

Frontal systems encountered between southern Africa and the Prince Edward Islands during April/May 1987

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On two surface sections between southern Africa and the Prince Edward Islands during April and May 1987, three of the four surface fronts south of Africa were detected by surface nutrient and temperature measurements. The Agulhas Front and Subtropical Convergence were found to be within their historical limits, while the Subantarctic Front was found north of its historical limit and moved south during the cruise. The presence of the latter front may have been detected at the Prince Edward Islands.

Op twee snitte aan die seeoppervlak tussen suider-Afrika en die Prins Edward-eilande gedurende April en Mei 1987, is drie van die vier oppervlakfronte suid van Afrika, deur middel van oppervlak voedingsout- en temperatuurlesings, waargeneem. Die Agulhasfront en die Subtropiese Konvergensie is tussen hul historiese grense gevind terwyl die Subantarkiese Front noord van sy historiese grens gevind is. Dit het gedurende die vaart suidwaards beweeg. Daar is aanduidings dat die laasgenoemde front by die Prins Edward-eilande waargeneem was.

Introduction

Four major sea surface fronts are found between southern Africa and Antarctica. These have been described for this region by Lutjeharms and co-workers (Lutjeharms & Emery 1983, Valentine & Lutjeharms 1983, Lutjeharms & Valentine 1984, Lutjeharms 1985, Lutjeharms & Foldvik 1986). The four fronts are the Agulhas Front, a strong thermal front, marking the southern edge of the Agulhas Return Current; the Subtropical Convergence, another strong thermal front, sometimes coincident with the Agulhas Front, marking the northward extent of sub-Antarctic surface water; the Subantarctic Front, a fairly ephemeral front with nonetheless distinctive surface and subsurface thermal and nutrient expressions (Lutjeharms and co-workers, Whitworth & Nowlin 1987); and the Antarctic Polar Front. The historically determined limits of these fronts are reported by Lutjeharms & Valentine (1984) whose summarized results for the limits of these fronts are shown in Table 1.

Table 1
Averaged historical locations and thermal characteristics for the surface expressions of four oceanic fronts south of Africa (From Lutjeharms & Valentine 1984.)

	Latitudinal Position			Temperature (°C)		
	From	Middle	To	From	Middle	To
Agulhas Front	39°09'	39°37'	40°01'	21,0	18,4	15,7
Subtropical Convergence	40°35'	41°40'	42°36'	17,9	14,2	10,6
Subantarctic Front	45°15'	46°23'	47°25'	9,0	7,0	5,1
Antarctic Polar Front	49°39'	50°18'	50°47'	4,1	3,4	2,5

The section of the Southern Ocean between southern Africa and the Prince Edward Islands (47°S, 38°E) in the south-west Indian Ocean was traversed four times by MV *S.A. Agulhas* during April and May 1987. On three of these traverses measurements of surface temperatures, nutrient and chlorophyll-a concentrations were made. On two of the legs, both outwards from South Africa to the Prince Edward Islands, the presence of three of these four fronts was shown. The Antarctic Polar Front usually occurs south of the Prince Edward Islands and was not crossed during the cruise of April and May 1987.

Methods

Near-surface water samples were collected from the scientific sea-cock on board *S.A. Agulhas*. The inlet of this sea-water supply is situated at about 3 m depth. All 'surface' measurements and samples were taken from this source.

Temperature was recorded from the vessel's thermograph trace. Readings from this trace were compared with surface measurements on conductivity, temperature, depth (CTD) casts taken at the Prince Edward Islands and were found to agree to within 0.5 °C. The CTD was calibrated after the cruise (Duncombe Rae 1989). The thermograph sensor is situated at the scientific sea-water supply inlet.

Nutrient concentrations were determined using a Technicon AutoAnalyzer II system following the methods of Mostert (1983). Nutrient analyses were done as soon after sampling as possible and kept frozen at -18 °C until analysis. Most analyses were done immediately. No samples were kept for longer than 36 hours before analysis. Initial problems with the nitrate and phosphate channels on the first leg necessitated discarding some of the nitrate and all the phosphate results for the leg.

Chlorophyll-a was determined using SCOR/UNESCO (1966) and analyses were done immediately.

Results and Discussion

MV *S.A. Agulhas* left Cape Town (34°00'S, 18°20'E) on 8 April 1987, arriving at Marion Island (47°S, 38°E) on 12 April 1987. Measurements were taken at two hourly intervals while the vessel was underway (Leg 1, Fig. 1). After work at the islands the vessel was required to depart for Port Elizabeth (34°00'S, 25°40'E) on 7 May 1987. Foul weather prevented work. On return to the Prince Edward Islands, however, from 11 May to 14 May, samples were taken again at two hourly intervals (Leg 3, Fig. 1). Returning to Cape Town, some samples were taken from 17 May to 18 May before work was stopped (Leg 4, Fig. 1).

The data collected on Leg 1 are shown in Figure 2. For this leg, the thermal expressions of the fronts (Fig. 2a) can easily be detected. The Agulhas Front (AF) was evident between 39°37'S and 39°54'S, with a range of 21,2 to 16,3 °C and a middle temperature of 18,8 °C. These ranges are within the limits for the

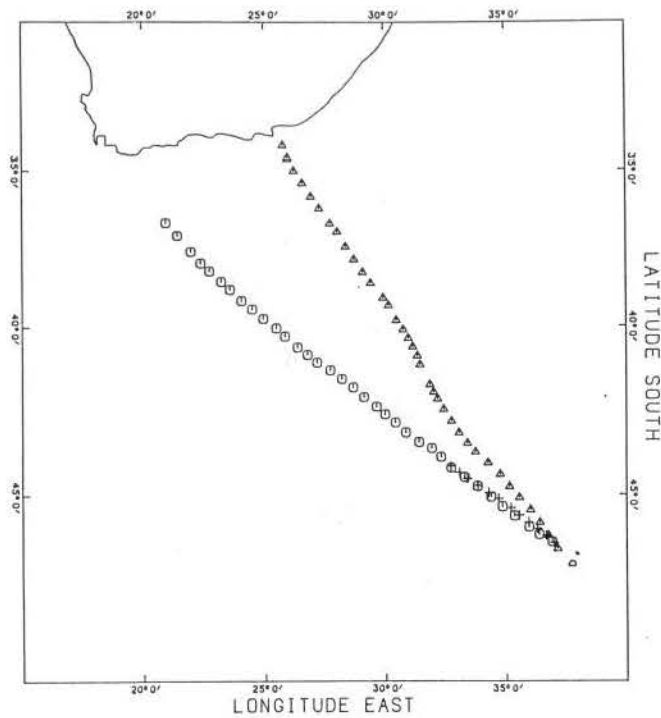


Fig. 1. The cruise track of MV S.A. Agulhas in April/May 1987, indicated by the positions of surface samples taken while underway. O Leg 1, Cape Town to Prince Edward Islands; Leg 2, Prince Edward Islands to Port Elizabeth, not shown; Δ Leg 3, Port Elizabeth to Prince Edward Islands; + Leg 4, Prince Edward Islands to Cape Town.

front given by Lutjeharms & Valentine (1984) [in this paper abbreviated to LV1984].

The Subtropical Convergence (STC) is also easily identified between $40^{\circ}51'S$ and $42^{\circ}06'S$ at 17.5 to $11.6^{\circ}C$ (middle temperature $14.5^{\circ}C$), being very close to LV1984's figures and also within their latitudinal limits.

The Subantarctic Front (SAF), however, on this leg at $43^{\circ}42'S$ to $44^{\circ}27'S$ (Fig. 2a), is well above LV1984's limits. It has the z-shape noted by them, and is the most pronounced frontal feature south of the STC. The most accurate definition of the SAF is a sub-surface one (Sievers & Emery 1978) and it is difficult to be certain of its position in the absence of sub-surface measurements.

Although there is some evidence that the Subantarctic Zone together with the SAF disappears somewhere to the east of the Prince Edward Islands (Gamberoni *et al.* 1982, Deacon 1983), Whitworth & Nowlin (1987) note that at 0° longitude the SAF can be recognized by large increases in the surface nitrate and phosphate concentrations and their figure shows a 5 mmol.m^{-3} increase in nitrate across the front. Jacobs & Georgi's (1977) sections taken near the Prince Edward Islands show an increase in phosphate associated with the STC and also with the SAF although they did not identify this front.

In April and May 1987, the surface nitrate concentration in the region of the thermally identified SAF increased by 9.6 mmol.m^{-3} (Fig. 2b). In conjunction with the surface temperature front, this nitrate front suggests that on this cruise the SAF did indeed lie further north and showed warmer characteristics than expected from historical data.

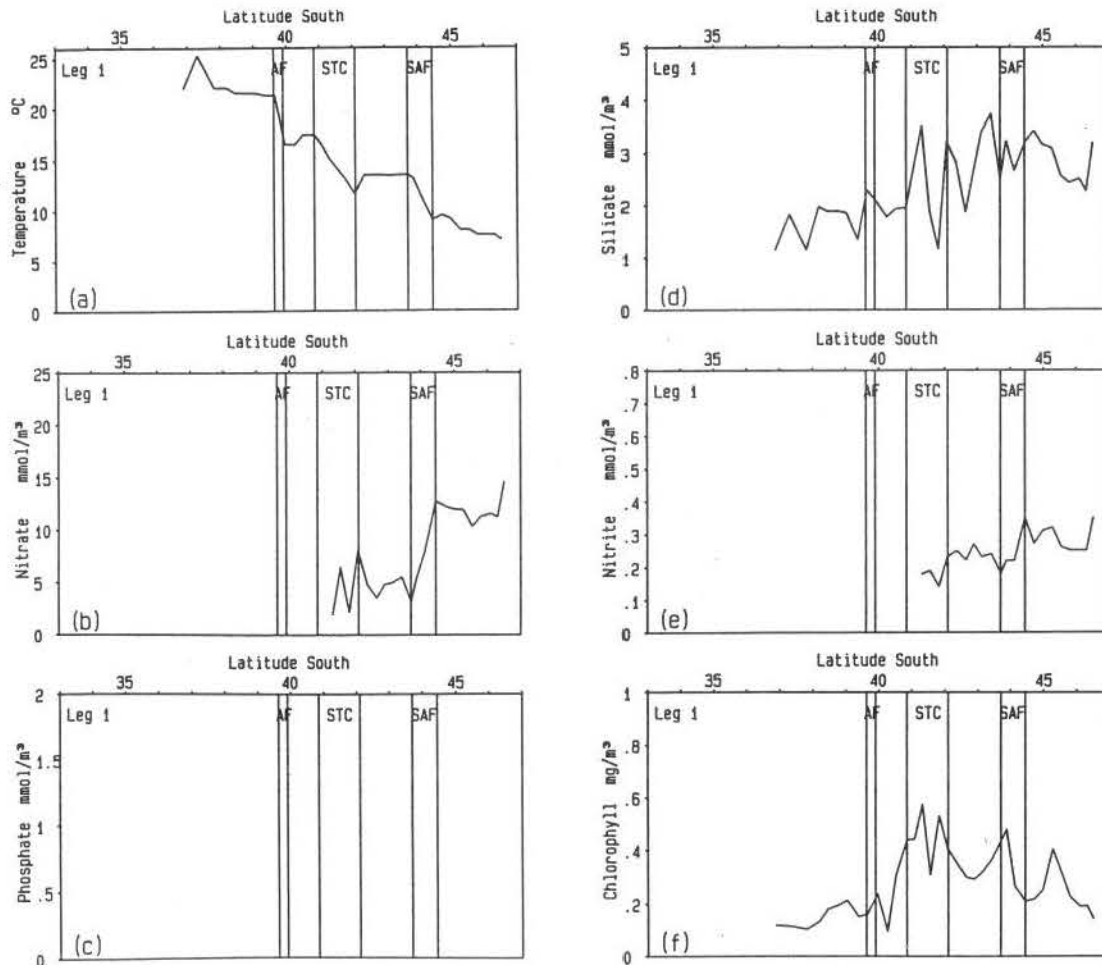


Fig. 2. Plots of the various parameters measured on Leg 1 against latitudinal position (a) temperature $^{\circ}C$, (b) nitrate mmol.m^{-3} , (c) phosphate mmol.m^{-3} , results discarded, not shown, (d) silicate mmol.m^{-3} , (e) nitrite mmol.m^{-3} , (f) chlorophyll-a mg.m^{-3} . The latitudinal limits of the fronts identified in the text are indicated (AF - Agulhas Front, STC - Subtropical Convergence, SAF - Subantarctic Front).

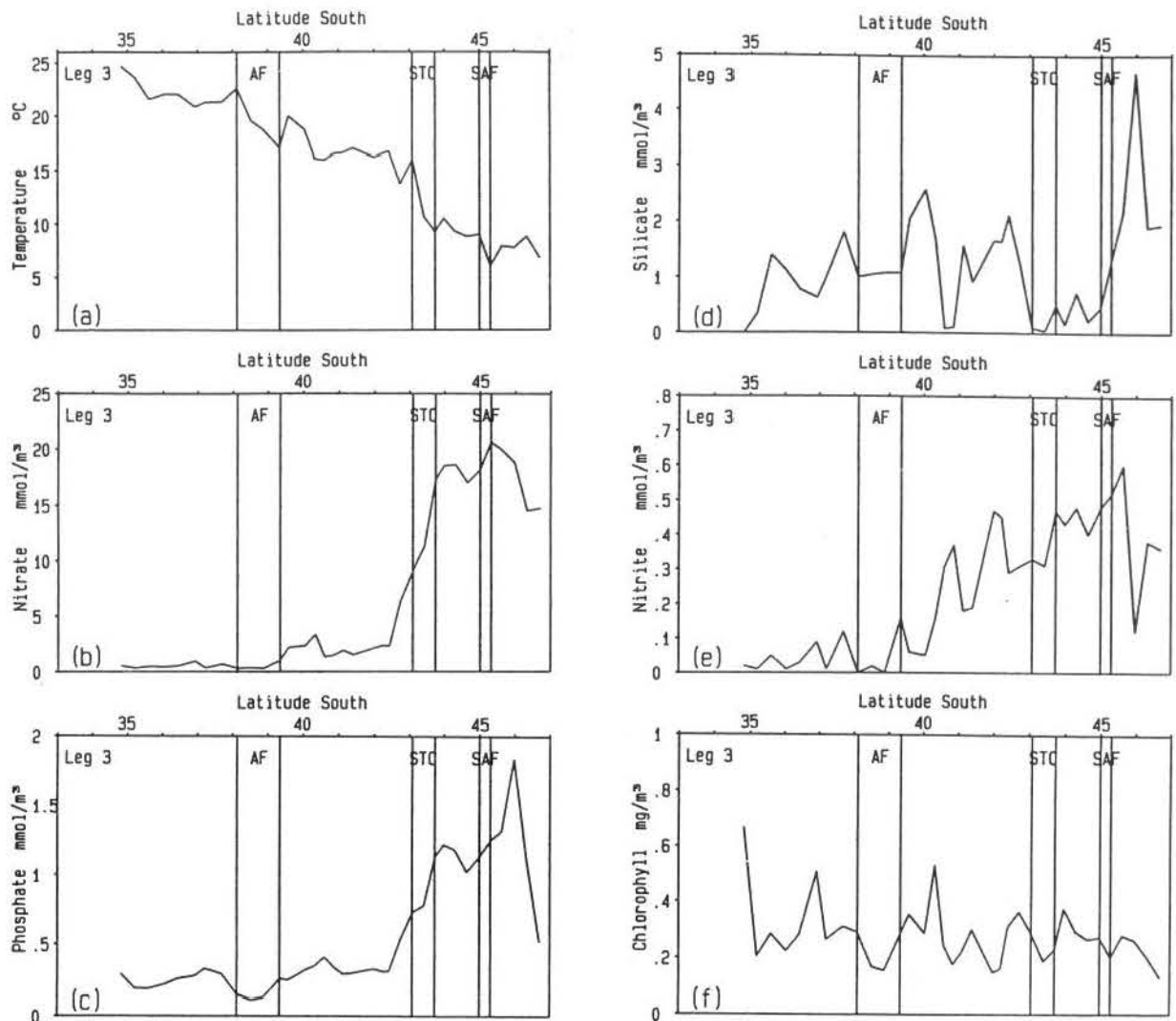


Fig. 3. Data for Leg 3. As for Figure 2.

Table 2
The latitudinal positions and thermal and nutrient characteristics for the surface expressions of the three oceanic fronts encountered between South Africa and the Prince Edward Islands during April and May 1987.

	Latitudinal Position		Temperature (°C)			Nitrate (mmol.m ⁻³)		Phosphate (mmol.m ⁻³)	
	From	To	From	Middle	To	From	To	From	To
LEG 1									
Agulhas Front	39°37'	39°54'	21,2	18,8	16,3	-	-	-	-
Subtropical Convergence	40°51'	42°06'	17,5	14,5	11,6	~2	8,1	-	-
Subantarctic Front	43°42'	44°27'	13,5	11,1	8,8	3,2	12,8	-	-
LEG 3									
Agulhas Front	38°07'	39°21'	22,6	19,7	17,0	0,3	1,0	0,2	0,3
Subtropical Convergence	43°05'	43°44'	16,0	12,6	9,2	9,1	17,3	0,7	1,1
Subantarctic Front	45°00'	45°18'	9,0	7,5	6,0	17,0	20,6	1,1	1,3

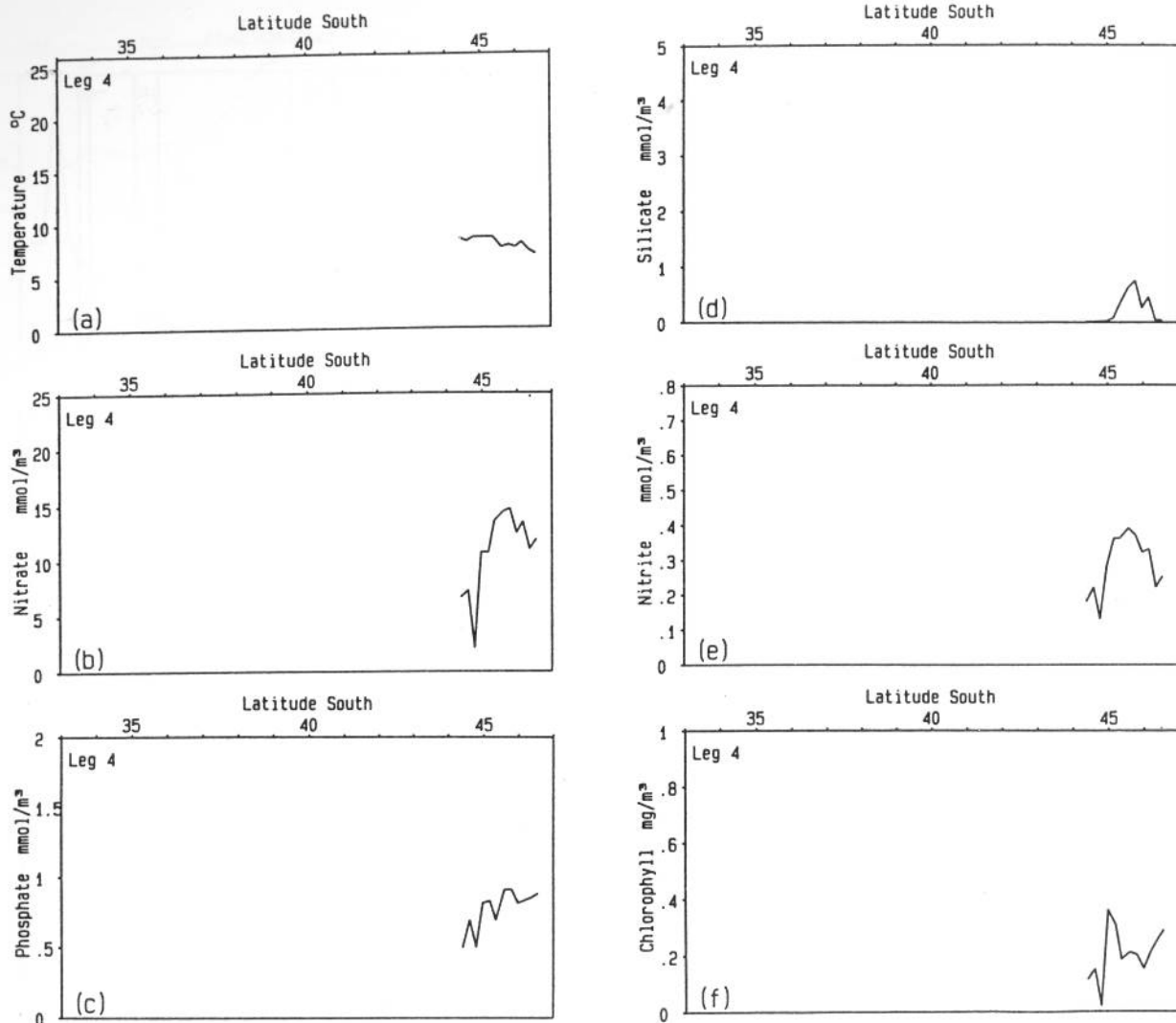


Fig. 4. Data for Leg 4. As for Figure 2.

Whitworth & Nowlin (1987) note that the temperature minimum associated with sinking Antarctic Intermediate Water in the Polar Front Zone south of the SAF descends rapidly at the front. North of the SAF the temperature minimum, below about 1 000 m, is weak or absent and the Antarctic Intermediate Water is characterized by a sub-surface salinity minimum at about 500 to 600 m, descending rapidly from the surface at the SAF.

Work done at the Prince Edward Islands shortly after completion of this leg showed that no salinity minimum was present in the water column although one did develop later, between 300 and 400 m depth. This is further evidence that the SAF was north of the latitude of the Prince Edward Islands on Leg 1.

On Leg 3 (Fig. 3), returning to the Prince Edward Islands from Port Elizabeth, it is more difficult to identify the fronts from the temperature trace.

Examining first the nitrate and phosphate records, (Fig. 3b, c) a large increase in both nutrient concentrations is noted between 42°25' and 43°59'S ($\Delta [\text{NO}_3] = 16,2 \text{ mmol.m}^{-3}$; $\Delta [\text{PO}_4] = 0,91 \text{ mmol.m}^{-3}$). Another, smaller, nutrient front can be seen farther south. Thermal fronts are associated with both nutrient concentration changes.

Assigning the SAF to the more southerly front and the STC to the northerly one places the SAF within the latitudinal and thermal zone proposed by LV1984 with a less dramatic nutrient change, contrary to that observed by Whitworth & Nowlin (1987), while the STC is found to be far south of LV1984's preferred position, within their thermal limits but with a far larger nutrient-concentration change than expected.

On the other hand, assigning the SAF to the more northerly

front and attempting to place the STC farther north creates further difficulties. The fronts found to the north are more characteristic of AF features, being of too high a temperature and also too far north of LV1984's reported position, in spite of satisfying Whitworth & Nowlin's conditions.

Thus, in this case, the AF is taken to be at 22,6 to 17,0 °C with a middle temperature of 19,7 °C, between 38°07' and 39°21'S. The STC, between 43°05' and 43°44'S and ranging from 16,0 to 9,2 °C (middle temperature 12,6 °C), is south of LV1984's limits while the SAF lies between 45°00' and 45°18'S; 9,0 to 6,0 °C (middle temperature 7,5 °C).

These findings are summarized in Table 2.

On Leg 4, shown in Figure 4, done from 17 to 18 May 1987, the temperature record shows a steady rise from the islands over the temperature range of the SAF found on Leg 3. These nitrate and phosphate concentrations, while lower overall, show a decrease, suggesting that the front had moved south, past the islands.

That the front was closer to the Prince Edward Islands on Legs 3 and 4 than on Leg 1 is supported by noting that on CTD casts done while at the islands, a salinity minimum was not evident in the water column on the earlier part of the cruise. Later in the cruise this feature developed between 300 and 400 m depth. The salinity traces from a line of CTD casts done to the north of the islands four days before leaving the islands for Port Elizabeth are shown in Figure 5. These traces show the development of a salinity minimum feature extending northward from Prince Edward Island.

Although it has frequently been observed that increased bio-

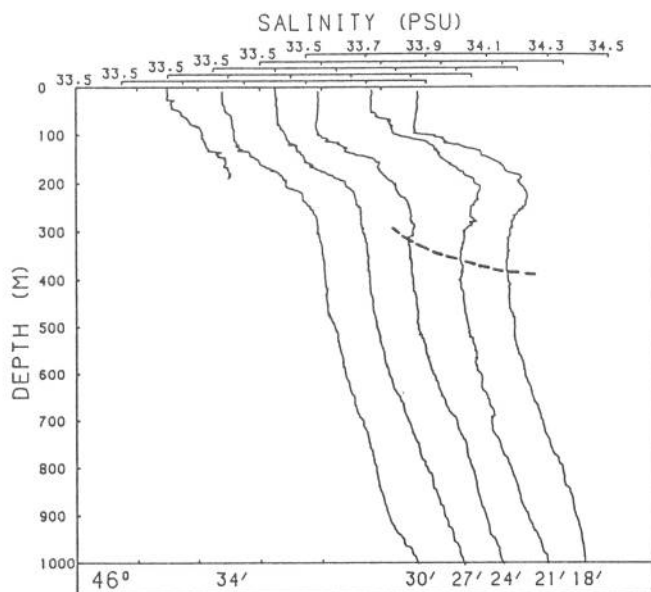


Fig. 5. Salinity traces from a line of CTD casts done extending northwards from Prince Edward Island. The developing salinity minimum is indicated by the broken line. The latitude of the cast is indicated at the base of each trace.

logical activity is a common characteristic associated with marked surface fronts (Pingree *et al.* 1975, Planke 1977, Allanson *et al.* 1981, Lutjeharms & Walters 1985, Lutjeharms *et al.* 1986) there does not appear to be a strong correlation between the identified major fronts and the chlorophyll concentrations on the April/May 1987 cruise. Although increased chlorophyll-a concentrations are noted within the STC and SAF on Leg 1 (Fig. 2f), on Leg 3 (Fig. 3f) major fronts exhibit the lowest chlorophyll concentrations. On the latter leg highest chlorophyll is associated with what appears to be a shed eddy south of the Agulhas Front.

Summary

Three fronts, the Agulhas (AF), Subtropical (STC) and Subantarctic (SAF), were found from surface measurements of temperature and nutrients between southern Africa and the Prince Edward Islands during April and May 1987. In the absence of sub-surface measurements it is not possible to identify precisely the positions of these fronts. However, with a knowledge of the historical surface expressions of these fronts determined when sub-surface measurements were available, it is possible to arrive at an estimate of the probable position of the fronts.

It appears from the available evidence that the Subantarctic Front, found initially north of its historical position, moved southwards from its first identified position through the latitude of the Prince Edward Islands and may thus have had a profound influence on the state of the water column, and thus the biological activity, at the islands during the cruise.

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