

Chlorophyll *a* Content in the Surface and Subsurface Waters
along the Course of the SHIRASE to Antarctica in 1984–1985Yasushi FUKUDA*, Masao OHNO**, Keisuke IWANAMI***
and Hiroshi TOUJU***「しらせ」航路 (1984–1985) における表面および船底海水中のクロロフィル *a* 量

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要旨: 1984年11月から1985年4月まで第26次南極地域観測隊による海洋生物定常観測の一環として、「しらせ」航路上に沿って表面海水中(バケツ採水)および亜表面海水中(船底からのポンプ採水,水深約8m)のクロロフィル *a* 量を測定した。

表面海水と亜表面海水中のクロロフィル *a* 量の値は,全測定値の平均値と比較すると,前者で 0.01 mg/m^3 高かった。しかし,両深度におけるクロロフィル濃度の変動のしかたは全航海を通して同じ傾向を示し,両者間にはきわめて高い正の相関が認められた。

南大洋のクロロフィル *a* 濃度は12月上旬,東経110度線上に沿った南下航路上において,オーストラリア亜南極前線と南極収束線の間で最大値 1.51 mg/m^3 を記録した。2カ月経過後の3月上旬,東経40度線に沿った北上航路では南緯62度付近で最大値 1.17 mg/m^3 を観測した。

Abstract: Chlorophyll *a* concentrations in the surface (by bucket sampling) and subsurface sea waters (by pumping from bottom of ship at ca. 8 m depth) were measured along the course of the icebreaker SHIRASE from November 1984 to April 1985, as part of the routine works of marine biology of the 26th Japanese Antarctic Research Expedition (JARE-26).

Mean value of the surface chlorophyll *a* was 0.01 mg/m^3 higher than that of the subsurface chlorophyll *a*. However, the fluctuations of chlorophyll *a* at both strata showed a similar tendency throughout the cruise. Positive correlation was clearly observed between the surface and the subsurface chlorophyll *a*. High chlorophyll *a* concentrations (more than 0.5 mg/m^3) were observed in the sea adjacent to Japan, the strait of Malacca and the Southern Ocean. In the Southern Ocean, the chlorophyll *a* content fluctuated from 0.04 mg/m^3 to 1.51 mg/m^3 . The maximum concentration on the southward leg in early December was 1.51 mg/m^3 between the Australasian Subantarctic Front and the Antarctic Convergence. On the other hand, the maximum value on the northward leg in early March was 1.17 mg/m^3 near Lat. 62°S .

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1. Introduction

The investigation of chlorophyll *a* distribution in the surface water along the cruise track of the icebreakers FUJI and SHIRASE has been carried out as part of the routine works of the marine biology of the 26th Japanese Antarctic Research Expedition (JARE-26).

The surface chlorophyll *a* concentration has been measured on the bucket samples in early cruises from JARE-7 to JARE-24. However, on the JARE-25 cruise, HAMADA *et al.* (1985) measured the chlorophyll *a* content of the subsurface sea water by pumping from an intake on the bottom of ship at *ca.* 8 m depth. In the present JARE-26 cruise, we employed both methods of pumping and bucket samplings, and compared the relationship between both results. We also reported the relation between the horizontal distribution of chlorophyll *a* concentration and the hydrographical data in the Southern Ocean.

2. Materials and Methods

The surface and subsurface sea waters were collected usually two to three times a day at 07:00, 12:00 and 17:00 by local time along the course of the JARE-26 cruise (see Appendix 1). The surface sea water was obtained by a plastic bucket. The subsurface sea water was pumped up from an intake on the hull. Pumping system was the same as the one employed by HAMADA *et al.* (1985) in the JARE-25. Samples of the surface and subsurface sea waters were usually obtained at the same time. One liter of sample water was filtered through a Whatman GF/C glass fiber filter (47 mm) under a reduced pressure. The concentration of chlorophyll *a* was determined by the fluorometric method with a SHIMAZU Model RF-500 spectrofluorometer, and the method and equation followed FUKUCHI and TAMURA (1982).

Surface water temperature and salinity were also measured as part of the routine works of the physical and chemical oceanographic observations of JARE. Water temperature and salinity were measured with a thermometer (precision: 1/10°C) and an inductive salinometer (Auto-Lab Model 601 MK-III), respectively. These data were used for comparison with the surface chlorophyll *a* concentration in the Southern Ocean.

3. Results and Discussion

All the results obtained for the surface and subsurface chlorophyll *a* concentrations and the relevant data are listed in Appendix 1. At 125 out of 136 stations, both surface and subsurface values were obtained.

Overall mean value of chlorophyll *a* concentration at the surface (0.28 mg/m³) was 0.01 mg/m³ higher than that at the subsurface (0.27 mg/m³). However, their horizontal distribution showed a similar tendency (Fig. 1) and a positive correlation was clearly observed between the surface and subsurface values (Fig. 2). The correlative equation obtained for 125 data sets was as follows:

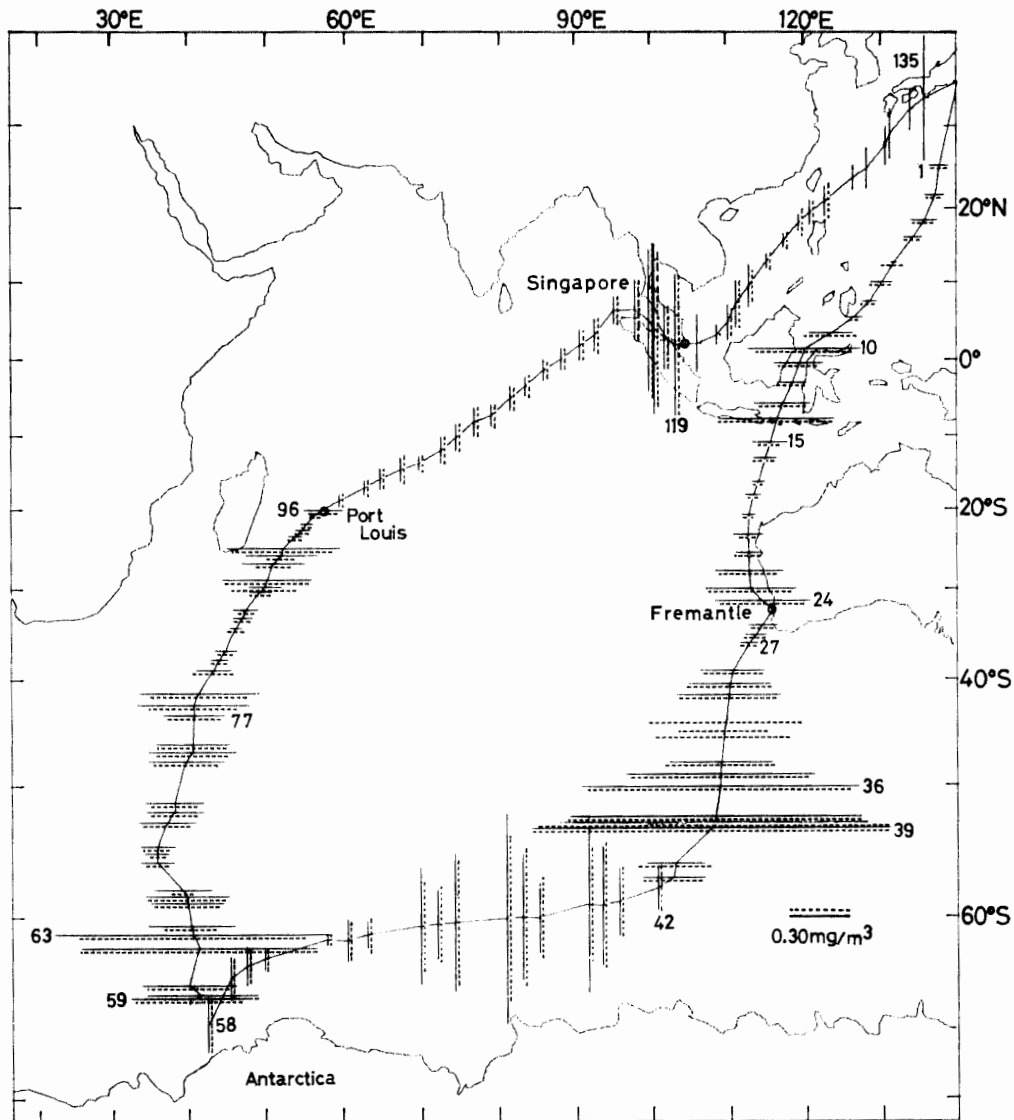


Fig. 1. The geographical distribution of chlorophyll *a* along the course of the JARE-26 cruise of the icebreaker SHIRASE in November 1984–April 1985. Chlorophyll *a* concentrations (mg/m^3) of the surface and sub-surface waters are shown by a solid and dashed lines, respectively. Numerals indicate serial numbers of sampling stations.

$$\text{Chl}_s = 0.017 + 1.013 \text{Chl}_{s,ub} \quad (r = 0.981)$$

where Chl_s and $\text{Chl}_{s,ub}$ are concentrations of chlorophyll *a* at the surface and sub-surface in mg/m^3 , respectively.

3.1. Tokyo to Fremantle (Stns. 1–24)

Chlorophyll *a* concentration was $0.06\text{--}0.12 \text{ mg}/\text{m}^3$ in the western part of the North Pacific, and it increased in the Celebes Sea to $0.13\text{--}0.49 \text{ mg}/\text{m}^3$. It decreased again in the northeastern part of the Indian Ocean to $0.06\text{--}0.15 \text{ mg}/\text{m}^3$. Near Fremantle, it became slightly higher than the previous value, *i.e.*, $0.12\text{--}0.39 \text{ mg}/\text{m}^3$. These trends closely resembled the results reported by the previous workers (HOSHINO, 1974; OHNO, 1976; TANIMURA, 1981).

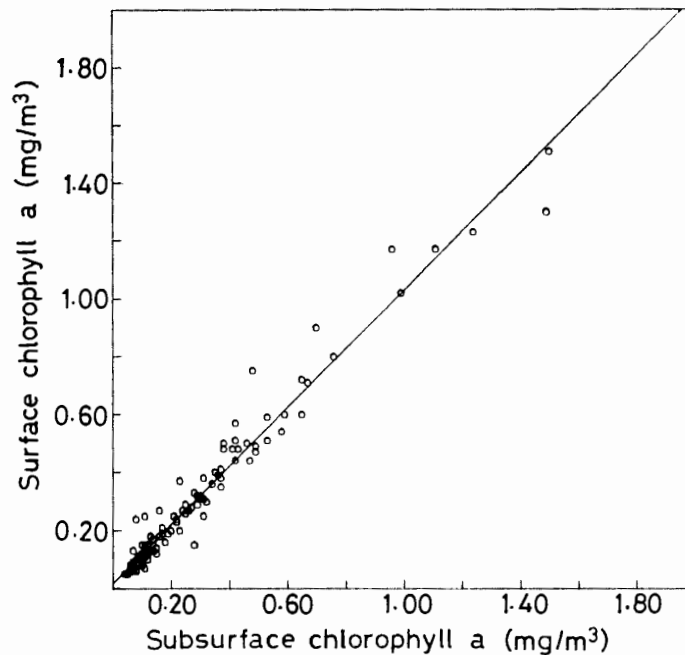


Fig. 2. Relationship between the surface chlorophyll *a* and the subsurface chlorophyll *a*.

3.2. Fremantle to off Lützow-Holm Bay

3.2.1. Southward leg (Stns. 25–41)

Stations on the southward leg were occupied between December 4 and 9, 1984. By analyzing physical and chemical data on the surface water, the Subtropical Convergence (STC) was detected around 38°S (Stns. 27 and 28). The Australasian Subantarctic Front (ASF) and the Antarctic Convergence (AC) were similarly found around 47°S (Stns. 33 and 34) and 55°S (Stns. 39 and 40), respectively (Fig. 3). The concentration of chlorophyll *a* was low (0.08–0.13 mg/m³) from Fremantle to Stn. 27 (36°36'S). An increase of the chlorophyll *a* concentration was observed in the area between the STC and the ASF. Around the ASF, the chlorophyll *a* concentration stopped to increase, and beyond the ASF it increased again towards the AC. The highest value was 1.51 mg/m³ at Stn. 39 (54°38'S). After passing through the AC zone, the chlorophyll *a* content abruptly decreased.

The water temperature gradually decreased from 35 to 57°S, in particular the rate of decrease was high in three zones of Stns. 27–28, Stns. 32–34 and Stns. 39–40. The salinity decreased markedly at stations from 29 to 32, but it was low and fluctuated slightly between Stns. 36 and 41.

3.2.2. Westward leg (Stns. 42–58)

The changes of chlorophyll *a*, temperature and salinity on the westward leg covering Stns. 42–58 were observed between 9 and 15 December 1984 and the results are given in Fig. 4. The chlorophyll *a* varied in a wide range from 0.05 to 0.90 mg/m³ between Stns. 42 and 58. But, the salinity and temperature did not vary widely. Stations 57 and 58 were located in the pack ice area and showed low chlorophyll *a* concentrations (0.22–0.23 mg/m³). In this area, the water temperature was lower than –1.2°C and the salinity was higher than 34.00 ‰.

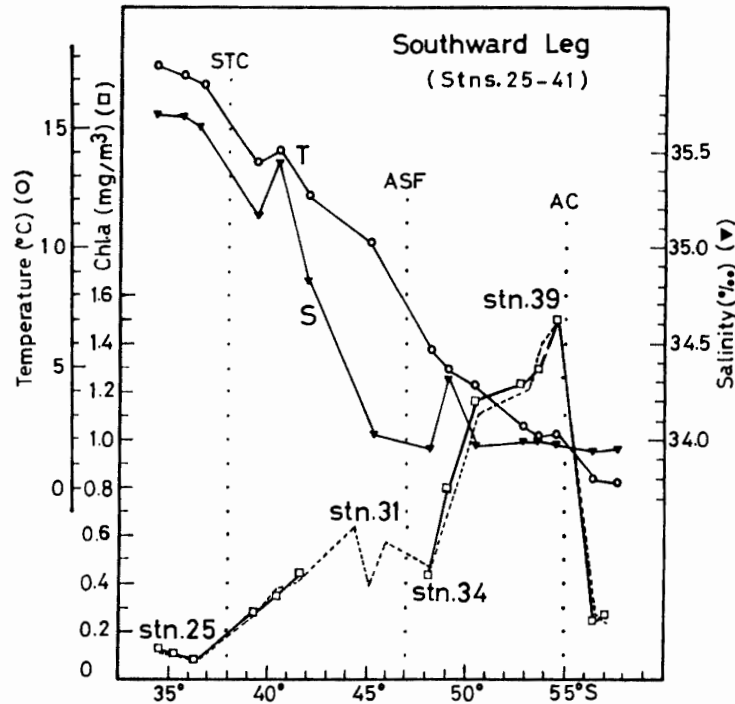


Fig. 3. Latitudinal variations of chlorophyll *a* (mg/m^3), water temperature ($^{\circ}\text{C}$) and salinity (‰) at the surface on the southward leg in the eastern Indian Sector of the Southern Ocean. Subsurface chlorophyll *a* (mg/m^3) is also shown by a dashed line. STC, ASF and AC denote approximate locations of the Subtropical Convergence, Australasian Subantarctic Front and Antarctic Convergence, respectively.

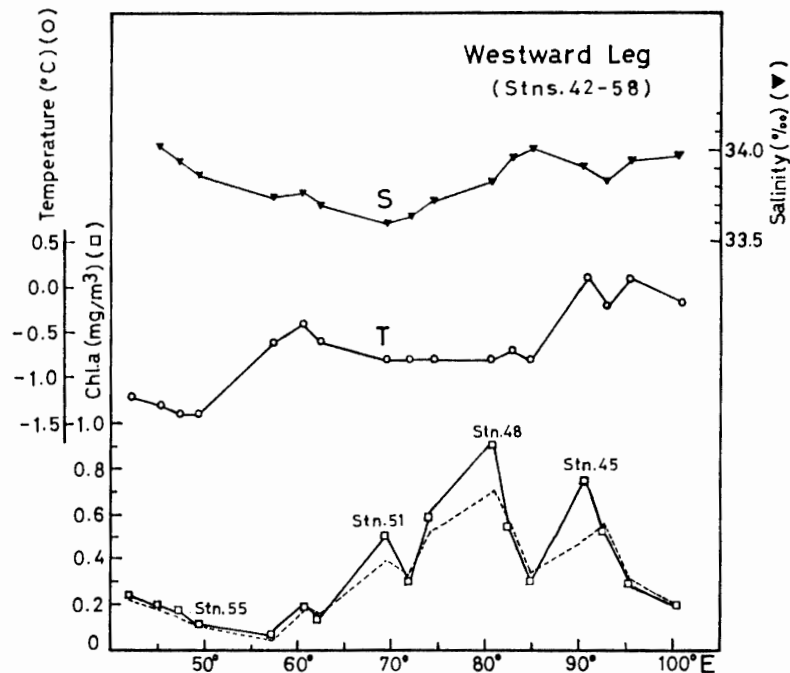


Fig. 4. Longitudinal variations of the chlorophyll *a* (mg/m^3), temperature ($^{\circ}\text{C}$) and salinity (‰) at the surface on the westward leg in the Indian Sector (42–103°E) of the Antarctic Ocean. Subsurface chlorophyll *a* (mg/m^3) is also shown by a dashed line.

3.3. Antarctic Ocean to Port Louis (Stns. 59–96)

Stations on the northward leg, which covered various sea areas from the Antarctic waters to the subtropical waters, were occupied between 2 and 14 March 1985. The distributions of chlorophyll *a*, water temperature and salinity between Stns. 59 (64°52'S) and 84 (34°05'S) are shown in Fig. 5. However, the data of Stns. 85–96, which were located in further north than the latitude of the northernmost station on the southward leg, are not shown in Fig. 5 because the latitudinal range differed between the northward leg and the southward leg. By analyzing physical and chemical data on the surface water, the Antarctic Convergence and the Subtropical Convergence zones were presumably situated at about 51°S (Stns. 73–74) and 40°S (Stns. 79–80), respectively.

The chlorophyll *a* concentration was high at Stns. 62 and 63 (0.96–1.17 mg/m³) between 62°02' and 61°10'S, but it decreased at Stn. 64 of 60°39'S (0.23 mg/m³ or 0.37 mg/m³). The chlorophyll *a* content was low (0.11 to 0.38 mg/m³) at Stns. 64 and 77. In the southern part of the STC zone, it became high (0.51 mg/m³ at Stn. 79) again. Toward north from the STC, it decreased gradually. In the area of Stns. 85–96 (33°18'–20°17'S), the chlorophyll *a* concentration was high (0.37–0.48 mg/m³) between Stns. 86 and 90 (30°57'–26°16'S), and low (0.05–0.07 mg/m³) between Stn. 91 (25°29'S) and Port Louis.

In the Southern Ocean, the high chlorophyll *a* concentration (more than 1.0 mg/m³) was detected over 50°12' and 54°42'S in the southward leg (Fig. 3). After two months, in early March, the high value was observed in 61°10'–62°02'S on the northward leg (Fig. 5). This difference in latitudinal position of the highest concen-

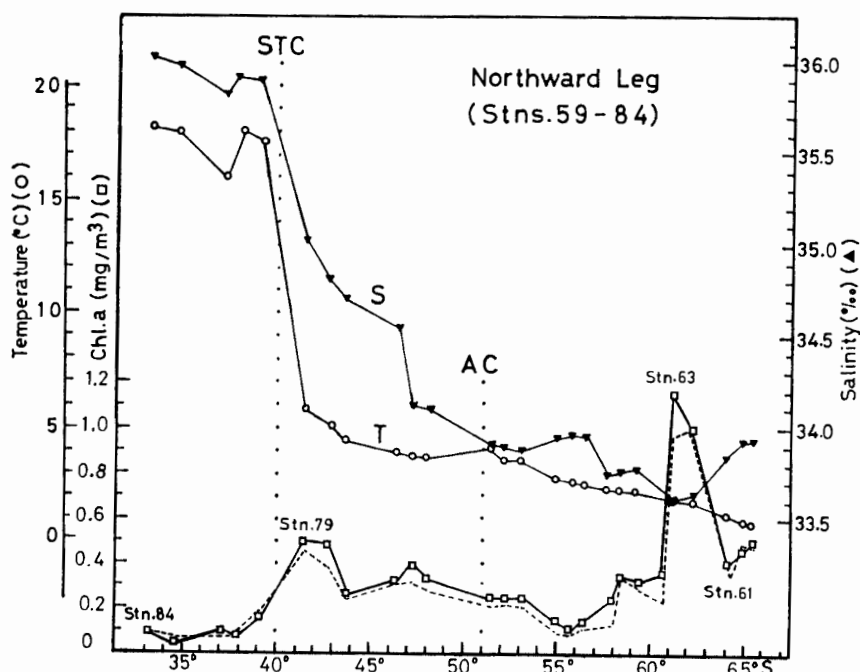


Fig. 5. Latitudinal variations of the chlorophyll *a* (mg/m³), water temperature (°C) and salinity (‰) at the surface on the northward leg in the western Indian Sector of the Southern Ocean. Subsurface chlorophyll *a* (mg/m³) is also shown by a dashed line. STC and AC as in Fig. 3.

tration between two seasons seems to be related to the seasonal periodicity of phytoplankton reported by FUKUCHI (1980).

3.4. Port Louis to Singapore (Stns. 97–119)

The chlorophyll *a* concentrations in the western and central areas of the Indian Ocean were low (0.05–0.15 mg/m³). The high concentrations of chlorophyll *a* were found in the Strait of Malacca (0.25–0.72 mg/m³). The present result coincided with those of the previous JARE investigations (HOSHINO, 1974; OHNO, 1976; TANIMURA, 1981).

3.5. Singapore to Tokyo (Stns. 120–136)

In the South China Sea and the Western North Pacific Ocean, the concentrations were low (0.06–0.21 mg/m³) and became high in the coastal area of Japan (1.51 mg/m³).

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Appendix 1. Chlorophyll *a* contents of surface and subsurface waters along the route of the SHIRASE between 16 November 1984 and 18 April 1985.

Station No.	Date	Time	Latitude	Longitude	Chlorophyll <i>a</i> (mg/m ³)		Water temp. (°C)
					Surface	Subsurface	
1	1984 Nov. 16	0700	24°34'N	137°57'E	0.09	0.09	25.6
2		1700	21 50	137 32	0.09	0.07	26.4
3	17	0700	18 26	135 25	0.12	0.10	28.2
4		1700	16 12	133 31	0.08	0.08	28.4
5	18	0700	13 06	130 58	0.08	0.10	28.4
6		1700	10 39	129 27	0.10	0.10	28.6
7	19	0700	7 31	127 45	0.07	0.07	28.8
8		1700	5 27	126 07	0.08	0.06	28.8
9	20	0700	3 24	122 57	0.20	0.23	29.2
10		1700	1 57	120 56	0.48	0.41	29.2
11	21	0700	0°45'S	119 11	0.21	0.17	29.6
12		1700	3 06	118 35	0.13	0.13	29.7
13	22	0700	6 06	116 49	0.24	0.22	29.6
14		1700	8 19	115 51	0.49	0.49	29.6
15	23	0700	11 29	115 01	0.15	0.10	28.8
16		1700	13 32	114 39	0.10	0.10	28.7
17	24	0700	16 26	114 02	0.06	0.06	26.6
18		1700	18 30	113 35	0.07	0.06	26.6
19	25	0700	21 24	112 53	0.06	0.06	24.1
20		1700	23 27	112 27	0.13	0.07	22.9
21	26	0700	26 02	112 04	0.12	0.12	22.4
22		1700	28 01	112 52	0.29	0.25	21.8
23	27	0700	30 38	114 19	0.39	0.36	20.6
24		1700	31 57	115 37	0.41	0.37	21.4
Fremantle							
25	Dec. 4	0700	34 26	113 16	0.13	0.11	17.7
26		1200	35 30	112 28	0.10	0.10	17.2
27		1700	36 36	111 46	0.08	0.08	16.8
28	5	0700	39 35	109 59	0.28	0.27	13.6
29		1200	40 46	109 56	0.35	0.37	14.1
30		1700	41 58	109 37	0.44	0.42	12.2
31	6	0700	44 36	109 35	—	0.65	11.3
32		1200	45 03	109 44	—	0.38	10.9
33		1700	45 34	109 52	—	0.57	10.4
34	7	0700	48 16	109 23	0.44	0.47	5.8
35		1200	49 15	109 10	0.80	0.76	5.0
36		1700	50 12	108 56	1.17	1.11	4.3
37	8	0700	53 00	107 57	1.23	1.24	2.6
38		1200	53 48	106 56	1.30	1.49	2.2
39		1700	54 42	106 23	1.51	1.50	2.3
40	9	0700	56 36	102 57	0.25	0.31	0.4
41		1200	57 42	102 35	0.27	0.26	0.2
42		1700	58 05	100 42	0.19	0.19	-0.1
43	10	0700	59 02	95 02	0.29	0.29	0.1
44		1200	59 00	92 58	0.51	0.53	-0.2
45		1700	58 60	90 54	0.75	0.48	0.1

Appendix 1 (Continued).

Station No.	Date	Time	Latitude	Longitude	Chlorophyll <i>a</i> (mg/m ³)		Water temp. (°C)
					Surface	Subsurface	
	1984						
46	Dec. 11	0700	60°00'S	84°48'E	0.30	0.32	−0.8
47		1200	60 00	82 30	0.54	0.58	−0.7
48		1700	60 04	80 14	0.90	0.70	−0.8
49	12	0700	60 12	73 55	0.59	0.53	−0.8
50		1200	60 24	71 32	0.30	0.32	−0.8
51		1700	60 36	69 13	0.50	0.38	−0.8
52	13	0700	61 09	62 17	0.12	0.15	−0.6
53		1200	61 19	60 07	0.18	0.16	−0.4
54		1700	61 41	57 34	0.05	0.04	−0.6
55	14	0700	63 00	49 38	0.10	0.10	−1.4
56		1200	63 28	46 58	0.17	0.14	−1.4
57		1700	64 21	45 14	0.19	0.17	−1.3
58	15	0700	66 29	42 29	0.23	0.22	−1.2
Off Lützow-Holm Bay							
	1985						
59	Mar. 2	0700	64 53	40 20	0.50	0.46	0.8
60		1200	64 51	40 21	0.47	0.49	0.9
61		1700	64 16	40 00	0.40	0.35	1.2
62	3	0700	62 02	40 16	1.02	0.99	1.8
63		1200	61 10	40 37	1.17	0.96	1.9
64		1700	60 39	40 54	0.37	0.23	2.1
65	4	0700	58 60	39 42	0.32	0.29	2.2
66		1200	58 54	39 52	0.36	0.34	2.3
67		1700	58 08	38 46	0.25	0.11	2.3
68	5	0700	56 15	35 58	0.15	0.11	2.6
69		1200	55 50	36 00	1.11	0.09	2.7
70		1700	55 27	35 58	0.15	0.12	2.8
71	6	0700	53 12	37 26	0.25	0.21	3.6
72		1200	52 56	37 41	0.25	0.21	3.6
73		1700	51 38	38 16	0.25	0.21	4.1
74	7	0700	47 41	39 59	0.33	0.28	5.8
75		1200	47 24	40 15	0.38	0.31	5.9
76		1700	46 16	40 46	0.32	0.30	9.4
77	8	0700	43 35	40 53	0.27	0.24	10.6
78		1200	42 56	40 56	0.48	0.38	11.5
79		1700	41 57	41 01	0.51	0.42	13.2
80	9	0700	39 25	43 06	0.16	0.18	20.2
81		1200	38 31	43 39	0.08	0.08	20.3
82		1700	37 30	44 19	0.10	0.08	19.6
83	10	0700	35 04	46 06	0.06	0.08	20.9
84		1200	34 05	46 49	0.09	0.08	21.2
85		1700	33 18	47 22	0.11	0.09	23.2
86	11	0700	30 57	49 08	0.10	0.10	22.6
87		1200	30 05	49 25	0.15	0.28	24.9
88		1700	29 13	49 25	0.38	0.37	24.7
89	12	0700	27 01	51 01	0.27	0.16	25.6
90		1200	26 16	51 42	0.31	0.13	25.8

Appendix 1 (Continued).

Station No.	Date	Time	Latitude	Longitude	Chlorophyll <i>a</i> (mg/m ³)		Water temp. (°C)
					Surface	Subsurface	
	1985						
91	Mar. 12	1700	25°29'S	52°10'E	0.48	0.43	26.4
92	13	0700	23 35	54 02	0.07	0.07	27.3
93		1200	22 56	54 33	0.07	0.07	27.3
94		1700	22 20	55 08	0.06	0.06	27.1
95	14	0700	20 46	56 38	0.05	0.05	27.6
96		1200	20 17	57 12	0.17	0.14	27.4
Port Louis							
97	21	1700	19 11	58 55	0.05	0.05	27.6
98	22	0700	17 37	62 17	0.06	0.07	27.5
99		1700	16 38	64 23	0.09	0.08	27.8
100	23	0700	15 02	67 18	0.10	0.12	28.0
101		1700	13 51	69 32	0.06	0.07	28.2
102	24	0700	11 58	72 21	0.11	0.11	28.4
103		1700	10 40	74 17	0.11	0.11	28.7
104	25	0700	8 45	76 59	0.12	0.12	28.2
105		1700	7 25	78 53	0.09	0.10	28.6
106	26	0700	5 31	81 20	0.10	0.10	28.6
107		1700	3 60	83 08	0.08	0.09	29.2
108	27	0700	1 47	85 42	0.09	0.07	29.4
109		1700	0 06	87 38	0.09	0.08	31.2
110	28	0700	2°13'N	90 25	0.13	0.12	29.6
111		1700	3 57	92 20	0.14	0.15	29.8
112	29	0700	6 12	94 52	0.12	0.12	29.6
113		1700	5 51	97 23	0.26	0.25	29.6
114	30	0700	4 13	99 49	0.60	0.65	30.1
115		1700	4 17	99 50	0.72	0.65	29.9
116	31	0700	4 20	99 52	0.71	0.67	29.7
117		1700	4 22	99 51	0.57	0.42	29.9
118	Apr. 1	0700	4 13	99 52	0.27	0.26	29.6
119		1700	2 42	101 11	0.60	0.59	29.9
Singapore							
120	9	1700	1 36	105 04	0.24	0.08	27.2
121	10	0700	2 52	108 05	0.08	—	27.9
122		1700	4 42	109 18	0.15	0.12	29.1
123	11	0700	7 37	110 55	0.20	0.20	29.5
124		1700	9 54	112 12	0.18	0.13	30.1
125	12	0700	12 47	114 41	0.06	0.07	28.9
126		2100	15 48	117 17	0.06	0.07	28.1
127	13	0700	17 26	118 44	0.07	0.11	26.8
128		1700	19 08	120 19	0.10	0.09	28.2
129	14	0700	21 09	122 52	0.13	0.14	26.1
130	15	0700	24 23	126 20	0.10	—	22.4
131		1700	25 46	127 53	0.17	—	22.6
132	16	0700	28 03	130 31	0.16	—	22.2
133		1700	29 35	131 47	0.21	—	21.3
134	17	0700	31 46	133 57	0.17	—	21.5
135		1700	33 18	135 43	0.53	—	21.5
136	18	0700	34 18	138 52	1.51	—	17.3

—: no data.