

Hydrographic CO₂ Data at Station KNOT

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1. Introduction

Anthropogenic CO₂ was taken up by the global ocean at a rate of 2.2 ± 0.4 Pg C yr⁻¹ during the 1990s (Denman et al., 2007). The most fundamental and reliable approach to the direct detection of the CO₂ uptake rate and its variation is to make more accurate and longer time-series observations at fixed stations, for example, station ALOHA in the subtropical North Pacific Ocean (e.g., Dore et al., 2003), BATS in the subtropical western North Atlantic Ocean (e.g., Bates et al., 2002), ESTOC in the subtropical eastern North Atlantic Ocean (e.g., Santana-Casiano et al., 2007), Ocean Station Papa (OSP) in the subarctic eastern North Pacific (e.g., Wong and Chan, 1991), and stations KNOT (Kyodo western North Pacific Ocean Time-series (Kyodo means "collaborative" in Japanese); 44°N, 155°E) (e.g., Tsurushima et al., 2002) and K2 (47°N, 160°E) (e.g., Honda et al., 2006) in the subarctic western North Pacific Ocean (Fig. 1). Time-series observations are essential to understanding temporal variation of dissolved inorganic carbon (DIC) in the ocean.

At least annually since 1997, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has conducted hydrographic observations at KNOT or K2 in the subarctic western North Pacific (Fig. 1). Station KNOT is located in the western subarctic gyre and just north of the Subpolar Front (Fig. 1) and has been a Japanese JGOFS time-series station since June 1998 (e.g., Tsurushima et al., 2002). Hydrographic studies in this region were also conducted by other organizations between 1992 and 2003 (e.g., Wakita et al., 2005; Tsurushima et al., 2002).

In this report, we compile data obtained at station KNOT by JAMSTEC and others and correct the systematic errors in the data, in order to investigate the temporal variation of DIC and related properties (total alkalinity (TA), temperature, salinity, oxygen, and nutrients (silicate, nitrate, nitrite, ammonium, and phosphate)) in the subarctic western North Pacific. Using this compiled KNOT data in addition to K2 data (Watanabe et al., 2007), the temporal variation of DIC and related properties in the subarctic western North Pacific were reported in Wakita et al. (2010).

Masahide Wakita, Shuichi Watanabe, Akihiko Murata, Makio Honda
Japan Agency for Marine-Earth Science and technology (JAMSTEC)

Nobuo Tsurushima

National Institute of Advanced Industrial Science and Technology

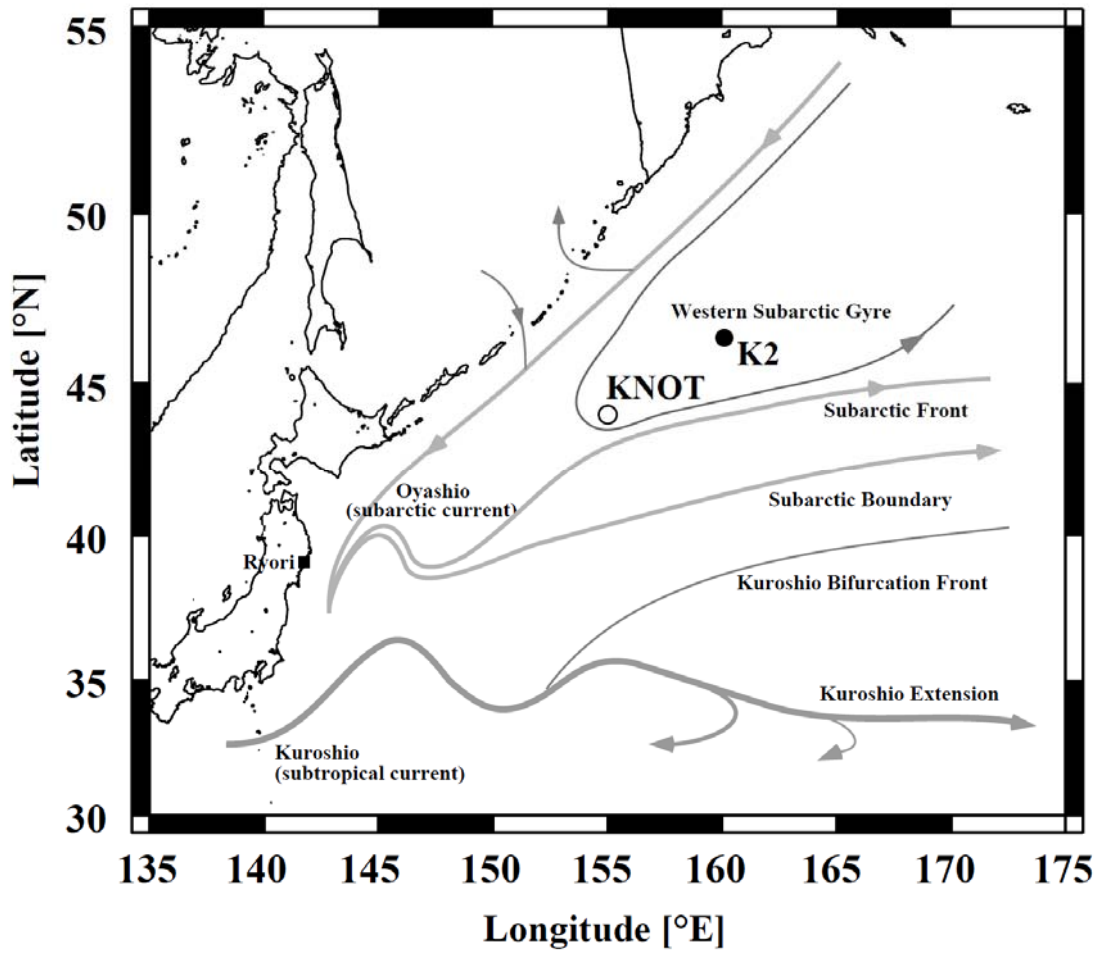


Figure 1. Time-series stations and main ocean currents in the subarctic western North Pacific. The Kuroshio and Oyashio are the subtropical and subarctic western boundary currents in this region, respectively.

2. Data sources and analyses

We prepared a set of data to investigate long-term climate change in the subarctic western North Pacific. All data were collected from the observations at the Japanese time-series stations KNOT from 1992 to 2008, which were made in 61 CTD casts on 44 cruises at KNOT; these cruises were made by 7 research vessels: T/S *Hokusei Maru* (Hokkaido Univ.), T/S *Oshoro Maru* (Hokkaido Univ.), R/V *Bosei Maru* (Tokai Univ.), R/V *Hakuho Maru* (Tokyo Univ.), R/V *Kaiyo Maru* (Japan Fisheries Agency), R/V *Hakurei No.2* (Metal Mining Agency of Japan), R/V *Natsushima* (JAMSTEC), and R/V *Mirai* (JAMSTEC) (Table 1). We merged the KNOT data obtained by JAMSTEC cruises with those published by Wakita et al. (2005), Tsurushima et al. (2002) and Tsurushima et al. (2004) for T/S *Hokusei Maru*, T/S *Oshoro Maru*, R/V *Bosei Maru*, and R/V *Hakuho Maru* cruises. In addition, we added the oceanic physical and chemical data from KNOT and K2 collected as part of WOCE-P1 (1999) (http://whpo.ucsd.edu/data_access/show_cruise?ExpoCode=49KA199905_1) and WESTCOSMIC (1998, 1999) (<http://www.kanso.co.jp/ocean/html-doc/english/top1.html>). Approximately 50% of all observations were done from the R/V *Mirai* and R/V *Natsushima* from JAMSTEC.

The analytical methods of DIC and related properties (total alkalinity (TA), oxygen, and nutrients (silicate, nitrate, nitrite, ammonium, and phosphate)) are listed in detail in Table 1. The cruise report during R/V *Mirai* and R/V *Natsushima* in Table 1 are available from the JAMSTEC data web site (<http://www.godac.jamstec.go.jp/cruisedata/e/index.html>). DIC and TA were measured by using coulometric and potentiometric techniques in JAMSTEC cruises, respectively. Measurement of TA since 2007 was made using a spectrophotometric system. The precision of both DIC and TA was $\pm 0.1\%$ or better from duplicate determinations. TA during R/V *Kaiyo Maru* (May 1999), T/S *Hokusei Maru* cruise (July 2000 to July 2001) and T/S *Oshoro Maru* cruise (June 2002) were determined by the improved single-point titration method, with precision of $\pm 0.2\%$ from duplicate determinations (Wakita et al., 2005, WOCE-P1). The DIC and TA values were determined with calibration against certified reference material provided by Prof. A. G. Dickson (Scripps Institution of Oceanography). The dissolved oxygen (DO) and nutrient concentrations since 1997 were measured with an automatic photometric titrator and a continuous flow analyzer, respectively (Table 1).

3. Corrections of systematic errors among cruises

The values of DIC, TA, DO, and nutrients (silicate, phosphate, and nitrate) had systematic errors among cruises, because the analytical methods used for these determinations (Table 1), and the precision and standards for analysis varied slightly from cruise to cruise. These systematic errors probably derive from the standardization because of the absence of a common reference material. DIC data for 1992 to 1997 during T/S *Hokusei Maru* cruise by Wakita et al. (2005) were not calibrated against certified reference material. Silicate during R/V *Mirai* cruises before 2006 (MR03-K01, MR04-02, MR04-04, MR04-06, MR05-01 and MR05-04) and since 2006 (MR06-03, MR07-01, MR07-05 and MR08-05) were measured based on standard solution made by Kanto Kagaku and Merck, respectively. However, because factors of standard solutions determined by Kanto Kagaku were found to be different from those by Merck, silicate data during R/V *Mirai* cruises from 2003 to 2005 were corrected based on standard solution by Merck (Table 2).

To investigate the temporal variation of chemical properties from the winter mixed layer to intermediate water, we corrected the systematic errors by assuming that ocean chemical properties in the North Pacific Deep Water (NPDW) were constant in our study area from 1992 to 2008 (Wakita et al., 2005; Watanabe et al., 2007). NPDW was defined as the water mass between $27.69\sigma_\theta$ (~2000 db) and $27.77\sigma_\theta$ (~3500 db), because chlorofluorocarbons were not detected below $27.69\sigma_\theta$ (Watanabe et al., 2001) and the bottom water deeper than the NPDW in the western North Pacific expanding from the Samoan Passage is characterized by potential temperature (θ) lower than $1.2\text{ }^\circ\text{C}$ ($\approx 27.77\sigma_\theta$) (Johnson et al., 1994). Because the residence time of NPDW is ~500 years (Stuiver et al., 1983), we can assume that the NPDW did not change significantly from 1992 to 2008 for the purpose of investigating the temporal variations in shallower waters.

The values of the correction factors were -6 to $19\text{ }\mu\text{mol kg}^{-1}$ for DIC, -15 to $8\text{ }\mu\text{mol kg}^{-1}$ for TA, 0.82 – 0.97 for DO, 0.95 – 1.09 for silicate, 0.98 – 1.12 for phosphate, and 0.96 – 1.04 for nitrate (Table 2). We corrected the values of these properties at the isopycnal surfaces of NPDW ($\sigma_\theta = 27.69, 27.70, 27.71, 27.72, 27.73, 27.74, 27.75, 27.76,$ and 27.77) to fit the mean observed values from 2006 to 2008 at the same isopycnal surfaces. The values at each of these isopycnal surfaces were obtained by linear interpolation. The minimum systematic errors were $\pm 0.2\%$ for DIC and TA, $\pm 3\%$ for DO, and $\pm 1\%$ for nutrients. The standard deviations of DIC, TA, DO, silicate, phosphate, and nitrate values in NPDW after the corrections were estimated to be $\pm 1.9, \pm 1.3, \pm 1.5, \pm 1.0, \pm 0.01,$ and $\pm 0.1\text{ }\mu\text{mol kg}^{-1}$, respectively.

Table 2. Correction factor of DO, DIC, TA, Silicate, Phosphate and Nitrate from 1992 to 2008 at KNOT

Cruise name ^a	DO (multiplicative)	DIC (additive)	TA (additive)	Silicate (multiplicative)	Phosphate (multiplicative)	Nitrate (multiplicative)
HO92-2	n.a. ^b	19.0	n.d. ^c	n.d. ^c	n.d. ^c	n.d. ^c
HO95-2	n.a. ^b	10.0	n.d. ^c	n.d. ^c	n.d. ^c	n.d. ^c
HO97-3	0.823	10.0	n.d. ^c	0.953	1.017	n.d. ^c
MR97-K02	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	1.042	n.a. ^b
HO98-1	0.961	n.a. ^b	-10.9	0.924	1.027	n.a. ^b
HO98-2	0.970	-5.7	-10.1	0.980	n.a. ^b	n.a. ^b
HO98-3	n.a. ^b	n.a. ^b	-14.6	0.982	n.a. ^b	1.013
HO98-3	n.a. ^b	n.a. ^b	-15.7	0.992	n.a. ^b	n.a. ^b
NH98	n.a. ^b	-4.2	-6.0	n.a. ^b	n.a. ^b	1.020
BO98-22	0.965	n.a. ^b	-12.8	0.965	0.986	n.a. ^b
BO98-22	0.965	n.a. ^b	-14.9	0.973	n.a. ^b	n.a. ^b
MR98-K01	n.a. ^b	n.a. ^b	n.a. ^b	0.991	1.015	n.a. ^b
MR98-K01	n.a. ^b	-3.7	-13.7	n.d. ^c	n.d. ^c	n.d. ^c
MR98-K01	n.a. ^b	n.a. ^b	4.4	n.a. ^b	1.014	1.010
MR99-K02	n.a. ^b	n.a. ^b	n.a. ^b	0.976	0.983	n.a. ^b
MR99-K02	n.a. ^b	n.a. ^b	n.a. ^b	0.976	n.a. ^b	n.a. ^b
MR99-K02	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	0.984	n.a. ^b
MR99-K02	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	0.986	1.021
KA99-01	n.a. ^b	10.3	n.a. ^b	n.a. ^b	1.119	1.030
HO99-1	0.959	4.3	-13.7	n.a. ^b	n.a. ^b	0.985
HO99-2	0.947	n.a. ^b	-11.7	n.a. ^b	1.019	n.a. ^b
HO99-3	n.a. ^b	n.a. ^b	-6.7	1.012	n.a. ^b	0.987
HO99-3	0.954	n.a. ^b	-11.3	0.974	1.018	n.a. ^b
NH99	n.a. ^b	-4.0	n.a. ^b	n.a. ^b	n.a. ^b	1.019
BO99-22	0.963	n.a. ^b	-11.2	0.985	1.032	0.986
BO99-22	0.954	n.a. ^b	-12.1	0.990	n.a. ^b	1.076
MR00-K01	n.a. ^b	n.a. ^b	-5.4	1.015	1.029	0.961
MR00-K01	n.a. ^b	n.a. ^b	-4.2	1.010	1.037	0.981
MR00-K03	n.a. ^b	n.a. ^b	-6.7	0.957	n.a. ^b	n.a. ^b
MR00-K03	n.a. ^b	n.a. ^b	-6.7	0.957	1.030	0.981
MR00-K03	n.a. ^b	n.a. ^b	-6.7	0.957	1.030	0.981
HO00-1	0.941	n.a. ^b	-13.3	0.988	1.024	n.a. ^b
HO00-2	0.903	6.4	-11.1	n.a. ^b	1.024	n.a. ^b
HO00-3B	n.d. ^c	n.a. ^b	-9.2	n.d. ^c	n.d. ^c	n.d. ^c
BO00-21	0.969	n.a. ^b	-10.4	n.a. ^b	1.034	1.010
BO00-21	0.969	n.a. ^b	-11.3	1.012	1.035	0.990
HO01-1	n.a. ^b	-6.3	n.a. ^b	n.d. ^c	n.d. ^c	n.d. ^c
MR01-K03	n.a. ^b	n.a. ^b	n.a. ^b	0.980	n.a. ^b	0.988
MR01-K03	n.a. ^b	n.a. ^b	n.a. ^b	0.981	n.a. ^b	n.a. ^b
HO01-3A	n.a. ^b	n.a. ^b	-8.3	n.d. ^c	n.d. ^c	n.d. ^c
OS02-01	n.a. ^b	11.4	-8.9	0.978	1.037	n.a. ^b
MR03-K01	n.a. ^b	n.a. ^b	n.a. ^b	0.987 ^d	1.029	n.a. ^b
OS-133	0.932	4.6	n.d. ^c	n.a. ^b	1.047	1.027
OS-135	0.939	n.a. ^b	n.d. ^c	n.d. ^c	n.d. ^c	n.d. ^c
OS-136	0.943	n.a. ^b	n.d. ^c	n.d. ^c	n.d. ^c	n.d. ^c
NT03-07	0.954	n.a. ^b	-10.5	1.018	1.019	1.015
OS-137	0.928	6.0	n.d. ^c	1.087	1.047	1.017
KH03-2	n.a. ^b	n.a. ^b	n.d. ^c	n.a. ^b	1.023	1.013
MR04-02	n.a. ^b	n.a. ^b	n.a. ^b	0.987 ^d	n.a. ^b	n.a. ^b
NT04-05	n.a. ^b	n.a. ^b	-10.4	n.a. ^b	1.018	1.012
MR04-04	n.a. ^b	n.a. ^b	-7.1	0.975 ^d	n.a. ^b	n.a. ^b
MR04-06	n.a. ^b	n.a. ^b	n.a. ^b	0.975 ^d	n.a. ^b	n.a. ^b
MR05-01	n.a. ^b	n.a. ^b	n.a. ^b	0.975 ^d	n.a. ^b	n.a. ^b
MR05-04	n.a. ^b	n.a. ^b	n.a. ^b	0.975 ^d	n.a. ^b	n.a. ^b
MR06-03	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b
MR06-03	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b
MR06-03	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b
MR07-01	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b
MR07-01	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b
MR07-05	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b
MR08-05	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b	n.a. ^b

^aThe ship name are also listed: HO = T/S Hokusei (Hokkaido Univ.), OS = T/S Oshoro (Hokkaido Univ.), NH = R/V Hakurei No.2 (Metal Mining Agency of Japan), BO = R/V Bosei (Tokai Univ.), KH = R/V Hakuho (Tokyo Univ.), KA = R/V Kaiyo (Japan Fisheries Agency), NT = R/V Natsushima (JAMSTEC), MR = R/V Mirai (JAMSTEC)

^bn.a. : no adjustment

^cn.d. : no data

^d: to see text

4. Future update of data and contact persons

We will continue to correction and update KNOT time-series observation data. These update data will be opened on the JAMSTEC data web site and CDIAC in future.

Contact Persons

Masahide Wakita (E-mail: mwakita@jamstec.go.jp)

Shuichi Watanabe (E-mail: swata@jamstec.go.jp)

Mutsu Institute for Oceanography

Japan Agency for Marine-Earth Science and Technology

690 Kitasekine, Sekine, Mutsu-city, Aomori 035-0022

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