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Numerical simulation of surface forest fire in Brazilian Amazon

Paulo Bufacchi [a,*], Guenther C. Krieger [a], William Mell [b], Ernesto Alvarado [c], José Carlos Santos [d], João Andrade Carvalho Jr. [e]

[a] Department of Mechanical Engineering, Escola Politécnica da Universidade de São Paulo, Cidade Universitária, São Paulo, SP, Brazil
[b] U.S. Forest Service Pacific Northwest Research Station, Pacific Wildland Fire Sciences Lab, Seattle, WA, USA
[c] Pacific Wildland Fire Sciences Laboratory, School of Forest Resources, University of Washington, Seattle, WA, USA
[d] Instituto Nacional de Pesquisas Espaciais-INPE, Cachoeira Paulista, SP, Brazil
[e] Universidade Estadual Paulista – UNESP, Guaratinguetá, SP, Brazil

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ABSTRACT

This paper investigates fire spread through surface fuels of the Brazilian Amazon by using a three-dimensional, fully transient, physics-based computer simulation approach. Computer simulations are obtained through the solution to governing equations of fluid dynamics, combustion, heat transfer and thermal degradation of the vegetative fuel. Surface fuel fires composed mostly of dead leaves and twigs were numerically simulated and the calculated rate of spread was compared to findings from field observations. The importance of air humidity, vegetation temperature, moisture content, surface to volume ratio and bulk density was evaluated through the variation of each one individually in numerical simulation runs. Conclusions show that in the range of parameter variation considered, the most important parameters are the vegetation moisture, surface area to volume ratio, and bulk density. The vegetation initial temperature and air humidity, in the range of variation studied, did not influence the fire rate of spread. The numerical simulations also showed that the radiation process is very important and directly affects the fire rate of spread. Convection is less important because of the absence of external wind. The model is able to capture the main effects of a surface forest fire typical of the Amazon, and can be used as a numerical tool for studying such fires.

1. Introduction

Many field and laboratory experiments and numerical simulations for the prediction of the rate of spread (ROS) of wildland fires have been run worldwide. These efforts, however, concentrate on ecosystems that are very different from those found in the Amazon. The closest fire systems studied were Mediterranean shrubs and grasslands, which have been experimentally studied by Santoni et al. [1] and Morandini et al. [2] and numerically by Morvan and Dupuy [3], Mell et al. [4] and Morvan et al. [5]. Numerically, the model ranged from simple geometrical models [6] to very complex ones [7–9]. A review of the literature showed an almost total absence of field and laboratory data on surface fire propagation in the Brazilian Amazon. As for numerical simulations, the subject has never been addressed.

It is very difficult, if not prohibitive, to study forest fires in large-scale repeatable field experiments, because of cost and safety implications and the adverse effects on local vegetation. In order to better understand the combustion processes that occur in forest fires, it is important to know the characteristics of vegetative fuels, specifically their chemical composition. This is a challenging problem in itself. Because of the wide variety of plant species and the difference in their chemical composition, average values are used to generically describe the vegetative material.

Excluding burns in already deforested areas, the most important fire in the Amazon ecosystem is surface fire, which is characterized by the burning of dead and undergrowth vegetation, such as herbs, layer of leaves and branches. These fires do not cause significant damage to large trees, but are extremely harmful to young plants and lower vegetation, mainly for forest regeneration [10].

Burning of tropical evergreen rainforests alters forest composition and structure. Common tree species suffer the greatest total mortality. Even 15 years after burning, forests show no evidence of regaining lost species. Prospects for species recovery are diminished because surface fires reduce seed availability by 85% in the litter layer and 60% in the upper 1.5 cm of soil, while flowering and fruiting of trees in and near burned forests also decreases. Recurrent fires rapidly reduce the size and density of surviving

* Correspondence to: Rua Dr. Thirso Martins, 200/62, 04120-050 São Paulo, SP, Brazil.
E-mail address: paulo_bufacchi@hotmail.com (P. Bufacchi).

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unburned forest fragments and kill regenerating vegetation, further depleting the prospects for recovery of mature forest species. Fires in tropical forests frequently occur in surface fuels, so understanding the characteristics and compositions of litter systems will be essential for predicting burning characteristics. Litter arrangement, loading, moisture content, type and composition are all important modifiers of fire behavior. Furthermore, litter from different species has large variations in energy values and flammability. Therefore, the phytosociological mix of litter-generating species can influence the flammability, sustainability, spread and heat-release characteristics of fires. The majority of tropical fires, however, are neither fast-spreading nor intense. They are severe nevertheless because the impact to the forest is quite large. Fires in tropical rainforests range from easily-extinguished litter fires to nearly impossible-to-extinguish ground fires. In recurrent wildfires, average fire intensities are ten times greater (30 versus 307 kW m^{-1}) and can spread twice as fast (0.25 versus 0.52 m min^{-1}). Closed-canopy forests are protected from the wind, and fire intensities and spread rates in such forests are also kept low by the high moisture content of fuels. However, even at low intensities, slow-moving fires are severe because of the mortality caused by the long fire-contact times and the resultant heat transfer at the base of trees [11].

The objective of this work is the prediction of a surface fire rate of spread in the Brazilian Amazon ecosystem and the determination of the most important parameters affecting the fire rate of spread. For the numerical simulation, we have used the physics-based model WFDS (Wildland-Urban Fire Dynamics Simulator), which is based on conservation equations governing fluid mechanics, combustion and heat transfer.

2. Field observations

Simulated rates of spread were compared to field surface fire observations in the States of Acre and Mato Grosso in the Brazilian Amazon (Fig. 1).

Field observations are not part of this work, but a brief description is made in this section for reference because their results are used for comparison with the numerical simulations presented in this paper.

Crude by design field observations were conducted in the cities of Cruzeiro do Sul (State of Acre) and Alta Floresta (State of Mato Grosso). These field observations were conducted by a team that performs similar observations regularly in the same region. These two field observations were not designed to fulfill the comparison needs with the numerical model (WFDS), but they are useful in that they provide a first comparison for WFDS results.

In Cruzeiro do Sul, a set of field observations was carried out near the fire site where a research group performed Amazon deforestation fire studies. The litter material in the adjacent area of the main burning experiment was collected and transported to a nearby farm. In this farm, the litter was spread in a grass field for drying. In a nearby location, the soil was cleaned and worked for parallelism and flatness. A set of small iron sticks marked a central point and a 1.5 m circumference around it. Litter was then collected, weighted and spread inside the marked circumference. Then litter load, humidity, and temperature were all measured prior to ignition. Wind speed and condensed phase temperature were also measured prior to fire propagation. Temperature was checked by an infrared measurement system and humidity by a Thermo-Technik device. Wind speed was measured by an anemometer, and its direction determined. Ignition took place in the center of the circumference by means of small amount of ethanol poured inside a 10 cm round area.

In each of the observation areas in the Alta Floresta site, a 50×50 cm^2 area was selected to quantify the corresponding litter biomass. The material was weighed with a spring scale. The depth of the litter layer was determined with a steel ruler. Litter moisture content was determined in the laboratory by collecting biomass samples in the 50×50 cm^2 area and letting them dry at 85 °C until no weight loss was observed. Air temperature and humidity were determined with a specific sensor (portable Vaisala Humicap). Air wind speed was not measured, but it is judged to be negligible, since no leaves movement was observed. Other field wind measurements conducted inside the forest confirmed this assumption

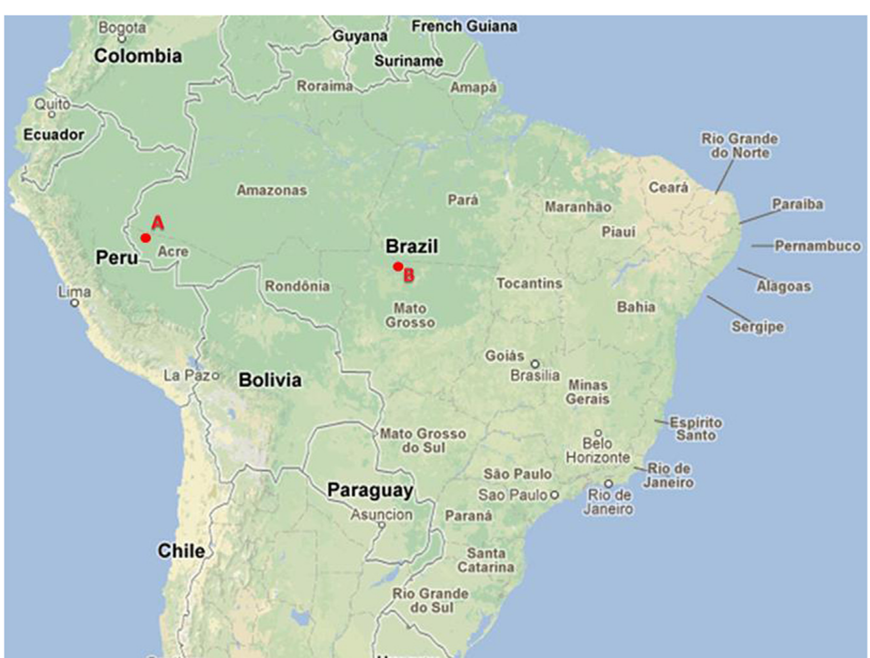

Fig. 1. Location of field observations. Site A is located in the city of Cruzeiro do Sul in the State of Acre, while site B is located in the city of Alta Floresta in the State of Mato Grosso.