Factsheet

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Climate Systems

National Environmental Science Program

Oceans and Coasts

The Indian Ocean: more to Australia than a backdrop for spectacular sunsets

Australia's western coastline is also the eastern boundary of the Indian Ocean. While it's smaller than the Pacific and Atlantic oceans, the Indian Ocean packs a punch when it comes to affecting our weather and the world's climate.

Having warmed faster since the 1950s than any other ocean, major environmental changes are occurring in the Indian Ocean. Understanding the role of a changing climate alongside non-climate pressures are important considerations for those managing the region's vulnerable resources.

NESP Climate Systems hub researchers collaborated with a wide range of experts to present the current state of knowledge and highlighting gaps that remain in our understanding of this globally significant region in: *The Indian Ocean and its role in the Global Climate System.*

The Indian Ocean provides food, water and energy security to 22 countries around its rim, home to one-third of Earth's human population (Hermes et al. 2019). Many of these countries have limited resources and rely on rain-fed, community-based agriculture and small-scale fishing. This depends heavily on favourable weather and climate patterns, in the ocean as well as the atmosphere. Despite there being so many people dependant on the Indian Ocean, it is one of the least studied oceans in the world.

How the Indian Ocean influences our climate

There are two significant ways in which the Indian Ocean affects our weather and climate; changing patterns of the ocean's surface temperature and the way the ocean and atmosphere move heat and fresh water around.

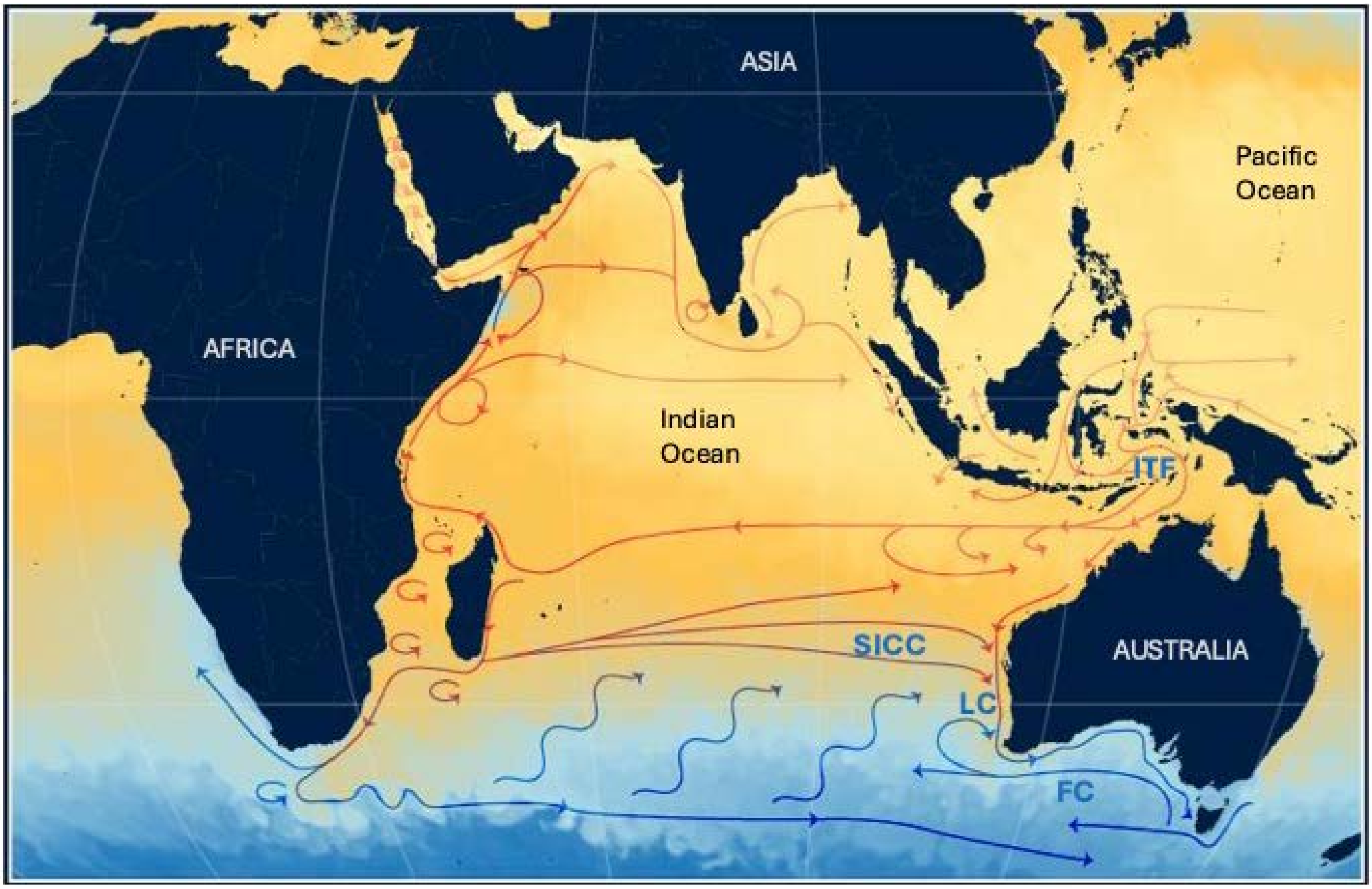


Figure 1. The near-surface currents of the Indian Ocean and Indian sector of the Southern Ocean during the southwest monsoon (July–August). Colour indicates sea surface temperature from warm (orange) to cold (blue) in background shading and currents. Acronyms for currents: ITF, Indonesian Throughflow; SICC, South Indian Countercurrent; LC, Leeuwin Current; FC, Flinders Current. Source: The Indian Ocean and its Role in the Global Climate System: https://doi.org/10.1016/C2019-0-04588-8

For example, the monsoon climate that brings wet and dry seasons to northern Australia exists because the Indian Ocean is blocked to the north by the Asian landmass (Figure 1). Frozen winters and hot summers over the Asian interior control air pressure patterns and winds that reverse from winter to summer. This shift causes the rainfall activity to move north and south to bring life-giving rain to the lands in their path, sometimes in excessive amounts.

The Indian Ocean and our climate drivers

The tropical waters north of Australia are the warmest on the planet, providing heat and moisture evaporated from the ocean surface building immense, towering cloud systems that gather rainfall and influence atmospheric circulation in regions across the world. These clouds follow the regions with sea surface temperatures warmer than 28 °C, which is the threshold for generating moisture-laden clouds that reach far up into the atmosphere.

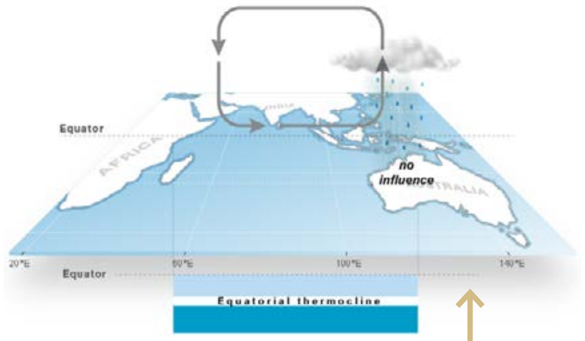
Changes in winds and ocean currents in the Pacific and Indian oceans, controlled by climate variations such as the El Niño–Southern Oscillation and Indian Ocean Dipole – key climate drivers for Australia – shift the warm surface temperatures east or west and take the rains with them.

El Niño is a warming of the central-east Pacific Ocean typically associated with drier than usual conditions in eastern Australia.

Its counterpart, La Niña, involves cooling in the central Pacific Ocean and a warming of waters to the north of Australia. La Niña is generally associated with wetter than usual conditions, for example those experienced from 2020 to 2022 in eastern Australia.

The Indian Ocean Dipole shifts tropical ocean heat between Australia and Africa, alternately influencing the likelihood of rainfall over Africa or over central and southern Australia.

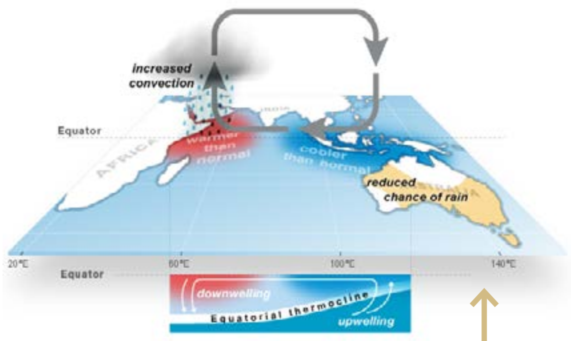
The positive phase of the Indian Ocean Dipole increases the chances of warmer and drier conditions across southern Australia. The negative phase is typically wetter than usual. These dry and wet conditions are usually amplified when these Indian Ocean Dipole events co-occur with El Niño and La Niña, respectively. The absence of negative Indian Ocean Dipole events has been linked with droughts in southeast Australia.



Neutral IOD phase

Water from the Pacific flows between the islands of Indonesia, keeping seas to Australia's northwest warm. Air rises above this area and falls over the western half of the Indian Ocean basin, blowing westerly winds along the equator.

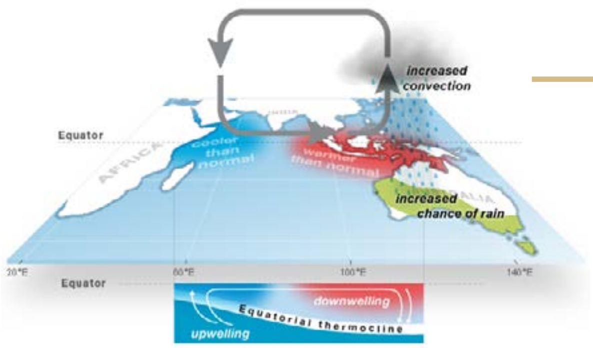
Temperatures are close to normal across the tropical Indian Ocean, and hence the neutral IOD results in little change to Australia's climate.



Positive IOD phase

Westerly winds weaken along the equator allowing warm water to shift towards Africa. Changes in the winds also allow cool water to rise up from the deep ocean in the east. This sets up a temperature difference across the tropical Indian Ocean with cooler than normal water in the east and warmer than normal water in the west.

Generally this means there is less moisture than normal in the atmosphere to the northwest of Australia. This changes the path of weather systems coming from Australia's west, often resulting in less rainfall and higher than normal temperatures over parts of Australia during winter and spring.



Negative IOD phase

Westerly winds weaken along the equator allowing warm water to shift towards Africa. Changes in the winds also allow cool water to rise up from the deep ocean in the east. This sets up a temperature difference across the tropical Indian Ocean with cooler than normal water in the east and warmer than normal water in the west.

A negative IOD typically results in above-average winter-spring rainfall over parts of southern Australia as the warmer waters of northwest Australia provide more available moisture to weather systems crossing the country.

Figure 2: representation of the neutral, positive and negative phases of the Indian Ocean Dipole. Source: Bureau of Meteorology © Commonwealth of Australia

The Madden–Julian Oscillation is another important climate driver that is modulated by underlying Indian Ocean sea surface temperatures. This eastward propagating atmospheric wave crosses the Indian Ocean towards the north of Australia, affecting rainfall in Australia.

The Indian Ocean has warmed faster since the 1950s than any other ocean. There is faster warming in the northwest and slower warming in the southeast near Australia. This means the Indian Ocean winds and sea surface temperatures are favourable to positive Indian Ocean Dipole events.

These positive events can reduce rainfall across southern Australia. Some climate model projections suggest more frequent and possibly more intense positive Indian Ocean Dipole events are likely.

The Indian Ocean warming has resulted in:

- rising sea level via thermal expansion of seawater,
- the potential increase in extremely severe cyclones and their rapid intensification
- a consistent increase in the frequency and intensity of marine heatwaves in the Indian Ocean, with the potential to impact fisheries and ecosystems.

How the ocean currents connect the world

North of Australia, warm waters flow into the Indian Ocean along the Indonesian Throughflow – a river of ocean water that winds its way from the Pacific Ocean through the passages between the Indonesian islands (Figure 1). This leaky path between the Pacific and Indian Oceans is the reason we have the Leeuwin Current flowing southward along Western Australia. It is also why the South Indian Countercurrent brings waters from as far west as Madagascar to merge with the Leeuwin Current. This confluence creates a downwelling environment that brings less cool, nutrient rich water to the surface than other eastern boundaries.

The warm Leeuwin Current and its eddies, combined with sporadic near-shore upwelling, provide enough nutrients to support valuable commercial fisheries and incredible natural ecosystems, like that found at Ningaloo Reef. When the Leeuwin Current is at its strongest, around May–June each year, it turns the corner of Cape Leeuwin and warm waters continue along southern Australia and as far east as Tasmania. We can track the Leeuwin Current by monitoring ocean temperature as in this image (Figure 2) from Australia's Integrated Marine Observing System.

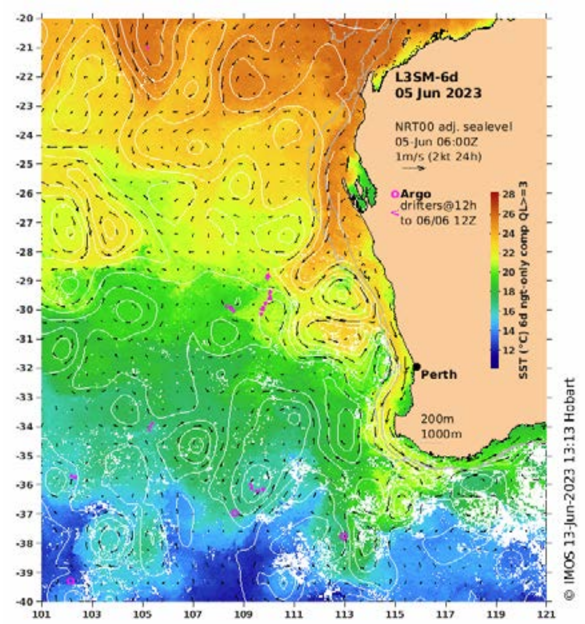


Figure 3: Integrated Marine Observing System sea surface temperature observations showing the Leeuwin and other currents off the Western Australian coast on 5 June 2023. Source: IMOS, https://oceancurrent.aodn.org.au/product php?product=daily&region=SW&date=20230605121913&rtype=SR

A stronger Indonesian Throughflow over the last decade or so has brought more warm, fresh water from the Pacific Ocean into the Indian Ocean. This has been a major contributing factor to the rapid warming of the Indian Ocean and has also strengthened the Leeuwin Current. The warmer, fresher environment along Western Australia was one of the factors leading to the intense marine heatwave there in 2011, dubbed the Ningaloo Niño.

Changing interactions between ocean and atmosphere

There is a strong coupling between the ocean and atmosphere and the impact of their variability on the chemical composition and biology of the Indian Ocean.

One example of change in the ocean-atmosphere coupling is due to the rapid warming of surface waters. Indian Ocean sea surface temperatures have warmed at a rate of 0.12 °C per decade since 1950, resulting in a sea surface temperature that is today 0.76 °C warmer than in 1950. The warmer waters are more buoyant, making them harder to mix with the waters below.

This means that oxygen from the air that is absorbed by the sea surface can't penetrate as deeply below the surface and nutrient-rich deeper waters aren't easily brought to the surface where it is light enough for phytoplankton to grow. Phytoplankton growth needs the key ingredients of nutrients and light. As the base of the food chain in the ocean, less phytoplankton is a concern for the marine life and communities that depend on it for food.

Expanding our understanding of the Indian Ocean

The Indian Ocean has been observed for 50 years, which is relatively recent in the history of oceanography. In 1962, an impressive international collaboration launched the International Indian Ocean Expedition (IIOE) to learn more about the under-studied ocean and atmosphere in this region. Fourteen countries sent forty-six research vessels to the Indian Ocean over several years, and many more countries engaged in analysis and discussions of the observations (Hood et al. 2014). Australia played an important part, providing oceanographic surveys of the southeastern side of the Indian Ocean and contributing to the first ever atlas of Indian Ocean waters (Wyrtki, 1971).

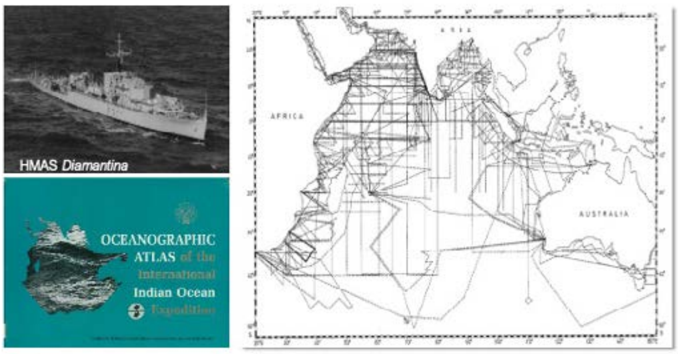


Figure 4. Australian oceanographers aboard HMAS Diamantina played an important role in the International Indian Ocean Expedition of the 1960s, conducting surveys of the southeast Indian Ocean to contribute to the first Indian Ocean atlas.

In 2015, the IIOE-2 was launched to re-invigorate oceanographic and atmospheric research from coastal environments to the deep sea, revealing new information on the Indian Ocean that is fundamental for future sustainable development and expansion of the Indian Ocean's blue economy. A major contribution from Australia was a voyage in 2019 on *RV Investigator* offshore of Western Australia to quantify change since 1963 in ocean currents.
They also studied the physical, chemical and biological characteristics in this region that are particularly vulnerable to climate change (Beckley et al., 2022). The Indian Ocean observing system was significantly disrupted by COVID-19. This led to backward steps in meeting some of the most pressing societal needs. A new roadmap to regain ground (Beal et al. 2020) has been proposed as part of the Global Ocean Observatory 2030 Strategy

The future of the Indian Ocean

Major environmental changes are occurring in the Indian Ocean and climate change is a primary driver.
These changes include ocean warming, increasing amounts of carbon dioxide leading to acidification of waters, reduction in the availability of nutrients, reduced oxygen levels and changing wind patterns. The multi-disciplinary assessment of changes in the Indian Ocean that is presented in the book provides a robust scientific background from which to manage the vulnerable resources of the region.

The *Indian Ocean and its role in the Global Climate System* makes clear that non-climate stressors such as overfishing and insufficient fisheries management can worsen the impacts of climate change alone. The recognition of rapid change in a region that is central to global climate and on which a third of Earth's population depends could motivate action to reduce emissions more rapidly.

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