CDIAC data management and archival support for a high-frequency atmospheric and seawater pCO_2 data set from 14 open ocean moorings

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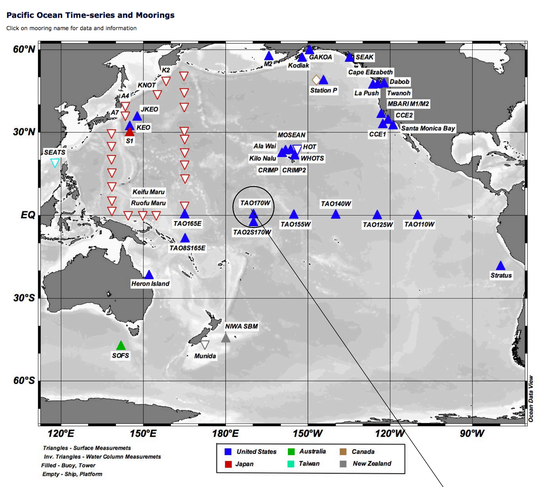
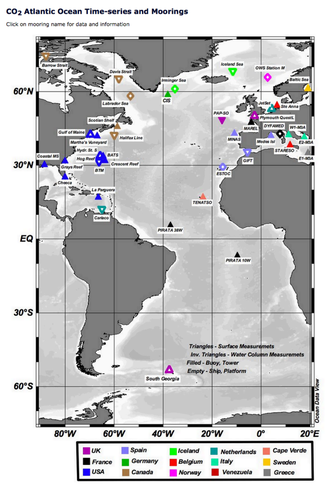
1. Introduction

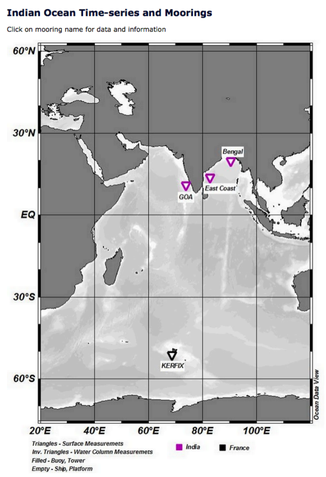
Rising atmospheric carbon dioxide (CO_2) and climate change are increasing ocean temperatures and affecting ocean chemistry (e.g., ocean acidification). Monitoring these important changes using ships and other platforms generates large amounts of data from heterogeneous sources. Since its inception in 1993, when it became a member of the DOE/NOAA Ocean Carbon Science Team engaged in the World Ocean Circulation Experiment (WOCE), the CDIAC Ocean Carbon Data Management Project has been organizing, quality assuring, documenting, archiving and distributing ocean carbon-related data collected via a number of U.S. and international ocean-observing programs. CDIAC's ocean carbon data collection includes discrete and underway measurements from a variety of platforms (e.g., research ships, commercial ships, buoys) in all oceans from the surface to seafloor. One important project at CDIAC is the data management support for the Global CO_2 Time-series and Moorings Project. This poster describes the collaboration between NOAA/PMEL Mooring group and CDIAC in the data management and archival of a high-frequency atmospheric and seawater pCO_2 data from 14 open ocean sites using moored autonomous systems. Advancements in the ocean carbon observation network over the last decade, such as the development and deployment of Moored Autonomous pCO_2 ($MAPCO_2$) systems, have dramatically improved our ability to characterize ocean climate, sea-air gas exchange, and biogeochemical processes. The Moored Autonomous pCO_2 ($MAPCO_2$) system provides high-resolution surface seawater and atmospheric CO_2 data that can help us understand inter-annual, seasonal, and sub-seasonal dynamics and provide constrains on the impact of short-term biogeochemical variability on CO_2 fluxes. CDIAC NDP-092 provides a description of the data as well as the methods and data quality control involved in developing an open-ocean $MAPCO_2$ data set including over 100,000 individual atmospheric and seawater pCO_2 measurements on 14 surface buoys from 2004 through 2011. The climate-quality data provided by the $MAPCO_2$ have allowed for the establishment of open-ocean observatories to track surface ocean pCO_2 changes around the globe. Data are available at doi:10.3334/CDIAC/OTG.TSM_NDP092

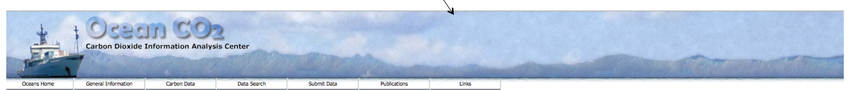
2. CDIAC Global CO_2 Time-series and Moorings Project

The international groups from 18 countries have mounted sensors on moored buoys to provide high-resolution time-series measurements of atmospheric boundary layer and surface ocean CO_2 partial pressure (pCO_2). The CO_2 Time-series and Moorings Project is also coordinated by IOCCP. The high-quality measurements of carbon-related parameters from the Moorings are available via CDIAC Time-series and Moorings Project Web site http://cdiac.ornl.gov/oceans/Moorings/ The Moorings data are also searchable in CDIAC Ocean Mercury.









CO_2 Moorings and Time Series Project

Mooring TAO170W (Buoy Position: 0°N, 170°W)

Data Set Name	Graphics	Platform	Place	Period	Carbon-related data Contributor	Variables in Data Set	Data	Project Link
TAO170W 2005-2011	See real time data graphics for this mooring	TAO170W	Equatorial Pacific Ocean	July 2005 - February 2011	Adrienne Sutton; Chris Sabine / PMEL	SST, SSS, Atm. press, xCO_2 water, xCO_2 air, fCO_2 water, fCO_2 air	Data files Metadata	PMEL Buoys and Autonomous Systems

Index of /ftp/oceans/Moorings/TAO170W_0N

Name	Last modified	Size	Description
Parent Directory		-	
TAO170W_0N_Aug2008_Jun2009.csv	05-Sep-2013 15:39	284K	
TAO170W_0N_Aug2008_Jun2009_Meta.pdf	05-Sep-2013 15:42	129K	
TAO170W_0N_Feb2010_Feb2011.csv	24-Sep-2013 18:11	570K	
TAO170W_0N_Feb2010_Feb2011_QFLog.csv	24-Sep-2013 18:11	48K	
TAO170W_0N_Jul2005_Jun2006.csv	21-Dec-2010 09:13	353K	
TAO170W_0N_Jul2005_Jun2006_Meta.pdf	10-Nov-2010 11:12	148K	
TAO170W_0N_Jul2007_Aug2008.csv	05-Sep-2013 15:40	381K	
TAO170W_0N_Jul2007_Aug2008_Meta.pdf	05-Sep-2013 15:43	200K	
TAO170W_0N_Jun2009_Dec2009.csv	05-Sep-2013 15:40	194K	
TAO170W_0N_Jun2009_Dec2009_Meta.pdf	05-Sep-2013 15:44	116K	

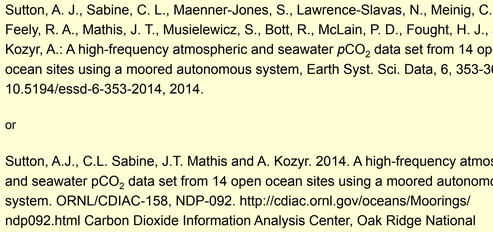
Please cite this data set as:

Sutton, A., C. Sabine, S. Maenner, S. Musielewicz, R. Bott, and J. Osborne. 2010. High-resolution ocean pCO2 time-series measurements from mooring TAO170W. http://cdiac.esd.ornl.gov/ftp/oceans/Moorings/TAO170W_0N/. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee. doi: 10.3334/CDIAC/OTG.TSM_TAO170W_0N

The clickable maps on the website allow users to find and download the data from Moorings and Time Series sites. Each Mooring data set sent to CDIAC for archival is separated by the mooring's deployment times. Each deployment data file is archived along with deployment metadata Mercury XML file or deployment QFLog file. Each Mooring data set is published at CDIAC with the publication reference and DOI.

3. NOAA/PMEL open-ocean moorings in the $MAPCO_2$ data set

In 2004, the National Oceanographic and Atmospheric Administration's (NOAA) Pacific Marine Environmental Laboratory (PMEL) began to work with the Monterey Bay Aquarium Research Institute to improve the accuracy, reliability, and ease of use of an early moored pCO_2 system developed for buoys in the equatorial Pacific. Like the well-established underway pCO_2 method (Wanninkhof and Thoning, 1993; Feely et al., 1998; Pierrot et al., 2009), this early moored system described by Friederich et al. (1995) and the $MAPCO_2$ system described by Sutton et al. (2014) combine an air–water equilibrator with an infrared (IR) analyzer for CO_2 gas detection. In 2009, the $MAPCO_2$ technology was transferred to Battelle Memorial Institute and is commercially available as the Sealogy® pCO_2 monitoring system. This system is now accessible to the larger scientific community and deployed at over 50 locations in open-ocean, coastal, and coral reef environments, including on NOAA's global moored CO_2 network (www.pmel.noaa.gov/co2/story/Buoys+and+ Autonomous+Systems) and Australia's Integrated Marine Observing System (http://imos.org.au).



Location of NOAA/PMEL open-ocean moorings in the $MAPCO_2$ data set. Inner circle color illustrates the mean ΔpCO_2 of the finalized data at that location. Inner circle size is relative to the environmental variability in the time series defined here as the standard deviation of seawater pCO_2 values. The outer ring shows the proportion of environmental variability in seawater pCO_2 due to the seasonal cycle (black) and inter-annual variability (gray). Seasonal variability is defined as the mean seasonal peak amplitude, and inter-annual variability is the average difference of annual mean values. Seasonal and inter-annual variability cannot be quantified at JKEO with a time series of < 1 year and is represented here by an outer ring with no color.

Mooring Name	Location	Deployment Start Date	Deployment End Date	Total n[1] of measurements	Data Link	Metadata Link
MOSEAN/WHOTS	22.8°N, 158.1°W	12/19/2004 05/29/2005 06/18/2006 01/28/2007 06/26/2007 06/05/2008 07/11/2009 08/01/2010	05/23/2005 01/20/2006 12/21/2006 07/30/2007 06/05/2008 02/12/2009 08/01/2010 07/13/2011	17645	Data	MOSEAN Metadata WHOTS Metadata
BTM	32°N, 64°W	10/02/2005 07/14/2006 03/13/2007	07/03/2006 03/02/2007 10/01/2007	5354	Data	Metadata
Papa	50.12°N, 144.83°W	06/08/2007 06/11/2008 06/13/2009 06/16/2010	06/10/2008 11/1/2008 03/27/2010 06/13/2011	9235	Data	Metadata
KEO	32.3°N, 144.5°E	09/28/2007 09/13/2008 09/05/2009 09/30/2010	08/08/2008 09/04/2009 09/24/2010 12/24/2010	9182	Data	Metadata
JKEO	37.9°N, 146.5°E	02/18/2007	10/03/2007	1837	Data	Metadata
CCE1	33.5°N, 122.5°W	11/11/2008 05/19/2009 12/15/2009 09/02/2010	02/06/2009 12/14/2009 09/01/2010 10/11/2010	4775	Data	Metadata
Stratus	20°N, 85°W	10/16/2006 10/27/2007 10/26/2008 01/19/2010	10/29/2007 10/27/2008 01/18/2010 07/07/2010	10889	Data	Metadata
TAO110W	0°N, 110°W	09/19/2009 03/15/2010 07/22/2010	11/03/2009 07/14/2010 10/28/2010	2148	Data	Metadata
TAO125W	0.2°S, 124.4°W	05/08/2004 03/16/2005 01/31/200 04/13/2007 10/16/2007 11/13/2008 04/22/2010	12/20/2004 09/15/2005 07/08/2006 07/17/2007 11/10/2008 10/21/2009 11/06/2010	13609	Data	Metadata
TAO140W	0°N, 140°W	05/23/2004 09/13/2004 03/02/2005 01/17/2006 09/14/2006 05/31/2007 05/10/2008 09/04/2009 11/26/2010	09/12/2004 03/01/2005 09/22/2005 05/14/2006 12/18/2006 11/20/2007 09/03/2009 01/30/2010 03/23/2011	14276	Data	Metadata
TAO155W	0°N, 155°W	01/13/2010	08/25/2010	1791	Data	Metadata
TAO170W	0°N, 170°W	07/04/2005 07/31/2007 08/26/2008 06/02/2009 02/04/2010	06/23/2006 08/13/2008 06/01/2009 12/12/2009 02/04/2011	12528	Data	Metadata
TAO165E	0°N, 165°E	02/23/2010	02/27/2011	2955	Data	Metadata
TAO165E8S	8°S, 165°E	06/22/2009 10/18/2010	09/19/2010 11/15/2011	6720	Data	Metadata

Table 1. Surface ocean pCO_2 mooring deployments including in this data set. Links are to each mooring data archive page at CDIAC.

Variable name	Description	Units	Equation (if applicable)
Mooring	mooring name as shown in Fig. 2 and Table 1	character string	
Latitude	average latitude during deployment	decimal degrees	
Longitude	average longitude during deployment	decimal degrees	
Date	date of measurement in UTC	MM/DD/YYYY	
Time	time of measurement in UTC	HH:MM	
xCO2_SW_wet	mole fraction of carbon dioxide in air in equilibrium with surface seawater at SST and humidity	μmol mol^{-1}	
xCO2_SW_QF	primary flag associated with seawater xCO_2 measurement	WOCE standards[a]	
H2O_SW	mole fraction of water in gas from equilibrator	μmol mol^{-1}	
xCO2_Air_wet	mole fraction of carbon dioxide in air at ~ 1.5 m above the sea surface at sample humidity	μmol mol^{-1}	
xCO2_SW_QF	primary flag associated with air xCO_2 measurement	WOCE standards[a]	
H2O_Air	mole fraction of water in air	μmol mol^{-1}	
Licor_Atm_Pressure	atmospheric pressure at ~ 1.5 m above the sea surface	hPa	
Licor_Temp	licor temperature	°C	
Percent_O2[b]	% oxygen in surface seawater divided by % oxygen in air at ~ 1.5 m above the sea surface	%	
SST[c]	sea surface temperature	°C	
SSS[c]	sea surface salinity		
xCO2_SW_dry	mole fraction of carbon dioxide in dry air in equilibrium with surface seawater	μmol mol^{-1}	1
xCO2_Air_dry	mole fraction of carbon dioxide in dry air at ~ 1.5 m above the sea surface	μmol mol^{-1}	1
fCO2_SW_sat	fugacity of carbon dioxide in wet air (100 % humidity) in equilibrium with surface seawater	μatm	4
fCO2_Air_sat	fugacity of carbon dioxide in wet air (100 % humidity) at ~ 1.5 m above the sea surface	μatm	4
dfCO2	fCO2_SW_sat – fCO2_Air_sat	μatm	
pCO2_SW_sat[d]	partial pressure of carbon dioxide in wet air (100 % humidity) in equilibrium with surface seawater	μatm	5
pCO2_Air_sat[d]	partial pressure of carbon dioxide in wet air (100 % humidity) at ~ 1.5 m above the sea surface	μatm	5
dpCO2[d]	pCO2_SW_sat – pCO2_Air_sat	μatm	

Notes: [a] SOCAT flags used in this data set: 2 = acceptable measurement; 3 = questionable measurement; 4 = bad measurement (note: bad data values are reported in the final data file submitted to CDIAC prior to QC software upgrade in June 2013 but reported as –999 in files submitted after the upgrade). [b] Oxygen measured in the $MAPCO_2$ system is exposed to air and likely modified within the system prior to measurement. Rapid changes in oxygen are not properly captured using this method. This data should not be used as a quantitative measure of oxygen. [c] Usually measured by other academic partners at each site. See metadata for each deployment for details on SST and SSS measurements. [d] $pCO2$ only presented in data sets submitted to CDIAC after June 2013 when QC software was upgraded to include this calculation. Data users of earlier data sets can calculate $pCO2$ as defined in Eq. (4).

Table 2. Final data variable names and descriptions.

Please cite this data set as:

Sutton, A. J., Sabine, C. L., Maenner-Jones, S., Lawrence-Slavas, N., Meinig, C., Feely, R. A., Mathis, J. T., Musielewicz, S., Bott, R., McLain, P. D., Fought, H. J., and Kozyr, A.: A high-frequency atmospheric and seawater pCO_2 data set from 14 open-ocean sites using a moored autonomous system, Earth Syst. Sci. Data, 6, 353-366, doi: 10.5194/essd-6-353-2014, 2014.

or

Sutton, A.J., C.L. Sabine, J.T. Mathis and A. Kozyr. 2014. A high-frequency atmospheric and seawater pCO_2 data set from 14 open ocean sites using a moored autonomous system. ORNL/CDIAC-158, NDP-092. http://cdiac.ornl.gov/oceans/Moorings/ndp092.html Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee. doi: 10.3334/CDIAC/OTG.TSM_NDP092

Conclusions

Mooring observations can play a critical role in improving our ability to model, understand, and describe the ocean carbon cycle on all timescales. In particular, time series from remote, data-sparse areas of the ocean collected on moorings fulfill a unique niche by providing the high-resolution data necessary to explore questions about short-term variability at fixed locations. Here we provide a data set of 3, hourly surface seawater and marine boundary layer atmospheric pCO_2 observations on 14 open-ocean moorings in the Pacific and Atlantic from 2004 to 2011. When using the in situ and post-calibration methods described here, overall uncertainty for the $MAPCO_2$ data is < 2 µatm for seawater pCO_2 and < 1 µatm for air pCO_2, making the $MAPCO_2$ system a climate-quality method for tracking surface ocean pCO_2. These types of sustained, temporally resolved observations allow us to improve our understanding of the role of shorter-term variability and key biogeochemical processes on the global carbon system. Potential uses of these data to inform our understanding of a changing ocean include investigating high-frequency variability in surface ocean biogeochemistry, developing seasonal CO_2 flux maps for the global oceans (e.g., Takahashi climatology and SOCAT), studying ocean acidification, and evaluating regional and global carbon models.

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