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MAPPING BUSHFIRE HAZARDS AND IMPACTS

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Australian Government
**Department of Industry,
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Cover: Pierces Creek Fire ©Marta Yebra

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EXECUTIVE SUMMARY

This annual report is the output from the Bushfire and National Hazards CRC (BNHCRC), Project A1 'Mapping Bushfire Hazard and Impacts'. It summarises the project objectives, introduces the team members as well as documents the project progress and outcomes during the **financial year 2018/2019**.

During this financial year we have:

1. Worked on a comprehensive characterization of fire risk conditions through the integration of fire weather, dead Fuel Moisture Content (FMC) and total biomass into the Australian Flammability Monitoring System (AFMS);
2. Worked on AFMS website version 3 that incorporated feedback on the trial utilisation of the data service;
3. Evaluated the feasibility and benefits of the operational use of alternative satellite data in AFMS to ensure long-term data continuity;
4. Coupled a process-based model that simulates litter fuel moisture and a distributed biophysical model (the Australian Water Resources Assessment system Landscape model) to predict dead fuel moisture content;
5. Published six journal manuscripts, seventeen conference abstracts and one milestone reports with another one in preparation. We have also had eight appearances in the media;
6. Hosted two international exchange visits and were approached by more than 30 domestic and international applicants for a PhD scholarship or postdoc position in bushfire research; and
7. Submitted an application for utilisation funds from the BNHCRC to develop a high-resolution prototype version of AFMS.

Over the next year (2019-2020), this research project will focus on finishing the analysis on the fire risk index as well as using remote sensing data to derive spatial and temporal explicit fuel accumulation curves. In terms of utilization, we will liaise with Geoscience Australia (GA) on transitioning the AFMS as GA has agreed to be in charge of the long term operationalization and maintenance.



END-USER PROJECT IMPACT STATEMENT

Stuart Matthews, *NSW Rural Fire Service*

Over the past year, this project has demonstrated the value of researchers working closely with end users to bring research to utilization. The Australian Flammability Monitoring System has been useful not only in sharing research outputs with operational users but also allowed users to provide feedback during the project, leading to an improved interface to the data.

The project team have also been doing excellent work to expand the impact of their research and ensure the longevity of the work. This includes reviewing potential alternatives to the aging MODIS remote sensing platform, revising the flammability index to include dead fuel moisture effects, and coupling dead fuel moisture models with soil moisture products. These efforts are building an integrated suite of observational and modelling tools that will enable users to better understand and predict potential fire occurrence and behavior.



PRODUCT USER TESTIMONIALS

Adam Leavesley, *ACT Parks and Conservation Service*

The ACT Parks research partnership with the Mapping Bushfire Hazards and Impacts research group has yielded some exciting operational advancements in the past 12 months. These are: 1) Improved estimates of the extent of flammable land in mountainous terrain; 2) application of LiDAR-derived fuel maps to bushfire suppression; and 3) greater experience in the use of LiDAR-derived fuel maps in prescribed burning operations. In addition, the usability of the Australian Flammability Monitoring System (AFMS) has greatly advanced following additional utilization investment by the CRC during the last financial year. At a national level, fuel moisture information has been identified as a key gap in available inputs for bushfire risk assessment.

Analysis of fire severity mapping

The research group has provided expert advice to ANU to ACT Parks analysis of prescribed burning patterns from five years of data collection. The analysis yielded important information about the relative flammability of different topographic aspects during the prescribed burning season. The information was used to produce the next 10 year burn plan for the ACT, improving the reliability of the risk reduction analyses and the benefit-cost analyses conducted for the plan.

Operational experience of LiDAR-derived fuel maps for fire suppression

The 2018-2019 bushfire season was the first opportunity for ACT Parks to evaluate the use of LiDAR-derived fuel maps for fire suppression. The maps clearly indicated where fuel had been reduced by prescribed burns conducted in 2013 and this supported decision-making in the IMT. A poster demonstrating the example will be on display at BNHCRC/AFAC conference in Melbourne in August.

Use of LiDAR-derived fuel maps for prescribed burn planning.

The maps are a valuable tool for prescribed burn planning in forested mountainous terrain and the trials have shown that the data can be useful for more than five years. It is intended to acquire more LiDAR to update the maps.

Australian Flammability Monitoring System (AFMS)

The usability of the AFMS has greatly increased following investment by the CRC during the last financial year. It is becoming clear that at a national level fuel moisture is a key missing component of inputs for estimating bushfire risk. New work will ensure continuity of the system when MODIS is decommissioned. Having identified the need for this information, the bushfire sector must now develop a robust and efficient way to apply it.



INTRODUCTION

Understanding and predicting fire risk and behaviour is a priority for fire services, land managers and often individual businesses and residents. This is an enormous scientific challenge given bushfires are complex phenomena, with their behaviour and resultant severity driven by complicated interactions among living and dead vegetation, topography and weather conditions.

A good understanding of fire risk across the landscape is critical in preparing and responding to bushfire events and managing fire regimes, and remote sensing data will enhance this understanding. However, the vast array of spatial data sources available is not being used very effectively in fire management. This project uses remote sensing observations to **produce spatial information on fire hazard needed by planners, land managers and emergency services** to effectively manage fire at landscape scales. The group works closely with ACT Parks and Conservation Service and agencies beyond the Australian Capital Territory (ACT) to better understand procedures and information needs, thus allowing evaluation of these in the context of spatial data and mapping methods that are readily available, and developing the next generation of mapping technologies to help them prepare and respond to bushfires.



RESEARCH APPROACH AND KEY MILESTONES

SUMMARY OF MAIN RESULTS

Evaluation of feasibility and benefits of the operational use of alternative satellite data in AFMS to ensure long-term data continuity

The Australian Flammability Monitoring System (AFMS) is the first, continental-scale prototype web service providing spatial information on Live Fuel Moisture Content (FMC) and landscape flammability conditions derived from satellite observations (Yebara et al. 2018). The system uses data from the MODerate resolution Imaging Spectrometer (MODIS) instruments on board the Terra and Aqua satellites, providing estimates of FMC and flammability over a fortnight leading up to the day of interest and at 500 m spatial resolution. The Terra and Aqua satellites have already exceeded the expected lifetime and, at some point in the not-too-distant future, will become inoperative.

To support the AFMS continuity and redundancy strategy, we evaluated the feasibility and relative benefits of using alternative remote sensing imagery in the AFMS to provide finer spatial and temporal resolutions. The data sources evaluated include the geostationary Japanese Himawari-8 satellite (10min, 2km), the European Sentinel-2 (5 days, 20 m), the Landsat (16 days, 30m) and VIIRS (daily, 750 m) satellites (Table 1).

TABLE 1. SUMMARY OF THE SENSORS EVALUATED IN THIS STUDY. AMONG SEVERAL SPECTRAL BANDS AVAILABLE, THE ONES SELECTED HERE ARE THOSE THAT RELEVANT TO FMC RETRIEVAL ALGORITHM.

Satellite Sensor	Spatial resolution (m)	Temporal resolution	Spectral resolution		Year Launch	Designed Life (Years)
			Spectral range (µm)	Multi-spectral Bands		
MODIS	500	1-2 days	458-2155	7	2000	5
Landsat-8 OLI	30	16 days	433-1390	8	2013	6
VIIRS	750	Daily	4412-2250	10	2011	7
Himawari-8	2000	10 minutes	470-2256	6	2014	15
Sentinel-2A/2B MSI	20	5 day	442-2202	13	2017	12

We use Radiative Transfer Models to build a database of simulated spectra for the different sensors, corresponding to different FMC conditions (Figure 1). The database was then used to test the suitability of the different sensor to retrieve FMC based on their different spectral characteristics and goodness of retrieval (e.g. r^2 and RMSE between retrieved and modelled).

VIIRS obtained the highest accuracy retrieval ($r^2=0.8$, RMSE=19%, $n=6178$) followed by Sentinel-2 ($r^2=0.8$, RMSE=23%, $n=6178$), Landsat-8 ($r^2=0.8$, RMSE=24%, $n=6178$) and Himawari-8 ($r^2=0.7$, RMSE=24%, $n=6178$) (Table 2). These results were expected as VIIRS has a larger number of sensor bands (5 bands) in the Short Wave Infrared (SWIR) followed by Sentinel-2 (3 bands), Landsat and Himawari-8 (two bands each).

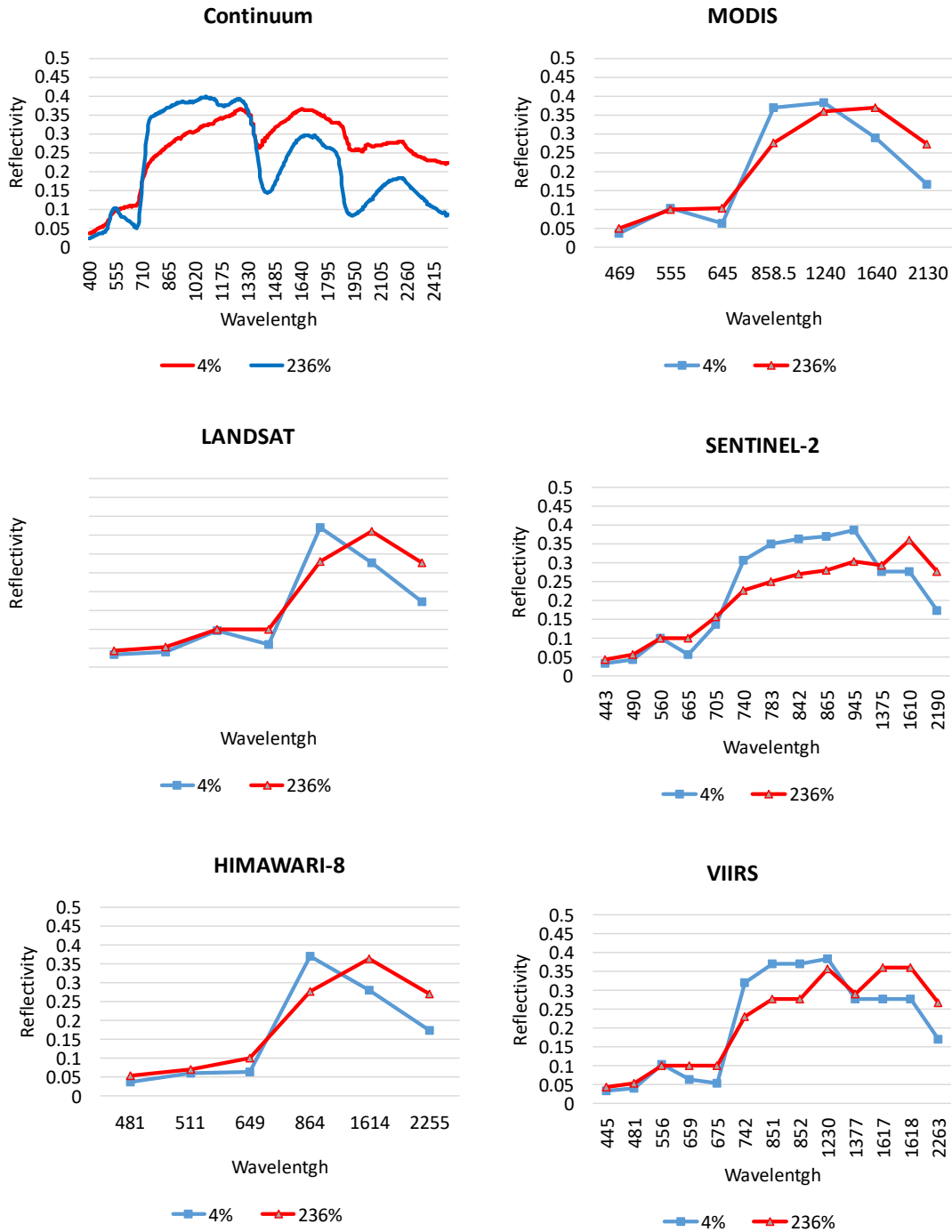


FIGURE 1. DRY (4%) AND WET (236%) VEGETATION SPECTRA FOR THE STUDIED.

Therefore, VIIRS is likely the best candidate to ensure the AFMS website data provision continuity. Sentinel-2 (3 bands) and Himawari-8 are the best second and third candidates that obtain similar accuracies while increasing the spatial (Sentinel-2, 20m) and temporal (Himawari-8, 10 minutes) resolutions of the products displayed in the AFMS.

Future work will focus on integrating estimates from these different data sources to better support a range of fire management activities such as prescribed



burning and pre-positioning of firefighting resources and inform the future National Fire Danger Rating System.

TABLE 2. QUANTITATIVE MEASURES OF MODEL INVERSION PERFORMANCE IN RETRIEVING FMC USING DIFFERENT SENSORS.

RMSE, ROOT MEAN SQUARE ERROR; RMSEs, RMSE SYSTEMATIC; RMSEu, RMSE UNSYSTEMATIC. 40 SOLUTIONS

Sensor	Slope	intercept	R ²	RMSE (%)	RMSEs	RMSEu	n
Landsat-8 OLI	1.2	-21	0.8	24	7	23	6178
Sentinel-2A/2B MSI	1.2	-22	0.8	23	7	21	6178
VIIRS	1.2	-18	0.8	19	6	18	6178
Himawari-8	1.2	-19	0.7	26	6	25	6178
MODIS	1.14	-16	0.7	24	5	24	6178

Comprehensive characterization of fire risk conditions through the integration of fire weather, dead Fuel Moisture Content and total biomass into AFMS

The AFMS provides the first Australia-wide product of flammability from satellite estimates of live FMC. The flammability index was adjusted using a continuous logistic probability model between fire occurrence and live FMC (Yebra et al. 2018). However, live FMC is only one of the variables that influence fire occurrence, and therefore the importance of other factors (e.g. fire weather, dead FMC, total fine live and dead fuel load, and ignition) should also be considered for a comprehensive characterization of flammability, where possible. Such an approach will provide a more observation-based and comprehensive assessment of flammability, where current national approaches (e.g. the McArthur-type methods) are focused on meteorological variables.

During this financial year, we have started the analysis for a comprehensive flammability index. Following Yebra et al. (2018) logistic regression models were first tested for predicting FI using relationships between dependent (categorical) variables and independent (significant) variables.

FI was described by cumulative logistic distribution (Eq. 1),

$$FI = \frac{1}{1 + e^{-(\alpha + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n)}} \quad (1)$$

Where FI was the Flammability Index; α was the model intercept; $\beta_1, \beta_2, \dots, \beta_n$ were the equation coefficients fitted using the maximum likelihood estimation; and x_1, x_2, \dots, x_n were the significant (independent) variables.

The independent variables we selected to add to satellite derived-live FMC were the maximum temperature (T_{max}) in °C and vapour pressure (VPD_{15}) at 3 pm in hPa (which indicates the atmospheric humidity) and represented at 5 kilometres spatial resolution. Similarly to Yebra et al. (2018) four explanatory variables were selected from each variable (Table 3)



TABLE 3. DEFINITION OF EXPLANATORY VARIABLE "X", WHERE X CAN BE T, TEMPERATURE; RH, RELATIVE HUMIDITY, LFMC, LIVE FUEL MOISTURE CONTENT

Acronym	Definition
X _{t-1}	Variable corresponding to the 8-day period prior to the 8-day period including the fire date
X _{t-2}	Variable values of the 8-day period prior to X _{t-1}
X _{Difference}	Variable variation between these two periods (X _{t-1} -X _{t-2}), representing a rate of change
X _{Anomaly}	Departure of X _{t-1} from the average X value for that period (\bar{X}) in the time series (2002–2014)

Following the Receiver Operating Characteristic (ROC) plot method, the Area Under the Curve (AUC) was calculated and used for assessing the logistic models (Table 4). The ROC plot is a diagnostic test that demonstrates the performance of binomial classification from its various discrimination thresholds. In the ROC space, more accurate model performance is demonstrated when the curve comes closer to the top border and left-hand border (AUC closer to 1), while a less accurate performance is demonstrated when the curve follows closer to the 45-degree diagonal.

Preliminary results show that the prediction capability of the logistic models increases when T, RH and the satellite-based FMC are used altogether (Table 4). T and RH are more related to dead FMC, whereas the satellite product provides information on live FMC. Further research is still undergoing to finalise this analysis and refine the methodology.

TABLE 4. QUANTITATIVE MEASURES OF LOGISTIC MODEL PERFORMANCE USING DIFFERENT DEPENDENT VARIABLES. T, TEMPERATURE; RH, RELATIVE HUMIDITY, LFMC, LIVE FUEL MOISTURE CONTENT; AUC, AREA UNDER THE CURVE.

Dependent variable	Fuel class	Equation	AUC
LFMC	Grassland	$0.18-0.01*LFMC_{t-1}+0.02* LFMC_{Difference} -0.02* LFMC_{Anomaly}$	0.70
	Shrubland	$5.66-0.09*LFMC_{t-1}+0.005* LFMC_{Difference} -0.28* LFMC_{Anomaly}$	0.78
T, RH	Grassland	$0.2007-0.0062*T_{max_{t-1}}$	0.51
	Shrubland	$-0.0017-0.00097*V_{ph15_{t-1}}+0.00266* V_{ph15_{t-2}}$	0.50
T, RH, FMC	Grassland	$2.94-0.06*LFMC_{t-1}+0.08*LFMC_{Difference}-1.21*LFMC_{Anomaly}+0.0057*T_{max_{t-1}}$	0.93
	Shrubland	$4.64-0.078*LFMC_{t-1}-0.021* LFMC_{Difference} -0.075*LFMC_{Anomaly}+0.0013*V_{ph15_{t-1}}+0.0021* V_{ph15_{t-2}}$	0.80

Coupling of a process-based model that simulates litter fuel moisture and a distributed biophysical model (the Australian Water Resources Assessment system Landscape model) to predict dead fuel moisture content

Dead FMC is critical for fire ignition and is an input to, or implicit in, most fire danger and fire behaviour predictions. Several models have been developed for forecasting dead FMC. However, none of these litter moisture models explicitly considers the role of soil moisture dynamics in determining FMC.

This research aims to determine how soil moisture content affects dead FMC forecast by coupling litter and soil moisture dynamics (Zhao *et al.* 2018). A physical-based Koba model (Matthews, 2006), which simulates physical processes for litter fuel moisture prediction, is being coupled with a grid-distributed biophysical model, the Australian Water Resources Assessment system Landscape model (AWRA-L) (Van Dijk, 2010; Frost *et al.*, 2016), used by the Bureau of Meteorology (BoM) to estimate soil moisture, among others. Figure 1 shows the coupling model.

Preliminary results from a study case (Figure 3, Table 5 and Figure 4) show that:

- Dead FMC modelling is affected by soil moisture, especially with relatively high soil moisture content when there is flux from the soil to the litter;
- Dead FMC estimation can be improved by coupling soil moisture; and
- The coupling method we used does not improve model predictions much, which might be explained by the coarse weather input data.

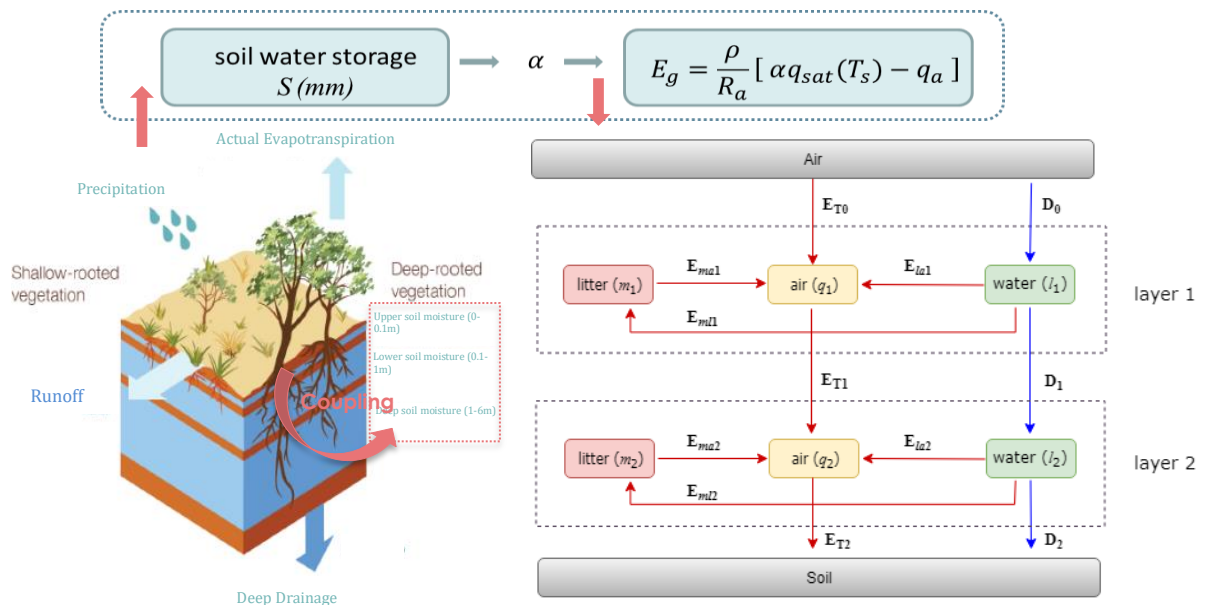


FIGURE 2. THE COUPLING MODEL. LEFT FIGURE SHOWS THE CONCEPTUAL AWRA-L GRID CELL WITH KEY WATER STORES AND FLUXES. RIGHT FIGURE SHOWS STRUCTURE OF WATER BALANCE IN THE Koba MODEL: EACH LAYER INCLUDES LITTER, WATER AND AIR AND THE WATER CONTENT OF THEM ARE m , l and q RESPECTIVELY. RED ARROWS REPRESENT VAPOR FLUX BETWEEN MATERIALS (VAPOR FLUX BETWEEN LITTER AND AIR E_{m} , VAPOR FLUX BETWEEN WATER AND AIR E_{l} , AND TURBULENT VAPOR FLUX E_T) AND BLUE ARROWS REPRESENT LIQUID WATER DRAINAGE (D).



This comparison with field FMC was a preliminary test and only considered the coupling of vapour fluxes. Future research will improve the coupling method by considering the capillary flow.

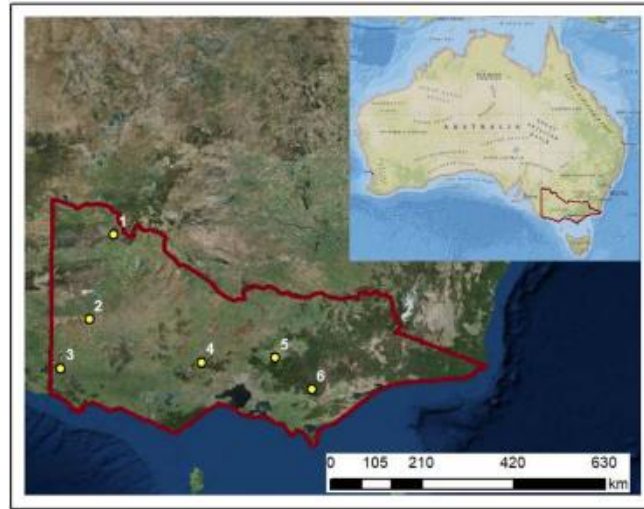


FIGURE 3. LOCATION OF AUTOMATED FUEL STICKS

TABLE 5. PEARSON CORRELATION BETWEEN MODELING AND OBSERVATIONS AT ALL SITES FOR ALL FMC OBSERVATIONS.

Sites	Surface litter layer		Bottom litter layer	
	No Coupling	With Coupling	No Coupling	With Coupling
1	0.68	0.74	0.75	0.80
2	0.73	0.78	0.69	0.70
3	0.7	0.74	0.73	0.77
4	0.68	0.75	0.74	0.76
5	0.70	0.75	0.67	0.74
6	0.44	0.44	-0.16	0.06

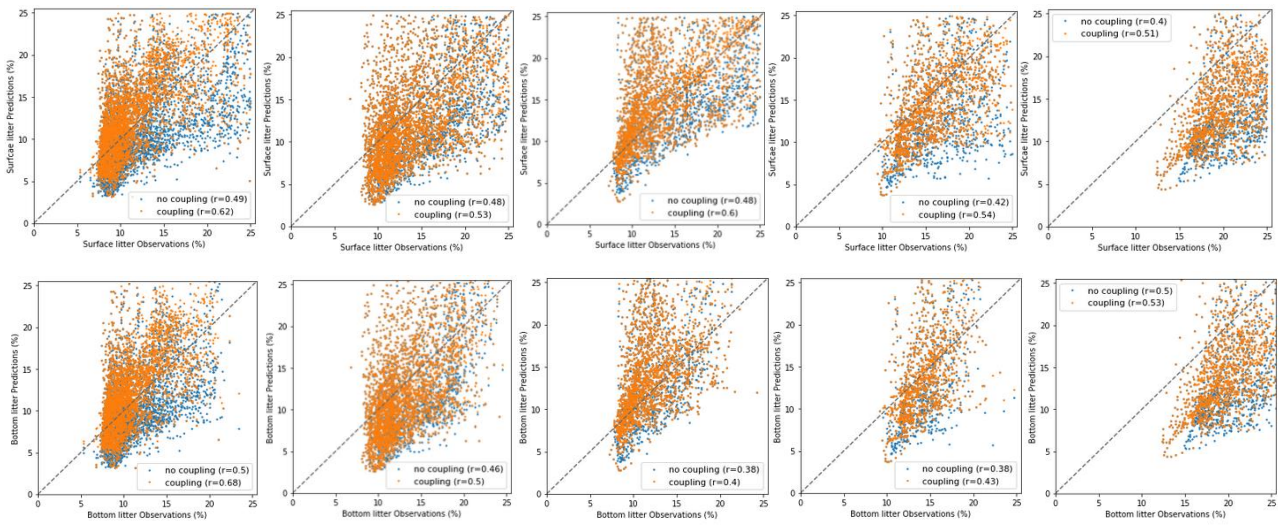


FIG 4. PEARSON CORRELATION BETWEEN OBSERVATIONS AND MODEL PREDICTIONS FOR FUEL MOISTURE CONTENT VALUES <25%



Major Field Research Highlights

The research team helped ACT Parks to assess the severity of Pierces Creek fire via a visual assessment and aerial photograph interpretation (Nov, 2018). We expect to use the fire severity observations collected over this fire as a case study to evaluate the NSW-RFS new fire severity method and compared its performance to other recently developed algorithms (Massetti et al., 2019, Yin et al., 2018 and Collins et al., 2018). The results will guide ACT Parks on their decision on which method to implement on the ACT.



FIG 5. ASSESSING THE SEVERITY OF PIERCES CREEK FIRE FROM A HELICOPTER.



UTILISATION AND IMPACT

SUMMARY

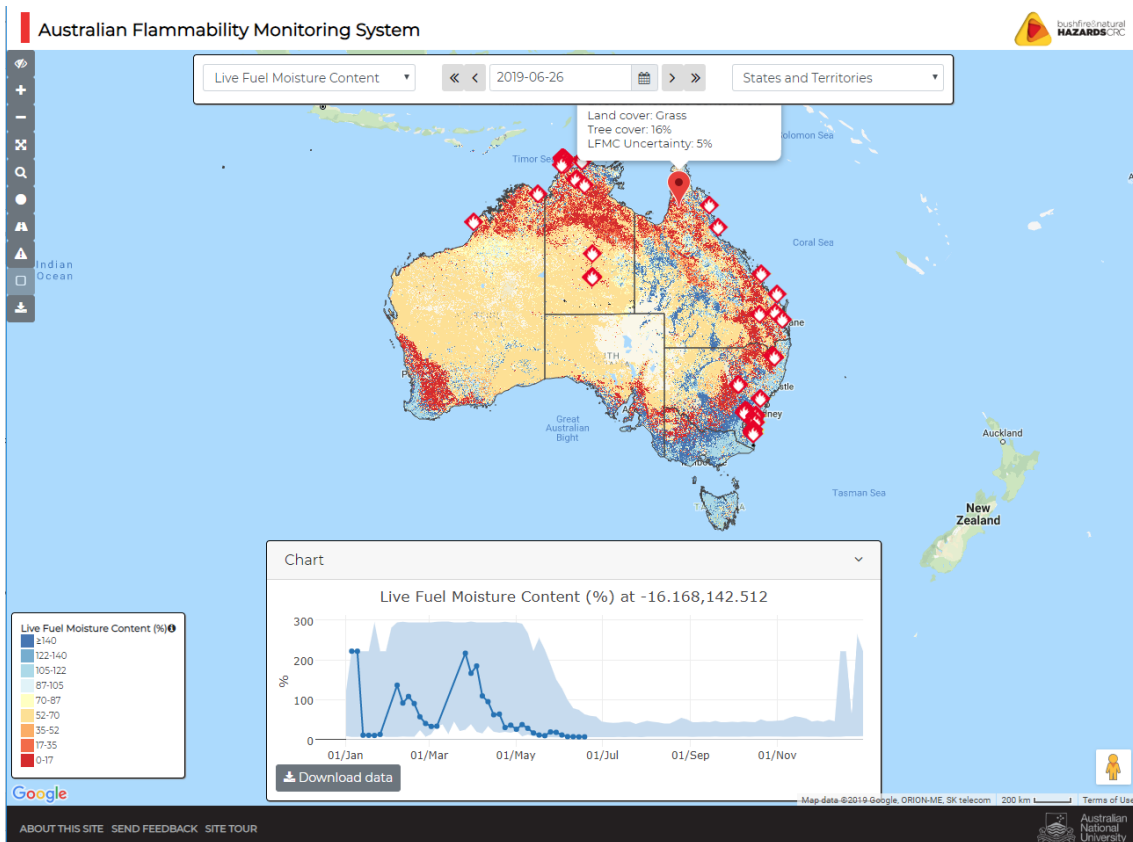
We have further developed the AFMS website on response to the feedback provided by end user and version 3 will be released at the AFC 2019 conference.

THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM

Output Description

The project team has been working on the AFMS website version 3.0 a web-based spatial data explorer (Figure 5) that provides easier and faster access to spatial information on:

- Live FMC, in kg water per kg dry matter, expressed as a percentage;
- Uncertainty in the FMC values, in the same units;
- A Flammability Index (FI), providing a relative measure of fuel flammability between 0 and 1;
- Soil moisture content near the surface (0-10 cm), in m³ water per m³ of soil volume);
- Soil moisture content in the shallow soil (10-35 cm), in the same units.



• FIGURE 5. SCREEN CAPTURE OF THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM VERSION 3.



The AFMS allows users to visualise and interpret information on the above information as maps or graphs for any part of Australia. Data can be compared to preceding years or downloaded for further analysis.

The FMC and Flammability are derived from MODIS observations available at a resolution of 500 m and a 4-day time step (Yebra *et al.* 2018). Flammability is an index that is calculated using empirical relationships between historical FMC and the occurrence and spread of bushfires. At each time step, the values are derived from observations during the previous eight days (Yebra *et al.* 2018).

The soil moisture data are produced by the Bureau of Meteorology's JASMIN modelling system (Dharssi and Vinodkumar, 2017), also developed as part of the BNHCRC research program. They are available at 5 km resolution and daily time step.

Data layers showing the outlines of Fire Weather Areas, Local Government Areas, States and Territories, National Parks, and Natural Resources Management regions can be selected to combine with the map and assist in spatial orientation. The map can also be made semitransparent to discern underlying a road map or satellite imagery.

Based on end-user feedback after the trial use, the new website launch will allow users to:

- (1) Display information as decile maps to identify areas of low or high values, relative to normal conditions at a location and time of year;
- (2) Make direct data downloads for a region of interest as GeoTIFF for further post-processing in GIS by the end user;
- (3) Visualise current fire incident via automatic, live feeds;
- (4) Obtain information on the forest cover for each pixel.

Extent of Use

The AFMS is available to anyone, including fire and land managers and other industries such as insurance and agricultural sectors and electricity and water suppliers. Individual community members such as farmers could also use the AFMS to assess how dry their property is when preparing for fire season.



Utilisation Potential

The AFMS is a new capability that was created to support fire risk management and fire operation response activities such as hazard reduction burning and pre-positioning firefighting resources and, in the longer term, the new National Fire Danger Rating System (Figure. 6). Research has shown that the live FMC information generated by the AFMS is a strong predictor of fire behaviour and spread.

There are, however, some significant barriers to adoption by the Australian bushfire sector. The first of these is that LFMC is not presently used in any operational fire prediction models or systems. This means that the sector needs to familiarise itself with the information and develop suitable ways to use LFMC; it is not something that can simply be slotted into existing systems. However, the AFMS can give useful information for all fire management stages (Figure 6).

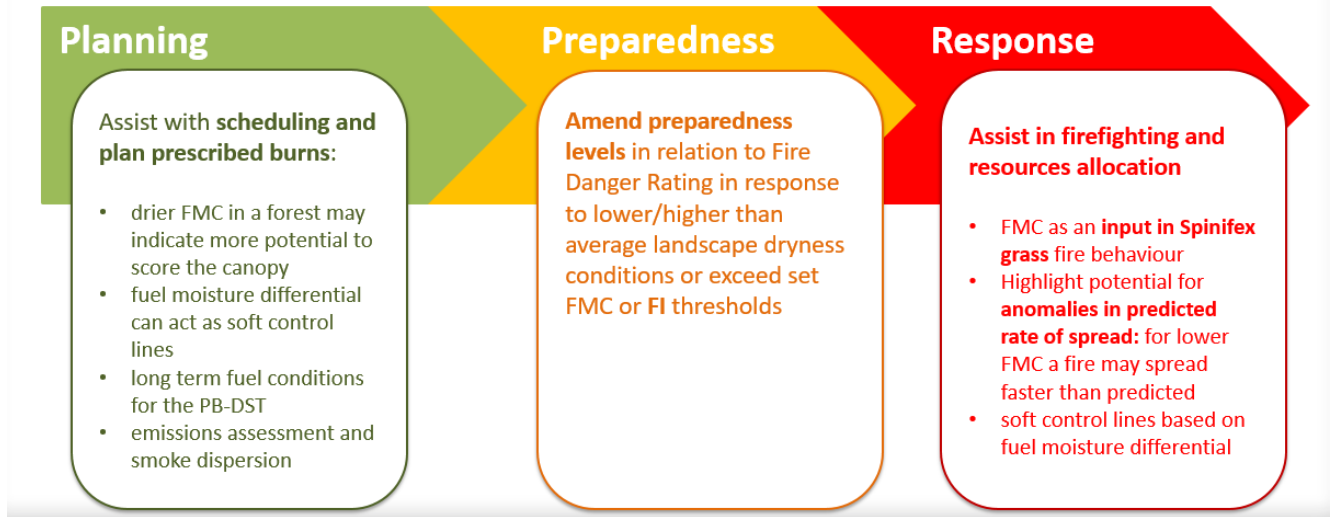


FIGURE 6. CURRENT AND POTENTIAL USES OF THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM IN FIRE MANAGEMENT.



Utilisation Impact

The resulting implementation of the AFMS into daily fire management operations will take fire management in Australia into a new dimension and result in improved fire management decisions. Annually, across Australia, fire is estimated to cause approximately 7.5 fatalities and over 3,000 injuries and significant resources are allocated to mitigate the risk. The estimated annual total cost of fire in Australia is estimated to be \$650 million (NFDRS, 2015). The improvement in fire management decisions (e.g. better allocation of scarce resources in fire management) will result in a decrease of economic, social and environmental impacts across spatial and temporal dimensions.

Utilisation and Impact Evidence

Operational use of AFMS in Australia is growing. The average use of the AFMS is 90 unique visitors per month, with visitors from all 8 Australian capitals in the last 2 months. The AFMS is now increasingly referred to during presentation at high-level bushfire conferences. For example, it was mentioned in three different talks by government fire organizations at the recent 6th International Fire Behaviour & Fuels Conference in Sydney (29 April-3rd May). We have also had several appearances in the media that further evidence our research impact. Some examples include

- 20-Sept. The UN Space-based information for Disaster Management and Emergency Response knowledge portal featured the AFMS.
- 8 Oct. The Asia Pacific Fire magazine featured the AFMS.
- 2 Nov. The Canberra Times used the AFMS to support a statement on the dryness conditions of the landscape by the Emergency Services Commissioner Dominic Lane at the Canberra Times Pierces Creek bushfire live updates.
- 5 Nov. Marta talked about the AFM on ABC radio Canberra, Breakfast with Dan Bouchier.
- AFAC news featured on how our research partners at ACT Parks manage fire risk.



NEXT STEPS

UTILIZATION

After the last Research Utilization Forum in Sydney, NSW, there was a consensus between end users on the need of a higher spatial resolution version of the AFMS to allow the identification of local Life Fuel Moisture Content (LFMC) gradients in the landscape that are currently not identifiable using the 500 m pixel resolution of the MODIS product currently underpinning the AFMS.

Therefore, we applied for BNHCRC utilization funds to support a pilot version of a high-resolution AFMS using high spatial resolution (<30m) satellite imagery included in the Geoscience Australia Digital Earth Australia (DEA). DEA incorporates an integrated approach to image data correction that incorporates normalising models to account for atmospheric effects and topographic shading. As a result, it provides surface reflectance products that are analysis-ready and could be used to directly implement the algorithms used in the AFMS to derive LFMC. There are several spectral satellites currently in DEA from three Landsat satellites (Landsat 5, 7 and 8) 30 m, every 16-days since 1979 and from Sentinel-2A (since 23 June 2015) and Sentinel-2B (since 7 March 2017) at 20 m every 5 days (combining both S-2A and S-2B). We will assess the readiness of those imageries to be used in the AFMS (in terms of the quality of the products, e.g. cloud masks) and apply the algorithms to the most suitable source of information.

We asked for utilization funds from the BNHCRC to run the pilot prototype of high-resolution AFMS in two study areas

1. The Australian Capital Territory (to be evaluated by ACT Parks and Conservation Services);
2. Sydney Basin (to be evaluated by NSW Rural Fire Service).

This pilot project would not only result in a higher spatial resolution version of the AFMS with higher potential to be used for detail planning of prescribe burning and wildfire firefighting resources allocations but also will facilitate the utilization and sustainability of the AFMS in the longer term given that we will use imagery in GA-DEA and the ultimate intent is probably that the experimental service we provide gets transitioned to GA.

RESEARCH

We plan to finalise the analysis towards a comprehensive characterization of fire risk conditions through the integration of fire weather, dead Fuel Moisture Content and total biomass into AFMS (see section on “summary of main results”)

Remote sensing data will be used to derive spatial and temporal explicit fuel accumulation curves across defence lands following Massetti et al (2019) methodology.



PUBLICATIONS LIST

PEER-REVIEWED JOURNAL ARTICLES

1. Wang, L.; Quan, X.; He, B.; Yebra, M.; Xing, M.; Liu, X. Assessment of the Dual Polarimetric Sentinel-1A Data for Forest Fuel Moisture Content Estimation. *Remote Sens.* 2019, 11(13), 1568; <https://doi.org/10.3390/rs11131568>. <https://www.mdpi.com/2072-4292/11/13/1568>
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TECHNICAL REPORTS

1. Evaluation of feasibility and benefits of the operational use of alternative satellite data in AFMS to ensure long-term data continuity. 2018. BNHCRC

MEDIA

1. Dr Marta Yebra: Balancing a Thriving Career and a Rich Personal Life". IEEE Geoscience and Remote Sensing Magazine. June 2019, Volume 7, Number. The article, highlights BNHCRC ongoing research



<https://ieeexplore.ieee.org/abstract/document/8738013/>

2. Featured on the ANU webpage for the International Day of Women and Girls in Science. 11-02-2019.
3. Australian Science Media Centre, EXPERT REACTION: 10 years on from Black Saturday - what have we learnt? 05-02-2019
4. ABC radio Canberra, Breakfast with Dan Bourchier. 05-11-2018
5. Featured at UN Space-based information for Disaster Management and Emergency Response knowledge portal. 20-09-2018
6. Featured at the Asia Pacific Fire magazine featured the AFMS. 08-10-2018
7. Canberra Times Pierces Creek bushfire live updates. 02-11-2018
8. Media video " Predict, Respond, Recover: science and natural disasters ", Aus. Academy of Science



TEAM MEMBERS

The official project team is composed of three principal researchers and one PhD student.

MARTA YEBRA



Senior Scientist at the ANU Fenner School of Environment & Society and Project Leader. Marta's research combines field measurements with on-ground sensor networks, airborne and satellite observations and high-performance computing technology and modelling to monitor, quantify and forecast vegetation and landscape processes, with applications in natural resources management, natural hazards, and ecosystem function at local, regional and global scale.

ALBERT VAN DIJK



Professor in Water Science and Management at the ANU Fenner School of Environment & Society. Albert has expertise in retrieving vegetation structure and density information from optical and passive microwave remote sensing, and in the application of remote sensing observations and biophysical models into downstream operational environmental monitoring and forecasting methods.

GEOFF CARY



Associate Professor in Bushfire Science at the ANU Fenner School of Environment & Society. Geoff's research interests include evaluating fire management and climate change impacts on fire regimes using landscape-scale simulation and statistical modelling, ecological investigation of interactions between fire and biota from genes to communities, empirical analysis of house loss in wildland fire, and laboratory experimentation of fire behaviour.

LI ZHAO



PhD candidate at the ANU Fenner School of Environment & Society. Li is under the supervision of Marta Yebra, Albert van Dijk and Geoff Cary. She is working on the forecasting of dead FMC.



LIST OF OFFICIAL PROJECT END USERS

1. Simon Heemstra, NSW Rural Fire Service (lead-end-user)
3. Adam Leavesley and Neil Cooper, ACT Parks and Conservation
4. Frederick Ford, Department of Defence
5. Stuart Matthews, NSW Rural Fire Service
6. John Bally, Bureau of Meteorology
7. Andrew Sturgess, QLD Fire and Emergency
9. Simeon Telfer, Department of Environment, Water and Natural Resources, SA
10. Belinda Kenny, NSW Rural Fire Service
11. David Taylor, Tasmania Parks and Wildlife Service
13. Frank Crisci and Ali Walsh, SA Power Networks
14. Yuan Fang and Norman Mueller, Geoscience Australia
15. Felipe Aires, NSW National Parks and Wildfire Service.

OTHER CONTRIBUTING STUDENTS AND COLLABORATORS

1. **Mr Sami Shah**, a new PhD student at ANU under the supervision of Marta Yebra, Albert van Dijk and Geoff Cary. Sami commenced his studies in February 2018. He will be working on an integrated fire risk index for Australia and will apply for an associate student status with the BNHCRC.
2. **Mr Andrea Massetti**, a PhD candidate from Monash University, UNSW and BNHCRC Associated Student, is integrating our satellite products, and coarser-scale remotely sensed soil moisture into CSIRO's Spark framework.
3. **Dr Xingwen Quan**, a lecturer at the University of Electronic Science and Technology of China. He is supporting the validation of the Australian Flammability System on a global scale.
7. **Dr Samsung Lim** (UNSW), an expert on full-waveform LiDAR, is providing expert advice on the full-waveform LiDAR processing. .
9. **Dr Philip Frost** (Council of Scientific and Industrial Research, South Africa) has collected field live fuel content measurements to validate our satellite product over South Africa. Other international researchers have contacted us and joined the initiative, this include **Dr Florent Mouillot** (UMR CEFE CNRS, University of Montpellier), **Dr Carlos Di Bella** (Instituto de Agua y Clima, Argentina), **Dr Mariano Garcia** (Center of landscape and climate research, University of Leicester, UK), **Prof Emilio Chuvieco** (University of Alcalá, Spain) and **Prof Susan Ustin** (UC-Davis).



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