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Chlorophyll *a* and macro-nutrient concentrations and photosynthetically active radiation during the training vessel *Umitaka-maru* cruise of the 59th Japanese Antarctic Research Expedition in January 2018

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Abstract: Chlorophyll *a* concentration is the most common indicator of phytoplankton biomass, fundamentally regulated by macro-nutrients and light intensity. Therefore, long term monitoring of these parameters gives us basic information on ecosystem changes with climate changes. As part of the monitoring programs of the Japanese Antarctic Research Expedition (JARE), chlorophyll *a* concentration and macro-nutrients (nitrate, nitrite, phosphate and silicic acid) have been measured on board icebreakers *Fuji* and *Shirase* since JARE-14 (1972/73 season) and JARE-7 (1965/66 season), respectively. The same monitoring has also been conducted during the cruise of the training vessel (T/V) *Umitaka-maru*, Tokyo University of Marine Science and Technology since JARE-55 (2013/14 season). *Umitaka-maru* takes almost same course every year; after leaving Fremantle, goes down to sea ice edge (ca. 65°S) along 110°E meridian and then goes back to Hobart. The course thus covers sub-tropical to polar waters in the Southern Ocean. During the cruise, water sampling from underway pump for chlorophyll *a* and macro-nutrient concentrations were obtained twice a day, and photosynthetically active radiation was continuously measured by a sensor mounted on the navigation bridge deck of the ship. The vertical water sampling for chlorophyll *a* concentration was conducted at 6 stations along 110°E meridian, although concentration of macro-nutrients at the same stations

were determined by another monitoring program. This report is the latest data collected during the T/V *Umitaka-maru* cruise in 2017/18 season.

1. Background & Summary

The phytoplankton community is the main primary producer in oceanic ecosystems. Their productivity can affect not only heterotrophic communities but also air-sea CO_2 flux. Phytoplankton biomass has usually been monitored by chlorophyll *a* concentration, which is a common indicator, in various coastal and oceanic regions. In the Indian Sector of the Southern Ocean, inter-annual changes in surface chlorophyll *a* concentration were evident on a cycle of less than 10 years (Hirawake *et al.*, 2005)[1]. This means that frequent observation of chlorophyll *a* is needed for understanding ecosystem responses to not only long term climate changes (e.g. global warming) but also decadal or shorter time scale environmental changes (e.g. El Niño and Southern Annular Mode). Under such a variability in chlorophyll *a* concentration, size fractionated chlorophyll *a* measurements are important, because both global warming and changes in sea ice dynamics affect on phytoplankton size spectrum (Montes-Hugo *et al.*, 2008;[2] Daufresne *et al.*, 2009;[3] Morán *et al.*, 2010)[4]. Macro-nutrients and photosynthetically active radiation in surface mixed layer, which would also vary with climate changes, are essentials for phytoplankton growth. A model simulation from 1980 to 2100 suggested that dominant factors affecting phytoplankton biomass and their distributions vary meridionally (Marinov *et al.*, 2010)[5]. Namely, while nutrients and temperature are dominant in the equator to mid latitude regions, light intensity and temperature become dominant in the polar to subpolar regions. Therefore, these measurements with chlorophyll *a* concentration and the size composition help us for better understanding of spatio-temporal variability in phytoplankton biomass.

One of the routine observation program of the Japanese Antarctic Research Expedition (JARE), named “Biological Oceanography”, has been renamed to the monitoring observation “Marine Ecosystem Monitoring” since JARE-38. Chlorophyll *a* concentrations have been measured on board icebreakers *Fuji* and *Shirase* from JARE-14 in the 1972/73 season under routine monitoring observations. Chlorophyll *a* concentration has been closely related to water column structures (e.g., temperature and salinity) and macro-nutrients (nitrate, nitrite, silicic acid and phosphate), which have been measured under the other routine observation programs; “Physical Oceanography” and “Chemical Oceanography” started from JARE-7 in the 1965/66 season. The programs “Physical Oceanography” and “Chemical Oceanography” on *Shirase* were terminated in JARE-51 (2009/10 season) and restarted as a routine observation program “physical and chemical oceanography” using the training vessel (T/V) *Umitaka-maru*, Tokyo University of Marine Science and Technology since JARE-54 (2012/13 season). We also started the marine ecosystem monitoring during the same cruise from JARE-55 (2013/14 season).

This report mainly documents the phytoplankton chlorophyll *a* concentration in seawater at depths shallower than 200 m, measured during a cruise by the T/V *Umitaka-maru* (UM17-09) as part of the 59th Japanese Antarctic Research Expedition (JARE-59) during the austral summer of 2017/18. The chlorophyll *a* concentration was measured in two series: (1) spatial variations in chlorophyll *a* concentration within the surface water along a cruise track, and (2) vertical profiles of chlorophyll *a* in the Indian sector of the Southern Ocean.

The similar data sets collected by previous JARE have been published in JARE DATA REPORTS and this journal (e.g., Takamura *et al.*, 2016; [6] Makabe *et al.*, 2019)[7].

2. Study sites

Field sampling was conducted from Fremantle to Hobart during the UM17-09 cruise in January 2018. Surface waters from the underway pump, of which inlet was located at approx. 5 m depth, were generally sampled twice a day along the cruise track (Fig. 1). Vertical water sampling was conducted at 6 sites (KC1-6) located along 110°E meridian from 40°S to around 65°S located near the ice edge (Fig. 1). The other physical and chemical oceanographic data set during the same cruise can be downloaded from NiPR database (http://polaris.nipr.ac.jp/~parc/usr/di_list.php?pid=271).

3. Materials and methods

3.1. Chlorophyll *a*

Surface seawater was collected twice a day during the cruise from water that was continuously pumped through the vessel from an intake in the hull. At stations where water-column water sampling was performed, surface seawater was collected using a plastic bucket. Water samples were collected over the upper 200 m of the water column by Niskin bottles attached to CTD/Carousel Water Sampling System, which is a 24-position Carousel water sampler with CTD (SBE9plus, Sea-Bird Electronics, Inc.). On all occasions, water samples were collected from two dark bottles and filtered onto glass-fiber filters (Whatman, GF/F), while size-fractionated samples were collected onto membrane filters (Whatman Nuclepore Track-Etch Membrane, pore size: 10 and 2 μm) and a Whatman GF/F. The filters were immediately soaked in N,N-dimethylformamide (Suzuki and Ishimaru, 1990)[8] and pigments were extracted for 1-20 days. The samples were stored in a freezer (–18°C) until analysis on board. Concentrations of chlorophyll *a* were determined fluorometrically (Welschmeyer, 1994)[9] with an on-board fluorometer (10-AU; Turner Design, Sunnyvale, California, USA). The fluorometer was calibrated against a chlorophyll *a* standard (Wako Chemical Co.) at a laboratory on land prior to the cruise, using a spectrophotometer and the specific absorption coefficient of chlorophyll *a* (Porra *et al.*, 1989)[10]. The results of fluorometer calibration are shown in

Fig. 2. Fluorescence of all samples presented in this MS was higher than the minimum fluorescence during the calibration (0.389).

3.2. Macro-nutrients

Surface seawater for macro-nutrient analysis was collected from the underway pump at the same time when seawater for chlorophyll *a* was sampled. Vertical measurements of macro-nutrients at 6 stations were conducted as part of JARE routine observation (Shimada *et al.*, 2020)[11]. The surface water was stored in a freezer (–18°C) until analyses on land laboratory. The analytical method after melting frozen samples was according to Shimada et al. (Shimada *et al.*, 2020)[11]. Precision in the coefficient of variation from the replicate analyses using 5 replicates of nitrate, nitrite, silicic acid and phosphate was 0.15%, 0.23%, 0.18% and 0.18%, respectively.

3.3 Photosynthetically Active Radiation

Photosynthetically Active Radiation (PAR) at the sea surface was measured by a Pocket-size PAR logger (DEFI2-L, JFE Advantech CO., Ltd.) mounted on the navigation bridge deck of the ship. The detection limit and accuracy of the logger is 0.2 μmol m^{-2} s^{-1} and ±4.0% (0-2000 μmol m^{-2} s^{-1}), respectively.

4. Data Records

Vertical profiles of chlorophyll *a* concentration and the size composition at six stations are shown in Figs. 3 and 4, respectively. Chlorophyll *a* concentration in surface waters and the size compositions in surface waters are shown in Fig. 5. Macro-nutrients concentration in surface water and PAR at the sea surface are shown in Figs. 6 and 7, respectively. All measurements are presented in three data sheets, “Surface”, “Stations” and “PAR”. The fields in the data sheets are:

CRUISE – the cruise code of the vessel
JARE NBR– the JARE number of this sampling season
SHIP – the name of the ship on which the sampling was conducted
STNNBR – the name of the station on which the sampling was conducted
DATE – the sampling date
TIME – the sampling time (UTC)
LATITUDE – the decimal latitude of the sampling station (negative value for South)
LONGITUDE – the decimal longitude of the sampling station (positive value for East)
DEPTH – the sampling depth (m)
CHL BULK – total chlorophyll *a* concentration (μg l^{-1})
CHL 10UM – composition of chlorophyll *a* in >10 μm fraction (%)

CHL 2UM – composition of chlorophyll *a* in 2 – 10 µm fraction (%)
CHL GF/F – composition of chlorophyll *a* in <2 µm fraction (%)
NITRAT – concentration of nitrate (µmol l^{-1} or µmol kg^{-1})
NITRIT – concentration of nitrite (µmol l^{-1} or µmol kg^{-1})
SILCAT – concentration of silicic acid (µmol l^{-1} or µmol kg^{-1})
PHSPHT – concentration of phosphate (µmol l^{-1} or µmol kg^{-1})
PAR – Photosynthetically Active Radiation (µmol m^{-2} s^{-1}) at sea surface

5. Author contribution

R. Makabe performed the processing of sample analysis and writing of the manuscript. T. Odate directed the monitoring program. S. Takao and K.T. Takahashi carried out the field sampling on board the T/V *Umitaka-maru* and the macro-nutrients analysis in the land laboratory.

6. Competing interests

The authors declare no competing financial interests.

7. Figures

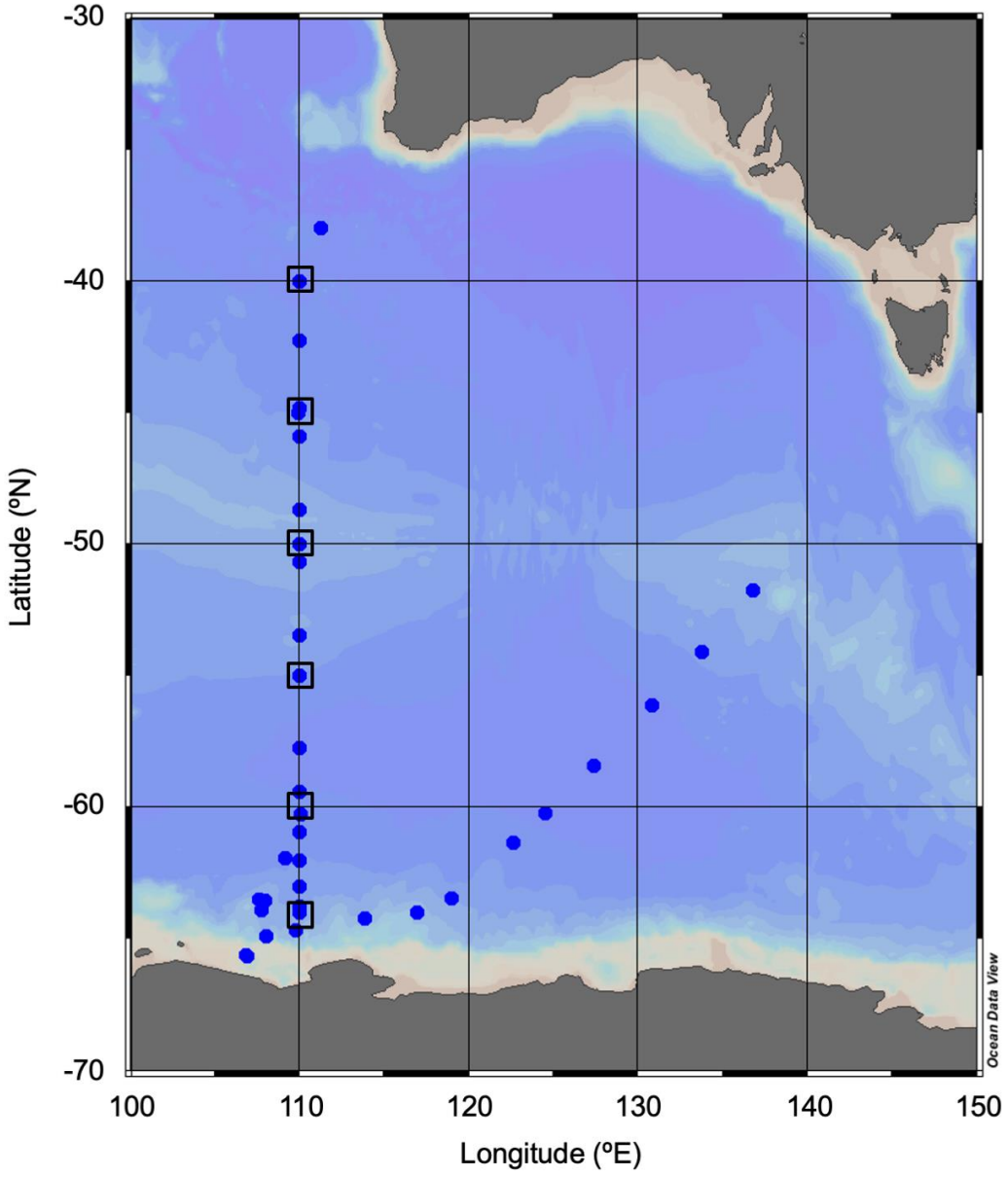

Fig. 1. Location of sampling sites during UM17-09 cruise. Open squares and blue circles show vertical and underway sampling stations, respectively.

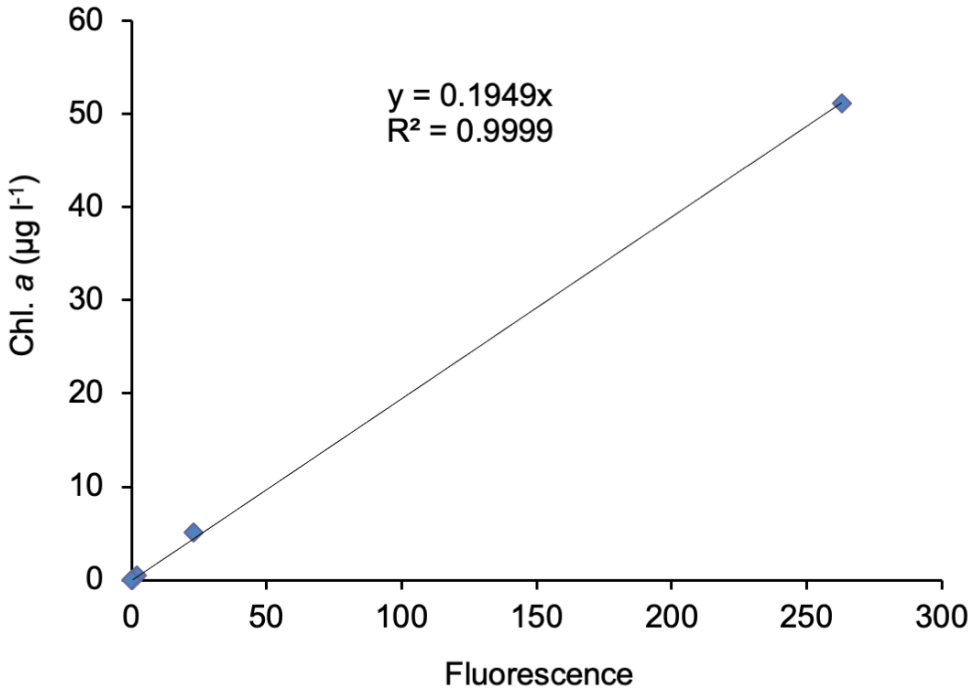

Fig. 2. Correlation between chlorophyll *a* and fluorescence during calibration of the fluorometer.

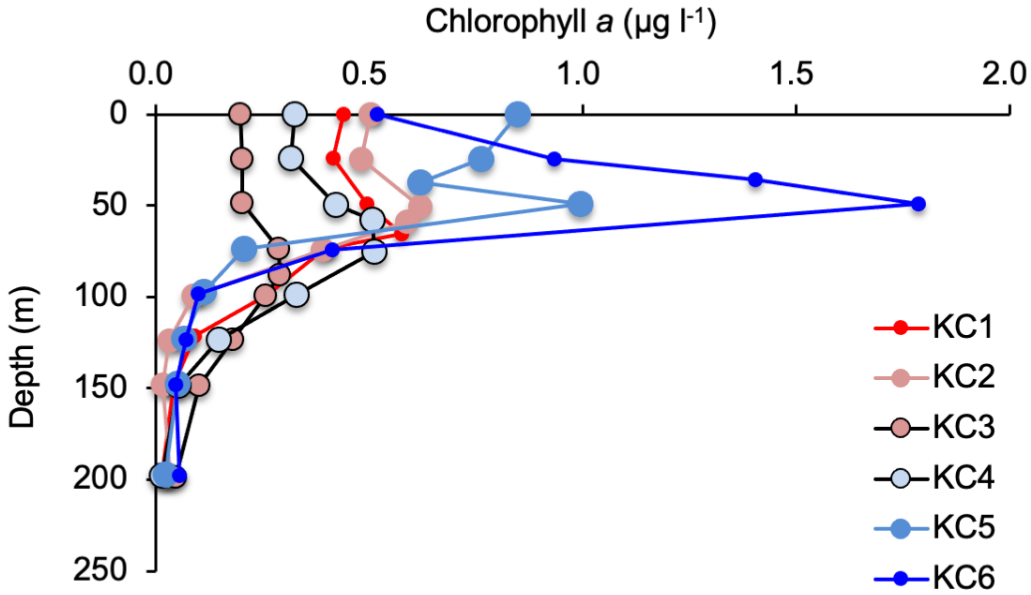

Fig. 3. Vertical profiles of chlorophyll *a* concentration at 6 stations.

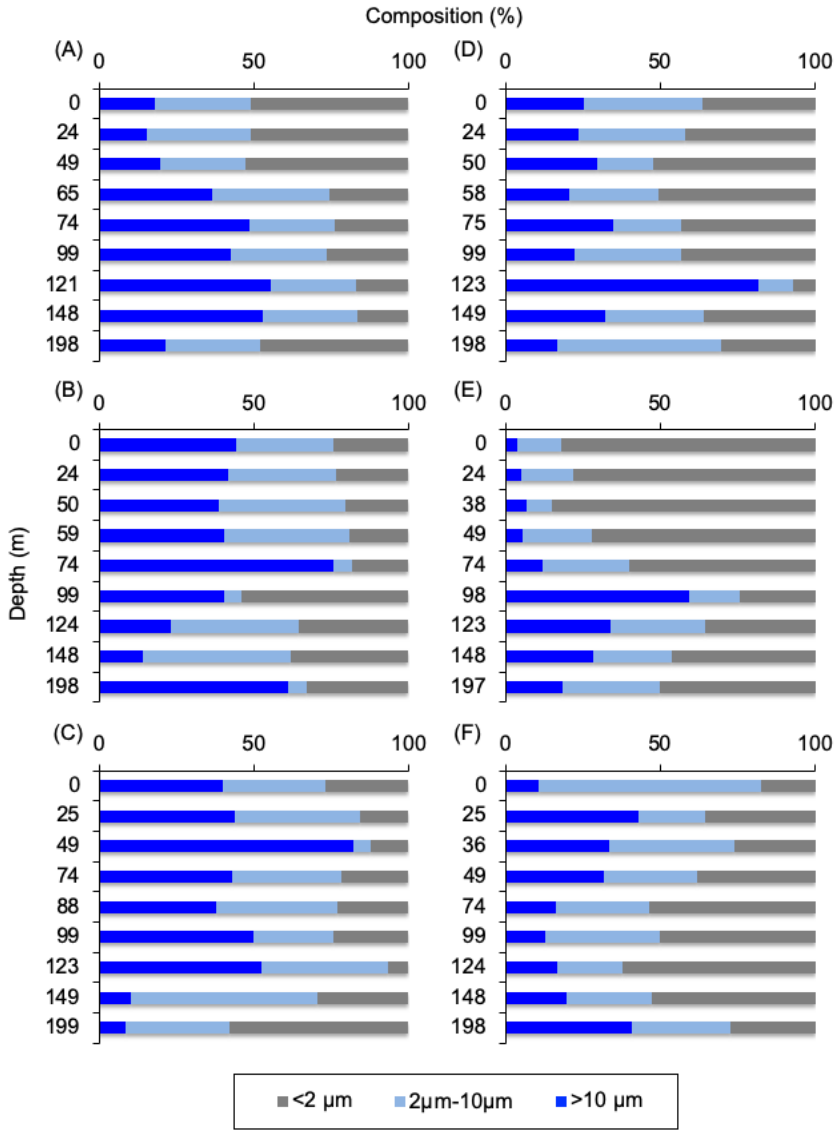

Fig. 4. Size composition of chlorophyll *a* at KC1 (A) KC2 (B), KC3 (C), KC4 (D), KC5 (E) and KC6 (F).

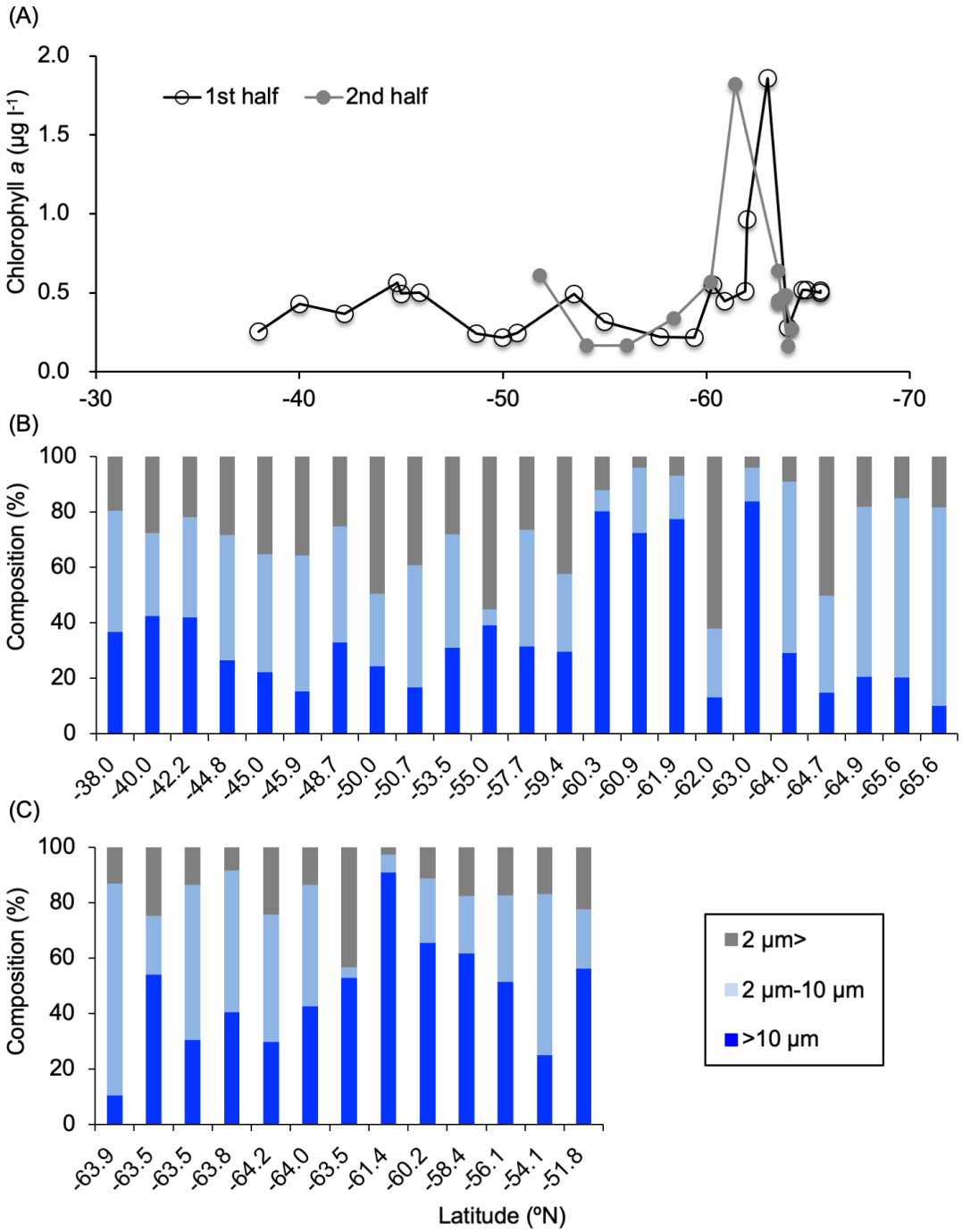

Fig. 5. Surface chlorophyll *a* concentration (A) and the size composition during the 1st (B) and the 2nd half (C) along the cruise track.

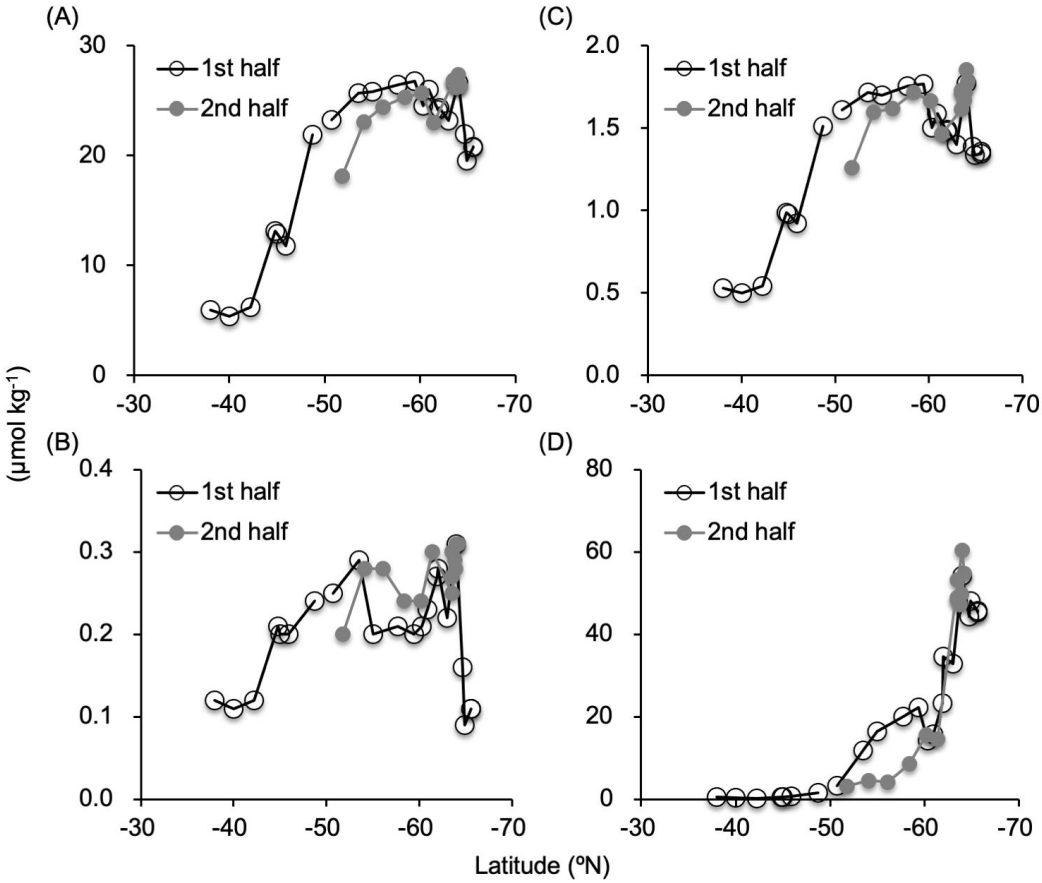

Fig. 6. Surface macro-nutrients concentration during the cruise. (A) nitrate, (B) nitrite, (C) phosphate , (D) silicic acid.

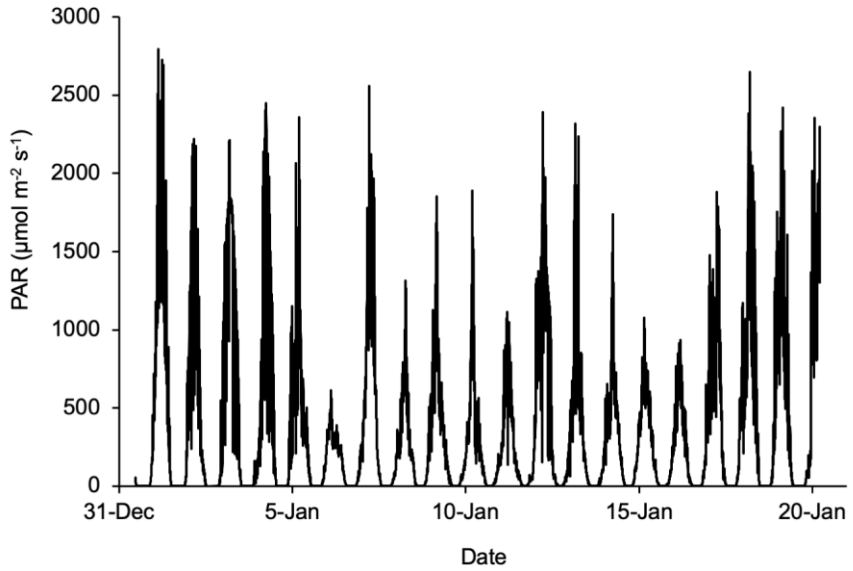

Fig. 7. Photosynthetically active radiation (PAR) at the surface during the cruise.

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Data Citations

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