ICE REGIME IN THE RIVERS OF RUSSIA, ITS DYNAMICS DURING LAST DECADES AND POSSIBLE FUTURE CHANGES

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ABSTRACT
During the last 20-25 years, ice regime in the rivers of Russia was subject to considerable changes because of a permanent positive trend in winter air temperatures. The dynamics of ice events in the rivers of Russia has been analyzed with the use of data series on ice regime and ice cover thickness at 65 hydrological stations on large and mid-size rivers in the European and Asian territories of Russia. The assessment of ice regime changes has been made for 1980-2000 and compared with the period of 1950-1979. A preliminary forecast of ice regimes in the Russian rivers for 2010-2015 has been made. It has been established that the duration of the complete ice coverage in the rivers of European Russia and large Siberian rivers during the last twenty years became 3 to 7 days shorter; the duration of ice coverage on lakes or reservoirs in the Asian territory of Russia is 4 to 14 days shorter because of earlier ice break-up. According to the forecast, this trend would be unchanged in 2010-2015. During the last twenty years the maximum ice cover thickness became 2-14 cm thinner practically on each large river in Russia on the average, if compared with the previous 30-year long period. During the next 10 to 15 years, the maximum ice cover thickness is expected to thinner on all large rivers in Russia.

KEY WORDS: Ice regime; Russian rivers; Changes; Past and Future.

INTRODUCTION
During the last 20-25 years ice regimes in the rivers of Russia were subject to significant changes mainly caused by a stable positive trend of winter air temperatures on the background of the rise of mean annual air temperature typical of most of the country. Remind that such ice regime characteristics as dates of ice-on and ice-off, duration of ice events, and ice cover thickness are very important and often limiting factors of river use in winter time. Dates and duration of ice events are associated with navigation and specific features of hydraulic structures construction in winter. The ice cover thickness is a determining factor to estimate the ice-bearing capacity and dates of ice-routes operation across rivers. This is why the problem of the assessment of ice regime changes in rivers affected by possible future climate change are acute.

1. METHODOLOGICAL APPROACHES
Analysis of ice events dynamics in the rivers of Russia has been made with the use of observation data series on ice regimes and ice cover thickness published in hydrological yearbooks. Data from 65 hydrological stations installed on large and mid-size rivers within the European and Asian Russia have been used for the analysis. An electronic database has been prepared on the basis of these data for the period from the beginning of observations up to 2000-2004. Assessment of ice regime changes has been made for 1980-2000 in comparison with the period of 1950-1979. A preliminary forecast of ice regimes in the Russian rivers for 2010-2015 has been made.
with 1950-1979. The period 1950-1979 was selected as a base period because that time winter air temperatures were close to the climatic norm. Preliminary computations have been also made on possible change in ice regimes in the rivers within the study territory for the next 5-10 years.

As there are great areal differences in the ice regimes, gaps in data, low quality of the data and a necessity to use additional data characterizing winter temperature background adjacent to the study river basins, two methodological approaches have been applied. The first approach is based on a comparison of averaged characteristics of ice regimes for 1950-1979 and 1980-2000 to determine the gradients of these changes and their use for future assessments. The second approach is based on the establishment of correlation between ice regime characteristics and winter air temperatures for the study periods with its future use with the account of prognostic values of winter air temperature. In most cases both of these approaches were used for the analyses.

2. ASSESSMENT OF CHANGES IN ICE EVENTS CHARACTERISTICS AND ICE COVER THICKNESS OCCURRED FOR THE LAST TWENTY YEARS; FORECAST OF THE EXPECTED CHANGE IN THESE CHARACTERISTICS

In the rivers of the North West of European Russia a stable positive tendency was observed during the 50-year period (1950-2000) on the dynamics of the dates of the start of ice-on and a negative tendency – in the dynamics of the dates of ice-off, i.e. later dates of ice-on and earlier dates of ice-off. If compared with the base period 1950-1979, this shift during the last twenty years of the last century equaled 5-7 days on the average. In large rivers in the North West of European Russia, earlier ice-on (by 2-6 days) was observed during the last twenty years, if compared with the period of the climatic norm, which in general corresponded to a certain mean air temperature fall in autumn. Meanwhile, the dates of spring ice-off became earlier, too. This tendency in these regions would be kept during 2010-2015. Ice-on and ice-off would be 2-10 days earlier, if compared with the period 1950-1979.

It has been established that the beginning of the ice-on the large Siberian river basins during the last 20-25 years became 2-3 days later on the average, whereas the ice-off was 3-5 days earlier. During the next 10-15 years, a further time shift would be expected; ice-on on large rivers in the Asian Russia would be 5-10 days later and ice-off would be 8-20 days earlier if a tendency of temperature series is kept as it is now.

Mean ice cover duration in the last twenty years in large rivers of European Russia became 2-10 days shorter, if compared with the previous 30-year period. Moreover, there is an evident tendency towards a shorter ice cover duration by 25-30 days on the average observes in the rivers of the North West of European Russia during the whole 50-year period; meanwhile in the rivers of North East of the European Russia the ice cover duration is practically the same as it was in 1950-1979. In accordance with the forecast of further air temperature rise in winter and spring, the ice cover duration in the rivers of the European Russia would be shorter. In some rivers (Pechora, Northern Dvina, and Onega) this shortening in 2015 may be 10-15 days. The ice cover duration in large rivers within the Asian Russia during the last twenty years also became shorter by 3-7 days because of later ice-on and earlier ice-off (Fig.1).
In accordance with the forecast of further air temperature rise in winter and spring, the ice-on duration in the rivers of the European Russia would be shorter. In some rivers (Pechora, Northern Dvina, and Onega) this shortening in 2015 may be 10-15 days. The duration of ice cover duration in large rivers within the Asian Russia during the last twenty years also became shorter by 3-7 days because of later ice-on and earlier ice-off. In accordance with the forecast of spring and autumn air temperatures, the observed tendency would be the same.
during 2010-2015. Most significant changes in ice cover duration may be expected in the rivers within the Yenisei basin (-10-15 days).

Practically in all large rivers in Russia a decrease of maximum ice cover thickness by 2-14 cm on the average was observed during the last twenty years if compared with the previous 30-year period. In the rivers of the European Russia a decrease of the maximum ice cover thickness equaled 2-7 cm (Fig.2).

Figure 2 Tendency towards changes in the maximum ice cover thickness in the Northern Dvina river for the period 1954-2002 (the North East of the European Russia).

Moreover, in the rivers of North West of the European Russia, a positive tendency towards a thinner maximum ice cover thickness during 1950-1979 was observed during the whole 50-year period, whereas in the rivers of the North East of the European Russia, the maximum ice cover thickness during 1950-1979 was not subject to great changes; on the contrary, in the river reaches of the Pechora at Ust-Tsila and in the Northern Dvina at Ust-Pinenga the maximum ice cover thickness became a bit thicker. Most intensive thinning of the maximum ice cover thickness occurred in the Siberian rivers (-5-10 cm in the lower Ob reaches, -6-14 cm in the Yenisei basin –11-15 cm in the lower Lena reaches) (Fig.3). This tendency was observed in these rivers during the second half of the XXth century.
Most evident decrease of the maximum ice cover thickness occurred during 1950-1974 in the upper and middle reaches of these rivers; meanwhile this characteristic was subject to slight change in the lower reaches; in the Ob at Salekhard a slight negative tendency was even observed. In accordance with a tendency towards higher spring and winter air temperatures, a further thinning of the maximum ice cover thickness is expected in all large rivers. In large rivers of the European Russia this thinning by 2010-2015, if compared with the present time, would be small and would equal 3-7 cm. More significant thinning of the maximum ice cover thickness is expected in the Siberian rivers. According to the prognostic assessments on the level of 2010-2015 it may be by 16-25 cm thinner in the Yenisei river and in its large tributaries, and by 20-30 cm thinner in the lower Lena reaches.

Combined data on the changes in ice cover duration and maximum ice cover thickness in large rivers of Russia are given in Table 1.

**Table 1** Changes in mean ice cover duration and maximum ice cover thickness in large rivers of Russia in 1980-2000 relative to 1950-1979

<table>
<thead>
<tr>
<th>River</th>
<th>Changes in mean ice cover duration, days</th>
<th>Changes in mean maximum ice cover thickness, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Волхов</td>
<td>0-1</td>
<td>-1-2</td>
</tr>
<tr>
<td>Luga</td>
<td>-2-4</td>
<td>-2-4</td>
</tr>
<tr>
<td>Northern Dvina</td>
<td>-4-6</td>
<td>-2-5</td>
</tr>
<tr>
<td>Onega</td>
<td>-2-6</td>
<td>-1-3</td>
</tr>
<tr>
<td>Pechora</td>
<td>-2-4</td>
<td>-2-6</td>
</tr>
<tr>
<td>Ob (low stream)</td>
<td>-2-3</td>
<td>-4-5</td>
</tr>
<tr>
<td>Yenisei (upper stream)</td>
<td>-5-7</td>
<td>-7-9</td>
</tr>
<tr>
<td>Yenisei (middle stream)</td>
<td>-4-7</td>
<td>-8-10</td>
</tr>
<tr>
<td>Yenisei (low stream)</td>
<td>-3-5</td>
<td>-4-6</td>
</tr>
<tr>
<td>Lena (middle stream)</td>
<td>-4-6</td>
<td>-8-12</td>
</tr>
<tr>
<td>Lena (low stream)</td>
<td>0-2</td>
<td>-4-6</td>
</tr>
</tbody>
</table>
CONCLUSION

As further climate warming is most probable for the next decades in the territory of Russia, positive trends of winter air temperatures in particular, it is possible to expect a development of those tendencies towards changes in the ice regimes in rivers which were established for the last twenty years of the XXth century. Therefore, it is very important to adapt different branches of economy to the changes in ice river regime which may cause both positive and negative results.

REFERENCES