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Fire modeling in forest fire management

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Abstract:

Models are helpful tools for scientists and engineers. Fire modeling is used to understand fire behavior without getting burned.

Fire models are used in different aspects of fire management:

- *Before fire, for risk factor calculation - this would help fire fighters to focus on area with higher risk and develop better infrastructure*
- *Before fire for fire fighter training purposes – developing a scenario for training.*
- *During fire, for planning fire fighting strategies - This would help fire crews position equipment on the ground so that they can minimize damage and stay safe.*

Existing models used for fire modeling are usually classified into:

- *Empirical models – model based primary on statistics collected by observation of experimental or historical fires.*
- *Physical models based on physical principles of fluid dynamic and laws of conservation of energy and mass.*
- *Semi empirical models – based on physical laws, but enhanced with some empirical factors.*

There is a need to model fire in ground, crown, and surface fuel.

The paper will present and explain different forest fires models, together with a technique for deciding which model is best for particular application.

This work on forest fire modeling is part of more complex integral project of forest fire protection in Split and Dalmatia County. The integral forest fire protection system will be based on information system for integration all activities connected with early fire detection by 24 hours video and micro locations meteorological monitoring, management of forest fire fighting and post-fire recuperation of burned landscape. The module for the forest fire spread modeling is one of its modules.

Basic principles of forest fire spread

Fire is present on earth all since the lightning hit the tree and ignites it, and we can be sure it will be presented here for many more years. It causes natural fear in every living being on earth, only humans are ones who found the way to control it and use it in a way to raise the quality of life on earth.
Anyway even humans can't control it in every situation so sometimes it happens that the fire gets out of control and causes large damages.

Fire propagation can be observed as the progressive modification in time of the status of all fuel cells distributed in space. Fuel is the matter subject to combustion and, in this case, is limited to vegetal particles either live or dead, and generally it is addressed as forest fuel. The pass from one to next status is a process which entails the production, transfer and absorption of heat progressively, and this depends on the environment and fuel of every point.

Hence, looking at the basic scheme of forest fire propagation, there exist three basic processes subject to modeling:
- Production of heat by heat sources, mainly due to combustion of unburned material
- Heat transfer from heat sources (fire) to heat sinks
- Absorption of heat by heat sinks (fuel ahead, surrounding atmosphere, soil etc.)
Each of these processes are governed by environment conditions

How fire spreads:
Ones a part of land is burning, combustion of fuel produces heat, which is a form of energy. Heat is transferred to nearby particles, and if conditions are right, the energy is used first for evaporation of particle and then for ignition of it.

Spread of fire in landscape depends of following factors:

- Bed fuel characteristics
- Meteorological conditions
- Topography of the land

Bed fuel characteristics

Forest fuel is the source of heat, heat sink, and in some cases mean of transportation for the heat. It is responsible for ignition, spread and consolidation of crown fire. Forest fuel is made of small particles of different size, live and dead. Forest fuel formations are compound out of different particle sizes of alive and dead vegetal matter, arranged in complexes which include some or various of the following components:

- Duff, present in ground fires, they burn very slowly
- Litter, frequently associated to presence of trees
- Slash, as result of natural decay of twigs and branches or due to treatments in the
- stands
- Grass
- Shrubs, with an enormous variation, high energy release and high fire spread rates
- Trees (crowns), governing crown fires

Parametars of forest fuels

Fuel load: the weight of fuel that can participate in combustion
Particle size and proportion: Particle size has a direct effect on fire behavior. Smaller particles have a larger surface for the same volume, and can accept more moisture.
Heat content: the amount of heat that can be produced as a result of combustion.
Surface to volume ratio: Directly related to particle size, is a direct measure of the proportion of the exposed surface to mass and heat transfer. Fuel components with high surface to volume ration are more prone to initiate and propagate the fire, have a quicker response to relative humidity changes, so particles divided finely are the most important ones inn defining ignition probability and fire spread rate.
Packing ratio: This parameter expresses the amount of actual fuel present in bulk volume (bulk means the total volume, including air, measured as bulk density). Packed fuels even if they have a large surface to volume ratio, offer less permeability to air and gases transport and acts as a thicker heat sink
Mineral content, waxes and oils: waxes and oils are used for heat transfer and heat sinks.

Meteorological conditions

Meteorological conditions accounts for more then 90% of forest fire behavior.
Fuel dryness is strongly related to its flammability and combustibility, and consequently to fire occurrence and behavior (VIEGAS et al. 1991), and wind plays a generally recognized key role during the flame front propagation (ROTHERMEL 1972).

Topography of the land

The presence of topography affects the way a fire is initiated and propagated. Topography affects fire spread by slope steepness. Fire is more likely to spread uphill then downhill. Also the slope and aspect of terrain causes different amounts of insolation of fuel. Fuel affected by sun contents less moisture and is more likely to burn.

Most of presented fire models have these factors as input parameters of the model.

Wildfire modeling

Numerous fire spread models have been proposed following several methods that can be grouped according its approach as

- empirical (or statistical),
- semi-empirical (semi-physical or laboratory models),
- physical (theoretical or analytical).

In the broad synthesis of ANDRÉ *et al.* (1992) , covering virtually all aspects of research on the physics of forest fires four main criteria are used to organize the state-of-the-art of research, based, respectively, on:

- the concept of fire development phase; the concept of *fire regime*
- the main aspect of the fire behavior that is predicted; and
- the more or less applied character of the research.

Although they are used essentially in parallel, there is some cross linking among these criteria.

Fire regime refers to the patterns of fire that occur over long periods of time, and the immediate effects of fire in the ecosystem in which it occurs. Fire regime is a function of the frequency of fire occurrence, fire intensity and the amount of fuel consumed. The frequency is determined largely by the ecosystem characteristics, the duration and character of the weather (whether the season is drier or wetter than normal, etc.) and ignition sources. The intensity of a fire is determined by the quantity of fuel available, the fuel's combustion rates and existing weather conditions. Interactions between frequency and intensity are influenced by wind, topography and fire history. There are many other factors that can come into play when talking of fire regimes, though this simple definition will work for most cases.

Empirical models

Statistical, stochastic, also called empirical models are predicting more probable fire behavior from average conditions and accumulating acknowledges obtained from laboratory and outdoor experimental fire, or historical fires.
There are two empirical models widely in use, Australian and Canadian.

Australian model

Australian fire research is very pragmatic. The most widely used model is McArthur's model for grassland fires and forest fire. Those models make no attempt to include any physical mechanisms for fire spread, they are purely statistical description of test fires of such spread. The model is tested in dry regions of South Eastern Australia. Initially it was presented in form of circular slide rule, but later mathematical relationship for calculating rate of spread an fire danger index was developed.

Canadian model

Canadian Forest Service has integrated 25 years of researching experimental and real scenario fires to develop Canadian Forest Fire Behavior Prediction System which is now available in book and electronic form. It consists of 89 formulae developed empirically and it is usually presented in tabular form.

We can expect the prediction of the model to be quite accurate if our study area is reasonably represented by one of the choices available.

Semi-empirical models

Semi-empirical models are based on a global energy balance (FRANDSEN 1971) and on the assumption that the energy transferred to the unburned fuel is proportional to the energy released by the combustion of the fuel, several terms of the model being fitted to laboratory fire experimental results (ROTHERMEL 1972). The simplicity of this approach has allowed to develop operational tools.

Rothermel model

The model most widely used in United States is named after R.C. Rothermel who provided the equation for calculating rate of fire spread and fire intensity.
the equation given by Rothermel for rate of spread is

$$ROS = \frac{I_R \; \xi \; (1 + \phi_w + \phi_s)}{\rho_b \; \epsilon \; Q_{ig}}$$

The equation is developed governing the energy balance equation and fitting some parameters to laboratory results.
The equation is now part of many fire behavior prediction systems.

BEHAVE

Behave is a system for fire behavior prediction and fuel management presented by P.L. Andrews. It creates tables of fire behavior in conditions given by user.
It can be a useful tool for managing areas with prescribed fire. Main withdraw is the representation of results in the form of table, when graphical visualization is more apropriate

SPREAD

SPREAD is the fire modeling tool directly implementing Rothermel's equation.

CELLULAR AUTOMATA MODEL

The most common approach has been to simulate fire growth as a discrete process of ignitions across a regularly spaced landscape grid (hereafter referred to as cellular models). The model by Kourtz and O'Regan (1971) computed the time for fire to travel between the eight neighboring cells or nodes on a rectangular grid. Successive calculations were performed for the individual cell that had the soonest arrival time. Geometric distortion to the fire shapes is produced by the fixed number of regular pathways for fire travel. Distortion is reduced by increasing the number of neighboring cells considered to be influenced by each cell in the fire spread calculations.
Computational methods are used to automate the application of fire shape models to non uniform conditions by assuming local uniformity (local to segments of the fire perimeter).

FARSITE
FARSITE is the two dimensional deterministic fire growth model.

Physical models

Currently used semi-empirical and empirical models have certain limitations.
Such models are useful, relatively fast to compute, but also inherently limited in their range of applicability.
Models based on physical principles, on the other hand, have the potential to accurately predict the parameters of interest over a broader range of input variables than empirically based models. Physics based models can also provide the basic information needed for proper description of physical processes (i.e., fluid flow, heat transfer, and chemical kinetics). But physics-based models also include inherent weaknesses; they imply that the developer has an adequate understanding of the underlying physical relations sufficient to achieve the desired objectives, that the underlying physics can be represented mathematically in a manner that permits numerical solution while retaining adequate realism, that the informational needs of the mathematics can be met by the user, and that the predicted variables are in a form to be useful by the practitioner. Improved models are needed for increased accuracy in fire behavior prediction, fire danger rating calculations, and fuel hazard assessment. The International Crown Fire Modeling Experiment was designed to address the need for increased understanding and capability to predict crown fire behavior (Stocks et al. 2004).

Mark A. Finney,*FARSITE*: Fire Area Simulator—Model Development and Evaluation, United States Department of Agriculture Forest Service **Rocky Mountain Research Station** Research Paper RMRS-RP-4 Revised March 1998, revised February 2004

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