FLOW PREDICTION THROUGH CANOPIES

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A SIMPLE MODEL OF FLOW THROUGH A TREE CANOPY AND COMPARISON WITH LARGE-EDDY SIMULATIONS

- The presence of a canopy reduces the local wind speed, resulting in a slower rate of spread of a wildfire than in the open
- This phenomenon has a major impact on firefighting operations as accurate predictions of fire spread are required for managing the fire
- We want a reliable model of McArthur's wind reduction factor [1] from easily obtained input data

HARMAN AND FINNIGAN'S CANOPY MODEL [2]

- Balance shear production of turbulence with the aerodynamic drag from the canopy, assuming all other factors (ie advection, viscous diffusion) are not important
- Analytical monotonic solutions possible assuming a dense (large drag) canopy with negligible variation in drag with height
- Assume that drag is related to the volume fraction occupied by vegetation
- Example plot of wind speed within and above a canopy is shown in figure 1(a)

Variation of drag with height

- Non-uniform drag profiles can be important in some forests [3]
- We extend the Harman and Finnigan model to allow drag $\alpha f(z)$ to vary with height and solve the equation numerically

$$\frac{d}{dz}\left(\frac{du}{dz}\right)^2 = \alpha f(z)u^2 \qquad (1)$$

where $\alpha = c_D/2l^2$, c_D is the drag coefficient and l is the mixing length

- Example plot is shown in figure 1(b)

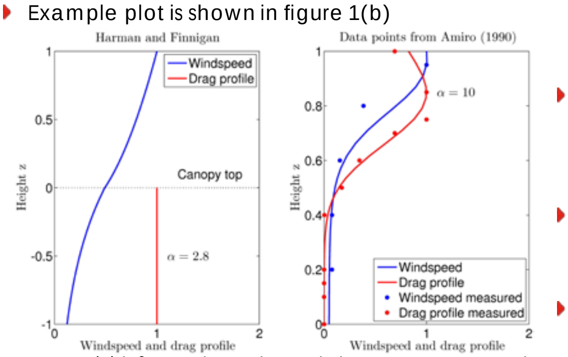

Figure 1 (a) left. Wind speed in and above a canopy according to the model of Harman and Finnigan. Figure 1 (b) right. Wind speed according to the extended model equation (1), compared with data from Amiro 1990 [4]. The parameter α was estimated using the data in [4] and the method of Harman and Finnigan. The profiles have been normalised by maximum values.

NUMERICAL SIMULATION OF A SIMPLE CANOPY

- We can conduct full numerical simulations over a modelled canopy (figure 2).
- Solve the full Navier-Stokes equations with the canopy represented by a drag force

$$F = c_D f(z)u^2$$

- Use Large Eddy Simulation (LES) using Fire Dynamics Simulator [4]

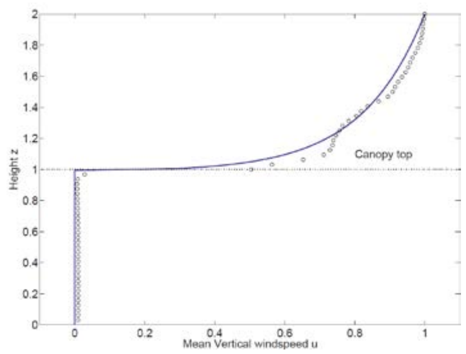

Figure 2 The mean vertical wind speed (circles) profile from a LES over a uniform canopy with $c_D = 1$. The blue line is the model of Harmann and Finnigan. The velocity has been normalised to unity on the top of the domain. No slip boundary conditions are enforced at $z = 0$. Free slip boundary conditions are enforced at $z = 2$.

LIMITATIONS OF THE SIMPLE MODEL

- Model appears to match observed data only if the canopy is sufficiently dense
- Need an estimate of α and $f(z)$. Currently the estimates come from observations
- We can work towards models of $f(z)$ for a canopy by constructing a model for a single tree

LARGE EDDY SIMULATIONS OVER A SINGLE TREE

- It is possible model a canopy of trees by resolving the major branches of trees and using a subgrid scale model for the smallest branches and leaves
- ReNormallised Simulation (RNS) [5] has been developed to compute the drag of a fractal tree directly from simulated flows
- A fractal tree is a self similar object which resembles the complicated shape of a tree, but which have a simple standard description
- A pre-fractal tree is a fractal tree which has been truncated at some number of branch generations
- RNS has been applied to large canopies and validated against wind tunnel data
- Can be used to check the simple model and develop models of drag profile $f(z)$

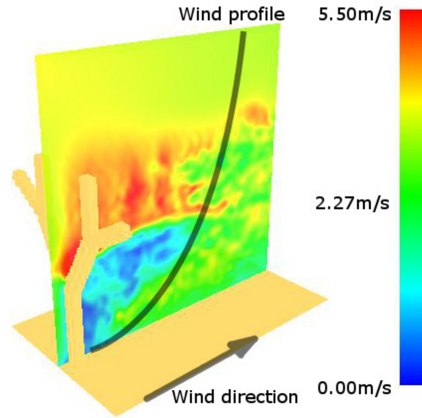

Figure 3. Simulation of the developing wake behind a two generation pre-fractal tree using an open source LES. code [4]. The domain is a box with a no slip boundary condition (BC) on the ground, an inflow BC on the left face, and outflow BCs on the other faces. A power law wind model is enforced in the direction shown. The instantaneous magnitude of velocity is shown at t=50s.

FUTURE DIRECTIONS

- Verification of simple canopy model using numerical simulation over a fractal canopy(in progress)
- Development of a simple model of $f(z)$ starting from models of single trees (in progress)
- Definition of a wind reduction factor by comparison to a canopy free wind
- Investigation of the effect of the canopy on the rate of spread of a fire

REFERENCES

[1] McArthur A.G. (1967) Comm. Aust. For. Timb. Bur. Leaflet 107

[2] Harman, I. N., & Finnigan, J. J. (2007). *Boundary-layer meteorology*, *123*(2), 339-363.

[3] K. Moon, K, Duff, T.J., & Tolhurst, K.G., (2013) 20th International Congress on Modelling and Simulation, Adelaide

[4] McGrattan, Kevin, Simo Hostikka, and Jason E. Floyd. *NIST special publication* 1019 (2013).

[5] Chester, S., Meneveau, C., & Parlange, M. B. (2007) *Journal of Computational Physics*, *225*(1), 427-448.

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