African Group of Negotiators Experts Support

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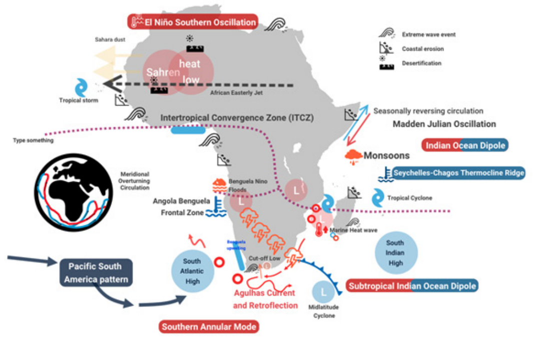
Extremes, Abrupt Changes and Managing Risks



KEY MESSAGES

1. **Extreme events (droughts, floods, cyclones, marine heat waves) impacting Africa are linked to natural modes of variability in the ocean and amplified by climate change.**
2. **The Indian Ocean is warming faster than global oceans and will continue to warm even after emissions reach Net Zero, having severe consequences on the African continent.**
3. **Short-term predictions and longer decadal and century-scale projections are made more challenging because ocean features around Africa are not well represented in climate models.**
4. **Interocean exchange south of Africa is a key modulator of the Meridional Overturning Circulation and has far reaching impacts on global climate.**
5. **Scientific knowledge, indigenous knowledge and local knowledge can complement one another by engaging both quantitative data and qualitative information, including people's historical experience, observations, responses and values.**
6. **Investment in long term, sustained observations is essential to support early warning systems (EWSs) necessary to enhance preparedness to extreme events and abrupt changes.**

Introduction

It is unequivocal that the climate is changing as a result of global warming which is mainly driven by an increase in concentration of greenhouse gases (GHGs) in the atmosphere. The increase in temperature has been experienced globally, with recent years recording the highest temperature. Africa experiences a heavy burden of climate change impacts due to its location and a large proportion of its population living in impoverished and vulnerable conditions. The continent is adversely affected by climate change owing to its low adaptive capacity to the impacts of the changing climate. The impact of climate change in the ocean and cryosphere is increasingly driving climate and weather extreme events across the globe.

Given that Africa is surrounded by three diverse oceans and extends into the subtropics in both hemispheres, its regional climates are highly variable and strongly influenced by oceanic change (Figure 1). However, changes in these oceans also influence weather and climate patterns in the northern hemisphere and are key modulators in the global climate system. Thus, understanding climate change impacts in the neighbouring Indian, Atlantic and Southern Oceans is essential to helping forecast extremes and abrupt changes over Africa as well as in managing climate risks.

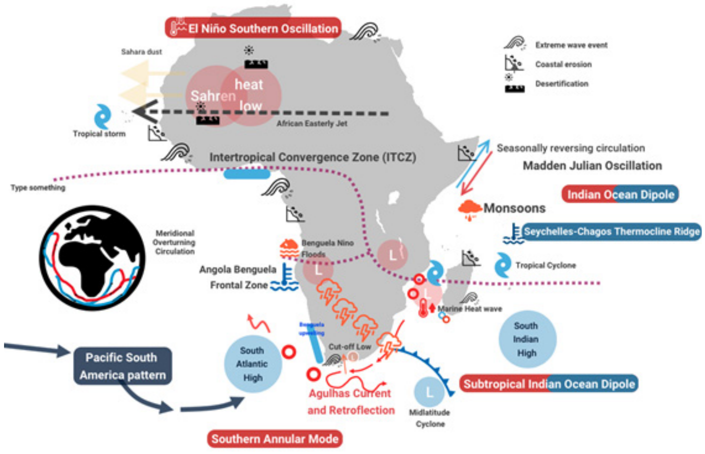


Figure 1, key ocean phenomena and key weather patterns over Africa (acknowledgement Caitlin Ranson). A general schematic and these are seasonally dependent e.g. tropical cyclones occur during the summer half of the year in each hemisphere, and the ITCZ is drawn here in its austral summer approximate location.

Climate change influences on Extreme events

Although understanding the risks associated with impacts of predictable (slow onset) events like sea-level rise is relatively straightforward, those associated with severe weather events such as tropical cyclones (TCs) or mesoscale convective complexes is challenging. Climate change is increasing the frequency and intensity of El Niño related events, leading to more frequent and severe droughts and floods over Africa, and shifting TC patterns in the Indian Ocean. Increasing sea surface temperatures (SSTs) in this ocean will likely lead to an increase in the intensity of the Indian Ocean Dipole (IOD) events and their associated rainfall impacts over East and southern Africa. In addition, the frequency of IOD events is expected to increase, weakening the ability of affected communities to recover from the associated extremes. Attribution studies help to identify which extreme events were exacerbated by climate change and to what degree. Unfortunately, in Africa there is a gap in attribution studies as a result of limited technical and resource capacity in the continent.

The characteristics of extreme weather or climatic events vary from place to place. Extreme events in the oceans around Africa can have far reaching effects beyond their impact on regional weather. Often linked to extreme El Niño events, coral bleaching events are on the rise in recent years. Every few years, anomalous warm and cold coastal events occur (Benguela Niños) in the southeastern Atlantic and are detrimental for Angola, Namibia, and South Africa, as they affect regional fisheries and rainfall in a similar way to the El Niño impacts in the eastern Pacific. The understanding of how this will change under various climate change scenarios differs, although climate models predict that the southern Benguela area will experience an increase in wind stress, while the region to the south of Africa and the northern Benguela will record a decrease in wind stress. This has strong implications on the wind driven, productive upwelling system.

Climate projections under 1.5 and 2 oC global warming levels show that the Greater Horn of Africa (GHA) region is likely to warm faster than the global mean. The region is strongly influenced by the SW and NE monsoons over the tropical Indian Ocean and hence, large-scale ocean-atmosphere interaction which controls the seasonal migration of the tropical rainfall belt between the hemispheres. For example, warming of the eastern Indian Ocean led to severe drought across Kenya, Tanzania, Ethiopia and Somalia in 2016/17. This extreme event followed flash floods in 2015/16 which were associated with the very strong El Niño that left 28 million people in the region in need of humanitarian aid. On the other hand, the 2015/16 El Niño led to severe drought over many parts of southern Africa.

In North Africa, the most common extreme climate phenomena are drought and heat waves. The drought frequency is in the range of 1 to 2.5 events per year. The frequency is generally high in Morocco, Northern Algeria and along the coast of the Mediterranean Sea. In west Africa, the low-lying Senegalese sandy coast and the Gulf of Guinea coast are extremely vulnerable to coastal flooding and erosion. Research has shown a remote connection between Atlantic climate modes and coastal wave variability in Senegal causing devastating storm surges. Coastal areas of the Gulf of Guinea also experience accelerated degradation as a result of erosion and flooding associated with intensification of extreme marine-meteorological phenomena.

Multi-year droughts are a notable feature of the southern African climate. A recent notable example is the Day Zero drought over the greater Cape Town region during 2015-2018 which resulted from a poleward shift in westerly moisture fluxes across the South Atlantic and Hadley Cell expansion. On the other hand, heavy rainfall days in parts of Angola, Botswana, South Africa and Zimbabwe during the summer rainy season have increased in recent decades.

Changes in tracks, intensity and frequency of tropical and extratropical cyclones and associated ocean influences

Tropical cyclones (TCs), also known as hurricanes in the Atlantic are among the hazardous natural events affecting some African coastal regions. Variability and change in the number, intensity and rate of intensification of the TCs due to their response to global warming is difficult to disentangle from the impact of natural modes of variability.

Although the frequency of TCs is likely to decrease or remain unchanged, given the significant increase in SST and upper ocean heat content during the last two decades, it is likely that there will be intensification of cyclones with maximum wind speeds and precipitation rates increasing. As a result, wave heights along the tracks of the TC will increase and may further impact sea level rise and related coastal inundation and floods. In the Southern Hemisphere, it is expected that there will be a poleward movement of storms and cyclones with associated downward rainfall trends in the mid-latitudes and positive trend further polewards, with enhanced wind speeds leading to increases in significant wave heights and swells generated in the Southern Ocean.

The Southwest Indian Ocean is one of the main TC formation regions globally with cyclones impacting Madagascar, Mozambique and the Small Islands Developing States (SIDS) of Mauritius, Reunion and Comoros. In recent years, the intensity of TC over this basin has increased, with Mozambique being hit by severe tropical cyclones Idai and Kenneth in 2019 (Case study 3) resulting in heavy loss of lives and destruction of property. There has been also, a recent increase of extremely severe cyclonic storms over the Arabian Sea in the post-monsoon season and hurricanes in the west Africa (Case study 2). With the increasing warming of SSTs and sea level rise, intense cyclones and storm surges are expected to become more prevalent. The impact of storm surges is heightened when accompanied by strong winds and large waves, creating devastating flood conditions.

Case study 1: Tropical cyclones Idai, Kenneth and Jobo

During late austral summer 2019, Mozambique was devastated by TCs Idai and Kenneth, the first time two Intense Status tropical cyclones have ever made landfall here in the same season. In March, 2019, Idai made landfall in central Mozambique near Beira. Combined extreme winds and huge rainfall were responsible for widespread storm surge floods on the central coastal region of Mozambique, affecting both urban and rural areas killing over 1300 people, and directly affecting more than 3 million people. It is one of the costliest cyclones in the southwestern Indian Ocean, with total damage estimated at approximately $2.2 billion. Based on a configuration of a hydrodynamic circulation model for the Mozambique region, the storm surge height due to TC Idai was about 4.5 m and the total water levels were about 5.7 m above the mean sea level. The storm surge height was even higher than the model-estimated total water levels' 50 year return period (~3 m) for the region.

Just four weeks after cyclone Idai, another intense cyclone 'Kenneth' made landfall near Pemba in northern Mozambique. Kenneth underwent rapid intensification prior to landfall after crossing an anticyclonic warm ocean eddy in the northern Mozambique Channel with favourable ocean heat content and enthalpy fluxes. Luckily, a cyclonic (cool) eddy was present at the coast where it made landfall otherwise Kenneth may have intensified further. TC Kenneth was the first in many years (1872 and 1952) to make landfall so far north. In April 2021, TC Jobo tracked even further north in the South West Indian Ocean before weakening to a tropical depression after which it made landfall near Dar es Salaam with minimal impacts. TCs with similar strengths to Idai or higher are becoming more frequent in the Southwest Indian Ocean and this is consistent with the projected changes for a warmer climate.

Case study 2: Hurricane Fred (2015)

On 31 August 2015, Hurricane Fred passed through the West African coast, causing severe damage. This storm rapidly intensified from a tropical depression off the Guinea coast on 30 August to a hurricane as it traversed Cape Verde on 31 August. It caused seven fatalities associated with a fishing vessel off the coast of Guinea-Bissau and damaged more than 200 homes on the coast of Senegal. In Cape Verde, 7 of the 10 islands were significantly impacted with the most extensive damage occurring in Boa Vista and São Nicolau (~$500,000). The rapid intensification of Hurricane Fred occurred when SST was up to 2°C above average. Warmer SST due to anthropogenic climate change in the future may lead to rapid intensification in coastal zones when tropical cyclogenesis occurs with a possible increase in frequency.

Storm surges

Storm surges have become a global issue due to their damaging and costly impacts on many coastal areas around the world. They can be seen as sea-level anomalies in a coastal or inland body of water in the time range of a few minutes to a few days, driven by atmospheric weather systems (e.g TC). In shallow waters, the wind contribution is usually dominant. Coastal flooding usually happens and reaches several kilometers inland when a large storm surge peaks at the same time as an astronomical high tide. The extent to which coastal flooding can reach inland depends on the strength of the TC and the type of coastline the TC encounters. Climate change not only causes sea level rise but also makes TCs more intense. A category 4 TC can go inland for 24 km or more. In low-lying coastal areas of Africa, particularly in the Southwest Indian Ocean, where TC frequency is higher, a storm surge is likely to cause more damage because of enormous coastal developments, large human populations and significant socioeconomic activities. West Africa may also experience storm surges as cyclone activity has also been reported. Storm surges are directly or indirectly responsible for most deaths associated with land-falling tropical cyclones yet, in many areas around Africa they are poorly understood and there are limited mitigation plans.

Marine heatwaves and their implications

Marine Heat Waves (MHW) – sustained periods of anomalously high near-surface sea temperatures – have doubled in frequency since the 1980s. It is projected that MHWs may become four times more frequent by the end of the century even if the world limits warming to 1.5-2oC. Although extensive work on MHWs has been done in all ocean basins over the last two decades, MHWs around Africa's coasts remain poorly studied, which is a concern, given the relatively high rates of warming in the neighbouring oceans. Many coastal regions in Africa and nearby islands contain ecologically sensitive areas with high marine biodiversity, important to their economies. The MHWs may also pose additional risks on the long-term viability of marine organisms and the sustainability of the fisheries sector which support local livelihoods.

Extreme warm temperature events have led to substantial damage to coral reefs (16% of reefs suffered lasting damage in 1998 alone due to the very strong 1997/98 El Niño event), with some parts of the western Indian Ocean (e.g., Kenya, Tanzania, Seychelles, Mayotte) losing 50-90% of their coral cover. Besides the El Niño Southern Oscillation (ENSO) being central to increasing MHW occurrences across the tropical Pacific and Indian Oceans, other interannual climate modes, such as the Subtropical Indian Ocean dipole (SIOD) may also impact MHWs at a regional scale.

MHWs may also be triggered by small-scale ocean processes such as ocean mesoscale eddies. For instance, the southwestern Madagascar 2017 MHW recorded a peak in intensity through horizontal advection associated with the presence of an anticyclonic eddy (Case study 3). MHWs predominantly occur within warm core eddies near warm currents. The termination of MHWs may also be caused by small-scale ocean processes or changes in the local atmospheric weather patterns. For instance, strong winds, and changes in heat fluxes associated with tropical cyclone Dineo appear to have briefly weakened the southwestern Madagascar MHW 2017 event in mid-February whereas those associated with ex-tropical cyclone Enawo appear to have contributed to its end in mid-March 2017. However, studies on the impact of MHWs on the marine ecosystems in many African coastal regions are limited.

Case study 3: Marine heatwaves

TThe recent 2014-2017 high ocean temperatures in the tropics and subtropics triggered one of the highest MHW event on record off the southwestern coast of Madagascar in austral summer 2017. The southwestern Madagascar 2017 MHW also emerged during one of the strongest SIOD positive events since 1982 that led to positive sea level anomalies (deeper thermocline) and a build-up of warm water in the Southwest Indian Ocean. In addition to the large-scale anticyclonic anomaly over the South Indian Ocean during austral summer 2017, characteristic of a positive SIOD event, there was also a high-pressure system present locally over the Mozambique Channel. This anomaly acted to weaken the Mozambique Channel Trough (MCT) which forms over the central and southern channel every summer in response to the dynamical adjustment of the easterly trade winds to the Madagascan mountains. Austral summer 2017 was a weak MCT year which is often associated with strong positive SIOD events and a westward extension of the Mascarene High. This extension of the Mascarene High led to less cloud cover (increased insolation) and a weakening of the surface winds southwest of Madagascar, contributing to warmer temperatures. Given that high-pressure anomalies have large spatial scales and can persist for weeks (as occurred during December 2016-mid-February 2017), they have the potential to substantially raise ocean temperatures over a large geographic region for a considerable duration.

Extreme El Niño-Southern Oscillation events and other inter annual climate modes

El Nino-Southern Oscillation (ENSO) events influence Africa's weather via atmospheric teleconnections but also through changes in the Atlantic and Indian Oceans. El Niño frequency is projected to increase with increase in global warming. The most recent decades have witnessed the three strongest events (1982/83, 1997/98, 2015/16) in the last few centuries as well as severe protracted La Niña events (1998-2001). In addition, the swings from extreme El Niño to extreme La Nina are projected to occur more frequently as well as the increase of central Pacific El Niño events. These events have led to severe droughts and floods over several parts of East and southern Africa in particular.

ENSO impacts on Africa have been well documented but are difficult to untangle when other climate modes also have strong influences and are also changing with climate change. Other modes of interannual climate variability which involve the neighbouring oceans, impact different regions of Africa as well as interacting with ENSO include the Southern Annular Mode (subtropical southern Africa), the SIOD (southern Africa), the IOD (eastern Africa), the Benguela Niño (southwestern Africa), the North Atlantic Oscillation (parts of North and West Africa and the Congo) and the Atlantic Niño (central and West Africa). However, there is limited understanding of how these modes of variability may change in future.

Inter-ocean exchange and global change

The southern tip of Africa is near the meeting place of three oceans, and the interocean exchange that occurs there influences global climate via its ability to modulate the Atlantic meridional overturning circulation (AMOC). Over the past 2 decades Agulhas leakage into the southeast Atlantic has increased, contributing to changes of temperature and salinity structure in the Atlantic Ocean, impacting the AMOC which in turn may then impact European and North American climate. However, global forecast models do not accurately represent the Agulhas and have large biases in the tropical Atlantic having implications on predictions for climate change over Africa.

Although its northern boundary is about 1000 km south of Africa, the Southern Ocean plays a key role in global change through heat stored in the water masses formed in this ocean, which then slowly circulate into the other ocean basins. In addition, changes in sea ice here impact weather and climate patterns in at least the Southern Hemisphere. Melting of glaciers on the Antarctic continent contributes to global sea level rise.

Risks of abrupt changes in ocean circulation and potential consequences

The AMOC plays an important function in transporting excess heat and anthropogenic carbon from the surface to the deep ocean, setting the pace of global warming. Any changes in the AMOC will have a far-reaching global impact, in particular the tropical areas. A collapse of the AMOC may have the potential to induce a cascade of abrupt events, related to the crossing of thresholds from different tipping points. However, such a worst-case scenario remains very poorly constrained quantitatively due to the large uncertainty of responses in the ocean to global warming.

The AMOC is believed to be a key tipping point of the Earth's climate system, and this is strongly influenced by what happens off the southernmost tip of Africa. Given the role of the Agulhas Current in modulating the AMOC it is essential that improved observations are in place. The poor representation of this region in models has far reaching effects on their ability to accurately represent global climate forecasts.

Compound events and cascading impacts

Compound events are characterised by multiple failures that can amplify overall risk and/or cause cascading impacts. A key example of this is that western boundary currents (WBC) are predicted to intensify and expand poleward, which, combined with intensified cyclogenesis can increase the likelihood of multiple hazards including increased sea level rise, severe storms, and storm surges. However, the Agulhas Current, off the East Coast of Africa has been shown to broaden, not strengthen.

Managing Risks and Building Resilience

Coastal systems are subject to a slow-onset of climate-related stressors (climate change), such as warming, sea-level rise, ocean acidification, and discrete weather-related stressors (extreme weather events), such as tropical cyclones. These factors are exacerbated in addition to climate-variability, e.g., El Niño Southern Oscillation, Pacific Decadal Oscillation, and the North Atlantic Oscillation. The impacts caused by these stressors include sea flooding, storm surges, inundation, loss of habitats, and coastal erosion, which affect both the human and natural systems, as well as socioeconomic sectors (e.g., ecosystems, fisheries, landscape, settlements, infrastructure, tourism, health and wellbeing, as well as people's livelihoods). The coastal systems' resilience is usually enough to cope with the typical fluctuations of these stressors. However, under the current climate change trends and the unsustainable practices affecting the natural resilience, there is an increasing need to reduce the climate-related vulnerabilities and the exposure, and foster adaptive capacity and readiness to climate change.

Indigenous knowledge accumulated over long periods of time, based on trial and error methods in various contexts, makes it possible to assess climate change risks that do not only consider the nature (e.g. severity, frequency, and etc.) of the risk but also the vulnerability (i.e. the extent to which the change can affect a person) of those who may be affected. Thus, the holistic understanding of climate change related issues of the indigenous communities and the discipline-based understanding of climate change for scientific research need to be aligned to achieve a comprehensive understanding of climate change, its impacts to co-produce adaptation and mitigation plans that are not only evidence based but locally verified by those who are affected by climate change.

Early warning systems

The Paris Agreement, Article 8 recognises the need to avert loss and damage associated with extreme events and that there needs to be cooperation and facilitation with regards to Early Warning Systems (EWSs) and contigency plans. Interventions are necessary to reduce risk, enhance resilience and contribute to the realization of SDGs. These factors on different timescales (prevention and post response) and different spatial scales (local risk management, regional and international coordination at multiple geographic scales).

To ensure maintenance and development of coastal areas at risk from storm surge, including mitigation of underlying losses, knowledge of the potential inundation zones or the expected disaster occurrence is required. Real-time monitoring systems such as tidal stations are important to predict sea level changes and tracking track severe storm events. In addition, ocean models have been widely and successfully applied by research communities' to hindcast historic events. However, operational storm surge models are crucial to predict sea surface elevations corresponding to TCs in relatively short time intervals to provide appropriate EWSs for the general public. Although monitoring of storm surges are needed these aforementioned capabilities are not always available in most countries around Africa which makes adaptation efforts difficult.

Furthermore, operational forecasting and multi-hazard early warning systems are an essential component of a policy response to mitigate the loss of life and damage in African countries, which are exposed to impacts of climate change in recent decades. A key aspect of EWSs is ensuring timely and effective risk communication with the end users. In an effort to improve applicability of EWSs, indigenous early warning knowledge and practices need to be institutionalized through continuous research and education. Traditional means of adaptation to risks from natural phenomena need to be integrated in the development of comprehensive disaster risk reduction strategies.

What can be done to reduce the future impact of cyclones?

Even before a cyclone is present there are activities which can either increase or decrease the ability of coastal communities to cope with their impacts. For example, the destruction of mangroves decreases the natural protection of the coastal zone to storm surges. However, there are ways by which the impact of tropical cyclones could be minimized:

a) **Using in situ data and satellite imagery:** Tropical cyclones can be detected and monitored prior to landfall using satellite imagery. For example, monitoring of oceanic and atmospheric conditions by the RAMA array, especially in the Seychelles Chagos Thermocline Ridge region, is important in determining the likelihood of TC activity during a particular cyclone season. This could be complemented by improvements in understanding of local air-sea interaction processes during these events and modern weather forecasting have the potential to lead to more accuracy in forecast storm track and intensity.

b) **Developing appropriate Early Warning Systems (EWS) and contingency plans:** EWS and contingency plans can help in reducing fatalities or injuries suffered by local populations. The severity of past storms should give impetus to build knowledge of the potential impacts of extreme weather amongst decision-makers, disaster management authorities and the public.

Knowledge Gaps

1. **Understanding natural climate variability in oceans around Africa:** this is important as it has major implications for forecasting. However, there is limited knowledge as to how this variability and subsequent extreme events will be impacted by climate change.

2. **Shortage of reliable measured data from oceans around Africa:** Knowledge gaps can be driven by gaps in FAIR[1] data which is essential in understanding and managing climate risks. There is a need to strengthen regional *in situ* observing initiatives[2] to generate data necessary to improve operational oceanography and climate forecast models. In addition real time monitoring, such as sea level stations are essential for EWSs.

3. **Information on potential inundation zones or the expected disaster occurrence of storm surges** is essential to support EWSs and provide adaptation and mitigation advise.

4. **Further work on decadal prediction systems:** decadal predictions can be useful for the development of climate services. Many user-groups need scenarios of potential changes on decadal scales to allow sufficient time for mitigation and adaptation.

5. **Co-generation and sharing of knowledge:** There are isolated ocean literacy initiatives for coastal communities but there remains a need for cooperation and a culturally sensitive way of integrating indigenous knowledge and applying transformative governance and adaptation.

6. **Capacity development and retention in climate information services, including early warning systems:** Capacity development of African regional and national institutions and experts should be done in a way that considers countries' needs and resources as well as the ability to retain that capacity.

Conclusion

Extreme events driven by natural modes of variability are further compounded by climate change. On its east coast, Africa has witnessed the fastest warming of the global oceans and on the west coast, an ocean which has large discrepancies in global forecast models. To the south of the continent these two oceans, Indian and Atlantic, meet with the Southern Ocean in an area that modulates global climate. The weather and climate of the continent, as well as the livelihoods of millions of Africans, is driven by changes in these oceans. As such, strengthening of climate services, information and EWSs is essential to protect lives and property and advance social economic transformation. This needs to be complemented by indigenous and traditional knowledge to ensure that the relevant and contextualised climate information in African contexts is used to inform decision making. Building human capacity in the co-generation of weather and climate information and services through cooperation and engagement is key. Also, investments in weather and climate infrastructure, including ocean observations, are urgent to support and strengthen climate governance processes in Africa.

Recommendations

1. **Enhancing understanding of natural modes of climate variability in the oceans around Africa** will improve the ability to forecast extreme events and provide more accurate climate change predictions, enhancing our ability to adapt.
2. **Implementing sustained observing systems in our oceans and coasts** through a coordinated, collaborative and culturally appropriate process is essential to achieve an improved understanding of extreme events and climate change impacts. This observing system needs to incorporate indigenous and local knowledge, and meet identified local, national and regional needs.
3. **Communication with coastal communities** has to be improved throughout Africa to ensure EWSs and adaptation and mitigation strategies are effective.

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[1] *Findable, accessible, interoperable and reuseable*
[2] *CLIVAR Indian Ocean Regional Panel supporting the Indian Ocean Observing System, the Atlantic panel, the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) and the Southern Ocean Observing System*

4. **Enhance regional collaboration and partnerships** by sharing capacity, infrastructure, best practices and data will ensure sustainable African solutions driven by Africa for Africa.
5. **Increase modeling capabilities among the African scientists** in oceanography and meteorology to support early warning and contigency plans to enhance adaptation to extreme events and abrupt changes.

Further Reading

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