Hydrographic CO_2 Data at Station K2

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Contents

1. Introduction

Anthropogenic CO_2 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 CO_2 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 and/or K2 in the subarctic western North Pacific (Fig. 1). Station K2 is located in the western subarctic gyre (Fig. 1) and has been a time-series station since 2001 by Mutsu Institute for Oceanography in JAMSTEC (e.g., Honda et al., 2006). Data sets from K2 from 1999 to 2006 (Watanabe et al., 2007) are published at the Carbon Dioxide Information and Analysis Center (http://cdiac.ornl.gov/) and the JAMSTEC data web site (http://www.godac.jamstec.go.jp/k2/index.html).

In this report, we add data obtained at station K2 by JAMSTEC since 2007 to the data from 1999 to 2006 (Watanabe et al., 2007) 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 K2 data in addition to KNOT data (Wakita et al., 2010), the temporal variation of DIC and related properties in the subarctic western North Pacific were discussed in Wakita et al., (2010).

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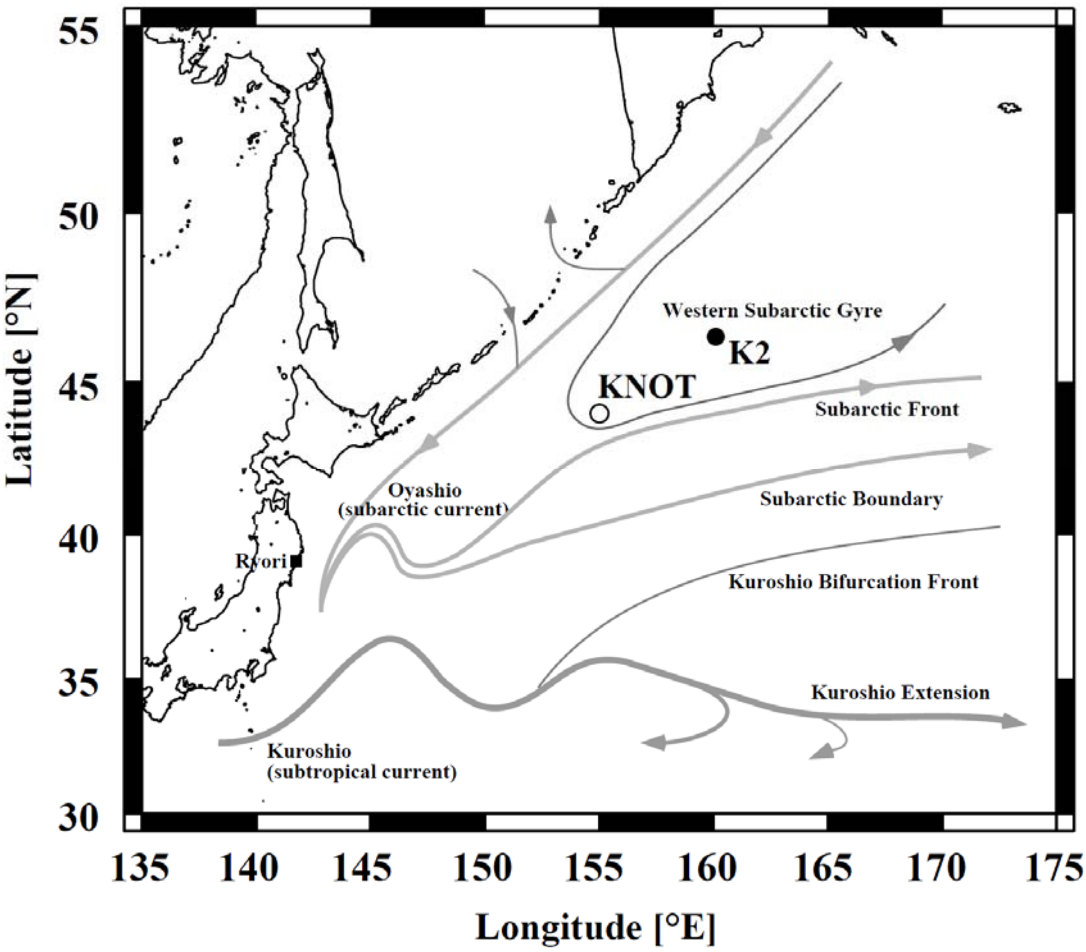

Figure 1. Time-series stations and main ocean currents in the subarctic western North Pacific. The Kuroshio and Oyashio are the subtropical and subarctic western boundary currents in this region, respectively.

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 station K2 from 1999 to 2008, which were made in 29 CTD casts on 15 cruises; these cruises were made by 3 research vessels: R/V *Kaiyo Maru* (Japan Fisheries Agency), R/V *Natsushima* (JAMSTEC), and R/V *Mirai* (JAMSTEC) (Table 1). We merged the K2 data obtained by JAMSTEC cruises since 2007 with those published by (Watanabe et al., 2007). In addition, we added the oceanic physical and chemical data from K2 collected as part of WOCE–P1 (1999) (http://whpo.ucsd.edu/data_access/show_cruise?ExpoCode=49KA199905_1).

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. Measurements of TA since 2007 were made using a spectrophotometric system. The precision of both DIC and TA was ± 0.1% or better from duplicate determinations. 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 concentration were measured with an automatic photometric titrator and a continuous flow analyzer, respectively (Table 1).

Table 1. Observations carried out from 1999 to 2008 at Station K2 and methods and instrumtents of DO, DIC, TA, nutrinets analyses.

Cruise name	Date	Maximum pressure of sampling [db]	DO	DIC	TA	Silicate Phosphate Nitrate	Reference
KA99-01	1999/05/28	Bottom	Winkler/auto･HIRAMA	Coulometry/UIC	Single point titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	WOCE-P1
MR01-K03	2001/06/10	Bottom	Winkler/auto･Metrohm	Coulometry/UIC･Nippon ANS	Potentiometric titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR01-K03 Cruise Report
MR01-K04	2001/09/07	Bottom	Winkler/auto･Metrohm	Coulometry/UIC･Nippon ANS	Potentiometric titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR01-K04 Cruise Report
MR02-K05	2002/10/21	Bottom	Winkler/auto･Metrohm	Coulometry/UIC･Nippon ANS	Potentiometric titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], Kawakami et al. [2007], MR02-K05 Cruise Report
MR03-K01	2003/02/25	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], Kawakami et al. [2007], MR03-K01 Cruise Report
NT03-07	2003/07/11	3500	Winkler/auto･Kimoto Electric	Coulometry/UIC･Kimoto Electric	Potentiometric titration/Kimoto Electric	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], Kawakami et al. [2007]
MR04-02	2004/04/07	3000	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], Kawakami et al. [2007], MR04-02 Cruise Report
NT04-05	2004/05/27	3500	Winkler/auto･Kimoto Electric	Coulometry/UIC･Kimoto Electric	Potentiometric titration/Kimoto Electric	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], Kawakami et al. [2007]
MR04-04	2004/08/16	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], Kawakami et al. [2007], MR04-04 Cruise Report
MR04-06	2004/10/20	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR04-06 Cruise Report
MR05-01	2005/03/04	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR05-01 Cruise Report
MR05-04	2005/09/24	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Radiometer	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR05-04 Cruise Report
MR06-03	2006/06/03	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/06/03	200	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/06/12	200	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/06/22	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/06/25	200	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/06/29	200	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/07/01	200	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/07/08	200	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/07/10	200	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/07/14	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR06-03	2006/07/16	200	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Potentiometric titration/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Watanabe et al. [2007], MR06-03 Cruise Report
MR07-05	2007/09/11	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Spectrophotometry/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Wakita et al. [2010], MR07-05 Cruise Report
MR07-05	2007/09/12	50	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Spectrophotometry/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Wakita et al. [2010], MR07-05 Cruise Report
MR07-05	2007/09/24	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Spectrophotometry/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Wakita et al. [2010], MR07-05 Cruise Report
MR07-05	2007/09/25	70	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Spectrophotometry/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Wakita et al. [2010], MR07-05 Cruise Report
MR08-05	2008/10/23	Bottom	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Spectrophotometry/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Wakita et al. [2010], MR08-05 Cruise Report
MR08-05	2008/10/26	50	Winkler/auto･Kimoto Electric	Coulometry/UIC･Nippon ANS	Spectrophotometry/Nippon ANS	Continuos flow analysis/BRAN+LUEBBE	Wakita et al. [2010], MR08-05 Cruise Report

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. 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).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.

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 1999 to 2008 (Wakita et al., 2005; Watanabe et al., 2007). NPDW was defined as the water mass between 27.69σ_θ (~2000 db) and 27.77σ_θ (~3500 db), because chlorofluorocarbons were not detected below 27.69σ_θ (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 °C ($\approx$ 27.77σ_θ) (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 maxima of 5 μmol kg^{-1} for DIC, 8 μmol kg^{-1} for TA, 0.92 for DO, 1.04 for silicate, 1.10 for phosphate, and 1.04 for nitrate (Table 2). We corrected the values of these properties at the isopycnal surfaces of NPDW (σ_θ = 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 ± 0.2% for DIC and TA, ± 3% for DO, and ± 1% for nutrients. The standard deviations of DIC, TA, DO, silicate, phosphate, and nitrate values in NPDW after the corrections were estimated to be ± 1.9, ± 1.3, ± 1.5, ± 1.0, ± 0.01, and ± 0.1 μmol kg^{-1}, respectively.

Table 2. Correction factor of DO, DIC, TA, Silicate, Phosphate and Nitrate from 1999 to 2008 at K2

Cruise name[a]	Date	DO (multiplicative)	DIC (additive)	TA (additive)	Silicate (multiplicative)	Phosphate (multiplicative)	Nitrate (multiplicative)
KA99-01	1999/05/28	n.a.[b]	4.7	n.a.[b]	1.045	1.095	1.041
MR01-K03	2001/06/10	n.a.[b]	n.a.[b]	n.a.[b]	0.977	n.a.[b]	n.a.[b]
MR01-K04	2001/09/07	n.a.[b]	3.1	n.a.[b]	1.017	0.980	1.020
MR02-K05	2002/10/21	n.a.[b]	n.a.[b]	n.a.[b]	0.994	1.027	n.a.[b]
MR03-K01	2003/02/25	n.a.[b]	n.a.[b]	n.a.[b]	0.987[d]	1.020	n.a.[b]
NT03-07	2003/07/11	0.925	4.5	-7.3	1.026	1.023	1.021
MR04-02	2004/04/07	n.a.[b]	n.a.[b]	7.9	0.987[d]	1.014	n.a.[b]
NT04-05	2004/05/27	n.a.[b]	n.a.[b]	n.d.[c]	n.a.[b]	1.018	1.015
MR04-04	2004/08/16	n.a.[b]	n.a.[b]	-5.7	0.975[d]	n.a.[b]	n.a.[b]
MR04-06	2004/10/20	n.a.[b]	n.a.[b]	n.a.[b]	0.975[d]	n.a.[b]	n.a.[b]
MR05-01	2005/03/04	n.a.[b]	n.a.[b]	-4.8	0.975[d]	n.a.[b]	n.a.[b]
MR05-04	2005/09/24	n.a.[b]	n.a.[b]	3.9	0.975[d]	n.a.[b]	n.a.[b]
MR06-03	2006/06/03	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/06/03	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/06/12	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/06/22	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/06/25	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/06/29	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/07/01	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/07/08	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/07/10	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/07/14	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR06-03	2006/07/16	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR07-05	2007/09/11	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR07-05	2007/09/12	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR07-05	2007/09/24	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR07-05	2007/09/25	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR08-05	2008/10/23	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]
MR08-05	2008/10/26	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]	n.a.[b]

[a]The ship name are also listed: KA = R/V Kaiyo (Japan Fisheries Agency), NT = R/V Natsushima (JAMSTEC), MR = R/V Mirai (JAMSTEC)

[b]n.a. : no adjustment

[c]n.d. : no data

[d] : to see text

4. Future update of data and contact persons

We will continue to correction and update K2 time-series observation data. These update data will be opened on the JAMSTEC data web site and CDIAC in future.

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