Carbon cycle changes in the North Pacific

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Dr. Christopher Sabine is an oceanographer at NOAA’s Pacific Marine Environmental Laboratory. His research focuses on understanding the role of the ocean in the global carbon cycle. This includes examining the air-sea exchange of CO2 at the ocean surface and the basin-scale distributions of both natural and anthropogenic carbon in the ocean’s interior, understanding multiple tracer relationships, evaluating ocean carbon cycle GCMs with data-based global carbon distributions, and examining carbonate and organic matter re-mineralization within the ocean. Chris has been heavily involved with PICES serving as a member of WG 13 and WG 17 and organizing a number of special sessions/workshops. He also sits on several international committees such as the IGBP/IHDP/WCRP Global Carbon Project (GCP) and the International Ocean Carbon Coordination Project (IOCCP), and has recently helped develop the science and implementation plans for the Ocean Carbon and Climate Change (OCCC) and the North American Carbon Program (NACP) in the United States.

PICES has played a major role in advancing our understanding of the North Pacific carbon cycle over the last six years. In 1998, PICES Working Group 13 was established to promote collaborative carbon cycle research among the PICES member nations, to conduct international CO2 inter-comparison studies, and to help the development of strategies for international data exchange. By 2001, WG 13 had conducted six workshops on topics ranging from comparisons of dissolved inorganic carbon (DIC) and total alkalinity (TA) techniques to North Pacific data integration.

In 2002, a new Working Group (WG 17) was established to continue the progress started with WG 13. In addition to conducting an inter-comparison study of pCO2 systems and developing a handbook of recommended methods, WG 17 has also helped to facilitate the synthesis and interpretation of North Pacific carbon cycle data. The latest contributions to this effort were a workshop held this summer and a follow-up session at PICES XIII in Honolulu this October. This article outlines the approach used to encourage collaboration at the PICES member nations, some of the intriguing results and recommendations for future research.

Background

Studies of the ocean’s role in the uptake and storage of anthropogenic CO2 and modulation of future atmospheric CO2 levels are critical for understanding the global carbon cycle and for the prediction of future climate change. The North Pacific is an important sink region for atmospheric carbon dioxide in the ocean and, consequently, plays a significant role in controlling the long-term fate of CO2 on Earth. Some biogeochemical processes relating to the oceanic CO2 system are unique to the North Pacific. For example, the fact that the North Pacific is the final destination of deep water circulation means that high levels of preformed nutrients and DIC are brought into the region. In addition, the strong equatorial upwelling in the Pacific brings high CO2 waters to the surface making the southern portions of the North Pacific a large natural source of CO2 to the atmosphere.

Evidence is accumulating that there is substantial variability in the cycling of carbon and related biogeochemical elements over a wide range of time-scales, including inter-annual and decadal scales which have been the focus of many climate change studies. Most of these studies, however, have been limited in time, space or number of parameters examined, preventing a full appreciation of the scale and magnitude of the changes. Numerous studies have been conducted in the North Pacific, but a lack of coordinated approaches has hampered our ability to fully appreciate the regional to basin-scale dynamics of the system. For example, Emerson et al. (2001) and Ono et al. (2001) both detected increases in apparent oxygen utilization (AOU) in the North Pacific Ocean, but examined different regions, depth zones and time periods using differing approaches that made it difficult to determine whether the signals were coherent across the North Pacific. Keller et al. (2002) examined a larger area and also found AOU changes, but indicated that compensating changes in the opposite direction may be found on deeper surfaces. Large variability has also been observed in North Pacific carbon measurements and other parameters (Feely et al., 1997; Chavez et al., 1999; Feely et al., 1999, 2002, 2004; Karl, 1999; Karl et al., 2001).

Recognizing the need to synthesize this diverse array of studies, the North Pacific Carbon Cycle Workshop was organized in Seattle in the summer of 2004. The workshop was sponsored by NOAA’s Office of Global Programs with contributions from PICES, the Global Carbon Project, and the University of Washington's Program on Climate Change. The organizing committee of R. Feely (PMEL), N. Gruber (UCLA), R. Key (Princeton), C. Sabine (PMEL)
and J. Sarmiento (Princeton) proposed that rather than simply organizing another meeting where participants come and listen to talks then return to their home institutions to continue their individual research, the workshop should be designed to encourage the synthesis of individual studies and create an environment of collaboration. The format for this workshop brought together modelers and observationalists representing different biogeochemical and physical specialties and different regional expertise to combine their latest model runs and data sets into a common format determined in preparation for the meeting. The goal of this meeting was to encourage real-time exchange and development of ideas among scientists who do not regularly collaborate, but have a common interest (i.e., North Pacific), with the objective of generating synthesis publications that draw from the unique perspective of each participant. This way we can develop an understanding that could not be easily achieved by any individual.

A three-step approach

The workshop was organized using a three-step approach with active coordination, communication and collaboration among the participants before, during, and after the actual meeting. First, the workshop organizers contacted a team of international and diverse scientists that were interested in contributing data and new research to a collaborative study. To help focus the group, participants were divided into three Task Groups (TG) centered on one of three fundamental questions:

(1) How are air-sea CO₂ fluxes in the North Pacific affected by interannual, decadal and long-term variability?

(2) How and why are the North Pacific distribution patterns of carbon, nutrients and oxygen in the water column changing with time? and

(3) what are the requirements for detecting a climate change signal in the North Pacific carbon cycle?

Prior to the meeting, an e-mail discussion was initiated to assess the state of our knowledge on the identified topic and to define the relevant data sets, model results and analysis approaches that could be used to improve this understanding. Data and model results were collected and made available to all the participants through the World Wide Web. Each Task Group established a common framework and guidelines for the presentation of data with specific data-analysis goals. The standardization of approaches/formats and communication prior to the meeting allowed speakers to prepare presentations that could be more easily compared to other presentations at the workshop held on June 2-4, 2004, at the Harbor Steps Conference Center in downtown Seattle (Fig. 1). For example, several participants showed model results at specific locations where direct measurements were also presented. A significant amount of meeting time was spent in Task Groups discussing the similarity and differences of the various studies and considering follow-up analyses that could be used to address intriguing findings. Approximately half of the meeting time was spent in plenary to ensure that all of the participants were well informed of the progress and findings of the Task Groups, and to look for synergies and investigate cross-cutting issues between the three topics. Individual participants from one Task Group were frequently asked to come speak with other Task Groups to maximize everyone’s contribution. By the end of the meeting, a total of 14 synthesis manuscripts were identified to work on.

Fig. 1  Participants of the North Pacific Carbon Cycle Workshop outside the Harbor Steps Conference Center in Seattle, June 2-4, 2004.
After the Seattle meeting, participants were encouraged to continue the interactions over e-mail, and to develop the collaborative manuscripts synthesizing the results of the workshop. A Topic Session on the North Pacific carbon cycle was organized at PICES XIII to provide an opportunity for many of the participants to meet together again and share the results of their collaborative interactions with the broader PICES community. A majority of 18 oral presentations in the session and several posters were related to the June workshop, including an invited talk by Nicolas Gruber outlining the motivation behind the workshop and some of the key results. Although many of the workshop participants were familiar with PICES, this was the first time some of the participants had experienced a PICES Annual Meeting. Results were presented from most of the synthesis manuscripts outlined at the workshop, suggesting that great progress had been made since June. The synthesis manuscripts generated from this workshop are being assembled into a special journal volume on the North Pacific carbon cycle, and should be published in 2005.

**Air-sea fluxes**

Many new ideas were introduced and examined as a result of the preparatory discussions. For example, as a part of TG 1 on air-sea fluxes, Taro Takahashi (LDEO) showed data suggesting that at least three different pCO2 trends can be observed on decadal scale in the North Pacific surface water. Data along the west coast of North America and the eastern sub-polar North Pacific region appear to show a steady increase in surface water pCO2 that roughly tracks the atmospheric CO2 increase for the last couple of decades. Data sets from the equatorial Pacific and subtropical regions around Hawaii indicated that in the 1980s surface water pCO2 was increasing at a slower rate than atmospheric CO2. In the early to mid-1990s, however, the rate appears to have changed such that today, surface water pCO2 is growing faster than the atmosphere (e.g., Fig. 2). By contrast, some regions such as the western sub-polar North Pacific actually show decreasing surface pCO2 values over the last few decades. Modeling studies indicate that shifts in the Pacific Decadal Oscillation (PDO) can influence the air-sea fluxes and, in some cases, have helped to explain some of the changes observed in the data. For example, pCO2 changes in the equatorial and tropical Pacific coincide with a slowdown in meridional circulation during the 1990s that may have been driven by a PDO regime change.

**Water column changes**

Many of the presentations and much of the discussion in TG 2 on changes in the biogeochemistry of the water column focused on the general observation that dissolved oxygen seems to have decreased in the thermocline over large regions of the North Pacific in the last few decades. The apparent increase in the consumption of oxygen resulting from the decomposition of organic matter could stem from either a slowdown in the meridional circulation or an increase in organic matter fluxes from the euphotic zone. Modeling work conducted in this area suggests that changes in circulation are generally sufficient to account for the observed changes, but additional studies are needed to confirm this. Decomposition of organic matter increases dissolved inorganic carbon (DIC) while it consumes dissolved oxygen. The observed changes in DIC, however, are significantly larger than the changes expected based on Redfield stoichiometry suggesting that the anthropogenic signal is an important, identifiable component of the decadal DIC changes (e.g., Fig. 3).

**Fig. 2** pCO2 at SST in surface seawater during non–El Niño periods in the Niño 3.4 area (5°N to 5°S, 120°W to 170°W). The measured values are indicated with dots and the monthly mean values with open squares. The monthly values are used for estimating the decadal mean by linear regression: \(-0.9\pm1.3 \text{ µatm yr}^{-1}\) for the pre-phase shift decade and \(+1.8\pm0.7 \text{ µatm yr}^{-1}\) for the post-phase shift decade. The uncertainties are expressed in terms of 1 SD for six mean rates of change evaluated by using each of the phase shift years of 1987, 1988, 1989, 1990, 1991, and 1992 (adapted from Takahashi et al., 2003).

**Detecting climate change**

TG 3 was a cross-cutting group tasked with addressing the question of how to distinguish a climate change signal from natural variability. This question is extremely difficult to answer, particularly given the fact that our biogeochemical records tend to be much shorter than historical records of climate or fisheries. The group focused on outlining the questions that need to be considered and how to begin answering these questions.
- What are the observed magnitudes of natural variability?
- What are the anticipated magnitudes and patterns of change resulting from long-term climate change?
- When do we expect to be able to distinguish climate change from the natural variability?
- What is required to properly attribute observed changes to climate change (e.g., better constraint on effects of natural modes of variability)?

Although we cannot properly answer these questions at the moment, the outcomes of this workshop will help us to address the first two of these questions. Several complications in the North Pacific make detection of climate change difficult. High variability in the tropics, Bering Sea, and Kamchatka regions currently hinder our interpretation of long-term climate trends. With most data series collected since 1980, the recent shift in the Pacific Decadal Oscillation (PDO) complicates our ability to attribute observed changes to long-term climate change. Longer and less patchy time series data are essential, as well as the development of uniform detection approaches. Synthesis studies are needed for a wide variety of geochemically relevant parameters including DIC, alkalinity, oxygen and nutrients which may provide us with a better understanding of carbon speciation changes in the water column. We need to utilize models to provide a link between physical forcing mechanisms, water column changes and surface ocean expression. These studies will help us to better understand the physical, chemical and biological changes in the Pacific that will produce the major oceanic feedbacks for climate change. The group promoted the idea of adopting the formal detection and attribution approach for studying the ocean in a manner similar to the “optimal fingerprint analysis” approach that has been used for climate (e.g., Hasselmann, 1997). The group is developing a specific set of model sensitivity runs and data analyses that can be used to assess when a climate change signal will become detectable in the North Pacific. The protocols will be posted on the web and available for anyone that wishes to participate in this exercise. For more information on the workshop results and future directions, visit the workshop web site at http://www.pmel.noaa.gov/co2/NP/.

Conclusions

The model of the North Pacific Carbon Cycle Workshop promotes the level of collaboration necessary to address large-scale complex environmental issues that can benefit from the coordinated efforts of a variety of scientific perspectives. This workshop was much more than a meeting. It is the first step in a long-term framework for future studies of the North Pacific Ocean. One of the exciting aspects of this workshop was that it brought together an international contingent of researchers that had a common interest, but were not regularly collaborating. PICES has been a model organization for facilitating collaborations such as these and, hopefully, will continue to promote interdisciplinary studies. Understanding the carbon cycle in the North Pacific, however, only provides us with part of the picture. Global understanding of carbon cycling in the ocean and atmosphere, and ultimately, the detection of climate change, will depend on the propagation of collaborative research efforts like this one to other oceanic regions.
Collaboration and communication aids in establishing standard collection methods as well as the exchange and comparison of data and results. Our challenge for the next decade will be to continue to find ways to bring observationalists and modelers together to allow for greater synthesis of global data and results.

References


New and upcoming PICES publications


We are proud to announce that the widely anticipated PICES Report on Marine Ecosystems of the North Pacific is now published. It can also be downloaded from the PICES website. Simply follow the icon-link on the main page at www.pices.int.