Introduction to "Oceanic-Atmospheric Carbon Dioxide Interactions"

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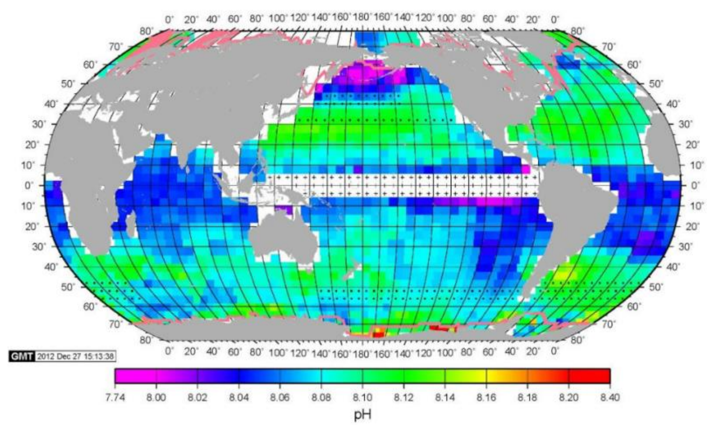
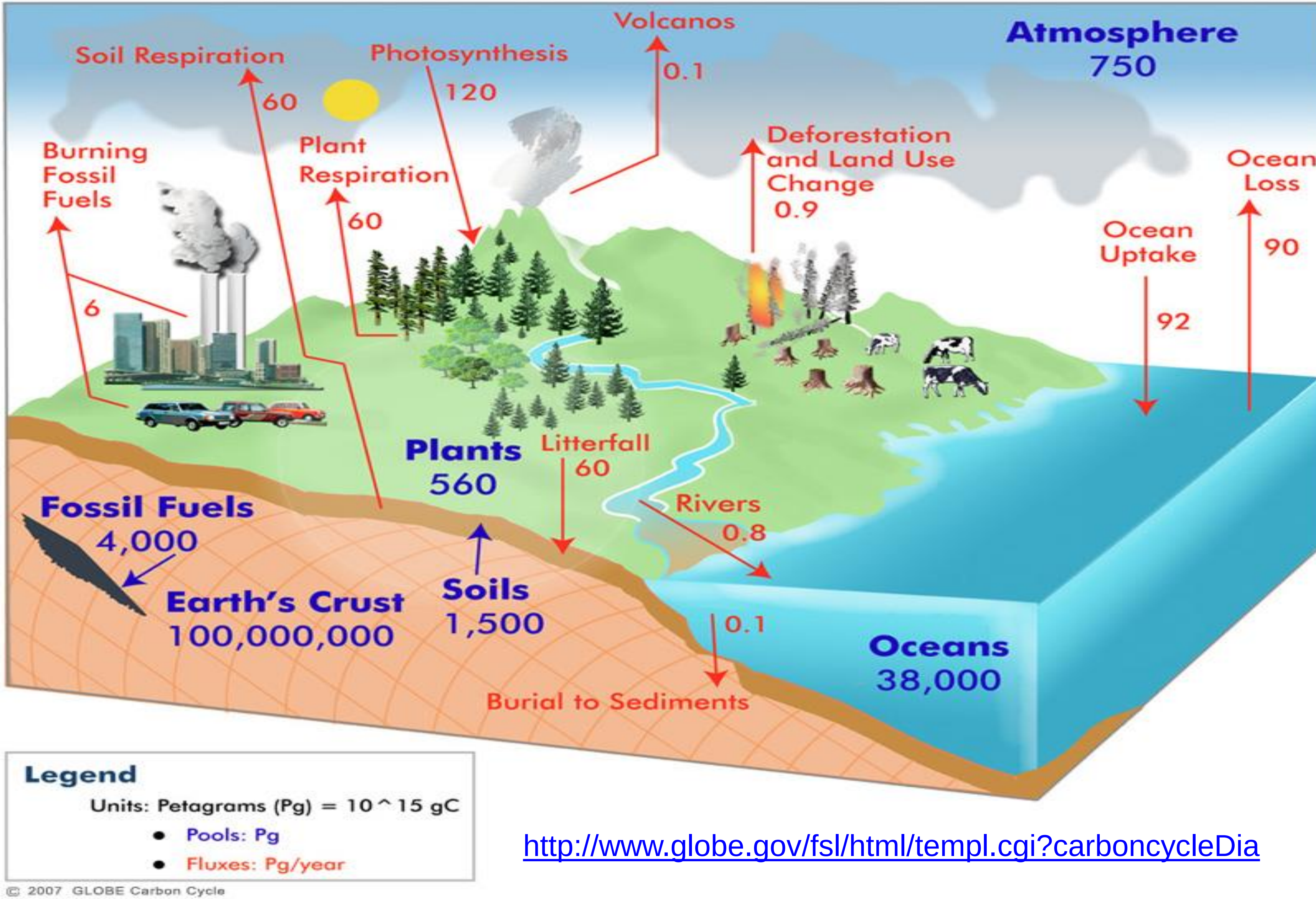


The Importance of the Carbon Cycle

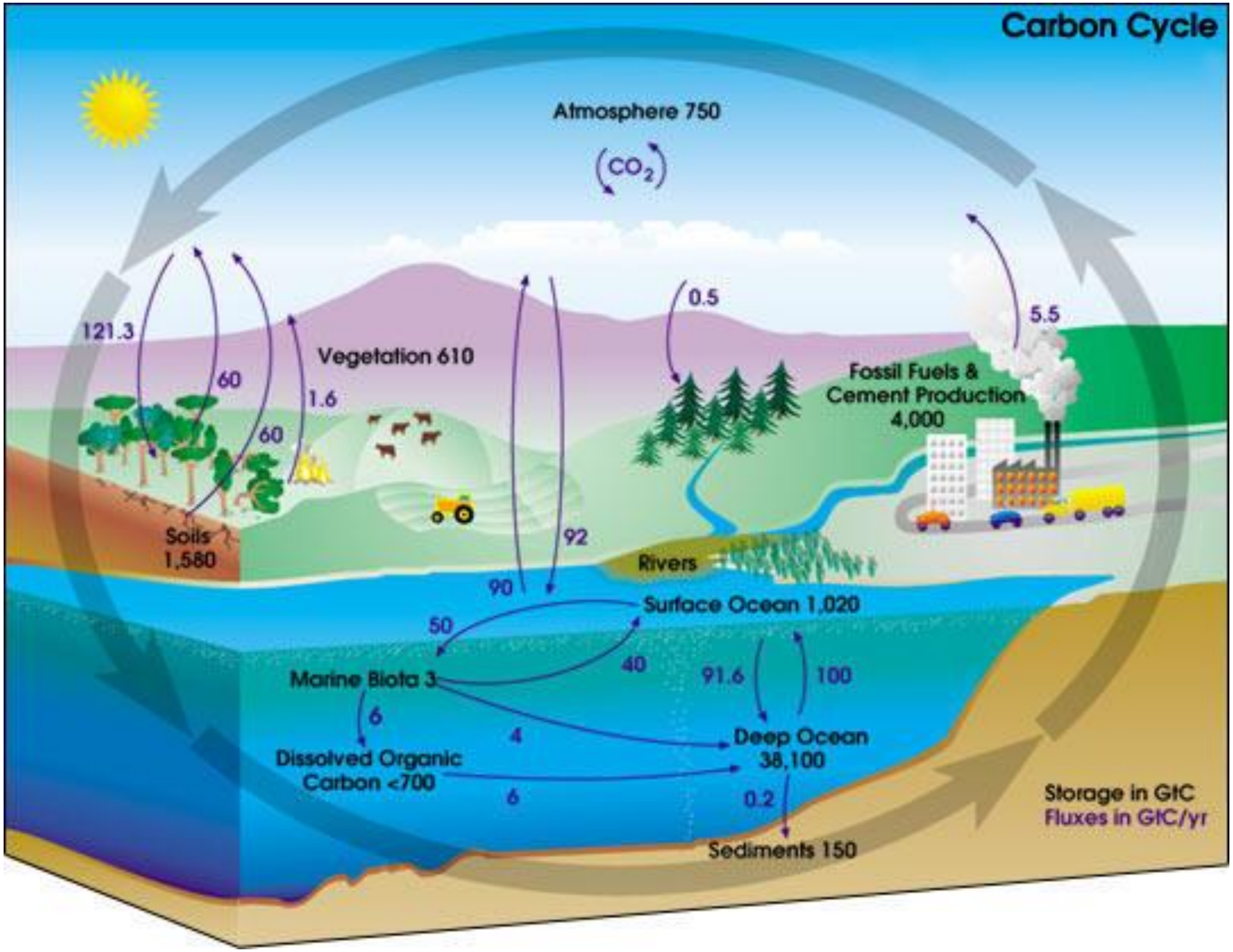
- Carbon is the key to Life as we know it—most biological molecules (carbohydrates, lipids, proteins, DNA and RNA) are carbon-based
- C is very reactive and rarely uncombined
- Biological energy – either photosynthetic or chemosynthetic—require carbon compounds
- C is also a major building block of structures in organisms, from coccolithophoridae to corals to shells to whale bones

Global Carbon Cycle



http://www.globe.gov/fsl/html/templ.cgi?carboncycleDia

This is another way to show the key role of organisms



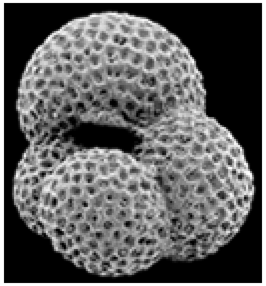
http://earthobservatory.nasa.gov/Library/CarbonCycle/carbon_cycle4.html

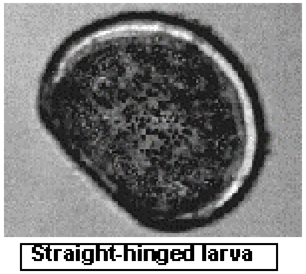
Before We Begin: Some Essential Terms

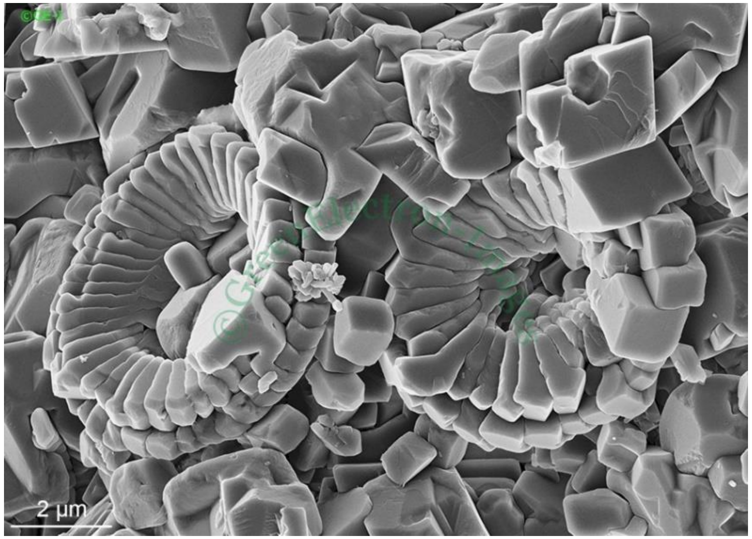
- "**Biogeochemical cycle**": model representing movement of a substance among Earth's 4 'spheres'
- "**Flux**": amount of a quantity (such as heat or CO_2) that flows through a unit area in a unit time
- "**Reservoir**": component of a system separate from other components, such as 'ocean' vs. 'air' or 'land'
- "**Sequestration**": amount of a compound 'locked away' in a reservoir so as not to be available

Key Organisms wrt the C Cycle

- Corals
- Calcareous algae
- Foraminifera (“forams”)
- **Coccolithophoridae (“coccoliths”)**
- “Symbiotic algae”
- Mollusks
- Others





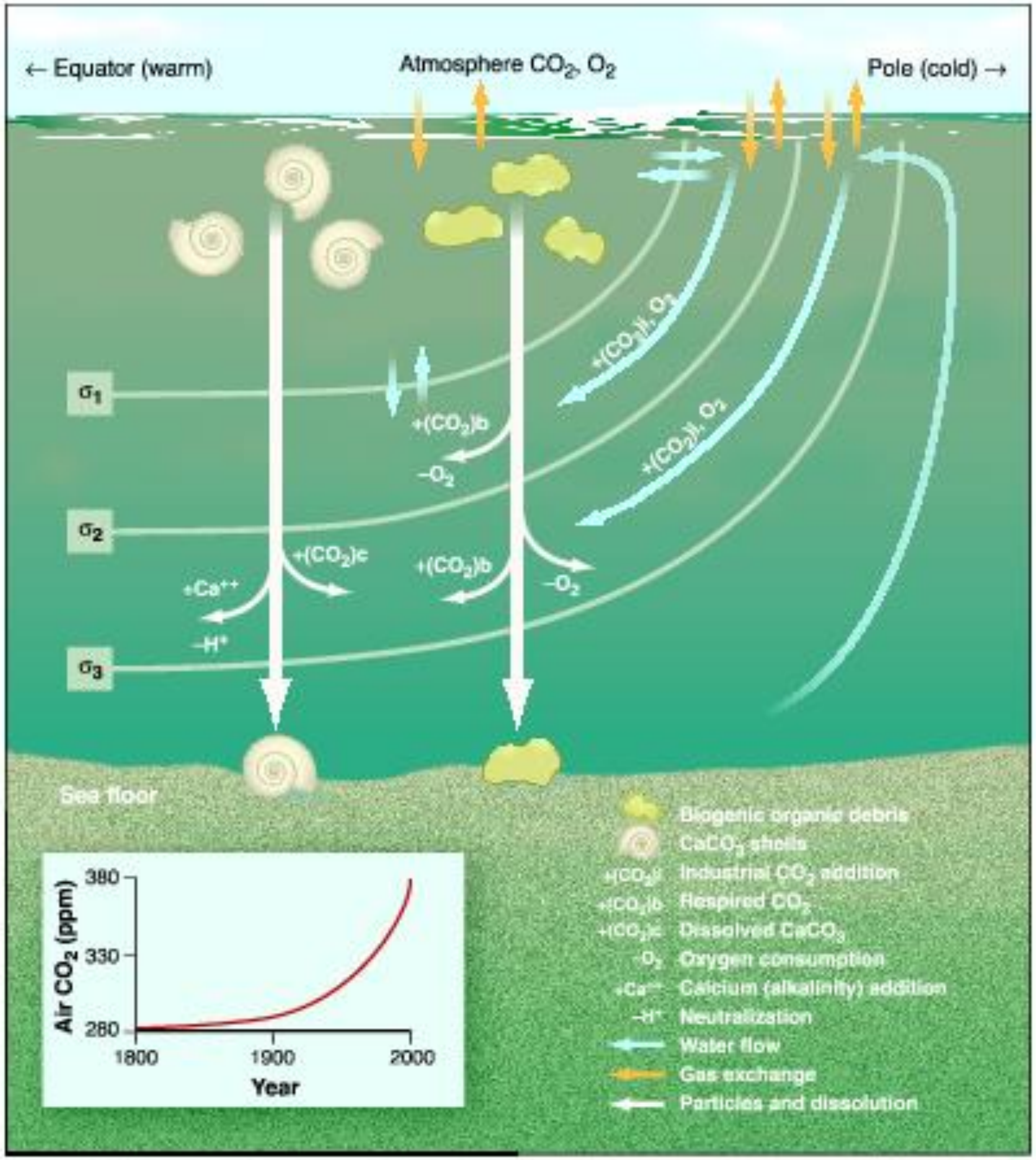


Additional Terms to Understand

- Physiology
- Temperature-dependent
- Seasonal variations
- Calcification
- Saturated/Unsaturated
- Time-series
- Buffering

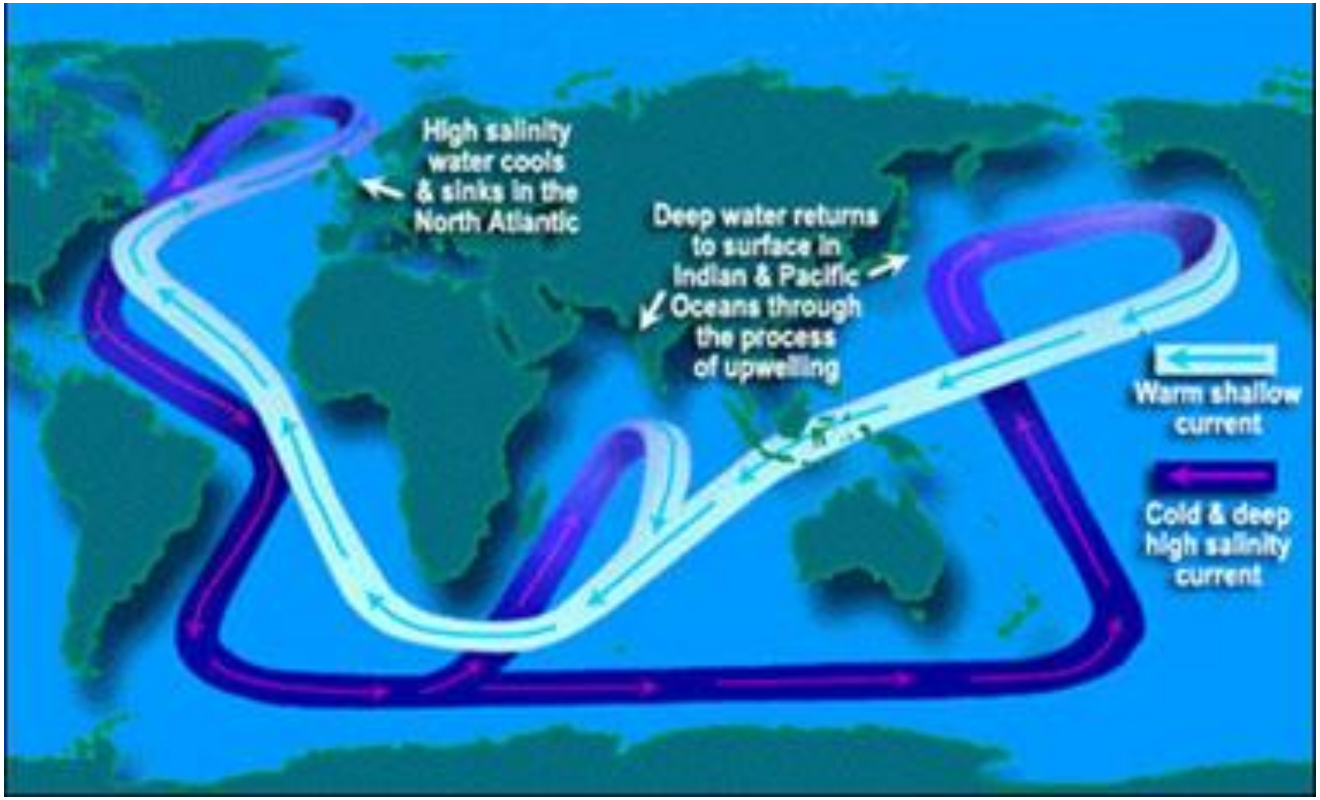
Some Points to Know as We Begin

- Global ocean holds fifty times more CO_2 than the atmosphere
- The two exchange carbon readily at the sea surface
- The ocean is largely responsible for natural variations in atmospheric CO_2
- Pleistocene ice age cycles were associated with CO_2 changes that were smaller than the increase observed in the last century



Takahashi (Science, 2004)

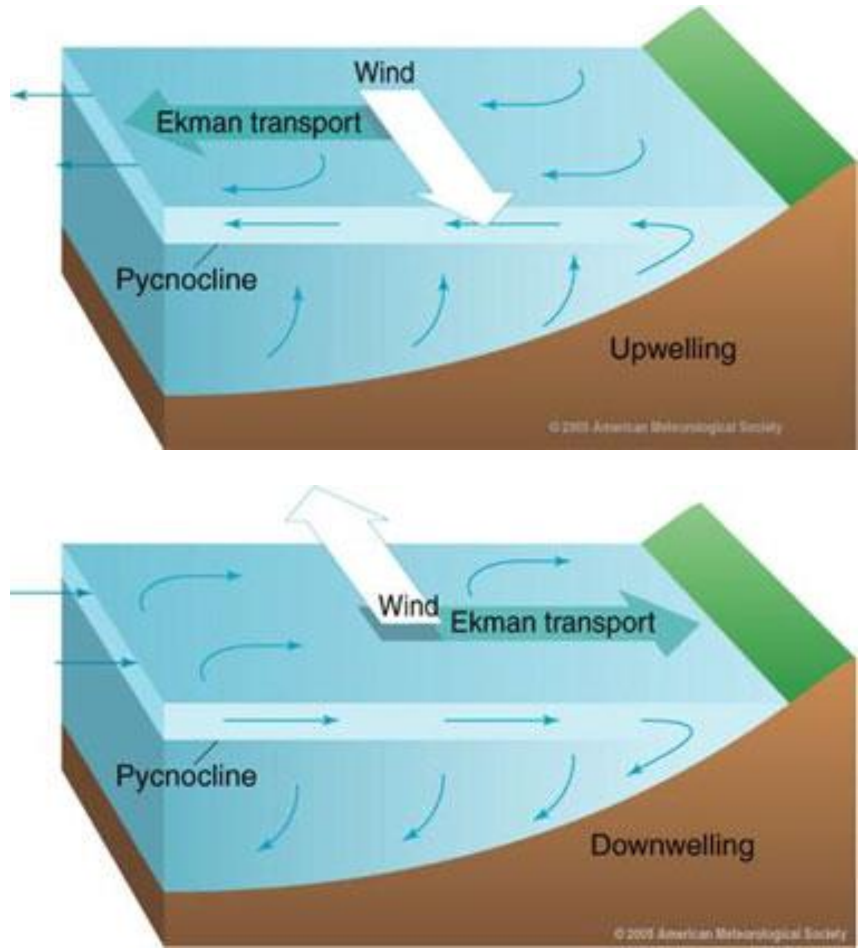
Oceanic CO_2 flow is part of the "Ocean Conveyor Belt"



http://oceanmotion.org/html/background/ocean-conveyor-belt.htm

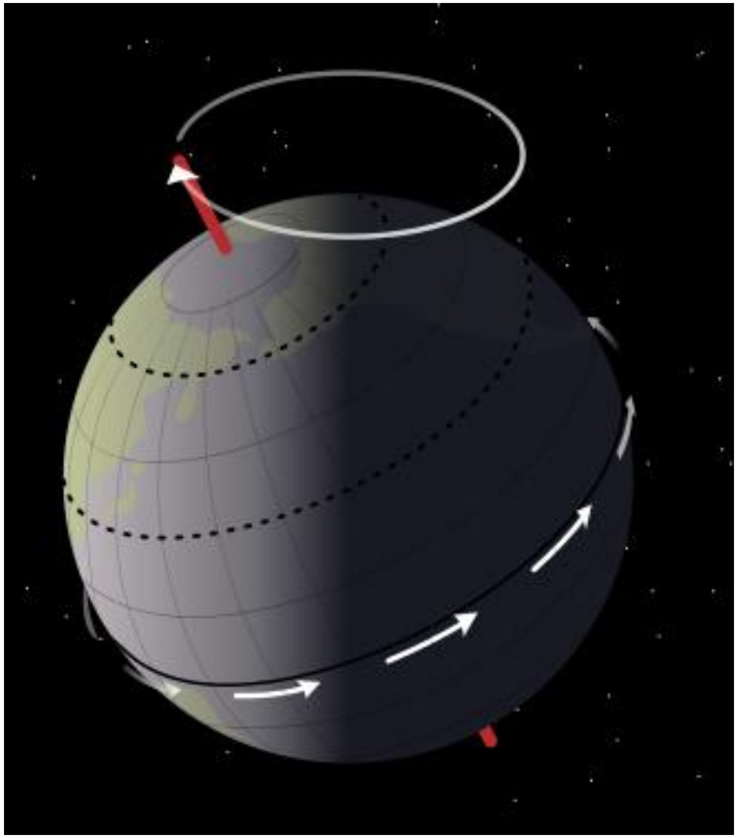
In the oceans, CO_2 transport is also vertical

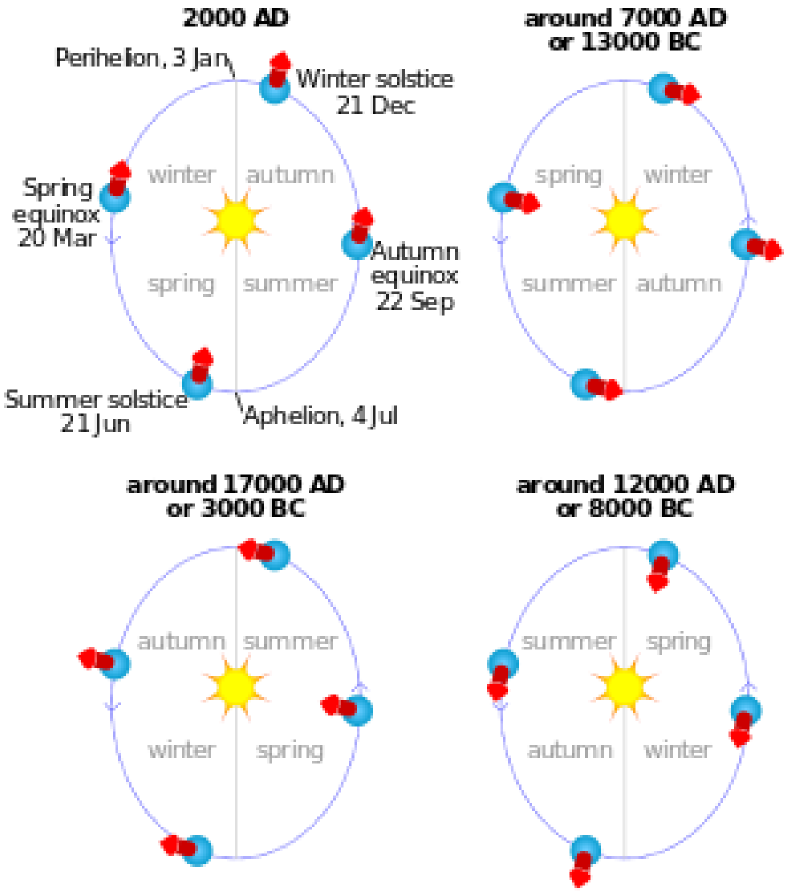
- Upwellings bring cooler waters (often rich in dissolved gases) to the surface
- Downwellings send surface waters into the depths and begin circulation patterns that may last for centuries



http://oceanmotion.org/html/background/upwelling-and-downwelling.htm

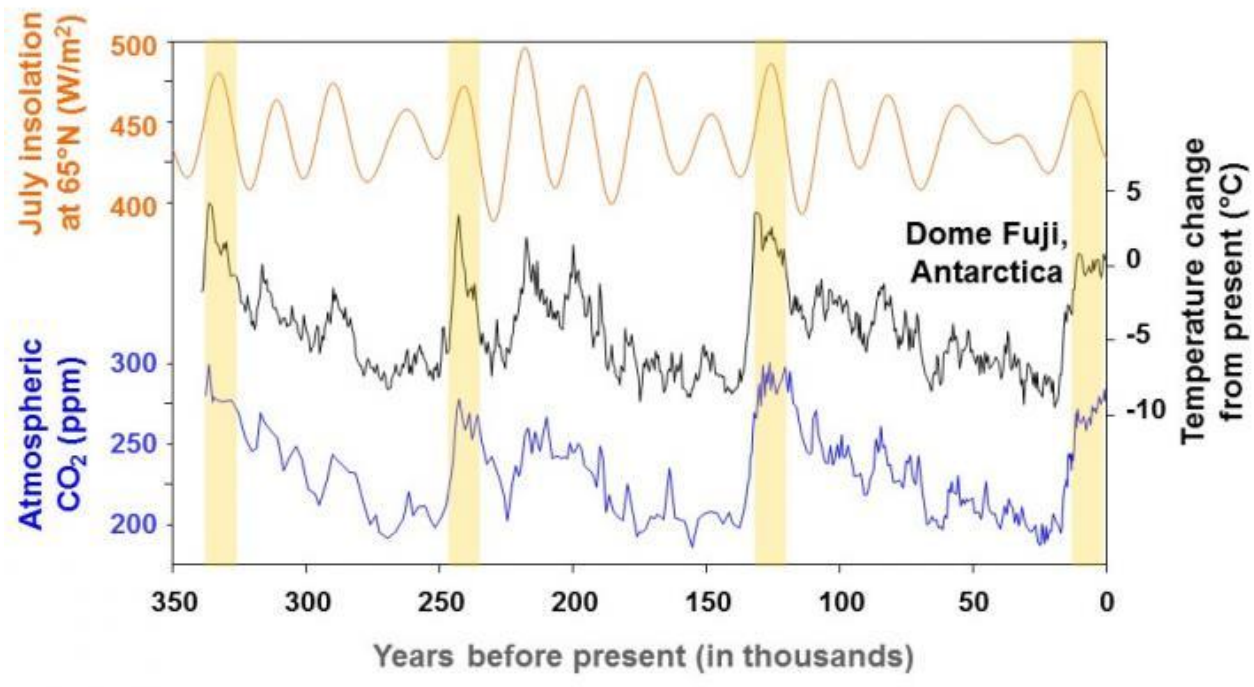
Orbital Influences on Climate
Cyclical changes in Earth's motion greatly influence climate





https://en.wikipedia.org/wiki/Axial_precession

Several "Proxies" Enable Reconstruction of Past Environmental Conditions



https://www.ncdc.noaa.gov/abrupt-climate-change/Glacial-Interglacial%20Cycles

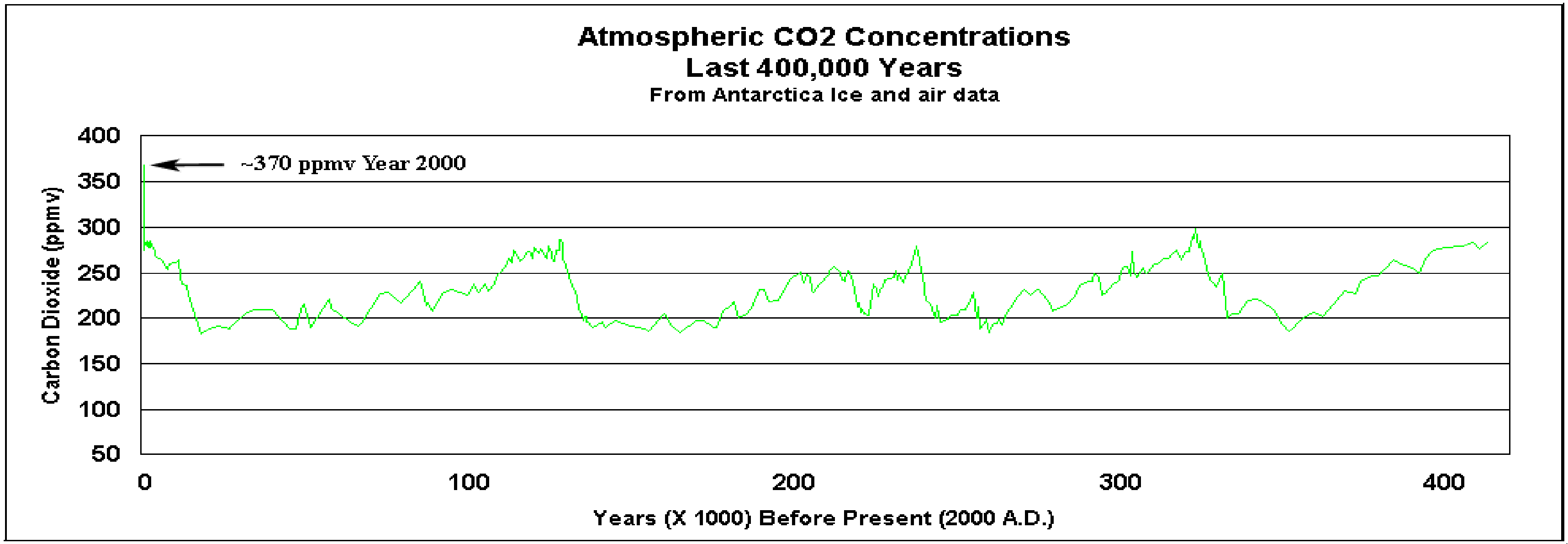
Examples of Useful Climate Proxies

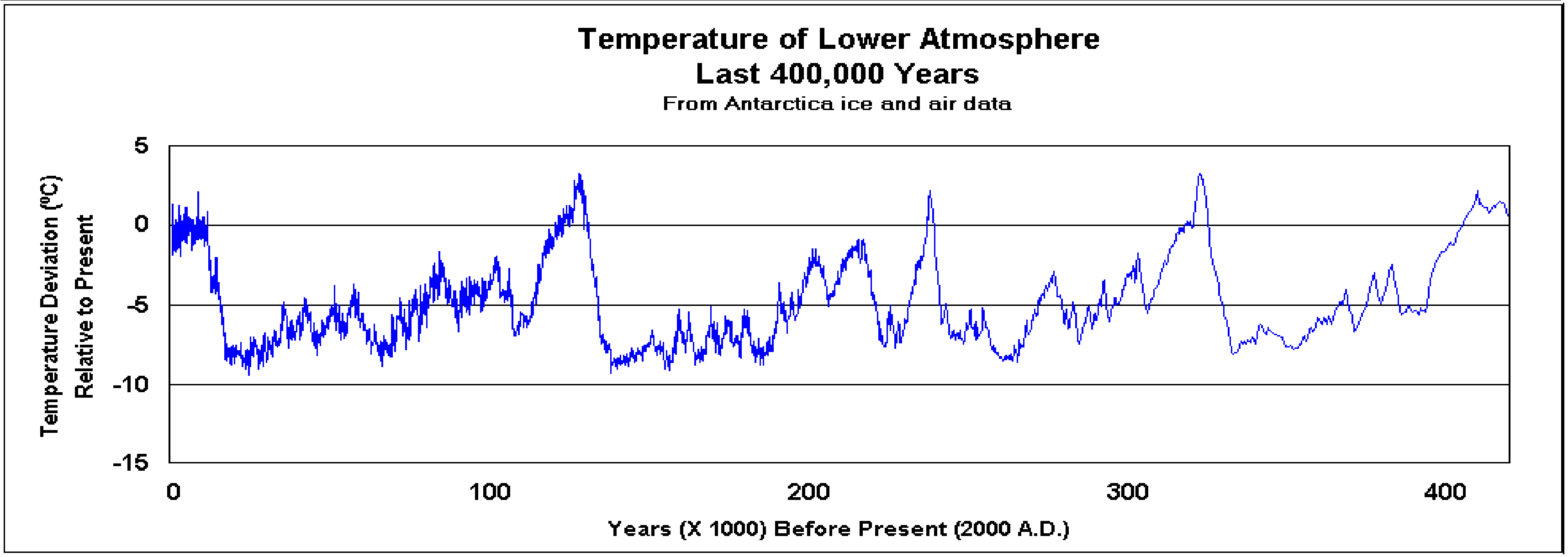
- Air bubbles trapped in layers of the ice sheets in Greenland and Antarctica;
- Isotopes of oxygen that are temperature markers;
- Isotope markers of diverse elements in layers of deep ocean sediments;
- Ancient coral reefs and speleothems;
- Salt marsh core samples;
- Physical evidence of ancient shorelines, above and below the present

http://www.johnenglander.net/chart-of-420000-year-history-temperature-co2-sea-level/

Another Set of Data

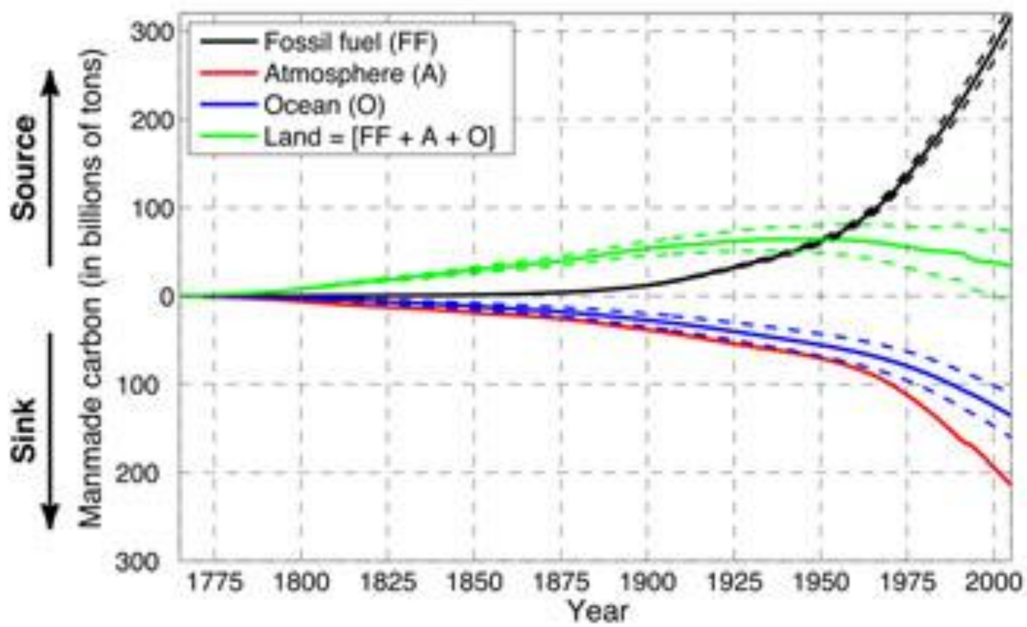
http://www.geocraft.com/WVFossils/last_400k_yrs.html





How Fast Are Oceans Absorbing CO_2?

- One of the most important questions investigated by the LDEO CO_2 group http://www.ldeo.columbia.edu/news-events/oceans-uptake-manmade-carbon-may-be-slowing



Measuring CO_2 exactly in all reservoirs and fluxes becomes critical for understanding the Earth System

- Many instruments are available to monitor CO_2 under a wide variety of conditions
- Deployment of instruments and collection of samples provide many challenges

pH

- Measure of the **acidity** or **baseness (alkalinity)** of a solution
- term derived from German “power of Hydrogen”
- generally defined as the “negative logarithm of the hydrogen ion concentration”
- Acidic: less than 7   Basic: more than 7

Neutral 7.0

definition of pH

$pH = \log 1/[H^+] = -\log [H^+]$

Acidic waters, pH < 7
H^+ > 1 x 10-7 mole/L,
Soda drinks, pH ~4

Alkaline waters, pH > 7
H^+ ~ 1 x 10-8 mole/L
Human blood and seawater, pH ~8

Neutral water, pH = 7
H^+ = 1x 10-7 mole/L

pH and Marine Organisms

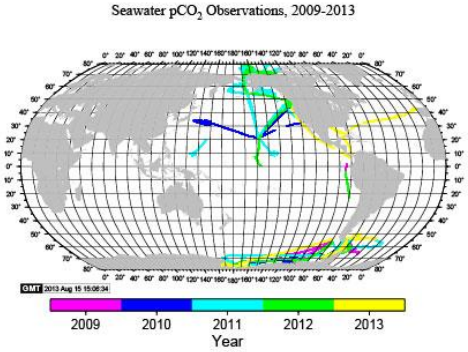
- Marine organisms live in the complex solution known collectively as “seawater”
- On the chemical scale, constant interactions among dissolved gases and solids cause a wide variation in the pH, generally from about 7.3 to more than 10
- Changes in oceanic pH can have great impacts on many marine organisms

pCO_2

- Another standard of measurement in chemical oceanography is referred to as "pCO_2"

http://www.ldeo.columbia.edu/res/pi/CO2/carbondioxide/pages/pCO2data.html

Measurements are routinely collected aboard many NOAA, Navy, Coast Guard, and other research vessels.

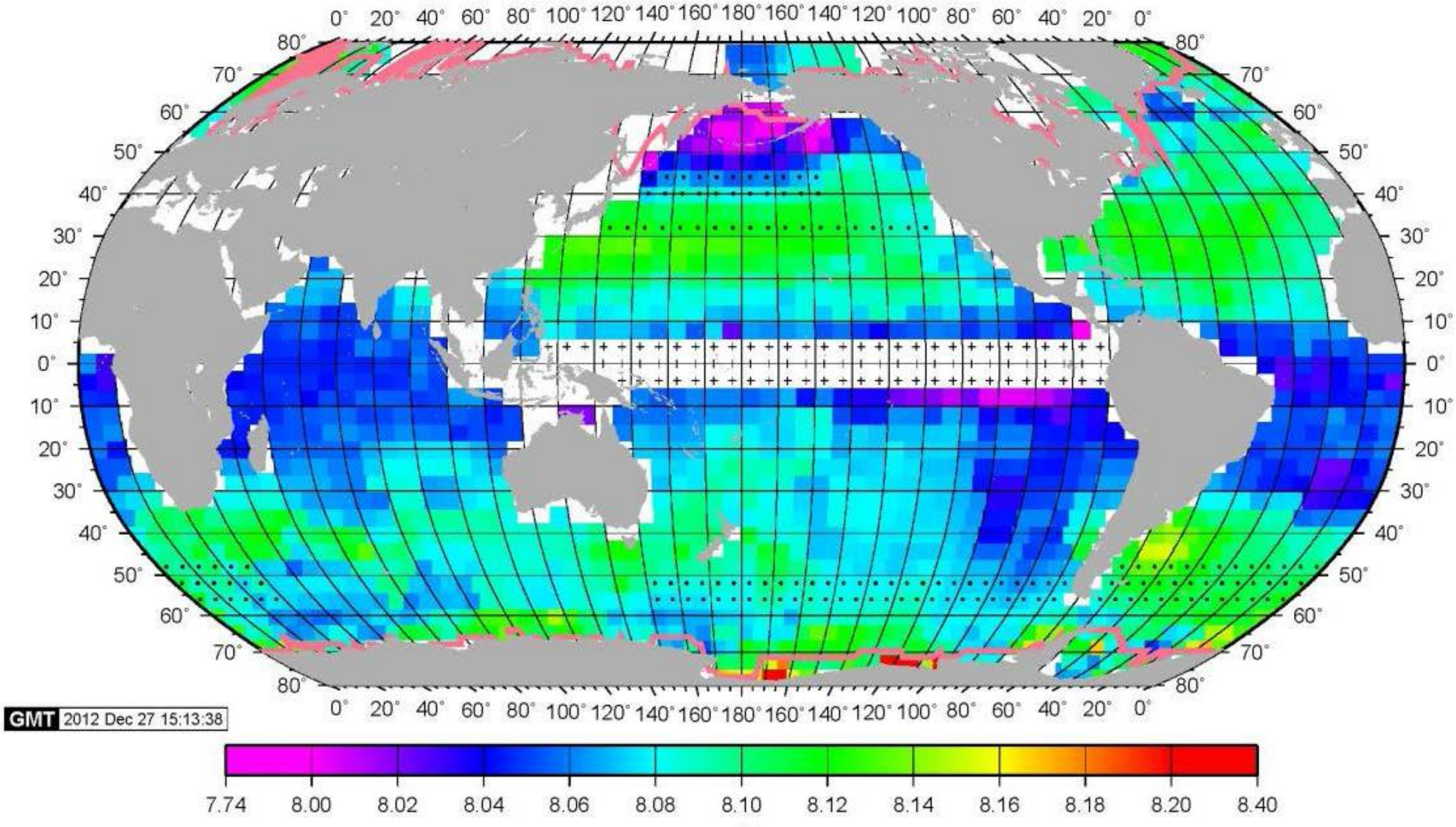


Clumps and Patterns

http://uploads2.wikiart.org/images/vincent-van-gogh/the-starry-night-1889(1).jpg

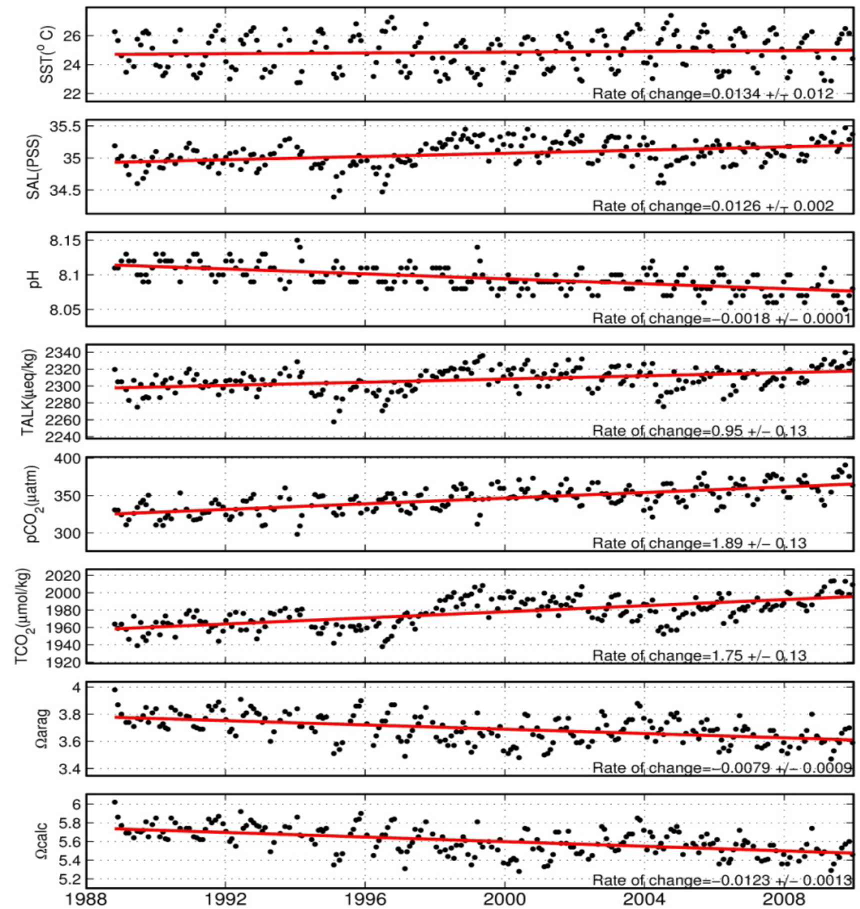
Skill: Finding Meaning in Clumps and Patterns

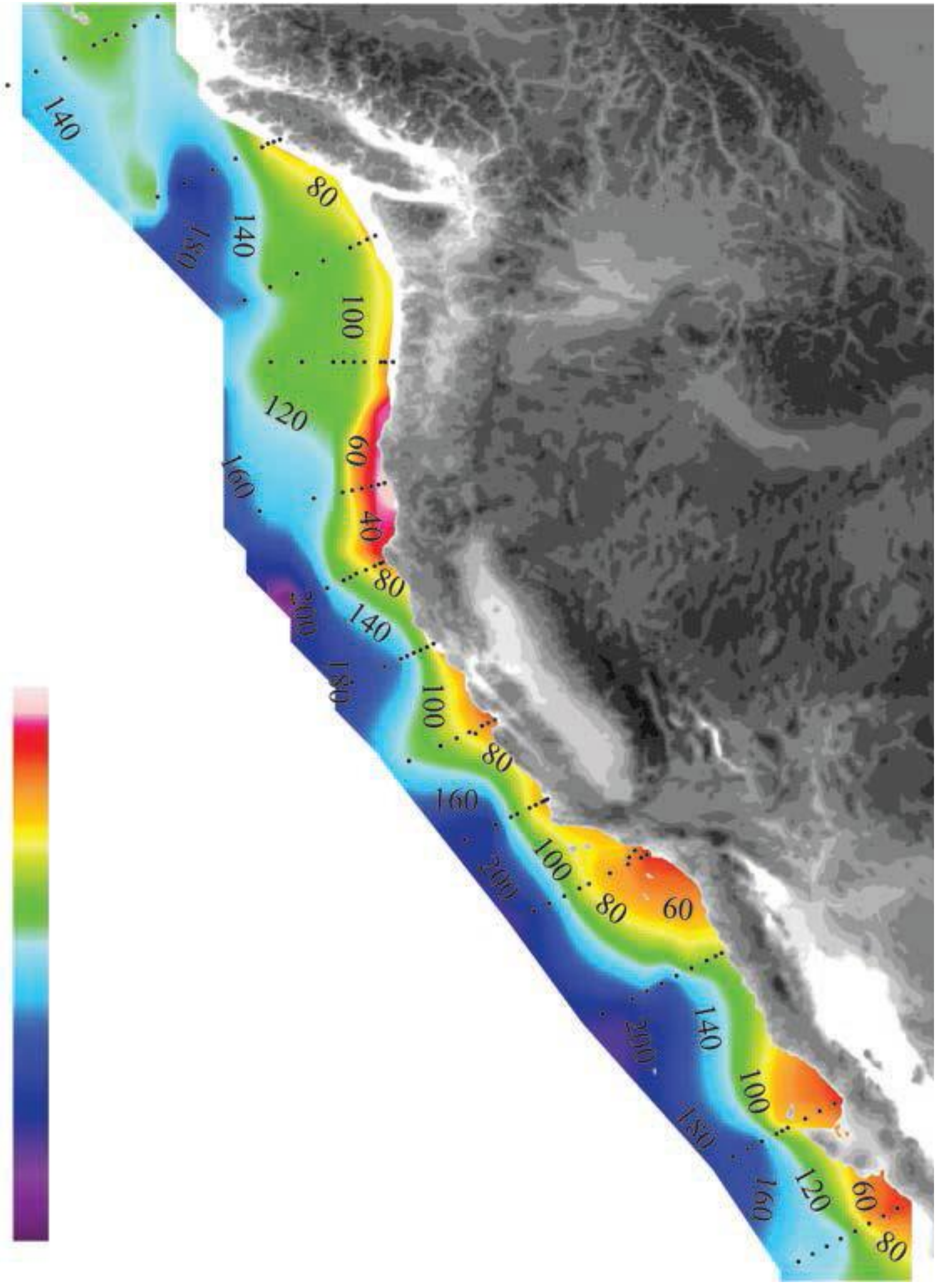
http://earth2class.org/site/wp-content/uploads/2015/08/Session8-Meaning-from-Maps.pdf



"Small Multiples"--Edward Tufte

- Similar images placed next to each other
- Seek to identify "similarities" and "differences"
- Well-established design solution for analyzing problems

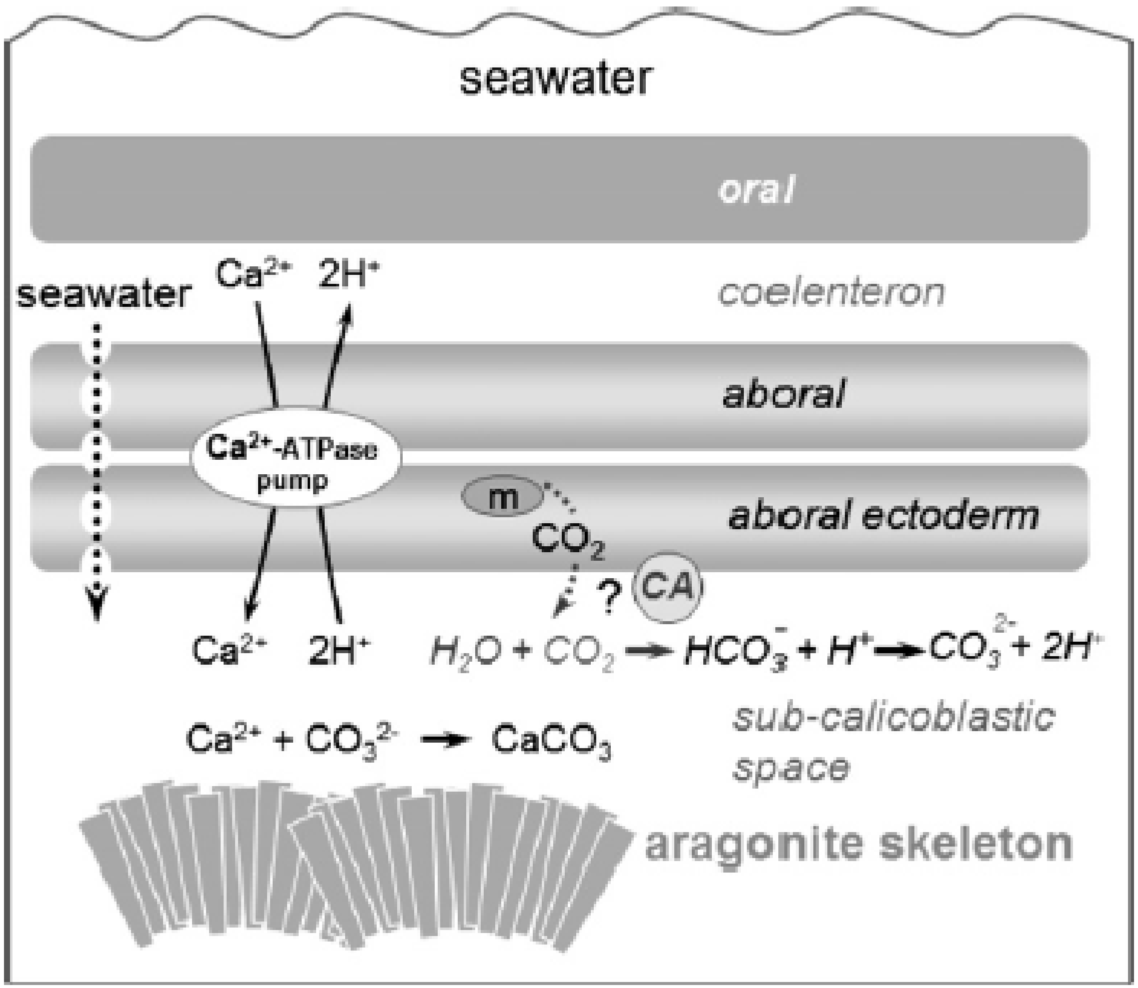




Color-Coded Maps

- Examine legend colors
- Focus on patterns
- Continuous

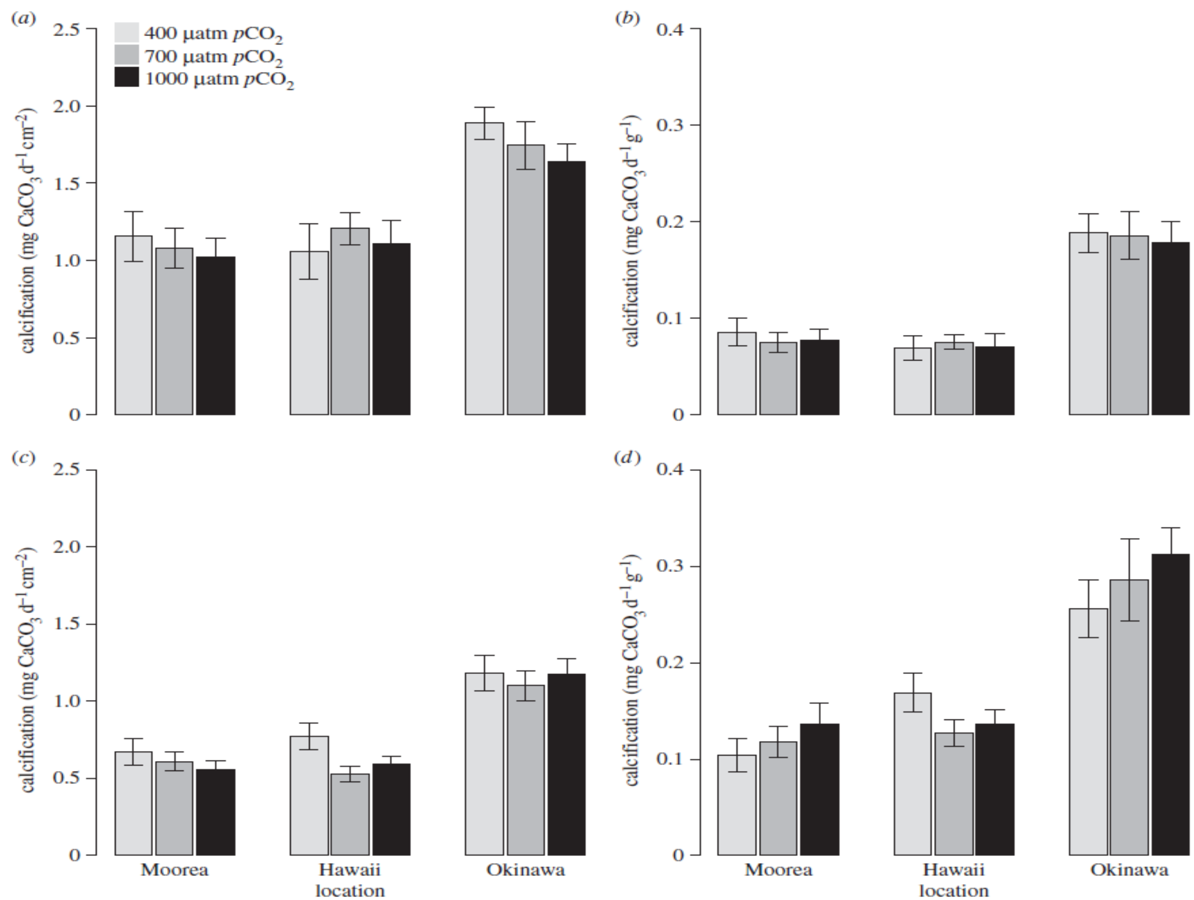
Interpreting Diagrams



Representational Correspondence

http://www.earth2class.org/er/vc/spatial%20thinking/Spatial%20Think%20Sess%203%20RepCorrespond.pdf

Commonalities and Dissimilarities



igure 2. Calcification of the corals massive *Porites* spp. and *P. damicornis* maintained in three pCO_2 levels (400, 700 and 1000 µatm) in Moorea, Okinawa and lawaii, respectively. The first row represents: (*a*) the area-normalized calcification and (*b*) the biomass-normalized calcification of massive *Porites* spp. The second ɔw shows: (*c*) the area-normalized calcification and (*d*) the biomass-normalized calcification of *P. damicornis*. The bars correspond to the mean calcification and the ertical error bars show the s.e. in the measurement of calcification ($n = 12$).

Some Key Ideas

- Biogeochemical cycles are complex, difficult to reproduce in the lab
- Modern and ancient CO2 levels can be measured and impacts analyzed directly and with proxies
- Oceans are becoming more acidic
- Acidification affects all ecosystems
- Impacts seem to vary in different parts of the world ocean
- More research is needed—Will we support it?