Addressing climate change in the Indian Ocean Region: knowledge, capabilities and networks





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At the time of writing in February 2023, two backto-back cyclones-Cyclone Freddy and Cyclone Gabrielle-formed off the coast of Australia. Both had wind speeds exceeding 150 km per hour that resulted in wind and flood damage in Mauritius, Madagascar, Australia and New Zealand.

In the northern Indian Ocean, more than 80% of global fatalities from tropical cyclones occur mostly due to coastal flooding, particularly in India, Bangladesh and Myanmar, despite accounting for only 6% of global cyclone occurrences.¹ Fortunately, cyclone forecasts have improved in the Indian Ocean due to better monitoring of ocean-atmospheric conditions that help to provide more accurate forecasts of cyclone tracks and landfall, reducing the fatalities in the recent period.²

However, ocean warming is resulting in new challenges such as rapid intensification of cyclones, which is difficult to forecast, and there has been a detectable increase in the frequency and duration of these cyclones.



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In May 2021, Cyclone Amphan rapidly intensified into an extremely powerful cyclone, exceeding 270 km per hour wind speed. The storm surges and rains from the cyclone, combined with a rising sea level and high tide, resulted in severe flooding along the east coast of India and Bangladesh, damaging infrastructure and agriculture.

Such unpredictable climate patterns call for enhancing our existing monitoring marine networks to improve our ability to address emerging challenges in the Indian Ocean Region (IOR).

Sovereign states that either border on or are in the Indian Ocean are home to one-third of the world's population. The security of food, water and energy in the region's countries and islands are intrinsically tied to its climate, with marine environmental goods and services, as well as trade within the Indian Ocean basin, underpinning their economies. Many people in these countries are dependent on fisheries and rain-fed agriculture that are vulnerable to climate variability and extremes.

Kamaljit Ray et al, "An Assessment of Long-term Changes in Mortalities due to Extreme Weather Events in India: A study of 50 years' Data, 1970-2019," 2 Weather and Climate Extremes 32 (2021).

Vineet Kumar Singh and M.K. Roxy, "A Review of Ocean-atmosphere Interactions during Tropical Cyclones in the North Indian Ocean," Earth-Science Reviews 226 (2022). https://doi.org/10.1016/j.earscirev.2022.103967

Hence, monitoring and understanding the state of the Indian Ocean and its influence on climate is of critical importance to the populous nations that line its rim, as well as being of strategic importance for maintaining stability in the regional and global economy.

Impacts of climate change

The Indian Ocean appears particularly vulnerable to accelerating climate change with greater intensity of tropical cyclones, marine heatwaves and sea level rises, that all have negative impacts on the economies of the densely populated bordering countries. Recent studies suggest the Indian Ocean has stored a quarter of the global oceanic heat uptake from the atmosphere over the last two decades, despite only covering around 13% of the Earth.³ The western tropical Indian Ocean has been warming for more than a century, at a rate faster than any other region of the tropical oceans. This warming has had farreaching global impacts, causing droughts in the West Sahel, the Mediterranean and South Africa, and increased occurrence of tropical cyclones in the northern Indian Ocean. Indian Ocean warming has also been linked to strengthened winds south of Greenland and cooled the subpolar North Atlantic, increasing droughts in South Asia and Eastern Africa that are predicted to increase the number of undernourished people by 50% by 2030.⁴

What further compounds the effects of this warming are short-term extreme warming events known as marine heat waves, which consist of periods of extremely high temperatures that persist from

Figure 1: Artist's illustration of the Indian Ocean Observing System and its societal applications



Source: JAMSTEC³

- 3 L.M. Beal et al, "A Roadmap to INdOOS-2: Better Observations of the Rapidly Warming Indian Ocean," Bulletin of the American Meteorological Society 101, no. 11 (2020). https://doi.org/10.1175/BAMS-D-19-0209.1.
- 4 Chris Funk et al, "Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development," Proceedings of the National Academy of Sciences 105, no. 32 (2008): 11081-11086.

days to months and can extend up to thousands of kilometres over an oceanic region and penetrate hundreds of metres into the ocean.

Marine heat waves have an enormous impact on marine life, their habitats and ecosystems, including: mass mortality of fish, mammal and bird species; toxic algal blooms; loss of kelp forest and coastal vegetation; ocean biodiversity reduction; low ocean productivity; and coral reef decay. Over the past two decades, such heat waves have become stronger, more widespread over larger regions and have occurred more often.

A better understanding of what is driving the warming Indian Ocean and the occurrence of marine heat waves will have great value for aquaculture and fisheries forecasts and management, marine habitat conservation and restoration, and improve the resilience of regional Indian Ocean countries.

Other examples of the climate risks are changing monsoon patterns, reflected in the droughts and heavy rains that threaten the food and water security of IOR countries. Such temperamental patterns also increase the occurrence of floods that result in the loss of human lives, animals and property. They have also led to sea level rises, culminating in the inundation of small islands in the Indian Ocean and the loss of the first mammalian species, the Bramble Cay melomys.⁵ Clearly, there is societal and scientific impetus for establishing observation systems that can accurately detect and attribute changes in the climate system to improve scientific understanding and support reliable decision-making among policymakers.

Indian Ocean circulation

The whole Indian Ocean basin is intimately linked through coupled atmosphere/ocean processes and through many distinct inter-basin oceanic connections that provide an important conduit for the exchange of heat, salt and other biogeochemical properties. Unlike other major ocean basins, the Indian Ocean is restricted to the north by the Asian landmass, with high mountainous terrain that sets up a surface temperature gradient between the land and the ocean. This drives the endless rhythm of the seasonally-reversing monsoon winds and associated rainfall.

In addition, the Indian subcontinent effectively creates two sub-basins where differences in evaporation, precipitation and river runoff account for pronounced differences in the oceanic properties between the Arabian Sea and Bay of Bengal. Monsoonal changes dominate the northern Indian Ocean.

In the tropical eastern Indian Ocean, the gappy Indonesian archipelago permits the only low latitude exchange between two major ocean basins with tropical water flowing from the Pacific into the Indian Ocean. The vast amount of rainfall and strong ocean mixing within the Indonesian seas results in a freshwater stream that exits into the Indian Ocean, with parts flowing southward off the coast of Western Australia in the Leeuwin Current-the only poleward-flowing eastern boundary current in the world-and the remainder visibly streaking across the whole Indian Ocean basin to the northern tip of Madagascar. From there, the flow passes to the north of Madagascar, with some of it inputting into the East African Coastal Current and feeding into the north Indian Ocean's monsoonal circulation, and the rest heading through the Mozambique Channel.

The flow to the south of Madagascar joins the Mozambique Channel waters to form the Agulhas Current, the strongest western boundary current in the Southern Hemisphere, flowing poleward along the east coast of the southern African continent. Most of the Agulhas retroflects sharply eastward back into the Indian Ocean, but some eddies are shed at the tip of Africa and find their way into the Atlantic Ocean. This process introduces heat and salt into the basin, which in turn moderates Earth's climate. Thus, boundary currents like the Agulhas and the Leeuwin play an important role in heat

⁵ N.L. Waller et al, "The Bramble Cay melomys *Melomys rubicola* (Rodentia: Muridae): a first mammalian extinction caused by human-induced climate change?," *Wildlife Research* 44, no. 1 (2017): 9, 21.



Figure 2: Schematic of major surface Indian Ocean Currents overlaid on the mean current speed **Note:** Thin black lines show bathymetry at 200, 3000m.

Source: Dr Laura Braby

distribution in ocean basins: they dominate the poleward transport of warm water and are major drivers of climate variability, extreme weather events and marine heatwaves that influence weather and regional ecosystems. Communication between the coast and open ocean is regulated by these boundary currents that flow along the continental slopes, and affects ecosystems, sea level, flood levels, erosion and commercial activity.

Indian Ocean observations and partnerships

The complexity of the Indian Ocean circulation calls for an integrated and basin-wide approach for a marine observing system that will provide the needed climate data to make accurate predictions of sea level, tropical cyclones, monsoon rains and marine heat waves. To address this need, a partnership of many IOR countries was formulated to support the Indian Ocean Observing System (IndOOS)³, a sustained observing system that monitors basin-scale ocean-atmosphere conditions and permits a flexible framework for more regional and coastal monitoring.

As prioritised by IndOOS, backbone oceanographic measurements of velocity, temperature and salinity -provided by various platforms such as profiling floats, surface drifters and moored arrays along with satellite measurements (including sea surface height and wind) -are needed basin-wide. In the dynamic regions of the boundary currents, dense, daily-to-monthly observations of velocity, temperature and salinity are required to detect smaller time and length scales.

More innovative strategies of integrated observing systems are called for (e.g. combining current meter arrays, gliders, and acoustic measurements with periodic full-depth hydrographic sections for important climate variables such as carbon, nutrients, and oxygen). It is important that data information is returned in real time in order to feed directly into weather and climate forecast models.

Promoting partnerships and continuing to grow the capacity of developing states of the region is critical to the continued success and maintenance of IndOOS, both on international and regional levels. Building and maintaining ocean observing systems can be expensive, so it is essential that the international community supports the regional efforts undertaken by the various IOR governments, which will arguably see the most value because of the direct impact of extreme weather on their coastlines.

Along with IOR countries that include Australia, India, Indonesia and South Africa, international investment in IndOOS also comes from the US, China, Europe, Japan and Korea.⁶ Such partnerships are crucial as millions of dollars are needed to sustain such observing systems, from the original cost of the infrastructure to the costs associated with the ships' operations in deploying instruments.

In addition, intergovernmental bodies such as the World Meteorological Organisation (WMO) and the International Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organisation (UNESCO), as well as international scientific bodies such as Climate and Ocean: Variability, Predictability and Change (CLIVAR) and the Scientific Commission for Oceanographic Research (SCOR) can be used to help facilitate this. These programs also serve a vital role with regards to performing observations and accessing data held within countries' exclusive economic zones (EEZs).

The utility of IndOOS ultimately depends on the identification of, and engagement with, end-users and decision-makers, and on the practical accessibility and transparency of data for a range of products and for decision-making. A key factor affecting investment in

scientific research is the level of national appreciation for the importance of the marine sector to the country's economy and resources. The Global Ocean Observing System (GOOS) and associated regional alliances are in a unique position to be able to make the case to national governments and stakeholders through the UNESCO IOC. Moving forward, it will be essential to improve evaluation mechanisms for what has been achieved to date, and to enact long-term thinking around maintaining existing, and pursuing new, funding mechanisms.

As with any observing system, it is important the IndOOS continues to evolve. With emerging new technologies and improving capabilities, there is little doubt global ocean observing systems will look different 10 years from now and any future vision needs to be flexible.⁷

Sensor developments will lead to a much greater range of physical and biogeochemical variables and allow for more autonomous measurement. Voluntary observing ships with more automated equipment will enhance the system and feedback into realtime observations and provide data for assimilation into models for operational oceanography. Data dissemination for operational applications should form a key part of any vision, as should end-user engagement. Without a systematic approach to secure and disseminate in situ observations, stakeholder communities will not fully realise the benefits of in situ observing investments.

Empowering communities and people

Ocean observing does not just concern technology. It also involves people, and a community of many cultures and capabilities. Effective communication between scientists from different parts of the world, enhancing collaborations, as well as sharing knowledge and data, technology and equipment should not be something for the distant future.

⁶ Juliet Hermes et al, "IndOOS, the Indian Ocean Regional Panel and OceanObs19," CLIVAR Exchanges 78 (2020): 59, 63.

⁷ D.M. Legler et al, "The current status of the real-time in situ Global Ocean Observing System for operational oceanography," Journal of Operational Oceanography 8 (2015): 189, 200. https://doi.org/10.1080/1755876X.2015.1049883.

Communication within and to the ocean and coastal communities is also essential to avoid vandalism to the isolated and vulnerable components of the observing system. Increasing the literacy of these communities of the benefit of the observing system to their daily life is essential. Capacity development necessarily involves a meaningful engagement that contributes to the global ocean observing system while aiding developing countries to manage their own resources. We need to strengthen and broaden leadership and communities for sustained observations, and provide the tools for that community to cross-collaborate. This includes documented best practices, training and an open, collaborative environment. Building capacity through monitoring will build scientific literacy, which in turn will enable all countries to engage purposefully in the global dialogue. Sustained observing requires a coordinated, collaborative and culturally appropriate process, incorporating Indigenous and local knowledge, with long-term resourcing, that meets identified local, national and regional needs.

Given the influence this will have on economic stability for the impacted countries, it is essential that the longterm resourcing continues to be a combination of both international and local efforts.

Conclusion

Knowledge of the Indian Ocean climate and ecosystems, and the ability to predict its future, depends on a wide range of socio-economic and environmental data, a significant part of which is provided by IndOOS. Although we can monitor and track cyclonic systems due to the buoys and instruments in the oceans, satellites in the sky and weather models running on high-performance computers, improving IndOOS and incorporating the global warming signals in the weather models can help us tackle the challenges of intense cyclones in the future. What happens in the Indian Ocean goes beyond Indian Ocean countries. The Indian Ocean can be seen as a 'canary in a coalmine' for what the other ocean basins are going to see. Hence it is critical for IOR countries and those further afield to monitor these oceanic changes if we want to build better resilience for other ocean basins tomorrow. 🏈





Indian Ocean Futures Prospects for shared regional success



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