Large-eddy simulations of bushfire plumes in the turbulent atmospheric boundary layer

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The potential for the lofting of firebrands by fire plumes is determined by interaction between the atmospheric boundary layer, topography and the fire convective column. Here we perform high-resolution three-dimensional simulations of the turbulent atmospheric boundary layer, in order to then allow us to investigate plume dynamics in realistic conditions.

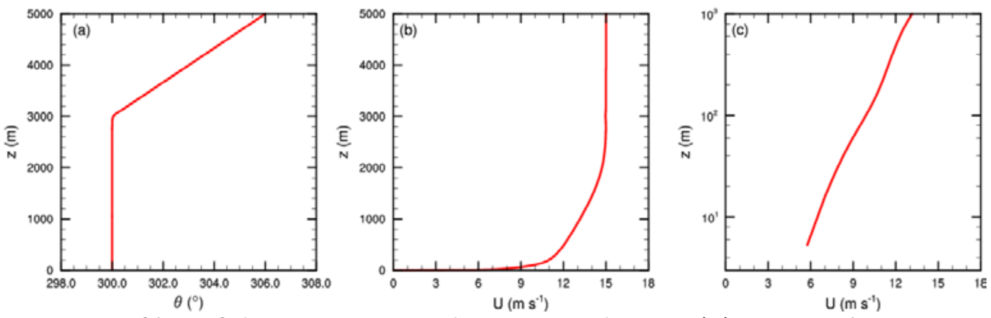

Fig. 1. Profiles of domain-averaged mean conditions. (a) Potential temperature; (b) horizontal velocity; and (c) horizontal velocity in the lowest 1 km on a logarithmic height scale to emphasise the log layer.

Previous plume modelling studies have either been two-dimensional or have not included the effects of atmospheric turbulence, both of which have an effect on the rate of entrainment of ambient air into the plume and consequently on its dynamics. Therefore we use the UK Met Office Large-Eddy Model (LEM) to first "spin up" turbulent atmospheric boundary layers, with a temperature profile representative of high fire danger conditions and a range of wind speeds. The model is configured with horizontal dimensions of 40 km by 20 km and a grid spacing of 50 m. Domain-averaged profiles in a modelled boundary layer, with a background wind of 15 m s^{-1}, are shown in Figure 1.

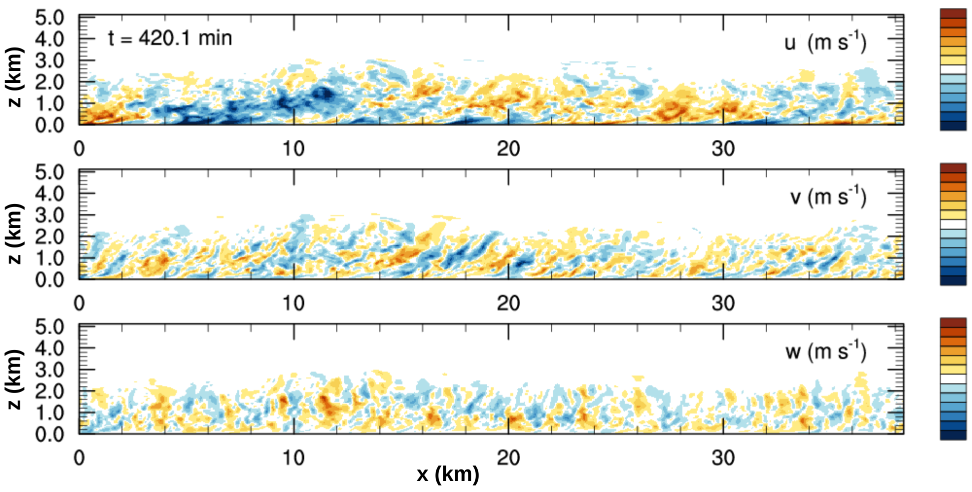

Fig. 2. Cross-sections of instantaneous velocity component fluctuations from the mean flow (m s^{-1}) in the 15 m s^{-1} background wind case.

The domain-averaged profiles consist of a 3 km deep boundary layer, well mixed in potential temperature and exhibiting a realistic log layer in velocity. The snapshot of the three velocity components shown in Figure 2 illustrates the turbulent nature of the boundary layer. Departures in excess of 2 m s^{-1} from the mean horizontal flow due to eddies are seen and there is also considerable vertical turbulent mixing. These eddies propagate throughout the domain. The domain-averaged profiles of the velocity variances and vertical momentum flux, shown in Figure 3, are consistent with previous studies of the shear-driven turbulent boundary layer, indicating that we have generated a realistic turbulent boundary layer.

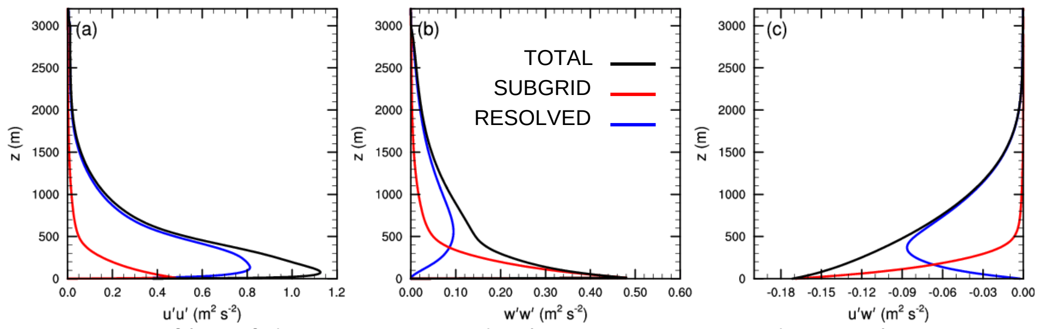

Fig. 3. Profiles of domain-averaged velocity variances and vertical momentum flux. (a) $\overline{u'u'}$; (b) $\overline{w'w'}$; and (c) $\overline{u'w'}$.

The realistic turbulent boundary layers spun up over a range of wind speeds now serve as initial conditions for simulations of plume behaviour. We impose a circular heat flux anomaly (radius 250 m, intensity 1×10^5 W m^{-2}) at the model's surface to represent a large fire, then study the behaviour of the resulting plume.

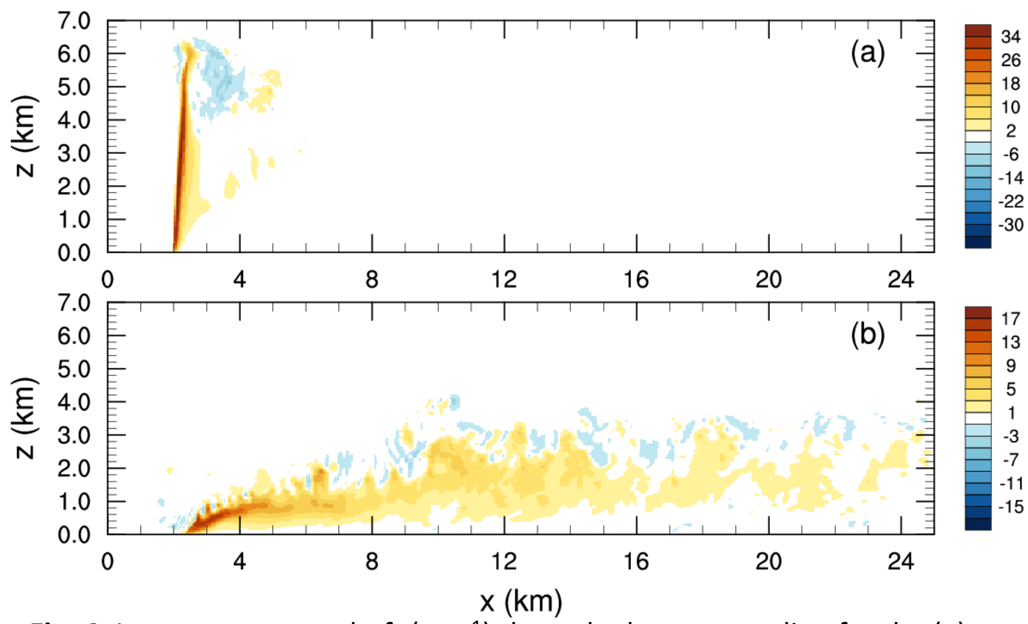

Fig. 4. Instantaneous updraft (m s^{-1}) through plume centreline for the (a) 2 m s^{-1} and (b) 15 m s^{-1} background wind conditions. Background wind is directed left to right.

Snapshots of plume updrafts formed under weak and strong background wind conditions are shown in Figure 4. Under the 2 m s^{-1} background wind, the plume has updrafts in excess of 40 m s^{-1}, reaches a height of 6 km and is vertically aligned. Under the 15 m s^{-1} background wind, the plume is much weaker, with updrafts not exceeding 20 m s^{-1}. The plume is also much broader and more bent over, extending more than 20 km downwind of the fire, and much more turbulent in nature than under the 2 m s^{-1} background wind.

Summary: We have used the UK Met Office LEM to simulate realistic turbulent atmospheric boundary layers over a range of wind speeds, then simulate fire plumes in these boundary layers. Under weak winds, plumes are intense, vertically aligned, narrow and smooth. Under strong winds, plumes are comparatively weak, bent over, broad and turbulent. Using this model setup, we further explore plume dynamics and the spotting implication in the accompanying poster "*Idealised numerical modelling of bushfire plumes and their potential for firebrand lofting*".

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