· Article ·

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Dissolved nutrient distributions in the Antarctic Cosmonaut Sea in austral summer 2021

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Abstract Dissolved nutrients are essential to marine productivity and ecosystem structures in the Southern Ocean. The spatial distributions of dissolved nutrients in the Cosmonaut Sea were studied during the 37th Chinese National Antarctic Research Expedition in 2021. The relative standard deviations of the nitrate (NO_3-N), nitrite (NO_2-N), ammonium (NH_4-N), phosphate (PO_4-P), and silicate (SiO_3-Si) concentrations found in duplicate samples (*n*=2) were 1.01%, 9.04%, 6.45%, 0.94%, and 0.67%, respectively. The mean NO_3-N, NO_2-N, NH_4-N, PO_4-P, and SiO_3-Si concentrations in the mixed layer were 26.41±4.13, 0.15±0.09, 0.51±0.22, 1.73±0.23, and 41.48±6.94 μmol·L^{-1}, respectively, and were higher than the relevant limitation concentrations. The concentrations were generally bounded horizontally by the Southern Boundary (SB) of the Antarctic Circumpolar Current, the NO_3-N, NO_2-N, NH_4-N, and PO_4-P concentrations being higher northeast than southwest of the SB but the SiO_3-Si concentrations being higher southwest than northeast, indicating that the SB dominates nutrient distributions in the mixed layer. The NO_3-N, NH_4-N, and PO_4-P concentrations gradually increased moving vertically down from the mixed layer to 200 m deep and then remained at 33.73±3.51, 0.26±0.13, and 2.28±0.10 μmol·L^{-1}, respectively, to the bottom. The SiO_3-Si concentration increased as depth increased and reached a maximum in the bottom layer. The NO_2-N concentration decreased rapidly as depth increased and was ~0 μmol·L^{-1} at >150 m deep. Circumpolar Deep Water upwelling may cause high nutrient concentrations in shallower layers up to the 100 m layer between 62.5°S and 64°S.

Keywords **dissolved nutrients**, **water masses**, **mixed layer**, **circulation**, **Antarctic**, **Cosmonaut Sea**

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1 Introduction

Dissolved nutrients are required for the growth of phytoplankton (i.e., primary productivity) in the ocean, which is critical to marine ecosystems (Millero, 2013). The Southern Ocean generally has high nutrient and low chlorophyll concentrations (Boyd et al., 2000). The Antarctic marine biological pump is markedly different from the other oceans because of the geographical environment characteristics of Antarctic Ocean (Arrigo et al., 2008). Upwelling of Circumpolar Deep Water (CDW) and Antarctic Intermediate Water off Antarctic coasts provide abundant nutrients near Antarctica (Pollard et al., 2006). An ocean circulation model has indicated that nutrients exported from the Southern Ocean leads to ~75% of primary productivity in the oceans north of 30°S (Weber and Deutsch, 2010). Nutrient supplies and cycles in the Southern Ocean are therefore very important to marine primary productivity across the world.

The Cosmonaut Sea, which is west of Enderby Land in

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East Antarctica and borders the Cooperation Sea (to the east) and the Lisser–Larsen Sea (to the west), is an important fishery and component of the Southern Ocean ecosystem (Nicol and Foster, 2003; Wright et al., 2010). In recent decades, global warming has quadrupled the rate at which Antarctic glaciers are melting (Shepherd et al., 2018) and increased interannual sea ice changes in the Cosmonaut Sea (Geddes and Moore, 2007). These changes may cause fluctuations in the availability of light, the mixed layer depth (MLD), and the concentration of bioavailable iron, which may affect nutrient cycles and the ecosystem of the Cosmonaut Sea. A systematic multi-disciplinary study called the BROKE-West survey was performed in the austral summer of 2006. In that study, interactions between nutrient cycling and circulation, light, trace elements, and plankton in the Cosmonaut Sea and adjacent seas were investigated (Westwood et al., 2010; Williams et al., 2010; Wright et al., 2010). Since then, however, few spatial and temporal studies of dissolved nutrients and their effects on primary productivity and ecosystem structures in the Cosmonaut Sea have been performed. More research into the distributions of dissolved nutrients in the Cosmonaut Sea is required to improve our understanding of marine ecosystems and changes in these ecosystems.

In this study, we present the concentrations and distributions of dissolved nutrients detailly in the Cosmonaut Sea in austral summer 2021, collected during the 37th Chinese National Antarctic Research Expedition (CHINARE). The data under high-quality control updated nutrient data set in the Southern Ocean. This study would provide an important reference for further study on nutrient dynamics and the ecosystem in the Cosmonaut Sea.

2 Materials and methods

2.1 Oceanography

Water masses and circulation are key to dissolved nutrient distributions in the Cosmonaut Sea. The CDW and three important surface/subsurface circulations (the Weddell Gyre (WG), the Southern Boundary (SB) of the Antarctic Circumpolar Current, and the Antarctic Slope Current (ASC)) affect the Cosmonaut Sea (Figure 1). CDW and Antarctic surface water above it are the main water masses in the top 250 m of the water column (Orsi et al., 1995). Strong CDW intrusion can cause local increases in dissolved nutrient concentrations (Meijers et al., 2010). The WG (the dominant circulation in the western part of 40°E in the Cousmonaut Sea) causes the seasonal mixed layer to be shallower, warmer, and fresher in the western than eastern research region (Williams et al., 2010). East of the WG, the SB extends southeastwards, reaching 65.5°S and 60°E, and is a key factor leading to high nitrate concentrations in the northeastern part of the Cosmonaut Sea (Westwood et al., 2010). The ASC, which is a robust narrow westward flowing jet, has flow rates as high as 30 cm·s^{-1} and causes high chlorophyll *a* concentrations along the shore (Meijers et al., 2010).

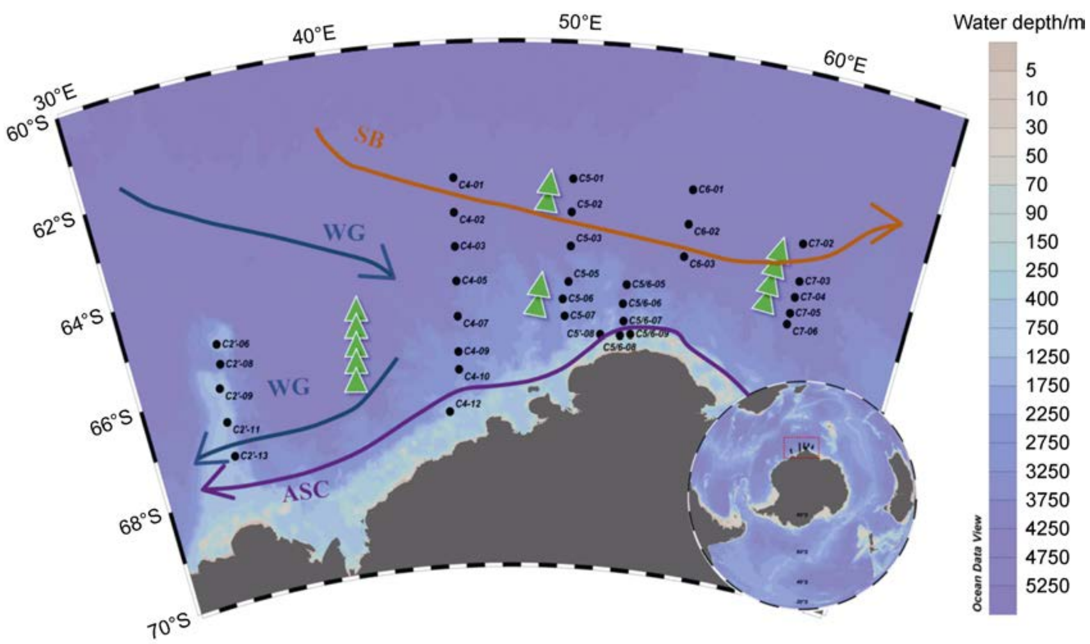

Figure 1 Stations at which samples were collected to determine dissolved nutrient concentrations in the austral summer between 5 and 25 January 2021 as a part of the 37th CHINARE. The green triangles indicate areas with strong upwelling. The solid orange line indicates the southern boundary of the Antarctic Circumpolar Current (SB), the solid blue line indicates the Weddell Gyre (WG), and the solid purple line indicates the Antarctic Slope Current (ASC) (Westwood et al., 2010; Williams et al., 2010).

2.2 Sample collection

Hydrological parameters (potential temperature, salinity, and potential density) were determined and recorded using a pre-calibrated Sea-Bird SBE-9/11 plus CTD (conductivity-temperature-depth) system (SeaBird, USA). A total of 419 water samples, including 28 parallel samples from 33 stations on six transects (C2', C4, C5, C5/6, C6, and C7), were collected from the Cosmonaut Sea by the R/V *Xuelong 2* between 5 and 25 January 2021 as part of the 37th CHINARE. The sampling depths were widely accepted standard water layer sampling depths (the surface layer (i.e., 5 m in Table 1 and Table S1), depths of 25, 50, 75, 100, 150, 200, 300, 500, 1000, 2000 and 3000 m, and the bottom layer) (Figure 1 and Table S1). Each water sample was passed through a Whatman cellulose acetate filter membrane with 0.45 μm pores (Whatman, USA). The filtrate was collected in a clean Nalgene polyethylene bottle (HDPE, Nalgene, USA) and stored at −20℃.

2.3 Experimental methods

The ammonium (NH_4-N) concentrations in the samples were determined onboard the research vessel using the indophenol blue photometric method using a calibrated 7230G visible light spectrophotometer (INESA, China). The analytical procedure is described in detail in "Specifications for the oceanographic survey – Part 4: Survey of chemical parameters in sea water" (GB/T 12763.4—2007) (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China and Standardization Administration of China, 2007). The nitrate (NO_3-N), nitrite (NO_2-N), phosphate (PO_4-P), and silicate (SiO_3-Si) concentrations were determined onboard the research vessel using the cadmium copper column reduction diazo method, the diazo azo method, the phosphomolybdenum blue method, and the silicon-molybdenum blue method, respectively, using an AA3 automatic nutrient analyzer (SEAL, Germany). The analytical procedures are described in the "Code of practice for marine monitoring technology Part 1: seawater" (HY/T 147.1—2013) (State Oceanic Administration, 2013). Artificial seawater with a similar salinity to the samples was used to prepare the standards and to clean the injector to prevent differences in salinity affecting the results. The concentrations of various dissolved nutrients in the seawater samples were calculated from the linear relationships between the light absorption values and nutrient concentrations for the standards. Natural seawater samples containing NO_3-N, NO_2-N, NH_4-N, PO_4-P, and SiO_3-Si at concentrations of 2.25, 0.42, 1.30, 2.88, and 18.54 μmol·L^{-1}, respectively, were determined, and the relative standard deviations (RSDs) were 2.4%, 2.6%, 1.2%, 5.2% and 6.4%, respectively. Duplicate samples were collected from one layer at each station and used as quality control samples (Table 1). The standard solutions (GBW 08617-08645) used were produced by the Marine Reference Material Center, Second Institute of Oceanography, Ministry of Natural Resources of China.

2.4 Calculating the MLD

The potential seawater density (ρ, in kg·m^{-3}) was calculated from the potential temperature, salinity, and pressure data collected *in situ*. The MLD for the water column was calculated from the depth of the maximum water column buoyancy frequency (N^2, in rad^2·s^{-2}) (Carvalho et al., 2016) using Eq. (1),

$$N^2 = \frac{g}{\rho} \cdot \frac{\partial \rho}{\partial z}, \qquad (1)$$

where g and z are gravity and water depth, respectively.

2.5 Statistical analysis

Two-tailed tests of significance were performed using SPSS 25 software (IBM, USA) to identify significant relationships between the measured parameters.

3 Results and discussion

3.1 Parallel sample analyses

The RSDs for the NO_3-N, NO_2-N, NH_4-N, PO_4-P, and SiO_3-Si concentrations found in the samples from the parallel sample stations were 0.08%–3.23%, 0%–47.14%, 0%–17.31%, 0%–4.31%, and 0.01%–5.79%, respectively, and the mean concentrations were 1.01%, 9.04%, 6.45%, 0.94%, and 0.67%, respectively, as shown in Table 1. The RSDs for most of the samples were better than the acceptable thresholds for the analytical methods. Some of the RSDs, particularly for the NO_2-N and NH_4-N concentrations, were poor because of their low concentrations. The results for the parallel samples generally indicated that the dataset was reliable.

3.2 Horizontal dissolved nutrient distributions

The mean NO_3-N, PO_4-P, and SiO_3-Si concentrations in the surface layer samples were 25.84±3.31, 1.66±0.27, and 41.63±6.62 μmol·L^{-1}, respectively, which were higher than the relevant nutrient limits (15, 0.1, and 5 μmol·L^{-1}, respectively) (Justić et al., 1995; Franck et al., 2000). The mean NO_2-N and NH_4-N concentrations were 0.15±0.09 and 0.49±0.22 μmol·L^{-1}, respectively. The NO_3-N, NO_2-N, NH_4-N, and PO_4-P concentrations in surface water generally decreased from the northeast to the southwest of the SB (Figure 2, see Figure 1 for the location of the SB). The highest NO_3-N, NO_2-N, NH_4-N, and PO_4-P concentrations were 30.17 μmol·L^{-1} (C5-06), 0.29 μmol·L^{-1} (C4-02), 1.37 μmol·L^{-1} (C5-03) and 1.96 μmol·L^{-1} (C5-05 and C5-06), respectively, which were all found at northeast of the SB. The lowest NO_3-N, NO_2-N, NH_4-N, and PO_4-P concentrations were 17.11 μmol·L^{-1} (C4-09), 0.02 μmol·L^{-1} (C4-07, C4-09 and C4-10), 0.22 μmol·L^{-1} (C5'-08), and 0.96 μmol·L^{-1} (C4-10), respectively, which were located at

Table 1 Concentrations, mean concentrations, and relative standard deviations (RSD) of dissolved nutrients in the samples from the 28 parallel sample stations

Station	Depth /m	NO_3-N/(μmol·L^{-1})				NO_2-N/(μmol·L^{-1})				PO_4-P/(μmol·L^{-1})				SiO_3-Si/(μmol·L^{-1})				Depth for NH_4-N /m	NH_4-N/(μmol·L^{-1})			
		A	B	Average	RSD /%	A	B	Average	RSD /%	A	B	Average	RSD /%	A	B	Average	RSD /%		A	B	Average	RSD /%
C7-06	5	28.12	29.34	28.73	3.00	0.22	0.22	0.22	0.00	1.48	1.54	1.51	2.81	28.40	28.13	28.27	0.68	5	0.50	0.39	0.45	17.31
C7-05	5	24.91	24.80	24.86	0.32	0.24	0.25	0.25	2.89	1.57	1.56	1.57	0.45	30.43	30.30	30.37	0.30	5	0.45	0.50	0.47	8.16
C7-03	5	23.30	23.27	23.29	0.09	0.24	0.24	0.24	0.00	1.44	1.43	1.44	0.49	24.66	24.59	24.63	0.20	5	0.64	0.60	0.62	4.98
C7-02	5	24.48	24.51	24.50	0.09	0.26	0.26	0.26	0.00	1.54	1.56	1.55	0.91	26.29	26.21	26.25	0.22	50	0.94	0.86	0.90	6.01
C6-01	5	27.38	27.30	27.34	0.21	0.22	0.23	0.23	3.14	1.81	1.82	1.82	0.39	37.90	37.00	37.45	1.70	4962	0.16	0.16	0.16	0.00
C6-02	5	26.49	26.62	26.56	0.34	0.21	0.22	0.22	3.29	1.77	1.77	1.77	0.00	35.30	35.27	35.29	0.06	4852	0.40	0.34	0.37	12.53
C6-03	5	26.97	26.94	26.96	0.08	0.24	0.26	0.25	5.66	1.85	1.86	1.86	0.38	39.96	40.42	40.19	0.81	25	0.60	0.57	0.58	3.98
C5/6-06	5	28.01	27.18	27.59	2.14	0.23	0.17	0.20	21.21	1.86	1.75	1.81	4.31	43.55	43.76	43.66	0.34	200	0.18	0.23	0.21	15.00
C5/6-08	5	28.11	28.44	28.27	0.82	0.15	0.15	0.15	0.00	1.85	1.85	1.85	0.00	44.37	44.25	44.31	0.19	510	0.29	0.30	0.30	2.59
C5’-08	5	27.41	27.16	27.29	0.65	0.08	0.09	0.09	8.32	1.73	1.78	1.76	2.01	45.10	45.03	45.07	0.11	5	0.22	0.22	0.22	0.00
C5-07	5	28.46	28.21	28.34	0.62	0.13	0.13	0.13	0.00	1.87	1.86	1.87	0.38	45.85	45.82	45.84	0.05	200	0.22	0.23	0.22	3.47
C5-06	5	30.32	30.02	30.17	0.70	0.18	0.18	0.18	0.00	1.96	1.96	1.96	0.00	46.69	46.65	46.67	0.06	75	0.24	0.28	0.26	11.86
C5-05	5	29.69	29.33	29.51	0.86	0.17	0.19	0.18	7.86	1.97	1.95	1.96	0.72	47.18	47.19	47.19	0.01	300	0.22	0.23	0.22	3.47
C5-03	5	28.80	29.05	28.93	0.59	0.20	0.19	0.20	3.63	1.93	1.91	1.92	0.74	46.21	46.23	46.22	0.03	5	1.34	1.41	1.37	3.37
C5-02	5	27.63	26.88	27.26	1.94	0.22	0.20	0.21	6.73	1.82	1.79	1.81	1.18	37.86	37.94	37.90	0.15	5	0.31	0.30	0.31	2.49
C5-01	5	27.88	27.84	27.86	0.10	0.26	0.26	0.26	0.00	1.82	1.83	1.83	0.39	36.90	37.44	37.17	1.03	75	0.43	0.45	0.44	1.75
C4-01	5	26.87	27.44	27.16	1.48	0.27	0.26	0.27	2.67	1.91	1.85	1.88	2.26	41.68	40.11	40.90	2.71	5	0.51	0.45	0.48	9.67
C4-02	5	27.64	27.42	27.53	0.56	0.29	0.28	0.29	2.48	1.93	1.93	1.93	0.00	43.65	43.43	43.54	0.36	1000	0.19	0.22	0.21	7.50
C4-03	5	27.41	27.47	27.44	0.15	0.27	0.28	0.28	2.57	1.80	1.87	1.84	2.70	46.34	46.07	46.21	0.41	300	0.35	0.37	0.36	4.30
C4-05	5	25.25	25.86	25.56	1.69	0.09	0.08	0.09	8.32	1.80	1.80	1.80	0.00	46.36	46.32	46.34	0.06	5	0.21	0.25	0.23	13.56
C4-07	5	23.28	23.07	23.17	0.64	0.01	0.02	0.02	47.14	1.23	1.25	1.24	1.14	43.90	43.76	43.83	0.23	50	0.87	0.88	0.88	0.88
C4-09	5	16.72	17.50	17.11	3.23	0.01	0.02	0.02	47.14	1.20	1.21	1.21	0.59	44.23	44.13	44.18	0.16	5	0.88	0.89	0.89	0.87
C4-10	5	19.35	19.95	19.65	2.16	0.02	0.02	0.02	0.00	0.96	0.96	0.96	0.00	45.46	45.24	45.35	0.34	100	0.27	0.29	0.28	5.47
C4-12	5	19.07	19.83	19.45	2.76	0.03	0.03	0.03	0.00	1.45	1.43	1.44	0.98	45.30	45.26	45.28	0.06	5	0.35	0.29	0.32	12.05
C2’-08	5	20.52	20.19	20.35	1.14	0.04	0.02	0.03	47.14	1.40	1.41	1.41	0.50	49.45	49.41	49.43	0.06	5	0.38	0.34	0.36	8.61
C2’-06	5	24.64	24.32	24.48	0.92	0.02	0.02	0.02	0.00	1.23	1.22	1.23	0.58	45.25	41.69	43.47	5.79	–	–	–	–	–
C2’-09	5	25.47	25.61	25.54	0.39	0.04	0.03	0.04	20.20	1.23	1.22	1.23	0.58	47.78	46.12	46.95	2.50	5	0.27	0.24	0.25	9.08
C2’-13	5	24.65	24.82	24.73	0.48	0.05	0.06	0.06	12.86	1.77	1.82	1.80	1.97	54.11	53.95	54.03	0.21	150	0.15	0.14	0.15	5.30

southwest of the SB. The SiO_3-Si concentrations in the surface water samples had the opposite distribution: lower in the northeast side of SB and higher in the southwest side of SB. The highest SiO_3-Si concentration (54.03 μmol·L^{-1}) was found at station C2’-13 and the lowest SiO_3-Si concentration (24.63 μmol·L^{-1}) was found at station C7-03 (Table S1).

The MLDs in the study area ranged from 14 m at station C4-09 to 85 m at station C5’-08, and the mean MLD was 37±17 m, which was similar to the MLD found in the BROKE-West survey (MLD 26±15 m, p>0.05) (Figure S1). The low MLD between 30°E and 60°E may have been caused by the WG. The NO_3-N, NO_2-N, NH_4-N, PO_4-P, and SiO_3-Si concentrations in the mixed layer were 26.41±4.13 (15.74–39.76), 0.15±0.09 (0–0.29), 0.51±0.22 (0.18–1.37), 1.73±0.23 (1.01–1.99), and 41.48±6.94 (22.87–55.11) μmol·L^{-1}, respectively. Similar NO_3-N and SiO_3-Si concentrations (25.9±2.5 and 48.0±8.8 μmol·L^{-1}, respectively) were found in the BROKE-West survey (Westwood et al., 2010), indicating that little interannual variation in dissolved nutrient concentrations occur in the mixed layer in the Cosmonaut Sea.

The mean NO_3-N, PO_4-P, and SiO_3-Si concentrations in the 200 m layer (33.23±2.50, 2.30±0.13, and 69.36±9.80 μmol·L^{-1}, respectively) were higher than the concentrations in the surface layer, but the mean NO_2-N and NH_4-N concentrations (0 and 0.25±0.14 μmol·L^{-1}, respectively) were lower than the concentrations in the surface layer. The horizontal NO_3-N, PO_4-P, and SiO_3-Si concentration distributions in the 200 m layer and surface layer were similar, indicating that circulation strongly affects the distributions of NO_3-N, PO_4-P, and SiO_3-Si in the euphotic zone. The NO_2-N concentrations were below the detection limit, and there was no clear trend in the NH_4-N concentration distribution.

The mean NO_3-N, NO_2-N, NH_4-N, and PO_4-P concentrations in the bottom water were 38.46±4.66, 0±0.01, 0.34±0.14, and 2.26±0.09 μmol·L^{-1}, respectively, which were not significantly different from the concentrations in the 200 m layer (p>0.05). The SiO_3-Si concentration in the bottom water was 99.70±14.20 μmol·L^{-1}, which was significantly higher than the concentration in the 200 m layer (p<0.01). The NO_3-N

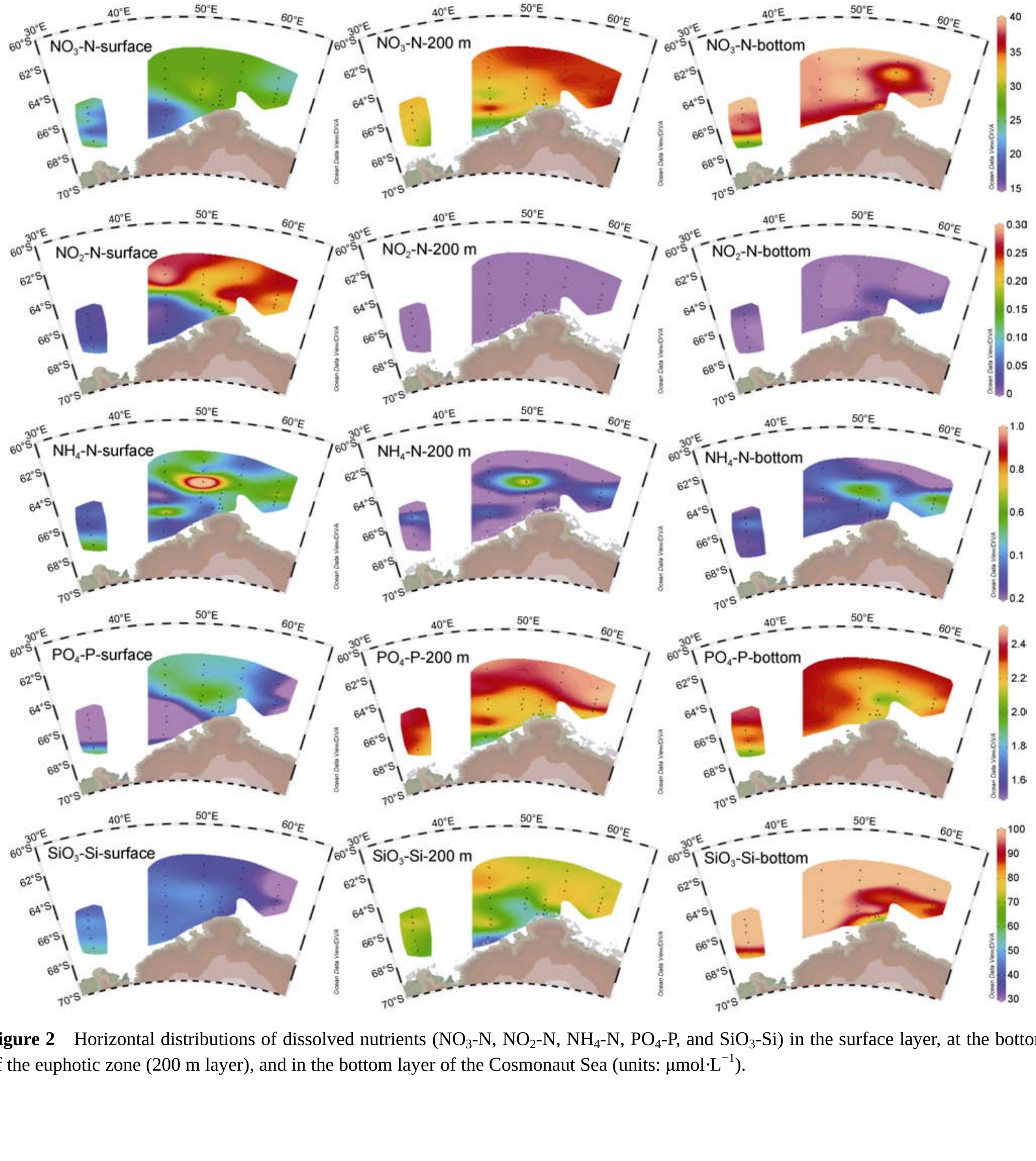

Figure 2 Horizontal distributions of dissolved nutrients (NO_3-N, NO_2-N, NH_4-N, PO_4-P, and SiO_3-Si) in the surface layer, at the bottom of the euphotic zone (200 m layer), and in the bottom layer of the Cosmonaut Sea (units: μmol·L^{-1}).

concentrations in the bottom water were generally higher near the shore and lower in the open ocean, unlike the concentrations in the surface layer. Significantly lower PO_4-P and SiO_3-Si concentrations and higher NO_2-N concentrations were found in the ice-edge region between 55°E and 60°E than elsewhere.

3.3 Vertical dissolved nutrient distributions

The vertical NO_3-N and PO_4-P concentration distributions were similar (Figures 3 and 6), the concentrations gradually increasing moving down from the surface layer to the 200 m layer and then remaining stable at >200 m. The NO_2-N concentration decreased rapidly as depth increased and was ~0 μmol·L^{-1} at >150 m deep (Figure 4). The maximum NH_4-N concentration was generally reached at 75–200 m deep, then the concentration decreased slightly as depth increased and then remained stable as the depth increased further (Figure 5). The NO_3-N, NO_2-N, NH_4-N, and PO_4-P concentrations at >200 m deep were 33.73±3.51, 0±0.01, 0.26±0.13, and 2.28±0.10 μmol·L^{-1}, respectively. In contrast, the SiO_3-Si concentration increased as depth increased and was highest in the bottom layer (Figure 7), the concentrations being 78.46±12.67 μmol·L^{-1} at 200–1000 m deep and 100.40±10.59 μmol·L^{-1} at >1000 m deep. Along transects C4 and C5, the NO_3-N, NH_4-N, PO_4-P, and SiO_3-Si concentrations near the 100 m layer were all higher between 62.5°S and 64°S than further south. This may have been because large inputs of dissolved nutrients caused by CDW upwelling (Meijers et al., 2010) affected the nutrient concentration distributions.

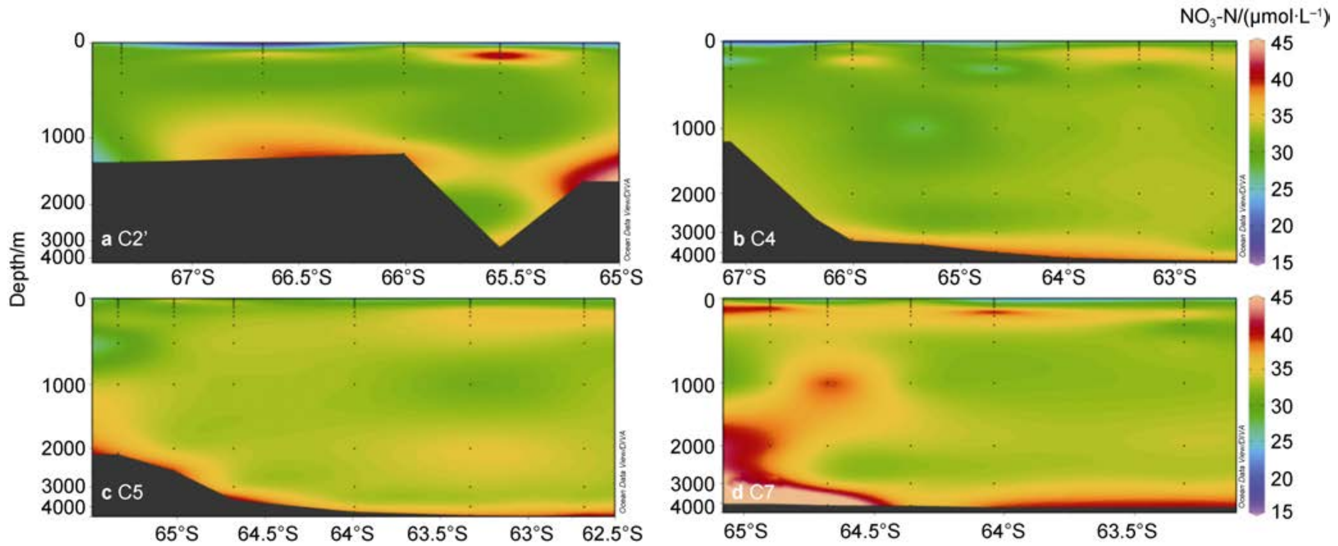

Figure 3 Vertical nitrate (NO_3-N) distribution along transect C2' (**a**), transect C4 (**b**), transect C5 (**c**), and transect C7 (**d**) in the Cosmonaut Sea.

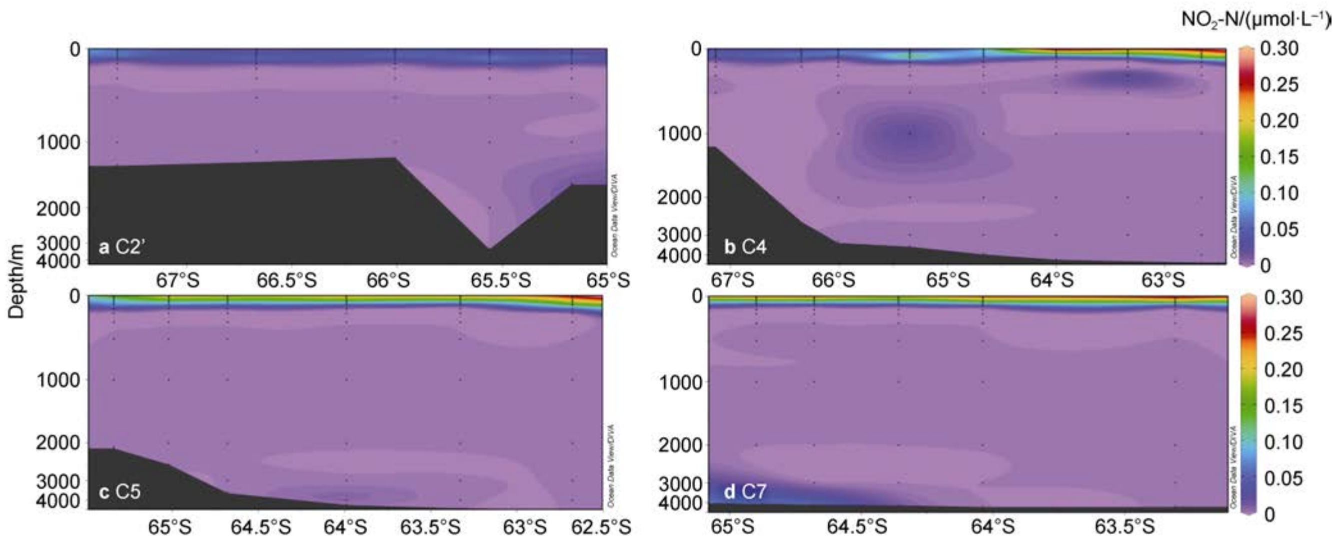

Figure 4 Vertical nitrite (NO_2-N) distribution along transect C2' (**a**), transect C4 (**b**), transect C5 (**c**), and transect C7 (**d**) in the Cosmonaut Sea.

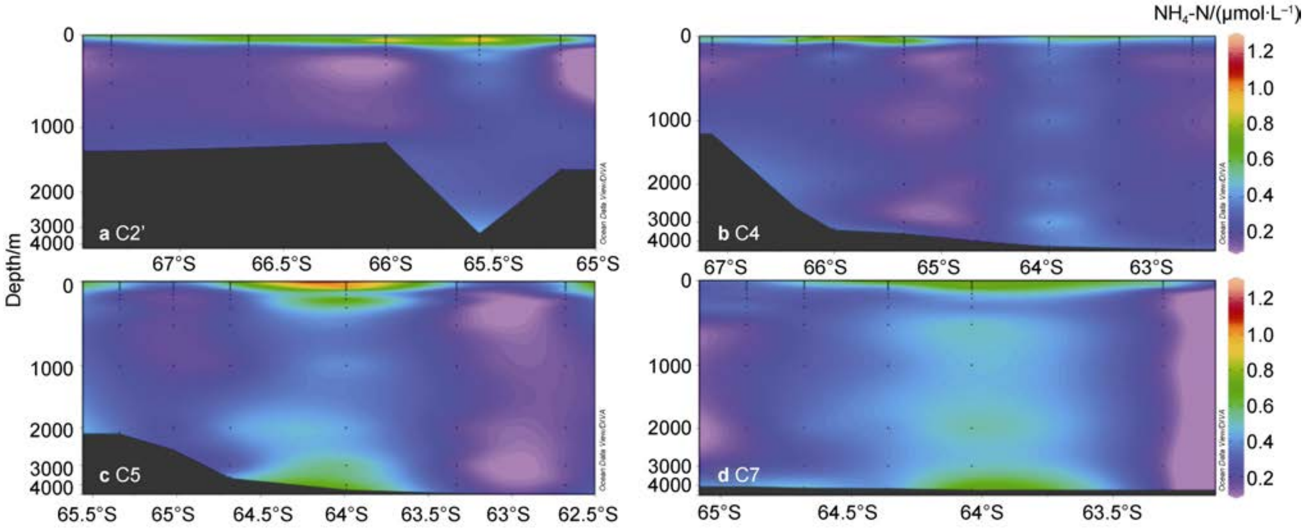

Figure 5 Vertical ammonium (NH_4-N) distribution along transect C2’ (**a**), transect C4 (**b**), transect C5 (**c**), and transect C7 (**d**) in the Cosmonaut Sea.

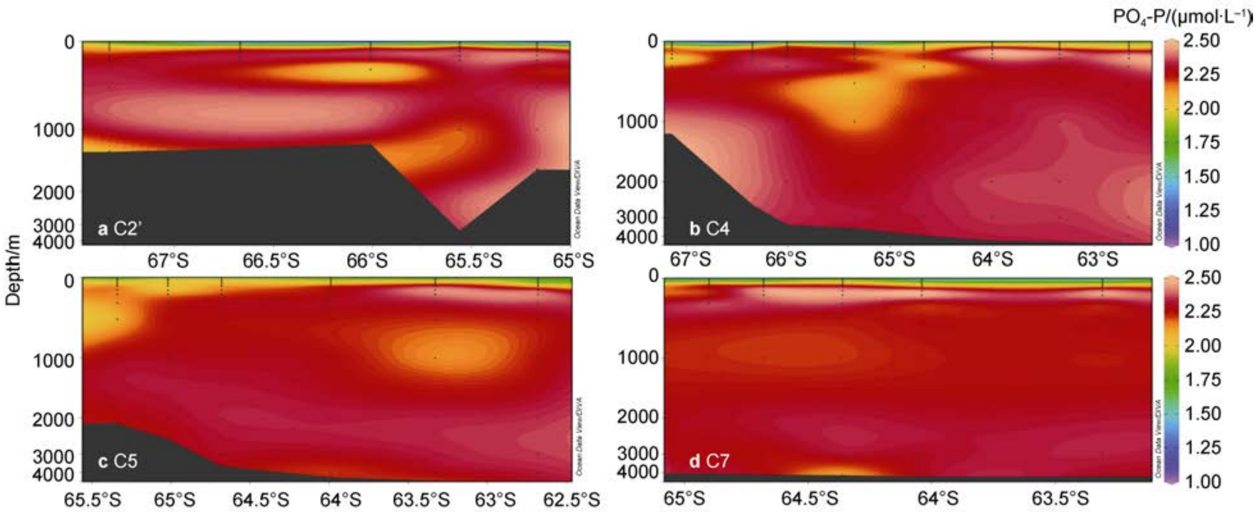

Figure 6 Vertical phosphate (PO_4-P) distribution along transect C2’ (**a**), transect C4 (**b**), transect C5 (**c**), and transect C7 (**d**) in the Cosmonaut Sea.

4 Summary

We investigated the spatial characteristics of dissolved nutrient concentrations in the Cosmonaut Sea during the 37th CHINARE in the austral summer of 2021. The sample analyses gave good quality data, and the RSDs for the NO_3-N, NO_2-N, NH_4-N, PO_4-P, and SiO_3-Si concentrations found in duplicate samples (n=2) were better than required. The horizontal NO_3-N, NO_2-N, NH_4-N, and PO_4-P concentration distributions in the mixed layer were similar, increasing gradually from southwest to northeast of the SB. The SiO_3-Si concentration distribution followed the opposite trend. This indicated that circulation strongly affected the nutrient distributions in the mixed layer. The NO_3-N and PO_4-P concentrations gradually increased moving down from the surface to 200 m deep and then remained stable moving further down. The NO_2-N concentration decreased rapidly as depth increased and was ~0 μmol·L^{-1} at >150 m deep. The maximum NH_4-N concentration was generally at 75–200 m deep. The SiO_3-Si concentration increased as depth increased and reached a maximum in the bottom layer. We found that CDW upwelling locally affects the vertical distributions of dissolved nutrients. The dissolved nutrient concentrations were generally higher than the limiting concentrations throughout the study area, indicating that no macronutrient limitation occurred in the Cosmonaut Sea in the austral summer of 2021, similar to results in the BROKE-West survey. The data will be useful for reference in future studies of nutrient dynamics and ecosystems in the Cosmonaut Sea.

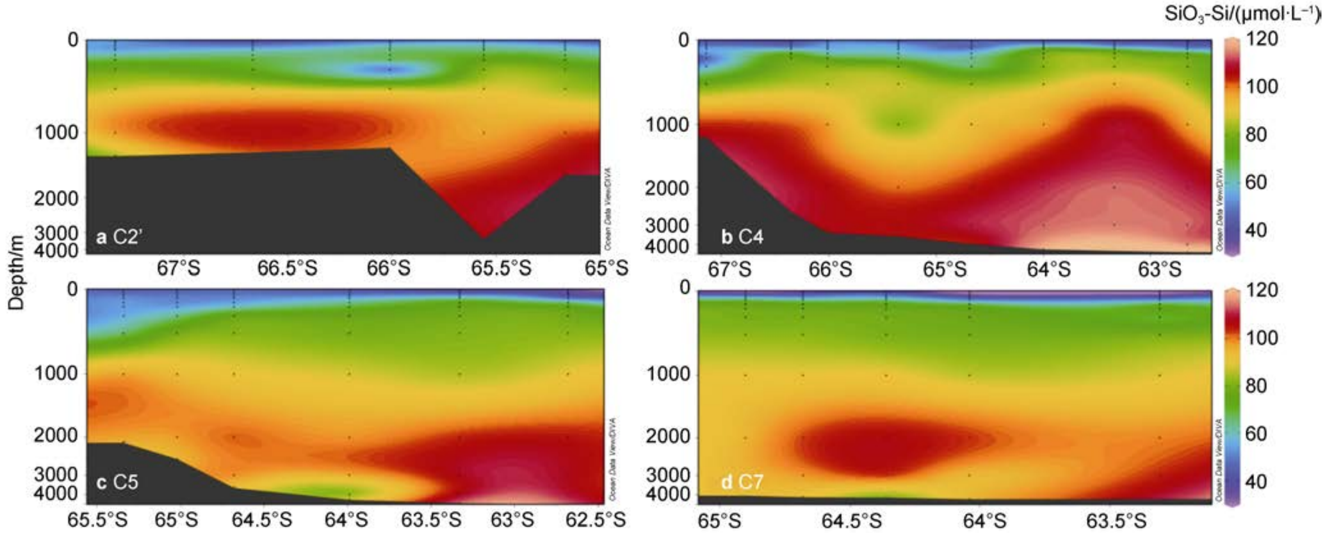

Figure 7 Vertical silicate (SiO_3-Si) distribution along transect C2' (**a**), transect C4 (**b**), transect C5 (**c**), and transect C7 (**d**) in the Cosmonaut Sea.

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Supporting Information

Text S1 operational quality supervision

The whole polar field operation and sample analysis follow the operational quality supervision, including human, machine, sample, method, and environment. The “human” means all executors on sampling and analyzing of dissolved nutrients have received professional train for the projects; “machine” means all instruments for sampling and analyzing of dissolved nutrients have been verified and calibrated during the investigation, and all measuring instruments are traceable to their sources using comparison and relevant documents; “sample” means all related processes, including sampling, storage, and transportation of dissolved nutrients, are strictly carried out by relevant provisions; “method” means corresponding rules and regulations are followed during the whole process on sampling and analyzing of dissolved nutrients, including laboratory management regulations, equipment operating procedures, and investigation operation standards and norms; and “environment” means the environment for sampling, analysis and storage of dissolved nutrients are clean and in order.

Table S1 The concentrations of dissolved nutrients (NO_3-N, NO_2-N, NH_4-N, PO_4-P and SiO_3-Si) in the Cosmonaut Sea of the whole water depth

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
C7-06	59.92°E	64.90°S	4056	5	28.73	0.22	0.45	1.51	28.27
				25	25.95	0.20	0.29	1.58	31.36
				50	31.44	0.15	0.28	2.12	46.02
				75	33.67	0.07	0.43	2.21	55.73
				100	44.40	0.02	0.21	2.32	68.47
				150	37.26	—	0.37	2.15	76.31
				200	35.96	—	0.23	2.23	77.99
				300	34.51	—	0.36	2.39	79.31
				500	33.59	—	0.17	2.29	82.21
				1000	33.23	—	0.21	2.23	90.26
				2000	39.53	—	0.17	2.30	94.96
C7-05	59.95°E	64.68°S	4179	5	24.86	0.25	0.47	1.57	30.37
				25	27.30	0.18	0.53	1.70	36.56
				50	30.14	0.15	0.55	1.92	44.98
				75	32.36	0.09	0.29	2.19	50.78
				100	35.07	—	0.40	2.39	63.41
				150	36.46	—	0.27	2.47	74.72
				200	35.55	—	0.29	2.42	77.48
				300	35.22	—	0.24	2.35	79.56
				500	34.63	—	0.28	2.27	82.10
				1000	40.15	—	0.28	2.22	89.77
				2000	34.41	—	0.35	2.32	102.85
				3000	35.14	—	0.27	2.26	97.74
				4156	53.98	0.05	0.49	2.29	91.96
C7-04	60.02°E	64.36°S	4215	5	27.68	0.20	0.71	1.78	39.48
				25	29.19	0.16	0.77	1.91	41.68
				50	36.42	0.15	0.52	1.96	46.59
				75	32.20	0.09	0.40	2.21	54.07
				100	34.55	—	0.38	2.35	65.27
				150	35.87	—	0.35	2.45	74.95

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
				200	34.84	—	0.31	2.45	76.32
				300	34.80	—	0.37	2.38	78.96
				500	32.86	—	0.40	2.25	79.81
				1000	32.62	—	0.36	2.22	90.87
				2000	33.97	—	0.39	2.33	106.88
				3000	34.43	—	0.40	2.33	105.00
				4207	36.32	0.01	0.41	2.11	79.86
C7-03	60.08°E	64.04°S	4359	5	23.29	0.24	0.62	1.44	24.63
				25	25.13	0.21	0.72	1.63	26.05
				50	29.00	0.17	0.84	1.97	37.73
				75	28.63	0.15	0.71	1.99	39.65
				100	30.83	—	0.63	2.09	48.14
				150	44.07	—	0.43	2.52	71.16
				200	35.59	—	0.46	2.50	74.38
				300	34.93	—	0.36	2.20	77.14
				500	32.66	—	0.50	2.28	79.29
				1000	32.29	—	0.47	2.25	85.85
				2000	33.56	—	0.53	2.31	103.37
				3000	33.88	—	0.49	2.30	93.48
				4343	39.60	—	0.73	2.31	95.36
C7-02	59.91°E	63.31°S	4347	5	24.50	0.26	0.55	1.55	26.25
				25	25.54	0.24	0.25	1.44	26.79
				50	34.61	0.21	0.90	1.90	36.58
				75	27.63	0.16	0.35	1.97	40.91
				100	30.89	—	0.18	2.15	50.30
				150	35.56	—	0.15	2.47	71.82
				200	35.32	—	0.17	2.47	75.61
				300	30.06	—	0.14	2.22	67.45
				500	33.07	—	0.18	2.28	80.34
				1000	32.51	—	0.15	2.25	88.90
				2000	33.97	—	0.17	2.32	99.85
				3000	34.31	—	0.14	2.34	104.19
				4326	40.94	—	0.17	2.30	110.18
C6-01	55.02°E	62.67°S	4992	5	27.34	0.23	0.35	1.82	37.45
				25	33.17	0.24	0.30	1.73	36.64
				50	27.20	0.18	0.26	1.84	36.46
				75	28.31	0.17	0.33	2.01	41.91
				100	31.52	0.08	0.18	2.23	53.93
				150	35.60	—	0.14	2.49	71.50
				200	35.58	—	0.15	2.46	74.37
				300	34.72	—	0.12	2.44	77.67
				500	32.93	—	0.12	2.27	80.42
				1000	22.99	—	0.13	2.11	60.69

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
				2000	33.56	—	0.15	2.33	106.70
				3000	33.40	—	0.14	2.35	102.21
				4000	33.79	—	0.35	2.33	112.40
				4962	38.36	—	0.16	2.31	124.14
C6-02	55.01°E	63.35°S	4868	5	26.56	0.22	0.46	1.77	35.29
				25	17.89	0.13	0.40	1.49	22.87
				50	27.80	0.15	0.45	1.96	40.63
				75	30.05	0.17	0.38	2.12	47.80
				100	25.96	0.01	0.19	2.04	47.18
				150	32.67	—	0.22	2.19	64.21
				200	35.26	—	0.23	2.44	76.01
				300	32.40	—	0.18	2.34	75.47
				500	33.19	—	0.14	2.27	81.21
				1000	44.34	—	0.19	2.21	88.78
				2000	28.99	—	0.17	2.16	92.70
				3000	34.49	—	0.25	2.15	102.17
				4000	39.21	—	0.22	2.34	112.95
				4852	32.61	—	0.37	2.27	99.04
C6-03	54.98°E	63.99°S	4454	5	26.96	0.25	0.59	1.86	40.19
				25	23.61	0.19	0.58	1.74	33.17
				50	28.17	0.19	0.48	1.84	40.00
				75	31.80	0.11	0.34	2.21	55.19
				100	35.07	0.02	0.27	2.44	69.62
				150	34.41	—	0.27	2.34	73.50
				200	35.56	—	0.28	2.40	78.09
				300	41.82	—	0.27	2.33	79.30
				500	37.58	—	0.27	2.27	82.93
				1000	32.23	—	0.31	2.22	93.24
				2000	32.96	—	0.24	2.31	109.23
				3000	32.09	—	0.33	2.19	105.11
				4444	35.89	—	0.31	2.18	88.98
C5/6-05	52.60°E	64.66°S	4079	5	28.63	0.27	0.43	1.95	43.82
				25	29.46	0.16	0.25	1.94	46.14
				50	29.32	0.16	0.33	1.95	46.50
				75	33.07	0.09	0.27	2.25	61.54
				100	33.89	0.03	0.18	2.32	70.87
				150	34.03	—	0.18	2.32	75.05
				200	33.57	—	0.16	2.22	76.25
				300	27.80	—	0.15	2.10	67.65
				500	31.70	—	0.17	2.19	84.41
				1000	32.53	—	0.15	2.26	98.61
				2000	30.03	—	0.59	2.04	87.52
				3000	32.34	—	0.46	2.22	102.22
				4043	37.32	0.03	0.51	2.02	86.93

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
C5/6-06	52.50°E	65.03°S	2999	5	27.59	0.20	0.53	1.81	43.66
				25	29.00	0.18	0.40	1.91	44.81
				50	38.28	0.15	0.35	1.96	45.74
				75	33.07	0.07	1.38	2.16	55.15
				100	26.59	0.01	1.53	2.00	44.55
				150	27.26	—	1.58	2.08	50.81
				200	34.00	—	0.21	2.26	72.98
C5/6-07	52.59°E	65.36°S	2793	5	28.27	0.18	0.42	1.85	44.26
				25	25.64	0.16	0.41	1.65	38.96
				50	29.48	0.12	0.46	1.94	46.33
				75	29.55	0.08	0.41	2.02	48.56
				100	32.66	0.05	0.30	2.15	54.72
				150	32.52	—	0.19	2.16	55.92
				200	33.04	—	0.27	2.15	58.38
				300	31.25	—	0.21	2.19	67.50
				500	33.17	—	0.26	2.23	82.13
				1000	33.00	—	0.22	2.26	98.48
				2000	33.27	—	0.29	2.25	105.55
				2783	39.38	—	0.36	2.26	105.48
C5/6-08	52.48°E	65.64°S	570	5	28.27	0.15	0.55	1.85	44.31
				25	28.31	0.14	0.49	1.89	44.90
				50	28.68	0.05	0.49	1.96	49.08
				75	32.05	0.04	0.40	2.13	54.06
				100	32.60	0.02	0.43	2.13	54.95
				150	32.55	—	0.33	2.15	55.77
				200	30.64	—	0.29	2.10	54.30
				300	29.36	—	0.23	2.04	55.28
				510	42.02	—	0.30	2.21	84.90
C5/6-09	52.95°E	65.60°S	456	5	28.18	0.18	0.53	1.81	38.84
				25	24.98	0.11	0.60	1.78	39.38
				50	28.81	0.05	0.40	1.94	50.05
				75	27.39	0.06	0.55	1.92	44.42
				100	32.20	0.03	0.87	2.13	53.90
				150	33.47	0.02	1.10	2.04	48.66
				200	30.81	—	0.18	2.12	54.45
				300	30.87	—	0.18	2.14	64.69
				435	27.22	—	0.23	2.10	64.71
C5’-08	51.57°E	65.65°S	1345	5	27.29	0.09	0.22	1.76	45.07
				25	26.88	0.06	0.18	1.74	45.11
				50	28.55	0.06	0.72	1.93	48.34
				75	29.20	0.06	0.77	1.99	49.15
				100	37.40	0.06	0.79	2.06	51.44
				150	30.79	0.02	0.63	2.14	53.37

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
				200	32.08	—	0.16	2.18	54.83
				300	28.70	—	0.12	2.08	52.02
				500	31.21	—	0.17	2.11	75.76
				1000	33.49	—	0.16	2.29	98.95
				1314	35.35	0.02	0.23	2.14	82.32
C5-07	49.90°E	65.34°S	2117	5	28.34	0.13	0.47	1.87	45.84
				25	28.74	0.14	0.46	1.85	45.52
				50	29.00	0.11	0.50	1.94	46.76
				75	30.97	0.06	0.48	2.09	51.07
				100	31.68	0.10	0.34	2.20	52.64
				150	31.72	0.01	0.21	2.16	53.39
				200	32.48	—	0.22	2.16	53.89
				300	32.45	—	0.30	2.15	55.66
				500	27.87	—	0.22	2.09	65.70
				1000	34.08	—	0.25	2.30	97.56
				2092	38.41	—	0.35	2.27	96.53
C5-06	49.79°E	65.02°S	2504	5	30.17	0.18	0.36	1.96	46.67
				25	39.76	0.22	0.36	1.93	44.57
				50	29.28	0.14	0.34	1.99	47.46
				75	32.13	0.10	0.26	2.15	52.18
				100	30.43	0.08	0.19	1.92	50.08
				150	31.08	—	0.18	2.05	51.24
				200	32.35	—	0.17	2.18	54.44
				300	32.51	—	0.18	2.24	64.04
				500	33.06	—	0.17	2.28	79.76
				1000	33.48	—	0.18	2.30	93.56
				2000	33.63	—	0.22	2.30	97.68
				2503	39.77	—	0.24	2.28	94.82
C5-05	50.01°E	64.68°S	3568	5	29.51	0.18	0.59	1.96	47.19
				25	29.94	0.18	0.67	1.95	47.42
				50	36.27	0.18	0.51	1.96	47.49
				75	31.13	0.06	0.55	2.10	50.87
				100	32.37	0.08	0.29	2.16	52.52
				150	31.94	—	0.27	2.17	53.18
				200	33.29	—	0.25	2.21	59.95
				300	33.38	—	0.22	2.30	78.02
				500	33.64	—	0.25	2.26	80.77
				1000	33.11	—	0.18	2.29	90.46
				2000	33.78	—	0.42	2.34	102.28
				3000	33.99	—	0.24	2.31	99.62
				3520	41.25	—	0.42	2.29	93.88
C5-03	50.05°E	63.99°S	4443	5	28.93	0.20	1.37	1.92	46.22
				25	25.78	0.18	0.53	1.83	40.92

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
				50	28.88	0.19	1.23	1.93	46.53
				75	30.80	0.11	1.24	2.06	51.68
				100	32.35	0.04	0.46	2.33	56.33
				150	32.87	—	0.35	2.22	64.27
				200	33.26	—	0.85	2.26	68.80
				300	33.89	—	0.53	2.31	76.55
				500	33.57	—	0.39	2.26	79.27
				1000	33.08	—	0.42	2.29	88.46
				2000	33.68	—	0.45	2.33	97.73
				3000	33.93	—	0.59	2.30	97.38
				4000	33.22	0.01	0.61	2.19	75.28
				4417	39.78	—	0.70	2.26	93.80
C5-02	50.03°E	63.33°S	4853	5	27.26	0.21	0.31	1.81	37.90
				25	27.54	0.21	0.45	1.83	38.28
				50	29.39	0.13	0.48	1.99	43.84
				75	32.85	0.13	0.33	2.23	55.92
				100	33.62	—	0.19	2.37	64.80
				150	35.99	—	0.14	2.46	74.14
				200	35.22	—	0.24	2.40	76.56
				300	34.99	—	0.13	2.32	78.62
				500	34.05	—	0.13	2.23	81.09
				1000	31.09	—	0.18	2.14	84.75
				2000	34.96	—	0.16	2.34	104.35
				3000	34.09	—	0.14	2.33	109.07
				4000	33.94	—	0.21	2.31	107.73
				4834	38.84	—	0.27	2.21	115.29
C5-01	50.04°E	62.68°S	5000	5	27.86	0.26	0.59	1.83	37.17
				25	27.42	0.25	0.47	1.78	36.94
				50	27.63	0.21	0.41	1.81	36.37
				75	35.38	0.17	0.44	1.90	39.49
				100	29.64	0.18	0.51	2.03	43.91
				150	36.53	0.04	0.35	2.45	68.93
				200	35.94	—	0.14	2.40	74.82
				300	34.57	—	0.21	2.36	77.85
				500	32.95	—	0.18	2.27	81.64
				1000	32.82	—	0.15	2.26	89.94
				2000	33.84	—	0.16	2.35	105.14
				3000	33.79	—	0.16	2.36	107.81
				4000	34.17	—	0.16	2.33	109.08
				4984	41.63	—	0.25	2.31	113.88
C4-01	45.07°E	62.66°S	4749	5	27.16	0.27	0.48	1.88	40.90
				25	27.84	0.26	0.46	1.91	41.99
				50	28.61	0.18	0.37	1.94	41.46

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
				75	36.10	0.19	0.37	2.07	45.66
				100	30.94	0.17	0.33	2.19	52.19
				150	34.66	—	0.17	2.46	73.58
				200	34.73	—	0.18	2.45	78.17
				300	33.55	—	0.15	2.39	79.58
				500	32.43	—	0.18	2.30	83.98
				1000	32.47	—	0.16	2.32	96.69
				2000	33.44	—	0.23	2.39	110.53
				3000	33.32	—	0.24	2.39	114.32
				4000	33.48	—	0.24	2.36	114.81
				4749	39.49	—	0.33	2.35	126.53
C4-02	45.04°E	63.34°S	4595	5	27.53	0.29	0.63	1.93	43.54
				25	27.63	0.16	0.54	1.92	43.33
				50	29.73	0.15	0.45	2.00	44.88
				75	35.75	0.17	0.33	2.06	47.89
				100	35.49	—	0.37	2.46	75.09
				150	35.36	—	0.21	2.41	79.65
				200	34.32	—	0.23	2.34	82.01
				300	30.77	—	0.18	2.28	83.13
				500	32.79	—	0.23	2.30	95.48
				1000	33.31	—	0.21	2.37	110.31
				2000	33.50	—	0.21	2.36	114.08
				3000	33.80	—	0.23	2.35	114.95
C4-03	45.02°E	64.00°S	4425	5	27.44	0.28	0.50	1.84	46.21
				25	27.73	0.25	0.58	1.92	45.91
				50	28.42	0.13	0.57	2.04	48.17
				75	32.92	0.10	0.37	2.38	67.15
				100	34.32	0.01	0.39	2.47	76.84
				150	34.00	—	0.36	2.49	79.43
				200	33.77	—	0.38	2.40	81.59
				300	33.52	—	0.36	2.32	82.87
				500	31.88	—	0.34	2.29	86.35
				1000	32.10	—	0.38	2.30	96.12
				2000	32.95	—	0.38	2.37	111.15
				3000	33.77	—	0.47	2.36	113.52
				4413	39.16	—	0.37	2.33	120.09
C4-05	45.03°E	64.67°S	3971	5	25.56	0.09	0.23	1.80	46.34
				25	25.97	0.09	0.26	1.83	46.71
				50	28.95	0.09	0.59	2.11	51.65
				75	21.17	0.08	0.33	1.97	35.70
				100	36.51	0.07	0.15	2.18	53.43
				150	30.89	—	0.17	2.21	56.87

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
				200	31.25	—	0.16	2.24	64.01
				300	25.89	—	0.17	2.05	63.11
				500	32.19	—	0.12	2.27	82.39
				1000	32.34	—	0.16	2.31	95.59
				2000	32.86	—	0.14	2.33	104.87
				3000	33.10	—	0.14	2.32	111.03
				3924	38.95	—	0.19	2.32	104.07
C4-07	45.03°E	65.35°S	3501	5	23.17	0.02	0.26	1.24	43.83
				25	22.65	0.01	0.69	1.64	47.13
				50	34.44	0.10	0.88	2.16	55.24
				75	29.95	0.13	0.66	2.22	55.96
				100	30.00	0.14	0.39	2.21	55.74
				150	30.37	—	0.18	2.25	60.41
				200	29.96	—	0.18	2.15	65.13
				300	31.91	—	0.14	2.33	81.85
				500	31.56	—	0.22	2.06	87.29
				1000	27.29	0.02	0.14	2.13	80.53
				2000	32.21	—	0.22	2.27	100.48
				3000	32.40	—	0.14	2.33	106.31
				3482	38.87	—	0.34	2.31	107.15
C4-09	45.00°E	66.01°S	3319	5	17.11	0.02	0.89	1.21	44.18
				25	33.73	0.05	0.96	2.11	53.25
				50	37.11	0.10	0.50	2.24	54.74
				75	30.39	0.04	0.28	2.20	55.29
				100	30.43	0.01	0.16	2.20	55.06
				150	31.75	—	0.26	2.24	58.66
				200	37.80	—	0.40	2.34	70.52
				300	32.03	—	0.30	2.37	80.68
				500	31.13	—	0.23	2.21	85.47
				1000	31.37	—	0.21	2.33	98.97
				2000	32.56	—	0.30	2.36	106.92
				3246	37.64	—	0.34	2.34	107.30
C4-10	44.99°E	66.35°S	2573	5	19.65	0.02	0.24	0.96	45.35
				25	19.16	0.01	0.53	1.48	30.83
				50	34.65	0.08	0.96	2.24	58.10
				75	29.61	0.05	0.42	1.91	33.34
				100	30.02	0.06	0.28	2.28	62.74
				150	31.07	—	0.16	2.33	73.84
				200	31.40	—	0.18	2.34	78.79
C4-12	44.47°E	67.14°S	1174	5	19.45	0.03	0.32	1.44	45.28
				25	21.53	0.02	0.62	1.65	47.01
				50	26.82	0.05	0.69	1.95	39.90
				75	29.36	0.05	0.23	2.19	55.14
				100	29.38	0.03	0.17	2.17	55.04

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
				150	29.92	—	0.21	2.18	54.55
				200	24.56	—	0.18	1.92	44.45
				300	29.74	—	0.13	2.23	56.17
				500	30.83	—	0.16	2.26	77.16
C2'-06	34.01°E	65.17°S	1588	5	24.48	0.02	0.33	1.23	43.47
				25	19.68	—	0.43	1.42	47.57
				50	29.52	0.02	1.17	2.18	56.97
				75	35.00	0.07	0.40	2.23	57.70
				100	31.83	0.06	0.23	2.30	61.13
				150	32.31	—	0.15	2.42	67.49
				200	32.69	—	0.11	2.37	69.85
				300	32.81	—	0.12	2.24	79.59
				500	32.49	—	0.12	2.35	83.98
				1000	33.37	—	0.27	2.40	101.65
				1578	41.83	0.01	0.25	2.40	108.27
C2'-08	33.98°E	65.56°S	3276	5	20.35	0.03	0.36	1.41	49.43
				25	22.46	0.01	0.75	1.62	50.86
				50	38.02	0.03	1.54	2.35	62.14
				75	33.12	0.06	0.39	2.34	64.74
				100	41.36	0.08	0.65	2.32	64.52
				150	43.37	0.02	0.29	2.34	68.01
				200	32.08	—	0.51	2.38	76.39
				300	31.15	—	0.35	2.34	82.14
				500	30.53	—	0.35	2.31	88.27
				1000	30.06	—	0.24	2.19	96.52
				2000	30.94	—	0.29	2.37	107.87
				3264	37.53	—	0.45	2.36	107.01
C2'-09	33.72°E	66.01°S	1194	5	25.54	0.04	0.25	1.23	46.95
				25	21.49	0.02	0.48	1.49	49.37
				50	41.73	0.06	1.47	2.25	60.30
				75	30.93	0.05	0.74	2.28	63.94
				100	31.52	0.04	0.22	2.30	65.11
				150	31.82	—	0.21	2.34	65.63
				200	31.58	—	0.18	2.30	70.68
				300	29.44	—	0.07	1.94	44.85
				500	32.23	—	0.12	2.32	87.13
				1000	32.80	—	0.15	2.37	102.04
				1194	38.22	—	0.26	2.21	99.68
C2'-11	33.71°E	66.67°S	1256	5	18.15	0.02	0.41	1.32	46.97
				25	15.74	0	0.75	1.49	37.71
				50	25.25	0.04	0.99	2.12	51.00
				75	29.10	0.04	0.37	2.16	51.55
				100	38.69	0.07	0.29	2.28	62.04
				150	31.46	—	0.22	2.30	64.34

Continued

Station	Longitude	Latitude	Water depth /m	Sample depth /m	NO_3-N /(μmol·L^{-1})	NO_2-N /(μmol·L^{-1})	NH_4-N /(μmol·L^{-1})	PO_4-P /(μmol·L^{-1})	SiO_3-Si /(μmol·L^{-1})
				200	31.50	–	0.21	2.34	69.50
				300	28.96	–	0.18	2.23	71.45
				500	31.77	–	0.18	2.33	88.60
				1120	38.40	–	0.24	2.35	105.07
C2’-13	33.72°E	−67.33°S	1308	5	24.73	0.06	0.57	1.80	54.03
				25	26.60	0.06	0.58	1.88	55.11
				50	25.21	0.05	0.50	2.01	51.33
				75	39.30	0.10	0.29	2.19	56.47
				100	23.55	0.01	0.23	2.11	49.55
				150	30.43	–	0.15	2.26	64.68
				200	30.65	–	0.19	2.27	67.92
				300	30.73	–	0.14	2.33	78.24
				500	31.00	–	0.17	2.35	86.26
				1000	30.64	–	0.21	2.33	98.55
				1300	28.18	–	0.25	2.08	84.39

Note: “–” means below the detection limit. Parallel samples (see Table 1 for detailed information) were presented with mean values.

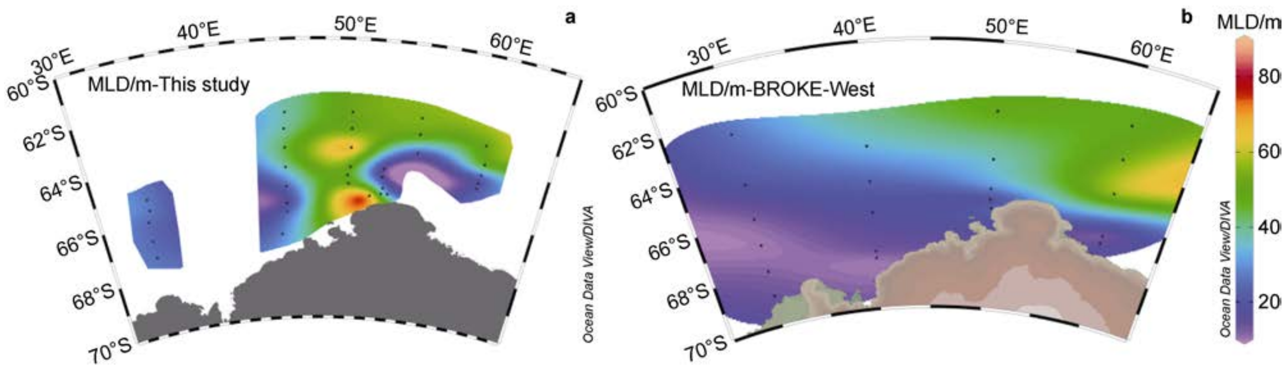

Figure S1 The horizontal distribution of the mixed layer depth (MLD) in the Cosmonaut Sea from this study (**a**) and BROKE-West survey (**b**, 22 stations between 30°E and 60°E were selected) (Westwood et al., 2010).

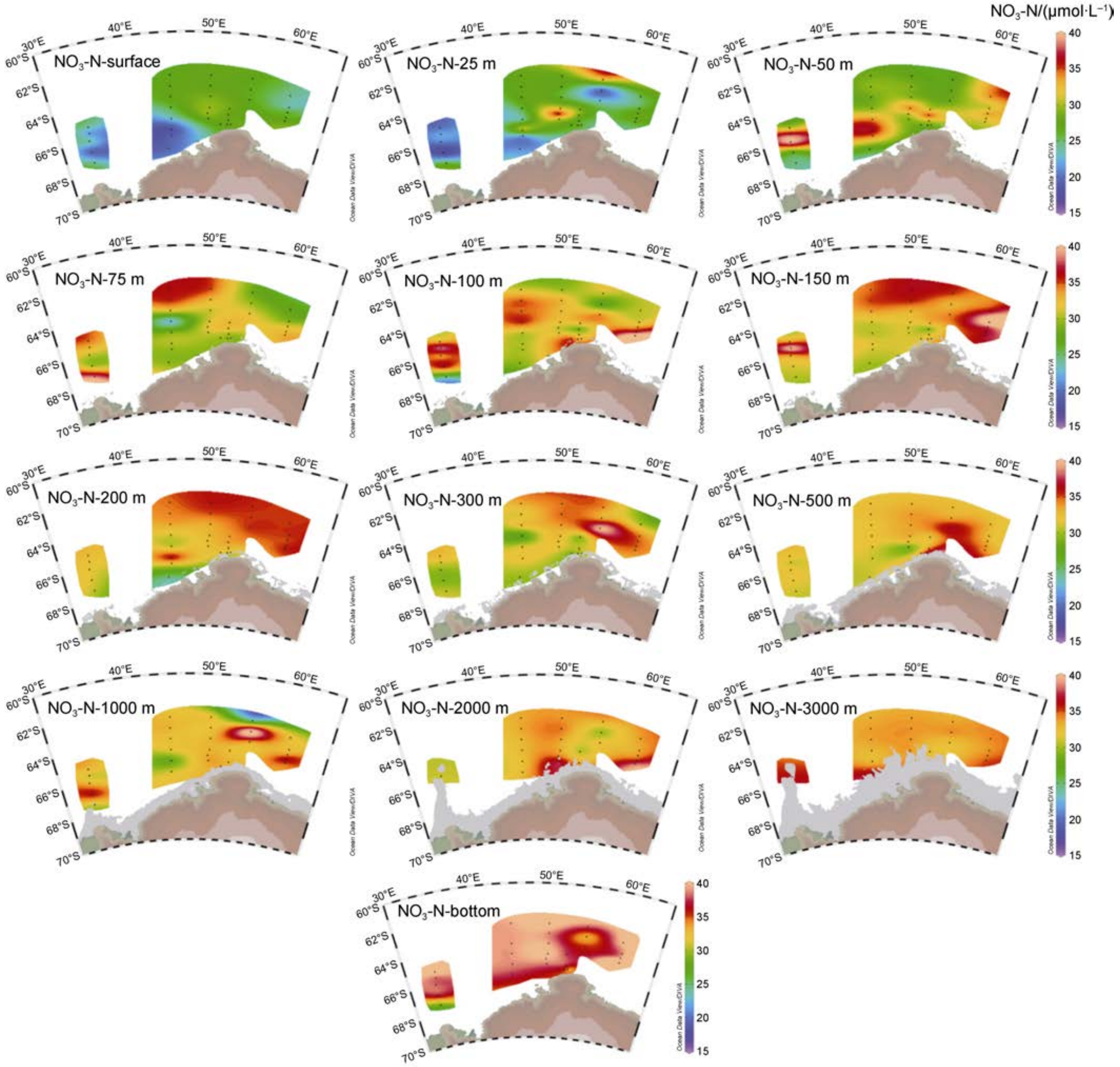

Figure S2 The concentrations of nitrate (NO_3-N) in the Cosmonaut Sea of the whole water depth.

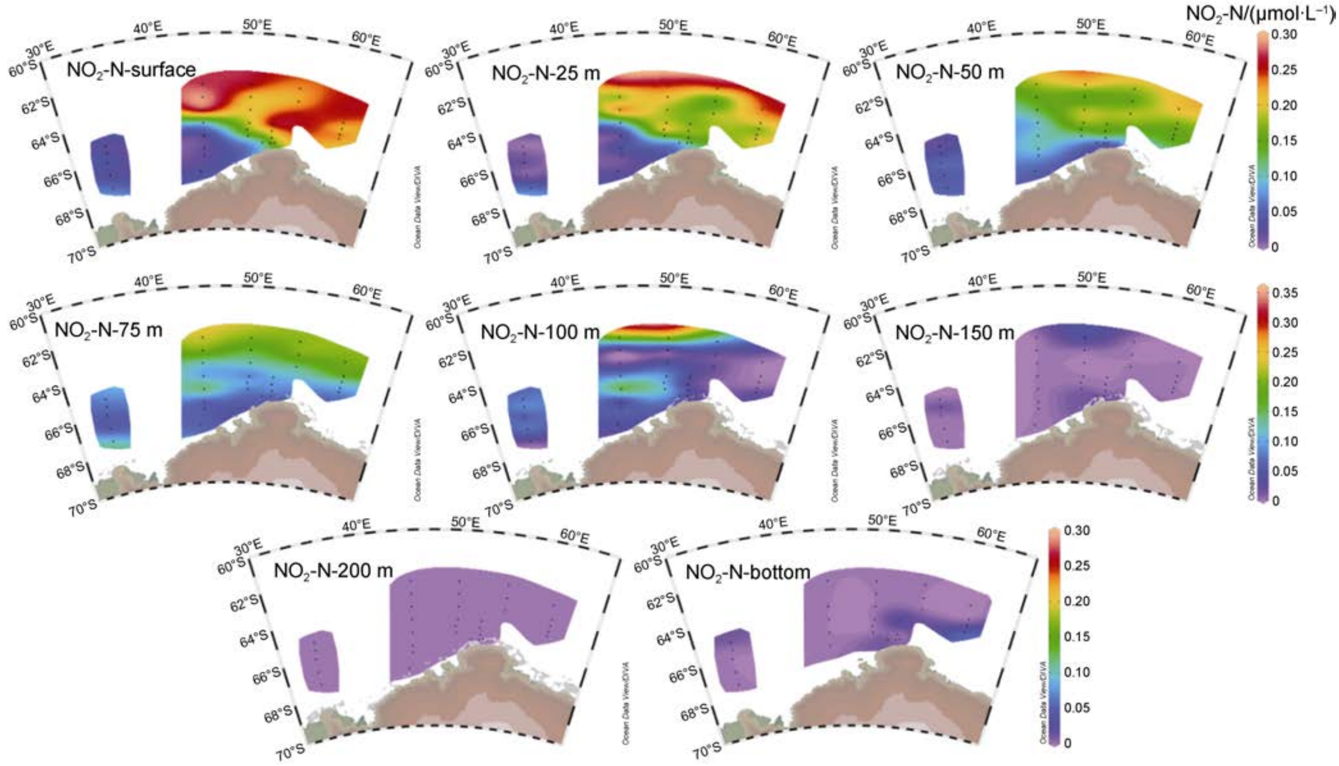

Figure S3 The concentrations of nitrite (NO_2-N) in the Cosmonaut Sea above 200 m (the concentrations of NO_2-N below 200 m were lower than the detection limits and therefore were not shown here) and the bottom layer.

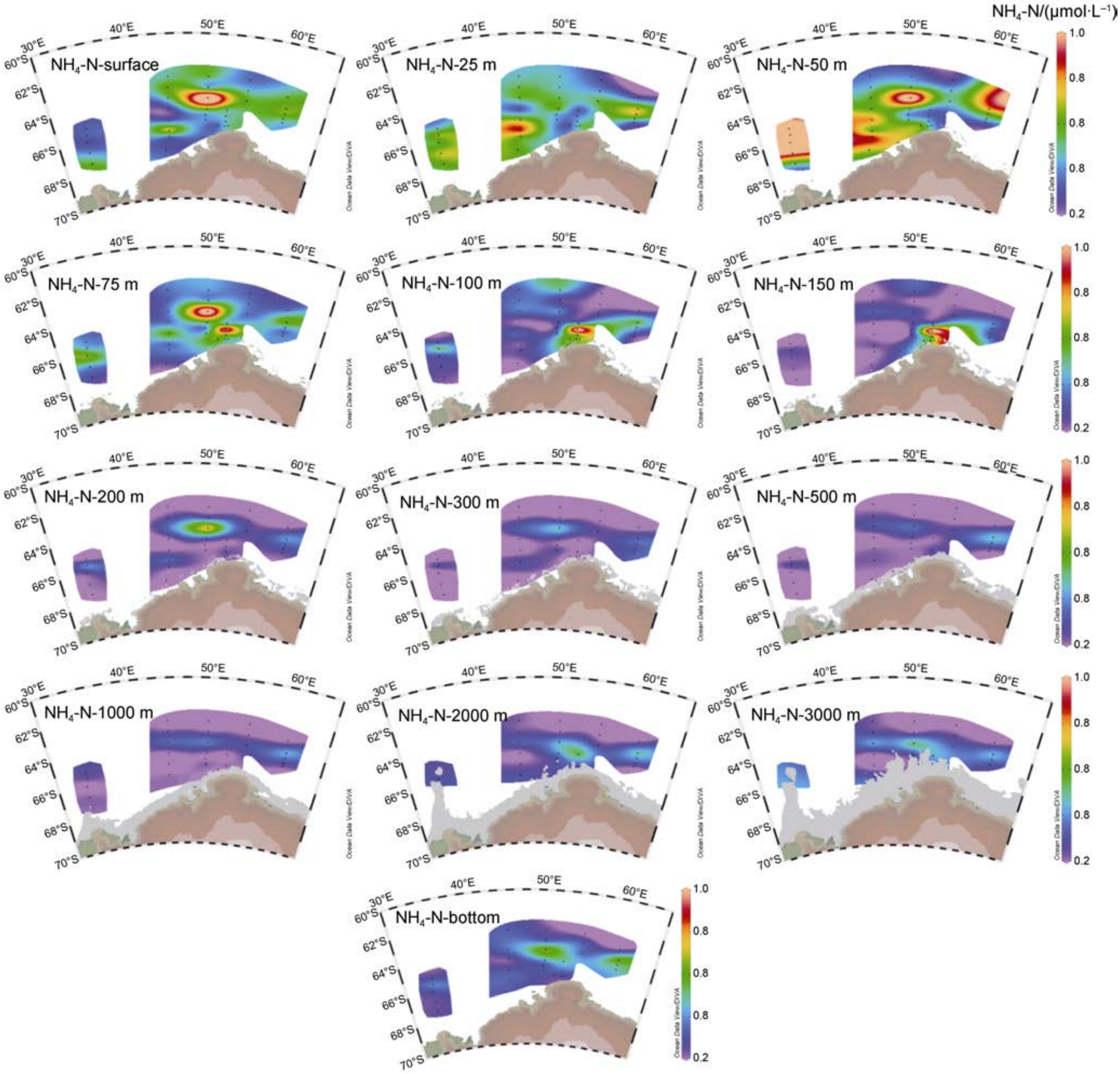

Figure S4 The concentrations of ammonium (NH_4-N) in the Cosmonaut Sea of the whole water depth.

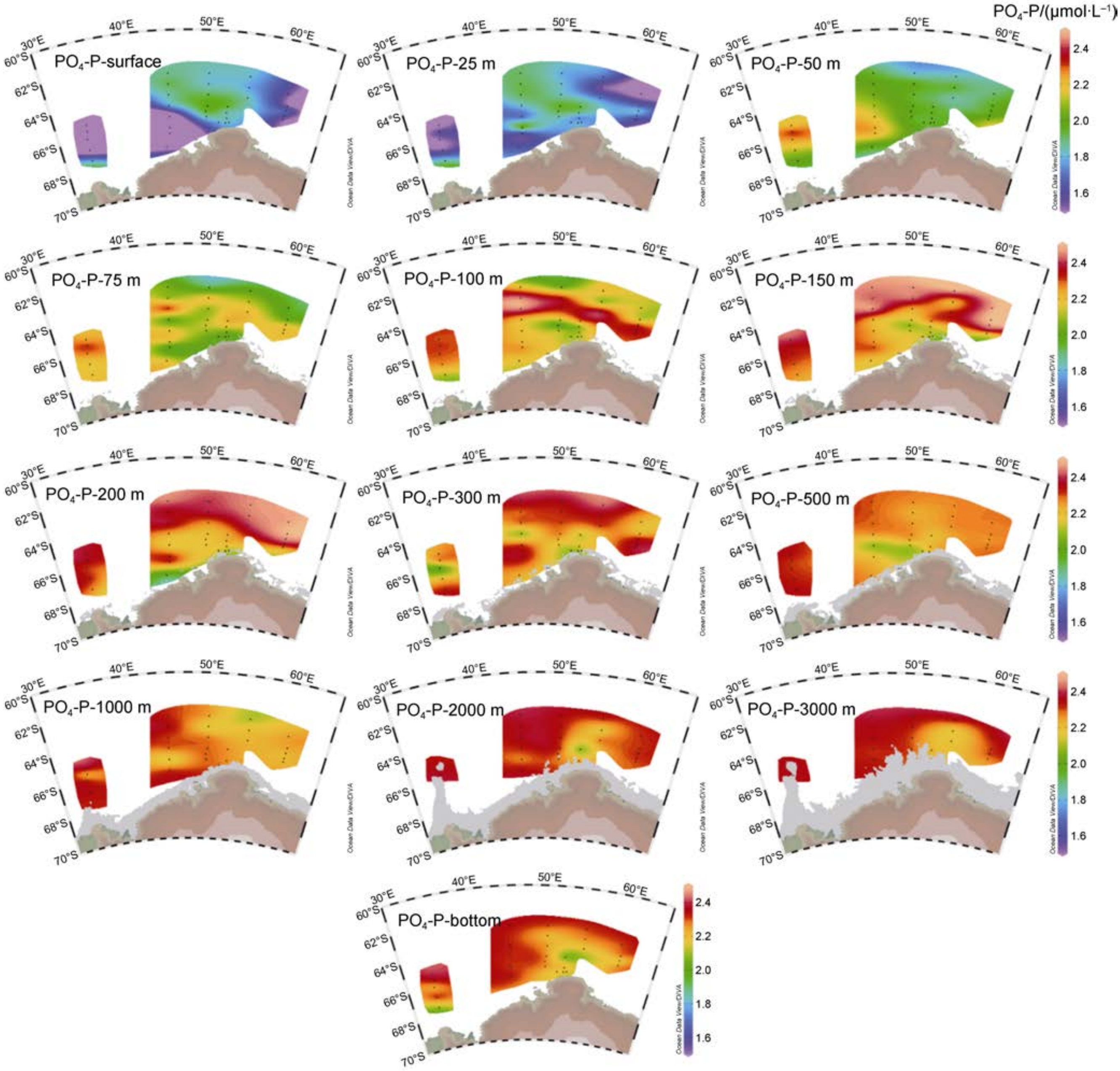

Figure S5 The concentrations of phosphate (PO_4-P) in the Cosmonaut Sea of the whole water depth.

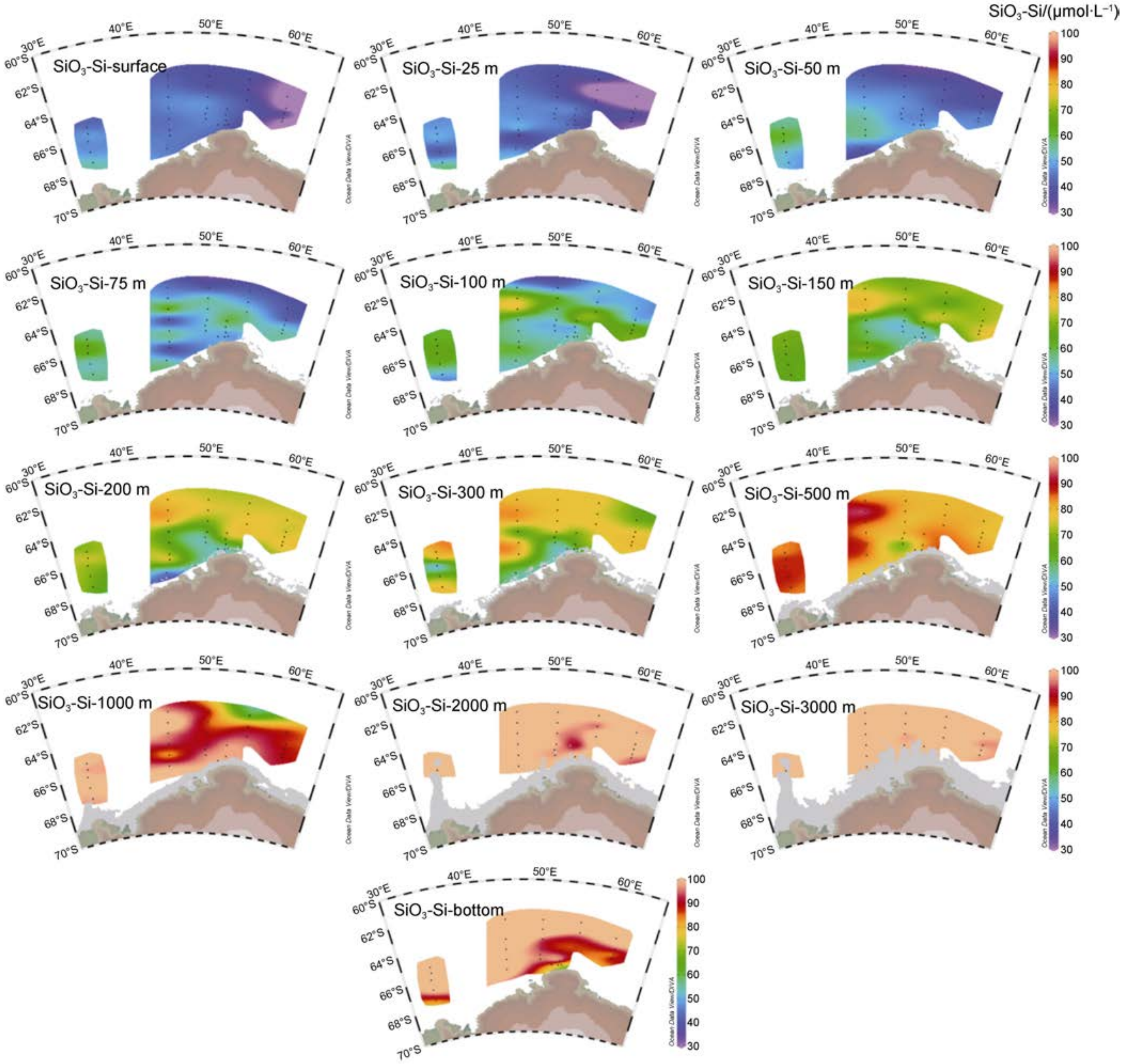

Figure S6 The concentrations of silicate (SiO_3-Si) in the Cosmonaut Sea of the whole water depth.