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The 225-year precipitation variability inferred from tree-ring records in Shanxi Province, the North China, and its teleconnection with Indian summer monsoon

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ABSTRACT

Understanding the interactions between the East Asian summer monsoon and Indian summer monsoon is a challenging task because of the insufficient proxy records. In this study, we reconstructed a 225-year precipitation record by combining ring widths of *Pinus tabulaeformis* and stable oxygen isotope ratios of *Larix principis-rupprechtii* using a multi-proxy dendroclimatology approach in the North China. The reconstructed record explained 51.9% of the variance in the observed precipitation during 1955–2003. The precipitation series could indicate the intensity of the East Asian summer monsoon. A spatial field analysis indicated that the series was strongly correlated with the reconstructed records of the surrounding area and a large part of the Indian subcontinent. The reconstructed records were significantly and positively correlated with All Indian Precipitation records ($r = 0.32$, $n = 132$, $p < 0.001$) and with a proxy of the Indian summer monsoon. These findings suggest that a persistent teleconnection exists between the reconstructed record and the Indian summer monsoon records from the past 225 years. The observed interannual synchronisation potentially resulted from the transport of partial water vapour from the Indian summer monsoon area to NC; however, this synchronisation could not be attributed to the El Nino-South Oscillation (ENSO). When considering an interdecadal time scale, the synchronisation with the North Atlantic Oscillation (NAO) has varied since 1779, implying that the NAO may serve as an additional atmospheric pattern that affects this teleconnection.

1. Introduction

The Asian Summer Monsoon system, including the East Asian summer monsoon (hereafter, EASM) and the India summer monsoon (hereafter, ISM), is important for economic development and agricultural production in dozens of countries and impacts approximately half of the world's population (Wu et al., 2012a). In the EASM area, especially in the North China (NC, between 32°–42°N and 110°–120°E), meteorologists have shown that precipitation declines when the ISM is below normal (Feng and Hu, 2004; Hu et al., 2005; Huang and Wang, 2007; Liu and Ding, 2008; Zhang, 1999). However, the dynamic mechanisms of this decline are not fully understood (Wang et al., 2003), and the above results are based on a short series of meteorological measurements (typically since the 1950s in China) that were obtained during a time of rapidly changing atmospheric chemistry (Crowley, 2000; Etheridge et al., 1998), possible unprecedented warming (D'Arrigo et al., 2006; Frank et al., 2010; Mann et al., 2008) and unusual solar activity (Solanki et al., 2004). In addition, based on observational data and numerical simulation experiments, a previous study indicated that the precipitation in the EASM area is sustained by a branch of the ISM water vapour (Wu et al., 2012a). It is unknown if such water vapour transport existed before the instrumental era.

A long-term perspective is needed to interpret the stability of the proposed links between the precipitation of NC and ISM, infer the likely mechanistic controls, and explore the implications for modelling future climate change. In the NC, a large number of tree-ring based climate reconstructions have been published in the past decades. Some temperature reconstructions (Bao et al., 2012; Ma et al., 2015) and moisture-related reconstructions (Chen et al., 2012; Fang et al., 2009; Li et al., 2006, 2007; Liang et al., 2006; Liu et al., 2010; Shen et al., 2008; Yi

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et al., 2012) have been carried out. However, few comparisons of precipitation in NC and the ISM region before instrumental measurements have been published. Additionally, only a few decades of observed meteorological records are available, limiting our ability to understand the low-frequency characteristics of the long-term relationship between precipitation of NC and ISM.

In this study, we combined tree-ring widths and stable oxygen isotope ratios from two different tree species to produce an annual resolution reconstruction of the precipitation variations in Shanxi Province, NC, since AD 1779. Next, the precipitation reconstruction was compared with the ISM index using instrumental precipitation measurements that extended to 1871 in India and a longer reconstruction of the ISM index based on coral proxies. Finally, possible forcing mechanisms of the interactions at different time scales were examined by employing large-scale atmospheric circulation indexes.

2. Materials and methods

Our sampling sites are located in the semi-arid Shanxi Province in NC. Tree rings were sampled at two sites with different hydrological conditions. The distance between the two sampling sites is only 25 km (Fig. 1). The Ningwu site is located on a dry, rocky ridge (38°50′N, 112°05′E; 1600–2100 m asl) where 37 cores were collected from 17 Chinese pine trees (*Pinus tabulaeformis*) and carefully cross-dated to build a ring-width chronology. The detailed statistical data are shown in Table S1. The effective length, where the subsample signal strength (SSS) is at least 0.75 (Wigley et al., 1984), corresponds with the period from 1779 to 2003 because of low sample depth (Li et al., 2006), whereas the Expressed Population Signal (EPS) is higher than 0.85 since 1810. The sample size and running Rbar (mean of the correlation coefficients among the samples) are also shown in Fig. S1.

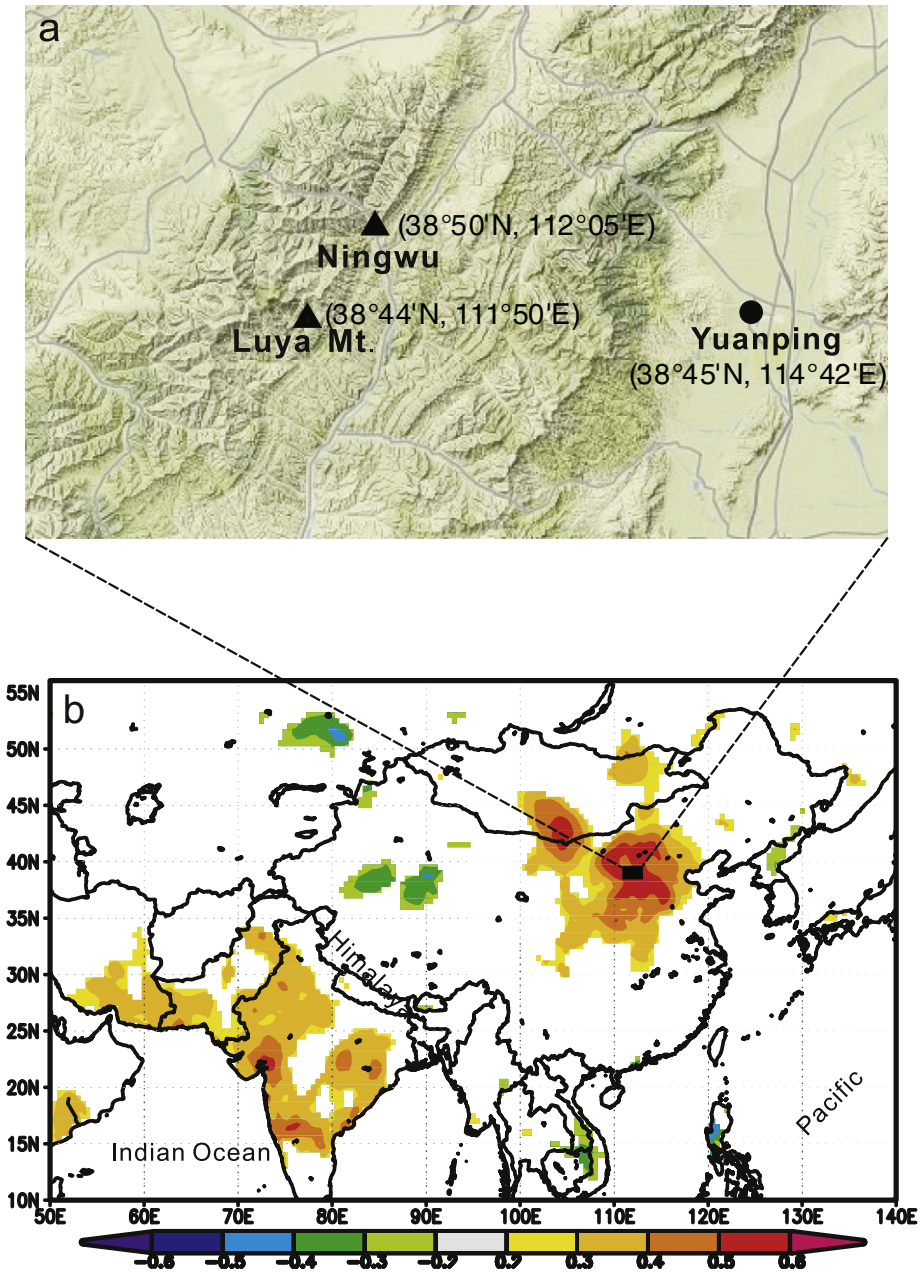

Fig. 1. Map showing the locations of the sampling sites (triangles) and the nearest meteorological station of Yuanping (circle) (a), and the spatial correlation pattern between the reconstructed precipitation with the CRU TS3 precipitation gridded datasets ($p < 0.1$) (b).