



# Annual Report 2013

**Nansen-Tutu Centre  
for Marine Environmental Research**

**affiliated with the University of Cape Town**

## 2013 – 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 Fridtjof Nansen and Desmond Tutu.

The priority research activities at the Centre are:

- Ocean modeling and prediction
- Ocean-atmosphere, climate and regional impact
- High resolution satellite remote sensing of the regional shelf seas
- Regional sea level variability and global change.
- Capacity building and education

### ACKNOWLEDGEMENT

The Nansen-Tutu Centre's activities are enabled through financial contributions from its Norwegian partners. In 2013 the Nansen Environmental and Remote Sensing Center, the Nansen Scientific Society, the Institute for Marine Research and the University of Bergen contributed funding to the Centre. In kind contributions are received from the other partners.

### ORGANISATION

The Nansen-Tutu Centre (NTC) is a non-profit research centre

hosted at the Marine Research Institute and the Department of Oceanography at the University of Cape Town (UCT). The administrative and legal responsibilities reside with the University of Cape Town. It is a joint venture agreement between the signatory partners from South Africa, Norway and the United States. From South Africa including the Marine Research Institute (Ma-Re)/Department of Oceanography, University of Cape Town, the Applied Centre for Climate and Earth System Studies (ACCESS), the Council for Scientific and Industrial Research (CSIR) – Earth Observation research group, the South African Environmental Observation Network (SAEON), and the International Centre for Education, Marine and Atmospheric Sciences over Africa (ICEMASA). From Norway including the Nansen Scientific Society, the University of Bergen, the Nansen Environmental and Remote Sensing Centre (NERSC), and the Institute of Marine Research (IMR), and from the USA the Geosciences Department, at the Princeton University. The extension of the joint venture for 3 years (Phase II) was initiated in July 2013, with seed funding committed from NERSC and the Nansen Scientific Society. Additional 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 2013, the Nansen-Tutu Centre staff comprised 12 persons, including 3 MSc students and associate researchers from some of its founding partners, including the Marine Research Institute and the Department of Oceanography at the University

of Cape Town, the Council for Scientific and Industrial Research, South African Environmental Observation Network, and the Nansen Environmental and Remote Sensing Center.

### SCIENTIFIC PRODUCTION, CAPACITY BUILDING AND TEACHING

A total of 15 publications emanated from the Centre, which included: twelve papers in peer-reviewed journals published or in press; two chapters in books; and one news and views article.

In 2012, the Centre provided a Post-doctoral research fellowship to Dr Nicolas Raschle. His work led to two publications in 2013.

In 2013, the Nansen-Tutu Centre supported three MSc students, two from South Africa and one from Mozambique, providing study bursaries to two MSc students and travel support to one MSc student to attend an international workshop. All three students will graduate in 2014.

- Mr Kyle Cooper (South African). *Key performance indicators of global operational models around southern Africa*. MSc by dissertation, Department of Oceanography, University of Cape Town, South Africa. Supervisor(s) at the Nansen-Tutu Centre: B. C. Backeberg, J. Jackson-Veitch. Co-funded by the NTC.
- Ms Isabelle Giddy (South African). *A HYCOM representation of low frequency variations in the Agulhas Retroflection region in the South Atlantic*. MSc by dissertation, Department of Oceanography, University of Cape Town, South Africa. Supervisor(s) at the Nansen-Tutu Centre: B. C. Backeberg. Funded by the NTC, through the South Atlantic Meridional Overturning Circulation project.

**Cover image:** Mean cloud free ocean colour image of chlorophyll-a for the Southeast Atlantic, Southern and Southwest Indian Ocean from December to February. Obtained from the SeaWiFS project home page: <http://oceancolor.gsfc.nasa.gov/SeaWiFS/>



- Mr Bernardino Nhantumbo (Mozambican). *Coastal trapped waves along the Africa shelf-measurements and numerical model simulation*. Ocean and Climate Dynamics MSc by course work, Department of Oceanography, University of Cape Town, South Africa. Supervisor(s) at the Nansen-Tutu Centre: F. A. Shillington. Funded by the NTC.

Additionally, NTC staff and associates were involved in the co-supervision of fourteen Honours, MSc and PhD students, as well as teaching in the Department of Oceanography's undergraduate and post-graduate programmes, the Applied Marine Science MSc programme and the African Climate and Development Initiative MSc programme.

### Awards

Dr Issufo Halo was awarded Eugene La Fond gold plated medal, in recognition for the Best oral presentation at the International Association for Physical Sciences of the Ocean meeting. Paper: "Eddy Properties in the Mozambique Channel: a comparison between Satellite altimetry observations and two numerical Ocean circulation models" - Gothenburg, Sweden, July 2013.

### NATIONAL COOPERATION

The Centre actively participates in national research and development activities, including the OceanSAfrica initiative, a multi-institutional initiative that will develop operational oceanography capabilities in South Africa and Africa, the Department of Science and Technology and National Research Foundation development of a National Marine Research Plan, the South Atlantic Meridional Overturning Circulation – SA project, and projects under the Water Research Commis-

sion (WRC).

### INTERNATIONAL ACTIVITIES

The Centre facilitated 6 research exchanges between South African and Norwegian researchers during 2013. In addition to this the Centre contributed to a number of international projects. These include two European Seventh Framework Programmes, the Marie Curie Actions, People International Research Staff Exchange Scheme for the project "The role of the Southern Ocean carbon cycle under climate change" (SOCCLI), and the project "Enhancing prediction of Tropical Atlantic climate and its impacts" (PREFACE). Other projects include Angolan, Mozambican and Madagascan partners.

### NATIONAL AND INTERNATIONAL COMMITTEES

Dr Bjorn Backeberg served on the Scientific Committee for the International Workshop on Operational Oceanography in Developing Countries, which was held in Beijing, China. An outcome of the workshop was the proposal for the formation of a Forum for Operational Oceanography in Developing Countries (OODC) in which the NTC will be a partner. Together with Prof Johnny A. Johannessen he also served on the Programme Committee for the GODAE OceanView Symposium 2013. Prof Frank Shillington and Dr Bjorn Backeberg are currently on the Scientific Committee for the South African Marine Sciences Symposium 2014. Assoc Prof Mathieu Rouault is president of the South African Society for Atmospheric Science, committee member of Clivar Africa and Clivar Atlantic and chairman of the PIRATA Southeast Extension committee. Dr Marjolaine Krug is a member of the Scientific Council of the

postgraduate college RAMI.

### FINANCIAL SITUATION

The start-up of Phase II of the Centre was approved in July 2013. The majority of funds for Phase II currently come from NERSC (300,000 NOK per annum) and the Nansen Scientific Society (200,000 NOK per annum). In kind contributions are also made available from UCT staff funds. In collaboration with its partners, the Centre has also been successful in attracting funds through project proposals including the South Atlantic Meridional Overturning Circulation – SA project, the Enhancing prediction of Tropical Atlantic climate and its impacts project (PREFACE), the European Seventh Framework Programme, Marie Curie Actions, People International Research Staff Exchange Scheme (SOCCLI), the National Research Foundation, the Applied Centre for Climate and Earth System Science (ACCESS), the Water Research Commission, and through sub-contracting in commercial activities for Anchor Environmental.

### PHASE I (2010-2013) MILESTONES ACHIEVED

During Phase I, the Centre supported 4 MSc and 4 PhD students from South Africa and Africa who graduated from the University of Cape Town.

Two workshops were held. In 2011, the Centre helped organize and coordinate the "African Operational Oceanography Workshop", and in 2012 organised the "Ocean, Climate and Space Colloquium".

A total of fourteen research exchanges were facilitated through the Centre, with eight South African researchers visiting Norway, and six Norwegian researchers visiting South Africa.

A total of forty-nine publications emanated from the Centre of which twenty-four were in scientific peer-reviewed journals.

Through the Centre's collaboration and activities in the Global Ocean Data Assimilation Experiment OceanView (GOV), South Africa was awarded observer status in its science team.

## PROSPECTS FOR 2014

One new MSc and five new PhD students from South Africa and Africa will be joining the Centre in 2014. All students have co-supervisors in South Africa and in Norway:

- Daniel Schilperoort from South Africa (MSc, Synthetic Aperture Winds over the Agulhas), co-supervised by Marjolaine Krug (CSIR/NTC), Mathieu Rouault (NTC/UCT) and Johnny Johannessen (NERSC).
- Imbol Kounge Rodrigue Anicet from Cameroon (PhD, Tropical Southeast Atlantic Circulation), co-supervised by Mathieu Rouault (NTC/UCT), Marek Ostrowski (IMR) and Julie Deshayes (ICEMASA).
- Neil Malan from South Africa (PhD, Modelling upwelling cells inshore of the Agulhas), co-supervised by Chris Reason (UCT), Juliet Hermes (SAEON), Mike Roberts (DEA), Bjorn Backeberg (NTC/UCT/NERSC) and Annette Samuelsen (NERSC).
- Bernardino Nhantumbo from Mozambique (PhD, Sea level variability), co-supervised by Frank Shillington (NTC/UCT) and Ola M. Johannessen (NSS).
- Georges-Noel Tiersmondo Longandjo from DRC (PhD, Tropical Atlantic teleconnections), co-supervised by Mathieu Rouault (NTC/UCT) and Noel Keenlyside (UiB).
- Patrick Vianello from South

Africa (PhD, Mascarene Ridge circulation), co-supervised by Mathieu Rouault (NTC/UCT), Marek Ostrowski (IMR) and Isabelle Ansorge (UCT).

Continue to support Mr Kyle Cooper and Ms Isabelle Giddy for their MSc projects.

Continue to support Dr Issufo Halo in his Post-doctoral research fellowship and co-support (with SAEON) Dr Charine Collins as a Post-doctoral research fellow working on assimilating Argo data in HYCOM.

Develop CODAR coastal current initiative with pilot site near Port Elizabeth and links to Sentinel-1 validation campaign.

Kick-off meeting of the Seasonal to decadal Changes Affecting Marine Productivity: an Interdisciplinary investigation (SCAMPI) project funded by the South Africa - Norway Research Co-operation on Climate Change, the Environment and Clean Energy (SANCOOP) programme – April 2014.

Joint ICEMASA/NTC/Ma-Re strategic workshop on co-ordinating the intersecting activities of marine research within our groups – April 2014.

Summer School on Dynamics of the oceans around Southern Africa and relation to the tropical Atlantic in December 2014.

*Cape Town, April 2014*

*J. G. Field, Executive Chairman*

*J. A. Johannessen, Co-Chairman*

*S. Bernard*

*Å. Bjordal*

*J. Hermes*

*O. M. Johannessen*

*N.-G. Kvamstø*

*F. Marsac*

*G. Philander*

*J. Stander*

*N. Sweijid*



**NANSEN-TUTU CENTRE**  
MARINE ENVIRONMENTAL RESEARCH

## THE BOARD

### EXECUTIVE CHAIRMAN

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### CO-CHAIRMAN

Prof. J. A. Johannessen, Nansen Environmental and Remote Sensing Center

### MEMBERS

Dr. S. Bernard, Council for Scientific and Industrial Research

Prof. Å. Bjordal, Institute for Marine Research

Dr. J. Hermes, South African Environmental Observations Network

Prof. O. M. Johannessen, Nansen Scientific Society

Prof. N.-G. Kvamstø, University of Bergen

Dr. F. Marsac, International Centre for Education, Marine and Atmospheric Sciences of Africa

Prof G. Philander, Princeton University

Mr. J. Stander, South African Weather Service

Dr. N. Sweijid, African Centre for Climate and Earth System Science

## THE LEADER TEAM

### CO-DIRECTORS

Prof. F. Shillington, Department of Oceanography, University of Cape Town

Dr. B. Backeberg, Nansen Environmental and Remote Sensing Center

### RESEARCH DIRECTOR

Assoc. Prof. M. Rouault, Department of Oceanography, University of Cape Town

### ADMINISTRATION

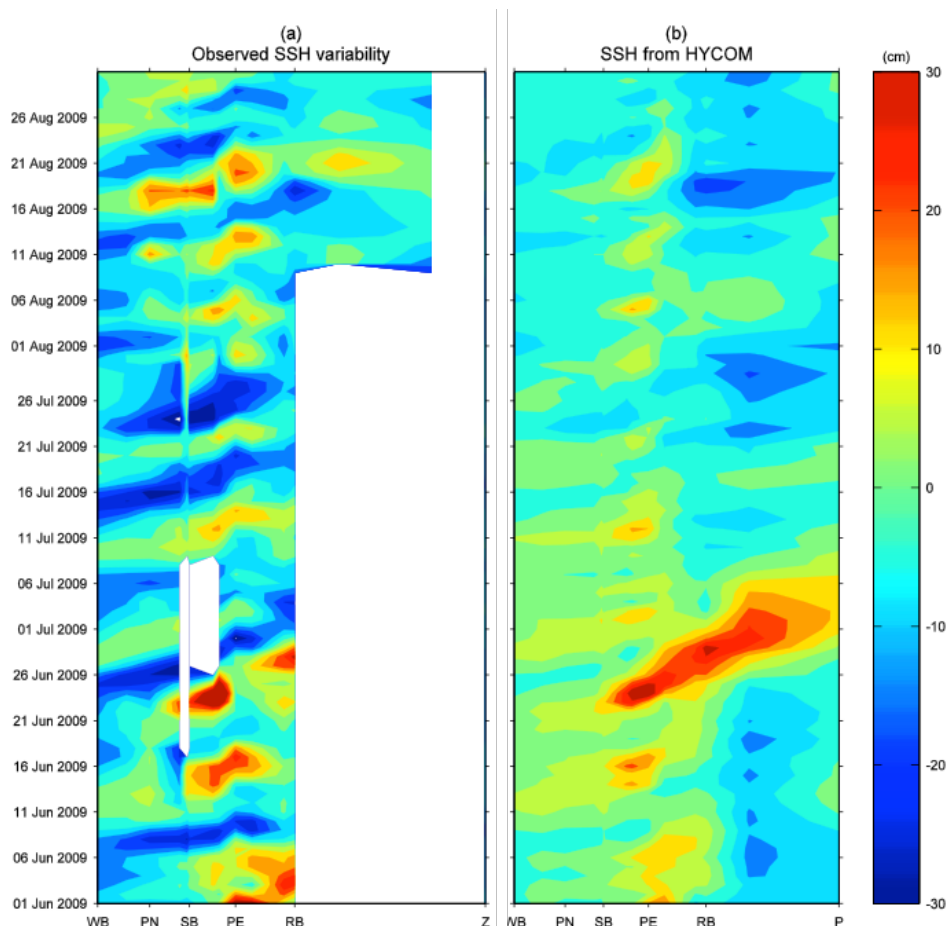
Mr. E. Balarin, Marine Research Institute, University of Cape Town



## SEA LEVEL VARIABILITY AND COASTAL TRAPPED WAVES AROUND SOUTHERN AFRICA

**Bernardino J. Nhantumbo & Frank Shillington**

The propagation characteristics of the coastal trapped waves (CTWs) around the coast of southern Africa were investigated by analyzing the observed daily mean sea level data from 16 coastal tide gauges, as well as sea level anomalies from a regional Hybrid Coordinate Ocean Model at corresponding grid points closest to each tide gauge station (Figure 1). The observed records showed sea level variability dominated by the short time variability with a period shorter than one month. This short time variability varies from season to season with the largest CTW amplitude during austral winter. The short time variability propagates anticlockwise as a coastal trapped wave around the coast of southern Africa with a propagation speeds ranging from 3 to 6.5 m/s, and from 1 to 7.5 m/s, along the west and south coasts, respectively. These propagation speeds are forced by synoptic atmospheric disturbances mainly in term of wind variability. Coastal trapped waves were observed propagating equatorward on the east coast of southern Africa in the opposite direction of Agulhas Current on a few occasions. This may be a result of a good resonance between a strong and persistent weather system and the coastal trapped wave. It is believed that more precise response and better explanation for some discrepancies that were found would be achieved when the longer time records from Inhambane are included in future studies. The Hybrid Coordinate Ocean Model (HYCOM) showed very similar propagation characteristics to the observed data. Along the south coast, the behaviour of the CTW is well reproduced. Unfortunately the



**Figure 1:** Hovmöller plot for (a) the observed sea level variability and (b) the sea level variability from HYCOM model from 01 June to 31 August, 2009. The x-axis represents the distance along the coast from Walvis Bay (WB) to Zanzibar (Z) for the tide gauges, and Pemba (P) for the model output. This spatial difference is due to the model domain. White square indicate missing values.

model does not reproduce very well the variability along the west coast. While it seems to underestimate the west coast response, at same time it seems to overestimate it along the south coast of southern Africa. Although the model demonstrated some CTWs travelling northwards along the east coast, such disturbances were infrequent and difficult to find in the observed data.

## INTERNAL WAVES AND INTERNAL TIDES IN THE ALGOA BAY REGION

**Wayne Goschen & Marjolaine Krug**

Internal waves in the ocean occur at surfaces of different densities in the water column and are found in layered or continuously stratified seas. The most common interface to identify internal waves is the thermocline where there

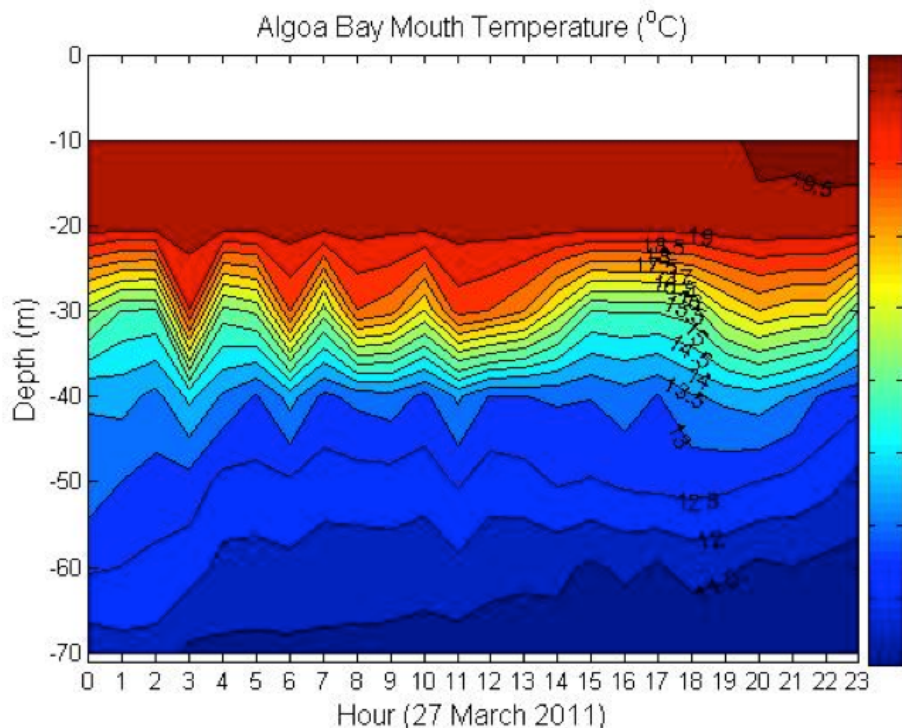
is a sharp vertical temperature gradient, but they may also occur at haloclines such as is common in coastal waters. Internal waves may be generated at the air/sea interface (atmospheric pressure and wind systems), at bottom obstacles or lateral boundaries (e.g. capes) and from the interior of the ocean at the shelf break, for example the Agulhas Current. Internal waves are important for marine ecosystems because nutrients, phytoplankton, copepods and larvae are uplifted nearer to the surface at the crests of the internal waves. This will also be a place of high chlorophyll concentrations where zooplankton grazing is most effective. Thus high concentrations of biomass will be associated with the crests of internal waves and low biomass concentrations with the troughs.

Internal waves are likely to play a role in the local food chain but their influence is yet to be undetermined in the Algoa Bay region. Previous oceanographic studies in Algoa Bay, using current meter measurements, have mentioned in passing that there are reasonable energies in oscillations matching internal wave frequencies, in particular internal tides oscillating at about the M2 tidal period (12.42h). However, those investigations could not find much internal wave activity in the shallow reaches of the bay, although the moorings were not specifically designed to search for internal waves. The knowledge of internal waves in the bays of the Eastern Cape, off the coastline and over the inner shelf over the eastern Agulhas Bank remains poor. This project aims to gain a deeper understanding of internal waves and internal tides in this region.

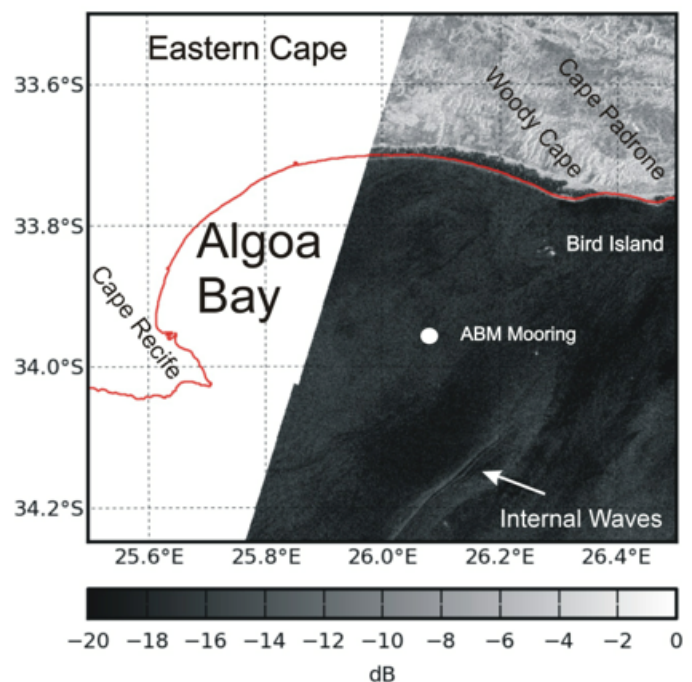
The South African Environmental Observation Network (SAEON) has deployed an array of underwater temperature records (UTRs) and acoustic Doppler current profilers (ADCPs) in and around Algoa Bay as part of their

Sentinel Sites programme. The moorings have bottom depths of between 30 m and 80 m and range from the southern shore of Cape St Francis to Port Alfred. The first instrument was deployed in November 2008. We give acknowledgements to Angus Paterson and Kim Bernard for initiating the programme and to Tommy Bornman and Shaun Deyzel for building on the programme and

maintaining the continuous monitoring platform. Oscillations in temperature records at periods of between 2.5 hours and 21.4 hours (the inertial period), which appear to have the signature of internal waves,



**Figure 2:** Isotherms at 0.5 ° intervals from the Algoa Bay Mouth mooring (80 m bottom depth) on 17 March 2011 showing internal waves with period of 2.75 hours.



**Figure 3:** A SAR image taken on 18 November 2007 of a possible internal wave train that appears to be generated at the shelf edge offshore Algoa Bay (see southeast corner of the image, from about 34.23°S/26.0°E towards the northeast). The Algoa Bay Mouth (ABM) thermistor string mooring is marked on the image.

have been observed in the deeper (bottom depth > 60 m) SAEON UTR data. All these events have not been investigated fully since this project is in its infant stage, but at start has been made in identifying periods of internal wave activity in some records. Figure 2 shows one such event on 27 March 2010. An internal wave with period of 2.8 hours was recorded by the Algoa Bay Mouth UTR string (Figure 3) moored near the mouth of Algoa Bay (between Cape Recife and Cape Padrone) in 80 m bottom depth. During that period the thermocline lay at a depth of about 30 m, below a well mixed upper layer at a temperature of 19 °C, and oscillated with a vertical displacement of 5-10 m during the morning of 27 March. The waves were also recorded at a mooring in the centre of Algoa Bay (60 m bottom depth) but not at the shallower moorings (30 m bottom depth) along the shoreline of Algoa Bay. Orbital motions associated with internal wave propagation cause



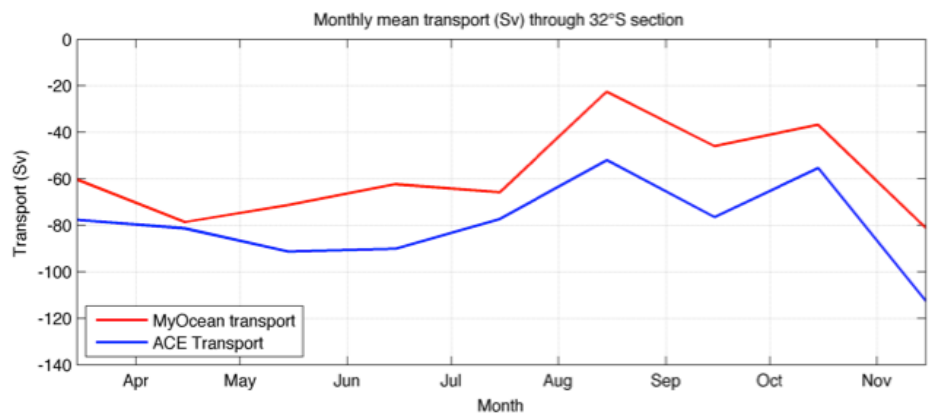
regions of converging and diverging flow at the ocean's surface. These short-scale modulations in the surface current affect the properties of the Bragg waves observed with Synthetic Aperture Radars (SAR). In SAR images, internal waves manifest themselves on the sea surface as alternating bands of rough and smooth water, which appear as light and dark strips. Figure 3 shows the Normalized Radar Cross Section (NRCS) derived from a wide-swath image acquired from the Advanced Synthetic Aperture Radar (ASAR) on 18 November 2007. The selected SAR image shows low values of backscatter over most of the sampled region due to weak winds and associated smooth sea surfaces. A band of increased backscattering intensity aligned in the south-west/north-east direction and east of 26°E, suggests the presence of an internal wave. This internal wave is thought to have been generated at the shelf edge by the Agulhas Current. Although no measurements were made during this time, it is likely that the wave train propagated northwestwards towards Algoa Bay. Several images showed similar surface structures near the shelf break off Algoa Bay.

The next step in the project is to identify more internal waves in SAR images and find the corresponding event in the data. The data will also be analysed to determine their properties (period, speed, wavelength, amplitude etc), frequency of occurrence, place and method of generation and direction of propagation.

#### VALIDATION METHODS FOR GLOBAL OPERATIONAL OCEAN MODELS OVER THE AGULHAS CURRENT

**Kyle Cooper, Bjorn Backeberg, Juliet Hermes, Jennifer Veitch, & Julie Deshayes**

Due the role in regional and global climate, economic value, and



**Figure 4:** Mean monthly transport of the ACE moorings and GLORYS2V1 during 1995.

environmental impacts the need for a dedicated operational model for the Agulhas Current is vital. But currently no dedicated operational forecast system exists over Southern Africa. The development of validation methods from global operational forecasting systems is an obvious step to a regionally dedicated model. The validation methods were developed using the GLORYS2V1 model run from MyOcean Ocean Monitoring and Forecasting system against independent observations and further applying them to other major forecasting systems such as the U.S Naval Research Laboratory (HYCOM), and BlueLINK (OFAM3). As a first step, transports and ocean stratification in vertical sections were analyzed over the region, focusing on those where independent in situ observations were available, namely the Long-term Ocean Climate Observations (LOCO), the historical 32°S line in the Agulhas Current (ACE), and the Good Hope line. The sections extracted from the GLORYS2V1 run were compared against transport estimates from historical literature. Transport sections from the moorings at LOCO and 32°S compared to GLORYS2V1 run (Figure 4) shows the model is able to reproduce the monthly variability of the transport, but underestimates total mean.

To analyze the structure, the mean velocity section from GLO-

RYS2V1 was compared to the 32°S mooring line, shows a difference of 40km and 20cm/s in current width and maximum velocity respectively. In comparison the model run shows a narrower, shallower, more concentrated current core, while observations show a wider and deeper current core, although the location of the undercurrent is similar for both. When compared, the mean surface velocity of SAR (Synthetic Aperture Radar) at 32°S to the surface velocities of ACE and the GLORYS2V1 run at 32°S shows that GLORYS2V1 is not able to represent the correct near coastal structure, but the representation of the currents is realistic offshore, while ACE mooring compared to SAR derived surface velocity estimates show similar magnitude patterns across current.

Finally the mean Sea Surface Velocities of the GLORYS2V1 model compared to mean Sea Surface Velocity derived from Synthetic Aperture Radar reproduces the structure of the current well, but underestimates the velocity up to 1m/s in places.

Overall, the MyOcean GLORYS2V1 model run reproduces the Agulhas System satisfactorily. Validation of transport and velocity from MyOcean GLORYS2V1 model shows it underestimates transport and velocity of the current, but is able to reproduce the

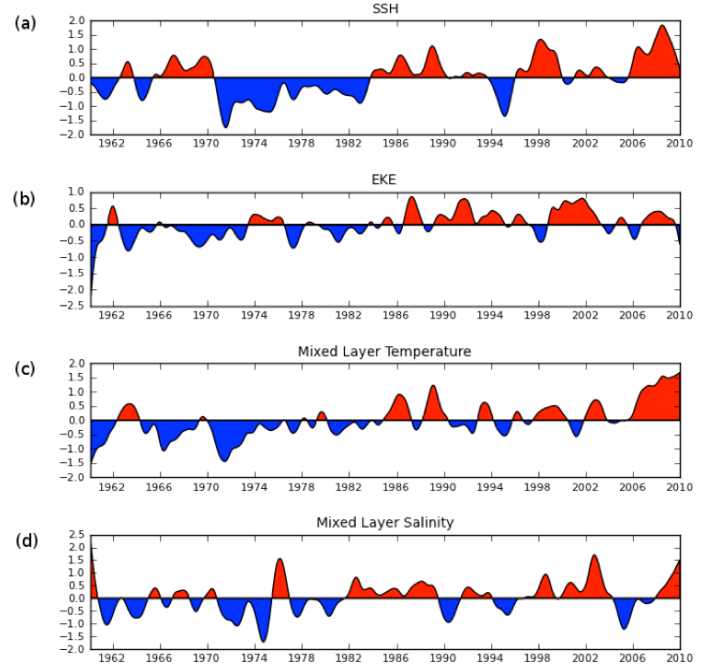
monthly variability. The development of validation methods for global operational ocean models over the Agulhas Current is still ongoing, and will be extended to the HYCOM and the BlueLINK systems.

### A 1/12° HYCOM SIMULATION IN THE AGULHAS RETROFLECTION REGION

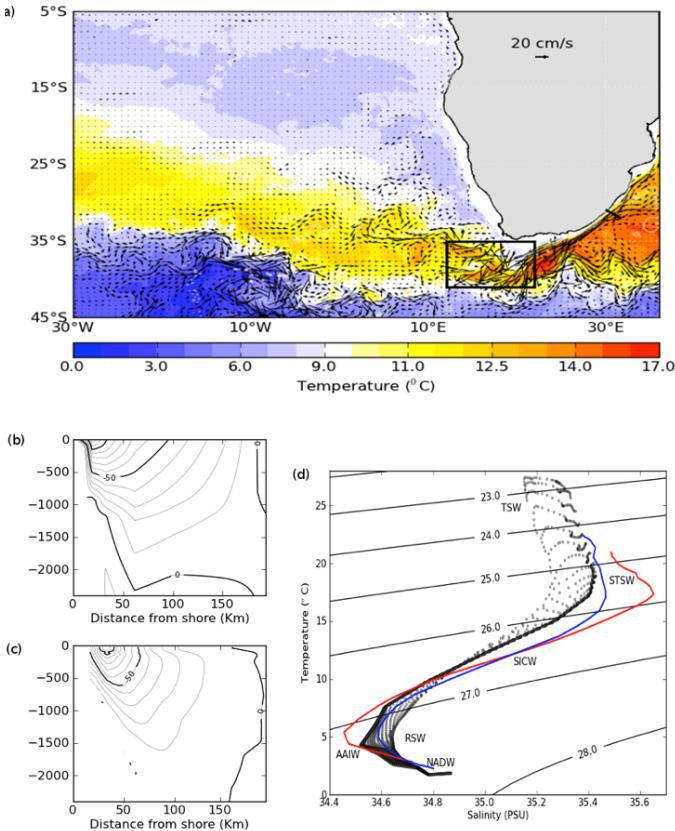
Isabelle Giddy, Bjorn Backeberg, Isabelle Ansorge, Chris Reason, & Edmo Campos

A 1/12° resolution HYCOM simulation (AT1b0.08) of the South Atlantic Ocean (domain: 12°-22°E, 35°-41°S) is evaluated. The objective is to use the model to analyse long term variability in the Agulhas Retroflection region in the light of the global importance of the Agulhas Current System and the increasing trend of Agul-

has Leakage. This eddy-permitting high resolution model is forced by inter-annual varying NCEP/NCAR Reanalysis monthly data for the period 1960-2010. The model is being run by Labmon at the Institute of Oceanography in the University of Sao Paulo, Brazil. The flow of the subtropical gyre is well-represented, although SSH is in general 20cm less in AT1b0.08 than that of altimetry (figure not shown). The main differences



**Figure 6:** Normalised anomalies in time (1960-2010) of (a) SSH (b) EKE (c) Mixed Layer Temperature and (d) Mixed Layer Salinity in a averaged box (12-22oE, 35-41oS) in the Agulhas Retroflection region.



**Figure 5:** Overview of the Agulhas System. (a) Snapshot of the Agulhas System on the 16th September 2004 showing major features (b) Cross section of the Agulhas Current at 32S from observation taken by bryden et al (2005) (c) Same cross-section taken from AT1b0.08 output (d) T/S section taken across 32S: AT1b0.08 (dots), Argo floats (red), WOA09 (blue)

are located at the southern boundary of the model. The variability of the Brazil-Malvinas Confluence, one of the most energetic regions of the world oceans (BMC) is under-represented in relation with altimetry and is located further north than seen in altimetry. From the BMC, the Brazil and Malvinas currents break-off from the continental shelf and flow eastwards as part of the South Atlantic Current. The South Atlantic Current is located further north and confined to a narrower region than represented by observations from

altimetry. Moreover, the Zapiola Anticyclone which is evident in altimetry is not resolved by the model. The failure of the model to represent the Zapiola Anticyclone may contribute to the South Atlantic being located further north and being confined to a narrower region. Following this, over the mid-atlantic ridge, the model produces an anomalous circulation which is not evident in observations. This anomaly may be a result of the South Atlantic Current being located further north than it is located in reality, as well as over-sensitive barotropic interactions with bathymetry. Over the Agulhas Region, the model appears relatively similar to observations in both flow and variability. In a more detailed analysis of the Agulhas Region, the main features of the region are identified (Figure 5a): the Agulhas Current following the coastline of South Africa, the retroflection at ~20°E and the Return Current flowing eastwards. Agulhas Rings can be seen to be breaking off and flow-



ing northwestwards with the south equatorial current. The structure of the current at 32°S is compared with mooring array observations (Figure 5b,c). The location in depth of the 100cm/s and 50cm/s isolines are similar to observations, although the current in AT1b0.08 is narrower in structure. The Agulhas Current transport across this line  $62.54 \pm 7.5 \text{ Sv}$  which is  $\sim 10 \text{ Sv}$  less than recorded by the observations:  $78.9 \pm 19.7$ . This may be attributed to the narrower structure of the current resolved by the model. In terms of thermohaline characteristics, the water masses of the Agulhas Current are identified (Figure 5d). In comparison with WOA09 climatology, the upper waters are slightly less saline, this may be a result of the model being relaxed to salinity. At depth, the model is similar to WOA09.

In comparison with ARGO floats, the model is again less saline at the surface, at depth, the model is more saline than ARGO observations. At the surface, the model has warmer waters than both WOA09 and ARGO floats. This may be related to the fact that the model is allowed to freely calculate temperatures.

Following this analysis of the simulation, and taking into account that the isopycnal vertical grid structure of HYCOM is well suited for studies of long term change, it is concluded that the model can be used in order to study long term variability in the Agulhas Retroflection Region. On an initial look at anomalies in a box averaged in the region 12-22°E, 35-41°S (Figure 6), it can be seen that there is an increase in positive anomalies from 1980. This study will continue from this point to explore the

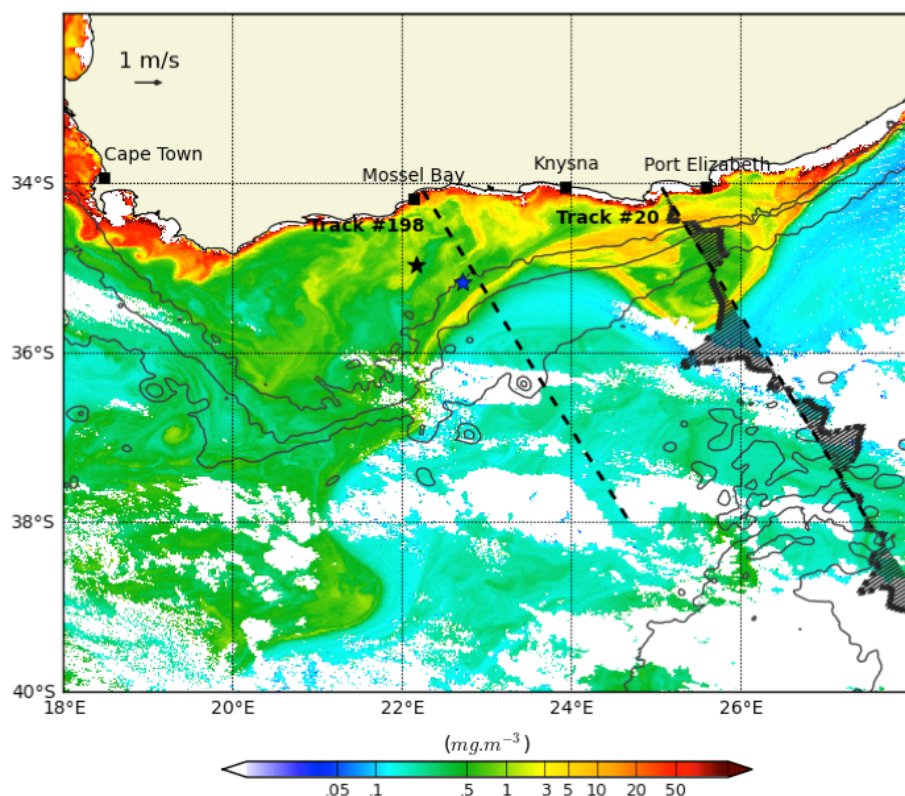
possible forces that are driving these anomalies.

## INTERACTIONS BETWEEN THE AGULHAS CURRENT AND THE EASTERN MARGIN OF THE AGULHAS BANK

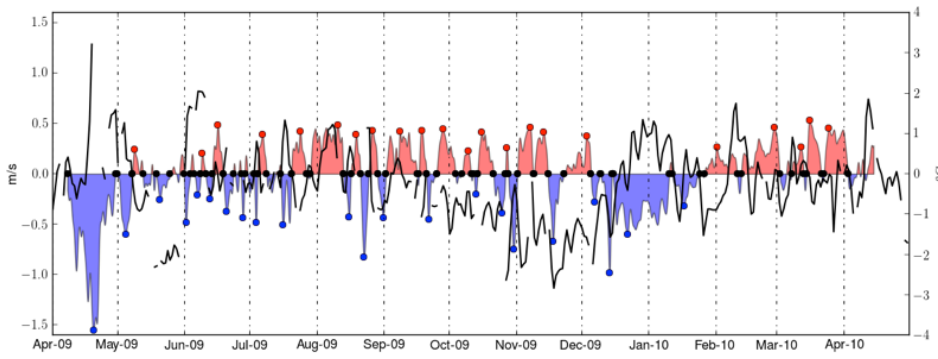
Marjolaine Krug

The Agulhas Bank, which encompasses the shelf and coastal regions south of Port Elizabeth (between 18°E-29°E and 34.8°S-36.9°S), is one of the major nursery and spawning area along the South African coastline. On its eastern margin, the oceanography of the Agulhas Bank is directly influenced by the Agulhas Current, which flows southward along the continental shelf break. The Agulhas Current impacts on the circulation and hydrography of the Agulhas Bank through a range of processes such as: variations in the Agulhas Current's strength, Agulhas Current intrusions onto the outer Agulhas Bank, Agulhas Current meanders, filaments, and water plumes (e.g. Figure 7). Our research aimed to better characterise interactions between the Agulhas Current and the coastal and shelf regions located on the eastern margin of the Agulhas Bank. Particular focus was placed on the influence of Natal Pulses on the surrounding flow. Natal Pulses are large meanders of the Agulhas Current which originate near the Natal Bight (29°S). Natal Pulses occur at irregular intervals with on average between 1 and 2 Natal Pulses per year progressing to the southern Agulhas Current region. Lagrangian float observations have revealed that Natal Pulses can extend to the full depth of the Agulhas Current. In-situ observations in the northern Agulhas region (at 30°S) have shown that Natal Pulses can drive upwelling near the continental slope to the order of 50 m to 100 m per day.

Our analysis combined high res-



**Figure 7:** MODIS Chlorophyll A concentrations observed on the 7 April 2009 during the passage of a Natal Pulse near Port Elizabeth. Overlaid are cross-track geostrophic velocities derived from the high resolution (20Hz) altimetry at the Topex / Jason Track 020. The Agulhas Current is associated with intense currents and low chlorophyll A concentrations. Strong horizontal shear is observed within the Natal Pulse meander between the south-westerly flowing Agulhas Current and the return north-easterly flow over the continental slope. The blue star shows the position of the ADCP mooring.



**Figure 8:** Periods of eastward (red) and westward (blue) flows recorded at a 30m depth from an ADCP located in water depths of 250m in the central Agulhas Bank region. The black line shows SST derived from the SEVIRI sensor onboard the geostationary Meteosat 2 satellite. The two periods of strong westward flow in April/May 2009 and December 2009/January 2010 were caused by the leading edge of Natal Pulses intruding over the shelf.

olution along-track altimetry, merged mapped altimetry and in-situ measurements of current speed and direction undertaken from a moored Acoustic Doppler Current Profiler (ADCP). Comparisons between current observations collected from the ADCP (Figure 8) and the satellite altimeters were made to evaluate the validity of the analysis conducted on the altimetry. Both altimetry and in-situ observations showed that Natal Pulses are a major driver of variability along the eastern margin of the Agulhas Bank. On average, it is estimated that the circulation along the eastern margin of the Agulhas Bank is influenced by Natal Pulses for 110 days per year. In the outer shelf region, the offshore displacement of the Agulhas Current's front associated with the passage of the Natal Pulse meander drives a strong cyclonic circulation. Closer to the shore, the impact of a Natal Pulse is felt primarily through the intrusion of the Natal Pulse's leading edge onto the shelf. While Natal Pulses are responsible for the largest temperature and current velocity anomalies recorded in the in-situ dataset, most of the intra-annual variability observed along the continental slope of the Agulhas Bank and east of 20°E, occurs over shorter time-scales

(typically a week) and is currently not adequately observed using altimetry.

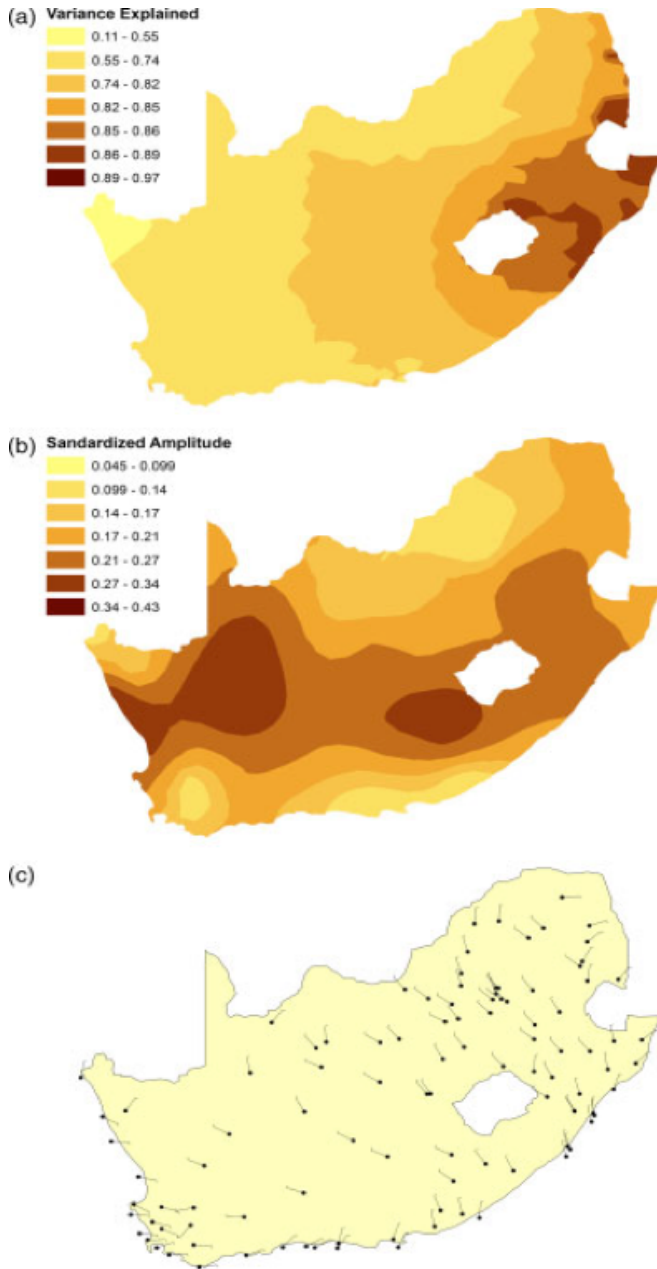
### ROLE OF THE AGULHAS CURRENT ON SOUTHERN AFRICAN RAINFALL Mathieu Rouault

We analyse 104 SAWS hourly rainfall stations from 1998 to 2007. First, we used harmonic analysis to study the diurnal rainfall patterns in South Africa. Then we look at changes in extreme events over the study period. We find that proximity of the Agulhas Current has a role on the timing of the diurnal cycle and that the increase in extreme events could be linked to the warming of the Agulhas Current.

The maximum timing of frequency of hourly rainfall reveals several coherent patterns: a morning maximum in the west, a late afternoon and early evening maximum in the interior, and a night maximum along the coast (Figure 9). There is also a night maximum in the northeast. Amplitude and variance of hourly total and frequency are low for the west coast and more pronounced over the interior and along the east coast. The west coast receives most of its rainfall in winter from May to September mainly through cold fronts and cut-off lows that are

large-scale systems landing randomly from the east. Cold fronts shift poleward during austral summer. In that respect it is interesting to observe a coherent diurnal signal there in summer, where time of maximum for frequency of rainfall occurs on average at 0600 LST and time of maximum for rainfall total occurs on average about half an hour earlier. The time of maximum for precipitation frequency increases roughly from southwest (0400 LST) to northwest (0800 LST). Average amplitude for frequency and total amount of rainfall is the lowest on the west coast of the study area (0.18 and 0.15, respectively). An analysis of hourly winter rainfall also reveals a similar early-morning maximum for precipitation frequency and total amount, with even lower values for the standardized amplitude. We note that in other parts of the world and during cold seasons, precipitation has a much weaker diurnal cycle than in summer, with a morning maximum in winter over most land areas that is at least partially enhanced by the morning maximum in lower tropospheric relative humidity because higher relative humidity increases the formation of condensates. This could well apply to the south west region of South Africa. Along the southern coast the maximum timing of frequency of summer rainfall veers regularly clockwise from early morning at Struiss Bay near Cape Agulhas, Africa's southernmost point, to around midnight from Port Elizabeth to Durban and back to early morning at the far east near the Mozambique border when coastal water are the warmest. Maximum timing of maximum total is on average an hour earlier but in fact increases from west (half an hour) to east (two hours). The amplitudes for the frequency and total amount of rainfall during summer are low from Struiss Bay to Port Elizabeth





**Figure 9:** Results of harmonic analysis for frequency of precipitation events during austral summer (November to March): (a) map of variance explained (values greater than 0.25 significant at 0.01 level of confidence), (b) standardized amplitude, and (c) time of maximum in the diurnal cycle for 103 stations located across South Africa. An arrow pointing to north indicate midnight, pointing to the east: 0600 LST, to the south: 1200 LST, to the west 1800 LST. Standardized amplitude of 0.10 implies that the probability of precipitation in the peak period is 1.20 times the 24-h mean value.

(an average of 0.13 for frequency and 0.14 for total amount of rainfall) and begin increasing at East London where they remain higher (an average of 0.25 for frequency and 0.4 for total amount of rainfall) all the way to the east of our study area. The nocturnal coastal maximum is typical of a

mer season. Average amplitude for frequency and total are 0.20 and 0.28, respectively. Timing of maximum amplitude occurs on average an hour before the timing of maximum frequency. Average explained variance for frequency is 76 % and 62 % for total. The region of maximum frequency

region influenced by a warm ocean, and it is similar to that observed in India and the US. Temperatures of 24 to 30°C are found along South Africa's east coast in summer. Measurements of the Agulhas Current show substantial transfers of water vapor in the marine boundary layer, and a deepening of the marine boundary layer due to intense mixing and unstable atmospheric stability created by the advection of colder, drier air above the current.

The nocturnal maximum amplitude for frequency and total amount of rainfall during summer in the vicinity of Durban is well documented and is attributed to the combined effect of the Drakensberg range and of the warm Agulhas Current. Except for the northeast, the interior has a clear diurnal cycle with maximum amplitude and variance explained there during the sum-

and amplitude coincide with the occurrence of times of maximum mostly from 1900 to 2300 LST, except for isolated locations or in the northeast where the maximum frequency and total overlapped with times of maximum occurring from around midnight to early morning. In the northeast, average amplitude for frequency and total are lower (0.16 and 0.25, respectively).

We analysed spatial patterns of trends in hourly extreme precipitation events in South Africa. The climate of South Africa is highly variable with a relatively high prevalence of extreme heavy rainfall events concentrated within short time periods. Given the wide-ranging impacts such extreme precipitation events can have in the form of floods, it is important to determine the most vulnerable areas. The analyses were conducted at the seasonal scale to identify regional-level variations as a result of different synoptic processes. The following indices have been used in this study: Frequency and total amount of precipitation events above the 90th, 95th, 97.5 percentile, yearly seasonal maximum amount, largest seasonal total amount of precipitation recorded over five and three consecutive hours for each year. The main findings of the study are summarized below:

Trends in extreme precipitation events during summer were predominantly positive across South Africa. The strongest positive trends were observed along the south-eastern and western coasts.

Neutral to weak positive trends were found to be scattered within small areas in the interior.

The spatial patterns of trends were reversed during the winter season with coastal areas experiencing negative trends, while positive trends were observed in the interior high altitude areas.

There were fewer variations in the winter spatial patterns relative to those in the summer season patterns. This may be a result of the influence of localized convective processes during the summer season, compared to larger synoptic processes, such as frontal systems, during the winter months.

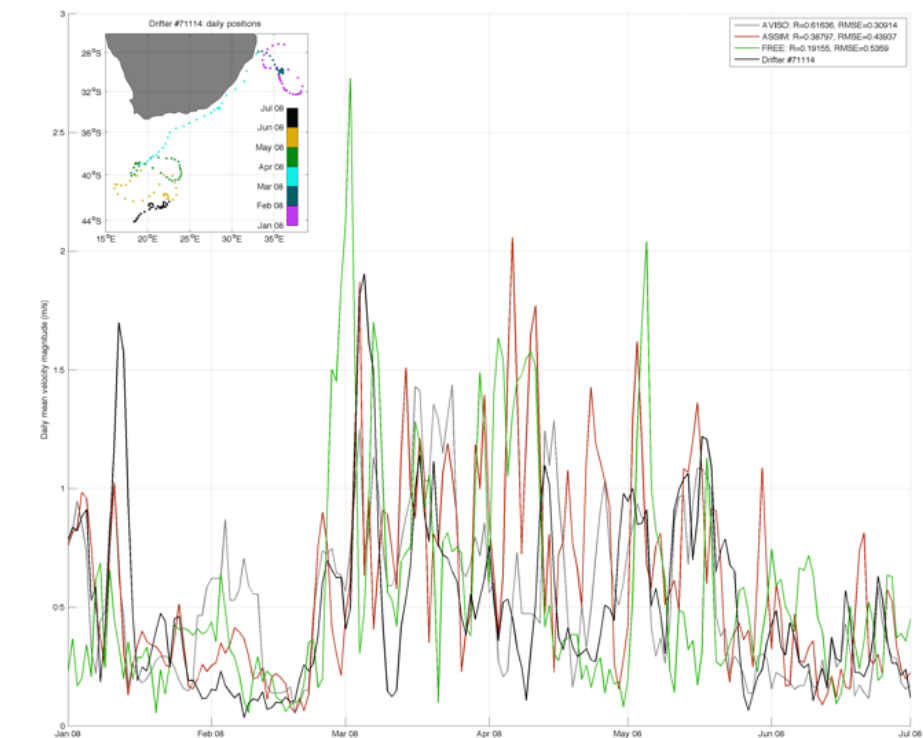
The stronger positive trends in extreme precipitation events observed along the south-eastern coast during the summer might be due to higher sea surface temperatures associated with the Agulhas Current that is getting warmer.

Finally, it is also noteworthy that the south-eastern region associated with the highest positive trends in extreme precipitation events overlaps areas of high summer precipitation. From the above analyses it is evident that the south-eastern and western coastal areas of South Africa are especially vulnerable to extreme precipitation events during summer, the main rainy season.

#### ASSIMILATING ALONG-TRACK SLA DATA USING THE ENOI IN AN EDDY RESOLVING MODEL OF THE AGULHAS SYSTEM

**Björn C. Backeberg**, François Counillon, **Johnny A. Johannessen** & Marie-Isabelle Pujol

The greater Agulhas Current is one of the most energetic current systems in the world playing a fundamental role in the marine environment, its resources and ecosystem, the regional weather and global climate. Advancing the predictability of the intense currents surrounding southern Africa represents a direct benefit to the industrial, commercial and leisure activities in the region, including the monitoring of accidental pollutants, such as oil spills as well as harmful algal blooms. While there are various global operational data assimila-



**Figure 10:** Magnitudes of daily velocity (m/s) from Aviso persistence forecasts (grey), ASSIM (red), FREE (green) and drifter 71114 (black) at the corresponding daily median positions of the drifter. The inset shows the map of its positions, the colour-scheme indicates the corresponding month. The daily velocity magnitudes and positions are plotted from 1 January to 1 July 2008. The correlation with drifter 71114 and RMSE from Aviso, ASSIM and FREE are given in the legend.

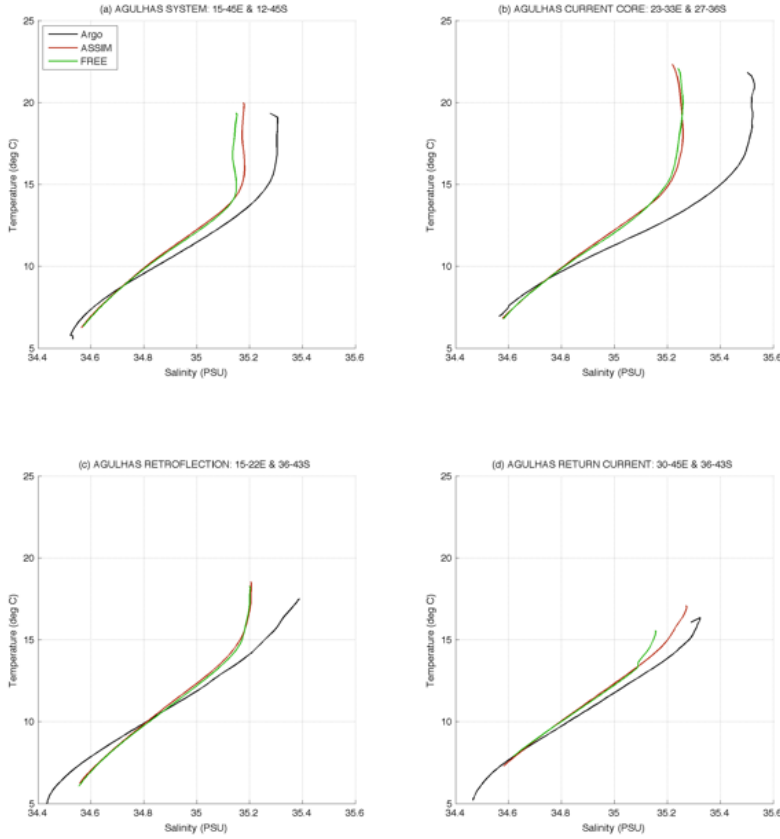
tion systems (e.g. MyOcean, Blue-Link and the HYCOM consortium), none are specifically developed for the southern African regional ocean. Indeed, there have been no regionally focused data assimilation experiments in the Agulhas since 1996.

Data assimilation provides the means to estimate a physically consistent 3-dimensional estimate of the ocean state, combining a dynamical forecast model and observations together with their relative errors. Due to inaccurate numerics and boundary conditions, model solutions are imperfect. By repeatedly assimilating data, models may be constrained to provide a more realistic estimate of the ocean state and hence, more accurate forecasts. Using this approach, it is also possible to produce ocean reanalysis products tailored specifically for the greater Agulhas Current sys-

tem. Such a system would play an important role in advancing the understanding of the complex ocean circulation and dynamic variability that characterises the region.

In this study we present a regional data assimilation system of the greater Agulhas Current system, where we assimilate satellite altimeter along-track sea level anomaly (SLA) data into a HYbrid Coordinate Ocean Model (HYCOM) using the Ensemble Optimal Interpolation (EnOI) data assimilation scheme. HYCOM has been shown to provide a reasonable representation of the salient oceanographic features in the greater Agulhas Current system, and the EnOI has been successfully applied in dynamically similar regions. This work forms part of an ongoing effort to develop a regional ocean prediction system, and the objective here is





**Figure 11:** Mean temperature–salinity diagrams from all Argo profiles for 2008–2009. (a) Averaged for the greater Agulhas Current system ( $15^{\circ}$ – $45^{\circ}$ E,  $12^{\circ}$ – $45^{\circ}$ S), (b) the Agulhas Current core ( $23^{\circ}$ – $33^{\circ}$ E,  $27^{\circ}$ – $36^{\circ}$ S), (c) the Agulhas retroflection ( $15^{\circ}$ – $22^{\circ}$ E,  $36^{\circ}$ – $43^{\circ}$ S) and (d) the Agulhas Return Current ( $30^{\circ}$ – $45^{\circ}$ E,  $36^{\circ}$ – $43^{\circ}$ S).

to evaluate the system within a forecast framework, focussing on determining the impact of assimilating only along-track SLA data from satellite altimeters. The impact has been assessed by comparing the assimilated run (ASSIM) to a free-running model (FREE) and persistence forecasts derived from satellite altimetry observations. The differences are quantified using surface drifter observations, Argo profiling float measurements and their respective drift at about 1000 m depth. In general, assimilating along-track SLA data using the EnOI assimilation scheme improves the characterisation of the mesoscale dynamics and reduces the uncertainties in HYCOM. Mesoscale features are placed in more consistent agreement with drifter trajectories (Figure 10), and the RMSE in the eddy kinetic ener-

gy and surface velocities are reduced.

The correlation between the  $u$  and  $v$  velocity components, which can be viewed as proxies for the positioning and evolution of mesoscale features, are not as accurate in ASSIM compared to persistence forecasts from Aviso. However, the satellite altimetry product significantly underestimates the EKE in the region, while the levels of EKE in ASSIM are more comparable. This highlights the benefit of combining a high resolution dynamical model with the altimetry observations. Moreover, satellite altimetry data cannot provide information about the interior of the ocean, and it is shown that assimilating altimetry observations into a dynamical model improves both the water mass properties (Figure 11) as well as the velocities at  $\pm 1000$  m.

While the mesoscale variability, water mass properties and deep velocities are improved, the SST distribution, on the other hand, is slightly degraded. This is due to a SSH bias in the static ensemble resulting in an incorrect correlation with SST. As a result, the overall SST RMSE is not improved and a slight warming is introduced in places of the Agulhas Return Current.

The misrepresentation of the Agulhas Return Current and the degraded SST field will be investigated in future work. The bias may be corrected by assimilating satellite SST and Argo profile data. However, a more satisfactory solution would be to improve the free-running model simulation from which the static ensemble is derived. It is well-known that simulations of the Agulhas Current in the retroflection region are problematic. A number of sensitivity experiments will therefore be run to advance the understanding of the sources of model deficiencies. In anticipation of an improved dynamical model, it is expected that the modelling and data assimilation system tailored to the greater Agulhas Current regime will provide more reliable forecasts of the mesoscale features of the Agulhas system, and in reanalysis mode advance the understanding of the regional ocean dynamics and quantify their importance in the regional and global climate.

## PUBLICATIONS IN 2013

### PEER-REVIEWED PAPERS

**Halo, I., B. C. Backeberg, P. Penven, C. J. C. Reason, I. Ansorge, J. Ulgren** (2013). Eddy properties in the Mozambique Channel, based on satellite altimetry and two ocean circulation models. *Deep Sea Research II*, in press.

**Krug, M., J. Tournadre, F. Dufois** (2013). Interactions between the Agulhas Current and the eastern margin of the Agulhas Bank. *Continental Shelf Research*, accepted.

Maluene, B. S., M. J. Roberts, **F. A. Shillington** and C. L. Moloney (2013). Cool, elevated-chlorophyll-a waters off northern Mozambique. *Deep-Sea Research II*, in press.

Mead A, C. L. Griffiths, G. M. Branch, C. D. McQuaid, L. K. Blamey, J. J. Bolton, R. J. Anderson, F. Dufois, **M. Rouault**, P. W. Froneman, A. K. Whitfield, L. Harris, R. Nel, D. Pillay and J. B. Adams (2013). Human-mediated drivers of change, with emphasis on the impacts to marine biota and ecosystems along the South African coast. *African Journal of Marine Science*, 35, 3, 403-425.

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### CHAPTER IN BOOK

**Johannessen, J. A., B. Chapron, F. Collard and B. C. Backeberg** (2013). Use of SAR data to monitor the greater Agulhas Current. Remote Sensing of the African Seas, editors: V. Barale and M. Gade, *Springer*, in press.

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### NEWS & VIEWS / POPULAR LITERATURE

**Halo, I., B. Backeberg, A. Brito, C. Collins O. Cossa F. Gemo, et al.** (2013). JEAI-MOCAs: A multi-institutional initiative to build marine research capacity in Mozambique. *South African Journal of Science*, 109, 7-8.

### SUBMITTED PAPERS

**Backeberg, B. C., F. Counillon, J. A. Johannessen**. Assimilating along-track SLA data using the EnOI in an eddy resolving model of the Agulhas system. *Ocean Dynamics*, submitted.

Mead, A. C. Griffiths, **M. Rouault**, K. Tunley. Range shifts by native and invasive species on the South African coast: a response to regional climate change, *Journal of Biogeography*, submitted.



**Rouault, M., P. Verley, B. Backeberg.** Wind increase above warm Agulhas Current eddies. *Ocean Science*, submitted.

Penven, P., **I. Halo**, S. Pous, and L. Marie. Cyclogeostrophic balance in the Mozambique Channel. *Journal of Geophysical Research*, submitted.

Roshin, P. R., L. Chafik, J. E. Ø. Nilsen, T. Eldevik, and **I. Halo**. The Lofoten Vortex of the Nordic Seas. *Deep Sea-Research I*, in review.

## STAFF IN 2013

### SCIENTISTS

Dr. Bjorn Backeberg (Co-director) – Oceanography, modeling and data assimilation

Dr. Wayne Goschen (Associate researcher) – Coastal oceanography

Dr. Jennifer Jackson-Veitch (Associate researcher) – Oceanography and modeling

Prof. Johnny A. Johannessen (Associate researcher) – Oceanography and remote sensing

Dr. Marjolaine Krug (Associate researcher) – Oceanography and remote sensing

Assoc. Prof. Mathieu Rouault (Research director) – Ocean-atmosphere interaction and climate

Prof. Frank Shillington (Co-director) – Oceanography and remote sensing

Mr. Christo Whittle (Associate researcher) – Oceanography and remote sensing

### POST-DOCTORAL RESEARCH FELLOWS

Dr. Issufo Halo (100%) – Oceanography and modeling

### MSC STUDENTS

Mr. Kyle Cooper – Oceanography

Ms. Isabelle Giddy – Oceanography

Mr. Bernardino Nhantumbo – Oceanography

### ADMINISTRATIVE AND TECHNICAL STAFF

Mr. Emlyn Balarin (Associate staff) – Finances

## USEFUL LINKS

Nansen-Tutu Centre  
<http://ma-re.uct.ac.za/nansen-tutu-centre/>

Marine Research Institute  
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<http://oceanographydonuttalks.blogspot.com/>



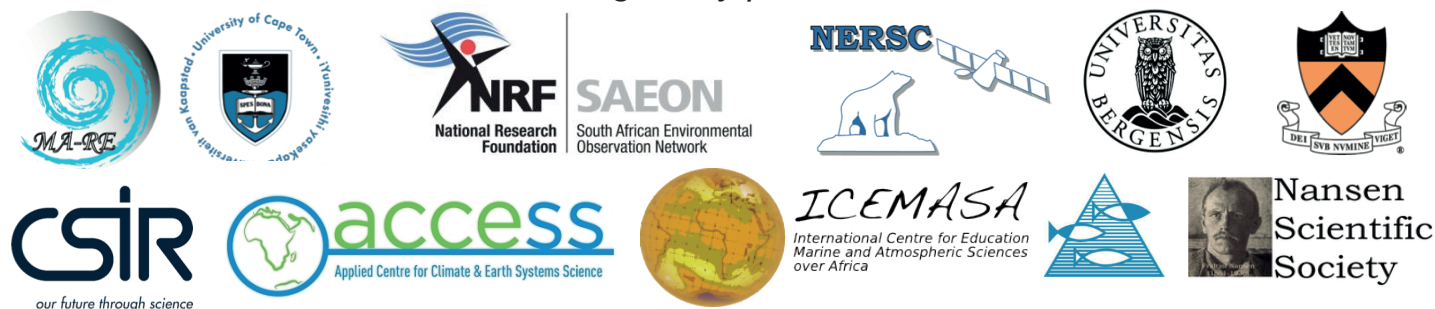
Participants of the 12th CAS-TWAS-WMO Forum, the international workshop on operational oceanography for developing countries, which was held in Beijing, China, September 9-12, 2013.



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