Atmospheric precipitation and its anomalies in Western Siberia against the background of global climate change from reanalysis and numerical modeling data

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Abstract. Based on the ERA-Interim reanalysis data, an analysis of atmospheric precipitation characteristics, their linear trends and anomalies in the cold and warm seasons is carried out for the north and south regions of Western Siberia (50°-70°N, 60°-90°E) over 1979-2015. The derived values are also compared with those for adjacent regions, such as Eastern Siberia and the Far East. In general, the tendency of precipitation decrease in 1979-1998 is replaced by the tendency to its increase in 1999-2015. The most significant rise is observed in the northern part of the region in the warm season. There is an increase in the convective precipitation area of up to 10%. The large-scale precipitation characteristics are not changed from one period to the other. At that time, in the south there is a tendency to the formation of negative anomalies in precipitation amount. Using results of numerical modeling methods, a feedback of the regional climatic system of Western Siberia on global climate change is revealed; a tendency in the anomalies of convective and large-scale precipitation is also obtained.

1. Introduction

In spite of the fact that, in general, the beginning of the 21st century is the warmest period on the globe during the whole history of instrumental observations [1], from 2000 the main feature of global climate change is a significant slowdown in the rate of warming and the regional climate — winter cooling in the middle latitudes of Eurasia [2].

The observed tendencies led to considerable changes in the atmospheric circulation regime and, consequently, these changes influence the atmospheric precipitation characteristics, forming anomalies of this parameter. Regularities of the precipitation field formation are determined by the action of various factors, the main of which are the water content in the air mass, its temperature, and the possibility of vertical lifting due to the turbulent fluxes or ordered convection. Such features are formed under the influence of the circulation factors and relief [3].

In the beginning of the 21st century the meridional type circulation begins to dominate over Eurasia [4]. Even when the change in a circulation mode does not contribute greatly to the mean regional climate change, a climate mode may still play an important role in the regional climate variability and extremes. Natural variations, such as those due to the modes of variability, are a major source of uncertainty in the future projections of mean regional climate [5].

Atmospheric precipitation mainly increased over most regions in the high and middle latitudes of the Northern Hemisphere during the 20th century. However, in some regions the amount of precipitation decreased [6].

Thus, for the Asian territory of Russia it was revealed using observational data over 1955-2000 that there is a tendency to precipitation decrease over 80% of the territory [3].
According to [1], the amount of precipitation over the whole territory of Russia increases, however, the trend value is statistically insignificant. Moreover, there is a tendency to increase in the extreme precipitation over the whole territory with a synchronous increase in the dry periods [7]. At that time the value of the amount of precipitation in Western Siberia was higher or near the normal value [1], but at the beginning of the 21st century events with heavy precipitation became more often, which led to great socio-economic losses. For example, the extreme precipitation in May 2014 in the southern part of Western Siberia – in the Altai territory – caused an emergency situation: a high flood with almost billion losses.

There is a general tendency towards a greater frequency of heavy precipitation events over the past four decades [8], especially at the high latitudes of the Northern Hemisphere, consistent with the observed changes [9]. According to [10], there will be a greater change in the extreme precipitation than in the mean one over the globe, in general. Moreover, changes in observations of short-lasting extreme precipitation depend on the region [11] and on the analysis method being used [12].

From this point of view, investigation of the regional feedback of the climatic system of Western Siberia is considered a topical question against the background of slowdown of the global temperature rise, choosing atmospheric precipitation as an indicator of climate change. Moreover, it is important to reveal the tendencies in anomalies of this parameter under the conditions of the global climate change applying not only the statistical approach.

The main goal of this study is to estimate the spatio-temporal variability of the atmospheric precipitation characteristics, including its large-scale and convective types, over the territory of Western Siberia at the end of the 20th and at the beginning of the 21st centuries from the reanalysis dataset and to reveal tendencies in its anomalies using numerical modeling methods.

2. Materials and Methods
Within the framework of this study, analysis of the obtained values of atmospheric precipitation (total, convective, and large-scale precipitation), its linear trends and anomalies in the cold and warm seasons over the north and the south of Western Siberia (50°-70°N, 60°-90°E) was carried out over 1976-2015. Estimates were derived from the ERA-Interim reanalysis dataset with a spatial resolution of 1.125°x1.125° [http://www.ecmwf.int/en/research/reanalysis/era-interim]. To compare the precipitation characteristics, observational data from RIHMI-WDC (http://meteo.ru/data) were also used.

The median of the cumulative distribution function (CDF) was used as an average value over the territory. To reveal tendencies and to reduce the signal noise in the time series of the climatic parameters, low-pass filtering with a 10-year window width was applied.

The averaged fields of the studied parameter and its trends were calculated over two time intervals: over the period of intensive global warming (1976-1998) and over the period of slowdown in temperature rise (1999-2015).

To obtain and describe the cause-and-effect relationships using short time series, it is necessary to combine the results of statistical analysis and numerical modelling. Within the framework of the study, the “Planet Simulator” model [13] with the RCP8.5 scenario (http://climate.uvic.ca/EMICAR5/) was used.

The distribution function curve was also used to reveal the anomalies: values below 10th percentile were considered as anomalously low ones, and values above the 90th one, as anomalously high values.

Separation into the northern (the Arctic zone) and southern parts was made along 60°N. The period from November to March was accepted as a cold season, and that from April to October, as a warm one.

3. Results and Discussion
The spatio-temporal variability of the atmospheric precipitation characteristics using observational data was studied in [14]. In general, it was revealed that the precipitation field is zonally distributed over the territory and the amount value decreased from north to south.
The annual averaged value of the amount of precipitation became higher over the second interval in the northern part of the region than that in the southern one, and the most significant changes were observed in the warm season. The estimates calculated from the observational data were compared with those derived from the reanalysis data using analysis of the CDF. It was revealed that the values from these datasets are in a good agreement only if the median values are investigated (Figure 1). And one should be more careful when analyzing anomalies in the amount of precipitation. Moreover, it follows from Figure 1 that the difference in the northern part of Western Siberia is larger than in the southern one.

![Figure 1. CDF for the amount of precipitation in the northern (a) and the southern (b) parts of Western Siberia over 1999-2015.](image)

The obtained annual and seasonal estimates of the precipitation in Western Siberia using the reanalysis data were also compared with those derived for adjacent regions: Eastern Siberia (50°-70°N, 90°-130°E) and the Far East (45°-70°N, 130°-180°E). The corresponding values are presented in Table 1.

| Region      | Western Siberia | Eastern Siberia | Far East |
|-------------|-----------------|-----------------|---------|
| Period      | 1979-1998       | 1999-2015       | 1979-1998 | 1999-2015 |
| Warm        | 395             | 399             | 430      | 416       | 466      | 454      |
| Cold        | 155             | 154             | 95       | 97        | 286      | 295      |
| Year        | 550             | 553             | 525      | 513       | 752      | 749      |

It follows from the table that the highest annual values were observed in the Far East. The amount of precipitation at the beginning of the 21st century was less than at the end of the 20th century. The tendency to decrease was also observed in Eastern Siberia. Such features were mainly determined by the changes of this parameter in the warm season. There was a tendency to a slight increase over 1999-2015 in Western Siberia, in contrast to the other regions of the Asian territory of Russia.

As for the linear trends of the amount of precipitation, there is a tendency to an increase of this parameter in the warm season in the northern part of Western Siberia over the second time interval. In the southern part the changes are not pronounced; the trend values are much less. It should be noted
that at the beginning of the 21st century there is a tendency to lengthening of the function tail in the area of anomalous negative values (below 10th percentile). This was obtained for the northern part in the cold season and for the southern part in both the cold and warm seasons. It means that a significant decrease in the amount of precipitation was observed in some areas of Western Siberia over the last decade, which can deal with a rise in the number of events with decreased amount of precipitation, for example, with droughts in the summer time and anticyclonic weather in winter. This tendency is in a good agreement with the results obtained in [15], where according to observational data the greatest changes in dry periods duration were revealed in the southern part of Western Siberia. Probably, such a situation was caused by atmospheric circulation variability, in particular, with cyclonic activity and atmospheric blocking processes development [16].

In the beginning of the 21st century about 80% of the whole territory is in the area of positive annual values. Areas with increased rates of precipitation are located along the east boundary of the region, and areas with decreased ones, along the Ural mountains.

To better understand the nature of the atmospheric processes, monthly averaged and seasonal values of both convective and large-scale precipitation were derived from the reanalysis dataset (here the precipitation characteristics are presented for these types).

A comparison of the median values using the CDF derived for two time intervals (1979-1998 and 1999-2015) showed that at the beginning of the 21st century there was an increase in the convective precipitation area of up to 10% in the warm season in the northern part of the region, whereas over the whole territory its statistically significant decrease was observed (Figure 2a). As for the large-scale precipitation, its characteristics were not changed from one period to another (Figure 2b).

Probably, such tendencies deal with an increased frequency of the events of convective cloudiness development (cumulonimbus clouds) in this region.

![Figure 2](image_url)

**Figure 2.** CDF for the amount of precipitation (mm) in the warm season in the northern part of Western Siberia: a) convective precipitation, b) large-scale precipitation. Blue line: median values for each time interval.

The trend values for each type of precipitation were also calculated over two time intervals. Due to the fact that all obtained trend values for large-scale precipitation are statistically insignificant (α=0.05), it could be assumed that there is a tendency to its increase in the cold season (-0.15±1.10 mm/decade and 0.90±1.61 mm/decade over the first and second time intervals, correspondingly).

The trend values in the warm season are: 0.19±0.74 mm/decade (1979-1998) and -0.65±1.27 mm/decade (1999-2015).
However, over the whole territory of Western Siberia a statistically significant decrease in the amount of convective precipitation was observed: -2.12±1.21 mm/decade (1999-2015) in comparison with 0.31±0.90 mm/decade (1979-1998).

As for the trend values of the precipitation characteristics in the adjacent regions, at the beginning of the 21st century convective precipitation also decreased in Eastern Siberia (-1.83±0.81 mm/decade) and increased in the Far East (1.56±0.41 mm/decade) in the warm season. It should be noted that, in contrast to Western and Eastern Siberia where the large-scale precipitation trends were much less than their standard errors, in the Far East the amount of this type of precipitation had a statistically significant tendency to increase, especially pronounced in the cold season (4.6±2.5 mm/decade). Perhaps, this situation was formed under the monsoon circulation variability over the last decade.

Based on the constructed maps of spatial distribution, it should be noted that the revealed increase in the convective precipitation was observed only in the warm season in the northern part of the region, whereas its decrease, in the southwestern part (Figure 3a).

The amount of large-scale precipitation increased in the east of Western Siberia, and an extensive area with negative trends was located along the western boundary of the region (Figure 3b).

![Figure 3a](attachment:figure3a.png)  ![Figure 3b](attachment:figure3b.png)

**Figure 3.** Spatial distribution of annual precipitation trends (mm/decade) in Western Siberia using observational a) convective precipitation, b) large-scale precipitation. Left panel: 1976-1998, right panel: 1999-2015.

Applying numerical modeling methods allowed us to reveal the tendency in the amount of large-scale and convective precipitation anomalies in each region at the background of the most aggressive
anthropogenic forcing (RCP 8.5). The projected changes in the CO₂ concentrations will lead to strengthening of the changes observed in the north of Western Siberia by the end of the 21st century: here we can expect a significant rise for the amount of convective precipitation in the summer time, whereas the large-scale precipitation will decrease (Figure 4). It should be noted that in autumn a slight increase for both types is expected. Extreme increase of the carbon dioxide concentration in the atmosphere can lead to changes in the precipitation characteristics also in the Far East: the annual averaged amount of the large-scale precipitation will increase by approximately 30% by 2081-2100 in relation to 1999-2015.

![Figure 4](image)

**Figure 4.** Annual variability of the amount of atmospheric precipitation in the northern part of Western Siberia using numerical modeling results: a) convective precipitation, b) large-scale precipitation.

Accurate estimates of precipitation are very important for the study of climate variability, for weather, climate, and hydrological forecasting. Rainfall databases are gauge-based, related to satellites and reanalysis data. The spatio-temporal structure of precipitation is not accurately measured and described in climatic models because of its relatively rough resolution and imperfect parameterizations. Mean values of precipitation are calculated with much better accuracy than extreme precipitation [7]. Interpolation of gauge observations to grid points leads to smoothing the extreme values and affects the long-term trends, especially in regions with sparse gauges (for example, Siberia). Hence, estimates of extreme precipitation have large uncertainties in the magnitude and have to be tested using other databases.

4. Conclusions

An analysis of the atmospheric precipitation characteristics obtained by the authors, their linear trends and anomalies in the cold and warm seasons was carried out for the north and south of Western Siberia (50°-70°N, 60°-90°E) over 1976-2015. The derived values were also compared with those for adjacent regions, such as Eastern Siberia and the Far East.

In spite of the fact that statistically significant values of the annual sum of precipitation over the last decades were not derived, in general, the tendency of precipitation decrease in 1979-1998 is replaced by the tendency to its increase in 1999-2015. The most significant rise was observed in the northern part of Western Siberia in the warm season. At that time, a tendency to the formation of negative anomalies in the precipitation amount appeared in the south.

According to the ERA-Interim reanalysis data, at the beginning of the 21st century there was an increase in the convective precipitation area up to 10% in the warm season in the northern part of the region, whereas over the whole territory a statistically significant decrease was observed. As for the large-scale precipitation, its characteristics were not changed from one period to the other. Such
tendencies are probably connected with the increased frequency of events of convective cloudiness development (cumulonimbus clouds).

Based on numerical modeling methods, a feedback of the regional climatic system of Western Siberia on global climate change was revealed; a tendency in the anomalies of convective and large-scale precipitation was obtained.

However, due to the coarse grid resolution in the ERA-Interim reanalysis the derived estimates do not have the required accuracy. Thus, to validate and describe the spatio-temporal variability of precipitation characteristics (especially, its different types) in more detail based on reanalysis data, it is also necessary to test values derived from other datasets.

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