

# Physical oceanographic activities in South Africa: 1995-1998

M.L. Gründling<sup>a</sup>, J.R.E. Lutjeharms<sup>b</sup>, G. Brundrit<sup>b</sup>,  
J.J. Agenbag<sup>c</sup>, A. Boyd<sup>c</sup>, G. Nelson<sup>c</sup>, A. Johnson<sup>c</sup>,  
M. Roberts<sup>c</sup>, L. Shannon<sup>c</sup> and E.H. Schumann<sup>d</sup>

**T**his report provides the reader with an overview of research activities in the South African marine and coastal environment during the period 1995-1998. The report is being submitted to IAPSO (International Association for the Physical Sciences of the Ocean) in preparation for the IUGG General Assembly in 1999 and covers the years since the previous meeting (August 1995). The presentation is arranged in terms of the various marine research organizations in the country, to indicate the distribution of effort. The oceanographic activities for each organization is separated according to the focus areas of each institution. To achieve some consistency with the previous report to IAPSO, this account also contains two brief sections on South African vessels used in oceanographic research, and aspects of marine data management, respectively.

As with previous reports, an attempt is made to present as comprehensive a bibliography as possible, but only including references that are readily accessible to readers. Research reported only in the form of theses, intra-organizational documents and contract reports, or with a 'submitted' status, has been omitted. References to conference proceedings are only included if they are considered of an international nature and have been published.

## The South African marine environment

The main oceanographic feature of the South African marine environment is the Agulhas Current flowing along the east coast, downstream of the Mozambique Current and the East Madagascar Current. South of the continent the Agulhas Current meanders, fragments and injects

subtropical water into the southeast Atlantic in the form of Agulhas rings, while the main part of the Agulhas returns, or retroflects, eastwards into the interior of the Indian Ocean.

Along the west coast of southern Africa the wind-induced upwelling regime underpins the extensive fishing industry along the coast. The Benguela Current is a broad, sluggish, equatorward flow along this coast.

To the south of the African continent the vast expanses of the Southern Ocean form fertile spawning areas for many processes affecting southern Africa. The atmospheric fronts of the region are drawn northward by the South Atlantic anticyclone to affect local weather conditions, while at the same time generating storm swell that

impinges on the coast and interacts with the Agulhas Current to the detriment of shipping along the 'Cape shipping route'. Other features of importance in the Southern Ocean are the Antarctic Circumpolar Current, the Subtropical Convergence and many other fronts.

Physical oceanographic research in South Africa is conducted mainly by the Department of Oceanography, University of Cape Town, and the Sea Fisheries Research Institute, Department of Environmental Affairs and Tourism, Cape Town (Fig. 1). Organizations also involved with physical oceanography, albeit to a lesser extent, are the University of Port Elizabeth and the CSIR's Division for Water, Environment and Forestry Technology in Stellenbosch (near Cape Town). The research conducted by the Institute for Maritime Technology (Simon's Town), which falls mostly in the Navy's strategic domain, is not reported here.

## Research organizations

### University of Cape Town

#### Greater Agulhas Current and climate

The Agulhas Current system continues to receive considerable national as well as international attention because of the role

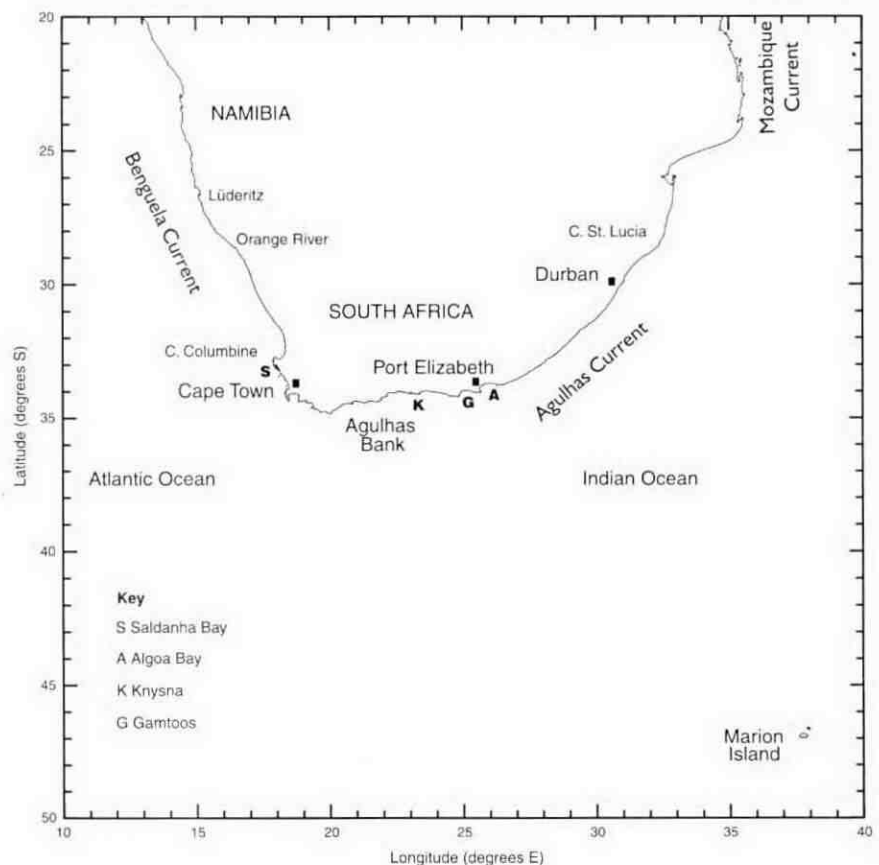


Fig. 1. Location chart for the sites mentioned in the text.

<sup>a</sup>CSIR, P.O. Box 320, Stellenbosch, 7599 South Africa. E-mail: mgrundli@csir.co.za

<sup>b</sup>Department of Oceanography, University of Cape Town, Rondebosch, 7701 South Africa.

<sup>c</sup>Sea Fisheries Research Institute, Private Bag X2, Rogge Bay, 8012 South Africa.

<sup>d</sup>Department of Geology, University of Port Elizabeth.

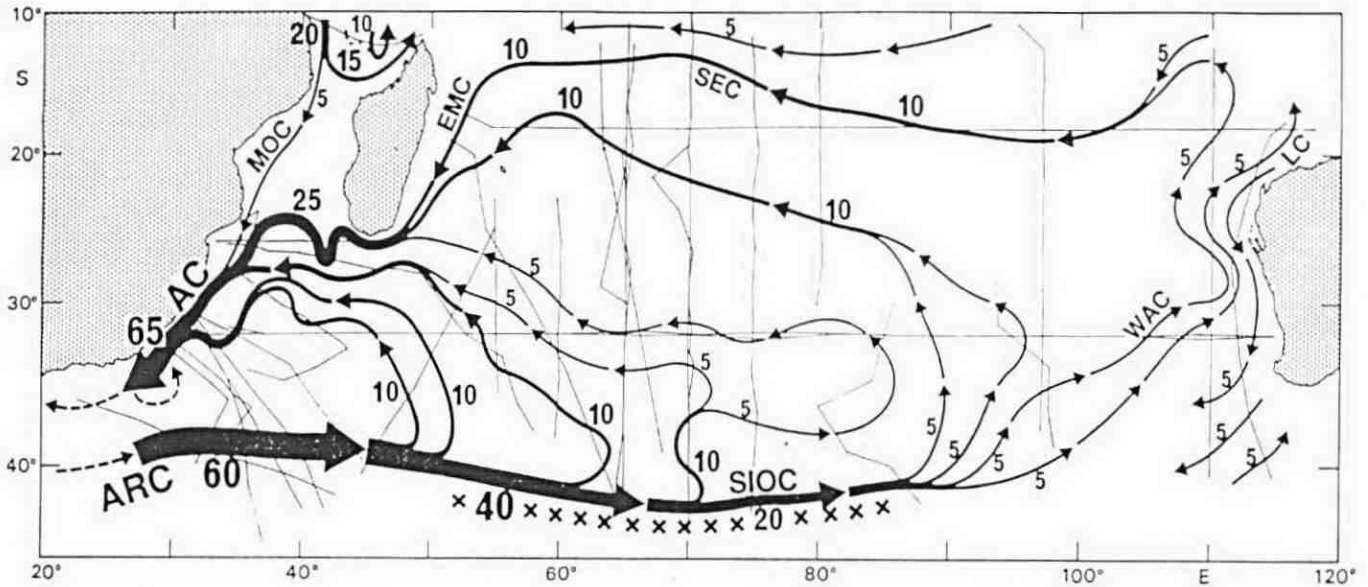


Fig. 2. The flow pattern and volume fluxes of the upper 1000 m of the Indian Ocean (after Stramma and Lutjeharms, 1997). Numbers give the flux in  $10^6 \text{ m}^3 \text{ s}^{-1}$ ; thin lines are the cruise tracks from which hydrographic data have been derived for this analysis.

it is perceived to play in the climatically important, global thermohaline circulation. The along-track nature of the Agulhas Return Current has been extensively described for the first time, demonstrating that it terminates at about  $60^\circ \text{ E}$ . The East Madagascar and the Mozambique currents were found to contribute very little to the Agulhas Current proper whereas the wind-driven, subtropical gyre is more concentrated in the southwest Indian Ocean than in any comparable basin (Fig. 2). Based on data from an extensive cruise designed specifically for this purpose, the input into the South Atlantic has been estimated at 6.3 Sv of water warmer than  $8^\circ \text{ C}$  by ring-shedding from the Agulhas retroflection. By contrast, the inter-ocean salt flux contributed by Agulhas Current filaments is only about 15 % of that by Agulhas rings. A number of reviews of current knowledge on the inter-basin exchanges south of Africa have been published. The FRAM (Fine Resolution Antarctic Model) has been used successfully to simulate ring shedding at the Agulhas retroflection. It has also demonstrated how sensitive the current is to bottom topographic features. This sensitivity also holds once Agulhas rings have been shed and they traverse the relatively shallow Walvis Ridge in the southeastern Atlantic.

Most of these studies on the inter-basin exchanges south of Africa have concentrated on the waters in the upper water layers. To study the motion of the intermediate waters using hydrographic data, the largest multi-institutional and multinational observational programme ever

to study South African waters is making use of bottom-mounted sound-sources and a large collection of Rafos floats (KAPEX: Cape of Good Hope Experiment). At the time of writing, a number of these floats have already surfaced and the first Lagrangian portrayals of the motions at intermediate depths in this region are starting to emerge.

Topographically induced upwelling, initially recognized inshore of the Agulhas Current at Cape St Lucia, has now been shown to occur at the eastern edge of the Agulhas Bank as well. This particular upwelling cell is also clearly evident in the distribution of dissolved nutrients on the Agulhas Bank, and plays an important role in the supply of water masses to this shelf region.

Summer rainfall along the east coast of South Africa depends in part on the average distance of the Agulhas Current from the coastline. This distance may be a function of the frequency of perturbations in the trajectory of the current, generated in the vicinity of Durban. Because of the southward propagation of these anomalies, and their role in triggering the shedding of Agulhas rings south of the continent, these findings are of considerable importance to an understanding of how inter-basin exchanges are modulated south of Africa.

Sea level and acoustic travel time were used as indicators of the ocean climate and of the impact of sea-level rise on the coastal environment of southern Africa. The related estimates of temperature change in the world's oceans through global underwater acoustic propagation

is being studied through modelling and field studies.

#### Atmosphere-ocean interaction

The deep-sea regions around southern Africa are characterized by the most variability in the oceans, so that a greater knowledge of these processes will play a critical role in advancing understanding of southern African as well as global climate. In addition, variations of the ocean environment, and specifically those short-term meteorological events such as high-pressure cells, subtropical troughs and tropical cyclones, are used to predict southern African rainfall and temperature. Collaborative studies with scientists from neighbouring African countries form an important part of these activities.

It has been demonstrated that changes of as little as  $2^\circ \text{ C}$  in sea-surface temperatures in the Agulhas retroflection region may have a noticeable effect on the atmospheric pressure systems over southern Africa. The effect on winter cyclones as they move over the warm waters of the Agulhas Current is one of the synoptic changes that has been studied. Variability of the sea-surface temperatures in the South Indian Ocean that bring about these atmospheric modifications may themselves be forced largely by atmospheric changes on an infra-annual time scale. Over longer periods, it is probably the ocean dynamics that are decisive for driving this important variability.

To investigate the influence of the Agulhas Current on the overlying atmos-

where the University of Cape Town (UCT) conducted a number of cruises over the ocean region between Cape Town and Marion Island and over the core of the Agulhas Current itself. The moisture uptake in the boundary layer above the Agulhas Current was shown to be critically dependent on wind direction. Under synoptic conditions of along-current winds the formation of cumulus clouds is usually a visible result of the vertical moisture flux. When the wind is landward, moisture is advected over the continent to a height of 1000 m.

### *Benguela*

The waters overlying the continental shelf of the greater Benguela region were also investigated, to establish the nature of the physical environment and its relevance to the fisheries of South Africa's west and south coasts. In this field there is close collaboration with associated research groups at the Sea Fisheries Research Institute, and also internationally. The Angola-Benguela front separates the Benguela upwelling system in the south-eastern Atlantic from the Angola Current to the north. Using satellite images, cruise data and wind observations, it was shown that the surface location of this front reacts to the local winds with a two-day time lag. The available collection of ships' drift observations has been used to quantify this motion for the first time on a seasonal basis.

### *Southern Ocean*

The Prince Edward islands that lie in the Indian sector of the Southern Ocean have a terrestrial ecosystem that is largely dependent on the surrounding ocean. Major cruises have been staged around the islands as part of the South African Antarctic programme. Analysis has shown that the speed of the Antarctic Circumpolar Current has a decisive influence on the flow disturbances around the islands, with important consequences for the primary productivity in the region. The direct influence of the islands on the surrounding ocean waters is mainly by water runoff and is geographically restricted to a distance of about 100 km from the islands. There is evidence of enhanced primary productivity in eddies close to the islands, but it is uncertain whether these eddies are part of the wake of the island group or are advected from the Atlantic-Indian ridge located up-stream of the islands.

The island of Tristan da Cunha lies in the South Atlantic near the generic border of the Southern Ocean, the Subtropical

Convergence. It has been postulated that this front exhibits a seasonal meridional excursion that may have an effect on the species composition of the fish caught from the island. The distribution of myctophids between the southern Indian and Atlantic oceans has been shown to be strongly correlated with the southern Agulhas Current, its ring-shedding process and the subsequent drift of these rings into the South Atlantic Ocean.

## **Sea Fisheries Research Institute**

### *Southwest Indian Ocean*

A significant discovery in terms of the circulation surrounding the Agulhas Current was made when two current meters deployed along the 200 m contour of the Agulhas Bank revealed a strong eastward-moving current near the bottom. The eastward flow varied with a period of approximately six days, approaching zero or reversing weakly at times, with a peak observed in eastward velocity of  $74 \text{ cm s}^{-1}$ .

### *Southeast Atlantic Ocean*

A time-series of wind from Cape Columbine lighthouse was used to calculate the relative rate of upwelling for the Columbine upwelling cell. The results displayed large swings from winter to summer of  $2.5\text{--}40 \text{ } 10^3 \text{ m}^3 \text{ s}^{-1}$  with a yearly average of  $7.5 \times 10^3 \text{ m}^3 \text{ s}^{-1}$ .

A collaborative project between scientists from UCT, the Sea Fisheries Research Institute and France, has produced some important preliminary results on the structure of flow around a cape in upwelling areas. Combining modelling and observation, this work is aimed at understanding the potential for retention in shelf areas downwind of prominent capes, such as Cape Columbine.

Between 1990 and 1995, sixteen current meters were moored in Saldanha Bay, and their results were analysed during the present period under review. The most significant observation is that water is forced into the bay in the deeper layers from the shelf with a period of 4–6 days throughout the year. This corresponds to the passage of shelf waves, generated by wind. The eastward phase of these waves was seen at one current meter at the mouth of the bay to last 48 hours and the westward, or flushing phase, 62 hours on average.

The variability of the surface flow of the Benguela Current on the shelf and shelf-edge off the southern Cape Peninsula was investigated by means of drogues and ADCP (acoustic Doppler current profiler) measurements, and the

results reflected the periodic leakage of Agulhas Current filaments into the coastal Atlantic. In spring the equatorward flowing 'jet' was often strongest on the inner shelf (within 30 km of the coast), and moved offshore only after sustained upwelling in summer. Poleward flow at the surface was measured at various distances offshore, but was most often encountered on the inner shelf in summer, autumn and winter. Causes of this variability include the interaction between coastal trapped waves and local upwelling as well as large-scale pressure differences in the South Atlantic driving the coastal circulation.

The meridional sea-level atmospheric pressure difference (an index of the east/west geostrophic wind component in the west wind belt) showed a relationship between the three Pacific ENSO (El Niño-Southern Oscillation) events since 1982 and reductions in the local summer easterly wind component. In each case the local index reached a maximum deviation within two months of the corresponding peak in the Southern Oscillation Index negative phase and indications are that the teleconnection takes place via pressure fluctuations in the west wind belt. A second index, based upon the position of the  $16 \text{ } ^\circ\text{C}$  SST isotherm in the southern Benguela system, produced evidence for an extensive warm period during the 1991/93 ENSO, but suggests that the 1982/83 and 1986/87 events had little influence on the sea-surface temperature environment in the southern Benguela.

Climate change may influence pelagic fish by altering advective processes or by changing where fish choose to spawn. Simulation models were developed to explore the effects of altered advection and spawning localities on recruitment of anchovy and sardine in the Benguela.

Anchovy spawn in the Agulhas Bank region and partly up the west coast in some years. By means of currents, their eggs and larvae are transported west- and northwards to nursery grounds along the west coast. Passive transport by currents may account for a substantial proportion of variability in year-class strength of small pelagic fish. Reduced westward and northward advection, which is likely to occur during ENSO events, accumulated more than half the young of the year anchovy in the region between the Orange River and Cape Columbine, with a large proportion of young accumulating near the coast or in bays. This may affect availability of fish to the purse seine fishery operating off South Africa. The Central Agulhas Bank, characterized by

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weak circulation, acts as a retention area for eggs and larvae of small pelagic fish.

## CSIR

### Southwest Indian Ocean

Research focused on the enhancement or attenuation of wave heights as a result of interaction between the swell and the Agulhas Current, using waves recorded by the Geosat and Topex/Poseidon satellite altimeters. Similar to the enhancement of wave heights approaching from the south (propagating against the Agulhas Current), it was found that waves approaching from the northeast (propagating with the Agulhas Current) are attenuated.

Farther south, in the vicinity of Marion Island, wave heights recorded by the Geosat satellite were used to indicate the effect of the island on storm waves approaching from the west. The results indicated that waves are attenuated in the lee of the island, and that this may have an effect on the mixing in the surface layers.

### Southeast Atlantic Ocean

Sea-surface topography data collected by the Topex/Poseidon satellite were employed to locate and track eddies in the southwest Indian ocean and the southeast Atlantic during 1992/93. Altogether 57 eddies were identified. The anticyclonic Agulhas rings drifted at 3–7 cm s<sup>-1</sup> in a westerly to northwesterly direction, and it was estimated that five rings are generated annually. In the southwest Indian Ocean, cyclonic eddies were observed to adhere to the offshore edge of the Agulhas Current, and entrain water from the current.

In an extensive study of the flow field off Namibia, 48 satellite-tracked buoys were deployed and tracked between July 1994 and September 1995. *In situ* supporting wind information was collected from a weather buoy moored off Lüderitz, from coastal stations and from voluntary observing ships. Buoy drift tracks were compared with surface topography data from the Topex/Poseidon satellite and infrared images. Most of the buoys drifted in a northwesterly direction, those deployed in the south generally moving faster and diverging more from the coast than the northern buoys. The overall maximum daily drift velocity was 72 cm s<sup>-1</sup>, but typical speeds were 10–30 cm s<sup>-1</sup>. In the proximity of the coast some buoys experienced transient southward sets associated with the effect of coastal trapped waves, while tracks north of 23° S showed inertial oscillations.

## University of Port Elizabeth

### Southwest Indian Ocean

Marine research has been largely aimed at understanding the currents and water properties in the vicinity of Algoa Bay, a large, crenulated bay on the Cape south coast. The Agulhas Current is the major large-scale oceanographic feature of this coast, and there is an influx of Agulhas water, probably driven by wind, into the shallower reaches of the bay. It is likely that such events are important in flushing out any effluent build-up from the urban area in the western sector. The upwelling that occurs around the prominent headland of Cape Recife has also been investigated. Easterly winds cause upwelling on the southern part of this cape, while westerly winds bring this cold water into the Bay.

Two chapters of *SA Sailing Directions*, containing the relevant meteorological and oceanographic conditions around the coast of South Africa, have been updated for the sailing fraternity. A broad review dealt with known conditions in the coastal ocean off the east coast of Africa, including Madagascar, and formed part of a reference volume dealing with coastal oceans globally.

To study the inter-annual and short-term variability of sea temperature and mixed-layer processes on the South African south coast, upwelling statistics were investigated using temperature records 12–31 years long. There is a correlation between these temperatures and ENSO events. Part of the study focused on the nature of the mixed layer off the southern Cape coast and showed that the upwelling cycle is much shorter on this coast than in the west coast upwelling environments.

### Estuaries

Investigations have continued in a number of Cape estuaries. A violent storm, coincident with the crest of a coastal trapped wave and spring tide, resulted in sea level more than 1 m above the expected height. This resulted in an influx of sea water into the Gamtoos estuary, with consequent flooding and erosion.

Analyses of data collected during an intensive three-year programme in the Gamtoos estuary revealed intense thermoclines, with structures varying with freshwater inflow. Wind-mixing is only evident in sections of the estuary, and for limited periods. Irrigation return flow is a problem only in the upper reaches of the Gamtoos estuary, where there is an indication of nutrient build-up

during low flow conditions.

Surface temperature measurements in the Knysna estuary over a period of about four years proved to be a useful tool to investigate the hydrodynamics of the estuary. They revealed that changes of more than 10 °C are fairly common in summer when coastal upwelling occurs in the adjacent ocean.

Current structures and sediment patterns have been analysed in the lower Kowie estuary, and a novel proposal has been made to flush out unwanted sediment accumulations using the ebb tidal flows.

In a comprehensive book on the estuaries of South Africa, a chapter dealt specifically with the hydrodynamics of South African estuarine processes.

## Research vessels

*FRS Africana* (1982): A multipurpose fisheries research vessel owned by the Department of Environmental Affairs and Tourism (DEAT). She is 77.85 m long, has an endurance of 45 days and a range of 20 000 n. miles. Accommodation is provided for 17 scientists. The vessel has advanced acoustics, CTD, ADCP, mid-water trawl, bottom trawl, stern ramp, fixed aft gantry, swing-arm davit and three hydraulic cranes.

*SA Agulhas* (1977): Owned by DEAT and used mainly as an Antarctic supply vessel. She is 109.45 m long, endurance is 90 days and range is 21 000 n. miles. She can accommodate 93 scientists. Swing-out A-frame gantry aft.

*RV Sardinops* (1958): Owned by DEAT, is used for lobster trapping and line-fishing, hydrographic and biological research, CTD, swing-out A-frame gantry aft. The vessel is 36.6 m long, has a range of 3600 n. miles and an endurance of 15 days, can accommodate 4 scientists.

*Algoa* (converted 1993): Owned by DEAT, is used for multipurpose fisheries research, advanced acoustics, CTD, ADCP, mid-water and bottom trawling, stern ramp, swing-arm davit, swing-out side A-frame, hydrographic and biological sampling. Accommodation for 12 scientists.

*SAS Protea* (1972): Owned by the South African Navy, used as hydrographic survey vessel. No special accommodation for scientists, range of 12 000 n. miles.

All the oceanographic research organizations have smaller motor launches for use in the surf and inshore zones. The research vessels seem not to be used to their full capability, mainly due to financial constraints.

## Data management

There has never been an encompassing, national policy regarding the storage and archiving of oceanographic data in South Africa. Nevertheless, the Southern African Data Centre for Oceanography (SADCO) has been archiving and disseminating physical oceanographic data in the target area extending from 10° N to 70° S, and from 30° W to 70° E for more than 30 years. The centre is jointly funded by all oceanographic research organizations in South Africa and Namibia. Services (including data provision in an on-line and off-line mode; newsletters) are supplied to the entire oceanographic community in southern Africa, and also to neighbouring countries. SADCO has also been charged to ensure that data collected by foreign vessels entering South African territorial waters is made available to the country, and is the contact for the Inter-governmental Oceanographic Commission in terms of data exchange. Most research organizations maintain in-house databases for internal use.

## Conclusion

Oceanography experienced significant changes in funding during the years under review, causing a decrease in the number of researchers, although the output in terms of publications has not reflected these changes yet. Oceanographic research is at present located mainly in and around Cape Town.

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## A review of research in South African meteorology and atmospheric sciences: 1995-1998

Compiled by J. Olivier\*

**T**his report reviews research activities in South Africa in the fields of meteorology, climatology, atmospheric physics and chemistry, boundary layer meteorology and applied climatology. The main topics since the XXIst General Assembly of the IUGG held in Boulder, Colorado, 2-14 July 1995, are reviewed briefly. This report reflects the important advances made in local research on long- and short-term weather prediction, climate change and variability, developments in rainfall enhancement and techniques used for estimating the spatial distribution of rainfall. It also briefly discusses the research and operational use of several general circulation models (GCMs) as well as advances made in boundary layer meteorology and a trace-gas monitoring programme.

Research was funded by the Water Research Commission (WRC), the Foundation for Research Development (FRD), the departments of Environmental Affairs, Health, Agriculture as well as Water Affairs and Forestry. Important contributions were also made by the CSIR, Eskom as well as the universities of Pretoria, Witwatersrand, Cape Town, Stellenbosch, Natal, Orange Free State and the North.

The list of completed and ongoing re-

search projects as well as of selected publications serves to provide a guide to the scope of atmospheric research in South Africa.

### Meteorology and weather prediction

#### Weather and weather systems

An exposition has been prepared by J. Taljaard on the atmospheric circulation systems in the region, the synoptic climatology of South Africa and a selection of the weather phenomena peculiar to the region. These phenomena include the characteristic pressure and wind phenomena as related to rain; diurnal variations of the wind related to topography and vertical exchange processes; explanation of temperature distribution in summer and winter; characteristic temperature fluctuations such as during the occurrence of bergwinds; the occurrence and distribution of rain in relation to circulation systems; the origin and movement of moist air masses over the region; the 18-year rainfall cycle and many more. These overviews were published in six SAWB Technical Reports during 1995 and 1996.

#### The South African Weather Bureau radar network

The South African Weather Bureau has acquired several C-band weather radars

since the late 1980s. These have been deployed in a network used to provide quality radar data or for use in the weather-watch service, in flood forecasting and precipitation measurement. The project has advanced to the point where real-time radar images are displayed in the central forecasting office (CFO) from four of the nine planned radars. The available products consist of accumulated precipitation fields and reflectivity fields and are in the form of a mosaic from the four radars. A graphics system has been developed to display these images in the CFO. Images are updated automatically as soon as new data become available. The local forecasting offices also have TITAN (thunderstorm initiation, tracking and nowcasting) software as a local aid for weather-watch purposes. The five other radars will eventually be incorporated into the network.

The Bethlehem Precipitation Research Project (BPRP) forms part of the SAWB's research section. It operates the WRC's MRL-5 dual-wavelength research radar and the SAWB's C-band radars at Bethlehem and Ermelo. The BPRP deploys almost 100 automatic rain gauges over specific catchments to verify the relationships between radar, gauge and streamflow measurements. A new method called DISPLACE, which processes output from a weather radar's logarithmic receiver, has been developed and tested. It proved to have many applications and is computationally efficient and accurate. Its applications include the processing of digitized logarithmic receiver output to simulate different receiver functions, the processing of multi-parameter radar measurements and the filtering of ground clutter. It facilitates the computation of CAPPis (constant altitude plan position images) and radar-rainfall accumulation.

The radar system is being expanded to include other radars in South Africa as

\*Geography Department, University of the North, Private Bag X1106, Sovenga, 0727 South Africa. E-mail: janao@unin.unorth.ac.za



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