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Spatial Structure of Periodicity in the Conifer Tree Radial Increment in the Republic of Komi

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Abstract—Spectral analysis of tree ring data sets of Siberian spruce (*Picea obovata*) and Scots pine (*Pinus sylvestris* L.) was carried out to study the effects of climatic factors on the conifer tree radial growth in the territory of the Komi Republic. Analyses were performed for different natural subzones in the Komi Republic: the forest-tundra transition zone and the northern, middle, and southern taiga. The results show that several groups of periodicities can be found in the tree radial growth. One from groups of periodicities is related to internal processes in the atmosphere–ocean system; the other is related to the fluctuations in solar activity.

Keywords: tree rings, dendrochronology, climate change, boreal conifer forest, Komi Republic

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INTRODUCTION

The Komi Republic is located in the northeast of the European part of Russia in the foothills of the Ural Mountains. It is an ideal region to study the influence of different physical factors on climatic parameters. The physical factors can have either global origin or be related to the internal processes in the atmosphere–ocean system. It is necessary to take into account that the northern part of the Komi Republic is located at a latitude of 67° N, i.e., near the aurora zone and intense penetration of cosmic rays into the atmosphere. The general location of the territory at the boundary of the North Atlantic and Arctic regions determines the influence of the North Atlantic (NAO) and Arctic (AO) oscillations on the climate [Mielikainen, Sennov, 1996; Overpeck et al., 1997; Polonskii, Semiletova, 2002, Mokhov et al., 2006, 2008; Bezuglova, Zinchenko, 2009]. The climate variability in the region can be influenced by the variation in the area of the ice cover in the Arctic region [Proshutinssky, Johnson, 1997; Goose et al., 2002; Petoukhov, Semenov, 2010].

The territory of the Komi Republic has a long meridional extension (approximately 700 km) from the tundra zone to the southern taiga. Therefore, the variation in the climatic parameters can have a regional structure here. One should also take into account the influence of the Ural Mountains on atmospheric circulation.

The goal of this work included distinguishing the physical factors of the global and inside-atmospheric origin that influence the formation of climatic variability in the northeastern sector of the European part of Russia to perform its climatic zoning. We used biological data on the radial increment of the coniferous trees (pine and spruce) from several regions of the Komi Republic as information objects about the climatic variability [Lopatin, 2007; Raspopov et al., 2007; Lopatin et al., 2008; Solomina et al., 2009].

The method of climatic-variation analysis is based on the fact that different climatic periodicities can be identified either with different internal processes in the atmosphere–ocean system or with external forcing related to the periodicity in solar activity.

STUDY REGION, MATERIALS, AND METHODS OF RESEARCH

General characteristic of the study region. Locations of sampling the dendrochronological data and the method of their initial processing. The Komi Republic is a forest region in the northeast of European Russia in which forest massifs were conserved to the present time without notable anthropogenic and technogenic influence [Lopatin et al., 2006, 2007, 2008; Lopatin, 2007]. The annual mean temperature varies from +1°C in the southern part to –6°C in the northern part. The vegetation season (days with a mean temperature close to +10°C and higher) lasts from 10 to 45 days. The annual mean amount of precipitation

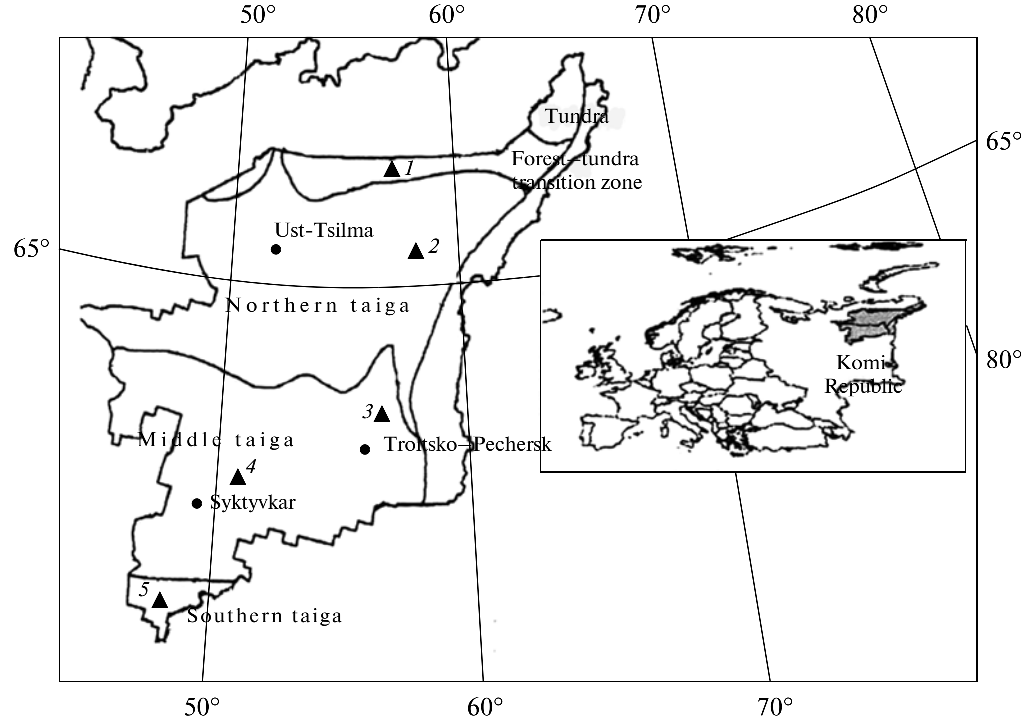

Fig. 1. Natural geographic zoning of the territory of the Komi Republic (based on [Kozubov, Degteva, 1999]) and locations of wood sampling sites (triangles). The geographical location of the Komi Republic is shown in the inset (gray color).

varies from 700 mm in the south to 450 mm in the north of the region.

The time series of radial increment of coniferous trees from the following natural zones were taken as the initial data to reveal and analyze the periodicities: forest–tundra transition zone, northern, middle (two sites), and southern taiga. The dendrochronological data were collected for two species of coniferous trees: Siberian spruce (*Picea obovata* Ledeb.) and Scots pine (*Pinus sylvestris* L.). 1 shows the locations of the natural zones on the territory of the Komi Republic according to G.M. Kozubov and S.V. Degtyareva [1999].

The collection of dendrochronological data samples was carried out in 2003–2004. The selection of locations for sampling was based on the data of land mapping of forests and TERRA ASTER satellite data that surveyed the territory in frames with a size of 60 × 60 km and a spatial resolution of 15 m. First and foremost, we took into account the absence of forest cutting, fires, or any other anthropogenic or technogenic impact. In addition, we selected sites with approximately similar natural conditions (topography, surrounding vegetation, soils, and domination of coniferous tress). While selecting the sites, we checked for the presence of trees of different ages and lack of depression of young trees by dominating specimens. This factor is important to study the climatic influence on the radial increment of the trees.

The variations in the radial increment of trees were studied on the basis of drilled samples, which were visually analyzed immediately after drilling to exclude wood decay. The samples were taken at a height of 1.3 m from the earth's surface. If possible, transverse sections of the trunks were made. If it was difficult to collect samples, sampling was performed by age drilling in two orthogonal directions, one of which was directed to the north. The radial increment of the tress was measured with an accuracy of up to 0.01 mm. The cross correlation between the results of measurements of the tree ring width was performed using the COFECHA programming code [Crissino-Mayer et al., 1997]. The programming code ARSTAN was used for the further processing of the time series [Holmes, 1999]. The constructed generalized chronologies containing variations in the tree ring width at each place of sampling and each type of tree were used for the spectral analysis of the radial increment of trees to reveal periodicity.

The general database of the available dendrochronological data and its main characteristics are given in Table 1.

THE METEOROLOGICAL DATABASE

We used a meteorological database (annual mean temperatures and precipitation) to compare the periodicities of the radial increment of trees in different

Table 1. Main characteristics of the dendrochronological database and distinguished quasi-periods in the generalized tree-ring chronologies on the territory of the Komi Republic

Natural zone, subzone	Type of the tree, chronology duration	Data type	Quasi-periods, years							
Forest–tundra transition zone (66°41′ N, 56°49′ E)	Spruce (12)*, 1812–2003	OR**	30	23	20	15	13		7	
		DR***	28	22	19		14		7	
Northern taiga (65°59′ N, 57°48′ E)	Spruce (14), 1878–2003	OR				16		11	7	
		DR				15				
	Pine (14), 1924–2003	OR				17			7	5
		DR					13			
Middle taiga, west (61°44′ N, 50°34′ E)	Spruce (40), 1878–2003	OR	30	21		15		10	7	
		DR	26, 31	22		17	13			
	Pine (45), 1924–2003	OR	31	21			14	11		6
		DR	32	25		17	13	10	8	
Middle taiga, east (63°25′ N, 57°57′ E)	Spruce (51), 1826–2004	OR	29	22			13		7	5
		DR	31	24	19	16		12		
	Pine (5), 1842–2004	OR	31	22		16		11		
		DR	32	23		18		10		
Southern taiga (60°33′ N, 49°26′ E)	Spruce (9), 1917–2003	OR			19		14	11	9	6
		DR						11	9	
	Pine (21), 1877–2003	OR				18		10		6
		DR				17		12	8	5

* Number of sampled trees.
** Generalized time series.
*** Longest time series.

subzones of taiga with climatic periodicities and further analysis (Table 2).

In addition, this database included the annual mean temperature measured at the stations of Kola and Murmansk in 1878–1999, which were united into one time series.

The meteorological data were presented by the Center for Meteorology and Monitoring of the Environment of the Komi Republic and also taken from literature sources [Razuvaev et al., 1995].

In the research we also analyzed the following:

(i) variations in the temperature and atmospheric pressure at the sea-level average over the entire Arctic zone (data from 1875 to 1999);

(ii) variations in the ice-covered area in the Barents Sea (data from 1900 to 2005);

These data were given to us by G.V. Alexeev, a scientist from the Arctic and Antarctic Research Institute.

All the data were analyzed using spectral analysis by the same method that was applied to construct the spectra of variations in the radial increment of the trees.

The Method for Distinguishing Periodicities in Dendrochronological and Hydroclimatic Data

To study in detail the time structure of the time series mentioned above, we applied a modified method of spectral analysis [Dmitriev et al., 2006]. The modification included the following.

A selective estimate of normalized spectral density [Jenkins, Watts, 1972] for the initial time series was calculated, not with respect to frequency, but with respect to a tested period, which was stipulated by the

Table 2. Characteristics of meteorological stations whose data were used in the research

Name	Location		Period of observations, years
	latitude, °N	longitude, °E	
Syktyvkar	61.7	50.9	1888–1995
Troitsko-Pechersk	62.7	56.2	1888–1995
Koinas	64.8	47.7	1912–1995
Pechora	65.1	57.1	1943–1995
Ust-Tsilma	65.5	52.2	1895–1995
Murmansk	69.0	33.1	1936–1995

formulation of the problem to reveal hidden periodicities in the initial data [Serebrennikov, Pervozvanskii, 1965]. It was based on the assumption that the initial time series consists of two components: polyharmonic, with a limited number of harmonics having different amplitudes and periods, and "noise." The latter includes a random signal and any other deterministic signal, but not the harmonics of the first polyharmonic components. The search for the values of periods of polyharmonic components in the initial signal was carried out using the so-called test period, whose values were sorted out from a range of possible values specified by the physical conditions of the studied phenomenon.

In addition, the initial time series were preliminarily processed by a high-frequency filter [Alavi, Jenkins, 1965] with the initially specified cutoff frequency of the filter at the half-power of the signal, which corresponds in the time domain to the "division" period T_f. The filtration of the initial data was applied to eliminate the trend and more powerful low-frequency components. A series of values of parameter T_f is selected arbitrarily, usually from the physical conditions of the considered problem: characteristic peculiarities of the time structure of the processed data and a hypothetical assumption about the possibility of the existence of different groups of periodical components in the data.

Then an estimate of the normalized spectral density as a function of the period was again calculated for each filtered high-frequency component (HFC) with a specific value of parameter T_f. Eventually, all these estimates calculated for difficult values of parameter T_f were superimposed in one graphic field forming a combinatory spectral periodogram (CSP).

Such a modification of the commonly accepted spectral analysis method allows us to do the following:

(1) study the stability of the location of a distinguished period on a periodogram. Hence, this modification makes the revealed values of the hidden periodicity independent of the parameters of the initial time series, which can influence the result of the applied mathematical method of processing, in particular, the length of the time series, because the length of the filtered component is smaller than the length of the initial time series.

(2) find shorter periods in the initial signal with small amplitudes. This occurs due to the elimination of the trend and powerful long-period components from the initial signal, which make the main contribution to the variance of the signal. Thus, only weak short-period components contribute to the variance of the filtered high-frequency component of the signal. Owing to the normalization of the spectral power, the contribution of these components to the combinatory periodogram becomes comparable with the contribution of the longer and powerful components of the signal.

The search for the number and values of the harmonics in the polyharmonic part of the initial signal was organized using the so-called test period, whose values were sorted from the range of possible values specified by the physical conditions of the studied phenomenon.

In this case, the accuracy of the location of peaks on a periodogram (the accuracy of distinguishing hidden periodicities) is determined by the selectivity of the method (integral Fourier transform, or more precisely, by its discrete analog) and the length of the step specified on the periodogram along the axis of the test periods. For CSP this is $\Delta T \approx 2T^2/N$ [Serebrennikov, Pervozvanskii, 1965], where ΔT is the step of the periodogram for the current value of the test period T and length N of the initial time series.

It follows from this that, according to the selective properties of the discrete Fourier transform, the grid specified for the test periods should not be uniform, because the step of periodogram ΔT proportionally depends on the area of the current test period, which is not convenient for organizing the calculation algorithm or the graphic interpretation of their results. Therefore, when calculating the CSP values similarly to [Serebrennikov, Pervozvanskii, 1965], we use a nonuniform step with respect to the test periods. However, in this case the resolution of the periodogram in the range of small periods is lower than in the range of the large values. Therefore, the peaks on the CSP are narrower for the small values than for the large ones. A situation appears when the step between the neighboring test periods in the range of small periods is larger than the frequency pass band, which results in an inaccurate determination of harmonics in this range.

For example, if the length of the initial time series shown in Fig. 2b is 192 points (or $192\backslash\Delta_t$ years, where Δ_t is the time step of the initial time series equal to one year) and the step of the test period ΔT is equal to the same value Δ_t, the resolution of the CSP up to the value of the test periods $\approx 10\backslash\Delta_t$ years would not be sufficient, and after this period the resolution would be excessive. In the case of time series shown in Figs. 3–6, where their length is shorter (on average slightly greater than $100\Delta_t$ years: from 106 to 125 points) the value would be equal to $\approx 8\backslash\Delta_t$ years.

The resolution of the initial time series considered in this work is one year; therefore, the organization of the search for periods of harmonic components was performed with the same resolution.

RESULTS OF INVESTIGATIONS

Spectral Analysis of Dendrochronological Data

It was already emphasized that the data of the radial increment of pine and spruce were processed using spectral analysis. The data were collected in three subzones of taiga and transition zones between tundra and forest from specific species of trees within the land-

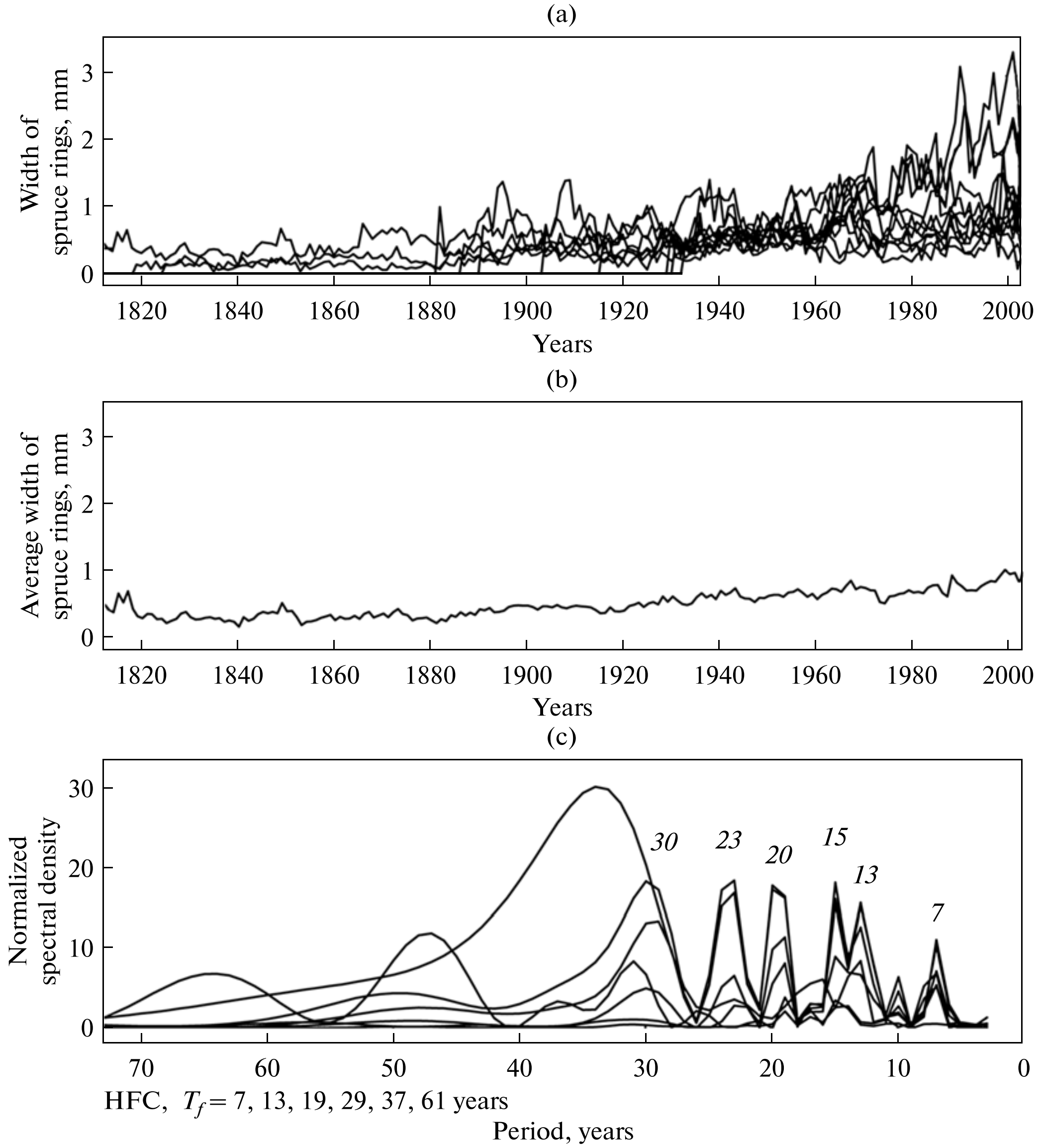

Fig. 2. Variations in the width of spruce rings for the transition zone between tundra and forest (a, b) and the results of a spectral analysis of their generalized time series (c). (a) Initial values; (b) average data.

scape zone or a site in this zone. The data were also collected for the longest individual time series of dendrochronological data in each landscape subzone.

Groups of periodicities in the radial increments of trees were found in each landscape subzone. Some of them characterize almost all subzones (for example, a period of 16–18 years); others are distinguished only in individual subzones. The results of the analysis of generalized time series and the longest individual time series demonstrated a similar pattern of existing periodicities.

Figure 2 shows an example of the spectral analysis data of the radial increment of spruce in the transition zone between tundra and forest. The radial increment of the trees in all landscape subzones is characterized by periodicities of 5–9, 10–12, 13–14, 15–19, 21–24, and 26–32 years (see Table 1).

Significant differences in cyclic variability are not distinguished (excluding individual cases) if we analyze periodicities of spruce and pine separately based on generalized chronologies (see OP in Table 1). For example, a 14-year periodicity was found in the spectrum of the spruce data from the southern taiga, while it was not found in the data of pine. In its turn, in the northern taiga, a 13-year periodicity was found in the data of pine and a 16-year periodicity in the data of spruce. It is necessary to have a data of a more dense network of meteorological stations to analyze more strictly the differences in the cyclic response of the radial increment of trees to climatic variations.

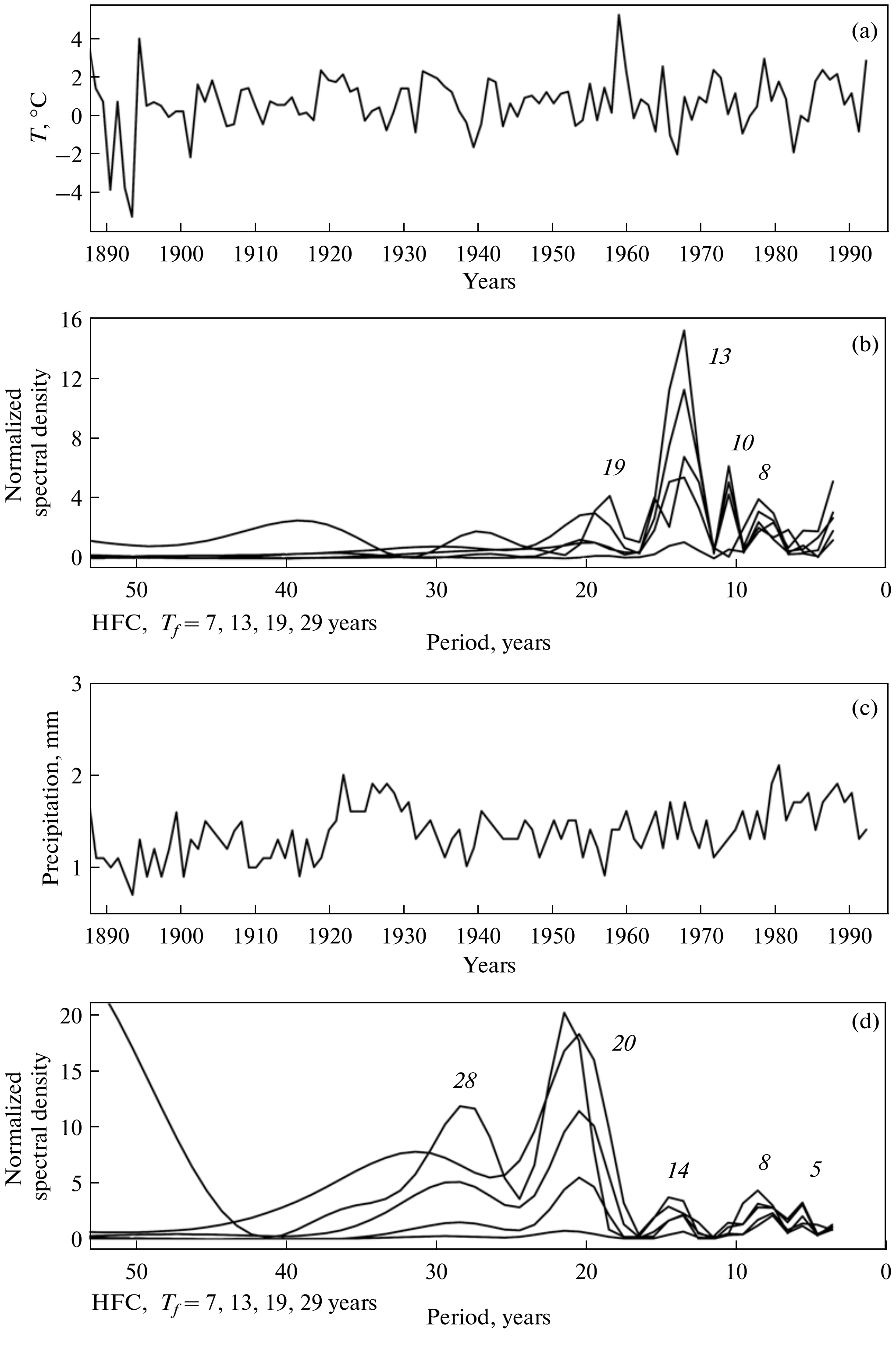

Fig. 3. Annual mean values of air temperature (a) and daily average precipitations (c) in Syktyvkar from 1888 to 1995 and the results of their spectral analysis (b, d), respectively.

Hydrological and Climatic Data

Hydrological and climatic data were processed with spectral analysis similarly to the dendrochronological time series. The periodicities were found in these data similar to the periodicities in the radial increments of trees. However, these periodicities in different hydrological and climatic parameters (temperature, precipitation, baric pressure, and area of ice

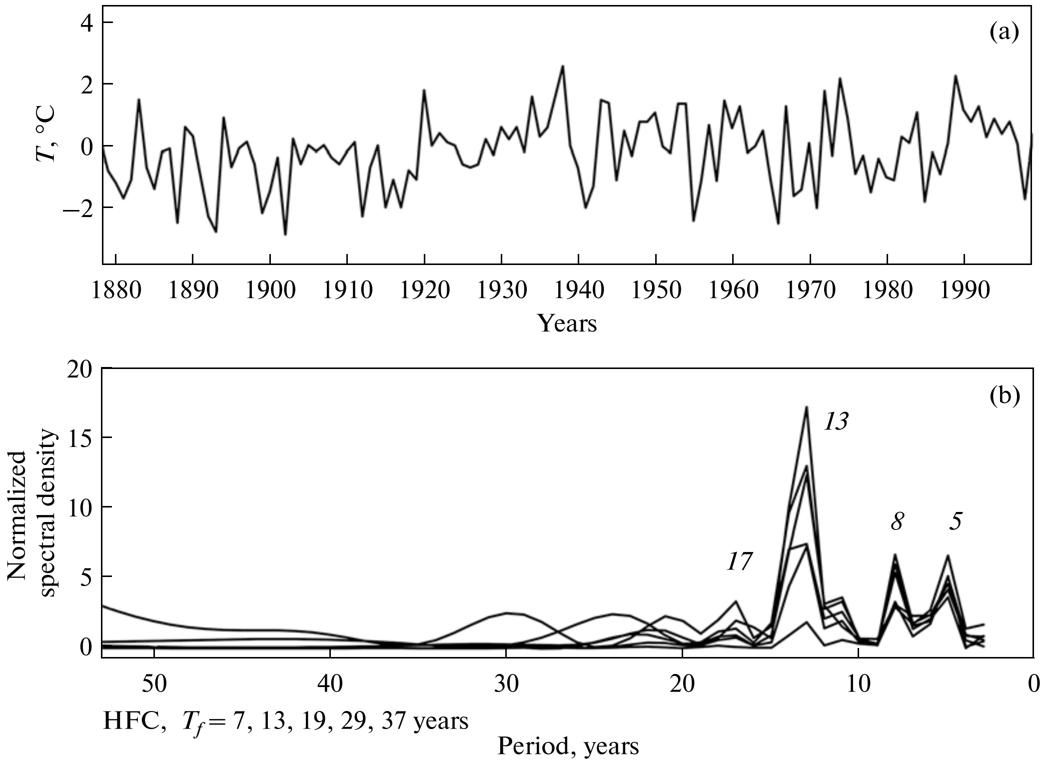

Fig. 4. Annual mean values of air temperature on the Kola Peninsula from 1879 to 1999 based on the data from the Murmansk-Kola meteorological station (a) and the results of their spectral analysis (b).

in the Arctic seas) manifest themselves differently and, in addition, they have regional peculiarities.

Figure 3 presents the results of a spectral analysis of temperature variations in Syktyvkar located in the subzone of the middle taiga. Figure 4 presents an analysis of the temperature variations on the Kola Peninsula. Figure 5 shows the analysis of variations in the area of the ice cover in the Barents Sea. Figure 6 shows the temperature variations and variations in the atmospheric pressure in the Arctic zone.

It is worth noting that an analysis of the variations in the climatic conditions in the North Atlantic and along the coast of the Arctic Ocean (for example, annual variations in the area of the ice cover in the Barents Sea) is principally important for understanding the climatic conditions in the territory of the Komi Republic because the variations in the climate conditions in the North Atlantic have a global response and influence the climate of the territory considered here. Table 3 presents a generalized pattern of periodicities in the annual mean climatic data.

DISCUSSION

The results of the analysis of the radial increment of two coniferous tree species (pine and spruce) in the territory of the Komi Republic and the analysis of the climatic parameters provide evidence that data variability is not white noise but has clearly pronounced quasi-periodicities (see Figs. 2–6), which can be grouped as follows: 5, 6–7, 8–9, 10–12, 13–14, 15–19, 20–24, and 26–32 years (see Tables 1, 3).

We note that a period of 4 years appears in the temperature variations in Syktyvkar (see Fig. 6) and also in the variations of precipitation in Ust-Tsilma, Pechora, Koinas, and Troitsko–Pechersk. Some of the revealed periodicities, such as 10–12 and 20–24 years, are characteristic of periods of the solar activity, while others can reflect the processes in the atmosphere–ocean system. Let us consider the revealed periodicities in detail.

The periodicities in the range of periods 5–9 and 13–14 years are characteristic both of the radial increments of pine and spruce and also of the hydrological and climatic parameters. They manifest themselves in all subzones in the increment of tree ring and also in all analyzed hydrological and climatic parameters excluding the mean climatic parameters of the Arctic zone. The periodicities are characteristic of the climatic oscillations NAO and AO, in which quasi-eight-year and 4- to 5-year oscillations were found [Ramos da Silva, Anissar, 2005].

The influence of quasi-eight-year NAO oscillations on different hydrological and climatic parameters is reported in some publications [Polonskii, Semiletova, 2002; Garcia et al., 2005]. The influence of the

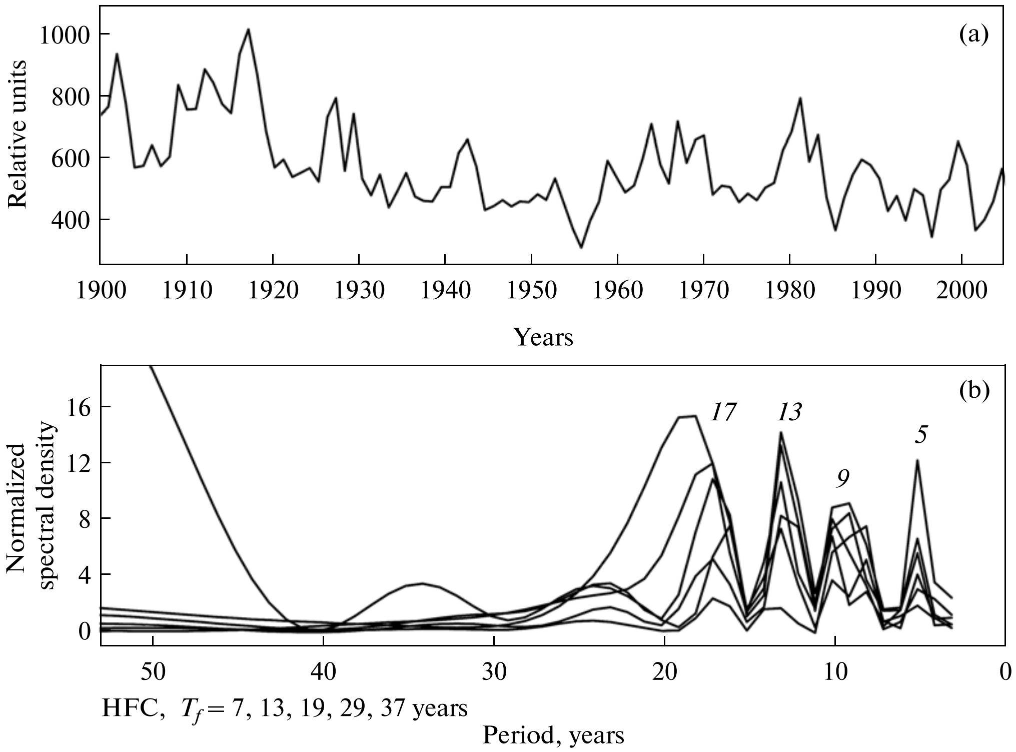

Fig. 5. Variations in the area of the Barents Sea ice cover from 1900 to 2005 (a) and the results of their spectral analysis (b).

NAO in the range of periods within 5–9 years was revealed in an analysis of precipitation intensity in the southern part of Western Siberia [Bezuglova, Zinchenko, 2009], while the 5- to 8-year AO fluctuation influences the variations in the ice regime of the Baltic Sea [Jevrejeva et al., 2003]. Quasi-eight-year and 9-year, as well as 5-year, fluctuations are very clearly manifested in the variations of the ice cover of the Barents Sea (see Fig. 5), which no doubt influences the climatic regime of the territory of the Komi

Table 3. Quasi-periods in the annual mean data of the meteorological stations on the territory of the Komi Republic and in the oscillations of the ice-covered area in the Barents Sea found from the analysis

Region/meteorological station, period of observations	Indicator	Quasi-periods, years							
Arctic Zone, 1875–1999	Temperature	32	23	17			8	6	
	Pressure		21			10	7	5	
Barents Sea, 1900–2005	Ice-covered area			17	13		9	5	
Kola-Murmansk, 1878–1999	Temperature			17	13		8	5	
Syktyvkar, 1888–1995	Temperature			19	13	10	8		4
	Precipitation	28	20		14		8	5	
Ust-Tsilma, 1895–1995	Temperature			18	13	10	8	6	
	Precipitation		20		15	11	8		4
Pechora, 1943–1995	Temperature					10	7	5	
	Precipitation				13		9		4
Koinas, 1912–1995	Temperature				14		9	6	
	Precipitation					11	7		4
Troitsko–Pechersk, 1888–1995	Temperature			19	13	10	8	5	
	Precipitation			18	13		9	6	4

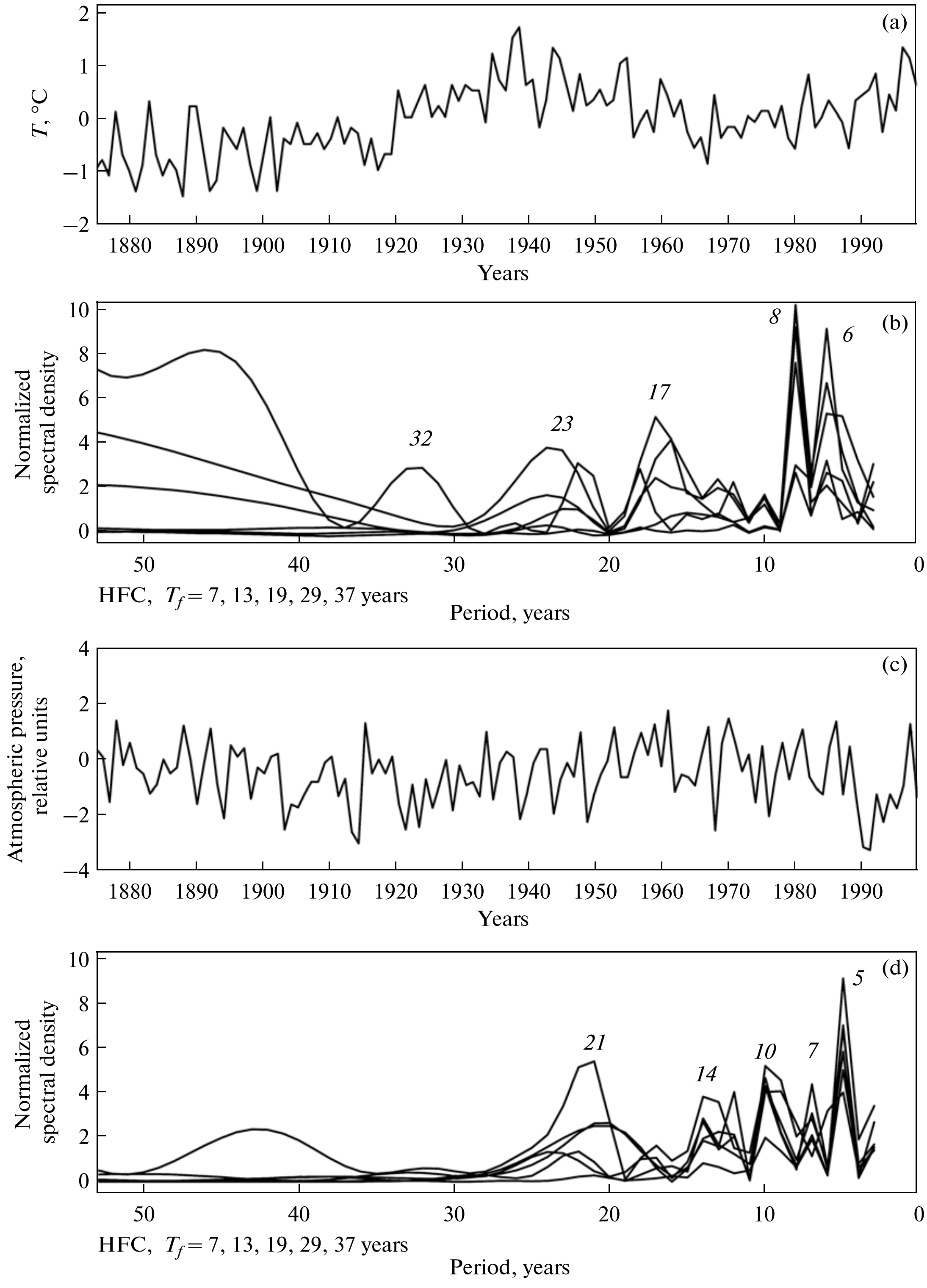

Fig. 6. Annual mean values of temperature (a) and atmospheric pressure (c) in the Arctic region from 1875 to 1999 and the results of a spectral analysis of their variations: (b) temperature; (d) atmospheric pressure.

Republic. These periodicities are the main ones also in the temperature regime in the north of the Kola Peninsula (Murmansk city) (see Fig. 4).

At the same time, periodicities of 13 and 17 years were found in the oscillations of the ice regime in the Barents Sea (see Fig. 5). A periodicity of 13–14 years manifests itself in all landscape zones of the Komi Republic and the analyzed climatic time series in the Murmansk region and northeastern part of European Russia. This periodicity is reflected in the NAO variations and also in the cyclonic regime of the Arctic region [Proshutinsky, Johnson, 2001] and in the temperature regime of the city of Murmansk (see, Fig. 4).

In its turn, a periodicity of approximately 17 years is characteristic not only of the variations in the ice cover of the Barents Sea: a variability of 15–19 years is manifested in all landscape zones of the Komi Republic. It was also revealed in the modeling of variations in the volume of ice in the Northern Hemisphere as a whole [Goosse et al., 2002] and in the AO [Ramos da Silva, Avissar, 2005].

Thus, periodicities of 5–6, 7–9, 13–14, and 16–19 years revealed in the radial increment of spruce and pine are related to the internal dynamic processes in the atmosphere–ocean system. First and foremost they are related to the development of the NAO and AO and also the variations in the area of the ice cover of the Barents Sea and the Northern Hemisphere as a whole.

These periodicities were recorded in all landscape zones of the Komi Republic; hence they characterize the climatic variability that embraces the whole region. It is worth focusing attention on the fact that these periodicities do not coincide with the fundamental cyclicity of the solar activity.

Let us now consider the manifestation of periodicities close to the periodicity of the solar activity in the radial increment of trees. A periodicity of 10–12 years is manifested in coniferous trees in all landscape zones on the territory of the Komi Republic, excluding the forest–tundra transition zone. It was not found in the temperature variations in the Arctic zone (see Fig. 6) nor in the temperature variations in Murmansk (see Fig. 4). We note that the city of Murmansk is located near the boundary of the forest on the Kola Peninsula, i.e., in the forest–tundra transition zone. The development of this periodicity can be reasonably related to the 11-year solar cycle (the Schwabe cycle), while a lack of such a periodicity in the forest–tundra transition zone can be related to the regional character of the climatic response to the solar influence.

A periodicity of 21–24 years correspond to the 22- to 23-year solar cycle (the Hale cycle). This periodicity was found only in the forest–tundra transition zone and middle taiga. It is not manifested in the northern and southern taiga. Once again, this points to the regional character of the climatic response to the solar influence.

A climatic periodicity of 28–33 years is called the Bruckner periodicity. Its physical nature is not clear. However, it can be interpreted as a result of the generation of combination frequencies under the simultaneous influence of the solar 80- to 90-year (Gleissberg cycle) and 22-year variations on the strongly nonlinear atmosphere–ocean system [Raspopov et al., 2001]. The data obtained in this work support such an interpretation of the Bruckner cycle: the manifestation of 28- to 33-year oscillations in the forest–tundra transition zone and in the middle taiga, where we also find 21- to 24-year oscillations and their absence in the northern and southern taiga (where the 21- to 24-year oscillations were also not found). This can indicate that these two groups of periodicities are physically related in climatic processes.

In order to find the peculiarities of the climatic response of the North Atlantic region to the long-term variability in solar activity, the authors carried out corresponding investigations in six different regions of the globe [Raspopov et al., 2007]. It was shown that there are regions on the earth's surface with positive and negative temperature responses to an increase in solar irradiance. In the boundary zones between these regions, the climatic response to the variations in solar activity can be unstable. Modeling the temperature response of the atmosphere near the earth's surface to the global influence of the solar irradiance in the range of periods from 9 to 25 years (Fig. 7), i.e., in the same range of periods that is discussed in this paper, was carried out in [Waple et al., 2002].

It is seen from Fig. 7 that, if solar irradiance intensifies, a positive temperature response to this intensification appears on a significant territory of the globe; however, in some regions the temperature response is negative, which is related to the peculiarities of the atmospheric circulation and heat transport in the atmosphere–ocean system. Territories appear at the boundaries between the regions with positive and negative responses to variations in the solar irradiance, in which the variations in the solar irradiance are not recorded or the temperature response to them is unstable. The region of the Komi Republic is related to such boundary regions. The spatial variability of the climatic response to the solar influence in the Komi Republic can be related to the regional peculiarities of the atmospheric circulation along with the close location of this region to the territories of unstable climatic response to solar variability.

In considering the regional peculiarities of the rate of the annual radial increment of coniferous trees in the territory of the Komi Republic, it is necessary to focus attention on the results reported in [Solomina et al., 2009], in which the authors apply a wavelet analysis to variations in the annual radial increment of larch and spruce to study the rhythmic of climatic cycles in three regions in the northern part of European Russia over the last 300 years. One of the regions is located in the northern part of the Russian Plane (the northern parts of Archangelsk oblast and the Komi Republic) in the longitudinal zone from 40° to 60° E. However, unlike this study, in which we formulate the problem of zoning the territory of the Komi Republic on the basis of climatic peculiarities, the

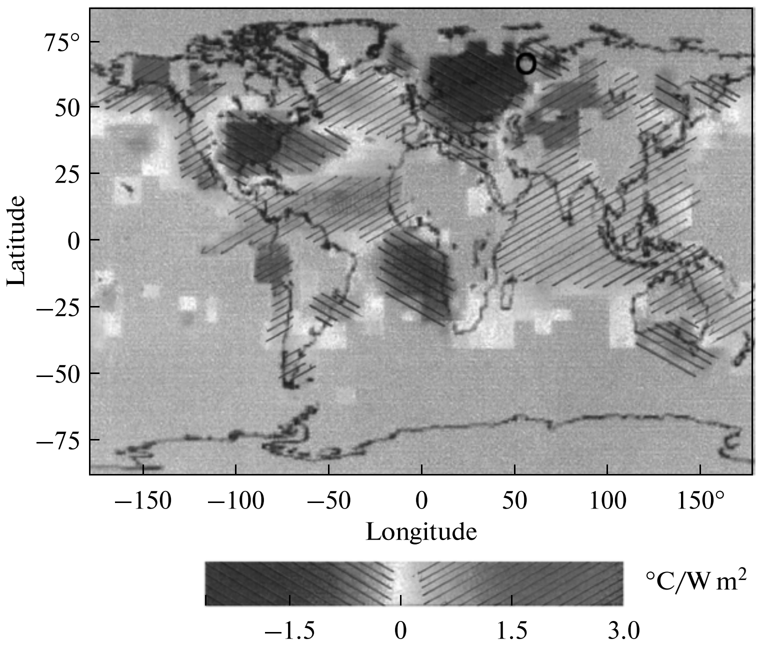

Fig. 7. Modeling results of the temperature response of the surface atmosphere to the variations in the solar irradiance in the range of periods 9–25 years (based on [Waple et al., 2002]). The location of the Komi Republic is indicated.

authors of [Solomina et al., 2009] did not try to solve such a problem. The average chronologies of the variations in the parameters of tree rings (the maximum density and width of the young wood) were processed using wavelet analysis and the results were compared with the results of the wavelet analysis of the climatic parameters. The wavelet analysis of the chronologies of young wood in the north of the Russian Plane revealed the existence of approximately 100-year and 55- to 60-year cycles. In addition, the appearance of periodicities of 30–32 years, 18–20 years, 7, and 10–11 years was found. The wavelet analysis of the variations in the maximum density of tree rings on the territory of the Komi Republic also revealed periodicities of 10–11 years and 18–20 years. Thus, approximately the same periodicities that were revealed on the territory of the Komi Republic were found using the data of a larger region.

We note that we analyzed periodicities shorter than 40 years. At the same time, it is seen in Fig. 2 that periodicities on the order of 45–60 and approximately 65 years exist in variations of the tree ring width on the territory of the Komi Republic, which was revealed also in a region with a greater territory [Solomina et al., 2009]. It is worth noting that the authors of this paper excluded some local chronologies whose correlation coefficients with other chronologies were insignificant. This means that climatic variability is different in different parts of the region, which we demonstrated in our work.

Thus, the variability of the radial increment of the coniferous trees on the territory of the Komi Republic is influenced by climatic factors related to the internal processes developing in the atmosphere–ocean system and to the processes that originate due to the variability in solar activity. The periodicity of the solar influence and inside atmospheric processes do not coincide, which allows us to separate them in an analysis of the response of the radial increment of tree rings to the climatic variability and makes zoning the Komi Republic on the basis of their responses to periodical solar forcing possible.

CONCLUSIONS

Several groups of periodicities, namely 6–9, 10–12, 13–14, 15–19, 21–24, and 28–33 years, were revealed from an analysis of the annual increment of coniferous trees growing in different botanical and geographical zones and subzones of the Komi Republic (forest–tundra transition zone and northern, middle, and southern taiga). The analysis of the hydrological and climatic data, development of the North Atlantic and Arctic climatic oscillations, and variability in solar activity allowed us to divide the revealed periodicities into two classes based on their possible physical nature. A number of periodicities (6–9, 13–14, and 15–19 years) are related to the internal processes in the atmosphere–ocean system in the North Atlantic and the Arctic region. For example, a periodicity of 6–9 years is related to the cyclonic processes in the North Atlantic, NAO, and AO, while periodicities of 13–14 and 15–19 years are related to the variations in the ice cover of the Barents Sea and in the Arctic Ocean. These periodicities are manifested in all subzones on the territory of the Komi Republic.

The second class of periodicities can be interpreted as a result of the global impact of solar activity. Periodicities of 10–12 and 21–24 years correspond to the Schwabe and Hale solar cycles, respectively, while the Bruckner periodicity (28–33 years) is likely a result of the nonlinear influence of the Hale and Gleissberg cycles on the atmosphere–ocean system. Unlike the periodicities of the internal origin, which manifest themselves in all subzones of the region, the influence of the periodicities of the solar origin is different in different subzones. For example, a periodicity of 10–12 years does not exist in the forest–tundra transition zone, and periodicities of 21–24 and 28–33 years are not found in the northern and southern taiga. The lack of these periodicities can be interpreted as a result of the differences in the atmospheric circulation on the territory of the Komi Republic related to the nonlinear response of the atmosphere–ocean system to solar forcing. Thus, several regions can be distinguished in the territory considered in this research based on the response to periodical solar forcing.

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