The South African SIBEX I Cruise to the Prydz Bay region, 1984: III. Detail of the upper thermal structure of the Southern Ocean between South Africa and Prydz Bay during March-May 1984

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Lines of expendable bathythermograph stations were occupied between Cape Town and Prydz Bay, Antarctica, in support of the South African SIBEX I cruise of 1984. These measurements of the thermal detail of the upper water column as well as closely spaced sea surface readings located unambiguously the locations of the major ocean fronts in the area. The conclusion is reached that the upper water column exhibited a well-developed summer regime with a distinct Continental Water Boundary at about 64°30'S in the Prydz Bay experimental area.

Ter ondersteuning van die Suid-Afrikaanse SIBEX I vaart in 1984 is 'n tweetal afskryfbare batitermograaf-vaartlyne uitgevoer tussen Kaapstad en Prydzbaai, Antarktika. Hierdie en ander nougespasiëerde seeoppervlak-waarnemings het die ligging van die belangrikste oseaanfronte ondubbelsinnig vasgestel. Daar word tot die slotsom gekom dat die boonste oseaanlaag tydens hierdie tydperk die eienskappe van 'n goedontwikkelde somer-regime vertoon het met verder 'n duidelike Kontinentale Watergrens by ongeveer 64°30'S in die Prydzbaai eksperimentele gebied.

Introduction

To investigate the poorly known thermal detail of the upper ocean layers south of Africa, a measurement programme was launched in 1978 using for the greater part ships of opportunity sailing to Antarctica (Lutjeharms 1985). Longitudinal geographic coverage during the project has extended from the South Sandwich Islands at 26°W to Marion Island at 40°E. The decision of the BIOMASS committee that South Africa should make its major contribution to SIBEX in the Prydz Bay area of Antarctica, at about 65°E, afforded the opportunity to extend the coverage of the research programme mentioned above further eastwards and, in the process, to provide environmental support information about oceanic conditions in the surrounding oceans as well as in the experimental area of the South African SIBEX itself.

The Southern Ocean is characterised by strong and consistent frontal regions. These were first described in detail by Deacon (1937) and Macintosh (1946) and numerous descriptions from many sectors of the Southern Ocean have been presented subsequently (Burling 1961, Botnikov 1964, Gordon 1967, Emery 1977). In the Southern Ocean sector south of Africa most measurements since 1956 have consisted of closely spaced surface readings (Fukase 1962) from supply vessels steaming to relieve Antarctic bases, closely spaced expendable bathythermograph (XBT) readings (Taylor *et al.* 1978, Lutjeharms *et al.* 1985) and continuous thermograph readings (Lutjeharms & Emery 1984). Lutjeharms & Valentine (1984) have assembled and statistically analysed all available sea surface temperature readings in this area and have shown that the thermal fronts have consistent and narrow thermal characteristics. Preliminary results of studies on the upper 500 m of the water column in this ocean area (Lutjeharms 1985) have defined the extent to which fronts may vary in time and space.

Results and Discussion

The location of the cruise track and station positions of expendable bathythermograph (XBT) measurements during the two cruise legs which are reported on here and which form part of the South African SIBEX, is given in Figure 1. Due to a shortage of XBT probes the return leg did not cover the full distance between Prydz Bay and Cape Town, but did cover the area in which the main fronts were expected. In these specific areas the spacing between XBT stations was furthermore reduced to achieve greater resolution on the fronts themselves. Spacing was also reduced south of 62°S where the South African SIBEX area was crossed to establish the thermal background regime before the onset of measurements in aid of the SIBEX proper. Sea surface temperatures by Crawford bucket (Crawford 1972) and sea surface salinity measurements were undertaken simultaneously. Details on the methods used for data reduction and quality control have been described elsewhere (Lutjeharms & Emery 1984, Lutjeharms & Foldvik 1985, Allanson *et al.* 1981).

Results of these readings are portrayed in Figures 2 & 3. The locations of the major fronts are indicated on these illustrations. The definitions used to identify these fronts unambiguously are given elsewhere (Lutjeharms & Emery 1984, Lutjeharms & Foldvik 1985) and are not repeated here.

Figure 2 shows the warm surface water of the Agulhas Current, in excess of 23°C, lying between 35° and 36°S. The Agulhas Return Current could be identified by the upward sloping isotherms at 40°S, just north of the Agulhas Plateau (Harris & Van Foreest 1978, Gründlingh 1978, Lutjeharms & Van Ballegooyen 1984). On the Agulhas Plateau itself a warm eddy is seen, the location of which corresponds well with the buoy tracks reported by Gründlingh (1978) but not well with the results from satellite remote sensing reported by Lutjeharms & Valentine (1985). The edge of this eddy may be considered to be the Agulhas Front (Lutjeharms & Valentine 1984) while the most significant drop in the sea surface salinities at 42°S defines the location of the Subtropical Convergence. Comparing the locations of these fronts

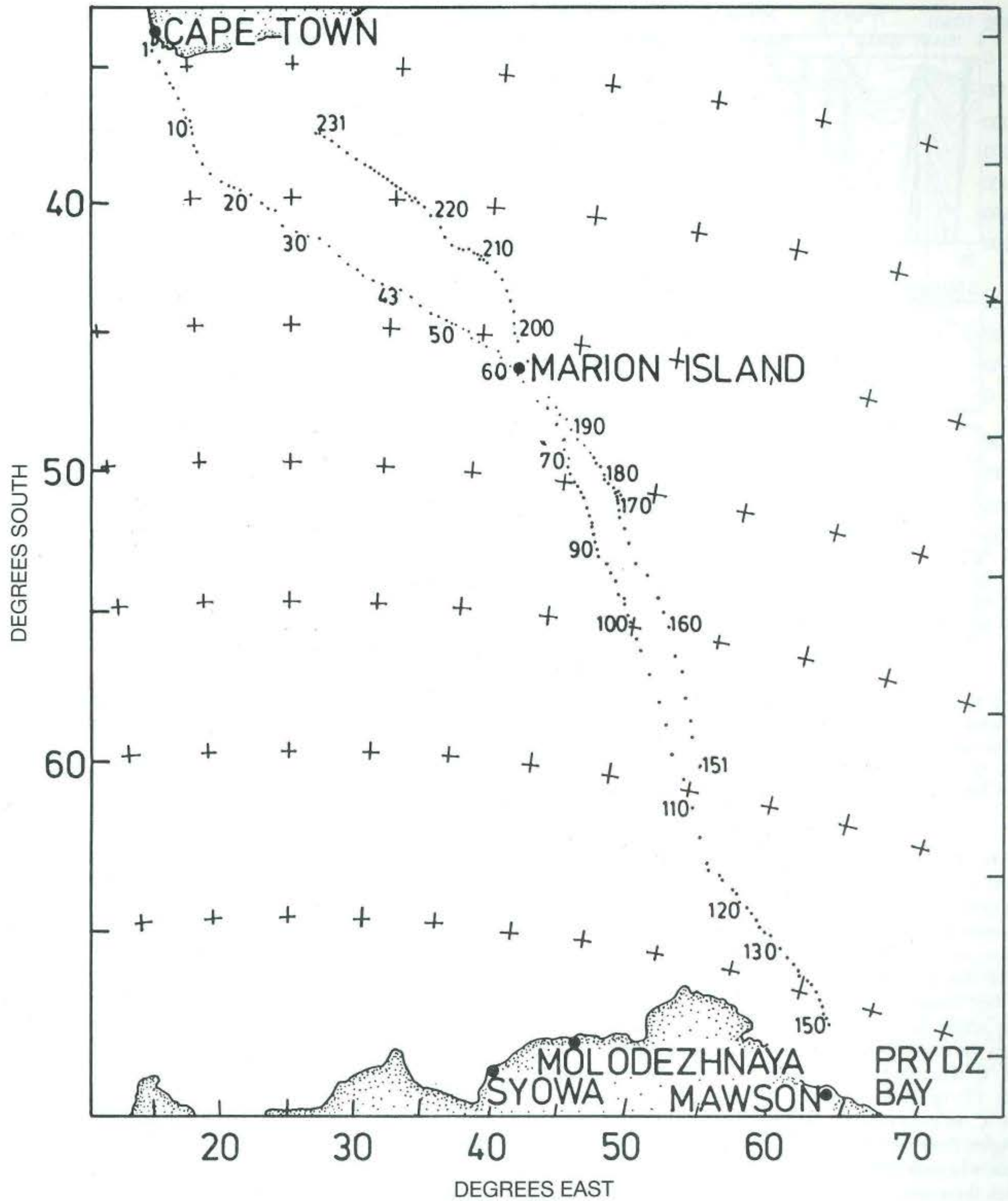

Fig. 1. Chart showing the geographic location of the cruise tracks and the expendable bathythermograph stations carried out from on board the R V *SA Agulhas* as part of the South African SIBEX programme in March to May 1984. Numbers are for XBT probes used.

with average results for the whole South Indian and South Atlantic sectors of the Southern Ocean, presented by Lutjeharms & Valentine (1984) and by Lutjeharms (1985), shows that the fronts were at the southern limits of their normal geographic range.

The averaged results that have been reported by Lutjeharms & Valentine (1984) cover a latitudinal area which includes both the South Atlantic and the South Indian Ocean sectors of the Southern Ocean. At least seven series of known sea surface measurements have been made in the general area between Southern Africa and Prydz Bay over a period from 1956 to 1974 (Valentine & Lutjeharms 1983). Comparing the results of the SIBEX cruise with those seven may give a truer indication of the degree of development of the fronts on this occasion than by comparing them with wide latitudinal averages from Lutjeharms & Valentine

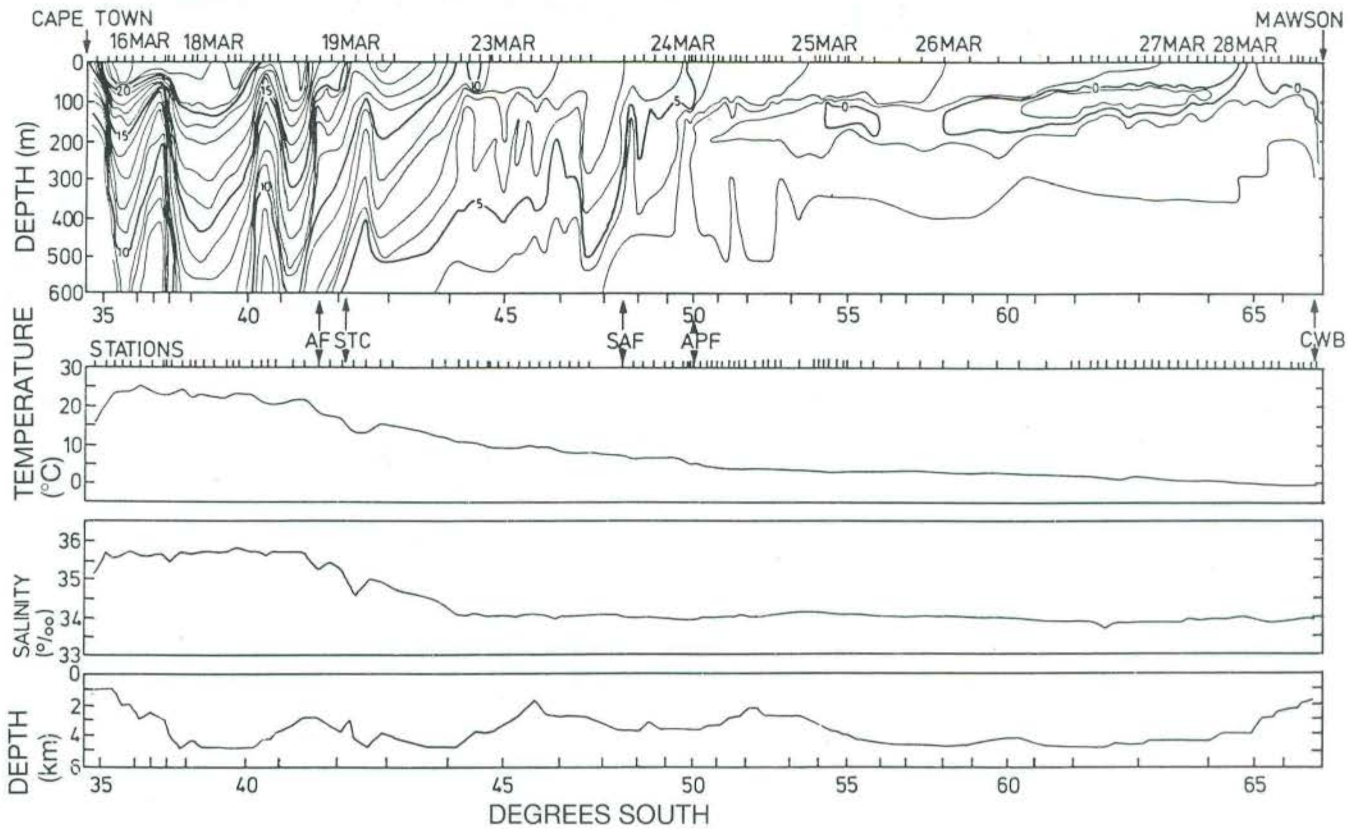

Fig. 2. Results of a detailed XBT-section between Cape Town and Prydz Bay as part of SIBEX during March 1984. The upper panel shows the isotherm distribution in the upper 600 m of the water column, the second panel the sea surface temperature determined by Crawford bucket, the third panel the sea surface salinities and the bottom panel the bottom topography. The geographic location of the Agulhas Front (AF), the Subtropical Convergence (STC), the Subantarctic Front (SAF), the Antarctic Polar Front (APF) and Continental Water Boundary (CWB) is shown.

(1984). The results of these seven sets of measurements across each front and those achieved during SIBEX are therefore set out in detail in Table 1. They include the middle latitude, middle temperatures, temperature ranges, time of year, etc. of each front.

The ship's thermograph trace for the northern portion of the first cruise leg is shown in Figure 4a. The temperature drop across the Agulhas Front from 21° to 16 °C approximates the statistical average for three other cruises of 21° to 16,8 °C. The drop across the Subtropical Convergence was from 17° to 12 °C compared to the average of 17,9° to 10,4 °C. In each case the temperature of the lower boundary is higher than average, which may be due to the fact that this cruise was undertaken later in the year than most cruises on which these averages are based. This agrees with the higher low limits measured by the *R.D. Conrad* in January and March of 1974 (Table 1). This may therefore indeed be a summer effect.

On the first leg (Fig. 2) the Subantarctic Front was crossed at 47°30′S according to the thermal structure in the upper 600 m. The middle temperature of its sea surface expression was about 7 °C, while the reported average is 7,8 °C. The front was further south than usual (Table 1) with lower temperatures in its surface expression and a smaller temperature range. This is also noticeable on the thermograph traces (Fig. 4b) where the Subantarctic Front is barely noticeable as a sea surface thermal feature. The Antarctic Polar Front was located at 50°S by subsurface expression but at 48°10′ by surface expression, which compares to the average latitude of 50°51′S (Table 1), but had a surface expression consisting of a temperature drop exceeding 2 °C from 6,0 °C to 3,3 °C (Fig. 4b). The average drop is from 4,2 °C to 1,7 °C (Table 1). Although the range is thus comparable, the absolute temperatures are about 2 °C higher.

South of the Antarctic Polar Front a well-developed subsurface temperature minimum existed (Fig. 2), as is to be expected at this time of year. This layer was weakened at about 65°S, possibly indicating the location of the classical Antarctic Divergence. The Continental Water Boundary was found on the Antarctic shelf off Mawson Station. Both these fronts are of particular importance to the South African SIBEX and are discussed in detail elsewhere in this volume.

The Antarctic Polar Front was crossed on the return leg of the cruise about 140 km to the east of the first leg (Fig. 3). Very closely spaced XBT readings were taken, spaced about 10 km apart in places, which showed that the terminal region of the subsurface temperature minimum was broken up into lenses of water colder than 2 °C. The northernmost extent of this sub-2 °C water was found at 49°S. A noticeable surface gradient coincided with the subsurface expression of the Antarctic Polar Front on this occasion. Finding the surface and subsurface expression in such close proximity is rare (Lutjeharms & Valentine 1984, Fig. 7). This also may be a result of the well-developed summer thermal regime. The temperature increase from south to north across the Antarctic Polar Front was 2,8 °C from 4 °C to 6,8 °C (Fig. 4e). Both the range and the absolute temperatures were in excess

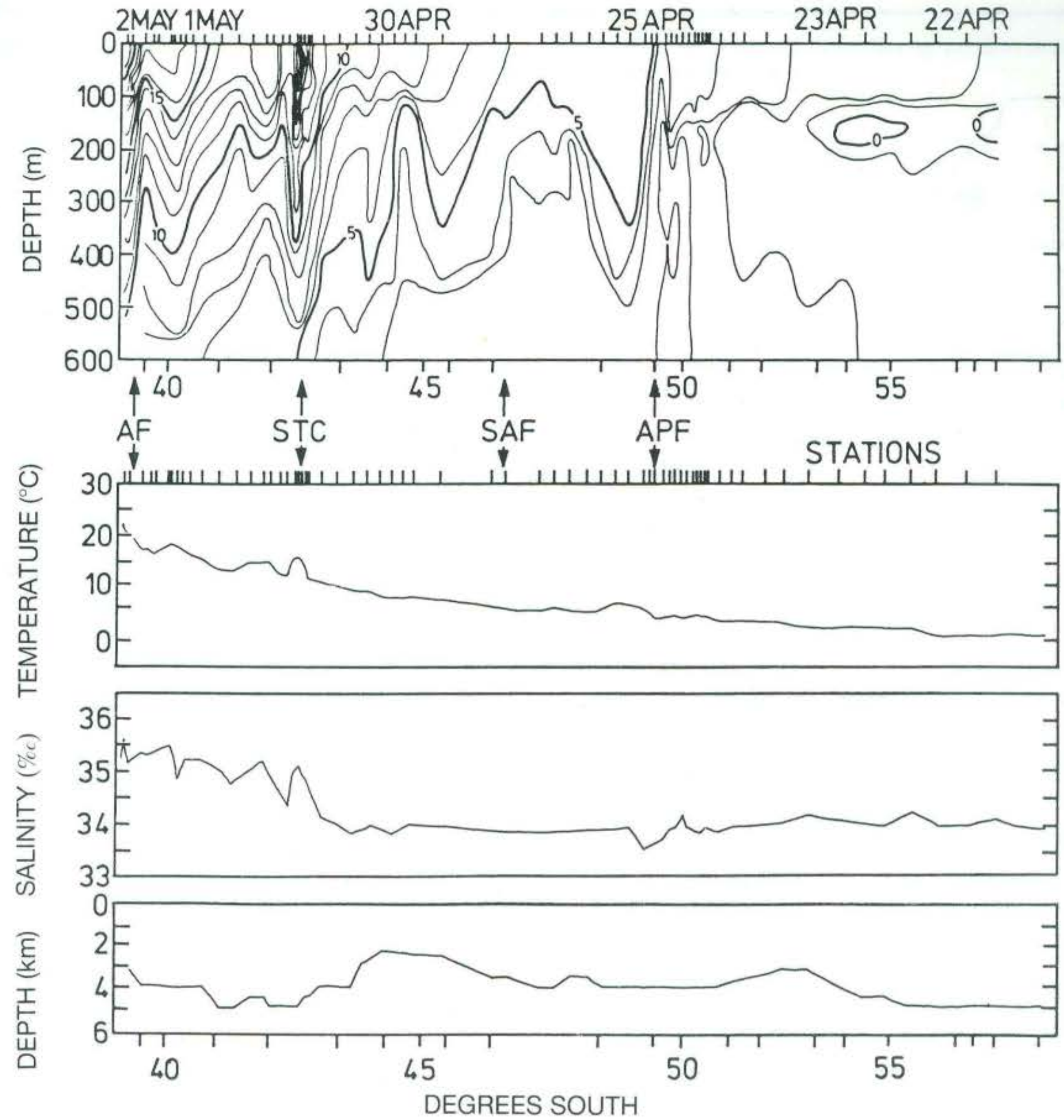

Fig. 3. Results of a detailed XBT-section on the return voyage from Prydz Bay to Cape Town as part of SIBEX during April and May 1984. The upper panel shows the isotherm distribution in the upper 600 m of the water column, the second panel the sea surface temperature determined by Crawford bucket, the third panel the sea surface salinities and the bottom panel the bottom topography. The geographic location of the Agulhas Front (AF), Subtropical Convergence (STC), the Subantarctic Front (SAF) and the Antarctic Polar Front (APF) is shown.

of those encountered on average. Temperatures were higher than on the first leg. The change in surface salinity at the Polar Front was also unusually large (Fig. 3). This may be related to the feature found just north of the Antarctic Polar Front which to all intents and purposes could only be identified as a warm-core, saline eddy with a probable origin north of the Subantarctic Front. Such a feature has not been observed before.

The Subantarctic Front was located at 47°S and showed hardly any surface expression (Fig. 4d). Stations were spaced very closely at the Subtropical Convergence at 42°19'S (Fig. 3) thus resolving a very small, but identifiable eddy bordering the Convergence with surface temperatures exceeding 15 °C. The surface temperature increase across the front was from 11,8 °C to 17,0 °C which again shows a higher temperature for the lower boundary for this front than the average (Table 1). The measuring programme ceased as the edge of the Agulhas Front was observed, once again with slightly higher than usual temperatures (Table 1).

Conclusions

The measurements, reported here in a preliminary manner, are unusual in that the temperatures are in general higher than the averages of those reported in the literature. This may be a result of the fact that these readings were taken later in the season than most of the measurements on which the averages are based. The proximity of a strong surface expression, of higher than usual temperatures, at the subsurface expression of the Antarctic Polar Front is also unusual. These two features as well as a well-developed subsurface temperature minimum south of the Antarctic Polar Front leads to the conclusion that the setting for the SIBEX experiment in Prydz Bay in 1984 was a well developed summer

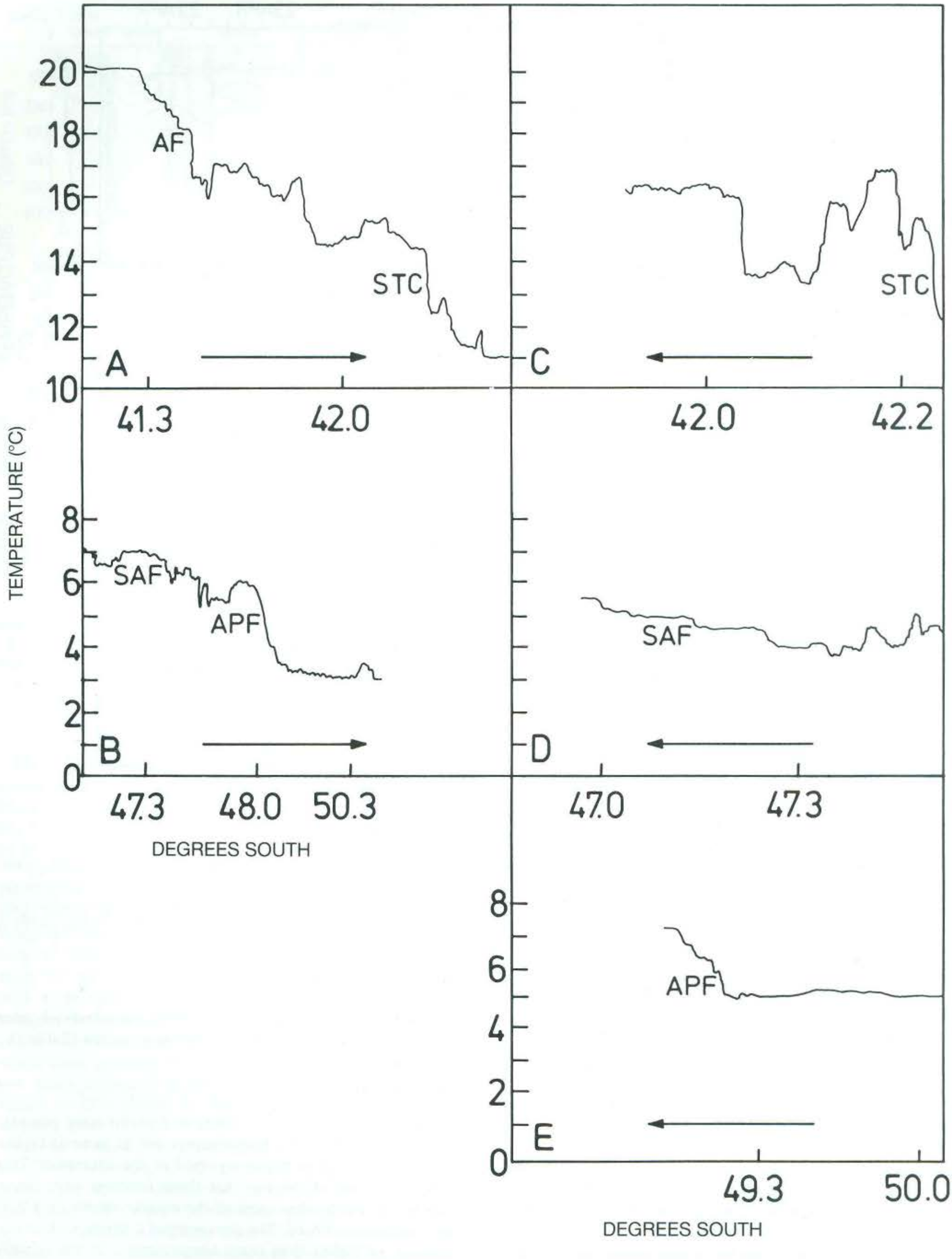

Fig. 4. Traces of the thermograph on board the R V *SA Agulhas* from the engine room intake for (a) the Agulhas Front and the Subtropical Convergence and (b) the Subantarctic and the Antarctic Polar Front on the first leg of the SIBEX cruise to Prydz Bay during March 1984, (c) the Subtropical Convergence, (d) the Subantarctic Front, and (e) the Antarctic Polar Front on the second leg of the SIBEX cruise from Prydz Bay during April and May 1984.

Table 1

Comparison between temperatures measured at the four major fronts between Cape Town and Prydz Bay by previous cruises and by the SIBEX cruise on the *SA Agulhas* of March-May 1983.

Agulhas Front

Middle Latitude °S	Temperature °C				Vessel	Year	Source
	From	To	Middle	Range			
—	—	—	—	—	Umitaka Maru	November 1956	Ishino *et al.* 1958
39°38′	21,0	16,2	18,6	4,8	Soya	December 1958	Fukase 1962
40°24′	20,6	16,8	18,7	3,8	Soya	December 1959	Fukase 1962
—	—	—	—	—	Soya	December 1960	Ichimura *et al.* 1963
—	—	—	—	—	Soya	December 1961	Kuga *et al.* 1963
40°36′	22,0	17,4	19,7	4,6	R.D. Conrad	January 1974	Jacobs *et al.* 1980
—	—	—	—	—	R.D. Conrad	March 1974	Jacobs *et al.* 1980
40°12′	21,2	16,8	19,0	4,4	Average		
41°40′	21,2	15,9	18,6	5,3	SA Agulhas	March 1984	—
39°41′	22,0	17,2	19,6	4,8	SA Agulhas	May 1984	—

Subtropical Convergence

Middle Latitude °S	Temperature °C				Vessel	Year	Source
	From	To	Middle	Range			
43°00′	16,0	10,0	13,2	6,3	Umitaka Maru	November 1956	Ishino *et al.* 1958
41°36′	16,8	11,0	13,9	5,8	Soya	December 1958	Fukase 1962
42°27′	17,0	9,2	13,1	7,8	Soya	December 1959	Fukase 1962
42°30′	18,0	7,8	12,9	10,2	Soya	December 1960	Ichimura *et al.* 1963
41°54′	20,8	10,8	15,8	10,0	Soya	December 1961	Kuga *et al.* 1963
42°15′	17,2	12,4	14,8	4,8	R.D. Conrad	January 1974	Jacobs *et al.* 1980
41°03′	19,3	12,2	15,8	7,1	R.D. Conrad	March 1974	Jacobs *et al.* 1980
42°06′	17,9	10,4	14,2	7,4	Average		
42°09′	16,8	12,0	14,4	4,8	SA Agulhas	March 1984	—
42°19′	17,0	11,8	14,4	5,2	SA Agulhas	May 1984	—

Subantarctic Front

Middle Latitude °S	Temperature °C				Vessel	Year	Source
	From	To	Middle	Range			
45°00′	10,0	7,3	8,7	2,7	Umitaka Maru	November 1956	Ishino *et al.* 1958
45°06′	12,0	6,2	9,1	5,8	Soya	December 1958	Fukase 1962
48°06′	6,9	2,8	4,9	4,1	Soya	December 1959	Fukase 1962
48°03′	7,4	4,0	5,7	3,4	Soya	December 1960	Ichimura *et al.* 1963
45°18′	11,0	6,0	8,5	5,0	Soya	December 1961	Kuga *et al.* 1963
45°33′	11,0	5,6	8,3	5,4	R.D. Conrad	January 1974	Jacobs *et al.* 1980
44°06′	12,2	6,2	9,2	6,0	R.D. Conrad	March 1974	Jacobs *et al.* 1980
45°53′	10,0	5,4	7,8	4,6	Average		
47°06′	7,9	6,1	7,0	1,8	SA Agulhas	March 1984	—
47°14′	6,5	4,0	5,3	2,5	SA Agulhas	May 1984	—

Antarctic Polar Front

Middle Latitude °S	Temperature °C				Vessel	Year	Source
	From	To	Middle	Range			
—	—	—	—	—	Umitaka Maru	November 1956	Ishino *et al.* 1958
51°24′	2,9	1,4	2,2	1,5	Soya	December 1958	Fukase 1962
50°42′	4,7	1,0	2,9	3,7	Soya	December 1959	Fukase 1962
51°27′	3,8	1,5	2,7	2,3	Soya	December 1960	Ichimura *et al.* 1963
49°00′	4,5	2,0	3,3	2,5	Soya	December 1961	Kuga *et al.* 1963
49°15′	4,3	2,3	3,3	2,0	R.D. Conrad	January 1974	Jacobs *et al.* 1980
53°21′	5,0	1,9	3,5	3,1	R.D. Conrad	March 1974	Jacobs *et al.* 1980
50°51′	4,2	1,7	3,0	2,5	Average		
48°10′	6,0	3,3	4,7	2,7	SA Agulhas	March 1984	—
49°04′	6,8	4,0	5,4	2,8	SA Agulhas	May 1984	—

regime in the surface layers of the Southern Ocean. A clear Continental Water Boundary and a front at 64°30′S were significant features in the area of the SIBEX itself. The latter front may have been induced by Eckman drift of the surface layers.

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