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The Variability of Summer Air Temperature at High Latitudes in the Northern Hemisphere for the Last 1.5 ka: A Comparative Analysis of the Data on Annual Tree Rings and Ice Cores

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Indirect sources of information on climatic variations, such as annual rings of trees, as well as layers of ice and sediments, possess high temporal resolution and encompass time intervals from one season and one year to hundreds of millennia [1]. As the data on climate variability in the past have accumulated, it has become quite possible to analyze them comparatively and reveal variations of a global character, covering considerable territories of the globe [2]. It is equally important to use such data for the calibration of indirect sources which have a low temporal resolution [3].

The main objective of this work is to compare the long series (1000–1500 yr) of tree growth variations (the indices of annual ring width, ARW) that record summer air temperature oscillations in the northern Urals and western and Central Siberia, as well as to check them against the data of another indirect source of temperature variations at high latitudes in the Northern Hemisphere, i.e., the content of oxygen isotopes in the Greenlandian glacier layers [5, 6].

The work analyzes the long-term tree-ring chronologies obtained for the Polar Urals, Southern Yamal, lower reaches of the Taz River near the ancient city of Mangazeya, as well as for the eastern Taimyr (the lower reaches of Kheta and Kotui rivers). The chronologies were obtained on the basis of the oldest, growing tree specimens of Siberian larch and larch of Gmelin (aged up to 580 yr), remains of extinct trees preserved at the surface, and semifossilized wood from alluvial deposits of minor rivers [4]. The absolute dating of annual rings was accomplished by the method of cross-dating. The "corridor" method was applied during the treatment and standardization of individual series in order to preserve as much as possible the long-term temperature variations in the indices of annual ring width [7]. Standard statistical methods were used for analyzing generalized chronologies, such as the determination of synchronism and concordance coefficients (to assess the coordination in annual and more long-term variations), the determination of the sensitivity coefficient and signal/noise ratio (to assess climatic signal reliability), the estimation of climatic response functions (to reveal the leading climatic variables affecting tree growth variability), the estimation of spectral density functions (to assess cyclic components) [8, 9]. The climatic calibration of chronologies was carried out on the basis of data obtained from the Salekhard (1883–1990), Dudinka (1906–1990), Turukhansk (1878–1990), and Khatanga (1933-1990) meteostations.

The principal characteristics of generalized tree-ring chronologies are summarized in Table 1. The high sensitivity coefficients (0.33–0.47) and signal/noise ratios (26–37) are indicative of the fact that the chronologies obtained contain a strong climatic signal. The estimation and analysis of climatic response functions showed that 60–70% of the series dispersion (R = 0.75–0.83) is due to the variability of summer (June–July) temperature. The chronologies reliably record both annual (with the maximum range 8–10°C) and more long-term temperature variations (intrasecular, secular, and even supersecular). For the data smoothed by the 5-yr moving averaging, the correlation between the growth indices and summer temperature variations increases to 0.8–0.91 (see also [7, 10]); i.e. the variability of indices of annual tree ring width can be considered as a reliable indicator of the summer temperature trend. The synchronism coefficient values between the series show that the synchronism of annual growth index variations decreases with the increase of distance between the areas. The synchronism completely disappears between the Yamal–Ural chronologies and the Taimyr chronology (Table 2). That is, the regional features prevail in the annual (high-frequency) oscillations of summer temperature in different sectors of Subarctic Siberia. During the past 400 yr, only 28% of these oscillations reveal the simultaneous occurrence of warm or cold years throughout the whole of Subarctic

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Table 1. Basic statistical characteristics of generalized tree-ring chronologies

Area and number of chronology	Period and duration (yr)	Root-mean-square deviation	Sensitivity	Signal/noise ratio
Southern Yamal (1)	1–1994(1994)	0.47	0.47	30
Polar Urals (2)	745–1996(1252)	0.41	0.41	27
Taz River (3)	1103–1994(892)	0.35	0.33	37
Eastern Taimyr (4)	38–1996(1959)	0.40	0.42	26

Siberia [4]. The concordance coefficient values testify that the coordination in tree growth variability in different areas is governed mainly by long-term (not annual) temperature oscillations. Figure 1 compares the tree-ring chronologies obtained, in which the high-frequency oscillations within the period of less than 5 yr are eliminated by the moving averaging. A great number of revealed depressions and accelerations in tree growth caused by temperature decrease are common for all the chronologies. For example, the coolings at the beginning of the 11th century, at the end of the 13th–the beginning of the 14th centuries, in the first half of the 17th century, at the beginning of the 19th century, etc. can be clearly distinguished. Evidently, the common (for a given area) temperature variations are reflected, to a greater extent, in the long-term variations of tree growth than in its annual oscillations. Therefore, one can combine the data of all four generalized chronologies to obtain the maximum characterization of the common climatic signal.

The combined chronology resulting from the averaging of the four generalized chronologies is shown in Fig. 2 and is compared to the temperature reconstruction data based on the oxygen isotope content in ice cores from Greenland [5, 6]. The synchronous trend of the presented curves is clearly seen. For example, the long-term and relatively cold periods revealed by the data of ice cores (the end of the 13th, the end of the

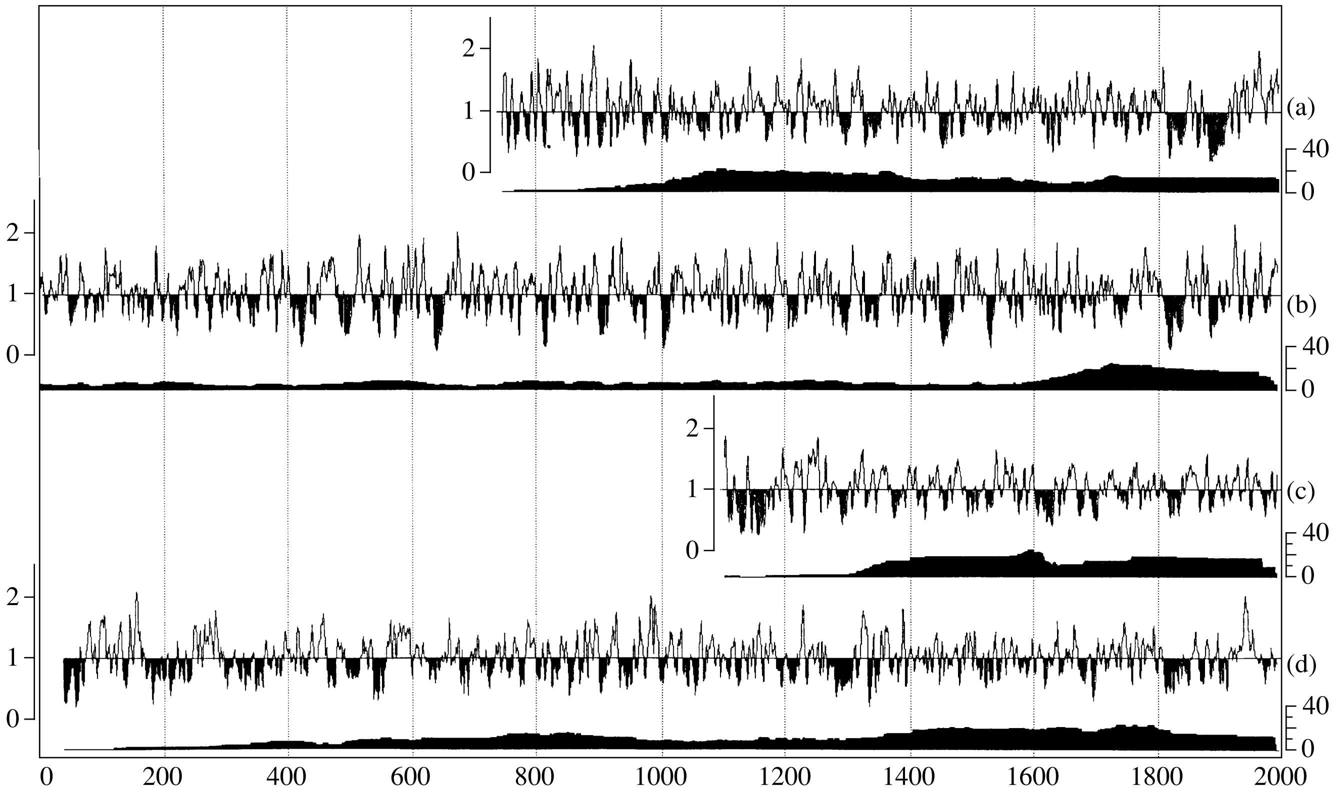

Fig. 1. The generalized tree-ring chronologies for larch (smoothed by the 5-yr moving-average): (a) Polar Urals, (b) southern Yamal, (c) Taz River, (d) eastern Taimyr. The diagram under each chronology (for a specified time interval) shows the number of tree specimens used for constructing the chronology. The left-hand abscissa shows the standardized growth indices, the right-hand abscissa indicates the number of specimens, and the ordinate shows calendar years.

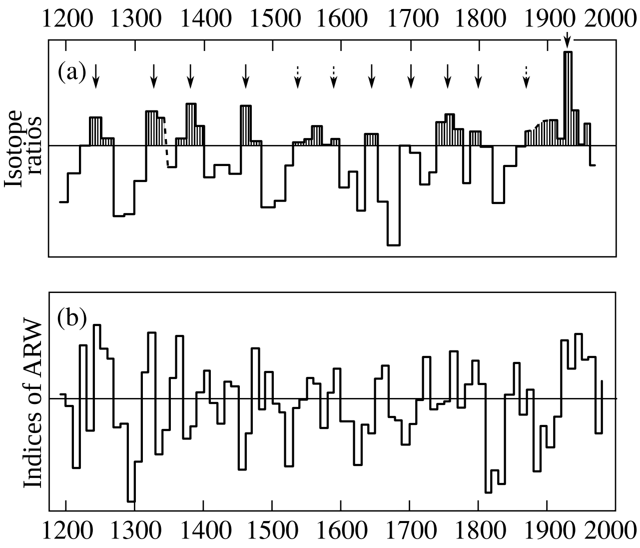

Fig. 2. (a) Comparison of the long-term temperature variations obtained from the analysis of the oxygen isotope ratios in the ice layers of Greenland [5, 6] and (b) the generalized ring-tree chronology for the Subarctic western and central Siberian sectors (the average over decades).

15th–the beginning of the 16th, the beginning of the 17th, the end of the 17th, the beginning of the 18th, the first half of the 19th centuries) correspond completely to those found in the tree-ring chronologies for the northern Urals and Siberia. Similarly, the warmest periods are reliably fixed by both indirect sources of temperature oscillations in the middle of the 13th, during the 14th, at the end of the 15th, in the middle of the 16th, in the second half of the 18th, and in the middle of the 20th centuries. Note, that the temperature increase in the middle of the 20th century (extremal, according to the ice core data) has not been confirmed by the tree-ring chronology data: the temperature increase in the middle of the 13th century has a similar amplitude. The similarity of long-term temperature variations in the Subarctic region with the ice core data from Greenland is also supported by the analysis of spectral density functions (Fig. 3), which display significant cyclic variations of temperature based on the oxygen isotope variations with the 181- and 78-yr duration, as well as considerable peaks of spectral density for the tree-ring chronologies at the same frequencies (182 and 76 yr).

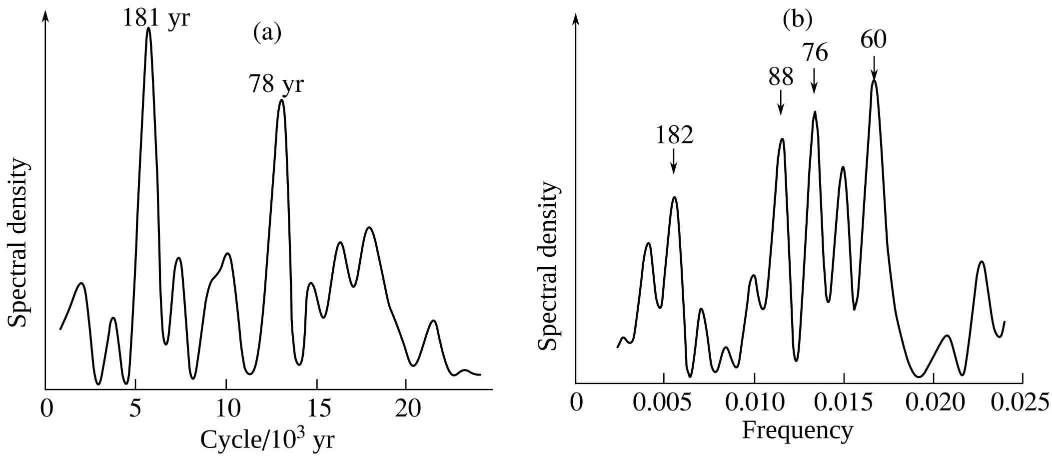

Fig. 3. (a) Fragments of spectral density function for oxygen isotope variations in the ice layers [5, 6] and (b) indices of tree growth.

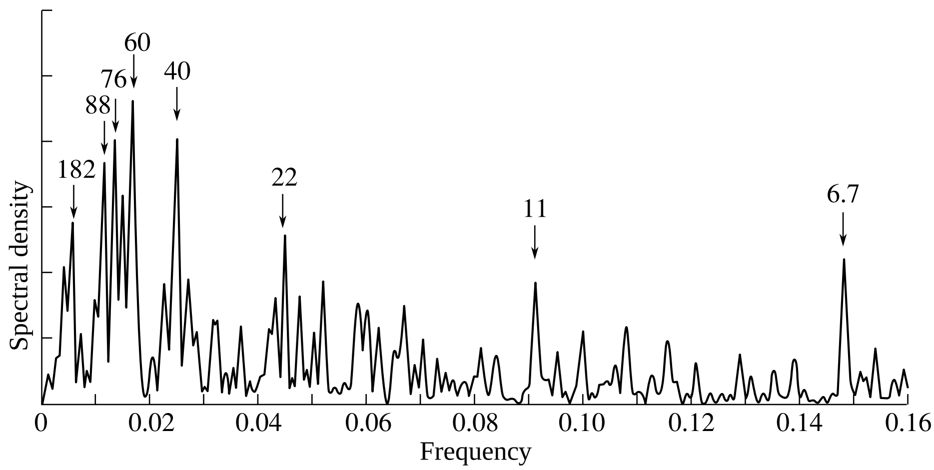

Fig. 4. The spectral density function for the generalized tree-ring chronology.

Table 2. Coefficients of concordance (above the diagonal line) and synchronism (below the diagonal line) between tree-ring chronologies for the common period from 1101 to 1994

Number of chronology	1	2	3	4
1	1.0	0.81	0.71	0.51
2	76	1.0	0.64	0.56
3	62	63	1.0	0.65
4	51	57	60	1.0

Note: The assessment of the coordination of variations between the growth indices. Based on the concordance coefficient: (0.4–0.5) low, (0.5–0.6) medium, (0.65–0.75) high, (> 0.75) very high; based on the synchronism coefficient, %: (45–56) no coordination, (57–67) low, (68–78) medium, (79–89) high, (> 90) very high.

The range of long-term oscillations of summer temperature in northern Siberia was variable during different periods of the last millennium (see Fig. 2). The thermal conditions were most variable in the 14th, the first half of the 15th, in the 19th and 20th centuries. According to the estimated model of reconstruction, the amplitude of such long-term oscillations attained 2.5°C. The difference between the coldest period at the beginning of the 19th and the warmest period in the middle of the 20th centuries amounts to 4.9°C [7, 10]. If a fragment of the generalized series for the past 200 yr is considered, it is possible to contemplate a clearly pronounced trend of temperature increase. However, such a trend is connected to the strong cooling at the beginning of the 19th century, which obviously is of a natural rather than technogenic origin [4, 11]. The spectral analysis data of the generalized series as a whole, as well as of its individual 500-yr fragments, indicate that its principal cyclic components have persisted over the course of the past 2000 yr, and, hence, the temperature oscillations detected in annual tree rings are caused by natural factors. The tree-ring chronologies, used as indirect sources of climatic oscillations with a high (a season, a year) temporal resolution, also allow the identification of intrasecular cyclic components. The oscillations with the frequencies that are typical of solar activity (22 and 11 yr) are present (with a high degree of reliability and significance) in the variability of annual tree rings (Fig. 4).

CONCLUSION

(1) The long-term (intrasecular, secular, and supersecular) variations of summer temperature in the territory of the Subarctic region (from the Polar Urals to the eastern Taimyr) occurred synchronously throughout the past 1500 yr, in contrast to the short-term (annual) oscillations.

(2) Since the Subarctic region sectors are located within the zone of influence of Atlantic air masses, the common component of long-term temperature variations is not of a regional but a global character. This is confirmed by the comparison of the generalized tree-ring chronology with the long-term temperature variations obtained from another indirect source (ice cores).

(3) The analysis of the range of long-term summer temperature variations shows that the warming in the middle of the 20th century was not extraordinary, since the temperature increase in the middle of the 13th century had a similar amplitude.

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