Central Coast Climate Science Education

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Lesson 10: Ocean Acidification: A Consequence of a Higher CO_2 World.

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We insert this short lesson between those discussing the consequences of a warming world to explain another impact of a CO_2-rich atmosphere on our world that is not directly connected with a warming world: namely, ***ocean acidification.*** It is already having observable consequences that may become very serious and damaging as explained near the end of this Lesson.

Ocean Acidification: The Under-the-Radar Threat of Increasing CO_2 Emissions

Ocean acidification has been sometimes called the "hidden evil twin of global warming", since it has received much less attention by the media and the public than global warming. The basics of the ocean chemistry are well understood by ocean chemists and ***the fact of increasing ocean acidity is well documented by observations.***

An excellent and very detailed discussion of the chemical aspects of this topic consisting of a multi-part series can be found starting at this web address: http://www.skepticalscience.com/Mackie_OA_not_OK_post_0.html

If the thought of reading something about chemistry scares you, give it a try anyway. The truth is, however, that like so many other aspects of science (and climate science in particular), the deeper you get into a subject the more subtleties one encounters. This means that a shallow understanding of ocean chemistry can, and has, led to misunderstandings of the situation just as happens with global warming. In this Lesson we use a few chemical reaction formulas and one mathematical relation, but I believe the material will be useful for those without any background in chemistry or math.

One of the most common misunderstandings is that the term "ocean acidification" implies that the ocean is, or is going to be, an "acid" in the sense that chemists (or your spa testing kit) define the boundary between an acidic or alkaline solution: This is measured by the ***pH*** of the solution which itself is a logarithmic measure of the number of hydrogen ions in the solution (in our case, sea water). Pure water (not sea water) has a pH of 7.0. Mathematically:

$$pH = -\log_{10}(HIC)$$

where HIC stands for “hydrogen ion concentration”—the number of hydrogen ions in a given amount of water. (We don’t need to get into the exact definition of “concentration”.)

A true hydrogen ion (written as H^+) is a hydrogen atom with its single negatively charged electron missing, so it has a positive charge. But surrounded by water, (H_2O), the H^+ attaches itself to a water molecule to form the positive ion called “hydronium” whose formula is therefore H_3O^+. In ***pure water*** most of the molecules are in the form of H_2O, but a tiny fraction of the molecules are in the form of the positively charged hydronium ion (with an equal number of negatively charged hydroxide ions, OH^-.)

But in “naturally occurring” seawater, containing other elements, notably calcium and carbon, the pH is higher. “Naturally occurring” here means when the carbon cycle was in balance (see Lesson 6 on the carbon cycle) as it much more closely was prior to the industrial revolution. Then the pH averaged about 8.25. As explained in Lesson 6, the carbon balance, like the energy balance of the climate, has been upset by adding CO_2 to the atmosphere by fossil fuel burning at a rate much faster than natural processes can restore a balance. As the link above explains in detail, some of this added CO_2 becomes dissolved in the ocean.

A famous law of chemistry “Henry’s law, requires that as the amount of CO_2 in the atmosphere increases, the amount of CO_2 dissolved in the ocean increases proportionately. (This is how carbonated water in soft drinks is produced—shake it and/or heat it and open up the can and you will reverse the process in a hurry!)

Through further chemical interactions in the ocean, explained in the series linked to above, this results in the production of more positive ions and thus a ***lowering*** of the pH. At present, the pH in the upper layers of the ocean have been lowered to an average of about 8.14 compared to the value of 8.25 that existed for thousands of years prior to the industrial revolution. ***When ocean chemists use the phrase “ocean acidification” they simply mean that the pH has been, and continues to be, lowered by human intervention in the carbon cycle.***

These two pH values lead to a second misunderstanding, namely that “*the difference between 8.25 and 8.14 is so small---only about 1.3%-- that it is nothing to be concerned about”*. This is ***WRONG***, since pH is a ***logarithmic*** measure—the change in pH of 8.25 – 8.14 = 0.11 implies through the definition of the logarithm that the number of positive ions is now about 1.29 times higher than it was prior to the industrial revolution. Moreover, given present trajectories of fossil fuel consumption the pH may drop to about 7.85, implying an increase in the number of positive ions by 2.5 times by the end of this century.

This has profound implications for marine life in the ocean, not simply because of the increased acidity but because of the further chemical reactions that the additional CO_2 and decreased pH lead to. In particular, many marine organisms, including very tiny ones at the bottom of the food chain, protect themselves by building small hard shells. They do this through a chemical reaction that can be written:

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$$

The Ca^{2+} is a doubly positively charged calcium ion. The calcium comes from weathering of rocks (see the "slow time scale" part of the carbon cycle in Lesson 6) and the CO_3^{2-} is the doubly negatively charged carbonate ion. The product, $CaCO_3$, is ***calcite*** which comes in a couple of different mineral forms that compose the shells of these organisms. If the concentration of the CO_3^{2-} ions is too low the little critters have a tougher time forming their shells.

The form of the chemical reaction above leads to yet another misunderstanding: namely, that adding more dissolved CO_2 to the ocean ought to make more CO_3^{2-} and thus make it easier to form the shells. In fact, as the series in the link above explains, another reaction involving the ***bi***carbonate ion (HCO_3^-) increases as ocean acidification proceeds, but reacts with, and significantly ***reduces*** the concentration of the CO_3^{2-} so the end result is indeed that shell formation is inhibited by ocean acidification. There is a wonderful animated series that shows this very nicely:
http://www.whoi.edu/home/oceanus_images/ries/calcification.html

In fact, if it proceeds too far, ocean acidification can potentially lead to the calcium carbonate in the shells dissolving.

Another excellent source of information "Frequently asked questions about ocean acidification", has been produced as a joint effort between the U.S. Ocean Carbon and Biogeochemistry Program and the U.K. Ocean Acidification Research Programme. It can be downloaded in pdf format by going to https://darchive.mblwhoilibrary.org/handle/1912/5373?show=full and scrolling down to "Files in this item" where you can download the 28 page booklet. This material is revised from time to time and the latest version as of this writing is the Sept. 15, 2012 version. It is very readable and I strongly recommend it.

Rather than trying to summarize it in detail, I will simply quote some portions of it. As in the case of global warming and its impacts on living organisms however, the key point is not just the overall change in the ocean chemistry being experienced, but the ***rapidity*** of this change compared to the time for species to adapt through evolution to this change.

Herewith a few key extracts from the "frequently asked questions" document:

The current rate of decrease in pH is thought to be ten to a hundred times faster than *anytime in the past 50 million years, and many important species like corals, oysters, mussels, clams, crabs and plankton may be adversely impacted and may not have sufficient time to evolve mechanisms to cope with this changing chemistry….it is clear that the rise in CO_2 is decreasing the corals' ability to build their skeletons…While some organisms may grow their shells at normal rates under ocean acidification, the exposed parts of the shell may dissolve more quickly, so that the organism may need to spend more energy in shell maintenance, and less in reproduction or other important life activities like growth and stress tolerance…It seems unlikely, therefore, that corals could succeed in adapting to new temperatures and water chemistry in a few decades to respond to OA* [**short for ocean acidification**]. *Thus, species will be affected differently by changing ocean chemistry, depending upon their existing tolerance for environmental change versus their potential for evolutionary change. If OA drives large shifts in the abundance of key organisms in food webs, or significant rates of extinction, we can expect important changes in the function of ecosystems--- how energy and material flow from primary producers like plankton to top predators like fish and mammals.*

As noted in the excerpt above, corals are likely to be especially vulnerable to ocean acidification, especially when combined with the warming of the ocean that is occurring.

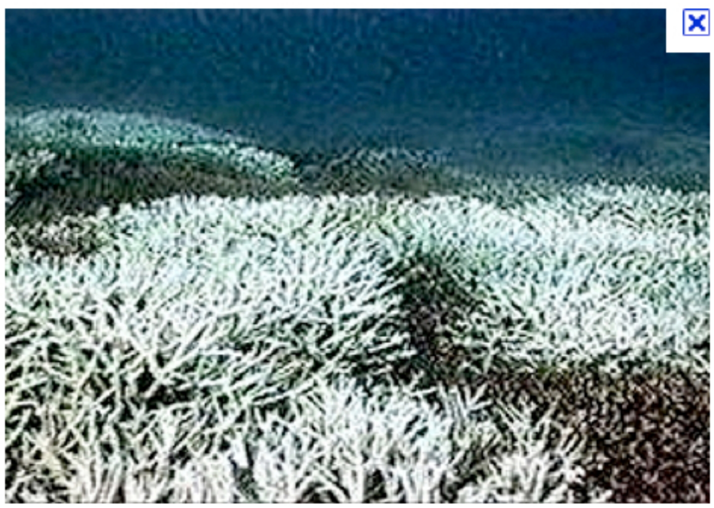
Here is the abstract of a review paper in "SCIENCE" VOL. 318 p. 1737 (December 2007) entitled "Coral Reefs Under Rapid Climate Change and Ocean Acidification" by a group of 17 of the world's leading experts on coral reefs and climate change:

Atmospheric carbon dioxide concentration is expected to exceed 500 parts per million and global temperatures to rise by at least 2°C by 2050 to 2100, values that significantly exceed those of at least the past 420,000 years during which most extant marine organisms evolved. Under conditions expected in the 21st century, global warming and ocean acidification will compromise carbonate accretion, with corals becoming increasingly rare on reef systems. The result will be less diverse reef communities and carbonate reef structures that fail to be maintained. Climate change also exacerbates local stresses from declining water quality and overexploitation of key species, driving reefs increasingly toward the tipping point for functional collapse. This review presents future scenarios for coral reefs that predict increasingly serious consequences for reef-associated fisheries, tourism, coastal protection, and people. As the International Year of the Reef 2008 begins, scaled-up management intervention and decisive action on global emissions are required if the loss of coral-dominated ecosystems is to be avoided.

Here is some concluding material from this paper:

It is sobering to think that we have used the lower range of IPCC scenarios in our analysis yet still envisage serious if not devastating ramifications for coral reefs. Emission pathways that include higher $[CO_2]_{atm}$ *(600 to 1000 ppm) and global temperatures of 3° to 6°C defy consideration as credible alternatives…contemplating policies that result in* $[CO_2]_{atm}$ *above 500 ppm appears extremely risky for coral reefs and the tens* *of millions of people who depend on them directly, even under the most optimistic circumstances.*

With the adage that a picture is worth 10,000 words we end this Lesson with the stark difference between healthy coral and the rich diversity of marine life it hosts and dead “bleached” coral resulting from a combination of warming and ocean acidification.



In Lesson 11 we will return to further discuss consequences of a warming world, as they impact humans and the ecosystem.