Exploring the Influence of Bottom Oxygen Gradients on Marine Heatwave Severity in the Gulf of Mexico (1992-2023)

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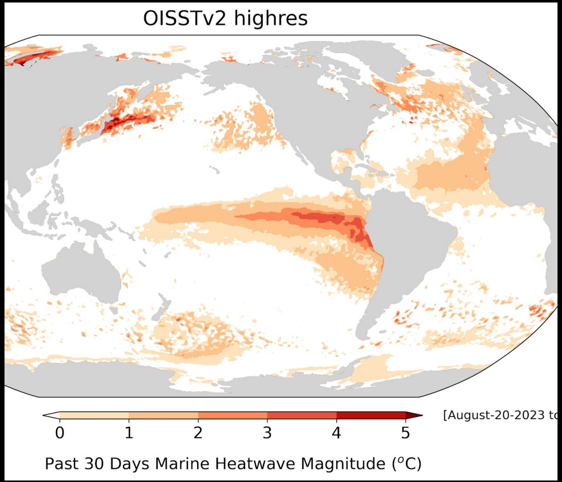
PROJECT TIMELINE–

Tracking changes over time → Comparing long-term patterns of oxygen and marine heatwave severity

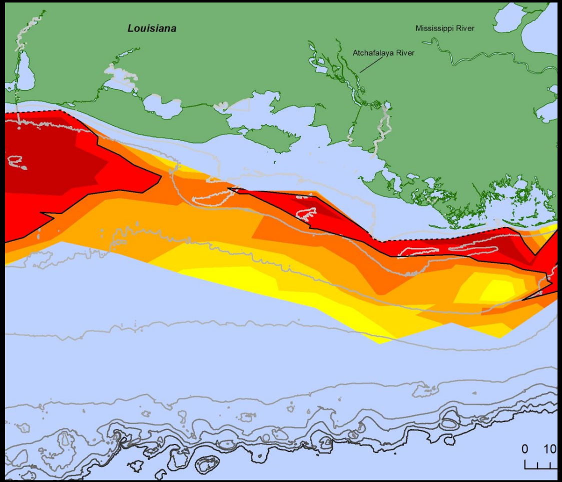
Initial Plan	• Are changes in ocean circulation patterns influencing the formation and movement of oxygen-depleted dead zones in major ocean basins?
Revised Plan	• Is the severity of marine heatwaves (MWHs) in the Gulf of Mexico associated with the expansion of oxygen-depleted dead zones in the coastal area?
→ First Setback:	• NOAA Gulf Hypoxia data inconsistent across years and locations • OISSTv2.1 high-res daily satellite v.s. sparse ship-collected points
Final Research	• **Does the natural spatial gradient of baseline bottom-oxygen concentrations in the Gulf of Mexico correspond to patterns of marine heatwave severity?**

Definitions–



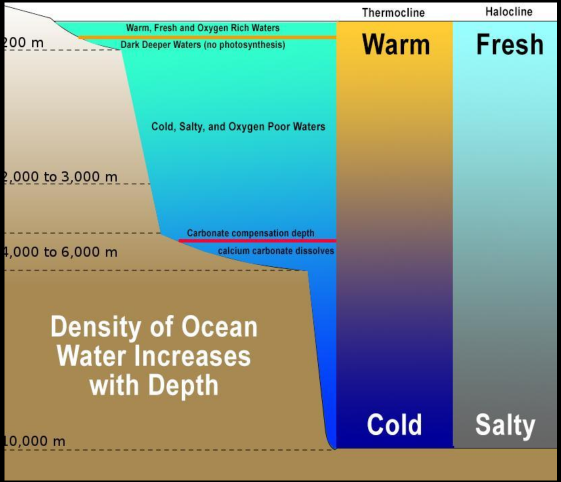
Marine Heatwaves

Detection algorithm based on Hobday et al. (2016): "periods when SST exceeds the local 90th percentile threshold for at least 5 consecutive days."



Bottom-Oxygen Levels

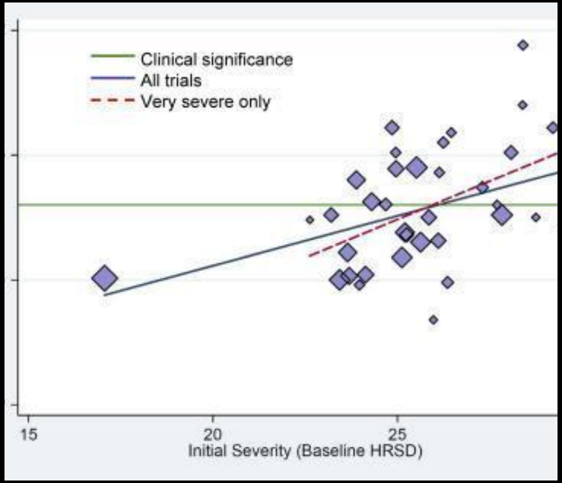
The concentration of oxygen dissolved in seawater near the seafloor, measured in micromoles per kilogram (μmol/kg).
Project Target Depth: ~50m



Stratification

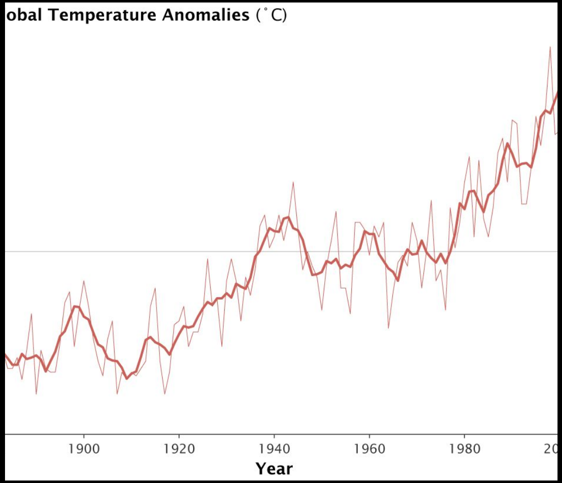
Layers of the ocean form because warmer water is lighter, floating on top of colder, denser water which prevents mixing between surface and deep sea layers.

More Definitions–



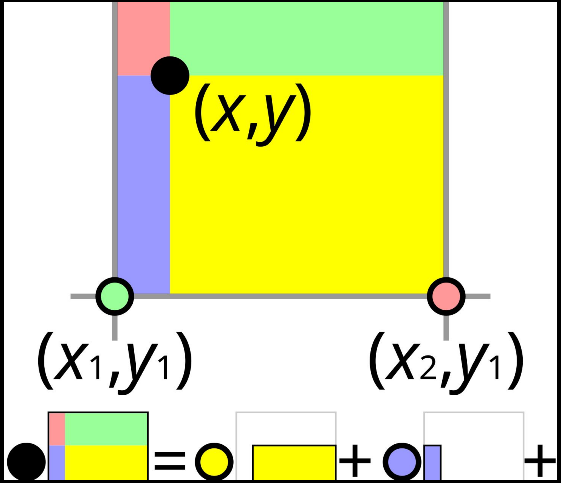
Baseline

The average conditions over a long period of time used for comparative analysis.



Anomaly

Measurement of how much the current condition differs from the baseline.



Interpolation

Method to estimate data at locations where it wasn't directly measured by using surrounding known values.
Used to fill in gaps in the oxygen data.

Data Sources–

OISSTv2p1: NOAA Satellite SST Data

→ Daily sea surface temp 1981-2024

WOA23: World Ocean Atlas 2023

→ Climatological averages of bottom oxygen (~50m depth)

m_mhw Toolbox: MHW Detection

→ MATLAB adapted algorithm

Methods-

1. Load SST data, convert variables, calculate monthly climatology and get daily SST anomalies

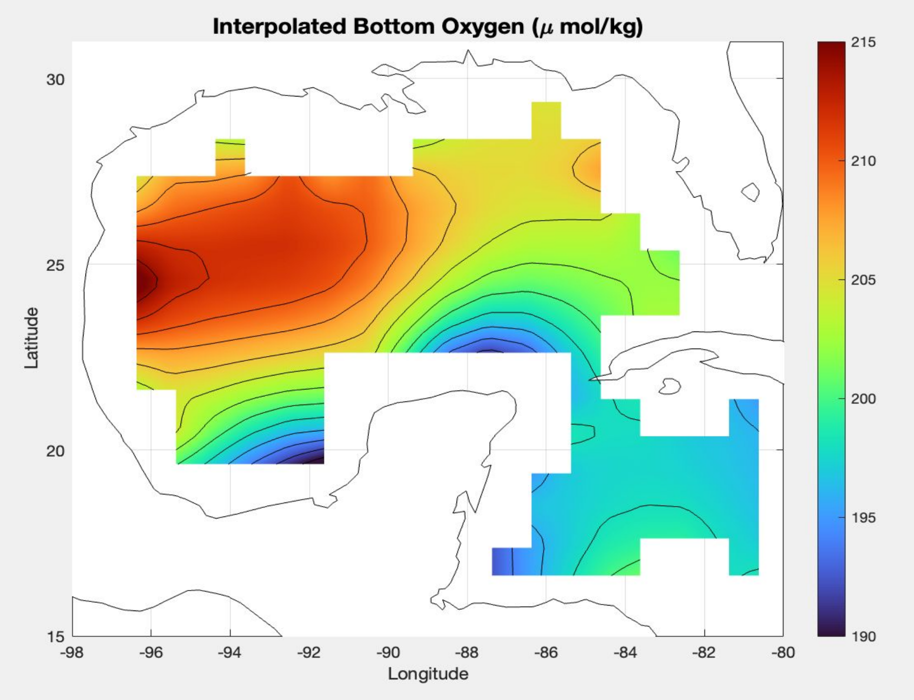
2. Use MHW detection algorithm to calculate total MHW days at each grid cell in the Gulf of Mexico from 1992-2023

3. Load Bottom Oxygen data, coarser grid than SST (1° v.s. 0.25°) so interpolate to fill in missing values

4. Align both datasets and run spatial analysis
   - Correlation measurements
   - Coastal v.s. Offshore averages

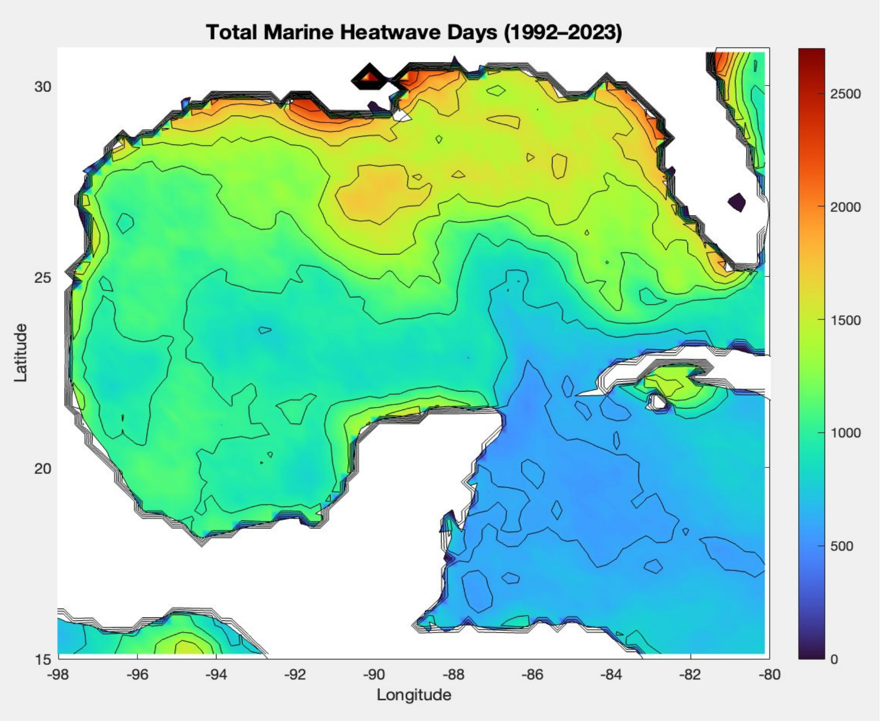
Interpolated Bottom Oxygen (µmol/kg) Map

This map shows bottom oxygen concentrations across the Gulf of Mexico at ~50 m depth, interpolated to match the SST grid. Values appear higher in the western Gulf, and lower in the southeast.



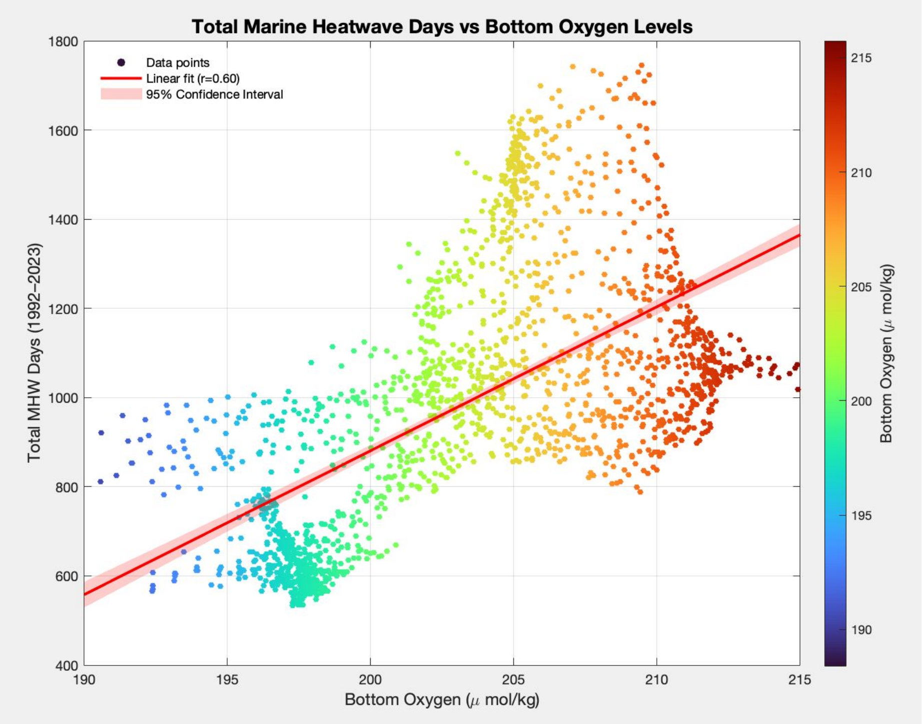
Total Marine Heatwave Days (1992-2023) Map

This map shows the total number of marine heatwave days at each location in the Gulf of Mexico from 1992 to 2023. The northwestern Gulf and coastal regions show the highest marine heatwave persistence.



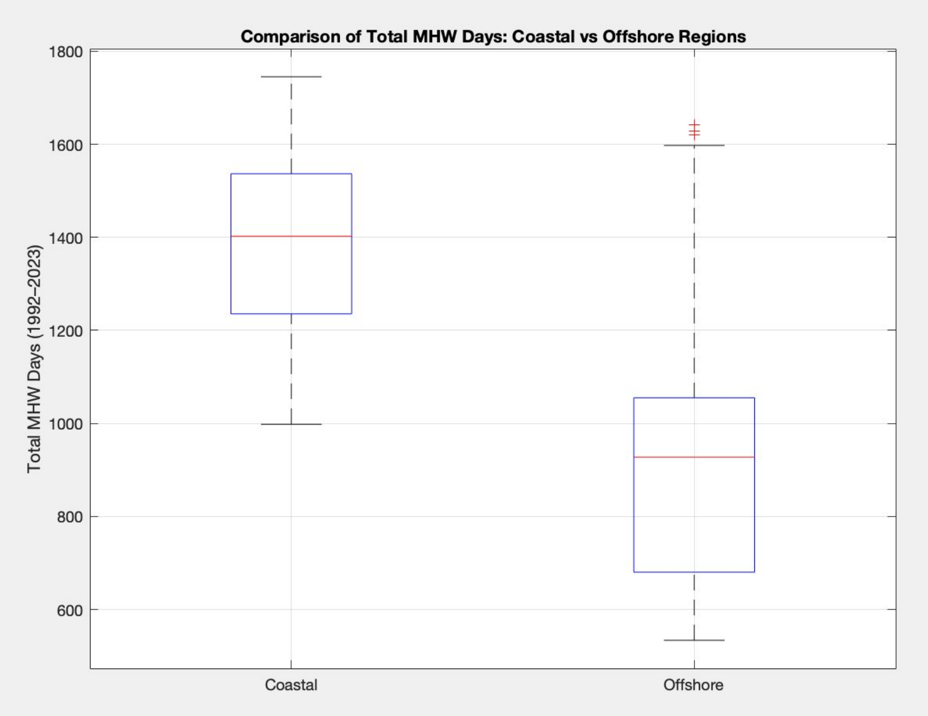
Relationship between Bottom Oxygen Levels and MHW Days

This scatterplot shows each grid cells' bottom oxygen concentration compared to its total marine heatwave days. The positive trend suggests areas with higher bottom oxygen have more marine heatwave days overall.



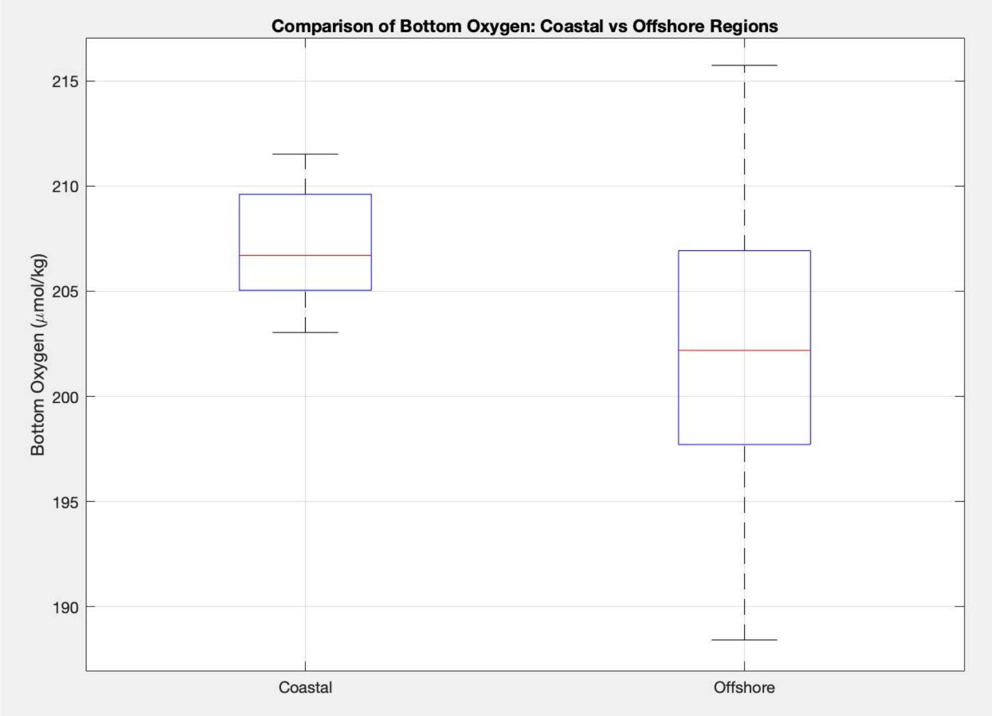
Coastal vs. Offshore Comparison – MHW Days

This boxplot compares the number of marine heatwave days between coastal and offshore regions. Coastal areas very clearly had more marine heatwave days on average.



Coastal vs. Offshore Comparison – Bottom Oxygen

This boxplot compares bottom oxygen levels between coastal and offshore regions. Coastal values were slightly higher, but the difference was much smaller than for marine heatwave days.



* Coastal Region outlined:
(lat > 26°, -95° < lon < -86°)

Key Statistical Findings–

Correlations between bottom oxygen levels & marine heatwave days

r = 0.60157
→ positive correlation
→ moderate to strong
→ as bottom oxygen levels rise, the number of marine heatwave days also tends to rise

p-value = 2.7767e-175
→ $p < 0.001$, statistically significant trend

Average bottom oxygen levels at 50 m by region

Coastal: 207.2388

Offshore: 202.6267

→ Bottom oxygen levels were slightly higher (~4.6) on average near the coast than offshore

2-sample t-test p-value: 5.408e-43
→ $p < 0.001$, statistically significant trend

Average marine heatwave days at 50 m by region

Coastal: 1384.3928

Offshore: 911.6643

→ On average, coastal locations had 473 more MHW days over 30 years than offshore areas.

2-sample t-test p-value: 1.4499e-179
→ $p < 0.001$, statistically significant trend

Conclusion–

- Areas with higher bottom oxygen in the western Gulf of Mexico had more total marine heatwave days from 1992 to 2023.
- There is a moderate positive correlation ($r = 0.60$) between bottom oxygen concentration and MHW days.
- Coastal areas had significantly more MHW days than offshore areas, but only slightly higher bottom oxygen.
- Bottom oxygen gradients seem to be related to patterns of marine heatwave severity, but that does not certify causality.
    - Other factors like stratification, currents, nutrient runoff, etc.
- TO NOTE: Coastal hypoxia could still be underestimated due to gaps in oxygen data right along the coast.

→ **SO WHAT NOW?**

Future Directions–

- Fill coastal data gaps
- Explore temporal trends between bottom oxygen and MHWs: is the relationship consistent over time as well as space?
- Test how oxygen at other depths interacts with stratification and heatwave persistence
- Investigate other factors

Why Does This Matter?

Marine heatwaves threaten fisheries, ecosystems, and coastal economies. This correlation between bottom and surface conditions could inform resilience strategies.

Even without proven causality, this strong correlation raises new questions about coastal dynamics, oxygen cycling, and climate extremes.

Understanding the role of bottom oxygen can help us better predict which regions are more vulnerable to prolonged marine heatwaves.

If areas with higher bottom oxygen are really more prone to prolonged MHWs, this could reflect deeper physical processes like stratification.

Questions?

Thank you for listening!

References–

https://www.ncei.noaa.gov/access/world-ocean-atlas-2023/

https://www.ncei.noaa.gov/products/optimum-interpolation-sst

https://github.com/ZijieZhaoMMHW/m_mhw1.0?tab=readme-ov-file