Effects of vegetation description parameters on forest fire behavior simulated with FIRETEC

François Pimont, Jean-Luc Dupuy, Rodman R. Linn, Dominique Morvan

Effects of vegetation description parameters on forest fire behavior simulated with FIRETEC

François Pimont (*), Jean-Luc Dupuy (*), Rodman R. Linn (**), Dominique Morvan (***)

(*) I.N.R.A. Unité de Recherches Forestières Méditerranéennes, Prévention des Incendies de Forêt. UR629, F-84914 Avignon.
email: pimont@avignon.inra.fr

(**) Los Alamos National Laboratory MS: D401, Los Alamos, New Mexico, 87544, USA

(***) Université de la Méditerranée, UNIMECA. 60 rue Joliot Curie Technopôle de Château Gombert 13453 Marseille cedex 13, France

Abstract :
This study focuses on the effects of vegetation characteristics on fire propagation, with the coupled atmosphere-wildfire behaviour model HIGRAD/FIRETEC. On the basis of an idealized *Pinus pinaster* ecosystem, the sensitivity of the model to fuel load, cover fraction in a stand and horizontal tree dimensions was investigated. The results are discussed in terms of influence on rate of spread, torching or crowning activities, and damage to canopies. The vegetation distribution can affect very seriously fire propagation and damage to crown. Propagation characteristics depend on some thresholds on vegetation descriptors. However, this first part of the study was done with wind profiles that did not reproduce accurately the turbulence due to the canopy itself.
The use of the code with cyclic boundary conditions can help to compute more accurately wind-flows in canopies. A validation of FIRETEC's wind prediction based on experimental data has been done. These accurate wind-flows will be used in a close future to simulate ambient wind during fire propagation to investigate the influence of resolved fluctuations in a heterogeneous landscape.

Résumé :
Cette étude s'appuie sur le modèle physique de propagation HIGRAD/FIRETEC, pour évaluer les effets des caractéristiques de la végétation (charge en combustible, recouvrement, dimensions des bouquets d'arbres) sur la propagation du feu. Les résultats de calcul sont analysés en terme de vitesse de propagation, de mode de propagation (propagation en cime active ou passive) et de dégâts aux canopées. Les caractéristiques de la propagation s'avèrent dépendre de seuil sur le recouvrement et la charge et peuvent être largement influencées par la structure de la végétation. Cependant, cette première partie de l'étude a été réalisée sans reproduire fidèlement les turbulences générées par la canopée elle-même sur le vent ambiant simulé.
L'usage de conditions limites périodiques et le pré-calcul de l'écoulement permettent de s'appuyer sur des champs de vents plus réalistes. Une validation de ces calculs d'écoulements est présentée ici, et l'objectif à court terme est d'intégrer ces champs de vent à notre étude sur les effets de la structure spatiale de la végétation.

Key-words : *Physically-Based Model, Fire Behavior, Fuel effects*

1. Introduction

Fuel breaks planning and forest protection raise questions about the way to treat vegetation. Fire propagation can also be affected by spatial patterns of vegetation, like variations in fuel distribution and continuity of vegetation (cover fraction and tree dimensions). Investigating the way these spatial patterns affect fire propagation could help forest managers to better plan fuel breaks. HIGRAD/FIRETEC is a three dimensional physically-based model (Linn 1997). This model has started to be validated through comparisons with experimental data, in grasslands (Linn & Cunnigham, 2005) but also in crown fires in complex situations (Linn *et al.*, 2005b). Simulations can be run at a scale of two meters near the ground and effects due to vegetation structure can be taken into account explicitly at this scale. Linn *et al.* (2005a) compared different fuel treatments on a *Pinus ponderosa* canopy. In this case, a *Pinus pinaster* with an *Erica umbellata* understorey was chosen and the effects of vegetation characteristics were tested more systematically.

2. A first evaluation of heterogeneity effects on fire

2.1. Description of fuel patterns and of simulations

Simple fuel patterns of *Pinus pinaster* stands with different levels of accuracy in spatial description were used for fire simulations with HIGRAD-FIRETEC. The sensitivity of the model to several parameters like fuel density (mass of vegetation per unit volume) was firstly tested. Seven homogeneous canopies with a wide range of local densities were used to represent light to dense canopies (Vigy *et al.*, 2005). Seven horizontal spatial patterns were introduced and fire behaviours were compared in these cases. Rectangular idealized trees of two and ten meter width were introduced, with various cover fractions, ranging between 25 and 75 %.

The domain for the simulations was a 200 m×150 m×615 m. Each simulation was run on 12 processors. In this part of the study, a log profile was used for wind initialization (inlet flow), blowing in the x direction. Wind speed was 6 m.s^{-1} at 10-meter height.

2.2. Homogeneous canopies: effects of fuel load

Propagation in homogeneous canopy depends on a threshold on fuel density. Light canopies are characterized by only sparse torching (FIG. 1). Canopy with higher densities drive active crown fires. A sharp increase in rate of spread (ROS) was observed at the threshold. In these active fires, the decrease in ROS with fuel load was in agreement with laboratory experiments (Catchpole *et al.* 1993).

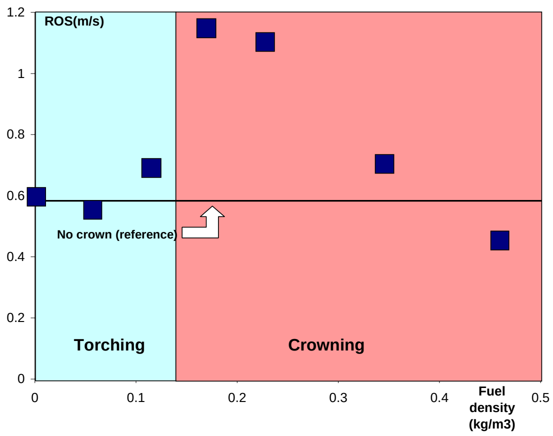
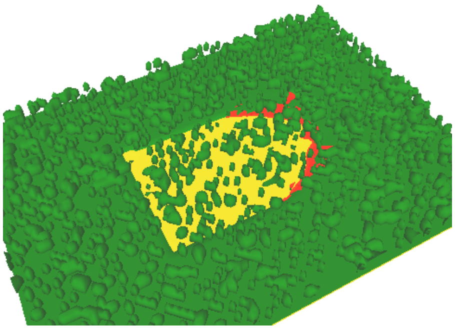


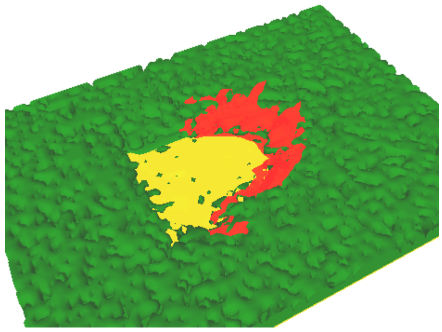
FIG. 1 – Rate of spread of the fire as a function of crown load in homogeneous stands

2.4. Heterogeneous canopies: effect of cover fraction and heterogeneity size

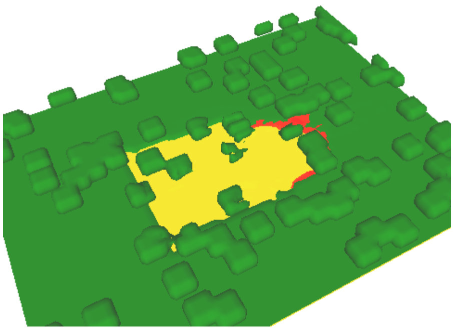
For cover fraction lower than 50 %, we did not have crown fire propagation (FIG. 2a and c). It was only sparse torching, that did almost not affect ROS (FIG. 3). For upper values, we had fully-developed crown fires (FIG. 2b and d), with a ROS increasing with continuity of vegetation for light trees (FIG. 3).



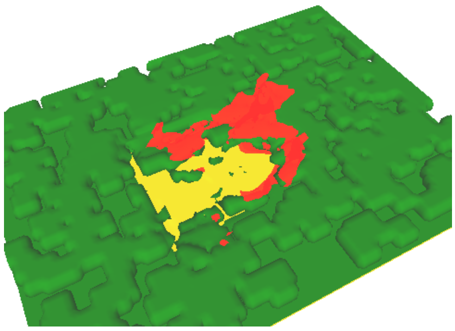
a) Narrow trees, low cover (25 %)



b) Narrow trees, high cover (75 %)



c) Wide trees, low cover (25 %)



d) Wide trees, high cover (75 %)

FIG. 2 – Torching/crowning of the fire for several heterogeneous crowns (dense trees)

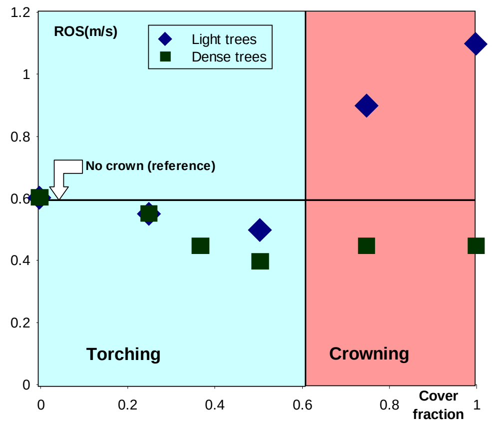


FIG. 3 – Rate of spread as a function of cover fraction in heterogeneous stands

Increasing the cover fraction tended to increase ROS and increasing local density tended to decrease it. In terms of total fuel load, these effects were opposite. As a consequence, for a same average fuel load, we could have very different ROS according to the way the vegetation was represented. If cover fraction was low and local density was high, the fire was quite low (ROS=0.45 m.s^{-1}). In this case, it was lower than the reference value (surface fuel only, no crown). On the other hand, when the cover fraction was high and the density was low, the fire was a fast crown fire (ROS=1.15 m.s^{-1}). In both cases, average fuel densities were the same.

Damage to crown was also computed, expressed as the percentage of crown fuel burnt. Damage to crown highly increased with cover fraction and decrease with heterogeneity size (FIG. 4).

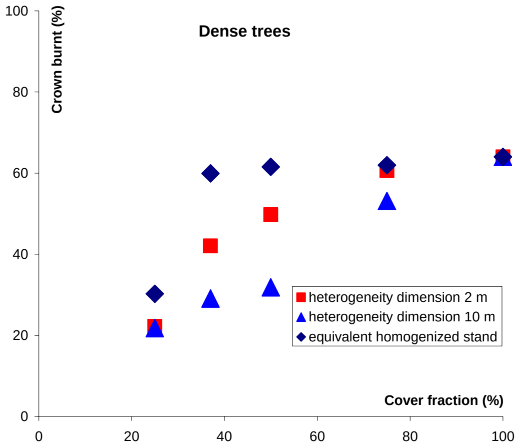


FIG. 4 – Damage of the fire to crown

2.4. Conclusion and limitations

The structure and description parameters of canopies have significant effects on simulated fires. They controlled the threshold between torching and crowning propagation. Moreover, even in crown fire propagation, the ROS depended on vegetation properties. Finally, damage to crown depended highly on structure of canopies.

Here, as in Linn *et al.* (2005a) wind profiles were initialized with constant values. Because of domain size and computational time, turbulence due to canopy shear did not have the time to settle well, especially in the resolved part of the flow.

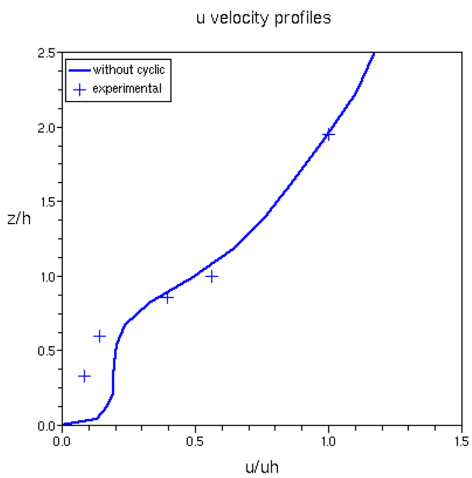


FIG. 5 – Normalized u-velocity against experimental data, without cyclic boundary conditions

It rose to wind profiles as in FIG. 5 (or figure 8 of Linn *et al.*, 2005a). The very high winds just at the top of ground fuel in the stem space were not very realistic, as well as over-prediction of fluctuation on w velocities. Pre-computation of wind field with cyclic boundary conditions can help to develop more realistic wind profiles, turbulence and intermittence (gusts).

3 Accurate computation of wind-flows with FIRETEC

3.1 Model validation

In canopies, wind-flows are known to be dominated by turbulent regime, with short period of strong gusts due to Kelvin-Helmholtz instability (Raupach et al. 1996). A physically-based model like FIRETEC simulates explicitly a part of this turbulence. In this part, we focused on validation of wind simulations, against very detailed experimental data, available from another study (Raupach et al. 1987). Several hours of simulated data of velocities and modelled turbulence were used to calculate mean profiles of velocities and turbulence on the plot (Fuel-break experiment, FIG. 6). Cyclic boundary conditions were used on x for this computation.

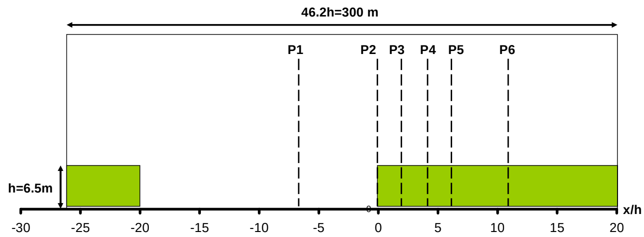
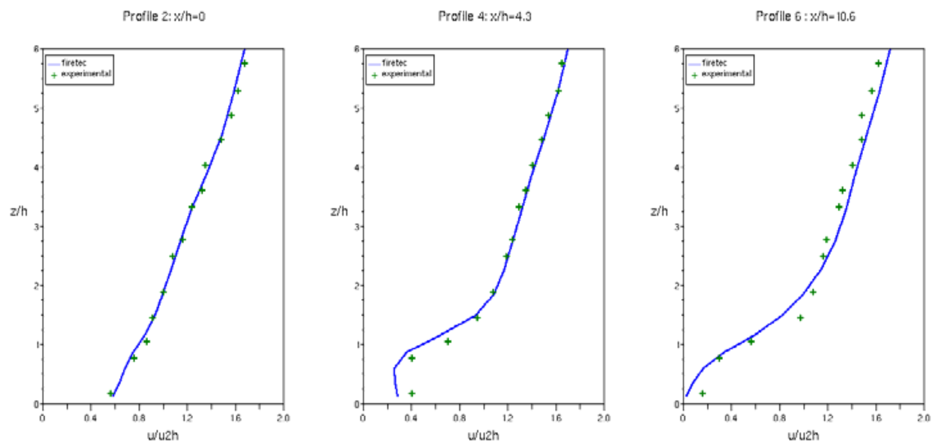


FIG. 6 – Side view of the fuel-break plot and positions of experimental profiles

Simulated data were compared to experimental data and were generally in good agreement with these data (FIG. 7), even if wind velocity vertical fluctuations were slightly under-estimated (data not shown).

a)



b)

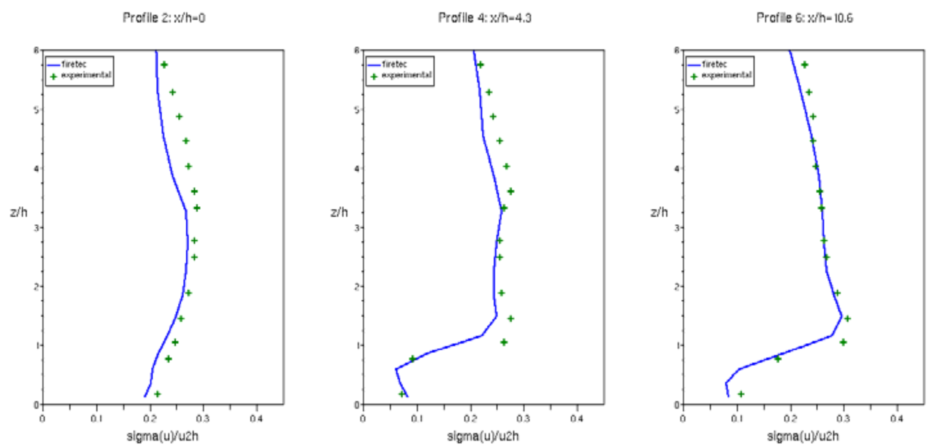


FIG. 7 – Selection of simulated profiles of u velocity (a), and u standard deviation (b) normalized by *u2h* (velocity at *x/h*=0 and *z*=2*h*), against experimental data

3.2 Effects of vegetation heterogeneity on fire propagation under gusty winds

Analysis of simulated data shows that gusts can be very strong and that their directions are very unstable. They should be taken into consideration for our investigation of fuel-break design. This work is still to be done.

4 Conclusions

Structure and description parameters of canopies were likely to show strong effects on fire behaviour. Moreover, a model like FIRETEC is likely to accurately compute wind-flows using cyclic boundary conditions. Combining these two approaches will entail to simulate fire propagation in complex terrain in a realistic physical context.

This kind of comparisons done with physically based models can help better understanding of the way to design fuel-breaks. If physically-based models are not ready for direct operational use, they help understanding fire behaviour in complex contexts and can provide solutions for managers.

References

Catchpole, E.A., Catchpole, W.R., Rothermel, R.C. 1993 Fire Behavior Experiments in Mixed Fuel Complexes. *Int. J. Wildland Fire* **3 (1)**, 45-57

Cheney, N.P., Gould, J.S., Catchepole, W.R. 1998 Prediction of fire spread in grasslands, *Int. J. Wildland Fire* **8 (1)**, 1-13

Dupuy, J.L., Morvan, D. 2005 Numerical study of a crown fire spreading toward a fuel break using a multiphase physical model. *Int. J. of Wildland Fire* **14 (2)**, 141-151

Linn, R.R. 1997 A transport Model for Prediction of Wildfire Behavior. Sci. Rep. LA -13334-T, 195pp. Los Alamos National Laboratory, Los Alamos, NM

Linn, R.R., Reisner, J., Colman, J.J., Winterkamp, J. 2002 Studying wildfire behavior using FIRETEC. *Int. J. of Wildland Fire* **11**, 233-246

Linn, R.R., Cunningham, P. 2005 Numerical simulations of grass fires using a coupled atmosphere-fire model: basic fire behavior and dependence on wind speed. *J. of Geophysical Research* **110**, D13107. 19pp.

Linn, R.R., Winterkamp, J., Colman, J.J., Edminster, C., Bailey, J. 2005a Modeling interactions between fire and atmosphere in discrete element fuel beds. *Int. J. of Wildland Fire* **14**, 37-48.

Linn, R.R., Canfield, J., Winterkamp, J., Cunningham, P., Colman, J.J., Edminster, C., Goddrick, S.L. 2005b Numerical Simulations of Fires Similar to the International Crown Fire Modelling Experiment. In: Proceedings of the Sixth Symposium on Fire and Forest Meteorology, American Meteorological. Society, Canmore, Alberta, 25-27 October

Raupach, M.R., Bradley E.F., Ghadiri, H. 1987 A wind tunnel Investigation Into Aerodynamic Effect of Forest Clearing on the nesting of Abbott's Boody on Christmas Island, Internal report, Csiro Centre for environmental Mechanics, Canberra.

Raupach, M.R., Finnigan, J.J., Brunet, Y. 1996 Coherent eddies and turbulence in vegetation canopies: the mixing-layer analogy. *Boundary-Layer Meteorol*ogy **78**, 351-382.

Vigy, O., Rigolot, E., Valette, J.C. 2005 Fire Star Wildland Fuel Structure: Model Results. FIRE STAR EVG1-CT-2001-00041. Deliverable D6-04.