Dendrochronologia 42 (2017) 73–79

Contents lists available at ScienceDirect

Dendrochronologia

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

Warm-induced aridification in eastern Inner Mongolia evidenced by tree rings

Bo Sun[a,b], Yu Liu[b,c,d,*], Ying Lei[b], Lingxia Guo[a]

[a] School of Resources, Environment and Historical Culture, Xianyang Normal University, Xianyang, China
[b] State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, China
[c] Joint Center for Global Change Studies (JCGCS), Beijing, China
[d] School of Human Settlements and Civil Engineering, Xi'an, Jiaotong University, Xi'an, China

ARTICLE INFO

Article history:
Received 29 November 2016
Received in revised form 19 January 2017
Accepted 26 January 2017
Available online 31 January 2017

Keywords:
Tree ring
Relative humidity
Warm
Drought
Eastern Inner Mongolia

ABSTRACT

To explore the relationship of long-term drought variations with climate warming, the relative humidity from April to September (RH_{49}) in eastern Inner Mongolia was reconstructed based on tree-ring width over the past 135 years. There was also good correlation between the ring-width index and the average April–September temperature at a low frequency. The dry and wet periods in the reconstruction generally coincided with other nearby reconstructions and corresponded with warm and cold periods, respectively, indicating that the low-frequency reconstruction could reflect decadal temperature variations in the study area. It was also found that there was significant correlation between RH_{49} and temperature on decadal scale, while for RH_{49} and precipitation, they correlated well on annual scale. Temperature dominates the trend in RH_{49} at low frequency, and precipitation affects the annual variations. The profound drying trend since 1950 AD in the study area resulted from a large warming component, which outweighed the slight reduction in precipitation. In addition to the land surface temperature influencing drought conditions via water evaporation, the sea surface temperature of the Pacific Ocean may also have affected drought conditions in the study area by dominating water vapor sources. Therefore, temperature is the main cause of regional drought tendencies.

1. Introduction

Drought occurs more frequently in north China under global warming conditions. Studies have noted that the weakening of the East Asian monsoon pushes the monsoon rain belt southward and contributes to the drought (Wang, 2006; Cook et al., 2010), although the latest research has shown that under the background of global warming, the East Asian summer monsoon rain belt will move northward, which will bring more precipitation to north China (Yang et al., 2015). However, when evaluating dry-wet conditions in a region, precipitation is not the only factor to consider. Precipitation and evaporation are two important parameters of the surface water budget, and temperature has a significant influence on evaporation. For example, as one index of drought, the Palmer Drought Severity Index (PDSI) is more closely related to precipitation in some places (Cook et al., 2010; Fang et al., 2010; Liu et al., 2016), while it is more closely related to temperature in other places (Song and Liu, 2011; Cai and Liu, 2013; Cai et al., 2015), indicating that the intensification of evaporation due to changes in temperature will lead to drought conditions. In the context of global warming, increased temperatures result in increased surface evaporation, which may aggravate drought conditions (Dai et al., 2004; Dai, 2011; Briffa et al., 2009; Zhai et al., 2009), and warming has become an important factor for droughts (Zhang and Chen, 1991; Zepp, 1994; Ma and Fu, 2001).

Climatic studies based on tree-ring information have been conducted for the eastern part of Inner Mongolia, showing that tree-ring data can represent the drought variations in this area (Bao et al., 2015; Liu et al., 2015; Sun et al., 2016); drought in this area may be related to the Pacific Ocean and the Indian Ocean (Bao et al., 2015; Liu et al., 2015). For drought itself, this climate variable relates closely with temperature and precipitation. And it is an integrative reflection of many climate factors especially temperature and precipitation. Thus, the study of the occurrence and development of drought should be considered connecting local temperature and precipitation variations (Ma, 2005; Ma and Ren, 2007), rather than

* Corresponding author at: The State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710061, China.
E-mail address: liuyu@loess.llqg.ac.cn (Y. Liu).

http://dx.doi.org/10.1016/j.dendro.2017.01.006
1125-7865/

just considering the relationship with large-scale climate circulations. The effects of large-scale climate circulations on drought are relatively indirect, while the influence of the temperature and precipitation is more direct. Therefore, compared to previous tree-ring based drought studies, which have primarily speculated on relationship of drought with large-scale external forces, this study intends to reconstruct relative humidity (RH) based on tree-ring width samples, and focus on local temperature and precipitation to explore their role in drought variations in eastern Inner Mongolia, a typical monsoon marginal area which has ecological vulnerability and climate sensitivity in China, so as to provide a scientific basis for the long-term strategy of coping with drought for the study area.

2. Materials and methods

Tree-ring samples in this study were collected from the Baritu forest farm in eastern Inner Mongolia, where the largest forest of sandy *Scotch pine* (*Pinus sylvestris* var. *mongolica*) is located in China. The sampling site was denoted by BRT2 (119°29.617′E, 47°50.391′N, 842 m a.s.l.) and is located at the west side of the Da Hinggan Mountains. In total, 43 cores were collected from 26 trees, with two cores taken from one tree in most cases. And only a few trees were taken just one core due to difficulties in sampling. It is characterized by a temperate continental climate (Sun et al., 2016), with long-cold winters and short-cool summers. The sunshine here is abundant, and the rainfall is more concentrated in the July and August (Wang, 1990). Meteorological data (temperature, precipitation and RH) were preliminarily selected from the Hailar and Arxan stations near the sampling site (Fig. 1). From the monthly distribution of climatic data from the two stations, high temperatures and precipitation occur primarily in June, July and August, and RH exhibits a W-type distribution, with two valleys in May and October (Fig. 2).

Tree ring samples were fixed, dried and sanded to a smooth surface. Cross-dating (Stokes and Smiley, 1996) was carried out to ensure that every growing ring has an exact calendar year. Each annual ring was then measured within 0.001 mm, and quality control was done by the COFECHA program (Holmes, 1983). Ring width chronologies were established using the Arstan program (Cook and Kairiukstis, 1990). To eliminate tree-age related growing trends and inconsistent disturbances among trees, and to minimize the removal of any long-term climatic variance, conservatively negative exponential functions or linear regression were selected to fit each individual ring-width measurement series. The detrended index series were then combined into a single chronology using a biweight robust estimate of the mean and three kinds of chronologies were obtained, standard (STD), residual (RES) and arstan (ARS). A preliminary analysis indicated that the correlation coefficients between the standard (STD) chronology and meteorological data were higher than the residual (RES) chronology. Therefore, accounting for the better responses to climatic factors and a greater low-frequency signal, the subsequent analysis was based on the STD chronology. The longest tree-ring series spanned 211 years (1799–2009 AD). The mean correlation coefficient for each series with a master series was 0.58, and the absent ring rate was 0.06%. The starting year of the STD chronology was determined by the expressed population signal (EPS), in which values exceeding 0.85 were considered acceptable (Briffa and Jones, 1990), and the effective period for the chronology was 1875–2009 AD (Fig. 3)

Correlation function analysis was employed to detect climate signals in tree-ring width. The correlation coefficient of the STD chronology with the climatic data from the Hailar station was higher than that of the Arxan station and the average of the two stations. Considering the geographical location of the two stations, Hailar was closer to the sampling site, while Arxan was far and higher in the mountains. Therefore, data from the Hailar station were used for the further correlation analysis.

3. Results

3.1. Correlation analysis

According to Fig. 4a, there were seemingly strong correlations (exceeded 95% significance level) between the STD chronology and both monthly temperature and RH for most months, besides temperature in previous November, December, RH in previous June, November to February and current October. In addition, the coefficients between the STD and monthly precipitation were not

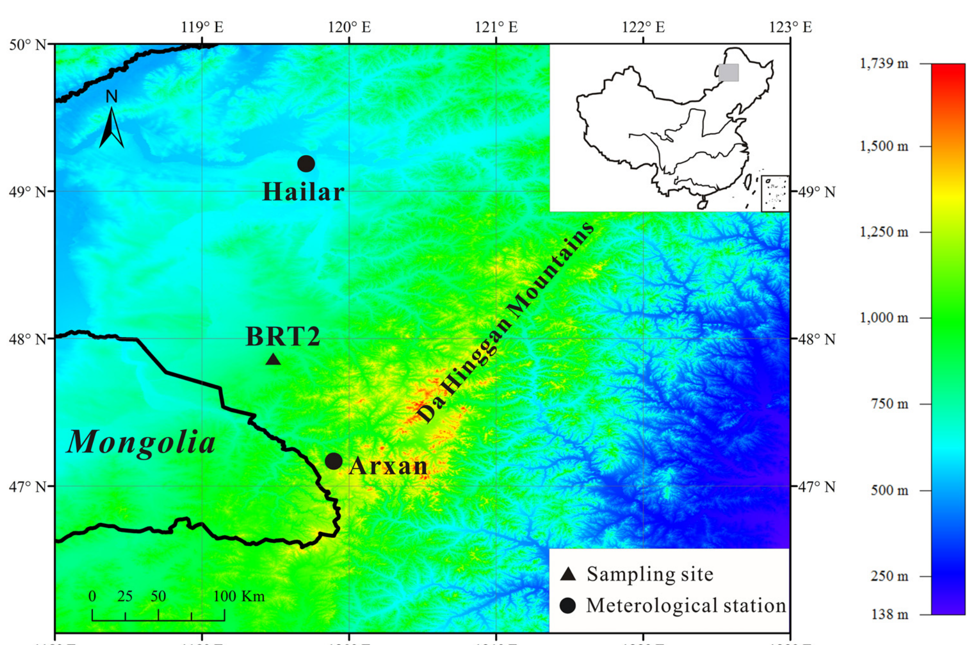

Fig. 1. Sampling site and nearby meteorological stations.