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Modeling Wildland Fire Propagation and Spotting

by

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Abstract

Firebrand spotting is a primary mechanism for the spread of both wildland and wildland-urban-interface fires, particularly under dry, hot, and windy conditions during which the most devastating fires occur. Spotting can lead to rapid fire spread because firebrands generated by burning vegetation are lofted by the fire plume and transported downwind to ignite secondary fires or structures far from the flaming fire front. Spotting can create hazardous conditions because people can become trapped between spot fires with no escape route. Among the many factors that affect spotting are weather, topography, firebrand properties (energy content at landing, temperature, smoldering/flaming condition) and ignition propensity of the receptive fuel bed (moisture content, bulk density, porosity, etc.). Dense short-range spotting may occur continuously while isolated spots may occasionally be present. In addition to propagation by firebrand spotting, many wildland fires are initiated by heated metallic particles (e.g., from conductor clashing, overheated catalytic converters, hot work/welding, etc.). Although several studies have been conducted regarding firebrand/heated particle trajectories and physical characteristics at landing, only a few studies have examined the conditions that can lead to a fire initiation after the landing of the firebrand or heated metallic particle. Furthermore, no rigorous theoretical models have yet been developed to analyze this problem. Such theoretical models would improve the predictive capabilities of physics-based models of fire spread at the landscape scale. In this presentation the modeling of the embers/metal particles trajectories and their potential

for ignition of a fuel a bed at landing is reviewed. First the modeling of embers/particles trajectories is visited and summarized. Then the problem of theoretically predicting the conditions for flaming ignition of a fuel bed from a smoldering or flaming ember landing on it is explored. Finally the potential implementation of these models into landscape models of fire spread propagation is discussed.

The problem of the embers or metal particles trajectories has been given considerable attention because knowing how the embers are carried by the wind can lead to a better understanding of how fires are initially started and then spread. In most works published to date numerical models of more or less complexity are developed that predicts how embers of different shapes, (spheres, cylinders and disks) are carried by the wind. These geometrical shapes may be viewed as representative of wood particles, twigs, leaves or shingles. The particles may be initiated at a predetermined height, as in a crowning tree, arcing power lines contacting a tree, a burning wooden structure, or from a fire at ground level where the embers are then lofted by the fire buoyant plume. Plume correlations for axisymmetric and line fires can be used in conjunction with drag coefficients to determine the lofting (vertical) force applied to an ember; similarly, the lateral (horizontal) force components applied on a firebrand or heated particle by ambient winds can be determined through knowledge of drag coefficients and the wind's velocity profile. Then, calculating the trajectories of embers or particles follows directly from application of Newton's laws of motion. Simple burning models often based on experimental observations are available to estimate the burn time and temperature of firebrands. Since the embers or particles are burning, consequently their mass decreases with time, which affects both their trajectories and lifetimes. The models generally allow for various terrain conditions and variable wind properties. Various sizes of particles are generally examined. Results show that for particles of equal initial mass, disks flying perpendicular to the wind are carried the farthest by the wind and have the highest remaining mass fraction on ground impact. Spheres carry the shortest distance and cylinders have the smallest mass fraction on impact. For disks in the range of diameters examined, the initial diameter of the disk has no effect on the distance carried in the wind. Various charring and extinction criteria are also examined.

The fact that an ember or metal particle may land burning into a fuel bed does not necessarily implies that it will spot a fire. Multiple conditions affect the problem such as vegetation bulk density, porosity, humidity, propensity to ignite, etc. The problem is complex and only a few studies have examined the conditions that can lead to fire initiation after the landing of the firebrand or particle. These studies are primarily experimental, and no rigorous theoretical studies have yet been conducted to analyze the problem. Such theoretical models could vastly improve the predictive capabilities of physics-based models of fire spread at the landscape scale, which do not yet have the ability to reliably determine whether or not a firebrand causes a spot fire when it lands. This capability would greatly increase the value of such computer models since their inability to predict spotting makes them unable to reliably simulate fire spread under fire weather conditions conducive to spotting. To help understanding the problem, a preliminary comprehensive 2D numerical model for the potential ignition of a porous fuel bed by an ember or hot metal particle is presented here. The model consists of a computational fluid dynamics (CFD) representation of the gas-phase coupled to a heat transfer and pyrolysis model that simulates condensed-phase phenomena. The coupled model is used to simulate ignition of a powdered cellulose porous fuel bed by glowing pine embers in a laboratory experiment. The model provides qualitative information regarding the mechanisms leading to ignition, smolder, or flame propagation on a porous fuel bed that agree qualitatively with experimental observations. This work provides the foundation for a more complete study of the problem where the effects of different factors (moisture content, humidity, temperature, porosity, particle size/heat content, etc.) are quantified.

The presentation is finished with a brief description of two models of wildland fire propagation, one empirically based and the other CFD based, and their predictive capabilities. A case study where a power line contacting a tree initiated a wildland fire in rugged terrain is presented and discussed.