Geoecological problems of agricultural environmental management in conditions of climatic fluctuations within the Voronezh forest-steppe

Lidia Mezhova[1*], *Alexander* Lugovskoy[2], *Pavel* Chertkov[3], *Viktor* Inpushkin[1], and *Oksana* Kuvshinova[4]

[1]Voronezh State Pedagogical University, Voronezh, 394043, Russia
[2]Moscow State University of Geodesy and Cartography, Moscow, 105064, Russia
[3]Branch of Kuban State University, Novorossiysk, Krasnodar Territory, 353900, Russia
[4]Voronezh State Forest Engineering University named after G.F. Morozov, Voronezh, 394087, Russia

Abstract. The article describes the rhythmicity of climatic processes in the European part of Russia. An analysis of short-period climate rhythmicity is carried out against the background of 1850 summer rhythms. A forecast of temperature and precipitation for the 21st century is given. A methodological approach to assessing various types of responses to changes in climate processes and their impact on agriculture in the region is suggested. At the same time, changes develop structurally mainly in 3 directions: irreversible, qualitative and reversible. The necessity of considering climatic fluctuations when creating landscape-adaptive agriculture in the Voronezh forest-steppe is proved. To increase the accuracy of forecasts, it is necessary to expand the base of regional climate monitoring and to conduct monitoring and scientific research on the response of agricultural crops to climate change. The calculations made allow identifying trends in temperature and precipitation changes for the period of the 21st century. The proposed methodological approach can be applied in regional agricultural environmental management.

1 Introduction

In modern conditions of intensive agricultural environmental management, priority. areas include geoecological assessment of climate change. The high degree of development of forest-steppe and steppe geosystems requires effective approaches to the methodological and methodological aspects of predicting climate change. The relevance of the research topic is due to changes in regional geo-ecological processes in connection with global climate change. Each region is characterized by its own characteristics of the manifestation of climate fluctuations. The purpose of the study is to identify climatic fluctuations within the Voronezh forest-steppe to optimize agricultural environmental management. Currently, methodological approaches to assessing global climate change in the Northern Hemisphere are being

* Corresponding author: lidiya09mezhova@yandex.ru

developed by: J. T. Abatzoglou, S. Outten, B. Gvozdikova. Issues of climate modeling and the creation of a database for forecasting are dealt with by: S. G. Yeager, R. K. Cornes, S. Kravtsov, S. Grimm, M. E. Mann, B. A. Steinman, D. J. Brouillette and S. K. Miller, S. F. Feng, H. Yu. Wu, Z. K. Hao, etc. Methodological approaches to assessing climate fluctuations are reflected in the works of A.E. Lobanov, I.V. Shatilov. Despite the fact that there is great interest in the study of global climate change in the scientific literature in Russia and abroad. At the same time, there is insufficient data on the impact of climate change on agricultural activities in the Voronezh forest-steppe region.

2 Methods

To solve the problem, the following methods were used: statistical, cluster and factor analysis.

3 Results and discussion

The study of short-period climate rhythmicity was based on harmonic analysis and superposition of epochs. The main method of data processing was sliding smoothing of the natural series over 10 years using the "smuthing FFT" option in "Origin". Forecasting the course of the main climatic indicators was based on rhythmic extrapolation. Using this modification of the extrapolation method allows the forecast to be constantly adjusted over time, increasing its accuracy. At the same time, at the moment we can assume the main features of the dynamics of the process within significant periods of time.

The secular variability of atmospheric precipitation in the Voronezh forest-steppe is determined mainly by the rhythm of the western transfer of air masses. A comparison of fluctuations in precipitation during the warm and cold periods of the year indicates that they do not occur synchronously. This is explained by the fact that air masses from the Atlantic Ocean come to the territory of the Voronezh forest-steppe in summer transformed. The secular rhythm of the shift of the westerly transport determines, first, the dynamics of precipitation during the cold period of the year. The secular rhythm of global humidity manifests itself insignificantly on the territory of the Voronezh forest-steppe. It has some influence only on the course of summer precipitation. The next secular maximum precipitation can be expected around 2038. The dynamics of the secular rhythm of precipitation are presented in Figure 1.

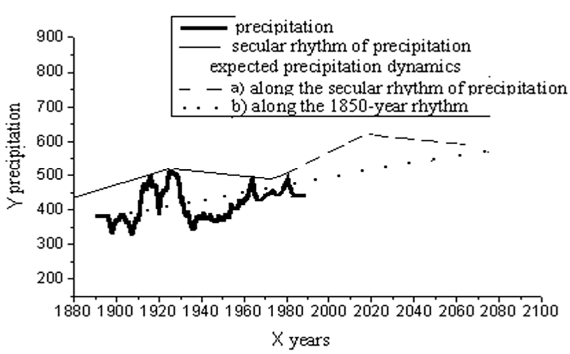

Fig. 1. 1850-year and secular rhythmicity of precipitation dynamics in the warm period of the year using the example of the Stone Steppe. Note: The natural series is smoothed by 10 years using the "smuthing" option of the "Origin" program.

It is necessary to note that the intensity of the entry of sea air masses has a certain effect on the temperature regime. During periods of weakening of the western transport, continental climate features hypertrophy. Average temperatures in July are rising and in January they are falling. A feature of temperature fluctuations is a noticeable difference from precipitation dynamics. If changes in precipitation show regional characteristics, then the dynamics of temperature basically coincide with the planetary one. The role of 11- and 44-year-old rhythmicity is quite clearly manifested. There is a clear tendency for the temperature to increase, probably along the course of the 1850-year rhythm. Secular rhythm is weakly expressed. The expected results were obtained by comparing fluctuations in the average annual temperature with a curve reflecting the dynamics of Wolf numbers. The 11-year maximums of heat supply are timed to coincide with the minimums of solar activity. Considering the trend of increasing heat supply along the 1850-year rhythm, it can be assumed that average annual temperatures will increase by 1.2 - 1.4 °C by the end of the 21st century, compared to the first quarter of the 20th century. It is likely that by the end of the 21st century. There will be a shift in thermal conditions at the level of natural subzones. Here we compare the implementation of 4 cycles of solar activity and the dynamics of average annual temperature. In the figures you can see that the maximum heat supply is timed to coincide with the minimum solar activity.

If regional features are extremely evident in changes in the amount of precipitation, then the dynamics of heat supply basically coincides with the planetary one. This can be established by comparing data from the Kamennaya Steppe weather station with the course of global temperature. The dynamics of the temperature regime are shown in Figure 2.

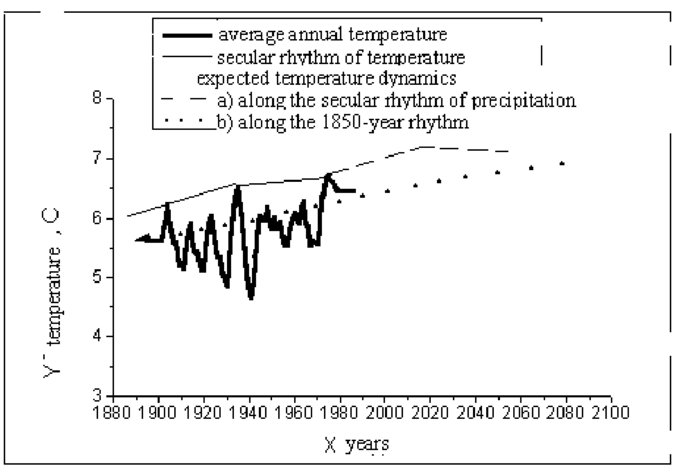

Fig. 2. 1850-year and secular rhythmicity of the dynamics of average annual temperature using the example of the Stone Steppe. The natural series is smoothed by 10 years using the "smuthing" option of the "Origin" program.

The Voronezh region is characterized by a temperate continental climate. At the same time, the average annual air temperature in the 20th century was +5.4 °C. There are no significant differences when moving from west to east, the temperature ranges from +5.4 °C to +5-9 °C. When moving from North to South, the temperature increases from +4-8 °C to +6-9 °C. The average July temperature was + 20.5°C, and in January -9.5°C. In the region, absolute maximums and minimums were recorded ranging from +41.2 °C to – 40.1 °C. Based on the study of changes in average annual air temperature using the cluster analysis method, it was revealed that there are differences in temperature between the west and the east within 1-3 °C. For the western part of the region, it was noted that the trend of temperature fluctuations is mainly stable; an increase in temperature and an increase in the trend were noted at the turn of the 20th-21st centuries. In the east of the region, 11-year cycles of trend fluctuations have been identified, which are characterized by both an increase and a decrease in the indicator. At the beginning of the 21st century, the trend is increasing. Increases in air temperature have been noted, associated with global climate processes that affect not only the temperature regime, but also the amount of precipitation. The Voronezh region is located along the lines of optimal moisture, but in a zone of risky agriculture. This is due to the frequency of droughts; they create a critical situation for agricultural environmental management. The number of droughts increases from the north-west to the south-east and is mainly characterized by one- or two-year droughts. They are typical in spring, summer, and autumn. Catastrophic droughts were noted at the turn of the 19th and 20th centuries. After research by V.V. Dokuchaev, the climatic conditions of the region were adapted through the creation of pond-forest landscapes. The annual interval of precipitation can vary from 250 to 900 mm. And it is typical that the region experiences drought every 4 years. An increase in precipitation was noted from 429 mm in the 60s of the 20^{th} century to 582 mm by the turn of the 21st century. In this case, it is necessary to cancel the increase in precipitation in winter. Climatic fluctuations will affect agricultural environmental management by accelerating many negative natural processes. In increasing the erosion of soil loss processes, in increasing the mass of energetic soil processes.

Thus, the goal of optimizing agricultural environmental management is to create conditions for predicting the speed of response of agro geosystems to changes in climatic processes at the turn of the 21st century. The reaction rate of agrogeosystems is functionally related to the level of change in climatic processes, which create chain reactions in environmental components, and this affects the results agricultural environmental management. The reaction rate of agrogeosystems can be assessed by the magnitude of the reduction in losses R_c,

$$R_C = \sum_{i=1}^{l} \sum_{j=1}^{m} \sum_{k=1}^{n} r_i \cdot r_j \cdot r_k, \tag{1}$$

where r_i (1, 2, …, l) – irreparable losses associated with climatic disasters expressed in the destruction of individual biological populations and changes in the structure of agrogeosystems and natural geosystems that are beyond the boundaries of self-healing;

r_j (1, 2, …, m) – qualitative losses of components of the natural environment, which include deterioration of soil fertility, changes in the hydrological regime of rivers and hydrochemical water quality, relief, disruption of biological processes representing chain reactions to changes in climatic processes;

r_k (1, 2, …, n) – reversible losses of components of the natural environment that have not lost their self-healing functions due to both the self-regulating properties of geosystems and creating a balanced system of agricultural environmental management.

To determine the functional regime of natural geosystems in climate change and their compensation, it is important to estimate the time of their restoration and the degree of deviation from the original natural state. The functional regime of the compensatory capacity of the natural geosystem can be represented as the equation:

$$\frac{dR_C}{dt} = \oint \left[\sum_{i=1}^{n} \left(\frac{a_C}{e_O}\right)_i ; t\right], \tag{2}$$

where $\left(\frac{a_C}{e_O}\right)_i$ is a climatic ratio that takes into account the deviation of the i-th factor (aC) of environmental components from the initial, natural (eo) value of this factor;

t – time and period of recovery,

The condition for effective restoration of the disturbed geosystem will have the following form

$$max\left(\frac{dR_C}{dt}\right)\Bigg|\begin{matrix}\left(\frac{a_C}{e_O}\right)_i = 1 \\ t = t_{min}\end{matrix}, \tag{3}$$

The natural balance in the geosystem is disrupted due to climate change and tends to shift, manifested in local forms of loss of quality of agrogeosystems, which are reflected in the transformation of its components. For the further development of agricultural environmental management, it is necessary to consider the patterns of climate change.

4 Conclusion

The study of the rhythmic features of climate dynamics allows us to draw the following practically significant conclusions. Changes in the amount of precipitation on the territory of the Voronezh forest-steppe along secular oscillations are caused mainly by the rhythm of western transport. The coming decades will be characterized by a general trend towards an increase in precipitation and an increase in average annual temperature. A pronounced deterioration in bioclimatic conditions for the development of agriculture in the Voronezh forest-steppe can occur in 2040 - 2070, which is determined by the potential aridization of the climate due to a decrease in precipitation along secular variability against the background of a continuing rise in temperature. The proposed approach can be used to identify patterns of development of agrogeosystems of the Voronezh forest-steppe in the climatic realities of the new century.

References

1. J. T. Abatzoglou, S. Z. Dobrowski, S. A. Parks et al., Scientific Data **5,** 170191 (2018). https://doi.org/10.1038/sdata.2017.191
2. S. Outten, R. Davy, Changes in the North Atlantic Oscillation over the 20th century, EGUsphere [preprint] (2023). https://doi.org/10.5194/egusphere-2023-2832
3. T. Benabdelouahab et al., Theory. Application. Climatol. **141,** 309-320 (2020)
4. B. Gvozdikova, M. Müller, Atmosphere. Res. **248,** 105182 (2021). https://doi.org/10.1016/j.atmosres.2020.105182
5. D. I. V. Domeizen, J. Geophys. RES Atmosphere **124,** 3180-3194 (2019)
6. S. G. Yeager, J. I. Robson, Curr. Clim. Change Rep. **3,** 112-127 (2017)
7. R.C., Cornes, G. van der Schrier, E.J. van den Besselaar, P.D. Jones, J. Geophys. Res. **123,** 9391-9409 (2018)
8. S. Kravtsov, S. Grimm, S. Gu, Npj Clim. Atmosphere Science **1,** 34 (2018)
9. A.E. Lobanova, I.V. Shatilova, Bulletin of Moscow University. Series 5. Geography **2**, 66-72 (2018)
10. M.E. Mann, B.A. Steinman, D.J. Brouillette, S.K. Miller, Science **371,** 1014-1019 (2021)
11. N.-E. Omrani et al., Sci. **9,** 3014 (2019)
12. D. Faranda, G. Messori, E. Coppola, T. Alberti et al., Climaticometer: Contextualizing extreme weather in a changing climate, Egusphere [preprint] (2023). https://doi.org/10.5194/egusphere-2023-2643
13. S. F. Feng, H. Y. Wu, Z. Q. Hao et al., Weather and climate extremes **30,** 100299 (2020) https://doi.org/10.1016/j.wace.2020.100299
14. K. Hamal, S. Sharma, B. Pokharel et al., Atmosphere. Res. **262,** 105798 (2021). https://doi.org/10.1016/j.atmosres.2021.105798