

Operational tools for improving efficiency in wildfire risk reduction in EU landscapes

FIREfficient

Protocol for testing fire spread models

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1. Rationale

Wildfire simulation models have a variety of uses that include:

- Operational firefighting (e.g. predicting fire behavior at prescribed burns)
- Wildfire preparedness (e.g. conducting “what-if” scenarios)
- Wildfire investigation (e.g. evaluating suppression effectiveness)

A full list of potential uses of fire growth simulation models can be found in our review of *Fire grown simulation models and landscape fire risk* (Section 2.2 in Piqué & Ramón González-Olabarria, 2014) and elsewhere (e.g. Pearce, 2009). Wildfire models for predicting rate of spread and fire intensity were developed independently in the United States (FARSITE), Canada (Prometheus), and Australia. Following model development, these models became widely used and evaluated within the US, Canada, and Australia for the purposes of fire management. Increasingly, these model systems, or components of these systems are being adapted and applied for use in countries with fuels and climates that differ significantly from those for which the models were originally designed (e.g. Portugal, China, Indonesia, the UK etc.). Robust evaluation of the application/adaptation of these models to new fuel types (e.g. heather moorland which is unique to northern Europe) requires significant investment in experimental fire campaigns that is often beyond the budgetary commitments of regional or national governments. This protocol outlines the main ways by which new, non-standard fuels can be included as “custom” fuel models in the US and Canadian model systems, before a discussion of a variety of methods that may be employed to evaluate the rate of spread and fire intensity outputs of such customized models.

2. Modelling fire spread in northern European fuels

As far as the author is aware, there is no existing literature on the use of wildfire spread models within northern European fire & rescue services, and there is no dedicated effort to build a national or European-specific wildfire spread model equivalent to those developed in the US and Canada. As such, it is likely that any future application of wildfire spread models in northern Europe will involve the customisation or abstraction of either FARSITE or Prometheus, as has been the case in Mediterranean Europe where FARSITE has been applied to the study of fire spread in shrublands (Dimitrakopoulos, 2001; Bigili & Saglam, 2003; De Luis et al., 2004).

2.1 Custom fuel models

FARSITE and Prometheus simulate the spread of fire across landscapes and are both fully publically available systems that use spatial data on fuel characteristics, topography, and meteorology to simulate fire spread. The main difference between these two modelling systems is their underlying fire behaviour prediction (FBP) frameworks, which have two very different methods for the treatment of fuels and how different fuels are related to modelled rates-of-spread and fire intensity. FARSITE relies upon surface fire predictions of Rothermel (1972), whose equations were derived from a series of small-scale laboratory burns based on homogeneous dead fuel beds. In FARSITE, rate of spread and fire intensity are controlled by fuel parameters such as fuel loading, surface-area-to-volume, fuel bed depth,

and heat content of the fuel. As such, the implementation of new fuel models in FARSITE requires extensive field measurements of these fuel variables (see Table 1 for a comparison between the standard shrub fuel models, and a customised fuel model for heather moorland). Unlike FARSITE, the underlying fire behaviour model in Prometheus is based upon measurements of landscape scale fires, where the rate of spread and fire intensity in a particular fuel type are correlated with the Initial Spread Index (ISI) and Build-Up Index (BUI) components of the Canadian Fire Weather Index (FWI), respectively. This approach requires long-term monitoring of the FWI meteorological variables and the measurement of fire rate of spread and fire intensity at dozens or hundreds of experimental fires per fuel type (see Figure 1). The implementation of any new fuel type in Prometheus, therefore, requires an extensive field campaign at numerous experimental fires to establish the necessary correlation coefficients (a, b, c). An example of results from such a campaign to parameterise shrubland fuels in Nova Scotia is presented in Figure 1.

Table 1 Parameters used for a FARSITE custom heather fuel model (FM14) taken from Davies (2005), compared with the standard FARSITE shrub fuel models, SH6 and SH3 Scott & Burgan (2005).

FM Code	FUEL LOADING (tons ha ⁻¹)					SURFACE AREA:VOLUME (cm ² cm ⁻³)			DEPTH (cm)	XtMoist (%)	HEAT CONTENT (kJ Kg ⁻¹)	
	1h	10h	100h	LH	LW	1h	LH	LW			Live	Dead
FM14 (HIGH)	2.73	0	0	0	12.17	96	88	100	42.4	25	20808	20808
FM14 (LOW)	1.28	0	0	0	6.5	96	88	100	19.7	25	20808	20808
SH6 (HIGH)	7.16	3.58	0	0	3.46	246	N/A	525	61	30	18608	18608
SH3 (LOW)	1.11	7.41	0	0	15.32	525	N/A	459	73	40	18608	18608

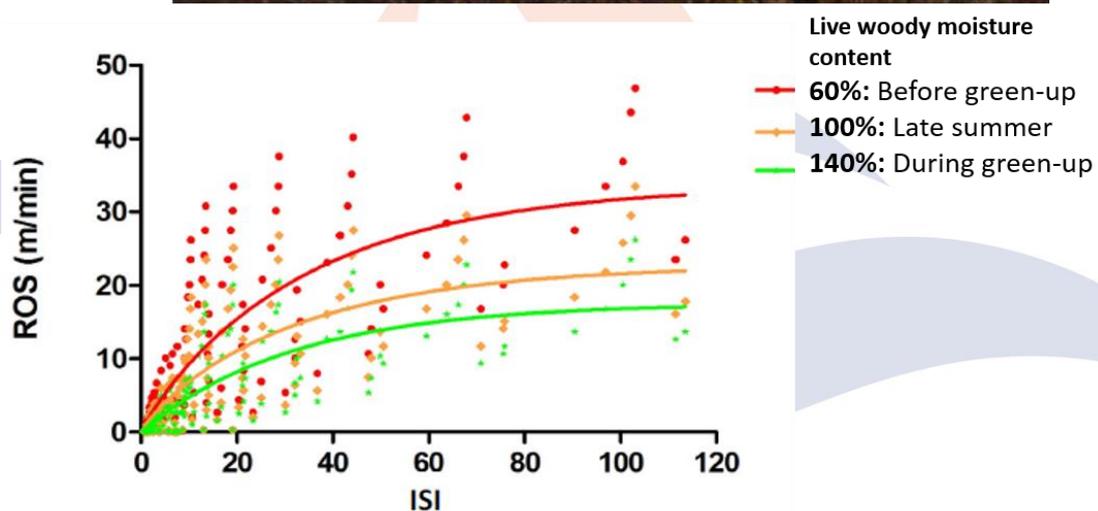


Figure 1 Customised shrub fuel model for Prometheus, developed by Pépin (2010). Prometheus uses an empirical model to relate fire rate of spread to the Initial Spread Index (a function of antecedent temperature, relative humidity, rainfall, and wind speed). This relationship is established from dozens of experimental landscape fires (each point in the plot above represents one experimental fire).

2.2 Proxy fuel models

An alternative to customising new fuel models in FARSITE or Prometheus is to take one of the standard native fuel models (e.g. SH6 shrub fuel in FARSITE) and assume that the native fuel model can behave as a proxy for the new fuel. For example, New Zealand fire and rescue services use Prometheus as their preferred model of wildfire spread. To enable the use of Prometheus in New Zealand fuel types, a number of standard Prometheus fuel types (e.g. conifer plantation) are used as proxies for New Zealand fuels, whilst other new fuel models were parameterised for Prometheus through a series of experimental fires in New Zealand fuels. Any standard FARSITE or Prometheus fuel-type that is used as a proxy for new fuels in northern European applications would also need to be evaluated in the same way as a newly customised fuel type.

The rate of spread and/or fire intensity predicted for a custom/proxy fuel type by FARSITE or Prometheus, or by any other model system, will need to be evaluated by comparing predicted variables with observed fire behaviour. The remainder of this protocol outlines the main approaches that may be taken to assess these model outputs, and evaluate the parameterisation of new fuels in fire spread models.

3. Evaluating wildfire spread models for northern European fuels

Whilst most wildfire spread models offer a full suite of model outputs (see Section 2.2 of Piqué & Ramón González-Olabarria, 2014 for more details), the core outputs that are of most interest to operational firefighting, wildfire preparedness, and wildfire investigations, are fire rate of spread (which ultimately governs the wildfire extent) and fire intensity (which may determine the risk to fire service personnel/civilians, and/or property). Here we will discuss a range of approaches that may be used to evaluate predicted rate of spread and fire intensity. For all approaches discussed below, it is important to have a long-term (at least 2 months) meteorological record for the sites of observed fires (including wind speed, wind direction, temperature, relative humidity, and rainfall), as well as an accurate measure of slope and aspect of the site (e.g. from a good Digital Terrain Model, or field survey). These variables will serve as inputs for the wildfire spread models, in addition to the fuel type (more details on model inputs and model implementation can be found in the FIREfficient *Specific tools for training fire and landscape planners the use of fire-spread simulation models*: http://fireefficient.ctfc.cat/?page_id=259).

Rate of spread and fire intensity is most often assessed on the ground using equipment deployed before an experimental fire. We discuss these methods briefly here, but focus on novel aerial remote sensing techniques that may be used without prior deployment and at wildfires as well as planned experimental fires.

3.1 Ground measurements

There are two main sets of methods for estimating rate of spread from ground-based monitoring. The first method involves timing the arrival of the fire front at marker posts separated by set distances. Davies et al. (2005) used four 2 m-high posts separated by 5 m in heather-dominated moorland in Scotland. An alternative approach is to use sets of

thermocouples places near the surface of the fuel, or buried slightly below the surface. Davies et al. (2005) also use two sets of thermocouples located 5 m apart in their experimental fires in heather fuels.

Ground measurements/surveys may also be used to assess fire intensity/damage. Ground surveys (e.g. Figure 2) can often be used for qualitative assessment of model outputs, as was the case when Prometheus was used for an investigation into the Swinley-Crowthorne forest fire in Berkshire, UK (Figure 2).

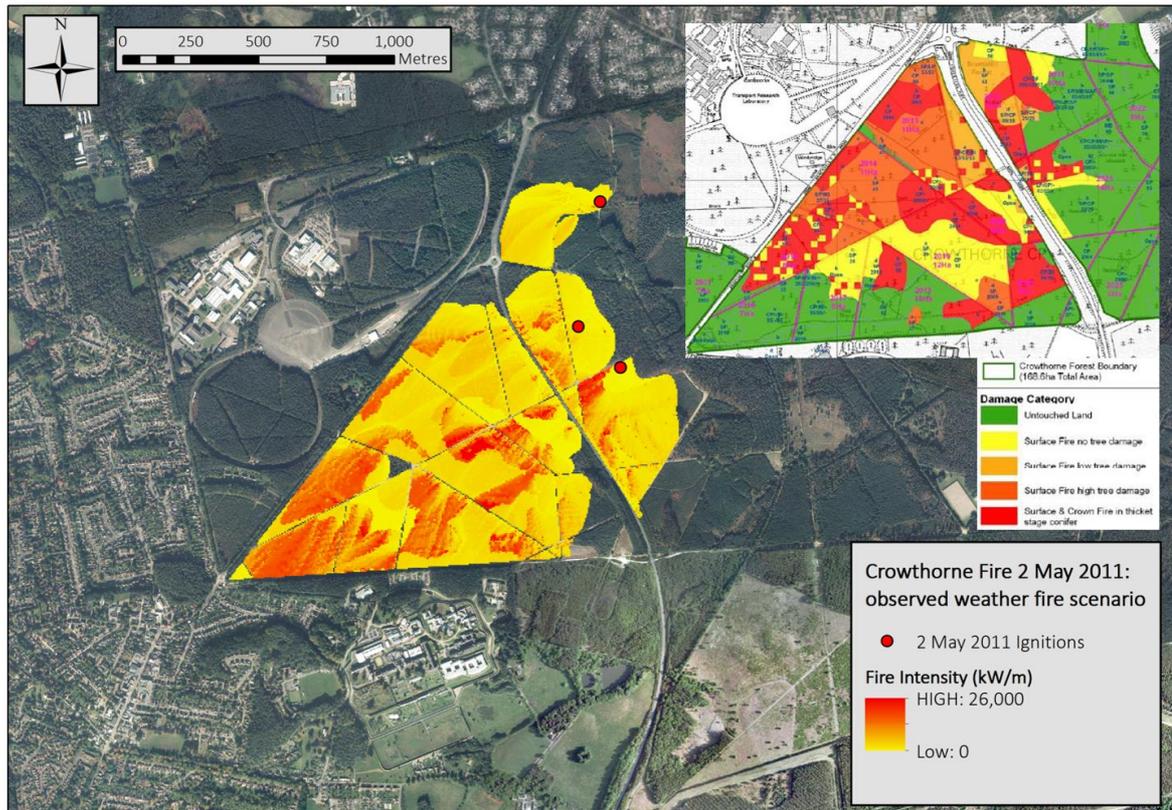


Figure 2 (top right) a ground-based visible assessment of post-fire damage, where red corresponds to damage from a surface and crown fire, dark orange is a surface fire with high tree damage, orange is surface fire with some tree damage, yellow is surface fire with no tree damage; (main figure) fireline intensity output from Prometheus (in kW/m), areas of high fire intensity correspond well with areas of high damage.

3.2 Airborne remote sensing

A remote sensing method for determining fire rate of spread, pioneered by a team from King's College, involves using aircraft-mounted thermal camera imagery to determine the rate of spread (Figure 3). The method accounts for any changes in the off-nadir viewing angle by using a series of thermal ground control points (these must be larger than the average pixel size in the aerial thermal camera image). The ground control points are used to warp each frame of the thermal imaging camera to a nadir geometry. The resulting dataset is a time series of georeferenced thermal imagery from which maps of the fire front rate of spread and measures of fire intensity (Fire Radiative Power and Fire Radiative

Energy) may be derived (Figure 4). Full details of the processing algorithm and results from a case study of an experimental heather moorland burn are presented in Paugam et al. (2013).

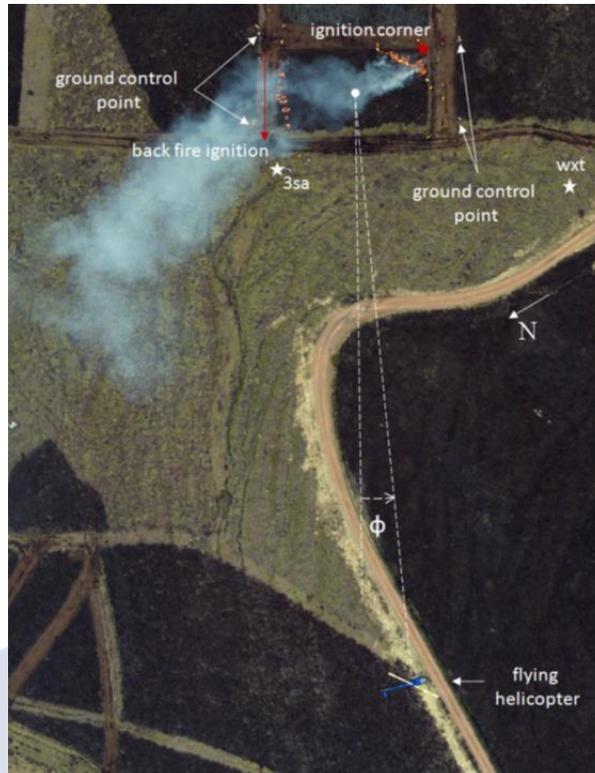


Figure 3 Aerial photograph of a helicopter with onboard handheld thermal camera system for recording imagery of the experimental heather moorland fire at the top of the image. See Figure 4 for the corresponding map of rate of spread and fire intensity (taken from Paugam et al., 2013).

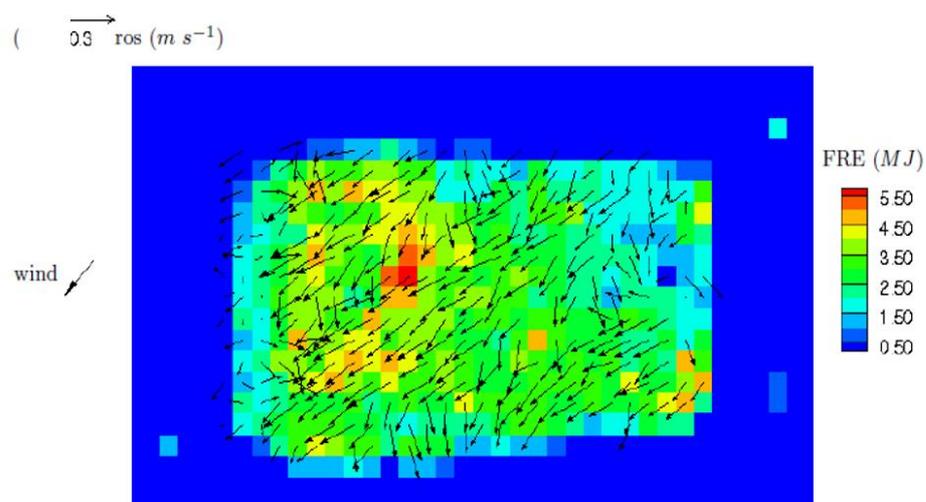


Figure 4 Vector arrows representing rate of spread, and coloured map representing Fire Radiative Energy (FRE, in megajoules). Fire intensity is a function of FRE (taken from Paugam et al., 2013).

3.3 Unmanned Aerial Vehicles (UAVs) and tethered platforms

One problem with the airborne remote sensing approach outlined above is the reliance on a manned helicopter with a pilot and additional personnel to operate the thermal camera and deploy ground control points. Measurements of rate of spread and fire intensity would need to be undertaken at dozens of experimental fires for a robust evaluation of fire spread models for new northern European fuels. As such, the airborne remote sensing approach may be prohibitively expensive. Alternative approaches include the use of Unmanned Aerial Vehicles (UAVs) or tethered platforms (helium balloons or helikites). Here we will discuss three solutions that mostly differ in the camera system deployed:

3.3.1 UAV or tethered platform with thermal camera system

This approach is similar to the airborne remote sensing approach in that ground control points would be needed for the georeferencing algorithm. This approach would also yield information on rate of spread and fire intensity, as shown in Figure 3. Small, UAV-mountable thermal cameras are expensive though, and these costs might similarly limit the scope of any fire model evaluation.

3.3.2 UAV or tethered platform with visible camera system

This is the most readily available option, with off-the-shelf UAV hardware capable of capturing useful imagery. Imagery captured from a visible camera could be used to generate a time series of georeferenced visible imagery of an experimental fire (akin to the thermal georeferencing discussed in Section 3.1.2, but without the necessity for ground control points), from which rate of spread may be determined. Proof-of-concept imagery of a heather moorland fire in Northumberland, UK, was captured by a visible camera mounted on a tethered helikite (a kite-stabilised helium balloon) as part of this project (Figures 5 and 6). One drawback of using visible imagery is that it is difficult to reliably determine any information on fire intensity.

3.3.3 UAV or tethered platform with Near-Infrared (NIR) camera system

This is similar to the visible camera system, but offers a number of advantages. NIR cameras record imagery that is less likely to be obscured by smoke (see Figure 7), and may be used to present information on the temperature of the fire, from which fire intensity parameters may be derived. Visible cameras may be converted to NIR cameras at low cost, and ready-converted cameras are readily available.

Video imagery of an experimental fire in heather moorland captured from a helikite platform is available to view at the FIREfficient website, on the *Protocol for testing fire spread models* webpage.



Figure 5 (top right) theory of helicite flight (taken from www.allsopp.com); (bottom left) helicite on the ground; (right) helicite deployed at an experimental heather fire, see Figure 6 for imagery from this deployment; (centre) example lightweight visible camera system for deployment on the helicite, live imagery can be transmitted to the ground or captured on the device.



Figure 6 (left) raw imagery from the visible camera system on the helicite (right) georeferenced warped imagery overlaid on an aerial photograph of the experimental heather fire sites. This georeferenced imagery can be used to assess rate of spread. In the example above, the fire moves 12 m in 170 seconds (4.2 m/min).



Figure 7 Example imagery captured from a near infrared (NIR) camera system on board a helikite. NIR light from the fire can penetrate smoke which is a significant advantage over visible camera systems (see imagery in Figure 6).

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