Introduction to Ocean Acidification and Its Effects on Marine Life

Dr. Michael J Passow
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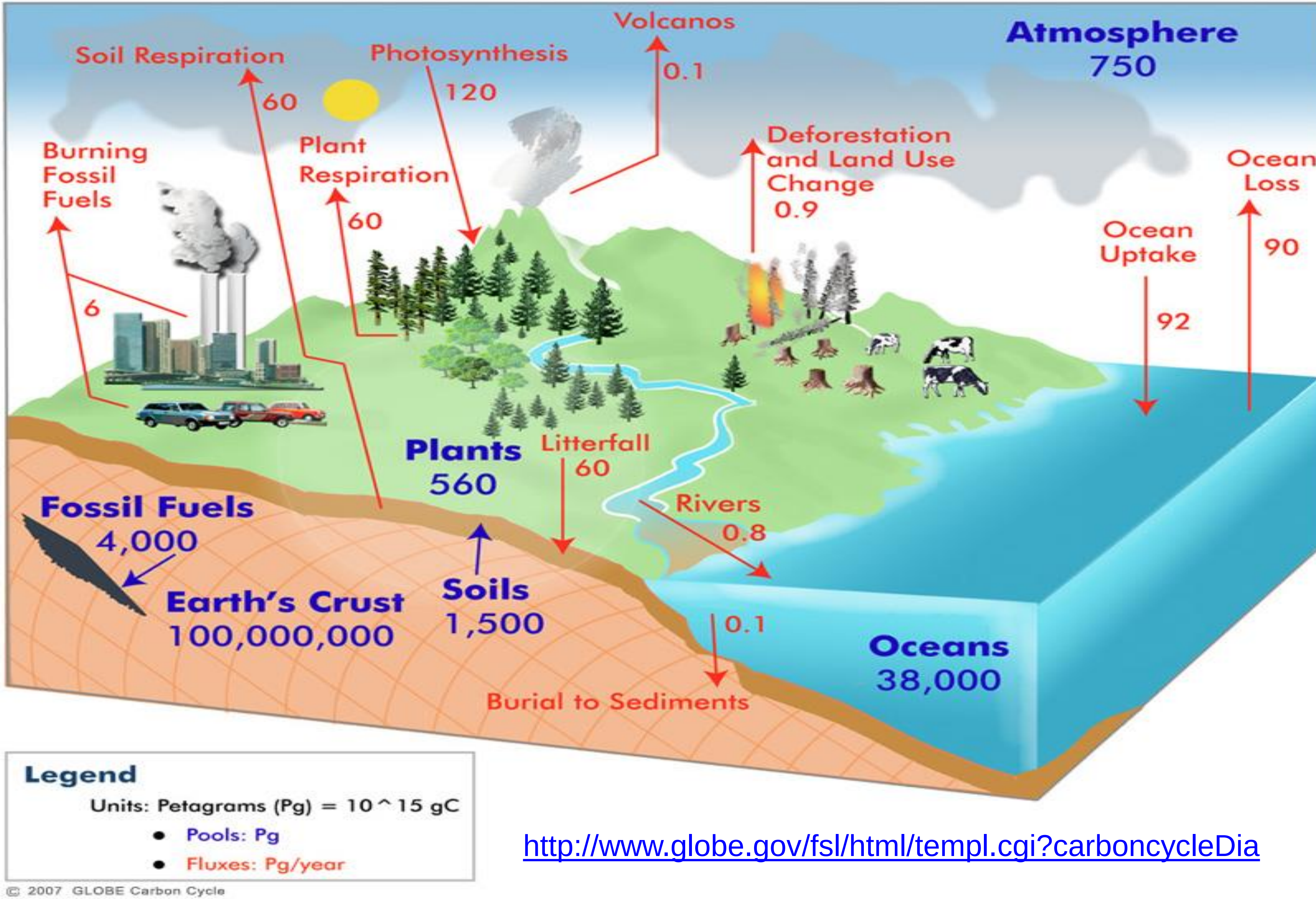
Guest Scientist: Dr. Taro Takahashi

The Importance of the Carbon Cycle

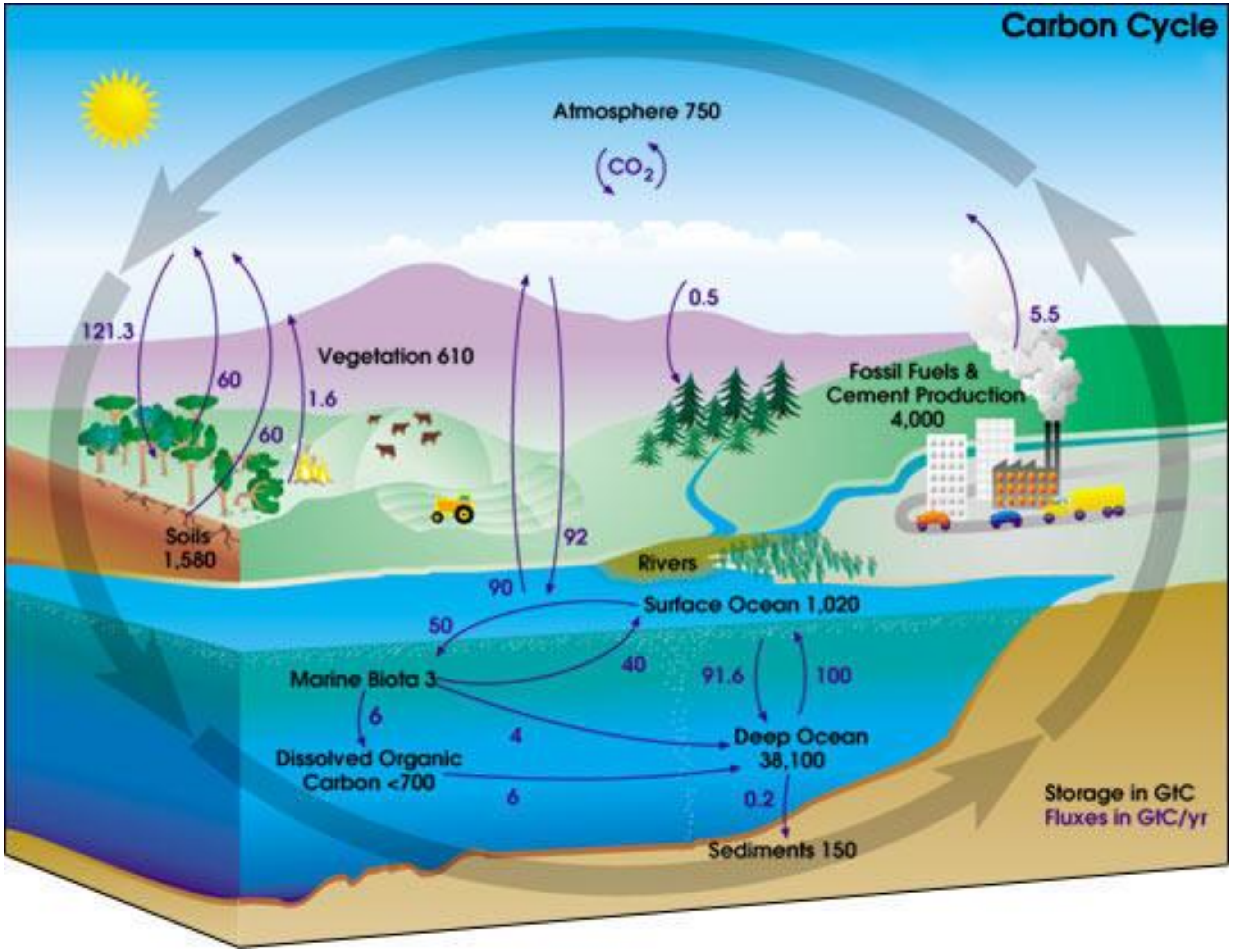
- Carbon is the key to Life as we know it—most biological molecules (carbohydrates, lipids, proteins, DNA and RNA) are carbon-based
- C is very reactive and rarely uncombined
- Biological energy – either photosynthetic or chemosynthetic—require carbon compounds
- C is also a major building block of structures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

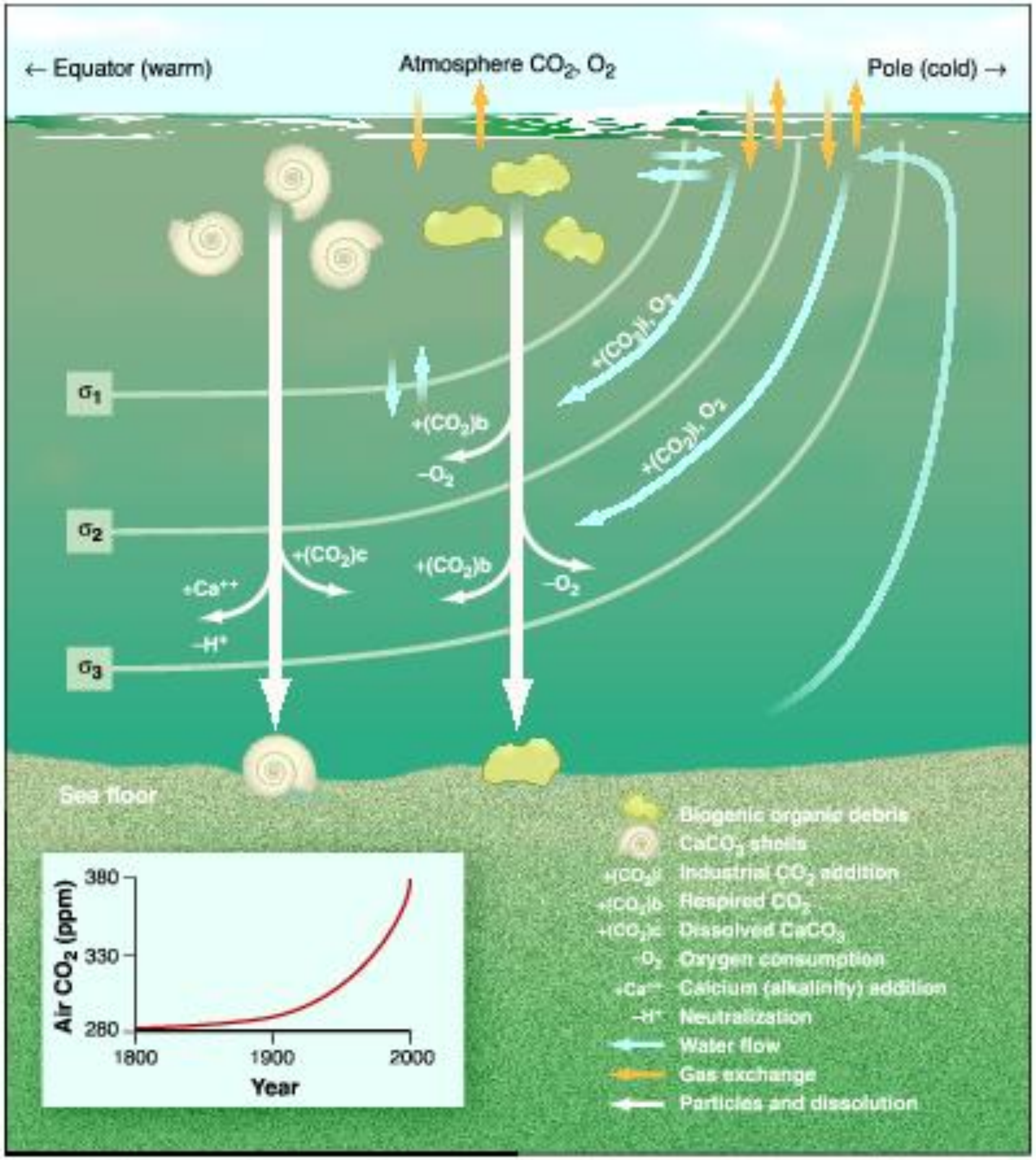
- "**Biogeochemical cycle**": model representing movement of a substance among Earth's 4 'spheres'
- "**Flux**": amount of a quantity (such as heat or CO_2) that flows through a unit area in a unit time
- "**Reservoir**": component of a system separate from other components, such as 'ocean' vs. 'air' 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

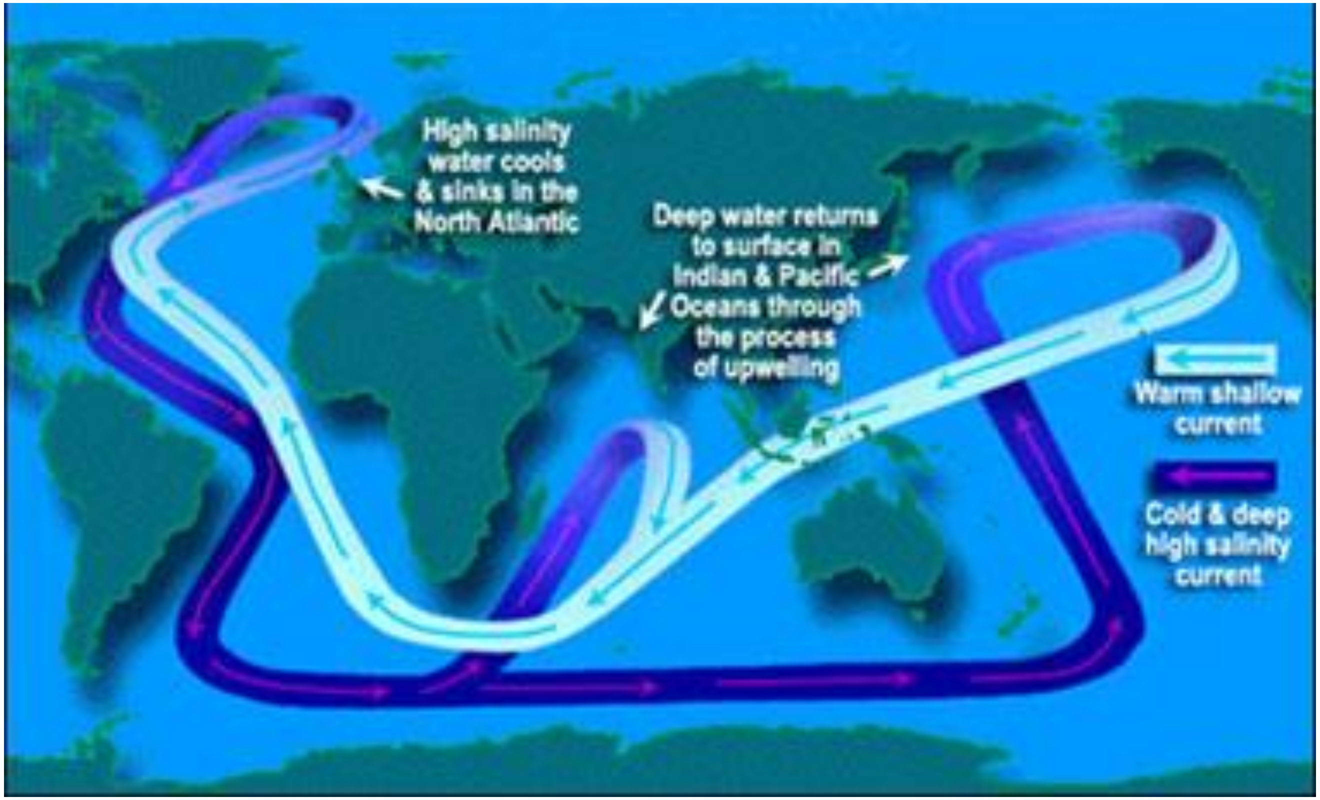
Additional Terms to Understand

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



Takahashi (Science, 2004)

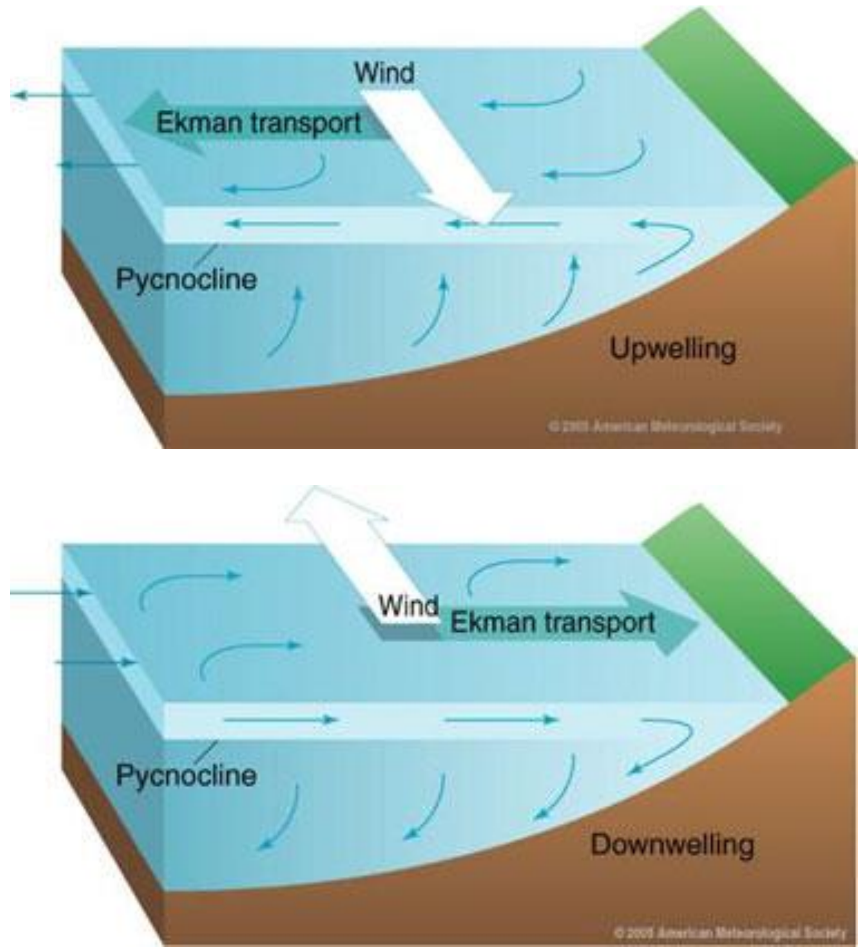
Oceanic CO_2 flow is part of the "Ocean Conveyor Belt"



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



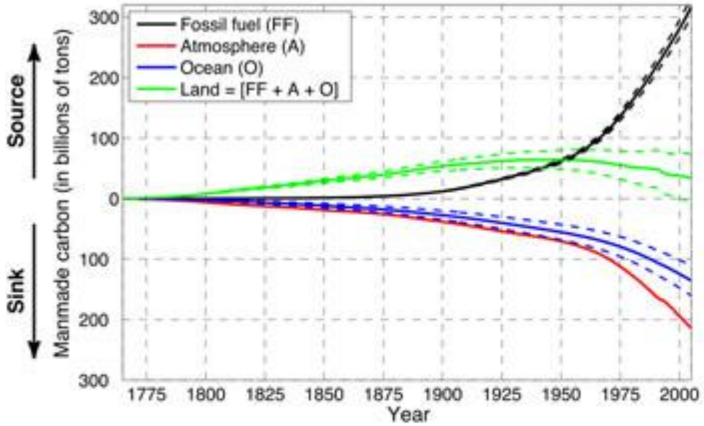
http://oceanmotion.org/html/background/upwelling-and-downwelling.htm

Factors Affecting Dissolving and Diffusing

- Gases dissolve in liquids.
- How much depends in part on temperature colder = higher concentrations (think 'soda')
- Gas diffuse from higher concentrations to lower concentrations

How Fast Are Oceans Absorbing CO_2?

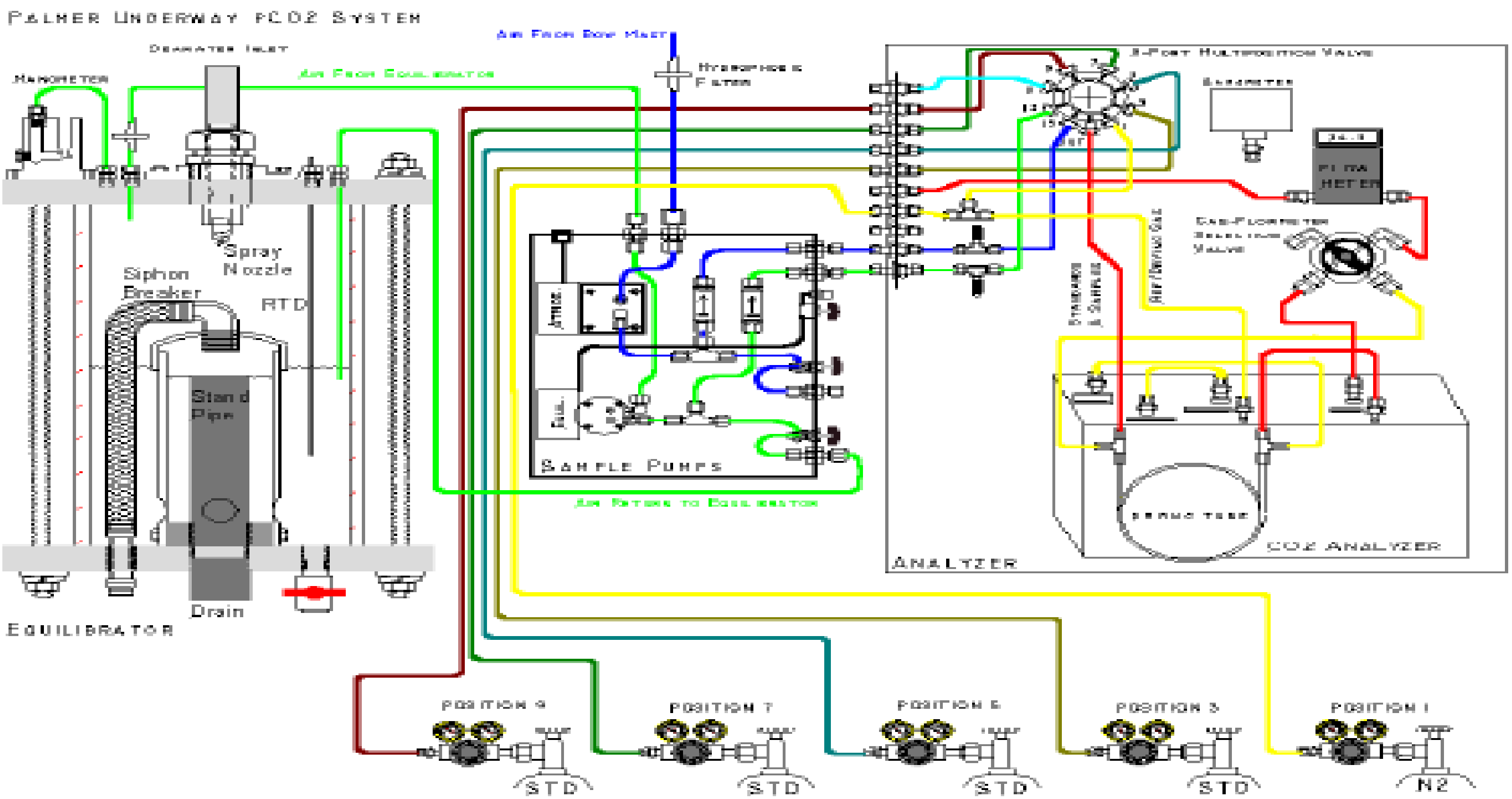
- This is one of the most important questions investigated by the CO_2 group http://www.ldeo.columbia.edu/news-events/oceans-uptake-manmade-carbon-may-be-slowing



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

Dr. Takahashi's research focuses large on in-site measurements at sea



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

$H^+ > 1 \times 10\text{-}7$ mole/L, $OH^- < 1 \times 10\text{-}7$ mole/L

Soda drinks, pH ~4

Alkaline waters, pH > 7

$H^+ \sim 1 \times 10\text{-}8$ mole/L and $OH^- \sim 1 \times 10\text{-}6$ mole/L

Human blood and seawater, pH ~8

Neutral water, pH = 7

$H^+ = 1 \times 10\text{-}7$ mole/L and $OH^- = 1 \times 10\text{-}7$ mole/L

pH and Marine Organisms

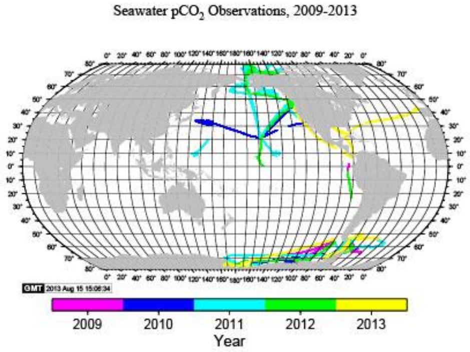
- Marine organisms live in the complex solution known collectively as "seawater"
- On the chemical scale, constant interactions among dissolved gases and solids cause a wide variation in the pH, generally from about 7.3 to more than 10
- Changes in oceanic pH can have great impacts on many marine organisms

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.



DEFINITION OF OMEGA Ω
Degree of Saturation of $CaCO_3$ in seawater

Solubility product of $CaCO_3$

$$(Ksp) = [Ca^{++}]\,[CO_3^{=}] \text{ at saturation}$$

$$\Omega = [Ca^{++}]\text{ sw} \cdot [CO_3^{=}]\text{ sw} / Ksp$$

$\Omega = 1$, saturated

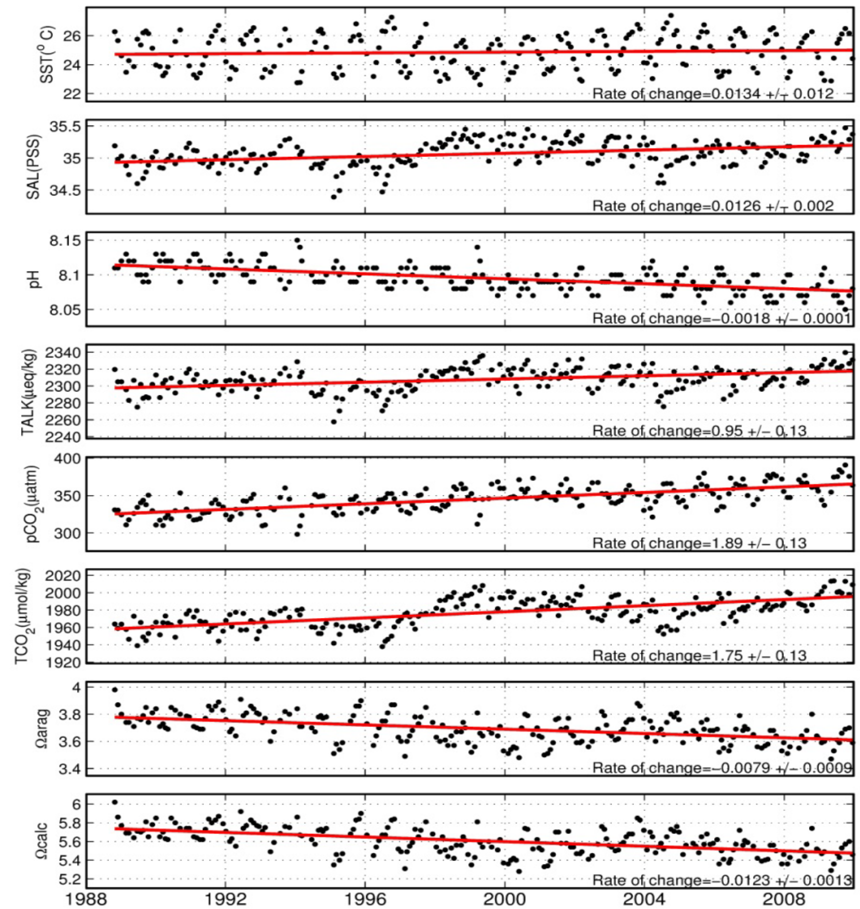
$\Omega > 1$, favors precipitation or formation of $CaCO_3$

$\Omega < 1$, dissolution of $CaCO_3$

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

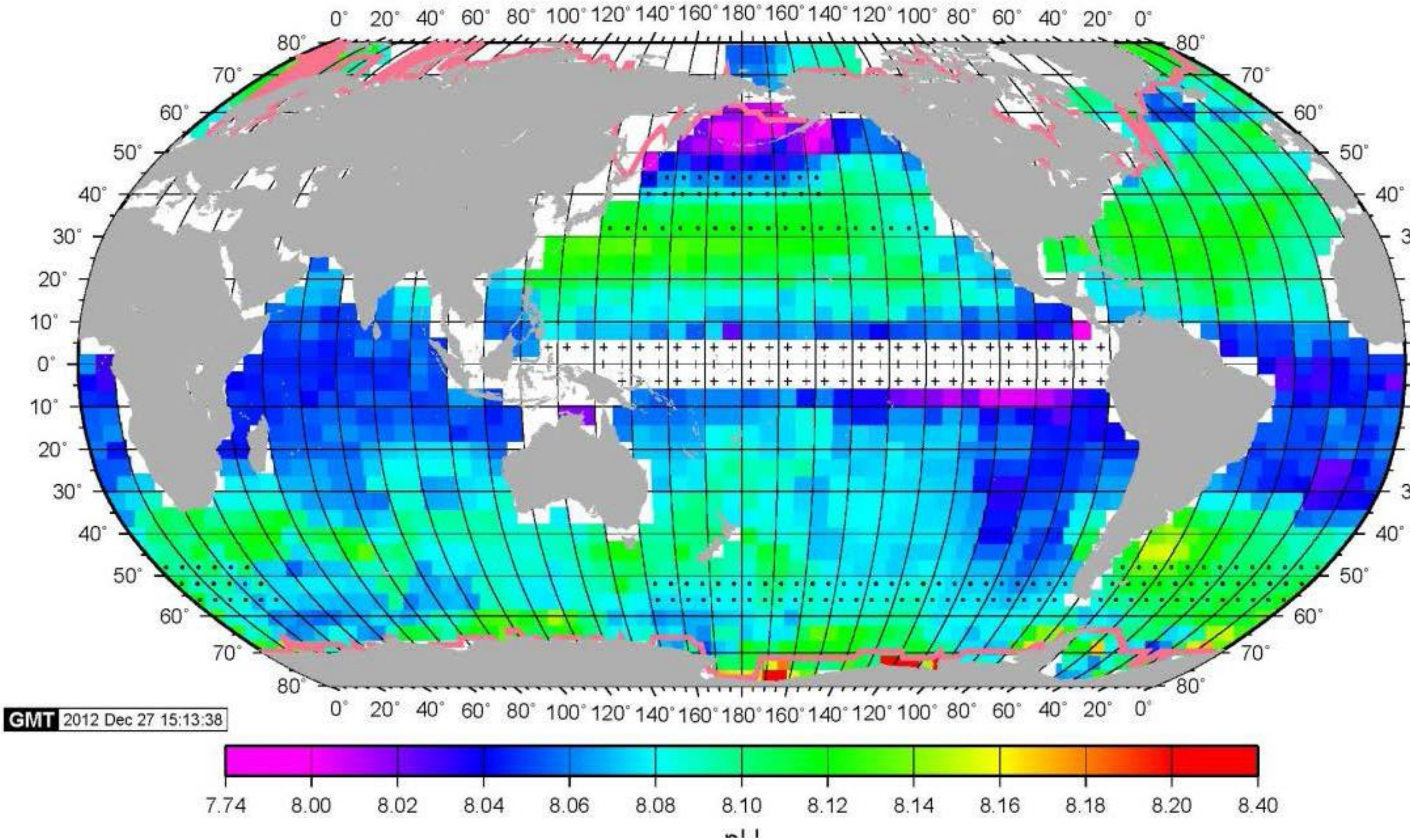
“Small Multiples”--Edward Tufte

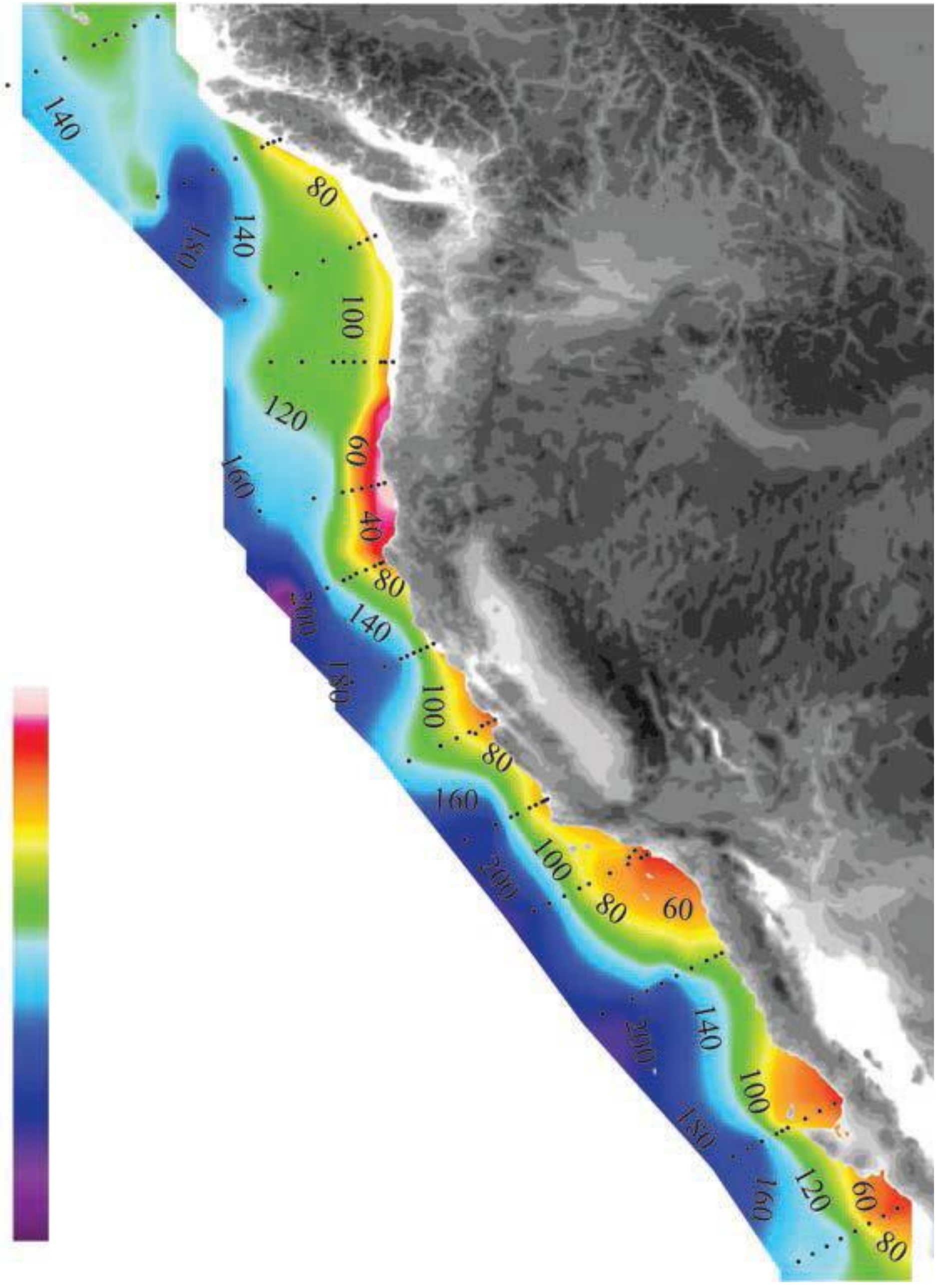
- Similar images placed next to each other
- Seek to identify “similarities” and “differences”
- Well-established design solution for analyzing problems



Skill: Finding Meaning in Clumps and Patterns

http://www.earth2class.org/er/vc/spatial%20thinking/Session8%20Meaning%20from%20Maps.pdf





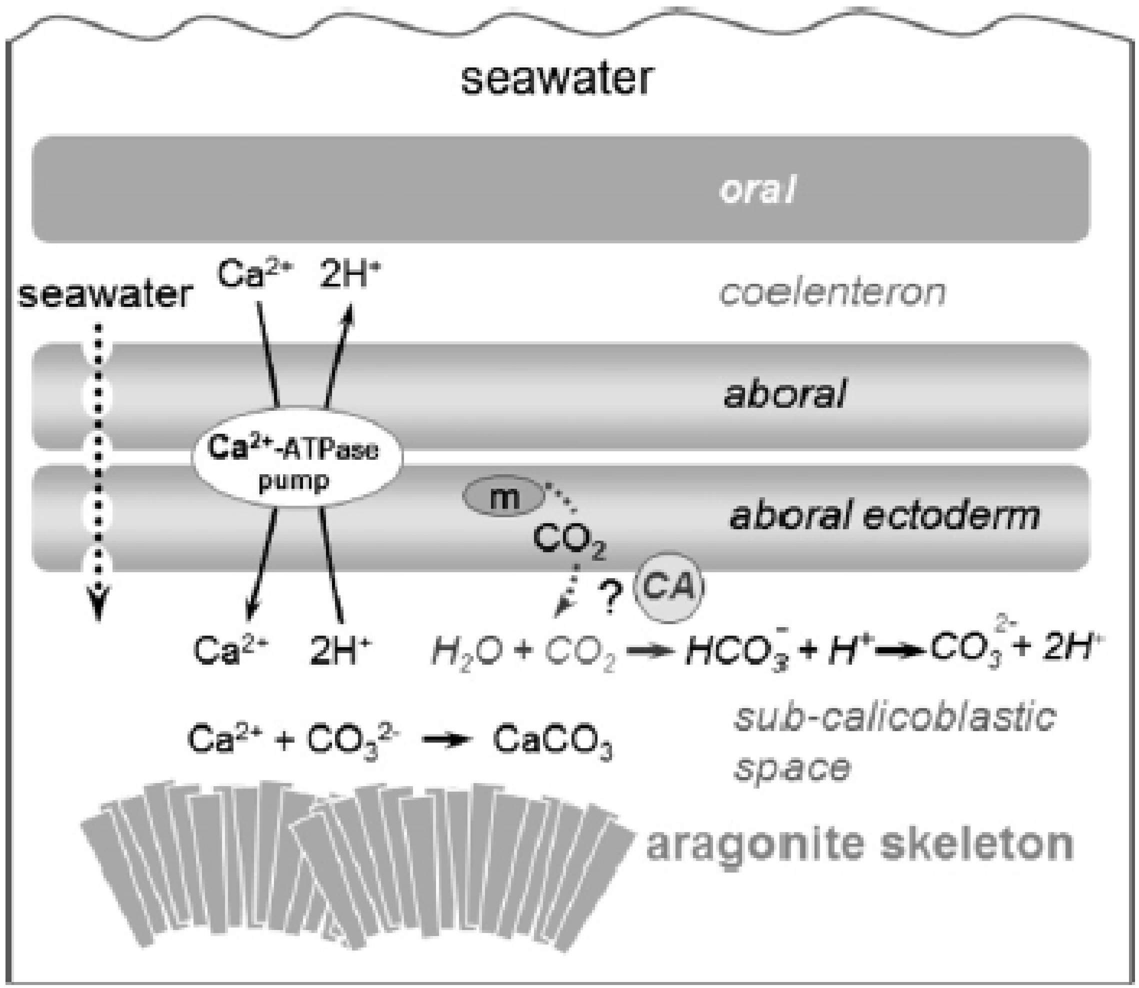
Color-Coded Maps

Examine legend colors

Focus on patterns

Continuous

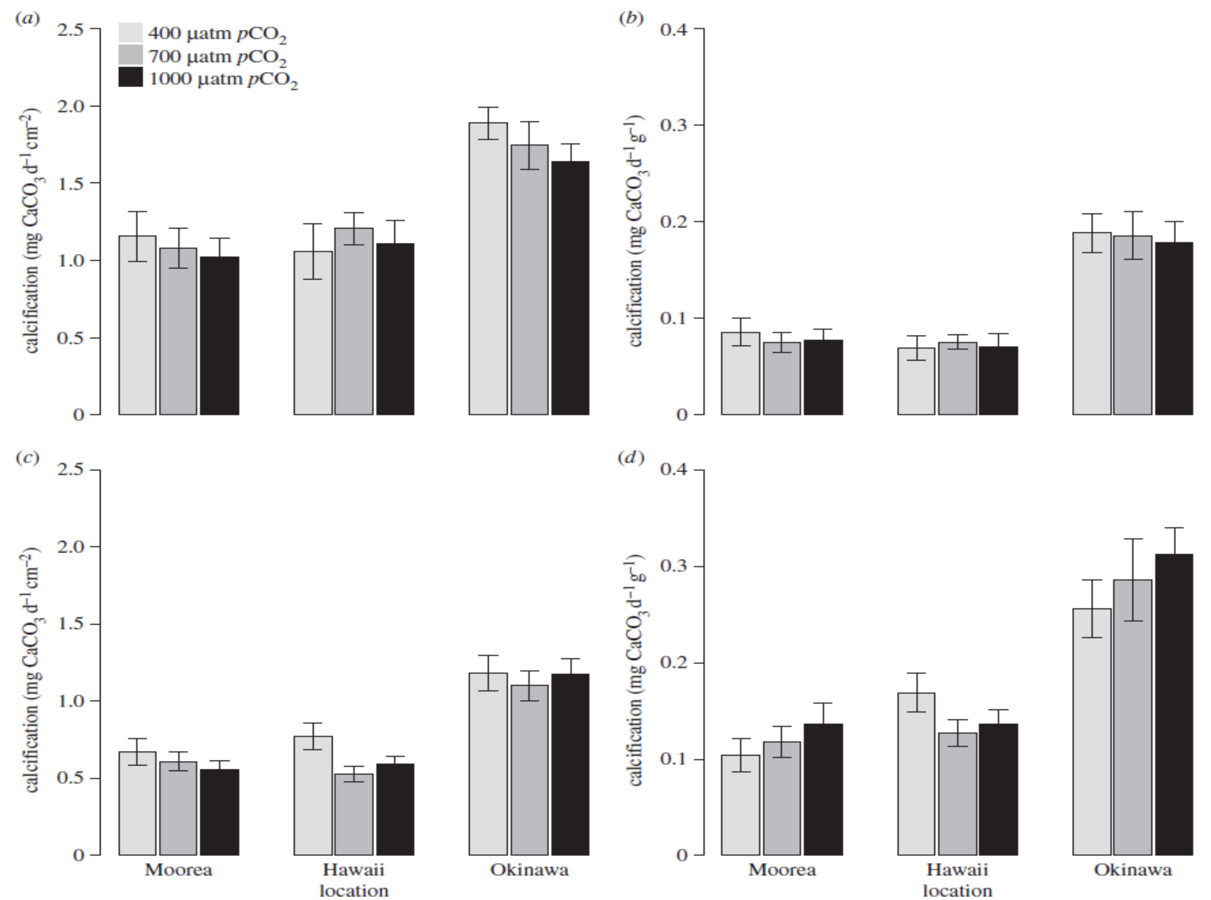
Interpreting Diagrams



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

- Oceans are becoming more acidic
- Acidification affects all ecosystems
- Increases in CO_2 affects pH, p CO_2, Ω, etc.
- Biogeochemical cycles are complex, difficult to reproduce in the lab
- Impacts seem to vary in different parts of the world ocean
- More research is needed