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AUGUST TO JULY PRECIPITATION FROM TREE RINGS IN THE FOREST-STEPPE ZONE OF CENTRAL SIBERIA (RUSSIA)

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ABSTRACT

The goal of this research report is to describe annual precipitation reconstruction from *Pinus sylvestris* trees on three sites in the Abakan region, located in the Minusinsk Depression, at the confluence of the Yenisei and Abakan Rivers, Russia. The study was performed during the 4th annual international summer course "Tree Rings, Climate, Natural Resources and Human Interaction" held in Abakan, 5-19 August 2013. The reconstruction, for the 12-month total precipitation ending in July of the growth year, is based on a reliable and replicable statistical relationship between precipitation and tree-ring growth, and shows climate variability on both interannual and interdecadal time scales. The regional tree-ring chronology accounts for 56% of the variance of observed annual precipitation in a linear regression model, with the strongest monthly precipitation signal concentrated in May and June of the current growing season. Composite 500 mb height-anomaly maps suggest that the tree-ring data from this site, supplemented by other regional tree-ring data, could yield information on long-term atmospheric circulation variability over the study area and surrounding region.

Keywords: dendroclimatology, drought, detrending, SEASCORR.

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INTRODUCTION

Dendroclimatology is the science of determining past climate variability from tree rings. Time series of tree-ring measurements spanning several centuries serve as proxy records of past climatic conditions (Cook *et al.* 1999). Such records provide us with knowledge of the past frequency and severity of climatic anomalies, such as drought and wet periods, and can be used to help anticipate the probability of such events in the future.

Dendroclimatology studies in the Khakasian region of southern Siberia began with an investigation by Vaganov *et al.* (1985) of a wide range of ecological factors and climatic factors influencing tree-ring formation. This work was followed by other dendroclimatological and ecological studies (Magda *et al.* 2002, 2004, 2011; Block *et al.* 2003; Vaganov *et al.* 2006; Knorre *et al.* 2010), culminating in a reconstruction of June temperature in the forest-steppe of the Republic of Khakassia by Babushkina *et al.* (2011).

This report describes dendroclimatological aspects of the 4th annual international summer course “Tree Rings, Climate, Natural Resources and Human Interaction” (Figure S1). The main purpose of the course was training of participants in basic dendrochronology and in dendroclimatic application of tree-ring data. As part of the course, we produced a regional tree-ring chronology of *Pinus sylvestris* from the Abakan region, investigated the seasonal climatic signal of the chronology with correlation methods, and applied the chronology to reconstruct annual precipitation for the monthly grouping of previous August to current July (prior August-current January = PA-CJ). A 138-year reconstruction for the Abakan region is analyzed for time series features of variability relevant to water resources planning. The association between unusually dry years and wet years in Abakan, with broad-scale atmospheric circulation anomalies, is summarized by analysis of 500 mb height reanalysis data.

MATERIALS AND METHODS

Study Area

Three sites near Abakan were selected (Figure 1). The site GRN (53.66°N latitude and 91.59°E longitude) is 11 km southwest Abakan at an elevation of 273 m a.s.l. MAM and MIN (53.75°N latitude and 92.04°E longitude) are 30 km east of Abakan at 497 m a.s.l. and 506 m a.s.l., respectively. At the GRN site *Pinus sylvestris* forms pure stands but in MAM and MIN it grows in association with *Betula pendula*. The soil is similar at all three sites and is sandy with a humus layer at 10–15 cm. However, soil density at GRN is higher as compared to the other two sites, MAM and MIN. The relief of GRN has small depressions with slopes 2–15° whereas sites MAM and MIN are on a hill with slopes of 2–45°.

Chronology

Increment cores were taken from living trees at all sites. A total of 128 cores were taken from 67 trees. Samples were fine-sanded and crossdated using standard dendrochronological techniques (*e.g.* Stokes and Smiley 1968). The width of each annual ring was measured to the nearest 0.01 mm using TSAP-LINTAB (Rinntech 2011). In addition, CooRecorder and CDendro software (http://www.cybis.se/forfun/dendro/) were used to obtain measurements from digital scans of core samples. Crossdating and measurement accuracy were verified using COFECHA (Holmes 1983; Grissino-Mayer 2001).

Each tree-ring width series was fit with a cubic smoothing spline having a 50% frequency response cutoff equal to 67% of the series length to remove the non-climatic trends caused by tree age, size, and the effects of stand dynamics (Cook and Briffa 1990). The detrended series were then prewhitened with low-order autoregressive models to remove persistence, which was observed to be appreciably higher in the tree-ring series than in seasonal and annual precipitation. The resulting series is called a “residual” index. Combining of individual indices into the regional chronology was done using a bi-weight robust estimate of the mean (Cook 1985), designed to minimize the influence of outliers.

We used expressed population signal (EPS) to assess the adequacy of replication in the early years of the chronology (Wigley *et al.* 1984). We limited our analysis to the period with an EPS of

Figure 1. Locations of tree-ring sites (▲) and climate station (●).

at least 0.85 to ensure the reliability of the reconstructed precipitation. These thresholds correspond to a sample depth of 6 trees (12 series), and allow for reconstructing the period A.D.1875–2012 (Figure 2A).

Climate Data

Monthly precipitation (P) and temperature (T) were obtained from the Minusinsk meteorological station (Khakassian Centre of Hydrometeorology and Environmental Monitoring) (Figure 3). The period of availability of monthly data for the station is 1935–2012 for P and T.

We conducted correlation analysis of the residual ring-width chronology against the climate data using the seasonal correlation (SEASCORR) procedure developed by Meko *et al.* (2011). We used individual months as well as seasonal values integrating 3, 6, and 12 months. We considered a 14-month window starting in the August prior to the growth year and ending in the current September.

A transfer function analysis (TFA) was conducted between the regional tree-ring chronology and the seasonal climate series identified by SEASCORR. A regression equation of seasonal precipitation on the regional tree-ring chronology for the calibration period 1935–2012 was developed. The validity of this equation as a transfer function model for converting tree-ring values to precipitation values was examined using regression statistics (R^2 and adjusted R^2), and the PRESS procedure for cross-validation (Weisberg 1985; Fritts *et al.* 1990; Meko 1997; Touchan *et al.* 2011). A split-sample procedure (Snee 1977; Meko and Graybill 1995; Touchan *et al.* 2011) that divides the full period (A.D. 1935–2012) into two subsets (1935–1973 and 1974–2012) was also used to verify model stability. In the two verification periods, the reduction of error statistic (RE) was calculated as a measure of reconstruction skill (Fritts 1976). An RE value greater than 0 indicates positive skill. The calculated transfer function was then applied to the regional residual chronology to produce the time series of reconstructed PA-CJ total precipitation for as many years as the adequately-replicated portion of the chronology allowed.

Dry years and wet years were defined as reconstructed precipitation below or above specified thresholds corresponding to percentiles of the observed precipitation for the base period 1935–2012. Percentiles for the thresholds were based on exploratory scatter plots of reconstructed precipitation on observed precipitation, recognizing the threshold must be high enough to represent a significant departure from average conditions. A five-year moving average of reconstructed precipitation was used as an alternative summary measure of drought severity.

The association of extremely dry or wet years in Abakan with atmospheric circulation anomalies

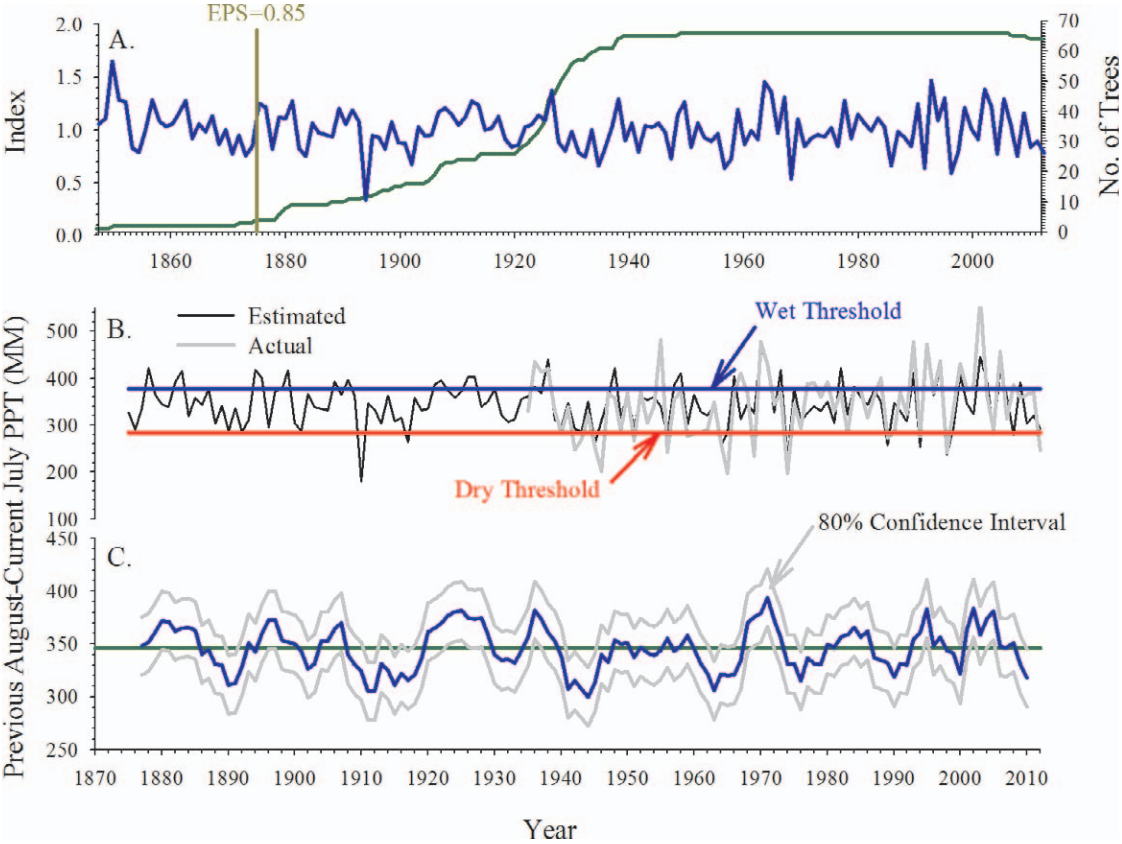

Figure 2. (A) Tree-ring residual chronology of *Pinus sylvestris* along with number of trees; (B) Time series plot of reconstructed PA-CJ precipitation; (C) Five-year moving average of reconstructed PA-CJ precipitation. Values are plotted at the center of each 5-year period. Uncertainty values are shown at 80% confidence interval.

in the warm season was studied with the aid of composite maps of 500 mb geopotential height anomaly drawn with the mapping tool provided by NOAA/ESRL Physical Sciences Division (http://www.esrl.noaa.gov/psd/) using NCEP/NCAR Reanalysis data (Kalnay *et al.* 1996).

RESULTS AND DISCUSSION

A regional chronology was built using material from three sites in Abakan (Figure 1). The tree-ring series of the three sites show strong similarities in terms of visual crossdating of the wood and computer-based quality control. The high degree of common variation in trees is supported by the EPS, which reaches a critical value of 0.85 at a sample size of 6 trees (Figure 2A).

The combined chronology is 138 years long (A.D. 1847–2012), which is slightly longer than the period deemed suitable for climate interpretation (A.D. 1875–2012). Average series inter-correlation among all radii is 0.51. The mean sample segment length (MSSL) of the regional chronology is 97 years and is adequate to investigate multi-decadal climate variability (Cook and Peters 1997).

PA-CJ total precipitation was selected as a reconstruction target (predictand for the reconstruction model) based on program SEASCORR results relating the residual chronology, 1935–2012, to P and T (Figure 3). The analysis identifies the strongest annual P signal as a 12-month total from previous August to current July. Individual months with most significant P correlation are previous August, previous November, current

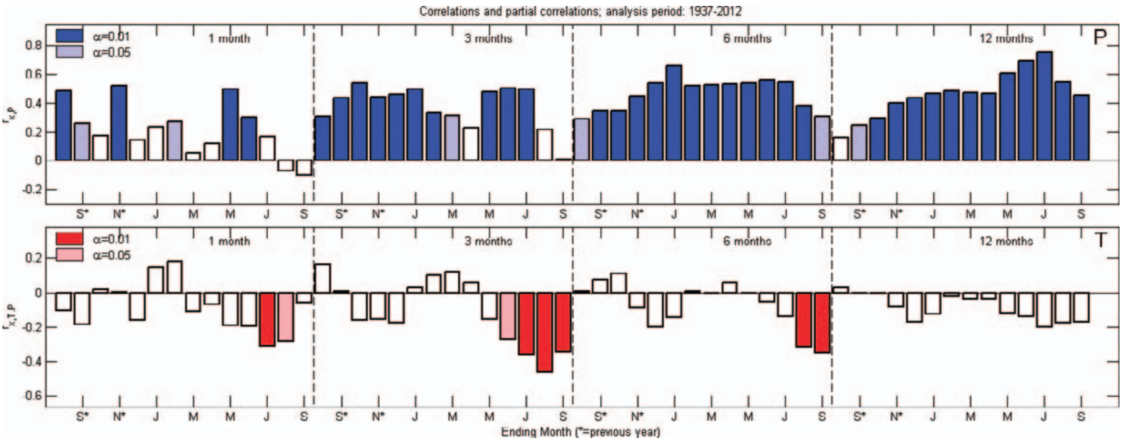

Figure 3. Program Seascorr summary of seasonal climatic signal in the residual chronology data. Climatic variables are monthly precipitation and temperature of Minusinsk meteorological station. (Top) Correlation of tree-ring variable with monthly, 3-month total, 6-month total, and 12-month total precipitation for ending months from August preceding the growth year through September of the growth year. (Bottom) Partial correlations (controlling for precipitation) of tree-ring variable with monthly average temperature. Colors indicate Monte-Carlo-derived significance of correlation or partial correlation (Meko *et al.* 2011) for α-levels 0.01 and 0.05. Analysis period is tree-ring years 1937–2012.

May and current June. Temperature's influence, summarized by partial correlations in SEASCORR, is significant for the single months of current July and August. The negative sign of partial correlations for those months indicates that high temperature exacerbates the negative tree-growth anomaly associated with a given precipitation deficit.

The final regression statistics for the 1875–2012 precipitation reconstruction, obtained from the relationship between the regional tree-ring chronology (predictor) and precipitation record (predictand), are highly significant (Figure 2B). The predictor variable accounts for 56% of observed precipitation. Cross-validation using the PRESS procedure indicates the model performs adequately in estimating precipitation data not used to produce the model (prediction R^2 = 0.54). The split-sample calibration-validation exercise indicated stability of the relationship over halves of the available instrumental data period. The computed RE statistics indicated skill of reconstruction in the calibration/validation exercises using different sub-periods. On this evidence, the full calibration period (1935–2012) was then used for the final reconstruction model (Table S1).

Empirical thresholds for the dry and wet events defined the 30th percentile of the observed P as 320 mm and the 70th percentile as 366 mm (Figure 2B). The long-term reconstruction for the period 1875–2012 contains 41 dry years according to these criteria. Twenty-two events have duration of one year, eight have duration of two years, and one has duration of three years (1915–1917). The driest single year of the reconstruction is 1910 (179.9 mm). The driest year in the instrumental data is 1965 (197.8 mm; reconstructed is 283.9 mm).

The reconstruction contains 41 wet years. The wettest year in the reconstruction was 1995 (472.9 mm; reconstructed is 469.8 mm). The wettest year during the instrumental data was 2003 (566.5 mm; reconstructed is 445.9). Nineteen wet events had duration of one year, five a duration of 2 years, and four lasted 3 years (1897–1899, 1921–1923, 1925–1927, and 1936–1939).

A five-year moving average of the reconstruction demonstrates multi-annual to decadal variation in PA-CJ precipitation and suggests several prolonged dry and wet events (Figure 2C). The driest five-year reconstructed period is 1940–1946 (300 mm). The second and third driest periods are 1910–1914 and 1961–1965. The wettest five-year reconstructed period is 1969–1973 (393 mm). Two other wet periods were 2000–2004 and 1993–1997.

The association of dry and wet years with circulation anomalies was studied with composite

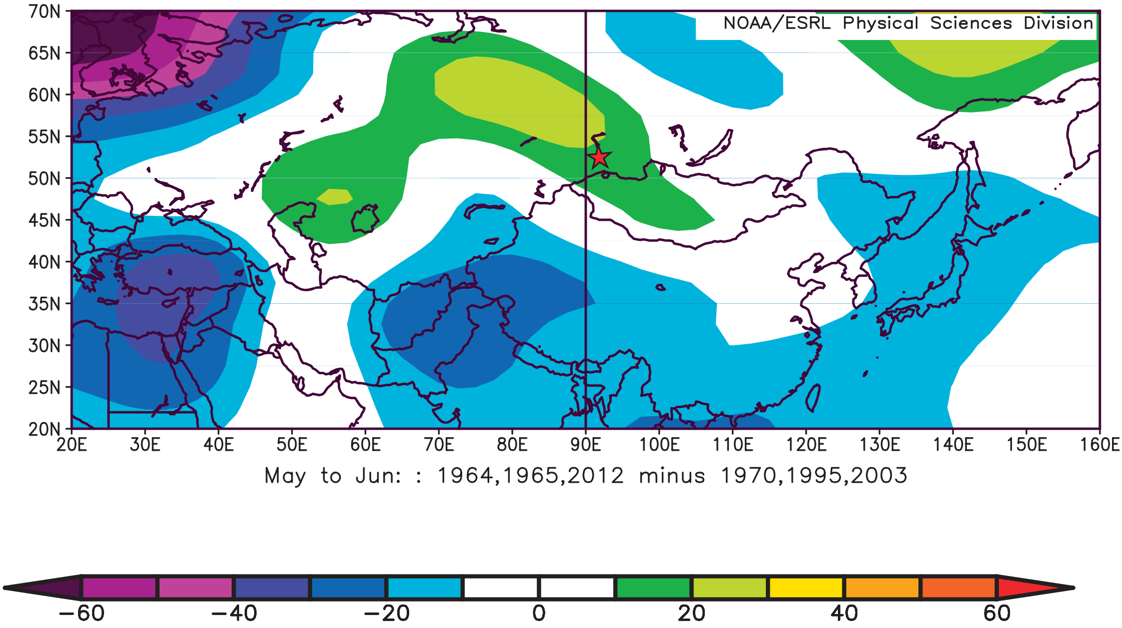

Figure 4. Composite map of difference in May-June 500 mb height anomalies in dry years and wet years. Years for composites are among driest (or wettest) ten years both in the precipitation reconstruction and in May-June observed precipitation at Minusinsk. Dry years are 1965, 1964 and 2012. Wet years are 1970, 1995 and 2003. Anomalies (color bar) are departures (m) from 1981–2010 climatology. Map drawn with online mapping tool from the NOAA Earth System Research Laboratory (http://www.esrl.noaa.gov/psd/cgi-bin/data/getpage.pl).

maps of the difference of average 500 mb geopotential height anomalies in dry and wet years (dry minus wet), 1949–2012 (Figure 4). To avoid mixing seasons with different characteristic circulation patterns, we focused this analysis on height anomaly and precipitation in the two-month season May-June: May and June are the only two consecutive months in the annual (PA-CJ) period for which the correlation between precipitation and tree-ring index is highly significant ($p < 0.01$).

First, the precipitation record was examined to identify the 10 driest and wettest observed and reconstructed years, 1949–2012. Second, the subset of years among the driest 10 by both observed and reconstructed data was identified. A subset of common wet years was likewise identified. These subsets focus on wet and dry years effectively captured by the tree-ring data. The procedure yielded three common dry years (1964, 1965, 2012) and three common wet years (1995, 1970, 2003).

The composite difference (dry-wet) 500-mb anomaly map for those subsets of years shows that the tree-ring site (red star) is located at the eastern edge of an anomalous high (Figure 4). This position is climatologically consistent in indicating a more stable atmosphere and more northerly flow at the site in dry years than in wet years.

CONCLUSIONS

The report represents the first precipitation reconstruction for the Abakan region. It demonstrates that tree-ring reconstruction provides a baseline for studying past climate variability beyond the instrumental data. The reconstruction can help natural resource managers apply low-risk and long-term plans to use, conserve, and sustain water and other natural resources that are the foundations of social, political, and economic systems in the region. Additional tree-ring collections from this region, combined with tree-ring datasets elsewhere, may be useful in studying long-term variability of atmospheric circulation anomalies, especially in the warm season.

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