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Timing and Structure of the 4.2 ka BP Event in the Indian Summer Monsoon Domain from an Annually-Resolved Speleothem Record from Northeast India

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Abstract

A large array of proxy records suggests that the '4.2 ka event' marks an ~ 300-year period of major global climate anomaly. However, the climatic manifestation of this event, including its onset, duration, and termination, remain less clear in the Indian summer monsoon (ISM) domain. Here, we present a new speleothem oxygen isotope ($\delta^{18}O$) record from Mawmluh Cave, Northeast India, which provides an annually-resolved record of changes in ISM strength between ~4.440 and 3.780 ka BP. Our $\delta^{18}O$ record is constrained by 18 ^{230}Th dates with an average age uncertainty of ±13 years and a dating resolution of ~40 years, which allow us to characterize the timing and structure of the '4.2 ka event' with an unprecedented detail. The overall expression of the 4.2 ka event in our record shares broad similarities with a previous $\delta^{18}O$ record from the Mawmluh Cave as well as with other previous lower-resolution proxy reconstructions of the ISM. However, unlike some previous ISM records, where the '4.2 ka event' has been described as a singular multi-centennial period of anomalously weak ISM, our data suggest a more variable nature of ISM during this period. The '4.2 ka event' in our record exhibits a three-stage structure, characterized by highly variable ISM between ~4.255 and 4.070 ka BP and a distinct pluvial phase from ~4.070-4.010 ka BP. The latter abruptly (<10 years) culminated into a relatively weaker phase of ISM, which was punctuated by a number of multidecadal periods of anomalously drier condition. While our record shows evidence of a discernible beginning of the 4.2 ka event, there is no clear evidence of its 'end' thus, suggesting that the ISM experienced a major regime-shift or transition at ~ 4.0 ka BP.

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1. Introduction

The interval between 4.2 and 3.9 ka BP (thousand years before present, where present =1950 AD) constitutes an important period of time from both climatological and archeological perspectives (e.g., Weiss et al.,1993; Cullen et al., 2000; Staubwasser et al., 2003; Berkelhammer et al., 2012). A global suite of proxy records shows widespread climate anomalies during this time (commonly referred as the '4.2 ka event') (e.g., Cullen et al., 2000; Staubwasser et al., 2003; Arz et al., 2006; Drysdale et al., 2006; Menounos et al., 2008; Liu and Feng, 2012; Berkelhammer et al., 2012; Dixit et al., 2014; Cheng et al. 2015; Nakamura et al., 2016; Dixit et al., 2018; Railsback et al., 2018). Additionally, a number of archeological studies also suggest that the '4.2 ka event' may have been associated with a series of cultural and societal changes in the Mediterranean, Middle East, Africa, South and East Asia (e.g., Weiss et al.,1993; Enzel et al., 1999; Cullen et al., 2000; Staubwasser et al., 2003; Marshall et. al., 2011; Liu and Feng, 2012; Dixit et al., 2014; Weiss, 2016). For example, the '4.2 ka event' has been proposed to have contributed to collapses of the early Bronze age civilizations, including the Longshan Culture in China (Change, 1999; Liu and Feng, 2012), Egyptian Old Kingdom by the Nile River (Stanley et al., 2003), and the Akkadian Empire in Mesopotamia (Weiss et al.,1993; Cullen et al., 2000). In South Asia, the 4.2 ka event has been linked to a weakening of the Indian summer monsoon (ISM) and the ensuing deurbanization of the Indus Valley Civilization (Staubwasser et al., 2003; Madella and Fuller, 2006; Dixit et al., 2014; Giosan et al., 2012; Berkelhammer et al., 2012; Kathayat et al., 2017; Dixit et al., 2018).

A number of proxy records from the Indian subcontinent suggest that a major weakening of ISM occurred during the '4.2 ka event' (Staubwasser et al., 2003; Berkelhammer et al., 2012; Ponton et al., 2012., Dixit et al., 2014; Nakamura et al., 2016; Hong et al 2014; Hong et al., 2016; Shukla et al., 2018) (Fig. 1).

This event has been generally described as an approximately a two centuries-long interval of aridity, which was superimposed on a long-term gradually declining trend in ISM in response to decreasing northern hemisphere summer insolation (e.g., Kathayat et al., 2017). However, the timing, structure and magnitude of the 4.2 ka event in the ISM regime remain unclear. For example, while a speleothem record from Mawmluh Cave in Northeast India shows an abrupt onset of the event at ~4.1 ka BP (Berkelhammer et al., 2012), the onset/duration timings of the 4.2 ka event in other records differ considerably (e.g., Staubwasser and Weiss, 2006; Prasad and Enzel, 2006; Nakamura et al., 2016; Dixit et al., 2018). Furthermore, a speleothem oxygen isotope ($\delta^{18}O$) record from Sahiya Cave, North India

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70 (Kathayat et al., 2017) indicates a long-term drying trend in ISM from ~4200 to 3500 years but does not contain a clear expression of the event.

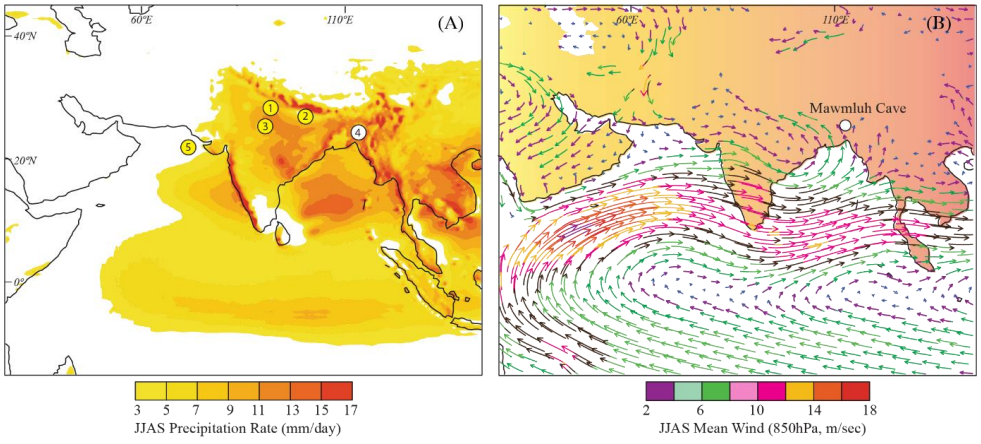

Figure 1. Location map and spatial structure of mean JJAS precipitation and low-level winds. (A) JJAS precipitation from the Tropical Rainfall Measuring Mission (TRMM). The 75 locations of Mawmluh Cave (white circle) and other proxy records mentioned in the text (yellow circles and numbers). The numbering scheme is as follows: 1, Sahiya cave (Kathayat et al., 2017); 2, Lake Rara (Nakamura et al., 2016); 3, Kotla Dhar (Dixit et al., 2014); 4, Mawmluh Cave (Berkelhammer et al., 2012); and 5, Indus Delta (Staubwasser et al., 2003). (**B**) 850 hPa-level monsoon vector from zoomed Laboratoire de Meteorologie Dynamique 80 (LMDZ) general circulation model with telescoping zooming (figure adapted and modified from Sabin et al., 2013). The zoom version shows a well-defined cyclonic circulation with westerlies on the southern flanks and easterly winds on the northern flanks of the Monsoon Trough. The Mawmluh Cave is ideally located to record upstream variations in the overall strength of the ISM (see text).

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However, the latter may also stem from relatively large age uncertainties and low temporal resolution of the Sahiya Cave record around this time interval, which preclude a definitive assessment of the '4.2 ka event' (Kathayat et al., 2017).

A high resolution (~ 6 years) $\delta^{18}O$ record from Mawmluh Cave (KM-A), Northeast India 90 has previously provided a clear evidence of the '4.2 ka event' from the ISM domain (Berkelhammer et al. 2012). The 4.2 ka event in the KM-A record event can be described as a 'pulse-like' change in the ISM, characterized by a sharp increase in the speleothem $\delta^{18}O$ values (implying weaker ISM) at ~ 4.07 ka, which was followed by a large and abrupt decrease in the $\delta^{18}O$ values at 3.88 ka BP. However, the exact timing and structure of the 4.2 ka event from 95 the KM-A sample has some uncertainty associated with the fact that it is only constrained by only two ^{230}Th dates. Furthermore, the termination of the event occurs near the top ~2 mm

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portion of KM-A, where the $\delta^{18}O$ values may have been potentially influenced by recent morphological changes in the shape of KM-A stalagmite. Here, we provide two new replicated speleothem $\delta^{18}O$ records from Mawmluh Cave (ML.1 and ML.2) (Fig. 2) with an average $\delta^{18}O$ resolutions of ~1 and ~5-year, respectively.

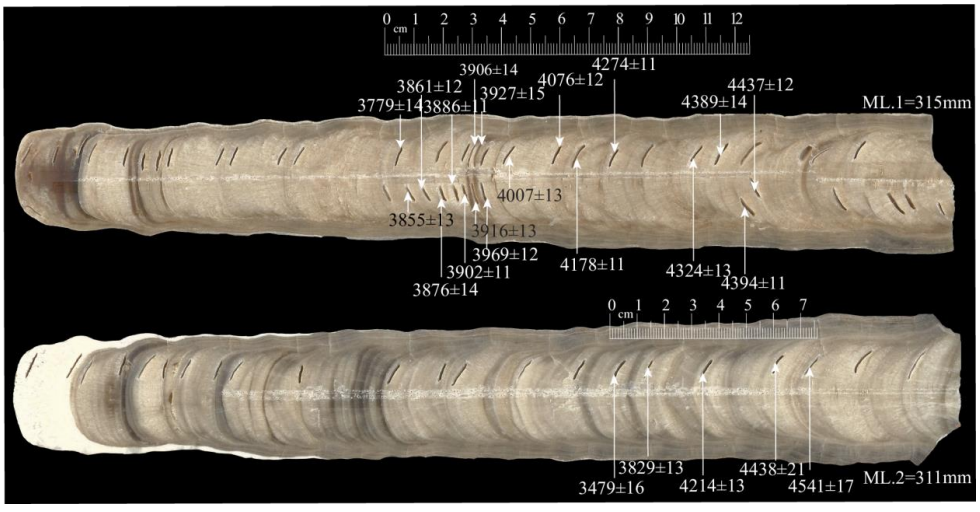

Figure 2. Samples photograph: The total length of ML.1 and ML.2 samples is 315 & 311mm respectively. The arrows indicate the dating sub-sampling location and the ^{230}Th dates with the 2σ analytical error (also see Supplementary Table 1). The cm scale indicates the location of isotopic measurements, enclosing the interval of interest within both the samples.

The ML.1 and ML.2 $\delta^{18}O$ records span from 4.440 to 3.780 ka BP and 4.530 to 3.370 ka BP, respectively. Our new record is sub-annually to annually resolved, has precise chronologic constraints. The ML.1 and ML.2 chronologies are established by 18 ^{230}Th dates with age uncertainty of ~±13 years (average dating resolution of ~40 years) and 5 ^{230}Th dates with age uncertainty of ~±16 years, respectively (Fig. 3) (also see Supplementary Table 1), which allow us to precisely characterize the timing, structure, and manifestation of the 4.2 ka event in the ISM regime. Particularly, we aim to provide better constraints on the timing of the onset of the event and refine the nature of the event's termination.

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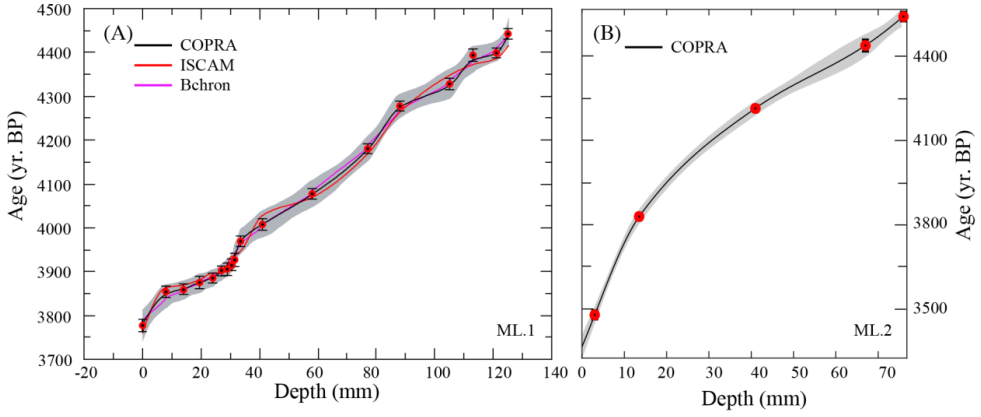

Figure 3. Age Models of ML.1 and ML.2 records. We adopted COPRA and generated 2000 realizations of age models to account for the dating uncertainties (2.5 and 97.5% quantile) confidence limits. **(A)** ML-1 age models and modeled age uncertainties using 3 different age-modeling algorithms, COPRA (black), Bchron (purple) and ISCAM (red). The gray band depicts the 95% confidence interval using COPRA. Error bars on ^{230}Th dates represent a 2σ analytical error. (**B**) ML.2 age model and modeled age uncertainties using COPRA.

2 Samples and Methods

2.1 Cave location, climatology & characteristics

Mawmluh Cave (25°15′32″N, 91°42′45″E, 1290 m asl) is located near the town of Sohra (Cherrapunji) at the southern fringe of the Meghalaya Plateau, Northeast India (Fig. 1). The mean annual rainfall is ~11,000 mm in the region, 70% of precipitation falls during the peak ISM months (June-September) (Murata et al., 2007). The rainfall at the cave site during the ISM period is mainly produced by convective systems and the low-level air parcels originated from the Bay of Bengal, which propagates further northward and penetrate deep into the Tibetan Plateau (Breitenbach et al., 2010; Sengupta and Sarkar, 2006). The non–monsoonal component of the rainfall is trivial and consists of the westerly related moisture as well as recycled local moisture (Breitenbach et al., 2010 and 2015; Berkelhammer et al., 2012). The cave is overlain by ~30–100 m thick and heavily karstified host rock (limestone, sandstone, and a ~40–100 cm thick coal layer) (Breitenbach et al., 2010). The soil layer above the cave is rather thin (5–15 cm) and covered mainly by grasses and bushes. The cave monitoring data (Breitenbach et al., 2010) indicate that the relative humidity inside the cave is more than 95% even during the dry season (November to April). The temperature variations in the cave are small (18.0–18.5°C) and close to the mean annual temperature of the area (Breitenbach et al., 2010 and 2015). A 3-year monitoring study in Mawmluh Cave (Breitenbach et al., 2010)

suggests that drip-water $\delta^{18}O$ signals in the cave lag the local rainfall by less than 1 month, and thus preserves the seasonal signal of ISM rainfall. Previous studies have indicated that variations in the $\delta^{18}O$ of speleothem calcite from Mawmluh Cave reflect changes in the amount-weighted $\delta^{18}O$ of precipitation ($\delta^{18}O_p$) values (Breitenbach et al., 2010 and 2015; Berkelhammer et al., 2012; Myers et al., 2015; Dutt et al., 2015).

2.2 Proxy Interpretation

The temporal $\delta^{18}O$ variations in monsoonal rainfall and consequently in speleothem in the study area have been previously interpreted to dominantly reflect spatially-integrated upstream changes in the ISM strength (Sinha et al., 2011; Berkelhammer et al., 2012). A number of studies with isotope-enabled general circulation models (GCMs) also suggest a significant inverse relationship between ISM upstream summer (June to September) rainfall amount and $\delta^{18}O_p$ variations over the Indian Subcontinent (e.g., Vuille et al., 2005; Pausata et al., 2011; Berkelhammer et al., 2012; Sinha et al., 2015; Midhun and Ramesh, 2016). As such, the low and high $\delta^{18}O$ values of our records are used to refer to strong and weak monsoons, respectively, consistent with a number of previous studies (e.g., Dayem et al., 2010; Breitenbach et al., 2010; Sinha et al., 2011; Cheng et al., 2012; Sinha et al., 2011; Berkelhammer et al., 2012; Breitenbach et al., 2015; Myers et al., 2015, Dutt et al., 2015; Cheng et al., 2012; Kathayat et al., 2016; Kathayat et al., 2017).

2.3 Samples preparation

The ML.1 and ML.2 samples from Mawmluh Cave were collected ~4–5 m above the cave floor in November 2015 ~700 meters from the cave entrance. The diameters of ML.1 and ML.2 are ~170 and 165 mm, and the length ~315 and ~311 mm, respectively. Both stalagmite samples were cut along their growth axes, using a thin diamond blade. The sub-samples for isotopic measurements for the ML.1 and ML.2 samples were obtained from depths between ~125–250 mm and ~182–255 mm (with respect to the top), respectively. Accordingly, we report our data with depths of zero set at 125 mm and 182 mm from the top for samples ML.1 and ML.2, respectively. Both samples do not have any visible changes in the texture or hiatuses in the above intervals for this study (Fig. 2).

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2.4 ^{230}Th dating

Subsamples from ML.1 and ML.2 for ^{230}Th dating (~30 mg) were drilled using a 0.5 mm carbide dental drill. The ^{230}Th dating was performed at the Xi'an Jiaotong University, China using Thermo-Finnigan Neptune-*plus* multi-collector inductively coupled plasma mass spectrometers (MC-ICP-MS). The methods were described in Cheng et. al., 2000 and 2013). We used standard chemistry procedures (Edwards et al., 1987) to separate uranium and thorium. A triple-spike (^{229}Th–^{233}U–^{236}U) isotope dilution method was used to correct instrumental fractionation and to determine U/Th isotopic ratios and concentrations (Cheng et al., 2000; Cheng et al., 2013). U and Th isotopes were measured on a MasCom multiplier behind the retarding potential quadrupole in the peak-jumping mode using the standard procedures (Cheng et al., 2000). Uncertainties in U/Th isotopic measurements were calculated offline at 2σ level, including corrections for blanks, multiplier dark noise, abundance sensitivity, and contents of the same nuclides in spike solution. The U decay constants are reported in Cheng et al. (2013). Corrected ^{230}Th ages assume the initial ^{230}Th/^{232}Th atomic ratio of 4.4 ±2.2 ×10^{-6}, the values for material at secular equilibrium with the bulk earth ^{232}Th/^{238}U value of 3.8. The corrections are small because the uranium concentrations are high (~6 ppm) and detrital ^{232}Th components are low (average <170 ppt) in both the samples (Supplementary Table 1).

2.5 Age models

We obtained 18 and 5 ^{230}Th dates for samples ML. 1 and ML. 2, respectively. The average dating resolution for ML.1 is ~40 years with a precision of ~ ± 13 years. In addition, the portion of the 4.2 ka BP event (between 27 and 88 mm depth in ML.1) is constrained by a total of 9 ^{230}Th dates with the average spacing of 7 mm between successive dates. All the dates are in chronological order within an average dating uncertainty of ±12 years. The ML.1 and ML.2 age models and associated uncertainties were constructed using COPRA (Constructing Proxy Records from Age model) (Breitenbach et al., 2012), Bchron (Haslett et al., 2008) and ISCAM (Fohlmeister, 2012) age modeling schemes (Fig. 3), respectively. All three modeling schemes yielded nearly identical age models and the conclusions of this study are not sensitive to the choice of the age models (Fig. 3).

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205 **2.6 Stable isotope analysis**

The ML.1 and ML.2 $\delta^{18}O$ records are established by ~970 and ~238 stable isotope measurements, respectively (Fig. 4, Supplementary Table 2).

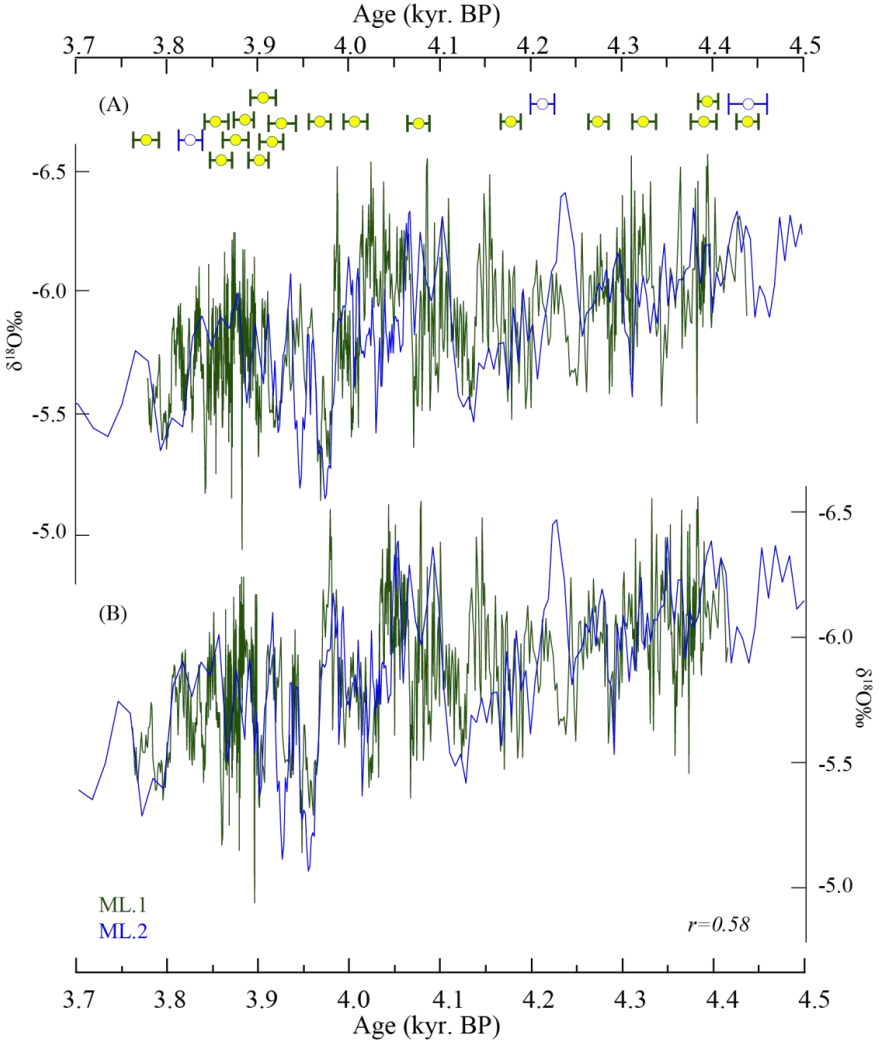

Figure 4. Comparison between ML.1 and ML.2 $\delta^{18}O$ records over the period of overlap.
210 The ML.1 and ML.2 $\delta^{18}O$ profiles replicate convincingly over the period of overlap, but with some offset between their absolute $\delta^{18}O$ values (see text). The horizontal error bars on ^{230}Th dates represent a 2σ analytical error. (**A**) The raw data of ML.1 (green) and ML.2 (blue) samples on independent COPRA age model, the horizontal error bars depict ^{230}Th dates and errors (2σ). (**B**) We used intra-site correlation age modeling (ISCAM) algorithm (Fohlmeister,
215 2012) to find the best correlation between ML.1 and ML.2 profiles (also see, Supplementary Table 2).

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We used New Wave Micromill, a digitally controlled tri-axial micromill equipment, to obtain subsamples. The subsamples (~80 μg) were continuously micromilled from ML. 1 and ML. 2 with typical increments between 50 and 100μm (dependent on growth-rates) along the stalagmites growth axes. The $\delta^{18}O$ and $\delta^{13}C$ were measured using Finnigan MAT-253 mass spectrometer coupled with an on-line carbonate preparation system (Kiel-IV) in the Isotope Laboratory, Xi'an Jiaotong University. Results are reported in per mil (‰) relative to the Vienna PeeDee Belemnite (VPDB) standard. Duplicate measurements of standards NBS19 and TTB1 show a long-term reproducibility of ~0.1‰ (1σ) or better.

2.7 Replication

We assessed the replication between ML.1 and ML.2 $\delta^{18}O$ records by using the ISCAM (Intra-Site Correlation Age Modeling) algorithm (Fohlmeister, 2012). The ISCAM finds the best correlation between the proxy records by using a Monte Carlo approach. Significant levels were calculated against a red-noise background from 1,000 pairs of artificially simulated first-order autoregressive time series (AR1). The ML.1 and ML.2 $\delta^{18}O$ time series on ISCAM derived age models display a statistically significant correlation (r =0.58 at 95% confidence level) during their contemporary growth period between ~4.4–3.8 ka BP. The minor discrepancies between the two profiles may result from slight differences in their ^{230}Th dating resolution and/or growth rate variations (Fig. 4).

3 Results and Discussion

3.1 Results

The ML.1 and ML.2 $\delta^{18}O$ values range between -6.6‰ and -4.4‰ with mean values of -5.80‰ and -5.43‰, respectively. A slight but systematic offset in the mean $\delta^{18}O$ values of 0.4‰ between the two records may possibly stem from karst-related difference in the drip and /or degassing rates. Temporal resolutions of the ML.1 record range from ~0.1 to ~3 years with an average resolution of ~1 year. The average temporal resolution of the ML.2 record is ~5 years (Figs. 4 and 5).

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3.2 Comparisons between KM-A and ML.1 and ML.2 $\delta^{18}O$ records

The ML.1 and ML.2 $\delta^{18}O$ record displays broad similarities with the previous KM-A $\delta^{18}O$ record from the same cave (Berkelhammer et al., 2012) but some differences are also evident (Fig. 5).

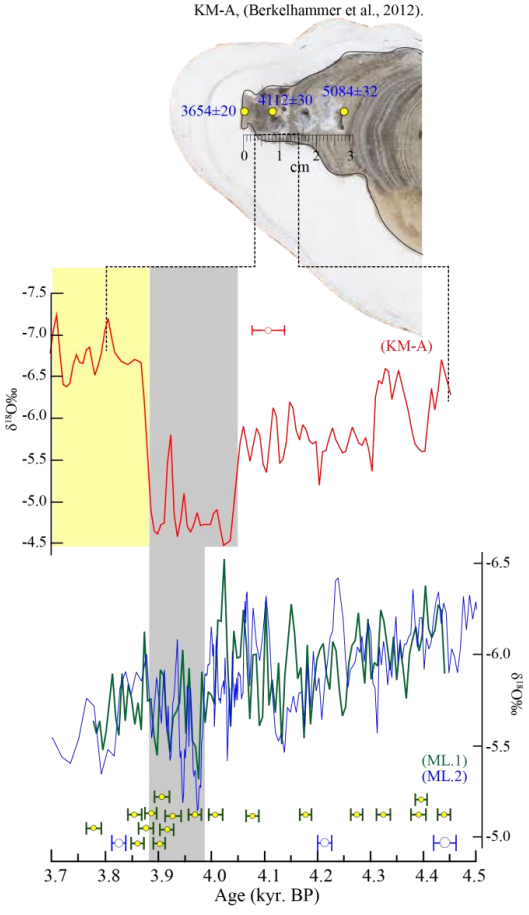

Figure 5. Comparison between KM-A and ML.1, ML2: The KM-A stalagmite sample picture from Mawmluh cave (Berkelhammer et al., 2012). The 4.2 ka event occurs at the top portion of the sample (0-29 mm) which tapers towards the top and is constrained by three ^{230}Th dates (yellow dots). The dotted lines indicate the $\delta^{18}O$ depth from 4400 to 3654 years BP on the KM-A sample. Previously published stalagmite (KM-A) $\delta^{18}O$ record (red) from Mawmluh Cave (Berkelhammer et al., 2012). The raw $\delta^{18}O$ profile (blue) from ML.2 (this study) is overlaid by 6-years interpolated $\delta^{18}O$ profile (green) of ML.1 (this study, also see, Supplementary Table 2). The horizontal error bars (red, green and blue) on the ^{230}Th dates represent a 2σ analytical error. The vertical grey bar indicates the duration of the weak (driest phase) ISM variability recorded between KM-A and ML $\delta^{18}O$ profiles. The yellow bar indicates the anomalously depleted $\delta^{18}O$ values in KM-A record.

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The '4.2 ka event' in the KM-A record manifest as a two-step change, marked by an initial increase in $\delta^{18}O$ values (~0.6‰) between ~4.315 and 4.303 ka followed by a second and more abrupt increase between ~ 4.071 and 4.049 ka BP. The latter is characterized by the most enriched $\delta^{18}O$ values over the entire record (~1.5‰ higher than the background values before the event) (Fig. 5). The timing of most significant increase in both ML.1 and ML.2 $\delta^{18}O$ values is similar to that observed in the KM-A profile (within the margin of age uncertainties) however, the amplitudes of $\delta^{18}O$ change in our records are smaller by ~0.5 ‰ relative to the KM-A profile (Fig. 5). The key difference between our and the KM-A records however, is the absence of a sharp decrease in the $\delta^{18}O$ values in ML.1/Ml.2 profiles after 3.88 ka BP, which mark the termination of 4.2 ka event in the KM-A record. In contrast, the Ml.1/Ml.2 profiles exhibit a longer-term gradual increase in the $\delta^{18}O$ values throughout the entirety of the record, punctuated by several intervals of anomalously enriched $\delta^{18}O$ values. One plausible explanation of the apparent differences between the two records could stem from partial dissolution of top most portion of KM-A sample (Fig. 5), where the most depleted $\delta^{18}O$ values were recorded. This is evident from deposition of a layer of white aragonite that apparently occurred in the recent several decades after at the top of the old portion of the KM-A stalagmite (Fig. 5), implying a possibility that the structure of the '4.2 ka event' in the KM-A record could have been altered to some extent. It is unlikely this affected the onset of the event, as it is consistent between all record, but it does suggest the event may be better described as a "regime shift" as opposed to a "pulse".

3.3 The ISM variability between 4.440 and 3.778 ka BP

A three-phase sequence of changes in the ML.1 $\delta^{18}O$ record (Fig. 6) characterize the structure of the '4.2 ka event' in the ISM domain (Fig. 6). The first phase is marked by an abrupt transition at ~4.255 ka BP from a pluvial-like condition (i.e., lower $\delta^{18}O$) to highly variable ISM (dry/wet) state that lasted for ~185 years (Fig. 6). This pattern of change in ISM is broadly consistent with other proxy records from the ISM region (e.g., Staubwasser et al., 2003; Kathayat et al., 2017). Within this phase, we infer the presence of two distinct decadal-length droughts (see Fig. 6 for definition) centered at about ~4.2 ka BP (~13 years) and ~4.175 ka BP (~10 years), respectively (Fig. 6). The second phase, between ~4070 and ~4010 years BP, is marked by persistently depleted $\delta^{18}O$ values indicating a relatively stronger ISM period of ~60 years (Fig. 6). The third phase of the 4.2 ka event in ML.1 record is marked by an abrupt

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weakening of ISM at ~4.01 ka BP inferred by ~1.0‰ shift in the $\delta^{18}O$ from -6.5‰ to -5.5‰ (Fig. 4) within ~10 years. Notbaly, this phase is punctuated by two multidecadal weak monsoon events centered at ~3.970 (~20 years) and ~3.915 (~25 years) ka BP, respectively (Fig. 6). Overall, the ML.1 record suggest that ISM was generally weaker between 3.8 and 4.0 ka BP and intermittently experienced multidecadal droughts rather than a sustained multicentennial episode of drought as commonly inferred from previous ISM reconstructions.

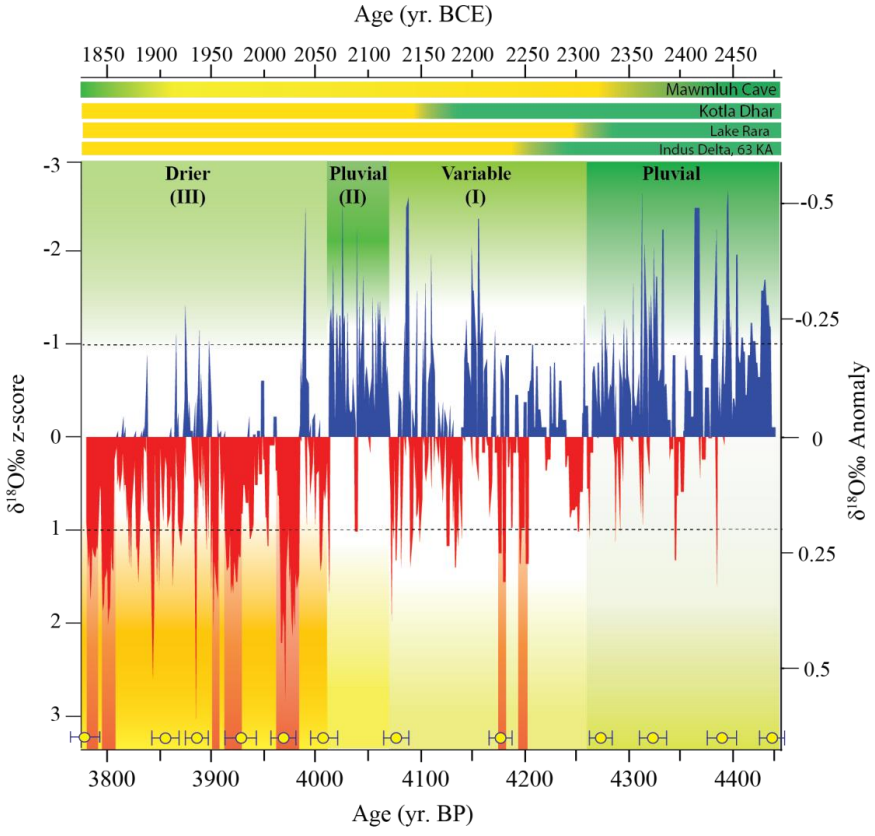

Figure 6. The inferred ISM variability during the 4.2 ka BP Event: The ML.1 $\delta^{18}O$ record is shown as z-score and anomaly (with respect to the mean $\delta^{18}O$ value of the entire record). The vertical shaded bars denote inferred periods of drier, pluvial and variable conditions. The horizontal shaded bar indicated the transition timing from pluvial to drier in other proxy records mentioned in the text (also see Figure 1). The dotted black dash lines indicate the 1 standard deviations. The vertical red bars delineate the inferred periods of the droughts (z-score > 1). The horizontal error bars show a subset of ^{230}Th dates with 2σ analytical error (for complete listing of ^{230}Th dates, see Supplementary Table 1).

4 Conclusions

The ML.1/ML.2 records from Mawmluh Cave, Northeast India provide a new record of ISM covering the period from ~4.440 to 3.780 ka BP. The record has unprecedented high-resolution (annual) and precise age control (~±13 years), thus characterizes the timing and structure of the '4.2 ka event' in much more detail. It is now evident that the '4.2 ka event' in Northeast India displays a three-phase structure: a dry (weak ISM) – wet (strong ISM) – dry (weak ISM) rhythm corresponding to the first (~4.255–4.070 ka BP), second (~4.070–4.012 ka BP) and third (~4.020–3.890 ka BP) phases, respectively as inferred from the $\delta^{18}O$ records. The new record also provides the most precise ISM variability up till now in the time range, which may potentially play a critical role in correlating and calibrating the climate variability around the '4.2 ka event' globally.

5 Author Contributions

G.K. and H.C. designed the research and experiments. GK wrote the first draft of the manuscript. H.C. A.S. and M.B. revised the manuscript. G.K., H.C. and L.X.L. did the fieldwork and collected the samples. G.K., H.C., H.W.Z., and R.L.E. conducted the ^{230}Th dating. G.K., P.Z.D. and L.H.Y conducted the oxygen isotope measurements. All authors discussed the results and provided inputs on the manuscript.

6 Competing interests

The authors declare no competing financial interests.

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8 Data and materials availability

All data needed to evaluate the conclusions in the paper are presented in the paper. Additional data related to this paper may be requested from the authors. The data will be archived at the NOAA National Climate Data Center (https://www.ncdc.noaa.gov/data-access/paleoclimatology-data). Correspondence and requests for materials should be addressed to G.K. (kathayat@xjtu.edu.cn) and H.C. (cheng021@xjtu.edu.cn).

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