PROBABILISTIC APPROACH TO SIMULATE ANTHROPOGENIC LOAD IN CONTEXT OF FOREST FIRES OCCURRENCE

Assoc. Prof. Dr. Nikolay Baranovskiy[1]
Assoc. Prof. Dr. Oleg Kritski[2]
[1, 2] Tomsk Polytechnic University, Russian Federation

ABSTRACT

Baikal is a natural heritage, the value of which is obvious to the entire world community. The unique nature of the Lake Baikal basin is subject to various negative impacts. One of the factors that disturb Baikal basin nature is forest fires, mainly due to the anthropogenic load. In this paper stochastic model is proposed to estimate the probability of forest fire from the anthropogenic load. A point source of anthropogenic load is considered. For example, a rural settlement, a camp, an industrial site, which are located in a controlled forest-covered area. Mathematically, the following model can be formulated. Let's consider circle with radius in the some set. Then the cumulative distribution function (C.F.D.) of ignition near the neighborhood of the point X0 can be defined. Obvious that all properties of c.d.f. are satisfied. Note, that all the points X=(x,y) that lying on the circle Gρ have the same probability P of ignition in the set G.

Further mathematical calculations show that the Rayleigh probability density can be considered. Preliminary calculations of the forest fire probability from a point source of the anthropogenic load on the basis of scenario modeling are carried out. Conclusions are drawn regarding the influence of a point source of the anthropogenic load on the probability of forest fire occurrence in an adjacent territory.

***Keywords**: forest fire danger, probability, anthropogenic load, simulation*

INTRODUCTION

Baikal is a natural heritage, the value of which is obvious to the entire world community [1]. The unique nature of the Lake Baikal basin is subject to various negative impacts. One of the factors that disturb Baikal basin nature is forest fires, mainly due to the anthropogenic load. In this paper stochastic model is proposed to estimate the probability of forest fire from anthropogenic load. A point source of anthropogenic load is considered. For example, a rural settlement, a camp, an industrial site, which are located in a controlled forest-covered area.

It should be noted that, in the general case, deterministic, deterministic-probabilistic and probabilistic approaches to the assessment of forest fire danger due to the anthropogenic load on forested areas can be considered. All these methods are related to hard computing. At the same time, soft computing technologies applied to the forecast of forest fire danger are also noted in the literature [2]. The authors believe that soft computing technologies are suitable only in relatively constant conditions. The most promising approach is a combination of probabilistic criteria and deterministic mathematical models for modeling a specific scenario of a forest fire [3].

BACKGROUND

The structure of the NFDRS is an abstract model of the influence of various factors and conditions on the process of occurrence and spread of fires. The system issues four indices [4]: the Man-caused fire occurrence index (MCOI), the Lightning-caused fire occurrence index (LOI), the burning index (BI)) and the fire load index (FLI). The MCOI and LOI indices are determined taking into account the ignition component (IC) and allow estimating the expected number of forest fires. All forest fuels are divided into typical models. The system introduces a number of pyrological characteristics of forest fuel, which allow to indirectly take into account the ignition process. The final fire danger rating (FLI) is determined depending on the values of the MCOI, LOI and BI indices on a 100-point scale. Thus, the system uses a large number of corrections obtained on the basis of empirical data.

- The Fire Potential Index (FPI) was developed to combine satellite and field measurements into an index that correlates well with the occurrence of forest fires and can be used on a local or national scale along with GIS.

The European Forest Fire Information System (EFFIS) has been supported by a team of experts since 1998 [5]. At present, the group includes experts from 40 countries [5]. The forest fire danger forecasting subsystem generates daily maps of the level of forest fire danger for 1 to 10 days ahead using the forecast of meteorological conditions. Previously, several fire danger indices were tested [6] and the Canadian Forest Fire Weather Index System was also adopted.

The information system for remote monitoring of forest fires (ISDM-Rosleskhoz) [7] was established in 2003 and put into operation in 2005 [8]. ISDM-Rosleskhoz is designed to solve the following problems [8]: 1) prompt detection, registration and subsequent monitoring of areas suspected of forest fire; 2) obtaining operational assessments of the parameters of existing forest fires; 3) obtaining operational estimates of the consequences of forest fires.

Thus, all forest fire danger prediction systems widely used in the world practice provide the calculation of a certain index indicating the probability of forest fires occurrence. The most elaborated question is the occurrence of forest fires from thunderstorms. Technologies to forecast forest fire danger as a result of anthropogenic load are very poorly developed. This is due to the complex nature (often stochastic) of the anthropogenic load. Previously, a probabilistic criterion for assessing forest fire danger was developed taking into account thunderstorm activity and theanthropogenic load [9]. However, only statistical data on anthropogenic fires are used, which are available for individual sites or blocks of forest area.

SYSTEM REQUIREMENTS

The results of the preliminary study show that the development in the foreseeable future of the domestic forest fire danger prediction system, which possesses competitively capable qualities, will require the attraction of up-to-date information-computing technologies and physically-meaningful models and criteria.

The main requirements that must be met in the way of creating a forest fire danger prediction system are:

1. Presence of the state concept to create and develop the domestic system of forest fire danger prediction caused by anthropogenic load.
2. Ranking of all sources of anthropogenic load to point, linear and area.
3. Ranking and grouping of various reasons of forest fires caused by anthropogenic load and corresponding sources of high temperature.
4. Presence of physical and mathematical models of drying and ignition of forest fuel by anthropogenic sources.
5. The network to register vehicles, as well as methods for assessing the initial and boundary conditions for anthropogenic load models in a particular area.
6. Presence of physical and mathematical models to simulate anthropogenic load on forested areas.
7. The presence of a physically and mathematically based criterion for assessing the level of forest fire danger.
8. Presence of a database of initial parameters to simulate physical and chemical processes occurring in the forest fires initiation.
9. The methodology should be implemented in the form of a software package that allows to forecast forest fire danger in a mode that is ahead of the real time of the fire process development.
10. The methodology for forecasting forest fire danger and its software implementation should be able to upgrade and update individual models and subsystems.
11. The existence of a state standard is not based on a specific methodology with all fixed components, but on the specification of the compliance of the methodology to certain requirements.
12. Presence of standards, specifications for files of input, processed and output information in the system of forecasting forest fire danger caused by anthropogenic load.
13. The availability of technologies that allow consumers to promptly receive predicted information about forest fire danger in a particular forested area. For example, using technologies of web-based geographic information systems [10].
14. The availability of technologies and data, which allow to track the reliability of obtained forecasts on the basis of modeling physicochemical processes of forest fuel ignition by an anthropogenic source of high temperature.
15. The availability of suitably trained professionals capable of servicing the system.

16. Understanding of the forecast information for persons who make a decision (possibly without special physical and mathematical training).

MATHEMATICAL MODEL

Let $G=\left\{(x,y),(x-x_0)^2+(y-y_0)^2=R^2\right\}$ is an arbitrary circle of fixed radius R. Let $X_0=(x_0,y_0)$ is a center of the circle G. Let $\rho\le R$ is a radius of circle $G_\rho=\left\{(x,y),(x-x_0)^2+(y-y_0)^2=\rho^2\right\}$ included in the set G. Then the cumulative distribution function (C.F.D.) of ignition near the neighborhood of the point X_0 can be defined as follows:

$$F(\rho)=P(\xi<\rho)=\frac{\mu(G_\rho)}{\mu(G)}=\left(\frac{\rho}{R}\right)^2, \tag{1}$$

where $\mu(G)$ is an area of G and $\mu(G_\rho)$ is an area of G_ρ.

Obvious that all properties of c.d.f. are satisfied.

Remark: Note, that all the points $X=(x,y)$ that lying on the circle G_ρ have the same probability P of ignition in the set G. It grows from zero in the center of circle G_ρ to unit on its boundary. By changing parameter R we can simulate point source of the fire behavior in some Russia region.

Complete the model with heat equation in G. It is well-known that in polar coordinates (r,φ) it can be written as follows:

$$c_p\rho\frac{\partial T}{\partial t}=\frac{k}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{k}{r^2}\frac{\partial^2 T}{\partial \varphi^2}, \tag{2}$$

where c_p is a specific heat capacity, ρ is a density, $T=T(r,\varphi)$ is a temperature and k is a thermal conductivity.

Set the boundary conditions provided that there is no heat flow at the boundary of G:

$$\left.\frac{\partial T}{\partial \mathrm{n}}\right|_{\partial G}=0. \tag{3}$$

Equations (1) – (3) are forming our model with two parts that can be solved separately. Namely, we can solve eqs. (2), (3) and collate the temperature T in each point of G to the probability calculated by eq. (1).

RESULTS AND DISCUSSION

In this paper, a point source of anthropogenic load is considered. R is the boundary of that forested area within which forest fires are recorded as a result of human activity. Different scenarios can be entered depending on the distance from the source to this boundary. The article discusses three scenarios:

1) The low level of anthropogenic load distribution corresponds to a border of 3 kilometers around the source;
2) The average level of anthropogenic load distribution corresponds to a border of 4 kilometers around the source;
3) The high level of anthropogenic load distribution corresponds to a border of 5 kilometers around the source.

Figure 1 shows the distribution of C.F.D. around a point source of anthropogenic load. This paper discusses the homogeneous distribution of C.F.D. on the angular coordinate. In reality, it may differ from uniform or the border will be curvilinear, not a circle.

Figure 2 shows the distribution of C.F.D. along the radial coordinate for various scenarios of anthropogenic load distribution from a point source.

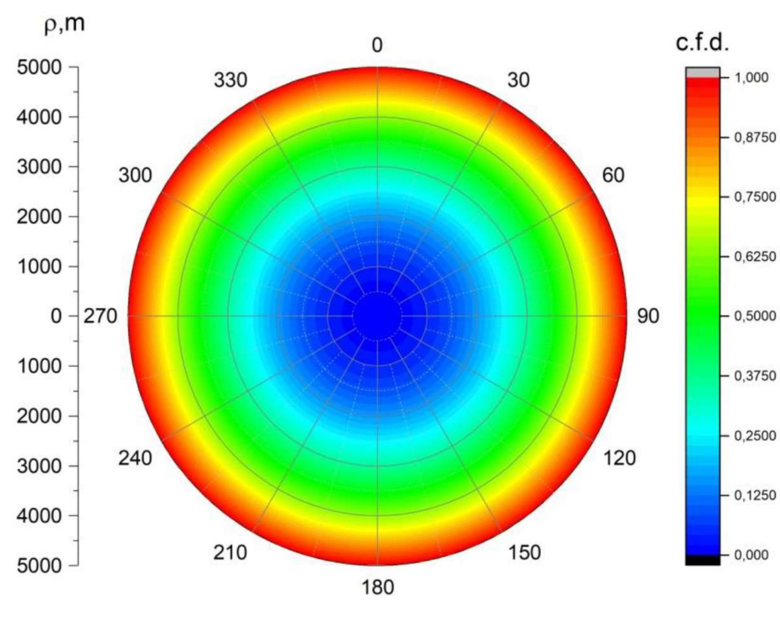

Fig.1 C.F.D. distribution around a point source of anthropogenic load

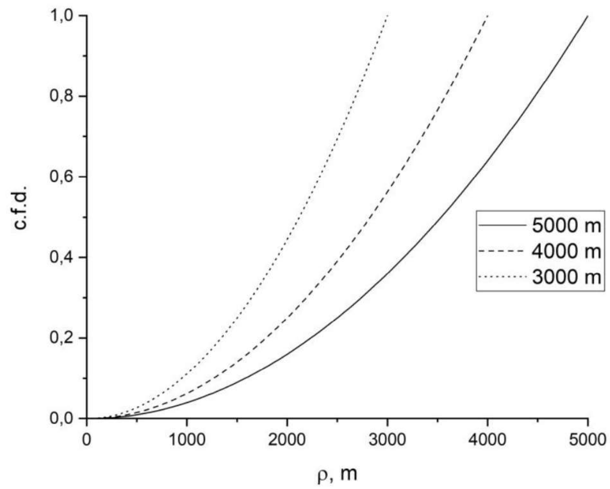

Fig. 2. C.F.D. distribution align radius for different R value

CONCLUSION

The final aim of the research in the area of anthropogenic load on forest-covered areas should be a subsystem for the data assimilation on the level of anthropogenic load. Such a subsystem should perform an objective analysis of the data. By analogy with meteorological data assimilation systems [11], [12], it can perform the analysis and forecast stages.

The article discusses three scenarios:

1) The low level of anthropogenic load distribution corresponds to a border of 3 kilometers around the source;
2) The average level of anthropogenic load distribution corresponds to a border of 4 kilometers around the source;
3) The high level of anthropogenic load distribution corresponds to a border of 5 kilometers around the source.

It is proposed a predictive mathematical model for the system of data assimilation on the level of anthropogenic load. Subsequent studies will present a parametric analysis of this model. The use of this model in the forest fire danger prediction system will increase the level of detail when taking into account such an anthropogenic load factor. The use of this model will provide a hybrid deterministic-probabilistic forecast of the forest fire occurrence from anthropogenic load, when the spread of anthropogenic load is modeled as a probabilistic process, but the spread of a forest fire is calculated using deterministic mathematical model.

ACKNOWLEDGEMENTS

This work is supported by the Russian Foundation for Basic Researches. Scientific project N 17-29-05093.

REFERENCES

[1] Migoń P. Chapter 13: Geoheritage and World Heritage Sites // in Geoheritage. 2018. P. 237-249.

[2] Bui D.T., Le H.V., Hoang N.-D. GIS-based spatial prediction of tropical forest fire danger using a new hybrid machine learning method // Ecological Informatics. 2018. Vol. 48. P. 104-116.

[3] Hadden R.M., Scott S., Lautenberger Ch., Fernandez-Pello C. Ignition of Combustible Fuel Beds by Hot Particles: An Experimental and Theoretical Study // Fire Technology. 2011. V 47. N 2. P. 341 – 355.

[4] Deeming J.E., Burgan R.E., Cohen J.D. The National Fire Danger Rating System - 1978. United States Department of Agriculture, Forest Service, General Technical Report INT-39, Intermountain Forest and Range Experiment Station, Odgen, Utah. 1977. 66 P.

[5] European Forest Fire Information System. Official site. Access: http://effis.jrc.ec.europa.eu (Available 13 November 2018)

[6] Viegas D.X., Bovio G., Ferreira A. et al. Comparative study of various methods of fire hazard evaluation in Southern Europe // International Journal of Wildland Fire. Vol. 10, 1999. pp. 235-246.

[7] Information system for remote monitoring of forest fires ISDM-Rosleskhoz. Official site. Access: https://nffc.aviales.ru/main_pages/index.shtml (Available 13 November 2018)

[8] Podolskaya A.S., Ershov D.V., Shulyak P.P. Application of the method for assessing the probability of occurrence of forest fires in ISDM-Rosleskhoz // Modern problems of remote sensing of the Earth from space. Vol. 8, 2011. pp. 118 - 126. (In Russian)

[9] Baranovskiy N.V. Forest fire hazard assessment using SPMD-model of computation for massive parallel system // International Review on Modeling and Simulations. Vol. 10, 2017. pp. 193-201.

[10] Pew K.L., Larsen C.P.S. GIS analysis of the spatial and temporal patterns of human-caused wildfires in the temperate rain forest of Vancouver Island, Canada // Forest Ecology and Management. Vol. 140, 2001. pp. 1-18.

[11] Apte A., Hairer M., Stuart A.M., Voss J. Sampling the posterior: An approach to non-Gaussian data assimilation // Physica D, Vol. 230, 2007. pp. 50-64.

[12] Srivas T., de Callafon R.A., Crawl D., Altintas I. Data Assimilation of Wildfires with Fuel Adjustment Factors in farsite using Ensemble Kalman Filtering // Procedia Computer Science, Vol. 108C, 2017. pp. 1572-1581.