ABRUPT CLIMATE CHANGE IN THE SOUTHERN GREAT PLAINS DURING THE LAST GLACIAL INTERVAL

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Abrupt Climate Change in the Southern Great Plains during the Last Glacial Interval

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Understanding how the climate of the North American Great Plains may change in the future is of tremendous socioeconomic importance, yet the regional response to previous abrupt global climate events, such as the Dansgaard-Oeschger (D/O) cycles of the last glacial interval, are poorly known. Here, we present two absolutely dated (U/Th), partially replicated oxygen isotope ($\delta^{18}O$) records from calcite speleothems in Central Texas (30° N, 98° W) that grew during marine isotope stage 3 (MIS 3) (31 to 49 ky BP). The study site experiences boreal spring and fall maxima in precipitation with rainfall moisture sourced almost exclusively from the Gulf of Mexico. The two samples exhibit reproducible $\delta^{18}O$ means and variability during overlapping growth intervals. Weak correlations between paired oxygen and carbon isotopic values coupled with reproducible $\delta^{18}O$ strongly suggest that dripwater $\delta^{18}O$ and calcite formation temperatures are the primary drivers of speleothem $\delta^{18}O$ variations through time. We interpret more depleted (enriched) $\delta^{18}O$ values to reconstruct warmer and wetter (cooler and drier) conditions based on observations of modern rainfall stable isotope variations at the study site. We find that warmer and wetter conditions in the Southern Plains are contemporaneous with MIS 3 D/O interstadials, while cooler and more arid conditions prevail during stadials and Heinrich Events 4 and 5. Our

results show a response opposite that of hydrologic reconstructions from the American Southwest, where wetter conditions occur during stadial conditions. Our speleothem data indicate that further intensification of rainy seasons in the Southern Plains should not be ruled out as a response to anthropogenic global warming. Future work includes exploration of paleoclimate model results to examine potential mechanisms responsible for this opposite phasing.

DEDICATION

I would like to dedicate this research thesis to my parents. They are supportive of my endeavors in all ways. My mom and dad taught me to value education and take care of your belongings, including the Earth.

ACKNOWLEDGEMENTS

I would like to thank my advisors, Professor Brendan Roark, and Dr. Chris Maupin. They have taught me how to become a scientist. I am thankful for their guidance, supporting words, and time over the past two years. As well, I'd like to thank my colleague, Celia McChesney, for sticking by side and going through this undergraduate research experience together. Other honorable mentions who helped with my project are Chuan-Chou Shen, Oruç Baykara, Kemble White, Stephen Van Kampen-Lewis, and Kaustubh Thirumalai.

Figure 1- Celia (Lorraine) McChesney, Chris Maupin, and I in Cobb Cave located in Central Texas

NOMENCLATURE

D/O	Dansgaard-Oeschger
U/Th	Uranium Thorium
MIS3	Marine Isotope Stage 3
Sample FM	Sample FM2243-C
Sample RM	Sample RM620B
CE	Common Era
BCHRON	Bayesian Radiocarbon Chronology package
NGRIP	North Greenland Ice Core Project

CHAPTER I

INTRODUCTION

Background Information

The North American Great Plains spans a region from the Gulf of Mexico to the borders of Canada and is known as the "breadbasket of America" (Basara, 2013). In 1983, the Great Plains grain production was 12-15% of the world production with 60-65% of the grain production used within the United States (Basara, 2013). While the Great Plains can experience extreme climatic conditions, droughts are of serious concern given their impact on agriculture, water resources, human well-being, and the economy (Basara, 2013). These direct impacts are why it is important to understand how global climatic conditions and climatic change affect the region. Despite the importance of the region, little is known about how critical climate parameters, such as precipitation, respond to abrupt climate change events.

Scientific Question

Significant climatic events documented by global paleoclimate records include the Dansgaard-Oeschger (D/O) cycles and Heinrich ice rafting events that punctuated the last glacial period (Dansgaard, 1993; Yang, 2014). The impact of these events on Southern Great Plains hydrology is completely unknown, making them an ideal target for paleoclimatic reconstruction in the region. D/O events are defined by dramatic climate transitions between cold stadials and warm interstadials (Schulz, 2002). The twenty known D/O events are thought to originate from internal oscillations of the ocean-atmosphere system, melting of the Greenland ice sheet, and possibly external forcing mechanisms (Schulz, 2002). Another important climatic event are the so-called Heinrich events, which mainly affect the Northern Hemisphere (Yang, 2014). Heinrich events are characterized by massive iceberg discharges from northern hemisphere ice sheets near the end of cold, stadial climate intervals (Yang, 2014; Heinrich, 1988). Both of these known climatic events are of significant importance because they appear in paleoclimate records globally and can indicate how the hydroclimate of the Southern Great Plains responded to abrupt climate change.

Setting

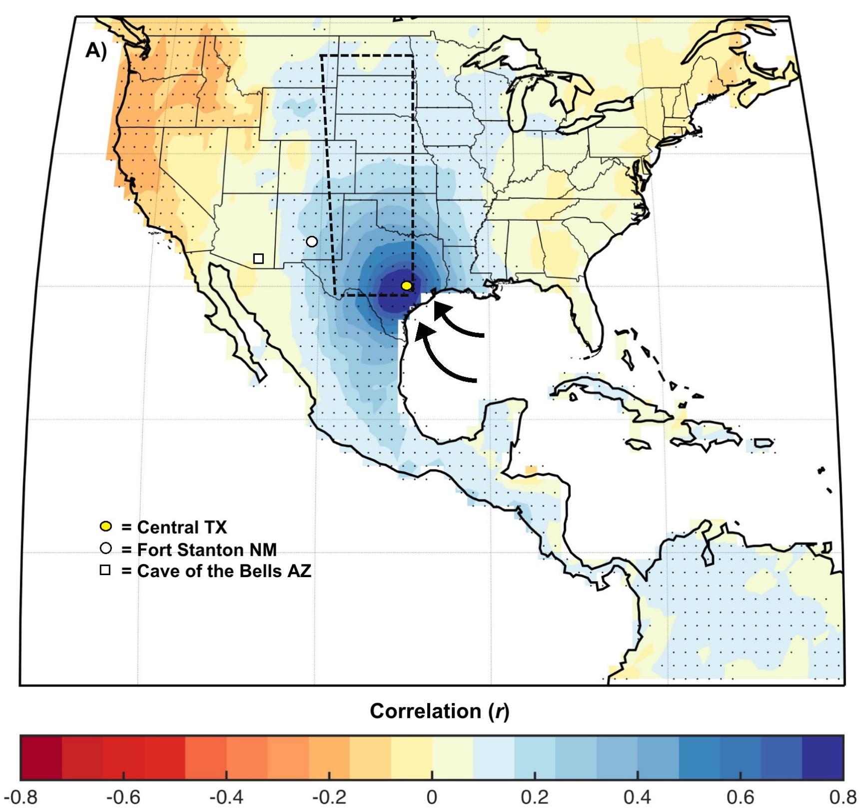


Figure 2- Hydrological significance of the North American Great Plains. A correlation map showing how rainfall at our study site (yellow dot) is correlated to rainfall in the broader North American continent at a 95% confidence, sourced from Global Precipitation Climatology Centre with data from 1901-2011 CE. The arrows indicate the Gulf of Mexico as the major moisture source for the region.

For the paleoclimate reconstruction to be significant, it is important we check for a regional precipitation signal across the Southern Great Plains. With a local precipitation signal at our study site, we would not be able to assume the Southern Great Plains responds to abrupt climate change in the same way. Here, we compare monthly land rainfall totals at our study site, (noted by the yellow circle), to rainfall in the broader North American continent measured at a 1° x 1° grid resolution, sourced from the Global Precipitation Climatology Centre (GPCC) ranging from 1901 – 2011 CE (Figure 2)(Schneider, 2015). The dashed box represents the North American Great Plains, situated in the middle of the United States. Pacific moisture is blocked by the Rocky Mountains on the west side of the Great Plains, thus rainfall moisture is sourced almost exclusively from the Gulf of Mexico (Kunkel, 2013). On the map, the color represents the strength of the correlation; the black dots indicated areas that are significantly correlated at the 95% confidence interval. The white square and circle are the locations of two other cave paleoclimate records in the Southwestern United States. These study sites are the closest locations of paleoclimate records to our study site and prove the lack of, and therefor need for paleoclimate records in Central Texas. A positive blue correlation displays a corridor of coherent rainfall variability that spans the north-south length of the Great Plains with the strongest signal in the Southern Great Plains representing a regional signal for abrupt climate change events. This is significant because the correlation map demonstrating rainfall changes at our study site is likely to be representative of regional changes across the Southern Great Plains.

Precipitation Climatology

Central Texas experiences boreal spring and fall maxima in precipitation, as this is when moisture supply from the Gulf of Mexico and upper atmospheric conditions are most favorable for precipitation (Wang and Chen, 2009). Along with agriculture, studying the regional climate trends of the Great Plains is important because some of the most extreme weather in continental North America, e.g., tornados, droughts, flooding, extreme heat and cold, and hurricanes, occurs in this region (Kunkel, 2013). To demonstrate the bimodal rainy seasons, we looked at the precipitation climatology of Central Texas using an 82 year long rain gauge record in Camp Mabry of Austin, Texas, located 25km from our study site (Figure 3).

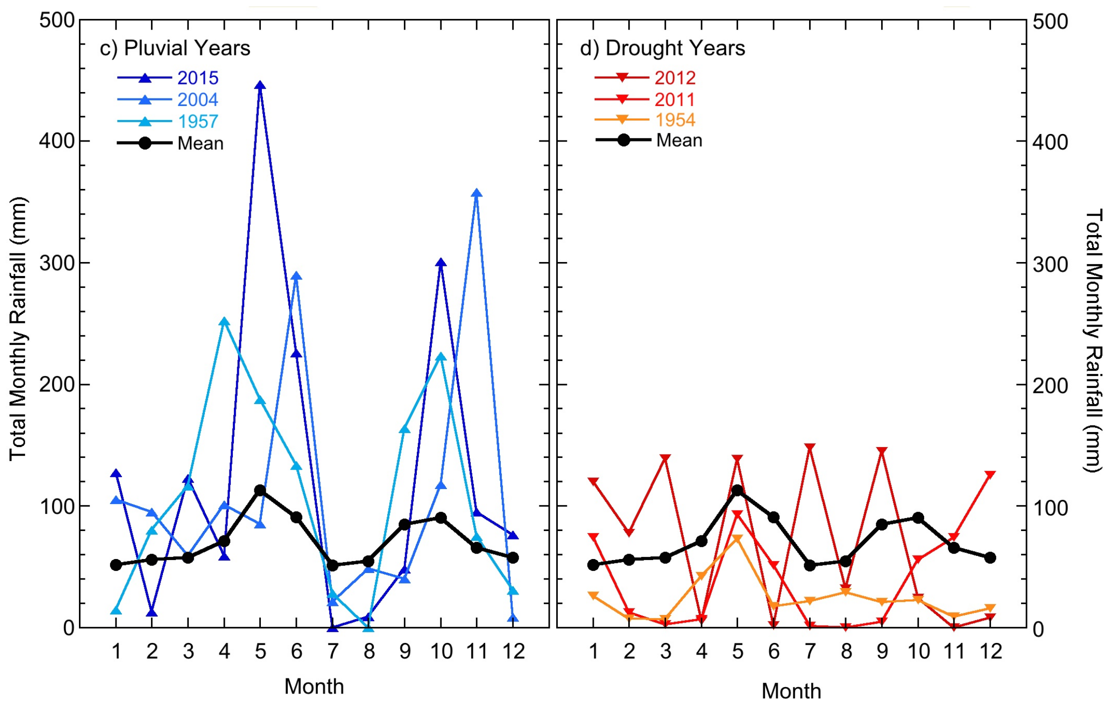


Figure 3- Precipitation Climatology in Central Texas. C) The mean monthly precipitation climatology of the three highest annual rainfall totals from an 82 year long rain gauge record in Camp Mabry of Austin, Texas located 25 km from the study site compared with the mean monthly precipitation. D) The same as C) but with the three lowest annual rainfall totals.

The black line in each of these plots shows the mean monthly precipitation climatology over the 82-year record. The clearest feature of the mean monthly climatology is a bimodal distribution of rainy seasons, with peaks in the spring and fall, punctuated by summer and winter dry intervals. Shown in the left panel are the three years with the highest annual rainfall totals and in the right panel, the three years of most intense drought. High precipitation years tend to exhibit an amplified bimodal rainy season relative to drought years. Therefore, using speleothems as proxies, we propose that a stalactite precipitation reconstruction will be recording strong versus weak rainy seasons.

Stalactite samples

Speleothems are calcium carbonate ($CaCO_3$) cave deposits categorized into stalactites, which grow from the cave ceiling, and stalagmites, which grow from the cave floor. To form the speleothems, first, groundwater interacts with soil and absorbs CO_2. Once in contact with limestone, the more acidic solution dissolves $CaCO_3$ (Hendy, 1971). Upon the water entering the cave, there is CO_2 disequilibrium between the dripwater and the cave so the loss of CO_2 in the dripwater to the cave atmosphere creates calcite formation (Hendy, 1971). Calcite speleothems are excellent proxies for climate reconstruction because they can be absolutely dated with a high degree of precision using U/Th disequilibrium techniques (Shen, 2008). The ratio of stable oxygen isotopes in the speleothem calcite at the time of deposition records the dripwater, and therefore the $\delta^{18}O$ of the rainwater (Lachniet, 2009). We see in Central Texas the rainfall oxygen isotopic composition at our study site is a reflection of precipitation amount (Kurita, 2013).

Stalactite time series from Central Texas

Here, we present a U/Th-series dated $\delta^{18}O$ record of rainfall variability from 30,000 – 50,000 years before present (ky BP) from two stalactites in Central Texas, collected from separate caves located 5km apart in the Edwards Plateau. We will reconstruct the response of the Southern Great Plains climate to show D/O and Heinrich events during the last glacial interval. The $\delta^{18}O$ signal produced by the stalactites will display how abrupt climate change events affect the hydrology of the region (Maupin, 2016). Despite the socioeconomic important of the region, little is known about the past hydroclimate of the Southern Great Plains. With advances in warming trends, this research project gives some light on the hydroclimate of the Southern Great Plains in the future.

CHAPTER II

METHODS

Speleothem Collection and Dating

Two stalactites from Central Texas (30° N, 98° W), sample RM620B and sample FM2243-C, were collected from two different caves of opportunity located less than 5km apart in the Central Texas area (Figure 4 and 5). Caves of opportunity mean these cave were on private land that were filled in with concrete during construction. Before construction, these samples were inactive and recovered from the cave floor by our collaborators at SWCA and Cambrian Environmental.

While we were given the stalactites for this research project, I have participated in speleothem collection in Cobb Cave, a private cave located in Central Texas. After collection, we used a MK 101 series tile saw to cut the speleothems into halves (Figure 6 and 7). One half of the speleothem is sent off for U/Th dating to the High-Precision Mass Spectrometry and Environment Change Laboratory (HISPEC) of National Taiwan University (NTU).

Figure 4- Sample RM620B

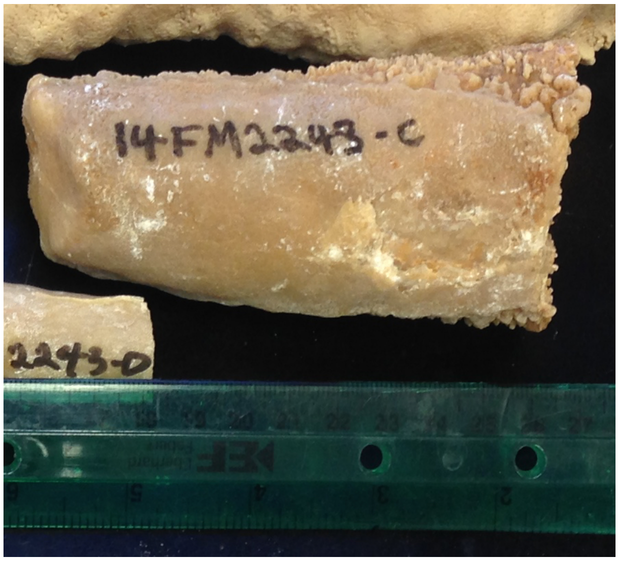


Figure 5- Sample FM2243-C

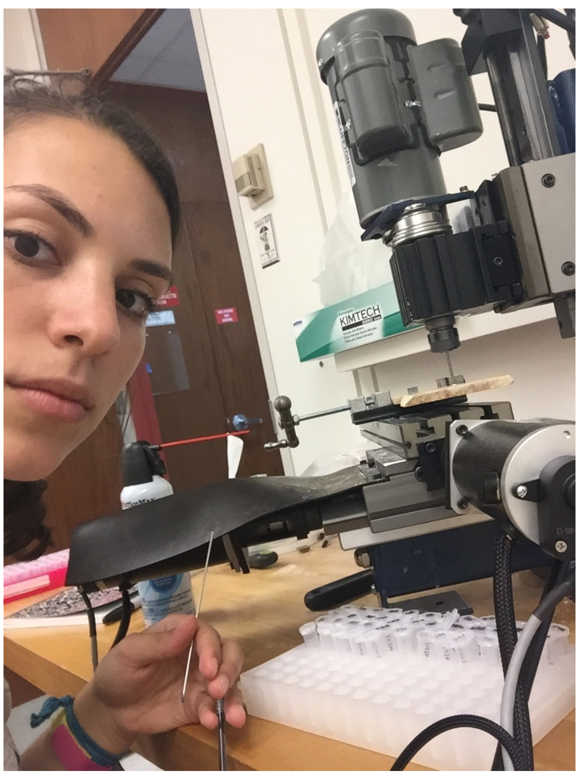
Figure 6 - Research collaborator, Lorraine McChesney, using the tile saw

Figure 7- Examples of speleothem halves

Speleothem Analysis

The other half of the speleothem stays in the Stable Isotope Geoscience Facility (SIGF) lab and used to drill for samples. Powdered calcite samples were obtained by drilling along the speleothem growth axis at a resolution of 500 μm per sample, using a computer-controlled micromill (Figure 8). A small spatula was used to collect the powdered sample; compressed air cleared the previous calcite powder of the speleothem; and the samples were stored in plastic centrifuge tubes until weighing. We analyzed 40-80 μg subsamples using a Thermo Electron Kiel IV automated carbonate device attached to a Thermo Electron MAT 253 dual inlet stable isotope ratio mass spectrometer housed in SIGF at Texas A&M University (Figure 9).

A)



B)

Figure 8- Micromilling a speleothem. A) View of the computer-controlled micromill. B) Up close view of milled speleothem

Several speleothems were micromilled before finding sample RM and sample FM. We were fortunate to have two samples from Central Texas within the same age range. The resulting oxygen isotopic data, once paired with U/Th ages, was converted from a depth scale to a time scale using BCHRON, an age modeling R package. The results were interpreted in the context of other global paleoclimate records such as ice cores from Greenland and Antarctica, marine sediment records, and other cave sites from around the world that spanned the same time period.

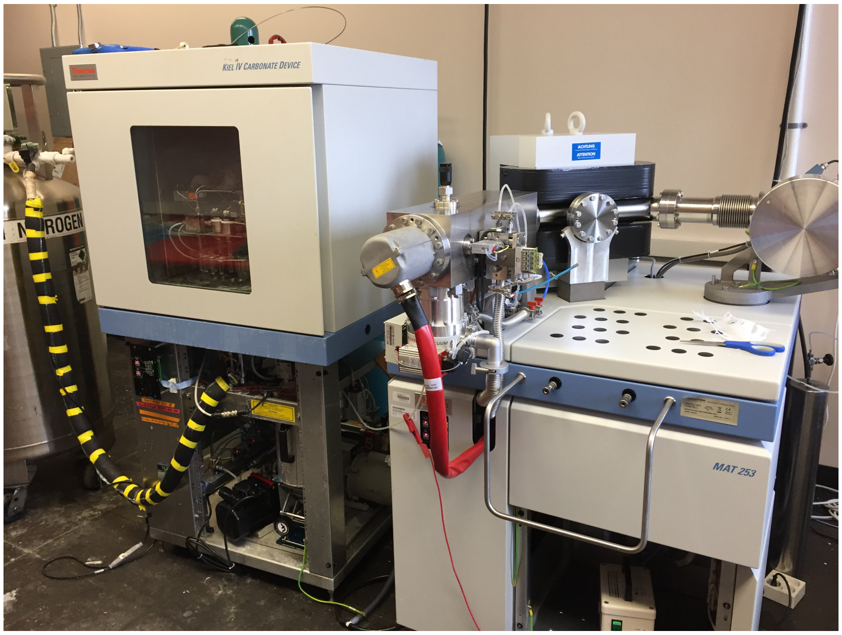


Figure 9- Kiel IV (left) attached to MAT 253 (right)

Speleothem Fieldwork

Because our study site were caves of opportunity, we explored Cobb Cave instead. Cobb Cave is located in Central Texas and close to our study sites. It is one of the longest vertical caves in the region. One half of the cave was an old show cave so there is a paved path with large cavern ceilings. The other side is known as the wild side. It has high CO_2 levels, and is full of mud, water pools, three tight crawl spaces and untouched, active, speleothem samples. We visited each side once with the purpose of collecting speleothems and dripwater samples, and installing temperature loggers. Collecting this data adds to my research project as well as created a graduate level project involving a 300,000 year old stalagmite we discovered in the wild side of Cobb Cave (Figure 10). This fieldwork experience was unlike no other and I loved coming out the cave covered in mud (Figure 11).

Figure 10- First look at a 300,000-year-old stalagmite in Cobb Cavern. Chris Maupin on left followed by Lorraine McChesney, and I

Figure 11- Caving group with collaborators from Cambrian Environmental and SWCA

CHAPTER III

RESULTS

Age Modeling

The first step after obtaining U/Th dates from our collaborators and measuring $\delta^{18}O$ in the stalactites is to combine the data into an age model. This model describes how the stalactite grew through time but does not denote growth rate. Marine isotope stages (MIS) denote alternating cooling and warming periods based on the $\delta^{18}O$ records. We find that both our stalactites grew during MIS 3.

Sample RM620B age model

A)

B)

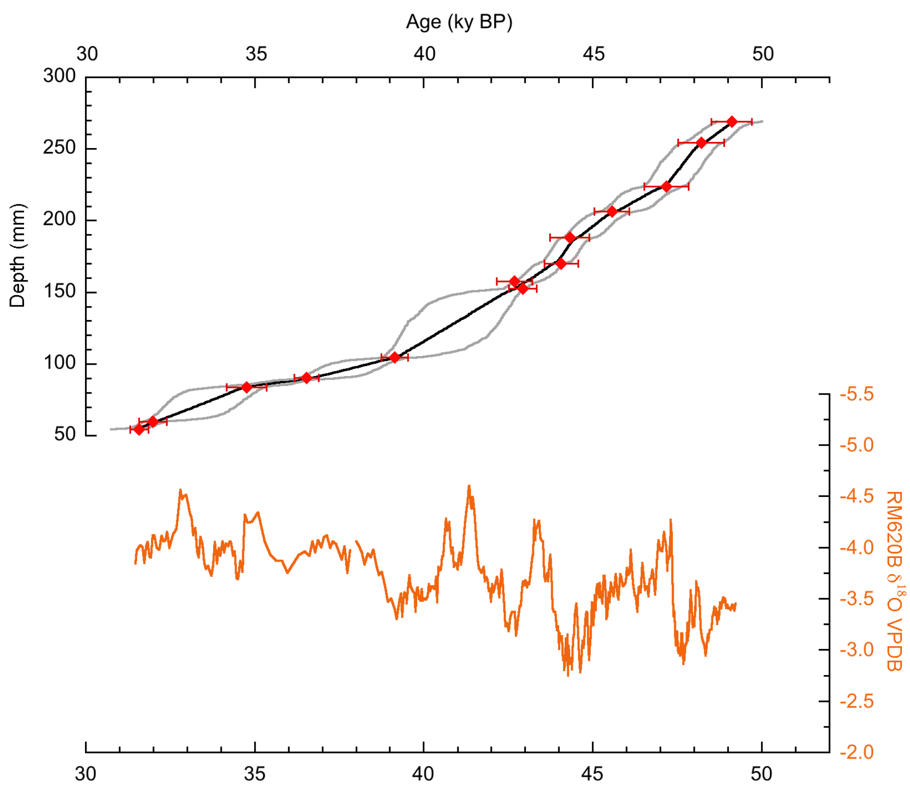


Figure 12- Time series and age model for sample RM. A) Age model for sample RM. B) Time series for sample RM

The growth interval for sample RM620B (sample RM) is constrained by 13 U/Th dates. The top graph is an age model comparing the age in thousands of years to the depth along the stalactite (Figure 12). The red circles indicate our U/Th dates with their error bars denoting the associated uncertainties for each age. The black line is the median age model calculated by BCHRON; the grey lines are the BCHRON 95% confidence intervals for the median age model. The U/Th dates show our stalactite grew over a time period of 30 to 50 ky BP with $\delta^{18}O$ ranging between -5.0 to -2.5. This means that our stalactite grew during MIS 3 so we should expect millennial scale events in our $\delta^{18}O$ record. Here, it is important to note more dates would reduce the age uncertainties of this age model.

Sample FM 2243-C age model

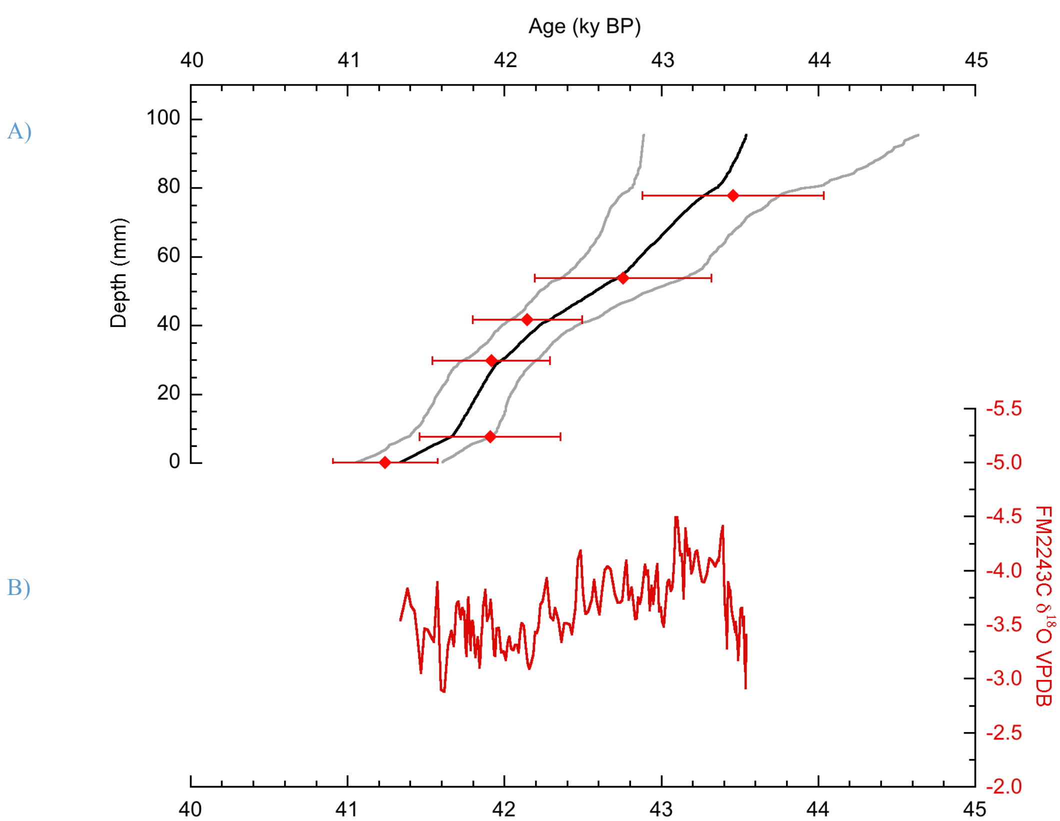


Figure 13- Time series and age model for sample FM2243-C (sample FM). A) Age model for sample FM. B) Time series for sample FM

This smaller stalactite is constrained by 6 U/Th dates with a growth occurring between 41 and 44 ky BP (Figure 13). The age model of sample FM2243-C (sample FM), in the top panel, displays a better age control and a smaller average age uncertainty because there is a higher resolution compared to sample RM. The age of the FM stalactite shows it grew over an interval that overlaps with sample RM. With this age interval, we would expect to see one millennial event to occur and reproducibility between the two stalactite records.

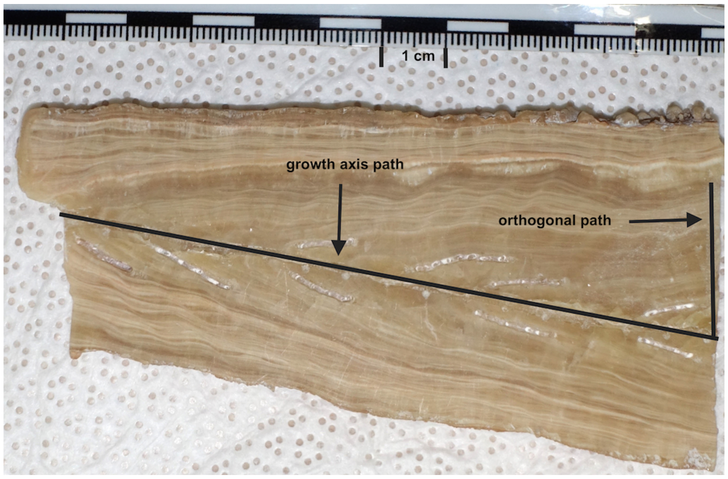
No Occurrence of Kinetic Fractionation

Isotopic fractionation occurs when one isotope is favored over another isotope during a phase change where the process may be kinetic, or equilibrium (Lachniet, 2009). While fractionation controls the isotopic signatures in the environment, it is important that there are no kinetic fractionation effects within our stalactites. We conducted several tests to verify the $\delta^{18}O$ signal represents the rainwater (Lachniet, 2009).

Hendy Path

Kinetic fractionation can occur in a cave environment if the dripwater carrying the calcite is not in isotopic equilibrium (Hendy, 1971). We performed a hendy test on sample FM and drilled a path orthogonal to the main growth axis path to see if the $\delta^{18}O$ is reproducible along the drilled path (Figure 14). If there were kinetic isotope effects, the growth axis path would have a more enriched $\delta^{18}O$ because the drop has a longer travel time down the side of the stalactite allowing for kinetic isotope fractionation to occur (Lachniet, 2008). We see that this is not the case in our stalactite because the $\delta^{18}O$ is reproducible (Figure 14). By aligning the beginning and end growth band of the orthogonal path to the growth axis path shows no progressive $\delta^{18}O$ enrichment. Therefore, there are no suspicions of kinetic isotope effects in this sample. This method could not be employed for sample RM because the growth layers were too steep.

A)



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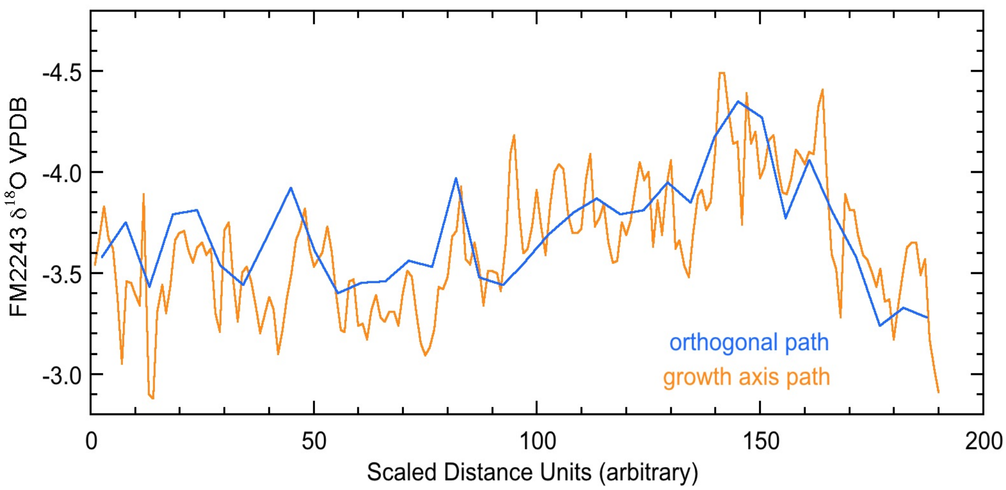


Figure 14- Hendy path to test for kinetic fractionation on sample FM. A) Orthogonal and growth axis path drilled on Sample FM. B) Alignment of $\delta^{18}O$ drilled paths on Sample FM.

Inter-Sample Reproducibility

One of the best ways to confirm that there is no kinetic fractionation is to have multiple overlapping reproducible speleothem records (Lachniet, 2009). The red, longer time series is the RM stalactite and the orange, higher resolution time series is the FM stalactite (Figure 15). The top graph is the $\delta^{18}O$ time series and the bottom graph is the $\delta^{13}C$ time series for both stalactites. Here, we see that both the $\delta^{18}O$ and $\delta^{13}C$ are reproducible in two stalactites from different caves. The only alignment is the moving the major millennial scale features of the RM time series model to fit with the FM time series. It was easy to do this alignment because there is only one millennial scale feature in sample FM and sample FM consists of a higher resolution time series with lower age uncertainty. This alignment is acceptable because it is within the uncertainties of RM's age model (Figure 16). It is important to note there were no mean adjustments and our records are on the same isotope scale. The stalactites are from two different caves and have reproducible records for both $\delta^{18}O$ and $\delta^{13}C$ within the age model uncertainties, which point to a system that is not kinetically altered. This suggests $\delta^{18}O$ reflects the dripwater entering the cave and represents the hydroclimate of the region.

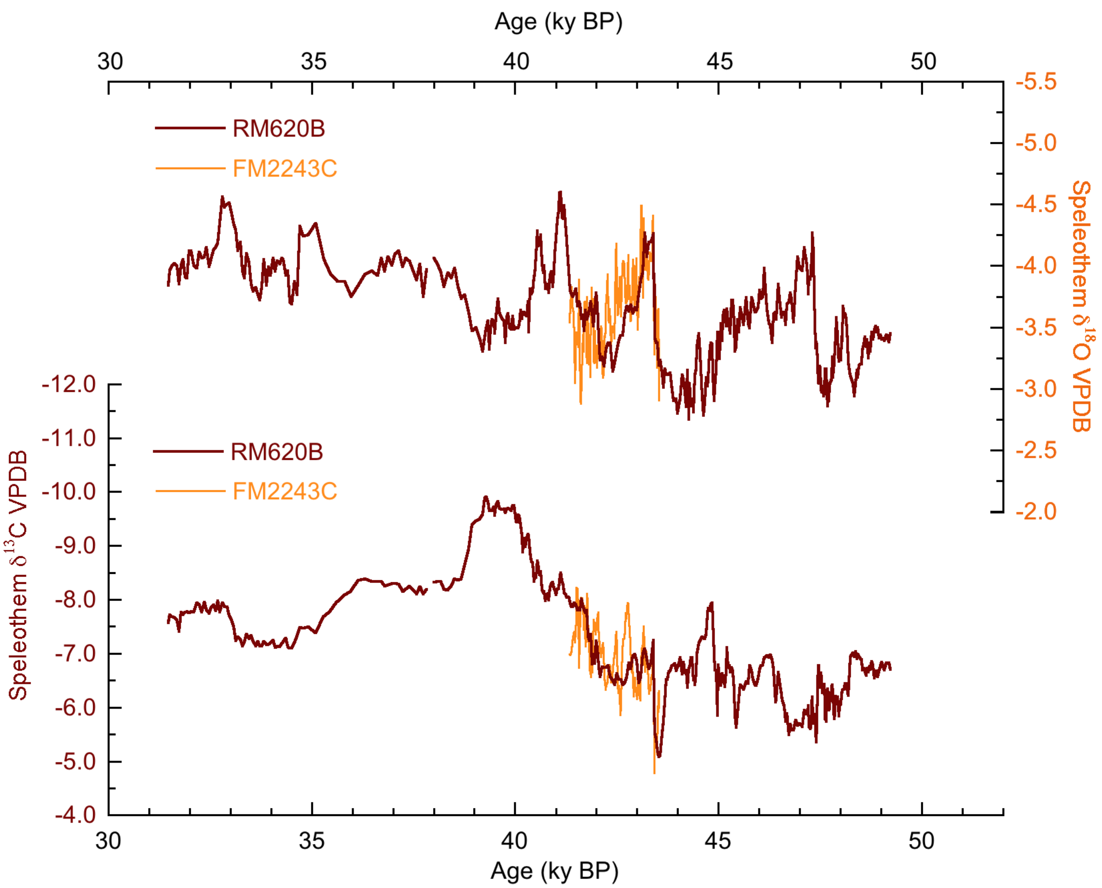


Figure 15- No evidence for kinetic isotope effects during deposition. Graph displays inter-sample reproducibility for $\delta^{18}O$ and $\delta^{13}C$. The stalactites are from two different caves and have reproducible records within age model uncertainties. This suggests the stalagmite $\delta^{18}O$ signal reflects the dripwater $\delta^{18}O$ entering the cave.

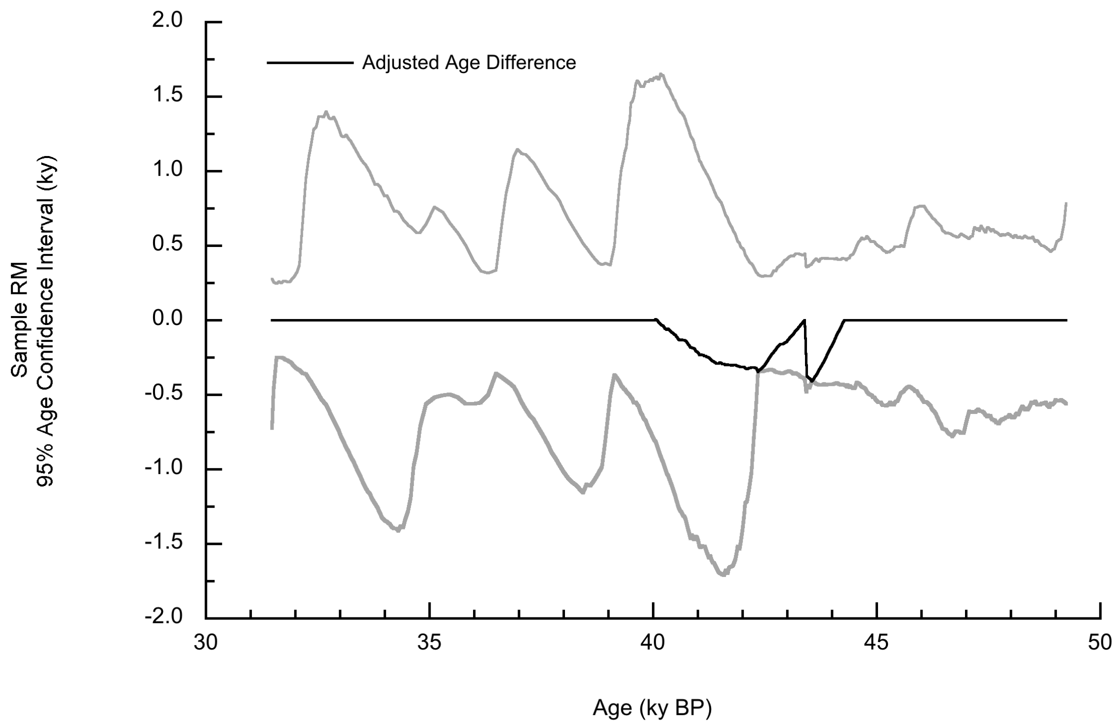


Figure 16- Adjusted age of sample RM after millennial scale alignment. Adjusted age difference in black after alignment to sample FM's millennial scale feature. The grey lines are the 95% age confidence intervals displaying the adjusted age difference is within sample RM's age uncertainties.

Carbon vs. Oxygen

Another indication of kinetic fractionation within speleothems is a positive correlation between $\delta^{18}O$ and $\delta^{13}C$ (Lachniet, 2008). Here, we have the standard oxygen and carbon cross plot (Figure 17). There is a slight correlation in sample RM with $r = 0.31$ and little to no correlation in sample FM with $r = 0.07$. However, from the oxygen and carbon time series, it its clear that $\delta^{13}C$ is not related to millennial scale events (Figure 17). $\delta^{13}C$ is just related to the overall trend in the both speleothem time series. Therefore, we continue to see no kinetic fractionation occurring within our speleothem samples and millennial scale events in the $\delta^{18}O$ record.

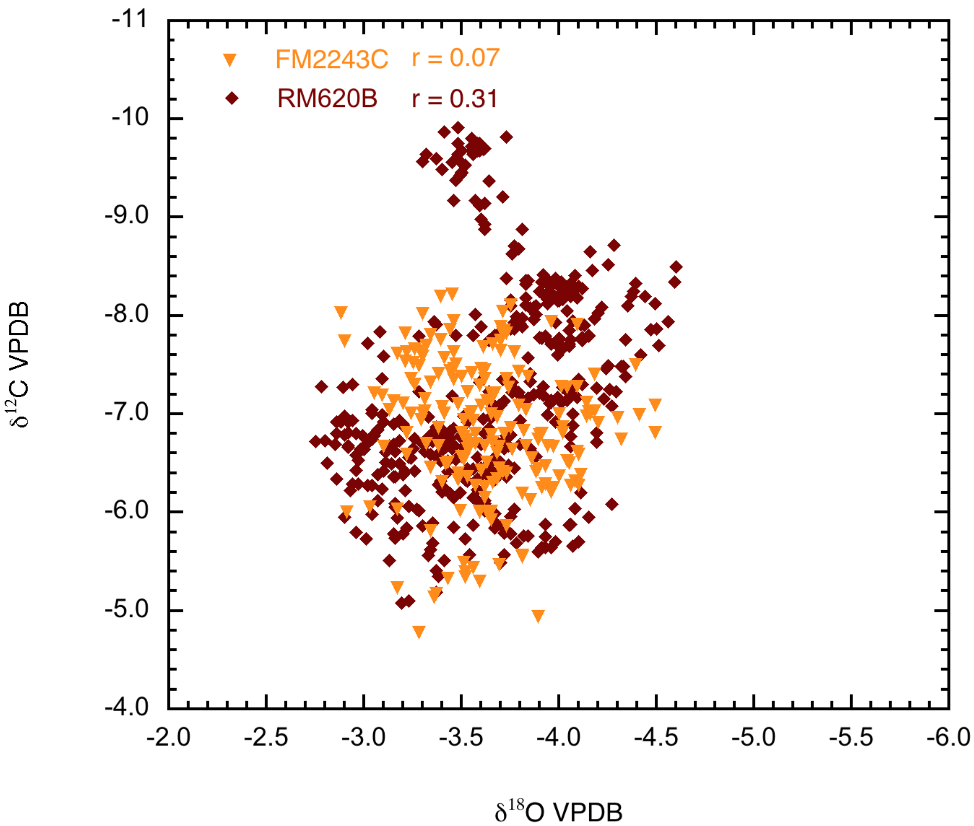


Figure 17- Standard $\delta^{18}O$ and $\delta^{13}C$ cross plot. Little to no correlation between oxygen and carbon proving no kinetic fractionation occurred within the speleothems

Millennial Variability

We compared our record with the standard records of the North Greenland Core Project (NGRIP) in blue and the Hulu cave record in green and red to see millennial scale variability (Wang, 2001; Svensson, 2008). We numbered our $\delta^{18}O$ depletions as Dansgaard-Oeschger interstadials the same way NGRIP and Hulu cave labeled their interstadials (Figure 18). These records are on their own independent age scales. Heinrich events 4 & 5 are labeled in our record and align with the well-known climate records of Hulu cave and NGRIP as well. When there are more depleted $\delta^{18}O$ values in our record, there are more enriched $\delta^{18}O$ values in NGRIP indicating warming in Greenland and more depleted $\delta^{18}O$ in Hulu cave indicating a more intense East Asian Monsoon. NGRIP and Hulu cave records are well accepted, with highly resolved age models. Our record notes the same millennial scale $\delta^{18}O$ variations as NGRIP and Hulu Cave. This cyclic pattern shows that our record also has Dansgaard-Oeschger cycles, these global abrupt climate change events.

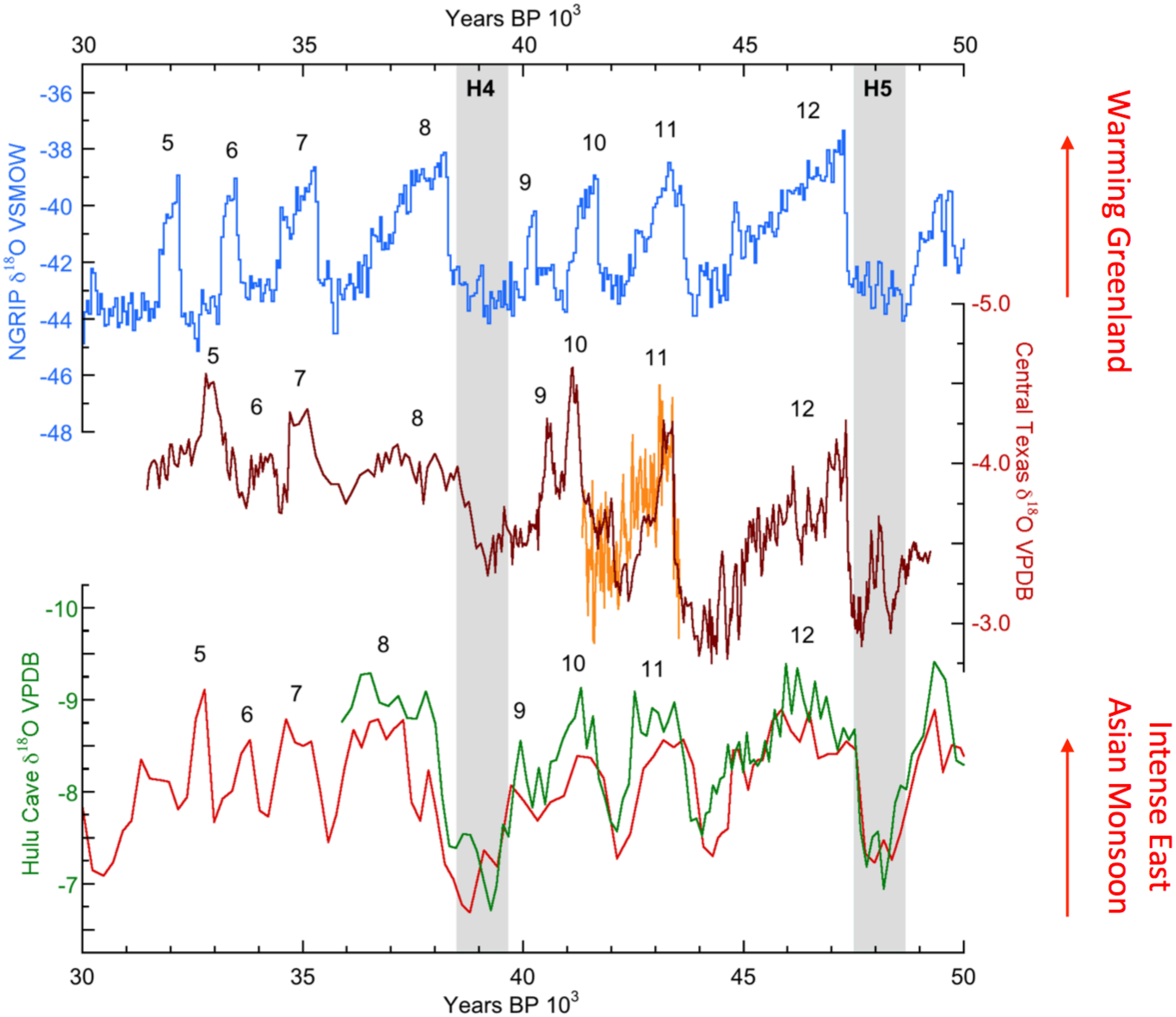


Figure 18- Texas stalactite record plotted with standard record of NGRIP and Hulu Cave. We labeled $\delta^{18}O$ depletions as Dansgaard-Oeschger interstadials. NGRIP and Hulu cave records are well accepted, with highly resolved chronology noting millennial variability. Here we see the same variability in our Central Texas record.

Trend vs. Insolation

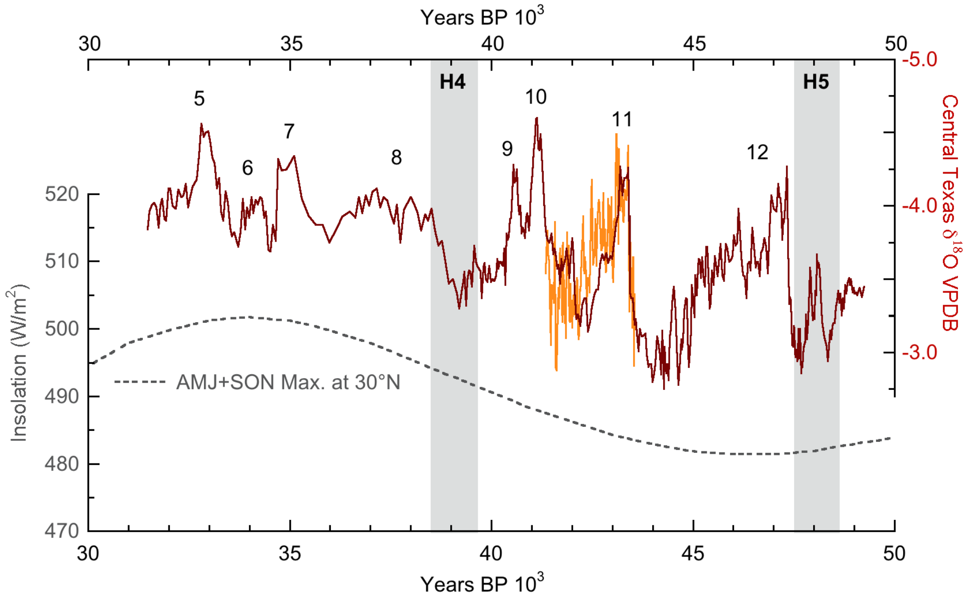


Figure 19- Insolation trend increasing to more depleted $\delta^{18}O$ during periods of increased solar insolation.

In our record, we noticed an upward trend with decreasing $\delta^{18}O$ amplitudes towards the younger end of the stalactite (Figure 19). We are not sure why this occurs but the trend follows the trend in solar insolation as controlled by changes in earth's orbital parameters. With increased solar insolation, there are more depleted $\delta^{18}O$ values. Increased insolation leads to more energy reaching the Southern Great Plains. This energy affects the Gulf of Mexico moisture supply source and increases the amount of rain delivered to the Southern Great Plains because of the amplified continent-ocean temperature difference (Wang, 2001). Here, the amount effect controls the $\delta^{18}O$ isotopic signature where greater rainfall amounts cause more depleted rainfall $\delta^{18}O$ values (Sharp, 2007). We believe the trend towards more depleted $\delta^{18}O$ values in our graph correlates with the increasing insolation pattern.

Stable Isotopic Composition Control

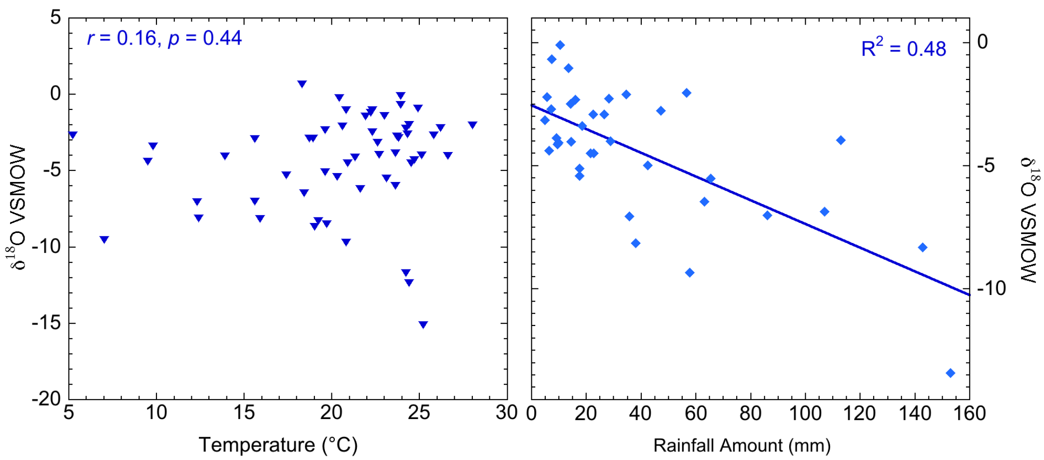


Figure 20- δ^{18}O relationships with temperature and rainfall amount. Amount effect correlates with the isotopic signature so warmer conditions in the cave reflect wetter conditions above.

An important aspect of interpreting the δ^{18}O record in our Texas stalactites is to understand what controls the stable isotopic composition. Temperature, altitude, rainfall amount and rain source can all have effects on the isotopic composition (Sharp, 2007). In the Southern Great Plains, temperature or amount of precipitation would likely have the most effects because the altitude and moisture source of the cave site is constant. Rainfall samples, temperature and rainfall amount samples and data were collected in Central Texas over the past year. My colleague, Lorraine McChesney used the Picarro CRDS for isotopic analysis. We see a strong relationship between rainfall amount and a weak relationship between temperature therefore the rainfall amount has the most control of the δ^{18}O signal in Central Texas (Figure 20)(Maupin, 2016). This implies when we see warmer conditions in the cave, there are wetter conditions in the atmosphere.

Anti-phasing of Southwest Records

The closest paleoclimate study to our research site is located in the American Southwest (New Mexico and Arizona). At this site, wetter conditions are contemporaneous with stadial, cold phases of D/O cycles, while more arid conditions occur during interstadial, warmer conditions (Asmerom, 2010). The lack of paleoclimate information in Central North America makes it unclear whether our study site in the Southern Great Plains will exhibit this same climatic relationship. Here, we compare our Southern Great Plains record to the Fort Stanton, NM cave record in green and the Cave of the Bells in red which is located in Arizona (Figure 21) (Asmerom, 2010; Wagner, 2010). These records were chosen because they contain MIS3 variability and are less than 1000 km away from our study site. Again, Heinrich events 4 & 5 are labeled with grey bars and the D/O interstadials are numbered. One of the most interesting things in our record is that it has the opposite response as the caves located in the Southwestern United States. During MIS 3 interstadials (warmer conditions), when it is wetter in the Southern Great Plains, it is more arid in the Southwestern United States. Conversely, during stadials, when it is drier in the Southern Great Plains, it is wetter in the Southwestern United States.

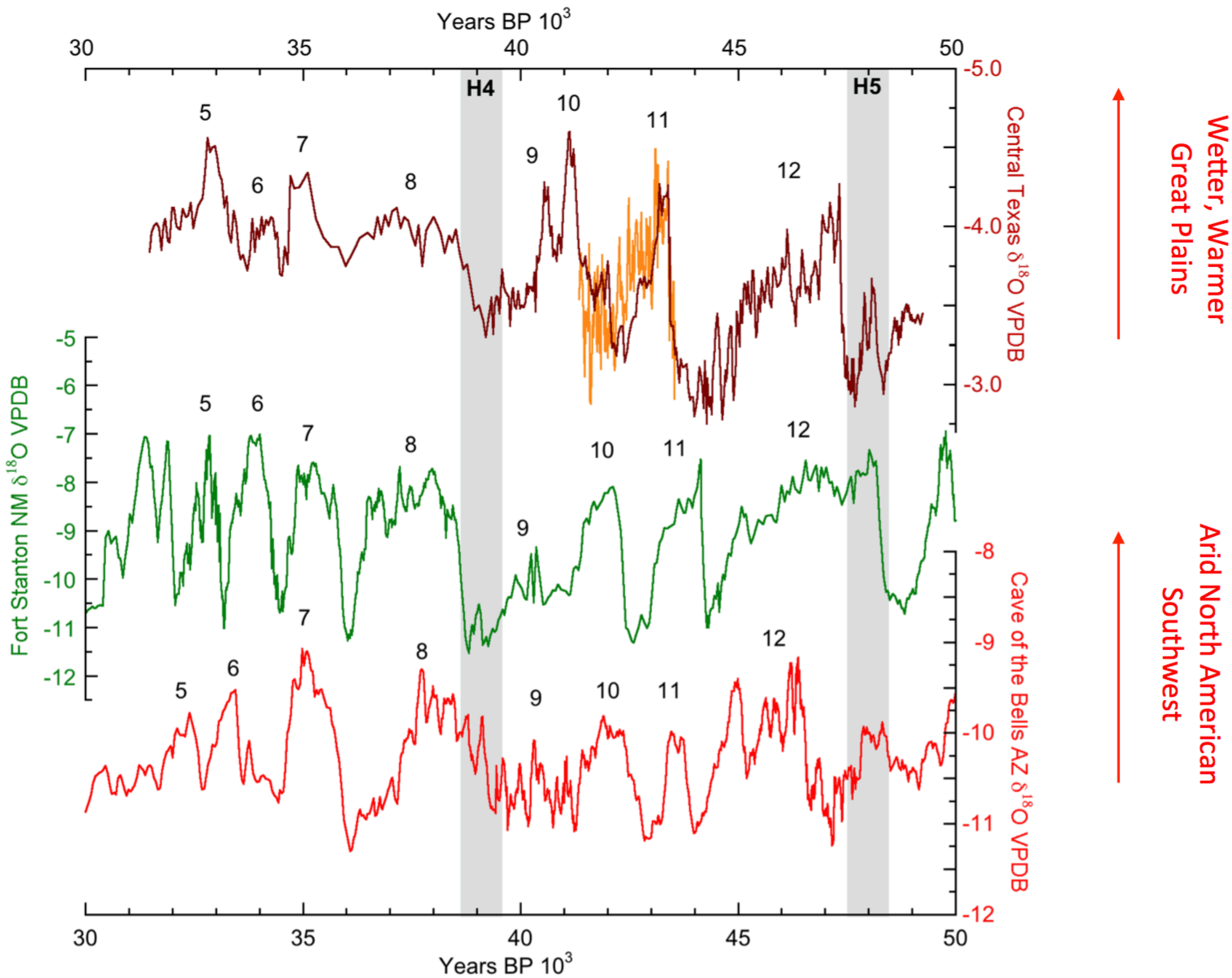


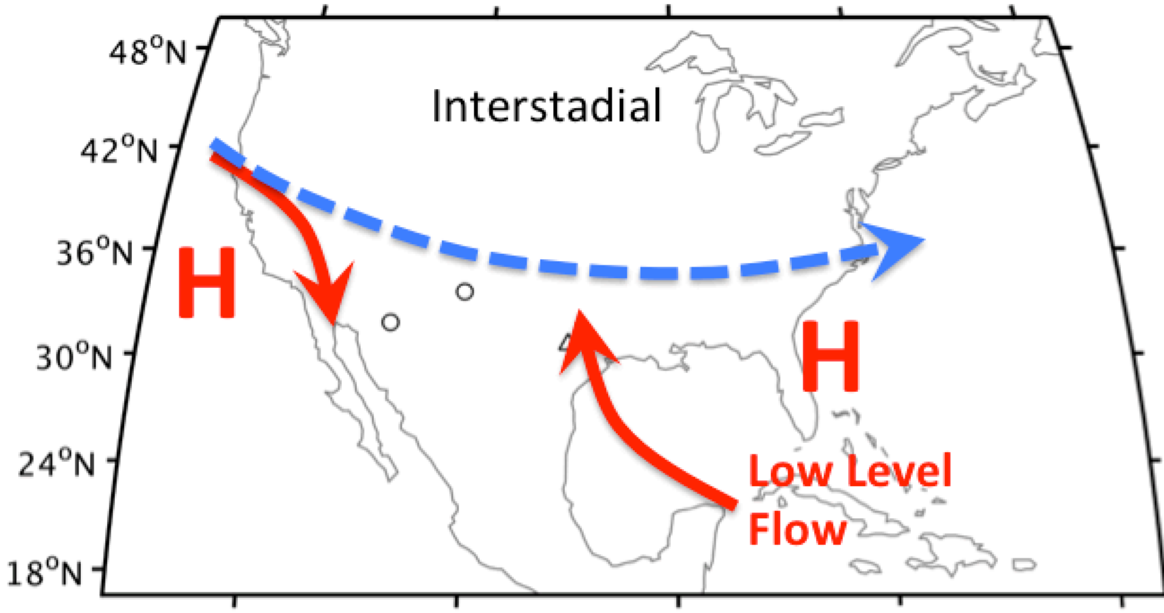
Figure 21- Texas stalactite record plotted with Fort Stanton, NM, record and Cave of the Bells, AZ, record. These records contain MIS 3 variability and are less than 1000 km away from our study site. Our record has the opposite response as the Southwestern records. During interstadials, when it is wetter in the Southern Great Plains, it is drier in the southwest.

CHAPTER IV

CONCLUSION

Interpretation

A simple hypothesis of the anti-phasing between the Southwest and our Central Texas records could result from a lost of Gulf of Mexico airflow to the Southern Great Plains during stadials. The interstadial climate schematic shows the polar jet stream coming across North America and two high-pressure systems, which dominate our current climate (Figure 22). The stadial climate schematic displays a southerly shift in the polar jet stream from cold northern air and a shift in the high-pressure systems to the east (Asmerom, 2010). These shifts could reduce the moisture supply source to the Southern Great Plains and provide a Pacific moisture source to the Southwest. However, further analysis of paleoclimate model output is needed in order to continue exploring this antiphasing phenomenon.



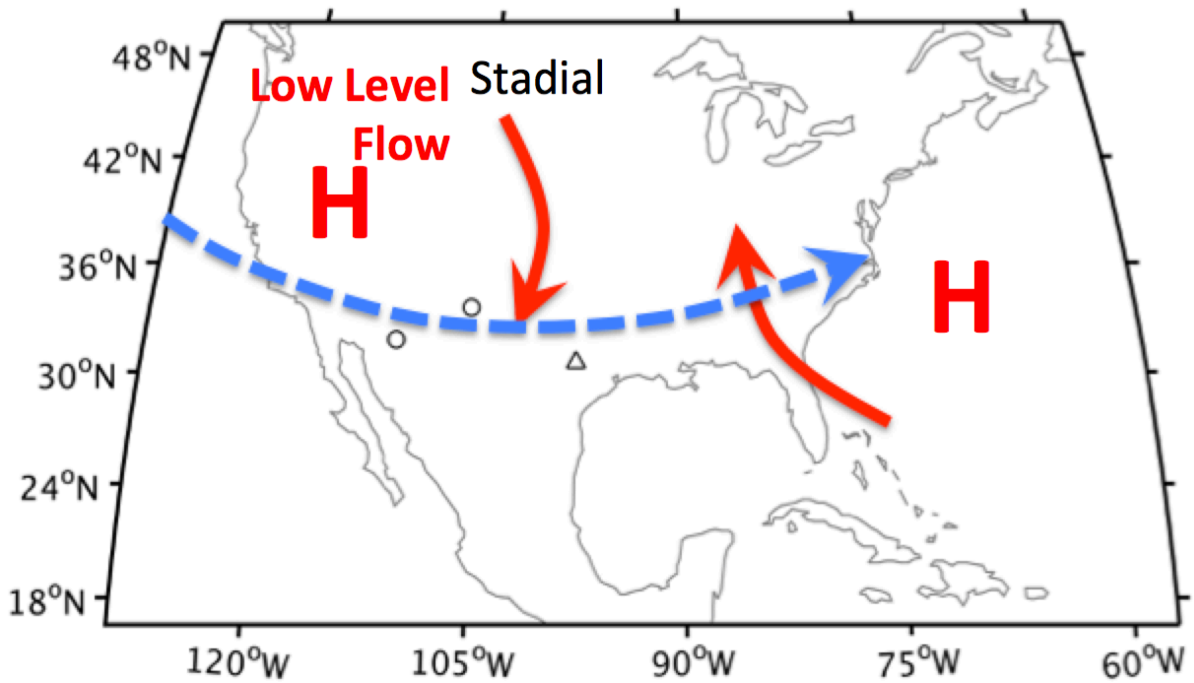


Figure 22- Reduction of Gulf of Mexico moisture supply could be the cause for anti-phasing. A) Current interstadial conditions, with the polar jet stream in blue and two high-pressure systems. B) Stadial conditions with a southerly shift of the polar jet stream and eastward shift of the two high-pressure systems.

Summary

In this research project, we presented a record from two stalactites from Central Texas reconstructing the regional hydrological response to abrupt climate change during Marine Isotope Stage 3 (MIS 3) over several D/O and Heinrich events. We see interstadials (stadials) correspond to warmer and wetter (cooler and drier) conditions on the Southern Great Plains. We found this is the opposite response to the cave records in the North American Southwest. This anti-phased response could be caused by reduction of Gulf of Mexico moisture source during stadials, however future analysis of paleoclimate model outputs needs to be done to confirm this hypothesis. Overall, this research project provides insight into how this region may continue to respond to abrupt climate change, such as anthropogenic global warming, in the present and future with a potential increased amplification of the Texas bimodal rainy season.

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