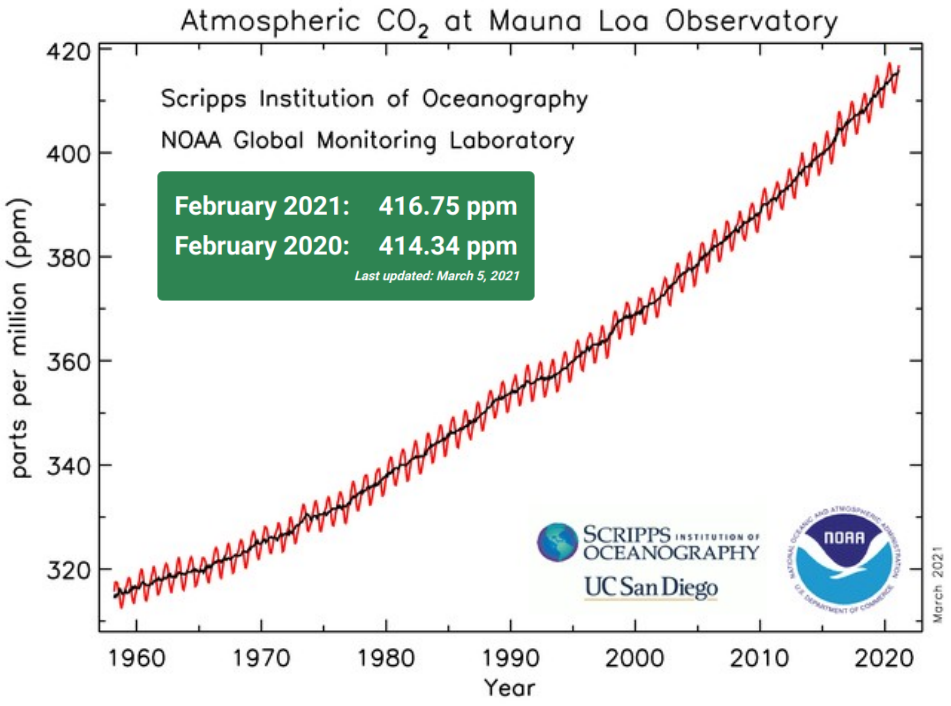
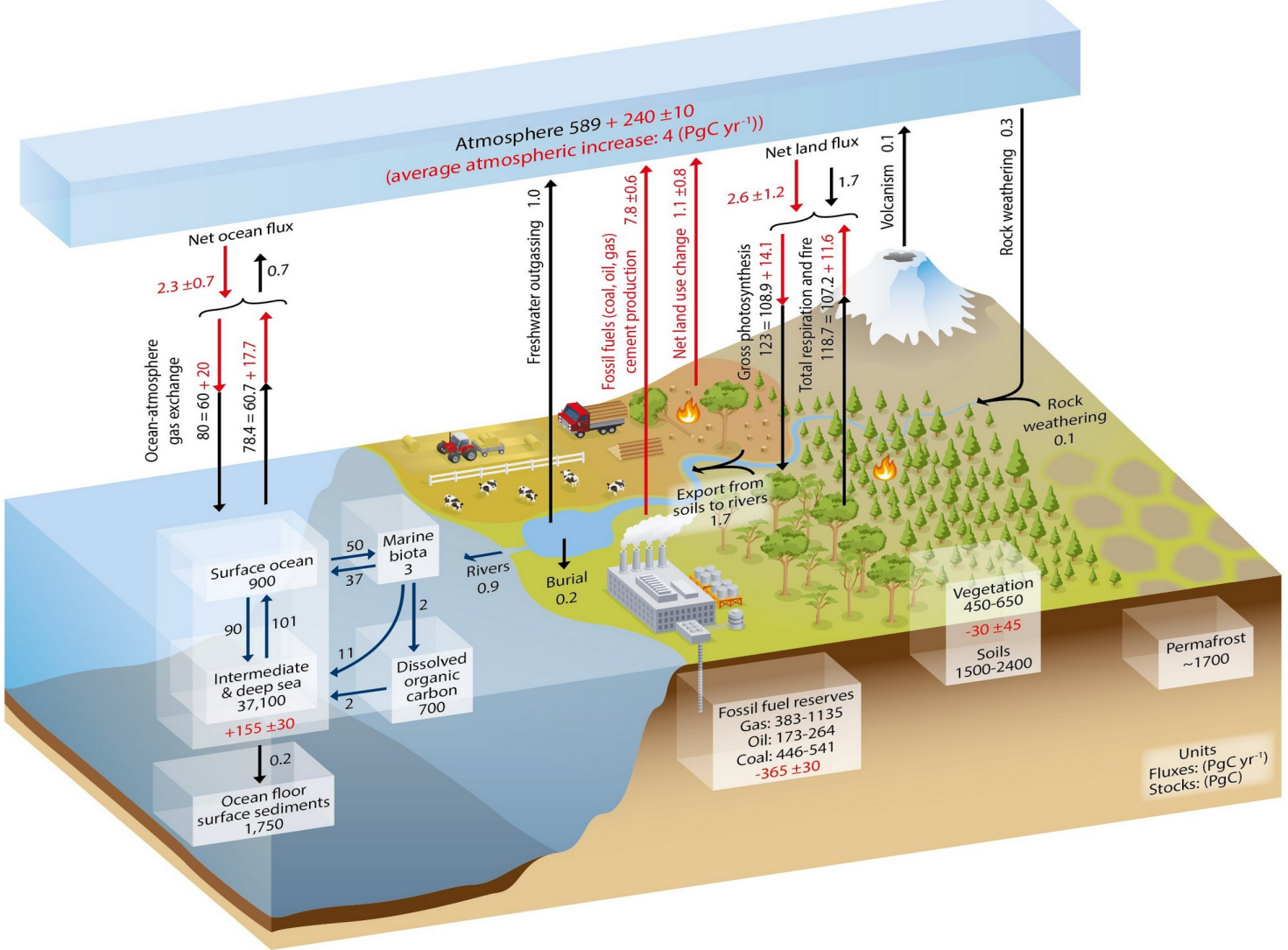
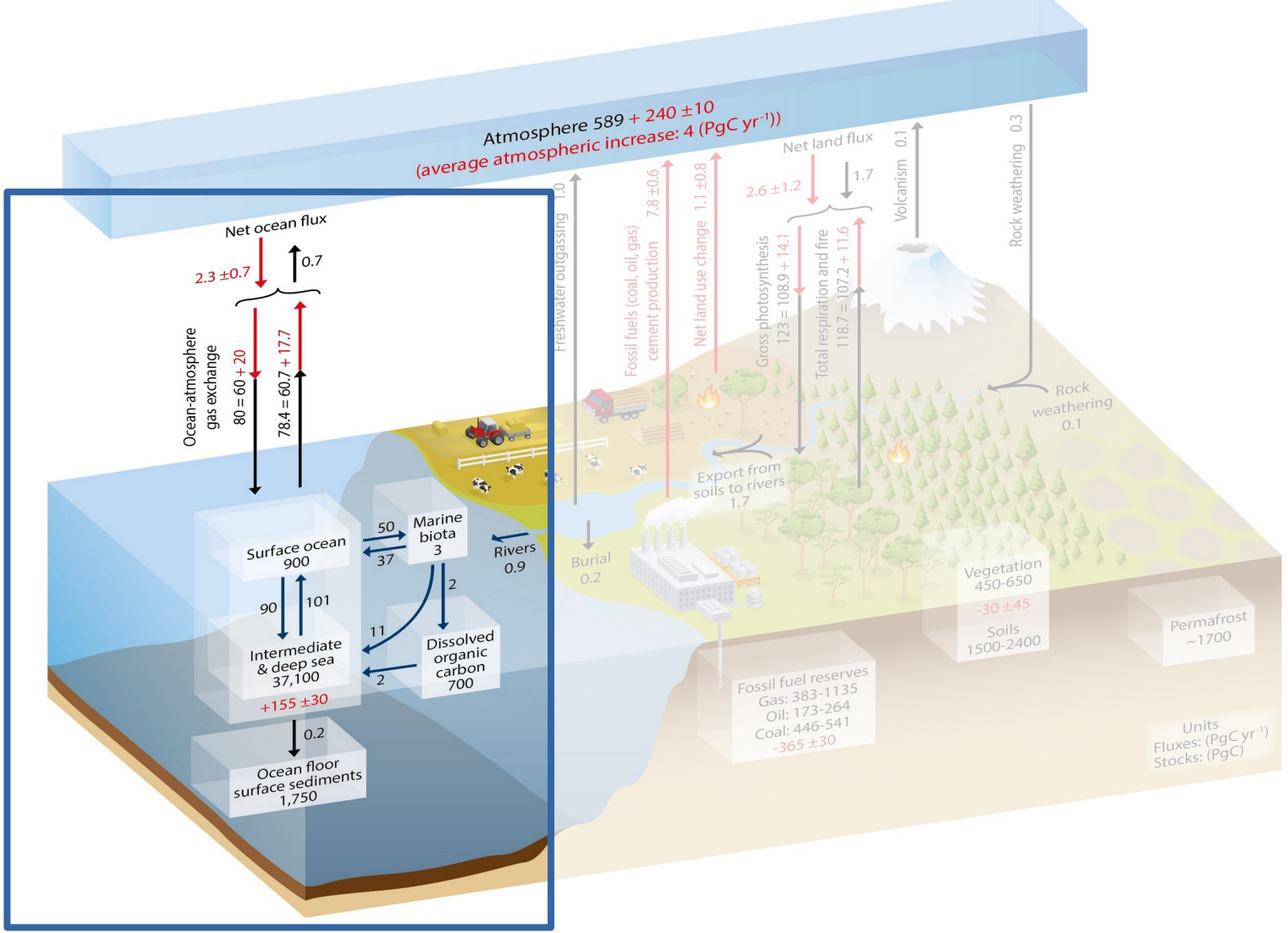
Ocean-Atmosphere Carbon Fluxes





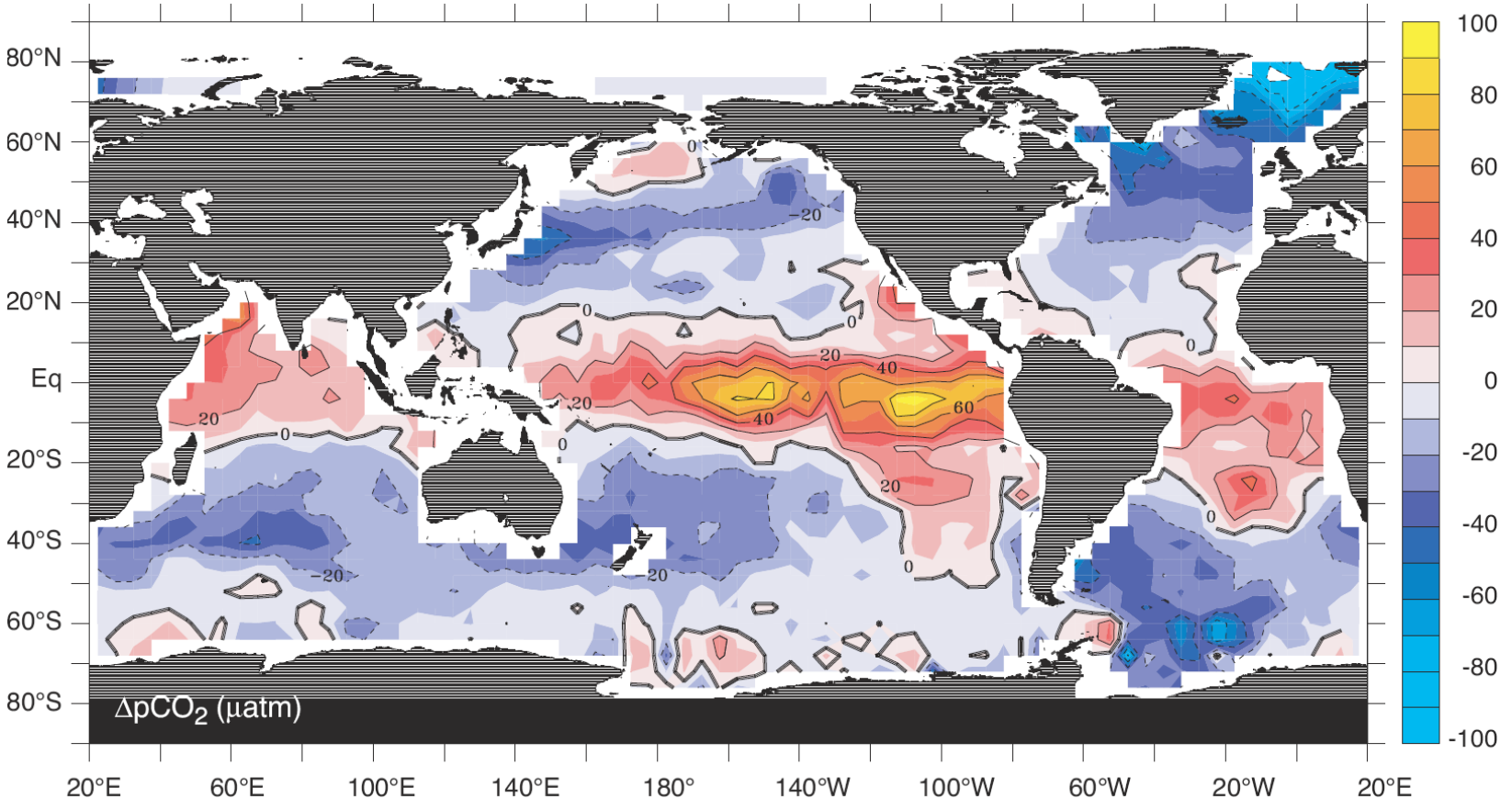
IPCC, AR5, Chapter 6



Ocean has absorbed ~30-40% of the CO_2 we've released.

IPCC, AR5, Chapter 6

Ocean-Atmosphere Carbon Fluxes



Ocean-Atmosphere Carbon Fluxes

Factors:

Physical

Ocean Circulation & Mixing

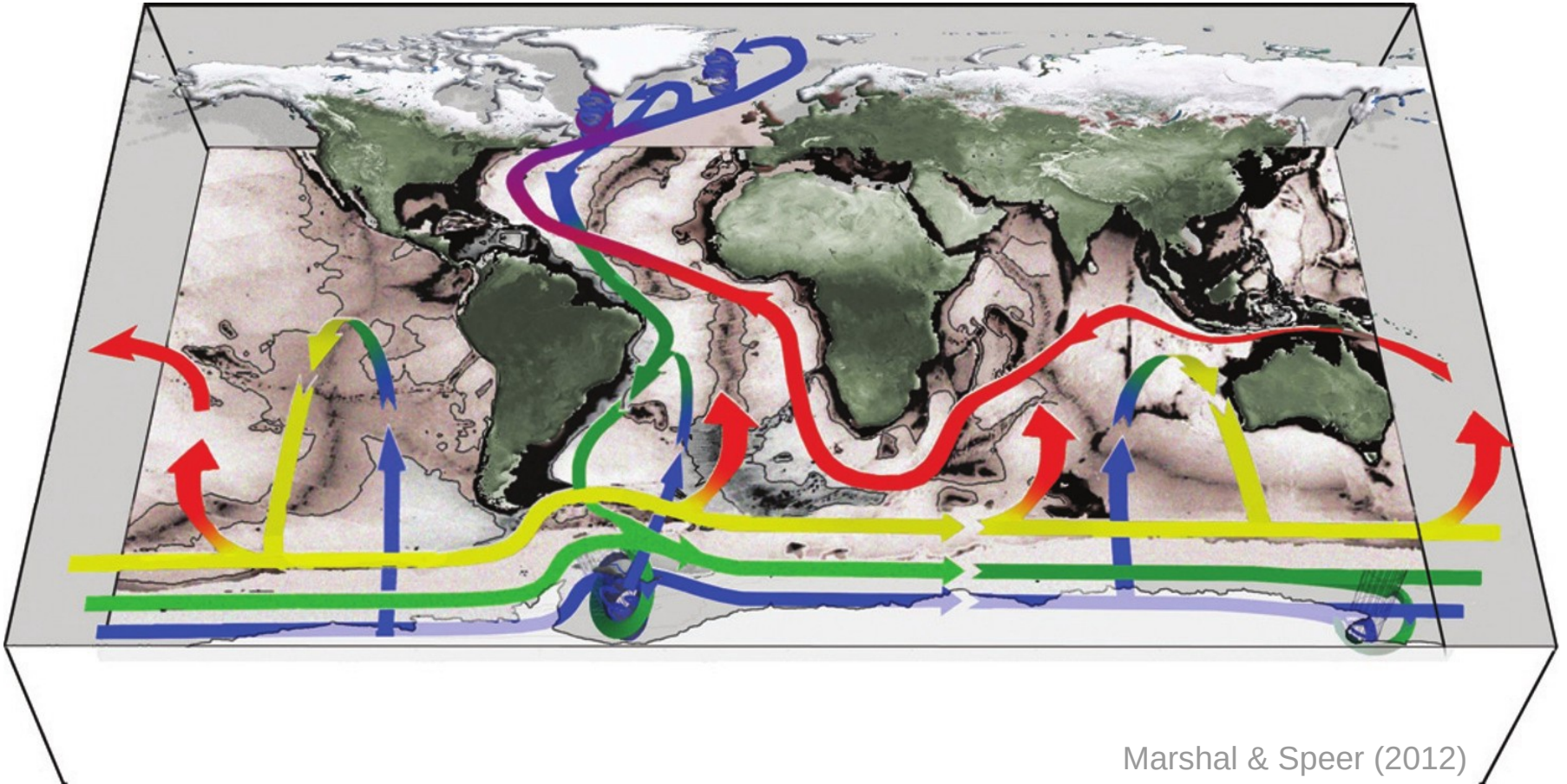
Chemical

Dissolved Inorganic Carbon (DIC)

Biological

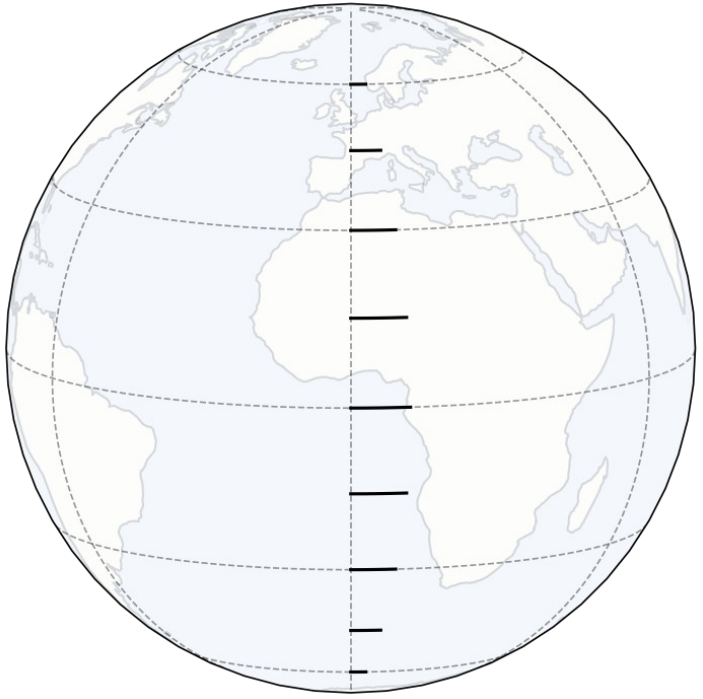
Carbon capture (‘productivity’) and export.

Ocean Circulation



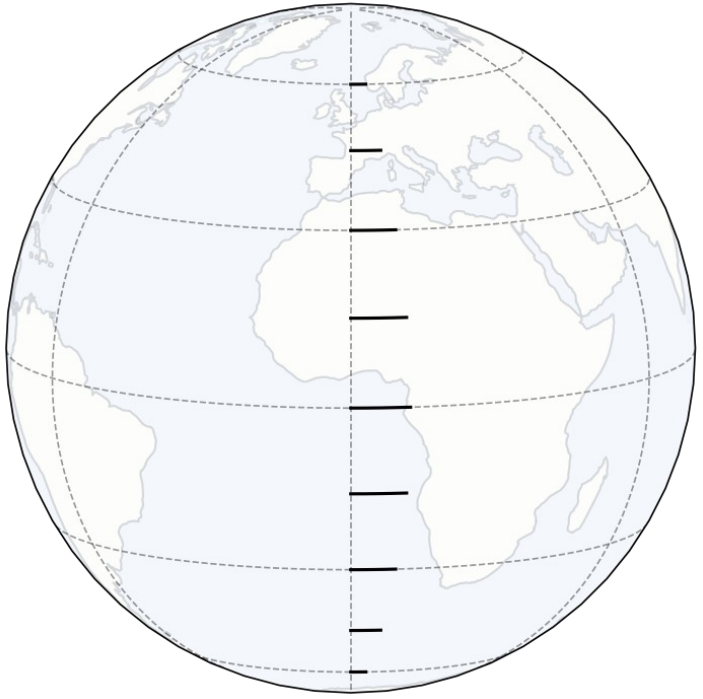
Marshal & Speer (2012)

Ocean Circulation: Coriolis

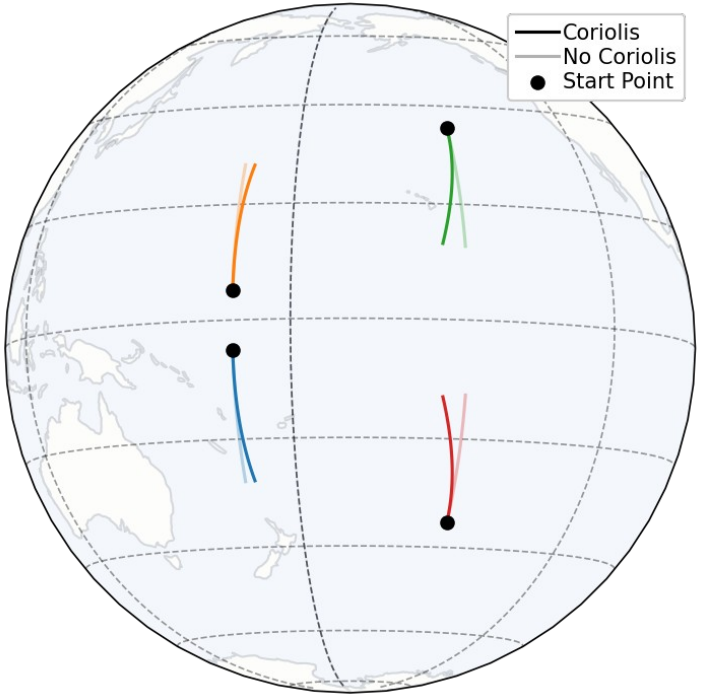


Eastward Velocity

Ocean Circulation: Coriolis

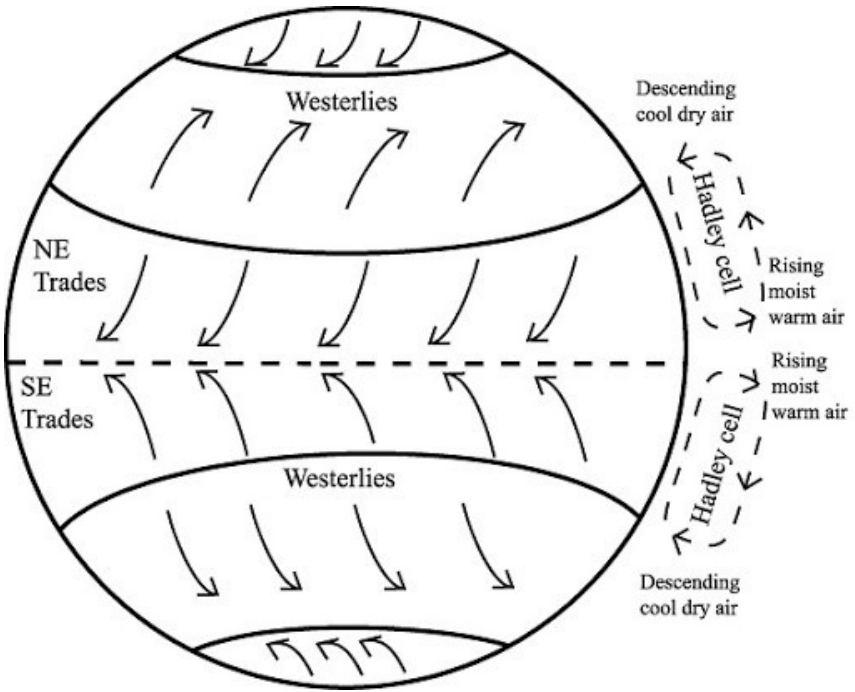


Eastward Velocity

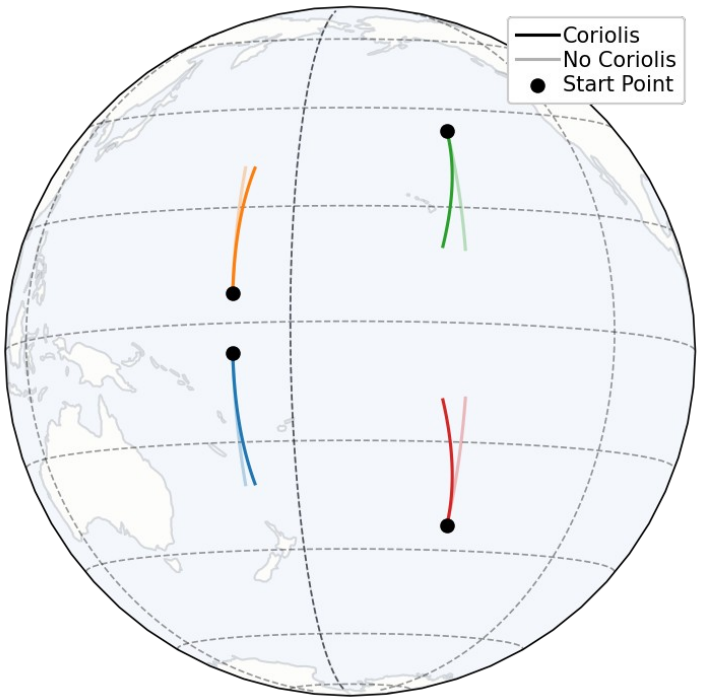


Deflection

Ocean Circulation: Wind

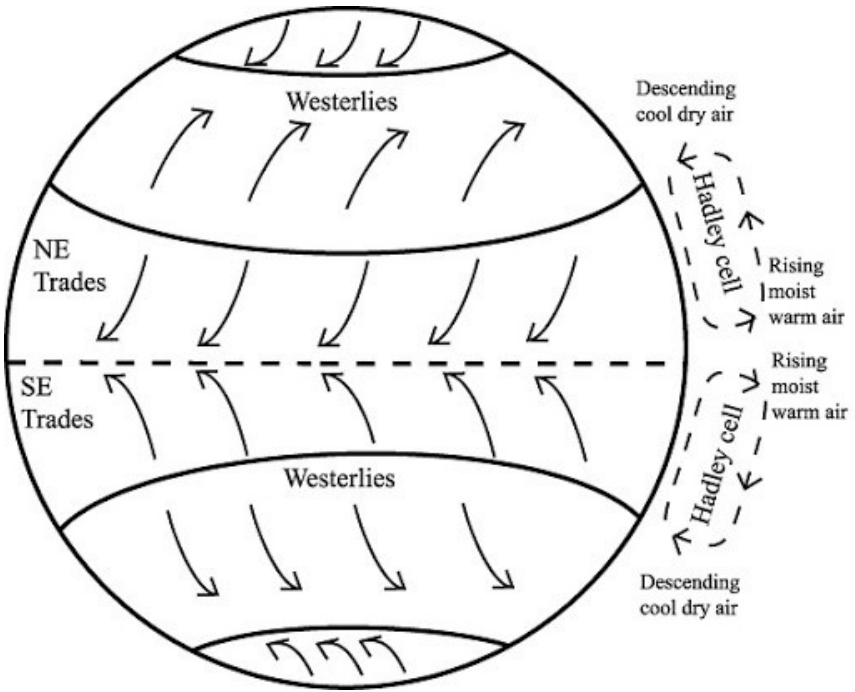


~Surface Wind



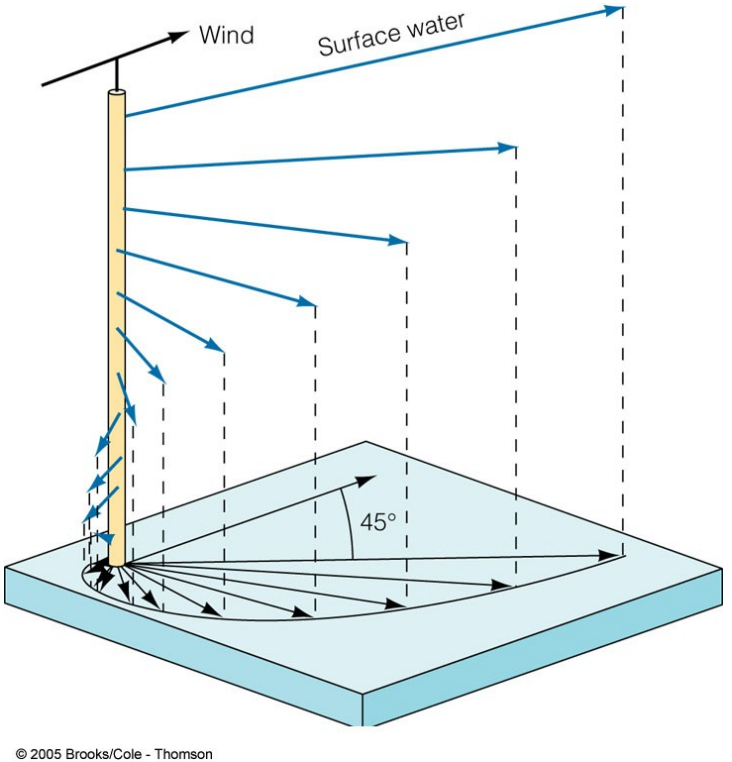
Deflection

Ocean Circulation: Wind



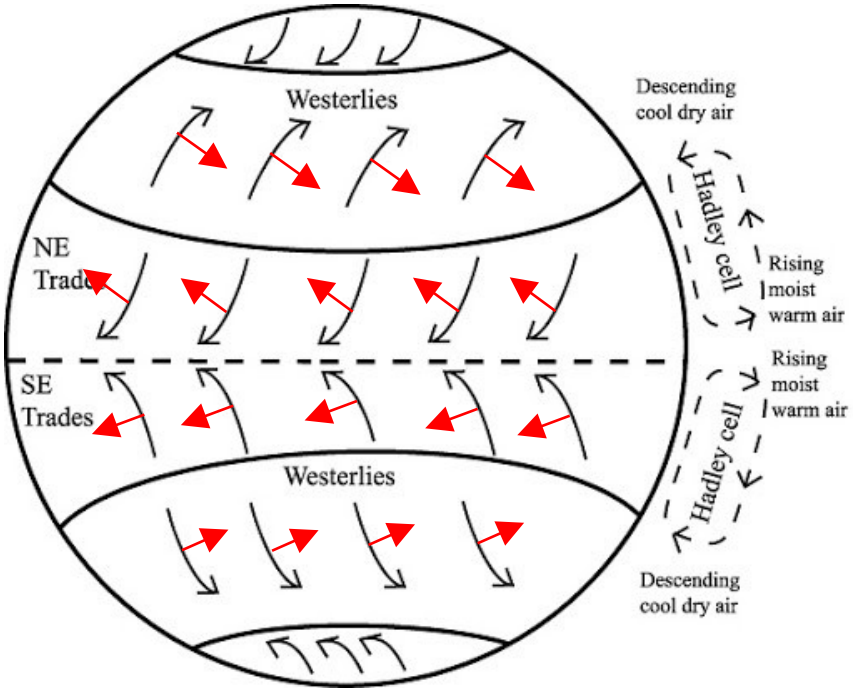
~Surface Wind

Northern Hemisphere



Eckman Transport

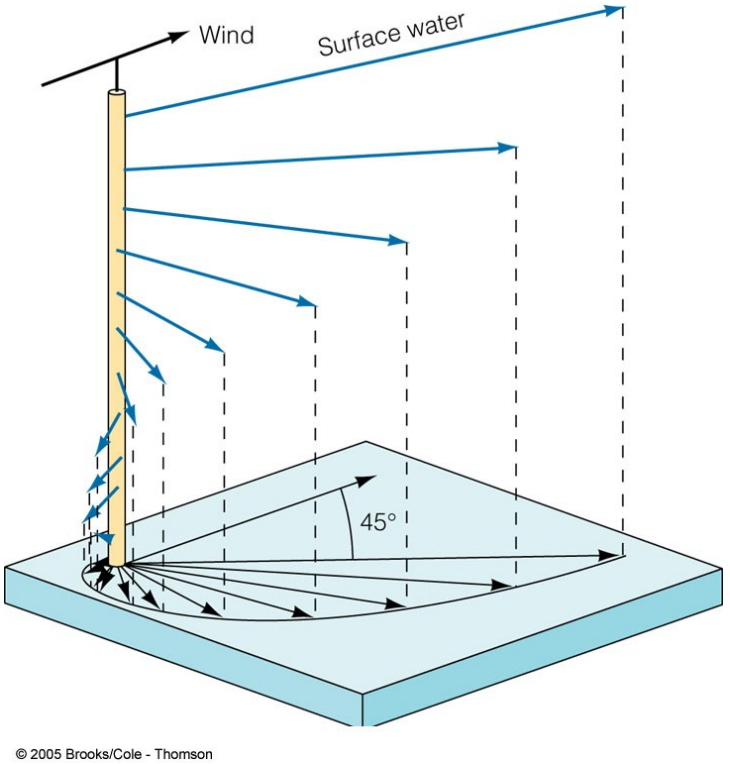
Ocean Circulation: Wind



~Surface Wind

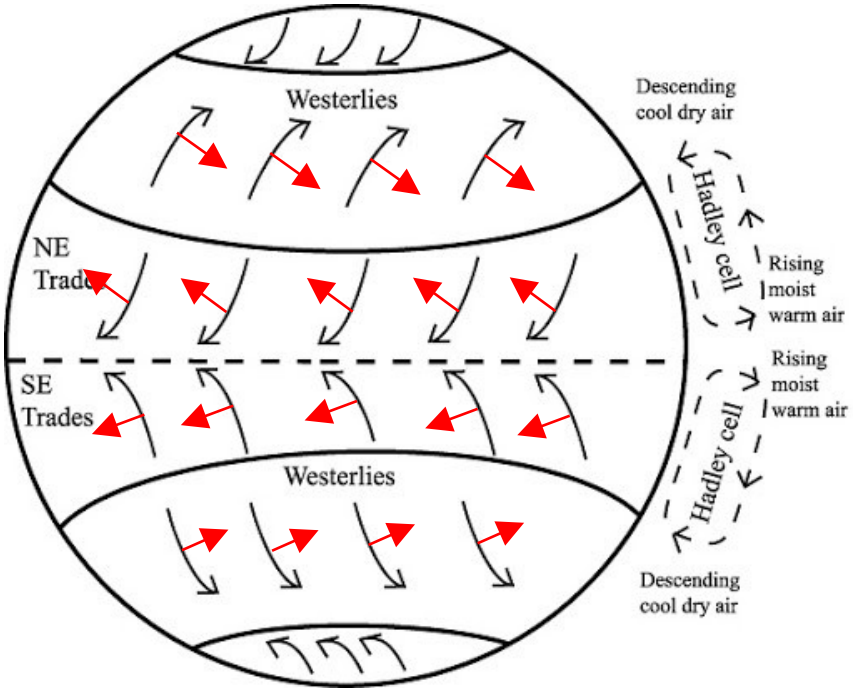
~Surface Water

Northern Hemisphere



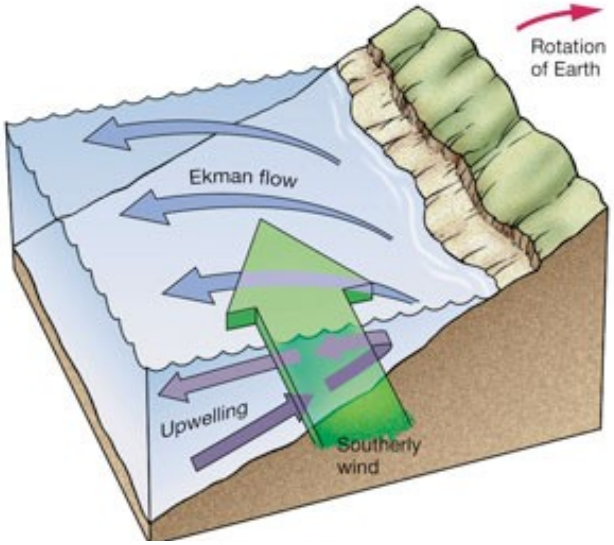
Eckman Transport

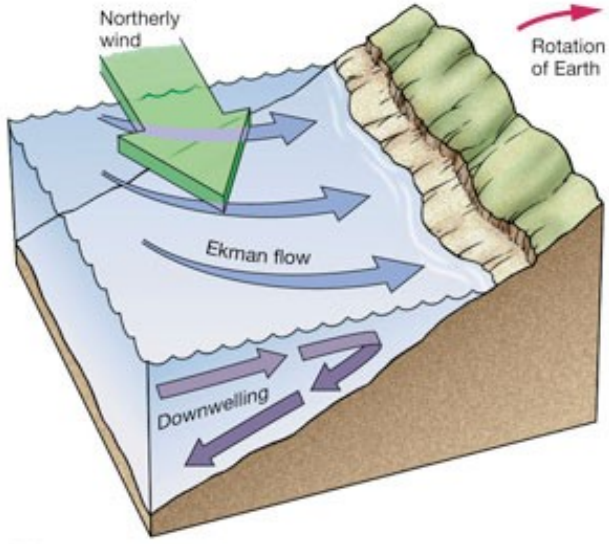
Ocean Circulation: Wind



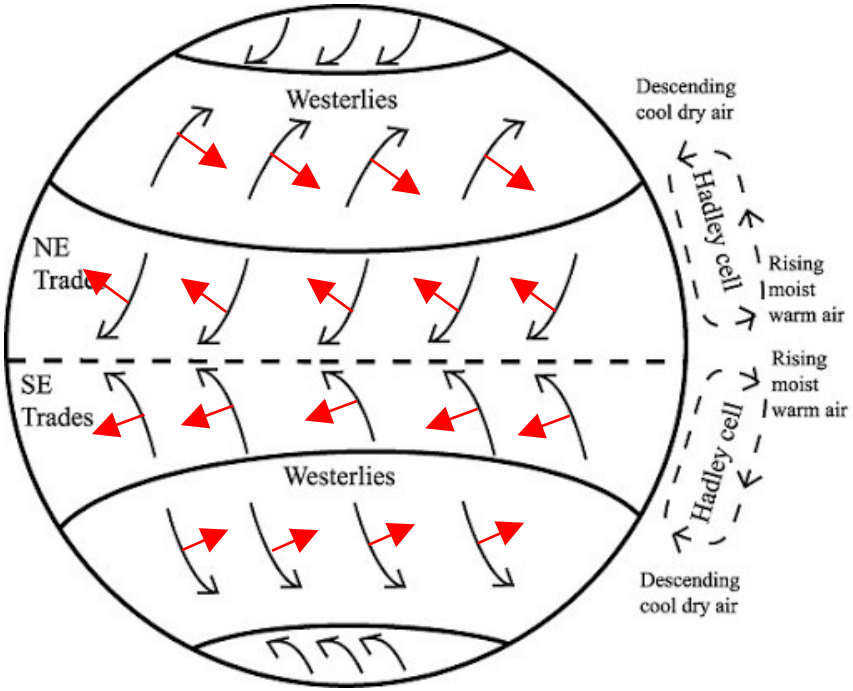
~Surface Wind

~Surface Water



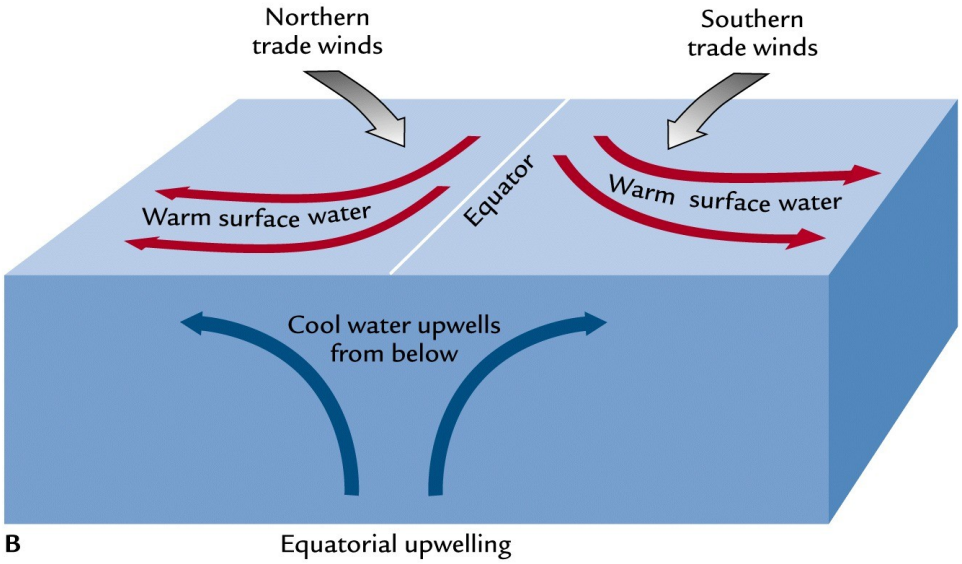


Ocean Circulation: Wind

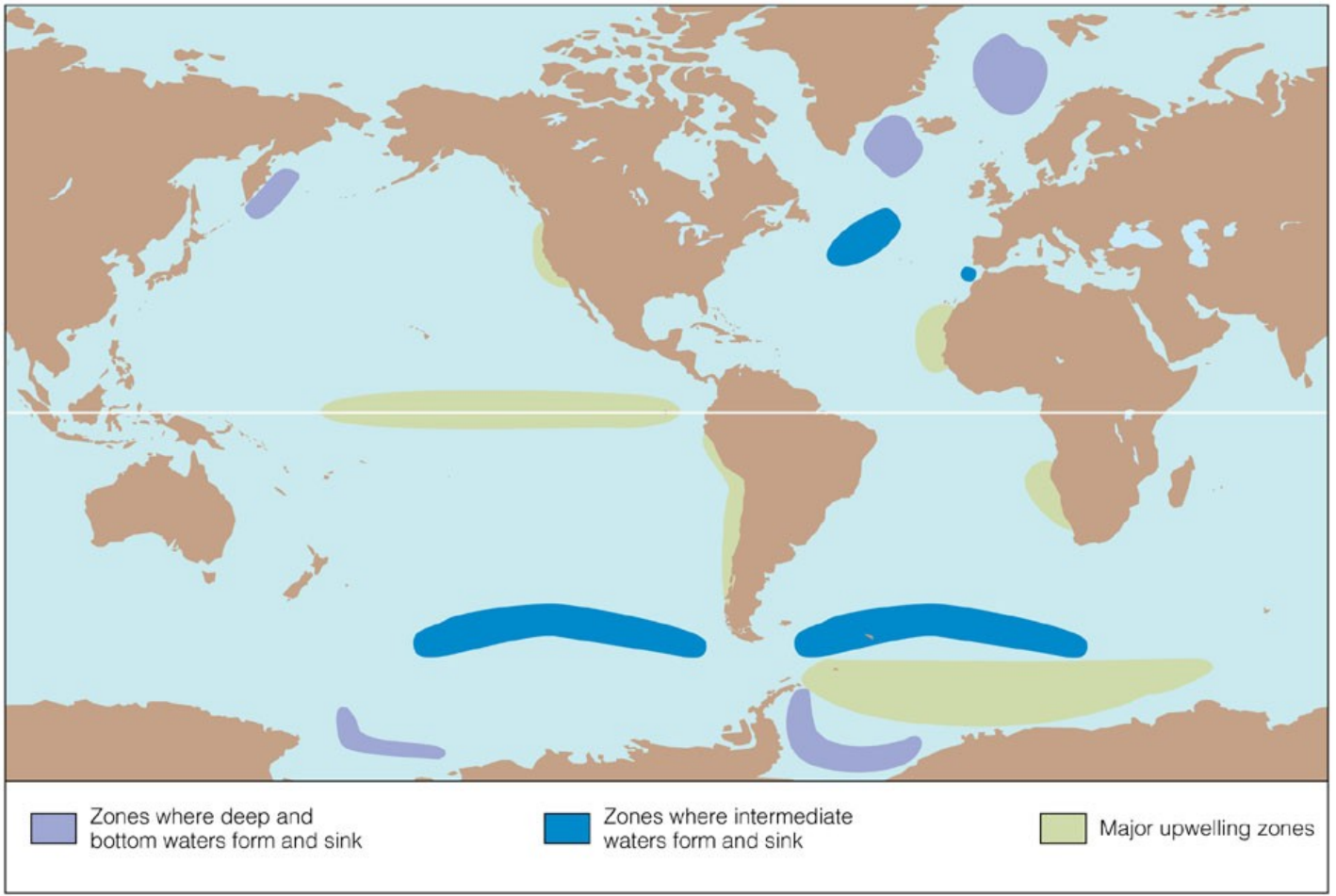


~Surface Wind

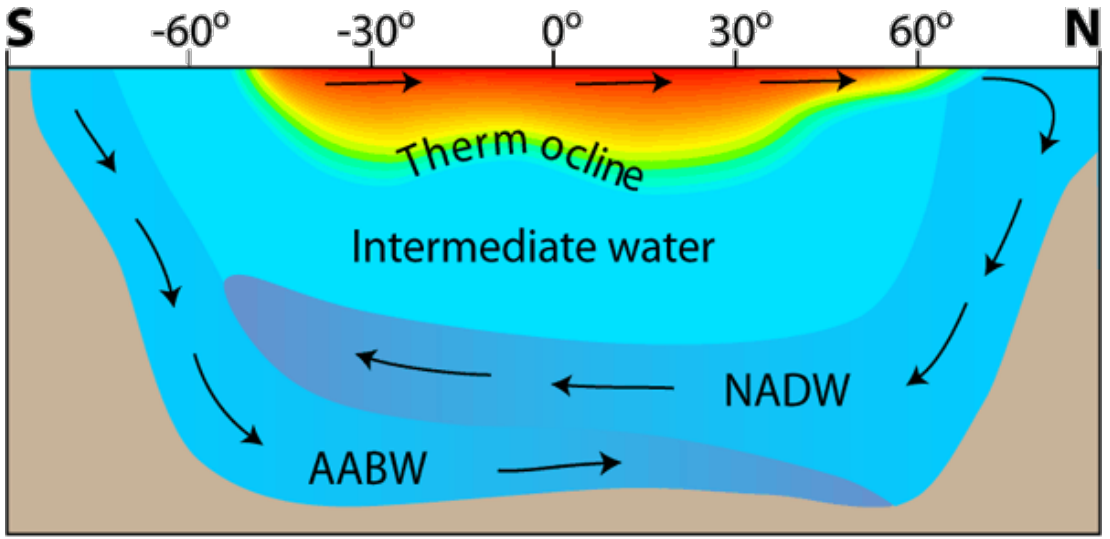
~Surface Water



Ocean Circulation: Up and Down

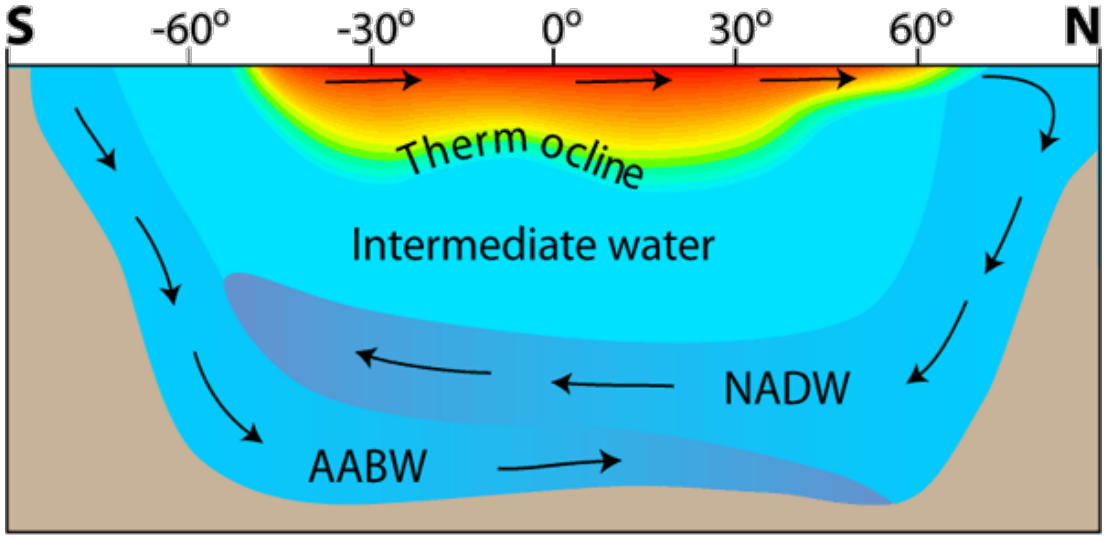


Ocean Circulation: Density

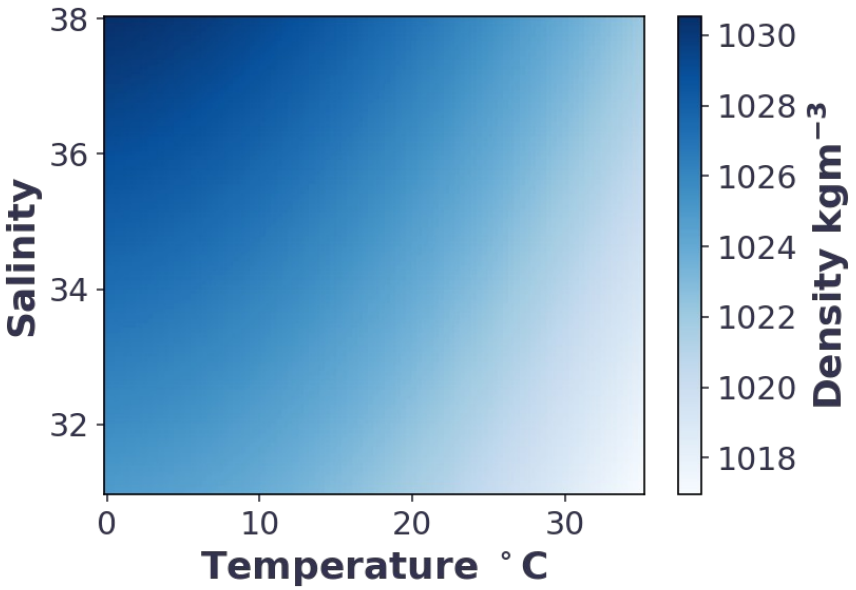


Atlantic Water-Bodies

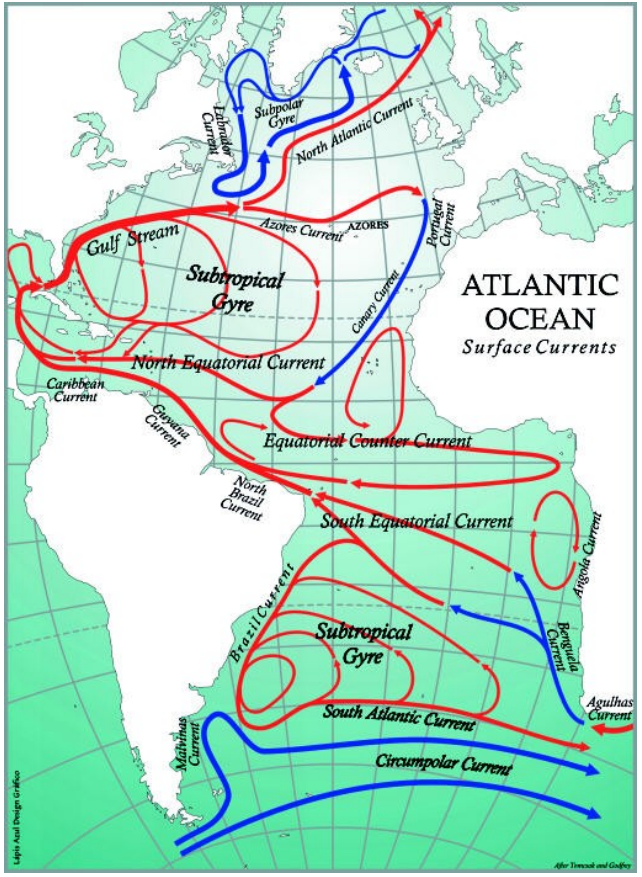
Ocean Circulation: Density

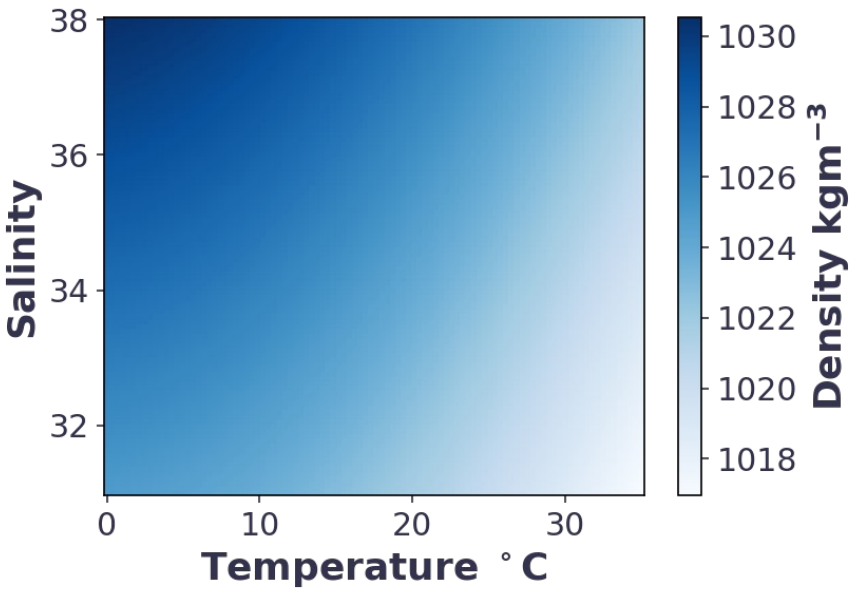


Atlantic Water-Bodies



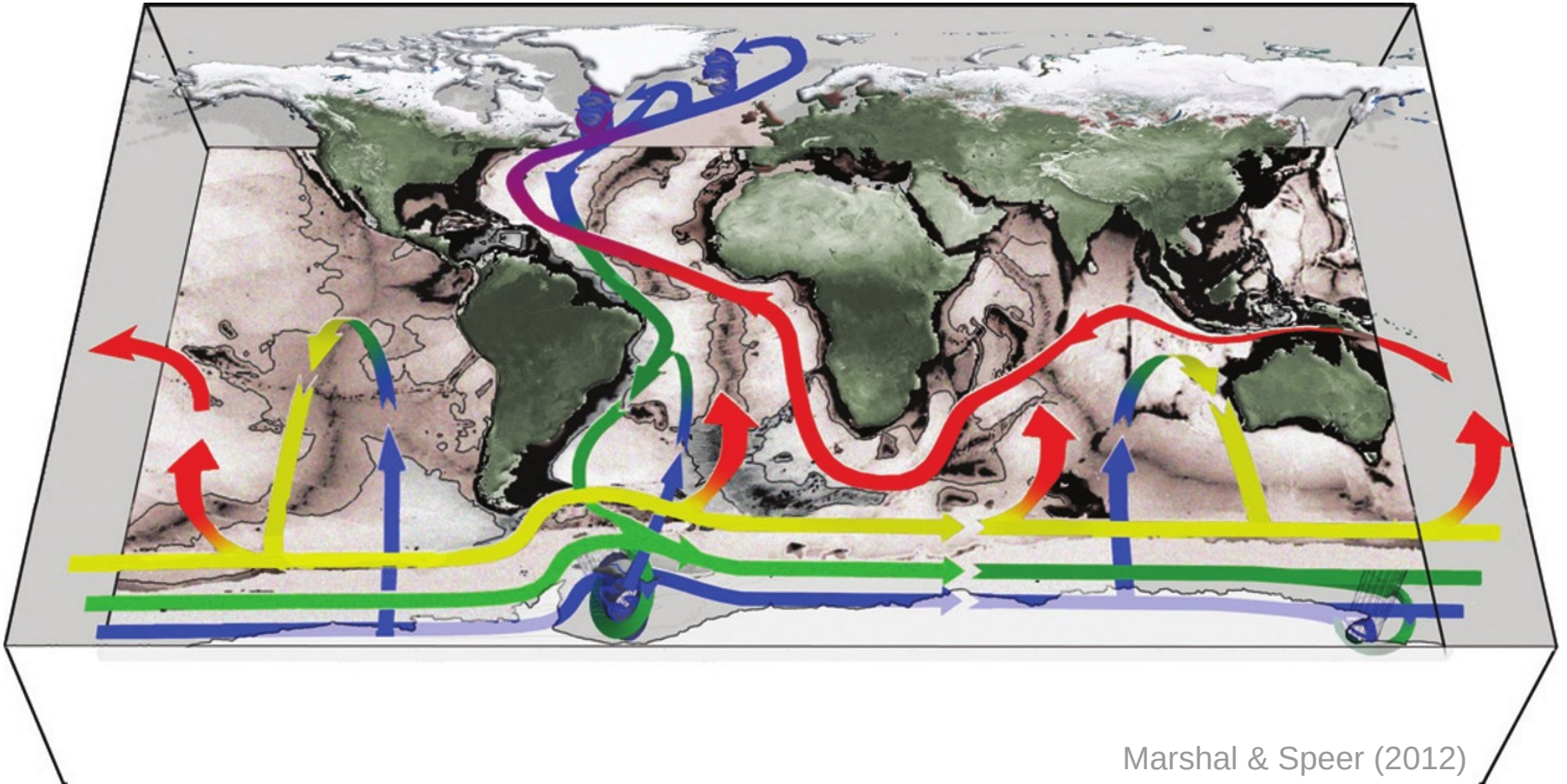
Ocean Circulation: Density





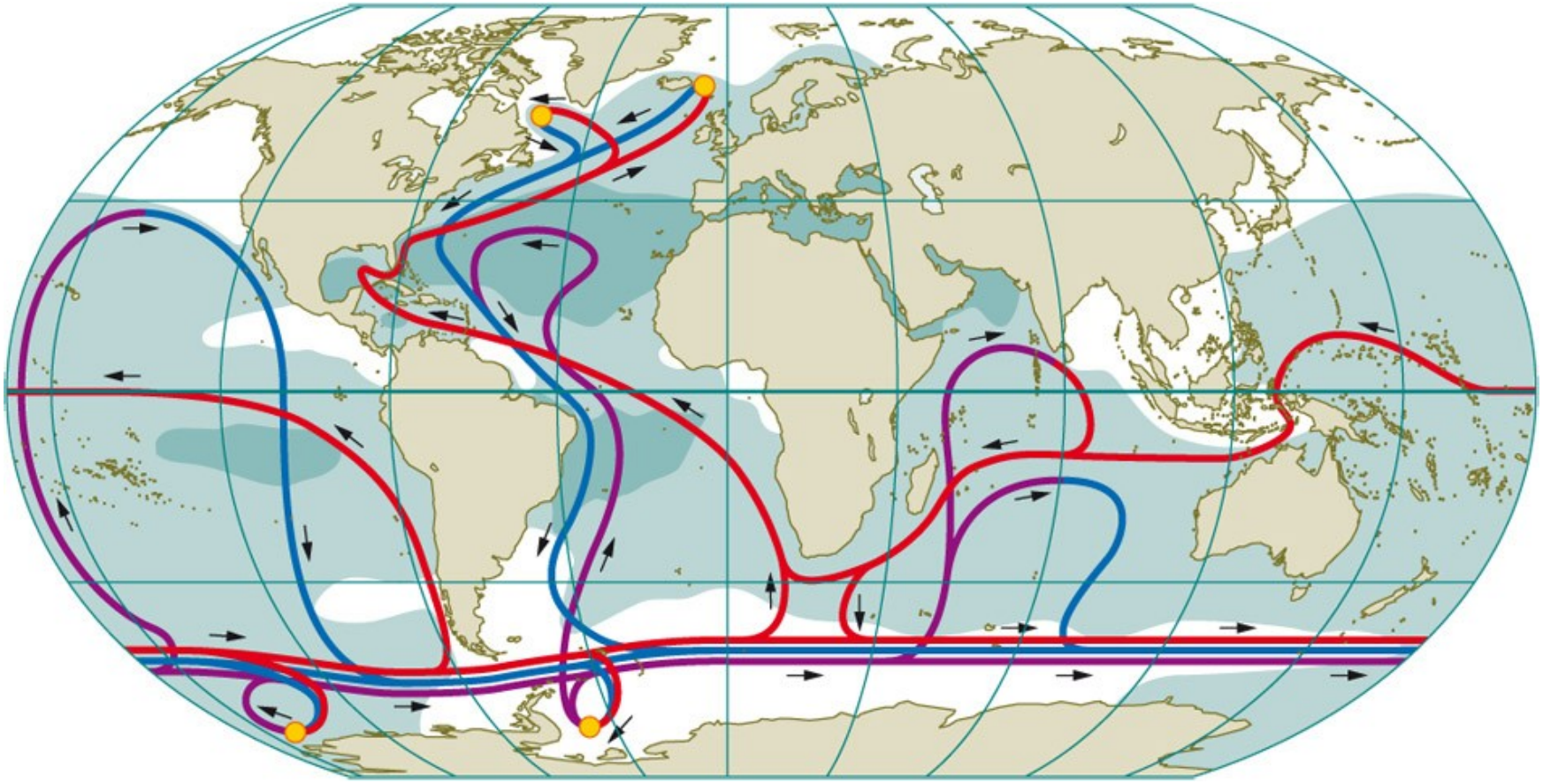
Ocean Circulation

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



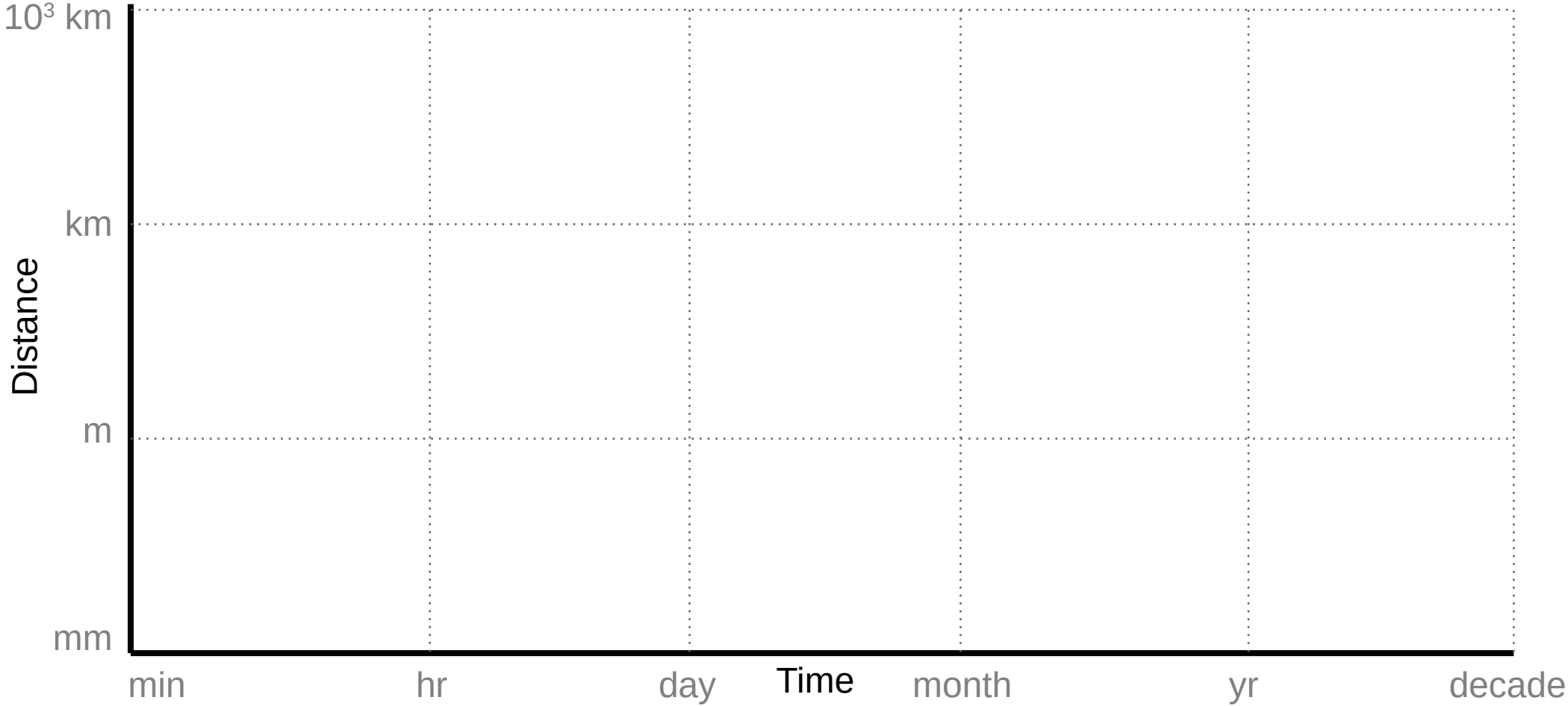
Marshal & Speer (2012)

Ocean Circulation

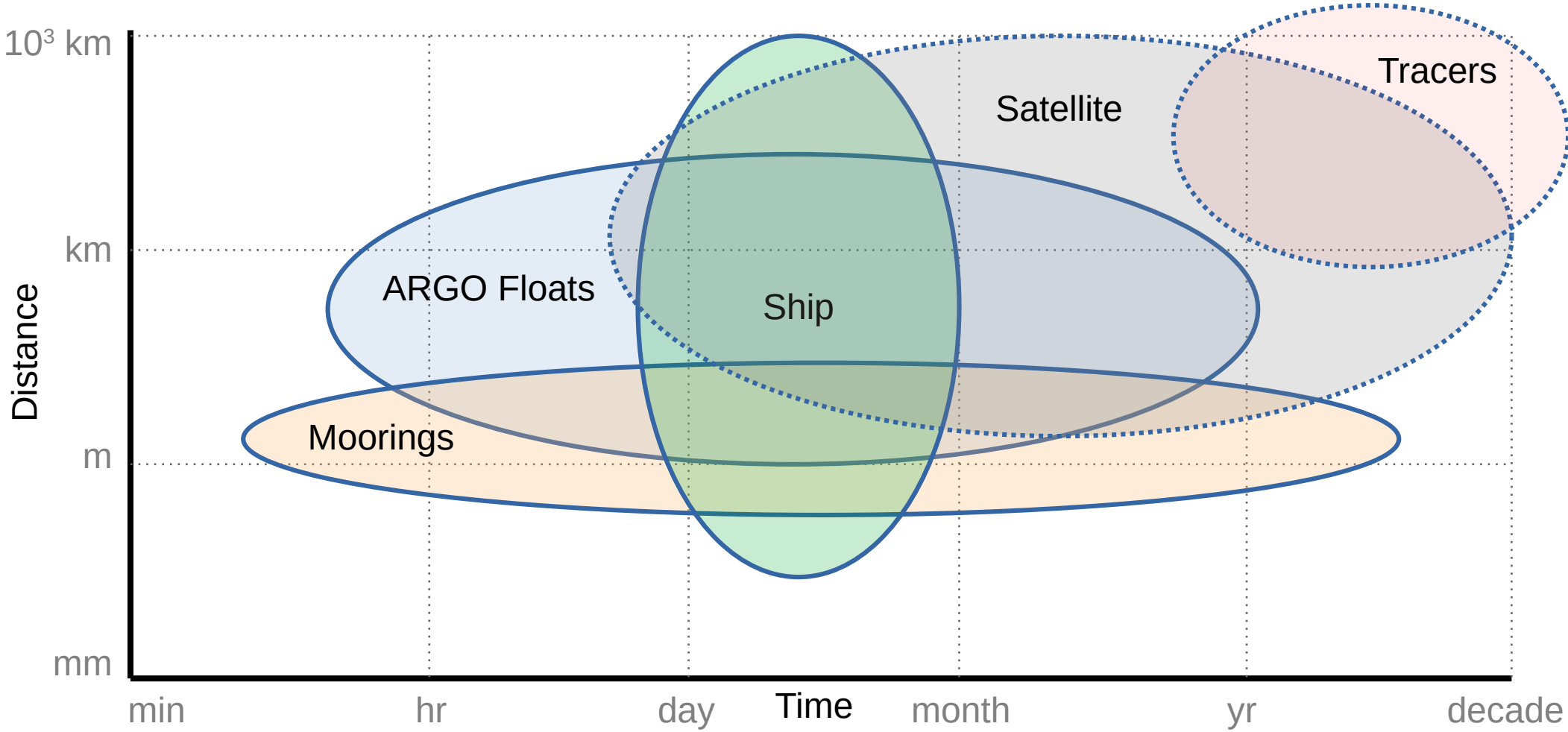


Transport driven by wind and density flows. Turnover time ~1-3000 years.

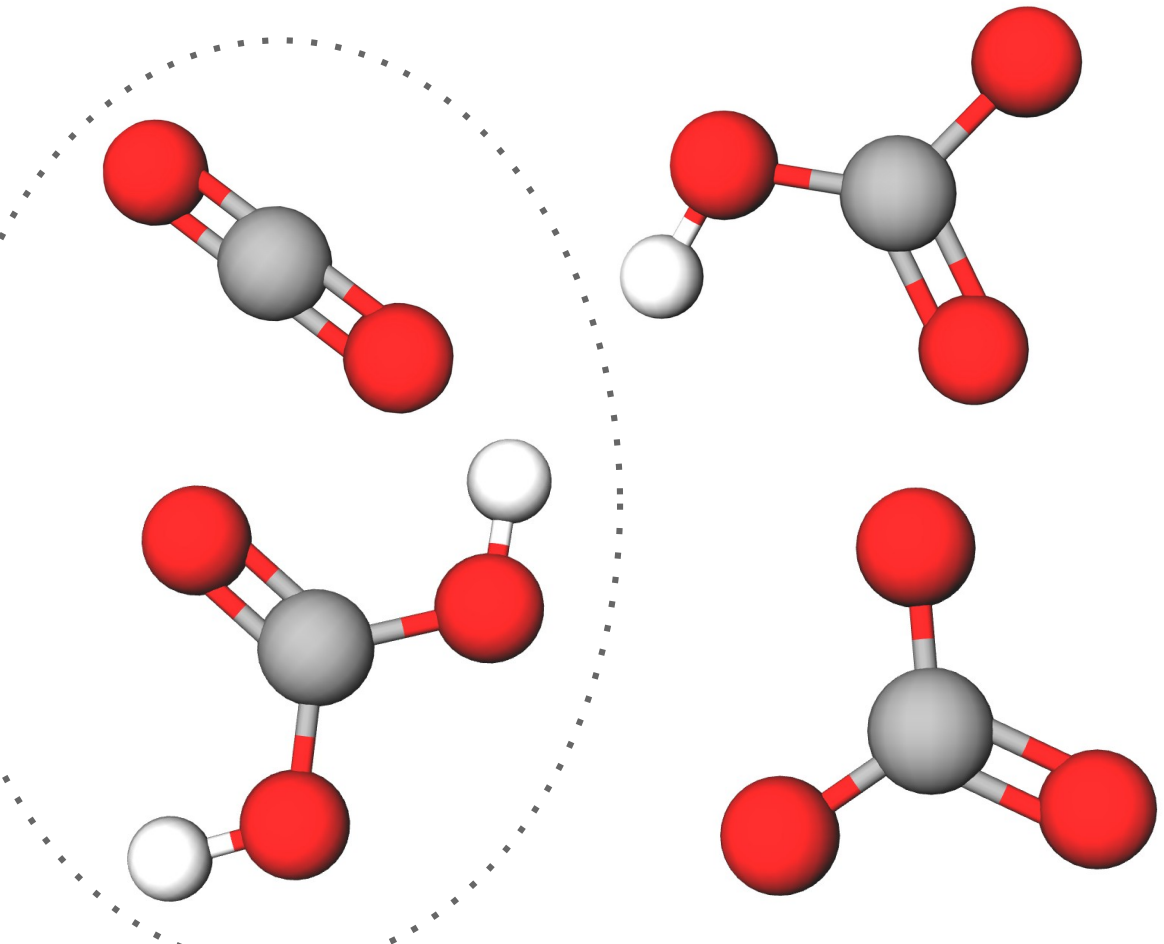
Ocean Circulation: Measurement



Ocean Circulation: Measurement



Carbon in Seawater



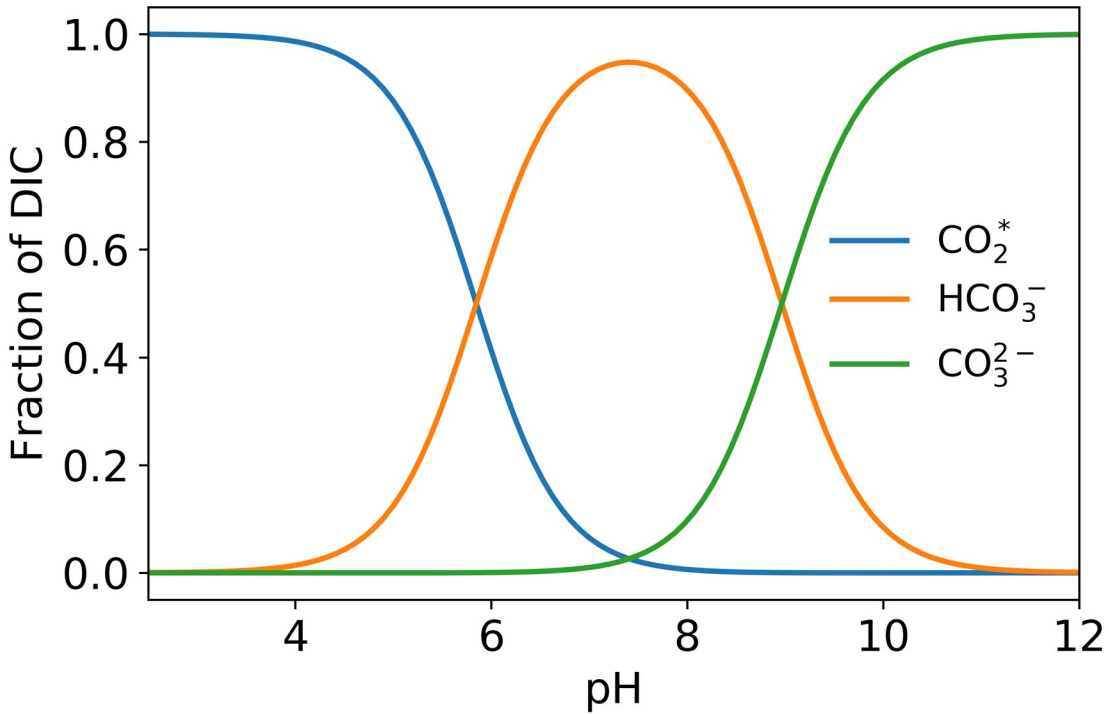
$$CO_2^* \leftrightarrow H^+ + HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$$

Dissolved Inorganic Carbon

$$DIC = CO_2^* + HCO_3^- + CO_3^{2-}$$

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

Carbon in Seawater



CO_2^*

$\leftrightarrow$

$H^+ + HCO_3^-$

$\leftrightarrow$

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Dissolved Inorganic Carbon

$DIC = \mathbf{CO_2^*} + HCO_3^- + CO_3^{2-}$

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

Carbon in Seawater

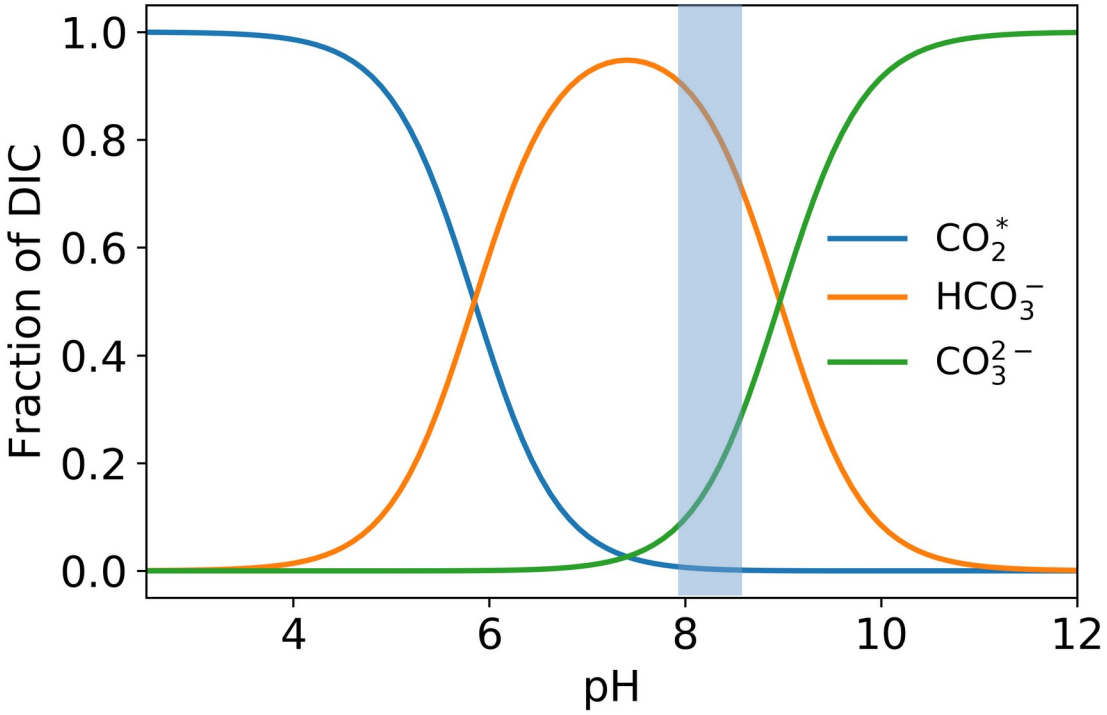
CO_2^*

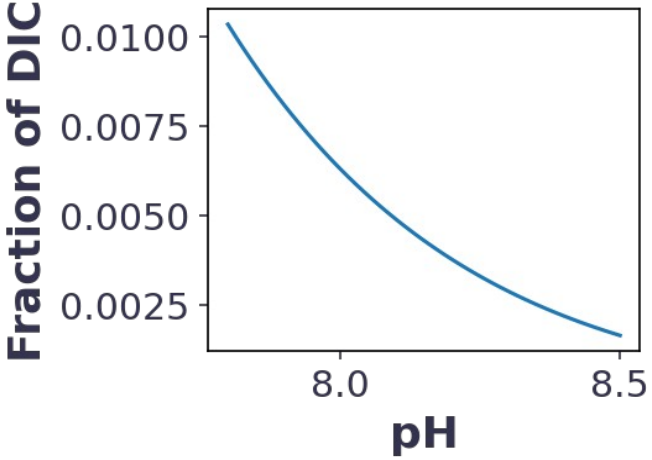
$\updownarrow$

$H^+ + HCO_3^-$

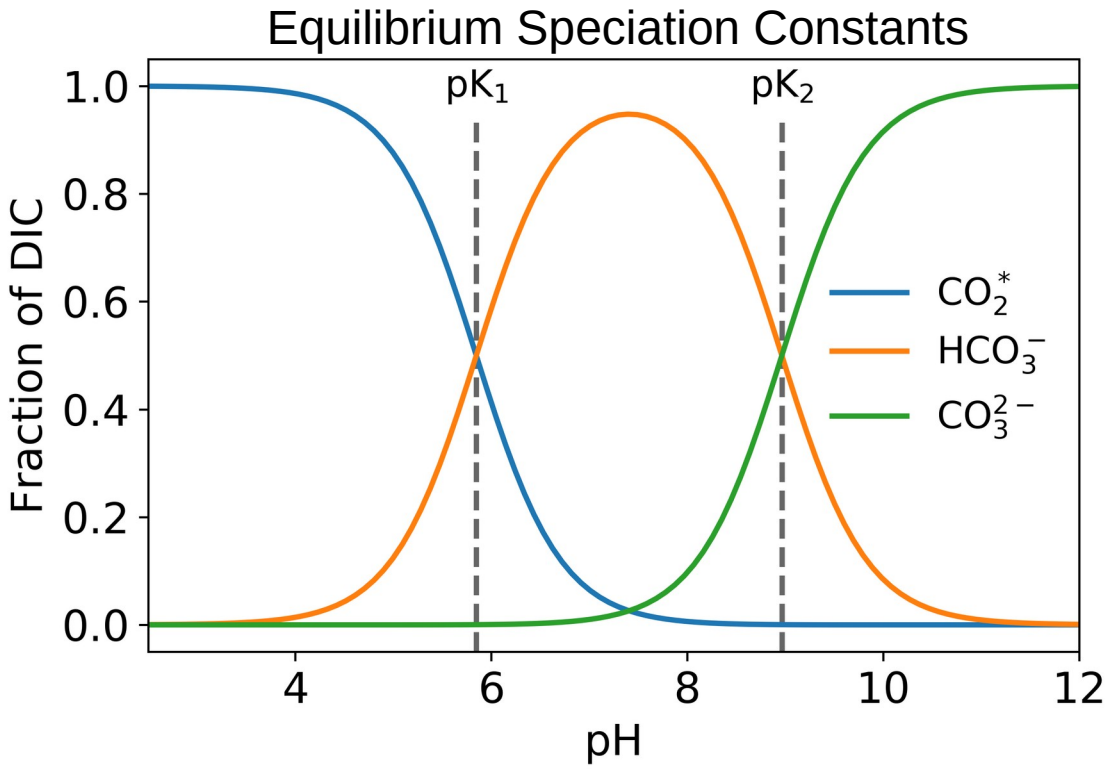
$\updownarrow$

$H^+ + CO_3^{2-}$





Carbon in Seawater



$$CO_2^* \leftrightarrow H^+ + HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$$

$$K_0 = \frac{[CO_2^*]}{fCO_2}$$

$$K_1 = \frac{[H^+][HCO_3^-]}{[CO_2^*]}$$

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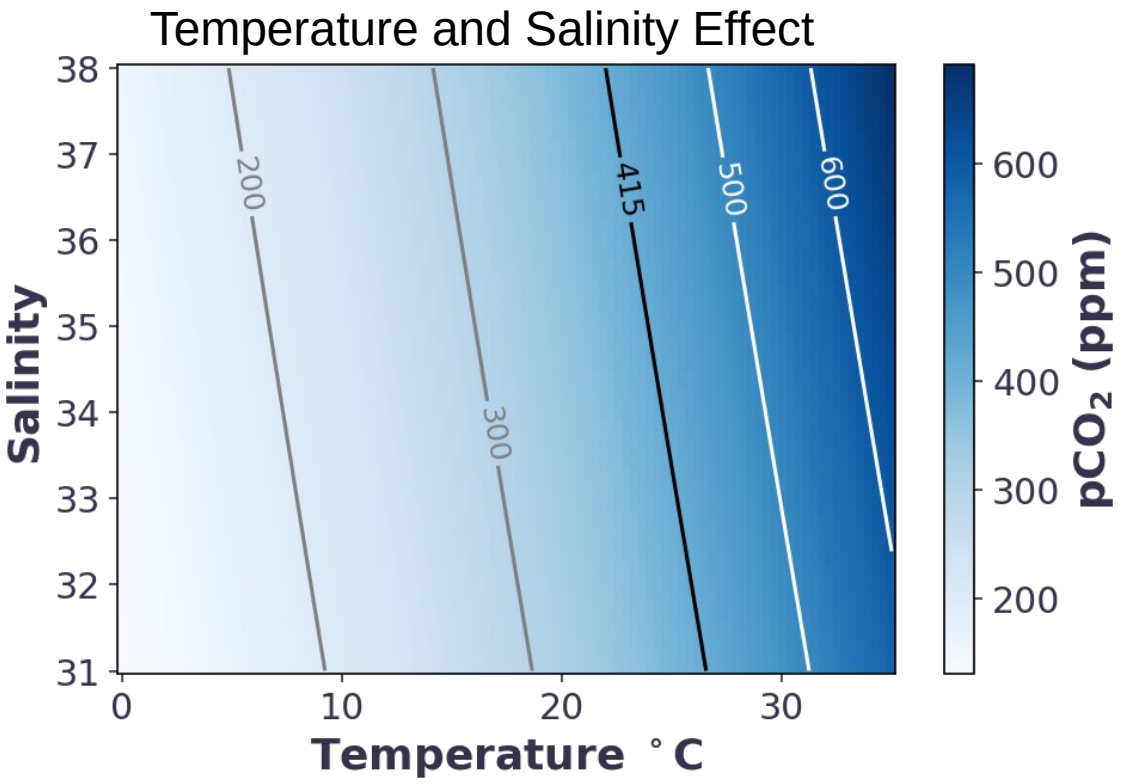
Carbon in Seawater



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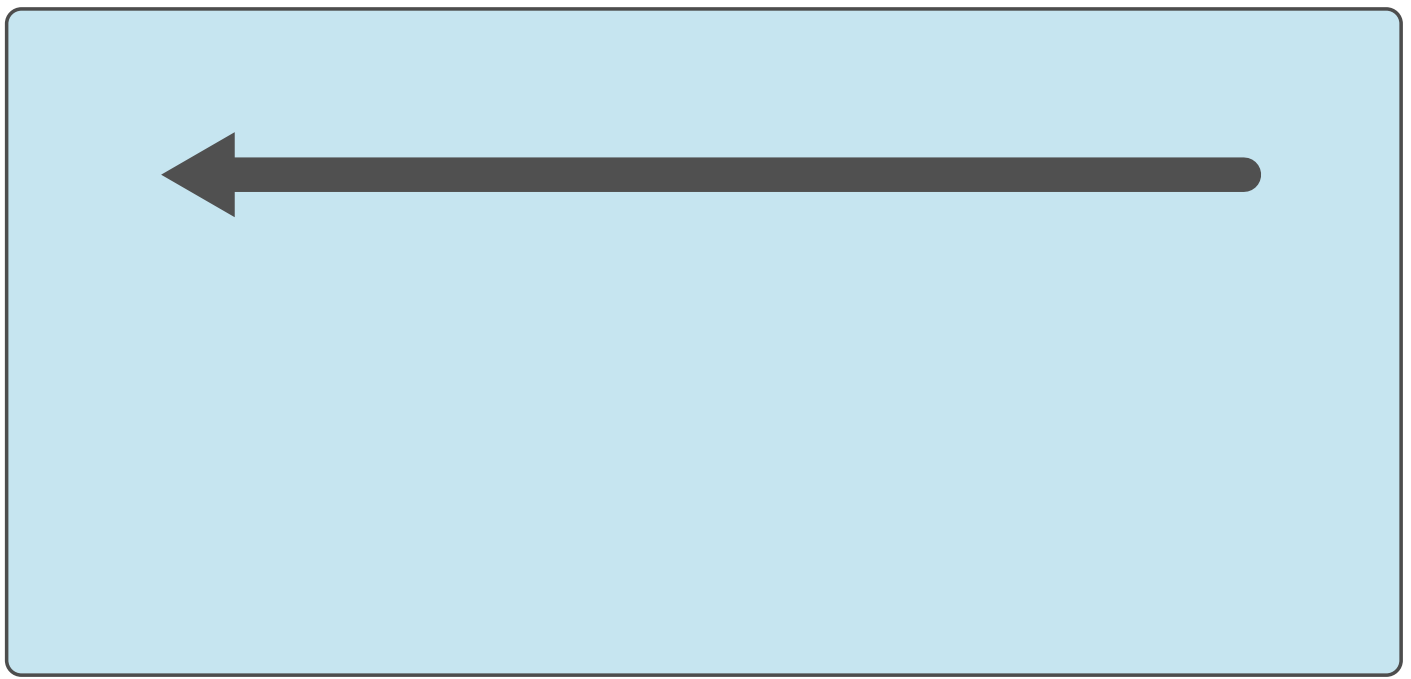
Think: Circulation + Chemistry

High Lat

Equator

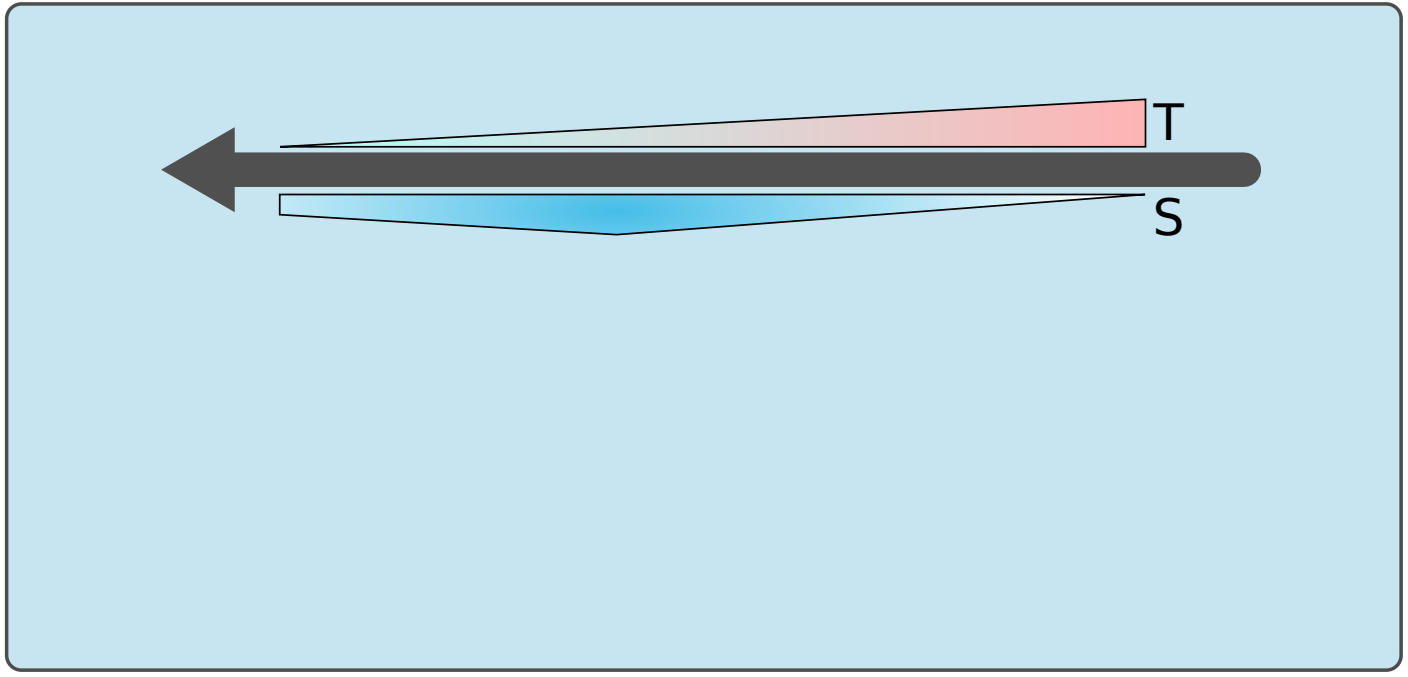


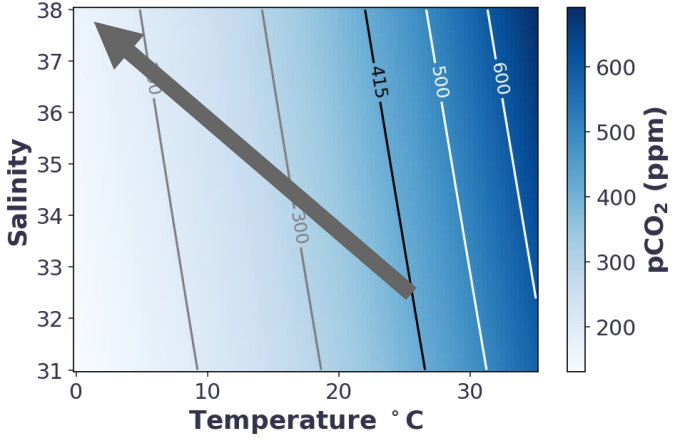
Think: Circulation + Chemistry

High Lat

Equator

pCO_2 ~400ppm





Think: Circulation + Chemistry

High Lat

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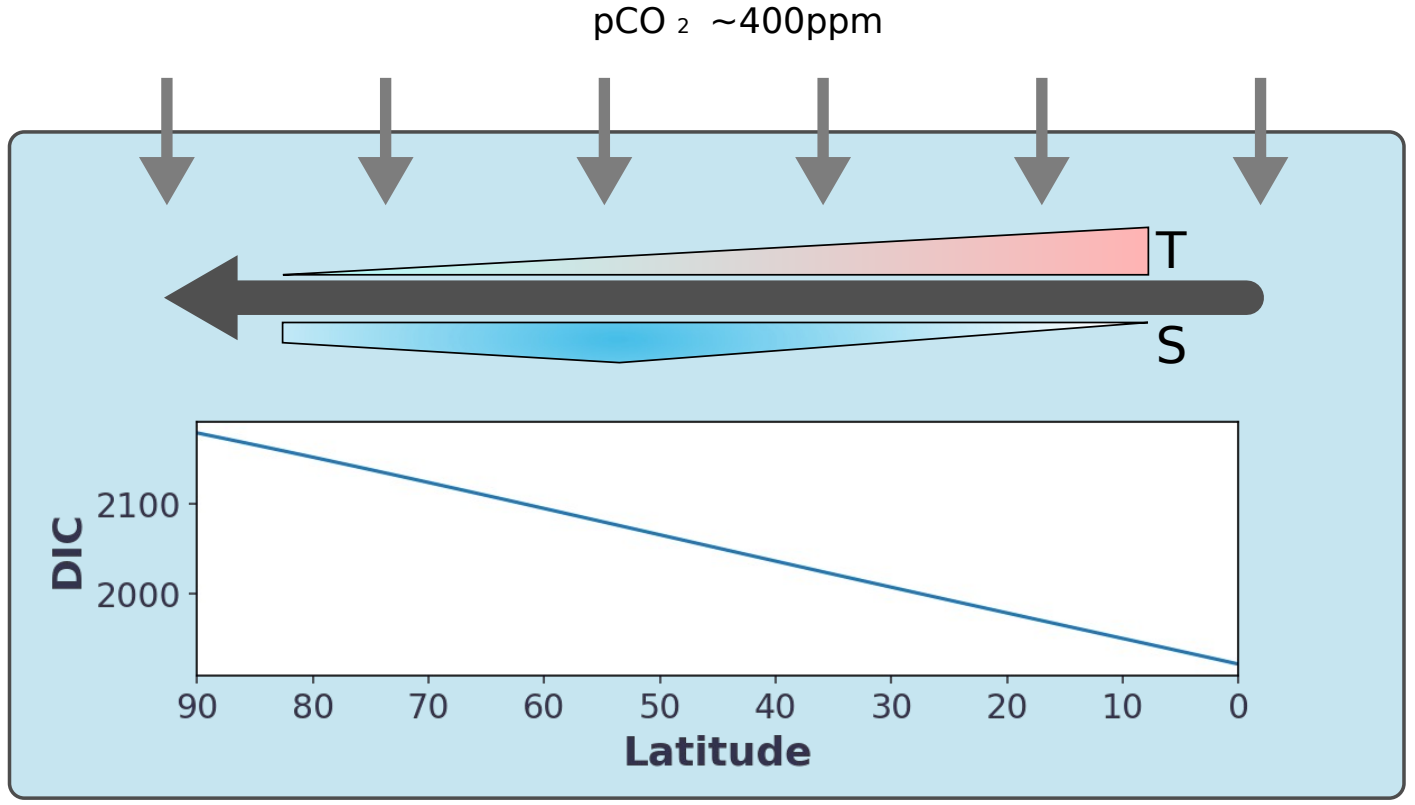
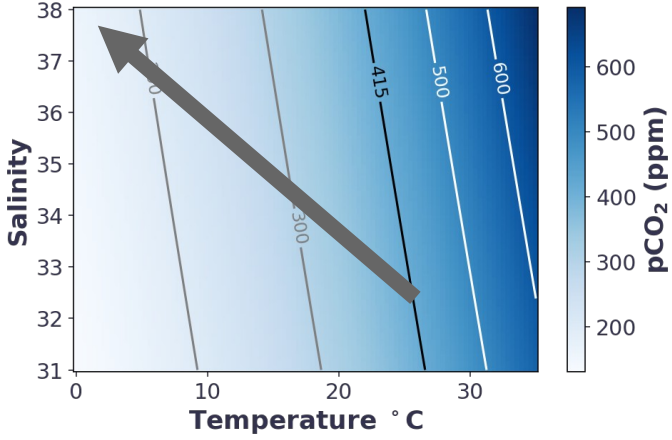
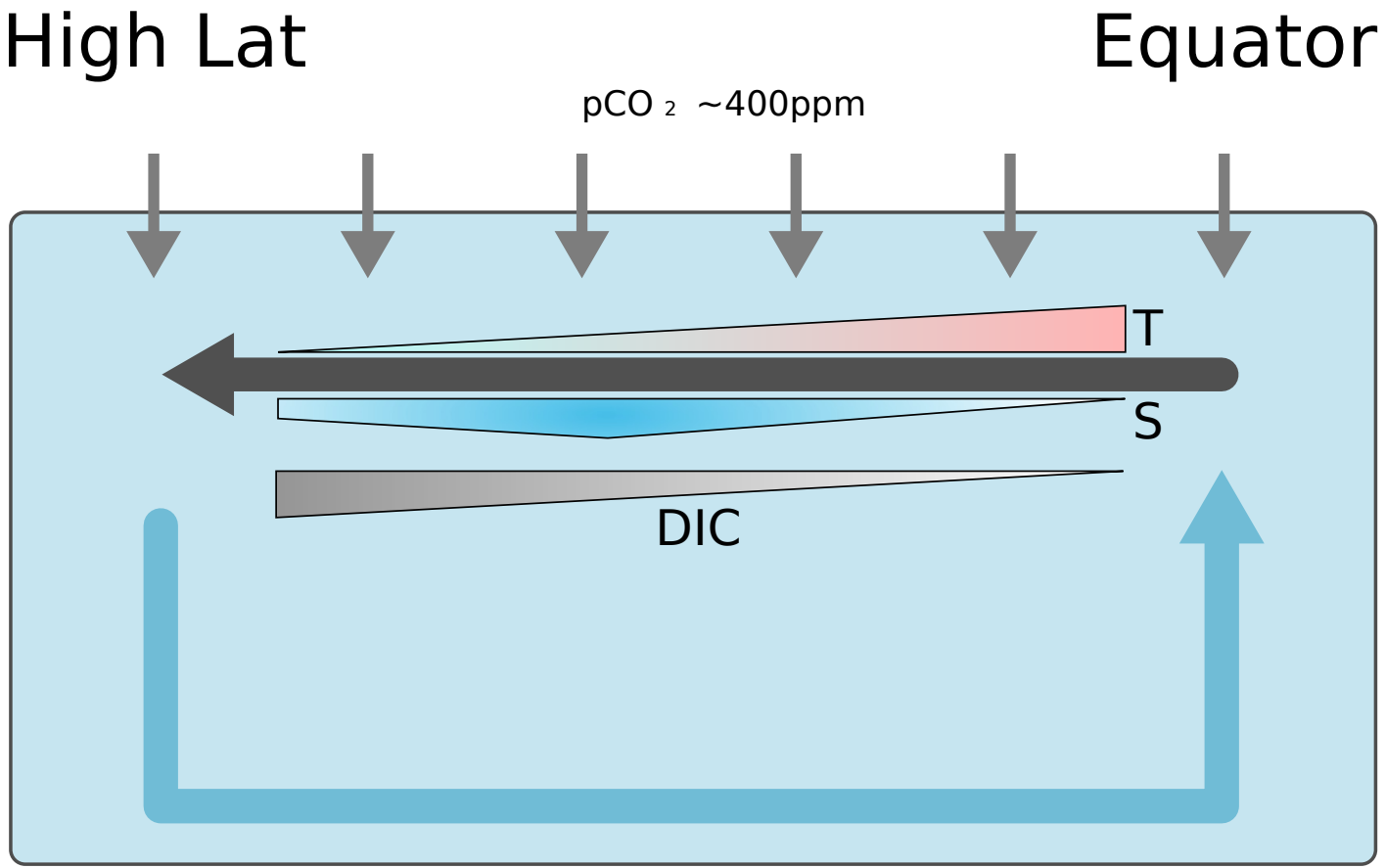
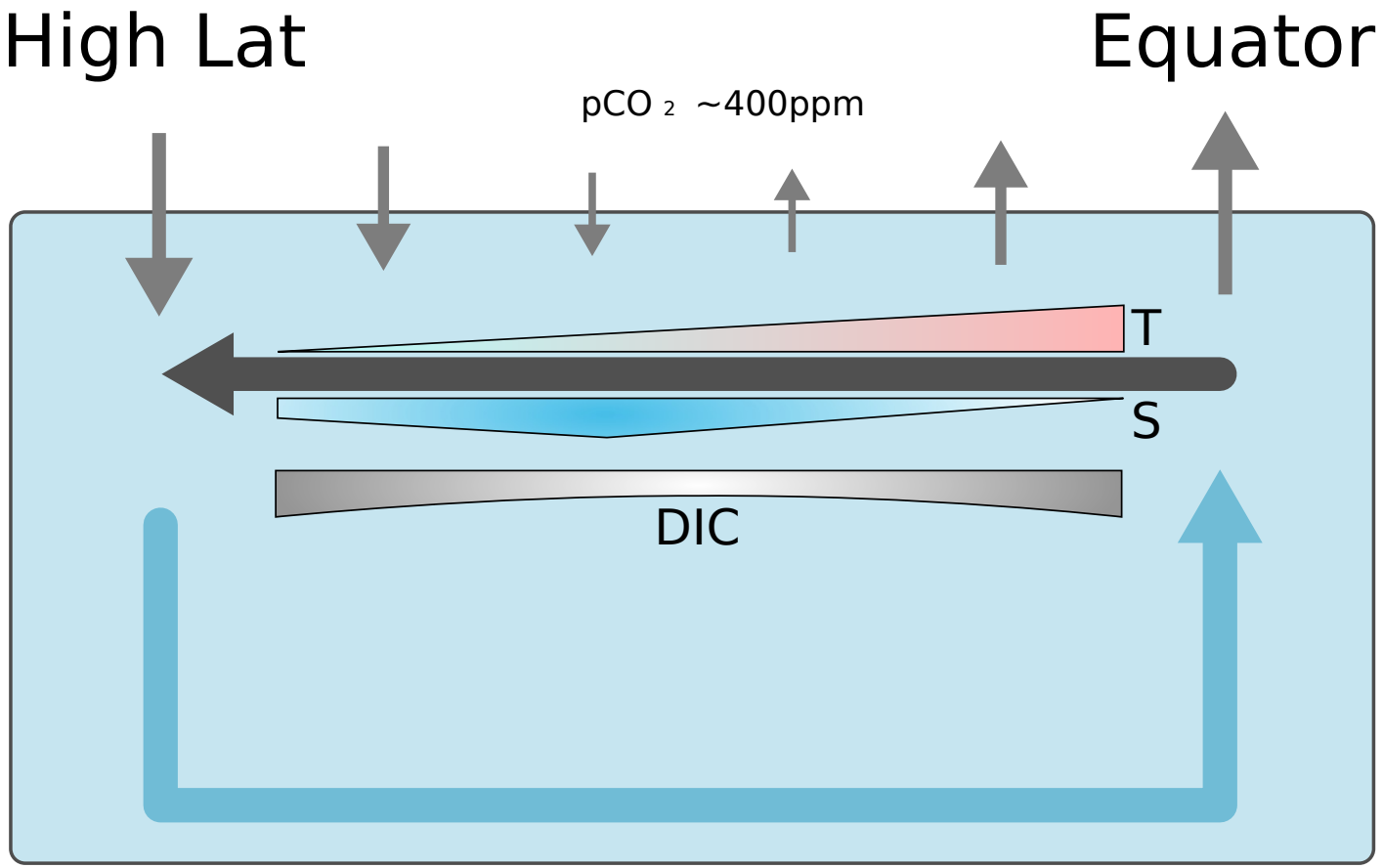




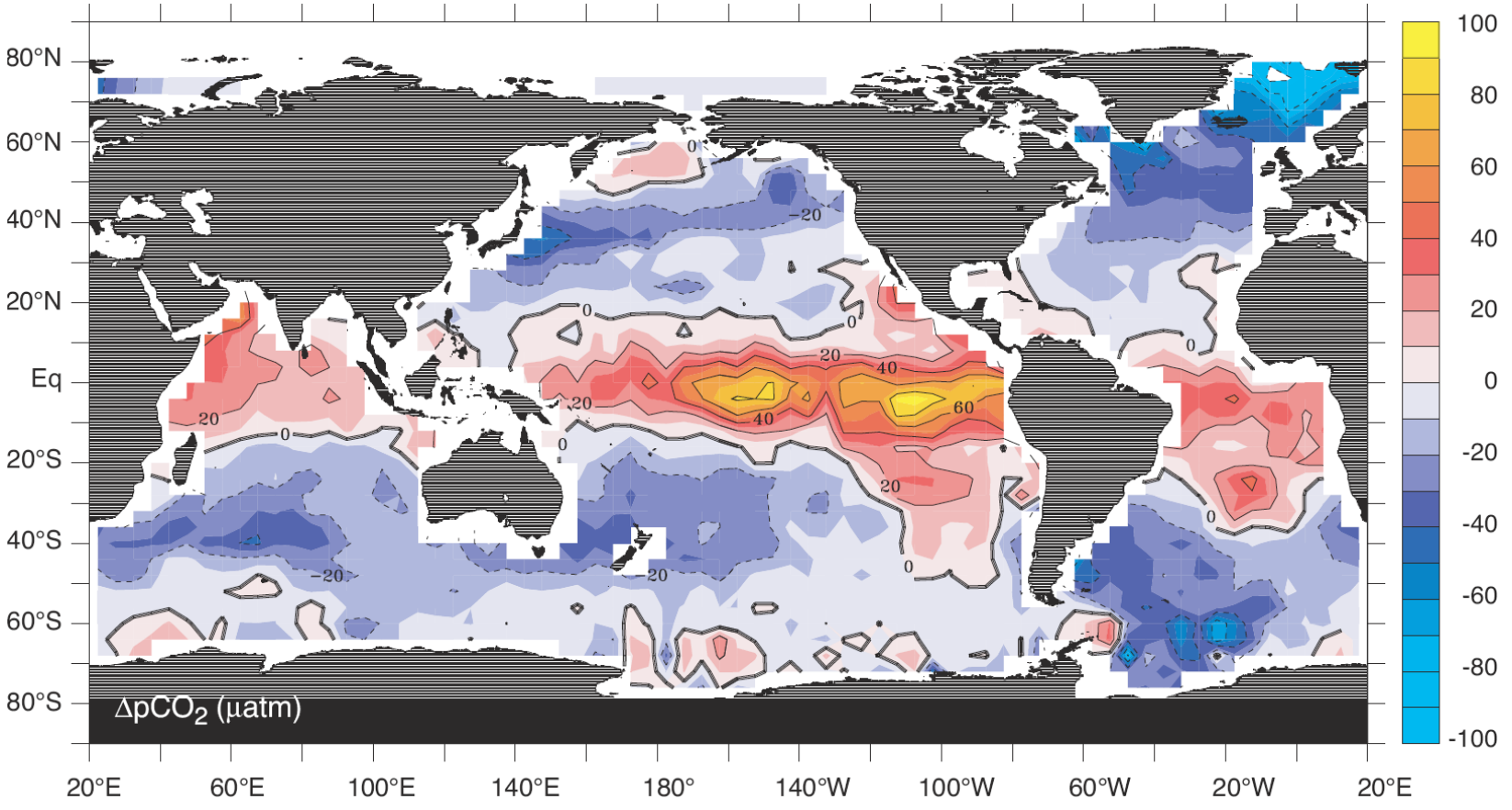
Think: Circulation + Chemistry



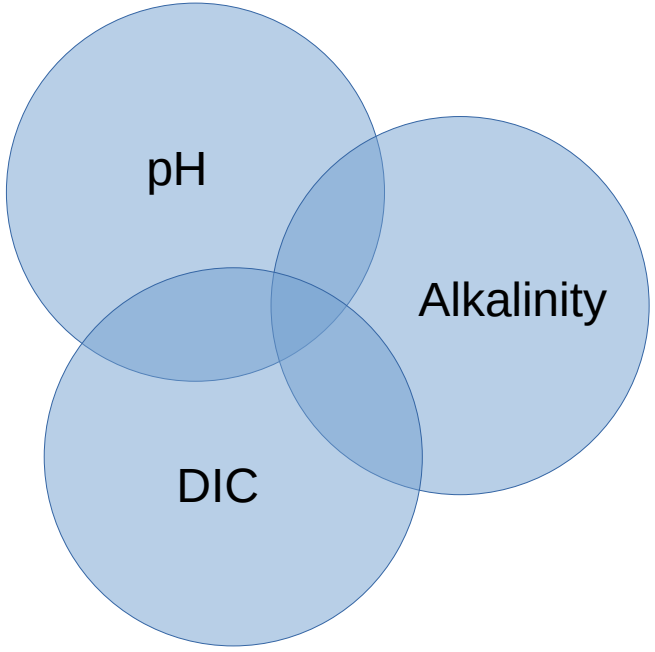
The Solubility Pump

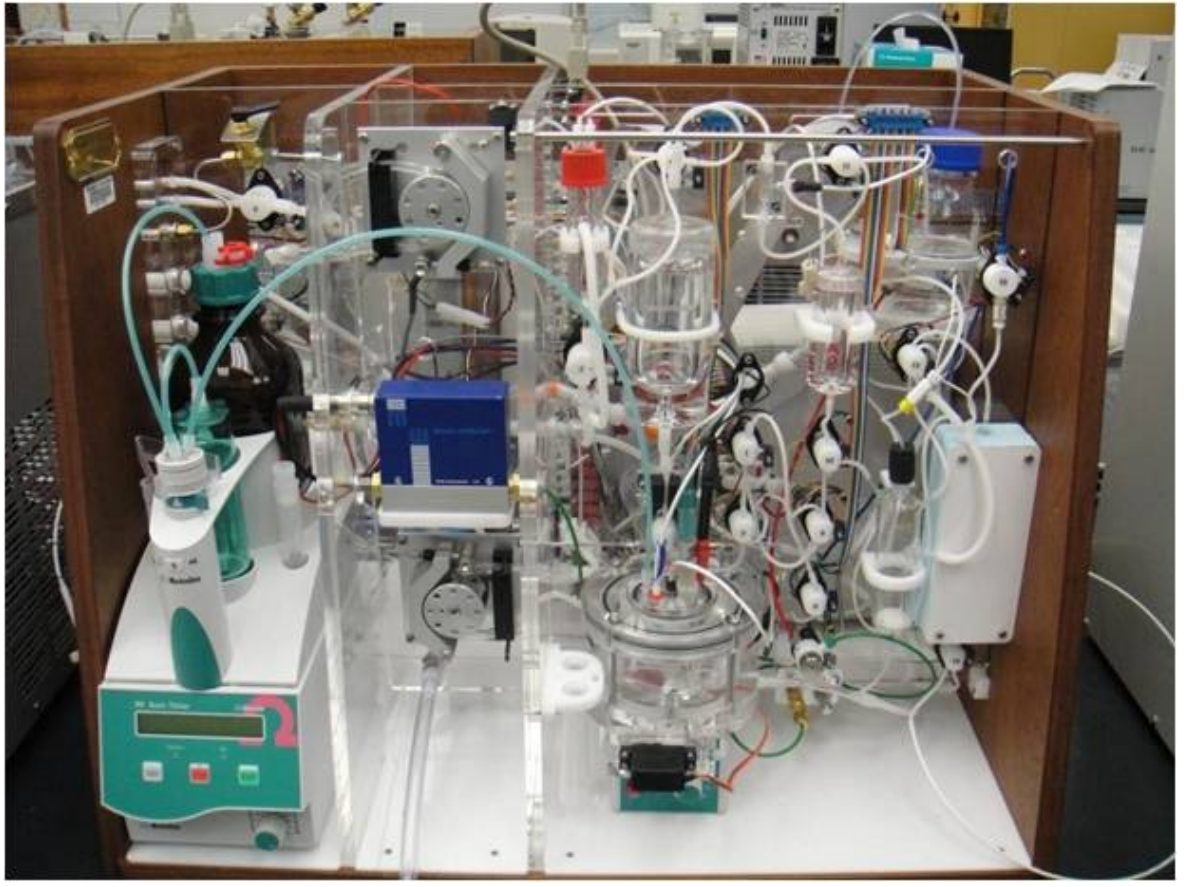


Ocean-Atmosphere Carbon Fluxes

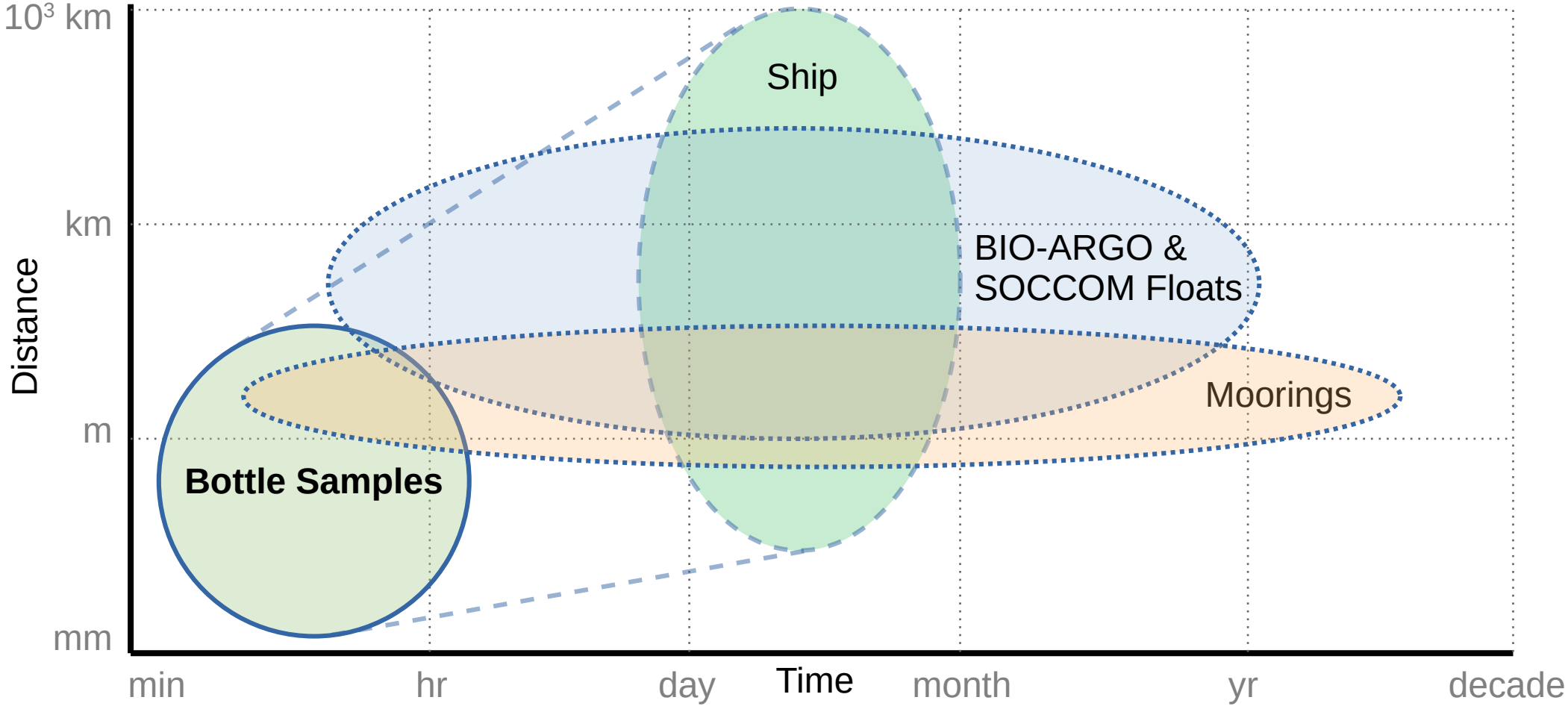


Carbon in Seawater: Measurement

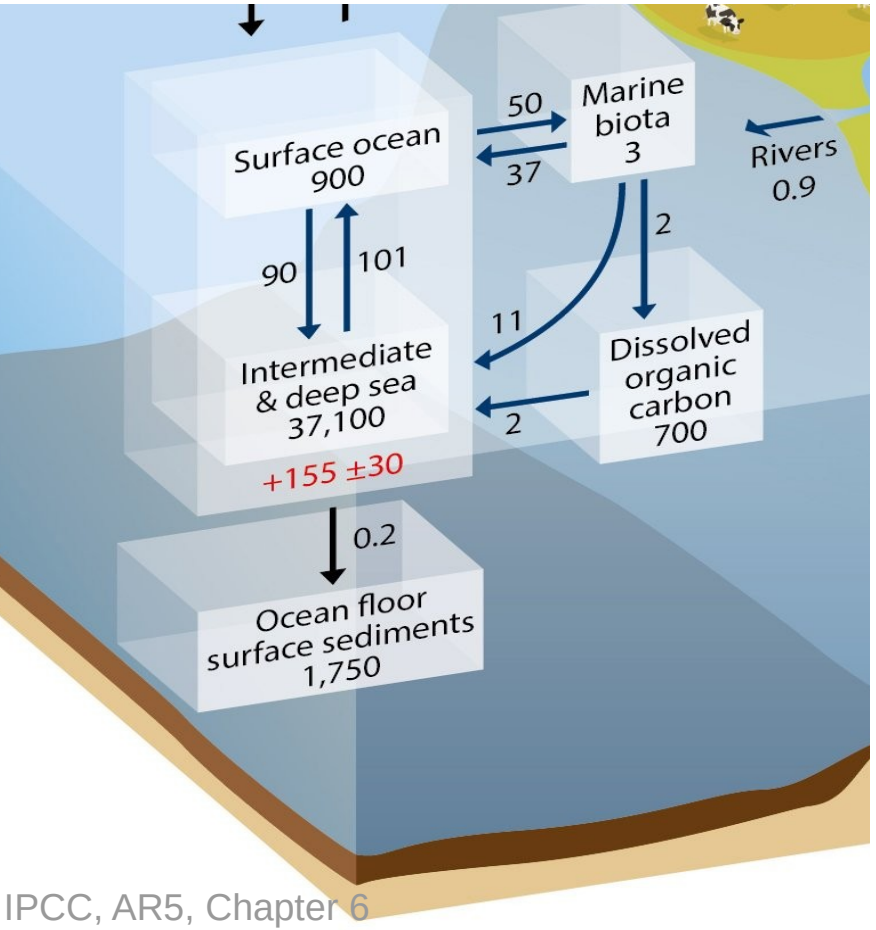




Carbon in Seawater: Measurement

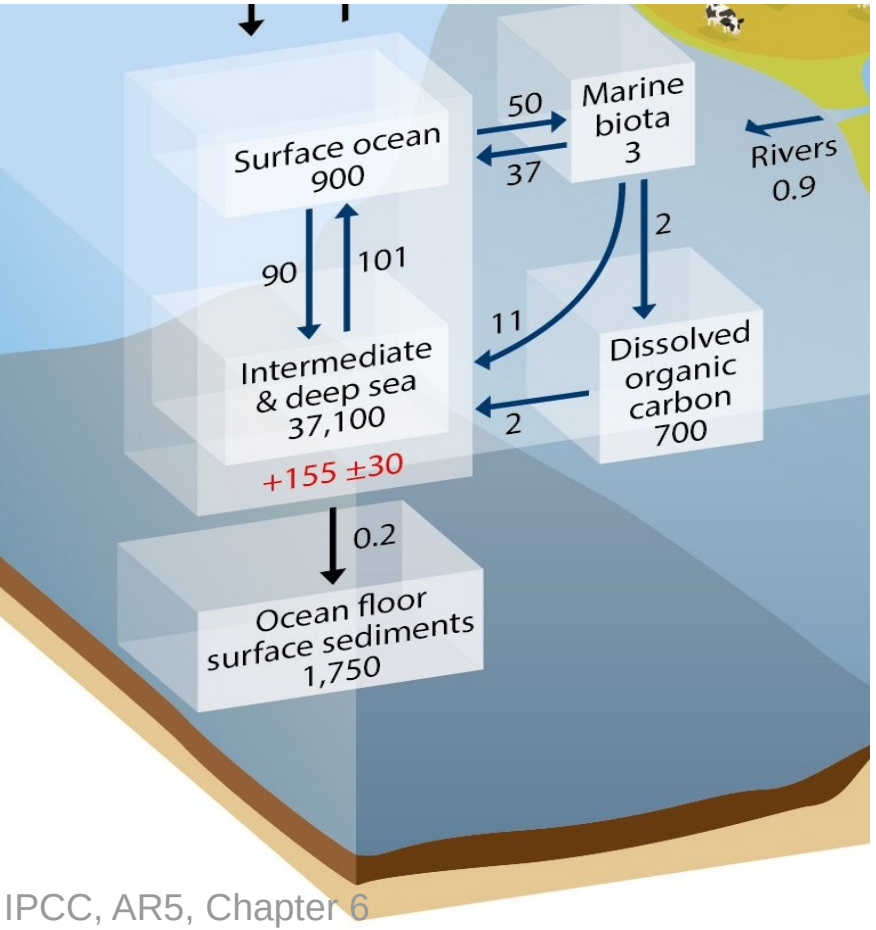


Carbon in Seawater: Biology



IPCC, AR5, Chapter 6

Carbon in Seawater: Biology



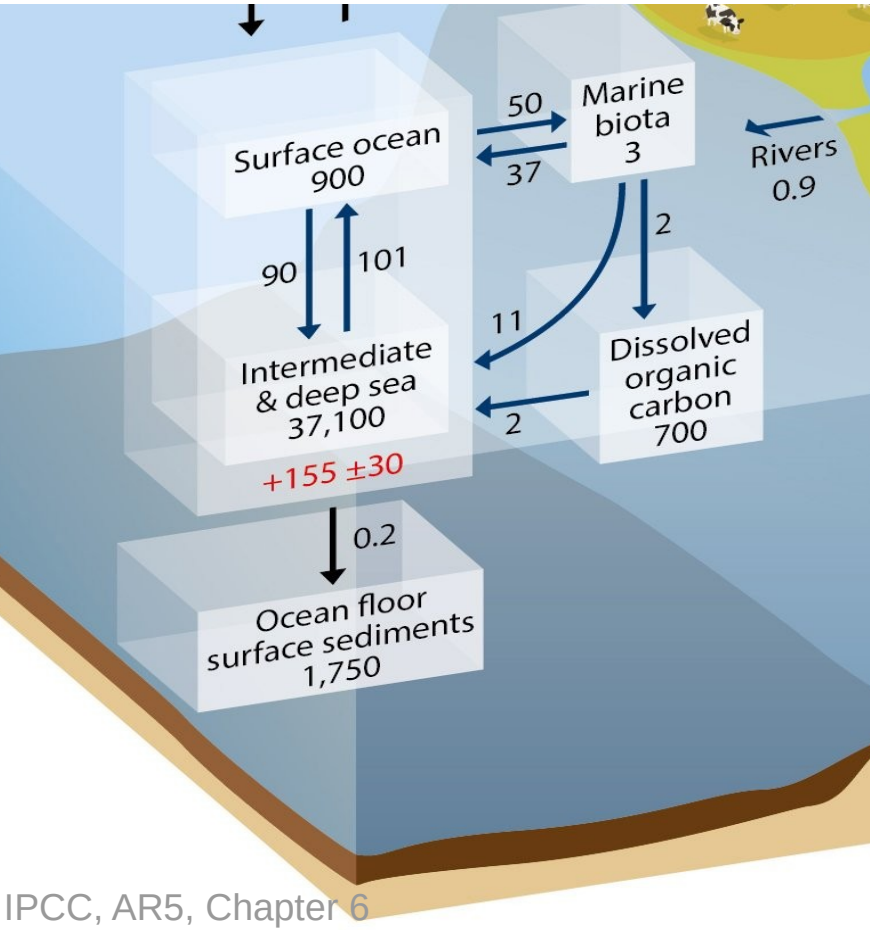
Total Biological Export: ~13 GtC

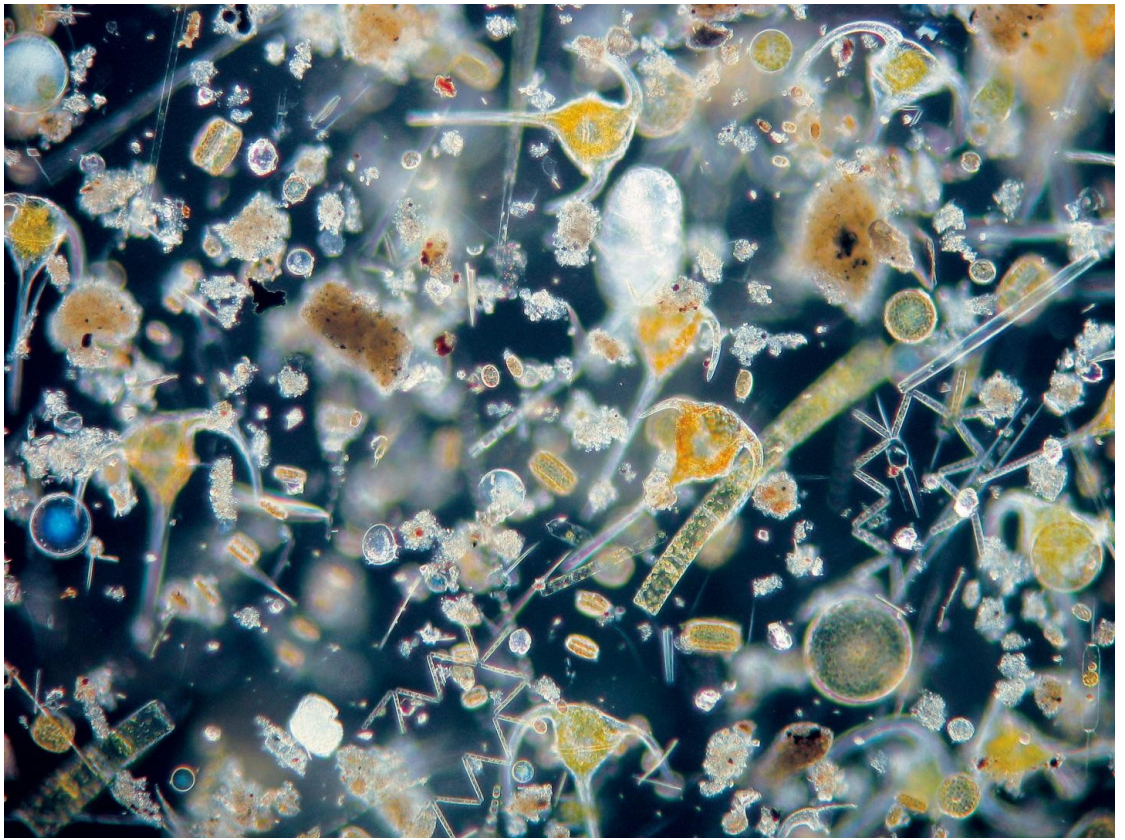
Annual fossil fuel release: 7.8 +/- 0.6 GtC

Small compared to solubility, but still BIG!

IPCC, AR5, Chapter 6

Carbon in Seawater: Biology

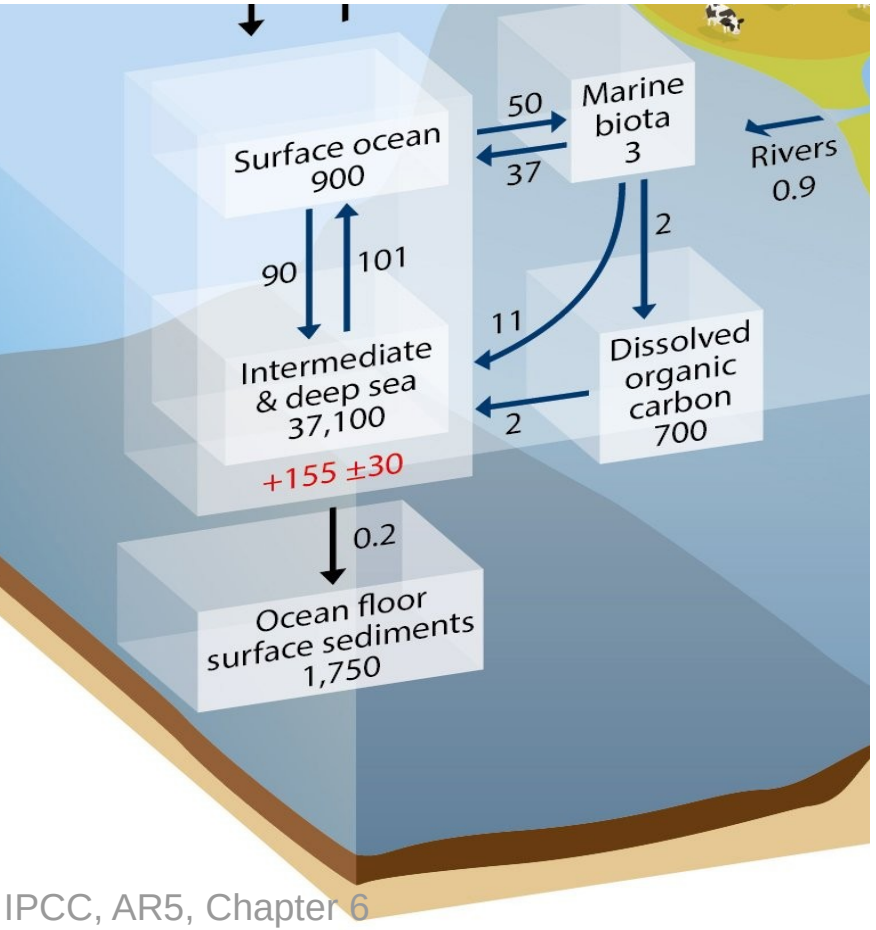




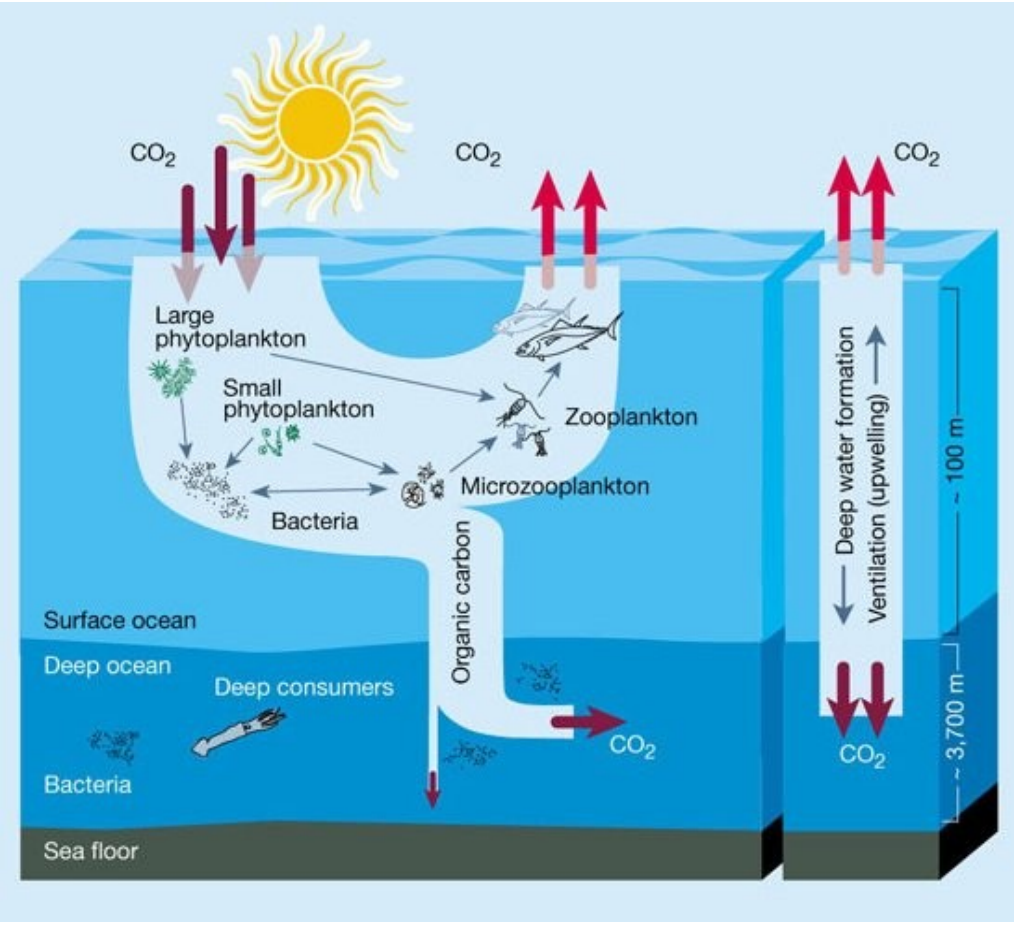
IPCC, AR5, Chapter 6

A. Stuhr, GEOMAR.

Carbon in Seawater: Biology



IPCC, AR5, Chapter 6



Carbon in Seawater: Biology

$$\mathbf{C_{106}}H_{175}O_{42}N_{16}P + 150O_2$$

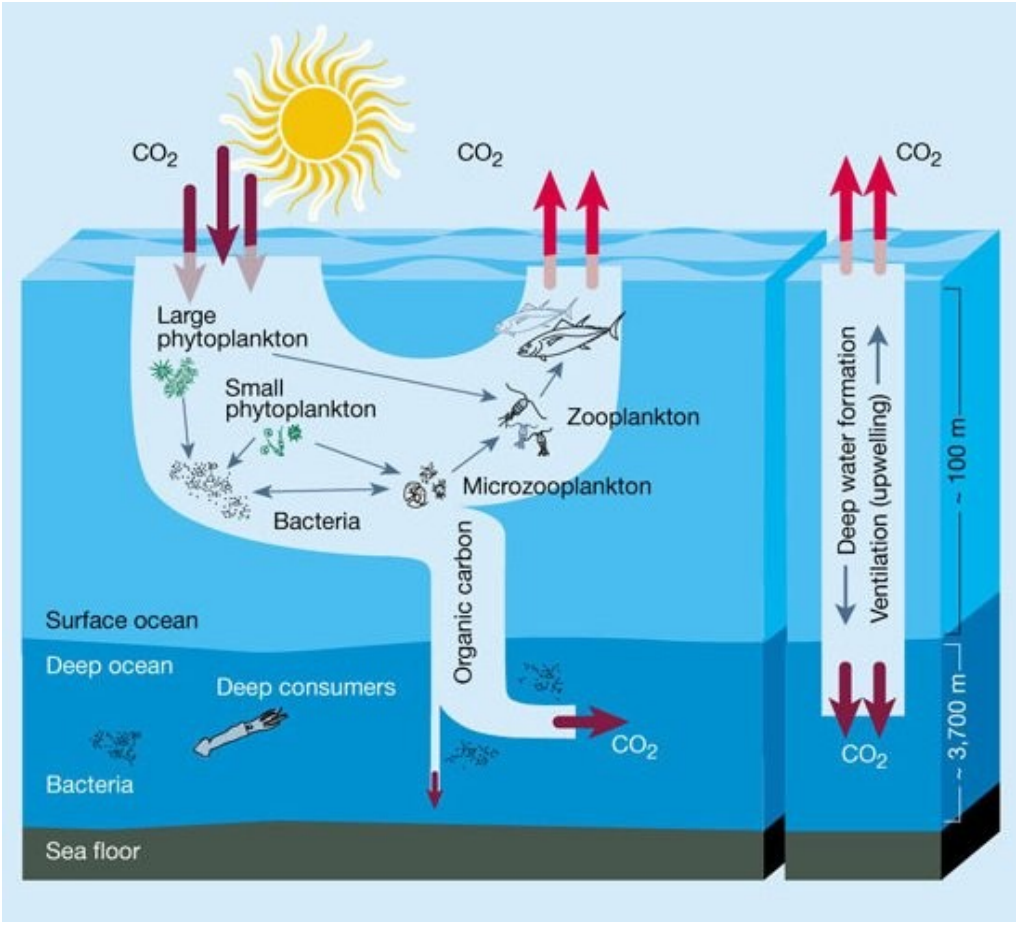
Photosynthesis ↑

Respiration (Remineralisation) ↓

$$\mathbf{106CO_2} + 16NO_3 + H_3PO_4 + 78H_2O + 18H^+$$

Photosynthesis captures CO_2 in the surface

Remineralisation releases CO_2 in deep



Carbon in Seawater: Biology

$\mathbf{C_{106}}H_{175}O_{42}N_{16}P + 150O_2$

Photosynthesis

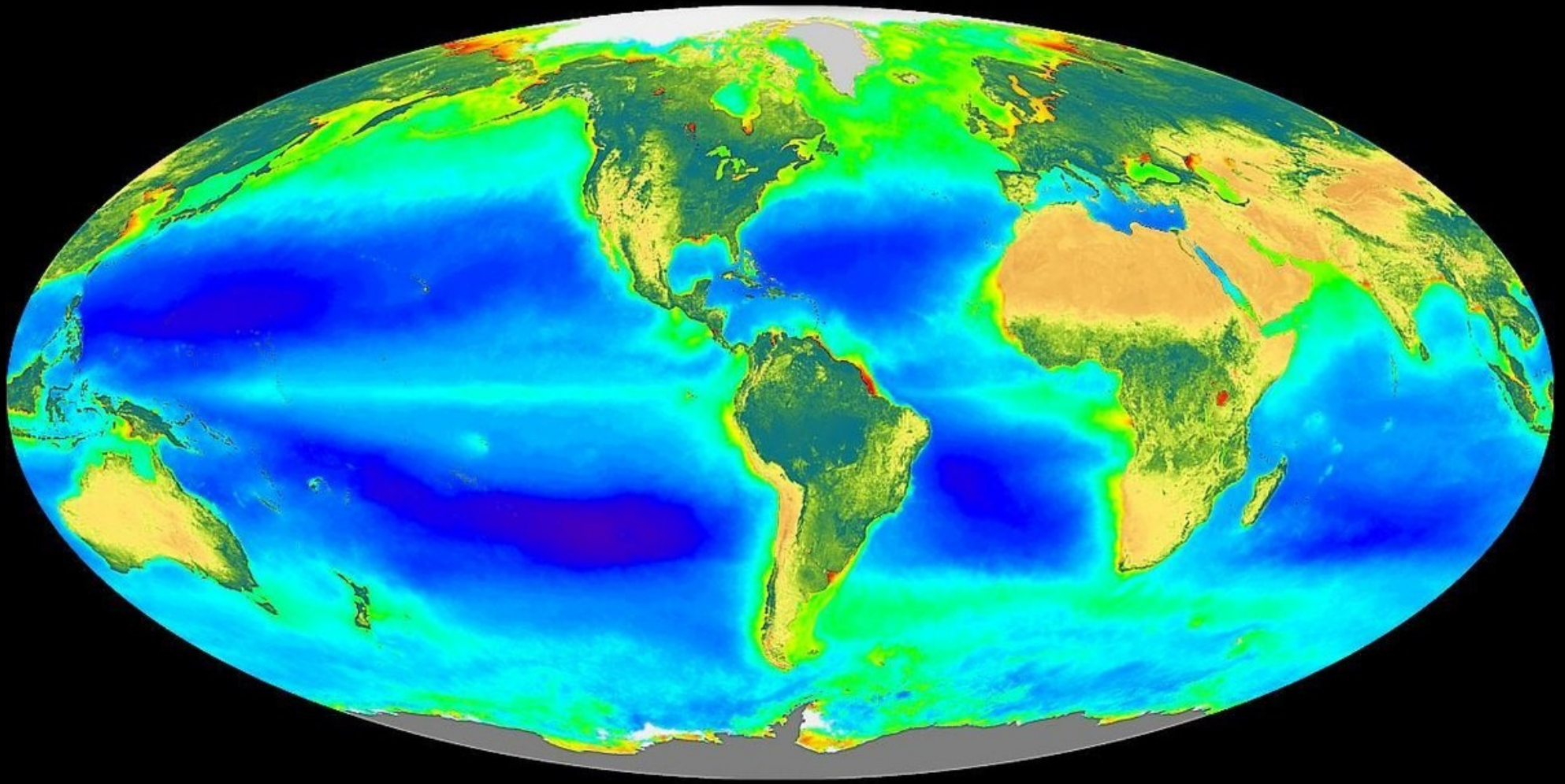
Respiration (Remineralisation)

Light

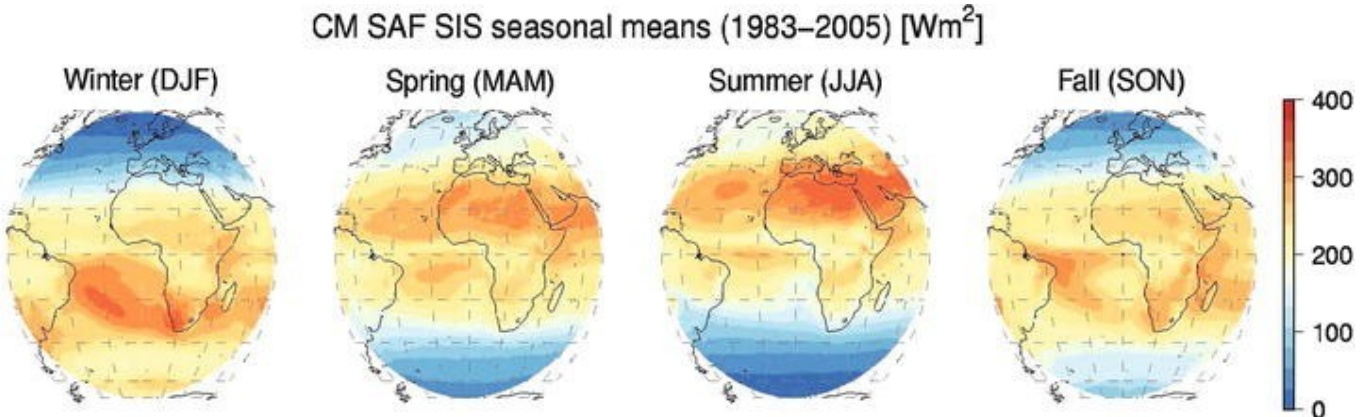
and

Nutrients

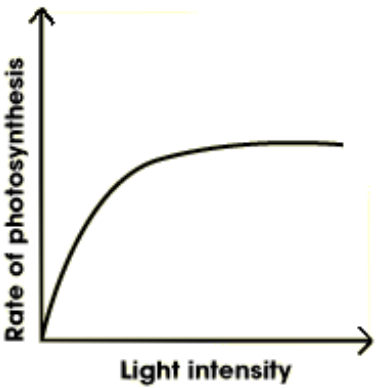
$\mathbf{106CO_2} + 16NO_3 + H_3PO_4 + 78H_2O + 18H^+$


>01 .02 .03 .05 .1 .2 .3 .5 1 2 3 5 10 15 20 30 50
Ocean: Chlorophyll a Concentration (mg/m3)
Maximum
Minimum
Land: Normalized Difference Land Vegetation Index

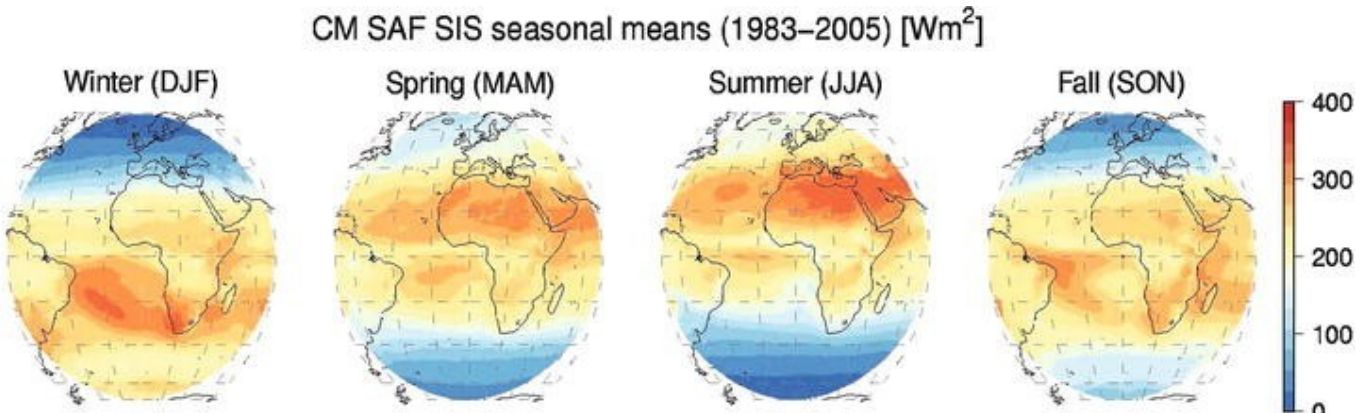
Biology: Light



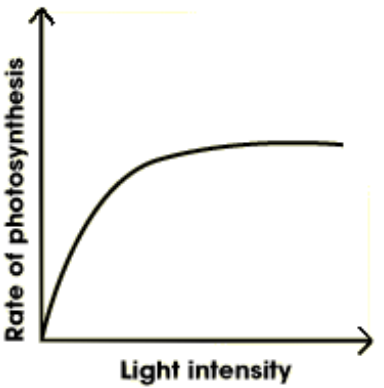
Mueller (2016)

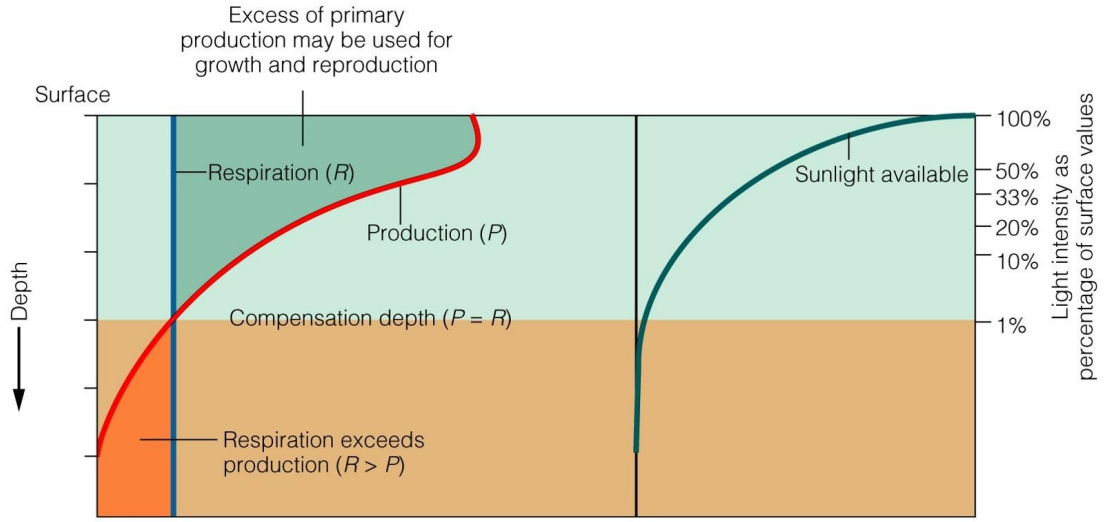


Biology: Light



Mueller (2016)



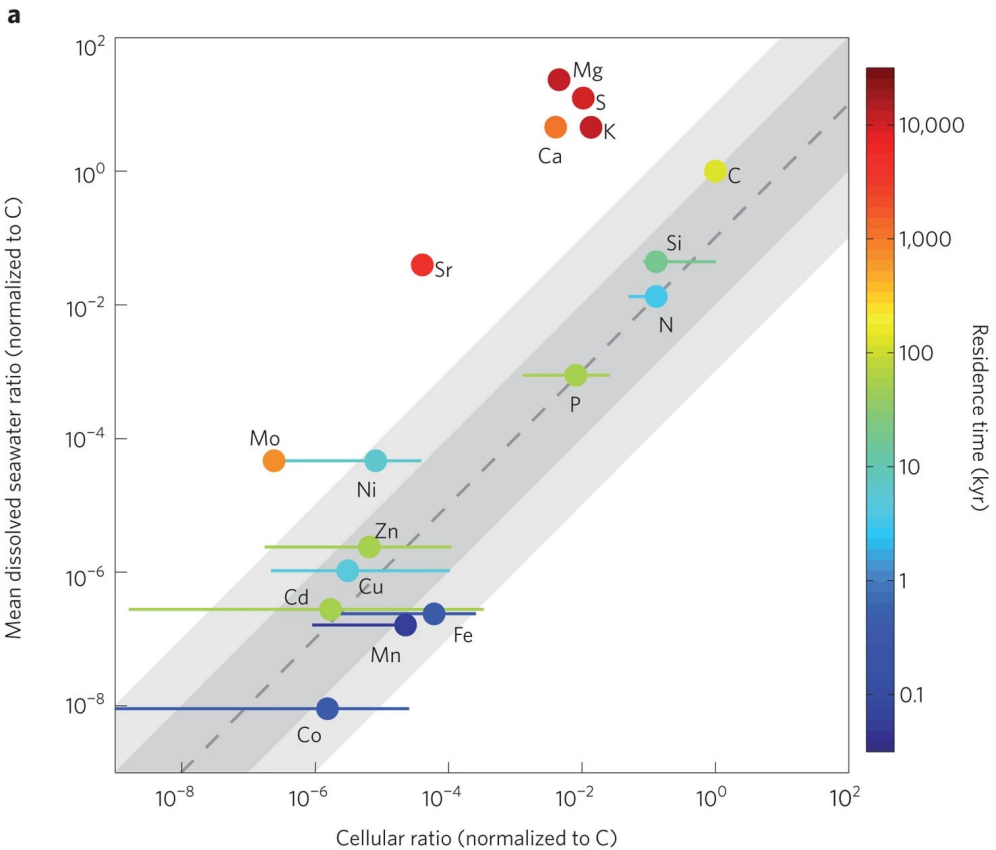


Mixed Layer Depth is critical

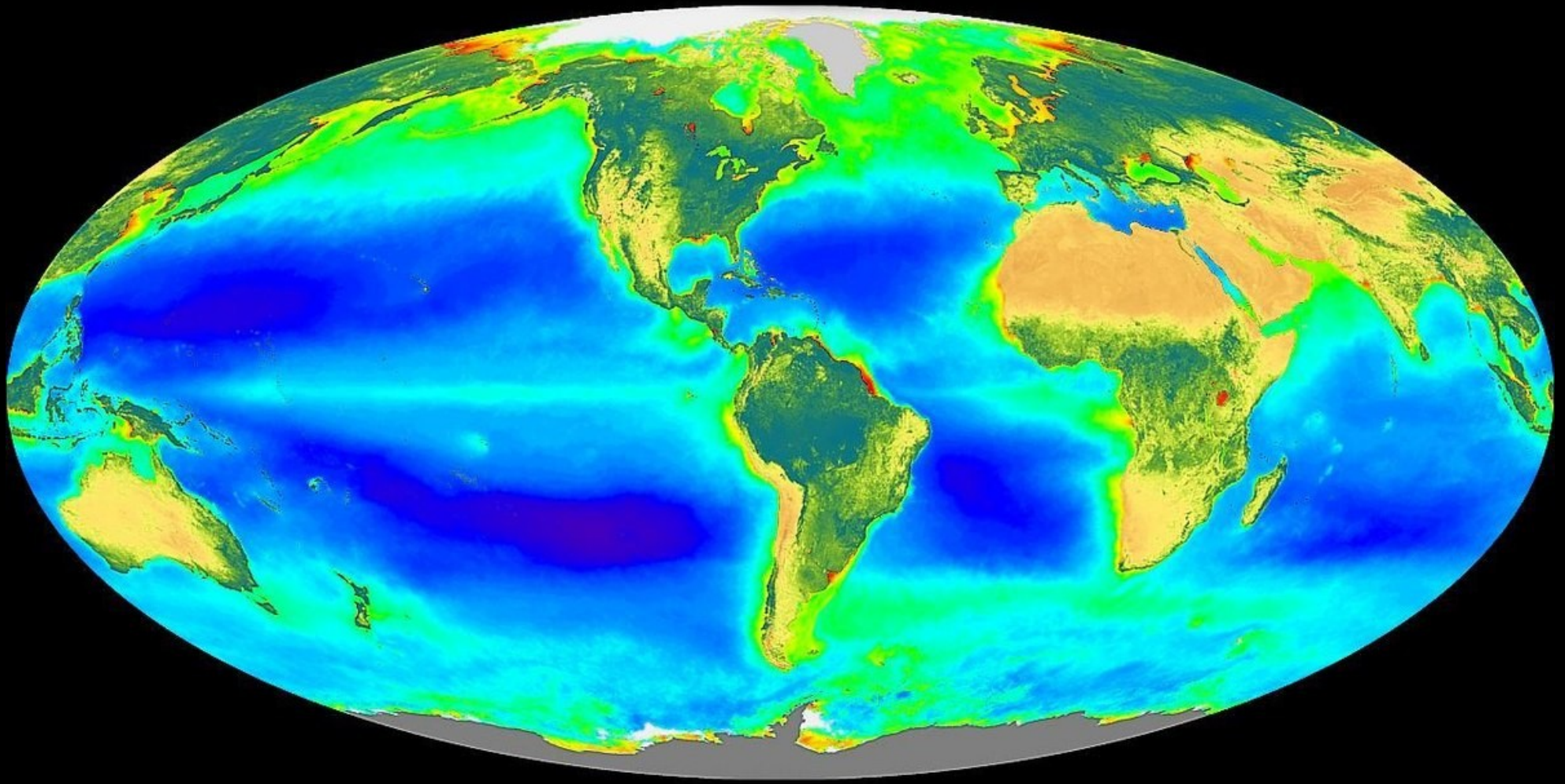
Biology: Nutrients

Productivity is limited by:

- P
- Fe
- Mn
- Co



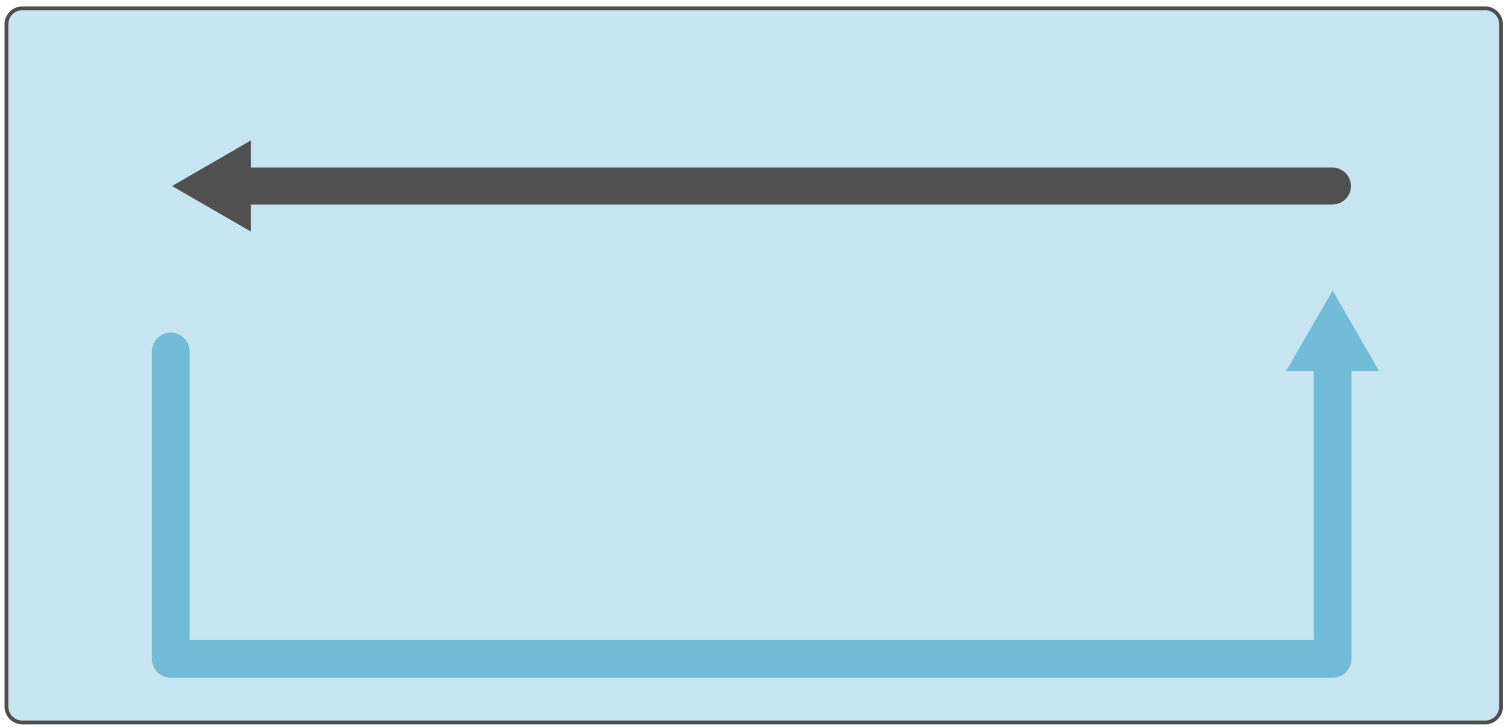
Moore et al. (2013)


>01 .02 .03 .05 .1 .2 .3 .5 1 2 3 5 10 15 20 30 50
Ocean: Chlorophyll a Concentration (mg/m3)
Maximum
Minimum
Land: Normalized Difference Land Vegetation Index

Think: Biology + Circulation

High Lat

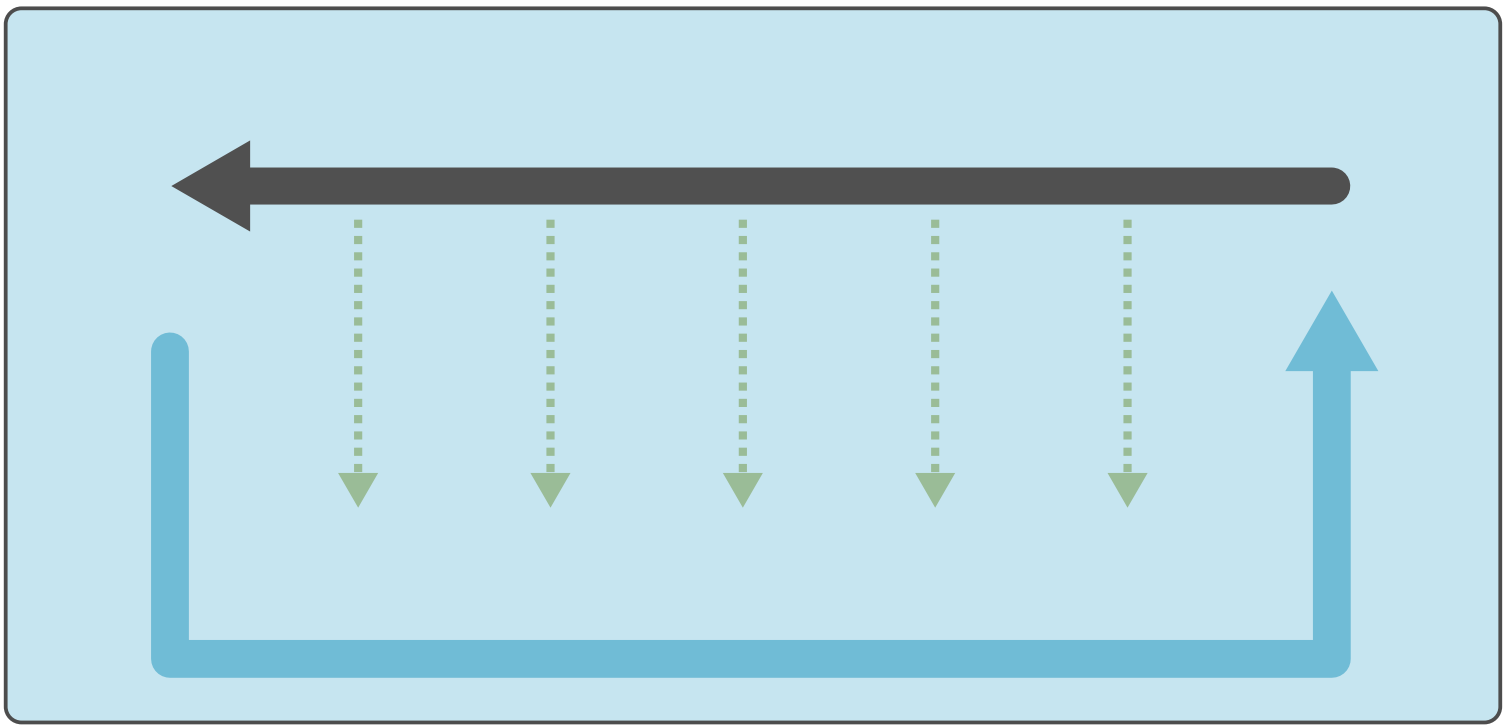
Equator



Think: Biology + Circulation

High Lat

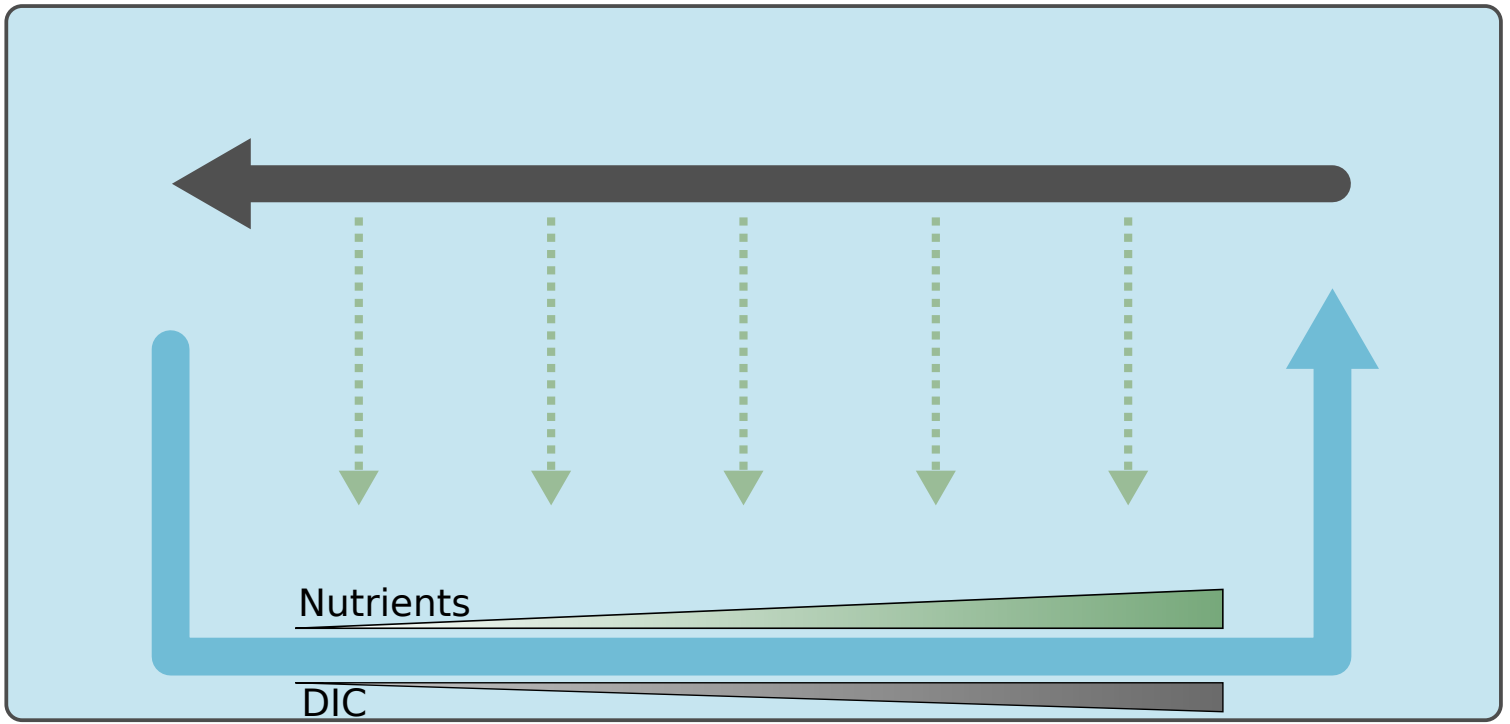
Equator



Think: Biology + Circulation

High Lat

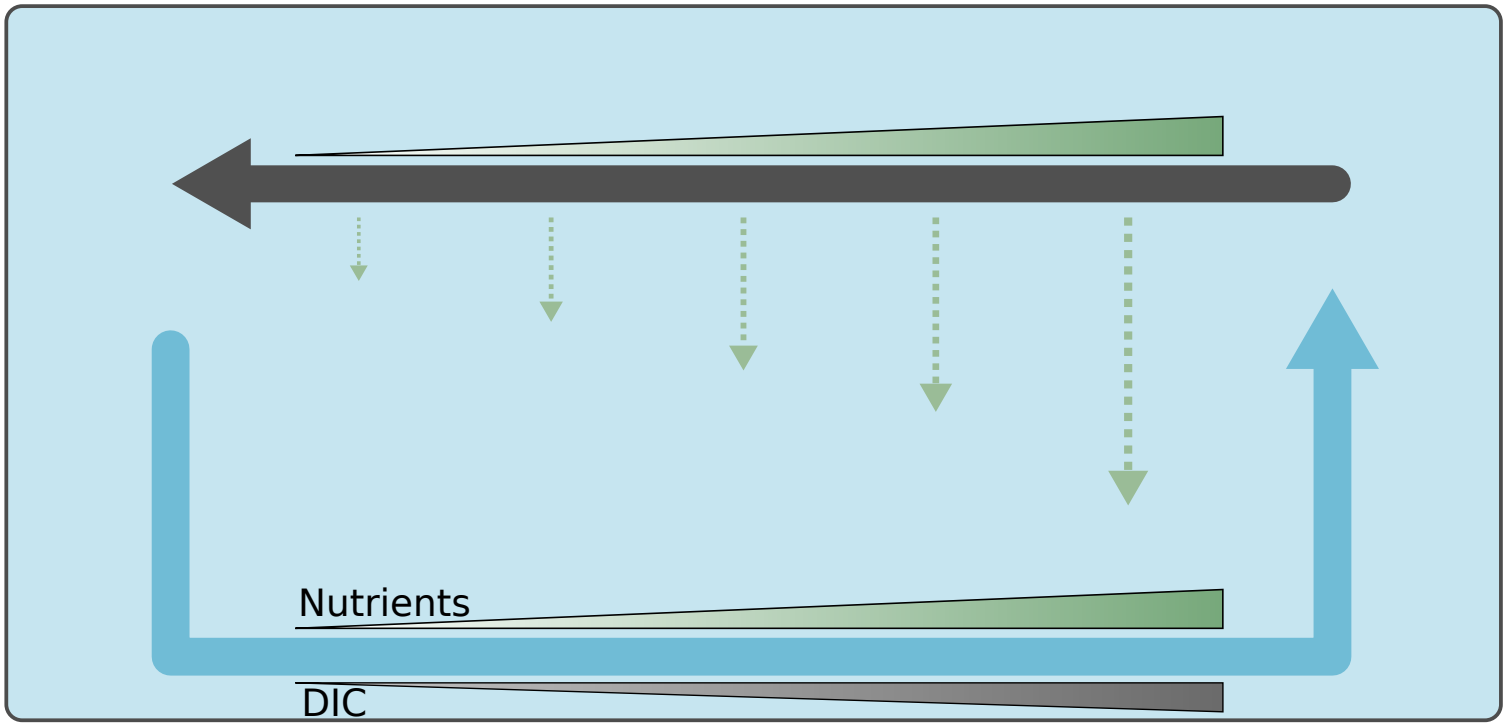
Equator



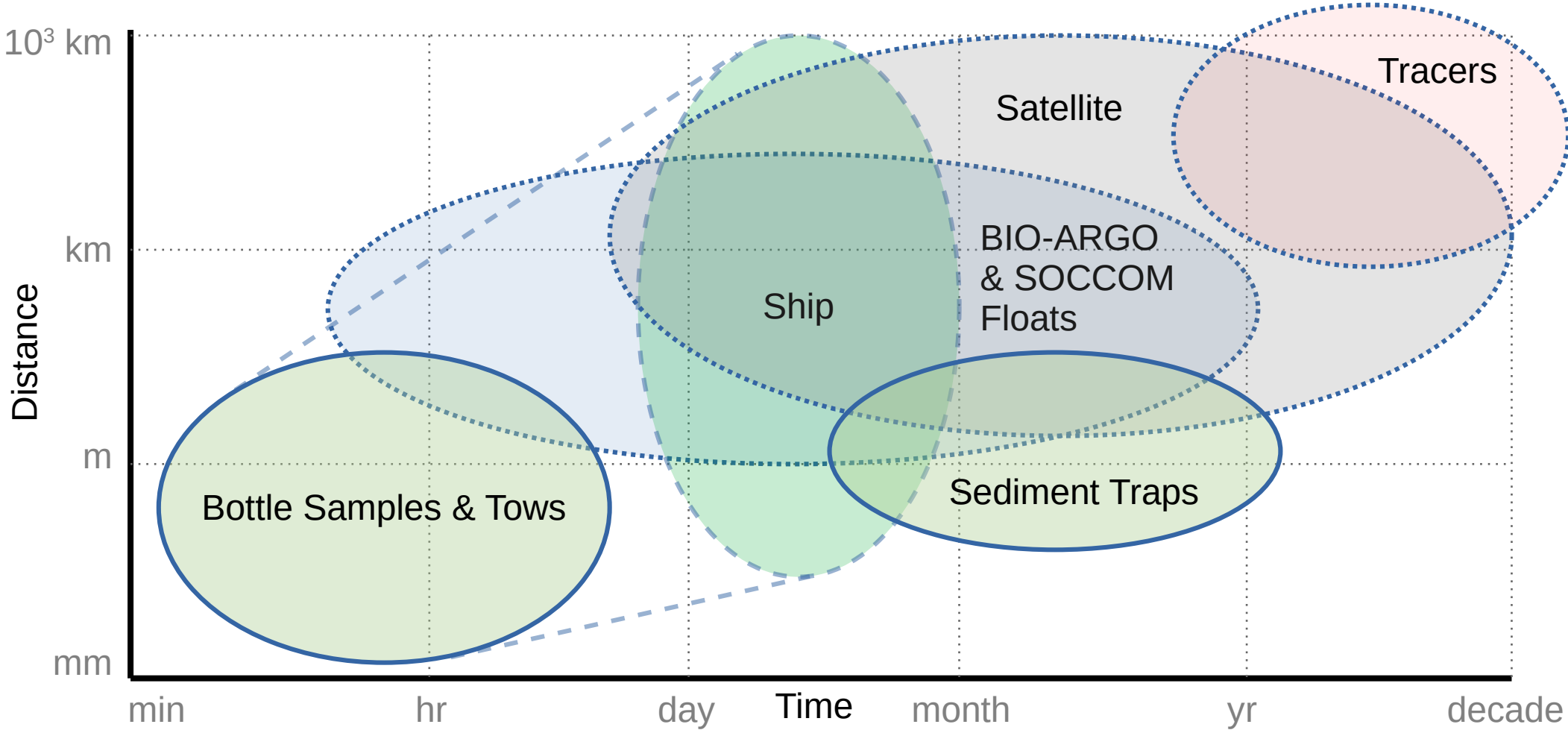
The Biological Pump

High Lat

Equator



Measuring Biology



Ocean-Atmosphere Carbon Fluxes