Forecasting model of forest management fire index at the thematic area of the Trans-Baikal Territory

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Abstract. The article presents a forest fire forecasting model based on recursive filtering of the fire weather index. The relevance of the study is presented, statistical data are presented, including economic aspects, on the basis of which the scientific task is set. For the approbation, the fundamental issues to be solved have been identified. A geo-information resource is considered that assists in the choice of the study area, while calculating a complex indicator of fire hazard. Data were sampled on the basis of Columbia University's International Research Institute for Climate Prediction. A recursive filter based on the combination of Kalman and Levinson algorithms is used as the central part of the model. The program model of the filter is presented. Approbation was carried out with a visual result in the form of a predictive assessment graph. General results of work are substantiated.

1. Introduction

Almost two thirds of the territory of Russia is covered with forest. From a resource and economic point of view, the forestry fund as of February 2021 is approximately 1.147 million hectares. Throughout the country, up to 40 thousand forest fires of various degrees of classification are registered annually, while covering areas up to 3 million hectares. Touching upon financial losses, it can be noted that the annual losses amount to about 20 billion rubles, including forest as a resource - wood, mechanisms for fighting fires, eliminating consequences (death of animals, damage to social infrastructure, environmental aspects, and others). The seasonality of fires occurs from early spring to late autumn, depending on the region.

Excluding the economic component, forest fires pose a serious threat to the safety of the population, in particular the nearest settlements to the forest. Thus, ensuring the safety of the population, as well as, accordingly, forest fire prevention and timely extinguishing are priority tasks.

There are many techniques and technologies for preventing and fighting forest fires. The most effective are:
- artificial increase in precipitation and drought control;
- insulation of forest combustible materials;
- direct mechanized extinguishing;
- annealing of territories;
- intelligence activities;
- forecasting forest fires;
- and others.
In order to ensure all-round safety and reduce economic losses, it is necessary to mark in advance potentially dangerous areas of possible forest fires. Moreover, the more detailed the data are described, the more efficiently future measures will be taken. Hence it follows that it is necessary to obtain data related to forest fires in advance, that is, to carry out a forecast.

In the scientific field, a considerable number of models and methods for forecasting forest fires are presented [1, 2]. Forecasting forest fires means determining the probability of occurrence and growth of forest fires in time and space based on the analysis of forest fire monitoring data.

Based on the above statistical data, as well as the information contained on federal portals, in particular on the Rosleskhoz resource, it can be confidently asserted that the trend of a fire hazard situation does not change for the better, which in turn indicates the insufficient effectiveness of existing methods of forest fire early warning. Thus, the development of a new forecasting model based on the data of the fire weather index is an urgent task [3].

2. Methods and Materials

In order to conduct an experiment, during which a forest fire forecasting model will be built, it is necessary to define a number of tasks:

- determine the initial data for approbation;
- determine the forecasting algorithm;
- define the area under study (territorial component);
- choose a software environment for the implementation of the algorithm.

In order to determine the area under study (select a territorial region), it is necessary to calculate statistical data on a number of the most promising, in relation to the occurrence of forest fires, fire hazard parameters. Thanks to the resource «Kosmosnimki» [4] it is possible visually (figure 1) to get acquainted with the most prone to forest fires in the territories of the country. However, since the graphical representation does not give an accurate mathematical assessment in the form of a kind of fire coefficient, it is necessary to calculate with respect to the resulting cartographic image.

For the calculation and further selection of the study area, it is necessary to calculate the fire hazard indicator. The calculation of the complex indicator (CI) of fire hazard is calculated by the following expression:

\[
CI = \sum_{i=1}^{n} t_w (t_w - v)
\]

where, CI — complex fire hazard indicator; \(t_w\) — atmospheric temperature; \(v\) — dew point; \(n\) — number of days.

Thus, CI is the product of temperature by the difference between the temperature value and the dew point for a certain number of days after precipitation.

Calculations showed that most often in relation to forest fires, the Trans-Baikal Territory was exposed. It is from this region that geodata will be sampled.
3. Results and Discussion

The main input data will be the Forest fire weather index. The Fire Weather Index (FWI) is a meteorological index (forest fire risk assessment) used worldwide to assess fire hazard. It consists of various components that take into account the influence of fuel moisture and wind on the behavior and spread of fire. The higher the FWI, the more favourable the meteorological conditions for a forest fire. The index is an integer that is calculated from five components. The first three components are numerical estimates of the moisture content in litter and other finely dispersed fuels, the average moisture content of weakly compacted organic layers of medium depth, and the average moisture content of deep dense organic layers. The last two components are the rate of fire propagation, if fuel is available for combustion, and the intensity of the frontal fire.

To calculate this index, the following parameters are required:

- air humidity at the beginning of the afternoon (when it has the lowest value);
- mid-day temperature (when it matters most);
- the amount of precipitation in 24 hours (from noon to noon);
- maximum average wind speed.

The FWI geodata is sampled thanks to the IRI / LDEO Climate Data Library resource (Columbia University's International Research Institute for Climate Prediction (IRI) and Lamont-Doherty Earth Observatory (LDEO)).

Consider the independent grid variables:

- \( \text{lat} \) (latitude)
  - grid: /lat (degree_north) ordered (52N) to (53N) by 0.5 N= 3 pts :grid
- \( \text{lon} \) (longitude)
  - grid: /lon (degree_east) ordered (109.3333E) to (110.6667E) by 0.6666679 N= 3 pts :grid
- \( \text{Time} \) (time)
  - grid: /T (days since 1980-01-01 00:00:00) ordered (1 Feb 2009) to (31 Dec 2015) by 1.0 N= 2525 pts :grid

Based on the presented grid data, it can be seen that the unloading was carried out from the territorial area in the Trans-Baikal Territory with the coordinate polygon 52N to 54N and 109E to 111E. This archive provides for the period from February 1, 2009 to December 31, 2015. Accordingly, FWIs are sampled for each day.
Having determined the investigated geolocation, having unloaded the necessary data, it is necessary to designate the forecasting algorithm. Based on recent studies, the most preferable for this task is the algorithm based on recursive filtering, which is based on the combined Kalman-Levinson filter.

Based on the generally accepted basic equations of the Kalman and Levinson algorithm [5-7], we present the conceptual forecasting model in the form of a block diagram (figure 2).

![Figure 2. Conceptual block diagram of a predictive model based on the combined Kalman-Levinson filter.](image)

The implementation of the hybrid filter model is based on two independent algorithms, while a new combined mathematical algorithm is not being developed. The splicing of two digital filter models (Kalman and Levinson) is purely software driven. The essence of the work lies in the fact that the algorithm, in which the processes of the implemented filters work sequentially. This means that when submitting geodata to the input, the program will determine the sequence for connecting one or another filter. So if zero values are fed to the input, or values that cannot be adjusted by the Levinson-Durbin filter, then the switch to the Kalman-Bucy filter occurs. After the filter has finished calculating,
the resulting data is fed to the input of a previously unused filter for further correction. Observing the necessary conditions of the output data and supplying a voluminous amount of information to the input, the Levinson-Durbin filter is connected, and further processing takes place exactly the opposite.

The presented diagram definitely traces two conditionally independent algorithms presented by (Kalman and Levinson). There are a number of developed variables needed to analyze and process imported geodata.

As an approbation, software will be developed using the MS Visual Studio Community 2019 environment, in the C# programming language. An experiment of synthesizing the developed model of the combined Kalman-Levinson digital filter is implemented on the basis of the previously obtained FWI geodata.

4. Conclusion
The testing results are very impressive. The graph (figure 3) shows a comparative predictive assessment of the FWI parameter. That is, a priori FWI values are input to the input (blue curve), a forecast is made in parallel, with a set step of 1 year (yellow line).

![Figure 3. Results of testing the predictive model based on FWI data.](image)

The difference, reflected in the graph, between the a priori values and the result of the forecast of the Kalman-Levinson filter is minimized, in most cases is absent.

It is worth noting the existing error. The main factors of error are: the use of a digital filter at the software level, which is based on sequential processing of geodata; since the filtering algorithms have not been changed, the effects of error factors inherent in both filters appear. The solution to these "problems" is the development of a combined filter based on a "smart", parallel connection of interconnected filtering algorithms that depend directly on the loaded values in real time. The approach requires the creation of a new unified mathematical apparatus and a complete redesign of the algorithms.

Nevertheless, given due to the results of this model, it is at least possible to support the existing method of forecasting forest fires, thereby reducing the negative consequences[8, 9].
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