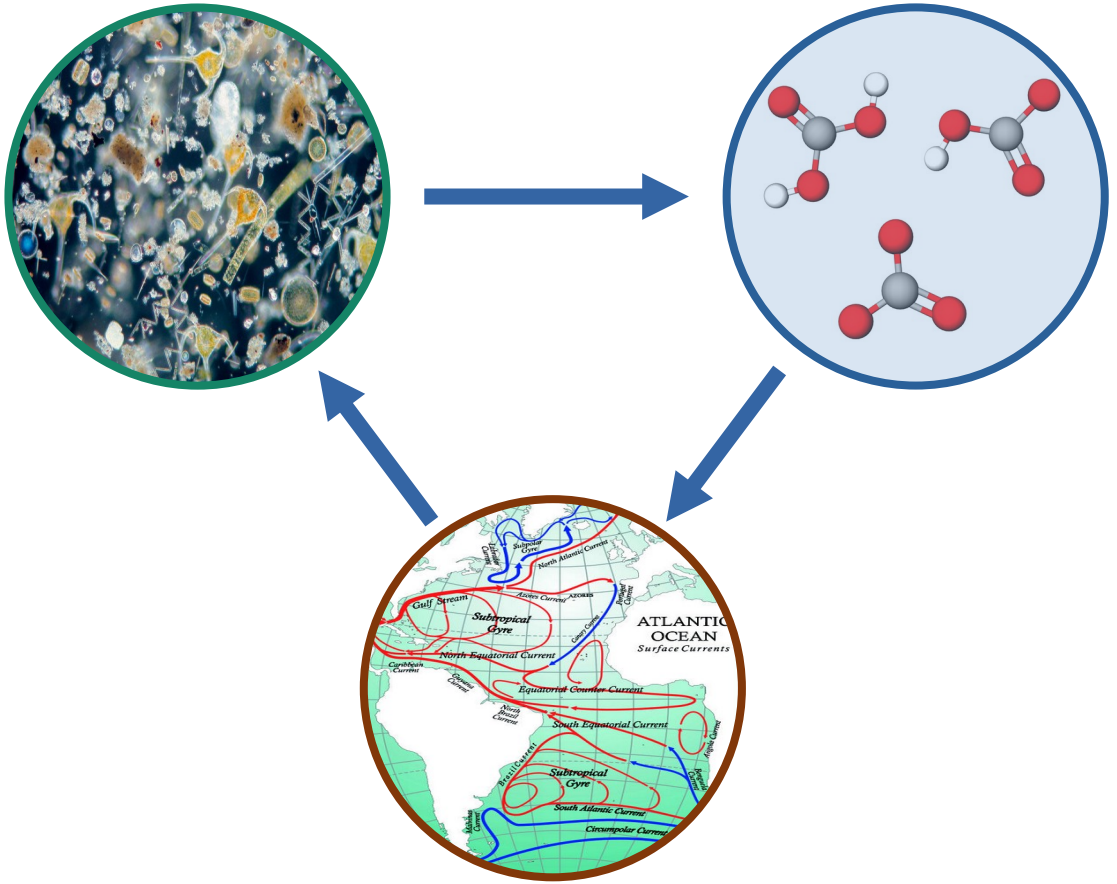
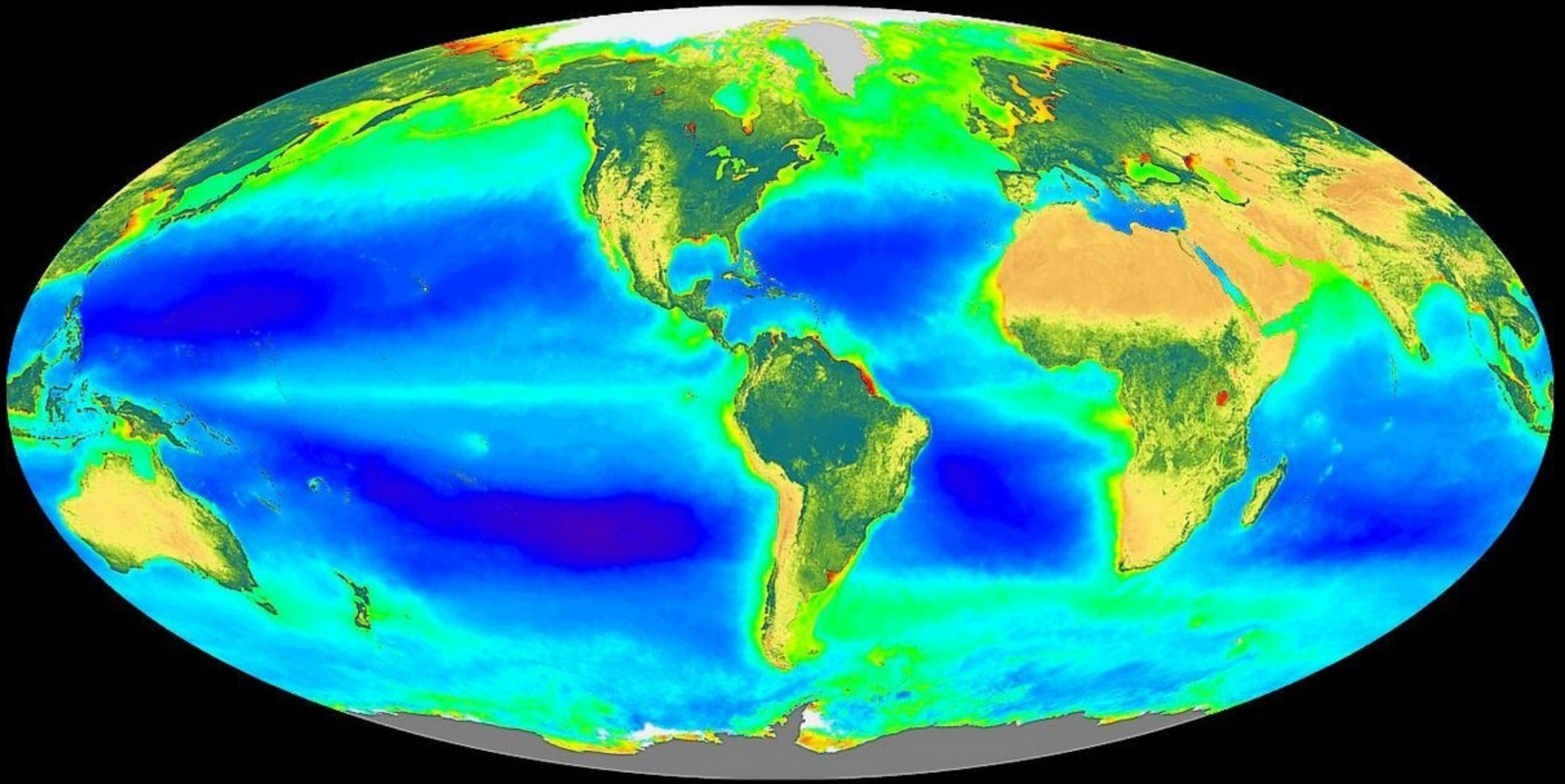
Ocean Biogeochemistry

https://www.sciencephoto.com/

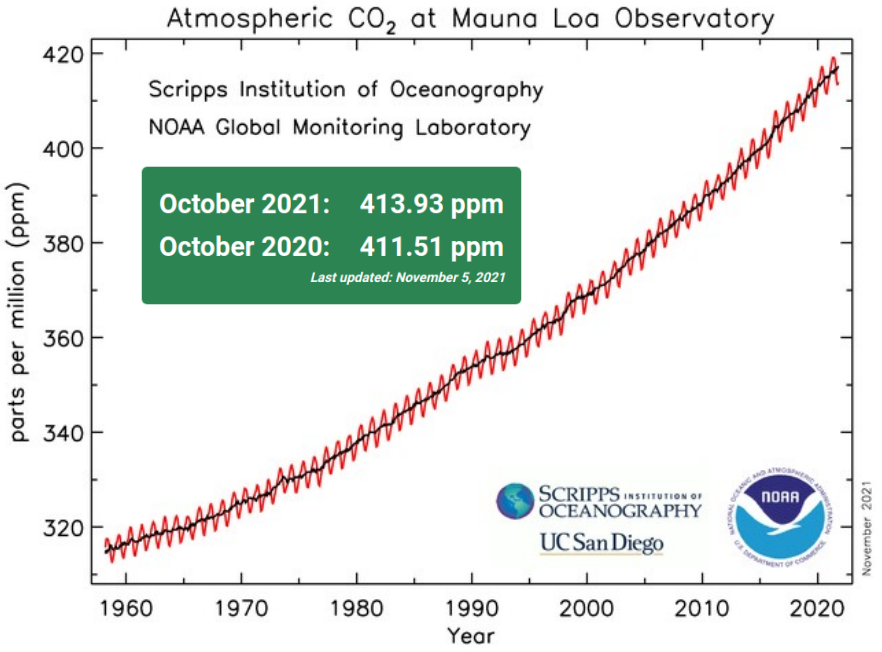
Oscar Branson, Department of Earth Sciences – ob266@cam.ac.uk

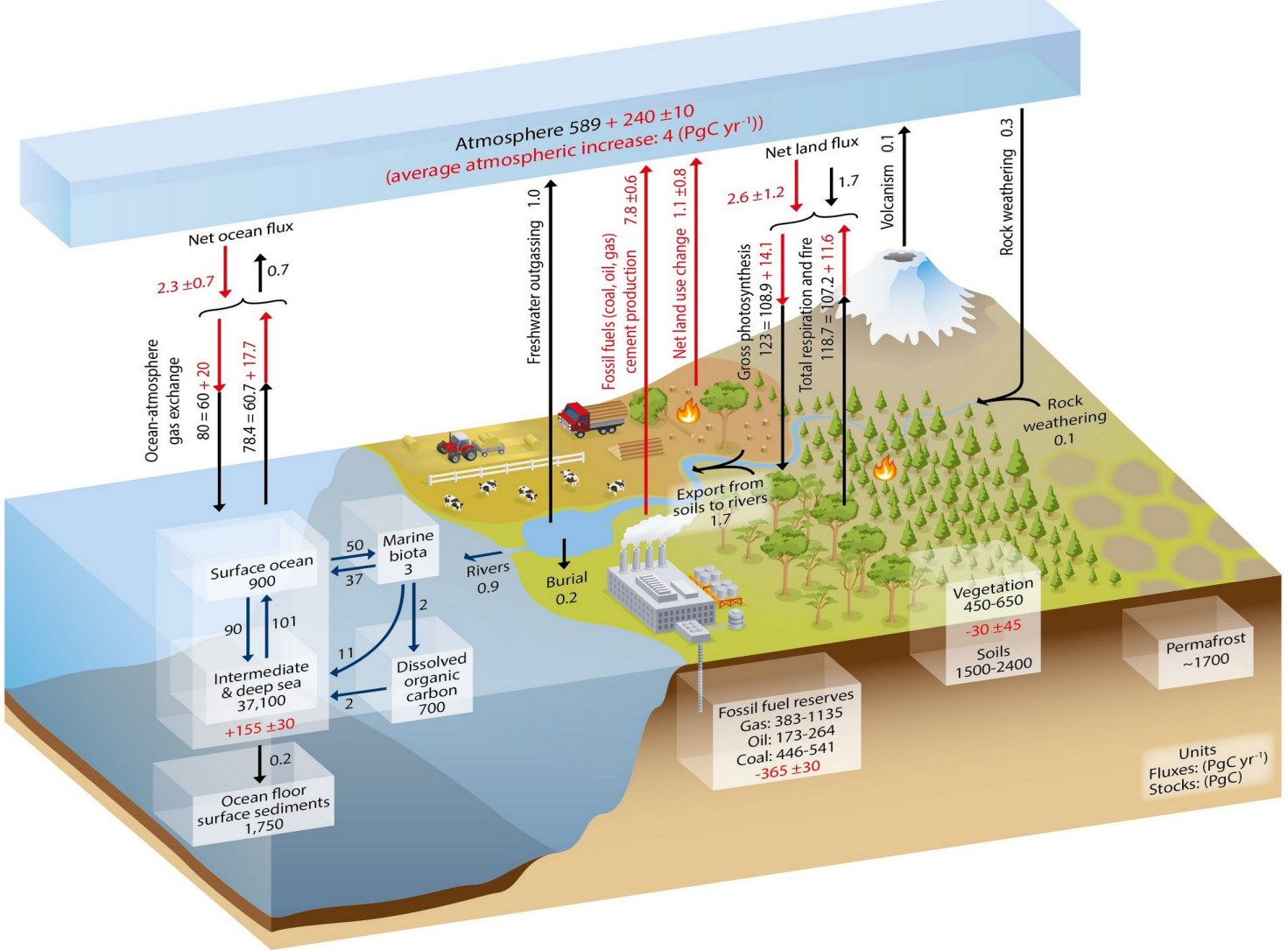
Ocean Biogeochemistry



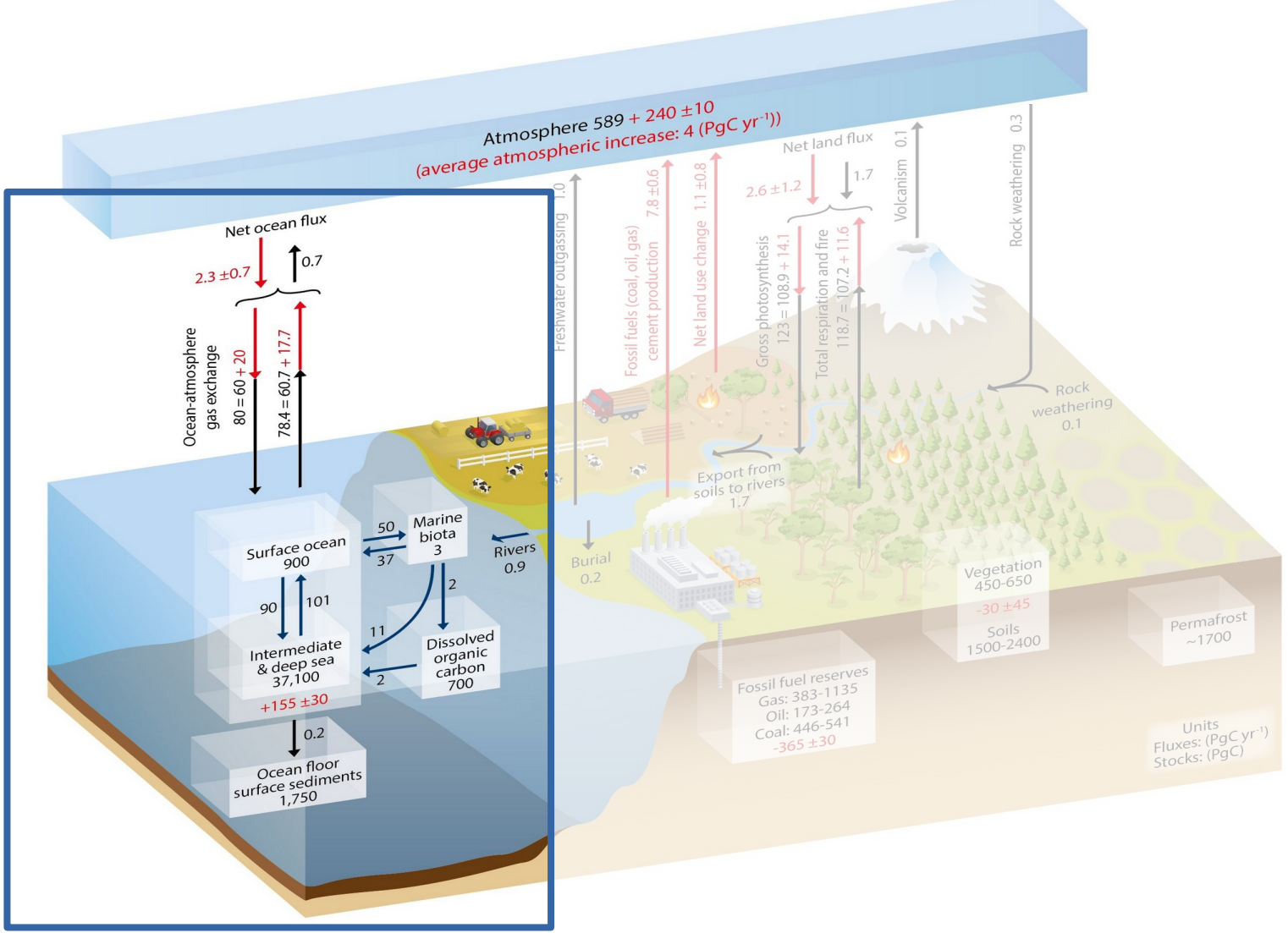

>01 .02 .03 .05 .1 .2 .3 .5 1 2 3 5 10 15 20 30 50
Ocean: Chlorophyll a Concentration (mg/m3)
Maximum
Minimum
Land: Normalized Difference Land Vegetation Index

Atmospheric Carbon





IPCC, AR5, Chapter 6

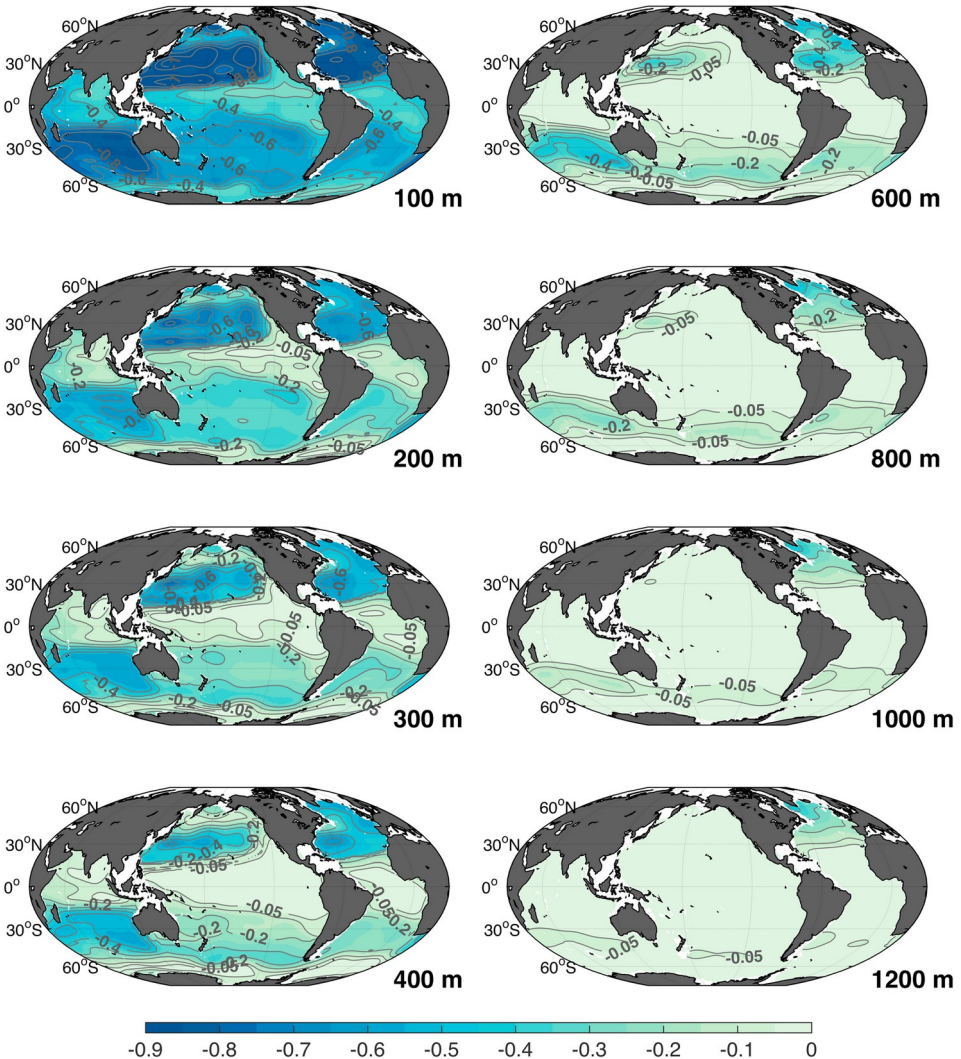


Ocean has absorbed ~30-40% of the CO_2 we've released!

IPCC, AR5, Chapter 6

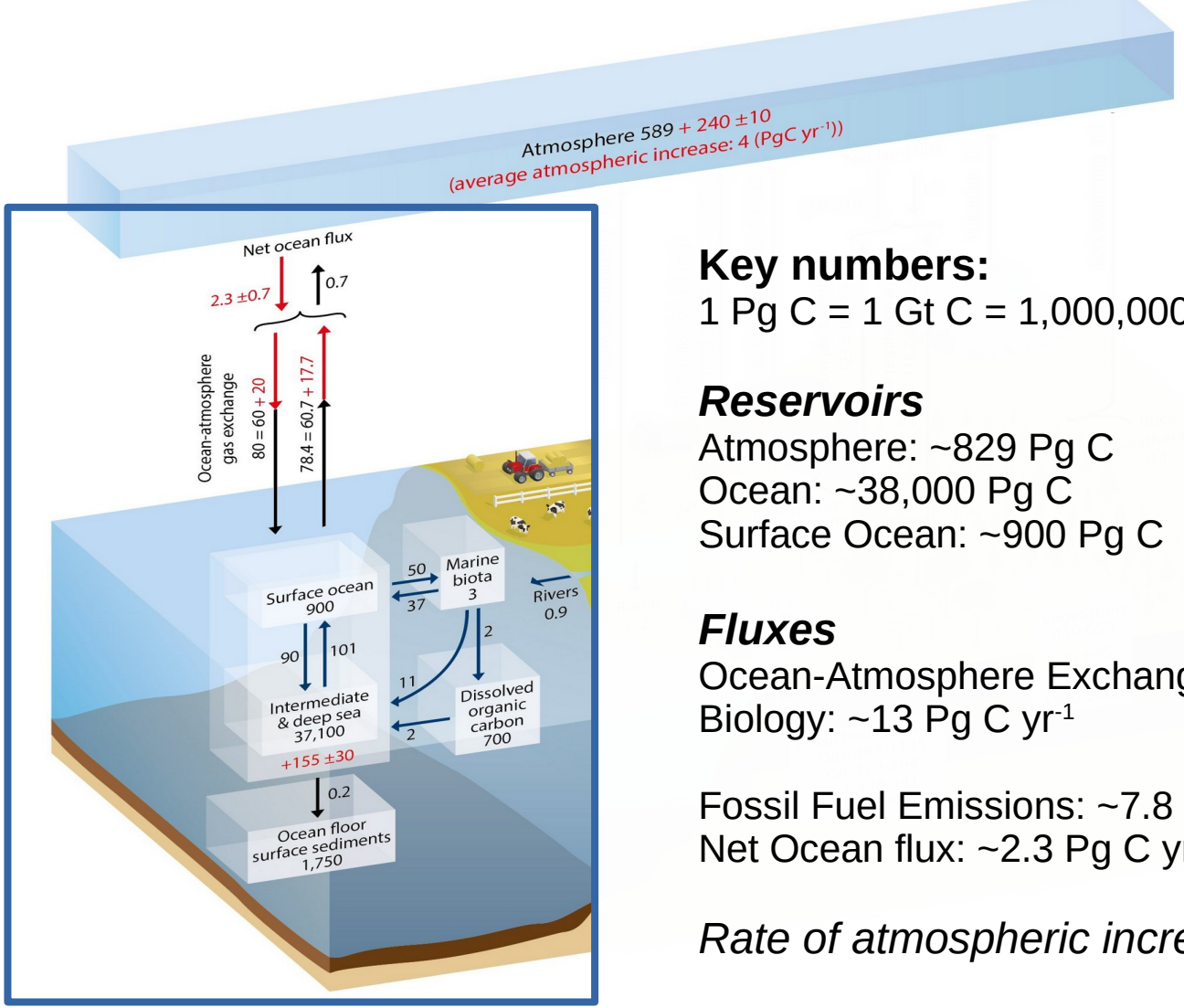
The Suess Effect

$\delta^{13}C$ from fossil fuels



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

Eide et al, 2017



Key numbers:

1 Pg C = 1 Gt C = 1,000,000,000,000,000 (10^{15}) g C

N.B. C, not CO_2

Reservoirs

Atmosphere: ~829 Pg C

Ocean: ~38,000 Pg C

Surface Ocean: ~900 Pg C

Fluxes

Ocean-Atmosphere Exchange: ~80 Pg C yr^{-1}

Biology: ~13 Pg C yr^{-1}

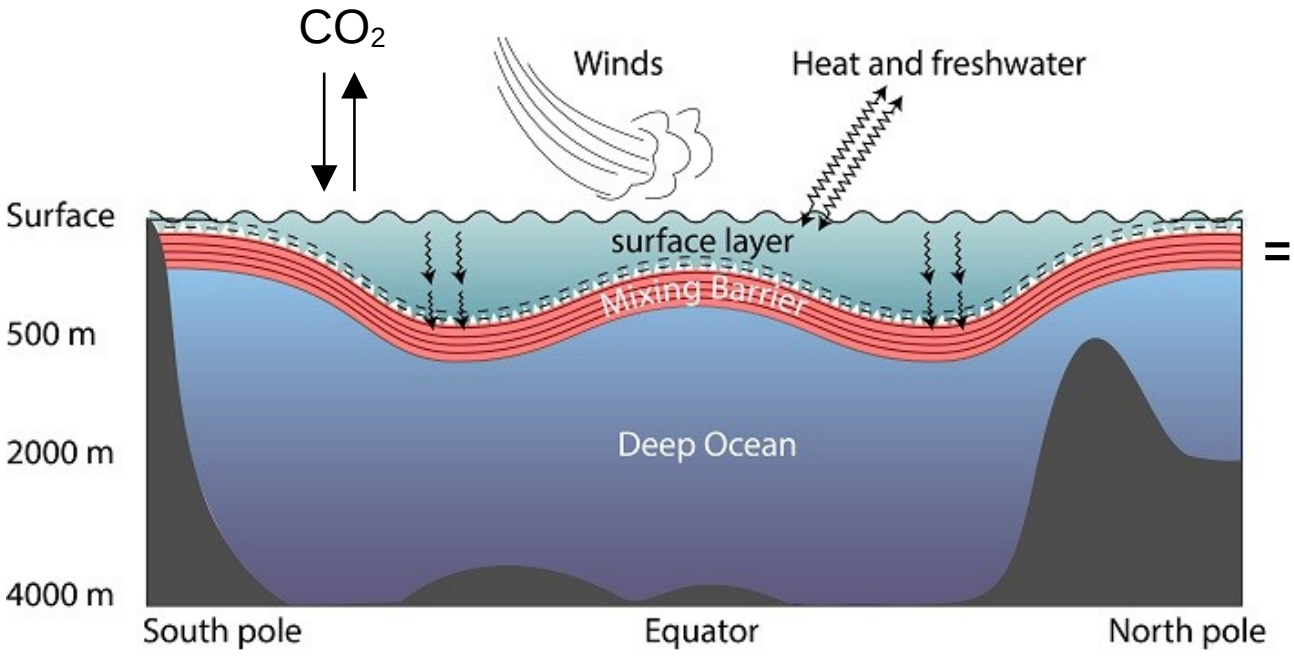
Fossil Fuel Emissions: ~7.8 Pg C yr^{-1}

Net Ocean flux: ~2.3 Pg C yr^{-1}

Rate of atmospheric increase: ~4 Pg C yr^{-1}

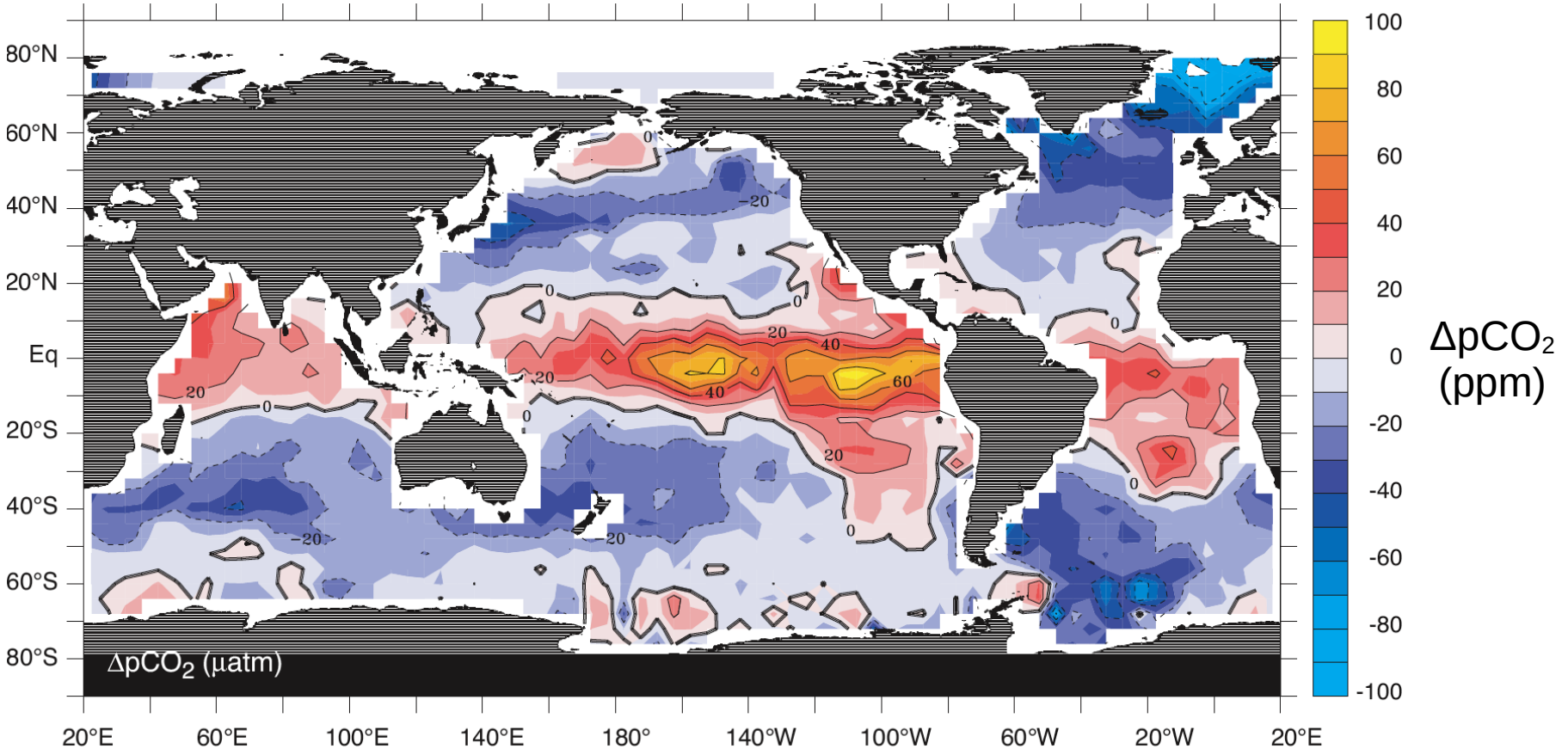
IPCC, AR5, Chapter 6

‘Surface’ Ocean?



= Density change
- **Temp**
- **Sal**
- **Press**

Ocean-Atmosphere Carbon Fluxes



Sarmiento & Gruber, 2006

Ocean Biogeochemistry and Carbon

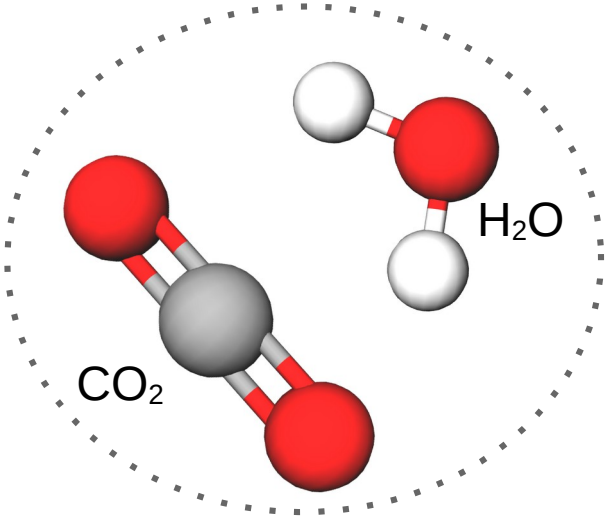
1. Chemistry

Carbon in Seawater.
The ‘solubility’ pump.

2. Biology

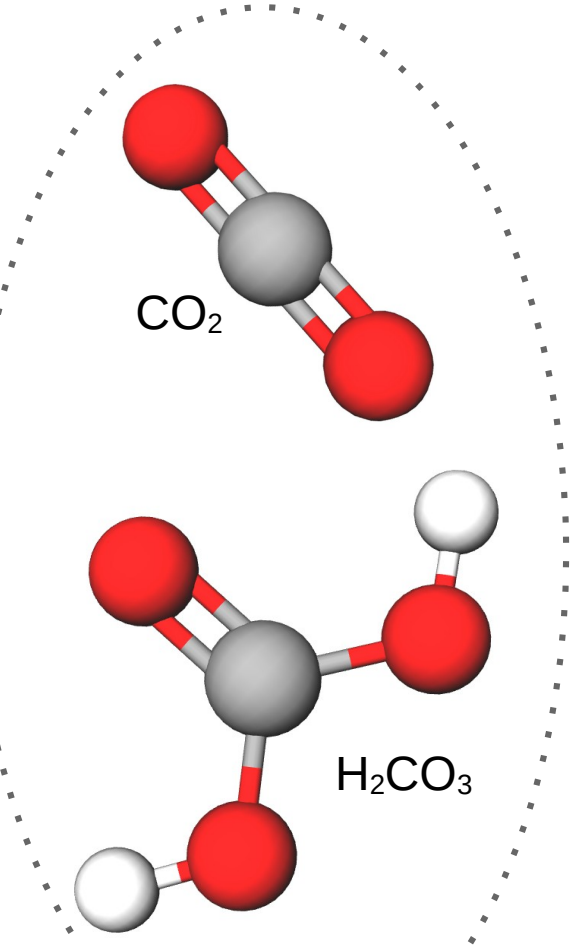
Carbon capture (‘productivity’) and export.
The ‘biological’ pump.
Calcification & Acidification

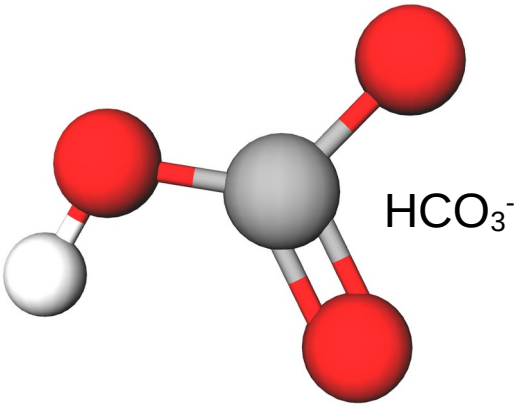
Carbon in Seawater

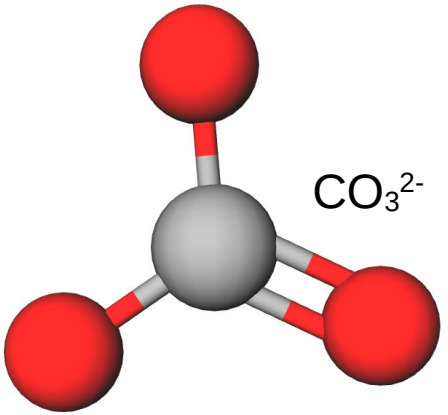


Carbon in Seawater

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



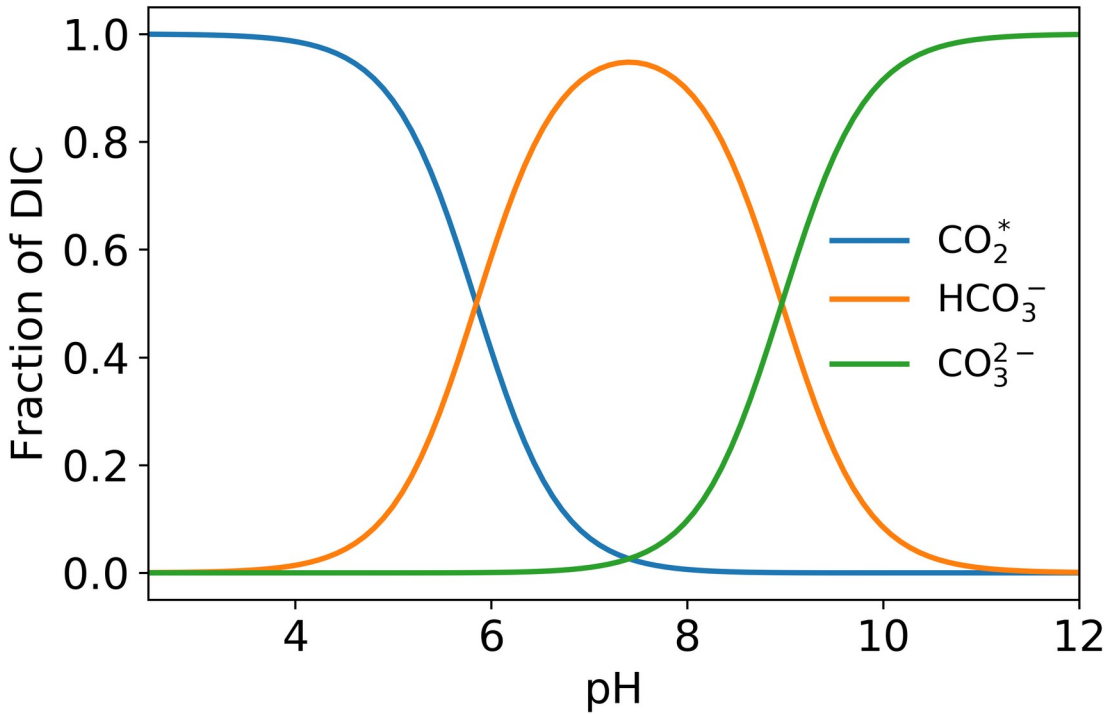




Dissolved Inorganic Carbon

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

Carbon in Seawater



CO_2^*

$\leftrightarrow$

$H^+ + HCO_3^-$

$\leftrightarrow$

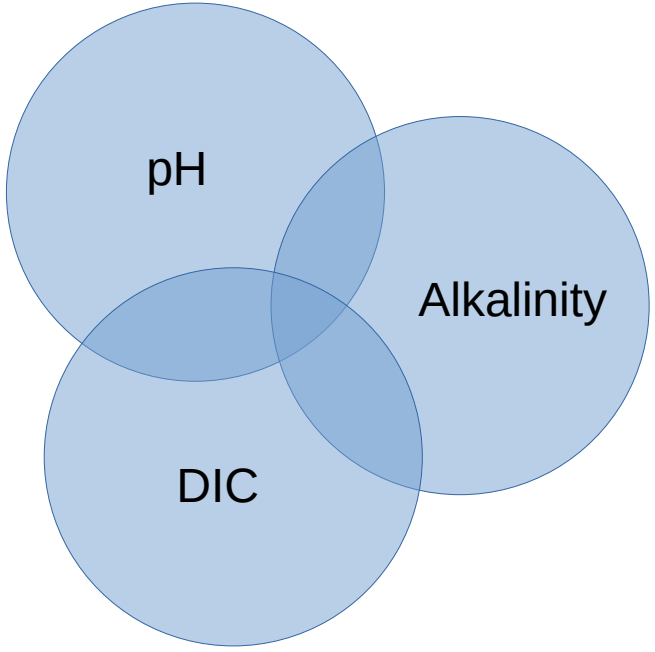
$H^+ + CO_3^{2-}$

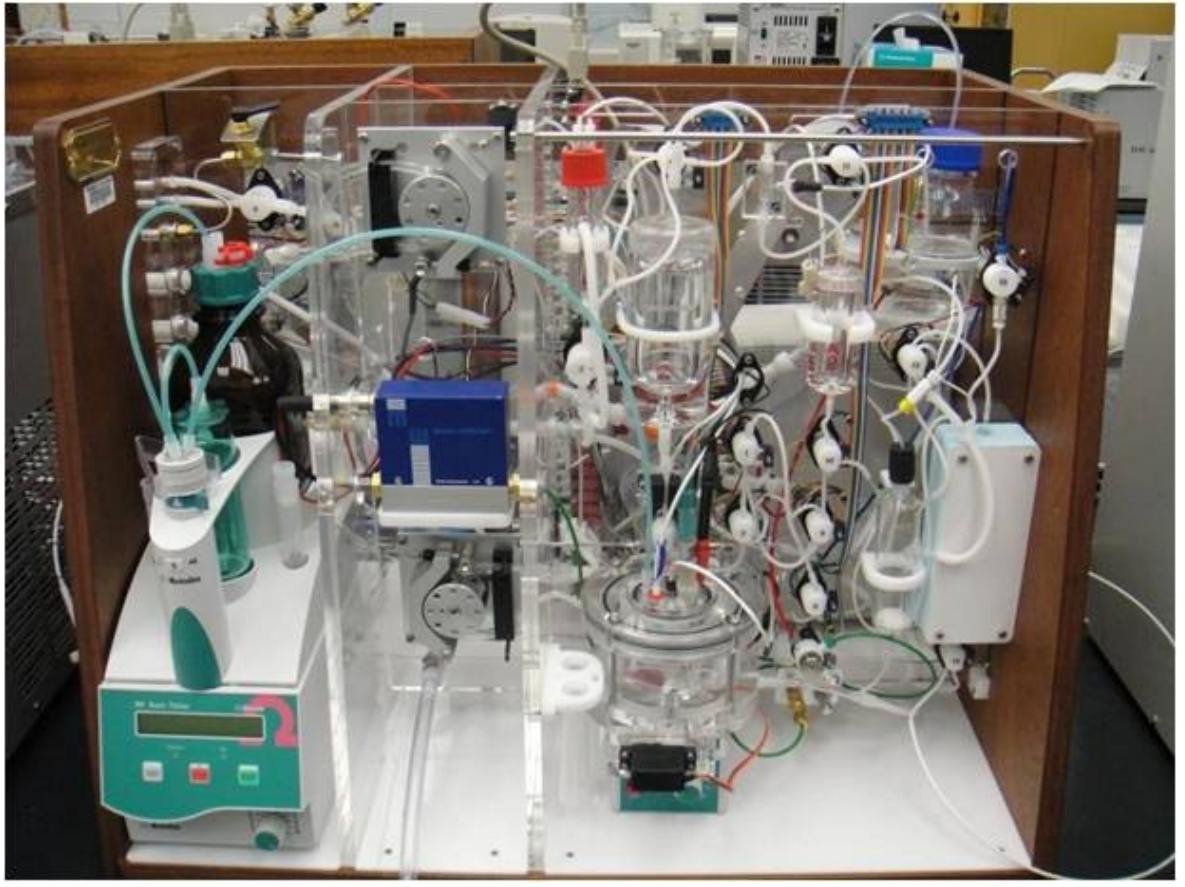
Dissolved Inorganic Carbon

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

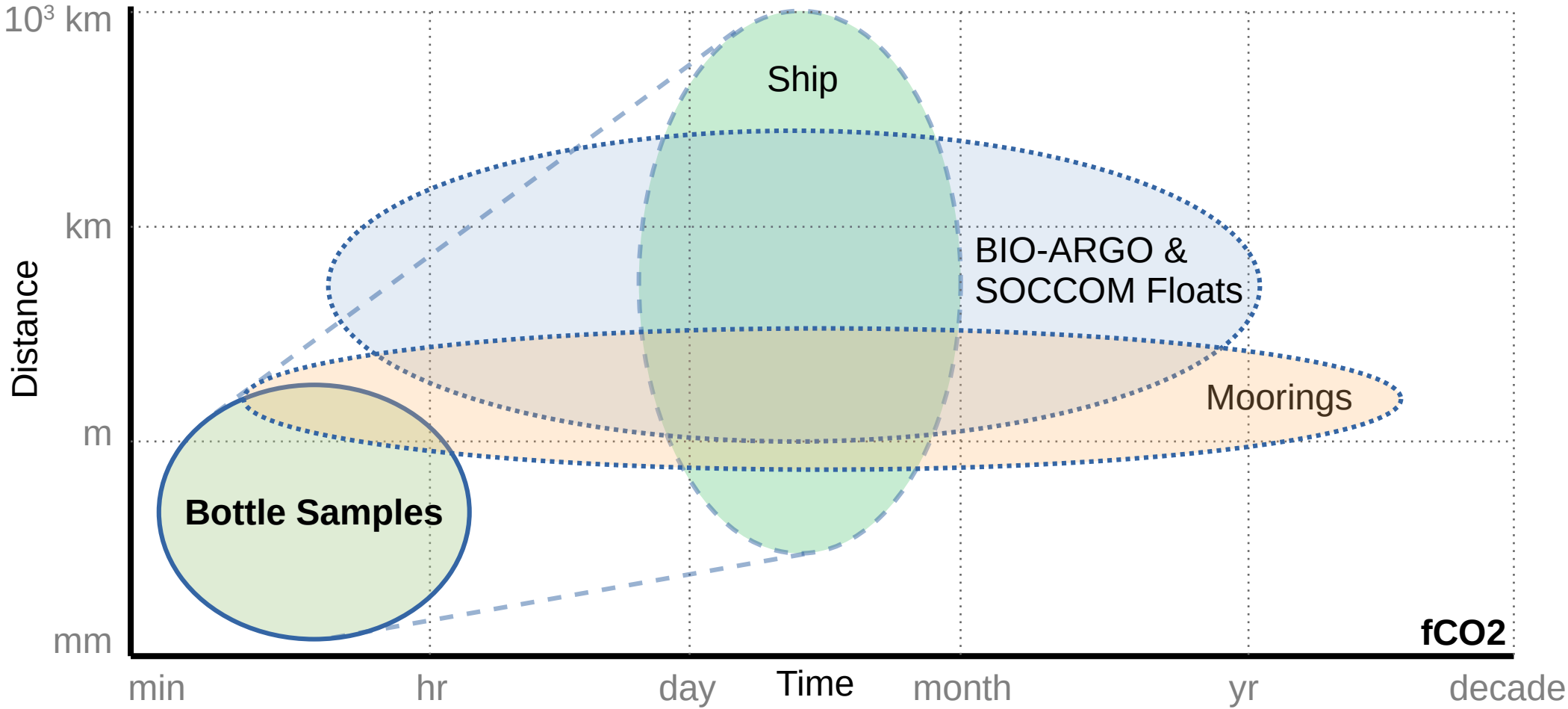
$pH = -\log_{10}([H^+])$

Carbon in Seawater: Measurement





Carbon in Seawater: Measurement



Carbon in Seawater

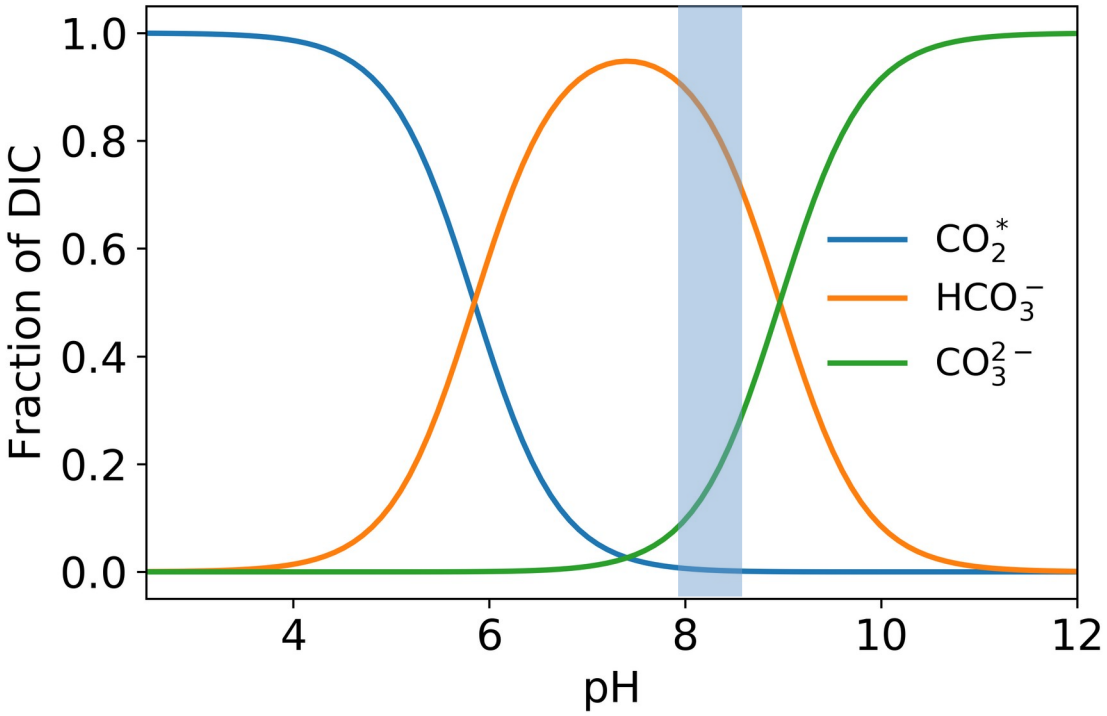
CO_2^*

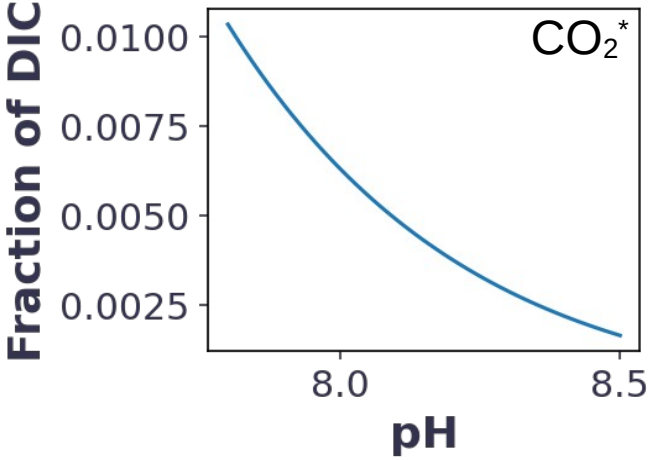
$\updownarrow$

$H^+ + HCO_3^-$

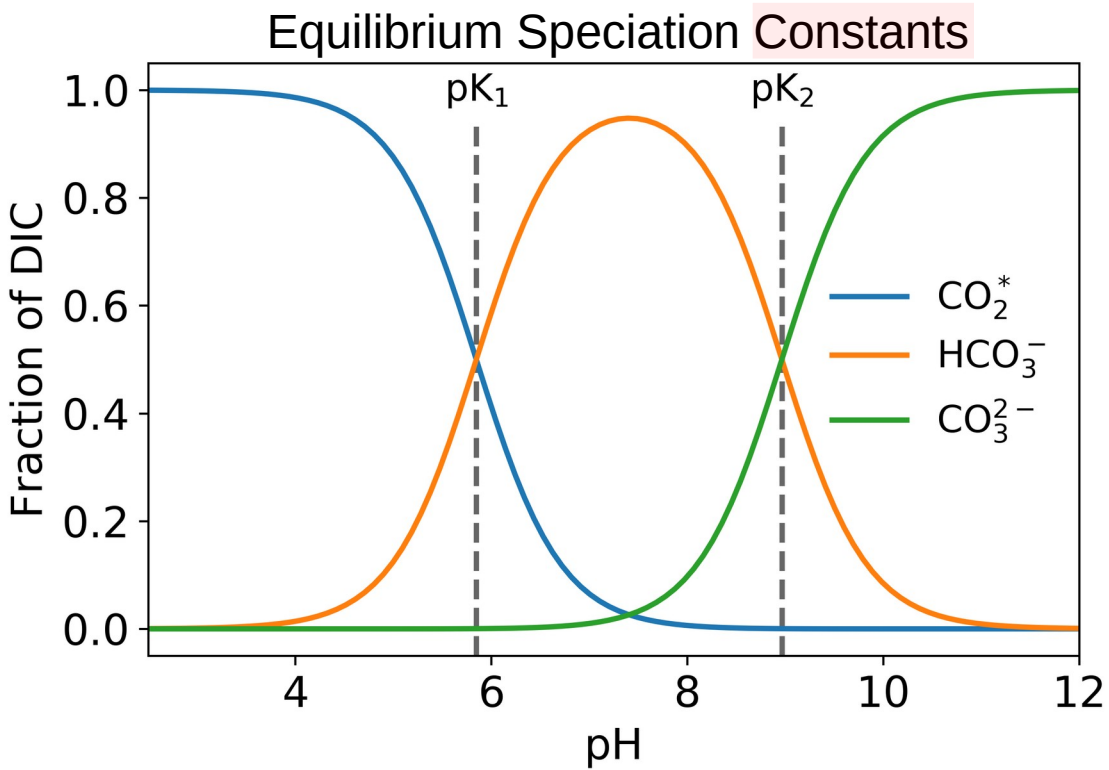
$\updownarrow$

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





Carbon in Seawater



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

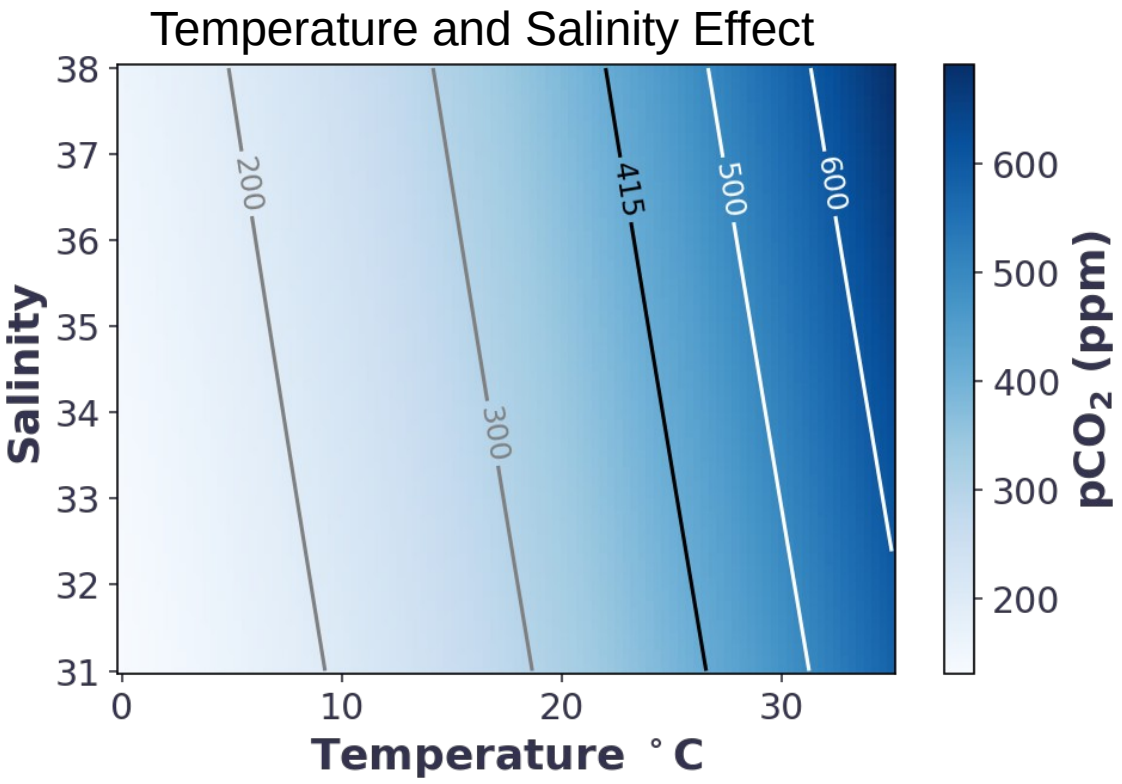
$$K_0 = \frac{[CO_2^*]}{fCO_2}$$

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

$$K_2 = \frac{[H^+][CO_3^{2-}]}{[HCO_3^-]}$$

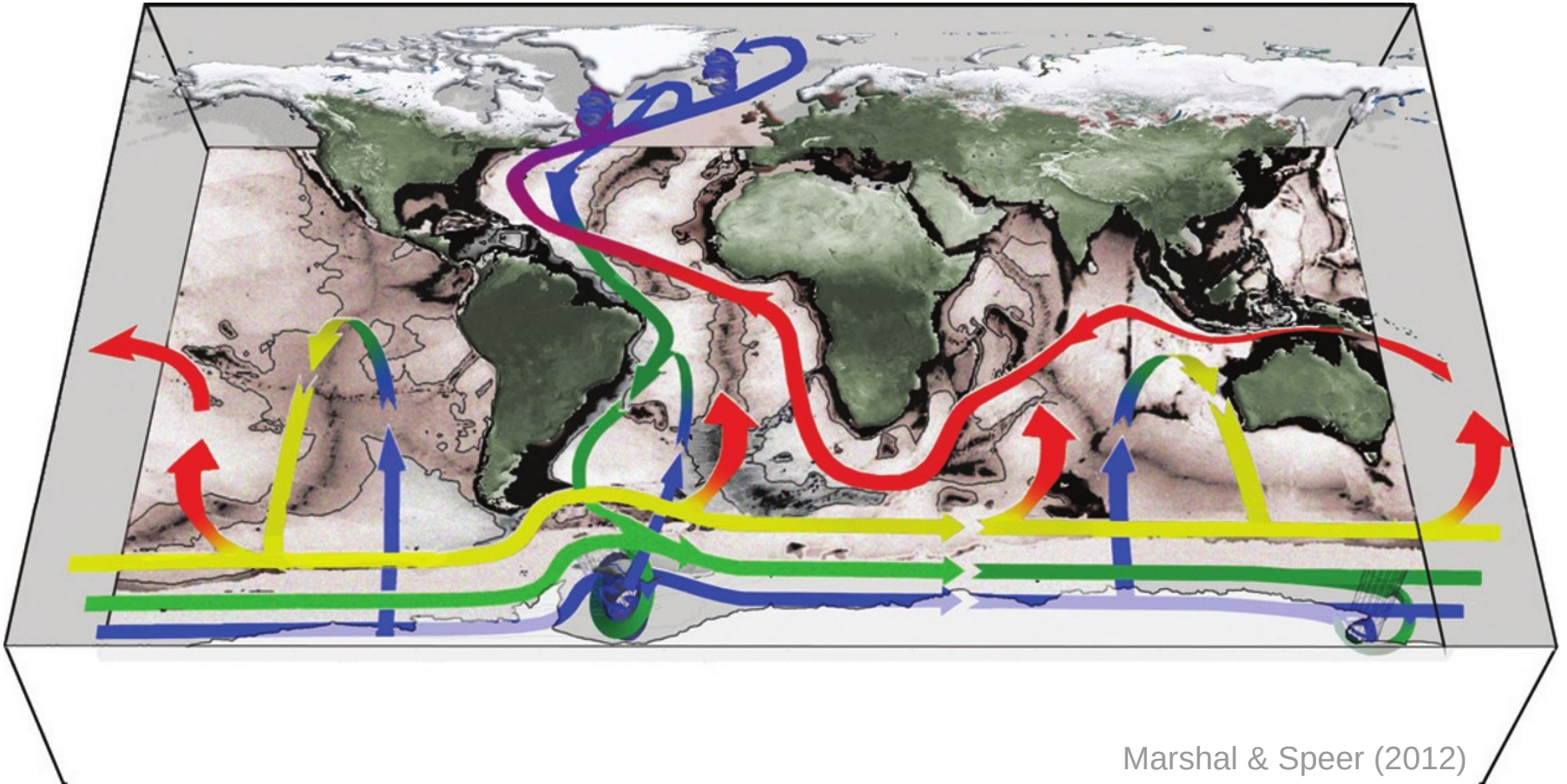
Carbon in Seawater

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



Ocean Circulation (Dan's Lecture)

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

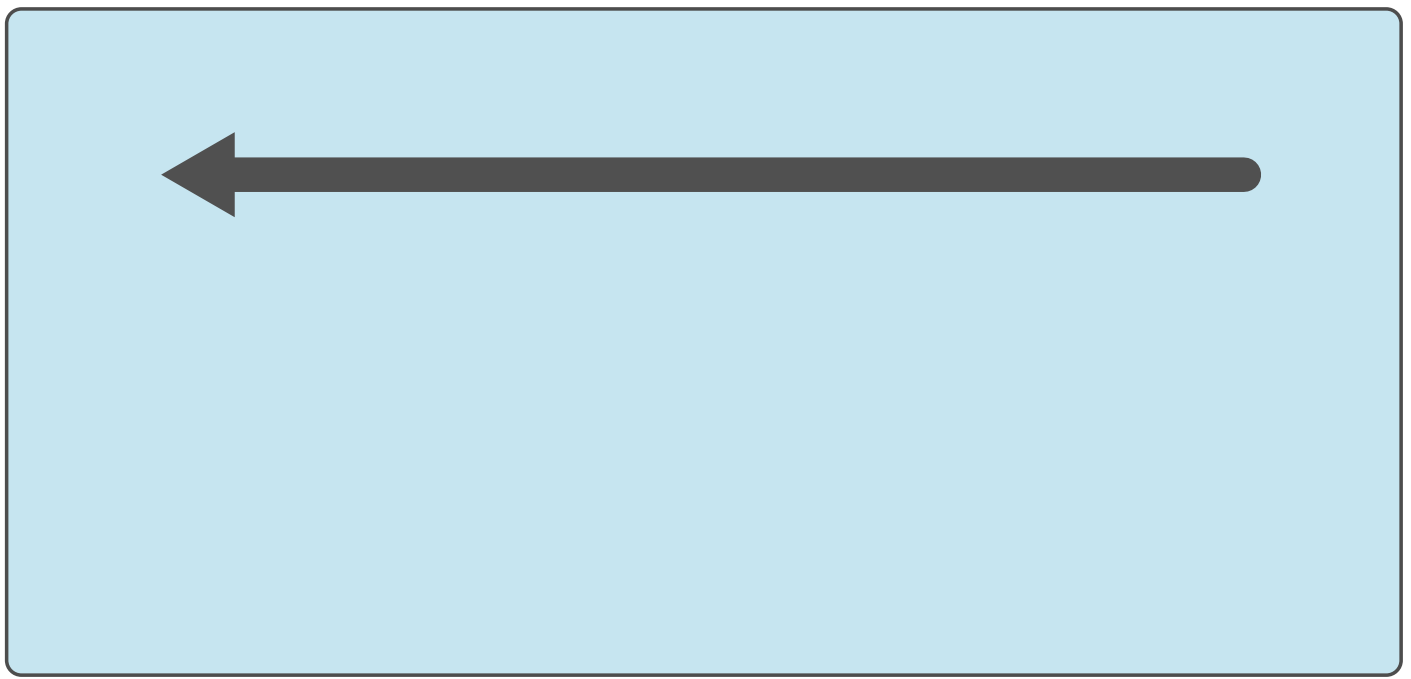


Marshal & Speer (2012)

Think: Circulation + Chemistry

High Lat

Equator

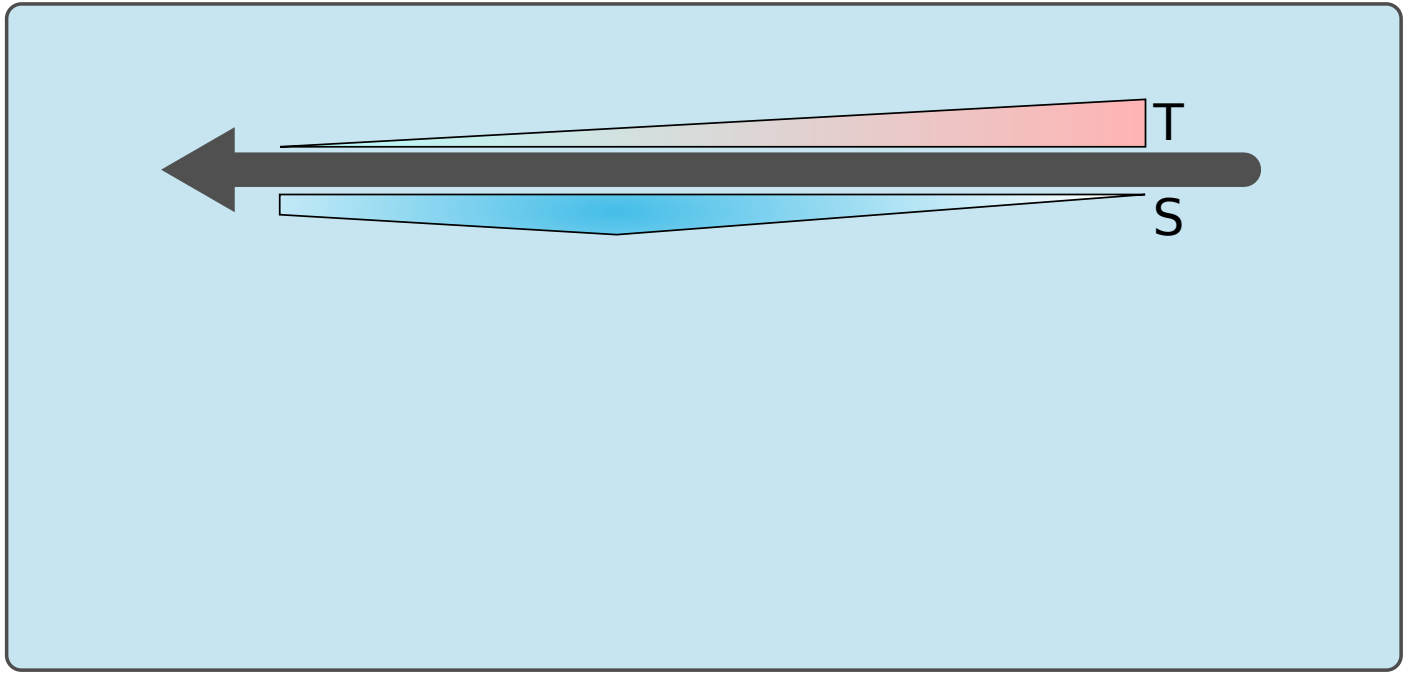


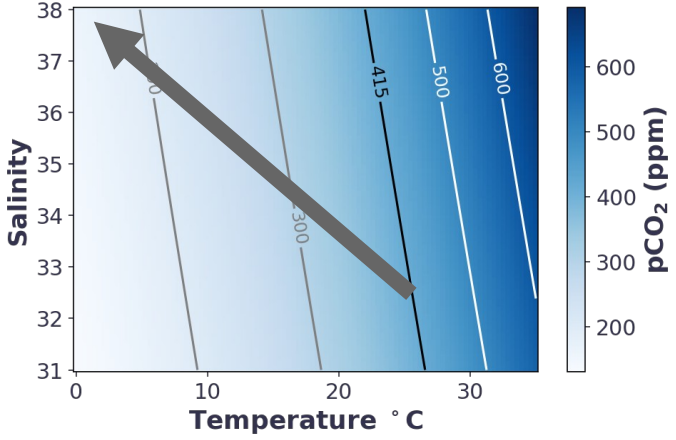
Think: Circulation + Chemistry

High Lat

Equator

pCO_2 ~400ppm





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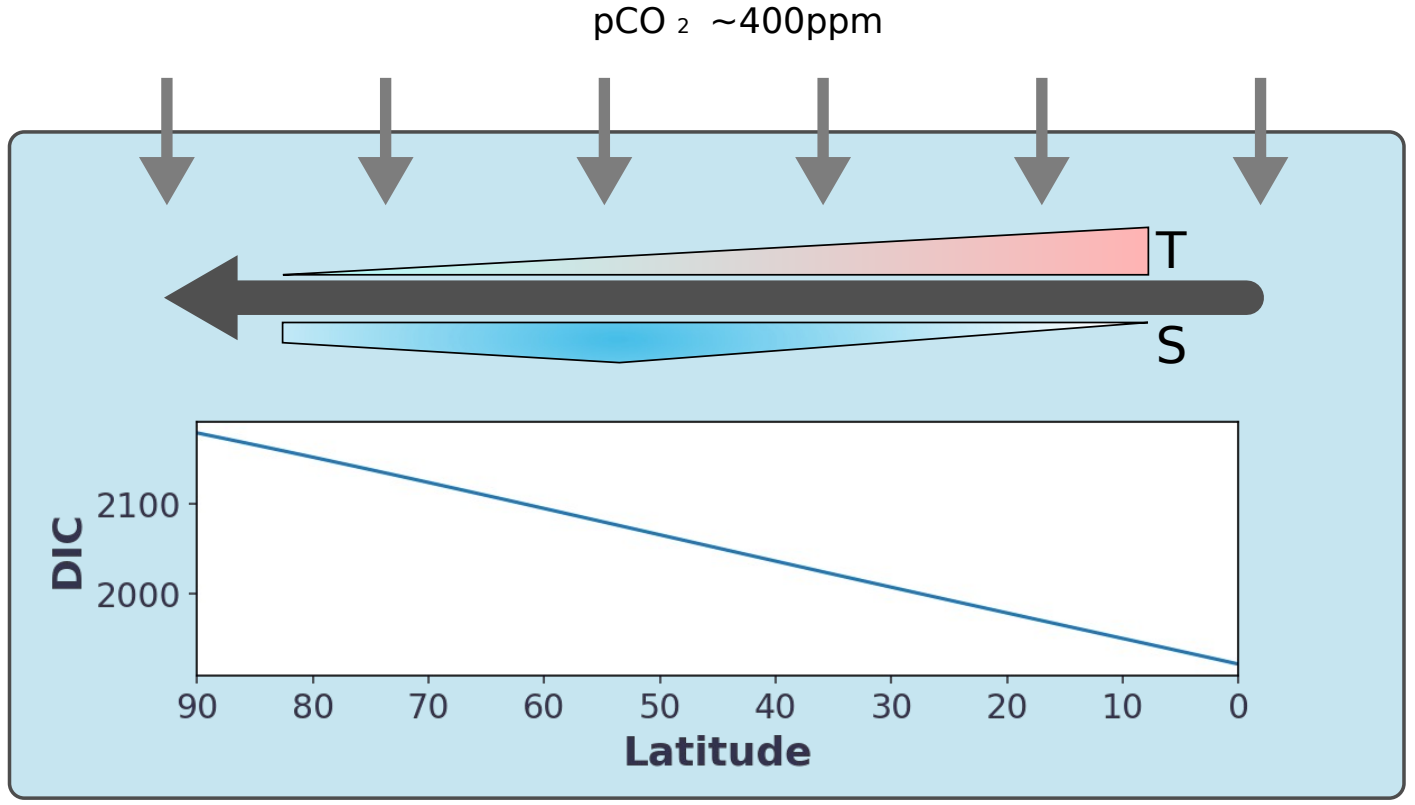
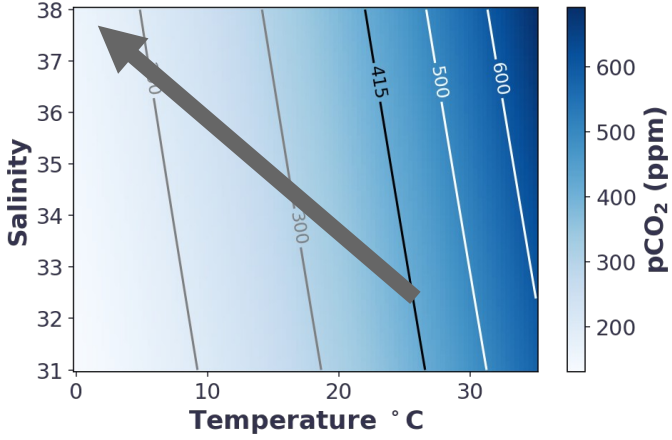
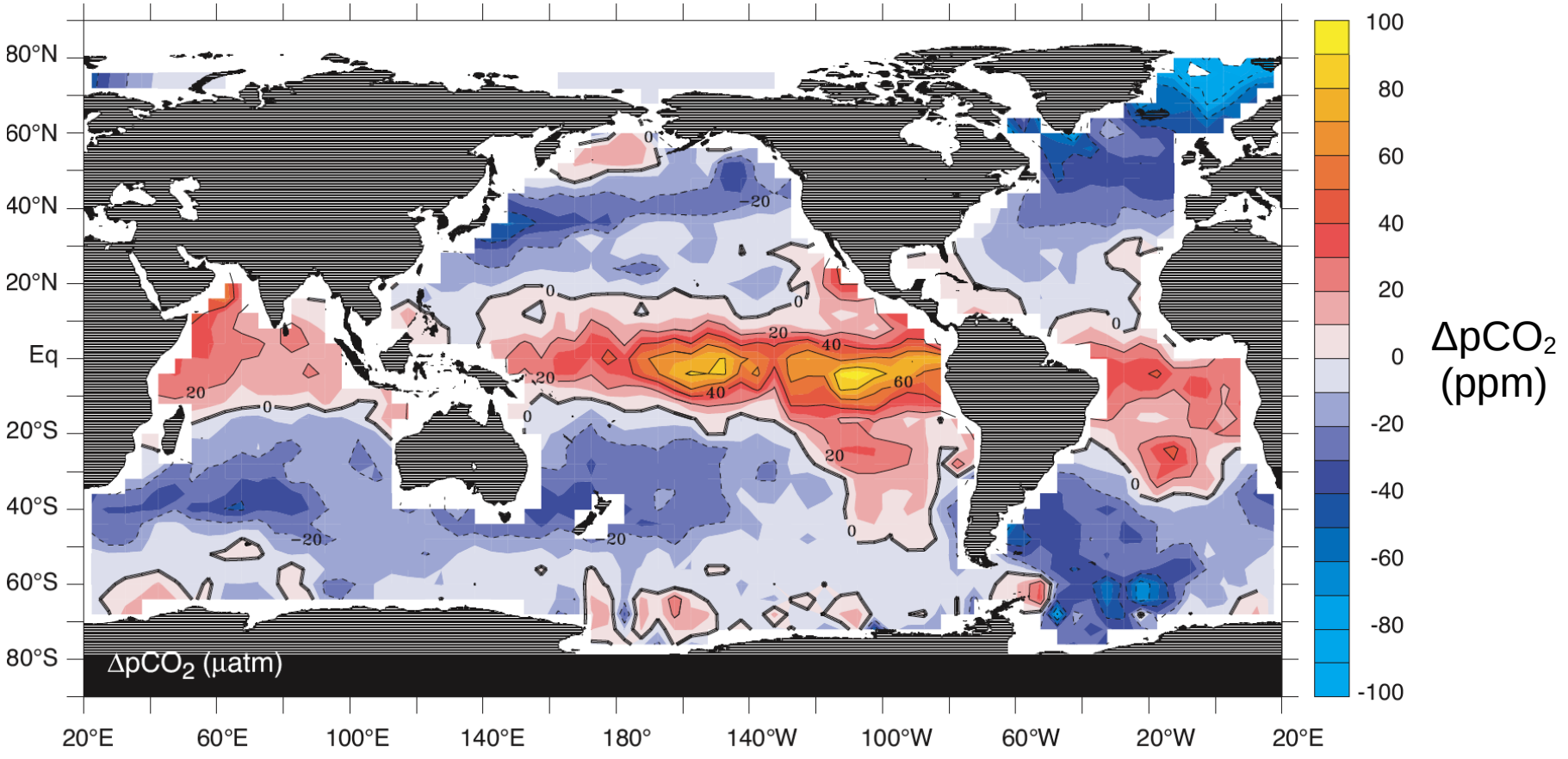
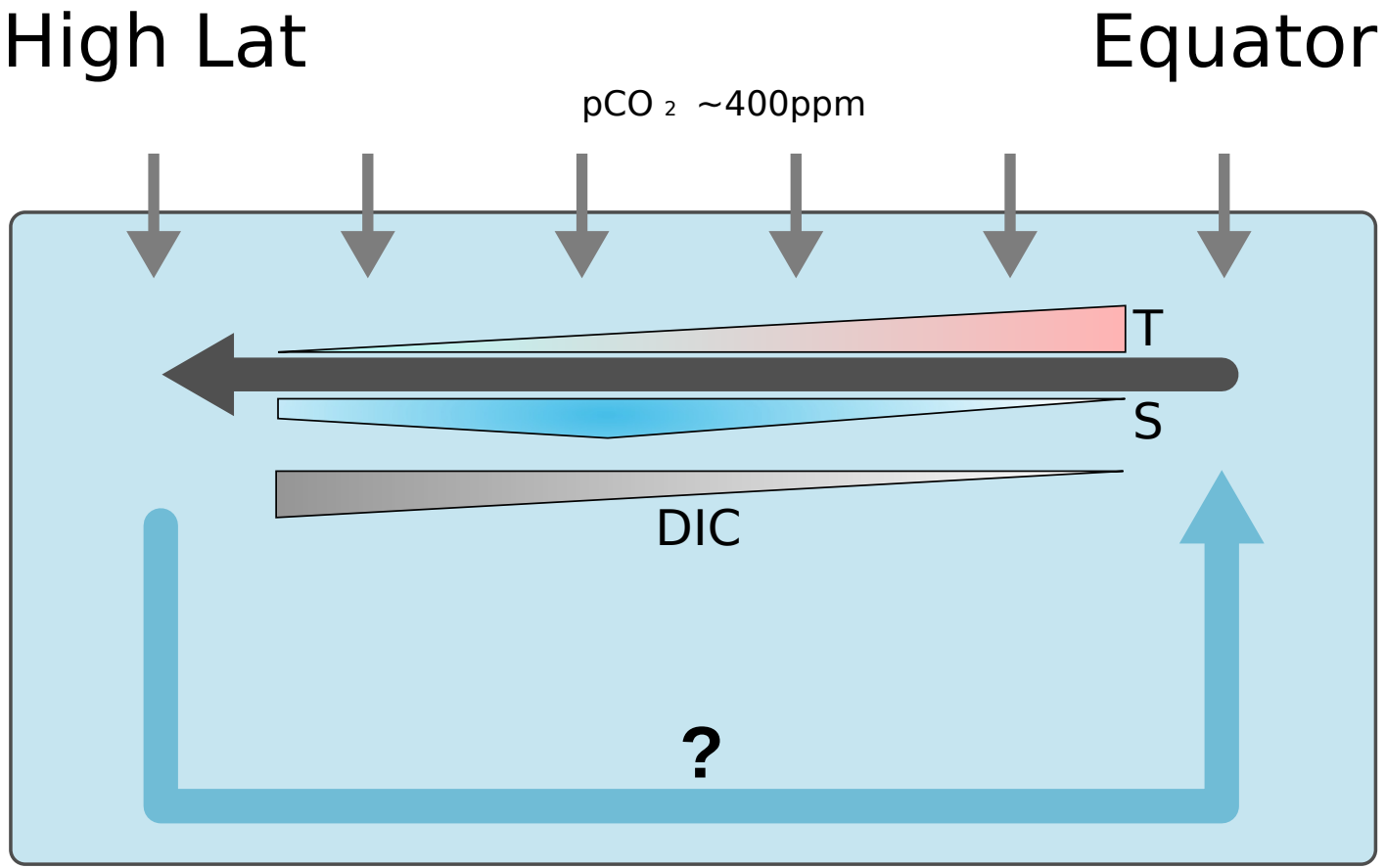




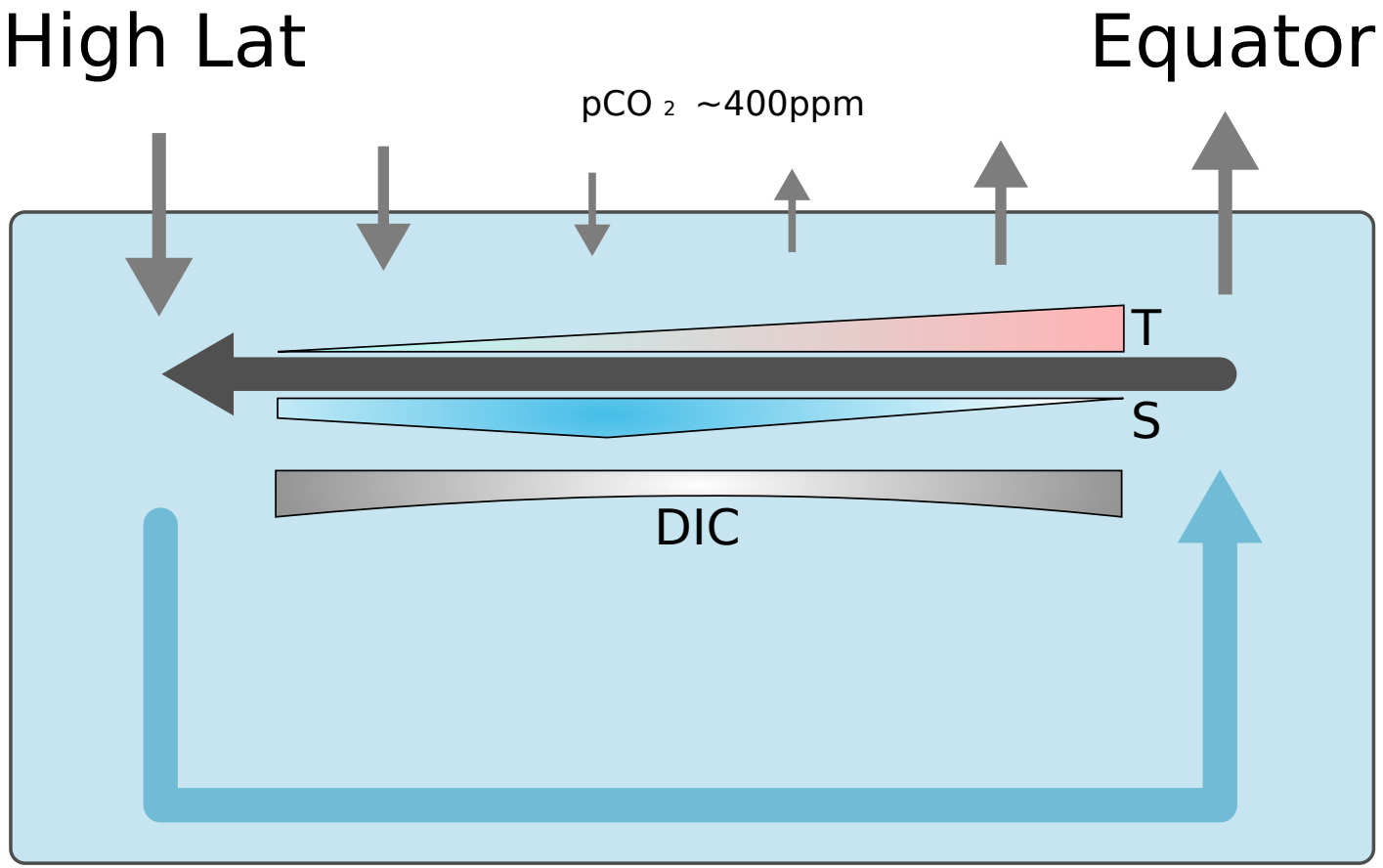
Ocean-Atmosphere Carbon Fluxes



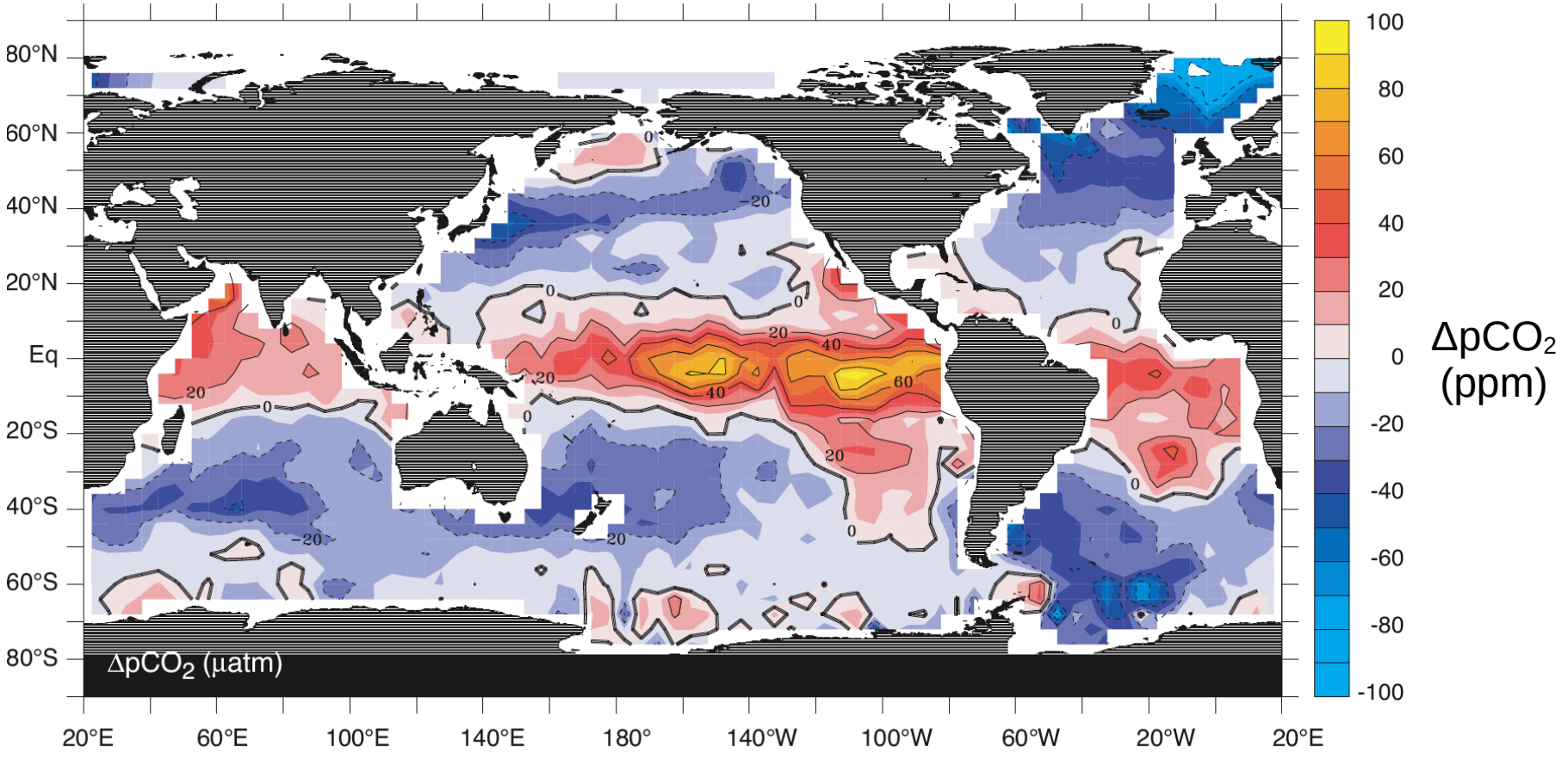
Think: Circulation + Chemistry



The Solubility Pump



Ocean-Atmosphere Carbon Fluxes



Future Uncertainties

Temperature – surface warming?

https://oscarbranson.github.io/interactprac/

Mixing – storms, wind strength, eddies?

https://earth.nullschool.net/#current/ocean/surface/currents/orthographic=329.89,-1.72,592

Ocean Biogeochemistry and Carbon

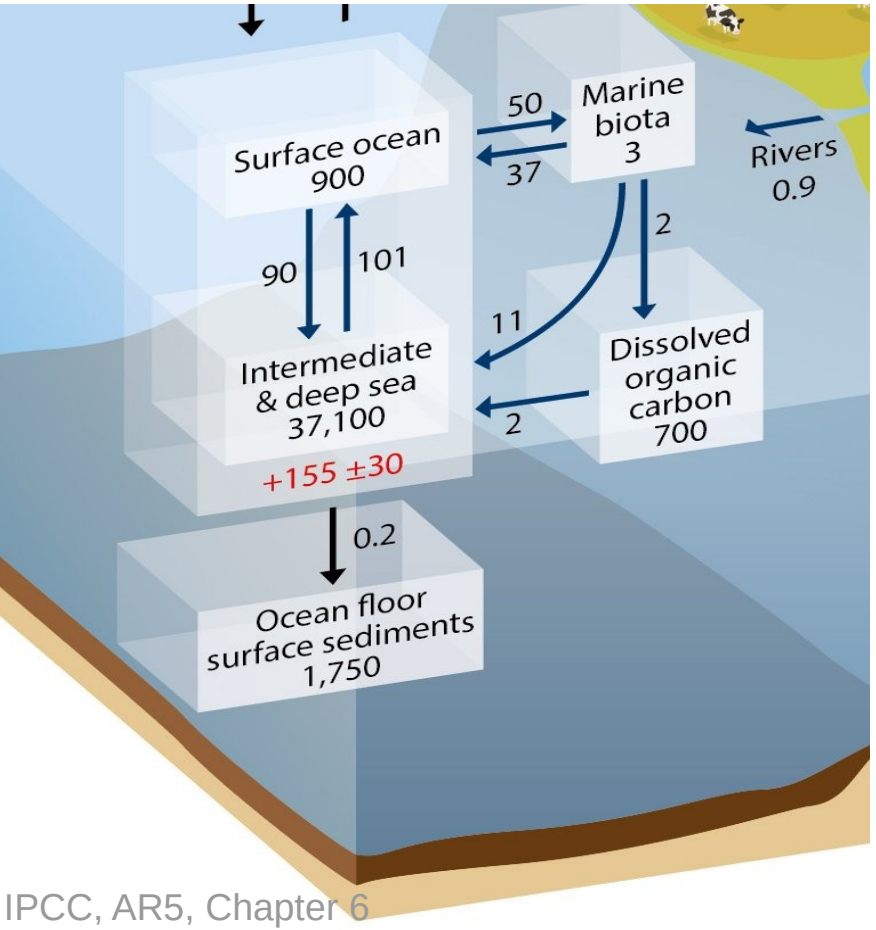
1. Chemistry

Carbon in Seawater.
The ‘solubility’ pump.

2. Biology

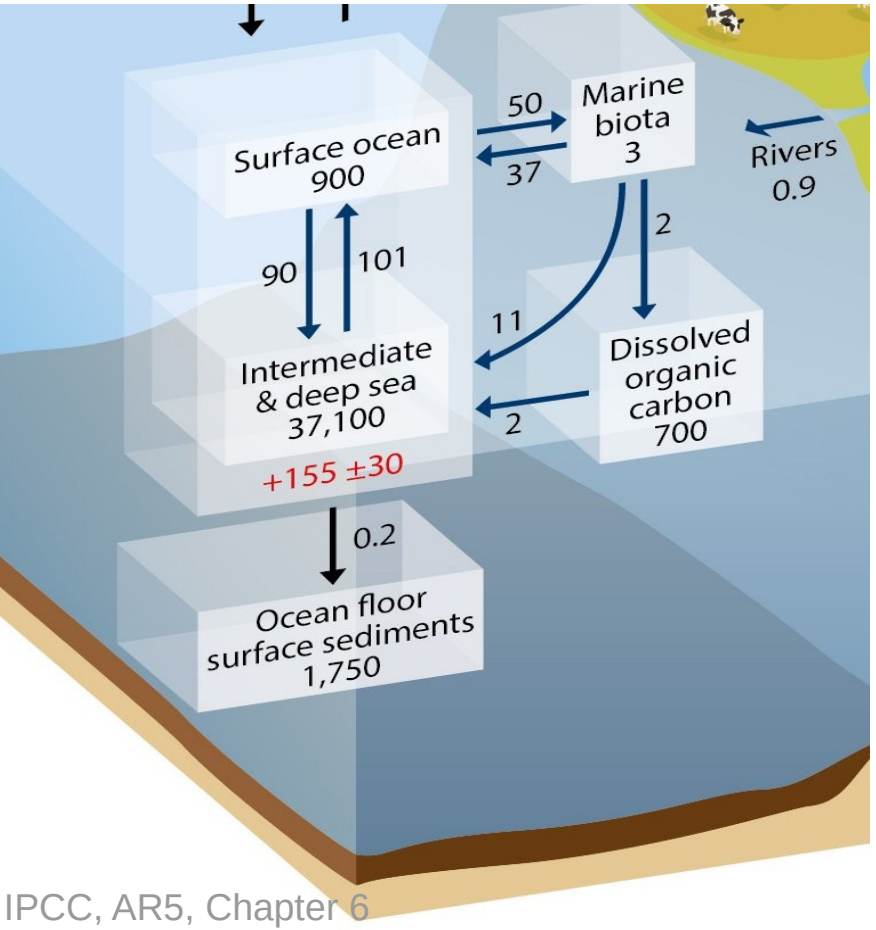
Carbon capture (‘productivity’) and export.
The ‘biological’ pump.
Calcification & Acidification

Carbon in Seawater: Biology



IPCC, AR5, Chapter 6

Carbon in Seawater: Biology



IPCC, AR5, Chapter 6

Solubility Pump: 90-100 Pg C
Total Biological Export: ~13 Pg C

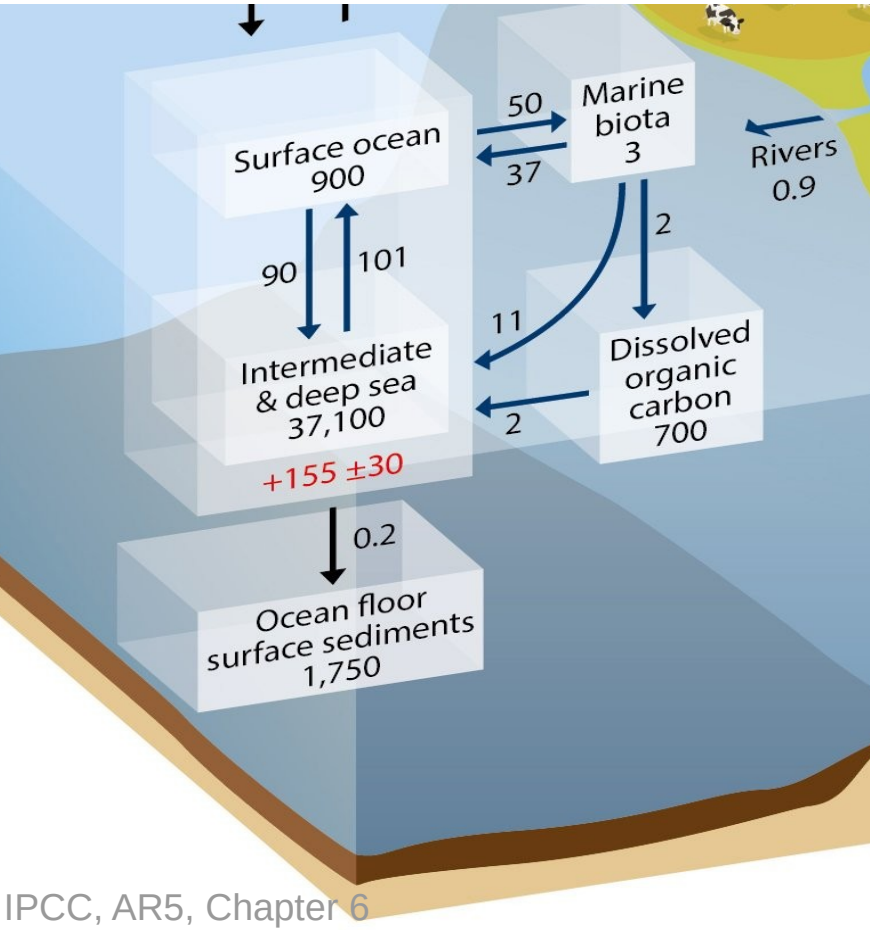
Annual fossil fuel release: 7.8 +/- 0.6 Pg C

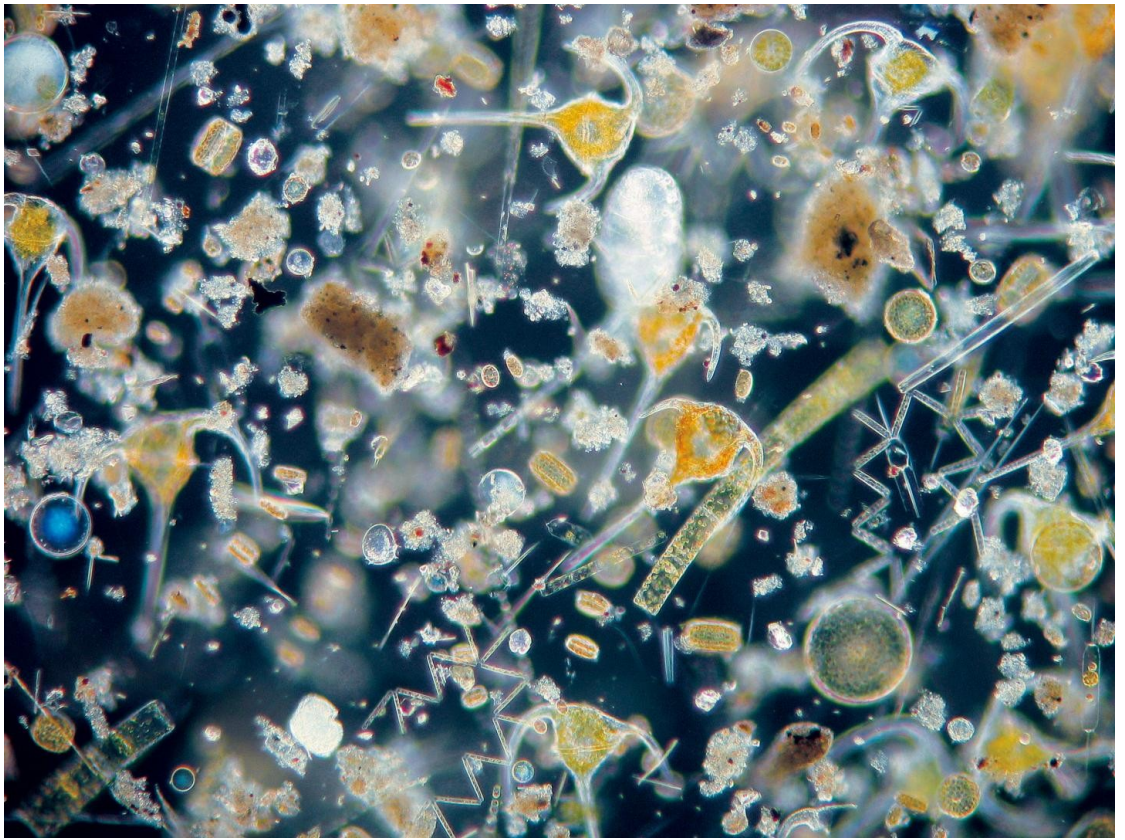
Biological export small compared to solubility, but…
- larger than fossil fuel flux
- sensitive to changing climate

What if there was no biology?

https://oscarbranson.github.io/interactprac/

Carbon in Seawater: Biology

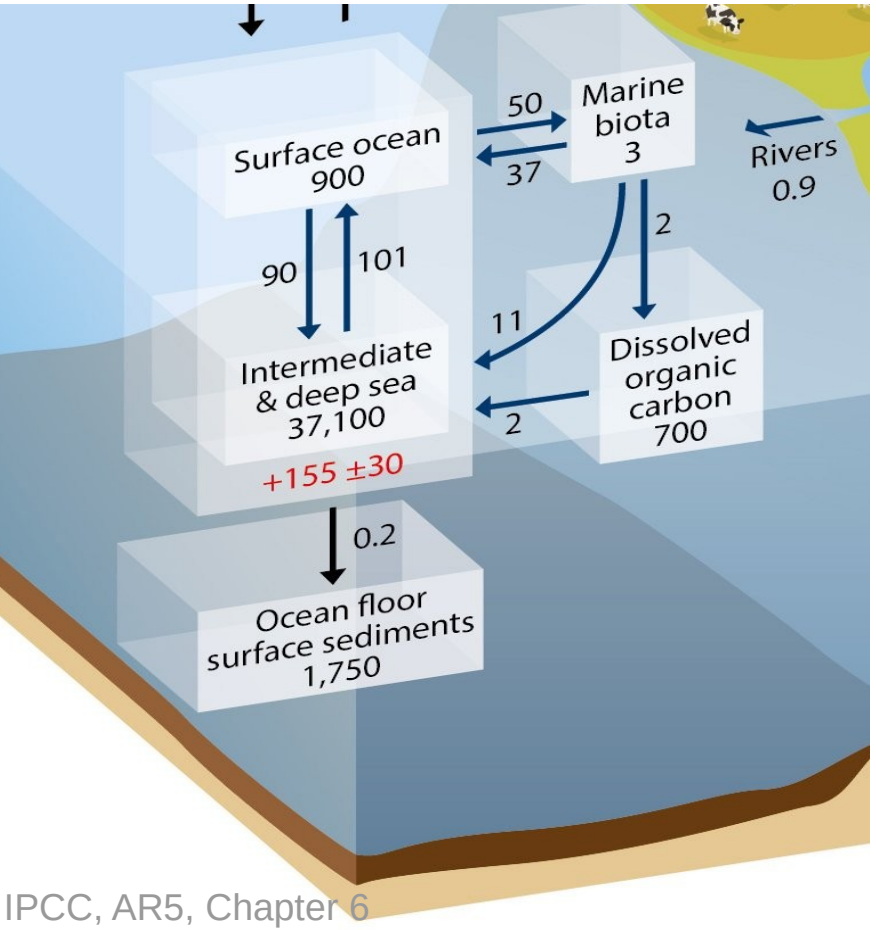




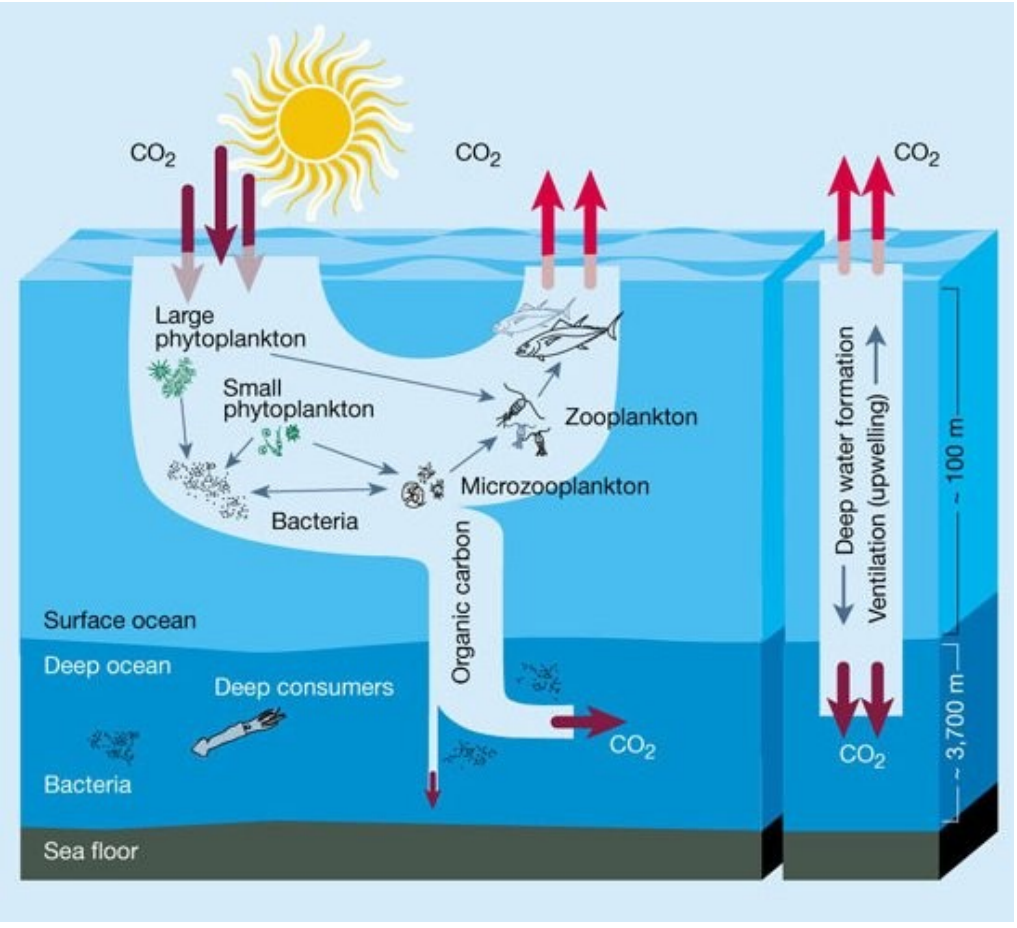
IPCC, AR5, Chapter 6

A. Stuhr, GEOMAR.

Carbon in Seawater: Biology



IPCC, AR5, Chapter 6



Carbon in Seawater: Biology

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

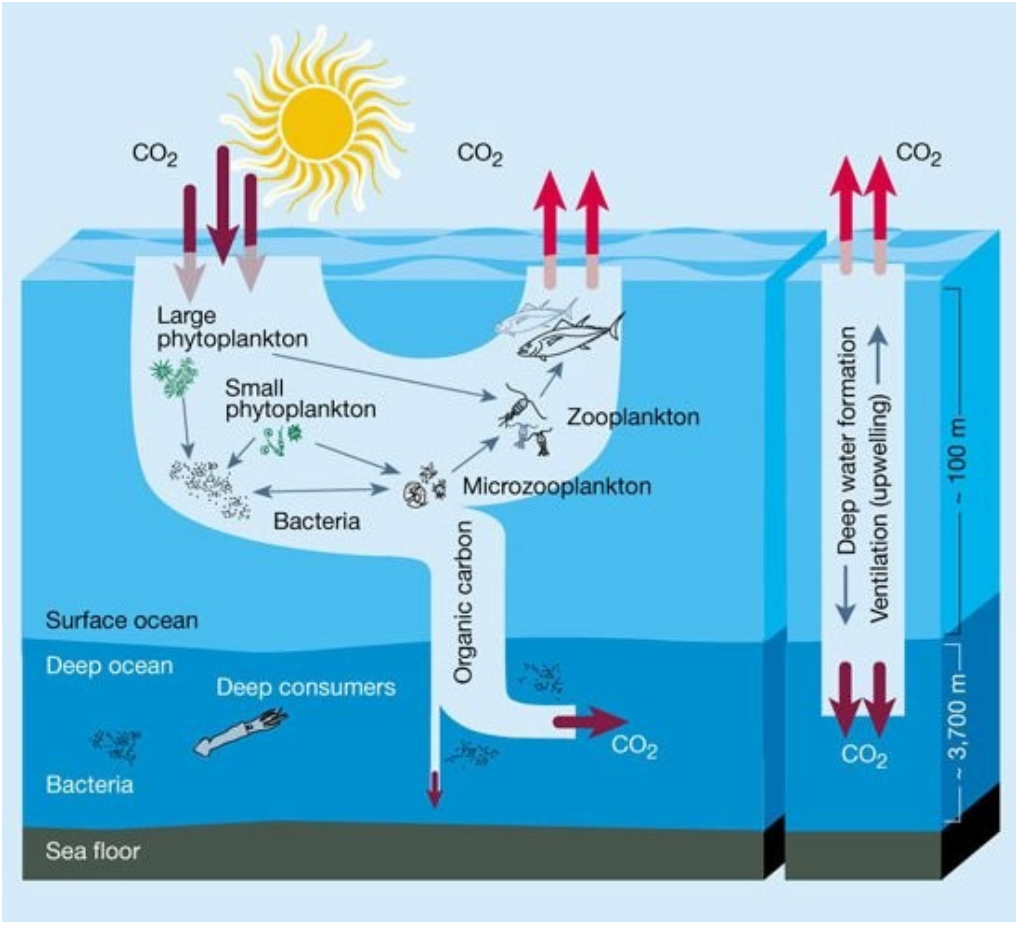
Photosynthesis ↑

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

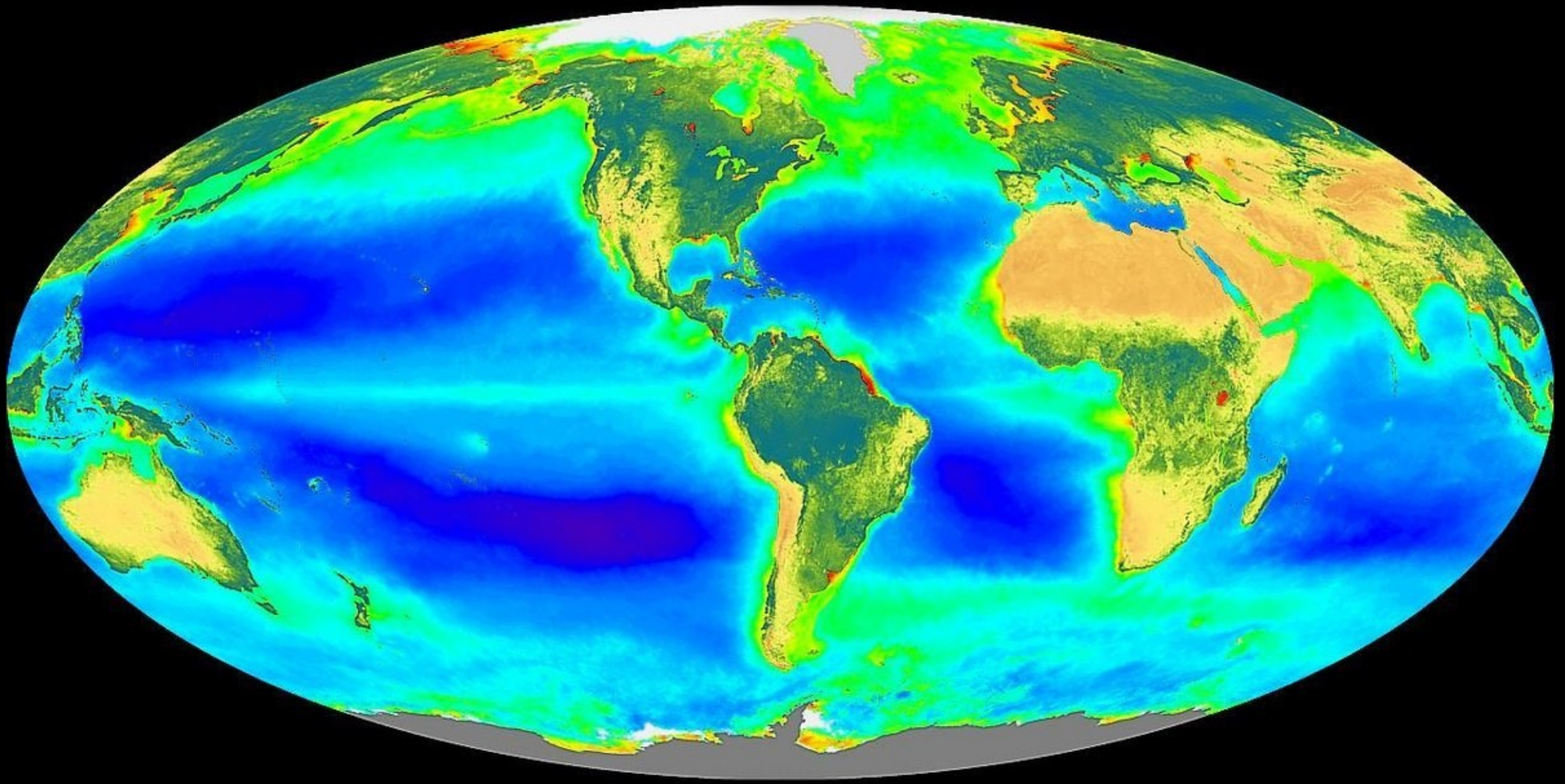
Respiration (Remineralisation)

Light

and

Nutrients

$\mathbf{106CO_2} + 16NO_3 + H_3PO_4 + 78H_2O + 18H^+$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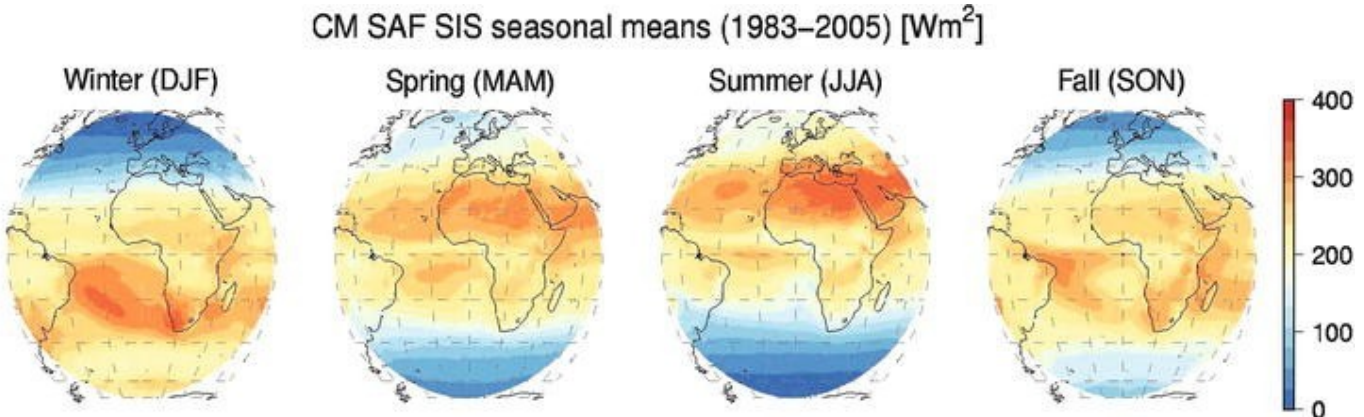
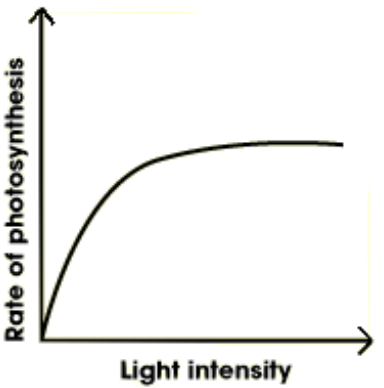
Maximum
Minimum
Land: Normalized Difference Land Vegetation Index

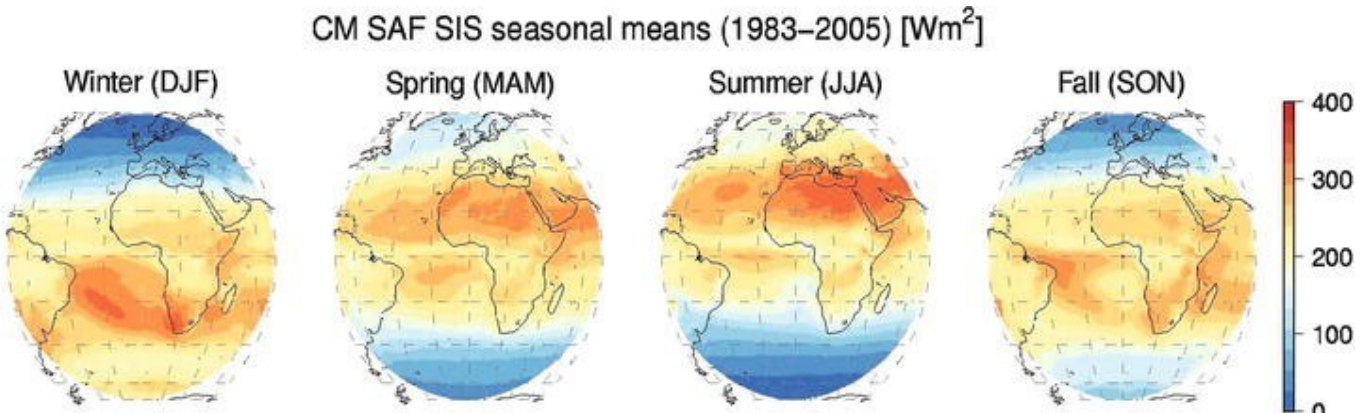
Biology: Light



Mueller (2016)



Biology: Light



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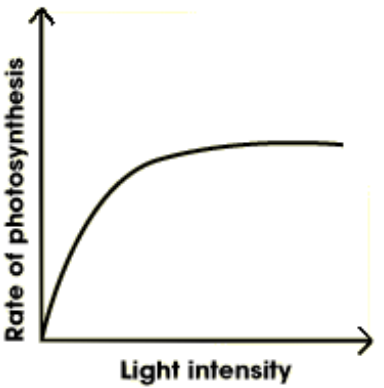
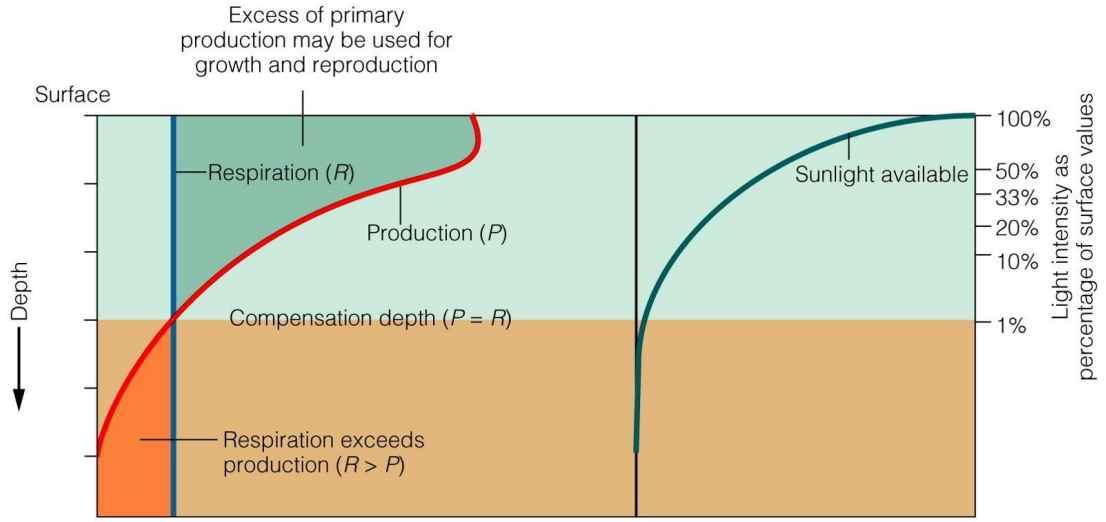
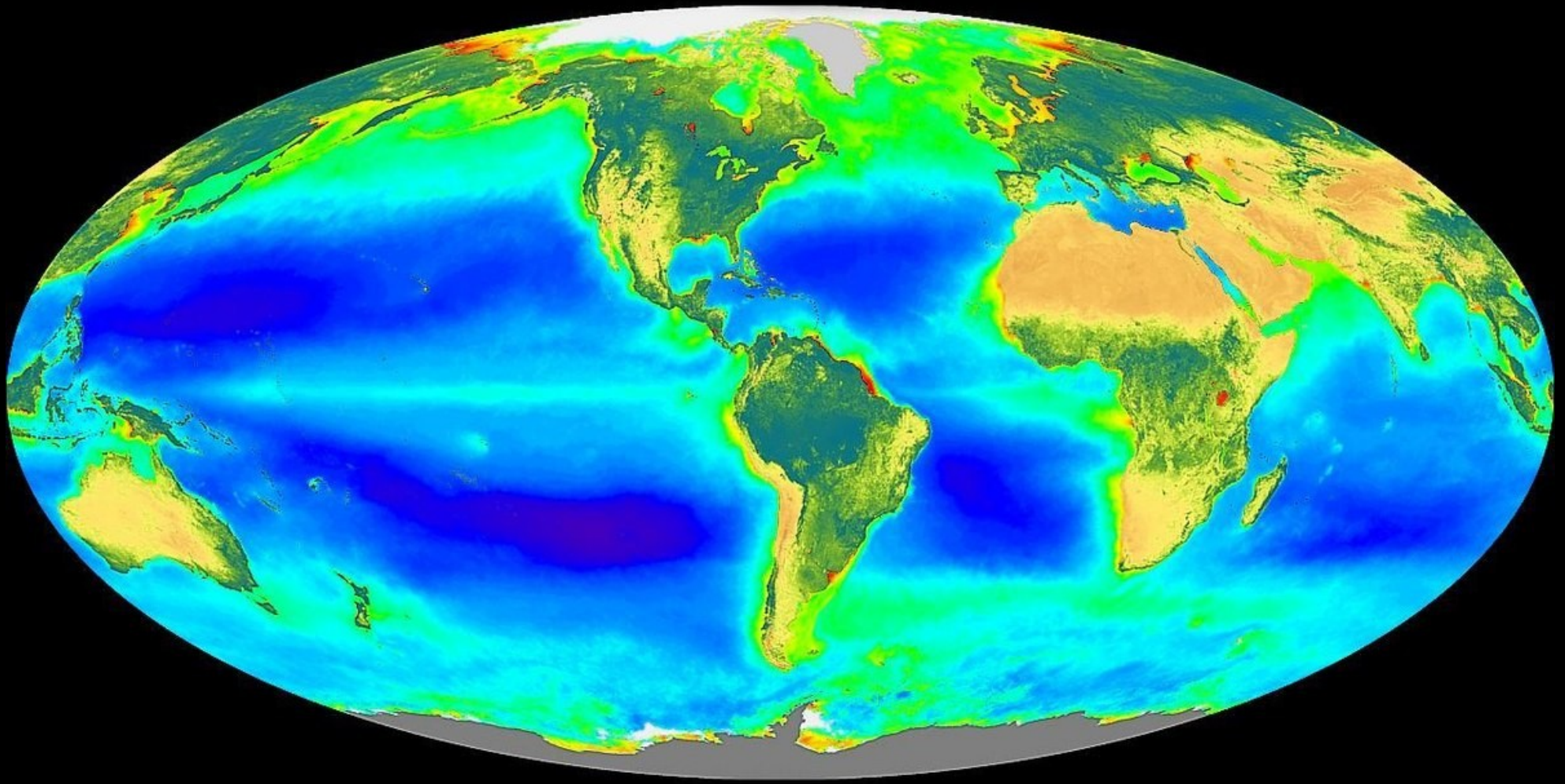




Mixed Layer Depth is critical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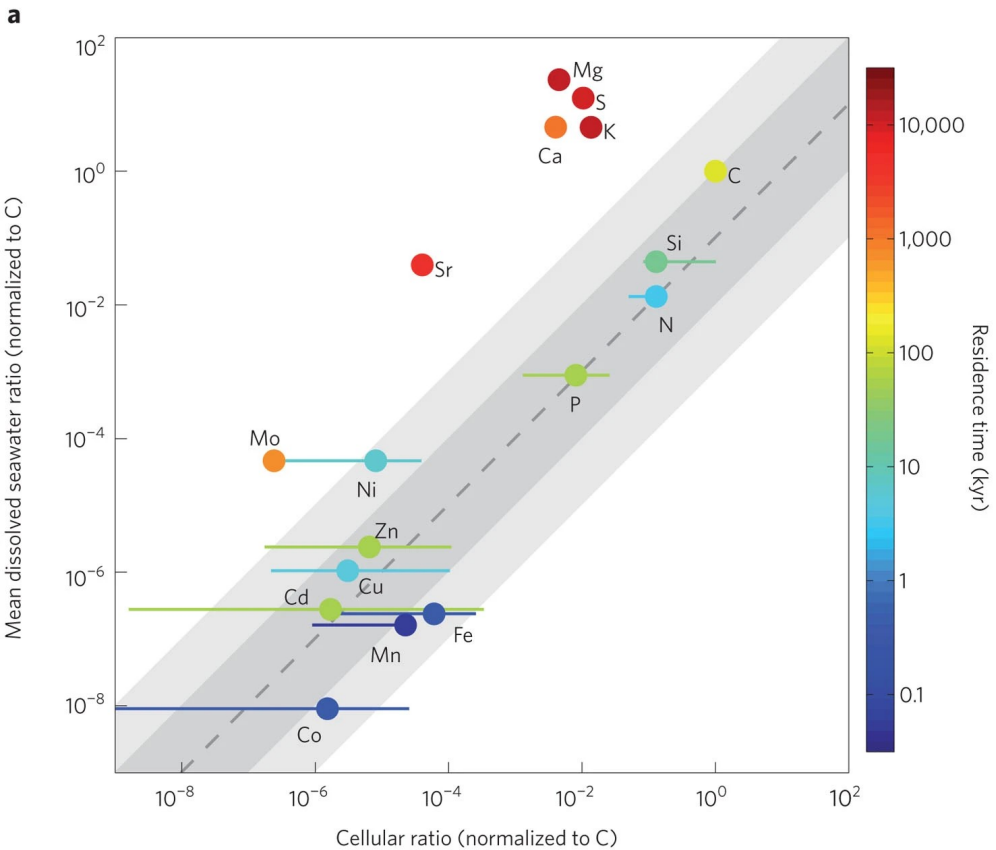
Ocean: Chlorophyll a Concentration (mg/m3)
Maximum
Minimum
Land: Normalized Difference Land Vegetation Index

Biology: Nutrients

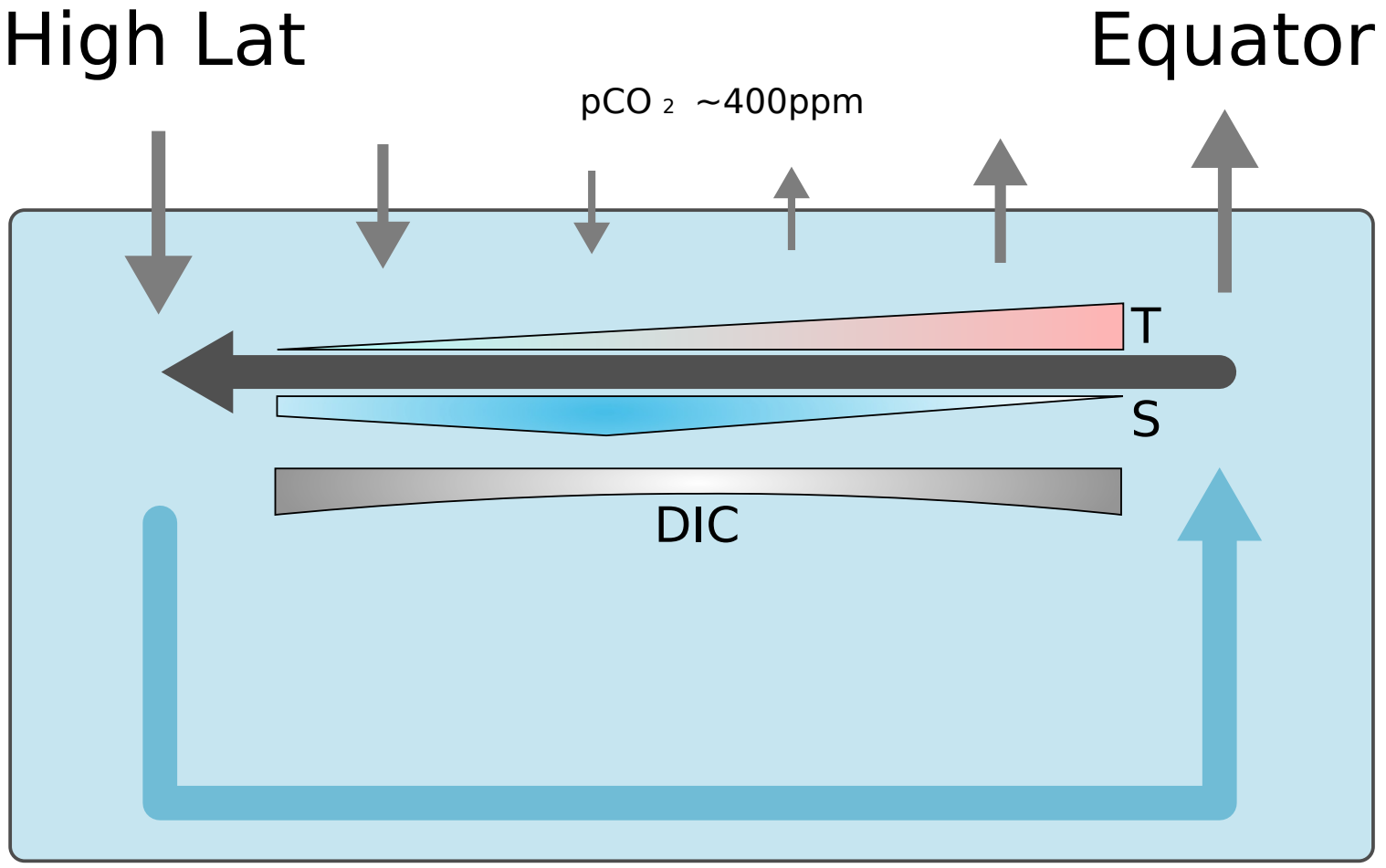
Productivity is limited by:

- P
- Fe
- Mn
- Co



Moore et al. (2013)

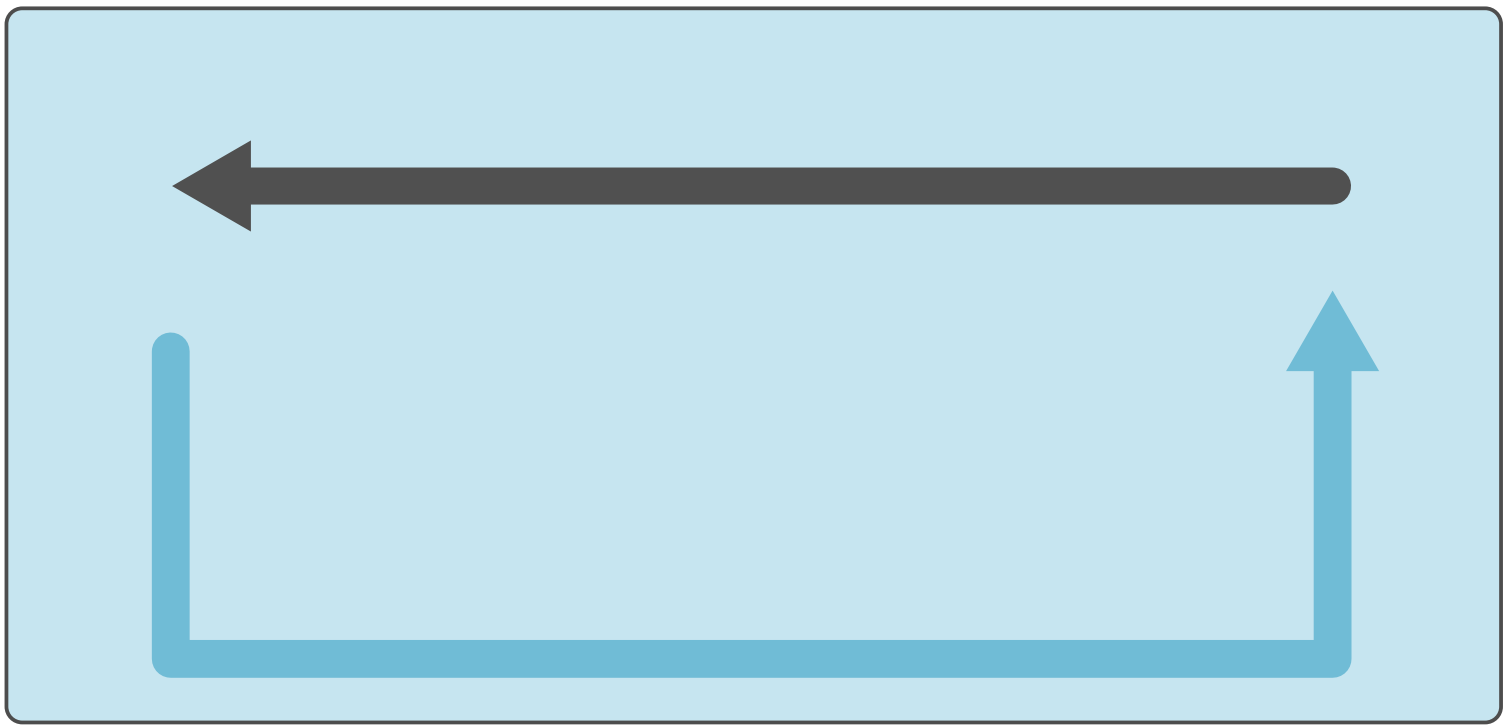
Think: Biology + Circulation



Think: Biology + Circulation

High Lat

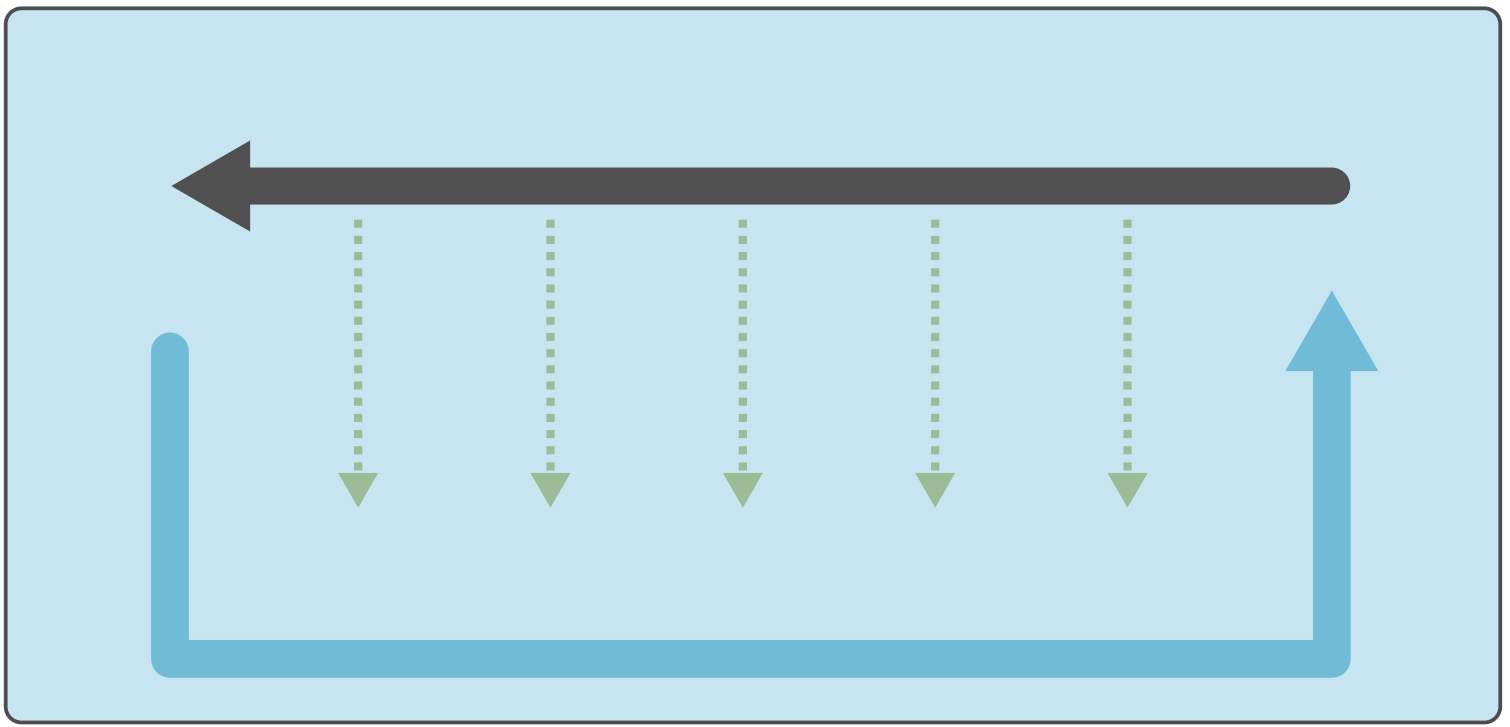
Equator



Think: Biology + Circulation

High Lat

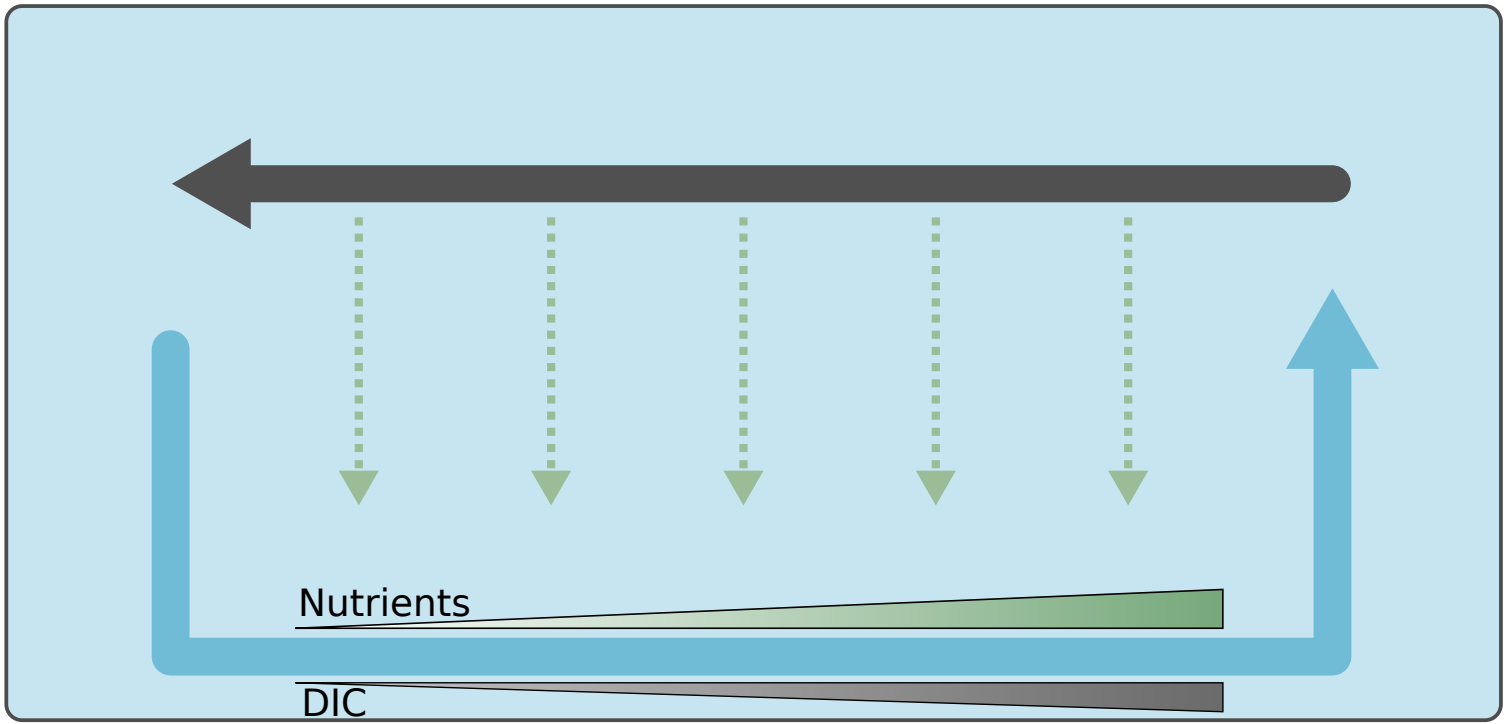
Equator



Think: Biology + Circulation

High Lat

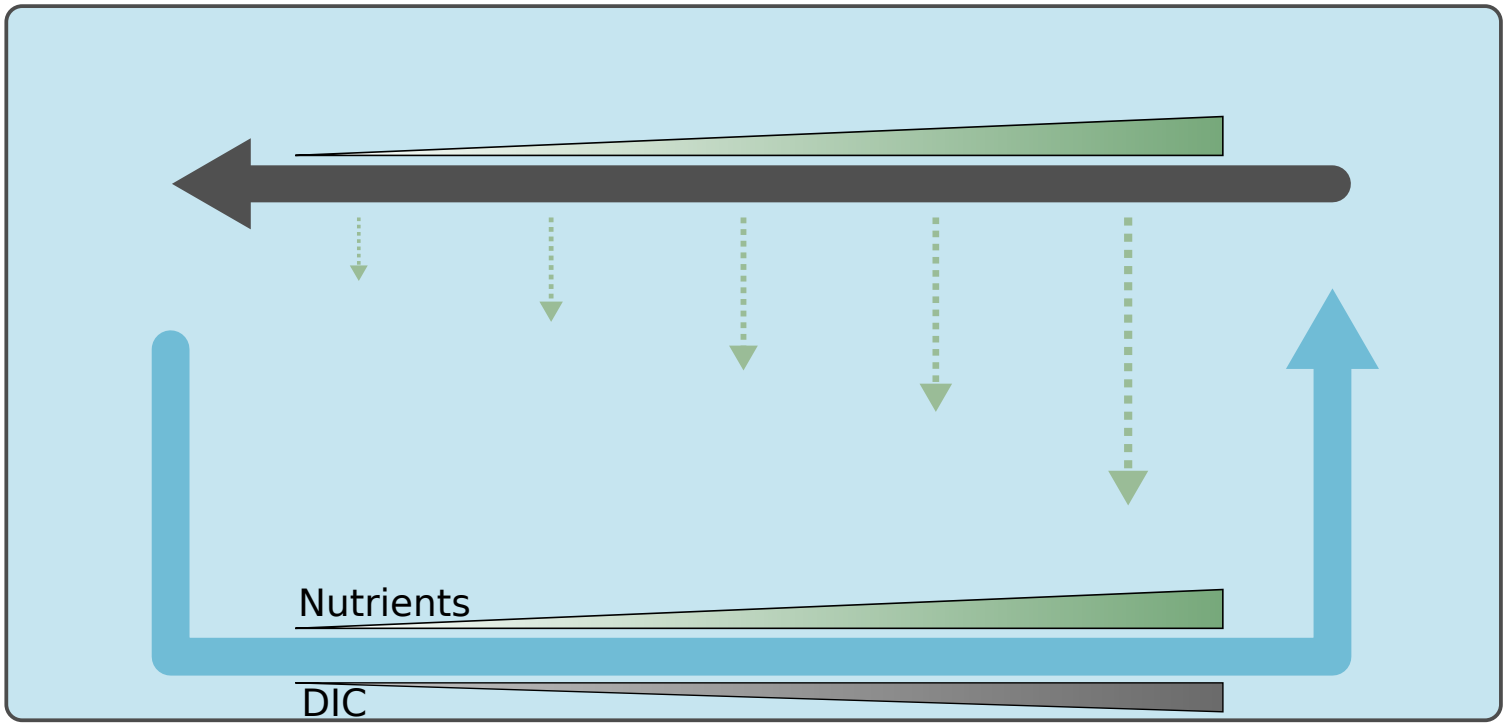
Equator



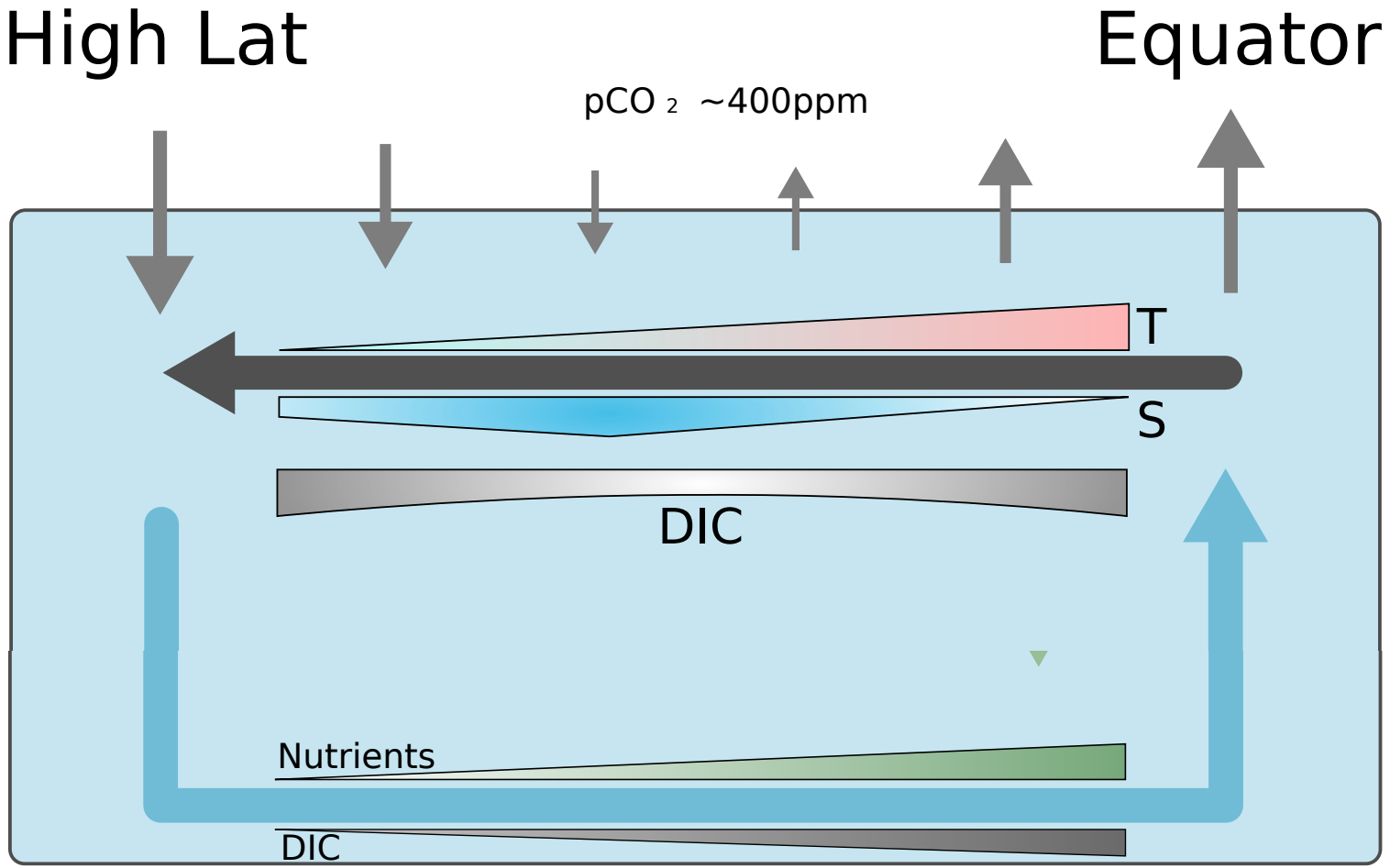
The Biological Pump

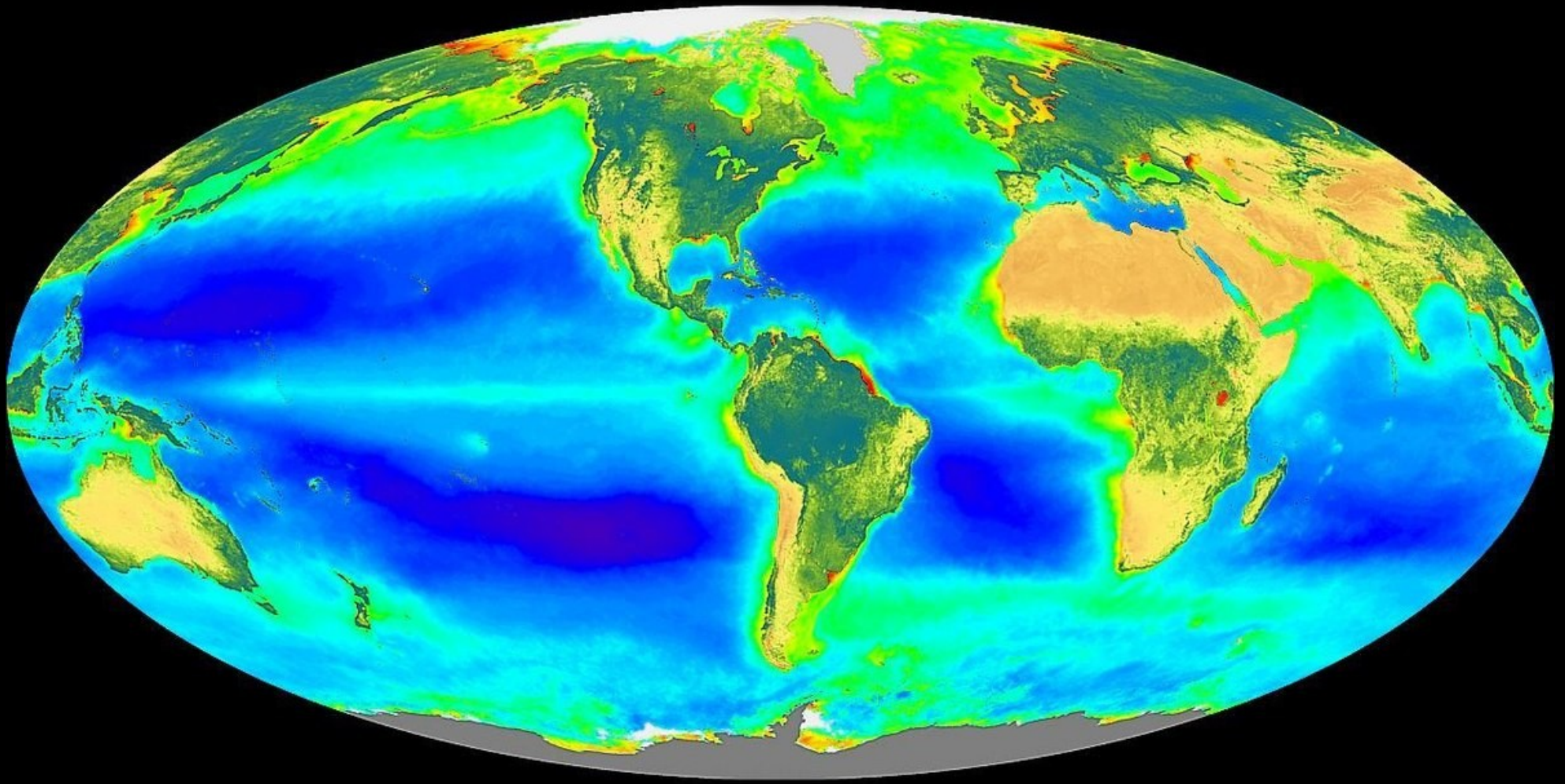
High Lat

Equator



Biology + Solubility + Circulation




>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

Future Uncertainties

Temperature – surface warming?
Change in planktic community structure? Influence on export?

Mixing – storms, wind strength, eddies?
Increased nutrient supply and higher productivity?
Or delayed spring blooms and lower productivity?

Biology 2: Calcification

Foraminifera

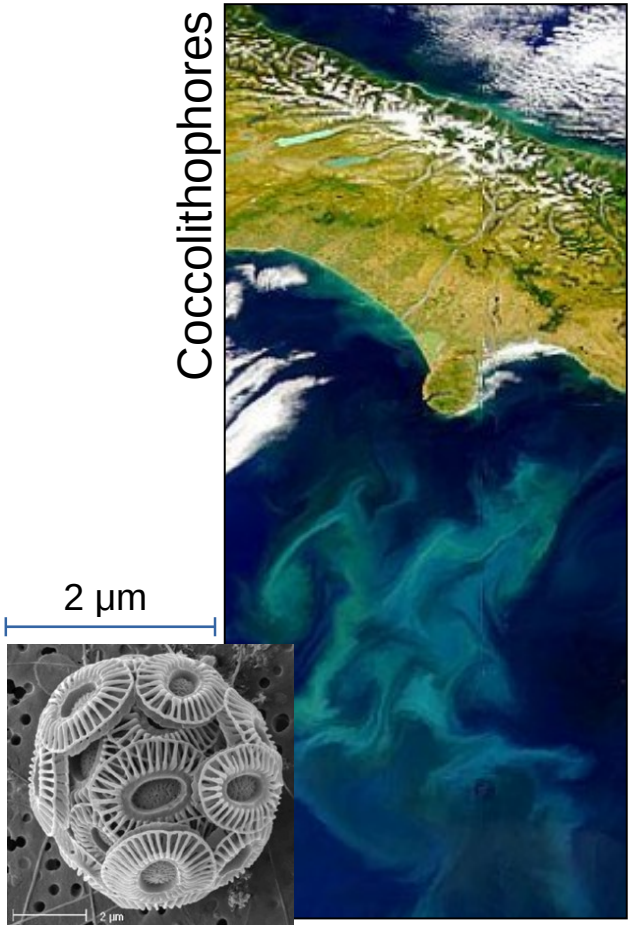
1 mm

Pteropods

1 mm

Corals

Coccolithophores

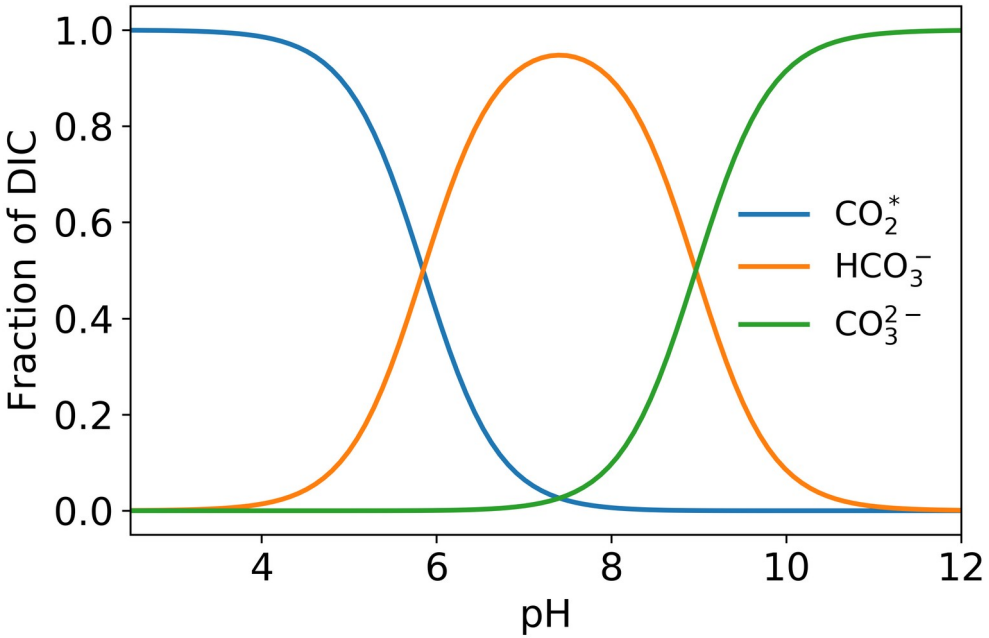


2 µm

Biology 2: Calcification

$$Ca^{2+} + 2HCO_3^- \rightleftharpoons \mathbf{CaCO_3} + CO_2 + H_2O$$

$$Ca^{2+} + CO_3^{2-} \rightleftharpoons \mathbf{CaCO_3}$$



1. Calcification *produces* CO_2

2. Calcification depends on $[CO_3^{2-}]$

$$\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}}$$

$\Omega > 1 \rightarrow CaCO_3$ formation

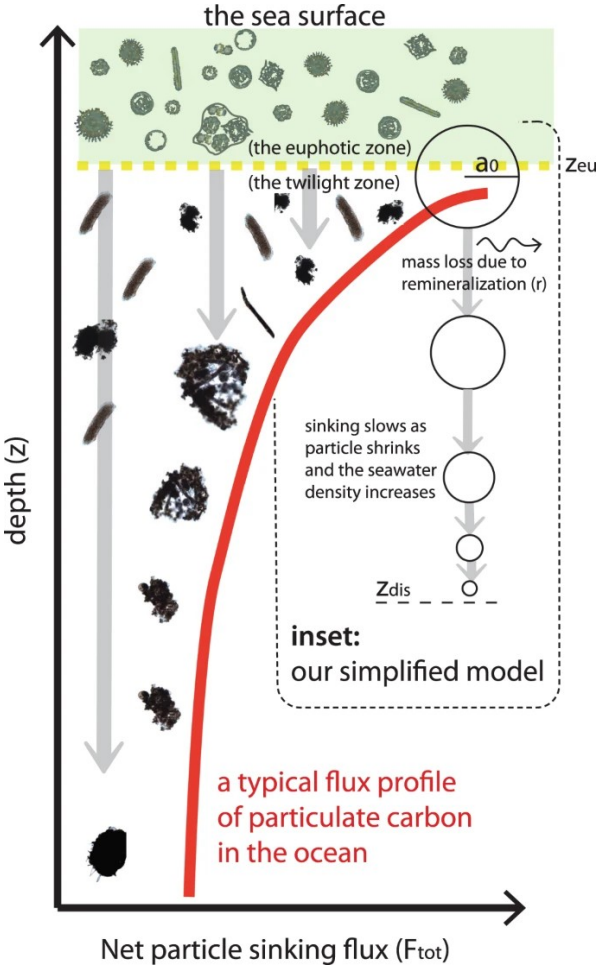
$\Omega < 1 \rightarrow CaCO_3$ dissolution

$[CO_3^{2-}]$ controlled by pH.

Biology 2: Ballasting

Calcification is an immediate *source* of CO_2, but 'ballasting' (increasing density) of sinking organic particles can increase sinking speed and increase efficiency of biological pump.

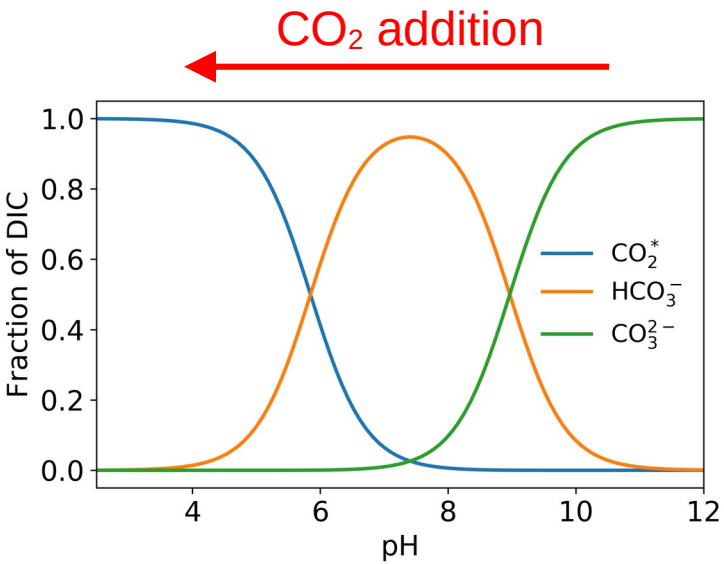
Net effect of calcification depends on $CaCO_3$:Organic matter ratio.



Biology 2: Acidification

Calcification requires CO_3^{2-}, but elevated pCO_2 lowers pH and $[CO_3^{2-}]$.

May reduce calcification in future? But...



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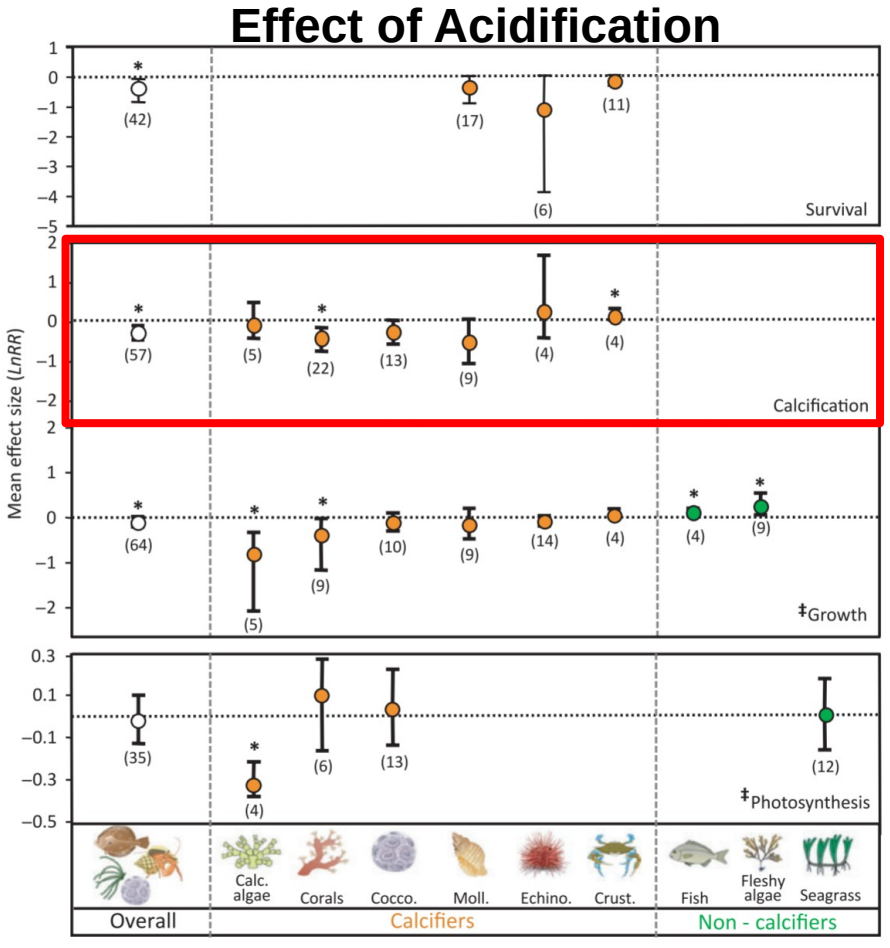

Kroeker et al., 2010

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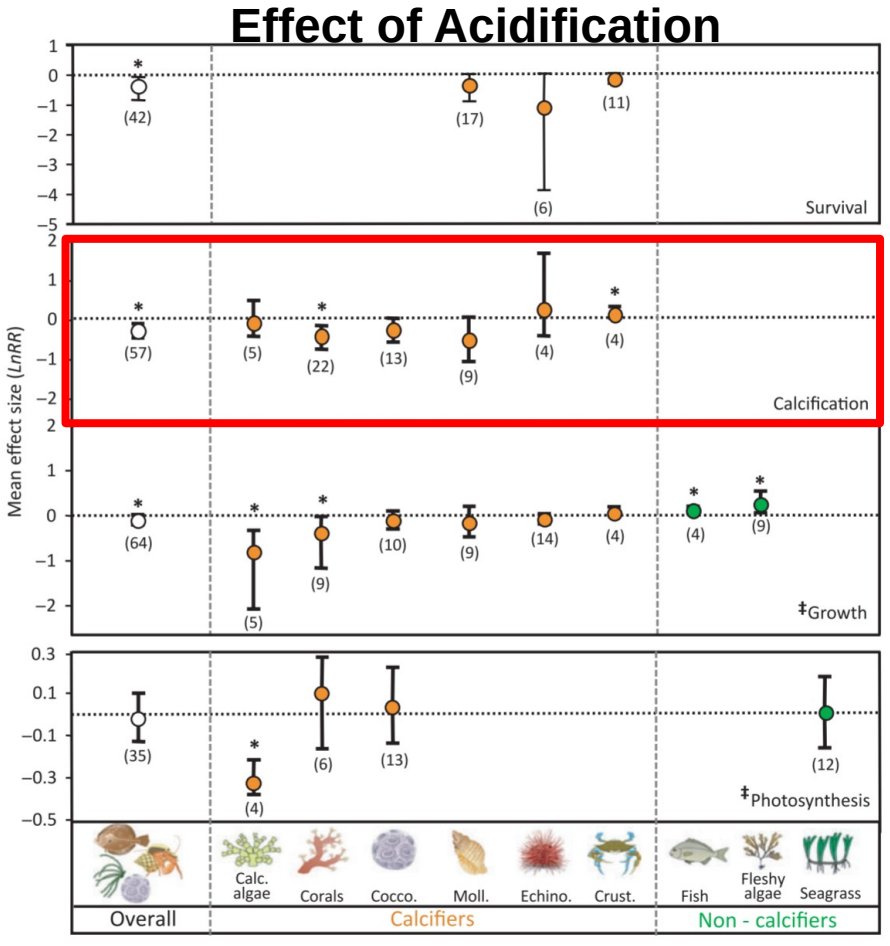
How will inorganic:organic carbon ratio changes i future?



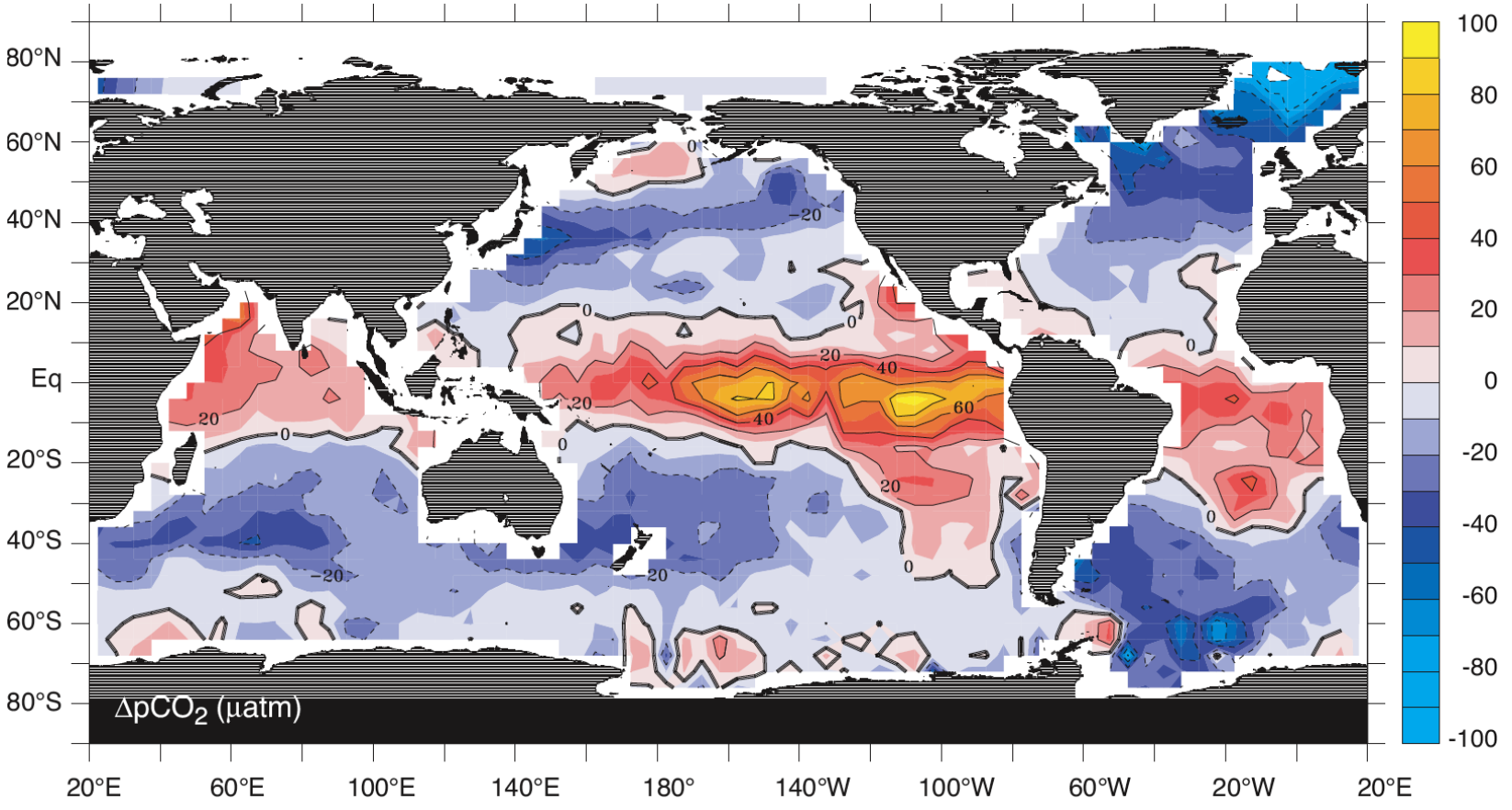
Kroeker et al., 2010

Future Uncertainties

Ocean acidification

How will calcification change in a high-CO_2 ocean?
How will inorganic:organic ratio change in future?
How will this change biological pump efficiency?

Practical: Predicting ΔpCO_2



SST
SSS
SSH
ChlA
MLD
xCO2