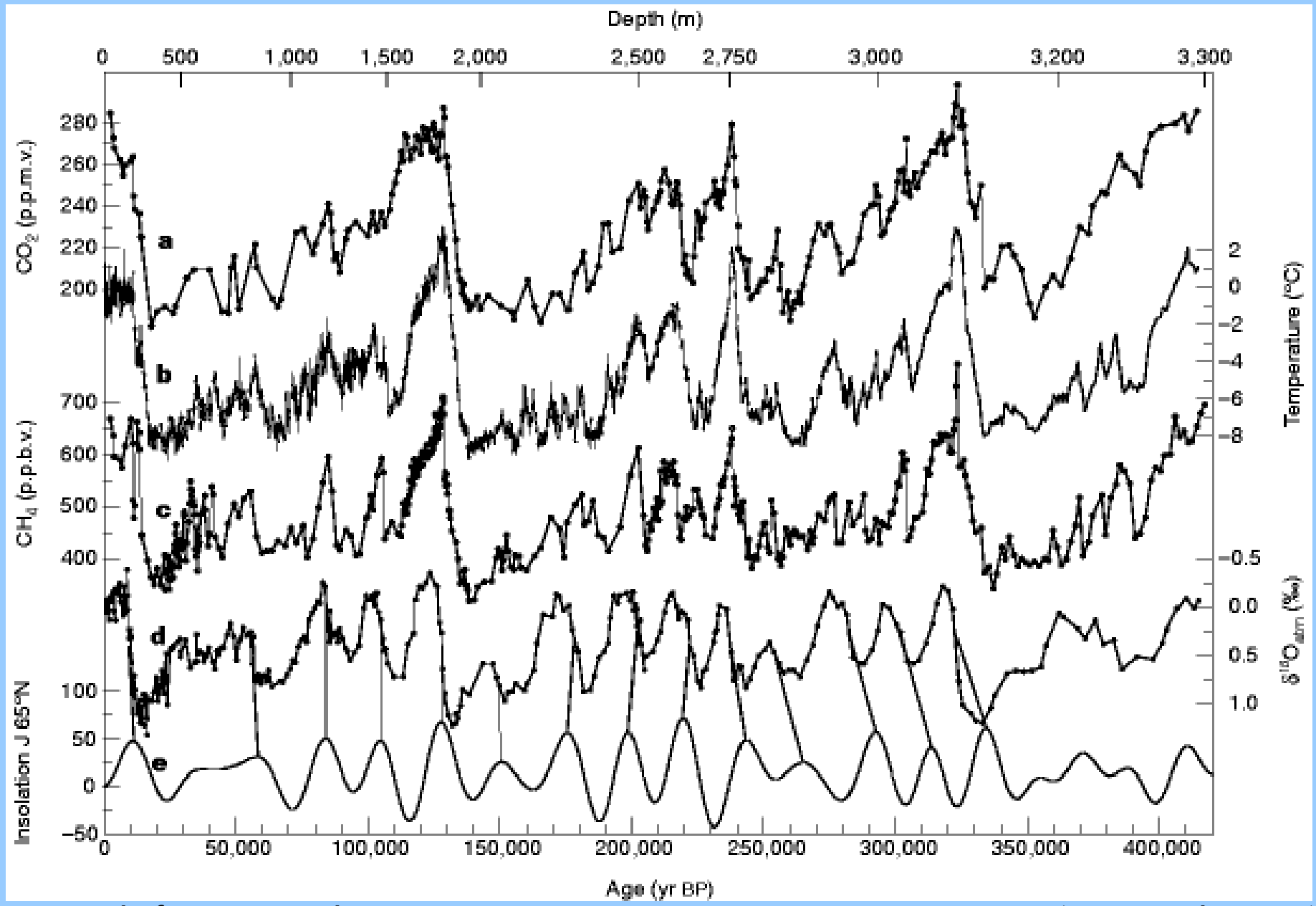
A Very Brief Introduction to the Ocean Carbon Cycle

Mick Follows

Dec 2004

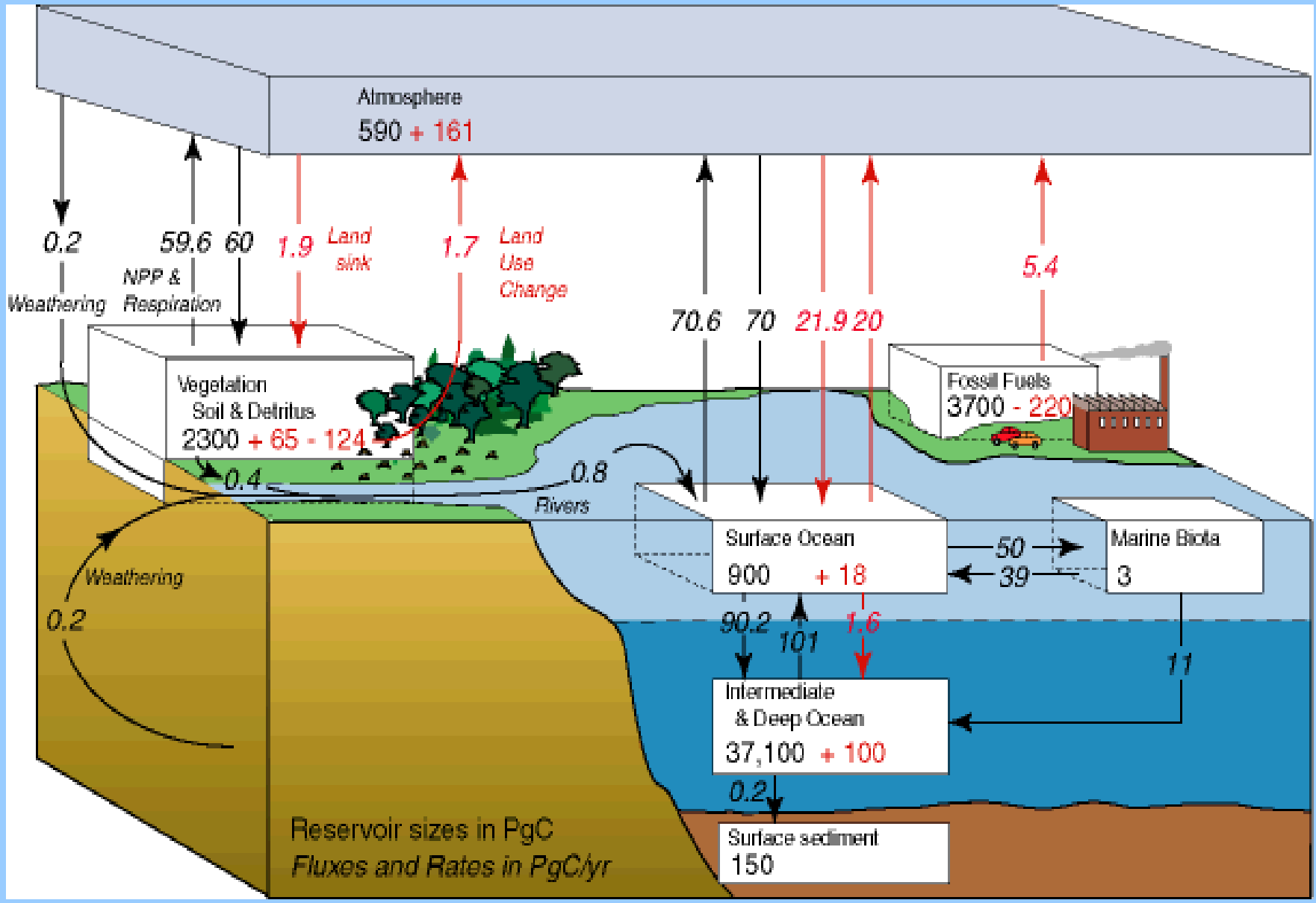
http://ocean.mit.edu/~mick/Docs/carbon-intro.pdf

- What controls glacial-interglacial variation of atmospheric CO_2?
- What is the connection to climate change?



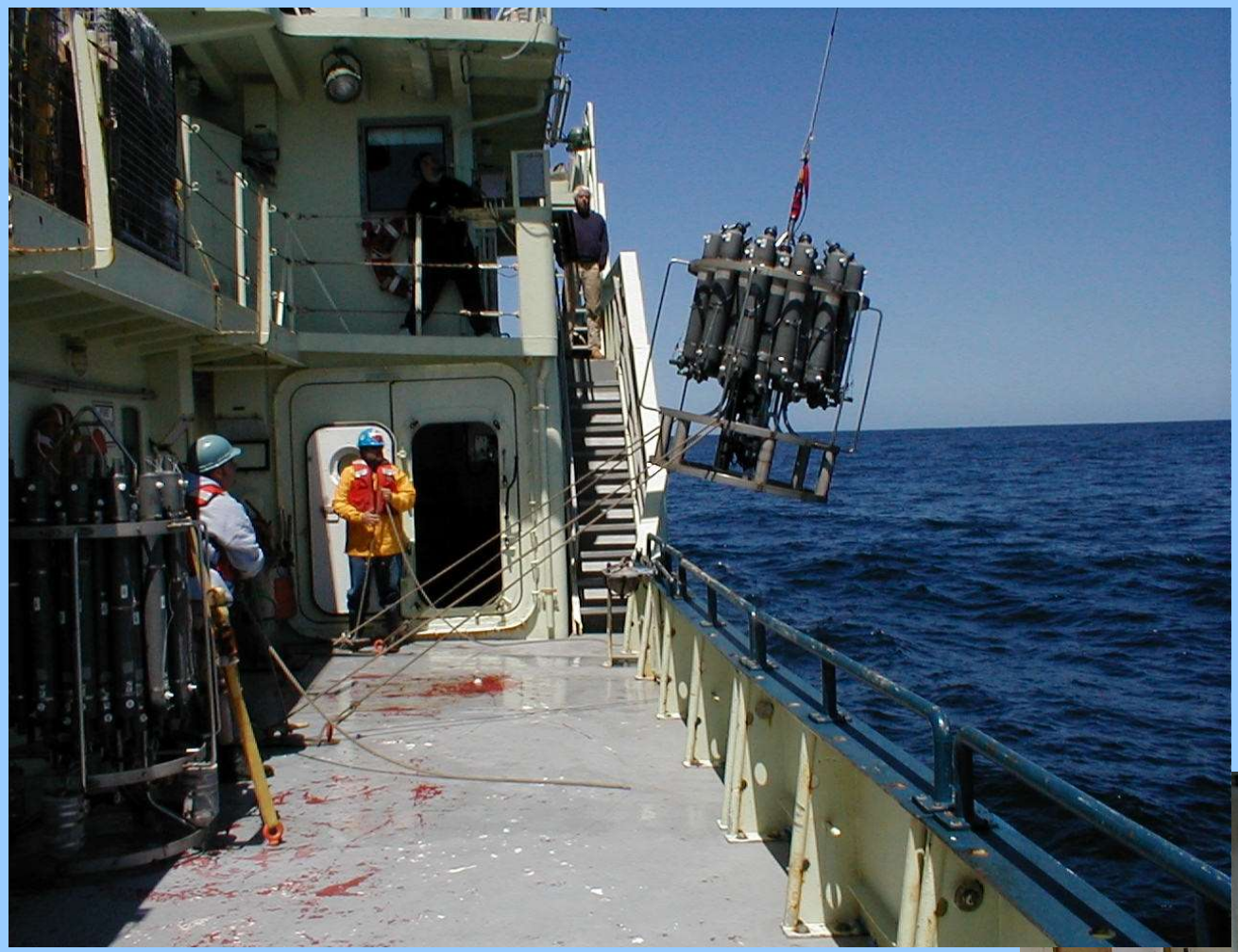
Ice core records from Vostock, Antarctica (Petit et al., 1999)

The Global Carbon Cycle



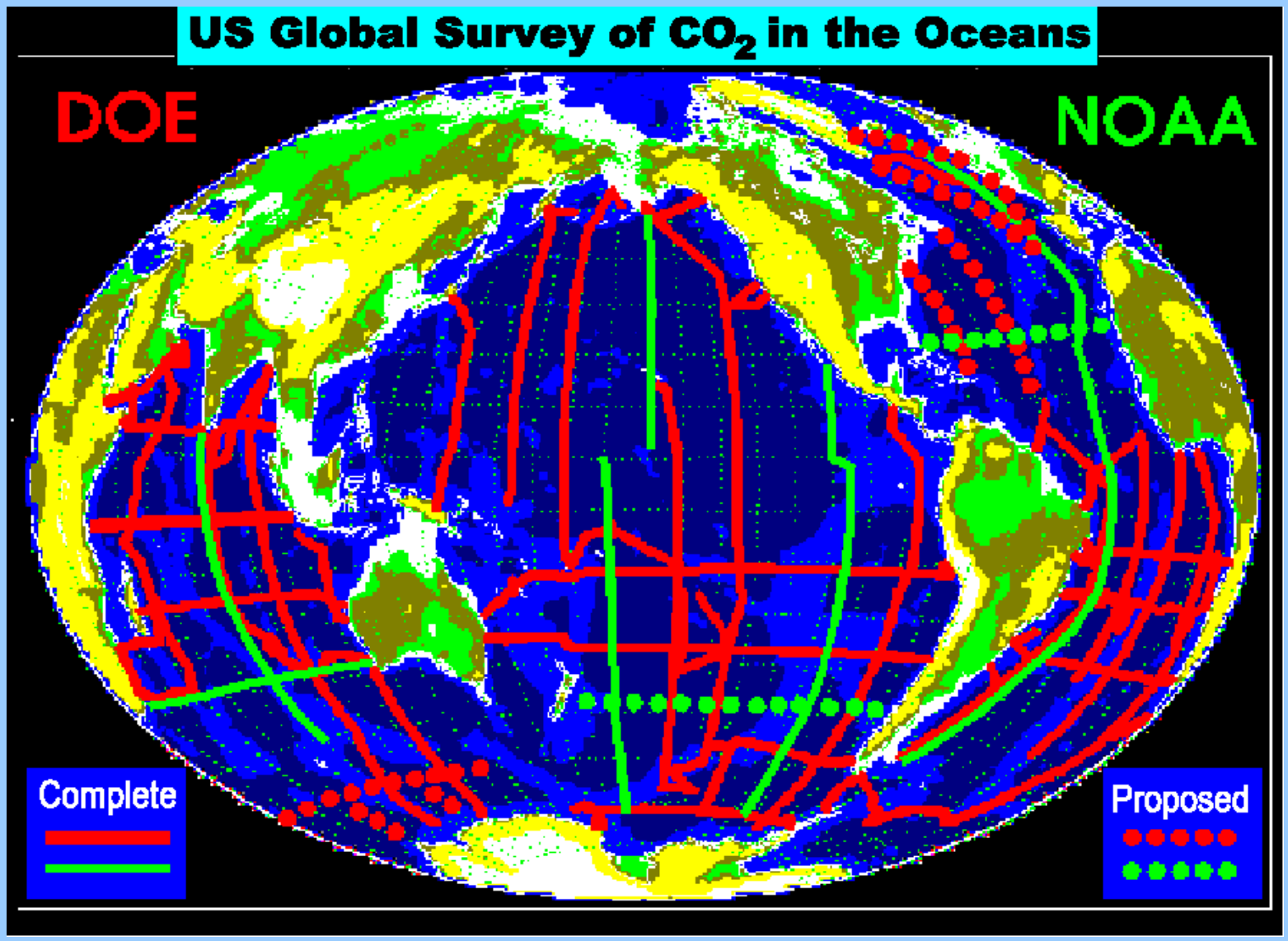
Gruber & Sarmiento (2002)

Observing ocean biogeochemical properties

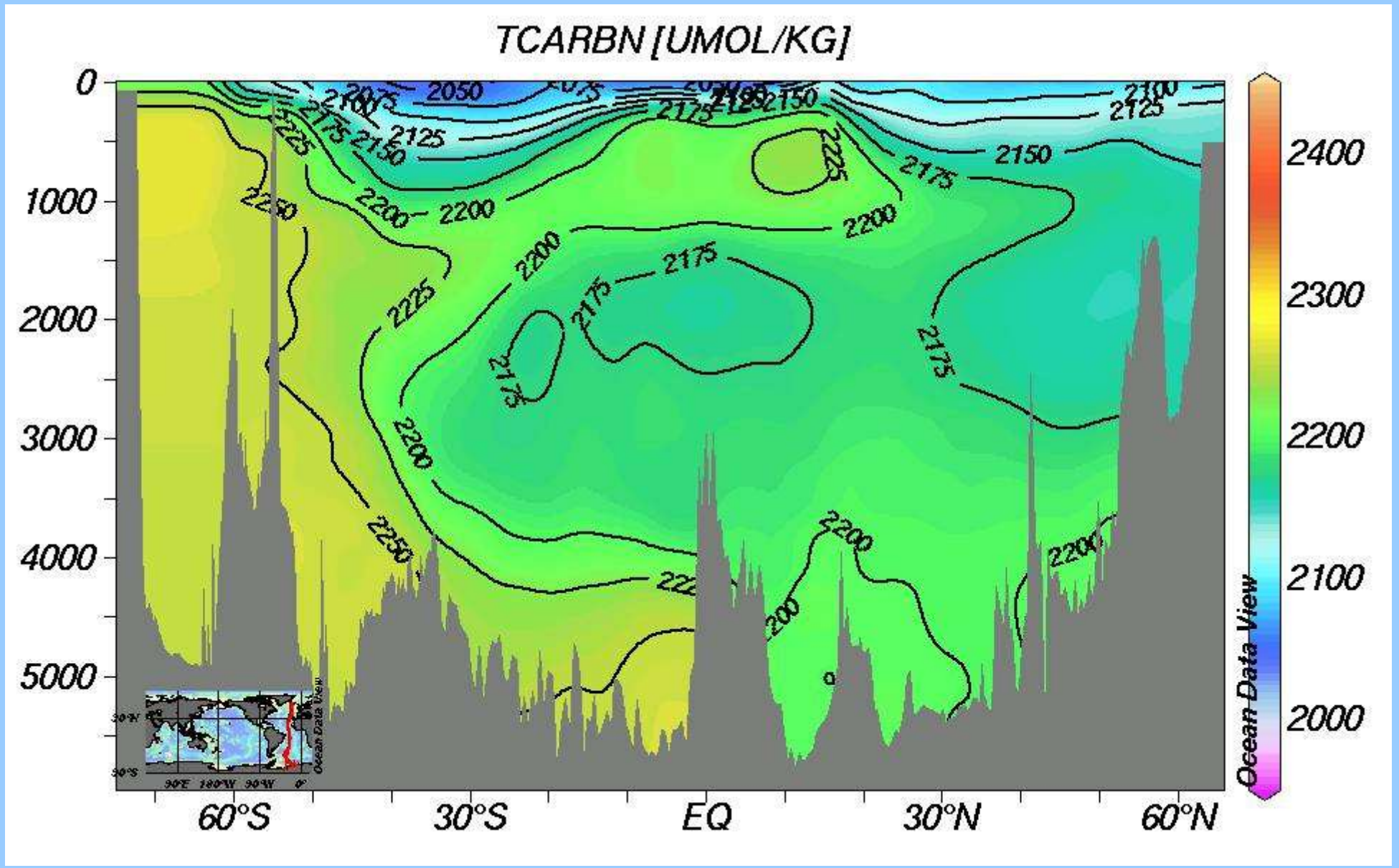


What is the distribution of carbon in the ocean?

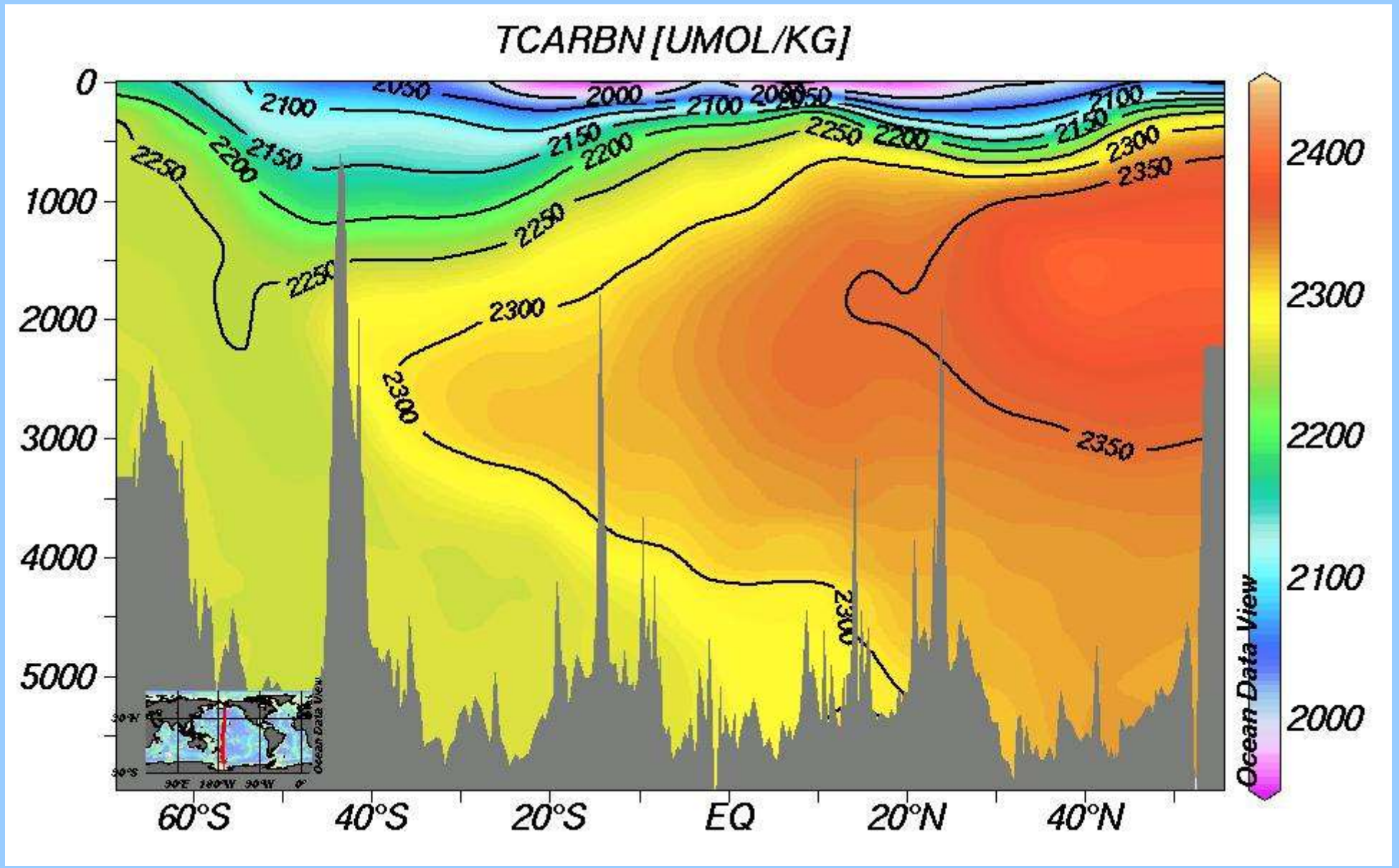
WOCE-JGOFS Global Ocean Survey (1990's)



Observed Atlantic Dissolved Inorganic Carbon, DIC

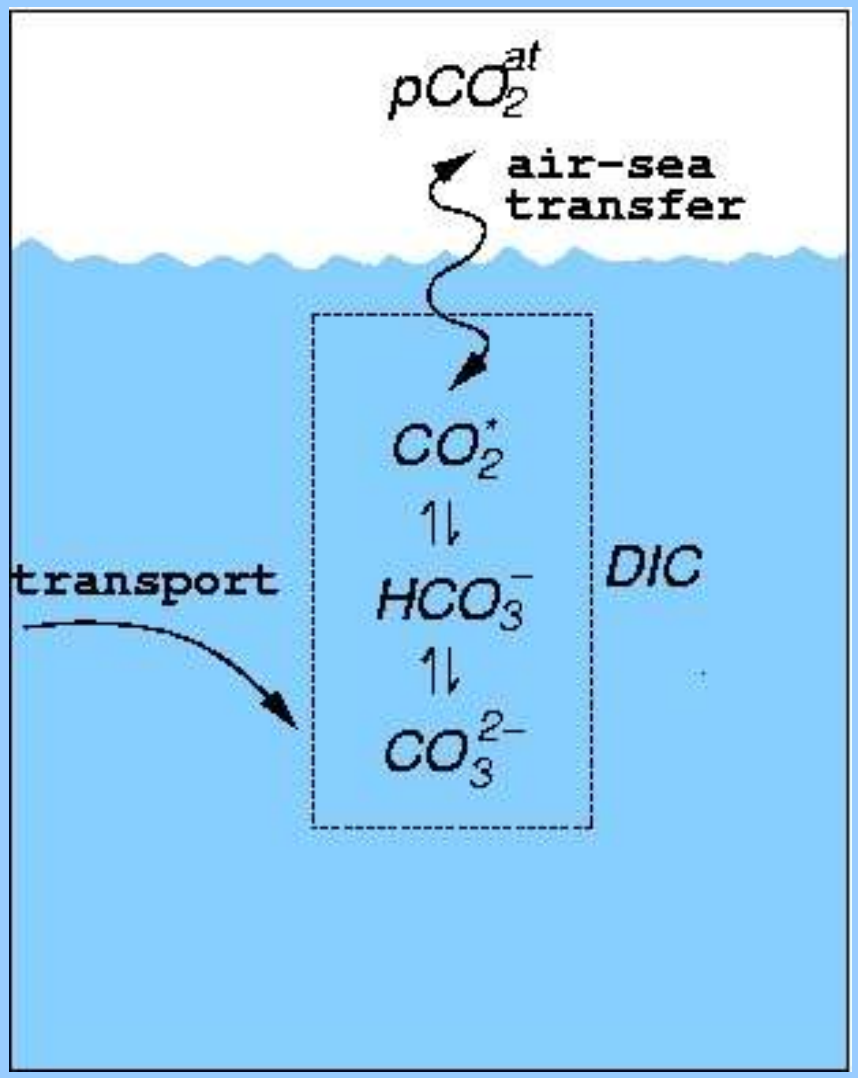


Observed Pacific Dissolved Inorganic Carbon, DIC



- Background concentration of DIC ~ 2000 micromol kg^{-1}
- Why so much carbon in the ocean?

Carbonate chemistry.



dissolved inorganic carbon

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

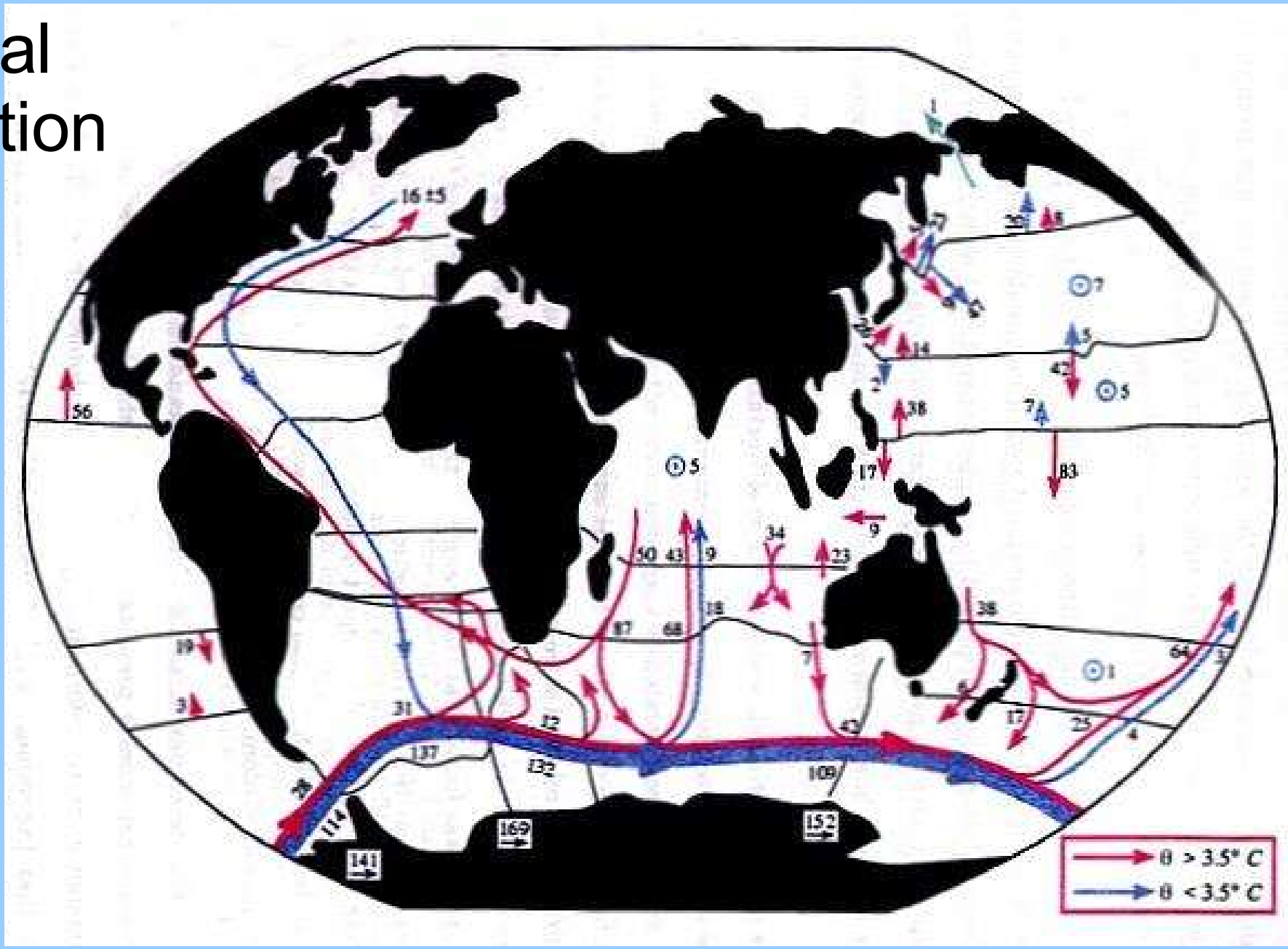
$[CO_2^*]$	:	$[HCO_3^-]$	:	$[CO_3^{2-}]$
1		100		10

What sets the distribution of carbon in the ocean?

- Combination of transport by circulation, chemical and biological processes.

1. Transport – relationship to S
2. “Solubility Pump” – relationship to T
3. “Biological Pumps” – relationship to PO_4^{3-}

Global circulation

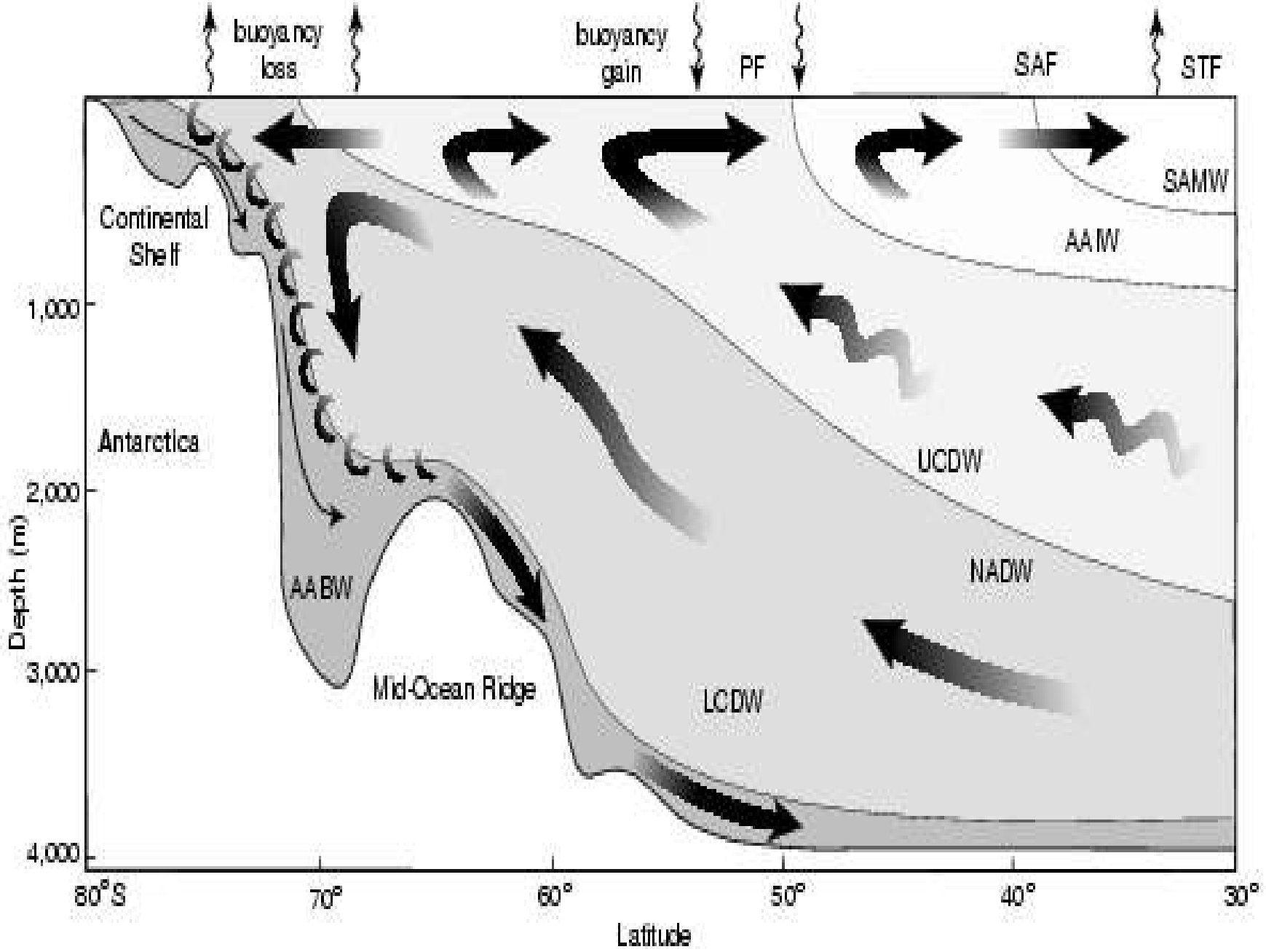


Volume flux of warm & cold water

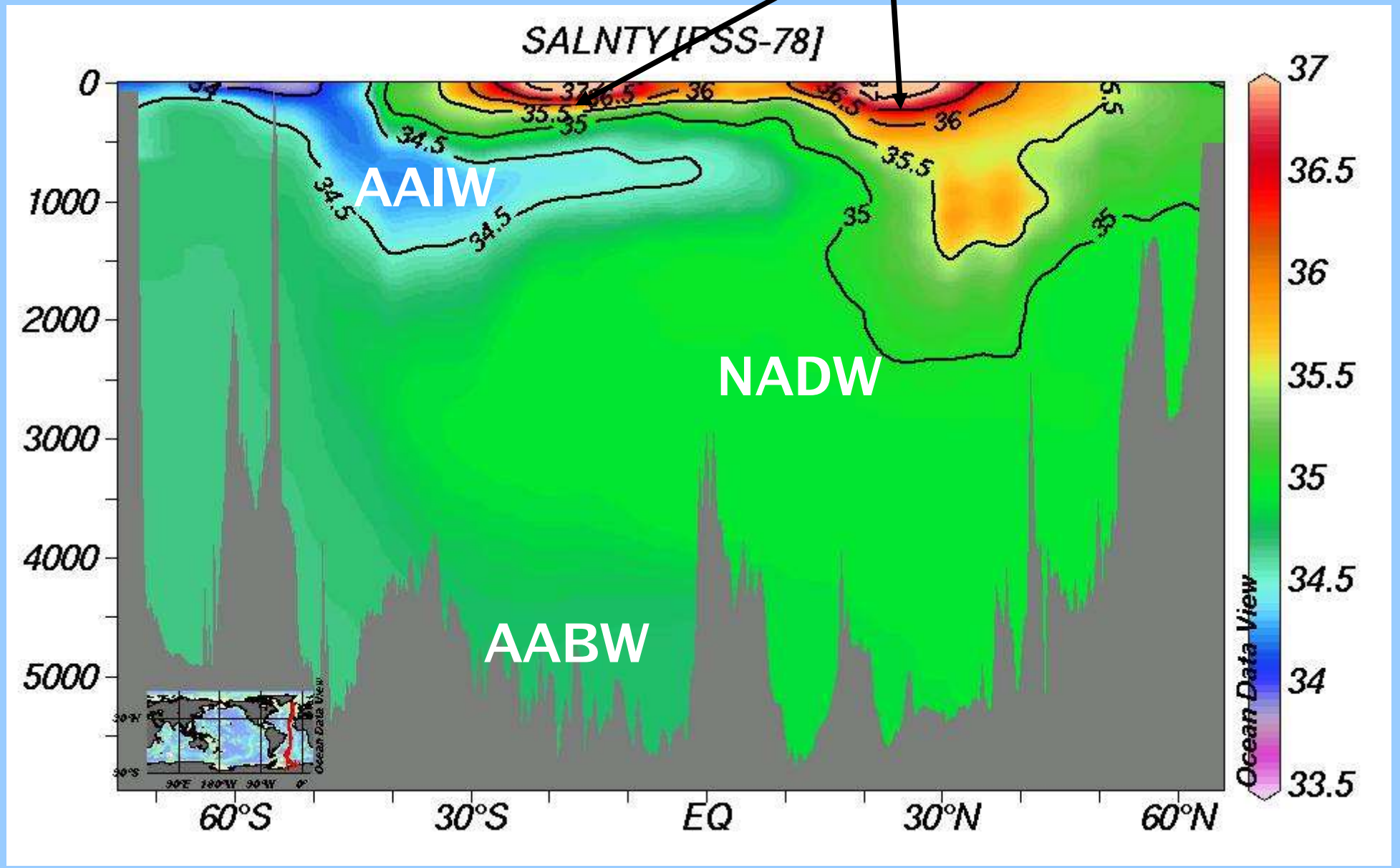
Macdonald and Wunsch (1996) inversion

Southern Ocean

Speer et al. (2000)

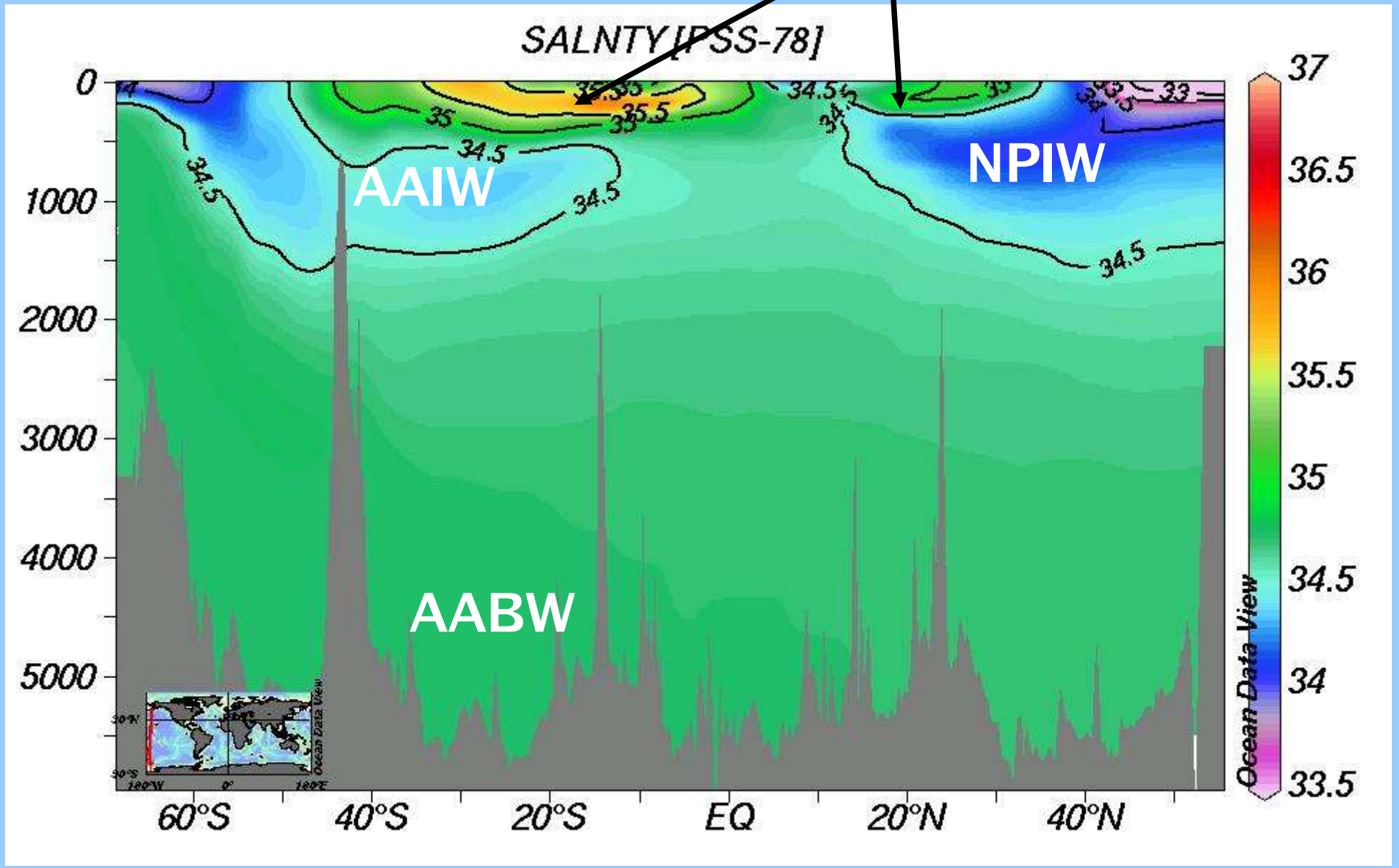


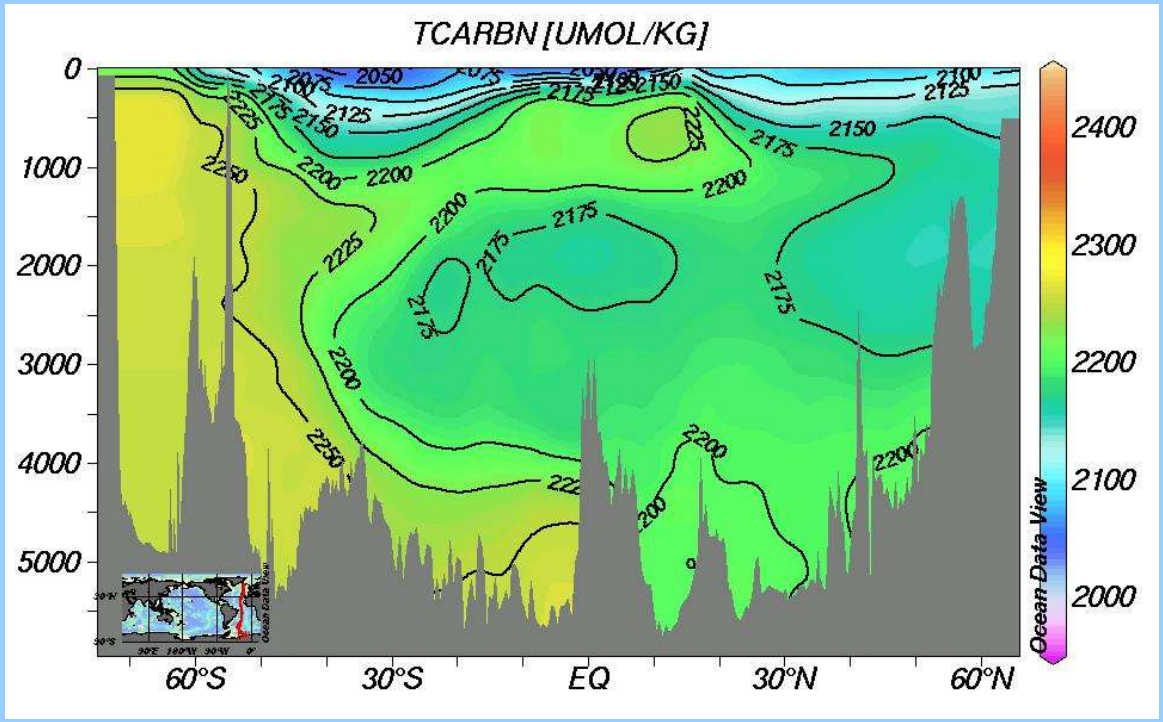
Atlantic, salinity (psu)

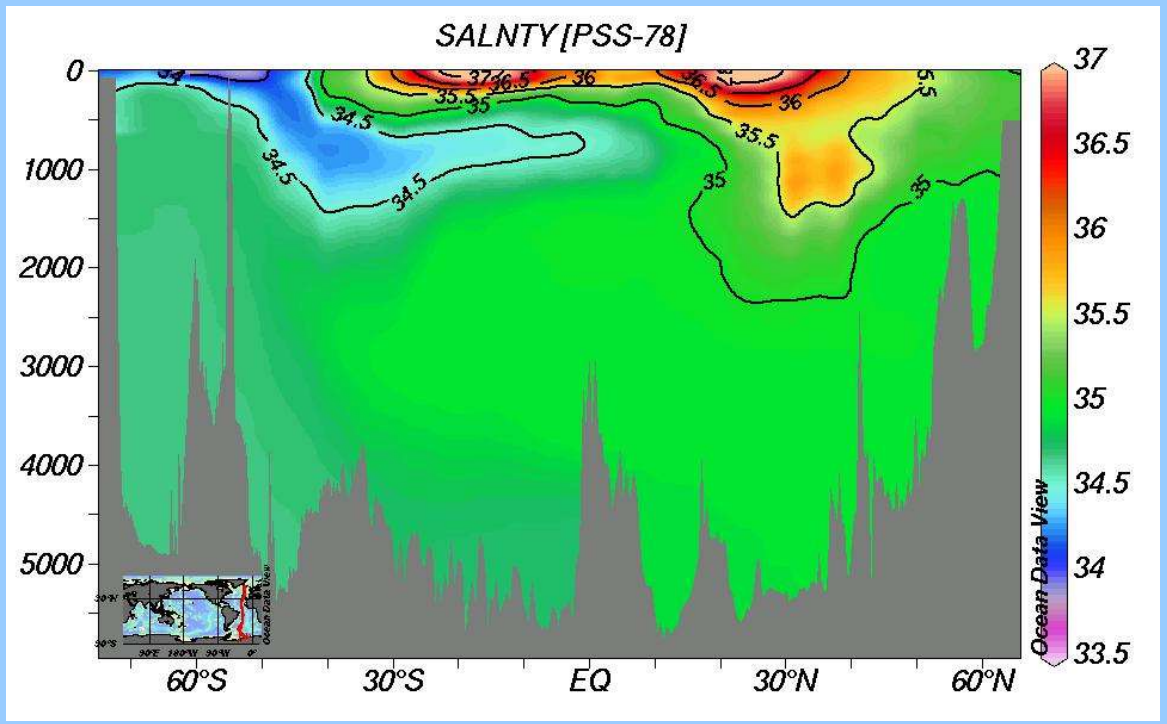


Pacific, salinity (psu)

ventilated thermocline

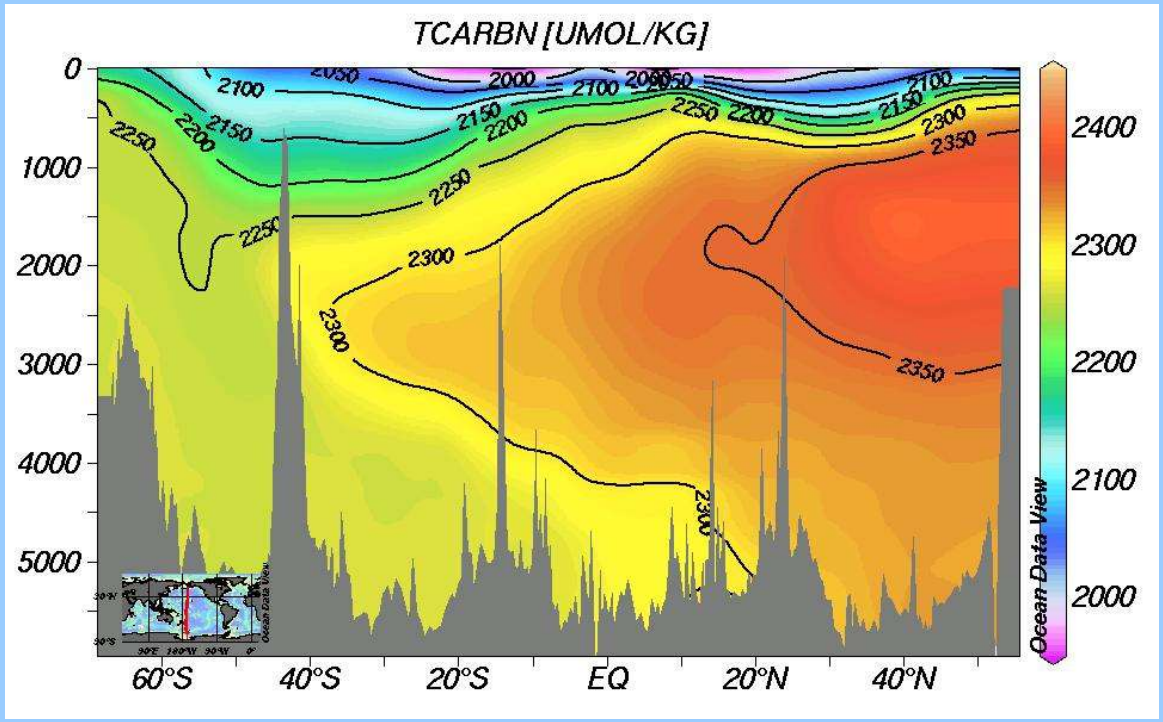


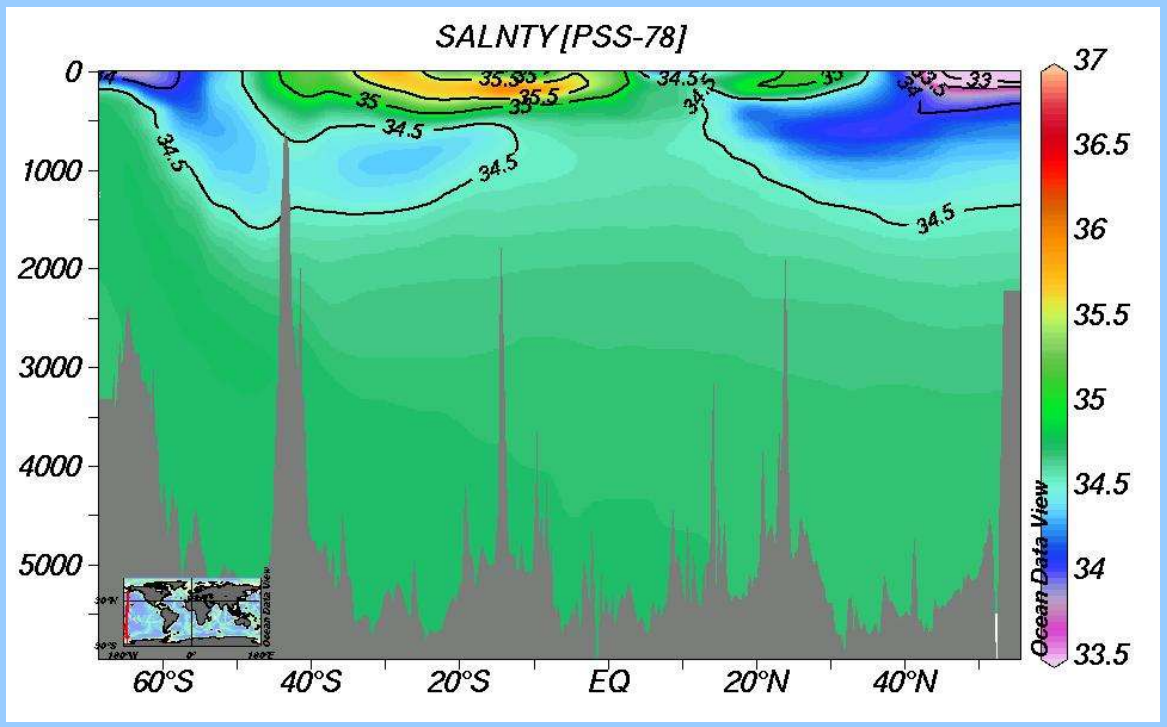




DIC and S distributions show some common structures:

- **Common ocean transport processes**

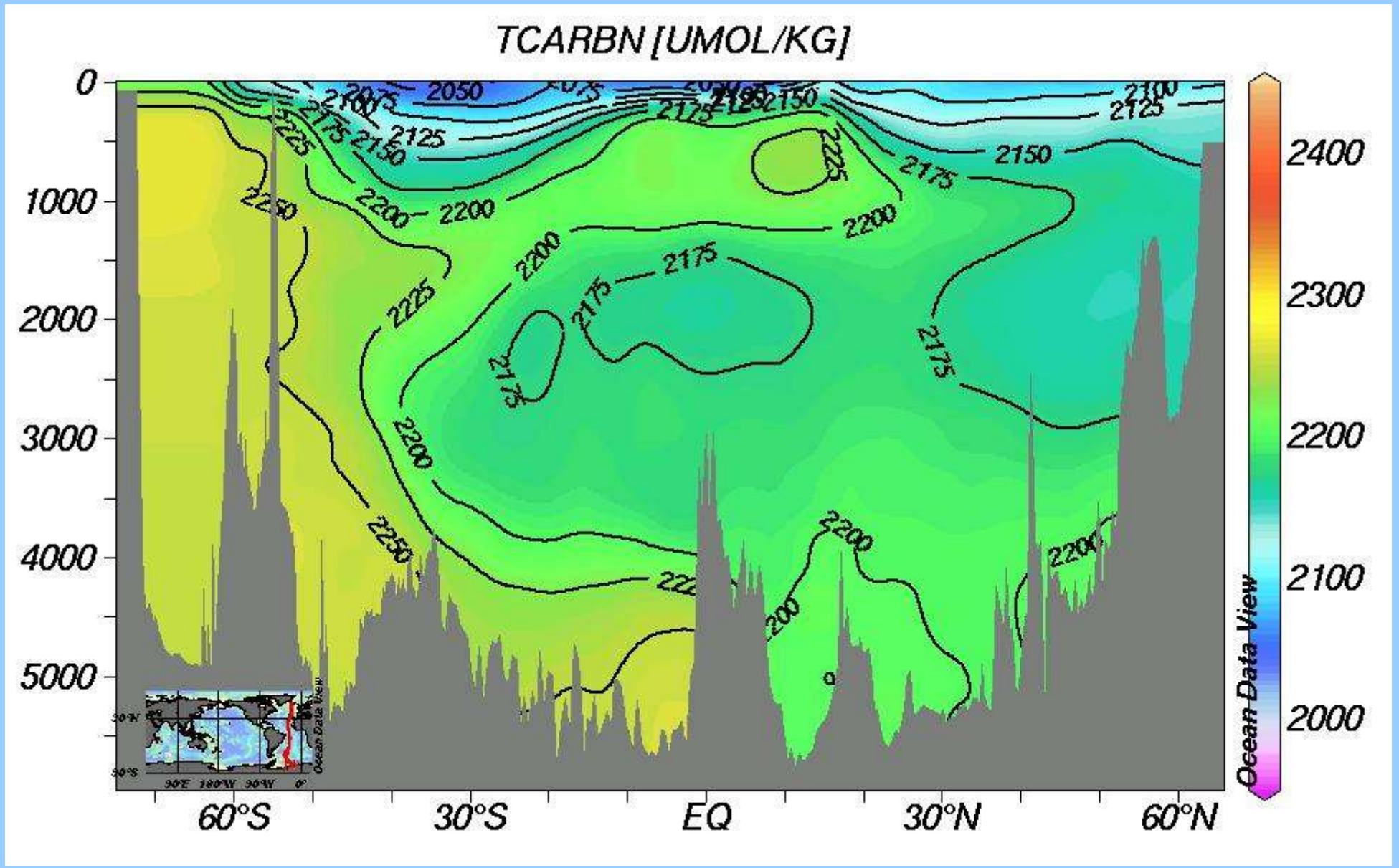




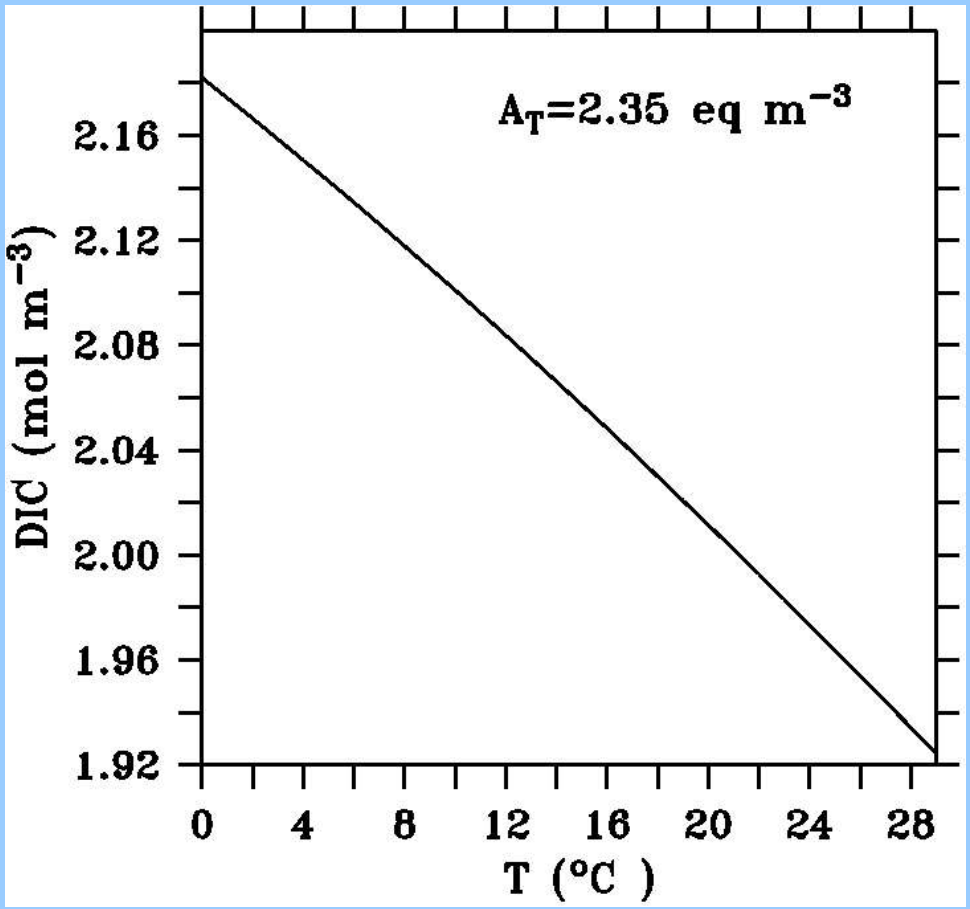
DIC and S distributions show some strong differences:

- **DIC affected by biological processes but S is not**

Observed Atlantic Dissolved Inorganic Carbon, DIC



Relationship of DIC at equilibrium with overlying atmos pCO2=280ppmv

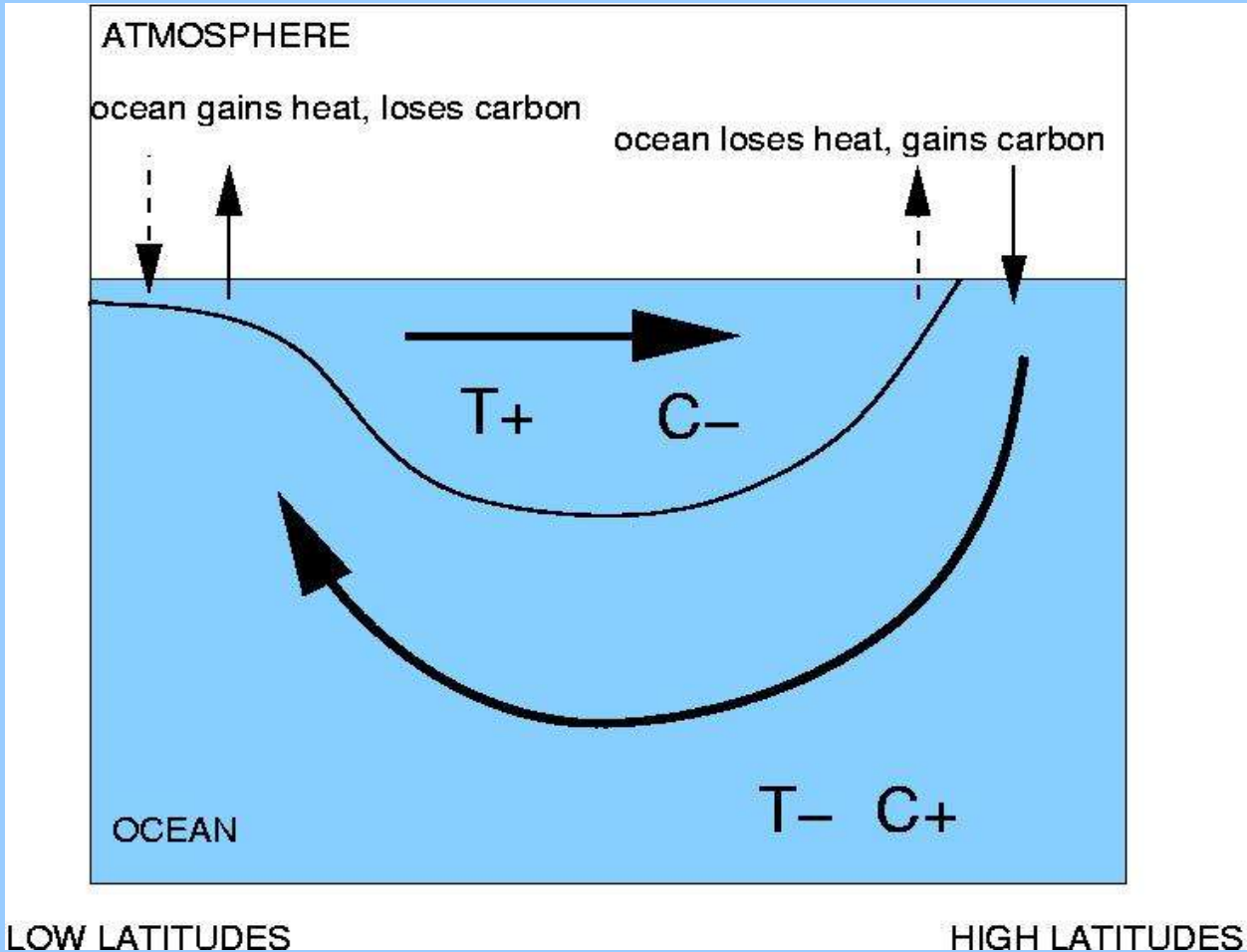


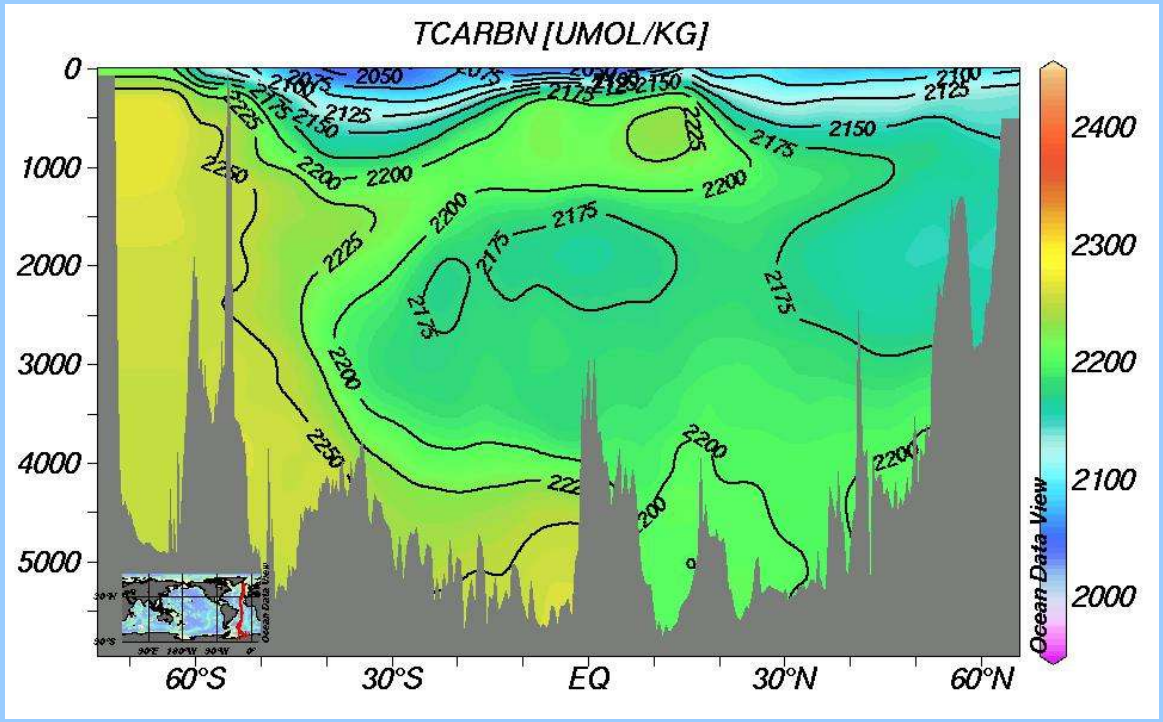
Cooler waters hold more carbon at equilibrium

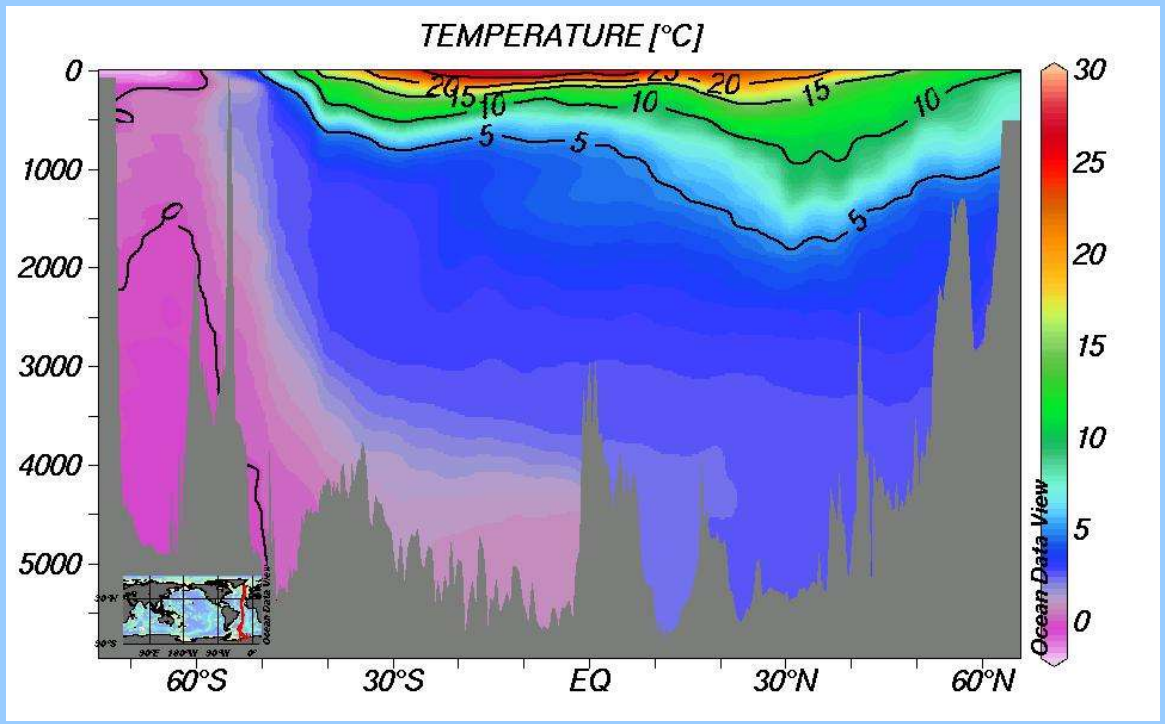
mol m^{-3} = micromol kg^{-1} / 10^3

“Solubility Pump”

- cooler water holds more DIC at equilibrium for given atmos pCO_2
- cooler waters are denser and form deep waters
- creates vertical gradient of DIC in the ocean
- air-sea heat fluxes drive air-sea carbon fluxes



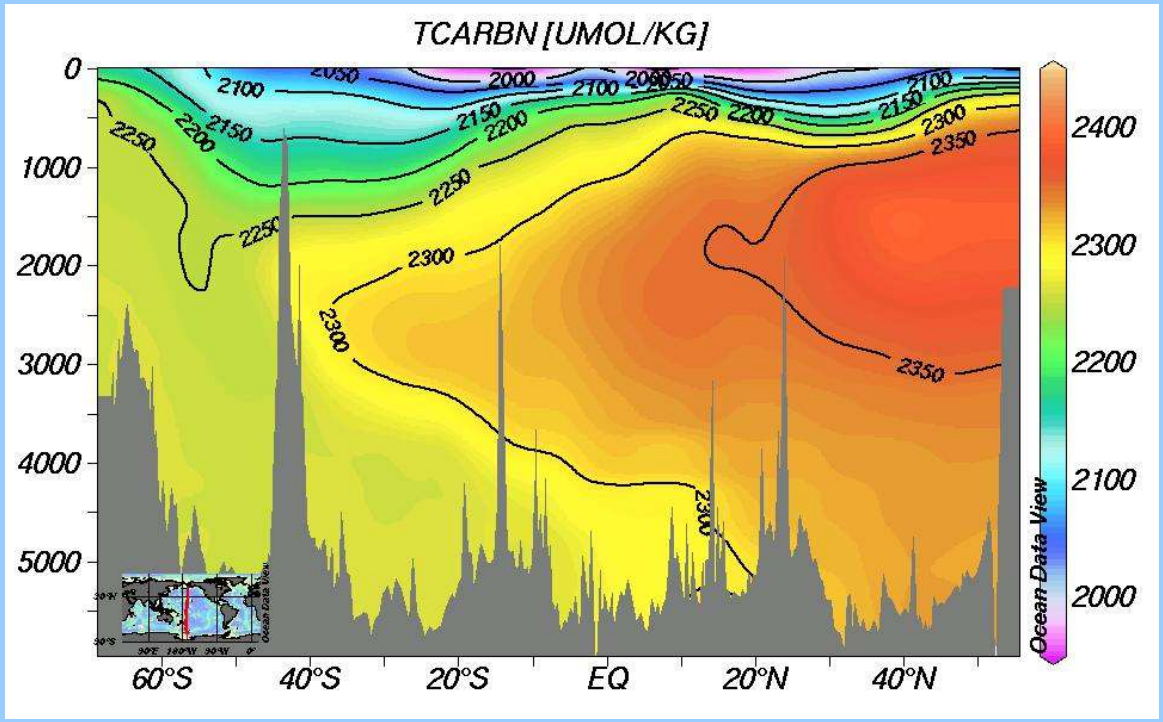


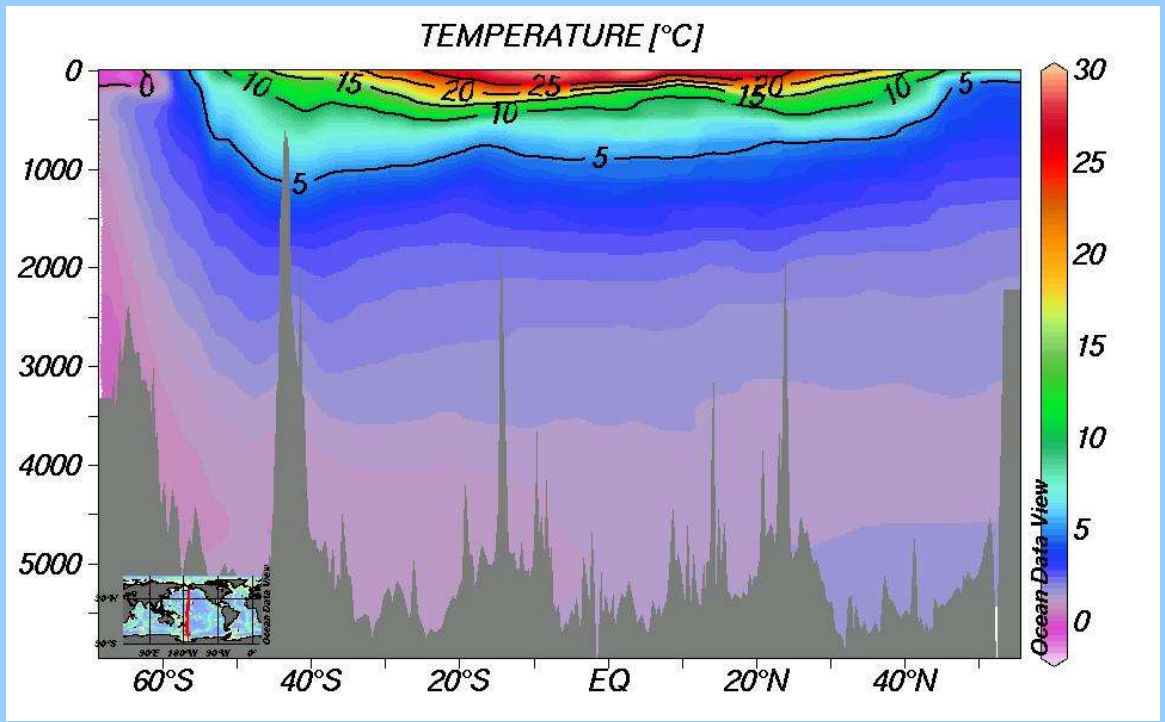


Atlantic

Vertical gradients of DIC and T generally inversely related:

Solubility Pump



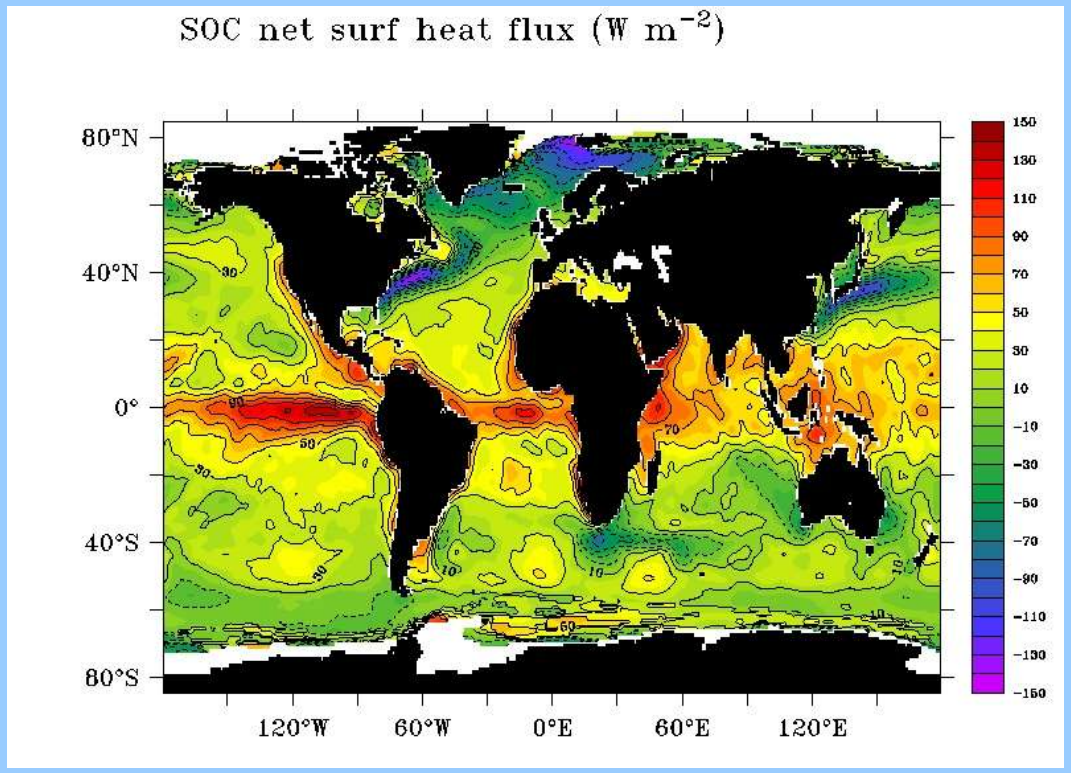


Pacific

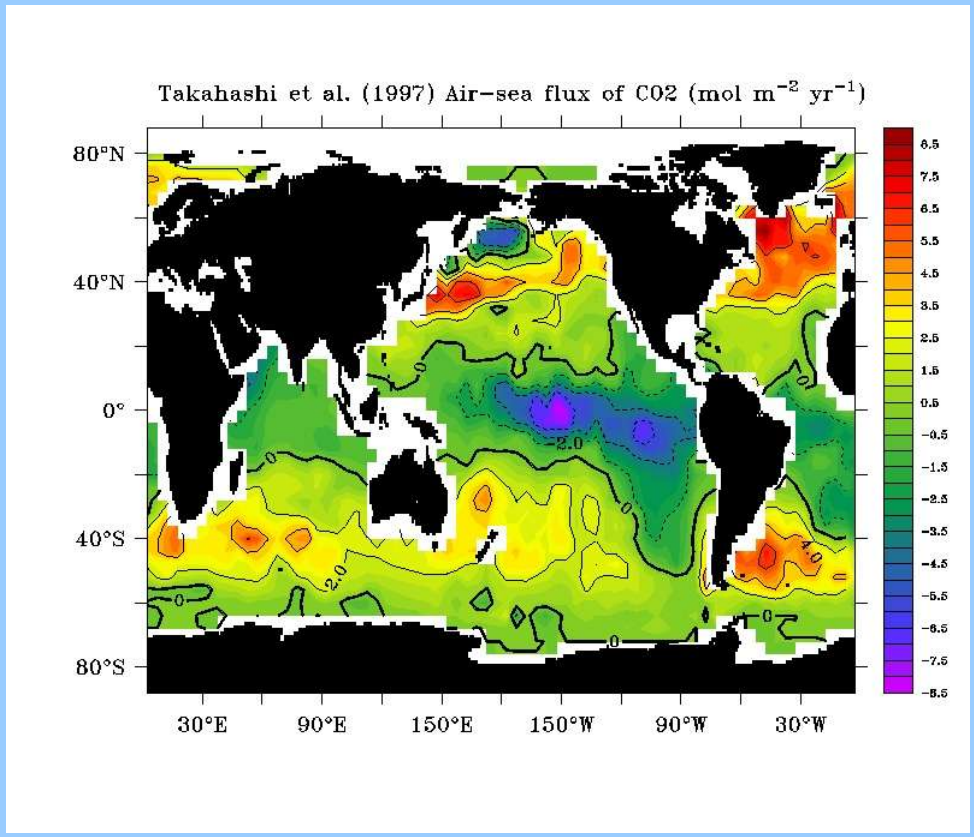
Vertical gradients of DIC and T generally inversely related

Solubility pump

Air-sea flux of CO2 inversely related to air-sea heat flux

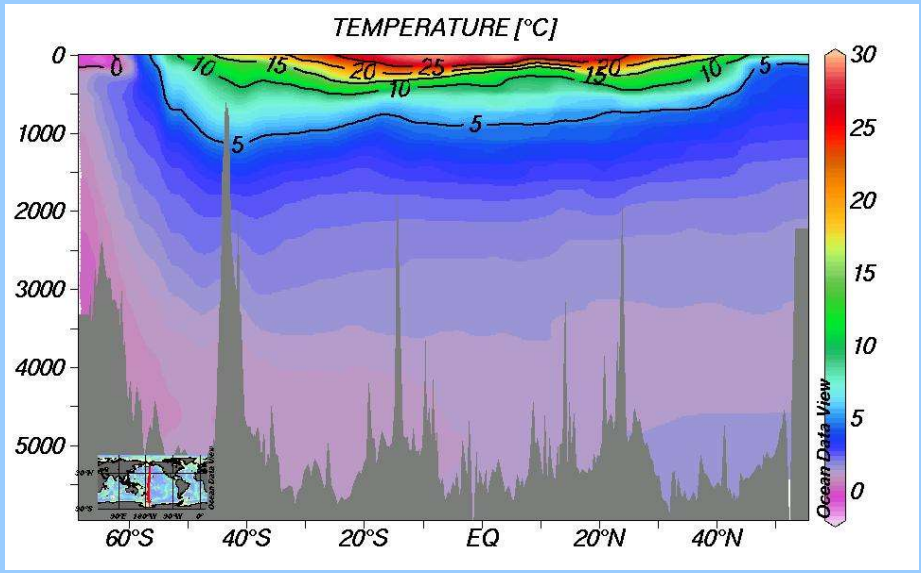


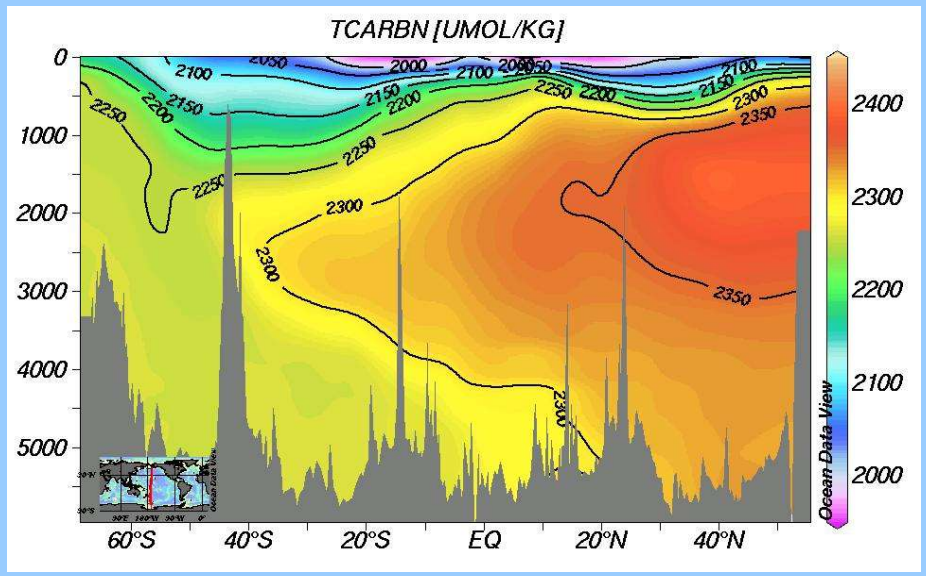
red – ocean gaining heat

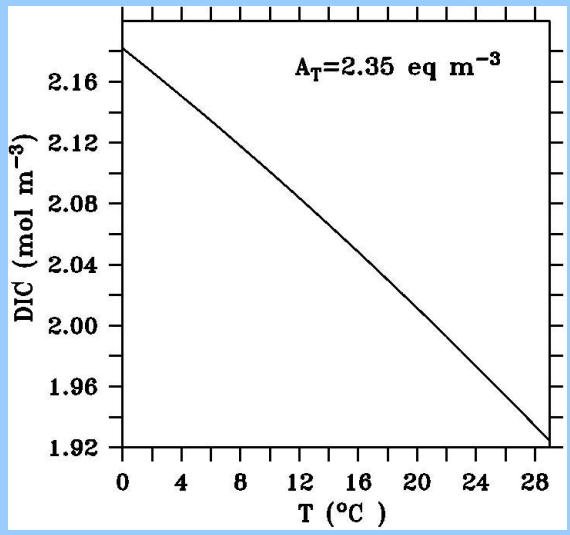


red – ocean gaining carbon

But DIC in the deep ocean exceeds the equilibrium concentration at that temperature... why?



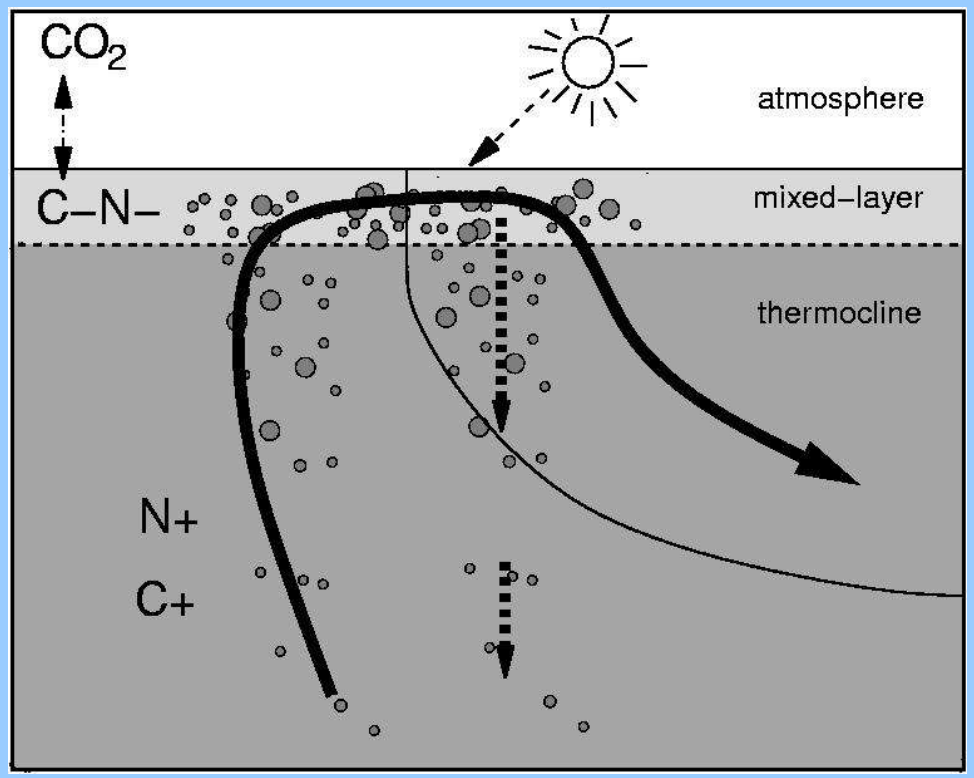




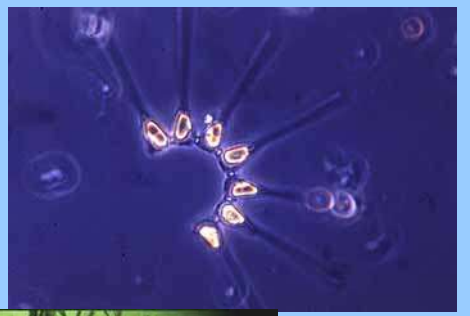
Biological (soft tissue) Pump

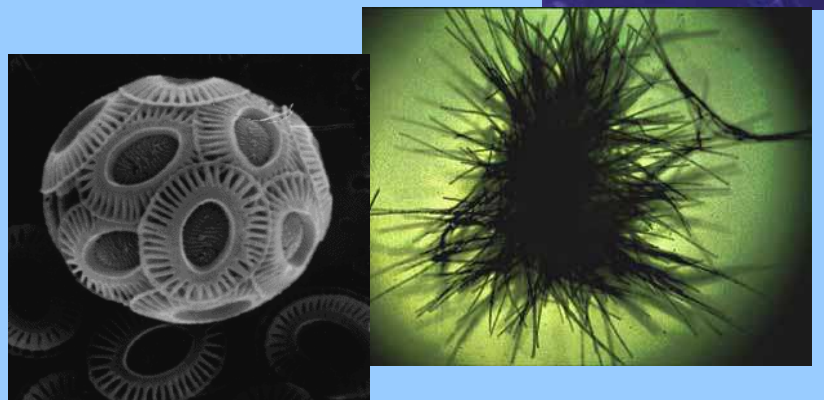
Photosynthesis occurs in sunlight region (upper 150m)
Requires light and nutrients, creates oxygen

Respiration; remineralization of organic matter, consumes oxygen



Phytoplankton



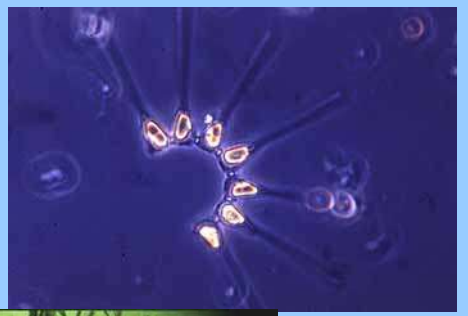


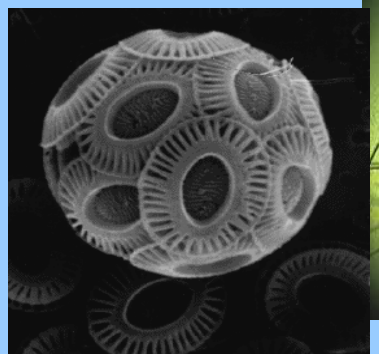
Biological (soft tissue) Pump

$$106\ CO_2 + 16\ NO_3^- + H_2PO_4^- + 122\ H_2O + X\ h\nu \xrightleftharpoons[\text{respiration}]{\text{photosynthesis}} C_{106}H_{263}O_{110}N_{16}P + 138\ O_2$$

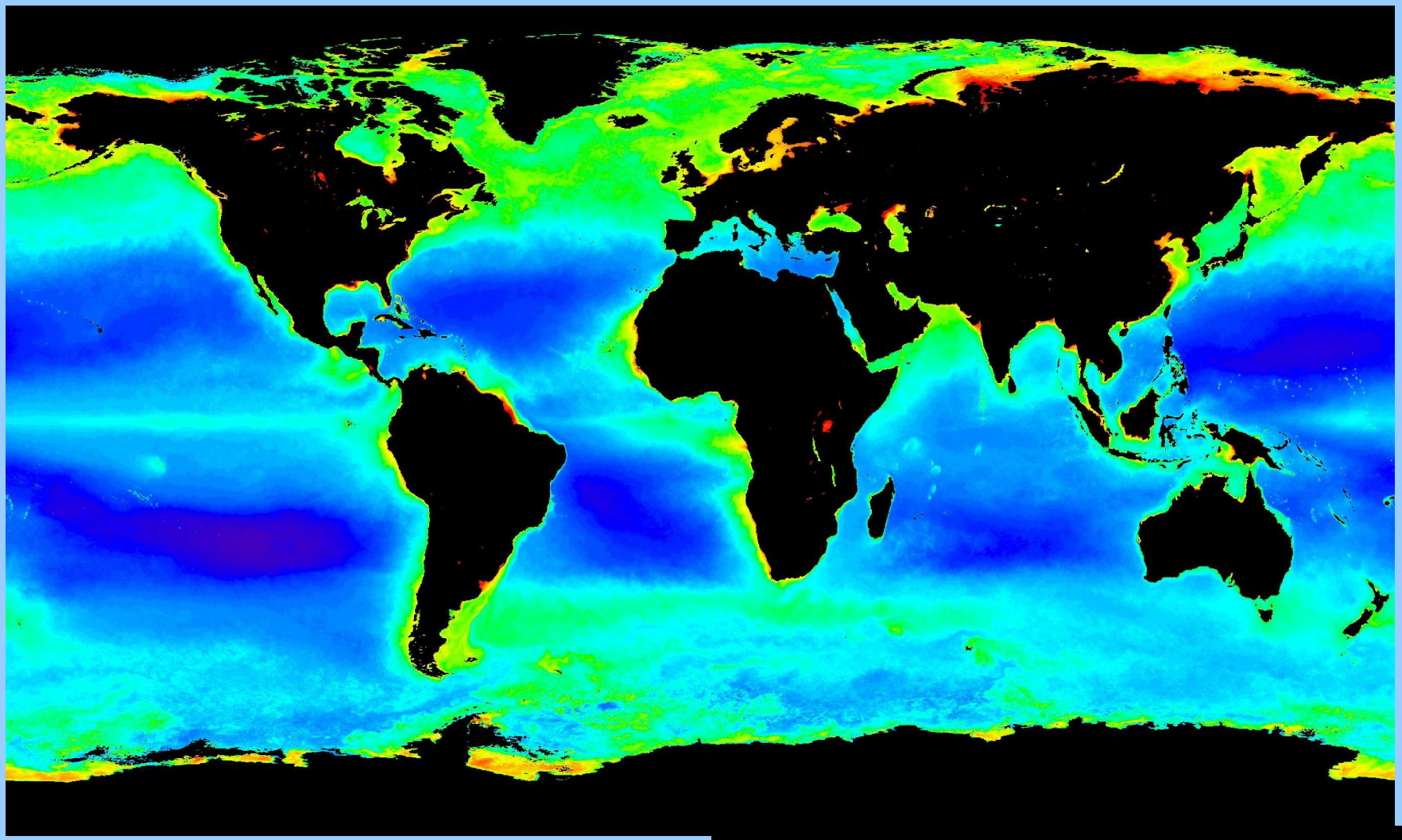
Redfield Ratio – oceanic organic matter has "fixed"ratio of carbon and nutrients

Phytoplankton



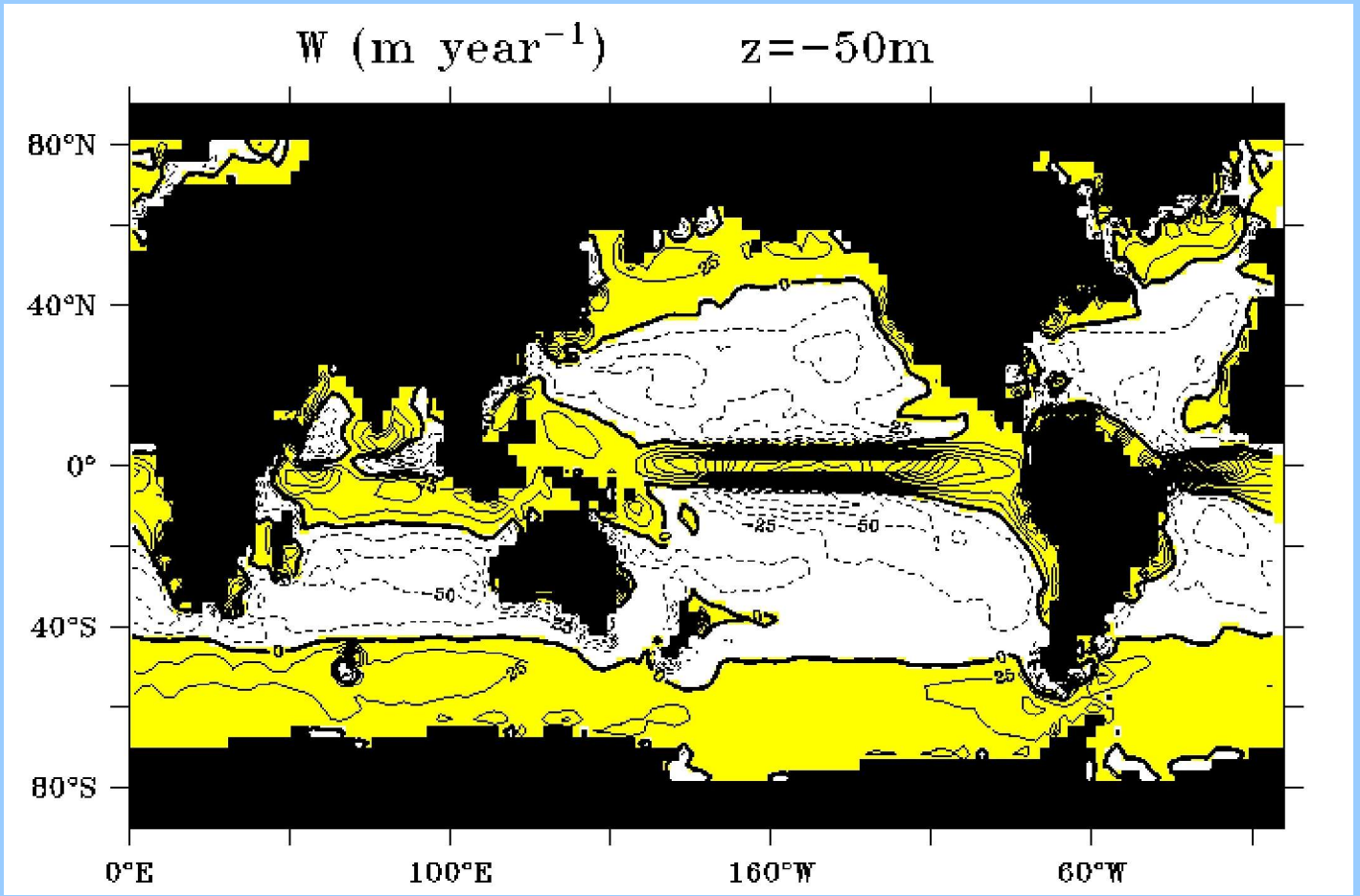


Distribution of chlorophyll in surface ocean observed from space (SeaWiFS, 1997-2000 mean)

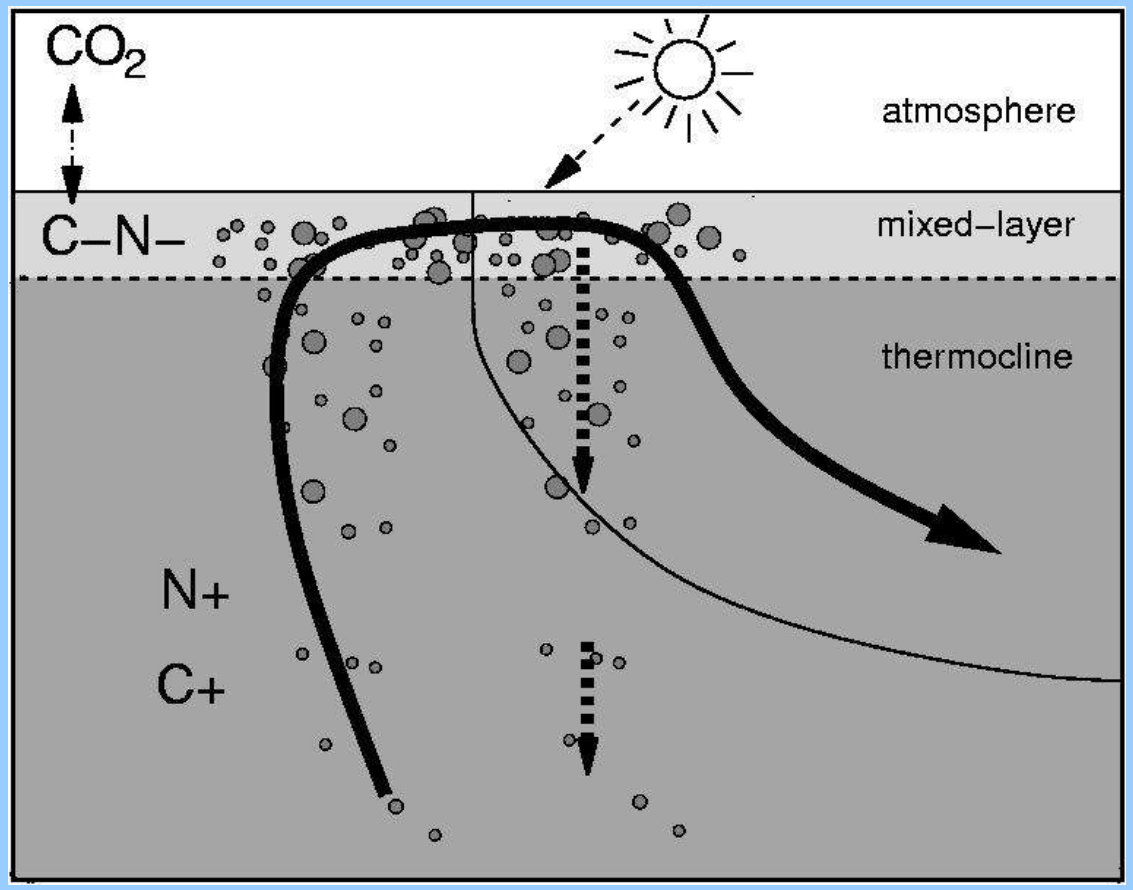


Lots of carbon around so productivity is limited by availability of other nutrients (e.g. PO_4^{3-}) and light

Supply of nutrients to sunlit surface ocean largely dependent on wind driven upwelling



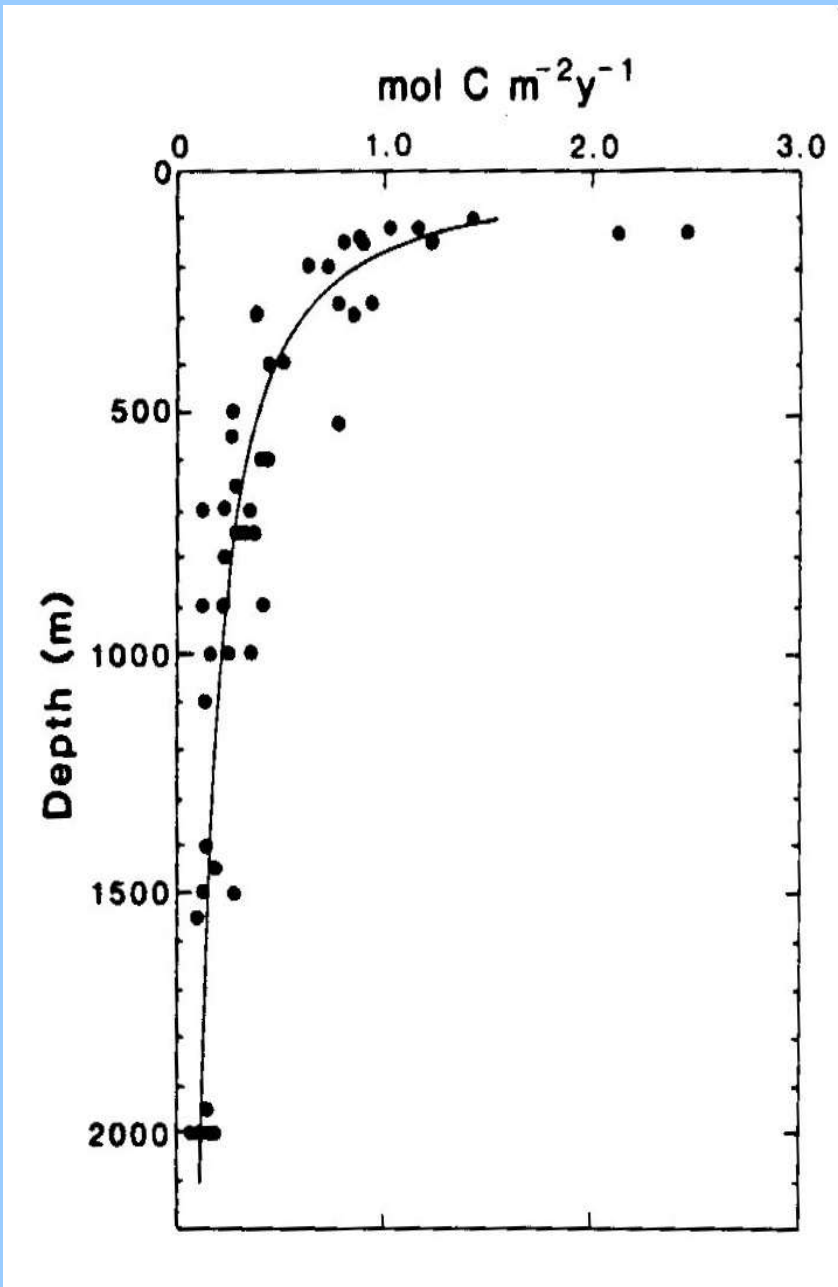
Modelled upwelling at 50m

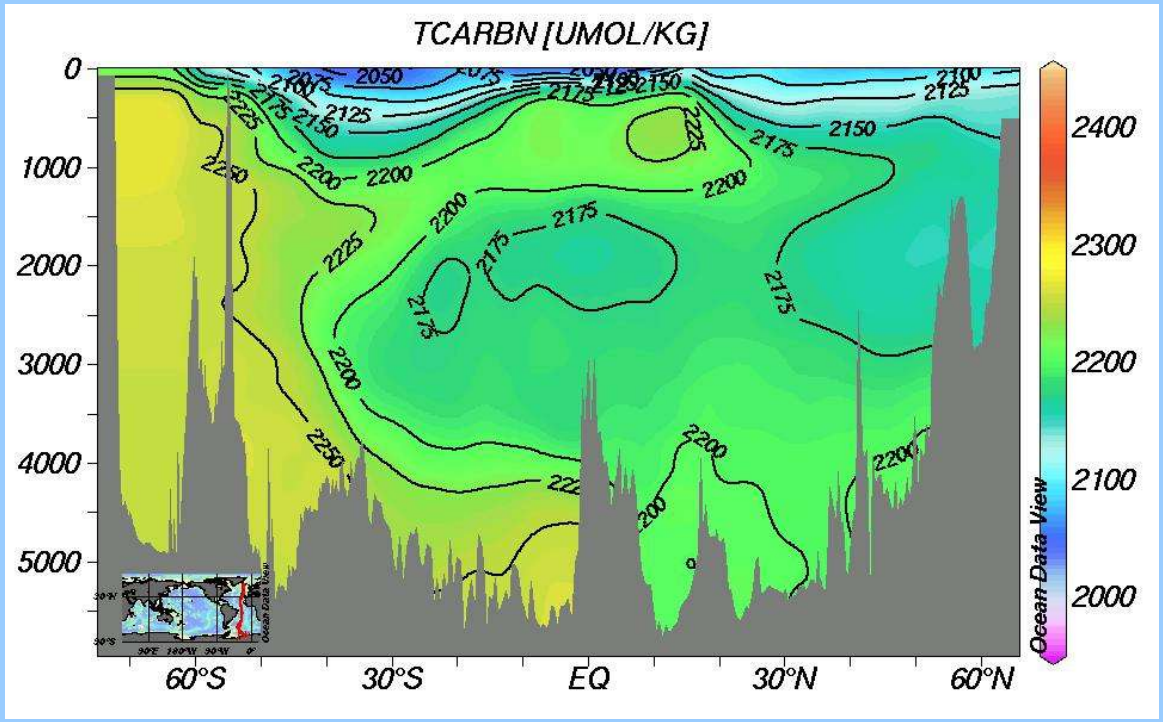


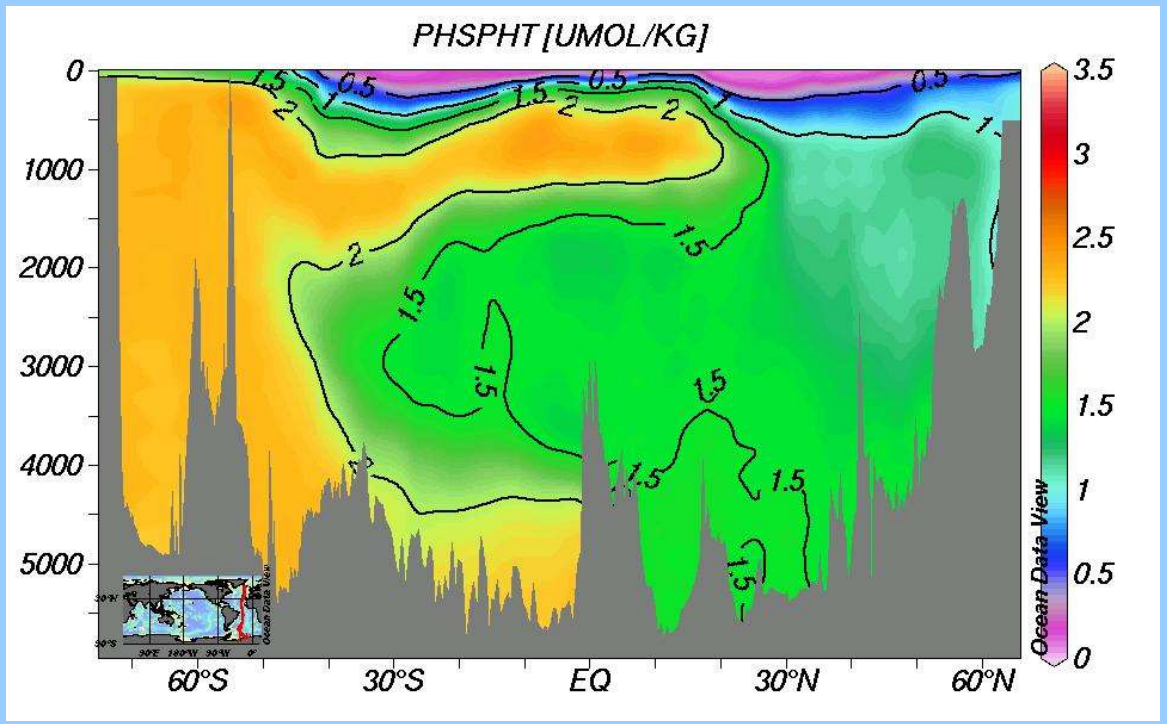
"Soft tissue pump"

Organic carbon flux in sinking particles

Martin et al. (1987)



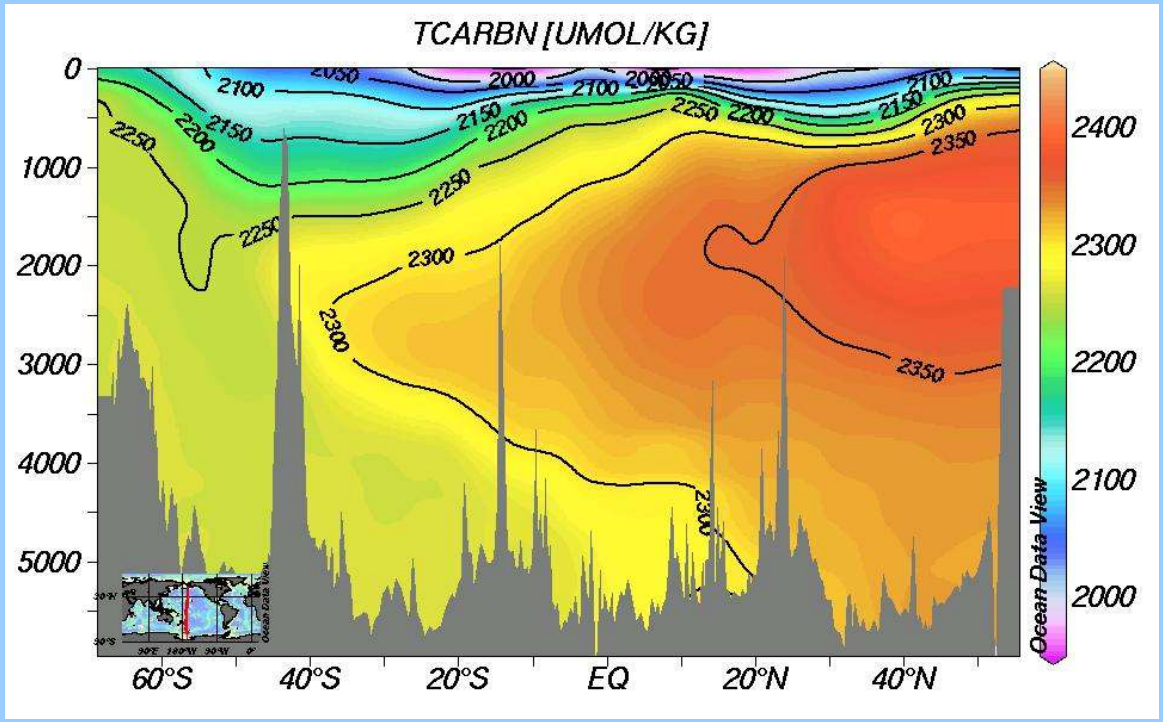


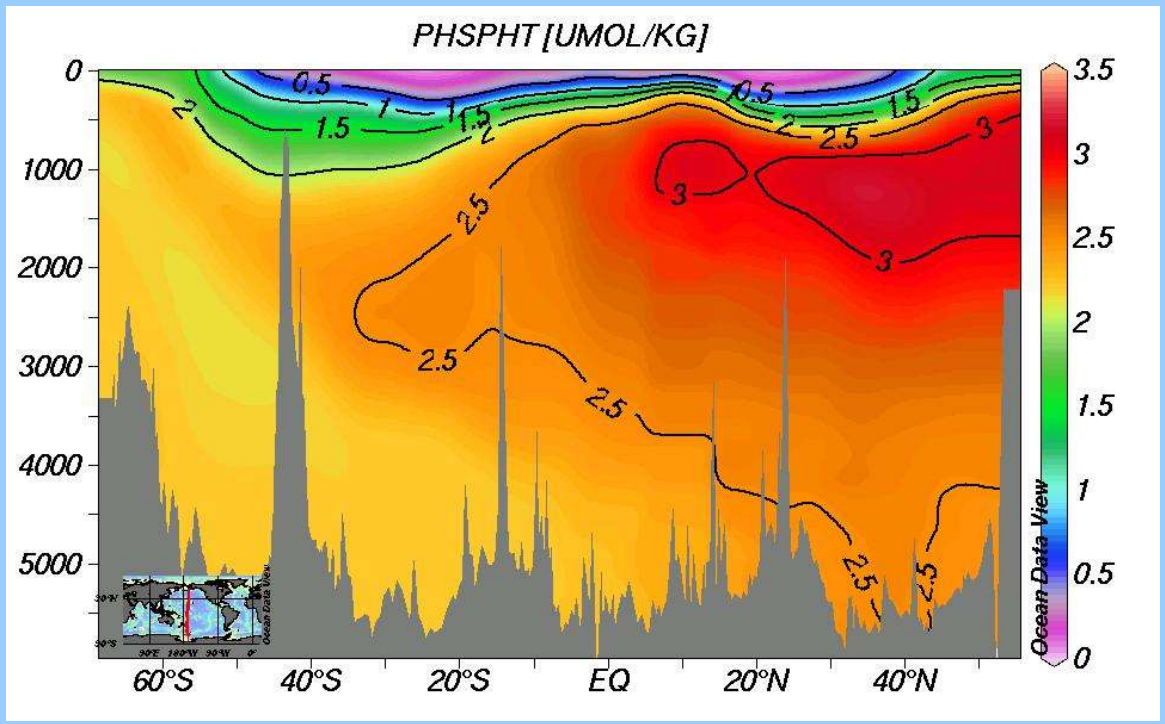


DIC and PO4

- common biological processes

- **soft tissue pump**



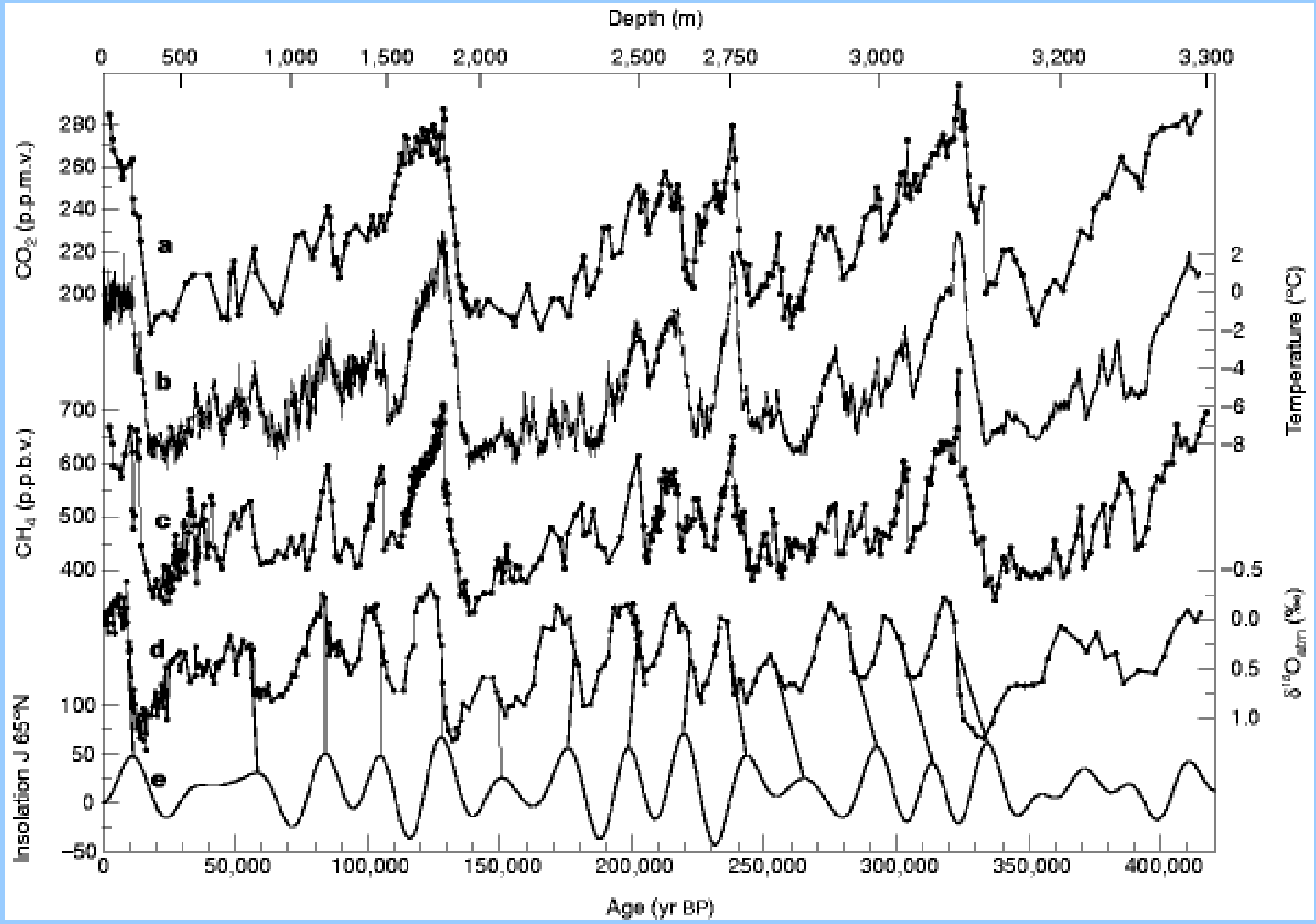


DIC and PO4

- common biological processes

- **soft tissue pump**

Could change in ocean carbon cycle cause glacial-interglacial changes in atmospheric pCO2?



Vostock (Petit et al., 1999)

Could changes in the oceans have reduced atmospheric pCO_2 by >80ppmv at the Last Glacial Maximum?

Changes in solubility pump:

Cool deep ocean by 2°C	-20ppmv
Cool upper ocean (thermocline) by 5°C	-20ppmv

Changes in biological pumps:

Extreme enhancement of biological export efficiency	-40ppmv

Changes to circulation and mixing?

STILL AN OPEN QUESTION