Physical and biological processes at the Subtropical Convergence in the South-west Indian Ocean

P.W. Froneman[a*], I.J. Ansorge[b], N. Richoux[a], J. Blake[a], R. Daly[a], J. Sterley[a], B. Mostert[a], E. Heyns[a], J. Sheppard[a], B. Kuyper[b], N. Hart[b], C. George[b], J. Howard[b], E. Mustafa[b], F. Pey[b] and J.R.E. Lutjeharms[b]

A detailed hydrographic and biological survey was conducted in the region of the Subtropical Convergence in the Indian sector of the Southern Ocean in April 2007. Hydrographic data revealed that the subsurface expression of the Subtropical Convergence (at 200 m), marked by the 10°C isotherm, appeared to meander considerably between 41°S and 42°15′S. Total surface chlorophyll-*a* concentration was low and ranged from 0.03 to 0.42 μg l^{-1} and was always dominated by the pico- (<2 μm) and nano- (2–120 μm) size classes, which contributed between 81% and 93% of the total pigment. The total chlorophyll-*a* integrated over the top 150 m of the water column showed no distinct spatial trends, and ranged from 12.8 to 40.1 mg chl-*a* m^{-2}. There were no significant correlations between the total integrated chlorophyll-*a* concentration and temperature and salinity ($P > 0.05$). The zooplankton community was dominated, numerically and by biomass, by mesozooplankton comprising mainly copepods of the genera, *Oithona, Paraeuchaeta, Pleuromamma, Calanus* and *Clausocalanus.* An exception was recorded at those stations in the region of the front where the tunicate, *Salpa thompsoni,* dominated the total zooplankton biomass.

Introduction

The Subtropical Convergence (STC) is one of the principal frontal systems in the world ocean. It is not just simply a biogeographical boundary, but forms a unique biological habitat of its own.[1] Although the STC circles most of the globe, geographically its intensity varies considerably.[2] In the South Atlantic, for instance, it is weak[3] and ephemeral,[4] whereas south of Africa between 10–170°E it is enhanced by the juxtaposition of the warm Agulhas Return Current.[5] The horizontal salinity gradient here can exceed 0.06 psu km^{-1} (ref. 5) and the temperature gradient by 0.15°C km^{-1} (ref. 6). Satellite remote sensing indicates that—on average—it is a region of intense mesoscale turbulence, presenting enhanced levels of chlorophyll-*a*[7] and thus a presumed prime region of carbon drawdown from the atmosphere.[8] Such higher levels of chlorophyll-*a* at the Subtropical Convergence have previously been measured directly at sea,[9,10] but only intermittently. More recent investigations at the STC, using both satellite remote sensing as well as modelling data,[11] have demonstrated, however, that primary production at this front occurs as event-scale blooms and not as a persistent enhancement as was suggested previously.[7] In the past, the research effort in the vicinity of the STC has largely concentrated in the region south of Africa. The latitudinal variability in the role of the front within the Southern Ocean ecosystem is thus poorly understood. The aim of the survey reported here was to investigate the spatial and biological behaviour of the Subtropical Convergence within the Indian sector of the Southern Ocean.

Research teams from the University of Cape Town and Rhodes University participated in the annual relief voyage to the Prince Edward Islands (Voyage 135), on board the supply and research vessel *S.A. Agulhas,* from 5 April to 14 May 2007. The cruise consisted of 6 transects between 46° and 138°S, and 38° and 41°45′E. Stations were occupied along meridional transects at 15′ intervals (Fig. 1).

Physical data

A total of 54 CTD (conductivity–temperature–depth) and 66 XBT (expendable bathythermograph) stations were carried out across the STC zone. Sippican T7 XBTs were deployed to a maximum depth of 900 m. At each CTD station, vertical profiles of salinity, temperature and density were obtained with a Seabird SBE 9/11 underwater unit, to a maximum depth of 1500 m at a maximum descent speed of 1.2 m s^{-1}. Water samples were collected during the up-cast on average at 10 standard depths (1500, 1000, 750, 500, 150, 100, 75, 50, and 25 m) and analysed onboard for dissolved oxygen. In addition, nutrient (silicate, phosphate, nitrate and nitrite) samples were collected at each depth and frozen in order to be analysed back on land.

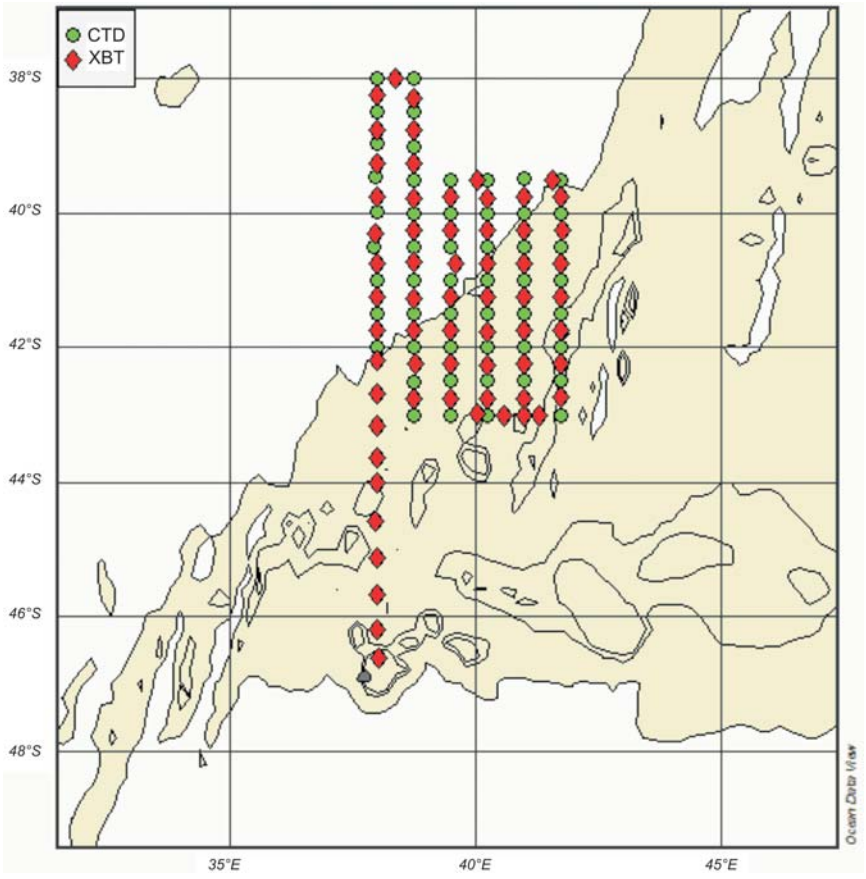

Fig. 1. Cruise plan, showing the distribution of XBT and underway chlorophyll stations (red), and CTD and biological stations (green), occupied during the survey. The shading represents bathymetry shallower than 4000 m.

[a]Southern Ocean Group, Department of Zoology and Entomology, Rhodes University, Grahamstown 6140, South Africa.
[b]Department of Oceanography, University of Cape Town, Private Bag, Rondebosch 7701, South Africa.
*Author for correspondence.
E-mail: w.froneman@ru.ac.za

Biological data

Surface seawater was collected with a Crawford bucket at each station and chlorophyll-*a* (chl-*a*) concentrations were measured for micro- (>20 μm), nano- (2–120 μm) and picophytoplankton (<2 μm). Total chl-*a* concentrations at selected depths (25, 50, 75, 100 and 150 m) within the top 150 m of the water column (collected using the CTD) were measured and integrated to provide an estimate of areal chl-*a* concentrations in the region. The mesozooplankton community structure was determined from samples collected using a Bongo net fitted with a 200-μm mesh size. The net was attached to a Universal Underwater Unit (U^3) to monitor the depth and with a mechanical flow meter to determine the volume filtered during each tow. Tows were conducted to depths of 200 m at night and 300 m during the day, to account for the diel vertical migrations of the zooplankton. All zooplankton collected were bottled and preserved in 6% buffered formalin. The grazing impact of the numerically dominant mesozooplankton at each station was estimated employing the gut fluorescent technique.[12] In all, 53 grazing experiments were conducted during the survey.

Preliminary results and discussion

A single transect between the Prince Edward Islands and 38°S (the start of the survey region – Fig. 1) was undertaken to establish the position of the main frontal bands north of the islands. The SAF was identified at 45°S and the Subtropical Convergence, characterized by a strong frontal surface gradient of 11–18°C, was identified initially at 41°S. The STC was crossed on six occasions during the subsequent survey period. The subsurface expression of the STC (at 200 m), marked by the 10°C isotherm, appeared to meander considerably between 41°S and 42°15′S (Fig. 2). Evidence of the southern boundary of the Agulhas Return Current—the Agulhas Front—was observed along transects 3–6. The frontal boundary associated with the STC was pronounced throughout the entire water column with geostrophic velocities exceeding 58 cm s^{-1}.

Typical upper-layer profiles of temperature and salinity across the frontal system show a strong transition from warm (>20°C), saline (>35.4) water masses typical of subtropical water masses north of the STC, with cool (<13°C), fresh (<34.3) water masses south of the front (Fig. 3). South of the STC, water masses were typically Subantarctic, with a distinct subsurface salinity maximum (~34.5) indicative of the high precipitation of the mid-latitudes. Furthermore, surface oxygen concentrations varied considerably between subtropical (~5 ml l^{-1}) and Subantarctic (>6.75 ml l^{-1}).

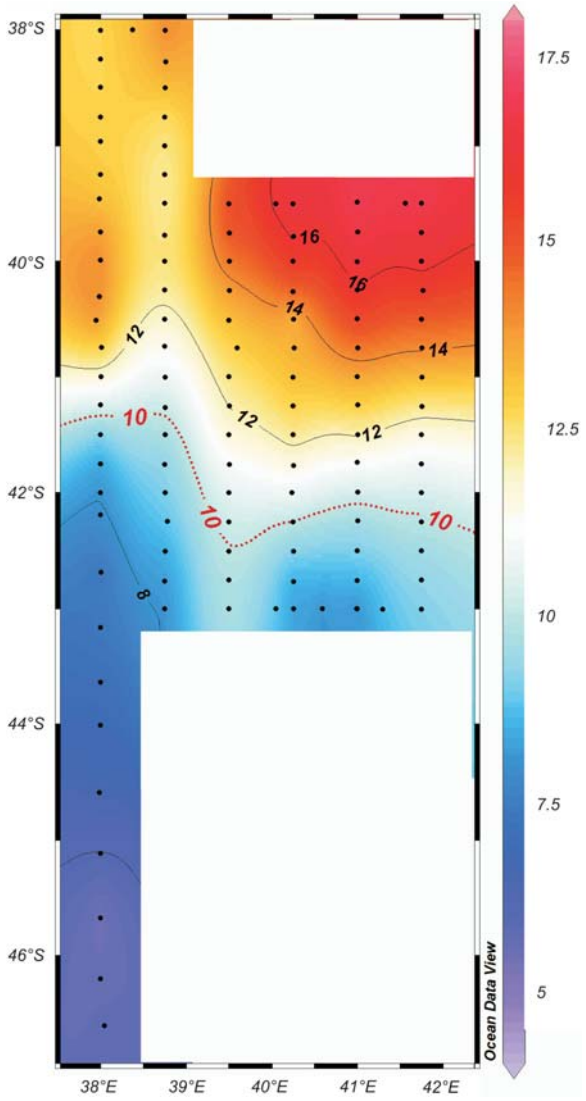

Fig. 2. Surface plots of temperature (°C) at 200 m within the survey area. The subsurface position of the Subtropical Convergence is clearly delineated by the 10°C isotherm.

Total surface chlorophyll-*a* concentration was characteristically low and ranged from 0.03 to 0.42 μg l^{-1} and was always dominated by the pico- and nano-size classes, which contributed between 81% and 93% of the total pigment. Large microphytoplankton (>20 μm), mainly diatoms, contributed <10% of the total pigment at all stations. The total chl-*a* integrated over the top 150 m of the water column showed no distinct spatial trends, and ranged from 12.8 to 40.1 mg chl-*a* m^{-2} (Fig. 4). There were no significant correlations between the total integrated chl-*a* concentration and selected physico-chemical (temperature and salinity) variables ($P > 0.05$; Pearson correlation analyses).

The zooplankton community throughout the survey area was dominated, numerically and by biomass, by mesozooplankton (200–12000 μm), comprising mainly copepods of the genera *Oithona, Paraeuchaeta, Pleuromamma, Calanus* and *Clausocalanus* spp. An exception was recorded at stations occupied in the vicinity of the front, where the tunicate, *Salpa thompsoni,* dominated the total mesozooplankton biomass. Among the larger zooplankton community (>2000 μm), the chaetognaths, *Eukrohnia hamata, Sagitta gazellae* and *S. maxima,* and the amphipods, *Themisto gaudichaudi* and *Primno macropa,* dominated the zooplankton, numerically and by biomass. The contribution of these species to total zooplankton abundances was, however, always <10% at all stations. Grazing data are currently being analysed.

What are the initial conclusions that can be drawn from the observations recorded during this cruise? Sea colour from satellite remote sensing (SeaWiFS) accessed prior to the cruise indicated enhanced chlorophyll-*a* at the STC. There was a storm with strong winds in the region just before the research vessel arrived at the area to be investigated. The subsequent absence of a clear correlation of chlorophyll-*a* density and the STC therefore

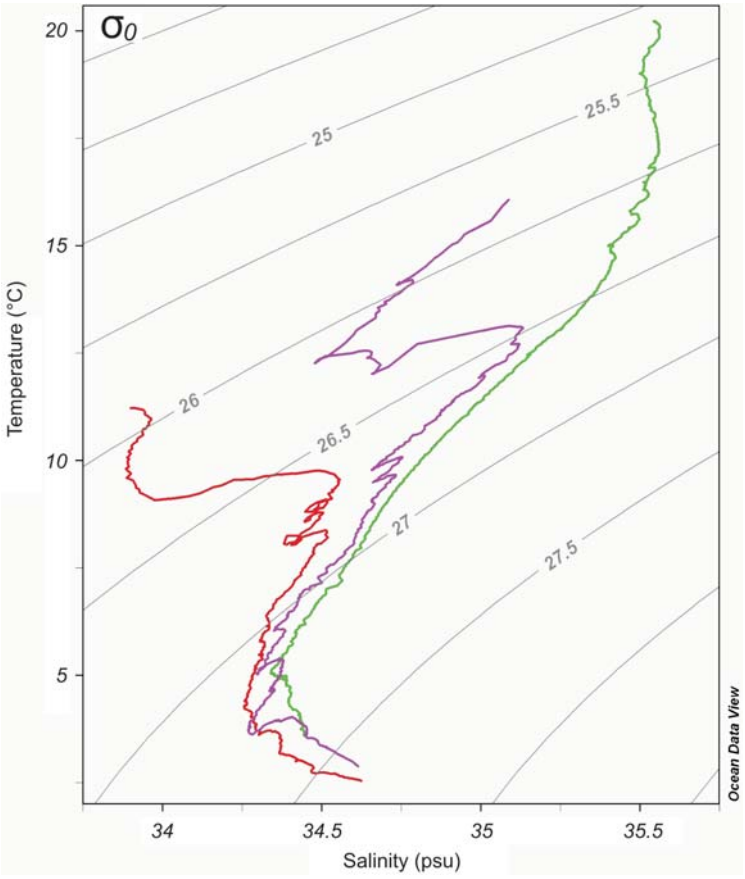

Fig. 3. Temperature/salinity profiles (Transect 1), highlighting the water mass characteristics north (green) and south (red) of the Subtropical Convergence. In addition, a third station (purple) is shown, indicating the complexity of the STC as a region of enhanced water mass mixing.

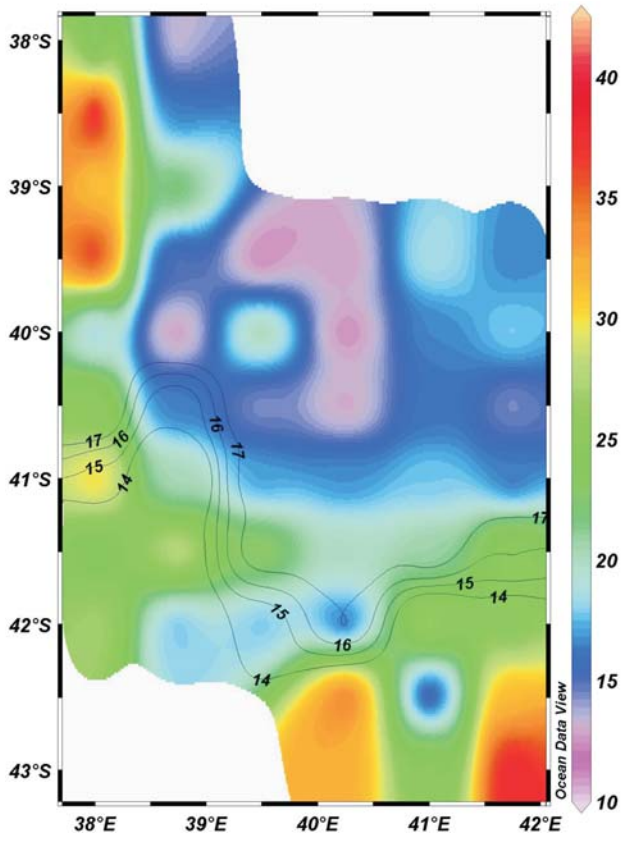

Fig. 4. Integrated chlorophyll-*a* concentrations (mg chl-*a* m ^{2}) in the top 150 m of the water column. Isotherms represent the surface expression of the Subtropical Convergence.

suggests that the type of frontal bloom described by Llido *et al.*[11] that occurs at this front can be sensitive to wind mixing and be rapidly dissipated. The persistence of cloud cover in the area makes a study of this process by satellite remote sensing extremely difficult. The high density of organisms at higher trophic levels—such as tunicates—suggests furthermore that whereas the phytoplankton and smaller zooplankton can be easily dispersed and mixed out, the larger animals may still reflect the preceding state of the bloom. These hypotheses will be addressed in further analyses of this data set and in future cruises forming part of the South African National Antarctic Programme.

The ocean region southeast of Africa lends itself particularly well to a study of the intermittently enhanced productivity of the waters associated with the Subtropical Convergence, and investigation of the processes involved.

We thank the officers and crew of the MV *SA Agulhas* for their invaluable assistance at sea. This research was funded by the Department of Environmental Affairs and Tourism through the South African National Antarctic Programme, administered by the National Research Foundation. We also thank Rhodes University and the University of Cape Town for funds and facilities for this survey.

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