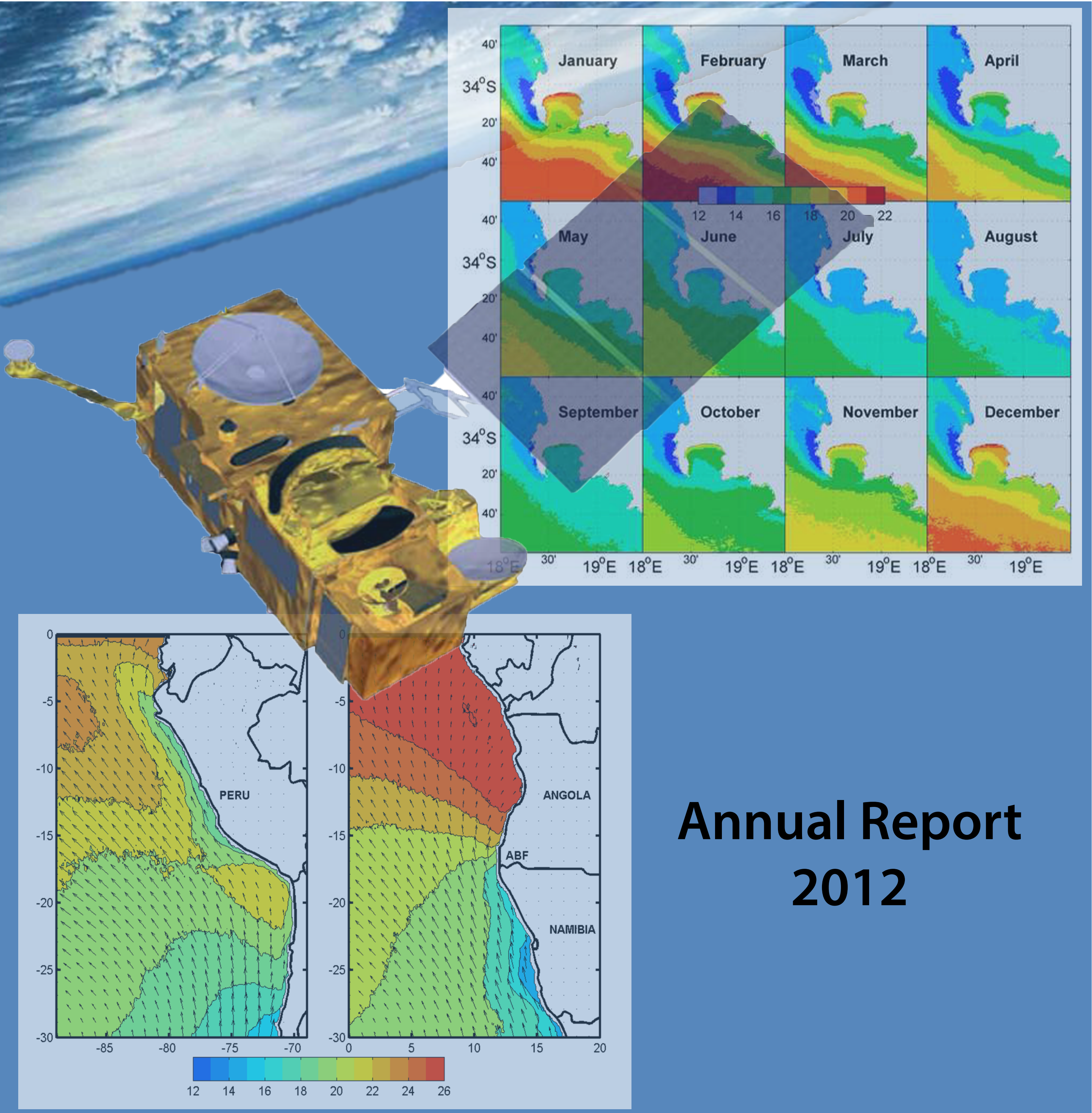

Annual Report 2012

Nansen-Tutu Centre for Marine Environmental Research

affiliated with the University of Cape Town
Cape Town, South Africa

2012 – Report from

The Board

Vision

The vision of the Nansen-Tutu Centre for Marine Environmental Research is to serve Africa through advancing knowledge of the marine environment and climate system in the spirit of Nobel Peace Laureates Desmond Tutu and Fridtjof Nansen.

Research Activities

The aim of the Centre is to improve the capacity to observe, understand and predict marine ecosystem variability on timescales from days to decades in support of scientific and societal needs including fisheries, coastal management, maritime security, recreation and tourism. To this end, one of the core activities at the Centre will focus on education and exchange of young researchers and students from different cultures and countries through the Nansen- Tutu Scholarship Program. The approach adopted by the Nansen- Tutu Centre is to develop and implement state-of-the-art ocean observing and modelling systems related to the unique position of South Africa at the meeting place of the cool Benguela Current adjacent to the warm Agulhas Current, and close proximity to the Southern Ocean. The focus is to study the variability of these current and ocean systems on a variety of time scales in relation to their mutual local and regional interaction with the atmosphere and land, rainfall patterns, and other weather patterns vital to society.

In developing and implementing the technology and expertise to observe and model ocean and climate variability, the skills needed in southern Africa will be updated and expanded through priorityresearch and development activities.

***Cover image:** ESA's Sentinel-3 satellite. Sea surface temperatures of False Bay, sea surface temperatures and winds of the Benguela and Peru upwelling systems. Courtesy: Mathieu Rouault (Nansen-Tutu Centre for Marine Research, UCT, Cape Town, SA)*

Organisation

The Nansen-Tutu Centre is a non-profit research institute hosted at the Marine Research Institute and the Department of Oceanography at the University of Cape Town. The administrative and legal responsibilities reside with the University of Cape Town. It is a joint venture agreement between the founding partners: Marine Research Institute (MA-RE)/Department of Oceanography, University of Cape Town, Cape Town, South Africa, African Centre for Climate and Earth System Science (ACCESS), Council for Scientific and Industrial Research (CSIR), South Africa, the Nansen Environmental & Remote Sensing Centre (NERSC), Bergen, Norway, Institute of Marine Research (IMR), Bergen, Norway, Geophysical Institute, University of Bergen, Bergen, Norway, and Princeton University, USA. Funding for projects is applied for externally. Potential funding agencies include South African and Norwegian bodies, bilateral funding agreements, the European Union's Framework Programmes, space agencies, industry and private sponsors.

Staff

During 2012, the Nansen-Tutu Centre staff comprised 12 persons, including 1 PhD student, 2 MSc students and seconded researchers from some of its founding partners, including the Marine Research Institute and the Department of Oceanography at the University of Cape Town, the African Centre for Climate and Earth System Science at the Council for Scientific and Industrial Research, Princeton University, the Institute for Marine Research, the University of Bergen and the Nansen Environmental and Remote Sensing Center. In addition the Nansen Scientific Society has contributed support to the MSc and PhD students.

Scientific Production

2012 was a productive year for the Nansen-Tutu Centre. One co-funded PhD candidate (Issufo Halo) completed his PhD, and will join the NTC as a Post-Doctoral researcher in 2013; two fully supported Masters students completed the Ocean and Climate Dynamics Taught MSc course.

- Dr Issufo Halo. The Mozambique Channel Eddies: Characteristics and Mechanisms of Formation. Department of Oceanography, University of Cape Town, South Africa. Supervisor(s) at the Nansen-Tutu Centre: N/A. Co-funded by the NTC in 2012.
- Mr Francisco Gemo Albino Francisco. Wave energy distribution across the Agulhas Bank, a source of renewable energy for a seawater pumped storage scheme. Department of Oceanography, University of Cape Town, South Africa. Supervisor(s) at the Nansen-Tutu Centre: C. J. C. Reason. Funded by the NTC.
- Mr Joseph Amollo. Aspects of sea level variability in the southwest Indian Ocean and the east coast of Africa – (latitude 0-35°S and from the coast to 60°E). Department of Oceanography, University of Cape Town, South Africa. Su-

pervisor(s) at the Nansen-Tutu Centre: F. A. Shillington and J. A. Johannessen. Funded by the NTC.

Thirteen on-going students at BSc (Hons), Masters and PhD level were co-supervised by the NTC scientists.
A total of thirteen publications emanated from the centre, which included: nine papers in peer reviewed journals published or in press; one chapter in a book; two conference proceedings; and one popular article.

Awards

Drs Bjorn Backeberg and Chris Reason were awarded the **Stanley Jackson Award** by the South African Society for Atmospheric Sciences (SASAS), for the best published paper contributing to the atmospheric and oceanic sciences in South Africa during 2012 for the paper *"A connection between the South Equatorial Current north of Madagascar and Mozambique Channel Eddies"*, which was published in 2010. Only papers published within two years of the SASAS annual meeting are eligible for the award.

National cooperation

OceanSAfrica Technical Task Group (TTG)

The Centre has been actively involved with driving and helping the collaborative *"Operational Oceanography Group"*, so called *OceanSAfrica Technical Task Group (TTG)*, which comprises personnel from the four main oceanographic institutions in Cape Town and the South African Weather Services (SAWS). This group met four times during the year, with active input from the NTC and members of the Department of Oceanography.

Collaboration with ICEMASA and DEA

Scientists at the NTC continue to collaborate with French and South African partners on research in the Mozambique Channel through the MESOBIO project. A special issue on the research in the Mozambique Channel is scheduled for publication in 2013 in Deep-Sea Research.
Following on from the successful MESOBIO project, the NTC contributed towards the ACEP proposal, led by Dr Mike Roberts. This project now accepted is in collaboration with partners at ASCLME, Oceans & Coasts DEA, Oceanographic Research Institute, South African Institute for Aquatic Biodiversity, Rhodes University (Dept Zoology and Ento-mology), University of Cape Town (Oceanography Dept), University of KwaZulu-Natal (School of Biological and Conservation Sciences), Paris Museum, Barcode of Life (University of Guelph), Institut d'Halieutique et des Sciences Marines - University of Toliara, Natural History Museum, London, South West Indian Ocean Fisheries Project, South African Environmental Observation Network. The project revolves around the importance of eddies from Madagascar, providing the link between ecosystem similarities on the East Coast of Africa and Madagascar.

International activities

SANORD Symposium

Prof. Johnny A. Johannessen attended the SANORD 2012 Symposium in Århus, Denmark on 6-7 June 2012. The symposium addressed three important questions in the context of collaboration between universities in Southern Africa and the Nordic countries:

- *University governance: Building institutional capacity for participation in international knowledge networks,*
- *Synergies in North-South collaboration: From bilateral collaboration to knowledge coalitions,*
- *Tomorrow's common research priorities for Nordic and Southern African universities.*

Prof Johnny A. Johannessen presented information on the Nansen-Tutu Centre for Marine Environmental Research in the session: *Tomorrow's common research priorities for Nordic and Southern African universities* and emphasized the multidisciplinary areas of research that are prioritized in the Nansen-Tutu Centre for Environmental Research, and where the collaboration between Southern African and Norwegianinstitutes and universities has special merits in a global context. More information on SANORD is found at http://sanord.uwc.ac.za/.

Joint France - South Africa Marine Science Workshop on a satellite and in-situ field experiment in a turbulent ocean

Profs Frank Shillington, Johnny Johannessen, and Drs Bjorn Backeberg and Mathieu Rouault attended the international workshop on mesoscale and sub-mesoscale processes at the Centre for High Performance Computing, Rosebank, SA in June 2012. The workshop that took place on 11-12 June 2012 and brought together scientists from South Africa, France and Norway to consider the potential for collaboration in setting up a joint, extensive and innovative field (both satellite and in-situ) experiment, specifically devoted to the monitoring of sub-mesoscale processes, in order to quantify their impact on the spatial organization, functional biodiversity and ecosystem dynamics as well as on the atmosphere- ocean fluxes. The workshop attempted to define the criteria for the section of locations for the experiment in the Southern ocean and/or Agulhas current regions, with a focus on the Agulhas Retroflection and the Cape Basin. Given the strong collaboration that has existed and continues today among South Africa, French and Norwegian groups, and the development of South African marine science (with the recent acquisition of the SA Agulhas II), implementing a major field experiment in the South African waters over the next four years would be an ideal way of furthering these relationships. In addition, this experiment can serve as a platform for participation of other nations with expertise and experience in the region.A second follow-on workshop on *"Diagnosis of vertical exchanges at the sub-mesoscale and their impact on ecosystems, from integrated satellite and in-situ observations"* took place at Ifremer, Brest, France on 28-29 November 2012. The purpose of the 2nd workshop was to share ideas and experiences and discuss what would be the most appropriate field experiment (in terms of satellite and in situ observing systems and strategies) in order to: (i) monitor the dynamical interactions between sub-mesoscale structures and mesoscale eddies; and (ii) quantify the impact of meso/sub-mesoscale dynamics on the spatial organization of biomass density. In addition the workshop aimed at gathering interest in the international community around a future field experiment that may take place in South African waters in 2015 and or 2016.

The Agulhas System and its Role in Changing Ocean Circulation, Climate, and Marine Ecosystems (Stellenbosch, South Africa, 7-12 October 2012)

The main goal of this International Chapman – AGU conference held in Stellenbosch, South Africa, was to identify the most pressing questions and to design modeling experiments in combination with paleo-oceanographic and (sustained) modern observations to establish the role of the Agulhas system from regional to global scales (see http://chapman.agu.org/agulhas/). Scientists from the Nansen-Tutu Centre actively participated in the conference, giving both oral and poster presentations, including invited keynote presentations from Drs Bjorn Backeberg, Mathieu Rouault and Prof Chris Reason.

Seventh Framework Programme, Marie Curie Actions, People International Research Staff Exchange Scheme

The Centre contributed to the successful Seventh Framework Programme proposal, Marie Curie Actions, People International Research Staff Exchange Scheme. The proposal entitled *"The role of Southern Ocean Carbon cycle under Climate change"* includes collaborators from UiB, CNRS-IPSL, NERSC, NTC-UCT, and the CSIR – a South Africa, France, and Norway collaboration. The Nansen-Tutu Centre is tasked with developing data assimilation capabilities; this highlights the first project for which Centre has received EU-funding.

Nansen-Tutu Centre / University of Cape Town - University of Sao Paulo - NERSC collaboration

The Centre was involved in a proposal led by Prof Edmo Campos (University of Sao Paulo), which was accepted in the India-Brazil-South Africa (IBSA) program for ocean numerical modeling with the main goal to develop a downscaling system to investigate impacts of large-scale climate changes on coastal regions of the three countries.

This collaboration resulted in Dr Bjorn Backeberg visiting the University of Sao Paulo in November 2012, following which a Memorandum of Understanding was signed between the Universities of Cape Town and Sao Paulo. Funding was allocated to the Centre from the South African National Research Foundation under the South Atlantic Meridional Overturning Circulation project for 2013/2014 (145 000 ZAR per annum) including student bursaries, travel and equipment. Dr Isabelle Ansorge is the South African lead scientist for this project.

GODAE OceanView Science Team

Dr Bjorn Backeberg was invited to attend the 4th annual meeting of GODAE OceanView Science Team (GOVST-IV) in Rio de Janeiro, Brazil from 5-9 November 2012.He presented an overview of the South African operational oceanography initiative: OceanSAfrica, in which the NTC is actively involved.

Inauguration of the Kongsberg Satellite Services (KSAT) antenna at Hartebeesthoek ground station

KSAT has recently completed the construction of a satellite tracking facility hosted and maintained by the South African National Space Agency (SANSA) at its space operation site in Hartebeesthoek.

The facility will strengthen the links between South Africa and Norway and the Norwegian Embassy is happy to see how this cooperation fits into the long tradition of South African and Norwegian partnership in various advanced technical areas. Many institutions benefit from the discussion of developing new opportunities in these areas. Some examples are the combination of satellite data reception and maritime surveillance services for oil spill and ship detection, as well as environmental monitoring for land applications.

To mark the inauguration of facility an Earth Observation Workshop was held in Muldersdrift, Johannesburg, on 4 December 2012. Participants included KSAT, SANSA, NSC, Department of Science and Technology, SA Maritime Safety Agency, Council for Scientific and Industrial Research, DIRCO, The Norwegian Coastal Administration, University of Pretoria, Earth Observations, Marine Data Solutions, The Nansen Tutu Centre, The Nansen Centre, Innovation Norway and the Royal Norwegian Embassy. Presentations on future possible areas for cooperation were made. In the discussion, several ideas came up, both within maritime monitoring and forest carbon tracking. Norway has operational services based on satellite radar data, and cooperation between South Africa and Norway would be beneficial for both countries. The Government of Norway has placed a priority on Reduced Emissions from Deforestation and Forest Degradation (REDD) activities. These have strong worldwide support in establishing national forest monitoring systems, in which satellite data play a pivotal monitoring role. Possible South African involvement in this global initiative was discussed.

Nansen-Tutu Centre colloquium on Ocean, Climate and Space: How satellite remote sensing helps us to understand our planet

Dr Mathieu Rouault arranged a one day colloquium hosted by the NTC on satellite remote sensing in the SW Indian Ocean on 7 December 2012, during which scientists from the NTC presented their research activities to students from Madagascar and the Southwest Indian Ocean Region.

National and international committees

Dr Bjorn Backeberg was invited to become a member of the GODAE OceanView Symposium & Review Programme Committee for the GODAE OceanView Symposium & Review to be held in Washington DC, November 2013.

Dr Mathieu Rouault is the President of the South African Society for Atmospheric Science, and responsible for organising its annual scientific conference. He is a member of the international CLIVAR Atlantic committee, the international CLIVAR Africa committee, chairman of the international PIRATA SEE program and member of the observation com-mittee of the international TACE experiment.

Financial situation

The majority of funds for the NTC came from Norway: 1,200,000 NOK from NERSC (500,000 NOK); IMR/CDF (500,000 NOK); Nansen Scientific Society (100,000 NOK); University of Bergen, GFI (100,000 NOK) and the Norwegian Embassy (280,00 NOK). Substantial support also came from ACCESS (ZAR 748,213) and in kind contributions from UCT staff funds.

Prospects for 2013

- Develop South African data assimiliation capabilities at the University of Cape Town.
- Support 1 new MSc student and continue supporting Dr Issufo Halo in his Post-doctoral research fellowship.
- Continue successful cooperation with national and international partners.
- June 2013 board meeting to discuss the way forward.

Signed, the Board members
Cape Town, 7 June 2013

NANSEN-TUTU CENTRE
MARINE ENVIRONMENTAL RESEARCH

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IMPACT OF INTENSIFIED INDIAN OCEAN WINDS ON MESOSCALE VARIABILITY IN THE AGULHAS SYSTEM

Björn C. Backeberg, Pierrick Penven and **Mathieu Rouault**

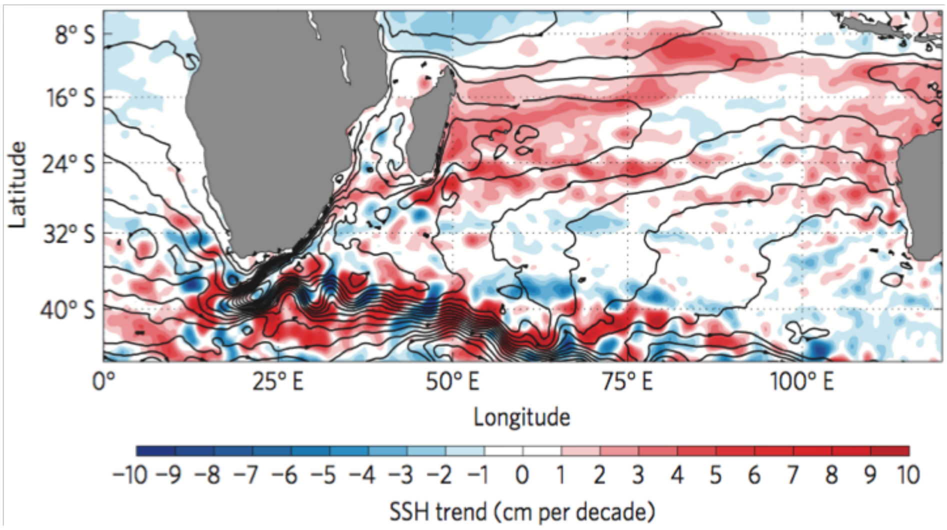

***Figure 1**: Decadal trend of gridded SSH data from 1993 to 2009, a uniform global mean decadal trend of 3.4 cm per decade has been removed to account for the global sea level rise since 1993. The black contours indicate the mean SSH for the period.*

South of Africa, the Agulhas Current retroflects and a portion of its waters flows into the South Atlantic Ocean, typically in the form of Agulhas rings. This flux of warm and salty water from the Indian to the Atlantic Ocean (the Agulhas leakage) is now recognized as a key element in global climate. An Agulhas leakage shutdown has been associated with extreme glacial periods, whereas a vigorous increase has preceded shifts towards interglacials. In the absence of a coherent observing system, studies of the Agulhas have relied heavily on ocean models, which have revealed a possible recent increase in Agulhas leakage. However, owing to the high levels of oceanic turbulence, model solutions of the region are highly sensitive to their numerical choices, stressing the need for observations to confirm these important model results.

Ocean current information derived from sea surface height measurements from satellite altimeters play a very important role in advancing our understanding of the mesoscale variability in the global ocean. Moreover, almost 20 years of altimetry data is now available, allowing us to study long-term changes in the ocean, including sea level rise. On a global scale, sea level rise is not geographically uniform. Figure 1 presents the decadal trend of sea surface height (SSH) in the Indian Ocean for the period 1993–2009. An increase reaching 5 cm per decade is evident between 8º and 30ºS east of Madagascar, whereas there is a marked decrease in the north. South of 30ºS the pattern is less clear, showing a tendency towards a negative trend between 30º and 40ºS and an increase between 40º and 45ºS.

Mean SSH contours are overlaid to help analyse regional changes with respect to major surface currents (Figure 1). East of 100ºE, SSH has increased by 2 cm per decade in the Indonesian Throughflow region. A strong positive trend, reaching 4 cm per decade, is centred near 10ºS, between 70º and 100ºE, in the core of the South Equatorial Current. North of the South Equatorial Current and the North Madagascar Current from the African coast to 70ºE, a decreasing trend of 3 cm per decade is observed. A striking feature is the large increase (5cm per decade) within the gyre (12º–30ºS,

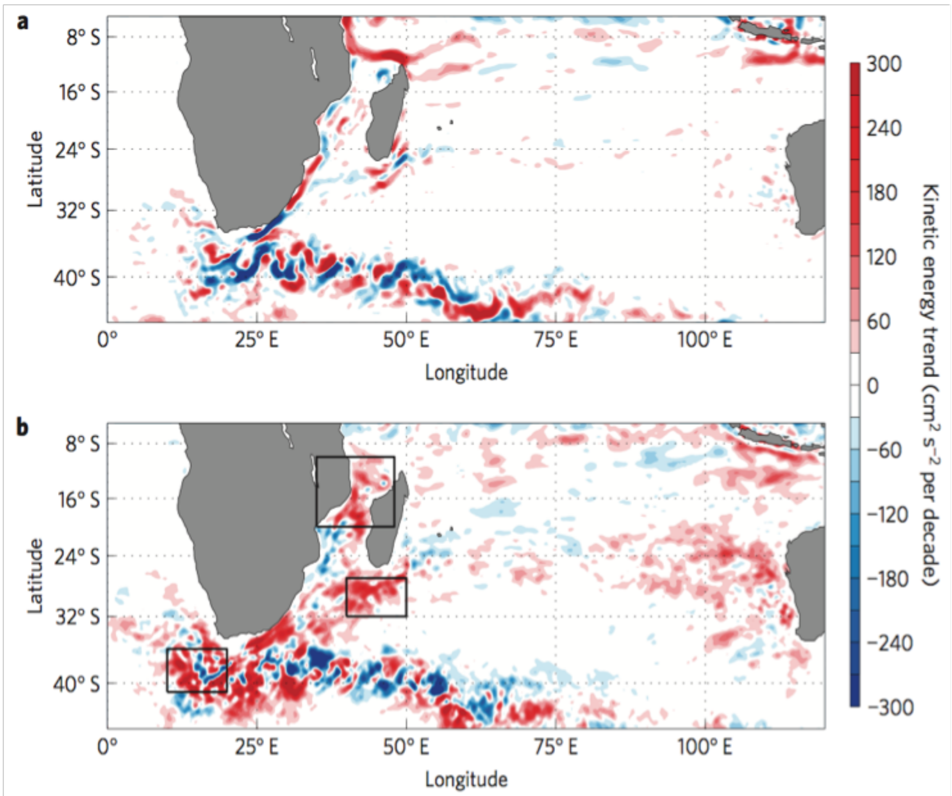

***Figure 2:** (a) Decadal trend of the MKE calculated from absolute geostrophic velocities derived from altimetry SSH measurements for the period 1993–2009. (b) The corresponding decadal trend of the EKE for the same period.*

40º–80ºE) that is associated with the North Madagascar Current and the East Madagascar Current. This positive trend extends from south of Madagascar to the Agulhas Current. The pattern is more complex in the Agulhas Current region, with a decrease along the South African south and east coasts (20º–30ºS) and a general increase downstream of the Agulhas retroflection and in the Agulhas Return Current between 35º–45ºS and 20º–75ºE.
The geostrophic approximation leads to a simple relationship between ocean currents and the slope of the sea surface: SSH gradients are proportional to surface geostrophic currents. Considering the geostrophic circulation associated with the observed changes in SSH gradients, Figure 1 suggests a general increase in surface currents within the western subtropical Indian Ocean, particularly between 50º–75ºE and 8º–30ºS, with an enhanced pressure gradient north of Madagascar and an intensified anticyclonic gyre east and south of Madagascar.
These increased large-scale circulation and pressure gradients are reflected in surface geostrophic velocities, particularly for the western side of the domain (Figure 2a,b). The mean and eddy kinetic energies show that the mesoscale variability of the Agulhas system—in particular its source regions—has intensified from 1993 to 2009, owing to an increased South Equatorial Current. By implementing an eddy tracking algorithm, the impact on the eddies was quantified, showing that enhanced mesoscale variability is reflected in accelerated eddy propagation throughout the Agulhas system. In the retroflection, from which eddies propagate into the South Atlantic Ocean, this suggests that the Agulhas leakage may have increased from 1993 to 2009, confirming previous modelling results that have further implied an increased Agulhas leakage may compensate a deceleration of meridional overturning circulation associated with a freshening of the North Atlantic Ocean.

Understanding the development of Benguela Ninos in the tropical East Atlantic Ocean

Mathieu Rouault

Benguela Niños are warmer than normal oceanic events occurring along the Angola and Northern Namibia coastline. They have a strong impact on the marine ecosystem, fisheries and rainfall of the region. Our recent work shows that there is an important bi-annual transport of tropical water across the Angola Benguela Front (ABF) and that this transport follows a bi-annual harmonic, quasi-synchronized to the annual cycle of sea level anomaly in the eastern tropical Atlantic. Advection across the ABF is a key factor for the development of Benguela Niños in the Northern Benguela. Principal forcings for Benguela Ninos include a remotely driven deepening or shoaling of the thermocline, advection and variation of local net heat fluxes at the air-sea interface for Southern Angola and local wind stress and advection for Northern Namibia. Model results indicate that there is a net transport of tropical water in the Benguela upwelling system across the ABF at 17ºS and this transport follows a bi-annual harmonic (Figure 3) quasi-synchronized to the annual cycle of SLA in the eastern tropical Atlantic.
A possible scenario, is that the twice yearly relaxation of wind stress along the equator triggers coastal waves that propagate poleward and interact with the Angola Current, deepening

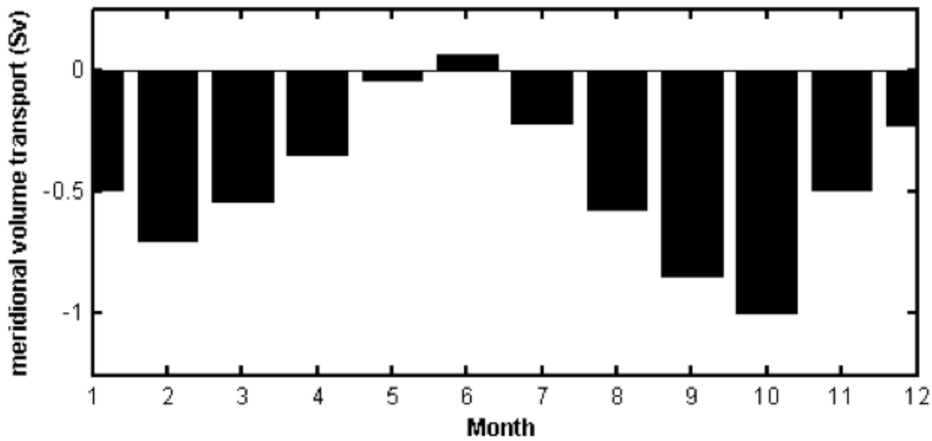

Figure 3: *Annual cycle of near surface meridional volume transport in Sverdrup at the Angola Benguela Front. (0 to 250 m depth and 8.75ºE to the coast at 11.5ºE).*

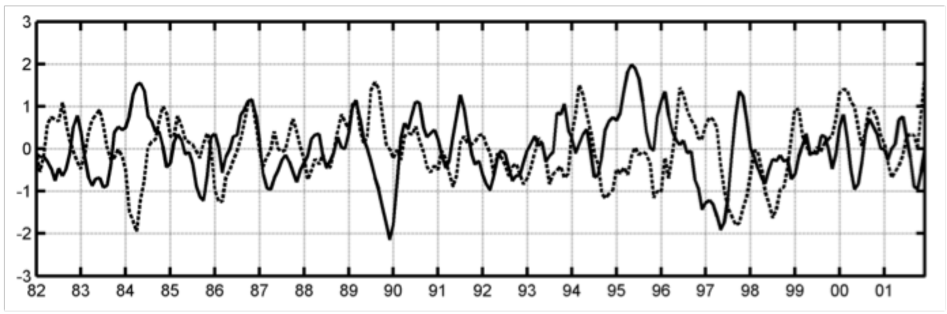

Figure 4: *Monthly detrended normalized anomalies of near surface meridional volume transport (dashed line) at the Angola Benguela Front (17ºS) and monthly detrended normalized anomalies of SST downstream averaged from 19ºS to 24ºS and from the coast to 1o offshore. A negative value of the transport indicates poleward motion.*

the thermocline and increasing the polewards flow leading to a stronger seasonal leakage of Angolan water across the ABF. The two to four months lead time (Figure 4) in late summer, the peak Benguela Niños season, between transport anomalies (leading) at the ABF and SST anomaly a few degrees downstream enable prediction of these events.

A cross-stream approach to studying the variability of the Agulhas Current

Marjolaine Krug

The Agulhas Current is the most intense western boundary current of the southern hemisphere and a key component of the global climate. Despite its importance at both global and regional scales, little remains known of the Agulhas Current's variability with an ongoing debate on its seasonality. Numerical ocean models show annual variations in the Agulhas Current transport, with a minimum in austral winter (August) and a maximum in austral summer (February). Previous observational studies however were unable to highlight evidence of a seasonal cycle in the Agulhas Current. Past analyses of observations in the Agulhas Current have relied on Eulerian time-averages of moored observations or remote sensing variables to estimate the current's variability. Numerous studies have shown that stream-coordinates are better suited to estimate the true synoptic structure of western boundary currents as they minimize the contamination caused by meandering flows on the time-averaged structure of the current. A previous study suggested that in the southern Agulhas region, south of 34S, large fluctuations in the path of the Agulhas Current could be captured using altimetry datasets. In this study, close to 20 years of Sea Surface Height (SSH) observations from altimeters are used to characterize the variability of the Agulhas Current along the Topex / Jason altimeter's Track #020 (Figure 5). The altimetry dataset used consists in the AVISO daily DT-MADT product. The AVISO product combines sea level anomaly signals from the OSTM/Jason-2, Jason-1 and Envisat altimeters to the mean dynamic topography of Rio09. The AVISO product is provided on a rectilinear grid with a spatial resolution of 1/3º and consists in 7-day moving averages of merged SSH observations. To determine the variability of the Agulhas Current, an algorithm to track the position of the current is developed and applied to the merged-altimetry along Track #020. The central position of the Agulhas Current determined from altimetry is defined as the local maxima in the along-shore current flow.

In agreement with pervious studies, variations in the position of the Agulhas Current are dominated by irregular offshore displace-

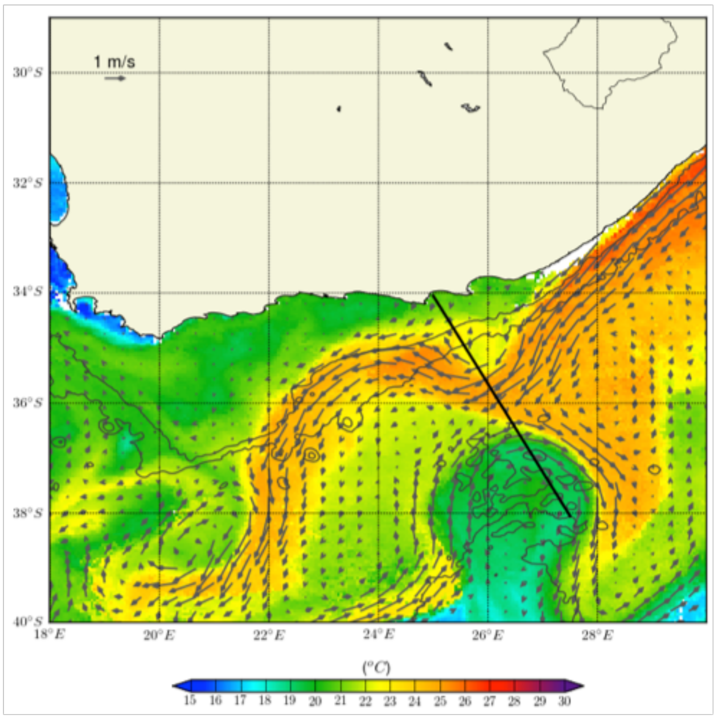

Figure 5: *Colour contour of a 5-day weighted average of SST over the greater Agulhas Current region. Overlaid vectors show the absolute geostrophic current vectors derived from the AVISO merged altimetry. Variations in the position and strength of the Agulhas Current are determined along Track #020.*

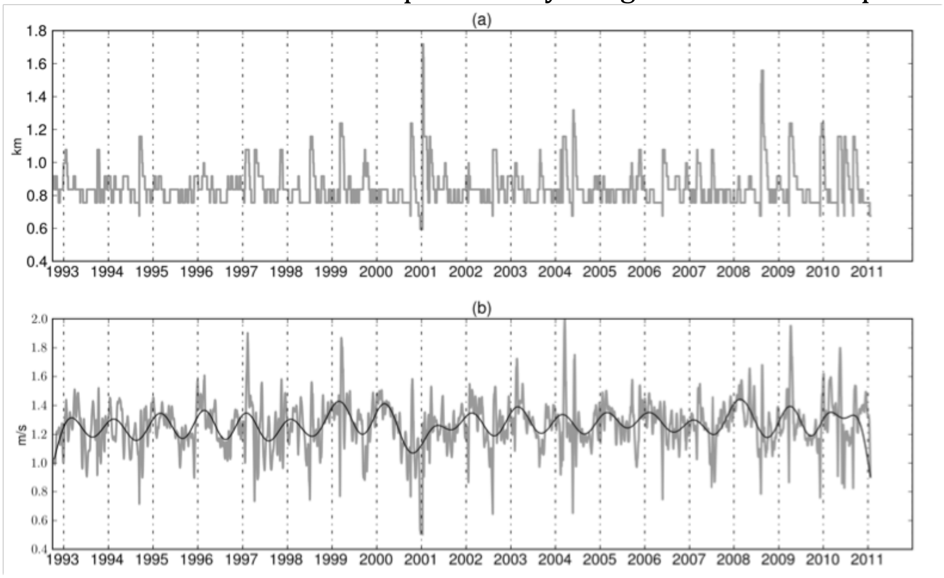

Figure 6: *(a) Distance from the Agulhas Current's core to the coast estimated from altimetry along the transect line plotted in Figure 5. (b) Absolute geostrophic current speed at the position of the Agulhas Current core (grey). The black line in (b) shows current speeds low-passed with a cut-off at 300 days.*

ments associated with the southward propagation of meanders at the inshore border of the Agulhas Current (Figure 6a). By following the path of the Agulhas Current, it becomes possible to separate the variability of the Agulhas Current from that of its surrounding waters. This stream-coordinate approach allows us to show that while the position of the Agulhas Current does not display an annual cycle, the geostrophic current speed at the current's core exhibits distinct seasonal variations, with a stronger flow observed in austral summer (Figure 6b). A spectral analysis conducted on the current velocities at the position of the moving Agulhas Current core (not shown) reveals that although intra-seasonal frequencies associated with offshore meanders do modulate the strength of the Agulhas Current flow, the main spectral peak occurs at a period of 1 year.

This study shows that within the Agulhas Current proper, it is the annual cycle that dominates the variability with a stronger flow in austral summer. This study also strongly emphasized the need for a stream-coordinate approach to adequately capture the variability of the Agulhas Current.

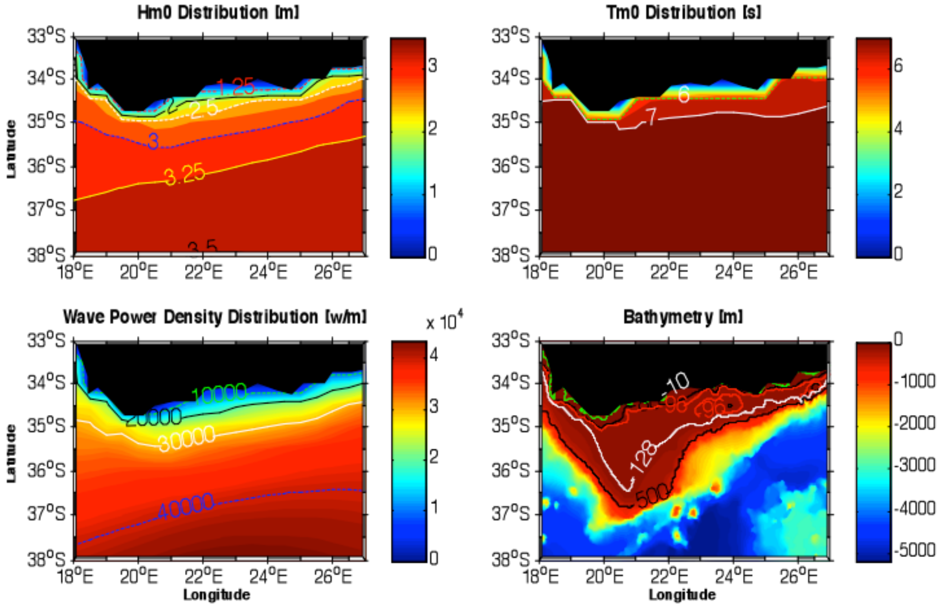

Figure 7*. Average spatial distribution of: (a) Hm0; (b) Tm0; (c) Wave power density; (d) Bathymetric contours of interest.*

Wave Energy Distribution Across the Agulhas Bank, a Source of Renewable Energy for a Seawater Pumped Storage Scheme

Francisco Francisco, **Chris Reason** and Mike Roberts

In South Africa, the demand for electricity is rising, and as the national grid expands so does the need for backup systems that can respond quickly to sudden surge demands or failure of base-load plants. The Pumped Storage Scheme (PSS) concept can provide suitable systems to support the national grid during these times. From site-screening studies, Eskom has identified several sites along the South-Western Cape coast suitable to build seawater pumped storage dams where wave and wind energy can be converted and used to pump sea water to a reservoir atop mountain. During peak periods or failure of the base-load plant, the sea water in the reservoir can be released and allowed to flow down to the ocean through a penstock (waterway or pipeline) past a turbine generator.

This study was undertaken to assess whether the available and recoverable wave power density resource on the Agulhas Bank is sufficient to support a pumped storage scheme. 5 months of in-situ wave data collected at a depth of 80 m near Cape Agulhas, Mossel Bay, Tsitsikamma and Cape Recife, was analysed together with modeled wave data from the National Centre for Environmental Prediction (NCEP) - WAVEWATCH III - IWOAGA. The wave power density resource was estimated by calculating the wave energy flux across a unit diameter circle of the wave field, and the resource available by the lateral transfer of wave energy along a linear array of wave energy converting devic-

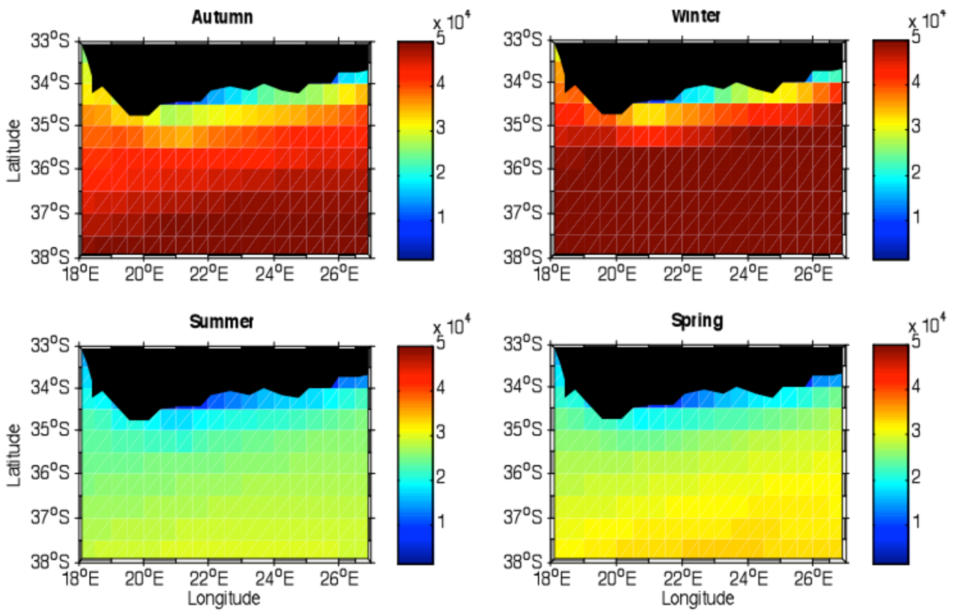

Figure 8*. Seasonal variability of wave power density (W/m) across Agulhas Bank: (a) Autumn; (b) Winter; (c) Summer; (d) Spring.*

es. The results showed that Cape Agulhas had the most available wave power density (75% for 40 kW/m, 25% for 17 kW/m, with an average of 31 kW/m) followed by Mossel Bay (75% for 34 kW/m, 25% for 14 kW/m, with an average of 25.2 kW/m), Tsitsikamma (75% for 32 kW/m, 25% for 13 kW/m, with an average of 25.0 kW/m), and Cape Recife (75% for 30 kW/m, 25% for 12 kW/m, with an average of 23.7 kW/m). For the entire nearshore domain, the wave power density most frequently lies between 30 kW/m and 50 kW/m. The dominant wave direction is from the southwest (Figure 7). On average, the diurnal cycle was characterised by a nearshore energy peak in the evening and an offshore afternoon peak. The seasonal cycle was characterised by a peak in winter (40 – 50 kW/m) and a trough in summer (20 – 30 kW/m) (Figure 8). The interannual variability signal had a strong correlation with regional Sea Level Pressure, surface westerlies winds, and regional sea surface currents. It is also correlated to El Niño Southern Oscillation (NINO3) and the Southern Annular Mode (SAM). In terms of the total annual wave energy resource, approximately 380 TWh/yr, are available in 80 and 128 m deep waters. For the PSS, it was estimated that for a moderate flow rate of 50 m3s-1, the required power to pump sea water to an upper reservoir with a volume of 5 and 15 million m3 is approximately 43 and 150 MW. The pumping process would take between 28 and 82 hours. This study concludes that the entire Agulhas Bank has sufficient wave energy resource to supply a large scale PSS.

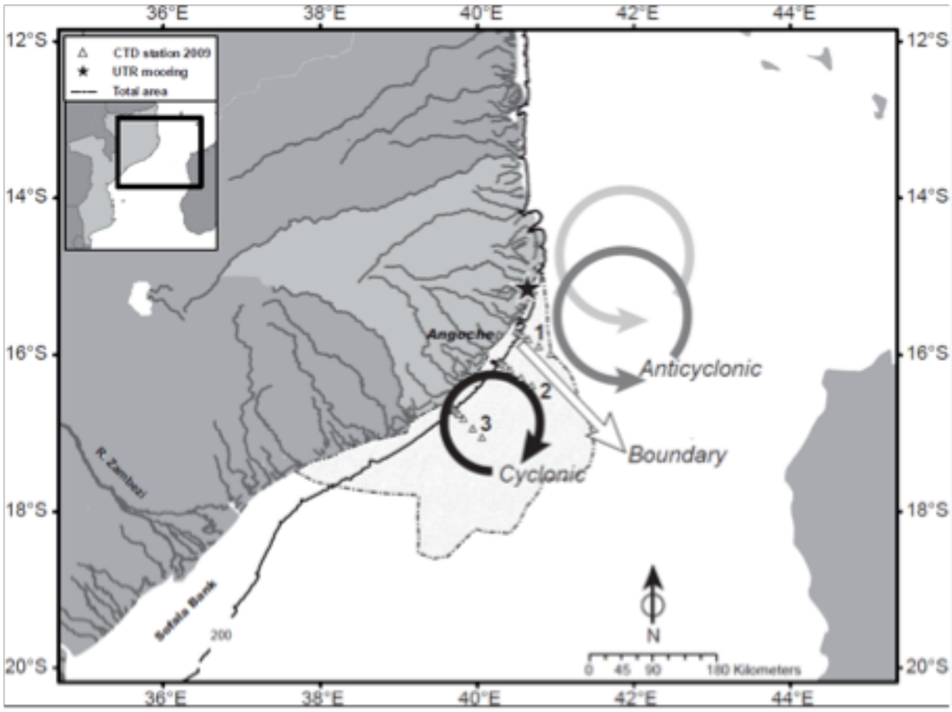

Figure 9: *Map of the study area showing the location of the 18 m deep UTR mooring (star) and the CTD stations (triangle) with the numbers 1 – 3 representing the three selected cross-shore transects for the ASCLME cruises 14 – 16, August 2009 (MC09A). It includes a schematic eddy circulation (rings, not to scale) superposed to the composite area of the spatial extent of the cool, elevated Chl-a waters off northern Mozambique near Angoche.*

Cool, elevated chlorophyll-a waters off northern Mozambique

Bernardino Malauene, **Frank Shillington**, Mike Roberts, and Coleen Moloney

Direct in-situ observations from a shallow underwater temperature recorder on the continental shelf and from a shipboard oceanographic survey, were combined with MODIS satellite sea surface temperature and chlorophyll-a data to assess the temporal and spatial variability of surface temperature and chlorophyll-a in the Mozambique Channel near the coastal town of Angoche, situated at 16ºS (Figure 9). Intermittent, relatively cool surface water and elevated chlorophyll-a signatures were found indicating upwelling near Angoche over an area between 15–18ºS. A five-year (2002–2007) analysis of temperature from an 18 m deep in-situ underwater temperature recorder (UTR), daily alongshore blended sea surface wind velocity component, (see Figure xxa) and the MODIS satellite SST revealed two distinctly different periods of variability during the annual cycle: (1) the August–March period punctuated with intermittent “cool water” events and (2) the April–July period with relatively little “short term event” variability. These two periods of the year tend to favour north-easterly and south-westerly wind directions respectively, with the periods of cooling occurring at approximately two-month intervals, but punctuated with shorter period (8–30 days) of cool coastal events. Two possible forcing mechanisms are hypothesised to be dominant: (1) wind forced coastal upwelling caused by favourable north easterly wind-driven Ekman–type coastal upwelling and (2) the interaction of both anti-cyclonic and cyclonic passing eddies drawing the cool chropophyll-a large distances offshore. The Ekman type coastal upwelling was investigated using satellite blended sea surface wind derived from NOAA/NCDC archives (see Figure 10b), while the transient eddy dynamics was assessed using sea level anomalies from AVISO al-

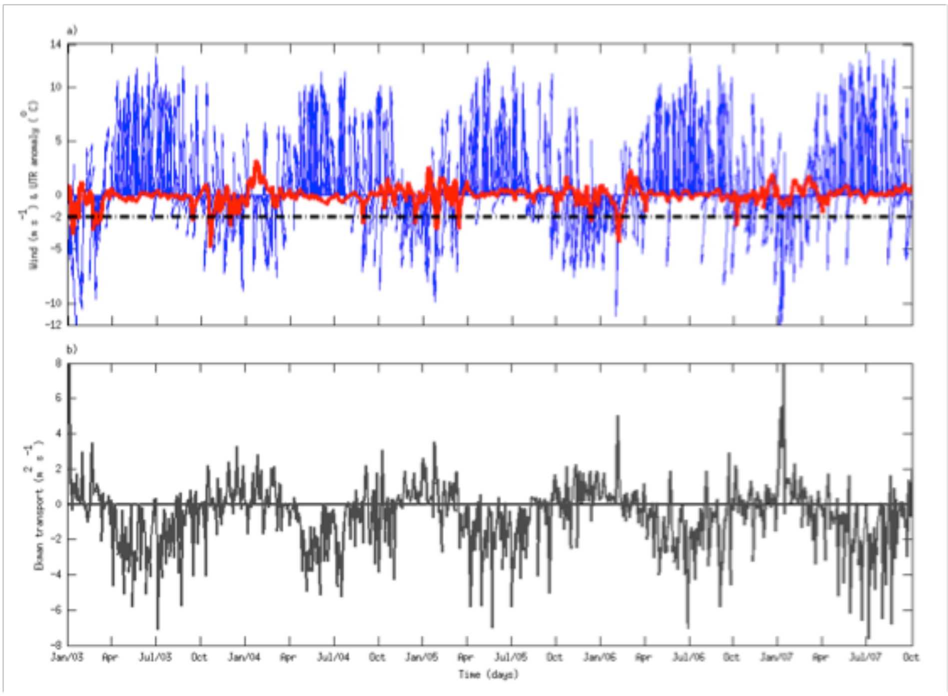

Figure 10: *(a) Time series of daily temperature anomaly (ºC, red line) derived from the 18 m deep UTR and daily alongshore blended sea surface wind velocity component (m s-1, blue line) derived from 0.25º grid multi-satellite observation (NOAA/NCDC) at the UTR site (near Angoche) for the period January 2003 to September 2007. Positive y-axis wind values refer to SW wind and negative wind value to NE wind, the oceanographic convention. (b) Time series of Ekman transport (m2s-1) calculated from the NOAA/NCDC wind at the same location and period as (a). Positive y-axis Ekman transport (per m of coastline), indicates offshore surface Ekman transport and negative Ekman transport values, onshore surface Ekman transport.*

timetry. Whilst the details probably involve a complex interaction of the two major processes, it is suggested that the surface cool, elevated-chlorophyll-a waters are first "primed" by the favourable wind-driven Ekman offshore transport, responding to alongshore north-easterly monsoon winds between August–March, and are then enhanced and advected further offshore by passing anti-cyclonic/cyclonic eddy pairs.

Aspects of sea level variability in the southwest Indian Ocean and the East Coast of Africa

Joseph Amollo, Frank Shillington and **Johnny A. Johannessen**

Sea level has changed and the changes will continue on all time scales in response to various factors, which include tidal effects, atmospheric pressure variations, precipitation changes and wind effects on short time scales. On a global scale and longer time scales, temperature changes resulting from the changes in solar radiation that reach the surface of the earth due to variations in Earth's orbit around the sun, mass addition into the ocean from glacier and ice melt and tectonic activities which alter the shape of the ocean basin are the main processes that influence sea level variations. Additional contributions to sea level change emanate from the water storage on land, in lakes, rivers, dams, wetlands, soil moisture, snow cover, permafrost and aquifers which are largely influenced by both climate variations and anthropogenic activities. Sea level investigations have encountered major challenges in the recent decades. These challenges include the inability to quantitatively describe the observed 20th century sea level rise, which were more than the total estimated contributions on decadal time scale.

The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, AR4) estimated the global mean sea level rise during the 1993-2003 decade at 3.1±0.7 mm/yr with nearly half the rise being linked to thermal expansion and about 40 percent being associated with the contribution of ice melt. More recent investigations (2003-2009) using datasets acquired through altimetry observations have estimated the global rise in sea level at 2.6±0.4 mm/yr and indicated reduced level of contribution to sea level rise by ocean thermal expansion in comparison to the 1993-2003 decade. Mass addition into the ocean through accelerated ice melt due to increased global warming and steric change caused by the general warming

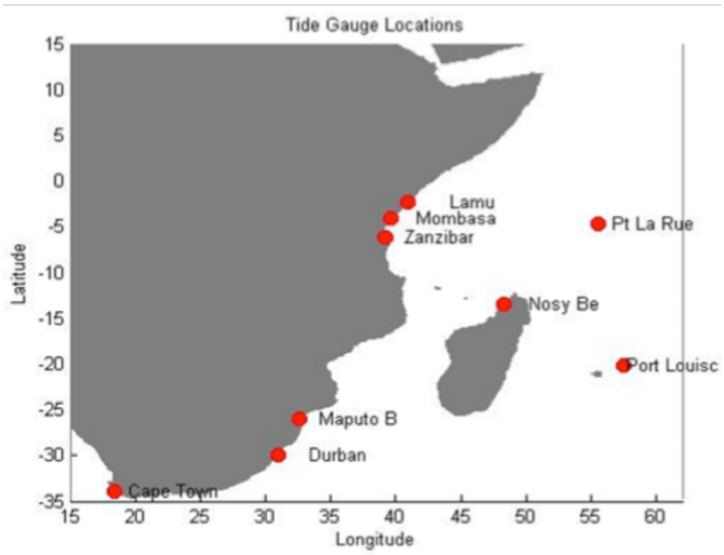

Figure 11*: Location of tide gauges considered for this study (stations are labelled with their names).*

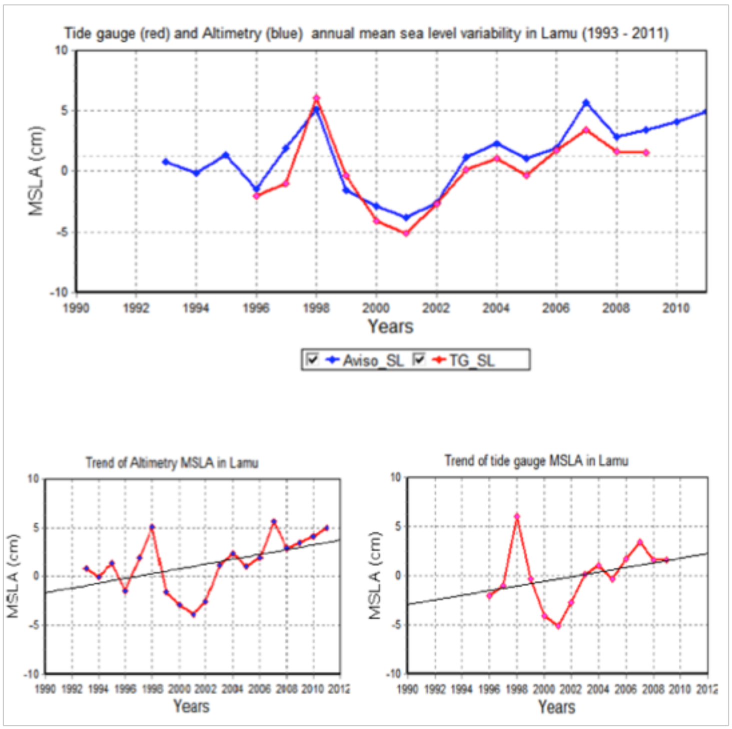

Figure 12*: Altimetry and Tide gauge correlations of interannual sea level variability and trends patterns in Lamu (tide gauge data from 1996 – 2009 and altimetry data from 1993 - 2011).*

are the reliable explanation for the observed differences in observed sea level change.

Variability of sea level at regional scales is important because the impacts on the environment and the society are due to regional or local sea level rise and local land shifts. Regional variability in sea levels has been revealed by tide gauge and altimetry observations and is largely related to weather and climatic variations especially in the equatorial Pacific Ocean. The observed pattern in regional variability of the sea level is associated with the variable wind patterns that are related to climatic phenomena like the El Nino Southern Oscillation and manifest themselves in the regional pattern of ocean thermal expansion. Non-uniform heating of the ocean on regional scales and the subsequent thermal expansion of the sea water together with mass loss of the ice caps and glacier due to melting and dynamical response to warming climate has influenced sea level change on longer time scale and on a wide area. The contribution of ice sheets is not uniformly distributed and results to a lower relative sea level near decaying ice sheets and a larger than globally averaged rise (by about 20%) far from decaying ice sheets.

Analysis of tide gauge sea level observations of varying durations in the southwest Indian Ocean and the East coast of Africa (Lamu, Mombasa, Zanzibar, Durban, Port La Rue and Port Louis – Figure 11) show variability which are related to global, regional time scales, local weather and climatic changes, oceanographic and hydrological forcing that manifest in both short and long time scales. The investigations on the tide gauge sea level observations are conducted through the separation of the total sea level measurements into the contributing components (tides and residuals) using a Matlab in built software (t-tide).

Short time scale sea level variability in the southwest Indian Ocean is due to the effects of tides which exhibit tidal range variations with latitude and shelf width, storm surges resulting from tropical cyclones passage especially in the mid-latitude region, atmospheric pressure fluctuations over the surface of the sea and local wind fields. Sea surface temperature variations during summer and winter result in differential heating of the ocean surface and contribute to the observed sea level variability at seasonal time scale especially in the region 25°S and southwards where the temperature differences are large. The equatorial region is characterized by a near constant sea surface temperature that sustains thermal expansion of the upper layer of the ocean water throughout the year. Monsoon periods show significant and variable wind speeds that impact on sea level variability in the southwest Indian Ocean and the East coast of Africa and are greatest during the summer monsoon (from June to August). On longer time scales (Interannual and decadal), sea level variations in this region is mostly influenced by the El Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). During the 1997/98 El Nino event, the sea levels are significantly higher than normal at the coast and the islands (e.g. Figure 12). During the 2000/2001 La Nina, the sea levels are significantly lower than normal at the coasts in the southwest Indian Ocean. Indian Ocean Dipole effects are significant in the southwest Indian Ocean during the period 2006 through to 2008 and are more enhanced in 2007. The annual highest sea levels in this region are influenced by the year to year changes in weather pattern and the perigean cycle of the tides on a 4.4 year period but their secular trends are not statistically significant.

Eddy-Mean Flow interaction in the southern extension of the East Madagascar Current

Issufo Halo, Pierrick Penven and Isabelle Ansorge

The large-scale ocean circulation in the region south of Madagascar is dominated by the South East Madagascar Current (SEMC), flowing southwestward along the Madagascar coast, and the South Indian Countercurrent (SICC), flowing northeastward at the

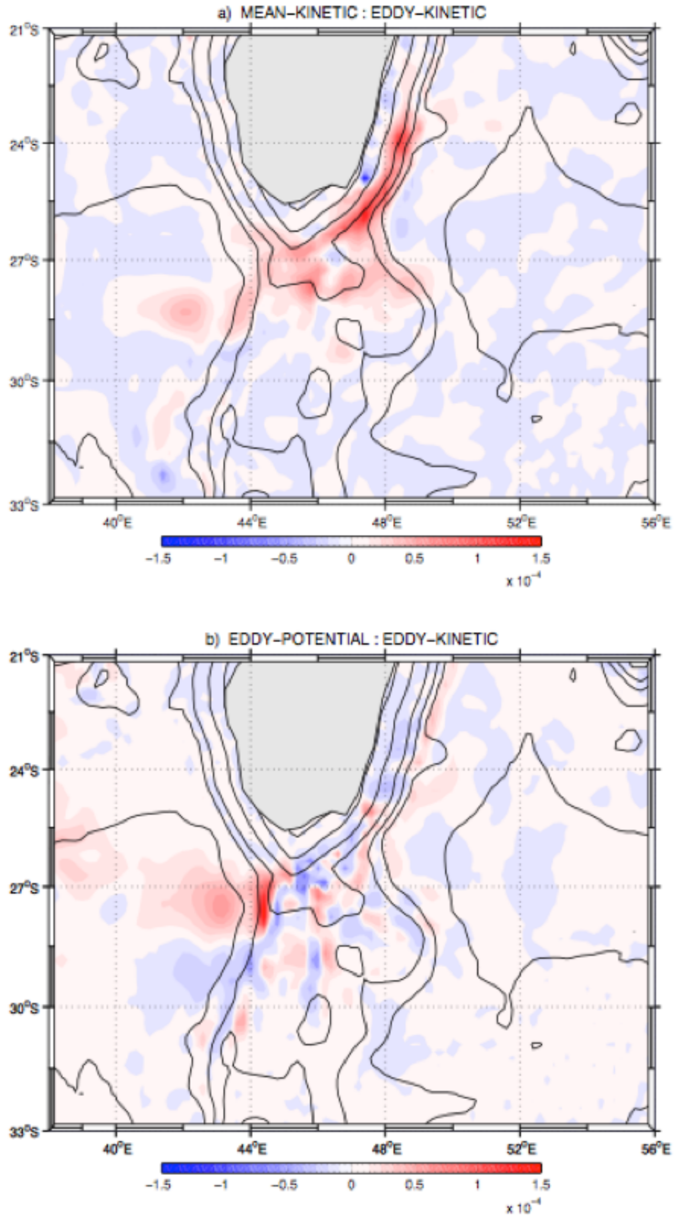

***Figure 13**: Energy conversion terms derived from 7-years SWIM outputs, vertically integrated throughout the ocean column. Conversion from mean kinetic to eddy kinetic (a), and from eddy potential to eddy kinetic (b). The background contours show the isobaths of 200 500 1000 2000 3000 4000 5000 and 6000 m.*

seaward edge of the SEMC. The mesoscale circulation in this region is dominated by intense eddies and dipoles, that propagate towards the Agulhas Current. The interaction between these oceanographic features at different time-scales is known to impact the behavior of the termination of the SEMC at the southern tip of Madagascar in 2-dynamical modes: The SEMC flows mostly westward, close to the southern Madagascar continental slope, where interaction with the bathymetry generates cyclonic circulation, with cyclonic eddies being formed at the in-shore edge of the flow. The second mode is characterized by the SEMC flowing in a predominantly southwestward direction, away from the Madagascar slope, favouring anticyclonic circulation and a retroflection of the SEMC. The nature of these interactions have, to-date, not been substantially investigated. In fact in-situ data in this region is scarse and sparse. Here we used the validated outputs from the South-West Indian Ocean Model (SWIM), to investigate the mechanisms of these interactions calculating the conversion terms of the oceanic energy budget in the water column. SWIM is based on the Regional Ocean Modelling Systems (ROMS), and the configuration domain extends from 0º to 77.5ºE, and from 2.8ºS to 47.5ºS. It is forced at the surface by 1/2º gridded climatological fields (COADS05), at the lateral boundaries by 1º×1º gridded climatology (Wold Ocean Atlas, WOA05), and its bathymetry is based on the higher resolution topography from the General Bathymetric Chart of the Oceans (GEBCO). The configuration runs at 1/5º horizontal grid resolution, with 45 vertical sigma layers, for 10 years. It has a spin-up period of 3-years, and the output is averaged at 2-day intervals. The results (Figure 13) show that two dynamical processes concurrently occur for the generation of eddies in the southern extension of the East Madagascar Current: barotropic instability, energy transfer from mean kinetic to eddy kinetic (Figure 13a), dominates in the south and southeast of the Madagascar shelf, where u', v' are the perturbation in time of the zonal and meridional components of the geostrophic flow field calculated from sea surface variations, and u-bar and v-bar are the time mean, x and y are zonal and meridional direction respectively. The baroclinic instability is the work performed by turbulent buoyancy forces on the vertical stratification, leading to changes on the potential energy (Figure 13b) that dominate the southwestern sector of the shelf. g - is the acceleration due to gravity, ρ' - is the fluctuation of the seawater density, computed via non-linear equation of state, ρ_0 - is the seawater density of reference and w' is the fluctuation of the vertical velocity component. The eddies are not observed to contribute towards the mean flow (Figure 13a), implying that they do not play an important role in maintaining the mean currents in the region. The eddies in the south and southeastern Madagascar shelf have different properties (amplitude and radius) from those in the southwestern side of the shelf, and their characteristics appear to be associated with the mechanisms of their formation.

The role of the Agulhas Current on the Benguela Current System: an experimental modelling approach

Jennifer Veitch and Pierrick Penven

The Benguela Current system is

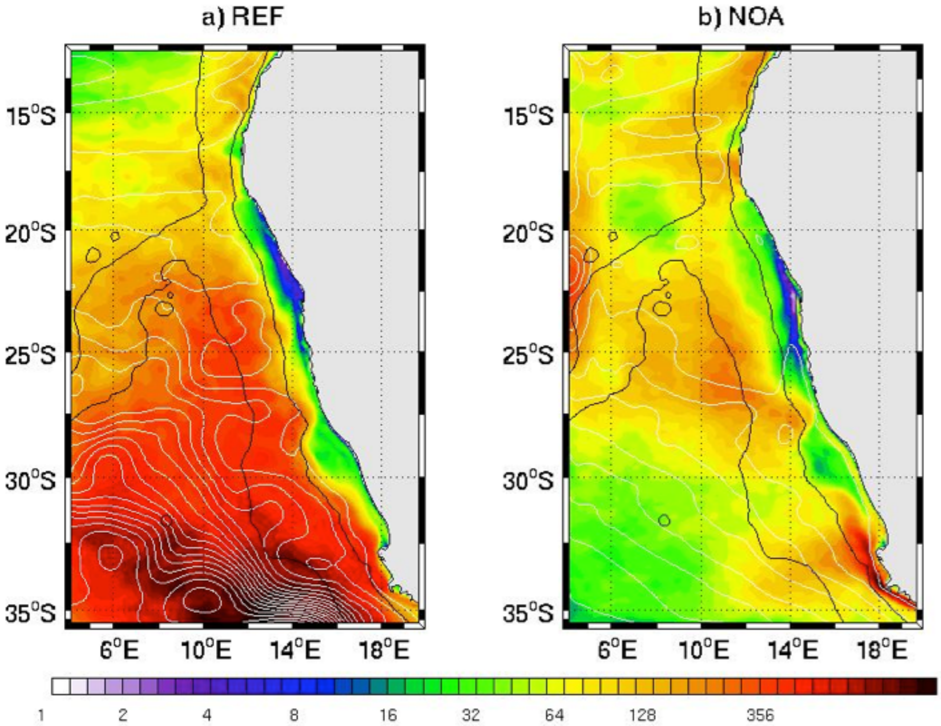

***Figure 14**: Surface mean eddy kinetic energy (EKE) with depth-integrated (0-1000m) transport streamlines overlaid in white for the reference experiment (REF, left) and the no Agulhas experiment (NOA, right)*

unique among the worlds four major eastern boundary upwelling systems in that it is in direct contact with the western boundary current of the South West Indian Ocean - the intense Agulhas Current. The Benguela Current can be thought of as the passage for Agulhas rings and eddies as they advect into the Atlantic Ocean after being shed at the Agulhas retroflection. As such, the southern Benguela system is a region of intense mesoscale turbulence. An experimental modelling approach, using the Regional Ocean Modelling System (ROMS), is used to assess the role of the Agulhas in both the large-scale hydrographic features as well as in the nearshore upwelling regime of the Benguela Current system. An idealized model experiment (NOA) is designed such that the Agulhas Current is diverted eastward before reaching the tip of Africa, thereby removing most of its influence on the Benguela Current system. Comparisons of a ROMS reference run (REF) and the idealized experiment provide an assessment of the importance of the Agulhas Current in driving salient features of the southern Benguela such as the Good Hope Jet, the upwelling front, cross-shelf volume fluxes, the generation of instabilities at the shelf-edge and the transport of the Benguela Current itself. It also allows for a quantification of eddy flux contributions of the Agulhas Current in the southern Benguela region.

This model experiment explicitly shows that the Agulhas contributes about 10Sv to the transport of the Benguela Current and that the large-scale, depth-integrated, circulation patterns deviate from the Sverdrup relation largely due to Agulhas influx. The meandering nature of the mean Benguela Current is shown to be driven by eddy fluxes associated with the Agulhas Current. Evidence of this can be seen in Figure 14, which shows the surface mean eddy kinetic energy (EKE) with depth-integrated (0-1000m) transport streamlines overlaid in white: regions of intense meandering mean flow in the REF simulation coincide with regions of most intense EKE. This implies that the meandering nature of the mean Benguela Current is a manifestation of the preferential passage of eddies derived from the Agulhas retroflection. The model suggests that the Agulhas contributes 46% to the annual mean heat flux into the Atlantic across 35ºS, from 5-20ºE, with a stronger seasonal signal evident in the reference simulation (with a peak in austral spring) than in the idealized experiment. Comparisons of EKE for the reference and no Agulhas simulations (Figure 14), suggest that the Agulhas results in up to 80 % of the mesoscale variability south of 30ºS. It also allows for a quantification of locally-driven mesoscale tubulence as opposed to turbulence connected to Agulhas influx. For instance, the high EKEs in the vicinity of the Good Hope Jet, the LUCORC (Luderitz Cell – Orange Rive Cone) region and the ABFZ (Angola-Benguela Frontal Zone) suggest that these are regions where instabilities are locally generated. The Agulhas Current is also shown to have a significant role in the transport of fish eggs and larvae to the St. Helena Bay nursery area. Aside from contributing to a broader and more perennial Good Hope Jet, the Agulhas influx in the southern Benguela is instrumental in driving the shoreward branch of the jet into St Helena Bay as it bifurcates downstream of Cape Columbine. It can be concluded that shelf-edge upwelling in the southern Benguela that has been observed and that is present in the reference simulation is due to the divergence of the Benguela Current at the shelf, which is related to mesoscale turbulence associated with Agulhas influx. Without the influence of the Agulhas Current in the southern Benguela, the poleward undercurrent that originates from north of the ABFZ and is a source of low oxygen water is shallower and more prominent. Large filaments are observed off Lüderitz for both the reference simulation and for the idealized experiment, thus suggesting that Agulhas rings are not necessarily connected to their extreme offshore extents. This experimental modelling investigation confirms that salient dynamic features of the southern Benguela, some of which are key drivers of ecosystem functioning, are closely related to Agulhas influx.

Use of SAR data to monitor the greater Agulhas Current

Johnny A. Johannessen, Bertrand Chapron, Fabrice Collard and **Björn Backeberg**

The strong and dynamic greater Agulhas Current is known to have significant influence on the local marine environment and ecosystem. It is also considered to play an important role in the global thermohaline circulation, notably due to the transport of heat and salt from the Indian Ocean into the South Atlantic Ocean. Regular monitoring of the dominant processes and variability within the greater Agulhas Current is thus highly needed. Recently Doppler-derived ocean surface velocities from the European Space Agency´s (ESA) Envisat Advanced Synthetic Aperture Radar (ASAR) have demonstrated abilities to manifest the intensity of surface currents. These estimates are assessed by direct comparison to other independent determinations of the surface current in the greater Agulhas Current obtained from surface drifter data, radar altimetry and an ocean circulation models. The results are promising and highlight that the Doppler-based ocean surface velocity retrievals offer a new innovative approach to monitor and advance the understanding of the dynamic processes of the greater Agulhas Current.

Here, a regional eddy resolving HYCOM simulation of the Agulhas was used. The HYCOM derived velocity field as well as the surface geostrophic velocity field derived by Rio09 was rotated by -15° (from North) to conform to the range velocities derived from the ASAR measurements (Figure 15). From this comparison, it is evident that the 1/10° (~10 km) HYCOM (Figure 15, right) underestimates the surface velocities in the Agulhas Current core, with maximum poleward range velocities only reaching 0.65- 0.70 m/s, compared to the > 1.00 m/s estimated from ASAR (Figure 15, left) and the ~0.90 m/s derived from Rio09 (Figure 15, middle). The width of the current compared well with the ASAR and altimeter derived fields (Figure 15, left, middle) while the HYCOM simulation has a tendency toward simulating a too wide current. Note that the spatial resolution varies from about 10 km for the ASAR velocity field, 25 km for the altimeter based field and 10 km for the model simulation. In the northern part of the Agulhas Current the three data are in fairly good agreement with each other. However, following the separation of the continental shelf from the coast near 26°E and 34°S, the Agulhas Current core tends to follow the 1000 m isobath revealing a distinct bending pattern at about 22.5°E and 35°S. The weaker mean HYCOM surface current is in closer agreement with the mean altimeter derived surface geostrophic current, which represents an integral of the current in the upper 5-10 m of the surface layer.

Near the Agulhas retroflection HYCOM seems to have a too strong westward extension compared to the ASAR and altimeter based observations. Similarly the simulated maximum in the return current is unrealistically elongated and centered to far west compared to the ASAR and altimetry observations. Furthermore the observed maxima at the northern tip of the Agulhas Plateau are not visible in the model field. This study demonstrates the powerful ability to conduct model validation of the surface fields in the Agulhas Current using satellite observations. In view of the strong surface expression found in the satellite data it is also a promising region to carry out data assimilation.

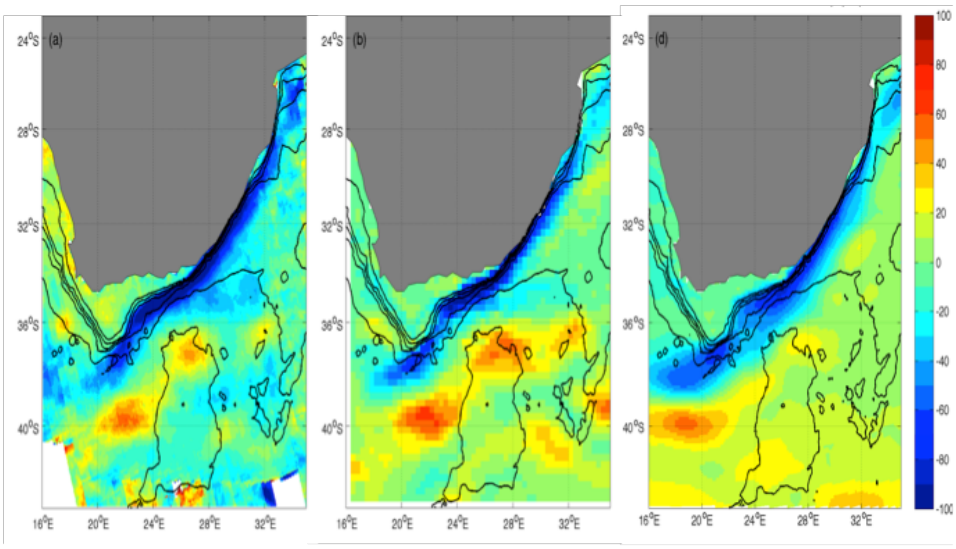

Figure 15. *Time-average maps of surface velocity from: (left) ASAR based range Doppler velocity from 2007-2009; (middle) surface geostrophic current derived from Rio09 at a spatial resolution of ¼°; (right) model surface velocities. Note that the velocities in the middle and right graphs are rotated by 15° to conform with the ASAR range velocities. Color bar indicates surface speed in cm/s. The 200, 500, 1000, 2000 and 4000 m isobaths are plotted in black.*

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J. Amollo. *Aspects of sea level variability in the southwest Indian Ocean and the east coast of Africa – (latitude 0-35°S and from the coast to 60°E)*. MSc. Thesis, Department of Oceanography, University of Cape Town, South Africa, 2012.

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Scientists

Björn Backeberg (100%) – Oceanography, modeling and data assimilation

Chris Reason (UCT, seconded) – Climate variability and modeling

Frank Shillington (UCT, seconded) – Oceanography and remote sensing

Jennifer Veitch (UCT, seconded) – Oceanography and modeling

Johnny Johannessen (NERSC, seconded) – Oceanography and remote sensing

Marjolaine Krug (CSIR, seconded) – Oceanography and remote sensing

Mathieu Rouault (50%) – Ocean-atmosphere interaction and climate

Post-doctoral research fellows

Issufo Halo (100%) – Oceanography and modeling

PhD students

Christo Whittle (UCT / CSIR, seconded) – Oceanography and remote sensing

MSc students

Francisco Fancisco (100%) – Oceanography

Joseph Amollo (100%) - Oceanography

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Ocean modeling blog
http://uctoceanmodelling.blogspot.com/

Oceanography and donuts
http://oceanographydonuttalks.blogspot.com/

SimOcean: Simulating and forecasting southern Africa's ocean
http://www.simocean.org.za

OceanSAfrica: South Africa's operational oceanography initiative
http://cfoo.co.za/oceansafrica/
(temporary development link)

Marine Remote Sensing Unit
http://www.afro-sea.org.za/

South Africa's new polar ship: the S.A. Agulhas II, started operating near the Antarctic mainland and sub Antarctic islands, including Marion and Gough islands this year (Courtesy: http://www.shipyearonline.co.za/articles/ice-breakers)

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