Winter is not coming: Simulating heat stress on Florida's Coral Reef

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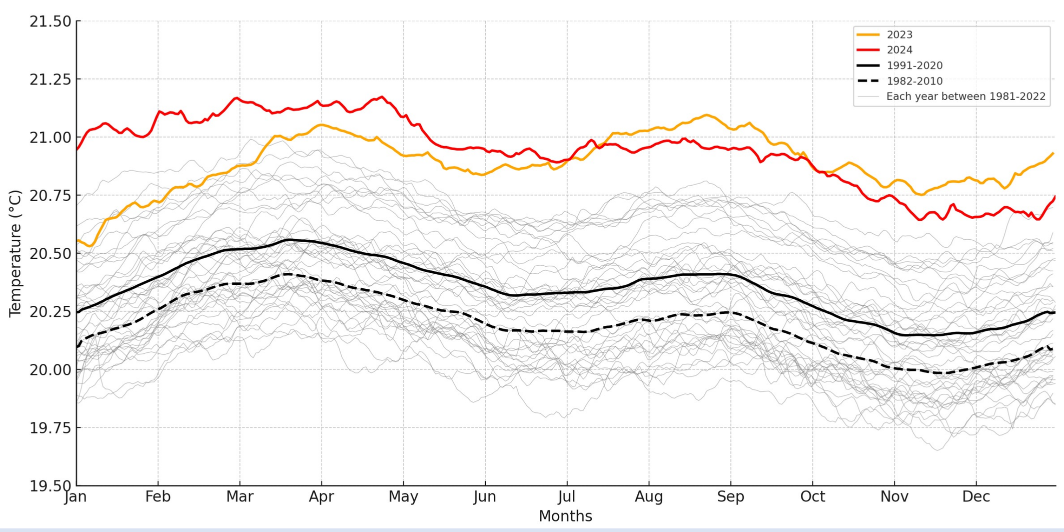
The recent heatwave devastated coral reefs

Coral reefs are very sensitive to temperature variations. Prolonged marine heatwaves can lead to bleaching, affecting their survival. In Florida, the summer of 2023 was marked by record sea temperatures. To understand the broad-scale bleaching patterns and their local variations, we have to combine the few observations available with high-resolution ocean models.



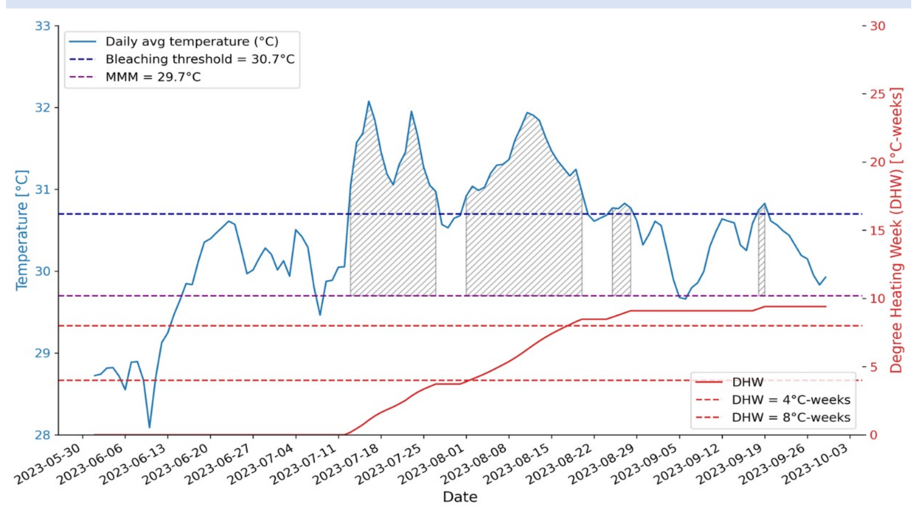
This work aims to simulate the hydrodynamics and thermal conditions of June-September 2023 period in the Florida's Coral Reef using a 3D hydrodynamic model. The main goals are to reproduce the vertical temperature stratification, identify spatial variations in thermal exposure between inshore and offshore reef areas, and provide an improved representation of the cumulative thermal stress experienced by coral habitats at different depths.

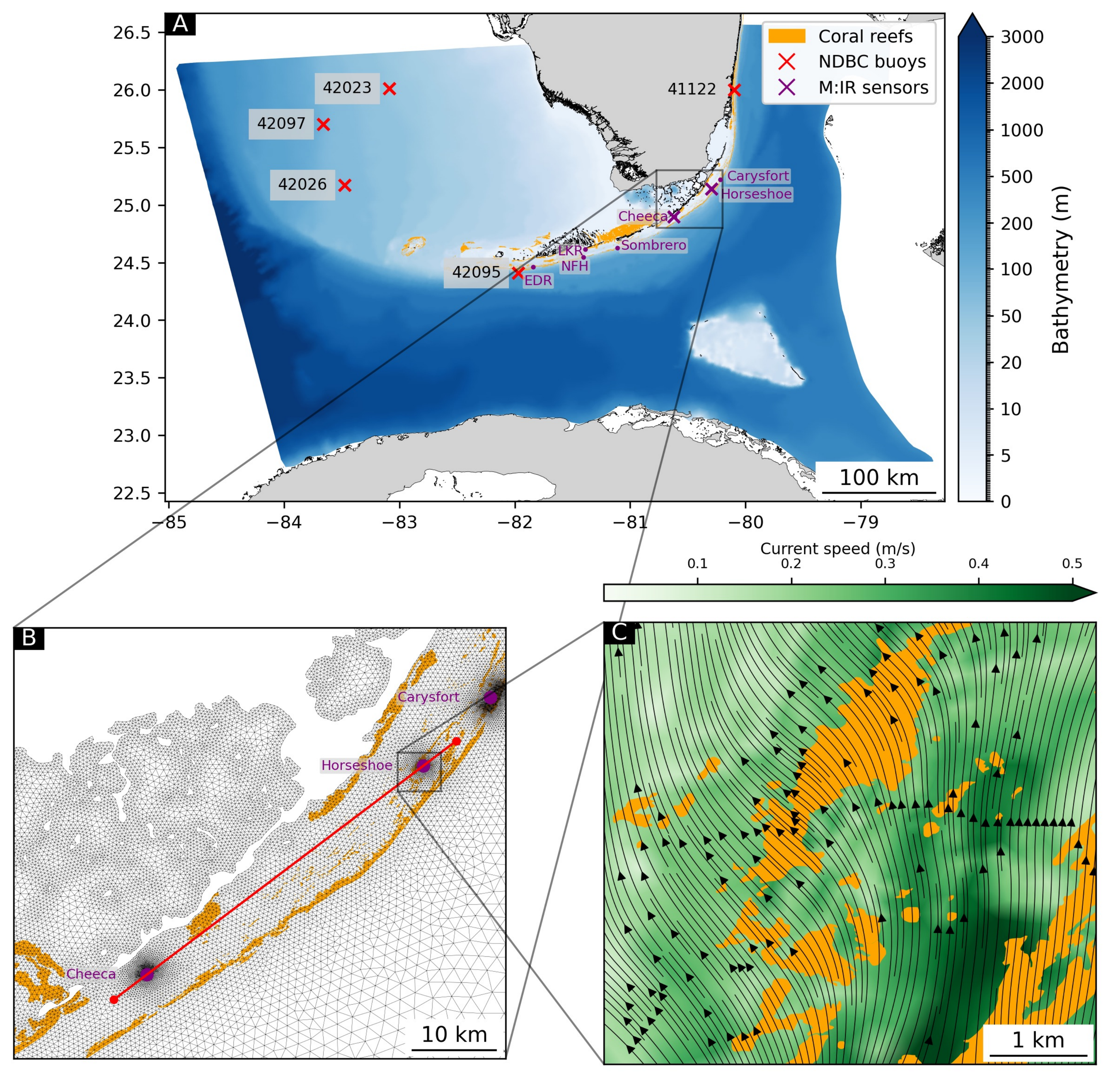
We use SLIM3D to simulate ocean dynamics and quantify thermal stress

We used the unstructured-mesh DG finite element ocean circulation model SLIM3D, a baroclinic ocean circulation model that can simulate fine-scale details of hydrodynamics and temperature variations.

To quantify the thermal stress experienced by corals, we use the Degree Heating Weeks (DHW) metric [°C-weeks]. It is used to quantify accumulated thermal stress over time, which is computed at each location to evaluate spatial patterns of exposure.

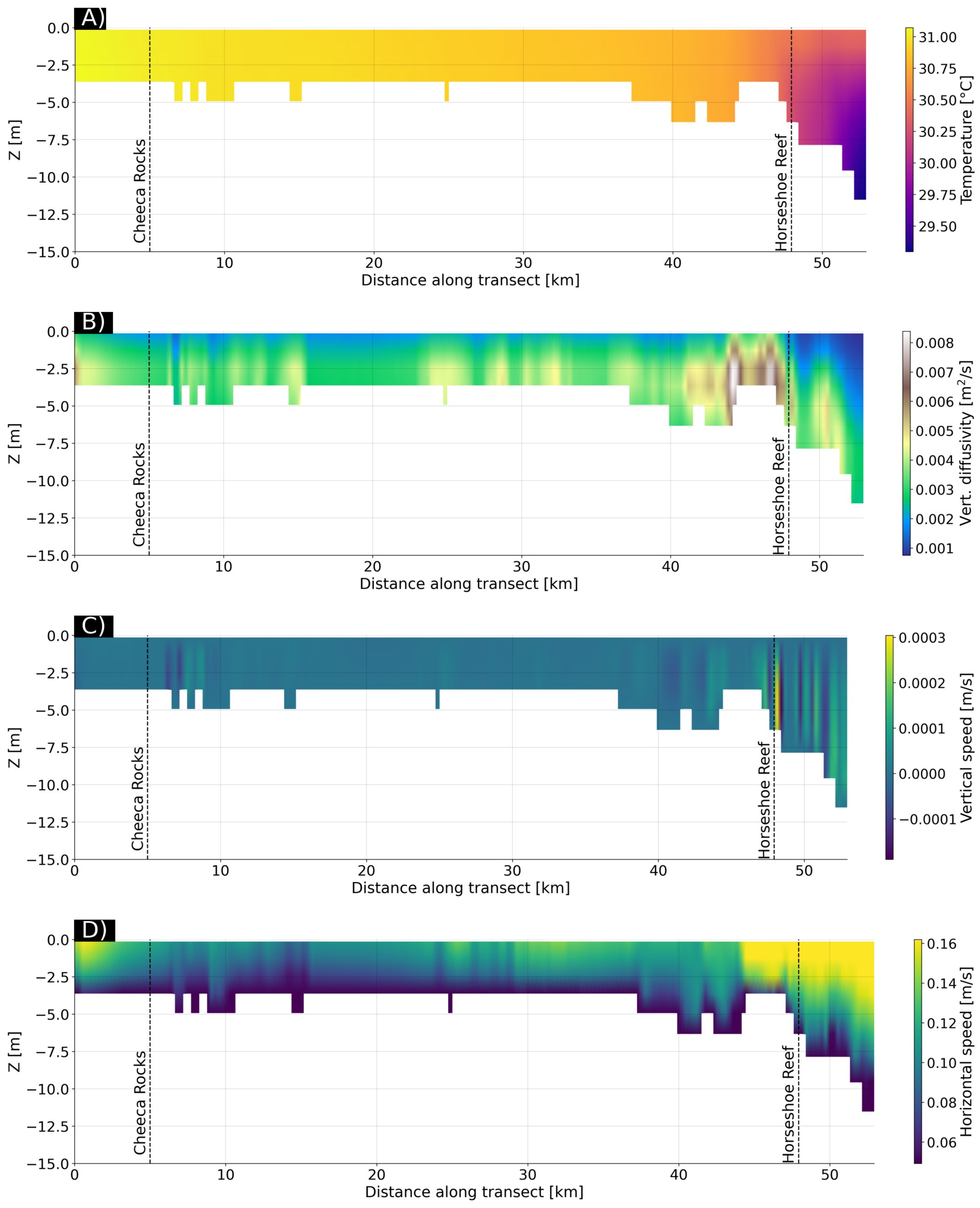
DHW were calculated at the surface and at reef depth and compared with satellite-derived surface DHW at coarser spatial resolution. At reef depth, the Maximum Monthly Mean temperature (MMM) and the associated bleaching threshold were adapted following the methodology of *Venagas et al. (2019)*[1], by applying a bias to reduce the MMM.





Our model setup uses a horizontal mesh composed of ~147,000 elements, with a resolution ranging from 60 m near reef sites to ~10 km offshore. The 2D mesh was then vertically extruded over 32 vertical layers, mainly concentrated near the surface with ~13 layers in the first 30 m with a thickness ranging from 1 to 4 m.

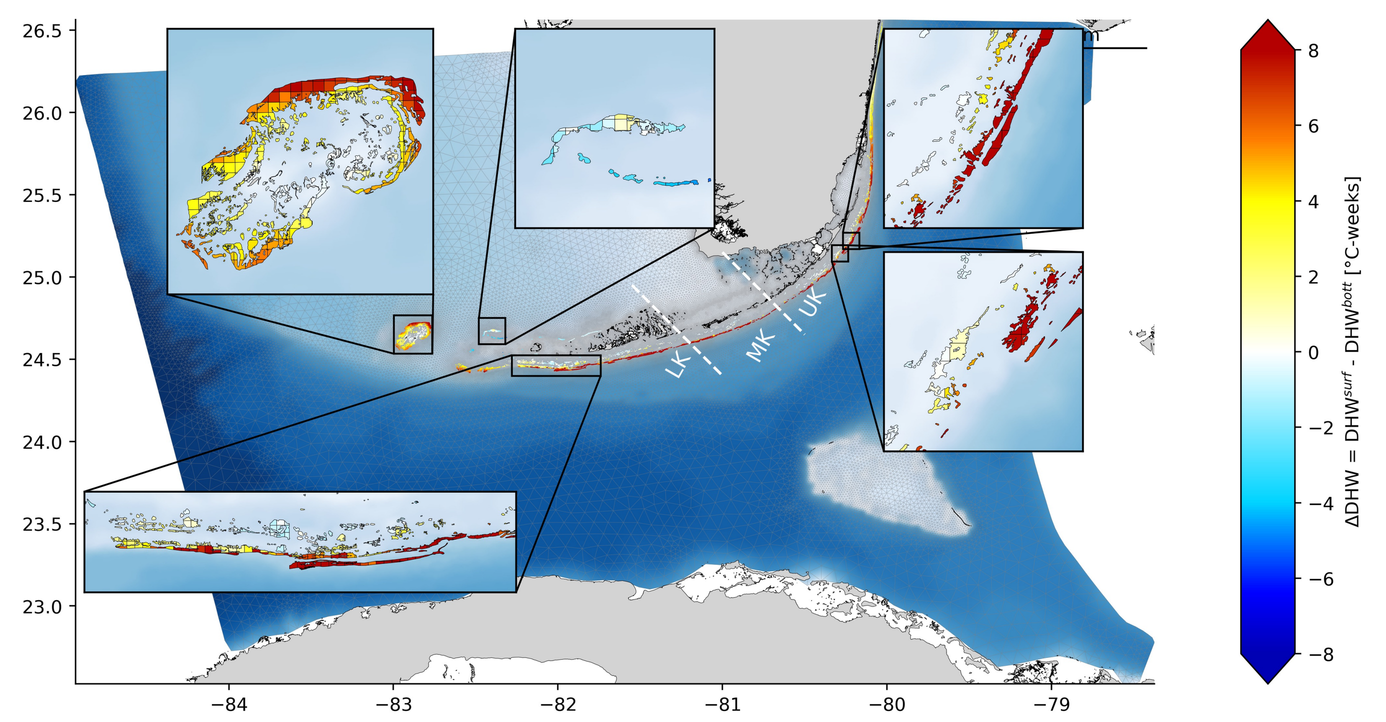
Coral reefs' thermal stress varies over very short distances, highlighting potential candidate thermal refuges

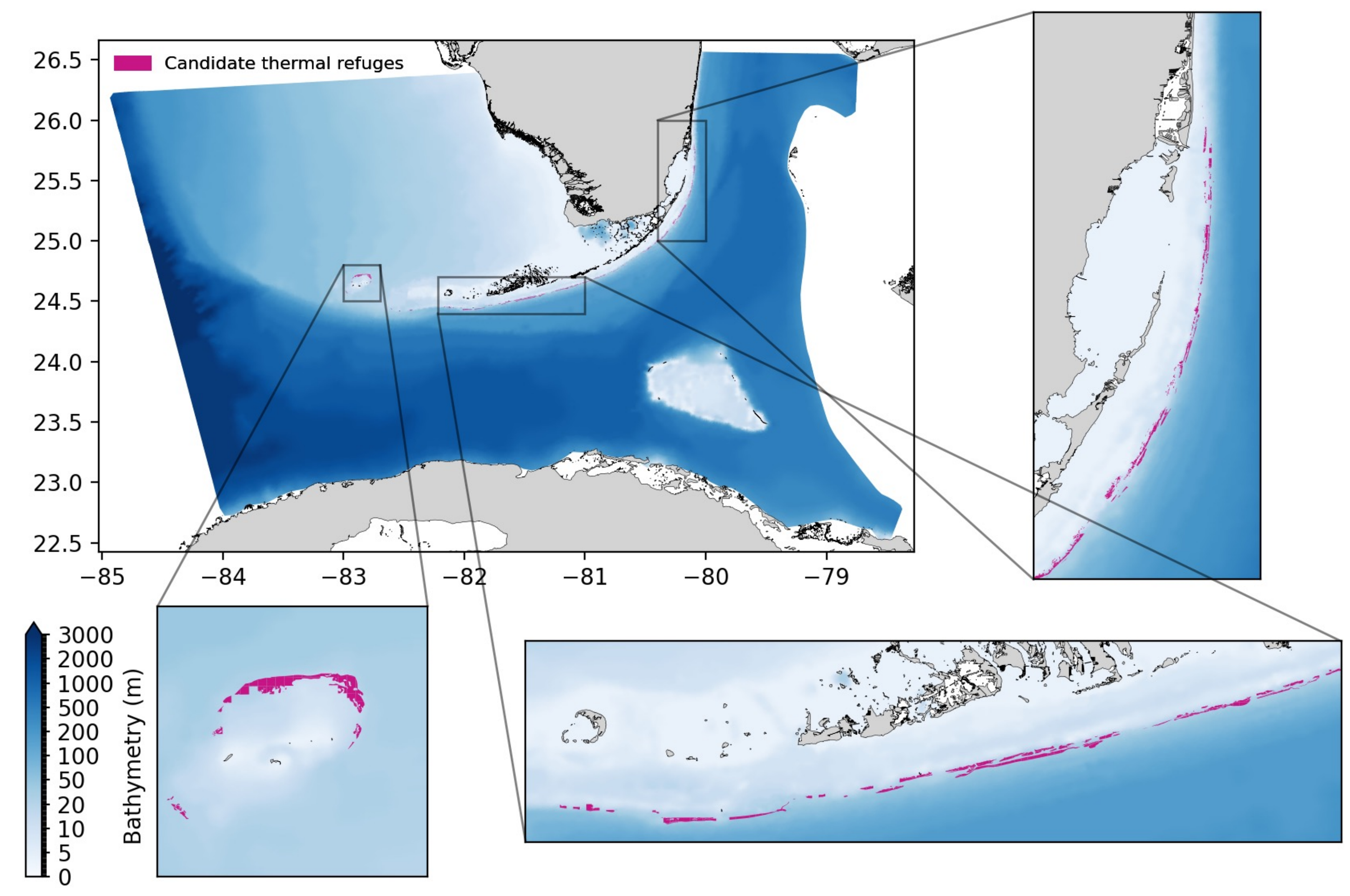


We identified areas where thermal stress is strongly reduced at reef depth relative to the surface. The upper right map highlights offshore reef with a larger vertical contrast in heat stress. We defined them as ***candidate thermal refuges*** using an explicit threshold-based criterion:

$$DHW_{surface} \geq 8 \ \& \ DHW_{bottom} < 4$$

Two nearby reefs could experience large differences in bleaching due to differences in bathymetry and local hydrodynamics. Cheeca Rocks (on the left plot) is a shallow, inshore reef with weak stratification and relatively uniform temperature profiles. Heat tends to accumulate there, also because of the less dynamic environment with no major currents around. In contrast, Horseshoe Reef, located farther offshore and in deeper waters, exhibits stronger vertical stratification, which contribute to lower bottom temperatures and reduced bleaching at depth.

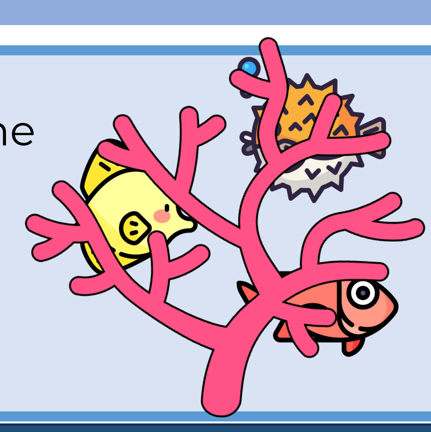




We identified potential candidate thermal refuges using thermal stress indicator… but that's only the first piece of the puzzle

- Some areas are less subject to bleaching than others due to hydrodynamic processes like upwelling.
- It's important to use a high-resolution ocean model like SLIM to capture small-scale temperature gradients between the surface and the reefs' depth, which might explain the bleaching variability observed between nearby reefs.
- Identifying candidate thermal refuges could inform coral reef management and restoration.
- This study however does not account for biological factors, such as the variable thermal stress tolerance across different coral species.

- Simulate the summer of 2024 to observe whether the candidate thermal refuges observed in 2023 persist.
- Simulate the dispersal of different analytes from wastewater to integrate water quality in our study.



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[1] https://doi.org/10.1038/s41598-019-56232-1