Sensitivity of physical parameters in wildfire modelling

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INTRODUCTION

- Wildland fire is a complex phenomenon, and one of critical importance due to its impacts on people and the environment.
- We currently have many physical and empirical models to describe wildland fire spread, but each has their limitations in terms of scope, assumptions, simplifications, and accuracy.
- Knowing the sensitivity of models to changes in their parameters is key to understanding the impact of the quality of input data, to know the accuracy of models based on input variability.

OBJECTIVES

- Develop a physics-based model to improve fundamental understanding of fire spread behaviour, involving study of effects of different parameters, including environmental and fuel conditions.
- Investigate the sensitivity of the model to different physical parameters, varied over ranges consistent with the literature.
- Find out if there are certain parameters which have more significant influence on the model, and if so, which ones, and why.

METHODS

Physical Model

- Model uses Fire Dynamics Simulator (FDS).
- Set-up is a bed of Douglas Fir needles, under an external flux of 50kW/m^2, based on McAllister et al. and Anand et al. [1,2]
- Main outputs are peak heat release rate (pHRR) and time to pHRR.

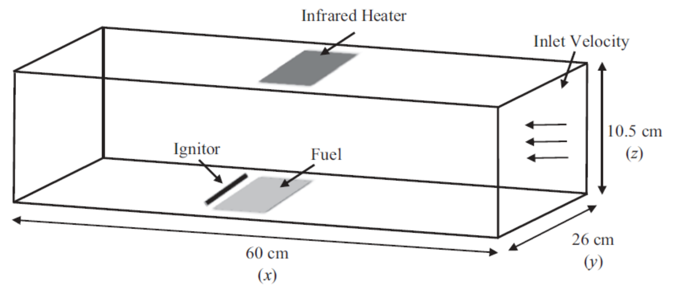

Figure from [2]

Parameters and sensitivity analysis

- Physical parameters were analysed: bulk density of fuel, dry basis fuel moisture content (FMC), fuel emissivity (e), wind, fuel density, fuel element length, fuel element surface area to volume ration (SVR), and drag coefficient (Cd).
- One-at-a-time (OAT) analysis [3], using sensitivity coefficient:

$$\bar{s} = \frac{y(X_0+\Delta X)-y(X_0)}{\Delta X}\frac{X_0}{y(X_0)}$$

with input X and output y.
- Scatter plot analysis [3] where each parameter is varied over a range and output is plotted against the variation.

RESULTS

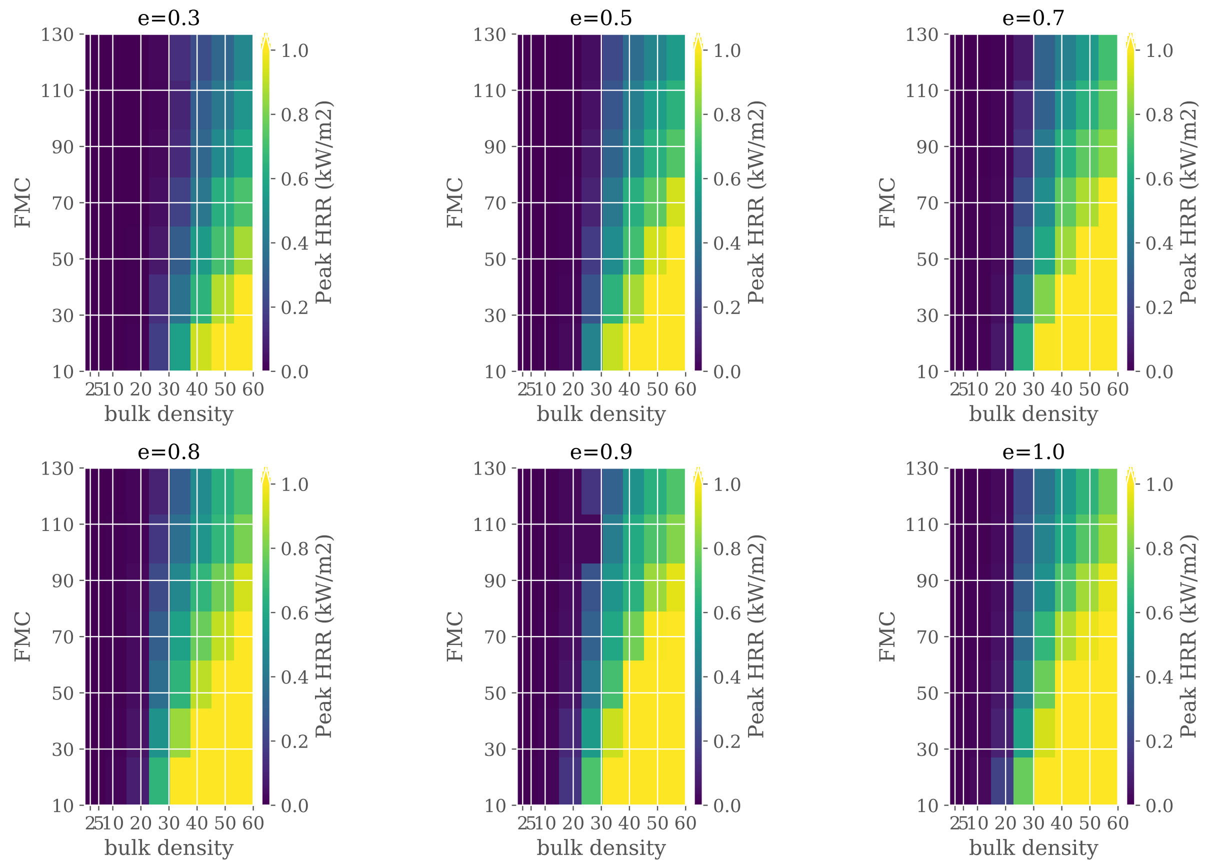

Figure 1: Plots of peak heat release rate for a range of different fuel moisture contents (FMC), bulk densities, and emissivities (e).

Fig. 1 shows the effect of varying FMC, bulk density, and emissivity coincidentally. Across all emissivities, the peak HRR increases for increasing bulk density and decreasing moisture content. Some results in the range of low moisture contents and high density were higher than 1kWm^{-3}, but the scale of pHRR was limited to this value to give more clarity in the mid-scale results, particularly for lower emissivities.

Fig. 2 shows OAT analyses giving a local sensitivity analysis at four different representative baselines across the model. These baselines were chosen to give a mixture of lower and higher bulk densities, as well as low and high moisture contents. Some of the most important parameters affecting pHRR are bulk density, emissivity, SVR, and wind. Fuel density and moisture content affect time to pHRR significantly.

Fig. 3. gives the scatter plot analysis of varying the parameters. It shows the pHRR (left) and time to pHRR (right) plotted against the normalised variation of the parameters, compared to a chosen baseline. As FMC increases, pHRR decreases, and the time to peak HRR increases. Increasing bulk density increases the pHRR, but decreases the time to pHRR, up to a point (around 20kgm^3), after which there is minimal change. Fuel density has the opposite effect. Increasing the emissivity increases the peak HRR and decreases the time to pHRR, with the lower emissivities significantly slowing time to pHRR, but decreasing in effect above around e=0.7. Increasing SVR increases the pHRR and reduces the time to pHRR. Drag coefficient, wind, and length all have similarly little effect on both outputs.

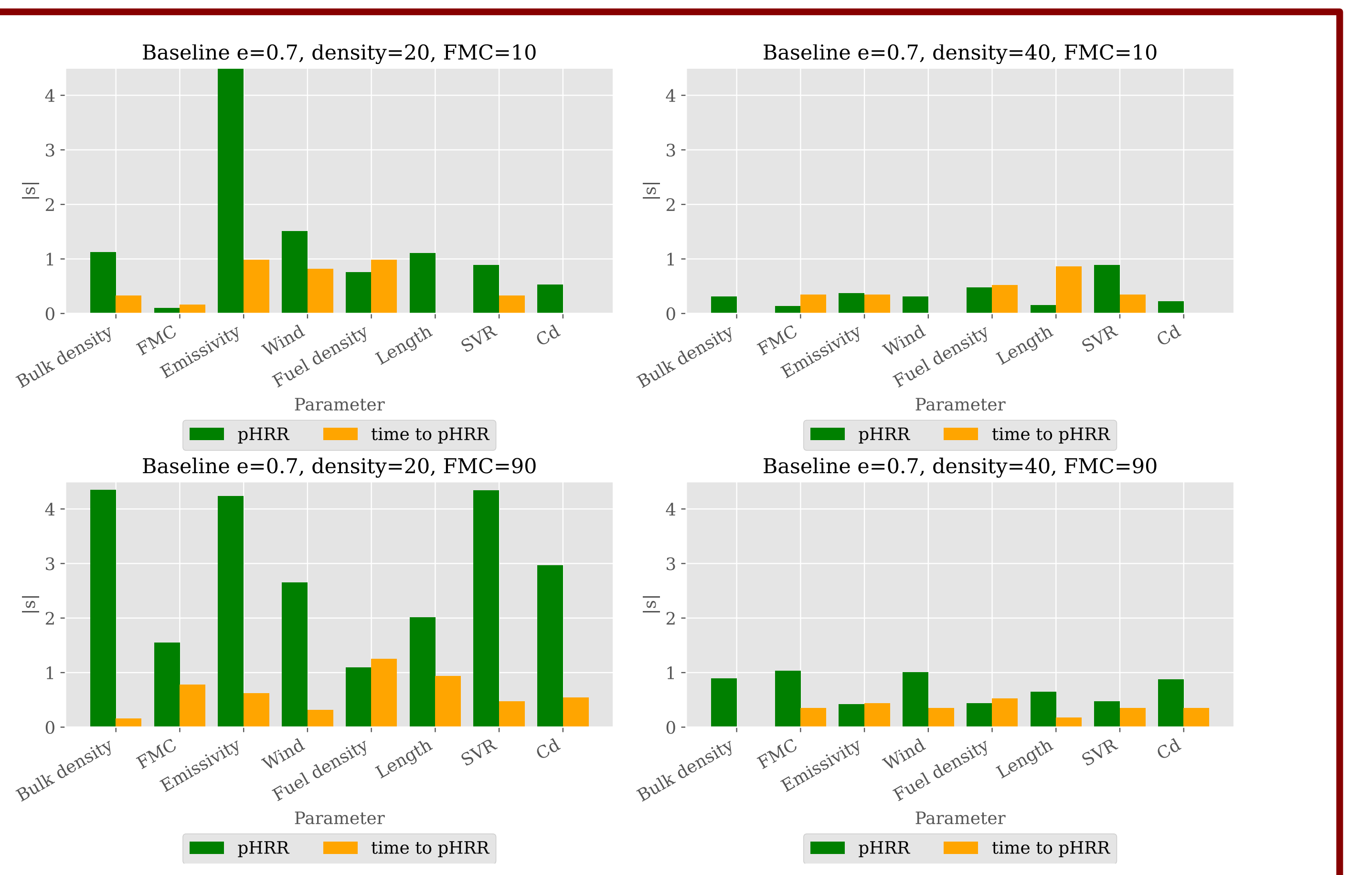

Figure 2: One-at-a-time analysis of the sensitivity of the model for different baselines.

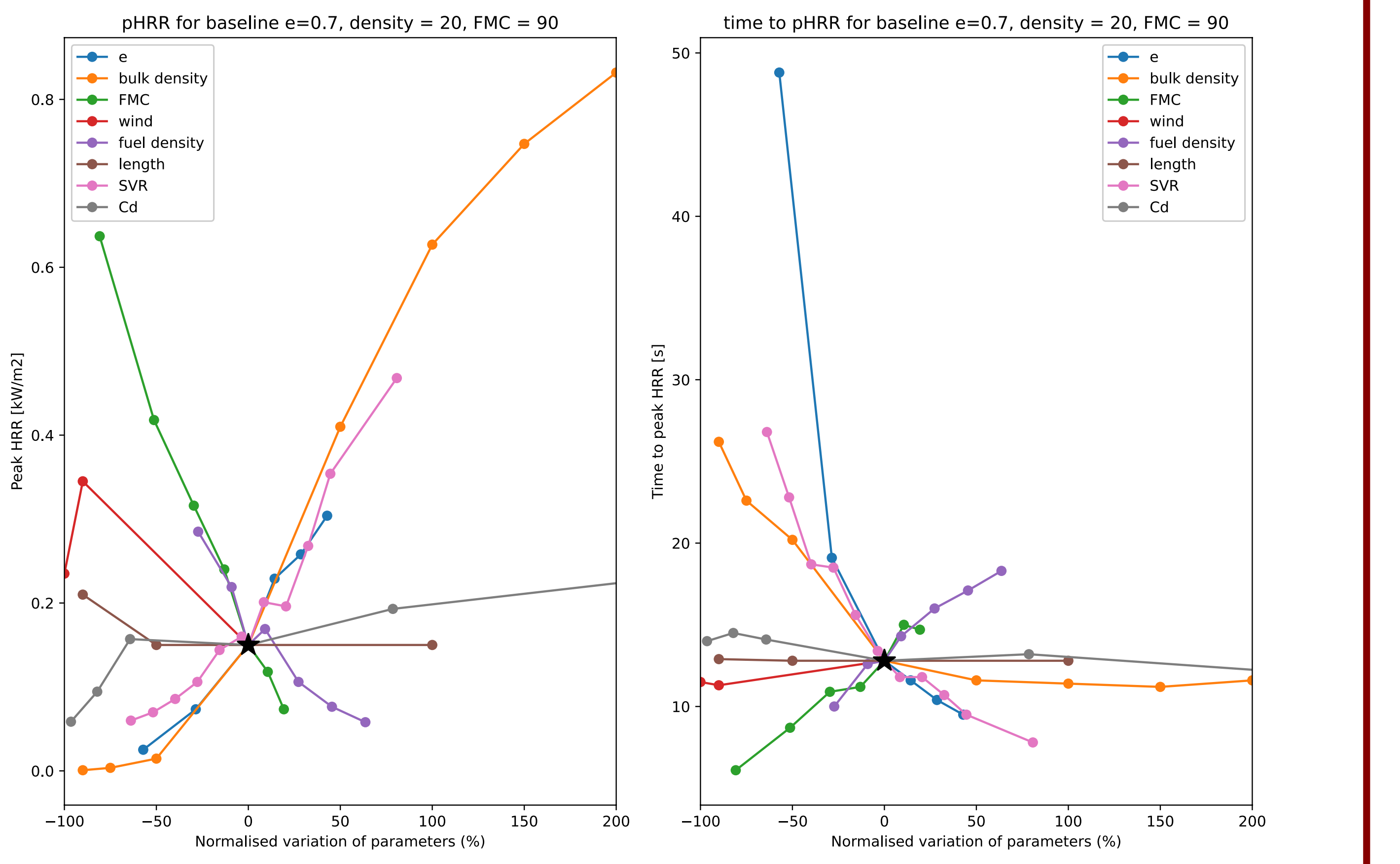

Figure 3: Scatter plot analysis of sensitivity of the model to different parameters, compared to a baseline marked by the black star.

DISCUSSION

- With increasing bulk density, there is more fuel to burn, so the heat release rate is higher. A higher moisture content means more energy is required to evaporate the moisture, so less heat is released from the fuel, hence HRR increases with decreasing moisture content. Increasing the emissivity (and hence the absorptivity) of the fuel has the effect of increasing the energy from the heater absorbed by the fuel, meaning it releases more energy when it burns.
- The effect of all parameters on time to pHRR is of a comparable order of magnitude across the different baselines, but for value of pHRR, the most variation by a significant amount occurs at the baseline of e = 0.7, bulk density = 20kgm^3 and FMC = 90%. This suggests that this is a significant point for testing to focus around in experimental work.
- Across the scatter plot, for the value of pHRR, the parameters emissivity, bulk density, FMC, fuel density, and SVR, all have a similarly significant effect, whereas for time to pHRR, the moisture content has the most consistent significant effect, as the emissivity and bulk density have much lesser effects above 0.7 and 20kgm^3, respectively.
- Future work will include expanding the sensitivity analysis to more parameters, including chemical parameters. This especially aims to capture the effect of live vs. dead moisture content through defining free vs. bound water. In particular this will be done via the activation energy and pre-exponential factors for water .

REFERENCES

[1] McAllister et al., *Fire Saf. J.,* 51 (2012) 133-142
[2] Anand et al., *Comb. Sci. & Tech.,* 189:9 (2017) 1551-1570
[3] Hamby, *Env. Monitoring and Assessment* 32 (1994) 135-154

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