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Uncertainty associated with model predictions of surface and crown fire rates of spread

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ABSTRACT

The degree of accuracy in model predictions of rate of spread in wildland fires is dependent on the model's applicability to a given situation, the validity of the model's relationships, and the reliability of the model input data. On the basis of a compilation of 49 fire spread model evaluation datasets involving 1278 observations in seven different fuel type groups, the limits on the predictability of current operational models are examined. Only 3% of the predictions (i.e. 35 out of 1278) were considered to be exact predictions according to the criteria used in this study. Mean percent error varied between 20 and 310% and was homogeneous across fuel type groups. Slightly more than half of the evaluation datasets had mean errors between 51 and 75%. Under-prediction bias was prevalent in 75% of the 49 datasets analysed. A case is made for suggesting that a ±35% error interval (i.e. approximately one standard deviation) would constitute a reasonable standard for model performance in predicting a wildland fire's forward or heading rate of spread. We also found that empirical-based fire behaviour models developed from a solid foundation of field observations and well accepted functional forms adequately predicted rates of fire spread far outside of the bounds of the original dataset used in their development.

1. Introduction

Wildland fire behaviour is broadly defined as the manner in which fuel ignites, flame develops, fire spreads and exhibits other related phenomena as determined by the interactions of fire with its environment – i.e. fuels, weather and topography. The immediate needs of fire operations personnel with respect to fire behaviour information can be decidedly different from the interests of fire researchers. Nevertheless, as Van Wagner (1985) has stated, "If one could boil down the whole science of fire behaviour to its practical essence, it might be to put in the hands of the fire boss a decent estimate of how fast his newly-reported fire will advance" (Fig. 1). In this respect, the knowledge of a free-burning fire's rate of spread (Albini, 1984) is often central to being able to compute or estimate other fire behaviour characteristics (Fig. 2).

Models for predicting rate of fire spread and other characteristics of behaviour are typically distinguished on the basis of three broad categories: (i) physical, (ii) empirical or (iii) semi-empirical models (Sullivan, 2009a,b). Physical or process-based models are mostly developed with theoretical purposes in mind, aiming to better understand the physical and chemical processes controlling fire propagation. The justification for empirical or semi-empirical models is largely to support a decision making process. Emphasis on the purpose and perfection of the process description is not necessarily sought (Alexandrov et al., 2011).

Irrespective of the model approach taken, a pertinent question facing any wildland fire behaviour modeller is: how accurately can one expect to predict the spread rate of a wildland fire with currently available models? The aim of this study was to address this question by examining error statistics associated with studies that have used independent datasets derived from field observations as means of evaluating the performance of models used in the prediction of surface and crown fires rates of spread for operational decision-making or as planning and research tools. Given the existing evidence we also wished to determine what should be considered an acceptable error.

2. Background information

2.1. Predicting wildland fire rate of spread

When observed closely, a free-burning fire spreads through highly variable and chaotic motions, although if one considers the

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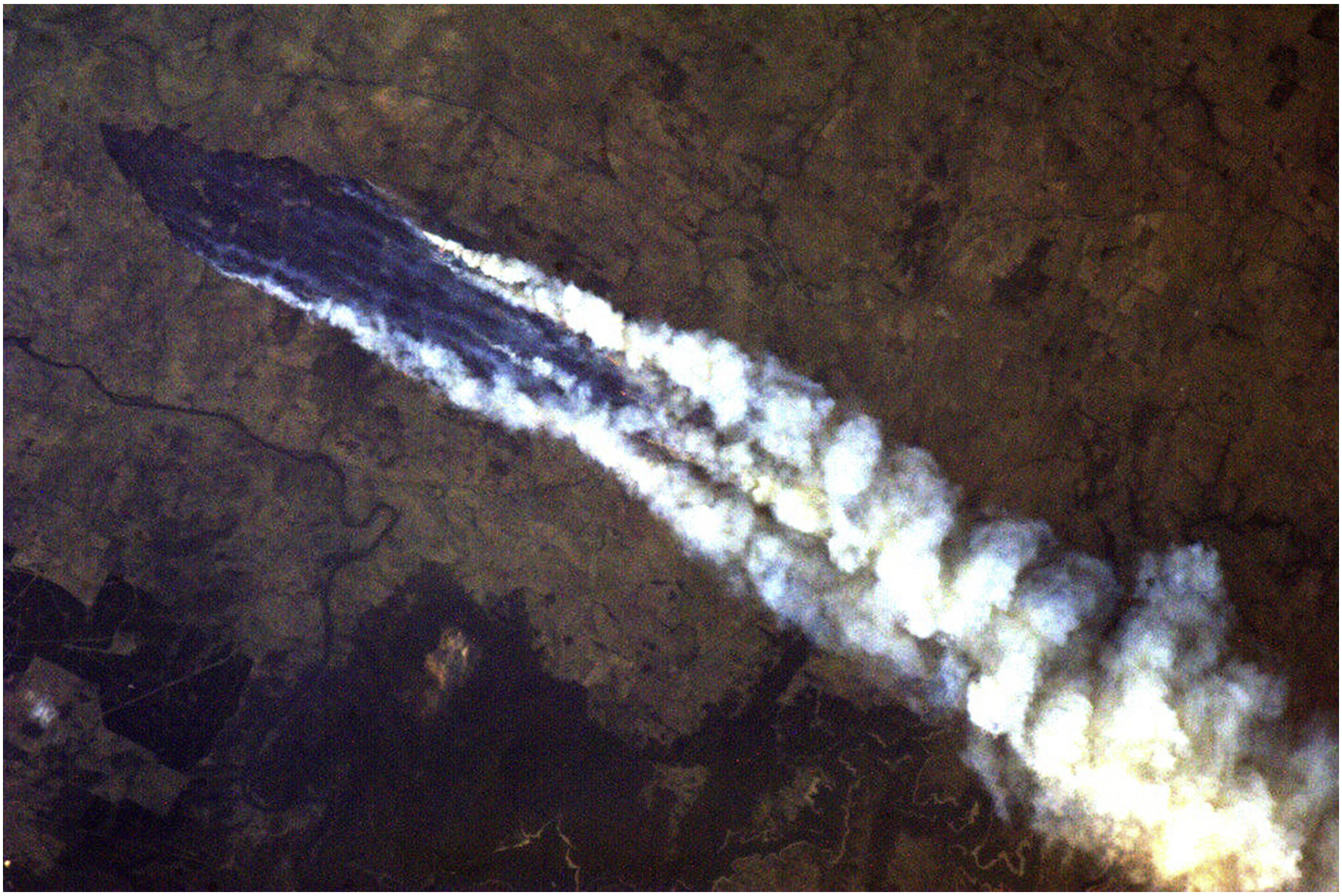

Fig. 1. The view from space of the Cobbler Road Fire near Yass, New South Wales, Australia, spreading through fully-cured grasslands on the afternoon of 8 January 2013 under the influence of exceptionally strong average winds (~50 km/h). Wind-driven fires typically exhibit very elongated, elliptical shapes in such situations. Photo credit: Chris Hadfield/NASA.

time scales of practical interest, spread can be taken as effectively continuous, giving rise to the concept of a ‘pseudo-steady’ fire propagation state. In near-real time forecasting of wildland fire behaviour, presently the objective is to be able to predict the spread rate of a fire propagating at this pseudo-steady state over time intervals of 30 min or longer (Rothermel, 1983, 1991; Andrews et al., 2007; Cheney and Sullivan, 2008).

Empirical-based models developed from experimental fires carried out under field conditions and covering a broad range of fuel complexes (from open grasslands to conifer and eucalypt forests) and weather conditions are typically but not always (e.g. Burrows et al., 2009) able to predict the source dataset with mean absolute percent errors between 20 and 40% (Fig. 3). The main sources of error in model predictions of wildland fire behaviour are considered to be a lack of model applicability, internal inaccuracy, and data input errors (Albini, 1976; Alexander and Cruz, 2013b). The error is expected to be higher when the models are applied to predict fire spread rates in an operational setting due to the natural variability in fuels and uncertainties in forecasted weather conditions over broad spatial and temporal scales (Rothermel, 1983). It is also expected that in general terms, fire behaviour data collected in an operational setting has a higher degree of uncertainty due to the logistical and time constraints to set up measuring equipment and directly observe fire behaviour.

2.2. Variability in rate of fire spread

The above mentioned wide variability in fire behaviour in time and space, in even the most homogenous environments, led Rothermel (1983) to point out that it is quite unlikely that the minute-by-minute movement of a fire will ever be accurately predictable with any degree of certainty in the foreseeable future. This is largely due to the capricious nature of the prevailing surface winds (Albini, 1982; Cheney et al., 1993; Sullivan and Knight, 2001), horizontal and vertical fuel heterogeneity (Hiers et al., 2009), chaotic nature of turbulent flow driving the fire propagation processes (Clark et al., 1999), and the dynamic feedback mechanisms associated with the fire and the surrounding environment (Nelson et al., 2012). These fine scale variations in the drivers of fire propagation are the cause of an apparent paradoxical phenomena where more accurate predictions are made in forecasting the spread of 15–30 min fire runs with average wind speeds then making predictions for short spread durations (i.e. 1–3 min) based on the nearby measured wind speed (Cheney et al., 1993).

Detailed measurements of rate of spread in experimental fires have revealed unsteady fire behaviour and high variability over short time periods but consistency over longer time periods (Fig. 4). Several authors have described how fluctuations in wind speed and direction (Crosby and Chandler, 1966), and subtle changes in fuel structure can lead to dramatic changes in fire spread (Anderson et al., 1982; Cheney and Gould, 1995; Fernandes et al., 2000, 2004). Cruz et al. (2013), for example, quantified fire spread variability in 200–400 m long experimental fire runs in shrublands, finding maximum rates of spread to be 1.8 to 5.9 faster than the average, and the coefficient of variation (i.e. the ratio of the standard deviation to the mean expressed as a percentage) varying between 56 and 167. Similarly, Taylor et al. (2004) found maximum rates of spread to be 1.6–2.9 times the average in 75–