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# THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM

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# TABLE OF CONTENTS

# ABSTRACT

The Australian Flammability Monitoring System (AFMS) is the first, continental-scale prototype web explorer providing spatial information on current Live Fuel Moisture Content (FMC) and landscape-scale fuel flammability derived from satellite observations. The satellite observations are converted into FMC using a radiative transfer modelling inversion approach. Evaluation of the FMC estimates using 408 observations at 35 locations around Australia shows similar accuracies ($r^2$=0.60, RMSE=39%) across the vegetation classes studied (grassland, shrubland and forest) to those derived elsewhere globally. Flammability estimates are calculated using logistic regression models relating fire occurrence to FMC. Separate prediction models were developed for grassland, shrubland and forest, obtaining performance metrics (Area Under the Curve) of 0.70, 0.78 and 0.71, respectively (where skillful predictions range between 0.5 and1). A web-based data explorer will be available to fire and land management agencies and any other interested parties in all states and territories. The AFMS can support a range of fire management activities such as prescribed burning and pre-positioning of firefighting resources and can inform the future National Fire Danger Rating System.

# INTRODUCTION

The Fuel Moisture Content (FMC) of live bushfire fuel affects fire danger and fire behaviour, as it strongly influences the key components of flammability including ignitability, fire sustainability and combustibility (Anderson 1970). Spatially comprehensive and temporally frequent estimates of FMC should be a fundamental component of fire danger rating systems in support of a wide range of fire risk management and response activities, such as prescribed burning and pre-positioning firefighting resources. In recent years, there has been considerable development in the estimation of FMC from satellite imagery. These developments have mainly been in Mediterranean and temperate ecosystems in Europe (Al-Moustafa et al. 2012; García et al. 2008; Jurdao et al. 2013a; Yebra and Chuvieco 2009b), Western North (Casas et al. 2014; Hao and Qu 2007; Peterson et al. 2008) and south-eastern Australia (Caccamo et al. 2012; Nolan et al. 2016). Further research is needed to assess the full utility of FMC estimation across other fire-prone ecosystems (Yebra et al. 2013).

The conversion of FMC values into a Flammability Index (FI) can be an important additional step that facilitates the inclusion of FMC estimates into an integrated fire risk assessment system (Chuvieco et al. 2004). Research has produced several methods for this conversion based on (i) the concept of moisture of extinction, defined as the moisture threshold above which fire cannot be sustained (Chuvieco et al. 2004); (ii) critical FMC thresholds derived from empirical statistical relations between FMC and fire occurrence (Dennison and Moritz 2009; Nolan et al. 2016); and (iii) fitting a continuous logistic probability model between fire occurrence and FMC (Chuvieco et al. 2009; Jurdao et al. 2012). However, so far none of these methods has been evaluated across a region as climatologically and ecologically diverse as Australia.

Through the use of remotely sensed data, this paper aims to present the first national-scale, pre-operational, near-real time FMC and flammability monitoring system for Australia. The overarching objective is to contribute to the development of operational tools that can assist in better resources allocation in fire protection and response and improved awareness of fire hazards to people and property.

# METHODS

The methodology used to map FMC in Australia is based on previous experience in retrieving FMC in Europe using MODIS reflectance data, ancillary information on vegetation type and Radiative Transfer Model (RTM) Look up Table (LUT) inversion techniques (Jurdao et al. 2013b; Yebra and Chuvieco 2009a, b; Yebra et al. 2008). Three different LUTs that contain spectra simulated for different moisture contents and fuel types (LUTgrassland, LUTshrubland and LUTwoodland) are used as reference tables. These tables were generated using three different RTM. The leaf-level PROSPECT (Feret et al. 2008) and the canopy-level SAILH (Verhoef 1984) were coupled to simulate the spectra of grasslands and shrublands whereas PROSPECT was coupled to the canopy-level GeoSail (Huemmrich 2001)to simulate the spectra of woodlands/forest. For each MODIS reflectance pixel and date, the MODIS land cover map was used to select the reference LUT corresponding to the specific land cover class covering that pixel. All the simulated spectra from the selected LUT were compared to the spectrum of every MODIS pixel that passes the quality control test.

Existing field FMC data collected in grassland (Newnham et al. 2015), shrubland (Caccamo et al. 2012) and forest (Nolan et al. 2016) between 2004 to 2014 were used to validate the algorithm retrievals.

The FMC retrievals were used to map a dimensionless Flammability Index (FI) based on logistic regression models between fire occurrence derived from the MODIS burned area product (the binary dependent variable) and predictor variables derived from the satellite FMC estimates described above. Following Jurdao et al. (2012) we use a cumulative logistic distribution function (Eq. 1-2):

$$FI = \frac{1}{1+e^{-z}} \quad (1)\ ; \ z = a + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n \quad (2)$$

where FI is the Flammability Index (equaling the probability of fire occurrence in the training sample), a is the model intercept, β1,…,βn are the equation coefficients, x1, x2,…,xn are the independent variables.

The training sample was constructed as a series of data pairs, in which each data pair includes (i) FMC of a pixel before burning, and (ii) the mean FMC of a representative sample of unburned pixels that is sufficiently close to represent a similar land cover class, but did not burn. Areas not affected by fires were selected from cells surrounding the burned pixels using the semi-variogram geostatistical technique (Jurdao et al., 2012).

# RESULTS

A result of this study is a multitemporal FMC and flammability dataset at an 8-day resolution for the period 2001 to 2016 over Australia. The dataset is accessible at, http://dapds00.nci.org.au/thredds/catalog/ub8/au/catalog.html.

Overall, the FMC algorithm explained 60% of the measured FMC across all sites and vegetation types with an RMSE of 39% (n=374). The slope (0.83) and offset (-4.68) of the linear regression between measured and retrieved FMC (Fig. 1) suggest no significant bias in the estimates.

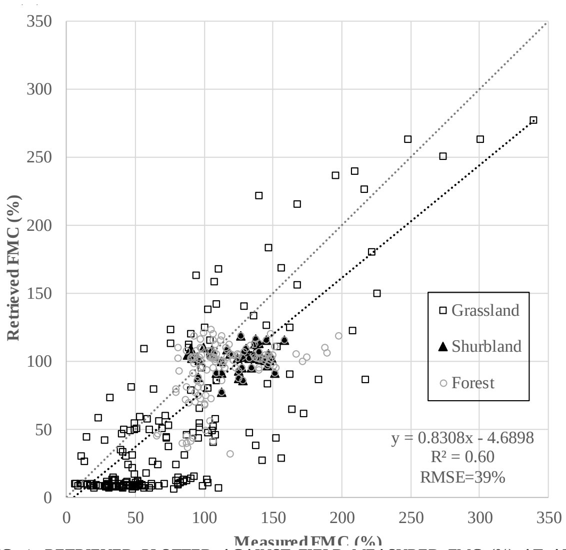


FIG. 1. RETRIEVED PLOTTED AGAINST FIELD MEASURED FMC (%) AT ALL VALIDATION SITES SYMBOLISED BY LAND COVER CLASS (GRASSLAND, SHRUBLANDS AND FOREST).

Three separate logistic regression models (Eq. 3-5) were fitted for grassland, shrubland and forest obtaining an area under the curve from the receiving operating characteristics curves of 0.70, 0.78 and 0.71, respectively.

$$FI_{grassland} = 0.18 - 0.01*FMC_{t-1} + 0.02*FMC_D - 0.02*FMC_A \quad (3)$$

$$FI_{shrubland} = 5.66 - 0.09*FMC_{t-1} + 0.005*FMC_D - 0.28*FMC_A \quad (4)$$

$$FI_{forest} = 1.51 - 0.03*FMC_{t-1} + 0.02*FMC_D - 0.02*FMC_A \quad (5)$$

where $FMC_{t-1}$ is the FMC corresponding to the 8-day period prior to the 8-day period including the fire date; $FMC_D$ is the FMC difference between the two consecutive 8-day periods prior to the 8-day period including the fire date ($FMC_{t-2}$ - $FMC_{t-1}$), representing a rate of change, and $FMC_A$ the departure of $FMC_{t-1}$ from the average FMC value for that period for the time series (2001-2016)

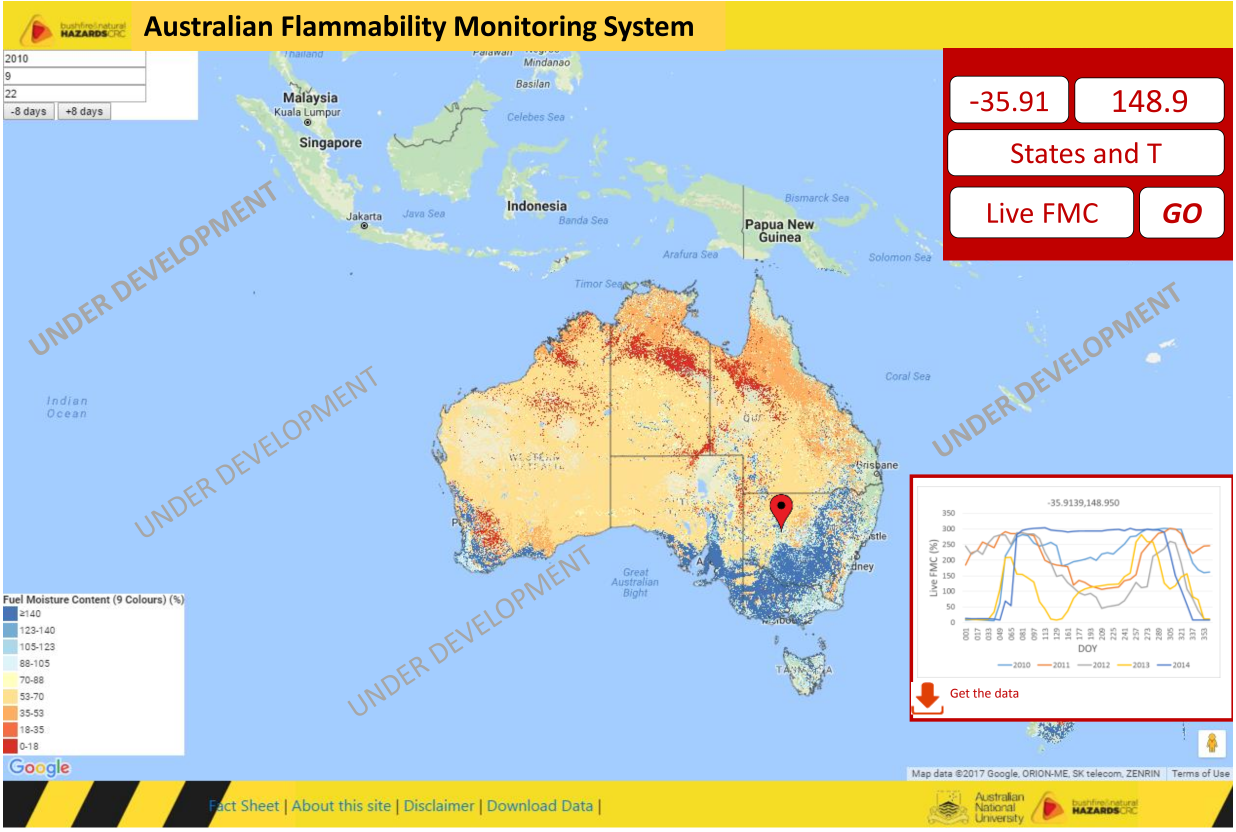


FIG. 2. A SCREEN CAPTURE OF THE AFMS WEB EXPLORER SHOWING THE CHANGE IN FMC FOR A SPECIFIC LOCATION

A prototype web explorer was built in consultation with end-users to make spatial information on FMC and FI easier and faster to access for interested users (Fig. 2). The AFMS offers advanced functions for professional users to interrogate the data and download options. It also offers the flexibility to incorporate other relevant information that might be currently available (e.g. fire weather, intensity and occurrence, soil moisture).

# DISCUSSION AND CONCLUSIONS

We presented the first Australia-wide product of FMC and associate flammability based on MODIS imagery and radiative transfer model inversion. The overall accuracy of the FMC algorithm was reasonable, although a reduction of estimation error is desirable to further improve fire risk estimation and use by practitioners. FMC was converted into a flammability index using logistic regression models. The advantage of these models is that they offer the possibility of predicting fires one week before the beginning of the event. The long-term objective is to integrate FMC with other key fuel structural properties and fire weather into fire propagation models, to derive more reliable estimates of flammability and rate of spread for local conditions.

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