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Pollen evidence for a mid-Holocene East Asian summer monsoon maximum in northern China

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ABSTRACT

There is a controversy regarding whether the high precipitation delivered by an intensified East Asian summer monsoon occurred during the early Holocene, or during the middle Holocene, especially in the context of the monsoonal margin region. The conflicting views on the subject may be caused by chronological uncertainties and ambiguities in the interpretation of different climate proxies measured in different sedimentary sequences. Here, we present a detailed record of the Holocene evolution of vegetation in northern China based on a high-resolution pollen record from Dali Lake, located near the modern summer monsoon limit. From 12,000–8300 cal BP, the sandy land landscape changed from desert to open elm forest and shrubland, while dry steppe dominated the hilly lands and patches of birch forest developed in the mountains. Between 8300 and 6000 cal BP, elm forest was extensively distributed in the sandy lands, while typical steppe covered the hilly lands and mixed coniferous–broadleaved forests expanded in the mountains. Our pollen evidence contradicts the view that the monsoonal rainfall increased during the early Holocene; rather, it indicates that the East Asian summer monsoon did not become intensified until ~8000 cal BP in northern China. The low precipitation during the early Holocene can be attributed to the boundary conditions, i.e., to the remnant high-latitude Northern Hemisphere ice sheets and the relatively low global sea level.

1. Introduction

The East Asian summer monsoon is an integral part of the global climate system (An, 2000), and is the most important moisture source for East Asia (Webster et al., 1998). In the context of continuing global warming, understanding the processes and mechanisms of the East Asian summer monsoon are essential for predicting future hydrological and ecological changes in this climatically sensitive region, especially in the monsoonal margin area in northern China. Over the past few decades there is an increasing availability of climate proxy records that reflect variations in the East Asian summer monsoon during the Holocene. However, two conflicting views regarding the timing of the monsoonal rainfall maximum have emerged: 1) That the monsoonal rainfall was intensified since the onset of the Holocene (e.g. Zhou et al., 2002; Feng et al., 2004; Jiang et al., 2006), and 2) that it did not become significantly intensified until the middle Holocene (e.g. Xiao et al., 2002, 2004, 2006; Wen et al., 2010a,b; Li et al., 2014; Chen et al., 2015; Liu et al., 2017). These contradictory views may be the result of chronological uncertainties and ambiguities in interpreting climate proxies obtained from different sedimentary sequences.

Recently, Goldsmith et al. (2017a,b) reconstructed the lake-level history of Dali Lake (Fig. 1) based on the dating of lake beach ridges and sediment outcrops, and concluded that the lake level was high, reflecting high rainfall, during the early and middle Holocene. We have reconstructed the vegetation evolution of the Dali Lake area during the past 12,000 years based on a high-resolution pollen record, with the aim of revealing the Holocene history of rainfall variations in northern China and improving our understanding of the processes and mechanisms of the East Asian summer monsoon. Our findings conflict significantly with those of Goldsmith et al. (2017a,b).

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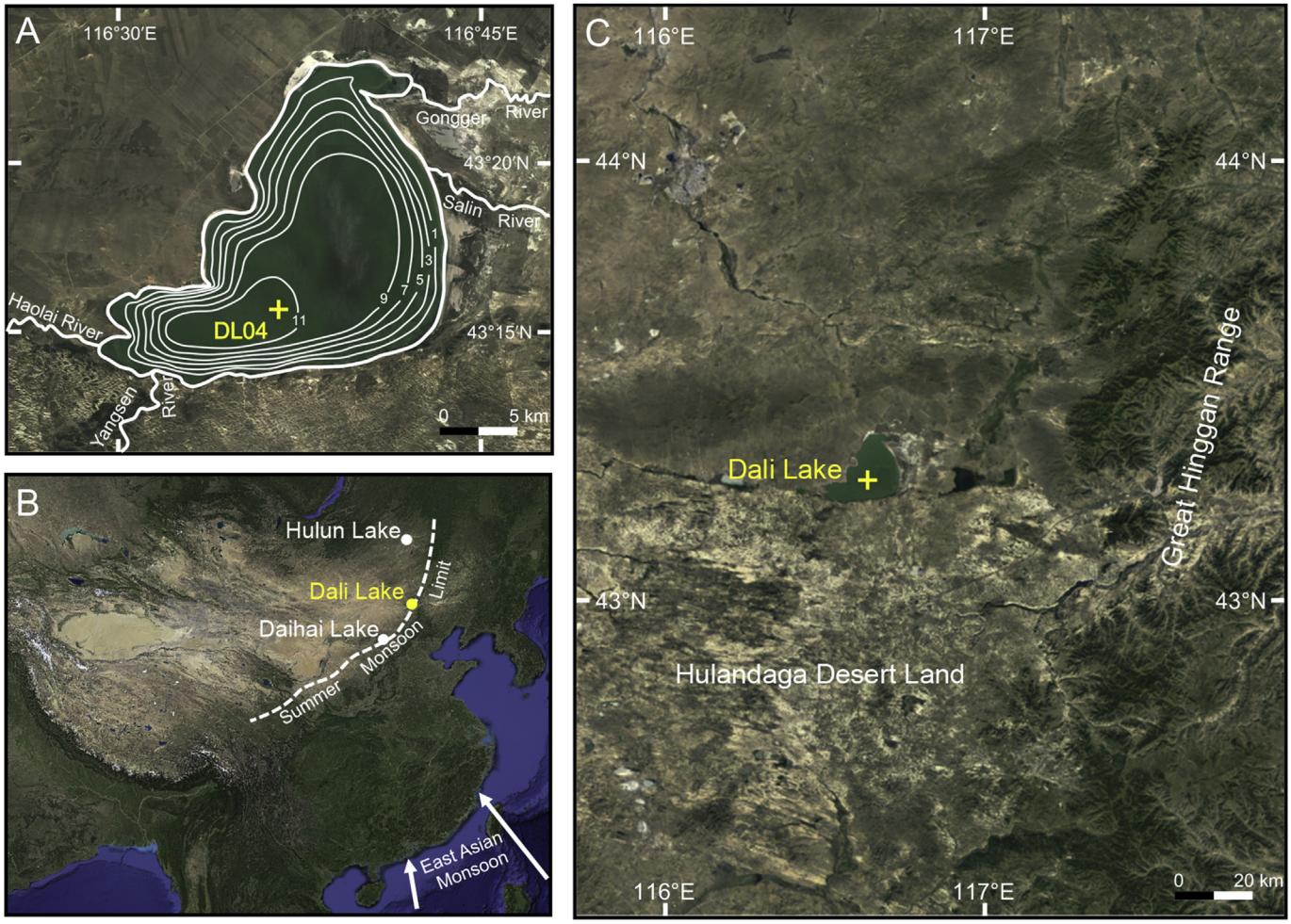

Fig. 1. (A) Map of Dali Lake showing the location of sediment core DL04. The bathymetric survey of the lake was conducted in June 2002 with a FE–606 Furuno Echo Sounder (contours in meters). (B) Map of East Asia showing the current northern limit of the East Asian summer monsoon and the locations of lakes mentioned in the text. (C) Map of the Dali Lake region. Dali Lake is on the northern margin of the Hulandaga Desert Land. Hills composed of basaltic rocks surround the lake to the north and west, and lacustrine plains are present along the eastern shore. The Great Hinggan Range is located 100 km east of the lake. All the satellite image maps are from http://www.earth.google.com.

2. Dali Lake and its environment

Dali Lake (43°13′–23′N, 116°29′–45′E), an inland closed-basin lake in central-eastern Inner Mongolia, China, has an area of 238 km^2, a maximum water depth of 11 m, and an elevation of 1226 m above sea level. The lake is fed by four rivers, among which the Gongger River is the most important and supplies 75% of the total inflowing water (Compilatory Commission of Annals of Hexigten Banner, 1993) (Fig. 1A).

Dali Lake is located near the northern margin of the current monsoon region (Compilatory Commission of Physical Geography of China, CAS, 1984; Zhang and Lin, 1985) (Fig. 1B). The area has a mean annual temperature of 3.2 °C, with a July average of 20.5 °C and a January average of −16.7 °C. Mean annual precipitation is 392 mm, and 66% of the annual precipitation falls in June–August. Mean annual pan evaporation reaches 1624 mm (Fig. 2).

The modern natural vegetation of the Dali Lake basin is categorized as middle temperate steppe (Compilatory Commission of Vegetation of China, 1980; Inner Mongolia–Ningxia Integrated Survey Team, CAS, 1985; Compilatory Commission of the Vegetation Map of China, CAS, 2007). Drought tolerant shrubs such as *Salix gordejevii*, *Ulmus pumila*, *Caragana stenophylla* and herbs such as *Artemisia desertorum*, *Agropyron cristatum*, *Agriophyllum squarrosum* grow in the Hulandaga Desert Land to the south of the lake, and grassland dominated by *Stipa grandis*, *Leymus chinensis*, *Cleistogenes squarrosa* is developed in the northern and western hilly lands and on the eastern lacustrine plains. Mixed coniferous–broadleaved forest composed of *Picea koraiensis*, *Larix*

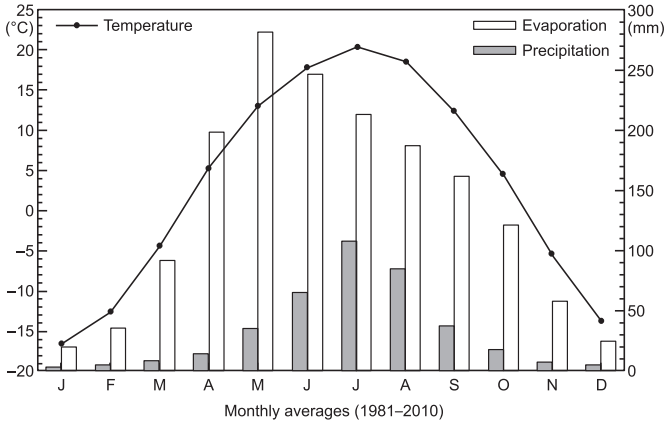

Fig. 2. 30-y monthly averages of temperature, precipitation and evaporation for 1981–2010 at Hexigten Banner Meteorological Station, 70 km east of Dali Lake (unpublished data courtesy of the Inner Mongolia Meteorological Bureau).