Research cruise of the Scandinavian/South African Antarctic expedition, December 1997 to February 1998

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The role of the Southern Ocean in the global carbon cycle is a leading concern in physical and biological oceanographic studies, largely because of its potential importance as a carbon sink.[1] The multidisciplinary research programme, Joint Global Ocean Flux Study (JGOFS), initiated in 1989, was dedicated to the measurement of the carbon cycle with particular focus on processes leading to CO_2 drawdown from the atmosphere and transfer of biogenic matter via vertical flux to the ocean interior and sediments. This included the role of the biology, the so-called biological pump, and physical processes which collectively are termed the solubility pump.[2] Within this broad context, several multidisciplinary studies in different sectors of the Southern Ocean, including the Bellingshausen and Weddell seas, were conducted.[3,4] These investigations have focused on areas characterised by high primary production rates including the neritic waters of Antarctica, the Marginal Ice Zone (MIZ) and the frontal regions. These regions are important in the biochemical cycles of the Southern Ocean as they have displayed a decrease in the partial pressure of carbon dioxide (pCO_2), suggesting that these regions may at times act as a sink for atmospheric CO_2.[2,3]

The extreme variability in the physicochemical parameters and consequently the biological processes in the different sectors of the ocean is well documented. These facts suggest that to understand fully the role that the frontal region and the MIZ play in the carbon cycle of the Southern Ocean, further studies in other sectors are required.

Between 4 December 1997 and 6 February 1998, the first collaborative Scandinavian/South African Antarctic expedition was conducted in the Lazarev Sea (Fig. 1). The Scandinavian delegation consisted of scientists from Sweden (as members of

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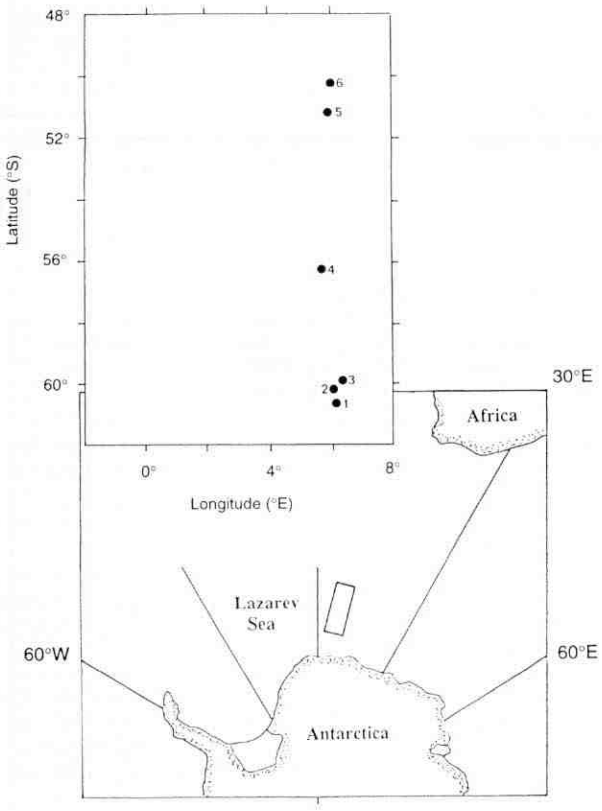

Fig. 1. Region of investigation with inset showing the position of the biostations occupied within the Marginal Ice Zone, interfrontal region and the Polar Front during the Scandinavian/South African Antarctic expedition conducted in the Lazarev Sea in austral summer (Dec./Feb.) 1997–98. Stations 1–3, Marginal Ice Zone; station 4, interfrontal region; stations 5–6, Polar Front.

SWEDARP, the Swedish Antarctic Programme), Norway (NARE, the Norwegian Antarctic Programme) and Finland (FINNARP, the Finnish Antarctic Programme). The data collected during the cruise formed part of a contribution to both JGOFS and the Antarctic Treaty, which stipulates that the signatory countries conduct research within the region south of 40°S.

Two main aims had been set for the cruise. The first was to determine the relative importance of the various factors (including the physical, chemical and biological) which control primary production, and the second to assess the consequences of these factors for the carbon cycle. The scientific programme, which lasted for 34 days, consisted of three main elements: a study of the Marginal Ice Zone, of the interfrontal zone (IF), and finally the Polar Front (PF). The investigation was conducted along the 6°E meridian in the region between 62° and 48°S (Fig. 1).

Continuous underway sampling of pigments, nutrients, bacterial abundance and productivity, and pCO_2 was undertaken between each of the regions. In each of the regional studies, an initial study was conducted with a 'Scanfish' undulating CTD to establish the hydrological context. This was followed by a CTD transect during which physico-chemical characteristics were determined. This included the measurement of nutrients (macro-nutrients and trace metals), oxygen, total alkalinity, salinity and light intensities. Immediately after the physical survey, the biostations were occupied. In total, six 36-hour biostations were occupied, three in the vicinity of the MIZ, two in the region of the PF, while a single station was occupied in the interfrontal region. At the biostations experiments were carried out on bacterial production, size-fractionated chlorophyll, primary production studies and grazing (protozoan and metazoan). In addition to the survey, mesocosm experiments were conducted with water collected from the MIZ and from the PF zone, with the aim of investigating the role of the shortwave radiation (UVa/b) and iron (Fe) in limiting or promoting phytoplankton production in the Southern Ocean. The durations of these experiments were 14 and 10 days, respectively.

Physical oceanography. The three regions surveyed during the investigation could be divided into two distinct regimes. Stations occupied in the vicinity of the MIZ and PF were characterised by relatively high water column stability and a shallow mixed-layer depth (Fig. 2). The water column stability in the MIZ appeared to be related to sea-ice melt, which imparts stability within the vicinity of the retreating ice. In the region of the PF, water column stability appeared to be related to physical attributes between the interacting water masses in the region of the front. In contrast, the biostation occupied in the interfrontal zone was characterised by low water column stability with a relatively deep mixed layer depth (Fig. 2).

Biological studies. Total chlorophyll *a* concentrations were highest at stations in the vicinity of the MIZ and in the region of the PF (Fig. 3). There, chlorophyll *a* concentrations were always >0.5 mg m^{-3} and were dominated by microphytoplankton (>20 μm). Here, microphytoplankton comprised up to 70% of the total. Among the microphytoplankton, diatoms generally dominated. An exception was found at stations in the MIZ where the colonial haptophyte, *Phaeocystis* spp., dominated. Adjacent to the PF and in the interfrontal region, diatoms of the genera *Chaetoceros, Fragilariopsis* and *Proboscia* numerically dominated. Size-fractionated primary production studies showed that total phytoplankton production demonstrated a similar pattern to total chlorophyll concentration with the highest rates recorded in the MIZ and PF. In the latter zones, microphytoplankton was the most important contributor to total areal production. The increase in production in these regions appears to be correlated with relatively high water column stability. Also, in the vicinity of the MIZ, phytoplankton production may have been enhanced through the availability of iron. At these stations, iron concentrations were among the highest recorded during the cruise. Indeed, mesocosm experiments using water from the MIZ showed that iron enrichment resulted in elevated phytoplankton growth rates. The iron may have been released into the water column during ice melt. As well as the higher

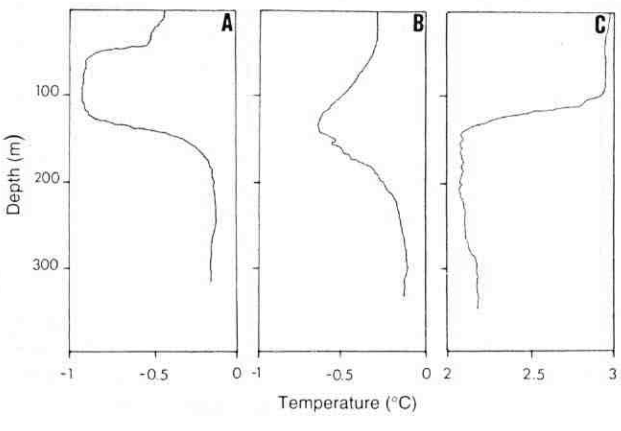

Fig. 2. Profile of upper water column in the vicinity of the Marginal Ice Zone (A), interfrontal region (B) and Polar Front (C) during the expedition.

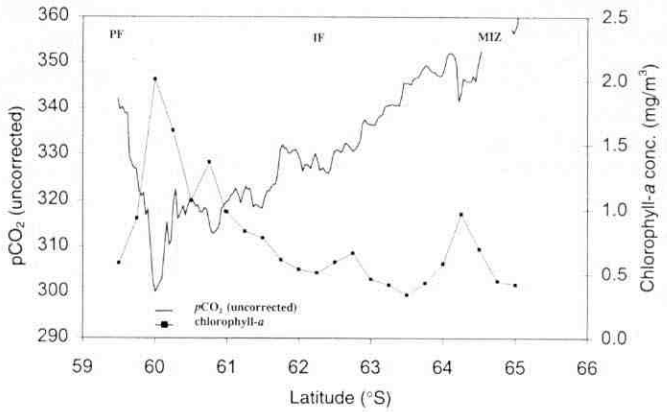

Fig. 3. Transect showing the correlation between total chlorophyll *a* concentration and partial pressure of carbon dioxide during the expedition.

phytoplankton production rates recorded near the MIZ and PF, we recorded enhanced biological rates, including bacterial production, halocarbon synthesis and humic fluorescence.

Total zooplankton abundance throughout the investigation was numerically dominated by mesozooplankton comprising copepods. Among the copepods, *Rhincalanus gigas, Metridia gerlachei, Calanoides acutus, Calanus propinquus* and *Oithona* spp. were particularly well represented. The larger macrozooplankton were almost entirely dominated by the tunicate, *Salpa thompsoni.* An exception was found at stations within the interfrontal zone, where two species of euphausiid, the Antarctic krill, *Euphausia superba,* and *Thysanoessa maxima,* numerically dominated the macrozooplankton counts. The absence of krill in the vicinity of the PF was unexpected as it is generally known as a region of high krill abundance.

Observations on grazing protozooplankton (heterotrophic organisms in the size range 20–200 µm) suggested that their influence was largely correlated with the size composition of the assemblages. Generally, the highest grazing impact (up to 30% of the standing stock) was recorded at stations within the interfrontal zone, where the contribution of the nano- and picophytoplankton (<20 µm) to total chlorophyll was highest. Outside this region, the grazing impact of the protozooplankton was equivalent to <15% of the standing stock. Moreover, preliminary studies suggest that the grazing influence of the meso- and macrozooplankton in the MIZ and PF was minimal. Within the interfrontal zone, however, the effect of grazing corresponded to 10% of daily phytoplankton production.

Conclusions

These results indicate that physical and biological processes are tightly coupled in the region of investigation. In particular, water column stability appears to be a major controlling factor in primary production within the Southern Ocean. This finding is consistent with previous studies conducted in other sectors of the ocean.[3,4] The availability of trace metals, in particular iron, in enhancing productivity in that region cannot be discounted. The importance of production in the MIZ to the carbon cycle of the Southern Ocean was evident from the prevailing pCO_2 levels. The results clearly show that there is a strong drawdown of atmospheric CO_2, which appears to be related to high phytoplankton productivity recorded in the vicinity of the MIZ. Furthermore, the findings also suggest that the partitioning of phytogenic carbon between the various size classes of grazers is strongly determined by the size structure of the phytoplankton assemblages. This has important implications for the localised efficiency of the biological pump.[2] Further investigation on the extent and persistence of the phytoplankton blooms in the vicinity of the MIZ is, however, needed.

We thank the Swedish Antarctic Polar Research Secretariat and the Department of Environmental Affairs and Tourism for making funds and facilities available for this expedition. Our thanks also go to the electronics officer, Chris Rohleder (Sea Fisheries Research Institute, Cape Town) for his invaluable assistance at sea. The success of the cruise was largely the result of the dedicated work undertaken by each member of the research groups. We also thank the officers and crew of the *S.A. Agulhas* for their assistance at sea.

1. Report of the Society of Limnology and Oceanography (1991). *What controls phytoplankton production in nutrient-rich areas of the open sea?* pp. 1–6. San Marcos, California.
2. Longhurst A.R. (1991). Role of the marine biosphere in the global carbon cycle. *Limnol. Oceanogr.* **36**, 1507–1526.
3. Turner D.R, Owens N.J.P. (1995). A biochemical study of the Bellingshausen Sea: overview of the STERNA expedition. *Deep-Sea Res. II* **42**, 907–932.
4. Reports on Polar Research (1997). The expeditions ANTARKTIS XIII/1–2 of the research vessel *Polarstern. Berichte zur Polarforschung* **221**, 1–136. Alfred Wegener Institute for Polar Research, Kiel.