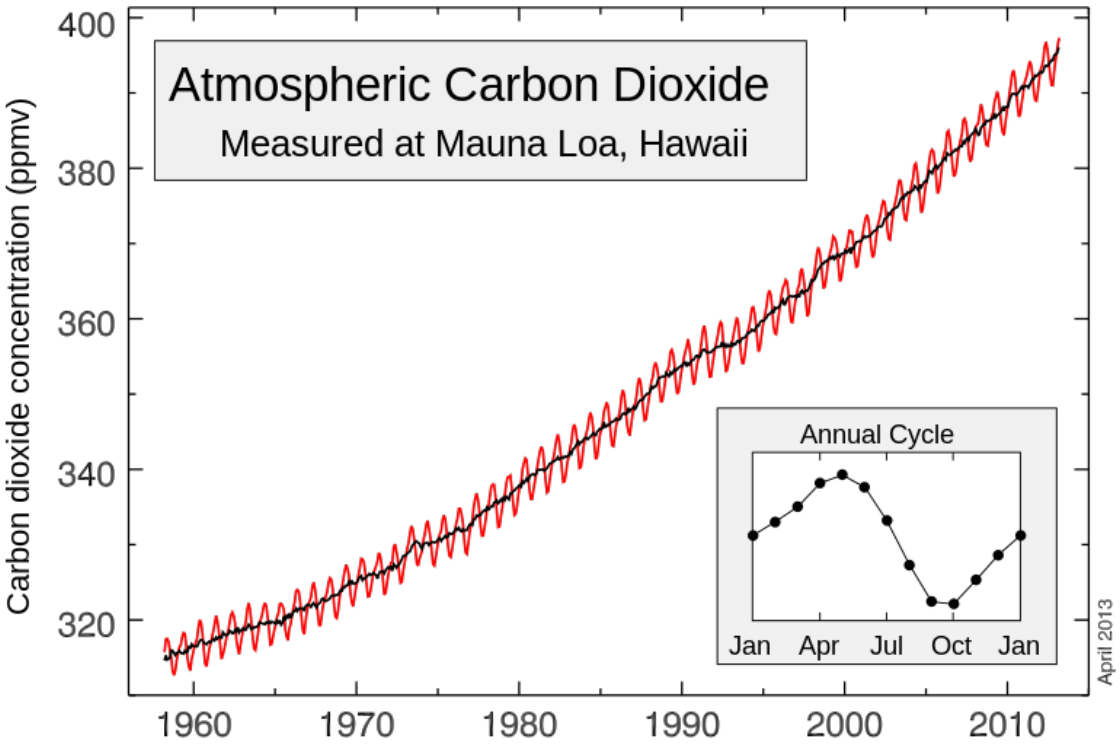
Changes in atmospheric CO_2 and the global carbon cycle



http://en.wikipedia.org/wiki/Keeling_Curve

How much carbon do marine and terrestrial plants fix each year?

How is the rate of CO_2 uptake impacted by climate forced changes in ocean physics and biology?

How much carbon is taken up by the ocean? How fast does this happen?

Agouron 2014 Summer Course in Microbial Oceanography

An overview of the Marine Carbon Cycle

What are the major reservoirs of marine carbon?

What are the major fluxes of carbon between them?

How do we measure do we measure reservoir size and fluxes?

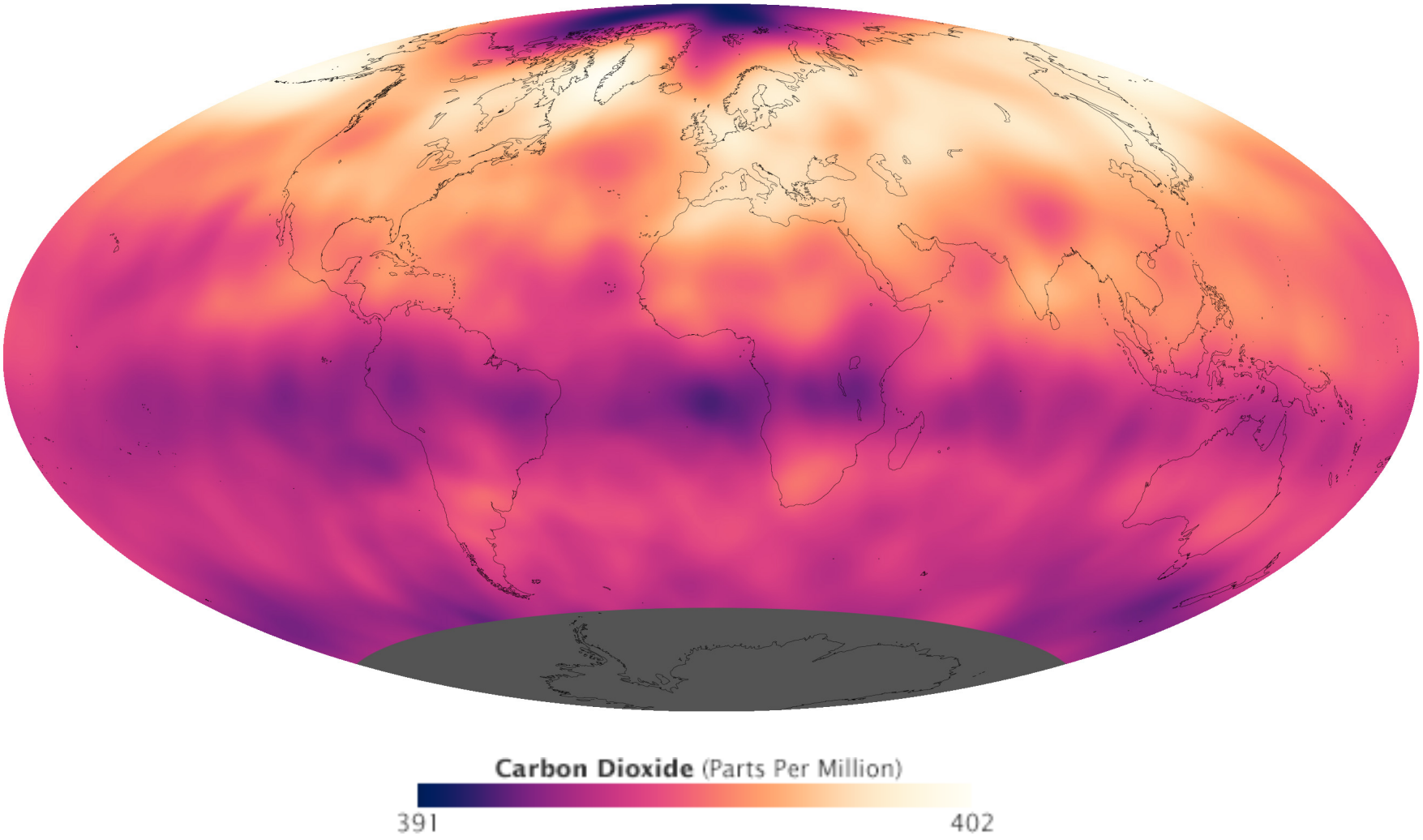
How well do we know this?

What are some of the ways by which microbes impact these reservoirs and fluxes?

What are the major reservoirs of Carbon on the planet? How do we measure them?

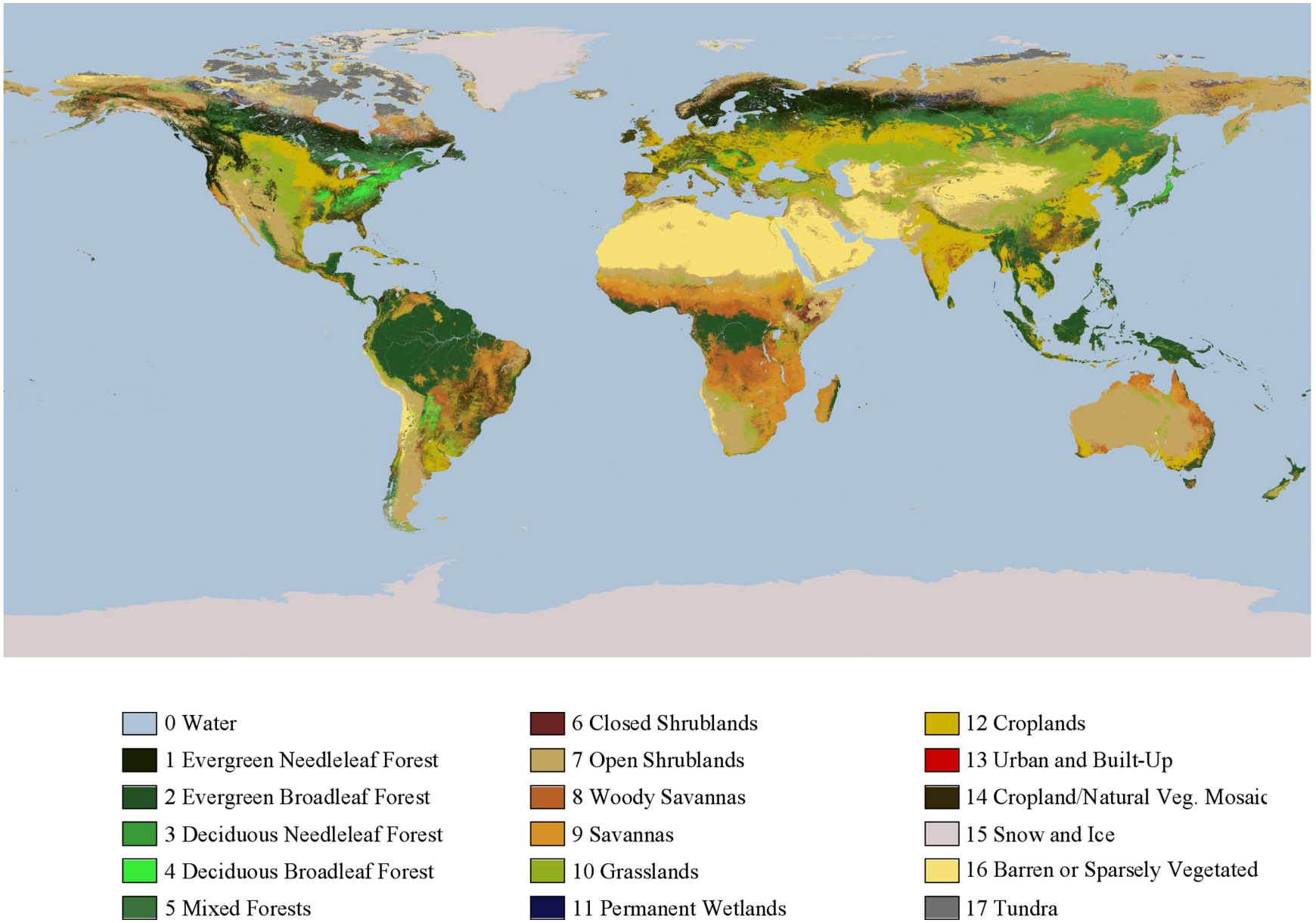
Visit the NASA Earth Observatory Website!
http://earthobservatory.nasa.gov

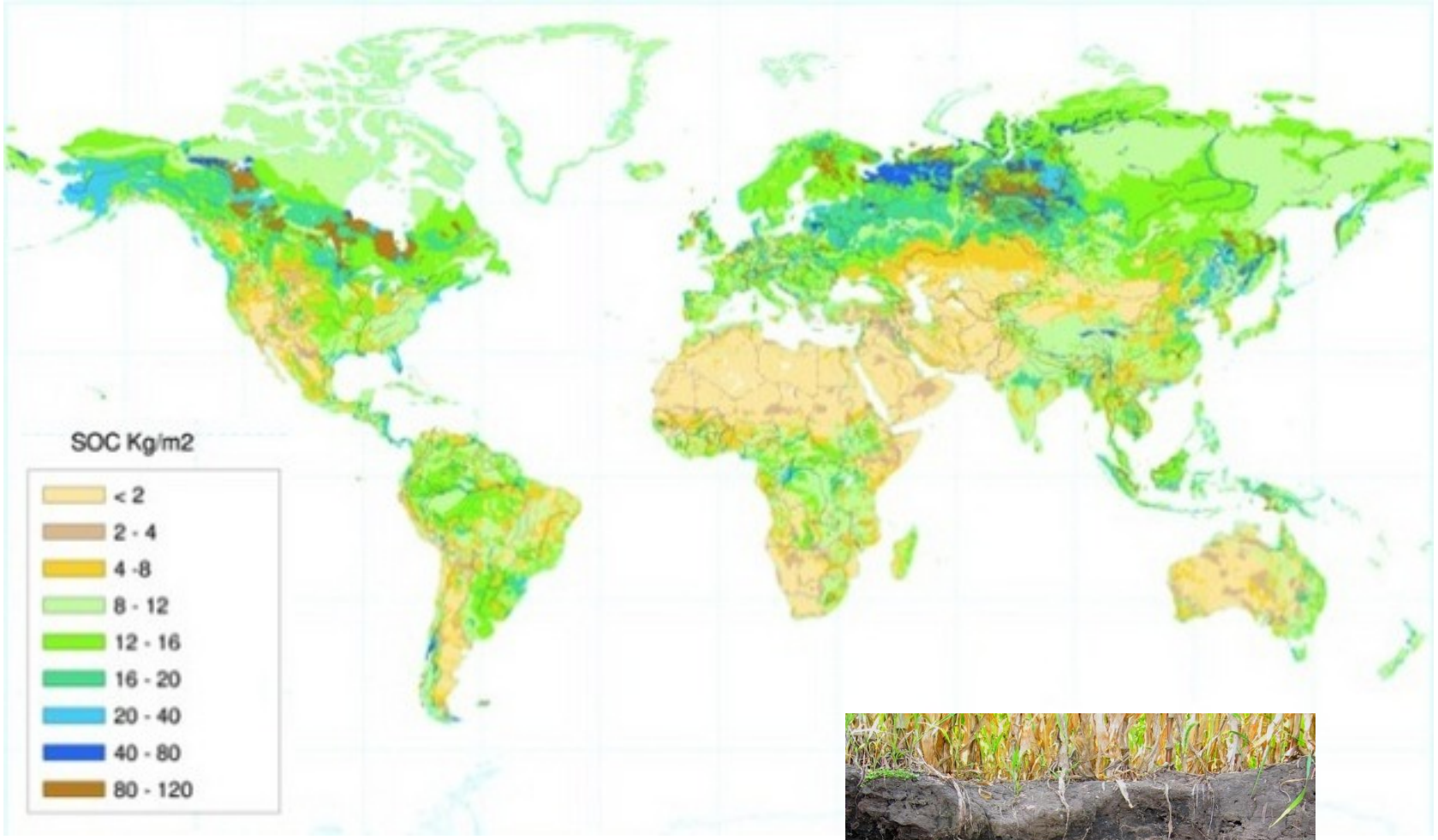
Carbon Dioxide in the mid troposphere, May 2013 (800,000 year high)



http://earthobservatory.nasa.gov/IOTD/view.php?id=82142

http://www.nasa.gov/images/content/121557main_landCover.jpg





Carbon Sequestration in soils

http://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790

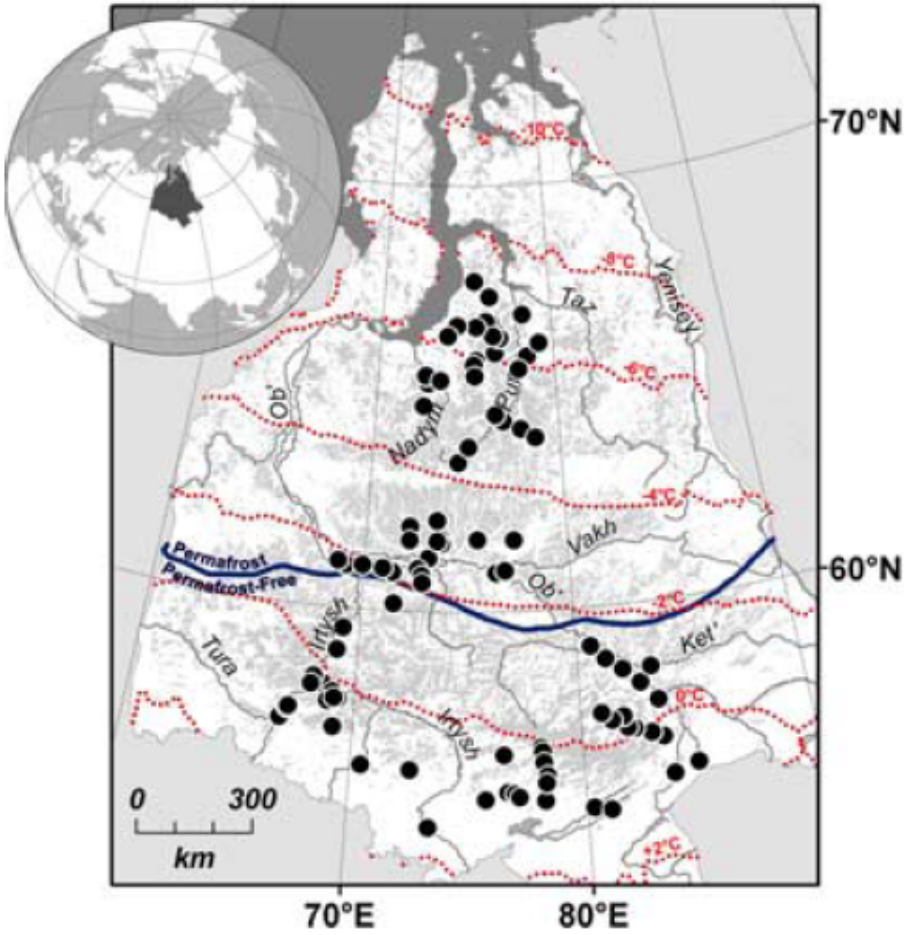
Arctic watersheds drain vast areas of Asia and North America

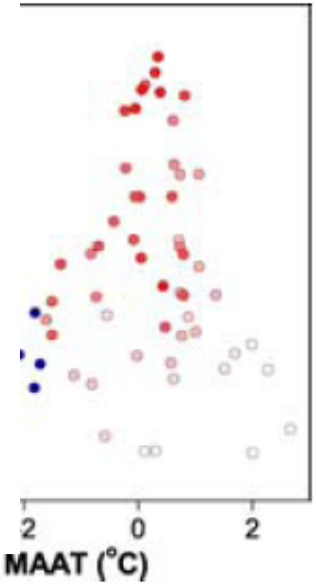
Arctic watersheds are dominated by 5-6 large basins that reach into and drain large portions of Asia and North America. Smaller rivers may contribute another 50% of the freshwater and carbon to these systems.

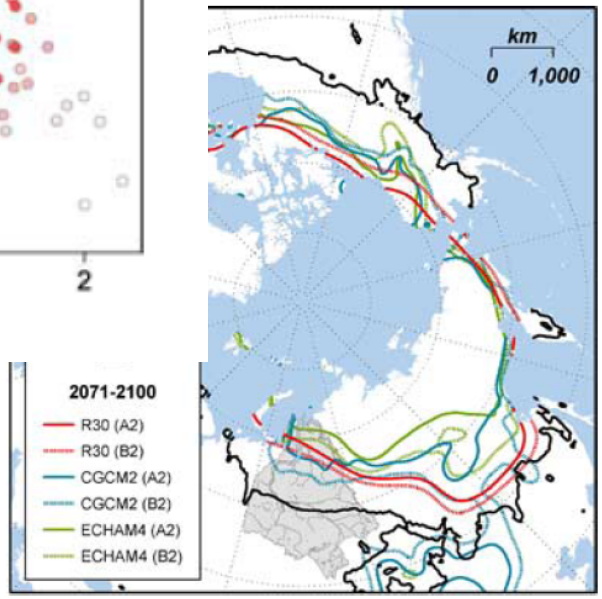
Max Holmes WHRC

Much of the arctic is characterized by low lands that have a swampy/peaty nature to them. They store lots of organic carbon that has been deposited over centuries and millennia That is locked away and frozen for much of the year.

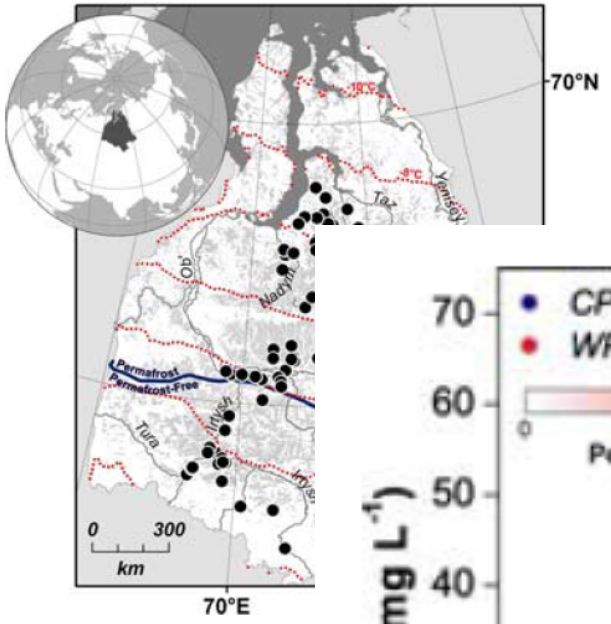
Possible impact of climate change driven arctic warming on DOC flux and fate

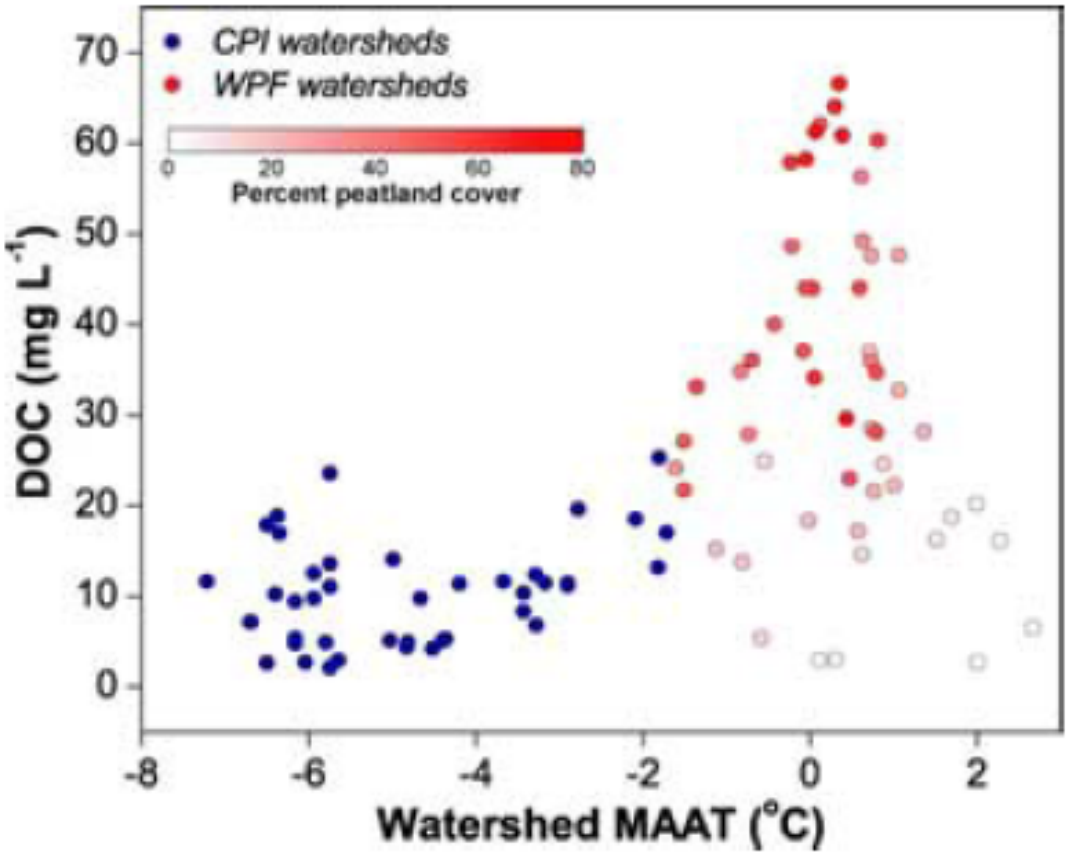


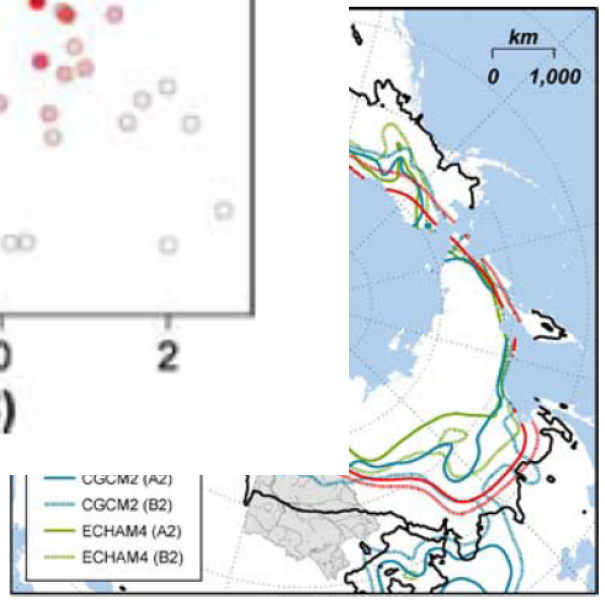


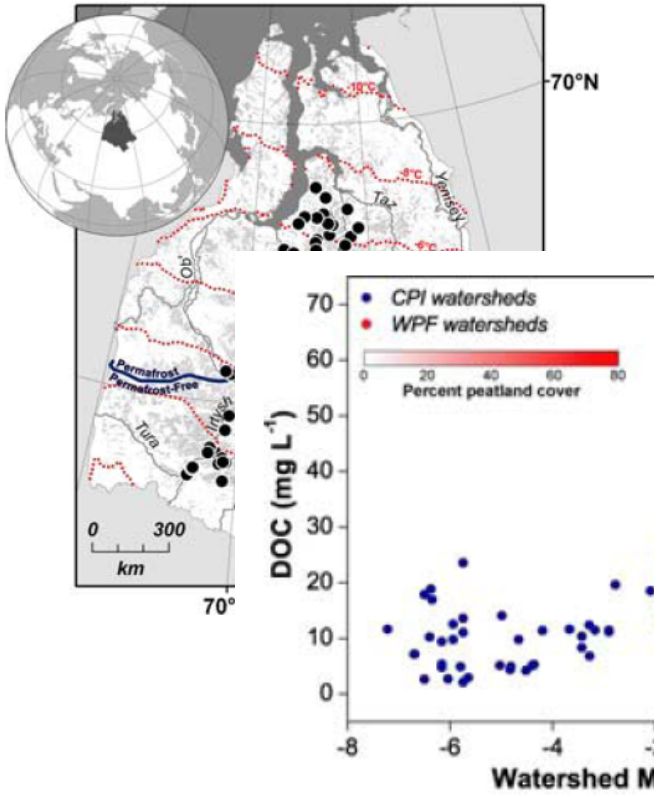


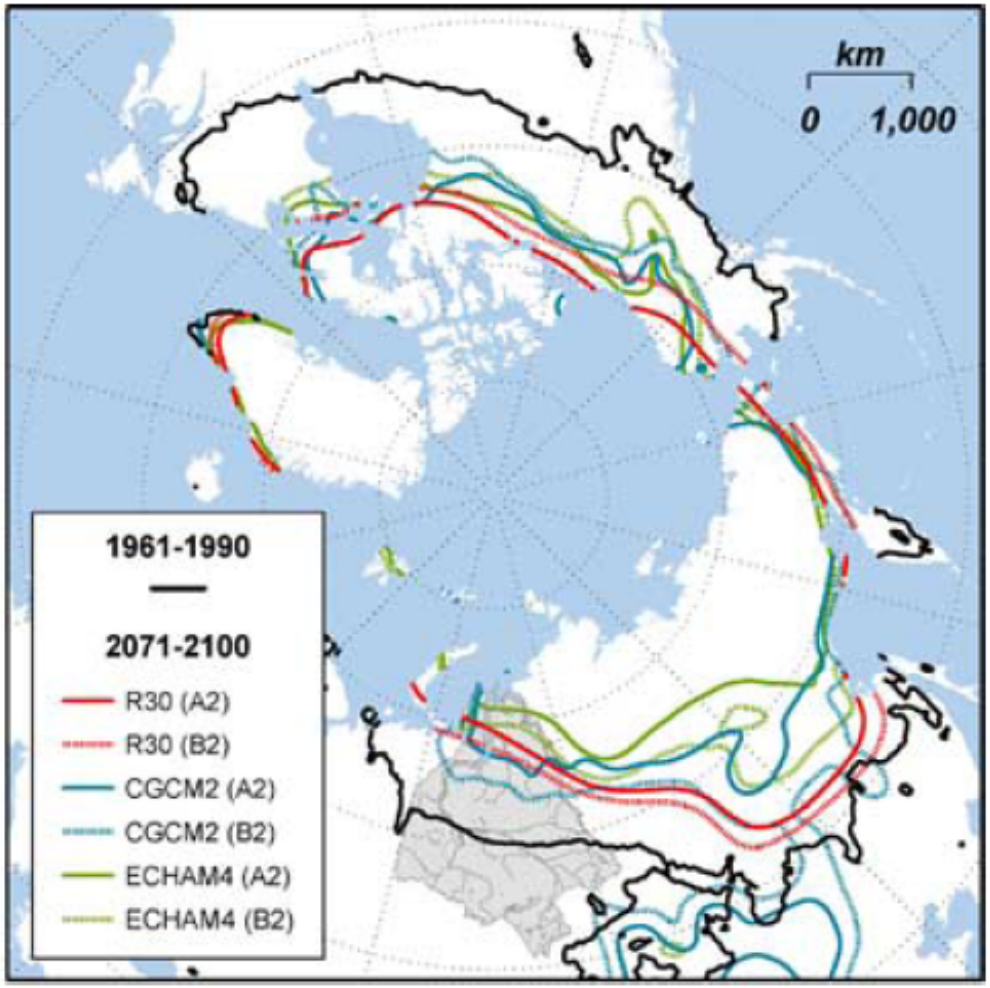
Frey and Smith, JGR 32 L09401 (2005)


70°N
70°E
0
300
km
Permafrost
Permafrost-Free
Ob'
Yenisey
Taz
Tura
Irtysh


CPI watersheds
WPF watersheds
0
20
40
60
80
Percent peatland cover
DOC (mg L-1)
70
60
50
40
30
20
10
0
-8
-6
-4
-2
0
2
Watershed MAAT (°C)

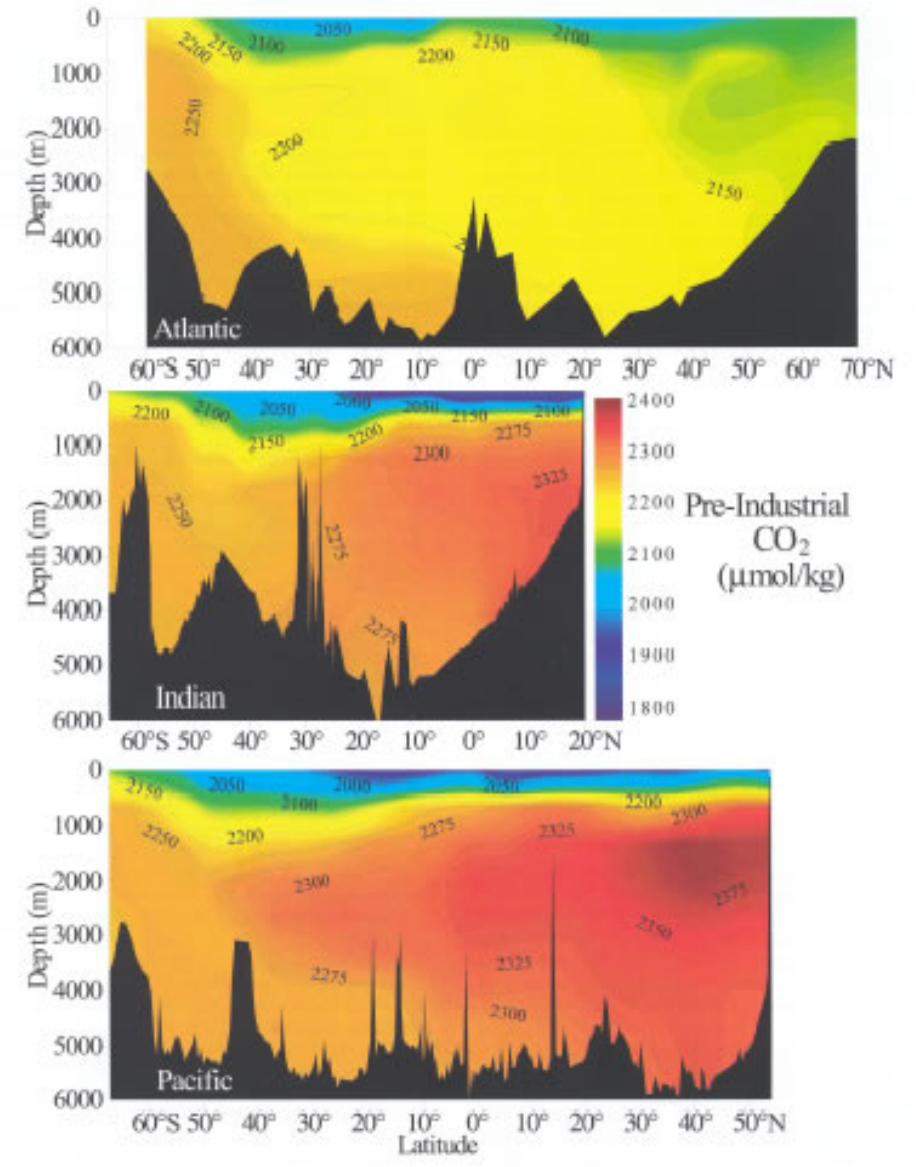

km
0
1,000
CGCM2 (A2)
CGCM2 (B2)
ECHAM4 (A2)
ECHAM4 (B2)





Frey and Smith, JGR 32 L09401 (2005)

The ocean carbon inventory is relatively easy to measure



http://www.pmel.noaa.gov/pubs/outstand/feel2331/images/fig07.jpg

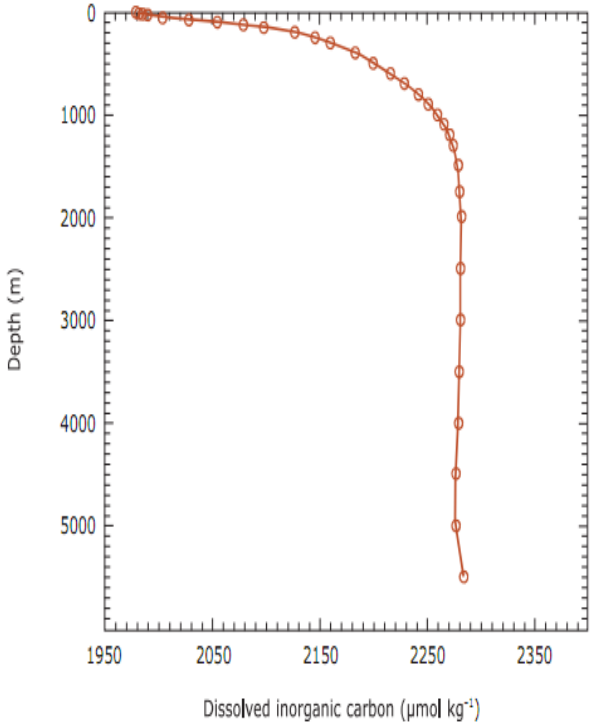
CO_2 (gas) -> CO_2 (aqueous)

CO_2 (aqueous) -> H_2CO_3 (carbonic acid)

H_2CO_3 -> $H^+ + HCO_3^-$ (bicarbonate)

HCO_3^- -> $H^+ + CO_3^{2-}$ (carbonate)

Figure 4.1: Vertical profile of horizontally averaged dissolved inorganic carbon in the ocean



Source: Based on the GLODAP data set of Key et al. 2004.

Inorganic carbon transport and CO_2 accumulation in higher plants (top) and eukaryotic algal cells (bottom)

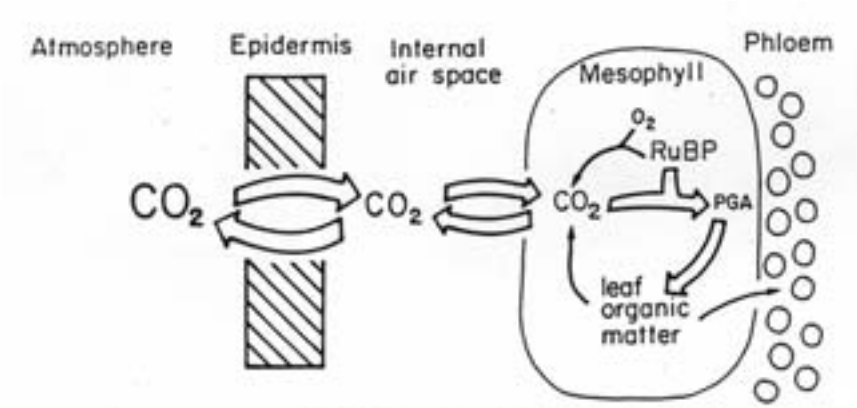
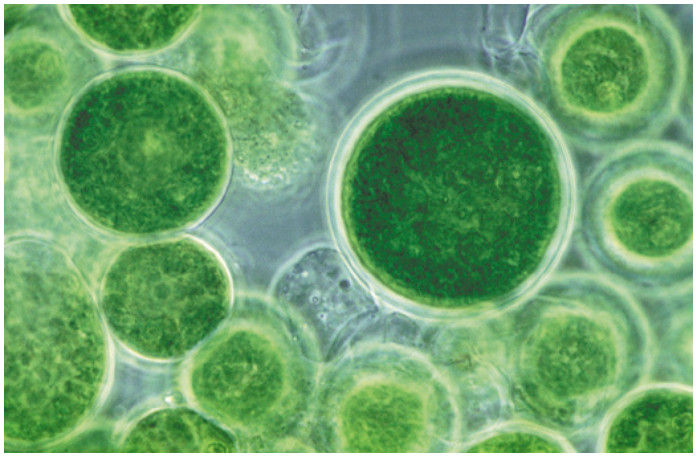
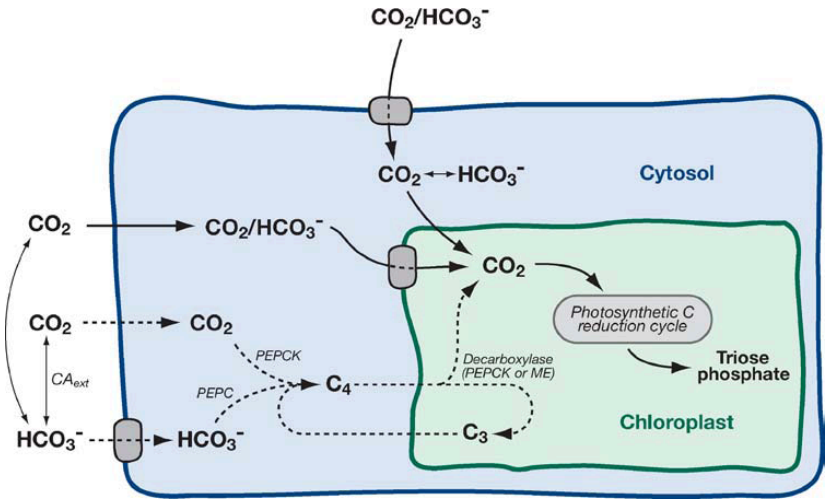


Figure 2. Important steps in CO_2 fixation during C_3 photosynthesis. Sizes of arrows indicate the relative fluxes through the various steps (including the reverse steps) according to the best models available. Sizes of symbols reflect relative concentrations of CO_2 at various stages.

www.orkron.com

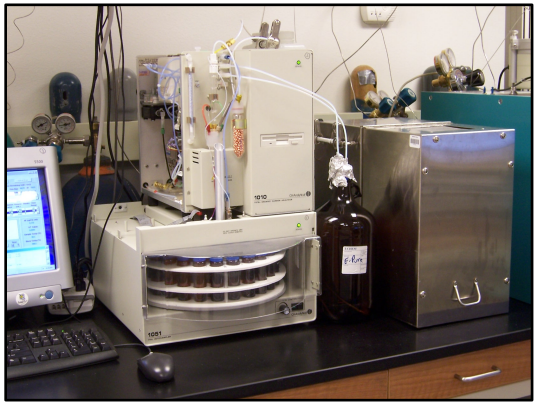


webberenergyblog.wordpress.com



From Giordono et al. 2005 Ann Rev Plant Biology

Typical 1D profile of dissolved organic carbon in the ocean

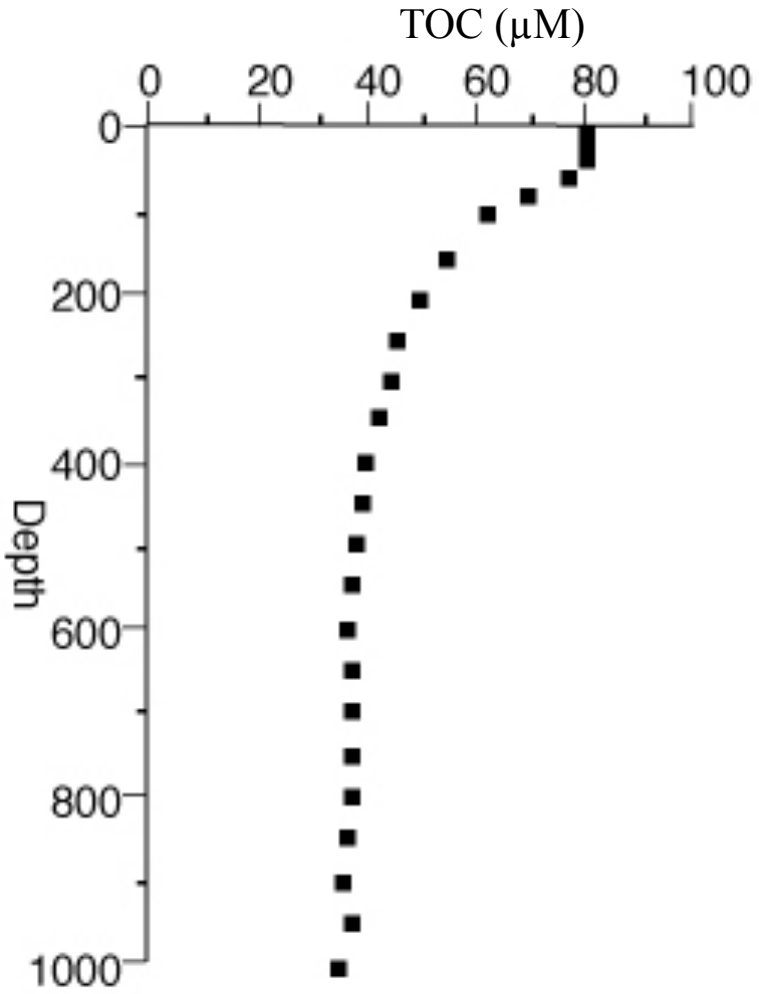


Often measured as TOC

Surface values typically 60-80 µM

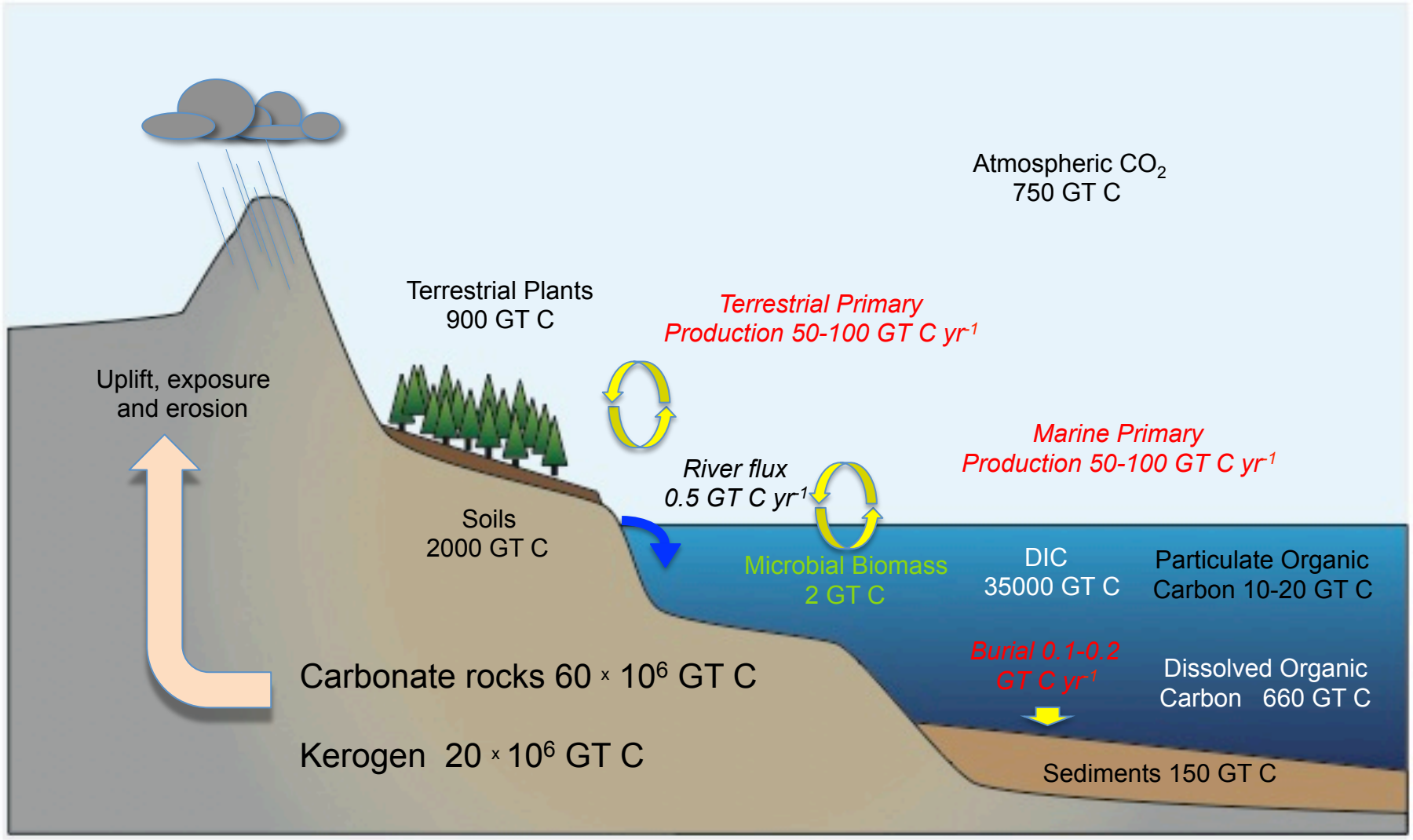
Deep water values @ 40 ±1 µM (implies some unknown feedback/ control of DOC values)

Global inventory about 660 GT C



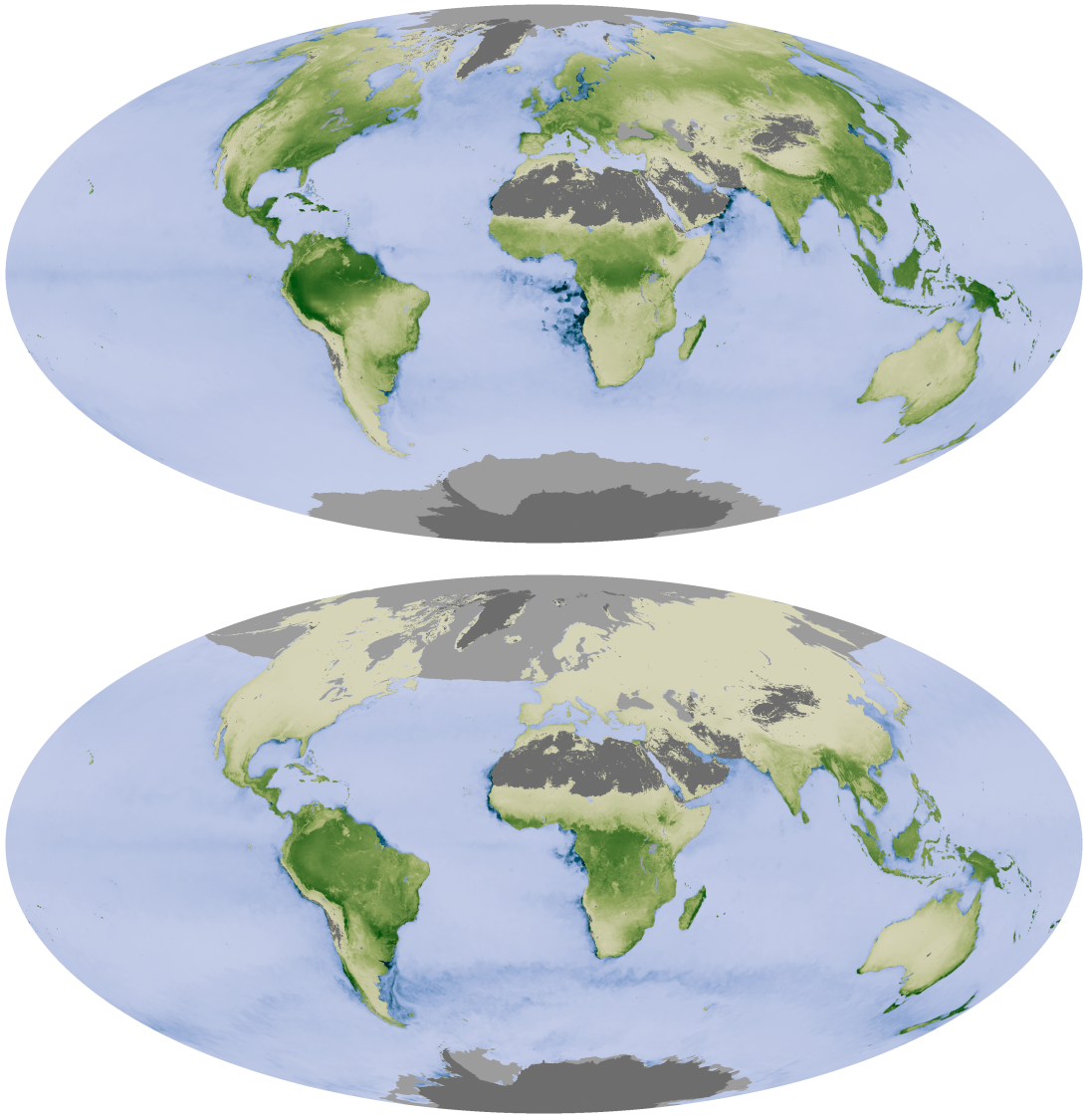
Data from Peltzer and Hayward (1996) DSR

Major Planetary Inventories and Fluxes of Carbon



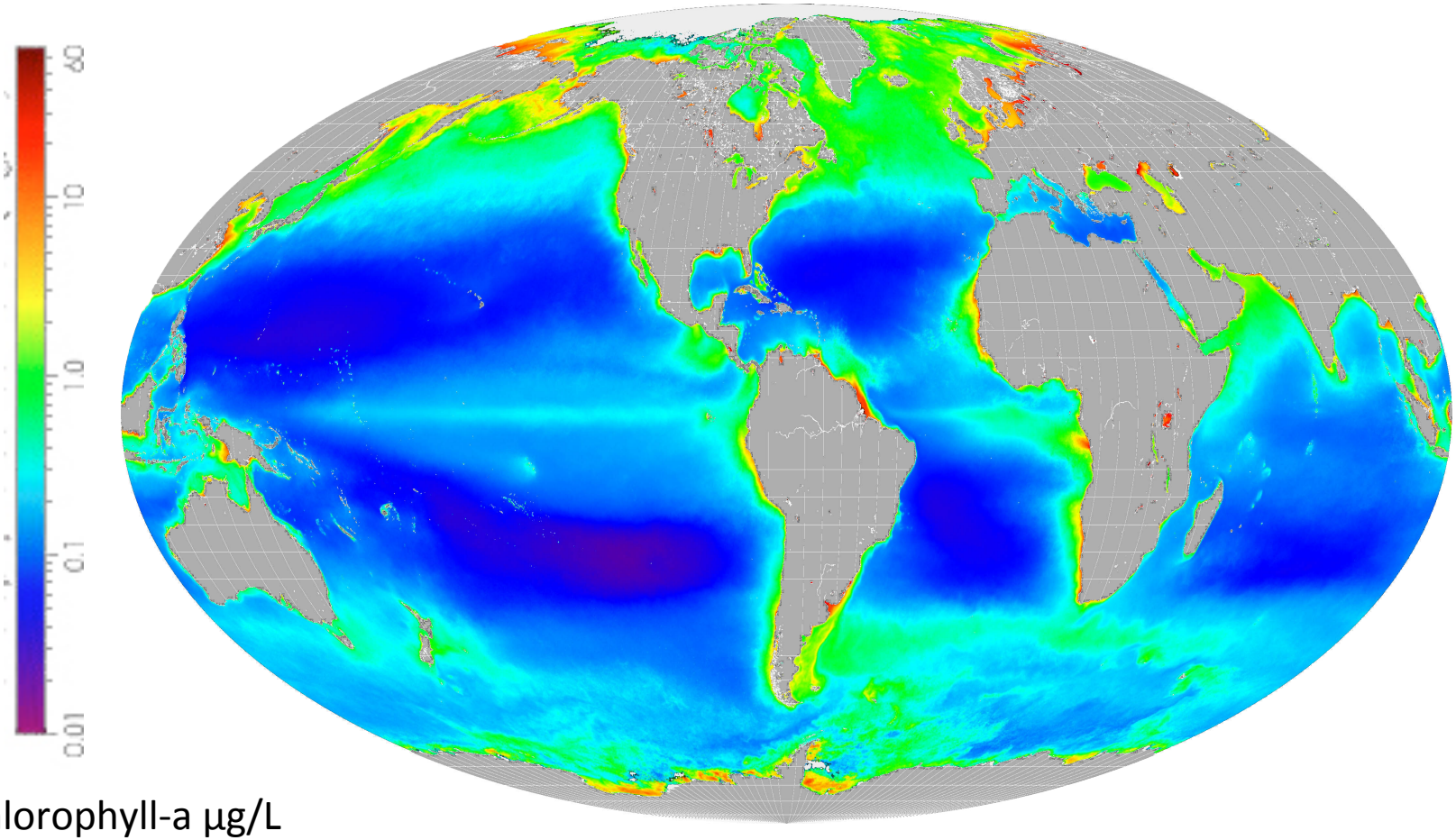
August 2010

December 2010



http://earthobservatory.nasa.gov

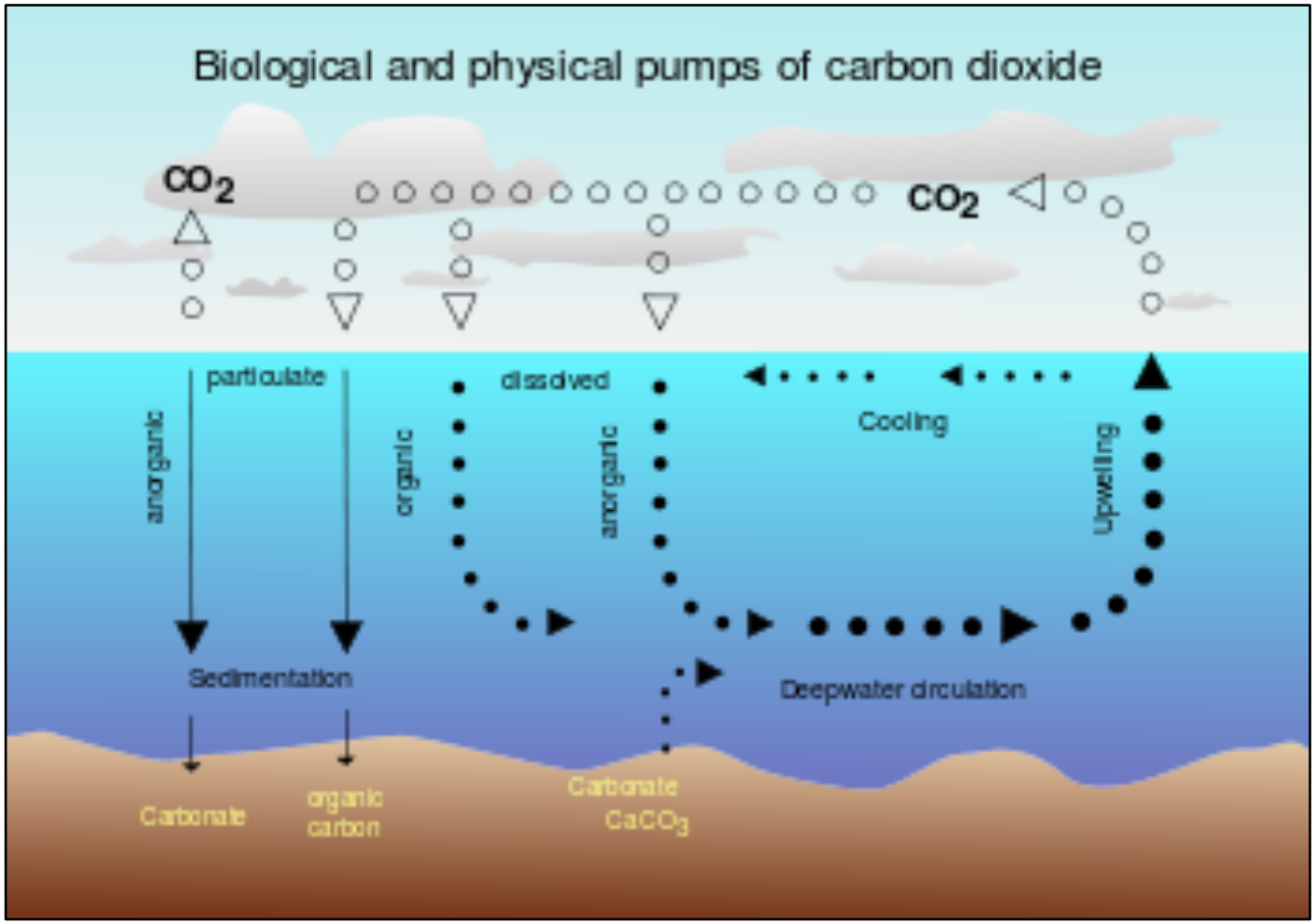
Global distribution of Chlorophyll-a as a proxy for biomass and productivity

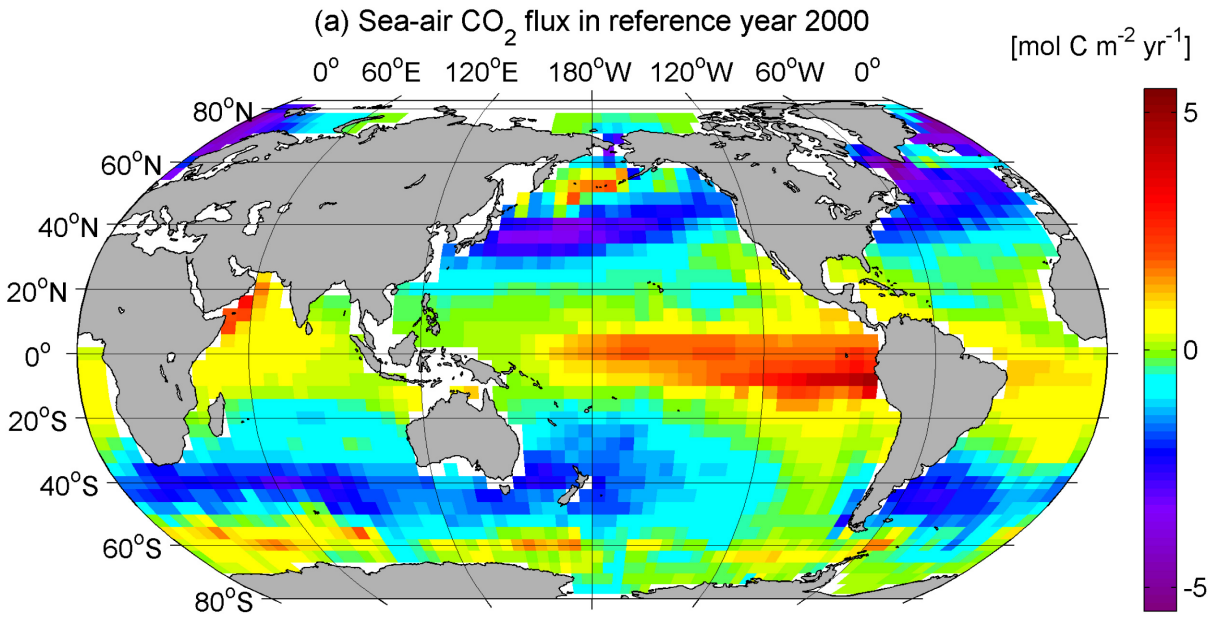


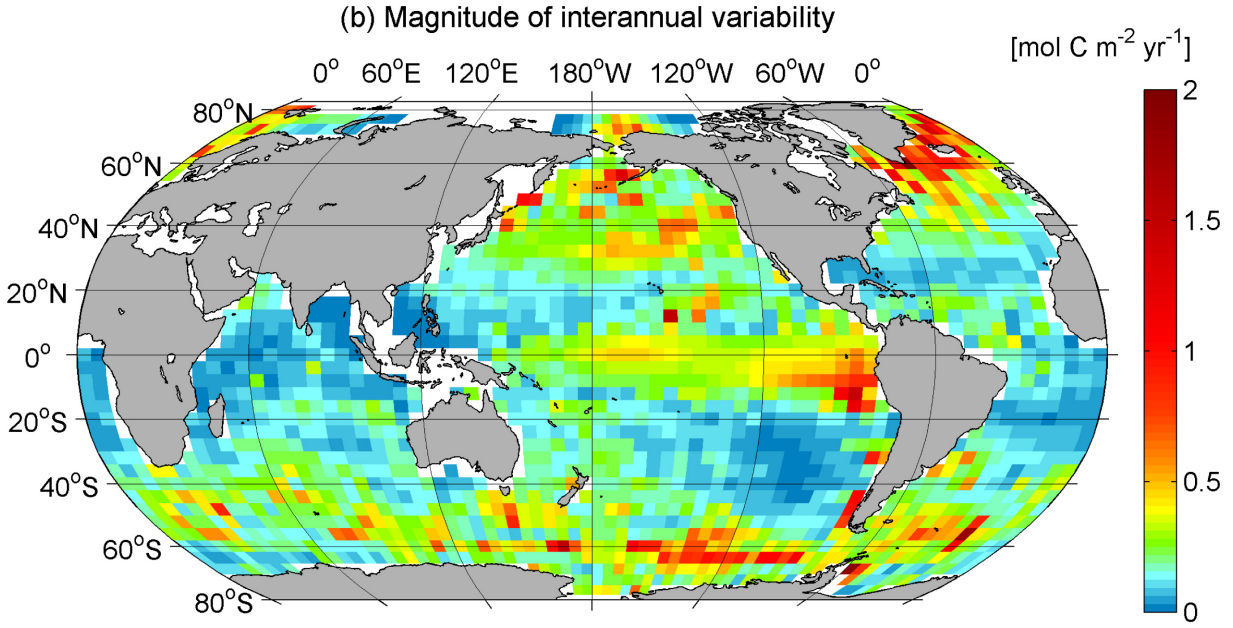
Chlorophyll-a µg/L

Hansell et al., GBC 2012
http://earthobservatory.nasa.gov

We distinguish a “physical” (solubility) pump and a “biological pump”

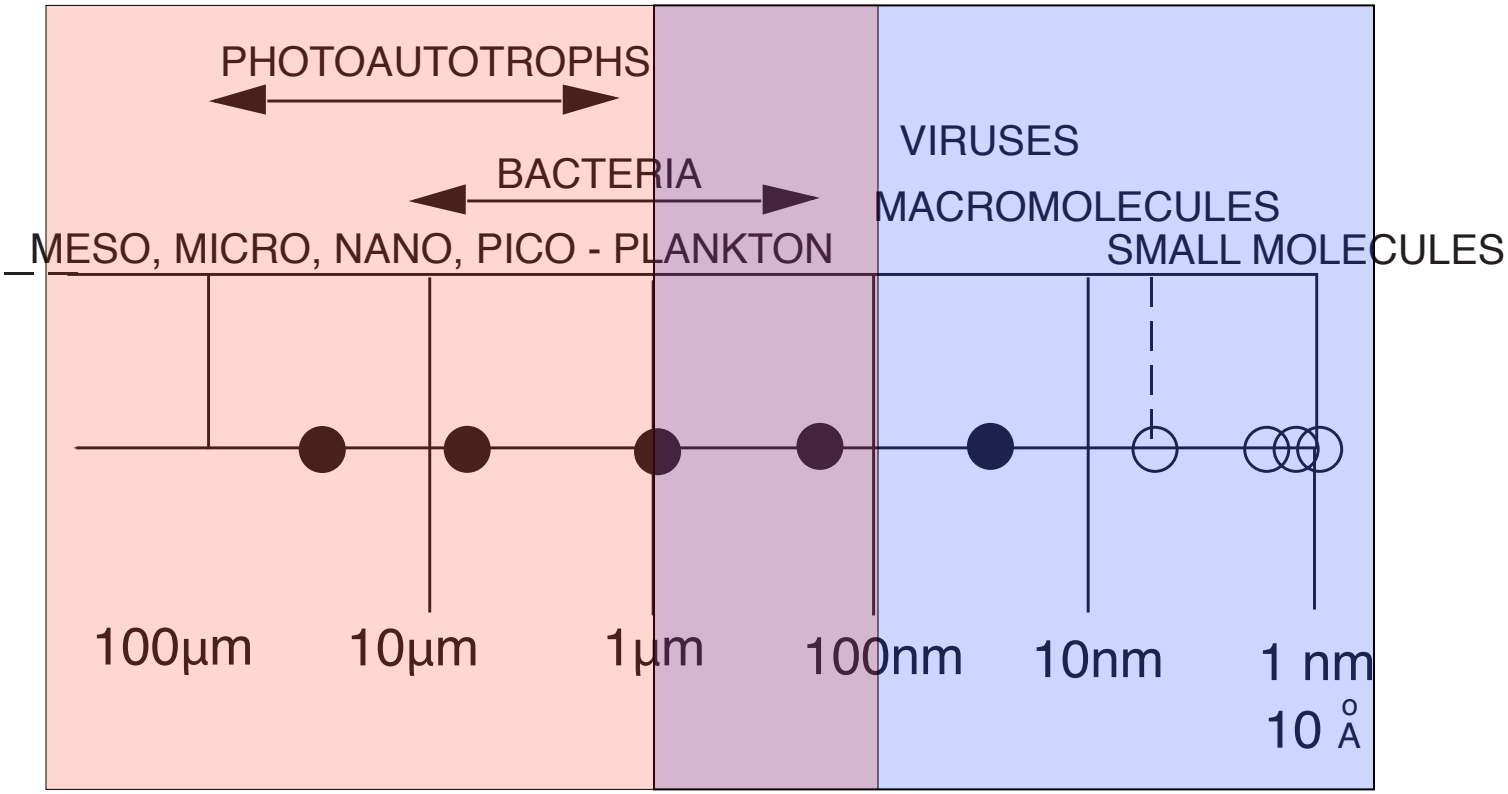



(a) Sea-air CO_2 flux in reference year 2000
[mol C m^{-2} yr^{-1}]
0° 60°E 120°E 180°W 120°W 60°W 0°
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
5
0
-5


(b) Magnitude of interannual variability
[mol C m^{-2} yr^{-1}]
0° 60°E 120°E 180°W 120°W 60°W 0°
80°N
60°N
40°N
20°N
0°
20°S
40°S
60°S
80°S
2
1.5
1
0.5
0

What is "particulate" and what is "dissolved" carbon?

Organic matter is classified by size, as defined by filtration

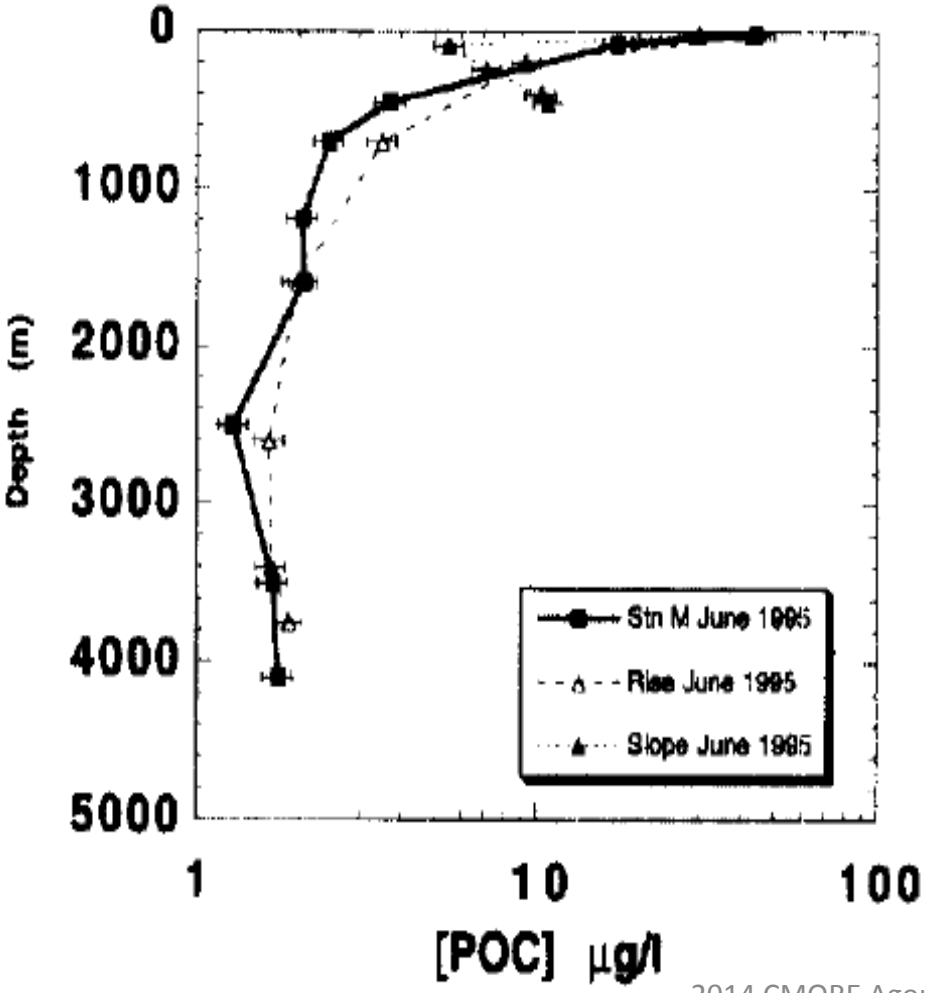


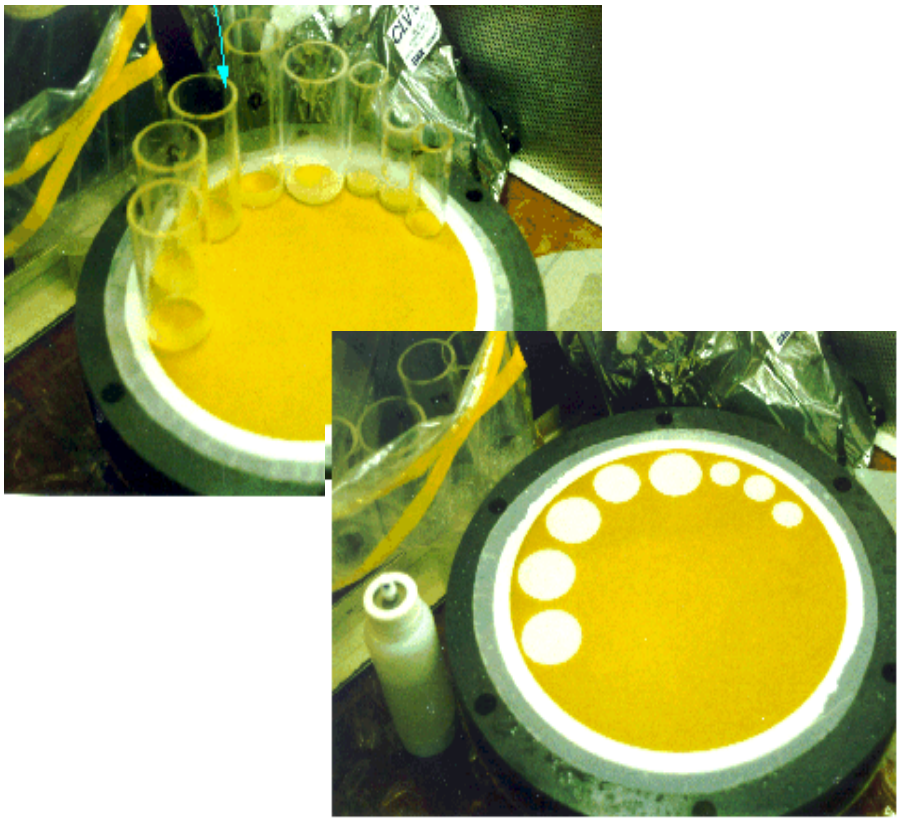
Particulate Organic Matter Dissolved Organic Matter

The biological pump and organic carbon transfer to the sea floor

"grain-by-grain deposition is by far the most common phenomenon of pelagic sedimentation"

Jacobs et al. (1973) Marine Geology v14, 117-128





Photos from Jim Bishop

The biological pump and organic carbon transfer to the sea floor

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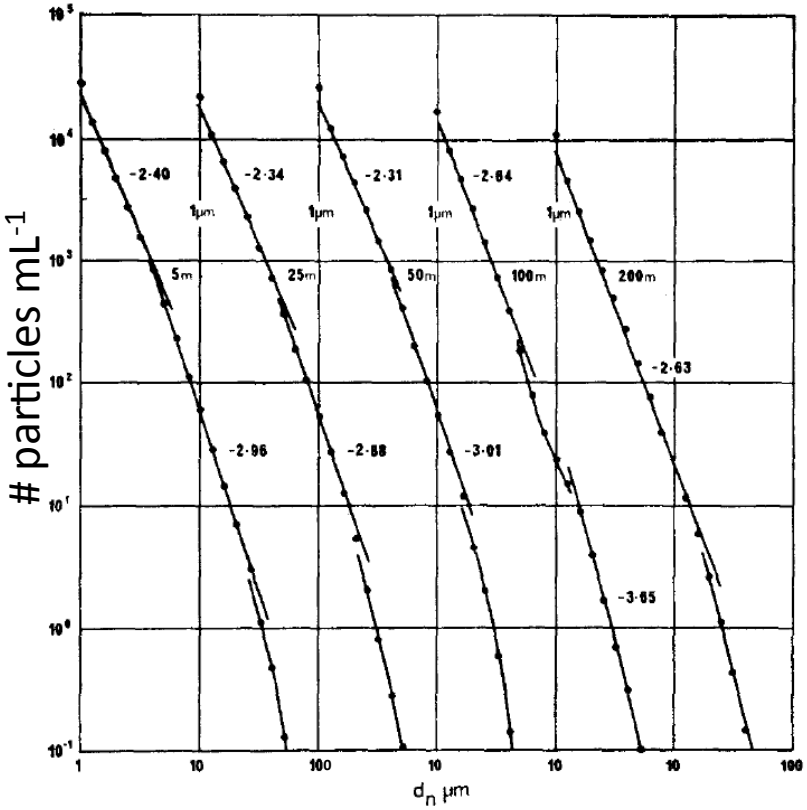
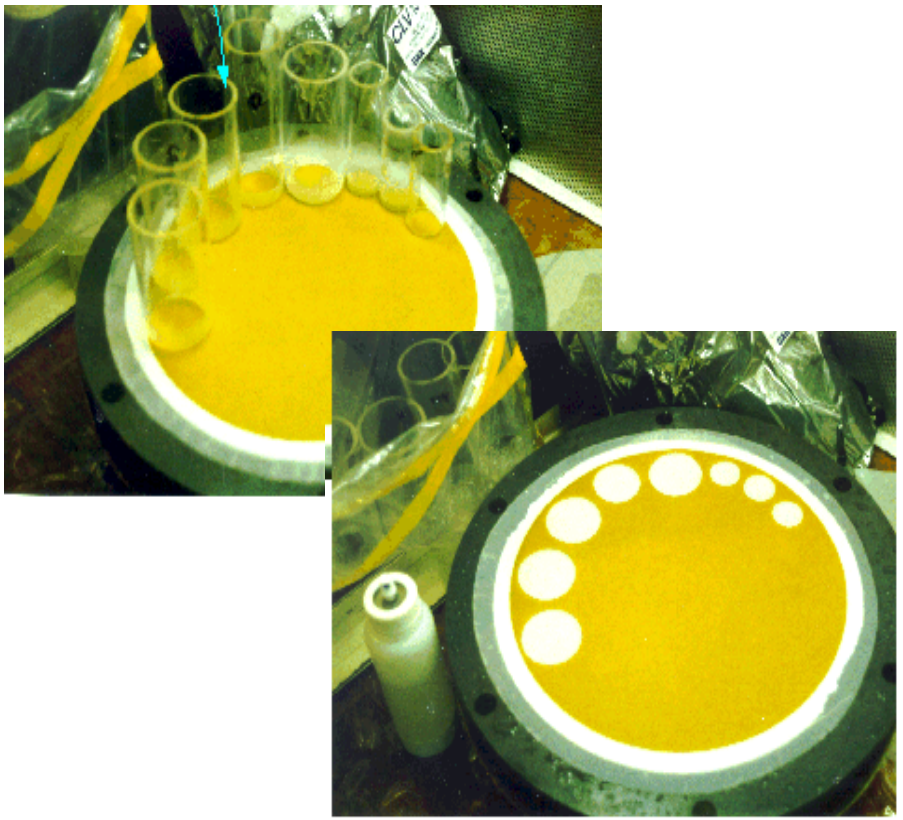
Jacobs et al. (1973) Marine Geology v14, 117-128



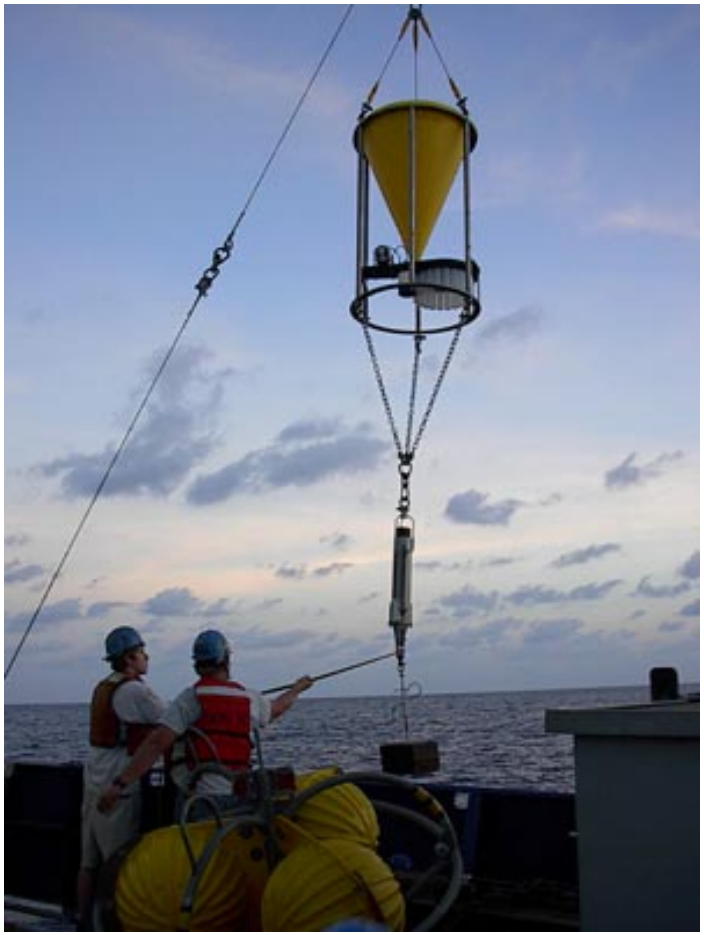
Particle diameter (µm)

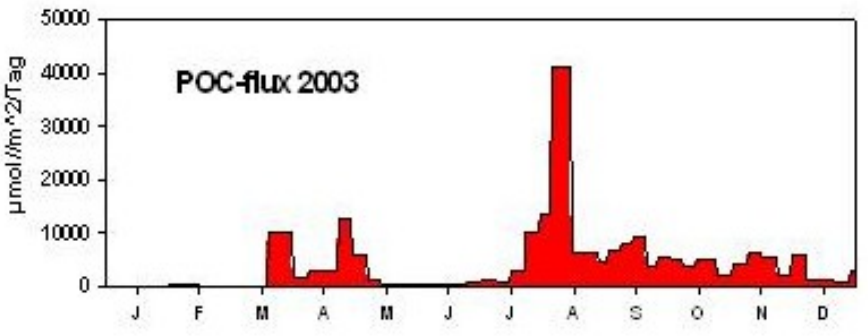


Photos from Jim Bishop

www.whoi.edu/science/B/people/lmullineaux/RIDiane.htm

Large, rapidly sinking particles are collected with sediment traps

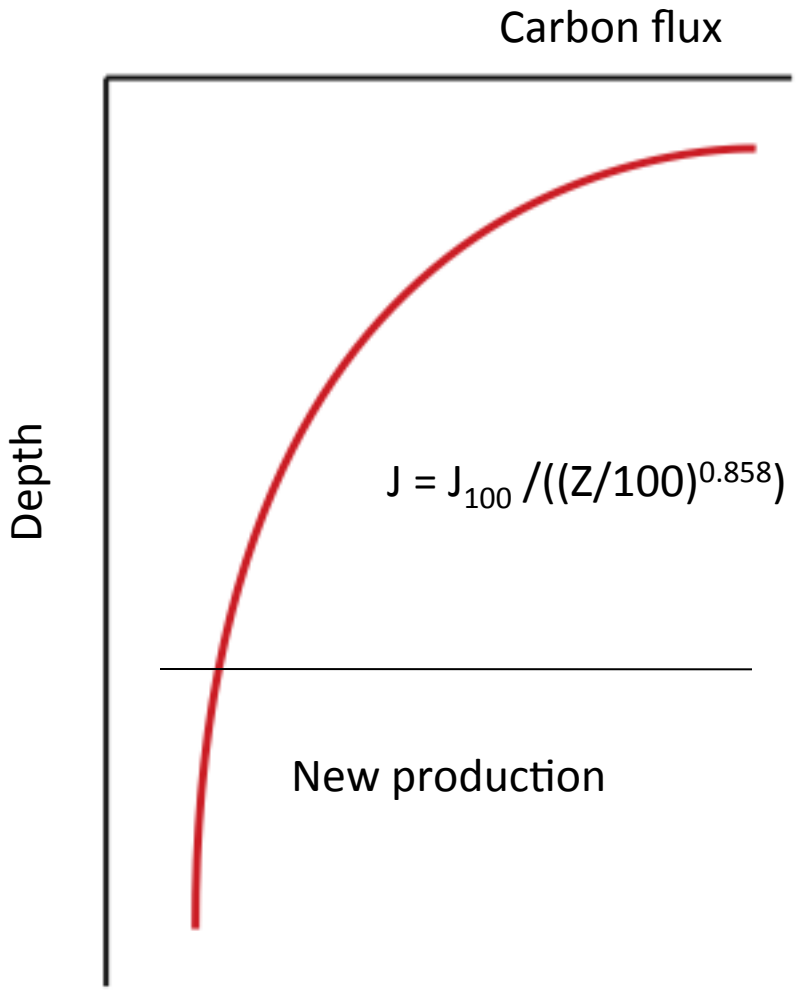




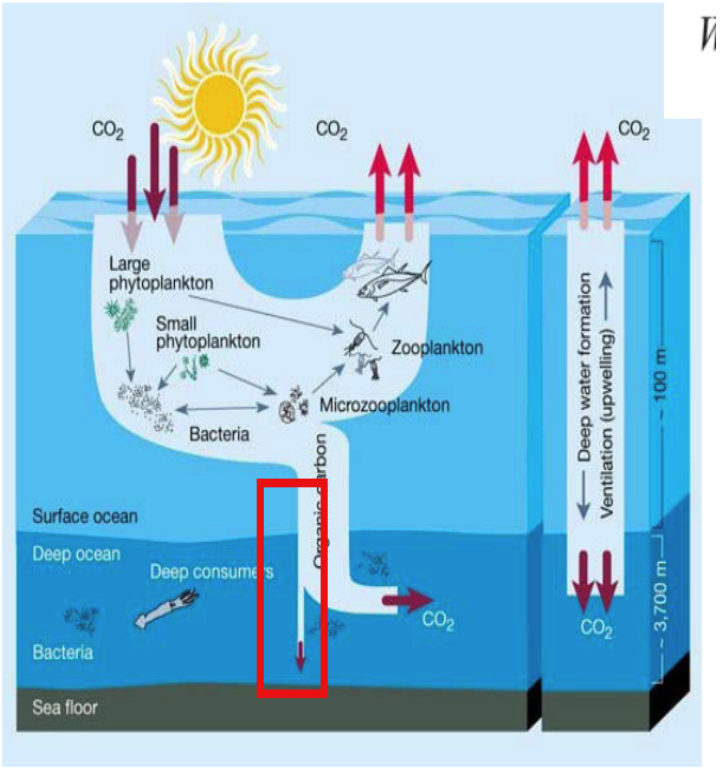
www.io-wamemuende.de

www.bbsr.edu

What drives carbon flux?

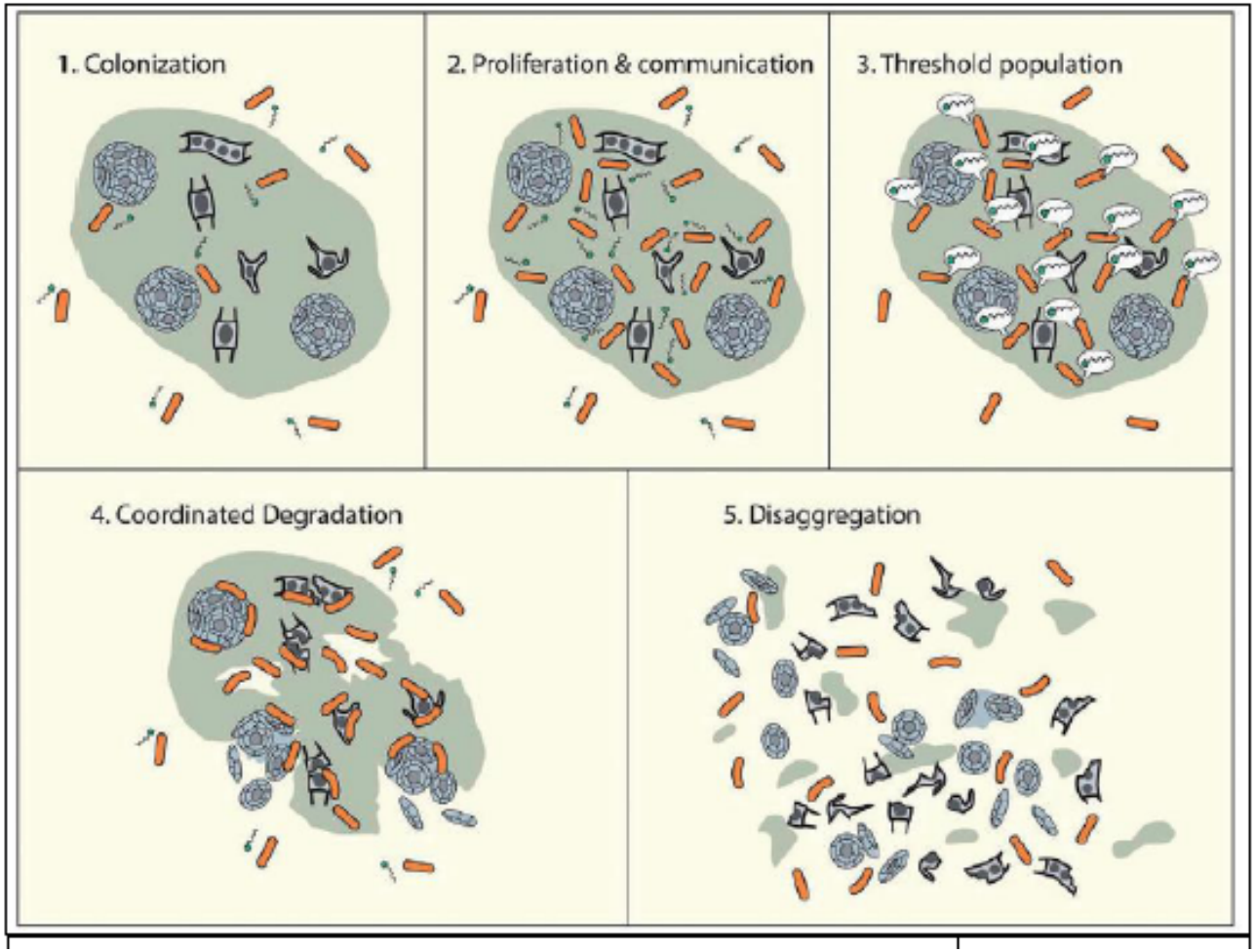


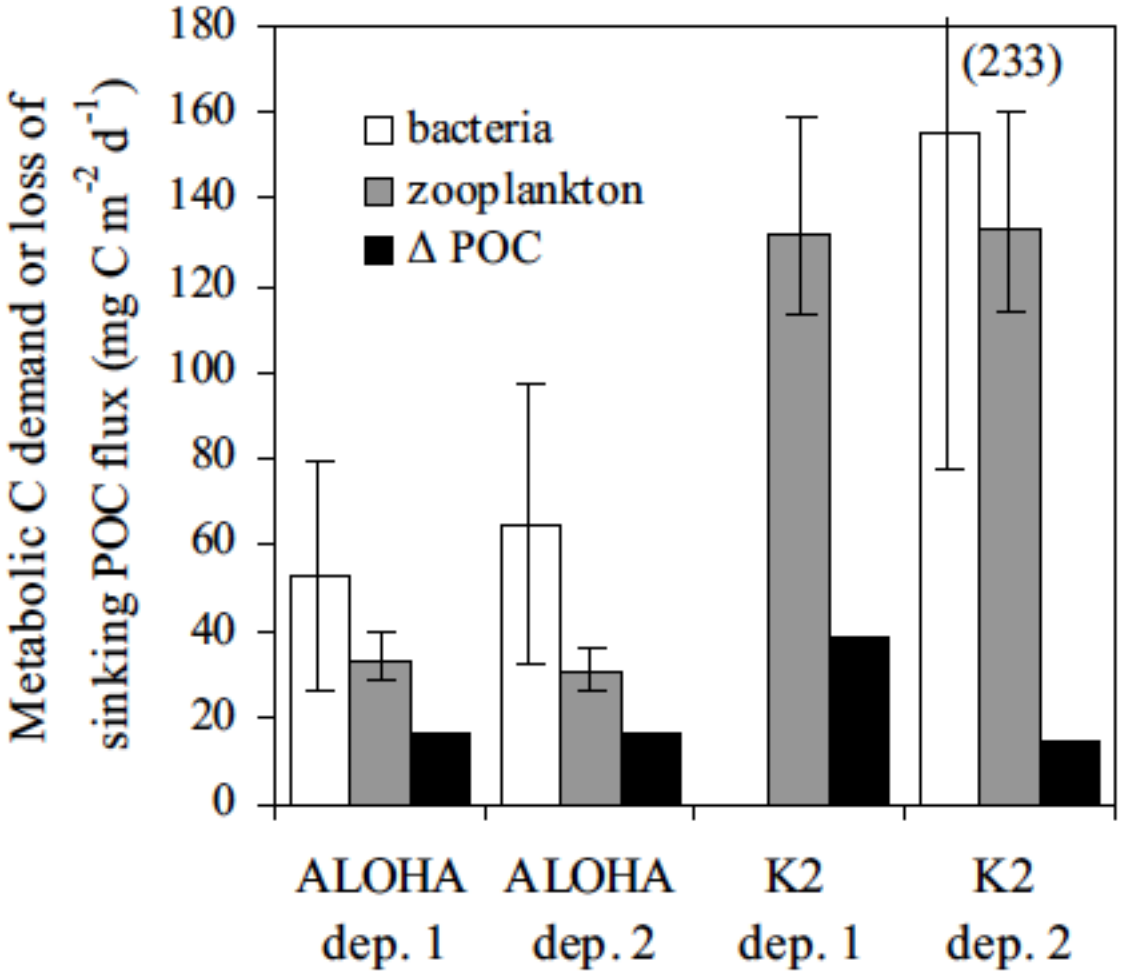
Martin et al (1987) DSR v 34; 267-285



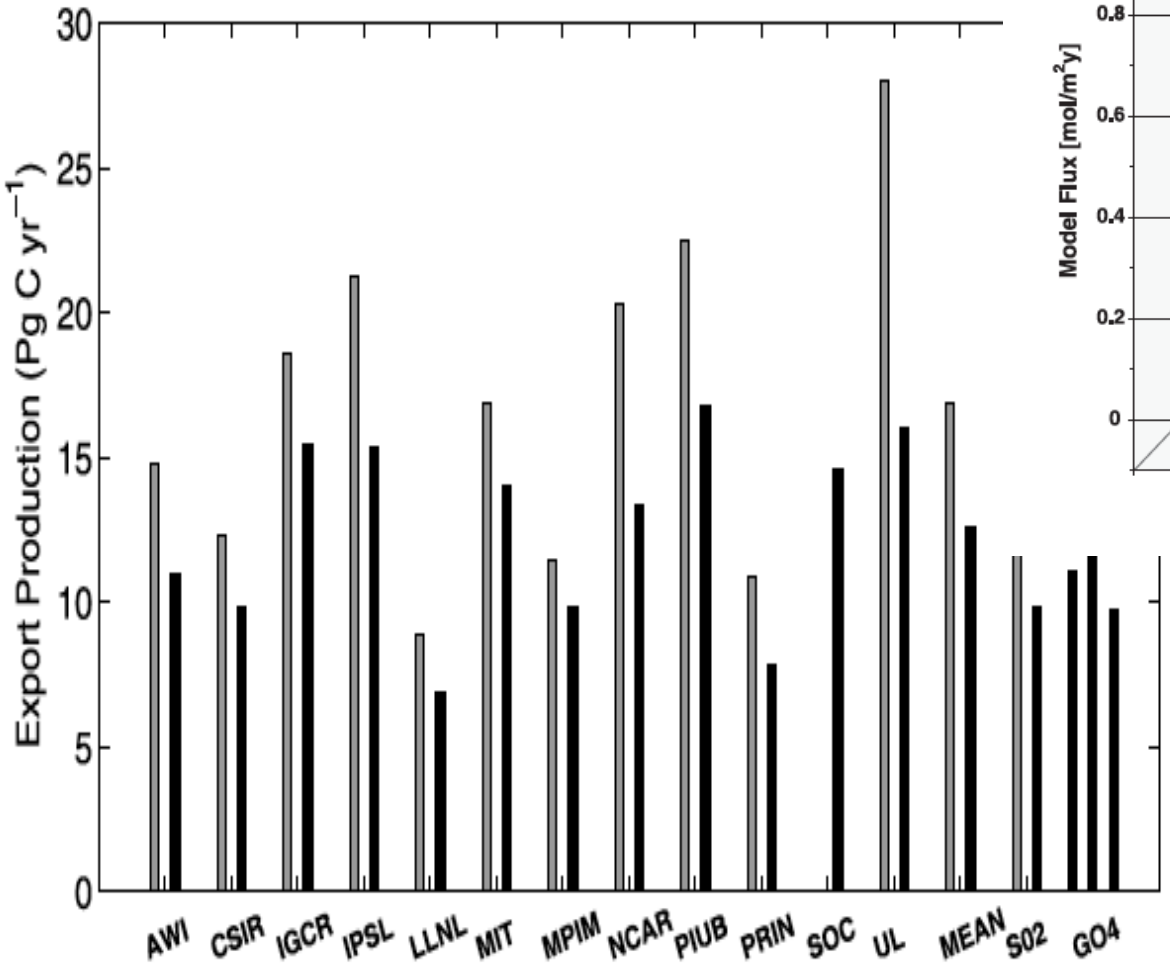
C flux is closely coupled to the biological processing of organic matter

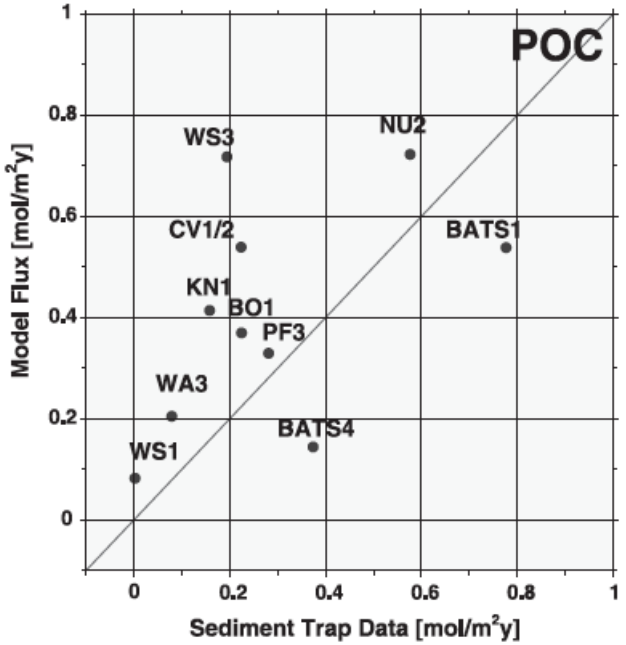
Microbial degradation of organic matter and attenuation of carbon flux
Dominates below 500-1000m




Metabolic C demand or loss of sinking POC flux (mg C m-2 d-1)
180
160
140
120
100
80
60
40
20
0
bacteria
zooplankton
Δ POC
(233)
ALOHA dep. 1
ALOHA dep. 2
K2 dep. 1
K2 dep. 2

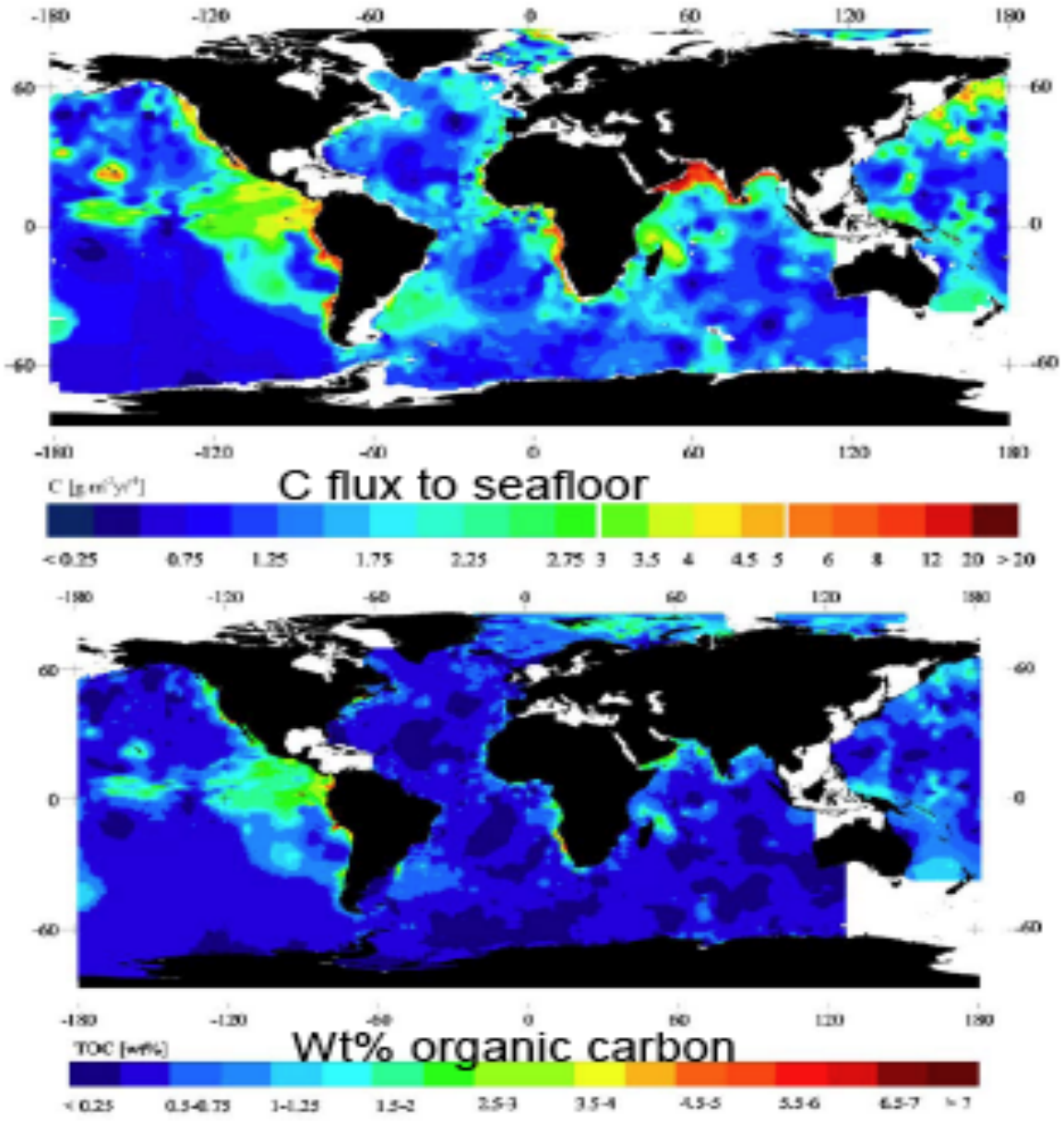
Intercomparison of 12 GCE models (Najjar et al., GBC; 2007)



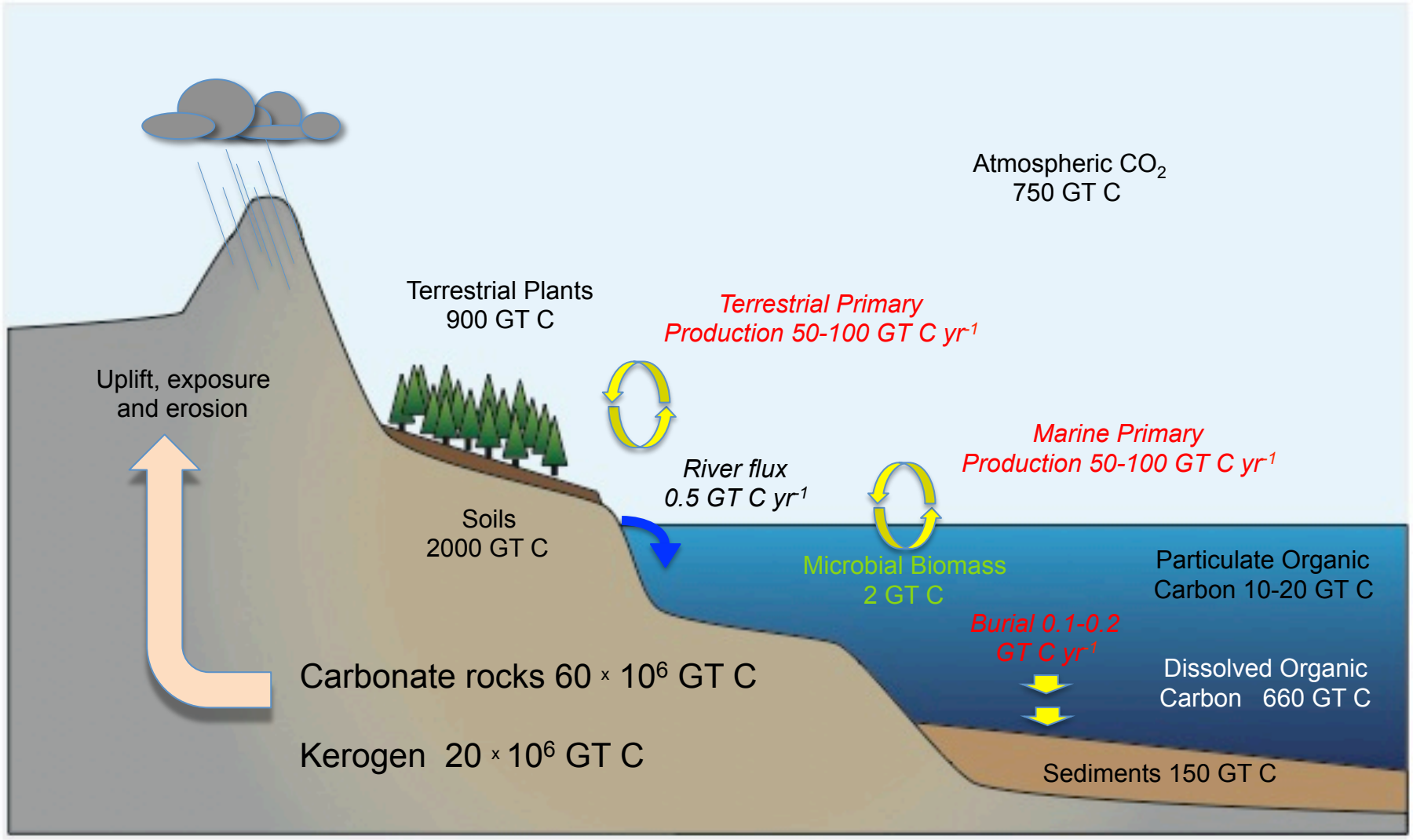


Usbeck et al., J. Mar. Systems 2003

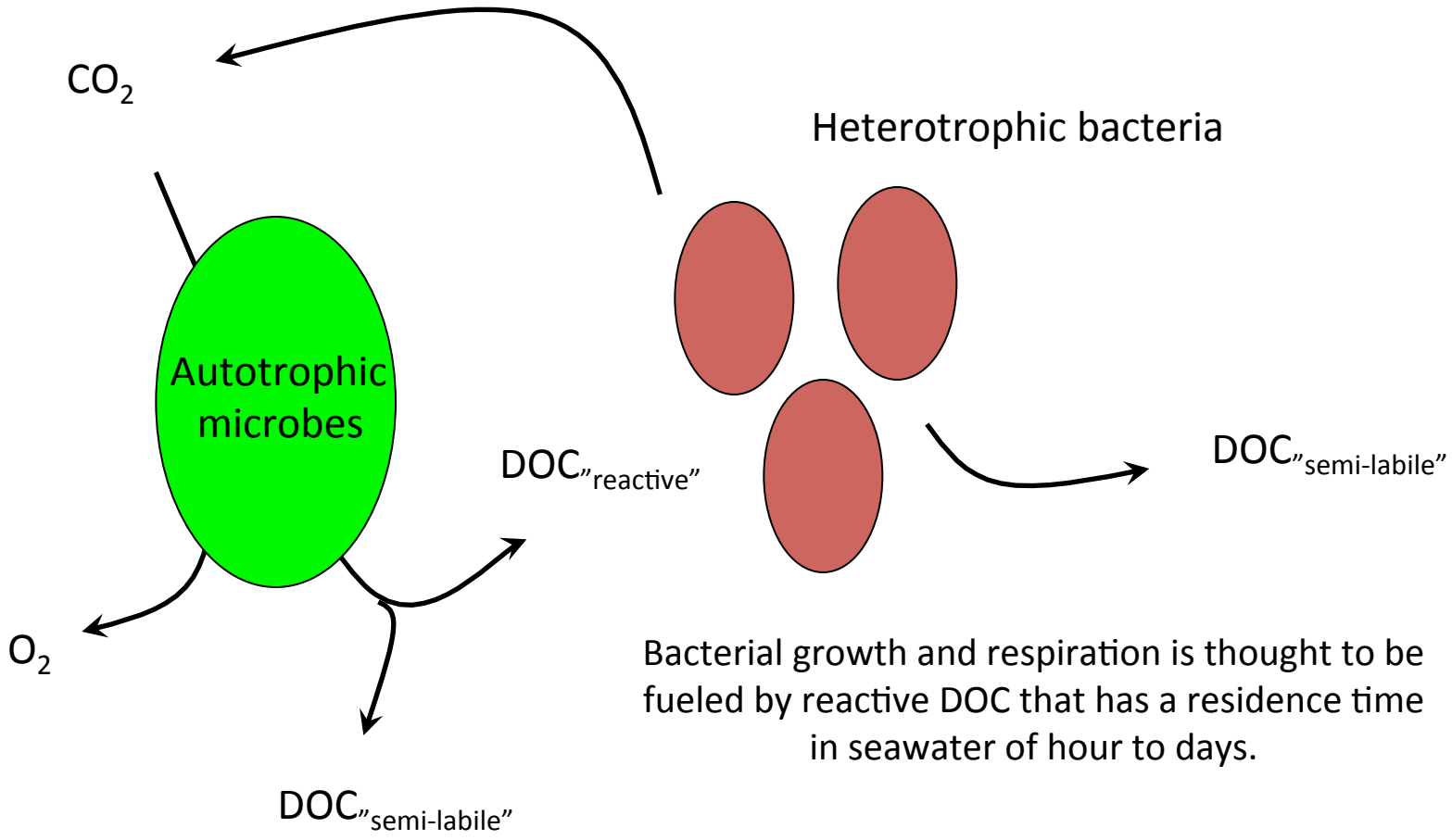
Geographic correlation between carbon flux and wt% C in sediments



Major Planetary Inventories and Fluxes of Carbon

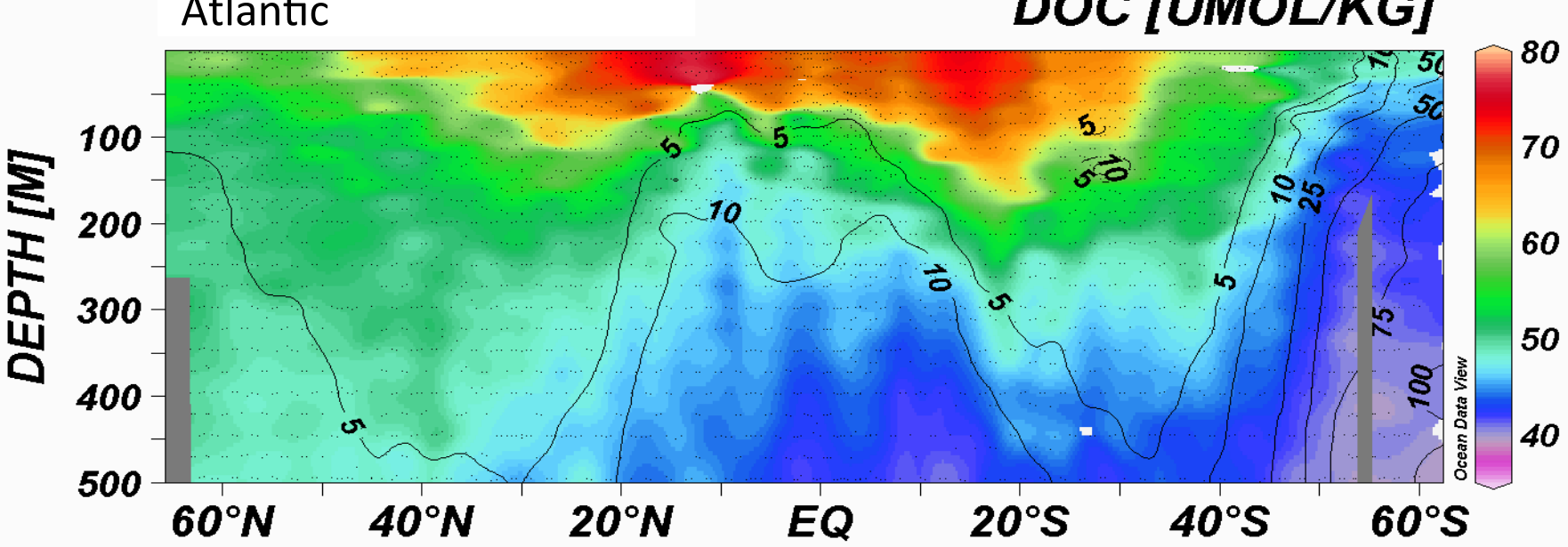


Cycling of reactive and semi-labile DOC by phytoplankton and bacteria

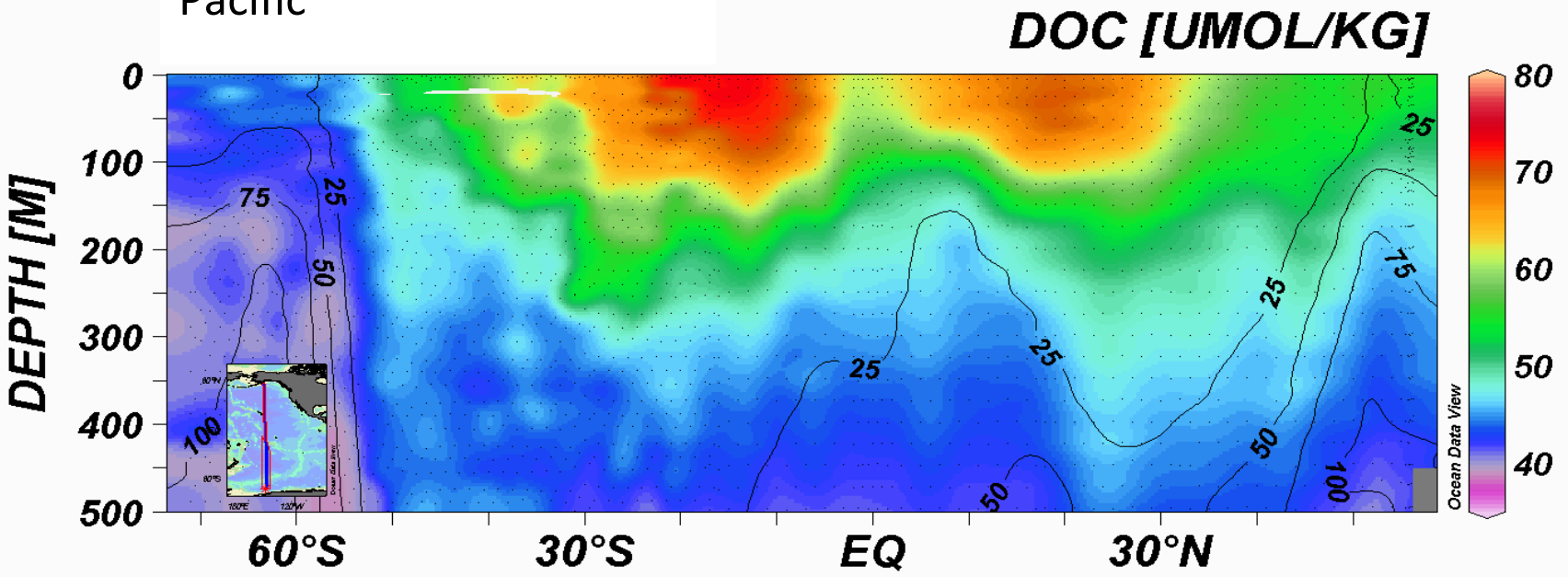


Bacterial growth and respiration is thought to be fueled by reactive DOC that has a residence time in seawater of hour to days.

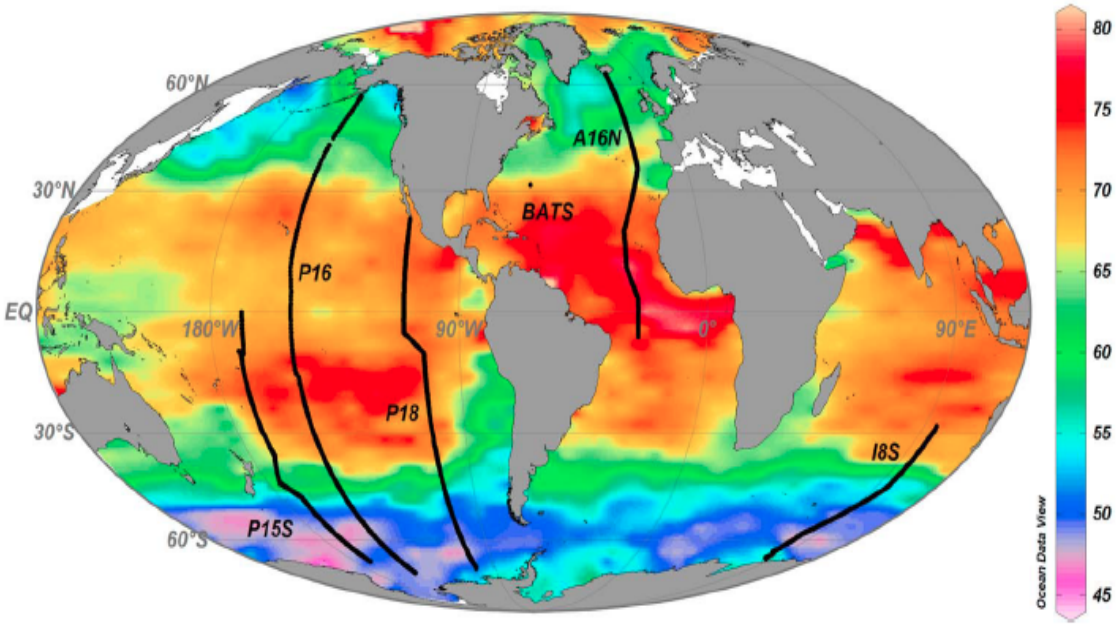
Atlantic



Pacific

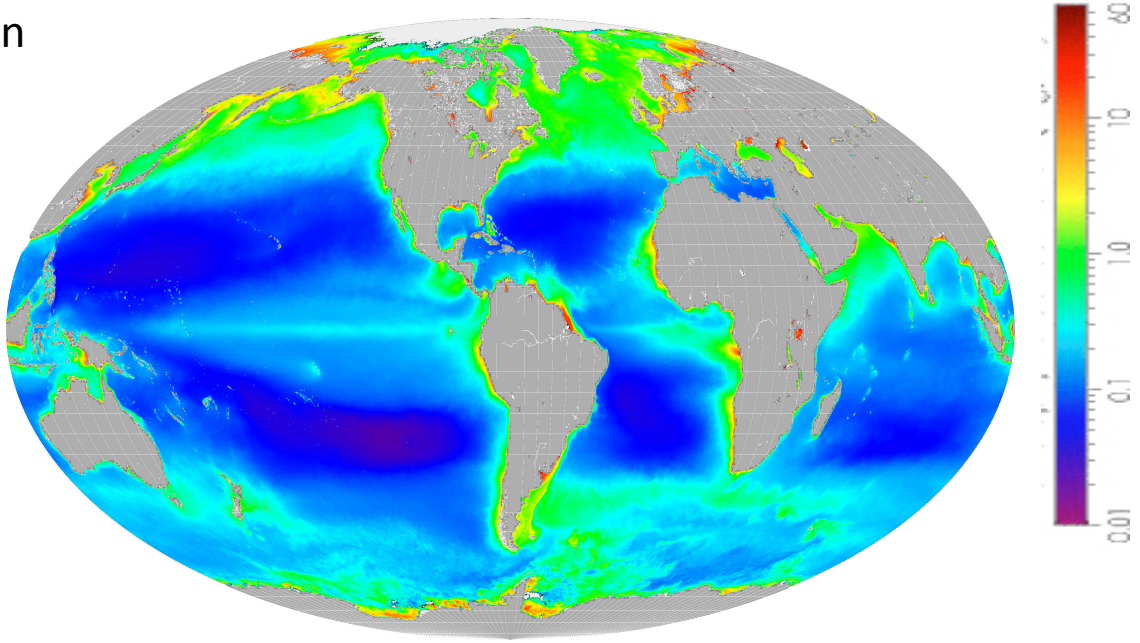


From Dennis Hansell CLIVAR data set



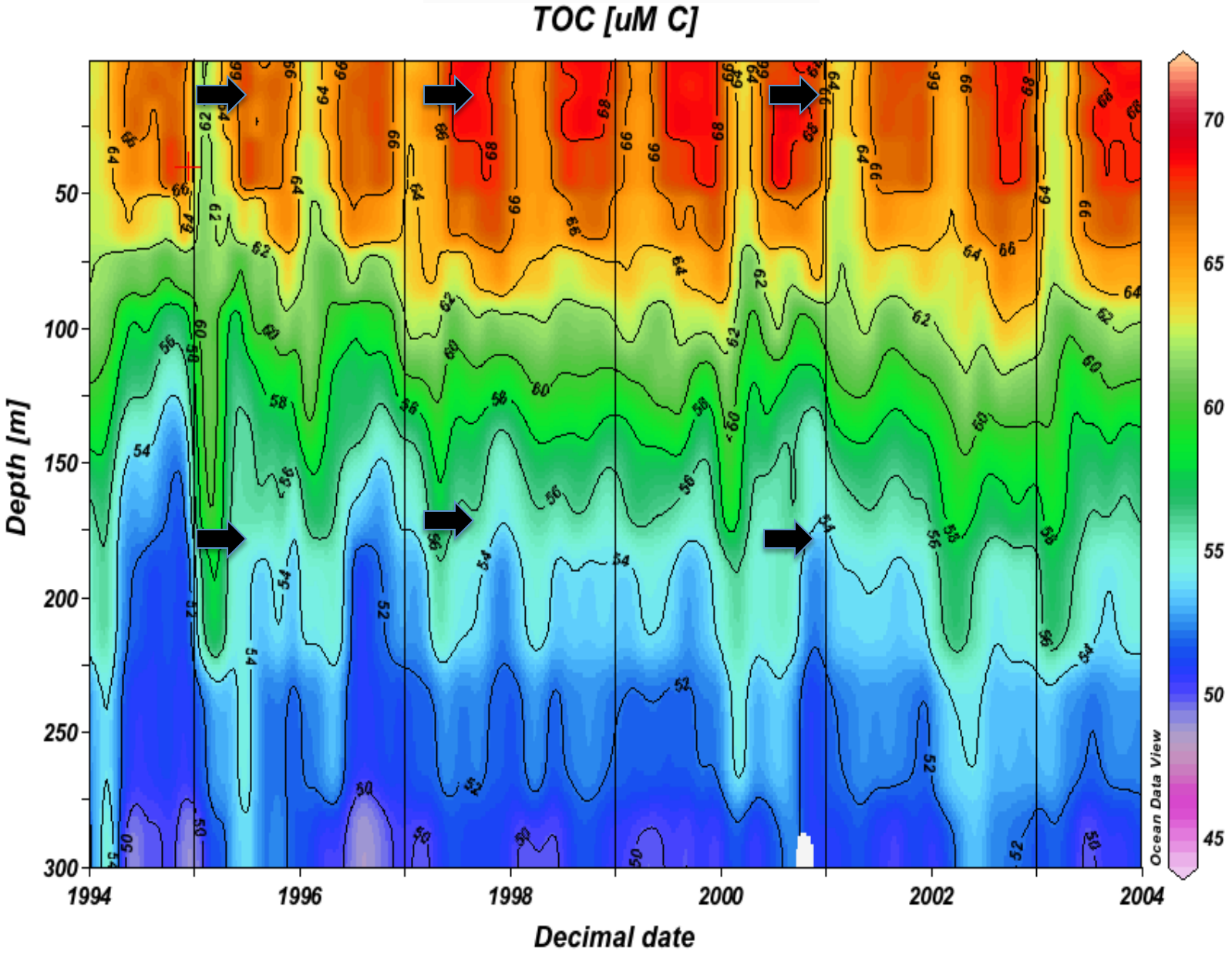
Dissolved Organic carbon

Chlorophyll-a



Hansell et al., GBC 2012
http://earthobservatory.nasa.gov

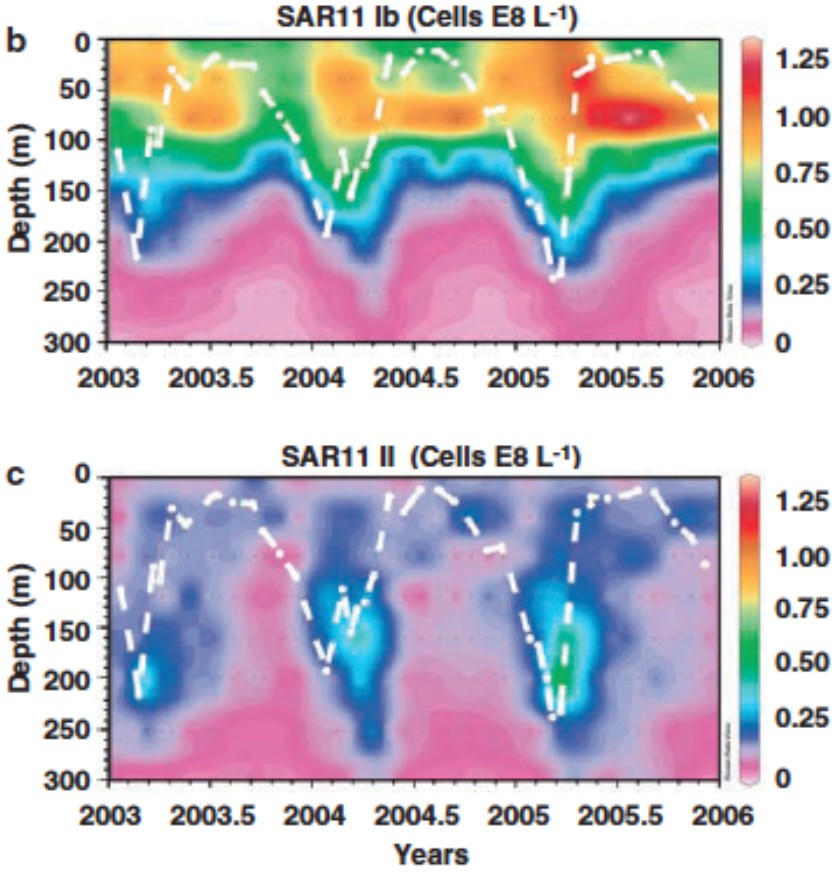
Time series analysis of DOC (µM C) at Bermuda

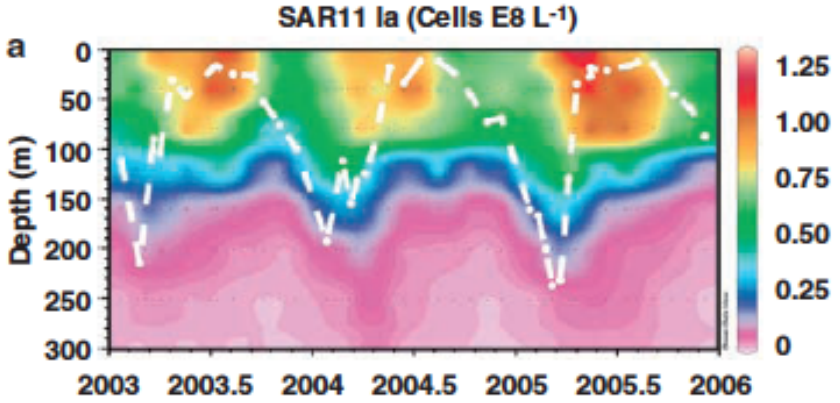


Data from Dennis Hansell and Craig Carlson

Seasonal dynamics of SAR11 populations in the euphotic and mesopelagic zones of the northwestern Sargasso Sea

Craig A Carlson[1,5], Robert Morris[1,2,5], Rachel Parsons[3,5], Alexander H Treusch[4,5], Stephen J Giovannoni[4] and Kevin Vergin[4]

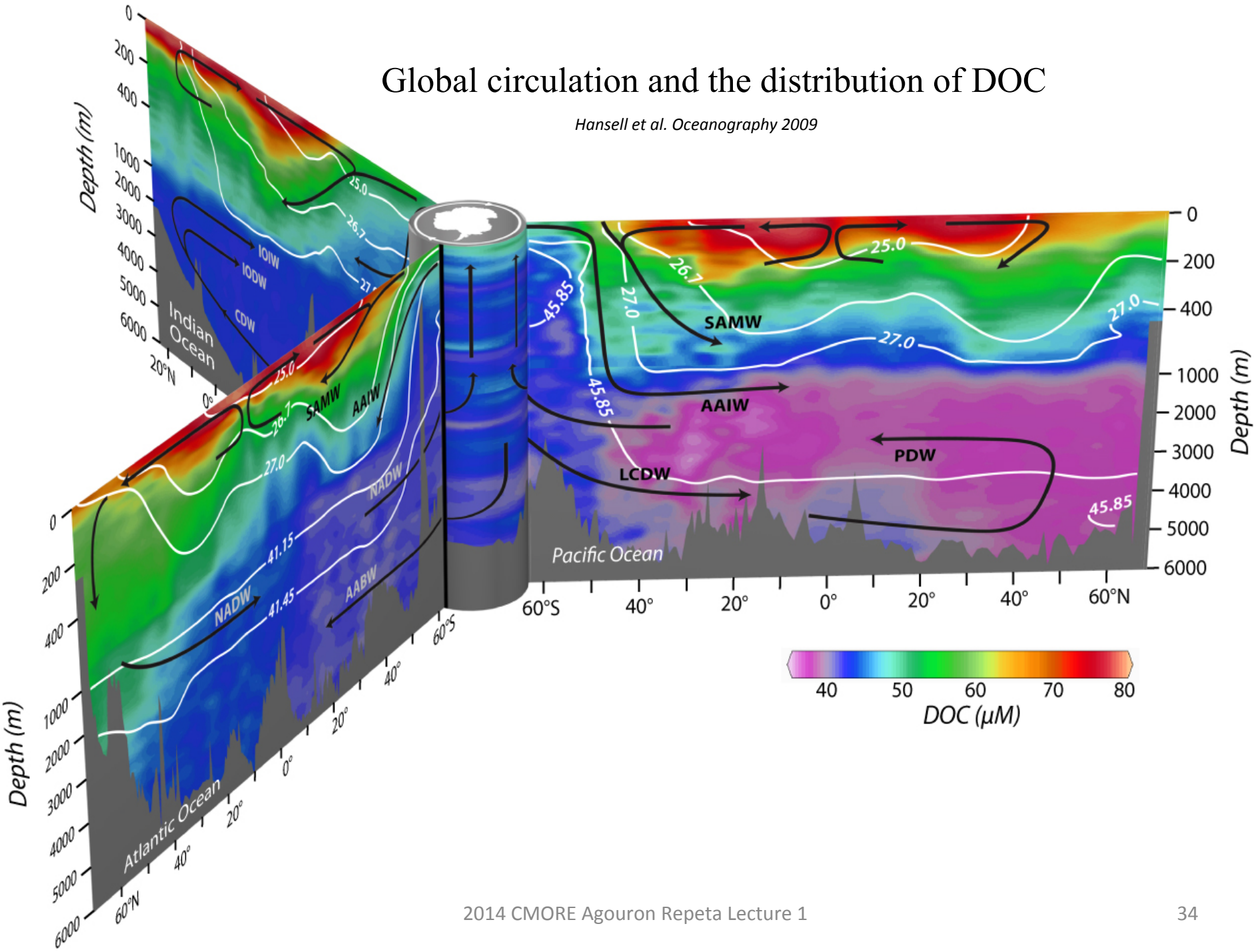




The ISME Journal (2009) 3, 283–295

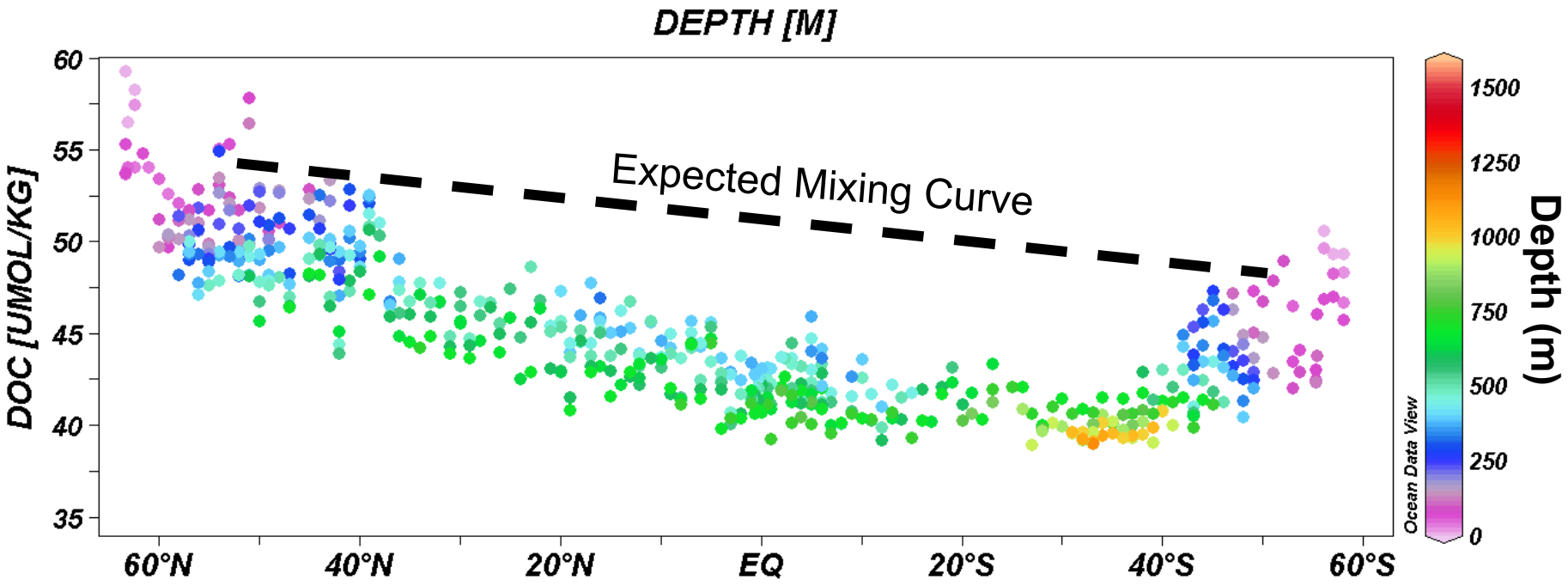
Global circulation and the distribution of DOC

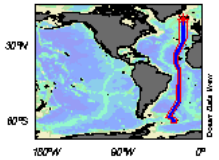
Hansell et al. Oceanography 2009



A16: DOC on δ_θ 27.0 – 27.3

Data from Dennis Hansell (www.rsmas.miami.edu/groups/biogeochem/Data.htm)





Globally, about 30% of dissolved organic carbon disappears
Between the poles and the North Pacific (200 GT C)
Are there enough active microbes in the deep sea to respire this?

Global carbon inventories and fluxes

1) Major inventories are fairly well known. Derived estimates from a combination of **area (or volume) x mass**. Mass is measured, and fairly well known for the atmosphere and ocean. Less known for terrestrial biomass and soils.

2) Globally, about 80,000,000 GT C. Most (essentially all) of it in sedimentary rocks as carbonates (75%) and organic kerogen (25%).

3) Of the reservoirs impacted by "climate" (<1000-2000 yr), inorganic carbon in seawater is the largest (35,000 GT C) followed by soil >terrestrial biomass = atmospheric CO_2 = dissolved organic carbon >>> particulate organic matter living biomass.

Global carbon inventories and fluxes

4) Terrestrial and marine primary productivity are modeled estimates based on proxies (ocean color, etc.) globally integrated by remote sensing. Each is about 50-100 GT C yr-1. Terrestrial biomass cycles slowly, marine biomass turns overmuch more quickly.

5) Fluxes between reservoirs are small and dynamic. Much harder to measure. Of critical importance for climate is the flux of carbon from the atmosphere into the ocean and terrestrial biosphere. This biological "pumping" of carbon is in large part mediated by microbes that fix and respire carbon. Decoupling of production and consumption allows for carbon to move between reservoirs and ultimately be sequestered in the deep ocean, soils and sediments.

6) Biological pumping occurs by gravitational settling of particulate organic carbon (operationally defined) and calcium carbonate. Most of the pumping comes through large, rapidly sinking particles.