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Implementation of models and the forecast system for the National Fire Danger Rating System

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Introduction

The National Fire Danger Rating System (NFDRS) Program is building a new fire danger rating system for Australia. The first part of the system to be built (the NFDRS Research Prototype) is a Fire Behaviour Index based on calculations from operationally ready fire spread models.

A computer system was built to calculate and display ratings. Calculations were performed daily by the Bureau of Meteorology using forecast weather at hourly intervals on a 1.5 x 1.5 km grid across Australia. Each grid cell was assigned to one of the eight major fuel types and then weather forecasts were used to calculate fire behaviour metrics: rate of spread, intensity, flame height, and spotting distance. The metrics were then classified into rating categories.

Two display systems were developed. The first was a static website sorted by each State and Fire Weather Area, updated daily, showing maps and tables of daily maximum ratings and red flag warnings. The second was an interactive website that displayed hourly outputs as maps and time-series plots.

This paper presents:

- The models used to implement the fire behaviour calculations, including explanation of adaptations made to the models to fill gaps in scientific knowledge,
- The calculation system that implemented the models and performed rating calculations,
- The two websites used to display and interrogate forecasts during a live trial of the NFDRS during a live trial that ran from October 2017 to March 2018,

Other papers in this session present the design of the ratings, the spatial data used to drive the system, the results of a live trial and remote sensing data analysis, and a climatology of ratings.

Fire Behaviour Models

In Australia, over 60 years of scientific research has produced rate of spread models for major fuel types; e.g. grasslands, forests and shrublands (Cruz et al. 2015a). Over time, fire behaviour models for certain fuel types have been revised or adjusted, and new models have been developed for specific conditions or fuel types that were not explicitly described before (e.g. pine plantations). For some fuel types, multiple models have been developed (e.g. dry eucalypt forest – McArthur 1967; Cheney et al. 2012). Table 1 gives an overview of the fire behaviour models that we have selected for the Research Prototype, after consultation with fire researchers at a workshop run by the NSW Rural Fire Service (RFS) on 07/06/2017. For fuel types for which fire behaviour models have not yet been developed (e.g. rainforests, arid shrublands, wetlands, crops, or rural areas) the model was assigned which most closely represented the fuel type's structure.

Table 1 Fire behaviour models used for the Research Prototype project

Fire behaviour model	**Reference**	**Recommended fuel availability model**	**Adopted fuel availability model**
CSIRO Grassland fire spread meter	Cheney et al. (1998) Cruz et al. (2015b)	Cruz et al. (2015b) curing function	Recommended, using observed curing.
CSIRO Grassland for northern Australia	Cheney et al. (1998) Cruz et al. (2015b)	Cruz et al. (2015b) curing function	Recommended, using observed curing.
Desert spinifex model	Burrows et al. (2018)	Burrows et al. (2018)	Recommended, using modelled soil moisture.
Buttongrass moorlands model	Marsden-Smedley and Catchpole (1995)	Marsden-Smedley and Catchpole (1999)	Recommended, using observed and forecast median rainfall.
Dry Eucalypt Forest Fire Model	Cheney et al. (2012)	None	Drought factor used to modify fuel amount
Mallee heath model	Cruz et al. (2013)	None	Marsden-Smedley and Catchpole (1999)
Heathland model	Anderson et al. (2015)	None	Marsden-Smedley and Catchpole (1999)
Adjusted Pine model	Cruz (pers. comm.)	Fine Fuel Moisture Code (van Wagner 1987)	Drought factor used to modify fuel amount

Drought and fuel availability

Dead fuel moisture is an important determinant of the potential for fires to start and spread. Two approaches have been used to estimate the effect of rainfall on fire spread: increasing moisture content above the fibre saturation point or reducing the amount of fuel available to burn.

Live fuel fraction is also important for some fuel types, notably grasslands (Cruz et al. 2015b) and spinifex fuels (Burrows et al. 2018). This effect may be included either using a curing function (grass) or by including the live component in a bulk moisture content estimate (spinifex).

Unfortunately, a complete set of drought or fuel availability models has not yet been developed for the eight major fuel types used in the Research Prototype. For the grassland, woodland, spinifex and buttongrass models we used the recommended fuel availability model with observed and forecast inputs as required.

For the remaining four fuel types we adapted existing models. Some of the modifications have been made without a proper scientific foundation and we recommend that development of fuel availability models is a high research priority.

The DEFFM/Vesta model does not include fuel availability or rainfall effects in its fuel moisture models and no recommendations are made for treatment of these effects on either fuel moisture or fuel hazard scores. While a model exists which can be used for forest fuel moisture (e.g. Matthews 2006) implementation of a system of this complexity was not feasible for the Research Prototype. Instead, we developed simple fuel availability curves as functions of drought factor loosely based on fire occurrence observations presented by Cawson et al. (2017). For dry forests:

$$Fuel\_availability = (DF \; * 0.1) \tag{1}$$

Where DF is the drought factor. For wet forests a logistic function was used:

$$Fuel\_availability\_WF = \left(\frac{1.135}{1 + e^{2*(9-DF)}}\right) \tag{2}$$

For all DEFFM/Vesta fire behaviour calculations both fuel hazard scores and fuel loads were multiplied by the fuel availability factor. Fuel heights were not modified.

The Cruz et al. (2013) mallee heath and Anderson et al. (2015) shrubland models do not include fuel availability or rainfall effects in their fuel moisture models and no recommendations are made for treatment of these effects. Because these fuel types are expected to become flammable more rapidly than a forest fuel type, we used the Marsden-Smedley and Catchpole (1999) fuel moisture modifier function originally developed for buttongrass. While these fuel types are structurally dissimilar, the buttongrass fuel moisture modification function has a response time of 1-2 days, making it suitable for fuel types with a large near-surface and elevated fuel component.

While a well-tested fuel moisture model is part of the Canadian Fire Weather Index (FWI) system (van Wagner 1987) it was not possible to implement this within the constraints of the Research Prototype. Instead we used a simple function to modify dead fuel amount (M. Cruz pers. comm.):

$$Fuel\ load = 0.3 + 0.075 * DF \tag{3}$$

Foliar moisture content was also modified:

$$Fuel\ moisture\ content = 150 - 5 * DF \tag{4}$$

Implementation of the Canadian FWI moisture models would be an obvious improvement for future work.

Model implementation

Apart from the fuel availability modification described above, all models except pine were implemented as described in Cruz et al. (2015a). Cruz et al. (2015a) recommend using the Cruz et al. (2008) model for plantation fires. Due to the complexity of the model, it was not possible to implement it for the Research Prototype. Instead, we used a simplified version originally developed for use with the Spark modelling framework (Miller et al. 2015; Cruz pers. comm.).

Forecast System

The Bureau of Meteorology (BoM) produced a daily 24hr run of the Research Prototype during the period of the live trial. To automate this a process was setup on internal BoM systems that took various daily weather inputs from within the BoM, combined them with static inputs provided by the RFS and ran them through the Research Prototype calculation system (Figure 1).

To run the calculations the Research Prototype needed various sources of information describing the current and predicted state of the atmosphere in a gridded format. One part of the system design was to collect a snapshot of these sources daily from various places within the Bureau, unify them into the same projection and dimensions and fill in any blanks ready for calculation. This was automated using a Jenkins job that would run various bash and python scripts to perform the ingestion, infill and unification of the data.

The unified data was then passed through the spread model calculations for the relevant fuel type, and also produced threshold red flags based on several factors. These outputs were then processed to produce images and tables summarising the results that were bundled into the static webpage. The RFS took the gridded outputs and fed them to their interactive web-based exploration tool.

The system collected and ingested data at 02:00 AEDT daily and calculated the results per region in parallel at 05:00 AEDT. Calculation time was around 15 minutes for Queensland with the rest of the states taking less time. The bundled outputs were made available as soon as a successful run took place.

The calculation system was built in Python using Miniconda which provided a consistent base. This allowed development to occur on both Windows and Linux with the final calculation system running on a Linux platform. Jenkins was used for the automation server and gitlab.com was used for source control and continuous integration. Automated tests were setup using py.test for much of the system to ensure stable integration as changes were made. These were automated in GitLab through their continuous integration tools. This made for a more robust system as it was being developed.

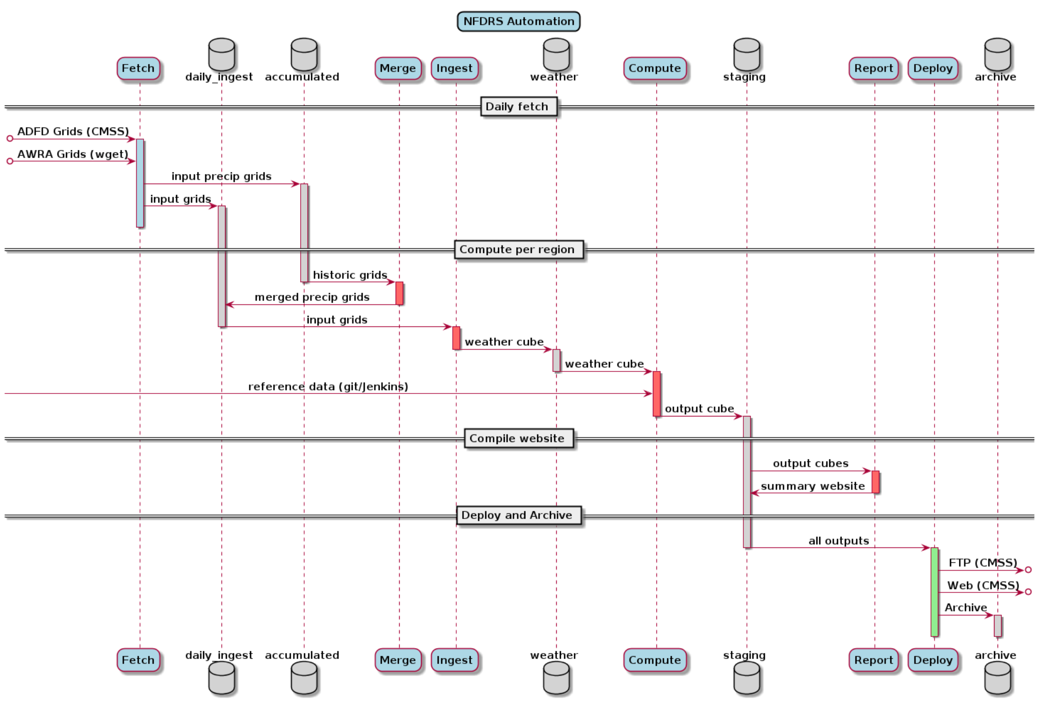
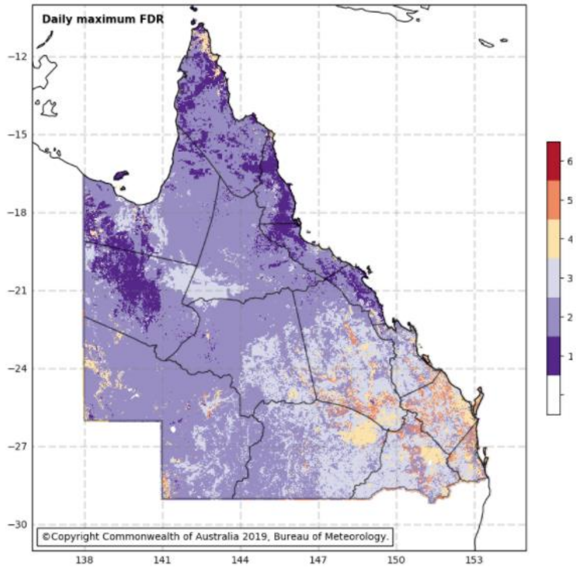


Figure 1 Research Prototype daily automation process

Websites

The BoM produced a static website summarising the daily run of the Research Prototype. This consisted of images summarising the FDR and FDI for the whole country and on a per state basis (Figure 2). Additional tables were generated summarising results for the fire areas using the same rules that summarise the current FDR. These tables included ‘red flags’ (identified as red cells) which flagged situations where CHaines, spotting distance and the wind change danger metric met predetermined thresholds. Images describing PyroCB and dry lightning were also included. This was delivered using the BoM's registered-users websites. This website was built using the Jinja2 templating engine. A standard form and layout was created, then the images and tables were added to the template to produce the final outputs.



Region	AAC	Rating	CHaines	Spotting dist (m)	WCDI
Gulf Country	QLD_FW002	Category 3	No	50	No
North Tropical Coast and Tablelands	QLD_FW004	Category 2	No	50	No
Northern Goldfields and Upper Flinders	QLD_FW003	Category 3	No	993	No
Herbert and Lower Burdekin	QLD_FW005	Category 2	No	316	No
North West	QLD_FW010	Category 3	No	50	No
Central Coast and Whitsundays	QLD_FW006	Category 3	No	450	No
Central Highlands and Coalfields	QLD_FW008	Category 4	No	3230	No
Central West	QLD_FW009	Category 3	No	3431	No
Channel Country	QLD_FW011	Category 3	Yes	2407	No
Capricornia	QLD_FW007	Category 4	No	2231	No
Wide Bay and Burnett	QLD_FW014	Category 5	No	2918	No
Maranoa and Warrego	QLD_FW012	Category 3	No	3260	No
Darling Downs and Granite Belt	QLD_FW013	Category 4	No	3237	No
Southeast Coast	QLD_FW015	Category 5	No	1968	No
Peninsula	QLD_FW001	Category 2	No	50	No

Figure 2 Example of static website NFDRS summary and table (QLD)

Hourly forecasts of fire danger rating and other components were displayed on an interactive website to support evaluation of the system by the live trial participants. The main features of the website (Figure 3) were: an interactive map display of ratings and other variables for the current and previous days at hourly intervals; the ability to view and download time series graphs for all variables at any location; and incident markers and information from agency feeds. The interactive website was implemented as an AngularJS single page application with data processed by the RFS and hosted on Amazon Web Services (Figure 4).

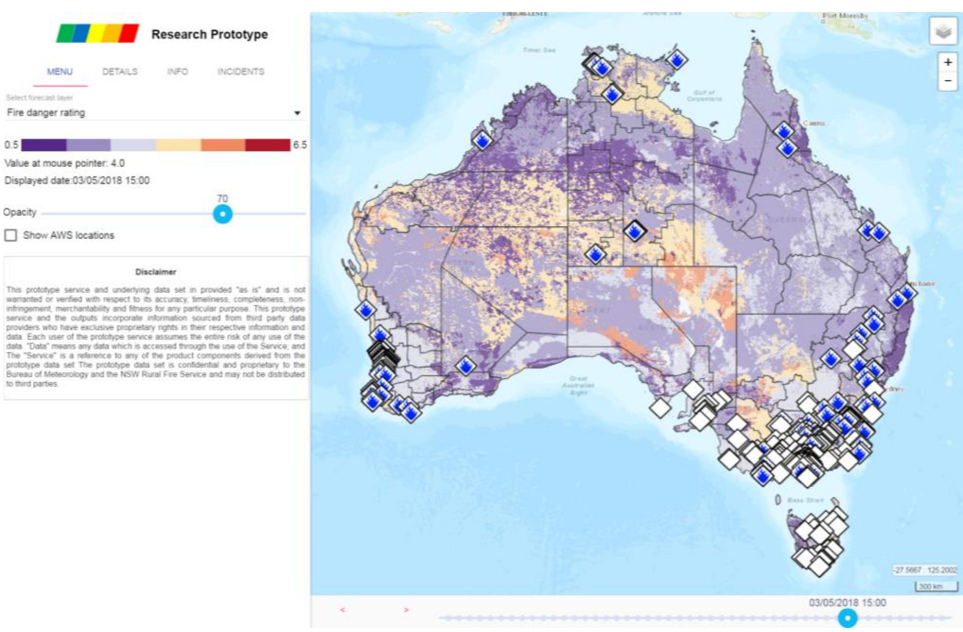


Figure 3 The interactive website showing fire danger ratings.

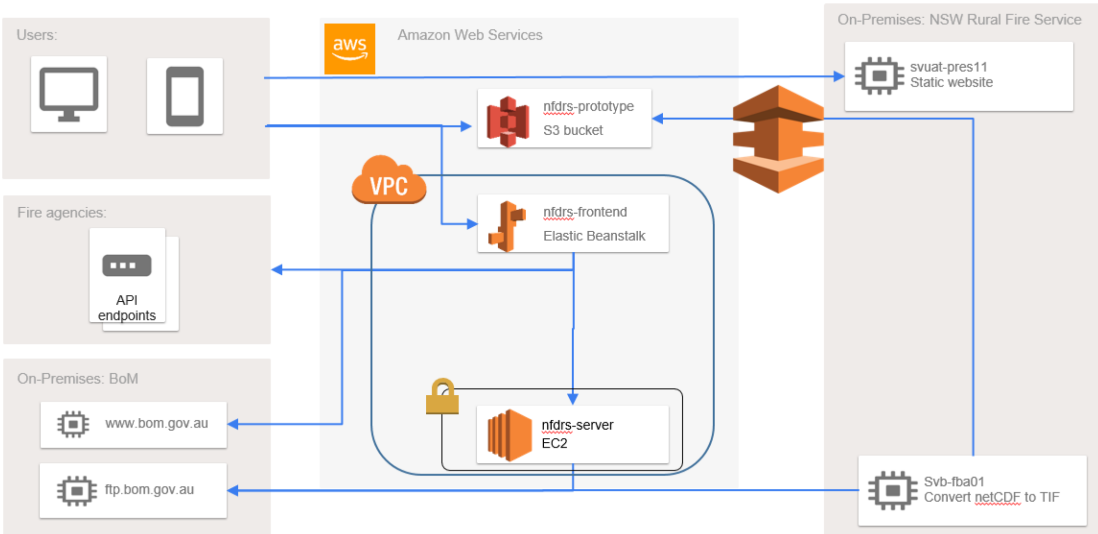


Figure 4 Data flows for the interactive website.

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