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Long-term changes in the hydroclimatic characteristics in the Baikal region

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Abstract. Since the end of the 19th century, global air temperature has been increasing. The period after 1976 is called the period of the most intensive warming. In Russia, the average annual air temperature rises at a rate of + 0.43 ° C / 10 years. The change of precipitation over the last 50-60 years on average in Russia is not significant. In the Baikal region, precipitation increase during the warm period (10-11%) and decrease during the cold period (4%). It is reflected on hydrological regime and the factors of river flow formation. The regional features of the hydrological regime dynamics of the Baikal region against the background of climate change are considered. Groups of the rivers with similar alternations of low water and high-water periods are allocated. Trends in runoff are analyzed. The increase in air temperature leads to intra annual redistribution of river flow. The majority of statistically significant trends of river run off are observed during the cold period of year.

1. Introduction

According to the data of instrumental observations, the global temperature and temperature in Russia have been increasing since the late 1880s. The period after 1976 is called the period of the most intensive warming [1]. The average annual rate of warming is +0.43 °C·(10 years)$^{-1}$. In this case, a statistically significant trend is not observed only in the winter. During the same period (1976-2012), the annual precipitation trend is positive (+0.8 mm·month^{-1}·(10 years)$^{-1}$), on average in Russia. It describes 24% of the total interannual variability of the series (that is, the trend is small, but statistically significant even at the 0.5% level). Basically, spring precipitation changes, and autumn precipitation increases slightly. On average, precipitation for the period 1961-1990 is less than precipitation for the period 1981-2010. This change is less than 1 mm/month. That is, on the average, there have been no significant changes in the mode of precipitation in the last 50-60 years on the territory of the Russian Federation.

According to data of weather stations, the trend of air temperature for the period 1976-2012 is calculated for the territory of the Predbaikalie and Transbaikalie [1]. A statistically significant trend in air temperature is observed for the whole year (0.32 °C·(10 years)$^{-1}$), in spring (0.53 °C·(10 years)$^{-1}$) and in summer (0.52 °C·(10 years)$^{-1}$). In winter and autumn, there are also positive trends (0.06 and 0.26 °C·(10 years)$^{-1}$, respectively), but they are not statistically significant. For the whole region, a statistically significant increase in annual precipitation is observed (1.1 mm·month^{-1}·(10 years)$^{-1}$). There is an increase in liquid and mixed precipitation (by 10-11%) and a decrease in solid precipitation (by 4%).

The instrumental observations (1961–2008) showed a persistent long-term tendency towards a rise in mean annual temperature (0.4 °C·(10 years)$^{-1}$), with the largest contribution coming from changes in the winter months [2]. The maximum air temperature changes were recorded in February (0.62–1.94 °C·(10 years)$^{-1}$). Minimum statistically significant trends were recorded in the summer months. The tendencies for a change of the monthly precipitation are insignificant, because they are 10–100 times lower than the interannual variability [3, 4]. At the same time, much research points to an increase in precipitation at the global (planetary) level, as well as in a large number of the individual regions of the Russia and neighbouring countries [5, 6].

Some researchers [7, 8] distinguish four gradatons of precipitation intensity (i, mm·h^{-1}). For these gradations, the duration of precipitation is determined by: weak precipitation ($i \le 1.8$ mm·h^{-1}), moderate precipitation ($1.8 < i \le 6$ mm·h^{-1}), strong precipitation ($6 < i \le 60$ mm·h^{-1}) and very strong precipitation ($I > 60$ mm·h^{-1}). In the Predbaikalie and Transbaikalie in recent years, a decrease in weak precipitation by 14% (about 140 h) has been observed. The duration of moderate, strong and very strong precipitation increases by 5, 7 and 10%. This is 1.8, 0.9 and 0.02 hours respectively.

A fair amount of attention has recently been focused on the issue relating to climate fluctuation and its consequences [9, 10]. The studied impact of the consequences of the climatic changes on the hydrological regime of rivers there is mainly observed on the macro level. However, the regional manifestation of climate change has a number of intrinsic properties associated also with local physical–geographical conditions [11, 12].

Baikal region is located in the center of the Eurasian continent, at a great distance from the oceans, which is the huge inertial accumulator of solar energy. It largely determines the direction and speed of warm oceanic and air masses on Earth, which affect the climate of the planet. The features of physical–geographical position of the region and sharply continental climate have to define the features of climate change.

The study of regional features of Baikal region rivers flow, the laws of their long-term fluctuations and intra annual redistribution, extreme values, taking into account the local geographical features of the runoff formation in the background of global climate change gets us closer to solving the problems associated with both economic and environmental tasks.

2. Objects and data

The Baikal region includes three subjects of the Russian Federation, united by belonging to the basin of Lake Baikal, they are the Irkutsk Region, the Republic of Buryatia and the Chita region. In the hydrographic relation the Baikal region includes the Lake Baikal basin, nearly all the Angara River basin, the Upper Lena River basin (with the Vitim and Olekma River basins) and the upper parts of the Lower Tunguska.

The long-term series of monthly and daily precipitation at weather stations are the initial information. Weather stations are located on the territory of the considered basins. The data were analyzed on the territory of the Angara river basin (9 weather stations), the Upper Lena River basin (14 weather stations) and Baikal Lake basin (5 weather stations). Extreme characteristics of atmospheric precipitation are calculated.

The objects of our study were the run-off series in majority for rivers with a catchment area not greater than 100 km^2. Such river flows are formed in a more or less homogeneous physical-geographical condition within the same geographical zone. River run off cross-sections were selected in such a way as to reflect the full range of physical-geographical features of the territory.

We used information on run-off obtained from hydrological gauging stations to assess changes in the hydrological regime. We examined the data series for mean annual and monthly run-off. Besides we examined run off series of genetically homogeneous phase of water regime – spring snow melt and summer rainfall maxima, annual and summer minima. Analysis of run-off trends was undertaken mainly for an identical 55-year-long period of instrumental observation, from 1961 to 2014, except the Lower Tunguska, where the period from 1961 to 1999 was conceded (due to the lack of data). We used information from 15 gauging stations within the Lena basin, 10 - within the Angara basin, 12 -

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within the Lake Baikal basin, and 3 gauging stations within the Lower Tunguska. We used long-term observational data from the Irkutsk and Ulan-Ude Administration for Hydrometeorology and Environmental Monitoring, and data from handbooks of the series Surface Water Resources of the USSR, the State Water Cadastre, as well as data from hydrological yearbooks.

3. Methods

The WMO Working Group on Climate Change Detection proposed a set of 27 extremal indexes for describing climatic extremes. Most of the indices determine the number of days when meteorological values go beyond a certain predetermined threshold. The maximum five-day precipitation (R5d), the daily precipitation intensity (SDII), the number of days with precipitation not less than the threshold set by the investigator (Rnnmm), the sum of strong precipitation above the specified percentile distribution (R95p and R99p) are the main indices in the analysis of extreme precipitation. Extremely large precipitation has a significant effect on the regime of rivers. A large amount of precipitation in winter and spring causes a high level of spring flood; in summer strong rains often cause catastrophic floods. According to the analysis of the indices, in the Baikal region the growth of heavy precipitation prevails throughout the year.

The assessment of long-term cyclic flow fluctuations with use of integral difference curves is executed. These curves reflect not only the annual fluctuations in flow, but also indicate long-term exhaustion (the descending curve sites) or accumulation (the ascending curve sites) of river flow. Allocation of water content phase is carried out on the main turning points of curves.

The coefficient of a linear trend determined by a method of the smallest squares is used as a measure of run off changes intensity. The statistical significance of the trends is estimated by the statistical test of the null hypothesis of no difference between the regression model and the experimental data from 95% confidence interval.

Only data series without gaps or with single gaps were used in processing. Missing values were replaced by an average value, calculated for the corresponding variable. Despite the low accuracy, this method is appropriate due to its simplicity and the small number of gaps. Values with a large deviation from the average value were estimated and also treated as missing values.

4. Results

Monthly precipitation for the period 1966-2015 was analyzed. In general, statistically insignificant trends predominate. A significant increase in precipitation over the cold period is observed at nine stations. Precipitation in November-March increases by 2-11 mm·(10 years)$^{-1}$, precipitation in October-April increases by 4-18 mm·(10 years)$^{-1}$. In the cold period, the maximum number of weather stations on which there is a significant increase in precipitation (6 stations) was recorded in October and December. The largest number of stations (5 in each month), where precipitation increases during the warm season, is in May and June. Moreover, in May, these are weather stations located in the basin of the Angara River, in June - in the basin of the Lena River. The trends in both cases are 4-7 mm·(10 years)$^{-1}$. Statistically significant positive trends in annual precipitation are observed at two stations in the Angara River basin and at five stations in the Lena River basin. The coefficients of the trend are equal to 19-24 mm·(10 years)$^{-1}$. The weather station Khamar-Daban (basin of Lake Baikal) deserves special attention. This weather station is most highly located in comparison with the other weather stations under consideration. Here the annual precipitation decreases (-24 mm·(10 years)$^{-1}$, R^2 = 2%), and the maximum decrease (-34 mm·(10 years)$^{-1}$, R^2 = 15%) is observed in July. A long-term change in the sum of atmospheric precipitation at weather stations located in the basins of Lake Baikal, the Angara River, and the Lena River is shown in figure 1, 2.

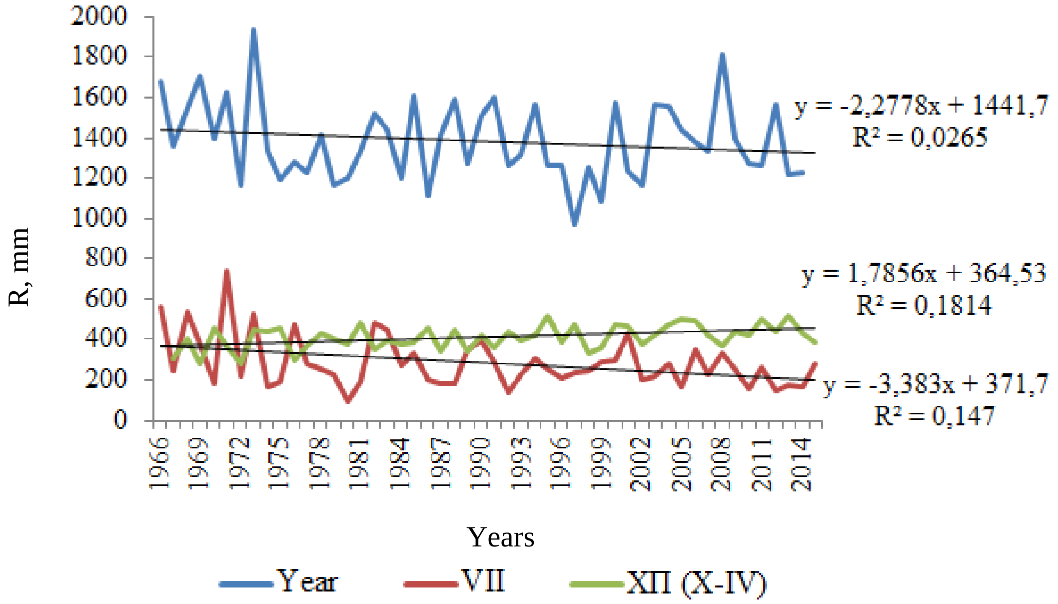

Figure 1. Long-term changes of precipitation at the weather station Khamar-Daban.

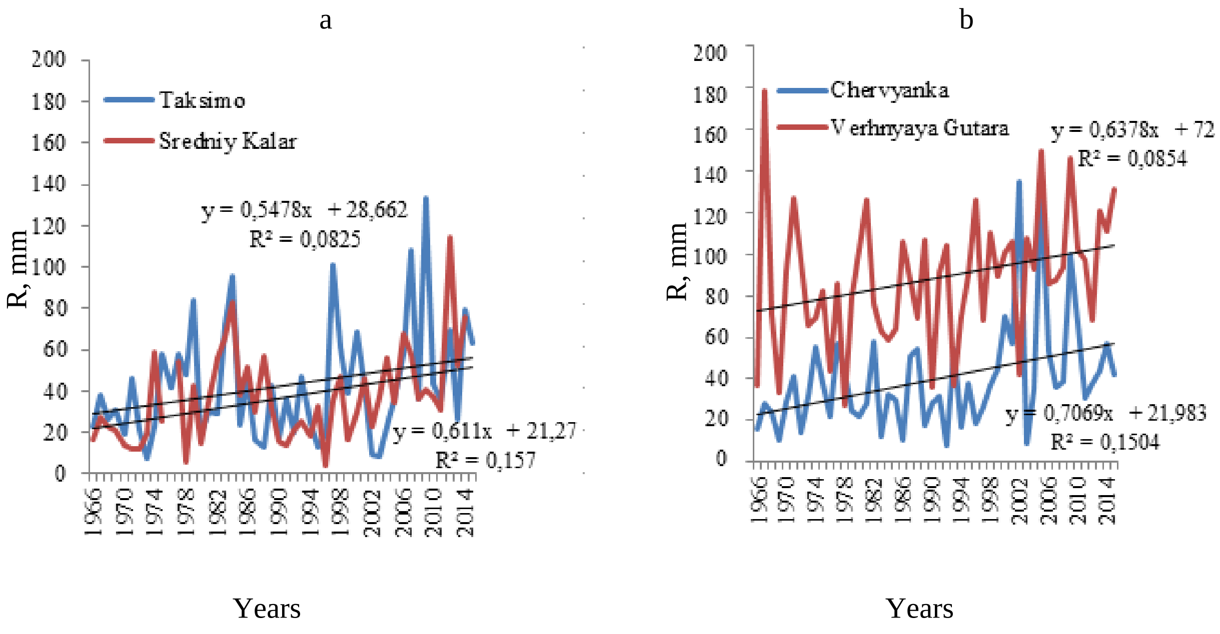

Figure 2. Long-term changes of monthly precipitation (May) at meteorological stations located in the basin of the river Angara (a), the river Lena (b).

Integral difference annual flow curves clearly illustrate the long periods of low and high water. They show the general tendency of long-term fluctuations of a flow in river basins. In the central and southern of Lake Baikal basin (figure 3, line 1) now is low-water period, which began in 1995. In the north of Lake Baikal basin is high-water period at the same time (line 2), which probably ended in 2012. The Angara basin is marked the small reduction of the flow on the number of rivers from 2008 (line 4). This low-water period replaced the high-water period, which was here from 1987 to 2006. In Upper Lena basin the high-water period ended which lasted from 2000 to 2012 (line 3).

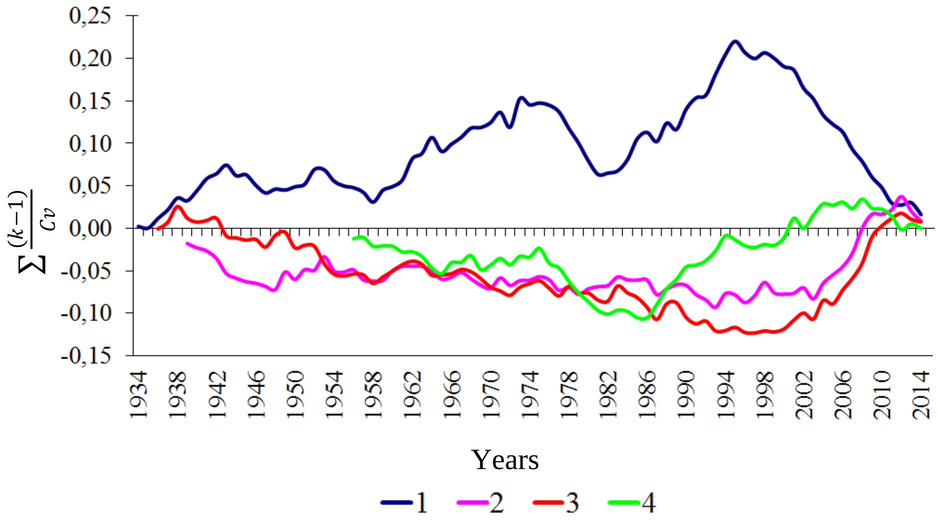

Figure 3. Integral difference curves of the river flow, where k – modular coefficient, Cv – variation coefficient: 1 - Selenga-Mostovoi (Lake Baikal basin), 2 - Verch.Angara-Zaimka (Lake Baikal basin), 3 - Lena-Zmeinova (Lena River basin), 4 - Irkut-Tibelti (Angara River basin).

Within the Angara and Upper Lena basins annual run-off changes were directed differently and were not generally statistically significant. A statistically significant positive tendency was observed here on most of the gauging stations considered in the cold season (from October to March–April). Within the Upper Lena river basin, a tendency for run-off reduction in May, Jun and July was observed. At the same time within the Vitim River basin a tendency for run-off increasing in May was observed. Within the Angara basins the statistically significant negative tendency of spring snow melt and summer rain fall maxima was predominate. At the same time within the Upper Lena basin the statistically significant positive tendency of spring snow melt and summer rain fall maxima was predominate in some rivers.

Within the Lake Baikal basin annual run-off changes were directed differently and were statistically significant in some cases. In the north of Lake Baikal basin a statistically significant positive tendency was observed in the cold season (from October to March–April). At the same time within central and southern Lake Baikal basin a tendency for run-off reduction was predominate for most of months. This is in accordance with the results obtained by the integral difference curves – now here marked low water period.

Floods repeatability as the number of excesses of the water levels corresponding to the beginning of flooding was calculated. On the majority of hydrological gauging stations the floods repeatability during 1981 - 2014 became less in comparison with earlier period. With the exception of some hydrological gauging stations, where there was a significant increase in floods repeatability, for example, Chuksha-Savelyevsky (from 10 to 18%), Vitim-Bodaibo (from 41 to 68%), Lena-Kirensk (from 55 to 74%), etc.

5. Conclusion

The increase in air temperature is mainly due to the winter months which leads to intra annual redistribution of river flow. The majority of statistically significant trends of river run off are observed during the cold period of year. Hence, there emerge more favorable (compared with the mid-20th century) heat balance conditions for flow during the winter and summer–autumn low water period. Winter run-off is determined first of all by underground power. It is possible to assume, that now in the Baykal region during the milder winters, the share of underground power increases because of the lower freezing and earlier thawing of the soil.

The local change in floods repeatability indicates rather its anthropogenic origin. Increased flood damage is associated with the active development of flood-prone areas in recent times.

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