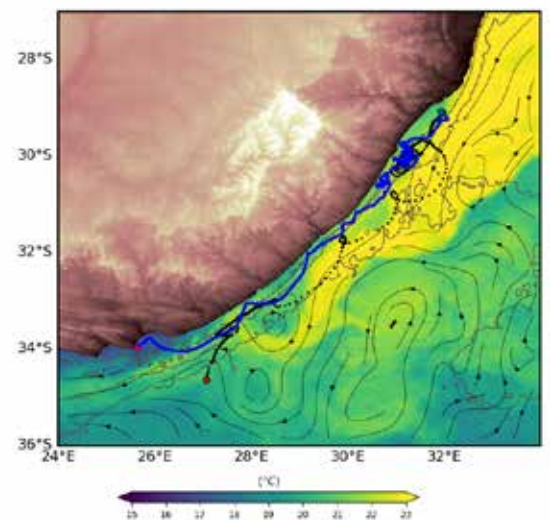# ANNUAL REPORT
# 2017

**NANSEN-TUTU CENTRE FOR MARINE ENVIRONMENTAL RESEARCH
AFFILIATED WITH THE UNIVERSITY OF CAPE TOWN**

# 2017 – 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 signatory partners and through project funding. In 2017, the Centre received funding from the Nansen Environmental and Remote Sensing Center, University of Bergen and the Institute for Marine Research. In addition, project funding was obtained from South Africa, Norway and France as well as from EU, ESA, industry and private sponsors. Moreover, in kind contributions were received from all partners of the Joint Venture.

## ORGANISATION

The Nansen-Tutu Centre (NTC) is a University of Cape Town accredited 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, France and the United States. In 2017, the signatory partners from South Africa included the Marine Research Institute (Ma-Re) / Department of Oceanography,

University of Cape Town; the Alliance for Collaboration on Climate and Earth System Studies (ACCESS), National Research Foundation; the Council for Scientific and Industrial Research (CSIR); the South African Environmental Observation Network (SAEON), National Research Foundation; the Department of Environmental Affairs (DEA), Oceans and Coasts Branch; the South African Weather Service (SAWS); the Cape Peninsula University of Technology (CPUT); and the Nelson Mandela University (NMU), Institute for Coastal and Marine Research. From Norway, the signatory partners included the Nansen Environmental & Remote Sensing Centre (NERSC); the University of Bergen (UiB); and the Institute of Marine Research (IMR). From France, the Institut de Recherche pour le Développement (IRD); and the Université de Bretagne Occidentale (UBO), are signatories and from the USA the Geosciences Department at the Princeton University.

New signatory partners to the joint venture included the Department of Environmental Affairs – Oceans and Coasts Branch, the South African Weather Service, the Cape Peninsula University of Technology and the Nelson Mandela University's Institute for Coastal and Marine Research, the Institut de Recherche pour le Dévelopement and the Université de Bretagne Occidentale replacing ICEMASAs. 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 Honours, MSc, PhD students and Post-doctoral research fellows. During 2017, the Nansen-Tutu Centre comprised 27 persons, including 1 Honours student, 4 MSc students, 7 PhD students, 1 Postdoctoral researcher fellows, 2 funded and 11 seconded researchers and 1 administrator.

## SCIENTIFIC PRODUCTION, CAPACITY BUILDING AND CONFERENCE ATTENDANCE

A total of 9 publications emanated from the Centre in 2017, which included: 7 papers published in peer-reviewed journals, 1 book chapter and 1 article in peer-reviewed conference proceedings. In addition 9 papers have been submitted to peer-reviewed journals.

In 2017, the Nansen-Tutu Centre supported the students listed below. They either received a full bursary, top-up funding towards their bursaries or travel support for research exchanges and conference attendance.

1. Marie-Lou Bachelery (co-funded: PREFACE and NRF SARChI) – Postdoctoral research fellow, France Supervisor: **Mathieu Rouault**
1. Juliano Dani Ramanantsoa (co-funded: NTC and UCT) – PhD, Madagascar Supervisors: **Marjolaine Krug, Mathieu Rouault** and Pierrick Penven
2. Rodrigue Anicet Imbol Koungue (co-funded: NTC, PREFACE and ACCESS) – PhD, Cameroon Supervisors: Mathieu Rouault, Serena Illig and **Marek Ostrowski**
3. Neil Malan (co-funded: NTC and SAEON) – PhD, South Africa Supervisor: Chris Reason, **Björn Backeberg,** Juliet Hermes and **Annette Samuelsen**
4. Bernardino Nhantumbo (co-funded: NTC and ACCESS) – PhD, Mozambique Supervisors: **Frank Shillington, Björn Backeberg, Jan-Even Nilsen** and Chris Reason
5. Arielle Stella Nkwinkwa Njouado (co-funded: AIMS and ACCESS) – PhD, Cameroon Supervisors: **Mathieu Rouault** and **Noel Keenlyside**
6. Georges-Noel Tiersmondo Longandjo (co-funded: PREFACE

*Cover Image: A map of ODYSSEA Global Sea Surface Temperature and GlobCurrent ocean currents on 20 July 2017 showing the Agulhas Current flowing along the eastern shores of South Africa. Overlaid are the paths of the two autonomous vehicles deployed during the "Gliders in the Agulhas" project in August/September 2017: an SV3 Liquid Robotics Waveglider in blue and a Seaglider in black. Courtesy of Marjolaine Krug.*

and ACCESS) – PhD, Democratic Republic of Congo Supervisors: **Mathieu Rouault** and **Noel Keenlyside**

7. Serge Tomety (NTC) – PhD, Togo Supervisors: **Mathieu Rouault** and **Thomas Toniazzo**

8. Estee Vermeulen (project funded: NRF) – MSc, South Africa Supervisors: Juliet Hermes, **Björn Backeberg**, Shane Elipot and Marcello Vichi

9. Tharone Rapeti (project funded: NRF) – MSc, South Africa Supervisor: **Björn Backeberg**

10. Hermann Luyt (project funded: NRF) – MSc, South Africa Supervisors: **Björn Backeberg, Jennifer Veitch** and Marcello Vichi

11. Bellinda Monyella (project co-funded: WRC and ACCESS) – MSc, South Africa Supervisor: **Mathieu Rouault**

12. Tumelo Maja (project co-funded: ESA GlobCurrent and NRF SARChI) – BSc Hons, South Africa Supervisor: **Mathieu Rouault**

Congratulations to Tharone Rapeti (MSc), Estee Vermeulen (MSc), Bellinda Monyella (MSc) and Tumelo Maja (BSc Hons) who completed their studies in 2017. 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 Ocean Science MSc programme and the African Climate and Development Initiative MSc programme. The Centre's researchers also taught at international training workshops, including the PIRATA PREFACE CMEMS Summer School held in Fortaleza, Brazil. Notably, Bernardino Nhantumbo, NTC PhD student, attended and taught at the C-Rise training workshop at Eduardo Mondlane University (UEM) in Maputo, Mozambique During 2017, the Centre facilitated 4 international research exchanges to Bergen, Norway, including 2 Ph.D. students, Arielle Stela Nkwinkwa Njouado and Bernardino Nhantumbo and 2 senior scientists; Björn Backeberg and Issufo Halo.

The students worked on their thesis dissertations under the supervision of Norwegian scientists, Noel Keenlyside and Jan-Even Nilsen respectively. In addition, Johnny Johannessen, Noel Keenlyside and Thomas Toniazzo visited Cape Town.

The Centre funded the attendance of Arielle Stela Nkwinkwa Njouado and Rodrigue Anicet Imbol Kounge to the 2017 GODAE OceanView International School "New Frontiers in Operational Oceanography" held on Mallorca, Spain. Funding was also provided to Rodrigue Anicet Imbol Kounge to attend the WE-Heraeus Summer School on Physics of the Ocean at GEOMAR, Kiel, and the PIRATA PREFACE CMEMS Summer School in Fortaleza, Brazil.

Our researchers, MSc and PhD students also gave presentations at the EGU Conference in Vienna, the Joint Assembly of the IUGG-IAPSO-IAMAS-IAGA conference in Cape town, the PIRATA PREFACE conference in Fortaleza, the WIOMSA conference in Dar es Salaam, the South African Marine Sciences Sympostium in Port Elisabeth and the South African Society for Atmospheric Science annual meeting in Polokwane. Rodrigue Anicet Imbol Koungue, Mathieu Rouault and Serena Illig won the Stanley Jackson Award for best published paper in 2017 award by the South Africa Society for Atmospheric Science for their paper "Role of interannual Kelvin wave propagations in the equatorial Atlantic on the Angola Benguela Current system".

## NATIONAL AND INTERNATIONAL ACTIVITIES

The Centre actively participates in national research and development activities, including projects funded through the National Research Foundation, the Department of Science and Technology, the Water Research Commission (WRC) and the Alliance for Collaboration on Climate and Earth System Studies (ACCESS). ACCESS is a NRF research program for 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" investigates 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.

Mathieu Rouault was awarded a research chair in "Ocean Atmosphere Land Modelling" by the NRF's South African Research Chair Initiative. The project started in July 2017, it aims to train African PhD students and study the role of the ocean on weather and climate including ocean atmosphere interaction.

In April 2017, together with UCT, SAEON and the CSIR, the Centre co-hosted and co-sponsored the 5th GODAE OceanView Coastal Ocean and Shelf Sea Task Team's International Coordination Workshop. Almost 50 international scientists attended the meeting and the Centre's researchers and students gave oral and poster presentations on their research.

The Centre contributed to a number of international projects. These include a European Seventh Framework Programmes, 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 NTC from 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 (SANCOOP) 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. The SCAMPI project Terminated in 2017. The ESA GlobCurrent supported a dedicated user led Agulhas study aimed to validate satellite remote sensing based estimates of ocean current in the Agulhas Current system.

The Centre's researchers serve on a number of international panels, including the GODAE OceanView Coastal Ocean and Shelf Sea Task Team, the GCSO/GOOS/WCRP Ocean Observations Panel for Climate (OOPC) and the committee for the extension of PIRATA in the Tropical Atlantic which funded an Atlas mooring deployed at 8ºE, 6ºS off the Congo River.

## FINANCIAL SITUATION
A total of 573 067 ZAR (350 000 NOK) seed funding for the Centre was made available from Norwegian partners in 2017: notably 249 454 ZAR (150 000 NOK) from NERSC;

155 806 ZAR (100 000 NOK) from UiB; and 167 807 ZAR (100 000 NOK) from IMR. In addition to this, almost 3.3m ZAR was raised through project funding in 2017. These include projects funded by the South African National Research Foundation, the South Africa - Norway Research Co-operation SANCOOP Program, the Water Research Commission, the European Framework 7 Programme, ESA's GlobCurrent user led Agulhas project, the Alliance for Collaboration on Climate and Earth System Science, the NRF's South African Research Chairs Initiative and CSIR's Strategic Research Programme. A significant challenge faced by the Centre is that projects often predominantly fund travel, running and student bursaries, while it is very difficult to raise funding for salaries.

## PROSPECTS FOR 2018
- Continue to support existing PhD students.
- Appoint new MSc and PhD students depending on available funding.
- Improve science outreach through popular articles, social media and newsletters.

- Participate in summer schools, international conferences and working groups.
- Raise funding for student exchanges and attendance at international summer schools and conferences.

*Approved by The Board*
*Cape Town, December 2017*

## MEMBERS OF THE BOARD
1. Prof. J. A. Johannessen, NERSC (Co-chair)
2. A/Prof. I. Ansorge, UCT (Co-chair)
3. A/Prof. M. Vichi, Ma-Re, UCT
4. Mr. A. Naidoo / Mr. A. Johnson, DEA
5. Mr. J. Stander / Mr. M. Majodina, SAWS
6. Dr. N. Sweijd, ACCESS
7. Dr. S. Bernard, CSIR
8. Dr. J. Hermes, SAEON
9. Dr. C. Sparks, CPUT
10. Prof. Andrew Leitch, CMR, NMU
11. Prof. N.G. Kvamstø, GFI, UiB
12. Prof. G. Philander, Princeton University
13. Prof. Å. Bjordal, IMR
14. Dr. F. Marsac, for IRD and UBO

# SCIENCE REPORT FOR 2017

## ATMOSPHERIC SIGNATURE OF THE AGULHAS CURRENT
### Arielle Stella Nkwinkwa Njouodo, Noel Keenlyside, Mathieu Rouault, Shunya Koseki

The impact of the Agulhas Current on the weather and climate of Southern Africa is not well-known. The core of the Agulhas Current, about 80–100 km wide, releases about 5 times as much water vapour to the atmosphere as does the surrounding water. This is due to a strong temperature contrast with the surrounding ocean leading to high turbulent latent heat fluxes and associated unstable condition. In this study, satellite observation and Climate Forecast System Reanalysis (CFSR) are used from the period 1998 to 2005. The objective is to understand the influence of the
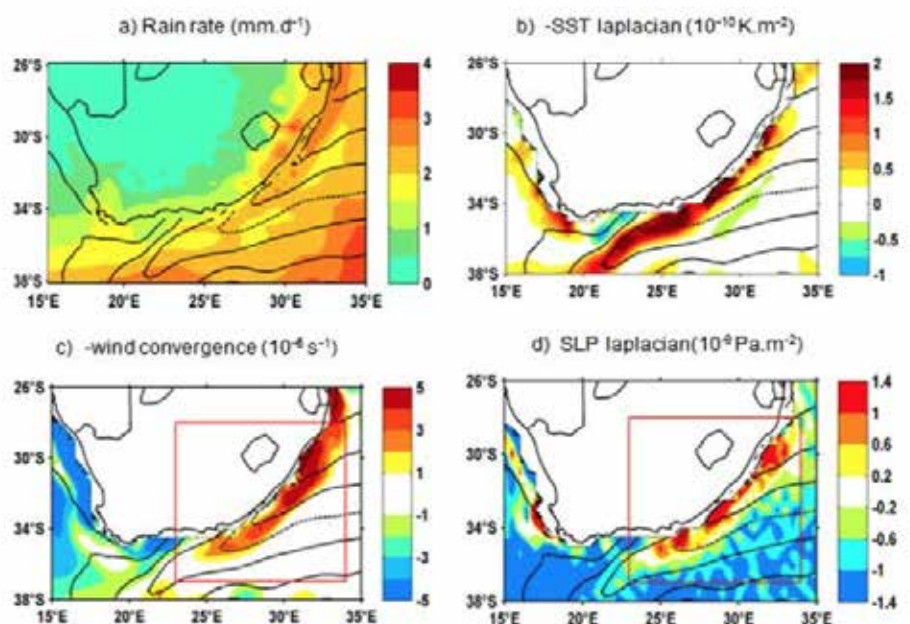


*Figure 1: CFSR annual climatology of: a) rain rate; b) sign reversed SST Laplacian; c) wind convergence (positives values); d) SLP Laplacian. Solid contours represent annual climatology of CFSR SST with 1° interval, dash line is 22°C SST.*

Agulhas Current on coastal South Africa precipitation (Figure 1a). The pressure adjustment mechanism is applied over the Agulhas Current region. Results unfold that the narrow band of precipitation above the Agulhas Current is collocated with surface wind convergence, sign reversed sea surface temperature (SST) laplacian and sea level pressure (SLP) Laplacian. The correlation between SLP Laplacian and wind convergence is 0.54, 95% statistically significant. In the Agulhas region, annual precipitation varies from 2 to 3 mm/day for CFSR (Figure 1a). Compared to TRMM-3B43, CFSR underestimates the rainfall along the coast by 1 mm/day, and in the interior of the continent. In order to understand the mechanisms responsible for rainfall over the core of the Agulhas Current, we compute the annual climatology of SST Laplacian, wind convergence and SLP Laplacian. The SST Laplacian (Figure 1b) exhibits a distinct structure along the eastern coast of South Africa, collocated with the rain band. A similar result is observed for the satellite-based OI SST Laplacian. Figure 1c shows the annual climatology of 10m wind convergence calculated from CFSR surface wind speed. Along the eastern coast of South Africa, a narrow band of wind convergence is predominant. The CFSR SLP Laplacian also shows a positive band along the eastern coast of South Africa (Figure 1d) that is collocated with the SST Laplacian, wind convergence and rainfall. This indicates that SLP above the Agulhas Current is linked to the underlying SST. This also suggests that the pressure adjustment mechanism is responsible for initiating the low-level convergence and cumulus convection above the Agulhas Current.

## INVESTIGATING THE RELATIONSHIP BETWEEN VOLUME TRANSPORT AND SEA SURFACE HEIGHT IN THE AGULHAS CURRENT SYSTEM

Estee Vermeulen, Björn Backeberg, Juliet Hermes, Shane Elipot.

The Agulhas Current System plays a vital role in global-climate circulation, being the strongest western boundary current in the
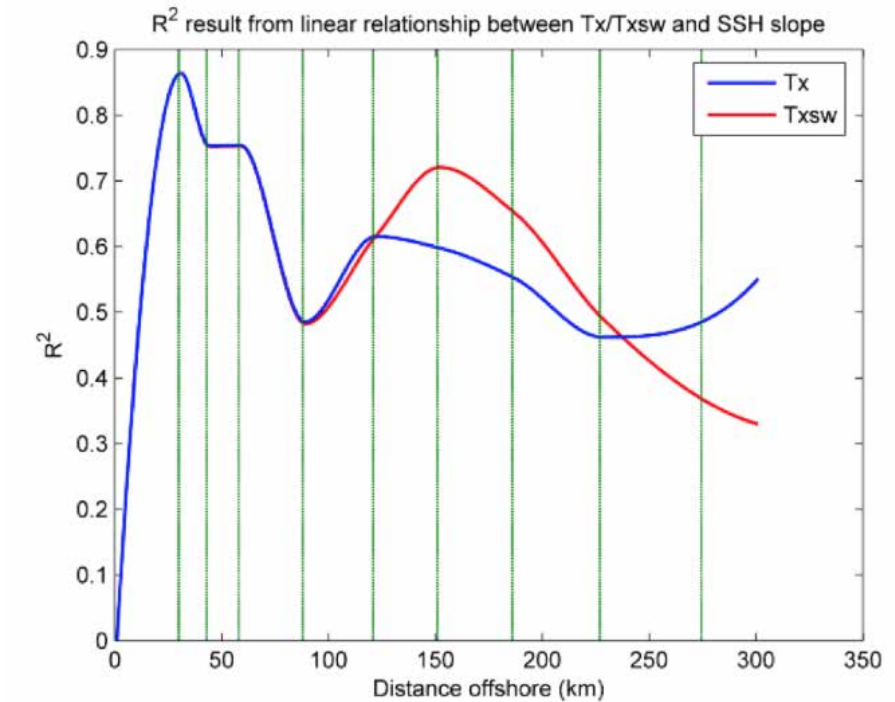


Figure 2: Percentage of explained variance for the nine linear regression models between sea surface slope (cm.km-1) and vertically integrated velocity Tx (Txsw) for the net transport and southwest transport proxy measured in m2.s-1. Vertical green lines represent the offshore distance of each mooring location and hence the locations of each linear regression model.

Southern Hemisphere. Several climate models have proposed that western boundary currents, such as the Agulhas Current, are becoming stronger due to the intensifying global wind systems and anthropogenic climate change. To validate such model predictions requires accurate long-term observational evidence. There is evidently a trade-off between spatial and temporal monitoring. In situ observations may accurately measure the dynamics of the Agulhas Current throughout the water column but are costly and spatially coarse. Whereas, satellite observations can provide high-temporal and spatial data of the surface ocean but lacks detailed information below the surface. Ultimately, in situ data and satellite altimetry should complement one another. Numerous studies aiming to monitor long-term changes in global current systems have adopted methods to combine various sampling tools, including the recent development of the Agulhas transport proxy. The Agulhas transport proxy developed by Beal and Elipot (2016) was built based on the physical principle of geostrophy, where along-track sea surface slope measured by an altimeter can be interpreted as

a measure of the volume transport across a portion of the current, assuming the current depicts an equivalent barotropic structure with depth. Thereby, regressing the three years of in situ observations, obtained from the Agulhas Current Time-series experiment (ACT) from 2010 to 2013, to T/P-Jason satellite altimeter data spanning the years 1993-2015, a 22-year transport proxy was built.

This modelling study aimed to recreate the Agulhas transport proxy within a regional HYCOM of the Agulhas Current System, attempting to test the validity of the underlying assumptions on which the satellite-altimeter proxy was based. Estimating 22 years of Agulhas transport, assuming a constant vertical stratification over the 3-year sampling period, and hence ignoring current changes that could potentially violate the linear relationship between sea surface slope and full-depth transport could become problematic. The 34-year regional-hindcast simulation from HYCOM provided the tools to test the sensitivity of the transport proxy to vertical changes in the current and the length scale of observations used to build a strong, constant linear relationship between
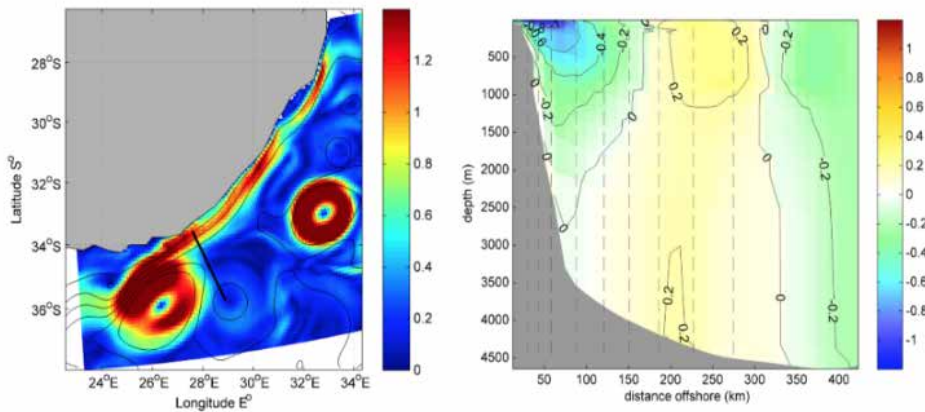
*Figure 3: (a) A weekly snapshot from HYCOM showing the surface structure and (b) cross-track velocity structure (b) during the presence of an impinging anticyclonic eddy. Note the change in direction of velocity at depth.*

volume transport and SSH slope. Two transport types, the net transport and the southwest transport component, were extracted from HYCOM in order to validate the net transport proxy (Tnet) and the southwest transport proxy (Tsw). The results indicated that the transport proxy was better suited to estimate the net transport rather than the southwest transport component. The 34-year net proxy captured 52% (r=0.72) of the transport variance whereas the southwest transport proxy only captured 26% (r=0.51), in correlation to the transport extracted directly from HYCOM. For this reason, the rest of the study focused mainly on the net transport proxy.

Throughout the investigation it was found that HYCOM contained exaggerated levels of offshore variability. In corroboration, Figure 2 shows that the correlations of the regression models decreased offshore. Previous studies have shown that the dominant mode of variability in the HYCOM simulation occurs in the form of large anticyclonic eddies, approximately 250-300 km in diameter (Backeberg et al., 2008; 2009). Weekly snapshots of the surface structure of the current clearly produced the distinct SSH signature of these mesoscale features, which were therefore detected by the input SSH gradient in the transport proxy (Figure 3a). However, weekly cross-track velocity sections revealed that the eddies were indeed baroclinic, effecting the entire water column and changing the direction of flow at depth (Figure 3b). Thus, the frequent, impinging, anticyclonic eddies consequently

violated the linear relationship between SSH slope and transport, more specifically for the offshore regression models. To improve the accuracy of the transport proxy in the model would therefore require decreasing the levels of mesoscale variability in HYCOM, possibly by improving the eddy dissipation schemes, correcting the current stress feedback between the ocean and the atmosphere or by adjusting the eddy advection scheme. These results support that the changes in the vertical structure of the current during the development of the model-transport proxy were important. Note that changes in the vertical structure of the Agulhas Current are lower in comparison to the approximation of the current in HYCOM, and occur as a result of mesoscale meander events or due to variability in the Agulhas Undercurrent, rather than impinging anticyclonic eddies. In addition, the implicit assumption of the fixed 3-year vertical current structure may become problematic on multidecadal timescales as thermohaline changes become important (Beal and Elipot, 2016).

The final objective of this study was to determine the optimal length scale of observations needed to build a strong linear relationship between transport and SSH slope. More hydrographic data will essentially provide more information on trends in stratification and hence improve the accuracy of the transport proxy. Calculating the linear relationship over longer time periods in the model did however not improve the skill of the transport proxy, suggesting that the

current dynamics for any three-year period were similar in the model.

This study motivates the need to improve long-term monitoring methods, where such improvements include advances in model development, combined with adequate validation studies, to help plan future experiments intending to monitor long-term changes in ocean circulation.

## OBTAINING OPTIMAL CONTINUOUS TIDE GAUGE RECORDS

Bernardino Nhantumbo, Jan Even Nilsen, Björn Backeberg, Frank Shillington and Chris Reason

Understanding the underlying processes generated in tide gauge sea level (SL) records is of great interest. These processes are complex since we still deal with mathematical limitations due to data non stationarity. Nevertheless, data gaps are the first challenge when it comes to southern Africa tide gauge records due to their frequency and length. As a consequence, a dedicated study to successfully fill in tide gauge records gaps has been conducted out aiming to obtain optimal continuous tide gauge records. The study intended exploring the reliability of combining satellite altimetry observations making use of the consistency since their inception. Additionally, we wanted to use the closest tide gauge SL records to fill in gaps in one site. The data consisted of all available tide gauge monthly mean SL records until December 2015, from seven sites along the east and south coast of South Africa. The data were obtained from the Permanent Service for Mean Sea Level (PSMSL; http://www.psmsl.org/). The altimetry data were based on the daily gridded multi-mission Copernicus Marine and Environment Monitoring Service (CMEMS; http://www.marine.copernicus.eu) altimetry observations from January, 1993 to December, 2015. Daily altimetry observations were then summed and averaged to compose monthly means. The raw in situ monthly SL time series were corrected to inverse barometer (IB) effect and the land motion. Monthly gridded sea surface pressure data sets from the National Centres for Environmental Prediction/

| Station | ID | ORIGINAL DATA | | | | CURRENT DATA | | |
|---------|----|-------|--------------------|---------------|----------------------------|----------------------------|---------------------|----------------------|
| | | Count | Data Coverage (%) | Starting Date | Longest gap period (months) | Missing Values (months) | Data coverage (%) | Longest gap (months) |
| Richards Bay | RB | 463 | 55 | Jun-77 | 73 | 30 | 93.5 | 12 |
| Durban | D | 540 | 69 | Jan-71 | 28 | 38 | 93 | 12 |
| East London | EL | 588 | 53 | Jan-67 | 75 | 94 | 84 | 66 |
| Port Elizabeth | PE | 450 | 78 | Jan-78 | 18 | 15 | 96.7 | 12 |
| Knysna | K | 665 | 71 | Aug-60 | 60 | 8 | 98.9 | 2 |
| Mossel Bay | MB | 690 | 79 | Jul-58 | 24 | 9 | 98.7 | 2 |
| Simons Bay | SB | 699 | 79 | Oct-57 | 49 | 49 | 93 | 12 |

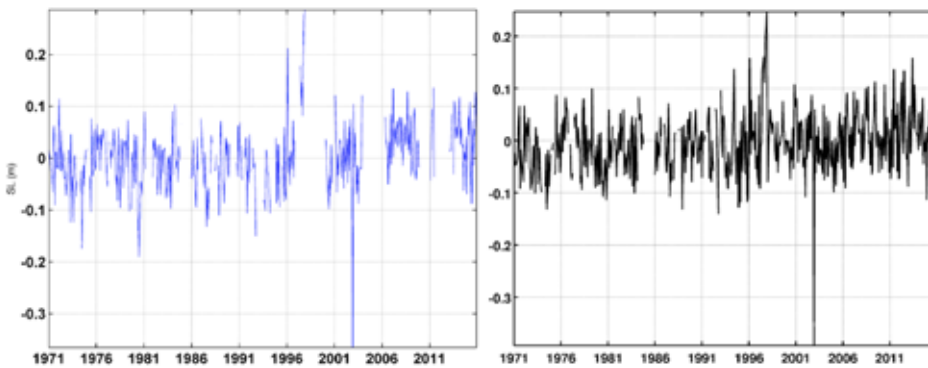*Table 1: Statistics of the data at Durban before and after gap filling process*



*Figure 4: Tide gauge records at Durban before the filling process (left) and after the filling process (right).*

National Centre for Atmospheric Research (NCEP/NCAR; http://www.ncep.noaa.gov/) were used for IB correction. The ICE-5G (VM2) model outputs were utilised to remove the glacial isostatic adjustment (GIA) signal as a correction to vertical land movement (VLM). Then the seasonal cycle and long-term linear trend were removed in both tide gauge and satellite altimetry data sets. The latter was done with respect to the time span in which the comparison had to be conducted for a proper gap filling process. As a result and at this stage, the reference issue arising when dealing with different sea level data types has been overcome. Therefore, at each studied tide site, in situ SL time series were subsetted in two set of data representing the periods before and after satellite altimetry era. During satellite period, the new in situ SL time series were correlated to regional altimetry observations

to identify the grip point with the maximum correlation. The data sets from the grip point with the maximum were correlated to regional altimetry observations for an identification of areas with a common variability pattern. The latter help to choose the pair of tide sites to be used to fill one another gaps, prior to satellite period. In fact, this approach avoided the use of the data from sites that are too further apart to the tide site to be filled. It should be emphasised that the studied tide gauge locations are far-between each other and unevenly distributed over the coast. Taking into account the coastal dynamics over the region, the choice was to use the sea level data at grid point with the maximum correlation to the tide gauge without any correlation value threshold. The results suggested that gridded altimetry sea surface height data may be used to fill the gaps in the monthly mean sea level records

following appropriate corrections, for instance IB effect, GIA, VLM, etc. The limitation, prior to satellite altimetry era, was the temporal co-occurrence of missing values, which constrained opportunities to recover tide gauge data. Moreover, situations where the neighbouring tide gauge sites are too far apart also constrained the gap filling process. Details of the gap filling process around found in Table 1 and Figure 4.

## SIMULATION OF PARTICLE TRAJECTORIES DURING BENGUELA NIÑOS AND NIÑAS

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

Benguela Niños and Niñas are intermittent, extreme warm and cold events that develop near the border between Angola and Namibia. These extreme events have been intensively studied these past years because of their significant impacts on the regional rainfall and the local marine ecosystem. Recently, Imbol Koungue et al. (2017) evidenced the role played by the Interannual Equatorial Kelvin waves during the onset of Benguela Niños and Niñas over 15 years (1997-2012). The present study is an update of the recent paper by Imbol Koungue et al. (2017). Therefore, the aims of this study are firstly to revisit most of the Benguela Niños and Niñas developing before 1998 along the Angolan and Namibian coastlines and secondly to simulate
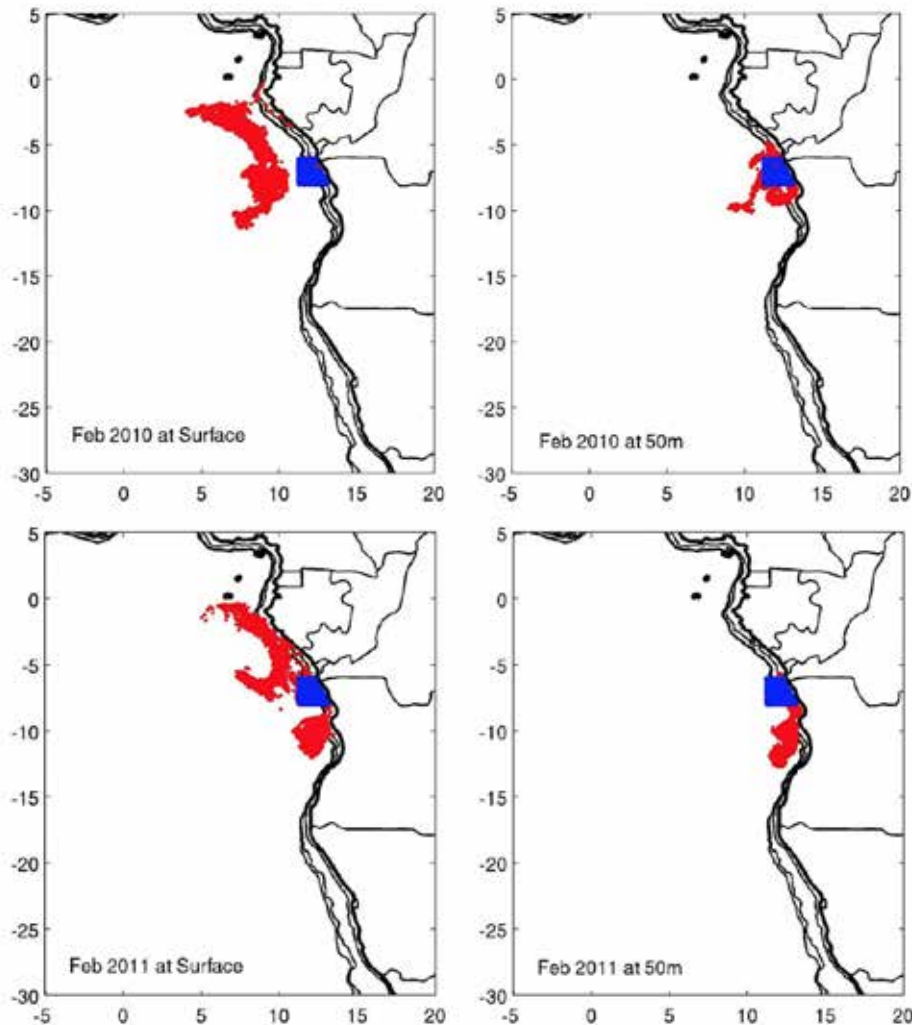
Figure 5: Observed particle trajectories in February 2010 (top) and February 2011 (top) after 30 days of transport at 0 m (left) and 50 m (right). Blue areas in the figure represent the zones of release (11.2°E – 13.84°E; 6°S – 8°S) of the 10.000 particles. Contour lines indicate the topography at 50 m, 300 m and 500 m.

onset of the coastal warm (cold) events in the Northern Namibia. 30 days transport patterns of particles released along the Angolan coast (Figure 5) in February 2010 (February 2011) suggest that during the Benguela Niña 2010 (Niño 2010-2011); particles are completely advected offshore (mostly alongshore) at the surface by surface currents. Conversely, at 50 m where the core of the poleward Angolan current is located, we observe a reduced effect of the current on the particles during February 2010, whereas in February 2011 the particles are advected poleward close to the Angolan coast.

## HOW LOW-FREQUENCY EQUATORIAL KELVIN WAVE ACTIVITY, LOCAL OCEAN STRATIFICATION, AND COASTAL WINDS MODULATE THE SOUTH-EASTERN INTERANNUAL ATLANTIC VARIABILITY?

Marie-Lou Bachèlery, Mathieu Rouault and Serena Illig

In this study, we aim at investigating how of the low-frequency modulation at interannual and decadal timescales of the Equatorial Kelvin Waves (EKW) activity, the local ocean stratification and the coastal winds modulate the interannual variability along the coast of south-western Africa and the phenomenology of the Benguela Niño/Niña events. To do so, we based our methodology on the development of a high resolution (1/12°) long-term (1980 - 2015) numerical simulation of the South-Atlantic Ocean using the Regional Ocean Modeling System (ROMS). This approach overcomes the time/space limitation of observational datasets as well as allows the evaluation of the subsurface variability where the EKW and Coastal Trapped Waves (CTW) signature is more intense. It also takes advantage of the adequate high resolution of the model to accurately determine the coastal processes involved. In order to include the equatorial and the Benguela upwelling System dynamics, our configuration extends from 34.9°S to 7°N, spanning from 10°W to the southwestern coast of the African continent (Figure 6a). The main issue was to find a suitable long-term wind forcing product

particle transports during February 2010 for the Benguela Niña 2010 and February 2011 for Benguela Niño 2010-2011 along the Angolan coast. To do so, we use monthly averaged from an Ocean General Circulation Model (OGCM) for the period 1958 - 2015 (58 years) which is validated using the available observation data sets. Among the observation data sets, we use temperature from World Ocean Atlas (WOA) 13, altimetric monthly Sea surface Height Anomalies (SSHA) from AVISO, monthly Dynamic Height from Prediction and Research Moored Array in the Tropical Atlantic (PIRATA). Activities related to wind forced equatorial waves are represented through an Ocean Linear Model (OLM) over the tropical Atlantic. Daily outputs from high resolution HYCOM model are used for the Lagrangian

transport of particles at the surface and at 50 m. Results show good agreement between the OGCM and the observation data sets mentioned above. We identify 55 coastal events (29 warm and 26 cold) between 1958 and 2015. We classify these events into 2 different categories (26 extreme and 29 moderated). Bootstrapped composite maps significant at 90% of March-April temperature anomalies at 10 m and lagged wind stress for 5 extreme warm and 5 extreme cold events reveal that coastal events are linked to large scale wind and their relationship is more pronounced with the February – March wind stress anomalies. Moreover, poleward (equatorward) modelled net mass transport of water in the upper 120 m across the Angola Benguela Front (ABF) around 17°S is mostly observed 1 month prior to the

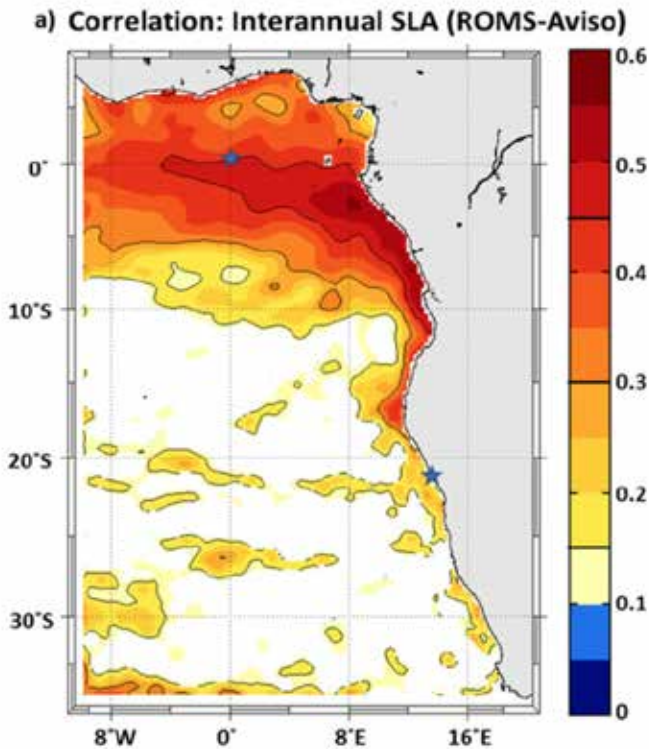**a) Correlation: Interannual SLA (ROMS-Aviso)**

*Figure 6: a) Correlation map between pentad ROMS interannual Sea Level Anomalies and observations from Aviso over 1993-2015 period. The white color denotes non-significant correlations (at 95% confidence level). b-c) Interannual SST anomalies at (b) 0°W-0°N, and average over 1°-width coastal band, at (c) 22°S of ROMS (black), Aviso (Red), and PIRATA in-situ observations (Blue). Correlation coefficients between ROMS and Aviso time series are displayed in the upper right corner.*

**b) Interannual SST anomalies (0°W – Equator)**

**c) 22°S – Coast**
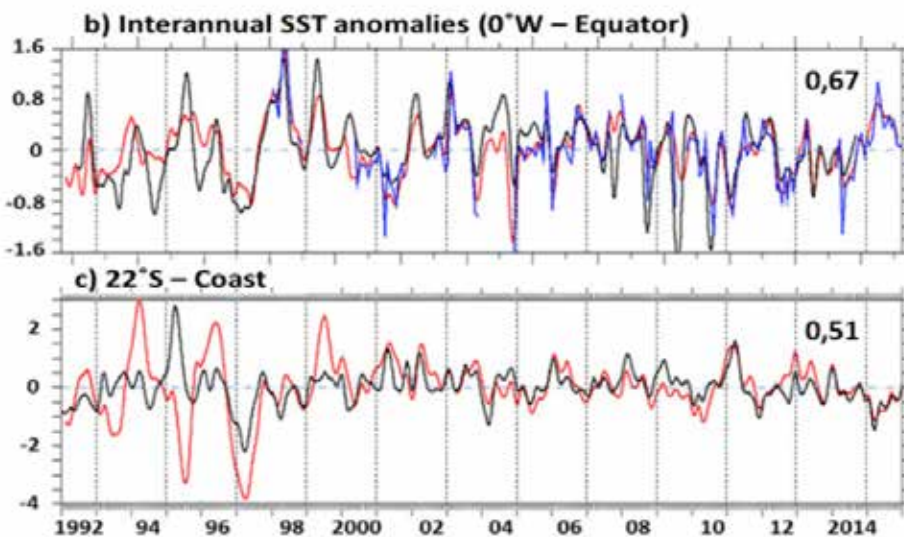
to realistically simulate the ocean dynamics in the BUS. A great effort has been devoted to find the best atmospheric forcing for our study. Results of numerous sensitivity experiments using various datasets (ERA-INTERIM, CFSR reanalysis, and a combined blended QuikSCAT/ASCAT satellite wind product) shows that the latest Drakkar Forcing Sets 5.2 (DFS5.2, a corrected version of ERA-INTERIM reanalysis) provide the most adequate forcing to the simulate the South-eastern Atlantic region. This daily product is available from 1958 to 2015. Lateral boundary and initial conditions of the model are provided by the outputs of the SODA (version 3.1) which extend from 1980 to 2015. We first

conducted an evaluation of the model performances over the 1992-2015 period (period corresponding to the satellites observations) to assess the model skills in reproducing the interannual variability. We focus our analysis in the key parameters associated with ocean dynamics. Figure 6b-c illustrates the good coherence between the pentad interannual SST anomalies of ROMS, GHRSST_cmc0.2 satellite and PIRATA in-situ data at the equator (0°S-0°E) and at the coast at 22°S. The model is skillful in capturing the surface signature of most of the observed extreme events. The correlation between modeled SST and observations is statistically significant (above 0.5) in the whole

domain. As a final illustration, Figure 6a shows the correlation coefficient between pentad ROMS interannual Sea Level Anomalies (SLA) and altimetric satellites data (AVISO). Correlation coefficients are statistically significant especially along the equatorial waveguide and the African west coast, with values larger than 0.5. This illustrates how far the equatorial dynamics remains coherent with the low-frequency variability along the south-western coast of Africa. Note that offshore the lack of agreement between ROMS and AVISO is attributed to mesoscale activity: in absence of data assimilation, simulated and observed eddies cannot be collocated in time and space. In summary, despite some bias, the simulation is found to reproduce well the temperature mean state and the coastal low-frequency variability in the southeastern Atlantic Ocean. The realism of our ROMS simulation gives confidence to investigate the EKW activity, the ocean stratification and coastal winds low-frequency variability in the Southeastern Atlantic sector. As a first step toward understanding the interactions and processes along the south-eastern African coast associated with the different stressors, the objective will be to describe the change in characteristics of interannual EKW at low-frequency in the equatorial band. This will be the focus of our next work.

## INTERCOMPARISON OF DECADAL TREND IN THE BENGUELA UPWELLING SYSTEM OVER THE PERIOD OF 1982-2016.

### Serge Tomety and Mathieu Rouault

Ocean temperatures, particularly Sea Surface Temperature is one of the environmental parameters that can be used to track climate change. SST is useful for monitoring El Niño events and multi-decadal ocean changes. It is a good indicator for upwelling strength in the Benguela Current system. Over the last 40 years, the global Ocean has warmed and is still warming. However, some local area affected by coastal upwelling which include Benguela upwelling system appear to show either cooling or no trend. Quantify SST trends is important to ascertain ocean coastal changes in the Benguela Upwelling system. Various SST data sets including optimal interpolated data set as well as new satellite based product with relatively high resolution are used to evaluated trend and to help to identify artificial discontinuities associated with operational changes over the analysis period. Two optimal interpolated Reynolds SST dataset (1/4° and 1° of resolution), two satellites only level 3 datasets (Pathfinder AVHRR 4km and Along-track scanning radiometer SSTs (ATSRs) at 0.1° x 0.1° resolution) and Hadley SST 1° (HADISST) are used in the study. Note that all the data set start from 1982 except ATSRs which start from 1991. We can clearly identified, in all datasets analyzed, a significant warming trend in SST up to 0.6°C per decade off of Angola/Namibia coasts and in the Agulhas Retroflection region during most months of year (Figure 7). This warming trend is more pronounced in November–December, off of the Angola and Namibian coasts in all datasets and February–March in a retroflection region in all datasets except HADISST. Overall there is a warm bias in OISST 1/4° in austral winter This may due to the artificial discontinuity in the data. Indeed OISST ¼o uses pathfinder 5.0/5.1 data as input from 1981–2006, and then operational U.S Navy daily SSTs after 2006. A significant cooling trend is observed in west coast in
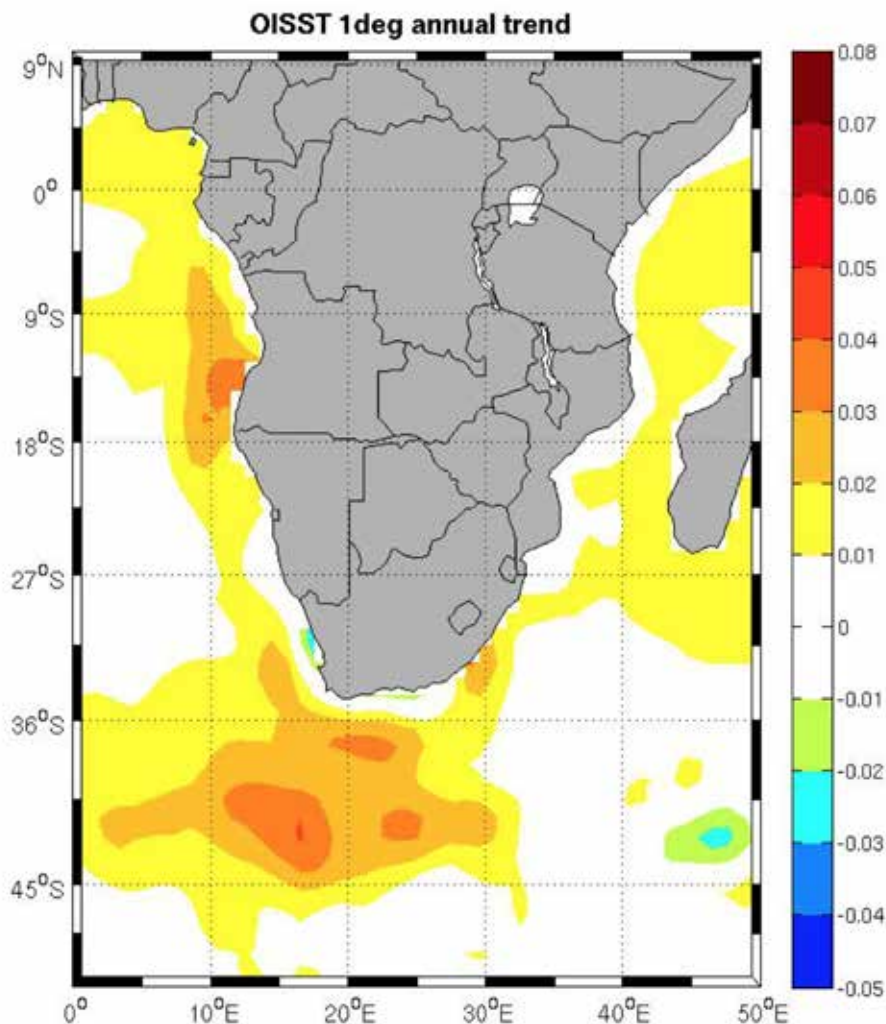


Figure 7: *Linear trend in ºC per decade for the 1° x 1° degree resolution OI Reynolds SST from 1982 to 2016*
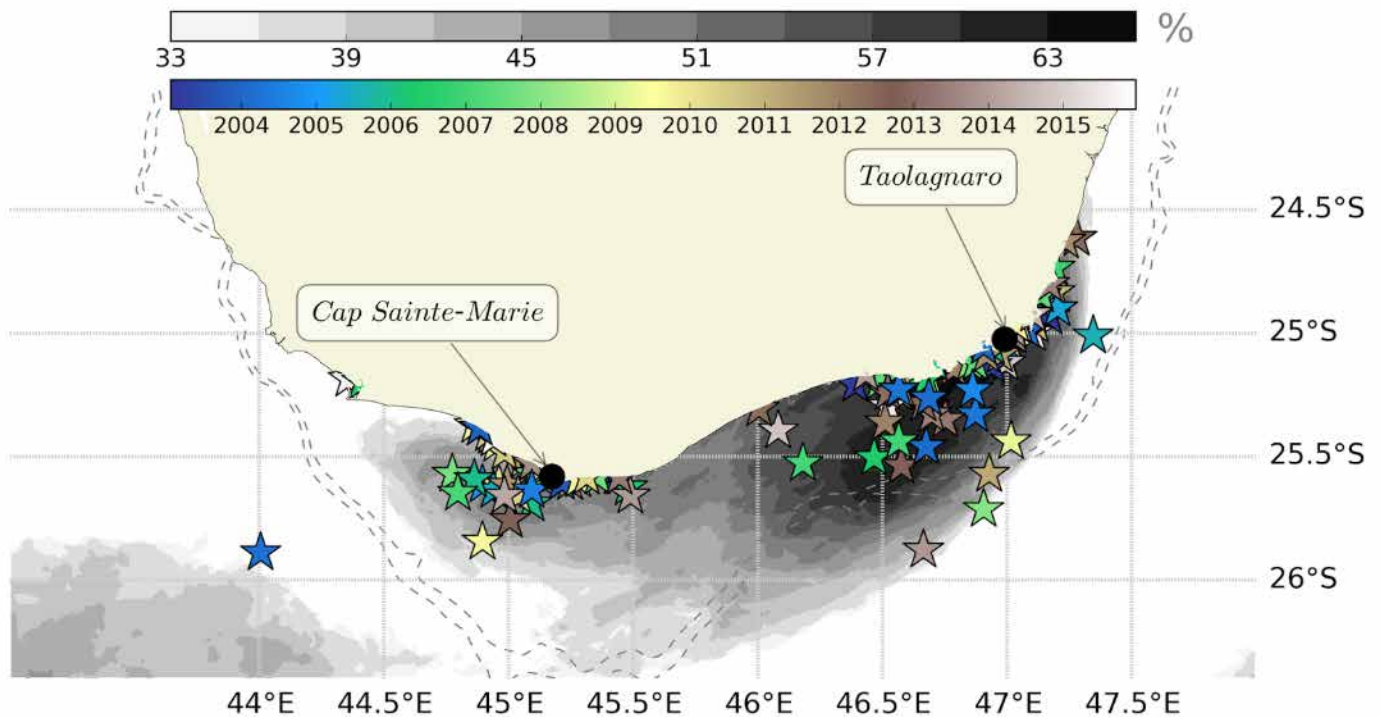
HADISST all of year and in OISST 1° only from January to August. No significant cooling trend is observed in others datasets.

## COASTAL UPWELLING SOUTH OF MADAGASCAR: TEMPORAL AND SPATIAL VARIABILITY

### Juliano Dani Ramanantsoa, Marjolaine Krug, Pierrick Penven, Mathieu Rouault, Jonathan Gula

Madagascar's southern coastal marine zone is a region of high biological productivity which supports a wide range of marine ecosystems, including fisheries. This high biological productivity is attributed to coastal upwelling. This research provides new insights on the structure, variability and drivers of the coastal upwelling south of Madagascar. Satellite remote sensing is used to characterize the spatial extent and strength of the

coastal upwelling. A front detection algorithm is applied to thirteen years of Multi-scale Ultra-high Resolution (MUR) Sea Surface Temperatures (SST), altimetry derived geostrophic current from GlobeCurrent as well and an upwelling index is calculated. The influence of winds and ocean currents as drivers of the upwelling are investigated using satellite, in-situ observations, and a numerical model. Results reveal the presence of two well-defined upwelling cells. The first cell (Core 1) is located in the southeastern corner of Madagascar (near Tolagnaro in Figure 8), and the second cell (Core 2) is west of the southern tip of Madagascar (At Lavanono, near Cap Sainte-Marie in Figure 8). Figure 8 illustrates the percentage of the upwelling Cores occurrence, including the locations of upwelled water at monthly timescale. These two cores are characterized by different seasonal variability, different

*Figure 8: Spatial distribution of upwelled water at south of Madagascar. Grey scales is the occurrence of the upwelling based on SST (in %) over the period 2003-2015 taken for the whole upwelling region. Stars are cold waters marker of upwelling at monthly time scale during the same period.*

intensities, different upwelled water mass origins, and distinct forcing mechanisms. Core 1 is associated with a dynamical upwelling forced by the detachment of the East Madagascar Current (EMC), which is reinforced by upwelling favourable winds. Core 2 appears to be primarily forced by upwelling favourable winds, but is also influenced by a poleward eastern boundary flow coming from the Mozambique Channel. The intrusion of Mozambique Channel warm waters result in an asynchronicity in seasonality between upwelling surface signature and upwelling favourable winds.

The Lagrangian analysis reveals the presence of a warm poleward flow along the west coast of Madagascar, which transports water particles from warm waters of the Mozambique Channel to Core 2. Such a warm poleward flow should result into a relatively deep thermocline along the south-western shores of Madagascar. This is confirmed by cross sections in the realistic model simulation for each season, south-west of Madagascar (Figure 8 left). In contrast with the section south-east of Madagascar, where the geostrophic balance across the EMC results in an uplift of the isotherms (Figure 8 right), the poleward coastal flow is associated with a coastal deepening of the thermocline (represented here by the 22 C isotherm, Figure 8 left). In this case, although winds are upwelling favourable, warm waters are upwelled, resulting in a weak

upwelling signature in SST. This situation can be compared with the California upwelling system, where a deepening in the thermocline occurs during El-Nino event.

## HOW DO CENTRAL AFRICAN EASTERLY JETS INFLUENCE WATER BUDGET OVER CENTRAL AFRICA?

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

One of the key features of atmospheric large-scale circulation over central Africa and its adjoining oceans is the prominent easterly circulation in the middle and upper troposphere. Many papers have described how low-level westerlies (i.e. below 700hPa pressure level), supplies moisture from Atlantic or what are the physical mechanisms governing low-level westerlies over central Africa. Little is known about middle and upper easterlies. Nicholson and Grist (2003) showed the existence of African easterly jet (AEJ) and tropical easterly jet (TEJ) in mid- (i.e. ~600hPa) and upper (200hPa) troposphere over central Africa respectively. Using ERA-Interim reanalysis and ECHAM5.3 datasets, this study investigates the dynamics

of central Africa mid-tropospheric (vertically averaged between 850 and 500hPa) circulation to outline the processes that cause the Central African easterly jet to maintain and control the water vapour budget variation over Central Africa. The Central African easterly jets and its associated water vapour transports are driven year-round by a dominant low-pressure system over Central Africa, namely the Central Africa low. In October to April, the southern and northern branches of Central African easterly jets are poles of variability; while in May to September, both branches are a dipole of variability. However, the maintenance of both branches of central African easterly jets is owed by the mid-lower troposphere friction, rather than the geopotential thickness gradient. In October–April, when the Central Africa low is dominant in the region, Central Africa is a sink of water vapour, with Indian Ocean as the main supplier. Over Central Africa, three incoming channels of water vapour exist: the southern, eastern and northern boundaries import channel and one export channel. The western boundary (Figure 9g) has two dominant channels at the eastern and northern boundaries (Figure 9). The water vapour transport over

Central Africa has a quasi-barotropic structure, as shown at low-levels (Figure 9a). Thus, the low-level water vapour transport channels are similar to those outlined above throughout the entire central Africa tropospheric column (Figure 9g), but with lower magnitudes year-round. In May–September, the weakening of the Central Africa low leads to a reversal of water vapour flow at the northern boundary channel, leading Central Africa to become a source of moisture, with both Atlantic and Indian Ocean as source of moisture. In addition, Congo basin rainforest can be considered as additional source. During this season, the low-level water vapour transport contributes substantially in the tropospheric water vapour transport over Central Africa. Moreover, Central African easterly jets control the moisture convergence flux over central Africa, through the modulation of moisture transport channels, with a crucial role of the southern branch. Further decomposition of moisture flux convergence $-<\nabla.(vq)>$ into the product of moisture and wind convergence $-<q\nabla.v>$ (dynamic term) and moisture advection $-<v.\nabla q>$ (thermodynamic term) indicates that Central Africa rainfall variability is primarily due to large-scale circulation variation, rather than by atmospheric water vapour variation.
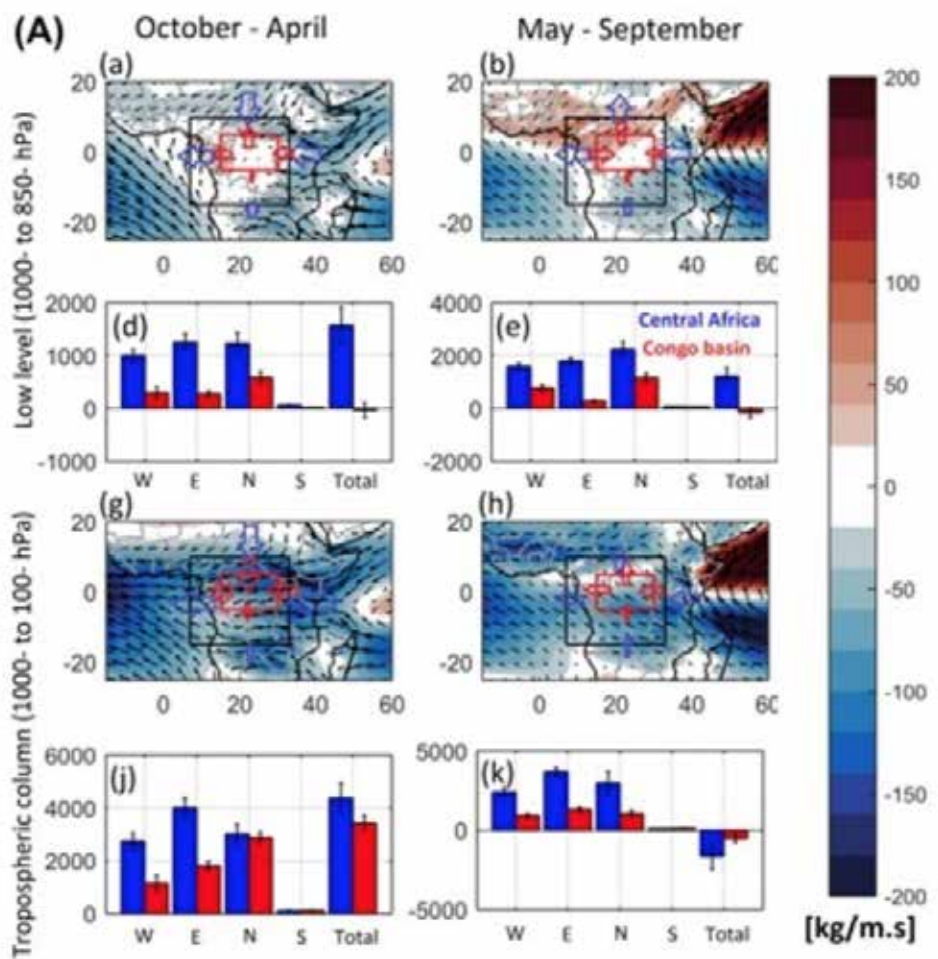


Figure 9. Vertically integrated water vapour transport at low-levels (surface to 850- hPa, arrows (g-i), first row) and throughout the entire tropospheric column (surface to 100- hPa, arrows, (a-c), third row). The intensities of each moisture transport channel at each boundary of Central Africa (blue bars) and Congo basin bars (red bars) (second row). In each panel, the zonal water vapour transport is overlaid (shading, kg/m.s).

# PUBLICATIONS IN 2017

## PEER-REVIEWED PAPERS

Holton, L., J. Deshayes, **B. Backeberg**, B. Loveday, J. Hermes, C. Reason (2017). Spatio-temporal characteristics of the Agulhas Leakage: a model inter-comparison study. Climate Dynamics, 48, 2107-2121, doi:10.1007/s00382-016-3193-5.

**Imbol Koungue, R.A.,** S. Illig and **M. Rouault** (2017). Role of interannual Kelvin wave propagations in the equatorial Atlantic on the Angola Benguela Current system. Journal of Geophysical Research: Oceans, 122, 4685–4703, doi:10.1002/2016JC012463

**Krug, M.,** S. Swart, and J. Gula (2017). Submesoscale cyclones in the Agulhas Current. Geophysical Research Letters, 44, 346– 354, doi:10.1002/2016GL071006

Maboya, M. L., M. E. Meadows, P. J. Reimer, **B. C. Backeberg** and T. Haberzettl (2017). Late Holocene marine radiocarbon reservoir correction for the south and east coast of South Africa. Radiocarbon, 1-12, doi:https://doi.org/10.1017/RDC.2017.139

**Ramanantsoa, J. D.**, M. Krug, P. Penven, **M. Rouault,** J. Gula (2017). Coastal upwelling south of Madagascar: temporal and spatial variability. Journal of Marine System, doi:https://doi.org/10.1016/j.jmarsys.2017.10.005.

**Rouault, M.,** S. Illig, J. Lübbecke. and **R.A. Imbol Koungue** (2017). Origin, development and demise of the 2010–2011 Benguela Niño. Journal of Marine Systems, doi:https://doi.org/10.1016/j.jmarsys.2017.07.007.

**Vianello P.,** I.J. Ansorge, **M. Rouault, M. Ostrowski** (2017). Transport and transformation of surface water masses across the Mascarene Plateau during the Northeast Monsoon season. African Journal of Marine Science. 39(4):453-66.

## BOOK CHAPTERS

Meyer, I., L. Braby, **M. Krug** and **B. Backeberg** (2017). Mapping the Ocean Current Strength and Persistence in the Agulhas to Inform Marine Energy Development. In Marine Renewable Energy: Resource Characterization and Effects on Physical Systems. Editors: Z. Yang and A. Copping, pp. 179-215, Springer International Publishing, doi:https://doi.org/10.1007/978-3-319-53536-4_8.

**Halo I.,** B. Malauene and **M. Ostrowski** (2017). Physical oceanography. In The RV Dr Fridtjof Nansen in the Western Indian Ocean: Voyages of marine research and capacity development. Editors: J.C. Groeneveld and K.A. Koranteng, pp 37-54, Food and Agriculture Organisation, Rome, Italy.

## PEER-REVIEWED CONFERENCE PROCEEDINGS

**Monyella, B.** and **M. Rouault** (2017): The 2014/2015 and 2015/2016 drought in the summer rainfall region of South Africa. Proceedings of annual conference of the South African Society for Atmospheric Science, Polokwane, September 2017.

## GRADUATION IN 2017

Tharone Rapeti – MSc: Assessing the impacts of assimilating satellite SST in addition to along-track SLA into a HYCOM of the Agulhas System. Supervised by **Björn Backeberg**

Estee Vermeulen – MSc: Investigating the relationship between volume transport and sea surface height in the Agulhas Current System. Supervised by Juliet Hermes, **Björn Backeberg,** Shane Elipot and Marcello Vichi.

Bellinda Monyella – MSc: Role of the Ocean in the 2014/2015 and 2015/2016 drought in South Africa summer rainfall region. Supervised by **Mathieu Rouault**

Tumelo Maja – BSc Hons: The Angola Current a view from Space. Supervised by Mathieu Rouault

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Prof. Mathieu Rouault (Co-director, 25% salary from NTC) – Ocean-atmosphere, climate and regional impact

Dr. Marie-Lou Bachelery (Postdoctoral research fellow, 17% fellowship from NTC) – Ocean modelling and prediction

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Dr. Issufo Halo (Associate researcher, seconded) – Ocean modelling and prediction

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Mr. Neil Malan – Ocean modelling and prediction

Mr. Bernardino Nhantumbo – Regional sea level variability and global change

Ms. Arielle Stella Nkwinkwa Njouado – Ocean-atmosphere interaction and climate

Mr. Georges-Noel Tiersmondo Longandjo – Ocean-atmosphere interaction and climate

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Sharon Bosma (Associate staff, 25% salary from NTC) - Finances

## USEFUL LINKS

Nansen-Tutu Centre: http://www.nansen-tutu.org

Marine Research Institute: http://mare.uct.ac.za/

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Participants of the 5th GODAE OceanView Coastal Ocean and Shelf Seas Task Team (COSS-TT) International Coordination Meeting (COSS-ICM5) jointly hosted by the Nansen-Tutu Centre and the South African Environmental Observation Network (SEAON) with support from the CSIR and the University of Cape Town (Dept. of Oceanography)."
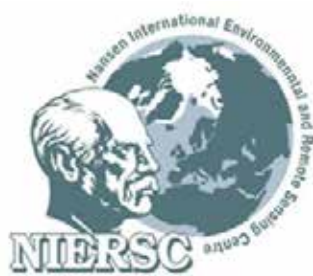


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