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Evaluations of temperature ranges forthe growing season period and their use in agriculture in southern west Siberia

N.K. Barashkova, I.V. Kuzhevskaya, O.V. Nosyreva

Tomsk State University, Tomsk

The article presents the of results of the use of methodological approaches for assessment the characteristics of the modes of the stable transition average daily temperature over 0, 5, 10, 15 °C in the south of Western Siberia, the length of temperature setting periods, related microcirculation processes, as well as the evaluation of growing season weather conditions influencing crop yield. The estimation of tendencies of variability of the specified characteristics is carried out. Therefore, the information of this kind is necessary for researchers to find out dependencies for their prediction. Our methods of evaluating climatic conditions (atmosphere circulation, statistic of temperature change over definite values) can be applied to weather forecast for the appropriate period as well as to estimation of expected crop yields in the study region. Early evaluation of weather trends in spring must be used as adjustment in decision making while developing agronomical strategy for the field season.

Key words: agro-climatic parameters, macro-circulatory conditions, southern West Siberia.

Introduction

The monitoring of temperature in current climate changes is of the utmost interest for Russian and foreign climatologists [1, 2, 5, etc.]. Maximal warming, either observed or expected, spread over considerable part of the Russian territory. In general, changes in surface air temperature averaged for a year as well as for longer annual periods (i.e. half-year, season, month) are considered for the northern hemisphere, large geographical locations and economic areas. The variations in daily temperatures ranged at 0, 5, 8, 10, 15, 20 °C in Western Siberia haven't been studied yet. These ranges are considered to be boundaries of warm (above 0 °C), growing (>5 °C and >10 °C), heating (8 °C), "hot" (>15 °C) and dry (>20 °C) periods. In addition, the length of temperature changeover (the time when the temperature was fixed for the first time up to its stable setting) and the duration of the periods mentioned above are studied. The assessment of parameters given above is crucial for the region with highly developed power and agricultural industries.

Long-term and qualitative evaluation of meteorological conditions affecting both economic complex and human activities as well as the possibility of responding to predicted weather change depends on the numerical characteristics determined for a certain territory at a definite time scale.

This research is aimed at studying the dates of stable surface air temperature change over 0, 5, 10, 15 °C, the length of temperature setting periods, related circulation processes as well as the evaluation of growing season weather conditions influencing crop yield. Therefore, the information of this kind is necessary for researchers to find out dependencies for their prediction.

Materials and methods

The climatic data used in this study were obtained from 14 weather service stations located in Tomsk, Novosibirsk, Kemerovo and Altai regions for the 1961–2005 period. The stations' data included daily mean surface air temperatures and daily total precipitation range. Circulatory conditions of inter-seasons were evaluated using planetary high altitude frontal zone (PHAFZ) parameters [7, 11, 14], elementary circulatory mechanisms (ECM) by B.L. Dserdseevsky indices [8]. In addition, the 1970–2005 data on crop yield in Altai and Tomsk regions were used in the study.

Dynamics of agro-climatic indices of temperature ranges during growing season period

For the total understanding of atmosphere temperature it is necessary to evaluate the data on stable daily mean temperature change over 0, 5, 10, 15 °C – D_0, D_5, D_{10}, D_{15}, respectively. Hence, the selection of method for defining the date of stable surface air temperature change over threshold values proves essential. At present use is made of D.A. Ped's method [13]. Based on D.A. Ped's method, the algorithm of automatic date definition was developed. Implementing this algorithm we succeeded in defining the dates of stable surface air temperature change over 0, 5, 10, 15 °C in spring and autumn for weather service stations at Tomsk, Kolpashevo, Rubtsovsk, Barnaul for 70 year period. The dates defined, the length of change periods P_0, P_5, P_{10}, P_{15} was calculated (table 1).

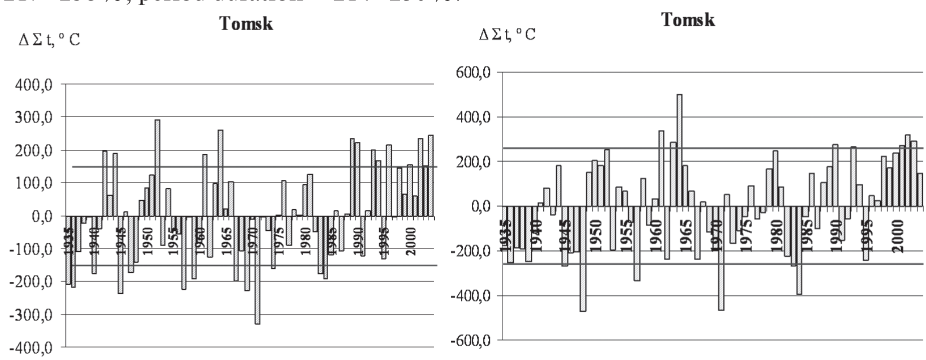
Table 1. Mean values for the period of surface air temperature change over 0 °C

Station	Characteristics	Transition date in spring	Transition date in autumn	Period duration, days
Tomsk	Mean least value	March, 30	October, 9	177
	Mean value	April, 12	October, 20	192
	Mean largest value	April, 26	October, 31	208
Kolpashevo	Mean least value	April, 5	October, 6	165
	Mean value	April, 18	October, 17	183
	Mean largest value	May, 4	October, 27	200
Rubcovsk	Mean least value	March, 24	October, 21	199
	Mean value	April, 3	October, 31	212
	Mean largest value	April, 14	November, 9	226
Barnaul	Mean least value	March,24	October, 18	192
	Mean value	April, 5	October, 28	207
	Mean largest value	April, 14	November, 5	224

In agro-meteorology it is considered reasonable to use data on daily total temperature and precipitation range. The dynamics of daily total temperature deviation from their mean values are shown in Figure 1.

Mean value or norm was derived as $X \varepsilon \bar{X} \pm \sigma$, where σ – standard deviation.

In deviation sign (positive or negative) of periods duration, total temperature and precipitation range in the warm period from their mean values, distinct recurrence with different time intervals is observed. Taken as a whole, the values are within norm although significant deviations are observed in individual years. For temperature change over 0 °C the deviations are: total temperature range – 171–202 %, total precipitation range – 217–238 %, period duration – 214–250 %.



a) *b)*

Fig. 1. Total temperature deviation from mean values for *a)* the warm period, *b)* < 10 °C period (±σ position is presented by lines)

For the temperature changing over 5 °C period the variability of values is more than for the similar rows of warm period and deviations from norm are observed more often (total temperature range – 189–223 %, total precipitation range – 225–276 %, duration period – 214–250 %).

Variability among values for >10 °C period is less than among the values for >5 °C period (total temperature range – 166–193 %, total precipitation range – 182–218 %, duration period – 321–346 %). Variability among values >15 °C period increases, the deviations from norm are: total temperature range – 121–159 %, total precipitation range – 204–239 %, duration period – 118–143 %.

The substantial positive deviation of values from their mean is observed for total temperature range from 1979, for total precipitation range –from the mid 1980s and for period duration above 0 °C from the late 1980s. For the period >5 °C the positive trend in values is observed from 1989, especially for the stations located in Altai region. As far as total precipitation range is concerned, this trend is typical only for Altai region for the 1990–1991 period.

For >10 °C period the positive trend is noticed from the end of 1980 to the beginning of 1990, for >15 °C period it is noticed from the end of 1990 to the beginning of 2000. The observed growth trend of parameters under study in the last 20–30 years are supported by the results of their investigation received within 5-year terms, precisely the positive dynamics of duration and total temperature range in the warm period is observed from the 1980–1990 period. The relevant information for the station at Tomsk is given in Table 2.

Table 2. Mean values for temperature changing above 0 °C period within 5-year terms

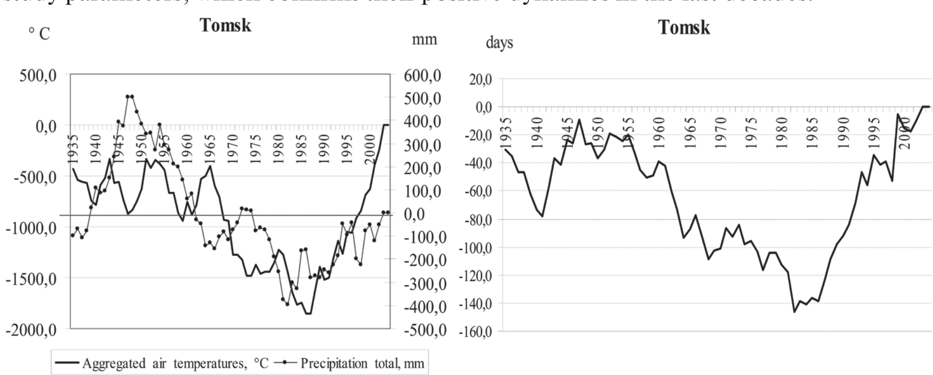
№	Period	Precipitation total, mm	Accumulated air temperatures, °C	Transition date in spring	Transition date in autumn	Period duration, days	Transition duration in spring, days
1	1936–1940	330,4	2119,0	April, 15	October, 14	183	24
2	1941–1945	392,6	2278,3	April, 10	October, 20	194	12
3	1946–1950	415,6	2133,1	April, 11	October, 22	194	35
4	1951–1955	300,8	2329,7	April, 14	October, 23	193	22
5	1956–1960	331,9	2127,1	April, 20	October, 23	187	19

6	1961–1965	296,8	2300,1	April, 14	October, 18	188	24
7	1966–1970	338,8	2150,4	April, 15	October, 17	185	25
8	1971–1975	365,6	2122,5	April, 5	October, 18	197	16
9	1976–1980	320,5	2239,5	April, 14	October, 18	188	23
10	1981–1985	309,0	2192,2	April, 15	October, 16	185	24
11	1986–1990	352,1	2237,5	April, 6	October, 21	198	23
12	1991–1995	363,5	2328,2	April, 6	October, 27	205	22
13	1996–2000	338,7	2290,0	April, 10	October, 17	191	25
14	2001–2005	390,7	2401,0	April, 7	October, 26	203	34

The mean values are considered to be stationary and it is difficult to note visible fluctuations in short-term process curve. They are more expressed in residual mass curves enabling cycles duration (epochs) to be distinguished. Long-term periods of enduring trend are referred to as epochs (cycle). The duration of epoch is defined as the distance between extremes in the curve. This method is widely used in meteorology in order to determine the epochs of atmosphere circulation.

The residual mass curves make it possible to determine the epochs of growth and decrease in the dynamics of duration, total temperature and precipitation range for the above 0 °C period, the 1950–80 epoch of decrease being completed. This epoch is 20–30 years for duration, 25–30 years for total temperature range and 25–50 years for total precipitation range.

We can conclude that more negative deviations from mean values were observed in the territory at that time. The epoch of growth proceeding the epoch of decrease can't be seen entirely in the curves because of insufficient length of data sets. However, it is supposed to be 30 years on the average and is part of quasi-60 year cycle peculiar to the forms of atmosphere circulation. The epoch of decrease was followed by the epoch of growth of study parameters, which confirms their positive dynamics in the last decades.



b) *a)*

Fig. 2. Aggregated deviations from mean values *a* — total daily temperature and precipitation range, *b* — duration of warm period

The residual mass curves of total temperature and precipitation range and >15 °C duration period are apt to point out the epoch. The epoch of decrease accounts for 30 years average for the stations, falling on the beginning of 1950 and ending up in the late 1980s. Thereafter the epoch of growth starts in the early 1990s.

For temperature changing >10 °C period it is total temperature range sets that point out the epoch of decrease. This epoch accounts for 20–40 years average for the stations.

The residual mass curves of values under study for >15° period exhibit the most complicated range of epoch manifestations, which is typical for northern stations (Kolpashevo, Tomsk) since weather variability is significant in this period.

In general our conclusions correlate with the results of other research carried out in Russia and in other countries, West Siberia included [4, 16, 17]. In particular, B.M. Mirvis and I.P. Gusev [9] found out that duration of warm period tends to be steady to a large extent in the south of region. On the contrary, while assessing expected climate change effects on agriculture in Russia, O.D. Sirotenko and I.G. Gringoff [15] failed to reveal large scale macro-aridization of climate. This implies that current climate change favors agro-industrial complex in southern West Siberia.

Macro-circulatory processes in atmosphere and temperature conditions of warm period

To identify the factors causing fluctuation of values for temperature change over 0 and 5 °C at Tomsk, Kolpashevo and Barnaul stations, the data on PHFZ condition and ECM kinds by B.L. Dserdseevsky indices for the 1961–2005 period were used [www.atmospheric-circulation.ru]. Based on statistical analysis [6, 10] the preliminary classification of dates and periods for long-term weather forecast was made:

norm $(\overline{X} \pm 0{,}5\sigma)$ – *n*,

abnormally $(\overline{X} \pm \sigma)$ early/late – *aeD/alD*,

extremally $(\overline{X} \pm 1{,}25\sigma)$ early/late – *eeD/elD*,

abnormally short/long – *aqP/alP*,

extremally short/long – *eqP/elP*.

Abnormality is defined as norm $\pm$ 0.5σ whereas extremality is defined as norm $\pm$ 1.25σ.

The resulting cluster which included data on D_0, P_0, D_5, P_5 and PHFZ position in 60, 70, 80, 90° longitude east in March and April (12 parameters) was arranged into 6 distinst steady classes (Figure 3).

The classes were described using PHFZ parameters:

1 – spacial location of PHFZ in relation to the stations under consideration; 2 – temparal variability of PHFZ; 3 – degree of sinuosity (zonal or meridianal configuration).

According to the first parameter PHFZ in the 1, 2, 3 classes was found to locate southward of the study territory; 4, 5, 6 classes describe PHFZ located over the study territory .

According to the second parameter PHFZ in 1, 5, 6 classes kept moving southwards from March to April (winter processes delay); on the contrary, PHFZ in 2, 3, 4 classes kept moving northwards from March to April (spring coming). Classes 3 and 5 are specified by the opposite dynamic from March to April.

According to the third parameter, zoning predominance can be seen over southern West Siberia; class 2 is specified by the crest extending from south to north (well-expressed meridianality of processes). Classes 1, 3, 5 comprise occurrences of meridianal PHFZ predominance.

Consequently, use of PHFZ as additional criteria in classifying parameters under study proves possible.

Furthermore, P_5 data set was arranged into 3 groups according to change rate: 1 – rapid, 2 – normal , 3 – slow. PHFZ position according to 3 groups is shown in Figure 4.

One can see that PHFZ for the period between March and April is located southwards from Tomsk, in the south of West Siberia and in the Altai foothills. What is more, its shift

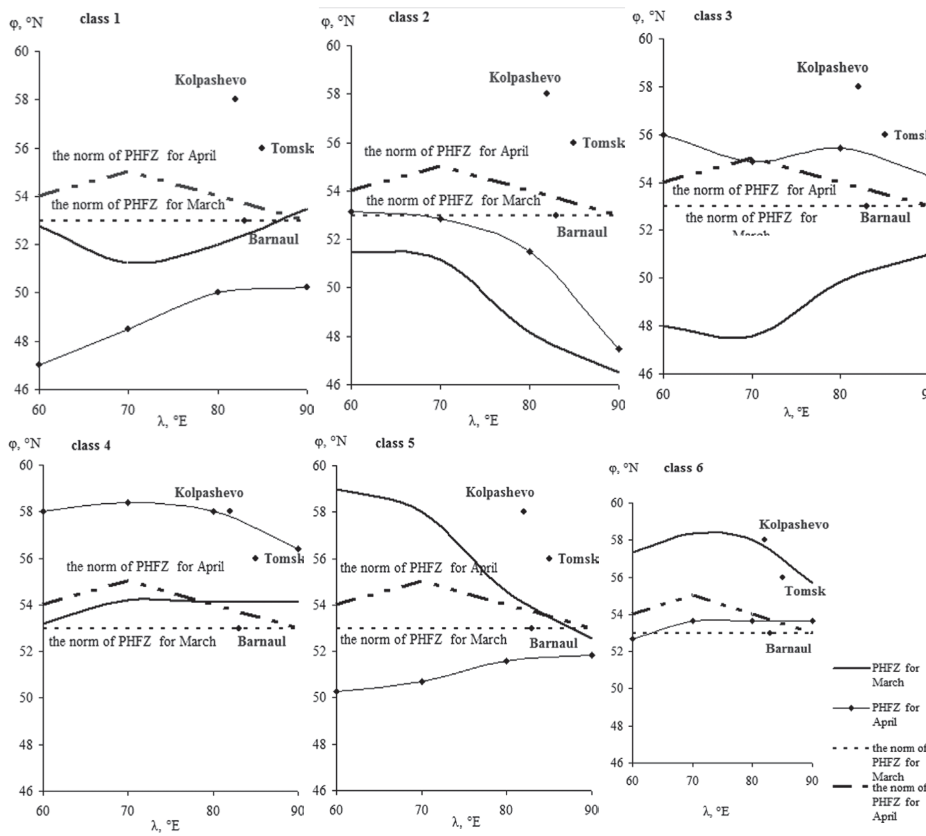


Fig. 3. Geographical position of PHFZ avaraged within classes

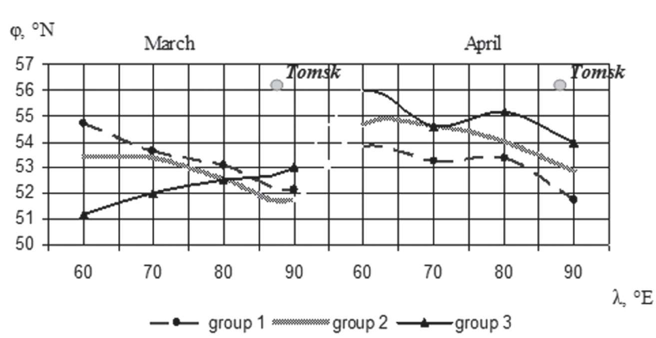


Fig. 4. PHFZ position in groups

northwards at 2º longitude from March to April is well expressed. There are some differences in PHFZ position in the 3 separate groups. Thus, PHFZ is in the most northern position in the "slow change" group. Consequently, Tomsk region is influenced by the active cyclonic processes, with polar air masses migrating into the back cyclones and passing its fronts. These weather conditions prevent bedding surface and surface air from warming up. On the contrary, in the "fast change" group the most southern PHFZ position is observed. Under these circumstances surface warming is attributed to the peculiarities of dominant anti-cyclonic processes over the study territory.

There is one more point to be discussed. Ascribing individual springs to the definite class is likely to require our classification to be widened at the expense of additional parameters of circulation and atmosphere condition in the periods of stable positive temperatures setting up.

Therefore, elementary circulatory mechanisms (ECM) by B.L. Dserdseevsky indices were used to calculate the frequency of every one of 13 elementary circulatory mechanisms in change – group P_0, P_5 (table 3).

Table 3. ECM frequency (%) in groups

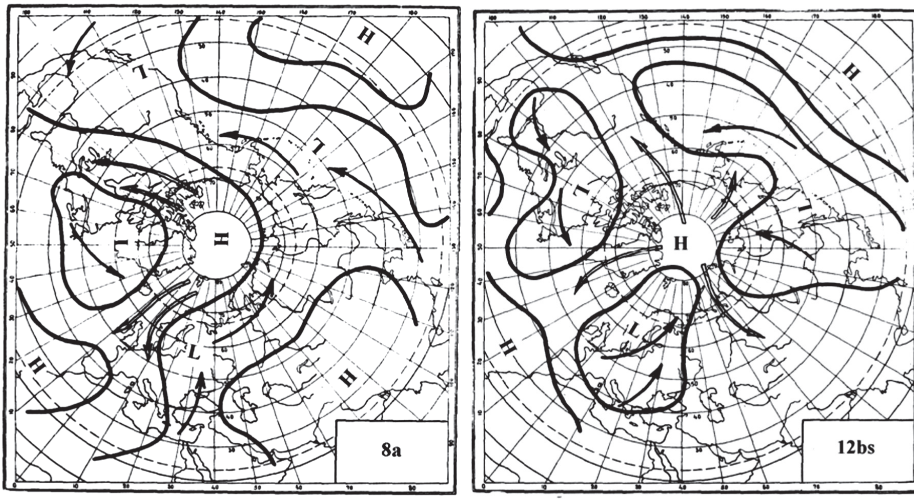
Transition group P_0, P_5	ECM 1a	1b	2a	2b	2c	3	4a	4b	4c	5a	5c	5d	6	7 aw	7 as	7 bw	7 bs	8a	8 bs	8 cw
rapid	0	0	5	2	0	3	0	2	3	0	0	0	0	2	10	0	2	5	2	2
norm	2	1	3	1	1	3	2	3	2	2	1	0	3	1	2	1	2	8	3	1
slow	1	1	3	0	0	0	1	3	3	0	0	1	1	3	4	0	1	4	1	0
	0			7		3		5			0		0		14					
Итого	3			5		3		7			3		3		6					
	2			3		0		7			1		1		8					

Transition group P_0, P_5	8 cs	8 ds	8 dw	9a	9b	10a	10b	11	11a	11b	11c	11d	12a	12 bs	12 bw	12 cs	12 cw	12d	13s	13w
rapid	0	2	2	11	2	2	2	0	0	2	0	0	11	8	0	3	7	2	10	2
norm	1	2	2	5	5	5	4	1	1	1	0	3	10	6	1	5	1	2	6	4
slow	4	0	1	7	3	4	4	0	3	1	1	3	6	7	3	4	1	1	6	6
		9		13		4				2					31				12	
Итого		12		10		9				5					23				10	
		5		10		8				8					12				12	

"Norm" group is characterized by the most frequency of ECM 8a and 12bs, which pertain to meridianal northern group and are featured by polar jet migrating to Asia, through Taimyr to the Ob river basin, or from Novaya Zemlya to the Yenisey river basin (figure 5). Quite often the blocking of western shift by Arctic anti-cyclone interlocking with Siberian crest is created. The least frequency in processes belonging to this group is observed in ECM 1-7.

None of the zonal circulation groups is observed in "rapid" group (ECM 1, 5 and 6), the most frequency of meridianal groups being 7, 8, 9, 12, 13 ECM. Maximum repeatability is of type 12 (12a, 12bs, 12cw). The 10 and 11 ECM processes are sufficiently weakened as compared to groups "norm" and "slow".

"Slow" group has uniform frequency of ECM 7-13, whereas ECM10 and 11 increase and ECM 12 frequency noticeably decreases. When ECM 10 is brought about, the study territory is in the low pressure area, meanwhile the blocking crest is over Eastern Europe, which correlates to the PHAFZ position identified above for slow change (when PHAFZ occupies the most northern position).



a) b)

Fig. 5. ECM subtype dynamic scheme a) 8a, b) 12bs; *1 – generalized trajectory of cyclones; 2 – generalized trajectory of anti-cyclones; 3 – demarcative lines dividing cyclonic and anti-cyclonic areas* [3]

Crop yield and temperature range in growing season period

The classes of date changes classified using PHAFZ parameters were compared with the data on crop yield that varies greatly through years (fig. 6 and table 4). The observed variability is appointed to the fluctuation of agro-meteorological conditions since crop yield biological factors such as crop genetics, soil fertility are more or less stable.

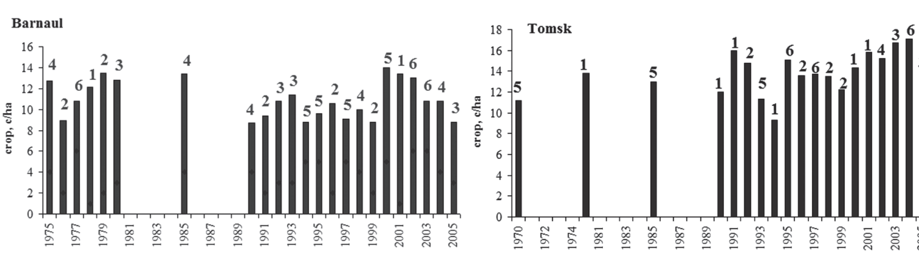


Fig. 6. Classes and crop yield

Our results suggest that there is no entire correlation between classes and crop yield caused by insufficient records of weather factors in spring.

Table 4. Average class parameters and average crop production (dt/ha) in classes for Barnaul and Tomsk stations

Barnaul					Tomsk				
Class	Average class parameters			Average crop production	Class	Average class arameters			Average crop production
1	D_0	29.3	early	12.6	1	D_0	9.4	norm	13.5
	P_0	17	norm			P_0	22	norm	
	D_5	15.4	early			D_5	2.5	norm	
	P_5	17	norm			P_5	23	norm	

2	D_0	9.4	late	10.2	2	D_0	27.4	late	13.5
	P_0	6	rapid			P_0	24	norm	
	D_5	25.4	norm			D_5	1.5	norm	
	P_5	16	norm			P_5	4	rapid	
3	D_0	9.4	late	11.1	3	D_0	11.4	norm	15.4
	P_0	16	norm			P_0	22	norm	
	D_5	14.4	early			D_5	19.4	early	
	P_5	4	rapid			P_5	8	rapid	
4	D_0	27.3	early	11.1	4	D_0	24.4	late	15.2
	P_0	3	rapid			P_0	49	long	
	D_5	30.4	late			D_5	3.5	norm	
	P_5	34	long			P_5	9	rapid	
5	D_0	25.3	early	10.4	5	D_0	15.4	norm	11.8
	P_0	3	rapid			P_0	16	norm	
	D_5	9.4	early			D_5	17.5	late	
	P_5	16	norm			P_5	31	long	
6	D_0	11.4	late	11.5	6	D_0	30.3	early	15.3
	P_0	33	long			P_0	2	rapid	
	D_5	24.4	norm			D_5	29.4	norm	
	P_5	13	norm			P_5	30	long	

In Barnaul, the high crop production is fixed in classes 1 and 6 (12.6 dt/ha and 11.5 dt/ha, respectively). Class 1 is characterized by early 0 and 5 °C setting and their change length within norm. In this case, favorable temperatures are found to set up rapidly. Long and late change to 0 °C as well as normal growing period setting is peculiar to class 2. Low crop production is fixed in classes 2 and 5 (10.2 and 10.4 dt/ha, respectively). Class 2 is characterized by late and rapid 0 °C setting and normal change to 5 °C, class 5 – chronologically early and rapid 0 °C setting but normal by change length of growing period setting.

In Tomsk high crop production is observed in classes 3, 4 and 6 (15.4, 15.2 and 15.3 dt/ha, respectively). In class 3 weather conditions of spring change-over correspond to normal 0 °C setting and early and rapid 5 °C setting. Class 4 is characterized by late and long change-over to positive temperatures, normal by date change-over but rapid, if account is taken of the change-over length, by growing period setting. In class 6 early and rapid 0 °C setting and normal by the date but long by change-over length 5 °C setting is observed. This implies favorable conditions for keeping winter moisture content in soil. Stable change-over to positive temperatures within normal range and late and long growing period setting correspond to class 5, which is featured by low crop production (11.8 dt/ha).

Climate- dependent increase in crop yields in West Siberia accounted for 6 % in the last decade, implying considerable increase in regional crop production on account of effective use of soil-climatic resources [12].

Based on bioclimatic potential estimation across Russia, the expected crop yield in combination with effective agriculture in modern climate condition may count for 55 dt/ha in West Siberia.

Conclusion

Our methods of evaluating climatic conditions (atmosphere circulation, statistic of temperature change over definite values) can be applied to weather forecast for the appropriate period as well as to estimation of expected crop yields in the study region.

Early evaluation of weather trends in spring must be used as adjustment in decision making while developing agronomical strategy for the field season.

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Поступила в редакцию ____________________

Сведения об авторах

Барашкова Надежда Константиновна – кандидат географических наук, доцент кафедры метеорологии и климатологии геолого-географического факультета Национального исследовательского Томского государственного университета (г. Томск, Россия) e-mail: meteo@ggf.tst.ru

Кужевская Ирина Валерьевна – кандидат географических наук, доцент кафедры метеорологии и климатологии геолого-географического факультета Национального исследовательского Томского государственного университета (г. Томск, Россия) e-mail: ivk@ggf.tsu.ru

Носырева Ольга Владимировна – кандидат географических наук, доцент кафедры метеорологии и климатологии геолого-географического факультета Национального исследовательского Томского государственного университета (г. Томск, Россия) e-mail: meteo@ggf.tst.ru; ov_nosyreva@mail.ru

About

Barashkova Nadezda K. – PhD, Associate Professor of the Department of Meteorology and Climatology of the Faculty of Geology and Geography at the National Research Tomsk State University, E-mail: meteo@ggf.tst.ru

Kuzevskaya Irina V. – PhD, Associate Professor of the Department of Meteorology and Climatology of the Faculty of Geology and Geography at the National Research Tomsk State University, E-mail: ivk@ggf.tsu.ru

Nosyreva Olga V. – PhD, Associate Professor of the Department of Meteorology and Climatology of the Faculty of Geology and Geography at the National Research Tomsk State University, E-mail: meteo@ggf.tst.ru; ov_nosyreva@mail.ru