

Addressing biogeochemical knowledge gaps

Ocean Carbon and Biogeochemistry Project Office co-investigators **Drs Heather Benway** and **Scott Doney** discuss the programme's mission to increase our understanding of the ocean's changing role in the global carbon cycle and its implications for marine ecosystems and biogeochemical cycles



What led to your appointment in the Ocean Carbon and Biogeochemistry (OCB) Project Office?

SD: I have been researching the marine carbon cycle in various forms for the last two decades, and I was one of the leaders of the synthesis and modelling component of a prior US ocean biogeochemistry research programme during the late 1990s and early 2000s. When that programme ended it became clear that the US research community needed a central focus to facilitate ongoing coordination and communication. After several years of discussions and planning, we started the OCB programme in 2006 in conjunction with the National Science Foundation (NSF), NASA and National Oceanic and Atmospheric Administration (NOAA) programme managers, and many other scientists across the research community. I served as inaugural chair of the Scientific Steering Committee and leader of the Project Office.

Could you touch upon your background in the field of ocean biogeochemistry?

HB: With two graduate degrees in oceanography, my research has focused on nutrient cycling and palaeoceanography, both highly interdisciplinary areas involving the complex interplay between marine ecosystems and biogeochemistry. I also have federal agency programme management experience and a broader interest in scientific planning and policy, which is why I

joined the OCB Project Office in 2007 upon completing postdoctoral research at the Woods Hole Oceanographic Institution.

How will OCB support community-building in this field?

HB: OCB will continue in its efforts to expand the multiple stressor and ocean acidification research communities, particularly engaging evolutionary and molecular biologists and social scientists. Continued partner activities with programmes such as IMBER, SOLAS, NACP, IOCCP, US CLIVAR, etc., will ensure that OCB is assembling the interdisciplinary body of expertise needed to effectively address these and other scientific questions related to ocean carbon uptake, biogeochemical cycling, and marine ecosystems. In addition, we will provide community input and justification for coastal biogeochemical observing programmes via activities like the North American coastal synthesis, which is revealing key gaps in our understanding of major carbon sinks and sources in continental margins (figure 1).

To what extent do you work with national agencies such as the Interagency Ocean Policy Task Force to coordinate effective policy implementation?

SD: Although OCB does not directly participate in policy implementation, it coordinates and compiles scientific input from its research community to inform effective policy. We work closely with federal agency programme managers and relevant interagency working groups. In recent years, the OCB community has provided important input to scientific activities such as the 2011 US Carbon Cycle Science Plan, national ocean acidification research planning, agency requests for information on ocean acidification monitoring in the coastal zone and ocean observing activities.

Can you highlight a few of the biggest breakthroughs in our current understanding of ocean biogeochemical interactions?

HB: Over the past couple of decades, ocean observing activities spanning a wide range of spatial and temporal scales including satellite ocean colour observations, ocean time-series, large-scale repeat hydrographic surveys, autonomous platforms and increasingly sophisticated biogeochemical models have helped researchers achieve many milestones. Recent breakthroughs include tracking the uptake of anthropogenic CO₂ by the world's oceans and assessing regional sensitivity to ocean acidification; quantifying key vertical fluxes associated with the biological pump and describing the roles of biota associated with these fluxes; identifying and quantifying key carbon sinks and sources in coastal waters (figure 1); measuring distributions of key micronutrients in the ocean; and better quantifying gas transfer velocities and air-sea CO₂ fluxes.

What are your ambitions for the future of the OCB Project Office?

SD: Ocean observations across multiple platforms and scales form the very foundation of OCB research. As such, it is critical that the project continues to facilitate ocean observing initiatives. Near-term goals for OCB include developing an international network of shipboard biogeochemical time-series, including detailed information on sampling and analytical methods and data access to promote global data intercomparability. We are also keen to engage the OCB community in a more routine and innovative use of space-based measurements to address science questions, as well as planning for the next NASA ocean colour mission.

The ocean carbon cycle

As a coordinating body for ocean carbon cycle science, the **Ocean Carbon and Biogeochemistry Office** is a pivotal resource to a growing body of knowledge on marine ecosystems and biogeochemistry

ATMOSPHERIC CO₂ IS rising sharply due to human activities such as fossil-fuel combustion, and considerable concerns surround the growing climate and ecosystem impacts. Much progress has been made in understanding the global carbon cycle and quantifying major carbon sinks. The next steps are to learn more about how ecosystems are responding to changes in greenhouse gases and climate, and examine in greater detail the linkages between humans and the carbon cycle.

The oceans cover approximately 72 per cent of our planet and represent a key player in the global carbon cycle. In the past two decades, the field of marine biogeochemistry – which involves the study of biological, chemical and geological processes and how they interact in the ocean – has advanced considerably through the development of more sophisticated observational, analytical and modelling tools. Marine biogeochemists have made tremendous breakthroughs in understanding fundamental processes involved in major elemental cycles such as carbon and nitrogen, as well as the distributions of trace elements in the oceans. Cutting-edge molecular tools are revolutionising our understanding of how organisms respond to changes in their environment.

Through its support and coordination of national and international activities, the Ocean Carbon and Biogeochemistry (OCB) Office promotes

the study of the ocean's role in the global carbon cycle. In particular, OCB is keen to improve predictions of oceanic uptake and release of greenhouse gases as well as increase our understanding of the environmental sensitivities of, and feedbacks between, marine ecosystems and biogeochemical cycles. Recognising the importance of ocean observations across multiple time and space scales in supporting this research, OCB facilitates ocean observing activities, including shipboard, satellite and autonomous measurement campaigns.

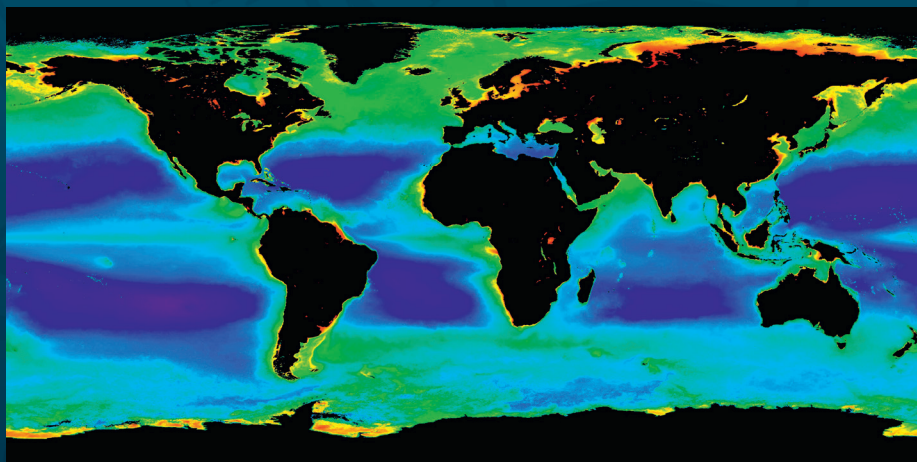
FACING THE CHALLENGES OF OCEANIC CHANGE

Executive Scientist of the OCB Project Office Dr Scott Doney explains that the rising greenhouse gas levels in the atmosphere have led to increases in both ocean heat content and sea surface temperatures: "In fact, the ocean accounts for roughly 80 per cent of the excess heat stored on Earth as a result of global warming. Increasing ocean temperatures are affecting circulation, weather patterns and ecosystems". Furthermore, as the oceans absorb more CO₂, they are becoming more acidic (figure 2). "Since the dawn of industrialisation," continues Doney, "surface ocean pH has decreased from 8.2 to 8.1, which, due to the logarithmic pH scale, represents approximately a 30 per cent increase in acidity over roughly 250 years; current rates are roughly 100 times faster than anything the

ocean and its inhabitants have experienced in tens of millions of years".

Executive Officer of the OCB Project Office Dr Heather Benway highlights that marine ecosystems are facing multiple anthropogenic changes such as warming, pollution, acidification and decreasing oxygen levels. Coastal waters are particularly vulnerable due to loss of key habitats, overloading of nutrients, expanding low oxygen regions and overfishing. "Although we have learned a lot about how individual changes impact ocean chemistry, there is less consensus on how these changes affect organisms and the marine food web, or the combined effects of these changes, which large parts of the world's oceans are experiencing concurrently," she reveals.

The projected rise in atmospheric CO₂ levels and the subsequent effects on the Earth's climate have prompted researchers and engineers to propose innovative ways to remove atmospheric CO₂. Some of these geoengineering strategies include addition of micro- or macro-nutrients to the ocean and deployment of artificial upwelling technologies to stimulate phytoplankton activity. However, before such approaches can be considered as viable mitigation strategies, an improved scientific understanding is needed to quantify their impacts on the global carbon balance and predict the outcomes and associated risks for the environment. OCB is in support



Average ocean chlorophyll-a concentration as derived from SeaWiFS, 1997-2003. © NASA

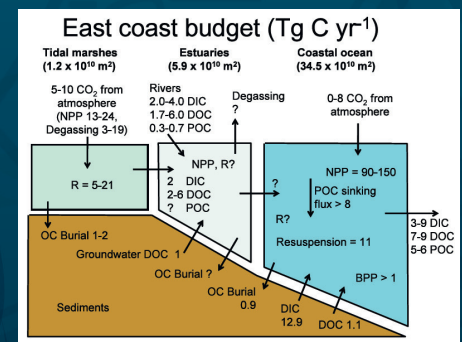


Figure 1. Preliminary carbon budget for the coastal zone of the eastern US based on joint OCB/NACP synthesis activities (Najjar et al., 2012). R = respiration, DIC = dissolved inorganic carbon, OC = organic carbon, DOC = dissolved organic carbon, POC = particulate organic carbon, NPP = net primary productivity, BPP = benthic primary production. A full report on the east coast carbon synthesis is available at www.us-ocb.org/publications/East_coast_syn_report_FINAL.pdf.

INTELLIGENCE

OCEAN CARBON AND BIOGEOCHEMISTRY PROJECT OFFICE

OBJECTIVES

- To organise community workshops, short courses and symposia
- To communicate OCB products and activities to the national and international scientific community and broader audiences, serving as a clearing house for information related to US and international ocean carbon cycle science
- To interface with other national and international carbon cycle science programmes and activities

PARTNERS

Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Programme • International Ocean Carbon Coordination Project (IOCCP) • North American Carbon Program (NACP) • Surface Ocean Lower Atmosphere Study (SOLAS) • US Climate Variability and Predictability (CLIVAR) Programme • GEOTRACES Programme

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SCOTT DONEY is a Senior Scientist in the Department of Marine Chemistry and Geochemistry and Director of the Ocean and Climate Change Institute at the Woods Hole Oceanographic Institution (WHOI). He was the inaugural chair of the US Ocean Carbon and Biogeochemistry (OCB) Scientific Steering Committee and Project Office.



of well-controlled *in situ* ocean perturbation experiments to better understand ocean processes and predict ecosystem responses to added ocean nutrients. “However,” Benway suggests, “this research should be planned, organised and reported in a transparent manner that upholds rigorous scientific standards and complies with international protocols.” To keep its community connected to ocean fertilisation science and policy activities, OCB has an ocean fertilisation subcommittee and maintains an informational website as a resource for scientists, educators, policy makers and the media.

SCIENCE LEADERSHIP, COMMUNITY BUILDING AND COORDINATION

Under the leadership of a Scientific Steering Committee, OCB has coordinated multiple activities to help advance high-priority research areas such as ocean carbon uptake and ocean acidification, and inform US and international ocean observing initiatives such as autonomous arrays and integrated molecular biological and biogeochemical sampling approaches at sea. Through these activities and partnerships with other programmes, OCB tries to assemble a broad range of expertise to promote community-building and foster new collaborations.

OCB coordinates an annual summer workshop that convenes scientists around broad interdisciplinary themes related to OCB research priorities. Given the breadth of expertise that is typically represented, the summer workshop provides an effective venue for interdisciplinary discussion and consensus-building. For example, the OCB community has provided input to science planning initiatives such as the 2011 US Carbon Cycle Science Plan.

OCB also administers smaller group activities to convene a more focused body of expertise to address targeted questions. OCB has supported seven scoping workshops to date, which have yielded a range of outcomes, including new collaborations, new funded projects, high-level publications, synthesis activities and implementation plans for new research and observational programmes. Partner activities also represent a critical component of OCB’s community-building success. Joint working groups with the US Climate Variability and Predictability (CLIVAR) programme have entrained the ocean physics and climate dynamics expertise necessary to address questions related to ocean carbon and heat uptake. Coastal carbon synthesis activities with the North American Carbon Program (NACP) have brought together researchers across the land-ocean continuum to quantify key carbon fluxes in the coastal zone, which is still a large unknown in the North American carbon budget.

An ongoing challenge for the OCB community is how to move from the planning stages to actual implementation, as OCB is a coordination network and does not have funds to support research projects. OCB helps create

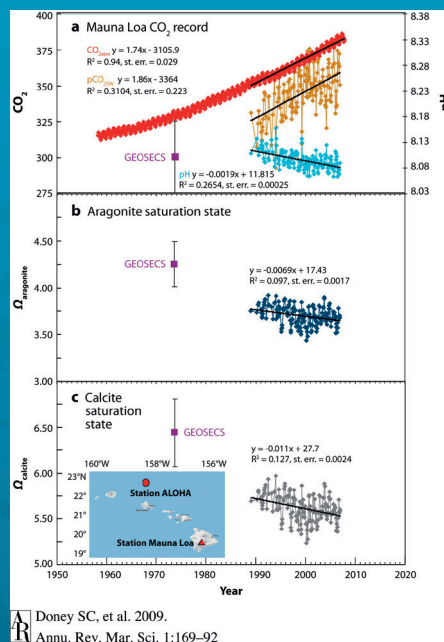


Figure 2. Time series of: (a) atmospheric CO₂ at Mauna Loa (in parts per million volume (red)), surface ocean pH (cyan), and pCO₂ μatm (tan) at Ocean Station ALOHA in the subtropical North Pacific Ocean; (b) aragonite saturation (dark blue); and (c) calcite saturation (grey). The increase in oceanic CO₂ over the past 17 years is consistent with the atmospheric increase within the statistical limits of the measurements (Doney et al., 2009, *Annual Review of Marine Science* 1(1): 169-192).

opportunities for the research community, but its energy and success since it ultimately depends on the involvement of individual scientists through participation in its activities and the development and submission of competitive proposals to funding agencies. “We always encourage scientists to leverage OCB materials and products when designing and writing their proposals,” emphasises Doney.

PROMOTING AWARENESS

OCB maintains websites with a range of information to serve the needs of scientists, educators, policy makers, and media, and publishes a regular newsletter to highlight new scientific findings. To foster education and awareness of marine ecosystems and biogeochemical cycling for a host of audiences and age groups, OCB coordinates activities like teacher workshops, local and national outreach events, and develops products such as ocean acidification FAQs, lab kits for teachers, web lecture series and museum exhibits. With a commitment to educating the next generation of ocean carbon scientists, OCB has provided support to early career scientists in many forms. In 2009, OCB coordinated and hosted a highly successful short course on ocean acidification with segments on seawater CO₂ system sampling and measurement, ocean acidification experimental design and modelling.

Through its coordination and community-building efforts, OCB and its network of scientists and partner programmes will continue to make waves in the study of our changing oceans.