Science of the Total Environment 628–629 (2018) 707–714

Contents lists available at ScienceDirect

Science of the Total Environment

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

Sunshine duration reconstruction in the southeastern Tibetan Plateau based on tree-ring width and its relationship to volcanic eruptions

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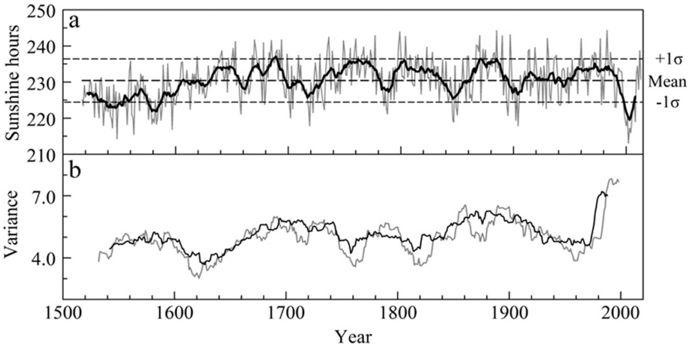
HIGHLIGHTS

- A 497-year sunshine duration was reconstructed in the southeastern Tibetan Plateau.
- Sunshine appeared a decreasing trend from the mid-19th to the early 21st centuries.
- Weak sunshine years matched well with years of major volcanic eruptions.
- Sunshine duration was possibly affected by large-scale climate forcing.

GRAPHICAL ABSTRACT

(a) The reconstructed monthly sunshine duration series from the prior September to the current June during 1517–2013 CE (gray line), an 11-year moving average (black line), the long-term mean (black horizontal line), and the mean value ± 1σ (gray horizontal lines); (b) 30-year (gray line) and 50-year (black line) running variance for reconstructed.



ARTICLE INFO

Article history:
Received 25 November 2017
Received in revised form 24 January 2018
Accepted 7 February 2018
Available online xxxx

Editor: R. Ludwig

Keywords:
Sunshine duration
Reconstruction
Southeastern Tibetan Plateau
Tree-ring width
Volcanic eruption

ABSTRACT

Sunshine is as essential as temperature and precipitation for tree growth, but sunshine duration reconstructions based on tree rings have not yet been conducted in China. In this study, we presented a 497-year sunshine duration reconstruction for the southeastern Tibetan Plateau using a width chronology of *Abies forrestii* from the central Hengduan Mountains. The reconstruction accounted for 53.5% of the variance in the observed sunshine during the period of 1961–2013 based on a stable and reliable linear regression. This reconstructed sunshine duration contained six sunny periods (1630–1656, 1665–1697, 1731–1781, 1793–1836, 1862–1895 and 1910–1992) and seven cloudy periods (1522–1629, 1657–1664, 1698–1730, 1782–1792, 1837–1861, 1896–1909 and 1993–2008) at a low-frequency scale. There was an increasing trend from the 16th century to the late 18th and early 19th centuries and a decreasing trend from the mid-19th to the early 21st centuries. Sunshine displayed inverse patterns to the local Palmer drought severity index on a multidecadal scale, indicating that this region likely experienced droughts under more sunshine conditions. The decrease in sunshine particularly in recent decades was mainly due to increasing atmospheric anthropogenic aerosols. In terms of the interannual variations in sunshine, weak sunshine years matched well with years of major volcanic eruptions. The

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https://doi.org/10.1016/j.scitotenv.2018.02.078

significant cycles of the 2- to 7-year, 20.0-year and 35.2-year durations as well as the 60.2-year and 78.7-year durations related to the El-Niño Southern Oscillation, the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation suggested that the variation in sunshine duration in the southeastern Tibetan Plateau was possibly affected by large-scale ocean-atmosphere circulations.

1. Introduction

Tree rings, as a high-resolution climate proxy, have been widely employed in reconstructing past millennial and centennial climate changes and research areas ranged from single sites to regions to hemispheres and the whole globe (Esper et al., 2002; Mann et al., 2008; Popa and Kern, 2009; Pumijumnong and Eckstein, 2011; Griffin et al., 2013; Linderholm et al., 2015; Wilson et al., 2016). In China, dendroclimatology also has resulted in many important achievements through several decades of development, especially in recent years (Yang et al., 2014; Zhang et al., 2015; Liang et al., 2016; Liu et al., 2017a). Although studies of climate reconstructions have been conducted throughout the country (Zhang, 2015), the majority of these studies focus on precipitation, temperature, runoff and drought indexes (Shao et al., 2005; Liu et al., 2009, 2015, 2017b; Bao et al., 2012, 2015; Zhang et al., 2014; Chen et al., 2016). Based on our knowledge, no studies on sunshine reconstruction been conducted in China. Sunshine plays an equally important role as precipitation and temperature on tree grow in terms of photosynthesis and respiration. In addition, sunshine is tightly associated with moisture stress in trees. Therefore, the width of annual tree rings is under direct and indirect effects of sunshine duration (Poljansek et al., 2013). Under a suitable sunshine environment, the net photosynthetic rate of trees is relatively fast, and nutrient accumulation is greater; thus it is easier for trees to form wider rings. If sunshine is beyond the adaptive range of trees, either too much or too little, sunshine is not beneficial to carbohydrate synthesis and tree growth, and then, this can lead to narrower rings. Thus, tree rings can record past sunshine changes to some extent (Fritts, 1976). The first reconstructed sunshine duration was conducted for the central United State of America based on tree-ring width chronologies of bald cypress and post oak (Stahle et al., 1991). Using the tree-ring width of black pine, Poljansek et al. (2013) reconstructed summer sunshine for the period 1660–2010 for the western part of the Balkan Peninsula. In addition to tree-ring width, a stable carbon isotope was also utilized to perform a sunshine reconstruction (Gagen et al., 2011; Loader et al., 2013; Hafner et al., 2014). For example, Loader et al. (2013) provided a millennial-length reconstruction of summer sunshine for northern Sweden and indicated that the Arctic Oscillation could influence sunshine through cloud cover. However, these sunshine studies were from Europe and America, so it is necessary to fill the vacancy in sunshine reconstructions in China.

In addition, sunshine as the most direct indication of the performance of solar radiation is one of the important factors in climate formation (Yu et al., 2011). Sunshine is also a major driving element influencing the ecosystems of the earth and human activities; therefore, sunshine is being given more attention in climate change studies (Yang et al., 2012). However, studies related to sunshine in China have been based on meteorological data (Kaiser and Qian, 2002; Zheng et al., 2008; Yang et al., 2009; Xia, 2010; Li et al., 2011), and the instrumental record of sunshine is too short to fully understand the characteristics of sunshine and its potential driving factors.

Due to the many virgin forests and old trees in the middle section of the Hengduan Mountains, southeastern Tibetan Plateau, some past climate reconstructions have been conducted in these regions (Fan et al., 2008; Liang et al., 2009; Zhu et al., 2011; Shi et al., 2015). *Abies forrestii* as one dominant species of Hengduan Mountains has a wide altitude distribution, and its tree rings contain climate signals, such as precipitation and drought (Fang et al., 2010; Gou et al., 2013; Li et al., 2017). Studies have indicated that precipitation influences changes in sunshine, and droughts can be affected by sunshine through evapotranspiration (Thomas, 2000; Du et al., 2007; Yu et al., 2011; Yang et al., 2012). Therefore, while *Abies forrestii* can be used to reconstruct precipitation and drought, it likely contains sunshine signals as well. In this paper, we first utilized the tree-ring width of *Abies forrestii* to identify climate responses, and then, we reconstructed past sunshine for the southeastern Tibetan Plateau and finally discussed the effect of volcanic eruptions on sunshine.

2. Data and methods

2.1. The study area

The tree-ring sites are in Xiangcheng County of Sichuan Province in the Hengduan Mountains, southeastern Tibetan Plateau (Fig. 1). The climate is continental monsoon plateau, and a subtropical high pressure controls the regional climate change. Precipitation is mainly driven by the southwest monsoon, East Asian monsoon and plateau monsoon (Zhao and Chen, 1999).

According to the nearest meteorological station, Daocheng (approximately 36 km east of the tree-ring sites), the mean annual temperature is 4.5 °C, the annual precipitation 640.6 mm, and the annual sunshine duration is 2582.1 h (Fig. 2). High temperatures always occur in June–September, and precipitation is also mainly concentrated in these months, especially in July and August when 54.0% of the precipitation occurs. However, sunshine during these four months is less, and sunshine in July and August only accounts for 10.1%. Because of the large elevational range, the zones of mountainous area vegetation are clearly divided, and the forested zones appear at approximately 2400–4000 m. The main conifers in this area are *Abies*, *Tsuga* and *Picea* (Zhao and Chen, 1999).

2.2. Chronology and meteorology

Two groups of *Abies forrestii* tree-ring samples (Cook et al., 2010; Li et al., 2017) from Xiangcheng, Sichuan were used in this study (Table 1). Due to the close location of the two samples and their high environmental homogeneity, all the ring-width index series from the same species were merged to develop one chronology. To eliminate the non-climatic signals caused by the growth trend and other factors that influence width chronologies, negative exponential or linear curves of any slope were used to fit the growth trend. The detrended index series were merged to form a biweight robust mean chronology, with its variance stabilized by the Rbar weighted method (Osborn et al., 1997; Frank et al., 2007). Finally, the “signal-free” approach was used to mitigate potential trend distortion problems in the traditional chronology (Melvin and Briffa, 2008). The expressed population signal (EPS) can be used to evaluate the reliability of the tree-ring chronology (Wigley et al., 1984). In general, the greater the sample size is, the higher are the EPS values. An EPS value above 0.85 is generally regarded as satisfactory (Cook and Kairiukstis, 1990). In this research, an EPS value exceeding 0.85 existed after 1523 CE and corresponded to five cores from four trees. When the EPS decreased to 0.80, the chronology could extend to 517 CE with three cores from two trees.