The potential for long-term climatic reconstructions in the Western Altay mountains from living and relict larch.

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Introduction

In cold or arid regions wood from trees that lived hundreds or thousands of years ago may be so well preserved that it can be used to build campfires. The information stored in the annual rings of such stems can also serve as an invaluable archive of past climatic variations. The oldest material included in Millennial-length annually resolved reconstructions of past temperature (e.g., Mann et al. 1999, Esper et al. 2002, D'Arrigo et al. 2006) comes to a large extent from such relict material. However these archives are exceptionally rare. No large-scale reconstruction currently includes tree-ring material from more than 6 locations at AD 1000 (D'Arrigo et al. 2006). Longer chronologies derived from living and relict material are known from Sweden (Grüdd 2006), Mongolia (D'Arrigo et al. 2001), Spain (Büntgen et al. 2006), Alaska (D'Arrigo et al. 2005), and Siberia (Naurzbaev et al. 2002, Jacoby et al. 2000), for example. Here in we discuss the potential of a 1000-year regional temperature reconstruction in the Russian Altay mountains based on newly collected and measured relict material in conjunction with living samples.

A survey of the International Tree-Ring Data Bank rapidly reveals that the majority of tree-ring data represents annual ring-width (RW) measurements. This fact largely arises from the ease, speed, and generally strong environmental signal from this parameter. From certain environments and species, separate measures of earlywood and latewood widths may contribute to a better understanding of seasonal climate than ring-width alone (e.g., Meko & Baisan, 2001). It is also known that measures of maximum latewood density (MXD) of trees growing near the lower thermal limit of survival at the upper or latitudinal treeslines is an exceptionally sensitive indicator of growing season temperatures (Schweingruber et al. 1979, Briffa et al. 2002, Frank & Esper 2005). In comparison to RW, MXD tends to more faithfully record the inter-annual climate signal, possess less biological autocorrelation, and contain a climatic signal that is less dependent upon specific site ecologies.

With the goal of exploring parameter specific climate response, and to maximize reconstruction potential, we have limited the data included in this study to only those sites for which both RW and MXD measurements are available. The data from living trees were collected in the mid 1990's as part of the "Schweingruber network" (e.g., Briffa et al. 1996). The relict material was collected over the past decades, with the most recent samplings and measurements conducted by D.O. and A.K. Below, we present this dataset, show the relationships between the RW and MXD parameters within and between sites and detail the climate response of the living data. We then discuss the critical transition between the living and relict material, which can be used to help ensure that these data reflect the same environmental forcing and when merged, yield a continuous estimate of the same climatic changes.

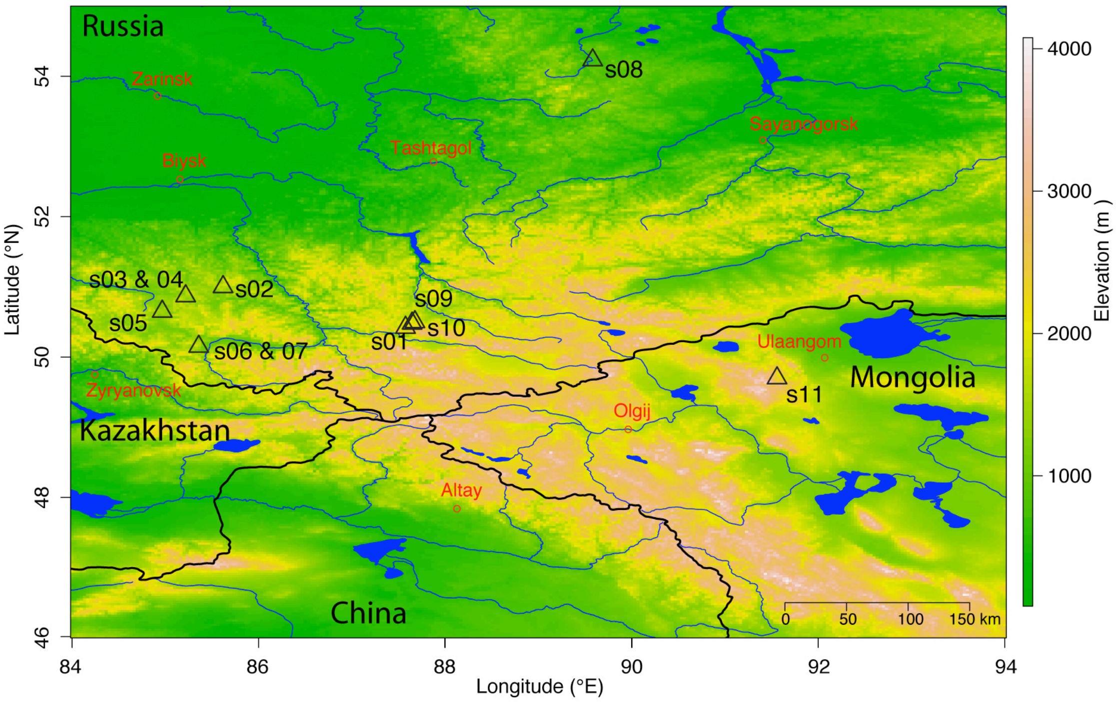

Figure 1: Map showing the location of the eleven living tree-ring sites concentrated in the Russian Altay mountains. For all sites both ring-width and maximum latewood density were measured. The relict material cover was primarily obtained in the same region as the living sites 1-7 and 9-10.

Data

Tree-ring chronologies

The majority of the living tree sites considered are located between 85-88°E longitude and 50-51°N latitude, with the relict material coming from a similar region. This area represents the westernmost limit of the Altay mountain chain, which continues eastward in Russia and south-eastward in Mongolia. The majority of the sampled living trees and all of the relict material are larch. Many sites are located at or near the timberline (**Fig. 1**), and with one exception all sites are located above 1450 m a.s.l. The living sites span at least the past two centuries, with 1570 being the earliest measured "living" ring (**Table 1**). The mean segment length (MSL, the number of years on a sample) at the living tree sites ranges from 137 years at Ust Koska Valley (s07) to 342 years at Ust Koska Hill (s06). The relict material has a generally higher MSL – a single has 807 measured rings. For all living tree samples, the number of rings to the trees center were estimated (**Fig. 2**), with the average (maximum) estimated number of unmeasured rings to the pith being 26 (181) years. These data were not available for the relict material at the time of writing. During the course of sample preparation and measurement, in many cases, continuous data from the full radii were not measured for reasons including breaks in cores, unsharp x-ray films, or exceptionally narrow tree-rings. Such gaps are illustrated in **figure 2**, but were estimated using data from other trees via the "gap-filling procedure" in the program ARSTAN (Cook 1985). This procedure allows measurement series to be detrended as a single continuous series, thereby allowing the longest possible wavelengths of climatic related information to be preserved (Cook et al. 1995).

Table 1: Listing of the tree-ring chronologies site names, species, position, maximum time span covered, the mean segment length, and the interseries correlations of the detrended measurements. LASI = Larix siberica, PCOB = Picea obovata, PISY = Pinus sylvestris, LAGM = Larix gmelinii.

Code	Name	Species	Lat. (°N)	Long. (°E)	Elev. (m)	Span	MSL	Rbar (TRW)	Rbar (MXD)
s01	Aktasch Valley	LASI	50.42	87.58	2000	1601 - 1994	287	0.41	0.39
s02	Ceminsky pass	LASI	51.00	85.63	1450	1611 - 1994	280	0.40	0.37
s03	Jablonsky Pass E.	LASI	50.87	85.23	1450	1636 - 1994	250	0.48	0.46
s04	Jablonsky Pass W.	LASI	50.87	85.23	1400	1761 - 1994	210	0.57	0.52
s05	Kirisky Pass	LASI	50.65	84.98	1500	1741 - 1994	229	0.54	0.53
s06	Ust Koksa Hill	LASI	50.15	85.37	1750	1581 - 1994	342	0.47	0.42
s07	Ust Koksa Valley	PCOB	50.15	85.37	1700	1775 - 1994	137	0.18	0.33
s08	Tyn Hill	PISY	54.23	89.58	650	1613 - 1994	214	0.45	0.26
s09	Ust Ulagan Bog	LASI	50.50	87.68	1950	1697 - 1994	269	0.48	0.42
s10	Ust Ulagan Lake	LASI	50.48	87.65	2150	1581 - 1994	229	0.42	0.47
s11	Turgen-charchira Mtn.	LAGM	49.70	91.55	2000	1570 - 1995	254	0.52	0.34
s12	Altay Relict	LASI	–	–	–	912 - 1812	315	0.43	0.49

For chronology development, the age-trend was removed in all samples by taking ratios from 300-year cubic smoothing splines. In the rare cases, where the detrending curve went below zero, more flexible splines were used. This detrending will allow preservation of climatic information at annual to ca. centennial time-scales. The variance of the mean chronologies were stabilized for changes in both interseries correlations and sample replication (Frank et al. 2006a, Frank et al. 2006b).

Instrumental data

The instrumental data used for comparison were taken from the CRU TS 2.1 0.5 x 0.5° gridded dataset (Mitchell & Jones 2005). This latest CRU release of high resolution land data contains a variety of climatic parameters at monthly resolution and maximally spans the 1901-2002 period. For this study we considered mean, minimum, and maximum average monthly temperatures, and total monthly precipitation. Climatic correlations were computed between tree-ring series and the grid-box data "covering" the site locations. Differences between the different gridboxes were for the most part rather minimal. For the purposes of this study, this dataset has the advantage of allowing comparison with many different climatic parameters, which are not easy to otherwise obtain. Disadvantages, however, include that in developing the gridded dataset, all station data were used without correction for possible inhomogeneities or trends arising from, for example, urban warming. This dataset was designed more to allow assessment of the most likely climatic conditions at any point in space at any point in time. Thus the seasonal cycle is designed to be well captured, but long-term trends in these data are not necessarily fully reliable indicators for the surrounding natural climate conditions.

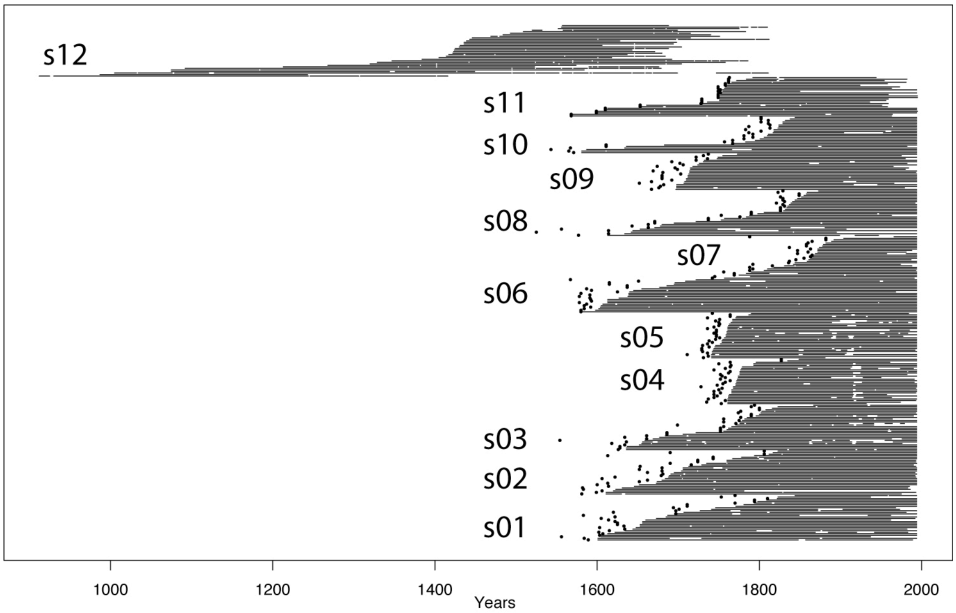

Figure 2: Beams showing the time spans covered by the individual measurement series ordered by sites. Gaps within beams reflect periods where no measurement data exists. Estimates of the years missing to the pith (pith-offset) are shown as black dots.

Results

Site chronologies

After detrending the average interseries correlation (Rbar) of the RW and MXD sites chronologies were very similar at 0.45 and 0.42, respectively. At the different sites, the correlation of the RW and MXD chronologies derivied from the same trees tend to be highly correlated (**Fig. 3**). With the unsmoothed data, correlations over the full chronologies time spans range between 0.11 and 0.74, with a median correlation of 0.61. These correlations increase after 15-year smoothing to 0.28 – 0.82 for the range, and 0.67 for the median, and accordingly decrease after 15-year high-pass filtering to 0.00 – 0.68, and 0.58. It is unclear what fraction of this common low-frequency behavior is driven by the common climate signal, or if there is some intrinsic relationship between between RW and MXD, where for example, the low frequency trends are contained in the RW, and are subsequently found in the MXD data due to a lack of independence between these two parameters. Recent explorations in the shared information has resulted in a new detrending method that better reveals the independent seasonal signal of the RW and MXD parameters (Kirdyanov et al. 2006).

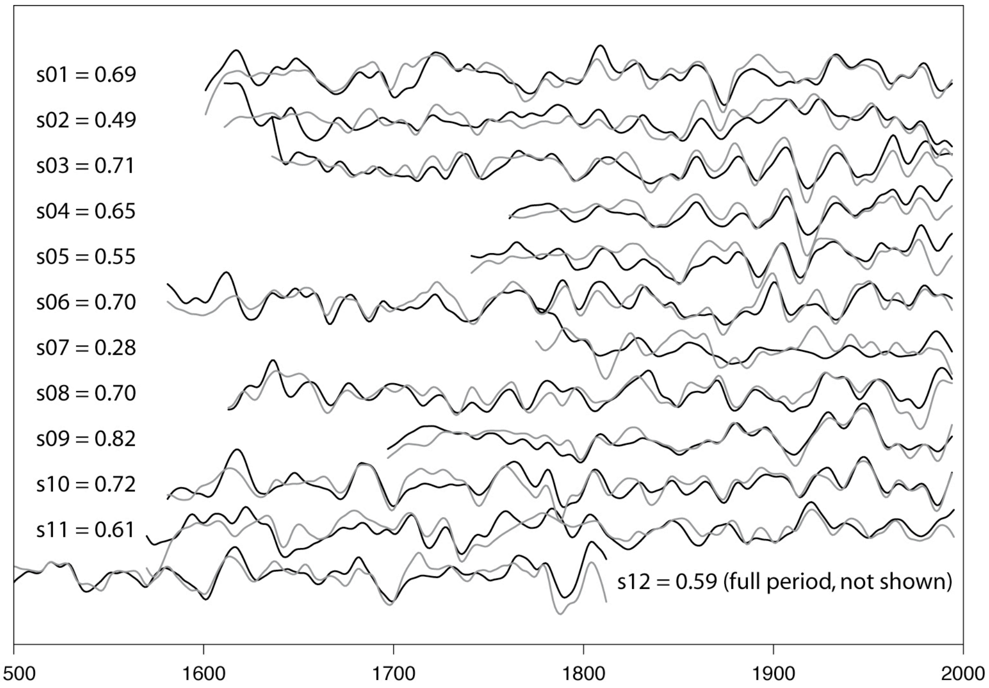

Figure 3: Decadal variation in the TRW and MXD chronologies shown after smoothing with a cubic-spline with a 15-year frequency response threshold.

The common signal between the various RW site chronologies is displayed in **figure 4**. The RW chronologies, tend to have unspectacular correlations with the median site having an average correlation of 0.23 with the other sites. This figure increases for the MXD chronologies to 0.32. As expected, correlations are highest between sites that are geographically proximal and are of the same species. These considerations are more important for RW, than for MXD. Based on these analyses, we retained data from eight living tree sites (s01-s06 and s09-s10) for more detailed consideration of the climatic response and possible merging with the relict material. These sites are all Larix and are concentrated in the western most portion of the Altay mountains.

Climate response

Correlations between the eight retained RW and MXD chronologies with the four climatic variables considered are shown in **figures 5 and 6**, respectively. The RW response to all three temperature variables is quite similar, with generally highest correlations to June in of the year of ring formation. Both significant ($p < 0.05$) positive and negative correlations are found to previous years conditions with particularly variable response during the winter. Four sites showing significant positive correlations with previous march temperatures. Of the seasonal means shown, correlations with average temperatures of the year prior to ring formation and for current June and July tend to be highest. Response to monthly and seasonal precipitation was generally found to be minimal, with the exception of four sites showing negative correlations to rainfall from the previous July.

The MXD response to the monthly and seasonal temperature variables is much stronger and more consistent between all of the sites. A positive temperature response maximum, beginning in May and ending in August is evident. Here different correlation levels to mean, maximum, and minimum temperatures are found, with the highest values obtained for the maximum monthly and seasonal temperature data. All eight of the chronologies show significant ($p<0.05$) response to May-August, June-August, and June-July maximum temperatures. In contrast, no more than six chronologies show $p< 0.05$ correlations with any minimum temperature seasonal mean. The response to mean temperatures (an average of maximum and minimum) is intermediate. Correlations between the MXD chronologies and precipitation during the summer of growth tend to be negative. This likely reflects the negative correlation between temperature and precipitation during these months. Three of the chronologies also show a significant ($p < 0.05$) correlations with precipitation from the preceding July.

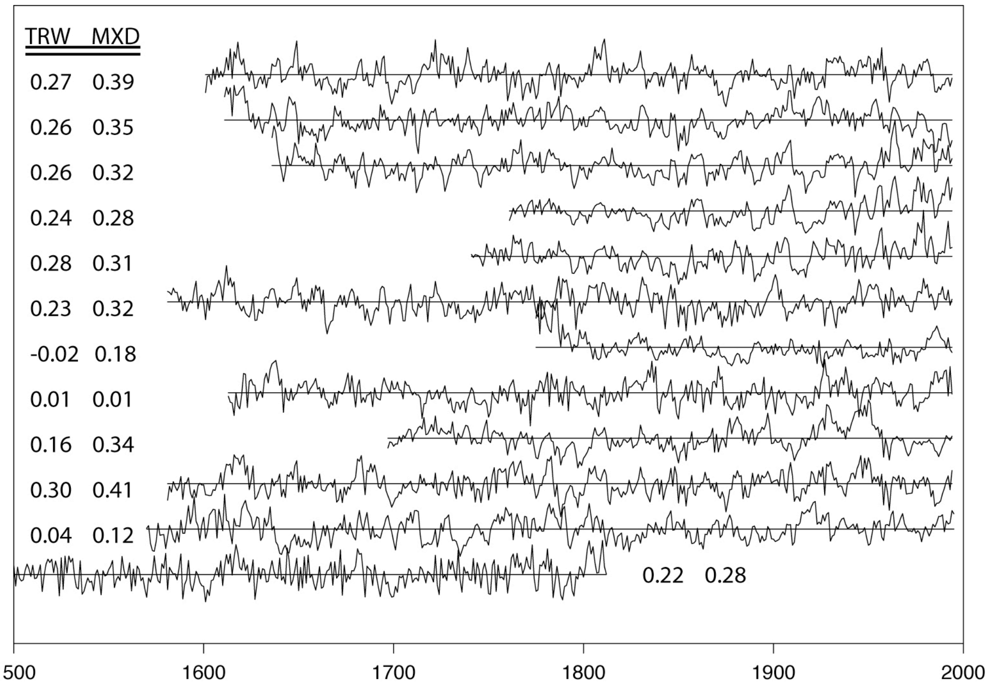

Figure 4: 300-year spline detrended TRW chronologies after normalization over their full lengths demonstrating the common signal. For the 12 sites the average correlation with the other sites over their individual overlap is shown for TRW (left) and MXD (right).

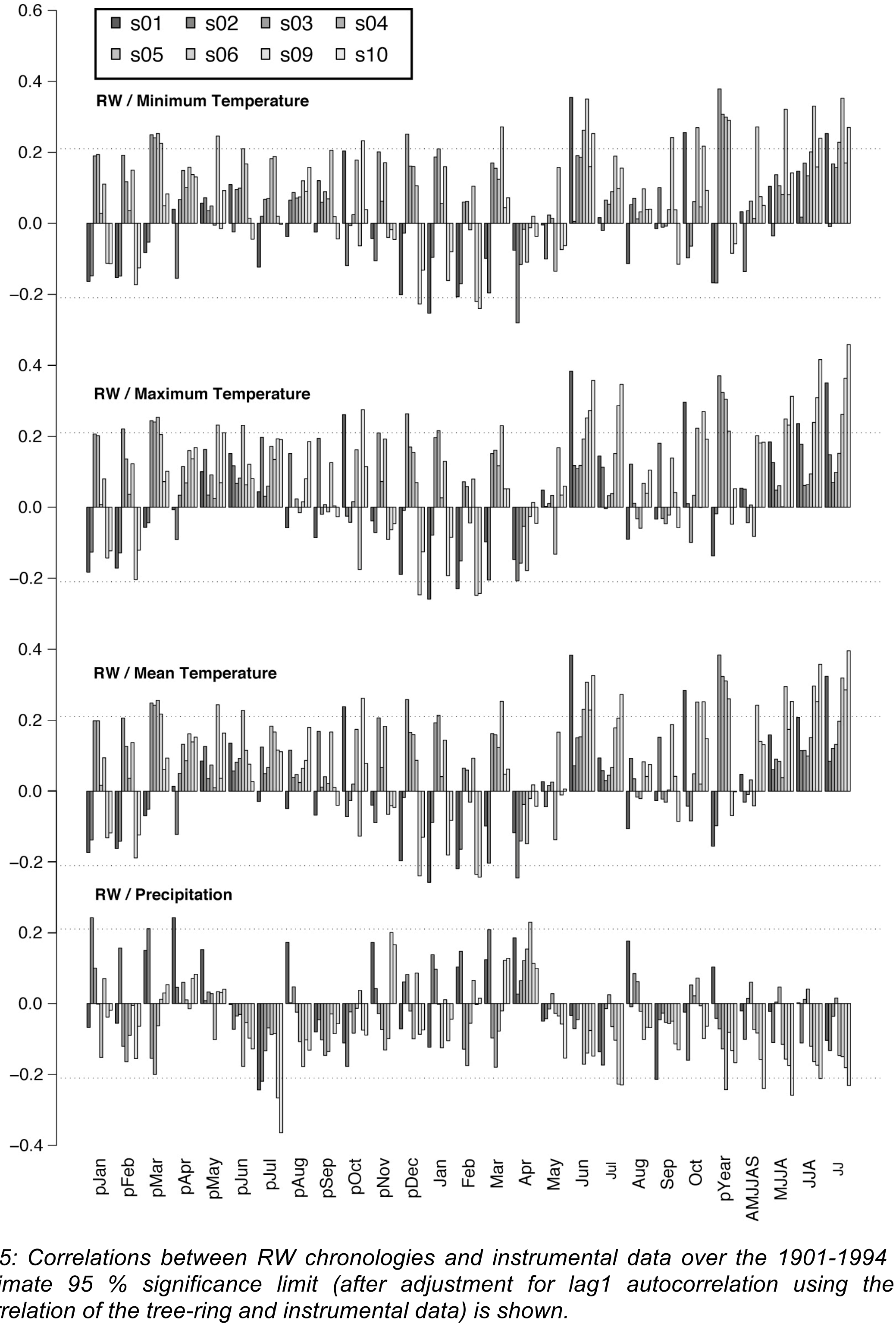

Figure 5: Correlations between RW chronologies and instrumental data over the 1901-1994 period. Approximate 95 % significance limit (after adjustment for lag1 autocorrelation using the mean autocorrelation of the tree-ring and instrumental data) is shown.

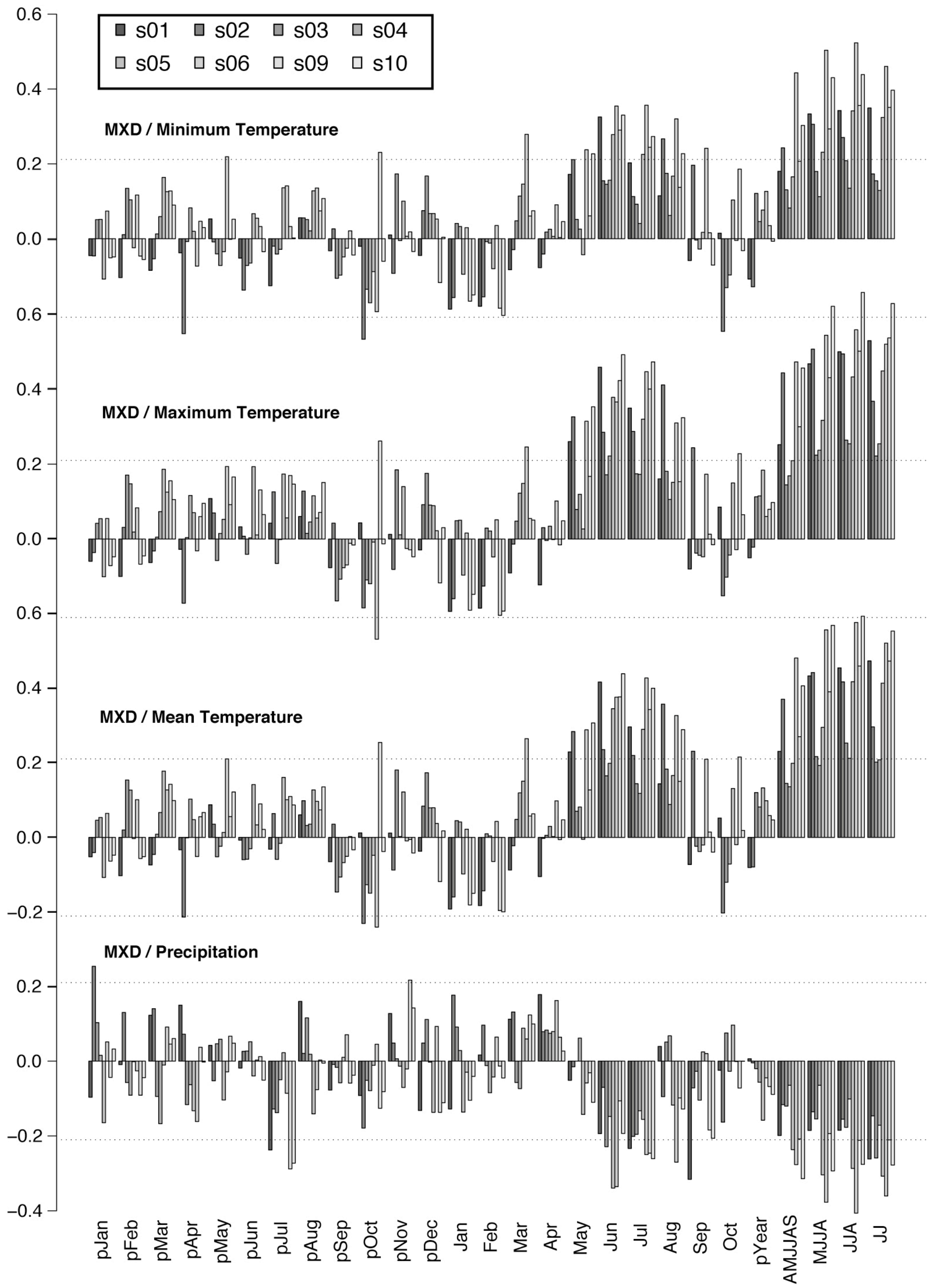

Figure 6: As for figure 5, but for MXD data.

Reconstruction potential

A new MXD chronology was computed as the variance stabilized bi-weight robust mean of the individual series from the eight retained living sites (and the detrended relict material). Based on the climate response, average June-August maximum temperatures from a single representative grid-point (center 50.25°N, 86.75° E) were chosen for further comparison with the MXD data. This Altay MXD composite was scaled to the mean and variance of the temperature "target" over the the 1901-1994 common period (**Fig. 7**). The MXD data explain

36% of the instrumental variance, and thus indicates reasonable reconstruction potential from these tree-ring data.

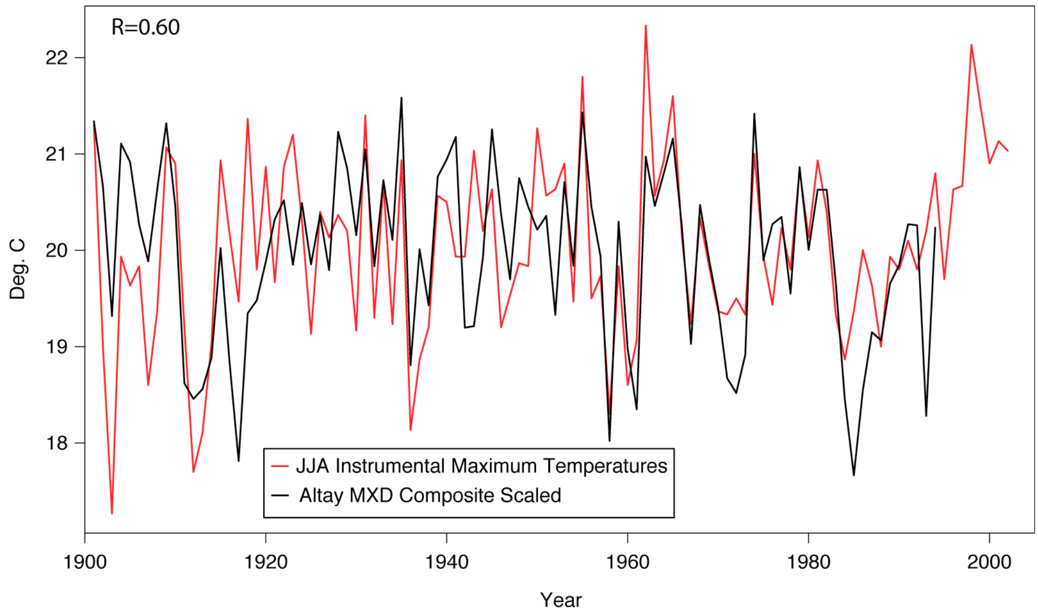

Figure 7: Altay regional composite chronology after scaling to average June-August maximum temperatures.

Discussion

The living and relict material described herein are well positioned to serve as a valuable regional archive of past summer temperature variations. This composite chronology extends prior to AD 1000, and contains more than five samples after 1075 AD making it one of only a handful of records containing MXD data early in the past millennium (Büntgen et al. 2006). From the central Asian region, a RW chronology of Siberian Pine (Jacoby et al. 1996, D'Arrigo et al. 2001) has played a prominent role in large-scale reconstruction efforts (Esper et al. 2002, D'Arrigo et al. 2006, Jones and Mann, 2004). The Russian Altay data are located approximately 800 km west thus widening the "covered" region. Perhaps more importantly, the climate signal which we have demonstrated in the MXD data suggests the potential for a very large contribution capturing central Asian interannual temperature variability more skillfully than existing millennial-length RW records.

The strongest response to maximum summer temperatures represents one of a few recent studies (e.g., Wilson and Luckman 2003, Büntgen et al. 2006) that show this pattern. Maximum temperatures are most clearly related to daytime conditions, and potentially also reflect the positive association between temperatures and solar radiation. For many parts of the world, modelled results indicate a slight to significant radiation limitation on plant growth (Nemani et al. 2003). It is plausible that these increased correlations seen in the MXD parameter, are a reflection of the synergistically increased photosynthetic activity during warmest and also sunniest months.

Climate correlations performed on both 15-year high and low-pass filtered tree-ring and instrumental data (not shown) show the dominant response for the RW and MXD data in the higher frequency domain. It is unclear how much of this relates to the poorer suitability of the high resolution gridded dataset for understanding longer- term behavior, the actual tree response, or other factors. This topic requires further investigation.

For the success and accurate preservation of low-frequency climatic information in a composite reconstruction using detrending methods such as Regional Curve Standardization (RCS, Briffa et al. 1992), living and relict material fused together should come from the same location and site-ecologies, and thereby hopefully contain the same environmental response. Initial tests (not shown) suggest that the form and relative levels of the mean age-aligned data from the living and relict material are reasonably similar. Plots of the mean level of growth vs. the segment length (not shown) also do not immediately reveal exceptional differences. One consideration which we have currently identified, is that the mean segment length (as well as maximum number of rings per sample) is substantially higher for the relict material.

Future field campaigns in this region to locate and sample relict material will hopefully be conducted to further increase the amount of early relict data, as well as to update the material from living trees to include rings from the most recent decade.

Acknowledgements

We are grateful to Daniel Nievergelt for measuring the living-tree chronologies. This work was supported by the Swiss National Science Foundation (NCCR-Climate and EuroTrans) .

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