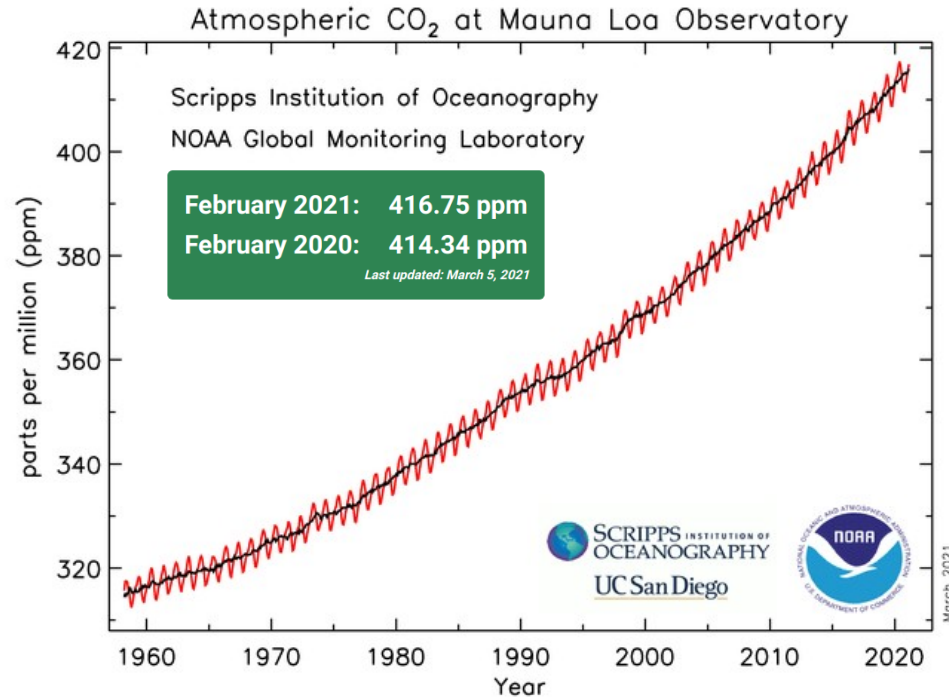
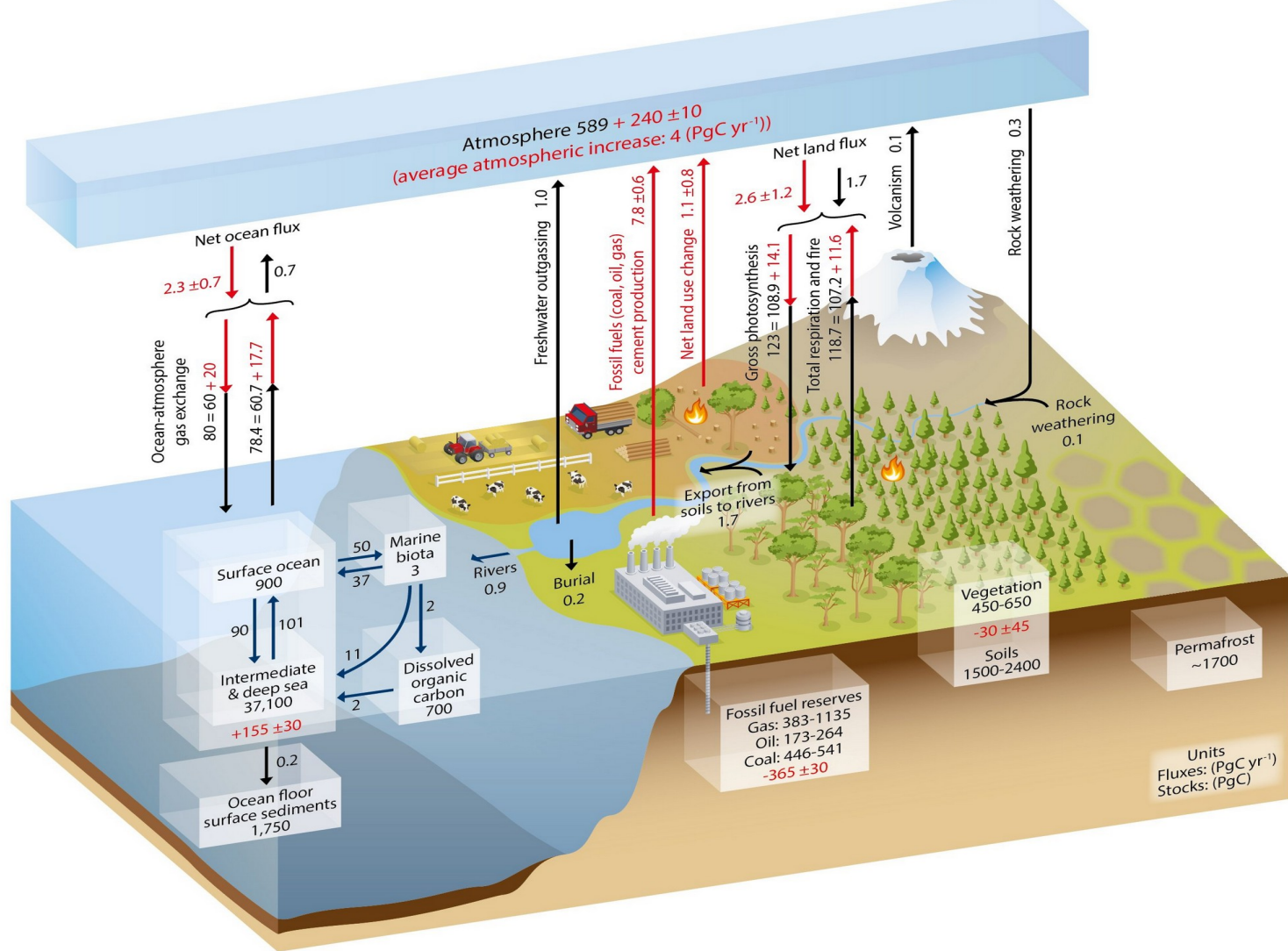
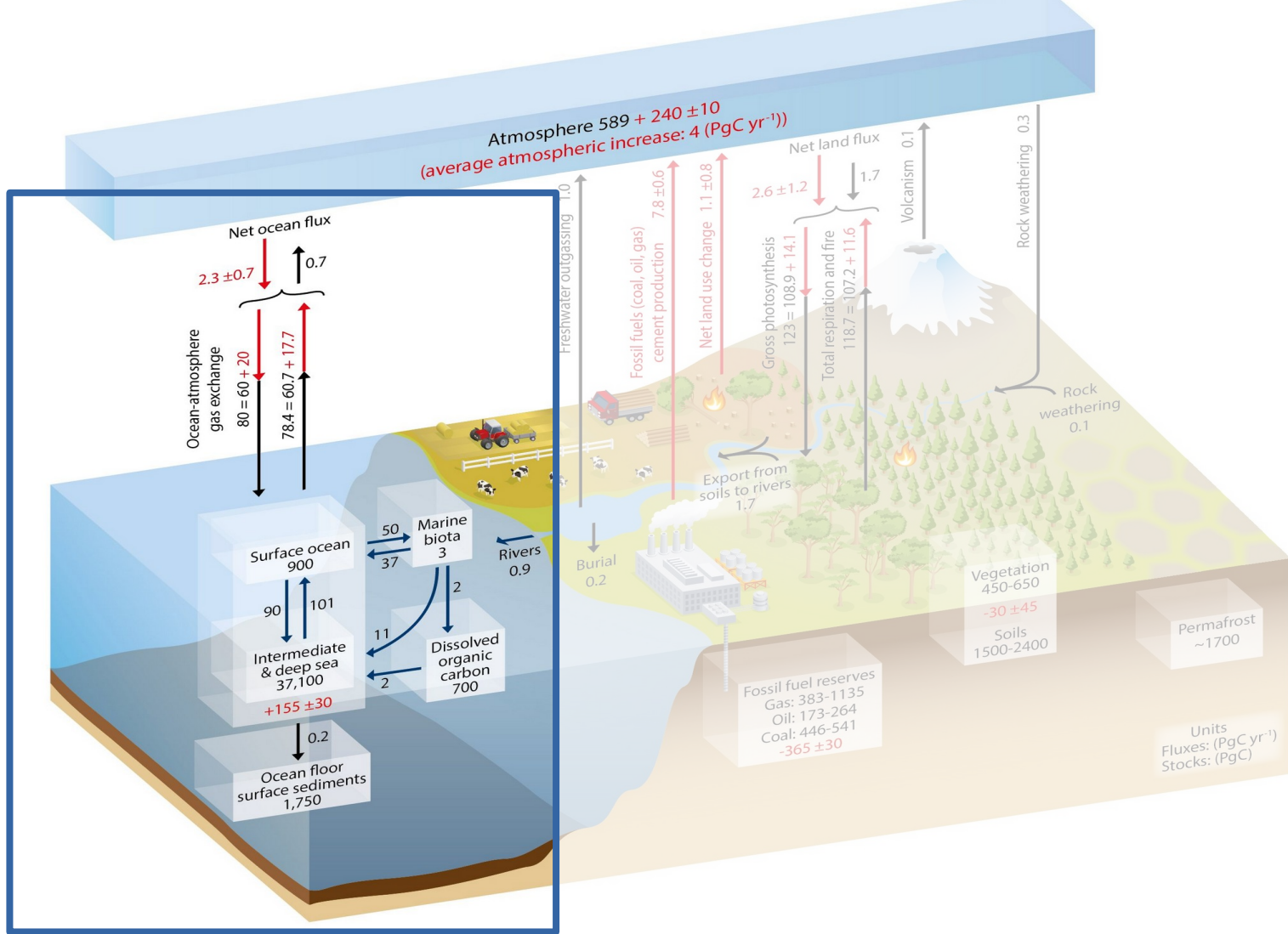


Ocean-Atmosphere Carbon Fluxes

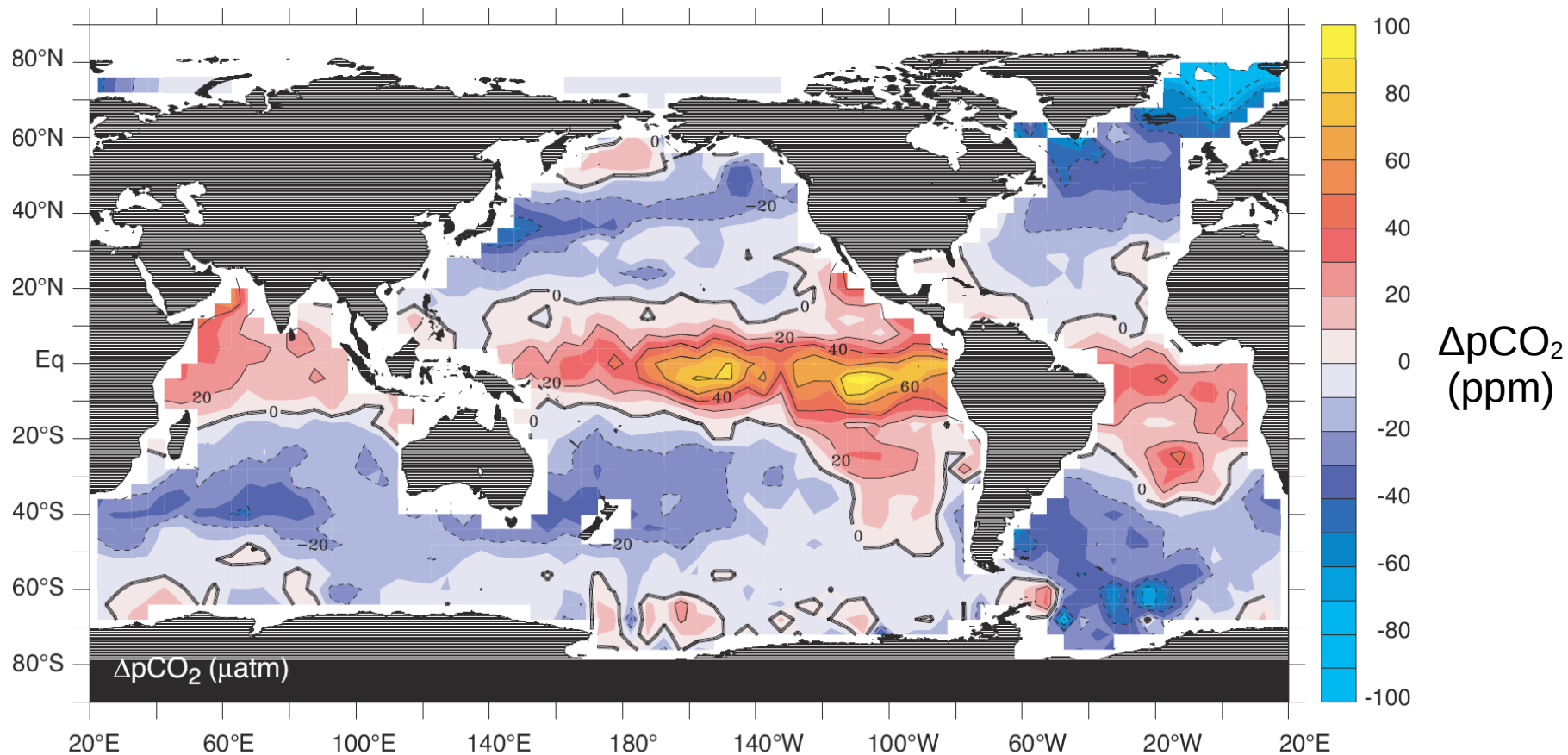






Ocean has absorbed $\sim 30\text{-}40\%$ of the CO_2 we've released.

Ocean-Atmosphere Carbon Fluxes



Ocean-Atmosphere Carbon Fluxes

Factors:

Physical

Ocean Circulation & Mixing

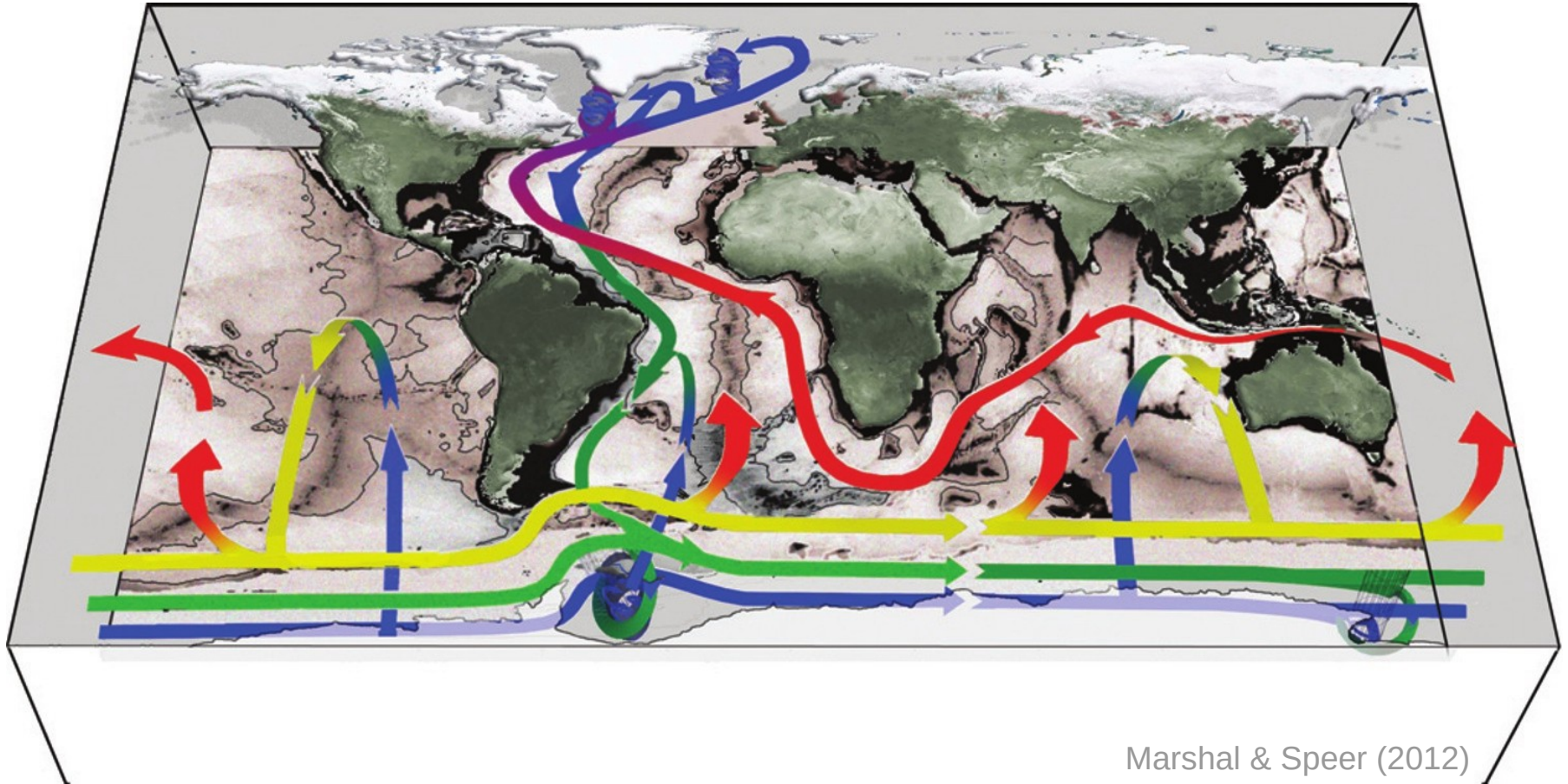
Chemical

Dissolved Inorganic Carbon (DIC)

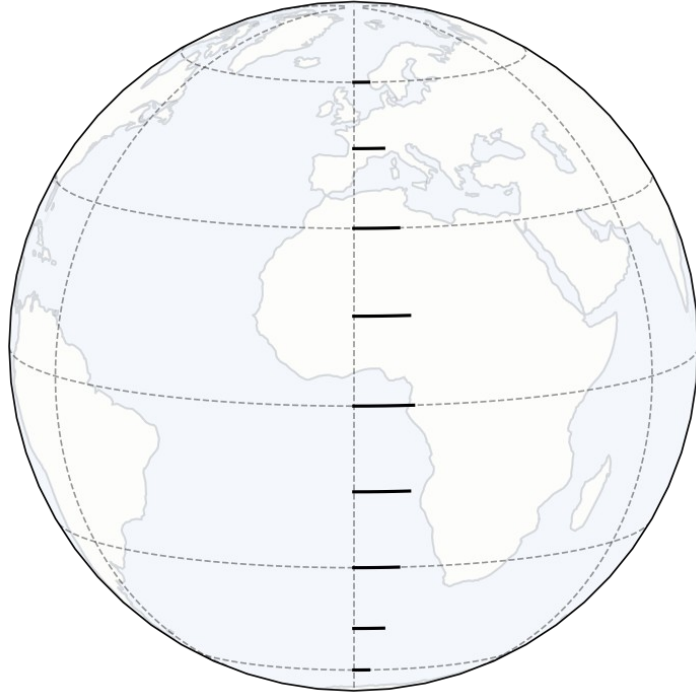
Biological

Carbon capture ('productivity') and export.

Ocean Circulation

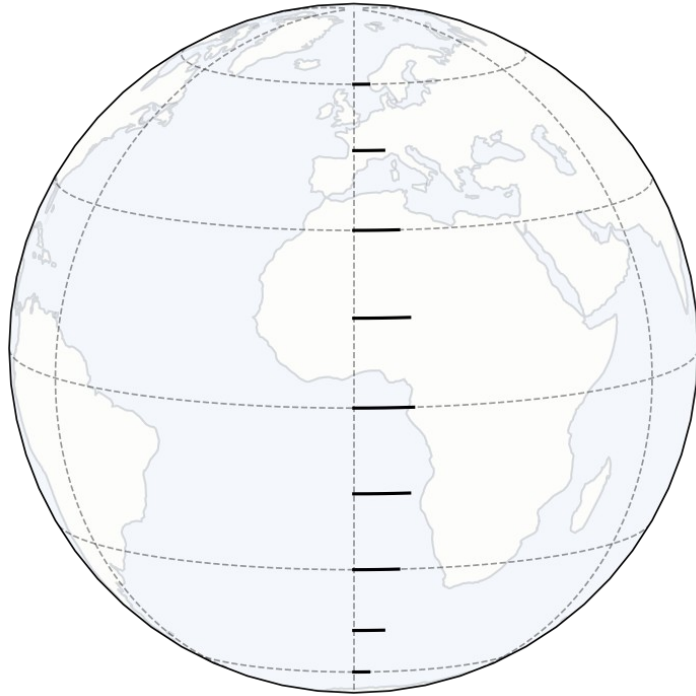


Ocean Circulation: Coriolis

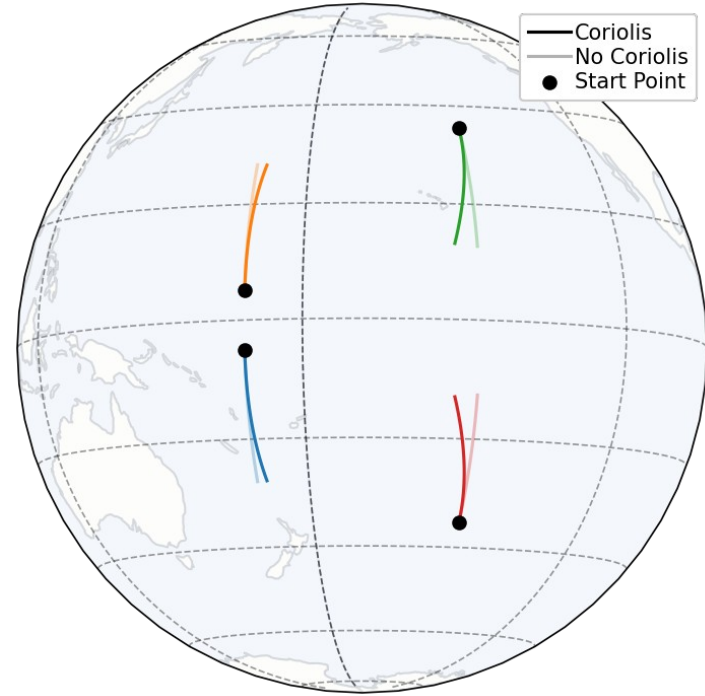


Eastward Velocity

Ocean Circulation: Coriolis

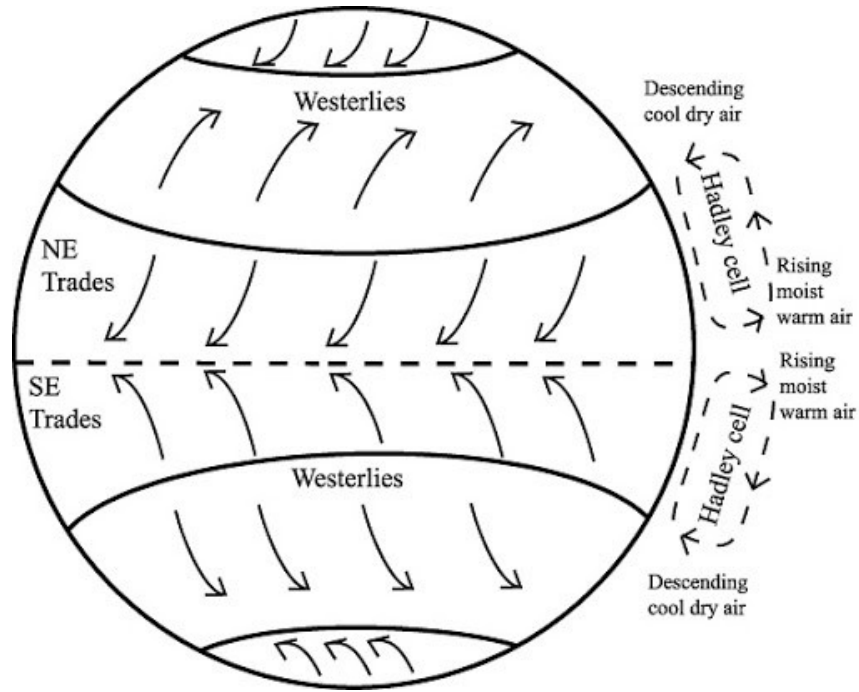


Eastward Velocity

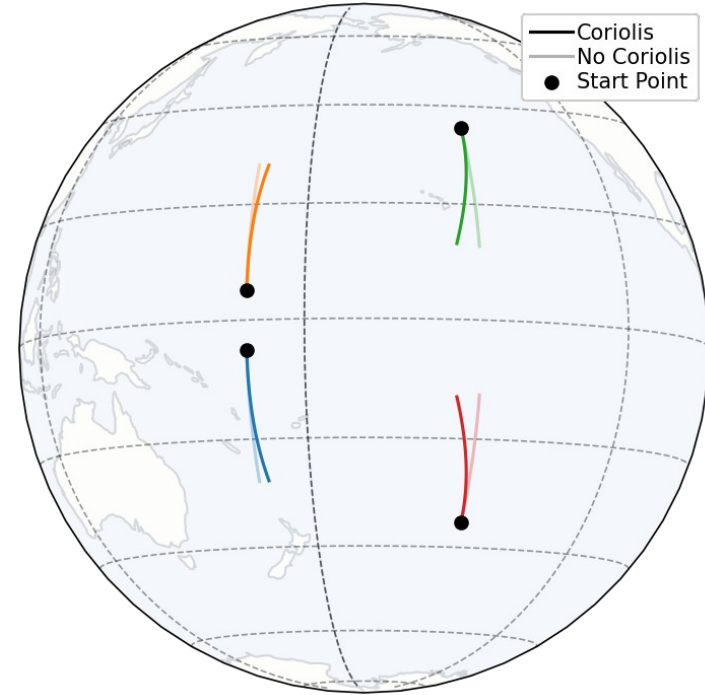


Deflection

Ocean Circulation: Wind

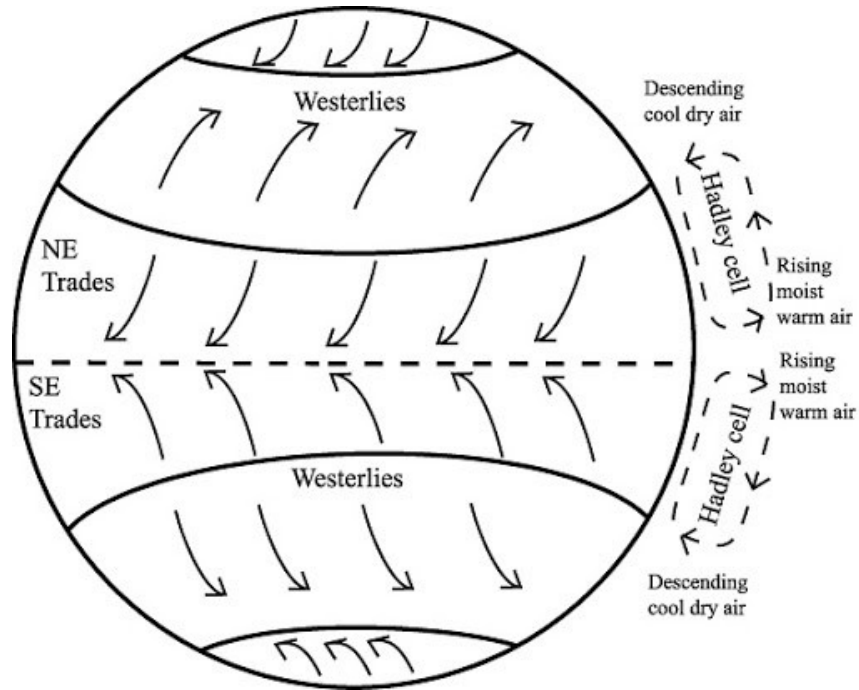


~Surface Wind

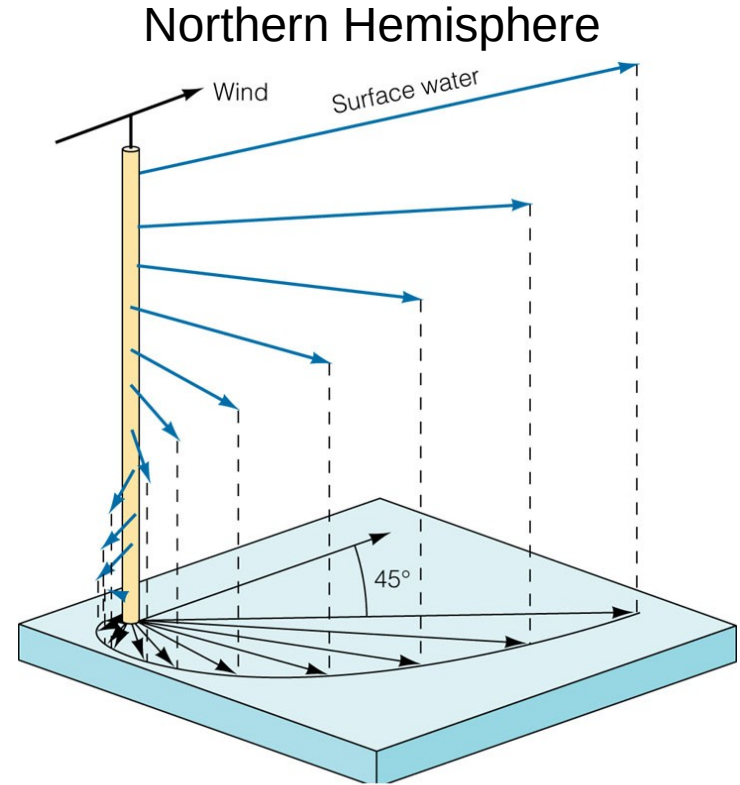


Deflection

Ocean Circulation: Wind



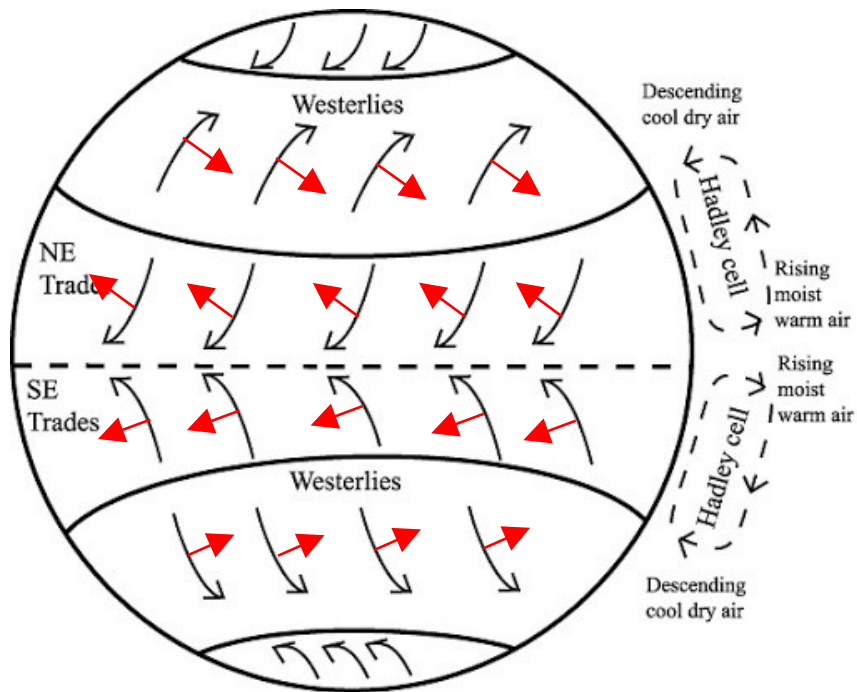
~Surface Wind



© 2005 Brooks/Cole - Thomson

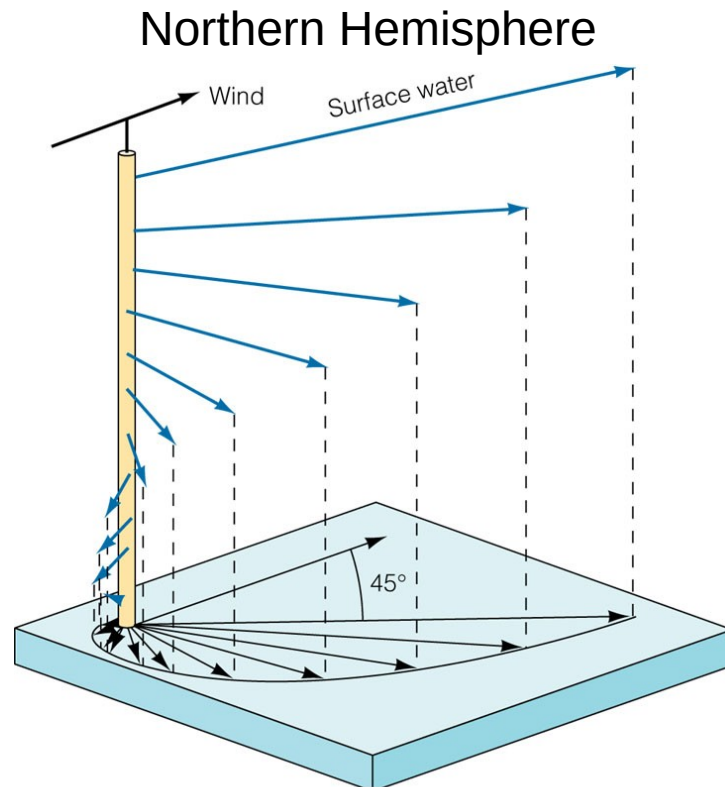
Ekman Transport

Ocean Circulation: Wind



~Surface Wind

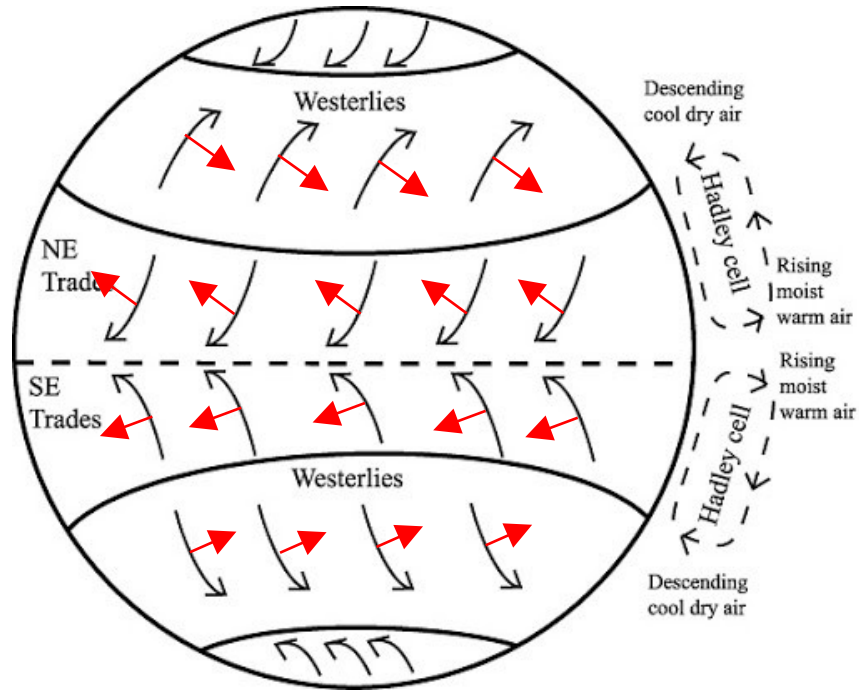
~Surface Water



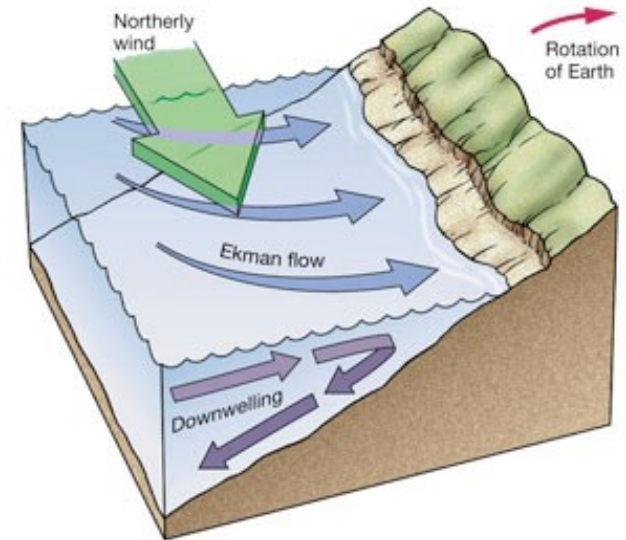
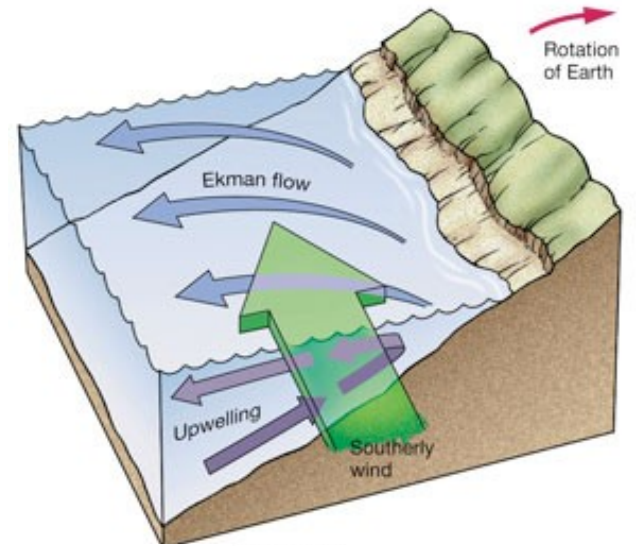
© 2005 Brooks/Cole - Thomson

Ekman Transport

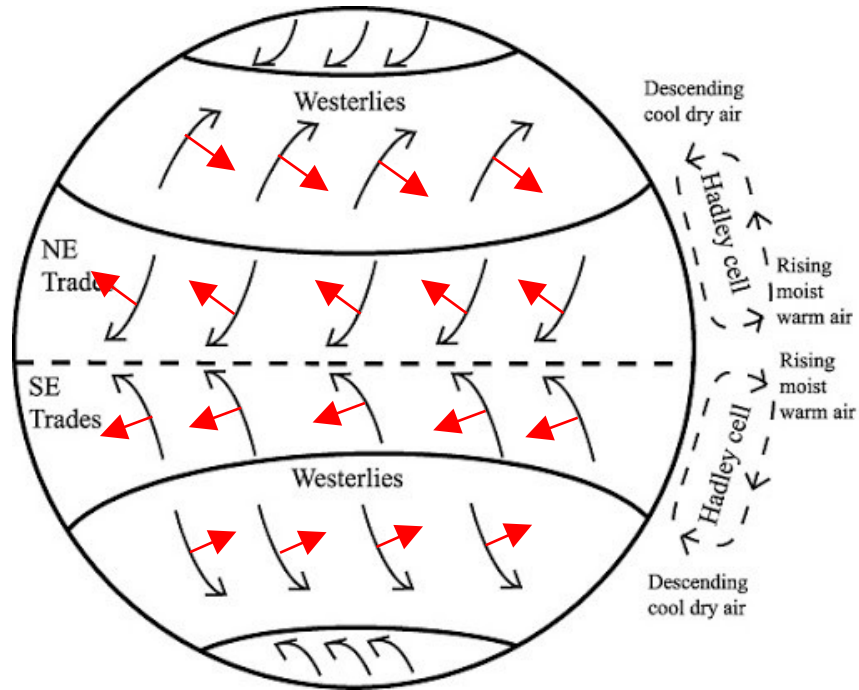
Ocean Circulation: Wind



~Surface Wind
~Surface Water

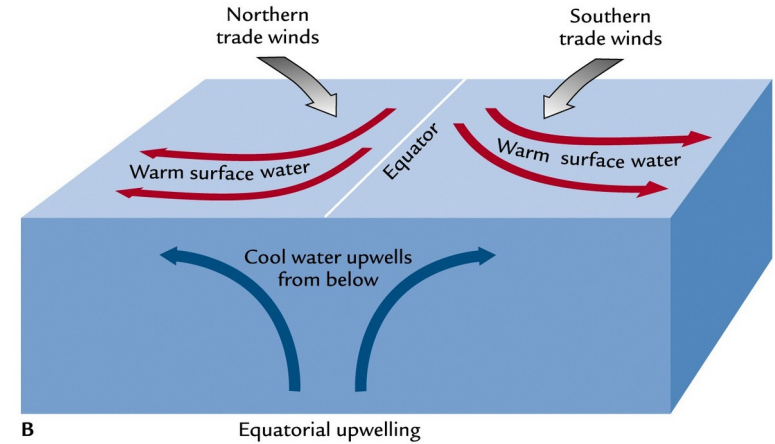


Ocean Circulation: Wind

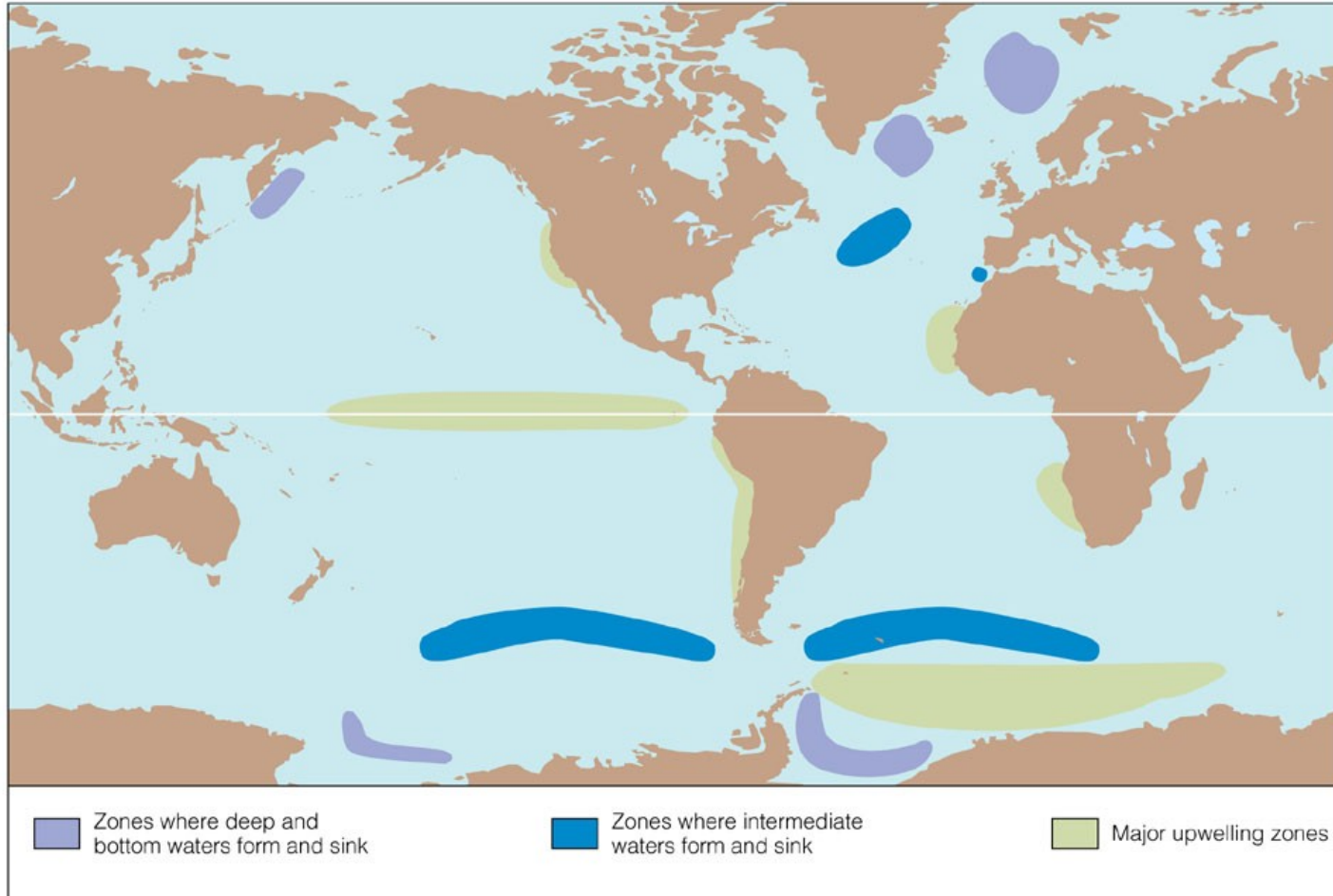


~Surface Wind

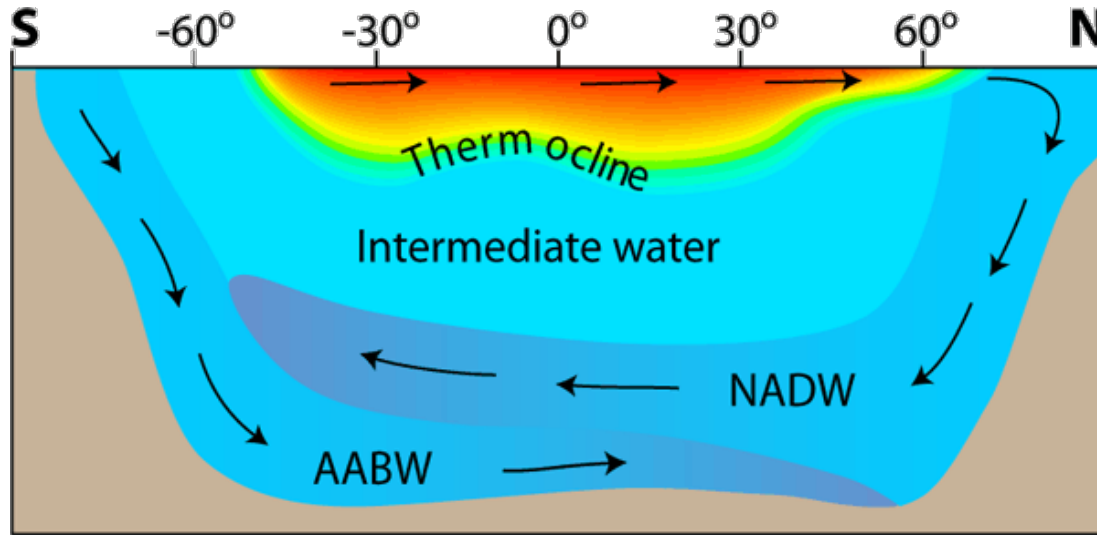
~Surface Water



Ocean Circulation: Up and Down

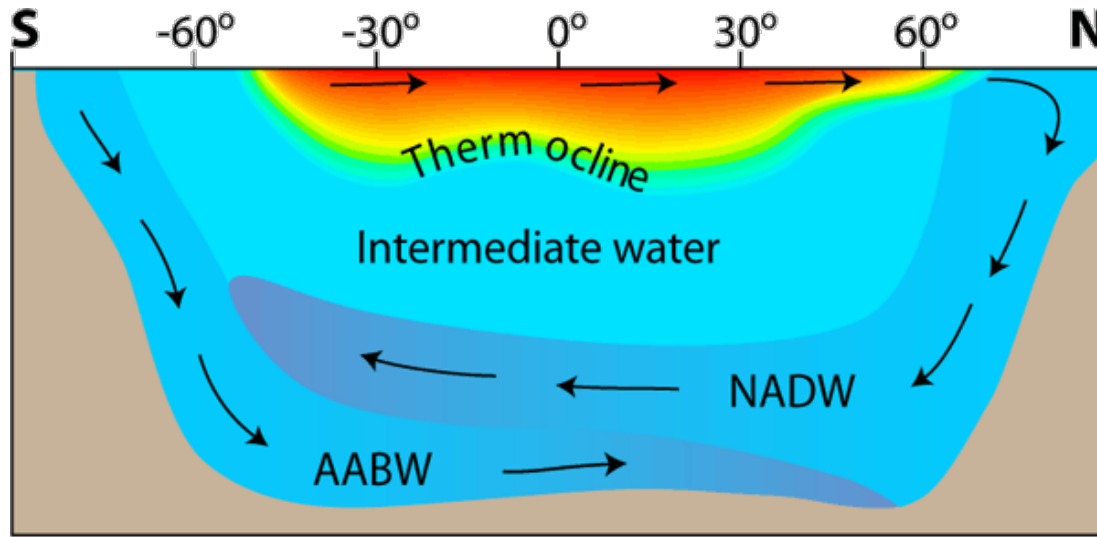


Ocean Circulation: Density

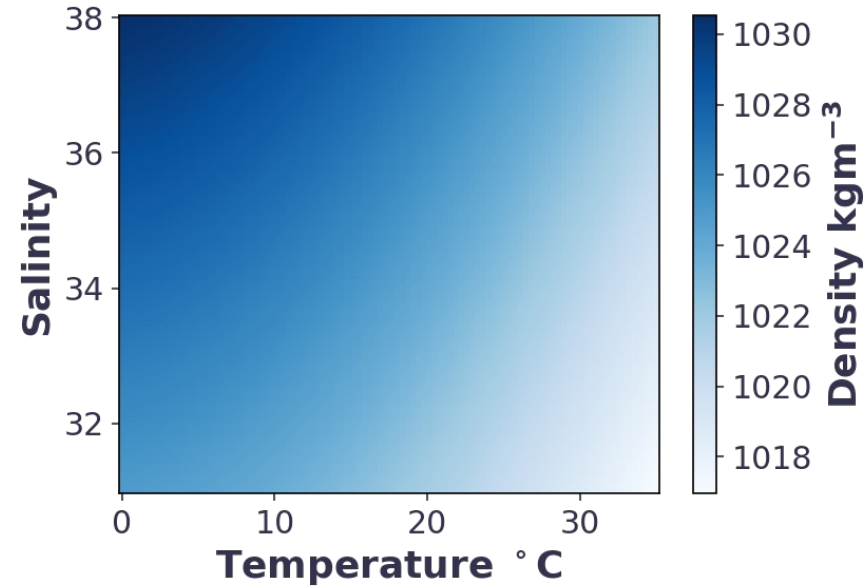


Atlantic Water-Bodies

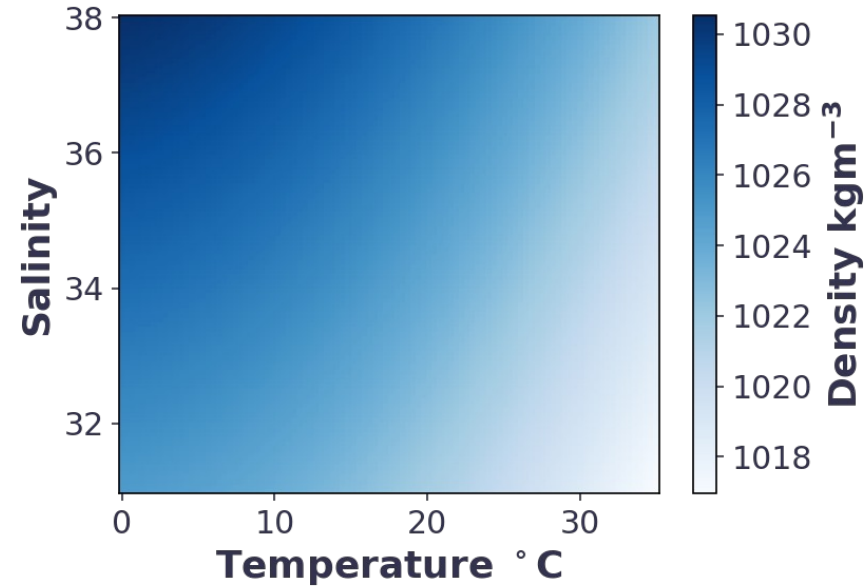
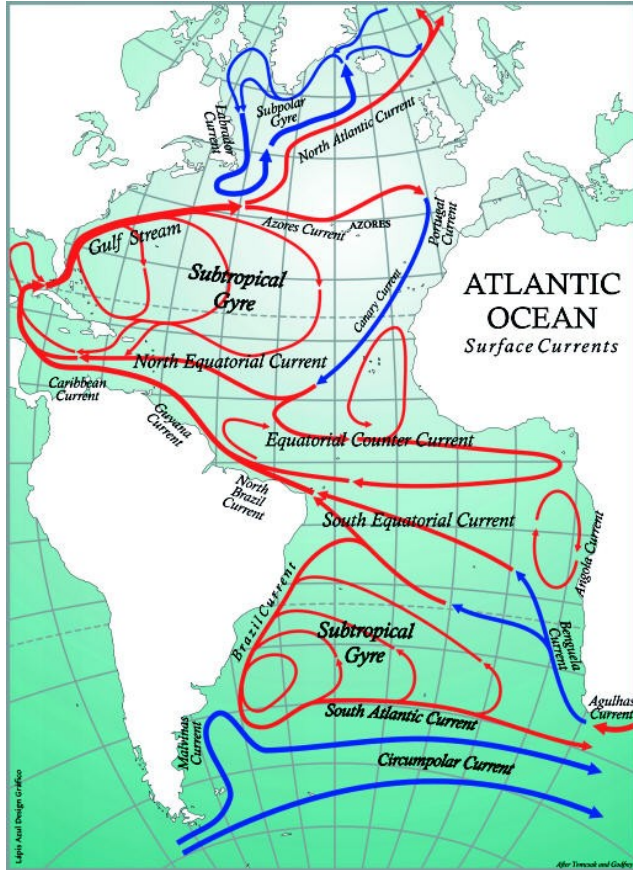
Ocean Circulation: Density



Atlantic Water-Bodies

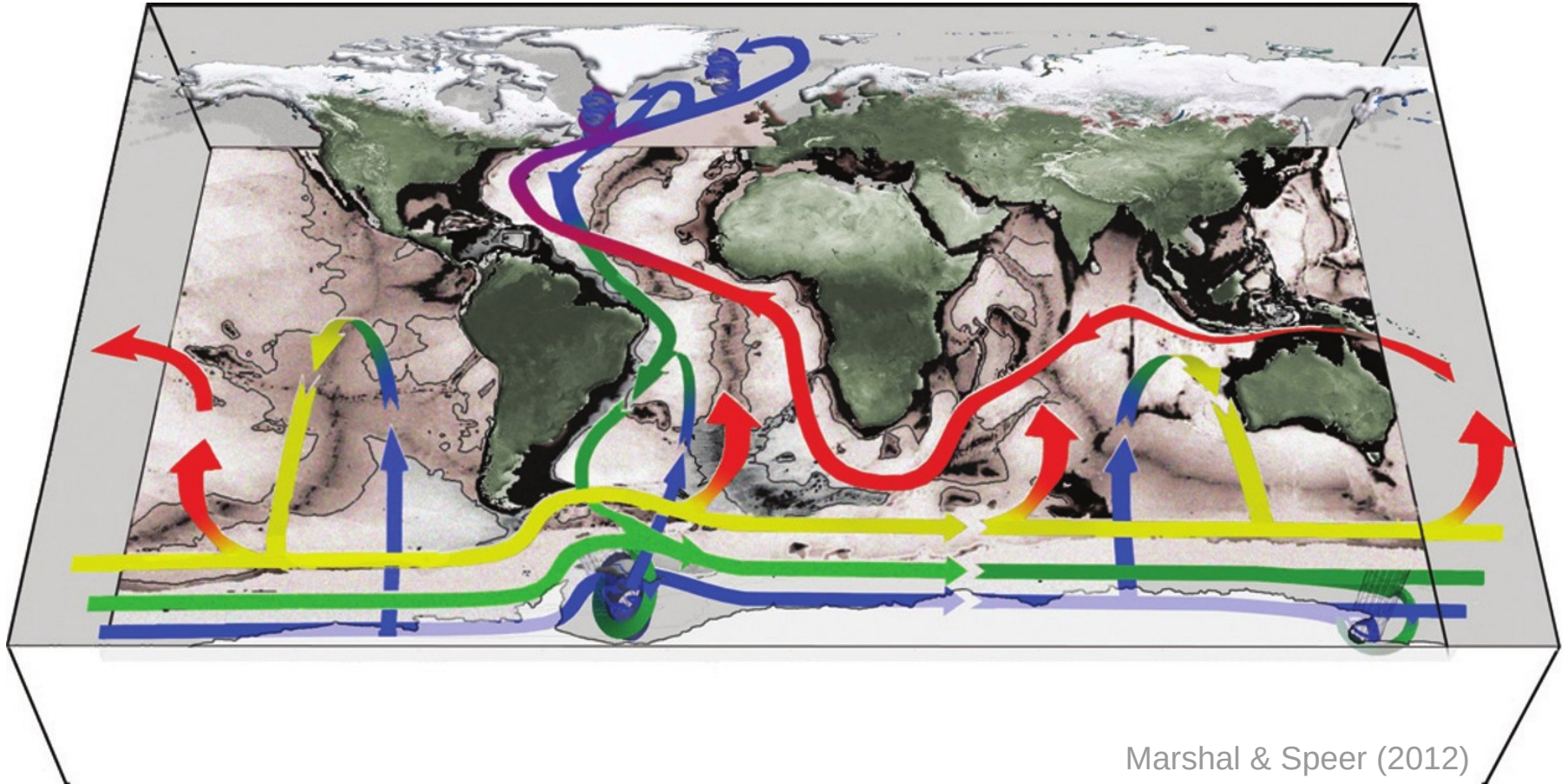


Ocean Circulation: Density

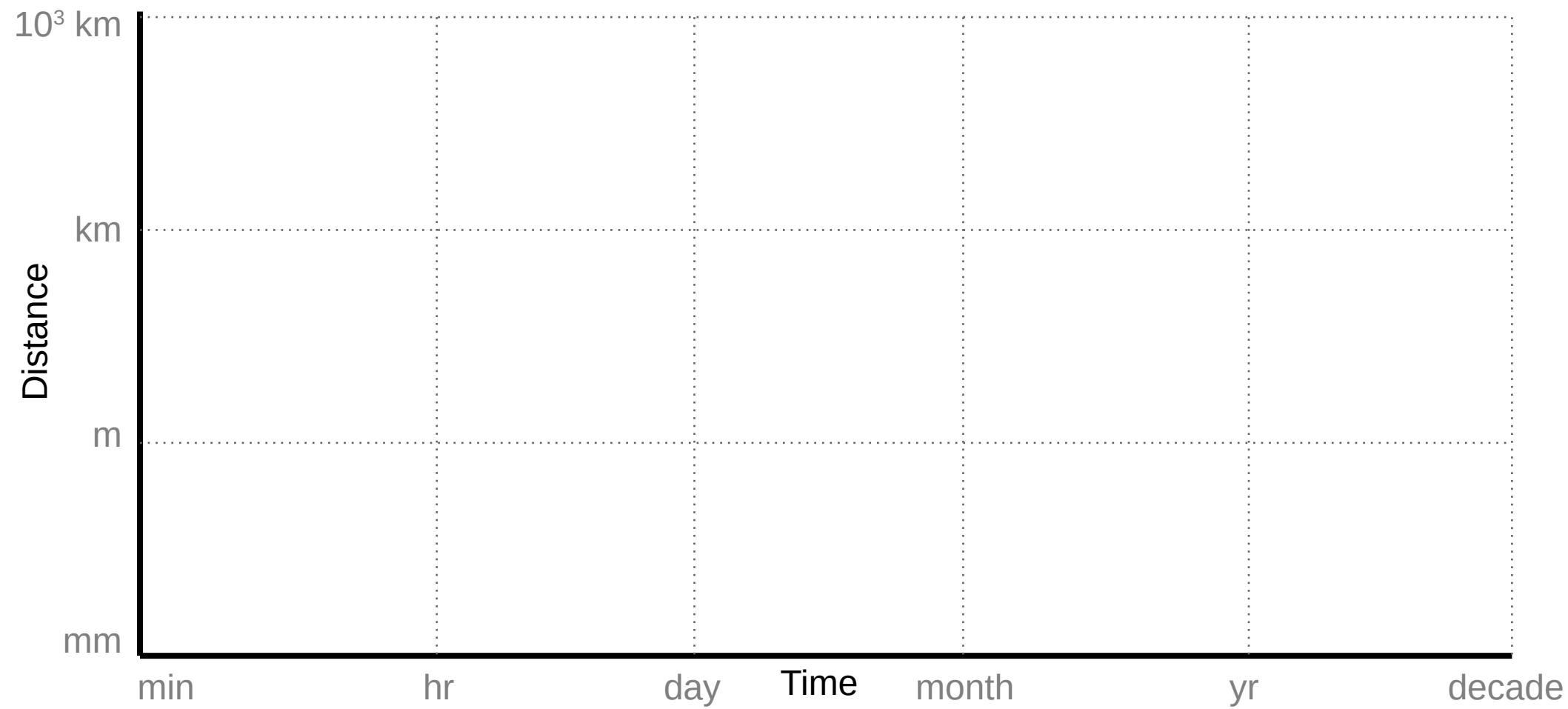


Ocean Circulation

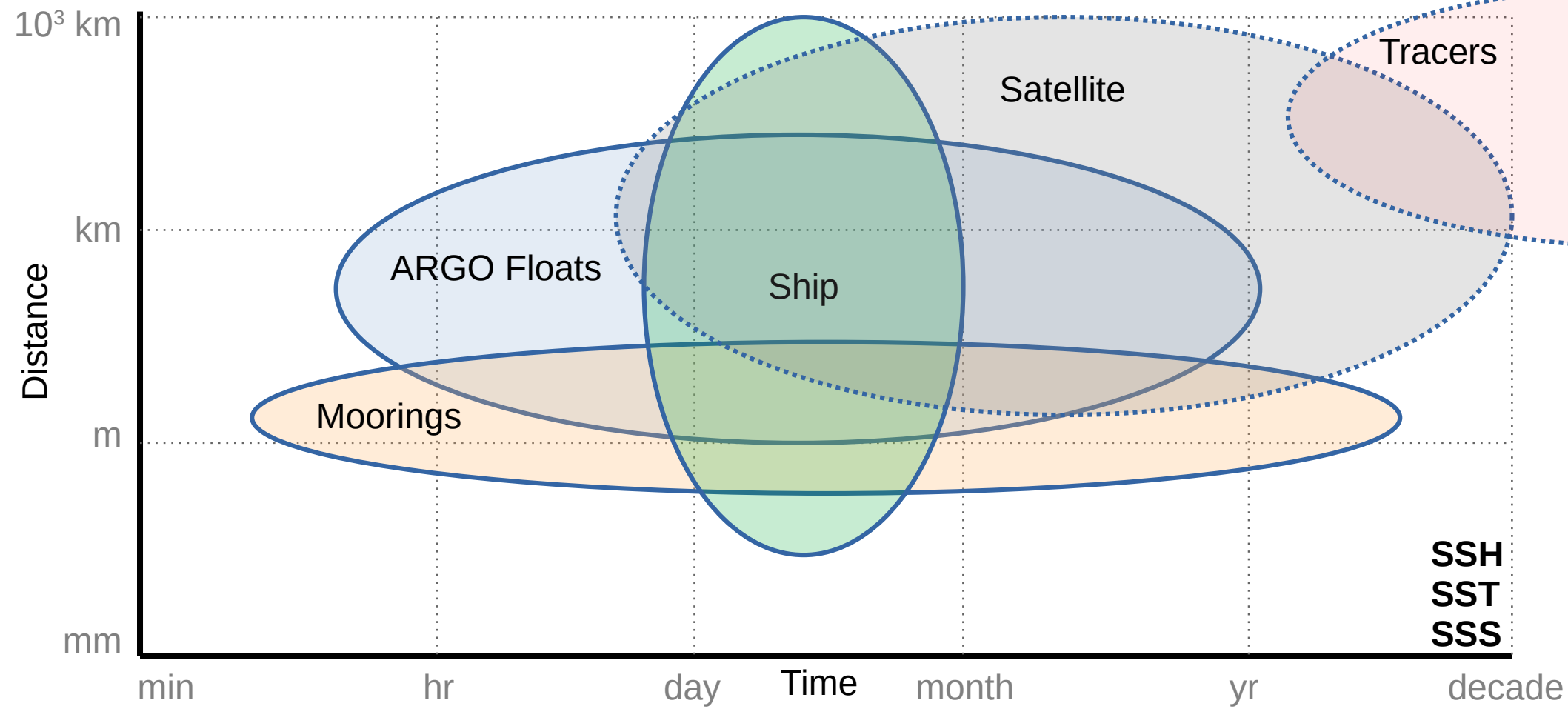
Transport driven by wind and density flows. Turnover time ~1-3000 years.



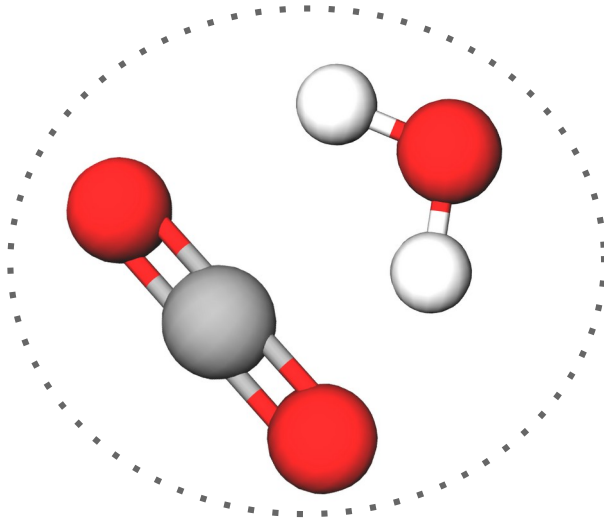
Ocean Circulation: Measurement



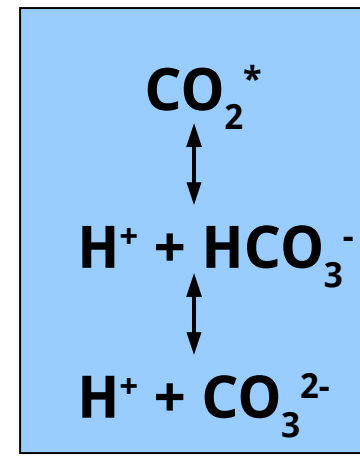
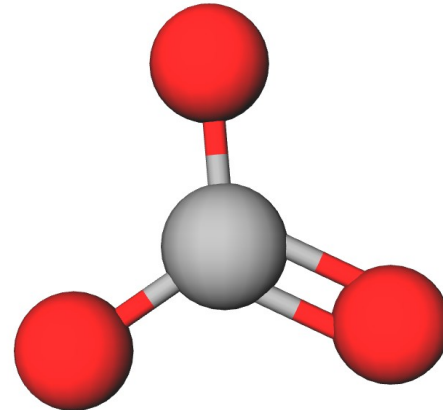
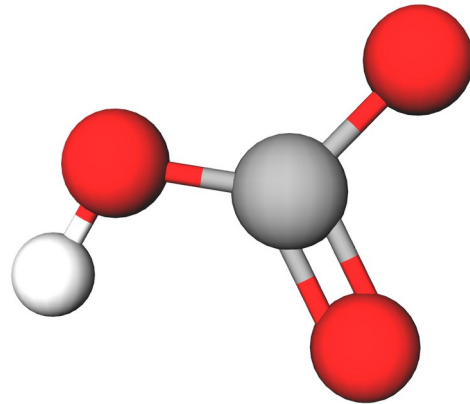
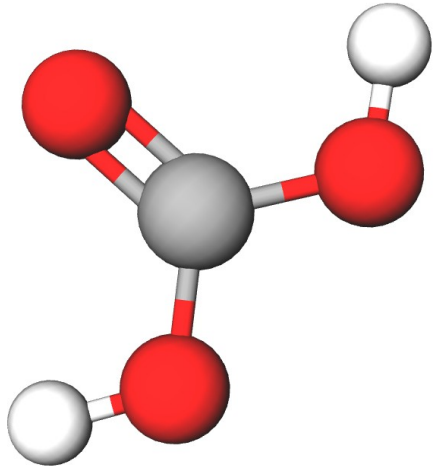
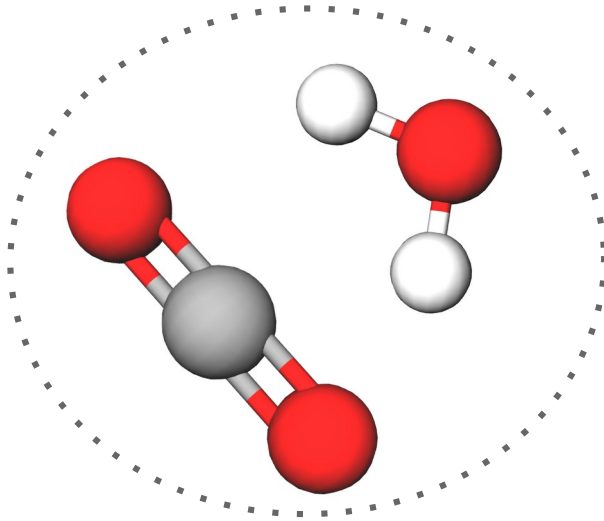
Ocean Circulation: Measurement



Carbon in Seawater



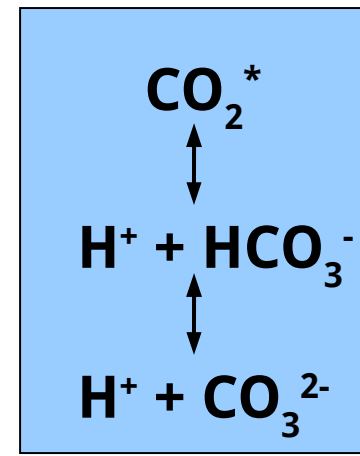
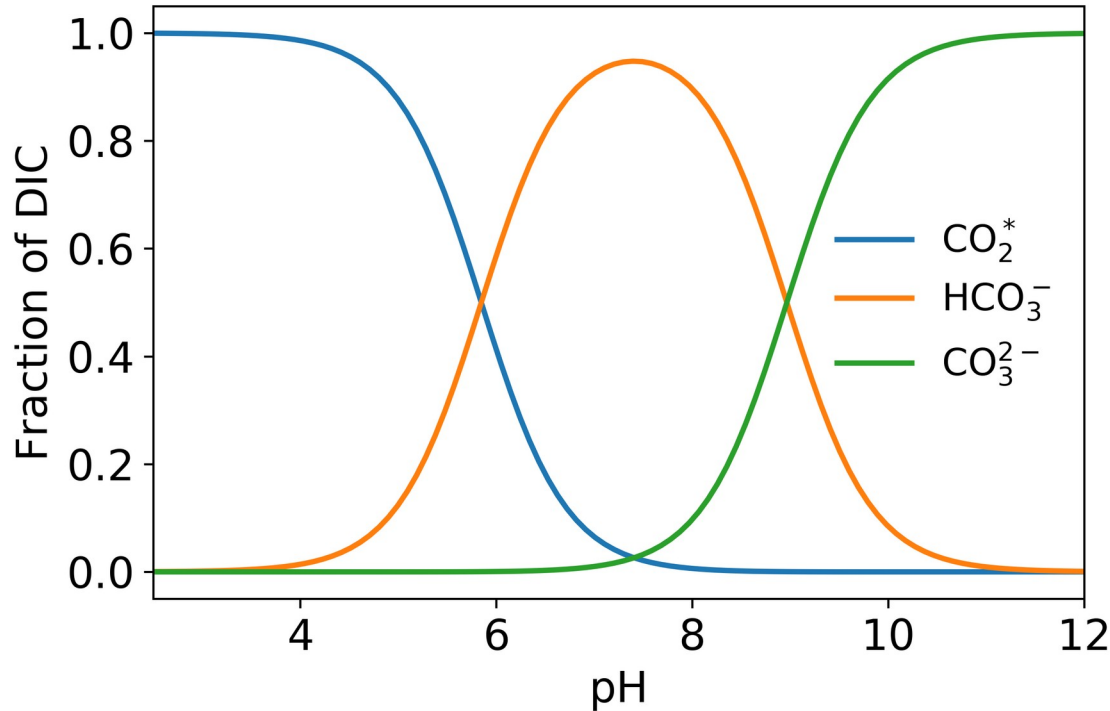
Carbon in Seawater



Dissolved Inorganic Carbon

$$\text{DIC} = \text{CO}_2^* + \text{HCO}_3^- + \text{CO}_3^{2-}$$

Carbon in Seawater

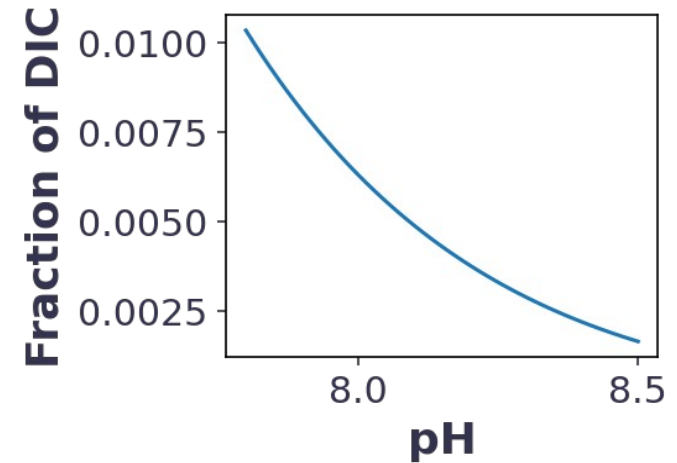
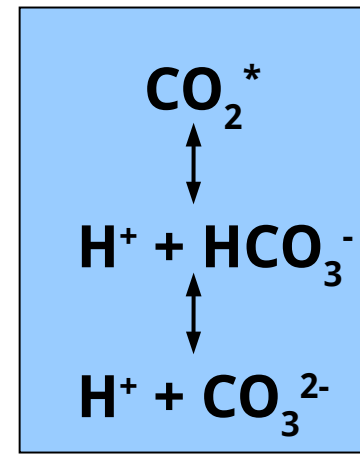
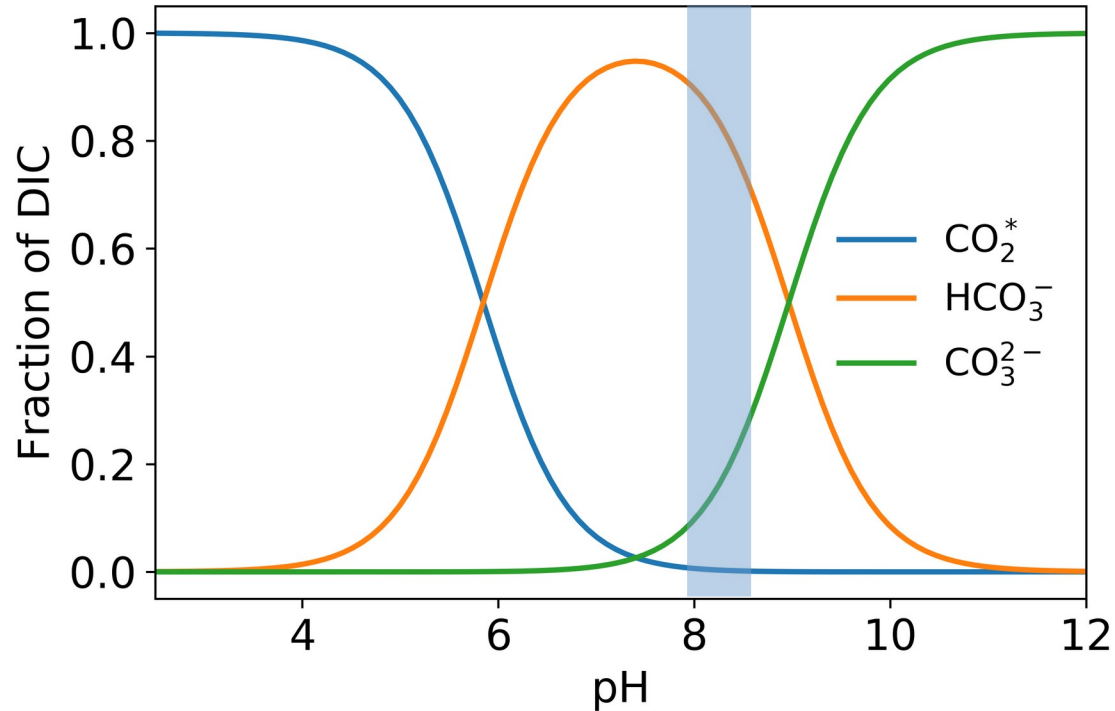


Dissolved Inorganic Carbon

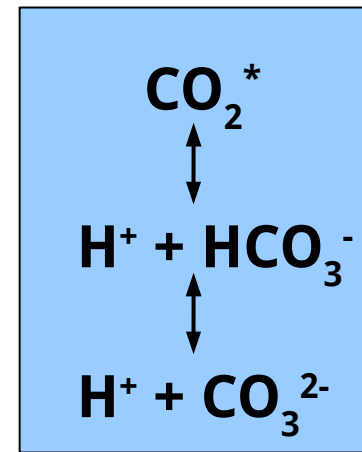
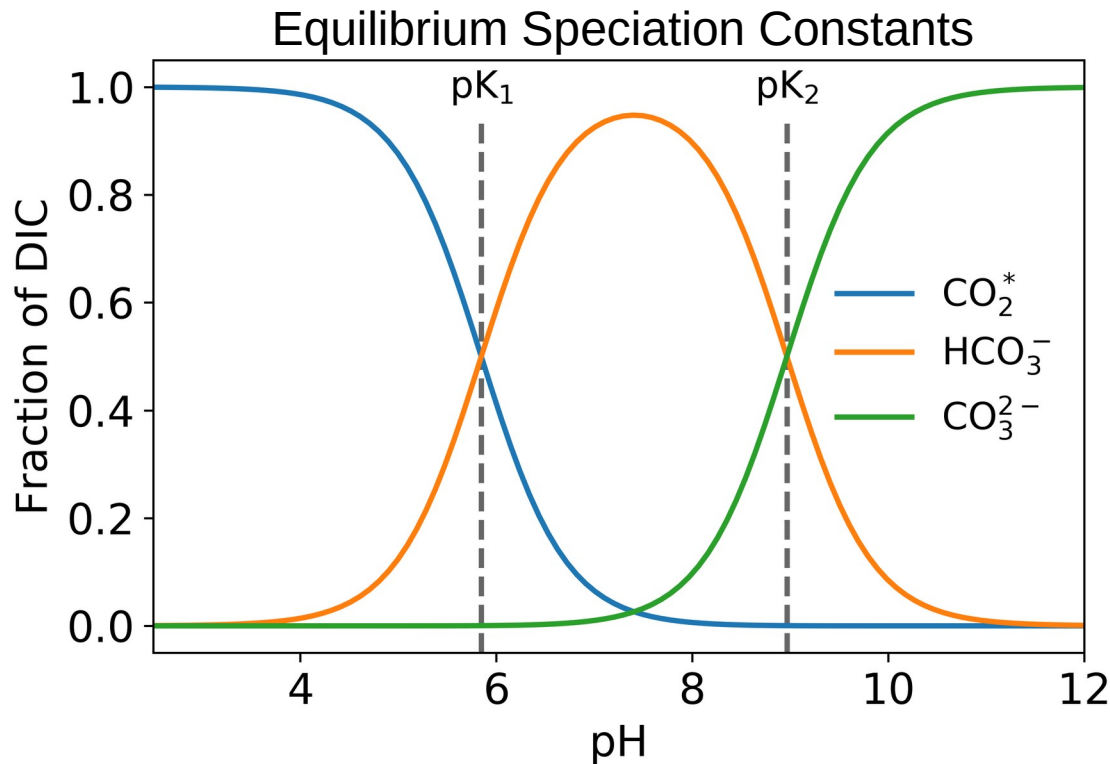
$$\text{DIC} = \text{CO}_2^* + \text{HCO}_3^- + \text{CO}_3^{2-}$$

$$\text{pH} = -\log_{10}([\text{H}^+])$$

Carbon in Seawater



Carbon in Seawater

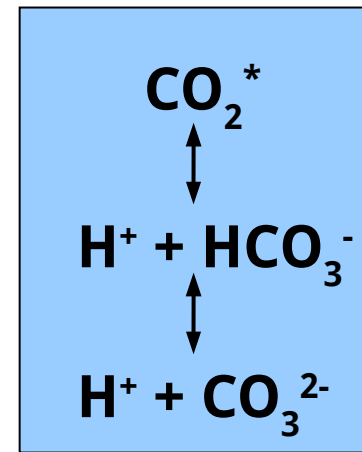
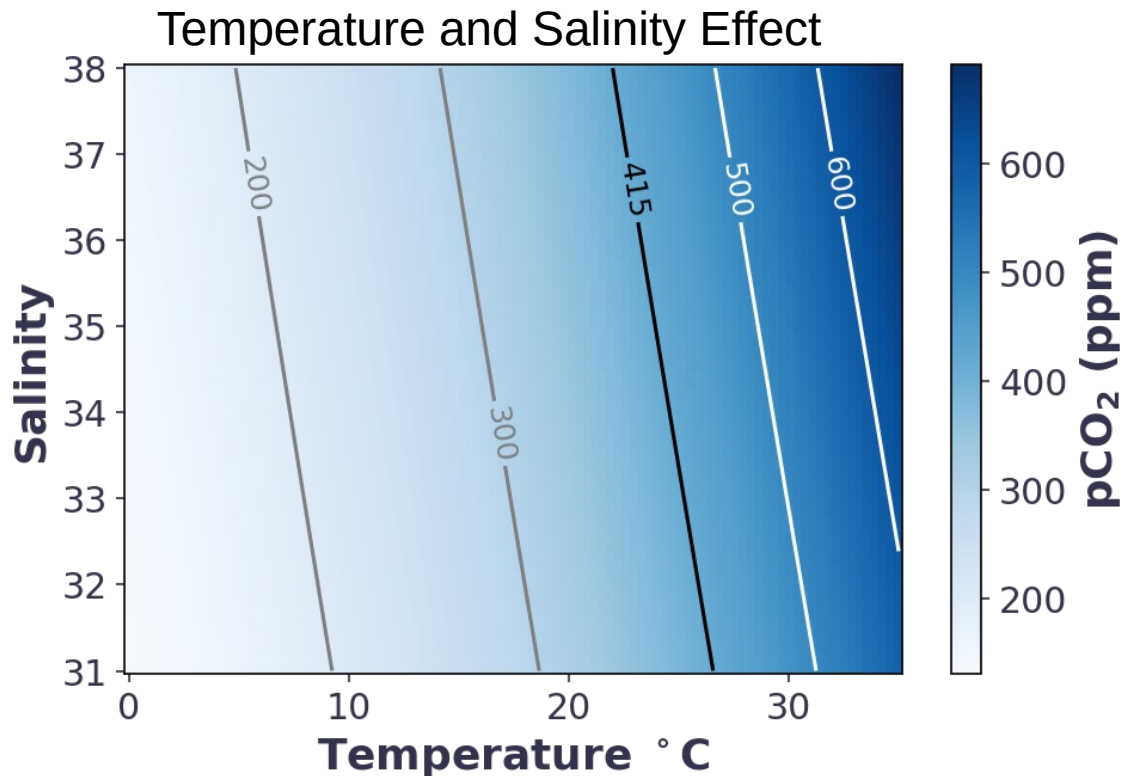


$$K_0 = \frac{[\text{CO}_2^*]}{f\text{CO}_2}$$

$$K_1 = \frac{[\text{H}^+][\text{HCO}_3^-]}{[\text{CO}_2^*]}$$

$$K_2 = \frac{[\text{H}^+][\text{CO}_3^{2-}]}{[\text{HCO}_3^-]}$$

Carbon in Seawater



$$K_0 = \frac{[\text{CO}_2^*]}{f\text{CO}_2}$$

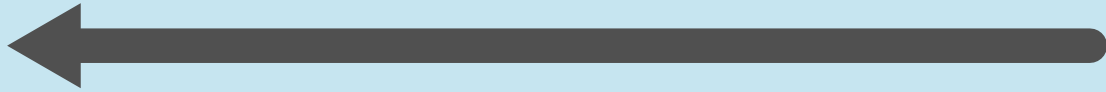
$$K_1 = \frac{[\text{H}^+][\text{HCO}_3^-]}{[\text{CO}_2^*]}$$

$$K_2 = \frac{[\text{H}^+][\text{CO}_3^{2-}]}{[\text{HCO}_3^-]}$$

Think: Circulation + Chemistry

High Lat

Equator

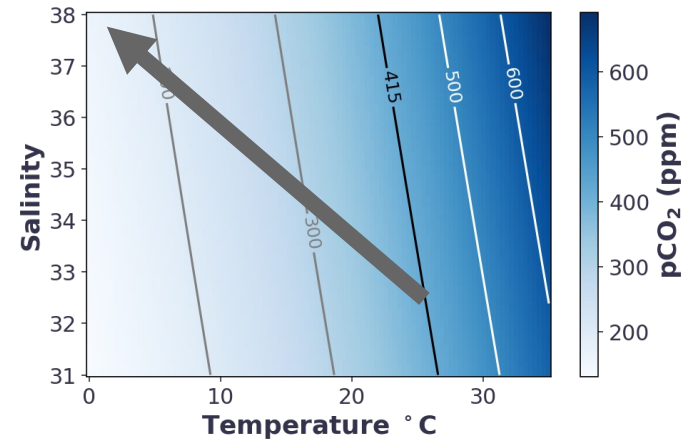
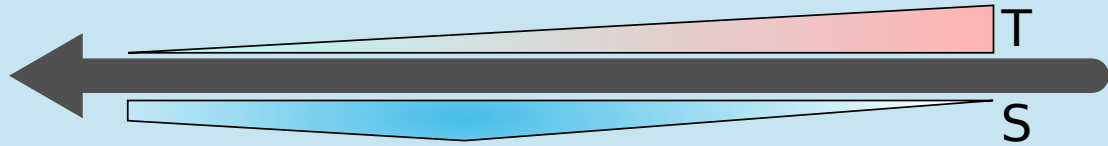


Think: Circulation + Chemistry

High Lat

Equator

$\text{pCO}_2 \sim 400\text{ppm}$

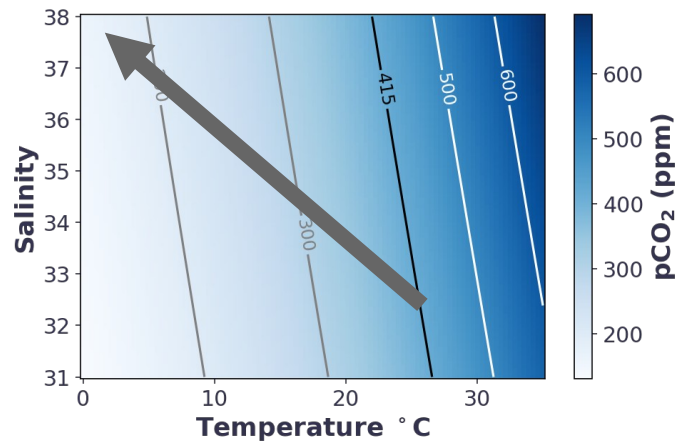
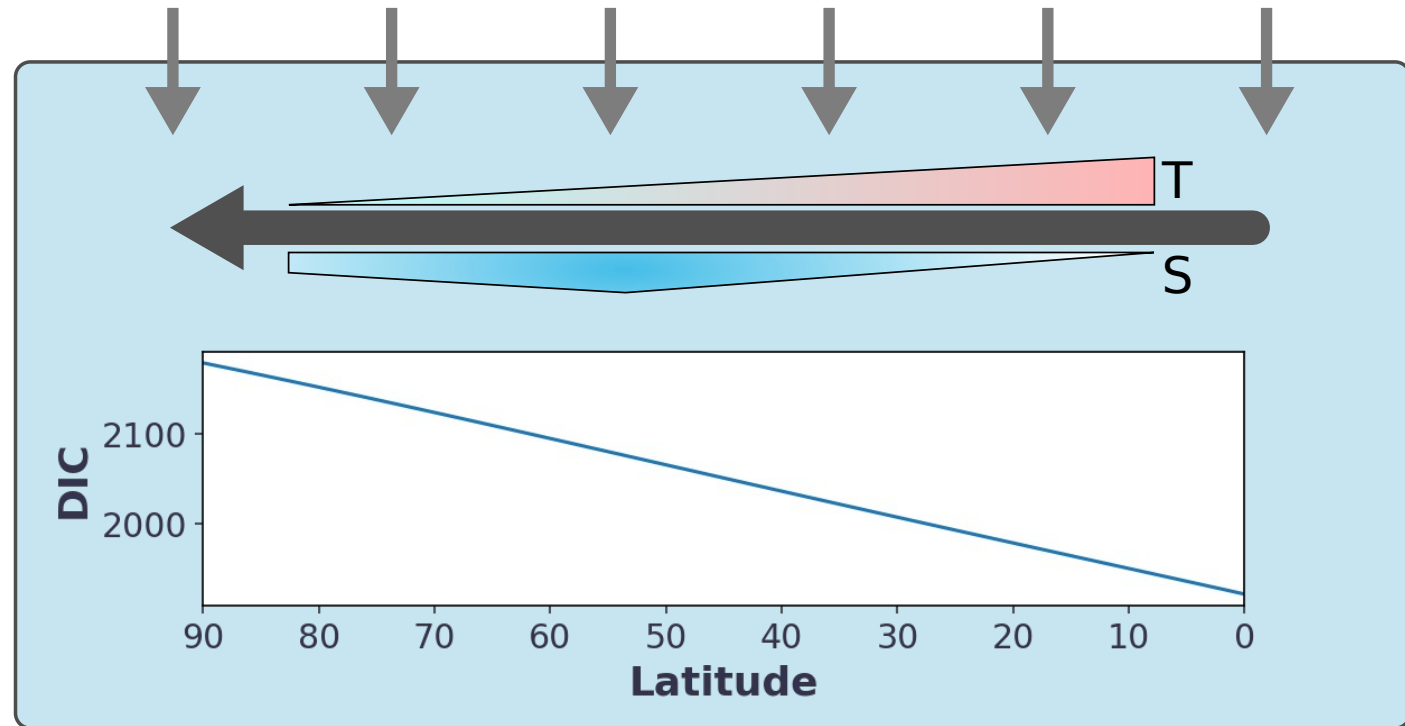


Think: Circulation + Chemistry

High Lat

Equator

$p\text{CO}_2 \sim 400\text{ppm}$

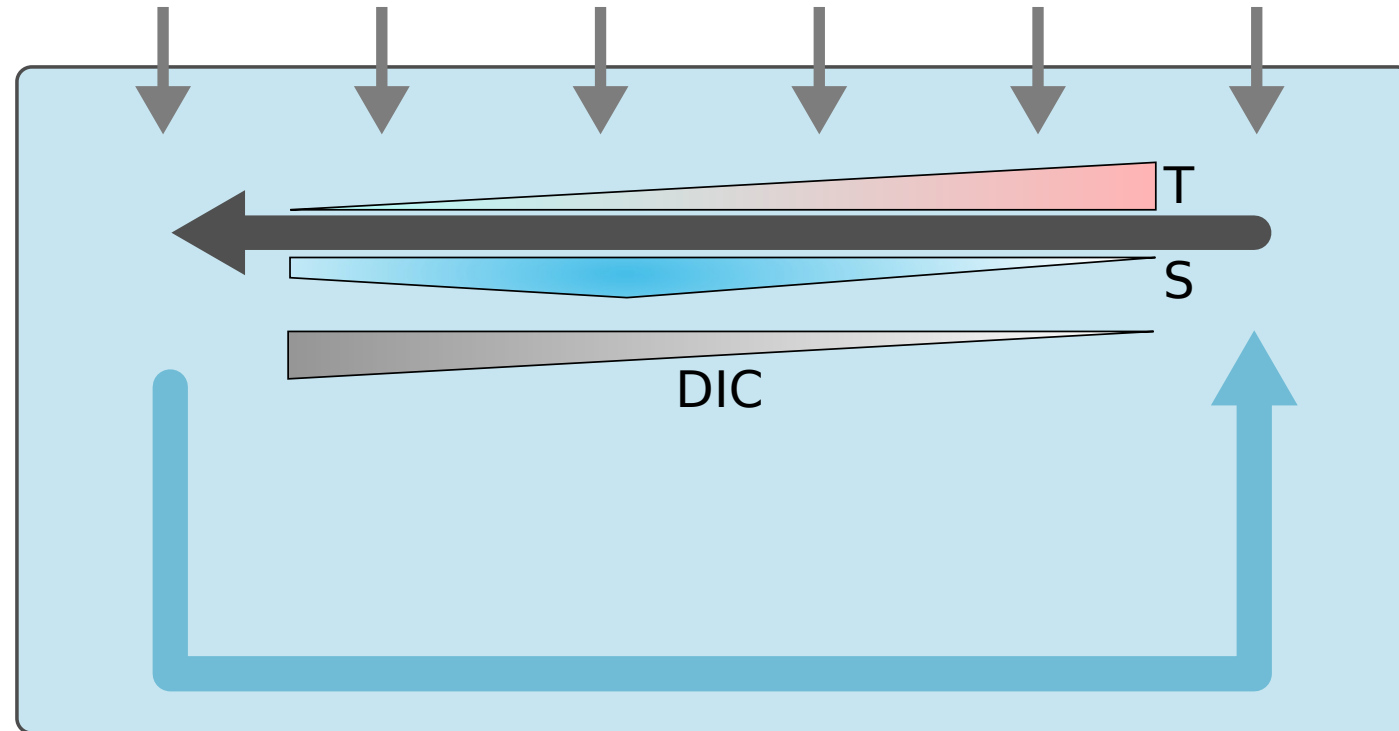


Think: Circulation + Chemistry

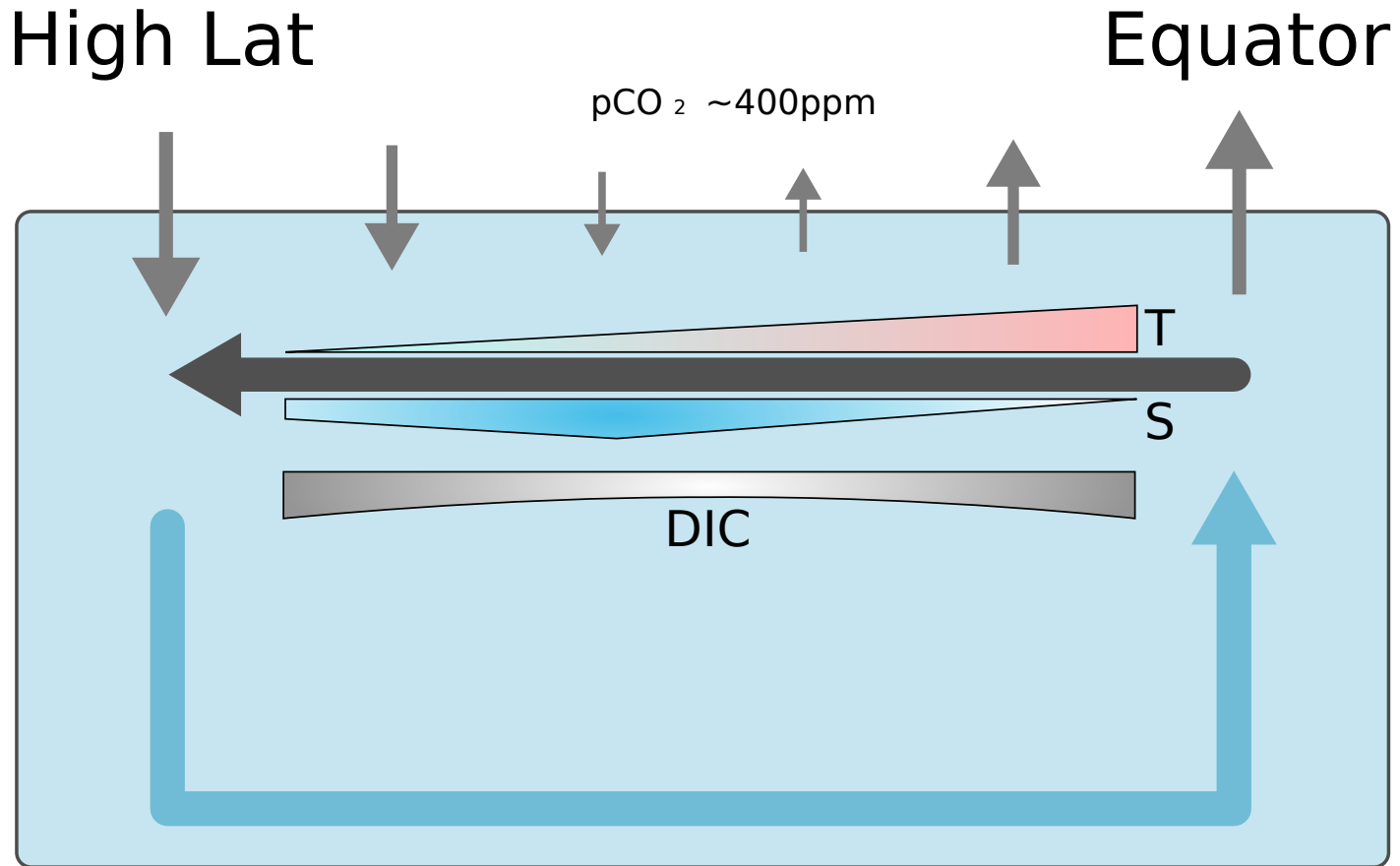
High Lat

Equator

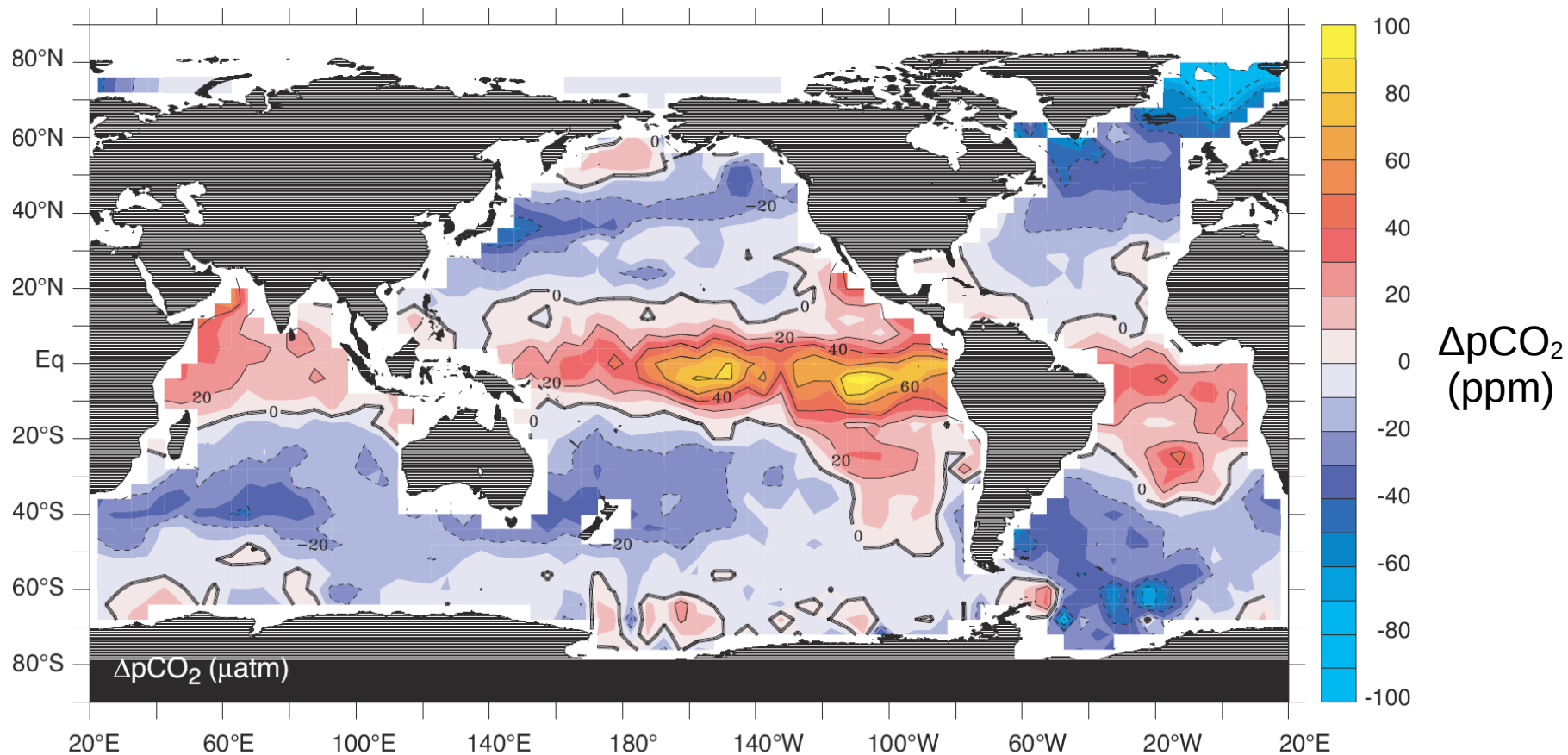
$p\text{CO}_2 \sim 400\text{ppm}$



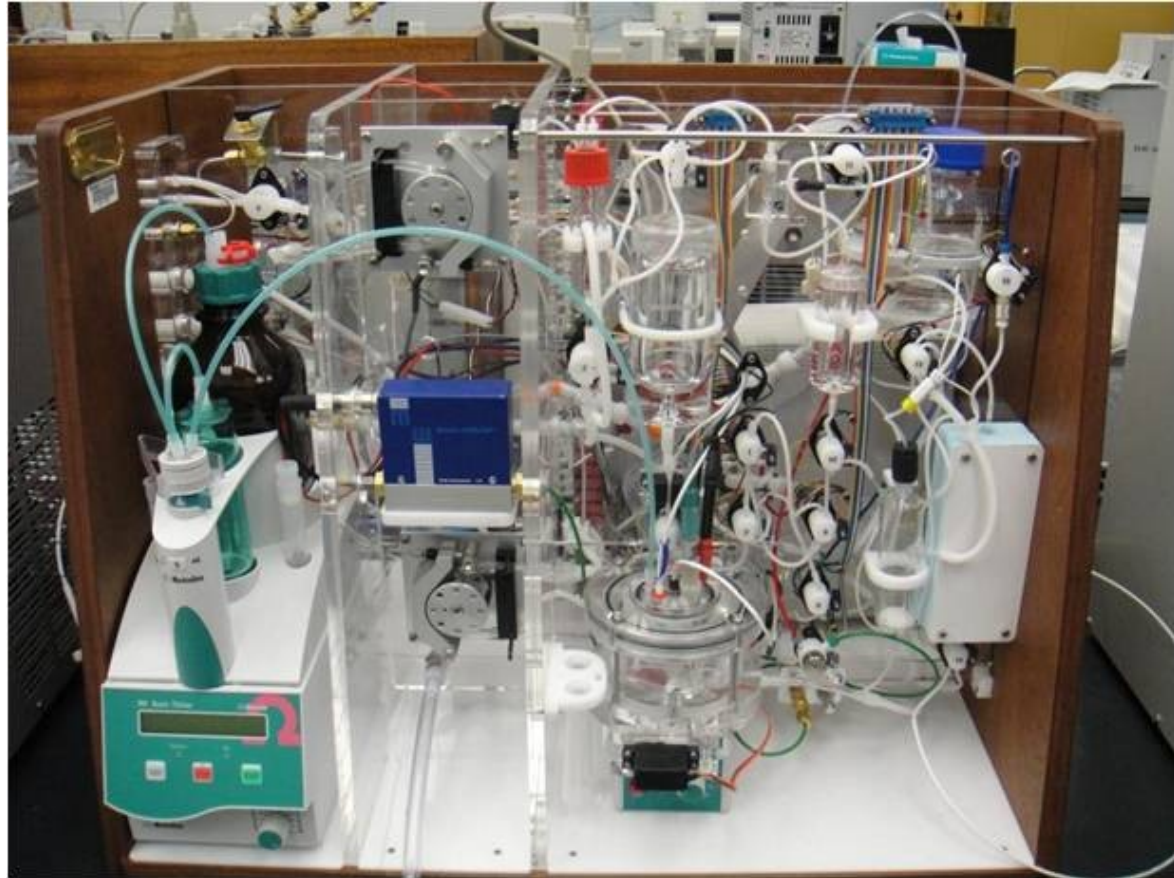
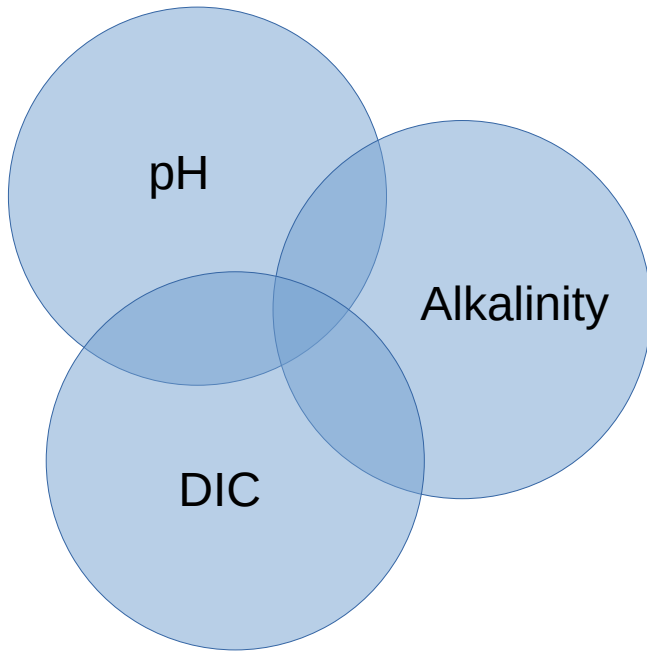
The Solubility Pump



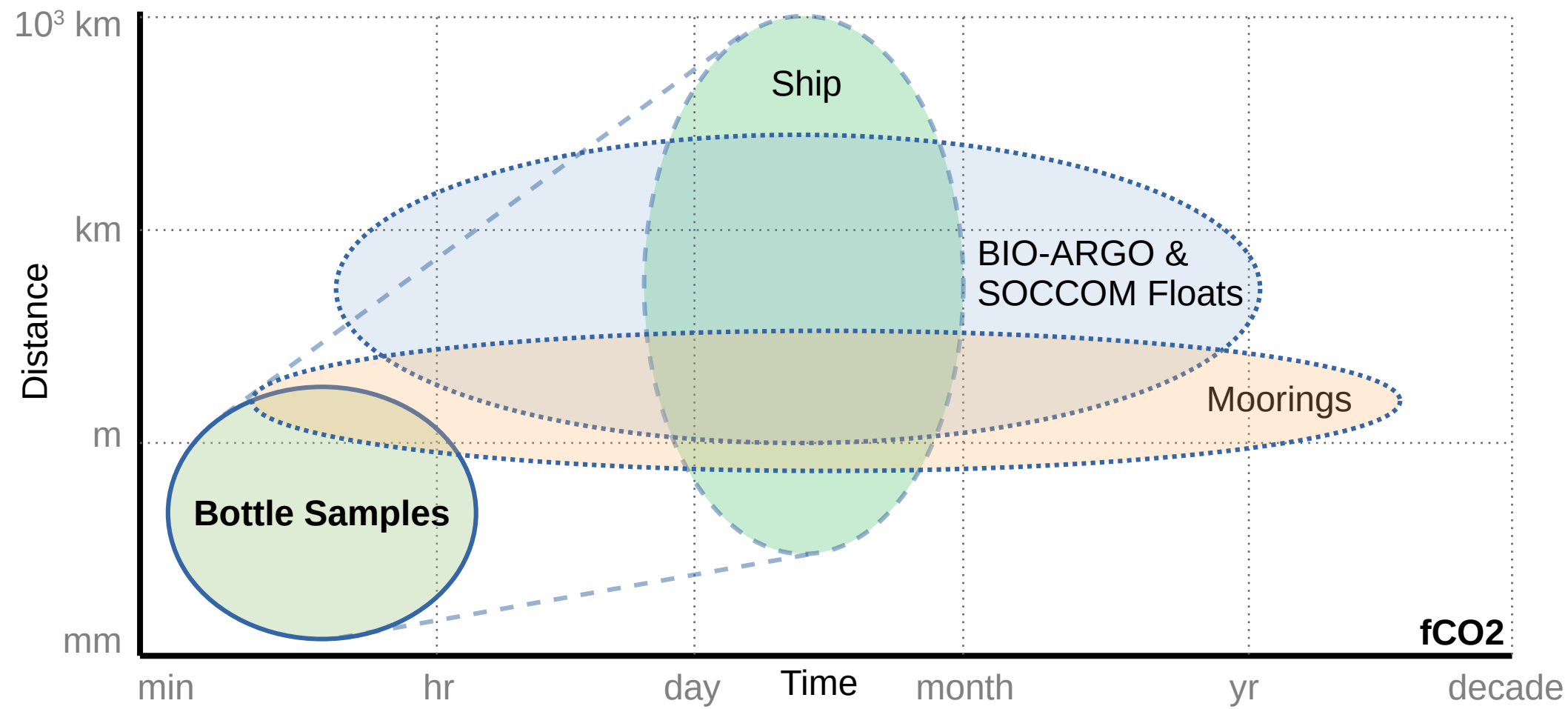
Ocean-Atmosphere Carbon Fluxes



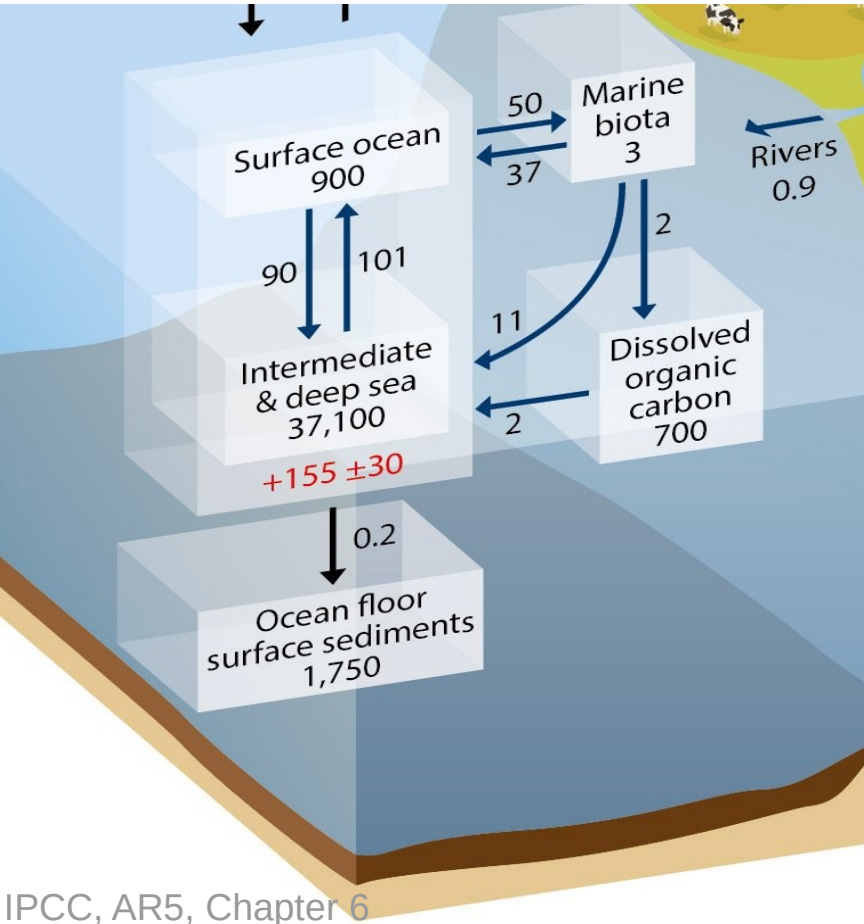
Carbon in Seawater: Measurement



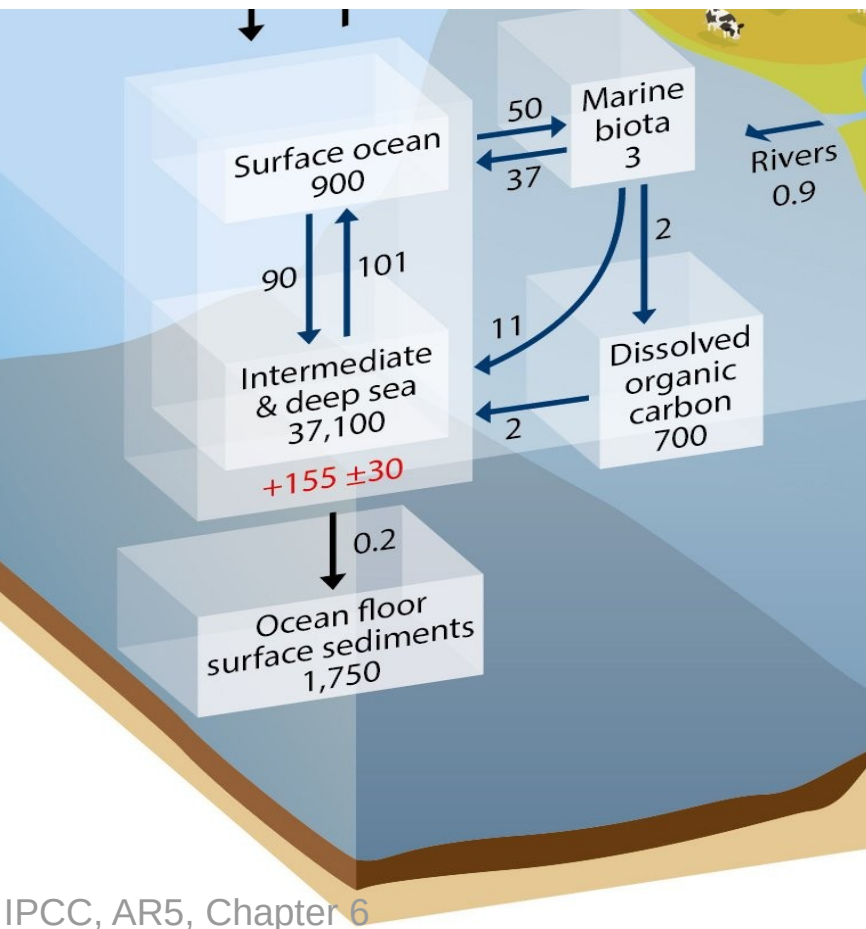
Carbon in Seawater: Measurement



Carbon in Seawater: Biology



Carbon in Seawater: Biology

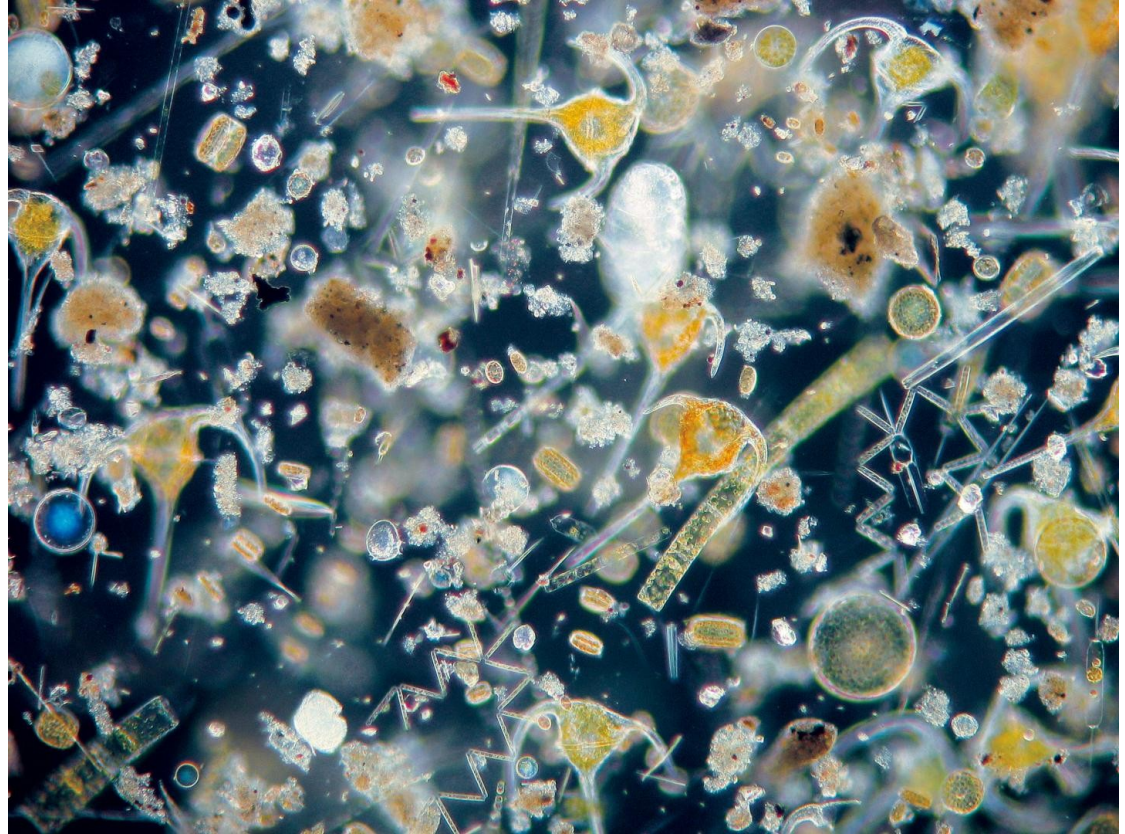
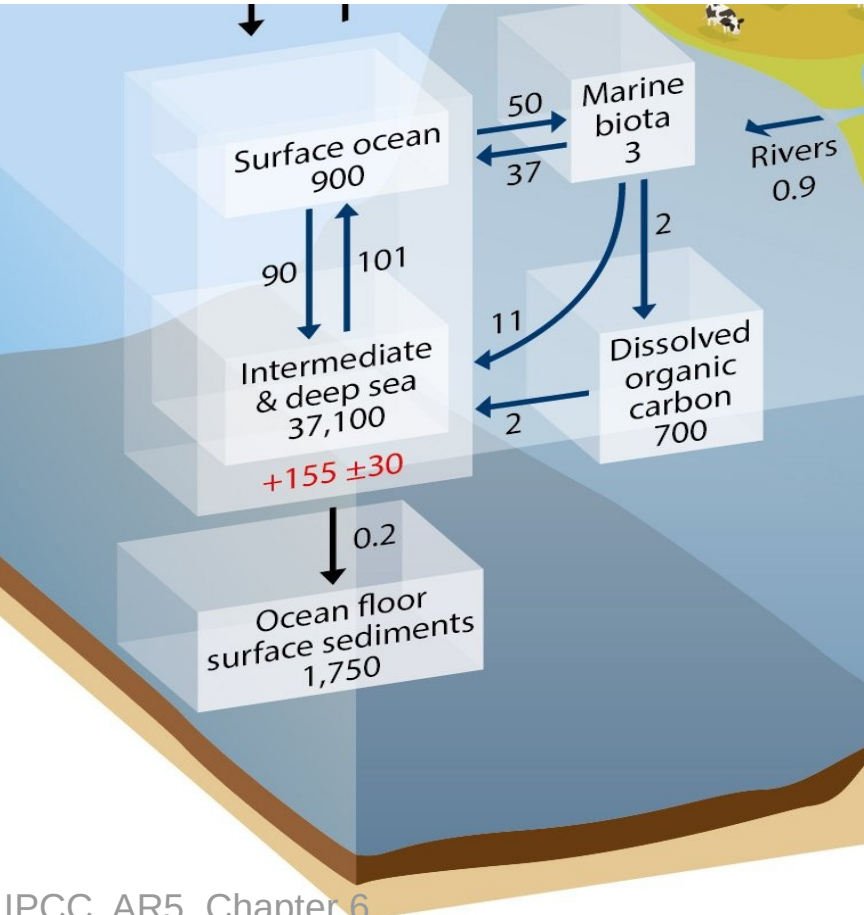


Total Biological Export: ~13 GtC

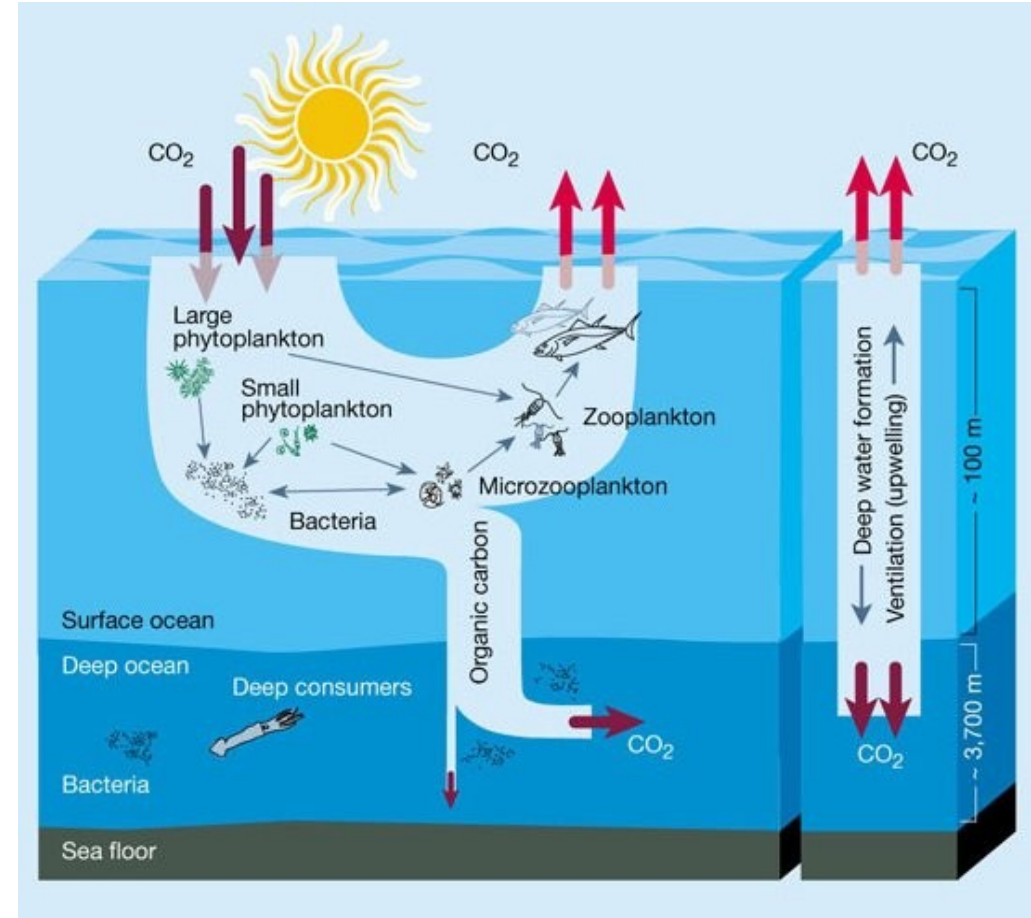
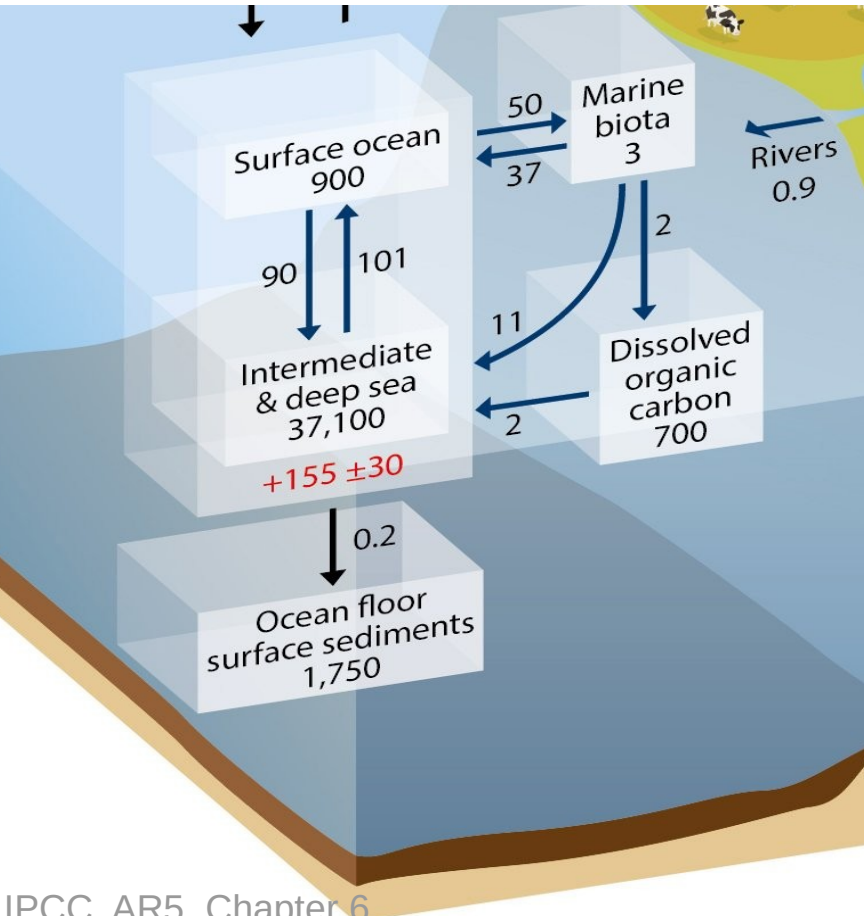
Annual fossil fuel release: 7.8 ± 0.6 GtC

Small compared to solubility, but still BIG!

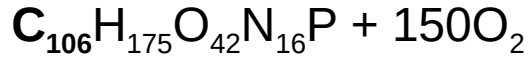
Carbon in Seawater: Biology



Carbon in Seawater: Biology

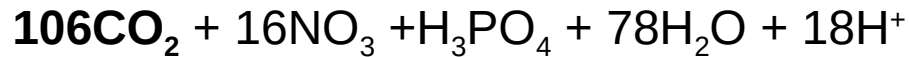


Carbon in Seawater: Biology

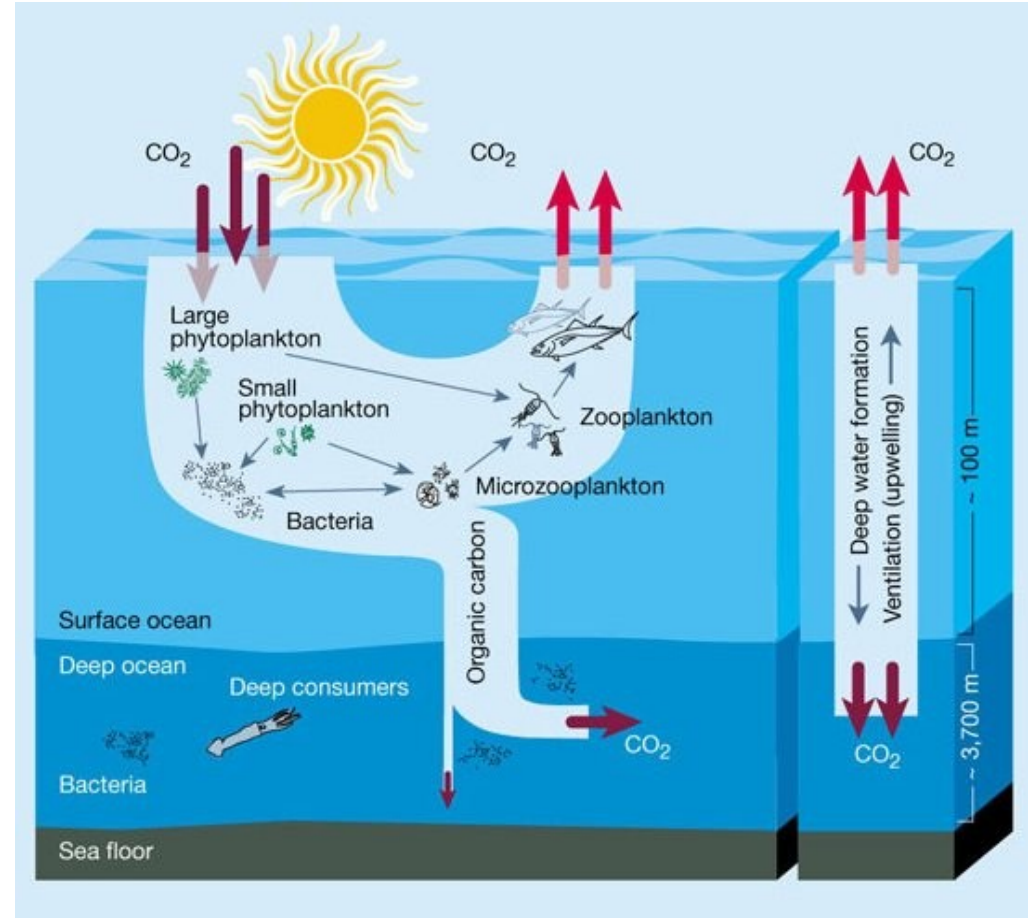


Photosynthesis

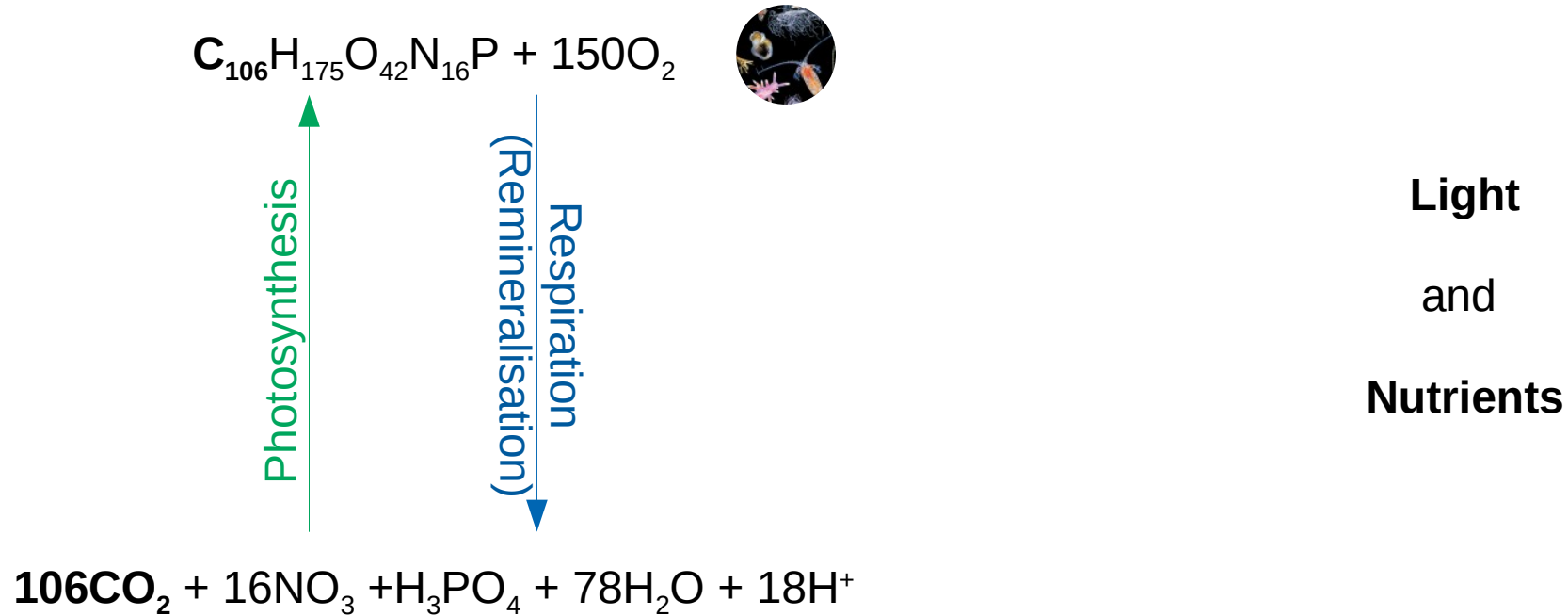
Respiration
(Remineralisation)

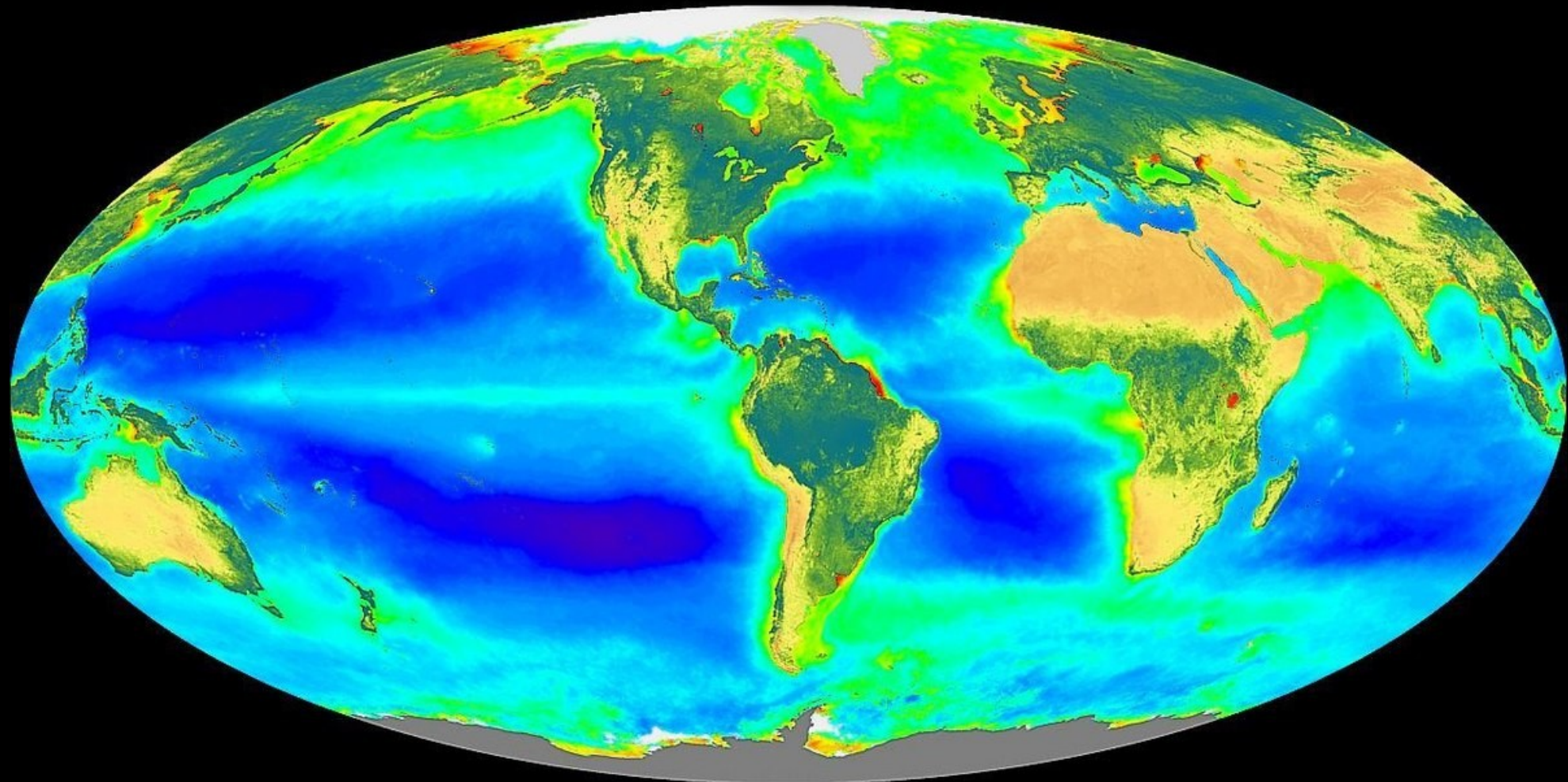


Photosynthesis captures CO_2 in the surface
Remineralisation releases CO_2 in deep



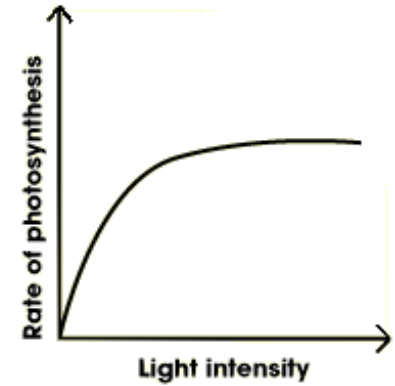
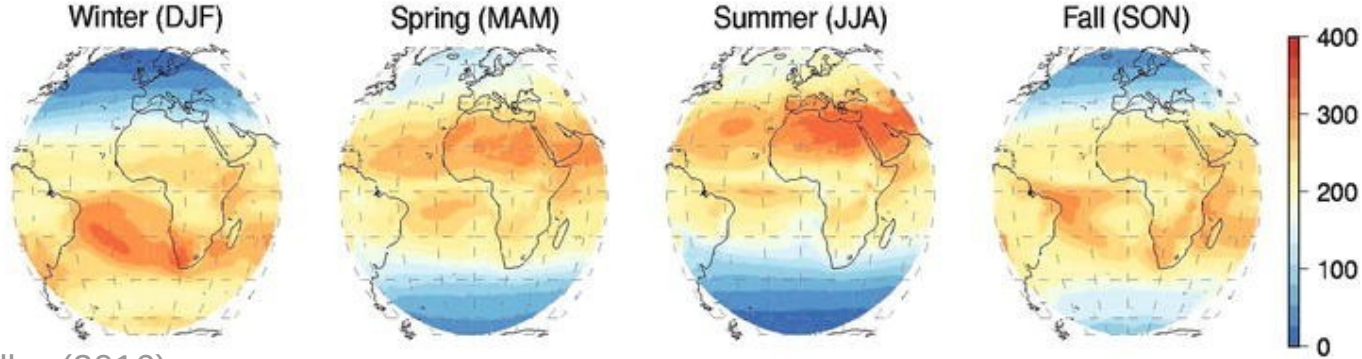
Carbon in Seawater: Biology





Biology: Light

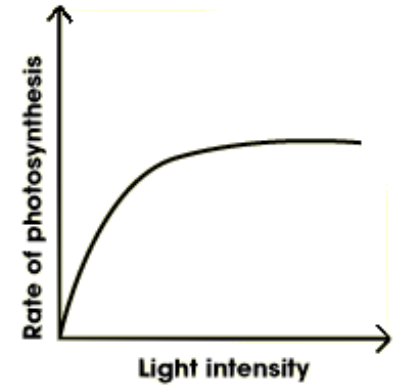
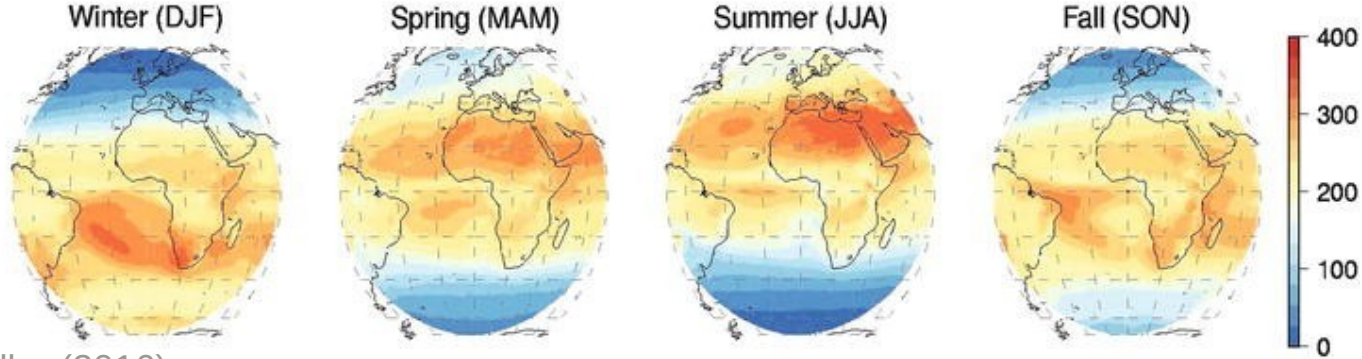
CM SAF SIS seasonal means (1983–2005) [Wm^{-2}]



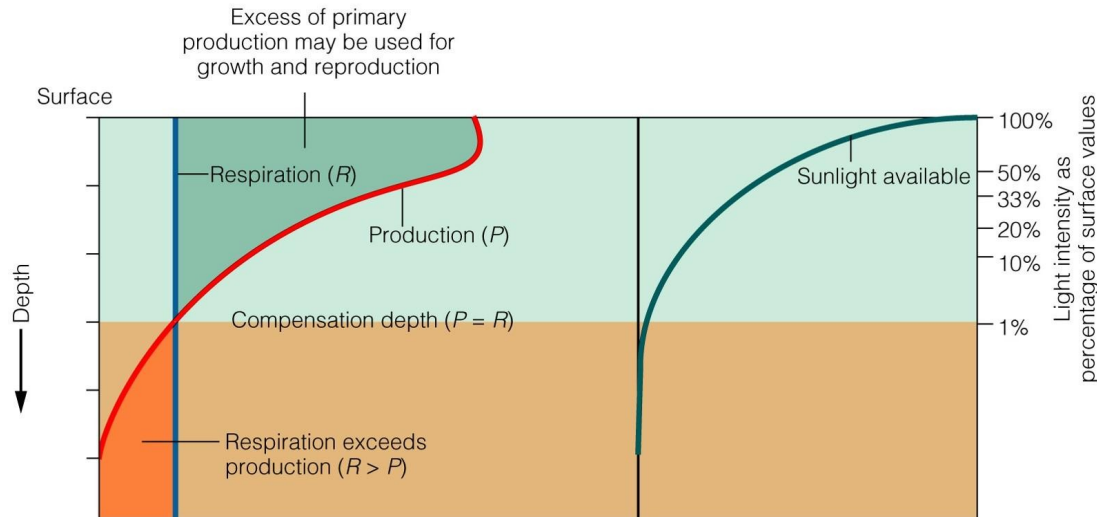
Mueller (2016)

Biology: Light

CM SAF SIS seasonal means (1983–2005) [Wm^2]



Mueller (2016)

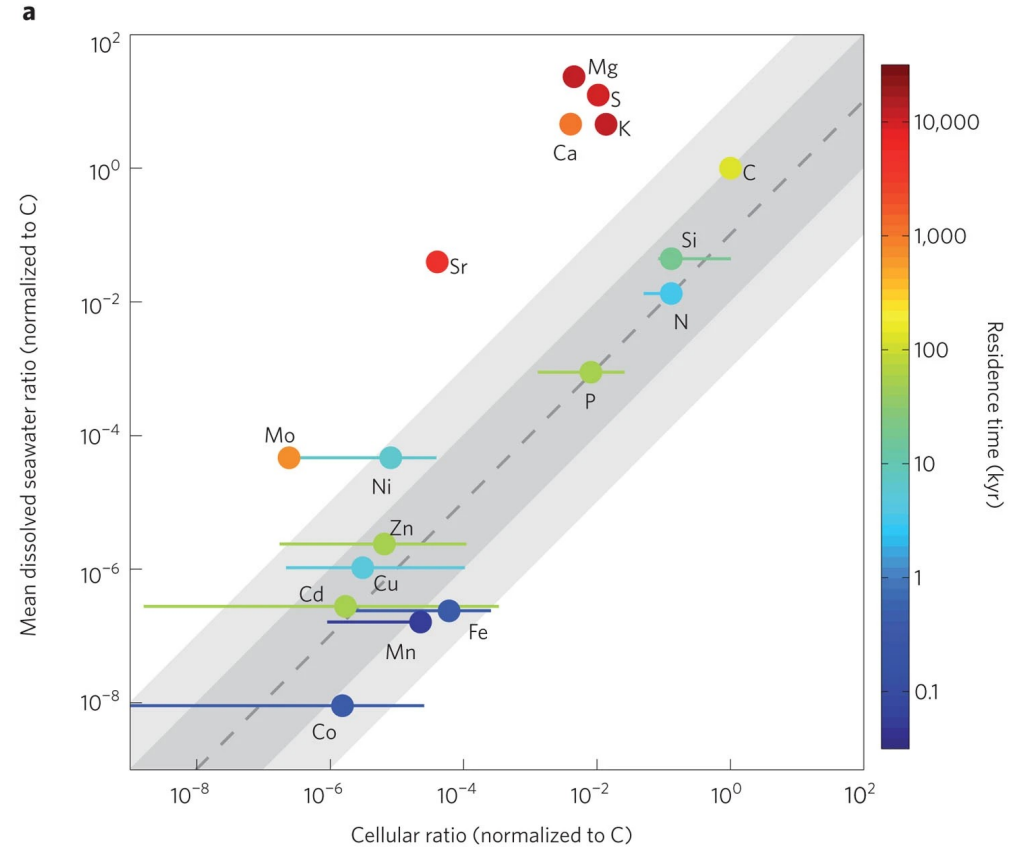


Mixed Layer Depth
is critical

Biology: Nutrients

Productivity is limited by:

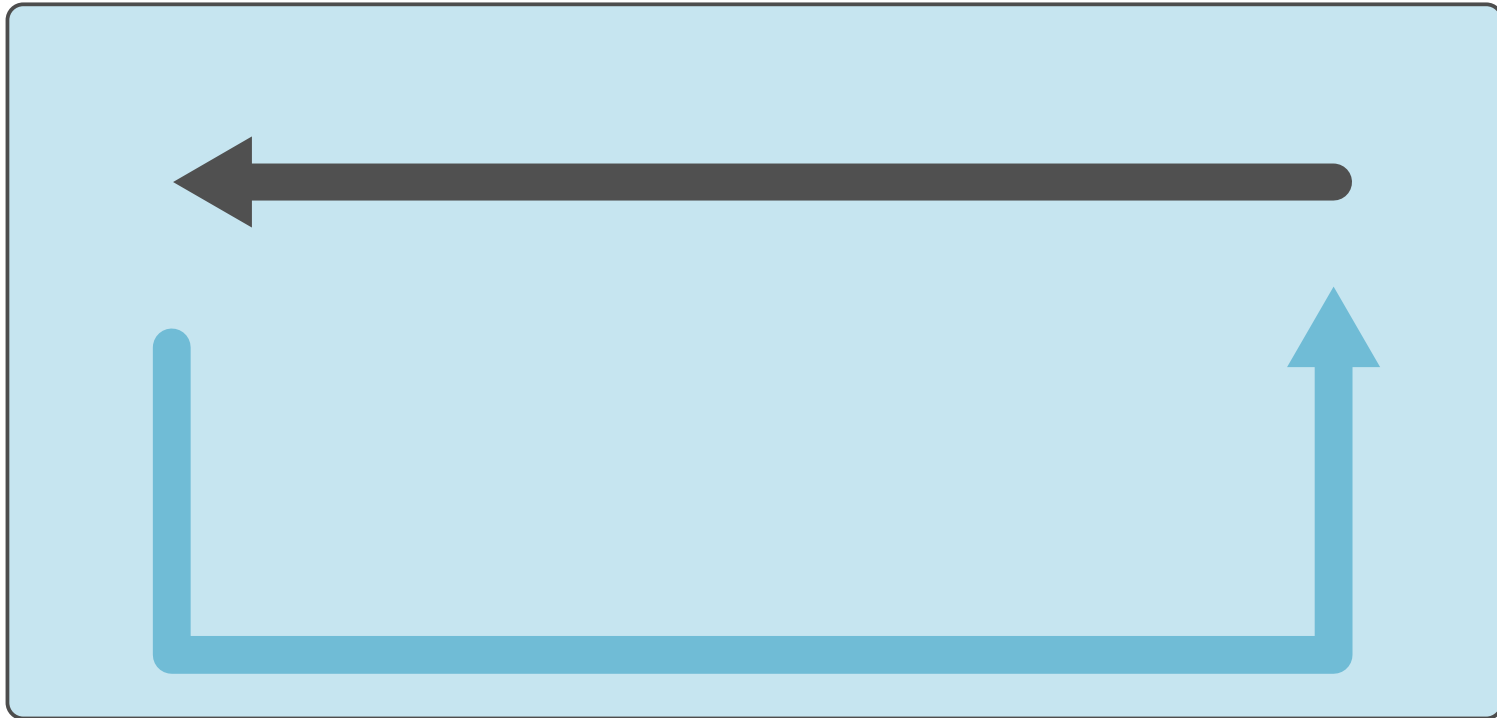
- P
- Fe
- Mn
- Co



Think: Biology + Circulation

High Lat

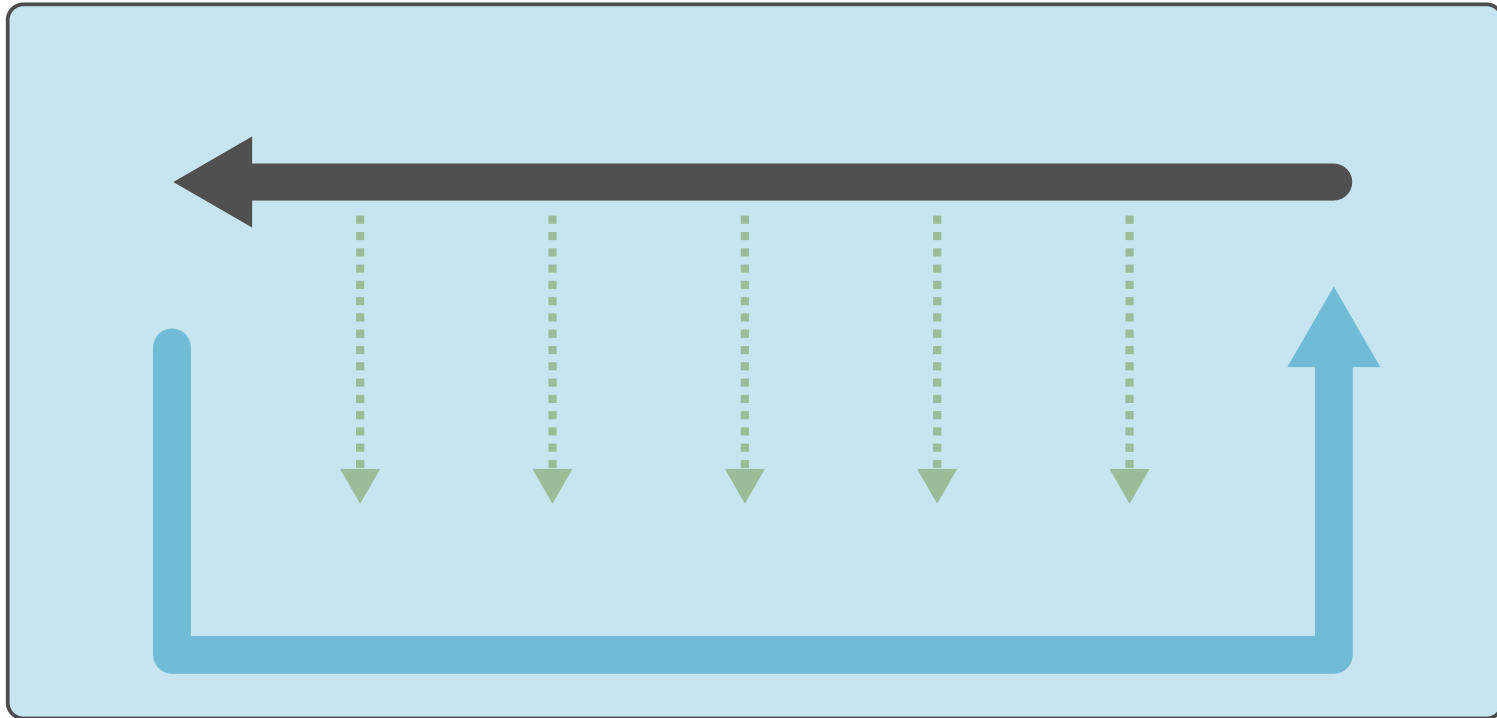
Equator



Think: Biology + Circulation

High Lat

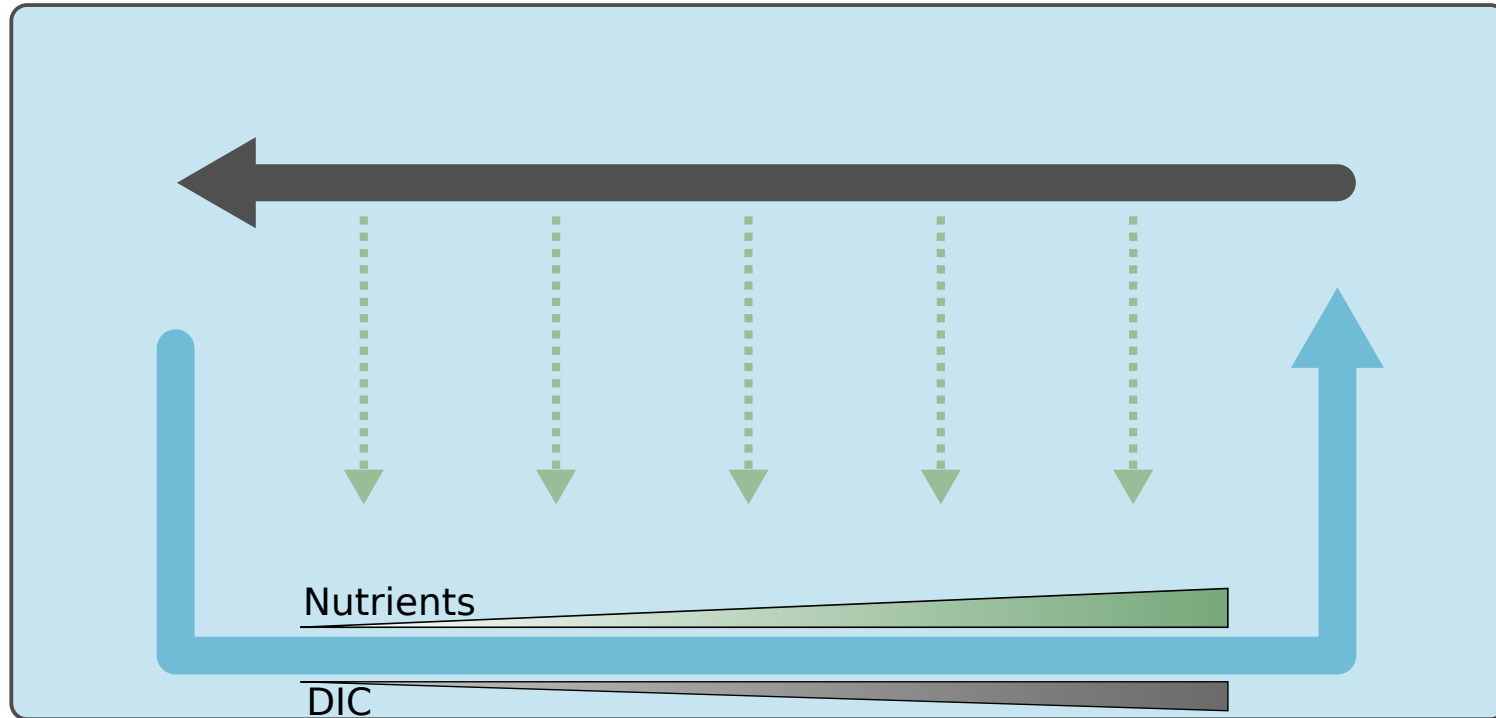
Equator



Think: Biology + Circulation

High Lat

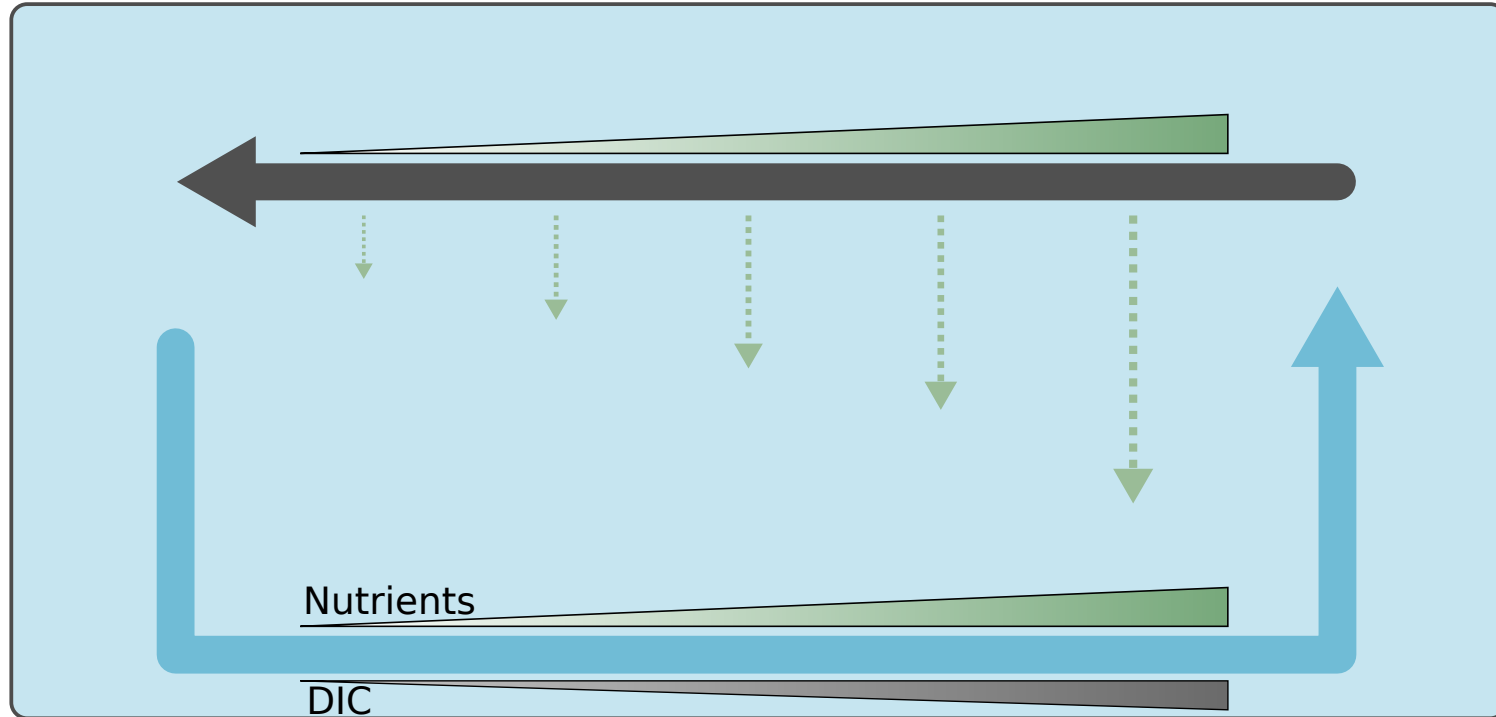
Equator

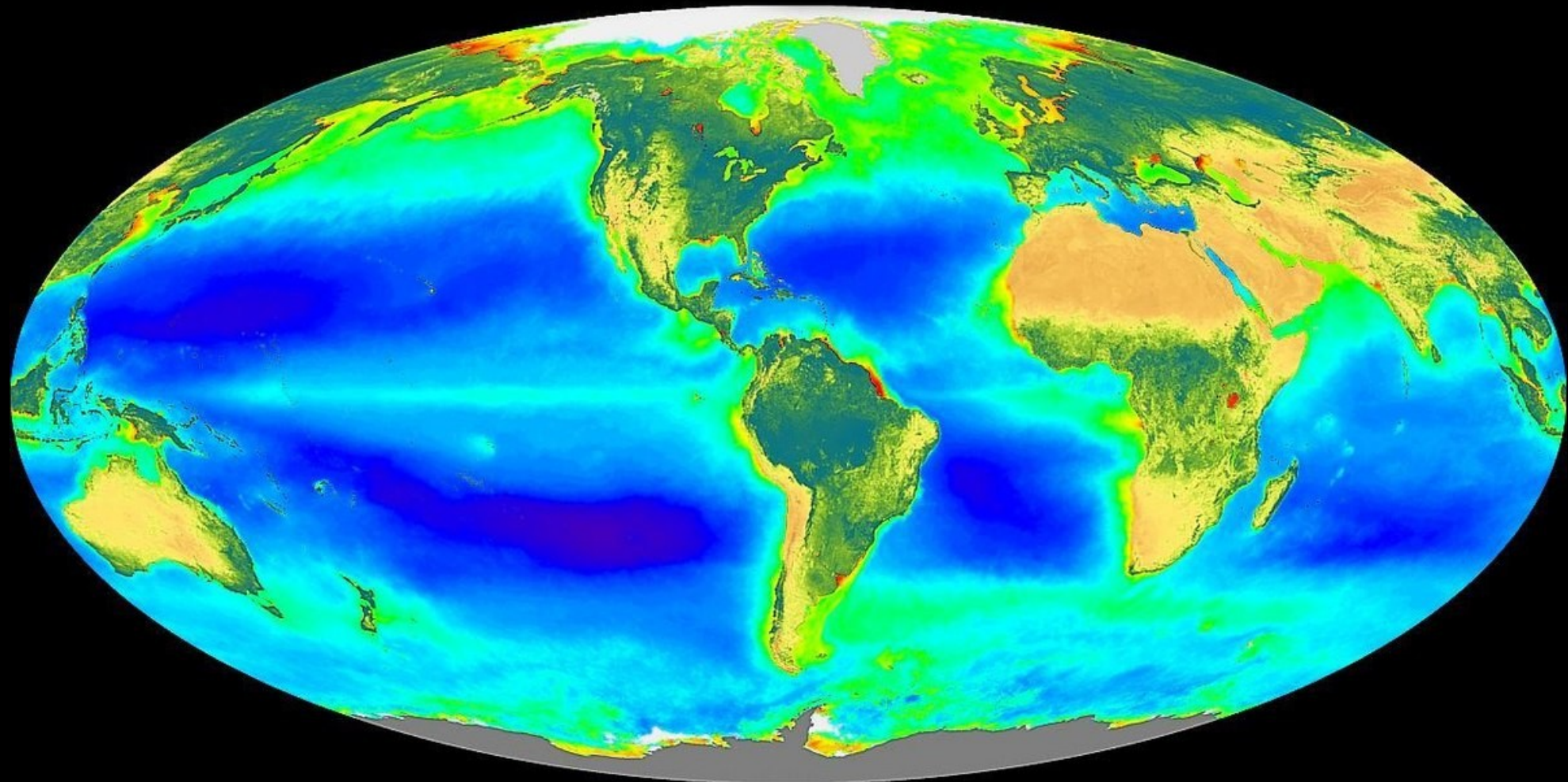


The Biological Pump

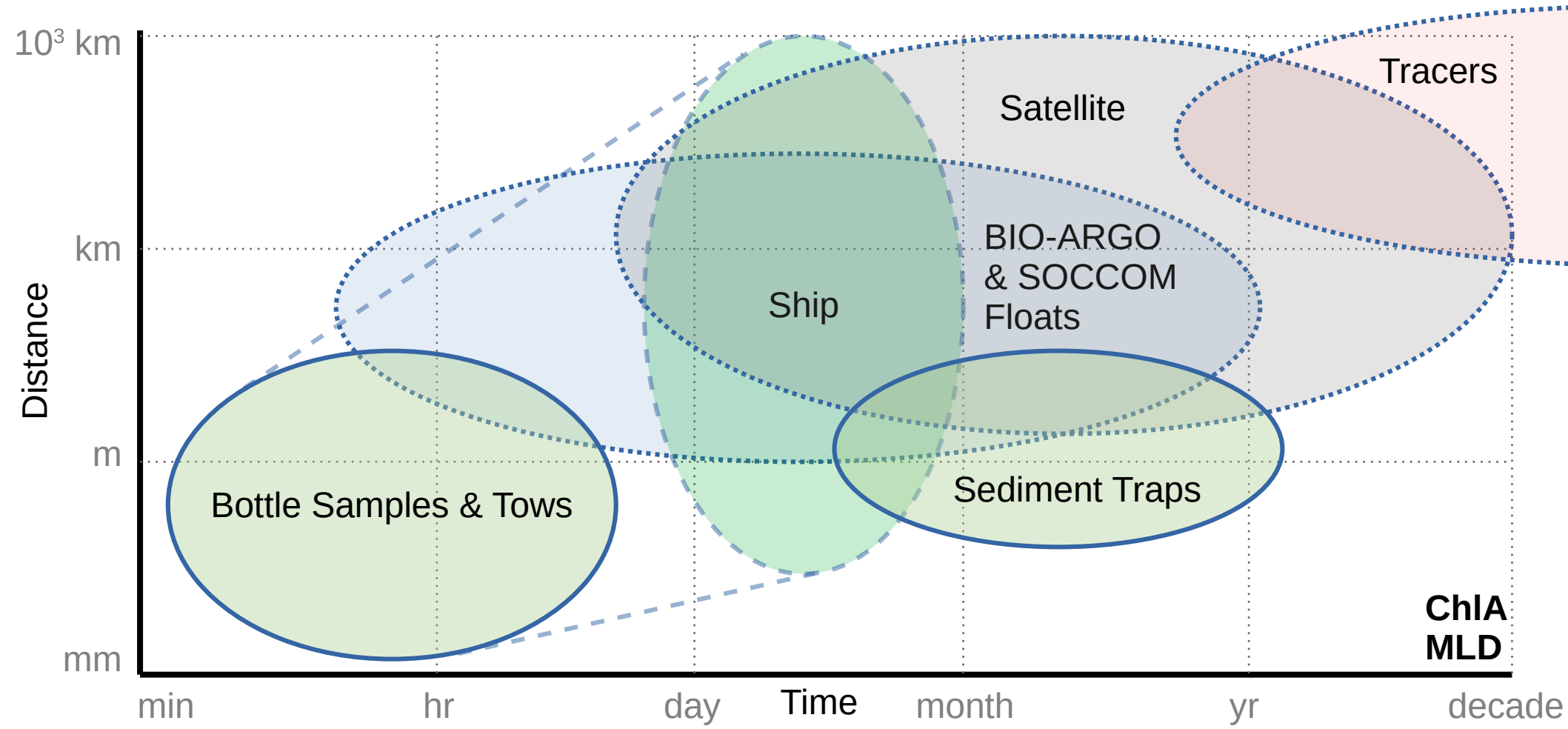
High Lat

Equator





Measuring Biology



Ocean-Atmosphere Carbon Fluxes

