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# Winter temperatures of southern China reconstructed from phenological cold/warm events recorded in historical documents over the past 500 years

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ABSTRACT

We reconstructed a 500-year long winter (November to February) temperature series with a yearly resolution in southern China. The series is based on six types of proxies extracted from historical documents, including the southern limits of frost disaster, freezing disaster and snow, along with snowfall days and the first/last frost disaster dates. In the reconstruction, linear regression models are established among each proxy and regional winter temperature. Variance matching, minimum selection, and envelope analysis methods are performed to eliminate non-homogeneous effects because of different proxy types, missing data, and the changing amount of records. Compared with the average temperatures during 1851–1950, the reconstruction shows that southern China experienced a cold period in the first 40 years of the sixteenth century with an average of −0.40 °C with frequent extremes. An upturning occurred during the 1540s to mid-1560s, followed by a stable phase until the 1620s. Then the temperature started to fall from the 1630s and reached its lowest in 1660, where it dropped to −2.01 °C. Moreover, the mean value was −0.49 °C between the years 1648–1697, which was the coldest 50 years over the last five centuries. The temperatures during the eighteenth century to the middle of the twentieth century was characterized by annual to decadal fluctuations, with two moderately warm intervals in the 1770s and 1840s–1850s, as well as three moderately cold intervals in 1790s, 1830s, and 1870s to the mid-1890s. Over the recent century, the warming rate since 1901 was 0.56 °C/100a, whereas the temperature reached 0.32 °C/10a after 1979. The hottest five years during the last five centuries all occurred after 1990.



## 1. Introduction

Regional high-resolution reconstructions for temperature of centennial to millennial scale are essential to understand the spatial/temporal variation and the dynamics on climate system (PAGES, 2009; IPCC, 2013). Over the past few years, many surface air temperature (SAT) reconstructions from a specific area to continental scale have been generated based on tree rings, ice cores, speleothems, corals, marine and lake sediments, as well as historical documents (PAGES 2k Consortium, 2013; Trouet et al., 2013; Mckay and Kaufman, 2014; Shi et al., 2015; Luterbacher, 2016). Among all proxy records, the majority are located in the mid to high latitudes; for example, the PAGES 2k Network contains a total of 522 metadata, where only 29 (5.6%) are in the tropics (PAGES 2k Consortium, 2013). Although some reconstructions for sea surface temperature (SST) of tropics (Tierney et al., 2015) exist, research for land SAT of lower latitudes is still needed.

In China, reconstructions of annual resolutions for the last several centuries in Central East have been made using historical documents (Yan, 2014; Hao et al., 2012); in the northeast, north, and northwest by tree rings (Chen et al., 2013; Li et al., 2013; Cai et al., 2013; Zhang et al., 2013, 2015) and in the Tibetan Plateau by tree rings, lake sediments, and ice cores (Shao, 2012; Yang et al.,

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2009). However, in southern China, which is located in the tropical and subtropical areas, only a few temperature reconstructions with a resolution of 10a over the past 500 years were converted by winter temperature indices or severe winter sequences (Zhang, 1980; Zheng, 1982; Wang et al., 1998), and these were conducted approximately 20 years ago. Recently, an annual winter temperature series since 1736 was reconstructed from the archives of the Qing dynasty; the reconstruction was enhanced by using the temporal resolution and quantitative method, and the period covered was not more than 300 years from the present (Ding et al., 2015). The high-resolution natural proxies in this region, which include the stalagmites and lake sediments, are mainly affected by precipitation (Jiang et al., 2012; Chu et al., 2002). Also, the longest tree-ring chronologies used for temperature reconstruction in the mainland are less than 200 years (Chen et al., 2012a, 2012b); only one chronology in northern Taiwan spans more than 500 years; this chronology has a strong positive relationship with the local November to March temperature and also partially correlates with the August to January temperature in southern China and Southeast Asia (Chen et al., 2015). Thus, extending the high-resolution temperature series of southern China is necessary. Here, we present a new reconstruction of the annual winter temperature anomalies dating back to 1500 using phenological cold/warm events recorded in historical documents.

## 2. Data and method

### 2.1. Study area and climatic data

Southern China is located in the southeast margin of the Eurasian continent (approximately 18–27° N, 105–122° E, Fig. 1a) and has a subtropical and tropical humid climate. According to the instrumental gridded (at the resolution of 1° × 1°) dataset of monthly temperatures (available during 1951–2007) in China (http://data.cma.cn/data/detail/dataCode/SEVP_CLI_CHN_TEM_MON_GRID), the regional mean annual temperature is 19.5 °C, and the coefficient of variation (CV) for annual variability is 2.1%. While the July mean temperature is 26.5 °C with CV of 1.9%, and the January mean temperature is 10.9 °C with CV of 11.4%. The mean temperature of November to February (cold season) is 11.8 °C with CV of 8.4% (Fig. 1b).

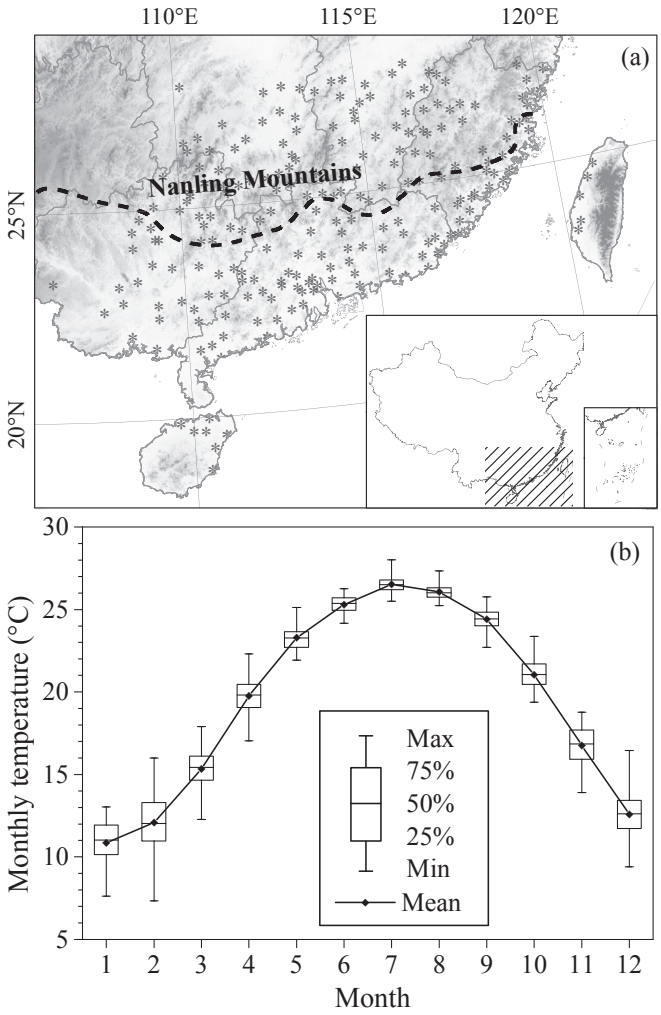


**Fig. 1.** (a) Study area and sites with cold/warm records for temperature reconstruction (star symbols). Dashed line is the northern borderline of the south subtropics (Zheng et al., 2010). (b) Monthly variability of the temperature change in southern China.

### 2.2. Proxy data

Previous studies (Zheng et al., 2016) demonstrated that six types of phenological cold/warm events exist in this region, including the snowfall days, the first/last frost disaster dates, and the southern limits of frost disaster, freezing disaster and snow; these events could well indicate NDJF temperature variability because it is dominated by the cold surge from high latitude. In detail, cold surge in winter arrives at the Nanling Mountains (see Fig. 1), where the humid air from Southern Branch Trough in the subtropical westerlies encounters the southward cold air. Therefore, frosting and snowing occur almost annually. Thus, the snowfall days and the first/last frost disaster dates around this band reflect the frequency of cold surge. During colder winters, the cold air reaches lower latitudes and usually results in frost, freezing disasters, and snow. Hence, the southern limits of these events indicate the intensity of cold surge.

By adopting the same criteria for data extracting as Zheng et al. (2016), we collect the ancient (before 1950 CE) southern limits (with an accuracy of 0.1° N) of frost disaster, freezing disaster, and snow, as well as the first/last frost disaster dates, from local gazettes since the Ming Dynasty (available during 1368 CE–1950, Zhang, 2013); the gazettes have special chapters that record the abnormal weather phenomena, with the time resolution of day, dekad, or month. Snowfall days and southern limits of snow are from the "Yu (rainfall): Xue (snowfall): Fen (Chinese length unit, 0.32 cm approximately): Cun (approximately 3.2 cm)" archives during the Qing Dynasty (available during 1736 CE–1911, Ge et al., 2005), which are memos to the emperor reported by government officers and accurately describe each snowfall event with the time resolution of hour. Table 1 shows the examples of the original description for these records. For the years since 1951 CE, the southern limits of snow and snowfall days were extracted from the Daily Precipitation Data in China from 1951 to 1970 (Central Weather Bureau, 1975), Days of Weather Phenomena Data in China from 1961 to 1970 (Central Weather Bureau, 1978), Report of Monthly Surface Meteorological Records in China during 1971–1996, and the Book of Monthly Surface Meteorological Records in China during 1997–2008 (Ding et al., 2015). Southern limits of frost disaster and freezing disaster are extracted from the Encyclopedia of Meteorological Disasters in China (Wen and Song, 2006; Wen et al., 2007; Wen and Yang, 2007; Wen and Wu, 2008). The first/last frost disaster dates are from Feng et al. (1985), where the dates are recorded by subareas (north, center, east, and west) in southern China.

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