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Chlorophyll *a* and macronutrient concentrations during the icebreaker *Shirase* cruise of the 60th Japanese Antarctic Research Expedition

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Abstract: Chlorophyll *a* concentration is the most common indicator of phytoplankton biomass, basically regulated by physico-chemical properties such as temperature, salinity, macronutrients and light intensity. As part of the monitoring programs of the Japanese Antarctic Research Expedition (JARE), water temperature, salinity, chlorophyll *a* concentration, and macronutrients (nitrate, nitrite, phosphate, and silicic acid) have been determined since 1965. This report presents the latest data collected during the *Shirase* cruise in the 2018–2019 season.

1. Background & Summary

Phytoplankton is the major primary producer of the ocean ecosystem. Its productivity not only affects heterotrophic communities but also the air-sea CO_2 flux. Phytoplankton biomass is usually monitored based on ocean chlorophyll *a* concentrations. In the Indian Sector of the Southern Ocean, surface chlorophyll *a* varies interannually with a cycle of a few years (Hirawake *et al.*, 2005)[1]. The abundance of chlorophyll *a* was closely related to water column structure (e.g., temperature and salinity) and macronutrients (nitrate, nitrite, silicic acid, and phosphate). Thus, frequent observations of chlorophyll *a* with the environmental parameters are required, to capture interannual variation that will allow us to understand ecosystem responses to long-term climate changes (e.g., global warming) and decadal environmental changes (e.g., El Niño and Southern Annular Mode).

Chlorophyll *a* has been measured by the research program "Marine Ecosystem Monitoring" (renamed from "Biological Oceanography" since JARE-38) as the routine observations of the Japanese Antarctic Research Expedition (JARE). It was also measured onboard the icebreakers *Fuji* and *Shirase* by JARE-7 during the 1965–1966 season and by JARE-25 during the 1983–1984 season, respectively. Macronutrients have been measured by another monitoring program, "Physical and Chemical Oceanography", since JARE-7. Since the program have been carried out during cruise of the training and research vessel Umitaka Maru, which belongs to the Tokyo University of Marine Science and Technology (TUMSAT), since JARE52, macronutrients measurements have been measured under the Marine Ecosystem Monitoring during *Shirase* cruise. Surface photosynthetically active radiation (PAR) has been measured since JARE-52.

This report documents the chlorophyll *a* concentrations, water temperature, salinity, and macronutrients measured during a cruise by the icebreaker *Shirase* as part of JARE-60 during the austral summer of 2018–2019.

2. Study sites

Field sampling was performed from Fremantle to Sydney in the Indian Sector of the Southern Ocean (Fig.1). Surface waters from the underway pump, of which the inlet was located at a depth of 8–9 m, were sampled twice daily along the cruise track outside of the Exclusive Economic Zone of Australia (Fig. 1). Vertical water sampling was conducted at 10 stations (L1–10) located in meridional transects along 110°E and 150°E (Table 1). Conductivity-temperature-depth (CTD) casts were conducted twice at L01 because a bottle leaked during the first cast. The CTD cast at Stn. L7 (60°S, 150°E) was canceled due to inclement weather.

3. Materials and Methods

3.1. Temperature, salinity, and *in situ* chlorophyll fluorescence

Temperature and salinity of the surface water, collected by the underway pump, were quasi-continuously measured by sensor probes (SBE 38 for temperature and SBE 45 for salinity; Sea-Bird Scientific, Bellevue, WA, USA). *In situ* chlorophyll fluorescence of the same surface water was measured with a fluorometer (WETStar, ex: 460 nm/em: 695 nm, Sea-Bird Scientific). The sensors were calibrated by Sea-Bird Scientific in 2017. All sensor data were collected once per minute.

Vertical profiles of temperature and salinity were determined at total of 10 stations using a CTD memory probe (SBE19 plus, Sea-Bird Scientific) attached to a water sampler with six 4-L bottles (SBE 55 ECO, Sea-Bird Scientific). The data were downloaded from the CTD to a laptop computer immediately after each cast. The CTD sensor was calibrated by Sea-Bird Scientific in 2018. The salinity data in this report were not corrected by the bottle salinity data measured by the salinometer.

3.2. Chlorophyll *a* sampling

Surface seawater was collected twice daily (day and night without the midnight sun) during the cruise from surface water pumped from the ship bottom. At the vertical sampling stations, seawater samples were collected from the upper 100 m of the water column using Niskin bottles attached to the water sampler, and surface water was collected using a plastic bucket. Samples for chlorophyll *a* measurement were collected in two 300-mL dark bottles; for bulk measurements, these samples were filtered using a glass-fiber filter (Whatman, GF/F). Samples collected for size-fraction measurements were sequentially filtered through 10- and 2-µm membrane filters and a GF/F filter. The filters were immediately soaked in N,N-dimethylformamide (Suzuki and Ishimaru, 1990)[2], and stored at –18°C for more than 24 h prior to extraction. The samples were stored (–18°C) until analysis. Concentrations of chlorophyll *a* were determined fluorometrically (Welschmeyer, 1994)[3] with an onboard fluorometer (10-AU; Turner Design, Sunnyvale, CA, USA). The fluorometer was calibrated using a chlorophyll *a* standard (Fujifilm Wako Pure Chemical Corp., Osaka, Japan) at an onshore laboratory before the cruise, using a spectrophotometer (Porra *et al.*, 1989)[4] (Fig. 2). All fluorescence measurements were within the range validated by calibration (0.286–678).

3.3. Macronutrients

Seawater samples for macronutrient analysis were collected at the same time as for chlorophyll *a* samples. Water samples were also collected from depths of 200 and 400 m at vertical sampling stations. The sampled water in a plastic spitz tube was stored at –18°C until analysis in an onshore laboratory. The detailed analytical procedure that followed after the frozen samples were melted has been described previously (Shimada *et al.*, 2020)[5]. The coefficients of variation calculated from five replicates of nitrate, nitrite, silicic acid, and phosphate were 0.16%, 0.31%, 0.19%, and 0.10%, respectively. The detection limits of nitrate, nitrite, silicic acid, and phosphate were 0.06, 0.01, 0.14, and 0.007 µmol L^{-1}, respectively.

3.4. PAR

Surface PAR was measured using a pocket-sized PAR logger (DEFI-L, JFE Advantech Co., Ltd., Tokyo, Japan) mounted on the navigation bridge deck of the ship. Data were recorded every minute. The logger has a detection limit and accuracy of 0.2 µmol m^{-2} s^{-1} and ± 4.0% (0–2000 µmol photons m^{-2} s^{-1}), respectively.

4. Data records

All measurements are presented in 13 csv files, named “JARE60_CTD_LXX (L01-L10),” “JARE60_Chl&Nuts_BtlSample,” “JARE60_Chl&Nuts_Underway,” “JARE60_Underway_

Fremantle to Syowa," and "JARE60_Underway_Syowa to Sydney." The fields in the datasheets of the three files are:

CTDPRS: Pressure (dbar)
CTDTMP: Temperature (°C)
CTDCND: Conductivity (S/m)
CTDSAL: Salinity
THETA: Potential temperature (°C)
SIGT: Sigma t (kg m^{-3})
CRUISE: Cruise code of the vessel
SHIP: Name of the ship on which samples were collected
STNNBR: Name of the station on which sampling was conducted
DATE: Sampling date
TIME: Sampling time (UTC)
LATITUDE: Decimal latitude of the sampling station (negative values indicate South)
LONGITUDE: Decimal longitude of the sampling station (positive values indicate East)
DEPTH: Sampling depth (m)
SIG0: Sigma θ (kg m^{-3})
CHL BULK: Total chlorophyll *a* concentration (µg L^{-1})
CHL 10UM: Composition of chlorophyll *a* in the >10 µm fraction (%)
CHL 2UM: Composition of chlorophyll *a* in the 2–10 µm fraction (%)
CHL GF/F: Composition of chlorophyll *a* in the < 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})
FLUOR: Chlorophyll fluorescence determined by a sensor (µg L^{-1})
PAR: Photosynthetically active radiation (µmol photons m^{-2} s^{-1}) at the sea surface

5. Competing interests

The authors declare no competing financial interests.

6. Figures

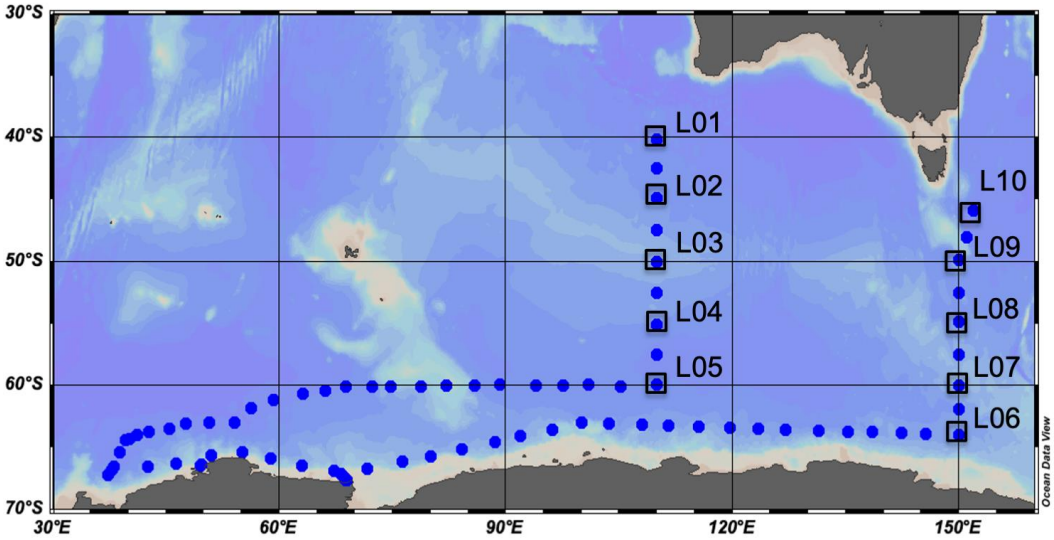

Fig. 1. Location of the sampling sites during the JARE-60 cruise. Open squares and blue circles indicate the vertical and underway sampling stations, respectively.

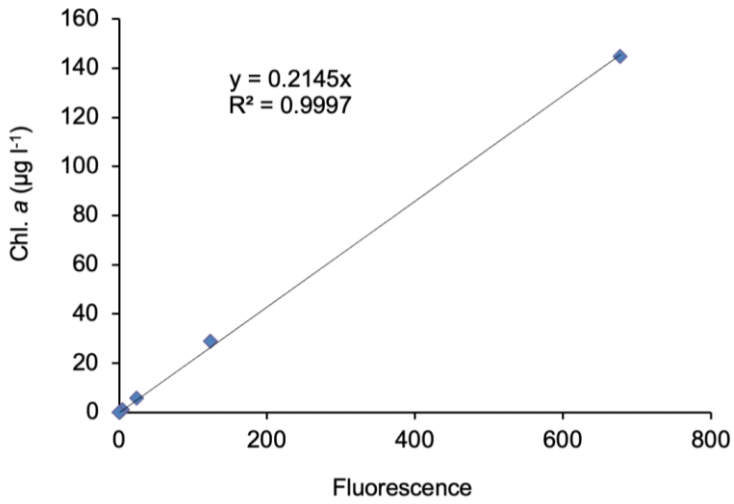

Fig. 2. Correlation between chlorophyll *a* and fluorescence during calibration of the fluorometer.

7. Table

Table 1. Dates and locations of the 10 stations. Conductivity–temperature–depth (CTD) casts were conducted twice at L01 because two bottles leaked during the first cast.

Station	Date (UTC)	Time (UTC)	Latitude (degN)	Longitude (degE)
L01	02/12/2018	0:02	-40.1432	109.9942
L01-2	02/12/2018	1:20	-40.1273	110.0385
L02	02/12/2018	23:57	-44.9255	109.9802
L03	03/12/2018	23:55	-50.0479	109.9439
L04	05/12/2018	0:00	-55.0655	110.0049
L05	06/12/2018	0:00	-59.9535	110.0030
L06	10/03/2019	5:22	-63.9994	149.9847
L07	11/03/2019	5:17	-60.0190	149.9980
L08	12/03/2019	20:51	-54.8546	149.9723
L09	13/03/2019	21:49	-49.9033	150.0545
L10	14/03/2019	21:47	-45.8870	151.9837

Author contributions

R. Makabe processed and analyzed the samples and wrote the manuscript. T. Odate and K.T. Takahashi directed the monitoring program. S. Takao carried out the nutrient analysis in the offshore laboratory and analyzed the sensor data.

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Data Citation

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