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Late Holocene environment of subalpine northeastern Taiwan from pollen and diatom analysis of lake sediments

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ABSTRACT

We used multi-decadal pollen and diatom records from sediment core TFL-1 from Tsuifong Lake to reconstruct the vegetation dynamics and hydroclimate in northeastern Taiwan during the past 3500 cal BP. Coarse grained sediments in association with higher percentages of wetland pollen (Cyperaceae) and upper conifer pollen (*Tsuga* and *Pinus*) in the lower part of the core indicate low lake levels and a relatively cold/dry climate between 3500 and 2030 cal BP, reflecting a decline of the East Asian summer monsoon (EASM). Muddy sediments coupled with reduction of wetland pollen represent the rise of lake levels, implying the re-strengthening of the EASM during the past 2000 years. Paleotemperature was inferred from the variation of pollen origin from the upper and lower mountain forest, indicating the global temperature anomalies of the Medieval Warm Period (MWP) and the Little Ice Age (LIA). In comparison to the main climate forces in the North Pacific, we suggest that the long-term climatic trend in Taiwan was controlled by variations in EASM intensity, while increased precipitation over the past 2000 years may also be linked to warmer sea surface temperature (SST) of the western Pacific Warm Pool (WPWP) and increased El Niño-Southern Oscillation (ENSO) events, which increased typhoon intensity. Higher diatom-inferred pH during 2930–2030 cal BP and the LIA suggest strong hydrological disturbances, reflecting more typhoons passing over Taiwan. The frequent typhoon events could be linked by an abrupt shift of typhoon track, due to the reduction of the WPWP and expansion of the Northwestern Pacific High, which move typhoons in a more westerly direction.

1. Introduction

The East Asian summer monsoon (EASM) and typhoon systems of the West Pacific have significant effects on the region's hydroclimate. The summer monsoon precipitation is an important factor for food production and maintaining ecosystem biodiversity. Its anomaly often induces extreme flooding or droughts in the world's most populated area (Zhang et al., 2011). Typhoons are one of the most extreme natural hazards and a major cause of forest ecosystem disturbances (Ito, 2010), catastrophic landslides (Tsou et al., 2011), and organic carbon transportation at tectonically active margins (Kao and Liu, 1997; Goldsmith et al., 2008) across the regions. A clear understanding of historical EASM and typhoon activities and regional precipitation-related variations is urgently required to improve future predictions of climate change.

Paleo-EASM studies from stalagmite, and marine and lacustrine sediment records revealed that EASM strength closely followed changes in long-term boreal insolation change, showing a continuously decreasing trend in association with drier climate in the low-latitude regions of East Asia since the late Holocene (~4500 cal BP) (Laskar et al., 2004; Selvaraj et al., 2007; Wang et al., 2014a; Yuan et al., 2004). Some monsoonal records derived from subtropical and tropical regions suggested that the return of EASM rainfall during the past 2000 years cannot be explained by Holocene summer insolation in the northern Hemisphere (Zhao et al., 2013). The spatial variations in precipitation represent the characteristics of regional climate, which are mainly affected by monsoon variations.

In recent years, studies on typhoon have focused on the variations in typhoons intensity, frequency and track on the

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intra-seasonal to inter-decadal scales using observational datasets over a 30 year period (Tu et al., 2009). Typhoon strength is generally linked to equatorial sea surface temperature (SST) (Lin et al., 2009), and the shift of typhoon tracks in the West Pacific is affected by the El Niño-Southern Oscillation (ENSO) phenomenon (Tu et al., 2009). However, studies on paleo-typhoons as well as their influences on the local hydrology and forest ecosystems are rare, especially those from the late Holocene period (Chen et al., 2012; Wang et al., 2014b).

The Medieval Warm Period (MWP) and Little Ice Age (LIA) are multi-centennial-scale temperature anomalies with global signatures during the past 1000 years. The MWP is characterized by relative warmth while the LIA is characterized by pronounced cooling (Mann et al., 2009). Although there are several regional differences, the temporal ranges of the MWP and LIA could be defined as 950–650 cal BP and 550–50 cal BP, respectively (IPCC, 2013). However, during both intervals, precipitation changes there were significant regional variations in precipitation changes (Chen et al., 2015; Hurrell, 1995).

Since Taiwan, is an island located near the North Pacific/Eurasia boundary, it is close to the turning track for most West Pacific typhoons, which is strongly influenced by EASM (Fig. 1). Paleoclimate records from lacustrine sediments have been shown to be useful in detecting EASM trends and typhoon activities (Chen et al., 2012; Wang et al., 2014b). Due to the high erosion rate and frequent occurrences of typhoons and earthquakes, undisturbed high-resolution late Holocene records are very rare in subalpine Taiwan (Chen et al., 2009; Liew and Huang, 1994). Selvaraj et al. (2012) first reconstructed the high-resolution climate variations using elemental and isotopic data from the sediments of Emerald Peat Lake (also known as Tsuifong Lake, TFL) in NE Taiwan. The intense precipitation during ~3730–2030 cal BP that was inferred using a geochemical proxy from the TFL record is contrary to most published late Holocene palynological reconstructions of Taiwan (Lee and Liew, 2010; Liew et al., 2014, 2006; Liew and Huang, 1994; Wang et al., 2014a). Further research is required to understand the contradictions between pollen and geochemical proxies, which will allow for an improved understanding of late Holocene precipitation patterns for Taiwan and potential links to typhoons and the EASM.

Pollen records are considered one of the most useful indicators for determining the decadal impacts of climate change on land ecosystems (Tinner and Lotter, 2001). Diatom analysis is also a constructive tool for establishing hydrological conditions. Because of methodological limitations in previous studies, the vegetation history and climate pattern in Taiwan during the late Holocene period remains incomplete and controversial. Taking this uncertainness and importance of climate trends in Taiwan into account, we used pollen and diatom records from well-dated TFL lake sediments to reconstruct reliable vegetation history and hydrological changes for the last 3.5 ka. We compared our results with the established paleoclimatological proxies in the North Pacific to examine whether variations in EASM strength and typhoon activities are relative to known climate forces during the Holocene epoch.

2. Study site

The TFL (24°30′N, 121°36′E, 1840 m above sea level (a.s.l.)) is a subalpine, hydrological-closed, seepage lake in northeastern Taiwan (Fig. 1). The lake is recharged mainly by precipitation, runoff and groundwater input from small catchments. The climatic condition of the area is mainly affected by subtropical monsoon system with a mean annual temperature of 12.5 °C (ranges from 3.3 to 17.9 °C), and a precipitation of 362 mm (ranges from 117 to 788 mm) based on records from the Taipinsan weather station (24°30′N, 121°31′E, 1810 m a.s.l.). Bedrock components of this lake

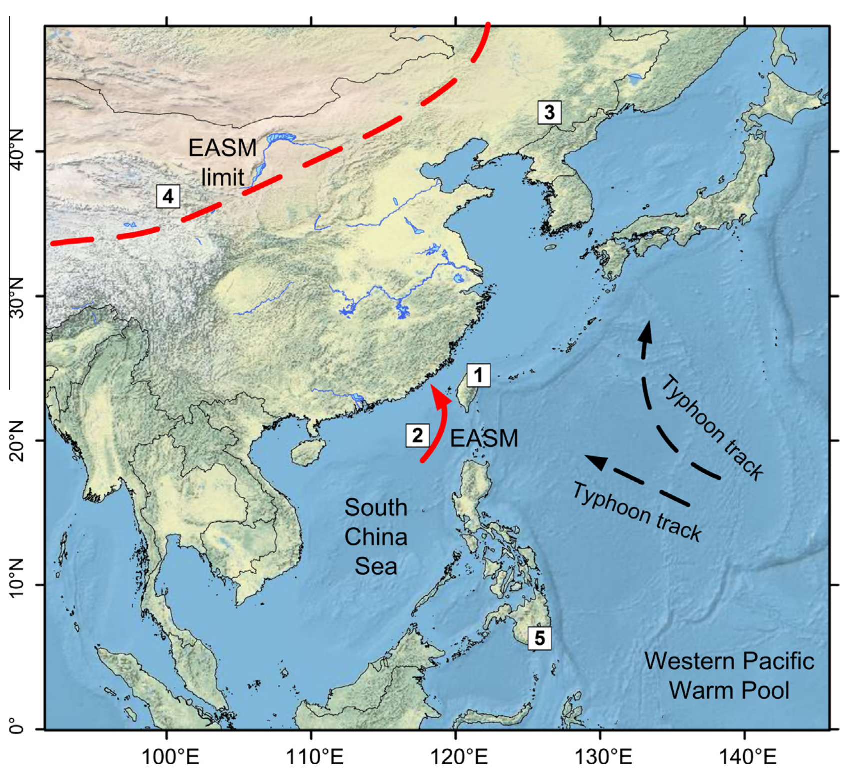

Fig. 1. Important climate features of Taiwan and the location of Tsuifong Lake (TFL). Locations (black squares) are denoted as follow: (1) TFL; (2) marine sediment core 17,940; (3) Hani peat bog; (4) Lake Qinghai; (5) marine sediment core MD982141. EASM = East Asian summer monsoon.