




Earth Systems and
Climate Change
Hub

National Environmental Science Programme

The background image is a composite. The top half shows a satellite view of a tropical cyclone with a distinct eye, swirling over a dark blue ocean. The bottom half shows a close-up, vibrant view of a coral reef with many yellowish-brown coral polyps. A diagonal line separates the two images.

Tropical cyclones and climate change in the Great Barrier Reef region

Tropical cyclones can devastate coastal and marine ecosystems in the Great Barrier Reef region.
Reef image: Matt Curnock

> The annual number of tropical cyclones in the Great Barrier Reef region shows large year-to-year variability, primarily due to the El Niño-Southern Oscillation phenomenon.

> There is no clear trend in the annual number of observed tropical cyclones impacting the Great Barrier Reef since 1980. However, during this time impacts from other stressors have increased in frequency and severity. Most notably, three episodes of mass coral bleaching since 2016 have compounded the effects of cyclones on the health of the reef.

> Climate models indicate that tropical cyclones will become less common over most of the Great Barrier Reef by the end of this century. The possible exception to this is the southern section of the reef, where some climate models indicate a slight increase in cyclone frequency in a warmer climate.

> Of the tropical cyclones which will occur in the Great Barrier Reef region, there is a projected increase in the proportion of high intensity cyclones with stronger winds, heavier rainfall and more damaging waves.

Tropical cyclones have the potential to generate extreme winds, heavy rainfall and large waves that can devastate agriculture and marine infrastructure and ecosystems in the Great Barrier Reef (GBR) region. Powerful wind gusts, storm surges and coastal flooding resulting from tropical cyclones can damage tourism infrastructure, such as damage to Hamilton Island from cyclone *Debbie* in 2017, and the combination of wind, flooding and wave action can uproot mangroves.

Wave action and flood plumes from river runoff can devastate seagrass (e.g. central GBR, cyclone *Yasi*, 2011) and coral reef communities (e.g. southern GBR, cyclone *Hamish*, 2009 and northern GBR, cyclone *Nathan*, 2015). Waves in particular can damage corals even when cyclones are several hundred kilometers away from the reef.

Recovery of ecosystems from this damage can take years to decades, such as the damage caused by severe tropical cyclone *Yasi* in 2011, which affected roughly 90,000 km² (15%) of the Great Barrier Reef Marine Park.

In recent decades, damage from tropical cyclones – compounded by the effects of climate change and other human-caused stressors – has caused substantial loss of coral cover in the GBR region.

Global temperatures continue to increase in response to rising concentrations of greenhouse gases in the atmosphere. In response, the impacts associated with extreme weather hazards and disasters, including those caused by tropical cyclones in the GBR region, are likely to change. Understanding how these changes to extreme weather hazards will manifest in the GBR region in the future is critical for increasing Australia's preparedness and resilience.

Researchers in the Earth Systems and Climate Change Hub have collaborated with stakeholders such as the Australian Institute of Marine Science and the Great Barrier Reef Marine Park Authority to provide tailored data, information and advice on past and future tropical cyclones and their hazards to help better plan for and deal with how climate change may impact the GBR region.



Impacts of tropical cyclones on coral reefs

Coral reefs worldwide are at increasing risk of damage from a combination of human impacts, marine heatwaves that bleach corals and kill seagrass, ocean acidification and physical damage from cyclone wave action.

In the GBR, three mass coral bleaching events (2016, 2017, 2020), poor water quality from land runoff and major cyclones in 2009, 2011, 2015 and 2017 have combined to cause major loss of hard coral, as well as a decrease in the average size of corals. When hard coral cover drops below a certain level, reefs may no longer be able to provide the key ecosystem services that underpin Australia's blue economy.

Cyclones that generate the most damaging waves are those that move slowly, have a large spatial footprint over which high winds occur and are intense. Consequently, when assessing the potential risk to the GBR, it is important to consider not just cyclone intensity, but also size and forward speed. For example, a relatively weak but slow moving and large sized cyclone like *Justin* (1997) can generate waves more damaging than a much more intense but smaller and fast-moving cyclone like *Larry* (2006).

In 2016, the largest marine industry in Australia in terms of jobs and earnings in that year was marine tourism. Coral reefs also play a key role in supporting tropical fisheries, are instrumental in protecting shorelines around the world from erosion and, as hotbeds of biodiversity, are sources

of new pharmaceutical discoveries. In addition to the ecological and economic impacts of tropical cyclones, they also pose a threat to significant Aboriginal and Torres Strait Islander cultural, social, environmental and economic values within and surrounding the GBR.

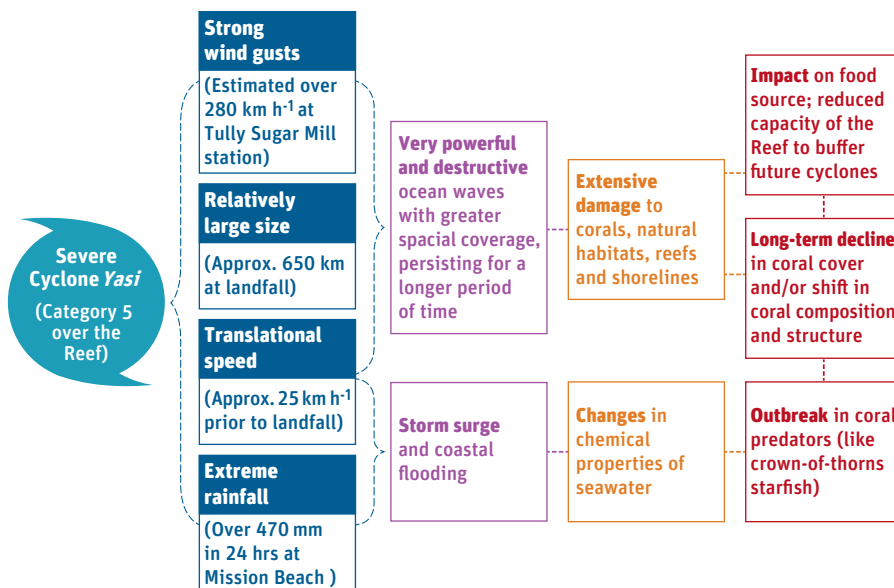


Figure 1: Tropical cyclones can devastate ecosystems within the Great Barrier Reef through strong winds, extreme rainfall, strong ocean waves and storm surges. This schematic illustrates the widespread destruction across the GBR caused by severe tropical cyclone *Yasi*. *Yasi* passed over the GBR and made landfall on the southern tropical coast near Mission Beach on 3 February 2011.



LEFT: Tropical cyclones can impact many Australian sectors in the Great Barrier Reef region, including agriculture. Image iStock.com/Jaykayl
ABOVE: Damaging waves resulting from tropical cyclones pose a particular risk to coral reefs. Image iStock.com/Velvetfish

Observed tropical cyclones in the Great Barrier Reef region

On average about 11 tropical cyclones form within or move into the Australian region (90°–160°E) every year. Of these, around 25% (approximately 3 tropical cyclones) pass within 250 km of the Great Barrier Reef Marine Park.

The Coral Sea region off the northeast coast of Australia (seaward of the GBR) is a hot spot for the formation of some of the strongest tropical cyclones to have impacted the reef. Tropical cyclones that form in the Gulf of Carpentaria may also track towards the reef (e.g. *Penny*, 2019 and *Oswald*, 2013) but they generally weaken substantially as they approach the GBR because they must cross land to do so.

Severe tropical cyclone *Yasi* in 2011 was one of the most powerful cyclones to affect Queensland since records began. Since this time, five more severe cyclones (i.e. category 3–5) have entered the GBR region. These include *Ita* (2014), *Marcia* (2015), *Nathan* (2015), *Debbie* (2017) and *Trevor* (2019).

Tropical cyclones that develop and track within the GBR region and greater Coral Sea are notoriously erratic in terms of their movement, sometimes completing several loops before either making landfall or moving further out to sea (e.g. *Rewa*, 1993–1994). In addition to their variable tracks, there is also large variability in the number of tropical cyclones that occur over different parts of the GBR. Tropical cyclones that tracked within 250 km of the GBR in the past four decades were most frequent in the central and northern parts of the GBR (between Lockhart River in Cape York Peninsula and Townsville), with fewer cyclones occurring over the southern parts of the reef.

Observations show that fewer tropical cyclones track near or within the GBR during El Niño years (~1.9 per year) than in La Niña (~2.9 per year). The overall number of tropical cyclones, as well as severe tropical cyclones, passing over the GBR has not changed significantly over the past four decades, despite a small downward trend in the overall number of cyclones in more recent

decades. There is some evidence of an increasing trend in the seasonal Accumulated Cyclone Energy (ACE) over the past decades, though this changes a great deal from year to

year. ACE is an index that combines tropical cyclone frequency, intensity and lifetime into a single measure of total wind energy for each season.

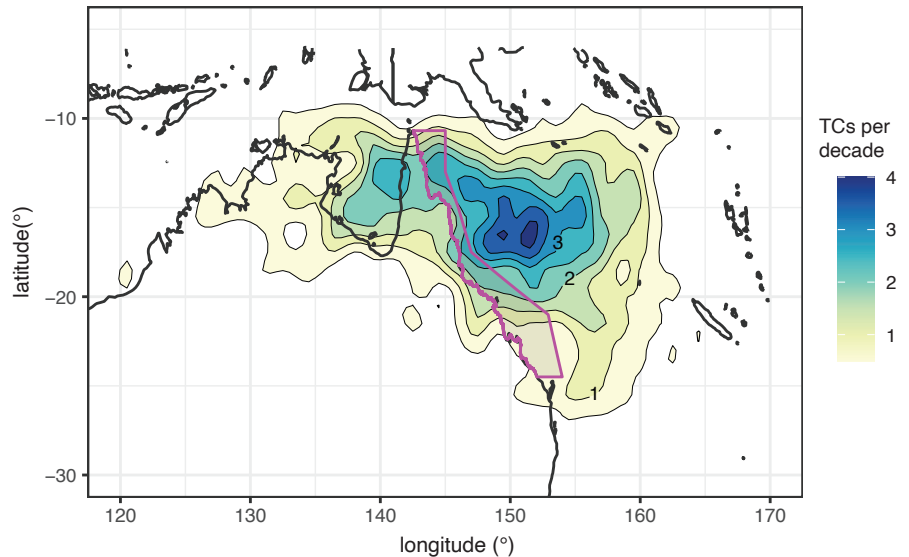


Figure 2: The average number of tropical cyclones in any 1 x 1 degree grid box that pass within 250 km of the Great Barrier Reef, per decade. These cyclones make up about 25% of all those that form in or move through the larger Australian region (90°–160°E). The Great Barrier Reef Marine Park is shown by the magenta boundary. Tropical cyclone tracks are sourced from the Bureau of Meteorology for the period July 1980 to June 2020.

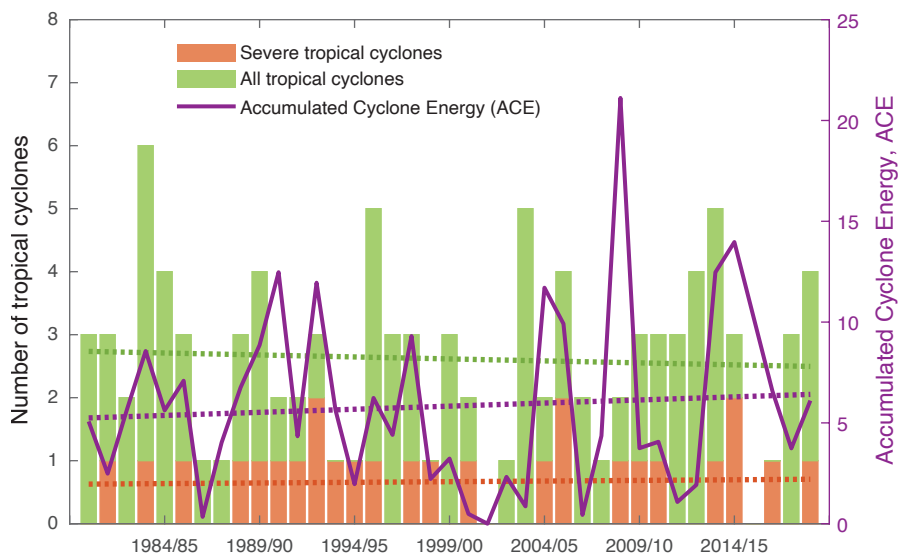


Figure 3: Very little change has been observed in the number of tropical cyclones and severe tropical cyclones in the Great Barrier Reef region since 1980, but a small upward trend in Accumulated Cyclone Energy (ACE, 104 kt²) has occurred. The overall number of tropical cyclones is shown (green), including severe cyclones in the GBR region (orange). The ACE is shown by the purple line. The dotted lines indicate the respective trends. As cyclones occur most often during the warmer months of the year, values are shown for individual cyclone seasons spread over the two calendar years (from July in one year to June in the next year, as listed in the figure).

Future changes to tropical cyclones in the Great Barrier Reef region

Projected frequency and intensity changes

Climate models indicate that the total number of tropical cyclones in the GBR region is expected to decrease by about 18% by the end of this century due to climate change, compared to the number observed in recent decades. Although there is reasonable confidence in the projected decrease of cyclone numbers for the GBR (and Australia more broadly), the exact magnitude of the decrease should be interpreted with caution due to the large spread in the local-scale changes projected by different climate models.

Although the overall frequency of tropical cyclones is expected to decrease with warming, those cyclones that do occur are expected to be more intense on average. As a result, the proportion of severe cyclones as a fraction of the total number of tropical cyclones that occur is likely to increase.

This is caused partly by increasing energy available from warmer waters to power cyclones. Some of the changes in tropical cyclones predicted by climate models are now beginning to bear out in observed data. For example, the proportion of time that a tropical cyclone exceeds 185 km/h (i.e. category 4–5 cyclones) has already increased globally, including for the broader Australian-South Pacific region, in line with climate change projections.



Globally, tropical cyclones are now more likely to be intense (exceeding 184 km/h), resulting in damaging wind gusts. Image iStock.com/imagedepotpro

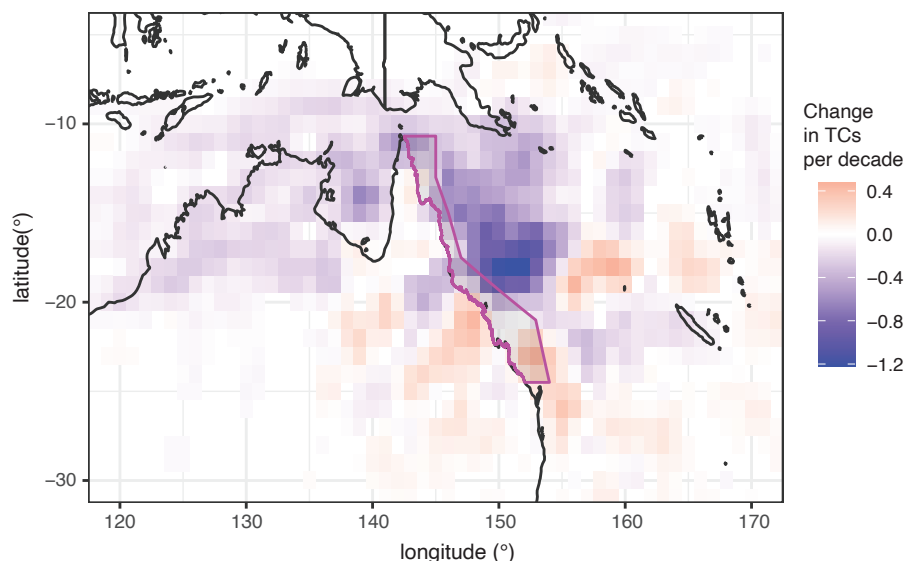


Figure 4: **Tropical cyclone occurrence may increase slightly in the southern part of the Great Barrier Reef region and decrease in central and northern regions under a future warming climate.** Projected changes in the average number of tropical cyclones (per decade in $1^\circ \times 1^\circ$ box) that pass within 250 km of the Great Barrier Reef Marine Park (magenta boundary). This is shown for the change between two periods based on a selection of CMIP5 models: the historical climate (1970–2000) and the future climate (2070–2100) under a high emissions pathway, RCP8.5.

Projected track changes

Climate model projections also indicate that tropical cyclones may track slightly further poleward under a warmer climate. This movement is associated with warmer oceans and changes in large-scale wind patterns. However, there are considerable uncertainties around this projected poleward movement based on current knowledge.

Further research into this possible slight southward movement of tropical cyclones in the Australian region is required, and will provide important information for future emergency preparation and management activities in areas of Australia which may not have experienced tropical cyclones in the past.

In the GBR region, some climate models project a future increase in occurrence of tropical cyclones in the southern part of the reef, despite a projected decrease in the number of tropical cyclones occurring in the GBR region overall. If this southern increase were to eventuate, more cyclones would be likely to impact on regions south of Mackay. However, like the potential projected poleward shift of tropical cyclones, there is relatively

low confidence in regional aspects of these future projections and as such these results should be interpreted with caution.

Projected rainfall changes

Rainfall produced by tropical cyclones is likely to increase in the future, particularly the intensity of extreme short-duration rainfall (e.g. hourly). This increase could be about 10% or more per degree of global warming, noting that about one degree of warming has already occurred.

Projected increases in extreme short-duration rainfall are primarily caused by a warmer atmosphere, which can hold more moisture (about 7% per degree of warming), and by the fact that more intense cyclones tend to produce more extreme rainfall.

This future increase in extreme rainfall could have implications for changes in runoff from the land adjacent to the GBR. Water pollution from nearby agricultural runoff (e.g. of soils, pesticides and fertilisers) can have dire impacts on the health of the reef. For example, freshwater runoff can devastate seagrass and cause an increase in outbreaks of crown-of-thorn starfish.



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Coral reefs worldwide are at increasing risk of damage from a combination of human impacts, marine heatwaves that bleach corals and kill seagrass, ocean acidification and physical damage from cyclone wave action.

Tropical cyclones, compounded by other human impacts, pose risks to the health of the Great Barrier Reef.

Climate change science to inform policies and decisions

Climate change science information is critical to help deal with current and future impacts of extreme weather hazards, including those caused by tropical cyclones in the Great Barrier Reef region.

The Earth Systems and Climate Change Hub has worked with partner agencies, such as the Australian Institute of Marine Science (AIMS) and the Great Barrier Reef Marine Park Authority (GBRMPA), to produce data and information and provide advice on changing tropical cyclone trends in the Great Barrier Reef region. For example, Hub researchers have worked with marine ecologists and reef strategists at AIMS and GBRMPA to assess recent historical trends of tropical cyclones impacting the GBR.

This informed the **Reef snapshot: summer 2019/20** report published by GBRMPA and highlights how climate change science information and advice provided by the Hub helps reef managers and decision makers better plan and prepare for the changing impacts on the GBR region under a warmer climate.

>>> FURTHER INFORMATION

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- Additional details on hazardous weather phenomena in Australia's changing climate are available from the ESCC Hub website: <http://nеспclimate.com.au/extreme-weather-hazards-in-a-changing-climate-project-5-5/>

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