The Role of Coastal Morphology in Modulating Sea Surface Temperatures of a Large Indian Ocean Fringing Reef System

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Introduction

- Ningaloo Reef is located in north-western Australia and is one of the worlds largest coastal fringing reefs at approximately 300 kilometres long.
- The area has been designated a UNESCO World Heritage Site due to its important biodiversity and geological features.
- Like many coral reefs around the world, it is at threat of collapse due to increasing ocean temperatures due to climate change.
- However, Ningaloo Reef's corals have historically avoided severe heat stress that has occurred in locations elsewhere throughout the globe.
- In this study we investigate the association between different temperature profiles of locations with different coastal morphologies, with future work planned to determine the underlying physical causes.

Methods

- We used satellite-derived sea-surface temperature (SST) data to assess historical temperature and heat stress trends across three distinct coastal areas of the Ningaloo Reef.
- The National Oceanic and Atmospheric Administration (NOAA) provides a 5 kilometre spatial resolution SST dataset, which is updated daily and goes back to 1985.
- Data for the Ningaloo region was masked to within 10 kilometres of the coastline.
- We examined three distinct study areas:
  - Exmouth Gulf. Often shielded from oceanic processes experienced on the west coast due to the presence of the Cape Range peninsula.
  - Coral Bay. Located further to the south on the west coast, experiences occasionally reduced temperatures due to its more southerly location and the shape of the coastline at this point.
  - Ningaloo/Tantabiddi. The west coast of the peninsula, likely to see higher temperatures than either of Coral Bay or Exmouth Gulf as it is not protected by coastal geography, and it is at a point where it is likely to be influenced by the mixing of the Leeuwin (from the west) and South Equatorial (from the north) Currents.
- Wave data was sourced from the Department of Transport for Coral Bay over the period December 2004 to March 2005, and for Tantabiddi over the period July 2019 to December 2020, as hourly observations of signficant wave height (Hs) resampled to a daily value and quantiles of Hs and SST data over these periods were compared. SST values were converted to a rank, and Hs values were converted to an inverted rank, representing when the wave height was relatively low.

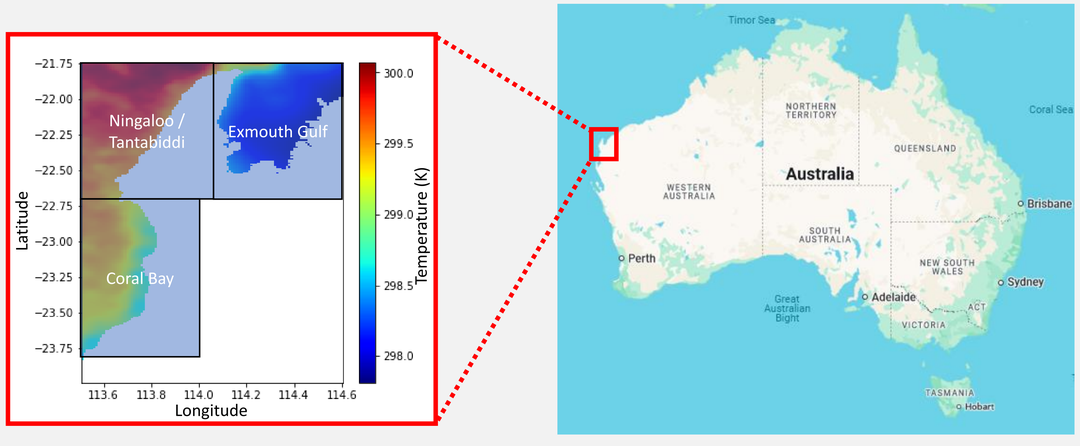

Fig. 1 *Location of the Ningaloo Reef in Australia (right), and the three separate study areas (Coral Bay, Ningaloo / Tantabiddi, and Exmouth Gulf), identified on a map of sea surface temperatures for 1 June 2002 (left).*

Results

- Long term trends in SST show there was an increase at all three study locations from 1985 to 2022. Ningaloo and Coral Bay had increased by 0.6 ºC, while Exmouth Gulf had only increased by 0.1 ºC.
- The distribution of SST values experienced in the first and final full year of the dataset showed a substantial shift in its profile to higher temperatures for all three sites, moving from a single mode to bimodal distributions of SST (Figure 2a and 2b).
- The annual average SST data correlates with the fluctuations of the Southern Oscillation Index (SOI) at all study locations. The best fitted correlation was found for the Ningaloo / Tantabiddi study zone (r = 0.69), which is likely influenced more strongly due to its exposure to main oceanic currents. Data for the Exmouth Gulf correlated most poorly (r = 0.59).
- Extreme value analysis of SST data was undertaken using an annual maximum method, indicating that Exmouth Gulf is likely to experience higher extreme temperatures, while Coral Bay will experience the lowest value of such extremes out of all three study zones (below table). Coral Bay is likely to experience temperatures of 30 degree Celsius once every 50 years, yet for Ningaloo and Exmouth Gulf these are likely to occur once every 5 years.

	Ningaloo		Coral Bay		Exmouth Gulf	
Period (Years)	SST (ºC)	95% CI	SST (ºC)	95% CI	SST (ºC)	95% CI
5	29.9	29.5 – 30.2	28.9	28.6 – 29.3	30.6	30.3 – 30.9
10	30.4	30.0 – 30.8	29.3	28.9 – 29.6	31.1	30.7 – 31.5
25	31.1	30.5 – 31.5	29.7	29.2 – 30.1	31.7	31.2 – 32.2
40	31.4	30.8 – 31.9	29.9	29.3 – 30.4	32.0	31.5 – 32.5
50	31.6	30.9 – 32.1	30.0	29.4 – 30.6	32.1	31.6 – 32.7
100	32.0	31.2 – 32.7	30.2	29.5 – 31.0	32.6	32.0 – 33.3

- SST and Hs ranks were combined, normalised and peak over threshold analysis performed to determined the time of year when combined values of high SST and low Hs were in the top 12.5% of observed values. This occurred during March and April, which is when SST data is at its highest, as wave height fluctuates frequently on a sub-annuluar timescale. SST temperatures were significantly higher at Ningaloo / Tantabiddi when wave heights were in the lower quantile.

Location	Quantile (Hs)	Mean SST (ºC)	95% CI	Sample (n)
Ningaloo	Upper	25.0	24.8 – 25.3	130
Ningaloo	Middle	25.1	24.9 – 25.3	259
Ningaloo	Lower	25.5	25.2 – 25.8	130

Location	Quantile (Hs)	Mean SST (ºC)	95% CI	Sample (n)
Coral Bay	Upper	24.4	23.6 – 25.2	25
Coral Bay	Middle	24.7	24.3 – 25.2	49
Coral Bay	Lower	25.0	24.2 - 25.7	25

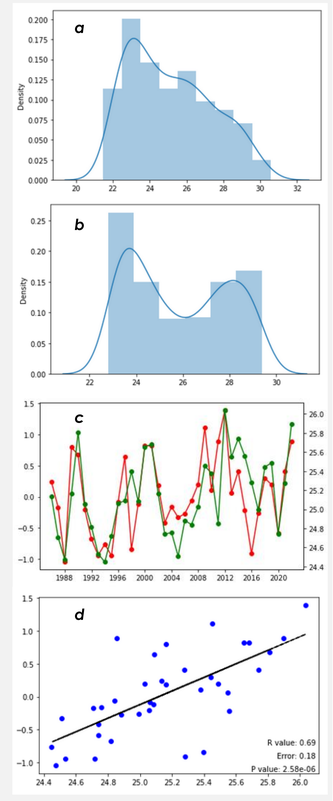

Fig. 2 *SST distributions for Ningaloo / Tantabiddi in 1985 (panel a), and 2022 (panel b). Annual SOI mean (red, left vertical axis) and annual average SST (green, right vertical axis) compared from 1985 to 2022 (panel c), and with linear regression (panel d).*

Discussion and Conclusion

- This study identifies differences in temperature profiles and their future forecast, and how these differences are associated with different coastal geographies. The next step in this project is to undertake thermodynamic numerical modelling of these locations to identify the underlying mechanisms that may be associated with increased or reduced temperatures.
- This study demonstrates that while sheltered locations experience less overall warming, they are still highly vulnerable to extreme temperature events. This underscores the need for spatially-explicit climate change mitigation strategies and localized adaptation plans to protect the Ningaloo Reef's diverse coral ecosystems.
- Results from SST trend analysis indicate that temperatures at Ningaloo / Tantabiddi and Coral Bay have increased over the past 36 years faster than the global average over the same time period. Conversely, Exmouth Gulf has risen over the same time period by an amount that is substantially lower than the local, regional, and global averages. Further work is required to determine whether this is due specifically to coastal geography or other factors.