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Variations in tree-ring width indices over the past three centuries and their associations with sandy desertification cycles in East Asia

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ABSTRACT

A database of 39 annually resolved, tree-ring width chronologies covering the Mongolian Plateau, northeastern China region, and the Yellow River drainage was established to identify variations in sandy desertification cycles over the past three centuries. Our results show that the arid, semiarid, and semi-humid East Asia experienced multiple sandy desertification cycles over the past 300 years. The Mongolian Plateau experienced sandy desertification from the 1730s to the 1750s and the 1810s to the 1910s. Northeastern China region was subject to sandy desertification from the 1700s to the 1720s, the 1770s to the 1820s, and the 1830s to the 1860s. In the Yellow River drainage, sandy desertification occurred from the 1700s to the 1730s, the 1750s to the 1780s, and the 1810s to the 1850s. The occurrence of sandy desertification was closely related to weakened summer monsoon and enhanced winter monsoon associated with decreases in precipitation and increases in aeolian activity during the Little Ice Age; reversals of sandy desertification resulted mainly from increases in precipitation and decreases in aeolian activity during the Current Warm Period. The sandy desertification cycles we reconstructed have been verified by monitoring results of modern sandy desertification trends and evidence from ancient archives and archaeological records.

1. Introduction

The Mongolian Plateau (MP), northeastern China region (NCR), and Yellow River drainage (YRD), located in arid, semiarid, and semi-humid regions of East Asia, are characterized by relative low precipitation with high inter-annual variability (Huang et al., 2011). Throughout the Holocene, frequent changes in the northern limit of the East Asia summer monsoon (Zhang et al., 2008) resulted in multiple climate changes (e.g., Cook et al., 2010; Shen et al., 2007). Such climate changes impacted human inhabitants through contributing to agricultural failures (Tao et al., 2004) and economic losses (Nkonya et al., 2011), and also led to environmental degradation through dust storms (Prospero and Lamb, 2003; Qian et al., 2002; X.Wang et al., 2004b) and desertification (Sivakumar, 2007). An important environmental issue, desertification currently jeopardizes the livelihoods of nearly 200 million people (X. Wang et al., 2008; Zhu and Chen, 1994) and had significant impacts on the subsistence of historical populations. Multiple desertification cycles that occurred in these regions (e.g., Dong et al., 1995; Wang et al., 2010) affected the livelihoods of inhabitants, impacted the prosperity and led to the abandonment of ancient cities (e.g., S.C. Wang and Dong, 2001), and may have influenced the rise and collapse of ancient Chinese dynasties (e.g., Wang et al., 2010).

The Convention to Combat Desertification and the United Nations Environment Programme (UNEP) define desertification as "land degradation in arid, semiarid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNEP, 1992, 1997). The term desertification mainly relates to forms such as salinization and sandy desertification (Wang, 2013). However, in China, because the areas of sandy desertification is over 80% of the total area of desertification (Shen et al., 2001), and because the key erosive force of sandy desertification is aeolian activity (Mason et al., 2008; Wang et al., 2007), the term sandy desertification and desertification are usually taken to have the same meaning. In arid, semiarid, and semi-humid regions of East Asia, the occurrence of sandy desertification mainly includes dune reactivation, coarsening of surface sediments, the desertification of grassland, and other related processes (Zhu and Chen,

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1994), which are triggered mainly by variations in aeolian activities. In these regions the variations in aeolian activity can be caused by short-term severe moisture deficits (i.e., at decadal scale, Schlesinger et al., 1990), long-term aridity (e.g., Pickup, 1998), and the strengthening of wind activity (e.g., X. Wang et al., 2008). In addition, in arid, semiarid, and semi-humid regions of East Asia, results of previous studies (e.g., Wang et al., 2006) have shown that even in modern times, although human activities promoted sandy desertification, climatic changes have had a much greater effects, even though it is undeniable that human impacts have exacerbated those effects (Wang et al., 2006).

Owing to the remarkable differences in the landscape in arid, semiarid, and semi-humid East Asia, there are differences in the factors that control aeolian activity in these regions. For instance, in regions of northeastern China and the Yellow River drainage, desertification occurred mainly in regions covered by vegetated dunes, and increases in desertification was usually exhibited by anchored or semi-anchored dunes/sand sheets being reworked into mobile or semi-anchored dunes/sand sheets (Wang et al., 2008). In the Mongolian Plateau, the dominant landscape is steppe where only a few vegetated dunes are developed. Therefore, although aeolian activity in this region is still mainly controlled by wind activity, aeolian activity and the occurrence of sandy desertification are more sensitive to aridity and extremely low temperatures in winter (Sternberg et al., 2009).

In arid, semiarid, and semihumid East Asia, although the occurrence of sandy desertification is controlled mainly by climate change, its cycles in historical periods are still poorly understood. In these regions, historical climate change has already been reconstructed using natural proxies (e.g., Deng et al., 2006; Liu et al., 2002) or through documentary evidences (Ge et al., 2003; Song, 2000). Among these, tree-ring width records have been frequently employed as natural proxies (e.g., Cook et al., 2004; Mann et al., 1998) because of their high resolution, relatively low dating error, wide distribution, and explicit indications of climate change. Therefore, sampled tree-ring width indices from arid, semiarid, and semi-humid areas of East Asia are of significance for reconstructing the climate change of these regions. Based on an integrated analysis of 39 annually-resolved tree-ring width chronologies (Fig. 1; Supplementary material Table S1) and the association of their variations with indications of desertification, we report on the desertification cycles over the past three centuries in arid, semiarid, and semi-humid East Asia, and discuss their association with climate change.

2. Tree-ring dataset

We established a database of 39 annually resolved ring-width chronologies from the International Tree-Ring Data Bank (ITRDB) (http://www.ncdc.noaa.gov/paleo/treering.html) and from previous literature as described in the supplementary materials. All the chronologies in Mongolia were created using the ARSTAN program (Cook and Holmes, 1999) based on the raw measurements downloaded from the ITRDB, and were detrended using a negative exponential curve or linear regression. The detailed chronology creation processes and detrending methods from other regions are described in their source publications (Supplementary Material Table S1). All source data are standard chronologies except for chronologies 'cbb', 'cbpi', and 'cbc'. The source data was unevenly distributed throughout the MP, NCR, and YRD. Only those chronologies exhibiting statistically significant ($p < 0.10$) positive correlations with their adjacent aeolian activities index, calculated from instrumental meteorological records, or the relative humidity grid data from the National Centers for Environmental Prediction/ National Center for Atmospheric Research (NCEP/NCAR) (Kalnay et al., 1996) were retained for our analysis.

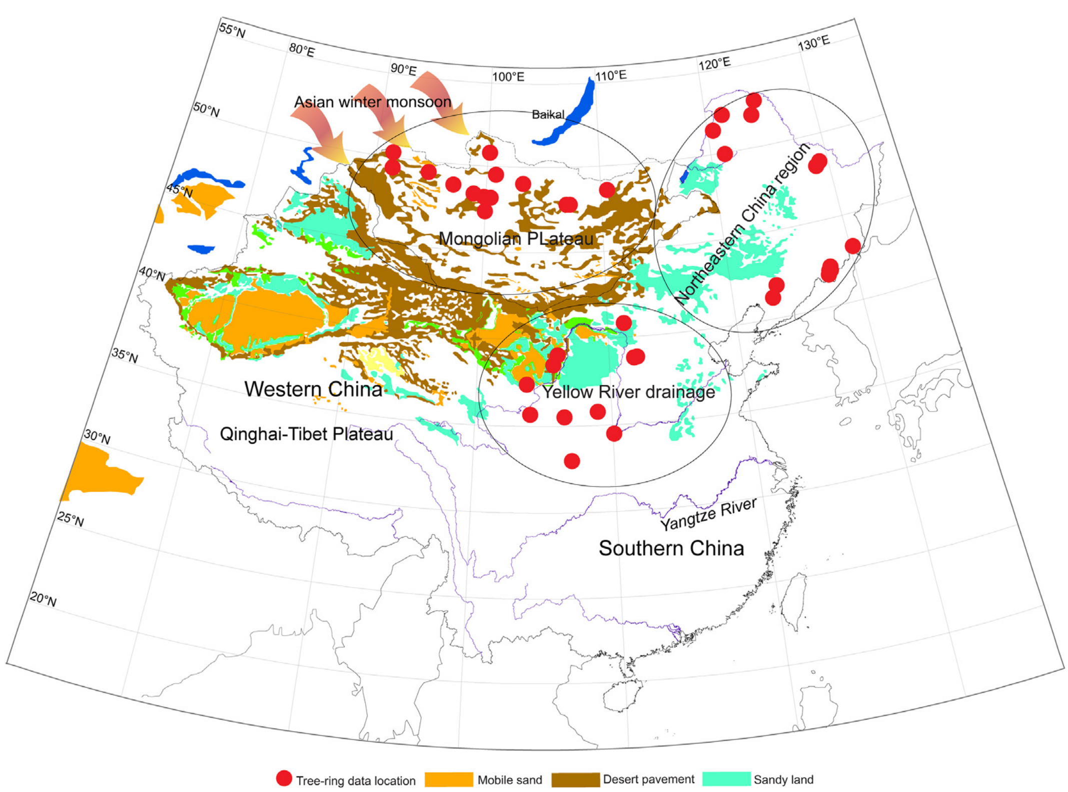

Fig. 1. Map of the Mongolian Plateau (MP), northeastern China region (NCR), and the Yellow River drainage (YRD), and sampling sites of tree-ring chronologies.