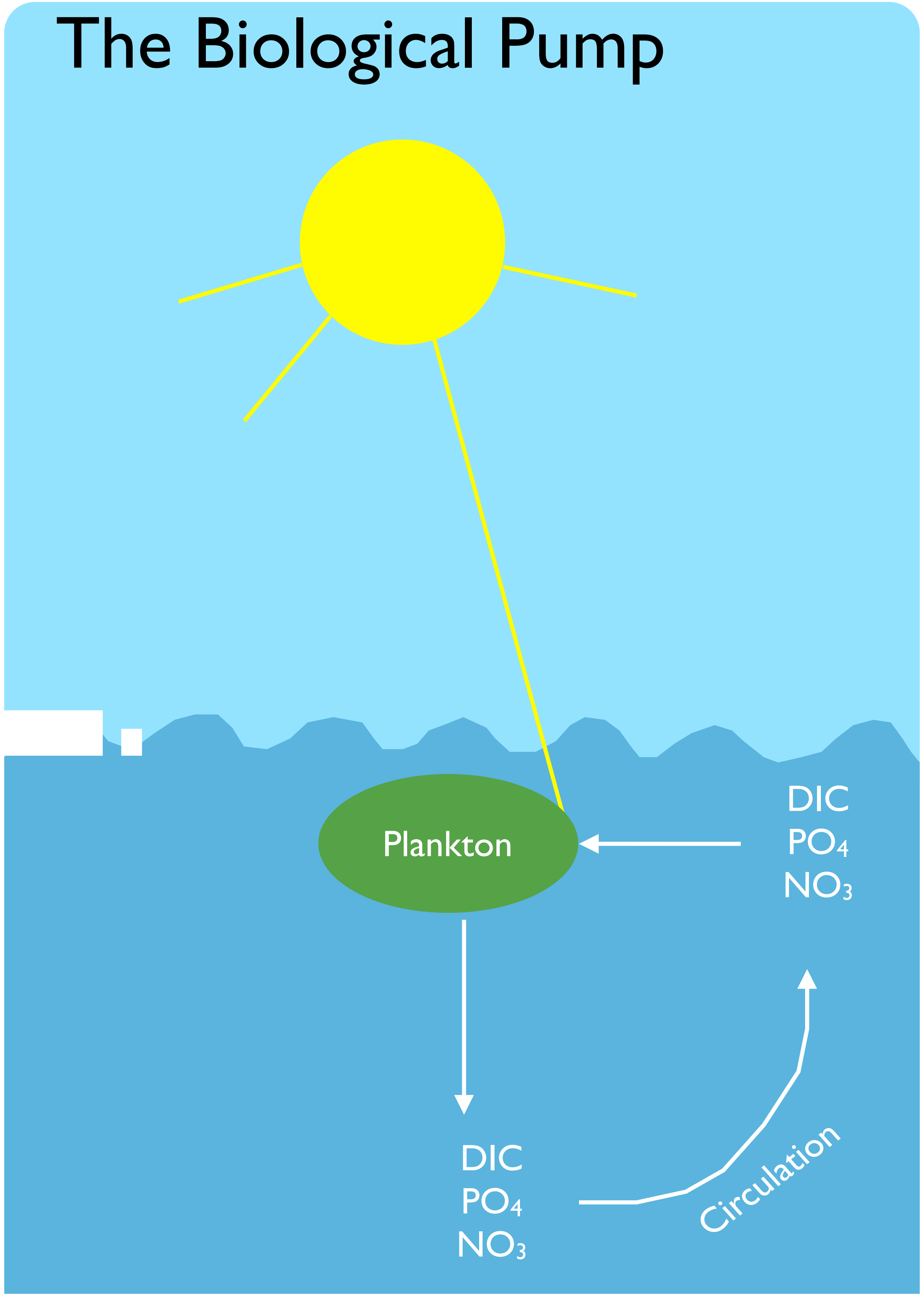
$$\Delta C_O^c - \Delta C_O^u =$$
$$= \gamma_O \Delta T^c$$

Ocean Biogeochemistry Models

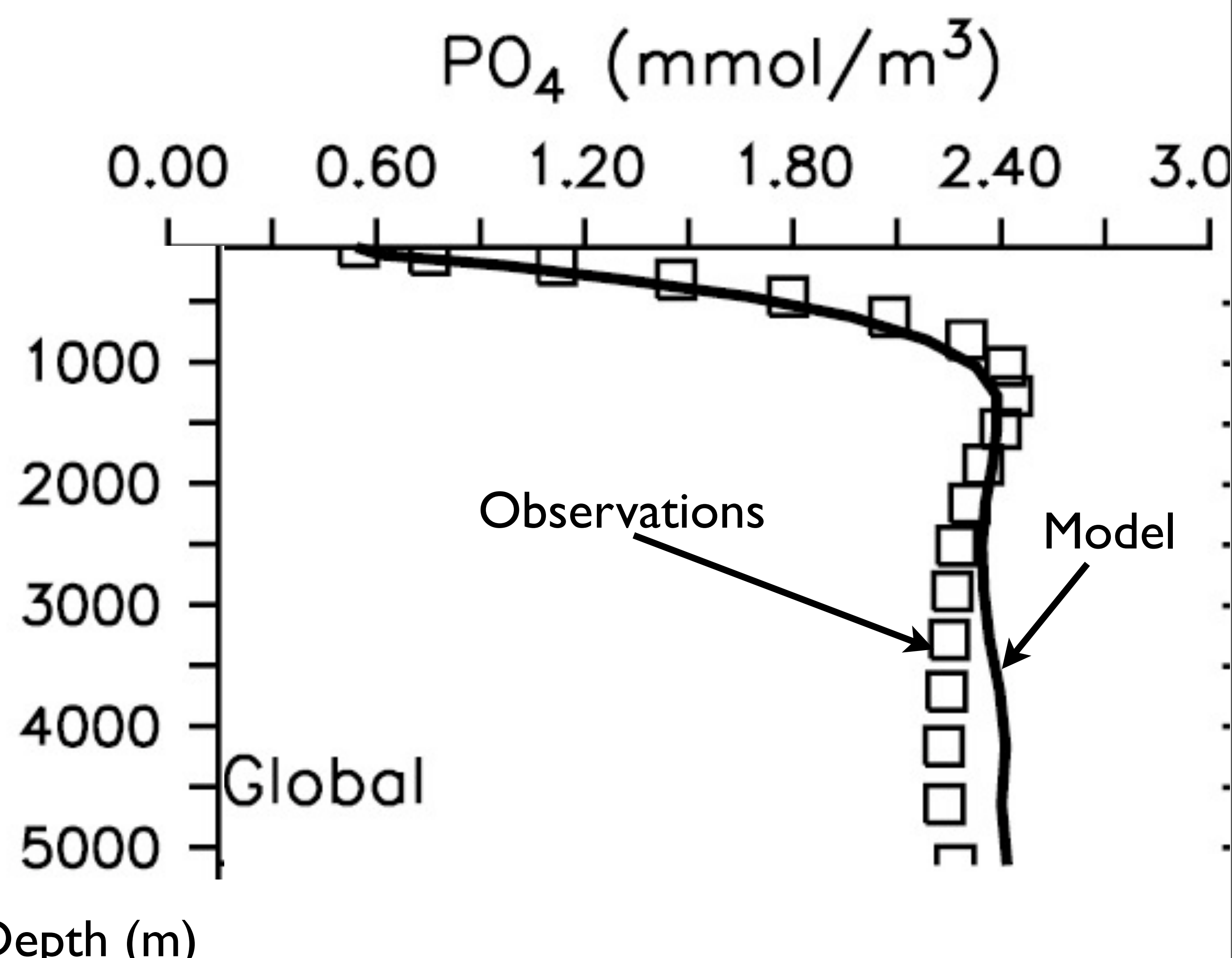
The Biological and Solubility Pumps

1. The Biological Soft Tissue (Organic Matter) Pump

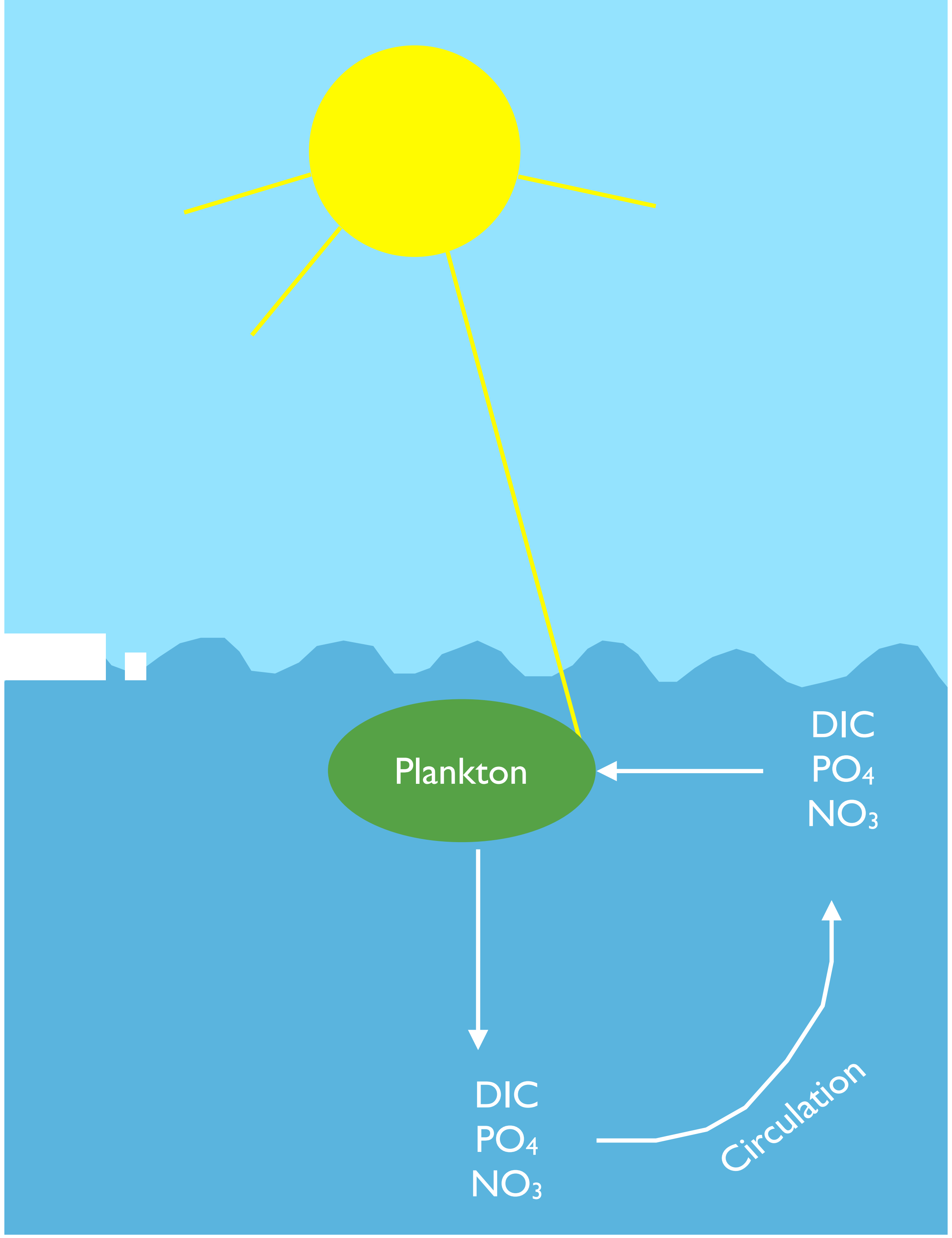
The Biological Pump

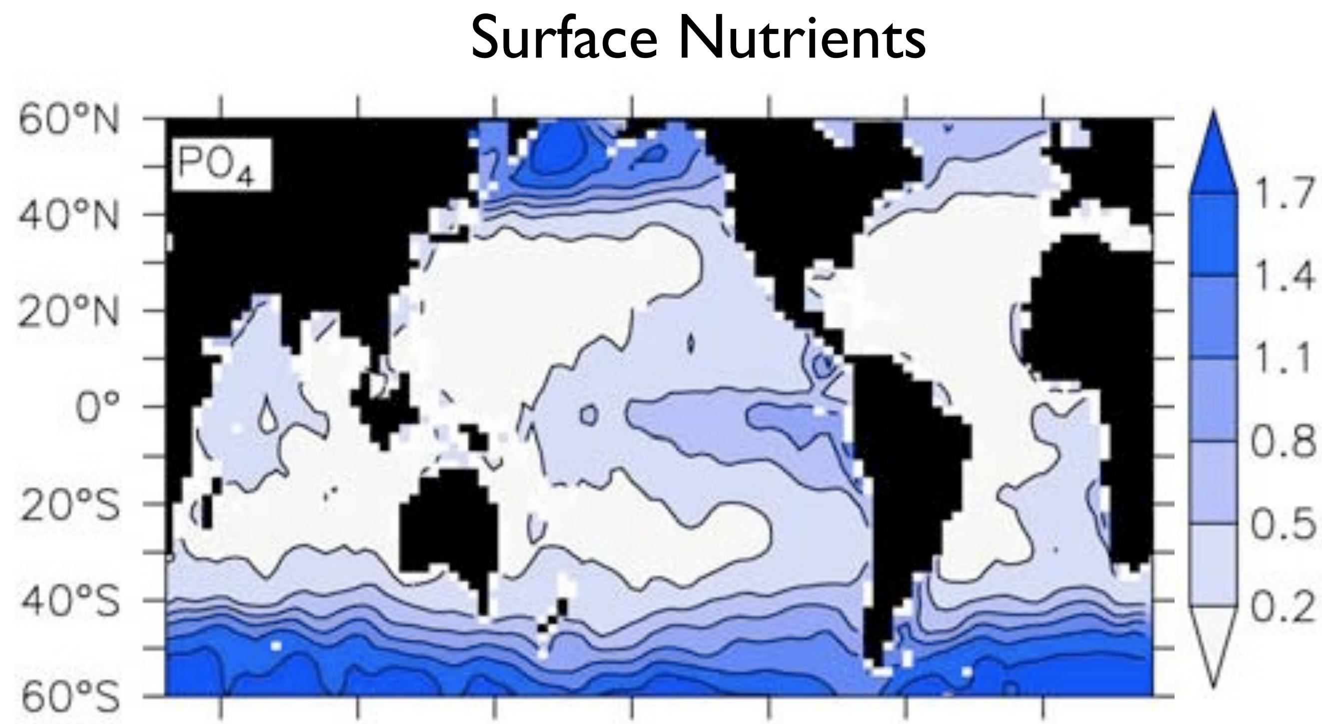


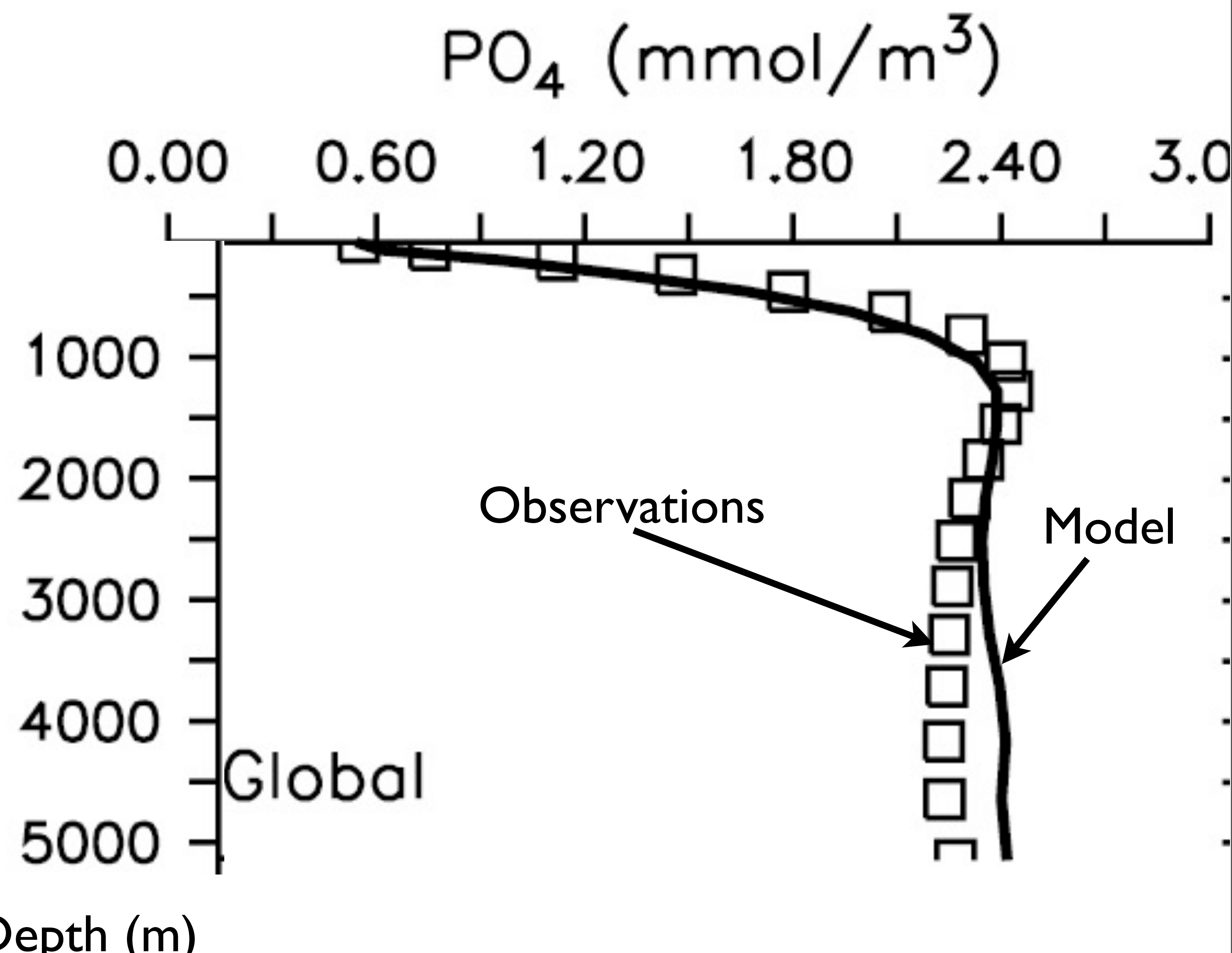
Surface Nutrients



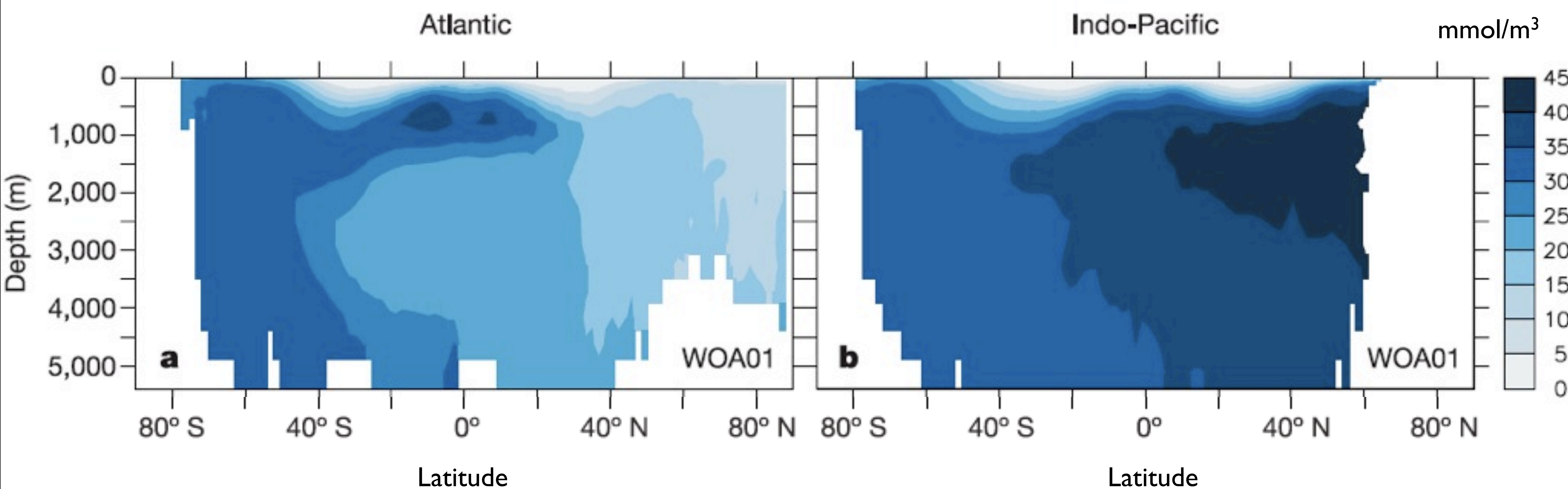
The Biological Pump

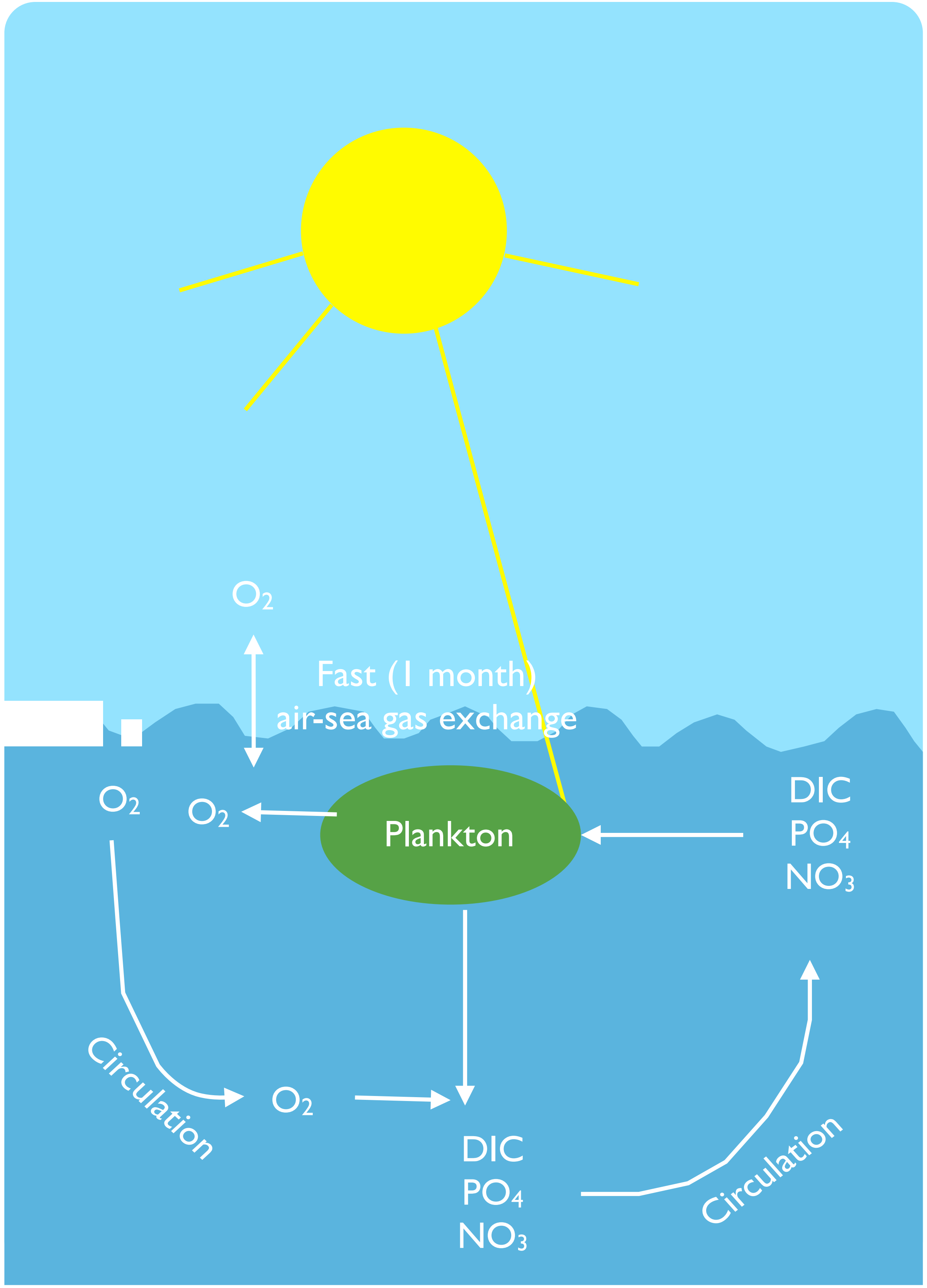






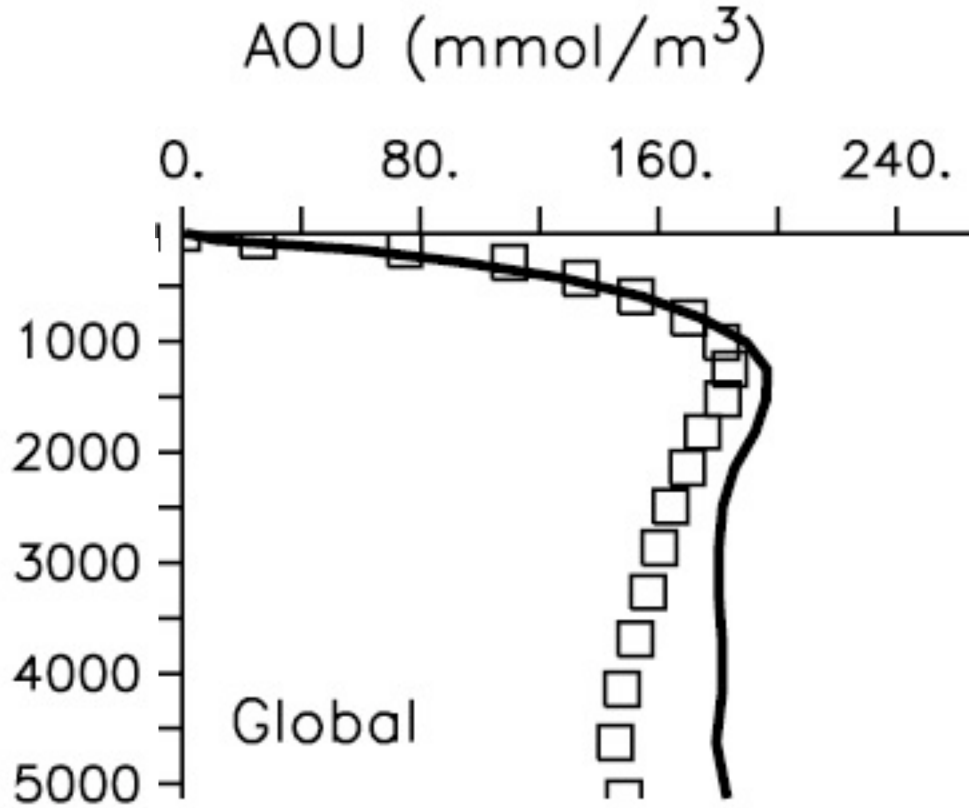
NO_3 in the deep ocean

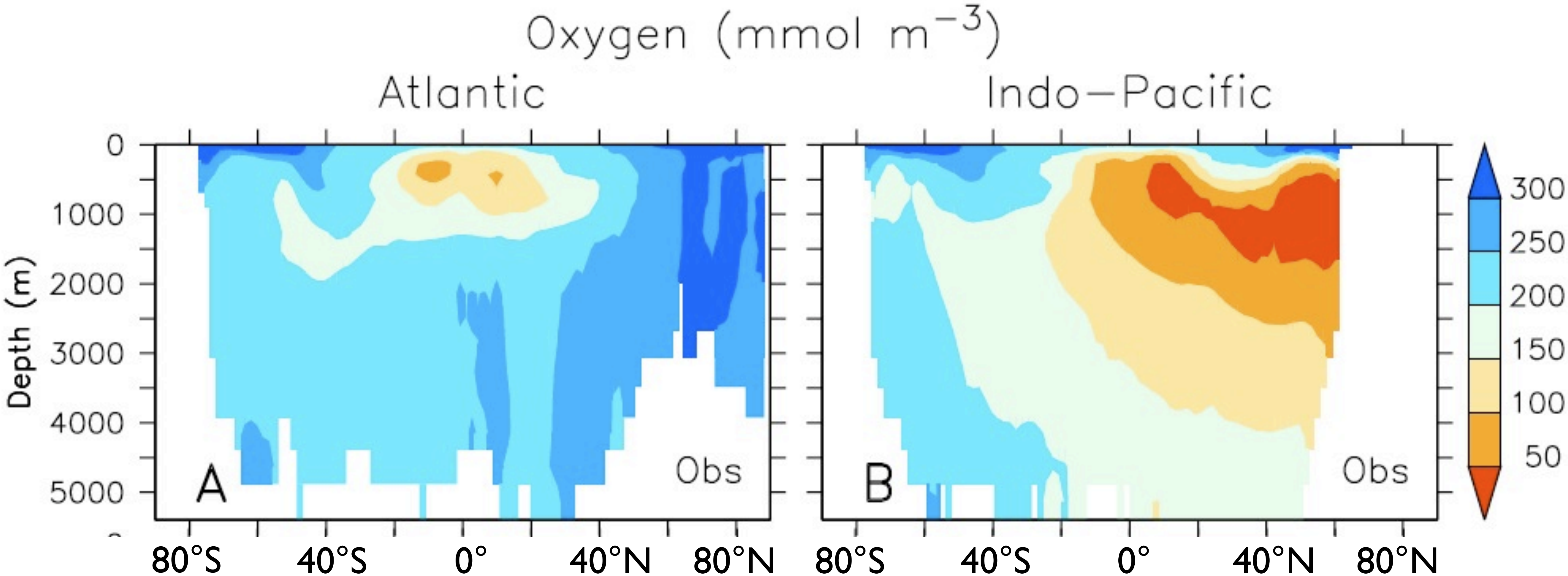




Oxygen and Apparent Oxygen Utilization (AOU)

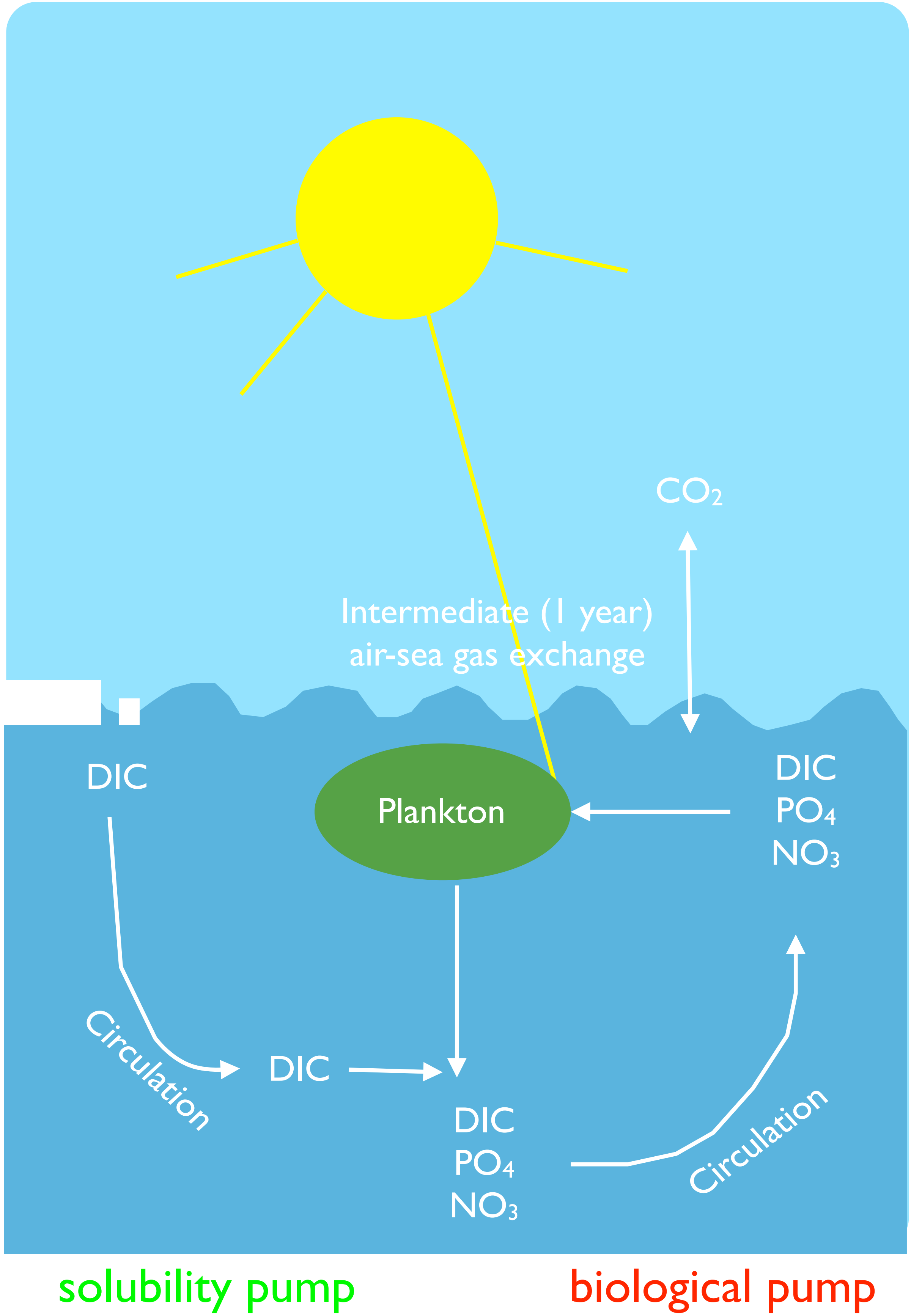
$$AOU = {}^{sat}O_2(T) - O_2$$

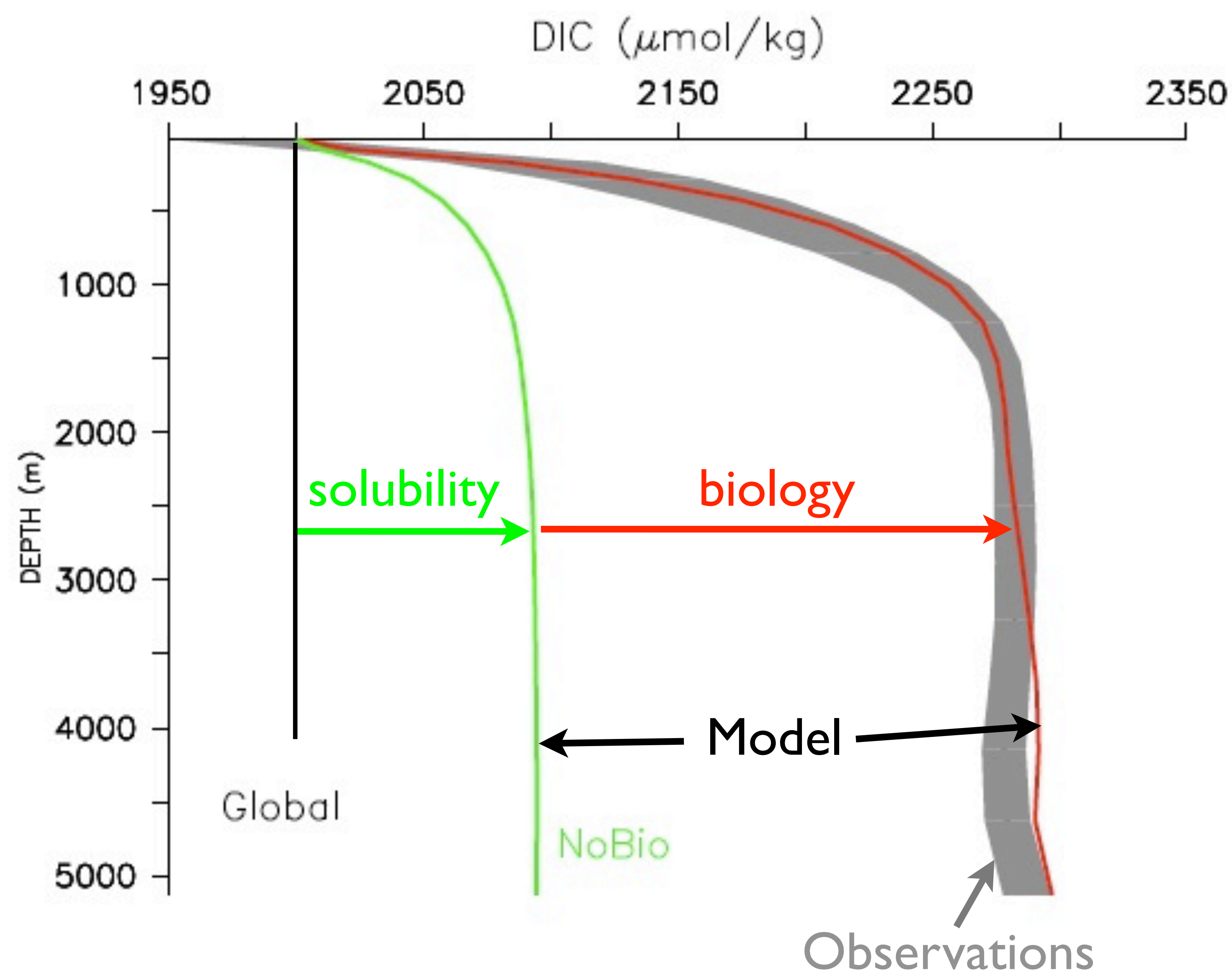




Oxygen (mmol m^{-3})
Atlantic
Indo−Pacific
0
1000
2000
3000
4000
5000
Depth (m)
A
Obs
B
Obs
80°S
40°S
0°
40°N
80°N
300
250
200
150
100
50

Solubility vs Biological Pumps





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

$$DIC = \sum CO_2 = \underbrace{[HCO_3^-]}_{\text{bicarbonate}} + \underbrace{[CO_3^{2-}]}_{\text{carbonate}} + \underbrace{[CO_2]}_{1\%}$$

The Biological Pump

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

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

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

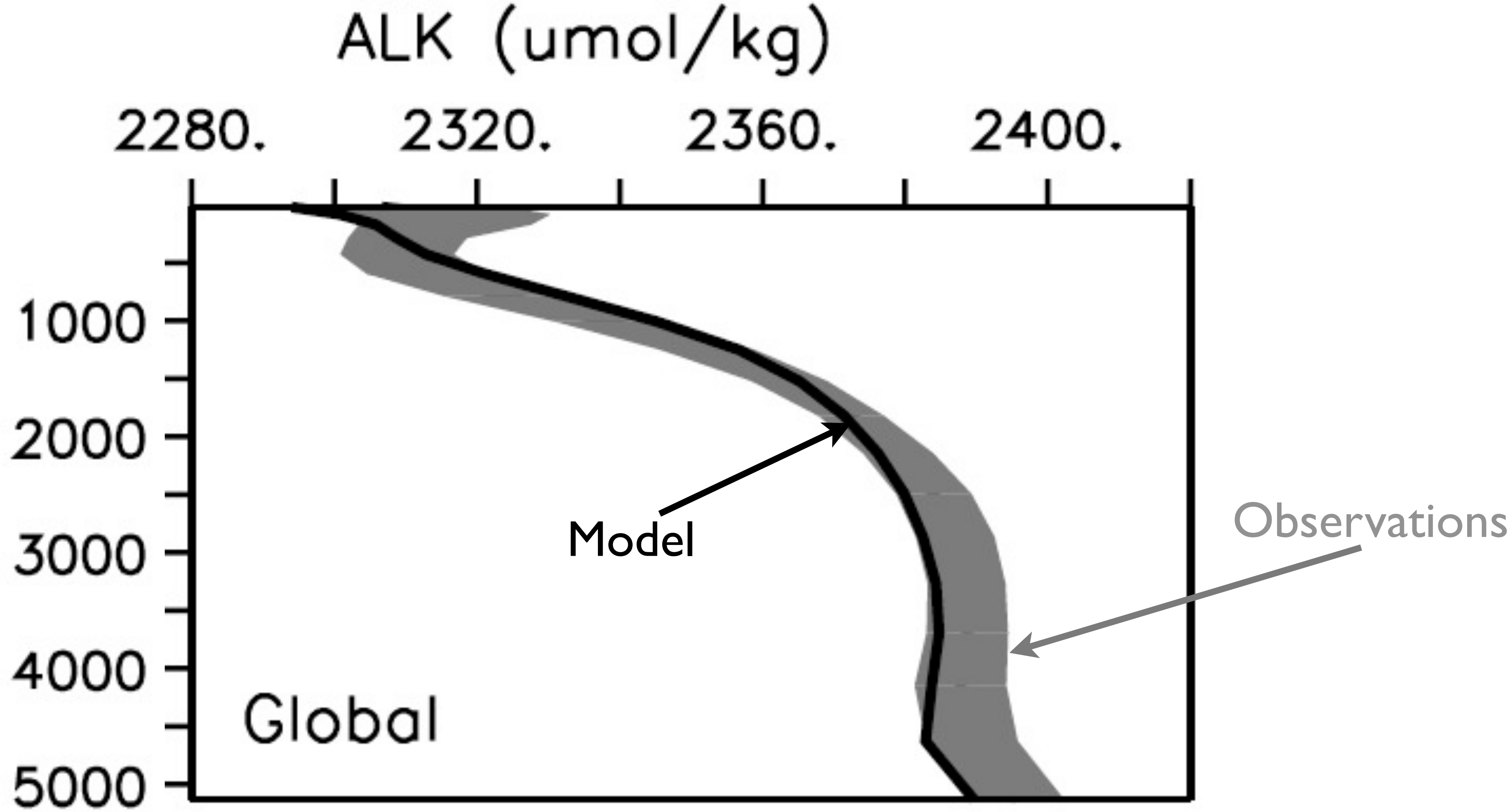
$CaCO_3$ production increases $[CO_2]$ because $[CO_3^{2-}]$ is taken up by organisms:

$\left.\begin{array}{l}\text{• Coccolithophorids (phytoplankton)}\\ \text{• Foraminifera (zooplankton)}\end{array}\right\}$ Calcite

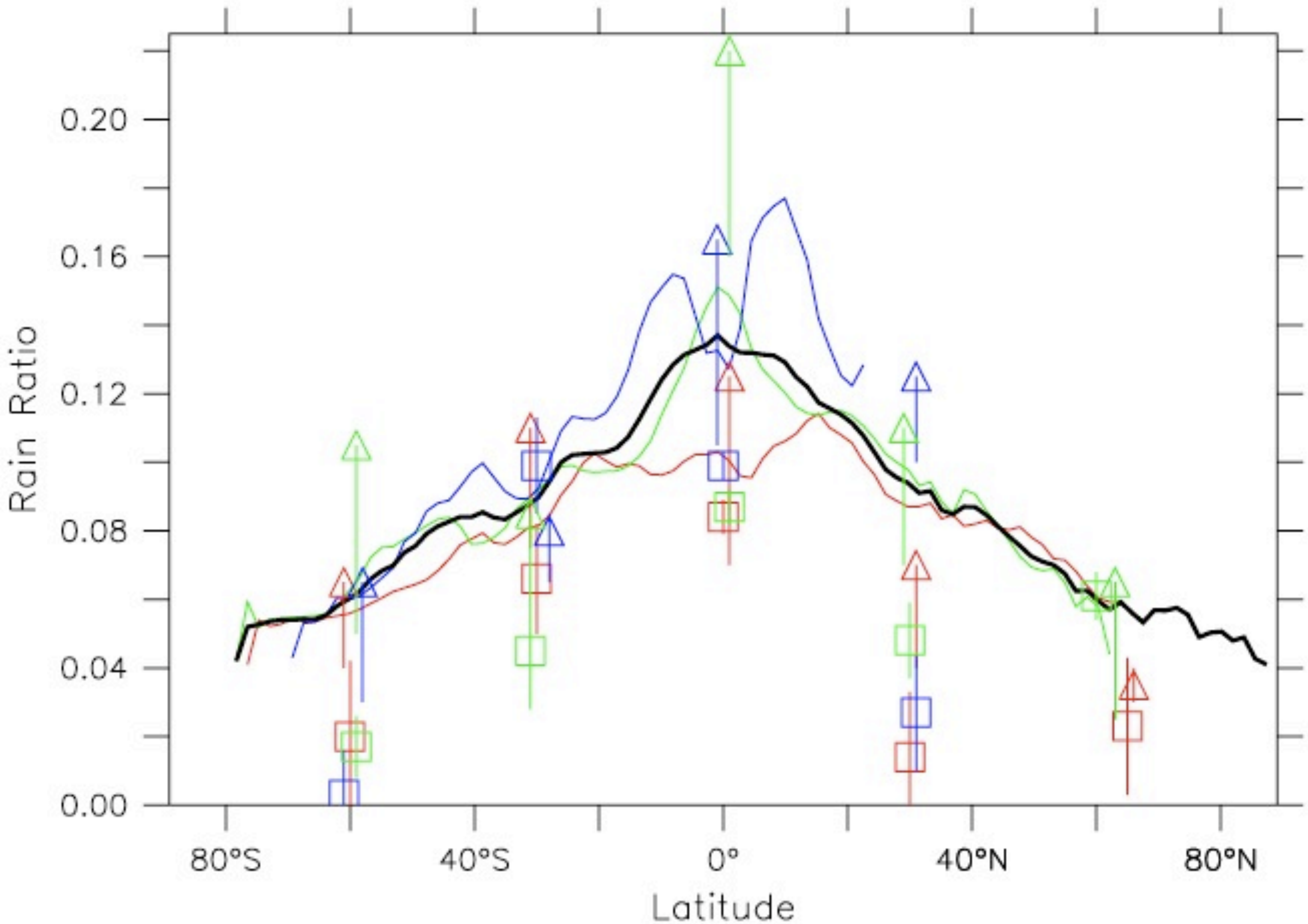
- Pteropods (zooplankton) — Aragonite

Carbonate Alkalinity

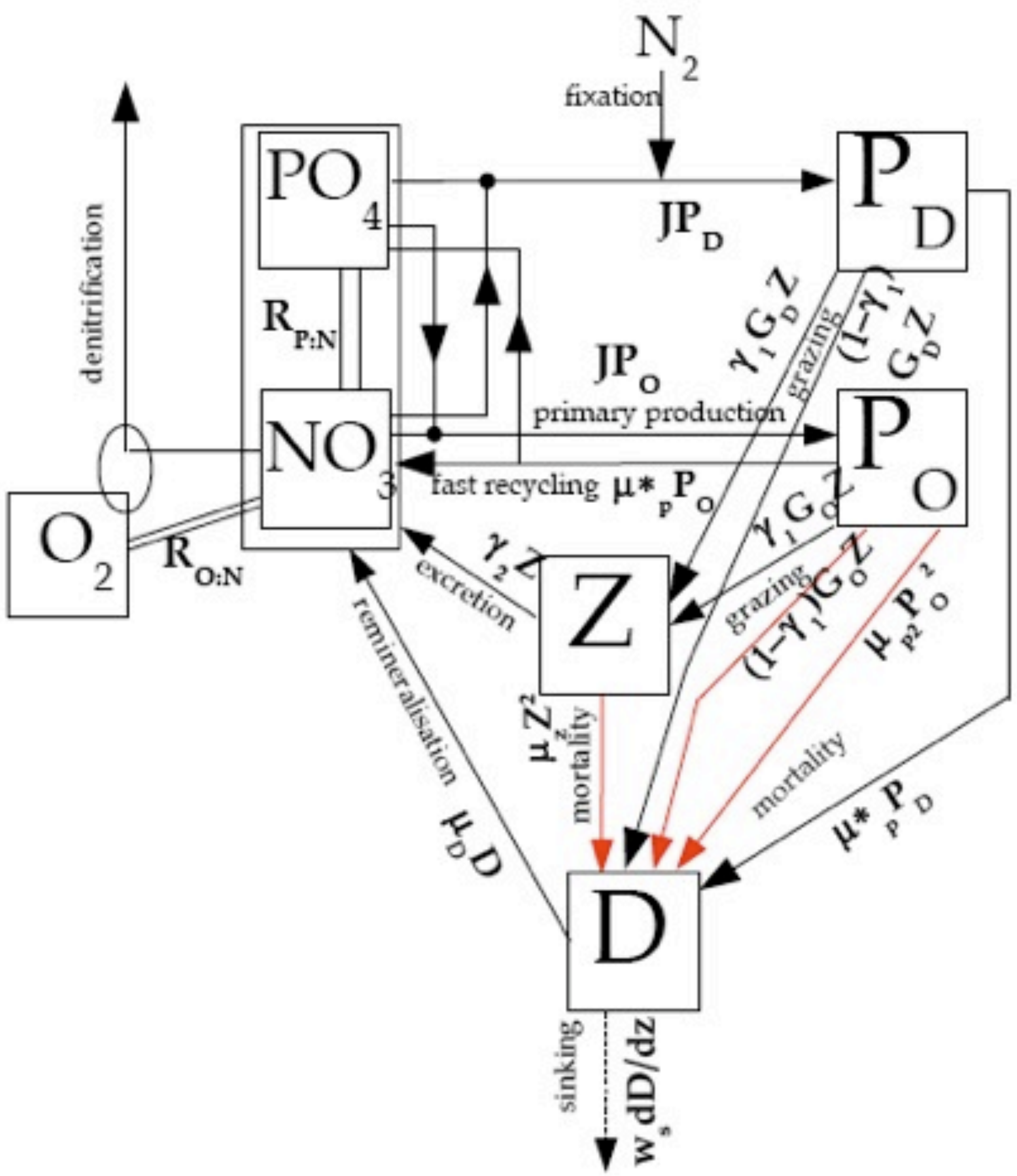
$$ALK=[HCO_3^-]+2[CO_3^{2-}]=2DIC-[HCO_3^-]$$



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



Details of Ecosystem and Carbon Cycle Model



$$\frac{\partial C}{\partial t} = T + S,$$

Transport

Biological Sources/Sinks

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

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

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

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

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

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

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

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

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

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

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

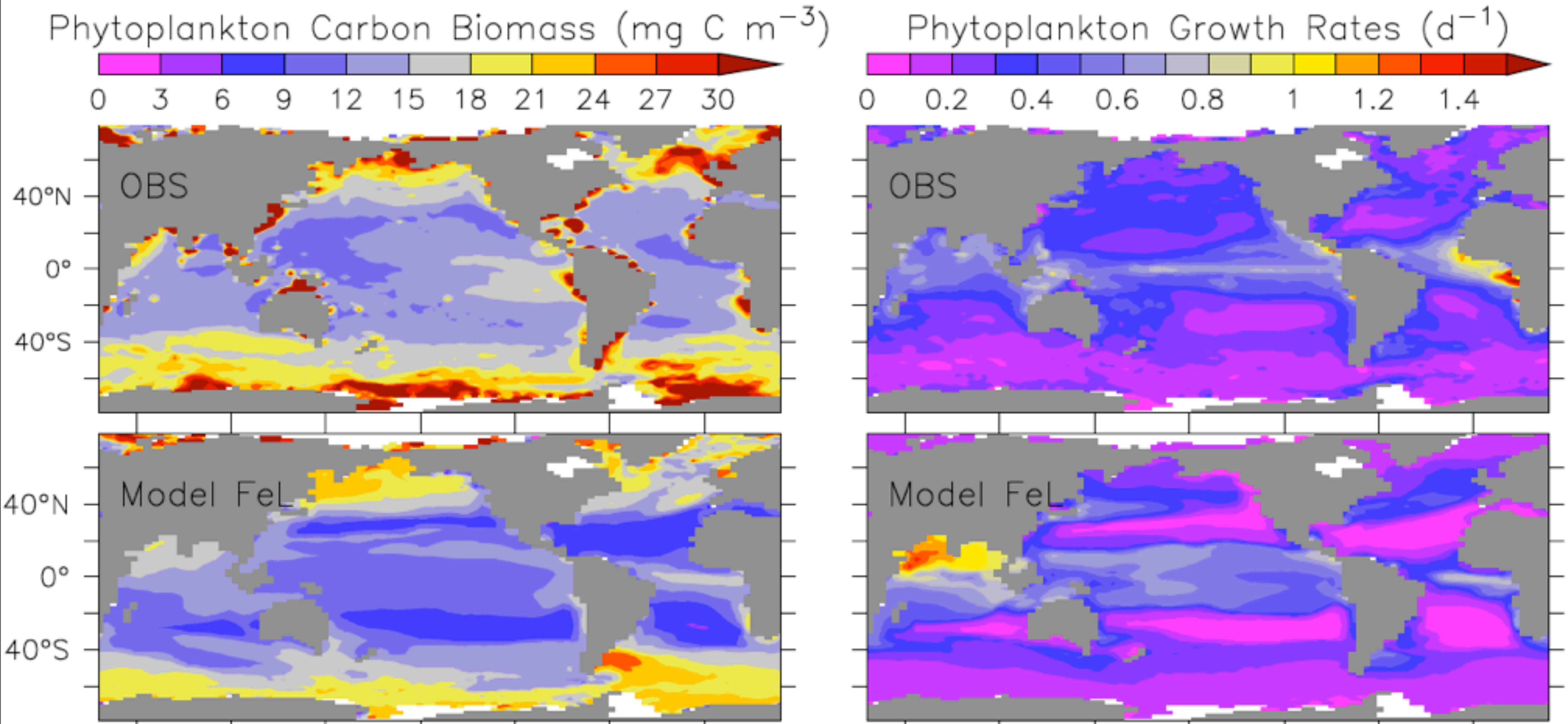
$$\Pr(\mathrm{CaCO_3}) = \left((1-\gamma_1)G(\mathrm{P}_O)\mathrm{Z} + \mu_{P2}\mathrm{P}_O^2 + \mu_Z \mathrm{Z}^2\right) R_{\mathrm{CaCO3/POC}} R_{C:P},$$

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

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

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

Schmittner et al. 2008 GBC



Schmittner et al. (submitted)