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Assessing uncertainty and sensitivity in forest fire behaviour models

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Abstract: Bushfires present a significant threat to the environment, property and life in Australia. Growing population, climate change and urban expansion lead to more people and assets being at greater bushfire risk. There is therefore a pressing need to use improved wildfire models to better forecast fire danger and protect communities. As a response to this need, the Australian Fire Danger Rating System (AFDRS) was launched in 2022. As the first nationally consistent framework, AFDRS has been implemented in all states and territories across Australia, with the aim of providing improved information, clearer communication and enhanced capability to support cross-border operations (Hollis et al., 2024).

In Australia, forest forms a critical component of fire danger forecasting, as it coincides with the most densely populated areas. However, despite its importance, the current forest model correctly forecast fire danger only 54% of the time (Grootemaat *et al*., 2024). It is also recognised as one of the most complex models in the AFDRS (also known as the Vesta model), owing to its detailed fuel characterisation and the use of adjusted weather indices. This study addresses two key questions: 1) What is the relative influence of the forest model's input variables? and 2) To what extent do uncertainties in the model inputs influence the specificity with which fire danger rating levels can be estimated?

To address the first question, formal sensitivity analysis was undertaken to identify the parameters driving variability in the Vesta model and its 'sibling' model Vesta Mk2. The analysis was conducted for a generic context taken from Southeast Queensland. Results show that both models are most sensitive to relative humidity and wind speed, suggesting these as key parameters for ensuring model accuracy and reliability. In the Vesta model, fuel-related parameters (e.g., fuel hazard scores and near-surface fuel height) exert much more influence on outputs than in Vesta Mk2, which is comparatively less sensitive to fuel parameters.

To address the second question, formal uncertainty analysis was applied using Monte Carlo simulations under mild, moderate, and extreme weather scenarios, each paired with fuel age categories (recently burnt, moderately, and long unburnt). A Gaussian copula model was used to capture dependencies between correlated variables such as fuel age and fuel load, while independent variables (e.g., wind speed) were sampled from uniform distributions. Across all scenarios, results show that Vesta Mk2 produces higher fireline intensity, with differences between the two models most pronounced under extreme weather and high fuel load conditions. The variance in the fireline intensity outputs further indicates that Vesta model exhibits considerably higher uncertainty under extreme weather and heavy fuel loads, whereas Vesta Mk2 produces less variance in the outputs. Interestingly, for recently burnt fuels, Vesta model shows reduced uncertainty compared with Vesta Mk2, suggesting that despite its simplified vegetation parameter set, Vesta Mk2 has greater uncertainty when fuel loads are low.

In conclusion, the results of this study show that the Vesta model is relatively sensitive to both weather and fuel parameters and produces results with a high uncertainty under moderate and extreme weather conditions. In comparison, for such extreme cases, Vesta Mk2 provides less uncertainty in the model outputs. The identification of impactful parameters points to an important direction for practitioners to reshape their decision-making on allocating resources to improve the fuel datasets to achieve better prediction. Importantly, fuel hazard scores are obtained using subjective judgment, which could have a significant impact on the fire danger ratings obtained.

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