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CANADIAN OCEAN SCIENCE NEWSLETTER
LE BULLETIN CANADIEN DES SCIENCES DE L'OCÉAN

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Ocean acidification

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The oceans have absorbed approximately half of anthropogenic CO_2 emissions to date. "Ocean acidification" is a term for the changes in ocean chemistry that arise principally from dissolution of fossil fuel CO_2. CO_2 combines with water to form carbonic acid, H_2CO_3, which then dissociates to form bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. Approximately 90% of the total CO_2 ($TCO_2 = CO_2+HCO_3^-+CO_3^{2-}$) in seawater is present as bicarbonate, 10% as carbonate and 1% as CO_2 gas. Dissociation of carbonic acid releases free protons and lowers the pH of seawater, hence the term "ocean acidification". But the real impact arises mostly from the change in the equilibrium between HCO_3^- and CO_3^{2-}. Seemingly paradoxically, adding more CO_2 to the ocean *reduces* the concentration of CO_3^{2-}. Many marine organisms have shells or skeletons of $CaCO_3$, so when the CO_3^{2-} concentration goes down (Ca is one of the major ions in sea salt so its concentration doesn't change much), it takes more energy to build these hard parts, or if the concentration goes low enough they will start to dissolve. If fossil fuel CO_2 emissions continue at current rates, at least some marine organisms will likely disappear from regions where they are now common by the end of this century.

The concentration of CO_3^{2-} is often expressed as the saturation state with respect to common carbonate minerals such as calcite and aragonite, known as Ω. If $\Omega<1$, the water is undersaturated with respect to the solid mineral phase and the mineral will dissolve. (Note: It was a Canadian, Alfonso Mucci, who made the first reliable measurements of the temperature and salinity dependence of the solubility of these minerals, and defined mathematical expressions that are almost universally used by marine chemists today.) Deep water is naturally undersaturated, in part because of the pressure-dependence of solubility, and in part because of accumulation of TCO_2 from remineralization of organic matter. The boundary between the supersaturated upper ocean ($\Omega>1$) and the undersaturated deep ocean ($\Omega<1$) is known as the *saturation horizon*. Older waters are more undersaturated because of cumulative remineralization, so the saturation horizon is naturally shallower in the Pacific than the Atlantic. Aragonite is far more soluble than calcite, so the aragonite saturation horizon (ASH) is much shallower than the calcite saturation horizon (CSH). Many marine organisms, such as reef-building corals and the pelagic snails known as Pteropods, have evolved to produce aragonite shells and so are especially vulnerable to ocean acidification. In parts of the North Pacific the ASH naturally occurs at depths as shallow as 100 m, so it takes very little additional acidification to make the entire water column undersaturated and therefore uninhabitable by aragonitic organisms.

The ocean carbon cycle is controlled by production of particulate matter by plankton in the surface layer and its remineralization and dissolution in the intermediate and deep ocean. Sinking particulate matter includes both organic and inorganic (calcium carbonate) carbon, and the ratio of the two (the "rain ratio") has far-reaching effects on ocean chemistry. Globally, this ratio is estimated at ~0.06 on average, i.e., there are about 6 moles of particulate inorganic carbon (PIC) for each 100 moles of particulate organic carbon (POC) in the flux out of the euphotic zone. Inorganic carbon sinks to a slightly greater depth, on average, than organic carbon, and a small fraction of each is buried in the sediments. While the total particulate flux (POC+PIC) determines the distribution of TCO_2, the rain ratio profoundly affects the speciation. Removal of PIC from the surface layer causes a reduction of CO_3^{2-} and decreases the saturation state (Ω) (it

also increases [CO_2], exactly the opposite of what happens when an equivalent amount of POC sinks out). Dissolution of PIC in the subsurface has the opposite effect: a relative increase of CO_3^{2-} and Ω. Dissolution of carbonate minerals buried in the sediments will eventually reverse the acidification induced by anthropogenic CO_2, but the time scale for this to occur is very long (tens to hundreds of thousands of years).

Almost all marine organisms will be affected in some way by ocean acidification. The variety of invertebrates that have carbonaceous skeletons is great. Coral reefs are the poster-children, but high-latitude organisms are probably more vulnerable because the saturation horizon is naturally shallow. Molluscs (clams, mussels, oysters, scallops, snails) are among the most familiar species that have carbonate shells, but crustaceans (crabs, shrimp, copepods, euphausiids) and echinoderms (starfish, sea urchins, sea cucumbers) also have carbonate minerals bound into organic matrices in their exoskeletons. Deep-sea corals are present in deep waters at all latitudes including Canadian waters and are particularly vulnerable; very little is known about their biology or present distribution so detecting impacts will be difficult. Acidification also affects noncalcifying organisms in a variety of ways. Some highly active pelagic squids, for example, already live near their limit of tolerance for excess tissue CO_2 due to their high metabolic rates.

There are numerous research topics related to ocean acidification where the present state of knowledge is woefully inadequate. We actually know very little about which organisms are primarily responsible for the carbonate component of the biological pump, where and how vertical transport of carbonates to the deep ocean occurs, or how and how fast dissolution occurs. We know that carbonate minerals contain magnesium as well as calcium, that the Mg/Ca ratio is highly variable, and that solubility depends strongly on this ratio, but we know very little about what regulates this ratio in the ocean or how its variability affects sedimentation of pelagic carbonates. We do not know how vulnerable different classes of organisms are to physiological stresses associated with reduced saturation states above the nominal saturation threshold, how quickly populations can evolve mechanisms to minimize these stresses, or what the ecological repercussions of such adaptation are.

A particular concern for Canadians is the Arctic Ocean, which has a unique configuration of vulnerabilities. Receding sea ice and expanding open water will present Arctic pelagic ecosystems with unprecedented environmental states just as acidification impacts mount. Moreover, the Arctic Ocean has very large freshwater inputs relative to its volume, and fresh water has very little buffering capacity compared to seawater (buffering capacity is a measure of how much the pH of a solution will change for a given input of acid). Much of this fresh water also has high concentrations of dissolved organic carbon, which will tend to exacerbate acidification and which may increase with climate change. At least some Arctic rivers also have very high alkalinity (which increases buffering capacity), which can help to mitigate acidification. Globally, we still know very little about the vulnerability of near shore waters. Terrestrial sources of alkalinity may help to mitigate acidification in the near shore waters where bivalve aquaculture and recreational and subsistence bivalve fisheries are concentrated, but the effects are likely to be highly variable from location to location, and intertwined with a range of other human impacts.

Further reading:

Royal Society, 2005. Ocean acidification due to increasing atmospheric carbon dioxide. available at http://royalsociety.org/document.asp?id=3249

Ocean Acidification Summary for Policymakers 2009. available at http://www.ocean-acidification.net

Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas, 2009. Ocean acidification: the other CO_2 problem. Ann. Rev. Mar. Sci. 1: 169-192.

Orr, J. C., and others, 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437: 681-686.

Steinacher, M., F. Joos, T. L. Fröhlicher, G.-K. Plattner, and S. C. Doney, 2009. Imminent ocean acidification in the Arctic projected with the NCAR global coupled carbon cycle-climate model. Biogeosciences 6: 515-533.

Zeebe, R. E., J. C. Zachos, K. Caldeira, and T. Tyrrell, 2008. Carbon emissions and acidification. Science 321: 51-52.

David Slauenwhite

Colleagues and friends at the Bedford Institute of Oceanography (BIO) and elsewhere in the Halifax community were saddened to learn of the passing on Friday, August 21, 2009 of Dr. David (Dave) Slauenwhite of BIO's Ocean Sciences Division (OSD). Dave was a graduate of Dalhousie University where he received his BSc. in Chemistry with Honours, and his Ph.D. in Chemical Oceanography with the late Dr. Pete Wangersky. He subsequently held a postdoctoral fellow position at Dalhousie and then was a laboratory manager at St. Mary's University.

Since 2006, Dave had been working at BIO, first with BDR Research and then as a Physical Scientist in the Ocean Circulation Section. Working with Dr. Kumiko Azetsu-Scott, he was the scientist responsible for the management and operation of OSD's chemical oceanographic laboratory measuring dissolved oxygen, alkalinity and inorganic carbon, chlorofluorocarbons as ocean tracers, and most recently, ocean acidity. He had fully participated in BIO's annual oceanographic survey of the Labrador Sea in May 2009, prior to his hospitalization and diagnosis. During his unfortunately short tenure at BIO, Dave had established himself as a congenial, conscientious, hard-working, highly-competent and reliable team member, and had become a good friend to many who worked with him. He will be greatly missed.

Dr. Wendy Watson-Wright named New Assistant Director General and Executive Secretary of Intergovernmental Oceanographic Commission of UNESCO

Dr. Wendy Watson-Wright, Assistant Deputy Minister (ADM), Science Sector at Fisheries and Oceans Canada (DFO) will move to Paris in January to take up new responsibilities as the Assistant Director General of UNESCO for the Intergovernmental Oceanographic Commission (IOC) and Executive Secretary of IOC.

In her new position as head of the IOC, UNESCO in Paris, she will be overseeing the very successful ocean science programs, ranging from important issues such as ocean observations, climate change, and tsunami warning systems, to ocean data management and many more important subjects.

Since 2001, Dr. Watson- Wright has been ADM of Science at DFO. She made significant contributions to DFO-academic collaborations by participating in the Advisory Boards of research networks such as the ArcticNet, GEOIDE, Ocean Networks Canada as well as the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS). She also established the Timothy Parsons Award for outstanding work in oceans science to recognize Canadian scientists.

During the past 8 years she oversaw her department's 15 research institutes across the country. This multifaceted job involved making policy, budget, human resource and other managerial decisions. She has worked with other science-based departments and agencies to help build a more integrated approach to science policy and programs across the government.

Though she will be greatly missed, we are proud of her achievements. We wish her well in these new endeavours and hope that her path will cross that of our Canadian ocean science colleagues.

Argo

The latest Argo Newsletter may be found at http://www-argo.ucsd.edu/Argonautics11.pdf. In this you will see an article by Steve Riser about the recent concerns surrounding the Druck pressure sensors which triggered a global recall. Note the summary picture showing active floats by country. Since the last newsletter floats have been deployed by Gabon and Kenya.

SCOR Newsletter No. 14 September 2009

The latest SCOR international Newsletter may be found at: http://www.scor-int.org/Publications/SCOR-NL-14.pdf It contains updates on many issues, including:

- Update on SCOR Finances
- Products from High-CO_2 Symposium
- SCOR Panel on New Technologies for Observing Marine Life
- SCOR Visiting Scholar Program
- Working Groups
    - Six proposals for new working groups
    - WG 126 on The Role of Viruses in Marine Ecosystems
    - WG 127 on Thermodynamics and Equation of State of Seawater
    - WG 128 on Natural and Human-Induced Hypoxia and Consequences for Coastal Areas
    - WG 129 on Deep Ocean Exchanges with the Shelf
    - WG 130 on Automatic Plankton Visual Identification
    - SCOR/IAPSO OceanScope WG 133
- Large-Scale Ocean Research Projects
    - GEOHAB
    - IMBER
    - SOLAS
- Ocean Mixing Group
- SCOR Annual Meetings
    - 2009 - SCOR Executive Committee Meeting, Beijing, China, on 20-22 October
    - 2010 - SCOR General Meeting in Toulouse, France.
    - 2011 - SCOR Executive Committee meeting in Finland.

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Les bulletins antérieurs se retrouvent sur le site web du CNC/SCOR.

Newsletter #47 will be distributed on December 10, 2009. Please send contributions to dick.stoddart@sympatico.ca
Bulletin #47 sera distribué le 10 decembre 2009. Veuillez faire parvenir vos contributions à dick.stoddart@sympatico.ca

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