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Evaluation of the net CO_2 uptake in the Canada Basin in the summer of 2008

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Abstract

The third Chinese National Arctic Research Expedition (CHINARE) was conducted in the summer of 2008. During the survey, the surface seawater partial pressure of CO_2 (pCO_2) was measured, and sea water samples were collected for CO_2 measurement in the Canada Basin. The distribution of pCO_2 in the Canada Basin was determined, the influencing factors were addressed, and the air-sea CO_2 flux in the Canada Basin was evaluated. The Canada Basin was divided into three regions: the ice-free zone (south of 77°N), the partially ice-covered zone (77°–80°N), and the heavily ice-covered zone (north of 80°N). In the ice-free zone, pCO_2 was high (320 to 368 μatm, 1 μatm=0.101 325 Pa), primarily due to rapid equilibration with atmospheric CO_2 over a short time. In the partially ice-covered zone, the surface pCO_2 was relatively low (250 to 270 μatm) due to ice-edge blooms and ice-melt water dilution. In the heavily ice-covered zone, the seawater pCO_2 varied between 270 and 300 μatm due to biological CO_2 removal, the transportation of low pCO_2 water northward, and heavy ice cover. The surface seawater pCO_2 during the survey was undersaturated with respect to the atmosphere in the Canada Basin, and it was a net sink for atmospheric CO_2. The summertime net CO_2 uptake of the ice-free zone, the partially ice-covered zone and the heavily ice-covered zone was (4.14±1.08), (1.79±0.19), and (0.57±0.03) Tg/a (calculated by carbon, 1 Tg=10^{12} g), respectively. Overall, the net CO_2 sink of the Canada Basin in the summer of 2008 was (6.5±1.3) Tg/a, which accounted for 4%–10% of the Arctic Ocean CO_2 sink.

Key words: Canada Basin, net CO_2 uptake, partial pressure of CO_2

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1 Introduction

Although the Arctic Ocean only accounts for 4% of the world's ocean surface area, it is an important potential sink for atmospheric CO_2 (Bates and Mathis, 2009). Recent studies showed that the Arctic Ocean contributed 5%–14% of the global oceanic CO_2 sink (Bates and Mathis, 2009; Bates et al., 2011). The central basin of the Arctic Ocean has lower CO_2 content than the atmosphere (Cai et al., 2010; Bates et al., 2011). At present, seasonal sea-ice cover provides a barrier to atmosphere-ocean gas exchange in the central basin. However, because the sea-ice cover of the central basin is rapidly decreasing under global warming, these areas are becoming potential sinks of CO_2 from the atmosphere. Therefore, the Arctic Ocean might have an important influence on the global carbon cycle.

The Arctic marine carbon cycle is particularly sensitive to environmental changes, including sea-ice reduction, changes in albedo, heat and light penetration, seasonal variations in marine phytoplankton primary productivity, water exchange, and the impact of ocean acidification (Chen and Gao, 2007; Gao et al., 2012; Mathis and Questel, 2013; Harada, 2016). As the ice continues to melt, the area of open water increases and the ice-free period becomes longer, the CO_2 sink in the Arctic Ocean is predicted to have a limited net increase (Cai et al., 2010). Various studies (Bates et al., 2005; Kaltin and Anderson, 2005; Bates et al., 2006; Harada, 2016) have suggested that the carbon cycle in the Arctic Ocean is undergoing severe stress due to rapid changes, such as sea-ice loss, warming and acidification, and that there would be substantial potential responses and feedbacks, including further sea-ice loss and enhancement of biological productivity increasing the uptake of CO_2 by Arctic surface waters. The greater amount of absorbed anthropogenic CO_2 would accelerate ocean acidification in the Arctic Ocean.

Over the last decade, the Arctic sea-ice extent has experienced an extreme reduction, particularly since 2007, and reached a record low in 2012. It is predicted that the entire Arctic Ocean will be ice-free in the summer of 2037 (Wang and Overland, 2009). Rapid sea-ice loss in the summer will have a profound impact on the biogeochemical properties of the Arctic Ocean. A re-

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duction in sea ice make more light available to the ocean surface and might thereby enhance phytoplankton photosynthesis and the supply of food for higher trophic level organisms. At present, the area south of approximately 75°N in the Canada Basin, which is a deep and expansive oceanic basin within the western Arctic Ocean, has become ice-free in the summer. Earlier reports on the Canada Basin in the 1990s found that the surface seawater under the sea ice had pCO_2 values (<260 μatm) lower than the atmosphere (Jutterström and Anderson, 2010). Very low seawater pCO_2 (200–270 μatm) and high air-sea CO_2 flux (–55 mmol/(m²·d)) were observed in the Canada Basin off the Chukchi Sea Shelf in the early 2000s (Bates et al., 2006). However, Yamamoto-Kawai et al. (2009) found that some surface areas of the Canada Basin had seawater pCO_2 close to equilibrium with the atmosphere in areas with heavy sea-ice loss. Cai et al. (2010) reported that ice-free surface areas of the Canada Basin had seawater pCO_2 close to equilibrium with the atmosphere, reflecting the uptake of CO_2 from the atmosphere and warming during the exposure of the surface water, which could be a small sink for atmospheric CO_2. Thus, the CO_2 sink of the Canada Basin is highly variable under a changing environment. Unfortunately, observation of the air-sea CO_2 flux in the Canada Basin has rarely been undertaken, and information regarding the net CO_2 uptake capacity in this region remains limited. In this paper, we studies the pCO_2, air-sea CO_2 flux and net CO_2 uptake in the Canada Basin on the basis of the third Chinese National Arctic Research Expedition cruise in the summer of 2008. The high-quality CO_2 data set reported here, covering three typical regions: the ice-free zone, the partially ice-covered zone, and the heavily ice-covered zone, provide an opportunity to reveal the net CO_2 uptake capacity of the entire Canada Basin.

2 Materials and methods

2.1 *Study area*

The Canada Basin is the largest subbasin in the Arctic Ocean and is one of the deepest parts of the Arctic Ocean, with a water depth greater than 3 000 m in most of the region. In the past, the Canada Basin was almost inaccessible and was characterized by year-round ice cover. In the last two decades, however, a dramatic loss of sea ice has occurred in the Canada Basin, especially in summer. The ice-melt water plays an important role in the hydrology of the Canada Basin. The Pacific Ocean water from the Bering Sea passes through the Chukchi Sea and enters the Canada Basin. During the summer, local ice-melt water transforms water of the Pacific Ocean origin to relatively warm, fresher polar mixed layer water. The mixed layer depth is very shallow (roughly 20 m), and the water column is strongly stratified (Codispoti et al., 2005; Woodgate et al., 2005; Bates, 2006).

The spatial area of the Canada Basin was calculated grid by grid based on geographical distances obtained from the 2-minute Gridded Global Relief Data (ETOPO2). In accordance with the topography and geographical location of the Canada Basin, we chose the basin boundary as the contour line, as shown in Fig. 1. This basin boundary was defined based on bathymetry data with a 3 000 m depth to the north and west, and 1 000 m depth to the south and east. The total area of the Canada Basin is 1.17×10^6 km².

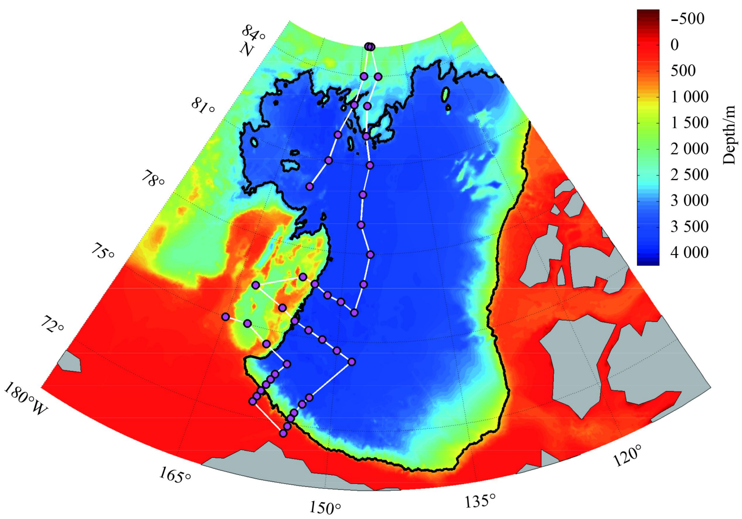

Fig. 1. The location of the Canada Basin. The thick black line denotes its boundary. The sampling stations are shown as pink dots, and the cruise track is shown as a white line.

2.2 *Sampling and analyses*

During August to September 2008, CHINARE-Arctic III was conducted onboard the R/V *Xuelong*, traversing the Canada Basin. Sea surface temperature (SST), salinity (SSS), and partial pressure of CO_2 (pCO_2) data were collected from our underway pumping system. An automated underway pCO_2 observation system (GO Flowing pCO_2 system, Model 8050, General Oceanics Inc., Miami, FL, USA) was installed onboard the R/V *Xuelong* in cooperation with investigators sponsored by the Office of Oceanic and Atmospheric Research (OAR) of the National Oceanic and Atmospheric Administration (NOAA). This GO system was designed to operate fully automatically. The surface seawater was continuously pumped from a side intake at a depth of ~5 m and was piped into a head-shower equilibrator at a flow rate of approximately 2 L/min. The equilibrated headspace gas circulated through the system and back to the equilibrator via a pump at approximately 100 mL/min. It was first dried by passing through a condenser operating at approximately 5°C, then a Permapure Nafion tube. The dried gas was then sent to a LICOR non-dispersive infrared analyzer (LI-840) where its CO_2 mole fraction was measured. Atmospheric air was constantly pumped from the upper deck at ~30 m above the sea surface for the measurement of CO_2 in the air. The outside air was dried and pulled into the LI-840. The equilibrated gas and atmospheric air were alternately measured by the system. The LI-840 was calibrated every 2.5 h using CO_2 standard gases from NOAA with a precision of 0.03 μmol/mol. The overall uncertainty in the reported pCO_2 was less than 1 μmol/mol (Pierrot et al., 2009). pCO_2 data were processed according to Pierrot et al. (2009). Sea surface temperature (SST) and salinity (SSS) were determined continuously using an SEA-CAT thermosalinograph (SBE21, Sea-Bird Co.). The seawater pump was sometimes frozen in the sea-ice zone; thus, the data are discontinuous at high latitude.

Seawater samples for dissolved inorganic carbon (DIC) and total alkalinity (TA) were collected in the Canada Basin. At each hydrocast station, seawater samples were drawn from a 24-bottle Niskin-Rosette water sampler, with a Sea-bird 911plus CTD sensor providing physical data. Samples for the CO_2 system were collected according to the "Guide to Best Practices for Ocean CO_2 Measurements" (Dickson et al., 2007) or the version translated into Chinese by Chen Liqi and Gao Zhongyong. Some DIC and TA samples were analyzed onboard; the rest were preserved and analyzed in the laboratory on land. For DIC determination, a 0.5 mL water sample was acidified, and the subsequently generated CO_2 was analyzed by a Li-Cor 6262, with a precision of ±2 μmol/kg. TA samples were analyzed by Gran titration of a 25 mL water sample, with a precision of ±2 μmol/kg (Cai and Wang, 1998; Cai et al., 2004; Sun et al., 2011). Certified reference materials from A.G. Dickson of Scripps Institution of Oceanography were used for calibration.

The net air-sea CO_2 flux, F, was determined by the following formula:

$$F = k \cdot \alpha \cdot \Delta p\mathrm{CO}_{2,} \quad (1)$$

where k is the gas transfer velocity (cm/h), α is the solubility of CO_2 gas in seawater (mol/(kg·atm); Weiss, 1974), and ΔpCO_2 is the difference between the surface seawater and atmospheric pCO_2. The gas transfer velocity, k, which is related to the wind speed, was calculated based on the Wanninkhof (1992) empirical function:

$$k = 0.31 U_{10}^{2} \left(S_{\mathrm{c}}/660\right)^{-1/2} \left(\mathrm{steady/short\text{-}term\ wind}\right), \quad (2)$$

where U_{10} is the field wind speed corrected to 10 m recorded by the shipboard meteorological station, and S_c is the Schmidt number for CO_2.

3 Results and discussion

3.1 *Ice conditions and hydrography*

Our investigation extended to the northernmost regions of 85.5°N, covering the sea-ice zone of the Canada Basin. The same cruise sea-ice concentration data were obtained based on aerial observations (Lu et al., 2010) provided by the Dalian University of Technology. During the investigation, the Canada Basin gradually transitioned northward from the ice-free zone to the sea-ice zone. South of 77°N was substantially ice-free, while north of 84°N, the ice concentration was as high as 90%.

The distributions of the sea surface temperature and salinity in the Canada Basin are shown in Figs 2a and b. The distributions of the temperature and salinity were closely related to sea-ice. Sea-ice albedo reached 80%–90%. The sea-ice loss indicates that heat absorption increased and the seawater was diluted. As a consequence, the surface water in the ice-free zone was warm and fresh, while the surface water in the sea-ice zone was cold and salty. SSS increased gradually northward, but SST decreased gradually northward. A wide range of SST and SSS was observed over the entire Canada Basin. SSS ranged from 23 to 30, and SST ranged from –1.7°C to 5°C.

3.2 *pCO_2 distribution in the Canada Basin*

The spatial distribution of the surface water pCO_2 in the Canada Basin varied greatly (Fig. 2c). pCO_2 in the Canada Basin ranged from 193 to 368 μatm (1 μatm=1.013 25×10^{-1} Pa), with an average of 302 μatm. The lowest pCO_2 was measured in the southern part of the Canada Basin, and the highest value was observed at 74°N, 148°W. Based on the sea-ice conditions and seawater pCO_2 variation in the summer of 2008, the Canada Basin was divided into three regions: the ice-free zone (south of 77°N), the partially ice-covered zone (77°–80°N), and the heavily ice-covered zone (north of 80°N). The average surface water pCO_2 in the three zones was (333.4±22.3) μatm, (262.4±13.6) μatm, (276.9±5.3) μatm (Table 1).

pCO_2 increased sharply northward at the southern edge of the

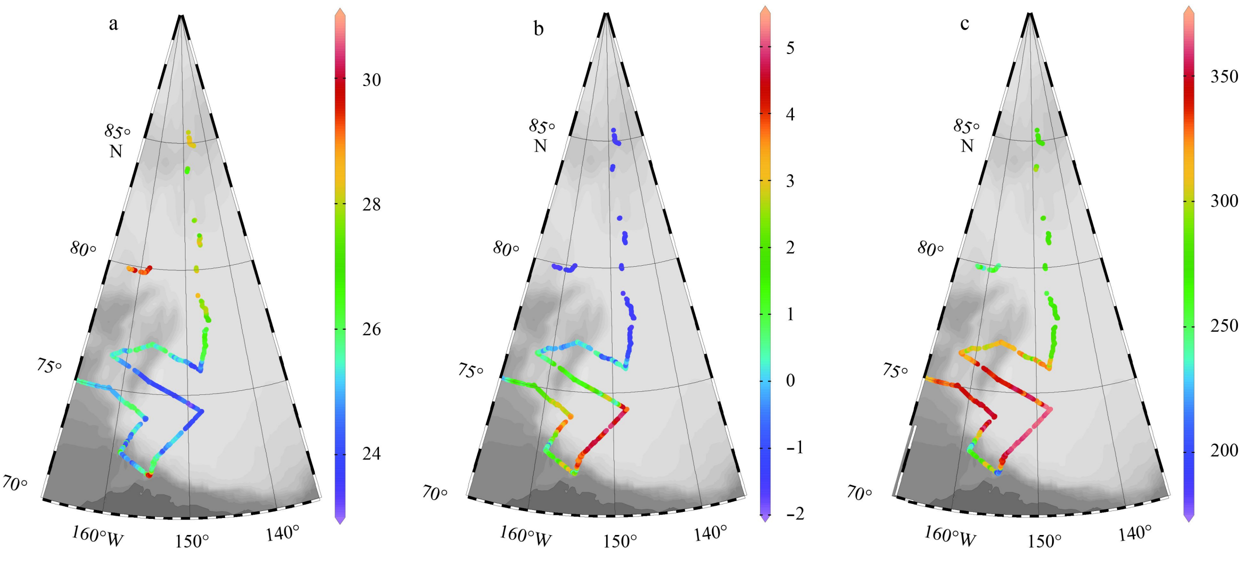

Fig. 2. Distributions of SSS (a), SST (°C) (b), and pCO_2 (μatm) (c) in the Canada Basin.

Table 1. SSS, SST and seawater pCO_2 in different regions of the Canada Basin

Region	Seawater pCO_2/μatm	SSS	SST/°C	Normalized pCO_2 at –1.5°C/μatm
Ice-free zone	333.4±22.3	24.9±0.7	1.6±1.7	292.0±7.8
Partially ice-covered zone	262.4±13.6	28.3±1.1	–1.4±0.1	261.8±13.0
Heavily ice-covered zone	276.9±5.3	28.1±0.4	–1.5±0.0	276.6±5.0

Canada Basin, and a high pCO_2 value area (320 to 368 μatm) was found at approximately 75°N, 155°W. However, in the northern part of the Canada Basin, which was covered in sea ice, pCO_2 remained low (250 to 290 μatm). The surface water pCO_2 in the ice-free open water, the ice edge and sea-ice covered zones showed significant differences. Although the surface water pCO_2 in the southern Canada Basin was high, it was still lower than the atmospheric pCO_2 (376 μatm) during the same period. Overall, the Canada Basin was a sink for atmospheric CO_2.

3.3 *Influencing factors of the pCO_2 distribution in the Canada Basin*

In the Canada Basin, the surface seawater pCO_2 may be affected by a suite of physical, chemical, and biological processes, including sea-ice melting/formation, SST variations, water mixing, photosynthesis/respiration, calcium carbonate precipitation/dissolution, and air-sea CO_2 exchange (Anderson et al., 2004).

Coccolithophore blooms, which can produce $CaCO_3$, have not been observed in the Canada Basin. There was no evidence in our data for significant impact of Coccolithophore blooms in the summer of 2008. Figure 3a shows that the distribution of TA in the Canada Basin has conservative behavior, largely following two mixing lines converging around salinity=30. At salinity>30, the seawater is mainly mixing with river runoff. At salinity<30, the seawater modified by river runoff is mixing with ice-melt water, partly following the seawater-ice melt theoretical mixing line and partly indicative of complicated three end-member mixing. SST is an important factor influencing pCO_2. The temperature effect on pCO_2 in seawater is 4.23% per degree Celsius (Takahashi et al., 1993). Seawater pCO_2 temperature normalization can be used to assess the impact of temperature on the changes in pCO_2. We assume that SST and pCO_2 in the basin before the ice melt were similar to the values in the heavily ice-covered zone measured during the survey. If the pCO_2 in the three zones was normalized to –1.5°C (Table 1), the increase in pCO_2 due to warming would reach 40 μatm in the ice-free zone, while the temperature effect in the other two zones would be minor.

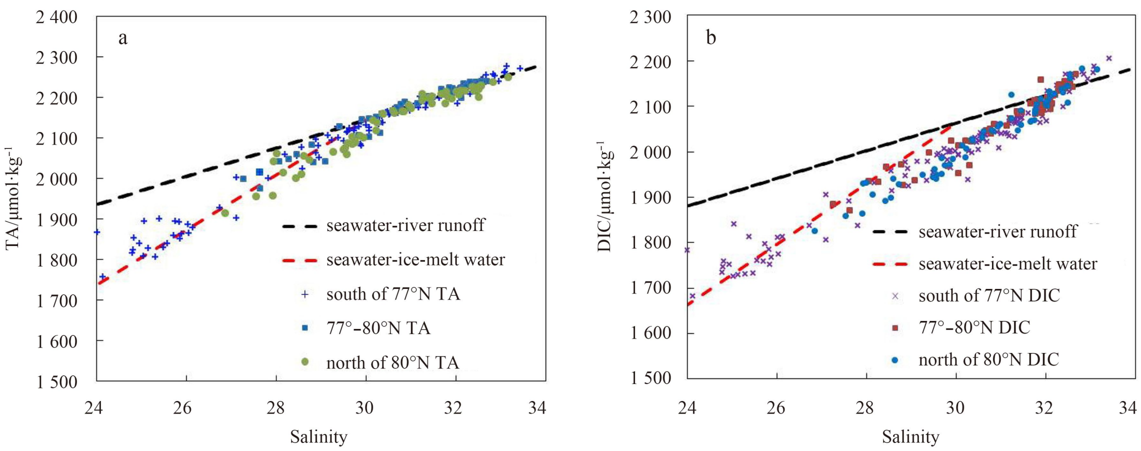

Fig. 3. Correlation of TA (a) and DIC (b) with salinity in the Canada Ocean. Data from 0 to 100 m are divided into south of 77°N, 77°–80°N and north of 80°N. The black dashed line is the theoretical mixing line of seawater and river runoff. The red dashed line is the theoretical mixing line of seawater (diluted by river runoff to salinity=30) and ice meltwater. According to reference (Cai et al., 2010), the TA and DIC of the seawater end-member are 2 257.9 μmol/kg and 2 161.4 μmol/kg, respectively; the TA and DIC of the river runoff end-member are 1 100 μmol/kg and 1 150 μmol/kg; and the TA and DIC of the ice-melt end-member are 450 μmol/kg and 400 μmol/kg.

Seawater is diluted by river runoff and ice-melt water as it flows through the ocean basin. The mixing of seawater with low-CO_2 meltwater would reduce pCO_2 by 50 to 60 μatm, as illustrated in Cai et al. (2010).

Biological effects play an important role in the distribution of pCO_2. The complex relationship between total DIC and salinity (Fig. 3b) indicated biological processes in the three zones of the Canada Basin. DIC data from below the theoretical mixing line reflect DIC removal due to the effects of biological production, and the data above that line reflect DIC regeneration from the degradation of organic matter. Figure 4 shows that in the Canada Basin (north of 73°N), the chlorophyll *a* concentration decreased approximately an order of magnitude and even reached zero at high latitude, indicating that biological removal is not as strong as that of the shelf area. Using data from the same sampling cruise, Cai et al. (2010) reported that the net primary production rate in the marginal seas was 114 mmol/(m^2·d), whereas in ice-free areas of the Canada Basin, it was only 1.88 mmol/(m^2·d). However, the lowest pCO_2 of 193 μatm was observed at the southern edge of the Canada Basin located at approximately 72°N, where biological removal was still strong. Bates et al. (2006) found low pCO_2 (200–270 μatm) at the southern edge of the Canada Basin, and minimal seasonal variation occurred, which could be attributed to the low pCO_2 water transported from the

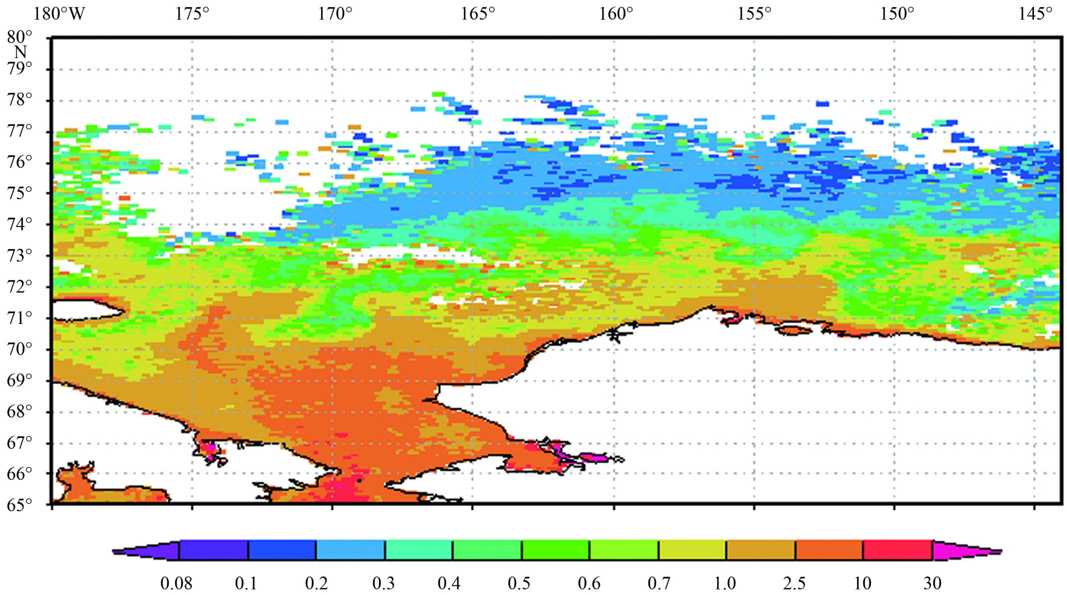

Fig. 4. Monthly average SeaWiFS chlorophyll *a* concentrations (mg/m^3) of the western Arctic Ocean in August 2008 (from NASA's Goddard Earth Sciences Data and Information Service Center).

Chukchi Shelf and northward cooling.

In the ice-free Canada Basin, the causes of the greater CO_2 were warming and stratification in the shallow mixed layer (less than 20 m), which caused rapid equilibration with atmospheric CO_2 over a short time (Cai et al., 2010).

In the ice-edge region of the Canada Basin (77°–80°N), sea surface $p$$CO_2$ was relatively low (250–270 μatm). Strong ice algae activity was observed in the region. Gosselin et al. (1997) indicated that ice algae contributed up to 57% of the total primary production in the Arctic Ocean Section study (AOS) in the summer of 1994. Several relevant studies (Arrigo et al., 2012, 2014; Zhang et al., 2015) completely changed the traditional concept of low biological activity below the permanent sea ice of the Arctic Ocean. The stratification of the mixed layer resulted in high stability, and ice algae were released during the ice-melt season, which can easily lead to ice-edge blooms. Moreover, the ice-melt water diluted the concentration of TA and DIC; thus, $p$$CO_2$ was reduced.

In the perennially ice-covered Canada Basin (north of 80°N), the surface seawater $p$$CO_2$ remained at a relatively low level (270–300 μatm) for the reasons described below. First, biological removal of CO_2 occurred below the sea ice according to Fig. 3b and recent studies (Arrigo et al., 2012). Second, low $p$$CO_2$ water in the nearby ice edge transited northward. Third, the perennial ice cover inhibited the air-sea exchange.

3.4 *Evaluation of the net CO_2 uptake in the Canada Basin*

Using *in situ* wind speeds and other related parameters, the computed air-water CO_2 flux for the ice-free zone, the partially ice-covered zone, and the heavily ice-covered zone was –(4.2±2.3) mmol/(m^2·d), –(11.5±1.4) mmol/(m^2·d), –(10.1±0.5) mmol/(m^2·d) (negative values represent a CO_2 sink, and vice versa), respectively. If rough corrections for sea-ice concentrations of 0%, 25%, and 75% are applied for the three zones based on the sea-ice conditions during the survey, the resulting fluxes become –(4.2±2.3) mmol/(m^2·d), –(8.6±1.4) mmol/(m^2·d), and –(2.5±0.5) mmol/(m^2·d), respectively.

Few previous studies reported the air-sea CO_2 flux of the Canada Basin due to obstruction of sea ice in the past. As the sea-ice cover of the Arctic Ocean continues to retreat rapidly, there will be more and more open water in the Canada Basin during summer. Studies on the air-sea CO_2 flux in this region could provide a better understanding of the Arctic Ocean carbon sinks in the future. Bates et al. (2006) reported that the air-sea CO_2 flux would reach –55 mmol/(m^2·d) if the southern Canada Basin was ice-free, based on data collected at the partially ice-covered southern edge of the Canada Basin during the summers of 2002 and 2004. In our study, however, the same area became a relatively low CO_2 sink, –4.2 mmol/(m^2·d). Evidently, CO_2 sinks and sources are highly variable in a changing environment. According to the ice concentrations of 2002, 2004 and 2008, the southern Canada Basin in the summer of 2002 and 2004 was partially ice-covered, where ice-edge blooms might occur, and it became an ice-free area during the summer of 2008, in which the nutrients were almost depleted after the early high primary production season and the shallow mixed layer caused rapid equilibration with the atmospheric CO_2 over a short time. In this study, the air-sea CO_2 flux of the partially ice-covered zone was –8.6 mmol/(m^2·d), and it was –11.5 mmol/(m^2·d) if we did not consider the impact of sea-ice cover, which was still much less than ~55 mmol/(m^2·d). However, we found that the surface seawater $p$$CO_2$ values in the partially ice-covered zone of both studies were comparable. Our study used field-measured wind speed data rather than data from the assimilation model used in Bates et al. (2006). Thus, the substantial difference in the air-sea CO_2 flux may be attributed to different wind speeds, which could cause major differences.

To determine the net CO_2 uptake of the Canada Basin, the areas south of 77°N, 77°–80°N, and north of 80°N were calculated as 5.38×10^5 km^2, 2.686 8×10^5 km^2, and 3.60×10^5 km^2, respectively. Additionally, the ice cover and CO_2 sink status of the three zones were in transition. Based on the sea-ice concentration data of the summer of 2008, south of 77°N shifted from a partially ice-covered zone to an ice-free zone, 77°–80°N shifted from a heavily ice-covered zone to a partially ice-covered zone, and north of 80°N shifted from a 99% sea-ice coverage zone to a heavily ice-covered zone. Considering a 100-day ice-free period, we assume that each condition of the three zones lasted for 50 days. Thus, the net summer CO_2 uptake of the Canada Basin can be calculated as follows:

(1) south of 77°N:

$(-11.5\ \text{mmol}/(\text{m}^2\cdot\text{d}))\times(1\%-25\%)\times(5.38\times10^5\ \text{km}^2)\times(50\ \text{d/a})\times(12\ \text{g C})+(-4.2\ \text{mmol}/(\text{m}^2\cdot\text{d}))\times(1\%-0\%)\times(5.38\times10^5\ \text{km}^2)\times(50\ \text{d/a})\times(12\ \text{g C})=-4.14\times10^{12}\ \text{g/a}$,

(2) 77°N–80°N:

$(-10.1\ \text{mmol}/(\text{m}^2\cdot\text{d}))\times(1\%-75\%)\times(2.68\times10^5\ \text{km}^2)\times(50\ \text{d/a})\times(12\ \text{g C})+(-11.5\ \text{mmol}/(\text{m}^2\cdot\text{d}))\times(1\%-25\%)\times(2.68\times10^5\ \text{km}^2)\times(50\ \text{d/a})\times(12\ \text{g C})=-1.79\times10^{12}\ \text{g/a}$,

(3) north of 80°N:

$(-10.1\ \text{mmol}/(\text{m}^2\cdot\text{d}))\times(1\%-99\%)\times(3.60\times10^5\ \text{km}^2)\times(50\ \text{d/a})\times(12\ \text{g C})+(-10.1\ \text{mmol}/(\text{m}^2\cdot\text{d}))\times(1\%-75\%)\times(3.60\times10^5\ \text{km}^2)\times(50\ \text{d/a})\times(12\ \text{g C})=-0.57\times10^{12}\ \text{g/a}$

In summary, the summertime net CO_2 uptake of the ice-free zone, the partially ice-covered zone, and the heavily ice-covered zone was –(4.14±1.08) Tg/a (calculated by carbon), –(1.79±0.19) Tg/a, and –(0.57±0.03) Tg/a, respectively, and the net CO_2 sink of the Canada Basin in the summer of 2008 was (6.5±1.3) Tg/a. Estimations of the net CO_2 uptake in the various areas of the Arctic Ocean are listed in Table 2. The entire Arctic Ocean acts as an atmospheric CO_2 sink. Since the marginal seas of the Arctic Ocean have different shelves (inflow shelves, interior shelves and outflow shelves), their CO_2 source and sink status varied significantly. In contrast, other studies indicated that the central basin of the Arctic Ocean has the potential to absorb significant amounts of CO_2, consistent with our study. The increased sea-ice free period and open water area contribute to positive feedback to the Arctic Ocean CO_2 sinks. The positive feedback revealed by our study indicated that the net CO_2 uptake of the Arctic Ocean would be enhanced in the next two or three decades, eventually resulting in completely ice-free Arctic Ocean Basins in the summer.

Table 2. The net CO_2 uptake in the various areas of the Arctic Ocean

	Annual CO_2 uptake/$\text{Tg}\cdot\text{a}^{-1}$	Reference
East Siberian Sea	–1.2 to –13	Semiletov et al. (2007)
	+0.3	Nitishinsky et al. (2007)
	–5.9	Anderson et al. (1998a, b)
Chukchi Sea	–11	Murata and Takizawa (2003)
	–36±6	Bates (2006)
	–53±14	Kaltin and Anderson (2005)
Beaufort Sea	–2.9	Anderson et al. (1998a, b)
	–2	Murata and Takizawa (2003)
Barents Sea	–70±27	Nakaoka et al. (2006)
	–77±12	Omar et al. (2007)
Laptev Sea	–1.2	Nitishinsky et al. (2007)
Kara Sea	–1.0	Fransson et al. (2001)
Central basin	–6 to –19	Bates et al. (2006)
	–4.6	Cai et al. (2010)
	–6.5±1.3	this study
Arctic Ocean	–58	Manizza et al. (2013)
	–66 to –199	Bates and Mathis (2009)
	–129±65	Anderson et al. (1990)
	–70±65	Anderson et al. (1994)
	–110	Lundberg and Haugen (1996)
	–31	Kaltin and Anderson (2005)

4 Conclusions

We presented seawater pCO$_2$ data from the Canada Basin in the summer of 2008 and assessed the net CO_2 uptake of the Canada Basin. The evaluation of the net air-sea CO_2 flux in the Canada Basin has rarely been undertaken because of the sea-ice barrier. The valuable data were the highlight of this paper. The main conclusions are as follows:

(1) South of 77°N, the surface water pCO$_2$ ranged from 320 to 360 μatm, and the summertime net CO_2 uptake was (4.14±1.08) Tg/a.

(2) From 77°N to 80°N, the surface water pCO$_2$ ranged from 250 to 270 μatm, and the summertime net CO_2 uptake was (1.79±0.19) Tg/a.

(3) North of 80°N, the surface water pCO$_2$ ranged from 270 to 300 μatm, and the summertime net CO_2 uptake was (0.57±0.03) Tg/a.

The Canada Basin was a sink for atmospheric CO_2 in the summer of 2008, with a net CO_2 uptake of (6.5±1.3) Tg/a. The results are important for predicting the Arctic Ocean carbon sink status in the future. However, the Arctic Ocean is currently undergoing rapid change. Studies have shown that the CO_2-carbonate chemistry of sea-ice melt ponds is highly variable, and the majority of melt ponds are potentially strong sources of CO_2 to the atmosphere (Miller et al., 2011; Geilfus et al., 2012; Bates et al., 2014). These studies indicated that there were many uncertainties in the factors affecting the future Arctic Ocean CO_2 sinks. It is difficult to accurately predict the Arctic Ocean carbon sink trend, and more *in situ* observations are needed to acquire more knowledge about the CO_2 dynamics in the Canada Basin.

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