WEATHER CONDITIONS SUITABLE FOR SPRING FLOODS IN NORTH EURASIA AND THEIR FREQUENCY DURING THE LAST DECADES

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ABSTRACT

Statistical analysis is carried out on weather conditions in North Eurasia, favorable for spring floods in the region. Change of frequency and intensity of such situations since the middle of 20th century is studied too. Specific weather conditions suitable for spring floods in North Eurasia include:

- extreme amount of snow accumulated during winter;
- snow depth at the beginning of intense snowmelt;
- fast warming above the melting point in the presence of snow;
- heavy rains with air temperature above the melting point, combined with the presence of snow.

Analysis of daily meteorological records over North Eurasia during 1950-2006 has been carried out for two distinctive time spans: from 1951 till 1980 (base period), and from 1989 till 2006 (contemporary climate warming). Among the weather conditions, favorable for the spring floods, snow accumulation is changing most intensively. Over most of Siberia and in the north-east of the East European Plain, it is increasing during the last decades as compared to the middle of 20th century. In some regions such as West Siberia and parts of Central Siberia, as well as in Sakhalin island, the increase of snow amount is rather significant. This can result in larger frequency of spring discharge, and, under certain circumstances, spring floods. However, the frequency of other weather situations favorable for the spring floods didn't change so much on the scale of sub-continent. The snow depth just before fast melting has increased in some areas (parts of Pechora, Ob and Yenisey basins). Frequency of spring heat waves has increased in Pechora basin and parts of Ob river basin. The rain sums falling on snow have increased in relatively small areas, mostly in the East European Plain. Overall, the basins of Pechora and middle flow of Yenisey, and to some extent upper part of Lena river have become more threatened by the contemporary climate change in terms of spring floods. On the scale of the entire sub-continent, potential threats from the viewpoint of spring floods increase only in few areas of North Eurasia, while in other areas this danger has become less frequent.

Keywords: Spring flood, North Eurasia, Snowmelt, Climate change

INTRODUCTION

Spring floods represent a major threat to many of the regions in North Eurasia. Typical hydrological regime of the North Eurasia rivers includes a spring phase when the snow mass, accumulated during several months, melts with high intensity, and the melt water increases the discharge abruptly, sometimes by an order or two of magnitude. The spring melt water constitutes the largest share of the annual runoff in many of the North Eurasia rivers, and in certain months of certain years rivers like Yenisey or Lena can be the 2nd-3rd largest in the world by the discharge volume. If the runoff of a river is well above the average, a flood can take place. In particular conditions of North Eurasia, the floods can originate also from the ice dams on rivers, and such situations are especially dangerous in terms of the flood level. In Siberia, many rivers flow from the south to the north, and such situation can be favorable for the ice dams, as fast melting in the upper part of the basins typically is accompanied by cold weather downstream.

With the climate change, the regime of spring floods can change too, and the most important question here is: does climate change result in higher frequency of the situations favorable for the spring floods? Off course, the events like ice dams originate from a number of reasons, from which the climatic ones are only a part. However, without the weather-related pre-requisite, no flood can happen, so the study of frequency of the situations favorable for the spring floods is essential.

DATA AND METHODS

Daily data on air temperature, precipitation and snow depth at about 170 stations distributed over Russia and former USSR are used for the analysis. The time series cover years from 1951 until 2006, with some gaps at several stations. The period from 1951 till 1980 is chosen as a base one, while since 1989, the period of contemporary climate warming has started. The periods have been chosen according to our earlier statistical studies (Shmakin, Popova, 2006). Using the daily data, several specific characteristics were calculated for the analysis of conditions favorable for spring floods in North Eurasia. The characteristics include:

- snow depth at the end of February as a snapshot at the time when snow cover is present and well-developed in most of North Eurasia,
- maximum snow depth for each year, regardless to the time of its appearance,
- snow depth (more than 3 cm deep) at the time of mean air temperature increase above 3ºC (i.e. at the beginning of intensive melting),
- frequency of fast air temperature increase (by more than 4ºC per day, with mean air temperature exceeding 3ºC) above snow (more than 3 cm deep),
- sum of rain falling on the snow cover (more than 3 cm deep) with daily sum of the liquid precipitation above 4 mm.

The threshold values were obtained from the analysis of multi-year time series.

Each parameter has been determined for each year (depending on availability of the data), and then averaged by the two mentioned periods (1951-1980 and 1989-2006). The parameters were compared between the two time spans, and statistical significance of the differences was evaluated according to t-test. Only statistically significant differences were then taken into account when plotting the maps of the differences; the statistically insignificant were set to zero. The maps (both of absolute values and the differences) were created using the kriging interpolation, and in some areas anomalies of low absolute values appeared due to the interpolation procedure. In such cases, the statistically significant anomalies were distinguished on the maps.

RESULTS

The results of the statistical analysis are shown in a series of figures. Figure 1 represents mean snow depth for the base period (1951-1980) at the end of February – the time when the snow cover extent is usually at its maximum on continental scale. Although in many areas of North Eurasia the snow depth can yet increase later in the season, in some regions it starts to melt in early March, so the continental-scale specifics of the snow accumulation would be masked by this seasonality. However, the map of annual maximum snow depth, regardless to the time of its appearance, is demonstrated later too. In Figure 1, one can distinguish the main spots of largest snow accumulation in North Eurasia. The highest one is located in Kamchatka peninsula, where low air temperature is accompanied by ice-free ocean nearby, and the cyclonic circulation during the cold season is rather intensive, providing large sums of precipitation. Another significant maximum of the snow depth is located in the middle part of Yenisey river basin, where low temperatures and intensive cyclonic circulation take place in the region with low- and middle-height mountains. Other local maxima of the snow depth occur near Ural mountains and in the north-east of the East European Plain, also caused by high frequency of snowfalls and highlands. Basically the maxima of the snow depth are located along the typical paths of cyclones. The minimum snow depth is observed in the south of East European Plain (due to relatively warm winters) and in Southern Siberia, as well in Chukotka peninsula in the very north-east of Asia (due to low winter precipitation in the Asian anticyclone and in near the Arctic coast respectively).

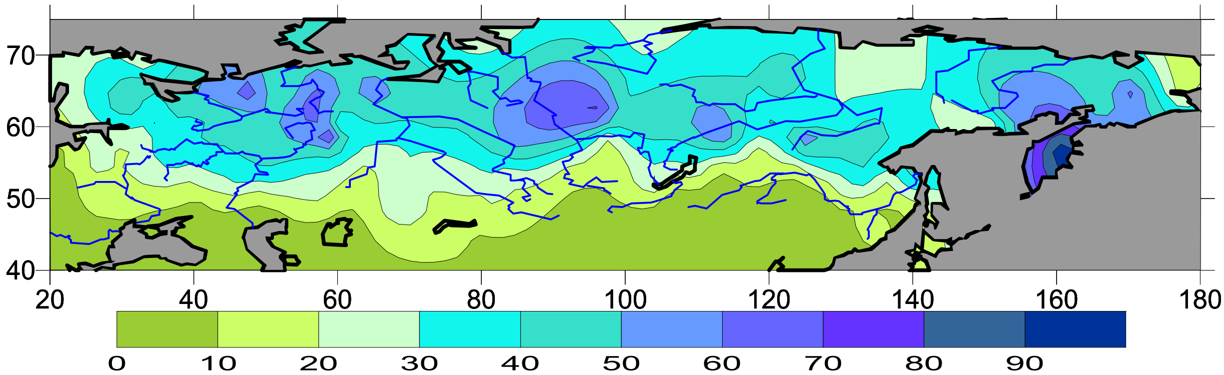

Figure 1. Snow depth in North Eurasia (cm) at the end of February, averaged over 1951-1980. The regions beyond ex-USSR borders are not covered by observed data.

The snow depth in North Eurasia in February has changed during the time of contemporary global warming. The difference between mean 1951-1980 values and 1989-2006 is shown in Figure 2. The most important result here is that on most of North Eurasia, the snow depth is increasing, although the area of significant growth of the snow depth occupies less than half of the territory. The largest increase of the snow depth takes place in the north-east of the East European Plain, in Western and Central Siberia, as well as on Sakhalin island and in adjacent coastal areas. It has been demonstrated that this increase is mostly related to more intensive cyclonic circulation over the subcontinent (Popova, 2007). Considerable decrease of the February snow depth takes place in the north of Kamchatka peninsula (due to less solid precipitation) and in the western part of the East European Plain (due to warmer winters).

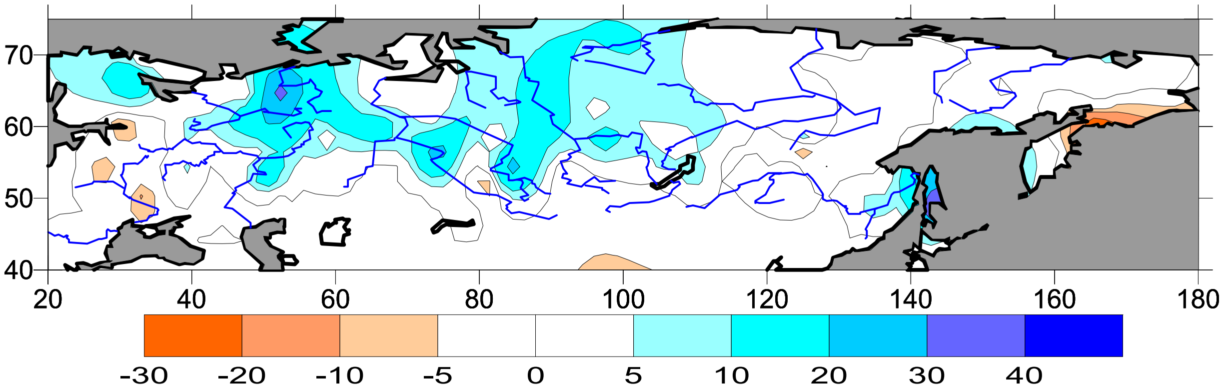

Figure 2. Change of the snow depth (cm) at the end of February in 1989-2006 as compared to 1951-1980. The areas with insignificant change are shown in white. The regions beyond ex-USSR borders are not covered by observed data.

Figure 3 represents maximum annual snow depth, averaged over the base period of 1951-1980. Depending on the location, the maximum occurs from February to May, i.e. just before the melting season. The map, thus, demonstrates amount of snow available for the melt water runoff. Maximum of the snow cover depth is observed in Kamchatka peninsula (more than 120 cm in average), while other significant maxima are found in the middle part of Yenisey river basin and the north-east of the East European Plain. Geographically, location of the extreme values is the same like with the February snow depth, although with more pronounced maximum near the Pacific coast of Kamchatka. Again, the belt of local maxima is located along the main route of cyclones across the Eurasian continent. Minimal values of the seasonal maxima are located in the south of East European Plain (due to warm winters) and in the south of Siberia (due to low precipitation in the anticyclone). Somewhat limited snow accumulation also takes place in several areas near the Arctic coast, also due to low precipitation in very cold air.

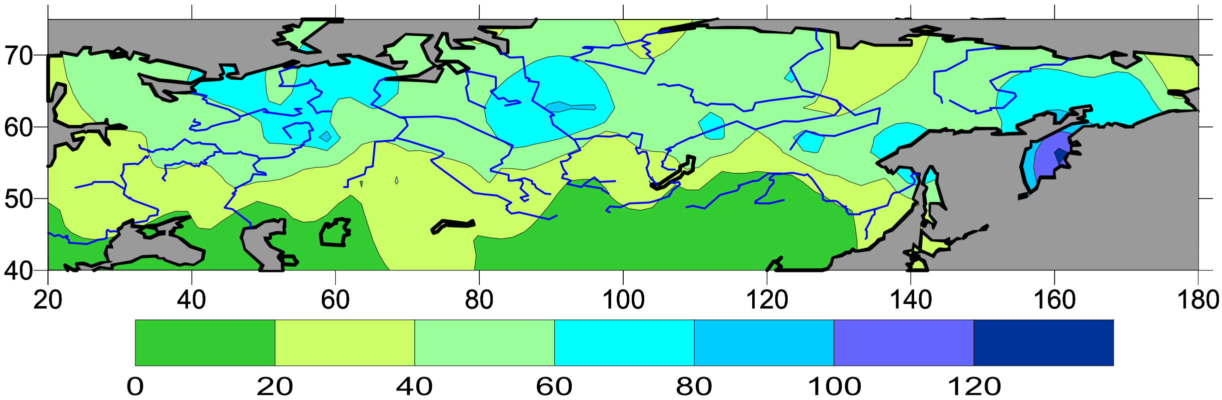

Figure 3. Maximum annual snow depth in North Eurasia (cm), averaged over 1951-1980. The regions beyond ex-USSR borders are not covered by observed data.

The maximum annual snow depth has changed quite significantly during the contemporary climate warming (Figure 4). Obvious decrease of the snow maximum takes place in the south-west of the territory due to warmer winters. Other local spots of the snow decreases are scattered throughout Siberia and are associated with lower precipitation. Largest increase of the maximum snow depth is observed on Sakhalin island and in the north of the East European Plain, as well as in Central Siberia. However, the increase in most of the areas is not so large by absolute values, and does not provide large additional amount of the snow for melting.

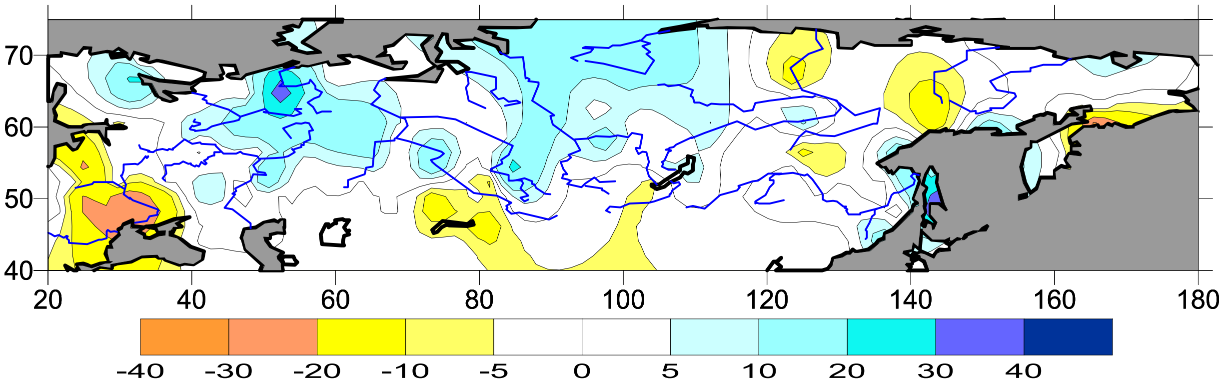

Figure 4. Change of the maximum annual snow depth (cm) in 1989-2006 as compared to 1951-1980. The areas with insignificant change are shown in white. The regions beyond ex-USSR borders are not covered by observed data.

Another parameter in terms of the snow amount is snow depth at the time when average daily air temperature exceeds 3ºC, i.e. in the situations of fast snow melting. The average daily air temperature over 3ºC suggests that its maximum is no less than 7-8ºC, and the minimum is above zero or just below the melting point. The map (Figure 5) is quite different from those shown in Figures 1 and 3: the largest maxima are observed in the middle part of Yenisey river basin and near Ural mountains, as well as in the north of East European Plain and in the upper part of Lena basin, while the Far East maximum is much less pronounced. Generally, one can expect rather fast snow melting and situations favorable for floods in the marked areas. In fact, the spring floods are regular in the spots of maximum snow depth under relatively high temperatures: for example, the town of Lensk located in the upper part of Lena basin was extensively flooded in 1966, 1998 and 2001. Other regions with large snow accumulation (like Kamchatka peninsula), obviously, are characterized by less intensive snow melting under lower air temperatures, and are not so favorable for the spring floods.

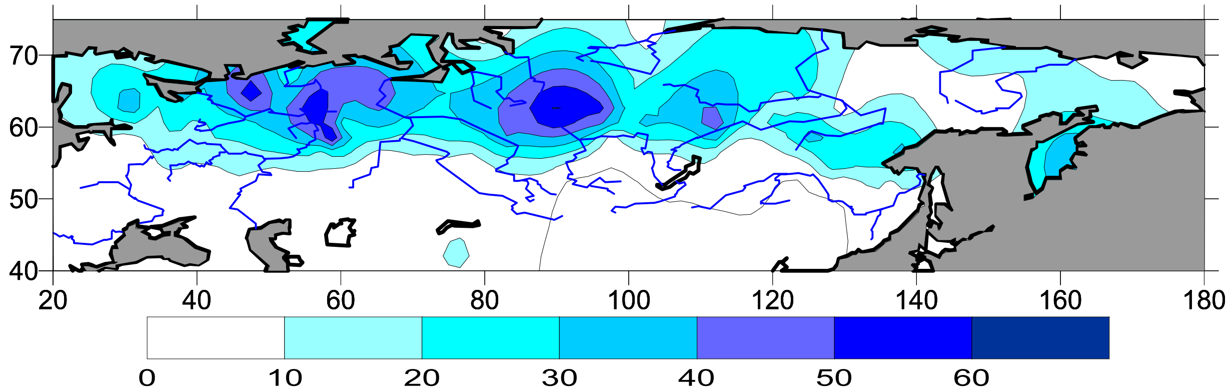

Figure 5. Snow depth at the time when average daily air temperature exceeds 3ºC (cm), averaged over 1951-1980. The regions beyond ex-USSR borders are not covered by observed data.

The snow depth at the time of air temperature exceeding 3ºC has changed in several large areas over North Eurasia (Figure 6). The only area with significant decrease of the spring snow depth is located in the upper part of Aldan river (the largest tributary of Lena). At the same time, significant increase of the snow accumulation at the beginning of the warm weather takes place in Pechora basin in the north-east of the East European Plain, as well as in other parts of the East European Plain, and in Western and Central Siberia. In several of the areas, where the snow accumulation before the warm weather beginning is on increase, it was already high enough during 1951-1980. That implies even higher risk of the flood-favorable conditions in Pechora, Northern Dvina and parts of Ob basins, as well as near the west coast of White Sea. However, on the scale of sub-continent, these areas are not very large.

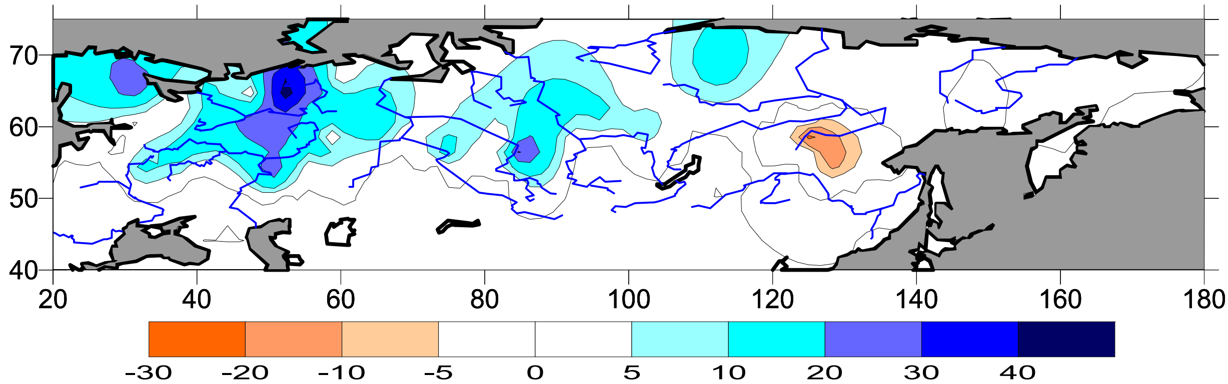

Figure 6. Change of the snow depth (cm) at the time when average daily air temperature exceeds 3ºC in 1989-2006 as compared to 1951-1980. The areas with insignificant change are shown in white. The regions beyond ex-USSR borders are not covered by observed data.

Another characteristic of the weather favorable for fast snow melting is frequency of abrupt air temperature growth (by more than 4ºC, with the average value above 3ºC) in the presence of snow cover no less than 3 cm deep. The map of its average distribution over 1951-1980 is shown in Figure 7. Maximum frequency of such situations is observed in several spots along the main route of cyclones across Eurasian continent. The most often spring heat waves are observed in the upper part of Pechora basin, in Ural mountains, in the middle part of Yenisey river and in the upper part of Lena basin. A local maximum is also observed in the mountains of Central Asia.

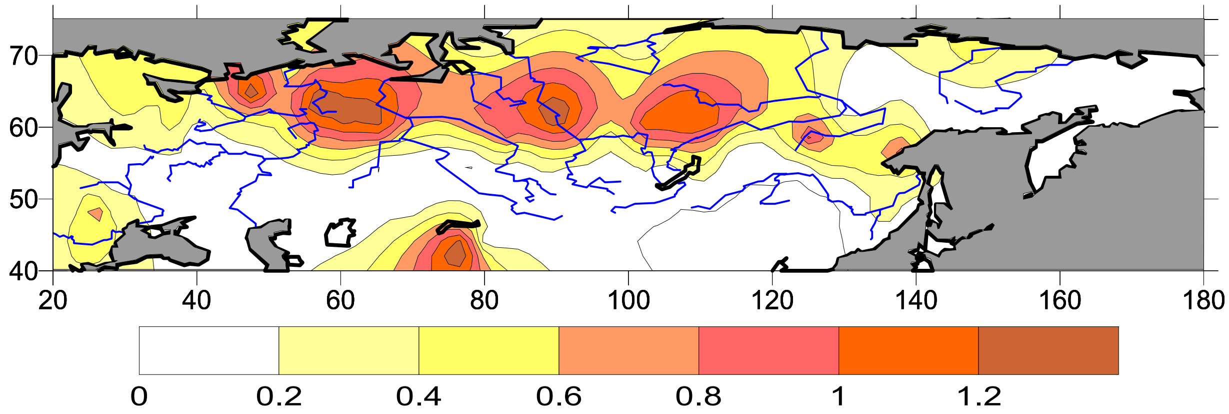

Figure 7. Frequency of days with mean air temperature increase by more than 4ºC and average air temperature above 3ºC above snow, averaged over 1951-1980. The regions beyond ex-USSR borders are not covered by observed data.

Frequency of the fast warming above snow is changing during the last decades in only limited areas of North Eurasia (Figure 8). The largest increase takes place in the lower part of Pechora basin (where, however, its frequency was not so large until 1980). Other maxima are located in the basin of Anabar river to the west from Lena (almost uninhabited area), and in the middle and lower parts of Ob river basin. In the last two areas, the frequency of fast temperature growth was already high enough before 1980, so the potential danger of fast snow melting is slightly increasing here. In most of the North Eurasia territory, there is no increase of the spring heat waves frequency.

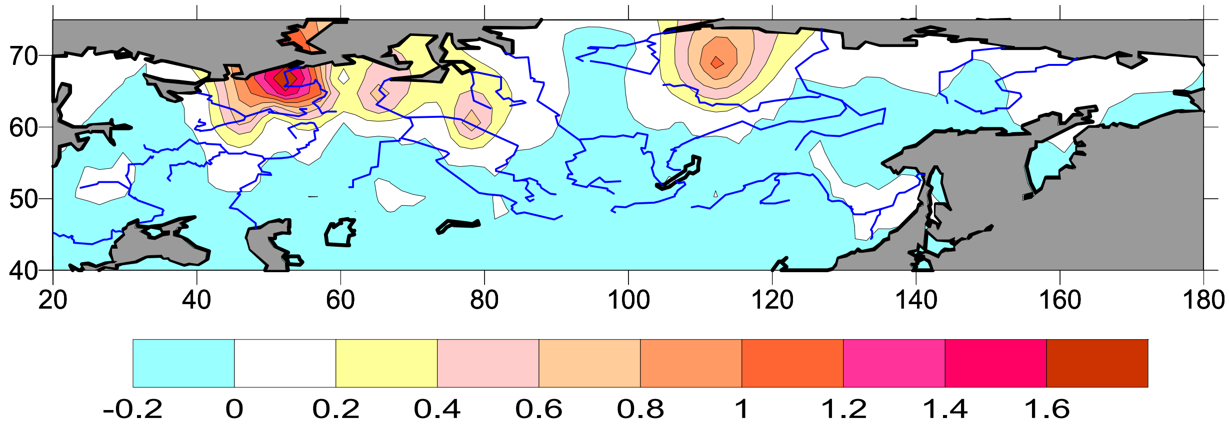

Figure 8. Change of frequency of days with mean air temperature increase by more than 4ºC in 1989-2006 as compared to 1951-1980. The areas with insignificant change are shown in white and light blue. The regions beyond ex-USSR borders are not covered by observed data.

The last analyzed parameter is the sum of liquid rain falling on snow, when the daily sum of precipitation exceeds 4 mm, and the snow depth is no less than 3 cm (Figure 9). Such weather situations are also favorable for fast snow melting, and can potentially lead to the spring floods. Generally, the areas of largest sums of liquid precipitation over snow are located in the regions under the oceanic influence: Kamchatka peninsula and the Sea of Okhotsk coast, Sakhalin island and the Sea of Japan coast, as well as the East European Plain (except for its southern part). Two more areas of relatively high rain sums over snow are located in the mountains of Central Asia (probably due to not so cold winters) and in the middle and lower parts of Yenisey river basin (probably due to late presence of snow, well into the season of liquid precipitation).

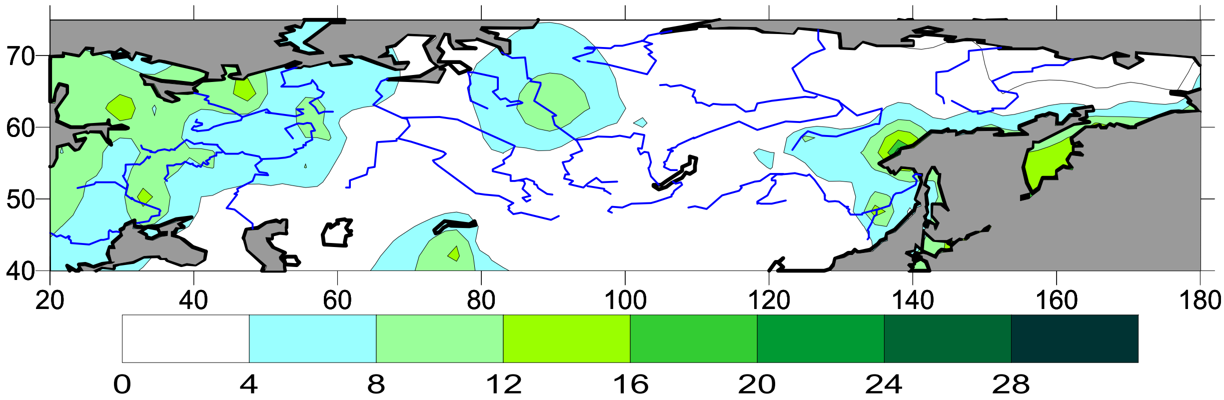

Figure 9. Sum of rain (mm) exceeding 4 mm per day, falling on snow deeper than 3 cm, averaged over 1951-1980.

The sums of rain falling on snow have changed insignificantly since 1989 on the sub-continental scale (Figure 10). The only area of significant decrease is located in the west of the East European Plain, mostly due to shorter winter season there. Four areas of increasing rain sums over snow are located near the Gulf of Finland and in the center of the East European Plain, in Pechora basin, in the middle part of Yenisey tributaries (Angara, Stony Tunguska, Lower Tunguska) and in the lower part of Northern Dvina basin. However, in most of the North Eurasia the changes of this parameter are insignificant.

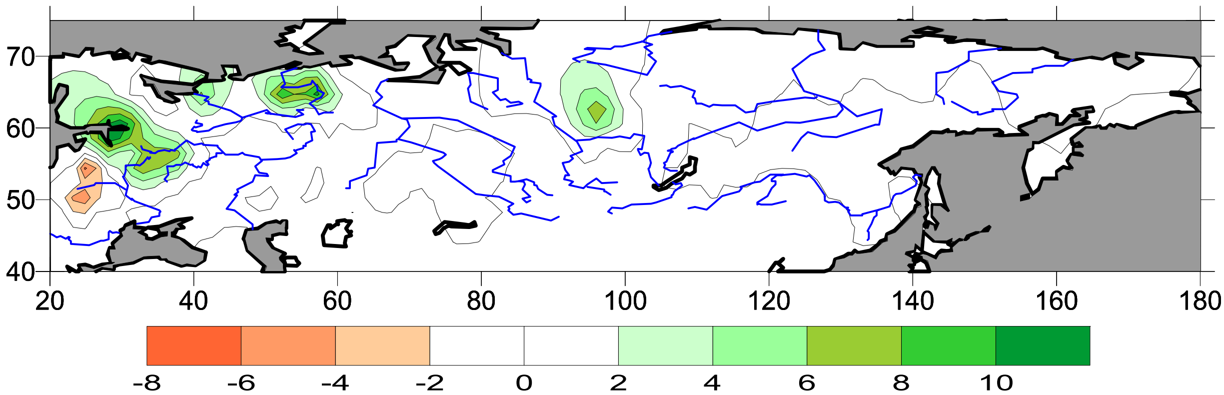

Figure 10. Change of sum of rain (mm) exceeding 4 mm per day, falling on snow deeper than 3 cm, in 1989-2006 as compared to 1951-1980. The areas with insignificant change are shown in white and light blue. The regions beyond ex-USSR borders are not covered by observed data.

CONCLUSIONS

The analysis has shown that among the weather conditions, favorable for the spring floods in North Eurasia, snow accumulation is changing most significantly. Over most of Siberia and in the north-east of the East European Plain, it is increasing during the last decades as compared to the middle of 20th century. This relates mostly to average snow depth in February and maximum annual snow depth. The snow depth at the time of air temperature increase above 3ºC (which provides conditions for fast snow melting) changes most significantly in Pechora basin, and in other parts of the East European Plain, as well as in parts of Ob and Yenisey basins. This can result in larger frequency of spring discharge, and, under certain circumstances, spring floods. Frequency of fast air temperature growth above snow has also increased during the last decades in lower Pechora river basin and in limited parts of Ob river basin. The rain sums falling on snow have increased in Pechora basin, in the west of the East European Plain and in parts of Yenisey tributary basins. One can conclude that overall, the basins of Pechora and middle flow of Yenisey, and to some extent upper part of Lena river have become more threatened by the contemporary climate change in terms of spring floods. In most of the North Eurasia, however, the changes can be regarded as occasional fluctuations, without any significant trends. In general, potential threats from the viewpoint of spring floods increase only in few areas of North Eurasia, while in other areas this danger has become less frequent.

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