Tendencies in current climate change and atmospheric circulation variability in the Arctic region of West Siberia

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Abstract

The main goal of this study is to carry out the investigation of the climatic parameters variability and the role of global atmospheric circulation in their trends over the Arctic region of West Siberia (60-70°N, 60-90°E) using reanalysis data. The characteristics of spatial and temporal variability of meteorological parameters (surface air temperature and soil temperature, atmospheric pressure, snow depth and surface albedo) were calculated using ERA-Interim reanalysis data over the period of 1979–2015. It was established that in the beginning of XXI century, there is an air and soil temperature decrease in winter and autumn and its statistically significant increase in spring and summer. The tendency to permafrost area degradation is observed for the Arctic region. The maximal changes are observed in low-temperature permafrost soils than in soils with higher temperature. This trend is accompanied by the decrease in snow cover depth and surface albedo. Global circulation indices variability, its relationships with meteorological parameters in West Siberia and with sea ice cover extent in the Arctic Seas indicate that atmospheric blocking processes, which are responsible for anticyclonic type of weather, were developed in the region during last decades.

Key words: *air temperature, soil temperature, circulation indices, permafrost*

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Introduction

According to the Fifth Assessment Report of Intergovernmental Panel on Climate Change (2013) - [1], global surface air temperature has increased since the end of the XIX century. One of the most specific features of the ongoing global climate change is the spatial inhomogeneity in temperature variability (IPCC 2013 - [1]). As for regional climate, winter cooling in the mid-latitudes of Eurasia has been revealed since the beginning of XXI century (Petoukhov et Semenov 2010). At that time, in contrast to this tendency, in the high latitudes the intensive warming is indicated: annual average temperature trends in the Arctic region are more than two times higher than

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the average global estimates (Report on climate change 2015 - [3]). It leads to sea ice melting in the coastal Arctic seas and, as a consequence, to decrease of meridional temperature gradient and weakening of west transfer, which brings heat to this region from the North Atlantic (Overland et al. 2008, Outten et al. 2012). Thus, global warming is accompanied by the changes of atmospheric circulation, which is responsible for spatial distribution of heat and moisture and, as a result, for spatio-temporal climate peculiarities. Changes in circulation could be revealed through zonal and meridional wind speed components, meridional temperature gradient in the lower troposphere, global circulation indices and through cyclonic and anticyclonic circulation. It was revealed that the processes of west transfer blocking by mesoscale baric systems (vortices and ridges in the North Atlantic) play a significant role in atmospheric circulation changes in the North Eurasia (Popova 2006). In particular, this tendency is clearly observed in West Siberia (Kharyutkina et al. 2016a).

Under the global climate change the question of high interest is the investigation of permafrost zone parameters in this region, because, first of all, their variability influence on the infrastructure of the Far North (Streletskiy et al. 2012). Furthermore, there is an opportunity for the increase of greenhouse gases concentration during the process of permafrost thawing, which leads to the changes of both global and regional climate (Anisimov 2007). The cryolythic zone covers approximately 65% (11 mln. km^2) of the territory of Russia (Brown et al. 1997). To describe the thermal state of this zone several data sources could be used. The most long-term measurements (since the year of 1965) are from meteorological stations on soil temperature at the depth of 3.2 m (Sherstyukov 2009). To estimate and forecast the permafrost characteristics some authors apply numerical simulation methods (Anisimov et al. 1997, Arzhanov et al. 2007). As for the investigation in regional climate variability, local measurements could be unrepresentative due to the influence of nonclimatic, *i.e.* landscape factors, and models have some scale restrictions (Pavlov et al. 2002, Arzhanov et al. 2007). Therefore, for description of regional climate it is more preferable to use data in regular grid from reanalysis dataset.

However, in the latitudes above 66° in the Northern Hemisphere is the region of high interest to be investigated in the terms of its specific climatic processes under the conditions of global warming.

Thus, main goal of this study is to carry out the investigation of the climatic parameters variability and the role of atmospheric circulation characteristics in their trends over the Arctic region of West Siberia during last decades using reanalysis data.

Material and Methods

The region of under study is West Siberia (50-70° N, 60-90° E) and its northern (60-70° N, 60-90° E) and southern (50-60° N, 60-90°E) parts, separately. The characteristics of spatial and temporal variability of meteorological parameters (surface air temperature and soil temperature, atmospheric pressure, snow depth and surface albedo) were derived using ERA-Interim reanalysis data with spatial resolution 1.125° × 1.125° over the period of 1979–2015 [WP 1].

The large-scale atmospheric circulation indices (Arctic Oscillation (AO) and Scandinavian Index (SCAND)), describing the main atmospheric circulation modes over West Siberia, were selected from the set of Northern Hemisphere circulation indices [WP 2].

Sea ice extent in the Arctic Seas were derived from [WP 3]. It was also an attempt to estimate a permafrost area, which was understood as an area, limited by characteristic isotherm: 0°C - to determine the area of high-temperature permafrost soil (-3°C – 0°C); -3°C - to determine the area of low-temperature permafrost soil (-3°C and lower). This range was chosen, according to the classification of different type of permafrost: discontinuous and continuous, correspondingly (Gavrilova 1993, Zhang et al. 2000). The calculations were made using annual average soil temperature estimates at the lowest depths, presented in ERA-Interim reanalysis data: 28 – 100 cm and 100-255 cm.

To derive descriptive statistics such as median, standard deviation, sample distribution functions of corresponding meteorological parameters were calculated. Median of distribution function is used as an average value over the territory. Robust estimates of linear trend coefficients were calculated as a characteristic of the interannual variability for each grid point.

As for correlation analysis, correlation coefficients between circulation indices and meteorological parameters were calculated in each grid point and then they were averaged over the territory. The influence of sea ice concentration in the Kara and the Barents Seas was derived in the same way. To estimate the significance of correlation coefficient, the Fisher transformation was used with further two-sided *t*-test of the null hypothesis at significance level $\alpha=0.05$ (von Storch et al. 2003). The error of reanalysis data was estimated using the cross-validation procedure: the meteorological values in the reanalysis dataset were interpolated to the geographic coordinates of the stations using Kriging algorithm and then were compared with the observational data from meteorological stations. To reveal the most informative components of signals in time series of climatic parameters, low-frequency filter with the 10 year-window width was applied.

To describe and compare current tendencies in meteorological parameters variability with previous trends and their correlation with atmospheric circulation and sea ice cover the whole time period was divided into two subintervals: 1979-1998 – the period of global warming, 1999-2015 – the period of slowdown of air temperature increase.

Results and Discussion

Climatic parameters variability

In previous studies (Kharyutkina et al. 2016a), based on observational data [WP 4], it was established that the warming process became less intensive in West Siberia than in the end of XX century. A large role in the slowdown of this process belongs to the winter months (December, January, February) when the tendency to warming process was replaced by the cooling one. At that time, the atmospheric pressure rise was observed. These estimates were derived for the whole region of West Siberia. However, the changes in warming rates had a patchy distribution over the territory (Ippolitov et al. 2014). So, in the framework of this study to describe the specific features of climate change in more detail it was necessary to divide the large area of West Siberia into two zones: the northern (Arctic) and the southern zones, and then, to compare the tendencies.

Based on ERA-Interim data from 1979-2015 surface air and soil temperatures, atmospheric pressure, snow depth and surface albedo were calculated for each season. Spatial distribution in trends of some of them is presented in the Fig. 1. Tendencies in climatic parameters changes, observed in the northern part and the southern one were mainly revealed in winter. There was a tendency to air temperature decrease in the south and its increase in the north of the territory. It should be noted that maximal rates of warming were revealed in spring. As for atmospheric pressure, it rose over both zones. Temporal variability of soil temperature in the first layer (28-100 cm) was similar to that of surface air temperature: the decrease was observed in autumn and winter, and the statistically significant increase in spring and summer. Maximal trend value over the period of 1999-2015 was indicated over the Arctic zone in spring (median value is 1.90°C/decade and standard deviation is ±0.60°C/decade). However, in spite of air temperature zero variation during summer months, soil temperature continued its rise. Similar tendencies were also observed in the layer of 100-255 cm, but trend values are less here. These estimates are in a good agreement with the values derived by other authors (Pavlov 2008).

Soil temperature at the depth is one of the major characteristic of the thermal state of permafrost zone. To describe the dynamics of this state in the Arctic region, temporal variability of area values, limited by annual average isotherms of 0°C and -3°C (S(0) and S(-3)) in the layer of 28-100 cm, were constructed (Fig. 2). From the Figure it follows that there was an opportunity of permafrost area destruction in the beginning of XXI century. The process of low-temperature permafrost soil area (-3°C and below) reduction was faster than that for high-temperature permafrost soil area (-3°C – 0°C) by 1.8 times (22% and 12% of the Arctic zone area, correspondingly). Obtained tendencies are in a good agreement with values presented in (Assessment Report 2014 - [2]), and could be explained by the differences in heat losses for evaporation, which is necessary for phase transitions. Since there is no seasonal thaw depth and heat losses for phase transitions in winter, an increase of air temperature in cold period causes a greater increase of soil temperature than an equal increase of air temperature in warm period, when a significant part of heat is used to heat the ground, but not to phase transitions (Shur et al. 2005). The increase of soil temperature and the formation of seasonally thawed layer are mainly due to warming in the near-surface layer, accompanied by an increase in the depth of the snow cover (Assessment Report 2014 - [2]).

Moreover, as it was noted in (Sherstyukov 2008), changes in the average annual soil temperature trends are mainly determined (up to 50%) by changes in snow depth, while the contribution of air temperature variations to the whole variability of permafrost temperature is not exceed 15%.

Therefore, when analyzing soil temperature variability and permafrost dynamics, it was also important to take into account changes in the depth of snow cover during last decades (Fig. 1). Based on ERA-Interim reanalysis data, this parameter in cold period had slight increase in the south and more evident decrease in the Arctic region of the territory (Fig. 3a). In addition, the interannual variability in seasonal values of albedo was constructed over the territory of West Siberia (Fig. 3b). Its trend coincides with that of snow depth: there was an albedo decrease (~5%) in winter in the northern part. However, the magnitude of reduction was higher in spring and up to ~10%.

Thus, it was established that in the beginning of XXI century, there was an air and soil temperature decrease in winter and autumn and its statistically significant (according to the trend value and its standard deviation) increase in spring and summer, especially in the Arctic zone of West Siberia. The maximal changes were observed in low-temperature permafrost soils than in permafrost soils with higher temperature. This trend was accompanied by the decrease in snow cover depth and surface albedo. It could lead to permafrost degradation in the region of under study.

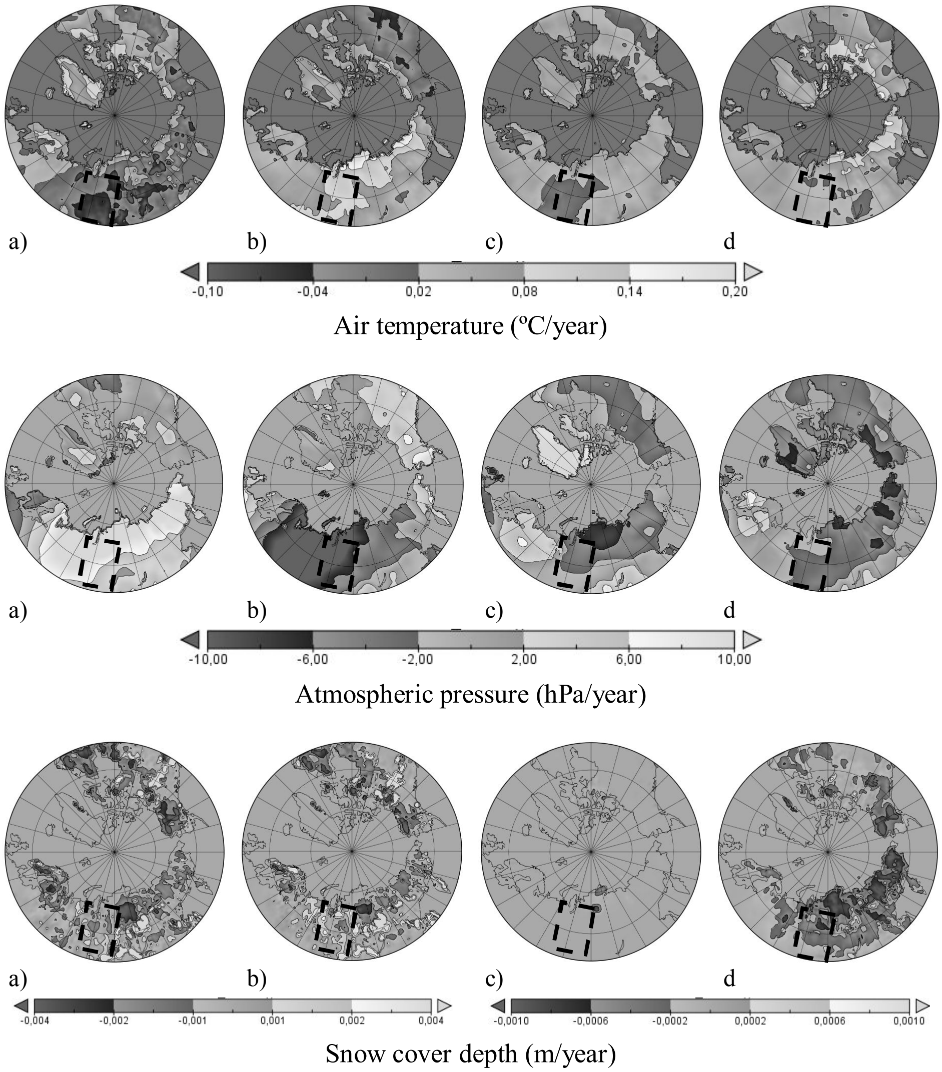

Fig. 1. Spatial distribution in meteorological parameters trends using ERA-Interim reanalysis data over the period of 1979-2015: a) winter, b) spring, c) summer, d) autumn. Dash figure is the region of West Siberia.

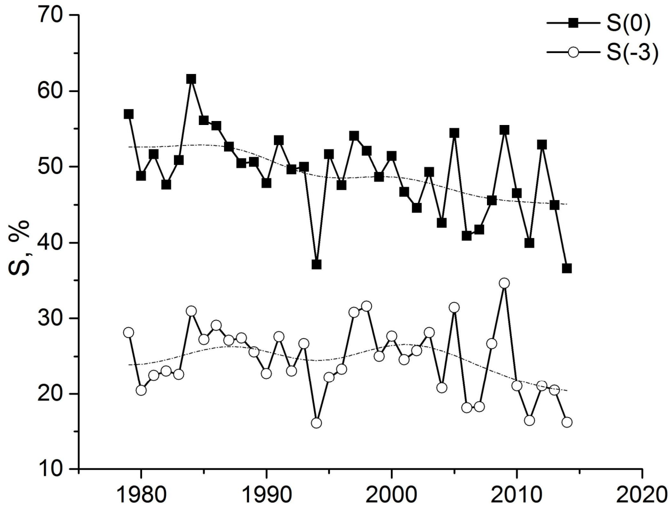

Fig. 2. Interannual variability of permafrost area in the Arctic zone of West Siberia. Explanation of S(0) and S(-3) could be found in the text.

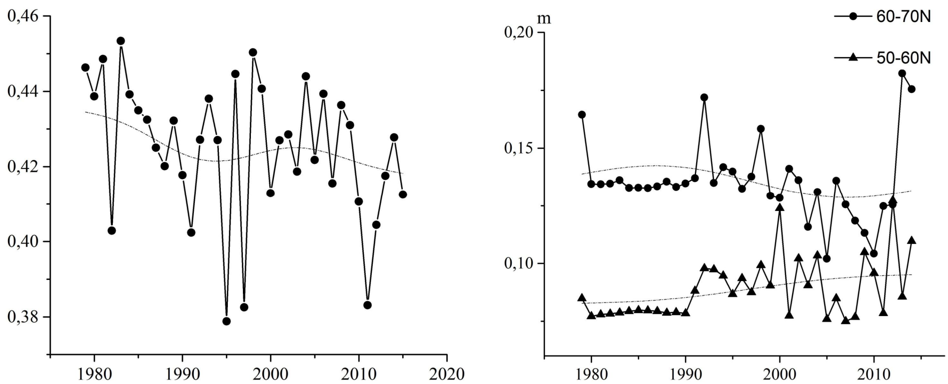

Fig. 3. Interannual variability of meteorological parameters over West Siberia: a) snow cover depth (meters) – in winter; b) albedo (dimensionless value) – in spring.

Relationship with atmospheric circulation

As for circulation indices variability it was revealed, that among the set of global circulation indices (Barnston et Livezey 1987) the highest correlation with temperature over the territory of West Siberia was observed with Arctic Oscillation (AO) index and Scandinavian (SCAND) index. Correlation analysis had also shown statistically significant (α=0.05) relationship between these indices and snow cover depth in winter season over this period: 0.56 and -0.83 for AO and SCAND, correspondingly. High correlation coefficients were also revealed between surface albedo and indices: 0.72 (AO) and -0.45 (SCAND).

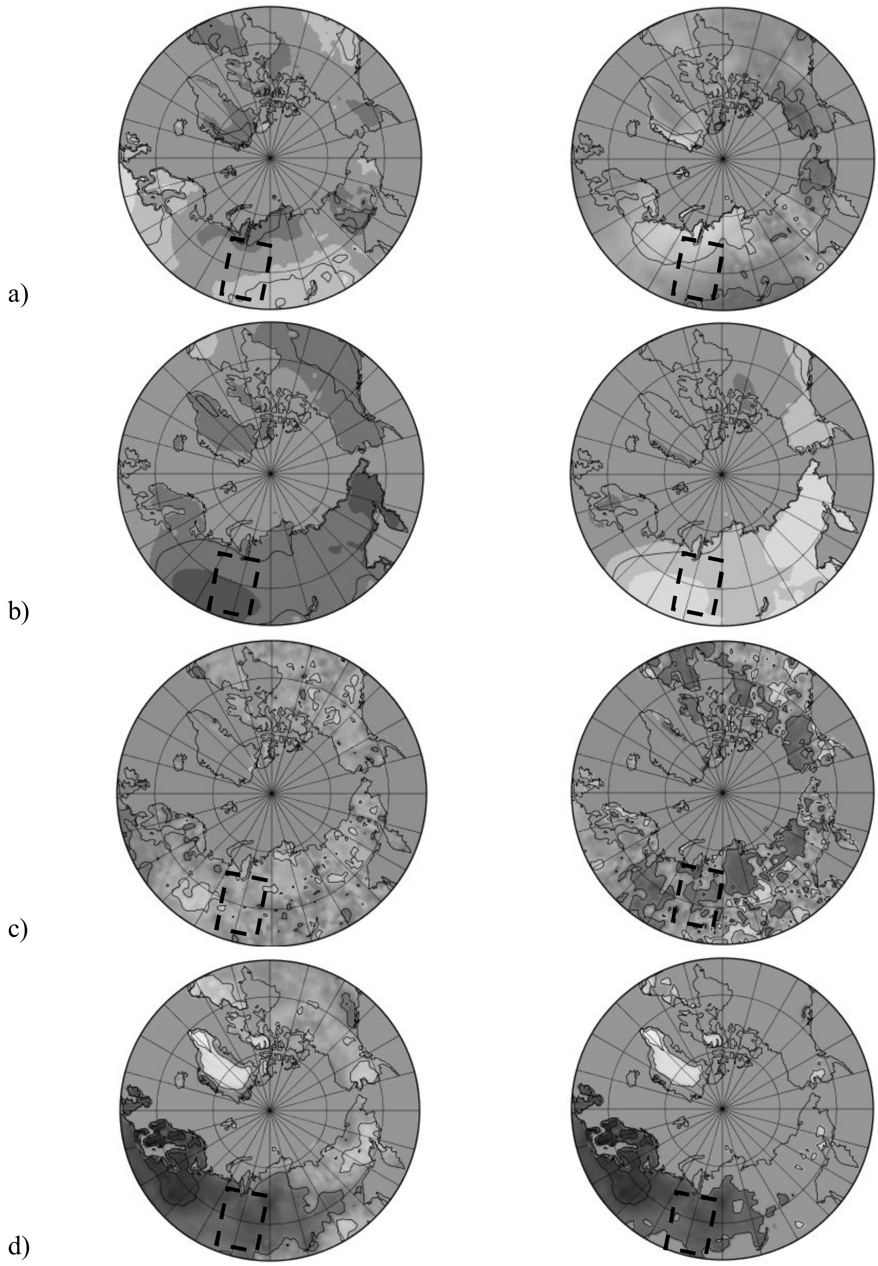

Fig. 4. Spatial distribution of correlation coefficients between meteorological parameters and global circulation indices (AO - left panel, SCAND - right panel) in winter over the period of 1979-2015: a) air temperature, b) atmospheric pressure, c) snow cover depth, d) soil temperature gradient (it is the difference of soil temperature values between two layers: 28-100 cm and 0-7 cm). Dash figure is the region of West Siberia.

Interannual variability of indices, their eigen vectors (EOFs) and correlation analysis indicate the weakening of midlatitude west transfer and, as a result, the development of blocking processes of air masses. It should be noted that the influence of these processes on meteorological parameters was higher in the Arctic zone of West Siberia than in its southern part, and it has enhanced in the beginning of XXI century (Kharyutkina et al. 2016b).

Based on the analysis of spatial distribution of correlation coefficients between meteorological parameters and circulation indices, we can conclude that coefficient values have opposite signs (Fig. 4): they are negative with AO index and positive with SCAND index. The only exception is the correlation with snow depth (Fig. 4c). Furthermore, relationships with SCAND index were higher than that with AO index. Thus, observed changes in most of parameters were mainly described by SCAND index, which is responsible for atmospheric blocking processes, *i.e.* anticyclonic type of weather.

The influence of sea ice concentration in the Kara and Barents Seas was also taken into consideration. Since there is a trend to sea ice extent decrease in the Arctic Seas [WP 5], ice-free sea surface areas lead to the decrease of meridional temperature gradient due to the heating of ocean layers; it causes changes in atmospheric circulation processes. This is one of the mechanisms of the impact of global climate change on regional climatic system. It was revealed that reduction in the sea ice cover extent in the Barents Sea leads to soil temperature gradient increase in winter and spring over the region of under study, whereas there was no significant relationship with the variability of sea ice cover characteristics in the Kara Sea. Hence, this mechanism acts indirectly on climate variability in West Siberia through atmospheric blocking processes, described by SCAND index.

Concluding Remarks

Thus, in the framework of this study the climatic parameters variability over the Arctic region of West Siberia and the role of atmospheric circulation characteristics in their trends were revealed.

It was established that there was air and soil temperature decrease in winter and autumn and statistically significant increase in spring and summer over the Arctic region of West Siberia in the beginning of XXI century. The trend to permafrost area destruction was also observed in this zone. In winter and spring the sea ice extent decrease in the Barents Sea had more significant influence on soil temperature changes, than the influence of sea ice cover reduction in the Kara Sea. The mechanism of global circulation acts indirectly on climate change in West Siberia, especially in its high latitudes, through atmospheric circulation processes (described by SCAND index), which are responsible for the development of anticyclonic type of weather in the region during last decades.

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[WP 4] ftp://ftp.cdc.noaa.gov/pub/data/gsod/

[WP 5] http://www.ncdc.noaa.gov