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ORIGINAL ARTICLE

Uniform growth trends among central Asian low- and high-elevation juniper tree sites

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Abstract We present an analysis of 28 juniper tree-ring sites sampled over the last decades by several research teams in the Tien Shan and Karakorum mountains of western central Asia. Ring-width chronologies were developed on a site-by-site basis, using a detrending technique designed to retain low-frequency climate variations. Site chronologies were grouped according to their distance from the upper timberline in the Tien Shan (∼3,400 m a.s.l.) and Karakorum (∼4,000 m), and low- and high-elevation composite chronologies combining data from both mountain systems developed. Comparison of these elevational subsets revealed significant coherence ($r = 0.72$) over the 1438–1995 common period, which is inconsistent with the concept of differing environmental signals captured in tree-ring data along elevational gradients. It is hypothesized that the uniform growth behavior in central Asian juniper trees has been forced by solar radiation variations controlled via cloud cover changes, but verification of this assumption requires further fieldwork. The high-elevation composite chronology was further compared with existing temperature reconstructions from the Karakorum and Tien Shan, and long-term trend differences discussed. We concluded that the extent of warmth during medieval times cannot be precisely estimated based on ring-width data currently available.

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Introduction

Because of their effect on large-scale synoptic patterns, mountain systems in central Asia modulate global scale climate variability, but at the same time are highly sensitive to such variations (Ives and Messerli 1989). Yet high-resolution palaeoclimatic studies documenting regional longer term climate fluctuations were broadly missing until the 1990s. Since then, several studies have been published – many focusing on past temperature variations. Examples include tree-ring based reconstructions from Mongolia (D'Arrigo et al. 2001; Davi et al. 2006), Tibet (Bräuning 1994; Bräuning and Mantwill 2004), Nepal (Cook et al. 2003), Pakistan (Esper et al. 2002b), and Kyrgyzstan (Esper et al. 2003a). These records need to be linked with other proxy evidence, such as ice core data from the Himalayas (Thompson et al. 1989), documentary records from China (Wang and Wang 1989; Zhang 1994), and multi-proxy records from China (Yang et al. 2002) to better estimate millennium-scale climate variability in central Asia.

Here, we present an overview of the current status of palaeoclimatically relevant tree-ring data from the Karakorum mountains in northern Pakistan, which are influenced by westerly synoptic fronts and isolated monsoonal clusters, and the more continental Tien Shan mountains in southern Kyrgyzstan, influenced by westerlies and the Siberian high (Weischet and Endlicher 2000), and assess the coherence of tree growth along elevational gradients. We developed chronologies using an age-related composite tree-ring detrending method (Regional Curve Standardization, RCS; Briffa et al. 1992, 1996) on a single site basis, and stress this technique with regard to minimum sample size and age structure requirements (Esper et al. 2003b). Using 27 RCS site chronologies, common signals from sites located near the upper timberline were analyzed, and compared with signals obtained from sites near the lower timberline. To do this, we divided and combined the ring-width data into high- and low-elevation subgroups regardless of their geographical origin from the Karakorum or Tien Shan. The rationale for this approach relied on findings indicating common growth variations between Karakorum and Tien Shan juniper trees (Esper 2000b; Esper et al. 2002b). The comparison of high- and low-elevation composite chronologies allowed the assessment of growth patterns that are reported to be temperature controlled, with data from lower elevation sites from which a more ambiguous signal has been reported (Esper et al. 2002c). The high-elevation composite chronology is then compared with previously published temperature reconstructions from the Karakorum and Tien Shan indicating warmth during medieval times similar to 20th century conditions. We discuss the differing detrending approaches utilized for chronology development and potential biases associated with these methods.

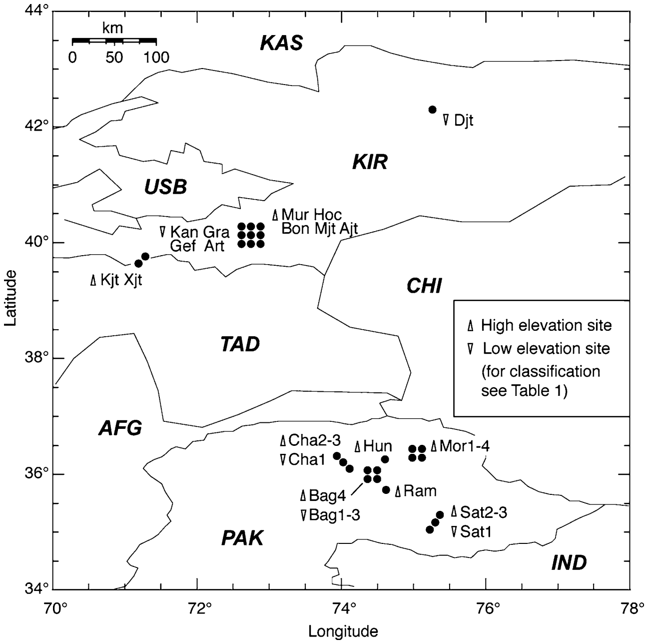


Fig. 1 Map showing the high- and low-elevation juniper sampling sites in the Karakorum, Pakistan and Tien Shan, Kyrgyzstan

Material and methods

The western central Asia juniper collection

778 samples from 28 juniper sites are utilized in this study. These were sampled by Russian/US (1988) and German/Swiss (1996) expeditions in the Tien Shan, and by German/Swiss (1989) and German (1995 and 1998) expeditions in the Karakorum (Fig. 1). Data, commonly one to two cores per tree, were processed in Tucson (USA) by Funkhouser and Graybill, in Ekaterinburg (Russia) by Mazepa and Shiyatov, and in Bonn (Germany) by Esper and Treydte, with a total of 264,636 annual ring widths measured.

The western central Asian juniper dataset is a collection of *Juniperus semiglobosa*, *J. seravchanica*, and *J. turkestanica*, with the latter being the dominant species at high elevations. These species are nearly identical in their morphology and growth characteristics, and a test for growth behavior within a homogenous sampling site revealed no species-specific ring-width variations (Esper 2000b).

Sampling sites in the Karakorum range from 2,700 m a.s.l. near the lower timberline to 3,900 m near the upper timberline, and similarly from 2,550 to 3,400 m in the Tien Shan. Depending on slope aspect, the upper treeline varies slightly within the mountain systems but is generally located between 3,900 and 4,000 m in the Karakorum and between 3,400 and 3,500 m in the Tien Shan. Detailed descriptions of site ecology, relevant climate parameters, including differentiations between low- and high-elevation sites, and the growth/climate response of Juniperus species are detailed in Cramer (1994), Esper (2000a, b), Esper et al. (1995, 2002b), Graybill et al. (1992), Treydte (2003), Treydte et al. (2006), and Weiers (1998). According to these descriptions, we divided the tree-ring data into “Pakistan low” and “Pakistan high” at the 3,500 m threshold, and in “Kyrgyzstan low” and “Kyrgyzstan high” at 2,900 m. Mean elevations of these low and high composites were 3,090 and 3,750 m in Pakistan, and 2,690 and 3,100 m in Kyrgyzstan, respectively. Mean elevations of the combined high- and low-elevation groups after merging data from Pakistan and Kyrgyzstan were 2,860 and 3,440 m, respectively. These mean values were calculated by averaging the elevations of the sampling sites weighted by the number of series per site (Table 1).

The western central Asia juniper site data are characterized by varying growth rates, mean segment lengths (MSL; i.e., average number of years per sample; Cook et al. 1995), and chronology lengths along the elevational gradients (Table 1). Trees near the upper timberline systematically grew slower and reached greater ages (higher MSL), resulting in longer chronologies. MSL was, however, not only affected by increased stresses near the upper timberline, but also by the differing sampling strategies during the various expeditions. For example, during the German/Swiss expedition in 1996, all tree-age classes (i.e., juvenile, adult, mature) were sampled, resulting in larger samples of the Kyrgyzstan sites collected by Esper (see Table 1). By also considering the younger trees, MSL were lower compared to sites where only old individuals were sampled.

Table 1 Western central Asia juniper tree-ring data

Group	Lat/Long	Site	Elevation (m)	# Series	Period	MSL*	AGR* (mm)	Source
Kyrgyzstan low	40°10′/72°35′	Kan	2550	28	1781–1995	73	1.213	Esper
	40°10′/72°35′	Gra	2800	65	1378–1995	214	0.635	Esper
	40°10′/72°35′	Gof	2800	33	1591–1995	189	0.554	Esper
	40°10′/72°35′	Art	2600	51	1839–1995	87	1.087	Esper
	40°30′/75°25′	Djt	2550	21	1674–1987	161	0.885	Shiyatov
Kyrgyzstan high	40°10′/72°35′	Mur	3000	49	1157–1995	181	0.418	Esper
	40°10′/72°35′	Hoc	3200	50	1316–1995	296	0.406	Esper
	40°10′/72°35′	Bon	2900	34	1346–1995	301	0.544	Esper
	39°50′/71°30′	Xjt	3400	24	694–1987	574	0310	Shiyatov
	40°12′/72°37′	Mjt	2900	18	1427–1987	309	0.521	Shiyatov
	39°50′/71°30′	Kjt	3150	23	1019–1987	496	0.369	Shiyatov
	40°12′/72°37′	Ajt	3200	27	1420–1987	361	0.432	Shiyatov
Pakistan low	35°10′/75°30′	Sat1	3300	14	1412–1993	328	0.654	Esper
	36°20′/74°02′	Cha1	2700	23	1587–1993	164	0.778	Esper
	36°02′/74°35′	Bag1	3100	31	1593–1993	174	1.527	Esper
	36°02′/74°35′	Bag2	3300	38	1369–1993	255	0.890	Esper
	36°02′/74°35′	Bag3	3050	37	1438–1993	217	0.994	Esper/Treydte
Pakistan high	35°10′/75°30′	Sat2	3700	29	736–1993	664	0.279	Esper
	35°10′/75°30′	Sat3	3900	28	388–1993	497	0.297	Esper
	36°35′/75°05′	Mor1	3900	33	476–1999	697	0.369	Esper/Treydte
	36°35′/75°05′	Mor2	3900	17	968–1990	525	0.311	Esper
	36°35′/75°05′	Mor3	3800	20	554–1990	600	0.334	Esper
	36°35′/75°05′	Mor4	3600	18	1069–1990	922	0.348	Esper
	36°00′/75°00′	Hun	3900	8	568–1990	687	0.431	Esper
	36°20′/74°02′	Cha2	3500	31	1032–1993	435	0.491	Esper
	36°20′/74°02′	Cha3	3900	18	1141–1993	448	0.338	Esper
	36°02′/74°35′	Bag4	3750	25	1240–1999	250	0.918	Esper/Treydte
	35°74′/74°59′	Ram	3600	12	1540–1999	278	0.516	Esper

* MSL = Mean segment length; AGR = average growth rate per year.

MSL of all juniper data was 340 years, incorporating younger trees from lower and older trees from higher elevation sites (Fig. 2). While reasonably replicated chronologies from lower elevation sites reached back into about the fourteenth century, some of the higher elevation chronologies spanned the entire millennium and more. The current juniper dataset contains 31 measurement series extending prior to AD 1000; all obtained from high-elevation sites in the Karakorum and Tien Shan.

RCS detrending applied on a site-by-site basis

Analyses using RCS demonstrated that this method is suitable to retain multi-centennial variability in tree-ring chronologies (Büntgen et al. 2005, 2006; Briffa et al. 1992, 1995; Cook et al. 2000; Esper et al. 2002a; Luckman and Wilson 2005; Naurzbaev et al. 2002). These studies, however, also showed that RCS requires greater sample replication than normally needed for individual detrending methods (overview in Cook and Kairiukstis 1990; Fritts 1976), and that suitable datasets combine measurements from living trees and dead (e.g., sub-fossil, dry-dead, historic) material (Esper et al. 2003b). These conditions were only partly fulfilled here. First, we applied RCS on a single-site basis where sample replication per RCS-run was occasionally rather low (Fig. 2). Second, the juniper dataset contained samples from living trees only, i.e., the age-structure was characterized by monotonically increasing tree ages toward the chronologies recent ends. While the application of RCS on a site-by-site basis allowed the assessment of potential low-frequency variation per site, the conditions listed above constricted the interpretation of individual site chronologies. Consequently, we have focused our interpretation and conclusions on the results obtained from the merged high- and low-elevation composite chronologies integrating many site records, which minimizes the bias at the site level.

RCS was performed on all 28 juniper sites. Measurements were first power transformed to reduce heteroscedacity commonly found in ring-width measurements (Cook and Peters 1997). On the site level, these series were aligned by cambial age and "site noise functions" were fit to the arithmetic mean of the age-aligned data using a smoothing spline. These noise functions represent calendar-year-independent estimates for the age trend. Subsequently, residuals of all measured series from these functions were calculated (details in Esper et al. 2003b), and site chronologies developed using a bi-

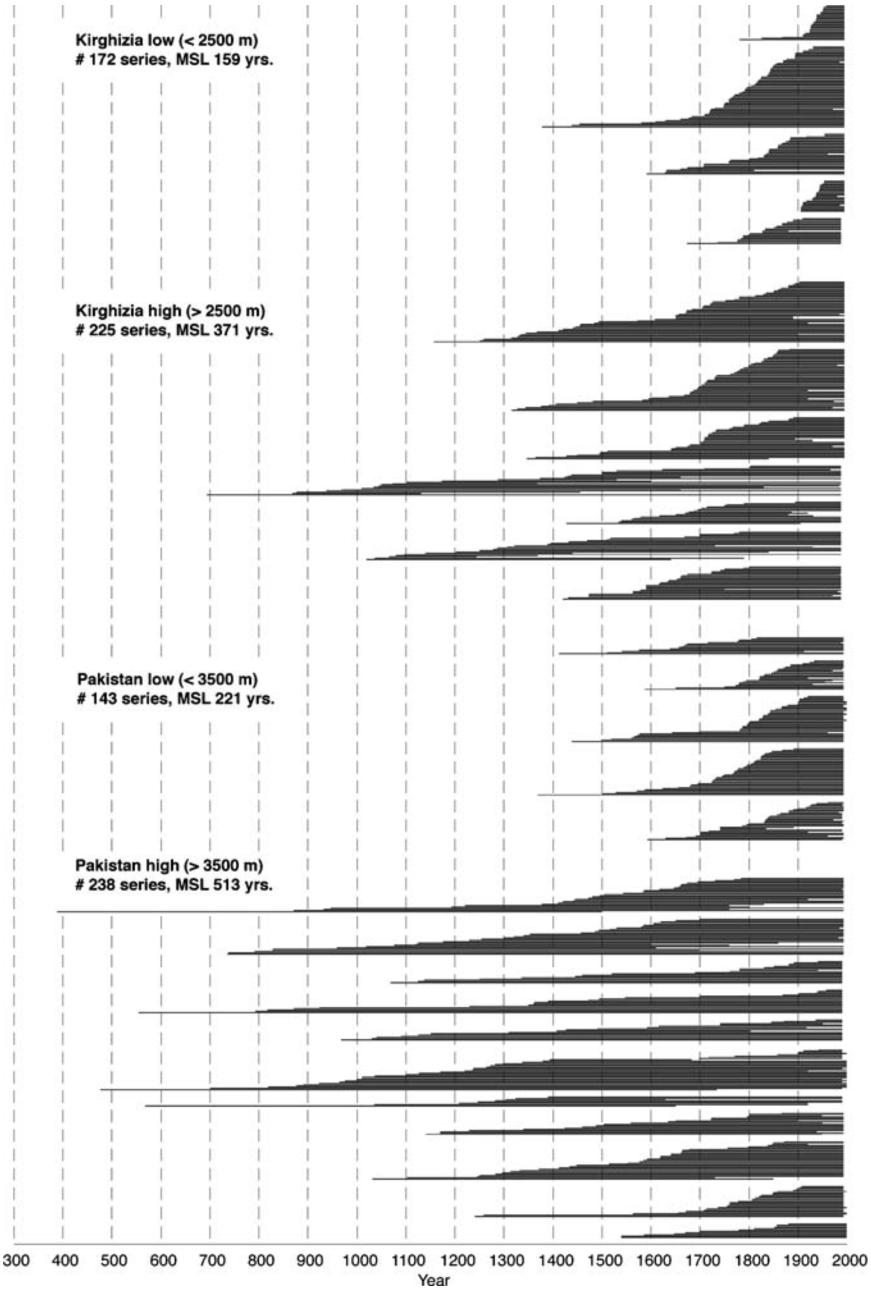


Fig. 2 Sample replication of western central Asia juniper tree-ring data used in this study

weight robust mean. The resulting 28 RCS site chronologies were grouped by elevation (low and high) regardless of their geographical origin, and inter-site correlations over 50-year periods lagged by 25 years calculated to estimate the common variance within these two composites.

Results

Low- and high-elevation composite chronologies

Comparison of 17 high- and 10 low-elevation RCS site chronologies revealed substantial common variance between the high-elevation sites, and slightly less shared variance between the low-elevation sites (Fig. 3). The Hun site from the Karakorum has been excluded from this analysis, since the site was too poorly replicated ($n = 8$ series) for RCS. Overall, the number of site records declined back in time, with three chronologies available back to AD 737 and AD 1412 for the high- and low-elevation groups, respectively.

The high-elevation site chronologies were characterized by common long-term variability, with high values centered around the 11th and 12th centuries and low values during the beginning of the longer records (8th–9th centuries) and an extended period in the 15th and 16th centuries (Fig. 3a). Inter-chronology correlations were reasonably high and sta-

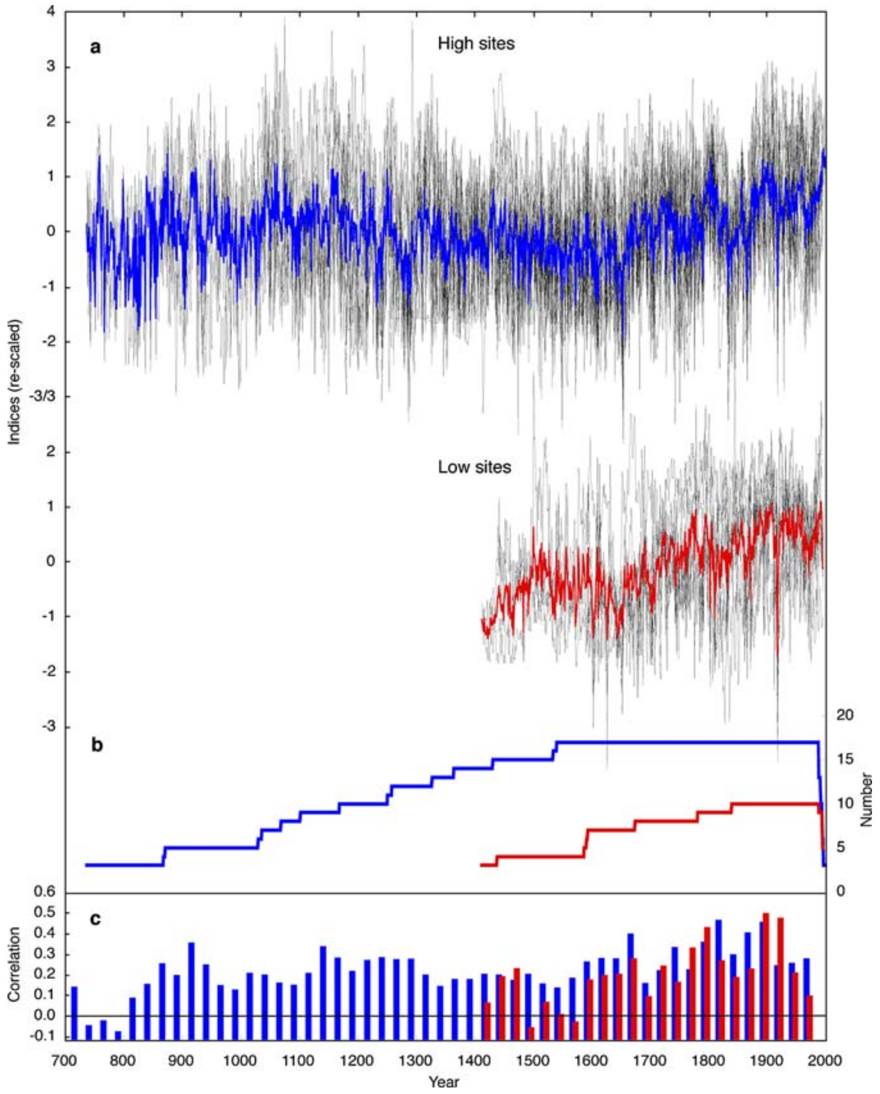


Fig. 3 (**a**) RCS detrended site chronologies and mean curves of high- (*blue*) and low-elevation (*red*) juniper sites. Site chronologies and mean curves are shown from 737 and 1412 where the high and low composites reached three sites, respectively. All site chronologies were truncated at $n = 2$ series and normalized over the total individual chronology lengths. (**b**) Numbers of site chronologies, and (**c**) inter-chronology correlations calculated over 50-year periods lagged by 25 years

ble over time back to about AD 850 (Fig. 3c), indicating common variance likely related to larger scale temperature patterns in western central Asia limiting tree growth in high-elevation environments.

Greatest uncertainty in the high-elevation group appeared during a period of transition from high growth levels in the 11th and 12th centuries into a prolonged period of lower values during the following centuries. During this transition period, some of the site chronologies persisted on a higher level, while others declined. This shifted timing resulted in an increased variance between the site chronologies (see black curves in Fig. 3a), seemingly greater than over the following 500–700 years.

In comparison to the high-elevation group, common variance between the low-elevation sites was slightly reduced. This was not surprising, since less clear and varying climatic signals and no common temperature forcing has been reported from lower elevation tree sites (Esper 2000b; Esper et al. 2002c). However, except for the 16th century, reasonably high inter-site correlations were found, with the changes from lower to higher correlations being quite similar to the pattern recorded in the high-elevation group (Fig. 3c).

Comparison of the mean records of the low- and high-elevation site chronologies revealed highly similar ring-width variation over the last couple of centuries (Fig. 4). These composite chronologies correlated at 0.72 ($n = 558$; AD 1438–1995), increasing to 0.81 after applying a 15-year low-pass filter (Rsmoothed). Interestingly, the correlation between the two composites remained reasonably high after high-pass filtering the data (Fig. 4, Rresiduals = 0.55, note the reduced autocorrelation at lag 1). This finding was unexpected and is inconsistent with previous results on low- and high-elevation growth variations in western central Asia (Esper 2000b; Esper et al. 2002c) and elsewhere (e.g., Buckley et al. 1997; Fritts et al. 1965; Kienast et al. 1987; La Marche 1974; Wilson and Hopfmueller 2001).

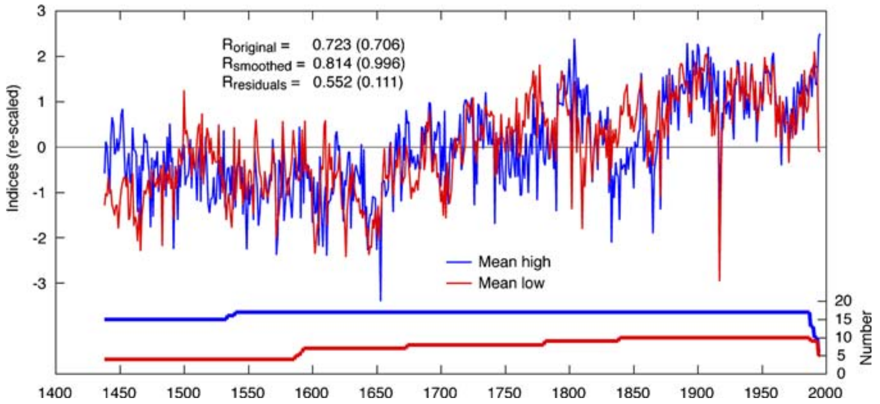


Fig. 4 Comparison of the high- (*blue*) and low-elevation (*red*) composite mean chronologies from western central Asian juniper sites. The series are shown back to 1438, where Mean low reached four site chronologies (*lower panel*). Correlations refer to the 1438–1995 period (558 years). Rsmoothed and Rresidual are the respective correlations of the low and high pass (15-year spline) filtered of the original composite series. Numbers in parentheses are the mean autocorrelations of the series at lag 1

Our analysis, however, also indicated sensitivity of the high- versus low-elevation match to the number of sampling sites averaged to form a composite chronology. For example, in recent years when sample replication for both groups is lower, as well as further back in time when sample replication of the low-elevation composite is constantly decreasing (see bottom of Fig. 4), substantial differences between the composite records can be seen. In addition, some divergence exists during better-replicated periods, such as around AD 1840, where the low-elevation composite showed higher values than the high-elevation composite series. While the low values were common to all high-elevation site chronologies, the high values in the low-elevation record resulted from highly variable site chronologies (Fig. 3a).

To further assess the similarity between the high- and low-elevation composites with respect to replication and elevation, we stepwise removed the lowest elevation sites from the high composite and the highest elevation sites from the low composite, thereby increasing the elevational difference between the high- and low-elevation mean records (Fig. 5). Removal of site records resulted in increased variances and short-term deviations, particularly in the less-replicated low-elevation data back in time (Figs. 5b), but did not substantially change the overall characteristics and long-term behavior of the composite series. Comparison of these stepwise modified mean records revealed no decay in correlation with reduced sample replication (Fig. 5c, grey bars). This finding differed from a similar approach in which we systematically decreased the elevational difference between the high- and low-elevation composites (green bars in Fig. 5c), suggesting sensitivity to sample replication after removal of the extremely high- and low-elevation sites. These results indicate that the correlation between high- and low-elevation composites is generally robust, although adding weight—via removal of extremely high /low sites—to the intermediate sites, with likely less clear climate signals, results in a decrease in coherence between the subgroups.

Comparison with existing temperature reconstructions

For both the Karakorum (Esper et al. 2002b) and Tien Shan (Esper et al. 2003b) significant coherence between high-elevation juniper ring-width chronologies, and annual and warm season temperature variations has been reported. The temperature forcing revealed for trees growing above 3,500 m a.s.l. in the Karakorum and above 2,900 m in the Tien Shan allowed the development of two millennium-long climate reconstructions and comparison of these regional series with hemispheric-scale records (e.g., Esper et al. 2002a).

In comparison to these strictly regional reconstructions, we have provided a comprehensive record of high-elevation tree growth variations integrating data, processed using RCS on a site-by-site basis, from the Karakorum and Tien Shan mountains. Comparison of this newly processed record allowed an evaluation of growth variations over the past millennium and comparison of differently processed long-term chronologies. Note, however, that due to data overlap between the existing regional records and the newly developed composite chronology, it is not surprising that these series share a high fraction of common variance in their inter-annual to multi-decadal frequency domains (Fig. 6a).

More interesting were the similarities and differences in the lowest frequencies, emphasized by smoothing spline functions fitted to the chronologies (Fig. 6b). Generally, if the differing methodological detrending approaches (see below) had no effect on the long-term course of the records, the composite chronology would be expected to lie between the regional records as the new chronology integrates data from both the Karakorum and Tien Shan Mountains. This was, however, not the case. Relative to the other records, the composite chronology showed higher values in the 19th and

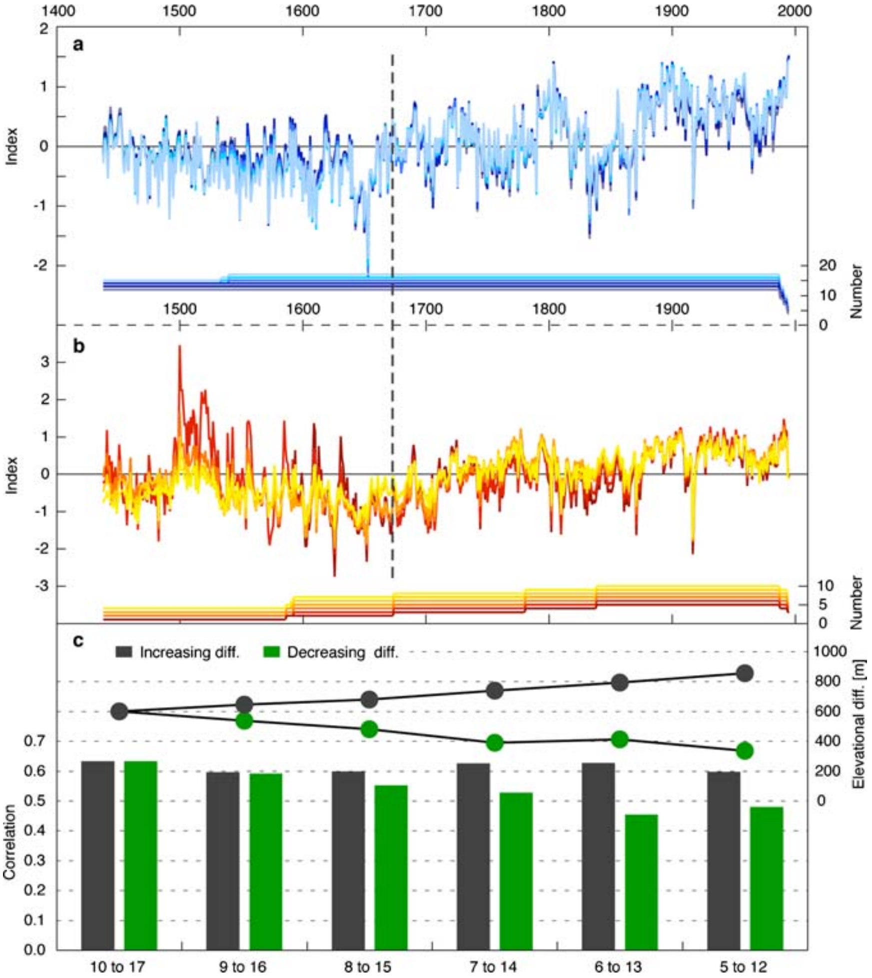


Fig. 5 Effect of elevation and replication on the characteristics of the high- and low-elevation composite chronologies. **a** High-elevation composite chronology including all 17 site records and chronology versions, including 16, 15, 14, 13, and 12 site records (see replication curves at the bottom). Reductions resulted from the stepwise removal of the lowest (remaining) site, i.e., mean elevation of the data combined in the high-elevation composite increased during this process. **b** Low elevation composite chronology including all 10 site records and chronology versions, including 9, 8, 7, 6, and 5 site records. Reductions resulted from the stepwise removal of the highest site, i.e., mean elevation of the combined data decreased during this process. **c** Intercorrelation results for various combinations of high- and low-elevation composite chronologies (*bars*) and mean elevational differences between the chronology pairs used for correlation calculation (*curves*). X-axis indicates the numbers of site records included in the composite chronologies, i.e., 10 to 17 is 10 low and 17 high-elevation records. Grey bars show results for pairs of increasing elevational difference as indicated in (**a**) and (**b**). Green bars show correlations for pairs that resulted from the stepwise removal of the lowest sites from the low composite and the highest sites from the high composite, i.e., reducing the elevational difference. Correlations were computed over the 1674–1995 period (see *dashed curve* in (**a**) and (**b**))

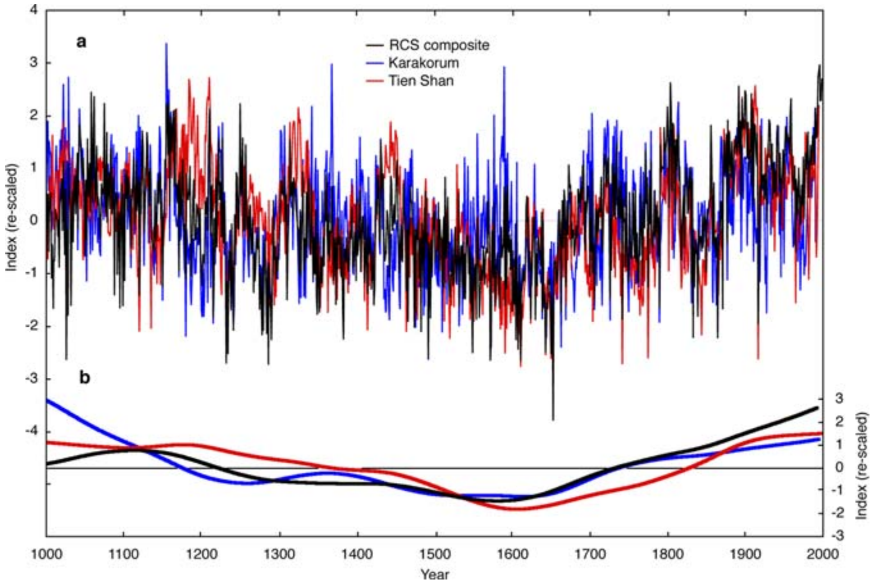
20th centuries and lower values in the 11th century (Fig. 6b), suggesting methodological uncertainty in estimating the true extent of medieval warmth in the study area.

In detail, our results suggest that warmth during medieval times has been overestimated in the regional record representing the Karakorum only (Fig. 6b, blue curve; Esper et al. 2002b). This conclusion rests upon the likelihood that a mixture of tree-age related noise (age trends) and climatic signals affected the early portion of this record, even after removal of the first 50 to 100 rings from the Karakorum samples sought to eliminate high values associated with juvenile growth (Fritts 1976). In light of the comparison presented here, it appears likely that some of this age-related bias remained in the regional Karakorum record, resulting in overestimated temperatures in the early portion of this timeseries.

For the Tien Shan data, Esper et al. (2003a) developed two alternative chronologies: the first used the RCS technique after combining data from high-elevation sites, and the other used a long-term mean standardization approach, including only very old high-elevation trees. It was argued that these two records were biased in opposite directions, and we here show the arithmetic mean of these timeseries (Fig. 6b, red curve).

In comparison to the composite record presented here, the increased values during medieval times and reduced values in

Fig. 6 (**a**) Comparison of the high-elevation RCS composite chronology (this study) with the Karakorum (Esper et al. 2002b) and Tien Shan (Esper et al. 2003a) reconstructions. All series were re-scaled to have the same mean and variance. (**b**) Same data smoothed with a 300-year spline low-pass filter



the 20th century as reconstructed in the Tien Shan timeseries, either reflected a regional signal in long-term temperature variations restricted to continental western central Asia, or an artificial inflation of index values during recent times in the RCS site-by-site composite record (Fig. 6b, black curve). This latter observation refers to potential biases in the application of RCS on a single-site basis, including failure of the juniper data to meet age-structure and sample depth requirements, as outlined in the literature (Briffa et al. 1996; Esper et al. 2003b; Melvin 2004). Accordingly, the combination of data from living trees with material from dry-dead/sub-fossil trees, as well as the inclusion of more than 20–40 measurement series in one RCS run has been recommended to establish robust noise functions (regional curves) necessary for successful chronology development. Failure of these requirements could explain some of the increased variance between the high-elevation RCS site chronologies, as seen in the 10th to 12th centuries, for example (Fig. 3a). The missing inclusion of sub-fossil material in the western central Asia data collection has likely biased the recent chronology level toward higher values, thereby relatively devaluing the chronology's earliest portion (Fig. 6b, black curve). The rationale for these changes could be a systematic tendency for faster growing trees in earlier times to have died long ago, thereby resulting in a long-term increase toward the 20th century when only the (remaining) faster growing trees entered the RCS chronology.

Conclusions

By applying the RCS method on a single site basis, and by merging the information from Kyrgyzstan and Pakistan, we were able to process two composite chronologies emphasizing common growth variations in lower (~ 2,860 m a.s.l.) and higher (~ 3,440 m) elevation environments in western central Asia. This approach revealed surprisingly similar ring-width variations along elevational gradients in high mountain systems, questioning the concept of changing climatic signals with elevation in central Asia. This concept refers to findings revealing drought signals in tree-ring data from sites near the lower timberline, and temperature signals in data from sites near the upper timberline (e.g., Esper 2000b; Esper et al. 2002c; La Marche 1974; overview in Schweingruber 1996).

The similarity of growth variations between low- and high-elevation ring-width chronologies detailed herein, refers to a region from which steep precipitation gradients have been reported (Winiger et al. 2005). In the Karakorum mountains, for example, annual rainfall increases from only 130 mm at 1,500 m a.s.l. in Gilgit, to ~ 300 mm near the lower timberline at about 2,900 m above the Artemisia steppe in the Bagrot valley (see Table 1, Bag), and to > 1000 mm at the upper timberline at about 4,000 m (Cramer 1994). This gradient and the associated temperature changes constitute the emergence of a forest belt, framed by semiarid conditions in the valley bottoms and cold-moist conditions toward the summits.

Testing the underlying cause for the growth similarity reported here would require accurate observational climate data, which are broadly missing for the mountainous regions of western central Asia. In particular, high-elevation instrumental precipitation data necessary for calibration are not available. Since the investigated sampling sites in the Karakorum and Tien Shan mountains receive very high quantities of solar radiation—in the Karakorum up to 1,300 W/m^2 (Cramer 1994; Troll 1942; Weiers 1998) – we assume that regional radiation variations controlled via cloud cover changes could be the underlying and unifying cause for the similarity in growth variations in western central Asia. This hypothesis, however, requires further tests utilizing field experiments and model studies (e.g., Nemani et al. 2003).

The development of a large western central Asian juniper dataset by several research teams further enabled the estimation of past climate variations in a region from which such long-term records were largely missing. The high-elevation data are particularly relevant for hemispheric to global scale studies aiming to reconstruct long-term temperature variations because of their location. In general, the existing high-resolution large-scale temperature reconstructions (Briffa 2000; D'Arrigo et al. 2006; Esper et al. 2002a; Jones et al. 1998; Mann et al. 1999) suffer from little or no data coverage at lower latitudes (Esper et al. 2004). The juniper data detailed here will help fill this gap in the central Asian region.

Comparison of the high-elevation composite record, integrating RCS detrended site chronologies, with published temperature reconstructions from the Karakorum (Esper et al. 2002b) and Tien Shan (Esper et al. 2003a) has generated additional doubt that the low-frequency temperature history in western central Asia is fully understood. The timeseries presented here differ in the low-frequency domain from previously published records, indicating lower values during medieval times—well below those during the 20th century. The variance between these records (Fig. 6b) suggests limitations to age related standardization methods (e.g., RCS), primarily arising from the age structure of the western central Asia juniper collection integrating data from living trees only.

As a consequence of this uncertainty and the lack of reliable high-elevation observational climate (particularly precipitation) data, reliable calibration and reconstruction of quantified climate variability are not feasible using the ring-width data of old juniper trees from the Karakorum and Tien Shan mountains (see also Esper et al. 2005a,b for a discussion of this issue on hemispheric scales). The situation would, however, likely improve, if some sub-fossil material could be added to the dataset. Additionally, analysis of δ^{18}O measurements processed from Karakorum juniper trees revealed evidence for long-term precipitation variations (Treydte et al. 2006), and we expect further insight into temperature variations by analyzing the corresponding δ^{13}C measurements from the same samples. These efforts will help to detail the relative magnitude of recent warmth, that is additionally forced by industrial-era anthropogenic greenhouse gases, along with the warmth seen about 1000 years ago during medieval times.

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