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Supplementary Materials for

The Indian monsoon variability and civilization changes in the Indian subcontinent

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Other Supplementary Material for this manuscript includes the following:
(available at advances.sciencemag.org/cgi/content/full/3/12/e1701296/DC1)

- table S1 (Microsoft Excel format). The composite Sahiya Cave oxygen isotope record.
- table S2 (Microsoft Excel format). ^{230}Th dating results.

Supplementary Text

The Guge Kingdom emerged at the middle of the 10th century during the MCA period and flourished till the 16th century (Fig. 4). The kingdom was well known by a large population (~20,000), advanced techniques of metal smelting, art culture, and trade (*12–13*). The kingdom advocates Buddhism, and many versions of Buddhism were created here and which then spread into other Tibetan regions. The collapse of the Kingdom in the 17th century is rather puzzling. A religion conflict and subsequent war in 1620's were regarded as the direct cause. The arrival of a few Jesuit missionaries in 1624–1625 AD broke the long-term persistent advocation of the Kingdom to Buddhism. The missionaries were strongly supported by the king and other members of the royal family. It is speculated that too many lamas confined in Buddhism activities might have hampered the kingdom's economic and military capability, which might have changed the king's advocation from Buddhism to Christianism, and forced all lamas (~6000) to resume their secular life. As a consequence, the long-term enemy, Ladakh, invited by Guge's Buddhist leader, overthrew the king and ended the kingdom in 1630 (*12–13*). It remains a mystery why the last king, Khri-bKra-shis-Grags-pa-lde, did not tolerate lamas any longer in 1620's, just prior the kingdom demise? The lama is a very important characteristic of Buddhism system that had been dominated the Guge culture throughout its history. However, during 1620's, a weak ISM extreme event as inferred by the Sahiya record occurred between 1593 and 1623 AD (±20 years), coinciding within age uncertainties with widespread droughts and famines in North India (*28*, *52*). This event is a most severe one with the ISM reached its minimum in the past 5700 years (contemporary with NH temperature minimum), significantly worse than today's arid climate, which is uninhabitable already (Fig. 4). Evidently, this event is contemporary with the religion conflict during the 1620's within age uncertainties and we thus consider that the last king might have to abandon lamas in order to survive from the multidecadal extremely severe hydroclimate event, and the presumably weakened kingdom could no longer win the war against its long-term enemy, the Ladakh like it always did in the past.

Supplementary Figures

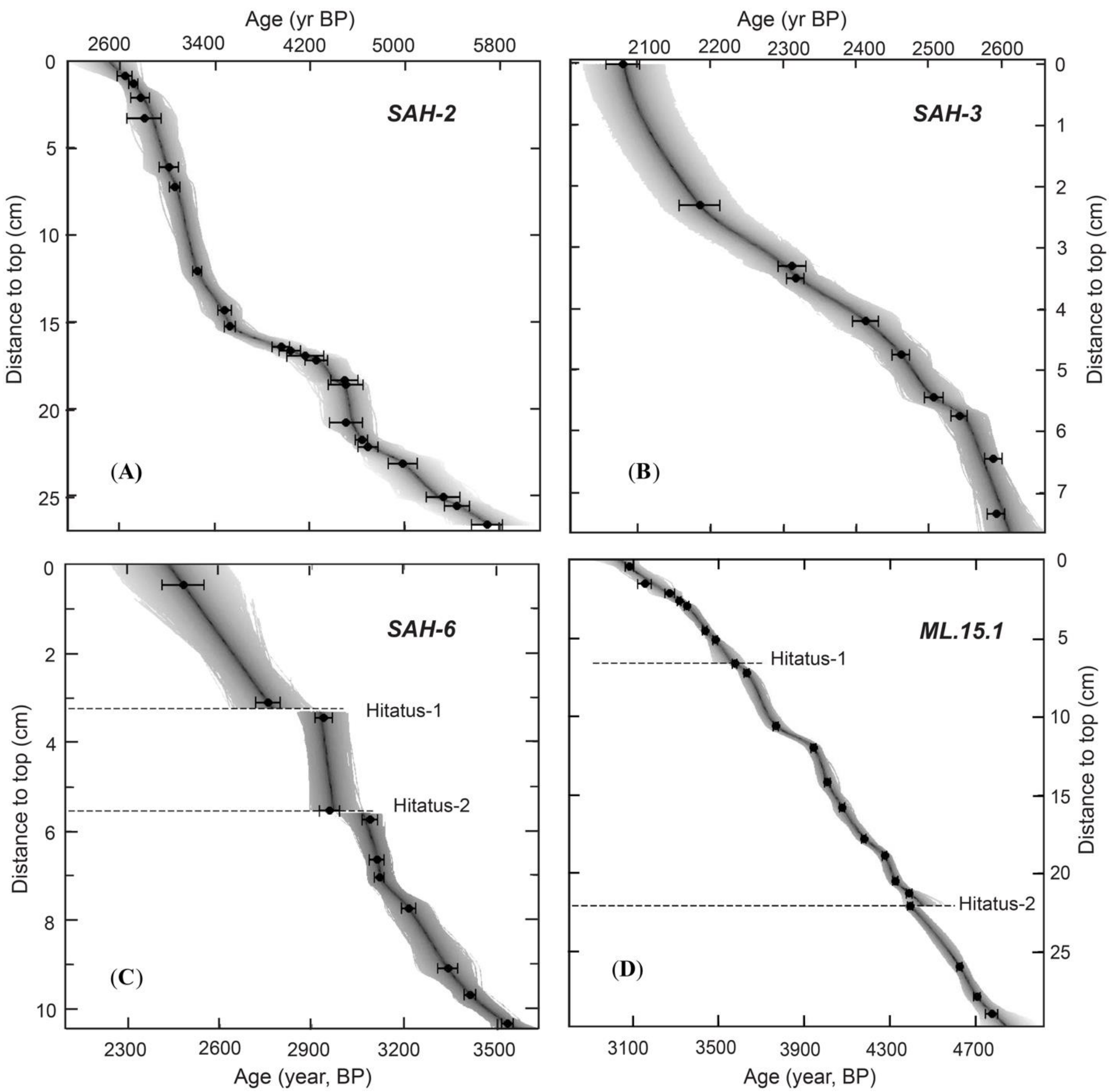

fig. S1. Age models of stalagmites. (**A**) to (**C**) are the age models for stalagmites SAH-2, 3 and 6, respectively. Age models are established by COPRA age model program (*53*). The vertical error bars depict ^{230}Th dating errors (2σ). Lengths of SAH-2; SAH-3 and SAH-6 are 26.6; 7.6 cm and 10.5 cm respectively, with two hiatus in SAH-6 at the depths of ~3.25 cm and ~5.56 cm. (**D**) The age model for stalagmite ML.15.1 from Mawmluh cave, northeast India. The length of ML.15.1 is 29.8 cm with two hiatuses at depths ~6.20 and ~21.90 cm respectively. The ML.15.1 record is comprised of total ~300 δ^{18}O data and the age model is constructed by 21 ^{230}Th dates using COPRA age model program (*53*).

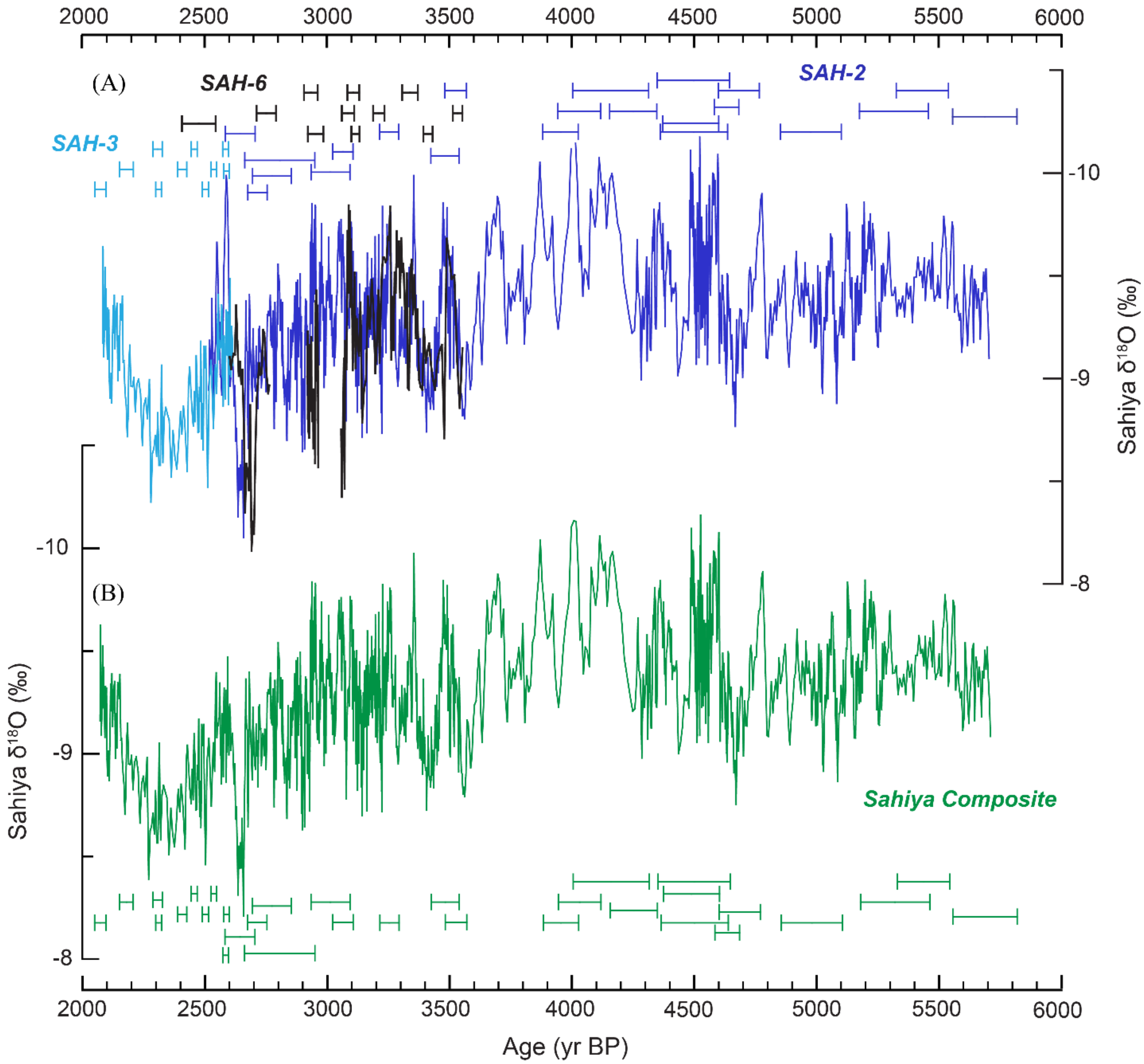

fig. S2. New Sahiya δ^{18}O records between 5700 and 2000 yr BP. (**A**) SAH-2 (blue), SAH-3 (light blue) and SAH-6 (black) δ^{18}O records, respectively. The δ^{18}O records of different samples in contemporary growth periods replicate within age uncertainties. (**B**) The composite Sahiya δ^{18}O record is constructed by combining the SAH-2 and SAH-3 records onto a common age scale. Horizontal error bars depict ^{230}Th dates and errors (2σ).

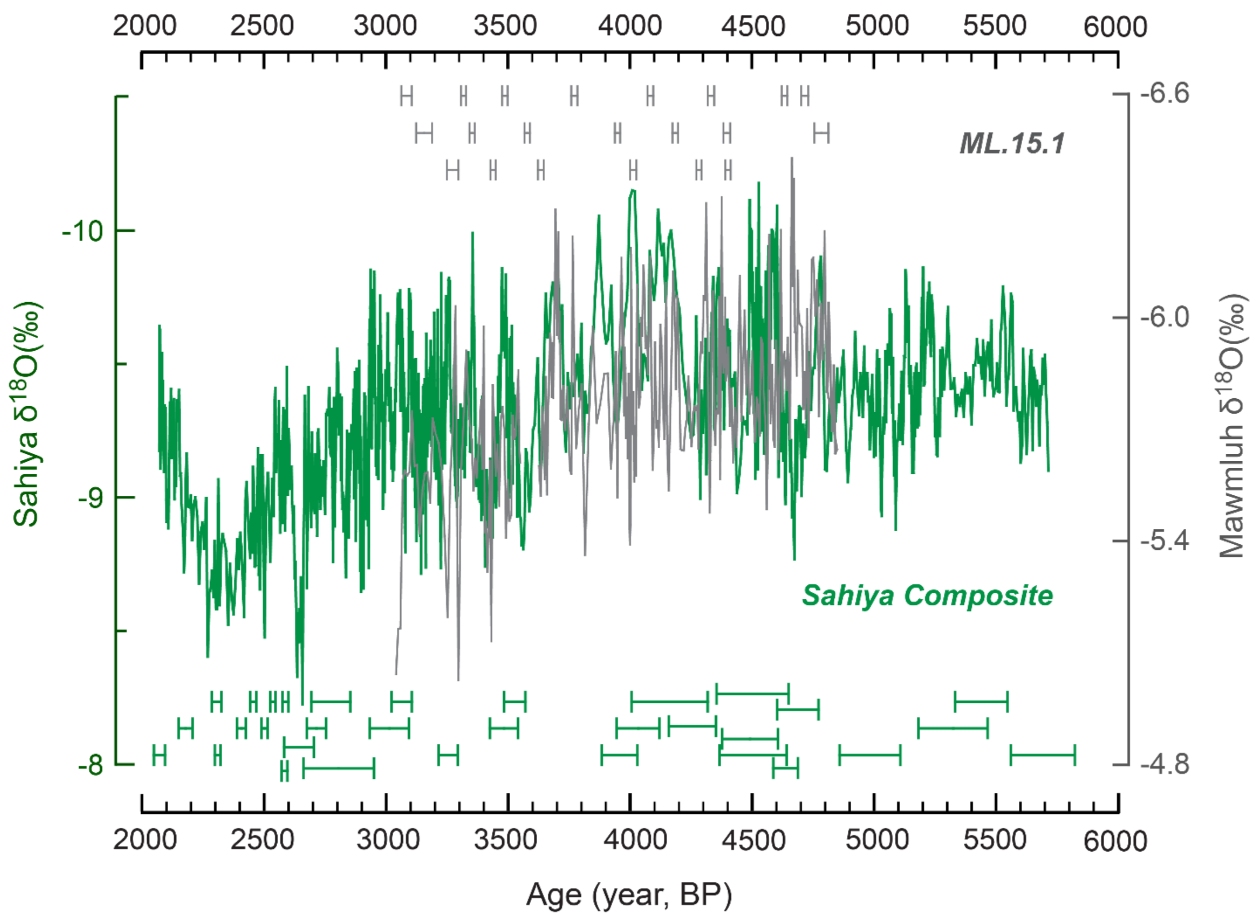

fig. S3. Comparision of the Sahiya $\delta^{18}O$ record with the Mawmluh $\delta^{18}O$ record. Mawmluh cave (25°15′44″N, 91°52′54″E, elevation 1290 m a.s.l.) is located in Meghalaya state near Cherrapunji city, in Northeast India. Green and gray curves are Sahiya composite record and Mawmluh (stalagmite ML.15.1) record, respectively. The length of ML.15.1 is 29.8 cm. The ML.15.1 record is comprised of total ~300 $\delta^{18}O$ data and the age model is constructed by 21 ^{230}Th dates via COPRA age model program (*53*). There are two hiatuses at depths of ~6.2 cm and ~21.9 cm, respectively. Mawmluh and Sahiya records show broad replications during their contemporary growth periods.

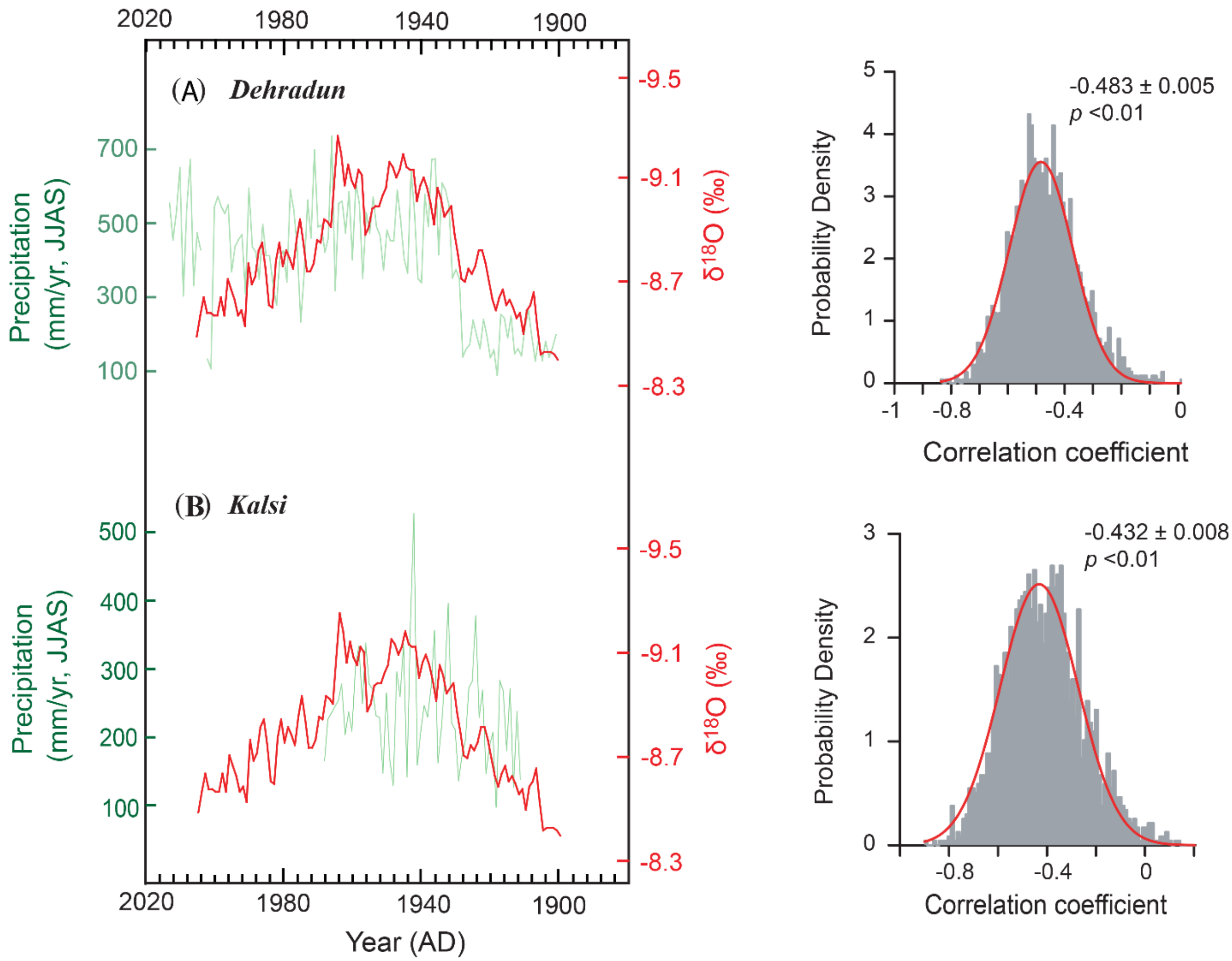

fig. S4. Comparison of the Sahiya $\delta^{18}O$ record with instrumental precipitation records in the cave area. (**A**) Comparison of the Sahiya $\delta^{18}O$ data (red, 11 years running mean) with Dehradun annual precipitation data (light green, 11-year running mean). (**B**) As same as (A), except the Kalsi precipitation data, are used. The right panel: Results of statistical analysis. Red curves are the probability density curves fitted by the Gaussian distribution. The correlation coefficients are labeled together with standard errors. The ranges of these correlation coefficients (shadow areas) generally do not cross the origin point, further demonstrating their statistical significances. We also calculate the Pearson correlation coefficients for the paired datasets (see the Method section). The Sahiya $\delta^{18}O$ not only shows a similar trend to precipitation in the cave region but also to the rainfall on the sub-continental scale (*28*).

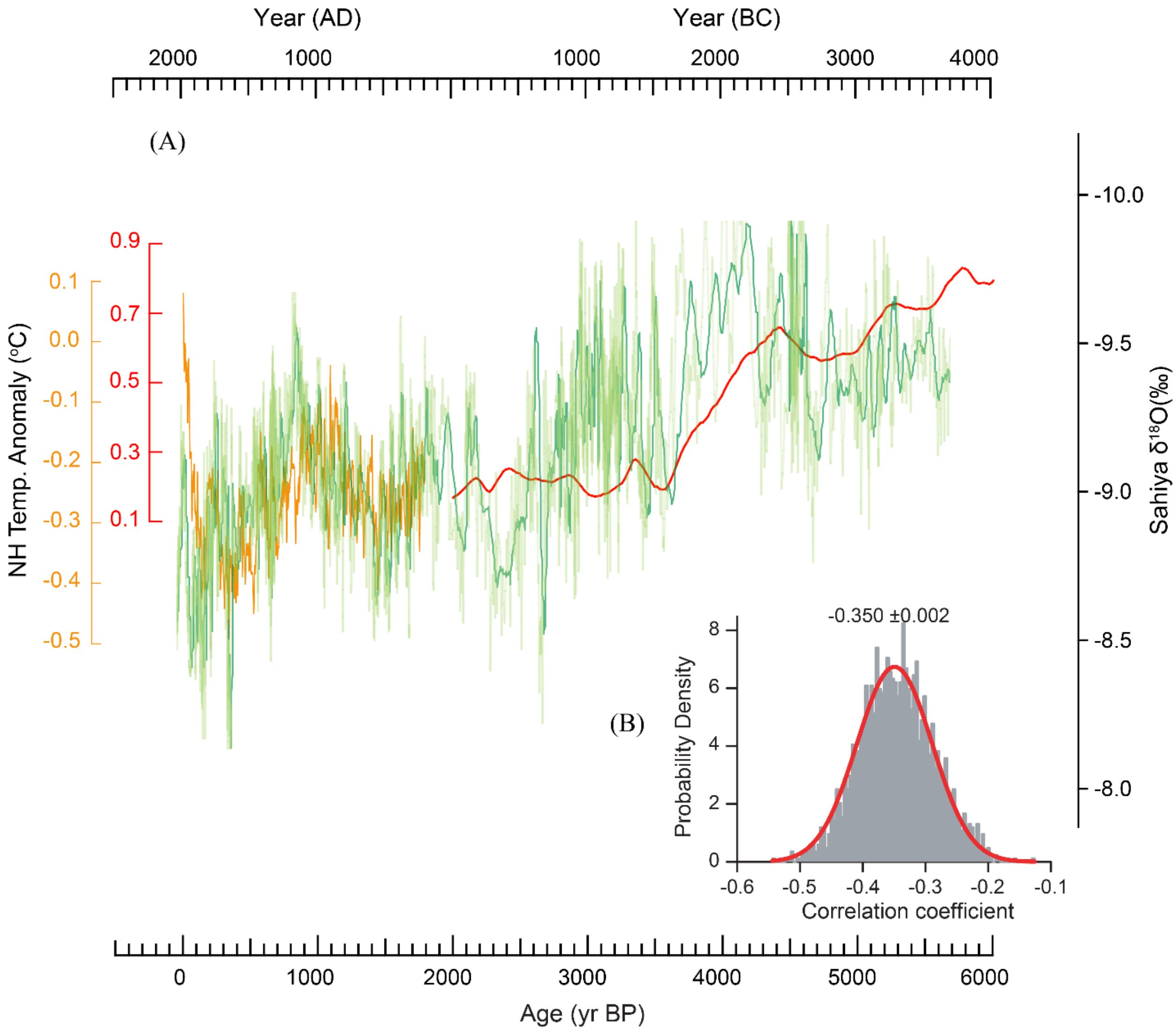

fig. S5. Comparison of the Sahiya δ^{18}O record with the proxy NH temperature reconstruction. (**A**) Comparison of the Sahiya δ^{18}O data (light green, the original data; green, 11-year running mean). The NH temperature curves are as same as those in Fig. 2. (**B**) Results of statistical analysis of the correlation between NH temperature anomaly and the Sahiya record over the last 2000 years. The red curve is the probability density curves fitted by the Gaussian distribution. The correlation coefficient is labeled together with standard errors. The ranges of these correlation coefficients (shadow areas) generally do not cross the origin point, further demonstrating their statistical significances. We also calculate the Pearson correlation coefficients for the paired datasets (see the Method section). A broad covariance is apparent between NH temperature and the Sahiya δ^{18}O record.