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PALEOENVIRONMENT. THE STONE AGE

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MILLENIAL RECONSTRUCTION OF THE SUMMER TEMPERATURE IN THE POLAR URALS: TREE-RING DATA FROM SIBERAN JUNIPER AND SIBERIAN LARCH*

Introduction

Dendroclimatic investigations in the Polar Urals have quite a long history. A large amount of remains of trees that died many hundreds of years ago can be found here. This allows the extension of tree-ring chronologies beyond the age of the oldest larch and spruce trees, which here reach the age of 400 – 500 years. In particular, there is a large amount of dead-and-down trees within the limits of the sub-golets zone and above the upper treeline in the foothills of the Chernaya Mountain and the Rai-Iz Massif, which are located on the eastern macroslope of the Polar Urals within the Sob River basin. A strong climatic signal is recorded in tree-rings in this region. Using wood samples of currently living and dead Siberian larch trees (*Larix sibirica* Ledeb.) a millennial tree-ring chronology has been obtained for the first time in the subarctic zone (Shiyatov, 1986), and a quantitative reconstruction of mean June – July temperature has been done based on this chronology (Graybill, Shiyatov, 1992; Shiyatov, 1995). Later, a chronology was constructed based on measurements of the maximal density of wood in each annual layer, permitting the reconstruction of mean air temperature for a longer period of the year (from May to September) (Briffa et al., 1995). Now the tree-ring chronology based on the width of annual rings has been extended back to 645 AD, a duration of 1350 years.

It is believed (Hantemirov et al., 1999) that one of the best ways of getting more reliable dendroclimatic reconstructions is to create chronologies by using species of trees and bushes which significantly differ in biological and ecological characteristics from those most often used for these purposes. For this reason, we have conducted a study directed at the search for species of trees and bushes which reach an older age, and whose annual rings accurately reflect the variability of climatic conditions. Special attention was paid to a small evergreen bush – Siberian juniper (*Juniperus sibirica* Burgsd.), reaching a height of 1.0 – 1.5 m and a diameter at the base of the most developed branch of 18 cm. This arctic-alpine species is widespread in the Polar Urals. It grows both under the canopy of light spruce-larch forests and above the upper timberline, in the subbelt of low bush tundra. Siberian juniper reaches an exceptionally old age. The oldest living bush found in this region is 850 years old; 500 – 600 year old specimens are encountered rather often. In other words, the maximum age of Siberian juniper is twice that of large trees (Siberian larch and Siberian spruce) growing there and it should be considered the longest-living woody species in the Urals.

Earlier, based on the width of annual rings of the Siberian juniper, we developed a 636-year chronology for the Polar Urals and, proceeding from it, we reconstructed changes in summer temperatures for the last 450 years (Ibid.). In this study it has been demonstrated that the juniper annual rings contain a strong climatic signal reflecting the mean temperature of May, June and July of each year of growth, whereas the chronologies of Siberian larch and Siberian spruce in this region provide information about the mean temperature of June and July only. In addition to this, values of the parameters of relationship and synchronicity with temperature conditions of individual months have revealed differences between chronologies constructed from juniper and other woody species. In particular, larch annual rings generally contain information about July and,

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to a lesser extent, June temperature conditions, while juniper annual rings mostly provide data about the June temperature. This gave us the idea to combine the chronologies developed by larch and juniper and to analyze the climatic signal contained in them. It has been shown that a combined chronology increases the reliability and quality of dendroclimatic reconstruction.

In connection with this, over the last two years we have carried out an intensive search for both living old juniper specimens and remains of long-ago dried bushes and branches in order to extend the chronology into the remote past. As a result, a chronology has been reconstructed back to 641 AD, and in terms of duration it achieved equality with the chronology which was earlier obtained from the Siberian larch.

The task of this research is to examine the issues of construction and further chronological extension of the Siberian juniper tree-ring chronology, to obtain a combined chronology from juniper and larch, to analyze the climatic information contained in this chronology, and finally to reconstruct the climatic conditions over the last 1000 years.

Objects and methods

In order to develop a chronology from Siberian juniper, stem discs were sawn off from the forty-five oldest living bushes growing more or less isolated on the eastern macroslope of the Polar Urals (Chernaya Mountain, Rai-Iz Massif) near the upper limit of the light larch forest distribution (200 – 280 m above sea level). In each bush, the most well-developed branch was selected and a stem disc was detached from its lower portion. In addition, stem samples were taken from thirty-nine dead branches and bushes.

The branches bent and outspread near the ground display highly eccentric annual rings, since the growth of wood layers takes place generally in the direction opposite the ground. Therefore, measurement of annual tree-ring width, especially in case of the oldest specimens, can only be done in one direction, where the radial growth is maximal. Measurements were often made along the curve line, because during their lifetime branches repeatedly change their spatial orientation as well as the direction of maximum growth.

The cross-dating and determination of calendar dates of tree-ring formation was carried out by COFECHA and TSAP computer programs as well as by eye-estimated comparison of the growth curves on the monitor screen and on graphs. The results have demonstrated that the oldest living branch contained 840 rings and the dried branches and bushes died during the period from 900 to 100 years ago (the oldest branch has rings formed from 641 to 1105 AD).

Indices of annual ring width were calculated by the corridor method (Shyatov, 1986). It was found that in junipers each year's growth strongly depends on the growth of the two previous years. In order to make the comparative analysis of a "cleaner" climatic signal recorded in the tree-ring chronologies, the so-called "prewhitening" procedure has been performed, i.e., in all individual chronologies, the influence of the previous years' growth on the growth of each year has been eliminated.

In order to develop a mean chronology from juniper, 84 individual chronologies have been used. The samples used had from 61 up to 840 yearly rings. The duration of the obtained chronology is 1359 years (from 641 to 1999 AD). The interval from 641 to 945 AD is represented by only one or two samples and from 1000 to 1999 AD – by at least nine from each year. In order to carry out a dendroclimatic reconstruction, the last 1000-year interval provided by a sufficient quantity of samples was used. In order to develop a combined juniper-larch chronology, a 997-year-long interval of the chronology based on Siberian larch was used (from 1000 to 1996 AD) (Shiyatov, 1995; Vaganov et al., 1998). The evaluation of the relationship between growth indices and climatic parameters has been done based on the 117-year record of meteorological observation in the city of Salekhard (1883 – 1999), which is situated 50 km east of the research area. In order to expose long-term climatic fluctuations the linear filtration method was used (Mazepa, 1986).

Results and discussion

Reconstructions of the summer temperatures obtained through the use of the mean chronologies based on juniper and larch differ from each other considerably: the correlation coefficient between them over the whole interval under reconstruction is quite low (0.32). The differences are caused by the fact that these chronologies contain various climatic signals. As it was mentioned above, a growth of juniper reacts more to the temperature changes of early summer, while a growth of larch reacts mostly to mid-summer temperature changes. To a certain extent this is supported by instrumental observation data. As a rule, the higher the difference between the mean July and May – June temperatures, the higher the discrepancy during the same year between the two examined reconstructions.

The combined chronology was based on the evaluation of the multiple regression parameters between the growth indices of the mean chronologies of juniper and larch and the mean June – July temperatures. The summer temperature reconstruction obtained by the combined chronology shows higher similarity with instrumental data, if compared with those based on the chronologies developed separately by juniper and larch. The correlation coefficient between actual temperatures and those reconstructed by the combined chronology for June – July of 1883 – 1996 is 0.73 and the synchronisation coefficient is 76%, whereas these values from juniper and larch chronologies are 0.61 and 71%, 0.60 and 73%, respectively. It is important to note that during the period in question, the relationship between the climate and the ring width indices remains invariably high (correlation coefficient for the period 1883 – 1941 is 0.73 and for the period 1942 – 1996, 0.71). Fig. 1, *b* shows the actual fluctuations of summer temperatures and those reconstructed using the combined chronology smoothed by a 20-year low pass filter. As the figure demonstrates, the curves coincide.

The reconstructed annual fluctuations of the summer temperatures for the last 1000 years are shown on Fig. 1, *a*. Their large range, reaching 8°C, draws attention. Considering the fact that the range of the air temperatures reconstructed by tree-ring chronologies is usually less than that of the actual temperatures, it is possible to that it was actually no less than 10°C. It should be noted that this changeability was different in different periods (Fig. 2); during the warm summer seasons it was higher. Evidence of extremely cold summer seasons presents particular interest, because they have significant impact on the functions of various components in northern ecosystems as well as on economic activities of the population. During the last 1000 years, the coldest summer seasons in the Polar Urals were in 1312 (the deviation from the mean was –4.3°C), 1328 (–3.3°C), 1342 (–4.2°C), 1466 (–3.0°C), 1783 (–4.0°C), and 1855 (–3.8°C). Most often cold summer seasons were observed in the 19th and 14th centuries and most rarely in the 12th, 13th and 15th centuries (see Fig. 1, *a*).

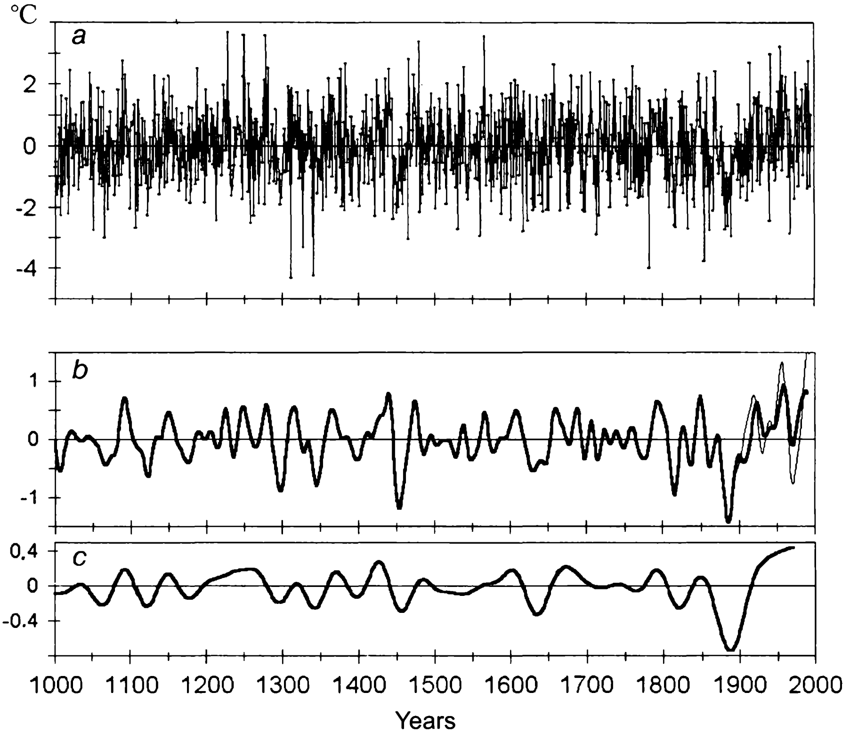

Fig. 1. Dendroclimatic reconstruction of mean June – July air temperature anomalies. *a* – annual data; *b* – intracentennial fluctuations (the thin line shows data obtained through instrumental observations in Salekhard); *c* – centennial fluctuations.

Dendroclimatic method permits revealing not only annual, but also intracentennial (from 2 – 3 to 60 years) and centennial (above 60 years) fluctuations. Intracentennial (*b*) and centennial (*c*) changes of summer temperatures in the Polar Urals are demonstrated in Fig. 1. Although the range of these fluctuations is smaller than that of annual fluctuations (4.3 and 1.5°C respectively), it is evident that natural intracentennial and centennial changes of the summer temperature were characteristic of the whole period of time under study.

While analyzing the intracentennial fluctuations, two exceptionally cold periods should be noted at the end of the 19th and in the middle of the 15th centuries. In addition, cold summer seasons took place at the end of 13th – beginning of the 14th centuries, in the middle of the 14th and at the beginning of the 19th centuries (see Fig. 1, *b*). As a rule, during these periods the lowering of summer temperatures proceeded gradually, with the exception of the middle of the 15th century, when the temperature dropped almost instantly: in 1445 the mean summer temperature was 1.5°C above the mean and in 1446 it was 2.4°C below the mean; after that the summer temperature did not rise above the mean for many years. Among the warm intracentennial periods, the end of the 11th – beginning of the 12th century, the first half of the 15th, the end of the 18th century and two periods within the 20th century (the middle and the end of the century) should be noted.

Among the centennial climatic changes an exceptionally cold period in the second half of the 19th – beginning of the 20th century – the coldest in the last millennium – draws particular attention. This cooling ended with a drastic rise in summer temperatures that continues to the present time. It should be pointed out that warming of the climate during the 20th century in the Polar Urals was most intensive if compared with other sectors of the Siberian Subarctic region (Vaganov et al., 1998). Long and intensive warming also occurred in the 13th century. During this period, forest vegetation reached its highest level in the mountains (Shiyatov, 1995). The 14th century was generally cold.

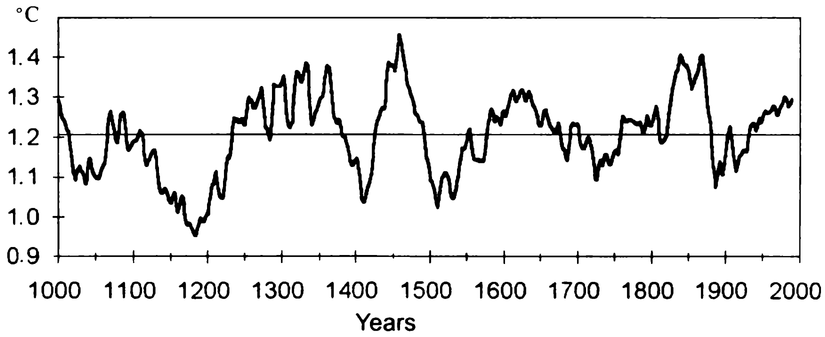

Fig. 2. Dynamics of the annual variability of the reconstructed air temperatures, expressed in changes of standard deviation during the 50-year periods.

Conclusion

The millennial reconstruction of summer temperature fluctuations with an annual resolution presents an interest for understanding of natural and anthropogenic variability of the climate and also the exploration history of the region. Such fluctuations influenced certain species of plants and animals as well as the formation of land and water ecosystems. These fluctuations also impact the economic activity of the people living in these extreme climatic conditions. The conclusions and inferences concerning the climate variability which were obtained through the analysis of the annual rings of trees and bushes in the Polar Urals can be extrapolated to a major portion of the northern part of West Siberia, since under the conditions of the Far North homogeneous temperature fields occupy vast territories (to 500 – 800 km in diameter) (Vaganov et al., 1996). In addition, long-term tree-ring chronologies are of a particular importance for absolute dating of historical, archaeological, and ethnographical sites (Shiyatov et al., 2000).

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