Reconstructing millennial-scale hurricane activity on the Yucatan Peninsula: climate drivers and cultural impact

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Richard M. Sullivan[1], Pete van Hengstum[1,2], Jeffrey P. Donnelly[3] , Tyler S. Winkler[1], Shawna N. Little[4], Luis Mejita-Ortiz[5], Eduard Reinhardt[6], Sam Meecham[7], Courtney Schumacher[8], Rob Korty[8]

1. Department of Oceanography, Texas A&M University, Bizzell St, College Station, TX 77840; *richardmsullivan@tamu.edu
2. Department of Marine Sciences, Texas A&M University at Galveston, 1001 Texas Clipper Road, Galveston, TX 77553
3. Geology & Geophysics, Woods Hole Oceanographic Institution, MS #22, 266 Woods Hole Rd, Woods Hole, MA 02543
4. Department of Marine Biology, Texas A&M University at Galveston, 1001 Texas Clipper Road, Galveston, TX 77553
5. División de Desarrollo Sustentable, Universidad de Quintana Roo, Blvd. Bahía s/n, Del Bosque, 77019 Chetumal, Q.R., Mexico
6. School of Geography and Earth Sciences, McMaster University, Hamilton, ON, L8S 4K1, Canada
7. CINDAQ - El Centro Investigador del Sistema Acuífero de Quintana Roo, A.C., Puerto Aventuras, Mexico
8. Department of Atmospheric Sciences, Texas A&M University, Bizzell St, College Station, TX 77840

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1. Introduction

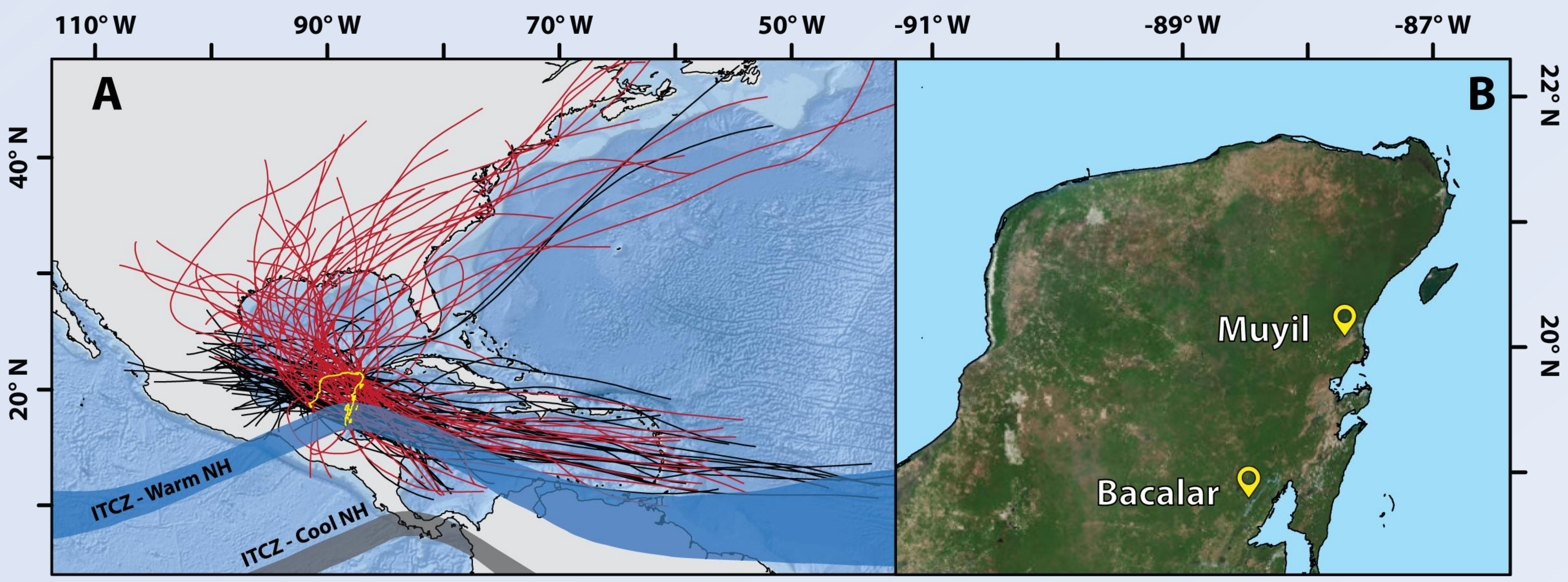


Figure 1: A) All storms (≥ TS) intersecting the Yucatan peninsula (in yellow) since 1850. Of the 122 storms passing over the Yucatan, 53 (43%, in red) have made landfall on US coasts.. Summer ITCZ position in blue, winter in black. B) Laguna Muyil and Lake Bacalar (Black Hole) on the Yucatan separated by 170km.

Statement of Purpose:

- Tropical Cyclones are the costliest & deadliest natural threats shared by Mexico & the USA. (Klotzbach 2018)
- TC genesis & track are influenced by the meridional position of the Intertropical Convergence Zone (ITCZ). (Klotzbach & Gray, 2006)
- 87% of TCs form just north of the ITCZ. A warming Earth is expected to shift the ITCZ north. (Klotzbach & Gray, 2006)
- Climate variability impacts societal stability. Drought may have contributed to Mayan cultural collapse (Kennett, 2012). The role of hurricanes is unknown.
- Cores collected in the North and South Yucatan in 2017 contain storm induced overwash reflecting regional hurricane variability

Research Questions / Hypothesis

I. How has hurricane activity on the Yucatan Peninsula varied over the last 2000 years?
H1: Shifts between active and inactive periods.

II. How has hurricane activity on the Yucatan Peninsula over the last 2000 years contributed to regional rainfall?
H2: Regional rainfall will mostly covary with storm frequency

III. How did Yucatan hurricane activity impact cultural development and demise in the northern Maya Lowlands?
H3: The Terminal Classic Drought likely coincides with suppressed hurricane strikes.

IV. How have zonal migrations of the Intertropical Convergence Zone affected Yucatan hurricane activity over the Common Era?
H4: A northern (southern) shifted ITCZ will increase (decrease) hurricane activity over the peninsula.

2. Sites: Laguna Muyil and Black Hole

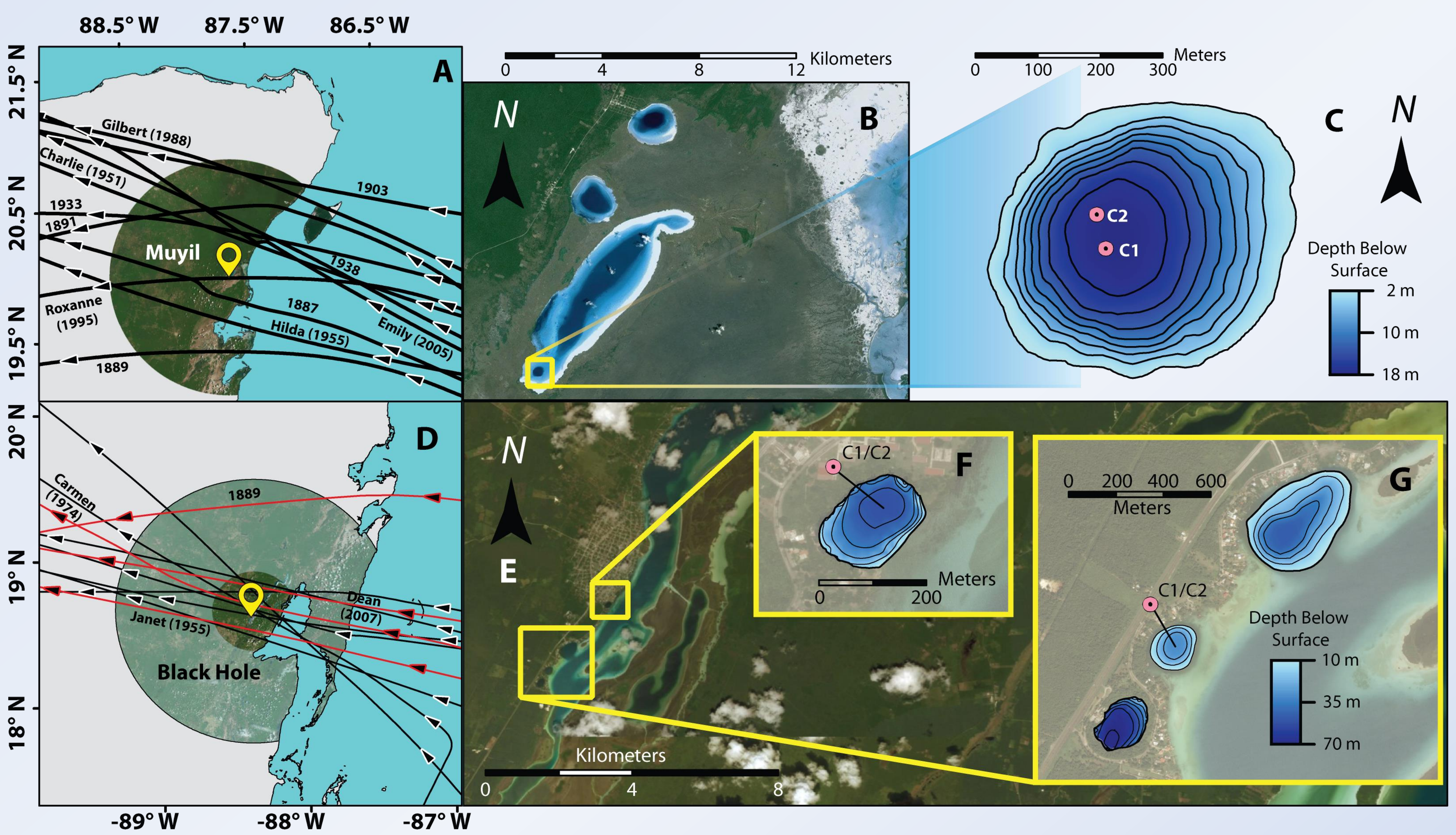


Figure 2: A) Major storms (11), Cat ≥ 3, passing within 100km of Laguna Muyil since 1879. B) Aerial image of Sian Ka'an bioreserve and Laguna Muyil (Sinkhole in gold) in Quintana Roo. C) Bathymetric map of Muyil Sinkhole, a 17 meter deep oxygenated fresh water cenote. Core locations are shown. Contour lines mark 2 m intervals. D) All TS, H1, H2 events (in Black) passing within 30 km of Black Hole, and events Cat ≥ 3 (red), passing within 100km. Only the storm of 1899 pass beyond the 30km radius. E) Aerial of Bacalar showing multiple coring location within the freshwater lake and sinkhole system. F) Inset showing Black hole coring location and bathy (contour lines in 10 m intervals) down to a max depth of 68 meters. G) Bathy and coring locations for other cenotes in the Bacalar system

3. Textural analysis and age control

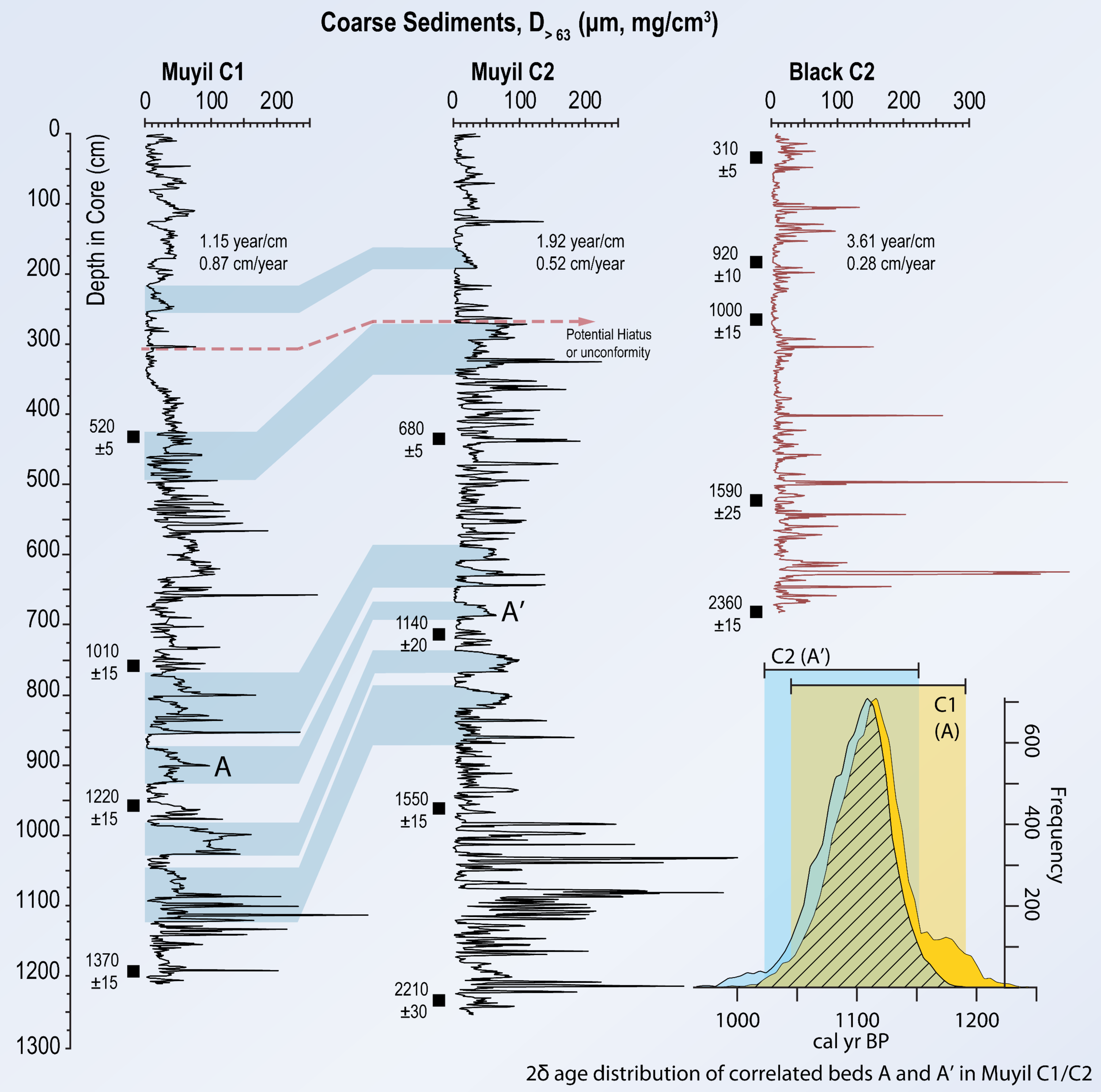
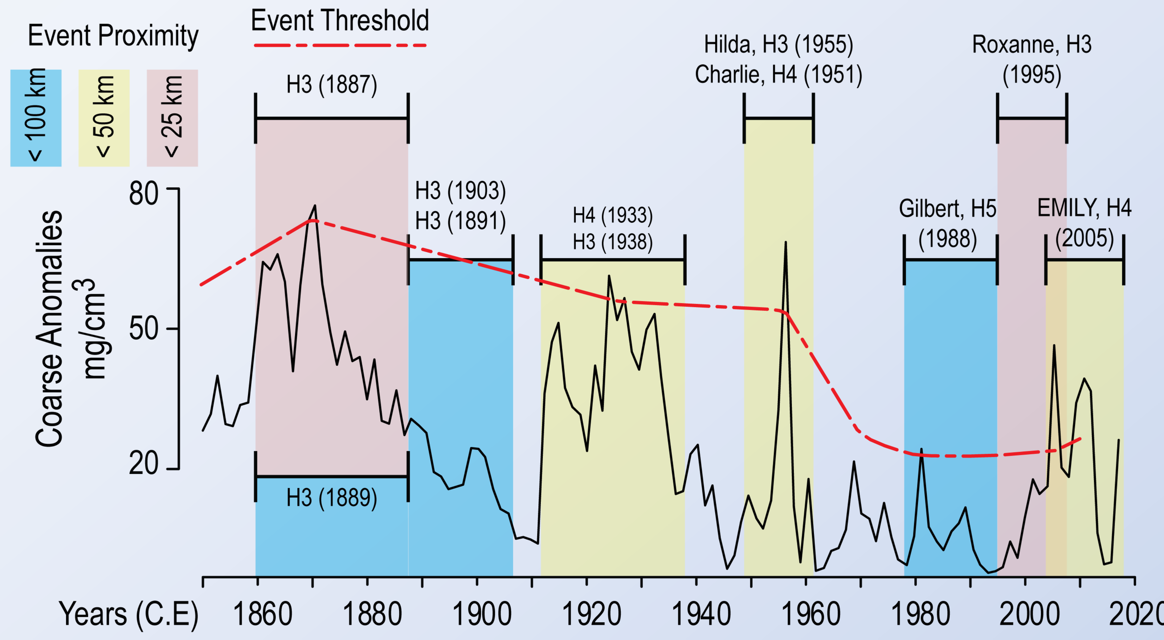


Figure 3: Downcore grainsize (> 63 μm) variability plot for Muyil C1 (left), C2 (middle) and Black C2 (Right). Black squares mark C14 sample locations. Blue bars indicate identifiable stratigraphic features between Muyil cores. A potential hiatus is apparent in Muyil C2 (260 cm). C2 grainsize above the shoalest C14 date (436 cm) is excluded in subsequent analysis. Lower right plot shows 2σ age range for deposits A and A' in Muyil C1 and C2.

Modern Storm Detection: Muyil



Modern Storm Detection: Bacalar

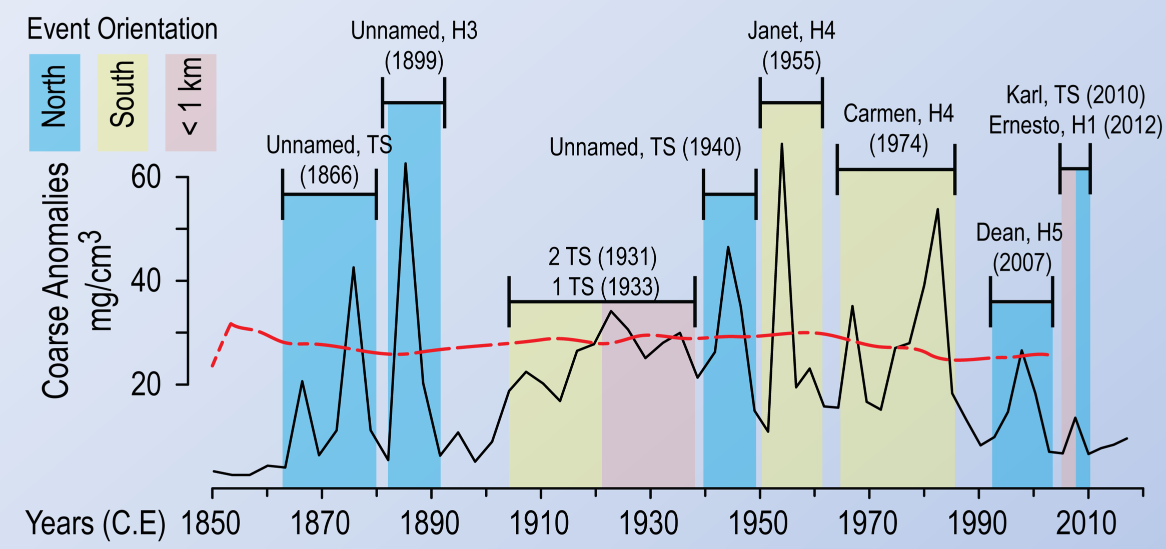


Figure 4: (Top) Recent 150 years of Muyil C1. Red dashed line shows final event threshold derived from 50 year moving mean anomaly. Major events passing within 100km of Muyil are identified. Note that only events (n = 7) passing within 50 km of the site are recorded. Shaded regions denote deposits likely associated with historical storms considering ^{14}C dating and age model uncertainties.

(Bottom) Recent 150 years of Black C1. Red dashed line shows final event threshold derived from 50 year moving mean anomaly. TS and greater events passing within 30km of Black Hole are recorded. Note, the only major event passing between 30 & 100km was the unnamed storm of 1899. Angle of approach is likely more significant factor in event deposition at Black Hole than proximity.

4. Event Frequency

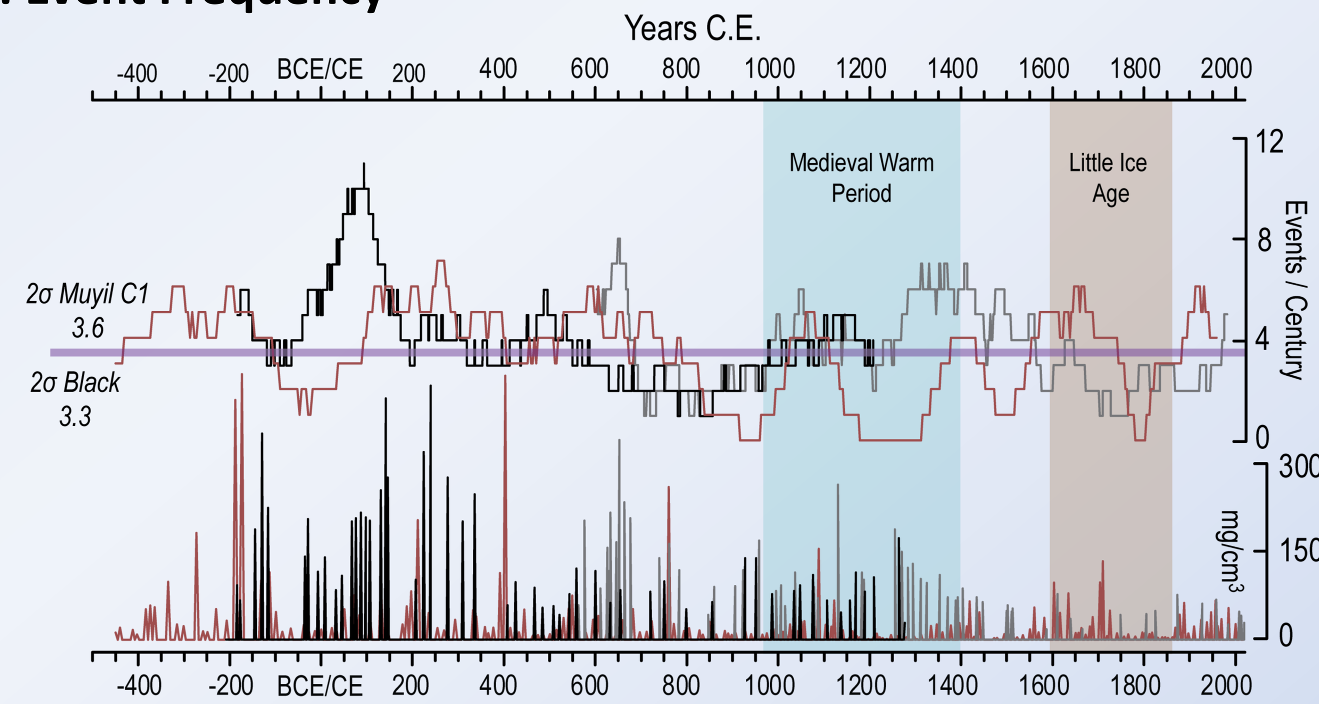


Fig. 5: (Bottom) Events that exceed established event threshold (Muyil C1 shown in grey, C2 black, Black C1 in red. (Top) Event count along a 100 year moving window. Purple bar denotes 2δ intervals in Black Hole and Muyil C1. Counts exceeding 3.3 (3.6) storms per century are considered anomalously active. Note that the Medieval Warm period coincides with an active interval at Muyil (20.0° N) and both active and inactive periods at Black Hole. The Little Ice Age falls on an inactive period at Muyil and decreasing activity at Black.

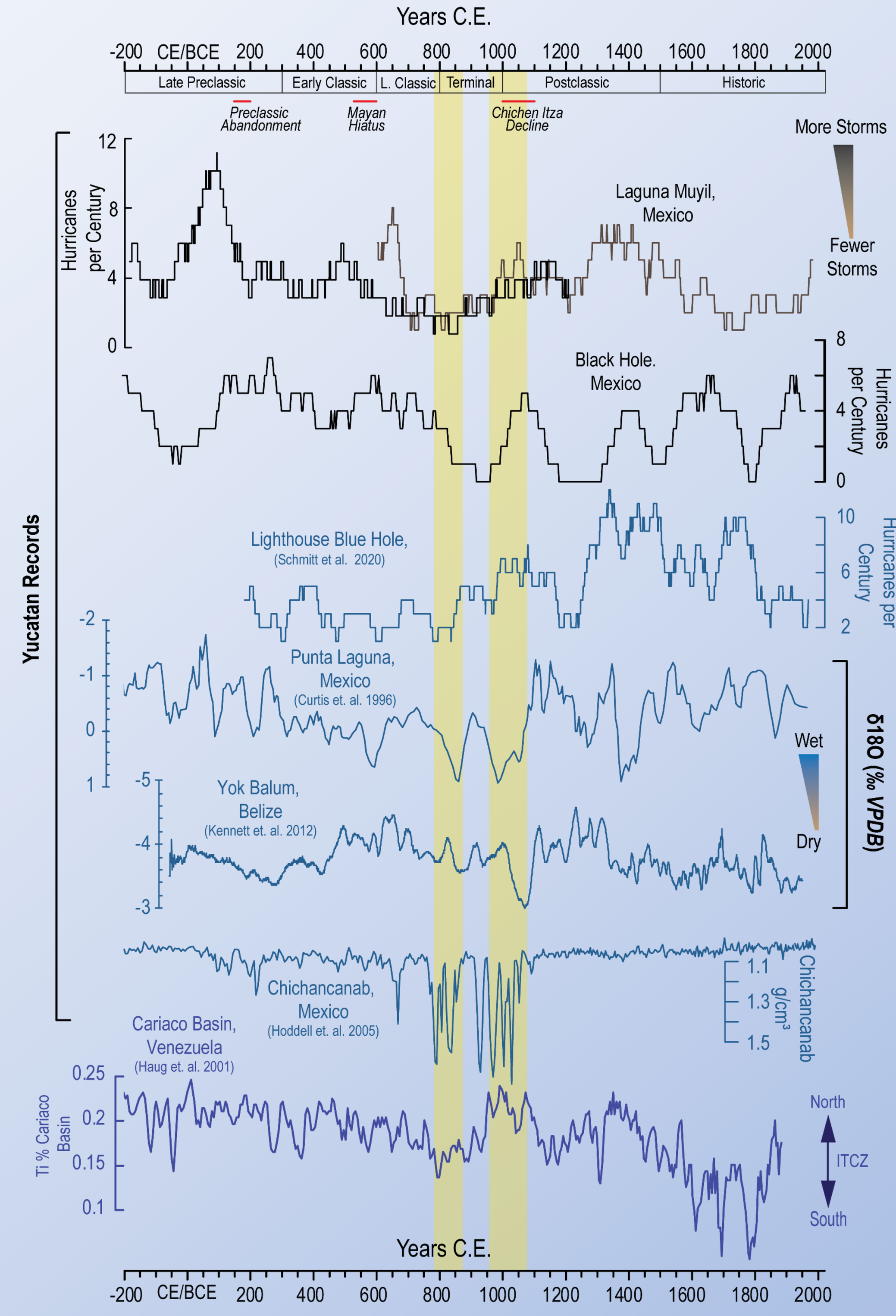


Figure 6: Related paleo datasets shown in conjunction with Muyil and Black reconstructions and Mayan cultural phases.

5. Paleo Comparisons

- (Top) Mayan cultural periods. Known periods of site abandonment/hiatuses in construction in red. (Kennett, 2012)
- The two phases of the Terminal Classic Drought Are shown in yellow (~770 – 850 & ~950 – 1100 C.E.)
- Hurricane frequency count for Laguna Muyil and Black Hole 170 km to the south. Note decreased activity during the Terminal Classic Phase, but increasing in the early and late Postclassic.
- Reconstruction from Lighthouse Blue Hole Belize (Schmitt et. al. 2020) reveal a similar pattern to Muyil and Black Hole in the Postclassic.
- δ18O records from (top) freshwater ostracods (Cytherideila ilosvayi) (Curtis et al. 1996), and (bottom) a speleothem in Belize (Kennett et. al. 2012). Depleted (negative) values indicate wetter conditions in both records.
- Gypsum concentrations from Lake Chichancanab (Hoddell et. al. 2005). Increasing gypsum concentrations signal increased evaporation.
- Record of % Ti from Cariaco Basin as a proxy of terrestrial runoff and ITCZ displacement (Haug, et. al., 2001). Higher values indicate northerly shifted ITCZ.

6. Conclusions

- Periods of increased hurricane activity on the eastern Yucatan occur with northern displacements of the ITCZ, related to northern hemispheric warming.
- Proxy rainfall records from the Yucatan often show reduced rainfall during inactive hurricane periods and wetter conditions during active intervals. However, during the late Terminal Classic Collapse (~950 – 1100 CE) and between ~1350 – 1450 C.E., we see increasing storm events despite a significant reduction rainfall.
- Terminal Classic Collapse Mayan cultural dissolution was likely motivated by drought and initiated during a period of reduced storm activity. However the later stages of the collapse, as well as the earlier hiatus and pre-classic abandonment, were coincident with increasing storm activity.
- More age control is need to better constrain the record and examine the role of additional climate drivers

7. References

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