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From climate refugium to heatwave epicentre: Will the 2025 Ningaloo bleaching become a new normal?

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Abstract: The 2025 Ningaloo coral bleaching event highlights that even climate refugia are vulnerable to severe thermal stress, suggesting that events of this magnitude will likely become more common. We used a machine learning approach to downscale five high-performing CMIP6 models to a 10 km resolution, correcting for a ~1°C warm bias. Our projections show that the Ningaloo Coast's sea surface temperature (SST) is expected to warm by about 0.5°C at a 1.5°C global warming level, increasing to over 1.5°C at a 3°C level. This projected warming will lead to a substantial increase in Degree Heating Weeks (DHW), directly linking future warming to a greater risk of widespread coral bleaching similar to the event in 2025.

Keywords: *Machine learning, climate downscaling, marine heat wave, coral bleaching*

1. INTRODUCTION

The unprecedented coral bleaching event at the Ningaloo Coast World Heritage Area (NCWHA) in 2025 has raised alarm that even globally recognized climate refugia are now susceptible to severe thermal stress. While large-scale events on the Great Barrier Reef (GBR) have dominated headlines, this latest event at Ningaloo highlights that localized, yet unprecedented, marine heatwaves can override a reef system's inherent resilience. The complexity and fine-scale nature of the 2025 bleaching event, driven by a unique convergence of regional oceanographic and atmospheric anomalies, have demonstrated the urgent need for a focused climate downscaling study to resolve these fine-scale processes, essential for evaluating climate vulnerability of marine values of the Ningaloo Coast World Heritage Area and the Ningaloo Marine Park. The predictive capabilities of coarse-resolution global climate models to forecast future marine heatwaves are in doubt as they often fail to resolve the mesoscale processes—such as localized upwelling, eddy dynamics, and specific current reversals—that are crucial for accurately diagnosing the drivers of regional thermal stress (Sun et al., 2024). A precise diagnosis of the "perfect storm" of conditions that led to the unprecedented 2025 Ningaloo bleaching event will help the forecasting of such extreme events in the future.

2. METHODOLOGY AND RESULTS

To evaluate future climate conditions at the Ningaloo Coast, we have chosen five of the best-performing CMIP6 climate models for the Australian Region (Grose et al., 2023). We use machine learning (ML), which is capable of rapidly downscaling climate models for different Shared Socioeconomic Pathways (SSPs) to inform a range of likely outcomes. A deep learning model was trained to downscale the SST projections from 100 km resolution to 10 km resolution using the BlueLink OFAM model simulations (Cyriac et al., 2025).

We first assessed and corrected biases in SST from these climate models using 30 years of satellite SST observations (Skirving et al., 2020). A quantile delta mapping method was used (Cannon et al., 2015), which corrects biases across the entire distribution of values. This method is based on the statistical relationship between the model and observations and helps preserve the model's physical variability and sequencing of events (e.g., the timing of seasons or weather patterns). Our analysis shows all five models to have a warm bias in SST of approximately 1°C, which was successfully corrected by this method.

The downscaled ensemble mean of the five climate models at 10 km resolution show that SST at the Ningaloo Coast region is projected to warm by about 0.5°C under a global warming level (GWL) of 1.5°C, increasing to ~1°C under a GWL of 2°C. At a GWL of 3°C, the warming would exceed 1.5°C. As global warming levels (GWL) approach 3°C, the degree heating week (DHW), a measure of cumulative heat stress, is projected to increase substantially. This increase is a major concern because higher DHW values are directly linked to a greater risk of severe coral bleaching and widespread mortality. On the other hand, sea level along the west coast of Australia will remain slightly below the current level under the high emission scenario (RCP8.5) by the end of 21st century, with likely very little change under a moderate emission scenario [*Zhang et al, 2017*].

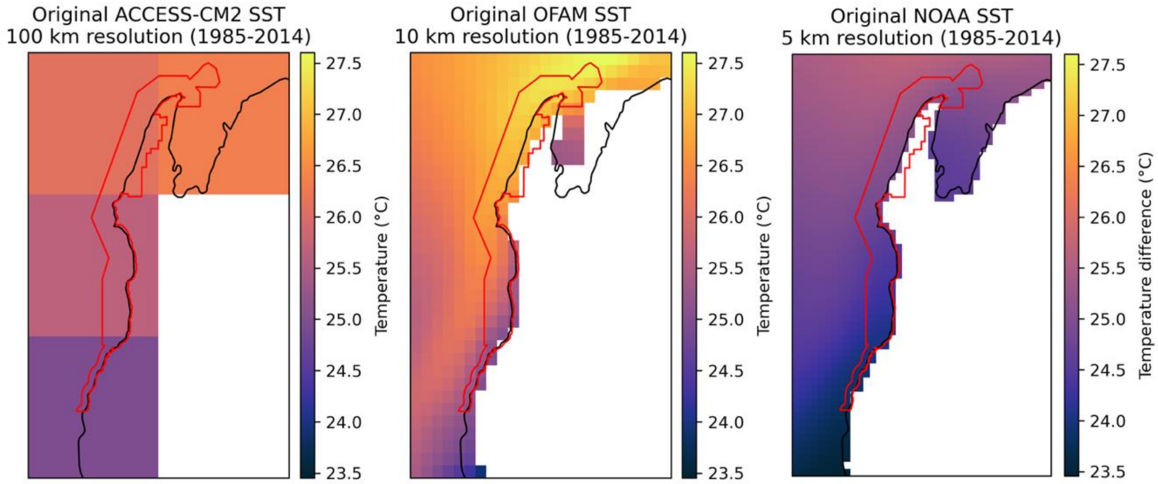

Figure 1: Comparison of resolutions for the SST Data for the Ningaloo Coast (1985-2014). (left) CMIP6, (centre) OFAM, (right) NOAA.

3. CONCLUSIONS

The unprecedented 2025 bleaching event at Ningaloo highlights the urgent need for fine-scale climate projections to inform conservation and management strategies. Our study shows that the Ningaloo Coast, once considered a climate refugium, is highly vulnerable to future marine heatwaves. The projected increase in SST and DHW values under all but the most ambitious climate scenarios suggests that bleaching events of a magnitude similar to the 2025 event are likely to become more common. Accurate forecasting of these extreme events is crucial for effective climate action.

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