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Comparison of historical and speleothem (paleo)climate records from northwest Yucatán (Mexico)

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1 Introduction: The Postclassic Maya

Fig. 1 Mayapán, capital of the Postclassic Maya, located in the northwest Yucatán.

Fig. 2 Cenote Ch'en Mul is located at the edge of the Temple of Ch'en Mul and next to the Pyramid of Kukulkan.

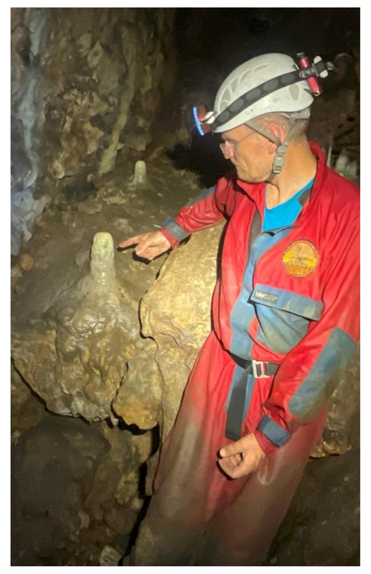

Fig. 3 Stalagmite MAYA-22-7 in-situ next to S.B.

- The **Postclassic Maya city of Mayapán** became a **regional capital** between 1000 and 1100 CE. At its peak, it housed 15-20,000 inhabitants and was governed by factions of rival noble families (the Cocom and the Xiu)
- Recent paleoclimate and archaeological studies have **linked evidence** of **repeated drought conditions** to times of **violent conflict** amongst these rival families. Between 1350-1450, **an extended dry period culminated in site abandonment** just prior to the **Spanish conquest of the Yucatán** from 1527 to 1697 CE (Kennett et al., 2022)
- Located next to the Temple of Kukulkan, the Cenote Ch'en Mul was of great ritual and religious importance. Speleothems from this site have **distinct potential** to capture a **localized climate signal** and examine **land use change (LUC)** and **human-climate-environment interactions**

2 Methods

- **Sample Collection:** MAYA-22-7 was collected in 2022 at Cenote Ch'en Mul
- **U-Th Dating:** The chronology of MAYA-22-7 was constructed via **5 U-series dates** (see Fig 4). Sample preparation, analytical chemistry, and mass spectrometry were conducted by S.C. at the Department of Earth Sciences, Oxford
- **Stable Isotope Analysis:** 2000 powder samples were milled at **0.1 mm resolution (~3 samples/year)** along 6 growth axes (see Fig 4). Stable isotopes ($\delta^{18}O$, $\delta^{13}C$) were measured via GasBench IRMS
- **Trace Element Analysis:** Trace element-to-Ca ratios (Li, Mg, Al, Si, Ti, Mn, Fe, Cu, Zn, Sr, Ba, Y, La, Ce, Nd, Yb, Lu, Pb, Th, U) were measured via LA-ICP-MS along tracks parallel to stable isotope measurements

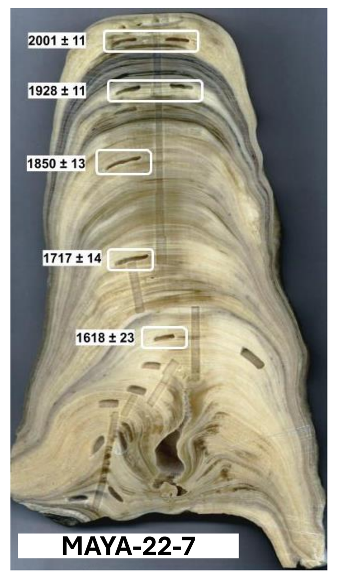

Fig. 4

3 Results: Analysis of multiple stalagmites at Mayapán

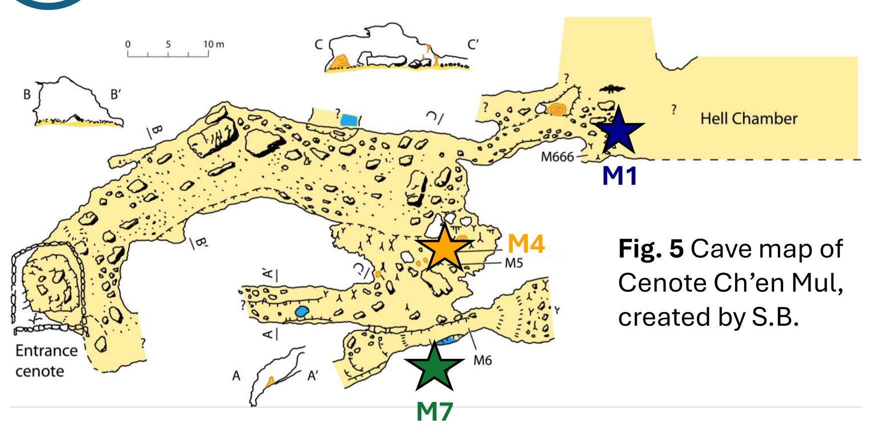

Fig. 5 Cave map of Cenote Ch'en Mul, created by S.B.

- **7 stalagmites were collected in Cenote Ch'en Mul**: M1, M3, M4, M5, M6, M7, M666
- Analysis of multiple stalagmites from a single cave can help **account for flow-path heterogeneity** when inferring local paleoclimate signals, as climate interpretations can be distorted by **karst processes** (e.g., PCP, ventilation, overburden thickness)

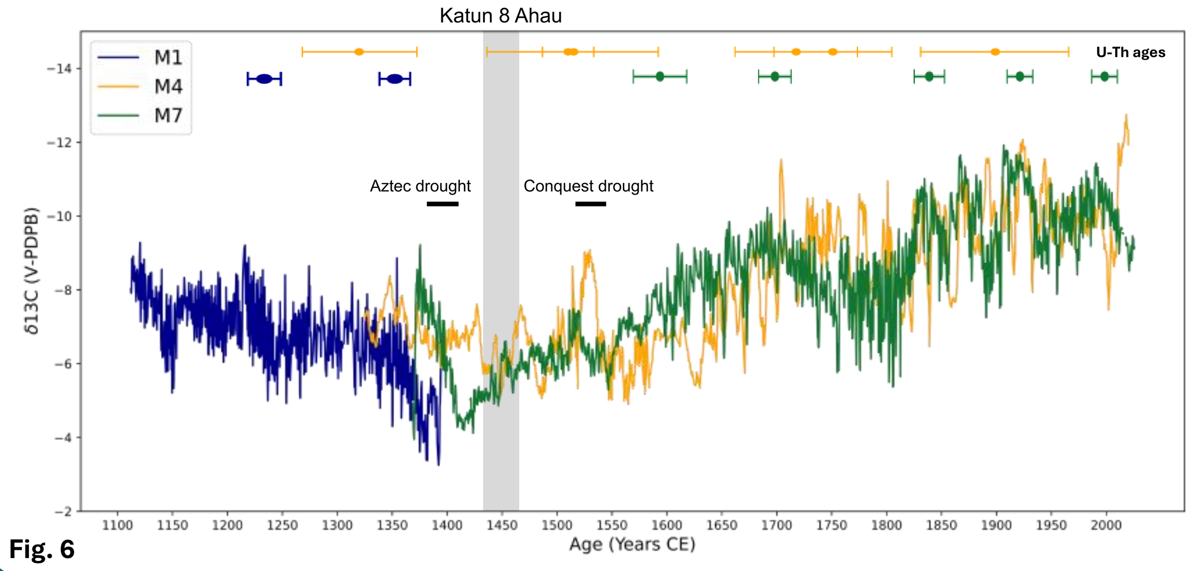

Fig. 6

- Despite variability, **d13C shifts in M4 and M1 generally agree** (± 1 ‰) across 1350-1980 CE
- From **1150-1400 CE**, an **increase from -8 to -4 ‰ is replicated across M1 and M4**, suggesting a possible **decrease in soil respiration**
- This period terminates with **depopulation, site abandonment** and **Katun 8 Ahau** (a time of "demolition and destruction" according to Maya texts)

4 Results: Speleothem MAYA-22-7

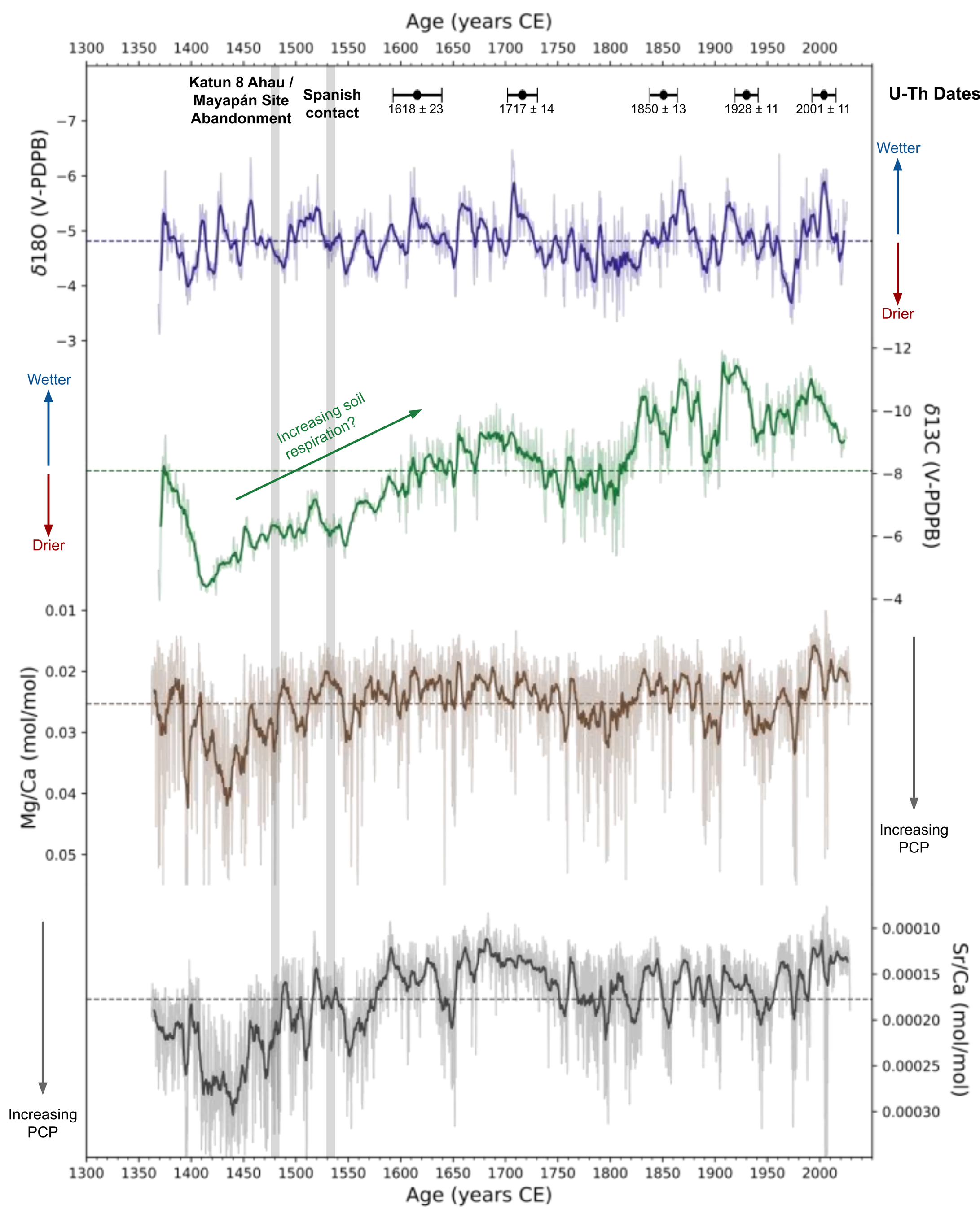

Fig. 7 MAYA-22-7 proxy records against age (age-depth model linearly interpolated; see Fig. 8).

Age-depth model

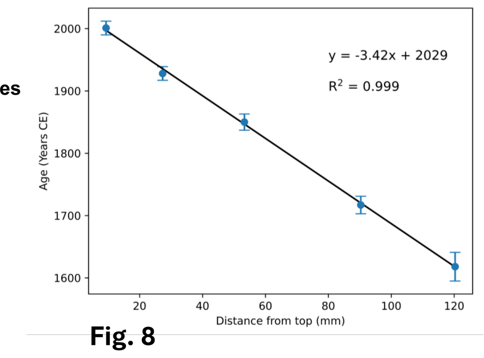

Fig. 8

- The upper 120 mm section of stalagmite MAYA-22-7 is chronologically constrained by **5 U-Th dates** between **1618 ± 23 (2σ) and 2001 ± 11 (2σ)** and grew at a **near-constant rate of 0.3 mm/year**

- $\delta^{18}O$ record capture **abrupt shifts** (1-2 ‰) **above/below baseline**, tracking **changes in precipitation amount** ("Amount Effect") above the cave
- *180 to 120 mm dft:* $\delta^{13}C$ values steadily shift from -5 to -9 ‰, replicated by a muted shift in Mg/Ca and in Sr/Ca, indicating an **increase in soil respiration** (increased plant activity and/or increased soil cover), possibly **related to re-forestation after Maya dispersal**
- *139 to 87 mm dft:* $\delta^{13}C$ values demonstrate distinct 2 ‰ shifts from -10 to -8 ‰ and **frequent (3-5 year) repeated oscillations**, suggesting a strong, rapid response of the overlying ecosystem's carbon budget to climate variability, **perhaps related to the El Niño/Southern Oscillation (ENSO)**

Prior Calcite Precipitation

- The 1-year and 5-year cross-plots of trace element values (not shown) are consistent with a PCP control; the slope falls within the estimated slope related to prior calcite precipitation (m=0.7-1) (Sinclair et al. 2011)
- This indicates that PCP reflects the degree of water infiltration into the cave (e.g., increasing PCP = higher aridity)

5 Results: Capturing the historic record

- MAYA-22-7 captures historic droughts with **± 2 years precision,** additionally capturing **an extensive dry period spanning 1725-1830 CE** in both the d13C and d18O
- This extensive dry period, amongst earlier dry intervals, is **well-replicated** by YOK-1 d13C, a speleothem from the **southeast** Yucatán, which provided a paleoclimate background for the relationship between civil conflict and climate change at Mayapán (Kennett et al., 2022)

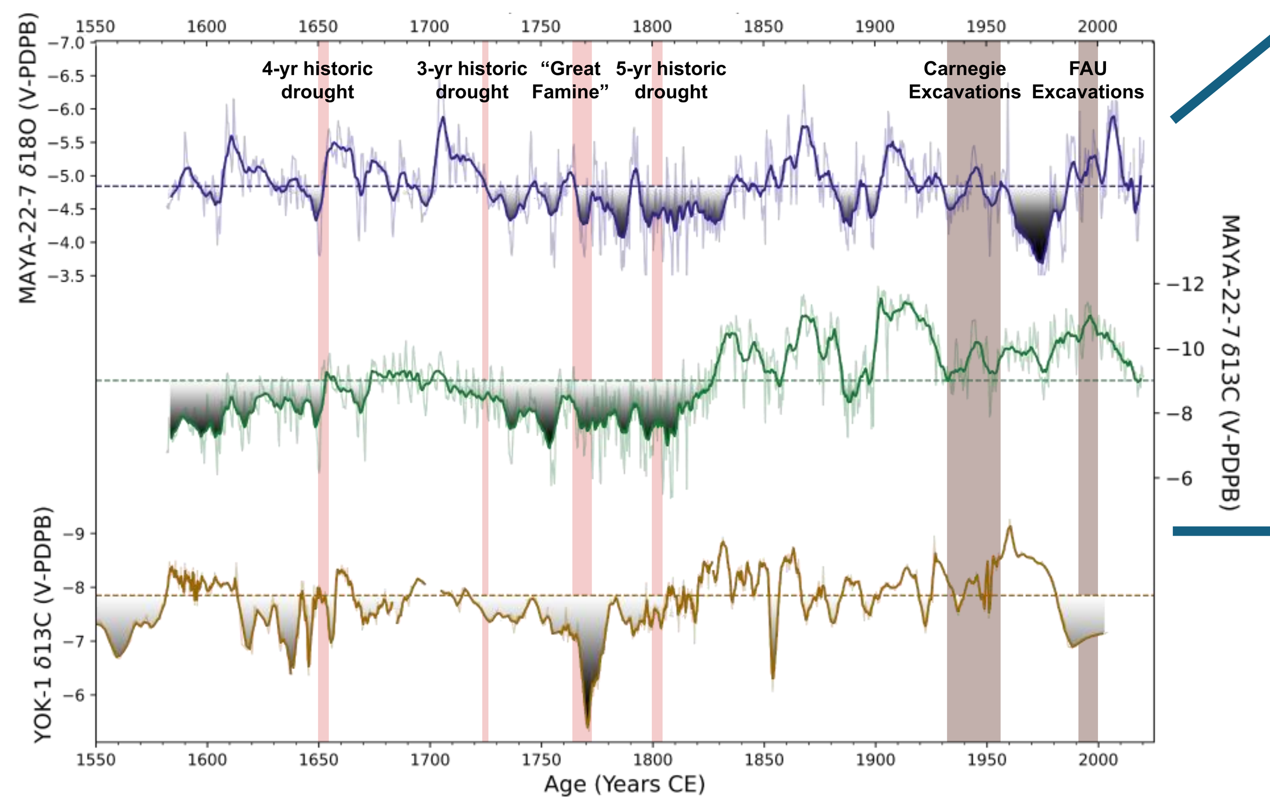

Fig 9. Historic droughts documented via Spanish conquest records, as compiled by Hoggarth et al., 2017.

4-year historic drought of 1650-1654

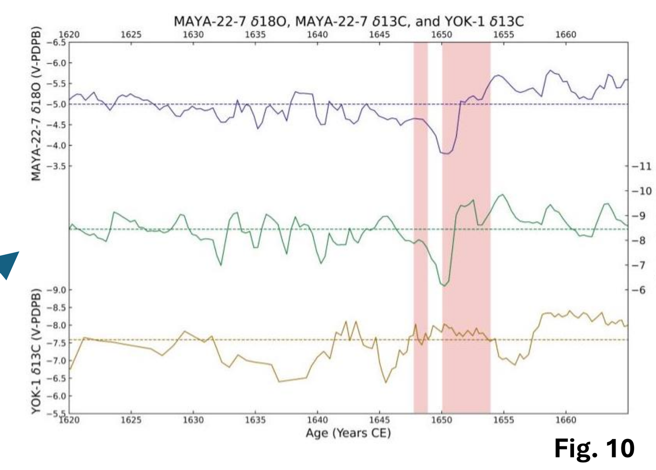

Fig. 10

"Great Famine" of 1765-1773 and 5-year historic drought of 1800-1805

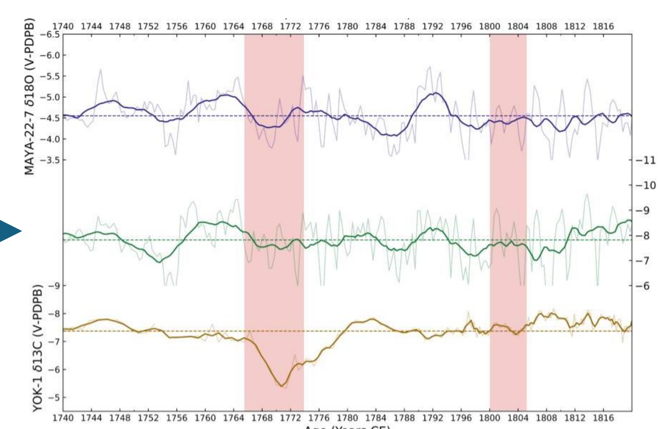

Fig. 11

Corresponding historic records of drought

"**In the year [16]50** at harvest time it was not understood that the **harvest would be extremely brief**, at the start of the year [16]51 word began to spread of **the very great shortfall of maize** for that year's sustenance"

-López de Cogolludo, 1957

Table 1. Population change in Yucatán from 1528 to 1781

Year CE	P	t	Per capita (%)	Population change (%)	Expected change
1609	176,320	30	.6	18	+
1639ᵃ	208,749	4	.1	<1	−
1643	**209,188**	**23**	**−2.9**	**−48**	−
1666	108,060	22	−.4	−8	+
1688	99,942	12	3.7	56	+
1700ᵃ	156,250	10	<.1	<1	+
1710	**156,788**	**26**	**−.8**	**−19**	+
1761ᵃ	175,188	4	1.3	5	+
1765ᵃ	**184,500**	**8**	**−6.1**	**−39**	−
1772/1773ᵃ	112,900	8	5.5	55	+

Population estimates via Hoggarth et al., 2017

"The **pastures and cornfields that were not eaten by locusts dried or did not germinate** because in 1769 there was a shortage and lack of rain. But the **drought worsened in 1770**. The population of the peninsula **suffered imponderable havoc** from the defect of water"

- María Isabel Campos Goenaga

6 Results: Instrumental validation

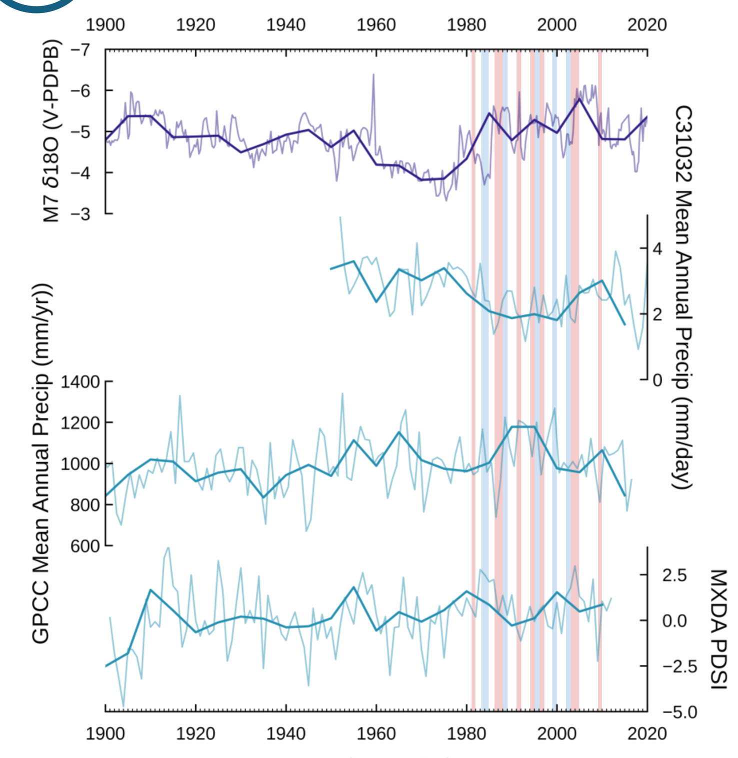

Fig. 12

Fig. 13 (left)
MAYA-22-7 against instrumental records: C31032 (local meteorological station), GPCC (NOAA meteorological station compilation), and MXDA PDSI (GPCC-derived Palmer Drought Severity Index, where >+4 represents very wet conditions and <-4 represents an extreme drought).

- Under the existing age-depth model, **MAYA-22-7 performs poorly in capturing the instrumental record**
- MAYA-22-7 5-year mean is offset from 5-year meteorological station data (15-yr offset) and 5-year NOAA GPCC (5-year offset)
- From 1980-2011, MAYA-22-7 **does not consistently capture annual variations in precipitation** (De la Barreda 2020; horizontal red shading represents a dry period and blue represents wet)

7 Results: Regional proxy comparison

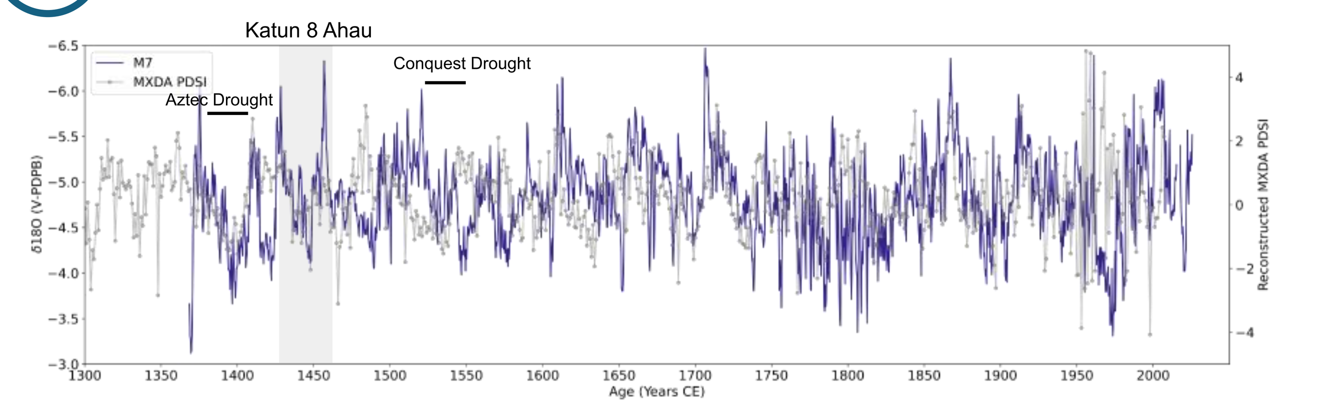

Fig. 13. MXDA PDSI reconstructed from tree-ring-record compilation across Central Mexico (Stahle et al., 2011) compared against MAYA-22-7 d18O. **Despite a lack of tree-ring records in the Yucatán,** MAYA-22-7 d18O displays **good agreement.**

8 Next steps

- Employ **Hierarchical Dynamic Time Warping** to match proxy records of disparate resolution
- Introduce **wavelet analysis** to identify periodicity and forcings
- Compare **greyscale variations to dO18** (capture archaeological excavations, flood layers)
- Verify age-depth model through the analysis of **8 additional U-Th dates**
- Analyze **lime plaster** used as **Maya paving material** to decouple impact on speleothem trace element ratios

9 Conclusions

- We present MAYA-22-7, a new speleothem record from Mayapán, northwest Yucatán spanning **1318-2022 CE (linear age-depth model)**
- Despite poor coherence with instrumental records, speleothem MAYA-22-7 exhibits **good agreement with historic compilations of drought** (see Fig 9) and the **tree-ring-derived Palmer Drought Severity Index** (see Fig 13)
- We provide initial insights into LUC (**soil disturbance and reforestation**) preceding and following **Katun 8 Ahau** and **site abandonment** at the terminal Postclassic

Acknowledgements

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