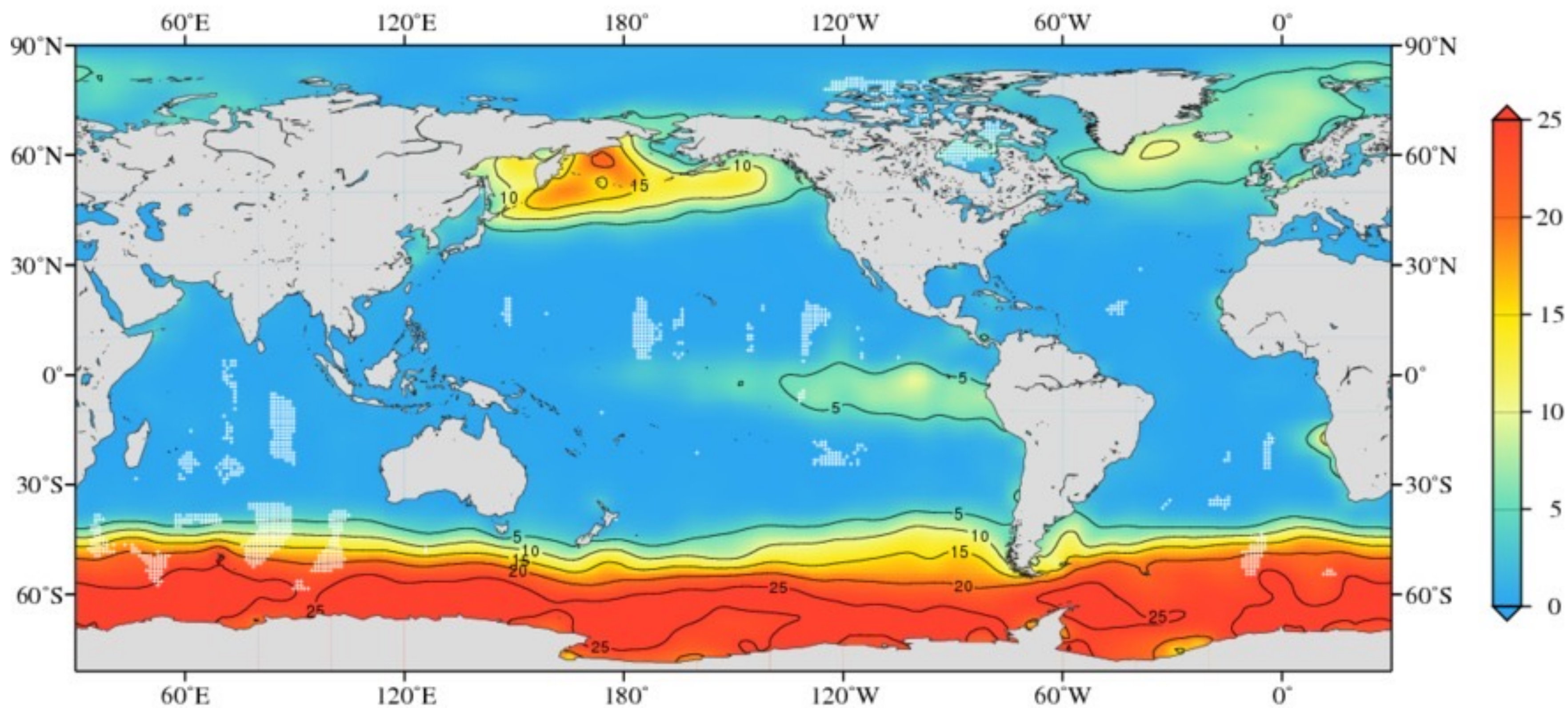
Biology and nutrients

- Spatial and temporal patterns of biological production, respiration, and associated tracers
- Stoichiometric ratios for biological processes
- Fluxes of organic matter in the upper ocean

Annual Mean Nitrate distribution

World Ocean Atlas Climatology

Contour Interval=5



Annual nitrate [umol/kg] at the surface (one-degree grid)

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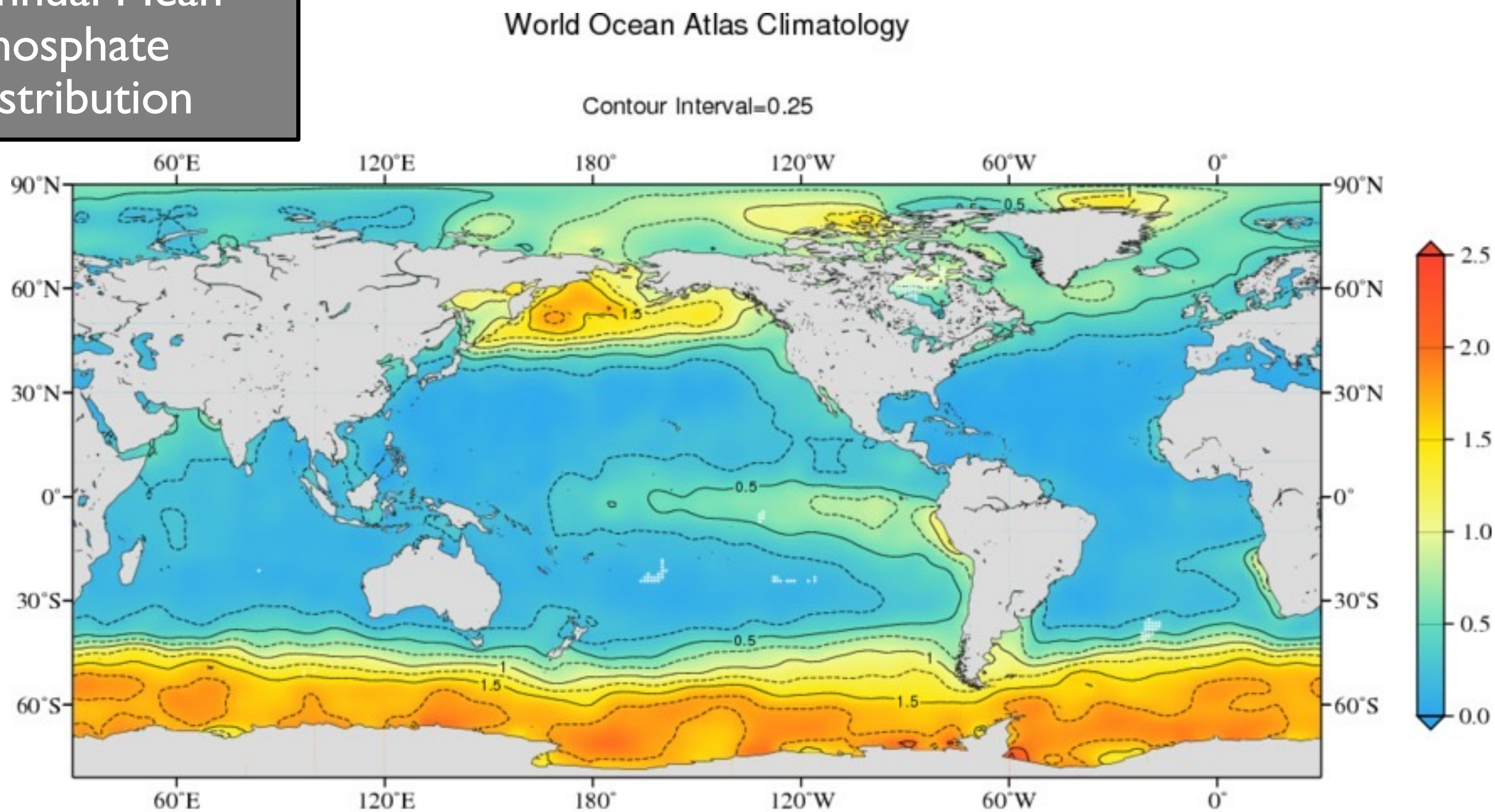
Annual Mean Phosphate distribution



Annual phosphate [umol/kg] at the surface (one-degree grid)

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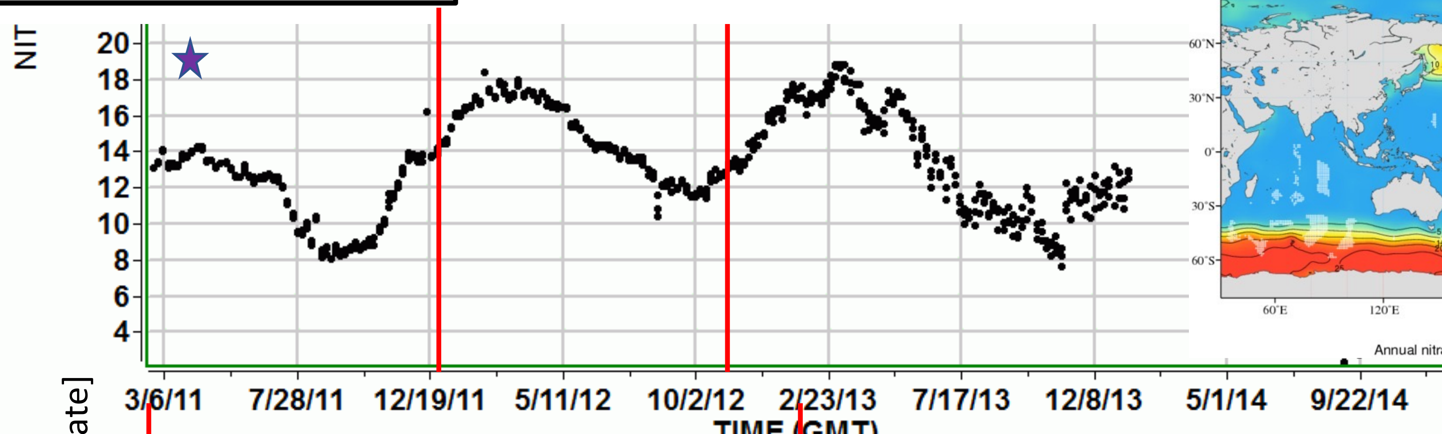
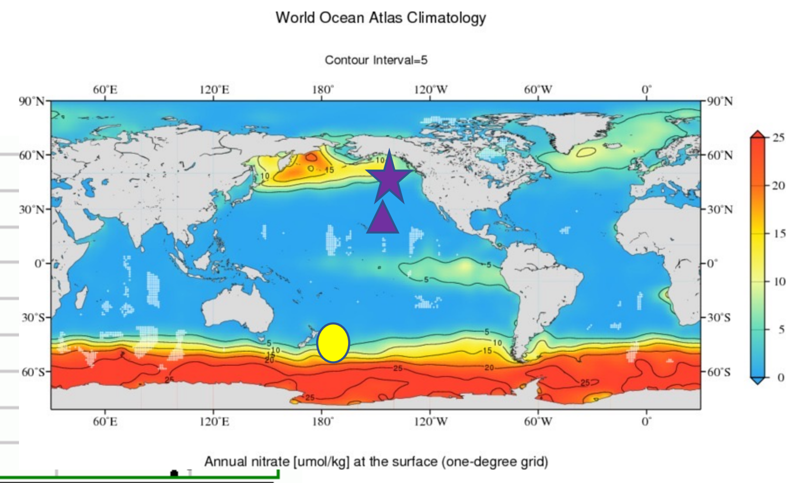
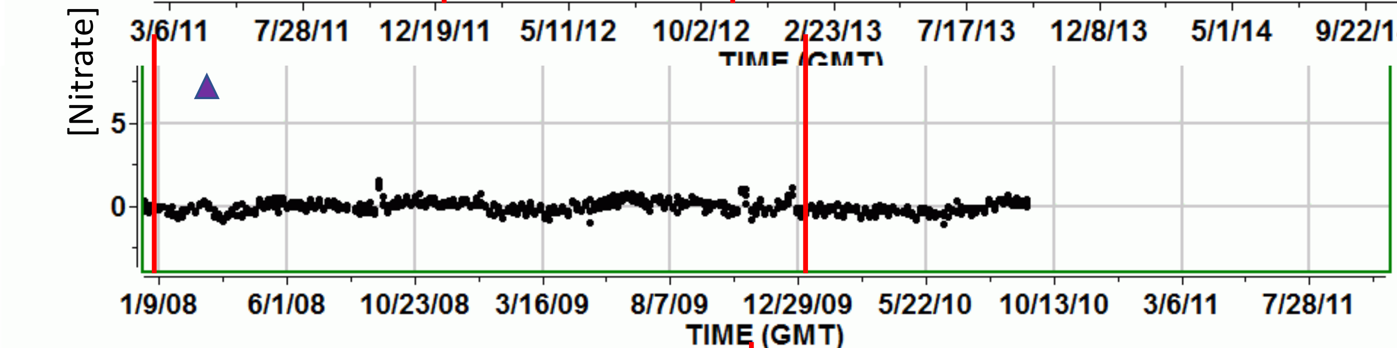
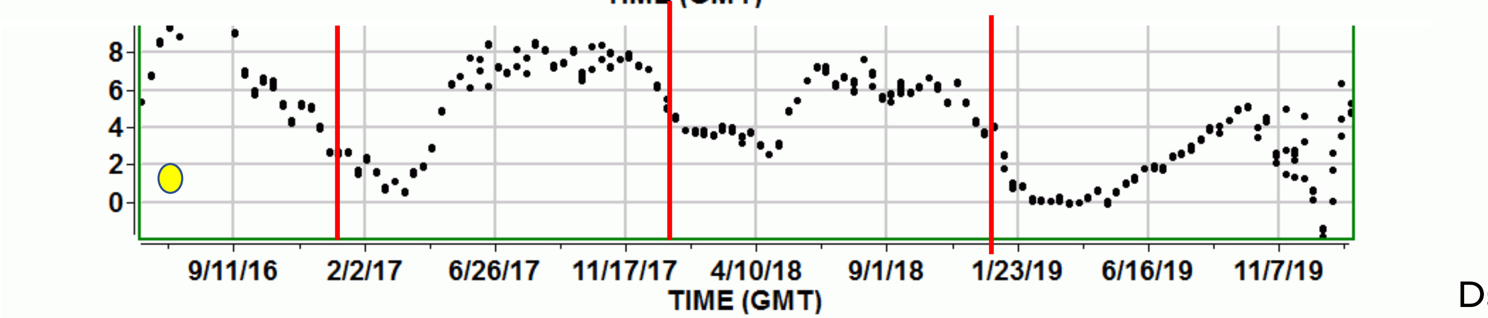
Seasonal variance









- How do we think the interior distributions of nutrients looks?

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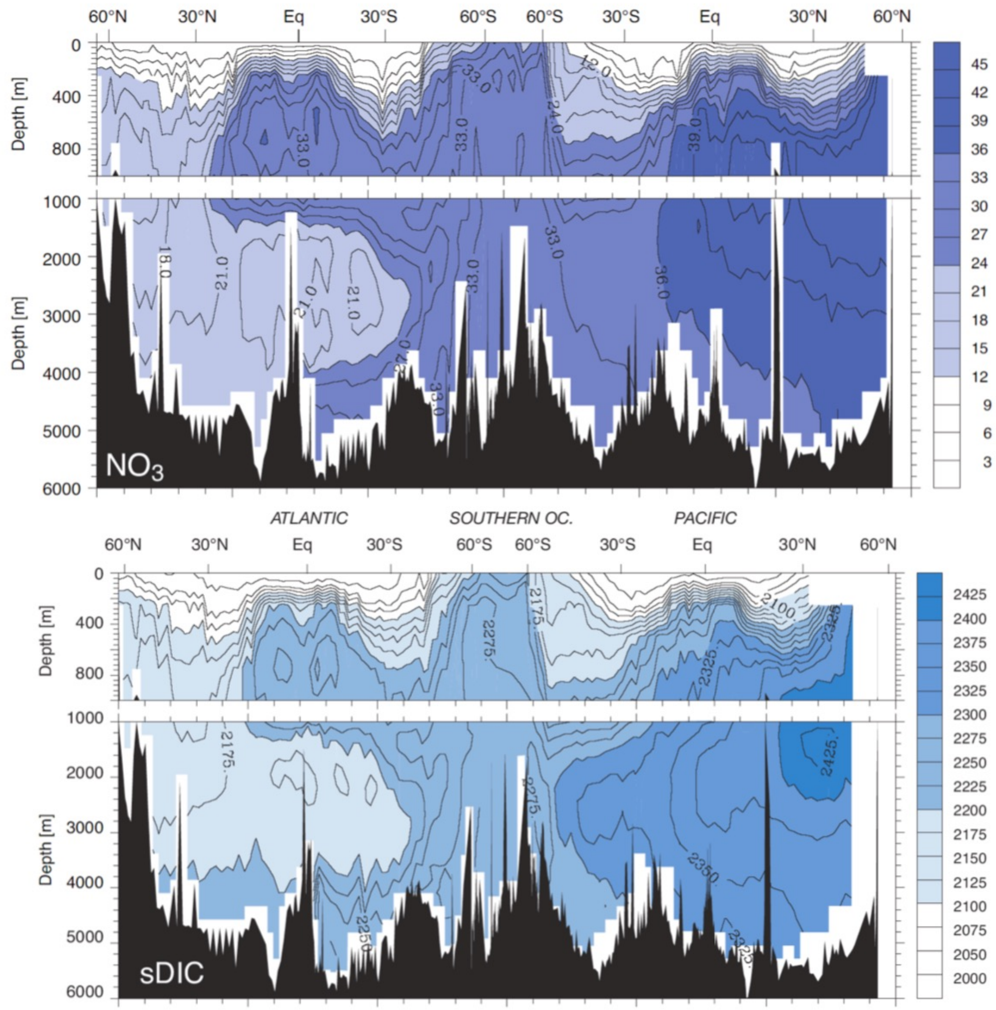
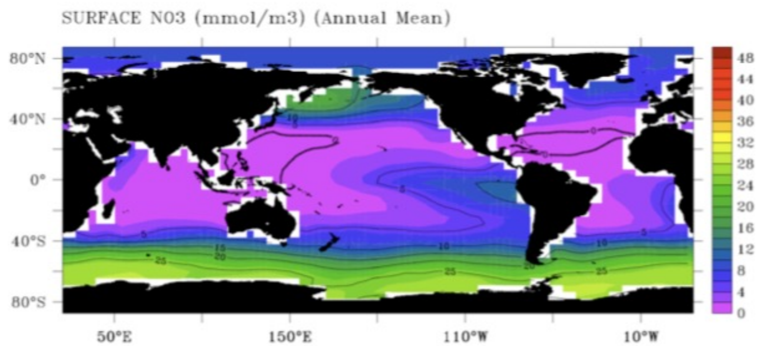
Data from MBARI Floatviz

Oceanic distributions of nutrients and carbon are linked!

How do physics and biology combine to yield these cross sections?



Sarmiento and Gruber (2006)



What would happen if we turned off biology?

In 5 years?

At equilibrium?

Sarmiento and Gruber (2006)

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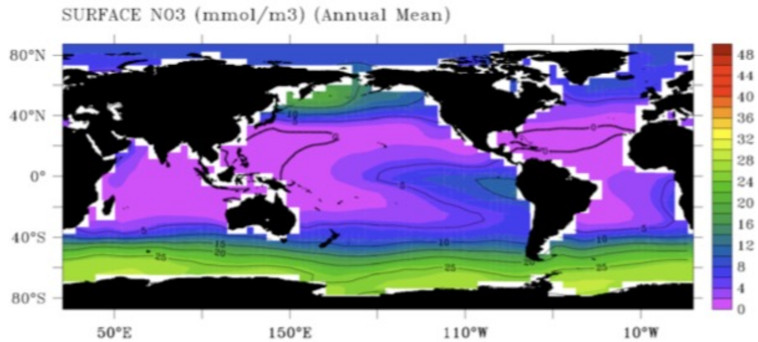

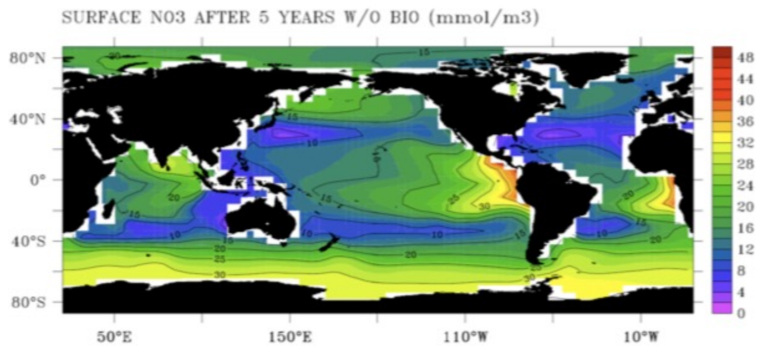

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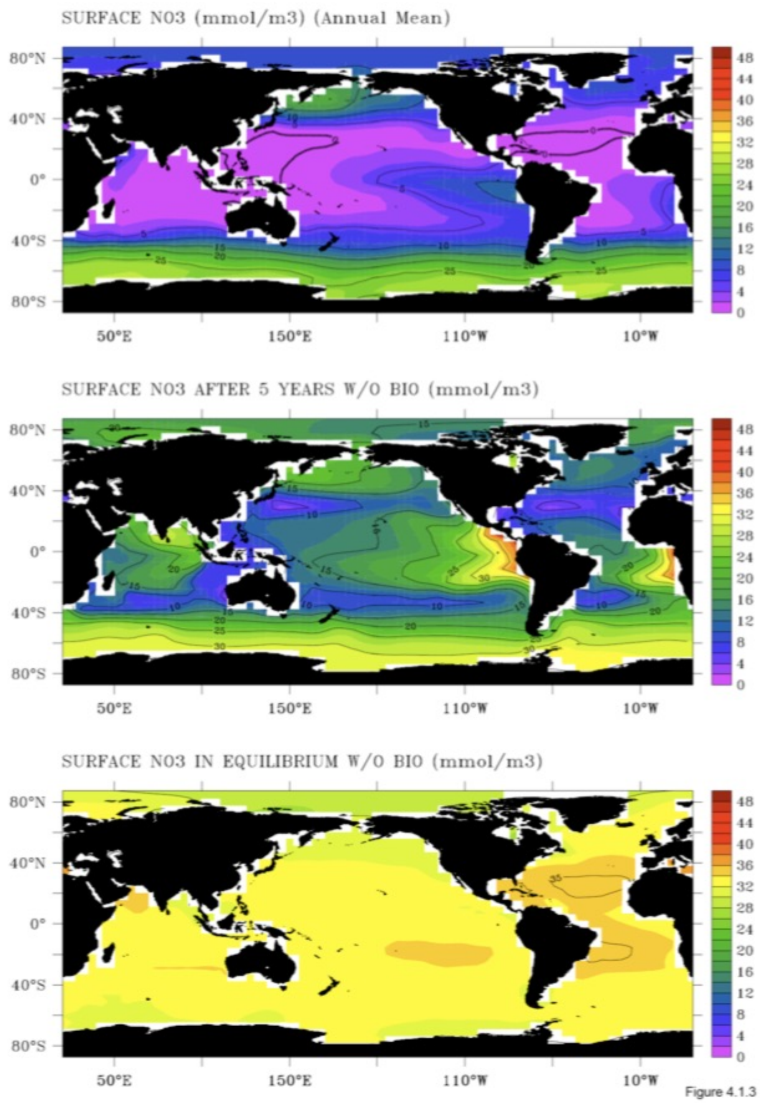

What would happen if we turned off biology?

In 5 years?

At equilibrium?

Global mean NO_3^- is ~31 µmol kg^{-1}

Sarmiento and Gruber (2006)

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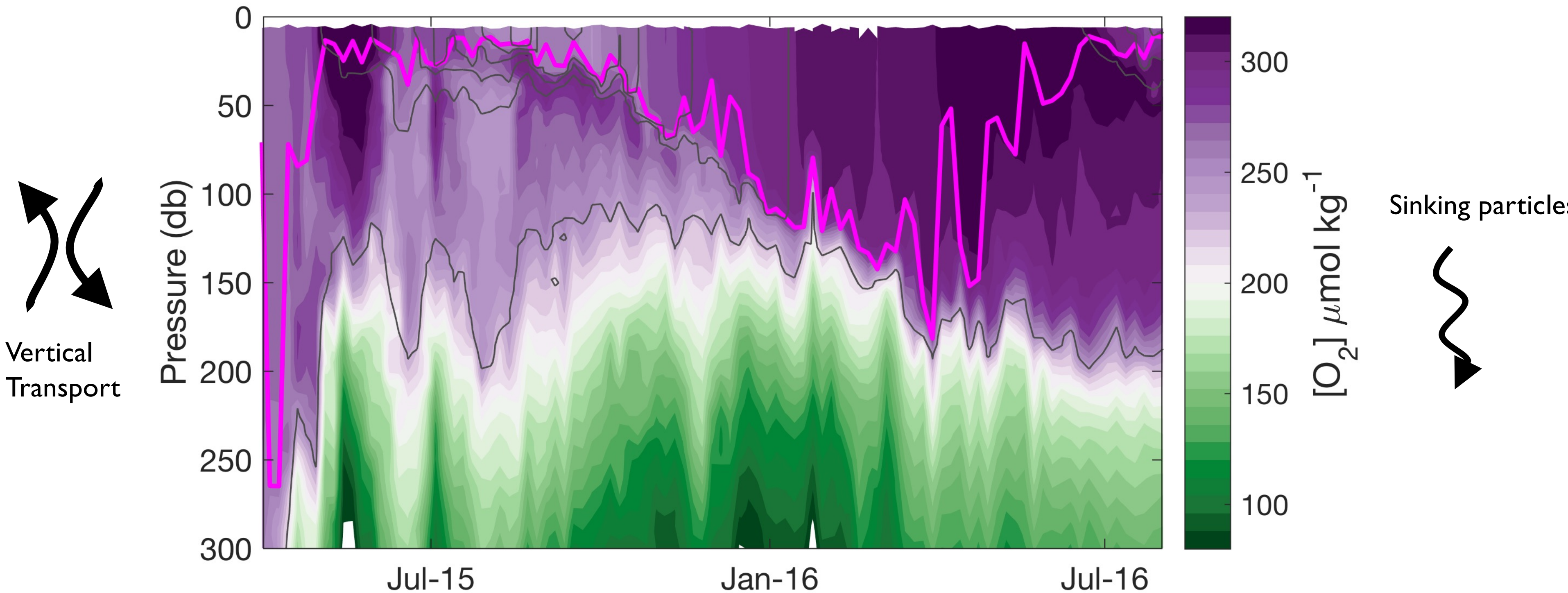
$CO_2 + H_2O +$ nutrients (N, P, trace) $\underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}}$ Organic matter $+ O_2$



$CO_2 + H_2O +$ nutrients (N, P, trace) $\xleftarrow{\text{Respiration}}$ Organic matter $+ O_2$

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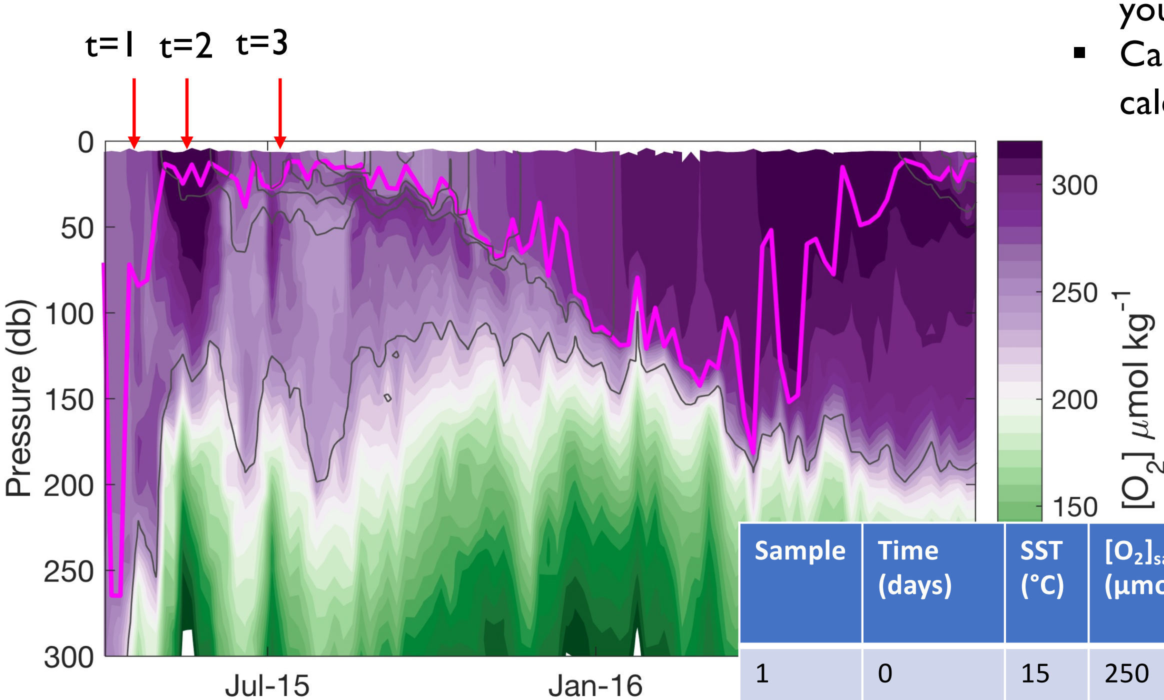
$CO_2 + H_2O +$ nutrients (N, P, trace) $\underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftarrows}}$ Organic matter + O_2

Given:

- G = 4 m d^{-1}
- ρ = 1000 kg m^{-3}

- Case 1: No Biological production, what do you expect the $[O2]_{ML}$ to be?
- Case 2: Using observed [O2], what do you calculate for a biological production rate?



Sample	Time (days)	SST (°C)	$[O_2]_{sat}$ (µmol kg^{-1})	MLD (m)	Case 1 - $[O_2]_{ML}$ (µmol kg^{-1})	Case 2 – $[O2]_{ML}$ (µmol kg^{-1})	F_{bio} (mmol m^{-2} O_2 d^{-1})
1	0	15	250	70	250	250	-----------
2	10	21	220	20	?	320	?
3	20	27	200	20	?	240	?

The Redfield or "RKR" Equation (A Model)

The mean elemental ratio of marine organic particles is given as:

P : N : C = 1 : 16 : 106

- The average ocean photosynthesis (forward) and aerobic (O_2) respiration (reverse) is written as:

106 CO_2 + 16 HNO_3 + H_3PO_4 + 122 H_2O + trace elements (*e.g. Fe, Zn, Mn…*) → $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)$ + 138 O_2

- Reduction half reactions:

$$CO_2 + 4H^+ + 4e^- \rightarrow CH_2O + H_2O$$

$$NO_3^- + 9H^+ + 8e^- \rightarrow NH_3 + 3H_2O$$

- Oxidation half reaction:

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

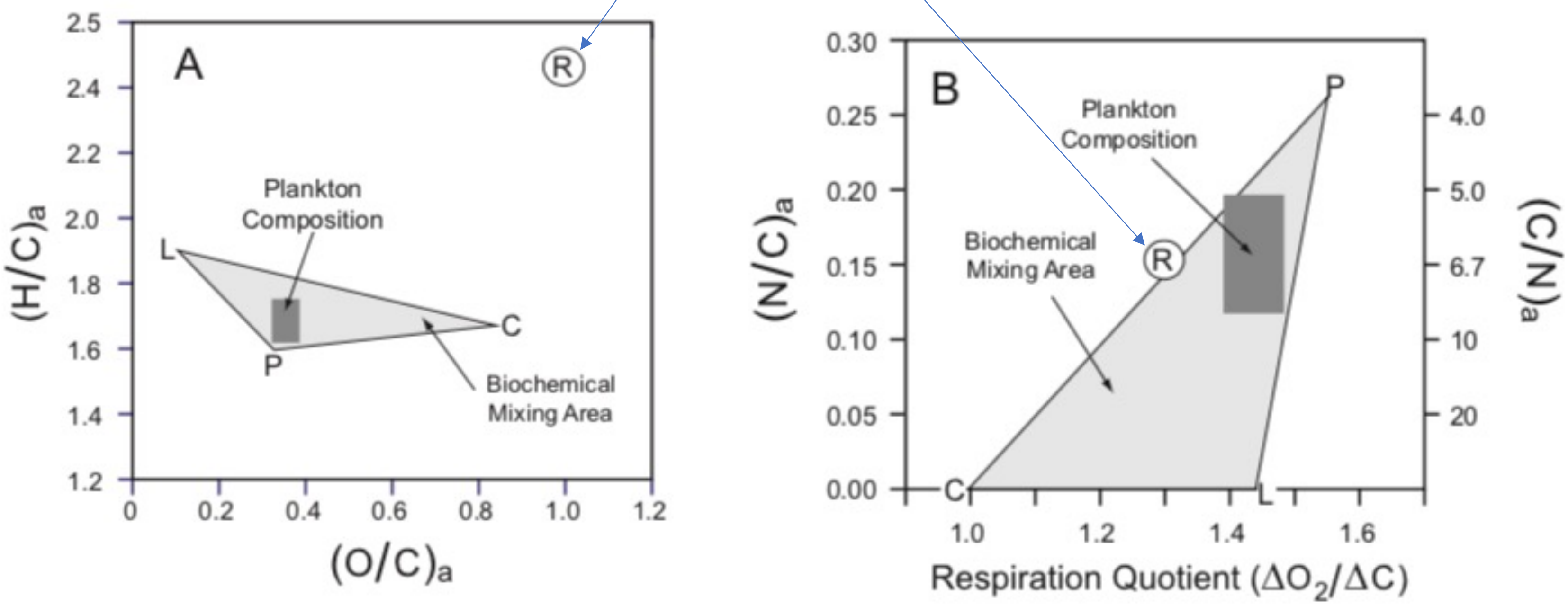
- From plankton tows
- O_2 production was estimated theoretically, assuming 1 mol of O_2 released for every atom of carbon converted into biomass and 2 moles of O_2 for every atom of nitrogen.
- Assumes all OM is carbohydrates (and represents OM as an average "molecule")

Actual ratios of C/N/P/O vary considerably

C – Carbohydrates
P – Proteins
L - Lipids

Redfield

Emerson and Hamme, 2021



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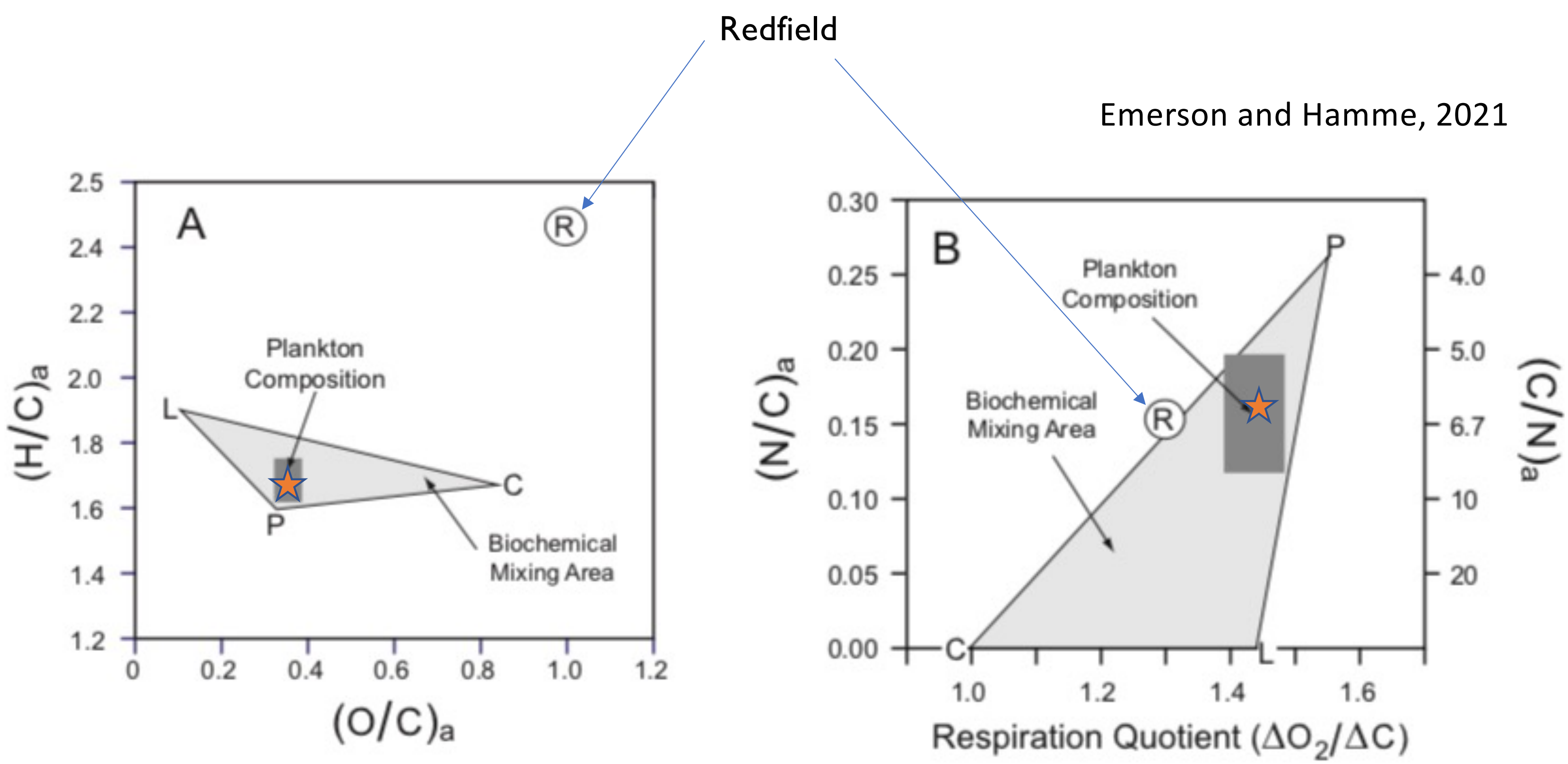


Modified RKR using actual stoichiometry of plankton:

$$106CO_2 + 16HNO_3 + H_3PO_4 + 80H_2O \rightarrow C_{106}H_{179}O_{38}N_{16}P\ (OM) + 153O_2$$

Biological production: limitations

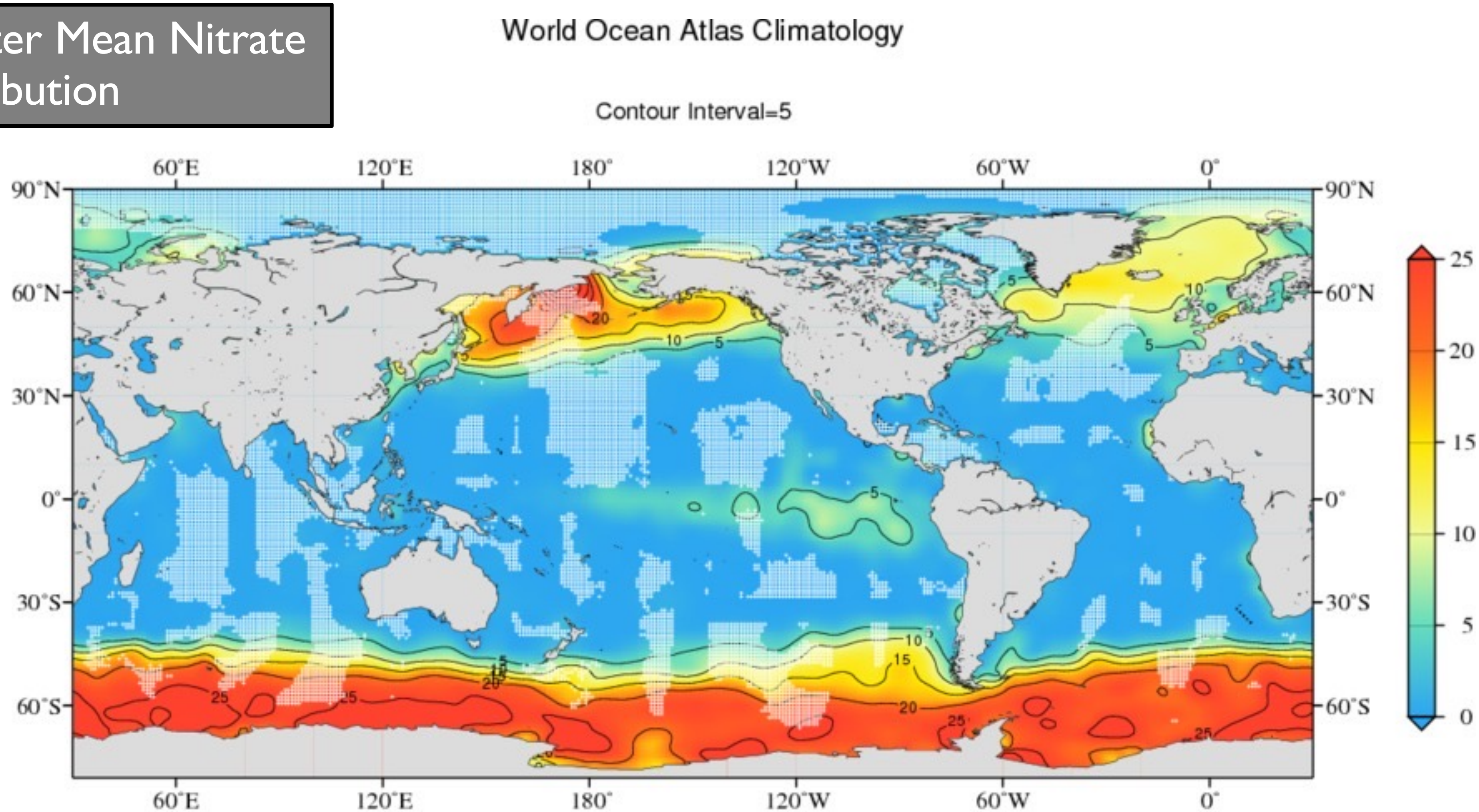
$$CO_2 + N + P + H_20 \underset{R}{\overset{P}{\rightleftarrows}} \text{Organic matter} + O_2$$

"*inorganic nutrients*": N, P and Si

They are also called "*biolimiting elements*" -- Why?

1. Small reservoir size in oceans
2. Fast turnover time
3. Required for many kinds of biological activity

Winter Mean Nitrate distribution



Winter (Jan.-Mar.) nitrate [umol/kg] at the surface (one-degree grid)

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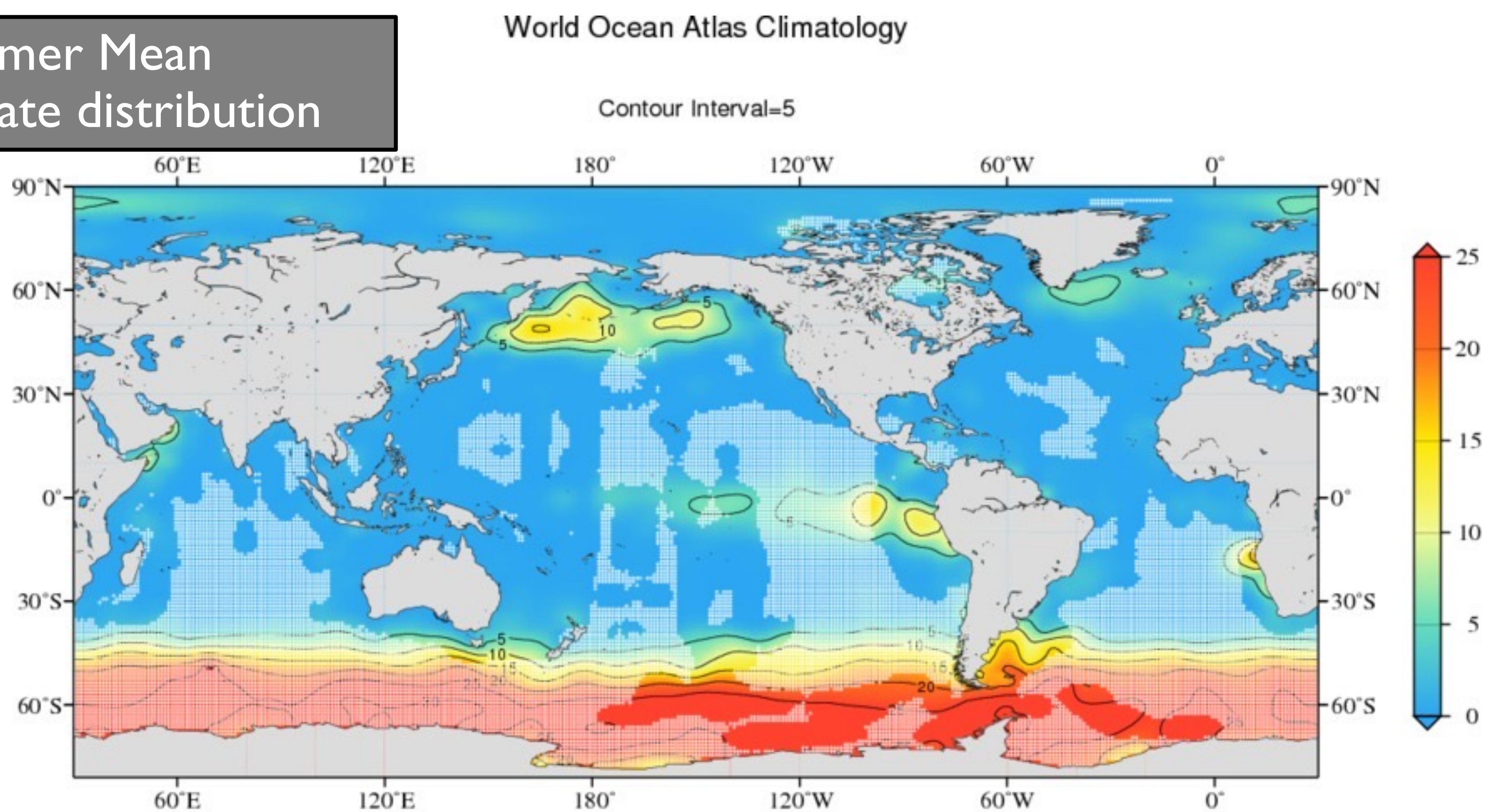
Summer Mean Nitrate distribution



Summer (Jul.-Sep.) nitrate [umol/kg] at the surface (one-degree grid)

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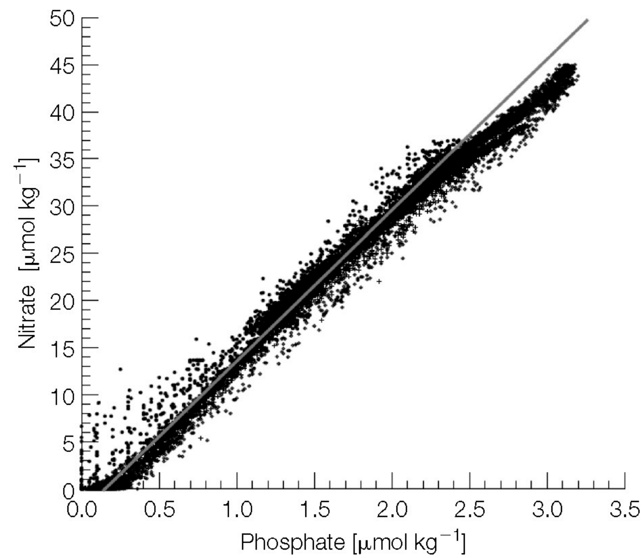
Biological production: limitations

$$CO_2 + N + P + H_20 \underset{R}{\overset{P}{\rightleftarrows}} \text{Organic matter} + O_2$$

"*inorganic nutrients*": N, P and Si – macronutrient limitation

Global DIN:DIP



Biological production: limitations

$$CO_2 + N + P + H_2 0 \underset{R}{\overset{P}{\rightleftarrows}} \text{Organic matter} + O_2$$

"*inorganic nutrients*": N, P and Si – macronutrient limitation

Trace metal needs:

Fe (photosynthesis, uptake of NH_4^+, N_2 fixation)

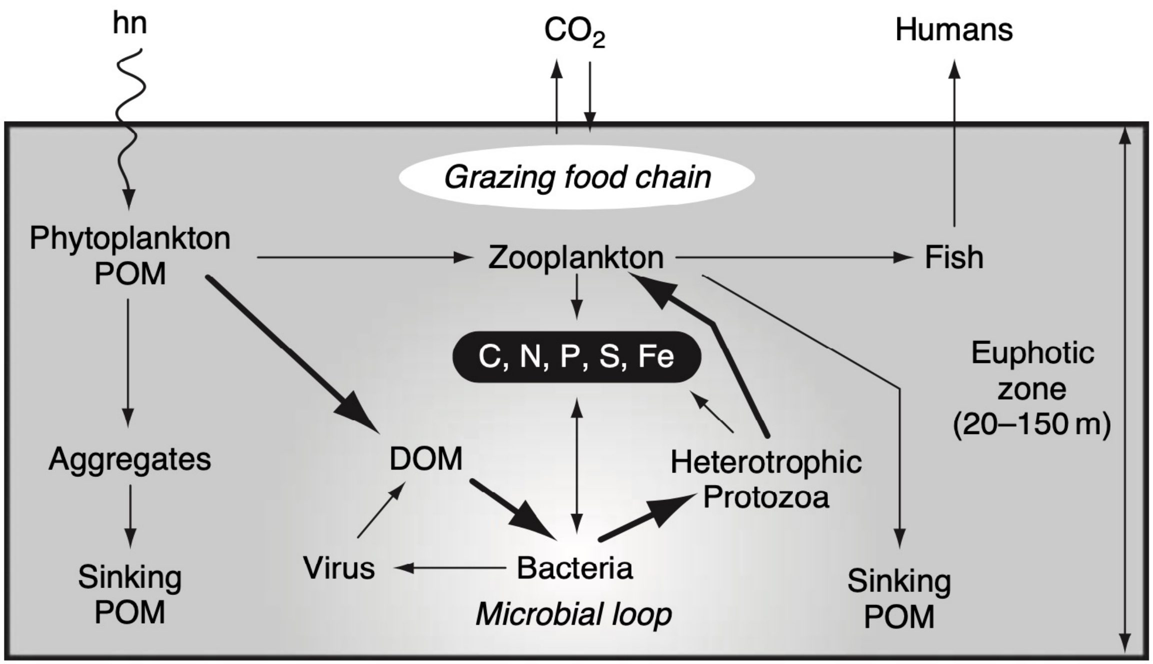
Mn (phtoynthesis)

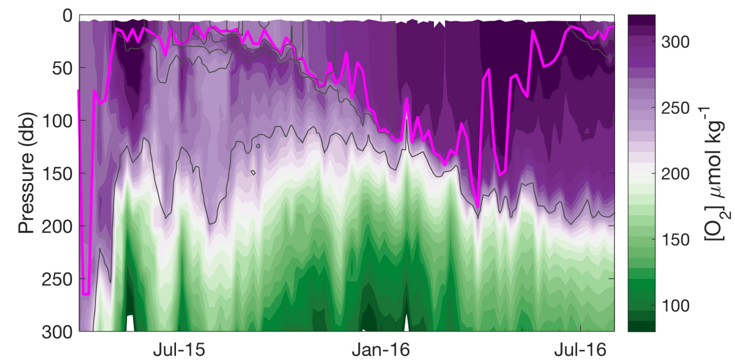
Zn (carbonic anhydrase, enzyme that catalyses HCO_3^- to CO_2)

Cu, Co, Ni

Can be limiting: High-Nutrient, Low Chlorophyll regions (HNLC)

What happens to that primary production?





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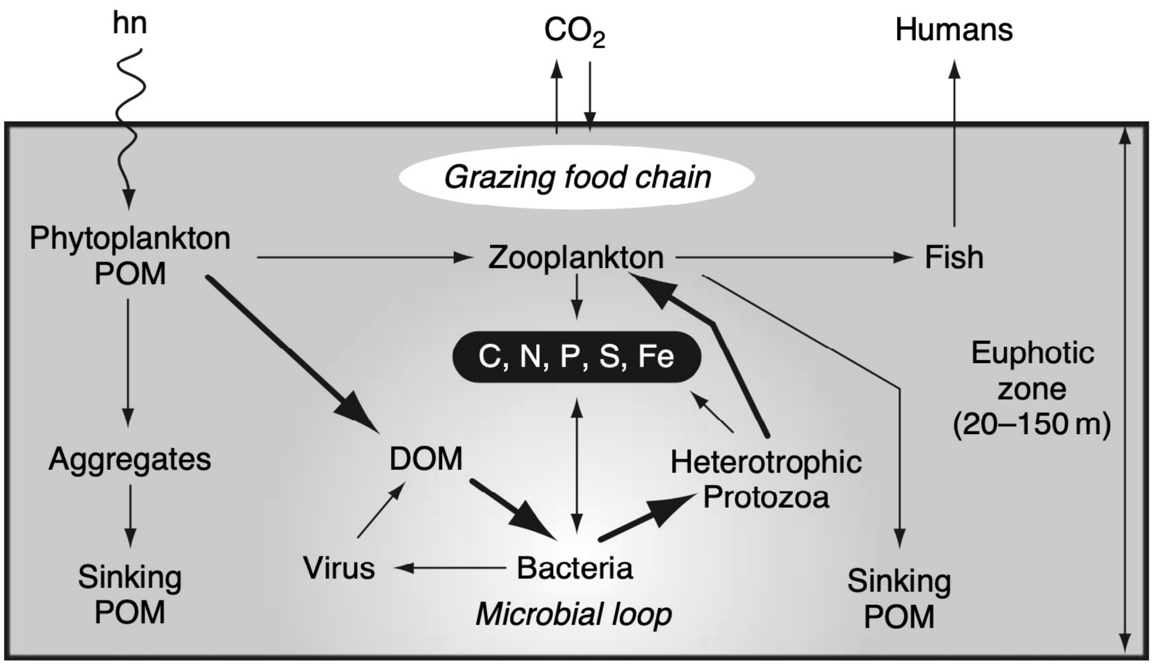
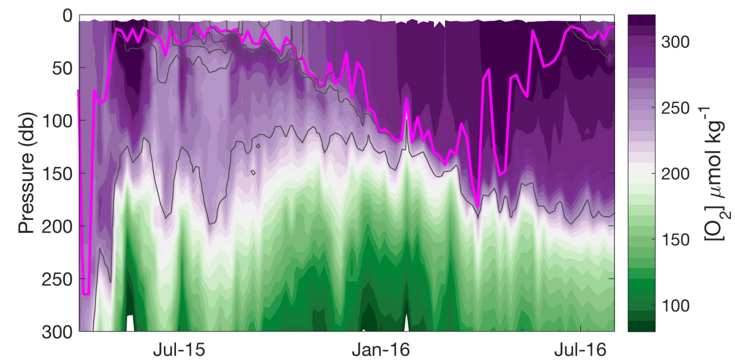
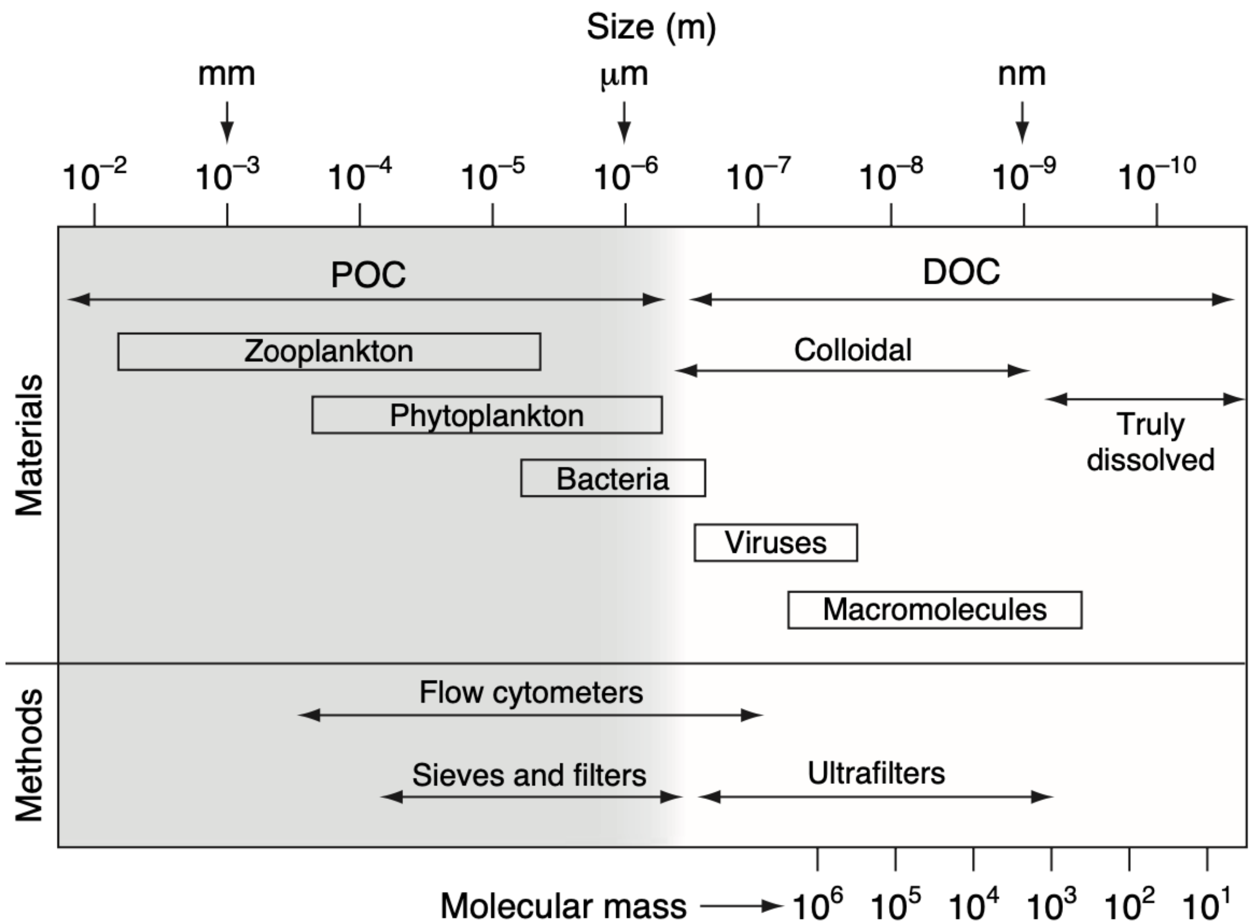




- **Primary production**: autotrophic production
- **Net primary production**: PP minus respiration by autotrophs
- **Net community production**: PP minus all respiration (auto and heterotrophic)
- **Annual net community production**:The amount of organic matter that is produced but is removed from contact with the upper ocean on time scales >1yr

Dissolved vs. Particulate: Operational definition



Emerson and Hedges 2008

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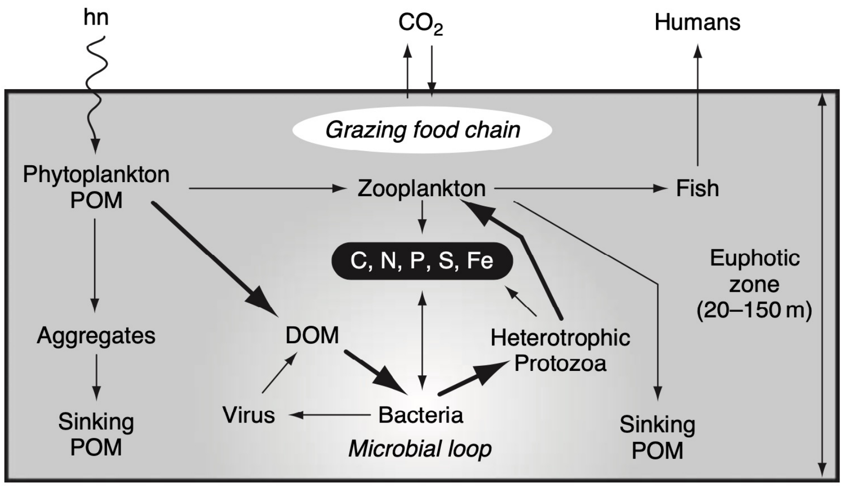
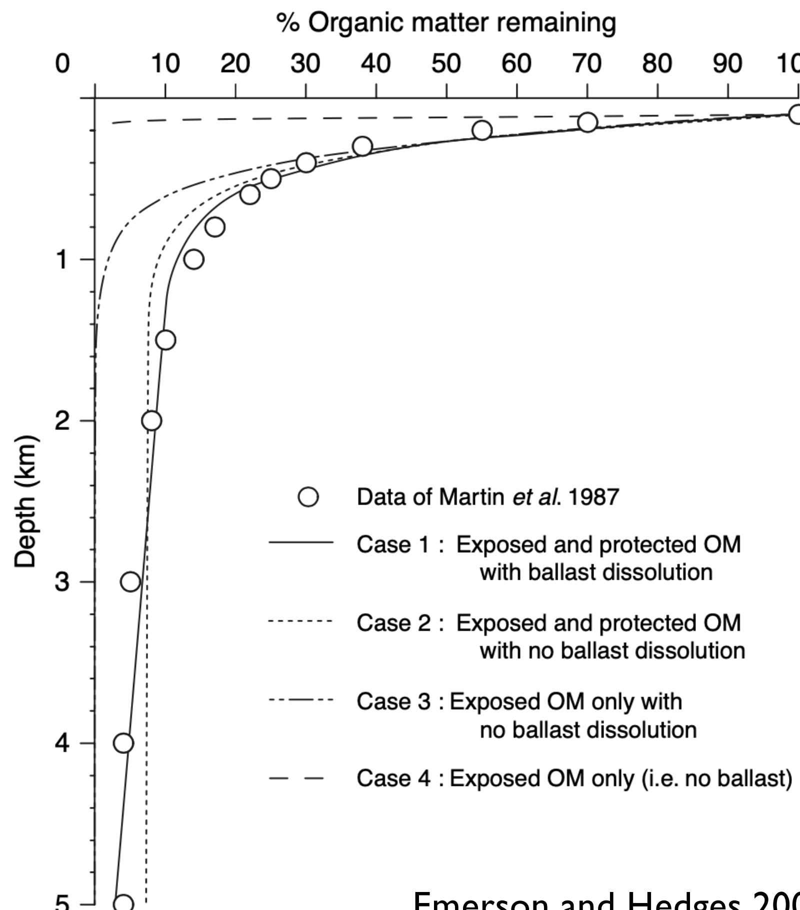
The Martin Curve: How much OM sinks out of the upper ocean?



- Carbon leaving upper ocean is a mix of soft (OM) and hard parts (silica and calcium carbonate shells)
- ~6% of carbon leaving upper ocean is $CaCO_3$
- SiO_2 is often ~2x the $CaCO_3$
- Weights down OM, also can protect from grazing



Emerson and Hedges 2008

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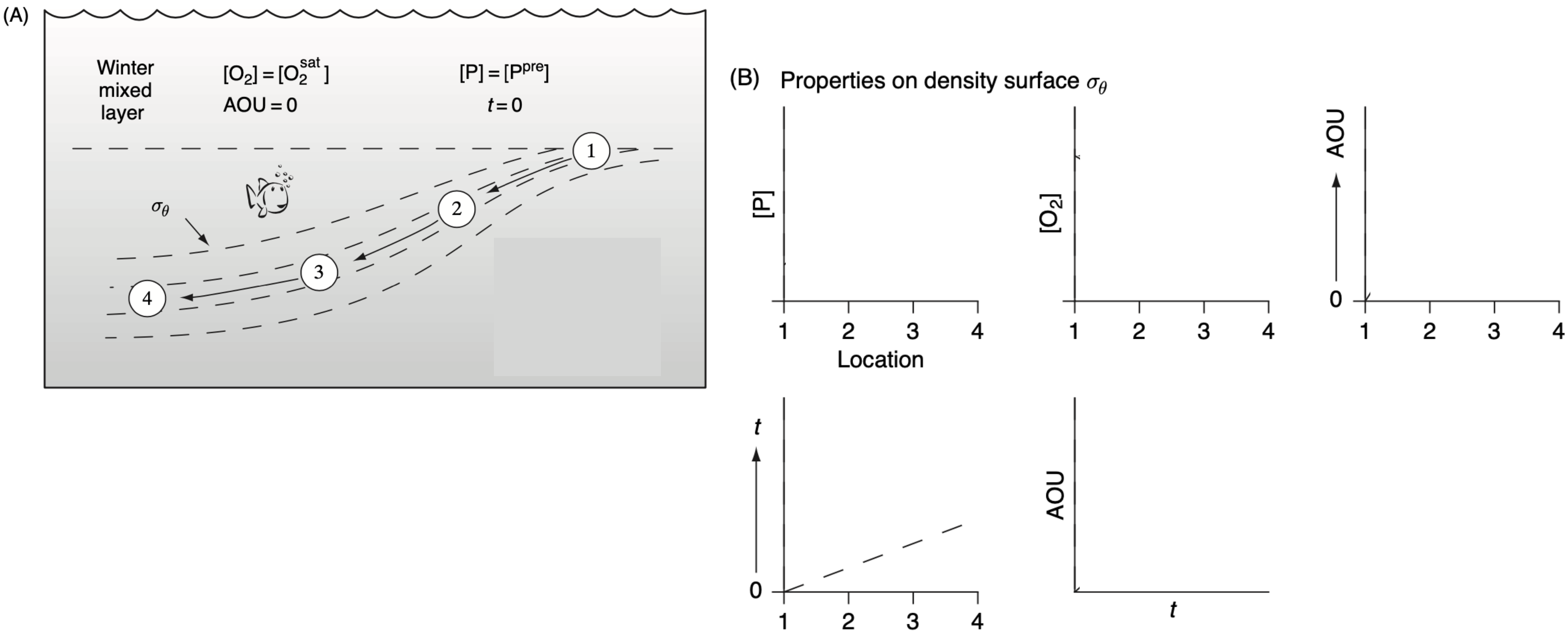
Property evolution after a water parcel leaves the surface



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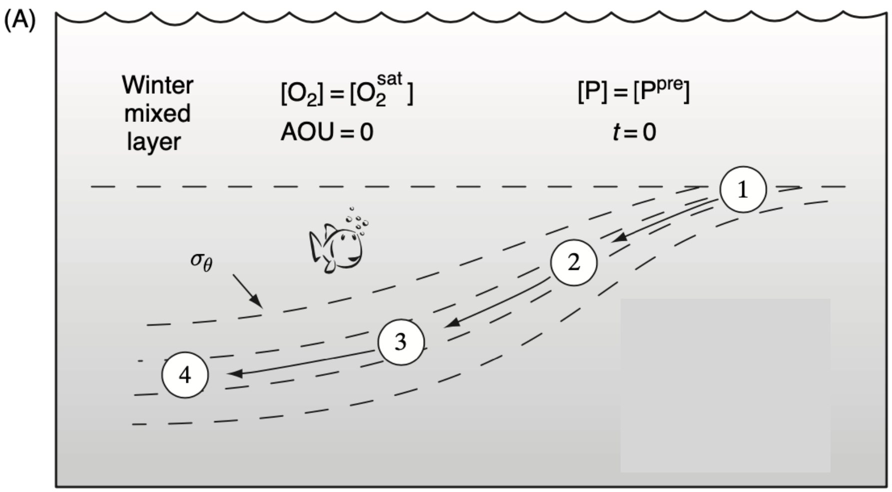

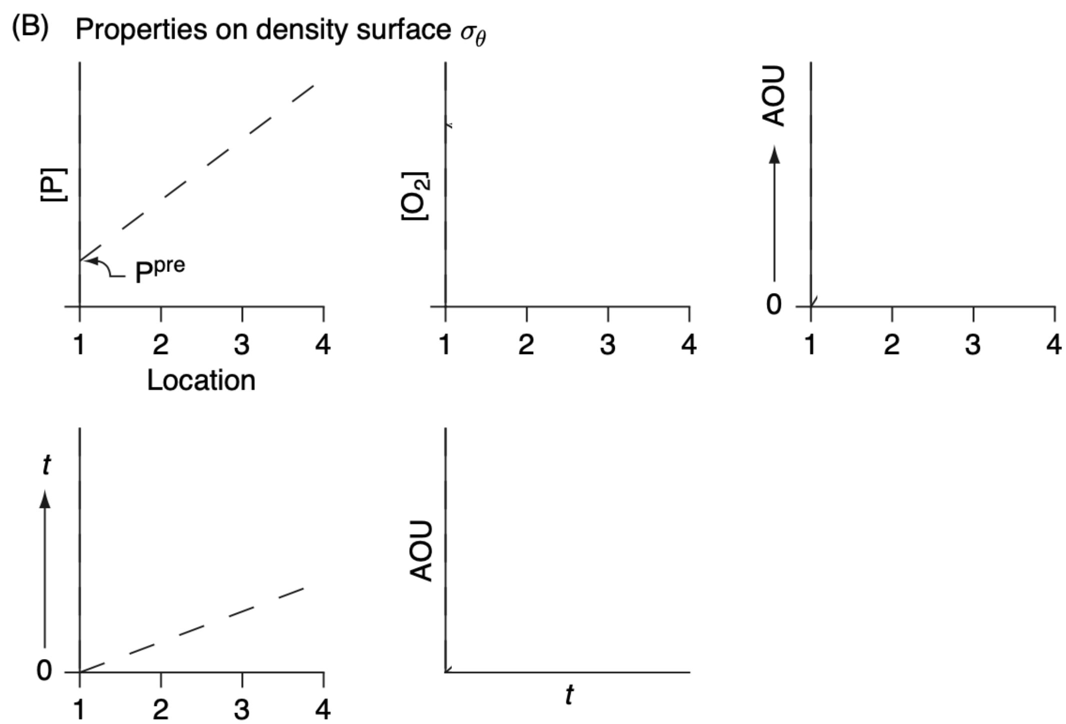

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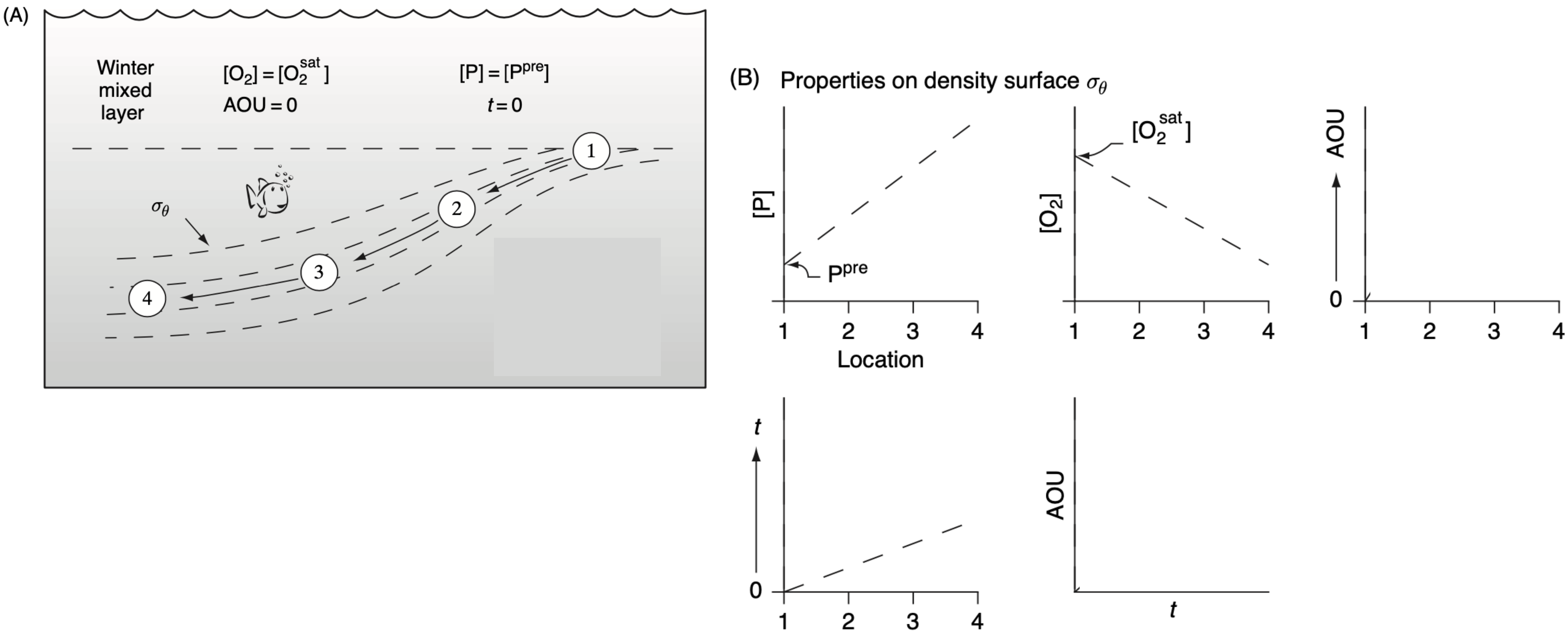

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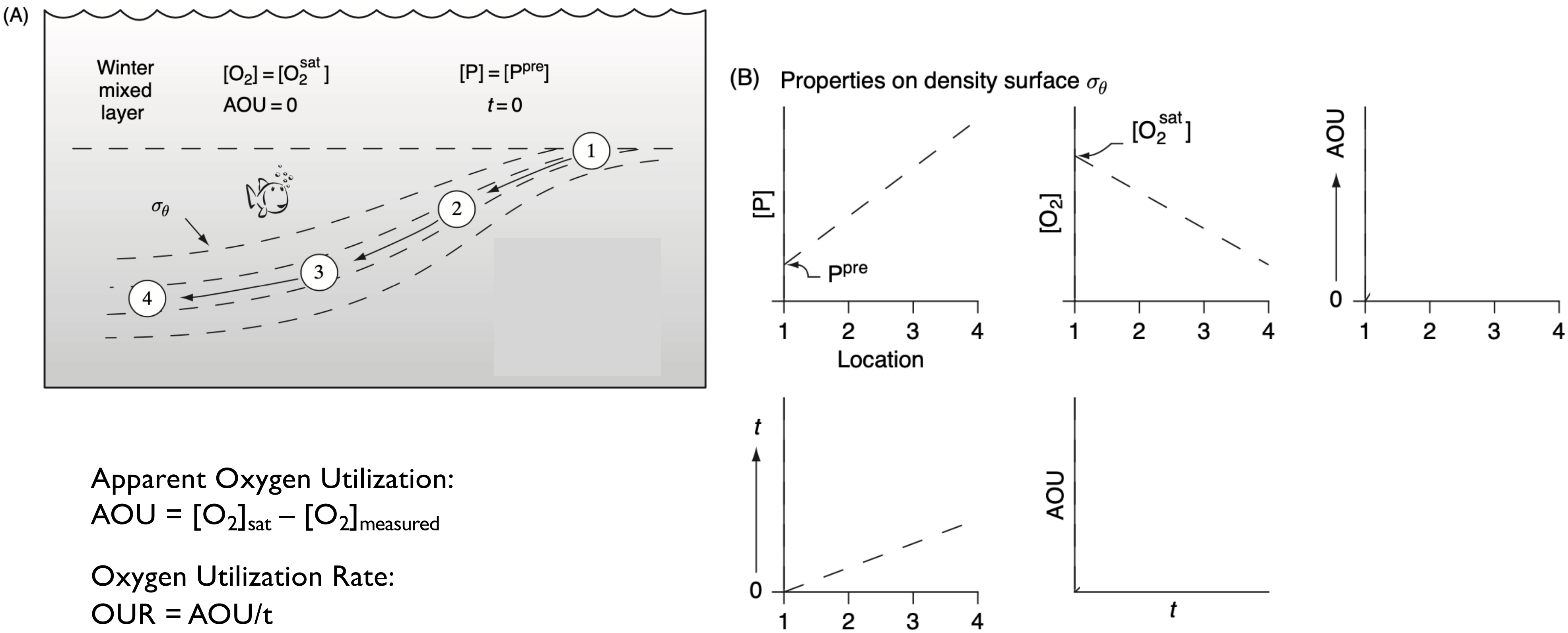

Apparent Oxygen Utilization:
$AOU = [O_2]_{sat} - [O_2]_{measured}$

Oxygen Utilization Rate:
$OUR = AOU/t$

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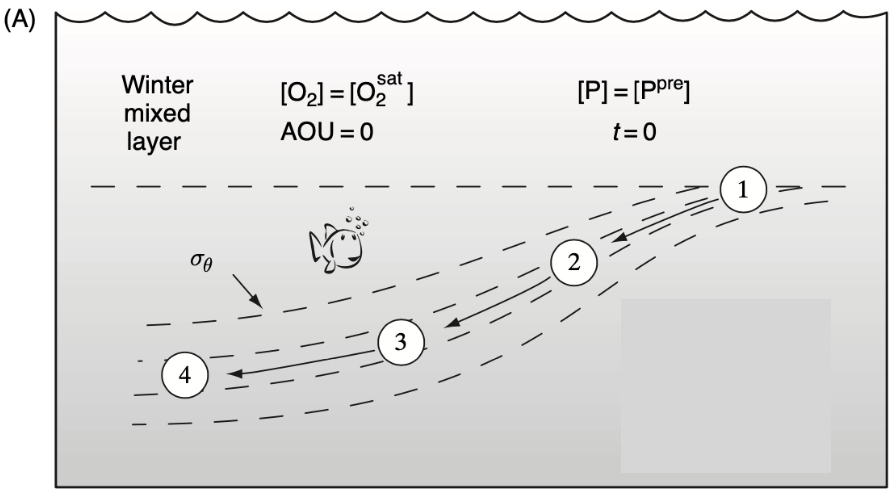
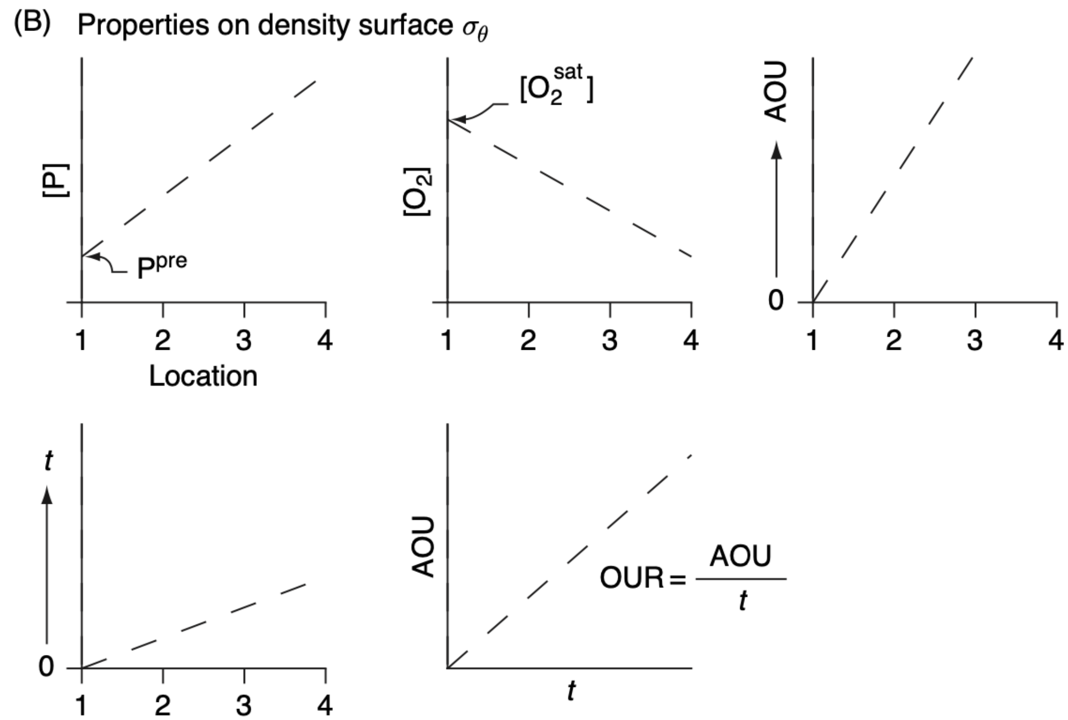
Property evolution after a water parcel leaves the surface





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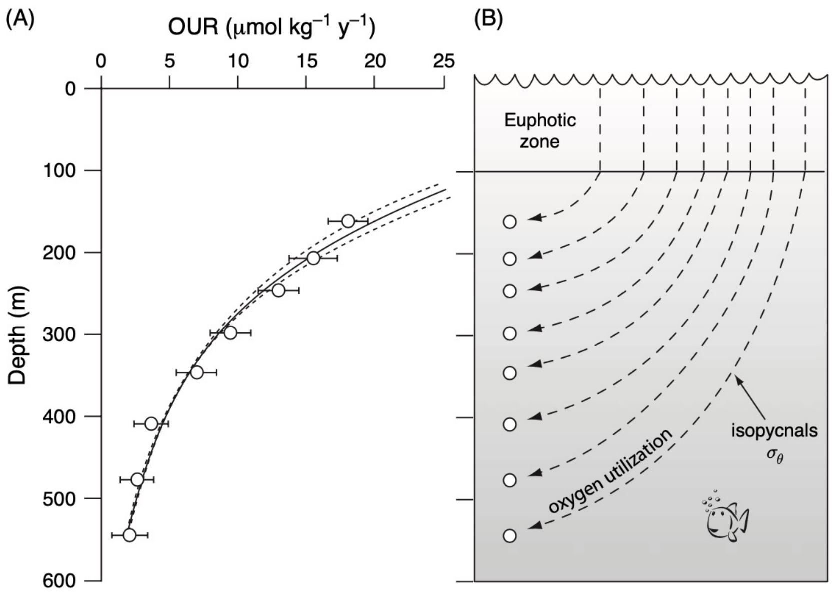
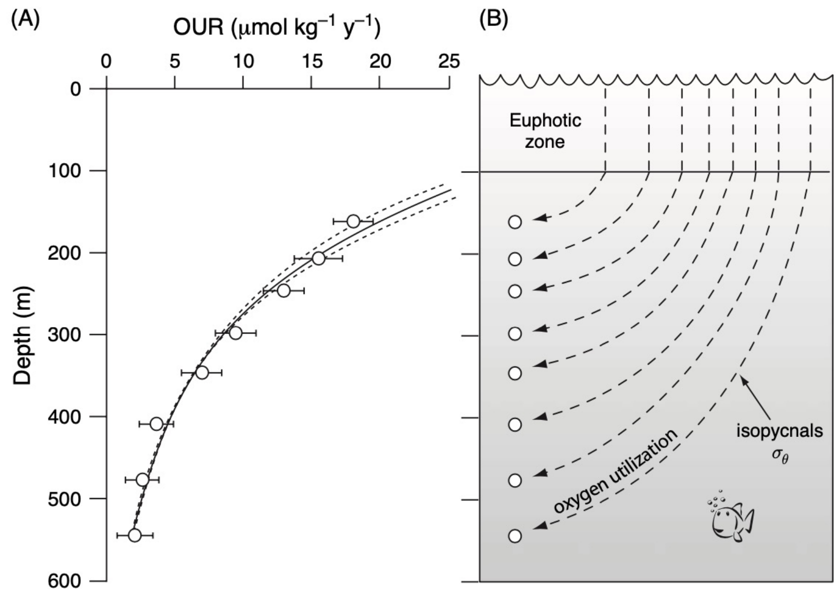


- Why does OUR decrease with depth?

- Most of the organic matter that crosses 100m is respired by 200m (1/e remains at ~165 m)

Property evolution after a water parcel leaves the surface



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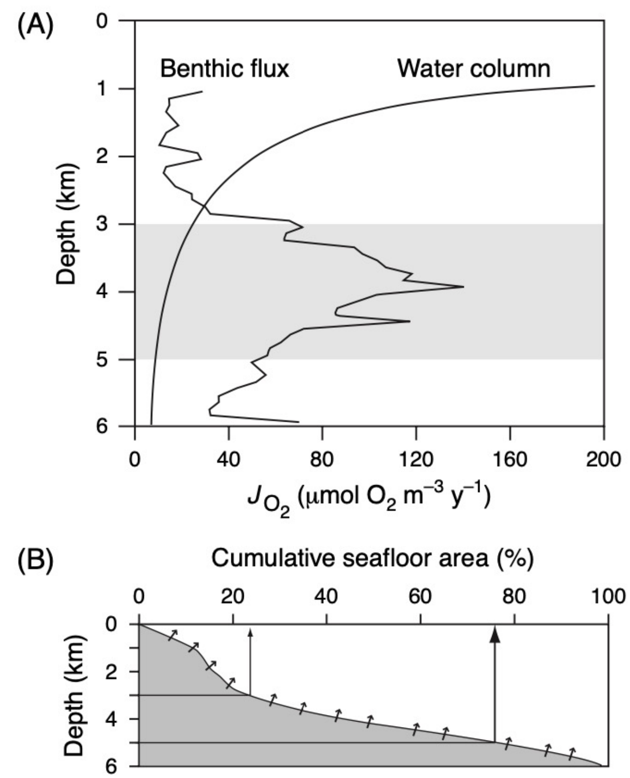

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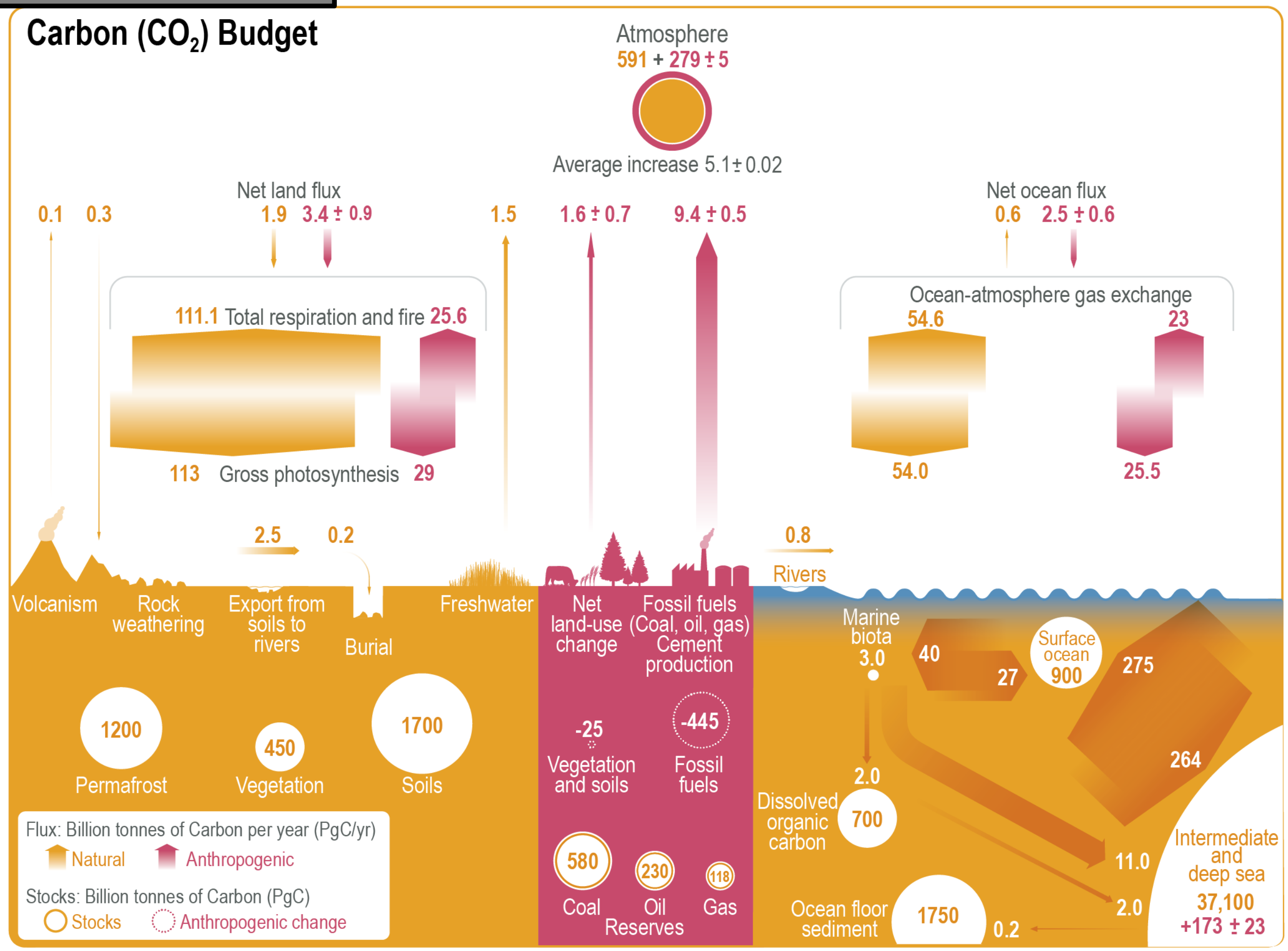
Global Carbon budget



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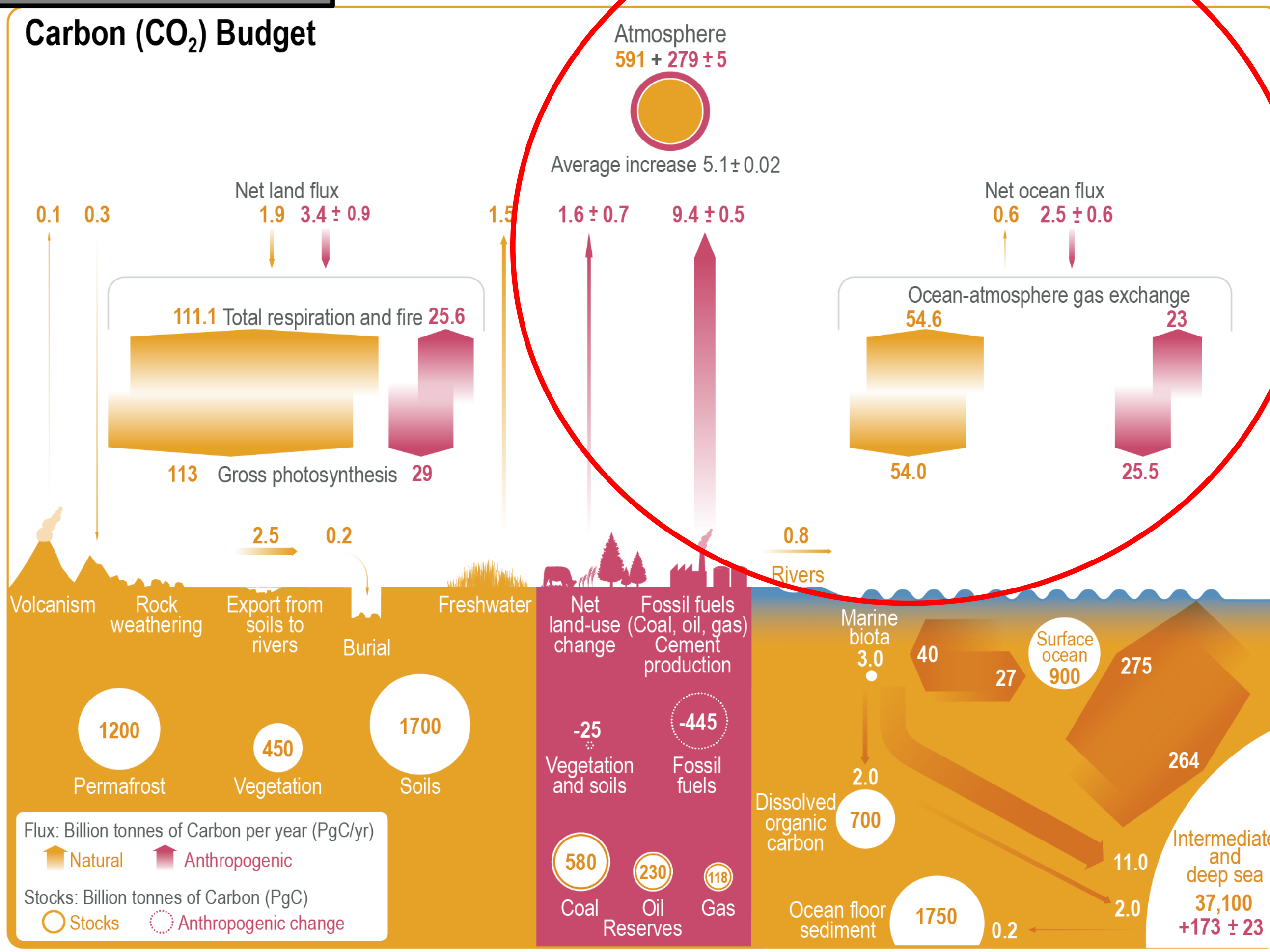
Global Carbon budget



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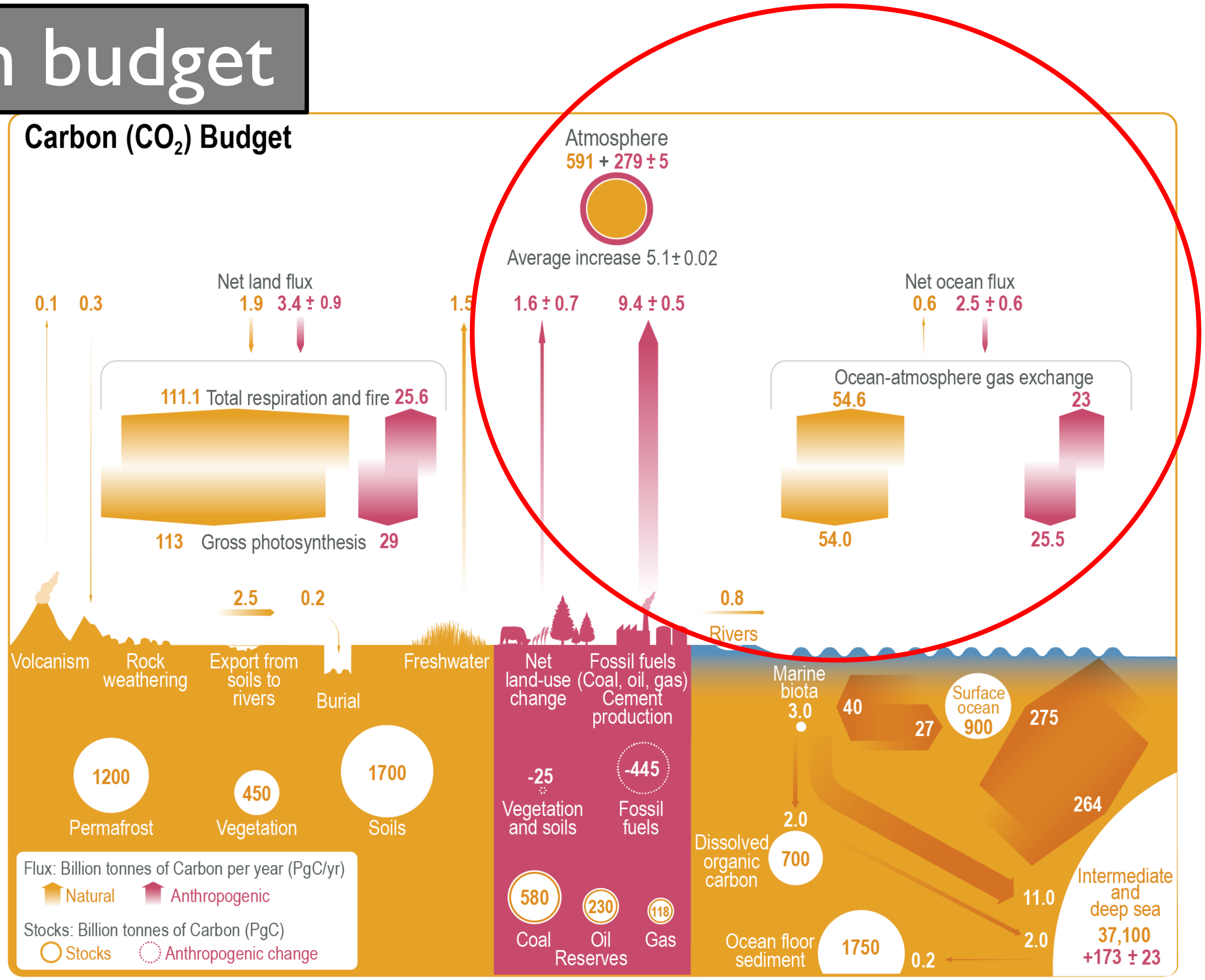
Global Carbon budget

Units: Pg C yr[-1]

- Atmospheric increase: 5
- Emissions (FF and Land use): 11
- Ocean uptake: 2.5
  - -0.6 Natural outgassing + 2.5 anthropogenic uptake = 1.9 Contemporary Ocean uptake



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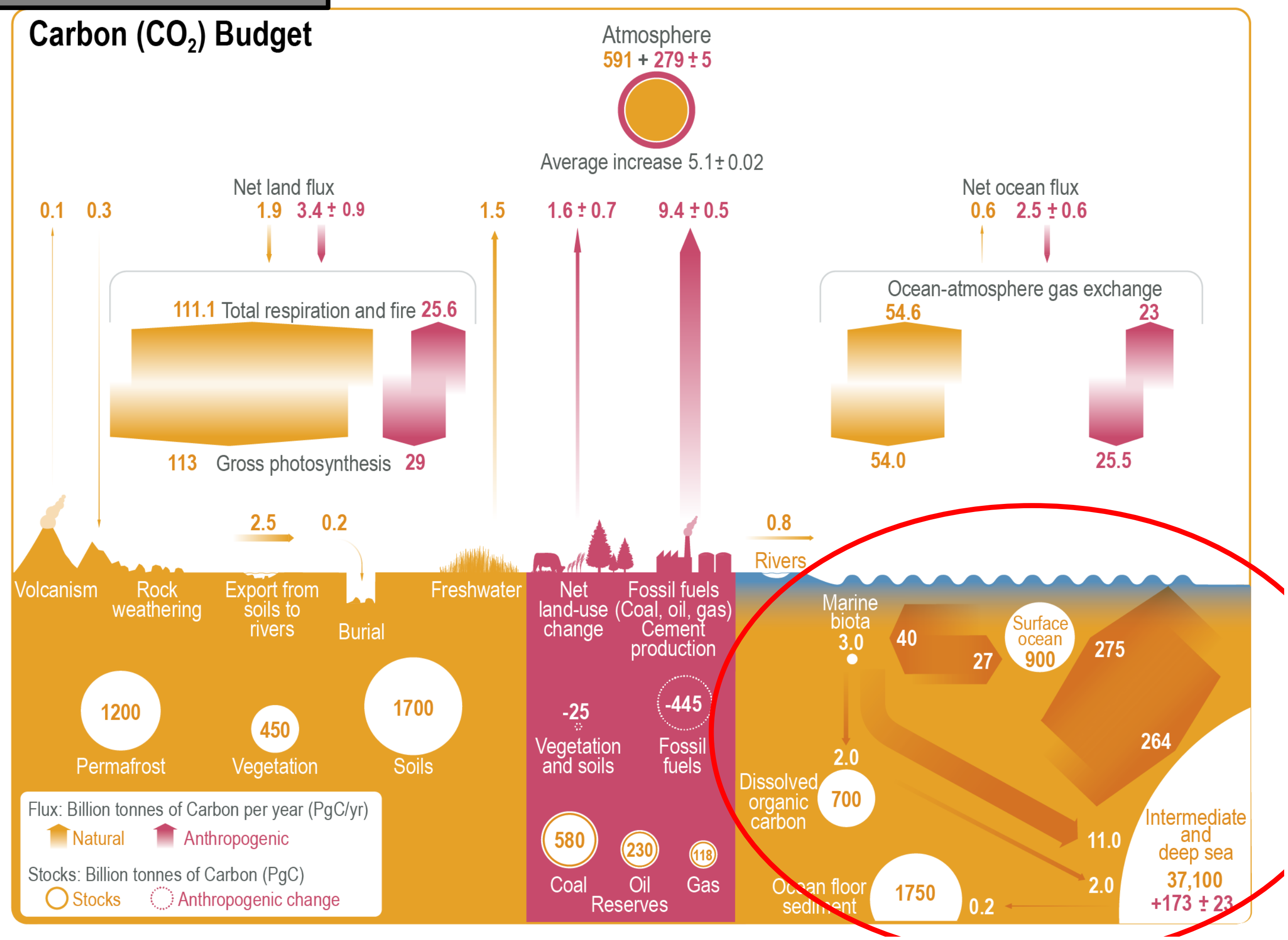
Global Carbon budget



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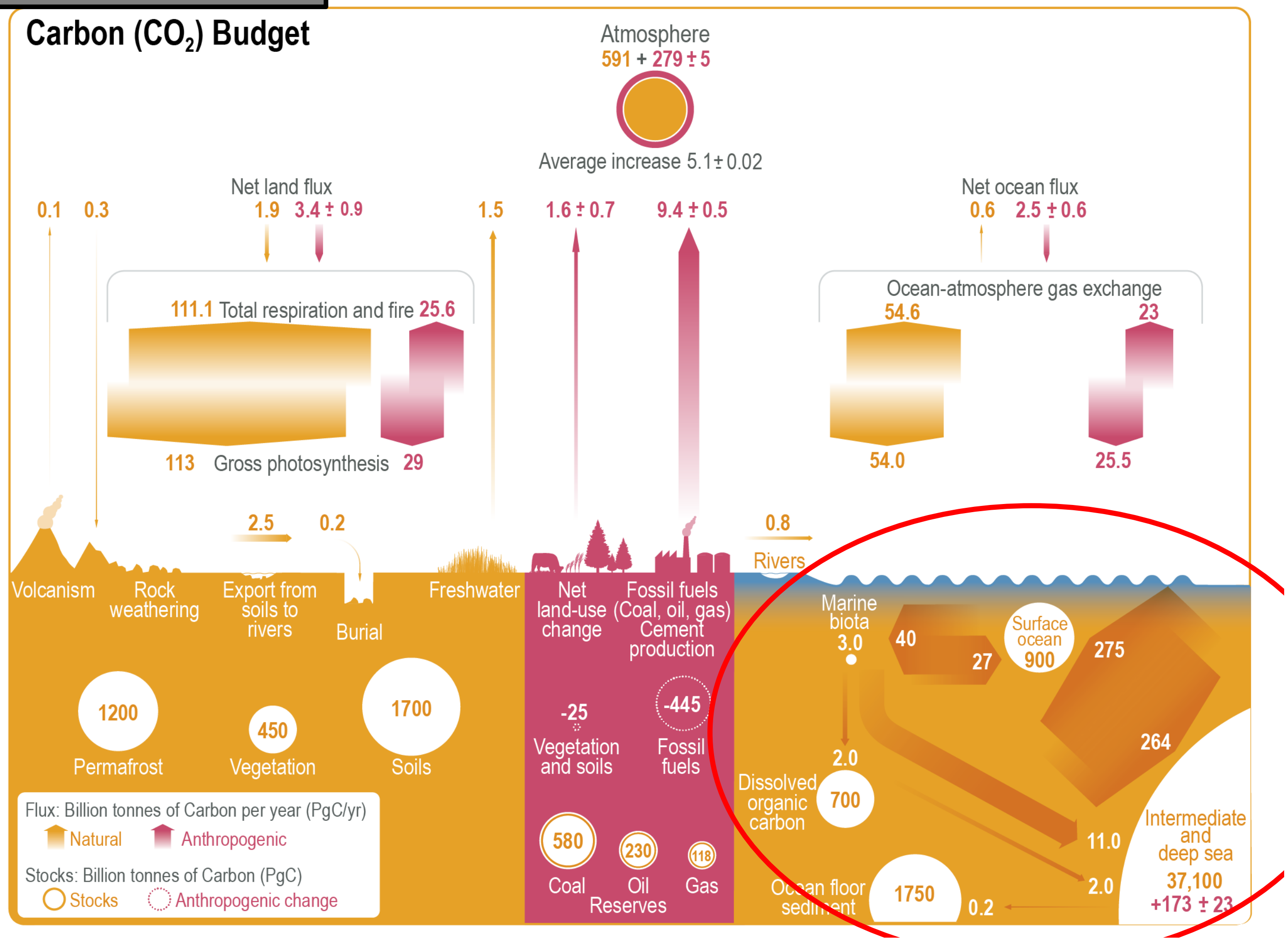
Global Carbon budget

Units: Pg C yr[-1]

- Bio pump (ANCP): ~13
- Solubility pump: 264 down, 275 up
- Biological carbon export is ~5-10% the magnitude of the solubility pump
  - Significant uncertainty in control / response to changes
  - Provides an avenue for long-term burial

- Sediment: 0.2
- Does biological carbon pump contribute to ocean's uptake of anthropogenic carbon?



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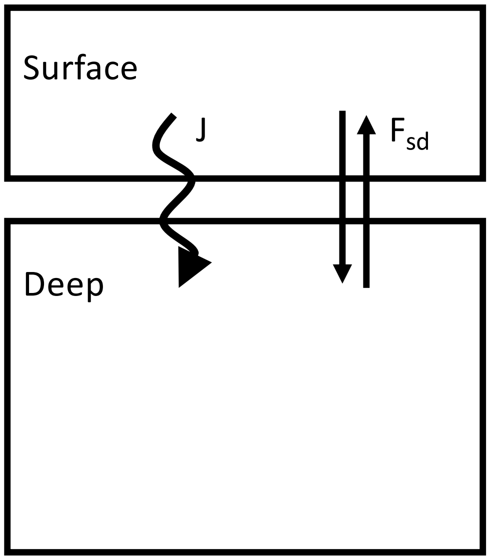
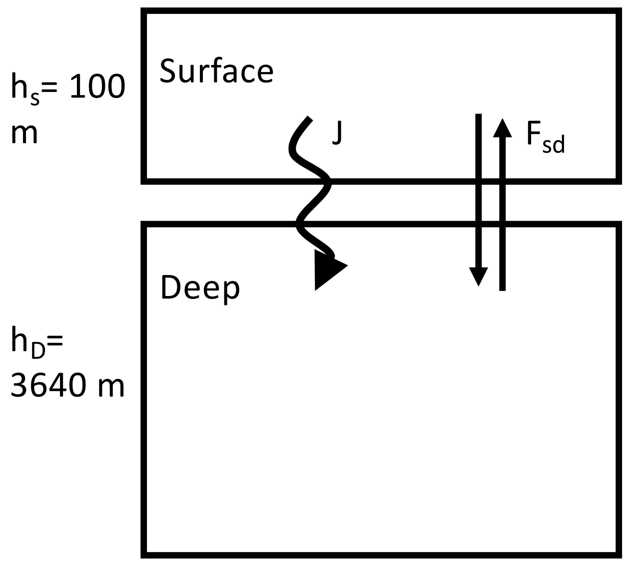
Box models: two boxes



- What are the mass balance equations in the upper ocean? What about the deep ocean?

Box models: two boxes

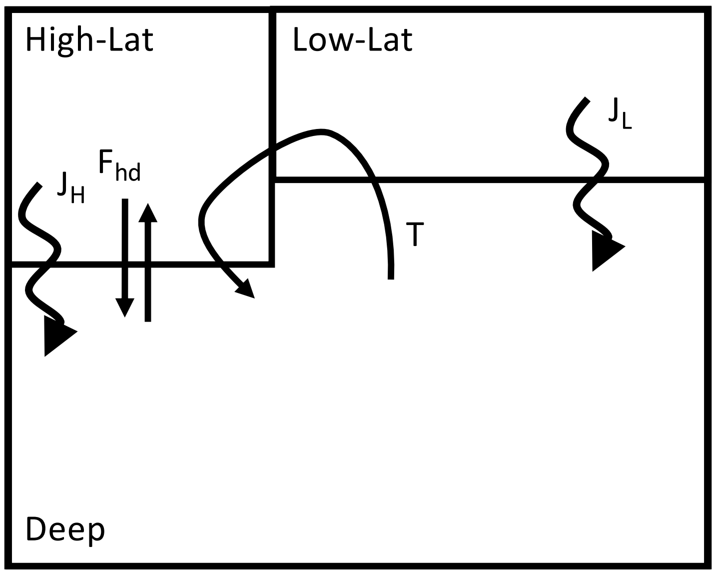


- What are the mass balance equations in the upper ocean? What about the deep ocean?

Given:
$[PO_4^{3-}]_{deep}$ = 2.2 µmol/kg
$[PO_4^{3-}]_{surface}$ = 1.0 µmol/kg
$[O_2]_{surface}$= 275 µmol/kg (the saturation value)
P:N:C:O_2 ratio in particles is 1:16:106:-154
All particles are respired in the deep ocean.

F_{SD} = 1.26 x 10^{15} m^3 yr^{-1}, what is the particle flux of phosphate and carbon?

Box models: three boxes



- Mass balance equations for three boxes?