Introduction to “Ocean Acidification and Its Effects on Marine Life”

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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 coccolithophoridaceae to corals to shells to whale bones
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 \( \text{CO}_2 \)) 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
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

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\textsubscript{2}?

• This is one of the most important questions investigated by the CO\textsubscript{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 often focuses 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

\[ pH = \log \frac{1}{[H^+]} = -\log [H^+] \]

Acidic waters, \( pH < 7 \)
\( H^+ > 1 \times 10^{-7} \) mole/L, \( OH^- < 1 \times 10^{-7} \) mole/L
Soda drinks, \( pH \sim 4 \)

Alkaline waters, \( pH > 7 \)
\( H^+ \sim 1 \times 10^{-8} \) mole/L and \( OH^- \sim 1 \times 10^{-6} \) mole/L
Human blood and seawater, \( pH \sim 8 \)

Neutral water, \( pH = 7 \)
\( H^+ = 1 \times 10^{-7} \) mole/L and \( OH^- = 1 \times 10^{-7} \) 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
Another standard of measurement in chemical oceanography is referred to as “pCO$_2$”


Measurements are routinely collected aboard many NOAA, Navy, Coast Guard, and other research vessels.
DEFINITION OF OMEGA $\Omega$

Degree of Saturation of CaCO$_3$ in seawater

Solubility product of CaCO$_3$

$$(\text{Ksp}) = [\text{Ca}^{++}] [\text{CO}_3^{-}]$$ at saturation

$$\Omega = [\text{Ca}^{++}] \text{sw} \cdot [\text{CO}_3^{-}] \text{sw} / \text{Ksp}$$

$\Omega = 1$, saturated

$\Omega > 1$, favors precipitation or formation of CaCO$_3$

$\Omega < 1$, dissolution of CaCO$_3$
Clumps and Patterns
Skill: Finding Meaning in Clumps and Patterns

“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

Seawater flows into a coelenteron, where calcium ions and hydrogen ions are pumped into the aboral ectoderm. Carbon dioxide is added, and calcium carbonate is precipitated, forming an aragonite skeleton.
Representational Correspondence


Commonalities and Dissimilarities

Figure 2. Calcification of the corals massive Porites spp. and P. damicornis maintained in three pCO₂ levels (400, 700 and 1000 μatm) in Moorea, Okinawa and Hawaii, respectively. The first row represents: (a) the area-normalized calcification and (b) the biomass-normalized calcification of massive Porites spp. The second row shows: (c) the area-normalized calcification and (d) the biomass-normalized calcification of P. damicornis. The bars correspond to the mean calcification and the vertical 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—Will we support it?