Эмпирико-статистическая модель климатических изменений в Приволжском федеральном округе

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При изучении климатических процессов на территории ПФО нами используются данные метеонаблюдений (из фонда ВНИИГМИ-МЦД) на 183 станциях, а также реанализы NCEP/NCAR, ERA-Interim. Была выполнена работа по сравнению данных реанализа ERA-Interim по температуре воздуха с данными метеосети. Коэффициенты корреляции r оказались очень высокими (r>0,9), что позволяет использовать данные реанализа в климатических исследованиях. Сопоставление реанализов ERA-Interim и NCEP/NCAR за 1979-2017 гг. (рассчитывались коэффициенты корреляции и разности среднемесячных температур) также привело к хорошим результатам. Поэтому с использованием данных NCEP/NCAR за 1979-2016 гг. с пространственным разрешением 1,8 × 1,8° были построены распределения средней температуры воздуха и коэффициентов наклона линейного тренда (КНЛТ) на территории ПФО для центральных месяцев сезонов для стандартных уровней 1000, 925, 700, 500, 300, 100, 50, 10 гПа. Отметим, что на уровне 1000 гПа в январе значения КНЛТ в ПФО были отрицательными (-0,1 ÷ -0,2 °С/10 лет), а в июле положительными 0,15 0,65 °С/10 лет. В целом в тропосфере до уровня 300 гПа на всей территории ПФО значения КНЛТ больше нуля, что свидетельствует о потеплении, а начиная с уровня 200 гПа, КНЛТ отрицательны и эта тенденция сохраняется и в нижней стратосфере (до 10 гПа). Так, в январе на уровне 10 гПа КНЛТ меняются в пределах -0,15 -0,75 °С/10 лет.

Было проведено исследование по оценке качества моделирования реальных изменения температуры в округе с 1861 по 2005 гг. с помощью 7 отобранных климатических моделей из проекта CMIP5 (всего рассматривалось 39 моделей). Анализ результатов показал, что в теплое время года модели лучше воспроизводят ход температуры, чем в холодный. Выявлены статистические погрешности в результате тестирования ансамбля климатических моделей. С использованием 7 моделей CMIP5 (BNU-ESM, CMCC-CM, MPI-ESM-LR, MPI-ESM-MR, GISS-E2-H, EC-EARTH, FIO-ESM) получены достаточно реалистические тренды температуры воздуха для 4-х периодов 1896-2005 гг. и оценены значения КНЛТ (°С/10 лет) для каждого месяца года при различных сценариях RCP 2,6; RCP 4,5 и RCP 8,5. Представлен расчет распределения среднемесячных значений температуры воздуха в январе и июле в период 2005-2098 гг. при различных сценариях. В январе по «жесткому» сценарию RCP 8,5 среднемесячная температура может повыситься на 8°С, а в июле на 6°С.

Рассчитывались средние значения на каждом уровне по сезонам и в целом за год, средние квадратические отклонения (СКО), линейные тренды, коэффициенты корреляции между уровнями и по горизонтали со значениями температуры умеренной зоны и первого естественно-синоптического района. Дана оценка связей между изменениями температуры воздуха и индексами Арктической осцилляции (АО), с целью выделения колебаний с периодом более 10 лет временные ряды на различных уровнях подвергались низкочастотной фильтрации фильтром Поттера, вычислялись коэффициенты детерминации линейного тренда и низкочастотной компоненты (НЧК).

Empirical-statistical model of climatic changes in the Volga Federal District

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The study of the climate of the Middle Volga region has a long 200-year history, the main stages of which are presented in [2]. In recent decades, due to the active phase of global warming, interest in regional climate change has increased. This circumstance is promoted by development of modern information and computing technologies, free access to reanalysis, results of ensemble calculations in the CMIP5 program, etc. [3-6].

The present report focuses on the analysis of the distribution of air temperature characteristics to the level of 0.1 hPa (64 km) that is done for the territory of the Volga region for the first time.

As source material, ERA-Interim reanalysis data on the air temperature of the Northern Hemisphere for the period 1979-2016 were used. In the territory of the Volga Federal District (VFD) average monthly air temperatures at 26 levels in 24 knots of the geographical grid with a step of 2.5 ° reanalysis were used, that made it possible to receive temporary ranks as a result of averaging. In order to isolate the oscillations with a period of more than 10 years, time series at various levels were subjected to low-frequency filtering by Potter's filter, the coefficients of determination of the linear trend and the low-frequency component (LFC) were calculated. Some of the materials are presented in the report.

Table 1 presents vertical distribution of long-term means for air temperature Av (°C), SD and linear trend slope A°C / year on 26 isobaric surfaces. The averaged data for Volga Federal District for both winter (XII-II) and summer (VI-VIII) periods show a decrease of temperature Av with altitude in the troposphere and the lower stratosphere (50-30 hPa), an increase in the middle and upper stratosphere and its decrease in the mesosphere. There is a significant annual temperature variation. In winter, it takes negative values throughout the thickness of the atmosphere, in the summer period is above the level of 700 hPa. In winter SD takes the greatest value at the earth's surface (2.26 °C), then the values of the interannual variability characteristic decrease and again increase from the level of 30 hPa, reaching 6.41 °C at the level of 3 hPa. In the summer period, the SD in terms of magnitude is significantly inferior to winter ones at all levels.

The process of changing the air temperature with time takes place non-uniformly along the vertical. In the troposphere, in winter and summer, the values of the CILT are positive, which indicates the tendency of its warming, which occurs in 1979-2016 more intensively in summer than in winter. In the stratosphere, cooling (A <0) is particularly noticeable in the layer 150-20 hPa, in the 1-0.29 hPa layer warming occurs again, at the highest level (0.1 hPa) a decrease in temperature.

Fig. 1 shows the long-term course of average temperatures in the territory of the Volga Federal District, which reflects the nature of temperature changes at selected levels over the past 38 years. As can be clearly seen, trends based on seasonal values indicate a warming in the troposphere, a cooling in the lower and middle stratosphere, an increase in temperature in the upper stratosphere and its fall in the lower mesosphere. The low-frequency component isolates levels of 5, 1 and 0.5 hPa in the upper stratosphere, where the most intense temperature fluctuations occur.

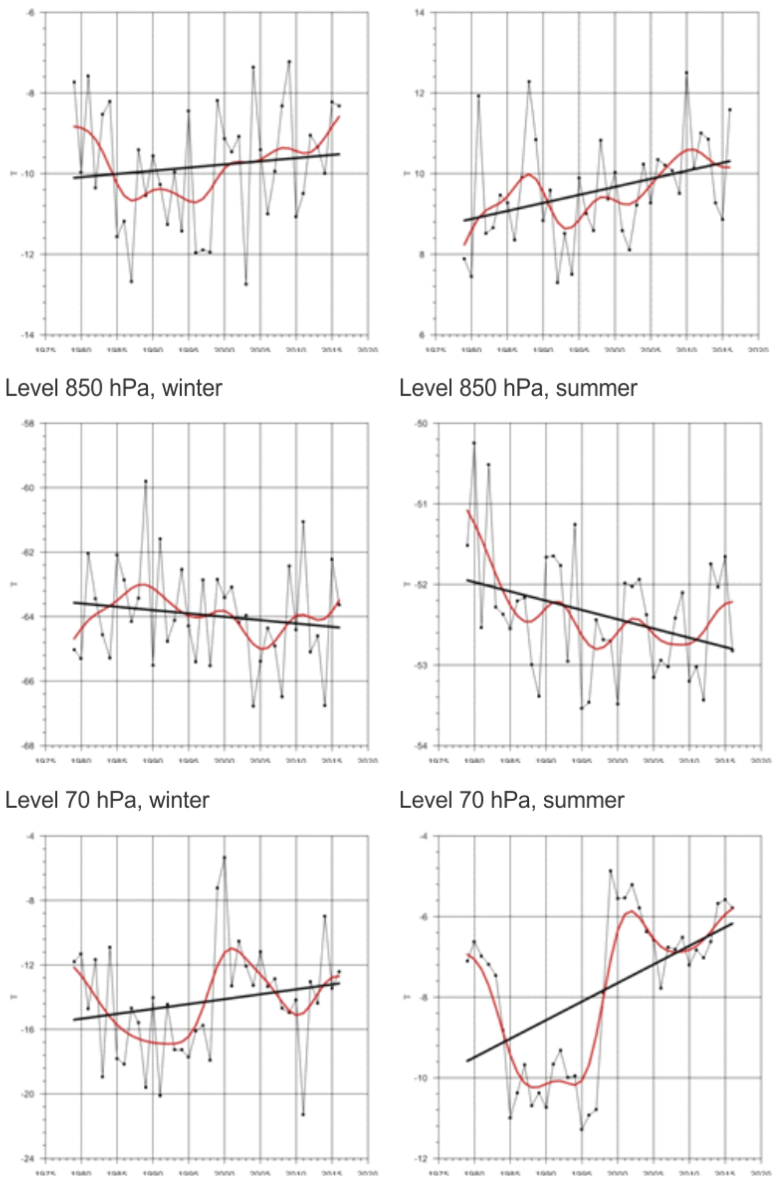
Table 1. Characteristics of low-frequency variability of mean air temperature.

P, hPa	H, km	Winter					Summer				
		Av °C	Rms °C	A °C/ year	R^2L %	R^2F %	Av °C	Rms °C	A °C/ year	R^2L %	R^2F %
Earth	0.0	-10.84	2.26	0.009	-5	40	17.73	1.28	0.045	11	34
1000	0.1	-9.12	2.12	0.004	-6	37	19.21	1.38	0.054	14	38
925	0.8	-9.42	1.67	0.008	-5	24	14.71	1.38	0.050	11	37
850	1.5	-9.81	1.49	0.016	-4	27	9.57	1.28	0.040	7	37
700	3.0	-15.90	1.32	0.021	-2	33	0.06	1.00	0.035	10	41
600	4.3	-22.47	1.17	0.011	-4	34	-6.78	0.91	0.031	9	40
500	5.7	-31.03	1.01	0.000	-6	31	-15.45	0.95	0.030	7	41
400	7.3	-42.15	0.81	-0.013	-3	30	-27.30	0.96	0.026	4	41
300	9.4	-54.99	0.59	-0.011	-1	52	-42.87	0.82	0.028	9	43
250	10.6	-59.97	1.02	0.003	-5	57	-50.17	0.63	0.021	8	28
200	12.0	-60.85	1.49	0.004	-5	46	-51.50	1.42	-0.020	-3	23
150	13.9	-59.75	1.31	-0.008	-5	38	-50.01	0.92	-0.009	-4	22
100	16.3	-61.73	1.37	-0.018	-3	27	-51.95	0.83	-0.020	2	23
70	18.5	-63.95	1.55	-0.021	-3	21	-52.38	0.77	-0.023	6	36
50	20.5	-65.55	1.75	-0.026	-3	23	-51.40	0.68	-0.029	18	53
30	23.7	-66.29	2.10	-0.018	-5	27	-48.96	0.57	-0.026	21	46
20	26.3	-64.55	2.58	-0.005	-5	32	-45.06	0.45	-0.019	18	42
10	30.9	-56.57	3.92	0.011	-5	33	-36.48	0.41	-0.027	49	69
7	33.3	-48.84	4.90	-0.037	-5	35	-31.13	0.37	0.018	23	60
5	35.6	-40.88	5.75	-0.085	-3	36	-25.38	0.72	0.037	28	83
3	39.3	-31.21	6.41	-0.053	-5	25	-13.11	1.06	-0.074	57	89
2	42.3	-25.96	6.37	-0.005	-6	21	-5.51	1.24	-0.071	36	86
1	47.5	-18.37	4.34	0.045	-4	30	-1.36	2.02	0.079	14	84
0.8	49.3	-16.30	3.82	0.057	-3	37	-1.97	2.22	0.104	22	86
0.51	52.7	-14.27	3.41	0.061	-2	46	-7.88	1.97	0.092	22	88
0.29	56.9	-18.17	3.55	0.037	-4	37	-22.53	1.48	0.033	1	79
0.1	64.4	-30.21	3.79	-0.041	-4	29	-51.50	2.01	-0.099	25	66

Note: R2L is the corrected coefficient of determination of a linear trend showing the percent of dispersion of an initial row explained with a trend. R^2F is the coefficient of determination of the low-frequency component (LFC), which shows the percentage of variance of the initial series explained by the LFC.

The extent to which the processes occurring in different layers of the atmosphere are related to each other can be judged from the behavior of the correlation coefficient calculated between the levels in the air temperature field. The analysis of the obtained results shows that in the winter and summer in the troposphere in the 1000-400 hPa layer, the bonds are high (r ~ 1.0), then in the 400-250 hPa layer in winter and 300-200 hPa in summer the ties are sharply weakened, the influence of the tropopause is affected. In the winter stratosphere, the links are closer, in summer in the upper stratosphere and in the 0.29-0.1 hPa layer they sharply weaken, indicating a stratification of the atmosphere. The levels of 10 and 7 hPa (r = -0.04), 5 and 3 hPa (r = -0.07) are weakly related. At this time, the ozone layer plays an important role in the thermal regime, and dynamic mixing is not so pronounced (weakening of the vertical wave interaction) [1].

To establish a link between air temperature fluctuations in the PFD and Arctic oscillations (AO), correlation coefficients for 26 levels for winter and summer were calculated. In the winter period, in the lower troposphere, the correlation coefficients between the temperature and the AO are rather high (r = 0.60 at 1000 hPa), which indicates a warming in the PFD due to the circulating factor. There is also an increase in the connection in the upper troposphere (in the 300-200 hPa layer) and in the middle and upper stratosphere (7-3 hPa). In the stratosphere, the connection has a negative sign, in contrast to the troposphere (r = -0.43 at 7 hPa). This may be due to the spread of the Rossby planetary waves from the troposphere to the stratosphere, the occurrence of winter stratospheric warming, leading to the destruction of the circumpolar cyclone. In this case, the zonal flow weakens, and the temperature will rise, which leads to a negative connection between them. The correlation coefficients for the summer period turned out to be insignificant.



Level 850 hPa, winter — Level 850 hPa, summer

Level 70 hPa, winter — Level 70 hPa, summer

Level 0,5 hPa, winter — Level 0,5 hPa, summer

Fig.1. The long-term course of average air temperatures in the territory of the Volga Federal District. Winter (December-February) and summer (June-August). The initial row, the linear trend and the low-frequency component with a period of more than 10 years, 1979 - 2016.

The estimation of the horizontal links between temperature changes in the PFD and in the temperate zone in the NH indicated that in winter the links are less tight than in the summer period in the atmosphere. If in the summer, with the exception of the layer 200-150 hPa, the correlation coefficients are significant and have a large numerical value (in the troposphere $r > 0.6$, and in the stratosphere $r > 0.7$), then in the winter period everything becomes more complicated. In the troposphere, only in the lower layer r> 0.6. Then the tightness of the links increases in the upper stratosphere ($r > 0.6$). The analysis of altitude-time sections of the first differences of low-frequency components with a period of more than 10 years of air temperature (°C / year) indicated the following: in winter, in the troposphere, since 1988, positive differences prevail, i.e. the temperature increases with time. In the stratosphere up to a height of 30 km, the tendency of falling (cooling) is more expressed.

Much more contrast events take place in a layer of 30-64 km where sources occur with large temperature differences. There is a warming in the period 1996-2004 and a strong cooling in 1986-1990 and 2004-2010. In the summer period, the picture is calm. There are no big contrasts. In the troposphere there is a tendency to warming, in the stratosphere to cooling.

CONCLUSIONS

1. There is a significant difference between winter and summer in the vertical distribution of air temperature: so at the level of 12-13 km in winter, the greatest warming is observed, and in summer, on the contrary, there is a noticeable cooling. In the stratosphere, the greatest cooling of air takes place in the 35-40 km layer in winter and in the 35-45 km layer in summer.
2. The character of vertical correlation links in the temperature field is revealed: the links between the layers sharply weaken in the tropopause area both in winter and in summer. In the summer period, negative links are established between the troposphere and the lower stratosphere, indicating an anti-phase nature of the temperature change.
3. According to the correlation analysis, the influence of the Arctic oscillation in the winter has the greatest effect on the surface layer of the troposphere (temperature increase) and the 7-3 hPa layer in the stratosphere, where the temperature decreases.
4. In the upper stratosphere and the lower mesosphere, according to the results of the analysis of the first differences of LFC with a period of more than 10 years, sources of growth or decrease in temperature with cyclicity of 8-10 years are noted in winter.

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