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June–September temperature reconstruction in the Northern Caucasus based on blue intensity data☆

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ABSTRACT

Although long-lived trees grow in the Northern Caucasus, no single tree-ring chronology has been reported thus far from this area in the International Tree-Ring Data Base (ITRDB), neither has one been published in international journals. Extensive tree-ring studies were conducted over the last decade, and a tree-ring network was developed for the investigated area. The data on the minimum blue intensity based on 33 series of pine (*Pinus sylvestris* L.) and fir (*Abies nordmanniana* (Steven) Spach) is presented in this study. The minimum blue intensity (BI) chronology covers the period 1596–2011 with EPS value ≥0.85. The BI chronology strongly correlates with the mean June-September temperature ($R = 0.74$; $p < 0.05$) from the weather station "Kluhorskij Pereval" (1951–2011). Mean June-September temperature anomalies were reconstructed using the rescaling method. Based on the reconstruction provided in this study the twentieth century is characterized by highly increased June-September temperature. According to this study, the minimum blue intensity approach demonstrates a great potential for paleoclimatic research in the Caucasus. Vast spatial coverage of the new BI-based reconstruction based on data from only two locations in the Northern Caucasus provides prospects for reconstruction of temperature variations for a great region in the Middle East and Northern Africa.

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1. Introduction

Tree-ring studies in the Northern Caucasus were initiated by V.I. Turmanina in the 1960s (Turmanina, 1977) and continued over the next decades (Kovalyov et al., 1984; Lukyanova et al., 1987). The challenge of these research was a weak and mixed climatic signal (both temperature and precipitation) in conifer ring-width variations. Therefore, no reliable reconstructions could be made. However, the region is of high interest and importance for climatologists as being located on the boundary of subtropical and temperate climatic zones. In order to investigate the area dendrochronologically in more details, extensive tree-ring studies were started by a research group from the Institute of Geography, Russian Academy of Sciences around 2000. As a result, a tree-ring network consisting of 10 ring-width chronologies of Scots pine (*Pinus sylvestris* L.) and 4 chronologies of Nordmann fir (*Abies nordmanniana* (Steven) Spach) was developed for the Northern Caucasus from the East (North Osetia) to West (Adygeya).

There have been several attempts to use tree-ring data from Caucasus in dendroclimatology. Thus, the reflected light values of pine tree rings as well as ring widths were used to reconstruct past summer air temperatures (Dolgova and Solomina, 2010). The annual mass balance of the Garabashi Glacier (Dolgova et al., 2013), and the runoff variations of the Teberda River for the period 1800–2005 (Matskovsky et al., 2010) were reconstructed based on tree-ring data. The pilot project focused on the $\delta^{13}C$ analyses of pine tree rings revealed a correlation with the air humidity (Brugnoli et al., 2010). In spite of these numerous attempts, high-resolution and reliable tree-ring-based temperature reconstruction in the Caucasus is still absent. However, climate reconstructions in other regions with a mid-latitude temperate climate, such as the Alps (e.g., Büntgen et al., 2005), Carpathians (Popa and Kern, 2009), etc., were successful. These examples motivated the continuation of similar efforts in the Caucasus.

Dendroclimatic studies worldwide show that the maximum latewood density (MXD) of conifer tree-rings is more sensitive to temperature variations compared with the ring width: in Europe (Frank and Esper, 2005), North America (D'Arrigo et al., 1992) and Siberia (Briffa et al., 2001; Kirdyanov et al., 2008). However, the high cost of hardware and software, time-consuming sample preparation, operational permissions required for the use of X-ray densitometric equipment are the reasons why this method could not be applied in each laboratory. A potential surrogate for the maximum density is the blue intensity (BI), which is based on the

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measurements of high-resolution images of the wood (McCarroll et al., 2002). The BI and latewood density of resin-extracted samples of Scots pine from northern Finland have been shown to respond to climate in a similar manner (Campbell et al., 2007). McCarroll et al. (2013) included BI chronology in a 1200-year multiparameter June–August temperature reconstruction for northern Fennoscandia. Wilson et al. (2014) used a composite of the ring width and BI of Engelmann spruce to develop one of the versions of May–August air temperature reconstruction from British Colombia. Despite a high correspondence between the maximum latewood density and blue intensity of Scots pine from northern Sweden, the main difficulties in developing BI-based temperature reconstruction are heartwood-sapwood discoloration and the differential discoloration between wood samples (Björklund et al., 2014).

The low cost of recently developed software and relatively easy sample preparation could make BI method to be available in many laboratories, which could potentially increase the amount of regional tree-ring-based climate reconstructions. This novel technique is still under development and several procedures using sample preparations have been published recently (Campbell et al., 2011; Björklund et al., 2014, 2015; Rydval et al., 2014). There are still specific questions concerning BI-based temperature reconstructions that remain to be addressed, for example, the ability of BI to capture low-frequency variations. However, the feasibility of the BI method to represent variations in the domain from high- to mid-frequency is evident. It is obvious that more BI data obtained from different regions with different climatic conditions could contribute to our understanding of the method's weaknesses.

The primary focus in this paper is BI tree-ring summer temperature reconstruction for the Caucasus and understanding how this reconstruction is able to capture a regional temperature signal.

2. Materials and methods

2.1. Study area

The study area includes the western and central sectors of the Northern Caucasus Mountains (Fig. 1). The Caucasus Mountains are located to the south of the East-European Plain between the Black Sea to the west and the Caspian Sea to the east. The Caucasus is part of the middle sector of the Alpine-Himalayan mountainous belt. The highest summits of the Caucasus are Mount Elbrus (5644 m.a.s.l.) and Mount Kazbek (5033 ma.s.l.). The modern landscape is intensely eroded with the typical features of erosive and accumulative glacier activity. There are widespread evidences of glacier recession in the late 19th–21st centuries since the end of the Little Ice Age (Solomina, 1999; Bushueva and Solomina, 2012).

The crest of the Greater Caucasus forms a boundary between the temperate zone and the subtropics. The northern macroslope belongs to the temperate zone, whereas the southern macroslope belongs to the subtropics. Due to the southern position of the Caucasus Mountains, the incoming solar radiation is high (from 120 kcal $cm^{-2}a^{-1}$ to 170 $cm^{-2}a^{-1}$). The subtropical high pressure in the West and the Asian depression in the East influence the climate during the summer. In winter the Caucasus is dominated by the western branch of the Siberian high. The regional circulation is impacted by the air masses from the Black and Caspian seas as well as by the complex relief of high mountains. Winter precipitation is associated with the Mediterranean and Iranian depressions regenerated over the Black and Caspian seas. The influence of the Black Sea is greater compared to the Caspian Sea due to the dominant Westerlies. Cyclonic activity in the winter results in high precipitation, which is greater along the Black Sea coast (Volodicheva, 2002). The Caucasus mountain chains are a barrier for the cold air masses coming from the North over the Russian Plain. Fig. 2 shows the temperature and precipitation variability of the instrumental records from the Kluhorskij Pereval weather station located in the western sector of the Caucasus (43°15′00″N, 41°49′48″E, H = 2037 m a.s.l.). According to records, the mean air temperature and sum of the precipitation for the cold period (November–March) are −2.9 °C and 733 mm, respectively. For the warm period (April–September), these values are 9.3 °C and 873 mm, respectively.

2.2. Tree-ring data

Fig. 1 shows the location of the sites used in this paper. Site of fir D18P (*A. nordmanniana*) is located in the western part of the Caucasus in the Teberda State Preserve at the altitude of 2300 m a.s.l. Another site, D09S, of pine (*P. sylvestris*) is located in the central part of the Caucasus in Elbrus National Park, representing the upper tree-line at 2300 m a.s.l. Healthy old trees at each site were chosen for sampling and two increment cores per tree at breast height were extracted.

Pine typically contains resins, which is a source of distortions when measuring the BI. Therefore, pine samples should be chemically treated. For this purpose, pine cores were refluxed in ethanol (99.5%) in a Soxhlet apparatus for approximately 48 h. Fir does not contain normal resin ducts, but it may contain traumatic resin canals that are a result of injury to the tree (Schweingruber, 2007). In this study, the untreated material of fir was used for image analysis, because wood of fir is characterized by very small differences in the color of the heartwood and sapwood (Vikhrov, 1959). Samples were dried and glued to wooden beams. Core flatness was achieved by sanding. The cores were then scanned using a commercially available flatbed line scanner, Epson Expression 1680, with a resolution range of 1500–2400 dpi. To avoid the penetration of light during the scanning process, the cores were covered with a black box (Rydval et al., 2014). Before each scan, a calibration procedure was applied using IT8Calibration Target color cards (SilverFast Auto IT8 calibration software). The resulting JPEG pictures were then processed using CooRecorder/CDendro software (Larsson, 2013).

The entire raw BI series was inverted prior to detrending by subtracting the BI values from 256 (Björklund et al., 2014; Rydval et al., 2014). The 'Signal-Free' detrending technique was applied to develop the BI chronology using RCSsigFree software (Melvin and Briffa, 2008). Indices of the chronology were calculated as residuals from a 50-year smoothing spline. The chronology quality was estimated by means of the Expressed Population Signal (Briffa and Jones, 1990), applying a 30-year moving window with a 29-year overlap to calculate the EPS values. EPS values >0.85 were used as a threshold representing the reliable part of the chronologies (Wigley et al., 1984).

2.3. Climatic data

Monthly temperature and precipitation records from Kluhorskij Pereval weather station were used for the dendroclimatic analysis. The data are available for downloading from an open-source database of the European Climate Assessment & Dataset project (ECA&D, Klein Tank and Wijngaard, 2002). Kluhorskij Pereval weather station is located at approximately 2037 m.a.s.l. in the western sector of the Caucasus (Fig. 1). Data are available for the period 1951–2013CE.

2.4. Reconstruction model development

The relationship between the BI chronology and climate records was established using Pearson's correlation. Application of the regression model for climate reconstruction typically results in a variance reduction effect and loss of variance. Thus, scaling was

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