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**J. Esper · S. G. Shiyatov · V. S. Mazepa · R. J. S. Wilson
D. A. Graybill · G. Funkhouser**

Temperature-sensitive Tien Shan tree ring chronologies show multi-centennial growth trends

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Abstract Two millennia-length juniper ring width chronologies, processed to preserve multi-centennial growth trends, are presented for the Alai Range of the western Tien Shan in Kirghizia. The chronologies average the information from seven near-timberline sampling sites, and likely reflect summer temperature variation. For comparison, chronologies are also built using standard dendrochronological techniques. We briefly discuss some qualities of these "inter-decadal" records, and show the low frequency components removed by the standardization process include a long-term negative trend in the first half of the last millennium and a long-term positive trend since about AD 1800. The multi-centennial scale Alai Range chronologies, where these trends are retained, are both systematically biased (but in an opposite sense) in their low frequency domains. Nevertheless, they represent the best constraints and estimates of long-term summer temperature variation, and reflect the Medieval Warm Period, the Little Ice Age, and a period of warming since about the middle of the nineteenth century.

J. Esper (✉)
Swiss Federal Research Institute WSL,
Zürcherstrasse 111, 8903 Birmensdorf, Switzerland
E-mail: esper@wsl.ch

S. G. Shiyatov · V. S. Mazepa
Institute of Plant and Animal Ecology,
Ural Division of Russian Academy of Sciences,
8 Marta Street 202, 620144 Ekaterinburg, Russia

R. J. S. Wilson
School of GeoSciences, Grant Institute,
Edinburgh University, West Mains Road,
Edinburgh EH9 3JW, UK

D. A. Graybill · G. Funkhouser
Laboratory of Tree-Ring Research,
University of Arizona, Tucson,
Arizona 85721, USA

1 Introduction

From a hemispheric perspective (e.g., Briffa and Osborn 2002), more high-resolution, millennia-length temperature reconstructions are needed to better understand climate history on a regional scale. However, when dealing with such millennia-length tree ring based temperature reconstructions, we are confronted with the limitation that such reconstructions frequently do not capture low frequency, multi-centennial climate variability (Esper et al. 2002b). Unfortunately, potential low frequency, multi-centennial information is often lost during the processes of tree ring data standardization and chronology building (Cook and Kairiukstis 1990; Fritts 1976). Here we use the phrases "multi-centennial", "inter-decadal", and "inter-annual" for ring width and temperature variations with wavelengths of > 100 years, > 10–100 years, and 1–10 years, respectively.

Losses in low frequency often occur during the individual standardization of tree ring measurements. "Individual standardization" describes the technique of fitting a stochastic or deterministic function to individual ring width measurements (tree ring series in mm), to remove non-climatic noise from the data by calculating ratios or differences between measurements and the fitted function. Such non-climatic noise is often a long-term decreasing trend related to the aging process of trees (Fritts 1976), but could be other disturbance signals (Cook 1985). The term "segment length curse" was introduced into dendrochronology by Cook et al. (1995) to describe the fact that the maximum wavelength of recoverable information by a tree ring chronology is related to the mean sample length. More specifically, the ages of single trees determine the maximum low frequency loading of a reconstruction when measurements are individually standardized. This is an inherent obstacle in individual tree-ring standardization, and is why many tree ring based climate reconstructions show only inter-annual to inter-decadal variations (overview in Schweingruber 1996). Exceptions include reconstructions using long-lived species such as Bristlecone pines, where the segment lengths are much greater than multi-centennial time scales. In this species age trends tend to be rather small, so that individual ring width measurements can be reasonably standardized in relation to their total means (e.g., LaMarche 1974).

The segment length curse is a major limitation when using tree ring series to study longer scale climatic trends such as the Medieval Warm Period, Little Ice Age, or recent warming. Methods to overcome this limitation are rare (Briffa et al. 1996, 2001) and require high sample replication (numbers of trees). On a hemispheric scale, Esper et al. (2002b) studied these limitations and merged 14 tree ring sites from the Northern Hemisphere extra-tropics. The resulting well-replicated data set allowed the application of an age-related standardization method, Regional Curve Standardization, or RCS, (Mitchell 1967; Becker et al. 1995; Briffa et al. 1996), to preserve multi-centennial temperature trends in this reconstruction (hereafter, ECS) (Esper et al. 2002b). RCS and age-banding (Briffa et al. 2001) are presently the only methods that enable the reconstruction of common low frequency variation from tree ring samples with segment lengths typically below ∽300 years (e.g., Briffa et al. 1992, 1995; Cook et al. 2000, 2003).

In this study, we exclusively address regional, longer period climatic trends in an effort to develop a reconstruction of common multi-centennial growth trends from a temperature sensitive tree ring network. To this end, a subset of high elevation juniper tree sites from southern Kirghizia is analyzed. These sites are part of two larger networks sampled on a Russian/US expedition in 1988, and a German/Swiss expedition in 1996. Work on the inter-annual to inter-decadal climatic response of Western Central Asian juniper trees (Esper 2000b; Esper et al. 2002c, d) indicates that the growth variations of these high elevation, near-timberline sites are predominantly limited by temperature. The mid-to-low elevation sites from these networks (Esper 2000b; Graybill et al. 1992) are not considered in the present analysis, as they are not exclusively temperature sensitive.

Combining the data from both fieldtrips, we believe that a sufficient amount of high elevation, extremely old juniper exists to study long-term, multi-centennial ring width (and climate) variation over the last millennium. To reach this objective, we use standard dendrochronological techniques (Cook and Peters 1981), to build an "inter-decadal" scale Alai Range ring width chronology. This chronology has a high signal strength, which we define as the common variance in a group of samples, back to ∽AD 1100. The inter-decadal scale records are then exploited to demonstrate that some long-term negative trends before 1600 and some long-term positive trends after 1800 were removed during chronology development. The search and rescue for this missing low frequency variation, and particularly to estimate the amplitude of multi-centennial trends is non-trivial, and accordingly, two alternative chronologies retaining such variations are calculated. We demonstrate that both multi-centennial chronologies are systematically biased in their low frequency domains. However, we also argue that these tree ring time series are currently the best estimates of multi-centennial summer temperature history for the western Tien Shan region, and that these records are not limited to higher frequency variations only. The multi-centennial records are finally compared with the ECS reconstruction.

2 Data and methods

The juniper sites from the 1988 and 1996 multi-species networks are concentrated in the south of Kirghizia in the Alai Range, where *Juniperus seravchanica* Komarov., *J. semiglobosa* Regel and *J. turkestanica* Kom. are the dominant tree species (Fig. 1).

From a total of 14 juniper sites, we utilize the seven highest elevation *J. turkestanica* chronologies, all situated above 2900 m a.s.l. near the upper timberline (Table 1). The ring width data of these seven sites were combined to develop three valley composite series; West, East 1, and East 2. Each composite group (XJT + KJT; AJT + MJT; HOCH + MUR + BON) was defined due to the close proximity of the sites within a valley and their high inter-site correlation results (XJT and KJT 0.697, AJT and MJT 0.524, HOCH and MUR and BON 0.759; all calculated over 1800–1987).

A detailed description of the ecology of the high elevation juniper sites is given elsewhere (Esper et al. 1995; Esper 2000b; Graybill et al. 1992). Herein, we detail only those data properties that are relevant to the main objective of recovering common low frequency variations. The high elevation sites are composed of *J. turkestanica*, growing in open forests with distances of ∽10 m between single trees. Junipers build star shaped, often twisted stems, and frequently develop strip bark growth forms (Esper 2000a). Strip bark growth forms, where the bark does not cover the entire circumference of the stems, are also described for species in North America (e.g., Ferguson 1968; Kelly et al. 1992; Wright and Mooney 1965). In western Central Asia, the ages of Juniper trees correlate positively with elevation (Esper 2000b), suggesting that the cold conditions near the upper timberline are likely accountable for trees reaching ages older than 1000 years.

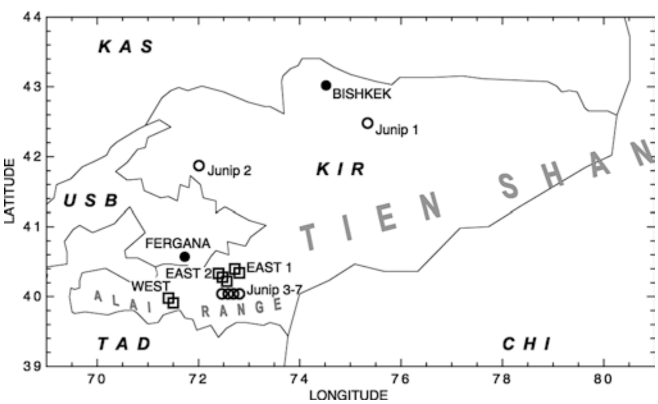

Fig. 1 Juniper sampling sites in Kirghizia and location of the Fergana meteorological station. Junip 1–7 (*circles*) are low-to-mid elevation sites not used in this study. High elevation *Juniperus turkestanica* sites (*squares*) are located in the Alai Range, southern Kirghizia. From these, XJT + KJT and AJT + MJT and HOCH + MUR + BON are combined to make the composite groups West, East 1 and East 2, respectively

Table 1 Alai *Juniperus turkestanica* site chronologies

Group	Latitude/Longitude	Site	Elevation	Series (trees)	Period	MSL (STD)	AGR
West	39°50′/71°30′	XJT	3400 m	24 (18)	694–1987	574 (311)	0.310 mm
		KJT	3150 m	23 (18)	1019–1987	496 (203)	0.369 mm
East 1	40°12′/72°37′	AJT	3200 m	27 (25)	1420–1997	361 (109)	0.432 mm
		MJT	2800 m	18 (17)	1427–1987	309 (107)	0.521 mm
East 2	40°10′/72°35′	HOCH	3200 m	50 (30)	1316–1995	296 (146)	0.406 mm
		MUR	3000 m	49 (25)	1157–1995	365 (206)	0.418 mm
		BON	2900 m	34 (20)	1346–1995	301 (136)	0.544 mm

MSL Mean segment length, AGR average growth rate calculated over the total individual lengths of all trees

During both fieldtrips, dominant and co-dominant trees were sampled using an increment borer, with the number of trees sampled ranging from 18 at MJT to 30 at HOCH. The first year of site chronologies range from AD 694 in XJT to 1427 in MJT (Table 1). Due to the irregular stem growth forms many core samples miss the pith by an unknown number of rings. Even though all sites lie close to the upper timberline, significant differences in mean segment lengths are recorded, indicating different age-structures of sampled stands. Average growth rates, influenced by local site ecology and tree age, are also different between the sites and range from 0.310 mm in XJT to 0.544 mm in BON (Table 1).

Three standardization methods are applied to the Alai data: (1) spline standardization (SPL), (2) long-term mean standardization (LTM), and (3) regional curve standardization (RCS).

1. SPL. To build conventional inter-decadal scale chronologies, the West, East 1, East 2 data, after a power-transformation, were standardized by fitting cubic smoothing splines with a 50% frequency-response cutoff width equal to 67% of the series length to each individual series (Cook and Peters 1981). The data-adaptive power transformation stabilizes the heteroscedastic variance that is commonly found in ring width series. The power applied to a series is $1 - x$, where x is the slope of a linear regression in logarithmic space between the local spread (standard deviation from year-to-year) and local level (ring width in particular year). The resulting ring width series are thus homoscedastic (details in Cook and Peters 1997). Indices are obtained by calculating differences between power transformed ring width measurements and fitted splines. This method, relying upon individually fit splines, removes multi-centennial variation from the Kirghizian data.

2. LTM. To build multi-centennial scale chronologies, only the series with lengths $>$ 500 years are used. Series were standardized by calculating differences between the ring width measurements and their long-term means (average growth rate per series) (LaMarche 1974). A power transformation was again applied prior to standardization. This method retains multi-centennial information in the resulting chronology, but biases the early chronology levels towards higher values if ring width age-trends (i.e., noise) exist in the raw measurements. A positive bias in this early portion causes a relative deflation in latter values.

3. RCS. The second approach to recover multi-centennial variation is the regional curve standardization method applied to all series (after power transforming them) from West, East 1, and East 2. In this method, all series are aligned by cambial age and a regional (noise) curve is fit to the arithmetic mean of the age-aligned data using a cubic smoothing spline with a 50% frequency-response cutoff width equal to 10% of the mean curve's length. This regional curve represents a time independent estimate for the age trend, and subsequently anomalies of all measurement series from the regional curve are calculated using differences (details in Briffa et al. 1996; Esper et al. 2002a). As with the LTM approach, this method also recovers potential low frequency variation in the resulting chronology, but here, biases the more recent chronology levels to higher values, when the younger, systematically faster growing samplings (Table 1, e.g., MJT) enter the calculation.

All chronologies were calculated as the arithmetic mean of the standardized single series, and a variance stabilization method was applied to adjust for changing sampling sizes by utilizing the sample size information and the average correlation between single series (Osborn et al. 1997).

To estimate the signal strength of the inter-decadal scale chronology, the expressed population signal (EPS, Wigley et al. 1984) is calculated for 50-year intervals with an overlap of 25 years. The EPS considers the inter-series correlation and the sample size information and estimates how well a finite number of samples represents the theoretical population average. Although the EPS is a useful measurement for inter-annual to inter-decadal scale variations, it is a poor measure of signal strength for multi-centennial variation. For the multi-centennial LTM and RCS chronologies, the coefficient of variation, which measures the vertical spread of the single series contributing to a mean chronology in each chronology year, is applied. Systematically increasing, and more generally, temporally changing coefficient of variation values indicate lower confidence accompanying the low frequency chronologies. The parameter is independent of the chronology level, and thus a useful measurement of common variance in multi-centennial chronologies (details in Esper et al. 2001).

3 Inter-decadal Alai chronologies

The SPL chronologies of West, East 1, and East 2 show common inter-annual to inter-decadal variations over the last few centuries (Fig. 2). For example, Fig. 2A visually highlights the strong inter-decadal signal in the West detrended single series. In most periods since ~AD 1100, many (often all) standardized ring width measurements synchronously record inter-decadal periods of common above or below average growth within a range of 0 to ~2 index values. Examples are the positive period around 1800, the negative period around 1840, the positive period, with higher variances between single series, around 1900, and the slightly below average values during most of the 20th century, and so on. The signal becomes weak before ~1100, where sample replication is low. Periods of reduced variance between single series (e.g., the fifteenth century) have higher signal strengths than periods of increased variance (e.g., last two thirds of the thirteenth century). Common inter-decadal variation is an indicator for climatic forcing, and temporally changing signal strengths are typical for tree ring proxy records (Cook and Kairiukstis 1990; Fritts 1976).

A comparison of the inter-decadal signal between the West, East 1, and East 2 chronologies shows high degrees of common variance (Fig. 2B). Examples of regionally common inter-decadal signals are the positive indices around AD 1800 or around 1900, and the negative indices around 1760 or around 1840, and so on. The similarity between East 1 and East 2 is generally higher than that between the eastern and western data.

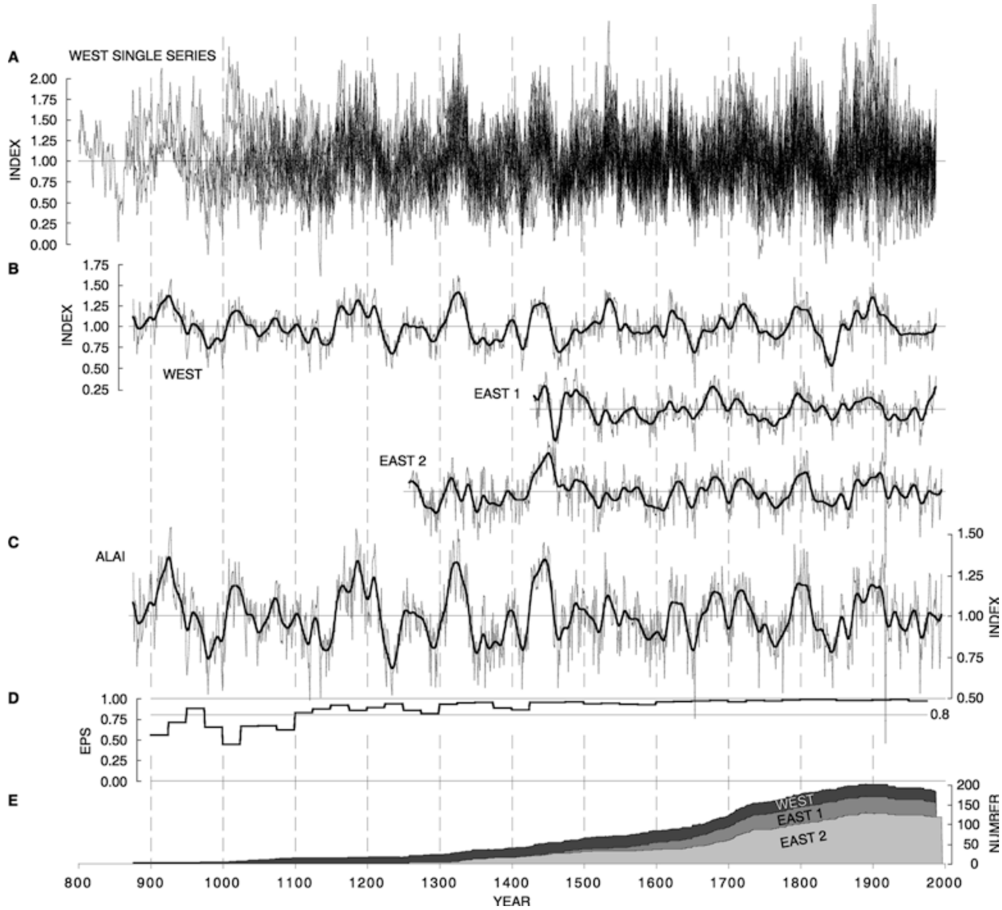

Fig. 2A–E Inter-decadal scale Alai chronologies. **A** SPL standardized single series West. **B** Inter-decadal chronologies West, East 1, and East 2. **C** Inter-decadal regional Alai chronology, and **D** EPS measurements of this record. **E** Sample size information. Bold curves in **B** and **C** are spline low-pass filters. All chronologies are truncated at sample sizes < 4 series

Differences in amplitude and persistence between the three SPL chronologies (e.g., the negative deviation around AD 1840) might be caused by differing site ecologies or climatic forcing. Differences increase again in the early periods of the site chronologies (e.g., fifteenth century), where replication is relatively low (Fig. 2E).

The strong common inter-decadal variance between the West, East 1, and East 2 chronologies suggests that all the ring width data can be combined to calculate a regional Alai Range inter-decadal scale chronology (Fig. 2C). This regional SPL standardized chronology is built using all individual measurements and is thus weighted by the number of series contributing from each data set (Fig. 2E). It would also be reasonable to calculate a mean function from the three chronologies West, East 1, and East 2 rather than using the individual measurements, but the resulting chronology is not significantly different to that shown in Fig. 2C.

The inter-decadal chronology (Fig. 2C) benefits from averaging different sampling site information and shows essentially the regionally common growth patterns for the Alai Range. However, increases in variance occur before ∽AD 1470 as the eastern series drop out of the calculation. This change in amplitude appears, even if the variance has been stabilized using the method detailed by Osborn et al. (1997). Thus, it is most likely the result of different signals recorded in the locations West, East 1, and East 2. We did not correct this feature in the inter-decadal scale Alai Range chronology, because (1) it reflects the data availability from this region, (2) it shows a typical limitation of dendrochronological networks, and (3) no calibration and verification exercise is applied to transfer the chronology into temperature anomalies. The inter-decadal Alai Range chronology has sufficient signal strength back to AD 1100, if a threshold value of 0.8 for the EPS is considered (Fig. 2D).

4 Multi-centennial Alai chronologies

So far, the analysis has followed standard dendrochronological procedures to build an inter-decadal scale (SPL) chronology and estimate the signal strength of the record. We now search for potential missing low frequency information by analyzing the spline high-pass filters fitted to the original measurements in the process of individual SPL standardization, and then try to develop reconstructions (from the same data) that preserve these multi-centennial trends.

Some of the long-term trends removed from the inter-decadal chronology can be seen by looking at the splines used in the detrending. Here, we look at only the series with lengths > 500 years. For better visualization the mean of each of the 51 splines from the West and East 2 sites that meet this criterion are normalized to 1 (Fig. 3A). In so doing, the overall trends show long-term increasing trends from ∽AD 1800 and long-term decreasing trends until ∽1600. These trends have been removed from the inter-decadal scale chronology. Between ∽1600 and 1800 all splines show low values.

We argue that most, perhaps all, of the positive trends over the last two centuries represent common forcing signals (presumably climate related), and that the negative trends over the early centuries represent a mixture of common forcing signals and noise. The reason for this assessment is that the increasing temperatures recorded at many locations in the Northern Hemisphere (Jones et al. 1999) are likely forcing the positive trends seen here after ∽1800. On the other hand, the long-term negative trends might be caused by a combination of aging effects (noise, Bräker 1981) and climatic forcing. Conversely, the assumption that the early negative trends represent noise only, would rest on the postulation that no long-term cooling trend existed over the last millennium. It should be emphasized, however, that neglecting such trends at the beginning of an investigation, and removing them just because they mirror and cannot be easily distinguished from age-related trends, would systematically overemphasize the recent warming signal (Esper et al. 2002b).

In response to these observations, we calculated a LTM standardized chronology using the 51 ring width series with lengths > 500 years from West and East 2 (Fig. 3B), and a RCS standardized chronology using all measurements from East 1, East 2, and West (Fig. 3C). In addition to the quite similar inter-decadal variations, these chronologies also show multi-centennial trends. These trends, however, appear to be on different levels. The LTM chronology shows highest values in the first half of the last millennium while the RCS chronology shows higher values towards the end. The explanation for these differing levels lies in the differing standardization methods used. The mixture of noise and signal in the measurements of the > 500 year old trees in the first half of the last millennium likely causes an overestimation of growth levels in the LTM chronology through that period. As a result, these early levels are probably too high relative to the levels recorded towards the end of the record (Fig. 3B). On the other hand, the systematically faster growing trees from sites with younger trees (Table 1), which are incorporated in the RCS chronology (Fig. 3C, sample size at the bottom), likely cause an overestimation of growth levels towards the end of the

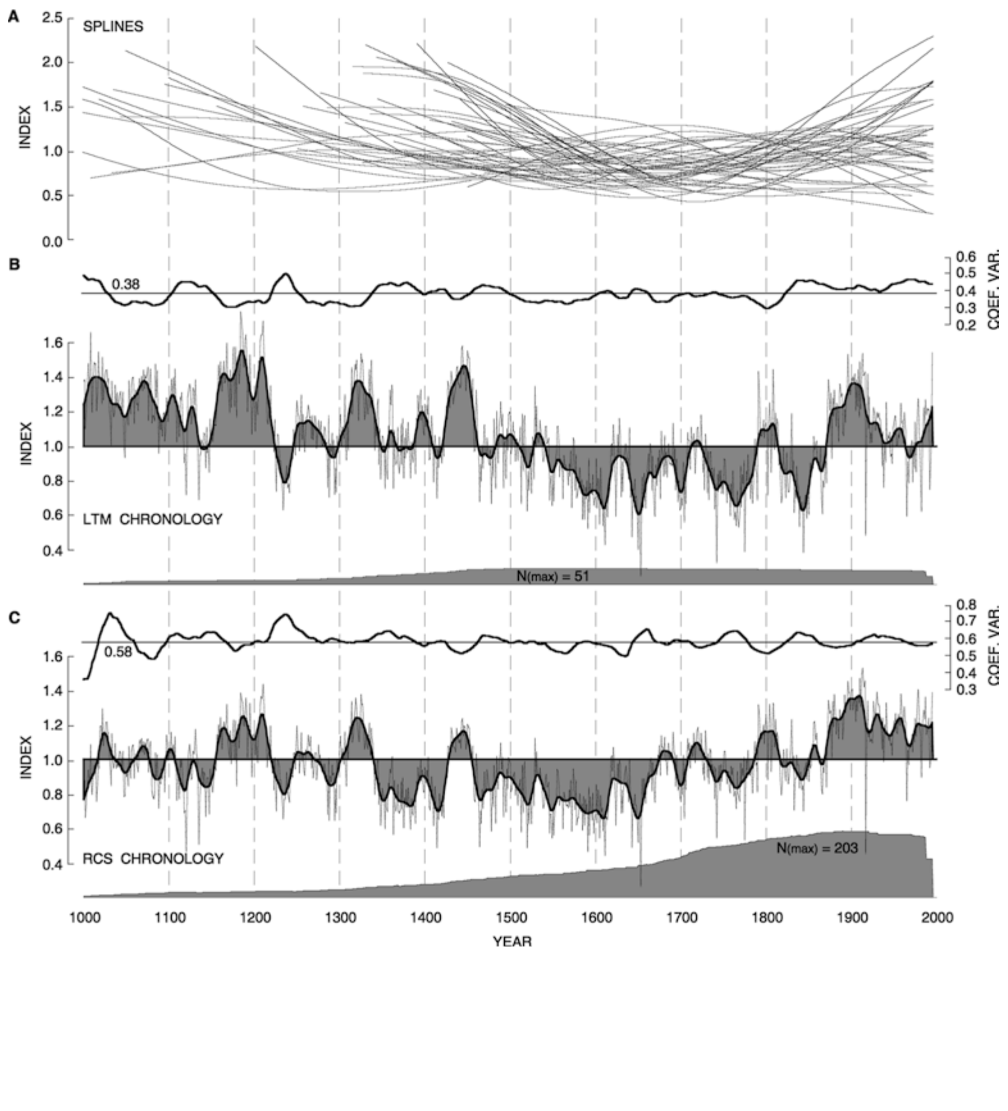

Fig. 3 **A** 51 spline high-pass filters applied in the process of SPL standardization to series > 500 years. **B** LTM standardized multi-centennial chronology, coefficient of variation (mean is 0.38), and sample size information. **C** RCS standardized multi-centennial chronology, coefficient of variation (mean is 0.58), and sample size information. Chronologies and coefficient of variation plots have been smoothed with a low-pass filter

record. As a result, these late levels are probably too high relative to the levels recorded in the first half of the last millennium. The coefficient of variation values calculated for the LTM and RCS chronologies are fairly stable over time indicating that both records are quite robust, even in the periods where perhaps some non-climatic bias was introduced (e.g., the early LTM chronology levels). However, it is also revealed that the spread of the individual series averaged to the RCS chronology is significantly higher than the variance accompanying the LTM chronology, thus validating the noisier nature of the RCS technique in comparison to individual (LTM) detrending methods (Esper et al. 2002a).

In the context of these results, we do not believe that there exists a better way to recover multi-centennial growth trends with these data. We also tested, for example, the RCS method using only the >500 year long series (not shown). The resulting chronologies, however, display quite similar patterns, but have significantly wider confidence relative to the record shown here. The main reasons for the lowered confidence are the reduced sample size and a temporally more uneven age-structure when considering sub-samples of the Kirghizia data (details in Esper et al. 2002a). A RCS chronology calculated with the same selected long series as used with LTM, does not have sufficient sample size to establish an equally robust regional growth curve. In general, no practical or objective solution exists in the sense of a true threshold number or strategy that might assist in deciding which series/sites should or should not enter an RCS calculation.

Since (a) a long-term negative trend in the early period and a long-term positive trend in the late period are certainly missing in the inter-decadal scale SPL chronology, and (b) no unbiased, single, multi-centennial chronology can be calculated, comparisons with climate data and the ECS reconstruction are performed using both the LTM and RCS chronologies (Fig. 4). Averaging the two records is not done here, because no empirically precise weighting procedure can be performed that might overcome the biases described for both chronologies.

The main feature of the LTM and RCS Alai Range chronologies (Fig. 4B) is a multi-centennial wave with high values towards both ends. From AD 1000–1200 and 1330–1600 the LTM chronology exceeds the RCS chronology, and from 1650-1989 the RCS chronology exceeds the LTM chronology. Both chronologies reach lowest values in the Seventeenth century. Superimposed on this wavelength are inter-decadal fluctuations, with the most significant positive deviations around AD 1200, in the early fourteenth and fifteenth, and the turn of the nineteenth centuries.

A comparison of these regional records with the ECS record (Fig. 4B), reflecting Northern Hemisphere extratropic temperature variation (Esper et al. 2002b), shows reasonable similarities in these overall patterns.

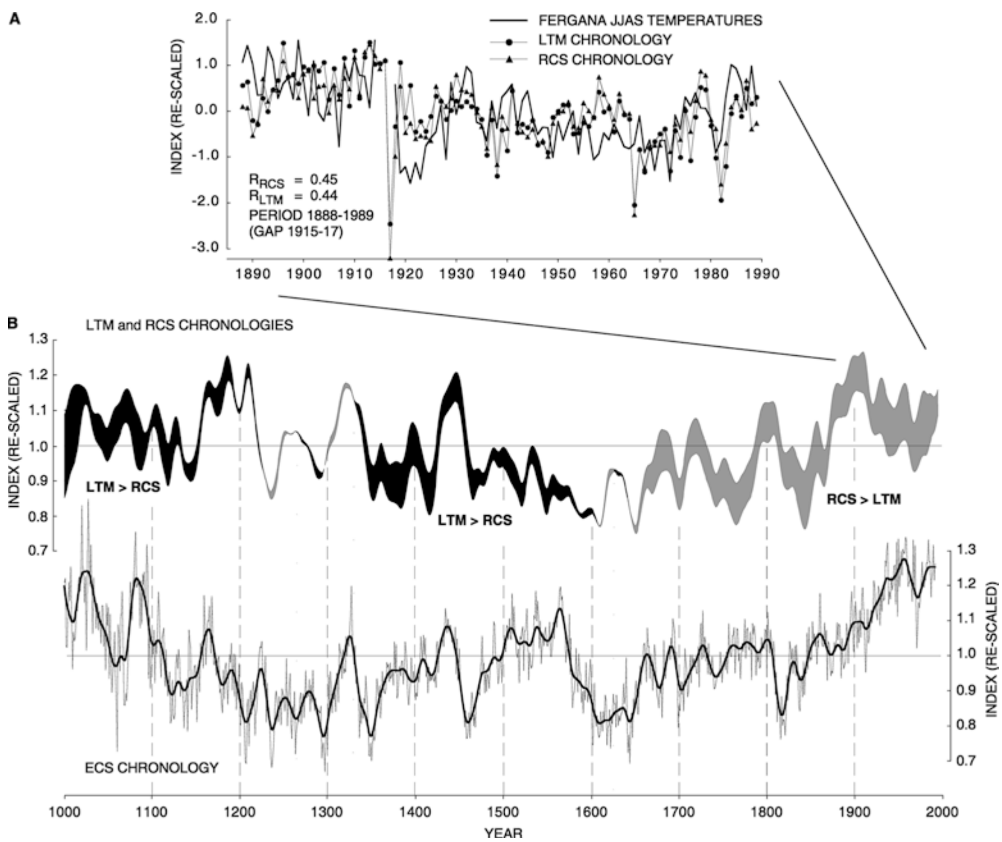

Fig. 4A, B Multi-centennial Alai chronologies. **A** Comparison of the normalized multi-centennial chronologies with JJAS temperatures measured at Fergana since AD 1888 (note the gap 1915–17 in the instrumental record). **B** Comparison of normalized and low-pass filtered multi-centennial RCS and LTM chronologies with the ECS (Esper et al. 2002b) reconstruction

Nevertheless, the differences in amplitude of inter-decadal variation seem to be caused by differing spatial scales (i.e., regional versus hemispheric). The most significant differences between the Alai Range and the ECS chronologies are the positive deviation centered around the middle of the Sixteenth century that is not present in the Kirghizia data, and the trends in the most recent ∽120 years. Over the past two centuries, the Alai records have highest values around the turn of the nineteenth century followed by decreasing values and a final increase after ∽AD 1965, while the ECS record reaches highest values ∽1970.

We analyzed this pattern in the Alai Range chronologies by comparing it with JJAS temperature data recorded at the nearest meteorological station (Fergana; 577 m a.s.l., 40°37′N/71°75′E; Fig. 4A). The high values around the turn of the nineteenth century, the decreasing values until ∽1965 and the final increase in the tree ring chronology are verified by fluctuations in the JJAS temperature record. The relatively low correlation results ($R_{RCS} = 0.45$, $R_{LTM} = 0.44$) are likely influenced by the large difference in elevation between the tree ring sampling sites (>2900 m a.s.l.) and the meteorological station (<600 m a.s.l.), questioning the overall optimality of the station measurements.

It should also be noted that the inter-decadal Fergana JJAS temperature variations are similar to the Fergana annual temperature variations, as well as to the temperature variations recorded at other more remote stations like Naryn (41°43′N/76°00′E), Leninabad (40°22′N/69°73′E), Turkestan (43°27′N/68°22′E) or Khorog (37°50′N/71°50′E). All these stations show the same patterns of higher temperatures around the turn of the nineteenth century, followed by cooling and warming trends (analysis not shown). These observations indicate that (1) a statistically valid differentiation between summer and annual temperature signals is not possible for the inter-decadal scale frequency, and (2) the tree ring inter-decadal variations reflect *regional* temperature variations. However, since the highest correlations are obtained between tree rings and Fergana JJAS temperatures, the multi-centennial scale Alai Range chronology is almost certainly weighted towards these growing season months.

5 Conclusions

Regional temperature reconstructions over the last millennium are of critical importance to understand the spatial patterns of the long-term evolution of climate history, and to assess the modern temperature increase that might additionally be forced by greenhouse gases (IPCC 2001). The records presented here, show striking similarities in the low frequency domain with a recently developed temperature record for the Northern Hemisphere extratropics (ECS, Esper et al. 2002b). However, there are also some obvious differences in the inter-decadal frequency domain, with the fluctuations in the most recent ∽120 years being most prominent. Comparisons with regional instrumental data, nevertheless, validate the declining ring width trend recorded in the twentieth century for the Alai Range.

We found several lines of evidence indicating that a long-term cooling in the first half and a long-term warming in the second half of the last millennium took place at high elevations in the Alai Range. These are the overall patterns of the splines applied in the process of individual SPL standardization (Fig. 3), as well as the results obtained from the LTM and RCS standardization procedures (Fig. 4). If the tree ring reconstruction had been developed using 'standard' detrending procedures only, it would have been limited to inter-decadal scale variation and would have missed some of the common low frequency signal.

Although these long-term trends agree well with ECS, the amplitude of the multi-centennial scale variations is, however, *not* understood. This is because (1) no *single* multi-centennial scale chronology could be built that is not systematically biased in the low frequency domain, and (2) no evidence exists that would support an estimation of the biases either in the LTM nor in the RCS multi-centennial chronologies. Consequently, we also avoided providing formal climate calibration and verification statistics of the chronologies. Note also that the climate signal of the chronologies' low frequency components could not be statistically verified anyway. This is because the high autocorrelations, when comparing lower frequency trends, significantly reduce the degrees of freedom valid for correlation analyses. We believe that a formal calibration/verification/transfer function approach would leave the impression that the long-term climate history for the Tien Shan is entirely understood, which is not the case. Further research is needed to estimate the amplitude of temperature variation in the Alai Range over the last millennium.

Several recent dendroclimatic studies, carried out in the High Asia region, clearly show that the variance recorded in tree ring chronologies can be explained by temperature variation recorded at nearby meteorological stations. When comparing some of these studies, like the network analyses in Nepal (Cook et al. 2003), Mongolia (D'Arrigo et al. 2001) or Pakistan (Esper et al. 2002c), significantly different trends are reported for the twentieth century. For example, Mongolian tree rings and temperatures at Irkutsk show a strong increase, while Nepal tree rings and temperatures at Katmandu show almost no warming in the twentieth century. The reconstruction presented here might help to complete this picture for the High Asia region. We conclude that a detailed network analysis, including all regional dendroclimatic data (e.g., Borgaonkar et al. 1999; Bräuning 1994, 1999; Graybill et al. 1992; Hughes 1992; Jacoby et al. 1996; Yadav et al. 1997) would be highly useful to better understand the regional fingerprints of climatic change at different temporal and spatial scales.

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