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Anti-phase oscillation of Asian monsoons during the Younger Dryas period: Evidence from peat cellulose $\delta^{13}C$ of Hani, Northeast China

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ABSTRACT

Significant changes in the global atmospheric and oceanic circulation system occurred during the Younger Dryas cold period. Several researchers have demonstrated a weakening of intensity of the Indian Ocean Summer Monsoon during that period. However, the exact characteristics of the East Asian Summer Monsoon still remain vague. Here we present a late-glacial precipitation proxy record of the East Asian Summer Monsoon, based on the peat cellulose $\delta^{13}C$ found in Hani, Northeast China. Both the peat cellulose record and a pollen record from Lake Sihailongwan sediment indicate an abrupt increase in precipitation in the region during the Younger Dryas period. These results support the occurrence of wet conditions in the north and of dry conditions in the south of the Chinese Mainland during that period. By examining the activity of the East Asian Summer Monsoon on an interannual timescale, we propose a theory for the anomalous precipitation distribution that we attribute to the occurrence of an El Niño-like phenomenon in the Equatorial Pacific Ocean during the Younger Dryas. In this case, the intensity of the Western Pacific subtropical high may strengthen, and its position over the western Pacific Ocean may move northward. This could cause an enhancement of the East Asian Summer Monsoon and migration of a monsoonal rainbelt towards the northern region of the Chinese mainland, resulting in a precipitation distribution of wet conditions in the north and dry conditions in the south. Therefore, this anomalous rainfall distribution should be considered to indicate the strengthening of the East Asian Summer Monsoon, in anti-phase with the Indian Ocean Summer monsoon that weakened during the same period. This agrees with the previously revealed anti-phase variations of the two monsoons during the ice-rafted debris cold events of the North Atlantic Ocean. It appears that, in relation to the abrupt temperature drop in the Northern Hemisphere on centennial to millennial time scales, anti-phase variations of the two Asian summer monsoons occurred.

1. Introduction

During the Younger Dryas (YD) cold period, the global atmospheric and oceanic circulation patterns reorganized, and a series of abrupt climatic changes on centennial to millennial time scales appeared. Geological archives have revealed that since around 13 000 cal.yr BP, freshwater pulses have extended into the high-latitude North Atlantic Ocean on several occasions (Teller et al., 2002). Also, the meridional overturning circulation that crosses the equator slowed down (Rooth, 1982; Broecker et al., 1985; Knutti et al., 2004). The temperature of both the oceanic surface water and the atmosphere of the North Atlantic Ocean region decreased, and a large part of the Northern Hemisphere cooled (Bond et al., 1997; Alley, 2000; Hong et al., 2009). Meanwhile, the sea surface temperature (SST) of the middle-east equatorial Pacific Ocean tended to warm, the gradient of the SST in the equatorial Pacific Ocean decreased, and the El Niño-like pattern phenomenon appeared (Koutavas et al., 2002). During the same interval, the intensity of the Indian Ocean Summer Monsoon (IOSM) underwent an obvious abrupt weakening (Gasse et al., 1991; Roberts et al., 1993; Sirocko et al., 1996; Schulz et al., 1998). This phenomenon of global teleconnection provides a unique foundation for investigating changes in the Earth system. Several hypotheses or considerations related to the forcing mechanism for climate changes during the YD period have been presented. Examples are the hypothesis on the variation of ocean thermohaline circulation (THC) in the Northern high latitudes; the hypothesis on the driving of the ocean–atmosphere interaction in low latitudes; the variation of solar activity and the movements of the Intertropical Convergence Zone (ITCZ); and the combined effect of solar activity, THC, ENSO, and other phenomena (Bond et al., 2001; Broecker, 2003; Clement and Peterson, 2008; Hong et al., 2009).

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However, against this background of global changes, available knowledge of the East Asian Summer Monsoon (EASM) during the YD is still quite vague. Research studies examining lake sediments and loess paleosol have suggested an abrupt strengthening of the EASM during the YD interval (Kelts et al., 1989; An et al., 1993; Wang et al., 1994; Zhou et al., 1996), which means changes in the EASM and IOSM had an anti-phase relationship during this period. Conversely, other research based on marine sediments and stalagmite isotopes have indicated an abrupt weakening of the EASM during the YD, which indicates an in-phase relationship between the EASM and IOSM (Wang et al., 1999; Wang et al., 2001; Yuan et al., 2004; Huang et al., 2009). These contradictory results have aroused the concern of paleoclimate scholars. To better understand the teleconnections and the mechanism hypotheses mentioned earlier, it is essential to better clarify how the EASM strength varies, as this understanding is a weak link in global climatic change research on the YD interval.

Here, we present a high-resolution and sensitive proxy record of EASM monsoonal precipitation using Hani peat cellulose $\delta^{13}C$ from Northeast China. By comparing this proxy record with the pollen record from the sediments of Lake Sihailongwan near the Hani peat mire (Stebich et al., 2009), we demonstrate the abrupt strengthening of the EASM, indicating there was an anti-phase between the two Asian monsoons during the YD period. We also describe both the spatial variation of precipitation in the EASM domain of the Chinese mainland and a typical representative region of the EASM strength variation. These results may provide the basis for a deeper understanding of the seemingly contradictory results described previously, and the global climate teleconnection.

2. Materials and methods

Hani peat mire (42°13′ N, 126°31′ E) is located in Liuhe county in the Jilin Province of northeast China (Fig. 1), and it is close to the so-called Northern Peatlands region. The annual average temperature is about 5.5 °C and the annual mean rainfall is about 750 mm in this area. Under the effect of the EASM, the regional vegetation is a temperate deciduous broadleaf-conifer mixed forest. The major plant population in the Hani peatland is the sedge family of C_3 plants, including *Carex*, *Eriophorum vaginatum*, and *Kobresia*. The peat deposit of some thick layers on the Chinese mainland always develops in relatively stable sedimentary environments (such as Ruoergai peat at the eastern edge of the Tibetan Plateau) , or in a crater lake (Jinchuan peat in the Jilin province), or a dammed lake (Hani peat in the Jilin province); thus, the floristic composition is relatively stable in term of the peat profile. The importance of the relative stability of the floristic composition was highlighted in particular during the study of Jinchuan peat, which revealed that more than 80% of the plant residue on the profile was composed of vascular sedges of C_3 plants, while the *Sphagnum* residue took up an extremely small proportion (Hong et al., 2000). Located in southeast, Hani peatland is about 15 km from the Jinchuan peatland, which belongs to the middle–low mountain bioclimatic zone, and the peat profile is also mainly composed of the vascular sedge family plants. Since the frost period persists for around 250 days and the freezing period is over half a year, the vegetation residue in peat decomposes slowly, resulting in the formation of a thick and continuous herbaceous peat deposition in a barrier lake formed by volcanic activity.

We drilled an 8.78 m-long peat core using a Russian Peat Corer. The core sample was cut contiguously into 1 cm subsamples corresponding to a mean time resolution of around 20 yr. We used an improved sodium chlorite oxidation method to extract alpha-cellulose from the peat vegetation residues (Green, 1963; Hong et al., 2000). About 20 mg of the cellulose sample can be extracted from every 1.5 g of the dry peat sample. We conducted measurements for ^{14}C, $\delta^{13}C$ and $\delta^{18}O$ in these cellulose samples. Around 2 mg of the cellulose samples was loaded into a borosilicate tube together with preheated copper (II) oxide. After drying under vacuum conditions, the tube was sealed with an oxy-gas torch and heated in a muffle

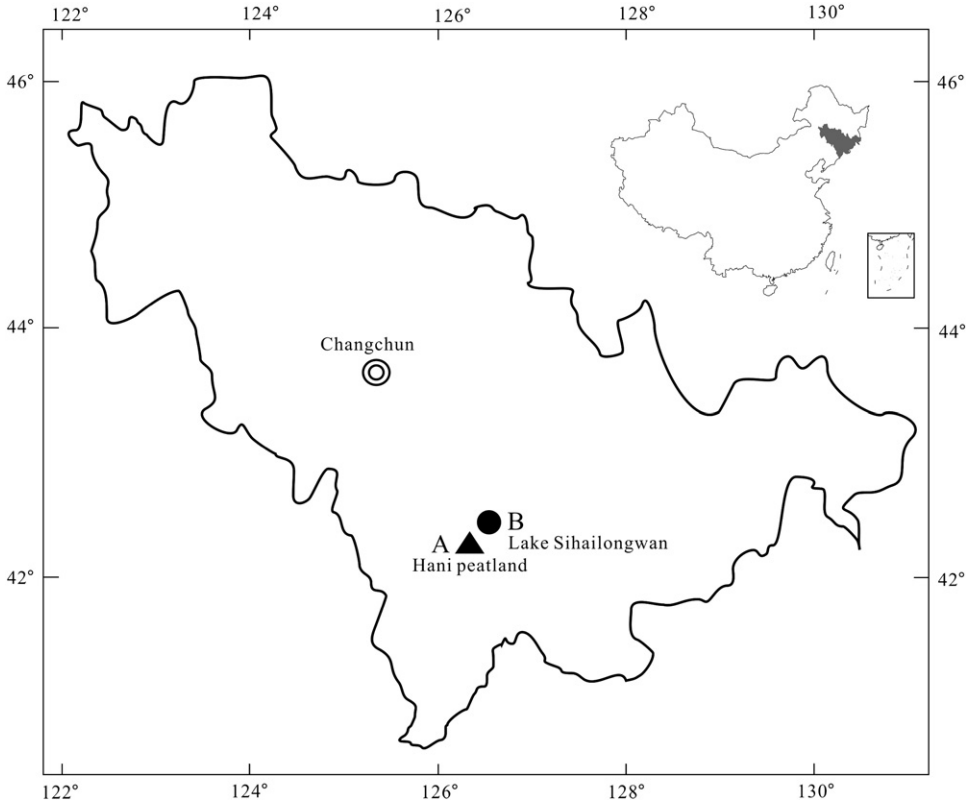

Fig. 1. Sketch map showing the location of research site. (A) and (B) indicate the location of Hani peat mire and Lake Sihailongwan in the Jilin Province, respectively. The upper right map shows the location of the Jilin Province in the mainland China.