Laminated stalagmite - based mean annual temperature reconstruction for middle reaches of the Yangtze River during the past 1200 years

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1、Introduction

Mean annual temperature reconstruction helps assess the predictive skills of climate models and is critical for climate prediction under different emissions scenarios. However, regional mean annual temperature patterns remain elusive, especially in regions where high-quality temperature records are lacking. The middle reaches of the Yangtze River (hereafter the MRYR region), Central China, is a classic example of this situation, where climate change is sensitively regulated by the East Asian monsoon system, and paleoclimate samples are difficult to preserve and interpret. Previous temperature reconstruction based on tree-rings in the MRYR region mainly reflect growing season temperatures, while most reconstructions from historical documents reflect winter temperatures.

Over the past two decades, a large number of cave observations and simulation studies have shown that the annual growth rate of stalagmites is significantly positively correlated with temperature, and the growth rate was expected to reconstruct paleotemperature. However, there is no research on the reconstruction of mean annual temperature used the growth rate of stalagmite in the East Asian monsoon region. Accordingly, it is unclear to what extent the specific patterns of temperature variations in the MRYR region reflect region-specific differences in internal climate variability or driving mechanisms.

In this study, we fill this gap and develop an annually-resolved growth rate record on HS4 stalagmites from Heshang Cave, Hubei, China. A new method was used to accurately measure the growth rate of stalagmites, and the growth rate data for the past 1189 years (800-1988 CE). We established the correlation between the growth rate of stalagmite and the mean annual temperature, and reconstructed the mean annual temperature variations in the MRYR region since 800 CE.

2、Materials and Methods

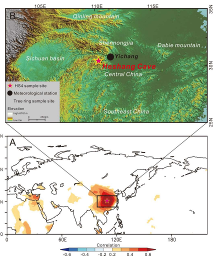

Fig. 1 Location of Heshang Cave. **A**. Spatial correlation of Yichang station with global mean annual temperature. **B**. Location of Heshang Cave (Red star) and Yichang station. Nearby tree-ring recording sites (triangle) are also displayed

Heshang Cave is located at 294 m above sea level (A.S.L.), on the Qing River, a tributary in the middle reaches of the Yangtze River (MRYR region), central China (30°27′, 110°25′) (Fig. 1).

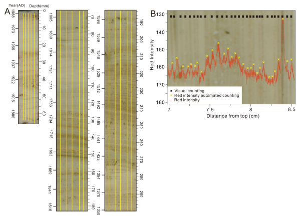

Fig. 2 The image of stalagmite HS4 A. The depth scale from 0-51.0 cm covers the last 1200 years(800-1189CE). **B**. Visual counting method and Red intensity automated counting method are show a consistent annual layer counting result.

In recent studies, the growth rate of stalagmite has been obtained by using the traditional visual measurement method of the annual layer. However, it is difficult to accurately quantify the growth rate due to the lack of standards to objectively define the boundary between each two layers

Here we propose a new method to accurately measure the growth rate of stalagmite by using stalagmite color reading. Stalagmite color value (RGB value) can indicate the color change of the stalagmite surface. When the color is dark, the stalagmite chroma value decreases, and vice versa(Fig. 2).

Finally, we used the median value of five GR (MOG) records per year to the reflect growth rate of stalagmite.

3、Results

The results show that the mean MOG is 0.41 mm/a in 1189 years (800-1988 CE) (Fig. 3). The MOG values range from 0.13 to 1.08mm, with a standard deviation of 0.13mm. The maximum MOG value is 8 times the minimum MOG, indicating that it can respond sensitively to climate change. After 30a low-pass filtering, the MOG has obvious characteristics of multidecadal fluctuation. For example, the growth rate of stalagmite was high during the 1900s-1988s (0.54 mm/a), 1720s-1800s (0.48 mm/a), 1510s-1580s (0.48 mm/a) and 1450s-1350s (0.51 mm/a). while slow during the 1800-1900s (0.39 mm/a), 1580s-1720s (0.40 mm/a) and 1450s-1510s (0.39 mm/a) (Fig.3). From the overall distribution, most of the annual layers (871 in total) are distributed in the range of 0.3-0.6mm, indicating that the sedimentary environment is stable in most cases, and the minimum and maximum values may respond to the occurrence of abnormal climate.

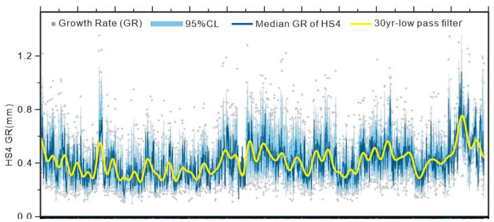

Fig. 3 Median of GR (MOG) of stalagmite HS4.

4、Discussion

➢Stalagmite growth-climate relationships

As can be seen in Fig. 4A, positive correlations were found between the MOG and temperature of each month in the year. The strongest correlations occurred in mean annual temperature and the MOG (r = 0.63, R^2=39.7%, N = 65, p < 0.001) (Fig.4). This is due to the fact that the growth of HS4 stalagmite is affected by the temperature throughout the year. Furthermore, the correlation coefficients between the MOG and mean annual temperature increased significantly after 10a low-pass filtering (r = 0.86, p < 0.001) (Fig.4B). This means that the growth of HS4 stalagmite is basically controlled by the external temperature on the interdecadal scale.

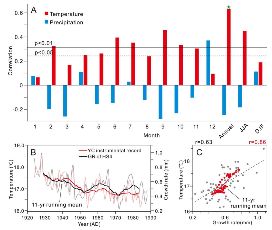

Fig. 4 Comparison between the MOG of HS4 with Yichang station observed temperature and precipitation. **A**. The correlation of the MOG and observed records. **BC**. Comparison between the MOG and observed temperature.

➢Temperature reconstruction and Comparisons with other temperature reconstructions

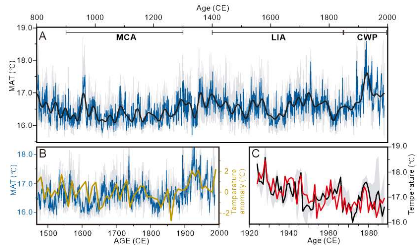

Fig. 4 MRYR region temperature reconstruction. **A**. The mean annual temperature (MAT) reconstruction of MRYR during the past 1200 years. **B**. Comparison between the MAT record and previews temperature from historical documents showed a similar trend. **C**. Comparison between the MAT record and observed temperature showed a similar trend and amplitude. Which demonstrating the ability of our records to quantitatively reconstruct temperature variations.

As shown in Fig5. A lack of consistency between temperature records in nearby areas, and the temperature variations are even more confusing in various seasons. The prominent difference between the various seasons is evident in existing reconstruction records, which can lead to seasonal bias in temperature assessment.

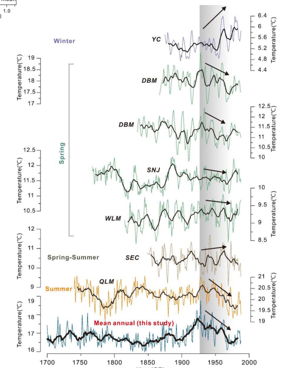

Fig.5 The MAT reconstruction was compared with other reconstructed temperature series based on tree ring from Yichang (Cai et al., 2016), Dabie Mountain (Zheng et al.,2012), Shennongjia (Zheng et al.,2016), Wuling Mountain (Zeng et al.,2019), Southeast China (Duan et al.,2013), and Qinling Mountain (Chen et al.,2021).

➢ The relationship between temperature and the El Niño-Southern Oscillation (ENSO)

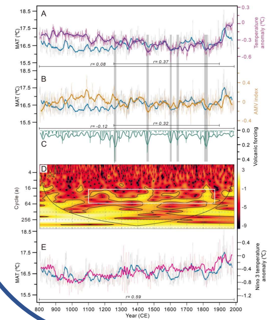

Fig. 6 Comparison between the MOG of HS4 with external forcing and internal variability **A**. The NH temperature from Pages2k. **B**. Atlantic multidecadal variation (AMV)(Wang et al.,2017) **C**. Volcanic eruptions. **D**. The wavelet transform of MAT record. **E**. the El Niño-Southern Oscillation (ENSO) (Mann et al.,2009)

The temperature variation in the middle reaches of the Yangtze River, which is different from that in the Northern Hemisphere during the MCA period, may suggest region-specific influencing factors. Correlation analyses showed the reconstructed MAT series were significantly and positively correlated with the reconstructed ENSO index (Mann et al.,2009), with r = 0.59 (p<0.001, after 21-year running mean), suggesting a significant influence of ENSO on multidecadal temperature variation over MRYR region. The cool phases of the ENSO were associated with negative temperature anomalies, and vice versa. The La Niña - like phase during MCA – may be the main reason for the abnormal cooling in the region.

5、Conclusions and Outlook

In this study, based the laminated stalagmite (HS4) at Heshang Cave in MRYR region, Central China, we obtained the annual growth rate of stalagmite using a new method since 800 CE. We investigated cave conditions and the relationship between growth rate of HS4 stalagmite and climate factors, then the mean annual temperature record for the MRYR region was reconstructed. We suggested that the seasonal bias in temperature records are significant and more caution should be exercised in future temperature composite temperature network. We also highlight that ENSO may plays a major role in temperature variations in MRYR region.

Recent studies indicated that ENSO and the West Pacific subtropical high variability may be stronger under four future emission scenarios, which implies that more attention should be paid to the role of ENSO in future temperature prediction of the East Asian monsoon region. Finally, due to the lack of high-resolution temperature records in MRYR region, more reconstruction and climate dynamics studies are highly recommended to uncover temperature-ENSO links over longer timescales.