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Circulation Factors in Climate Change in the Baikal Region

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Abstract. The paper presents the results of research conducted on large-scale and zonal atmospheric factors of climate variability over the territory of the Baikal region, which, according to Russian Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet) is considered to be one of the regions characterized by highest rates of climate change. On the basis of trend, correlation, and spectrum analyses, investigation was made of high- and low-frequency components in multidecadal timescales of climatic indices dynamics, which determine and distinguish variability in pressure fields and geopotential at high latitudes in the Northern hemisphere, in the northern parts of the Atlantic and Pacific oceans throughout the time period of 1950–2017. In the dynamics of climate indices, cyclicity is manifested. It reflects the contribution of short-term and long-term variations, which are close in duration to the variability of continental and oceanic centers of atmospheric action in the Northern Hemisphere. Among climatic indices, the highest levels of correlation with changes in average monthly temperatures in the city of Irkutsk can be traced for the Scandinavian index. With an increase in surface pressure in the territory of Scandinavia, the contribution of advective heat and moisture fluxes from the Atlantic is weakened. The latter have a warming effect in the winter months on the territory of the Irkutsk region. Particular emphasis was put on searching for causes of increasingly arid climate in the Baikal region in summer months of 2000–2017, when the number of forest fires in the region rose dramatically.

Keywords: climatic indices, circulation, Baikal region, air temperature, heat fluxes.

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Научная статья

Циркуляционные факторы изменения климата на территории Иркутской области

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Аннотация. Проведено исследование крупномасштабных и региональных атмосферных факторов изменчивости климата на территории Иркутской области, которая относится к числу регионов с наиболее высокими темпами изменений климата, согласно данным Росгидромета. На основе трендового, корреляционного и спектрального анализа исследованы высоко- и низкочастотная составляющие в многолетней динамике климатических индексов, характеризующих изменчивость полей давления и геопотенциала в высоких широтах Северного полушария, на севере Атлантики и Тихого океана в период 1950–2017 гг. В динамике климатических индексов проявляется цикличность. Она отражает вклад короткопериодных и долгопериодных вариаций,

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Полные сведения об авторах см. на последней странице статьи.

которые по продолжительности близки к изменчивости континентальных и океанических центров действия атмосферы на территории Северного полушария. Среди климатических индексов наиболее высокие уровни корреляционной зависимости с изменениями средних месячных температур в г. Иркутске прослеживаются для скандинавского индекса. При повышении приземного давления на территории Скандинавии ослаблен вклад адвективных потоков тепла и влаги с Атлантики. Последние оказывают отепляющее влияние в зимние месяцы на территорию Иркутской области. Особое внимание уделено поиску причин усиления засушливости климата Иркутской области в летние месяцы 2000–2017 гг., с которой связано увеличение числа лесных пожаров в регионе. Установлено повышение вклада ветров южной составляющей на высоте средней тропосферы, с которыми связано усиление адвекции тепла.

Ключевые слова: климатические индексы, циркуляция, Байкальский регион, температура воздуха, потоки тепла.

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Introduction

Climate change is one of the most pressing problems of our time, which affects various spheres of human activity. The Intergovernmental Panel on Climate Change defines climate change as a change in the state of climate that persists over a long period, usually decades, and can be identified by the variability of its properties. It is also climate change over time, due to natural variability or as a result of human activity [Ziegler, Morelli, Fawibe, 2019].

Extreme hydrometeorological phenomena are sensitive to climate change and become more dangerous for people, various spheres of the economy and ecosystems. Understanding the physical mechanism and the causes of observed climate change is important for predicting the occurrence of extreme climatic events and taking measures to reduce the associated effects.

For the study of climate change, the group of experts of the World Meteorological Organization for Climate Change Detection and Indices (ETCCDI) has approved a list of 40 indices, 27 of which are considered as the main indicators. In particular, it is necessary to clearly define the threshold values of these indicators, among which the frequency, intensity and trends of extreme temperatures and precipitation are most often used most often [Spatiotemporal variations of … , 2019]. As an example, studies carried out in China, where, based on daily data on the maximum and minimum temperatures collected from 1899 at meteorological stations, in the period from 1961 to 2015, are given. an increase in tropical nights (TR20), summer days (SU25), warm days (TX90p) and warm nights (TN90p), along with a decrease in the number of frosty days (FD0), cold days (TX10p) and cool nights (TN10p). It is noteworthy that variations in extreme temperatures correlated well with indices of atmospheric circulation, in particular, with changes in the Arctic oscillation, where a negative relationship was found for cold extremes and positive for warm extremes [Trends in temperature … , 2018].

Currently, temperatures have increased in most regions of the world, including the eastern United States, Northern Europe, West Africa and East Asia. Many researchers are increasingly analyzing the so-called “heat waves.” For example, according to meteorological observations on the territory of Pakistan, most areas are highly exposed to heat waves, and according to the output of the forecast models RCP -4.5, RCP -6.0 and RCP- 8.5, the warming intensity increases to 32 % by 2030; and in 2090 will reach 140 % [Future risk assessment … , 2018]. In the Middle East and North Africa during the three periods of 2010–2040, 2040–2070, and 2070–2100 compared with the control period 1970–2000. According to regional climate modeling models, average temperatures are expected to rise from 3 °C to 9 °C , and as a result, a significant decrease in precipitation is expected [Future projections of … , 2018].

Temperature is defined as the dominant factor for determining droughts in arid and semi-arid areas. The spatial-temporal characteristics of atmospheric drought in Syria, obtained using standardized precipitation indices (SPI and SPEI), indicate that the droughts of 2007–2010 were the most severe for the entire period of instrumental observations [Spatial and temporal ... , 2018]. Predicted on average from 3 °C and up to 7 °C for the period 2071-2100. in relation to the past period of 1971–2000, warming and a decrease in precipitation can adversely affect the ecological and socio-economic systems of Central Asia, which is already a predominantly arid and semi-arid region already [Future projections of ... , 2018].

Interestingly, the minimum temperature increases about twice as fast as the maximum temperature [Limsakul, Goes, 2008]. In Iraq, the maximum temperature increases in winter, and the minimum – in summer. According to the numerical models HadGEM2-AO, HadGEM2-ES, MIROC5 and MIROC-ESM, the average maximum temperature in the summer in Iraq can reach almost 50 °C, while negative temperatures will gradually become a rare event during the winter [Selection of climate ... , 2018]. On the territory of the globe, more than 70 % of agricultural zones showed a significant decrease in the annual number of cold nights and a significant increase in the annual number of warm nights [Alexander, Zhang, Peterson, 2006]. Against the background of increasing average temperatures, the depth, intensity and frequency of temperature inversions decrease [Surface-based temperature ... , 2010].

At the same time, in a number of regions, an increase in average temperatures is accompanied by an increase in precipitation. Future climate change projections on five independent GCM CMIP5 models and their multi-model ensemble show that in the future a significant increase in precipitation and air temperature is expected in the Tibetan plateau [Zhong, He, Chen, 2018]. In the eastern regions of the Himalayas, a significant increase is projected for 2006-2100. Recurrence of both heavy and very heavy rainfall, and of dry periods, leading to a higher risk of flooding and droughts.

The rise in average temperatures and the heat waves associated with these waves (HWs) are having an increasingly profound impact on public health and ecosystems, especially in conditions of developed urbanization. Therefore, it is not by chance that the current increase in global and regional temperatures is often associated with the influence of anthropogenic activity and the growing number of large cities. In the contribution of natural climate change and human activity to changes in temperature conditions in China was estimated using six large-scale variable circulation and emissions of four greenhouse gases [Contributions of natural … , 2018]. It is established that human activity leads to an increase in average temperatures in the period of rapid socio-economic development (1986-2012) than in the period of slow socio-economic development (1960-1985). Among the climate variables recognized as valid with respect to climate variability, aerosols continue to introduce one of the greatest uncertainties in the overall assessment of radiative forcing [Chedin, Capelle, Scott, 2018]. Atmospheric aerosols are believed to play an important role in the regional climate. This is clearly demonstrated by the example of the high-mountainous regions of Asia (Himalayas, Tibetan Plateau, Pamir, Hindu Kush, Karakorum and Tienshan), where the contribution of radiation effects caused by the influence of aerosol components has increased since 1990 [Investigation of mineral … , 2016].

Interesting results by assessment influences volcanic activities on climate received at [Guðlaugsdóttir, 2018]. According to the ensemble models of volcanic eruptions affect the climate, both on an annual and a ten-year time scale due to the dynamic interaction of various climatic factors. The North Atlantic Oscillation (NAO) tends to its positive phase in the first 1-2 years after large volcanic eruptions in the tropics, which causes warming in Europe. Evidence of a deepening polar vortex 2-4 years after eruptions is found, and a long-term signal manifests itself in the weakening of the polar vortex about ten years after the eruption. As an additional source of heat, we can consider the number of forest fires that has increased in recent decades, which is clearly reflected in the results of numerical modeling, according to which heat fluxes into the atmosphere and air temperatures rise to 225 $W \cdot m^{-2}$ and 3 K over burned areas respectively [Mölders, Kramm, 2007].

At the same time, there is a statistical relationship between the types of atmospheric circulation and the surface climate, which manifests itself both at the global and regional levels [Atmospheric circulation patterns …, 2015]. The synoptic climatological approach is based on the analysis of air mass characteristics. Thus, over the past 40 years, the rise in temperatures in the western North American Arctic may be associated with a shorter residence time of arctic cold air masses [Yel, Kalkstein, Greene, 1995].

Walker in 1932 and Lorenz in 1950 for the first time pointed out the importance of using for the study of weather and climate anomalies climatic indices of variability of the pressure field and geopotential. They are the eigenvectors of the covariance matrix and are obtained by calculating the covariance of time series in different regions; therefore, they are optimal for explaining climate variability. However, the interpretation of climatic and indices as physical or dynamic mechanisms is a rather difficult task.

Most often, climatic indices are determined by decomposing the natural orthogonal function (EOF) into its components. The EOF splits the original pressure or geopotential data fields into orthogonal components or the so-called “data modes”, which statistically describe the selected oscillations. The advantage of this method is that the EOF functions are determined from the observation data themselves.

Currently considered ring and regional modes of oscillation. An example of a ring mode is the Arctic Oscillation (AO), which is defined as the first component of the average pressure EOF in the Northern Hemisphere. The time scale varies from several weeks to decades in different calendar seasons of the year. The first and second components of the natural orthogonal mean pressure function in the winter in the Northern Hemisphere explain about 25 % and 14 % of the variance of the temporal variability of the surface atmospheric pressure field.

Over the past few decades, several regional modes of low-frequency variability of atmospheric circulation have been identified in the northern hemisphere. These modes, through the associated large-scale Rossby waves, changes in the cyclogenesis mode and anticyclonic blocking according to [Trends in temperature extremes ... , 2018] have a remote effect on the climate in certain regions of Eurasia, North America and Greenland.

Most often, studies of climate in Eurasia use the North Atlantic Oscillation Index (NAO), which reflects the change in air transport between the north Atlantic in the Icelandic region (Icelandic minimum) and the South Atlantic (Azores maximum) [Voskresenskaya, Worley, 2004; Nesterov, 2009]. It was revealed that this index has the greatest impact on the weather and climatic conditions of Eurasia in the winter months, when cyclonic activity in the Atlantic is well expressed. It is believed that this index characterizes the trajectories of the displacement of cyclones and the associated advective heat fluxes deep into the continent [Polonskii, Basharin, Kholton, 2004].

East Atlantic Oscillation (East Atlantic, EA or VAK) also manifests itself in the pressure fields of the Atlantic-European region, but its centers are usually shifted to the southeast with respect to the centers of the NAO. As a result, the HAC is often defined as the “SAC-biased” SAH mode [Nesterov, 2013]. In winter and autumn, during the positive NAO phase and the negative phase of the HAC index over most of the territory of Eurasia, zonal transfer is enhanced and positive temperature anomalies are noted.

In 1987, during the analysis of the EOF of the average monthly fields of the geopotential at 700 hPa (3 km), the EA/WR was found: the East Atlantic-Western Russia oscillation, the two main centers of which are in Western Europe and in the north of the Caspian Sea and a less pronounced center off the coast Portugal may shift towards Newfoundland. Similar to the previous indices, this index is most pronounced in the winter period.

In the region of the Scandinavian Peninsula, where the cold anticyclone often forms in the Arctic air, the Scandinavian Oscillation (Scand) is distinguished, in the high latitudes of the Northern Hemisphere – the Polar Index [Cholaw, 2007]. The positive phase of Scand is associated with positive anomalies in the height of AT-700 hPa and manifests itself in blocking processes over Scandinavia and the European part of Russia [Polonskii, Kibalchich, 2014]. In the Pacific region, WP – Western Pacific and PNA – Pacific-North American Oscillation.

Among the recent works, in which the influence of climatic indices of atmospheric circulation on the change in weather and climatic conditions in different regions of the globe is considered, the following can be noted. In [Ding, Wang, Lu, 2018], in the region of the Tibetan Plateau in China, temperature extremes in the period from 1961 to 2016 are closely correlated with changes in the winter index of the Arctic fluctuation (AO), the summer and winter North Atlantic fluctuation

(NAO), and the summer and winter subtropical index in the western Pacific Ocean (WPI). However, the Southern Oscillation Index does not significantly correlate with most extreme temperature indices. Droughts in southern Africa 1961/62-1965/66, 1980/81-1986/87, 1991/92, 2001/02-2005/06, 2009/10-2012/13 and 2014/15-2015/16 mostly coincided over the years of El Nino, therefore, the influence of the southern variations of El Nino on the drought cannot be ruled out [Analysis of long term ... , 2018]. The study of circulation causes of abnormal precipitation in Northeast China examines the temperature anomalies in the North Atlantic, the intensity of the development of the summer monsoon in the North Pacific, and the zonal transport in the subtropical zone of East Asia [Changing contribution rate … , 2017]. The intensity of convection development over South / Southeast Asia (northwest and northeast parts along the Himalayan foothills, as well as the Indochinese Peninsula and the South China Sea) decreases during El Nino (La Nina), which can increase be a direct consequence of the warming of the atmosphere due to the changing regional climate [Spatio-temporal variability ... , 2017]. When analyzing the correlation between the fluctuations of the East Atlantic – Western Russia and a geopotential height of 500 hPa revealed a region with a negative correlation in Russia, north of the Caspian Sea. In the last 20 years, positive temperature anomalies have been observed when EA / WRI <-1 and EA index > 1 [The influence of the large-scale ... , 2018]. Russian authors [Mokhov, Smirnov, 2018] obtained quantitative estimates of the contribution of the radiative forcing of greenhouse gases and the Atlantic quasi-ten-year oscillation (AMO) to the trends of global near-surface temperature and near-surface temperature in different latitudinal zones. At relatively short time intervals (15–30 years), the AMO contribution turned out to be comparable in absolute value to the contribution of greenhouse gases and could even exceed it, and at intervals of about 60 years or more, it is already insignificant. At the same time, in recent decades, the relative contribution of greenhouse gases to the trends of GPT and near-surface temperature in the tropics is greater, and to the trends of near-surface temperature in middle and high latitudes – less. T. Y. Vyruchalkina, G. N. Panin, I. V. Solomonova considers the effect of atmospheric indices on the formation of climate in Siberia [Vyruchalkina, Panin, Solomonova, 2012]. It is revealed that the NAO, SCAND, AO and SOI indices (southern oscillation) have the greatest influence on this territory. It is indicated that the variability of temperature over the territory of Siberia is mainly related to the variability of the SCAND and AO indices and is least related to the variability of the NAO and SOI indices.

For more deep of understanding existing and expected changes climate actively develop global and regional methods numerical modeling [Nayak, Mandal, Maity, 2018]. For example , the ensemble of 88 regional models climatic models (RCM) with spatial a resolution of 0.11 ° and 0.44 ° applies for research projected impacts changes climate on extreme quantity precipitation at Europe [Hosseinzadehtalaei, Tabari, Willems, 2018].

The territory of the Irkutsk Region is a unique region characterized by a wide range of atmospheric phenomena, some of which have a great influence on many aspects of human activity, safety and well-being. This region for a long time (October-March) falls under the influence of the winter continental center of action of the atmosphere (Asian anticyclone), and in summertime – monsoon circulation. Sharp changes in weather and climate are due to the frequent shift of the Atlantic and southern cyclones. Therefore, it is not by chance that this region falls into the number of regions with a high rate of climate change.

According to the data of paleoclimatic studies, the Holocene climate in the territory of the Irkutsk region was humid relative to the last ice age. Then the climate gradually became warmer and more humid from early to middle Holocene, after which it was warm and dry, which indicates that at that time the climate system transitioned from a glacial to an interglacial state. The rapid decline in precipitation in the early Holocene may have been a response to a decrease in temperature [Hydrological and climate changes ... , 2018]. The multi-element time series obtained from the study of the distribution of bottom elements in sediments on Lake Baikal (Irkutsk Region) show sharp climatic shifts that were synchronous with sudden warming events in the North Atlantic and Greenland during the last ice age [Decade–centenary resolution ... , 2007].

In recent decades, climate change has increasingly influenced the frequency, intensity, and duration of extreme climate and hydrological events in the Irkutsk region [Research papers Hydrologic ... , 2018]. Modeling of climate change predicts an increase in drought risk for the territory of Siberia in a changing climate [Trautz, 2015]. This is confirmed by an increase in the death of Siberian pine (Pinus sibirica) and fir (Abies sibirica) in the basin of Lake Baikal since the 1980s, which was caused by increased aridity and severe drought [Climate-induced mortality ... , 2017].

Changes observed in the temperature and humidity regimes observed from the late 1960s to the present are accompanied by the transformation of the composition of forest vegetation [Nazimova, Tsaregorodtsev, Andreyeva, 2010]. Siberian boreal forests are expected to expand northward during global warming. However, the transition processes, as well as the associated climate feedbacks, are still not understood.

Analysis method

Walker in 1932 and Lorenz in 1950 were the first to point out the significance of applying pressure field and geopotential variability indices for investigating weather and climate anomalies. They are eigenvectors of the covariance matrix and are obtained by calculating the covariance of time sequence in various regions, thus being highly representative for elucidating climate variability. However, interpretation of climatic indices as physical or dynamic mechanisms remains a complicated task.

The most frequently applied approach to determine climatic indices is through decomposing empirical orthogonal function (EOF) into its components. EOF rearranges source data for pressure or geopotential into orthogonal components, or the so-called “data modes”, which provide statistical description of the identified oscillations. The advantage of the method is in EOF being determined by using observation data.

Currently, annular and zonal oscillation modes are under consideration. Annular mode is exemplified by the Arctic oscillation (AO), which is defined as the first mean pressure EOF component in the Northern Hemisphere. The timescale ranges from several weeks to several decades in various calendar seasons of the year. The first and second EOF components of mean pressure in the wintertime in the Northern Hemisphere explain approximately 25 % and 14 % of dispersion in surface pressure time variability.

Throughout the recent decades, over the Northern Hemisphere a number of zonal modes of low-frequency variability in atmospheric circulation have been identified. It follows from data [Thompson, Wallace, 1998; Wallace, Gutzler, 1981] that through the associated large-scale Rossby waves and changes in cyclogenesis and anticyclonic blocking regimes, these modes provide a remote impact on climate in a number of regions in Eurasia, North America, and Greenland.

In conducting climatic research over the Eurasian territory, the most frequently used index is the North Atlantic Oscillation (NAO), which represents air transfer change between the North Atlantic area in Iceland (the Icelandic low) and the South Atlantic area (the Azores high) [Nesterov, 2013]. It was found that the index provides the highest impact on weather and climate conditions in Eurasia in winter months, when cyclonic activity in the Atlantic is well-defined. The index is considered to characterize cyclonic shift tracks and the associated advective fluxes transferring heat inland [Polonskii, Kibalchich, 2014].

Though the East Atlantic Oscillation (EA) is also observed in atmospheric pressure fields of the Atlantic-European region, its centers generally shift southeastward relative to NAO centers. As a result, EA is defined as “southward shifted” NAO [Nesterov, 2009]. In winter and in summer in positive NAO phase and negative EA phase over the most part of Eurasia the zonal transfer pattern is stronger and positive temperature anomalies are observed.

In 1987, the mean monthly EOF pattern exhibited EA/WR (East Atlantic – West Russia) oscillation at 700-hPa geopotential height (3 km) with two primary centers over the Western Europe and the northern area of the Caspian Sea and one less clearly defined center off the Portuguese coast, which is prone to shift towards Newfoundland. Similarly to the previous indices, this index is more clearly defined in wintertime.

Around the Scandinavian Peninsula, where cold anticyclones tend to frequently form in the Arctic air, the Scandinavian Oscillation (SCAND) is identified, and in high latitudes of the Northern Hemisphere the Polar–Eurasia pattern is identified [Cholaw, Hisashi, 2007]. The positive SCAND phase is associated with positive anomalies at AT-700 hPa geopotential height and is manifested in blocking processes over Scandinavia and the European part of Russia [Polonskii, Basharin, Kholton, 2004.]. In the Pacific area WP (West Pacific) and PNA (Pacific/North American) patterns are identified.

The impact of atmospheric indices on the Siberian climate formation is investigated by T. Yu. Vyruchalkina, G. N. Panin, I. V. Solomonova [2012]. It has been found that the Siberian area is subject to the highest influence of NAO, SCAND, AO, and SOI (the Southern Oscillation index). The researchers point out that the correlation between temperature variability over the Siberian region is significantly high with variability in SCAND and AO and is considerably low with that of NAO and SOI.

To provide statistical estimation of time sequence for climatic indices, mean values were calculated, time sequence variability was measured by using calculated values of mean square errors, and tertiary and quartic central moments were used as criteria for estimating time sequence for homogeneity (asymmetry and excess). In practical estimation asymmetry is considered small with $|A| \leq 0.25$, while with $|A|>1.5$ asymmetry is exceedingly large. Excess estimations vary within the range of [–2, ∞]. At $-0.5 < E_x < 3$ the distribution is considered close to normal.

To estimate long-term changes in time sequence of climatic indices, trend analysis (linear) was used, the significance of which was determined on the basis of coefficients of approximation (determination). Integrated spectrum (the periodogram method) was applied to do research on latent periodicity in long-term index values.

Using the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) reanalysis, monthly mean anomalies of air temperature and wind currents in mid-troposphere were estimated in order to investigate the extent of the impact provided by large-scale circulation factors upon temperature variability over the area of the Baikal region.

Results and discussion

Table 1 demonstrates statistical characteristics of the indices under research, estimated for the period of 1940-2017. In asymmetry value, which for all climatic indices did not exceed 0.25, and in excess value the distribution tends to normality.

Table 1

Statistical characteristics of the indices under research, 1950-2017, (obtained by the author)

Characteristic	NAO	AO	WP	PNA	EA/WR	SCA	POL
Mean value	-0.09	-0.22	0.02	-0.11	0.03	0.12	0.02
Mode	0.35	-0.54	0.60	-0.04	0.48	0.06	-0.19
Standard deviation	1.09	1.10	1.09	1.04	1.12	0.99	1.05
Sample variance	1.19	1.22	1.19	1.07	1.25	0.98	1.10
Excess	-0.28	-0.21	-0.02	-0.10	0.14	-0.17	0.00
Asymmetry	-0.15	-0.17	-0.18	-0.21	0.07	0.11	-0.05
Minimum	-3.14	-3.33	-3.45	-3.65	-4.17	-2.44	-3.44
Maximum	3.06	3.48	3.39	2.87	3.68	3.15	3.53

According to the trend analysis data, no significant coefficients of the linear trend were identified in any of the indices under consideration over the time period of 1950-2017. Moreover, long-term changes in the indices appear to be unrelated (table 2).

Table 2

Correlation matrix of the indices under research, estimated for the period 1950-2017

	NAO	EA	WP	PNA	EA/WR	SCA	POL
NAO	1						
EA	-0.01	1.00					
WP	0.08	-0.02	1.00				
PNA	0.03	0.10	0.03	1.00			
EA/WR	0.06	-0.06	0.06	0.02	1.00		
SCA	0.03	-0.06	0.00	0.00	0.01	1.00	
POL	-0.09	0.02	-0.05	0.00	-0.01	0.08	1.00

On the basis of the periodogram method the prevailing cycles in the climatic indices variability were identified. POL and SCAND cycles agree in time, which can be accounted for by the fact that in the locations in question the predominating anticyclonic type of atmospheric circulation is frequently observed. As is clear from the data provided in table 3, among the cycles predominating in temporal variability of climatic indices the following ones may be identified: annual and half-year cycles, intra-annual three- and four-month seasonal cycles, 13- and 14-year cycles, and a 33-year cycle.

Table 3

Predominant periods in long-term dynamics for the indices,1950-2017

NAO	EA	WP	PNA	EA/WR	SCA	POL
1 year 3 years 6 months 9 months	17 years 33 years 14 years 4 years	1 year 4 years 6 months 3 years 2 years	1 year 13 years 3 years 2 months 9 months	1 year 33 years 3 months 5 months	1 year 33 years 4 months 3 months	1 year 33 years 4 months 3 months

To investigate thermal response to circulation conditions, pair correlation values between monthly means of climatic indices and monthly air temperature means in Irkutsk station were estimated. The upper-range pair correlation coefficient values proved to have been found between mean monthly temperature variations in Irkutsk and SCAND values, with negative association remaining stable in all months. Thus it can be concluded that increasing atmospheric pressure in the Scandinavian area gives rise to decreasing air temperature in Irkutsk, which can be explained by blocking processes preventing cyclonic tilt and the associated heat currents shift into the area of Baikal region, especially in the cold season. Of interest is the fact that the association with POL values, conversely, remains positive in all months. No significant statistical associations were found with any other climatic indices reflecting circulation processes in the Atlantic and Pacific oceans.

Summer months of the years 2000–2017 are of particular interest when considered from the viewpoint of estimating how extensive the impact of circulation factors is upon temperature variability in the Baikal region. The researchers' interest in the issue is due to the fact that in recent years summer months in the Baikal region have been notable for rapidly rising temperature and increasing aridity. Besides, the research done on summer temperature change is relatively limited, unlike winter temperature regime that has been extensively studied.

Fig. 1 demonstrates the mean monthly temperature anomaly map based on NCEP/NCAR reanalysis data for June in 2000–2017. It is evident that over the territory of Eurasia the air temperature means in June are largely increasing, with the Baikal region being the area to experience the highest mean temperature rise. In July and August the increase is less strong, while in the Baikal region it remains stable.

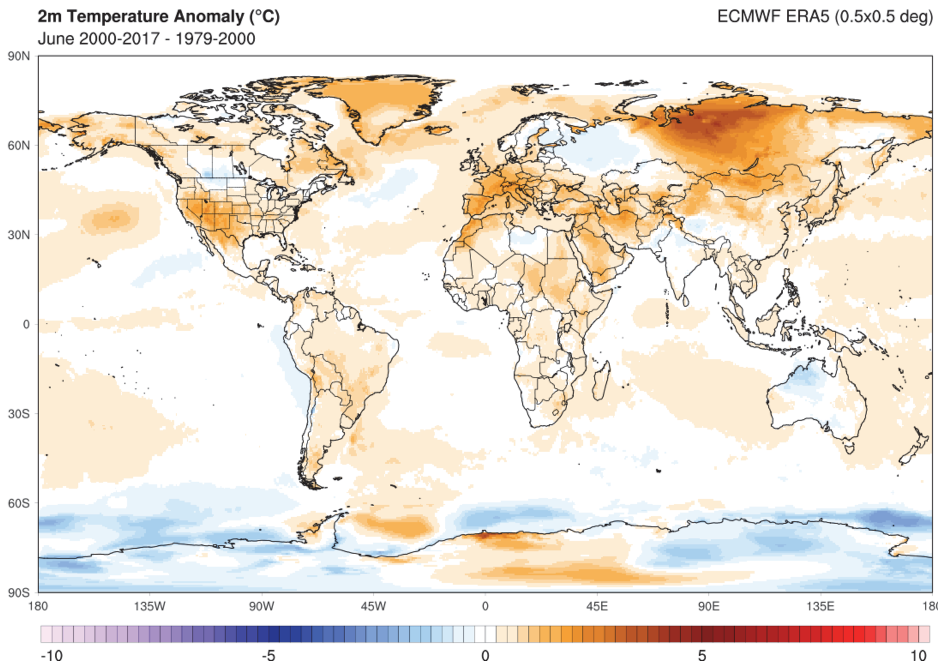

Fig.1. Anomaly map of mean monthly surface temperature in June 2000–2017 compared to 1979–2000

Investigation of air temperature anomalies at mid-troposphere height (AT-500 hPa) shows that in June in the Baikal region temperature increase prevails (fig. 2). In July at 5km-height the temperature increase is moderate, while in August in mid-troposphere over the Baikal region temperature decrease is observed.

Analysis of the predominating wind currents at height 850 hPa (1.5 km) shows that over the Baikal region in summer months 2000–2017 wind currents from the south, which are associated with heat transfer to the area, strengthened (fig. 3).

For quantitative estimation of heat fluxes, horizontal advection was calculated as product of air temperature mean at the height given and wind velocity mean in the northern (based on Nakanno station data) and southern (based on Irkutsk station data) areas of the Baikal region respectively. It turned out that despite temperature increase in the context of the prevailing decrease of wind in summer months heat advection decreases (fig. 4).

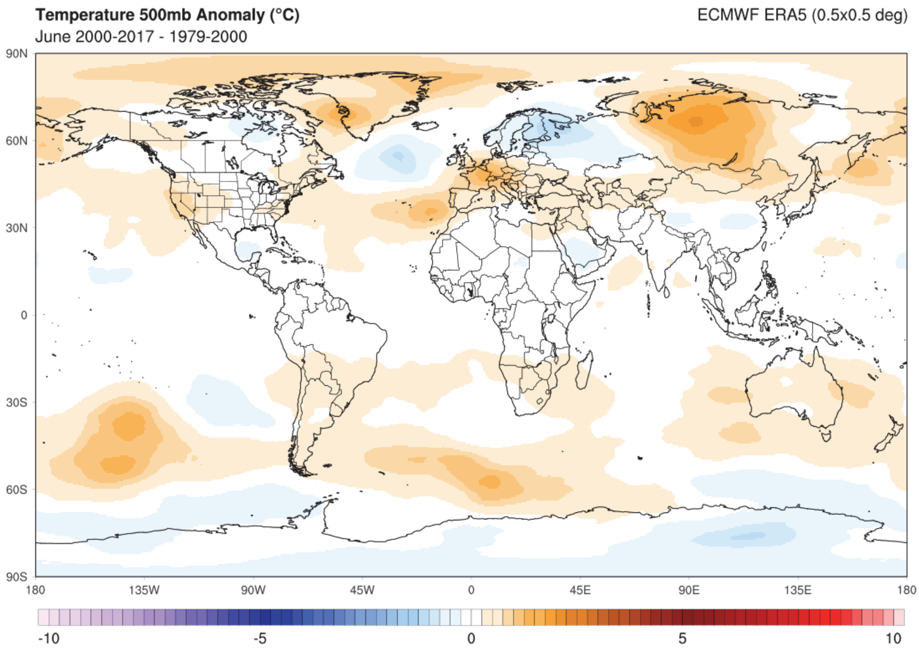

Fig. 2. Anomaly map of mean monthly surface temperature at AT–500 hPa (5 km) in June 2000–2017 compared with 1979–2000

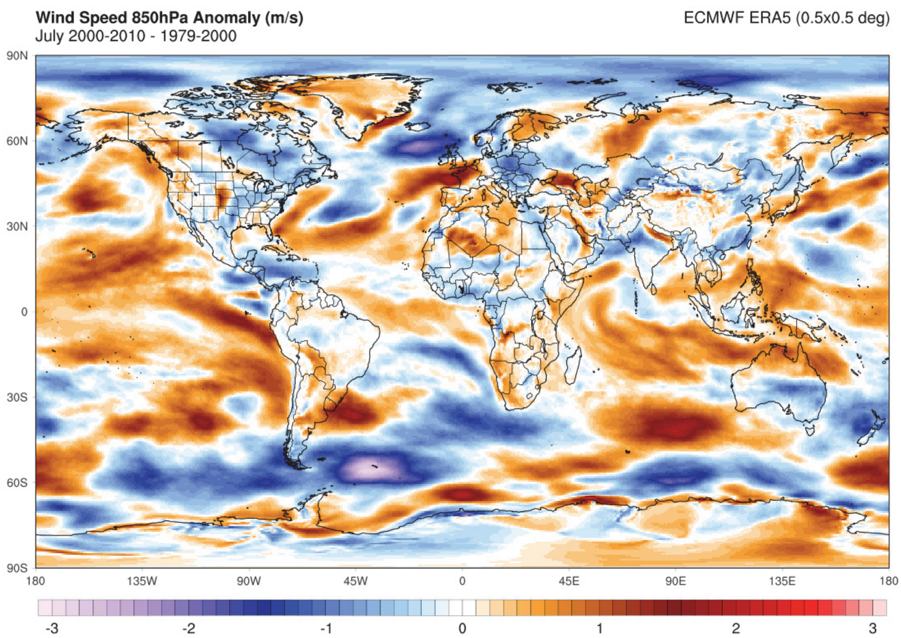

Fig. 3. Wind current anomaly map at AT–850 hPa (1.5 km) in July 2000–2010 compared to 1979–2000 (obtained by the author using Reanalysis data)

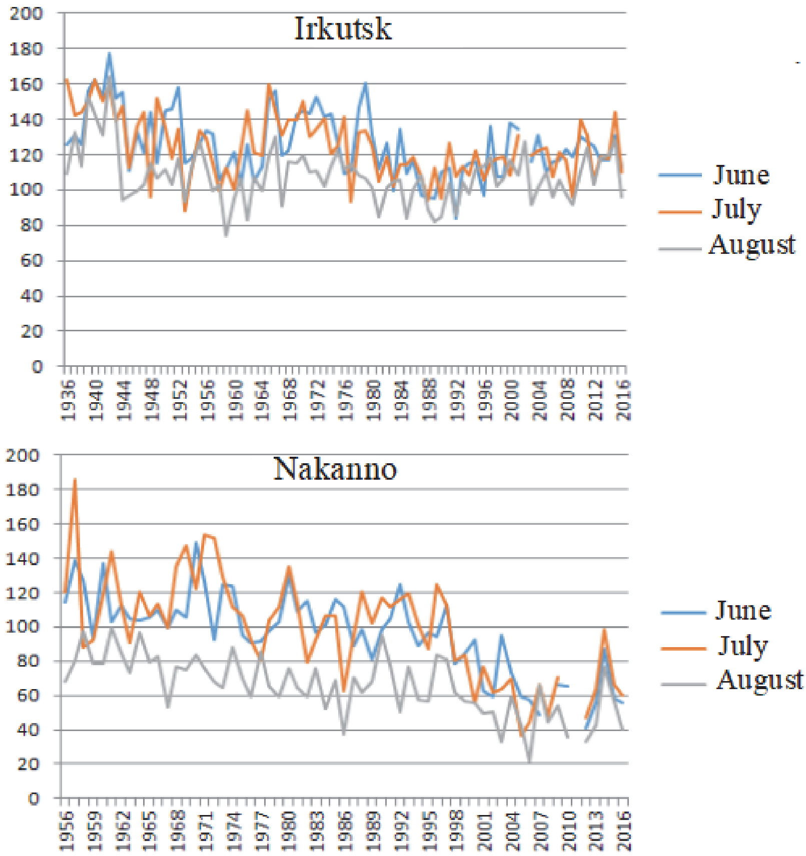

Fig. 4. Advective transfer (°C·m·c^{-1}) in summer months, 2000–2017, at meteorological stations Irkutsk and Nakanno

Therefore, over the Baikal region territory in summer 2000–2017, average temperature is increasing, especially in June, against the background of large-scale increase in summer temperatures. In June and July temperature increase is registered not only in lower, but also in middle troposphere.

Temperature increase in summer months correlates well with strengthening heat fluxes from the south. At the same time, summer decrease of wind observed in long-term dynamics results in significant decrease in heat advection over the Baikal region.

Conclusion

The investigation has shown that no linear patterns have been observed in long-term changes of atmospheric circulation indices in the Polar, Atlantic, and Pacific regions of the Northern Hemisphere in 1950-2017, while in zonal and global temperature change patterns linear relations appear more evident.

It is worth mentioning that long-term variations in climatic indices do not appear interrelated, thus making it more complicated to find the reasons for the climatic changes being observed in various regions of the Northern Hemisphere.

The cyclical nature is pronounced in climatic indices variability, with the following cycles being identified as predominating: annual and half-year cycles, intra-annual three- and four-month seasonal cycles, 13- and 14-year cycles, and a 33-year cycle.

For the first time a study was undertaken on the circulation factors affecting temperature increase observed in summer months in 2000-2017 over the area of the Baikal region. It was proved that temperature increase is closely associated with increasing frequency of wind currents having a southerly component.

Quantitative estimation of heat advection in northern and southern areas of the Baikal region was made having regard to the fact that heat advection is subject to significant influence not only from summer temperature increase but also from decrease of wind.

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