Nansen-Tutu Centre for Marine Environmental Research

ANNUAL REPORT 2021

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 2021, the Centre received direct funding from the Nansen Environmental and Remote Sensing Centre, the University of Bergen, the Institute of Marine Research, and the Nansen Society. In addition, project funding, travels and bursaries were obtained from South Africa, Norway, and France. In kind contributions were received from partners of the Joint Venture.

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 2021, the signatory partners from South Africa are the Department of Oceanography of 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 Forestry, Fisheries and the Environment (DFFE), 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.

Members of the Board

Prof J.A. Johannessen, NERSC (Co-chair)
Prof Isabelle Ansorge, UCT (Co-chair)
Dr A. Naidoo / Mr A. Johnson, Oceans and Coasts, DFFE
Dr Neville Sweijd, ACCESS
Mr Christo Whittle, CSIR
Dr Juliet Hermes, SAEON
Dr Rachida Toefy, CPUT
Dr Lorien Pichegru, CMR, NMU
Prof Øyvind Fiksen, UiB
Prof George Philander, Princeton University
Prof Peter Haugan, IMR
Dr Pierrick Penven, IRD
Dr Steven Herbette, UBO
Welcome to the new members of the board: Dr Lorien Pichegru, Prof Øyvind Fiksen and Rachida Toefy.

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 fellows. During 2021, the Nansen-Tutu Centre comprised 24 persons, including, 4 MSc students, 6 PhD students, 2

Cover: The Nansen-Tutu Centre has a remarkable team of students, post-doctoral fellows, research associates, staff, board members and collaborators. This Annual Report celebrates the people behind NTC with sincere thanks for their contributions.

postdoctoral researcher fellows and 12 associate researchers.

Scientific production

A total of 12 peer-reviewed journals publications, 21 peer-reviewed conference proceedings and one book emanated from the Centre in 2021. 14 oral presentations or posters were presented at national or international conferences and workshops.

Graduation

Congratulations to Kirstin Petzer (B.Sc. Honours), Tesha Toolsee, Liisa Shangeta and Sonia Heye (MSc) who graduated in 2021.

Student and postdoctoral fellows support and supervision

In 2021, 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.

Georges-Noel Tiersmondo Longandjo (NTC) - 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) - 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) - 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 and NTC) - 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

Frank Eitel Ghomsi (NANSI) - PhD, Cameroon, Regional sea level rise in the Tropical Atlantic. Supervisor Mathieu Rouault and R.P. Raj

Christo Whittle (CSIR) - PhD, South Africa. Optimized MODIS earth observation algorithms to characterize the spatial and temporal variability of harmful algal bloom occurrence on the southern Benguela shelf. Supervisors: Mathieu Rouault, Marie Smith, and Annette Samuelsen

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 Mathieu Rouault

Liisa Shangheta (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) - MSc, South Africa, Marine Heat Waves in the Southern Benguela Upwelling System. Supervisors: Tarron Lamont and Mathieu Rouault

Capacity building

Anette Samuelsen taught Data assimilation in marine ecosystem models lecture in the CHESS data assimilation crash course.

Georges Noel Longandjo taught Atmospheric Teleconnections: Climate Variability and Ocean Atmosphere Interactions for Honours students at the Department of Oceanography. He also taught Introduction to Mechanics of Fluids, for 3rd Bachelor students at the University of Lubumbashi, Dem. Rep. Congo as well as Atmospheric and Ocean Dynamics, and Applied Climatology, for Honours students, Faculty of Meteorology and Environmental Engineering, Kinshasa Institute of Applied Technology, Kinshasa, Dem. Rep. Congo. Mathieu Rouault taught Weather Forecasting for the Applied Master of Oceanography at the University of Cape Town while Johnny A. Johannessen gave 12 hours of virtual lectures in the same Master as did Christo Whittle.

Highlights

Dr Marjolaine Krug is the recipient of the 2021 Africa Award for Research Excellence in Ocean Sciences. This award was established in 2015 and is awarded annually by the American Geophysical Union. The expectations for this award include significant original contributions to earth or ocean science research in Africa, excellence in research, student mentorship, acting as the main driver of the science when working in collaborative teams, and outstanding service and outreach to society. Other highlights include Bjorn Backeberg's paper in Nature and Tesha Toolsee who not only got a Master's with distinction but got a paper published this year. Sonia Heye also got her master's with distinction. George Noel Longandjo was a contributing author for the 2021 IPCC report and had a paper cited in it while Tarron Lamont has one cited paper and Mathieu Rouault five. Additionally, George Noel Longandjo was featured in Geographical Magazine as an African leading climatologist. In December 2021, Christo Whittle participated in the Benguela Flux Experiment aboard the RV Algoa to investigate the air-sea flux of CO_2.

National and international activities

A memorandum of understanding between INAM (Mozambique), NERSC, NTC and NANSI was signed in July 2021. This MoU builds on the following common vision: to provide a facilitating mechanism for the member institutions to work together on joint research projects, supportive activities, education, and training in areas of Ocean studies and modelling, Climate studies including impacts of climate change on sea-level changes and coastal environments as the parties have expertise in complementary areas and desire to utilize their experience mutually.

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). The Nansen-Tutu Centre is involved in the Horizon 2020 TRIATLAS project, the Norway South Africa PCO2 project, The Germany-South Africa SPACE2 project and the Belmont Forum Exebus project.

The Centre's researchers serve on several international panels, Mathieu Rouault and Jenny Veitch are members of the CLIVAR research focus group on Eastern Boundary. Marjolaine Krug serves on the GCSO/GOOS/WCRP Ocean Observations Panel for Climate (OOPC), the Oceangliders Boundary Ocean Observing Network (BOON) and chairs the OOPC-led Boundary System Task Team. 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). Christo Whittle is a member of the Group for High Resolution Sea Surface Temperature (GHRSST) Science Team and co-chair of the CEOS Sea Surface Temperature Virtual Constellation.

Dr Marjolaine Krug was invited to be a panel member during the UN Ocean Decade

Laboratory Conference. She also convened and chaired one of the satellite activities of the UN Ocean Decade on "Designing Observing Systems for Ocean Boundaries". This satellite laboratory event was one of the virtual activities undertaken as part of the OOPC Boundary System Task Teamwork. One of the main objectives of the OOPC BSTT is to promote dialogues between the modelling and observing ocean communities towards improved ocean observing systems at ocean boundaries. She was also invited to contribute to a COP26 event entitled "Tracking ocean climate change and impacts on our fragile ocean."

Dr Georges-Noel T. Longandjo was invited for 3 months in Germany by Prof Andreas Fink at Karlsruhe Institute of Technology, Germany to implement collaborative research. Tesha Toolsee participated in the Marion Relief Voyage of April/May 2021 while Kirstin Petzer, participated in the voyage of the SA Agulhas II to Gough Island in October 2021.

Financial situation

A total of 1 100 000 ZAR (737 500 NOK) seed funding for the Centre was made available from Norwegian partners in 2021: 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 and 65 000 ZAR (37 500 NOK) from NANSI. In addition to this, almost 1 000 000 ZAR was raised through project funding in 2021. These include projects funded by the South African National Research Foundation, the NRF's South African Research Chairs Initiative and the EU 2020 TRIATLAS project.

PUBLICATIONS

Peer-reviewed papers

Carr, M., Lamont, T. and Krug, M., (2021). Satellite Sea Surface Temperature Product Comparison for the Southern African Marine Region. Remote Sensing, 13(7), p.1244.

Chenillat, F., Illig, S., Jouanno, J., Awo, F.M., Alory, G., Brehmer, P., (2021). How do climate modes shape the chlorophyll- a interannual variability in the tropical Atlantic? Geophysical Research Letters 48.14 (2021): e2021GL093769.

Hart-Davis, M.G. and Backeberg, B.C., (2021). Towards a particle trajectory modelling approach in support of South African search and rescue operations at sea. Journal of Operational Oceanography.

Imbol Nkwinkwa A.S., Rouault M., Keenlyside N., Koseki S. Impact of the Agulhas Current on Southern Africa Precipitation: A Modelling Study. Journal of Climate. 2021 Dec; 34(24):9973-88.

Lyttle, C., Rautenbach, C., Backeberg, B. and Jarre, A. An analysis of high-resolution modelled wave heights along the South African south coast suggests recent deterioration of sea state, Fisheries Oceanography, 30(6), pp.679-696.

Ramanantsoa, J.D., Penven, Raj, R.P., Lionel, R., Ponsoni, L, Dilmahamod, F, Ostrowski, M. and Rouault, M. (2021). How and where the East Madagascar Current Retroflection originates? Journal of Geophysical Research, 126, e2020JC016203.

Russo, C.S., Lamont, T. and Krug, M. (2021). Spatial and Temporal Variability of the Agulhas Retroflection: Observations from a new objective detection method. Remote Sensing of Environment., 253, 112239.

Toolsee, T., Lamont T., Ansorge A. and Rouault M. (2021). Characterising the seasonal cycle of wind forcing, surface circulation and temperature around the sub-Antarctic Prince Edward Islands, African Journal of Marine Science. 43(1), pp.61-76.

Nhantumbo, B., Backeberg, B.C., Nilsen, J.E.O., and Reason, C.J.C. (2021). Atmospheric and Climatic Drivers of Tide Gauge Sea Level Variability along the East and South Coast of South Africa. Journal of Marine Science and Engineering, 9(9), p.924.

Stirnimann L., Thomas G. Bornman, Hans Verheye, M.L., Bachelery and Sarah E. Fawcett, (2021). Plankton community composition and productivity in autumn near the Subantarctic Prince Edward Island archipelago; Limnology and Oceanography, 66(12), pp.4140-4158.

Ullah A., Pohl B., Pergaud J., Dieppois B., and Rouault M. (2021). Intra-seasonal descriptors and Rainfall Extremes in Austral Summer over Southern Africa. Part I: Relationship with large-scale modes of climate variability. International Journal of Climatology. 1–26.

van der Lubbe, H.J.L., Hall, I.R., Barker, S., Hemming, S.R., Baars, T.F., Starr, A., Just, J., Backeberg, B.C. and Joordens, J.C.A., (2021). Indo-Pacific Walker circulation drove Pleistocene African aridification. Nature, 598 (7882), pp.618-623.

Bethke, I., Wang, Y., Counillon, F., Keenlyside, N., Kimmritz, M., Fransner, F., Samuelsen, A., Langehaug, H., Svendsen, L., Chiu, P.G., Passos, L., Bentsen, M., Guo, C., Gupta, A., Tjiputra, J., Kirkevåg, A., Olivié, D., Seland, Ø., Solsvik Vågane, J., Fan, Y. and Eldevik, T. NorCPM1 and its contribution to CMIP6 DCPP, Geosci. Model Dev., 14(11), 7073–7116, doi:10.5194/gmd-14-7073-2021, 2021.

Staff in 2021

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, DFFE, 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, DFFE, 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, DFFE, 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

Prospects for 2022

- Resume travel to Norway
- Appoint new MSc and Honors students
- Appoint a NTC research officer.
- 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.
- Re-engage with SAWS.

SCIENCE REPORT

Decadal Variability in the Southern Benguela Upwelling System

F.S. Tomety and M. Rouault

The Benguela Upwelling System is one of the four most productive fisheries areas in the world. It is mainly driven by the persistent alongshore wind. Many studies of the Benguela Upwelling System have focused on SST variability at the interannual time scale, less on the long-term trend and no study on decadal variability to our knowledge. In this study, we investigate the decadal variability of the South Benguela upwelling System SST at the decadal scale and their links with the large-scale climate modes. We use a long-term ocean model simulation of 110 years (1900 - 2010) of the global ocean-ice components of the Norwegian Earth System Model (NorESM) for that matter. Firstly, we compare the NorESM model SST and the 10-ensemble members of HadiSST2 at lower frequency variability. The NorESM SST and HadISST2 show a marked low-frequency modulation with the same pattern. The correlation between NorESM SST and ensemble mean HadISST2 at lower frequencies is 0.61 and is statistically significant at the 95% level. Secondly, time scale analysis of variability is carried out using the wavelet transform. The result reveals that there are three significant time scales of variability: interannual (2-8 years), quasi-decadal (9-14 years) and interdecadal (19-26 years). The decadal dominant scales of variability (9-14 years and 19-26 years) are then reconstructed using the band-pass Butterworth filter. The reconstructed timeseries are then used to do composite maps. Figure 1 is the global SST composite anomalies based on warm periods of the reconstructed Southern Benguela SST timeseries at quasi-decadal (Figure 1a) and interdecadal (Figure 1b) time scales. The results reveal that at quasi-decadal scale the Southern Benguela SST is linked to the Agulhas Benguela current system and the Tropical Atlantic south Atlantic SST and north subtropical SST fluctuations, while at the interdecadal scale the Southern Benguela SST modulation is linked to the equatorial, subtropical and northeast Pacific SST, Indian Ocean SST and south Atlantic SST fluctuations in a pattern reminiscent of El Nino SST.

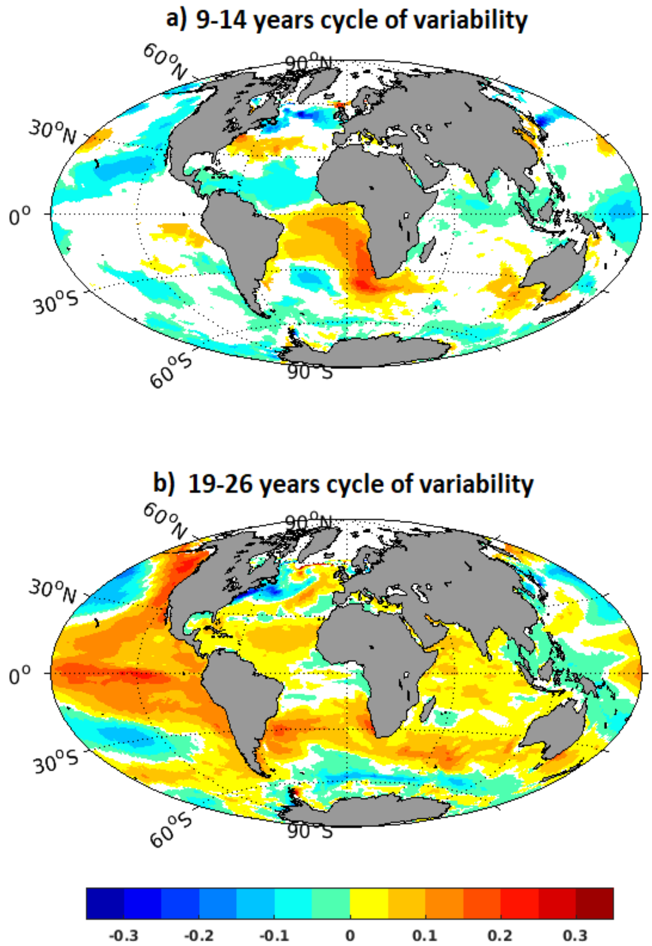


Fig. 1: *Composite SST anomalies associated with periods of high amplitude for the quasi-decadal (9-14 year) and interdecadal (19-26 year) cycles of SST variability in SB. (a) extreme warm period of 9–14-year cycle of SST variability (9–14-year reconstructed SB SST timeseries (Figure 5.4) ≥ 1 Standard Deviation (SD)). (b) same as (a) but for the interdecadal SST variability (19–26-year reconstructed SB SST timeseries (Figure 5.4) ≥ 1 SD). Coloured areas represent the 95% statistically significant correlations.*

Marine Heatwaves in the Southern Benguela

K. Petzer, M. Rouault and T. Lamont

The Southern Benguela Upwelling System is situated off the west coast of southern Africa, in the South Atlantic Ocean. The alongshore south-easterly winds induce coastal upwelling which drives cold, nutrient rich waters to the surface. The high concentration of nutrients form the basis of the high productivity in the region. One of the increasing threats to marine ecosystems are Marine Heatwaves (MHW). MHWs are prolonged periods of extreme warm Sea Surface Temperatures (SST) anomalies, which have severe ecological impacts. MHWs have the potential to affect marine ecosystems by decreasing biodiversity, negatively affecting cold water species, such as kelp, and increasing ocean stratification. In the Benguela upwelling, the ocean stratification can inhibit upward mixing of deep nutrients, which may decrease the supply of nutrients to the surface layer. We examined the occurrence of MHWs in the Southern Benguela using a CSIR half-hourly SST time series from January 2003 to March 2020. The MHWs are identified using if the SST values exceed the 90th percentile of the timeseries for at least five days. In the CSIR SST time series, 11 MHWs were identified at the Cape Point station. As there are only a few MHW events to analyse and the half-hourly data set is highly variable, this study also analyses warm events of shorter duration. In this study warm events have the same definition as MHWs except if the event has SST values below the 90th climatological percentile for less than 24 hours, the event will be defined as a single warm event. In the time series, 28 warm events were identified on top of the 11 MHWs and an example can be seen in Figure 1. The SST, in Figure 2, begins to increase from 11.6°C on the 12th of March to 16°C on 13th, the SST exceeding the 90th percentile and beginning the warm event. After increasing slightly, the SST decreases below the 90th percentile for 11 hours. The SST exceeds the 90th percentile again on the 14th and increases to 21.2°C on the 15th. From the 15th to the 18th the SST ranges between 19.4°C and 22.1°C. On the 18th of March, the SST decreases lower than the 90th percentile, ending the warm event. The highest frequency of MHWs and warm events occur in autumn followed by summer, spring, and winter. While the most events occur in autumn, the season with the highest maximum SST values occur in summer followed by autumn, spring, and winter.

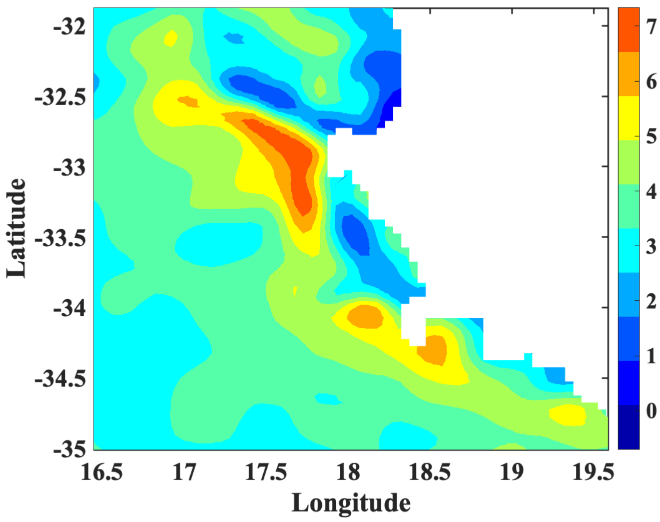


Fig. 1: *SST (°C) anomaly during a warm event on the 16th of March 2003.*

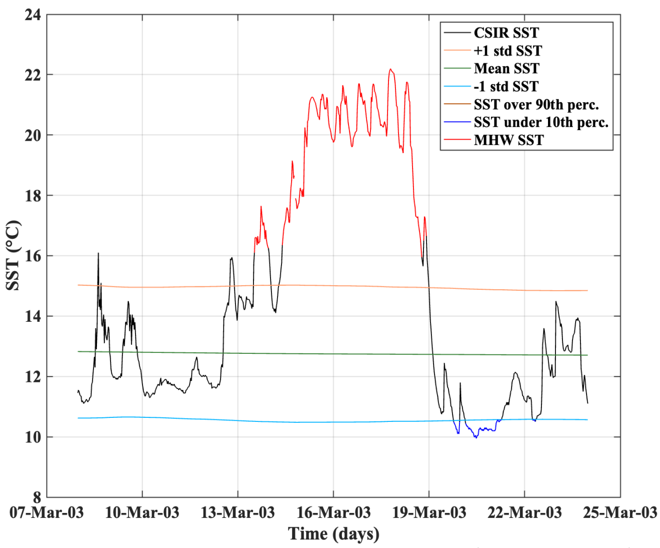


Fig. 2: *A warm event from the 13th to the 18th of March 2003 using CSIR SST (°C) off Cape Point in the Southern Benguela Upwelling System. Plotted is the CSIR SST (black), SST mean (green), SST under the 10th percentile (dark blue), SST defined warm events (red), mean +1 std (orange) SST and mean -1 std SST (light blue).*

Sea Surface Salinity responses to Benguela Niños in the South East Tropical Atlantic

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

The Angolan upwelling region is one of the most productive marine ecosystems in the southeast tropical Atlantic and serves as a gateway for communicating the equatorial oceanic variability to the Northern Benguela. Fisheries are widely developed along the Angolan shore and are critical for economic security and the employment of local coastal communities. Contrary to the Benguela upwelling system, supported by strong alongshore upwelling favourable winds, the highly productive Angolan system is under the influence of relatively weak surface winds blowing along the coast. The Angola Current transports the warm equatorial waters southward. The Angola upwelling is triggered by the poleward propagation of coastally trapped waves originating from the equator. The main Angola upwelling appears in the austral winter with temperature below 22.5°C while the sea surface salinity (SSS) is relatively high. The Angolan upwelling also presents a marked interannual variability, embedded in warm and cold anomalies referred to as Benguela Niños and Benguela Niñas. These events are remotely triggered by equatorial waves dynamic in the Tropical Atlantic. Easterly Trade winds drop in the western equatorial Atlantic leads to the generation of equatorial Kelvin waves which propagate to the African coast and then poleward along the coast of Africa as coastal trapped waves. Such wave dynamics are responsible for major warm and cold events in the Angola Benguela system. Studies have suggested increasing mortality in sardine and horse mackerel and their southward shift during Benguela Niños. A recent study has shown that in the warm event in 2016 off Angola, surface freshening of water originating from the Congo River plume, detected in satellite observations of 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. Here, the SSS responses to the Benguela Niños are investigated using observations and a regional ocean model. The model is shown to reproduce the main characteristic of the SSS along the Congolese and Angolan coasts, such as the freshwater discharge signature off the Congo plume and the low salinity observed along the Angolan coast. The analysis of the model salt budget reveals that the seasonal cycle of SSS along the Angola coast is controlled by the Angola current and mixing at the base of the mixed layer. The characteristics of the SSS pattern associated with the Benguela Niños are extracted from in situ and satellite-derived observations using Empirical Orthogonal Function. The SSS pattern is reproduced in the regional model and is characterized by a strong desalted water along the South East Tropical Atlantic coast during Benguela Niños (figure 1) which may be due to a combined contribution of freshwater flux and change in surface current during the events.

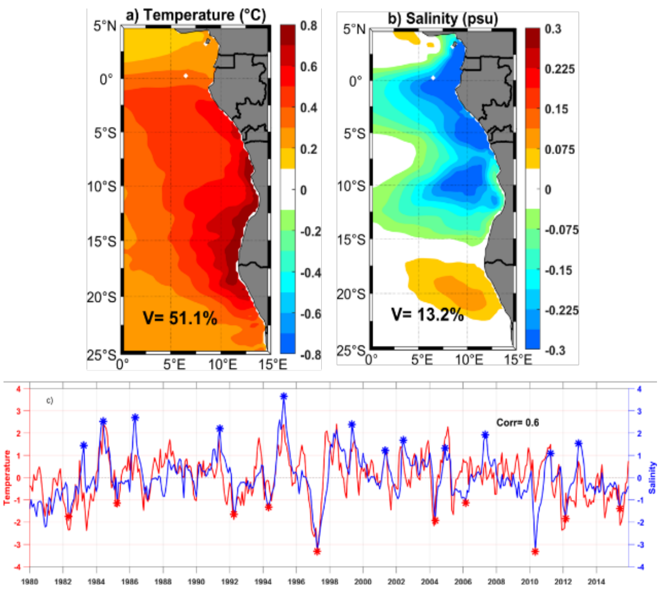


***Fig. 1**: First EOF analysis maps of the model mixed layer temperature (a) and Salinity (b) anomalies and for the 1980–2015 period. Red and blue stars in the time series denote extreme events that exceed ±1 standard deviation of the salinity time series.*

Impact of climate modes on Sea Surface Temperature at the sub-Antarctic Prince Edward Islands

T. Toolsee, T. Lamont and M. Rouault

The Prince Edward Islands (Marion Island and Prince Edward Island) are located in the sub-Antarctic region (46-60°S) of the Southern Ocean, between the sub-Antarctic Front and the Antarctic Polar Front. The islands lie in the direct path of the Antarctic Circumpolar Current and are frequently influenced by passing frontal systems, migratory anti-cyclones, and mid-latitude depressions.

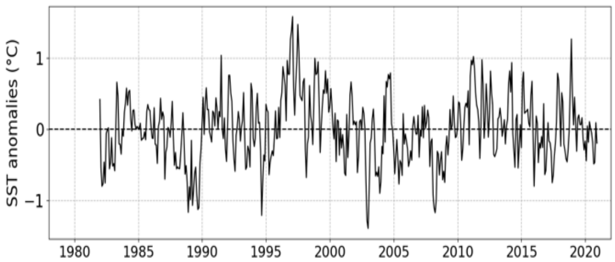


Fig. 1: *Standardised monthly anomalies of Sea Surface Temperature (°C) averaged within a 2°x2° area around the PEIs from January 1982 to December 2020.*

This study used an optimally interpolated SST dataset obtained from PODAAC at 0.25° spatial resolution to study interannual variability in the SST at the PEIs over a period of 38 years. In addition, climate indices for Oceanic Niño Index (ONI), Southern Annular Mode (SAM), and the Semi-Annual Oscillation (SAO) are obtained from NOAA CPC and NCEP air temperature data and used to investigate potential driving forces of these patterns. Substantial interannual and decadal variability was evident in the SST, whereby warmer-than-average temperatures occurred between 1990-2001 and 2009-2020 and cooler-than-average temperatures were seen between 1982 to 1990, and from 2001 to 2009 (Fig 1).

Pearson lagged correlations between SST at the PEIs and the climate indices are shown in Figure 2.

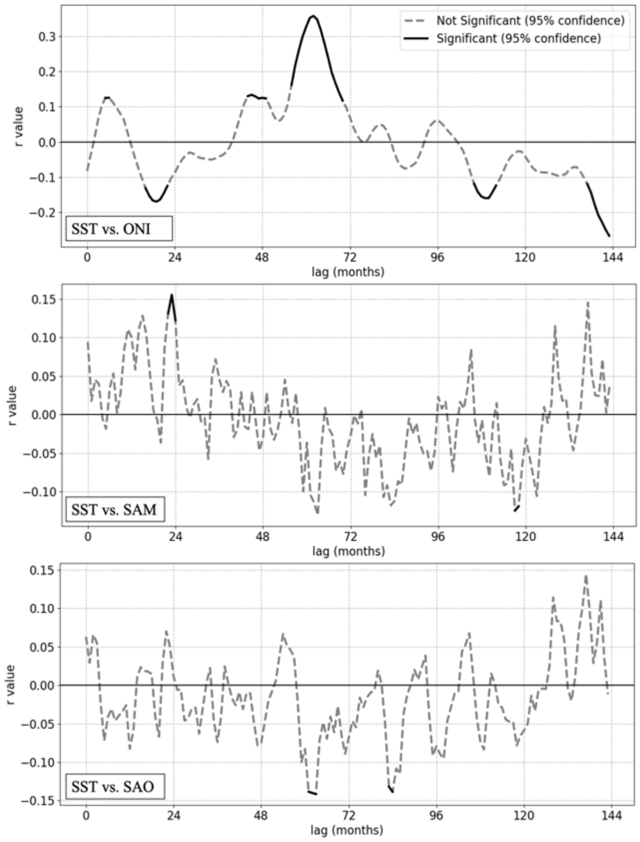


Fig. 2: *Pearson lagged correlations between the standardised SST anomalies and the (top panel) ONI, (middle panel) SAM, and (bottom panel) SAO. Statistically significant r values are indicated by a solid black line.*

Both positive and negative statistically significant correlations were observed between SST and the climate indices (Fig 2). Positive correlations were observed between SST and ONI at lags of 56 and 70 months ($R = 0.11 – 0.36$, $P < 0.05$), strongest at 62 months ($R = 0.36$, $P < 0.05$). The remaining statistically significant correlations were all considered negligible ($r < 0.3$). ENSO thus appeared to have a weak influence on the SST at the PEIs at a lag of 5 years after the occurrence of the ENSO event (Fig. 2). SAM and SAO both showed negligible lagged correlations with SST, and thus likely had no substantial influence on interannual and decadal-scale SST variations at the PEIs (Fig 2).

Validation of GPM IMERG Satellite Rainfall Product in Central Africa

G.-N. T. Longandjo and M. Rouault

In central Africa, more than 100 million people rely on food production systems that are among the most vulnerable due to heavy reliance on rain-fed agriculture and other water-related activities. Any change in the rainfall magnitude or variability will make those people more vulnerable. To this aim, the regional climate community noticed that hydroclimate advances in central Africa are hampered by inadequate ground-based observations and the difficulty of detecting changes in rainfall (Alsdorf et al. 2016). Improving observational data collection and reliability of in-situ datasets will open new frontiers for the hydrological and meteorological modelling community through enabling more rigorous model validations. Given this situation, advances in the study of rainfall patterns and variability over central Africa have been mostly achieved using precipitation estimates from satellite observations, reanalyses, and climate model simulations (Balas et al. 2007; Washington et al. 2013; Dezfuli and Nicholson, 2013; Diem et al. 2014; Maidment et al. 2015; Nicholson et al. 2018; Hua et al. 2016; Camberlin et al. 2019). Here, we used new daily rain-gauge datasets for ten weather stations to validate the rainfall estimate from the Integrated Multi-satellite Retrieval for Global Precipitation Measurement (GPM) (IMERG) V06B dataset (Huffman et al. 2019a, b). We represent, in Fig. 1, the quantile to quantile (Q-Q) plot to test the capability of IMERG product to capture a rainy day (i.e., rainfall > 0.2 mm). The IMERG product overestimates the drizzle (rainfall < 1 mm/day), whereas the high rain rate is underestimated in Bandundu, Boma, and Goma (Fig. 1). The IMERG underestimates the rain rate by 5% to 8% in Inga, Kananga, Kinshasa Binza, Kinshasa Ndolo and Mbuji-Mayi (Fig. 1). Whereas in Matadi, the IMERG product reproduces quite well the low rainfall rate, while overestimating the high rainfall and extremes (> 20 mm/day, Fig. 1). However, the ability of the IMERG product to correctly capture a rainy day in the rain-gauges is generally good in Lubumbashi (Fig. 1). The IMERG product also realistically reproduces the unimodal cycle of rainfall as shown in all rain-gauge stations – with one rainy season and one dry season (not shown). But the striking feature is that the rainy season shows two rainfall maxima in September and March, separated by a short drought season in January and February, except in Lubumbashi (not shown). During the rainy season, rainfall could be as high as 10–15 mm/day and drops by 30% in the short drought season (not shown). However, depending on the rain-gauge position, the difference of the annual cycle is highlighted by the length of the season, with the longest rainy season in Goma and the shortest in Lubumbashi (not shown). A high correlation is also evident between rain-gauge and IMERG, with values ranging between 0.77 (Goma) and 0.91 (Kinshasa Binza).

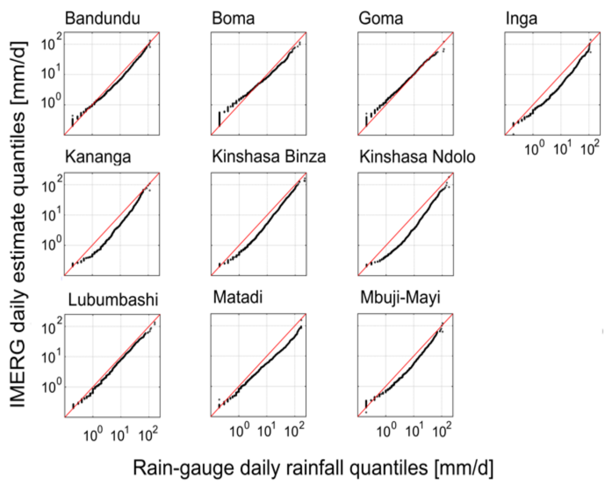


Fig. 1: *Q-Q plot of daily rainfall (rain-gauge and IMERG) for 10 rain-gauge stations in DRC from 2001 to 2018: (top panel) Bandundu, Boma, Goma and Inga; (middle panel) Kananga, Kinshasas Binza and Kinshasa Ndolo; (bottom panel) Lubumbashi, Matadi and Mbuji-Mayi. The red solid diagonal line is the 1:1 line (ideal fit). Axes have logarithmic scales and only days when both IMERG and RG > 0.2 mm are considered.*

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. 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. In order 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 synthesized into the forecasting system through data assimilation. Initial efforts towards this goal have resulted in a system using a regionally optimized Hybrid Coordinate Ocean Model (HYCOM) along with the Ensemble Optimal Interpolation (EnOI) data assimilation scheme. To find the most effective sea surface temperature (SST) dataset to assimilate, a test comparing four data product options was conducted. Gridded level-4 SSTs from the UK Met Office Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) and the European Space Agency SST observations. The second assimilated a blend of level-2 and level-3 observations from Advanced Very High Resolution Radiometer and Along Track Scanning Radiometer sensors, respectively. These four experimental simulations were compared with a free running experiment free of data assimilation for the period 2009-03 to 2012-02. The performance was compared to collocated, quality-controlled vertical temperature (Figure 1) Climate Change Initiative (CCI) were assimilated in the first two simulations, respectively. The final two simulations assimilated CCI along-track SSTs. The first assimilated purely level-2 processed profiles compiled in the UK Met Office EN4 dataset. These results show that there is an improvement in temperature representation in the surface layers, as expected. However, with an increase in depth temperature is often degraded compared to the free run. The level-4 assimilation simulations (OSTIA, CCI) perform best in the top 500 m after which the free run (FREE) is better. The along-track assimilation simulations (L2, L2+L3) perform worse than the free run almost everywhere except at the surface which suggests that there is an error in the assimilation of these datasets. The surface velocities also showed varied responses to the SST assimilation with the level-4 assimilation simulations exhibiting best performance and the along-track assimilation simulations exhibiting erroneous, increased surface velocities. Overall, the OSTIA assimilation simulation exhibits the best performance. It is currently uncertain why the along-track SST assimilation experiments performed poorly or why the level-4 assimilation simulations performed worse than the free running simulation at some depths. Why the simulations have performed as described is currently being investigated. For a reliable operational forecast system to be implemented, it is important to understand both how well, or poor, each simulation performs and why.

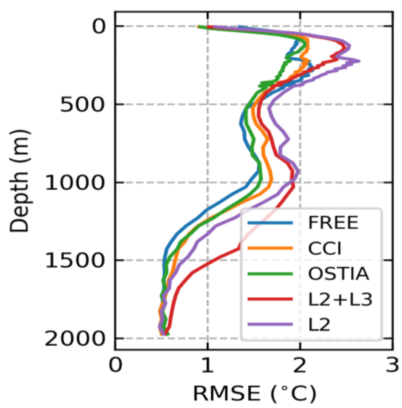


Fig 1: *Temperature RMSE of model simulations compared to EN4 profiles.*

Unpacking the Natal Bight Coastal Counter Current: a modelling study

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

Output from a high-resolution ocean model, wind reanalysis and particle tracking tools are used to improve our understanding of the shelf circulation in the KwaZulu-Natal (KZN) Bight. The KZN Bight is a small embayment off South Africa's east coast (Figure 1). Its offshore edge is influenced by the strong, south-westward flowing Agulhas Current, while its shelf is dominated by weak and variable currents. The KZN Bight is a retention region suitable for recruitment. On the KZN Bight's shelf, the model output used in this study reports a mean north-eastward flow for the first time, which is referred to as the Natal Bight Coastal Counter Current (NBC3). The NBC3 originates within the Durban Eddy in the southern KZN Bight and stretches over the KZN Bight's mid-shelf while gradually becoming narrower, weaker and thinner. It eventually disappears offshore of Richards Bay. The vertical structure of the mean current extends throughout the water column and at its origin, the NBC3 connects to the Agulhas Undercurrent at around 800 m depth. In this region, the NBC3 is about 8km wide and can exceed speeds of 100 cm/s. When anticyclonic eddies offshore of the Agulhas Current pass the KZN Bight, they occasionally replace the Durban Eddy and its associated NBC3 with a southward shelf flow. Therefore, the circulation in the KZN Bight appears to be primarily driven by perturbations at the Agulhas Current front, but there is also some indication of a direct wind-driven influence in coastal waters, inshore of the 50 m isobath and north of the Durban Eddy. Particle tracking tools are used to investigate the impact of the circulation on the connectivity of local Marine Protected Areas displayed in Figure 1a. The results show that the NBC3 does not connect uThukela Banks with iSimangaliso, but it may connect Aliwal Shoal with uThukela Banks if its origin is far enough south. Within uThukela Banks, it greatly increases the water retention and may trap nutrients from coastal origins on the shelf, together with any suspended particles, such as larvae. Therefore, the Natal Bight Coastal Counter Current has the potential to increase the suitability of the habitat for larval settlement.

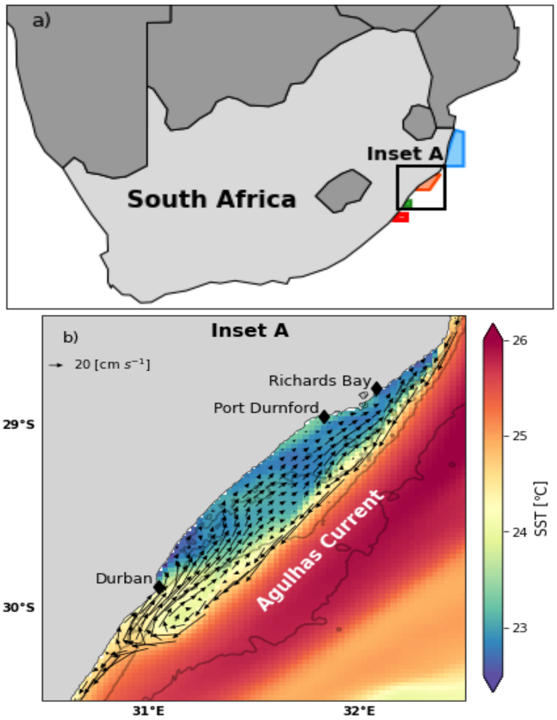


Fig 1: *a) A map indicating the KZN Bight by the black polygon and the four Marine Protected Areas used in this study by the colour coded polygons, where the blue polygon is iSimangaliso, the orange polygon is uThukela Banks, the green polygon is Aliwal Shoal and the red polygon is Protea Banks. A zoomed-in plot is shown in b), where the black polygon again indicates the KZN Bight region and the 50 m, 200 m and 1000 m isobaths are represented by the offshore grey lines. The arrows represent the surface velocities on the 21st of May 2007 and the background colour is the sea surface temperature on that day from the model output. Only velocities that are less than 0.7 m/s and are inshore of the 1000 m isobath are presented in the figure.*

WaveWatch III (WWIII) model forcing with different surface currents datasets along the South African coast

B. Gweba

The impact of the Agulhas current region on the wavefield requires special attention due to several reasons such as maritime activity and shipping routes. To account for the impact of surface currents on the significant wave height (Hs), a 4 km resolution WWIII model is forced with a 3 km resolution Coastal and Regional Ocean Community (CROCO), 8 km resolution Global Ocean Reanalysis (GLORYS) and 30 km resolution GlobCurrent surface currents (Fig 1). The goal of this analysis is to assess Hs fields differences induced by surface current resolutions. The surface current forced simulations from 2012 to 2014 are compared with Jason-2 denoised wave height (5,8 km) data over the whole domain. GlobCurrent forced simulations had a significantly better agreement with altimeter data, with a correlation coefficient of 0.94, RMSE of 0.41 m, and bias of 0.10 m for the entire domain for the monthly averaged data, presented in Fig 1. The GLORY'S forced simulations also demonstrated a good level of agreement, with a correlation of 0.93. It should be noted that CROCO does not assimilate observations, whereas GlobCurrent is observation based. The main differences between surface current products are found in the dynamical core of the Agulhas Current and Agulhas Return Current, as illustrated in Fig 1. The monthly averaged spatial distribution of reanalysis products and Hs model outputs is depicted in Fig 1. CROCO currents are stronger in the Agulhas currents core, as shown in Fig 1a, with current speeds exceeding 1.5 m/s. The Agulhas Current (AC) point in Fig 1c and 1e indicates that the current speed is less than 1.25 m/s. Fig 2 depicts a three-year time series between Hs and current speed that provides brief descriptive statistics for the AC point. The signatures of the Agulhas Current systems are clearly visible in the corresponding Hs fields for all current forced simulations, but particularly for CROCO forced simulations between 22.5°E and 25°E. The current values are in the 1.5 to 2.0 m/s range and correspond to Hs values greater than 5 m. At the AC point, the corresponding Hs fields in Figure 1d and 1f have Hs values less than 4.5 m. Based on these results, in Fig 1d and 1f, we are still not sure if forcing the wave model with the lower resolution currents could result in a misleading representation of wave-current interactions. This analysis is currently being looked into.

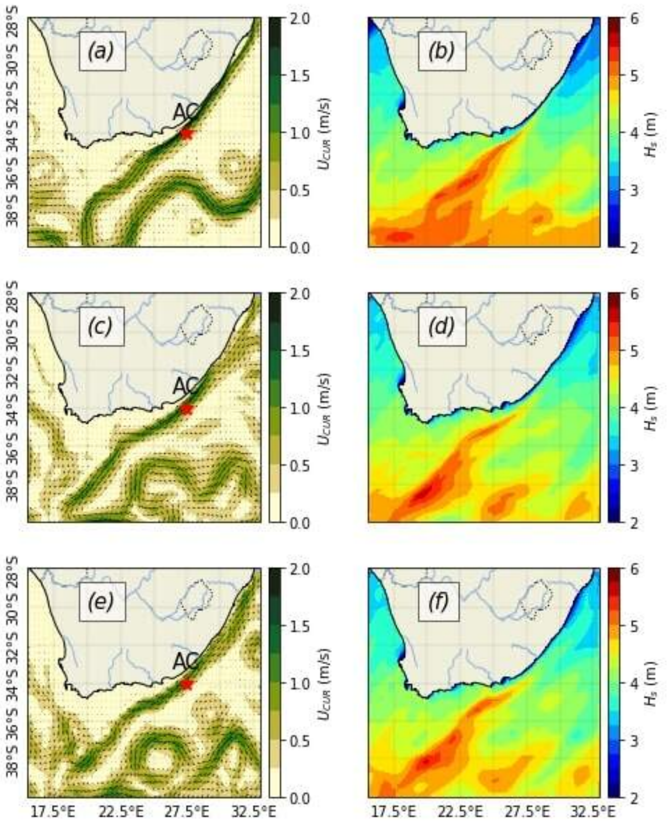


***Fig 1:** Monthly averaged surface current products and WWIII Hs fields along the Agulhas Current region for June 2014. (a) CROCO currents field. (b) Hs field forced with CROCO. (c) GLORYS currents field. (d) Hs field was forced with GLORYS. (e) GlobCurrent field. (f) Hs field forced with GloCurrent.*

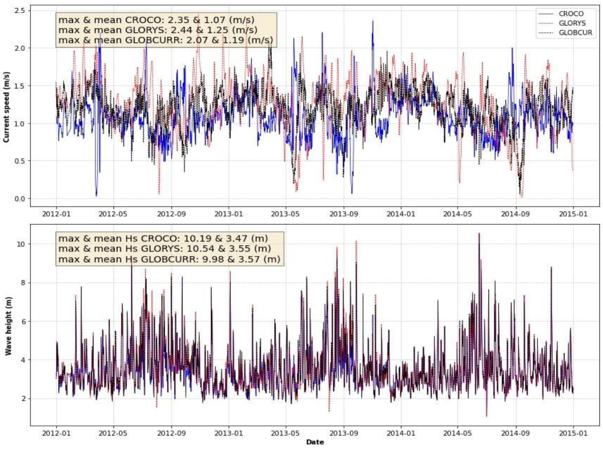


***Fig 2**: Time series comparison of surface current speed (top) and significant wave height (bottom) model results from 2012 to 2014 at the AC point (34°S,27.5°E).*

Assessing the surface expression of three global reanalysis models over the southern Benguela shelf and Agulhas Bank using regionally developed satellite sea surface temperature data

Christo Whittle, Christina Russo, Jennifer Veitch

Global ocean reanalysis products optimally assimilate various in situ and satellite ocean observations into an ocean general circulation model to provide estimates of the long-term state of the ocean at a global scale. In dynamically diverse regions, such as the Southern Benguela shelf, it is expected that reanalysis datasets should potentially represent features and variability with greater accuracy than estimates produced by models that exclude data assimilation. On the South African west coast, narrow bands of seasonal upwelling are mostly confined within the shelf width between Cape Agulhas and Cape Columbine. Coastal upwelling extent and intensity are often under-represented on hydrodynamic model data and L4 sea surface temperature (SST) products. The reanalysis products evaluated for the period 2000 to 2014 are the Mercator Ocean's Global Reanalysis (GLORYS), Commonwealth Scientific and Industrial Research Organization's (CSIRO) Bluelink Reanalysis (BRAN) and the Fleet Numerical Meteorology and Oceanography Centre's (FNMOC) global Hybrid Coordinate Ocean Model (HYCOM). Regionally optimized high resolution (1km) satellite sea surface temperature, developed at the CSIR, allows for a closer investigation of shelf scale surface dynamics. Since the regional SST product is not assimilated into the examined models, it serves as independent verification of model SSTs that represent shelf-scale surface dynamics. Pearson correlation analysis between the models and satellite SSTs revealed lower correlations coupled with high rmse values within west coast upwelling zones. BRAN performs considerably better than both HYCOM and GLORYS in its representation of hydrodynamic features delineated by the 1km SST.

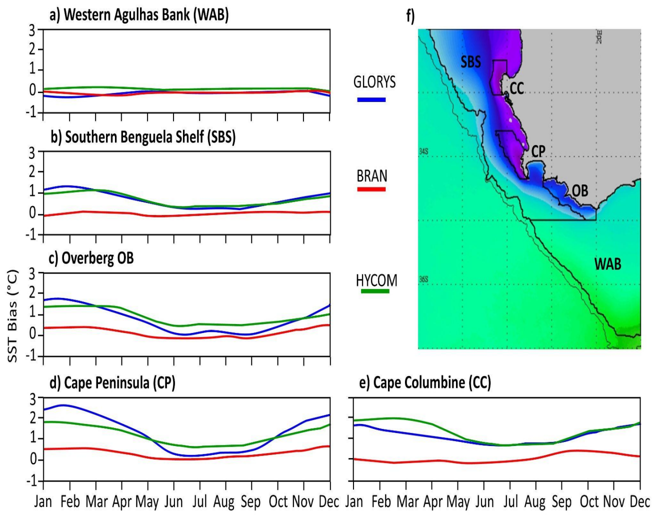
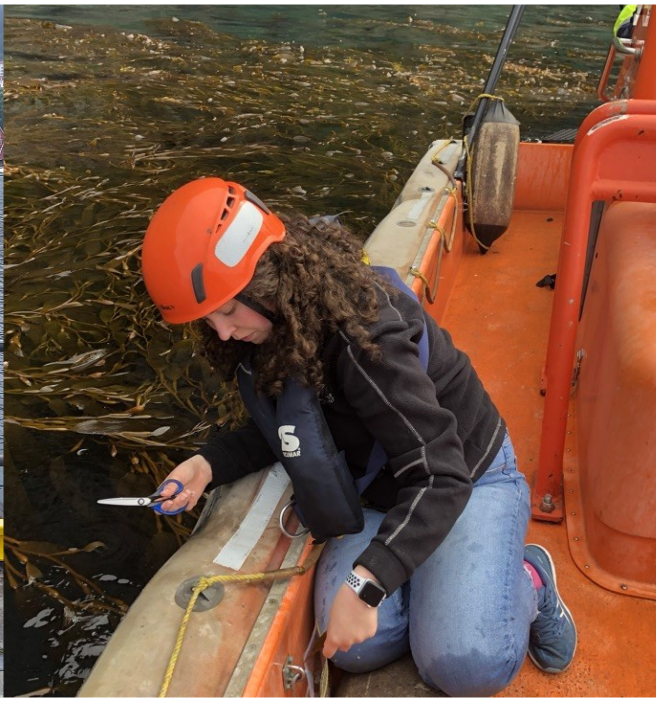


***Fig 1:** Spatially averaged SST bias (reanalysis - high resolution SST) monthly climatologies. f) Map of high resolution 1 km SST outlining upwelling regions and cells analysed. The Southern Benguela shelf (SBS), the Cape Columbine upwelling cell (CC), the Cape Peninsula upwelling cell (CP), the Overberg upwelling region (OB) and the Western Agulhas Bank (WAB).*

Figure 1 illustrates that all three models reproduce the seasonal cycle accurately, with almost zero bias, throughout the year over the Western Agulhas Bank (WAB); a region of very low spatio-temporal variability subject mostly to the seasonal solar insolation cycle. A divergence in the seasonal representation within the models become clear when inspecting the results of integrated SST over the Southern Benguela Shelf. BRAN performs exceptionally well over this region, whereas both HYCOM and GLORYS under-represent the seasonal upwelling signal. A closer inspection of the upwelling cells does indicate a slight warm bias in summer within BRAN at the Overberg and Cape Peninsula, but good performance at Cape Columbine. Evaluations of the reanalysis products against regionally optimized satellite SST revealed that GLORYS and HYCOM have significant warm biases on the Southern Benguela shelf. The mixed layer depth (MLD) within these models is deeper than observed in situ and this results in the upwelled water having warmer temperatures. This misrepresentation is exacerbated by atmospheric products that do not significantly capture the nearshore wind field. BRAN represents the MLD much more accurately, contributing to its good representation of coastal SSTs.


The Nansen-Tutu Centre has a remarkable team of students, post-doctoral fellows, research associates, staff, board members and collaborators. This Annual Report celebrates the people behind NTC with sincere thanks for their contributions.

Nansen-Tutu Centre
Department of Oceanography
University of Cape Town
Rondebosch, 7700
South Africa
www.nansen-tutu.org

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