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Precipitation changes recorded in the sedimentary total organic carbon isotopes from Lake Poyang in the Middle and Lower Yangtze River, southern China over the last 1600 years

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ABSTRACT

Lake Poyang, the largest freshwater lake of China, is well known for its ecological and hydrological importance as a dynamic wetland and lake system. The climatic change and its effect on ecological and hydrological system of the lake has aroused considerable interest in recent years. So, a sediment core from Lake Poyang was analyzed for δ^{13}C total organic matter (δ^{13}Corg) to study the hydrological changes in the Lake Poyang catchment. By comparing with modern meteorological data (precipitation and temperature) and hydrological data (volume of runoff), the result showed that the δ^{13}Corg values in the sediment are negatively correlated with the total runoff of the 5 main rivers supplying water to Lake Poyang and precipitation in this area over the past 50 years. Therefore, the δ^{13}Corg values of the Lake Poyang sediment can serve as reliable proxies for reconstruction of river discharge and regional precipitation, with negative δ^{13}Corg values representing increased precipitation in the Lake Poyang area. On this basis, the river discharge and regional precipitation variation in the Lake Poyang catchment over the past 1600 years were discussed. The δ^{13}Corg values suggest that the precipitation was highest in the period 340–880 AD, and then decreased with fluctuations to the minimum at approximately 1110 AD. During the period of Medieval Warm Period (1110–1350 AD, MWP), the precipitation was generally in the high level except low amount during period of 1140 AD to 1220AD. The precipitation was in low amount during the Little Ice Age (1350–1620 AD, LIA), except for a sudden increase at approximately 1550–1560 AD. The precipitation continuously increased with little fluctuation from 1610 AD until now. In general, changes in regional precipitation and river discharge were dominated by variations in the Asian Summer Monsoon (ASM) precipitation in the Lake Poyang area, consistent with other records from the ASM-controlled areas of China.

1. Introduction

The Middle and Lower Yangtze River is recognized as the cradle for the development of Chinese civilization with a flourishing rice agriculture that is strongly affected by climate change. Frequent flood/drought hazards directly threaten the food security and social stability of this area. Therefore, it is important to improve our understanding of the past and prospective changes in precipitation and to explore their factors to effectively manage water resources under the anticipated global warming in this region on a longer time-scale.

As the largest freshwater lake in China, Lake Poyang in the Middle and Lower Yangtze River, provides resources for local economic development, although multiple stressors from human actives and abiotic factors are imposed on the lake's ecosystem. Since its sensitivity to regional climate change, in recent decades, Lake Poyang has been chosen as an ideal place to investigate regional hydrological changes under climate changes at different time scales (Min and Wang, 1992; Gong, 1999; Wu et al., 1999; Ma et al., 2004; Hu et al., 2007; Guo et al., 2011; Hu and Lin, 2012; Han et al., 2015; Yao et al., 2015; Zhang et al., 2015). Multiple proxies, including grain

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size, pollen assemblage, magnetic susceptibility and TOC content, have indicated that Lake Poyang formed its water table through climatic changes 1500 years ago (Wu et al., 1999). The total organic carbon (TOC) content and its carbon isotopic compositions in Lake Poyang have been widely used to interpret paleoclimatic changes in this area because carbon isotope analysis of total organic matter from lake sediments is simple, dependable and efficient (Zeng et al., 2012; Liu et al., 2013; Lim et al., 2015). In one study, the carbon isotopic composition of lacustrine sedimentary total organic matter (TOM) from a 5 ka core was used to indicate relative changes in paleotemperature (Peng et al., 2003). One study of a long core collected from Lake Poyang suggested that the carbon isotopic composition of TOM might reflect variation in both temperature and precipitation related to the intensity of the East Asian summer monsoon since the middle Holocene (Ma et al., 2004). In these two studies, the changes of organic $\delta^{13}C$ in lacustrine sediments were frequently explained by variations in the biomass of the terrestrial plants and the related climatic changes in the catchment based on the hypothesis that the sedimentary TOM was generated from terrestrial sources in the Lake Poyang area (Peng et al., 2003; Ma et al., 2004). However, this hypothesis remains uncertain because little information was available regarding the carbon isotopic significance of TOM in modern Lake Poyang (Wang et al., 2014a, b).

To study the modern processes, carbon and nitrogen isotopes of surface sediments and suspended matter were used to determine the organic carbon sources of surface sediments in Lake Poyang (Wang et al., 2014a, b). The results of the studies showed that the C_3 plant is the main organic carbon source of suspended matter, and the terrestrial soils carried by the river water are the main organic carbon source of surface sediment in Lake Poyang (Wang et al., 2014a, b). However, the previous results were based on the carbon isotopic composition of total organic matter from lake sediment cores, and little information is available regarding the environmental significance of the carbon isotopic composition of total organic matter in modern lakes. The climatic implications of the carbon isotopes of TOM in the lake sediments are worthy of further study.

In this study, we evaluate the climatic significance of the carbon isotopes of TOM from the lake-sediment from Lake Poyang in the Middle and Lower Yangtze River zone, assisted by modern meteorological (precipitation and temperature) and hydrological data (volume of runoff) collected over the past 50 years, and water discharge of 5 rivers around Lake Poyang over the last millennium based on numerical simulation (Gao et al., 2015) and the organic carbon records from a sediment core. On this basis, the precipitation variability in the Middle and Lower Yangtze River recorded by the total organic carbon isotopes of a sedimentary core from Lake Poyang was reconstructed to better understand the local hydrological changes and their forcing factors in the monsoon-dominated southeastern region of China during the last 1600 years.

2. Study sites

Poyang Lake (28°22′–29°45′N, 115°47′–116°45′E), the largest fresh water body in China, is located in northern Jiangxi Province, south of the Yangtze River (Fig. 1). It is a graben-type basin formed by the rifting of the South China anticline during the late Mesozoic as a result of the Yanshan tectonic movement. The lake covers an area of ca. 3900 km^2 and reaches its maximum water depth of 21 m during the rainy season, which normally lasts from April to September. During other parts of the year, the lake is generally less than 10 m deep. Several rivers contribute sediment to the lake, of which the Ganjiang River system is the most important (Fig. 1). Because Poyang Lake is slightly higher than the Yangtze River, the Poyang Lake water normally flows into the Yangtze, except during the flood stage of the river. The catchment runoff from the five main rivers plays a primary role in influencing the lake water level and the development of severe floods, whereas the Yangtze River plays a complementary role of blocking outflows from the lake (Hu et al., 2007).

The climate of the region is humid subtropical and is strongly influenced by the East Asian monsoon. The mean annual temperature is 18 °C, with a mean maximum temperature of 37 °C in July and a mean minimum temperature of −3 °C in January (Guo et al., 2008; Yao et al., 2015). The July and January mean temperatures are 29.6° and 5.0 °C, respectively. Annual precipitation is approximately 1528 mm, with most of the rain falling between April and September, and the average surface evaporation is 1044 mm. Poyang Lake is in the northern vegetation subzone, also referred to as the mixed deciduous-evergreen forest subzone, of the subtropical evergreen broad-leaved forest region of China (Hou, 1988). The characteristic tree taxa of the northern subzone are mostly deciduous species of Quercus, along with Castanopsis (e.g., *C. eyrei*, *C. sclerophylla*), Liquidambar (sweetgum), Tilia (linden), and Ilex (holly). Several species of bamboos (e.g., *BambusaandPhyllostachys*) are native to the region (Hou, 1988). Today, much of the deltaic plain of the Ganjiang River and the southwestern coast of Poyang Lake are under cultivation (mostly rice) or covered by herbaceous plants and cultivated trees.

3. Materials and methods

Lake Poyang has unique water environment characteristics, namely, a river in the dry season and a lake in the wet season, with high fluctuation of the water levels. The site of the core used to study the hydrological changes is very important because the water table undergoes large changes in Lake Poyang. Because Lake Poyang is a river-type lake and the deeper lake water has higher water fluidity along the river channel, a shallow water site was chosen in a sub-basin, where the water's fluidity is relatively steady. In general, changes of the water depth at the selected site (approximately 2–3 m) are smaller than the average varied annual water depth of the Lake Poyang (over 10 m) because the altitude of the bottom sediment is high at this site. It is important that the selected site was always covered by water, and the sediment has been rarely disturbed by human activity according to our investigation from local people. Two long sedimentary cores were retrieved in August 2013 from the eastern sub-basin of Poyang Lake at a water depth of approximately 2 m (29°9′N, 116°25′E; Fig. 1). Although the cores were collected in August, the water table was still not very high (the average lake level of Lake Poyang was only approximately 15.3 m in August 2013, which was largely lower than normal value of 17.2 m) due to lower precipitation (70% less than normal) and high temperature at this time period. One of the approximately 770 cm long sedimentary cores (PYC13-3) was used in this study. The entire core was continuously sub-sampled at 1 cm intervals in the top 500 cm. The upper ~300 cm sediments mainly consisted of green-brown mud with no obvious sediment bedding, whereas there was a general alternation from mud to silty sand at the depth intervals of ~300–500 cm.

The total organic carbon of seven samples, including two terrestrial wood fragments and five sediments, were measured by radiocarbon dating by acceleration mass spectrometry (AMS) at the Beta Analytic Laboratory (Florida, USA) and Xi'an AMS Center, China (Table 1). All samples for radiocarbon dating were treated chemically according to the standard acid-alkali-acid procedure based on the labs' analytic standard pretreatment protocols. The reservoir effect (560 ± 30 years) of old carbon was calculated from the offset in radiocarbon ages between paired sediment (301 cm depth) and terrestrial wood fragments (302 cm depth) collected from almost

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