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Chlorophyll *a* and macronutrient concentrations during the icebreaker *Shirase* cruise of the 61st Japanese Antarctic Research Expedition

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Abstract: Chlorophyll *a* concentration is the most common indicator of phytoplankton biomass, basically regulated by physicochemical 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 measured since 1965. This report presents the latest data collected during the *Shirase* cruise in the 2019–2020 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[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* alongside 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 as part of the research program known as "Marine Ecosystem Monitoring" since JARE-38 (previously entitled "Biological Oceanography"), as a routine observation of the Japanese Antarctic Research Expedition (JARE). Chlorophyll *a* 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. Macronutrients have been measured by another monitoring program, "Physical and Chemical Oceanography", since JARE-7. Since JARE52, the program has been conducted during cruises of the training and research vessel *Umitaka Maru*, which belongs to the Tokyo University of Marine Science and Technology (TUMSAT), while macronutrient measurements have been obtained under the Marine Ecosystem Monitoring program during *Shirase* cruises. 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-61 during the austral summer of 2019–2020.

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 (Fig. 1). The conductivity–temperature–depth (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).

Vertical profiles of temperature and salinity were determined at total of 9 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.

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 20, 50, 75, 100, 200 m depth 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 water sample from 200 m depth was not used for the size-fraction measurements. The filters were immediately soaked in *N*, *N*-dimethylformamide[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[3] with an onboard fluorometer (10-AU; Turner Design, Sunnyvale, CA, USA).

3.3. Macronutrients

Seawater samples for macronutrient analysis were collected at the same time as for chlorophyll *a* samples. The samples were collected from depths of 0, 20, 50, 100, 200 and 400 m at vertical sampling stations. The sampled water was stored in a plastic spitz tube 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[4].

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.

4. Data records

All measurements are presented in 13 csv files, named “JARE61_CTD_LXX (L01-L10),” “JARE61_Chl&Nuts_BtlSample,” “JARE61_Chl&Nuts_Underway,” “JARE61_Underway_Fremantle to Syowa,” and “JARE61_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

CTDOXY: Dissolved oxygen (mL L^{-1})

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

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

5. Technical Validation

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

The sensors for underway and vertical observations were calibrated by Sea-Bird Scientific in 2017 and in 2018, respectively. All sensor data were collected once per minute. The salinity data in this report were not corrected by the bottle salinity data measured by the salinometer.

5.2. Chlorophyll *a* sampling

The fluorometer was calibrated using a chlorophyll *a* standard (Fujifilm Wako Pure Chemical Corp., Osaka, Japan) in *N*,*N*-dimethylformamide at an onshore laboratory before the cruise, using a spectrophotometer and the chl. *a*-specific absorbance[5] (Fig. 2). All fluorescence measurements were higher than the minimum value validated by calibration (0.149) and samples with fluorescence values higher than 700 were diluted.

5.3. Macronutrients

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

5.4. PAR

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.

6. Figures

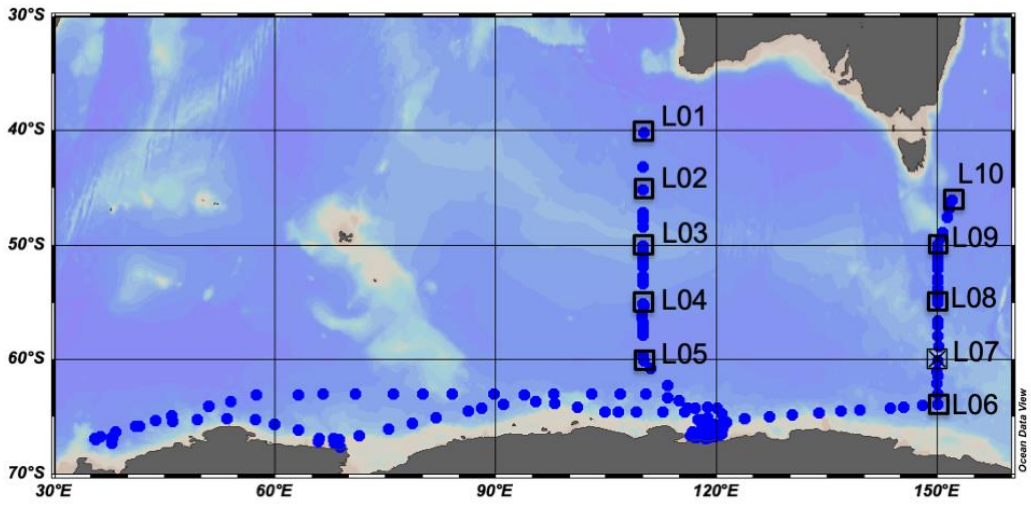

Fig. 1. Location of the sampling sites during the JARE-61 cruise. Open squares and blue circles indicate the vertical and underway sampling stations, respectively. The conductivity–temperature–depth (CTD) cast at Stn. L7 (60°S, 150°E) was canceled due to inclement weather.

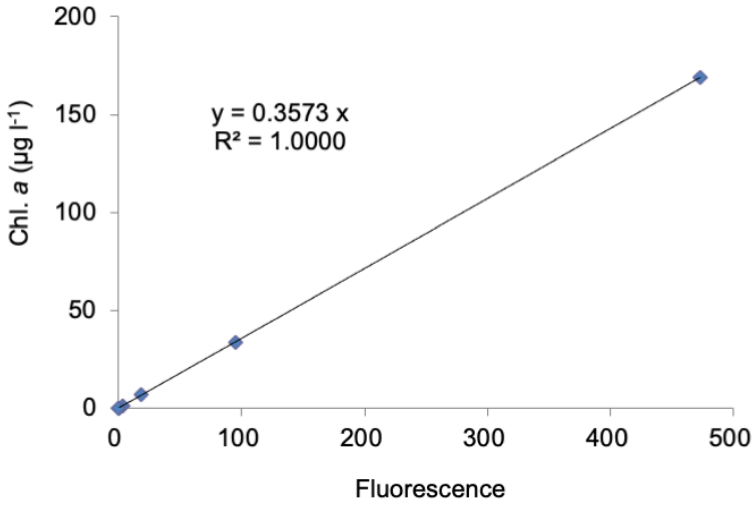

Fig. 2. Correlation between chlorophyll *a* and fluorescence during calibration of the fluorometer.

7. Table

Table 1. Dates and locations of the 9 stations.

Station	Date (UTC)	Time (UTC)	Latitude (degN)	Longitude (degE)
L01	03/12/2019	23:57	-40.1415	110.0363
L02	05/12/2019	0:47	-45.1475	110.0085
L03	05/12/2019	23:52	-50.1242	109.9547
L04	07/12/2019	0:21	-55.1100	110.0398
L05	08/12/2019	0:22	-60.0832	110.1327
L06	11/03/2020	22:02	-63.8745	149.9371
L08	13/03/2020	21:07	-54.8908	149.9600
L09	14/03/2020	21:03	-49.9259	150.0134
L10	15/03/2020	20:59	-45.8780	152.0136

Author contributions

R. Makabe processed and analyzed the samples and wrote the manuscript. K.T. Takahashi directed the monitoring program.

Competing interests

The authors declare no competing financial interests.

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Data Citations

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