Global and Planetary Change 86–87 (2012) 45–56

Contents lists available at SciVerse ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Tree-ring based precipitation reconstruction for the forest–steppe ecotone in northern Inner Mongolia, China and its linkages to the Pacific Ocean variability

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ARTICLE INFO

Article history:
Received 15 September 2011
Accepted 17 January 2012
Available online 25 January 2012

Keywords:
tree-rings
precipitation
Hulunbei'er steppe
dryness and wetness
Pacific Ocean

ABSTRACT

We present a precipitation reconstruction for the ecotone of Hulunbei'er steppe and Great Xing'an Mountain forest region, Inner Mongolia, based on tree rings of Mongolian pine (*Pinus sylvestiris* Linnaeus var. *mongolica* Litvinov) scattered in regional sandy dune forests. The ring-width chronology shows most significant correlation with precipitation from prior August to current June. Based on this relationship, a precipitation reconstruction (1806–2007 A.D.) was developed. The reconstruction was verified with independent data, and accounts for 39.7% of the actual precipitation variance during their common period (1953–2007). The reconstruction shows a relatively wet early half of the 19th century, a reversal from generally dry conditions during the late-19th century to generally wet conditions during the early 20th century, and a drying trend in general since the mid-20th century. The driest decades are found in 1856–1865 and 1889–1898, and the wettest decades occurred in 1944–1953 and 1826–1835, respectively. Multi-decadal (≥56.8 year) and inter-annual (2.3, 4.6, 4.8, 4.9, 5.7–6.0, 9.0 and 9.1 year) cycles are also detected in our reconstruction. Our precipitation reconstruction is significantly correlated with the East Asian Monsoon and Pacific Ocean signals, such as the El Niño-Southern Oscillation and Pacific Decadal Oscillation.

1. Introduction

Climate change is strongly affecting water supplies of terrestrial ecosystems, particularly in semi-arid and arid regions (IPCC, 2007), with water surpluses and deficits all resulting from the accumulated changes in precipitation over some period (Wilhite and Glantz, 1985). Like other parts of the Mongolian plateau, Hulunbei'er steppe has been utilized for grazing over a long period of time without deterioration till the latest decades (Zou et al., 2000; Yi, 2003). Recently, an increase of dust storm frequency and grassland degeneration, associated with reduced precipitation and increased warming, has occurred in the Hulunbei'er steppe and vicinity (Song, 2004; the Report of Climate Change in Northeast China: I, 2006; Wang et al., 2010). This change in hydroclimatic variability must be placed in a long-term context, because the Mongolian plateau and vicinity have been shown to possess considerable low-frequency variability over time (Pederson et al., 2001; Jacoby et al., 2003; Liu et al., 2003b; Gao et al., 2005; Davi et al., 2006; Liang et al., 2007; Liu et al., 2007, 2010). If we are to reasonably forecast droughts, it is critical that we understand these regional rainfall patterns as well as their potential forcings.

Quantitative information about long-term moisture variability is particularly valuable in climate studies, especially in areas where few extended paleoclimatic records are available. Such is the case for the Hulunbei'er steppe region where both instrumental and historical climate records are very limited before the 1950s, particularly in the remote inland zone of nomadic culture dominated grasslands and forests (Zhang et al., 2000; the Report of Climate Change in Northeast China: I, 2006). Thus, long-term paleoclimate records for the Hulunbei'er steppe are of great value for an enhanced understanding of regional climate variability.

Tree-ring series, especially those from grassland/forest ecotone sites in the west (Davi et al., 2006), central (Pederson et al., 2001; Jacoby et al., 2003) and southeast part (Liu et al., 2003b; Gao et al., 2005; Liang et al., 2007; Liu et al., 2007, 2010) of the Mongolian plateau and vicinity, have been used for paleoclimatic reconstructions with much success. However, tree-ring research in our study region is limited, which has restricted our ability to place current climate change in its proper long-term context (Liang et al., 2007; Liu et al., 2009). This deficiency motivated the tree-ring study presented here, which presents new long-term precipitation data for regional environmental planning and large-scale climatic analyses (Jacoby et al., 2003).

Furthermore, the Pacific Ocean regime significantly affects moisture condition over much of China and vicinity (Zhang et al., 2000; Lu, 2005; IPCC, 2007), especially its characteristic modes of atmosphere–ocean circulation like Asian monsoon (Li and Zeng, 2003), Pacific Decadal

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0921-8181/$ – see front matter © 2012 Published by Elsevier B.V.
doi:10.1016/j.gloplacha.2012.01.009

Oscillation (PDO) (Mantua and Hare, 2002) and El Niño-Southern Oscillation (ENSO) (Zhang et al., 1999; Li et al., 2011). It is thus important to explore the further linkages of regional long-term rainfall variability in northern Inner Mongolia with the Pacific Ocean through these specific characters.

In this paper, we present a new tree-ring width chronology developed from Mongolian pine (*Pinus sylvestiris* Linnaeus var. *mongolica* Litvinov) located in the ecotone region of the Hulunbei'er steppe and the Great Xing'an Mountain forest area. The relationships between tree growth and climatic factors were analyzed based on tree-ring width data, and seasonal (prior August to current June) precipitation over the 1806–2007 A.D. was reconstructed. The reconstruction was compared with other reconstructions from nearby regions as well as Asia monsoon index and global sea surface temperatures to explore their potential linkages to oceanic forcings.

2. Materials and methods

2.1. Study area

The study area is located in an ecotone between the eastern boundary of Hulunbei'er steppe (sandy plain) and the western margin of the Great Xing'an Mountains, Inner Mongolia, Northeast China (Fig. 1). This region is characterized by low rainfall, extreme temperature, strong wind, high evaporation, and poor soils (Zhu et al., 2003). The region is also a dividing zone of dry/wet and cold/warm climate in northeastern China, and is a typical monsoon boundary zone (continental monsoon climate) (Yang et al., 1992). It is semi-arid or arid to the west of the mountain ranges, with the temperature and precipitation decreasing gradually from east to west. To the east of mountains, it shows a temperate climate with increasing precipitation and warming temperatures. According to the regional average of instrumental records from the Haila'er and A'ershan stations, the frostless season is only about 90 days, early autumn-/late spring-frost usually occurs at the first ten days of September/June, and the mean annual temperature is −2.1 °C during 1953–2007, with a mean annual maximum temperature of 4.9 °C and a mean annual minimum temperature of −8.5 °C. The depth of frozen ground ranges from 240 to 260 cm. The local mean annual precipitation is 398 mm. Snowcover in this region usually lasts more than 140 days in a year (from prior October to current April and sometimes from prior September to current May) and snowpack depth is about 30–50 cm, the amount of melt water from the accumulated snow accounts for 20–35% of the total annual precipitation, and the evaporation is relatively low in this season, e.g. 5.5 mm in January and 126 mm in April. In contrast, total precipitation in July and August (summer season) accounts for 48% of the annual total (Fig. 2).

Mongolian pine is a geographical variety of Scotch pine (*P. sylvestiris* Linnaeus) (Jiao, 1989). Its natural distribution includes the Great Xing'an Mountains and the Hulunbei'er sandy plain of China, as well as parts of Russia and Mongolia (46°30′–53°59′ N, 118°00′–130°08′E). Its vertical distribution is from 600 m to 2000 m above sea level (a.s.l.) (Wang and Huang, 1996; Zhu et al., 2003), and its natural distribution on sandy land includes Honghuaerji (the largest area), Hailai'er, and A'ershan areas in Inner Mongolia, where it formed a natural forest belt about 200 km long and 14 to 20 km wide on the fixed sandy dunes (Zhu et al., 2003). The top and the south face of sloping uplift belt of the undulated grassland are the favorably growing places of Mongolian pine in this region. The pine stands are open with 6–20 m between trees and occasionally present with *Betula platyphylla* and *Populus davidiana* as well. All the pine's growing sandy dunes are consist of dry and poor sandy soil with high permeability of water and low retention of moisture, e.g. the poor nutrition of the sandy soil is shown through low content of soil organic matter (1–3%), soil available phosphorous (0.01–

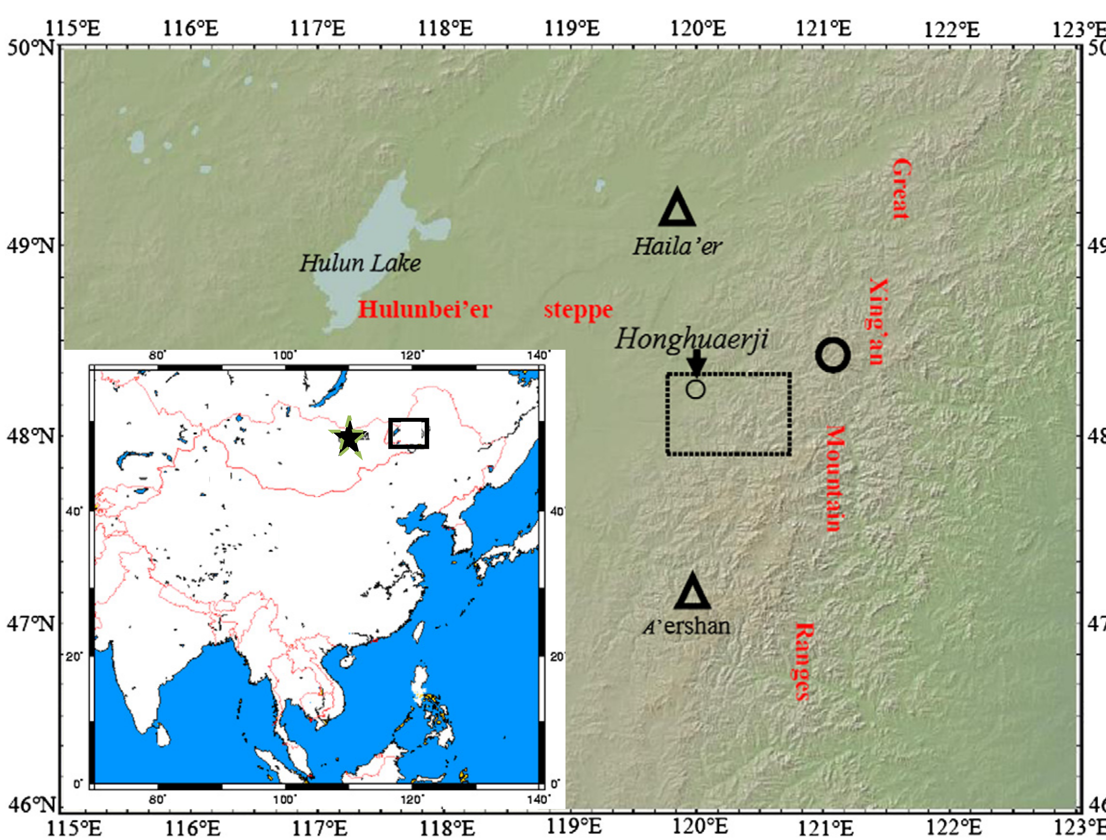

Fig. 1. Locations of tree-ring sample sites (rectangle with dashed line rim), meteorological stations (thick triangle), and gridded data PDSI (thick circle). PDSI: Palmer Drought Severity Index (Palmer, 1965). The asterisk in the low left panel of the map indicate the location of the precipitation reconstruction for Northeast Mongolia (Pederson et al., 2001).