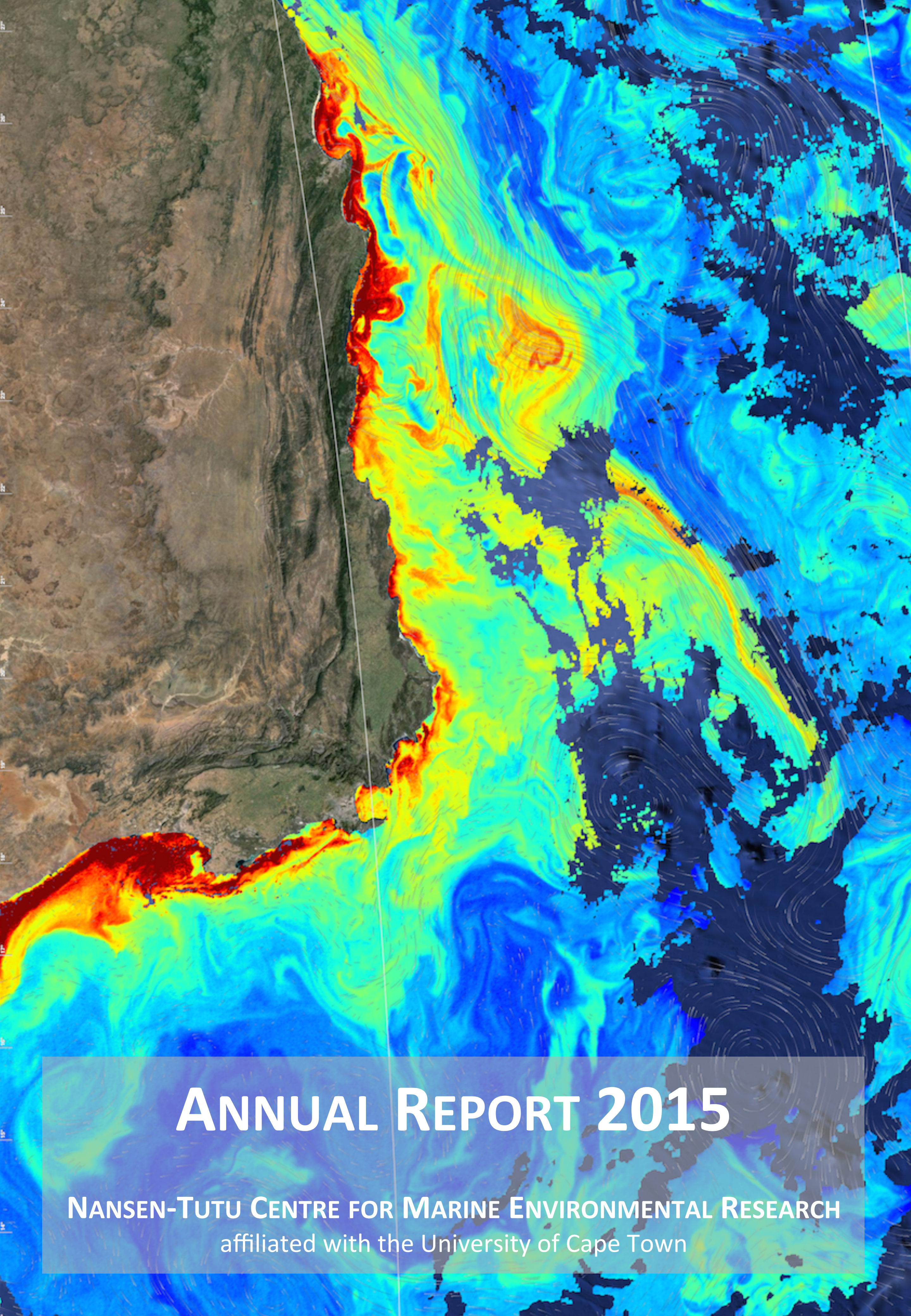

ANNUAL REPORT 2015

NANSEN-TUTU CENTRE FOR MARINE ENVIRONMENTAL RESEARCH

affiliated with the University of Cape Town

2015 – 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. In 2015 the Nansen Environmental and Remote Sensing Center and the Nansen Scientific Society contributed funding to the Centre. In kind contributions were 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 the partners include the Marine Research Institute (MaRe)/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), the South African Weather Service (SAWS) and the International Centre for Education, Marine and Atmospheric Sciences over Africa (ICEMASA). From Norway the partners are the Nansen Environmental and Remote Sensing Center (NERSC) and the Nansen Scientific Society 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 commitments from NERSC and the Nansen Scientific Society. Additional funding for projects is applied for externally notably South African and Norwegian funding bodies, bilateral funding agreements, the European Union's Framework Programmes, space agencies, industry and private sponsors.

Cover image: *Globcurrent (www.globcurrent.org) combined tidal, Stokes drift, geostrophic and Ekman-component currents overlaid onto NOAA's 8-day running composite chlorophyll-a obtained by the VIIRS aboard the Suomi-NPP space craft. Courtesy of F. Collard.*

STAFF

Nansen-Tutu Centre staff consists of partially funded and seconded associate researchers and administrators from the partner institutes, as well as fully or co-funded MSc, PhD students and Post-doctoral research fellows. During 2015, the Nansen-Tutu Centre comprised 25 persons, including 4 MSc students, 4 PhD students, 2 Post-doctoral research fellows, and 14 associate researchers and 1 adminstrator 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 14 publications emanated from the Centre, which included: 9 papers published in peer-reviewed journals; 1 chapter in a book; and 4 articles in peer-reviewed conference proceedings.

In 2015, the Nansen-Tutu Centre supported the students and Post-docs listed below. They either received a full bursary, top-up funding towards their bursaries or travel support for research exchanges or conference attendance.

1. Daniel Schilperoort (full bursary: NTC) – MSc, South Africa
2. Marc de Vos (co-funded: NRF and SCAMPI) – MSc, South Africa
3. Khushboo Jhugroo (co-funded: SANAP and SCAMPI) – MSc, South Africa
4. Imbol Koungue Rodrigue Anicet (full bursary, NTC) – PhD, Cameroon
5. Bernardino Nhantumbo (full bursary, NTC) – PhD, Mozambique
6. Georges-Noel Tiersmondo Longandjo (full bursary, PREFACE) – PhD, Democratic Republic of Congo
7. Arielle Stella Nkwinkwa Njouado (AIMS bursary and WRC project top up) – PhD Cameroon
8. Dr Charine Collins (top-up funding, NTC) – Post-doc, South Africa
9. Dr Issufo Halo (full bursary, NTC) – Post-doc, Mozambique

Congratulations to Patrick Vianello who was fully supported by the NT center in 2014 and visited

Bergen in 2014, and who graduated in 2015.

Additionally, NTC staff and associates were involved in the co-supervision of Honours, MSc and PhD students registered at the University of Cape Town and the University of Bergen, 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.

During 2015, the Centre facilitated six international research exchanges, all to the Nansen Environmental and Remote Sensing Center in Bergen, Norway, including 2 MSc students: Marc de Vos and Khushboo Jhugroo, who visted NERSC for 3 months to work on their thesis dissertations under supervision by NERSC scientists. 4 senior scientists from partner institutes in Bergen (NERSC, UiB, and IMR) visited the Nansen-Tutu Centre in 2015.

National cooperation

The Centre actively participates in national research and development activities, including the projects funded through the National Research Foundation, the Department of Science and Technology, the South African National Antarctica Programme, the Water Research Commission (WRC) and ACCESS. In addition, the Centre provides expert consultation for Anchor Environmental on some of their Environmental Impact Assessments projects and ExxonMobil. ACCESS is a consortium of several agencies, researcher councils, research programmes, universities and research groups who have combined efforts to deliver a range of outputs aligned to the Department of Science and Technology's Global Change Grand Challenge. It is a platform for an integrated and end-to-end research and education, services and training outputs and outcomes related to the opportunities and challenges emanating from a varying and changing environment, collectively referred to as Earth Systems Science. The Water Research Commission (WRC) project "Role of the Ocean on Climate" investigate mainly the impact of the Agulhas Current on weather and climate of Southern Africa, decadal variability of climate and the role of El Nino on drought in Southern Africa. In 2015 we experienced one of the strongest drought in South Africa history. The Centre played a key role in providing early warning of the impending drought and also in explaining the physics behind it. This included participation to high level national workshop and various TV apparitions. UiB and NERSC are partners of the WRC project.

International activities

The Centre facilitated six research exchanges for South African students and researchers during 2015, and supported two PhD student's attendance at international conferences.

The centre organised the International PIRATA-PREFACE-CLIVAR Conference on Tropical Atlantic and Adjacent Upwelling in cape Town in September 2015. There were 90 delegates from 25 countries that attended the Conference. This was a COP21 side events. The centre hosted the CLIVAR Atlantic panel at UCT prior to the event. In addition to this the Centre contributed to a number of international projects. These include 2 European Seventh Framework Programmes, the Marie Curie Actionsproject "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). PREFACE is a climate change project with 28 partners across 18 countries in Europe including UIB, IMR from Norway and NT and Africa, and 3 associate partners directly involved in the sustainable management of the three Eastern boundary large marine ecosystems of the Tropical Atlantic.The centre is a partner in a project funded under South Africa - Norway Research Co-operation on Climate Change, the Environment and Clean Energy, entitled "Seasonal to decadal Changes Affecting Marine Productivity: an Interdisciplinary investigation" (SCAMPI). SCAMPI aims to carry out interdisciplinary research in the marine environment, addressing different scales of variability in the oceans off southern Africa and providing knowledge that allows impacts of future climate change to be anticipated and adaptation strategies developed. The project spans the "Environment" and "Climate System" thematic areas of the SANCOOP call. It builds on the already-established, strong relationships between the University of Cape Town's Marine Research Institute (including the Nansen-Tutu Centre), the Nansen Environmental and Remote Sensing Center in Bergen, and the University of Bergen and the Centre for Ecological and Evolutionary Synthesis at the University of Oslo.

Financial situation

A total of 799 512 ZAR seed funding for the Centre was made available from Norwegian partners in 2015: 456 864 ZAR from NERSC and 342 648 ZAR from the Nansen Scientific Society. In addition to this, almost 3,300,000 ZAR was raised through project proposals in 2015. These include project proposals submitted to the South African National Research Foundation, the Department of Science and Technology, the Water

Research Commission, the South Africa - Norway Research Co-operation and the European Framework 7 Programme. Additional funds were procured by the Centre for contract research undertaken for Anchor Environmental and ExxonMobil.

Prospects for 2016

- Launch of Phase III of the Nansen-Tutu Centre Joint Venture Agreement.
- Contribute to the planning of an International Marine Research Institute in Cape Town.
- Continue to support existing PhD students.
- Appoint new MSc and PhD students depending on available funding.
- Participate in the Science Week jointly arranged by NRF and RCN
- Co-host the Benguela Symposium in November 2016.
- Enhance and formalise institutional collaborations.
- Improve science outreach through popular articles, social media and newsletters.

Approved by The Board
Cape Town, May 2016

NANSEN-TUTU CENTRE
MARINE ENVIRONMENTAL RESEARCH

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Research Director

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

Administration

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

Science report for 2015

The annual cycle of ocean atmosphere interaction above the Agulhas Current

Arielle Stella Nkwinkwa Njouado, Mathieu Rouault and Johnny Johannessen.

The aim of this study is to document the impact of ocean-atmosphere interaction above the Agulhas Current on the weather and climate of Southern Africa. To that effect we are using various parameters obtained from climate reanalyses and satellites remote sensing dataset. The first goal is to find out if those products do represent the intense exchange of moisture from sea to air that occurs above the core of the Agulhas Current and the retroflection region. We are using monthly fields of ERA INTERIM, MERRA and CFSR climate reanalysis sea surface temperature SST, latent heat flux, surface wind speed , temperature and humidity, from the period 1998 to 2005. Corresponding monthly satellite remote sensing estimates analysed are HOAPS3 (Hamburg Ocean Atmosphere Parameters and Fluxes) and SEAFLUX (Air-sea turbulent fluxes), SeaFlux is a high-resolution satellite-based data set of surface turbulent fluxes over the global ocean (0.25°x0.25°). It also provides parameters used to calculate the fluxes. We also use the 5x5 km degree resolution MODIS (Moderate Resolution Imaging Spectroradiometer) sea surface temperature aboard Terra and Aqua satellites from NASA as reference for SST and the SCOW wind climatology as reference for surface wind speed and direction. We first conducted an intercomparison of annual, seasonal, and monthly mean of all those products in the greater Agulhas Current system as latitude longitude charts and monthly time series at selected location (Figure 1).

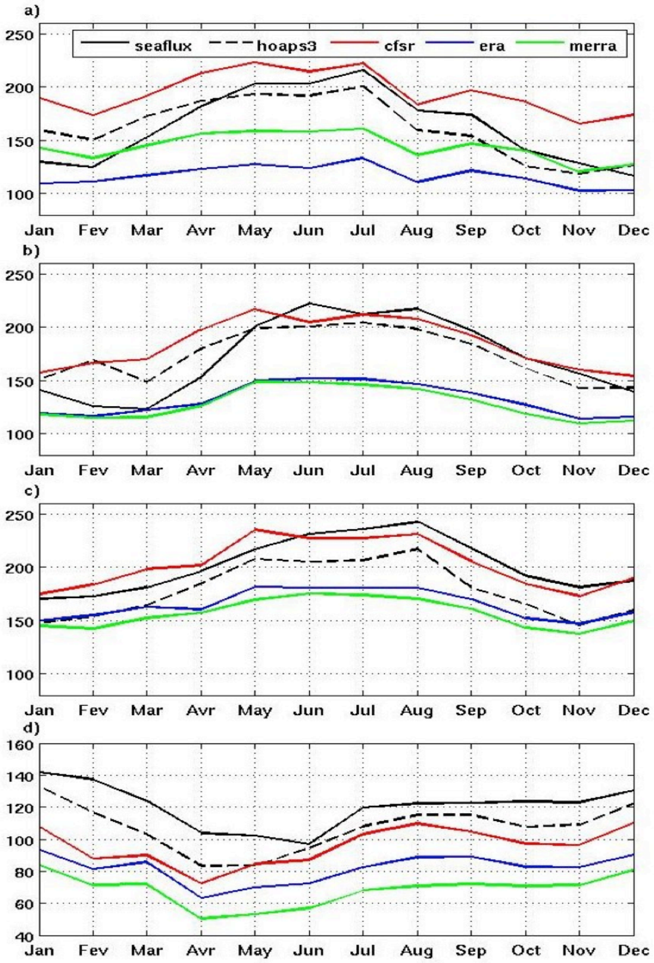

Figure 1: *Annual cycle of latent heat flux (W/m²) for the period 1998-2005 at a) Agulhas Current off Durban (32°00E, 29°94S), b) Agulhas Current off Port Elizabeth (25°36E, 35°11S), c) Agulhas Retroflection (21°88E, 37°62S) and d) Benguela upwelling off Cape Town (17°25E, 33°75S) for SEAFLUX (black), HOAPS3 (black dash), CFSR (red), ERA-INTERIM (blue) and MERRA (green).*

To illustrate the intercomparison of products, Figure 1 shows the annual cycle of latent heat flux in four locations: three in the Agulhas Current; offshore Durban (zone A), offshore Port Elizabeth (zone B), in the Retroflection area (zone C) and one offshore Cape Town in the Benguela upwelling (zone D). The latent heat flux is most important in winter from May to August in the Agulhas Current system. The highest value is around 250 W/m² in the Retroflection area in winter and the lowest value is off Cape Town with 50 W/m² in April. For latent heat flux, the average annual mean all locations taken together (Figure 1) give a mean of 163 W/m² for SEAFLUX, 155 W/m² for HOAPS, 168 W/m² for CFSR 123 W/m² for ERA INTERIM and for MERRA. To understand why the latent heat flux is higher in winter in the Agulhas Current system, we analysed SEAFLUX SST, specific humidity at 10m (Q10) and surface wind speed at those locations. Saturated specific humidity is calculated using the Clausius-Clapeyron relation and SEAFLUX SST. Offshore Port Elizabeth and in the Retroflection area and offshore Cape Town, the latent heat fluxes strength follow the strength of the wind speed which is not the case for Durban. Correlation between wind speed and latent heat fluxes for Durban, Port Elizabeth, Retroflection and Cape Town are -0.1, 0.93, 0.98 and 0.98 respectively. The correlation between latent heat flux and the difference between QSST and Q10, which is another driver of the latent heat flux, is for Durban, Port Elizabeth, Retroflection and Cape Town respectively 0.94, 0.96, 0.15 and 0.72. This indicates that QSST-Q10 is the main driver of the amplitude of the annual cycle of latent heat flux in Durban while it is the wind for the Retroflection area and it is a mix of the two for Port Elizabeth and Cape Town. We note that Durban is the zone with the weakest wind and the strongest SST and that QSST and Q10 follow the SST in all areas. At last Using MODIS as SST reference, we find that all products underestimate the core of the Agulhas Current SST off Port Elisabeth by 1.2°C to 0.5°C on average but reproduce the SST off Durban, retroflection and Off Cape town relatively better (more or less 0.5 maximum) which will have an impact on QSST and Q10.

Interannual equatorial Atlantic Ocean Variability from 1998 to 2012

Rodrigue Anicet Imbol Koungue, Mathieu Rouault, Marek Ostrowski and Serena Illig

We are investigating the link between equatorial Atlantic subsurface ocean variability and the coastal region of Angola and Namibia. We focus on warm and cold subsurface events at the seasonal scale because they have an impact on rainfall and the marine ecosystem. The ultimate goal is forecasting Benguela Niños, warm ocean events that are occurring off Angola and Namibia. We focus here on the 1998-2012 period because of the availability of ocean observations from PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) along the equatorial wave guide. We also use altimetry (sea level anomalies (SLA) derived from AVISO), an Ocean Linear Model and Optimally Interpolated Sea Surface Temperature (OI SST). The wind stress used for forcing the Ocean Linear Model comes from the DRAKKAR Forcing Set 5.2 (DFS5.2). The Ocean Linear Model is an ideal tool to understand equatorial wave dynamic along the equatorial Atlantic wave guide. The PIRATA's buoys located at 35°W, 23°W, 10°W and 0°E, sample the water column every 10 min with five temperature/conductivity sensors deployed at depths of 1, 10, 20, 40 and 120 m, five temperature sensors positioned at depths of 60, 80, 100, 140 and 180 m and two

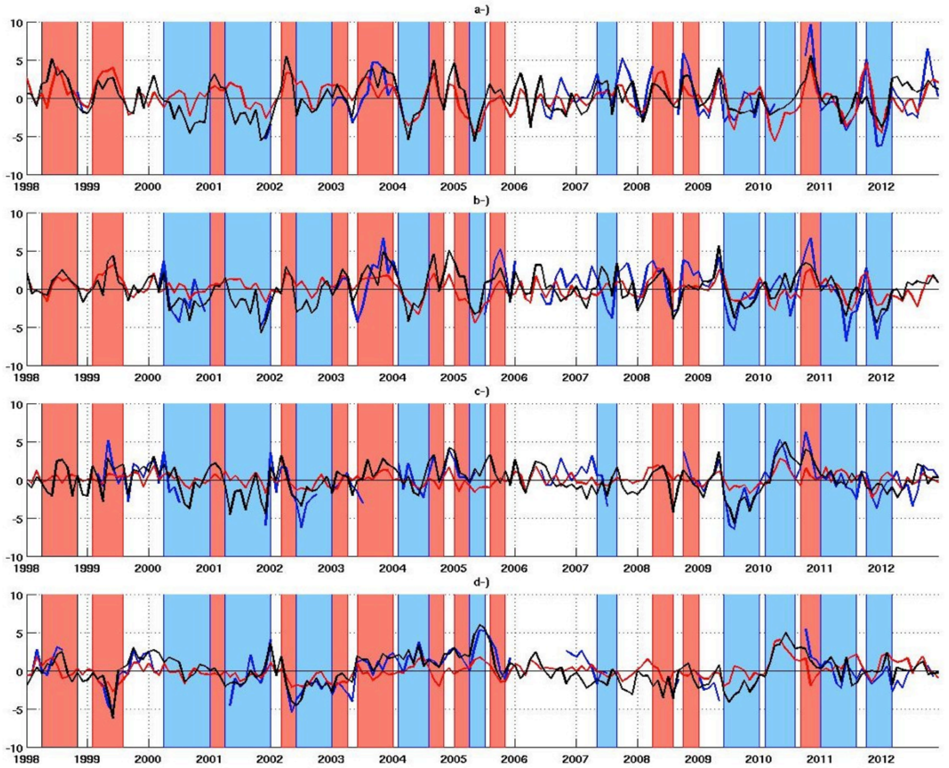

Figure 2: *Monthly Detrended anomalies of dynamic height (cm) calculated from PIRATA's buoys (blue line), Aviso Sea Level Anomalies (black line) and Ocean Linear Model sea level anomaly outputs (red line) at a-) 0°E-0°N, b-) 10°W-0°N, c-) 23°W-0°N and d-) 35°W-0°N. Warm and cold events at 0°E-0°N are represented by red and blue rectangles respectively.*

temperature/pressure sensors at 300 m and 500 m along the equatorial Atlantic. It allows detecting and monitoring the propagation of SLA and of the depth of the isotherm 20°C (d20) along the equator among other features. Hovmøller graphs of SLA complement the study and are especially useful when there are gaps in PIRATA data. The correlation between Pirata and altimetry SLA is 0.67 at 0°E-0°N at the monthly scale. There is also a correlation of 0.64 between the Ocean Linear Model derived SLA and Pirata SLA. Figure 2 shows from top to bottom the monthly detrended anomalies of SLA for PIRATA (blue), the Ocean Linear Model (red) and Aviso (black) from 1998 to 2012 at 0°E-0°N, 10°W-0°N, 23°W-0°N and 35°W-0°N respectively. Major warm and cold events are represented by the red and blue rectangles according to the buoy at 0°E-0°N in Figure 1. Warm events occurred in 1998, 1999, 2002, 2003, 2005, 2007, 2008, 2009, 2010/2011 and 2012.

Cold events occurred in 2000, 2001, 2004, 2005, 2007, 2010, 2011, and 2012. We also notice that for some events, for example warm event 2001 and cold event 2002, their signature in SST is not only seen along the equator, but also along the African coast up to northern Namibia (between 19-24°S). Some events occurred during the seasonal Atlantic austral winter cold tongue period but still propagated southward along the African coast up to 20°S. That was the case of 1998 (April-October), 2003 (June-December), 2004 (August-October), 2008 (April-July) for warm events. Cold events in austral winter occurred in 2001 (April-December), 2002 and 2009 (June-December), 2005 (April-June). We are demonstrating here that those warm and cold events (Figure 2) are remotely forced by ocean atmosphere interactions in the tropical Atlantic and that wave dynamics is a major factor in their development. The wind stress forcing anomalies calculated in the ATL4 domain (50-25°W, 3°S-3°N) explain most of the origin of warm and cold events all the way to the Benguela upwelling system. Warm events are associated with weaker than normal easterlies wind stress anomalies in the west equatorial Atlantic. The weaker wind stress triggers equatorial downwelling Kelvin waves as demonstrated by the Ocean Linear Model output and confirmed with Altimetry SLA and PIRATA SLA and D20 anomalies. A 0.6 lag correlation significant at 95% of one month exist between wind stress anomalies averaged in the ATL4 box and SLA from the Ocean Linear Model at 0°E, 0°N. The second baroclinic mode of these equatorial Kelvin waves is the most energetic. The opposite happens for cold events that are forced by stronger than normal wind stress in the West and that triggers upwelling Kelvin waves.

Does the variation in strength and position of the Agulhas Current induce sea level variation?

Bernardino Nhantumbo, Frank Shillington and Ola Johannessen

Research on sea level variability has been carried out worldwide from tide gauge records in order to ascertain the current rates of sea level rise (SLR). These rates of change vary from place to place due to several different local phenomena. The comprehensive 24 yearlong global altimeter records of sea level from satellite altimetry have shown that average global sea level is currently rising at about 3 mm per annum. A first goal of our study is to determine the rate of SLR and likely SLR acceleration at specific tide gauge locations along the east coast of

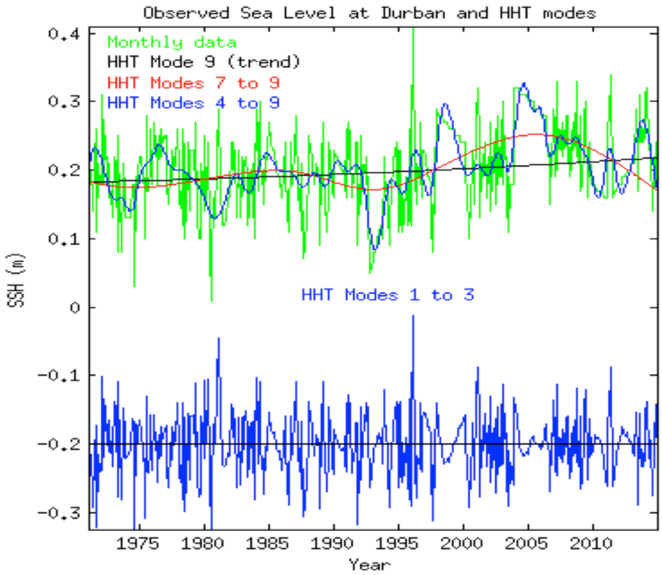

Figure 3: *An example of monthly tide gauge records at Durban (thin green line) when decomposed with the EMD/HHT analysis. As result, nine modes were found, where modes 1 to 3 (thin blue line at the bottom) are the combined "high-frequency" parts of the signal, modes 4 to 9 (heavy blue line) represent the "interannual-to-decadal" variability, modes 7 to 9 (heavy red line) indicate the "multi-decadal" (~25 year periods) and mode 9 (heavy black line) is the remaining residual or "trend", which also shows some evidence of a non-linear change.*

southern Africa, and to determine the important forcing mechanisms behind the changes. At Durban (the longest and most suitable continuous tide gauge measurements) show agreement with the average global SLR. Because the Agulhas Current (AC) flows very close to the coast off the east coast and is part of the greater Agulhas System in the southwestern Indian Ocean, analogies with the Gulf Stream off north east America indicate that the AC variability is likely to influence the coastal sea level. The second major goal of the study is to employ suitable along track satellite altimeter data across the AC to locate the position of the Agulhas Current core, and hence to examine its role in SLR variability. The AC is a major western boundary current with strong variability in velocity and position. A major open question is whether SLR and the AC variability are closely linked. To answer this question, a combination of in situ, satellite altimetry observations, and numerical model simulations along the south and east coast of southern Africa, will be used to identify distinct spatial patterns of sea level change. The data will consist of monthly mean sea level from tide gauge records, the monthly AC transport and the altimeter sea surface height data for the AC region. The monthly AC transport will be used to assess its possible slowdown/acceleration, while the altimeter data for the AC region will be used to identify if the maximum elevation gradient is centred close to the coast or farther offshore. The Empirical Mode Decomposition (EMD) and Hilbert - Huang Transformation (HHT) been employed to calculate the SLR trends and acceleration (See Figure 3). As shown in the figure, the EMD/HHT method decomposes the signal into a finite number of intrinsic mode functions with time-variable amplitudes and frequencies. The EMD/HHT analysis has advantages when compared with the traditional spectral analysis methods, because it is possible to identify oscillatory modes that are too long for the spectral analysis technique. Therefore, unlike most of the known spectral analysis methods, the EMD/HHT allows one to determine modes with periods two times longer than the record length. The technique also allows us to compute a non-linear trend in the data (Figure 3). Expected results of the research are that the AC changing velocity and position will impact on SLR rates in different locations along the south and east coast of southern Africa. The next two year phase of this project will be to obtain suitable in situ and model data on the Agulhas Current flow, in order to investigate the correlation and/or nature of a possible links between the AC and the coastal sea level variability.

The Effect of the Agulhas Current on Synthetic Aperture Radar Derived Wind Fields

Daniel E. Schilperoort, Marjolaine Krug, Morten Hansen, Mathieu Rouault

Synthetic Aperture Radar derived wind speeds contain inaccuracies in both magnitude and direction over strong western boundary currents due to the relative motion of the current as well as ocean-atmosphere influences. The relative motion of a wind field blowing parallel and against the flow of an underlying current has been shown to have a an effect of increasing the intensity of the Normalised Radar Cross Section (NRCS) and the resulting derived wind speed (Reference!). Increasing sea surface temperature (SST) have also been shown to destabilize the overlying marine atmosphere boundary layer and result in an increase in the true wind speed over the current (Reference!). The purpose of this study is to investigate the effect that a warm, narrow and intense boundary current such as the Agulhas Current would have on the derived wind speeds from the Envisat Advanced Synthetic Aperture Radar (ASAR). The goal is to isolate and differentiate between the wind speed changes which occur as a result of the current relative effect and those due to SST changes. The ASAR wind data are derived using the CMOD5.n Geo-

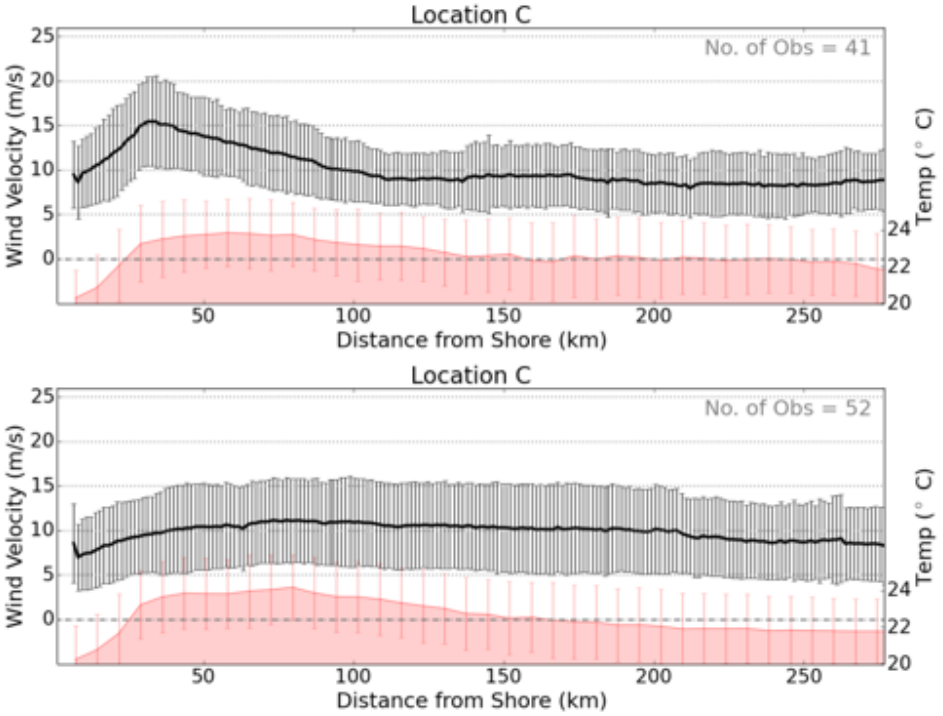

Figure 4: *Mean Upcurrent (Top) versus mean Downcurrent (Bottom) wind speed components plotted as perpendicular transects over the Agulhas Current for the location C. Data is co-plotted with the underlying SEVIRI SST (Red) as a representation of the location of the core of the Agulhas Current. Error bars show the standard deviations of each dataset along the transect.*

physical Model Function with Climate Forecast System (CFS) data assimilation numerical models as direction input. The transition to the next paragraph is abrupt and makes no reference to Figure 4.

The data are then refined into 6 locations of interest along the Agulhas Current to provide the best spatial coverage along the current. The wind data in each location is then spatially averaged and compared to the CFS and Metop Advanced Scatterometer (ASCAT) derived wind fields. Secondly the winds are grouped into four regimes according to their mean direction and the direction specific components are extracted using vector geometry. The direction regimes are: Upcurrent, Downcurrent, Crosscurrent West and Crosscurrent East. Transects are then extrapolated through each location of interest perpendicular to the Agulhas Current. The transects are then utilized to investigate the spatially changing wind speed characteristics of each direction regime as they flow over the current. We found that ASAR has a greater ability to represent higher intensity wind events and smaller scale wind speed and direction changes than Scatterometry due to increased resolution. Due to a combination of the current relative effect and SST and atmospheric effect, wind blowing in an upcurrent direction can result in a sharp mean 50 % increase in wind speeds over the inshore boundary of the current with individual events reaching as high 100% in spatial scales in the order of 10's of kilometres. For the downcurrent wind direction regime the current relative effect is overridden by an increase of wind speeds of up to 40% across the entire current cross section. Thus the mean effect of SSTs on wind speeds is a greater effect than the current relative effect on wind speed changes over the current. The wind speed differences are best represented under moderate wind speeds, between 5-15 m/s due to the surface roughness thresholds. The results from this investigation will serve to improve future satellite wind speed derivations by helping to identify the different wind speed and surface roughness altering effects. It will also serve to further understanding of high resolution wind features and sharp changes over ocean features.

Sea surface temperature rainfall relationship over eastern equatorial Atlantic

Georges-Noel T. Longandjo, Mathieu Rouault and Noel Keenlyside

It was argued that the relation between sea surface temperature (SST) over Atlantic and Indian Oceans and central Africa rainfall anomalies is nonlinear and seasonally variable. We also found that central Africa rainfall is more influenced by the SST gradient of SST anomalies between equatorial Atlantic Ocean and tropical Indian Ocean than by the surrounding ocean basins taken separately. To further understand mechanisms linking the SST gradient and Central African rainfall, we present here the relation between rainfall and SST above the tropical Atlantic. Over tropical Ocean, deep convection is highly modulated by the underlying SST. Eastern equatorial Atlantic (20°W-10°E; 5°N-5°S) is generally colder than its counterpart Pacific and Indian Oceans, with a pronounced seasonal fluctuation leading to relatively cold SST in austral winter, a phenomenon called the cold tongue. The tropical Atlantic SST mean (26 ±1.47 °C) is lower than the SST threshold, defined as the minimum SST (27.5°C) for which the rainfall mean over tropical Oceans exceeds 2 mm/d. However, that threshold is reached from January to May. Thus, how does and when SST play an active role on overlying rainfall over the eastern equatorial Atlantic? We are using here observations (Global

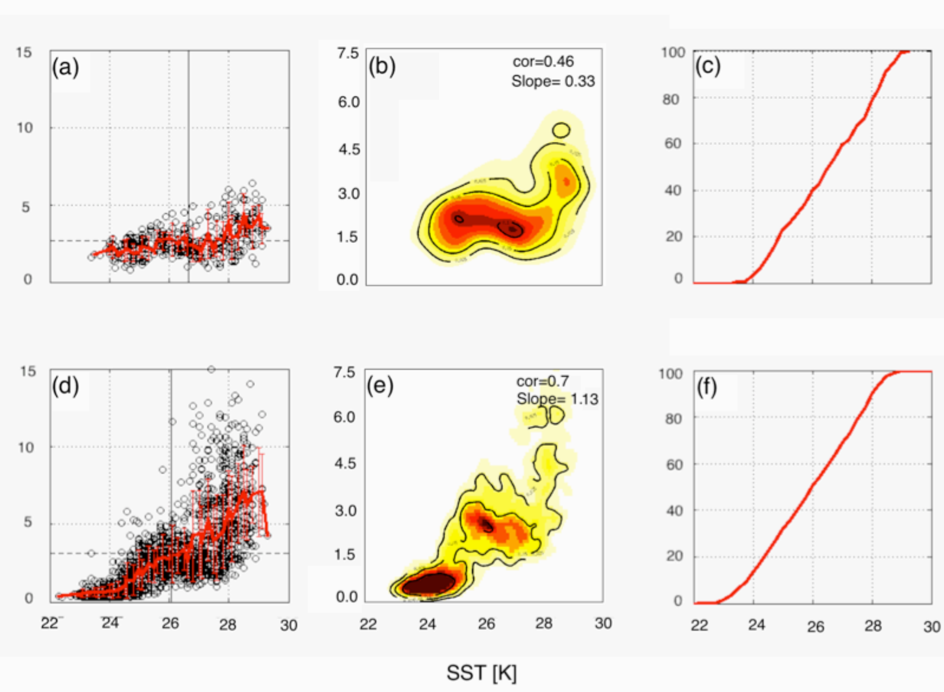

Figure 5: *Scatter diagram and probability density function of monthly – mean rainfall as function of local SST over eastern equatorial Atlantic of (a) and (b) observation (GPCP); (c) and (d) model (ECHAM) with SST (ERSST) over eastern equatorial Atlantic as sum of all months. Data are used respectively over 1979-2009 in (a), (b) and (c), while over 1870-2009 in (d), (e) and (f). Rainfall and SST are averaged at each 0.5K bin. Red line in (a) and (d) represents respectively the variation of mean rainfall with SST, whereas the length of vertical bars represents the standard deviation and in (c) and (e) the accumulated percentage at each 0.5K SST bin. Black dashed horizontal and solid vertical lines in (a) and (c) indicate respectively observed mean rainfall and SST values respectively.*

Precipitation Climatology Project (GPCP) version 2.2 and extended reconstructed sea surface temperature data (ERSST)), ERA Interim climate reanalysed sea level pressure, wind and geopotential height at various level, surface wind, downward surface shortwave radiation and low-cloud fraction and surface latent heat flux from MERRA and an atmospheric general circulation model (ECHAM version 5.3) forced by observed SST. The atmospheric stability is estimated as the difference of moist static energy between 200 and 850 hPa level: $\Delta MSE = MSE200 - MSE850$. First, to figure out how the rainfall is distributed over its underlying SST over eastern equatorial Atlantic, we compute the joint probability density functions (PDF) using an adaptative bivariate Gaussian kernel density estimator (Figure 5). Over eastern equatorial Atlantic, rainfall distribution is trimodal. The primary peak (where most rainfall occurs) is at 27°C for roughly 1.7 mm/d. The second peak is at ~26°C for ~2.3 mm/d and the third peak is at 29°C for 3.1 mm/d (Fig. 5b). The model mismatches the observed rainfall distribution and has a bimodal characteristic (Fig. 5e). However, for the annual cycle, we found no significant correlation between rainfall and SST. But the rate of rainfall change for an increase of 1°C ranges between -0.27 mm/d in March and 0.45 mm/d in May. In addition, we found that surface latent heat flux is strongly correlated to surface pressure, which is related to large-scale ascendance or subsidence. We also notice that surface pressure could produce more ascendance and atmospheric instability independently of SST values, while synoptic weather, represented here by surface pressure regulate the surface latent heat flux. Furthermore SST is dependent on wind speed, which in turn, is modulated by surface pressure. These findings lead us to infer that the seasonal rainfall distribution is largely controlled by surface dynamics and thermodynamics (as defined by surface latent heat flux and free atmospheric instability) than by local SST.

Regional features of the phytoplankton bloom cycle in the Sub-Antarctic Zone of the Atlantic

Khushboo Jhugroo, Marcello Vichi, Anton Korosov, Morten Hansen

The current estimates of phytoplankton growth in the Southern Ocean are generally biased and it is becoming more evident that the timing and intensity of the bloom in the Subantarctic Zone (SAZ) and frontal region is remarkably diverse. This study aims at documenting the current features of phytoplankton cycle as detected through ocean colour satellite observations, with a focus on temporal and spatial variations in the SAZ. Satellite data from ESA-CCI are being used to assess the phenology, regional extent, model biases and regional dependence of the chlorophyll cycle in the area.10-days mean mixed layer depth (MLD) data, a global gridded product at 2 degrees resolution for the period 2001-2014, developed by JAMSTEC was used to compute a weekly MLD climatology used in this study. The MLD dataset was computed using Argo temperature and salinity profile and is called "MILA GRV (Mixed Layer dataset of Argo, Grid Point Value)". 8-days mean ocean colour (Chlorophyll-a con-

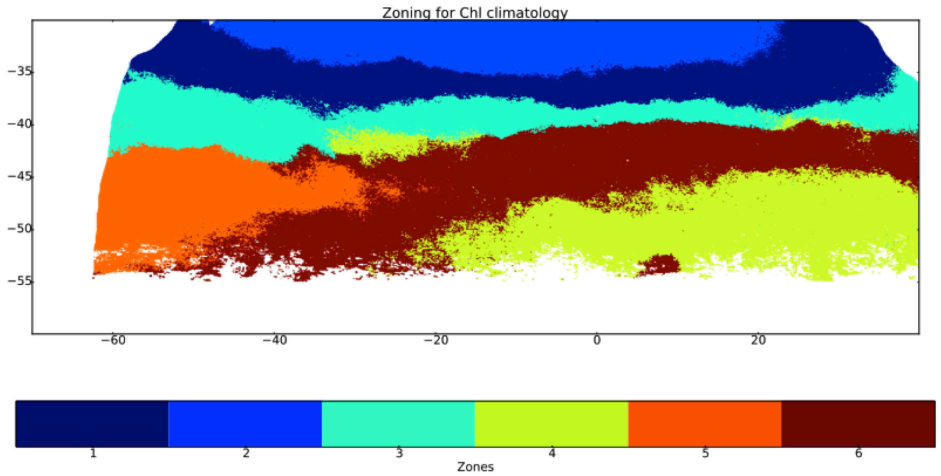

Figure 6: *K-means clustering in the PCA subspace for six zones from four principal components (with masked coastal regions around South Africa and South America) in the region of interest. The zoning procedure was performed only on the bloom period – also the period of the year when most data is available. This was done by skipping seven weeks in winter.*

centration) data (1998 - 2013) and daily sea surface temperature (SST) data (1998 - 2010) of 4 km resolution from ESA-CCI were used to compute weekly climatology for the Atlantic SAZ. Relevant Python packages, including the Nansat Python package were used for data processing and image analysis in this study. Data processing and analysis for this study were started at the Nansen Environmental and Remote Sensing Center in Bergen, Norway and were completed at the University of Cape Town, South Africa. Supervised latitudinal and longitudinal transects were chosen to study the bloom cycle, bloom growth rates and bloom initiation dates based on the hypothesis that the western side is different from the eastern side of the basin; there is more zonal variability as opposed to meridional. Analysis of Chl-a in the supervised transects showed that there is indeed a distinguishable western side of the basin. However, the differences did not show a clear and reliable zonal or meridional pattern for the region. This led to the belief that the basin could possibly be characterised by unsupervised clusters/zones with similar characteristics and dynamics throughout the basin instead of set patterns. Principal Component Analysis (PCA) was performed to classify different regions in the Atlantic SAZ based on their regional characteristics and dynamics. K-means clustering in the PCA subspace was applied to the Chl-a dataset and an appropriate number of zones were chosen for the Atlantic SAZ. The subtropical zone is clearly defined zonally by zones 1, 2 and 3 (Figure 6). The transition zone between the subtropical zone and the subantarctic zone (around 42S) is a region where there is high variability in terms of bloom initiation, bloom concentration and rate of change of chlorophyll-a concentration. It is also where the boundaries of the zones defining the Atlantic SAZ are located (zones 3, 4, 5 and 6 in Figure 6). This zoning technique also shows that the western side of the basin demarcates itself from the eastern side and the middle of the basin which are more zonally defined. Looking at bloom phenology in the Atlantic SAZ, it was found that bloom initiation dates tend to occur earlier on the western side of the basin and closer to the subtropical front. Zoning in this region showed that there is indeed some meridional variability in the Atlantic SAZ, however, the zones are more defined as randomly placed spatial patches in the basin. An attempt to address long term trends in the Atlantic SAZ, the phenology of the ecosystem and their impact on regional scale features and spatial variability was made in this study. This study provides more knowledge on the major processes affecting bloom dynamics in this region, and eventually serve as a starting platform to assess the quality of Earth System Models for the Atlantic SAZ of the Southern Ocean.

The impact of assimilating along-track SLA data on simulated eddy characteristics in the Agulhas System

Marc de Vos, Björn Backeberg and François Counillon

The Agulhas Current System is a vital element of the global ocean-climate system by virtue of its role in the transfer of energy, nutrients and organic material. In the context of working towards better climate change projections, it is necessary to develop a robust understanding of the complex dynamical mechanisms which facilitate this transfer. Mesoscale cyclonic and anticyclonic eddies transport heat energy, salt, organic matter and nutrients from the Indian Ocean into the South Atlantic Ocean. In so doing, they are key drivers of the Atlantic Meridional Overturning Circulation (AMOC). As such, it is important that they are adequately simulated by numerical models in order to advance the accuracy of climate prediction. In the absence of comprehensive in-situ observing systems, numerical models provide the capacity to describe the oceanographic conditions of the region. Given the complexity of the regional dynamics, and the challenges it presents to pure numerical modelling, data assimilation is a valuable tool in improving simulation quality. An important step in this continuing process is the objective, qualitative evaluation of model configurations, such that they can be continuously refined. In this study, the impact of assimilating along-track sea level anomaly (SLA) data is investigated with regard to the simulation of mesoscale eddies in the Agulhas System. Two configurations of a hybrid coordinate ocean model (HYCOM) configuration are analysed; one free run (hereafter 'FREE') and one with along-track SLA data from satellite altimetry assimilated (hereafter 'ASSIM') via an Ensemble Optimal Interpolation (EnOI) data assimilation scheme. The results of these two configurations are compared with each other, and against a set of corresponding observational data from satellite altimetry (hereafter 'Aviso'). To this end, an automatic eddy detection and tracking algorithm is implemented, in order to quantify eddy characteristics in a coherent and consistent manner. ASSIM shows global improvements in the simulation of eddy density distribution and dynamics over FREE (Figure 9a and b); i.e. better agreement with observation (Figure 9c). South of South Africa and south of Madagascar, ASSIM simulates a more realistic number of eddies than FREE, although the number south of Madagascar and in the south-west Indian Ocean remains too low. This is of particular interest, as previous analyses of the mesoscale variability in this region have shown sufficient and indeed excessive eddy kinetic energy (EKE). However, when computed only where eddies are known to exist (as opposed to from continuous velocity fields), levels of EKE fall short. This suggests that whilst model configurations are simulating adequate levels of variability, they are not simulating and sustaining eddies realistically in this region. Relative error calculations (Figure 9d) indicate that the simulation

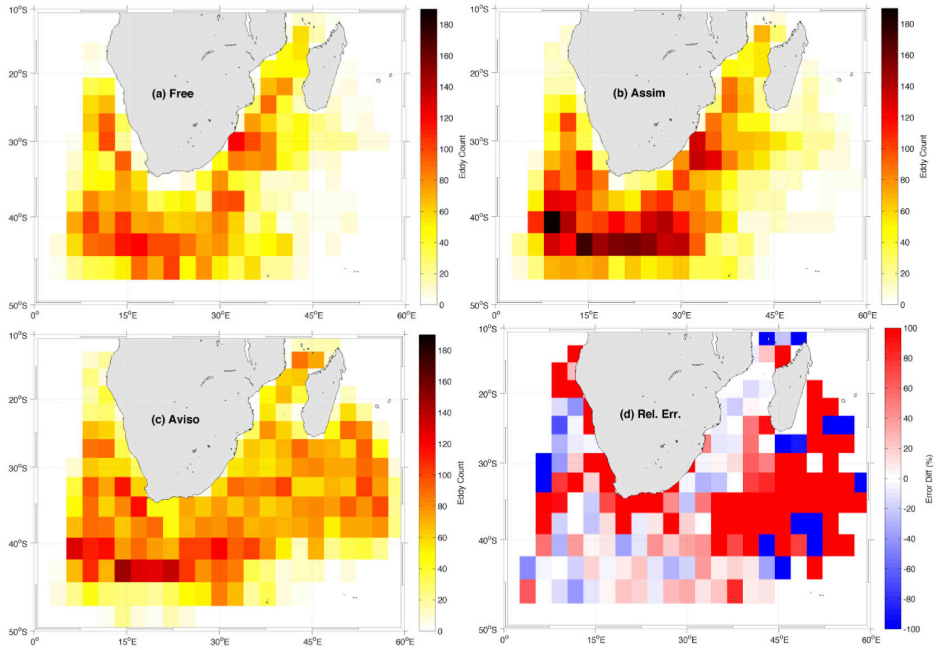

Figure 9: Spatial density distribution of eddies for 2008/9 for a) FREE, b) ASSIM, and c) Aviso. Tile d) shows relative error; positive (negative) percentage values indicate closer similarity of ASSIM (FREE) to the altimetry. Red therefore represents imporvement due to data assimilation, whilst blue represents degradation

of amplitude, rotational speed, surface eddy kinetic energy and anticyclone vorticity by ASSIM show general improvement. Regions of consistent improvement for these characteristics are those to the southwest and southeast of South Africa, the northerly reaches of the Mozambique Channel, and the coastal region immediately south of Madagascar. Translational (drift) velocities in ASSIM show some localised improvements, such as in the western reaches of the Mozambique Channel, but appear less accurate in other areas such as the region south of Madagascar. General translational velocities appear excessive south of South Africa. As a caveat, the translational velocities of 51 %, 43 % and 35 % of ASSIM, FREE and Aviso eddies respectively could not be analysed. This is due to their being inadequately tracked by the automatic tracking scheme, despite having coherent dynamic and geometric properties and is likely due to the temporal resolution of the data. The simulation of eddy geometry by ASSIM is slightly less accurate than by FREE. FREE shows closer similarity to Aviso in the simulation of eddy radius and area than ASSIM. In most cases, increased relative error in ASSIM is due to the underestimation of radius and area.This study provides further insight into mesoscale eddy properties themselves, as well as insight into how these properties are resolved by three different products. This is useful in providing recommendations for future configurations.

Assessing the benefit of assimilating satellite SST in addition to along-track SLA in the Agulhas System

Tharone Rapeti and Björn Backeberg

The greater Agulhas Current system, is one of the most energetic ocean current systems on the globe. The current system is a crucial factor for determining the mean state and variability of the regional marine environment, its influence on resources and ecosystem in the region, the regional weather, as well as the global climate on a broad range of temporal and spatial scales. Due to an absence of a coherent in-situ and satellite-based observing system in the area, modelling and data assimilation techniques are utilised, and play a major role in both furthering the quantitative understanding of the ocean dynamics, as well as providing better forecasts of this complicated western boundary current system. In this study, we compare two assimilation experiments using the Ensemble Optimal Interpolation (EnOI) data assimilation scheme in a regional implementation of the Hybrid Coordinate Ocean Model (HYCOM). In the first experiment we assimilate along-track satellite sea level anomaly (SLA) data only, and in the second experiment we assimilate both along-track SLA as well as satellite sea surface temperature (SST) data. The objectives of the study are to investigate the impacts of assimilating SST along with SLA into the regional HYCOM model, with the aim to improve the model performance. The end goal being to develop a regional ocean prediction system. To investigate the coherence between the persistence forecasts (hereafter Aviso), the modelled forecasts and the drifter data, the daily surface velocities from Aviso, ASSIMSLA, ASSIMSST and FREE are interpolated to the 6-hourly latitude and longitude positions of the drifters using a nearest neighbour interpolation. The daily mean u and v component velocities and their magnitude are then calculated and assigned to the median position for that day. An example is given in Figure 1, where the daily velocity magnitudes from Aviso (grey), ASSIMSLA (red), ASSIMSST (green), FREE (blue) and drifter #71114 (black) are plotted for the period 1 January to 1 July 2008. The velocity magnitudes of ASSIMSST are in better agreement with the drifter derived velocities than the ASSIMSLA and FREE, in particular when the drifter travels around the edges of mesoscale eddies (e.g. January 2008). The improvement is clearly reflected in the correlation (RSST = 0.45, RSLA = 0.39, RFREE = 0.19). While ASSIMSST is at times more accurate than Aviso, overall, for this example, the correlation in Aviso is higher (RAviso = 0.62). To quantify the improvement of the error, the root mean squared error (RMSE) for Aviso, ASSIMSST, ASSIMSLA and FREE is calculated. In the example (Figure 10) an increase of the RMSE in ASSIMSST compared to ASSIMSLA is evident, this is likely caused by the large biases present when the drifter travels into the retroflection region, as well as travelling along the coast, in the Agulhas Current. These biases will have to be reformed in future iterations of the model to improve upon the error. Although improvements over the FREE and ASSIMSLA model run are evident in ASSIMSST, the assimilation is unable to provide a better forecast of velocities compared to Aviso, whose RMSE is significantly better, a factor of approximately 2 times more accurate.

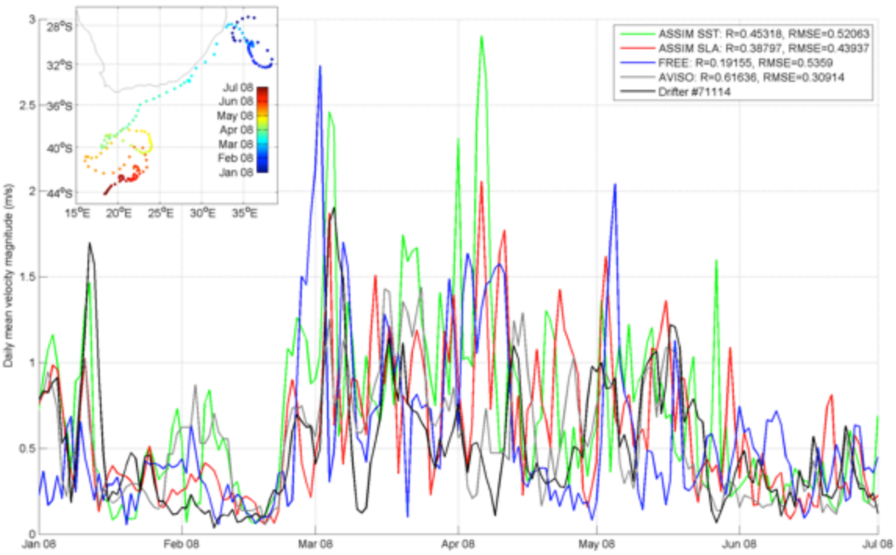

Figure 10: *Magnitudes of daily velocity (m/s) from Aviso (grey), ASSIM (red), FREE (green) and drifter 71114 (black) at the corresponding daily median positions of the drifter. The inset shows the map of its positions, the colour-scheme indicates the corresponding month. The daily velocity magnitudes 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.*

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