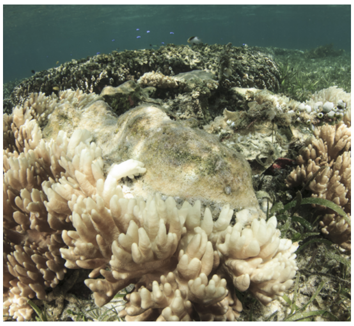
The role of clouds in coral bleaching events over the Great Barrier Reef

ARC Centre of Excellence for Climate Extremes Briefing Note

- Coral bleaching events continue to increase in frequency and intensity over the Great Barrier Reef (GBR) due to extremely warm ocean temperatures.
- In the GBR, changes in sea surface temperature (SST) are not always consistent with expected influences of large-scale ENSO patterns, suggesting that local scale climate factors such as cloud cover are important.
- Centre researchers found reduced cloud cover warmed sea surface temperatures over the GBR via increased incoming solar radiation.
- Reduced cloud cover is therefore a key risk factor influencing coral bleaching events.



Coral bleaching

Coral bleaching is increasing with climate change

Coral bleaching is the process in which coral expel symbiotic algae from their tissues, causing the coral to whiten. Without the algae, the bleached corals cannot photosynthesise, causing them to starve and ultimately die if bleaching conditions continue. Climate change has increased the frequency and severity of coral bleaching events, due to increasing ocean temperatures[1]. More frequent coral bleaching has been observed in the GBR. Extreme warm sea surface temperatures have been the cause of three mass thermal bleaching events occurring in 2016, 2017 and 2020[2], and a fourth event has been declared for this past summer of 2022. The Intergovernmental Panel on Climate Change (IPCC) predicts with very high confidence that the bleaching and mortality of coral will continue to become more frequent and severe over the coming decades[1].

They predict with very high confidence that even if climate change is restricted to 1.5°C of warming, 70– 90% of tropical coral reefs will die[1].

Given the vulnerability of coral reefs to a warming climate, it is vital we understand the mechanisms causing these bleaching events well enough to improve the protection and management of coral reefs. The GBR is an important provider of ecosystem services, including protection of the shoreline, a carbon sink, food provision, tourism and cultural heritage. Continued bleaching at the current rate will result in a loss of A$1 billion per year and 10,000 jobs due to a reduction in tourism[3]. The Centre is continuing to investigate the oceanographic and meteorological mechanisms impacting the occurrence of coral bleaching. This briefing note details research by the Centre on the relationship between cloud cover and the occurrence of coral bleaching events.

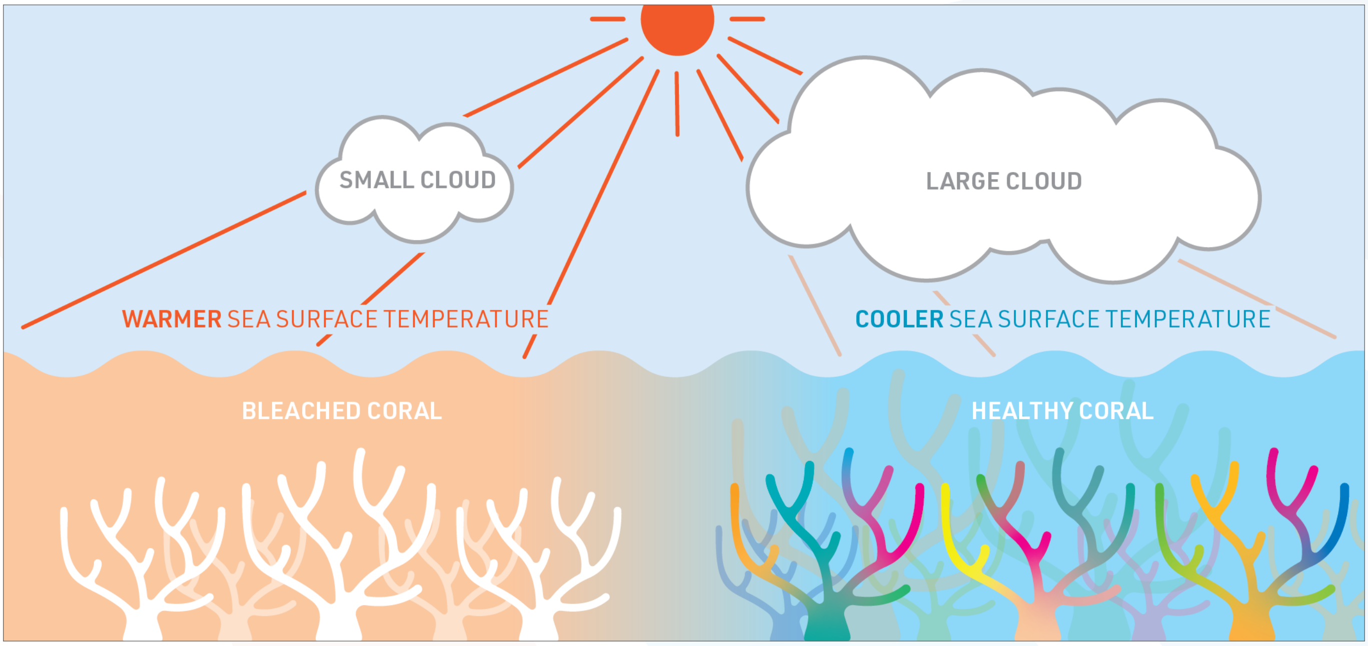


Diagram of the process in which cloud cover modulates water temperature and subsequent coral bleaching events, as found by our research.

The role of ENSO in driving water temperatures

Thermal coral bleaching events in the Pacific Ocean region have been associated with the El Nino–Southern Oscillation (ENSO)[3,4]. In general, El Nino, the warm phase of ENSO, has been associated with warmer sea surface temperatures over the eastern Pacific, while La Nina, the cool phase of ENSO, has been associated with cooler sea surface temperatures. Research on bleaching in the GBR has predominantly focused on events occurring during El Nino, the warm ENSO phase[5,6]. Bleaching events however, have also occurred during La Nina, the cool phase as well as the neutral phase of ENSO, indicating that there are other important mechanisms impacting changes in sea surface temperature.

Our researchers examined bleaching events across all three ENSO phases to better understand the relationship between ENSO and sea surface temperatures in the GBR[7]. The researchers hypothesised that local scale meteorological conditions, notably cloud cover, may be more important than ENSO in modulating sea surface temperatures, especially shallow coastal water areas, via the amount of solar radiation received by the ocean.

The role of clouds

Cloud cover is important for modulating incoming solar radiation and the subsequent warming of sea water. This interaction has been observed in the GBR and more broadly[8,9]. Cloud cover varies with the ENSO phase[10] and has been increasingly recognised to influence sea surface temperatures. However, the cloud-radiation-sea surface temperature relationship over the GBR under different ENSO regimes had not been thoroughly examined.

Our researchers examined the statistical correlation between ENSO, cloud cover, sea surface temperatures and coral bleaching events. Our analysis used newly published long-term (1996–2018) cloud and radiation satellite data over the coral bleaching season (January to April) over the GBR.

The physical process whereby reduced cloud cover increased the solar radiation entering the water, resulting in increased sea surface temperature was confirmed by our analyses. A statistically significant negative correlation between cloud cover and sea surface temperature was identified, whereby more cloud was associated with lower sea surface temperatures. The five coral bleaching events examined (figure 1) were associated with reduced cloud cover and increased solar radiation at the water surface, most notably in locations near the most severe coral bleaching sites. The correlation varied across the study site, with the sub and mid-tropics demonstrating the strongest correlation, and a weaker, but still evident relationship over the deep tropics (figure 2a). The weaker signal in the deep tropics can be attributed to the complex climatic environment, making it more challenging to determine a relationship between cloud cover and sea surface temperature.

Most significantly, this correlation between cloud cover and sea surface temperature remained across over two thirds of the study region when the ENSO signal was removed (figure 2b). This demonstrated that local cloud cover was a key component modulating water temperatures in the GBR. This effect of cloud cover is independent of the broader impacts of ENSO. These results suggest that the shallower waters of the GBR are more sensitive to solar insulation and less responsive to larger scale ENSO circulations. Contrastingly, this strong correlation between increased solar radiation and increased sea surface temperature did not occur in the deeper waters of the Coral Sea.

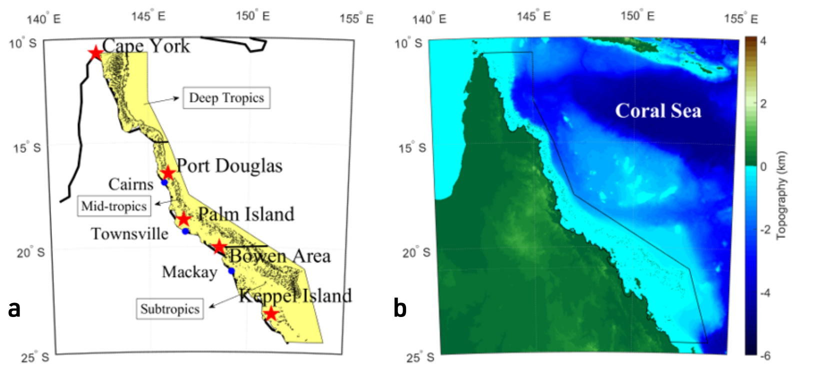


Figure 1. Study domain definition and locations of five thermal coral bleaching events (CBEs). (a) Region 140–155 E, 10–25 S is defined as the study domain. Yellow shading area indicates the Great Barrier Reef (GBR) general reference map with locations of five past CBEs (red stars). Three parts of GBR general reference map are defined as Deep Tropics, Mid-tropics, and Subtropics. (b) Bathymetric map of the domain.

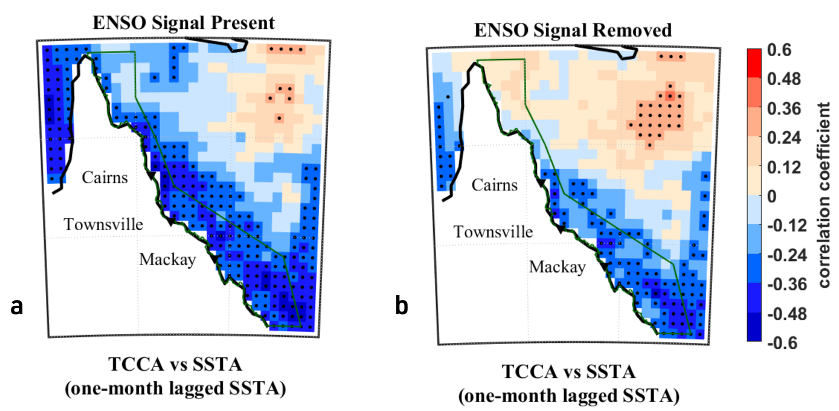


Figure 2. (a) Total correlation between total cloud cover anomaly (TCCA) and the one-month lagged SST anomaly (SSTA), and (b) Partial correlation of TCCA and the one-month lagged SSTA when El Nino-Southern Oscillation (ENSO) impact is removed during coral bleaching months (JFMA). Black dots indicate where the correlations are significant.

The Centre is improving predictions of ocean extremes

This research demonstrates the importance of decreased local cloud cover, alongside other risk factors, in providing optimal conditions for coral bleaching. Further understanding of the role of clouds may improve the knowledge of local atmosphere-ocean interactions, aiding the forecasting of coral bleaching events, calculating ocean heat budgets, and improving reef management solutions. The Ocean Extremes research program within our Centre is examining the key drivers of marine heatwaves to improve forecasts of these events[11,12,13]. Researchers are also improving models to better predict long-term ocean conditions to inform the management of ocean environments. These ocean model improvements include extremely high resolution models that capture more of the important processes associated with marine heatwaves[14].

References

1 Intergovernmental Panel on Climate Change (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. https://www.ipcc.ch/report/ar6/wg2/

2 Pratchett et al. (2021). Recurrent Mass-Bleaching and the Potential for 2 Ecosystem Collapse on Australia's Great Barrier Reef. https://doi.org/10.1007/978-3-030-71330-0_10

3 Leonard et al. (2016). Evidence of reduced mid-Holocene ENSO variance on the Great Barrier Reef, Australia. https://doi.org/10.1002/2016PA002967

4 Toth et al. (2012). ENSO drove 2500-year collapse of eastern Pacific coral reefs. Science, 337(6090), 81–84. https://doi.org/10.1126/science.1221168

5 Karnauskas et al. (2020). Physical diagnosis of the 2016 Great Barrier Reef bleaching event. https://doi.org/10.1029/2019GL086177

6 McGowan and Theobald (2017). ENSO weather and coral bleaching on the Great Barrier Reef, Australia. https://doi.org/10.1002/2017GL074877

7 Zhao et al. (2021). The role of clouds in coral bleaching events over the Great Barrier Reef. https://doi.org/10.1029/2021GL093936

8 Stephens (2005). Cloud feedbacks in the climate system: A critical review. https://doi.org/10.1175/JCLI-3243.1

9 Fischer and Jones (2012). Atmospheric dimethysulphide production from corals in the Great Barrier Reef and links to solar radiation, climate and coral bleaching. https://doi.org/10.1007/s10533-012-9719-y

10 Eastman et al. (2011). Variations in cloud cover and cloud types over the ocean from surface observations. https://doi.org/10.1175/2011JCLI3972.1

11 Holbrook et al. (2020). Keeping pace with marine heatwaves. https://doi.org/10.1038/s43017-020-0068-4

12 Sen Gupta et al. (2020). Drivers and impacts of the most extreme marine heatwaves events. https://doi.org/10.1038/s41598-020-75445-3

13 Holbrook et al. (2019). A global assessment of marine heatwaves and their drivers. https://doi.org/10.1038/s41467-019-10206-z

14 Hayashida et al. (2020). Insights into projected changes in marine heatwaves from a high-resolution ocean circulation model. https://doi.org/10.1038/s41467-020-18241-x

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