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Relationship between early summer precipitation in Japan and the El Niño-Southern and Pacific Decadal Oscillations over the past 400 years

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The El Niño–Southern Oscillation (ENSO) appears to strongly influence East Asian Summer Monsoon (EASM) rainfall, but the relatively short instrumental rainfall record hinders the development of a longer-term understanding of this teleconnection. To partially overcome this issue, here we reconstruct precipitation from tree-ring oxygen isotopes ($\delta^{18}O$) in central Japan during AD 1612–1935. Our results indicate that tree-ring cellulose $\delta^{18}O$ is significantly correlated with May–June (MJ) precipitation, allowing us to investigate the link between the EASM summer rainfall and ENSO over the past 400 years. Time- and frequency-domain comparison of the tree-ring $\delta^{18}O$ record and recent ENSO reconstructions reveal a common high-frequency (3–8 year) variability that characterized the mid-17th, late 18th and late 19th centuries. Similar analyses of instrumental MJ precipitation and several ENSO indexes during the 20th century indicate that this high-frequency oscillation reappeared from AD 1980. Comparison of ENSO and Pacific Decadal Oscillation (PDO) indexes indicates that the ENSO–EASM teleconnection is strong when ENSO variance is high, and the PDO phase may modulate the ENSO–EASM relationship over the past 400 years.

1. Introduction

Understanding the East Asian Summer Monsoon (EASM) system is of societal relevance because anomalous EASM activity can lead to severe floods or droughts. Previous work has identified the El Niño–Southern Oscillation (ENSO) has a potentially important controlling factor for the EASM (e.g., Wang et al., 2000; Wu and Wang, 2002). In turn, analysis of the instrumental precipitation records indicates that the Pacific Decadal Oscillation (PDO; Mantua et al., 1997) may influence the strength of the relationship between the EASM and ENSO as anomalous EASM rainfall is often observed when the PDO and ENSO are in-phase (e.g., positive PDO/El Niño, or negative PDO/La Niña; Chan and Zhou, 2005; Yoon and Yeh, 2010; Feng et al., 2014). This is potentially linked to the different influences of the two oscillations on the intensity of the subtropical high (Chan and Zhou, 2005), PDO-modulated fluctuations of extratropic summer rainfall (Yoon and Yeh, 2010), or perhaps El Niño duration controlled by the effect of PDO phase on tradewind strength (weaker during positive phase) (Feng et al., 2014).

Given the short duration of the instrumental temperature and precipitation records, Paleoclimate proxy-based environmental

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reconstructions are needed to better understand the longer-term variations in PDO-modulation of the ENSO–EASM teleconnection. Several studies have reconstructed both ENSO history throughout the Holocene (e.g., Cobb et al., 2003, 2013; McGregor and Gagan., 2004; Li et al., 2011, 2013; McGregor et al., 2013). Coral oxygen isotopes ($\delta^{18}O$) indicate that ENSO variance during the early 17th and late 20th centuries was abnormal relative to the past 7 ka (Cobb et al., 2013). Similarly, PDO reconstructions also reveal variability over several hundred years predating the instrumental record (e.g., D'Arrigo and Wilson, 2006; Shen et al., 2006; Felis et al., 2010). Shen et al. (2006) presented an annual PDO reconstruction based on Chinese historical documents from 1470 to 1900, revealing five warm PDO phases occurred in 1512–1542, 1607–1640, 1681–1723, 1784–1825, and 1859–1880.

However, reconstruction of the EASM at annual resolution in East Asia is complicated by several factors. Speleothem $\delta^{18}O$ (e.g., Shen et al., 2010) and pollen assemblages (e.g., Nakagawa et al., 2006) can generally not resolve ENSO-scale variability. While tree-ring width chronologies may be an excellent archive of monsoon history during the last millennium, records from East Asia are not only extremely sparse (e.g., Cook et al., 2010), but also generally reflective of temperature, rather than precipitation (e.g., Yonenobu and Eckstein, 2006).

Tree-ring cellulose $\delta^{18}O$ is theoretically controlled by relative humidity and $\delta^{18}O$ of the source water (Roden et al., 2000; McCarroll and Loader, 2004; Sternberg, 2009), and there is negative correlation between the source water $\delta^{18}O$ and the amount of summer precipitation at mid latitudes (amount effect: Dansgaard, 1964). Generally, atmospheric water vapor at mid latitude originates from the oceans at low latitude. In this particular location, variation in $\delta^{18}O$ of precipitation primarily reflects changes in relative humidity because $\delta^{18}O$ of the source water is relatively stable (e.g., Yokoyama et al., 2011). This has allowed for the successful reconstruction of precipitation from tree-ring cellulose $\delta^{18}O$ at multiple East Asian locations, including northern Vietnam (Sano et al., 2012), northern Thailand (Zhu et al., 2012), northern Laos (Xu et al., 2011, 2013a), southeast China (Xu et al., 2013b), and southwest China (Liu et al., 2012).

In central Japan, Yamaguchi et al. (2010) presented a tree-ring cellulose $\delta^{18}O$ series from AD 1612–1756 that was supplemented by additional analyses of discontinuous years between 1938 and 1998. Here we report new cellulose $\delta^{18}O$ results that extend the continuous portion of this central Japanese record from AD 1757–1935 and examine the influence of ENSO on the hydroclimate over the past ~400 years. This is the longest ENSO-scale record from this region, extending well into the pre-anthropogenic era and providing context from which to interpret the shorter instrumental record. This allows us to consider whether the observed recent PDO-modulation of the EASM–ENSO teleconnection is a recent phenomenon, perhaps related to anthropogenic change, or a more persistent feature of the tropical climate system.

2. Material and methods

2.1. Tree-ring $\delta^{18}O$ measurement

We measured cellulose $\delta^{18}O$ on the same Japanese cedar (*Cryptomeria japonica*) as Yamaguchi et al. (2010), which was acquired from the Muroji temple in Nara (34°32′N, 136°02′E, 405 m a.s.l.; Fig. 1) and previously dated by Miyahara et al. (2004) via a combination of dendrodating (ring-width pattern matching) and identification of the AD 1964 $\Delta^{14}C$ "Bomb peak". α-cellulose was directly extracted from a wood plate using the "plate method" after Xu et al. (2011). Individual growth rings were separated from the α-cellulose plate from 1757 to AD 1935, after which widths became too narrow to continuously separate individual growth rings. These samples (0.2 mg) were wrapped in silver foil for duplicate $\delta^{18}O$ measurements by both a continuous flow High Temperature Conversion Elemental Analyzer (TC/EA) and a Thermo Finnigan MAT 253 mass spectrometer at the Tokyo Institute of Technology. The α-cellulose was converted to CO gas at 1450 °C. The measurement uncertainties calculated by repeated analyses of a working standard (Merck cellulose) were less than 0.3‰. The oxygen isotope ratios are expressed as $\delta^{18}O = ((^{18}O/^{16}O)_{sample}/(^{18}O/^{16}O)_{standard} - 1) \times 1000$ (‰), in which the standard for oxygen is Vienna Standard Mean Ocean Water (VSMOW).

2.2. Meteorological data

Precipitation data from three stations in central Japan confirm the reliability of tree-ring $\delta^{18}O$ as a summer monsoon rainfall proxy. These data were obtained from the Japan Meteorological

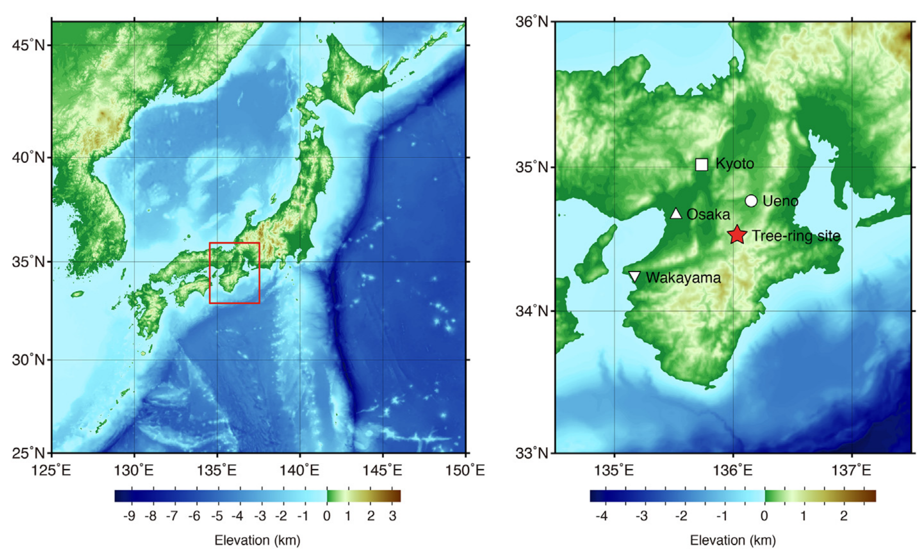

Fig. 1. Map of central Japan showing the tree-ring site and meteorological stations (Osaka, Kyoto, Wakayama and Ueno). Symbols indicate the tree-ring site (red star), Osaka (upward triangle), Kyoto (square), Wakayama (downward triangle) and Ueno (circle) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).