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Spatial and seasonal variability of temperature and salinity in Bransfield Strait and Admiralty Bay, Antarctica

ABSTRACT: Comparison of T and S values in areas 1, 2, and 3 in the Bransfield Strait and Admiralty Bay (Fig. 1) shows that the warmest waters are found in area 1, while the coldest in area 3. Surface salinity is the lowest in area 2 as a result of water outflow from land. In area 3 vertical salinity variations are the lowest, with the maximum occurring at the surface. At 500 m depth the highest salinity is recorded in area 1. The most homogeneous distribution of temperature and salinity is observed in area 3. In Admiralty Bay, in the annual cycle of 1995 water temperatures at 4 m, 10 m and 100 m are similar to those in 1979 except in the winter, when they are lower.

Key words: Antarctica, T/S stratification, annual cycles.

Introduction

Depending on latitude, season, water origin and dynamics, the marine Antarctic environment varies with regard to temperature and salinity, both horizontally and vertically. On a small spatial scale the differences between temperature of water, warming to more than +11°C in rocky pools, in the near shore shallow water of Admiralty Bay, amount to several or more than ten degrees centigrade (Rakusa-Suszczewski 1993, 1995). Various organisms occur in this zone of high temperature and salinity (greater than 10 ‰) variation. Temperature and salinity variations in the pelagic zone of the open sea far from land are lower. Water temperatures below zero (-1.8°C, and even -2.2°C) with fluctuations not exceeding 0.7°C occur over large areas of both shelf and coastal Antarctic waters (Littlepage 1965, Rakusa-Suszczewski 1972). In the area of Signy Island, to a 10 m depth, the lowest temperature of -1.78°C was recorded in August, while

the highest + 0.31 was noted in February (Clarke *et al.* 1980). In the area of the Antarctic Penninsula, in Paradise Harbour, the absolute maximum of +2.8°C occurred in the middle of January, and the absolute minimum -2.2°C in winter from June to September (Bienati and Comes 1970). In 1979, in the central part of Admiralty Bay, the lowest winter water temperature was -1.77°C, and the highest summer temperature was +1.70°C. Mean annual temperature in the entire water column down to 400 m was - 0.4°C (Lipski 1979).

Tidal currents and winds cause strong mixing of water in bays of the South Shetland Islands. This differentiates the bays from the more stratified warmer surface waters flowing northeastward during the entire year in the northern part of the Bransfield Strait (Madejski and Rakusa-Suszczewski 1990, Garcia *et al.* 1994). Cold Waters from the Weddell Sea flowing SW in the Bransfield Strait are separated from warmer waters flowing NE by a local front, a zone of eddies (Clowes 1934, Stein and Rakusa-Suszczewski 1983, Stein and Rakusa-Suszczewski 1984, Tokarczyk 1987, Garcia *et al.* 1994).

In the marine environment, temperature and salinity are among the most important factors affecting organisms and their populations. Antarctic organisms living in extremely low temperatures with minimal seasonal fluctuation, near freezing, have been termed hypostenothermic (Rakusa-Suszczewski 1975, 1980). They exibit a high metabolic variation, the highest in the lowest temperature, and hyperosmotic concentration of body liquids (Rakusa-Suszczewski and McWhinnie 1976).

The knowledge of the effects of both spatial and seasonal temperature and salinity variations on species and populations is still inadequate. For this reason temperature conditions in the aquatic environment of Antarctica are of special interest for the current program, the Coastal Shelf Ecology of Antarctic Sea Ice Zone. Within this program *Arctowski* Base has been designated as one of the core stations.

Material and methods

In the years 1976–1989 studies were conducted in the area of South Shetland Islands from early spring to late autumn out board the r/v *Profesor Siedlecki*. The results obtained show the spatial and seasonal variations of temperature and salinity in the 0–500 m water stratum.

Figure 1 illustrates three areas with the highest numbers of measurements taken.

Area 1: 61°00' and 61°30' S; 56°00' and 57°00' W; bottom depth ranges from 158 m to 3000 m. T/S measurements were done in the spring 1986 at 28 stations between 28 October and 15 November; during summer at 14 stations from 8 January to 26 March in the years 1976, 79, 81, 84, 87, 88, 89.

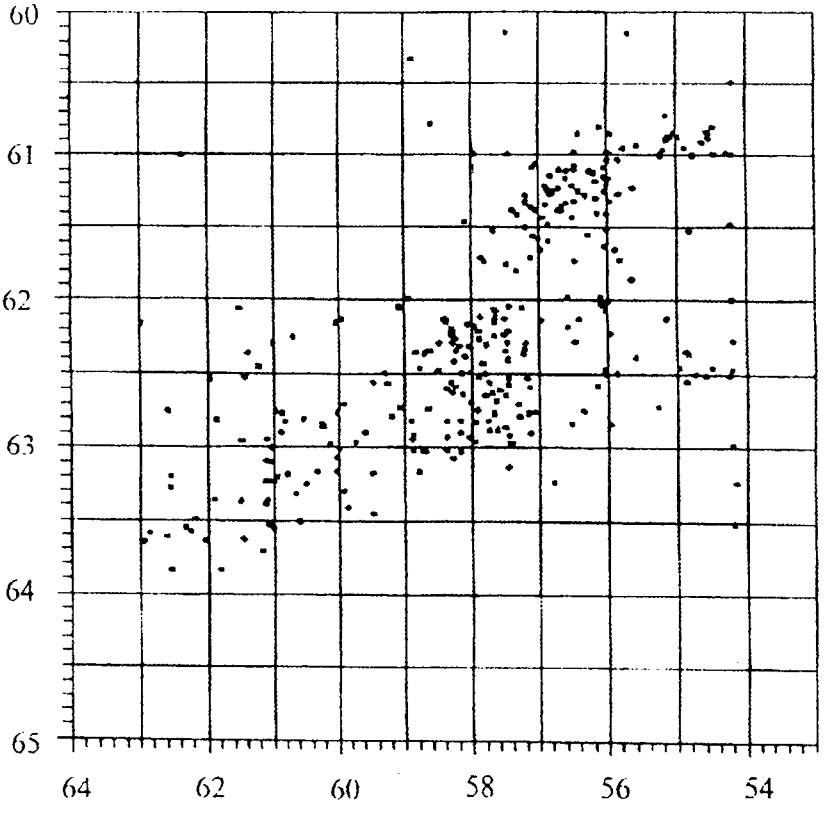

Fig. 1. Areas where the temperature and salinity were measured during the Polish expeditions. Dots — station location.

Area 2: 62°00' and 62°30' S; 58°00' and 59°00' W including Admiralty Bay. Bottom depth ranged from 132 m to 1850 m. T/S measurements were done in spring between 9 and 12 November 1986, and also on 26 and 27 December 1988 at 11 stations. Summer measurements were done at 13 stations on 30 January 1979 and 12 February 1987, as well as between 7 and 17 March 1981.

Area 3: 62°30' and 63°00' S; 57°00' and 58°00' W, depth ranged from 93 m to 1700 m. In spring T/S measurements were obtained at 20 stations between 6 and 8 November 1986. Summer measurements were done at 9 stations on 5 February 1977, between 5–14 March 1981, and on 2 January 1984.

T/S results for the three chosen areas are shown in the form of extreme values (Figures) and, as the corresponding mean values for spring and summer in Tables. Extreme annual temperature and salinity measurements in Admiralty Bay in 1979 are those of Lipski (1987).

Following the recommendations of the CSESIZ programme, temperature measurements in Admiralty Bay were carried out from 2 Februry 1994 to 5 No-

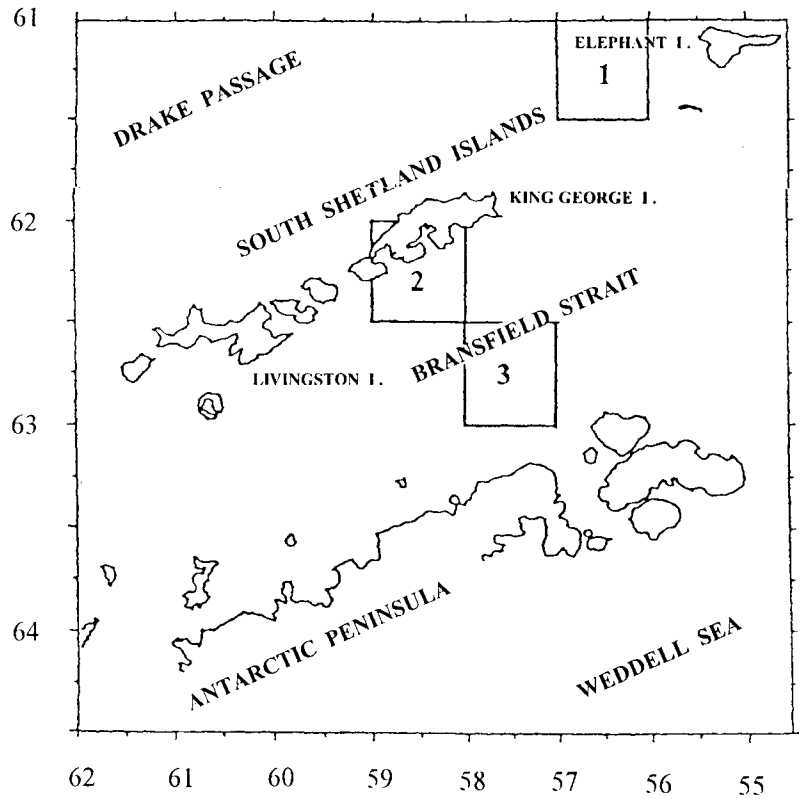

Fig. 2. Areas (1–3) where the temperature and salinity were measured more frequently.

vember 1995 in the central part of the bay at 4 m, 10 and 100 m , as well as in Martel Inlet at 10 and 100 m (Table 4). Ice thickness was measured after the entire freezing of the bay.

Results and discussion

Area 1 (Figs 1–2) is situated on the shelf between King George Island and Elephant Island, and also on the northern shelf slope of South Shetland Islands. The shelf in this area is cut by the Loopa channel which facilitates exchange of waters in the north-south directions.

Water temperature and salinity in area 1 (Figs 3–4 and Table 1) give an example of water stratification characteristic for the Weddell-Scotia Confluence (Rakusa-Suszczewski 1988a, b; Stein 1992), and for the Antarctic Slope Front (Jacobs 1986). Maximal surface temperature variations from spring to summer (Fig. 3) exceed 3.7°C. At the beginning of November in the north-western part

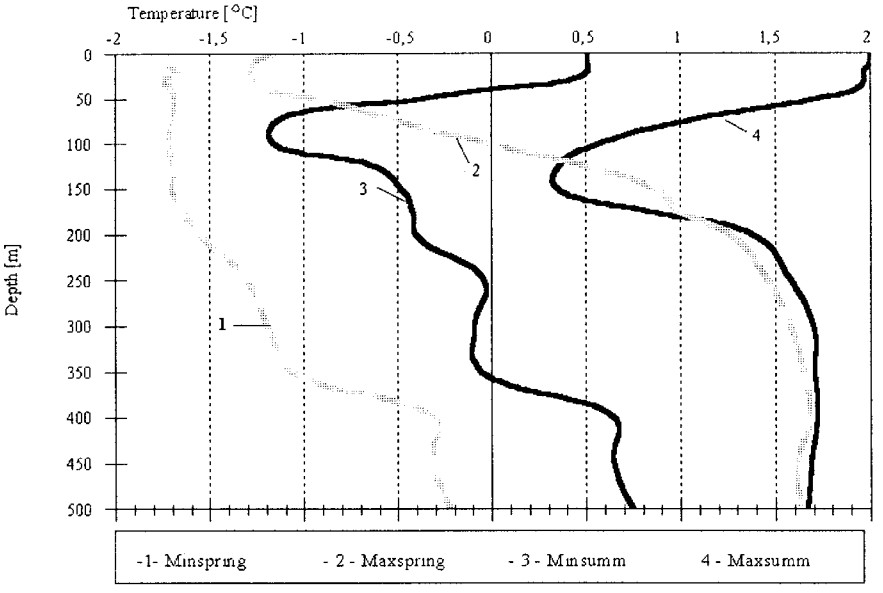

Fig. 3. Spatial and seasonal changes of water temperature in area 1.

Table 1

Mean temperature and salinity during spring (28 Oct.–15 Nov.) and summer (8 Jan.–26 Mar.) in area 1.

Depth in m	Mean spring temperature	Mean spring salinity	Mean summer temperature	Mean summer salinity	Spring and summer number of data
0	-1.44	34.12	1.49	33.95	28 + 14
10	-1.49	34.13	1.46	33.95	28 + 14
20	-1.46	34.13	1.37	33.96	28 + 14
30	-1.45	34.13	1.26	33.98	28 + 14
40	-1.44	34.14	1.06	34.0	27 + 14
50	-1.4	34.15	0.85	34.02	28 + 14
75	-1.39	34.2	0.21	34.11	28 + 14
100	-1.22	34.29	-0.13	34.18	28 + 14
125	-1.06	34.33	-0.12	34.26	28 + 14
150	-0.94	34.36	-0.04	34.33	27 + 14
175	-0.81	34.39	0.03	34.37	28 + 13
200	-0.62	34.41	0.15	34.42	27 + 12
250	-0.29	34.49	0.38	34.49	20 + 10
300	-0.1	34.53	0.47	34.54	24 + 10
350	0.09	34.57	0.69	34.59	24 + 11
400	0.25	34.6	0.79	34.62	24 + 7
450	0.35	34.61	1.08	34.66	21 + 5
500	0.6	34.62	1.05	34.67	16 + 4

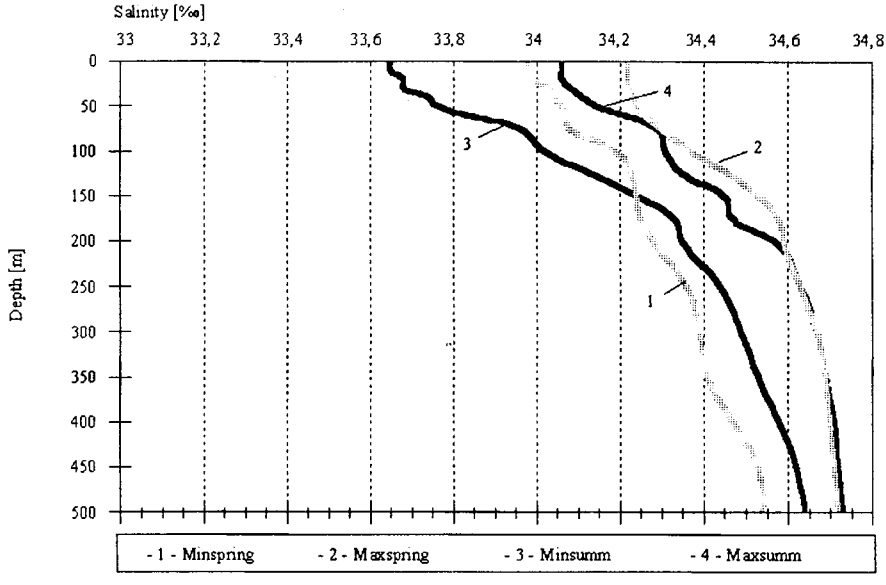

Fig. 4. Spatial and seasonal changes of water salinity in area 1.

of area 1 surface T was -1.8°C, while at 300 m a temperature +1.8°C was recorded. Thus the vertical temperature difference was the same as seasonal surface T differences. This is caused by the constant temperature (Fig. 3) of the Warm Deep Water flowing along the northern shelf slope of South Shetland Islands (Rakusa-Suszczewski 1988 b). Surface stratum temperature in the spring is low with small variations; these differences increase with depth and at 500 m in area 1 attains a temperature variation +1.9°C. The temperature at 120–150 m depths is most stable throughout the seasons, affected by winter conditions.

In area 1 water salinity (Fig. 4) increases rapidly with depth, about 1‰ down to 150–200 m; below that depth the increase is less pronounced and reaches 34.7‰ at 400 m. Intensive ice melting in summer causes the surface salinity to be lower than in the spring.

Seasonal salinity differences in area 1 are the lowest at 120–150 m, and this stratum is the most stenothermic and stenohaline.

Area 2 (Figs 1–2) includes the southern coastal zone with bays of King George Island, the abruptly descending shelf slope, and the central part of the Bransfield Strait. Waters from the South-East Pacific Basin and from Bellingshausen Sea enter the Bransfield Strait. Pacific waters might hinder the inflow of coastal surface waters from the Bellingshausen Sea (BIOMASS Rep. Ser. 1990). From the Drake Passage there can also be an inflow of water into the Bransfield Strait around the NE end of King George Island, while Weddell Sea water enters the Strait from the south-east (Tokarczyk 1987).

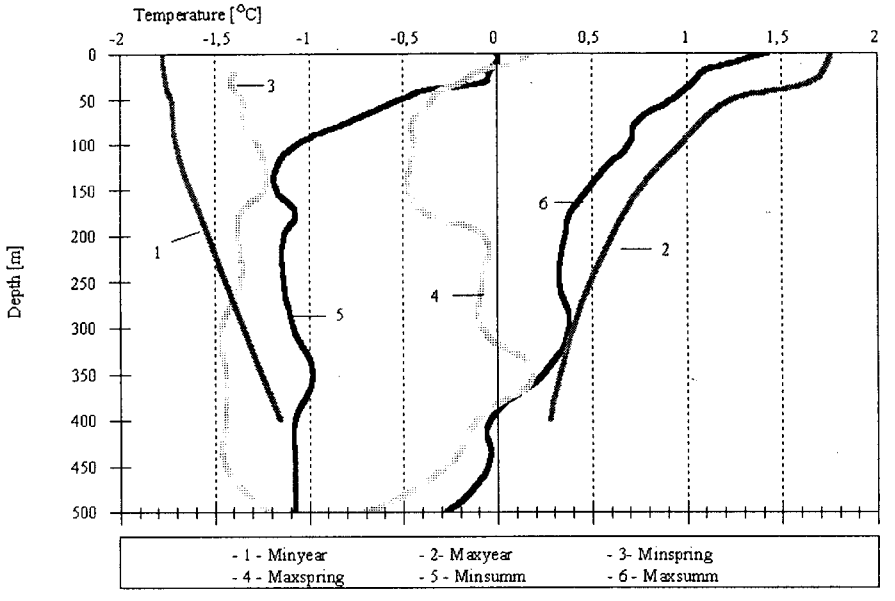

Fig. 5. Spatial and seasonal changes of water temperature in area 2.

Table 2

Mean temperature and salinity during spring (9 Nov.–27 Dec.) and summer (30 Jan.–17 Mar.) in area 2.

Depth in m	Mean spring temperature	Mean spring salinity	Mean summer temperature	Mean summer salinity	Number of data
0	-0.95	34.07	0.37	33.85	11 + 13
10	-0.94	34.08	0.35	33.91	11 + 13
20	-0.93	34.11	0.33	33.95	11 + 13
30	-0.94	34.12	0.33	33.96	11 + 13
40	-0.98	34.15	0.25	33.99	11 + 13
50	-0.98	34.17	0.21	34.0	11 + 13
75	-0.91	34.24	0.03	34.09	11 + 13
100	-0.82	34.28	-0.11	34.17	11 + 13
125	-0.81	34.31	-0.18	34.23	11 + 13
150	-0.85	34.33	-0.14	34.28	11 + 11
175	-0.8	34.35	-0.13	34.31	11 + 10
200	-0.68	34.37	-0.19	34.35	11 + 10
250	-0.59	34.41	-0.2	34.47	11 + 10
300	-0.63	34.43	-0.22	34.52	11 + 10
350	-0.71	34.46	-0.26	34.55	11 + 13
400	-0.84	34.49	-0.51	34.56	11 + 9
450	-0.85	34.5	-0.66	34.56	10 + 11
500	-0.99	34.51	-0.75	34.56	7 + 6

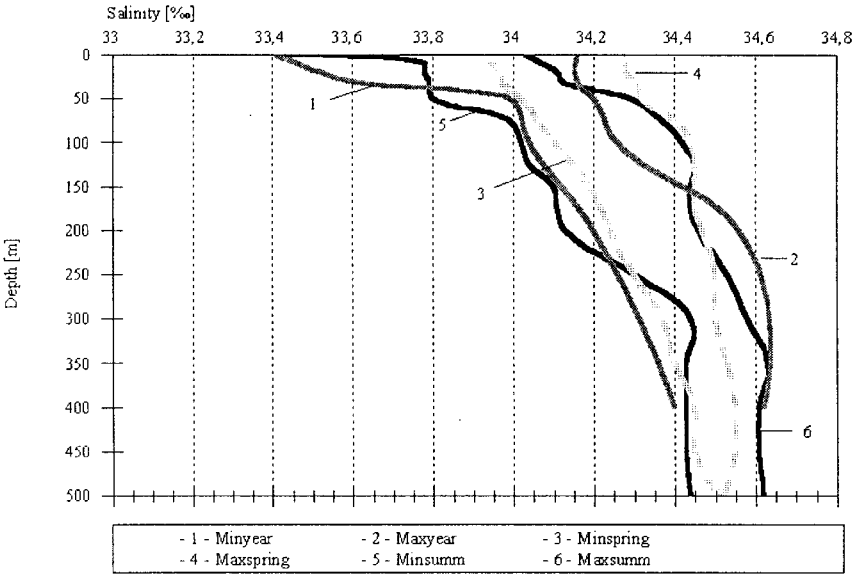

Fig. 6. Spatial and seasonal changes of water salinity in area 2.

Table 3

Mean temperature and salinity during spring (6–8 Nov.) and summer (2 Jan.–14 Mar.) in area 3.

Depth in m	Mean spring temperature	Mean spring salinity	Mean summer temperature	Mean summer salinity	Number of data
0	-1.31	34.42	0.05	34.26	20 + 9
10	-1.34	34.42	0.03	34.26	20 + 9
20	-1.36	34.44	-0.01	34.27	20 + 9
30	-1.31	34.45	-0.05	34.27	21 + 9
40	-1.33	34.46	-0.11	34.28	20 + 9
50	-1.3	34.45	-0.16	34.28	21 + 9
75	-1.33	34.47	-0.57	34.33	20 + 9
100	-1.33	34.47	-0.8	34.37	19 + 9
125	-1.33	34.48	-0.92	34.4	18 + 9
150	-1.3	34.48	-0.99	34.44	18 + 9
175	-1.23	34.48	-1.0	34.46	17 + 8
200	-1.23	34.48	-1.05	34.48	17 + 8
250	-1.19	34.49	-0.98	34.49	15 + 7
300	-1.2	34.5	-0.99	34.52	15 + 7
350	-1.21	34.5	-1.0	34.54	15 + 9
400	-1.2	34.5	-0.97	34.56	14 + 7
450	-1.07	34.51	-0.96	34.56	12 + 7
500	-1.0	34.52	-0.94	34.58	11 + 7

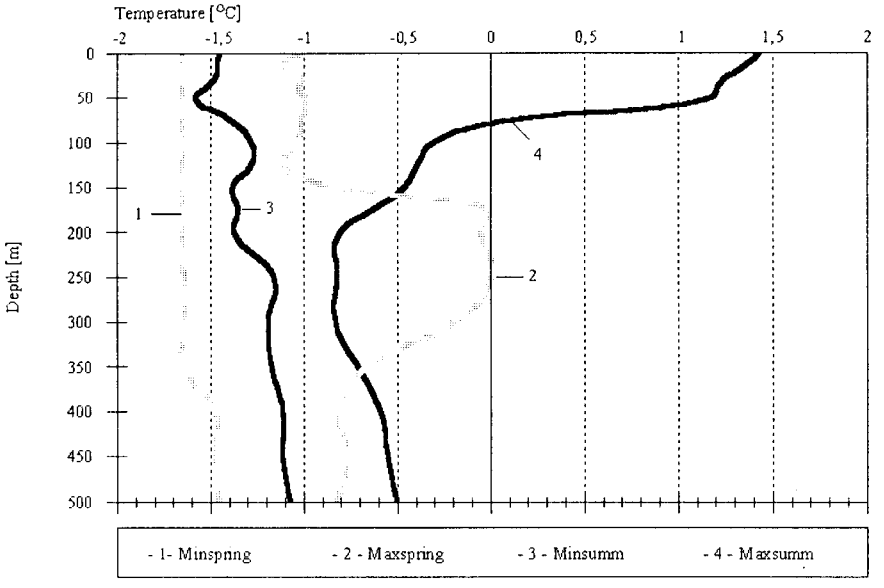

Fig. 7. Spatial and seasonal changes of water temperature in area 3.

In Area 2, in spring, minimal water temperatures (Fig. 5) are uniform to the depth of 500 m. Maximal T values indicate the warming of surface water. Warmer water inflowing from the west into the deeper levels is easily discernable.

Salinity in area 2 (Fig. 6) increases with depth and is higher in spring than in summer. The lowest salinity values are found in the nearshore zone which is affected throughout the year by the varying outflow of fresh water from land. This is also shown in the annual cycle by the lower salinity of surface water in Admiralty Bay. During the periods of study, the mean temperature and salinity values changed only slightly with depth (Table 2).

Area 3 is located on the shelf of the Antarctic Penninsula and includes the central basin of the Bransfield Strait. In this area two water masses meet and flow in opposite directions. Thus warm waters from the west flow NE, while cold waters from the Weddell Sea flow toward the SW (Clowes 1934, Stein and Rakusa-Suszczewski 1983, 1984).

In the spring, water temperatures are below zero in the entire water column (Fig. 7). An increase of 1°C in the 150–350 m stratum is an evidence of the presence of warm waters from the west. Only during the summer are surface temperatures above zero. Temperature and salinity changes in the whole water column are insignificant throughout the study periods (Table 3).

Comparison of all three areas (Figs 1–2) shows a distinct temperature decrease from north to south (Figs 3, 5, 7). The warmest waters are found in area 1, while the coldest are in area 3. The lowest surface salinity (Figs 4, 6, 8) is

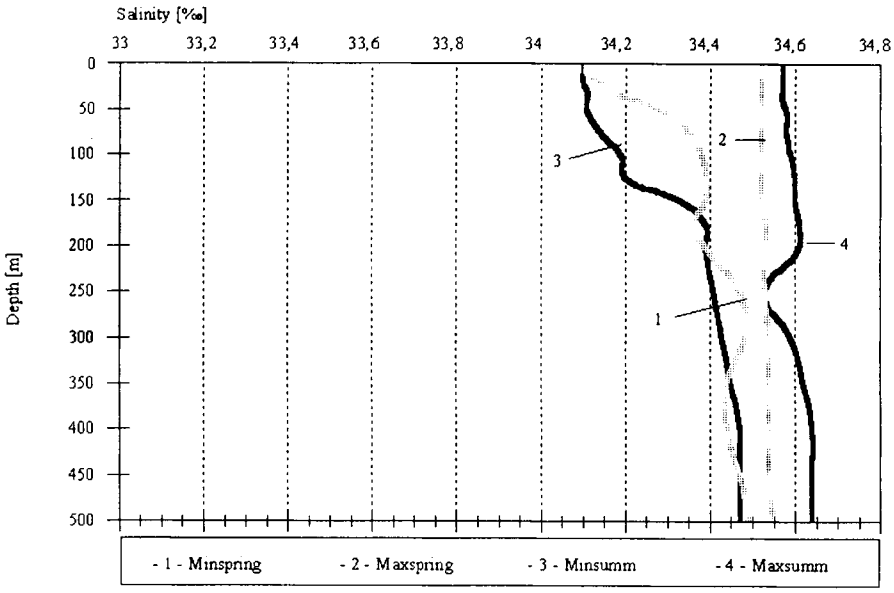

Fig. 8. Spatial and seasonal changes of water salinity in area 3.

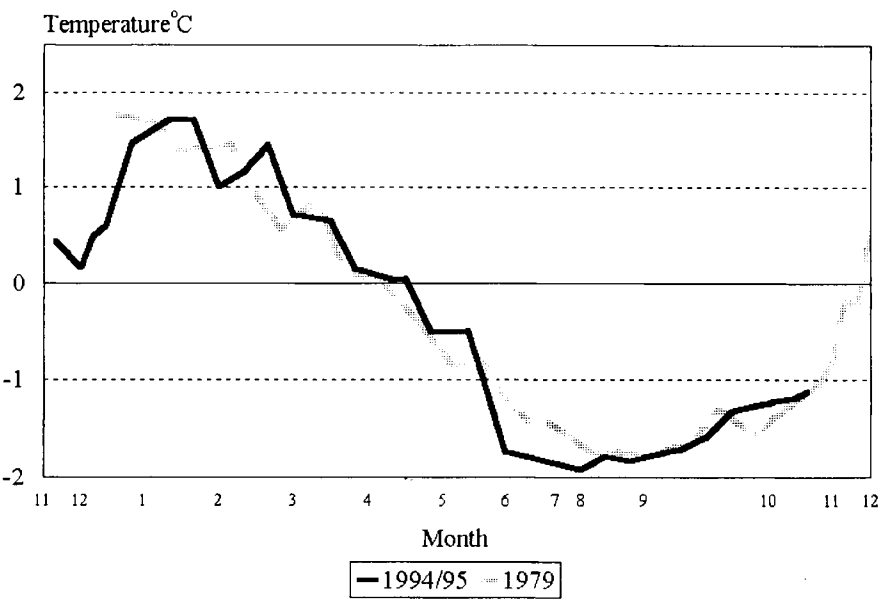

Fig. 9. The comparison of water temperature in Admiralty Bay at 4 m in 1994/95 and 0 m depth in 1979.

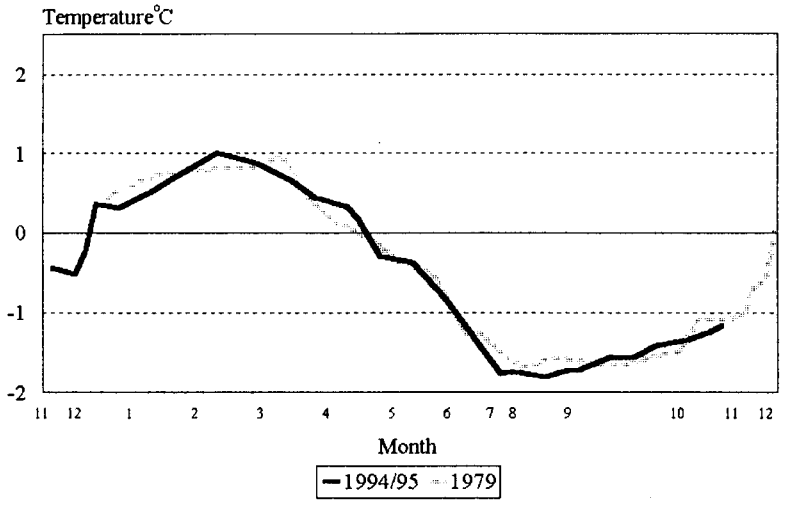

Fig. 10. The comparison of water temperature in Admiralty Bay at 100 m depth in 1994/95, and 1979.

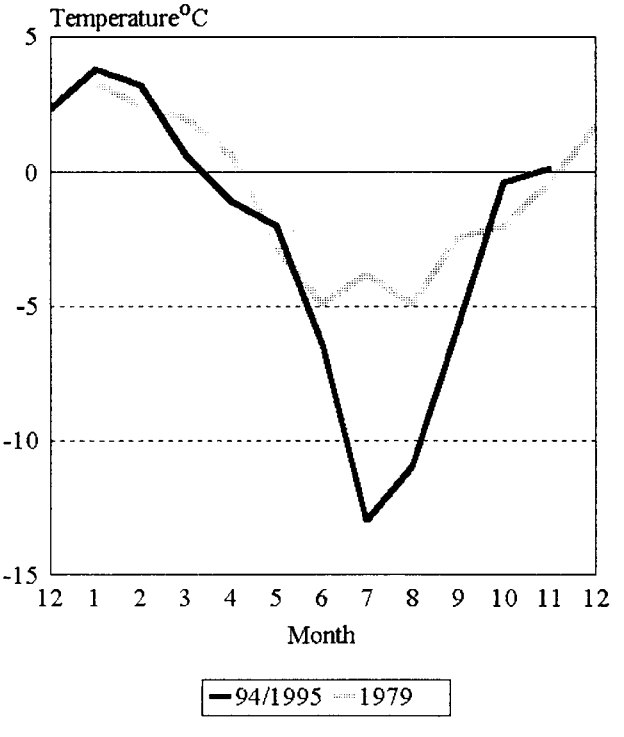

Fig. 11. The mean air temperature at *Arctowski* Station in the years when the temperature in Admiralty Bay was measured.

Table 4

Water temperature, air temperature and ice thickness, in the central part of Admiralty Bay and Martel Inlet (02.12.1994–05.11.1995).

Data	4 m Adm. Bay	10 m Adm. Bay	100 m Adm. Bay	10 m Martel	100 m Martel	Ice thick-ness (cm)
02.12.94	0.43	0.14	-0.44	x	-0.53	0
12.12.94	0.16	0.16	-0.52	0.24	-0.58	0
22.12.94	0.48	0.46	-0.23	0.84	-0.25	0
02.01.95	0.6	0.76	0.37	0.68	0.48	0
12.01.95	1.46	1.41	0.31	1.38	0.38	0
28.01.95	1.71	1.16	0.51	1.6	0.38	0
06.02.95	1.71	1.7	0.69	1.14	0.75	0
15.02.95	1.0	1.01	0.84	1.49	0.76	0
28.02.95	1.15	1.64	1.0	1.47	1.24	0
07.03.95	1.44	1.44	0.94	1.47	0.95	0
21.03.95	0.71	0.94	0.86	0.62	0.83	0
29.03.95	0.65	0.68	0.64	0.26	0.75	0
09.04.95	0.15	0.15	0.45	0.17	0.46	0
19.04.95	0.03	0.05	0.32	0.16	0.33	0
02.05.95	0.05	0.12	0.18	0.02	0.22	0
10.05.95	-0.51	-0.42	-0.29	-0.74	-0.14	0
31.05.95	-0.49	-0.52	-0.38	-0.67	-0.23	0
11.06.95	-1.74	-1.12	-0.83	-1.06	-0.63	0
17.08.95	x	-1.76	-1.76	x	x	40-60
23.08.95	-1.93	-1.88	-1.74	-1.82	-1.79	40-60
03.09.95	-1.79	-1.81	-1.81	x	x	45-60
07.09.95	-1.84	-1.83	-1.73	-1.81	-1.7	45-60
14.09.95	-1.8	-1.81	-1.73	-1.76	-1.71	45-60
21.09.95	-1.72	-1.75	-1.55	-1.79	-1.53	45-60
28.09.95	-1.59	-1.64	-1.57	-1.7	-1.61	45-65
15.10.95	-1.32	-1.39	-1.42	x	x	0
22.10.95	-1.23	-1.36	-1.34	x	x	0
30.10.95	-1.19	-1.2	-1.24	x	x	0
05.11.95	-1.12	-1.17	-1.17	x	x	0

evident in area 2 as a result of water outflow from land. In area 3 the lowest vertical salinity variations are observed, with the highest value occurring at the surface. At 500 m depth the highest salinity is recorded in area 1; lower and similar values are found in areas 2 and 3. The most homogenous temperature and salinity values with the lowest seasonal changes are evident in area 3.

Annual temperature measurements in 1979 in Admiralty Bay (Fig. 5, lines 1 and 2) indicate a range of changes a few tenths greater than that for seasonal

values in area 2. In 1994/95 water temperatures in Admiralty Bay at 0, 10 m, and 100 m, show small local variations within the bay (Table 4).

Comparison of surface water temperatures in Admiralty Bay in the annual cycles of 1979 and 1995 shows similarities during the fall, but the winter 1994/95 was colder.

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Streszczenie

Porównując bezwzględne wartości, średnie i stratyfikację temperatury i zasolenia w trzech wybranych obszarach 1, 2 i 3, (fig. 1–2) widać wyraźny spadek temperatury z północy na południe (fig. 3, 5, 7; tab. 1–3). Najcieplejsze są wody w obszarze 1, najzimniejsze w obszarze 3. Zasolenie (fig. 4, 6, 8) na powierzchni jest najniższe w obszarze 2, jako efekt spływu słodkich wód z lądu. W obszarze 3 różnice zasolenia w pionie są najmniejsze i na powierzchni jest ono najwyższe. Na głębokości 500 m najwyższe zasolenie stwierdzono w obszarze 1, nieco niższe i podobne jest w obszarach 2 i 3. Najbardziej homogeniczny pod względem temperatury i zasolenia i podlegający najmniejszym zmianom sezonowym jest obszar 3.

Temperatury wody w Zatoce Admiralicji w 1994/1995 roku wykazują niewielkie lokalne różnice (tab. 4). Porównanie temperatury wody w Zatoce Admiralicji w cyklu rocznym w latach 1979 i 1994/95 (fig. 9–10) wskazuje na wyraźną różnicę zimą. Zima w 1995 była chłodniejsza niż w roku 1979 (fig. 11).