

Method of minimizing the risk of reducing the production of agricultural products by means of fuzzy logic

Ruslan Bischokov
 Department of Higher
 Mathematics and Computer
 Science
 Kabardino-Balkaria State
 Agrarian University named
 after V.M. Kokov
 Nalchik, Russia
rusbis@mail.ru

Aslan Apazhev
 Department of Technical
 Mechanics and Physics
 Kabardino-Balkarian State
 Agricultural named after V.M.
 Kokov
 Nalchik, Russia
apazhev.aslan@mail.ru

Vladimir Trukhachev
 Department of Animal Feeding
 and General Biology
 Stavropol State Agrarian
 University
 Stavropol, Russia
rector@stgau.ru

Elena Didanova
 Department of Agronomy
 Kabardino-Balkaria State
 Agrarian University named
 after V.M. Kokov
 Nalchik, Russia
elenadidanova@gmail.com

Abstract— The results of the analysis and prediction of climatic changes in the empirical time series of precipitation regimes and air temperature regime of the initial observations of meteorological stations located in the territory of the Kabardino-Balkarian Republic for the period 1955-2017 are presented. Estimates of random errors and statistical significance of distribution parameters, homogeneity (according to the criteria of Dixon and Smirnov-Grubbs) and stability (according to Student's and Fisher's criteria) during the time trends of integral empirical distributions of meteorological characteristics are obtained. Using the values of the yield of selected crops for the 30 years period, a computer adaptive fuzzy-logical model of the dependence of crop yield on changes in natural factors has been developed. By setting the predicted values of the climatic characteristics in the computer model, we obtain the possible values of the yield for the next agricultural year. In case of unsatisfactory yield values, we determine the analogue-year from previous years in accordance with the next year and develop recommendations for making management decisions.

Keywords—*climate, precipitation, air temperature, air humidity, statistical analysis, random errors, piedmont zone, daily maximum precipitation, the number of days with precipitation of 5 mm or more, analog-year, fuzzy-logical model, crop yield.*

I. INTRODUCTION

The program "Digital Agriculture" provides for the development of information systems for processing data of agro-climatic resources and the transfer of effective information on broadband high-speed Internet communications to the agricultural producer.

Agricultural producers are at risk in the loss of invested financial and other funds in the cultivation of crops due to climatic cataclysms and anthropogenic processes in the territory. The climatic features of the Kabardino-Balkarian Republic are very changeable, often passing hail streaks that cover several localities. They kill poultry, and sometimes cattle are killed. Due to long torrential rains flooding of houses and agricultural land in villages occurs. Every year, hundreds of hectares of crops are damaged by hail, floods and other natural disasters.

The Kabardino-Balkarian Republican Center for Hydrometeorology and Environmental Monitoring has accumulated a large amount of data of long-term observations of climatic characteristics from all meteorological stations operating in the territories of the Kabardino-Balkarian Republic. A computer database has been created since 1955 with daily average, decade, monthly and annual values of meteorological parameters of precipitation, temperature of air and soil, air humidity and wind speed. The head office of the Russian Emergencies Ministry for the Kabardino-Balkarian Republic has collected data on the existing anthropogenic processes and natural disasters on the territory of the CBD since 1955. Registered data of climatic variations on the territory of the republic were observed, Hurricanes, hailstorms, heavy rains, floods, sharp drops in atmospheric pressure and air temperature, melting glaciers, floods, avalanches, mudslides and landslides. Often take place the Ministry of Agriculture of the Kabardino-Balkarian Republic has data on the yields of all agricultural crops sown on the territory of the republic for the last 30 years, by farms of all categories, districts and average for the region. [4, 5, 6]

The aim of the work is to develop methods to minimize the risk of damage to reduce agricultural production.

II. MATERIALS AND METHODS OF RESEARCH

To achieve this goal the following tasks were solved:

- analysis of climatic characteristics for the period 1955-2017; [2, 3]
- assessment of the homogeneity of integral empirical distributions according to the statistical criteria of Dixon and Smirnov-Grubbs we determine the sharply deviating extremes of the series, indicating possible anomalous processes; [10, 12, 13]
- development of a mathematical model for describing the dynamics of climatic characteristics and predicting their significance for the coming years;
- determination of years-analogues by predictive values for determining possible anomalies;

- development of an adaptive fuzzy-logical model of changes in crop yields, depending on the dynamics of natural factors;
- setting the predicted values of climatic characteristics, we determine the possible values of crop yields for the next agricultural year.

Development of recommendations for making management decisions for the upcoming agricultural year.

III. RESULTS OF RESEARCH

To analyze the dynamics of changes in climatic characteristics of the precipitation regime and the temperature regime of air and soil, we calculate the values of the main parameters (average value, dispersion, maximum and minimum, as well as asymmetry and kurtosis) and present them in tabular form by climatic seasons and zones.

TABLE I. PHYSICAL AND STATISTICAL CHARACTERISTICS OF THE TIME SERIES OF SEASONAL VALUES OF METEOROLOGICAL PARAMETERS ACCORDING TO MS NALCHIK FOR THE PERIOD 1955-2017.

Season	Average value	Dispersion	Asymmetry coefficient	Autocorrelation coefficient	Minimum	Maximum
<i>Average monthly air temperature</i>						
Winter	-1,85	3,31	-0,32	1,08	-6,67	1,70
Spring	9,42	1,64	-0,28	1,07	6,37	11,93
Summer	21,10	1,37	0,21	1,07	18,90	24,03
Autumn	10,26	1,80	-0,38	1,10	6,50	13,30
Year	9,74	0,98	-0,17	1,05	7,66	11,67
<i>Total precipitation (mm)</i>						
Winter	70,88	304,98	0,542	0,970	31,0	115,3
Spring	189,83	3182,44	0,115	0,968	63,3	348,0
Summer	235,78	5002,62	0,016	0,978	97,0	378,0
Autumn	134,93	2408,46	1,059	0,952	59,8	325,0
Year	631,58	12069,52	0,040	0,976	404,0	893,3

From table 1 it can be seen that for the average monthly air temperature during the winter period is cool and the dispersion around the average value is higher than in other seasons. In addition to the summer season, the asymmetry takes negative values. The autocorrelation coefficient takes a fairly large value and almost the same values with minor deviations during all seasons, which indicates the presence of a trend of the studied series. Autumn is warmer than spring. And the average air temperature for the year is approximately equal to spring. The largest deviation of the meteorological parameter values from the average is [-4.820C; 3.040C].

The greatest amount of precipitation is observed in the summer period, and the value of the variance indicates a large scatter of data relative to the average. The asymmetry coefficient takes positive values, and the autocorrelation coefficient is close to 1 and indicates the presence of a trend. The spread of data for all seasons is quite large, which indicates the instability of values.

We will analyze the dynamics of climate change for the period 1955-2017, for example, autumn values of precipitation and air temperature according to Nalchik weather station data.

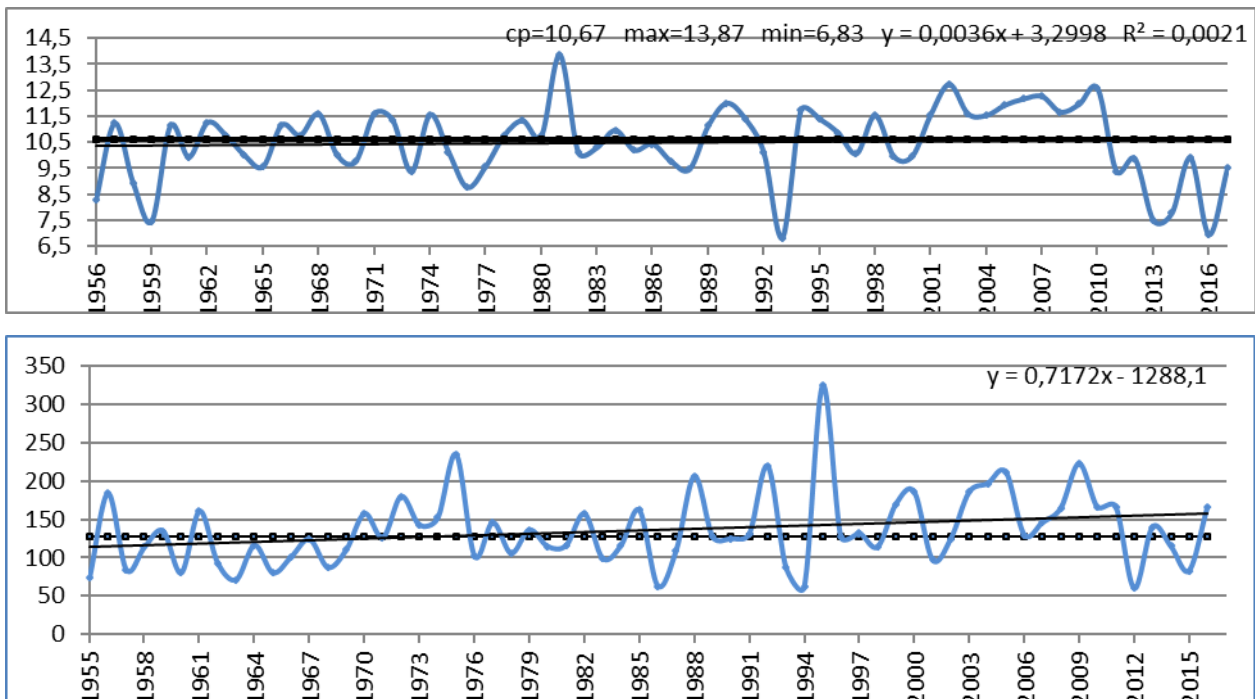


Fig. 1. Dynamics of changes in precipitation and air temperature

From Fig. 1 it can be seen that precipitation and air temperature increase with the trend. We define the adequacy of the time series of meteorological characteristics by evaluating the homogeneity of the integral empirical distributions according to the statistical criteria of Dixon and Smirnov-Grubbs. At the first stage, we rank the rows in ascending order of the sample and calculate the main parameters (mean, variance, asymmetry and autocorrelation) with the corresponding estimates of their random errors and statistics of the Dixon and Smirnov-Grubbs criteria. The second stage is based on the assessment of homogeneity by criteria, which consists of comparing the calculated value of the statistics of the criterion obtained from empirical data with its critical value from the tables at a significance level $\alpha=0,05$, sample size $n=62$, autocorrelation coefficients $[r(1)]$ and asymmetries (Cs), which are listed in Table 1. As a result, the null hypothesis of homogeneity can be accepted if the calculated statistics value is less than the corresponding critical value. [1, 10, 11, 12, 13, 14]. The calculated statistics values are less than the corresponding critical. This means the absence of sharp deviations for the entire period of lead, i.e. the decrease and increase from year to year occurs

smoothly without sudden emissions. For the constructed time series of autumn air temperature, the calculated Dixon statistics are $D3_1=0,242; D4_1=0,245; D5_1=0,221$, which is higher than the critical values, and this indicates the need for additional research using Student's and Fisher's criteria. [7, 8, 9, 10, 11, 12]

From Fig. 1 it can be seen that in 1981 there is an increase in air temperature by 3.30C, and in 1993 a decrease by 3.80C relative to the climatic norm and the previous year. Precipitation in 1995 increased by 263 mm compared with 1994 and by 198 mm relative to the climatic norm. Perhaps during these years there were natural disasters. If the predicted values of climatic characteristics for the next year show the same picture, then we need to use the Student and Fisher criteria and proceed to the analysis of decadal or daily values, dividing the interval into parts.

By their nature, climatic characteristics are considered cyclical with a certain periodicity and to build a mathematical model describing the process from the source data we build a phase portrait to determine the values of the periods:

TABLE II. FREQUENCIES OF PRECIPITATION CONTAINED IN TIME SERIES

Seasons	Periods											
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Winter	2,5	3,8	2,1	5,5	4,2	2,8	2	3,6	2,5	2	2,5	
Spring	3,7	2,7	4,1	3,3	2,1	2,2	3,1	3,3	3,8	2	2,2	
Summer	2,2	6,7	2	3,1	4	6,4	3,6	2,1	2,7	2,2	4,9	3,2
Autumn	2,2	3,4	3,1	1,7	3,5	1,9	2,9	3,7	3,4	3,6	4,8	2,5

It is assumed that the model describing the climatic characteristics consists of three components: natural-anthropogenic processes, natural processes, and natural-random processes. [2, 3, 5, 6, 7, 8, 9, 15]:

$$y = \alpha_0 x + \beta_0 + \sum_{i=1}^N \left(\alpha_i \cos \frac{2\pi x}{T_i} + \beta_i \sin \frac{2\pi x}{T_i} \right) + R_N(\alpha_i, \beta_i, x)$$

After testing the developed model, we obtain the predicted values for the coming years.

The next step is analyzing the values of crop yields for the study period.

Then we build a fuzzy-logical model of the dependence of yield on changes in natural factors.

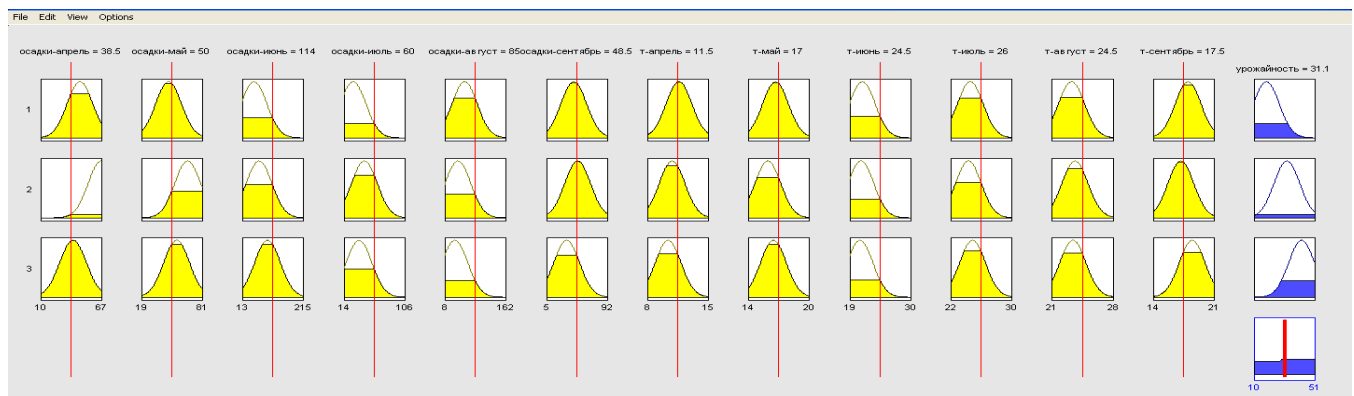


Fig. 2. A fuzzy-logical model of the dependence of the yield of winter wheat on changes in seasonal precipitation and air temperature.

Fig. 2 shows the control model, where you can set the predicted values of climatic characteristics (yellow) for the next year (vertical red bars) and get the crop yield values (blue) in the future. If the resulting value does not satisfy the user, then you need to find out the reasons for such a low yield. To do this, according to the estimates of Dixon and

Smirnov-Grubbs, we find an analogue-year from previous years and determine the possibility of abnormal processes for making management decisions. You can use crops with a short growing season and sow them before or after the anomaly. [five]

IV. CONCLUSIONS

According to the results of research, recommendations are being developed to minimize the risk of reducing the production of agricultural products.

This project is an information system that, according to the databases of climatic characteristics and crop yields for the study period, the agricultural producer will draw up a business plan for crop rotation for the upcoming agricultural year with maximum profit. This is one of the aspects of digitalization of agriculture.

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