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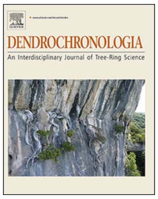

May–June drought reconstruction over the past 821 years on the south-central Tibetan Plateau derived from tree-ring width series

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ABSTRACT

Knowledge of drought variability and their possible mechanisms during the past hundred years is still limited in the mountainous region of south-central Tibetan Plateau (TP). In this study, a long-term tree-ring width chronology dating back to 1190 CE was combined using 328 increment cores from the Nagqu region. Based on the relationships between this tree-ring width chronology and climate data, we reconstructed May–June self-calibrated Palmer Drought Severity Index (scPDSI) for the past 821 years (1190–2010 CE). Additional comparisons with other available precipitation or drought reconstructions were conducted. We further investigated the influence of the South Asian summer monsoon (SASM) on the drought variability in our study region. Results indicated that our tree-ring width chronology contained stable drought signal in the early summer season (May–June). During the past 821 years, the longest dry and wet periods lasted for 116 and 90 years, respectively, based on a 21-year Fast Fourier transform filter. Specifically, longer than ten years' dry periods prevailed during 1211–1245 CE, 1280–1358, 1421–1471, 1500–1571, 1580–1598, 1650–1691, 1782–1807 and 1867–1982; while wet intervals occurred in 1190–1210 CE, 1246–1279, 1359–1420, 1472–1499, 1599–1649, 1692–1781, 1808–1866 and 1983–2010. Generally consistent dry and wet intervals across the southern TP were found by comparisons with other available datasets during their common periods. Interestingly, we detected an unstable influence of the SASM on the May–June drought variability in our study region, at least for the past three and a half centuries. This study therefore gives a new perspective of drought variability as well as their relationships with the SASM over a long-term period on the south-central TP.

1. Introduction

With an average elevation of more than 4000 m above sea level (a.s.l.), the Tibetan Plateau (TP) is particularly sensitive to climate change. On the one hand, the TP does not only affect the mid-latitude westerlies, but also modulates the Asian monsoon through its dynamical and thermal feedbacks (Wu et al., 2015). On the other hand, the influences of the Westerlies and Asian monsoon are critical for the advection of heat and moisture, and climate patterns on the TP (An et al., 2012). The interplay between different circulation systems is still poorly understood and motivates the need for a better understanding of climate change on the TP.

However, due to the limited available length of instrumental climate records, the assessment of climate change requires the use of reconstructed climate records to provide a long-term context. Among many others, the most widely used proxies for the reconstruction of past climate are ice-cores (Klein et al., 2016), speleothem data (Cheng et al., 2016), documentary records (Ge et al., 2016), varved lake sediments (Gebregiorgis et al., 2016), and tree-ring data (Büntgen et al., 2016; Yang et al., 2014). The latter are crucial due to their high resolution, sensitivity to climate and wide spatial distribution. Regional or large-scale variations in climate change during the past hundreds to thousands of years have been reconstructed using tree-ring data almost worldwide (Büntgen et al., 2016; Cook et al., 2010; Esper et al., 2012). Definitely, a great progress concerning dendroclimatological studies has also been achieved on the TP during the past several decades (Bräuning et al., 2016; Zhang et al., 2015b).

Specifically, numerous precipitation or drought reconstructions have been conducted on the eastern and western parts of the southern TP (e.g. Grießinger et al., 2017; He et al., 2012b; Li et al., 2016; Liu et al., 2012; Wernicke et al., 2015). On the south-central TP, especially in the Nagqu region which represents one of the most important pasturing areas in the Tibet Autonomous Region, drought related reconstructions have also been performed (Cook et al., 2010; Wang et al., 2008; Zhang et al., 2015b). However, open questions still exist. For example, the Monsoon Asia Drought Atlas by Cook et al. (2010) only

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implemented a very limited number of chronologies from the south-central TP. Zhang et al. (2015b) developed a network of moisture-sensitive tree-ring chronologies for the past five and a half centuries on the eastern TP, which included sampling sites of the Nagqu region. However, they focused on moisture dipole variations over the northern and southern TP. Herein, both network studies did not analyze drought variability on a local scale considering that precipitation or drought occurrence may show strong local variability in this mountainous region. Definitely, beside large-scale drought patterns, also single-site climate reconstructions were performed. Wang et al. (2008) reconstructed May–June Palmer Drought Severity Index (PDSI) based on 58 trees for the past 500 years. However, they did not compare their drought reconstruction with other existing paleoclimate records. Recently, a May–June Standardized Precipitation Evaporation Index (SPEI) reconstruction revealed two megadroughts in the Biru area of the southeastern TP (Nie et al., 2017). Accordingly, the two-century megadrought during the late 13th to late 15th centuries was considered as a stage of reduced Southwestern Asian Summer Monsoon. However, inherent relationships between drought reconstructions and associated monsoon variability were not yet successfully studied. In particular, according to the monitored stable oxygen isotope ratio in precipitation (recorded data since the 1980s), the region was classified as a transition area between the South Asian monsoon domain and the Westerlies domain (Yao et al., 2013). By analyzing two years (2004 and 2005) of monitored data, Yu et al. (2015) found that moisture over the Nagqu region during the summer season was strongly influenced by the Indian monsoon and by local convection. Hence, questions are therefore raised whether the South Asian Summer Monsoon (SASM) significantly influence drought variability in the Nagqu region over a long-term period. No related study has yet been conducted based on a local-scale.

In this study, we use a large sample depth of drought-sensitive tree-ring increment cores ranging from elevations from 4000 to 4500 m a.s.l. over the south-central TP. We aim to (1) reconstruct local drought history for the past eight centuries; (2) compare our local drought reconstruction with other available paleoclimate records near our study region; and (3) detect whether there exist stable significant relationships between SASM variability and local drought occurrence.

2. Materials and methods

2.1. Study region and tree-ring width chronology

Our sampling sites are located in the Nagqu region of the south-central TP (Fig. 1, Table 1). According to the meteorological stations at Jiali and Suoxian during their common period 1961–2010 (Fig. 1), mean annual temperatures vary between −0.41 and 1.83 °C, whereas mean annual precipitation change from 586 to 720. To minimize possible effects of inhomogeneities at individual station level and to highlight regional climatic features, we calculated a regional climate record using the method described by Jones and Hulme (1996). Accordingly, the mean annual temperature is 0.65 °C and the mean annual precipitation is about 638 mm from 1961 to 2010. July is the hottest month and January is the coldest one (Fig. 2). June is the wettest month (mean precipitation 133 mm). Tibetan juniper (*Juniperus tibetica* Kom.) is one of the dominant tree species in the alpine forests growing on hillsides.

All samples were taken from isolated juniper trees to maximize climatic signals contained in the tree-rings. One or two cores per tree were extracted at breast height (~1.3 m above ground). In total, 187 cores from 96 trees and 141 cores from 73 trees were retrieved at the sites of Jiali and Suoxian, respectively (Table 1). The tree-ring data used in this study were published before and the influence of altitude on the relationships of tree-ring width chronologies and climate factors had been analyzed (He et al., 2012a). Results showed that tree-ring width series was mainly determined by late spring or early summer drought variation, regardless of site elevation ranging from 4000 to 4500 m a.s.l. in the study region. However, the previous study provided no hydroclimate reconstruction and related analysis. Due to the significant coherence between the tree-ring width variations at the two distinct sites, we combined both tree stands to derive one regional chronology. This is a common approach to obtain a data record representative for a larger study region as also applied in He et al. (2012a) and Wang et al. (2008). In total, 328 increment cores from 169 trees of *Juniperus tibetica* Kom. were analyzed.

The synthesized tree-ring width chronology was built with the program ARSTAN (Cook and Kairiukstis, 1990). In order to remove biological trends of tree growth associated with tree age while preserving variations that are likely related to climate, all raw measurements were conservatively detrended by fitting negative exponential curves (Fritts, 1976). Tree-ring records that could not be fitted well by conservative curves were detrended applying a cubic spline curve with a 50% cutoff equal to 2/3 of the series length. The tree-ring indices were calculated as residuals after performing an adaptive power transformation (Cook and Peters, 1997). In order to reduce the potential influence of changing sample size, the chronologies' variance was stabilized using the method described by Osborn et al. (1997). A principal component analysis was conducted over the common period 1750–2000 CE to show the common variance explained by all the tree-ring width data. The expressed population signal (EPS) based on a 30-year window with 15-year overlap depicts the most reliable part (EPS > 0.85) of the tree-ring width chronology (Wigley et al., 1984). Herein, the EPS quantifies the degree to which an average time-series with limited number of samples approximates the theoretically infinite replicated time-series, which in turn be regarded as the potential climate signal. Considering the produced Arstan (ARS) chronology has the pooled autocorrelations of tree rings added in and thus can better preserve the low-frequency signals (Cook and Kairiukstis, 1990), we used it for the further analysis. Some others also used the ARS chronology for drought reconstruction in the southeastern TP (e.g., Fang et al., 2009a).

2.2. Relationships with climate data and building of reconstruction

Relationships between tree-ring width chronology and monthly temperature as well as precipitation data calculated as a regional mean from the nearest two meteorological stations (Jiali and Suoxian) were investigated during their common period 1961–2010 CE. Additionally, we selected two drought metrics of the SPEI (one month scale, Vicente-Serrano et al., 2010) and self-calibrated PDSI (scPDSI, van der Schrier et al., 2013) to study the combined effect of temperature and precipitation. The SPEI represents a simple climatic water balance that is calculated at different time scales (Vicente-Serrano et al., 2010). The scPDSI is an updated version of the PDSI (Palmer, 1965) and is verified to be suitable for regions with diverse climatology (van der Schrier et al., 2013). Considering the fact that the instrumental records in the area are commonly available after the 1960's, we truncated the SPEI and scPDSI data before 1960 to focus on the most common reliable data period spanning from 1961 to 2010. Relationships between tree-ring width chronology and climate data were calculated for a period from prior September to current October. This allows the presence of any carryover effect of climate changes to the following tree-ring formation to be assessed (Cook and Kairiukstis, 1990). All statistical procedures were evaluated at $p < 0.05$ level of significance using the program DENDROCLIM2002 (Biondi and Waikul, 2004). Tree growth-climate relationships were also calculated on seasonal and annual averages of climate variables following tree physiology, e.g., from May to June, June to August, or based on a hydroclimate year, for example from previous August to current July or from previous July to current June. The seasonal and annual climate factors were calculated as average values for temperature, SPEI and scPDSI, while accumulated data for precipitation were used. Furthermore, we performed partial correlation analysis to eliminate possible linear relationships among the climate