—研究ノート—
Scientific Note

Surface Chlorophyll *a* Measured Continuously in the Indian Antarctic Water in Summer 1985/86

Atsushi TANIMURA[1], Hiroshi HATTORI[2] and Mitsuo FUKUCHI[1]

1985/86 年夏季，南極海インド洋区における表面海水中のクロロフィル *a* 量の連続観測

谷村　篤[1]・服部　寛[2]・福地光男[1]

要旨：新たに製作した表面海水モニタリングシステムを用いて，1985/86 年夏季「しらせ」航路に沿った表面海水中の植物プランクトンクロロフィル *a* 濃度および海洋環境パラメター（水温，塩分，溶存酸素および栄養塩濃度）の連続観測を実施した．南極海インド洋区の三つの海洋前線（亜熱帯収束線，亜南極前線および南極前線）を横切る南北方向のクロロフィル *a* 濃度の変化は海洋環境パラメターの変化と良い対応がみられた．また，オングル海峡の定着氷上の定点でのクロロフィル *a* 量の経時的な変化は，栄養塩濃度の変化と負の相関が見られた．

***Abstract*:** Temporal and spatial variations of phytoplankton chlorophyll *a* concentration together with the variations of oceanographic parameters (temperature, conductivity, dissolved oxygen and nutrient salt concentrations) were studied with an automated data acquisition system, which was newly designed and installed on board the Japanese icebreaker SHIRASE. Variations of chlorophyll *a* concentration across three oceanic frontal zones (Subtropical Convergence, Subantarctic Front and Polar Front) in the Indian sector of the Antarctic Ocean showed positive and/or negative correlations with the oceanographic parameters. Temporal variations of chlorophyll *a* concentration at a fixed point in coastal fast ice area in the Ongul Strait showed a negative correlation with nutrient salts.

1. Introduction

Surface chlorophyll *a*, mainly in the Indian sector of the Antarctic Ocean, has been routinely measured in every JARE (Japanese Antarctic Research Expedition) cruise since 1967. Geographical variation of chlorophyll *a* standing stock, in relation to the oceanic frontal zones, was discussed by FUKUCHI (1980). In these previous cruises, sample water was bucketed two to three times a day and the spatial resolution of the sampling was 93–130 km, which seems too sparse to locate the exact position of the oceanic frontal zones. Therefore, more frequent sampling, at 2 hour intervals, was carried out in the JARE-20 in 1978/79 (FUKUCHI and TAMURA, 1982) and in the JARE-21 in 1979/80 (TANIMURA, 1981). Similar

[1] 国立極地研究所. National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173.
[2] 北海道東海大学工学部. School of Engineering, Hokkaido Tokai University, Minamisawa, Minami-ku, Sapporo 005.

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frequent observations were employed by PLANCKE (1977) for the Subtropical Convergence water as well as by LUTJEHARMS *et al.* (1985) and YAMAMOTO (1986) for the Antarctic Convergence water.

To obtain a finer scale distribution and variation of chlorophyll, *in vivo* fluorescence of pumped water was recorded continuously in the Southern Ocean (YAMAGUCHI and SHIBATA, 1982; HAYES *et al.*, 1984; TANIGUCHI *et al.*, 1986; WEBER *et al.*, 1986). These data, recorded on strip charts, were digitized at appropriate intervals. The new computerized system for surface water monitoring was designed for the JARE-27 (1985/86) cruise and installed on board the icebreaker SHIRASE not only to eliminate the digitizing process but also to increase the number of data items continuously measured (FUKUCHI and HATTORI, 1987).

The present paper describes the spatial variation of chlorophyll *a* concentration obtained with the system along the southward leg from Fremantle, Western Australia, to Syowa Station (69°00′S, 39°35′E), Antarctica, in early December of 1985 as well as the temporal variation obtained while the SHIRASE was moored in the fast ice area in Ongul Strait near Syowa Station in late January of 1986.

2. Materials and Methods

Instrumentation and data processing of the surface water monitoring system installed on board the SHIRASE were described by FUKUCHI and HATTORI (1987). Water pumped up from the bottom of the ship (8 m depth) was led into the sensor unit so as to measure flow rate, water temperature, conductivity, dissolved oxygen, fluorescence intensity, and concentration of nutrient salts of water. Concurrently, navigation information such as Greenwich mean time (GMT), position, ship's speed, sea depth, air temperature were recorded. Data on GMT and longitude of ship's position are used simultaneously to calculate local mean time (LMT). LMT is not equal to ordinary ship's time, which sometimes does not synchronize with actual solar time.

Dissolved oxygen concentration in this paper does not mean the absolute value but the relative value, because the sensor had not yet been calibrated. Manual measurements of chlorophyll *a* (after STRICKLAND and PARSONS, 1972) were made using subsamples taken twice a day from the outlet of the system. The regressions of chlorophyll *a* (Chl. *a*) concentration (μg/*l*) to readings of the fluorescence intensity (R) were

$$\text{Chl. } a = 0.01671\, R^{1.3457} \quad (n=29,\ r=0.913) \text{ in December}$$

and

$$\text{Chl. } a = 0.05222\, R^{1.0113} \quad (n=50,\ r=0.980) \text{ in January.}$$

A Technicon Auto Analyzer II was used to analyze nutrient concentration of nitrate-plus nitrite-nitrogen with use of a cadmium-copper reduction column (STRICKLAND and PARSONS, 1972). The efficiency of reduction was checked automatically at 6 hour intervals, with a control system consisting of 4 timers and 3 electric valves to alter the inflow of sample water to the blank and standard solution.

Data were sampled every five minutes throughout the present observations. Ship's speed along the southward leg (Fig. 1) was 13–15 knots. Spatial resolution of data along the cruise track was 2.00–2.31 km. Four day series data obtained in the Indian sector of the Antarctic Ocean along the southward leg from 0600 LMT on 4 December 1985 at 36°23.6′S, 112°04.9′E to 0600 LMT on 8 December 1985 at 54°25.9′S, 95°18.6′E were sorted out. Also, four day data from 1608 LMT on 24 January 1986 were sorted out while the SHIRASE was moored in the fast ice area in Ongul Strait at 69°00.3′S, 39°37.7′E (Sea depth: 600 m) near Syowa Station, Antarctica. The thickness of the fast ice was about 1 m.

Routine oceanographic work including XBT observations was concurrently done along the cruise track (IWANAGA and TOHJU, 1987).

3. Results and Discussion

Several attempts to measure surface chlorophyll concentration continuously have been reported from Antarctic waters (YAMAGUCHI and SHIBATA, 1982; HAYES *et al.*, 1984; TANIGUCHI *et al.*, 1986; WEBER *et al.*, 1986). All of them recorded chlorophyll data on a strip chart and they analyzed the data together with variations of either temperature, salinity or sea depth. The latter three data were sampled separately. The present surface water monitoring system is useful not only to increase the kinds of data items continuously measured, but also to acquire navigation information. Also the system makes possible quick data processing and editing, including data print out as well as plotting of time series (see Figs. 3 and 4) and geographical mapping (see Fig. 1).

Fig. 1. Cruise track of the icebreaker SHIRASE *in the 27th Japanese Antarctic Research Expedition (1985/86). The hatched part indicates approximate location for data shown in Figs. 2 and 3, respectively. A cross indicates the fixed station in coastal fast ice for data shown in Fig. 4.*

The cruise track during JARE-27 (1985/86) is shown in the Indian sector of the Antarctic Ocean (Fig. 1). However, results obtained on the northward leg are not dealt with in this paper.

Positions of three oceanic frontal zones (STC: the Subtropical Convergence; SAF: the Subantarctic Front; PF: the Polar Front) were determined based on the surface gradients of temperature and nutrient (nitrate-+nitrite-nitrogen) concentration. Ranges of variables are summarized in Table 1. The positions of three zones are also plotted on the vertical temperature profile in Fig. 2. Four day data along the southward leg are shown in Fig. 3. In the subtropical water, water temperature was above 15°C and salinity was more than 35.00 psu. Temperature and salinity decreased in parallel toward the south, and temperature and salinity became less than 5°C and 34.00 psu, respectively.

Nutrient concentration and temperature fluctuated inversely around the STC zone. Nitrate plus nitrite nitrogen concentration increased rapidly from north to south while crossing the STC (Fig. 3), which was also noted by LUTJEHARMS *et al.* (1985). Chlorophyll *a* was high, as much as 0.5 μg/*l*, in and around the STC zone. High chlorophyll *a* around the STC, in particular at the northern edge of the STC, was reported by PLANCKE (1977), LUTJEHARMS *et al.* (1985) and YAMAMOTO (1986).

Table 1. Ranges of temperature, salinity, nutrient (nitrate-+nitrite-nitrogen) concentration and chlorophyll a concentration at the Subtropical Convergence (STC), the Subantarctic Frontal (SAF) and the Polar Frontal (PF) zones.

Zone	Period	Location	Temp. (°C)	Salinity (psu)	NO_3-N + NO_2-N (μg-at/*l*)	Chl. *a* (μg/*l*)
STC	1985					
	Dec. 4, 18:15	38°55.1′S, 110°05.1′E	14.92	35.14	1.93	0.23
	~	~	~	~	~	~
	Dec. 4, 20:49	39°19.7′S, 109°45.4′E	14.64	35.00	3.86	0.19
SAF	Dec. 6, 10:46	46°02.0′S, 104°02.3′E	10.34	34.61	12.69	0.75
	~	~	~	~	~	~
	Dec. 6, 16:48	47°23.0′S, 103°21.5′E	8.03	34.34	20.88	0.24
PF	Dec. 7, 21:30	52°46.7′S, 97°35.7′E	4.38	33.85	25.95	1.94
	~	~	~	~	~	~
	Dec. 7, 01:36	53°34.8′S, 96°30.5′E	3.11	33.84	26.85	2.42

Chlorophyll *a* decreased to about 0.1 μg/*l* south of the STC and increased again to about 1.0 μg/*l* north of the SAF zone. Nutrient concentration fluctuated inversely to water temperature along the courses and did not show any consistent relationship to chlorophyll *a* concentration. In the SAF zone, chlorophyll *a* decreased slightly to 0.5 μg/*l*. LUTJEHARMS *et al.* (1985) and TANIGUCHI *et al.* (1986), however, showed increases of chlorophyll *a* in the SAF zone. A peak of chlorophyll *a* as high as 2.92 μg/*l* was recorded in the subantarctic water. The peak coincided with an occurrence of slightly lower temperature than the surrounding

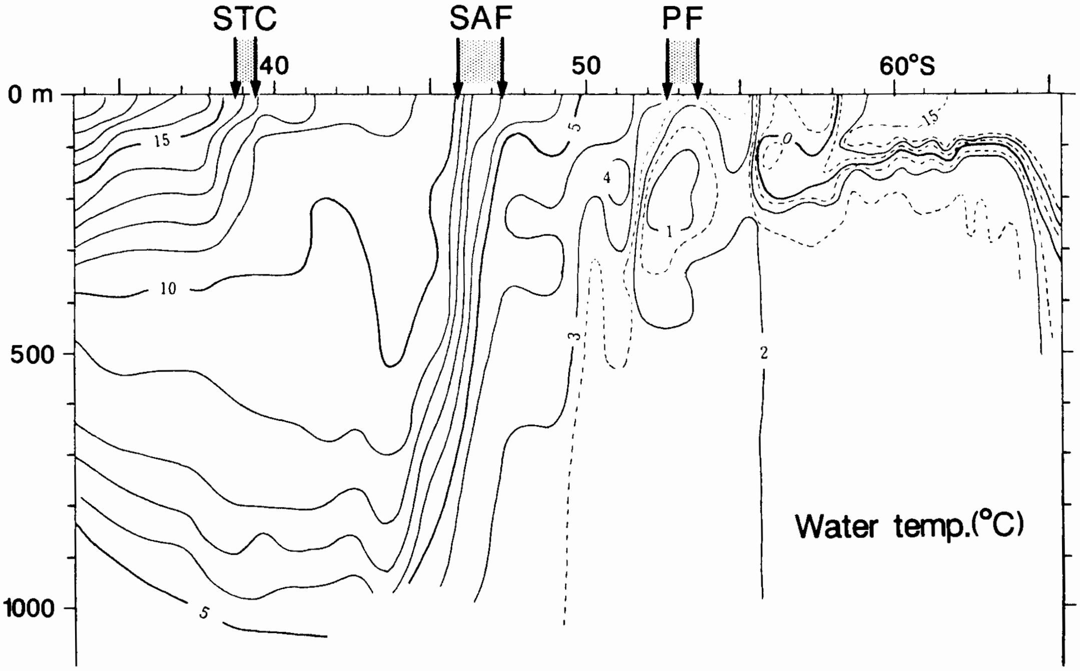

Fig. 2. Vertical profile of water temperature obtained with XBT observations on the southward leg in December 1985. STC, SAF and PF indicate approximate locations of the Subtropical Convergence zone, the Subantarctic Frontal zone and the Polar Frontal zone, respectively (modified from IWANAGA *and* TOHJU, *1987).*

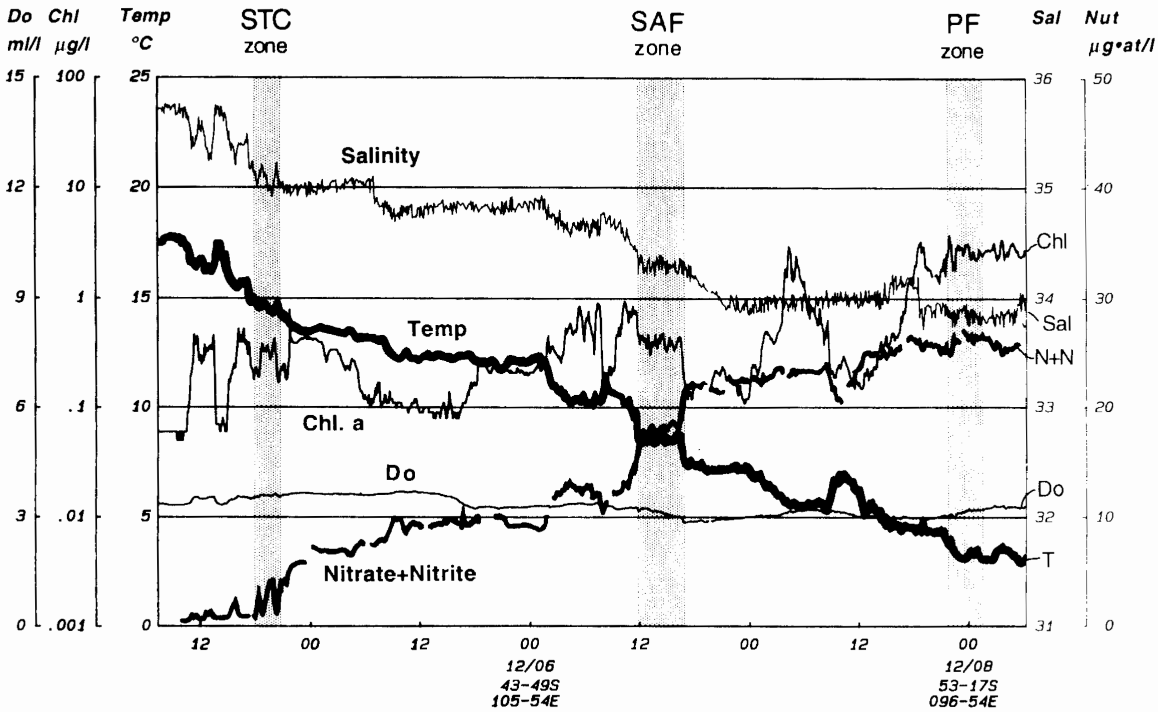

Fig. 3. A 4-day record of the surface water monitoring system on the southward leg in the Indian sector of the Southern Ocean from 4 to 8 December 1985 (modified from FUKUCHI *and* HATTORI, *1987). STC, SAF and PF as in Fig. 2. Do, Chl, Temp, Sal, and Nut indicate dissolved oxygen (ml/l), chlorophyll a concentration (µg/l), temperature (°C), practical salinity scale and nitrate plus nitrite concentration (µg-at/l), respectively.*

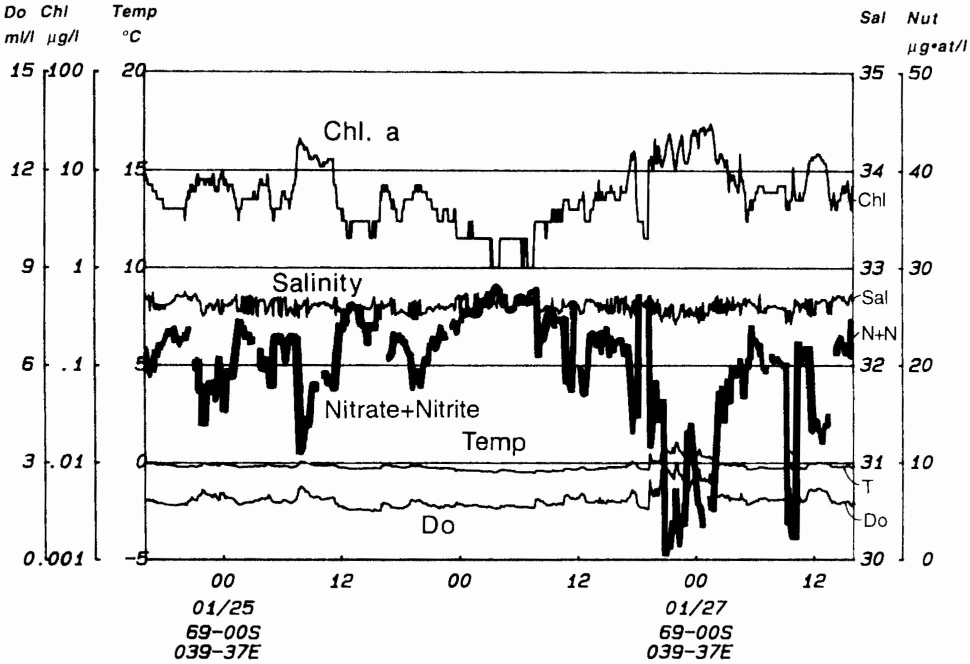

Fig. 4. A 4-day record of the surface water monitoring system from 24 to 28 January 1986, obtained while the SHIRASE *was moored in fast ice in Ongul Strait (69°00.3′ S, 39°37.7′E; sea depth 600 m) near Syowa Station, Antarctica. Do, Chl, Temp, Sal, and Nut indicate dissolved oxygen (ml/l), chlorophyll a concentration (µg/l), temperature (°C), practical salinity scale and nitrate plus nitrite concentration (µg-at/l), respectively.*

waters. This kind of peak has not yet been reported in previous work.

Higher chlorophyll *a*, more than 3 µg/*l*, was observed in and around the PF zone. Those high chlorophyll *a* concentrations in December are commonly observed by many workers in Antarctic waters (FUKUCHI, 1980; TANIMURA, 1981; FUKUCHI and TAMURA, 1982; YAMAGUCHI and SHIBATA, 1982; TANIGUCHI *et al.*, 1986; YAMAMOTO, 1986).

Temporal variations obtained at a moored point in the fast ice area near Syowa Station are shown for 4 days in 24–28 January 1986 (Fig. 4). Temperature did not fluctuate largely within a range of 0∼−0.5°C, except for a short period around midnight on 27 January when it increased to +1.0°C. Salinity was stable throughout the 4 days. Temporal variations of the three parameters, chlorophyll *a*, temperature and dissolved oxygen, showed similar tendencies. The most striking feature among the temporal changes is a negative correlation between chlorophyll *a* and nutrient concentration (nitrate-+nitrite-nitrogen). The two parameters varied inversely a manner like a mirror image; high chlorophyll *a* with low nitrogen concentration and vice versa.

HAYES *et al.* (1984) reported quite good agreement between temperature (+1.0∼−0.3°C) and fluorescence for a two day period observed alongside the shelf ice near Halley Station. FUKUCHI *et al.* (1988) observed temporal variations of temperature and chlorophyll *a* concentration for a 47 day period in Breid Bay (70°10′S, 24°00′E) and showed close correlations between temperature and chlorophyll *a* concentration. FUKUCHI *et al.* (1988) concluded that the correlation indicates a patchy distribution of phytoplankton and advection by water movement in the bay. The interesting features observed at the present moored point seem to have the same cause. A patchy distribution of chlorophyll *a* beneath the fast ice might have the nature of high chlorophyll *a* in waters of slight high temperature resulting in high oxygen level after consuming nutrient salt.

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