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REVIEW AND CLASSIFICATION OF EXISTING FOREST FIRE SPREAD MODELS

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Abstract: The forest and field fires are a growing problem in the world within the fire zones due to climate change and increasingly tangible greenhouse effect. Improved technology for sensor monitoring, geographic information systems, increased computing power of computers and the development of communication technology allows early detection of any fires, and also predicting the dynamics and spread of fire and extent of possible damage. This article offers an overview of developments in the modeling of fire, classification of models and some of the main developments in recent years.

Computer models can be used to predict fire behavior based on analysis of fuel (combustible) materials, climate and topography. These models are used to support taking decisions for management and control of fire as a tool for training to improve skills for firefighters, and also to visualize and explain to the general public the behavior of fire, and the strategies for controlling it. These estimates have inherent limitations and will never replace the knowledge of experienced firefighters, but they can provide tools to estimate the behavior of fire and possibly save time, money and lives.

Development of modeling of forest fires dates since 1920. Pioneers in this field are Hawley [6] and Gisborne [7]. They tended to identify factors influencing the spread of fire through measurements and observations. Their research produced a significant knowledge base describing the spreading of fire. This led to the appearance of the first operational models which even achieved satisfactory results.

In the late 30s and early 40s of the 20th century, Curry and Fons [8] proposed a new physical approach for the description of the behavior of fire.

In the 50s and 60s formal developments are carried out by the State Forestry Agency in the U.S., Canada and Australia. Their purpose is to build a fire alarm system incorporating a component for predicting the spreading of fire. Additional funds are provided for exploration and research of large fires linked to bomb attacks during the Second World War. This led to an unprecedented boom in development and publications related to the researching of forest fires.

In the 70s the sector is shrinking, but in the 80s the interest was revived. Since early 1990, the European Union countries (mainly those around the Mediterranean) are actively involved in the development, pushing the leading countries - U.S., Canada and Australia from the focus.

Classification

☀ In the description of the types of burning integrated in model FARSITE Mark Finney classified forest fires based on the type of burning material and the location of fire from the ground. He identifies four main types of forest fires: surface fire, crown fire, spotting fire and acceleration [11].

- Surface fires spread in areas with plants up to 2m in height. The main materials that burn in this type of fire are small trees, shrubs, herbaceous vegetation, fallen logs, stumps, cones, leaves. As a subtype of surface fire can be differentiated so-called ground fires. The main materials that burn in this kind of fire are layers between leaves and mineral soil - humus and fermentation. The main reason why this type of burning can be separated as a subtype is the time difference with surface fire. Usually ground fires start after crossing of surface fire, lighting consecutively leaves, fallen twigs, cones, roots (on the surface) and stumps. The last three types of materials burn longer than shrubs and trees. As a source of continuous burning directly connected to the the organic layer of soil, they can start a ground fire, if the composition of the soil permits it.
- The crown fire spread in areas with predominantly coniferous vegetation. Usually this type of fire occurs after active surface fire, which has dried tree crowns and has started the process of ignition. Burnable materials are located in 2 layers - earth and air. If the spread of the fire front is carried out simultaneously in two layers - we have an active crown fire. But if the fire burns the layer and just some of tree crowns, then we have a passive crown fire.

The crown fires are very difficult to control because the burning process includes all layers of burnable materials and releases a huge amount of heat. This causes the rapid spread of the fire front and makes its suppression extremely difficult. With such burning in most cases the woodland can not be saved - the fire burns until exhaustion of the burnable material or any change in weather conditions (rain, wind direction, etc.).

- Spotting fires occur mainly with the burning of trees with plenty of resin content. The main burnable materials are firebrands that convection carries beyond basic perimeter of the fire and flaming balls of resin that thermal radiation heats to the point of "explosion". Thus, fire can spread up to 30 meters in front of the fire. This is extremely dangerous and for present firefighters, because they may be trapped between two fire fronts. On the other hand this makes it difficult to predict the development of fire. All this makes the suppression of fires very difficult and sometimes impossible.
- Acceleration fires are typical for canyon areas where the slope has a key role in their spreading. The burning heat moved by convective flows has direct contact with burnable materials located higher and contributes to more rapid warming. They develop very quickly and release large amounts of heat. Extremely dangerous and difficult for suppression.

☀ Another approach by which models can be classified is the type of observed parameters.

- Models characterizing (determining) the movement of the front of the fire, describe the geometrical shape of the flame such as height, length, depth and slope.
- Models determining the spread of fire – they are used to obtain information related to the main variables determining the development of the fire. Most of the models monitor the following most important parameters: rate of forward spread, fire line intensity and fuel consumption.

☀ Models can be classified depending on the nature of the data used for calculation of the model. Models describing burning process in forest fires were structured by this principle in early 70s by Karplus [9]. He classifies them as purely physical, which are based on

fundamental physical and chemical laws or purely empirical, based on statistical data of monitoring the combustion process. Then Pastor [2], Weber and Grishin [10] add different shades of classification by creating terms such as semi-physical or semi-empirical methods without generally accepted convention for classifying models. Sullivan makes it in 2007 [3, 4, 5]. According to his classification variants of the modeling methods are:

1. Physical and semi-physical models;
2. Empirical and semi-empirical models;
3. Mathematical and simulation models.

Sullivan presents models developed mostly after 1990 and offers a short overview for the development before this year. In the description that we give below we will follow the sequence that Sullivan offers.

1. *Physical models*

Characteristic of physical models is that the description of the behavior of fires uses physical and chemical laws of combustion. This in turn leads to the use of a large number of parameters in the equations for the calculation of the models, making it difficult for computer simulations, and even harder to use in real situations with real data.

The group of physical models:

1. Weber - 1991
2. Aiolos-F (CINAR S.A, Greece)
3. FIRETEC (Los Alamos National Laboratory, USA)
4. Forbes, 1997
5. Grishin (Tomsk State University, Russia)
6. IUSTI (Institut Universitaire des Systemes Thermiques Industrieb, France)
7. PIF97
8. LEMTA (Laboratoire d'Energetique et de Mecanique Theorique et Appliquee, France)
9. UoS (University of Salamanca, Spain)
10. WFDS (National Institute of Safety Technology, USA).

2. *Semi-physical models*

In semi-physical models only the physical laws of heat and thermobalance are used and chemical processes of combustion are not reported. With some of the models attempts have been made with computers or wind tunnels to test wind parameters from real data required for calibration of a working model.

The group of semi-physical models:

1. Australian Defence Force Academy (ADFA) I, Australia
2. TRW, USA
3. Albini, USA
4. University of Corsica (UC), France
5. ADFA II, Australia / USA
6. Coimbra (2004)

The difference between purely physical and semi-physical model is that the representatives of the first type incorporate a description of chemical reactions in the ignition. Physical models describe in detail how much combustion heat is released, which successfully warms still unlit burnable materials in the area of the fire front. Semi-physical models in turn are primarily interested in the characteristics of the flames, which should be known a priori in

the descriptions of the fire with such an approach. Characteristic for both approaches is that they are made for two purposes: first to make experiments and subsequently to establish operational software implementations for the observed processes or pure scientific research interest. In both cases, these approaches are not popular enough and are rarely used in practice.

3. Empirical models

Empirical models are based on observations and / or conducted experiments, not theory. They are constructed through statistical correlations obtained from these experiments or the study of past forest fires. It is applicable only in systems in which the terms are identical to those in which the models were formulated and tested and can not be applied universally to all conditions.

The group of empirical models:

1. CALM Spinifex (1991)
2. Canadian Forest Fire Behaviour Prediction (CFBP) - System(1992)
3. Button (1995)
4. CALM Mallee (1997)
5. CSIRO Grass (1997)
6. Heath (1998)
7. PortShrub(2001)
8. CALM Jarrah I (1999)
9. CALM Jarrah II (1999)
10. Gorse (2002)
11. PortPinas (2002)
12. Maquis (2003)

Common for all empirical models is that the authors seek to identify key characteristics that describe the behavior of fire. Thus, all empirical models use formulas for determining the rate of spread of the fire signified in the literature as ROS. Other main parameters are the height and length of the flame, width, intensity of burning, corner of combustion, released heat energy, also fire form and coefficient of development in space. Particularly these models appear because of the need for fire crews to monitor the progress of fires in high winds. The aim was to monitor the behavior of fire and to plan the effective suppression of the fire. For this reason and due to the need for quick reaction most empirical models are one dimensional, and the following parameter is usually the rate of fire spread downwind. Their simple realization, their practical nature, their intuitive connection with the behavior of a real fire, and most importantly their development by the Forestry Agency for its own use determine why this approach is the basis for used up to now operational models.

4. Semi-empirical models

In semi-empirical models the data collected during the observations is analyzed using the laws of physics, looking for relationship or lack of it among certain parameters. The most popular example of a semi-empirical model is the model of Rothermel since 1972.

1. Rothermel - Based on the heat balance model proposed by Fransden in 1971. For analyzing the data obtained in laboratory experiments in tunnels with a wide range of

burnable characteristics and Australian field studies of grass fires in different winds. Most fires start from one source as their primary form is cylindrical, but later under the influence of the wind becomes elliptical with major axis in the direction of the wind.

2. *TRW*
3. *NBRU*
4. *USFS*
5. *Coimbra*

Other listed empirical models are not as popular. They are based on parts of the model Rothermel, modifying it for more or less specific terms.

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