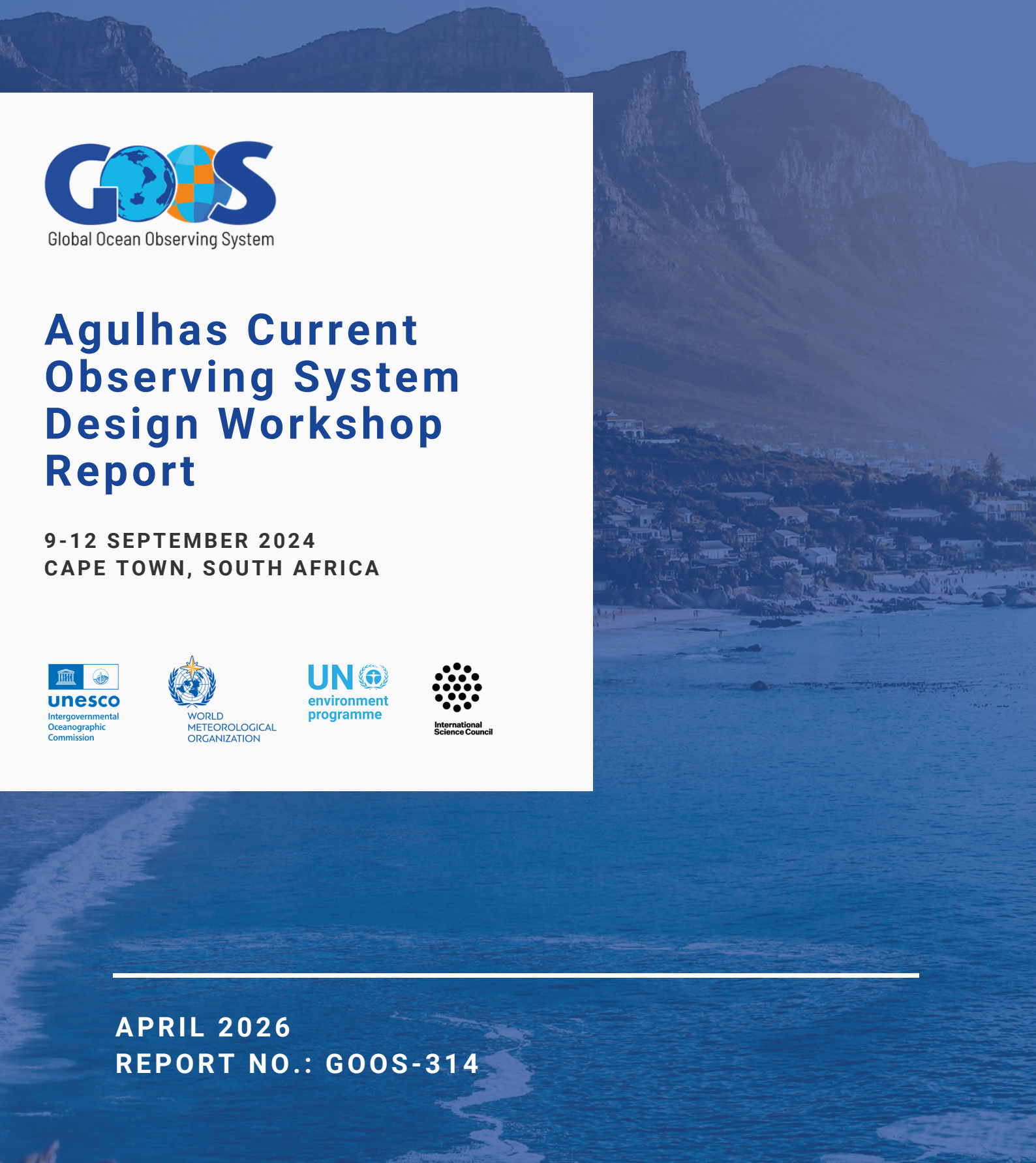
MEETING REPORT



Global Ocean Observing System

# Agulhas Current Observing System Design Workshop Report

**9-12 SEPTEMBER 2024**
**CAPE TOWN, SOUTH AFRICA**

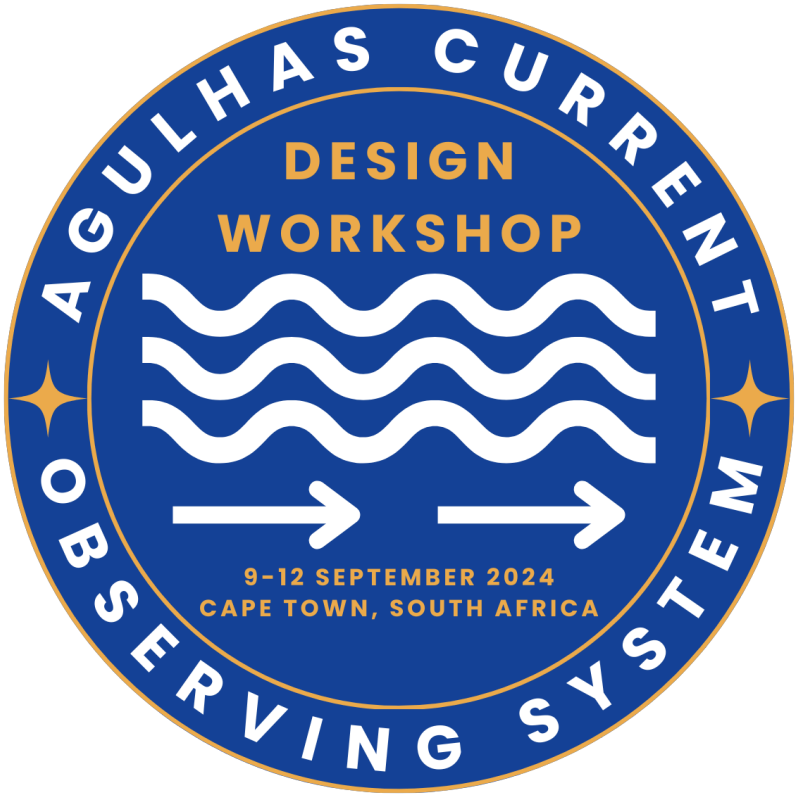
unesco Intergovernmental Oceanographic Commission

WORLD METEOROLOGICAL ORGANIZATION

UN environment programme

International Science Council

**APRIL 2026**
**REPORT NO.: GOOS-314**




# WORKSHOP REPORT

**Co-Chairs**: Tamaryn Morris[1] and Ann-Christine Zinkann[2]

[1]South African Environmental Observation Network (SAEON), Cape Town
[2]National Oceanic and Atmospheric Administration (NOAA), Washington, DC

**Steering & Planning Committee**: Elizabeth Rémy (Mercator Ocean, France) , Jennifer Veitch (SAEON, South Africa), Marjolaine Krug (University of Cape Town, South Africa), Weidong Yu (SOA First Institute of Oceanography, China), Riesna R. Audh (South African Polar Research Infrastructure, South Africa), Jordan van Stavel (South African Polar Research Infrastructure, South Africa), Robert Todd (Woods Hole Oceanographic Institution, USA), Yosuke Fujii (Meteorological Research Institute, Japan)

## 1. Executive Summary

The Agulhas Current Ocean Observing Design Workshop, held in Cape Town in September 2024, brought together approximately 90 participants to address a critical gap in global ocean monitoring. As the pilot region for the Global Ocean Observing System (GOOS) Co-Design Boundary Current Exemplar, a UN Ocean Decade endorsed program, the Agulhas Current represents one of the world's most powerful yet inadequately observed Western Boundary Currents.

The Agulhas Current transports approximately 76 Sv of volume and 3.8 PW of heat from the Indian to Atlantic Ocean, fundamentally influencing global climate dynamics through its impact on the Atlantic Meridional Overturning Circulation. Despite its critical role as the "drainpipe" for warm tropical Indian Ocean waters and its profound impacts on South African weather, fisheries, maritime safety, and coastal communities, the Agulhas Current lacks sustained long-term observations, a gap that distinguishes it from better-monitored systems like the Gulf Stream and Kuroshio.

Historical observations have been sporadic and project-based, with major mooring experiments (ACE, ACT, ASCA) providing 3-5 year snapshots of transport properties between 32-34°S. Ship-based surveys have focused primarily on west and south coast fisheries, leaving the east coast under-sampled. Autonomous observations remain limited, though recent efforts with Seagliders and high-resolution Argo deployments show promise. Both research and operational modeling efforts exist but require enhanced observational data for validation and improvement.

The workshop identified critical user communities and threats across multiple sectors:

- Maritime Safety: Extreme waves created by current-wind interactions pose severe hazards, generating rogue waves capable of sinking large vessels
- Meteorological Services: Degraded observation networks and limited model resolution compromise forecasting accuracy for increasingly frequent extreme weather events, including tropical cyclones
- Fisheries: Climate-driven species shifts, combined with overfishing and illegal fishing, threaten 27,000 formal jobs and vulnerable small-scale fishing communities
- Marine Heatwaves: Increasing frequency and intensity impact marine ecosystems, fisheries recruitment, and food security
- Marine Protected Areas: Poor understanding of oceanographic connectivity undermines conservation effectiveness

### Key Recommendations from the workshop include:

Governance and Data Management

- Establish clear institutional responsibility for sustained observing systems
- Implement FAIR data practices with robust infrastructure and cross-sectoral data sharing platforms
- Leverage lessons from the Benguela Current Large Marine Ecosystem program

Stakeholder Engagement

- Expand consultation with economists, fishing communities, social scientists, and key users (weather services, search and rescue, fisheries)
- Develop comprehensive engagement strategies for end-users

Scientific Priorities

- Focus backbone observing system on: mesoscale circulation, ocean-atmosphere-land interactions, shelf-edge upwelling, Indo-Atlantic exchange through the retroflection zone, and wave-current interactions
- Conduct Observing System Experiments (OSE/OSSE) to verify design effectiveness

Capacity and Funding

- Develop career pathways for scientists, technicians, and modelers
- Explore diverse funding sources including private sector, UN Ocean Decade programs, and industry partnerships
- Pursue economic assessments linking ocean and land economies

Integration with Benguela Current

- Design complementary observations recognizing the unique proximity and interaction between this Western and Eastern Boundary Current system
- Leverage shared resources, governance structures, and infrastructure

The workshop has initiated a systematic process including: presentations at international forums (POGO, ICSHMO, Ocean Sciences Meeting), development of a draft observing system design, establishment of a steering committee, comprehensive stakeholder mapping, and submission to Ocean20 as an Ocean Action. Critical immediate needs include postdoctoral support for OSE/OSSE work and engagement with World Meteorological Organization on boundary current impacts.

This initiative represents a transformative opportunity to co-design a sustainable, multi-platform ocean observing network that serves both regional operational needs and global climate understanding, while delivering tangible benefits to South African society.

# Table of Contents

## 2. Background

This section looks at the establishment of the Global Ocean Observing System (GOOS) Co-Design program, a UN Ocean Decade endorsed program, and the establishment of the Boundary Current Exemplar. We also detail preliminary workshops around Boundary Currents, collaboration with the Ocean Observations Panel for Climate's (OOPC) Boundary System Task Team (BSTT) and the pre-workshop around observations within the Agulhas Current. The work references the paper by Todd et al (2019) which highlights sampling strategies and infrastructure used in Boundary Current systems. Finally, we detail the work to establish the Agulhas Current Ocean Observing Design workshop which took place in September 2024.

### a) GOOS Co-Design Program and the Boundary Current Exemplar

The GOOS established three UN Ocean Decade Programmes, namely Ocean Observing Co-Design, Observing Together and CoastPredict. The Ocean Observing Co-Design Programme aims to evolve the ocean observing system so that it is co-designed with end-users and responds to their needs. Six exemplars were established under the programme that are either use areas or societal benefit areas around which pilots are established and used to refine the ocean observing system through establishing co-design processes. The six exemplars are: Boundary Currents, Tropical Cyclones, Marine Heatwaves, Storm Surge, Marine Life and Carbon.

Boundary current variability and prediction is critical to short-term and seasonal weather forecasts, climate adaptation, regional fisheries, food security and blue economies. The goal of the Boundary Currents exemplar is to co-design a sustainable and efficient ocean observing network of instruments, using a multi-platform approach, to enhance regional operational ocean modelling efforts, resulting in tangible products and services aimed at society. The Boundary Current exemplar is looking at both western and eastern boundary current systems, and though differing in their functional usage and thus end-users, are both large current-driven systems with similar value chains taking observations through model and prediction systems to end-user tools and services.

The pilot region determined for the Boundary Current exemplar is the Agulhas Current, with lessons learnt from more established boundary current systems such as those described through the BSTT series of webinars and subsequent publication by Ayoub et al (2024). Users of boundary current data and information include weather services, regional and artisanal fisheries, shipping and port authorities, search and rescue services and marine resource management. This is not an exhaustive list however, and stakeholder workshops are important to progress this knowledge.

### b) Initial Boundary Current workshops (2021-2023)

Three workshops were hosted prior to the Agulhas Current Ocean Observing Design workshop and focussed on various aspects of Boundary Currents in general from observing networks, opportunities for adjustment of traditional instrument observing missions to better capture needs, and identifying specific priority areas. A number of key questions were raised during a one-day interaction of researchers in June 2023 as a pre-workshop of the Observation Coordination Group (OCG) meeting held in Cape Town.

These included:

- Validation of models such as LACCE (Location of the Agulhas Current's Core and Edges) along altimetry transects and through in-situ observations.
- Where does the cooling inshore of the Agulhas Current originate from?
- What is driving seasonal differences in the Agulhas Current?
- What is driving the latitudinal variability in temperature, salinity, chlorophyll a, and oxygen, among other potential biogeochemical parameters?
- Tracking of mesoscale eddies along the inshore edge of the Agulhas Current and understanding their impacts on the shelf and coastal regions.
- Understanding of intrusions taking place along the shelf and coast in terms of both warming and cooling.

## c) The Agulhas Current Observing Design Workshop, 9-12 September 2024

The workshop was held as a hybrid event at the President Hotel in Sea Point, Cape Town, from 9-12 September 2024. Approximately 80 in-person participants, with a further 10 online, attended the workshop with various backgrounds ranging from observational researchers of different disciplines, modellers, operational forecasting, fisheries, search and rescue, academia and two South African national government departments (Department of Forestry, Fisheries and the Environment, DFFE, and Department of Science, Technology and Innovation, DSTI). The workshop also attracted participation from 25 Early Career Ocean Professionals (ECOPs), and a poster session was held to showcase some of their work as part of the event.

The purpose of this workshop was to create an overview of observations and modelling efforts already ongoing within the Agulhas Current, develop priority gap areas and thus observational requirements and a resulting backbone design of an ocean observing system to better understand key features in the Greater Agulhas Current region. The workshop also aimed to determine potential overlaps and opportunities for other key features to be considered in the design for monitoring and assessment purposes including (but not limited to) tropical cyclones, fisheries and marine heatwaves, all of which impact or are impacted by the Agulhas Current with a changing climate.

The workshop steering team looked to bring together the **intermediary**[1] user community to capture key gaps in a **backbone observing system**[2] of the Agulhas Current.

[1] **Intermediary users** are defined as - intermediaries to the end users; entities that integrate the ocean observing data into forecasts, assessments, or other products and services for delivery of information products and services to the end users.

[2] A **backbone observing system** is defined as - the minimum requirements for observations that need to be available to capture the critical processes determined by the team of experts gathered for this Agulhas Current Observing Design workshop. Being an iterative process, this backbone may be adjusted to the needs of end-users (not the focus of this workshop), available funding for such a system and advances in technology and understanding of the Agulhas Current system in coming years.

## 3. Why the Agulhas Current?

The Agulhas Current is the warm, narrow, fast-flowing, upwelling-favourable Western Boundary Current (WBC) of the Southern Indian Ocean subtropical gyre (Hood et al 2024), acting as a conduit of volume (~ 76 Sv, Beal et al 2015), heat (~ 3.8 PW relative to 0° C, McMonigal et al 2020) and salt (22.650 Sv psu at transport-weighted values of 12.38° C and 34.87 psu, Phillips et al 2024) from the Indian to the Atlantic Ocean (Beal et al 2011). It is constituted along the northern KwaZulu-Natal coast by most descriptions (Lutjeharms 2006) and is formed from three source-water regions; mesoscale eddy contributions from both the Mozambique Channel and from South West Madagascar, and the Agulhas Current recirculation system (Zhang et al 2023).

The Agulhas Current plays a fundamental interocean exchange role between the Indian and Atlantic Ocean basins (Hood et al 2024), influencing global climate dynamics, but also the transport of nutrients and pollutants, and connecting biodiversity hotspots. Given the extent of warming within the tropical Indian Ocean (Roxy et al 2024), the Agulhas Current also serves as the "drainpipe" of this warm water out to the South Atlantic and Southern Ocean (along the Agulhas Return Current), potentially impacting the Atlantic Meridional Overturning Circulation (AMOC) system. The Agulhas Current should thus not be considered in isolation to its upstream influences and downstream impact regions when designing long-term ocean observing systems.

Globally, there exists a number of eastern and western boundary current systems that could have been adopted by the GOOS Co-Design Boundary Current exemplar team as a pilot region. Of the larger WBC systems described in Todd et al (2019), the Gulf Stream, Kuroshio and East Australian Currents were relatively well monitored illustrated by decades-long observations and regional arrays (their Figures 7, 10 and 11). The Agulhas and Brazilian Currents were shown to have fewer observations across the length of the respective WBC's, with the Agulhas Current having no sustained observations as noted in Todd et al (2019).

By and larger, we know the Agulhas Current to be an important driving force along the east coast of South Africa, driving weather and climate systems, impacting shipping routes, tourism activities and fisheries, yet not enough of the current, and most importantly its impact on coastal regions, is understood to inform society from policy makers to the general public.

# 4. The Agulhas Current - our current understanding

Within this section we are summarising the current understanding of the Agulhas Current based on the presentations and discussions held during the Agulhas Current Ocean Observing Design workshop (hereinafter referred to as "workshop"). As a disclaimer, this may not represent all observations and modelling efforts which have historically, or are currently, taking place within the Agulhas Current system, but represents our best efforts to collate these information in order to understand gaps in our knowledge.

## a) Observations

Observations can be divided into a number of observing techniques - moored in situ measurements producing delayed-mode data, ship-based observations using overside and hull-mounted instruments, lagrangian and autonomous instruments and satellite observations. For this workshop report, we will focus on the first three techniques, and leave aside for now satellite based observations as these are global in nature.

### i) Moored in-situ observations

Historically, moored observations across or within the Agulhas Current have been funded through research projects and typically have been deployed for three to five years. Three major projects can be noted that have moored subsurface observations across the the fully constituted Agulhas Current between 34° and 32° S, namely the Agulhas Current Experiment (Bryden et al 2005), the Agulhas Current Time-Series or ACT (Beal et al 2015, Beal and Elipot 2016) and the Agulhas System Climate Array (ASCA) (McMonigal et al 2020, Gunn et al 2020. The primary process being investigated with all three of these experiments was to understand the mean transport of the Agulhas Current as it propagates southwestwards along the east coast of South Africa, with the latter experiment (ACSA) acquiring subsurface observations to understand the heat and salt transport of the Agulhas Current (McMonigal et al 2020 Gunn et al 2020).

Additional moored observations have taken place along the east coast of South Africa under projects led by the DFFE, Ocean and Coasts Directorate off of the Port Alfred region (Meyer et al 2017), the Port Edward region (Lamont et al 2021) and within the KwaZulu-Natal Bight as a research project under the African Coelacanth Ecosystem Programme (ACEP) (Roberts and Nieuwenhuys 2015). The processes being studied off the Port Alfred region was to gauge the strength of the Agulhas Current and generate knowledge on the potential for energy generation (Meyer and Van Niekerk 2016, Meyer et al 2017) and the Port Edward region to understand the dynamics of the Agulhas Current and its northeasterly reversals ((Lamont et al 2021). While the KwaZulu-Natal Bight moorings aimed to understand the cyclonic features impacting the Bight, but also being generated south of the Bight and propagating southwestwards (Guastella and Roberts 2016).

The SAEON Elwandle team operate the Shallow Marine and Coastal Research Infrastructure (SMCRI) and the SAEON Egagasini team the South African Polar Research Infrastructure (SAPRI) - both of which manage infrastructure within the coastal and open ocean regions of South Africa. SMCRI is the older of the two Research Infrastructures and has developed a coastal

moored array with Algoa Bay which is fairly extensive. These types of moorings will be rolled out to KwaZulu-Natal, False Bay and Table Bay in the near future with satellite sites of interest along both the east and west coasts of South Africa to provide long term monitoring.

### ii) Ship-based observations

The DFFE, previously known as Marine and Coastal Management, have historically undertaken three hydroacoustic pelagic surveys annually from the 1983 to present (Pre-recruit Survey in March / April, Recruit Survey in May / June and the Spawner Biomass Survey from October to December) from the border of Namibia with South Africa along the west coast of South Africa, through to approximately Port Elizabeth or Port Alfred (depending on available time) (Hutchings et al 2009). These pelagic resource surveys generally operated in less than 200 m of water (so surveys would extend to the shelf edge) along established transect lines. Pelagic trawls were coupled with CTD and zooplankton net casts to understand the environment in which pelagic fish were abundant (Hutchings et al 2009).

In addition, the DFFE has also undertaken West Coast and South Coast Demersal surveys as randomised trawl stations (no pre-defined transects) annually (and in some years, twice annually) from 1986 to present (Hutchings et al 2009). Once again with coupled CTD and zooplankton net surveys for environmental understanding of the ecosystem. Challenges with trawl gear changes, funding challenges and vessel reliability have resulted in breaks within these time series' especially in recent years.

Given the focus of fisheries along the west and south coasts of South Africa, these fisheries surveys were always limited to these regions with little to no intensive surveys along the east coast of South Africa. Data from the surveys are available through the Marine and Information Management System (MIMS) of the DFFE (https://data.ocean.gov.za).

Some dedicated experiments along the east coast of South Africa have been undertaken; understanding the Sardine Run phenomena through dedicated surveys and mooring deployments (Roberts et al 2010), the impacts of the Agulhas Current along the narrow shelf edge of the east coast of South Africa to the coastal regions (Russo et al 2019, Lamont et al 2024), and the work of Beal et al (2006) looking at water masses and mixing during the Agulhas Undercurrent Experiment. More recent studies using the dedicated CTD transect from the ASCA surveys produced the first observations of water masses at 34 S during austral winter (Braby et al 2022).

### iii) Lagrangian and autonomous observations

Dedicated autonomous observation deployments have been limited for the Agulhas Current region. Two Seaglider missions were undertaken offshore of Algoa Bay (SAGE, Krug et al 2017) and downstream along the Agulhas Current (GINA, Krug et al 2018).

Lagrangian Drifters and Argo floats are free-drifting autonomous instruments that do exit the South West Indian Ocean basin via the Agulhas Current and these data are available through open access platforms (Drifters and Argo open access platforms). Several experiments using Argo floats on high resolution profiling missions were deployed in cyclonic eddies in the source regions of the Agulhas Current allowing for better resolution of observations of the mesoscale

anomaly, along with the Agulhas Current itself (Morris and Lamont 2019, Morris et al 2019). This mechanism could be adopted opportunistically for Argo floats operating within a Western Boundary Current region to obtain greater resolution of data.

## b) Modelling

Modelling efforts in the Agulhas Current region can be divided into two categories; research models used to understand phenomena and operational models used for forecasting purposes.

### i) Research models

Several hydrodynamic models have been used to try to understand the Agulhas Current system (including but not limited to ROMS and CROCO, HYCOM, NEMO, ORCA), including its source water regions and downstream flow into the South East Atlantic Ocean. Critically, three aspects are still represented incorrectly within these models:

- Upstream destabilisation of the Agulhas Current
- Eddy kinetic energy is too high in the output
- Agulhas Rings follow a straight line in the South Atlantic Ocean

The following aspects need to be carefully considered to ensure the Agulhas Current is better represented in hydrodynamic research models:

- Lateral boundary conditions forcing fields at the sea surface are critical, given the influence of the greater Indian Ocean basin on the Agulhas Current.
- Effects of bottom topography need to be considered, particularly with regards to the narrow shelf along the east coast of South Africa.
- Effects of the model physics need to be considered (e.g. when the current detaches from the coast and results in an increase of energy).
- Model solutions are incredibly sensitive to tracer advection and / or diffusion schemes used and model parameterisations.

### ii) Operational models

Operational models have been developed in South Africa by SAEON's SOMISANA unit, which contributes to the DFFE-led OCIMS (Ocean and Coastal Information Management System) portal, and the South African Weather Service (SAWS) Marine Portal. Combined, these systems (which work closely together) are able to do forecast modelling of some of the coastal phenomena impacting South Africa's ecosystems, including oil spills, extreme waves and coastal dynamics. At this stage, neither of the operational systems assimilate ocean observations into their forecast models, but they do validate against data where possible.

Global forecast models used within South Africa include Mercator, the European Centre for Medium-Range Weather Forecasts (ECMWF) and similar.

## c) Connectivity with the Benguela Current

During the workshop discussions, it was noted that to design an observational system for the Agulhas Current system efficiently, input from the source water regions upstream (Mozambique

Channel, south of Madagascar and the Agulhas Current recirculation) and the downstream connectivity with the Benguela Current, would be beneficial to the process. Given the Benguela Current is an Eastern Boundary Current (EBC), linking closely to the work being undertaken by the GOOS Co-Design Exemplar, and propagates along the entire west coast of South Africa and impacting a number of societal interactions (fisheries, aquaculture, etc), the workshop focussed discussions on the Benguela Current connections primarily.

It was noted that the Agulhas Leakage directly impacts the strength of the Benguela Jet, the small jet-like tail end of the Benguela Current linking the wide Agulhas Bank region to the west coast of South Africa along the Cape Peninsula, and is driven by the warm Agulhas Current further offshore. The Benguela Jet is poorly understood in terms of long-term ocean observations, and is largely known from observations of fish egg and larvae transport, satellite observations, model studies (Veitch et al 2018) and periodic ship surveys. The Benguela Jet is estimated to have a volume transport of 10 Sv, and is influenced by the massive turbulence of Agulhas Rings and eddies spawned from the Agulhas Retroflection within the Cape Basin (Veitch et al 2018). Recent and future research projects such as QUICCHE and WHIRLS aim to diagnose this turbulent region to understand these anomalous interactions and the impacts these may have on global climate systems (transport of heat and salt into the South Atlantic Ocean), fisheries and ocean-atmosphere and biogeochemical interactions . The Benguela Jet also acts as a barrier to cross shelf exchange between the relatively narrow Cape Peninsula shelf region and offshore, constricting the flow of fish eggs and larvae, pelagic fish shoals and other parameters such as pollutants and nutrients.

Globally, the close proximity of a WBC and EBC with direct, albeit messy and not well understood interactions, is unique and through this initiative provides an opportunity for an integrated observing system design. Additional factors that promote the shared, or at least complimentary, design of observations for the two boundary current systems include:

- Shared resources such as fisheries (pelagic fisheries moving between ecosystems as noted above)
- Shared coastlines of the Western Province and the country itself
- Shared governance structures in terms of national institutions
- Lessons learnt from more established structures such as the Benguela Current Large Marine Ecosystem (BCLME) programme and later the Benguela Current Commission (BCC), and how these may be applied to the Agulhas Current system design
- Shared infrastructure, including ocean observation instruments, high performance computing systems used for running models, data management systems and human capacity.

## 5. Societal implications

The Agulhas Current, one of the world's strongest and fastest currents, is a primary driver of the climate and Blue Economy for South Africa and its neighbors like Mozambique. The current's warm, moist waters contribute significantly to the humid subtropical climate and rainfall of South Africa's east coast, directly supporting the region's agriculture and freshwater supply. Its nutrient-rich convergence zones boost fisheries productivity, providing essential food security and livelihoods. Conversely, the Agulhas Current is infamous as one of the world's most dangerous shipping routes; when the warm current opposes the powerful westerly winds off the Cape, it can create giant, steep rogue waves capable of sinking large vessels, leading to high-consequence maritime hazards. Furthermore, the volume of warm, salty water it "leaks" into the Atlantic (through the Agulhas Leakage) is a key mechanism that influences the global ocean conveyor belt, linking the Greater Agulhas Current system to major circulation patterns that have global implications.

### a) Meteorological Services

The South African Weather Service (SAWS) has significant opportunities to enhance its capacity and functionality to meet the challenges of a changing climate. Strategic investment in **expanding and modernizing the network of surface data stations**, combined with increased resolution of computer models, will substantially improve the accuracy and reliability of long-term forecasts. Strengthening cybersecurity infrastructure will safeguard critical ICT systems, ensuring uninterrupted delivery of vital aviation and marine weather forecasts that support safety and economic stability. By bolstering these technical capabilities, SAWS can significantly enhance its Early Warning Systems, providing vulnerable communities, particularly those in informal settlements at risk of flash flooding, with timely, accurate information to prepare for extreme weather events. This proactive approach will save lives, protect property, and build climate resilience across South Africa as weather patterns become more variable and intense.

### b) Fisheries

Fisheries are a globally competitive industry, providing food and jobs. Major fisheries vessels (pelagic and benthic) operate on the continental shelf off the west and south coasts of South Africa, with fisheries on the east coast being more limited to prawn trawling and line fish. **Ocean information (including, but not limited to, weather, currents, water color, wind direction) is critical to successful fisheries with ocean conditions being a threat particularly in the offshore areas.** This type of information would ensure more efficient fishing practices and reduce costs such as fuel usage. There currently does not exist a comprehensive data product platform that would work with fisheries to safeguard operations, increase efficiency and understand the drivers of fish abundance seen through anecdotal evidence (e.g. rainfall and westerly storms impacts on recruitment). In addition, working with fisheries (vessel masters, operators and associated science teams) looking at historical catch data with environmental information may allow for a better understanding of fisheries successes, species distribution and stock size.

A threat to South African fisheries is the devastating convergence of overfishing and widespread Illegal, Unreported, and Unregulated (IUU) fishing, which severely deplete key commercial and linefish stocks faster than they can recover. This crisis directly impacts the estimated 27,000 people employed in the formal fishing industry and, most acutely, the marginalized small-scale fishers who rely on daily catches for food security and livelihoods. Compounding this are the increasing effects of climate change, which cause target species like sardine, anchovy, and even snoek to shift their distribution or decline in abundance due to warming waters, forcing fishers to travel further for smaller catches. This environmental stress, combined with historical exclusionary policies and structural poverty, traps coastal communities in a cycle where they are both the victims and, sometimes, reluctantly driven to illegal harvesting, undermining the long-term sustainability and economic value of South Africa's marine resources.

### c) Tropical Cyclones

The South African coast and its people face an unprecedented threat from tropical cyclones through its associated weather events. Although landfalls are rare, these storms have significant secondary impacts through torrential rainfall over inland and coastal regions, which leads to severe flash flooding, riverine overflow, and landslides, causing loss of life, widespread property and infrastructure damage, disruption of essential services, and significant economic loss. Hurricane Freddy in 2023 caused record rainfall with a total of 500 - 1000 mm over 4 days leading to flooding, flash floods and landslides, displacing nearly 700k people, causing damages between $500-700M[3] (across all regions impacted).

Tropical cyclones predominantly form in the Southwest Indian Ocean and the remnant storm systems, particularly the ones that track through the Mozambique Channel, have severe impacts on the coastline. Projections indicate an increase in frequency of more intense storms, along with a southward shift of trajectories[4], demanding heightened preparedness and robust disaster management strategies.

The SAWS is mandated to issue weather warnings and primarily utilise satellite imagery with very limited in situ observations across the coastline to validate their model outputs. SAWS is undertaking research work simulating the landfall of tropical cyclones and associated weather conditions and actively developing a coupled model in collaboration with SAEON and UCT. **However, in-situ observations, particularly in the Mozambique Channel, are critical to inform and validate model predictions.**

### d) Extreme Waves and Rip Currents

Extreme waves and rip currents (narrow and fast moving currents that move rapidly away from shore) pose a significant threat to the South African coast causing a high number of drownings and severe risk to marine operations. Extreme waves are generated through storm systems like tropical cyclones exacerbating coastal erosion, damage to infrastructure and resulting in

[3] https://www.undrr.org/resource/southern-africa-cyclone-2023-forensic-analysis

[4] https://theconversation.com/rising-sea-temperatures-are-shaping-tropical-storms-in-southern-africa-73139

hazardous conditions for people living on the coast and operating at sea. SAWS launched a rip current forecasting system for six beaches in the Western Cape using a comprehensive data set to assign rip risk levels and are aiming to expand across the entire South African coast. **High resolution coastal observations of rip current dynamics are required to validate these models.**

### e) Marine Heatwaves

An extreme temperature event is categorised as lasting for more than two consecutive days where the daily maximum temperature exceeds the 90th percentile of the climatological observed maximum temperature for the date and location. Related to this are thermal shocks which occur during a sudden drop in temperature, causing fish die-offs along the coast. These events pose an escalating threat to South Africa in particular the Agulhas Retroflection region and are becoming more frequent, intense, and long-lasting. Impacts of these extreme temperature events can range from impacts on marine ecosystems (incl. mass mortality events, bleaching, toxic algal blooms), socio-economic impacts via the description of fisheries and aquaculture impacts (incl. distribution, recruitment success, die-offs), to health risks of people living in impacted areas and food security.

Regional studies have shown that areas experiencing the most intense heatweave are usually near the place of strongest kinetic energy and have shown correlation between the modes of variability in the eddy dynamics and responses in the heatwaves. In addition, inshore regions have experienced more pulses of cold water resulting in extreme thermal fluctuations causing significant ecosystem impacts like thermal shock events. To better understand these systems, especially in the coastal areas where satellite imagery is not of high resolution, **more in-situ observations are required to resolve smaller processes**.

### f) Marine Protected Areas

Marine Protected Areas (MPA) are critical to safeguarding South Africa's sustainable fisheries, food security, especially for coastal communities and biodiversity. About 30% of South Africa's population lives close to the coast with a majority depending on the ocean for its resources. MPAs are critical for tourism and recreation, preserving cultural and indigenous knowledge and conserving the biodiversity and ecosystem, while also creating jobs in various sectors.

Around South Africa 42 MPAs have been established all with unique flora and fauna compositions; however, the interconnectivity between them are not well mapped and the impacts of oceanographic features on MPA conditions are not well resolved (Gaines et al., 2003; Kirkman et al., 2019). Physical features such as the **stable and unstable components of the Agulhas current, retroflection and leakage area need to be better observed to assess the impacts these processes have on the conditions within MPAs.**

### g) Maritime Safety

The growing frequency and intensity of extreme weather events like tropical storms, extreme waves, wind and rainfall intensify and severely impact safe maritime operations. These conditions put a significant strain and safety hazard on responding to incidents at sea including

engine/steering gear failure, structural failure, fire, grounding, contaminated materials, sinking, cargo loss, and search and rescue operations. The stress on the structural integrity of cargo vessels, fisheries operators and port infrastructure itself can be impacted by severe weather. On the other hand, to safely operate in conditions, position the rescue vessels or determine drift models for search patterns **requires accurate data and models**.

An increase in traffic around South Africa could result in increased incidents further stressing the importance of developing accurate drift models and models informing search and rescue of ocean conditions and cargo vessels in order to avoid potential life threatening situations.

# 6. Key processes for a backbone observing system for the Agulhas Current:

## a) Mesoscale circulation

The Greater Agulhas Current system is characterised by mesoscale eddies in its source water regions, along the shelf slope and at its retroflection. Agulhas Rings are shed from the retroflection and these have a dynamic impact on the South Atlantic and climate variability. Continued studies of these dynamics, especially those impacting the shelf and slope along the east coast of South Africa, are incredibly important for ecosystem dynamics and food security.

## b) Ocean-atmosphere to land interactions

A warmer surface ocean will influence evaporation and the creation of extreme rainfall events including the lower atmosphere (boundary layer). With the tropical Indian Ocean warming faster than any other ocean basin, there exists an increase in moisture content over the Agulhas Current, influencing rainfall over inland regions. This will have an influence on agriculture, but also river levels leading to potential flooding. During ENSO events, South Africa also experiences drought conditions (particularly in the Western Cape during La Nina), having the reverse impacts on agriculture. There needs to be a greater relationship between ocean and atmospheric sciences, but also with disciplines relating to agriculture and freshwater systems.

## c) Shelf edge upwelling

Related to mesoscale circulation above, and wind systems along the coast, shelf edge upwelling is prominent in both the Agulhas and Benguela Currents. The enhancement of monitoring of east and south coast shelf edge upwelling, and through the Benguela region, would be instrumental to understand ecosystem dynamics, impacts on fisheries and thus food security. Shelf-slope exchanges with the coastal regions are of particular importance, thus monitoring from the shelf edge (slope) to the very inshore is critical.

## d) Retroflection zone, Indo-Atlantic Exchange, the Benguela Jet Current and the global climate system

The connectivity of the South West Indian Ocean to the South Atlantic involves a number of key regions, the Agulhas Current Retroflection, the Benguela Jet Current, the Agulhas Ring corridors and associated physical mechanisms, is critical to understand the Indo-Atlantic Exchange of water. Several international projects are operational in this region (QUICCHE and WHIRLS) but ideally these should be long term monitoring processes.

## e) Agulhas Transport

Related to the above, is the continued monitoring of Agulhas Current transport - volume, temperature, salinity, nutrients and pollutants. To close volume transport (end-to-end flow of water) is incredibly difficult given the number of pathways of flow. Continued monitoring however will help assess how the volume (heat, salt, productivity) is changing over time with climate change and the downstream impacts of these processes on society.

# 7. Key recommendations going forwards

## a) Governance

A system of systems governance approach should be analysed for this work with input around:

- Mandates of government departments, entities and stakeholders
- Previous large marine ecosystem reports such as the BCLME (Benguela Current Large Marine Ecosystem) and ASCLME (Agulhas Somali Current Large Marine Ecosystem).
- Should the two current systems be analysed and monitored as one, or as separate entities?

## b) Stakeholder engagement

Stakeholder engagement is needed to understand the needs of the community - subsistence fishers, coastal users, tourism, municipalities and similar - but also larger stakeholders such as shipping, commercial fishing, marine-based companies and similar.

Inland stakeholder engagement would be incredibly useful in terms of agriculture and freshwater river usage for communities and companies.

Very careful consideration needs to be given over to stakeholder fatigue - the consistent "mining" of information from user groups interacted with time and again. First considerations should be done through existing channels, published reports, etc.

## c) OSE / OSSE to verify observing system

Partner with the SynObs Project, a UN Ocean Decade endorsed project, to make use of model data outputs to understand what observations are useful (and where) within the Agulhas Current system to answer the key processes to determine a backbone system above. This would require the assistance of a FTE or PostDoctoral Researcher.

## d) Economic assessment of Agulhas and Benguela Current systems

In order to understand the value of the Agulhas and Benguela Current systems on South Africa's society and economy, a full economic assessment would be required which uses input from the wide range of activities captured under the Blue Economy. This work would be best placed in collaboration with DFFE for instance, who have an Ocean Economist as part of their team. In addition, the Cape Peninsula University of Technology (CPUT) hosts the Centre for the Sustainable Ocean (CSO) and collaborations here would be beneficial. Critically, the link should be made between ocean and land based economies.

## e) Funding analysis

Finally, a funding analysis of what infrastructure would be needed to undertake the backbone observations would need to be done in order to show the val;ue of such observations against the backdrop of a well-managed and well-measured Agulhas Current system. Multiple funding avenues could be explored include government funding, public-private partnerships, philanthropic opportunities and marine-related business opportunities.

## References


1. Ayoub, N.K., M.P. Chidichimo, E. Dever, X. Guo, S.Y. Kim, M. Krug, B.M. Míguez, T. Morris, M. Roughan, J. Sprintall, K. Tanaka, R.E. Todd, J. Wilkin, E. Álvarez-Fanjul, M. Andres, A. Bosse, C.A. Edwards, J. Gula, C.G. Kerry, Y. Miyazawa, P. Oddo, E. Oka, and K.D. Zaba. 2024. Observing ocean boundary currents: Lessons learned from six regions with mature observational and modeling systems. Oceanography, https://doi.org/10.5670/oceanog.2024.504.
2. Beal, L.M., De Ruijter, W.P., Biastoch, A., Zahn, R., Group, S.W.I.W., Hermes, J., et al. 2011. On the role of the Agulhas system in ocean circulation and climate. Nature, 472(7344), 429–436. https://doi.org/10.1038/nature09983.
3. Beal, L.M., Elipot, S., Houk, A., & Leber, G.M. 2015. Capturing the transport variability of a western boundary jet: Results from the Agulhas current time-series experiment (ACT). Journal of Physical Oceanography, 45(5), 1302–1324. https://doi.org/10.1175/jpo-d-14-0119.1
4. Bryden, H.L., Beal, L.M. & Duncan, L.M. 2005. Structure and Transport of the Agulhas Current and Its Temporal Variability. Journal of Oceanography 61, 479–492. https://doi.org/10.1007/s10872-005-0057-8
5. Beal, L. M., & Elipot, S. 2016. Broadening not strengthening of the Agulhas Current since the early 1990s. *Nature*, 540(7634), 570–573. https://doi.org/10.1038/nature19853
6. Beal, L. M., Chereskin, T. K., Lenn, Y. D., & Elipot, S. 2006. The sources and mixing characteristics of the Agulhas Current. *Journal of Physical Oceanography*, 36(11), 2060–2074. https://doi.org/10.1175/JPO2964.1
7. Braby, L. Deshayes, J. Beal, L.M., Morris, T., Guillaume, N., Maitland, J. Ansorge, I.A. and Hermes, J.C. 2022. First observations of seasonal variability in water mass properties across the Agulhas Current. JGR Oceans. https://doi.org/10.1029/2021JC018107
8. Gaines SD, Gaylord B, Largier JL (2003) Avoiding current oversights in marine reserve design. Ecol Appl 13:S32–S46. https://doi.org/10.1890/1051-0761(2003)013[0032:ACOIMR]2.0.CO;2
9. Guastella, L., & Roberts, M. 2016. Dynamics and role of the Durban cyclonic eddy in the KwaZulu-Natal Bight ecosystem. *African Journal of Marine Science*, *38*(sup1), S23–S42. https://doi.org/10.2989/1814232X.2016.1159982
10. Gunn, K.L., L.M. Beal, S. Elipot, K. McMonigal, A. Houk. 2020. Mixing of Subtropical, Central, and Intermediate Waters Driven by Shifting and Pulsing of the Agulhas Current, Journal of Physical Oceanography, https://doi.org/10.1175/JPO-D-20-0093.1
11. Hood, R.R., Ummenhofer, C.C., Phillips, H.E. and Sprintall, J. 2024. Introduction to the Indian Ocean. The Indian Ocean and its role in the global climate system. Elsevier. https://doi.org/10.1016/B978-0-12-822698-8.00015-9
12. Hutchings, L., Augustyn, C.J., Cockcroft, A., Van der Lingen, C., Coetzee, J., Leslie, R.W., Tarr, R.J. , Oosthuizen, H., Lipinski, M.R., Roberts, M.R., Wilke, C., Crawford, R., Shannon, L.J. and Mayekiso, M., 2009. Marine fisheries monitoring programmes in South Africa. South African Journal of Science, 105. 182-192. https://10.4102/sajs.v105i5/6.85
13. Kirkman, S.P., Mann, B.Q., Sink, K. J., Adams, R., Livingstone, T-C., Mann-Lang, J.B., Pfaff, M.C., Samaai, T., van der Bank, M.G., Williams, L. and Branch, G.M. (2021)

Evaluating the evidence for ecological effectiveness of South Africa's marine protected areas, African Journal of Marine Science, 43:3, 389-412, DOI:10.2989/1814232X.2021.1962975

14. Krug, M., Swart, S. and Gula, J. 2017. Submesoscale cyclones in the Agulhas Current. Geophysical Research Letters. https://doi.org/10.1002/2016GL071006
15. Krug, M., Swart, S. and Hermes, J. 2018. Ocean gliders ride the research wave in the Agulhas Current. *Eos*, *99*, https://doi.org/10.1029/2018EO100105.
16. Lamont, T., Halo, I. and Russo, C.S. 2024. Impacts of Agulhas Meanders on intermediate water masses along the adjacent continental slope and shelf. Continental Shelf Research, 274. https://doi.org/10.1016/j.csr.2024.105197
17. Lamont, T., Louw, G.S., Russo, C.S. and van den Berg, M.A. 2021. Observations of northwestward flow on a narrow shelf dominated by the Agulhas Current. Estuarine, Coastal and Shelf Science, 251. https://doi.org/10.1016/j.ecss.2021.107197
18. Lutjeharms, J.R.E. 2006. The Agulhas Current. Springer Berlin Heidelberg. https://doi.org/10.1007/3-540-37212-1
19. Phillips, H.E., Menezes, V.V., Nagura, M., McPhaden, M.J., Vinayachandran, P.N. and Beal, L.M. 2024. Indian Ocean circulation. The Indian Ocean and its role in the global climate system. Elsevier. https://doi.org/10.1016/B978-0-12-822698-8.00015-9
20. McMonigal, K., Beal, L.M., Elipot, S., Gunn, K.L., Hermes, J., Morris, T., and Houk, A. 2020. The Impact of Meanders, Deepening and Broadening, and Seasonality on Agulhas Current Temperature Variability. Journal of Physical Oceanography, 50(12), 3529-3544. https://doi.org/10.1175/JPO-D-20-0018.1
21. Meyer, I. and Van Niekerk, J.L., 2016. Towards a practical resource assessment of the extractable energy in the Agulhas ocean current. International journal of marine energy, 16, pp.116-132.
22. Meyer, I., Braby, L., Krug, M. and Backeberg, B., 2017. Mapping the ocean current strength and persistence in the Agulhas to inform marine energy development. In Marine Renewable Energy: Resource Characterization and Physical Effects (pp. 179-215). Cham: Springer International Publishing.
23. Morris, T. and Lamont, T. 2019. Using ocean robots on high-resolution profiling to capture the fast-flowing Agulhas Current. South African Journal of Science, 115 (1/2). https://doi. org/10.17159/sajs.2019/5523
24. Morris, T. Aguiar-Gonzalez, B., Ansorge, I and Hermes, J.C. 2019. Lagrangian evolution of two Madagascar cyclonic eddies: Geometric properties, vertical structure and fluxes. JGR Oceans. https://doi.org/10.1029/2019JC015090
25. Roberts, M.J. and Nieuwenhuys, C. Observations and mechanisms of upwelling in the northern KwaZulu-Natal Bight, South Africa. African Journal of Marine Science, *38*(sup1), S43–S63. https://doi.org/10.2989/1814232X.2016.1194319
26. Roberts, M.J., van der Lingen, C.D., Whittle, C. and van den Berg, M.A. 2010. Shelf currents, lee-trapped and transient eddies on the inshore boundary of the Agulhas Current, South Africa: their relevance to the KwaZulu-Natal sardine run. African Journal of Marine Science, 32 (2). https://doi.org/10.2989/1814232X.2010.512655
27. Roxy, M.K., Saranya, J.S., Modi, A., Anusree, A., Cai, W., Resplandy, L., Vialard, J. and Frölicher, T.L. 2024. Future projections for the tropical Indian Ocean. The Indian Ocean and its role in the global climate system. Elsevier. https://doi.org/10.1016/B978-0-12-822698-8.00015-9

28. Russo, C.S., Lamont, T., Tutt, G.C.O., van den Berg, M.A. and Barlow, R.G. 2019. Hydrography of a shelf ecosystem inshore of a major Western Boundary Current. Estuarine, Coastal and Shelf Science, 228. https://doi.org/10.1016/j.ecss.2019.106363
29. Todd, R.E., Chavez, F.P., Clayton, S., Cravatte, S., Goes, M., Graco, M., Lin X., Sprintall, J., Zilberman, N.V., Archer, M., Arístegui, J., Balmaseda, M., Bane, J.M., Baringer, M.O., Barth, J.A., Beal, L.M., Brandt, P., Calil, P.H.R., Campos, E., Centurioni, L.R., Chidichimo, M.P., Cirano, M., Cronin, M.F., Curchitser, E.N., Davis, R.E., Dengler, M., deYoung, B., Dong, S., Escribano, R., Fassbender, A.J., Fawcett, S.E., Feng, M., Goni, G.J., Gray, A.R., Gutiérrez, D., Hebert, D., Hummels, R., Ito, S., Krug, M., Lacan, F., Laurindo, L., Lazar, A., Lee, C.M., Lengaigne, M., Levine, N.M., Middleton, J., Montes, I., Muglia, M., Nagai, T., Palevsky, H.I., Palter, J.B., Phillips, H.E., Piola, A., Plueddemann, A.J., Qiu, B., Rodrigues, R.R., Roughan, M., Rudnick, D.L., Rykaczewski, R.R., Saraceno, M., Seim, H., Sen Gupta, A., Shannon, L., Sloyan, B.M., Sutton, A.J., Thompson, L., van der Plas, A.K., Volkov, D., Wilkin, J., Zhang, D. and Zhang, L. 2019. Global Perspectives on Observing Ocean Boundary Current Systems. Frontiers in Marine Science 6:423. https://doi:10.3389/fmars.2019.00423
30. Veitch J., Hermes, J. Lamont, T., Penven, P. and Dufois, F. 2018. Shelf-edge jet currents in the southern Benguela: A modelling approach. Journal of Marine Systems, 188. 27-38. https://dx.doi.org/10.1016/j.jmarsys.2017.09.003
31. Zhang, R., Sun, S., Chen, Z., Yang, H., and Wu, L. 2023. Rapid 21st century weakening of the Agulhas current in a warming climate. Geophysical Research Letters, 50, e2022GL102070. https://doi.org/10.1029/2022GL102070

The designations employed and the presentation of material throughout this publication do not imply the expression of any opinion whatsoever on the part of UNESCO concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The ideas and opinions expressed in this publication are those of the authors; they are not necessarily those of UNESCO and do not commit the Organization.

Published in 2026 by the Global Ocean Observing System Programme under the Intergovernmental Oceanographic Commission of UNESCO, 7, Place de Fontenoy, 75352 Paris 07 SP, France
©UNESCO

For bibliographic purposes, this publication should be cited as follows: Agulhas Current Observing System Design Workshop (2026), GOOS Report No. 314.