



PICES Working Group 13: CO₂ in the North Pacific Ocean

Richard A. Feely¹, Yukihiro Nojiri², Andrew Dickson³,
Christopher L. Sabine¹, Marilyn F. Lamb¹ and T. Ono⁴



Abstract

The North Pacific Ocean is an important sink region for atmospheric carbon dioxide and, consequently, plays a significant role in controlling long-term fate of CO₂ on Earth. Some biogeochemical processes relating to the oceanic CO₂ system are peculiar to the North Pacific. Much of our understanding of the distribution and fate of anthropogenic CO₂ in the North Pacific stems from the high-quality DIC and total alkalinity data that were acquired as part of the WOCE/IGOFS Global CO₂ survey and subsequent cruises. This research was supported, in part, by the member nations of the North Pacific Marine Science Organization (PICES).

Over the past four years, PICES, through the activities of its Working Group 13, has played a major role in fostering international cooperation among member nations towards the integration and synthesis of the WHP/IGOFS global CO₂ survey data in the North Pacific. The goals of the working group were as follows:

- Review the present level of knowledge on the processes controlling CO₂ in the North Pacific, and identify the gaps and problems;
- Review the existing methodology of CO₂ measurements including the preparation of standards and reference materials, and advise on intercalibration and quality control procedures;
- Identify and encourage ongoing and planned national and international CO₂-related scientific programs in the North Pacific region, including long-term time-series observations, and
- In coordination with TCODE, identify available and suitable data sets on the oceanic CO₂ system and recommend the mechanisms of data and information exchange.

Here we summarize the research and technical activities that have been conducted by member nations of PICES Working Group 13 to synthesize CO₂ data in the North Pacific and provide a comprehensive picture of the distribution of anthropogenic CO₂ in the North Pacific.

Summary of PICES Working Group 13 activities (1998 - 2001)		
Year	Location	Working Group 13 Activity
October 98	Portland, Alaska	Working Group 13 Meeting
January 99	Trinidad, Japan	CO ₂ in the Ocean Symposium
April 99	Trinidad, Japan	IGOFS Intercomparison Workshop
October 99	Trinidad, Japan	Working Group 13 Meeting
October 99	Trinidad, Japan	TALK Intercomparison Workshop
October 99	Trinidad, Japan	CO ₂ Data Symposium
October 99	Trinidad, Japan	Working Group 13 Meeting
January 01	Trinidad, Japan	CO ₂ Data Symposium
August 01	Trinidad, Japan	CO ₂ Data Symposium
October 01	Trinidad, Japan	CO ₂ Data Symposium

Members of PICES Working Group 13		
Name	Affiliation	Country
Richard A. Feely (Co-Chairman)	NOAA/PMEL, University of Washington	USA
Yukihiro Nojiri (Co-Chairman)	Yokohama Institute for Environmental Studies	Japan
Andrew Dickson	University of California, San Diego	USA
Marilyn F. Lamb	NOAA/PMEL, University of Washington	USA
Christopher L. Sabine	NOAA/PMEL, University of Washington	USA
David C. Johnson	NOAA/PMEL, University of Washington	USA
Kenji Taniuchi	NOAA/PMEL, University of Washington	USA
Kenji Taniuchi	NOAA/PMEL, University of Washington	USA
Kenji Taniuchi	NOAA/PMEL, University of Washington	USA
Kenji Taniuchi	NOAA/PMEL, University of Washington	USA

Synthesis of the WHP/IGOFS Global CO₂ Survey Data in the North Pacific

Between 1991 and 1999, carbon system measurements were made on twenty-five WOCE/IGOFS cruises in the North Pacific Ocean by investigators from 9 different laboratories and 3 countries. These data are an important

asset to the scientific community investigating biogeochemical cycling of carbon species in the oceans, and also provide a baseline against which future changes in ocean geochemistry can be assessed. At least two of the four measurable ocean carbon parameters (DIC, TALK, fCO₂, and pH) were analyzed on almost all cruises. The goal of this work was to assess the quality of the North Pacific carbon survey data and to make recommendations for generating a unified data set that is consistent between cruises (Feely et al., 2003). Several different lines of evidence were used to examine the consistency including comparison of calibration techniques, results from certified reference material analyses, precision of at-sea replicate analyses, agreement between shipboard analyses and replicate shore based analyses, comparison of deep water values at locations where two or more cruises overlapped or crossed, consistency with other hydrographic parameters, and internal consistency with multiple carbon parameter measurements. In order to develop an accurate, consistently unified data set, some adjustments are necessary. A summary of the recommended adjustments is given below.

Summary of final recommended adjustments for DIC and TALK for the North Pacific WOCE/IGOFS CO₂ survey cruises.

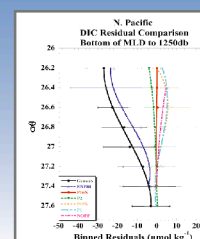
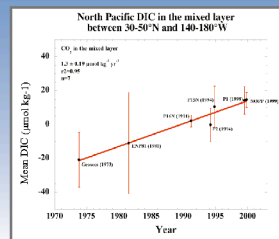
Recommended Adjustments	P14N	P14SLS	EQ92	P16N	P17C	P17N	P18	P1	P2
DIC (μmol kg ⁻¹)	NA	NA	NA	+4	NA	-7	NA	NA	-4
TALK (μmol kg ⁻¹)	NA	NA	NA	Calculated	-9	-12	NA	NA	+14

NA=No adjustment recommended
ND=No data reported

Temporal Variations in Anthropogenic Carbon Accumulation

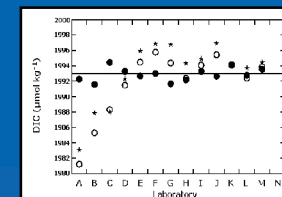
Multi-parameter Linear Regression (MLR) analysis was employed to estimate the anthropogenic CO₂ increase in the North Pacific from data collected between 1973 and 1999. In this procedure, a statistical model used salinity, θ, AOU, silicate (Si(OH)₄), and phosphate (PO₄) to predict DIC. The area chosen for this study was between 30-50°N, and 140-180°W. Data from all cruises within that region was used where high quality DIC data, along with other hydrographic parameters, was available throughout the water column (GEOSecs, NOAA ENP81, WHPs P16N, P15N, P2, P1, and NOPP).

Using P16N as a reference, the results of the MLR analysis show an estimated CO₂ uptake rate through the mixed layer of $1.3 \pm 0.2 \mu\text{mol DIC kg}^{-1} \text{ yr}^{-1}$ in the North Pacific. The estimated uptake of CO₂ below the MLD was determined to be $0.62 \pm 0.13 \mu\text{mol kg}^{-1} \text{ yr}^{-1}$. The total integrated CO₂ uptake from the surface to 1250db is estimated to be approximately $1.1 \pm 0.2 \text{ mol C m}^{-2} \text{ yr}^{-1}$.



Results of DIC and TALK Inter-comparison Studies for PICES Working Group 13

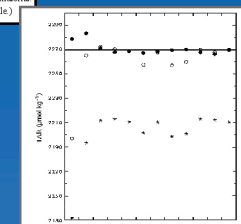
One of the first questions asked of analytical measurements is: how reliable are they? This was a key concern of the PICES Working Group 13 which desired that measurements made at different times, by different investigators, from different laboratories in the various PICES nations, be comparable and correct. In order to answer this key question, intercomparisons for DIC and TALK were conducted amongst the PICES laboratories. Four kinds of samples, based on natural seawater, were distributed to the participating laboratories: a Certified Reference Material (CRM) prepared at SIO, two unknown surface seawater samples, and an unknown deep sea water sample. The samples were analyzed, and workshops were held to discuss the results.



Results from 1999 analyses of DIC. Asterisks are measurements on the reference material (CRM45), open circles the values measured on the PICES test sample (CRM46). The closed circles are the values obtained for the PICES test sample after "calibration" with the reference material. (The horizontal line is the "true" values for the PICES test sample.)

For DIC, the results were very encouraging. After the values were corrected to a common calibration scale (CRM), the agreement between the various laboratories was $\pm 2 \mu\text{mol kg}^{-1}$ (see figure to left).

For TALK, the majority of the results (10 laboratories out of 12) were within a range of $5 \mu\text{mol kg}^{-1}$ (see figure below), after adjustment to the CRM.



Results from 2000 analyses of TALK. Asterisks are measurements on the reference material (CRM45), open circles the values measured on the PICES test sample (CRM46). The closed circles are the values obtained for the PICES test sample after "calibration" with the reference material. (The horizontal line is the "true" values for the PICES test sample.)

Conclusions

The future of PICES will involve support for the coordination of repeat measurements of carbon system parameters, tracers, hydrography and biological parameters at time-series stations and along repeat sections of the WOCE/IGOFS Global CO₂ survey. In addition, PICES will continue to support synthesis activities for carbon system parameters from these regional studies and foster integrated studies between the marginal seas and the open North Pacific. Through the new PICES Working Group 17, PICES will continue to support inter-laboratory method comparisons to assure future measurement quality and encourage the availability of suitable reference materials. PICES will also continue to sponsor symposiums and/or annual meeting sessions on the impacts of climate change on the carbon cycle in the North Pacific Ocean.

References

Feely, R.A., Y. Nojiri, A. Dickson, C.L. Sabine, M.F. Lamb and T. Ono, PICES Working Group 13 Final Report. CO₂ in the North Pacific Ocean. North Pacific Marine Science Organization (PICES) (Submitted for publication.)

¹NOAA/Pacific Marine Environmental Laboratory, 7600 Sandpoint WayNE, Seattle, WA 98115 USA

feely@pmel.noaa.gov <http://www.pmel.noaa.gov/co2/>

²National Institute for Environmental Studies, Tsurumi, Tokyo, Japan

³Stamps Institution of Oceanography, 9500 Gilman Drive, La Jolla, CA USA

⁴Hokkaido National Fisheries Research Institute, 116 Katsurakoi, Kushiro, Japan