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 coccolithophororidae 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 CO₂) 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”)
- Coccolithophororidae (“coccoliths”)
- “Symbiotic algae”
- Mollusks
- Others
Additional Terms to Understand

- Physiology
- Temperature-dependent
- Seasonal variations
- Calcification
- Saturated/Unsaturated
- Time-series
- Buffering
CO2 Cycle in the Oceans

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.

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

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

Acidic waters, pH < 7
\[ H^+ > 1 \times 10^{-7} \text{ mole/L}, \quad O\!H^- < 1 \times 10^{-7} \text{ mole/L} \]
Soda drinks, pH ~4

Alkaline waters, pH > 7
\[ H^+ \sim 1 \times 10^{-8} \text{ mole/L} \text{ and } O\!H^- \sim 1 \times 10^{-6} \text{ mole/L} \]
Human blood and seawater, pH ~8

Neutral water, pH = 7
\[ H^+ = 1 \times 10^{-7} \text{ mole/L and } O\!H^- = 1 \times 10^{-7} \text{ mole/L} \]
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 $\text{CaCO}_3$ in seawater

Solubility product of $\text{CaCO}_3$

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

$\Omega < 1$, dissolution of $\text{CaCO}_3$
“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

seawater

oral

coelenteron

aboral

aboral ectoderm

seawater → Ca^{2+} + 2H^{+}

Ca^{2+}-ATPase pump

H_{2}O + CO_{2} → HCO_{3}^{-} + H^{+} → CO_{3}^{2-} + 2H^{+}

Ca^{2+} + CO_{3}^{2-} → CaCO_{3}

sub-calicoblastic space

aragonite skeleton
Representational Correspondence

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

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 Hawai'i, 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 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 CO₂ affects pH, p CO₂, 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