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Tree-ring based evidence of the multi-decadal climatic oscillation during the past 200 years in north-central China

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ABSTRACT

As the northern fringe of the Asian summer monsoon region, north-central China (hereafter NCC) is highly sensitive to climate change. It is important to understand drought variability and the associated mechanisms in this region since precipitation changes have direct impacts on human society in this semiarid-arid area. In this study, a new tree ring-width based drought reconstruction (AD 1804–2010) was established in the Songmingyan Nature Reserve, which lies in NCC. This reconstruction illustrates the severe drought periods occurring in the 1860s, 1928–1932 and 1991–2000, with recurring drought intervals being about 60 years. The first principal component of the five chronologies from NCC shows strongly coherent drought variability with the other single-site records and can thus be used as an indicator of regional moisture variations. Combining the Monsoon Asia Drought Atlas (hereafter MADA) dataset and the dry-wet index (hereafter DWI) dataset from eastern China, the spatial distribution of moisture variability for three selected drought events is mapped. It is found that northern China and Mongolia experienced dry conditions during the three severe drought periods, whereas wet conditions prevailed in the middle and lower reaches of the Yangtze River. The Pacific Decadal Oscillation (hereafter PDO) might have been one of the possible causes responsible for multi-decadal drought variability over NCC, with the PDO warm phases being associated with drought conditions and the cold phases corresponding to wet conditions over NCC.

1. Introduction

Moisture variations in north-central China (hereafter NCC) are predominantly influenced by the Asian summer monsoon (hereafter ASM; Chen et al., 2008). The varying intensity of the ASM activity results in the occurrence of severe drought and floods, which impact on agricultural harvest yields in NCC and the economic wellbeing of many people. Therefore, detailed understanding of the intensity of climate change and its possible physical mechanisms over the NCC region is necessary. Based on meteorological records, previous studies have demonstrated the interconnections between precipitation variability in North China and the atmospheric circulation over the Pacific Ocean (Ma, 2007). Observational composite analysis reveal that the warm Atlantic Multi-decadal Oscillation (hereafter AMO) is linked to enhanced precipitation in the north of East China and reduced precipitation in the south (Li and Gary, 2007). However, the shortness of regional instrumental records limits the understanding of long-term drought variability and its forcing mechanisms in this area. Tree-rings are one of the most important proxy indicators for studying past climatic changes (Shao et al., 2007). A number of tree-ring studies have focused on the arid western regions of China (He et al., 2013; Yang et al., 2012a, 2013a; Qin et al., 2010, 2013). Tree-ring studies conducted in NCC have revealed climate changes during recent centuries (Fang et al., 2010; Li et al., 2007; Song and Liu, 2011). However, most of these dendroclimatological studies were conducted using single-site reconstruction. Meanwhile, new techniques of tree-ring record standardization have been developed and improved the strength of the paleoclimatic information stored in tree-ring variations (Yang et al., 2012b,c).

We have investigated regional moisture variations and their possible association with the air-sea coupling system in NCC. In this

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paper we firstly introduce a new tree-ring width chronology in Songmingyan Nature Reserve (hereafter SNR) from NCC, and identify extreme drought events recorded in tree-ring variations. Secondly, we compare our chronology to other precipitation and Palmer Drought Severity Index (hereafter PDSI) reconstructions from nearby regions to investigate regional signals of moisture variability. Thirdly, we map the spatial distribution of moisture conditions during three severe drought periods (1860s, 1928–1932 and 1991–2000) recorded in the regional tree-ring chronology using the two datasets of Monsoon Asia Drought Atlas (hereafter MADA) and the dry-wet index (hereafter DWI). Finally, multi-decadal drought variability over the NCC was analyzed by correlating the tree-ring chronologies with the Pacific Decadal Oscillation (hereafter PDO).

2. Materials and methods

2.1. The SNR sampling sites and datasets

The samples were collected in the Songmingyan Nature Reserve (102°43′ E to 103°42′ E, 35°02′ N to 35°36′ N). The SNR is situated in the eastern part of the NCC, an area of marginal ASM influence. Thus, the ecological and hydrological resources are sensitive to fluctuations in intensity of the ASM. The studied tree species is spruce (*Picea asperata*), a dominant tree species growing on south-facing mountain slopes. The vegetation at the sampling site comprises species such as *Syringa oblata*, *Caragana stenophylla* and *Artemisia gmelinii*, etc.

Three meteorological stations (Lintao, Linxia and Hezuo) are located very close to the SNR sampling areas elevations ranging from 1894 m to 2910 m. Monthly mean temperature and monthly total precipitation both peaks in July (Fig. 1). Data from Lintao meteorological station are strongly correlated with those from the Linxia and Hezuo stations. Taking into account the regional representation and maximum correlation with the tree-ring chronology, only the climatic records from Lintao were used in the further analyses. Mean annual precipitation and mean annual air temperature of the Lintao station for the 57-year period (1951–2007) are 530 mm and 7.2 °C, respectively.

The two nearest (33.75°N, 103.75°E; 36.25°N, 103.75°E) monthly PDSI (Palmer, 1965) grid-point data (2.5° × 2.5°, Dai et al., 2004, 2011) were used to investigate the combined effects of precipitation, temperature and soil moisture on the SNR tree growth during the period 1951–2010. Positive and negative values of the PDSI correspond to wet and dry conditions, respectively. We also used the PDSI dataset to analyze moisture variability in monsoonal Asia during the period 1991–2000 in this paper.

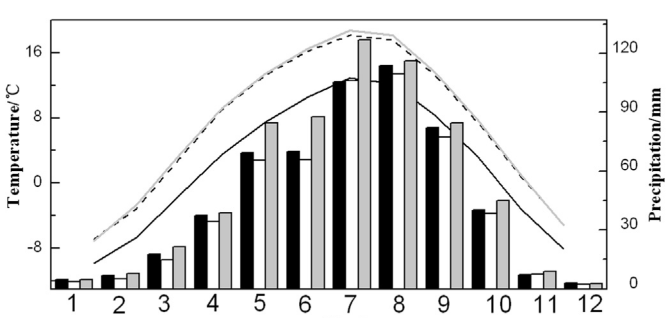

Fig. 1. Climate diagram for three meteorological stations in northern China. The gray and black lines and columns indicate temperature and precipitation at Hezuo and Linxia meteorological stations, respectively. The white columns and dashed line indicate precipitation and temperature at Lintao meteorological stations, respectively.

To study the regional moisture changes, we combined five moisture-sensitive tree ring-width series spanning the period 1804–1999 to extract the regional climate signals and discuss the regional climate mechanisms. Five tree-ring sites were selected in NCC along a belt running from northeast to southwest, as follows: Helan Mountains (Mts.; HL; Li et al., 2007), Hasi Mts. (HS; Kang et al., 2012), Xinglong Mts. (XL; Fang et al., 2009), Guiqing Mts. (GQ; Fang et al., 2010) and Songmingyan (this study). For the identification of common drought events, we used additional tree-ring sites located near NCC, namely the Kongtong Mts. (KT; Fang et al., 2012) and Changling Mts. (CL; Gao et al., 2006) chronologies, and a regional tree-ring record from the northeastern Tibetan Plateau (Yang et al., 2010).

To better understand regional climate variability, two moisture-related reconstruction datasets were used to analyze temporal and spatial variability. The DWI dataset published by the State Meteorological Administration (1981) mostly includes data from central and eastern China, which were derived from local historical documents, and are classified into five grades for each year: very wet (grade 1), wet (grade 2), normal (grade 3), dry (grade 4), very dry (grade 5). The DWI dataset can be adopted to analyze precipitation variability in eastern China for the last 500 years (Qian et al., 2012). We extracted 100 sites from the DWI dataset to analyze the moisture variation pattern in eastern China (east of 105°E) during the three drought periods recorded by tree-ring data from SNR.

The second dataset was the MADA (Cook et al., 2010) dataset, which is available at 2.5° by 2.5° resolution. It covers the past 700 years and was constructed by calibrating 327 tree-ring chronologies with 534 MADA grid points. This dataset has been used for studying spatial and temporal drought variations over the Tibetan Plateau and nearby regions (Wang et al., 2013; Yang et al., 2013b). However, the MADA dataset poorly represents drought variations in eastern China (Yang et al., 2013c). In this study, the MADA data were applied to investigate spatial and temporal patterns in the western region of monsoonal Asia (-20-60°N, 60-105°E), including a total of 347 MADA grid points. To facilitate comparison, these two datasets of DWI and MADA (hereafter MADA-DWI) were calculated to have consistent variation (for details, see Yang et al., 2013b). Positive values represent wetter conditions and negative values indicate dry conditions.

To investigate possible far-distant atmospheric influences on the moisture variability in NCC, the following data were also employed for further analysis: the PDO reconstruction (MacDonald and Case, 2005), PDO instrumental data (http://climexp.knmi.nl/) and AMO proxy (Gray et al., 2004).

2.2. Data analysis methods

Five single-site tree-ring chronologies (HL, HS, XL, GQ and Songmingyan) were subjected to a principal component analysis (Meeker and Mayewski, 2002; Yang et al., 2009) to identify the common signal of climate variations. The first PC expresses the strongest common component or the dominant similarity shared by the data and has broad scale spatial representation.

We processed the tree-ring data, AMO proxy and PDO index using a band-pass filter in the 50–70 year range.

2.3. The SNR chronology development

The SNR tree-ring data comprise 72 tree-ring cores extracted from 50 living trees in October 2010 at altitudes from 2540 to 2737 m a.s.l. To avoid the effects of tree competition within the tree population, the samples were taken from isolated living trees growing on steep slopes or cliffs. Wood cores were air dried and mounted on grooved sticks with the transverse surfaces facing up