Ecological Indicators 96 (2019) 421–429

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Tree-ring-based drought variability in the eastern region of the Silk Road and its linkages to the Pacific Ocean

Changfeng Sun[a], Yu Liu[a,b,c,*]

[a] The State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710061, China
[b] Interdisciplinary Research Center of Earth Science Frontier (IRCESF) and Joint Center for Global Change Studies (JCGCS), Beijing Normal University, Beijing 100875, China
[c] Open Studio for Oceanic-Continental Climate and Environment Changes, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266237, China

ARTICLE INFO

Keywords:
Tree rings
Drought index reconstruction
Silk Road
Northwest China
Pacific Ocean

ABSTRACT

Drought variability from 1568 to 2014 was presented for the eastern region of the Silk Road by using five tree-ring chronologies and an optimal information extraction method (i.e., one of the composite-plus-scale methods). The inspection results of the split calibration-verification procedure for the transfer functions showed that the reconstructed Palmer drought severity index (PDSI) was credible throughout the entire time interval. During the past 447 years, there were seven dry periods (1616–1622, 1629–1645, 1682–1730, 1760–1778, 1805–1884, 1919–1933 and 1990–2009) and seven wet periods (1573–1615, 1623–1628, 1646–1681, 1731–1759, 1779–1804, 1885–1918 and 1934–1989). The dry periods were well-documented historical drought events. Significant interannual periods of 2.1–3.8 years and interdecadal cycles of 17.1, 18.3, 23.8, 42.7, 51.3 and 73.0 years were identified via the multitaper method for spectral analysis. Similar patterns of drought fluctuations were found in the records of the drought/flood index and other drought reconstructions. By comparing the reconstructed PDSI with the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) at the multidecadal scale, it was discovered that when ENSO and PDO were in phase (i.e., high-PDO/warm-ENSO phase or low-PDO/cold-ENSO phase), the study region was dry or wet more often, respectively, especially before 1850. The influence of ENSO and PDO on the decadal variability of drought has been affected by global warming.

1. Introduction

The famous Silk Road played an important role in connecting China with central Asia and Europe and was the main route for commercial and cultural exchanges between the East and West. Performing a comprehensive study of the Silk Road and its peripheral regions can contribute to an in-depth understanding of the evolution of the natural environment and ancient human history and culture; the Silk Road is therefore a research focus for scientific and cultural communities (Chen and Wang, 2009; Gan, 2009; Ge et al., 2007; Li et al., 2011; Zhang et al., 2013). With the opening of the new Silk Road and the proposition of the Silk Road economic belt, studies of the Silk Road have become increasingly significant. However, most studies focus on its historical relics and archeology, with a particular focus on the history of trade and cultural exchange and the disappearance of old urban settlements (Dong et al., 2015; Li et al., 2014), while there has limited research on historical climate change along the Silk Road. By influencing economic and social development and wars among nations, climate can indirectly affect the rise and fall of the Silk Road. Additionally, climate fluctuations play an important role in the ecological environment of Silk Road routes and directly drive route changes (Du, 1996; Zu et al., 2003). Regional historical climate research can facilitate an in-depth understanding of the formation and disappearance of antiquities and monuments along the Silk Road. For example, some scientists have surmised that the disappearance of the ancient Loulan city along the Silk Road was due to the abrupt change in climate (Zhu and Tang, 1999). Given the high attention to global climate change, it is extremely significant to adequately understand climate patterns and change rules for the comprehensive construction of the Silk Road economic belt. Studying historical climate change can provide scientific data for the economic planning of agriculture, forestry, husbandry and other fields along the Silk Road.

* 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).

https://doi.org/10.1016/j.ecolind.2018.09.032
Received 2 December 2017; Received in revised form 7 September 2018; Accepted 14 September 2018
1470-160X/

Because they provide precise, high-continuity, high-resolution dating data and because duplicates are easily obtainable, tree rings have become ideal climatic and ecological indicators (Cai et al., 2017; Zhang, 2015) and have been widely employed to reconstruct regional and hemispherical climate histories spanning hundreds and millions of years (Cook et al., 2010; D'Arrigo et al., 2005; Linderholm et al., 2015; Liu et al., 2009, 2006; Mann et al., 2008; Wilson et al., 2016; Zhang et al., 2015). Interestingly, dendrochronology has also been used to re-evaluate the Silk Road's Qinghai Route (Wang and Zhao, 2013). In China, research has achieved several important results using tree rings (Zhang, 2015), such as reconstruction of temperature (Chen and Yuan, 2014; Liu et al., 2005; Lv and Zhang, 2013), precipitation (Cai et al., 2017; Shao et al., 2005; Yang et al., 2011), drought (Fan et al., 2008; Fang et al., 2010; Gou et al., 2015) and streamflow (Bao et al., 2012; Zhang et al., 2016). However, most studies have focused on specific sites, and few regional climate records have been reconstructed, especially in the region along the Silk Road. Regional temperature reconstructions with tree-ring networks have been developed for the Asian monsoon region (Shi et al., 2015) and southern South America (Neukom et al., 2011).

Cook et al. (2010) established the Monsoon Asia Drought Atlas (MADA), which is a comprehensive gridded spatial reconstruction of drought available for monsoonal Asia. Fang et al. (2012) pointed out that it was necessary to conduct additional drought reconstructions for regions without tree-ring chronologies. Because MADA was established using a large search radius (e.g., 1000 km) to locate candidate tree-ring predictors (Cook et al., 2010), its resolution may be too coarse to capture regional drought changes in the regions with incomplete coverage of tree rings. To our knowledge, no studies other than the work of Cook et al. (2010) involving regional drought reconstruction have been conducted in the region along the Silk Road. It is well known that regional drought disasters have significant social, economic and ecological impacts, particularly in climatic and ecologically sensitive regions (Zou et al., 2005; Zhao and Wu, 2013). Global warming causes the frequency of extreme droughts to increase and the degree of regional aridification to strengthen (Dai, 2013). Knowledge of past drought changes could aid in the evaluation of potential regional hazards in the future (Cook et al., 2010). Based on observation data, it was found that the Pacific Ocean has exhibited some influence on drought change in Northwest China (Gong and He, 2002; Li and Li, 2004; Liu et al., 2016; Su and Wang, 2007; Wang et al., 2007; Zhang et al., 2007; Zhou and Huang, 2010). However, information about the relationship between the Pacific Ocean and drought along the Silk Road at a long-term time scale is still lacking.

Therefore, there are two major objectives in this study. One is the reconstruction of past regional drought changes using several tree-ring chronologies for the eastern region of the Silk Road in China. The other is the analysis of the relationship between the Pacific Ocean and drought change during the past five centuries. We first determined the climate signal of the regional chronology from five tree-ring sites using a climatic response analysis and reconstructed past drought variations using a kind of composite-plus-scale (CPS) method; finally, we investigated the linkages between our reconstructed drought change and the climate variability of the Pacific Ocean.

2. Materials and methods

2.1. Study area and climatic data

The Silk Road region studied herein starts from Chang'an (now Xi'an), extends west to Wuwei, and passes though the Hexi Corridor to west and central Asia and Europe. In this study, we mainly focus on the eastern region of the Silk Road (Fig. 1). The eastern part of the Silk Road is divided into north, south and central routes, which all start from Xi'an. The north route passes through Jingchuan, Guyuan, Jingyuan and Wuwei; the south route passes through Fengxiang, Tianshui, Longxi, Linxia, Ledu, Xining and Zhangye; and the central route passes through Jingchuan, Pingliang, Huining, Lanzhou and Wuwei. The region along the three routes includes the Longzhong and Longdong Loess Plateau and the Guanzhong Basin. This region belongs to a continental monsoon climate zone with distinct seasons. On the basis of the observed climate data from 21 stations of the National Meteorological Center (Fig. 1), the annual mean temperature in the study area is 8.8 °C, and the total annual precipitation is approximately 520 mm. Generally, 49% of the total annual precipitation is concentrated in summer, and winter precipitation occupies only 3% of the total. The mean summer temperature is 20.0 °C, and the winter temperature is −3.5 °C (Fig. 2).

The most commonly used drought index, the Palmer drought severity index (PDSI), was employed to represent drought conditions in the study region. The index was calculated from a water-balance model that was forced with observed precipitation and temperature (Palmer, 1965). The calculation procedure for PDSI was proposed by Palmer (1965) and Hu and Willson (2000):

$$PDSI_i = b*PDSI_{i-1} + c*Z_i \tag{1}$$

Here, b and c are duration factors, which determine the sensitivities of the index to precipitation and the lack thereof. Subscripts i and i–1 indicate current and previous months at some arbitrary time. Z is the monthly anomaly index and is defined as follows:

$$Z_i = (Kd)_i \tag{2}$$

where K is a climate characteristic and d is moisture departure, which is the excess or shortage of precipitation compared to the precipitation of the climatically appropriate for existing conditions.

$$d = P - (\alpha_i*PE + \beta_i*PR + \gamma_i*PRO - \delta_i*PL) \tag{3}$$

In the above expression, P is the actual monthly precipitation. The terms in the parentheses on the right-hand-side of Eq. (3) combine to yield monthly 'climatologically appropriate rainfall'. In particular, PE is potential evapotranspiration; PR is potential water recharge, which is the amount of moisture required to bring the soil to filed capacity; PRO is potential runoff; and PL is the potential loss of soil water to evapotranspiration. The weighting factors α, β, γ, and δ are the water-balance coefficients defined by Palmer (1965).

Theoretically, PDSI is a standardized measure (ranging from approximately −10 (dry) to +10 (wet), with values of 0 ± 0.5 representing normal conditions) of surface moisture conditions that allows for comparisons across regions and time. PDSI has been widely used for monitoring drought, studying aridity changes and reconstructing paleoclimates (Cook et al., 2010; Li et al., 2007). Monthly PDSI data of four grid points from the University Corporation for Atmospheric Research (UCAR) were employed as the observed PDSI. According to the available records of precipitation and temperature, the monthly PDSI data during the period from 1951 to 2014 were ultimately used in the following analysis. The corresponding PDSI data series downloaded from the MADA data library (Cook et al., 2010), were used for comparison with the PDSI series reconstructed in this study.

The drought/flood index (DFI) (Chinese Academy of Meteorological Sciences, 1981), which is derived from more than 2200 local annals and many other historical writings, is a dry and wet grade index of rainfall in the main precipitation season and is of great importance in studying historical climate changes and is also used to compare with the tree-ring-based climate reconstructions (Liu et al., 2017; Ma et al., 2015). The DFI is classified into five grades: very wet, wet, normal, dry and very dry, which correspond to values ranging from 1 to 5, respectively (Chinese Academy of Meteorological Sciences, 1981; Zhang et al., 2003). In this paper, the mean DFI values of Lanzhou, Tianshui, Pingliang and Xi'an were compared with the reconstructed drought series of this study.