

Surface Distribution of Chlorophyll *a* Along the Course of the FUJI (1980/81) in the Southern Ocean

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「ふじ」航路（1980/81）における南大洋表面海中のクロロフィル *a* 分布

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要旨: 第22次南極地域観測隊の海洋生物定常観測の一環として、1980年12月から1981年3月にかけて、「ふじ」航路に沿った南大洋インド洋区において表面海中のクロロフィル *a* 量を測定した。クロロフィル *a* 濃度は亜熱帯水域で 0.2 mg/m^3 以下と低く、亜南極海域でやや高くなり、南極収束線 (AC) の北側では 0.50 , 0.24 mg/m^3 の極大値が得られた。AC の南側の外洋域では概してクロロフィル *a* 濃度は低かったが、AC のはるか南の 58°S 付近では 0.84 (南下航路上), 62°S 付近では 0.58 mg/m^3 (北上航路上) の高い値が測定された。1980年12月の西行航路上で行った測定において、浮氷域の中ないしは近くでクロロフィル *a* 濃度は極大を示し、水温・塩分ともに低下した。定着氷に囲まれた氷湖中では 0.66 , 0.80 mg/m^3 の高い濃度を測定した。これに対して北上航路上の浮氷域での値は低く、西行航路上での結果と異なった。これらの結果より、海氷とクロロフィル *a* 濃度とが何らかの関係を持つことが示唆される。

Abstract: The measurement of the chlorophyll *a* concentration of the surface water in the Southern Ocean was performed along the course of the icebreaker FUJI from December 1980 to March 1981 as a part of the 22nd Japanese Antarctic Research Expedition. The chlorophyll *a* concentration was low (less than 0.2 mg/m^3) in the Subtropical Water, which became a little higher in the Subantarctic Water and the maximum values of 0.50 and 0.24 mg/m^3 were observed on the north side of the Antarctic Convergence (AC). The value was generally low in the open water south of the AC, but high values of 0.84 (58°S) and 0.58 (62°S) mg/m^3 were measured farther south of the AC in the southward and northward legs respectively. In or near the pack ice water, the chlorophyll *a* concentration formed a peak in the westward leg in December 1980 where the water temperature and salinity decreased. In a polynya surrounded by the fast ice, high values of 0.66 and 0.80 mg/m^3 were recorded, whereas in the pack ice water, the value was low in the northward leg different from the results in the westward leg. These results suggest a relation between the chlorophyll *a* concentration and the presence of sea ice.

1. Introduction

The routine measurement of the chlorophyll *a* concentration of the surface water has been carried out annually since 1965 as a part of the Japanese Antarctic Research

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Expedition (JARE) on board the icebreaker FUJI. The results were reported by the scientists participated. FUKUCHI (1980), summarizing these results, estimated the regional standing stock of chlorophyll *a* in the Southern Ocean. The data from each cruise are quite valuable as well to study the annual variation of the surface distribution of the chlorophyll *a*, because the most part of the course and the season of the FUJI cruise are identical. The authors made the chlorophyll *a* measurement of the surface water on board the FUJI along the JARE-22 cruise from November 1980 to April 1981. In this report, the data from the surface water obtained between Fremantle and Port Louis are dealt with.

2. Methods and Materials

Surface water was collected with a plastic bucket, usually two times a day at 0800 and 1800 by local time, along the course of the FUJI (Fig. 1). Samplings four times a day (*i.e.* at 0800, 1300, 1800 and 2300 LT) were carried out from Fremantle to Port Louis except for the section from Stns. 86 to 122 where the vertical observations were made. Generally, 5–15 l of sea water was filtered with a 47 mm Whatman GF/C glass fiber filter. The concentration of chlorophyll *a* was determined by the colorimetric method with a HITACHI Model 101 spectrophotometer, following the method and equation of UNESCO (1966). Water temperature and salinity were measured by the oceanographers of JARE-22, KURAMOTO and KOYAMA (1982).

3. Results and Discussion

The surface distribution of chlorophyll *a* in the Southern Ocean along the course of the FUJI is shown in Fig. 1. The chlorophyll *a* concentration, temperature and salinity of the surface water samples taken during the JARE-22 cruise (1980/81) are given in Appendix 1. The vertical distribution of the chlorophyll *a* observed along the northward leg from Syowa Station to Port Louis was discussed in WATANABE and NAKAJIMA (1982).

3.1. Fremantle to Syowa Station

3.1.1. Southward leg (Stns. 31–63)

In the southward leg along 110°E, the Subtropical Convergence (STC) lay around 38°20'S between Stns. 34 and 35, the Australasian Subantarctic Front (ASF) lay around 45°40'S between Stns. 42 and 43, and the Antarctic Convergence (AC) lay around 54°00'S between Stns. 50 and 51 (Fig. 2). These positions were determined from the physical oceanographic data collected by KURAMOTO and KOYAMA (1982).

In the Subtropical Water north of the STC, the chlorophyll *a* concentration was in the lowest level (0.07–0.18 mg/m³) among stations from 31 to 63. Whereas in the area between the STC and the ASF, the value became higher to the range of 0.24–0.45 mg/m³. These tendencies were also observed by the JARE biologists (FUKUCHI, 1980; TANIMURA, 1981; FUKUCHI and TAMURA, 1982). At Stn. 42, almost in the ASF zone, the chlorophyll *a* concentration was low (0.16 mg/m³), where the water temperature was lower than that of the neighbouring stations. At Stn. 49, on the

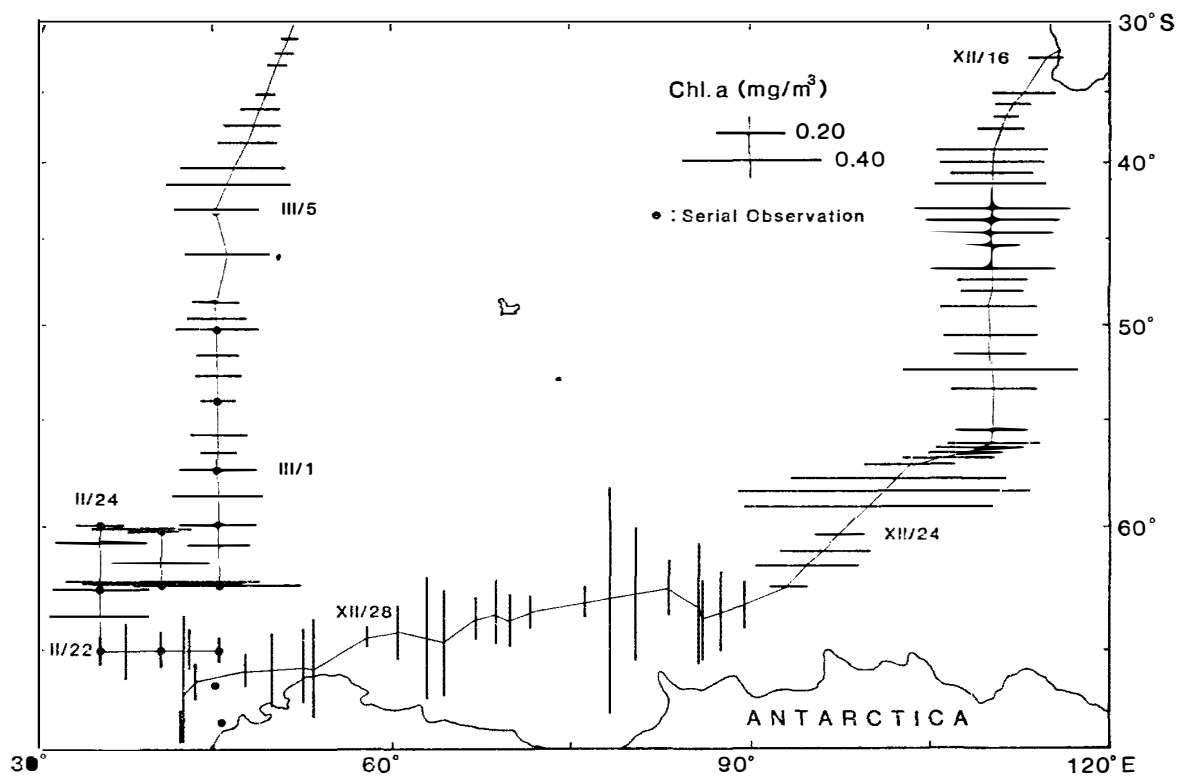


Fig. 1. The surface distribution of chlorophyll *a* in the Southern Ocean along the course of FUJI, 1980-81 (JARE-22).

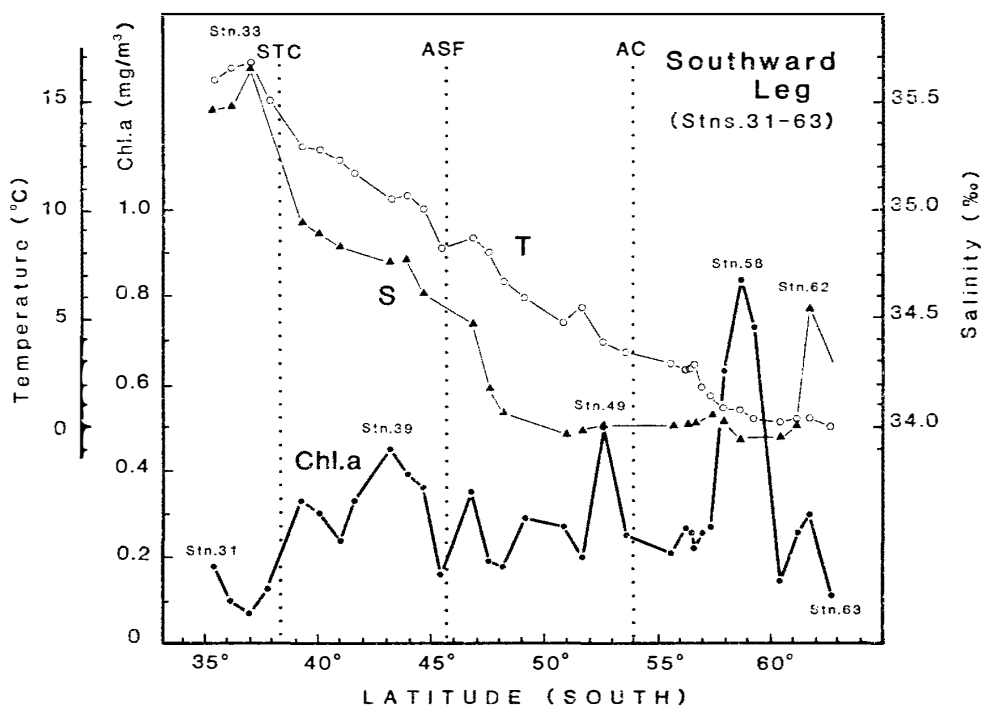


Fig. 2. The variations of the chlorophyll *a* concentration, temperature and salinity of the surface water in the eastern Indian Sector of the Southern Ocean (STC: Subtropical Convergence, ASF: Australasian Subantarctic Front, AC: Antarctic Convergence).

north side of the AC, the value rose to 0.50 mg/m^3 from the level of $0.20\text{--}0.29 \text{ mg/m}^3$ in the area between the ASF and the AC (Stns. 44–48). The remarkable increase in the chlorophyll *a* concentration was observed at Stns. 57–59 (from $57^\circ 56'S$, $102^\circ 09'E$ to $59^\circ 16'S$, $99^\circ 40'E$) in the Antarctic Water. The highest values ($0.63\text{--}0.84 \text{ mg/m}^3$) were recorded where little changes of salinity and temperature of the surface water were observed. At the other stations in the Antarctic Water, the concentration was not higher than 0.30 mg/m^3 , which is lower than the other JARE data as summarized by FUKUCHI (1980). The surface chlorophyll *a* concentration was not so high in the east Indian Sector of the Antarctic Ocean north of $63^\circ S$ except for some restricted area in December 1980.

3.1.2. Westward leg (Stns. 63–85)

The changes of chlorophyll *a*, temperature and salinity of the surface water in the westward leg from Stns. 63 to 85 are shown in Fig. 3. In some parts of this leg, the FUJI cruised near or in the pack ice region. Stations 66, 67, 73–75, 77 and 85 were located in the pack ice water and Stns. 65, 76, 80, 81 and 84 were near the pack ice water. The chlorophyll *a* concentration fluctuated largely from 0.11 to 0.48 mg/m^3 at these stations. At Stns. 67, 74, 77, 80 and 85, a peak of chlorophyll *a* concentration appeared and most of them were accompanied by the decrease of temperature and salinity. This decrease is accounted for by the situation of the stations, which were located in or near (Stn. 80) the pack ice waters. The occurrence of high chlorophyll *a* concentration in the pack ice surface water was reported by the JARE scientists (TOMINAGA, 1971; OHNO, 1976; OHYAMA and MAYAMA, 1976; KURODA, 1978; TANIMURA, 1981; FUKUCHI and TAMURA, 1982). Some of them suggested that the high values were contributed by the ice algae released from the sea ice. On the other hand, the high values at Stns. 69 and 70 (0.39 and 0.68 mg/m^3) were not associated

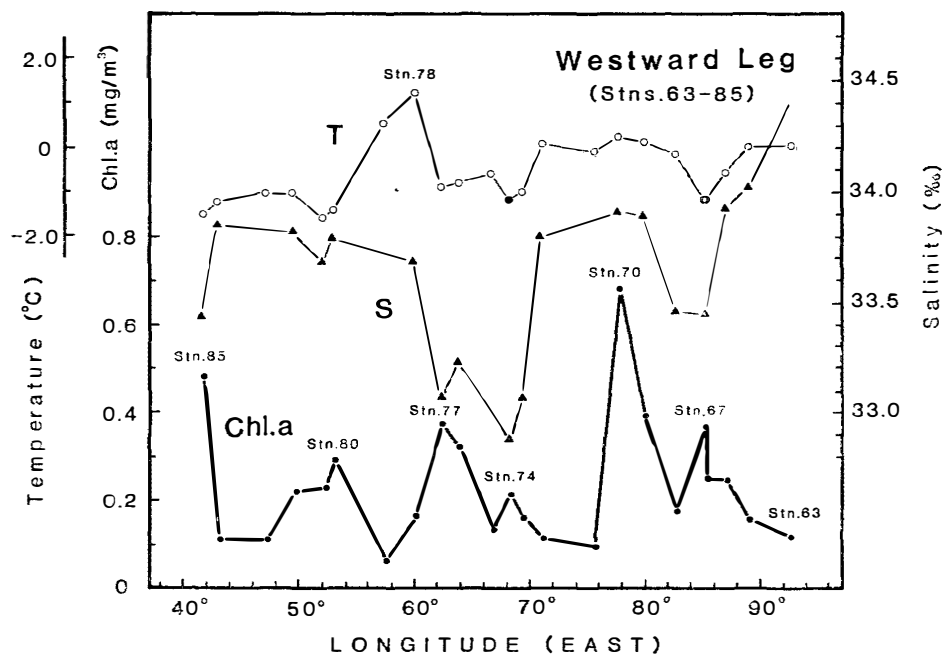


Fig. 3. The variations of the chlorophyll *a* concentration, temperature and salinity of the surface water in the Indian Sector ($41^\circ 37'\text{--}92^\circ 38'E$) of the Antarctic Ocean.

with the decrease of the water temperature and salinity as observed at Stns. 57–59 in the southward leg. In other area of the antarctic oceanic water south of 62°S, the chlorophyll *a* concentration was low between 0.06 and 0.22 mg/m³. This agrees with the observation of FUKUCHI and TAMURA (1982) that the values were low in the southern part of the antarctic surface water south of 63°S.

3.2. Syowa Station to Port Louis (Stns. 86–126)

The data of chlorophyll *a* concentration, temperature and salinity of the surface water were plotted and those near the 45°E meridian are linked with lines in Fig. 4. In the southern part of this leg, Stns. 86–89 and 92 were situated in the pack ice water and Stns. 90 and 91 were in a polynya surrounded by the fast ice. Stations north of 65°S (from Stn. 93 onward) were located in the open water. In the northern leg along the 45°E meridian, the STC and the AC were determined to lie around 41°00'S between Stns. 122 and 123 and around 51°30'S between Stns. 116 and 117 respectively.

High chlorophyll *a* concentrations (0.66–0.80 mg/m³) were observed at Stns. 89–91. As mentioned above, these stations had relations with the fast ice; two of them were situated in a polynya and the other was in the pack ice water near the edge of the fast ice. However, the values were low (0.11–0.22 mg/m³) in the pack ice area which differs from the results obtained in the westward leg where the peaks and high values of chlorophyll *a* concentrations appeared in the pack ice water. As the measurements were made in December for the southward leg and from February to March

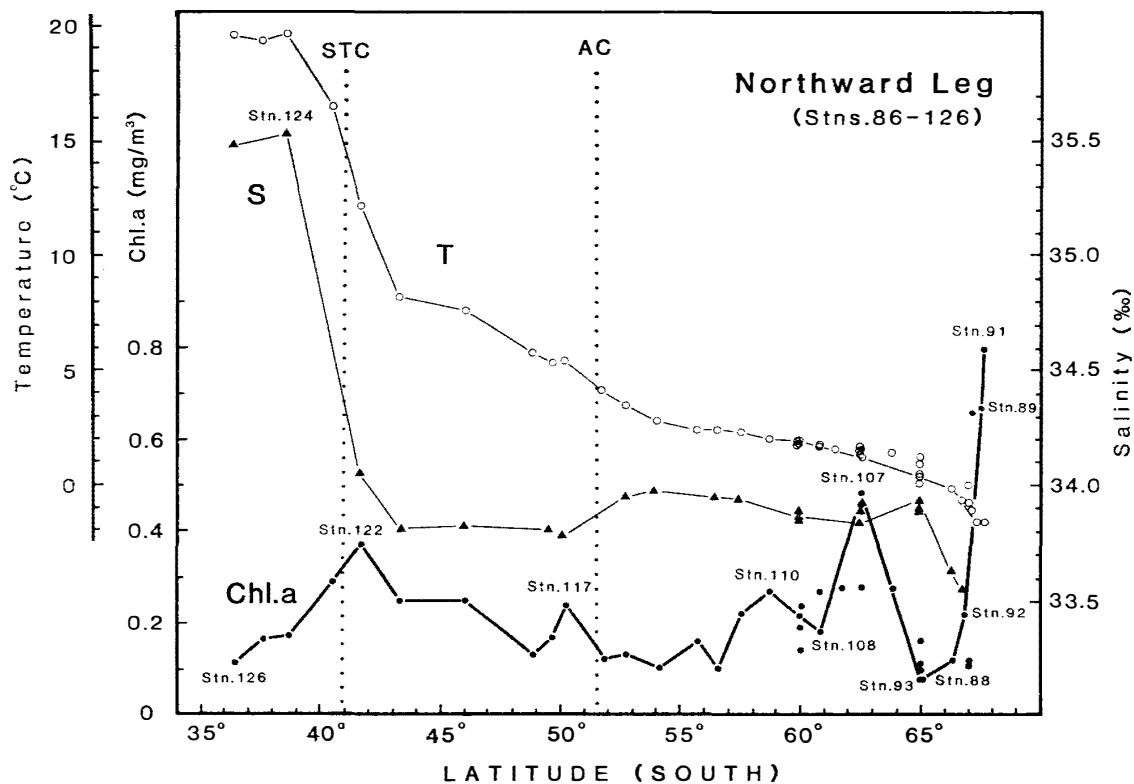


Fig. 4. The variations of the chlorophyll *a* concentration, temperature and salinity of the surface water in the western Indian Sector of the Southern Ocean (STC: Subtropical Convergence, AC: Antarctic Convergence).

for the northward leg, the difference of chlorophyll *a* concentration in the pack ice water may reflect the seasonal changes of the degree of the ice algal contribution to the surface chlorophyll *a*, or of the primary production. But the data from the pack ice water are still scarce to discuss the relation between the chlorophyll *a* concentration and the presence of the sea ice. At five stations on the 65°S latitude (Stns. 93–97) in the southern part of the open antarctic water (off the pack ice region), chlorophyll *a* concentrations were low (0.08–0.16 mg/m³). This agrees with the result obtained in the westward leg in the open water of the southern Antarctic Ocean. High values of 0.46–0.58 mg/m³ were observed at Stns. 105–107 (62°30'S) in the open water of the Antarctic Ocean where the values were generally low (0.08–0.28 mg/m³). This phenomenon was observed at Stns. 57–59 (*ca.* 58°30'S) in the southward leg. Moreover, it was also observed clearly in the southward leg of JARE-19 (KANDA and FUKUCHI, 1979), in the northward leg of JARE-20 (FUKUCHI and TAMURA, 1982) and JARE-21 (TANIMURA, 1981). It is suggested that a narrow zone of high chlorophyll *a* concentration might exist in the open water of the Antarctic Ocean where the values are generally low. The chlorophyll *a* concentration in the subantarctic water was generally higher than that in the subtropical water north of the STC. The value at Stns. 124–126 in the north of the STC ranged 0.11–0.17 mg/m³, which is comparable to that in the southward leg (0.07–0.18 mg/m³).

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Appendix 1. Chlorophyll a concentration, water temperature and salinity of surface water observed during the cruise of FUJI (JARE-22), 1980/81.

Stn. no.	Date	Time	Latitude	Longitude	Chl. a (mg/m ³)	Water temp. (°C)	Salinity (‰)
1	1980 Nov. 26	0800	32°33'N	139°05'E	0.25	22.9	34.770
2		1800	30 41	139 24	0.27	23.1	34.772
3		27 0800	27 57	139 15	0.16	23.5	34.795
4		1800	25 56	138 11	0.11	24.9	34.990
5		28 0800	23 04	136 45	0.09	26.8	34.862
6		1800	20 55	135 35	0.05	27.9	34.878
7		29 0800	18 13	133 53	0.05	27.9	34.869
8		1800	16 16	132 38	0.05	28.3	34.834
9		30 0800	13 30	130 55	0.06	28.7	33.988
10		1830	11 35	129 41	0.07	28.8	33.756
11	1980 Dec. 1	0800	8 45	127 59	0.04	28.7	33.507
12		1800	6 49	126 56	0.05	29.1	33.592
13		2 0800	4 02	124 00	0.14	29.0	33.976
14		1800	2 37	122 04	0.21	29.7	33.732
15		3 0800	0 44	119 46	0.25	28.7	33.205
16		1800	1 34S	118 55	0.14	30.2	33.408
17		4 0800	4 22	117 53	0.16	29.9	34.226
18		1800	6 11	116 46	0.20	30.1	34.298
19		5 0800	8 45	115 44	0.41	27.7	34.203
20		1800	10 40	115 12	0.07	30.3	34.494
21		6 0800	13 36	114 40	0.04	29.0	34.566
22		1800	15 34	114 20	0.02	28.2	34.821
23		7 0800	18 20	113 50	0.05	26.9	34.789
24		1800	20 14	113 27	0.04	26.6	34.917
25		8 0800	22 59	112 57	0.05	24.4	35.270
26		1800	24 49	112 35	0.18	22.9	35.197
27		9 0800	27 47	112 58	0.11	21.5	35.485
28		1800	29 49	113 56	0.07	21.0	35.696
29		10 0800	31 59	115 40	0.19	20.3	35.788
FREMANTLE							
30		16 1800	32 47	114 46	0.10	20.1	35.779
31		17 0800	35 23	112 47	0.18	15.9	35.456
32		1300	36 09	112 03	0.10	16.5	35.476
33		1800	37 03	111 26	0.07	16.8	35.656
34		2300	37 54	110 48	0.13	15.0	—
35		18 0800	39 18	110 20	0.33	12.9	34.941
36		1300	40 05	110 14	0.30	12.8	34.886
37		1800	40 56	110 08	0.24	12.3	34.831
38		2300	41 36	109 53	0.33	11.7	—
39		19 0800	43 11	110 10	0.45	10.5	34.761
40		1300	43 56	110 14	0.39	10.7	34.780
41		1800	44 42	110 12	0.36	10.0	34.616
42		2300	45 26	110 04	0.16	8.2	—
43		20 0800	46 50	110 05	0.35	8.7	34.479
44		1300	47 37	110 09	0.19	8.0	34.180
45		1700	48 14	110 09	0.18	6.7	34.069
46		2300	49 08	109 50	0.29	5.9	—
47		21 0800	50 51	109 57	0.27	4.8	33.970

Appendix 1 (continued).

Stn. no.	Date	Time	Latitude	Longitude	Chl. <i>a</i> (mg/m ³)	Water temp. (°C)	Salinity (‰)
48	1980 Dec. 21	1300	51°42'S	109°58'E	0.20	5.5	33.981
49		1800	52 38	110 00	0.50	3.9	34.005
50		2300	53 35	110 05	0.25	3.5	—
51		0800	55 40	109 58	0.21	2.9	33.999
52		1100	56 20	109 58	0.27	2.7	34.005
53		1400	56 29	109 03	0.26	2.7	—
54		1800	56 43	107 48	0.22	2.9	34.020
55		2300	56 57	106 11	0.26	1.9	—
56		0800	57 20	103 13	0.27	1.5	34.052
57		1300	57 56	102 09	0.63	0.9	34.015
58		1800	58 34	100 55	0.84	0.8	33.937
59		2300	59 16	99 40	0.73	0.4	—
60		0800	60 28	97 18	0.14	0.2	33.945
61		1300	61 08	95 50	0.26	0.4	34.006
62		1800	61 44	94 19	0.30	0.4	34.541
63		2300	62 40	92 38	0.11	0.0	—
64		0800	63 21	89 04	0.15	0.0	34.110
65		1300	63 37	86 57	0.24	-0.6	33.918
66		1800	63 52	85 19	0.24	-1.2	33.436
67		2300	63 12	85 17	0.36	-1.2	—
68		0800	62 41	82 40	0.17	-0.2	33.452
69		1300	62 51	79 54	0.39	0.1	33.882
70		1800	63 03	77 43	0.68	0.2	33.908
71		2300	63 11	75 35	0.09	-0.1	—
72		0800	63 34	71 02	0.11	0.1	33.789
73		1300	63 55	69 17	0.16	-1.0	33.060
74		1800	63 35	68 11	0.21	-1.2	32.873
75		2300	63 48	66 36	0.13	-0.6	—
76		0740	64 47	63 48	0.32	-0.8	33.225
77		1300	64 31	62 17	0.37	-0.9	33.073
78		1800	64 23	59 59	0.16	1.2	33.679
79		2300	64 28	57 18	0.06	0.5	—
80		0800	65 39	52 47	0.29	-1.4	33.795
81		1300	65 38	52 03	0.23	-1.6	33.688
82		1800	65 41	49 32	0.22	-1.0	33.822
83		2300	65 44	47 02	0.11	-1.0	—
84		0800	66 11	42 51	0.11	-1.2	33.856
85		1300	66 47	41 37	0.48	-1.5	33.440
ICE EDGE OFF SYOWA STATION							
86	1981 Feb. 7	0800	67 01	42 35	0.11	-0.8	—
87		8	1800	67 01	0.12	0.0	—
88		9	0800	66 18	0.12	-0.2	33.622
89		10	0800	67 31	0.67	-1.6	—
90		11	0800	67 11	0.66	-1.1	—
91		16	1800	67 36	0.80	-1.6	—
92		19	1800	66 47	0.22	-0.7	33.547
93		20	0800	65 00	0.08	0.4	33.924
94		2300	64 59	42 33	0.11	0.5	—
95		21	0800	65 00	0.10	0.9	33.884

Appendix 1 (continued).

Stn. no.	Date	Time	Latitude	Longitude	Chl. <i>a</i> (mg/m ³)	Water temp. (°C)	Salinity (‰)
96		2300	65°00'S	36°56'E'	0.16	1.2	—
97	22	0800	65 01	35 00	0.08	0.1	33.888
98		2300	63 52	35 00	0.28	1.4	—
99	23	0800	62 28	35 03	0.28	1.4	33.908
100		2300	60 51	35 02	0.27	1.8	—
101	24	0800	60 00	34 58	0.14	1.9	33.876
102		2300	59 59	37 43	0.24	1.8	—
103	25	0800	60 00	39 59	0.19	1.8	33.840
104		2300	61 43	40 03	0.28	1.6	—
105	26	0800	62 29	40 01	0.58	1.5	33.897
106		2300	62 26	42 26	0.46	1.6	—
107	27	0800	62 31	45 03	0.48	1.3	33.841
108		2300	60 52	45 00	0.18	1.7	—
109	28	0800	59 58	45 03	0.22	1.9	33.867
110		2300	58 46	45 04	0.27	2.0	—
111	1981 Mar.	1 0800	57 31	44 59	0.22	2.3	33.939
112		1800	56 35	45 00	0.10	2.4	33.946
113		2300	55 45	44 59	0.16	2.4	—
114	2	0800	54 06	45 00	0.10	2.8	33.968
115		1800	52 46	45 00	0.13	3.5	33.940
116		2300	51 47	45 00	0.12	4.2	—
117	3	0800	50 13	45 01	0.24	5.5	33.769
118		1800	49 41	45 04	0.17	5.4	33.798
119		2300	48 51	45 00	0.13	5.8	—
120	4	1800	46 02	45 52	0.25	7.6	33.814
121	5	0800	43 18	44 57	0.25	8.2	33.800
122		1800	41 39	45 55	0.37	12.2	34.050
123		2300	40 31	46 31	0.29	16.5	—
124	6	0800	38 37	47 34	0.17	19.7	35.530
125		1300	37 33	48 11	0.16	19.4	—
126		1800	36 22	48 44	0.11	19.6	35.481
127		2300	35 14	49 18	0.05	21.9	—
128	7	0800	33 13	50 18	0.05	22.7	35.423
129		1300	32 11	50 52	0.05	23.0	—
130		1800	31 06	51 20	0.04	25.4	35.487
131		2300	30 04	51 39	0.06	25.5	—
132	8	0800	27 57	51 02	0.12	26.5	35.214
133		1300	26 47	50 47	0.12	27.4	—
134		1800	25 34	50 44	0.05	27.5	35.221
135		2300	24 27	50 55	0.05	27.7	—
136	9	0800	23 16	52 44	0.07	27.8	35.218
137		1300	22 39	53 44	0.06	28.2	—
138		1800	22 01	54 47	0.08	27.9	35.228
139		2300	21 26	55 57	0.04	28.2	—
140	10	0800	20 08	57 28	1.85	28.1	—
PORT LOUIS							
141		17 1800	19 01	58 45	0.05	28.7	34.942
142	1981 Mar.	18 0800	17 21	61 18	0.05	28.7	34.994
143		1800	16 12	62 52	0.05	29.5	34.536

Appendix I (continued).

Stn. no.	Date	Time	Latitude	Longitude	Chl. <i>a</i> (mg/m ³)	Water temp. (°C)	Salinity (‰)
144		19 0800	14°27'S'	65°28'E'	0.15	28.8	34.330
145		1800	13 16	67 17	0.09	29.2	34.494
146		20 0700	11 29	69 52	0.13	29.5	34.656
147		1800	10 04	71 57	0.10	29.9	34.358
148		21 0700	8 27	74 12	0.12	29.5	34.234
149		1800	7 02	76 12	0.06	29.0	34.019
150		22 0800	5 04	79 03	0.12	29.7	34.629
151		1800	3 39	81 04	0.09	29.5	34.504
152		23 0800	1 48	83 32	0.07	29.8	34.485
153		1800	0 47	84 58	0.08	29.9	34.388
154		24 0800	0 41 N	87 06	0.11	29.5	34.381
155		1800	1 33	88 16	0.08	29.8	34.259
156		25 0800	3 03	90 33	0.09	29.7	34.816
157		1800	4 46	92 53	0.08	29.5	34.543
158		26 0800	5 44	94 11	0.12	29.5	34.391
159		1800	5 59	95 55	0.18	29.9	32.521
160		27 0800	4 55	98 36	0.24	29.3	32.702
161		1745	3 46	100 06	0.70	29.9	31.261
162		30 1800	2 29	101 35	0.76	30.1	32.726
163		31 0730	1 08	103 47	0.55	29.3	32.318
SINGAPORE							
164	1981 Apr.	8 1800	1 49	105 25	0.27	28.5	33.060
165		9 0800	3 10	108 23	0.21	28.5	33.236
166		1800	5 14	109 28	0.08	29.1	33.472
167		10 0800	8 01	111 01	0.11	28.5	33.754
168		1800	9 33	112 02	0.20	28.9	33.500
169		11 0800	12 09	113 49	0.17	28.7	33.217
170		1800	13 42	115 21	0.10	29.2	33.845
171		12 0830	16 03	117 46	0.11	29.1	33.283
172		1800	17 41	119 13	0.07	29.4	33.550
173		13 0800	19 55	121 25	0.12	26.9	34.450
174		1800	21 39	122 33	0.08	27.0	34.547
175		14 0800	24 19	123 25	0.20	25.6	34.496
176		1800	25 42	124 52	0.20	25.5	34.622
177		15 0800	27 50	127 46	0.16	23.1	34.574
178		1800	29 13	129 44	0.21	24.3	34.640