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Reconstructed summer Palmer Drought Severity Index since 1850 AD based on $\delta^{13}C$ of larch tree rings in eastern Siberia

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SUMMARY

We present a tree-ring reconstruction of Palmer Drought Severity Index (PDSI) in Ust-Maya region (60°00′N, 133°49′E), central part of eastern Siberia using total ring (TR) widths and latewood (LW) $\delta^{13}C$ chronologies from larch trees (1850–2008 AD). Summer (JJA) PDSI was correlated positively and negatively with the TR widths and LW $\delta^{13}C$, respectively. Using a multiple liner regression approach, we reconstructed summer PDSI using the time series of TR widths and LW $\delta^{13}C$. The reconstruction showed an interannual to decadal wet/dry fluctuation with several moist periods before 1950s and a severe drought event from 1991 to 1993. Comparison of the reconstruction with reconstructed July PDSI for the Yakutsk region, 300 km northwest of Ust-Maya, showed heterogeneous changes in the mean states of soil moisture, but synchronous year-to-year changes. These results indicate that regional studies are quite important to precisely depict the spatio-temporal variability of hydrological changes in the central part of eastern Siberia.

1. Introduction

Hydroclimatic records are sparsely available in many parts of the world. Paleohydrological proxies are important for precisely studying the current climate patterns in the long term context and predicting the anticipated changes in the near future. Above all, tree-ring records are the one of the proxies most often used due to their precise time resolution, availability of the records and the potential to extract hydro-climatic information over the past several hundred years (e.g., D'Arrigo et al., 2001; Cook et al., 2010).

Soil moisture is the major property of the soil in relation to plant growth, and therefore exerts an important control on the interaction of the hydrosphere, biosphere, and atmosphere. Despite the importance of the soil moisture variability, its nature is poorly understood because of the limitations in length and distribution of instrumental records all over the world (Dai et al., 2004; Dai, 2011).

In eastern Siberia, soil moisture records are short and often discontinuous. Although nearly 130 station records of the soil gravimetric measurements are available over the period of 1978–1985 in the International Soil Moisture Network (http://www.ipf.tuwien.ac.at/insitu/) data sets, longer records of soil moisture or some other hydrological variables are necessary to better understand the current moisture variability for this region.

A global data set of Palmer Drought Severity Index (PDSI) (Dai et al., 2004) may serve this purpose. PDSI (Palmer, 1965) was first intended to reflect regional moisture availability and is used widely to study the extent and severity of droughts and wet spells in the United States (e.g., Cook et al., 1999, 2004). Although PDSI does not reflect soil moisture conditions when the soil is frozen, it shows a significant correlation with observed soil moisture for the vegetation period (Dai et al., 2004; Dai, 2011). The global dataset includes a 2.5° latitude/longitude gridded record over eastern Siberia spanning 1888 to 2005.

Despite the importance of wide-area tree-ring reconstructions of PDSI, regional studies are still essential to better understand

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the physiological response of the boreal forest ecosystems and to precisely depict the spatio-temporal variability of hydrological changes. Recently, Tei et al. (2013b) reported that there is a strong relationship between in-situ soil moisture and tree-ring carbon isotope ratio ($r^2 = 0.81$) of larch trees in the central part of eastern Siberia, and successfully reconstructed the soil moisture over the past 100 years. The reconstruction agreed well with the documented severe droughts. An unprecedented wet event in 2006–2007 (Iijima et al., 2013) was well captured as a rapid decrease in tree-ring δ^{13}C. A longer reconstruction of PDSI was obtained over the past 229 years in the same region (Tei et al., 2013a). However, there still remains a lack for tree-ring reconstructions of hydroclimatic variables for this region. Further attempts at improving the coverage of tree-ring reconstructions are essential to establish better understanding of the current moisture variability for this climatically sensitive region.

In this study, we built ring-width and δ^{13}C chronologies using larch (*Larix cajanderi*) trees grown in Ust-Maya region, 300 km southeast of Yakutsk, in the central part of eastern Siberia. The chronologies were examined by means of correlation analysis using the monthly records of PDSI. Summer (JJA) PDSI was successfully reconstructed over the last 160 years and the reconstruction was compared with results of previous studies (e.g., Nikolaev et al., 2009; Tei et al., 2013a) to investigate the spatial homogeneity of soil moisture anomalies of the past 160 years in the region.

2. Material and methods

2.1. Study area

The study area is located in the Ust-Maya region, southern Lena River Basin in the central part of eastern Siberia (Fig. 1). The average summer (June–July–August) temperature and precipitation from 1950 to 2008 were 16.1 °C ($SD = 1.4$) and 141.1 mm ($SD = 44.7$) at Ust-Maya, respectively (Baseline Meteorological Data in Siberia (BMDS) Version 5.0, Yabuki et al., 2011). The area is dominated by larch (*L. cajanderi*) with birch (Betula spp.) and willow (*Salix* spp.). According to Kotani et al. (2014), the stand density of larch trees (with height > 1 m) is 1090 trees ha^{-1} and the mean stand height of the upper canopy is approximately 25 m. The understory vegetation is mainly composed of evergreen cowberry (*Vaccinium vitis-idaea*) mixed with several herbs.

2.2. Tree-ring width data

Sampling was undertaken in July of 2009, 2010 and 2011 at the Elgeeii meteorological station in the Ust-Maya region (60°0′N, 133°49′E). A total of 15 transversal disks and 49 paired cores were collected from living larch trees. Standard techniques of dendrochronology were employed in sample processing and chronology development (e.g., Baillie and Pilcher, 1973; Cook and Kairiukstis, 1990). These include measurement of early- and latewood widths (EW and LW, respectively) for two radii of a sample at a precision of 0.01 mm, followed by visual crossdating of the total ring width (=EW + LW, hereafter TR) series using the PAST4 program (SCIEM, Inc.). The quality of crossdating was later checked using the COFECHA program (Holmes, 1983). Finally, the ring-width chronology (ensemble mean of raw ring-width series) was computed, and was successfully crossdated with the russ112 ring-width data set drawn from the International Tree-Ring Data Bank (ITRDB, http://www.ncdc.noaa.gov/paleo/treering.html).

Detrending by a 128-year spline (Cook and Kairiukstis, 1990) was used to obtain standardized indices for our individual series of the earlywood (EW), latewood (LW) and total ring (TR), which were then averaged to generate standard chronologies using the ARSTAN program (version 41d; Cook, 1985). The quality of the chronologies was assessed by the expressed populational signal (EPS), whose value greater than 0.85 is a good compromise to determine the reliable part of a chronology (Wigley et al., 1984). The running EPS values were computed using a 51-year moving window.

After correlation analysis trials, it was clear that the TR widths show most pronounced relationship with climate variables (data are not shown) in ring-width dataset (EL, LW and TR). TR widths were used for the analysis hereafter.

2.3. Stable carbon isotope measurement

We used four samples for carbon isotope analysis. Each tree ring was separated into two parts, i.e., early- and latewood, with a surgical knife. Resin and oils were then removed from the wood

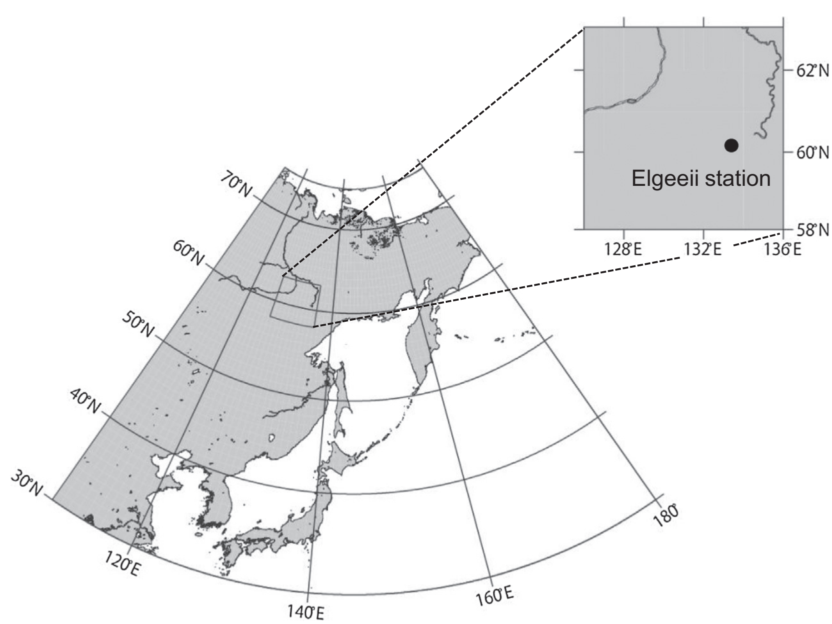

Fig. 1. Location of the study site (Elgeeii station) near Ust-Maya, eastern Siberia (60°00′N, 133°49′E).