Olga Solomina[1*], Olga Maximova[1], Edward Cook[2]
[1]Institute of Geography Russian Academy of Sciences, Staromonetny-29, Moscow, Russia, 119017; Tel: +7-495-959-00-34, Fax: +7-495-959-00-33,
e-mail: olgasolomina@yandex.ru
[*] **Corresponding author**
[2] Lamont-Doherthy Observatory, Palisades, New York 10964 USA;
Tel: 845-365-8618, Fax: 845-365-8152, e-mail: drdendro@ldeo.columbia.edu

PICEA SCHRENKIANA RING WIDTH AND DENSITY AT THE UPPER AND LOWER TREE LIMITS IN THE TIEN SHAN MTS (KYRGYZ REPUBLIC) AS A SOURCE OF PALEOCLIMATIC INFORMATION

ABSTRACT. We present here the results of spruce (*Picea schrenkiana Fish. et May.*) tree-ring research in the Tien Shan Mountains, Kirgiz Republic. We explore the connection between climatic parameters and spruce ring width and maximum density at the upper and lower tree limits and provide two reconstructions: the May–August temperature reconstruction from 1626 to 1995 based on a multi-site composite maximum density chronology from the upper tree limit and the drought index reconstruction from 1680 to 2000 based on the lower tree limit regional ring width chronology. The ring width chronologies from the upper and lower tree limits show a strong similarity. They both depend to a large extent on moisture availability. The maximum density chronology does not correlate with them: it depends on different climatic parameters, namely on the summer temperature. The correlations of the reconstructions with CRU TS3 temperature and precipitation grid point data confirm the results of the modeling using the meteorological data from the nearest stations. The 20th century does not look unusual in the context of the last three hundred years in the Tien Shan Mountains, either in terms of the drought occurrence and severity or in summer temperature changes. However the reconstruction does not encompass the last decade when the summer warming in Tine Shan has been especially prominent. In contrast, some change in precipitation is indicated with the 19th century being drier in the Issyk Kul region compared to the 20th century.

KEY WORDS: Tree rings, ring width, maximum density, summer temperature and drought index reconstructions, upper and lower tree limits, Tien Shan.

INTRODUCTION

Tree-ring based reconstructions are among the most reliable sources of high resolution paleoclimatic information. This kind of information is especially important in the remote mountain regions with poor meteorological networks. The Tien Shan Mountains in Kyrgyzstan is one of those regions. Meteorological observations in Tien Shan began in 1879 at the Karakol meteorological station, near Issyk Kul lake shore, but most of stations were established in the second half of 20th century only. Spruce forests, which are wide spread in this region, provide important dendrochronological material for potential dendroclimatic reconstructions. The spruce trees can be up to 700–800 years old and form clear annual rings. The study presented here aims to synthesize the achievements of spruce tree-ring research in the Tien Shan Mountains, namely to explore the connection between climatic parameters and spruce ring width (RW) and maximum density (MXD), and to reconstruct climatic parameters at the upper and lower tree limits in the Tien Shan Mountains in the Krygyz Respublic.

STATE-OF–THE-ART

Two kind of trees – juniper (*Juniperus sp.)* and spruce (*Picea schrenkiana Fish. et May.*) growing in the Tien Shan Mountains attracted most attention of dendrochronologists since 1960–1970s. Studying the juniper forests at the Northern slope of the Alaisky Range, Mukhamedshin [1977] discovered trees more than thousand years old. He demonstrated the general correspondence of the juniper ring width to summer temperature. Solomina and Glazovsky [1989] obtained similar results for juniper in the Issyk Kul area. However, these first attempts were based on poorly replicated chronologies, short meteorological series used for calibration, and weak correlations of ring width and meteorological parameters. Graybill et al. [1990] and Glazirin and Gorlanova [2005] sampled juniper in the vicinity of meteorological stations aiming to identify the climatic signal more clearly, but their results were similar: they identified weak correlations with climate. Later, Esper et al. [2002] constructed the longest juniper chronology (since AD 618) for one site in southern Kyrgyzstan. Due to the lack of statistically significant correlation between ring width and meteorological variables, they calibrated the juniper ring width against the maximum density chronology of spruce, which in turn correlates with July-August summer air temperature. The similarity between these series with others from Tien Shan and Karakomum provided evidence that the chronologies contained a regional climatic signal as well. Esper et al. [2003] used the "Regional Standardization Curve" to preserve the long-term temperature trend in the reconstruction based on the juniper ring width chronologies constructed in the Alai Mountains in the southern part of Kirgiz Republic.

In the early 1980s Borscheva [1981, 1983] published the results of her studies of *Picea Schrenkiana* ring width in Zailiiiskii Alatau along an elevational transect – 1400 m (lower spruce tree limit), 2200 and 2600 m (ecological optimum), and 2800 m (upper spruce tree limit). She discovered that the early wood ring width of spruce even at the upper tree limit depends mostly on the fall-winter-spring precipitation preceding the growth season. In the narrow shaded valleys the ring width also depended on the summer temperature [Borscheva, 1981]. At the lower tree limit the ring width depends on the combination of temperature and precipitation during the vegetation period [Solomina et al., 2007]. The ring width is influenced by the climatic parameters of several years preceding the growth [Borscheva, 1981]. Spruce RW chronologies from the Issyk Kul area [Solomina and Glazovsky, 1989] were also used to reconstruct an index of glacial activity. Recently, tree-ring (spruce) reconstructions of air temperature [Solomina et al., 2006] and drought index [Solomina et al., 2007] covering the last few centuries were published, but all of these publications are in Russian and were not internationally peer reviewed.

SPATIAL DISTRIBUTION AND ECOLOGICAL PREFERENCES OF *PICEA SCHRENKIANA* IN TIEN SHAN MOUNTAINS

Picea schrenkiana grows in the Kyrgyzky, Zailiisky, Kungey and Terskey Ala-too, Koeliu, Sarydzhaz, and Atbashi regions, as well as in the western Tien Shan. The optimum for Tien Shan spruce growth is attributed to the area with the mean annual air temperature from –2 to 2°C, annual precipitation from 500 to 700 mm, and an elevation range of 1400 to 3600 m asl. In the lowest part of its range, spruce grows on north-facing slopes, in the mid part on west- and eastfacing slopes, and in the uppermost part on south-facing slopes [Kozhevnikova, 1982]. This distribution suggests that at the upper tree limit the growth of spruce is limited by temperature. The soil moisture plays an important role in the spruce ecology. Spruce requires abundant water, but in the uppermost part at the northern slopes the thin soil layers can become too wet due to great amount of precipitation and low evaporation [Kozhevnikova, 1982].

MATERIALS AND METHODS

From 2000 to 2009 we collected tree-ring samples (cores and disks from dead trees) of spruce (*Picea schrenikiana*) from 15 high elevation and 9 low elevation sites in the Central Tien Shan in Kyrgyz republic (Fig. 1). We also used in this study the collections of ring width and density measurements (3 sites) from the International Tree-Ring Data Bank (Karabatkak, Sarykungey and Saryimek valleys) contributed by F. Schweingruber.

All samples were analyzed using the standard dendrochronological methods [Fritts, 1979; Cook and Kairiukstis, 1990]. Where possible we selected for sampling the trees standing apart from each other, without visual disturbances and wounds, and from the sites with homogeneous orographic, soil and other meso- and microclimatic characteristics. The coordinates of the selected sites were fixed with by GPS and mapped (see Fig. 1). We used COFECHA [Holmes, 1983] for evaluating the quality of the cross-dated series and used ARSTAN [Cook, 1985] to detrend the series and build the local chronologies. The growth trends were approximated by negative exponential or linear curves and the resulting tree-ring indices were calculated as the division of each annual ring width by its respective fitted growth curve value (see Cook and Kairiukstis [1990] for details). The individual detrended series were then averaged in local chronologies. The same procedure was used to detrend the MXD series of F.Schweingruber. Due to the unsufficient number of samples of the subfossil wood we were not able to use RCS detrending [Briffa and Melvin, 2010].

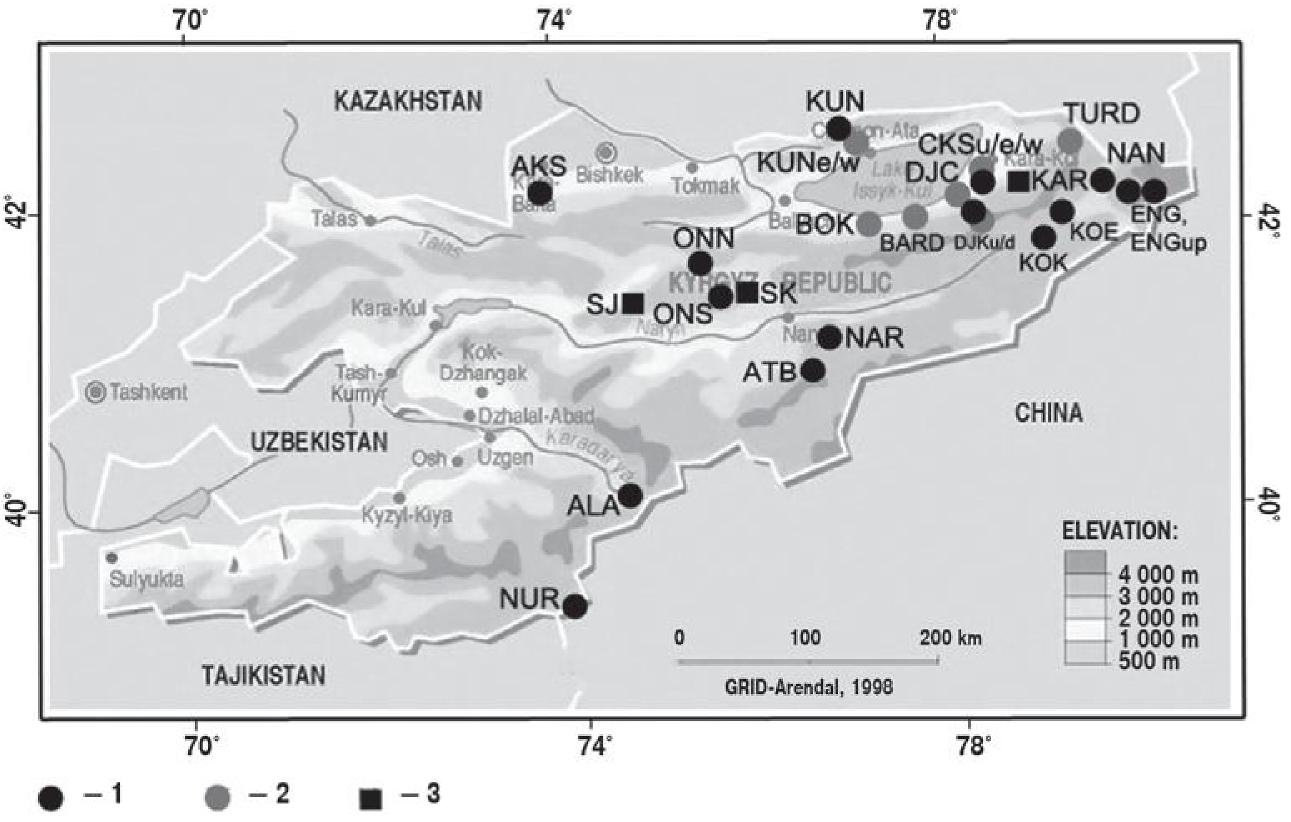

Fig. 1. Map of tree-ring sites: 1 – Upper tree limit, RW, 2 – Lower tree limit, RW, 3 – Upper tree limit, MXD (from the International Tree-Ring Data Bank contributed by F. Schweingruber)

We used DENDROCLIM [Biondi and Waikul, 2004] and correlation analyses to estimate the factors that influence both ring width and density. For this analysis, mean monthly temperature and total monthly precipitation measured at meteorological stations located near the sampling sites were used. In some cases due to the lack of meteorological stations at the high elevation we had to use records from elevations lower than 2000 m. The missing values in the meteorological time series were replaced by the medians of the same series. We could not calculate the response for the sites AKS and ATB due to the insufficient length of meteorological series.

RESULTS

Upper tree limit. Ring width. The correlation analyses demonstrates the high similarity of all 18 RW site chronologies from various locations in the Tien Shan Mountains., which is a sign of a common signal influencing the growth pattern at this large territory. In order to combine the site chronologies we used both correlation and principal component analyses. The similarity of sites by the first PC shows that there is a common factor explaining 50% of ring width variability. The 2^{nd} and 3^{d} PC explain 25 and 10% of the variance respectively. Based on these analyses three groups of chronologies were identified: 1 – AKS, ATB, KUN, ONS, ONN, NAR, CKSU; 2 – ENG, KOE, NAN; 3 – DJKU, KOK. The chronologies tend to group by the vicinity of their location, though this rule has some exceptions. For instance, DJKU does not correlate with any neighboring site except for the KOK. KUN has a high correlation with ATB, ONS, ONN, CKSU, though they are located far away from this site. ATB correlates well with even remote sites.

As soon as all samples cross-date well and the local chronologies correlate with each other they all can be averaged in a regional chronology – TSH UP (Fig. 2*)*. The earliest part of the chronology (AD1301-1360) was cut out due to the poor replication. According to the EPS-test (> 0,85) the remaining chronology is reliable from 1360 to 1460 and from 1510 to 2006.

In general the correlation of the meteorological variables with the ring-width chronologies is not high. This can be partly explained by the remote location of many meteorological stations from the tree-ring sites, but also by a complexity of climatic signal embedded in the spruce tree-rings in Tien Shan**.** In the Fig. 3 one can see that there is a tendency for positive correlation between ring width and total precipitation in August, October, November, December of the previous year. The correlation with temperature is less consistent: there is a negative correlation with the April–May temperature as well as with the summer months of the previous year. Temperature in

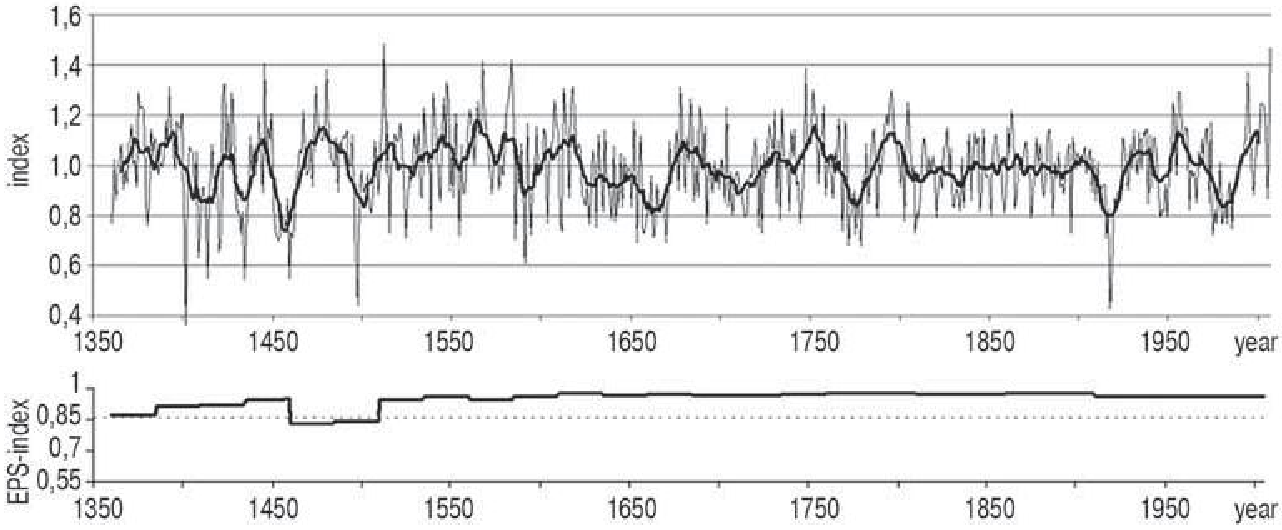

Fig. 2. Regional RW spruce chronology (TSH UP) and its EPS index

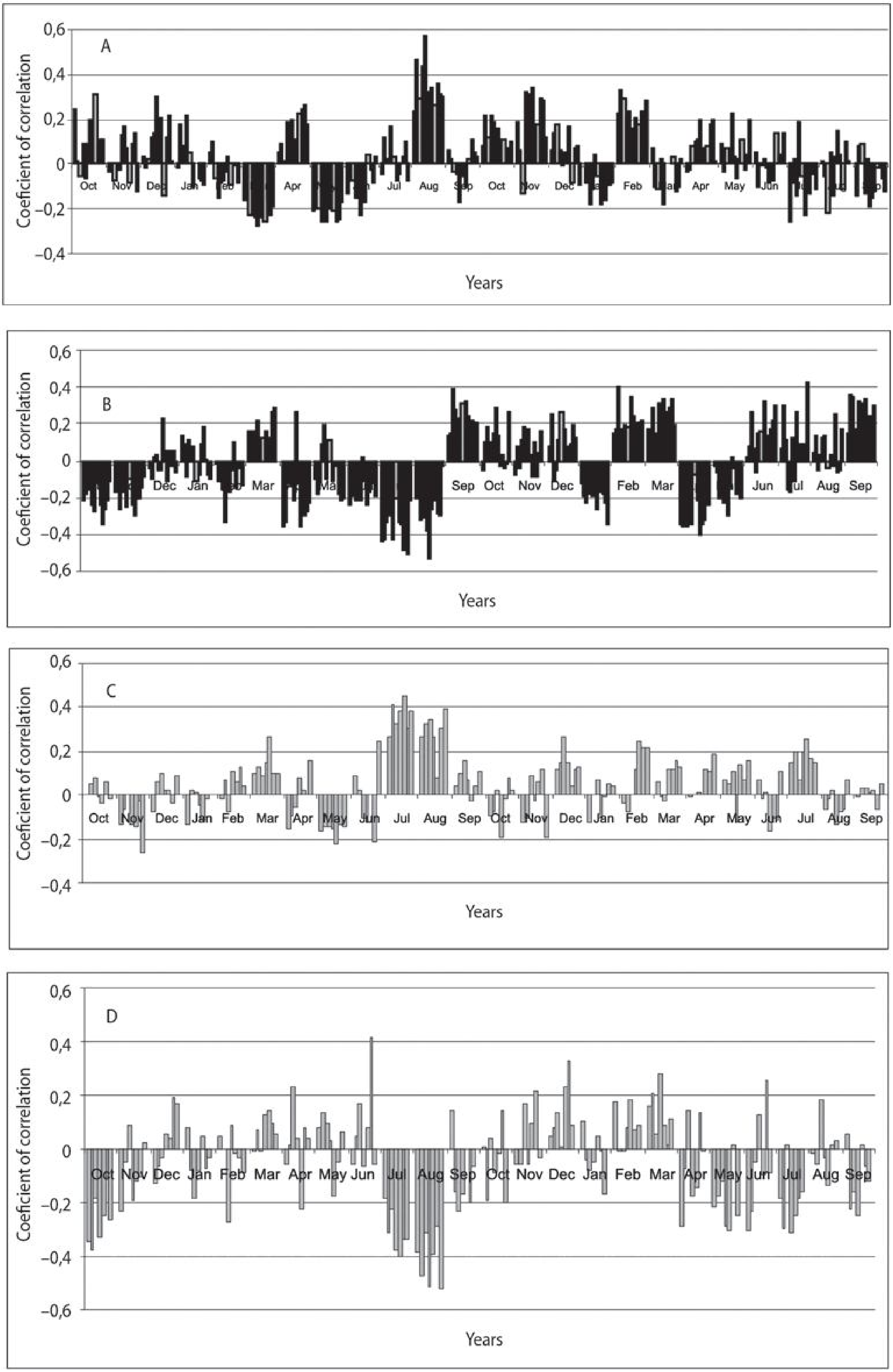

Fig. 3. Correlation functions: the correlation of ring width site chronologies (upper tree limit) with the monthly sum of precipitation (a) and monthly temperature (b) measured at the nearest meteorological stations. (c) and (d) – the same for the lower tree limit site chronologies. Significant at 95% level are coefficient of correlation exceeding 0,35

Table 1. The largest and narrowest tree rings at the upper tree limit

Largest rings		Narrowest rings	
year	ring width	year	ring width
1474	1.45	1451	0.61
1480	1.53	1452	0.67
1512	1.59	1453	0.65
1567	1.38	1454	0.67
1582	1.44	1457	0.64
1583	1.56	1459	0.54
1651	1.35	1496	0.54
1677	1.38	1497	0.45
1747	1.45	1535	0.66
1751	1.30	1538	0.65
1795	1.34	1549	0.62
1804	1.30	1591	0.65
1955	1.30	1771	0.65
1956	1.33	1917	0.49
1994	1.34	1918	0.60

June-September is to the contrary favorable for the growth at the upper tree line.

The low growth anomalies are identified in our regional chronology in 1970–80s, in the early 20th century, in the second quarter 19th century, in 1770–80s, in the late 17th – early 18th centuries, in the mid 17th century, and in the end of 16th century (see Fig. 2). The positive growth anomalies occurred in the mid 20th century, in the late 18th – early 19th centuries, in the middle of 18th century, and in the early of 17th century, in the late 16th – early 17th centuries, n the middle of 16th century. In the Table 1 we list the narrowest and largest rings.

Upper tree limit. Maximum density. The maximum density chronologies for KAR, SK, SJ demonstrate a very high similarity both at the level of interannual and decadal variability. This similarity means that a strong climatic signal is forcing maximum density formation. The correlation between the sites is high despite of long distance between them (r = 0,7–0,75). The response functions for all three sites are also similar [Solomina et al., 2006]. The maximum density significantly correlates also with April-September, but with lower coefficient of correlation when comparing with a shorter window for May–August (r = 0,63 and r = 0,79, respectively). The correlation is significant and negative with the sum of annual precipitation (r = –0,56).

The high similarity and correlation of the KAR, SK, SJ maximum density chronologies permit them to be averaged into a single chronology lasting from 1626 to 1995 and including 58 cores. According to the EPS-test (> 0,85) the chronology is reliable over the period AD 1650–1995. This regional Dmax chronology correlates (r^2 = 0,62) with the May-August temperature measured at the Chon-Kizil-su meteorological station (1948–1987). The correlation with the longer record from Tien Shan meteorological station (1930–1995) decreases, but remains significant at 99% level (r = 0,41). The three offsets of the growth in the years 1694, 1696, and 1698 look like local disturbances, but they reveal themselves in both SJ and KAR chronologies which are located more than 200 km apart from each other and even at the different mountain ranges. For this reason we consider them as a sign of a climatic signal.

The subdivision of the meteorological records into calibration and verification periods (1965–1995 and 1930–1964) shows that the correlation with May–August temperature remains significant for both intervals (r = 0,51 and 0,48 respectively). The highest correlation is observed for the period of 1950s–1980s.

According to our reconstruction (Fig. 4) the low May–August temperature in the Tien Shan occurred in the second half of 17th century, in the middle and the end of 18th century, in 1810s, 1830s, 1880–90s, 1950–60s and in 1980s. According to these data extremely cold years are 1664, 1674, 1676, 1694, 1996, 1698, 1722, 1755, 1761, 1783, 1803, 1813, 1816, 1841, 1869, 1920, 1957, 1972, 1989; warm extremes are 1705, 1708, 1716, 1720, 1727, 1732, 1747, 1807, 1822, 1878, 1881, 1916, 1926, 1933, 1944, 1978, 1984, 1994, 1995.

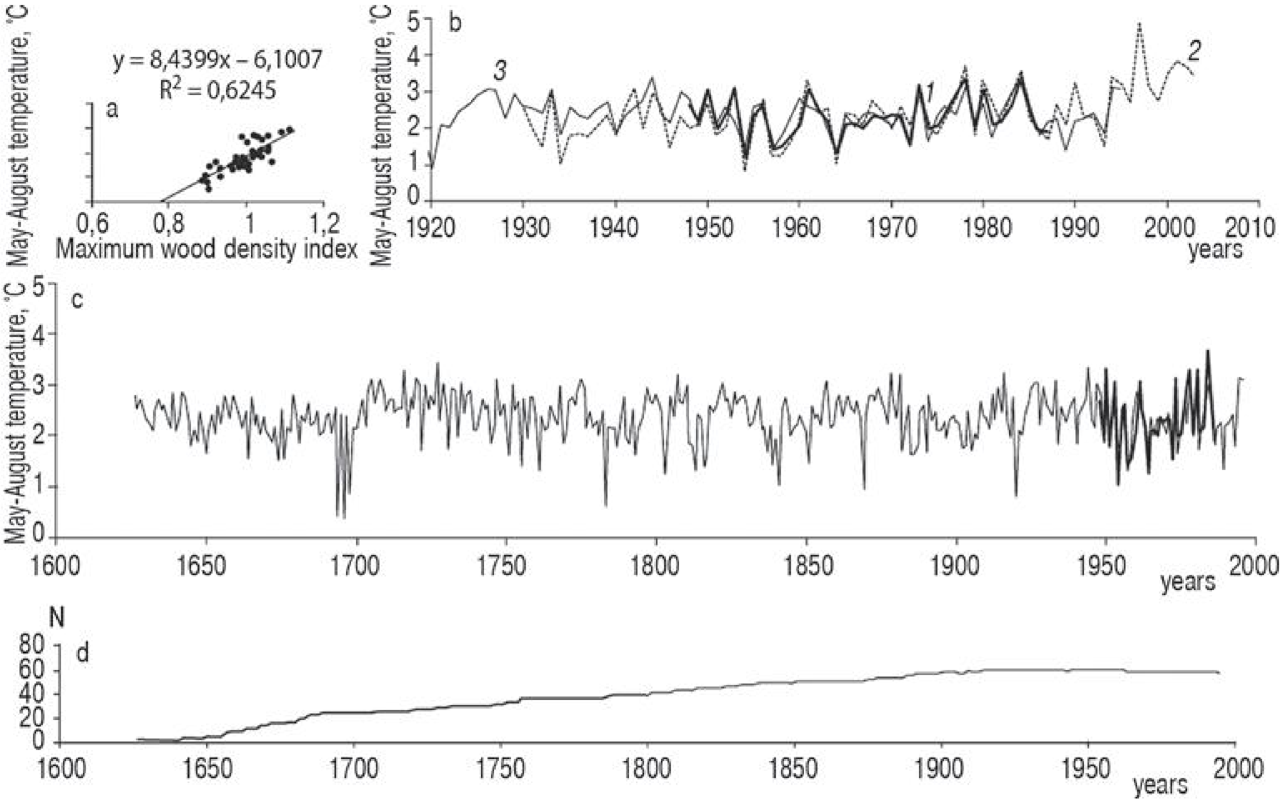

Fig. 4. Reconstruction of May–August temperature by maximum late wood density (mean of three chronologies SJ, SK, KAR):

(a) linear regression and coefficient of correlation of May–August temperature and indices of maximum density chronology; (b) May–August temperature measured at the Chon-Kizil-su meteorological station and adjusted to the elevation of 3600 m (for the comparison with Tien Shan station) (1), measured at the Tien Shan station (2), reconstructed by the maximum density on the base of linear regression coefficient (3); (c) May-August temperature, measured at the Chon-Kizil-su station and adjusted to the elevation of 3600 m and reconstructed by maximum density for 1626–1995; (d) number of samples N in the chronology used for the reconstruction

Maximum density of spruce at the upper tree limit does not correlate with the ring width. This is also clear from the response function, which shows that the DMAX is responsible mostly for the summer temperature, while the ring width is more influenced by the moisture supply.

Lower tree limit. Ring width. For the lower tree limit we analyzed 9 individual site chronologies. The length of the spruce tree-ring series at the lower tree limit is short for two reasons. Firstly, the spruce wood is intensely used for the building activity near the places where the population is concentrated. Secondly, the trees are almost always rotten inside at these sites and the remaining solid wood portion has relatively few rings in it. Thus the chronologies from living trees here rarely exceed the instrumental period (one century) and therefore are not very valuable for the paleoclimate reconstructions. In order to extend their length we sampled old buildings in the area. They are the Svetly Mis Monastery, the school in Pokrovka village, one of the first Russian house of Kolomiitsv in Teplokliuchenka village, and the house of Tien-Shan Physical Geography research station in Chon Kizil-su valley [Solomina et al., 2007]. We cross-dated the building samples with the living tree chronologies. With the exception of the last building all houses are located near the Issyk Kul shore at the elevation 1600–1800 m asl and most probably were built from the wood of the trees growing in the vicinity. Due to the late colonization of this region (19th century) we did not expect to extend the chronology far back more then a few more decades. The correlation of all individual samples with the living trees chronologies of the same valleys (CKS and KUN) is statistically significant. All samples of wood we used were around 200 years long and allowed the extension of the chronology back to AD 1680 (Fig. 5). According to the EPS-test (> 0,85) the chronology is reliable from 1750 to 2005.

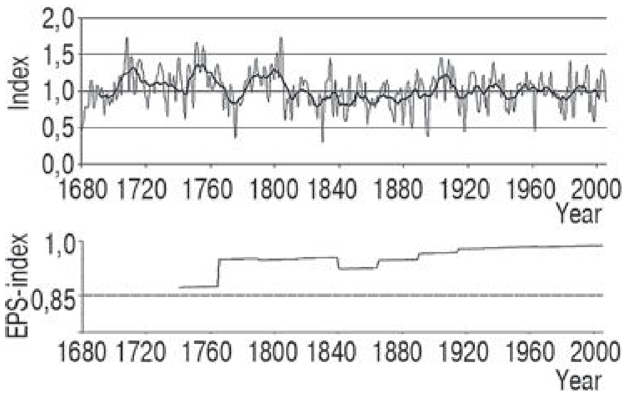

Fig. 5. Ring width regional lower tree limit chronology of spruce (TSH DOWN) and its EPS index

All local and regional average chronologies of the Issyk Kul area correlate with one another. The significant correlations also extend to the chronologies from the Zailiisky Alatau region except for the lowest chronology located at the elevation 1400 m a.s.l. [Borscheva, 1981]. It is of interest that this chronology also weakly correlates with the other sites in the same Talgar valley [Borscheva, 1981].

The correlation functions for the local RW chronologies from the lower tree limit are displayed at the Fig. 3 (c, d). The pattern of correlation function is generally similar to the upper tree limit (Fig. 3, a and b): both temperature and precipitation is July and August of previous year are most important for the tree growth. However the influence of the warm period temperature of the current year at the lower tree limit is negative.

We tested the correlation of the ring width with several modifications of the drought index combining the two parameters [Bitvinskas, 1974]. The highest correlations that we found are with the drought coefficient which includes both temperature and precipitation for the warm period for the current and previous year (June-September):

$$Q = P_1 + P_0/(T_1 + T_0)/2,$$

where P_0 (T_0) *u* P_1 (T_1) – precipitation (temperature) of June–September of the current and the previous years.

Using the longest Przhevalsk meteorological station (1887–1988) over its full length, the correlation of the regional low elevation chronology (TSH DOWN) with the drought coefficient is 0,41 (0,59 for five years running mean). The correlation is higher in the beginning of the records (for 1887–1959 R^2 = 0,50), but it decreases since the late 1950s.

We extended the Przhevalsk records from 1887 to 2000 using two neighboring meteorological stations Pokrovka (Kyzil-su) and Cholpon-Ata. We had to exclude the years (1986 and 1988–1990) from the Pokrovka time series because they demonstrate anomalous high precipitation in July–September exceeding two standard deviations and this anomaly is not recorded at other stations of the region. The drought coefficient based on these records correlates with the Przhevalsk drought index (r = 0,69) as well as with drought index reconstructed by tree-ring data for the period 1951–2000. However in the last case the correlation is not high (r = 0,34). The correlation between ring width and drought coefficient in the second half of the 20th century did not disappear, but it did weaken.

Thus, low precipitation and high temperature during the warm season limit the growth of *Picea Schrenkiana* at the lower tree limit. This allowed the reconstruction of the drought index for the the period 1750–2005 (Fig. 6). According to this reconstruction the droughts in the Issyk Kul region occurred in 1774–1775, 1828–1829, 1856–1857, 1873–1874, 1879–

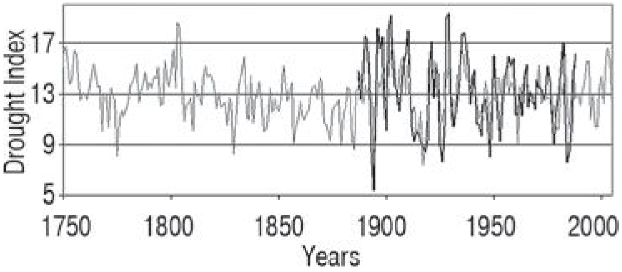

Fig. 6. Drought Index calculated from meteorological data (black) and reconstructed by tree rings (gray)

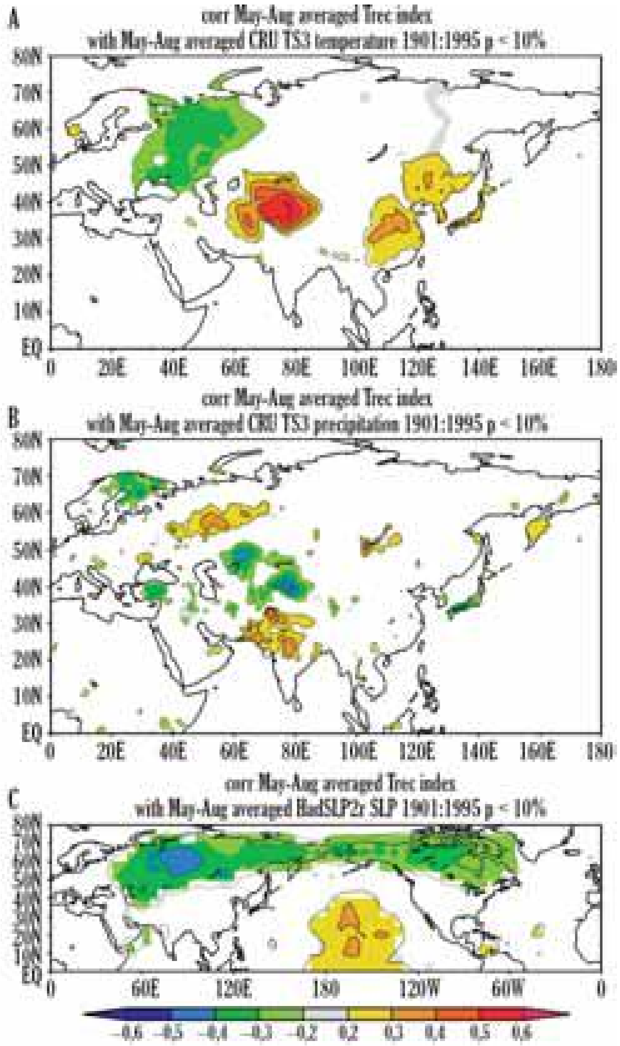

Fig. 7. Correlation maps of the May–August temperature in the Tien Shan Mts with CRU TS3 grid point parameters of the same period (a) temperature, (b) precipitation, (c) sea level pressure

1880, 1884–1885, including those during the instrumental period in 1894–1895 and 1916–1917. The longest drought occurred in 1768–1769/1774–1775. The tree ring based reconstruction demonstrates a lower interannual variability than the meteorological data due to lost variance due to regression, although it reproduces well the chronologies of the droughts. In general the 19th century was drier in the Issyk Kul region that the 20th century. The 20th century does not look unusual in terms of drought occurrence over the last three and a half centuries.

Spectral properties of the reconstructions. Spectral analyses of the two reconstructions presented above, namely for the May–August temperature and June–September Drought index was carried on using the online wavelet software http//paos.colorado.edu/research/waveleth. It shows a certain similarity in the spectral characteristics of both series with two significant peaks around 16–32 and 60–80 years. There is also some sign of consistent inter-annual variability in both series in the ENSO frequency (2–7 yrs) band, but there is little evidence for a strong teleconnection between ENSO and climate in the Tien Shan region.

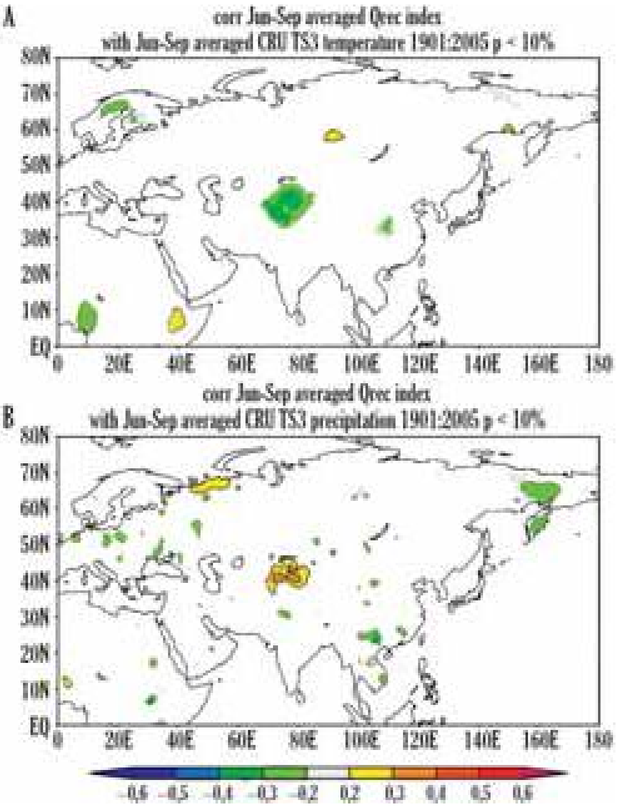

Fig. 8. Correlation maps of the June-September Drought index in the Tien Shan Mountains with CRU TS3 grid point parameters of the same period (a) temperature, (b) precipitation

Correlation maps. Using KNMI Climate Explorer [http://climexp.knmi.nl/], reconstructed May–August temperatures in the Tien Shan Mountains show a strong positive correlation with the CRU TS3 grid point temperature data especially over its northeast part of the region (Fig. 7a). The negative correlation of this reconstruction with CRU TS3 precipitation data over the same period is also observed (Fig. 7b). This is consistent with anti-correlation of summer temperature and precipitation in this region identified earlier basing on meteorological time series [Diurgerov et al., 1995]. A negative correlation of the reconstructed

May–August temperature with the HadSLP2 sea level pressure (same archive) over the large area of the high latitude from Siberia to the North America is a distinct pattern of the hemispheric significance (Fig. 7 c). The negative correlation means that during the negative anomaly of atmospheric pressure over Siberia warm air is advected from the southwest into its eastern periphery and brings hot summer weather to the Tien Shan Mountains.

The correlation fields of the June-September Drought Index reconstruction are somewhat smaller in space, but also consistent with the results on ring-width climatic response at the lower tree limit reported above. There is a positive correlation of our drought reconstructions with the precipitation and negative correlation with temperature in Tien Shan Mountains (Fig. 8 a, b).

DISCUSSION

We have shown that the ring widths of spruce in the Tien Shan Mountains depend mostly on moisture supply. For the upper sites the most important periods are precipitation of August, October–December and February, while at the lower sites the correlation is higher with July-August precipitation. Both conclusions generally agree with those of Borschova [1983] who used a more limited data set for both tree-ring and meteorological data. For the upper tree limit Borschova [1983] identified the October-May precipitation signal in the early wood ring width of spruce at the upper tree limit in Zailiisky and Kungey Alatau (for 5 years smoothed values). The summer precipitation of a previous year is important for both upper and lower tree limit sites. As the inner Tien Shan region is rather dry, thus making spruce quite sensitive to moisture supply [Kozhevnikova, 1982], the drought signal in ring width in spruce chronologies is logical.

At the upper tree limit one should also expect summer temperature to limit radial growth as well. This is indirectly supported by the results of Kozhevnikova [1982], who claimed that the poor soils at the northern slopes at the upper tree limit contain too much moisture, which can negatively influence tree growth, while high air temperature would on the contrary contribute the growth. None of our sites are south-facing, however, and we therefore suspect that they do not represent the potentially possible upper tree limit. Thus, the signal in their ring width is more typical for the lower-elevation belt of spruce forests. The actual real spruce forest is also lowered by anthropogenic and geomorphic activity. Use of the high elevations for pasturage is the traditional occupation of the local population, and the shepherds use wood to make fires and build huts. At the same time, the sheep are very efficient in destroying the natural vegetation. Avalanches, mud and debris flows, slope movement are also important natural agents in lowering the natural upper tree line.

The lower tree line in the Tien Shan is probably even more disturbed, but here human activity clearly dominates the natural processes: for centuries the spruce trees were used for building and heating. Most our sites in the lower locations are between 2000 and 2400 m a.s.l., while Borscheva [1983] was able to sample a much lower site at the elevation 1400 m a.s.l. At this site the ring width was limited by summer precipitation in a similar way to our cases, but with higher correlation between the ring width and meteorological parameters. At the elevation 2000–2400 m a.s.l. the signal becomes more mixed: the growth depends not only from the precipitation, but integrates also the influence of the temperature of spring, summer and early fall. This combination of integrated temperature/precipitation signal is typical for the semi-dry areas [e.g. Cook et al., 1999].

The individual samples and chronologies from the upper and lower tree limits cross-date against each other successfully. The combined chronologies from both locations also show a lot of similarity especially at the level of interannual variations. This might be explained as a common influence of moisture supply on tree growth of both locations (see figure 3). Wang, Ren and Ma [2005] came to the same conclusions studying the ring width of *Picea schrenkiana* in the adjacent territory of the Tien Shan Mountans along an altitudinal gradient from 1600–1700 to 2600–2700 m a.s.l. They found the correlation between the sites and the decreased response with the increasing of the elevation of the sites. These authors showed that precipitation was the most important factor limiting tree radial growth even at the upper tree limit in the arid Tian Shan Mountains. Esper et al. [2007] found a high degree of similarity among juniper ring-width chronologies along the altitudinal gradient by analyzing 28 juniper sites in the Tien Shan and Karakorum mountains (correlation between the upper and lower tree limit sites is up to 0,72 for the period as long as 1438–1995). These authors suggested that the tree growth might be forced by solar radiation controlled by cloud cover changes, but did not prove this hypothesis.

The maximum density chronology does not correlate with either upper tree limit or low tree limit chronologies, clearly demonstrating a different climate signal. It depends on a different climate influence from ring width, which is the summer temperature. Similar relations of maximum density with summer temperature have been reported for the trees of different species growing at the upper [Schweingruber et al., 1988, Esper, 2002, 2003, Buentgen et al., 2010] or northern tree limits [Briffa et al., 1998, 2002].

There are very few reconstructions for the northern periphery of the Tien Shan region available for the comparison with our data. Most reconstructions of climatic parameters come from Tibet and Himalaya with substantially different climate largely influenced by monsoon activity. Wilson et al. [2007] used the ring width and density data from the ITRDB for their temperature reconstructions for the Kyrgiz territory. These included two of the three sites we used here to model the May–August temperatures. In the Wilson et al. [2007] study the RW and MXD chronologies were utilized separately as potential predictors in a stepwise multiple regression against gridded June–July mean temperatures. The reconstruction explained 36% (r = 0,61) of the gridded temperature variance. In our case the calibration was with a longer window (May–August temperature) measured at the Chon-Kizil-su meteorological station, and the variance explained is higher ($r = 0{,}79$, $r^2 = 0{,}62$) as in Wilson et al. [2007]. The correlation between the two reconstructions is high (r = 0,66, for 1775–1995). In contrast, the Esper et al. [2003b] June–September temperature reconstruction was based on a *Juniperus turkestanica* regional RW chronology, which correlated with the Fergana meteorological station in eastern Uzbekistan (r = 0,46). The correlation with our temperature reconstruction is insignificant, but it is also not significantly correlated with the Wilson et al. [2007] reconstruction mentioned above, although for some periods the two curves show a similar pattern.

CONCLUSIONS

Spruce ring width variations over a large range of elevations in the Tien Shan Mountains depend mostly on moisture availability. At the upper elevations of the mountains, cold period precipitation plays the most important role for spruce growth, while at the warmer and drier lower elevations, the combination of warm period temperature and precipitation is more important. In contrast, MXD correlates positively with the summer temperature in a highly consistent and significant way. Overall, the spatial agreement between the chronologies supports the conclusion that significant external forcing of growth due to climate is occurring.

We have also presented here a drought index reconstruction for 1750–2000 based on the lower tree limit chronology constructed for the Issyk Kul area. The best fit model includes the sum June–September precipitation of previous and current years divided to the average temperature of the same period. The reconstruction accounts for 41% of the variance in observed drought index over 1887–1988. According to this reconstruction the 19th century was drier in the Issyk Kul region than the 20th century.

A summer temperature reconstruction was also presented here that is based on maximum wood density at the upper tree limit. The reconstruction accounts for 62% of the variance in the observed temperature data over 1951–2000. The significance of this correlation allows the reconstruction of May–August temperature from 1650 to 1995.

The correlation of the reconstructions with the CRU TS3 grid point data confirms the results of the modeling using the meteorological data from the nearest stations. We also identified a teleconnection pattern of the May-August temperature reconstruction in Tien Shan and the low pressure in the high latitudes in Siberia.

The reconstructions shows a certain similarity in the spectral characteristics with two significant peaks around 16–32 and 60–80 years.

According to these results the 20th century does not look unusual in the context of the last two hundred years, either in terms of frequency of drought occurrence or in terms of severity. The summer temperature reconstruction allows for a longer context over the past three and a half centuries. Again in this context the temperature variations of the last century do not look unusual, though they do not encompass the last decade when the summer warming in Tine Shan became especially prominent.

ACKNOWLEDGEMENTS

E. Cook was supported at the Lamont by National Science Foundation award ATM 04-02474. Lamont-Doherty Earth Observatory Contribution Number 0000, O.Solomina – by a RAS Program P4. ■

REFERENCES

1. Biondi, F. and Waikul, K. (2004) DENDROCLIM2002: AC++ program for statistical calibration of climate signals in tree-ring chronologies. Computers & Geosciences 30: 303–311.
2. Bitvinkas, T.T. (1974) Dendroclimatic research. Leningrad Gidrometeoizdat (in Russian).
3. Borscheva, N.M. (1981) Picea Schrenkiana ring width chronologies for Zailiiskiy Alatau mountains. Tree-ring chronologies of Soviet Union 2: 17–23 (in Russian).
4. Borscheva, N.M. (1983) Dendroclimatological analysis of *Picea Schrenkiana* radial growth in the Northern Tien Shan Mountains. Abstract of PhD Sverdlovsk (in Russian).
5. Buentgen, U., Frank, D., Trouet, V., Esper, J. (2010) Diverse climate sensitivity of Mediterranean tree-ring width and density. Trees 24: 261–273 DOI 101007/s00468-009-0396-y.
6. Briffa, K.R., Osborn, T.J., Schweingruber, F.H., et al. (2002) Tree-ring width and density data around the Northern Hemisphere: Part 1, local and regional climate signal. The Holocene 12 (2): 737–757.
7. Briffa, K.R., Jones, P.D., Schweingruber, F.H., Osborn, T.J. (1998) Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years. Nature 393: 450–455.
8. Briffa, K.R. and Melvin, M. (2011) A Closer Look at Regional Curve Standardization of Tree-Ring Records: Justification of the Need, a Warning of Some Pitfalls, and Suggested Improvements in Its Application in M K Hughes, H F Diaz, and T W Swetnam, editors Dendroclimatology: Progress and Retrospects Springer Verlag 113–145.

9. Cook, A.R. (1985) A time series approach to tree- ring standardization. PhD Disser tation. University of A rizona. U SA . Tucson, 171.

10. Cook, E.R., Stahle, D.W., Cleaveland, M.K. (1999) Drought Reconstructions for the Continental United States. J of Climate 12: 1145–1162.

11. Cook, E.R. and Kairiukstic, L.A. (1990) Methods of dendrochronology: applications in the environmental sciences. Dordrecht, Netherland, Kluwer Academic Publishers.

12. Diurgerov, M.B., Kunfkhovich, M.G., Mikhalenko, V.N., et al. (1995) Tien Shan Glaciation Moscow (in Russian).

13. Esper, J., Frank, D.C., Wilson, R.J.S., Buentgen, U., Treydte, K. (2007) Uniform growth trends among central Asian low- and high-elevation juniper tree sites. Trees 21: 141–150 DOI 101007/s00468-006-0104-0.

14. Esper, J., Schweingruber, F.H., Winiger, M. (2002) 1300 years of climatic history for Western Central Asia. The Holocene 12 (3): 267–277.

15. Esper, J., Shiyatov, S.G., Mazepa, V.S., Wilson, R.J.S., Graybill, D.A., Funkhouser, G. (2003) Temperature-sensitive Tien Shan tree ring chronologies show multi-centennial growth trends. Climate ynamics 21: 699–706.

16. Fritts, H.C. (1979) Tree rings and climate. London-New York.

17. Glazirin, G.E., and Gorlanova, L.A. (2005) Experience of dendroclimatic researches of junipers on Western Tien Shan. Proceedings of NIGMI 5 (250): 24–42.

18. Graybill, D., Shiyatov, S., Burmistrov, V. (1990) Recent dendrochronological investigations in Kirghizia, USSR. Tree Rings and Environment 123–127.

19. Holmes, R. (1994) Dendrochronology program library – users manual. Laboratory of Tree-Ring Research, Tucson, Arizona.

20. Holmes, R.L. (1983) Computer-assisted quality control in tree ring dating and measurments. Tree-ring Bulletin 44: 69–75.

21. Kozhevnikova, N.D. (1982) Biology and ecology of Tien-Shan spruce Frunze, Ilim.

22. Mukhamedshin, K.D. (1977) Juniper forests in Tien Shan and their importance as a forest resources Frunze, Ilim.ORIG.

23. NOAA Paleoclimatology: http://wwwncdcnoaagov/paleo/treeringhtml.

24. Schweingruber, F. (1988) Tree rings: basics and applications of dendrochronology. RPC, Dordrecht, Holland.

25. Solomina, O., Schweingruber. F., Nagornov, O., Kuzmichenok, V., Yurina, Yu., Mikhalenko, V., Kunakhovich, M., and Kutuzov., S. (2006) Reconstruction of summer temperature and ablation of glaciers in Central Tien Shan for the period of AD 1626–1995 using maximum ring density of spruce (Picea Schrenkiana). Data of Glacialogical Studies 100: 104–113 (in Russian).

26. Solomina, O.N., Abilmeizova, B., Griaznova, V.V., Yershova, I.V. (2007) Tree-rings drought index reconstruction in Near Issyk-Kul area, Tien Shan, Kyrgyz Republic for AD 1680–2005. Problems of ecological monitoring and ecosystem modeling 21: 183–202 (in Russian).

27. Solomina, O.N., Glazovsky, A.F. (1989) Tree-ring of Tien-Shan spruce and glacier variations on the northern slope of Terskey Alatau range. Data of Glacialogical Studies 65: 103–110 (in Russian).

28. Wang, T., Ren, H., Ma, K. (2005) Climatic signals in tree ring of Picea schrenkiana along an altitudinal gradient in the central Tianshan Mountains, northwestern China. Trees 19: 735–741 DOI 101007/s00468-005-0003-9.

29. Wilson, R., D'Arrigo, R., Buckley, B., Buentgen, U., Esper, J., Frank, D., Luckman, B., Payette, S., Vose, R., and Youngblut, D. (2007) A matter of divergence: Tracking recent warming at hemispheric scales using tree ring data. J Geophys Res 112 D17103, doi:101029/2006JD008318.

Olga Solomina – Expert in climate change, glacial morphology, leoclimatology. Deputy director of the Institute of Geography RAS. Author of more than 100 scientific papers including those published in the high rating journals (Nature Geoscience, Quaternary Science Reviews, the Holocene, Climate in the Past). Lead author of the 4th and 5th IPCC Assessments.

Olga Maximova – expert in dendrochronology, climate and glaciological reconstructions. PhD thesis: Tree-ring based hydrometeorological reconstructions for last centuries for Tien Shan (Kyrgyzstan). Participated in scientific expeditions in Tien Shan mountains (Kyrgyzstan), Russian Plain, North Enisey region, Transbaikal region and North Mongolia.

Edward R. Cook – Ewing Lamont Research Professor. Specialist in tree-rings, biology and paleoenvironment, Director of Tree-Ring Laboratory in Lamont-Doherty Earth Observatory in Columbia University, USA. One of the most eminent experts in tree-ring climate reconstructions (http://www.ldeo.columbia.edu/user/drdendro).