PAPER • OPEN ACCESS

Climatic changes in European Russia and the Republic of Belarus in the XX-XXI centuries under the influence of atmospheric circulation

To cite this article: Yu P Perevedentsev *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1023** 012002

Climatic changes in European Russia and the Republic of Belarus in the XX-XXI centuries under the influence of atmospheric circulation

Yu P Perevedentsev[1], B G Sherstyukov[2], K M Shantalinsky[1], V V Guryanov[1], N A Mirsaeva[1], P S Lopukh[3], Yu A Gledko[3], N V Ismagilov[1] and A A Nikolaev[1]

[1] Department of Meteorology, Kazan (Volga Region) Federal University, Kazan, Russia
[2] Russian Research Institute for Hydrometeorological Information – World Data Centre, Obninsk, Russia
[3] Belarusian State University, Minsk, Republic of Belarus

E-mail: Yuri.Perevedentsev@kpfu.ru
ORCID ID 0000-0002-3181-6227

Abstract. Climatic changes in the atmosphere from the Earth's level to the altitude of 80 km in Russia and the Republic of Belarus (RB) are considered using data from 1251 stations of RIHMI-WDC (1976-2019), ERA5 reanalysis (1979-2019), and 99 long-row stations located in the European part of Russia (ER) and the Republic of Belarus (RB). An analysis of constructed trends in the air temperature (AT) and atmospheric precipitation is made to assess the spatial and temporal variability of the thermal and humidity regimes in the territory. Some differences in the rates of warming between the winter and summer seasons, troposphere and stratosphere are revealed. Near the earth's surface, the rate of warming is maximum in polar latitudes; the summer stratosphere cools more strongly than the winter one. To assess the influence of atmospheric circulation on the thermal regimes of ER and RB, the correlation coefficients between AT and circulation indices AO, NAO, SCAND, and EAWR are calculated. Using a low-pass Potter filter, a 40-year periodicity of temperature fluctuations in the ER and RB in November is revealed. In the winter stratosphere, a relationship between temperature fluctuations in the polar zone and the Arctic oscillation index is found. The spring restructuring of the stratospheric circulation occurs with a delay if strong sudden stratospheric warmings (SSW) occur in the stratosphere in winter.

1. Introduction

Modern climatic challenges are widely discussed in scientific and socio-political circles, in connection with their possible negative consequences for natural and socio-economic systems. In order to protect states from adverse climatic consequences and ensure their sustainable development, the Paris Agreements were signed in December 2015 aimed at limiting greenhouse gas emissions into the atmosphere to avoid an increase in the average global temperature by 2°C. Subsequently, this bar was lowered to 1.5°C. In [3], the consequences for natural and socio-economic systems that may arise in the world in the event of an increase in the average global temperature by 1.5°C are discussed. In Russia, they treat the problem of global warming with understanding, since on its territory, and especially on the Arctic coast, the rate of warming is higher than in other regions of the world. In 2009, the Climate Doctrine of the Russian Federation was adopted, and a generalization of the results of modern climatic studies obtained by Russian scientists was presented in [2]. It should be noted that the nature of the current and future climatic changes is not entirely clear and there are various assumptions in this regard [4]. Among the most recent events, the climate conference in Glasgow (October 31 - November 12, 2021) should be noted, which discussed a wide range of issues to reduce the impact on the climate system.

The results of long-term studies of the spatial and temporal variability of the main climatic indicators in different periods of time in the Northern Hemisphere and in the Volga region, in particular, are contained in scientific articles [7-11] by the authors.

IOP Conf. Series: Earth and Environmental Science 1023 (2022) 012002 doi:10.1088/1755-1315/1023/1/012002

The purpose of this article is to consider the spatial and temporal changes in the main climatic indicators on the territory of Russia and the Republic of Belarus in the modern period of global warming in two periods, 1976-2019 and 2001-2019, as well as to describe the changes in the air temperature from the Earth level to an altitude of 80 km, the relationship between the layers of the atmosphere and the nature of spring rearrangements of the stratospheric circulation with the use of data from a more perfect ERA5 reanalysis in 1979 - 2019. In this reanalysis, data on AT and geopotential in the layer under consideration are presented on 51 isobaric surfaces with a resolution of 1x1°. The calculations were carried out using data from 1251 meteorological stations located in Russia from the RIHMI-WDC from the fund for 1976-2019.

2. Methods

Long-term series of ground-level initial data were subjected to statistical processing: mean values, standard deviations (SD), air temperature and precipitation anomalies, linear trends in the temperature and precipitation in Russia and the Republic of Belarus for 1976-2019 and 2001-2019 were found. At the tropos-stratospheric levels, mean values of AT, standard deviations, the linear trend slope coefficient (LTSC), and the coefficients of linear trend determination were calculated both for the entire Northern Hemisphere and its three zones: the polar (65 - 90°N), moderate (30 – 65°N), and tropical ones (0 – 30°N). To assess the degree of vertical interconnection of the processes, the correlation coefficients between AT at various levels were calculated, and the influence of the Arctic oscillations on AT oscillations was also assessed. The dates of spring rearrangements of the stratospheric circulation (replacement of the western flows by the eastern ones) were determined using the the A.L. Katz zonal circulation indices calculated on the isobaric surface of 10 hPa (31 km) in the latitudinal zone of 30 - 90°N.

3. Results

Air temperature trend maps were constructed for the central months of the seasons and annual values for the entire territory of Russia based on data from 1251 stations for 2 periods: 1976-2019 and 2001-2019. Let us first consider the spatial distribution of temperature trends over the entire 44-year study period (1976-2019). In January (Figure 1), the highest warming rate is observed in Central Siberia, the Arctic coast with a maximum on the Taimyr Peninsula, and the Arctic islands from Novaya Zemlya to the New Siberian Islands, where the linear trend slope coefficient (LTSC) reaches 1.2°C/10 years, a significant increase in AT (LTSC = 0.80 – 0.99°C/10 years) is observed in the Khabarovsk territory, in the European part of Russia (ER), the north-west stands out, where the LTSC in the Arkhangelsk region reaches 0.80-0, 99°C/10 years. The rest of the ER is also experiencing warming, but less intensity (LTSC varies within the range of 0.20-0.59°C/10 years). Cold snap centers were formed in the south of Western Siberia, where the LTSC is <0 and varies from -0.40 to -0.79°C/10 years, and in Eastern Siberia (Magadan region).

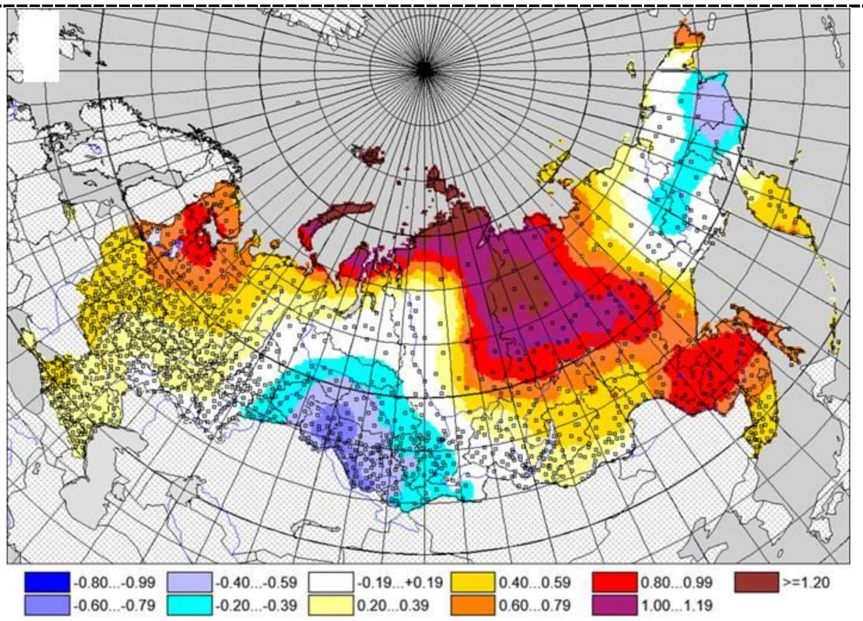

Figure 1. Temperature trend (°C / 10 years). January. 1976-2019.

In July (Figure 2), the west and southwest of ER are occupied by a fairly intense warming area (LTSC varies from 0.60 to 0.99°C/10 years), in the rest of Russia, with the exception of the middle zone of Western Siberia, where warming is practically absent, a weak AT growth prevails at a rate of 0.20 to 0.59°C/10 years. The trends in the average annual temperature indicate a moderate warming of the climate practically throughout the entire territory of Russia. It occurs most intensively on the Arctic coast of the Asian part of Russia and adjacent islands. Thus, in the Taimyr Peninsula area LTSC reaches a value of 1.2°C/10 years. At the same time, in the central and northern parts of Siberia the warming is more pronounced than in the ER, where Karelia and the south-west of the Central Federal District are distinguished (LTSC = 0.60-0.79°C/10 years).

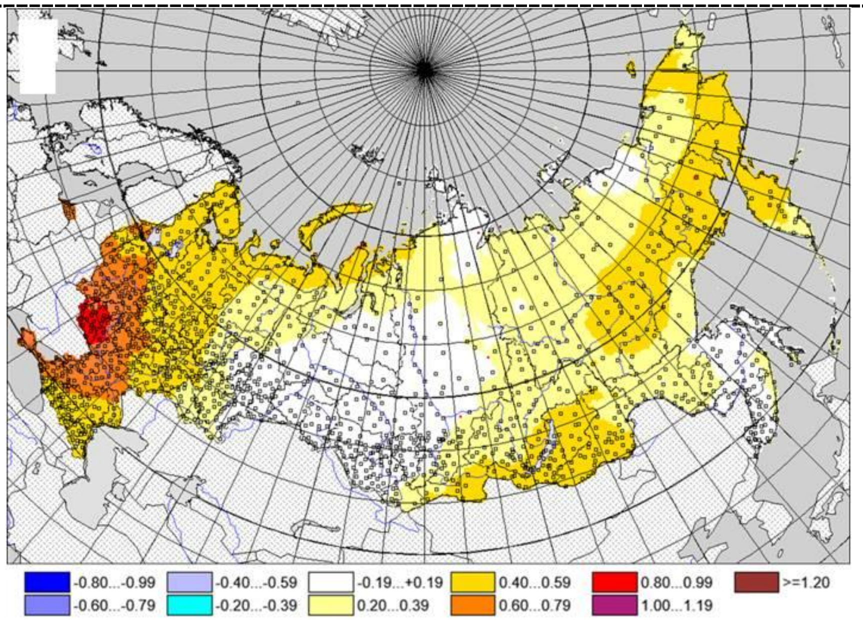

Figure 2. Temperature trend (°C/10 years). July. 1976-2019.

The AT trends plotted using the average annual values of 1251 stations for 2001-2019 do not reveal significant territorial contrasts in the temperature changes. Almost the entire territory of Russia, with the exception of a rather narrow strip in the south of Western Siberia, where the LTSC is of the order of -0.20-0.49°C/10 years, is occupied by warming, which is more intense in the north of the ER, Western Siberia, the Arctic coast, in Chukotka, where a rapid warming can reach 1.49°C/10 years. Thus, the distribution of trends in the average annual air temperature in 2001-2019 in contrast to the entire period of 1976-2019 reveals a noticeable cooling in the south of Western Siberia.

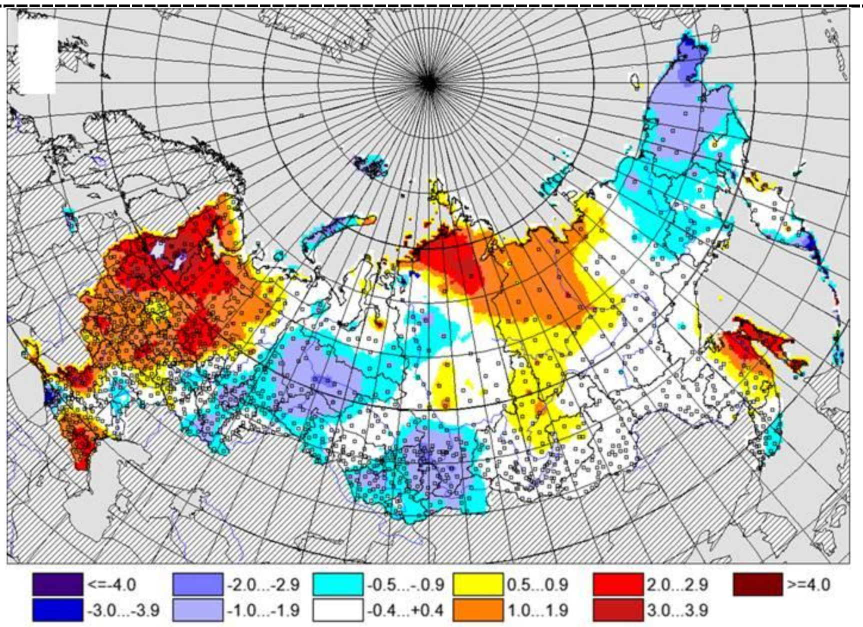

Figure 3. Precipitation trend (mm/10 years). January. 1976-2019.

Consider the regional features of the change in the precipitation regime in 1976-2019 on the Russian territory. The spatial pattern of the distribution of precipitation trends over the territory of Russia is very heterogeneous. Thus, in January (Figure 3) in ER there is an increase in the precipitation at a rate of 1.0-1.9 mm / 10 years with a maximum in the north-west, where LTSC = 2.0-2.9 mm/10 years. In the center and in the south of Western Siberia, in Altai and in the northeast of Eastern Siberia, including Chukotka, a decrease in the precipitation is noted (LTSC reaches -2.0-2.9 mm/10 years). At the same time, the northern region of Western and Central Siberia is distinguished from the Taimyr Peninsula to the New Siberian Islands, where the precipitation increases at a rate reaching 2.0-2.9 mm/10 years.

In July (Figure 4), almost the entire ER except for the north-west, the western part of Western Siberia, the Arctic coast from Taimyr to Chukotka, Magadan Oblast and Kamchatka, Prebaikalia and Transbaikalia are in the zone of decreased precipitation, so the LTSC is <-4 mm / 10 years in ER and Kamchatka, while the south of Eastern Siberia, Priamurye and Primorye are located in the zone of precipitation growth (LTSC > 4 mm/10 years). The trends based on annual precipitation values indicate an increase in the precipitation over most of Russia. Thus, on the coast of the Sea of Okhotsk, LTSC > 25 mm/10 years. A decrease in the amount of precipitation is observed in the center and in the south of the ER, the North Caucasus, where the LTSC is ~ -10-14 mm/year. Small foci with a precipitation decrease are noted on the island. Novaya Zemlya, the south of Central Siberia, the northeast of Chukotka. The annual picture of the trends in the amount of precipitation obtained by using data from 1251 stations in 2001-2019 is motley, contrasting. The northwest ER, the Middle Volga region, the Taimyr Peninsula, eastern regions of Russia are in the zone of precipitation growth at a rate of 40 mm/10 years. The greatest increase in the amount of precipitation occurs in the Amur and Primorye regions. A lack of precipitation is noted in the south of ER, the North Caucasus, in the northeast of ER, in Central Siberia, and on the Arctic coast near the New Siberian Islands. Thus, in the Black Sea region LTSC reaches -50 mm/10 years.

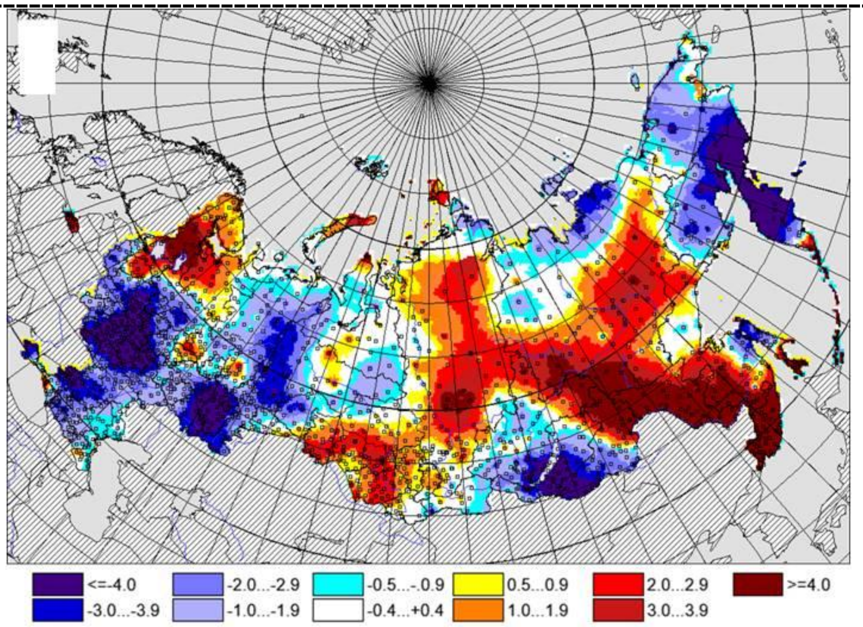

Figure 4. Precipitation trend (mm/10 years). July. 1976-2019.

According to data from 99 stations of long-period meteorological stations in 1900-2019 (120 years) for the European part of Russia and the Republic of Belarus, the variability of the temperature regime is considered. Climatic maps of air temperature distribution were constructed for different months of the year, seasons, and for the whole year. Additionally, maps of the spatial distribution of the correlation coefficients were constructed, calculated between the average temperature of the entire region under consideration and the temperature of individual stations for January, July, the winter and summer seasons.

In order to identify long-term trends in the thermal regime, linear trends in the air temperature were constructed for each of the months of the winter and summer seasons, and annual values. To highlight long-term temperature fluctuations in 1900-2019, low-frequency components (LFCs) were calculated with a period of more than 20 years. The calculation results are presented in Table 1.

As one can see from Table 1, on the territory under consideration the annual AT variation is clearly manifested with minimums in January (-11.30°C) and maximums in July (18.38°C). The annual amplitude is 29.68°C. The mean square deviations of the AT range are from 3.19°C (February) to 1.24°C (August). The highest value of the linear trend slope coefficient (LTSC) is in March (0.290°C/10 years), and the lowest one in August (0.068°C/10 years). December also stands out, where LTSC = 0.226°C/10 years. Thus, according to the averaged data for the territory, warming is observed in all months of the year, but with different intensity.

Table 1. Characteristics of changes in air temperature averaged over the European part of Russia and Belarus in 1900-2019.

Month	Av,°C	Rms,°C	A,°C/10 years	R^2L,%	R^2F,%
I	-11.30	3.02	0.165	2	12
II	-10.54	3.19	0.195	3	12
III	-4.95	2.50	0.290	15	24
IV	3.68	1.95	0.161	7	12
V	10.68	1.75	0.171	10	17

VI	15.89	1.33	0.081	3	11
VII	18.38	1.30	0.094	5	15
VIII	16.49	1.24	0.068	2	23
IX	10.84	1.34	0.090	4	15
X	3.83	1.78	0.127	5	15
XI	-3.12	2.20	0.094	1	18
XII	-8.51	2.83	0.226	6	12
I-XII	3.45	0.96	0.147	27	38
XII-II	-9.60	2.07	0.190	9	15
VI-VII	16.92	0.90	0.081	8	22

Note: Av – mean value (°C), Rms – standard deviation (°C), A – LTSC (°C/10 years), R^2L – coefficient of determination of linear trend (%), R^2F – coefficient of determination of low-frequency component (%).

As one can see from Table 1, the year-averaged LTSC value is 0.147°C/10 years, while in winter the warming rate (A =0.190°C/10 years) is twice the summer warming rate (A = 0.081°C/10 years). In general, the average annual AT for the entire territory under consideration is 3.45° C, Rms =0.96°C, and the warming rate is 0.147°C/10 years.

According to Figure 5, in the winter period in the region since the beginning of the 1970s, according to the LTSC curve, there has been an increase in AT by about 2.8°C, in the summer period an active increase in AT began in the mid-1970s and amounted to only 1.5°C of the LFC. On the annual basis, the warming was ~ 2°C. Thus, since the beginning of the 1970s a noticeable climate warming has been taking place in the region, which differs in its intensity and character in different months of the year, which is clearly seen from the behavior of the LFC of the air temperature. For example, in November the periodicity of temperature changes is clearly traced: the LFC curve has the form of a wave with a duration of ~ 40 years.

The constructed climatic maps of the air temperature distribution for January and July (1900-2019) show that AT decreases from the southwest to the northeast. Thus, the average January temperature on the territory of the Republic of Belarus is about -6°C, in the North Caucasus it is positive (~ + 4°C), and in the northeastern ER it drops to -22°C, in July the isotherms have a quasi-zonal character and AT increases from north of ER to south from 10°C to 24°C in the North Caucasus. On the territory of the Republic of Belarus, the average July temperature is ~ 18°C.

In winter, the average AT for Belarus is about -4°C, in the northeast of the ER it is about -20°C, it is warm in the Black Sea coast, where AT is ~ + 4°C, in summer the average AT in the North Caucasus is 22°C, in the Arctic on the coast of ER it drops to 8°C, on the territory of the Republic of Belarus ~ 18°C. The isotherms of the winter and summer temperatures practically coincide with the average January and average July temperatures.

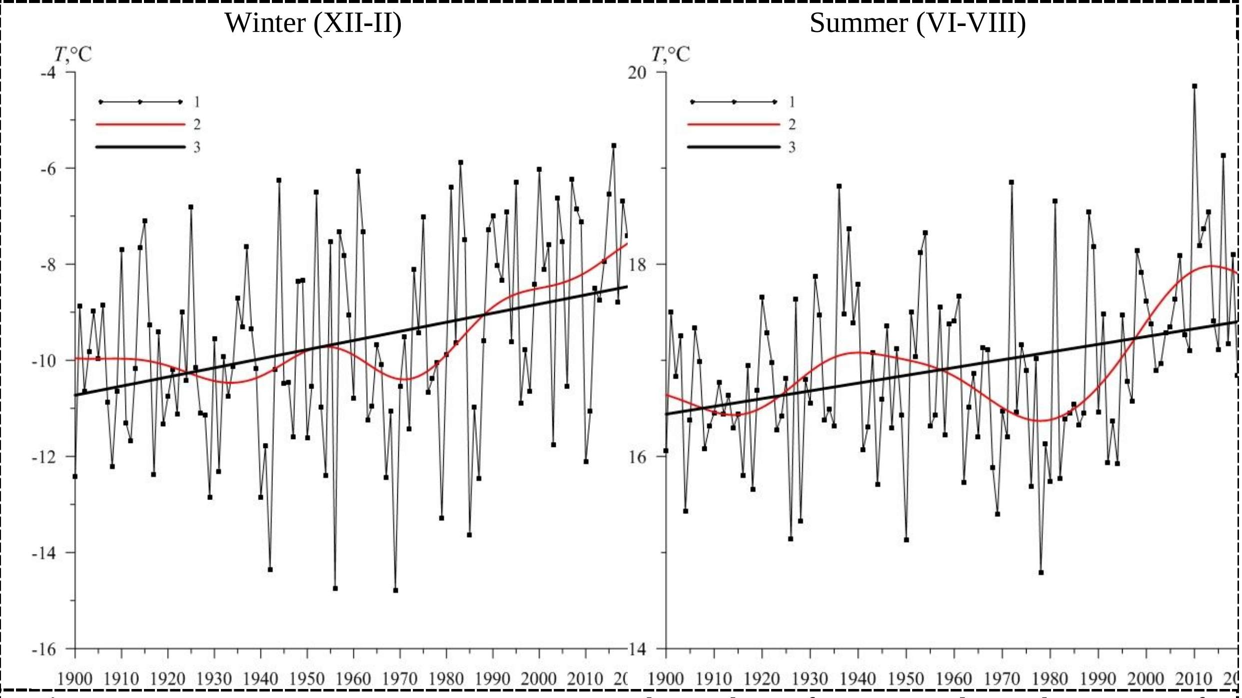

Figure 5. Long-term air temperature variation near the Earth's surface averaged over the territory of ER and RB (1900 - 2019) in winter and summer. 1 - initial row, 2 - LFC, 3 - linear trend.

The correlation coefficients (r) were calculated between the air temperature averaged over the entire region and the temperatures of 99 stations. Since the average temperature over a region refers to its center, the constructed isocorrelate maps allow one to estimate both the shape and the rate of decay of bonds in the temperature field with distance. Thus, if for January, as well as winter in general, the isocorrelates form an ellipse with a major axis directed from southwest to northeast (the direction of the defining flow), then in July (and in summer) the oval is elongated in the meridional direction. At the same time, the statistical connections in winter are closer with remote areas than in summer. Thus, in January the correlation coefficient between RB and the center of ER is about 0.8, then in July r = 0.4. The same is observed for the winter and summer.

To assess the effect of atmospheric circulation on the thermal regime of the region, we used the correlation coefficients r over a 120-year period between the time series of atmospheric circulation indices: the Arctic oscillation (AO), the North Atlantic fluctuation NAO, fluctuations of the Eastern Atlantic - Western Russia (EAWR), the Scandinavian oscillation (SCAND) and the air temperature at individual stations. Correlation maps were constructed for January and July. The following features were revealed. In January, with the Arctic Oscillation (AO), the connections are closer in the west of the region (in Pskov region r = 0.6); in the direction from west to east they weaken in the Cis-Urals (r = 0.4). In July, the connections are insignificant. The links with the North Atlantic Oscillation (NAO) index in January are also closer in the western part of the region (r = 0.6), in the eastern direction there is a noticeable weakening of the influence of NAO, and in the southeast of ER r decreases to 0.2 and lower values (Orenburg). In July, the values of the correlation coefficients are insignificant, ~ 0.2. Thus, the Arctic Oscillation and the North Atlantic Oscillation have a noticeable effect on the thermal regime of the region in winter, and primarily on its western part. This impact is positive, i.e., the atmospheric circulation contributes to the region warming during winter. The circulation mode of East Atlantic-Western Russia (EAWR) has the greatest influence in the summer, and mainly on the center and especially the east of the region, where r = -0.6, which indicates the cooling effect of the North Atlantic during this period. The relationship between the air temperature and the SCAND index in January is better expressed in the center and especially in the east of the territory (Ural, Orenburg region, North Caucasus), where r takes a negative value (r = -0.6). Thus, the formation of the blocking Scandinavian anticyclone noticeably affects the winter thermal regime in the east of ER and contributes to a decrease in AT. In July, the connection between the components is better in the northwest of ER (r = + 0.4) and weakens in the direction of the southeast.

Currently, the troposphere and stratosphere are often considered as a single thermodynamic system whose individual layers interact with each other and affect the weather and climatic processes near the Earth.

Let us consider the distribution of AT, SD, the values of the slope trend coefficient on 51 isobaric surfaces averaged over the entire Northern Hemisphere for the year, winter and summer. In the troposphere, AT decreases with height, its inversion is observed in the stratosphere, and in the mesosphere it decreases again, which corresponds to the physical concepts presented in [5]. At all levels, there is an annual amplitude of AT fluctuations, and if the temperature rises in the troposphere (LTSC > 0), then a cooling is observed in the stratosphere (LTSC <0). The greatest interannual variability, according to the SD distribution, is observed in the mesosphere, where the summer temperatures are lower than the winter ones. Thus, at the level of 0.01 hPa (80 km) in summer AT ≈ - 92 ° C, and in winter, - 75 ° C. The cooling trend at the stratospheric levels is better expressed in summer than in winter, when the dynamic processes in the atmosphere are more active (the emergence of SSW, wave interaction between the layers, etc.). At the same time, as follows from the peculiarities of the vertical profiles of LTSC AT for the polar and temperate zones, in the polar zone there are significant differences between the January, July, and annual distributions, while in the temperate zone these discrepancies are noticeable only from a level of 40 km. An analysis of the calculated correlation coefficients (r) between the temperatures of various isobaric surfaces shows that the bonds are closest in the troposphere; they weaken and change sign when passing through the tropopause. At the same time, in the stratospheric polar zone the connections between neighboring levels are closer in January than in July, and in the tropical zone the seasonal differences are not so pronounced. This is especially noticeable when analyzing the distribution map of r in the 20 – 10 hPa layer. Above the level of 10 hPa, especially in January, the vertical ties are strengthening.

The influence of atmospheric circulation on the temperature regime of the tropos-stratosphere was estimated using the calculated correlation coefficients between the AT oscillations and the Arctic oscillation index. As you know, the Arctic oscillation is largely the result of the interaction of the troposphere and stratosphere. The highest correlation is found in winter for the polar zone at a level of 10 km (r = -0.60), in summer the connection weakens, and at heights of 10 – 12 km r = 0.32. Indeed, during the positive phase of the Arctic oscillation the winter circumpolar vortex intensifies, which leads to a cooling of the stratosphere. This explains the negative sign of the correlation coefficient in winter. In the case of destruction of the polar vortex, AO weakens, and AT increases, which also leads to a negative relationship between them.

As is known, in winter, due to the appearance of a circumpolar cyclone, the west-east transport dominates in the stratosphere; in summer, under the conditions of a circumpolar anticyclone, the flows change their direction to the opposite. It is of scientific and predictive interest to estimate the timing of the spring restructuring of the circulation in the stratosphere, which has a significant interannual variability. In [3], the process of spring rearrangements of the stratospheric circulation (SC) on the isobaric surface of 10 hPa (31 km) in 1958 – 2000 was investigated, and their connection with large-scale circulation processes in the troposphere was established. In this article, all dates of the spring restructuring have been attributed to three types: April 5 separates the early and middle restructuring, and April 26, the middle and late one.

As a rule, the spring restructuring begins in the polar zone in the 30 – 45 km layer due to intense absorption of ultraviolet radiation by ozone [6]. To determine the timing of the spring restructuring of the SC, the indices of the Katz zonal circulation in the latitudinal zone of 30 – 90°N were calculated using the geopotential field at a level of 10 hPa in 1979 – 2019. The date of a stable transition of the zonal index from positive values to negative values was considered as the date of the SC restructuring.

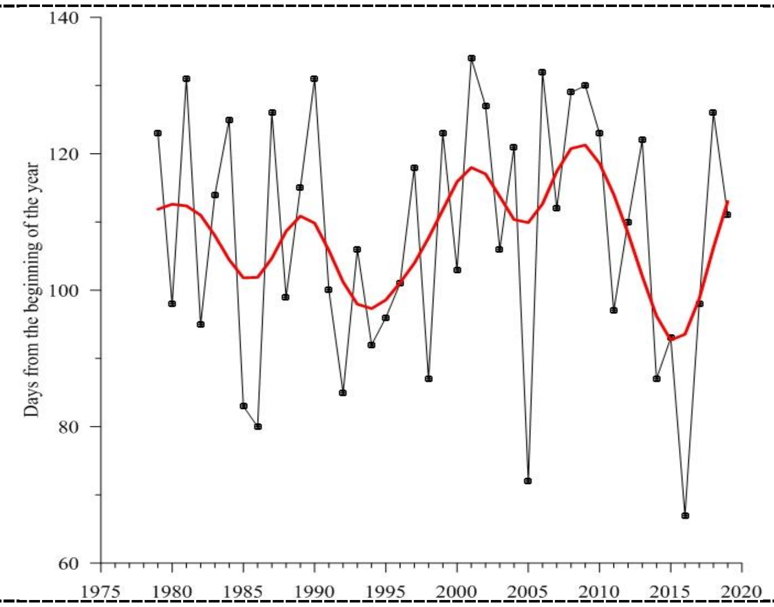

Figure 6. Dates (days from the beginning of the year) of spring circulation rearrangements (initial series and NPC with a period of more than 7 years) in the stratosphere at a level of 10 hPa in the latitudinal zone of 90-30°N.

Figure 6 shows a long-term variation of the dates of spring circulation rearrangements (in days from the beginning of the year) smoothed using the Potter filter (with a period of more than 10 years). As seen in Fig. 6, the scatter of the dates of the spring rearrangements of the SC is large (from 67 days from the beginning of 2016 (March 7) to 134 days (May 4, 2021). Table 2 shows the types and dates of the spring rearrangements of the SC.

A positive correlation (r = 0.70) was established between the LFC of the dates of stratospheric circulation rearrangements and solar activity (Wolf numbers) for 1979-2004. The dependence of the dates of the late SC rearrangements on the occurrence of a strong SSW in the winter stratosphere was also revealed. In [1], information about a strong SSW is given. A comparison of data on late perestroika with data from [1] shows that late perestroika occurs in years with strong SSW. In addition, in the polar zone (90 - 70°N) in 1986 – 2002 there was a tendency for the dates of spring rearrangements to be delayed at a rate of ~ 27 days /10 years, and in a later period (2002 - 2019), on the contrary, spring rearrangements began to occur earlier at a rate of 18 days/10 years.

Table 2 - Types and dates of spring rearrangements of the stratospheric circulation on the isobaric surface of 10 hPa in 1979 - 2019.

Rebuilding type					
Early		**Middle**		**Late**	
year	date	year	date	year	date
1982	5 April	1980	7 April	1979	3 May
1985	24 March	1983	24 April	1981	11 May
1986	21 March	1988	8 April	1984	4 May
1992	25 March	1989	25 April	1987	6 May
1994	2 April	1991	10 April	1990	11 May
1998	28 March	1993	16 April	1997	28 April
2005	13 March	1995	6 April	1999	3 May
2014	28 March	1996	10 April	2001	14 May
2015	3 April	2000	12 April	2002	7 May
2016	7 March	2003	16 April	2004	30 April
		2007	22 April	2006	12 May
		2011	7April	2008	8 May

	2012	19 April	2009	10 May
	2017	8 April	2010	3 May
	2019	21 April	2013	2 May
			2018	6 May

4. Conclusions

As a result of the above analysis of trends in the air temperature and precipitation in Russia and the Republic of Belarus, it has been revealed that in 1976–2019 almost throughout the entire territory of Russia and Belarus there was warming, with the exception of the southern regions of Western Siberia. In addition, in most of the territory under consideration, there was an increase in annual precipitation.

In the European part of Russia and in the Republic of Belarus in 1900 – 2019 the highest rate of warming is observed in March (LTSC = 0.290°C/10 years) and December (LTSC = 0.226°C/10 years). In the winter season, warming is twice as intense as in summer; the annual warming rate is 0.147°C/10 years.

An assessment of the effect of circulation modes on the thermal regime of ER and RB has shown that the North Atlantic Oscillation (NAO) acts most effectively in winter, which leads to an increase in the temperature; in summer, the EAWR oscillation leads to cooling of the territory. The Scandinavian anticyclone most greatly affects the east of ER (a strong cooling occurs).

On the average, for the Northern Hemisphere in winter and summer the air temperature LTSC is positive in the troposphere; in the stratosphere, from an isobaric surface of 100 hPa to a surface of 0.5 hPa, a cooling is observed, which is especially intense in the 35 – 45 km layer (LTSC <0). Some warming begins again in the mesosphere.

The correlation coefficients calculated between AT values on different isobaric surfaces become negative when passing through the tropopause. In winter, the spatial r distribution in the stratosphere is influenced by a wave interaction between the troposphere and the stratosphere.

There is a large time scatter (68 days) in the dates of spring restructuring of the stratospheric circulation from March 7 to May 14. It has been found that the dates of spring changes in SC depend on solar activity and the occurrence of sudden stratospheric warmings (after a strong SSW, as a rule, late changes are observed).

Acknowledgements

This research was supported by the Russian Foundation for Basic Research (grant no. 20-55-00014).

References

[1] Ageeva V Yu, Gruzdev A N, Elokhov A S, Mokhov I I and Zueva N E 2017 Sudden stratospheric warming: statistical characteristics and impact on the total content of NO_2 and O_3 *Izvestiya RAN. Physics of Atmosphere and Ocean* **53** (5) 545–55
[2] Ermolaev O P, Kotlyakov V M, Perevedentsev Yu P and Selivanovskaya S Yu 2009 Environment and sustainable development of the regions new methods and technologists *Izvestiya Akademii Nauk, Seriya Geograficheskaya* **6** 119-22
[3] Bakulina E A, Dunaeva E A and Ugryumov A I 2009 The relation between the spring reconstruction of stratospheric circulation and tropospheric processes in March–June *Russian Meteorology and Hydrology* **34** 83-8
[4] Gladilshchikova A A, Dmitrieva T M. and Semenov S M 2018 Special Report of the Intergovernmental Panel on Climate Change "Global Warming by 1.5°C *Fundamental'naya i prikladnaya klimatologiya* **4** 5-18
[5] Loginov V F and Lysenko S A 2017 *Modern changes in the global and regional climate* (Minsk: Belorusskaya nauka) p 318
[6] Mohanakumar K 2008 *Stratosphere-troposphere Interactions* (Springer) p 416
[7] Perevedentsev Yu P, Vereshchagin M A, Naumov E P and Shantalinsky K M 2001 Long-term fluctuations of the main characteristics of the hydrometeorological Volga basin regime *Russian Meteorology and Hydrology* **10** 16-24

[8] Perevedentsev Yu P, Vereshchagin M A, Naumov E P Shantalinsky K M and Nikolaev A A 2005 Regional display of the modern climate warming in tropo and strato spheres of the Northern Hemisphere *Izvestiya Akademii Nauk, Seriya Geograficheskaya* **6** 6-16

[9] Perevedentsev Y P and Shantalinskii K M 2014 Estimation of contemporary observed variations of air temperature and wind speed in the troposphere of the Northern Hemisphere *Russian Meteorology and Hydrology* **39** 650-59

[10] Perevedentsev Yu P, Shantalinsky K M, Aukhadeev T R, Ismagilov N V and Zandi R 2014 On the influence of macrocirculatory systems on the thermobaric regime of the Volga Federal District *Uchenye Zapiski Kazanckogo Universiteta Seriya Estestvennye Nauki* **156** (2) 156-65

[11] Perevedentsev Y P and Shantalinskii K M 2015 Changes in the near-surface air temperature of the Northern Hemisphere during the period of 1850 – 2014 *Uchenye Zapiski Kazanckogo Universiteta Seriya Estestvennye Nauki* **157** (3) 8-19

[12] *The second assessment report of Roshydromet on climate changes and their consequences on the territory of the Russian Federation* 2014, Scientific advisers V M Kattsov and S M Semyonov (Moscow: Roshydromet) p 1009