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THE EFFECTS OF TURBULENT PLUME DYNAMICS ON LONG-RANGE SPOTTING

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INTRODUCTION

Spotting is a hazardous phenomenon which leads to unpredictable fire behaviour and accelerated fire spread. Spot fires occur when embers are launched by bushfire plumes into the background wind, which then carries the embers a significant distance from the fire front. If the embers land in a suitable fuel bed and are still burning a spot fire may be ignited. The magnitude of the problem is illustrated by Cruz et al. (2012), who provide evidence of long-range spotting in excess of 30 km during the Black Saturday bushfires of February 2009. Therefore a better understanding of the processes that contribute to long-range spotting is essential for the prediction of fire spread. In this study we aim to assess the contribution of turbulent plume dynamics to the process of long-range spotting.

METHODOLOGY

We use a two-stage modelling approach to calculate the landing positions of potential firebrands launched by bushfire plumes. Firstly, we use the UK Met Office large-eddy model (LEM), described by Gray et al. (2001), to perform numerical simulations of idealised bushfire plumes. A number of plumes are simulated for background winds varying from 5 to 15 m s–1. Secondly, the three-dimensional, time-varying velocity fields produced by the LEM are used to drive a Lagrangian particle-transport model. More than 1.5 million potential firebrands are released near the base of the plume and then advected by the LEM velocity field minus a constant fall velocity of 6 m s–1, representative of jarrah and karri bark flakes (Ellis, 2010). In order to assess the contribution of the in-plume turbulence to the firebrand transport, the time-varying particle-transport calculations are then repeated using a steady-state plume velocity, calculated from the one-hour mean plume fields.

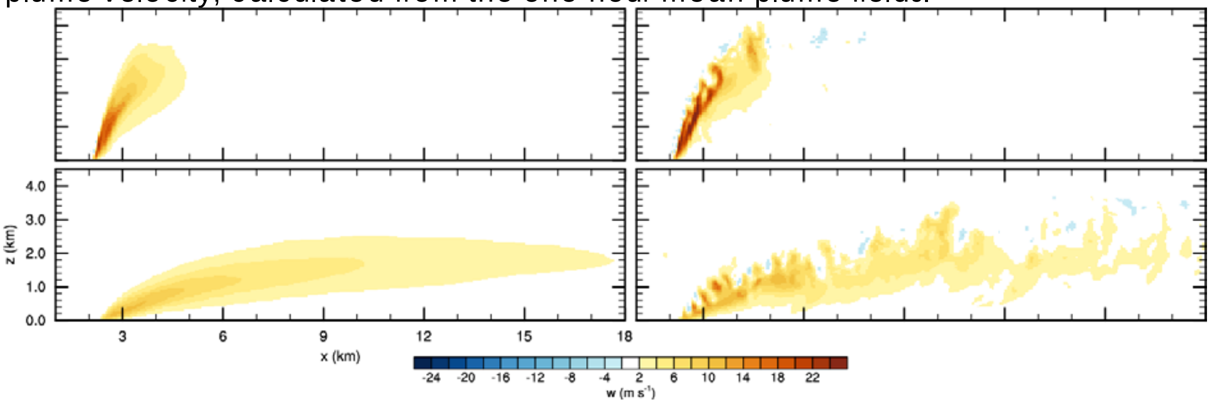

FIGURE 1. VERTICAL CROSS-SECTIONS OF THE MEAN (LEFT) AND INSTANTANEOUS (RIGHT) VERTICAL VELOCITY, M S–1, THROUGH THE PLUME CENTRE LINE, FOR BACKGROUND WIND SPEEDS OF 5 (TOP) AND 15 (BOTTOM) M S–1.

RESULTS

Vertical cross sections of the instantaneous and 1-h mean updrafts for plumes in the 5 m s–1 (weakest) and 15 m s–1 (strongest) background winds are shown in Figure 1. The instantaneous plumes in strong wind have weaker updrafts, and are more bent over than the plumes in weak wind. The instantaneous strong-wind plume is turbulent over its whole height, whereas its weak-wind counterpart is only fully turbulent above a height of about 2 km. Plan views of the weak-wind plume, (not shown here but seen in Thurston et al. (2014)), reveal that the plume has two updraft cores that form a counter-rotating vortex pair. The 1-h mean plumes do not exhibit any of the turbulence that is visible in the instantaneous plume updrafts, and as a result peak updraft is weaker, but more uniform.

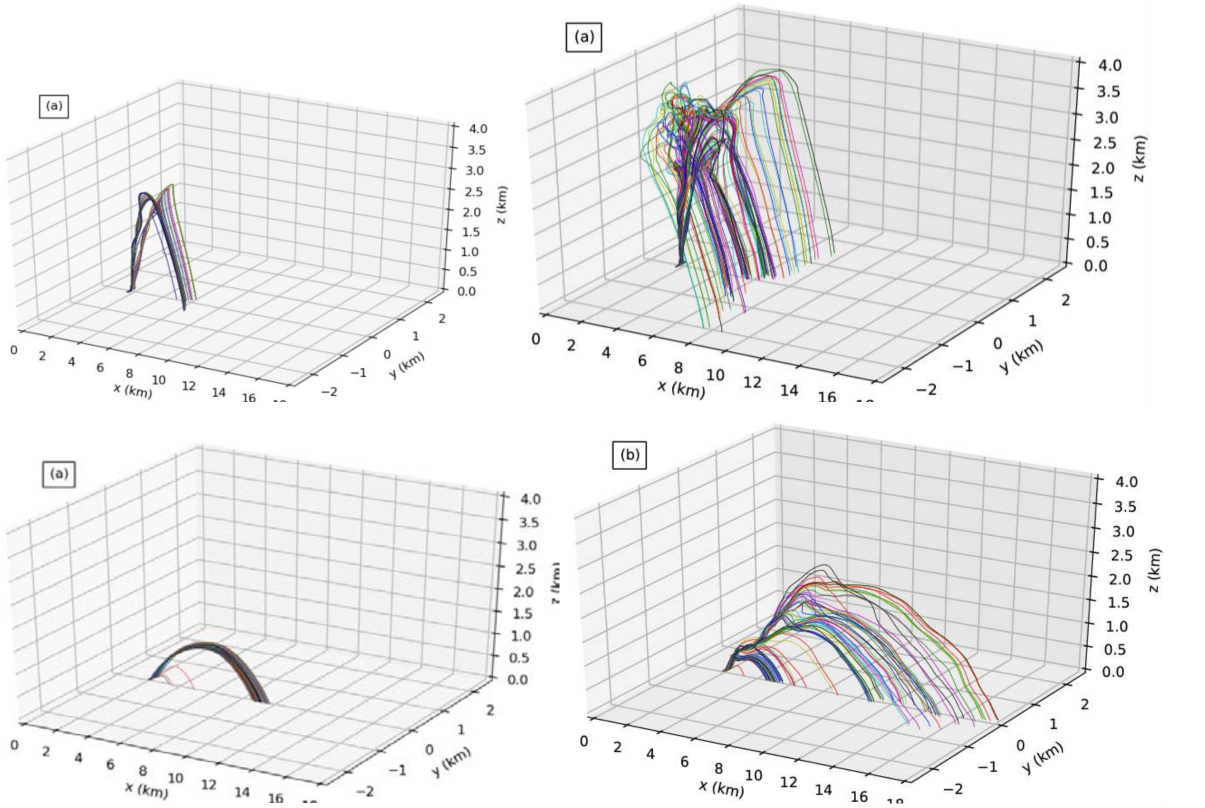

FIGURE 2. TRAJECTORIES OF 100 FIREBRANDS LOFTED BY THE MEAN (LEFT) AND TIME-VARYING (RIGHT) PLUMES UNDER BACKGROUND WIND SPEEDS OF 5 (TOP) AND 15 (BOTTOM) M S–1.

The trajectories of a sub-sample of 100 of the firebrands lofted by each of the plumes in Figure 1 are shown in Figure 2. Firebrands lofted by the time-varying weak-wind plume initially travel up the two branches of the counter-rotating vortex pair, and are then spread out further laterally as they reach the turbulent region of the plume above a height of 2 km. Firebrands lofted by the time-varying strong-wind plume do not exhibit any of this lateral spread, instead landing near the plume centre line. These firebrands appear to be lofted in clumps by the turbulent puffing of the plume, and hence tend to fall out in clusters. The trajectories of firebrands lofted by the 1-hr mean plumes highlight the importance of the in-plume turbulence. In the weak-wind case the firebrands still travel up the two branches of the counter-rotating vortex pair, but there is less lateral dispersion above 2 km. In the strong-wind case the effect of the in-plume turbulence is more pronounced, with most firebrands lofted by the 1-h mean plume now having similar trajectories.

Figure 3 shows the two-dimensional landing distributions for all of the 1.5+ million firebrands launched by each of the plumes in Figure 1. The counter-rotating vortex pair and upper-level turbulence of the time-varying weak-wind plume lead to the firebrands landing in a V-shaped pattern with considerable lateral spread. The landing positions of firebrands lofted by the 1-h mean plume in weak winds still form a V-shaped pattern, but there is less lateral spread due to the lack of in-plume turbulence. Firebrands lofted by the time-varying strong-wind plume travel on average about twice as far as their weak-wind plume counterparts, have more longitudinal spread and less lateral spread in their landing distribution. The landing positions of firebrands lofted by the 1-h mean plume in strong winds show much less spread and crucially the maximum spotting distance is reduced by half from about 16.7 km to 8.4 km.

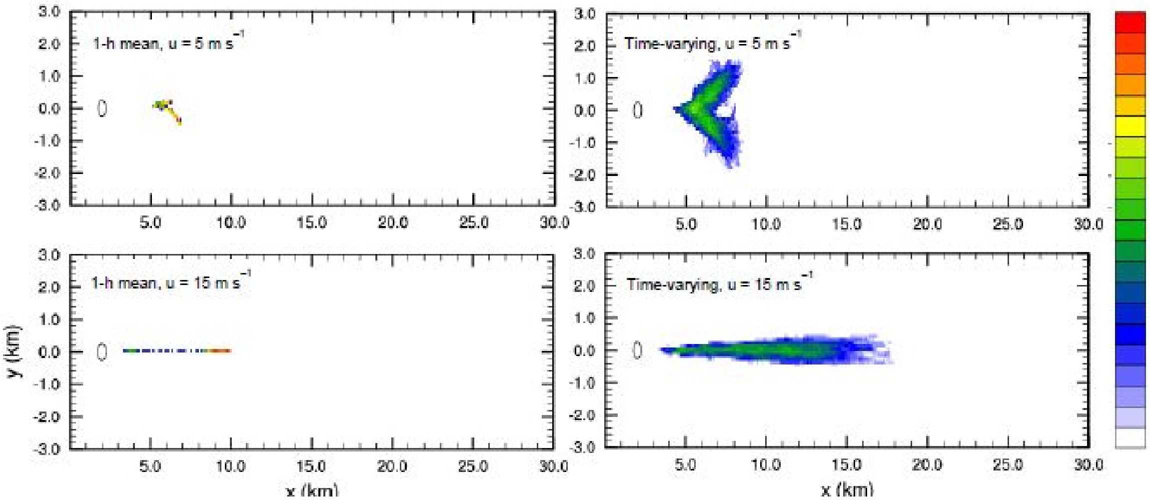

FIGURE 3. SPATIAL DISTRIBUTIONS OF FIREBRAND LANDING POSITION (PERCENT OF PARTICLES LAUNCHED PER KM2) FOR THE MEAN (LEFT) AND TIME-VARYING (RIGHT) PLUMES UNDER BACKGROUND WIND SPEEDS OF 5 (TOP) AND 15 (BOTTOM) M S–1.

A critical consideration in the potential for firebrands to start spot fires is whether they are still burning when they land. Therefore the flight times of the firebrands lofted by the time-varying weak-wind and strong-wind plumes are presented in Figure 4. Firebrands that are lofted by the weak-wind plume have a relatively long flight time, even if they do not travel a long distance. For example firebrands that are lofted by the weak-wind plume and subsequently travel only 0–2 km are in the air for 7.5–12.5 minutes, whereas firebrands that are lofted by the strong-wind plume and travel only 0–2 km are in the air for 1.5–3.5 minutes. This is caused by the plume dynamics seen in Figure 1; the weak-wind plume is more upright and has a stronger updraft, causing the firebrands to go almost straight up, reach a greater height and therefore be in the air for longer. This behaviour is confirmed by the trajectory plots of Figure 2. The firebrands that have travelled the furthest (16–18 km, in the strong-wind case) have a median flight time of 21.5 minutes and a 1st–99th percentile range of 19.3–23.4 minutes. This is similar to the maximum burnout time of ribbon gum bark observed in the wind tunnel studies of Hall et al. (2015) and would suggest that firebrands taking these trajectories would still be capable of starting spot fires.

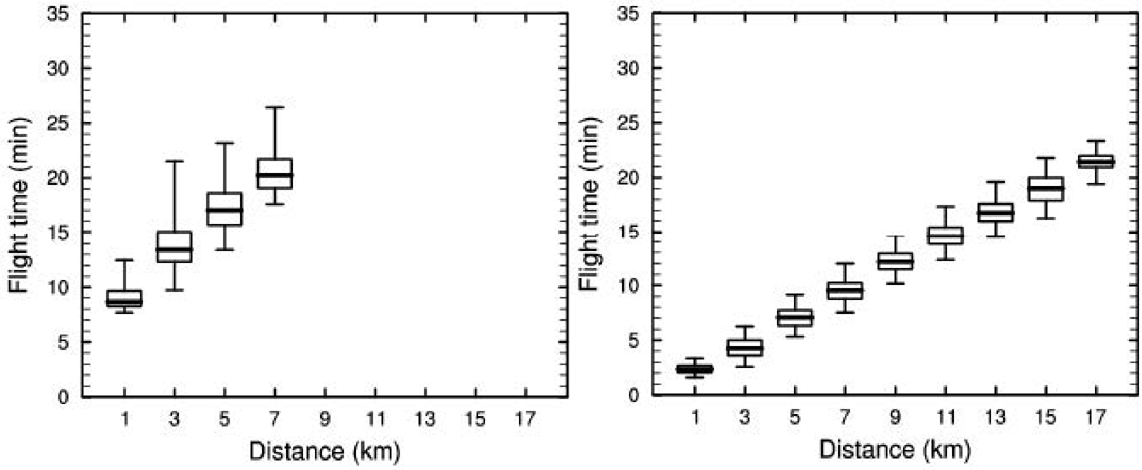

FIGURE 4. BOX AND WHISKER PLOTS OF FLIGHT TIMES FOR FIREBRANDS LOFTED BY THE TIME-VARYING PLUMES UNDER BACKGROUND WIND SPEEDS OF 5 (LEFT) AND 15 (RIGHT) M S–1. FLIGHT TIMES ARE BINNED ACCORDING TO THE DISTANCE TRAVELLED BY THE FIREBRAND, AT 2-KM INTERVALS. THE THICK LINE SHOWS THE MEDIAN FLIGHT TIME AND THE BOX SPANS THE INTERQUARTILE RANGE. WHISKERS REPRESENT THE 1ST AND 99TH PERCENTILE FLIGHT TIMES.

CONCLUSION

We have combined large-eddy simulations of bushfire plumes with Lagrangian particle transport modelling to investigate how turbulent plume dynamics can affect long-range spotting. Plumes exhibited different dynamical and turbulent behaviour depending on the strength of the background wind and this consequently leads to differences in firebrand transport. Plumes in weak winds contain a counter-rotating vortex pair, which leads to large lateral spread in firebrand landing position. Plumes in strong winds are more turbulent and bent over, leading to more longitudinal spread in firebrand landing position and a greater maximum spotting distance. In-plume turbulence was shown to substantially increase the lateral and longitudinal spread in firebrand landing position, and in the case of plumes in strong background winds increase the maximum spotting distance by a factor of two. Systematic studies such as this will inform the development of improved physically based spotting models.

REFERENCES

Cruz, M. G., A. L. Sullivan, J. S. Gould, N. C. Sims, A. J. Bannister, J. J. Hollis, and R. J. Hurley, 2012: Anatomy of a catastrophic wildfire: The Black Saturday Kilmore East fire in Victoria, Australia. *Forest Ecol. Manag.,* **284**, 269–285.

Ellis, P. F. M., 2010: The effect of the aerodynamic behaviour of flakes of jarrah and karri bark on their potential as firebrands. *J. Roy. Soc. West. Aust.*, **93**, 21–27.

Gray, M. E. B., J. Petch, S. H. Derbyshire, A. R. Brown, A. P. Lock, H. A. Swann, and P. R. A. Brown, 2001: Version 2.3 of the Met Office large eddy model: Part II. Scientific documentation. Turbulence and Diffusion Note 276, UK Met Office, 49 pp., Exeter, United Kingdom.

Hall J., P. F. Ellis, G. J. Cary, G. Bishop and A. Sullivan, 2015: Long-distance spotting potential of bark strips of a ribbon gum (*Eucalyptus viminalis*). *Int. J. Wildland Fire* **24**, 1109–1117.

Thurston, W., K. J. Tory, J. D. Kepert, and R. J. B. Fawcett, 2014: The effects of fire-plume dynamics on the lateral and longitudinal spread of long-range spotting. *Proceedings of the Research Forum at the Bushfire and Natural Hazards CRC & AFAC 2014 Conference*, M. Rumsewicz, Ed., Bushfire and Natural Hazards CRC, 85–94, ISBN: 978-0-9941696-3-15.