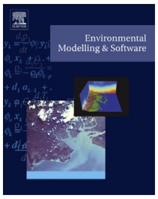
Environmental Modelling & Software 91 (2017) 1–12

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft



Improving the reliability and utility of operational bushfire behaviour predictions in Australian vegetation

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ARTICLE INFO

Article history:
Received 14 September 2016
Received in revised form
24 January 2017
Accepted 24 January 2017
Available online 2 February 2017

Keywords:
Wildfire
Wildland fire
Decision support system
Software
Fire spread
Amicus

ABSTRACT

Fire behaviour and spread predictions guides suppression strategies and public warnings during wildfires. The scientific understanding of fire behaviour forms the core of these predictions, but is incomplete, and expert judgement and experience are required to augment the evidence based knowledge. Amicus is a new decision support system that implements contemporary, published and operationalised bushfire behaviour models (e.g. rate of spread, flame height, fireline intensity, spotting distance) in the Australian bushfire context. It enables the inclusion of expert judgement and local knowledge, allows users to analyse temporal trends and uncertainty in inputs, and facilitates reliable and practical predictions. This paper provides a comprehensive overview of Amicus, including its operation and functionality, identifies the boundaries of the current understanding of fire science, discusses the major limitations in existing knowledge, and provides a framework for allowing deterministic and anecdotal/local knowledge to be incorporated into formal fire behaviour predictions.

Software availability

Name of software: Amicus
Developers: CSIRO, Data61
Contact address: Research Way, Clayton VIC 3168
Email: amicus@csiro.au
DOI: http://doi.org/102.100.100/20990
Availability: Download from https://research.csiro.au/amicus/
Current version: 0.5.39682
Download size: 71 MB
Documentation: https://research.csiro.au/amicus/resources/documentation/
Year first available: 2013
Supported platforms: MS Windows, Linux or Mac OS
Programming language: C++
Frameworks: Workspace, Qt
Program size: 251 MB
Hardware requirements: Basic desktop/laptop PC
Video tutorials available at: https://research.csiro.au/amicus/resources/videos/

1. Introduction

Fast and accurate prediction of the behaviour and spread of bushfires (or wildland fires as they are called in many parts of the world) are essential for planning safe and effective suppression strategies and tactics, issuing timely and specific public warnings, implementing safe and effective prescribed fires and undertaking fire risk analyses. Operational bushfire spread predictions are generally undertaken by a highly trained fire behaviour specialist (also referred to as fire behaviour analyst or fire behaviour officer), working either individually or in a team (Countryman and Chandler, 1963). They prepare a range of products (e.g. maps, reports, etc.) communicating the predicted progression and timing of fire spread across the landscape and identify the locations that will potentially be impacted. This information assists those in charge of fire operations when making critical decisions (Gibos et al., 2015). This role requires a highly skilled candidate with a working knowledge of fire behaviour, meteorology and relationships between fuels, fire, topography and weather, and successful operational deployment requires effective communication with field observers, independence from other duties and access to weather

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http://dx.doi.org/10.1016/j.envsoft.2017.01.019

forecasts (Chandler and Countryman, 1959).

Fire behaviour specialists use a broad range of formal and informal information when making predictions. These include site intelligence (e.g. field observations, situation reports, incident maps, video, photos, anecdotes, etc.), aide-memoires, local knowledge, personal experience, heuristic expert judgement and published science. Once a fire prediction task is assigned, the specialist must collate and process these information, quantify uncertainty in input data, select and run appropriate fire spread models, and assess the outputs against the uncertainty before presenting results as reports and maps. Prediction guides have often recommended that uncertainty be conveyed by using the thickest crayons (Rothermel, 2009; as cited in Andrews et al., 2011) and by clearly listing assumptions.

A survey of Australian fire behaviour specialists (Cruz et al., 2014b) revealed that fire behaviour predictions are made using a mix of published fire science, expert judgement and local knowledge with different weighting applied for each when making decisions. Formal science is incorporated in predictions through the application of published fire behaviour knowledge and models, with an appreciation of the limitations and applicability of each model. The specialist's expert judgement provides quality assurance for selecting appropriate models and enables verification for model inputs and outputs. This judgement is acquired through extensive first hand fireground experience and training which may be formalised as an aide-memoire (Ferguson, 2016). This expertise can take years to accumulate (McLennan et al., 2006) but is essential for filling voids where the formal knowledge is incomplete or non-existent, such as when input data are outside of the conditions covered by fire behaviour models. Local knowledge provides a more specific level of quality assurance for assessing inputs and predictions and is also acquired through experience.

1.1. Background

Formal bushfire behaviour prediction methods have been in development for nearly a century. Most models have focussed on the deterministic prediction of the rate of spread of the fastest moving part of the fire (the head-fire), as this is critical to the application and control of fire (Cheney, 1981). Two main approaches have been used to model fire spread, physical and empirical modelling, with a spectrum of approaches in between (Sullivan, 2009b, c). Physical and quasi-physical models attempt to represent the chemistry and/or physics of fire spread, while empirical and quasi-empirical models are based on the statistical relationships between variables observed during field and laboratory experiments and generally do not incorporate any physical understanding (Sullivan, 2009b, c). Physical models are generally computationally intensive as they attempt to solve the fundamental governing equations of conservation of mass, momentum and energy, and as a result are currently not operationally practical (Sullivan, 2009b). Empirical models utilise readily available fuel and weather data as inputs and as they are generally relatively simple analytical models that do not attempt to include any physical understanding of the combustion processes involved, can be solved relatively quickly. As a result these models form the basis of all operational fire behaviour models in use today (Sullivan, 2009a). Wind speed, slope and fuel moisture content are the key independent variables used as inputs in most empirical fire spread models, with wind speed mostly incorporated as a power function and a variety of methods used to incorporate the effects of fuel moisture (Sullivan, 2009c).

In Australia, empirical fire behaviour models have been developed over a number of years for a range of specific fuel types with limited vegetation categories. This approach reflects the evolution of Australian fire management, which was initially focussed on forest protection, and is different to that taken in other jurisdictions (e.g., the United States) where a single fire spread model with a range of predetermined input fuel models for different fuel types is used (Rothermel, 1972; Scott and Burgan, 2005). The interoperability of fire spread models between Australia and other countries has been limited when there are differences in vegetation structure, fuel attributes and resulting fire behaviour. Recent critiques of fire spread models applicable to Australian fuel types (Cruz et al., 2015a, b) have made best practice recommendations on the most appropriate models for operational use in a range of vegetation types based on their performance and stability.

A fire behaviour prediction system (FBPS) packages fire behaviour models (e.g. for predicting rate of spread, flame height, intensity and spotting distance) in a form that enables users to readily carry out predictions and undertake other tasks, such as developing prescriptions for planned burns, communicating the effect of fire management actions to the public and facilitating training (Andrews, 2014).

A FBPS formalises the numerical modelling process and provides clear instruction for the use of fire behaviour models. FBPS were originally presented in paper based forms including tables and nomograms (e.g. Albini, 1976; Gould et al., 2007b; McArthur, 1962) and slide rules designed for field use (e.g. McArthur, 1973).

Many of the older Australian tables, nomograms and slide rules were published without accompanying equations and as a result there have been retroactive efforts to reverse engineer their algorithms to extend their use in computer calculations (e.g. Beck, 1995; Gould, 1994; Noble et al., 1980). This indirect approach often leads to cumbersome regression equations that do not reflect their original intended interactions in a straightforward way and do not always agree with the original systems (e.g. McCaw and Catchpole, 1997).

Computerised FBPSs have been available since the 1980s. Examples include the BEHAVE and BehavePlus fire behaviour prediction and fuel modelling systems (Andrews, 2014); CFIS (crown fire initiation and spread), a collection of models for predicting crown fire behaviour in North American coniferous forests (Alexander et al., 2006); REDapp, a fire management decision support tool based on the Canadian Fire Behaviour Prediction System (McLoughlin, 2016); and SYPYDA a fire management program for Greek pine forests (Mitsopoulos et al., 2016). Recently some algorithms for calculating fire danger and spread rates at a point have been featured in applications developed for smart phones and tablets developed by amateur enthusiasts and some fire management agencies (Kulemeka, 2015).

A range of other computerised FBPS have been developed within existing software frameworks such as tabular spreadsheet computer programs and statistical computing environments. Only a few of these (e.g. Canopy Fuel Stratum Characteristics Calculator (Alexander and Cruz, 2010), PiroPinus (Fernandes et al., 2012), Rothermel R package (Vacchiano and Ascoli, 2015)) are accompanied by published technical documentation. A large number of user-developed spreadsheets have been constructed for planning and operational wildfire. These are easy to develop and share and generally use published algorithms for common fire behaviour models to make predictions from a range of inputs. However they usually do not warn users of model limitations and assumptions and the verification of algorithms, support, maintenance and version control is the responsibility of the software user. It is also easy for errors to creep into formulas in such spreadsheets for these to go unnoticed.

Over the last few decades a number of fire spread simulators that predict the progress of a fire perimeter across the landscape in two dimensions have been developed for research and operational