CLIMATIC FACTORS OF RADIAL GROWTH DYNAMICS OF CONIFEROUS SPECIES IN THE ANGARA REGION

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Для выявления климатических факторов динамики радиального прироста сосны обыкновенной на территории Приангарья рассмотрены древесно-кольцевые хронологии в Среднем и Верхнем Приангарье. Установлено доминирующее влияние на прирост хвойных пород в Верхнем Приангарье атмосферного увлажнения, в Среднем Приангарье — температуры воздуха. Выявлены ведущие климатические факторы прироста: средняя месячная температура апреля; суммы осадков за гидрологический год. Проведена реконструкция лимитирующих факторов прироста.

The territory named Baikal region includes the Irkutsk district and a part of Buryatia Republic. In spite of its appreciable variability, the nature of this territory has its specific character. The middle-mountain relief is dominating while plane areas are small. The main regions of our study belong to the middle and upper Angara areas. There, the vegetation is represented by the south-type pine-tree and combined deciduous and pine-tree forests (middle Angara), and sub-taiga of pine-tree and combined pine-tree and deciduous motley grass forests (upper Angara).

The region concerned belongs by character of its aerosynoptic processes to the zone of influence of Siberian anti-cyclone. The anti-cyclone formation in November and destruction in March control the natural synoptic periods of a year. The longest season is winter when meridional transfer of air masses are dominating. Due to solar radiance inflow at the end of March, atmospheric pressure is rising, the anti-cyclone destroys, and the spring season with predominantly western air transport unsets. In summer, the air flows are changing from latitudinal to south-west and north-west directions. The change of circulation character results to the end of summer in frequent invasion of south cyclones which bring intensive precipitation. Beginning of summer is normally dry which leads to forest conflagrations.

The amount of precipitation in the concerned territory varies on average from 4 mm (Sarma, Elantsy) in December and January to 91–98 mm in July (Bayanday, Irkutsk). In warm period (April-to-October), the amount of atmospheric precipitation reaches from 180 to 360 mm while in cool period it is from 50 to 130 mm. The total annual precipitation on these stations vary from 280 to 440 mm. The amount of precipitation was observed to reduce somewhat from middle 80s to middle 90s. Nowadays, however, the amount of precipitation is close to the climatic norm of the region. An appreciable amplitude of annual precipitation is characteristic of the Cuda river basin. They may reach 400 mm in warm and 18–20 mm in cold seasons. A pronounced increase in precipitation of cold period has been observed in 40s and 70s of 20th century, accompanied by some reduction in precipitation over warm period.

The dendroclimatic control system developed by Vaganov, Schiyatov & Mazepa (1996) and Vaganov & Schiyatov (1998) represents the methodical base for managing and performance of dendroclimatic works in the Baikal region [1, 2]. Samples of ordinary pine-tree (Pinus sylvesris Ledeb.) were used for dendroclimatic analysis. This tree has pronounced annual rings, long lives, ecological flexibility and its radial increments are highly sensitive to environmental factors. By its eco-biological properties, the pine-tree occupies the most warm and also most dry places thus subjected to strong influence of steppe which makes an impact on spread of steppe species in grass coverage and underbrush.

Long and uniform series of observations are most valuable for detections of climatic variations structure over recent decades and for calibration of the models of relation between tree-rings series and other data. Our work relies on temperature and precipitation data of those meteostations which provide the longest measurement series, i. e. those of Bratsk, Vikhorevka, Irkutsk, Homutovo, Bohan, Bayanday, Ust-Orda.

Computation and analysis of the function of radial increments response on basic climatic factors were performed using the program packages DPL-99 (the RESPO program) and 'STATISTICA V.5.5'. Evaluation of the response function was performed by computing the correlation between the increment indexes and monthly data on precipitation and air temperature for the period from June of preceeding year to August of the current one (about 30 variables in total).

The method of principal components, which employs the correlation matrix decomposition in terms of orthogonal functions, was used to estimate the dependence of tree increments variability on various factors. To estimate correctly the climatic component in a tree increments, the age trend should be filtered out. The process of low-frequency filtration of a series from aging variability is realized by standardization procedure [3]. Standardization of absolute chronologies provided the standard (Std) and residual (Res) chronologies. The residual chronologies resulted from modeling by an autoregression (AR) process [4] or by a process of autoregression moving average (ARMA) [5] which removed the autocorrelation component from the chronologies. The autoregression order was determined after Akaike's information criterion [6].

Spectral analysis of the tree-rings chronologies was performed with STATISTICA V.5.5. program. Wavelet analysis [7] of cyclic variations of the annual rings increment dynamics has been performed also. This method reveals cyclic (or quasi-cyclic) oscillations as well as their characteristic scales in dependence on time. The climatic parameters were reconstructed by the linear regression method.

We considered three groups of conifers growing in different landscape conditions: in taiga region of Bratsk storage pond, the sub-taiga region of the Cuda river basin district. Samples of 20 cerns from every region were used for age variability analysis of pine-tree annual rings of the steppe-forest zone. The sample selection was made by Yu.V. Polyushkin, V.I. Voronin.

The cross-correlation analysis and cross-dating resulted in three chronologies of the ordinary pine-tree (Pinus sylvestris L.) rings. The sensitivity coefficient and rms deviation are principal indicators for a qualitative estimation of annual increments variability due to environmental conditions. The former characterizes the relative magnitude of the variability while the later defines its amplitude. Not all chronologies of tree-rings have high sensitivity coefficients. The average value is 0.5 (from 0.31 to 0.73). Even this value, however, clearly indicates a substantial influence of environmental conditions (mainly climatic ones) on tree increments variability from year to year.

The autocorrelation characterizes mutual dependence of rings widths within a given series. It is mainly caused by physiological factors and to some extend by the age trend but may also result from climatic cycles [8]. The autocorrelation for the pine-tree ring chronologies are quite large, 0.42 on average. Minimum values of 0.29 were found for Baikal eastern coast while the maximum of 0.62 belongs to the Bratsk storage pond.

The principal components of the radial increments variability defined by eigenvectors computation show that dispersion in the series (Std-chronologies) is mainly controlled by the first three components which on average describe about 70 % (from 60 to 99 %) of the total dispersion. The first principal component provides on average 40 % (from 30 to 79 %) of the variability indicating once more a decisive role of a single climatic factor in the radial increment variability over entire territory under study. The degree of influence of climatic factors on tree increments as well as their mutual relations were estimated in terms of the response function [Fritts, 1976]. The response function of tree rings chronologies on climate was estimated using the series of meteorological observations data from the stations of Bratsk and Vikhorevka — for middle Angara region; Ust-Orda, Bohan, Bayanday — for upper Angara. The data on solar activity (Wolf numbers for 1700–2000) and on recurrence of the atmospheric circulation type (1881 to 2002) were also used.

For the middle Angara region, the response functions show high positive relation of pine-tree increments to the mean monthly air temperature in March — April (0.45–0.52). For the upper Angara region, the response functions show moderate but steady negative relation of the increments dynamics to the total precipitation in March and to the mean monthly temperatures in September of the current year and also a positive response on the total precipitation over the hydrological year (from September of preceeding year to August of the current one). The series for Cuda are similar in their responses on the later parameter. The importance of precipitation in these regions is just because they belong to the insufficient humidity zone.

For the period of the atmospheric circulation observations, confrontation of the circulation data with long-term variations in the increments of pine-trees and larch in the Pre-Baikal region revealed a dependence of widths of the tree rings on recurrence of the atmospheric circulation of western type over the year: in 70 % of cases of western transport, increments above the average (over 100 yr) were observed; the eastern transport provides a negative correlation — the increments are below the average in 65 % of cases. The meridional transport in Angara region does not provide a stable relation to the tree increments. A typical feature of the trees growth variation is the presence of regular long-term cycles. The clear dependence of the growth rates of trees in the insufficient humidity environment on precipitation shows that the annual increments of the trees reflect the humidity dynamics providing further confirmation of the basic principle of dendrochronology on limiting factors. The detection of steady oscillations in dendrochronological data promotes a determination of reliable relations between the growth and cyclic variations in environmental conditions (climate, solar-terrestrial relations, and others), an analysis of which can reveal the origin of the cycles. The sub-centurial cycles in nature coincide with the well known ones: with Brikner cycle of about 31 yr and with the solar cycle of about 11 yr. The Brikner cycle is believed to be related to the periods of humidity and the lakes level variations (35 yr).

Direct computing of harmonics provides the following periods: middle Angara — 67, 33, 15, 12, 10, 7, 5.2, 4.6, 4.2; upper Angara — 32.6, 32, 31, 16 years. One of the tools for detecting different kinds of irregularities (discontinuities, changing of amplitudes and frequencies with time, and so on) in time series is the wavelet method [7]. The wavelet method is more adequate to the non-steady phenomena than the standard Fourier transform. The dendrochronological series were wavelet transformed to obtain the coefficient matrix W(a,b). All the dendrochronological series possess the cycles of 11–22, 30–35, and 40–50 yr indicating connections with solar activity and with atmospheric humidity (Brikner cycle). The connection with the solar activity may, however, be not a direct one with the atmospheric circulation as a connecting agent.

Dendroclimatic reconstruction is one of the most reliable methods for reconstructing climate conditions in the past. Reconstruction of climatic elements by the linear regression method was attempted based on the generalized tree rings chronologies of the three regions, which is justified by sufficiently tight connection between the growth variability and climate characteristics. Figure shows the reconstructed monthly-averaged temperature of April for 270 years.

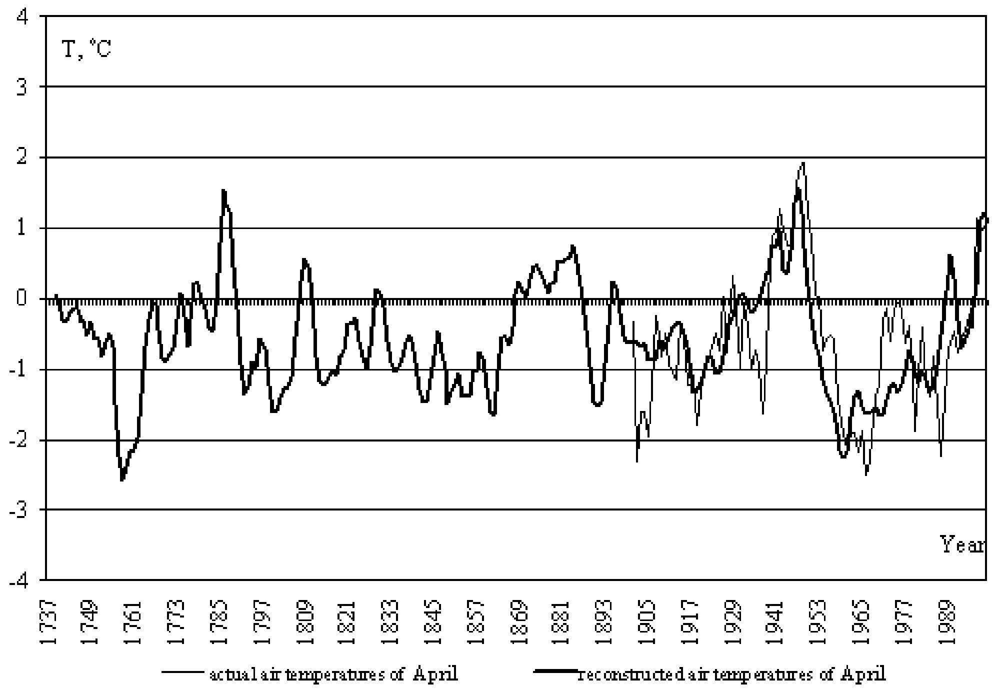
For the sub-taiga zone, the reconstructions of entire hydrological year Cuda river basin were made. In spite of appreciable variation in the annual precipitation, the 3–5 year moving averages agree well with long-term measurements of the concerned climatic parameters.

The correspondence between reconstructed and instrumentally measured climatic parameters is confirmed by Fourier analysis also. The spectral density functions show significant peaks at 10–14 and 24–35 yr. Fourier analysis of the reconstructed data on temperature and precipitation has shown that the cyclic oscillations did not change considerably over the last three centuries.

Conclusions:

1. High correlations between individual ring chronologies opened a possibility to combine them into generalized chronologies showing appreciable sensitivity to climatic factors.

2. It is shown by statistical analysis that conifers increments are mainly controlled by atmospheric humidity in the Upper Angara region and by air temperature in the Middle Angara region.



Reconstructed and actual tree-year-smoothed air temperatures of April (Middle Angara, Bratsk meteo-station).

3. Relation is established between radial increments of pine-trees and larches with atmospheric circulation. West-type circulation, prevailing in the Angara region, promotes the growth of trees by producing favorable hydrothermal conditions.

4. A series of cycles with periods of 2–4, 6–12, and 22–35 year is found in the radial increments of conifers of the Angara region. The cycles reflect atmospheric humidity dynamics in the region and show considerable influence of solar activity on the width of annual rings.

5. Limiting climatic factors for radial increments are revealed. This is the mean temperature of April for Middle Angara and total precipitation of hydrological year for the Upper Angara.

6. Statistical parameters of the multiple regression models for reconstruction of climatic factors controlling the radial increments have shown that the highest quality model was obtained for April temperature in taiga regions of the Middle Angara (correlation coefficient is 0.44).

7. The observed correspondence between reconstructed and instrumentally measured climatic parameters is confirmed by spectral analysis that also shows that the structure of cyclic variations did not change considerably over the reconstruction period.

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