Vertical Extent and Influence of Mesoscale Eddies on Marine Heatwaves in the Northeastern Caribbean

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Abstract

As the planet continues to warm—a well-documented expression of climate change—marine heatwaves (MHWs) are becoming increasingly frequent, more intense, and longer-lasting. These MHWs can increase the frequency and intensity of tropical cyclones, while also posing significant threats to coastal communities and marine ecosystems. To date, however, research on MHWs has primarily focused on their surface manifestations, often neglecting their subsurface characteristics due to the scarcity of continuous observations at depth. Consequently, the vertical structure of MHWs remains poorly understood. Here, we use data collected using the CARICOOS and AOML underwater 'hurricane gliders' to assess the vertical extent of the 2023 marine heatwave in the northeastern Caribbean. Additionally, we employ satellite altimeter surface height anomaly data to investigate the effect of mesoscale eddies on vertical temperature anomaly distributions. Preliminary observations reveal a surface-intensified MHW with average temperature anomalies exceeding 1°C to a depth of ~50 m. Under the influence of anticyclonic eddies, these warming anomalies can extend down to a depth of 500 meters. The effort here reported constitutes an initial step towards exploring the feasibility of estimating heat content and the subsurface temperature gradient using existing remotely sensed sea surface temperatures (SSTs) and altimetry observations.

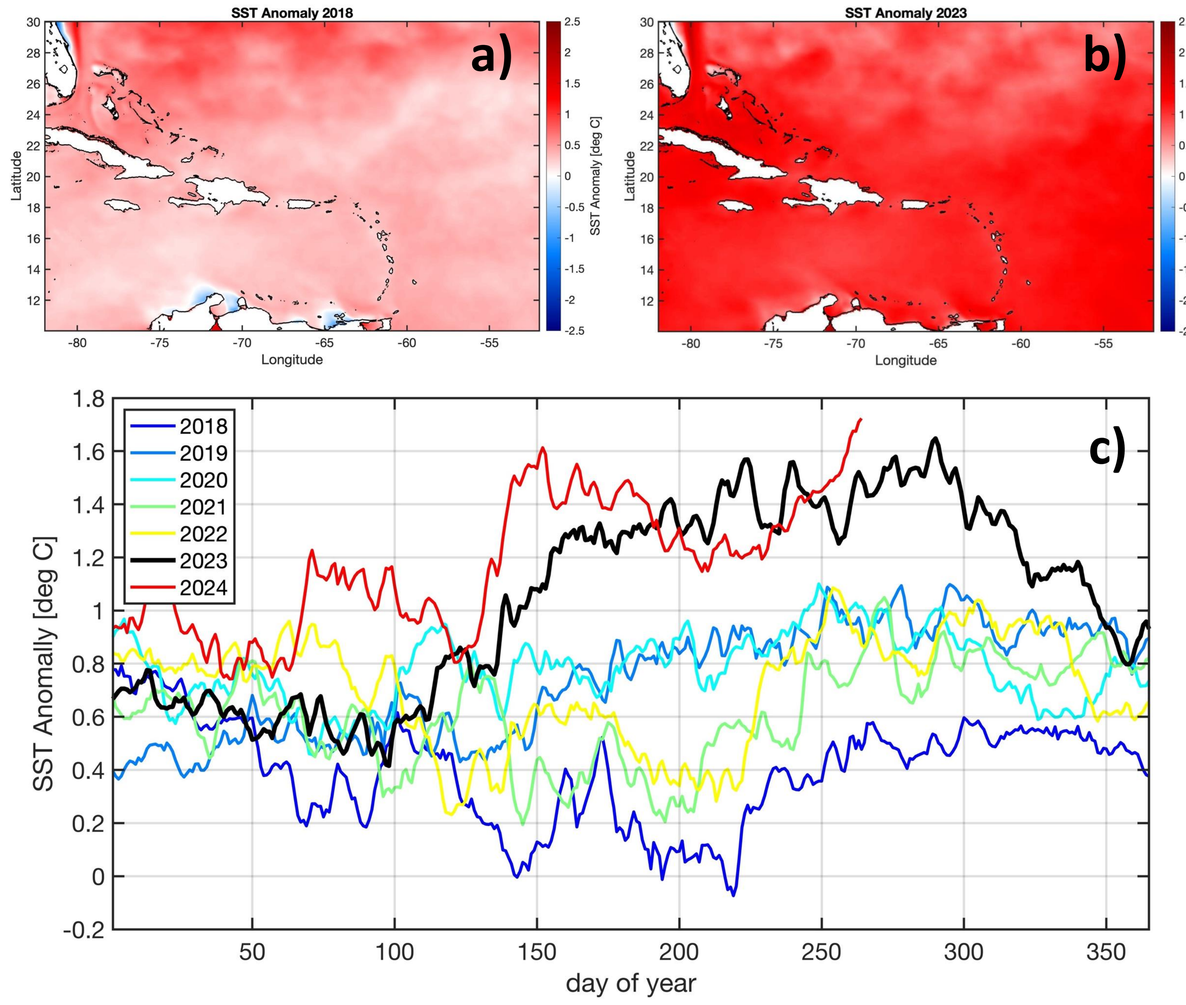


Figure 1. Map of average sea surface temperature (SST) anomalies for (a) 2018 and (b) 2023 in the Tropical North Atlantic. (c) Spatially-averaged SSTs for the domain shown in (a)-(b) plotted by day of year for the period 2018-2024.

Surface and Subsurface Observations

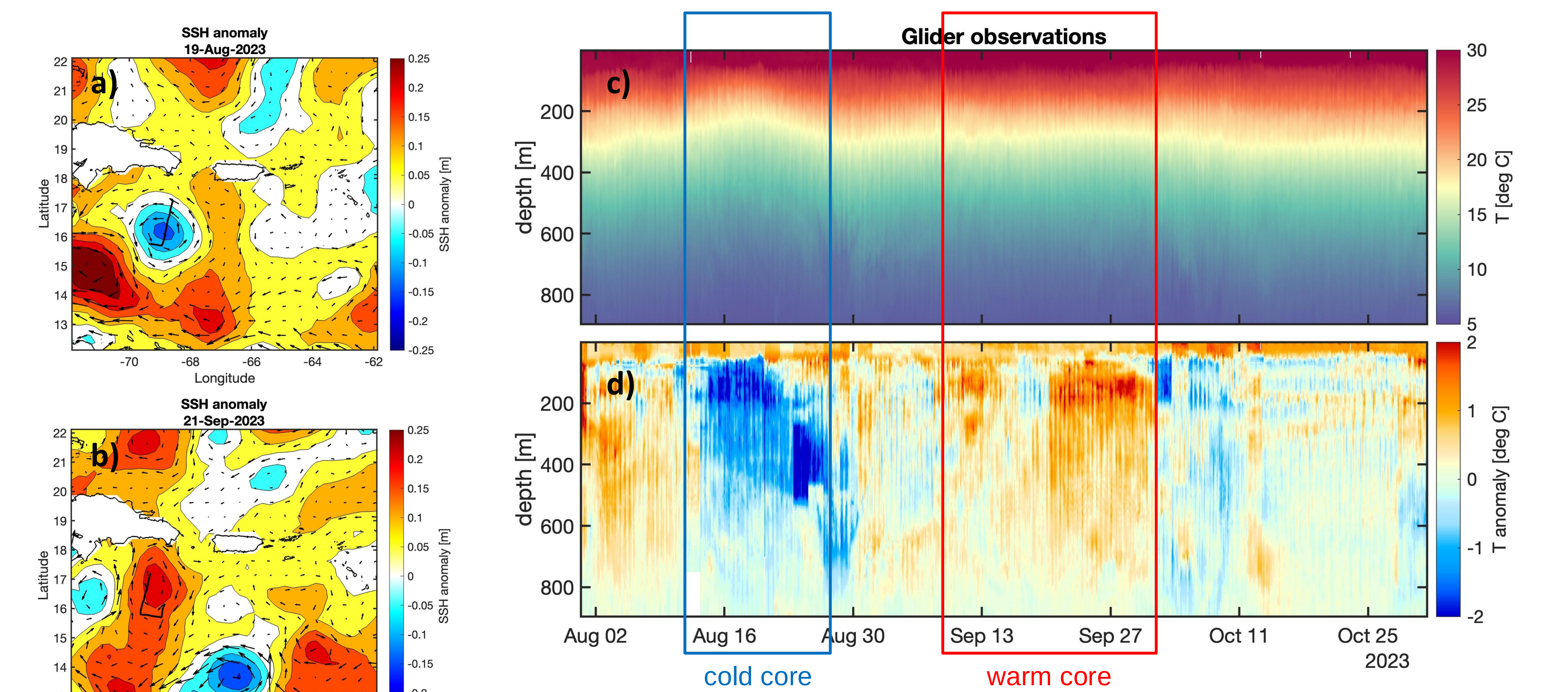
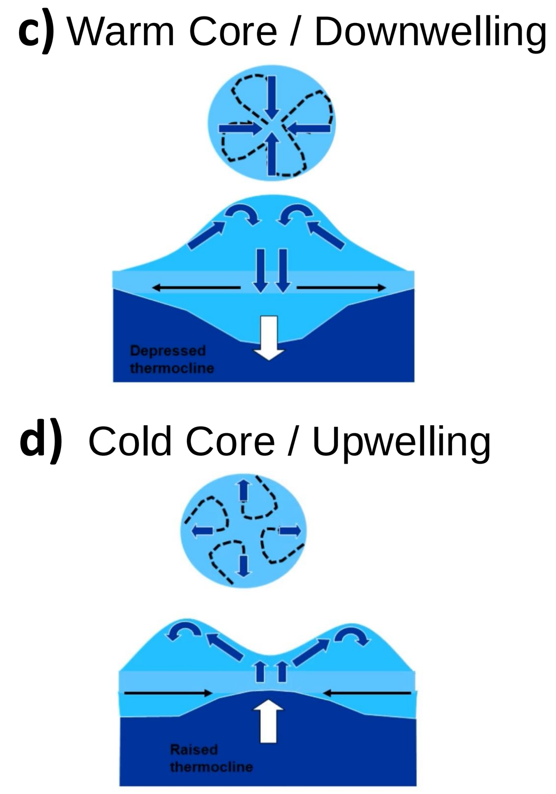


Figure 4. Examples of (a) cyclonic (CE) and (b) anticyclonic eddy (AE) sampling events. Red and blue tones indicate positive and negative sea surface height (SSH) anomalies, respectively. Black tracks illustrate underwater glider tracks, and vectors represent geostrophic currents. Glider observed (c) temperatures and (d) temperature anomalies.

Caribbean Mesoscale Eddies

The Caribbean Sea's mean flow is unstable, with mesoscale eddies, especially anticyclonic eddies (~140 km), being widespread. These eddies play a crucial role in dispersing larvae, river plumes, pollutants, and sargassum, while spreading cool, nutrient-rich waters from the Guajira upwelling system. They are also integral to the Atlantic meridional overturning circulation, transporting heat and salt, and modulating air-sea exchanges.

In Puerto Rico, mesoscale eddy impingements are common and believed to significantly affect subsurface temperatures through eddy pumping, where cyclones and anticyclones alter the thermocline. Recent studies suggest this process impacts reef habitats by providing thermal relief or increasing thermal stress. However, mesoscale ocean variability and internal-wave climates are often overlooked in MHW and coral bleaching assessments. A deeper understanding of oceanic forcing on subsurface temperatures is crucial to assess its influence on shelf edge reef ecosystems during extreme heat events.



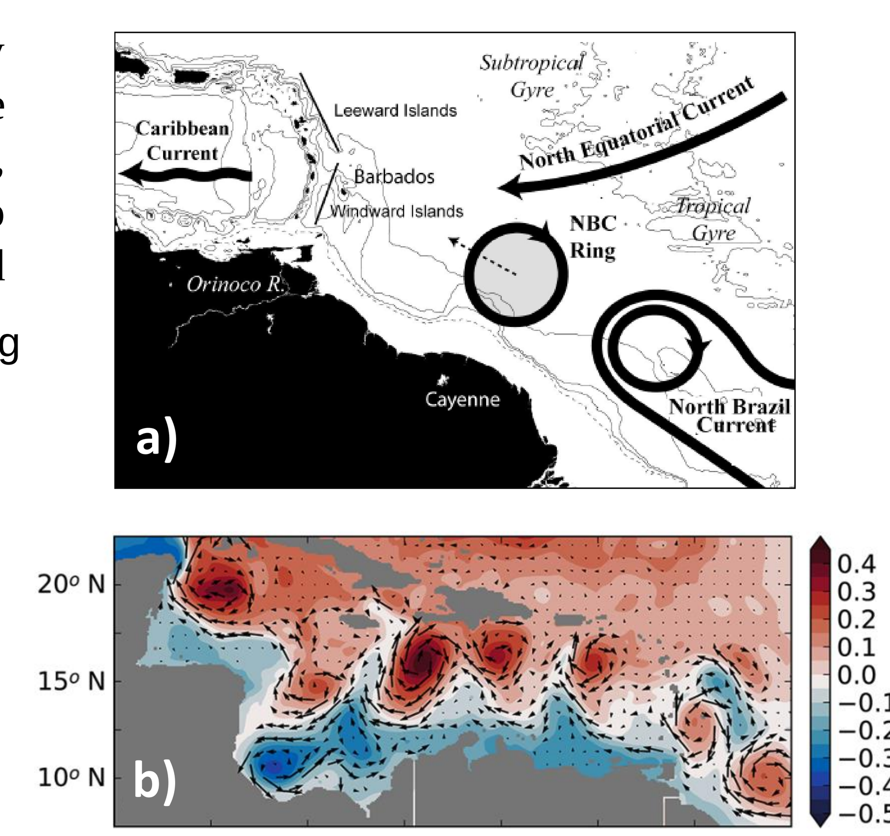
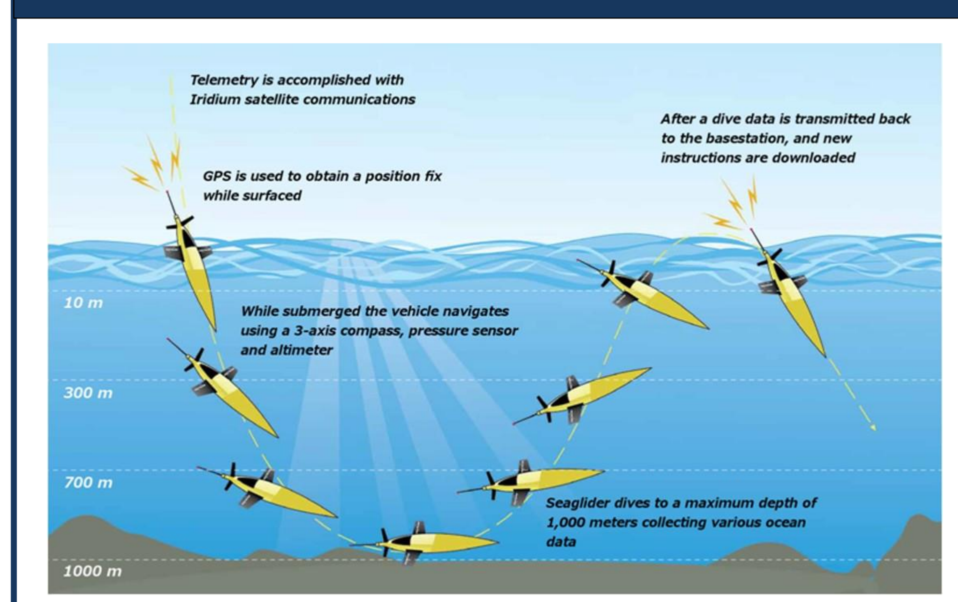


Figure 2. (a) Modified from Fratantoni & Richardson (2002) and (b) sea-level anomaly simulations from C. van der Boog et al. (2019). Mesoscale eddies provide a mechanism for (c) downwelling and (d) upwelling as well as vertical mixing.

CARICOOS & AOML Underwater Hurricane Gliders



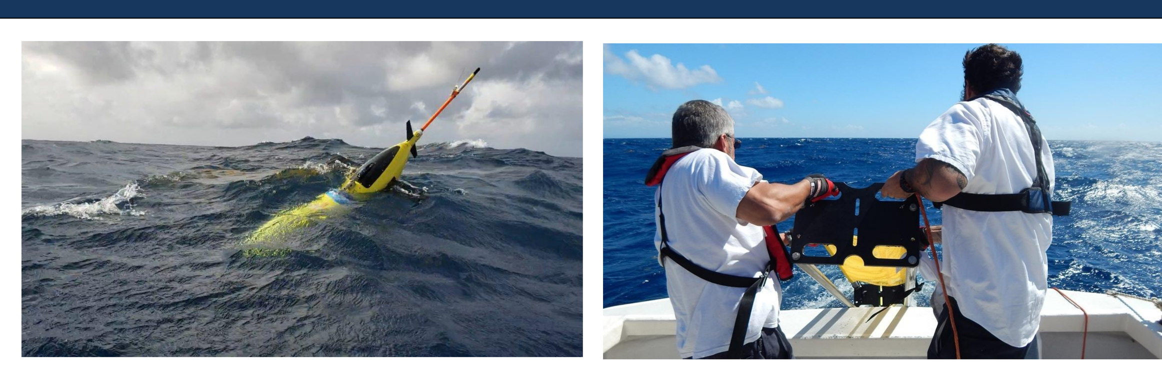


Figure 3. Underwater gliders propel themselves by using small buoyancy changes and wings to convert vertical motion into horizontal motion.

Since 2017, CARICOOS has partnered with NOAA's AOML to enhance hurricane intensity forecasting using underwater gliders. These gliders are launched from surface ships, remotely controlled, and use buoyancy and wings for forward motion. They can operate continuously for up to 2 months, traveling over 2,000 km while transmitting data in near real time via satellite when surfacing.

Preliminary Results: Average Profiles

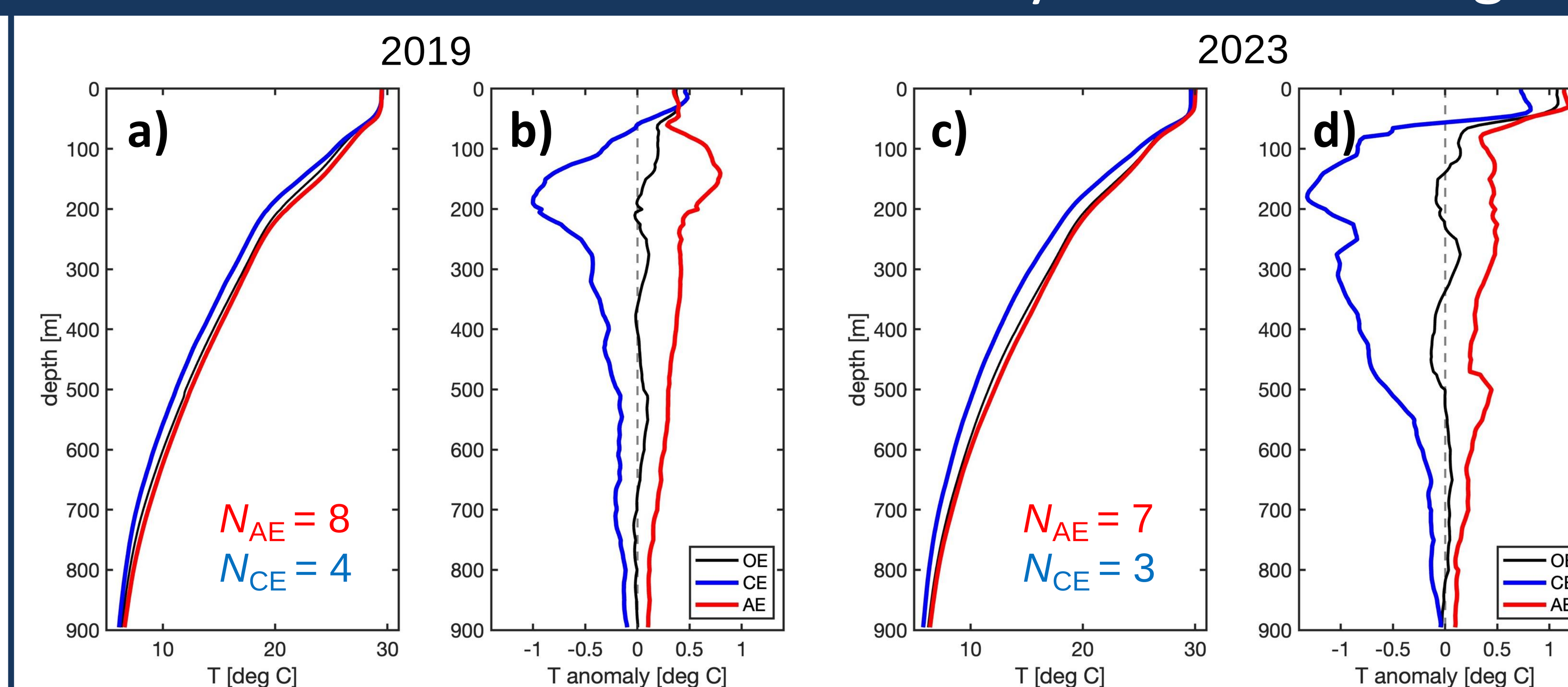


Figure 4. (a,c) Temperature and (b,d) temperature anomaly profiles from underwater glider observations during Jul-Aug for the years (a,b) 2019 and (c,d) 2023. The blue and red lines correspond to mean profiles collected within cyclonic (CE) and anticyclonic (AE) eddies, respectively, while the black lines indicate the mean profiles collected outside eddies (OE). The number (N) of AE and CE contributing to the average profiles is shown in (a) and (c) for 2019 and 2023, respectively.

Preliminary observations from the 2019 and 2023 'hurricane' glider deployments reveal distinct subsurface temperature structures. In 2023, a surface-intensified marine heatwave showed temperature anomalies over 1°C down to 50 m, decreasing to near 0°C by 150 m. Under AEs, moderate warming (~0.5-0.25°C) occurred between 100-500 m, while CEs showed cooling anomalies over 1°C between 150-300 m. In contrast, 2019 data indicated weaker warming (<0.5°C) in the mixed layer and subsurface anomalies for AEs and CEs. Despite being less frequent, CEs induced greater anomalies, but the small sample size limits conclusions.

Concluding Remarks & Future Work

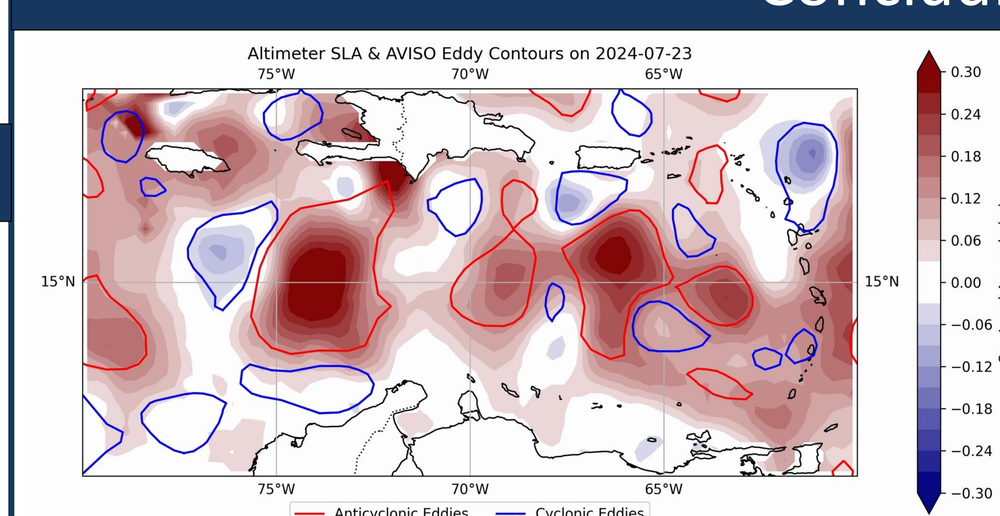


Figure 5. Example of SSH anomalies and AVISO Eddy contours.

The vertical structure of Caribbean eddies were analyzed using underwater glider data from 2019 and 2023. Composite analysis shows that eddy-induced ocean anomalies are mostly confined to the upper 500 m. Cyclonic eddies cause cooling anomalies exceeding 1°C, while anticyclonic eddies induce warming of about 0.5°C, with maximum anomalies between 100 and 500 m.

- **Automation:** Plans to automate glider identification within eddy footprints using the AVISO Mesoscale Eddy Trajectory Atlas Product. Automating this process will help us increase our sample size.
- **Ongoing Work:** Future analyses will consider glider position relative to the eddy core, sea surface height anomaly, and EKE.

Acknowledgements

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