UNDERSTANDING THE CROSS-SHELF EXPANSION OF A FULL WATER COLUMN MARINE HEATWAVE IN A RIVER-DOMINATED SYSTEM DURING HURRICANE SEASON

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Tropical Cyclones and Importance of Coastal Marine Heatwaves

- Marine heatwaves (MHWs): when extreme temperature anomalies persist in the ocean for a prolonged period.
  - MHW definition: Extreme temperature anomalies (above 90 pctl) persisting a minimum duration of 5 days and a maximum gap of 2 days (Hobday et al., 2016).
  - MHWs have severe economic and ecological consequences, such as coral bleaching and mass fish mortalities.
  - Rapid intensification of storms when extreme SST anomalies (MHWs) are present.
- Coastal oceans are shallow water environments (depths less than 300m).
  - Rapid changes in heat content; Limited cold reserve from the bottom.
  - Unique set of forcings and processes with shorter periods
  - Vertical mixing and stratification; Influence from the open ocean and rivers; Interaction with atmosphere and land.
- Cyclone forecast and disaster management
  - Shelf transit time of storms: less than 72 hours
  - High forecast skills are needed for damage prevention and evacuation.

Tropical Cyclones -Marine Heatwaves Links

- **Cases of MHWs- Tropical Cyclone interactions:**
  - Dzwonkowski et al. (2020): Compound events in shelf: How TC Gordon and an atmospheric heatwave transformed shelf conditions favorable for intensification of HC Michael in Oct 2018.
  - Rathore et al. (2022): Presence of a marine heatwave event under the track of tropical cyclone Amphan (2020) during its rapid intensification in the Bay of Bengal.
  - Pun et al. (2023): In the East China Sea, Typhoon Bavi (2020) amplified over a marine heatwave in a stratified water column.
- **Statistical relationships between MHW and tropical Cyclones:**
  - Choi et al. (2024): statistical connection between the strengthening of tropical cyclones in the Western North Pacific and Atlantic Ocean and marine heatwave events.
  - Radfar et al. (2024): Approx. 70% of hurricanes that formed between 1950 and 2022 were influenced by marine heatwaves, with rapid intensification 50% more likely during marine heatwaves.

Study Area : Gulf of Mexico

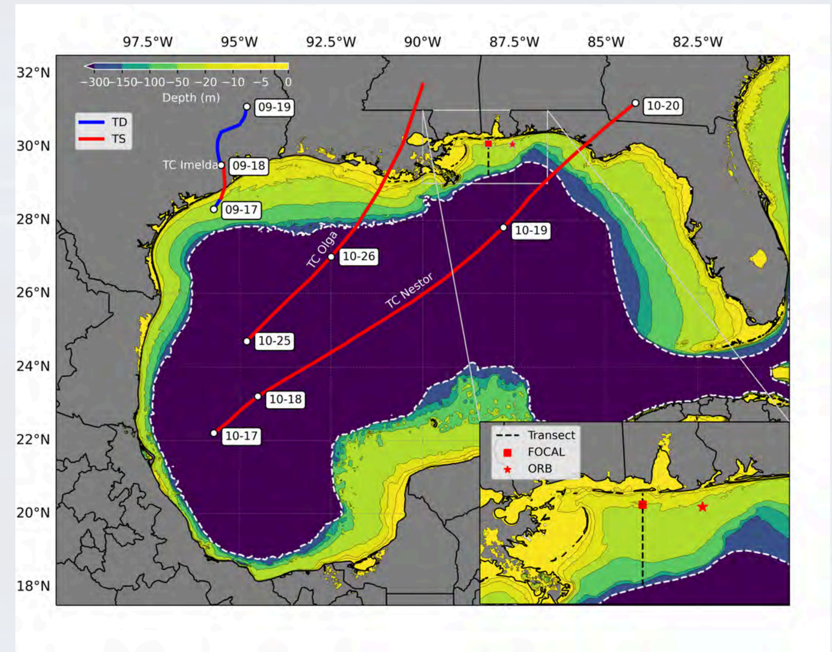

Figure 1: Map showing bathymetry with white dashed lines indicating the continental shelf break at 300 m. TC Imelda (17-19 Sept 2019), TC Nestor (17-20 Oct 2019), and TC Olga (25-26 Oct 2019). Inset map: Mississippi Bight. FOCAL &ORB are observation platforms.

- Known for tropical cyclones (i.e., hurricanes) and high river discharge
- Tropical cyclone activity from June to November.
- Recent examples of rapid intensification in the coastal regions include Hurricane Ida (2021) and Hurricane Idalia (2023).
- Peak hurricane season that runs between August to October
- Long-term statistical assessments of the marine heatwaves (Ameya et al.,2023; Feng et al., 2023)
- Balaguru et al.,(2022): Historical and future nearshore conditions in US coasts likely favoring intensification rates.

"A few studies have focused on mechanistic processing impacting marine heatwaves in seasonally stratified, river-dominated systems, particularly during peak hurricane season"

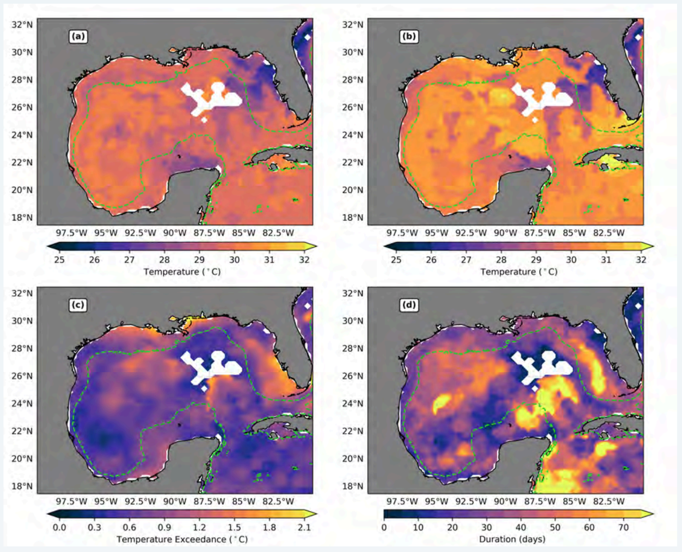

Figure 2: (a)mean SST, (b) peak SST, (c) peak SST exceedance above the 90th percentile threshold during the MHW events, and (d) total duration (in days) of the MHW events in the Gulf of Mexico in 2019 during the study period (Aug 15 - Nov 15) using OISST.

Extreme environmental conditions :

Atmospheric heatwave+high relative humiidty+weak wind conditions

=> reduced heat loss due to low latent and sensible heat fluxes

Offshore intrusion:

Advective heating from the outer continental shelf

Wind events (Imelda and easterly winds):

Inner shelf expansion of the MHW to depth through pre-storm mixing.

Easterly winds resulted in coastal downwelling in early October.

Decay of MHW

Heat loss at the air-sea interface TS Nestor and TS Olga

Freshwater discharge from the Mississippi River and regional river systems contributed to the insulation of subsurface layers and slower heat loss

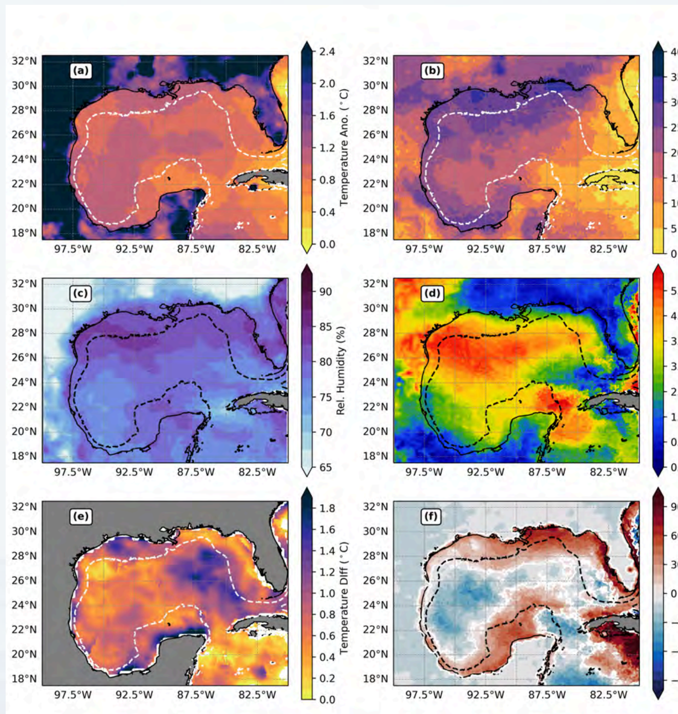

Figure 4: (a) mean deviation of 2m air temperature from 90 the percentile (°C), (b) total duration of atmospheric heatwaves (days), (c) mean relative humidity, (d) mean wind speed (ms-1), (e) max. diff. between daily max air temperature (2m) and SST (°C) and (f) mean total heat flux (Wm -2) during the atmospheric heatwaves at each individual pixel between 1 September and 31 October 2019.

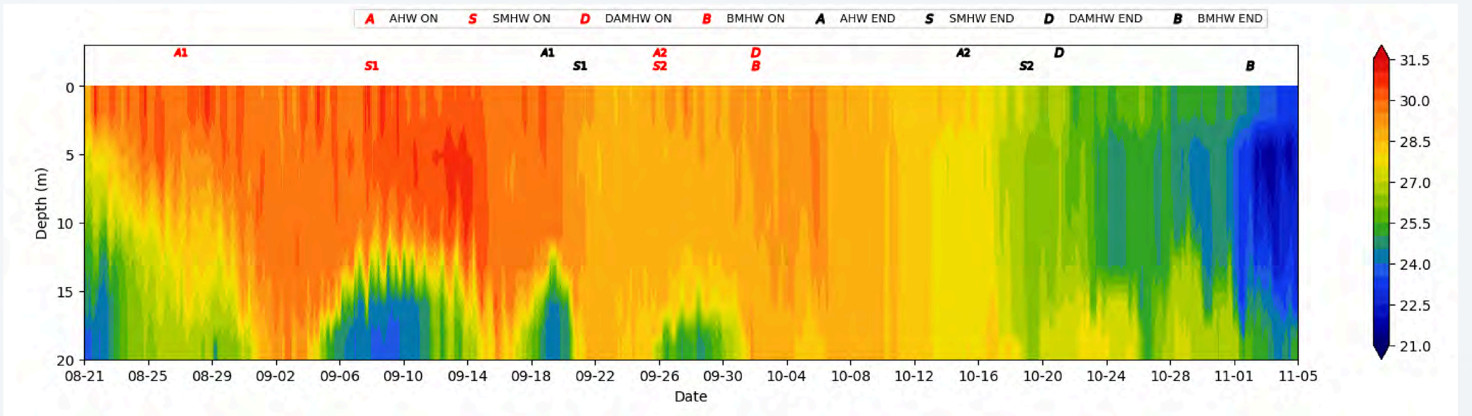

Figure 3: FOCAL interpolated temperature time series between Aug 21 and Nov 5 ,2019.

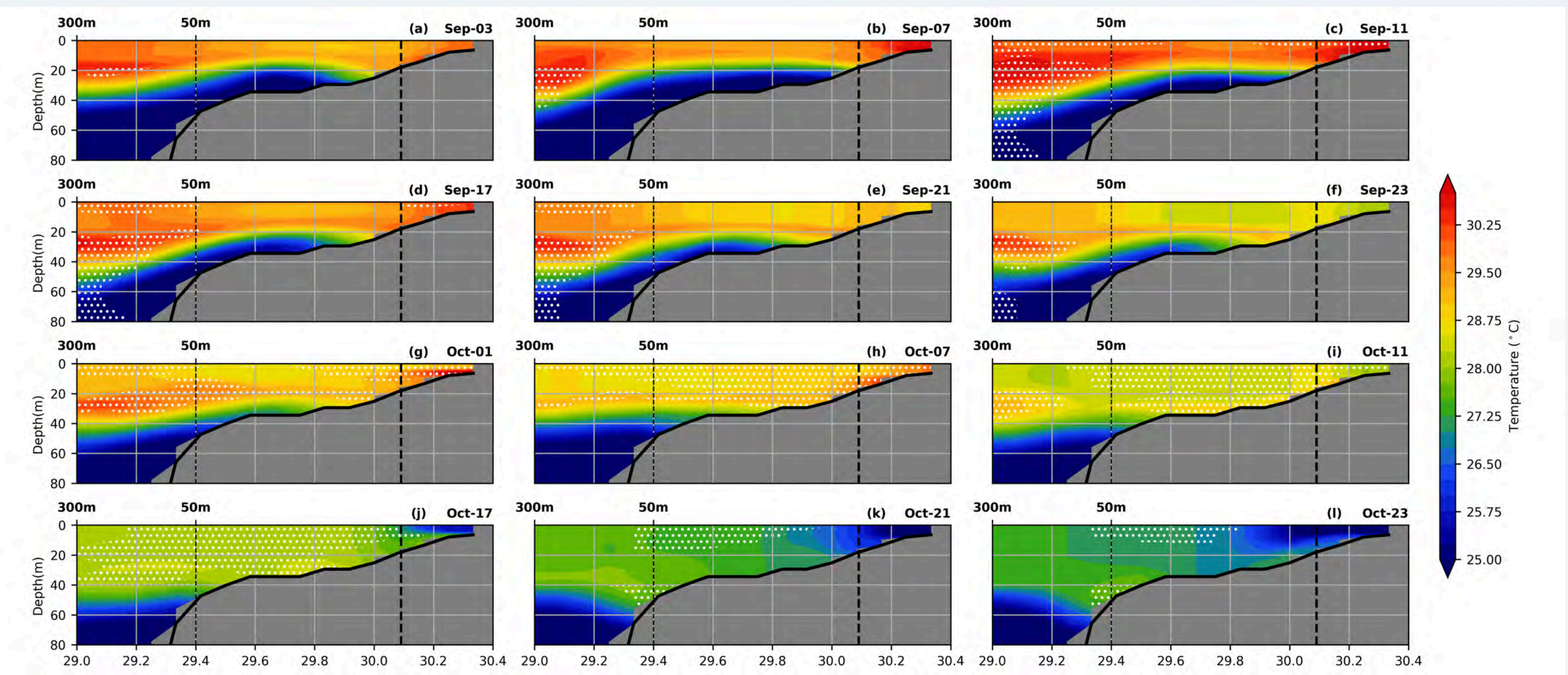

Figure 5. Selected daily snapshots from Global Ocean Physics Reanalysis (GLORYS) showing the evolution of the thermal structure across the continental shelf along 88.21°W between September 03 and October 23, 2019 that highlight four transition stages: (a) to (c): Increase in surface layer temperatures; (d) to (f): Surface cooling and mixing in the pycnocline ; (g) to (i): Rewarming and offshore heat transport from the coast along bottom layers; and (j) to (l): surface cooling and temperature inversion.

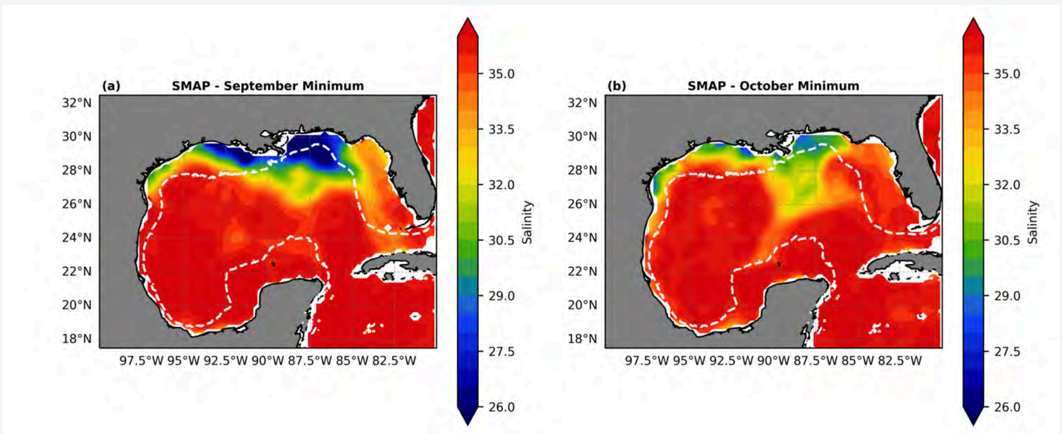

Figure 6: Map of monthly minimum sea surface salinity (SSS) from Soil Moisture Active Passive (SMAP) remote sensing data during the month of (a) September and (b)October.

"Influence of river discharge through salinity stratification preserved the bottom layers from heat loss and extended the duration of MHW"

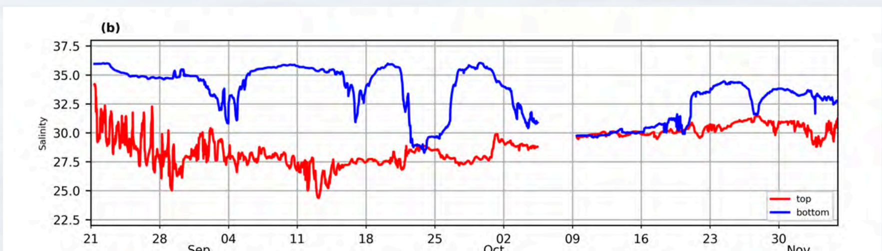

Figure 7: Time series of top (4 m, red) and bottom (19.5 m, blue) salinities from FOCAL during 1 Sept to 5 Nov 2019.

Summary and Future Work

- This study provides a broad understanding of a large-scale marine heatwave event in the 2019 hurricane season, making use of multiple data sources.
- This allows for the visualization of how marine heatwaves evolve in space and time across the Eastern Gulf of Mexico continental shelf.
- Highlights an event 'continuum,' where one event consists of the three types of marine heatwaves defined by Schaeffer et al. (2023), i.e., the connection between the surface to subsurface MHW events.
- Salinity stratification (role of river discharge) was found to be crucial in the extended duration of the bottom marine heatwave phase of the event.
- Interactions between marine heatwaves and tropical cyclones within the coastal zone during hurricane season, with no notable rapid intensification of storms likely due to unfavorable atmospheric conditions.

Ocean Observing Networks for Detecting the Coastal Climate Signal

- Fisheries Oceanography in Coastal ALabama (FOCAL) mooring and Orange Beach Buoy (ORB) datasets provided key aspects of the events, including identifying the MHW events and stages in evolution.
- Monitoring shelf-wide hypoxia events in spring-summer periods through hydrographic surveys.
- Alabama's Real-Time Coastal Observing System (ARCOS): meteorological and hydrographic data across Mobile Bay.
- New addition: Glider to monitor fisheries and environmental conditions.
- Mississippi Bight: River-influenced hurricane-prone location and one of the diverse ecosystems in the Gulf Coast LME.
- Partnering with GCOOS for real-time MHW alerts from ocean observing systems.

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