P1.6

STUDY ON IMPACTS OF LOCAL WIND AND TERRAIN ON WILDFIRE

Jiping Zhu*, Jianjun Zhou, Zhanrong Zhong, Chang Lu
State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei, Anhui, P. R. China

1. INTRODUCTION

The wildfire is effect by many factors, in which the wind and terrain are more important. In a mountainous forest area, the local wind field becomes very complex. Local wind and varied terrain make fire behavior more complicated to be predicted.

In this paper, some simulation experiments of local wind above several kinds of terrain models are carried out in the wind tunnel. Through analyzing the results of theoretical model, numerical calculation and experimental simulation, the paper has obtained some characteristic about the Impacts of local wind and terrain on wildfire, which may be helpful to fire behavior assessment and prediction.

2. EXPERIMENTAL SIMULATION

2.1 Experimental apparatus

Some simulation experiments of local wind above several kinds of terrain models are carried out in the wind tunnel in the State Key Laboratory of Fire Science of China. The wind tunnel can provide varied flows with different velocity, different distribution of velocity, or different structure. The section of the tunnel is 1.8mx1.8m, and the length of the experimental part is 6m (see Figure 1).

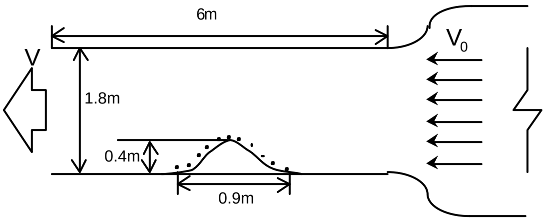

FIGURE 1

Two models of mountain were designed and were put into the experimental part of the wind tunnel respectively. One model is a curved surface of revolution (model A), and the other model is a camber (model B) of the curve, which can be described as follows, Qi (1993):

$$y = \frac{H \cdot a^2}{x^2 + a^2} \qquad (1)$$

where H is the height of the model, a the radius at H/2.

2.2 Experimental scale

The Reynolds number of experiment in wind tunnel is generally less than the really number. It's better to design larger scale model to gain bigger experimental Reynolds number. However, larger model will also cause more distributions due to the effect of the wall of the tunnel. So there are some limitations, Nan (1982), for design experimental model:

$$W_m / W_t < 0.7 \qquad (2)$$

where W_m is the width of the model, W_t the width of the wind tunnel.

$$A_m / A_t < 5\% \qquad (3)$$

where A_m is the area of the model section, A_t the area of the wind tunnel section.

According to these limitations, the width of the experimental model of topography W_m=0.9m, the height of the model H=0.4m.

2.3 Experimental results

The results of the experiments done on the two kinds of model are shown in Figure 2 and 3, respectively. In each figure, there are three curves that correspond to different condition of initial velocities, V_0. Compared with two figures, it can be seen that the trend of the change of flow velocity is similar. The velocities of model A in context are bigger than those

---

* *Corresponding author address*: Jiping Zhu, State key Laboratory of Fire Science, University of Science and Technology of China, Anhui, Hefei 230026, P. R. China; e-mail: jpzhu@ustc.edu.cn.

of model B on all corresponding measure points, except the top point. On this point, the velocity of model A is less than model B because the flow can past model A also from circular sides.

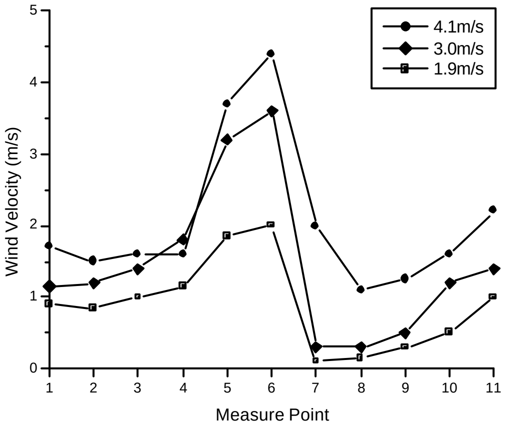

FIGURE 2. Experiment results of model A

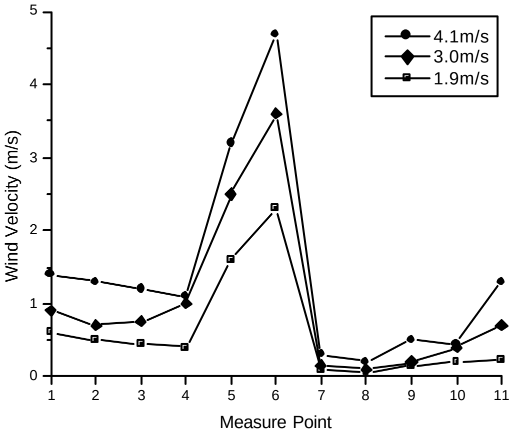

FIGURE 3. Experiment results of model B

3. NUMERICAL SIMULATION

In this paper a wind field model was set up for simulating atmospheric flows above topography. The condition of boundary is same as the experiments done in the wind tunnel.

The governing equations in Cartesian coordinates are written as follows:

3.1 Continuity equation, Traci (1978)

where F is the perturbation potential of the flow, x, y, the horizontal axes, z the vertical axis and u_0, v_0, w_0 the three velocity components of the initial mean wind field, along x, y, z respectively. The perturbation potential is calculated through equation (4) and then the velocity perturbations u', v', w' are calculated from the perturbation potential F to meet the constraint of minimum divergence of the wind field. Each of the velocity components u, v, w is the sum of the respective initial guess (u_0, v_0, or w_0) and velocity perturbation (u', v', or w').

$$\frac{\partial^2\Phi}{\partial x^2}+\frac{\partial^2\Phi}{\partial y^2}+\frac{\partial^2\Phi}{\partial z^2}=-\left[\frac{\partial u_0}{\partial x}+\frac{\partial v_0}{\partial y}+\frac{\partial w_0}{\partial z}\right] \quad (4)$$

3.2 Movement conservation equation, Lalas (1994)

$$\frac{\partial(r_0 w)}{\partial t}+\frac{\partial(r_0 uw)}{\partial x}+\frac{\partial(r_0 vw)}{\partial y}+\frac{\partial(r_0 ww)}{\partial z}=$$
$$-\frac{\partial P'}{\partial z}-gr'+\frac{\partial}{\partial x}\left[m_{eff}\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right]+ \quad (5)$$
$$\frac{\partial}{\partial y}\left[m_{eff}\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)\right]+\frac{\partial}{\partial z}\left[2m_{eff}\frac{\partial w}{\partial z}-\frac{2}{3}r_0 k\right]$$

where μ_{eff} is the effective dynamic viscosity calculated through a zero-equation turbulence closure scheme, O'Brien (1970), P' is the pressure perturbation from the hydrostatic state calculated through the SIMPLE algorithm, Patankar (1980), $?_0$ is the mean ambient density of the air and ?' is the density perturbation due to atmospheric stratification and/or thermal effects due to fires, g is the acceleration of gravity and $g?'$ is the buoyancy term, Pielke (1984). The time-dependent term *?(.)/?t* is due to the fact that a forest fire is a transient phenomenon. The air density is given by the formula:

$$r=r_0+r'=\frac{P}{nRT} \quad (6)$$

where P is the pressure of the air ($P=P_0+P'$), T the temperature and R the universal gas constant.

3.3 Numerical simulation results

The simulation area is 1600mX1600mX800m and it is divided into 40X40X20 grids. The simulated mountain can be described as Equation (1) with a height H=250m and a radius at half height a=120m. Initial velocity is 3m/s.

The results of the numerical simulation are shown in Figure 4 and 5, corresponding to model A and model B respectively.

The comparision of the results of experiment on model B and numerical simulation is shown in Figure 6.

The initial wind velocity is 3m/s. It can be seen the trend of experimental curve accords with the simulation one.

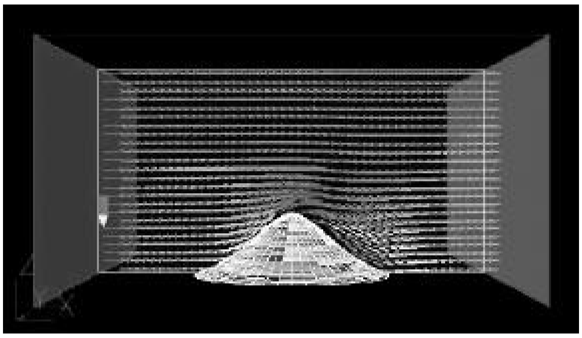

FIGURE 4. Numerical simulation result of model A

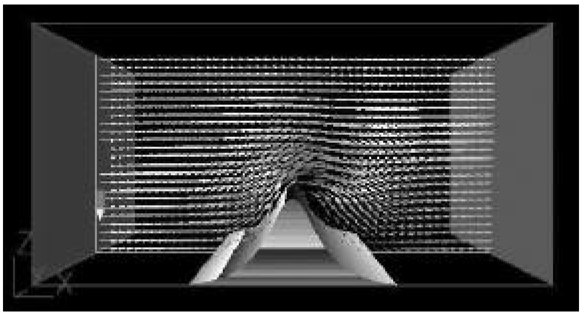

FIGURE 5. Numerical simulation result of model B

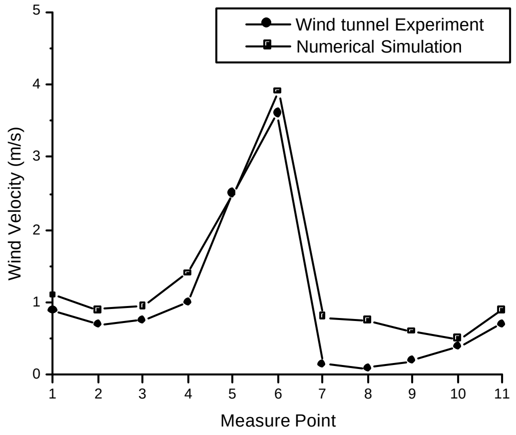

FIGURE 6. Comparison of results of experiment and numerical simulation

4. WILDFIRE PREDICTION

The well-known model of forest fire spread is the one developed by Rothermel (1972). All input parameters of this model have clear physical meanings. It has been widely applied in many operational applications.

The input parameters can be divided in three sets. The first is fuel bed parameters, including heat content, mineral content, particle density, depth, loading, mean size, moisture content; the second is static ambient parameters, mainly characterizing the topography; and the third is dynamic ambient parameters, characterizing the weather, of which the most important one is the wind parameter.

A computer system for forest fire predicting based on GIS has been developed by Zhu (1999). The equation of fire spreading velocity presented by Rothermel is accepted due to its manifest applicability. The system can make reasonable and reliable estimation for fire spreading boundaries under the circumstances of nonuniform fuels and complicated terrain. Although both the wind velocity and the direction can be are changed during the calculation proceduce, the wind is simply regarded as single even the terrain is much complicated.

In this paper, a simulation proceduce of wind field above topography is added so as to improve the results of fire spread impacted by local wind and terrain.

As a test-case, the forest fire ignited at Qiyun Mountain (Xiuning, Anhui, P. R. China) in June 1997 was studied with the system in context. The terrain topography can be seen through the contour lines in Figure 7. It also shows the real fire boundary at 1 hour. Figure 8 and Figure 9 show fire boundary as calculated by the earlier system using single wind model and the modified system with wind field model respectively. Comparision of the computational results with the real test forest fire showed that the boundary of the fire was accurately predicted by the two system. However, the spread rate of fire front along the wind direction of the eariler system was slightly over predicted due to the simple wind model. The effect of the forest fire on the local wind field and terrain is obvious.

5. CONCLUSIONS

A wind field model for forest fire predicting is developed upon physical laws of atmospheric boundary-layer flow and results of wind tunnel experiments and numerical simulation. The model is used to replace the single wind model in a forest fire prediction system. Several forest fire tests have been studied with the system and the estimated fire boundary was found to be in fairly good agreement with the real one. Nevertheless, further validation of the model is needed for well-documented forest fire.

The system can be used as a aid decision-making tool for the real time management of forest fire.

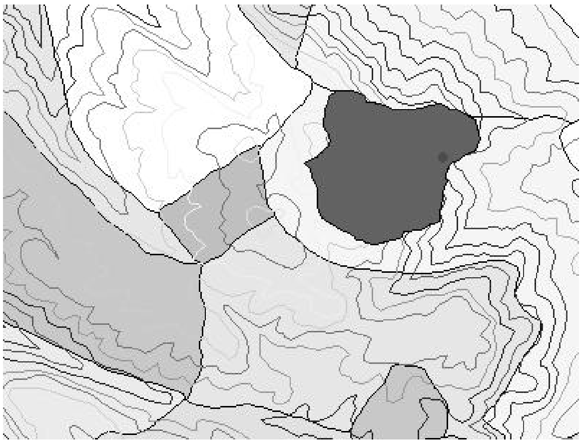

FIGURE 7. Boundary of test fire

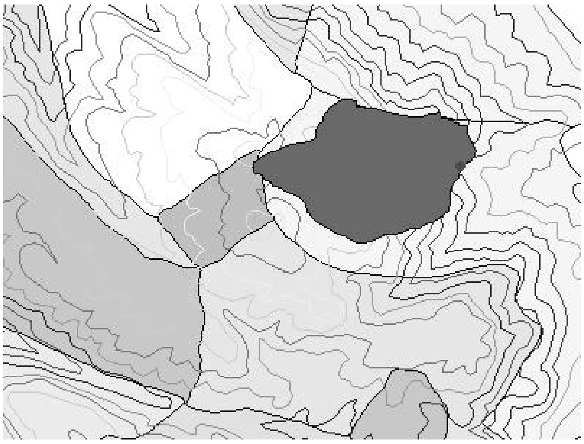

FIGURE 8. Boundary predicted by earlier system

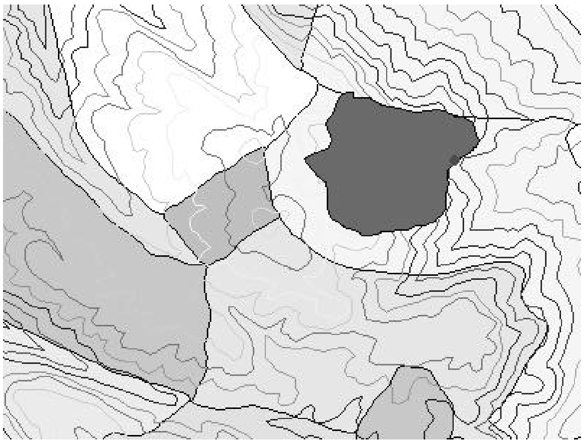

FIGURE 9. Boundary predicted by modified system

ACKNOWLEDGEMENT

This work was sponsored by National Natural Science Foundation of China under Grants 59936140.

The authors would also like to thank the Anhui Forest Police of China for their great help to the wild test.

REFERENCES

Lalas, D. P., Panagiotidis, T. C., and Tryfonopoulos, D. A., 1994: A hybrid micrositing model for wind flow simulation over complex topographies. *Proceed. of ECWEC '94*, Thessaloniki, Greece.

Lymberopoulos, N., 1999: Wind field – forest fire front interaction including buoyancy effects. *Proceed. of Inter. Symposium on Forest Fire: Needs and Innovations*, Athens, Greece, 198-210.

Nan, H., 1982: Experimental aerodynamics. *Press of Nanjing Aviation College*, Nanjing (in Chinese).

O'Brien, J. J., 1970: A note on the veertical structure of the eddy exchange coefficient in the planetary boundary layer. *J. of Atmospheric Science*, **27**, 1213-1215.

Patankar, S. V., 1980: Numerical heat transfer and fluid flow. *Hemisphere Publ. Corp.*, New York.

Pielke, R. A., 1984: Mesoscale meteorological modelling. *Academic Press*, New York.

Qi, Y., 1993: Mountanious aerodynamics in medium scale. *Academic Press*, Beijing (in Chinese).

Rothermal, R. C. 1972: A mathematical model for predicting fire spread in wildland fuels. *USDA-FS, Res. Pap.*, INT-115.

Traci, R. M.,, Phillips, G. T., and Patnaik, P. C., 1978: Wind energy site selection methodology development. *Science Applications Inc.*, La Jolla, California.

Zhu, J. P., 1999: An aid decision-making system for forest fire management based on GIS. *J. of Nature Disaster*, 8(1), 60-70 (in Chinese).