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Hydrometeorological changes in the North-East of Russia

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Abstract. The paper presents a comprehensive analysis of hydrometeorological changes at the river basins of the North-East of Russia for the period 1966-2015. Data from 61 meteorological stations showed an increase in the air temperature by an average of 2.3 °C and multidirectional changes in annual precipitation. Most stations are characterized by a significant negative trend of precipitation in winter and a positive annual trend of mixed and liquid precipitation with an increase in their share in autumn months. The presence of statistically significant positive streamflow trends in the autumn-winter period was established for 51 hydrological gauges. We hypothesize that the increase in the low flow is mainly due to the transition of precipitation type from solid to liquid and corresponding increase of runoff in September, continuing in the following months.

1 Introduction

As a result of climate changes, there are pronounced transformations of the hydrological regime, which particularly affect the territory of the North-East of Russia [1].

In general the Arctic territory is characterized by an increase in total water flow in the second half of the XX century. These assessments are based on the streamflow data at large river basins [2]. At the same time, changes in the flow of small and medium-sized rivers in the North-East were studied insufficiently. To a large extent, this also applies to mountainous areas, where most of the flow of large rivers is formed [3].

The purpose of this study was to quantify current changes in the river flow of the mountain part of the Kolyma, Yana, Indigirka, Alazeya River basins, Chukotka rivers and rivers of the Okhotsk sea as well as climate characteristics for the period from 1966 to 2015.

2 Study area, data and methods

The climate of the study area is continental, getting maritime features at the coastal areas. The average annual air temperature is -15.7˚C at Oymyakon station (726 m), -10.3˚C at Srednekan station (266 m) and -2.8˚C at Magadan station (118 m). The average annual

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precipitation at the Vostochnaya meteological station (1288 m) reaches 280 mm, at the Srednekan station (266 m) 455 mm, at the Magadan station 563 mm. Precipitation reaches 688 mm at high-altitude areas (Suntar-Hayata weather station, 2068 m). Most of the precipitation (at least 60%) falls in the summer.

The permafrost depth reaches more than 450 m in upper part of the watersheds and up to 180 m in river valleys and intermountain depressions, interrupted in fractured zones by taliks. The depth of thawing varies from 0.3 to 2 m. The rivers are characterized by the East Siberian type of water regime with spring-summer high flow, high summer-autumn rain floods and low winter flow. In winter, small and medium-sized rivers freeze over. The landscapes of the studied territory are represented by mountain larch forests. The highlands are characterized by the goltsy and glaciers. Also the aufeis are common, they are formed in river valley and intermountain depressions.

The analysis of data on monthly streamflow was carried out for the 51 hydrological gauges of the Roshydromet network in the Kolyma, Yana, Indigirka, Alazeya River basins, Chukotka rivers and rivers of the Okhotsk sea working in the period up to 2016. The catchment area is from 0.27 to 526 000 km^2, and their average annual streamflow varies from 58 mm to 782 mm.

To analyze climate change, we used monthly data on air temperature values and total precipitation for 61 meteorological stations in the region, with the altitudes range from 1 to 1288 m, and the amount of liquid, solid, and mixed precipitation for 35 stations with available observation data for the period 1966-2015.

The stationarity of time series of water monthly flow characteristics and meteorological elements (air temperature and precipitation) was checked for the presence of monotonous trends using the Mann-Kendall rank correlation criterion with the significance level $p < 0.05$ [4, 5]. The value of the linear trend K (unit year-1) was estimated using the nonparametric Teil-Sen method [6]. The function of the Teil-Sen in contrast to the least squares method is not sensitive to outliers and allows to obtain unbiased estimates. The total change in the considered value ΔQ since the beginning of the observation period (%) was calculated using the formula ΔQ= K/M n, where M is the average value for the entire period (units), n is the number of years of observations. The Mann-Whitney criterion with a significance level of $p<0.05$ was used to identify and estimate the time of occurrence of abrupt changes in the values under consideration.

3 Results

3.1 Air temperature and precipitation

The increase in annual air temperature varies from + 1.1°C to +3.4°C with an average value of +2.3°C. The positive significant trends are observed at 45 stations (2.4°C) in May. The temperature increases with average values of +1.9°C and +1.7°C in July and August respectively. In September, positive temperature trends are observed at 28 stations. In October, the temperature increased at 49 stations by an average of 4.0 °C. There is the most significant increase in air temperature at 56 stations by average + 6.2°C in November. In general, the North-East region is characterized by a significant increase in air temperatures, especially during the transitional autumn-spring periods.

Analysis of annual precipitation for 61 meteorological stations (m/s) showed the multidirectional changes. A significant increase in the average annual precipitation occurred at 18 stations, and a decrease at 20.

In this analysis we used the information about the aggregate state of precipitation (liquid, mixed and solid) from the observations at meteorological stations provided by the

RIHMI-WDC (http://meteo.ru/data). It was found that most of the stations are characterized by a significant negative trend of precipitation in the winter. The decrease in the annual amount of solid precipitation is observed at 22 stations with an average value of 77 mm (51 %) and at 21 stations the decrease in solid precipitation occurs at least in one winter month. Only at the Anadyr meteorological station there is a significant increase in the annual amount of solid precipitation by 21 mm (81 %).

There is an increasing trend of annual sum of mixed and liquid precipitation (on average by 79 mm, 41%) for 16 stations out of 34 (Fig. 1). The negative trend was observed only at three weather stations (by an average of 62%). During the summer, there is a decrease in the amount of mixed and liquid precipitation, as well as an increase. The largest increase is observed in August-September, when negative trends are not recorded. In September, the average statistically significant increase in liquid and mixed precipitation amounts to 67 % (16 mm).

Changes in the proportion of liquid and mixed precipitation were also analyzed. The increase of their shares in the transition months – in May and September – October, as well as in annual values was revealed. On average, the total annual share of liquid and mixed precipitation increased at 22 stations (the average share of liquid and mixed precipitation is 0.40, the trend is 0.08). In May, positive changes occurred at 12 stations (the average value of the proportion of liquid and mixed precipitation for stations with positive changes is 0.65, the positive trend is 0.25). In September, similar changes were observed at 20 stations out of 34 with an average value of the proportion of liquid and mixed precipitation of 0.77. The value of the positive significant trend reached 0.19.

Thus, there was a noticeable increase in the proportion of liquid and mixed precipitation in the transition months (May, September) and a significant decrease in solid precipitation in the winter months in the absence of a unidirectional trend in the total precipitation for the North-East of Russia.

3.2 Streamflow

Statistically significant positive trends in monthly flow are observed at most rivers in the autumn-winter period. Analysis of runoff data for 22 hydrological gauges at the Yana and Indigirka River basins (1936-2015) showed that statistically significant ($p<0.05$) positive trends were observed at most gauges during the autumn-winter period (September to December) and the spring flood (May-June). Statistically significant increase are observed in 12 basins of 19 in May, 17 of the 19 in September, 15 of 19 in October, 9 of 19 in November, 6 of 17 in December, 4 of 12 in January, 3 of 8 in February and 3 of 7 in March. In September, the flow increased by 5.8-36.8 mm (or 46-111%) at 17 gauges, and in October by 0.12 – 4.5 mm (or 31 – 118%) at 11 gauges of 19 considered. In November and December, positive trends are typical for larger basins (an area of 17600 km^2). The average increase in runoff was 0.4 mm (72%) at 11 and 0.1 mm (94%) at 6 of the 14 non-freezing hydrological gauges during these months. Also, significant changes in the annual flow of 24-115 mm were detected at 8 gauges of both small and large rivers.

The most significant increase in streamflow is also observed in autumn-winter period and in May at the Kolyma and Alazeya River basins. The total number of analyzed hydrological gauges is 18. In May, positive changes were observed at 11 hydrological gauges (+24 mm, 73 %). Of the 18 hydrological gauges only 5 did not show significant changes in September and 4 in October. The average change values reached 17 mm (69 %) in September and 4.3 mm (69%) in October. 9 gauges in December and 7 gauges in January-February showed positive changes during the winter low flow. Annual runoff increased by 9 gauges with an average of 107 mm (52 %).

Significant positive trends are observed for almost all months of the year, except for May, June and July for the rivers of the Okhotsk basin. The increase in annual runoff is observed for all 5 gauges (227 mm, 40 %). The largest increase is observed in February-April (by an average of 80%), August (80%) and September (60 %).

3.3 Possible reasons of flow changes at the North-East of Russia

The analysis showed that a statistically significant increase in the absolute amount of precipitation in the study region is not observed. Moreover, there is a decrease in the amount of solid precipitation in winter, as well as an increase in the proportion of liquid precipitation in the transitional months of May and August-September (Fig.).

The calculated correlation coefficients between the precipitation and streamflow in August and September for four small and medium-sized catchments (an area of no more than 3490 km^2) and neighboring meteorological stations vary from 0.45 to 0.80 (Table). We hypothesize that an increase in the proportion of liquid precipitation in the autumn period without change of their absolute amount leads to additional floods and increased river streamflow in the winter. Recessional curves of early autumn flood events extend later into the autumn and winter seasons. The streamflow change in October usually repeats the spatial pattern of changes in September, but with smaller amplitude. Thus, it is climate change that mainly determines the transformation of the hydrological regime, and all other factors play a secondary role in this process. Similar situation is observed in the subarctic part of the Northwest Territories of Canada [7].

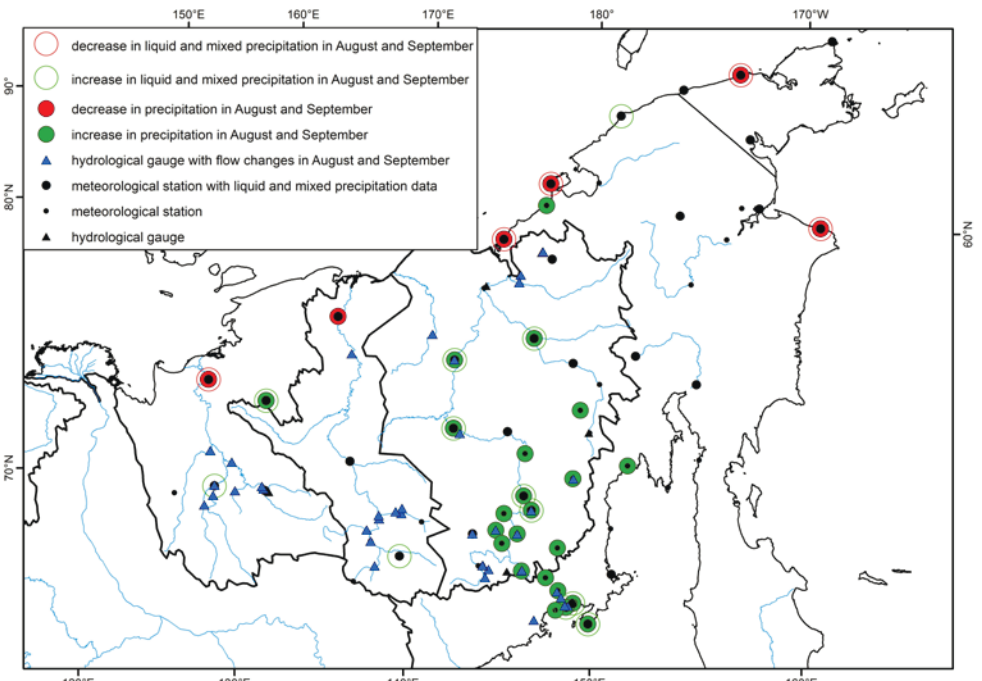

Fig. Changes in liquid, mixed and total precipitation and runoff layers in August and September.

Table. Correlation coefficient of monthly runoff and precipitation in September at small catchments.

Meteorological station, index	Altitude, m	Hydrological gauge, index	Basin area, km^2	Period	Month	Correlation coefficient with precipitation
Yagodnyy, 24796	487	1217	100	1966-2012	August	0.45
Ust'-Omchug, 24898	576	1619	583	1966-2012	August	0.80
Ust'-Omchug, 24898	576	1151	3490	1966-2012	August	0.52
Ust'-Charky, 24371	273	3478	22.6	1966-2007	September	0.60

4 Conclusions

The analysis of hydrometeorological values at the Kolyma, Yana, Indigirka, Alazeya River basins, the Chukotka rivers and the rivers of the Okhotsk sea basin was carried out for the period of 1966-2015. It was found that in average annual air temperature increased by 2.3 °C. Analysis of annual precipitation showed multidirectional changes for 61 meteorological stations. However, most of the stations are characterized by a significant negative trend of precipitation in the winter and a positive annual trend of mixed and liquid precipitation with an increase in their share in the autumn months.

The presence of statistically significant ($p<0.05$) positive trends in the autumn-winter period (from August to December) on most rivers was established based on the analysis of streamflow data for the 51 hydrological gauges. The increase in low flow is mainly due to the transition of precipitation type from solid to liquid and the corresponding increase in runoff in September, continuing in the following months.

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References

1. H. Madsen, D. Lawrence, M. Lang, M. Martinkova, T.R. Kjeldsen *A review of applied methods in Europe for flood-frequency analysis in a changing environment. NERC. Centre for Ecology and Hydrology,* (ESSEM COST Action ES0901, 2013)
2. A. I. Shiklomanov, R. B. Lammers, D. P. Lettenmaier, Yu. M. Polischuk, O. G. Savichev, L. C. Smith, A. V. *Environmental Changes in Siberia: Regional Changes and Their Global Consequences*. Ed. by P. Ya. Groismanand, G. Gutman, Chap. 4, (Springer, Berlin, 2013)
3. O. M. Makarieva, N. V. Nesterova, L. S. Lebedeva, T. A. Vinogradova, Geography and natural resources, **1**, 178-186 (2019)
4. H. B. Mann, Econometrica, **13**, 245–259 (1945)
5. M. G. Kendall, *Rank Correlation Methods* (Griffin, London, 1975)
6. P. K. Sen, Journal of the American Statistical Association, **63**, 1379–1389 (1968)
7. C. Spence, S. V. Kokelj, E. Ehsanzadeh, Cold Region Hydrology in a Changing Climate, IAHS publication, **346**, 3–8 (2011)