CHAPTER 5

Abrupt changes in Indian summer monsoon strength between 33,800 to 5,500 yrs BP

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5.1 Introduction

The sudden arrival of the rainy season after a period of hot and dry summer marks the onset of the summer monsoon in India (Chao, 2000). The Indian summer monsoon plays a major role in heat and moisture transport on Earth. Although, the ISM is a regular phenomenon, its intensity has never be same in two consecutive years and varied spatially and temporally in the past. The meteorological records of precipitation from India indicate that a departure of ~10% from the average rainfall can affect the economy of the country by reducing the agricultural production. And departure of ~30% from the average rainfall can cause huge losses by widespread famines and floods. The changes in ISM rainfall intensity and timing in the past led to the collapse and/or displacement of several cultures and civilizations in South Asia (Staubwasser et al., 2003; Buckley et al., 2010; Dixit et al., 2014).

Modelling and paleoclimatogical studies indicate the large scale changes in the Asian summer monsoon since Last Glacial Maximum (LGM). The ISM weakened and the MLW strengthened significantly during the Younger Dryas (YD) and the LGM (Porter and Zhisheng, 1995; Sinha et al., 2005). The East Asian summer monsoon precipitation also decreased significantly during the YD (Wang et al., 2001; Yuan et al., 2004). ISM strength decreased during North Atlantic cold intervals; the so-called Bond events in Holocene (Gupta et al., 2003). These studies also established a link between North Atlantic temperature changes and ISM strength. The lower temperature in the North Atlantic causes southward shift of the MLW, more snowfall in the Himalaya and affects the development of low pressure zone in northern India (Sun et al., 2011). This cold intervals in the North Atlantic lessen the summer monsoon rainfall in the Indian subcontinent.

Late Pleistocene speleothem records from the Hulu and Dongge Caves of China indicate centennial-to millennial-scale changes in East and South Asian monsoon precipitation (Wang et al., 2001; Yuan et al., 2004). However, such high-resolution, long-ranging ISM precipitation records are scarce from the Indian landmass especially from the Indian Himalaya (Sinha et al., 2005). To assess long-term changes in ISM strength and to understand whether LGM, YD, and Heinrich cold events were accompanied by decreased summer monsoon strength in the Indian subcontinent, we studied cave carbonate $\delta^{18}O$ from the Mawmluh Cave (25°15′32.27″ N, 91°42′45.37″ E altitude 1290 m, amsl), near Cherrapunji, Meghalaya (NE India) spanning in age from 33,800 to 5500 yrs BP. In this study, I have mainly focused significance of the abrupt changes recorded in this $\delta^{18}O$ time series.

5.2 Results

5.2.1 $\delta^{18}O$ and $\delta^{13}C$ from speleothem calcite

$\delta^{18}O$ values indicate very high amplitude of variations between 33,800 and 5,500 yrs BP, varying from -7.33 to -0.28‰ (Figure 5.1). The $\delta^{18}O$ values are low between 33,500 and 32,500 yrs BP followed by high values from 26,000 to

23,500 yrs BP Highest values are observed between 17,000 and 15,000 yrs BP which drops sharply thereafter during the Bølling-Allerød period. The interval of YD witnessed the abrupt transition to high values between 12,900 to 11,700 yrs BP. The values became very low with the onset of early Holocene. The changes in the $\delta^{13}C$ are of less magnitude compared to that of $\delta^{18}O$, and varies from -1.99 to 2.77‰ (Figure 5.1). The values are high between 33,800 and 15,000 yrs BP with a slight increasing trend from 23,000 to 15,000 yrs BP. After 15,000 yrs BP, the values abruptly decreased thereafter until a rise after 7000 yrs BP.

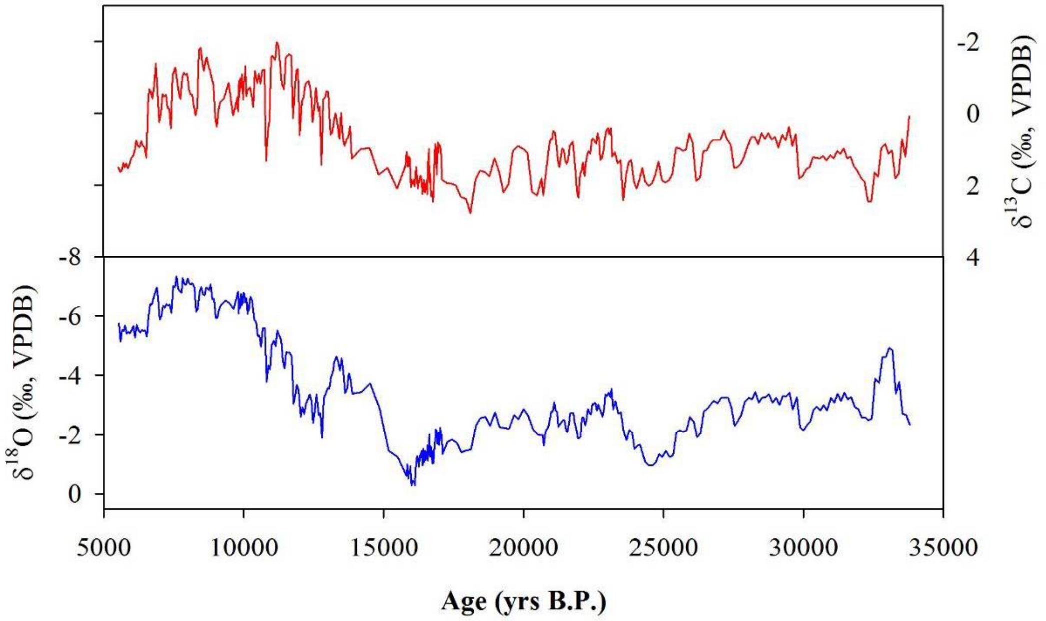

Figure 5.1 $\delta^{18}O$ and $\delta^{13}C$ proxy record of Indian summer monsoon strength from speleothem MWS-1, from the Mawmluh cave, NE Himalaya.

5.2.2 Hendy Test

Hendy test of the speleothem MWS-1 was carried out by correlation of $\delta^{18}O$ and $\delta^{13}C$ ratios of nine samples from a single lamina, extracted from centre to margin of the sample. There is no significant correlation between $\delta^{18}O$ and $\delta^{13}C$ values (R^2= 0.15), suggesting the deposition of speleothem MWS-1 in isotopic equilibrium with the dripping water (Figure 5.2). The comparison of our record with the earlier record from the Mawmluh cave (Berkelhammer et al., 2012) indicates a good match between two records which further supports that the isotopic signature in speleothem MWS-1 was not affected by kinetic fractionation during its deposition and capture the signal of regional climatic changes (Figure 5.4).

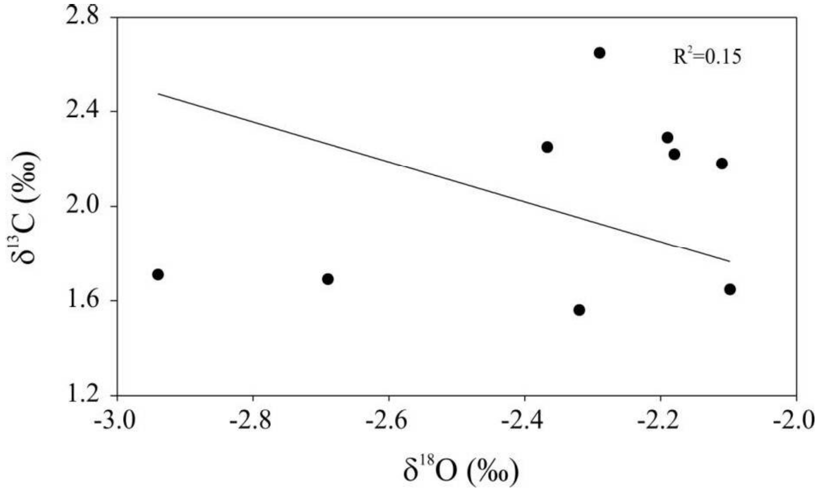

Figure 5.2 Hendy test correlation of $\delta^{18}O$ and $\delta^{13}C$ values from a single lamina of speleothem MWS-1 from the Mawmluh cave, NE Himalaya.

5.2.3 Spectral Analysis

Spectral analysis of $\delta^{18}O$ time series for the changes in Indian summer monsoon strength between 33,800 and 5,500 yrs BP indicate the major cyclicity of 1,700 yrs during that time span (Figure 5.3). The other observed periodicities are of 1118, 802, 602, 452, 383, 315, 236, 228, 176, 165 and 162 yrs (Figure 5.3).

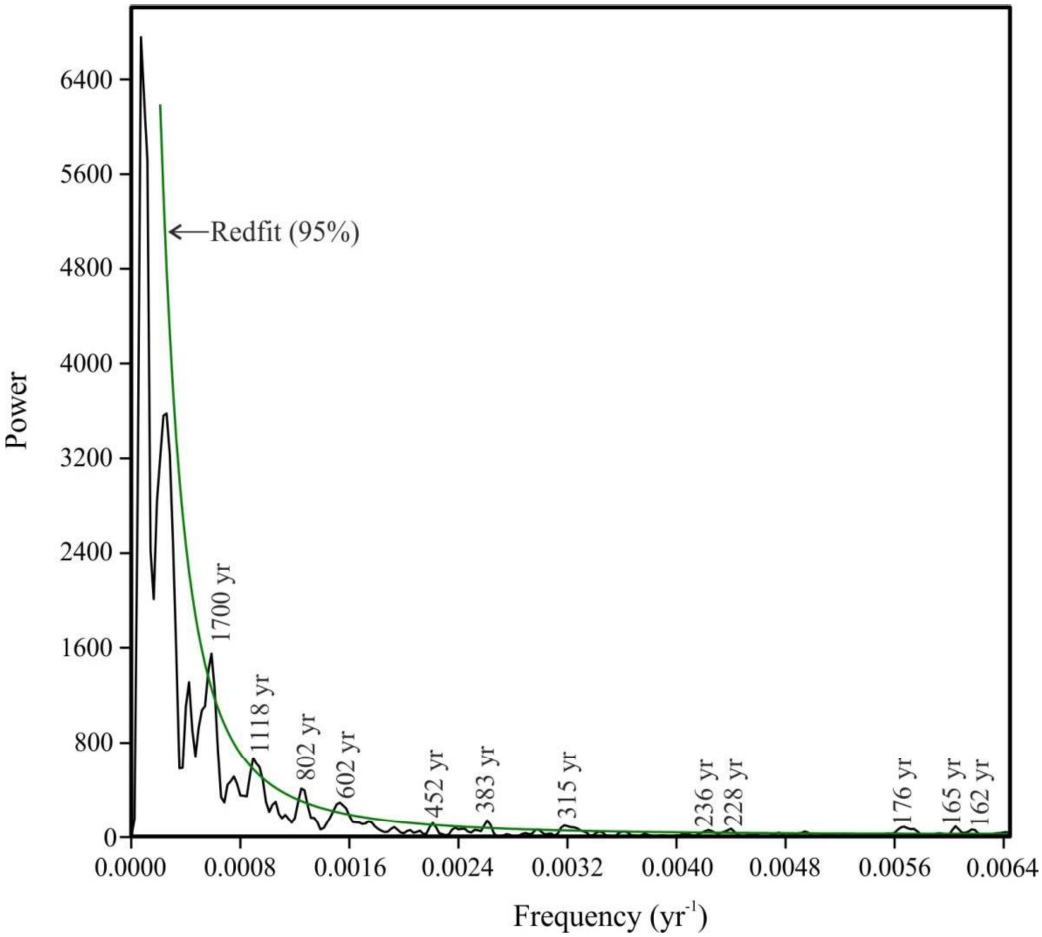

Figure 5.3 Spectral analysis of $\delta^{18}O$ time series from speleothem MWS-1 from Mawmluh cave, NE Himalaya for the period between 33,800 and 5,500 yrs BP.

5.3 Discussion

This ISM proxy record from the Mawmluh cave indicate a strong wet phase during 33,500–32,500 yrs BP followed by a weak/dry phase from 26,000 to 23,500 yrs BP and a very weak phase from 17,000 to 15,000 yrs BP. The record suggests an abrupt increase in ISM strength during the Bølling-Allerød and early Holocene periods and pronounced weakening during the Heinrich and YD cold events (Figure 5.4).

The $\delta^{18}O$ data set from the Mawmluh Cave shows a fair match the earlier published record from the same cave (Berkelhammer et al., 2012) (Figure 5.4). A small divergence in these two records after 7,500 yrs BP. Our record indicate the weak ISM conditions after 7,500 cal yrs BP which was also reported from the lake records from central India (Prasad et al., 2014; Sarkar et al., 2015). This conditions may have arisen due to different karst processes controlling different drips which fed the two cave samples (Figure 5.4). A comparison of MWS-1cave $\delta^{18}O$ with that of Hulu/Sanbao (Wang et al., 2001) and Dongge Caves (Yuan et al., 2004) from China suggests reasonable similarity which might be due to similar isotopic composition of source of air parcels in two regions (Figure 5.4). The caves in eastern China receive moisture from both the Indian and Pacific Ocean, whereas Mawmluh Cave receives moisture from the Indian Ocean including the BoB and Arabian Sea (Breitenbach et al., 2010; Liu et al., 2014). The $\delta^{18}O$ of MWS-1speleothem from the Mawmluh cave is typical signal of Indian monsoon. The comparison of our $\delta^{18}O$ record with the maximum insolation at 25°N (Huybers, 2006), orbital precession (Berger and Loutre, 1991) and the Greenland Ice Sheet Project 2 (GISP 2) record has been done to better understand the role of orbital insolation and high-latitude glaciation in driving changes in ISM strength (Figure 5.5). Mawmluh Cave $\delta^{18}O$ is exceptionally well aligned with GISP $\delta^{18}O$ from 25,000 yrs ago to the present. The most enriched Holocene values (−7‰ at 8 ka) lag maximum local solar insolation by 3500 yrs, consistent with the lag (relative to July 21 insolation) measured for the late Pleistocene Hulu/Sanbao record (Wang et al., 2001, 2008) (Figure 5.5).

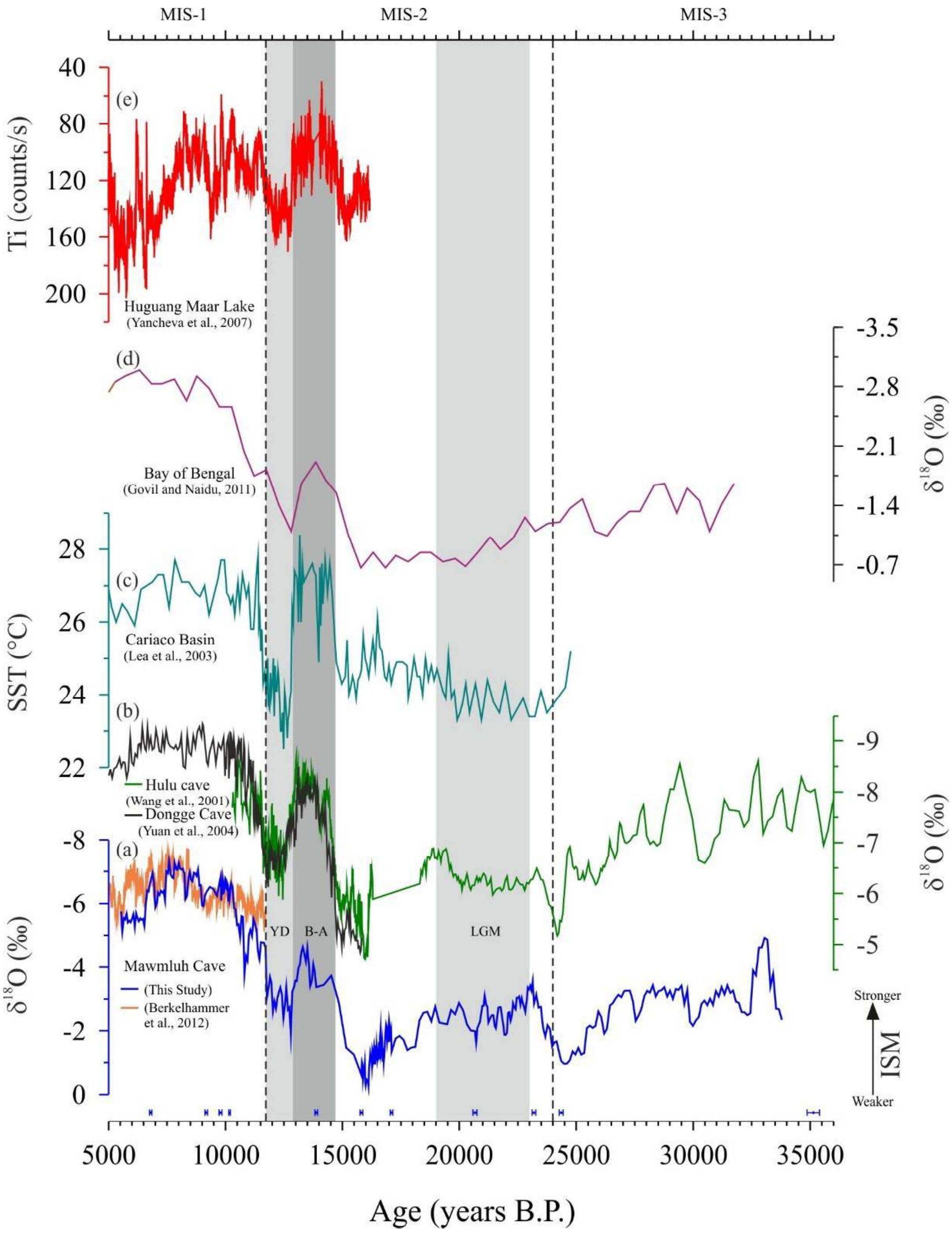

Figure 5.4 Indian summer monsoon (ISM) proxy record from the Mawmluh Cave, Meghalaya, India, compared with cave and lake records from China, and marine

records from the Bay of Bengal and Cariaco Basin. (a) Mawmluh Cave $\delta^{18}O$ record for the interval 33,800 to 5500 yrs BP (dated intervals are marked by diamonds with error bars in blue color); also superimposed is the published $\delta^{18}O$ record from the Mawmluh Cave (Berkelhammer et al., 2012). (b) Dongge Cave $\delta^{18}O$ record (black color) (Yuan et al., 2004) combined with Hulu Cave $\delta^{18}O$ record (green color) (Wang et al., 2001). (c) SST values from Cariaco Basin core PL07-39PC (cyan color) (Lea et al., 2003). (d) Bay of Bengal planktic foraminifer $\delta^{18}O$ record as proxy for precipitation change (Govil and Naidu, 2011). (e) Huguang Maar Lake record of Ti counts/s (Yancheva et al., 2007). Broken vertical black lines mark the boundaries between marine isotopic stages (MIS). Light grey bars mark the Younger Dryas (YD) period and Last Glacial Maximum (LGM), whereas the dark grey bar indicates the Bølling-Allerød (B-A) period.

These relationships indicate the links of the ISM to both solar insolation and North Atlantic climate signals transmitted via a westerlies teleconnection and sea ice. Increased North Atlantic sea ice extent causes cool temperatures throughout major parts of the Northern Hemisphere and the northern Indian Ocean. These cool anomalies, transported in the westerlies, delay the arrival of the Indian monsoon as well as reduce precipitation over the Indian subcontinent (Gupta et al., 2003; Pausata et al., 2011). Such changes are likely to be recorded in heavier δ^{18}O values of cave carbonates. Our record also shows good correlation with Northern Hemisphere tropical and subtropical climate proxy records from the BoB and Cariaco Basin, indicating both the tropics and subtropics were swept by similar climatic regimes during the studied interval (Figure 5.4).

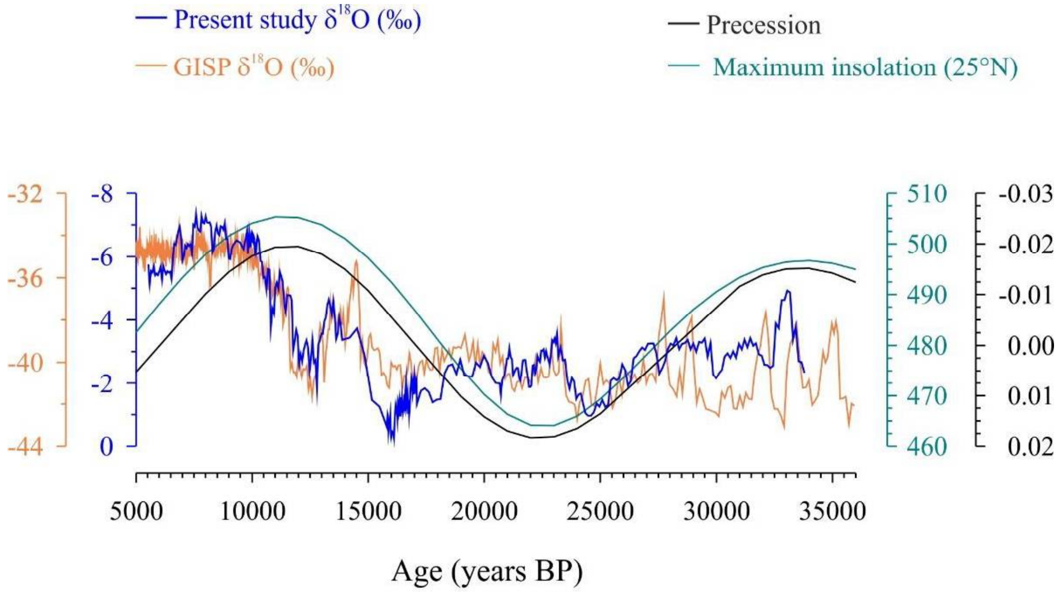

Figure 5.5 Mawmluh Cave $\delta^{18}O$ data (blue color) compared with Greenland Ice Sheet Project 2 (GISP2) core $\delta^{18}O$ data (orange color) (Stuiver and Grootes, 2000). Also superimposed are maximum solar insolation at 25°N (cyan color) (Huybers, 2006) and orbital precession (black color) (Berger and Loutre, 1991).

Gupta et al. (2003) linked such contemporaneous changes in the tropics and Northern Hemisphere to solar variability. The Mawmluh Cave δ^{18}O record indicates a strengthened ISM circulation from 33,500 to 32,500 yrs BP and weakened circulation in the later part of marine oxygen isotope stage (MIS) 3 and early part of MIS 2 with a weak ISM phase during 26,000 to 23,500 yrs BP coinciding with a cold phase in the North Atlantic (Figure 5.4, 5.5). During the latter interval, monsoon runoff to the BoB weakened owing to a reduction in ISM rainfall (Govil and Naidu, 2011). During the LGM, the ISM circulation strengthened similar to that during the late MIS 3 followed by its weakest phase lasting from 17,000 to 15,000 yrs BP (Heinrich event H1). The Mawmluh Cave $\delta^{18}O$ record shows an abrupt increase in ISM strength during the Bølling-Allerød from 15,000 to 12,900 yrs BP and early Holocene (~10,000 to 6,500 yrs BP) warm intervals suggesting increased ISM strength, which corresponds to increased river discharge to the BoB (Govil and Naidu, 2011). The Bølling-Allerød increase is consistent with the ISM maximum in northern India as documented in the speleothem $\delta^{18}O$ record from the Timta Cave (Sinha et al., 2005). ISM strength decreased significantly during the Heinrich events H1–H3 and YD cold event (Figure 5.4, 5.5).

Our results demonstrate that abrupt weak/strong phases in Indian summer monsoon (ISM) strength correspond to cold/warm intervals driven by weakening/strengthening of thermal contrasts between land and sea since MIS3. The novelty of our work lies in the fact that it is the southernmost longest record that is uniquely an Indian signal, offering the opportunity to assess isotopic contrasts relative to the Chinese records and the millennial-scale differences with other climate records. Our record also demonstrates explicitly for the first time the presence of YD cold event of Greenland with sharp boundaries in a cave carbonate record from the Indian subcontinent.