Monitoring the oceanic flow between Africa and Antarctica: Report of the first GoodHope cruise

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THE SOUTHERN OCEAN PLAYS A MAJOR role in the global oceanic circulation, as a component of the Meridional Overturning Circulation, and it is postulated that it has a great influence on present-day climate. However, our understanding of its complex three-dimensional dynamics and of the impact of its variability on the climate system is rudimentary. The newly constituted, international GoodHope research venture aims to address this knowledge gap by establishing a programme of regular observations across the Southern Ocean between the African and Antarctic continents. The objectives of this programme are fivefold: (1) to improve understanding of Indo-Atlantic inter-ocean exchanges and their impact on the global thermohaline circulation and thus on global climate change; (2) to understand in more detail the influence these exchanges have on the climate variability of the southern African subcontinent; (3) to monitor the variability of the main Southern Ocean frontal systems associated with the Antarctic Circumpolar Current; (4) to study air–sea exchanges and their role on the global heat budget, with particular emphasis on the intense exchanges occurring within the Agulhas Retroflection region south of South Africa, and (5) to examine the role of major frontal systems as areas of elevated biological activity and as biogeographical barriers to the distribution of plankton. We present here preliminary results on the physical and biological structure of the frontal systems using the first GoodHope transect that was completed during February–March 2004.

Introduction

The global oceanic thermohaline circulation, often referred to as the Meridional Overturning Circulation (MOC), is a vital link in the global transport of mass and heat across the oceans. In the Atlantic, the upper layer of the MOC is responsible for the transport of heat northwards across the equator. The physical structure of this circulation belt and its efficiency in regulating climate is substantially influenced by the nature of water mass exchange between ocean basins.[1–3] The Antarctic Circumpolar Current (ACC) is by far the largest conduit for such exchange. Extending unbroken around Antarctica, it is the primary means by which water, heat and salt are transferred between different ocean basins. As these exchanges play an important role in regulating global climate, sustained hydrographic observations are essential in order to describe and understand better the physical and dynamic processes responsible for the variability of the ACC.[4] The major part of the flow associated with the ACC is concentrated at a number of circumpolar fronts, which act as boundaries separating zones of uniform water masses[5] (Fig. 1). From north to south the fronts and associated zones of the Southern Ocean are: the Subtropical Convergence (STC), the Subantarctic Zone (SAZ), the Subantarctic Front (SAF), the Polar Frontal Zone (PFZ), the Antarctic Polar Front (APF), the Antarctic Zone (AAZ) and the Antarctic Divergence (AAD).

South of Africa, the Southern Ocean plays a unique role in providing a source for the equatorward flux of heat into the South Atlantic. However, it has been suggested[3,6] that water mass differences between the South Indian and Atlantic ocean basins would be far more prominent were it not for various smaller inter-ocean links. South of Africa, water masses originating in the Indian Ocean are injected into the South Atlantic both by anticyclonic ring shedding processes at the Agulhas Retroflection region[7] and by filaments of Agulhas Current water[8] (Fig. 2). Recent modelling studies on the global ocean circulation suggest that Indo-Atlantic inter-ocean exchanges through the Agulhas Current system are far more important for the thermohaline circulation than the direct input of water from the Drake Passage.[3,6] Estimates of the percentage of mode and intermediate waters entering the Atlantic via the Agulhas region is highly variable, ranging from 0%[1] to 50%.[9] In order to understand the role of this key component of the MOC on the global ocean circulation and its possible influence on climate, therefore, it is critical that the inflow of Indian Ocean water into the Atlantic be properly quantified and monitored.

The aim of the GoodHope programme is to establish an intensive monitoring platform that will provide detailed information on the physical structure and volume flux of waters south of South Africa, where the inter-basin exchanges occur. A key component of this programme is the implementation of the high-density, expendable bathythermograph (XBT) line AX25 that runs from Cape Town to Antarctica. The perceived advantages of the GoodHope programme are fourfold:

(1) It runs approximately along the TOPEX/POSEIDON–JASON 1 altimeter ground-tracks and will serve for ground-truthing altimetry-derived sea-height anomaly data.

(2) The southern fraction of this line (south of 50°S) is currently monitored by a mooring array, aimed at investigating the formation of deep and bottom water in the Weddell Sea, deployed during the WECCON project by the Alfred Wegener Institute for Polar and Marine Research.

(3) The northern section of the GoodHope line also overlaps the region being studied by the USA–ASTTEX programme, enabling observations in the Southern Ocean to be linked with data collected within the Benguela region and the west coast of southern Africa. ASTTEX examines the fluxes of heat, salt and volume entering the South Atlantic Ocean via the Agulhas Retroflection region, thereby providing a quantitative, Eulerian measurement of the strength and characteristic scales of the volume and mass transport of the Agulhas Current into the South Atlantic. It has been estimated that up to half of the Agulhas–South Atlantic exchange is contained in mesoscale rings and eddies[10] and that the strength of the mesoscale fluxes could potentially have a large temporal variability. Results from altimetry observations have shown that Agulhas rings are shed intermittently, with periods of several months when there is no ring formation. However, this remains to be confirmed by a single, consistent set of *in situ* and hydrographic observations.[10] GoodHope will provide additional support in determining the nature and scale of the injection of Indian Ocean water into the southeastern South Atlantic via the Agulhas Retroflection region.

(4) GoodHope will support and contribute to the data collected by two pressure

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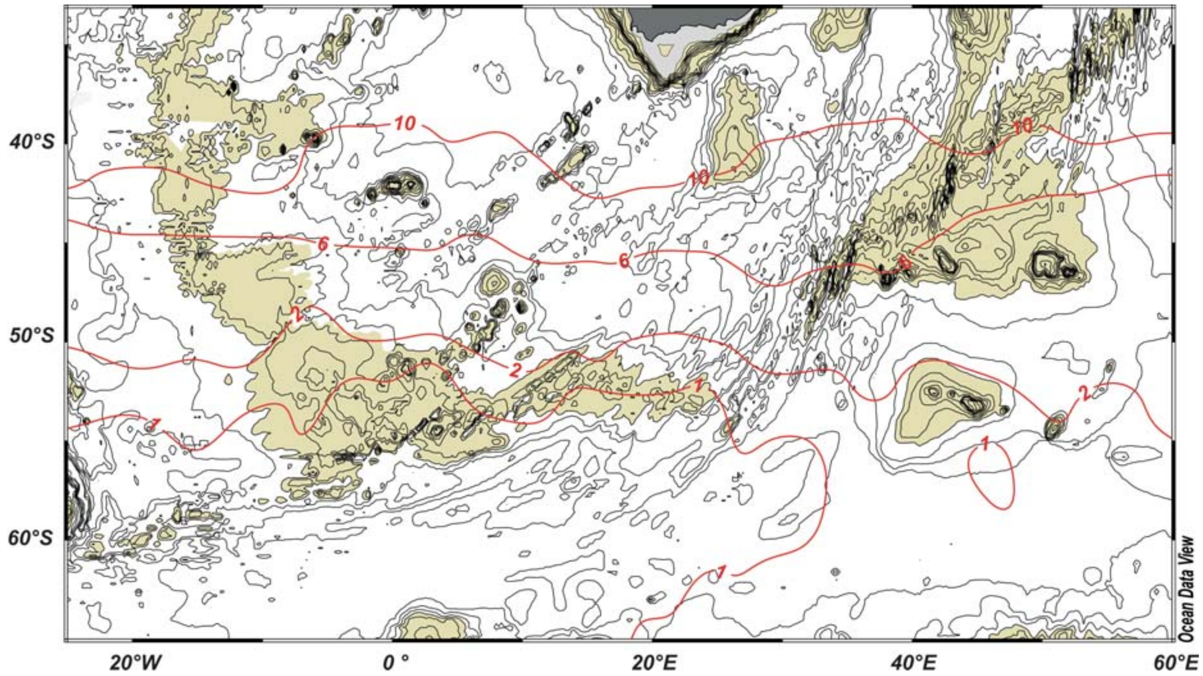

Fig. 1. Schematic diagram showing the average position of the subsurface temperature expressions of the Subtropical Convergence (10°C), the Subantarctic Front (6°C) and the Antarctic Polar Front (2°C) south of South Africa. The Southern Antarctic Circumpolar Front is represented by the 1°C isotherm and is found lying below the $T_{\min}$ contour. Bathymetry shallower than 3000 m is shaded.

inverted echo sounders (PIES) already deployed along the XBT line.

Sustained observations, such as repeat transects along the AX25 line, will provide the only means to monitor the vertical structure and to investigate the variability of the fronts in this region. The GoodHope programme will investigate year-to-year and longer-period variability in the fluxes, such as those related to the Antarctic Circumpolar Wave. Such intense and periodic monitoring has been under way in the Drake Passage[11] and south of Tasmania[4] since the 1970s. A repeat transect between South Africa and Antarctica, the third Southern Ocean 'choke point', was implemented only last year.

In this article, we describe the frontal structure in the upper ocean as determined from underway surface and XBT measurements during the first Good Hope transect along AX25, relating our findings to total chlorophyll-*a* concentrations as well as to air–sea interaction along this transect.

Data

The first GoodHope transect was conducted onboard the R.V. *SA Agulhas* between 25 February and 6 March 2004. In total, 188 Sippican Deep Blue XBTs were deployed between 33°59′S, 17°50′E and 69°05′S, 04°10′W en route to Georg von

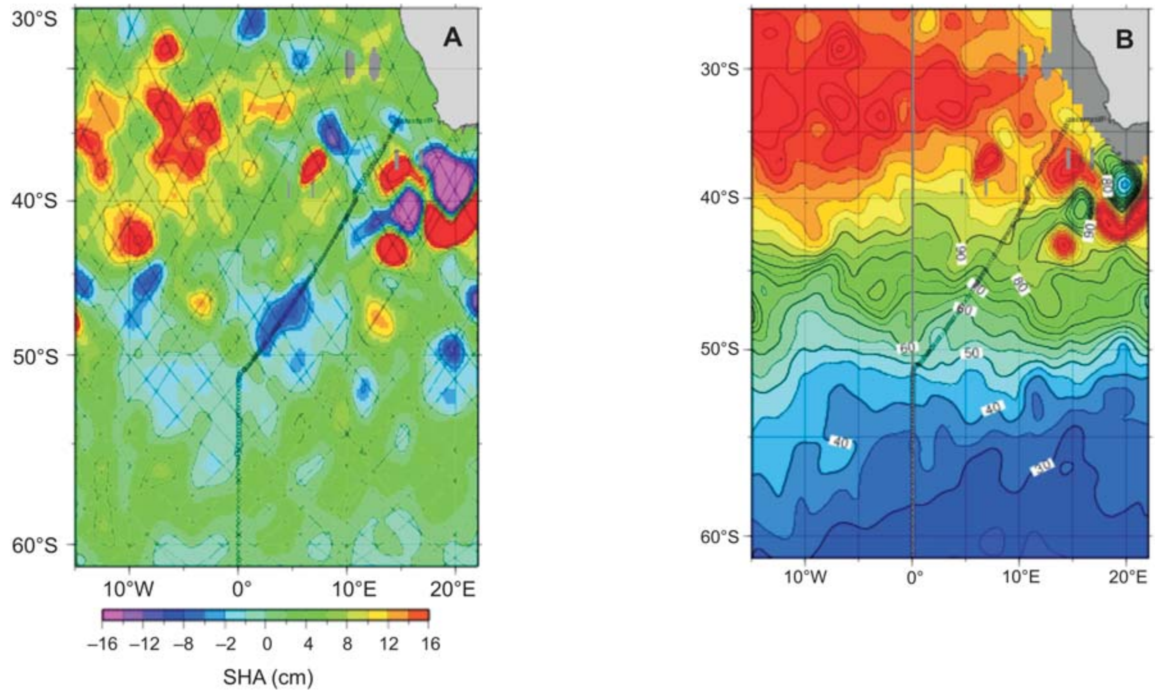

Fig. 2. A, Along-track sea-surface height data (cm) for the GoodHope region, showing the inter-basin leakage of Agulhas anomalies into the SE Atlantic Ocean. The ground paths of the Geosat Follow-On and JASON-1 missions have been superimposed on the diagram. **B**, Dynamic height (cm) of the SE Atlantic Ocean at the time of the first GoodHope transect, whose track is shown on both images.

Neumayer station, the German base in Antarctica. The XBTs were deployed at intervals of 90 minutes (~15 nautical miles), increasing to every 60 minutes (~10 n.mi.) over the main frontal regions associated with the ACC (Fig. 3). Prior to their deployment, each probe was placed in a water bath in order to minimize the difference between the storage temperature of the probe and expected sea-surface temperature (SST). In all, 20 XBTs (11%) failed, mainly as a result of strong winds and sea swell that blew the running signal wire against the hull of the ship, resulting in the XBTs' wire stretching and, thus, damaging the insulation. Surface temperature and salinity data were recorded continuously by the shipboard thermosalinograph. These data were averaged into 20-min intervals in order to reduce noise levels but to retain adequate information to identify the main frontal characteristics. The clear differentiation of surface fronts based on precise temperature and salinity definitions is difficult because of the variable nature of surface waters and the influence of precipitation, especially at mid-latitudes.[12] We use here the surface definitions given by Belkin and Gordon[13] (Table 1) as a guide to distinguishing the surface expression of the main fronts.

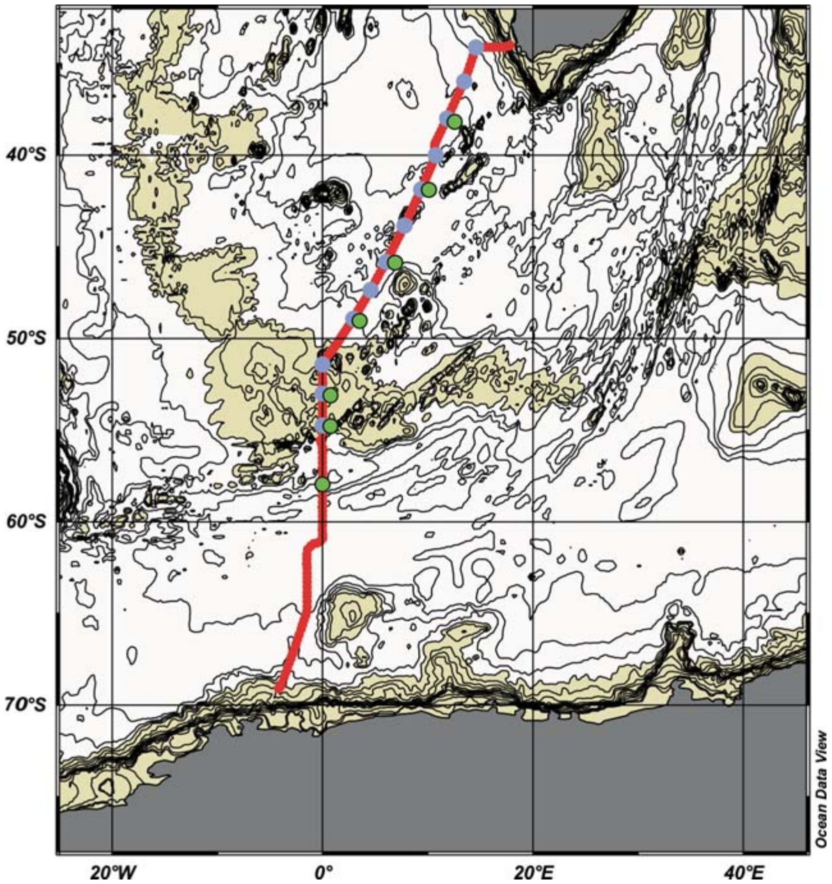

Fig. 3. The track of GoodHope I, which was occupied between February and March 2004. Blue dots represent the deployment of each PROVOR float, green dots represent SVP drifter deployments, and red dots mark XBT deployments and all underway chlorophyll-*a* stations. Bathymetry shallower than 3000 m is shaded.

In the remote regions of the Southern Ocean, the monitoring of changes in upper ocean temperature and salinity profiles is only possible using drifting platforms because of the lack of merchant ships to take measurements. Floats equipped with temperature and salinity sensors provide a cost-effective means of monitoring such regions. Along the first transect, 12 PROVOR CTF2/CTS2 floats were deployed at selected intervals (Fig. 3). Each float descended to a 'parking depth' of 1900 m before profiling the upper 2000 m, a cycle that was repeated every 10 days. In addition to these floats, 7 SVP surface drifters were deployed at predetermined locations along the Good Hope transect (Fig. 3). These surface drifters were drogued at a depth of 18 m and were able to measure surface temperature, velocity and geographic position, which were relayed to ARGOS ground stations. SVP drifters are designed to have a drag: area ratio of ~40 (i.e. the ratio of the drag area of the drogue to that of the tether and surface float), which yields a wind slippage of <1 cm s^{-1}.[14] Satellite-tracked drifters have become invaluable tools for studying ocean circulation and provide mixed-layer velocity and temperature observations over 5-year periods in all major ocean basins. Data can be obtained from the Drifting Buoy Data Assembly Center at http://www.aoml.noaa.gov/phod/dac/ for the SVP drifters and at http://www.ifremer.fr/coriolis/ for the PROVOR profiling floats.

Altimetric fields

The large variability in the upper ocean dynamics in the region makes the use of sea-height anomaly fields derived from satellite altimetry observations a very valuable tool. These fields respond mainly to changes in the steric, salinity, baroclinic, and barotropic components of the upper ocean. Blended along-track data from the Geosat Follow-On and JASON-1 altimetric missions are used here to construct gridded fields using a Gaussian interpolation radius of 0.5 degrees. The field corresponding to the period 25 February–5 March 2004 is used in this work together with other observations. Current jets associated with the APF and SAF have been identified in the ACC using Geosat altimetry observations.[15] We use sea-height anomaly fields along the cruise track to investigate the surface height signals associated with the jets and fronts of the currents during the first transect (GoodHope I). We expect that future transects will help to develop techniques to allow altimetry to refine the monitoring of these fronts and currents.

Biological observations

Primary production in the sun-lit upper water layer contributes to the biogeochemical fluxes in the ocean, is able to modify the ocean–atmosphere exchange of gases, and provides food supply for the upper trophic levels.[16] Whereas production is potentially high in the Southern Ocean owing to the abundance of nutrients, observed rates of primary productivity and the concentrations of phytoplankton biomass are low. Possible reasons to explain this include insufficient light for plankton growth, lack of trace nutrients such as dissolved iron,[17]

Table 1. Definition of the fronts, in terms of temperature and salinity, bordering the Antarctic Circumpolar Current.

Front	Surface range	Subsurface (200 m) range
STC	10.6–17.9°C: 34.3–35.5	8.0–11.3°C: 34.42–35.18 Axial value: 10°C, 34.8
SAF	6.8–10.3°C: 33.88–34.36	4.8–8.4°C: 34.11–34.47 Axial value: 6°C, 34.3
APF	2.5–4.1°C	Axial value: 2°C

and zooplankton grazing.[18] In contrast, increased phytoplankton biomass occurs at the main frontal bands of the ACC, notably at the APF.[19] Maximum chlorophyll concentrations appear to correlate with mesoscale frontal dynamics, in particular cross-frontal exchange as a result of baroclinic instability in these regions.

The role of frontal systems as regions of increased biological activity and as biogeographic barriers to the distribution of the plankton (mainly phytoplankton and mesozooplankton) in the Southern Ocean is now well established.[20,21] The elevated biological activity in the region of fronts is attributed largely to localized enhanced phytoplankton production rates due to increased water column stability and macronutrient availability.[22,23] Owing to the increase in food availability, frontal systems are generally characterized as areas of elevated secondary and tertiary production. Studies conducted in various sectors of the Southern Ocean suggest that there is marked spatial and temporal variability in the importance of the main frontal systems as biogeographic barriers to the distribution of plankton and as areas of enhanced biological activity. The variability in the role of the frontal systems as biogeographic barriers is thought to be attributed to mesoscale variability in the physical environment including meanders in fronts, the formation of eddies and cross-frontal mixing.[24] These processes facilitate the transfer of plankton across the fronts. The absence of biological enhancement in the frontal waters is generally believed to reflect the temporal variability in the stability of the water column. Shifts in the intensity and geographical position of major frontal systems as a result of global climate change are thus likely to coincide with alterations in the distribution of species and productivity in the Southern Ocean.

In total, 188 surface chlorophyll-*a* and 75 phytoplankton stations were occupied in conjunction with each XBT deployment (Fig. 3). Total chlorophyll-a concentration at each station was determined by gently filtering (vacuum <5 cm Hg) a 250-ml surface water sample obtained from the ship's scientific seawater supply through a GF/F filter. The filter was then extracted in 90% acetone for 24 h in the dark at –20°C. Chlorophyll-*a* concentration was then determined fluorometrically. The phytoplankton community structure at each station was determined from a 200-ml water sample obtained from the scientific seawater supply and preserved in a 2% buffered formalin and Lugols solution.

Meteorological observations

The Southern Ocean is powerfully affected by cyclones in the region between South Africa and Antarctica.[25,26] These mid-latitude cyclones (MCs) sweeping over the Southern Ocean from west to east are frequently associated with strong surface winds and rough seas that develop as a result of negative air–sea fluxes of momentum (wind stress). MCs over the Southern Ocean differ from those in the northern hemisphere, where the mid-latitudes (approximately 50–70°N) are mostly covered by land. Southern Ocean MCs mostly develop and propagate in a marine environment that encircles the entire Antarctic continent. These systems are exposed to strong meridional oceanic and atmospheric temperature gradients that contribute to their strength.[27] The impact of sea–air fluxes on MCs is not yet well understood. Positive surface heat fluxes might either strengthen MCs by encouraging convective activities, or weaken them by reducing temperatures in the cold air sector behind the cold front. The latter might affect the propagation velocity of MCs. In addition, cyclonic rotation in MCs might be slowed down by negative fluxes of momentum, and positive fluxes of mass (water vapour) might alter thermodynamic properties, cloud bands and rainfall in MCs.[28]

Higher-level wind, air temperature and relative humidity measurements were made continuously during the transect. These conditions were recorded by instruments located on the main crane on the bow of the *SA Agulhas* at an altitude of approximately 17 m above sea level. Data were collected at 10-min intervals. Corrections to take account of ship speed and direction were made to obtain true wind vectors. In addition, incoming short-wave and long-wave solar radiation was recorded at one-minute intervals using an Eppley pyranometer and a pyrgeometer, which were also installed on the ship's crane. Data were written to two Campbell Scientific CR10X data loggers, and downloaded daily. The purpose of these measurements was to investigate surface properties of MCs and to determine the magnitude of sea–air fluxes[29] along the cruise line between Cape Town and the Georg von Neumayer research station (Fig. 3). Recorded surface pressure and wind speed values as measured in 10-min intervals from 26 February to 8 March (days 1 to 12) along the first GoodHope transect are depicted in Fig. 4. Note how periods associated with relatively low pressure, presumably MCs, are associated with stronger winds and rough seas and therefore larger negative fluxes of momentum towards the ocean. The deep trough in near-surface pressure (<970 hPa) experienced on day 9 of the cruise (Fig. 4), accompanied by the strongest wind gusts measured during the period (>20 m s^{-1}), is of particular interest. Much lighter winds are associated with higher pressures. Fluxes of momentum might even alter the horizontal propagation of ocean-surface temperatures, emphasizing the importance of energy and mass exchange between atmospheric weather systems and the underlying ocean surface.

Frontal locations

The Southern Ocean is characterized by the strong zonal nature of its main frontal bands, and its spatial structure is strongly determined by the position and flow regime of a number of frontal system separating different ACC zones.[13] Extensive measurements have been made in the South Atlantic and South Indian sectors of the Southern Ocean over the past three decades.[30–33] Full-depth CTD measurements have been made during AJAX,[34] SR2 WOCE and opportunistically en route to the ice edge. Unlike other regions of the Southern Ocean where frontal systems display high bands of variability with enhanced eddy activity such as at the Drake Passage and South Georgia,[35] at the South-West Indian Ridge[36–38] and south of Australia,[4,39] the frontal characteristics in the region of the Greenwich Meridian line are less intense and variable, as can be inferred from altimetry and from historical hydrographic data.[40]

Identification of the main ACC fronts is essential in order to trace the upper-level circulation associated with the baroclinic shear. However, accurate identification of the fronts is not always simple, especially in regions where they remain merged. One difficulty is the various definitions that have been given to characterize the fronts bordering the Antarctic Circumpolar Current. Depending on the sources, these definitions are based on either surface or subsurface properties, whereas others have used phenomenological definitions.[38] Definitions for both surface and subsurface features are given in Table 1. However, in order to locate the fronts with confidence before describing their properties as observed along the Good Hope I transect, each one will be defined using its representative subsurface axial values at 200 m, where generally each front is most distinctive. The definitions used here are taken from Belkin and Gordon.[13]

Subtropical Convergence

The Subtropical Convergence marks the boundary between warm, salty subtropical surface water and cooler, fresher

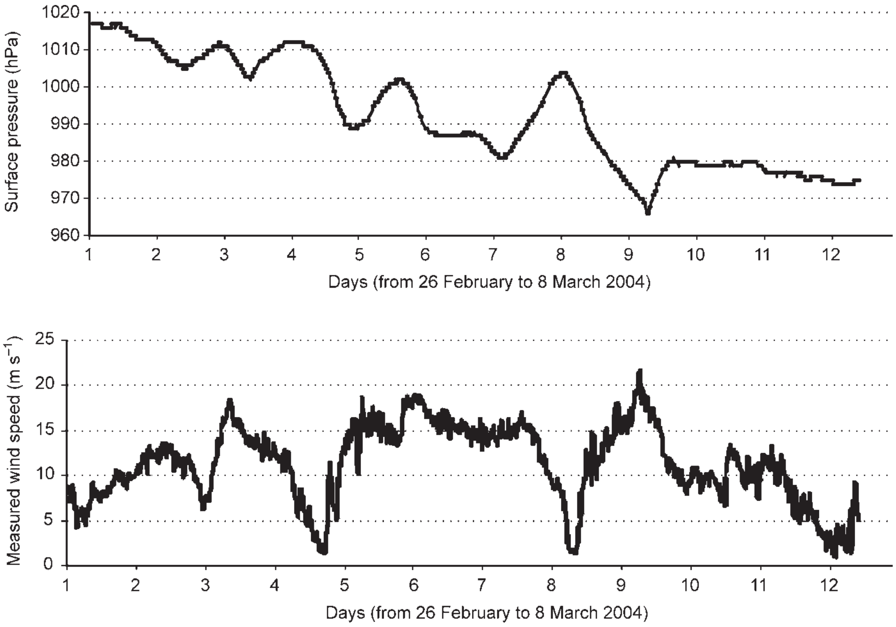

Fig. 4. Surface pressure (top) and wind speed (bottom) as measured in 10-min intervals from 26 February to 8 March 2004 (days 1 to 12) along the first GoodHope transect. Lower pressures (presumably associated with mid-latitude cyclones, or MCs) are associated with stronger winds and therefore larger negative fluxes of momentum are recorded due to poor sea conditions.

Subantarctic Surface Water to the south. It is the most northerly front associated with the ACC (Fig. 1) and the most prominent surface thermal front. XBT data collected from over 70 crossings of the STC have shown that in the South Atlantic the STC's mean position lies at 41°40′S.[33] The surface expression of the STC during GoodHope I was found between 39°39′ and 40°54′S and the subsurface core, identified by the 10°C isotherm at 200 m, at 40°42′S (Fig. 5). Previous studies in the South-east Atlantic sector of the Southern Ocean[41] identified two separate fronts associated with the northern and southern boundaries (NSTC and SSTC, respectively) of the STC. These observations have been made from over 10 datasets extending across the South Atlantic from the Brazil Current at 42°W to the Agulhas-Benguela region at 11°E. Surface temperature and salinity definitions given by Belkin and Gordon[13] cover the range 14.0–16.9°C, 34.87–35.58 for the NSTC and 10.3–15.1°C, 34.30–35.18 for the SSTC. The thermosalinograph data collected during GoodHope I (Fig. 6) revealed two distinct surface frontal features between 39°49′S and 40°06′S and between 40°20′S and 41°15′S, where surface temperatures dropped from 18.83°C to 15.16°C (and salinity from 35.49 to 34.02) and from 16.13°C to 11.13°C (and from 34.665 to 34.045), respectively. This provided further support for the belief that in the SE Atlantic the STC may exist as two separate bands.[13]

Subantarctic Front

The Subantarctic Front marks the northern boundary of the Polar Frontal Zone, which is a transitional zone between the SASW and AASW. Compared to the STC, which is clearly characterized by a sharp and consistent gradient in both surface and subsurface expressions, making identification extremely easy,[32–33] the SAF is less clear in its surface manifestation. The exact boundaries of the PFZ can therefore be difficult to identify due to the weak nature of this front. The SAF is predominantly a subsurface feature and can be defined by the most vertically orientated isotherm within a temperature gradient lying between 3°C and 5°C, while its surface expression extends between 8°C and 4°C.[33] Lutjeharms and Valentine[32] have identified the SAF as having a mean position of 46°23′S south of Africa. Using the criteria described by Belkin and Gordon,[13] in which the subsurface temperature and salinity range between 4.8–8.4°C and 34.11–34.47 at 200 m, with axial values of 6°C and 34.3, we observed the subsurface axis of the SAF at 44°07′S during GoodHope I transect (Fig. 5). Thermosalinograph data place the surface expression of the SAF between 44°05′S and 49°16′S (8.51–4.24°C, 34.031–33.618) (Fig. 6). This appears to be considerably wider than in other studies in this region of the Southern Ocean.[13] However, recent investigations[41] have shown that, in the South Atlantic, the SAF is often found as a broad frontal band extending over 250 km (45°54′–48°42′S). Closer examination of the SST and in particular the sea-surface salinity (SSS) data reveal a number of narrow reversals between 44°43′S (33.854–33.7) and 46°38′S (33.666–33.598) (Fig. 6). This observation is in agreement with Holliday and Read,[12] who identified a number of surface steps related to both temperature and salinity inversions. The cause of these inversions is not known; however, Lutjeharms and Valentine[32] and Wexler[42] have ascribed these inversions to either wind-induced upwelling or to the poleward shedding of eddies.

Antarctic Polar Front

The APF marks the northern limit of the Antarctic zone; the subsurface expression of the APF is historically identified by the northern limit of the 2°C temperature minimum at a depth of 200 m.[5,13] In some instances this is not coincident with the surface expression of the APF[32] and instead the surface expression can be

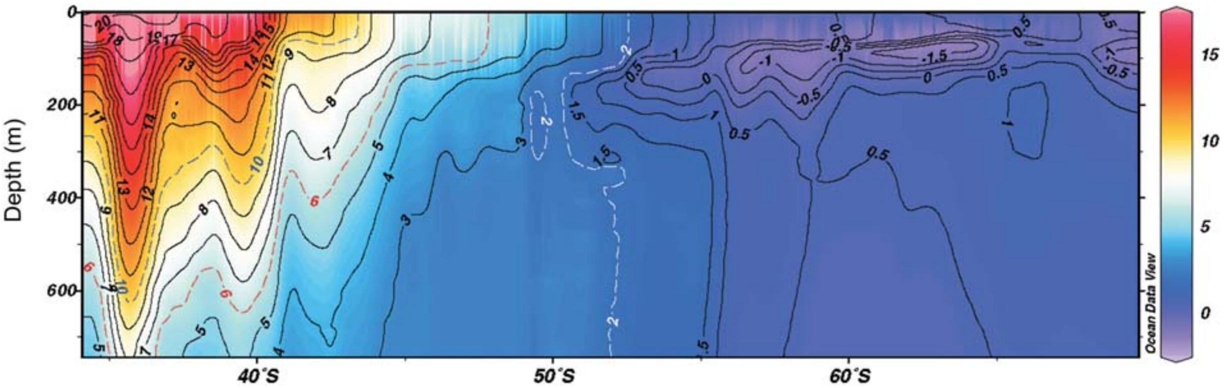

Fig. 5. Temperature section from XBT data along the first GoodHope transect. The dashed isotherms represent the subsurface axis of the STC (blue – 10°C), SAF (red – 6°C) and APF (white – 2°C). Scale in °C.

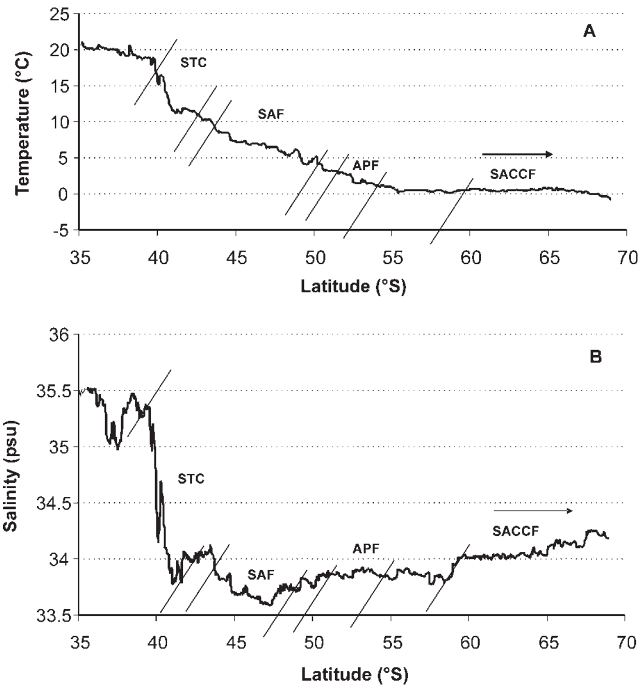

Fig. 6. Thermosalinograph of (**A**) sea-surface temperature and (**B**) sea-surface salinity data collected at 20-min intervals during the first GoodHope transect.

identified by the maximum temperature gradient between 6°C and 2°C. The APF is characterized by a shallow temperature minimum associated with the remnants of Winter Water, which lies at depths between 50 m and 150 m. It is seasonally variable; in winter it is nearly homogeneous, extending to 250 m, while in summer the mixed layer extends only to between 50 m and 100 m. Temperatures for this water mass range from –1.8°C to 6°C at the APF and salinity from 33.4 to 34.2. During GoodHope I, the subsurface expression of the APF was found to lie at 50°22′S (Fig. 5). The surface expression, identified from the thermosalinograph, lay between 50°14′S and 52°51′S (4.7–1.46°C, 33.796–33.894) (Fig. 6).

Southern Antarctic Circumpolar Front

Orsi *et al.*[43] have identified an additional ACC front, which they termed the Southern ACC Front (SACCF) and described as a circumpolar, deep-reaching front lying south of the APF. The position of this feature corresponds to that of the low-pressure Antarctic atmospheric trough, which separates the easterly and westerly wind belts at ~65°S. In contrast to the other fronts associated with the ACC, the SACCF does not separate distinct surface water masses; instead, it is defined by the temperature and salinity characteristics of the Upper Circumpolar Deep Water (UCDW).[12] Two branches of the SACCF, marked by a high salinity gradient from 33.80–33.63 at 63.4°S to 33.78–33.09 at 64.7°S in the range 0.9–0.7°C, were observed by Holliday and Read[12] in the SE Atlantic from their R.R.S. *Discovery* dataset. South of Australia,[4] the SACCF has been identified by the location of the 0°C isotherm along the $T_{\min}$ isotherm, which places the front at a mean position of 63°48′S. Increase in air temperatures between December and February results in the warming of the surface mixed layer and the northern extent of the $T_{\min}$ cooler than 0°C, forming a reliable indicator of the position of the SACCF.[43] This definition places the SACCF during GoodHope I between 53°S and 55°44′S (Fig. 5). In this region the $T_{\min}$ formed by the presence of the remnants of Winter Water averaged 80 m in thickness and centred at 150 m.

Total chlorophyll-*a* (chl-*a*) concentration during the cruise ranged from 0.07 to 2.81 mg m^{-3}. Peaks in total chl-*a* concentration were recorded in the continental shelf water south of Africa (>2.8 mg m^{-3}), at stations occupied in the vicinity of the major oceanic frontal systems and in the neritic waters of Antarctica (Fig. 7). The highest concentration in chl-*a* in the Southern Ocean (>0.75 mg m^{-3}) was observed between stations 106 and 109 at 50°54′S and 51°22′S and are associated with the APF. In addition, a further peak in total chl-*a* concentration (0.7 mg m^{-3}) was located at stations occupied in the region of 58°S (Station 140). Similar patterns in total chl-*a* concentrations have been observed in the South Atlantic[16] and appear to be associated with melt-water lenses left behind by the retreating ice edge. At these stations total chl-*a* concentration always exceeded 0.5 mg m^{-3}. At stations occupied within the inter-frontal regions total chl-*a* concentrations were in the range 0.07–0.35 mg m^{-3}. Data on the phytoplankton community structure along the transect are currently being analysed.

Conclusion

The Antarctic Circumpolar Current forms an important link in the global thermohaline overturning circulation. Modifications in the saline characteristic of water masses associated with the ACC play a vital role in maintaining both global heat and salt budgets.

Determining the transport flux of the ACC south of South Africa has been an observational goal for many years. Such observations have been conducted during the World Ocean Circulation Experiment (WOCE) during the 1990s, in which repeat transects across the ACC were restricted to three choke points. Intense and periodic monitoring of the Drake Passage and south of Tasmania have continued since WOCE; however, a regular monitoring line between South Africa and Antarctica was begun only last year.

Our understanding of how and why this transport varies with time and season remains incomplete due to a lack of observations. The sources, pathways and characteristics of these exchanges are not well enough established to allow their influence on the climate system south of South Africa to be quantified. The aim of GoodHope is to establish an intensive monitoring line that will provide new information on the volume flux of the region south of South Africa, in particular on the Indo-Atlantic exchange. An investigation to study the empirical relationship between upper ocean temperature and the baroclinic transport stream from repeat hydrographic sections across the ACC, south of South Africa is currently under way. Application of this relationship to all past and future observations will be necessary to monitor the variations and variability of the ACC south of South Africa. By further defining a second empirical relationship between surface dynamic height and cumulative transport (following Rintoul *et al.*[44]), it will be possible in future to extrapolate the ACC behaviour, in particular its seasonality and inter-annual variability, using satellite altimetry.

This is the start of a new and exciting multinational and inter-disciplinary endeavour aimed at integrating high-resolution physical, biological and atmospheric observations with along-track satellite and model data. Since the start of the GoodHope project in early 2004, a second line consisting of high-resolution CTD stations onboard the Russian research vessel *Academik Sergey Vavilov* has been completed. It is hoped that an outcome of

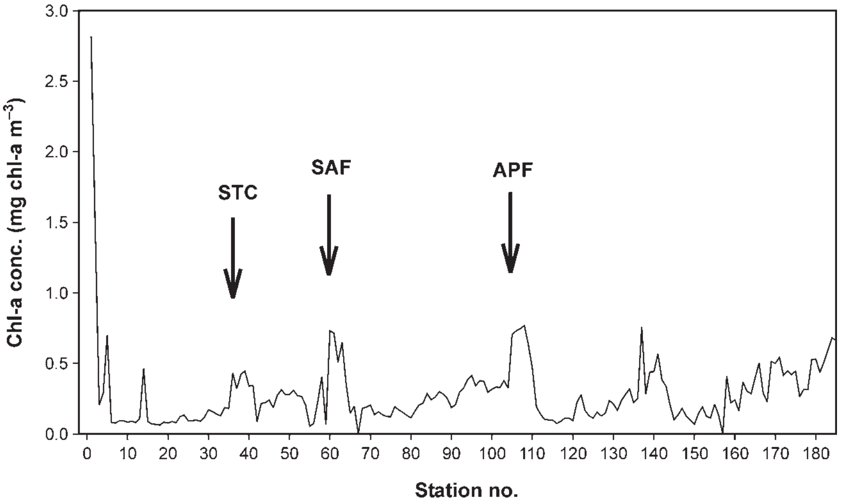

Fig. 7. Total chlorophyll-*a* concentration along the first GoodHope transect. The position of the main frontal systems was determined from the XBT data.

the GoodHope project will be improved understanding of the Indo-Atlantic inter-ocean exchanges in this region of the Southern Ocean and its impact on both regional and global climate change.

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