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The variation of summer monsoon precipitation in central China since the last deglaciation

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ABSTRACT

Two stalagmites (C996-1 and C996-2) collected from the Jiuxian Cave in the Shaanxi Province in central China have been studied with U-series dating and stable isotope analysis. Thirty-eight ^{230}Th dating results showed that the stalagmite C996-1 was continuously deposited through the last 8.5 ka BP (thousand years before present, present=1950 AD), and C996-2 was deposited through the last 19 ka BP excluding two growth hiatuses between 8.3 and 5.7 ka BP, and 15.4 and 11.9 ka BP. With a relatively stable boundary condition, we interpret the δ^{18}O of speleothem calcite as most indicative of the amount of summer monsoon precipitation, although temperature and other factors might have some minor impact. The δ^{18}O records show notable changes within the last glacial maximum (LGM), resembling other East Asian monsoon records such as those from the Hulu and Sanbao Caves, suggesting that significant monsoonal climate changes occurred in eastern Asia as far north as the Qinling Mountains during the LGM interval. A comparison of our records to precisely dated contemporaneous speleothem records from other caves shows that the increasing trend of δ^{18}O during the Holocene commenced as early as ~7.5 ka BP in the low-latitude monsoonal area, i.e. the Hoti Cave, while at higher latitudes this shift occurred later, such as ~7.0 ka BP in the Dongge Cave, ~5.3 ka BP in the Heshang Cave, ~4.7 ka BP in the Sanbao Cave and ~4.5 ka BP in the Jiuxian Cave. These results imply an asynchronous change of the summer monsoon precipitation occurred in East Asia during the Holocene. The asynchrony may be related to the responses of a coupled tropical and subtropical monsoon system to changes of the insolation and the differences in thermal forcing, which result from the complex geographical configuration. The variation of sea surface temperature (SST) in the western tropical Pacific may also have important impacts on the summer monsoon precipitation changes in central and northern China because it affects the Northwestern Pacific Subtropical High, a monsoon-front regulator. More robust tests are needed to confirm this phenomenon and to evaluate the contribution of different factors in detail.

1. Introduction

The Asian monsoon is an integral part of the global climatic system and plays a significant role in the global hydrological and energy cycles. The livelihood and well being of the monsoon societies, which include about 60% of humanity, depend on the monsoon because it provides vital precipitation for agriculture. However, the monsoon can also vary significantly, creating harmful periods of drought and flooding (Webster, 2006). Understanding the nature of Asian monsoon variability during the Holocene is essential both to understand the present climatic conditions and to predict future climatic processes. Therefore, the study of the Asian monsoon climate during the Holocene has been an area of increasing interest in the past few years (An et al., 2000; Cai et al., 2001; Chen et al., 2006; Cosford et al., 2008; Dykoski et al., 2005; Fleitmann et al., 2003, 2007; Hong et al., 2005; Peng et al., 2005; Selvaraj et al., 2007; Schettler et al., 2006; Wang et al., 2005; Yancheva et al., 2007).

Previously published high-resolution, precisely dated speleothem records and a peat record from southern China indicate that Asian summer monsoon (ASM) precipitation, an alternative to describe the summer monsoon intensity, increased shortly after the Younger Dryas (YD) at the onset of the Holocene, reached its highest level during the early Holocene, and then decreased gradually over the next several thousand years (e.g., Dykoski et al., 2005; Hong et al., 2005; Wang et al., 2005). This pattern closely follows the changes in summer insolation at low latitudes (Kutzbach, 1981) and agrees with earlier

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results from Oman, which demonstrated that the Indian summer monsoon intensity is closely linked to insolation (Fleitmann et al., 2003). Fleitmann et al. (2007) further suggested that the movement of the Intertropical Convergence Zone (ITCZ) might be the driving mechanism behind the monsoon variability.

By contrast, the variation of the monsoon precipitation during the Holocene retrieved from peat and lake sediments in northern China show different scenarios. For example, the grain size records from Lake Daihai (40°33′ N, 112°39′ E) indicate that the monsoon precipitation did not reach its maximum until 7.7 ka BP and began to decrease at 4.3 ka BP (Peng et al., 2005). The pollen assemblage zones from a terminal lake in northwestern China show that the East Asian summer monsoon precipitation optimum appeared in the early Holocene (11.6–7.1 ka BP), a dry climate occurred in the middle Holocene (7.1–3.8 ka BP) and then the summer monsoon strengthened but was weaker than that during the early Holocene (Chen et al., 2006). In addition, the comparison of peat bog records from Hongyuan in southwestern China and Hani in northeastern China indicates that the Indian and East Asian summer monsoons have an antiphased relationship (Hong et al., 2005). Although the general trends of the monsoon intensity during the Holocene are similar across China, the timing of the shifts in monsoon precipitation appears to be different in the southern and northern regions of China.

An et al. (2000) proposed a conceptual model to tie together the different climate records from monsoonal China, i.e., the Holocene Optimum, which is defined by the peak East Asian summer monsoon precipitation (effective precipitation), and noted that the Optimum was asynchronous (earlier in north and later in south) across China. They suggested that this asynchrony might be caused by the progressive decrease of Northern Hemisphere summer insolation through the Holocene. However, it seems that this model cannot reconcile the updated Asian monsoon cave records mentioned above as the cave records demonstrate that peak summer monsoon precipitation in southern China occurred in the early Holocene. Recently, Maher (2008) proposed that the differences between the speleothem records and other sediments, especially the loess profiles, might result from the fact that the speleothem isotope variations reflect changes in rainfall sources rather than in the Holocene rainfall amount. Why do we see differences between the speleothem records and the loess and lacustrine records? Were the speleothem isotope variations dominated by rainfall sources in the Holocene? To answer these questions, additional high-resolution, precisely dated records from monsoonal areas are necessary. Here, we present a high-resolution and precisely dated speleothem oxygen isotope record from the southern edge of the loess plateau in central China and reconstruct the history of monsoon precipitation in the study region since the last deglaciation. Our study aims to characterize the temporal and spatial variations of summer monsoon precipitation in China with speleothem records and to investigate the possible driving mechanisms.

2. Cave site, local climate, materials and methods

The Jiuxian Cave (33°34′ N, 109°6′ E, elevation = 1495 m) is located 5 km south of the Zhashui County Seat and approximately 85 km south of Xi'an City in central China (Fig. 1). The host rock is Ordovician limestone of the Shui-tian-ba Group. The current temperature in the cave is 10.1 °C, whereas the annual mean temperature (from 1969 to 1998) recorded at the nearest meteorological station (33°42′ N, 110°18′ E, elevation = 813 m) is 12.2 °C. The mean annual meteoric precipitation near the Jiuxian Cave is 759 mm.

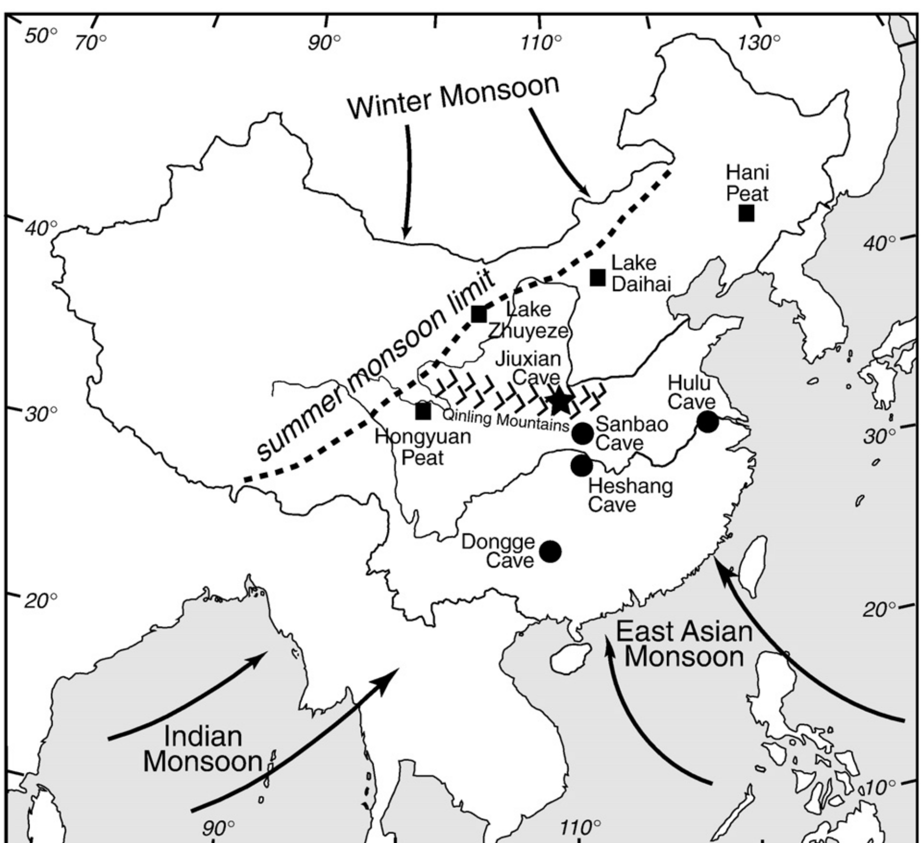

Fig. 1. The location of the Jiuxian Cave (33°34′ N, 109°6′ E) and the current monsoonal climatic system in China, including the East Asian and Indian summer monsoons, and the winter monsoon. The summer monsoon is a steady flow of warm, moist air from the tropical oceans, and the winter monsoon is a flow of cold, dry air associated with the Siberian–Mongolian High. The dashed lines represent the approximate summer monsoon limit at present. The locations of other records are also indicated.