NANSEN-TUTU CENTRE FOR MARINE ENVIRONMENTAL RESEARCH

ANNUAL REPORT 2020

Affiliated to the Department of Oceanography, University of Cape Town

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:

- Capacity building and education with a focus on African students
- Ocean modelling and prediction
- Ocean-atmosphere interaction, climatology and regional impact
- High-resolution satellite remote sensing of the regional seas
- Regional sea-level variability and global change

Acknowledgements

The Nansen-Tutu Centre's activities are enabled through contributions from its signatory partners and project funding. In 2020, the Centre received direct funding from the Nansen Environmental and Remote Sensing Centre, University of Bergen and the Institute for Marine Research. In addition, project funding, travels and bursaries were obtained from South Africa, Norway and France. Moreover, in-kind contributions were received from partners of the Joint Venture. Additionally, Nansen Environmental and Remote Sensing Centre, University of Bergen, the Institute for Marine Research, the Nansen Society and UCT gave substantial funding to the Nansen Tutu 10-anniversary Symposium.

Organisation

The Nansen-Tutu Centre (NTC) is a University of Cape Town (UCT) accredited non-profit research centre hosted at the Department of Oceanography at UCT. The administrative and legal responsibilities reside with UCT. It is a joint venture agreement between the signatory partners from South Africa, Norway, France and the United States. In 2020, the signatory partners from South Africa are the Department of Oceanography, UCT; the Alliance for Collaboration on Climate and Earth System Studies (ACCESS), National Research Foundation (NRF); the Council for Scientific and Industrial Research (CSIR); the South African Environmental Observation Network (SAEON), the Department of Environment Forestry and Fisheries (DEFF), Oceans and Coasts Branch; the South African Weather Service (SAWS); the Cape Peninsula University of Technology (CPUT); and Institute for Coastal and Marine Research of the Nelson Mandela University (NMU). From Norway, the signatory partners are 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 Princeton University.

Staff

The 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 2020, the Nansen-Tutu Centre comprised 27 persons, including 1 Honours student, 6 MSc students, 4 PhD students, 4 Postdoctoral researcher fellows and 12 associate researchers.

Cover: A stormy year: photo taken by Hermann Luyt during the Black South-Easter of 19 January 2020. View from Cape Point across False Bay towards Rooiels and Kogelbay.

Scientific production

A total of 20 peer-reviewed journals publications emanated from the Centre in 2020. 44 oral presentations or posters were presented at national or international conferences and workshops.

Graduation

Congratulations to **Bellinda Nhesvure** (MSc), **Jason O'Connor**, (MSc) and **Anathi Manyakanyaka** (MSc), who graduated in 2020.

Student and postdoctoral fellows support and supervision

In 2020, the Nansen-Tutu Centre supported the students and postdoctoral fellows listed below who received a full bursary and top-up funding to up their bursaries.

Marie-Lou Bachelery (co-funded: NTC and UCT URC) – postdoctoral research fellow, France
Supervisors: Mathieu Rouault, Annette Samuelsen and Serena Illig

Juliano Dani Ramanantsoa (NTC and NRF SARChI) – postdoctoral research fellow, Madagascar. Supervisors: Mathieu Rouault and Marek Ostrowski

Georges-Noel Tiersmondo Longandjo (NTC and ACCESS) – postdoctoral research fellow, Democratic Republic of Congo. Supervisors: Mathieu Rouault and Noel Keenlyside

Mesmin Awo (NTC and NRF SARChI) - postdoctoral research fellow, Benin. Supervisors: Mathieu Rouault and Marek Ostrowski

Serge Tomety (NTC and NRF SARChI) – PhD, Togo. Coastal change and Variability in the Benguela Upwelling System: Decadal Variability and Trend. Supervisors: Mathieu Rouault, Serna Illig, Noel Keenlyside and Annette Samuelsen

Hermann Luyt (NTC and ACCESS) – PhD, South Africa. Assimilating regionally tailored satellite SSTs in an assimilative model of the Agulhas and Benguela currents. Supervisors: Björn Backeberg, Francois Counillon, Jennifer Veitch and Santha Akella

Bellinda Monyella (UCT, NTC and NRF SARChI) – PhD, South Africa. Impact of ENSO on Southern African rainfall. Supervisor: Mathieu Rouault

Bafana Gweba (NTC and NRF SARChI) - PhD, South Africa. Modelling current wave interaction in the Agulhas Current. Supervisor: Marjolaine Krug, Pierrick Penven, Fabrice Collard and Johnny A. Johannessen

Bellinda Nhesvure (NTC and ACCESS) - MSc, Zimbabwe. Impact of ENSO on South African coastal sea surface temperature. Supervisor: Mathieu Rouault

Jason O'Connor (NTC and NRF SARChI) - MSc, South Africa. Impact of Agulhas Current on storm development. Supervisor: Mathieu Rouault and Noel Keenlyside

Anathi Manyakanyaka (NTC and NRF SARChI) - MSc, South Africa. The variability of retention in St Helena Bay. Supervisor: Jenny Veitch and Mathieu Rouault

Tesha Toolsee (NTC and NRF SARChI) - MSc, Mauritius. Interannual variability and long-term trends in surface hydrographic parameters around the Prince Edward Islands Archipelago. Supervisors: Tarron Lamont and Mathieu Rouault.

Sonia Heye (NTC and NRF SARChI) – MSc, South Africa. Investigating the presence of a northward flow in the KwaZulu-Natal Bight and its impact on MPA connectivity. Supervisors: Marjolaine Krug, Pierrick Penven, Michael Hart-Davis and Jenny Veitch

Liisa Shangeta (NRF and NTC) Long-term climate variability at the Prince Edward Islands in the Southern Ocean Supervisors: Tarron Lamont Isabelle Ansorge and Mathieu Rouault

Kirstin Petzer (NTC and NRF SARChI) BSc Honours, South Africa, Upwelling rates in the Southern Benguela Upwelling System. Supervisors: Tarron Lamont and Mathieu Rouault

Summer School

Hermann Luyt, Bafana Gweba, Juliano Ramanantsoa, Founi Mesmin Awo, Marylou Bachelery, Folly Serge Tomety attended The Nansen Tutu TRIATLAS Summer School on Ocean, Climate and Marine Ecosystem, 14-21 January 2020. The Summer school was organized by Mathieu Rouault from NTC and UCT, Lynne Shannon from UCT and Noel Keenlyside from the University of Bergen. It was a resounding success, with the participating students and early career researchers asking for new opportunities for interdisciplinary exchange. We brought together master, PhD and early career researchers together from physical and biological oceanography, and climate research, from Brazil, Africa, and Europe. The summer school served to initiate many into the exciting field of interdisciplinary research, as needed to solve the major challenges facing the Atlantic - management of human activities impact the marine ecosystem. This is the issue being addressed by the EU H2020 TRIATLAS project. More info and student presentations are available at https://www.nansentutusummerschool.com/

10th Anniversary Symposium

The celebration of the Nansen-Tutu Centre's 10th anniversary brought together around 90 researchers, postdoctoral fellows, PhD, and MSc students for a 3-day symposium at the University of Cape Town Graduate School of Business, located at the Waterfront in Cape Town, from 10-12 March 2020. Attendants came from Cameroon, Mauritius, Togo, Benin, Namibia, Mozambique, Madagascar, Tanzania, Kenya, Nigeria, Democratic Republic of Congo, South Africa, Ethiopia, France, Italy, Germany, Norway, Netherlands, United Kingdom and the USA. The anniversary symposium (www.nansentutusymposium.com) focused on "Ocean, Weather and Climate: Science to the Service of Society". The level of the presentations was very impressive and early career scientists from the African continent demonstrated the high scientific quality of their work in a multitude of ocean, atmosphere, and climate-related disciplines with significant importance to societies in southern Africa. The event also marked the signatory ceremony for the launch of the 4th 3-year phase of the Nansen-Tutu Centre Joint Venture Agreement from 2020 to 2022. A take-home message for the continuation into the 4th phase recommended that the Nansen-Tutu Centre should play a coordinating role to initiate a training workshop for early-career scientists targeting the UN Decade of Ocean Science for the sustainable development goals and to help to the development of Operational Oceanography in Southern Africa. The Symposium was also endorsed by CLIVAR.

Capacity building

Marielou Bachelery, Noel Keenlyside and Mathieu Rouault gave classes at the Nansen Tutu TRIATLAS Summer School on Ocean, Climate and Marine Ecosystem, 14-21 January 2020. Johnny A. Johannessen gave 12 hours of virtual lectures in Operational Oceanography and Satellite remote sensing for the Applied Oceanography Master of University of Cape Town, from 4-6 May 2020. Marjolaine Krug gave lectures on Introduction to Synthetic Aperture Radars and Introduction to Altimetry (3 hours) for the Applied Oceanography Master of the University of Cape Town. Mathieu Rouault gave 10 hours of lecture in Weather forecast and Weather forensic studies for the Applied Oceanography Master of the University of Cape Town in May and June 2020. Mathieu Rouault gave 10 hours of lectures in Air-Sea

Interaction for B.Sc. Honours class in the Dept. of Oceanography of University of Cape Town.

Exchanges with Norway

Because of COVID, no visits to Norway were made in 2020 but Peter Haugan (IMR), Dag Rune Olsen (Rector, UiB), Sebastian Menild (NERSC), Nils Gunnar Kvamstø (Marine Dean, UiB), Johnny A. Johannessen (NERSC), Annette Samuelsen (NERSC), Marek Ostrowski (IMR) and Noel Keenlyside (UiB) attended the Nansen-Tutu Centre 10th anniversary symposium in Cape Town, South Africa.

Conference and workshop attendance

Jennifer Veitch, Bjorn Backeberg, Tarron Lamont, Marie-Lou Bachelery, Serge Tomety, Marjolaine Krug, Johnny A. Johannessen, Annette Samuelsen, Mathieu Rouault, Juliano Dani, Mesmin Founi, Sonia Heye, Jason O'Connor, Anathi Manyakanyaka, Marek Ostrowski, Noel Keenlyside, Hermann Luyt, Michael Hart-Davis, Tesha Toolsee, George Noel Tiersmondo Longandjo, Nils Gunnar Kvamstø (Marine Dean, UiB), Peter Haugan (IMR), Dag Rune Olsen (Rector, UiB), Sebastian Menild (NERSC) attended the NTC 10th anniversary symposium in Cape Town from 10-12 March 2020. Marjolaine Krug and Tarron Lamont attended the Ocean Science Meeting 2020, 16-21 February 2020 in San Diego, Calif. Marjolaine Krug chaired the OCIMS stakeholder workshop, 3-5 March 2020, Cape Town, South Africa. Mathieu Rouault and Annette Samuelsen attended the Antarctic Season Launch seminar in Cape Town, 3. December 2019. Marie-Lou Bachelery, Mathieu Rouault, Mesmin Founi Awo, Annette Samuelsen, and Serge Tomety attended the TRIATLAS web General Assembly, 12-14 May 2020. Marie-Lou Bachelery attended the EGU online conference, 3-8 May 2020. Annette Samuelsen presented an overview of activities at the Nansen Tutu Centre when the Norwegian Minister of International Development visited NERSC on 21st November 2019. Hermann Luyt attended the 21st GHRSST International Science Team Meeting (GHRSST XXI) online, 1-4 June 2020. Jenny Veitch was invited as a panel member on the Ocean Modelling session of the Air Centre's All Atlantic Summit that was held virtually on 5-9 October 2020

National and international activities

The Centre actively participated in national research and development activities, including projects funded through the NRF, the Department of Science and Innovation (DSI), and the Alliance for Collaboration on Climate and Earth System Studies (ACCESS). ACCESS is an 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. Mathieu Rouault and Jenny Veitch are members of the CLIVAR research focus group on Eastern Boundary. The Centre's researchers serve on several international panels, including the GODAE OceanView Coastal Ocean and Shelf Sea Task Team, the GCSO/GOOS/WCRP Ocean Observations Panel for Climate (OOPC), the Oceangliders Boundary Ocean Observing Network (BOON). The Nansen-Tutu Centre is co-pi in the Horizon 2020 TRIATLAS project, the Norway South Africa PCO2 project and the Belmont Forum Exebus project. Jenny Veitch is a member of the Oceans Predict Coastal Ocean and Shelf Seas Task Team (COSS-TT) as well as a panel member of the CLIVAR Atlantic Region Panel (ARP).

Highlights

Michael Hart-Davis was the 2020 recipient of the prestigious S2A3 Masters Medal. Michael is the first Physical Oceanographic Masters student to win the award. The S2A3 Masters' Medals have been awarded since 1981 by the Southern Africa Association for the Advancement of Science to the most outstanding research student. Founded in 1902, it is the oldest scientific organization in South Africa. The 10th Anniversary Symposium and the Nansen-Tutu Triatlas Summer School were other highlights.

Financial situation

A total of 1 050 000 ZAR (700 000 NOK) seed funding for the Centre was made available from Norwegian partners in 2020: notably 450 000 ZAR (300 000 NOK) from NERSC; 450 000 ZAR (300 000 NOK) from UiB; and 150 000 ZAR (100 000 NOK) from IMR. In addition to this, almost 3 000 000 ZAR was raised through project funding in 2020. These include projects funded by the South African National Research Foundation, the Alliance for Collaboration on Climate and Earth System Science, the NRF's South African Research Chairs Initiative and the EU 2020 TRIATLAS project. At last, the University of Cape Town, the Nansen Centre, the Nansen Scientific Society, the University of Bergen, the Institute of Marine Research, and the Research Council of Norway are acknowledged for additional financial support which allowed to waive the conference fee for all students and postdoctoral fellows. In addition, the attendance of three African students was fully sponsored. The registration fee for the senior scientists was, moreover, substantially lowered thanks to the financial support.

Prospects for 2021

- 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, national and international conferences and working groups.
- Raise funding for student exchange visits to Norway and France and attendance to international summer schools and conferences.
- Appoint a NTC junior research officer.

Approved by The Board, Cape Town, December 2020

Members of the Board

Prof. J. A. Johannessen, NERSC (Co-chair)
Prof. Isabelle Ansorge, UCT (Co-chair)
Mr A. Naidoo / Mr A. Johnson, Ocean and Coast, DEEF.
Dr Johan Stander, SAWS
Dr Neville Sweijd, ACCESS
Mr Christo Whittle, CSIR
Dr Juliet Hermes, SAEON
Dr Conrad Sparks, CPUT
Dr Bernadette Snow, CMR, NMU
Prof. N.G. Kvamstø, GFI, UiB
Prof. George Philander, Princeton University
Prof. Peter Hagen, IMR
Dr Pierrick Penven, IRD
Dr Steven Herbette, UBO

Welcome to the new members of the board: Dr Bernadette Snow, Dr Pierrick Penven, Dr Steven Herbette, Prof. Peter Hagen, and Mr Christo Whittle. We want to thank the former members for their contributions.

PUBLICATIONS 2020

Peer-reviewed papers

Bachèlery, ML, S. Illig & M. Rouault, (2020): Interannual Coastal Trapped Waves in the Angola-Benguela Upwelling System and Benguela Niño and Niña events. *Journal of Marine Systems*, Vol 203, March 2020, 103262, https://doi.org/10.1016/j.jmarsys.2019.103262.

Braby, L., B. C. Backeberg, M. Krug, and C. J. C. Reason (2020). Quantifying the impact of wind-current feedback on mesoscale variability in forced simulation experiments of the Agulhas Current using an eddy tracking algorithm. *Journal of Geophysical Research: Oceans*, 125, https://doi.org/10.1029/2019JC015365

Cedras, R. B., Halo, I., Gibbons, M. J. (2020). Biogeography of pelagic calanoid copepods in the western Indian Ocean. *Deep-Sea Research II, Topical Studies in Oceanography*, https://doi.org/10.1016/j.dsr2.2020.104740

Da-Allada, C. Y., Baloïtcha, E., Alamou, E. A., Awo, F. M., Bonou, F., Pomalegni, Y., & Irvine, P. J. (2020) Changes in West African Summer Monsoon Precipitation under Stratospheric Aerosol Geoengineering. *Earth's Future*, e2020EF001595

Fearon, G., Herbette, S., Veitch, J., Cambon, G., Lucas, A. J., Lemarié, F., and Vichi, M. (2020). Enhanced vertical mixing in coastal upwelling systems driven by diurnal-inertial resonance: Numerical experiments. *Journal of Geophysical Research: Oceans*, 125, e2020JC016208. https://doi.org/10.1029/2020JC016208.

Flynn, R. F., Granger, J., Veitch, J. A., Siedlecki, S., Burger, J. M., Pillay, K., & Fawcett, S. E. (2020). On-shelf nutrient trapping enhances the fertility of the southern Benguela upwelling system. *Journal of Geophysical Research: Oceans*, 125, e2019JC015948. https://doi.org/10.1029/2019JC015948

Halo, I., Raj, P. R, (2020). Comparative oceanographic eddy variability during climate change in the Agulhas Current and Somali Coastal Current Large Marine Ecosystems, *Environmental Development,* https://doi.org/10.1016/j.envdev.2020.100586

Halo, I., Sagero, P., Manyilizu, M. and Shigalla, M (2020). Biophysical modelling of the coastal upwelling variability and circulation along the Tanzanian and Kenyan coasts. *Western Indian Ocean J. Mar Sc, Special Issue,* 1, 43-61, ISSN: 0856-860X. http://dx.doi.org/10.4314/wiojms.si2020.1.5.

Illig, S., Bachèlery, M.-L. and J. Lübbecke (2020). Why do Benguela Niños lead Atlantic Niños? *Journal of Geophysical Research: Oceans, 125, e2019JC016003.* https://doi.org/10.1029/2019JC016003.

Le Gouvello, D. Z. M., M. G. Hart-Davis, B. C. Backeberg, R. Nel (2020). Effects of swimming behaviour and oceanography on sea turtle hatchling dispersal at the intersection of two ocean current systems. *Ecological Modelling*, 31, https://doi.org/10.1016/j.ecolmodel.2020.109130

Longandjo, GNT and Rouault M (2020). On the Structure of the Regional-Scale Circulation over Central Africa: Seasonal Evolution, Variability, and Mechanisms. *Journal of Climate* 32(21) 145-162. DOI: 10.1175/JCLI-D-19-0176.1

Manyilizu, M., Sagero, P., Halo, I., Mahongo, S. (2020). A Comparative Study of Ocean Surface Interannual Variability in Northern Tanzania and Northern Kenya Bank, *Western Indian Ocean J. Mar Sc, Special Issue, 1, 1-8, ISSN: 0856-860X. http://dx.doi.org/10.4314/wiojms.si2020.1.1*

Nel, R., Dalleau, M., le Gouvello, D., Hart-Davis, M.G., Tucker, T., Rees, A.F., Phillott, A.D. and Whiting, S. (2020). Indian Ocean Loggerheads. *SWOT Report*, Vol. 15.

Nhantumbo, B., J. E. O. Nilsen, B. C. Backeberg, C. J. C. Reason (2020). The relationship between coastal sea level variability and the Agulhas Current. Journal of Marine Systems. *Journal of Marine Systems*, 211, DOI:/10.1016/j.jmarsys. 2020.103422.

Radenac, M. H., Jouanno, J., Tchamabi, C. C., Awo, M., Bourlès, B., Arnault, S., and Aumont, O. (2020). Physical drivers of the nitrate seasonal variability in the Atlantic cold tongue. *Biogeosciences*, *17*(2), 529-545.

Raj, R. P., Halo, I., Chatterjee, S., Belonenko, T., Bakhoday-Paskyabi, M., Bashmachnikov, I., Fedorov, A., Xie, J. (2020). Interaction between mesoscale eddies and the gyre circulation in the Lofoten Basin. *Journal of Geophysical Research: Oceans*, 125, e2020JC016102. https://doi.org/10.1029 /2020JC016102

Taguela TN, Vondou DA, Moufouma-Okia W, Fotso-Nguemo TC, Pokam WM, Tanessong RS, Longandjo, GNT [et al.] (2020). CORDEX multi-RCM hind cast over Central Africa: Evaluation within observational uncertainty. *Journal of Geophysical Research: Atmospheres*, 125: e2019JD031607.

Staff in 2020 Scientists

Dr Annette Samuelsen, NERSC, Norwegian co-director, Ocean modelling and prediction

Prof. Mathieu Rouault, South African co-director, Ocean-atmosphere interaction, climate and regional impact

Dr Issufo Halo, Associate researcher, CPUT, South Africa, Ocean modelling and prediction

Prof. Johnny A. Johannessen, Associate researcher, NERSC, Norway, Satellite remote sensing of regional shelf seas

Prof. Noel Keenlyside, Associate researcher, UiB, Norway, Ocean-atmosphere, climate and regional impact

Dr Marjolaine Krug, Associate researcher, DEFF, South Africa, Satellite remote sensing of regional shelf seas

Dr Marek Ostrowski, Associate researcher, IMR, Norway, Ocean-atmosphere, climate and regional impact

Dr Jenny Veitch, Associate researcher, SAEON, South Africa, Ocean modelling and prediction

Dr Taron Lamont, Associate researcher, DEFF. South Africa

Dr Mostafa Bakhoday-Paskyabi, Associate researcher, UiB, Norway, Ocean modelling and prediction

Dr Bjorn Backeberg, Associate researcher, Deltares, NERSC and NTC, Norway and South Africa, Ocean modelling and prediction

Dr Francois Counillon, Associate researcher, NERSC, Norway, Ocean modelling and prediction

Administrative and technical staff

Cashifa Karriem, secretariat and finances

Seasonal variability of Sea Surface Salinity in Angola upwelling system

F.M. Awo, M. Rouault, M. Ostrowski

The Angolan system is one of the most productive marine ecosystems in the southeast tropical Atlantic. Contrary to the Benguela upwelling system supported by persistent alongshore winds driving upwelling, the highly productive Angolan system is driven by different mechanisms because have relatively weak winds, for instance, tides, the Angolan alongshore surface current that transports the warm equatorial waters southward and the coastally trapped waves originating from the equator. Recent studies have shown that during the last warm event in 2016, surface freshening water, detected in satellite estimation of Sea Surface Salinity (SSS), caused a very shallow mixed layer, and enhanced upper ocean stratification that reduced the upwelling of the cool subsurface water into the mixed layer. These findings have highlighted the important role of ocean salinity in the Angolan coastline (figure 1. a.b). Our goal is to understand the SSS variability in the Angolan upwelling region using observations and to investigate SSS drivers with an ocean general circulation model. The first result is presented in figure 1, showing the behavior of surface water salinity during the development of upwelling along the Congolese and Angolese coasts (figure 1. a.b). Based on satellite estimation, the evolution of the seasonal cycle of SSS along the Angola coast shows that the low salinity appears during the austral autumn with a minimum in March-April, and then increases by reaching maximum values in austral winter and peaks in August (figure 1.d), corresponding to the high season of Angolan upwelling (figure 1. b). After winter, the low salinity intrusion off Angola occurs in spring, but with lower intensity compared to the first minimum. As the model reproduces consistently the observed seasonal variability, we use it with confidence to diagnose the dominant physical mechanisms that are responsible for this variability. Along the Angola coast, the diagnostics show the following results. The change in horizontal advection, related to alongshore surface current, is the main process that drives the seasonal SSS cycle, especially responsible for the low salinity intrusion off Angola. The alongshore current carries low salinity from the Congo River plume, located at 6°S, southward until the south Angola Coast during February-March and September-October (figure 1.d). But, during the austral winter, where salinization of surface water is observed (figure 1.d), results show that the vertical advection at the subsurface increases surface salinity along the Angola coast.

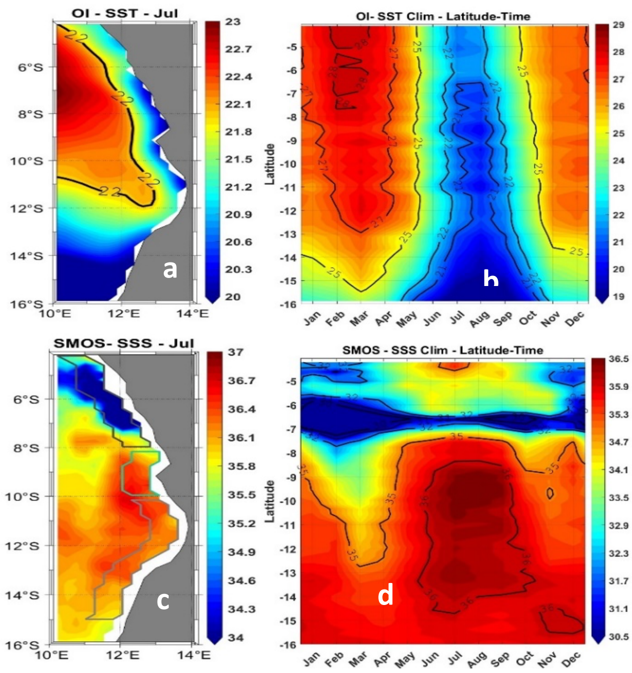


Fig 1: Sea Surface Temperature (SST) and Salinity (SSS) averaged in July (a, c), and Latitude-time seasonal cycle of SST (b) and SSS (d) averaged over 1° off along the coast using OI SST and Soil Moisture–Ocean Salinity (SMOS) satellite mission. The three domains (e) represent the Congo region and the northern and Southern Angola region, respectively.

Lagged Correlation between global Sea Surface Temperature and South African Rainfall

Bellinda Monyella and Mathieu Rouault

Southern Africa, defined here as the region between 15 °S and 33° S latitude and 12° E 36° E longitude receives most of its rainfall during austral summer (Figure 1). The region experiences less rainfall during the early summer season than during the late summer. The early summer includes October, November, and December while the late summer includes January, February, and March.

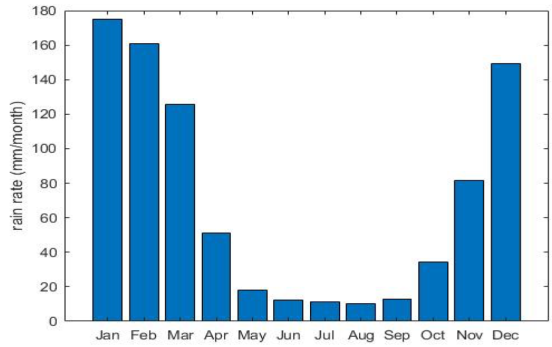


Fig 1: The annual cycle of rainfall over Southern Africa over a 38-year climatological period (1983 – 2020) using the ERA5 rainfall dataset.

Like many subtropical regions, rainfall variability in Southern Africa is related to sea surface temperature (SST) anomalies across the globe. The aim of this study is to calculate the lagged correlation of SST anomalies across the globe with Southern African rainfall during summer. The Southern African rainfall is significantly negatively lagged correlated to the Nino 3.4 region during OND and JFM when Nino 3.4 SST anomalies lead Southern African rainfall by up to 6 months. The significant correlation between Nino 3.4 and Southern African rainfall is maximum when SST in the Nino 3.4 region leads rainfall by two months (- 0.56), 1 month (-0.58), and peaks at zero lag (-0.61). The Southern African rainfall is also significantly positively correlated to the Atlantic Nino Index when SST in this region leads to rainfall by up to 3 months. It should also be noted that Southern rainfall is not significantly correlated to the South Indian Ocean Dipole (SIOD) and the South Atlantic Dipole. Figure 2 show a 3-months lagged correlation between early summer (DJF) global SST and Southern African late summer (FMA) rainfall from 1983 to 2020. The negative correlation implies that positive SST anomalies are correlated to negative rainfall anomalies and highlights the tropical Pacific and related ENSO patterns as the main driver of the correlation. The SST indices extracted from various domains and used in that study are respectively the Nino3.4 region in Central Pacific (5 °N - 5° S; 120° -170° W), Atlantic Nino region in Central Atlantic (3° S - 3°N, 20 °W - 0°), South Atlantic Subtropical Dipole (30°– 40°S, 10°–30°W minus 15°–25°S, 0°–20°W) and South Indian Ocean Dipole (55° - 65° E, 27° - 37° S minus 90° - 100° E, °- 28 °S).

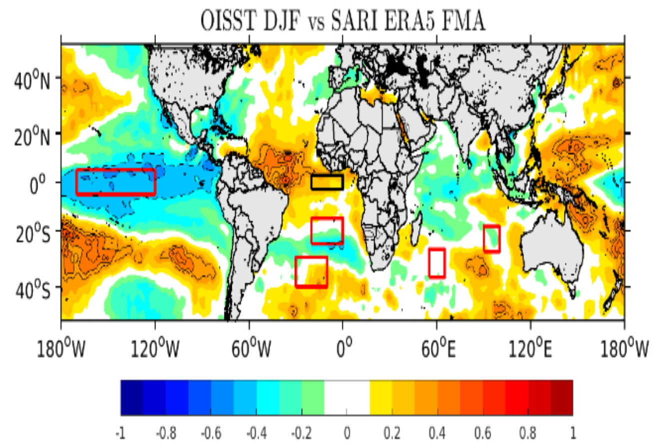


Fig 2: 3 months lagged correlation between DJF global ST and Southern African late summer (FMA) rainfall using ERA 5 dataset from 1983 to 2020. The significant correlations at 95 % confidence interval using Student's t-Test are depicted by contours. The negative correlation implies that positive SST anomalies are correlated to negative rainfall anomalies. The SST indices extracted from the above domains are from left to right are as follows: Nino 3.4 region, Atlantic Nino region, South Atlantic Subtropical Dipole and South Indian Ocean Dipole

Determining optimal SST for assimilation into a regional HYCOM EnOI system

Hermann Luyt, François Counillon, Björn C. Backeberg, Santha Akella, Jennifer Veitch

South Africa boasts a range of oceanographic decision support tools, an operational regional wave forecasting system and a bay-scale forecast product for Algoa Bay is currently under development. There is, however, no operational regional ocean forecasting system in place tailored to the unique South African environment comprising both the Agulhas and Benguela oceanic currents. Forecasts from such a system are invaluable to marine industries including those involved in search and rescue, fishing, and offshore mining. To get the most accurate forecast possible, it is vital that accurate and up-to-date observations of the true state of the ocean are synthesised into the forecasting system through data assimilation. Initial efforts towards this goal have resulted in a system using a regionally optimised Hybrid Coordinate Ocean Model (HYCOM) along with the Ensemble Optimal Interpolation (EnOI) assimilation scheme. Adding Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) to the assimilation did not seem to improve the forecast skill. Aiming to address this issue and improve the forecast skill, three contemporary sea surface temperature (SST) data sets from the European Space Agency's Climate Change Initiative (CCI) are assimilated in separate experiments. These data sets are the CCI SST analysis product, the CCI level-2 (L2) SST product and the CCI level-3 (L3) SST product. The analysis product is a level-4 (L4) product, meaning that it is produced for the entire globe, is gridded, and uses interpolation to ensure there are no gaps in the data. The (L2) and (L3) 'along-track' products contain SSTs from individual satellite tracks and include gaps in areas where the satellite has not passed over and where clouds obscure its view. The reasoning behind the use of along-track SST data is that, unlike the L4 products, they contain no interpolation or analyses in order to fill gaps in the data. Interpolation and analyses can introduce spurious data. L3 SSTs differ from L2 SSTs in that they are projected onto a grid. The L2 SSTs are obtained from the Along Track Scanning Radiometer satellites and the L3 SSTs from the Advanced Very High-Resolution Radiometer satellites. Initial results from a short run of just over 9 months are shown in Figure 1. The Root Mean Square Error (RMSE) calculated between the model and the SST data is shown for the experiments assimilating the three contemporary CCI SST data sets (CCI, CCIL2, CCIL3), an experiment assimilating OSTIA SSTs (OSTIA) and an experiment without any assimilation (Free Run). All experiments display a better agreement with the data compared to Free Run. Of the experiments containing assimilation, the assimilation of L2 data, CCIL2, shows the best agreement with data with an RMSE of 1.036 °C and CCIL3 shows the least agreement with the data (1.135 °C). The experiments assimilating the L4 data performed fairly similarly but with OSTIA showing an improved agreement (1.062 °C) over CCI (1.082 °C). These initial results do not discriminate between domains within the model and more validations against independent data need to be performed. Validations will include looking at the regions where improvements and deteriorations occur and using data from profiling floats to better understand the impact of the assimilations.

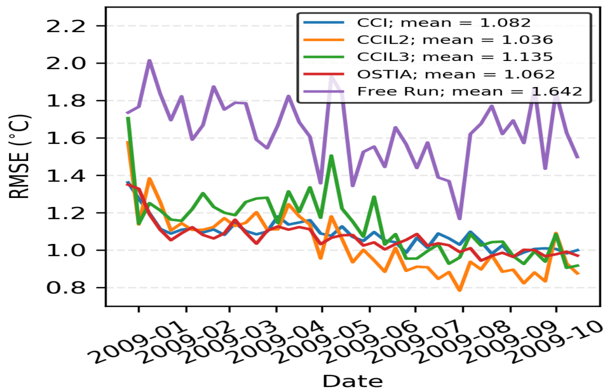


Fig 1: Time-evolution RMSE of the SST for experiments assimilating CCI L4 (blue), CCI L2 (orange), CCI L3 (green), OSTIA (red) and no assimilation (purple).

Where and how does the East Madagascar Current retroflection originate?

Juliano Dani Ramanantsoa, Marek Ostrowski, Pierrick Penven and Mathieu Rouault

The East Madagascar Current (EMC), a western boundary current located at the eastern side of the Indian Ocean, redistributes water and heat towards the lower latitude and recirculation to the large-scale Indian Ocean through retroflection modes of its southern extension. Five cruise data sets and remote sensing data are used to identify three states of the East Madagascar Current (EMC) southern extension: Early-Retroflection, Canonical-Retroflection and No Retroflection. Retroflections occur 47% of the time. EMC strength regulates the retroflection state, although impinged mesoscale eddies also contribute to the retroflection formation. The Early-Retroflection is linked to the EMC volume transport. Anticyclonic eddies drifting from the central Indian Ocean to the coast favour Early-Retroflection formation (Figure 1). Anticyclonic eddies near the southern tip of Madagascar promote the generation of Canonical Retroflection and No-Retroflection appears to be associated with a lower Eddy Kinetic Energy (EKE). Transfer of kinetic energy between mean flow and mesoscale eddy field is the main factor triggering Retroflection types associated with the EMC strength modulation. Knowledge of the EMC retroflection state could help predict: (1) coastal upwelling South of Madagascar, (2) the South-East Madagascar phytoplankton bloom, (3) the formation of South Indian Ocean Counter Current (SICC).

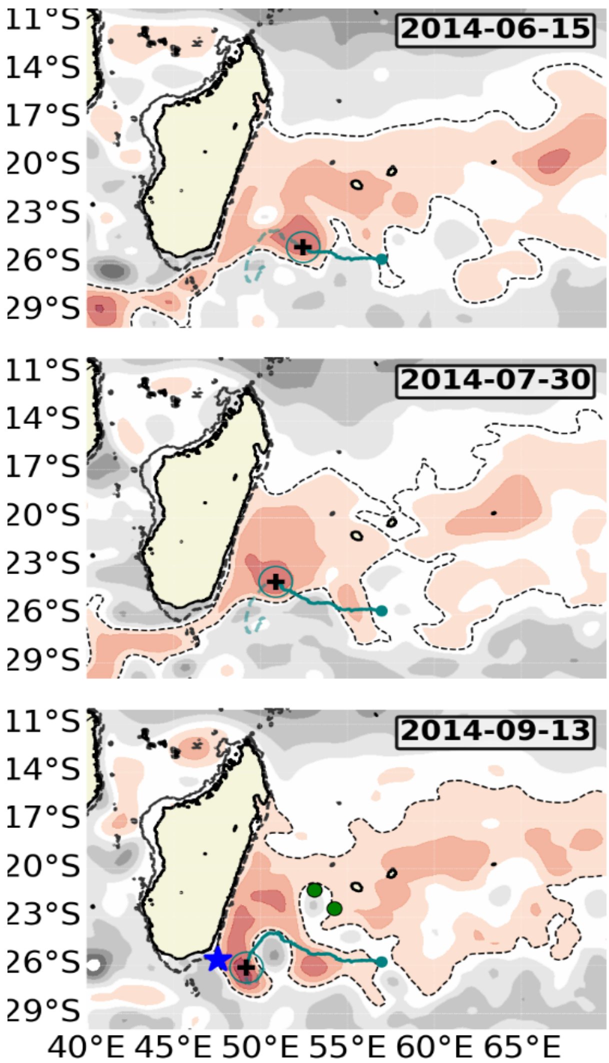


Fig 1: Evidence of the EMC Early-Retroflection. Synoptic development of EMC early Retroflection from onset to the full formation. Blue stars are the retroflection positioning, while the dotted black lines delineate the streamline of the flow. Maps in the background are the surface sea level. The line in dark cyan represents the path of tracked anticyclonic eddy triggering the early retroflection. The dot in dark cyan colour pins the location where the eddy was formed. The black cross surrounded by a circle denotes the progressive location of the eddy. Green dots illustrate the release of virtual particles to coincide with the full development of Early-Retroflection.

Origin of the warming along the Angolan and Namibian coast

Folly Serge Tomety, Mathieu Rouault, Founi Mesmin Awo, Noel Keenlyside

The Angola Benguela Front (ABF), is a very dynamic area, characterised by a high-temperature gradient of up to 4°C per degree latitude. In this study, we identify the processes responsible for the warming trend estimated since 1982 in Northern Benguela, the ABF and Southern Angola and the mechanism behind the changes. The OGCM NEMO model is used for that matter. Firstly, we compare the sea surface temperature (SST) NEMO trend at the monthly scale to the trend of a mean of three satellite-derived SST datasets (1x1 degree Reynolds SST, 0.25 x 0.25-degree Reynolds SST 1x1 degree Hadley SST) from 1982-2015. The comparison of NEMO and observation is shown in Figure 1. Along the Angolan coast (6°S to 17°S), the warming trend ranges from 0.1 to 0.8°C per decade throughout the entire year while a cooling occurs in austral winter in the model and in austral winter and autumn in the observations. Along Namibia south of 17°S, NEMO seems to overestimate a cooling trend of up to -0.4 °C per decade. The cooling trend is also found south of 22°S in austral winter (May-October) and is statistically significant from July to September in the observations. Overall, the model shows a good representation of the austral summer warming trend and winter cooling trend in the region except for the overestimation of the cooling trend in the south which could be due to due to an unrealistic higher than normal trends in NEMO wind forcing could artificially increase upwelling and related equatorward horizontal motion of cold water originating in the Benguela current. NEMO is then used to calculate quantities that will be related to various components of the upper-ocean heat budget to provide insight into potential mechanisms causing the trend in SST. The results suggest that, at the seasonal scale, the warming trend along the Angolan and Northern Namibian coast is explained by a positive trend in the poleward transport of tropical water. However, in autumn the modelled SST warming trend observed along the Angolan coast is associated with a positive trend in net surface heat flux and a weakening of vertical flow associated with the upwelling of cooler water to the surface. In early summer, November to January, the modelled SST warming trend observed along the Angolan and Namibian coasts is primarily associated with the intensification of the poleward flow bringing more warm water from the tropics into the area of study and a weakening of the vertical flow of cold water to the surface. The modelled SST cooling trend that occurs south of the ABF and probably in the observation too, especially in winter and early spring, is primarily associated with the horizontal current that advects cooler water from the south and intensification of upwelling of cooler water from the sub-surface to the surface.

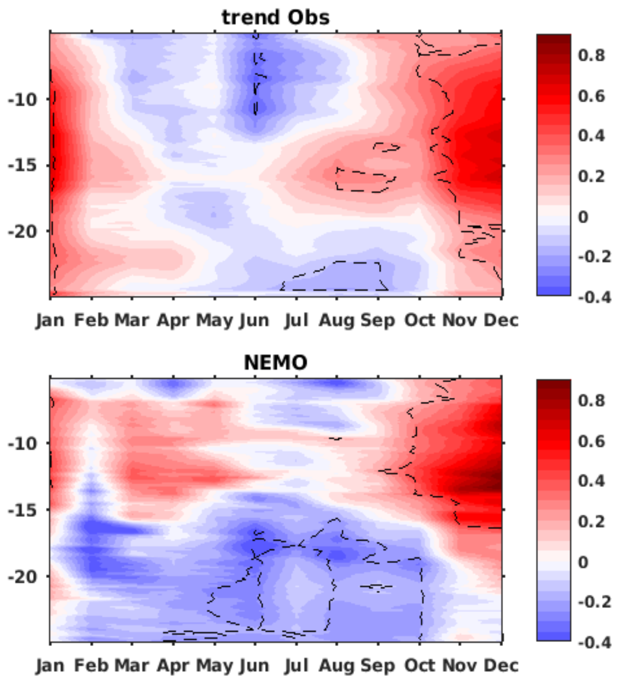


Fig 1: Hovmöller diagram of the monthly decadal linear trend of SST (°C per decade) from 1986 to 2015 averaged from the coast to 1 degree of the coast along Angola-Namibia for the mean of observation derived SST (top panel) and NEMO model (bottom panel). Broken contour lines denote values statistically significant at the 95% using Spearman rank correlation.

Investigating the Natal Bight Coastal Counter Current

S. Heye, M. Krug, P. Penven, M. Hart-Davis,

The KwaZulu-Natal (KZN) Bight is a region along Africa's southeast coast, which has a widened shelf compared to its surrounding. This pushes the adjacent Agulhas Current offshore, resulting in complex shelf circulation features, upwelling of nutrients and the retention of water, making it a biologically important region. Many of these features have been extensively studied, such as the cyclonic, semi-permanent Durban Eddy, offshore of Durban, but no research has focused on the Natal Bight Coastal Counter Current (NBC3). This north-eastward return flow is represented in the mean surface circulation of a high-resolution ocean model and strengthens the connectivity between local marine protected areas (MPAs). In this study, the output of this model is used to investigate the extent, the persistence, and drivers of the NBC3. Results of the model output show that this current originates in the inshore edge of the southern KZN Bight's cyclonic Durban Eddy. It then moves north-eastwards along the KZN Bight's mid-shelf, almost reaching Richards Bay, in the average surface circulation. It propagates parallel to the coast, along the northeast-southwest axis, and is about 8 km wide. On average, it is a slow current, rarely exceeding a mean flow of 5 cm/s. No strong seasonal patterns are observed, aside from a stronger coastal shoreward extent and a reduced northward extent of the NBC3 in winter. The northern KZN Bight has a mean cyclonic feature in its place in winter. The wind and offshore variabilities are investigated as potential drivers of the surface circulation in the KZN Bight. Both do not show a strong, instantaneous, linear correlation to the surface circulation, but if lag effects and non-linear relationships are considered, these correlations may be much stronger.

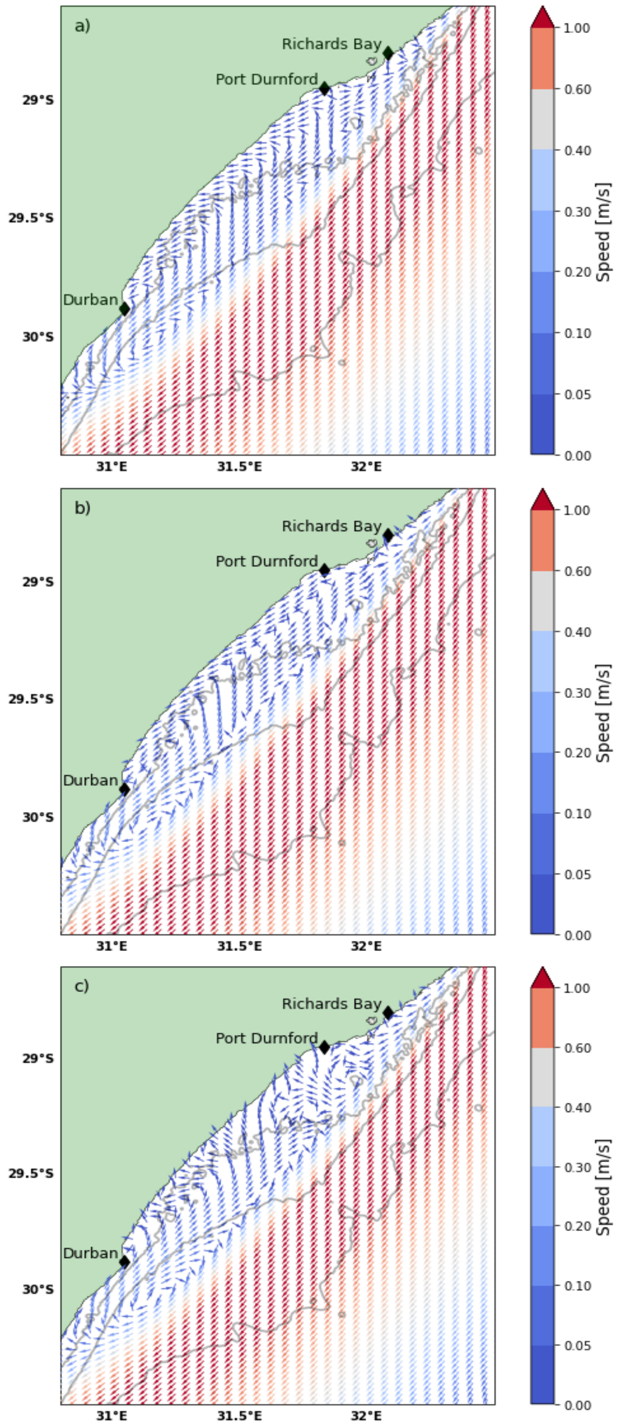


Fig 1: Maps of the model's mean surface current velocity fields from January 2005 to December 2014 in the KZN Bight region. The colours of the arrows represent their speeds and the 50 m, 200 m and 1000 m isobaths are the grey lines offshore. Vectors are normalised at every longitude and every second latitude and the climatological means for the a) annual, b) mean summer and c) mean winter circulations are provided.

Inter-annual variability in sea surface temperature, wind forcing and surface circulation around the Prince Edward Islands.

Tesha Toolsee, Tarron Lamont and Mathieu Rouault

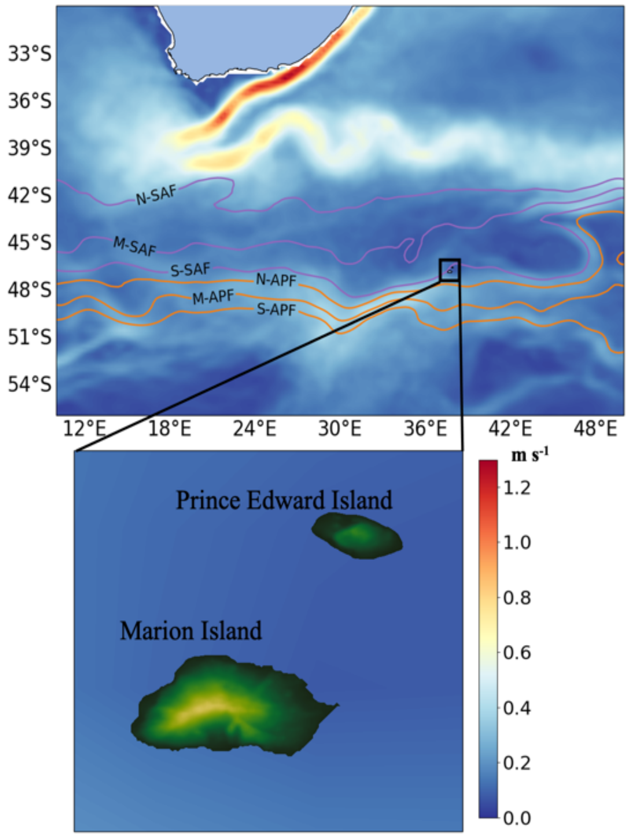


Fig 1. Map of geostrophic current speed (colour shading) indicating the position of the Prince Edward Islands archipelago, Marion, and Prince Edward Island. Long-term mean with positions of the fronts of the Antarctic Circumpolar Current (ACC): the northern, middle, and southern Sub-Antarctic Front (N-SAF, M-SAF, S-SAF) and the northern, middle, and southern Antarctic Polar Front (N-APF, M-APF, S-APF).

The sub-Antarctic Prince Edward Islands (PEIs) ecosystem thrives due to the close interaction between the terrestrial and marine components. Any changes in the atmospheric or oceanic processes around the islands can thus have immediate impact on the terrestrial ecosystem. This makes the PEIs a perfect natural laboratory to understand the impact of climate change in the Southern Ocean. A good understanding of the interannual and long-term changes in atmospheric and oceanic properties and processes is thus important to be able to better predict any ecosystem changes possibly resulting from global warming. This study investigated the interannual variability of sea surface temperature (SST; °C), wind speed (m s^{-1}), wind stress curl (WSC; N m^{-3}), surface geostrophic current (m s^{-1}) and surface Ekman current (results not shown) through a continuous Morlet wavelet transform which helps detect any time-dependent amplitude or phase changes in the anomalies in the parameters. The surface parameters were obtained from a combination of satellite and reanalysis products at a 0.25° x 0.25° spatial resolution. SST time series had a length of 37 years (1982-2019), wind speed and wind stress curl had a period of 40 years (1979 to 2019), and geostrophic and Ekman current had a period of 23 years (1993 to 2016). For each parameter, monthly mean data was extracted and averaged within a 2° x 2° region around the PEIs (Fig 1)

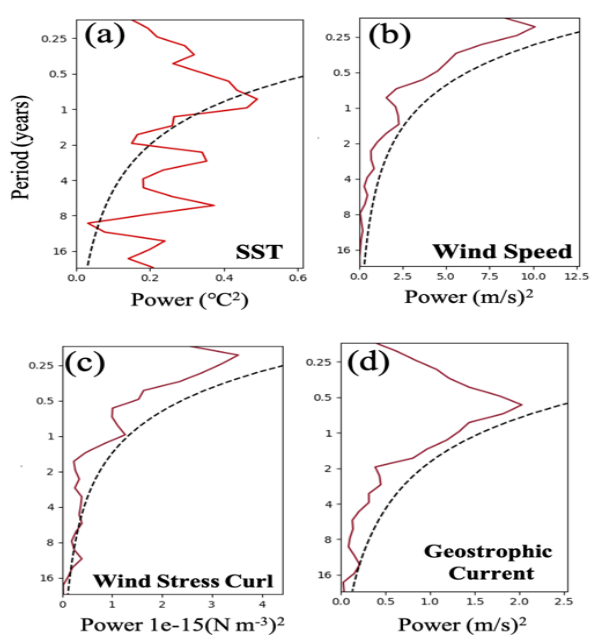


Fig 2. The Global continuous Morlet wavelet transforms (red lines) for the various surface parameters investigated around the Prince Edward Islands, with a 95% confident level indicated (dashed black line.

Of all the above-mentioned parameters, SST was the only one that showed clear inter-annual/decadal signals of variability (Fig 2a). Three significant peaks were observed in SST anomalies at periods of 0.8 years, 2.8 years, and 7.5 years. A fourth peak at 14 years was considered insignificant due to the study period not being long enough to properly identify any significant variability at periods greater than about 12 years. For the same reason, the peak at 12 years for the wind stress curl (Fig. 2c) was also considered to be insignificant. Possible large-scale atmospheric phenomena that could influence SST are the Antarctic Circumpolar Wave (ACW), the El-Niño Southern Oscillation (ENSO), the Semi-Annual Oscillation (SAO) or the Southern Annular Mode (SAM). The ACW is known to emerge in the western subtropical Pacific Ocean and consist of covarying SST anomalies that take 8 to 10 years to propagate across the circumpolar Southern Ocean. ENSO, also known to influence climate variability in the Southern Ocean, occur every 2 to 7 years. The periodicity of both ENSO and the ACW are thus aligned with the spectral energy peaks observed on the wavelet transform of SST anomalies (Fig 2a). Further analysis needs to be conducted to find any influence of SAM or SAO on the SST anomalies at the PEIs. The lack of significant signals for wind, wind stress curl, and Ekman current may have resulted from the ERA5 reanalysis product used. Alternatively, it is likely that the longer-term signals may be smeared by the intense short-term variability associated with winds in the region (strong spectral energy at periods around 3 months; Fig. 2). The lack of significant interannual variability in the geostrophic current may be due to the length of the time series (23 years), which is rather short for clear identification of climate related variations.

WaveWatch III model performance evaluation along the South African coast

B. Gweba, M. Krug, P. Penven, F. Collard

The study of sea state conditions for climatology, prediction or forecast purposes is of great importance for human activities at sea, in both economic and safety aspects. Hence, increasing demand over the past decades to develop numerical wave models to provide wave field conditions in open seas and coastal areas to aid marine applications is needed. The models compute sea state conditions to provide integrated wave parameters, for instance, significant wave height, period, and wave direction. Like any other geoscientific numerical ocean model, they are used to simulate ocean dynamics. Thus, it is necessary to quantify the accuracy of the wave model against measurements to meet the needs of safe operations in coastal and open seas. There have been a great number of efforts done for model validation globally and regionally. In the present study, various wave buoy measurements situated along the South African coastal regions have been used as the reference point to carry out model validation. Apart from the peak period and mean wave direction, the overall model results for significant wave height parameter showed good agreement with buoy measurements despite negative and positive biases noticed across all wave stations. Negative bias was noticed in the wind sea components and positive bias in the swell component. This suggests that a significant part of the error is due to model biases. The error sources could include the choice of wind forcing, numerical scheme and approximated physical process used. To the authors' knowledge, to reduce model errors, one could tune model parameters with source terms or adjust the value of *Betamax* which is the wind-wave growth parameter. We must note that the value of *Betamax* depends on the choice of wind forcing used. Studies have shown that icebergs have an impact in the Southern

Hemisphere wave field propagation and are strongly correlated with wave model errors. Studies have also indicated that wave-current interactions in the Southern Hemisphere, specifically in the Antarctic Circumpolar Current is another physical process that has the potential to impact wave model biases. For the analysis, to potentially reduce model biases, simulations with and without currents have been performed. In some regions, the inclusion of surface currents has shown a reduction in wave height. We must note that this is not enough to reduce model biases but it is an important physical process that significantly reduces systematic model errors. Figure1 shows the Taylor Diagram corresponding to the time series of wave heights with and without currents. Cape Point wave station has an increase in wave height due to currents. In that region, wave fields are predominantly from the south-westerly direction and meet up with the current field and as a result wave height increase. However, it is not the case in the eastern part of the coast at Ngqura, East London, Durban, and Richards Bay. Further investigation in the numerical wave model to reduce biases is needed for better model accuracy.

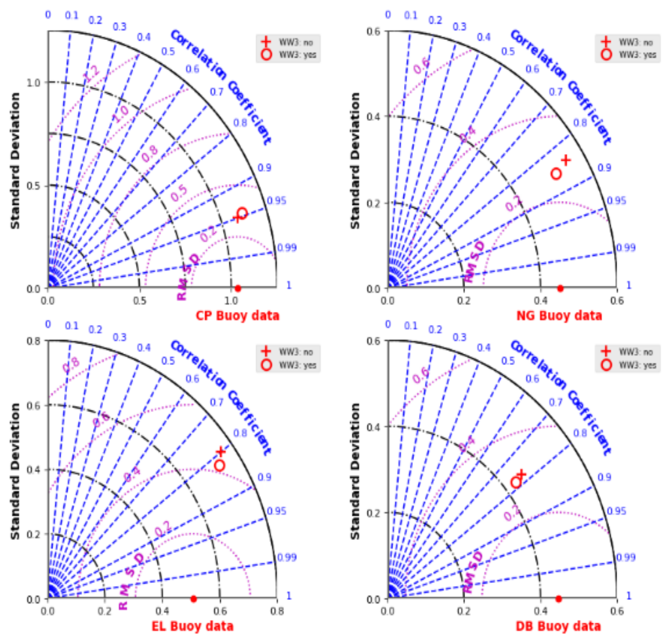


Fig 1: Taylor Diagram for the significant wave height with and without surface currents for the South African wave stations Cape Point, Ngqura, East London and Durban for the 2013 period. WW3 (no and yes) represent simulations with and without surface currents. The correlation coefficient, Root Mean Square Difference (RMSD) and Standard Deviation are given by dashed-dotted blue, magenta and black lines, respectively.

Upwelling Rates in the Southern Benguela Upwelling System

Kirstin Petzer, Tarron Lamont and Mathieu Rouault

This study aims to understand how upwelling rates vary seasonally in the Cape Peninsula upwelling cell, Southern Benguela. In this study, the CSIR Cape Point mooring SST time series and ERA5 wind datasets are used to understand how the upwelling rates vary and what the drivers are. This study confirmed the dominance of upwelling-favourable southeasterly winds during summer together with the lower SST while the higher SST periods during winter corresponds to a dominance of northwesterly winds due to cyclonic low-pressure systems south of Southern Africa. A diurnal cycle of SST was inferred from the hourly observation (Figure1) with the maximum in the afternoon. The diurnal range in SST is higher in summer with an average daily range of about 1°C. Four case studies are analyzed in detail including one extreme upwelling event from each season. The winter event has the lowest initial upwelling rate at -0.0678°C/hr and extremely low SST values (<10°C). While the initial upwelling rates for the autumn (-0.0911°C/hr) and spring (-0.1067°C/hr) events were lower than for the summer event (-0.1470°C/hr), longer periods of lower SST values (<10°C) occurred in these events than in winter. The extreme events occurred during sustained high wind speeds and the summer event was associated with the longest and strongest south-easterly winds events and the longest period of low SST values, despite a short reversal of 1.5 days during the event.

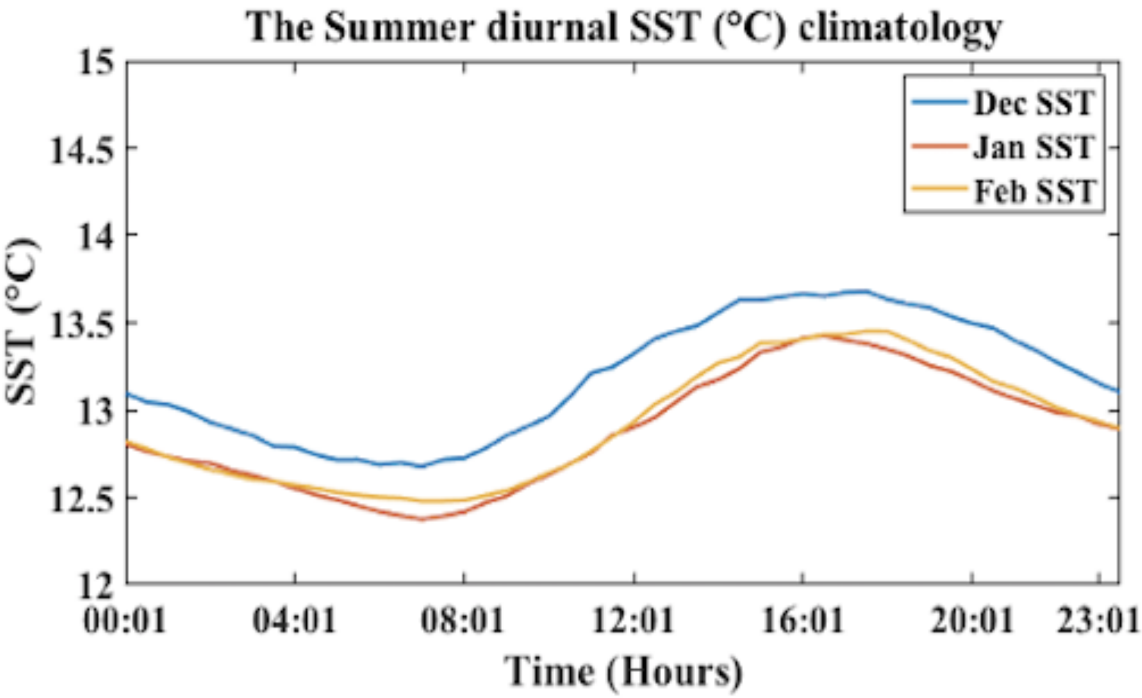
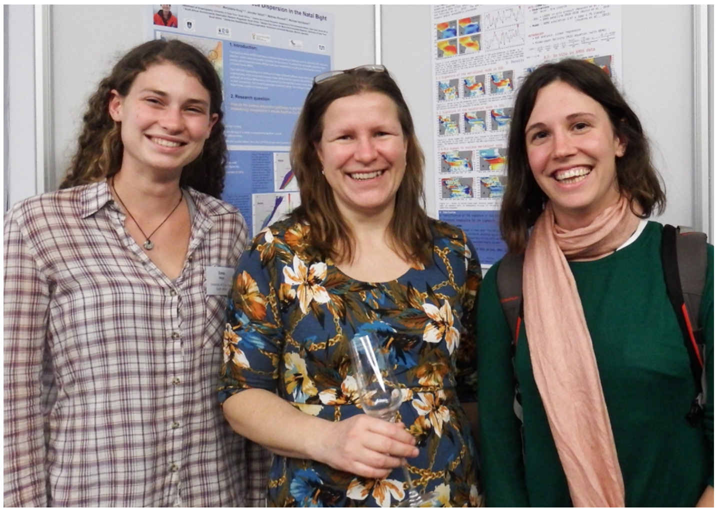


Fig 1: Diurnal SST climatology for each month in summer (December, January, and February) at CSIR Slangkop mooring in the Cape Peninsula upwelling cell from 2003 to 2020.



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