

Chlorophyll *a* and Phaeophytin Contents in the Surface Water of the Antarctic Ocean through the Indian Ocean

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南極海域及びインド洋海域における表面水中のクロロフィル *a* とフェオフィチン

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要旨 : 1967年11月から1968年4月にかけての第9次南極観測の海洋生物の定常観測として、南極海域及び関連海域の表面水中のクロロフィル *a* とフェオフィチン含量の測定を蛍光法を用いて行った。南極海域におけるクロロフィル *a* 及びフェオフィチンの平均含量 (それぞれ 0.24mg/m^3 , 0.51mg/m^3) はインド洋海域の平均含量 (それぞれ 0.17mg/m^3 , 0.39mg/m^3) よりも高い値を示した。南極海域内での両色素含量の分布は地域的にかなり変動を示した。又この分布の様相は、これまでに測定点付近で得られている結果とかなりの一致をみた。各測定点におけるクロロフィル *a* とフェオフィチン含量から求めた相関関係から、南極海域においては単位クロロフィル *a* 当りのフェオフィチン含量がインド洋海域よりも低いことが示された。

1. Introduction

Measurement of chlorophyll *a* as an index of the potential photosynthetic capacity of phytoplankton provides an indispensable background for the studies of marine ecosystem.

As a program of marine biology of the 9th Japanese Antarctic Research Expedition (JARE) in 1967-1968, chlorophyll *a* and phaeophytin determinations were conducted on board the icebreaker FUJI during the cruise to and from Antarctica.

The present paper deals with the results of observation on both pigments in the Indian sector of the Antarctic Ocean through the Indian Ocean.

2. Materials and Methods

The track chart of icebreaker FUJI is shown in Fig. 1. The sampling was regularly made at 08:00 and 19:00 or 20:00 from Fremantle to Colombo *via* Syowa Station,

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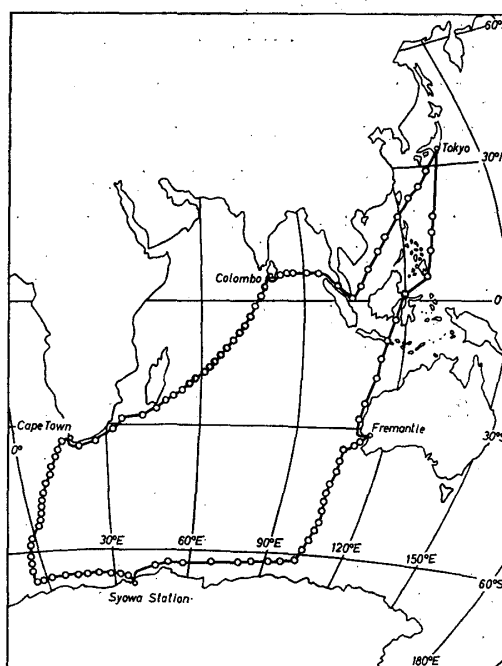


Fig. 1. Course of icebreaker FUJI with sampling stations.

but at 08:00 in other parts of the course. Chlorophyll *a* and phaeophytin were determined by the fluorometric techniques substantially the same as those reported by YENTSCH and MENZEL (1963). Surface water was scooped up by a plastic bucket and filtered through a glass fibre filter paper (Watmann GF/C, diameter 24 mm). For cell destruction and pigment extraction, the filter was ground for 10 minutes in a mortar with a 90% aqueous acetone solution. The resultant suspension was centrifuged for 5 minutes at 3000 rpm. Initial fluorescence of supernatant fluid was read with a fluorometer (Type FPL-2, made by Hitachi, Ltd.) equipped with a red sensitive photomultiplier (Hamamatsu Electric Co. Ltd., Type R-136). A Hitachi 436 filter was used for the excitation and a 66 filter was used for the emission. After the initial reading was made, the solution was acidified with two drops of 0.1 N hydrochloric acid and the fluorescence was again read. More than five minutes were spent to get a constant fluorescence reading.

The concentrations of chlorophyll *a* and phaeophytin were calculated with the following equations:

$$\text{chlorophyll } a \text{ (mg/m}^3\text{)} = \frac{K \cdot v \cdot (F_o - F_a)}{V \cdot 1000}$$

$$\text{phaeophytin (mg/m}^3\text{)} = \frac{K \cdot v \cdot [(F_o / F_a \text{ max}) \cdot F_a - F_o]}{V \cdot 1000}$$

where:

Fo: Fluorescence before acidification

Fa: Fluorescence after acidification

Fo/Fa max: Maximum Fo:Fa ratio=5 [as determined by SAIJO *et al.* (1969) using the same instrument]

K: Calibration constant obtained with chlorophyll *a* by chromatographic technique=5 [as determined by SAIJO *et al.* (1969)]

V: Volume of sample in *l*

v: Volume of acetone in *ml*

3. Results and Discussion

The longitudinal changes of chlorophyll *a*, phaeophytin and Fo:Fa ratio between 14°S at 115°E and the coast of Antarctica at 108°E are shown in Fig. 2. Low concentration of chlorophyll *a* (0.03-0.07mg/m³) was measured in the eastern area of the Indian Ocean between 14°S and about 35°S with little fluctuation. A gradual increase in concentration was evidently observed from 35°S to 43°S. After a slight decrease southward, a conspicuous increased value of 0.91mg/m³ was recorded

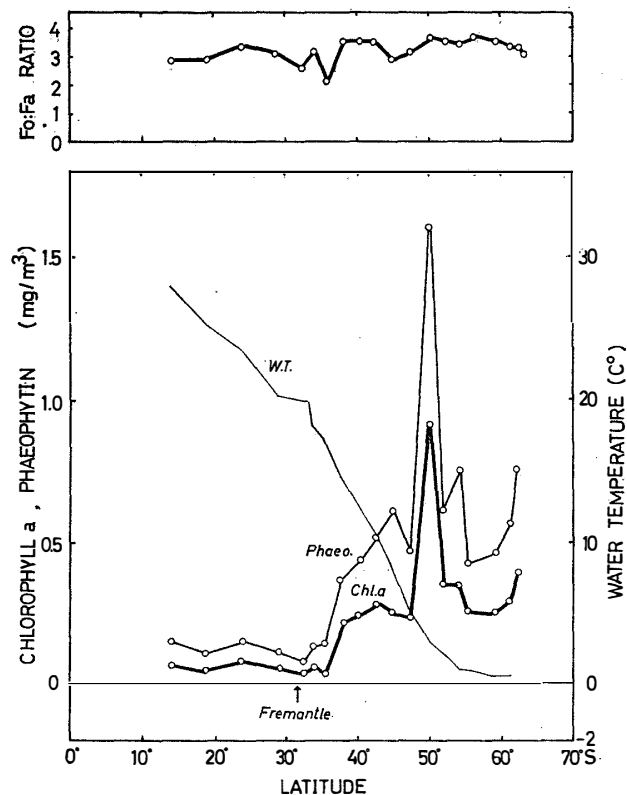


Fig. 2. Longitudinal change in chlorophyll *a* and phaeophytin concentrations, Fo:Fa ratio and water temperature on the way to Antarctica in November to December, 1967.

at 50°S. The concentrations of chlorophyll *a* and phaeophytin were estimated in the ranges from 0.25mg/m³ to 0.35mg/m³ and from 0.42mg/m³ to 0.68mg/m³ respectively, and these values showed a tendency to increase toward the pack ice zone.

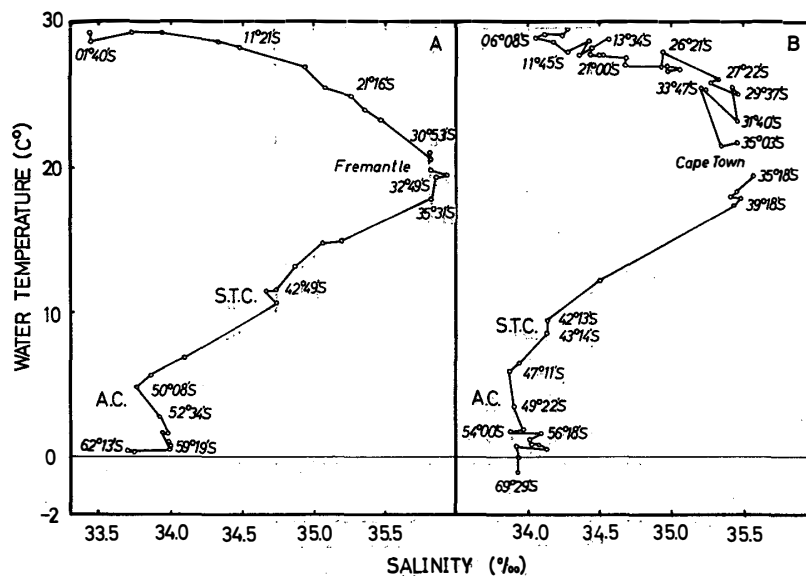


Fig. 3. Temperature-salinity relations in the surface water.

A; on the way to Antarctica.

B; on the way back from Antarctica.

The temperature-salinity (T-S) relations are presented in Figs. 3A and 3B, using the data obtained by WATANABE and HIGANO (1968) in JARE-9. Judging from the T-S relation in Fig. 3A, it may be said that the Antarctic Convergence and the Subtropical Convergence are located within or nearly at 43°S and 50°S respectively. By these convergences, the Antarctic Ocean was divided into the Subantarctic Upper Water mass and the Antarctic Surface Water mass. Accordingly, it may be concluded that the chlorophyll *a* concentration in the Subantarctic Upper Water mass was approximately equal to that in the Antarctic Surface Water mass, while the value was remarkably high in the regions of the Antarctic Convergence and the southern end of the Antarctic Surface Water mass. This result was quite similar to the data obtained by SAIJO and KAWASHIMA (1964) and HOSHIAI (1968). Horizontal distribution of phaeophytin closely resembled that of chlorophyll *a*. Significant change of the Fo:Fa ratio depending on the water mass was scarcely observed in this area.

In the area outside the pack ice zone along the Antarctic coast from 93°E to 30°W, both pigments were found to concentrate with a wide range of variation (Fig. 4); low values in both pigments (chlorophyll *a*: 0.05-0.08mg/m³, phaeophytin: 0.14-0.21 mg/m³) were measured in the region between 66°E and 54°E, while high values

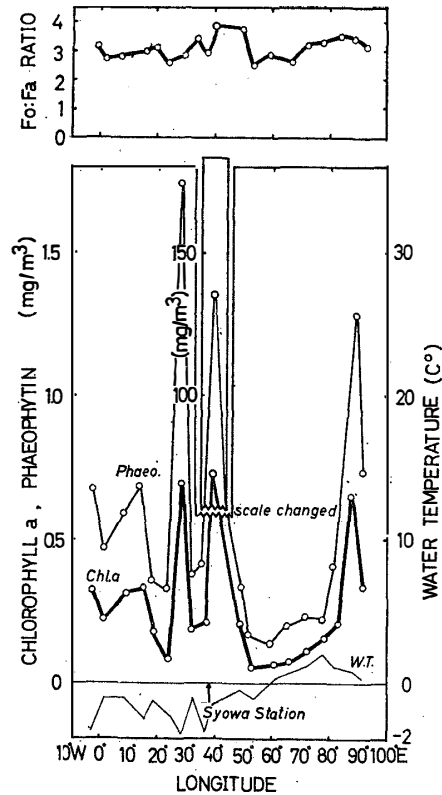


Fig. 4. Longitudinal change chlorophyll *a* and phaeophytin concentrations, Fo:Fa ratio and water temperature in the area off the coast of Antarctica in December, 1967 to February, 1968.

(chlorophyll *a*: 0.66-0.69mg/m³, phaeophytin: 1.28-1.75mg/m³) were recorded at 85°E and 29°E. The highest value (chlorophyll *a*: 72.8mg/m³, phaeophytin: 135mg/m³) was obtained in the Ongul Strait located between Antarctica and the Ongul Islands. The value of chlorophyll was approximately three times larger than the highest value of 27.3 mg/m³ obtained by BURKHOLDER and SIEBURTH (1961). Such uneven distribution of two pigments in this region are attributable to the irregular oceanic conditions caused by melting of pack ice and icebergs. Meaningful change in the Fo:Fa ratio could not be found.

Latitudinal variation of pigments and the Fo:Fa ratio from the area off the Antarctic coast (69°51'S, 02°51'W) to equatorial region of the Indian Ocean (01° 10'S, 75°55'E) via Cape Town is presented in Fig. 5. The T-S relation from Antarctica to Cape Town(Fig. 3B) indicates that the Antarctic Convergence, the Sub-tropical Convergence and the Agulhas Convergence proposed by FUKASE (1961) seemed to be located nearly at 49°S, 42°S and 38°S respectively. However, in the area from Cape Town to the equatorial region, this relation is too complicated to characterize the water masses. As may be seen in Fig. 5, relatively high values of chlorophyll *a* were estimated at 69°S, 54°S, 47°S and 38°S, which corresponded

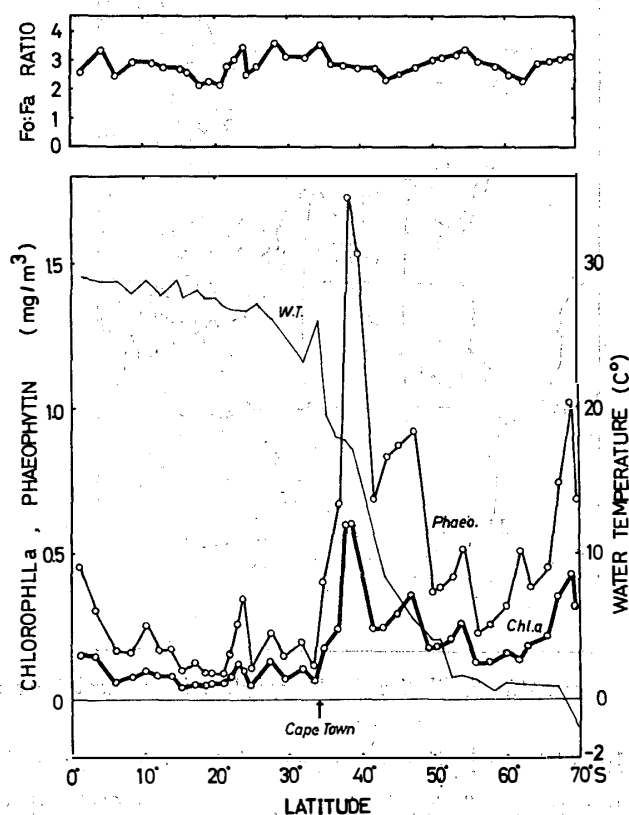


Fig. 5. Latitudinal change in chlorophyll *a* and phaeophytin concentrations, Fo:Fa ratio and water temperature on the way from Antarctica in February, 1968.

closely to the southern part and northern part of the Antarctic Surface Water masses, the central part of the Subtropical Upper Water mass and the northern area of the Agulhas Convergence respectively. On the other hand low values were measured in the region from 56°S to 62°S, at 50°S and 42°S, or roughly in the central part of the Antarctic Surface Water mass, the Antarctic and the Subtropical Convergences respectively. The profile of decrease in the content of pigments at these convergences was quite different from that obtained on the way to Antarctica. In a cruise of R/V UMITAKA-MARU sailing across four sections of the Pacific sector of the Antarctic Convergence, the increment of chlorophyll *a* within or near the convergence was observed in three sections (TOMINAGA, unpublished data). Thus, even in the region of the Antarctic Convergence the chlorophyll *a* concentration varies considerably from area to area.

ICHIMURA and FUKUSHIMA (1963) observed a high concentration of chlorophyll *a* in the area between 43°S and 58°S. According to HOSHIAI (1968) the chlorophyll *a* concentration was rather low between 50°S and 59°S, except the region of 62-23°S and 43-49°S, which agrees substantially with the present observation.

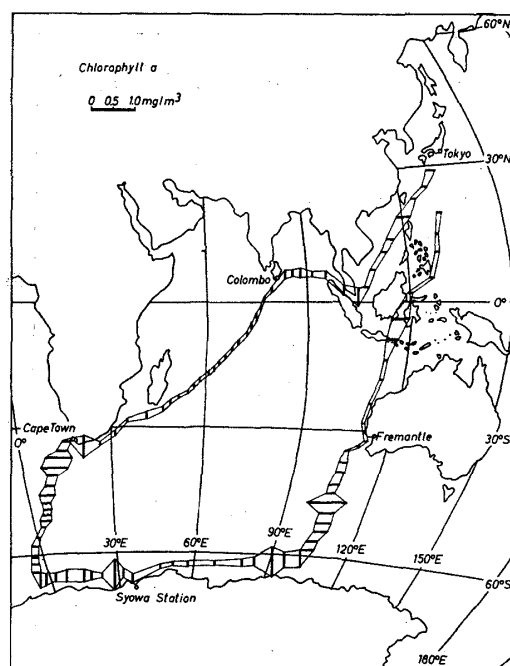


Fig. 6. Geographic distribution of chlorophyll *a* in the surface water.

Distribution of the chlorophyll *a* concentration in the area from Cape Town to the equatorial water mass of the Indian Ocean near Colombo showed a similar pattern obtained in 1966–1967 (HOSHIAI, 1968) and 1968–1969 (TAKAHASHI, 1969); fluctuation of the concentration was large from Cape Town to 22°S but small from 22°S to the equatorial region.

Finally, summarizing these results, the chlorophyll *a* concentrations of the Antarctic Ocean and of the Indian Ocean were in the range from 0.05 to 0.91 mg/m³ (averaging value 0.24mg/m³) and from 0.02 to 0.60mg/m³ (averaging value 0.17mg/m³) respectively. This indicates that the chlorophyll *a* concentration in the Antarctic Ocean was much higher than that in the Indian Ocean and its fluctuation also was more pronounced in the Antarctic Ocean (Fig. 6).

The concentration of phaeophytin in the Antarctic Ocean was found in the range from 0.14 to 1.75mg/m³ (averaging value 0.51mg/m³) and that in the Indian Ocean from 0.08 to 1.71mg/m³ (averaging value 0.39mg/m³). Distribution of phaeophytin appeared to be parallel with that of chlorophyll *a*. The correlations between phaeophytin (P mg/m³) and chlorophyll *a* (C mg/m³) are most satisfactorily fitted with the following equations:

$$P = 1.95 C + 0.05 \quad (r = 0.94) \text{ in the Antarctic Ocean}$$

and

$$P = 2.74 C + 0.01 \quad (r = 0.91) \text{ in the Indian Ocean}$$

where *r* is the correlation coefficient. It is apparent that the ratio of phaeophytin

to chlorophyll *a* content in the Antarctic Ocean is slightly lower than that in the Indian Ocean.

The Fo:Fa ratios in the Antarctic Ocean ranged from 2.2 to 3.9 (average 3.0), while in the Indian Ocean the values were from 2.0 to 3.6 (average 2.7). However, any significant change in these ratios with water mass was not observed. Further investigation is necessary to elucidate this subject.

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APPENDIX

Date	Time (LT)	Latitude	Longitude	Water temp. (°C)	Chlorophyll <i>a</i> (mg/m ³)	Phaeophytin (mg/m ³)	Fo:Fa ratio
Nov. 29 '67	08:00	19°09'N	131°13'E	26.3	0.08	0.20	2.8
30	08:00	14°05'N	129°19'E	26.7	0.05	0.13	2.6
Dec. 1	08:00	9°19'N	127°17'E	26.7	0.04	0.11	2.5
2	08:00	4°03'N	124°07'E	27.6	0.09	0.19	3.1
3	08:00	0°57'S	119°47'E	28.5	0.09	0.20	3.1
4	08:00	4°35'S	118°42'E	28.4	0.42	0.57	4.4
5	08:00	8°40'S	115°43'E	28.2	0.31	0.52	3.7
6	08:00	14°15'S	114°24'E	27.9	0.06	0.15	2.8
7	08:00	19°07'S	113°24'E	25.0	0.04	0.10	2.9
8	08:00	23°58'S	112°31'E	23.6	0.07	0.14	3.3
9	08:00	28°57'S	112°57'E	20.0	0.05	0.11	3.0
Fremantle							
15	20:00	32°49'S	113°45'E	19.8	0.03	0.08	3.2
16	08:00	34°11'S	111°17'E	18.0	0.06	0.13	3.2
	20:00	35°31'S	108°46'E	17.2	0.03	0.14	2.0
17	08:00	37°57'S	107°47'E	14.3	0.20	0.36	3.6
	20:00	40°21'S	107°16'E	12.4	0.24	0.44	3.5
18	08:00	42°49'S	106°48'E	10.4	0.27	0.51	3.4
	20:00	45°16'S	107°02'E	10.5	0.24	0.61	2.8
19	08:00	47°45'S	107°17'E	8.3	0.23	0.46	3.2
	20:00	50°08'S	108°08'E	4.8	0.91	1.60	3.6
20	08:00	52°34'S	108°55'E	2.7	0.33	0.60	3.5
	20:00	54°27'S	108°21'E	2.0	0.35	0.68	3.4
21	08:00	55°39'S	106°50'E	0.8	0.25	0.42	3.7
	20:00	59°19'S	105°11'E	0.8	0.25	0.47	3.4
22	08:00	61°40'S	103°40'E	0.4	0.28	0.58	3.2
	20:00	62°13'S	98°56'E	0.5	0.39	0.76	3.4
23	08:00	62°28'S	93°32'E	0.2	0.33	0.74	3.1
	20:00	62°51'S	88°31'E	0.4	0.66	1.28	3.4
24	08:00	62°58'S	83°08'E	0.6	0.22	0.39	3.5
	20:00	63°33'S	77°53'E	1.1	0.16	0.22	3.3
25	08:00	64°14'S	72°02'E	0.6	0.11	0.24	3.1
	20:00	64°28'S	66°20'E	0.2	0.08	0.21	2.7
26	08:00	64°40'S	60°53'E	0.2	0.05	0.14	2.8
	20:00	65°17'S	53°30'E	-0.5	0.05	0.17	2.4
27	08:00	65°29'S	49°14'E	-0.2	0.21	0.34	3.9

Date	Time (LT)	Latitude	Longitude	Water temp. (°C)	Chlorophyll <i>a</i> (mg/m ³)	Phaeophytin (mg/m ³)	Fo:Fa ratio
Jan. 5	08:00	68°29'S	38°50'E	-1.1	72.8	135	3.9
Syowa Station							
Feb. 13 '68	08:00	68°15'S	37°20'E	-1.7	0.21	0.42	2.8
14	08:00	68°07'S	33°37'E	-0.4	0.19	0.37	3.4
	20:00	68°31'S	29°16'E	-1.9	0.69	1.75	2.8
15	08:00	68°34'S	24°30'E	-1.2	0.08	0.23	2.6
	20:00	68°38'S	18°30'E	-0.6	0.18	0.36	3.0
16	08:00	68°32'S	15°00'E	-1.1	0.33	0.69	3.0
	20:00	67°57'S	07°38'E	-0.4	0.30	0.60	2.7
17	08:00	68°05'S	01°57'E	-0.5	0.22	0.47	2.7
	20:00	69°51'S	02°50'W	-1.8	0.31	0.69	3.1
18	08:00	69°28'S	02°36'W	-1.1	0.46	1.02	3.1
	20:00	67°23'S	02°42'W	0.6	0.35	0.74	2.9
19	08:00	66°02'S	02°40'W	0.8	0.21	0.45	2.9
	20:00	63°14'S	02°20'W	0.8	0.19	0.39	2.7
20	08:00	62°21'S	02°05'W	0.9	0.13	0.51	2.1
	20:00	59°52'S	01°55'W	0.9	0.15	0.31	2.4
21	08:00	58°08'S	01°20'W	0.6	0.12	0.25	2.7
	20:00	56°16'S	01°10'E	1.4	0.12	0.23	2.7
22	08:00	54°00'S	02°26'E	1.6	0.23	0.52	3.2
	20:00	52°49'S	02°35'E	1.5	0.21	0.42	3.1
23	08:00	50°23'S	04°09'E	4.0	0.18	0.39	2.9
	20:00	50°00'S	04°40'E	3.9	0.18	0.38	2.8
24	08:00	46°27'S	07°22'E	5.5	0.54	0.93	2.6
	20:00	44°52'S	08°38'E	6.5	0.35	0.90	2.6
25	08:00	43°14'S	10°09'E	8.4	0.23	0.87	2.2
	20:00	41°15'S	11°57'E	12.2	0.23	0.68	2.6
26	08:00	39°18'S	13°33'E	17.1	0.59	1.54	2.6
	20:00	37°50'S	14°42'E	17.5	0.60	1.71	2.6
27	08:00	36°56'S	15°19'E	17.8	0.23	0.66	2.6
	20:00	35°18'S	16°23'E	19.2	0.16	0.38	2.7
Cape Town							
Mar. 8	08:00	35°03'S	21°37'E	21.7	0.49	0.80	3.4
9	08:00	33°47'S	27°17'E	25.6	0.05	0.09	3.4
10	08:00	31°40'S	32°13'E	22.9	0.08	0.20	2.9
11	08:00	29°37'S	37°09'E	24.6	0.06	0.14	2.9
12	08:00	27°22'S	42°30'E	26.0	0.12	0.23	3.4
13	08:00	25°08'S	47°35'E	26.8	0.03	0.08	2.7
	19:00	24°10'S	49°54'E	26.6	0.10	0.34	2.4

Date	Time (LT)	Latitude	Longitude	Water temp. (°C)	Chlorophyll <i>a</i> (mg/m ³)	Phaeophytin (mg/m ³)	Fo:Fa ratio
14	08:00	22°59'S	52°31'E	26.5	0.12	0.25	3.2
	19:00	22°03'S	54°43'E	26.6	0.06	0.15	2.8
15	08:00	21°00'S	57°10'E	26.8	0.03	0.08	2.6
	19:00	19°42'S	59°03'E	27.3	0.03	0.08	2.4
16	08:00	18°01'S	60°59'E	27.3	0.02	0.08	2.1
	19:00	16°32'S	62°42'E	27.7	0.03	0.13	2.1
17	08:00	15°09'S	64°59'E	27.3	0.03	0.08	2.4
	19:00	13°34'S	66°41'E	28.8	0.06	0.17	2.5
18	08:00	11°45'S	68°32'E	27.5	0.06	0.16	2.6
	19:00	10°05'S	70°13'E	28.7	0.09	0.25	2.6
19	08:00	08°05'S	72°17'E	27.8	0.05	0.14	2.8
	19:00	06°08'S	73°40'E	28.6	0.04	0.15	2.3
20	08:00	03°27'S	74°53'E	28.8	0.14	0.30	3.1
	19:00	01°10'S	75°55'E	29.0	0.13	0.44	2.4
21	08:00	01°00'N	77°41'E	28.5	0.12	0.36	2.5
	19:00	02°43'N	78°31'E	28.6	0.08	0.21	2.7
22	08:00	05°11'N	79°33'E	28.6	0.11	0.29	2.8
Colombo							
28	08:00	05°54'N	83°13'E	27.8	0.19	0.50	2.8
	19:00	06°00'N	85°34'E	27.6	0.15	0.33	3.0
29	08:00	06°05'N	88°14'E	28.0	0.20	0.49	2.9
	19:00	06°08'N	90°39'E	29.6	0.07	0.18	2.8
30	08:00	06°12'N	93°32'E	28.3	0.15	0.35	3.0
31	08:00	04°49'N	98°27'E	28.8	0.17	0.33	3.4
April							
1	08:00	01°30'N	103°04'E	28.5	0.38	0.77	3.3
2	08:00	04°31'N	106°25'E	27.8	0.07	0.19	2.8
3	08:00	08°31'N	109°34'E	27.2	0.10	0.21	3.2
4	08:00	12°12'N	113°02'E	27.3	0.11	0.23	3.1
5	08:00	15°33'N	116°49'E	26.4	0.13	0.25	3.3
6	08:00	18°57'N	120°35'E	25.9	0.30	0.53	3.6
7	08:00	22°29'N	124°20'E	24.3	0.07	0.19	2.8
8	08:00	26°13'N	128°14'E	20.7	0.12	0.32	2.8
9	08:00	29°51'N	132°03'E	21.6	0.21	0.52	2.8
10	08:00	33°13'N	135°59'E	18.0	1.15	2.49	3.1