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Pollen records of the Little Ice Age humidity flip in the middle Yangtze River catchment

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ABSTRACT

High-resolution precipitation reconstructions of the Little Ice Age (LIA) are fundamental for investigating the driving mechanisms behind hydroclimatic changes, which would provide reference for predicting precipitation change in the future. However, current precipitation reconstructions mainly focus on mean conditions during the whole LIA, little attention was paid to internal changes. Here, we present a high-resolution precipitation reconstruction based on pollen records from the middle reaches of the Yangtze River, spanning from 1300 to 2010 CE. In this study, the LIA was defined as the period of 1300–1870 CE based on PC2 value and pollen assemblage, manifest as cold interval with internal fluctuations (early-LIA: 1300-1340 CE, mid-LIA: 1340-1720 CE and late-LIA: 1720-1870 CE). Negative PC1 value during the early-LIA and mid-LIA indicated dry condition, while positive PC1 value recorded wet late-LIA. Cold interval in the early-LIA increased effective moisture by reducing evaporation, which may contribute to high content pollen concentrations and wetland herbs pollen percentage. Dry condition in the mid-LIA probably induced by warm interval by increasing evaporation and less precipitation. During the late-LIA, high content pollen concentrations and more fine-grained sediment indicate there was standing water in the bog, which was induced by heavy precipitation and cold interval. Moisture variation recorded by PC1 value and grain size distribution indicated humidity-flip between the mid-LIA and late-LIA. This humidity-flip is also supported by the frequency of flood disasters reported in historical documents. Precipitation changes during the LIA could be associated with East Asian Summer Monsoon (EASM) and El Niño-Southern Oscillation (ENSO) variability. The dry early-LIA and mid-LIA caused by the weaker EASM and more La Niña-type conditions, during which the Western Pacific Subtropical High (WPSH) weakened and retreated northeastward, leading to less Mei-yu precipitation in the Yangtze River basin. Intensified EASM and more El Niño-type events during the late-LIA lead to longer Mei-yu season along the Yangtze River and more precipitation.

1. Introduction

The term "little ice age" was first introduced to describe the phenomenon of glacial regrowth in the Sierra Nevada, California, following glacial ablation in the Holocene hypsithermal (Matthes, 1939). Most recently, the term 'Little Ice Age (LIA)' contain glaciological and climatic concept (Matthews and Briffa, 2005). The LIA glacierization is the latest mountain-glacier expansion episode during the past centuries (Matthews and Briffa, 2005) and is characterized by glacier advances in the Alps (Holzhauser et al., 2005), Iceland (Lorrey et al., 2014), the Himalaya (Kayastha and Harrison, 2008), and North America (Luckman, 2000). The glacier expansion culminated with two or three advance phases (Bilt et al., 2017; Holzhauser et al., 2005; Masiokas et al., 2009) and reached its maximum extent worldwide (Barclay et al., 2009; Harning et al., 2016; Larsen et al., 2011, 2013) during the 17th to 19th centuries

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(Solomina et al., 2016). As a result, numerous farms and villages were lost to the advancing front of a nearby mountain glacier (Mann, 2002). The LIA climate is defined as a short time interval when Northern Hemisphere temperatures dropped by about 0.5 °C compared to the instrumental record mean temperature (Mann, 2002; Mann et al., 2009; Wilson et al., 2016).

As the most recent cold period, internal climatic fluctuation during the LIA had drawn widespread attentions. Numerous studies have reached an agreement that there were sub-cold intervals (Chen et al., 2015a), which were associated with solar irradiation minimum and high atmospheric sulfate loading (volcanic activity) (Bard et al., 2000; Mann et al., 2005; Gao et al., 2008). In addition, there was spatial-temporal difference in magnitude of cooling. In China, obvious cold period with three temperature variation periods were recorded by numerous historic documents (Zhang, 1991; Zhu, 1973). Moisture variations of the LIA show distinct hydrological responses to the cold condition and have different driving mechanisms. Previous studies linked the precipitation variability during the LIA to the seasonal movement (Lechleitner et al., 2017; Haug et al., 2001) or latitudinal contraction and expansion (Yan et al., 2015; Griffiths et al., 2016) of the Inter-tropical Convergence Zone (ITCZ) mean position, El Niño/Southern Oscillation (ENSO) variability (Asmerom et al., 2013), and East Asian Monsoon (EAM) intensity (Tan et al., 2009). In China, hydroclimatic changes during the LIA showed as “West-East” and “North-South” modes (Chen et al., 2015b). Wet western part and dry eastern part in mid-latitude Asia with the boundary of modern summer monsoon limit (Feng et al., 2013), the boundary of dry northern part and wet southern part within monsoonal eastern China approximate locate at the Huai River (Chen et al., 2015b). The “northern China drought and southern China flood” pattern during the LIA is also revealed by instrumental data from weather stations (Ding et al., 2008). Unexpectedly, Heshang cave stalagmites (Hu et al., 2008) in the middle reaches of the Yangtze River record a dry LIA rather than wet one, which is inconsistent with the “North-South” mode. In monsoon-dominated southeast China, a wet LIA more likely existed in regions closer to the coast (Chu et al., 2002; He et al., 2003; Hu et al., 2008; Tong et al., 1997; Zeng et al., 2012), while a dry LIA likely occurred in inland regions (Hu et al., 2008; Tong et al., 1996). The main reason of the controversy is that those studies above mainly focus on mean hydroclimatic condition during the entire LIA period, little attention was paid to internal changes within the LIA, which are important for accurately exploring hydro-climatic fluctuations and driving mechanisms.

Palynology can reconstruct vegetation assemblages and provide insights into precipitation fluctuations during the LIA. The rapid response of vegetation communities to climate change has been recorded in many studies, with a small time lag when the sampling resolution is sufficiently high (Gajewski, 1993). Here, palynological assemblages in XiYaoHu peat bog in the middle Yangtze River were analyzed to reconstruct local vegetation communities and precipitation variations during the LIA.

2. Regional setting

XiYaoHu (XYH) peat bog (28°44′N, 115°40′E, elevation: 735 m) is in northwestern Jiangxi Province, in the middle reaches of the Yangtze River (Fig. 1A), which is the largest (surface area: $12 \times 10^3\ m^2$) and thickest (maximum depth: 3.8 m) peat bog on Mount Hsishan. Meteorological data from a nearby weather station indicate that the study area belongs to a humid subtropical monsoon climate; mean annual precipitation and temperature are 1568 mm and 17 °C, respectively, and summer rainfall accounts for 54% of the annual total (Fig. 1B).

There are various types of vegetation distributing on the mount Hsishan. At the foot of the mountain, vegetation is dominated by cultural vegetation (double rice, rapeseed and tea-oil tree forest). From the foot to the hillside, landscape is characterized by widespread scrub (*Loropetalum chinense*, *Caccinium bracteatum*, *Rhododendron simsii* scrub), grass-forb community (*Arundinella setosa* community, *Miscanthus sinensis* community) and sporadic forest (*Phyllostachys pubescens* forest, *Pinus massoniana* forest with *Loropetalum chinense*, *Rhododendron simsii*, *Cunninghamia lanceolata* forest). The area above 700 m distribute abundant grass community, swamp (*Miscanthus sacchariflorus*, *Phragmies communis* swamp, *Carex* spp., *Juncus effusus* swamp), meadow (*Carex cinerascens* meadow) and scrubs (*Salix* spp. and *Lespedeza bicolor*). The XYH bog (Fig. 1C) is dominated by widespread grass community and sporadic scrubs, meadow and swamp (Fig. 1D) (Editorial Committee of Vegetation Map of China,CAS, 1980, 2007).

3. Materials and methods

Modern pollen samples were collected from the bog surface and the surrounding hillside (Fig. 1C). A sediment core XYH was retrieved from the center of the bog using a manual sampling drill and 200-cm-long PVC tubes with a diameter of 60 mm.

^{210}Pb, ^{137}Cs, and AMS ^{14}C were used to date the sediment core. Twenty-four bulk samples were selected at 2-cm intervals from the uppermost 50 cm for ^{210}Pb and ^{137}Cs measurements (Appleby et al., 1986). ^{210}Pb dates were calculated using the CIC model, and ^{137}Cs results were used as a supplement (Manies et al., 2012). All procedures were conducted at the Nanjing Institute of Geography and Lake Science, Chinese Academy of Sciences. Six terrestrial plant macrofossils were selected for AMS radiocarbon dating and a Bayesian model was constructed to constrain the range of the calibrated ages and refine the chronology to reasonable terms (Bronk Ramsey, 2009; Valentina et al., 2014). The age-depth chronology was established by fitting spline functions using WinBacon 2.2 (Blaauw and Christen, 2011) and R statistical software (R core team, 2017).

Subsamples were extracted at 2-cm intervals and vacuum-dried samples of 1–2 g were used for pollen analysis. All samples were added a piece of *Lycopodium* spores (27560 grain/per tablet) to calculate pollen concentrations before acid-alkali treatment (Faegri and Iversen, 1989). Sample residues were in glycerine and analyzed by ZEISS microscope. All palynomorphs were identified with the reference of modern Quaternary atlas (Guan, 2011; Tang et al., 2016; Wang et al., 1995), Samples contain abundant pollen types and high concentrations, we counted at least 500 terrestrial pollen grains in each sample. We used the software Tilia version 2.0.9 to process pollen data and plot pollen diagrams. Constrained cluster analysis about non-aquatic pollen type was conducted by computer program CONISS (a FORTRAN 77 program) (Grimm, 1987). The division of palynology sequence is based on the combination of pollen assemblages and cluster analysis results.

The ratio of AP/NAP (arboreal pollen/non-arboreal pollen) (Chen et al., 2014; Deng et al., 2002; Zheng et al., 2007) were calculated to aid the interpretation of the pollen records. Principal component analysis (PCA) of the pollen taxa with a relative abundance >1% in at least one sample was conducted with Canoco 5.0 to explore the main gradient changes in the vegetation.

Grain size was determined using a Malvern Mastersizer 2000 type particle size analyzer, guided by Lu and An (1998). The grain-size distribution was then transformed into different end-members for better characterization of the depositional environments (Weltje and Prins, 2003).