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Chlorophyll *a* and macronutrient concentrations during the icebreaker *Shirase* cruise of the 62nd and 63rd 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 2020/21 and the 2021/22 seasons, and is the fifth report for the monitoring on board *Shirase* from the first report of the 2016/17 season in this journal.

1. Background and 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 concentration of macronutrients (nitrate, nitrite, silicic acid, and phosphate). Thus, frequent observations of chlorophyll *a* alongside environmental parameters are required, to capture

the 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 "Marine Ecosystem Monitoring" since 38th Japanese Antarctic Research Expedition (JARE) (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 JARE-52, 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, which is the fifth report for the monitoring on board *Shirase* after four reports from the 2016/17 to 2019/20 season (Makabe *et al.*, 2020a[2], 2020b[3], 2021[4], 2022[5]) in this journal, documents the chlorophyll *a* and macronutrient concentrations, water temperature, salinity, and PAR, measured during a cruise by the icebreaker *Shirase* as part of JARE-62 and 63 during the austral summer of the 2020/21 and the 2021/22.

2. Study sites

Field sampling was performed in the Indian sector of the Southern Ocean (Fig.1a and b). 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 tracks outside of the Exclusive Economic Zone of Australia (Fig. 1a and b). The conductivity–temperature–depth (CTD) cast and vertical water sampling was conducted at two sites (L4 and 5) located in meridional transects along 110°E in the 2021/22 season (Fig. 1b). In the 2020/21 season, all vertical observations were canceled because of change in cruise track. In the 2021/22 season, the conductivity-temperature-depth (CTD) cast and vertical water sampling was conducted at two sites (L4 and 5) located in meridional transects along 110E (Fig. 1b). Three vertical sampling stations (L1–3) were canceled due to heavy 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). The SBE 38 was placed near water intake to avoid warming. *In situ* chlorophyll fluorescence of the same surface water was measured with a fluorometer (WETStar, ex: 460 nm/em: 695 nm, Sea-Bird Scientific) in both seasons.

Vertical profiles of temperature and salinity were determined at 2 stations using a CTD memory probe (SBE 19plus, 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 sensors for underway and vertical observations were calibrated by Sea-Bird Scientific 4–6 months before departure of the *Shirase*, 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 a salinometer.

3.2. Chlorophyll *a*

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, and 200 m depths 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. Details for the extraction and determination of chlorophyll *a* concentration with an onboard fluorometer (10-AU; Turner Design, Sunnyvale, CA, USA) were referred to Makabe *et al.* (2020a[2]). 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 chlorophyll *a*-specific absorbance (Porra *et al.*, 1989[6]) (Fig. 2). All fluorescence measurements were higher than the minimum value validated by calibration (0.149 for 2020/21, 0.283 for 2021/22) and samples with fluorescence values higher than 700 were diluted.

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 coefficients of variation calculated from five replicates of nitrate, nitrite, silicic acid, and phosphate in the 2020/21 season were 0.16%, 0.18%, 0.16%, and 0.11%, respectively. The detection limits of nitrate, nitrite, silicic acid, and phosphate were 0.030, 0.008, 0.185, and 0.006 µmol L^{-1}, respectively. In the 2021/22 season, the coefficients of variation calculated from five

replicates of nitrate, nitrite, silicic acid, and phosphate were 0.14%, 0.25%, 0.14%, and 0.11%, respectively. The detection limits of nitrate, nitrite, silicic acid, and phosphate were 0.017, 0.003, 0.068, and 0.011 μmol L^{-1}, respectively. The detailed analytical procedure after the frozen samples were melted followed Shimada *et al.*, (2020)[7].

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. 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. Data were recorded every minute. In the 2020/21 season, data was not obtained due to the sensor trouble.

4. Data records

All measurements are presented in 6 CSV files, named “JARE63_CTD_L4”, “JARE63_CTD_L5”, “JARE63_Chl&Nuts_BtlSample”, “JARE62&JARE63_Chl&Nuts_Underway”, “JARE62_Underway sensor” and “JARE63_Underway sensor”. The fields in the datasheets of the six 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. Figures

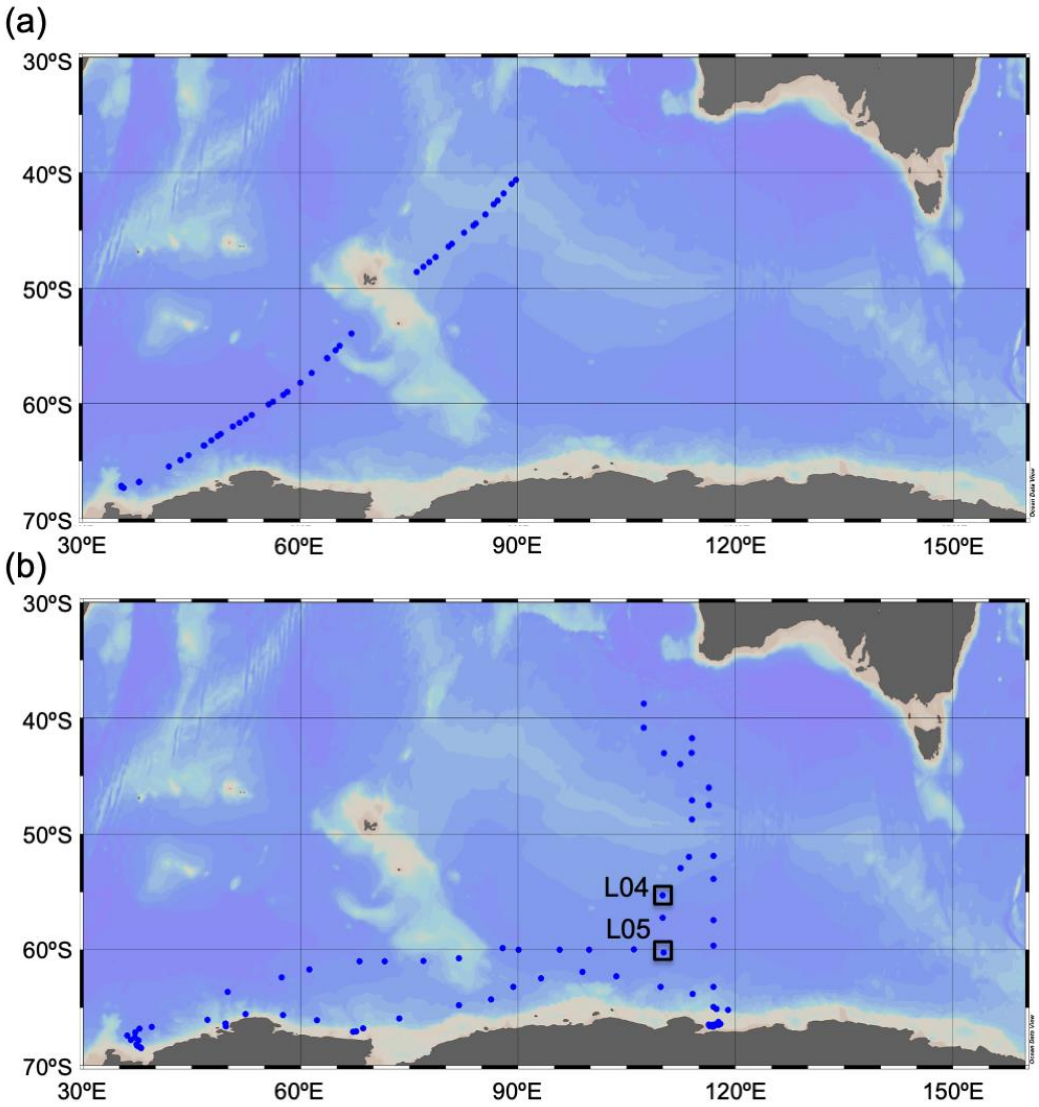

Fig. 1. Location of the sampling sites during (a) the JARE-62 and (b) JARE-63 cruises. Open squares and blue circles indicate the vertical and underway sampling stations, respectively.

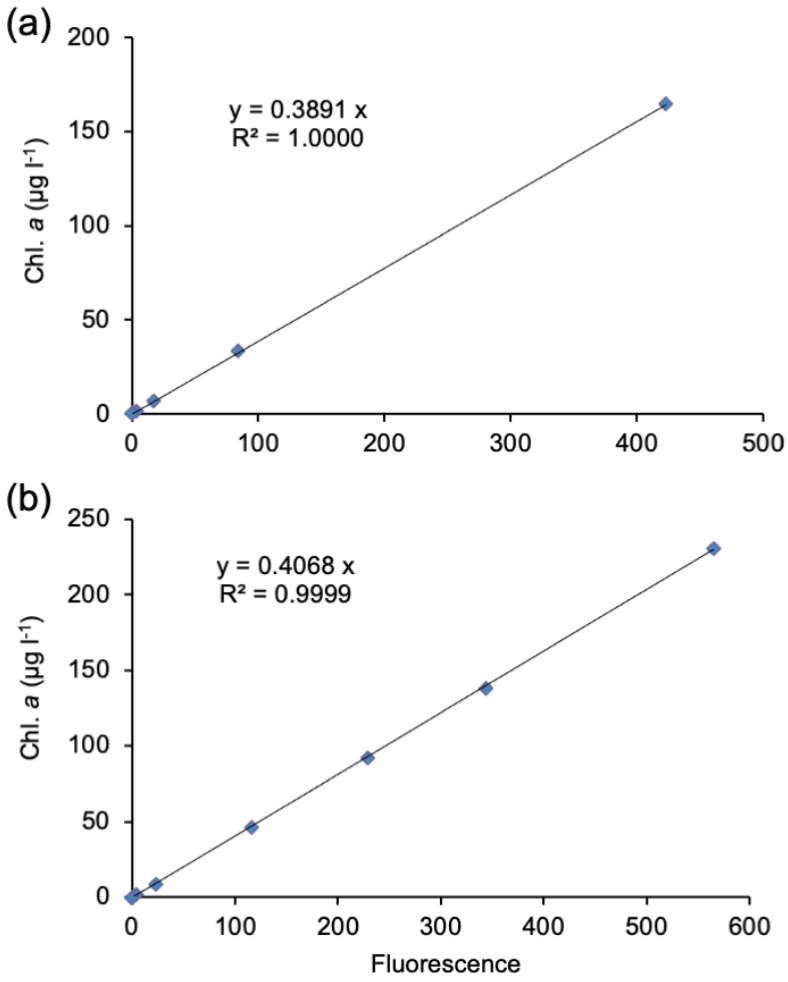

Fig. 2. Correlation between chlorophyll *a* and fluorescence during the fluorometer calibration for (a) JARE-62 and (b) JARE-63 cruises.

6. Table

Table 1. Dates and locations of two vertical sampling stations in the 2021/22 season.

Station	Date (UTC)	Time (UTC)	Latitude (degN)	Longitude (degE)
L04	2021/12/1	0:12	-55.0253	109.9907
L05	2021/12/2	0:14	-60.0222	110.0007

Author contributions

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

Competing interests

The authors declare no competing financial interests.

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Data Citations

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