A history of recent South African marine research in the Southern Ocean

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For many years South Africa's Antarctic research was focussed exclusively on the Antarctic continent and on the subantarctic islands Gough and Marion and their immediate vicinities, with only occasional interest shown in the ocean areas traversed. Since the 1970s, however, considerable work has been carried out on the Southern Ocean, on acoustic determinations of krill stocks and on the influence of subantarctic islands on their oceanic environment.

Suid-Afrika se Antarktiese navorsing het vir baie jare lank gefokusseer op die Antarktiese kontinent en op die subantarktiese eilande Gough en Marion sowel as op hul onmiddellike omgewing. Slegs terloopse aandag is gegee aan die oseaangebiede wat deurkruis is. Sedert die jare sewentig is daar egter aansienlike navorsing gedoen oor die Suidelike Oseaan self, veral oor sy watermassas, fronte en biologie. Belangrike bydraes is gemaak oor die hooffronte en die mesoskaalturbulensie van die Suidelike Oseaan, oor akoestiese meting van die krilstapel en oor die invloed van subantarktiese eilande op hul oseaanomgewing.

INTRODUCTION

South African Antarctic activities began in the previous century with sealing voyages from Cape Town (Headland 1989). On 29 December 1947 the national flag of the Union of South Africa was formally raised on Marion Island for the first time, as part of *Operation Snoektown*, a naval operation during which the uninhabited, Subantarctic archipelago of the Prince Edward Islands was officially annexed by South Africa. At least one relief expedition per year to the weather station on Marion Island has been carried out ever since. This was followed in 1956 by the establishment of a weather station on Gough Island with J J van der Merwe as the first team leader. This station was subsequently also relieved at least once a year. The first South African National Antarctic Expedition overwintered in "Norway Station" on Antarctica in 1961. This station was later renamed SANAE and has been in continuous operation since. It is usually resupplied during the months December or January of every year, the first time by the relief vessel *RSA* in 1962 and since 1979 by its replacement, the *SA Agulhas*.

With a national Antarctic vessel regularly crossing vast, virtually unstudied tracts of ocean, one would have expected that a considerable number of oceanographic measurements would have been made. Unfortunately this has not been the case. Some underway ornithologic work was done and carefully annotated records of sea surface temperatures were kept by ship's officers for each voyage. These latter data were passed to the Hydrographic Office of the SA Navy but were lost when this office moved from Youngsfield to Silvermine in the 1970s. A few reports on such early records are fortuitously extant (e g Taljaard 1958; la Grange 1961; Lloyd 1974) and have been amalgamated in a set of all available surface-temperature measurements between Cape Town and SANAE (Lutjeharms & Valentine 1984).

A few exploratory ventures to study the northern borders of the Southern Ocean were undertaken in the 1960s by the Division of Sea Fisheries, but the results achieved seem to have had little wider impact. So, for instance, a cruise was undertaken aboard the rv *Africana II* in the south-east Atlantic and south-west Indian sectors in 1968 (Henry 1975) to study the general hydrography.

One of the few experimental studies during this period was carried out by Shannon (Stander *et al* 1969) who had a large number of plastic drift cards deposited between South Africa and SANAE to study the average surface drifts of the Antarctic Circumpolar Current. A similar study used locally designed and built drifting weather buoys to investigate the velocities of the Antarctic Circumpolar Current south of Africa (Harris & Stavropoulos 1978). This latter work had a major international impact since it demonstrated unequivocally that such instruments were sufficiently robust to withstand conditions at high latitudes. It furthermore showed that drifters could be relied upon to stay operational for up to 18 months. On the basis of these results the international FGGE (First Global Garp Experiment), during which hundreds of drifters were placed in the Southern Ocean, was designed and carried out.

ISOS

In the 1970s the key role of the Southern Ocean as the major link between all the world's ocean basins and between the atmosphere and the deep ocean became increasingly recognised (National Research Council 1974).

As part of its International Decade of Ocean Exploration the USA initiated a special study of Southern Ocean dynamics, called ISOS, the International Southern Ocean Studies. One of the managers of this programme, Dr Vic Neal from Oregon State University, in 1976 attended the Third National Oceanographic Conference in Port Elizabeth to give a talk on the aims of this research effort. This presentation was enthusiastically received by a large audience. South Africa shortly after became an official participant in this Southern Ocean research programme, the first time it had done so.

With the limited research facilities on the supply vessel *RSA* little open ocean oceanographic research could be achieved as a contribution to ISOS. Cooperative ventures with colleagues in the USA were nevertheless established to launch XBTs (expendable bathythermographs) between Cape Town and SANAE. This led to the first study of the thermal detail of the upper layer of the ocean in this region (Lutjeharms & Emery 1983). With the help of ISOS participants from the University of Washington a sea level gauge was also placed at Gough Island. Unfortunately this instrument could not be located again when an attempt was made six months later to retrieve it.

Research on the Southern Ocean that did not require sea-going

ability was more successful. Using all available hydrographic data, studies were made on the geographic distribution of mesoscale turbulence for the whole ocean. It was shown for the first time that the Antarctic Circumpolar Current acts as an eddy generator along its full length (Lutjeharms & Baker 1980). A study using the complete hydrographic data set also for the first time established values for the baroclinic mass transport for the ocean as a whole (Lutjeharms 1982). As a final South African contribution to ISOS a catalogue of all extant sea level records in the Southern Ocean was compiled and published (Lutjeharms 1976).

SOUTHERN OCEAN PHYSICAL OCEANOGRAPHY

These preliminary investigations on the physical oceanography of the Southern Ocean that were carried out as South Africa's contribution to ISOS were particularly effective in accentuating scientific ignorance about this ocean region. To address the most urgent scientific questions a small research group at the then National Research Institute for Oceanology (NRIO) of the CSIR at Stellenbosch was formed and a plan was conceived to carry out extensive hydrographic surveys in the sector south of Africa, but in the most cost-effective manner possible. This plan therefore included the launching of large numbers of XBT probes from ships-of-opportunity, the regular gathering of satellite images of the area and cooperating in international projects to place drifting weather buoys.

In 1978 the *RSA* was replaced with a much larger and more functional vessel, the *SA Agulhas*. This vessel was immediately used to set the planned investigation in motion. On 29 September 1978 the *SA Agulhas* left for Marion Island on its first official cruise and XBT-launchings, the deployment of a few South African FGGE buoys as well as the placement of drift cards commenced.

The aims of this general survey programme were to map the main fronts and currents to a greater degree of detail than before and to study their dynamic behaviour. In general these aims were amply met (Lutjeharms 1991a). Over a period of about ten years the Southern Ocean sector broadly lying south of Africa was covered with XBT lines and the thermal detail of the frontal system established (Lutjeharms 1985a). Where possible use was made of foreign vessels and on occasion more than one vessel was at sea simultaneously. In this way the influence of the changing seasons on the upper layer of the ocean was also successfully studied.

As the facilities of the *SA Agulhas* became known, interest from the South African marine biology community also increased. Prof Brian Allanson established a Southern Ocean Group in the Department of Zoology and Entomology at Rhodes University that undertook the first South African cruises in the Southern Ocean to investigate the geographic distribution of chlorophyll and primary productivity (e g Allanson *et al* 1981). This biological research was supported by physical oceanographic studies by the above-mentioned group from Stellenbosch.

The interesting preliminary findings on surface drift determined previously using plastic drift cards (Stander *et al* 1969) stimulated a much more wide-ranging experiment. Plastic drift cards were released south of Africa over a 12-year period from a host of ships-of-opportunity. By 1981 a total of 40 000 cards had been released and an average return rate of 1,0% established a basis for estimating the drift rate of the upper ocean layer with an accuracy that was not available previously (Lutjeharms *et al* 1988).

South Africa also played a very active role in the international FGGE programme as part of which a large number of drifting weather buoys were simultaneously placed in the Southern Ocean during 1976-1977 (Taljaard 1977). Twenty-three buoys were built to local design at the NRIO workshops in Stellenbosch by Mr Erich Schiemann and placed in predetermined positions. An attempt was made to cover the Southern Ocean with a grid of drifters with dimensions 500 km x 500 km. Since gaps in this ideal pattern would develop due to buoy failure or due to shear in the currents, supplies of buoys were housed at strategic locations in the southern hemisphere to be used for filling such gaps with the help of commercial shipping. Such a depot was at Cape Town and was managed in an enthusiastic and energetic manner by Mr Christo Stavropoulos of the NRIO.

For political reasons South Africa's key contribution to the FGGE was not recognised at the time. Much of the work was done surreptitiously and at international gatherings Southern African buoys forming part of the international experiment were not denoted by country, as were all the other ones, but as "others". Nonetheless, South African researchers were the first to publish results of the FGGE buoy tracks, particularly in combination with satellite remote sensing (Lutjeharms & Valentine 1981). The major statistical analyses of all drifter tracks combined were done by others (e g Piola *et al* 1987).

In general this first period of active South African research in the Southern Ocean was highly effective and efficient. At relatively low cost a substantial increase in knowledge was gained on fronts and their biology, on surface drift and on water masses in the sector south of Africa. Much of this work was supported directly by the CSIR and came to a sudden end in 1990 when the CSIR, bent on "market-oriented" research, decided that open-ocean research had no "market" and abruptly terminated this activity. A solid foundation had nevertheless been laid on which future research could be built.

BIOMASS

With the precipitous decline in the whale catch once commercial exploitation had resumed after the Second World War, came a conviction that a deeper understanding of the unique ecology of this coldest of oceans was needed. One of the key components of the Southern Ocean food chain are the krill, *Euphausia superba*, that form the major food item of baleen whales and that were thought to be present in most parts of the Southern Ocean. Estimating their standing stock and its possible variability in space and time was considered to be impossible at the time since the problems of logistics and of statistically reliable samples seemed insurmountable.

In 1976 Dr David Cram of the then Sea Fisheries Branch of the Department of Industries put forward a motivation for a cruise to test his hypothesis that the acoustic determination of krill stocks was feasible. The South African Navy made its hydrographic research ship, the *SAS Protea*, available for this study and the experiment was conducted in the Drake Passage from February to April 1978. Results conclusively showed that acoustic methods were indeed applicable and highly efficacious. Cram showed that krill may congregate in superswarms of up to

1,5 km in dimension (Cram *et al* 1979). These early results placed South Africa in the forefront of acoustic studies on krill at the time.

Not long after, the observational phase of BIOMASS (Biological Investigation of Marine Antarctic Systems and Stocks) was launched as an international programme with, as one of its main aims, the determination of the standing stocks of krill. To this end a large number of vessels were employed over a number of years and every effort was made to standardise the methods employed by different nations (BIOMASS 1977). With the acknowledged prowess that South Africans had achieved in the acoustic estimation of standing stocks of krill, South African fishing experts such as Dr Garth Newman were much in demand and played key roles in the international planning.

The BIOMASS took place in two main phases, the first BIOMASS experiment (FIBEX; 1982-83) and the second (SIBEX; 1983-84). The South African contribution to the FIBEX consisted of a major cruise with international participation in the vicinity of Bonvetoya on the *SA Agulhas* in 1978-79. It was found that phytoplankton biomass was negatively correlated both with mean integrated krill density as well as with the number of krill swarms (Weber & El-Sayed 1985). Tentative hypotheses on the feeding behaviour of krill swarms in the region at the time were also put forward (Hampton 1985; Miller *et al* 1985).

South African participation in SIBEX consisted of two cruises to the Prydz Bay area. This region had previously been identified by Australian surveys as having a very high krill standing stock. The first cruise focussed primarily on the physics and on the lower trophic levels of the region. The cruise was a notable success (Orren 1984) and a special edition of the *South African Journal of Antarctic Research* (Allanson & Boden 1985) was devoted to its results.

The second South African SIBEX cruise was intended to concentrate to a greater extent on the plankton, both krill swarms and phytoplankton. This cruise on the rv *Africana* was particularly well reported in the South African media since the vessel became incapacitated when it developed rudder trouble and had to be towed home by a Soviet trawler. The scientific work planned for this particular cruise suffered in consequence (Miller 1986).

In addition to the above-mentioned official South African BIOMASS cruises, a number of important biological surveys in the same general framework were carried out by South Africans. Mr Denzil Miller of the Sea Fisheries Research Institute was the leader of a team that carried out an extensive survey around the Prince Edward Island group in May-June 1980 (Miller 1982a). This consisted of combined hydroacoustic and midwater trawling investigations. A similar combined cruise from the *SA Agulhas* took place during October-November 1980 around Gough Island (Miller 1982b; Miller & Tromp 1982). In each case low zooplankton abundance and biomass was found. These surveys were the first of their kind undertaken around these islands (Miller 1985).

Overall, South Africans made a sterling contribution to this effort, both in its planning and in its execution. There has been criticism that the international plan of BIOMASS was grossly over-ambitious in its aims of establishing the total standing stock of krill and that the enormous expense of the experiment could have been better directed at more well-focussed process studies of krill swarms or of the krill life cycle. Uncoupling physical observations from biological surveys clearly was inappropriate. Nevertheless, international attention was effectively alerted to the importance of the ecology of the Southern Ocean, much was learnt, be it sometimes by default, and considerable interest stimulated. One may hope that this scientific interest will continue to grow.

This may well be occurring already in the South African marine research community. As a result of their involvement in BIOMASS, they have made a substantial scientific contribution to CCAMLR (the Commission for the Conservation of Antarctic Marine Living Resources) research. In particular, expertise developed in the study of krill aggregations during BIOMASS (e g Miller & Hampton 1989) has formed the basis of a number of CCAMLR initiatives aimed at improving understanding of possible relationships between krill abundance and the commercial fishery (e g Butterworth & Miller 1987; Butterworth 1989). The need to understand krill aggregation as an integral feature of the ecology of the species was the main objective of a cruise on board the *Africana* to the South Orkneys and Elephant Island in 1990.

THE MOES

As mentioned above, before 1970 South African scientific interest in Antarctic regions was primarily concentrated on the terrestrial environment. Numerous biological and particularly ornithological investigations were, for instance, carried out on the Prince Edward Islands. The presence of numerous colonies of birds on these islands raised the question whether the birds were there in such large numbers only because of the nesting opportunity or also perhaps because the island itself created a particularly benign feeding habitat in its direct environment. In order to study this, the Marion Offshore Ecosystem Study (MOES) was designed in the early eighties by a working group under the auspices of the then South African Scientific Committee for Antarctic Research (SASCAR 1987). By making use of the regular visits of the *SA Agulhas* to Marion Island, frequent studies of the physical and biological environments of the archipelago could be made.

These studies led to a number of notable scientific advances. First, it was clearly established from regular observations in the region that the islands lie in a position where they are under the influence of Subtropical, Subantarctic as well as Antarctic waters, including indicator species from all of these waters (Boden & Parker 1986; Miller *et al* 1984). The taxonomy (Boden & Reid 1989) as well as the geographic distribution (Boden *et al* 1988) of the diatoms of the region were carefully documented for the first time. Two extensive cruises were carried out, the first (MOES I; Duncombe Rae 1989) close to the islands; the second (MOES II; Van Ballegooyen *et al* 1989) covering a very large area around the archipelago to place the possible influence of the islands on their direct environment in larger context. Published results on the MOES II are in preparation.

Interpretation of results on the MOES I and other surveys in the direct vicinity of the Prince Edward Island archipelago have been rich in new conceptual thinking. The Southern Ocean Group at Rhodes University has done a considerable amount of work on the physics, chemistry, phytoplankton biomass and primary production of the inter-island shelf. They have come to the conclusion that a trapped anticyclonic motion on the shelf retains organisms here and is instrumental in increasing biological productivity (e g Perissinotto & Duncombe Rae 1990; Perissinot-

to, Allanson & Boden 1990; Perissinotto *et al* 1990). The previous concept of persistent upwelling in the lee of Marion Island (Grindley & David 1985) was shown to be false and replaced by the concept of eddy-shedding from the lee of the island (Allanson *et al* 1985). This has subsequently, using the extensive data coverage of the MOES II cruise, been proved to be substantially correct.

In retrospect the MOES endeavour can be considered a qualified success. It is now clear that the original ideas on a possible island-effect were entirely too simplistic — this is a valuable research result. It is furthermore evident that the period allocated in the original plan for resolving this fundamental oceanologic problem was completely inadequate. A solid foundation has been laid, but much further work is required for a proper understanding of the influence of the island group on its environment.

SCARC AND INTERNATIONAL CRUISES

One of the Southern Ocean areas noted for its extremely high level of variability in mesoscale water movement is the area just south of Africa (e g Lutjeharms & Baker 1980) where the Agulhas Current retroflects and where the Agulhas Return Current flows eastwards along the Subtropical Convergence. This has important physical, chemical, biological and climatic implications.

From the termination of the Agulhas Current are shed both rings and eddies (Lutjeharms & van Ballegooyen 1988). Rings drift into the South Atlantic while many eddies may cross the Subtropical Convergence into the domain of the Southern Ocean. In this way heat, salt, momentum and foreign organisms are inserted into the Subantarctic. Instabilities in the Subtropical Convergence itself may also shed eddies, both cold and warm, which may drift into contrasting environments (Lutjeharms & Valentine 1988).

The importance of this region and of the processes occurring there were recognised at an early stage of planning of the South African Southern Ocean programme, but investigations in this region were hampered by the limited ship-time available for the lengthy cruises required to investigate these phenomena. Considerable efforts were therefore made to help plan and get involved in foreign cruises envisaged for this region.

One of the first of these was a multi-ship cruise on the American rv *Knorr*, rv *Meiring Naudé* of the CSIR and the *SA Agulhas* in November and December of 1983. During this hydrographic survey the southern Agulhas Current, its retroflection, a few Agulhas rings as well as eddies shed across the Subtropical Convergence, were successfully investigated (Gordon *et al* 1987). The shedding of an Agulhas ring was observed at sea for the first time (Lutjeharms & Gordon 1987) and the meridional heat flux due to an eddy crossing the Suptropical Convergence established (Lutjeharms 1988). Results from this cruise are still being analysed and published.

A second international cruise in which South Africans participated was one in February and March of 1985 during which a number of deep-sea current meter moorings were placed in this region. The leader for this particular cruise was Dr Jim Luyten of the Woods Hole Oceanographic Institution and it was carried out from the rv *Thomas Washington*. Results on this cruise are also still being analysed.

In February and March 1987 18 South African marine scientists from six institutions executed South Africa's own interdisciplinary cruise in the Subtropical Convergence region south of Africa called the SCARC (Subtropical Convergence and Agulhas Retroflection Cruise). This cruise coincided with one on board the rrs *Discovery* just to the east, producing an extensive and high-quality data set for the whole area (Lutjeharms 1987). Measurements on the SCARC included ones on the physics of the atmosphere and the water column, on phytoplankton, zooplankton, nekton, marine mammals as well as on birds. In all, six eddies in, along and north of the Subtropical Convergence were surveyed. It was established that they were in different stages of decay. Results on the surveys of the mammals (Cockroft *et al* 1991) and on the birds (Ryan 1989) have broken new ground, as have measurements concerning the influence of these features on the overlying atmosphere (Mey *et al* 1990). It has been established that during this cruise an anomalously large body of Subantarctic water penetrated the Subtropical Convergence and it has been documented how this water advected northward into the Benguela Current (Shannon *et al* 1989).

As in the case of the other major cruises mentioned above, many of the research results of the SCARC will only be appearing in print over the next few years. Nonetheless, it is already clear that, as in the case of BIOMASS, participation in international cruises are of great benefit to South Africa's Southern Ocean programme. Large, interdisciplinary South African cruises with well-focussed research objectives, such as the SCARC, have also been shown to be scientifically extremely productive and cost-effective.

FUTURE ENDEAVOURS

From the successes and the few limited failures of recent South African efforts in open ocean research in the Southern Ocean, a great deal has been learnt. These lessons have to a large extent been used in the design of a new South African Southern Ocean research plan that will run from 1991 to 1995. The main focus of this programme will shift from the Prince Edward island group to the areas involved in the Antarctic Convention and in CCAMLR, that is, the Antarctic Polar Front and south of it. It will consist of three major projects (Lucas *et al* 1992). First, a study of the water masses and fluxes between Africa and Antarctica, as well as the mesoscale processes occurring at the four major frontal areas. Results from this particular project will make a major contribution to WOCE (World Ocean Circulation Experiment).

Secondly, a study will be made of the carbon fluxes in the Southern Ocean including that between atmosphere and ocean, between various trophic levels and between the water masses and the ocean floor. These studies will contribute important information required to understand global climate change, a major aim of JGOFS (the international Joint Global Ocean Flux Study). Lastly, an attempt will be made to model the interactions between the water masses and the various organisms at a range of trophic levels, better to understand the ecological processes of the Southern Ocean. This will conceivably have to include a wide range of organisms and processes that have been identified as important for the Southern Ocean component of the international programme called GLOBEC (Global Ocean Ecosystem Dynamics).

As part of the programme, an attempt will also be made to monitor sea level and sea level change in cooperation with international efforts in this regard. South Africans have had only little

experience in this field near the Antarctic (e g Lutjeharms *et al* 1985), but the Sea Level Group at the University of Cape Town led by Professor Geoff Brundrit has already had notable successes with studies of sea level along South African coastlines, studies that are entirely applicable in the Southern Ocean.

All these intended South African efforts will depend critically on a suitable research platform from which to launch the investigations. It is planned that the *SA Agulhas* will undergo a total refurbishment in 1992 during which new winches, new laboratories and new navigational equipment will be installed.

With the growth and development of South African deep-sea expertise over the past decade, with an innovative and well-focussed research plan and with sufficient ship-time on a well-equipped research vessel, South African research seems poised for an exciting and productive investigation period on the Southern Ocean south of Africa.

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