PREDICTION ESTIMATION OF AVERAGE ANNUAL AIR TEMPERATURES AND PRECIPITATION NEAR CITY OF YAKUTSK

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ABSTRACT

This article presents the results of a study of trends in the main climate parameters - average annual air temperatures and precipitation.

Properties of a territory of distribution of permafrost rapidly change under the influence of any natural or man-made processes. This particularly applies to an increase in the air temperature. It is known that the increase in the temperature causes the increase in depth of seasonal thawing, enhances the defrost process that leads to a change of properties of permafrost rocks, and with high ice content of soils can cause a loss of their bearing capacity, which, in turn, may be hazardous to technical systems built in this territory. The increased precipitation may also lead to the development of waterlogging and increased permafrost degradation. Consequences of changes in climatic conditions are also evident in the growth of frequency of occurrence of hazardous hydrological phenomena.

In this article, the following specific tasks are considered: methodological approaches to an analysis of long-term temperature series and identification of structural components of the time series to build analytical and predictive models, on the basis of probabilistic and statistical tools the models are obtained to predict the changes in climate variables, the modern trend of the change in the average temperatures is determined.

For modeling and prediction of climatic norms of the average annual air temperature and precipitation near the city of Yakutsk, the time series of studied climatic characteristics from 1891 to 1999 are used and they made a numerical retro-forecast of the change in the average annual air temperature till 2002.

Keywords: *climate changes, technical systems, permafrost, statistical modeling, forecasting.*

INTRODUCTION

In the studies on impacts of natural and man-made factors on a trunk pipeline (TP) laid on the territory of permafrost, it was noted that the main causes of emergence and development of accidents are [1] complex natural and climatic conditions of operation, large length of the gas pipeline; permafrost soils;

thermokarst phenomena, non-projected sections of pipelines on weakly bearing soils (bogs, maris and floodplains of rivers), etc.

Permafrost rocks are very sensitive to any natural or technogenic processes occurring in the territory of their distribution. The increase in the temperature causes the increase in the depth of seasonal thawing, strengthens the defrosting process, which leads to the change in the properties of frozen rocks, and with the high ice content of soils can cause loss of their bearing capacity, which, in turn, can be dangerous for technical systems [1]. The increase in the amount of precipitation also has negative consequences associated with a rise in groundwater levels and the development of bogging processes, especially in areas of excessive moisture, causing activation of the permafrost degradation processes. The consequences of changes in the average annual air temperatures and the amount of atmospheric precipitation are also manifested in the growth of the frequency of dangerous hydrometeorological phenomena.

Therefore, problems of the study of the climate change, its prediction and assessment of the consequences of anthropogenic warming in the last decade have acquired particular urgency. To determine whether the climate change is manifested in the specific natural characteristics and in the particular area, it is necessary to carry out research and modeling of time series dynamics. The analysis and statistical modeling of time series of temperature and precipitation will allow one to assess climatic features of a region for the purpose of the further scientific studies and also will allow somebody to plan scenarios of sustainable development of the region.

The analysis of meteorological data, carried out in work [2], [3] for a number of countries in the Northern Hemisphere (Russia, Canada, USA-Alaska, China) shows that in the last 25-30 years, the moderate warming of the climate actually takes place. The increase in the air temperature over this period in most regions of Russia is 1-1.2 °C. A rate of the increases in the average annual air temperature over the past 25-30 years is 0.02-0.03 °C per year; in the European North, it is 0.03-0.07 °C per year in the north of Western Siberia and 0.01-0.08 °C per year in Yakutia [4]. The very increase in the air temperature over this period varies from 0.4 to 1.8 °C. The warming of the climate is mainly due to the increase in the winter air temperature. Complexity and multifactor nature of processes determining weather and climate are due to absence of effective methods of prediction of the climate changes [5]. The results of climate forecasts are contradictory, which, in turn, causes ambiguity in the permafrost forecasts. The meteorological data over the past 10-15 years show that the extreme scenarios of climate change are not justified, the warming is in progress, but at a more modest pace.

The results of physical and mathematical modeling allow us to estimate only the trends and values of the future climate characteristics averaged over certain spatial and temporal intervals, while uncertainties of such model values are greater than the predicted trend changes [6].

The statistical models allow someone to take into account some general laws of interannual fluctuations of the regional climate and to build their extrapolations for the next two to three decades more accurately than the physico-mathematical models. For the longer time periods, the statistical models are not yet suitable. In

many cases, the most urgent task is to obtain estimations of interannual climate fluctuations for the following one or two decades. On this time interval, an advantage of statistical models is obvious [7], [8].

The purpose of the work is to develop a methodology of the prediction of climatic characteristics, in this case the average annual air temperatures, the amount of precipitation and also the assessment of adequacy of such forecasts. To achieve this purpose, the following steps were carried out: construction of the spatial statistical models of climate characteristics for the selected territory; selection of the most effective models of climate parameters - the models for determining the average annual temperatures and amount of precipitation; determination of the future values of selected climate parameters, which are the base of the most effective climate models.

One of the methods of the probabilistic and statistical apparatus that can be used to predict the changes in the climate parameters is the time series analysis method.

MATERIAL, METHODS OF RESEARCH

The average annual air temperatures and amount of atmospheric precipitation in the area of the city of Yakutsk from 1891 to 1999 were used as starting materials, and the numerical forecast of the changes in the average annual air temperatures and amount of atmospheric precipitation till 2002 was compiled on the basis of the data.

The tasks of prediction of time series are as follows: the primary analysis of the "source" data, identification of the model suitable for a description of the available time series, the estimation of the model parameters, the study of the adequacy of the model, and the prediction.

A universal integrated system STATISTICA, designed for statistical analysis and data processing, presents a wide range of procedures that implement all of the above steps.

The forecasting method contains a sequence of actions, as a result of the implementation of which the prediction model of the particular time series is determined, i.e. it defines a functional dependence adequately describing the time series. In addition, the forecasting method contains the actions to assess a quality of the forecast values. We construct the prediction model using the three prediction methods.

1. The method of exponential smoothing

The efficient and reliable method of prediction is exponential smoothing. The main advantages of the method are an ability to take into account weights of initial information, simplicity of computational operations, and flexibility of the description of the various dynamics of processes. The method of exponential smoothing makes it possible to obtain the estimation of the trend parameters characterizing the trend developed by the time of the last observation, but not the average level of the process. The method was most used for the implementation of

the medium-term forecasts. For the method of exponential smoothing, the main and most difficult moment is a choice of the smoothing parameter α, the initial conditions and a degree of a predictive polynomial.

An exact formula of the simple exponential smoothing has the following form:

$$S_t = \alpha \cdot X_t + (1-\alpha) \cdot S_{t-1}$$

When this formula is applied recursively, each new smoothed value (which is also the forecast) is calculated as the weighted average of the current observation and the smoothed series. The empirical studies have shown that the simple exponential smoothing very often gives the fairly accurate prediction.

The results of the prediction showed that very often the simple exponential smoothing gives the fairly accurate prediction, the most successful model contains the additive seasonal component, with the smoothing constant α = 0.5.

2. The method of harmonic analysis

We will consider the features of application of the harmonic analysis method for the prediction of the time series with regular cycles (a Fourier approximation). Using the Fourier series, the dynamics of the phenomenon are represented by a function of time.

To predict the corresponding time series, we can apply the following methods for the identification of the time trend and periodic components: in the determination of both the type of the functions approximating the time dependence of the two components and the numerical parameters of these functions.

To approximate the time trend, the simplest and most commonly used approach is its polynomial representation, when the corresponding component of the time series is the function that is the polynomial, the coefficients of which can be found by the method of least squares. The standard method of the selection of the periodic components of the time series is to expand it into the Fourier series (the Fourier analysis).

An equation for the description of the cyclic component of the series of residues is based on the results of harmonic analysis.

3. The method of prediction based on ARIMA-models

The ARIMA-models cover a rather wide range of time series, and small modifications of these models allow the very accurate description of time series with seasonality.

The process of the construction of the ARIMA models can be divided into several stages: transformation of the series to the stationary form, the identification of the particular model and estimation of the model coefficients, using the statistical methods, guided by behavior of autocorrelation functions.

In this case, the behavior of the autocorrelation function (exponentially damped) is consistent with the ARIMA model (1.0).

RESULTS

At the last stage, the various diagnostic procedures are used to verify the adequacy of the selected model on the basis of the available data.

The study of the residues obtained after the procedure of removal of the trend and the cyclic component shows that a distribution density of the residues is successfully approximated by the normal distribution law, which is a sign of adequacy of the constructed forecast model.

Tables 1 and 2 show the numerical values of the predictions obtained by the three methods. The criterion for the quality of the model is magnitude of a model error in the description of the real climate [7]. As can be seen from the tables, in general, the forecast values are slightly different from the actual ones. The errors of the forecast show the sufficient adequacy of the selected statistical models.

Table 1. Comparative analysis of results of retro-forecasts of average annual temperatures in area of Yakutsk

Method	2000		Error	2001		Error	2002		Error
	Actual	Predicted	%	Actual	Predicted	%	Actual	Predicted	%
Exponential smoothing	-9.13	-9.23	1.1	-8.68	-9.12	5	-7.58	-8.4	10.8
Harmonic analysis	-9.13	-8.59	5.9	-8.68	-8.46	2.5	-7.58	-8.32	9.7
ARIMA	-9.13	-8.82	3.4	-8.68	-8.3	4.3	-7.58	-8.59	13

Table 2. Comparative analysis of results of retro-forecasts of amount of precipitation in area of Yakutsk

Method	2000		Error	2001		Error	2002		Error
	Actual	Predicted	%	Actual	Predicted	%	Actual	Predicted	
Exponential smoothing	14.47	13.6	6	12.31	13.53	9	12.46	14.3	12.7
Harmonic analysis	14.47	13.7	5.3	12.31	13.06	6	12.46	13.9	11.5
ARIMA	14.47	13.8	4.6	12.31	13.15	6.8	12.46	13.7	10

CONCLUSION

The analysis was carried out in comparison with the results of accuracy estimates from three statistical models. The method of exponential smoothing shows the best result when forecasting for the shorter period (the first prediction year) and the worst result when forecasting for the longer one (the third year). The method of harmonic analysis shows the worst result when forecasting for the shorter

period (the first year) and the best result when forecasting for the longer one (the third year).

The loss of stability of cryolithozone can have many adverse social, economic and environmental consequences. In the next few decades, the climate change can lead to a decrease in the strength properties of permafrost soils, which, in turn, will cause the decrease in the bearing capacity of foundations and damage or destruction of structures built on them. Deformations and accidents of the pipelines passing through the permafrost can be accompanied by discharges of oil products into the environment. The undeveloped areas of cryolithozone can develop the destructive geomorphological processes, causing soil subsidence and significantly altering northern landscapes.

The consequences of rapid variability of the climatic conditions are manifested in the growth of the frequency of dangerous hydrometeorological phenomena and in the increase of the adverse consequences that affect efficiency of activities of such vital sectors of the economy as energy, transport, construction, housing and communal services.

The resulting problems require the immediate and comprehensive study, as they jeopardize environmental safety of the Far North.

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