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Modelling the dynamics of fire whirls

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Abstract: Fire whirls are often created during wildfires on, or around, the head of the fire. These intense vertically oriented vortices have the potential to cause significant destruction by uprooting vegetation and breaking limbs from trees (Graham, 1955), creating projectiles hazardous to firefighters and ejecting burning debris in a complex pattern. Whirls may involve and contribute to flaming regions, but are more commonly comprised of smoke, hot gases and unburned fuel. The behaviour and formation mechanism of a whirl depends on its location with respect to the fire as well as the initial source of vorticity. Most often studied are stationary whirls that form directly over the burning area when subject to an external source of vorticity such as on the lee side of an obstruction to wind. Stationary whirls have been well characterised however less attention has been given to the mobile whirls which form periodically on the lee side of a fire plume and move downwind in a manner qualitatively similar to wake vortices. Despite being commonly observed the conditions necessary for the formation of the most hazardous whirls, with the strongest wind speeds, are not fully understood (Shinohara, 2022).

A model for simulating fire whirls was developed in the open source-computational fluid dynamics (CFD) package OpenFOAM utilising a Large Eddy Simulation (LES) approach. This approach allowed the full dynamics of the plume, resultant whirls, thermal transport and advection of particles (representing debris or embers) to be simulated. As the focus of study was fire-induced flows such as fire whirls, rather than the fire itself, combustion was modelled as a static volumetric heat source. The model was validated against data from a small-scale wind tunnel experiment and qualitatively compared against video footage of fire whirls from a large-scale fire from the Burning Man festival. Whirl core diameter and tangential velocity matched data from the wind tunnel experiment and there was good agreement in the case of the Burning Man fire in terms of whirl frequency and qualitative visual comparison. The model is suitable for further study of the fundamental behaviour of these fire whirls from both large and small-scale simulated fires. Detailed numerical study of these whirls will aid in better understanding of how their formation mechanism and properties are related to environmental factors such as topology, wind speed, fire shape and intensity as well as understanding the distribution patterns of debris and embers transported in these structures.

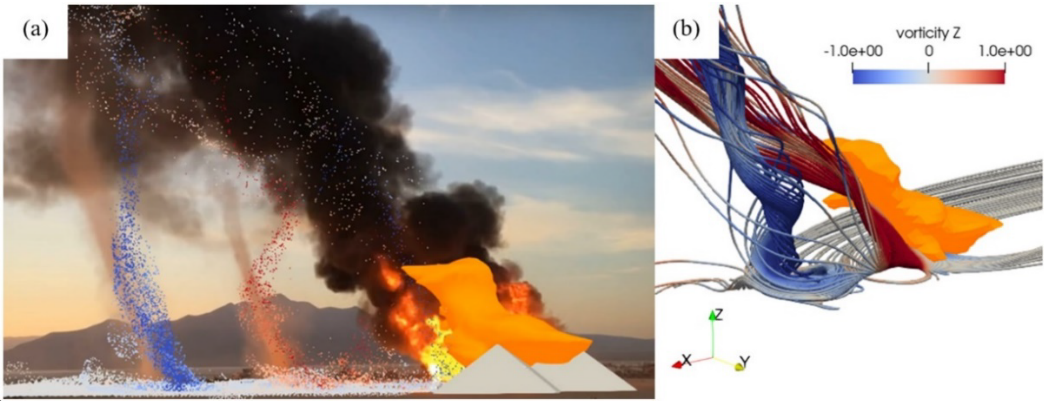

Figure 1. (a) Simulated fire whirls visualised by massless particle tracers superimposed on Burning Man fire video, where colour indicates local vertical vorticity (b) instantaneous streamlines of a whirl detaching from the lee side of a plume, where colour indicates vertical (z) vorticity

REFERENCES

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