THE GRAND CHALLENGE OF DEVELOPING *IN SITU* OBSERVATIONAL OCEANOGRAPHY IN SOUTH AFRICA

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ABSTRACT

With a view of implementing operational oceanography in South Africa, the scientific community in 2009 initiated a demonstration project, *OceanSAfrica*, which integrates ocean modelling, *in situ* observations, remote sensing, and data dissemination and products. This paper presents progress towards establishing the *in situ* observations component. Led by the newly formed Oceans & Coasts (Department of Environment Affairs), numerous existing monitoring efforts, which include ship surveys, tide gauges, underwater temperature recorders (UTRs), wave buoys, as well as locally developed *in situ* measurement sensor and platform prototypes (dial-out UTRs, coastal and deep ocean buoys) have been incorporated into a regional *in-situ* observational network. A modular process has begun which will expand this initial network into an operational *in situ* observational service by 2016. This will include regional high resolution underway observations during the SANAP relief voyages- namely Good Hope, Cape Town- Gough Island and Cape Town- Marion Island transects, participation in SAMOC, at least five coastal buoys, moorings across the Agulhas Current and the Benguela Jet, coastal radar, dial-out UTRs and coastal weather stations. Most will be linked in real-time. This network will be integrated with the regional *in situ* observational arrays of PIRATA in the Atlantic and RAMA in the Indian Ocean, and the Benguela Current Commission (BCC) and Agulhas and Somali Current Large Marine Ecosystem (ASCLME) programmes. Equally important will be the inclusion of science and technology projects to support and interpret the *in situ* observations. Apart from providing information to benefit local marine activities, these *in situ* data will ultimately be used to improve ocean and weather model skill through validation and assimilation, and contribute to international efforts in climate change research. Training and capacity building strongly feature in the *OceanSAfrica* initiative. Overall, this endeavour will strongly advance DEA's objective of providing an operational service on ocean state, DTi's (THRIP) objective to stimulate technology innovation, manufacturing and jobs, and DST's *2008–2018 Grand Challenge for Global Climate Change Science* strategy to use South Africa's unique proximity to the Antarctic, the Southern Ocean, the Agulhas and Benguela Currents to become a world leader in climate change science.

1. OCEANS AROUND SOUTH AFRICA

The marine environment around southern Africa is one of the most diverse, complex, variable and energetic systems in the world (Figure 1; Lutjeharms 2001). The east coast and outer Agulhas Bank are strongly influenced by the warm, fast-flowing (~2 m s^{-1}) Agulhas Current. This well-defined western boundary current with a volume transport of some 75 Sv has origins near 26° S where there is a confluence of flows from the Moçambique Channel, the East Madagascar Current and the South Western Indian Ocean gyre (Lutjeharms, 2001). At the southern tip of the Agulhas Bank, the Agulhas Current undergoes a number of configurations which include retroflection eastwards along the Subtropical Convergence into the South Indian Ocean (Agulhas Return Current), the formation of anticyclonic rings shed into the South Atlantic (Lutjeharms and Van Ballegooyen 1988; Duncombe Rae, 1991), or continuous flow along the shelf edge of the western Bank (Lutjeharms and Cooper, 1996). The latter two mechanisms inject water masses (freshwater, salt and heat) originating in the Indian Ocean into the South Atlantic forming a critical link in the Atlantic Meridional Overturning Circulation (MOC) — an important component of the global ocean circulation (Figure 2).

The oceanography on the outer Agulhas Bank is dominated by associated shear boundary processes, such as meanders, eddies, and break-away filaments (Lutjeharms *et al.*, 1989) of the Agulhas Current. Upwelling is common on the shelf east of Port Elizabeth caused by the Agulhas Current moving farther offshore (Lutjeharms *et al.*, 1999). Intense thermoclines, induced by shelf-edge upwelling and insolation, are characteristic of the eastern and central Agulhas Bank (Largier and Swart, 1987). The inner shelf is influenced by wind-driven coastal upwelling, particularly during summer (Schumann *et al.*, 1982). Upward doming of the thermocline in an offshore, elongated formation is often found on the central Agulhas Bank. This feature, referred to as a "cold ridge", is commonly associated

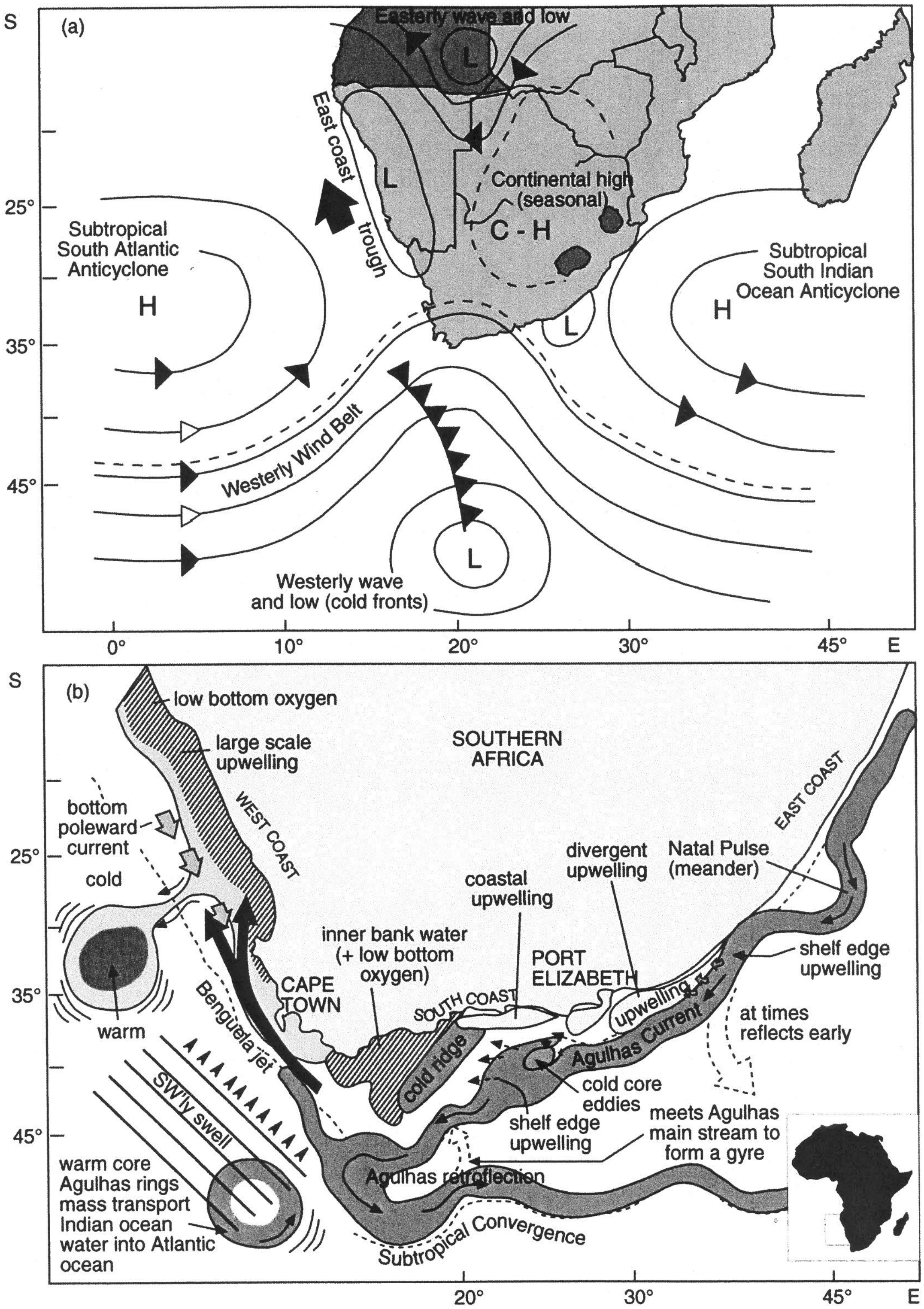

Figure 1: (a) The complexity and variability of the marine environment around southern Africa is partly due to the latitude and associated weather. In summer, the oceanic high pressure cells either side of southern Africa dominate the wind field, causing south-easterly winds on the west coast and north-easterly winds on the eastern Agulhas Bank and east coast. In winter, the westerly wind belt migrates north, moving cold fronts and strong westerly winds to southern Africa. (b) The oceanography is also dominated by the warm Agulhas and cold Benguela Currents. These drive many of the physical processes and key features on the shelf (taken directly from Roberts 2005).

with high levels of primary and secondary production (Boyd and Shillington, 1994). Large, solitary, transient meanders in the Agulhas Current, known as a "Natal Pulse", are found on South Africa's east coast 3–4 times a year (De Ruijter*et al.*, 1999). These have profound influences on the shelf oceanography and have been associated with early retroflection and ring formation (Roberts *et al.*, 2010; Van Leeuwen *et al.*, 2000). At times large freak (rogue) waves occur in the Agulhas Current known to inflict severe damage on ships, particularly super tankers (Grundlingh 1994).

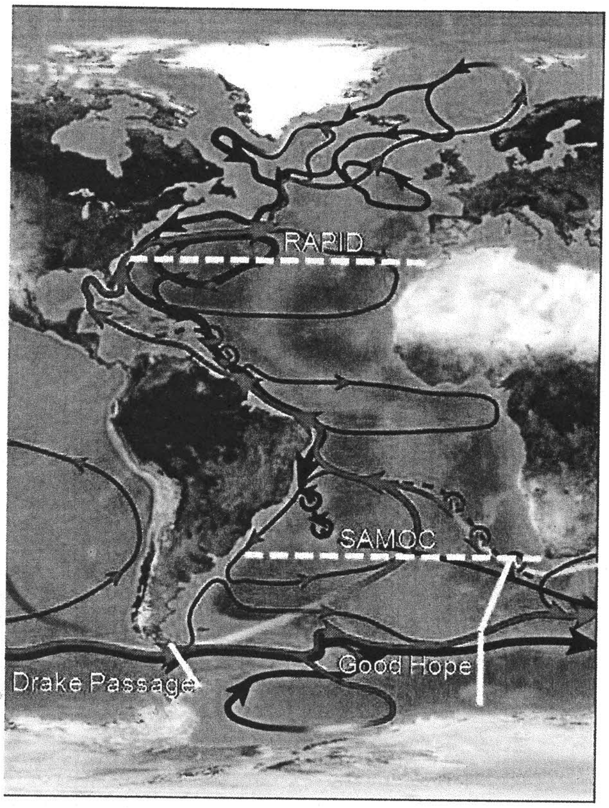

Figure 2: Schematic showing the Atlantic Meridional Overturning Circulation and the oceanic teleconnection between the south and north ocean basins. Red arrows represent surface flow (upper 1000 m) with blue corresponding to the deeper (>2000 m) return flows. The RAPID array in the North Atlantic, SAMOC line in the South Atlantic and mooring line across the Drake Passage are also depicted (white lines).

The west coast is very different to the east coast, and is dominated by the cold Benguela upwelling system (Shannon and Nelson, 1996). This is one of the largest eastern boundary upwelling systems in the world, driven by the South Atlantic High Pressure (anticyclone) and associated south-easterly winds. The region is abundant in production which frequently leads to low levels of dissolved oxygen in the bottom layer, and at times, almost anoxic conditions (Chapman and Shannon, 1987). The outer shelf is influenced by the slower north-flowing (0.25–0.50 m s^{-1}) Benguela Current (Boyd *et al.*, 1994). This eastern boundary current is less defined than the Agulhas Current and is the eastern element of the South Atlantic gyre. A narrow frontal jet, known as the Benguela Jet, is commonly found along the shelf edge between the Cape Peninsula and Cape Columbine. The Benguela Jet is a small current with maximum velocities reaching ~ 0.75 m s^{-1} and a transport of 1–7 Sv (Shannon and Nelson, 1996). It plays a crucial role in connecting the western Agulhas Bank to the west coast. North of Cape Columbine the jet undergoes bifurcation, moving onto the wider shelf and into the South Atlantic towards the Walvis Ridge. Agulhas rings (Duncombe-Rae *et al.*, 1992) and other offshore mesoscale features such as eddies and filaments (Lutjeharms and Matthysen, 1995; Nelson *et al.*, 1998) at times interact with the shelf causing water to be drawn offshore into the Atlantic Ocean. A poleward undercurrent on the shelf and continental slope varies in strength and seasonality (Nelson, 1989).

The Agulhas Current and the atmospheric high-pressure cells situated over the SE Atlantic and SW Indian are therefore major drivers of the many physical processes found on the shelf around southern Africa. Variability in the wind field is influenced by the north–south seasonal migration of the SE Atlantic and SW Indian Ocean High Pressure cells, and concomitantly, the expansion of the westerly belt (Tyson and Preston-White, 2000). The eastward tracking cyclones with their associated cold fronts produce strong westerly winds and large swells during winter, with cyclogenesis occurring in the southwest Atlantic Ocean. Modelling and observational studies indicate that increased transport of warm Agulhas water southwards and to the southwest of South Africa into the Atlantic strengthens local storms and increases rainfall over large parts of South Africa (Rouault et al., 2002). Many flood disasters have resulted from cut-off lows that intensify when the southern Agulhas Current is anomalously strong and warm (Singleton and Reason, 2007).

In summer, the westerly belt contracts southwards, and the wind field over the shelf is then largely driven by the two anticyclones often ridging and causing coastal upwelling on the west coast and Agulhas Bank (Shannon and Nelson, 1996; Schumann et al., 1982).

To the south of Africa lies the Southern Ocean with the region immediately south of the Agulhas Bank being a critical crossroad for the inter-ocean exchange of water, salt, heat, biota and anthropogenic tracers between the subtropical South Indian, South Atlantic gyres and the cooler Southern Ocean waters. The Southern Ocean, similar to the MOC, plays a major role in the global ocean circulation (Figure 2) and in particular on regional and global climate (Siedler et al., 2001).

2. MARITIME ACTIVITIES

The cold west coast of South Africa is stark and sparsely populated with few major cities. Apart from Cape Town, the only other major harbor on the 700 km coast is Saldanah Bay which is used to mostly export iron ore. Large scale commercial fishing, oil/gas and seafloor mining dominate activities on the shelf region. The high biological production (plankton) in the ecosystem which supports the commercial fish stocks often leads to harmful algal blooms (HABs) and rock lobster walkouts.

The east coast by contrast is rich in biodiversity but is low in biomass. It is heavily populated with most of the country's major ports located here. Industrialization and ocean outfalls are concentrated in Kwa-Zulu Natal, although the newly built Koega Industrialized Development Zone (IDZ) is destined to substantially expand industrialization in Algoa Bay.

Twenty three MPAs have been established between Saldanha Bay and the Mozambique border to conserve the diverse coastline with all but two east of the Cape Peninsula. Apart from protecting the biodiversity, these play important roles in the management of the much depleted line fishery. The warm water, beaches, biodiversity and close proximity to the hinterland large cities, has led to the east coast, particularly KZN, being a prime tourist destination. East of Algoa Bay, shipping lanes are close to the coast as a result of the narrow shelf and the southward flowing Agulhas Current.

Mariculture (mussels and oysters) is practiced in the sheltered embayments of Saldanah Bay, Knysna Lagoon and Algoa Bay. Marine ecotourism (whale watching, shark diving, sardine run) is also well established on the south and east coasts.

Of growing importance is the renewable energy sector interested in generating electricity from the Agulhas Current and using wave power in marine pump storage schemes.

3. EXISTING MONITORING

The complexity and high energy of the ocean systems surrounding southern Africa present a challenge to the many marine activities which occur here and affect parameters such as operations, performance and safety, as well as to the management of ecosystems, fisheries, coastal communities, disasters, and weather prediction. In recent times, the effects and implications of climate change are also becoming a concern. A number of monitoring initiatives have therefore been underway, some for many years, to provide information on the state of the ocean, and in cases, includes prediction.

3.1 Fisheries

Marine monitoring in South Africa has been strongly influenced by the need to manage the commercial fisheries — mainly pilchard, anchovy, rock lobster, hake and squid — all of which undergo fluctuations in biomass and catches (Hutchings et al., 2009a). The Sea Fisheries Research Institute (SFRI) which then became Marine & Coastal Management (MCM), and in 2010 dissolved into the Department of Agriculture, Forestry

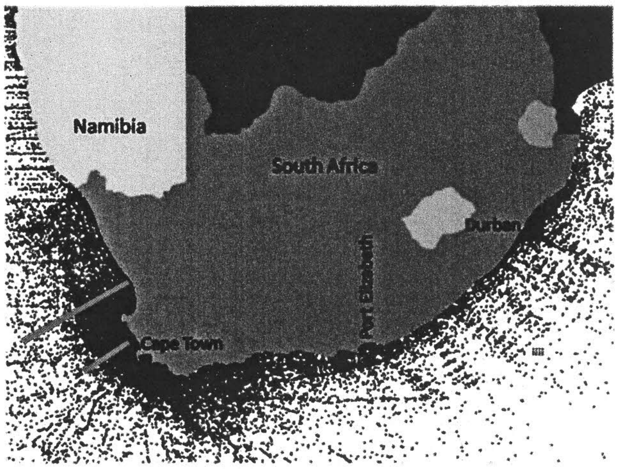

Figure 3: Positions of CTD stations undertaken between 1982 and 2008 using South African research vessels. These data are in the South African Data Centre for Oceanography (SADCO). The monthly sampled SHBML (red long line) and SARP (short red line) monitoring lines are shown

and Fisheries (DAFF), has conducted scientific cruises as far back as the 1950s, but routinely since 1982 using the research vessels *Agulhas*, *Africana*, *Benguela*, *Algoa* and more recently the *Ellen Khuzwayo*, regularly covering the Southern Ocean, the Agulhas Bank and the west coast (Figure 3). This dataset of 28 years is invaluable and almost unrivalled worldwide. To understanding fluctuations in the biomass of pilchards, anchovies, demersal species and rock lobster, the monthly sampled St Helena Bay monitoring (SHBML) and Sardine- Anchovy Recruitment Program (SARP) lines were established in 2000 (Hutchings et al., 2009b). This is an area of great interest in terms of the transport of pilchard and anchovy eggs and larvae from the Agulhas Bank via the Benguela Jet, development of Harmful Algal Blooms (HABs), low oxygen events and rock lobster walkouts.

3.2 Underwater Temperature Recorder (UTR) Network

With an increasing awareness of climate and ocean variability, the SFRI in 1990 also began establishing a long-term network of delayed-time Underwater Temperature Recorders (DT-UTRs) in depths of 5-15 m around the South African coast (grey triangles in Figure 4). These were deployed deliberately to monitor coastal processes, mainly coastal upwelling cells (Figure 1). At first the *Hugrun* self-recording temperature recorder was used but these were replaced in 2001 with the *Starmon mini.* Scuba divers service the instruments every 4-6 months and the data are uploaded to the internet (demonstration website www.cfoo.co.za). Two deeper sites were also established — one in the Tsitsikamma National Park on Middlebank in 36 m (1998), the other in Kromme Bay (St Francis Bay) in 25 m (1992). Both have thermistor arrays with the former an ADCP (Roberts and van den Berg 2005) which has recorded hourly currents since then.

During the first phase of the *African Coelacanth Ecosystem Program* (ACEP I), between 2002 and 2007, more UTR sites were established in the Mozambique Channel, Comoros Isles, Tanzania (including Zanzibar) and the Seychelles, but these were standardized at a depth of 18 m so as to measure subsurface physical processes such as shelf edge upwelling. When funding is available, every effort is made to establish new sites in the WIO. For example, in October 2010 an UTR was

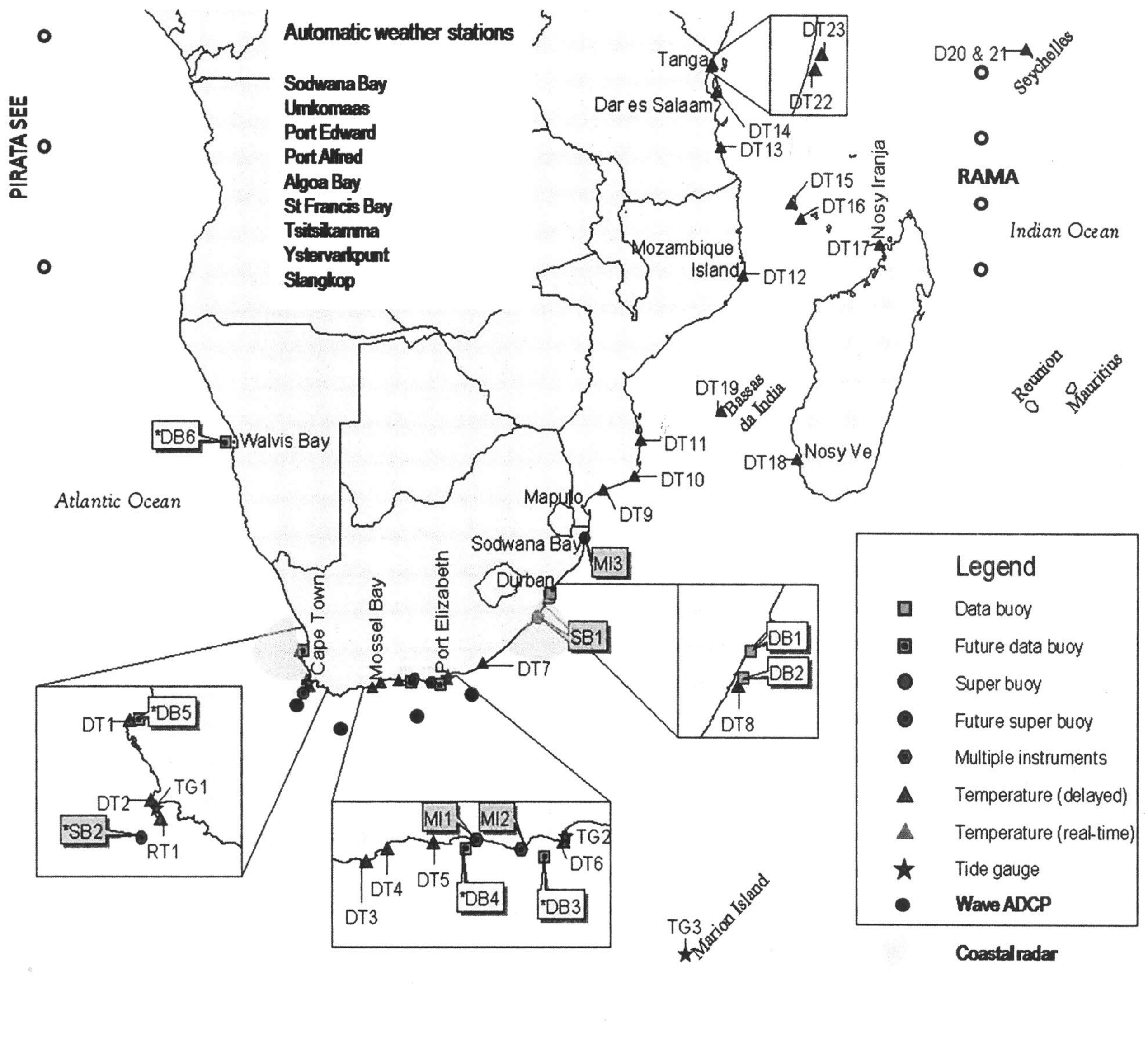

Figure 1: The *in situ* observational network around southern Africa: DT=Delayed time UTR, DB=Data Buoy, SB=Super Buoy, TG=Tide gauge. This network is strengthened by the PIRATA SEE Atlas buoys in the Atlantic Ocean and the RAMA Atlas buoys in the Western Indian Ocean. Note that not all DBs and SBs are deployed yet. Deployment of the automatic weather stations will begin in 2011 in collaboration with SAWS. All buoys also have meteorological sensors. Coastal radar stations will be established at Port Edward and St Helena Bay in 2013 and 2014 respectively

deployed on Mnemba Island off the east coast of Zanzibar, and in May 2011, an UTR was deployed near the north tip of Mauritius (1.4 km off Trouaux Biches). Two UTRs will be deployed on the Kenyan coast in November 2011.

3.3 CSIR WaveNet

The Council for Industrial Research (CSIR), which operates in commercial sectors of the marine environment, has developed a real-time monitoring network for waves (CSIR WaveNet) with a 48 hr prediction capability for the National Port Authority. This uses a combination of *Datawell Directional Waverider* surface buoys, and recently bottom-mounted ADCPs deployed at 9 sites on the South African coast (not shown in Figure 4). Twelve CSIR owned coastal weather stations located mainly at the harbours are also integrated into CSIR WaveNet. These are independent of the SAWS coastal AWSs (see section 3.8). These data are available on the internet at http://wavenet.csir.co.za. *In situ* deep sea wave measurements to the southwest of the continent are still required to improve model skill. More detail is provided in Rossouw et al. (1999) and Rossouw et al. (in prep.).

3.4 SANHO Sea Level Network

The South African Navy Hydrographic Office (SANHO) is responsible for the installation and maintenance of tide gauges in the principal harbours in South Africa. SANHO is also responsible for the acquisition, processing, archiving and dissemination of sea level data (www.sanho.co.za). The network which now comprises 10 sites was initiated in 1957 and completed in 1989. Initially the float and stilling well type of gauge was used but this method has now been replaced with radar tide gauges. Durban, Cape Town and Simons Town are connected to international networks — the Global Sea Level Observing System (GLOSS www.gloss-sealevel.org) and the UNESCO Tsunami Warning system (www.ioc-tsunami.org) — and are fitted with satellite transmitter and GPS for real-time data transmission and land movement monitoring. More detail is provided in Rossouw et al. (in prep.).

3.5 Long term monitoring in Algoa Bay

More recently, the *South African Environmental Observation Network* (SAEON) which has a mandate to establish key long-term environmental monitoring sites in South Africa, has initiated a substantial network of DT-UTRs, thermistor arrays and ADCPs in Algoa Bay (Figure 5) — one of the largest embayments on the South African coast (Goschen and Schumann, 2011). The intention is to track long-term changes in this open bay system. Data are available on request.

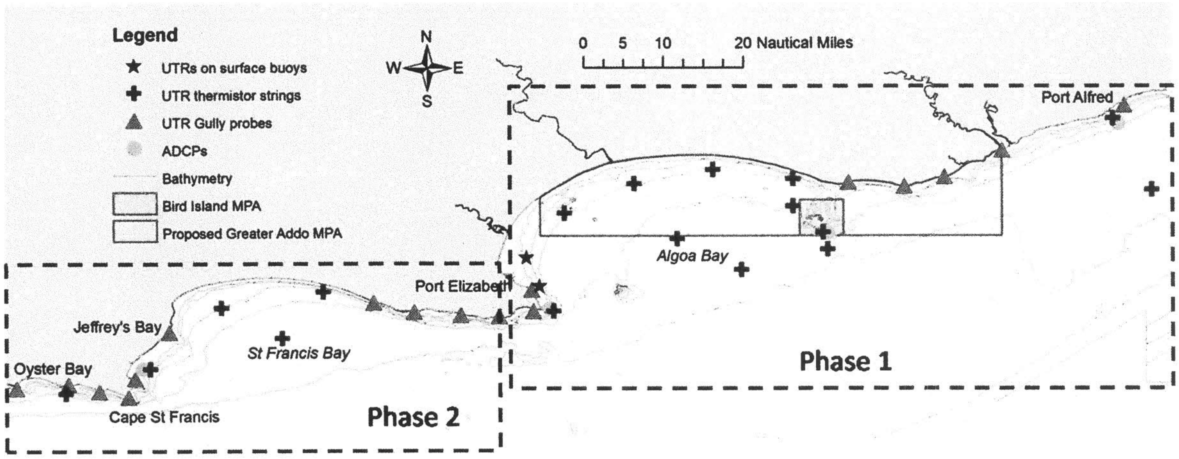

Figure 5: The SAEON long term monitoring network of instruments (see key). Phase 1 covering Algoa Bay and Port Alfred was initiated in 2008. Phase 2 to be implemented in 2011 will extend the network into the neighbouring St Francis Bay area

3.6 Regional ocean– climate monitoring

Good Hope transect

To understand the exchange mechanisms of water masses south of Africa, the equatorward flux of heat and salt in the MOC and the possible influence on climate — it is critical that the inflow of Indian Ocean water into the Atlantic is quantified and monitored. To this end the Good Hope programme was initiated in 2004 as a joint partnership between South Africa, France and Germany (Ansorge et al., 2004). This provides an intensive underway monitoring platform in which the physical structure, volume flux of waters, and carbon signature are measured where the inter-basin exchanges occur. The Good Hope line aims to integrate high resolution physical, bio-geochemical and atmospheric observations with along-track satellite and model data. To date over 22 underway lines have been completed along the Good Hope transect. It is anticipated that the occupation of the Good Hope line will continue indefinitely.

In addition to the Good Hope line, new underway transects between Cape Town- Gough and Cape Town- Prince Edward Islands are to commence in 2012 as part of the SAMOC international programme, Agulhas Current SCOR working group 136 strategic plan, and the SANAP.

South Atlantic Meridional Overturning Circulation (SAMOC)
At present there is only one monitoring system of the MOC in the North Atlantic, namely the RAPID/MOCHA array deployed at 25° N (Figure 2; Bryden et al., 2005). However, given the complexity and the worldwide extent of the MOC, it is necessary that monitoring change elsewhere is undertaken — in particular the teleconnection between the South and the North Atlantic oceans. This connection results in the southward flow of cold and salty water masses from the North Atlantic and a compensating northward warm water pathway. Recent investigations have shown that this pathway may be further intensified by regions of high mesoscale variability, particularly at the Brazil/Malvinas Confluence, at the Agulhas Retroflection and within the Southern Ocean. Indeed, given the close relationship between the north and south Atlantic basins it is likely that any change in the net heat, salt and mass fluxes will result in repercussions farther afield.

In 2008, a new MOC line was established across the South Atlantic at 40° S (Figure 2) as part of the *South Atlantic Meridional Overturning Circulation Programme* (SAMOC). This will be augmented with moorings adjacent to the continental shelves of South Africa and Brazil. To monitor the inter-ocean exchange between the South Atlantic and South Indian Oceans, and importantly the exchange associated with the Agulhas Current, as well the Pacific Ocean — SAMOC will incorporate a number of ongoing lines such as the Good Hope line south of Africa and the mooring line across the Drake Passage (http://www.clivar.org/organization/southern/timeseries.htm; Chereskin et al., 2009).

The inclusion of South Africa as a major collaborator in the Good Hope and SAMOC programmes, as well as the local establishment of sustainable monitoring transects to Gough, Marion and Prince Edward Islands will strongly advance the DST 2008- 2018 Grand Challenge for Global Climate Change Science strategy (reference): namely, to use South Africa's unique proximity to the Antarctic, the Southern Ocean, and the Agulhas and Benguela Currents to become a world leader in climate change science.

3.7 Agulhas Current Time series

Most recently in 2010 a large subsurface mooring array comprising 7 moorings and 4 C-PIES, spanning a distance of 340 km along a TOPEX/Jason altimetry ground track, was deployed across the Agulhas Current directly off Hamburg (Beal et al. 2009). This project, referred to as the Agulhas Current Time-series (ACT), is funded by the National Science Foundation (NSF) of the United States and aims to measure, *in situ*, the Agulhas Current transport for a period of 3 years. These measurements will be correlated with patterns of along-track sea surface height variability from a satellite altimeter to produce a proxy (or index) for Agulhas Current transport. This can be extended forwards and backwards in time — and will be a contribution to the Global Ocean Observing System.

3.8 South African Weather Service (SAWS)

The SAWS is responsible for the provision of maritime weather, forecasts and warnings in METAREA VII (second largest in the world; Figure 6). These are supported by their coastal Automatic Weather Stations

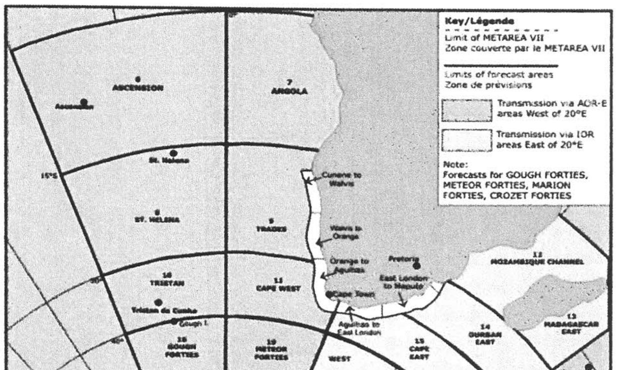

Figure 6: The SAWS is responsible for the provision of maritime weather, forecasts and warnings in METAREA VII (green and orange sectors).

(AWS) network, weather stations on the Sub Antarctic Islands and Antarctic base (SANAE), wave data and forecasts from CSIR WaveNet, and Voluntary Observing Ships (VOS). The SAWS deploy SVP drifter buoys and Argo floats for the JCOMM community. The SAWS has indicated that real-time measurements for air and water temperature, humidity, wind, pressure and swell are still required in the South Atlantic - Southern Ocean.

4. LOCAL DEVELOPMENT OF *IN SITU* SHELF MEASUREMENT PROTOTYPES

Already back in the mid 1990s, it was well recognised that marine monitoring capabilities in South Africa needed to be extended farther offshore and in real-time. But it was only in 2006 that a local project of this nature was established in the Technology and Human Resources for Industry Program (THRIP) using funding from the Department of Science and Technology (DST) and industry. Apart from delivering prototypes, this program emphasises innovation, capacity building, student training, and the creation of jobs with increased manufacturing capacity in South Africa.

4.1. Data Buoy project

Between 2006 and 2008 funding was obtained from THRIP to develop a coastal real-time monitoring buoy for South African conditions. *Sappi* and the *South African Squid Management and Industrial Association* (SASMIA), both with ocean monitoring requirements, were recruited as industrial research partners. The final product known as *Data Buoy* (Figure 7) was a pencil-shaped, light weight (80 kg), inexpensive, and easily deployable/retrievable coastal buoy which makes a variety of measurements throughout the water column. Data are transmitted from the surface buoy via satellite, GPRS or radio to a website for immediate access and data products (www.cfoo.co.za). Sensors depend on the application and include measurements of wind, air temperature, humidity, water temperature, dissolved oxygen, turbidity, ocean optics (fluorescence), currents, and waves.

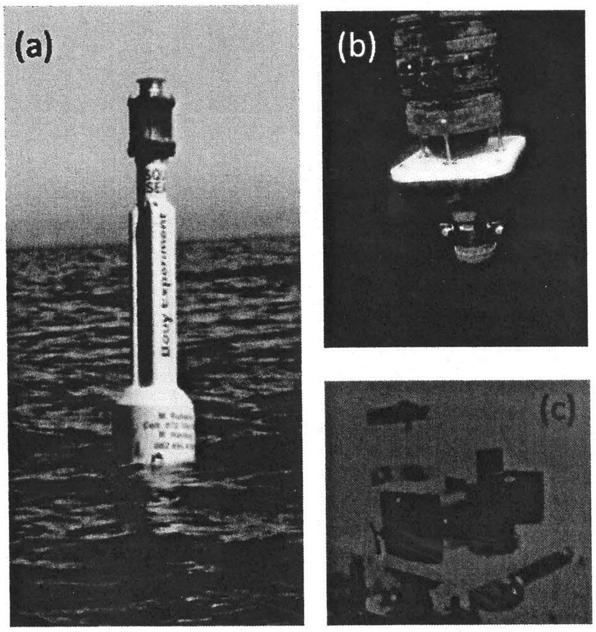

Figure 7: *Data Buoy* is a real-time coastal monitoring buoy (a) surface buoy which transmits data to a cellular network GPRS (b) data are received from a benthic instrument platform (c) using acoustic modems

The surface buoy uses a dual anchor mooring which withstands currents > 2 m s^{-1}, wave heights of 6 m, and maintains a tight buoy position. Instrumentation is attached to a benthic platform placed independently on the seafloor where it is safe from storms, ships and theft (Figure 7c). In depths < 40 m, scuba divers service the platform. Acoustic release technology is used for deeper deployments. Data Buoy can be deployed using a small craft such as an 8 m inflatable boat.

Complex data such as ADCP and wave measurements are processed on the seafloor and transmitted to the surface buoy via acoustic modems, eliminating cables (Figure 7b). *Data Buoy* and the associated instruments require maintenance approximately every 4 months. The first demonstration buoy was deployed in 36 m near the Sappi effluent pipeline in April 2008 and has been online 86% of the time. A second demonstration prototype *Data Buoy (II)*, was deployed off Amanzimtoti (KZN) in February 2011 to monitor ocean conditions for automated effluent discharge.

4.2. Super Buoy project

In 2009 funding was again obtained from THRIP to design and build a larger buoy system to monitor the Agulhas Current and the Benguela Jet — both key currents around South Africa. Eskom (national electricity utility) and SASMIA were recruited as industrial partners — the latter strongly committed to harnessing renewable marine energies. This is an ambitious project as few buoys have ever survived more than a few months in any of the western boundary currents world-wide, and non have transmitted data in real-time.

Super Buoy is a much larger system than *Data Buoy,* designed to withstand the harsh offshore environment with greater depths, currents in excess of 3 m s^{-1}, waves of 10 m, storm winds and distances of 10s of kilometers from the coast. It comprises a subsurface mooring positioned in the middle of the water column, in this case at a depth of 500 m, and a surface buoy which is position several kilometers way (Figure 8) on the nearby shelf where conditions are less severe. The name is

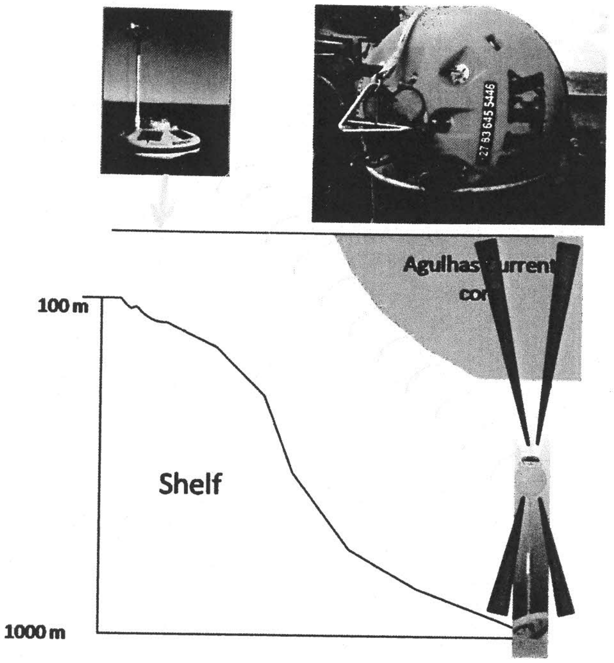

Figure 8: Super Buoy is a real-time monitoring system designed to withstand the severe conditions in the Agulhas Current. The syntactic float housing two ADCPs is deployed in 1000 m with the surface buoy deployed on the shelf edge in about 300 m. Data are transmitted from the ADCPs to the surface buoy using acoustic modems.

derived from the large syntactic float which has a diameter of 76 inches. The size and weight of the surface buoy and mooring requires a ship for deployment and retrieval.

The subsurface syntactic float accommodates two oppositely orientated Teledyne RDI 75 kHz, self contained, ADCPs. These instruments measure current velocity and direction above and below the mooring throughout the 1000 m water column, and temperature. Two acoustic modems, each dedicated to a single ADCP, transmit data to the surface. The surface buoy receives the transmitted data from the ADCPs, and together with data collected by surface metrological instruments, transmit these via GSM to a country-wide, land-based, cellular network approximately 20 km away, and then to a server based in Cape Town (www.cfoo.co.za).

Successful trails for the *Super Buoy* prototype were completed in the Agulhas Current off Port Edward between September 2010 and January 2011. After some minor improvements, and the installation of atmospheric sensors on the surface buoy, the system was permanent deployment in May 2011.

4.3. Multi-Mooring Single Surface Buoy Array (M2S2A) project

The *Super Buoy* project has paved the way for a second system to be deployed in the Benguela Jet off the Cape Peninsula in 2013. This current, although less energetic than the Agulhas Current and found in shallower water (~400 m), is narrow and displays substantial horizontal displacement. This is problematic when monitoring its behavior using a single bottom-mounted mooring.

A new 3-year THRIP project will be initiated in 2012 to develop a 5-point, real-time, bottom-mounted mooring system to monitor a horizontal distance of 20 km, ranging in depth between 100 and 800 m. The ADCP data will be transmitted horizontally from one mooring to another via acoustic modem (i.e. daisy chain) to the principal *Super Buoy* benthic mooring, and then to a surface buoy deployed inshore in 200 m of water. From here the data will be sent via GPRS to the main server in Cape Town.

The project will also attempt to incorporate into each mooring the new generation *Vemco* VR 4 acoustic tag receiver. These instruments will be supplied by the Ocean Tracking Network project (OTN) and used, in conjunction with the developed ADCP acoustic modem network, to provide an upload facility (node) for fish behaviour data collected by electronic tags deployed on various marine animals. These data will then be displayed on the worldwide web together with environmental data.

4.4. Real-time (RT) UTR project

The DT-UTRs have provided invaluable time series temperature data that have led to the discovery of physical processes and their monitoring. Now that some sites have 20 years of data, the network is used to track regime changes associated with climate change. Nonetheless, waiting for data for 6 months has caused frustration, particularly for fishermen who need near real-time temperature data.

To improve data delivery, the design of a cellular, dial-out UTR was locally initiated in 2010. The project was sponsored by the *South African Environmental Observational Network* (SAEON). The first prototype was deployed at Cape Point in June 2010 but lacked the battery power to meet the criteria of 6-monthly maintenance. Data are sent to www.cfoo.co.za. Prototype II, which now utilises a mini solar panel, will be deployed in June 2011. Once proven at Cape Point, three RT-UTRs will be deployed on the southern KZN coast to complement the *in situ* observational network being established there (see Module II).

4.5. Wave measurements from a moored ADCP

Well proven methods to measure sea surface waves include the real-time surface moored *Datawell Waverider* buoy and the DT quartz crystal shallow water pressure sensor which is limited to depths of 20 m. In the last decade however, ADCP technology has become more attractive because it also measures currents, and being moored subsurface, has less chance of suffering from a mooring failure or ship collision. The problem is, the ADCP needs to be attached to a fixed platform which limits this method to water depths of < 60 m. Mooring lines easily extend the depth range but the sway in large swells introduces error in the data.

In May 2011 a project was initiated to develop a method whereby waves can be measured using an upward orientated ADCP attached to a mooring line. The technique uses an accelerometer attached to the ADCP to remove mooring motion.

4.6. HABs real-time monitoring

A coastal buoy has also been developed for early detection of HABs in St Helena Bay by the CSIR and DAFF (Fawcett et al., 2006). This measures currents, fluorescence and reflectance, with data and products available at habs.org.za.

5. THE *OCEANSAFRICA* INITIATIVE

The collaborative *OceanSAfrica* initiative was first conceived at a workshop on operational oceanography arranged in Cape Town in July 2009 under the auspices of the Applied Centre for Climate and Earth Systems Science (ACCESS). International experience showed that operational oceanography is multidisciplinary in nature and cannot be done by one institution alone. Coalition with specialist organizations was necessary.

In view of this, *OceanSAfrica* aims to develop operational activities in South Africa, and through a combination of modeling and observations, to deliver regular and systematic information on the state of the ocean that is of known quality and accuracy on open ocean to shelf scales — ultimately with forecasts. Partners include the Department of Environmental Affairs (DEA), University of Cape Town (UCT), Council for Scientific and Industrial Research (CSIR), South African Environmental Observation Network (SAEON), Marine Remote Sensing Unit (MRSU), South African Weather Service (SAWS), the Institute for Maritime Technology (IMT) and Bayworld Centre for Education and Research (BCRE).

OceanSAfrica comprises 4 pillars — *in situ* observations led by DEA, remote sensing led by the CSIR, modeling led by the *Simocean* grouping (UCT, CSIR and Nansen Tutu Institute), and data dissemination led by SAEON. The four pillars host and manage their own websites, which are also accessible through the OceanSAfrica portal http://www.cfoo.co.za/oceansafrica (URL is temporary). Goals, R&D, collaboration and reporting are coordinated through the *OceanSAfrica* Technical Task Group (TTG) which meets bimonthly and is mandated by its Statement of Intent (see http://www.cfoo.co.za/oceansafrica). With the successful demonstration of the viability of an operational oceanography system, the emphasis will shift to designing and implementing a sustained operational oceanographic service for South Africa, under the leadership of DEA Oceans & Coasts. This will require the integration of all 4 pillars, a role out program of monitoring equipment, additional levels of technical support, data quality control and round the clock maintenance — aspects all well suited to government funded agencies.

6. INTEGRATION AND DEVELOPMENT OF A REGIONAL *IN-SITU* OBSERVATIONAL NETWORK

Advances in technology now allow for the most comprehensive real-time monitoring systems using fixed and mobile platforms, and satellites, all with an increasing number of reliable sensors types. Examples are the Atlas mooring arrays TAO/PIRATA/RAMA placed around the planets equatorial regions (http://www.pmel.noaa.gov/tao/data_deliv/deliv.html) and Subsea Cabled Observatory Network Systems with coupled use of gliders, ascending CTDs, ROVs, AUVs, etc (http://oceannetworks.ca/). Mindful of the costs of such systems and the resources needed to successfully maintain them, it is however only prudent that South Africa as a developing country selects a more modest approach which meets its specific needs, and importantly, is realistically sustainable.

A fully developed operational oceanographic service such as *MyOcean* (www.myocean.eu.org) is highly desirable, but this will take time to achieve. At the moment weather and ocean models, fisheries, MPAs (coastal and offshore) and ecosystem shifts as a result of global change are important activities and issues which require observational data and monitoring to address them. An *in situ* observational network will therefore need to be strongly orientated towards ecosystem functioning which implies measuring and monitoring key physical (and biological) processes such as currents, stratification, winds, upwelling, production as well as providing data to improve both atmospheric models, and long-term datasets (Figure 1). Some distant monitoring is also necessary to validate and ultimately improve the skill of both regional atmospheric and ocean models.

These will be complimented by satellite observations collected by the MRSU.

In January 2011, the newly formed branch *Oceans &Coasts* in DEA formally adopted *Operational Oceanography* as one of its 4 core programs with emphasis initially on establishing an operational *in situ* and long-term monitoring network and service. The domain was determined by the atmospheric and ocean models and South Africa's EEZ (Backeberg et al., this issue). The network, comprising both real-time and delayed time sites, will cover key coastal, shelf, and deep ocean processes and regions, and include atmospheric measurements (Figure 1). Deep ocean monitoring will be developed through collaboration with regional programs in the Atlantic, Indian and Southern Oceans.

A modular plan has been adopted by DEA Oceans & Coasts to be implemented between 2011 and 2016. While the modules link together to ultimately produce an operational *in situ* observational service, many can be and must be undertaken simultaneously.

6.1. Module I: Observational ship data

DEA Oceans & Coasts will immediately take over and manage the 28-year old research ship environmental dataset for the South African shelf region. It will maintain all principal physical (CTD, S-ADCP, continuous) and meteorological (atmospheric pressure, wind direction and speed) sensors on the research vessels, including calibration and data quality control. Copies will be provided to the South African Data Centre for Oceanography (SADCO) for back-up. The SHBML and SARP will similarly be maintained. In collaboration with SAEON, products for individual cruises and climatologies will be developed and made available online for model validation and users.

The observational system will be expanded to include three region monitoring lines outlined in section 3.6: the existing Good Hope line and the establishment of the two new monitoring lines Cape Town- Prince Edward/Marion and Cape Town- Gough Island.

6.2. Module II: Integration and demonstrated delivery — KZN observational node (2011-2013)

DEA Oceans & Coasts will integrate existing delayed mode and real-time monitoring networks to form the base of its *in situ* observational network, i.e. the routine ship-based sampling (DAFF), the South African UTR network, the CSIR WaveNet and the SA Navy Hydrographic Office tide gauge network. It will take over the maintenance of the two demonstration real-time coastal buoys off Umkomaas (*Data Buoy I)* and Amanzimtoti (*Data Buoy II*) which already monitor maritime conditions south of Durban harbour and perform important roles in ecosystem monitoring, effluent discharge management, recreational diving and fishing, and tanker activities at the petroleum refinery's Single Buoy Mooring (SBM) off the Bluff — these activities all beginning to define the user group of an operational system. Southern KZN has the greatest concentration of maritime activities in South African waters and is the ideal location for initiating operational oceanography.

In keeping with the theme of demonstrated delivery of a manageable but comprehensive operational system — the offshore *Super Buoy* project near Port Edward will also be adopted by DEA Oceans & Coasts, but this will be complemented in 2012 with a shore-based radar system to provide surface currents and waves: while the two upward and downward orientated ADCPs on *Super Buoy* can provide data throughout most of the 1000 m water column on the continental slope and in the core of the Agulhas Current, data deteriorate near (~50 m) the seabed and sea surface boundaries leaving gaps in the delivery of information. To complete an operational oceanography service, it is anticipated that the Port Edward *Super Buoy* and radar will also provide *in situ* data to calibrate satellite derived Synthetic Aperture Radar (SAR) data, which in turn will make available surface maps of the currents on the east coast of South Africa — a product long desired by shipping. Shore-based metrological stations will be deployed at Port Edward and Amanzimtoti.

Critical to the success of this operational oceanography service are (1) committed long-term budgets, (2) speedy procurement of equipment and services, (3) ship time for maintenance, (4) increased human resources with the necessary skill sets, and (5) easy public access to the data and products. These will need to be developed alongside the operational network to ensure the goal of 90% online for all measurement platforms. To assist in obtaining the correct skill sets, a training program is now in place with the Cape Peninsula University of Technology (CPUT) where students will obtain a Masters degree in Technology (M Tech degree) specialising in physical and observational oceanography.

Once established by the end of 2012, the southern KZN observational node consisting of one DT-UTR, three RT-UTRs, two metrological stations, the two coastal *Data Buoys*, *Super Buoy*, and a radar station will be maintained operationally for a period of two years to complete this phase.

6.3. Module III: Expansion of the *in situ* observational network in South Africa

This phase will see the upgrade and expansion of the UTR network along the South African coast with RT-UTRs, the deployment of *Data Buoys* in Algoa Bay to complement the SAEON network (Goschen and Schumann, 2011), the Tsitsikamma National Park existing monitoring site (Roberts and van den Berg, 2005), and St Helena Bay to complement the existing trans-shelf monitoring line (SHBML). A second *Super Buoy* will be deployed off the Cape Peninsula to begin monitoring the Benguela Jet (and complement the SARP line).

These will be complimented by an offshore delayed-time network comprising 5 ADCP moorings, which aside from bottom temperature and currents, will measure the wave field on the Agulhas Bank along the 80 m contour between Cape Columbine and Algoa Bay (Figure 4). These data will complement the existing CSIR's WaveNet as well as used to validate/calibrate models and remote sensed data from satellite and radar.

6.4. Module IV: Regional expansion, integration, data quality and training

The lack of funding and ship time to maintain the Western Indian Ocean (WIO) component of the UTR network is a major problem. This network of sensors, all at the depth of 18 m, is becoming extremely valuable as a long-term temperature dataset (Figure 4) and is unique to the region. It complements satellite data and other larger, deep ocean arrays such as the tropical RAMA and Mozambique Channel LOCO arrays by providing shelf data — all focused on climate variability and global change. Finding funding to maintain and expand the existing WIO DT-UTR network must be a priority and achieved before the data memory of the instruments in the field become full.

As indicated in Phase III below, the modelling pillar of *OceanSAfrica* will require *in situ* data from remote locations in the model domain to improve skill. Some of these data can be provided by the RAMA array in the Indian Ocean and the south-eastward extension (SEE) of the PIRATA array in the Atlantic Ocean. The latter in particular will only happen if South Africa shows a strong desire to have these observations, and moreover, is prepared to deploy and maintain Atlas buoys as Brazil is already doing on the western side of PIRATA. This implies South Africa must become a member of PIRATA and RAMA, develop the skills necessary to operate the Atlas buoys, guarantee ship time, and purchase several buoys. Training will need to come from the PIRATA and RAMA stake holders i.e. NOAA and IRD. Additional platforms outside of the PIRATA- SEE and RAMA areas of interest may well be required to improve model skill. Positions need to be directed by the model studies and analysis but clearly will involve large buoy systems such Atlas buoys.

6.5. Module V: Assimilation of *in situ* observational data into models

Once the *in-situ* observational network is operational and robust, the real-time transmitted data will be sent to the ocean modelling group (*Simocean*) based at the University of Cape Town for assimilation into, and validation of the regional ocean model. As indicated in module III, optimisation of the *in situ* measurement network (particularly position in the model domain) will need to be undertaken to improve model skill.

6.6. Module VI: Science and technology to support *in situ* observations

Paramount to any *in situ* observational system is a scientific understanding of the physical (and biological) environment it is measuring. In South Africa many of the physical (and biological) processes have received attention but this is mostly in the Benguela upwelling region on the west coast where the major commercial fisheries are based (e.g. Shannon and Nelson, 1996). The Agulhas Current has also received considerable attention as evident in Lutjeharms (2006). But in contrast, the Agulhas Bank and the east coast shelf have received much less attention.

Areas and processes which need attention for the *in situ* observational system to be most useful are: the cold ridge on the Agulhas Bank which is thought to be an important process for production. Notwithstanding several studies, the mechanism under laying this feature is still not known even with modelling (Chang 2008). The Benguela jet has also received considerable attention because of its importance in transporting eggs and larvae from the spawning grounds of the Agulhas Bank to the feeding grounds of the west coast. But the dynamics are not well understood. Another is the Tsitsikamma coastal counter-current (Roberts and van den Berg 2005). This plays an important role in the transport of biological material in the Tsitsikamma National Park, and also transports away from the cold ridge region. Its dynamics are quite well understood but its origin, termination and width are unknown. Apart from some S-ADCP cruise data (Boyd et al, 1994; Roberts 2005), very little is known about the mid and outer shelf currents on the eastern, central and western Agulhas Bank. Average S-ADCP data suggest a continuous net westward flow which feeds into the Benguela jet, but moorings need to be deployed to test this. Also the temporal behaviour of the Agulhas Current along with cyclo-genesis (Natal pulse and Durban break-away eddy) off southern KZN coast require attention. Of great importance is the effect of these cyclones on the shelf oceanography and ecosystem of the KZN, the Transkei and eastern Agulhas Bank. For example, monitoring cyclo-genesis could be useful in predicting the arrival of sardines in KZN. These studies will additionally provide information and data to improve and validate the oceans models (*Simocean*).

R&D must continue on the *in situ* observational system to improve the sustained delivery of reliable and accurate data. Platforms, sensors and communication technology will need improvement to meet local conditions and with latest products. For example, while *Data Buoy* has been successful in terms of ocean measurements, the surface buoy tilts in a current > 1 m s^{-1} which might be compromising the meteorological sensors. This could require a new buoy design necessitating wave and current tanks. There is also the development of the expanded *Super Buoy* project and the measurement of waves from deep, swaying moorings, these both requiring advances in modem acoustic data management and signal processing. The ADCP mooring wave project requires R&D in signal processing.

Although DEA Oceans & Coasts may not be directly involved with the development of SAR products, the radar data will be useful for calibration purposes which will provide the South African *in situ* observational system with horizontal regional current data.

7. CONCLUSION

The diversity, complexity and high energy of the ocean systems surrounding southern Africa have been highlighted. These present a challenge to the many marine activities which occur here and affect parameters such as operations, performance and safety, as well as to the management of ecosystems, fisheries, coastal communities, disasters, and moreover, weather prediction. In terms of climate change research, this region is also pivotal in the transportation of heat and salt from the Indian Ocean into the South Atlantic Ocean, providing a source for the equatorward flux in the Meridional Overturning Circulation (MOC). The *OceansAfrica* initiative, through its four complimentary pillar projects (*in situ* observations, remote sensing observations, modeling and data dissemination), is a partnered scientific community and governmental (DST and DEA) response to these challenges which aims to understand, monitor and predict key elements of these ocean systems and importantly to freely disseminate information into the public domain as a service. In this paper, the modular plan to develop and implement the *in situ* ocean observational network for the region is presented. This builds on existing monitoring efforts by a number of institutions and includes local R&D of buoy and sensor prototypes suitable for the energetic conditions found in this region. This observational network will be linked into the regional PIRATA and RAMA tropical arrays, and will form key components of the BCC and ASCLME proposed long term ecosystem monitoring programmes. Ultimately, these data will be used to provide an ocean state and prediction service to the public.

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