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Climatic factors affecting the Great Barrier Reef

Key Messages

1

High temperatures and exposure to sunlight are the main causes of coral stress, with prolonged exposure leading to bleaching and mortality.

2

The Great Barrier Reef has experienced six mass bleaching events, in 1998, 2002, 2016, 2017, 2020 and 2022 and is currently experiencing its seventh bleaching event in 2024.

3

Human induced climate change has led to warmer global ocean temperatures, exposing coral ecosystems to more intense and frequent extreme warm events which increases the risk of bleaching and mortality.

The Great Barrier Reef responds to different atmospheric conditions and ocean currents which impact regional areas of the reef. Understanding the key drivers of warm ocean temperature extremes on the Great Barrier Reef is complex. This is because of the local and remote contributions from atmospheric and oceanic systems to the region.

The Great Barrier Reef

The Great Barrier Reef, a UNESCO World Heritage Area, is one of the most iconic and biologically diverse ecosystems on the planet. Covering almost 350,000 square kilometers along the northeastern coast of Australia (Figure 1), it is roughly the area of Germany and comprises a complex network of coral reefs, islands, and marine life which hold immense ecological, cultural, and economic significance. However, the Great Barrier Reef faces grave challenges due to climate change, pollution, coastal development, and overfishing. Rising sea temperatures have led to coral bleaching events that threaten the reef's health and biodiversity.

Coral bleaching: understanding the when, where, how and why of it.

Found beneath the glistening surface of our oceans, coral reefs around the world are vibrant ecosystems that support approximately a quarter of the world's fish species. These underwater wonderlands are visually appealing whilst also playing a crucial role in maintaining the delicate balance of life within the ocean.

However, they are under threat by the increase in water temperatures which have triggered several substantial bleaching events in some of the most iconic coral ecosystems, including the Australian Great Barrier Reef [1]. Here we explore some of the factors influencing these bleaching events.

Figure 1: The extent of the Great Barrier Reef. Source: https://wavedancerlowisles.com/about-low-isles/what-is-the-great-barrier-reef/

Cover image Credit: Photographer: J. Stella, Copyright Commonwealth of Australia (Reef Authority)

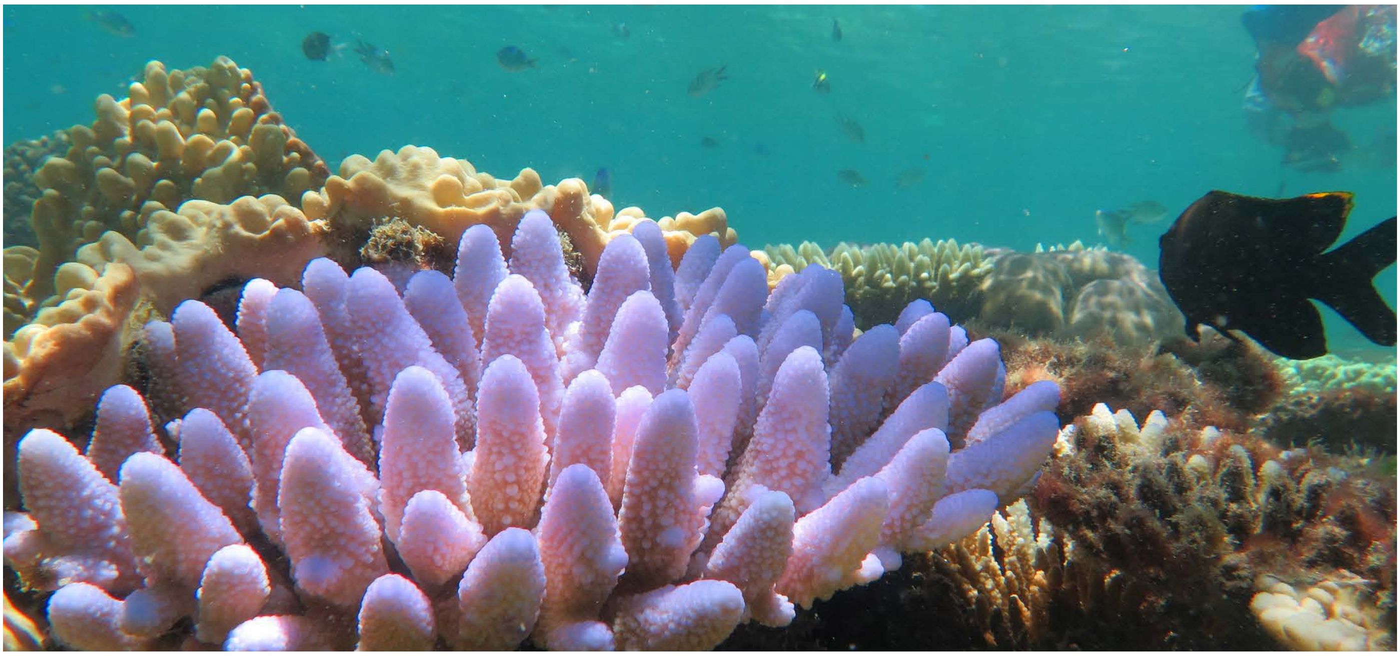


Figure 2: Example of bleached coral in the Cooktown management area. Photographer: J.Stella. Source: Commonwealth of Australia (Reef Authority).

What is coral?

Coral is a living organism which exists in a wide array of shapes, sizes, and vivid colours, ranging from branching forms to massive structures resembling human brain surfaces. One of the most fascinating aspects of coral biology is its close interaction or symbiotic relationship with tiny algae called zooxanthellae. The algae live within the coral's tissues and provide essential nutrients through photosynthesis, contributing to the varied pigments of healthy corals. Corals, in turn, provide the photosynthetic zooxanthellae with a protected environment and compounds needed for photosynthesis. The partnership is pivotal to the success of coral ecosystems, as it nourishes the corals and supports the entire reef community.

Photosynthesis in coral

Zooxanthellae are the organisms in coral responsible for photosynthesis. They contain pigments, including chlorophyll, which allow them to convert carbon dioxide and water into glucose using sunlight. The glucose supplies the zooxanthellae with the energy they need, and the rest is passed to the coral polyps. Corals rely on a balance between the energy supplied by the zooxanthellae and nutrients found in their surrounding water to grow and thrive.

Credit: Photographer: J. Stella, Copyright Commonwealth of Australia (Reef Authority)

What is coral bleaching?

Corals thrive in warm, clear, and shallow tropical waters, where sunlight can penetrate to support the zooxanthellae's photosynthesis. However, under unfavourable conditions such as elevated sea temperatures, pollution, or changes in water quality, corals become stressed, causing them to expel the zooxanthellae. This expulsion leads to the loss of the pigments that give corals their characteristic colours, revealing their underlying white calcium carbonate skeletons and resulting in the term "bleaching" (Figure 2).

Without zooxanthellae, corals lose a vital energy source and become more vulnerable to disease and mortality. While corals can recover if conditions improve, prolonged stress can lead to irreversible damage and even mortality, threatening the intricate ecosystems and biodiversity that rely on healthy coral reefs for survival (Figure 3). As corals die, the reef systems become far less hospitable and often results in a dramatic loss of biodiversity.

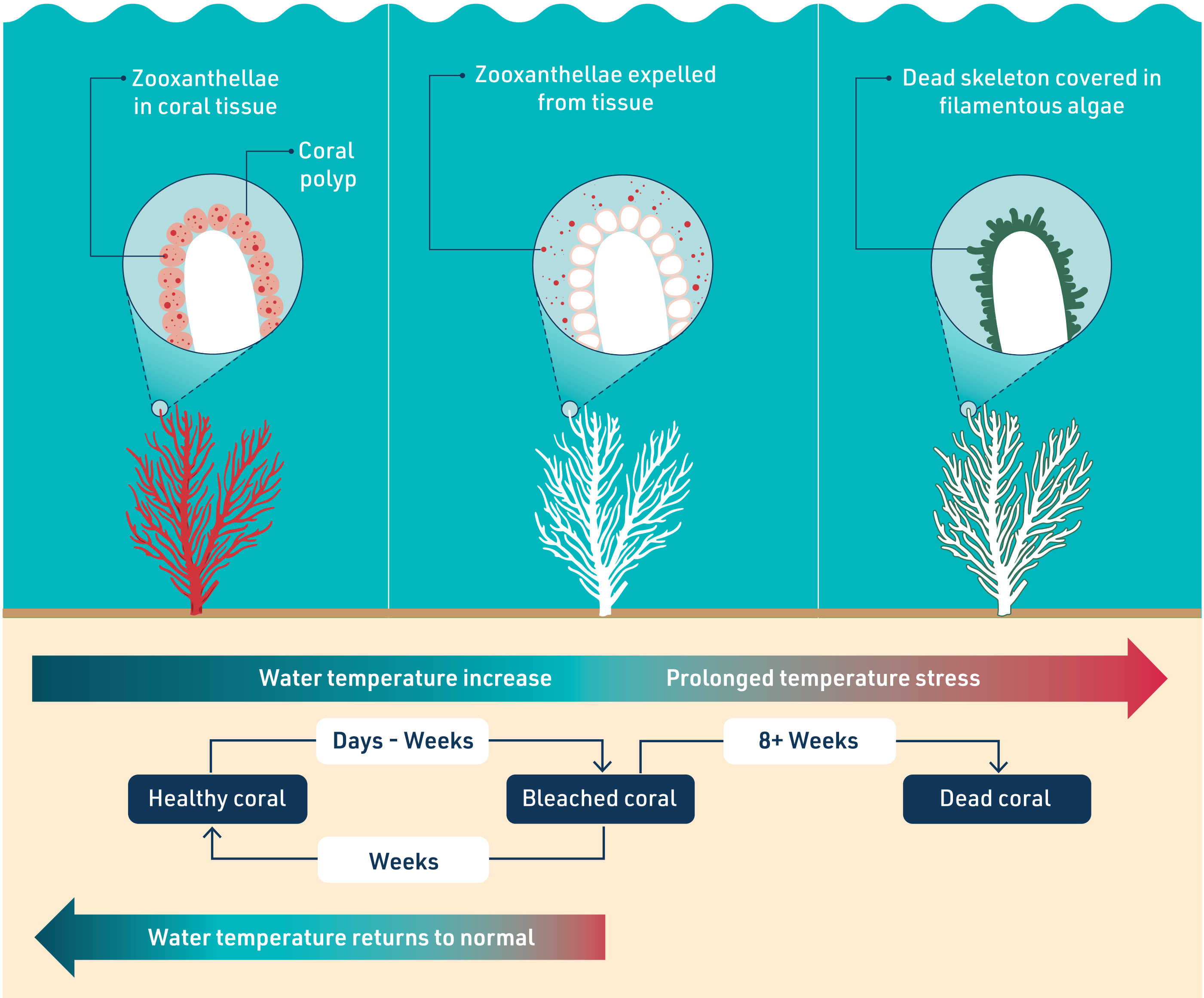


Figure 3: Diagram showing the effects of water temperature changes on corals. As temperatures increase the zooxanthellae that live within the coral become stressed and leave the coral. If the temperatures return to normal the zooxanthellae will return. If the temperatures remain high for longer than around 8 weeks, the bleaching will be irreversible and the coral will die.
Source: ARC Centre of Excellence for Climate Extremes adapted from Marshall and Schuttenberg 2006.

Sources of excess heat in the Great Barrier Reef

Increasing ocean temperature due to anthropogenic climate change is the biggest threat to coral reef systems around the world, including the Great Barrier Reef. However, the level of warming experienced during any given summer can be influenced by several factors.

The two main contributors to ocean temperature variabilty are:

Atmospheric:
Warmer air temperatures, low winds and minimal cloud cover all contribute to excess heat in the surface waters of the Great Barrier Reef [2]. The atmospheric conditions disproportionately affect the northern region of the reef which has a tropical climate with summers that are hotter, wetter and more humid compared to the southern part of the reef.

Oceanic:
Ocean circulation within the Great Barrier Reef region is complicated by the combined impacts of tides, winds, waves and topography. One of the major currents in the region is the East Australian Current (EAC), which brings warm water from the equator down the length of the east coast of Australia, starting in the central Great Barrier Reef region with the EAC Extension reaching Tasmania. This makes the EAC more important to the southern part of the reef.

The influence of El Niño Southern-Oscillation

El Niño-Southern Oscillation (ENSO) is the dominant interannual mode of global climate variability that modulates weather patterns across many regions of the world. The positive phase, known as El Niño, and the negative phase known as La Niña, can act to enhance or suppress the likelihoods of regional atmosphere and ocean phenomena, including tropical cyclones and marine heatwaves[3].

El Niño reduces (and delays) monsoon activity in the northern Great Barrier Reef which can lead to a decrease in cloud cover, allowing more sunlight to penetrate the water's surface[4,5]. Reduced monsoon activity also weakens the prevailing winds, reducing their capacity for vertical mixing of water layers[4] in the ocean. This reduced mixing traps heat in the upper layers of the water column, exacerbating thermal stress. The opposite patterns are present during the negative La Niña phase. These effects can be seen in figure 4.

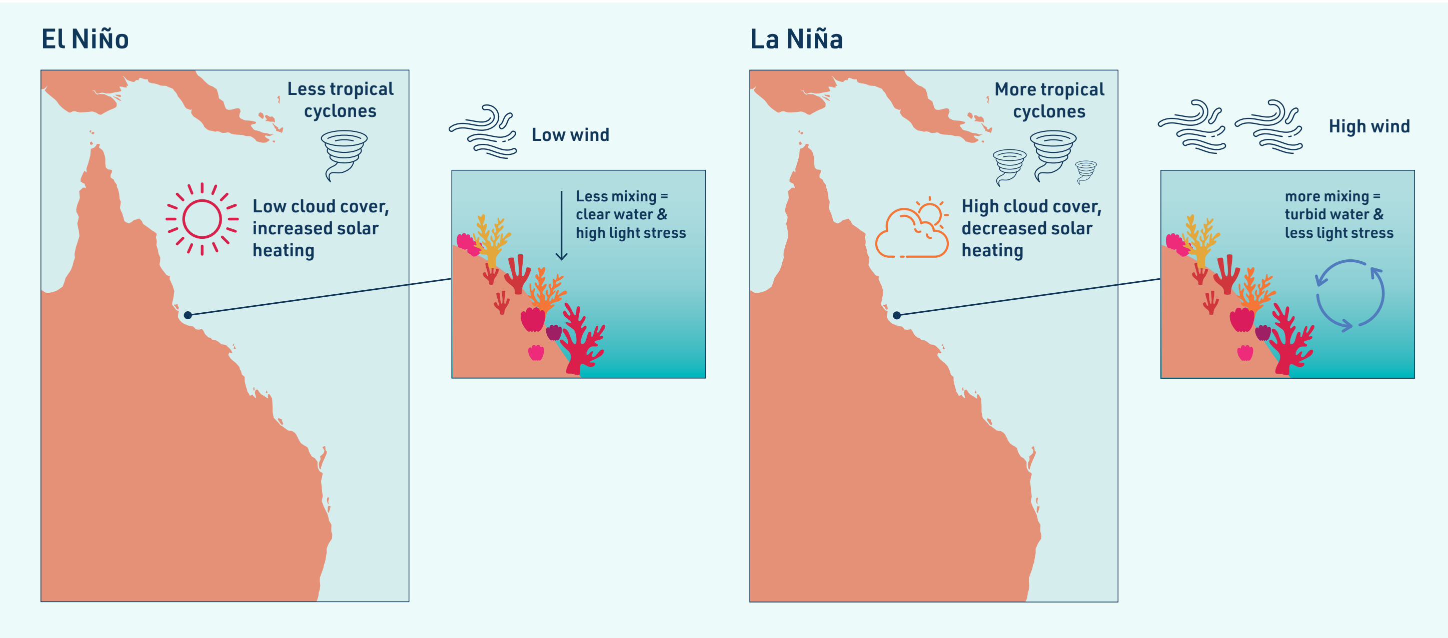


Figure 4: Atmospheric states during El Niño and La Niña events in the Great Barrier Reef region and how they impact the upper layers of the ocean. Source: ARC Centre of Excellence for Climate Extremes.

Other modes

ENSO is not the only mode of climate variability that influences weather patterns across the region[6]. While the phase of ENSO can influence the expected summer conditions in the Great Barrier Reef, other climate modes can alter the winds and possibility of storms which will determine the actual conditions. One such mode is the Madden-Julian Oscillation (MJO), which alters wind and cloud patterns in tropical regions. The MJO and ENSO can work together to alter the impacts of each other, and so understanding their individual and cumulative effects is essential to understand the possible impacts that they may have in the Great Barrier Reef region[7].

The Madden Julian Oscillation

The MJO is a storm pattern that moves in an eastward direction along the equator. Where the centre of the storm sits, there are stronger winds and more extensive cloud cover which result in cooler ocean temperatures. On either side of this convective centre, there are regions of dry, sunny conditions which lead to warmer temperatures in the upper ocean (Figure 5).

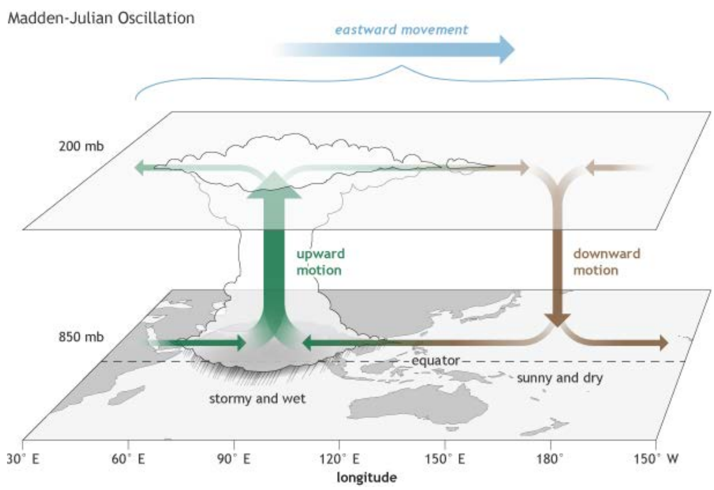
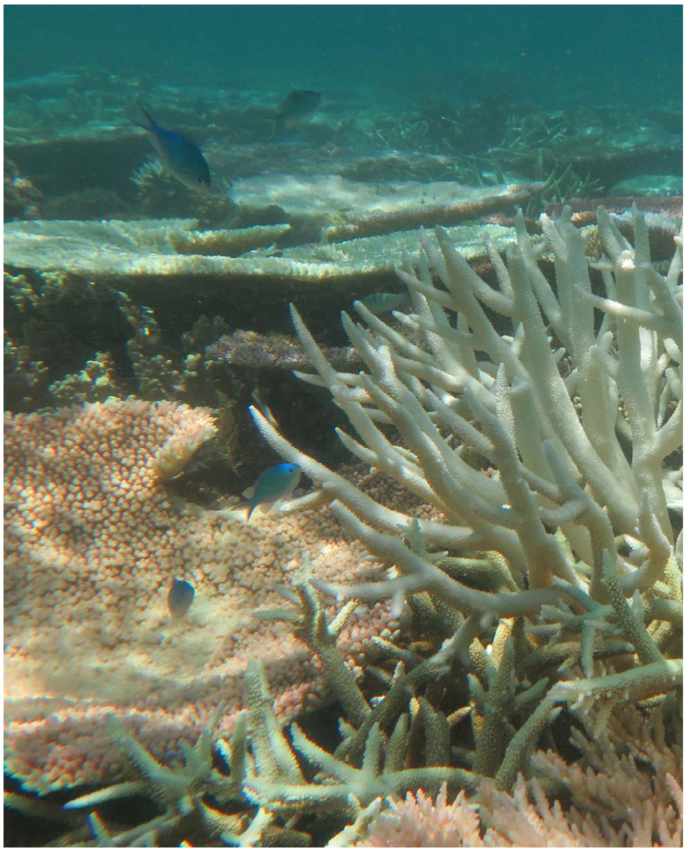


Figure 5: The Madden-Julian Oscillation.
Source: The Meteorological Office, UK.

Climate change: what can we do?

The reef has exhibited remarkable resilience throughout its long history. Over millions of years, it has adapted to changing conditions, including fluctuations in sea temperature. This resilience offers some hope for its potential survival in the face of the current threats.

However, increasing ocean temperatures under climate change are particularly concerning as this will lead to corals bleaching more regularly and with greater severity, making it difficult for reefs to recover between bleaching events. As the time interval between stress events decreases, the ability of marine ecosystems to recover can be reduced[8]. Importantly, with climate change, temperature stress from marine heatwaves superimposed on long term ocean warming trends are likely to cause even greater impact on coral reefs[9,10]. Further, the effect of increasing ocean acidification, caused by the ocean absorbing the carbon dioxide emitted by human activity[11], may add further stress on coral reefs by reducing the coral's skeletal density[12]. Unless greenhouse gas emissions are reduced, coral-dominated ecosystems are expected to face substantial losses, with lasting damage to ecosystems across the tropics.



Credit: Photographer: J. Stella, Copyright Commonwealth of Australia (Reef Authority)

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is a final year PhD candidate at the University of Tasmania researching the sub-seasonal to seasonal drivers of marine heatwaves around Australia. Her journey into marine research stemmed from her childhood growing up on the mid-north coast of NSW, where she developed a deep connection to the ocean and its inhabitants. She is particularly interested in exploring the dynamics of air-sea interactions and their influence on ocean temperatures, which can lead to serious consequences for marine ecosystems and organisms.

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Professor Neil Holbrook's research concentrates on developing process-based understanding and improved knowledge of the predictability of ocean and climate extremes, focusing on marine heatwaves – the ocean analogue of atmospheric heatwaves that can cause devastating impacts on life in the sea.

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