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Ice Phenomena of the Middle Siberia Rivers for the Period of the Last 300 Years (according to historical data) as a Reflection of the Climate Changes

Vladimir S. Myglan* and **Eugen A. Vaganov**
*Siberian Federal University,
79 Svobodny, Krasnoyarsk, 660041 Russia¹*

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The study represents the analysis results of the long-term time series of observation of ice breaking and freezing of the Siberian Rivers (the Ob, the Irtysh, the Yenisei, the Angara, etc.). There have been obtained statistic characteristics of the dependence of ice events dates on spring and autumn temperatures. We prove that during two last centuries there has been a steady trend towards shifting of ice-breaking moments for earlier ones and freezing dates for latter periods. We have specified common features of the variability of ice breaking and freezing periods, and there have been singled out the periods of fall in general temperature in the territory of Siberia for the last 300 years. On the basis of tree-ring chronologies data, there has been revealed a connection between the indirect indicator of summer temperatures change (tree growth) and the period of open water. The results of the work significantly enlarge the knowledge of variability of the Siberian climate for the previous centuries.

Two last centuries are characterized by the steady trend of shift of ice-breaking moments towards earlier dates and those ones of freezing - towards later periods. So the long-term time series of ice events (especially the period of open water) are the indication of warming over the considerable territory of Southern Siberia, that confirms the general tendency of warming in the temperate latitudes of the Northern Hemisphere.

There was found out a multi-directed trend in the ice events and long temperature-sensitive tree-ring chronologies after the 1950s. As the ice events are the consequence of physical processes, the cause of the divergence is necessary to be looked for in the biological response of trees for the climate changes or in other active biological factors of the environment.

The revealed close connection between ice events and the temperature of some months gives an opportunity to use the statistical characteristics for the forecast of ice events dynamics of the Siberian Rivers, especially for the warming impacts.

Keywords: ice breaking, freezing, Siberia, climate change, tree-ring chronology.

Introduction

As far as the impact of anthropogenic activity and greenhouse gases emission increases, the question of the correlation between natural and anthropogenic components under the modern

climate changes is desperately discussed at present (Shostakovich, 1909; Briffa et al., 1998; Mann et al., 1998; Bradley, 2000; Kondratyev, 2002; Briffa, Osborn, 2002). The question of global and regional climate changes and their

* Corresponding author E-mail address: vladimir@forest.akadem.ru

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one- and multi-directionality in large regions according to the climatic models computed data is of no less interest (Giorgi et al., 2001; IPCC, 2001).

As a rule, in the territory of Siberia, the time length of instrumental observations does not exceed one century, and it is just for a few number of meteorological stations. It makes the researchers use the indirect indicators of climate changes, such as tree rings, lake sediments sheets and so on, which significantly allow to prolong the time series of direct observations (Vaganov and others, 1996; Vaganov and others, 1998; Vaganov, Shijatov, 1999; Briffa et al., 2001). One of important, but indirect characteristics of temperature changes is the data on the variability of ice phenomena dates (Ginzburg and others, 1992; Ginzburg and others, 1996). These data are historically aged with exactitude and there are some examples of their successful use in the research of climate changes in Europe (Palecki, Barry, 1986; Yoo, D'Odorico, 2002).

In the course of the research in the Siberian territory and within the frameworks of RAS SD integration project №74, there has been gathered historically documented information, which includes the ice phenomena observations of the

Siberian major rivers from the XVIIIth to XXth centuries. Our main interest has been to obtain as long and homogeneous time series of ice breaking and ice formation periods as possible, to consider statistic features of the available historical time series and to compare them with the information on climatic changes, obtained from indirect sources on the time series of corresponding length.

Materials and methods

The Siberian Rivers' ice breaking and ice formation time series have been constructed on the basis of data from the pre-revolutionary researchers' works and historical archives. We have selected data on seven observation posts, which have had the least number of gaps and the longest continuance (Table 1). We have taken the day of the first ice motion during spring ice drifting (it is April 22, 1848 in the example given below) for the date of ice breaking. The date of steady ice cover formation has been taken as the date of freezing at the observation site. The values of ice breaking and freezing dates are given in the article according to the modern calendar, so, for the convenience of calculations, they have been re-arranged in the number of days from the top of the year (so called Julian Day).

Table 1. Hydrological stations

Stations (rivers)	Geographical coordinates		Period (year)	Sources
	Latitude (N)	Longitude (E)		
Tobolsk (Irtysh)	58° 12'	68° 14'	1812-1902	Berezovskiy E. 1927. Fedorov N.S. 1928. The History book of Yenisei province of 1863. The History book of Yenisei province of 1865 and 1866. Archival documents TFTRSA Data of Krasnoyarsk CHMS-R Shostakovich V.B. 1909. Irkutsk Chronicles (Chronicles of Pezhemskiy P.I. and Krotov V.A.)
Barnaul (Ob)	53° 20'	83° 48'	1751-1905	
Tomsk (Tom)	56° 30'	84° 58'	1830-1905	
Krasnoyarsk (Yenisei)	56° 01'	92° 52'	1779-1966	
Yeniseisk (Yenisei)	58 27'	92 06'	1821-2001	
Irkutsk (Angara)	52° 16'	104° 19'	1724-1907	
Kirensk (Lena)	56° 47'	108° 07'	1815-1907	

Geographical coordinates of the hydrological stations (Greenwich).

Though the information, which is contained in the historical sources, has high temporal resolution, nevertheless the question of correctness degree of ice breaking and freezing rows, being used in the article, needs in additional consideration. Thus, while estimating the exactitude of ice phenomena dating, we may indicate the following circumstances. The used historical materials (TFTRSA, «Irkutsk Chronicles», etc.) are remarkable for their particular thoroughness, with which the observers fix the moments of ice breaking or freezing and other natural phenomena. As an example, we shall give the description of the Irtysh River breaking near the Tobolsk town for 1848 - «On the 22nd of April the ice moved opposite the market hithe, on the 23rd of April it moved in other places. On the 25th of April the Irtysh was free from ice, but only opposite Tobolsk. ... On the 2nd of May the ice went to the Irtysh from the upstream... from the 8th to 9th of May it snowed» (TFTRSA, f. 329, st. 16, doc. 13). This example (the same is for other sources) illustrates quite well that the author does not only neatly connects the occurring natural phenomena to the days of the year, but, what is especially important, fixes the cases when the observed phenomenon takes place on the border between two days. Moreover, in order to check the gathered material (when it has been possible), we have correlated the data from different sources, and we have not found any discrepancy in the periods and moments of ice breaking and freezing. There have not been found any disagreements within the limits of one time series as well, in spite of the fact that the records were led by different observers. Thus, the analysis of the used information says that possible inaccuracy of the restored time series (for fixing the date of ice breaking and freezing) is within the limits of several hours and does not exceed one day.

Prevailing a secular interval, the historical time series at 4 observation sites have been taken for analysis and calculations of statistic characteristics, while the data from the rest of observation sites have been used for verification of the obtained results. The Yenisei River's data for the last years have had to be restored preliminarily excluding the impact of the stream control, because of Krasnoyarsk Hydro Power Station. In order to correlate the obtained rows of the Siberian rivers' ice breaking and freezing with the information on temperature and precipitation, we have used the data of the meteorological stations of the following cities: Barnaul (1838-1999, 1891-1999), Yeniseisk (1872-1999, 1891-1999), Krasnoyarsk (1891-1995, 1914-1999), Minusinsk (1886-1999, 1916-1999), Irkutsk (1820-1999, 1891-1999).

As an independent source of verification, there have been used indexed dendrochronological time series of tree-ring width installed in the North of Middle Siberia, the Altai and Sayan Mountains. The trees growing on the border of its habitation (sub-Arctic Regions, uplands) are sensitive only to summer temperature changes, what explains the variability of tree-ring chronologies up to 65-70% (Vaganov and others, 1996; Vaganov and others, 2000). The spatial analysis of the tree-ring chronologies in the North of Eurasia has not shown any significant influence of moisture level (precipitation) on the variability of tree growth (Vaganov and others, 1996; Briffa et al., 2001). Such a tight connection allows to make reliable quantitative climatic reconstructions of summer (June – July) temperatures, for instance (Vaganov and others, 1998; Ovchinnikov and others. 2002; Naurzbaev and others, 2003).

All the necessary calculations, graphic illustrations, and also correlative and regressive analyses have been made with the help of Statistica 6.0.

Results

1. Variability of Weather and Duration of the Rivers' Ice Breaking and Freezing Dates

Let us consider the main statistic characteristics of ice breaking and freezing dates of the chosen observation sites (Table 2). In the article, we have used the coefficients of variation and sensitivity, calculated according to the actual values of ice breaking and freezing dates, for statistic estimation of ice breaking and freezing time series. Sensitivity coefficient is widely used at dendroclimatology and characterizes the sensitivity of ice breaking-freezing periods to weather changes (Cook, Kairiukstis, 1990).

From the values, given in Table 2, we can see that the earliest ice breaking is registered on the Angara River in the Irkutsk region and the latest one – on the Yenisei River in the Yeniseisk region, what corresponds to geographic location of the sites and corresponding catchment areas. Though, we can see the opposite pattern in the dates of freezing - the earliest ice formation is observed at the southern sites, what have unfortunately failed to be clearly explained. The time series are characterized by relatively high weather variability, gaps between the dates of ice breaking and freezing average out to 4 weeks in most cases (± 2 standard deviations), i.e. a month on the average. According to the classification, suggested by Ferguson (Ferguson, 1969), the researched time series could be referred to highly sensitive (the values of coefficients exceed 0.20). Thus, in spite of the fact, that the chosen

observation sites are situated on the rivers with significant catchment area and water content (Marusenko, 1962), the observed time series are characterized by high variability and sensitivity to weather changes.

In order to carry out a comparative analysis, we have indexed the time series of observation (normalized to a standard deviation $t = (x - x_{cp}) / \sigma$) and represented them in graphics (Fig. 1). The diagram shows that there is certain simultaneity in the fluctuations of curves, which is probably the result of the influence of some common factors. Using the data of meteorological stations chain, we have compared the fluctuations of spring-autumn monthly temperatures with the ice breaking and freezing dates of the Ob, Yenisei and Angara rivers. Two criteria have been used for the selection of meteorological data: 1) the series length of observation time series (the data rows of most of meteorological stations are fragmentary and (or) of short length); 2) geographical position (the station must be at the observation site or upstream).

The estimation results of correlation between ice breaking and freezing dates of the Ob, Yenisei and Angara observation sites and the sum of monthly temperatures according to the data of meteorological stations are presented in Table 3. We do not present correlation indexes of ice breaking and freezing dates with precipitations in the research, as far as either they have turned out to be insignificant or the collected data have not been enough for analysis.

Table 2. Statistical characteristics of ice events of the Ob, Yenisei and Angara rivers

River	Hydrological station	Arithmetic mean		Average square deviation		Sensitivity index		Variation coefficient (%)	
		breaking	freezing	breaking	freezing	breaking	freezing	breaking	freezing
Ob	Barnaul	116.0	312.5	8.0	8.4	0,4	0,4	36,5	35,9
Yenisei	Krasnoyarsk	118.9	318.8	7.7	6.3	0,4	0,4	35,1	33,8
Yenisei	Yeniseisk	123.9	325.5	7.5	9.8	0,2	0,3	22,9	34,5
Angara	Irkutsk	98.8	376.8	9.4	9.5	0,4	0,3	36,5	32,1

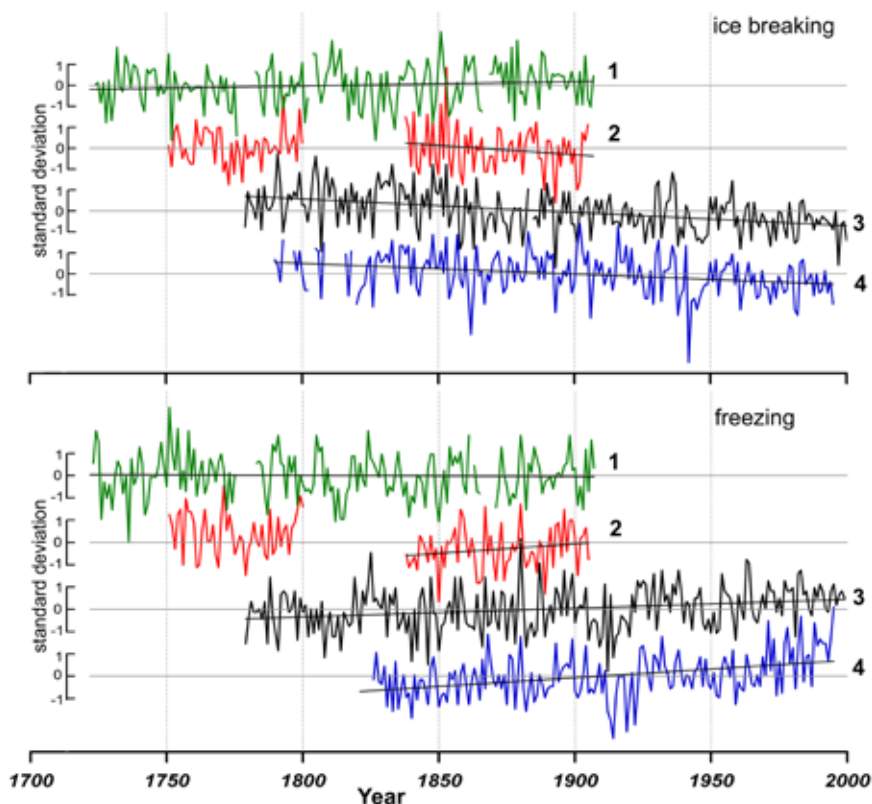


Fig. 1. Changes of the rivers' ice breaking and freezing dates according to the data of the following observation sites (1 Angara (Irkutsk), 2 Ob (Barnaul), 3 Yenisei (Krasnoyarsk), 4 Yenisei (Yeniseisk)). The average values of ice breaking and freezing dates are marked by the horizontal line; the revealed trends are marked by the slanting line

Table 3. Correlation of ice-event dates and the temperature of some months

Hydrological station	Meteorological station	March	April	May	N	October	November	December	N
Barnaul	Barnaul	-0.5**	-0.8**	-0.3	60	0.5**	0.5**	0.0	56
Yeniseisk	Yeniseisk	-0.4**	-0.5**	-0.3*	127	0.2*	0.5**	0.2*	128
	Krasnoyarsk	-0.5**	-0.5**	-0.3*	100	0.5**	0.7**	0.4**	99
Krasnoyarsk	Krasnoyarsk	-0.3*	-0.7**	-0.1	75	0.4**	0.4**	0.0	74
	Minusinsk	-0.3**	-0.8**	-0.1	79	0.4**	0.6**	0.0	75
Irkutsk	Irkutsk	-0.4*	-0.4*	-0.3	58	0.2	0.4*	0.5**	57

The significant correlation (* - $p < 0.01$, ** - $p < 0.00$, N – amount of sampling).

It is easy to notice that the March and April temperatures have the most important correlation with ice breaking and freezing dates for all 4 observation sites. This statistically high correlation is of negative meaning, as far as higher temperatures of the spring months

precipitate rivers' clearing from ice. Thereat, the highest correlation indexes are registered between the temperature of April and the dates of ice breaking for most of meteorological stations. The correlation of autumn months' temperatures and freezing dates is slightly lower, but it is also

highly significant. Correlation indexes of the sites, situated on the Ob River at Barnaul and on the Yenisei River at Krasnoyarsk, indicate a great dependence of freezing dates on the October and November temperatures. The temperature of December turns out to be also significant for the observation site, situated on the Angara River at Irkutsk, and it corresponds to the later dates of freezing. Such dispersion is a sign of a larger variability of freezing periods in time. The correlation between autumn temperatures and freezing dates is positive, as far as higher temperatures bring to later ice formation.

The revealed strong interrelation between the dates of ice breaking and freezing and temperature has been presented as statistic dependences – regression equations. The collected temperature data has allowed to restore the missing values in the time series of observation for the XXth century and to correct the dates of ice breaking and freezing of the Yenisei River taking into account the impact of the Krasnoyarsk Hydro Power Station. There have been made a reconstruction of ice breaking dates according to the April temperature and of freezing dates according to the October and November temperatures for the Krasnoyarsk and Yeniseisk observation sites. We have managed to restore the dates of suppositional ice breaking-freezing variations from 1967 to 1999 years for the Krasnoyarsk site, and for the Yeniseisk site – to neutralize «the jump», which has revealed itself in the shift of medium ice breaking and freezing dates (if the Yenisei broke on an average on the 4th of May, and froze up on the 20th of November before 1966, so in recent years, it has begun to break on an average on the 13th of April, and to freeze up on the 25th of December). In order to check the obtained results, we have made a comparison between the weather fluctuations of ice breaking and freezing dates of the original time series and the restored ones for the period from 1900 to 1966, and it has not found

out any significant discrepancy in the weather fluctuations of ice breaking and freezing dates (for example, the correlation index of the «restored» and original time series of the Krasnoyarsk site amounts to 0.70).

The revealed values of correlation indexes prove that the observed time series are tightly connected to the variations of spring and autumn average monthly temperatures. That is why the observations on variations of the long-term characteristics of ice regime provide for both the analysis of general variations and the reveal of climate changes trends within the Siberian territory for the period of study.

2. Analysis of the Long-Term Ice Trends in the Time Series of Ice Breaking and Freezing Dates of the Siberian Rivers

We have used the amended and restored time series of ice breaking and freezing dates for calculation (least square method) of linear trends for the Ob, Yenisei and Angara rivers. The term of linear trend is understood as the angular coefficient **a** of the equation $D=at+b$, where **D** is a period of ice phenomena coming, and **t** is a calendar year.

We can see from Table 4 that there is a subtle, but steady shifting of ice breaking dates towards earlier ones, and of freezing dates towards later ones at the Ob and Yenisei observation sites (Fig. 1). The comparison of trends values with mean-square deviations (Tables 2, 4) has shown that they do not exceed the latter in value. Predominance of the trend components over natural weather fluctuations is achieved only for a period of two centuries. Thus, the observation rows of the Ob and Yenisei rivers reflect a tendency of increase of average monthly temperatures of spring-autumn periods for the last two centuries. The trends, constructed according to the data of Tobolsk, Tomsk and Kirensk observation sites, have confirmed this general tendency.

Table 4. Shifting of the ice-events dates during 100 years

River	Hydrological station	Period	Trend (breaking, day)	Period	Trend (freezing, day)
Ob	Barnaul	1838-1905	-5.0	1838-1905	5.0
Yenisei	Krasnoyarsk	1800-1900	-5.0	1800-1900	3.0
		1900-2000	-5.0	1900-1999	2.5
Yenisei	Yeniseisk	1800-1900	-4.0	1821-1900	6.0
		1900-1995	-3.5	1900-1995	7.0
Angara	Irkutsk	1722-1800	1.5	1720-1800	-0.35
		1800-1900	2.0	1800-1900	-0.5

Table 5. Correlation coefficient for ice events and the period of open water of the Siberian Rivers

River	Ice breaking			Freezing			Period of open water		
	Ob	Yenisei (Kr)	Yenisei (Yen)	Ob	Yenisei (Kr)	Yenisei (Yen)	Ob	Yenisei (Kr)	Yenisei (Yen)
Ob	1.00			1.00			1.00		
Yenisei (Kr)	0.62	1.00		0.68	1.00		0.77	1.00	
Yenisei (Yen)	0.49	0.52	1.00	0.54	0.70	1.00	0.68	0.73	1.00
Angara	0.04	0.10	0.03	0.49	0.38	0.31	0.30	0.35	0.35

Kr – station near Krasnoyarsk, Yen – station near Yeniseisk. The bold type is used for represent significant level at $p < 0.05$

But the situation concerning the dates of ice breaking and freezing of the Angara River near Irkutsk is quite contrary. Thus, the Angara has begun to break approximately 3.5 days later and to freeze 1 day earlier than it did before (Fig. 1) for the study period. These peculiarities of the Angara's behavior near Irkutsk can be accounted for the influence of Lake Baikal. Thus, the Angara has maximum of fluctuations of the dates of freezing in comparison with the Yenisei and other Siberian rivers (and if the fluctuations of freezing dates of the Siberian rivers are on an average within the limits of 38 days, so the fluctuations of the Angara are within the limits of 58 days).

So we may indicate a steady warming trend for the territories of Western and Middle Siberia, as far as there is a trend for earlier ice breaking and later freezing throughout all the observation sites, presented in the given work, except for the Angara one, for the period starting from the XVIIIth century up to our days.

3. Secular Climatic Fluctuations and Duration of Open Water Period

Here open water period is considered as a period between the dates of ice breaking and freezing, i.e. a spell, when a river is free from ice. That indicator allows to consider climatic characteristic of summer period more objectively, for, in contrast with the moments of ice breaking and freezing as characteristics of spring or autumn periods, open water period integrates both of these events in itself. Thus, being the difference of ice breaking and freezing dates, this indicator allows to obtain a climatic signal, which is more integrated for a season. The calculations carried out on the observation sites have shown that the correlation indexes of the explored rivers for the open water period are on an average higher than the same indexes, calculated for the ice breaking and freezing periods (Table 5).

In order to eliminate the impact of local conditions and to single out common peculiarities of the duration dynamics of open water periods,

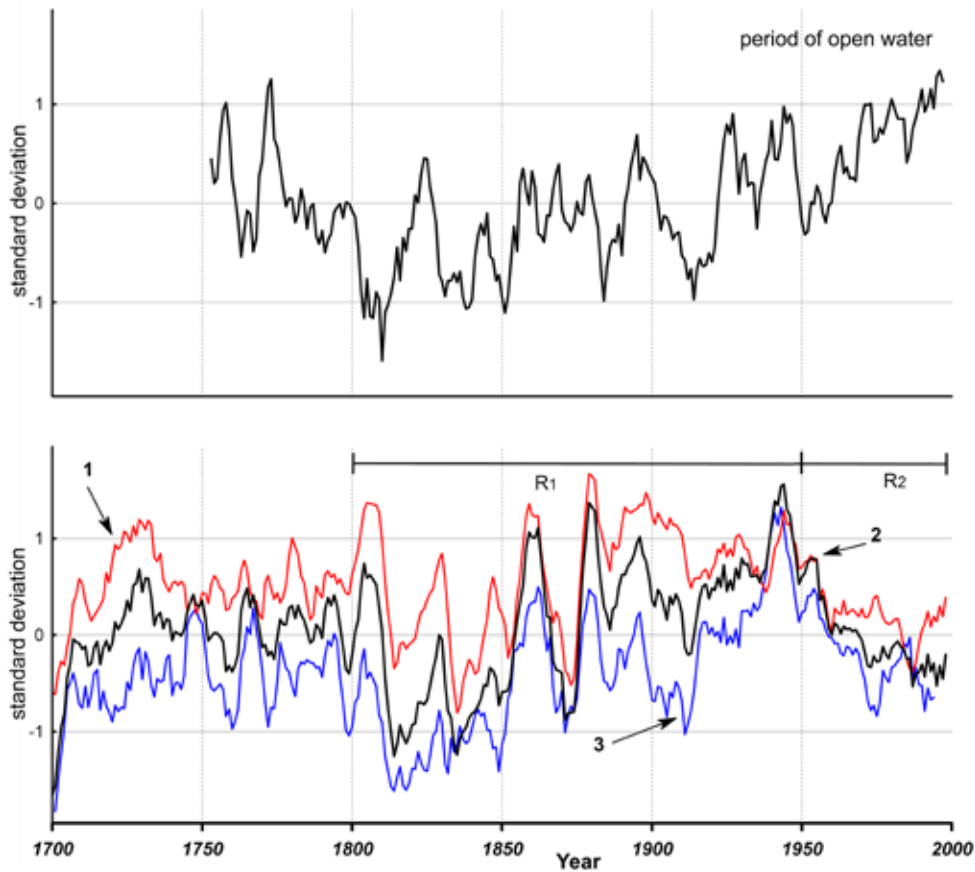


Fig. 2. Fluctuations of the indexes of tree growth and duration of open water period (the Ob and the Yenisei smoothed values). 1 - the Sayan tree-ring chronology, 2 - averaged values of the Sayan and Taimyr tree-ring chronologies, 3 - the Taimyr tree-ring chronology

the original time series have been smoothed by the 5-years moving average line. It has allowed to distinguish the periods of reduction of open water days, overstepping the limits of the standard deviation – 1734-38, 1744-45, 1762-68, 1804-16, 1837-41, 1846-52, 1883-90, 1907-21, 1950-52, 1957-58 years. The averaged and smoothed values of the open water periods of the Ob and Yenisei rivers in Fig. 2 are compared with the long-term tree-ring chronologies, obtained for the northern and southern parts of Middle Siberia, which distinctly reflect the changes of summer temperatures (Vaganov and others, 1996; Ovchinnikov and others, 2002). It is easy to notice that the curves show general changes of the thermal regime of the XIXth and XXth centuries.

Being fixed in the tree-ring chronologies, the fall of temperature of the first half of the XIXth century finds its substantiation in the dynamics of open water period. The general growth of summer temperatures of the beginning of the XIXth – the middle of XXth centuries corresponds to the tendency of duration increase of the open water period. Fluctuations of lesser length (20-30 years) can be seen from the tree-ring chronologies and well expressed in the time series of open water period. The greatest differences in the compared dynamics are registered after 1950-s, their direction becomes precisely the opposite – if there is a positive tendency in the dynamics of open water period, then, there is a negative one in the presented tree-ring chronologies. It is well

illustrated by the correlation indexes, calculated between two curves for the different periods: 1) 1800-1950 ($R= +0.51$, $p<0.0001$); 2) 1951-1998 ($R= -0.83$, $p<0.0001$).

Discussion of Results

The analysis results have shown that the dates of ice breaking and freezing are closely connected with the air temperature for the previous period and are the integral indicators of temperature regime in the territory of the catchment basin. According to the data of J.I. Marusenko (1962), the occurring synoptical processes (cyclonic, alternating and anticyclonic weather) play their main part in the dates of the Siberian Rivers' ice breaking. In this case, convectional heat exchange has a significant influence on the process of ice breaking because of synchronous temperature changing of the ground, water, and air. We can single out the following factors among the others, which have influence on the dates of ice breaking: ice cover thickness, stream speed, and other hydrodynamic characteristics. Unfortunately, we cannot always take into consideration all the peculiarities of these characteristics in the research, as far as the time series of instrumental observations take a very small period (thereat, for example, such an indicator as thickness of ice cover has a rather significant weather variability (The Main Hydrologic Characteristics, 1967)). In this case, the revealed of the ice regime changes can be also used within the territory of the catchment basin of the observation site according to the fact that the dates of ice breaking are defined not only by the temperature at the observation site, but also by the temperature at the territory of the catchment basin (the rate of snow cover melting and water influx depend upon the latter very much). In practice, interpretation of the ice freezing dates is also difficult, as far as in many cases, they are determined not only by meteorological conditions, but by the hydrologic

regime of a river as well. For example, the shifting of ice breaking dates of the Angara River (near Irkutsk) for the later dates in comparison with the other rivers can be explained by the above-zero temperature water influx from Baikal Lake in the period of freezing of the Angara River. Thereat, in some cases, the significant deviations towards later freezing can be referred to the years with abundant precipitation and high water level of Baikal Lake (Shostakovich, 1927).

The obtained results are important both for analysis of the long-term regional climatic changes and for a global aspect. Data analysis of the Siberian Rivers' ice breaking and freezing has shown that there have been observed a minor, but steady trend for earlier ice breaking dates and for later freezing dates in the Middle Siberia territory for the last two centuries. The revealed tendency, proving climatic warming in the middle latitudes of Eurasia, is in correspondence with the data of other indirect sources concerning the climatic warming, which has been taking place in the high Eurasian latitudes for the last 150 years (Myneni et al., 1997; Vaganov and others, 2000; Zhou et al., 2001; Esper et al., 2002). We notice that prolongation of the warm period, obtained from the result of ice-events analysis (open water period), gives the lowest values in comparison with the other materials. Thus, prolongation of the open water period for the last 100 years corresponds to 8–10 days (according to the data from Table 4), while the other indirect estimations of the prolongation of warm period give 18 days per a quarter of the century (Zhou et al., 2001).

There has been found a connection between the length of open water period and the tree-ring chronologies in the course of research. Taking into account that the former reflects changes of the duration of open water period (spring-autumn temperatures), and the latter – summer temperature changes in the corresponding sector of the North of Eurasia (Vaganov and others,

1998; Vaganov and others, 2000; Naurzbaev and others, 2003), we may assert that this connection characterizes climatic processes of a mesoscale level.

The fact of changing of connection sign between the trend of open water period and the tree-ring chronologies after 1950-s is of much interest. The close connection between the average monthly spring-autumn temperatures and the dates of the rivers' ice breaking and freezing for the whole period of calibration explains the fact that the well-expressed tendency to prolongation of open water period after 1950-s is connected with the increasing of average monthly temperatures. In this case, there can be given several hypotheses in order to explain the growth slowdown of trees in the temperature-sensitive Siberian regions (Briffa et al., 1998). One of the possible explanations can be a supposition that simultaneously with the prolongation of open water period there was observed a decreasing of June-July temperatures, defining radial tree growth in the temperature-limiting regions.

The other possible explanation is that the tree growth was suppressed by some other factors, also including those ones of non-climatic nature. As such there have been suggested the following ones: increase of ultraviolet radiation as the result of thinning of the atmosphere ozone layer, the nitrogen deficit, thickening of snow cover, etc. (Briffa, Melvin, 2004). Though, neither of the hypotheses has got its exact experimental confirmation. Suppression of tree growth in Alaska and in the North of Canada is connected either with increasing deficit of watering in the territory or with high temperatures, though there are no any strict proves of the mentioned for the North of Eurasia (Vaganov and others, 1996; D'Arrigo et al., 2004).

Conclusion

It is obvious, that using the climatic information from historical archives gives a unique possibility not only to prolong the existing observation time series, but also to consider the existing short-term and secular climatic changes.

So, the analyzed long-term time series of ice events on the Siberian Rivers (especially the period of open water) prove the tendency of warming within the considerable territory of Southern Siberia, that coincides with the general tendency of warming in the temperate latitudes of the Northern Hemisphere. The estimations of warm period changes by the ice-events on the Siberian Rivers show less values than other indirect characteristics of prolongation of warm (vegetative) period. The cause of the divergence is not quite clear and needs a more detailed analysis and ever more spatial data.

Another important result of the research is a multi-directed trend of ice events and the long temperature-sensitive tree-ring chronologies after the 1950s. As ice events is the consequence of physical processes, the cause of the divergence is necessary to be looked for in the biological response of trees for the climate changes or in other active biological factors of the environment. The revealed close connection between ice events and the temperature of some months gives an opportunity to use the statistical characteristics for the forecast of ice events dynamics on the Siberian Rivers, especially for the warming impacts. The observed work has been supported within the frameworks of the projects: «Scientific School» № SS – 2108. 2003.4 and RFFI 08-06-00253-a «Creation of the Ultra-Long-Term Tree-Ring Chronology for Archeological Monuments Dating and the Altai-Sayan Climate Reconstruction for the Period of the Last Two Centuries»

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