Ecological Indicators 82 (2017) 441–450

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Growing-season precipitation since 1872 in the coastal area of subtropical southeast China reconstructed from tree rings and its relationship with the East Asian summer monsoon system

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ARTICLE INFO

Keywords:
Subtropical southeast China
Tree ring
Growing season
Precipitation reconstruction
Spatial hydrological signal
East Asian summer monsoon

ABSTRACT

Tree rings from temperate zones of the world have provided abundant palaeo- ecological and paleo-hydroclimatic information. However, tree rings from subtropical to tropical regions remain relatively scarce, which greatly limit our fully understanding about the climate change issues. In the present work, tree-ring-width (TRW) measurements of Masson pine from Fujian province, the coastal area of subtropical southeast China were successfully crossdated and a TRW STD chronology was developed from 1854 to 2012. Significantly positive correlation was identified between the tree rings and April–November total precipitation ($r = 0.71, p < 0.01$). The reconstructed April–November precipitation exhibited two comparatively wet (1876–1886 and 1957–1962) and one comparatively dry (1986–2004) periods. An evident drying trend since 1959 was seen and it was mitigated after 1993. Most of the extreme low-precipitation years in the reconstruction were supported by the historical records. As revealed by the spatial correlation patterns, our precipitation reconstruction was also consistent with other hydroclimatic records along the coastal areas of southeast China, proving its ability to capture the large-scale hydrological signal in southeast China (mainly refers to the south of the middle-lower reaches of Yangtze River). The reconstructed precipitation showed significant correlation with the East Asian summer Monsoon (EASM) index. Moreover, it also indicated simultaneous variation with the monsoon precipitation in North China on a decadal scale, implying that growing season precipitation variations in both regions were influenced by the EASM strength. This work highlights the potential of using tree-ring width to reconstruct precipitation in subtropical southeast China, while the relevant issues about precipitation variation in this region is far from resolved.

1. Introduction

Freshwater resource is very important for human society, covering all social, economic, ecological and environmental activities. The acknowledged global warming has been accelerating the global hydrological cycle (Alan et al., 2003; Allen and Ingram, 2002; Jackson et al., 2016) and then altering the spatial-temporal patterns of precipitation, which will inevitably result in increased occurrences of hydroclimatic extremes (Easterling et al., 2000; Vizy and Cook, 2012), such as floods and droughts in many regions of the world (Dai, 2013; Zhang et al., 2017), including China (Yuan et al., 2015; Zhang et al., 2010, 2016a). To reasonably utilize water resources, mitigate water-related hazards under the influence of climatic change and human activities, adequate spatial and temporal scales hydroclimatological data are essential. Up to now, there are many studies addressing precipitation variations in southeast China (Jiang et al., 2012; Zhang et al., 2009, 2014), an area that is vulnerable to drought and flood disasters. However, the previous studies are mainly based on instrumental records or low-resolution proxies. Thus the long-term characteristics of climate change have rarely been revealed. To extend the limited climate observations and better understand the hydroclimatic variability, as well as improve the accuracy and reliability of regional hydroclimatic analyses in the future, more long-term hydroclimatic (e.g. precipitation, drought index) reconstructions with high resolution are required.

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http://dx.doi.org/10.1016/j.ecolind.2017.07.012
Received 23 January 2017; Received in revised form 18 May 2017; Accepted 6 July 2017
Available online 21 July 2017

Serving as an ideal climatic and ecological indicator (Fritts, 1976; Lyu et al., 2016; Zhang, 2015), high-resolution tree rings from temperate zones of the world have provided abundant paleo- hydroclimate data (Coulthard and Smith, 2016; Liu et al., 2010; Seftigen et al., 2015; Zhang et al., 2015). However, tree rings from tropical to subtropical areas are still playing a minor role due to hardly identifying exogenous factor inducing common periodic changes in wood anatomy, albeit stable isotopes in tree rings are proved to be useful in crossdating and providing hydroclimatic signals (Evans and Schrag, 2004; Fichtler et al., 2010; Ohashi et al., 2016). Though there were several successful cases in using tree-ring parameters (e.g. stable isotopes) to study the hydroclimatic variability in southeast Asia (Buckley et al., 2007, 2010; Sano et al., 2009), very few were in southeastern China (Shi et al., 2015; Xu et al., 2013).

In subtropical southeast China (SSEC), tree-ring width studies have made great progress during the last few years. In addition to detect the growth-climate relationship of different tree species (Cai and Liu, 2013; Chen et al., 2015), most efforts were given to reconstruct the temperature history (Cai and Liu, 2017; Cai et al., 2016; Chen et al., 2012; Duan et al., 2012). Up to now, only one ring-width based pre-growing season (February–April) precipitation was reconstructed in the lower reaches of the Yangtze River (Shi et al., 2015), while no growth-season precipitation was reconstructed using tree-ring-width (TRW) in SSEC.

Existing researches from SSEC reveal that TRW of Masson pine from the high latitudes generally reflects temperature signal (Cai et al., 2016; Duan et al., 2012), while TRW of Masson pine from the low-latitude has the ability to reflect precipitation signal (Shi et al., 2015). Therefore, we anticipate extracting precipitation signal and extending the precipitation record using TRW of Masson pine from the low-latitude in SSEC. In the present work, we collected a set of tree-ring samples from Masson pine (*Pinus massoniana* Lamb.), growing at a low-altitude area with poor soil condition in Fujian province, SSEC. The TRW chronology was developed coving the period of 1854–2012. The objectives of this study were to 1) detect the potential of using this TRW to reflect the precipitation signal; 2) reconstruct the first growing-season precipitation variation in Fujian, southeast China using TRW and assess its characteristics over the past 141 years, and 3) to investigate the relationship between precipitation in the study area and the East Asian summer monsoon system.

2. Materials and methods

2.1. Tree-ring material

Masson pine, a two-needle conifer species, has a wide distribution in SSEC and is an important afforestation tree in this region. It is a photophilous plant with developed root system, and prefers to live in areas with annual mean temperature ranging from 13 °C to 22 °C, and annual mean precipitation from 800 mm to 1800 mm. It is generally distributed below an altitude of 600–700 m in the downstream of Yangtze River, above 1200 m in the middle reaches and below 1500 m in the upstream of the Yangtze River. It can grow in very thin soil layer, and even survive in rock fracture.

Tree rings of Masson pine were collected from Yongtai county, Fujian province in SSEC. The sampling site (25.89°N, 119.09°E) is located at the Fangguangyan (FGY) scenic spot (Fig. 1), belonging to the eastward foothills of the Daiyun Mountains, the second largest mountains in Fujian province. The scenic area occupies about 10.5 square kilometers, with a mountain slope of 20°–50°. The highest peak is about 760 m a.s.l. In the scenic area, Masson pine is the dominant tree species with relatively open canopy, growing in rock cracks or in very thin soil. It shows a banding distribution along the hill with increasing altitude, and is accompanied by young *Cunninghamia lanceolata* (Lamb.) Hook, Phyllostachys pubescens, Phyllostachys aurea phr. and shrubs. In this site, precipitation is the only water source for tree growth. Generally, trees with large diameters are thought to be older than those with small

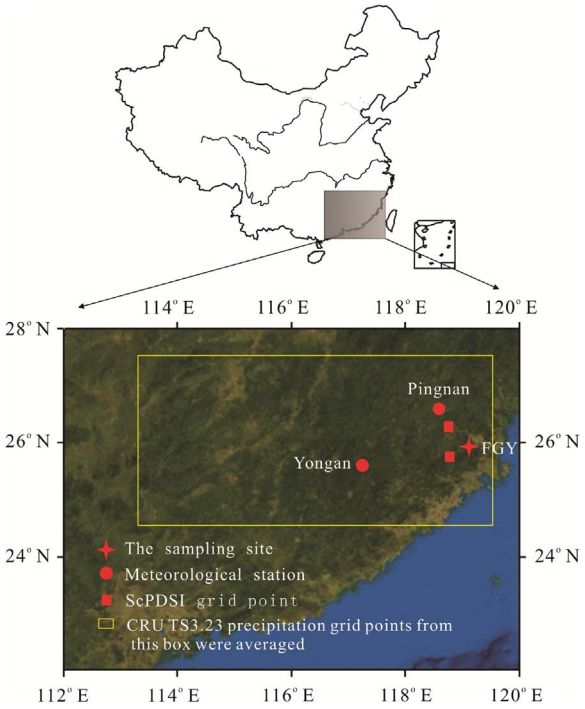

Fig. 1. Locations of the sampling site, meteorological stations and scPDSI grids.

diameters. Therefore, thick and healthy Masson pines were chosen for sample collection.

In October 29th, 2013, 72 cores from 36 Masson pine, more or less evenly distributed along an altitude from 70 m a.s.l. to 260 m a.s.l. were collected using the 5-mm diameter increment borer. Two cores from different direction (with angles of 90° or 180° according to the sampling convenience) of each tree were sampled. It is believed that the large sample quantity can enhance the reliability of tree-ring cross dating. It is worth noting that the late wood of the tree ring in 2013 had not appeared when the samples were collected, which indicated the growing season did not end in late October in the study area.

The tree-ring samples were treated according to the standard dendrochronological method (Cook and Kairiukstis, 1990). On the basis of visual crossdating, the calendar year was preliminarily assigned to each growth ring. Then the width of each annual ring was measured using LINTAB machine with the resolution of 0.01 mm. The COFECHA program (Holmes, 1983) was adopted to check the quality of the measurement and crossdating. The tree-ring chronology was therefore developed using the ARSTAN program (Cook, 1985) after detrending the "juvenile effect" caused by tree age. During this process, conventional negative exponential curve or straight line of negative slope, or horizontal line was firstly applied to each tree-ring series. Then all the dimensionless indexes, computed by dividing the original measurement of each ring by the value of the fitted curve in the corresponding year, were combined into a single standard (STD) chronology by computing a biweight robust mean (Cook, 1985). Low sample size in the early years usually reduces the reliability of the early chronology, thus we adopted sub-sample signal strength (SSS) (Wigley et al., 1984) to determine the reliable starting year of the chronology. To further evaluate the quality of the ring-width chronology, Rbar and the expressed population signal (EPS) were calculated over every 50-year window, with 25-year overlap between neighbouring windows (Wigley et al., 1984; Cook and Kairiukstis, 1990). EPS measures how well a limited-sample-size-based chronology approaches the theoretical chronology. Rbar is the correlation coefficient among the detrended ring-width indexes used for chronology development.