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Chlorophyll *a*, macronutrient concentrations, and photosynthetically active radiation measured during the Umitaka-maru cruise of the 61st Japanese Antarctic Research Expedition, January 2020

Ryosuke MAKABE[1,2,3]* and Kunio T. TAKAHASHI[1,2]

[1] National Institute of Polar Research, Research Organization of Information and Systems, 10–3 Midori-cho, Tachikawa, Tokyo 190-8518.

[2] Department of Polar Science, School of Multidisciplinary Sciences, SOKENDAI (The Graduate University for Advanced Studies), 10–3 Midori-cho, Tachikawa, Tokyo 190-8518.

[3] Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato, Tokyo 108-8477.

*Corresponding author: Ryosuke Makabe (makabe@nipr.ac.jp)

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Abstract: The chlorophyll *a* concentration is the most commonly used indicator of phytoplankton biomass, which is regulated by macronutrients and light intensity. Long-term monitoring of chlorophyll *a* provides basic information on the ecosystem changes associated with climate change. As part of the monitoring program of the Japanese Antarctic Research Expedition (JARE), the chlorophyll *a* concentration and macronutrients (nitrate, nitrite, phosphate and silicic acid) have been measured by the icebreakers Fuji and Shirase since JARE-14 (1972/73) and JARE-7 (1965/66), respectively, and during the cruise of the training vessel (T/V) Umitaka-maru, of Tokyo University of Marine Science and Technology, since JARE-55 (2013/14). The Umitaka-maru follows almost the same course every year; after leaving Fremantle, it travels to the sea ice edge (ca. 65°S) along the 110°E meridian and then returns to Hobart. Its course covers waters in the Southern Ocean that range from sub-tropical to polar. During the cruise, water samples for determining chlorophyll *a* and macronutrient concentrations are obtained from an underway pump twice a day, and photosynthetically active radiation is measured continuously by a sensor mounted on the bridge of the ship. Vertical water sampling to determine the chlorophyll *a* concentration is conducted at six stations along the 110°E meridian, and the macronutrient concentrations at the same stations are determined by another monitoring program. This report includes the latest data collected during the T/V Umitaka-maru cruise in the 2019/20 season. In 2019/20, three vertical sampling stations (KC7-9) were added to enhance the bottom water monitoring performed under the "Physical and Chemical Oceanography" routine observation program of the JARE.

1. Background & Summary

The phytoplankton community is the main primary producer in marine ecosystems. Its productivity affects both heterotrophic communities and air-sea CO2 flux. The phytoplankton biomass in coastal and oceanic regions can be monitored based on the chlorophyll *a* concentration. In the Indian sector of the Southern Ocean, inter-annual changes in the surface chlorophyll *a* concentration are evident during a cycle of less than 10 years[1], such that frequent chlorophyll *a* observations are needed to understand ecosystem responses to long-term climate change (e.g., global warming), and decadal or shorter-duration environmental changes (e.g., El Niño and the Southern Annular Mode). Given such variability in chlorophyll *a* concentrations, size-fractionated chlorophyll *a* measurements are important, because both global warming and changes in sea ice dynamics affect the phytoplankton size spectrum[2,3,4]. Macronutrients and photosynthetically active radiation (PAR) in the surface mixed layer, which also vary with climate change, are essential for phytoplankton growth. A simulation from 1980 to 2100 suggested that the main factors affecting phytoplankton biomass distribution vary meridionally[5]. While nutrients and temperature are dominant from the equator to mid-latitude regions, light intensity and temperature become dominant in the subpolar to polar regions. Therefore, measurements of these factors, together with the chlorophyll *a* concentration and size composition, help us to understand the spatiotemporal variability in phytoplankton biomass.

One of the routine observation programs of the Japanese Antarctic Research Expedition (JARE), named "Biological Oceanography", was renamed "Marine Ecosystem Monitoring" for JARE-38. Chlorophyll *a* concentrations have been measured routinely on board the icebreakers Fuji and Shirase since JARE-14 in 1972/73. The chlorophyll *a* concentration is closely related to the water column structure (i.e., temperature and salinity) and macronutrients (nitrate, nitrite, silicic acid, and phosphate), which have been measure routinely during the "Physical Oceanography" and "Chemical Oceanography" programs that began during JARE-7 in 1965/66. These two programs were terminated on Shirase during JARE-51 (2009/10) and restarted as a routine observation program, "Physical and Chemical Oceanography", on the training vessel (T/V) Umitaka-maru of Tokyo University of Marine Science and Technology during JARE-54 (2012/13). We also started marine ecosystem monitoring on this cruise during JARE-55 (2013/14). For JARE61 (2019/20), three vertical sampling stations (KC7-9) were added to the Physical and Chemical Oceanography program, along with enhanced bottom water monitoring.

This report documents the phytoplankton chlorophyll *a* concentration in seawater at depths shallower than 200 m, measured during the cruise of the T/V Umitaka-maru (UM19-08) as part of JARE-61 during the austral summer of 2019/20. The spatial variation in chlorophyll *a* concentration in the surface water along the cruise track was measured, along with the vertical profiles of chlorophyll *a* in the Indian sector of the Southern Ocean.

Similar data collected previously by 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 UM18-08 cruise in January 2019. Surface water was sampled twice a day along the cruise track from an underway pump, with its inlet at ca. 5 m depth (Fig. 1). Vertical water sampling was conducted at nine sites (KC1-9) along the 110°E meridian from 40°S to around 65°S, near the ice edge, although the observation at KC3 (50°S, 110°E) was canceled due to inclement weather (Fig. 1). No chl. *a* measurement was obtained at 25 m depth at KC2 due to leak of the Niskin bottle. The other physical and chemical oceanographic data from the same cruise can be downloaded from the NiPR database (DID: 448-451, http://polaris.nipr.ac.jp/~parc/usr/di_list.php?pid=271).

3. Materials and Methods

3.1. Chlorophyll *a*

During the cruise, surface seawater was collected twice daily from water that was continuously pumped through the vessel from an intake in the hull. At stations where water column sampling was performed, surface seawater was collected into a plastic bucket. Water samples were collected from the upper 200 m of the water column in Niskin bottles attached to a 24-position conductivity/temperature/depth carousel water sampling system (SBE 9plus; Sea-Bird Electronics, Bellevue, WA, USA). On all occasions, water samples were collected into two dark bottles and filtered through glass-fiber filters (Whatman GF/F; Whatman Inc., Florham Park, NJ, USA), while size-fractionated samples were collected on 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[8] and the pigments were extracted at –20°C over 24 hours. The samples were stored in a freezer (–18°C) until onboard analysis. The chlorophyll *a* concentrations were determined fluorometrically[9] using an on-board fluorometer (10-AU; Turner Designs, Sunnyvale, CA, USA).

3.2. Macronutrients

Surface seawater for macronutrient analysis was collected from the underway pump at the same time as the seawater for chlorophyll *a* was sampled. Macronutrients were measured vertically at nine stations as part of the routine JARE observations (Shimada *et al.*, in prep.). The surface water was stored in a freezer (–18°C) until analyses on land. The analytical method after melting frozen samples followed Shimada *et al.* (2020)[10].

3.3. Photosynthetically Active Radiation

The PAR at the sea surface was measured by a Pocket-sized PAR logger (DEFI2-L; JFE Advantech, Hyogo, Japan) mounted on the navigation bridge of the ship.

4. Data Records

All measurements were recorded on "Surface", "Stations", and "PAR" data. The fields were as follows:

CRUISE – Cruise code of the vessel

JARE NBR –JARE number of the sampling season

SHIP – Name of the ship on which the sampling was conducted

STNNBR – Name of the station where the sampling was conducted

DATE – Sampling date

TIME – Sampling time (UTC)

LATITUDE – Decimal latitude of the sampling station (negative values for south)

LONGITUDE – Decimal longitude of the sampling station (positive values for east)

DEPTH – 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 – Nitrate concentration (μmol L^{-1} or μmol kg^{-1})

NITRIT – Nitrite concentration (μmol L^{-1} or μmol kg^{-1})

SILCAT – Silicic acid concentration (μmol L^{-1} or μmol kg^{-1})

PHSPHT – Phosphate concentration (μmol L^{-1} or μmol kg^{-1})

PAR – Photosynthetically active radiation (μmol m^{-2} s^{-1}) at the sea surface

5. Technical Validation

5.1. Chlorophyll *a*

The fluorometer was calibrated against a chlorophyll *a* standard (Fujifilm Wako Pure Chemical Corp., Osaka, Japan) at a land laboratory before the cruise, using a spectrophotometer and the specific absorption coefficient of chlorophyll *a*[11] (Fig. 2). The fluorescence of all samples was within the validated calibration range (0.278−657), although the fluorescence of the bulk and > 10 μm fraction at 30 m depth at KC6 was slightly higher, at 853 and 743, respectively.

5.2. Macronutrients

The precision of the coefficients of variation for nitrate, nitrite, silicic acid, and phosphate from five replicates was 0.16%, 0.18%, 0.16%, and 0.11%, respectively and their respective detection limits were 0.03, 0.01, 0.18, and 0.006 μmol L^{-1}.

5.3. Photosynthetically Active Radiation

The detection limit of the logger was 0.2 μmol m^{-2} s^{-1} and its accuracy was ±4.0% (0–2,000) μmol m^{-2} s^{-1}.

6. Figures

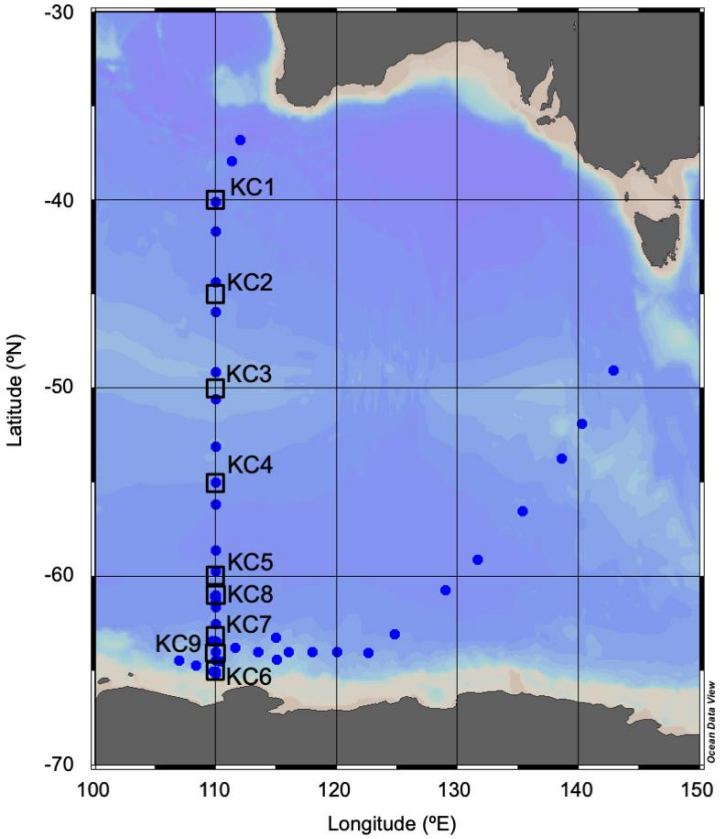

Fig. 1. Locations of the sampling sites during the UM19-08 cruise. Open squares, vertical sampling stations; blue circles, underway sampling stations.

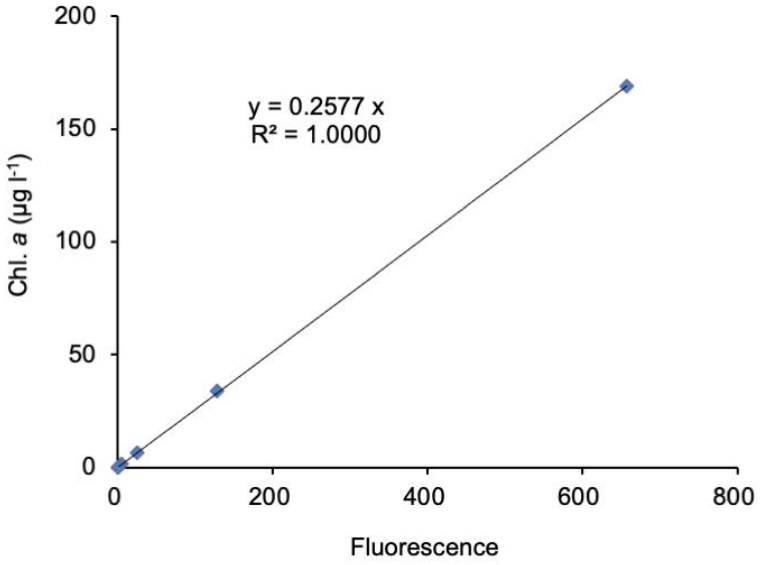

Fig. 2. Correlation between chlorophyll *a* and fluorescence during fluorometer calibration.

Author contribution

R. Makabe processed the samples for analysis and wrote the manuscript. K.T. Takahashi performed the field sampling on board the T/V Umitaka-maru, and the macronutrient analysis on land.

Competing interests

The authors declare that they have no competing financial interests.

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Data Citations

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