climate extremes
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Could understanding the Indian Ocean improve climate predictions for Australia?

ARC Centre of Excellence for Climate Extremes Briefing Note 17

- Conditions in the Indian Ocean can affect the risk of Australia experiencing droughts, floods, marine heatwaves and bushfires and alter the prospects for rainfed agriculture in some parts of the country.
- Reliable forecasts of conditions in the Indian Ocean a season in advance would help us predict upcoming changes in the risk of climate extremes in some parts of Australia. However, producing such forecasts requires us to better understand, and more accurately model, relevant Indian Ocean climate processes.
- There is strong evidence indicating that variations in the climate of the Indian Ocean are becoming more conducive to frequent extreme dry conditions in southern Australia. This, and climate model simulations of the future, suggest that human-caused climate change will result in the Indian Ocean becoming more important to Australia's climate than at any other time in recent centuries.

You may have heard about the influence of sea surface temperatures (SSTs) in the tropical Pacific Ocean on Australia's climate and how forecasts of the El Niño–Southern Oscillation (ENSO) help to give warnings of flood, drought and bushfire risk in Australia months in advance … but what about the tropical Indian Ocean? Although Indian Ocean SSTs are harder to predict seasons in advance[1], they are still an important driver of Australia's climate, including extreme climate conditions.

How do sea surface temperatures in the Indian Ocean vary?

SSTs in the Indian Ocean behave quite differently from SSTs in other ocean basins. Firstly, they do not vary much over time, though their small variations are important for the climate of Australia and other surrounding regions. Secondly, they are more strongly affected by conditions in other ocean basins. Specifically, the climate of the Indian Ocean is linked to the climate of the Pacific Ocean through atmospheric circulation patterns and ocean currents that span Indonesia. This means that SSTs in the Indian Ocean are strongly influenced by conditions in the Pacific and ENSO in particular[2,3]. For example, the tropical Indian Ocean tends to warm a season after the peak of strong El Niño events[4]. Strong La Niña events can sometimes trigger persistent warming of the seas off Western Australia in events called marine heatwaves[5,6].

However, not all of the SST variations in the tropical Indian Ocean that impact Australia's climate are entirely dependent on ENSO[7,8,9]. SST variations that are part of a phenomenon known as the Indian Ocean Dipole (IOD)[10] are also important and are partly due to upwelling of cool subsurface ocean waters along the coast of Java and Sumatra that can occur independently of El Niño. The IOD involves temporary changes in the contrast between SSTs in the eastern and western sides of tropical Indian Ocean. These changes are summarised by the Dipole Mode Index (Figure 1). When the DMI is far from average, the IOD it is said to be in a 'positive' or 'negative' phase, and temperature and rainfall in the Horn of Africa, southeast Asia and southern Australia can be affected by changes in the circulation of atmosphere. IOD events typically begin to develop around May and peak around October/November before rapidly dissipating as the Australian monsoon develops[11].

How does the Indian Ocean affect Australia's climate?

The climate interactions between the tropical Pacific and Indian oceans mean that the impacts that conditions in these oceans have on Australia are often compounded. For example, warming across much of the Indian Ocean in response to El Niño events tends to enhance the impacts of El Niño on Australia[3]. In addition, positive IOD events are more likely to occur during El Niño years, and both factors promote hotter and drier conditions, with less moisture in the soil, over Australia – especially in the eastern states[12]. Although the IOD is by no means the only Indian Ocean phenomenon to affect Australia's climate[13], a catalogue of recent impacts coincident with IOD events highlight how important Indian Ocean SSTs are on the climate of Australia.

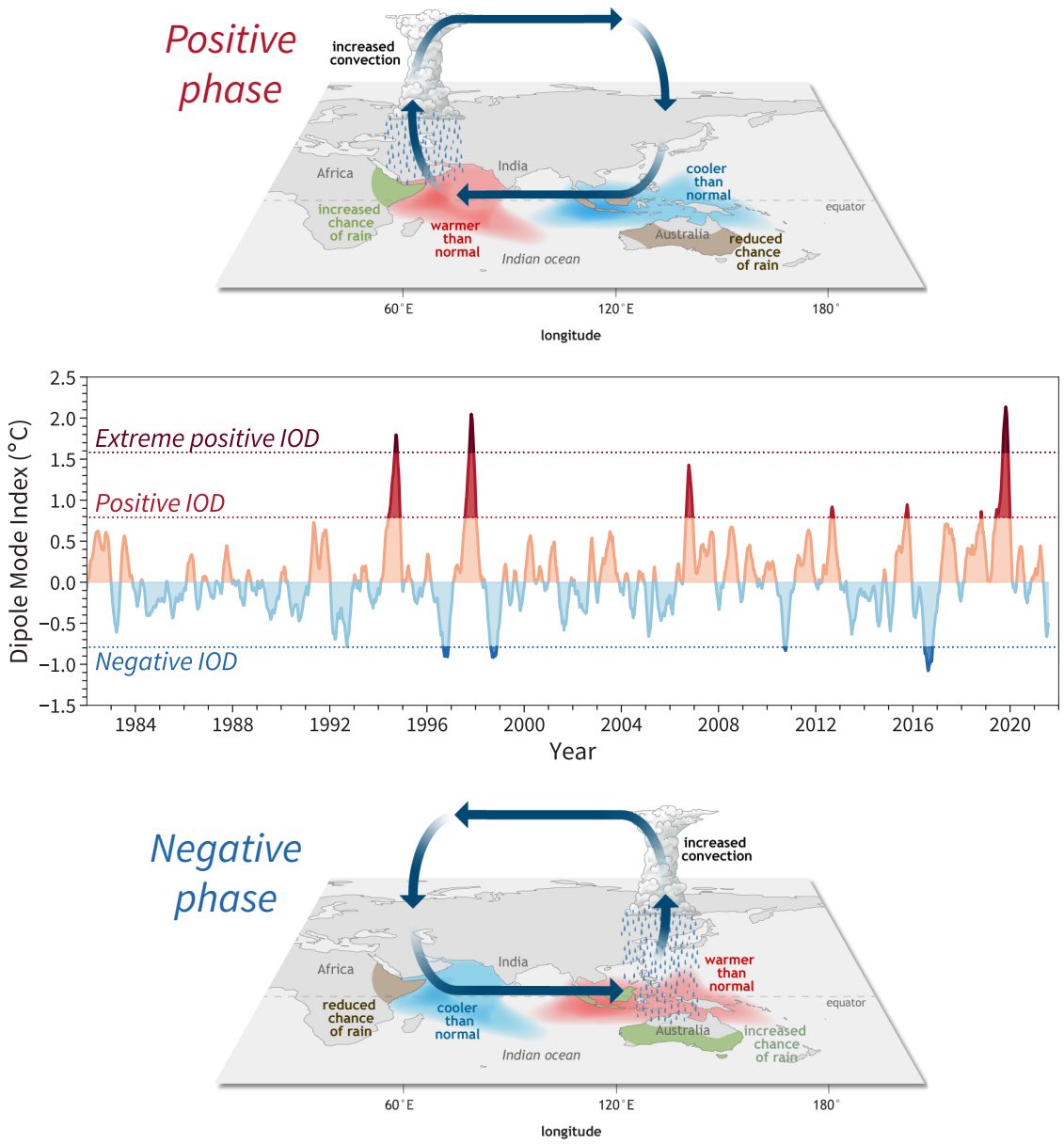

Figure 1: Phases of the IOD. Schematics from NOAA Climate.gov.
Dipole Mode Index calculated using the Reynolds OIv2 SST dataset sourced from NOAA/ESRL.

Excellent start to the growing season in 2021 - The IOD entered a negative phase in late May 2021 and a weak negative IOD state persisted through winter and spring. Unusually warm ocean temperatures in the eastern equatorial Indian Ocean contributed to plentiful moisture in weather systems crossing southern Australia, resulting in above average rainfall across much of the country during June 2021. The result was an excellent start to the crop growing season in many of Australia's main agricultural regions[14]. This negative IOD event may now be compounded by a developing La Niña event in the Pacific Ocean, which is expected to further promote good rainfall across eastern Australia through the summer.

Extended drought and bushfires in eastern Australia in 2019/2020 - One of the strongest positive IOD events on record developed during 2019. This extended and intensified a drought in eastern Australia associated with three years in a row (2017, 2018 and 2019) of failed cool season rainfall. The extreme hot and dry conditions brought by the event, compounded by a rare warming of the stratosphere that developed over Antarctica in August of 2019[15,16], played a role in Australia's Black Summer bushfire disaster[17,18].

Great Barrier Reef marine heatwave in 2019 - Indian Ocean SSTs can influence SSTs in other oceans around Australia, including the occurrence of marine heatwaves. For example, the strong positive IOD event in 2019 resulted in calm, cloud-free conditions over the Great Barrier Reef that allowed surface waters to warm to their highest temperature on record in February 2020, causing mass coral bleaching[19].

Record-breaking rains in 2016 - The strongest negative IOD event on record occurred in 2016[20] and in July–September 2016, southeast Australia suffered from record-breaking wet conditions. Warmth in the eastern Indian Ocean increased the likelihood of the record wet July–September in southeast Australia by at least a factor two[21].

How can we use this knowledge in seasonal predictions?

Tropical ocean–atmosphere variability has some predictability on the scale of months to seasons, which means that advance warming of climate risks can help communities, businesses and emergency services to be better prepared. For example, the expected impacts from the 2019 positive IOD event occurred in seasonal outlooks from the Bureau of Meteorology from as early as May 2019 and informed the seasonal bushfire outlook for Australia released in August 2019.

Using knowledge of the links between Indian Ocean SSTs and the Australian climate to forecast extreme conditions a season in advance is still challenging. To do this well, computer models used for seasonal predictions must be able to accurately predict the position, sign, and size of SST changes in the Indian and Pacific oceans, and simulate the complex atmospheric links between them and the Australian climate. Seasonal prediction systems, including the Australian ACCESS-S system, sometimes fail to do this. For example, these systems predicted that a negative IOD event would contribute to a wetter than average spring over eastern Australia in 2020[22]. However, the event had a different pattern of SSTs than predicted and decayed more quickly than expected[23]. This, and other factors that were not accurately forecast, resulted in parts of the country being drier than was predicted, with Queensland experiencing a severe shortage of rainfall.

How might the Indian Ocean and its influence on Australia's climate change in the future?

Future climate change will very likely change the influence that the Indian Ocean has on Australia's climate. Climate models project that an increase in the average temperature of the tropical oceans will be associated with changes in the patterns of circulation in the atmosphere, resulting in more rainfall in some places and less rainfall in others. The way in which tropical SSTs vary from year to year, and season to season, may also change, but climate models alone do not yet provide clear information on such changes.

Many climate models have serious failings when it comes to representing the variability of SSTs in the tropical oceans, including SST variability in the Indian Ocean[24]. The Indian Ocean behaves very differently in different models and further research is needed to understand this to improve our confidence in model-based conclusions about how the ocean and its influence on Australia's climate will change in the future. However, historically, the models that have done best at capturing the broad patterns of Indian Ocean temperatures have tended to show that human-caused climate warming results in more frequent positive IOD events. They suggest that strong positive IOD events may occur more often this century compared to last if greenhouse gas emissions continue to increase[25].

On its own, this information from the models would not be sufficient to draw strong conclusions about the future of SST variability in the Indian Ocean. In addition, direct instrumental measurements of the temperature of different parts of the tropical Indian Ocean do not go back far enough in time to definitively establish whether trends consistent with the model projections are occurring.

Fortunately, palaeoclimate data can provide another line of evidence on how Indian Ocean conditions are changing, based on behaviour that extends back into pre-industrial times. Multiple centuries of coral data show that, although the frequency and strength of positive IOD events is highly variable, they have been becoming significantly stronger and are occurring more often since the 1960s[26,27]. If current trends continue, as some models suggest they will, the frequency with which positive IOD events affect our climate will soon be unprecedented in recent centuries (Figure 2)[7].

When viewed together, the multiple independent lines of evidence provided by paleoclimate data, direct observations and climate model simulations, all point towards an IOD phenomenon that is being altered by human-caused climate change. This increases our confidence that we expect positive IOD events to become a stronger and more frequent influence on Australia's climate extremes.

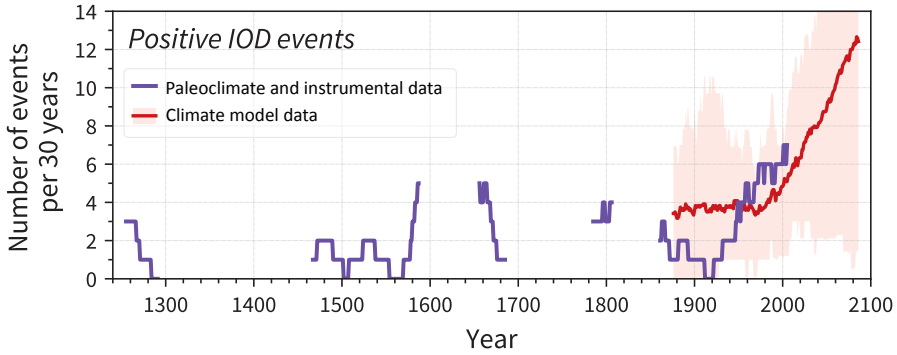

Figure 2: Frequency of positive IOD events from paleoclimate and instrumental measurements (purple), overall trend from 35 climate model simulations with continued increases in greenhouse gas emissions (red line) and range of results from the model simulations (pink shading). Adapted from Abram et al. (2020) Palaeoclimate perspectives on the Indian Ocean Dipole. Quaternary Science Reviews. https://doi.org/10.1016/j.quascirev.2020.106302

What further research is being done by the ARC Centre of Excellence for Climate Extremes?

Ongoing research by the ARC Centre of Excellence for Climate Extremes aims to transform our understanding of how large-scale climate processes in the tropical Indian and Pacific Oceans, and their interactions with each other, affect Australia's weather. Improved scientific understanding and modelling of these processes and interactions will provide the knowledge needed for more confident seasonal predictions relevant to Australia's drought, flood and fire risk. The Centre is also conducting research that will help long-term climate projections for Australia better account for the effects of future changes in the tropical oceans.

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