Late Holocene Paleohurricane Reconstruction from the Central Texas Shelf, Western Gulf of Mexico

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Abstract

Paleotempestology assists in extending the instrumental storm record through sedimentary-based, high-resolution records of storms over millennia. A fundamental understanding of the paleorecord provides essential context for modern climate models and, therefore, a broader understanding of our climate system. The Texas (TX) coastline receives the second largest number of hurricane landfalls per year in the United States; since 1900, 92 tropical storms and hurricanes have made landfall on the TX coast. During storm impacts, coastal downwelling storm channels deliver coarse sediment to the muddy shelf. This return flow or "backwash" process results in thin but expansive storm deposits in the region, making it ideal for paleotempestological reconstructions. In this work, three sediment cores from the central TX shelf, approximately six kilometers off the coast of Matagorda Island, were collected and analyzed. Several historic and Holocene storm events have been identified in cores by conducting detailed grain size analysis at one-centimeter intervals. Bayesian-based age models couple short-lived isotopic dating techniques (210-Pb and 137-Cs) with radiocarbon ages. X-ray fluorescence (XRF) analysis is used to determine geochemical signatures of the sediments and thus the material source for cross validating the depositional mechanism. Specifically, XRF is utilized to differentiate the effects of the 1929 Colorado River diversion relative to marine deposition. Our new record of tropical cyclone (TC) occurrence from the TX shelf is compared to paleoclimate models and proxy records of El Niño Southern Oscillation (ENSO) and Gulf of Mexico (GOM) sea surface temperature (SST). Preliminary results suggest that periods of decreased ENSO and increased GOM SST correspond with enhanced TX TC activity. Understanding these complex climatic interactions will help us to understand the changes in TC activity expected in the future against the background of accelerating climate change. Given that the frequency of extreme ENSO events is projected to increase, changes in the occurrence and severity of ENSO-TX TC events may prove detrimental to many coastal populations.

Study Area & Background

- NW Gulf of Mexico
- High TC frequency
- Primary sediment sources: Brazos, Mississippi,
- and Colorado Rivers
- 1930s: CO River diversion
- Longshore transport currents converge
- Louisiana-Texas Coastal Current dominates
- Matagorda Island formed during Late Holocene Transgression (4.9 to 1.6 ka)

Figure 1: Study area; sediment cores were collected approximately 6 kilometers off the coast of Matagorda Island, Central TX.

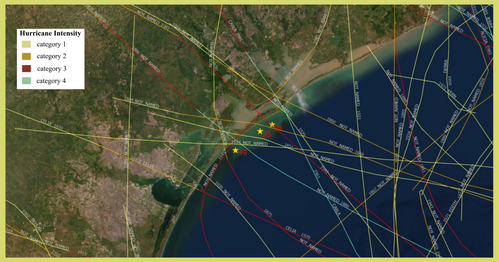


Figure 2: Historical Hurricane Tracks 1851-1997 (IBTrACS).

Figure 3: Historical Hurricane Tracks 1851-1997, category 3 and above (IBTrACS).

Background Continued

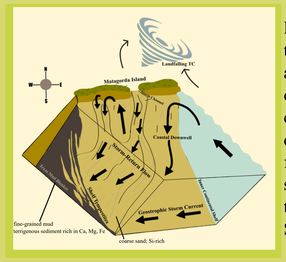


Figure 4: Schema depicting the formation of storm channels and the tempestites deposited on the shelf following tropical cyclone inundation. Coastal downwelling, storm channel return flow ("backwash"), and the geostrophic storm current transport coarse sediment to the muddy shelf. Figure adapted from Siringan and Anderson 1994.

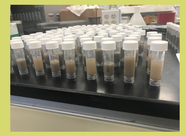
Methods

Grain Size Analysis
- Sampled at 1 cm-intervals, downcore
- Deflocculated ~1 week w/ sodium hexametaphosphate
- -Malvern Mastersizer 3000

X-ray fluorescence (XRF)
- Olympus Vanta Hand-Held XRF
- Dried and crushed sediment samples (~5g)
- 3-beam analysis (10s/20s/20s)

Short-lived Isotopes
- 210Pb and 137Cs
- 3 day run

Handheld XRF



Sediment samples deflocculating prior to Malvern analysis.

Preliminary Results

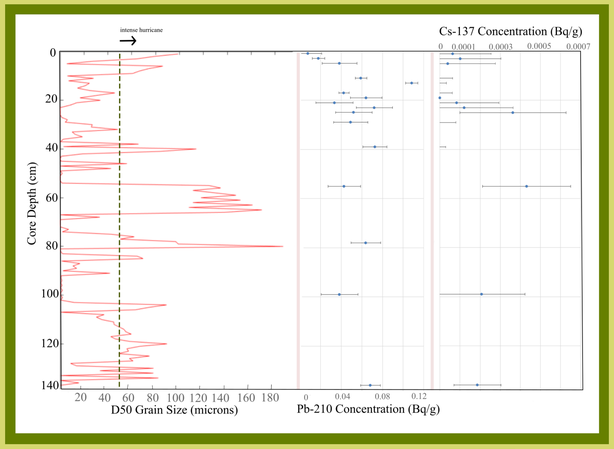


Figure 5 (left): MAI49 D50 grain size, MAI 49 short-lived isotope results (Pb-210 and Cs-137), where peaks in grain size are indicative of potential storm events. Low lead and cesium concentrations suggest a rapid sediment accumulation rate - much different than MAI35.

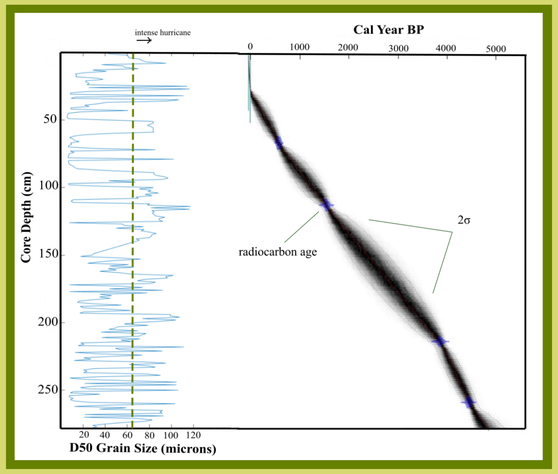


Figure 6 (above): MAI35 D50 grain size and MAI35 BACON model (version 2.2). Blue stars denote the location of radiocarbon ages within the core. The linear nature of the age/depth plot implies a constant rate of sedimentation over the past ~4500 years. Approximate sedimentation rate is 0.57 mm/yr.

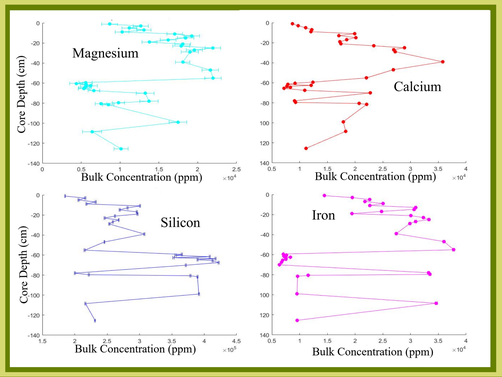


Figure 7 (left): X-Ray Fluorescence results for core MAI49. In general, excursions in Ca, Fe, and Mg correspond to peaks in Si. Note: due to laboratory restrictions, core was sampled at 2 cm intervals for upper 30 cm and intermittently below. Future work includes a complete XRF analysis of MAI49 and MAI35.

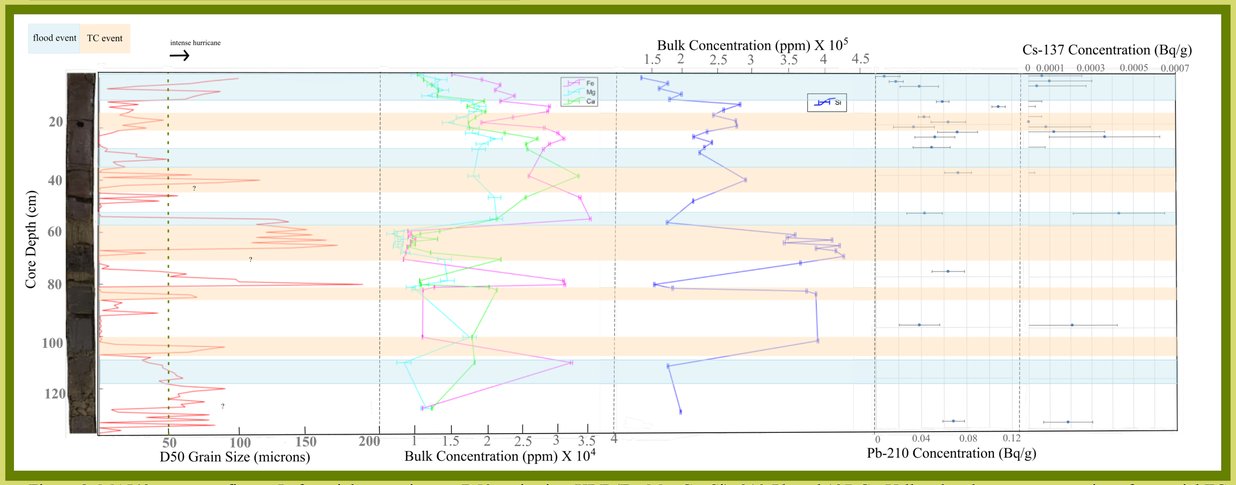
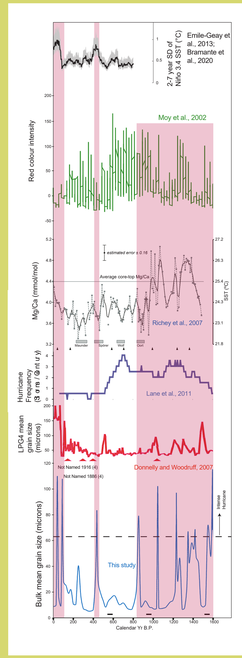


Figure 8: MAI49 summary figure. Left to right: core image, D50 grain size, XRF (Fe, Mg, Ca, Si), 210-Pb and 137-Cs. Yellow bands are representative of potential TC events in which Si peaks correspond with decreased Fe and Mg. Blue bands indicate potential flood events or non-events wherein moderate Fe, Ca, and Mg concentrations correspond with an decrease in Si. In most cases, Ca excursions occur where Fe and Mg also decrease but because Ca is present in the marine environment as well, this is not always the case.

Discussion

Figure 9 (right): Paleoclimate comparisons from top to bottom: Standard deviation (SD) of ENSO-band over 31-year moving window (Bramante et al., 2020) using multi-proxy reconstruction of SST anomalies (Emile-Geay et al., 2013); El Niño Southern Oscillation, Moy et al. 2002 (green), Sea Surface Temperature from Gulf of Mexico, Pigmy Basin, Richey et. al 2007 (black); Paleohurricane Record,Mullet Pond, Florida, Lane et al. 2011 (purple); Paleohurricane Record, Puerto Rico, Donnelly and Woodruff, 2007 (red); bulk mean grain size of core MAI35 (blue). Red bars indicate periods of increased TX TC activity. Note that during these periods, ENSO is decreased and GOM SST is increased. Paleohurricane records from Puerto Rico and Florida offer additional comparisons.



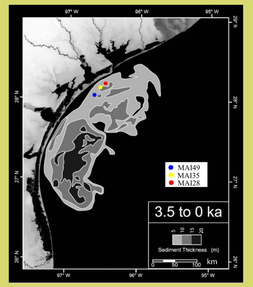


Figure 10 (left): Approximate core locations within the Texas Mud Blanket 3.5 to 0 ka. Rapid sediment accumulation on the shelf during the Late Holocene due to climatic changes and subsequent increase in sediment transport efficiency may be a potential cause for the differing sedimentation rates across cores (adapted from Weight et al., 2011).

Takeaway

1. Sedimentary records from the shelf have a high viability for high-resolution TC reconstructions.
2. Preliminary findings suggest that periods of increased W. GOM TC activity correspond with decreased ENSO/ENSO variability and increased GOM SST.
3. Future work is necessary to:
   a. Cross-validate the findings of MAI35 and MAI49
   b. Compare Texas TC activity to global and local paleoclimate records

Future Work / In Progress

- BACON Age Model (MAI49)
  - 14C dating via calcareous microfossils
  - Complete short lived isotopes profile
- XRF entire core - 1 cm intervals (both cores)
- Analyze deeper core section (MAI49)
- Use one core to validate the other and:
  - Paleoclimate comparisons (TX and global)
  - Identify modern storm analogues
  - Inverse sediment transport modeling to approximate storm surge height

Acknowledgements, References, & Contact Information

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References

Contact Information