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MAPPING BUSHFIRE HAZARDS AND IMPACTS

Annual project report 2017-2018

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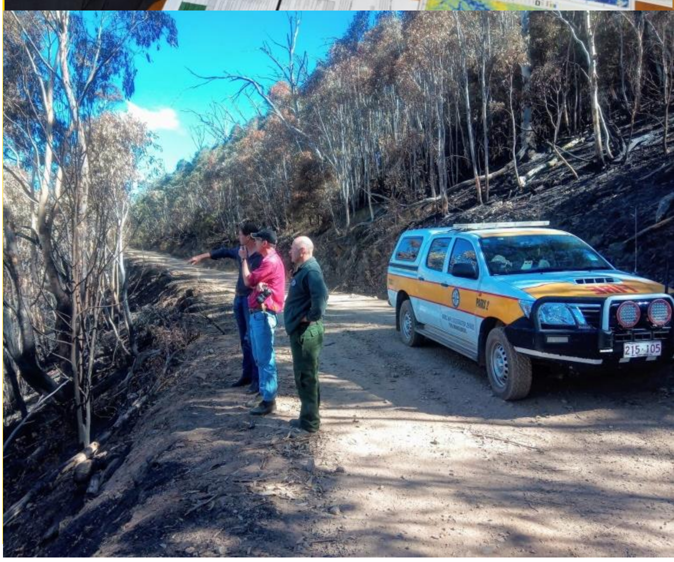


Version	Release history	Date
1.0	Initial release of document	7/11/2018

Australian Government
Department of Industry, Innovation and Science

Business
Cooperative Research Centres Programme

Publisher:
Bushfire and Natural Hazards CRC

November 2018

Cover: Collaborative work between the research team and ACT Parks and Conservation Service to enhance the usability of the Australian Flammability Monitoring System and other LiDAR derived spatial maps of fuel loads to conduct their prescribed burning program. ©Geoff Cary and ©Marta Yebra.

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ACKNOWLEDGEMENTS

This report was made possible through funding from the Bushfire and Natural Hazards CRC and the project 'Mapping bushfire hazard and impacts'.

We thank end users across different jurisdictions, students, web developers and collaborators as well as AFAC Predictive Services Systems Working Group for their support and contributions.

EXECUTIVE SUMMARY

This annual report is output from the Bushfire and National Hazards CRC, 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 2017/2018**.

We were granted support from utilisation funds from the BNHCRC to develop the "Australian Flammability Monitoring System" (AFMS), and we released the website version 1.0 in March 2018 as an experimental information service undergoing active research. In consultation with the end users, we have identified a subset of key uses of the Australia Flammability Monitoring System (AFMS) as well as a set of priorities for future development that may potentially be addressed by the BNHCRC and the project team in future via further utilisation funds.

Additionally, we have:

1. incorporated estimates of soil moisture data into the AFMS. These estimates 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 c. 5 km resolution and daily time step;
2. submitted an application for utilisation funds from the BNHCRC to further develop the AFMS website and address the agreed priorities for further development of the AFMS website base on collected feedback;
3. analysed the changes in flammability and FMC across fire weather districts containing several Defence Training Areas;
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 two journal manuscripts with another four currently in review and one invited book chapter in preparation, eleven conference abstracts and two milestone reports; and
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.

Over the next two years (2018-2020), this research project will focus on increasing the understanding, reliability and long-term continuity of the AFMS, and through this, its acceptance and adoption in fire management. Also, a small number of promising, low-cost in-field techniques will continue to be investigated to improve their cost/benefit ratio and utility.

END-USER STATEMENT

Adam Leavesley, *ACT Parks and Conservation Service*

This project has grown into a globally-significant hub of bushfire-related remote-sensing expertise. The international linkages with top research groups in Europe, North America, China, South Africa and Argentina are impressive. Also, the group has demonstrated a steadfast commitment to engagement with end-users in the Australian bushfire industry, and this is reflected in an excellent understanding of current industry practice and the role which the research may ultimately play. The pilot product, the Australian Flammability Monitoring System is now accessible to practitioners and the strategy for utilisation appears sound. The provision of accurate, spatially explicit, near real-time estimates of FMC and flammability at a range of spatial resolutions would permit more accurate targeting of scarce bushfire fighting resources in time and space, improve burning programs and feed into the National Bushfire Danger Rating System. There remain some important challenges ahead in developing a work-ready product. Specifically in assisting the industry to interpret the outputs of the system accurately.

PRODUCT USER TESTIMONIALS

Adam Leavesley, *ACT Parks and Conservation Service*

'The Australian Flammability Monitoring System has enormous potential to improve the efficiency of bushfire operations across Australia and drive expansion of our capability. The provision of accurate, spatially explicit, near real-time estimates of FMC and flammability at a range of spatial resolutions would permit more accurate targeting of scarce bushfire fighting resources in time and space. It would no longer be necessary to estimate jurisdiction-wide readiness based on anecdotal extrapolation of conditions at a few locations'.

INTRODUCTION

Understanding and predicting fire behaviour is a priority for fire services, land managers and sometimes 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 and impacts 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 ACT to better understand their procedures and information needs, comparing these with the 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

A fuel moisture content and flammability monitoring methodology for continental Australia based on optical remote sensing (Milestone 1.1.2)

Live Fuel Moisture Content (FMC) is one of the primary drivers affecting fuel flammability that influences fire occurrence and behaviour. In newly published work,we used satellite observations to estimate FMC and flammability for the first time at a continental-scale (Yebra *et al.* 2018a). The methodology includes a physically-based retrieval model to estimate FMC from MODIS (Moderate Resolution Imaging Spectrometer) reflectance data using radiative transfer model inversion. The algorithm was evaluated using 360 observations at 32 locations around Australia with mean accuracy for the studied land cover classes (grassland, shrubland, and forest) close to those obtained elsewhere (r^2=0.58, RMSE=40%) but without site-specific calibration.

Logistic regression models were developed to generate a flammability index, trained on fire events mapped in the MODIS burned area product and four predictor variables calculated from the FMC estimates. The selected predictor variables were actual FMC corresponding to the 8-day and 16-day period before burning; the same but expressed as an anomaly from the long-term mean for that date; and the FMC change between the two successive 8-day periods before burning. Separate logistic regression models were developed for grassland, shrubland and forest. The models obtained an "Area Under the Curve" calculated from the Receiver Operating Characteristic plot method of 0.70, 0.78 and 0.71, respectively, indicating reasonable skill in fire risk prediction.

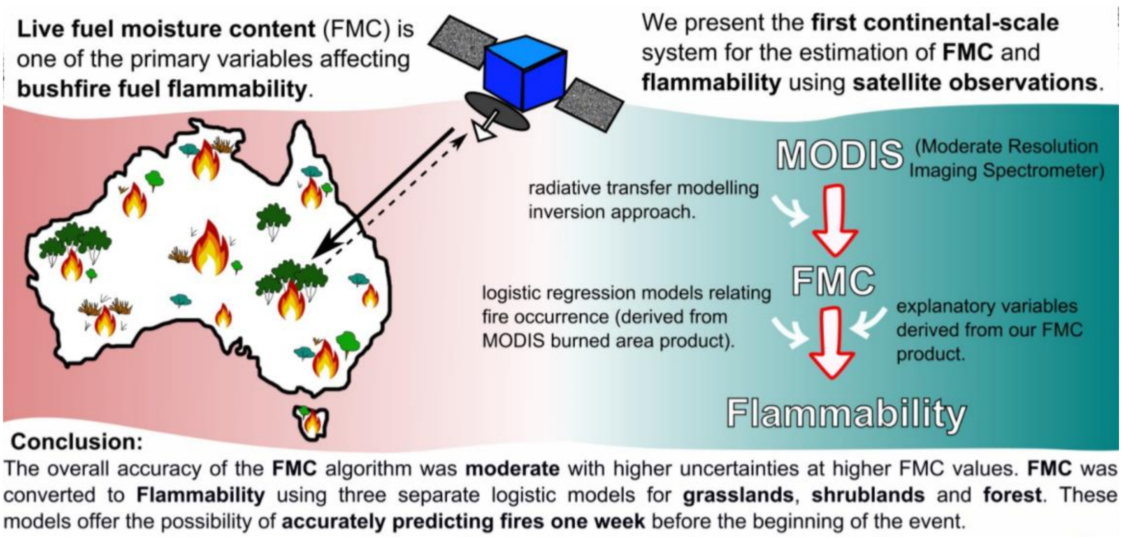


FIGURE 1. GRAPHICAL ABSTRACT ILLUSTRATING THE METHODOLOGY TO DERIVE FUEL MOISTURE CONTENT AND FLAMMABILITY FOR AUSTRALIA FROM YEBRA *ET AL.* 2018.

Case study: Changes in FMC and flammability across Defence lands (Milestone 1.2.2)

The Department of Defence receives information on fire danger from the Bureau of Meteorology for relevant fire weather districts. However, it is known that there is high spatial variability in fuel condition within the districts. For example, early in the fire danger period, the Kapooka Training Area may show low flammability throughout, even if the surrounding Riverina fire ban district is categorised as subject to high fire danger on any particular day. Over a month or so the relative flammability across the district tends to equalise out as curing spreads eastwards through spring/summer (Frederick Ford, Dept. Defence, personal communication). The Australian Flammability Monitoring System (see Utilisation Outcomes) can provide more detailed information within the district on FMC and flammability.

The objective of this project milestone was to analyse the changes in flammability and FMC across four fire ban district which contains four defence training areas.

More specific objectives were:

1. To detect the times of year when flammability in the training area is typically more different (higher or lower) than the fire danger reported for the entire Riverina fire ban district.
2. To detect the times of year when the variability of flammability conditions over the training area is larger and therefore more caution should be taken when using the information on FDR for the fire district.

To achieve those objectives we compared FMC and FI values for the Fire Ban District containing four different Defence Training Areas (Figure 2). As an example, the Greater Hunter district generally has higher FMC and lower flammability (FI) than the Singleton defence training area within it. The district tends to have higher spatial variability in the values than the defence land (Figure 3) (Yebra *et al.* 2018b)

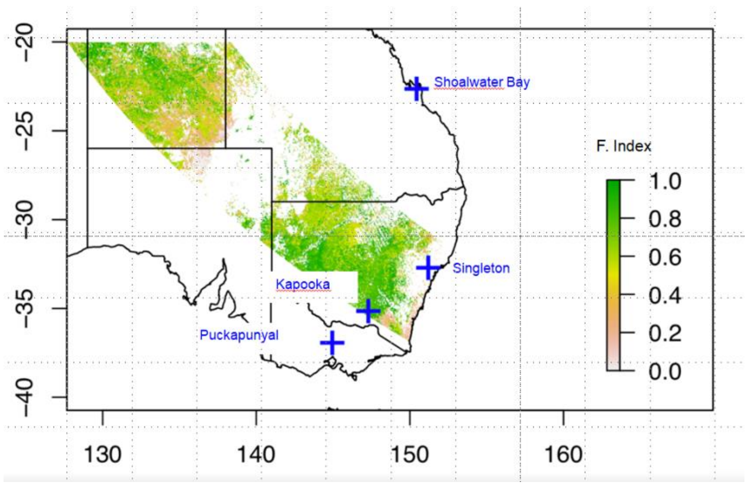
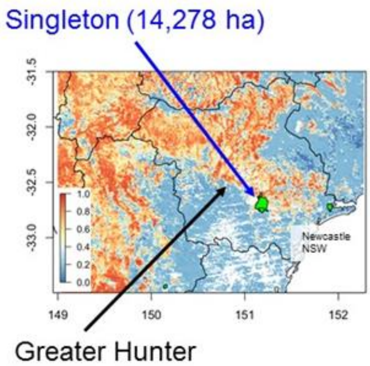


FIGURE 2. CASE STUDIES



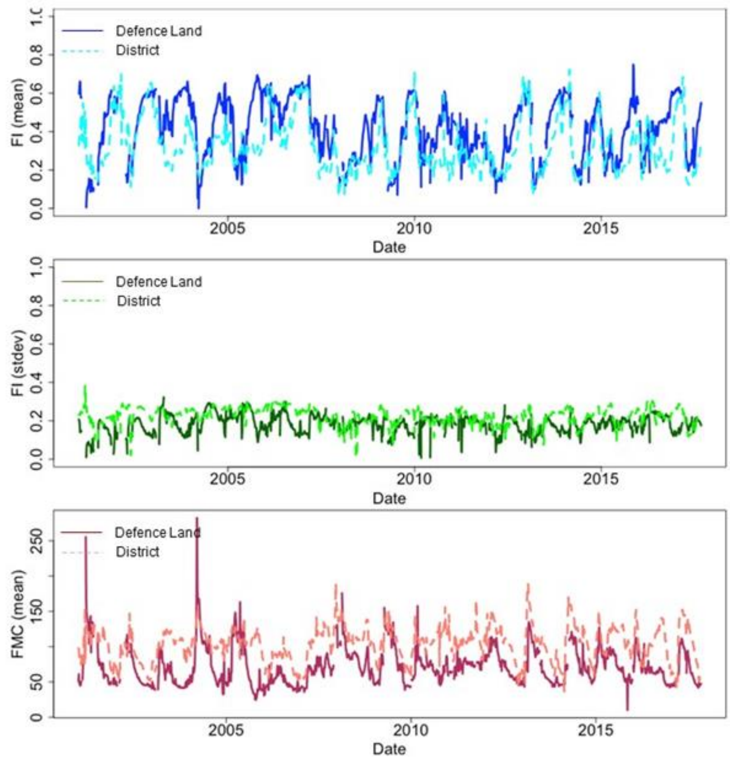


FIGURE 3. CHANGES IN FUEL MOISTURE CONTENT (FMC) AND FLAMMABILITY (FI) ACROSS THE GREATER HUNTER FIRE DISTRICT AND THE SINGELTON DEFENCE LAND

Australian Flammability Monitoring System version 1.0 – User feedback and priorities for further development (Milestone 1.3.1)

In response to the information requirements expressed by end users, the Bushfire & Natural Hazards CRC project ‘Mapping Bushfire Hazards and Impacts’ (Project A1) developed the Australian Flammability Monitoring System (AFMS) website (version 1.0). The AFMS makes spatial information on fuel condition and flammability easier and faster to access.

This report summarises feedback received from end users and discusses priorities for future development that may potentially be addressed by the BNHCRC and the project team in future (Yebra *et al.* 2018c).

All end users involved in the project, and participating in several seminars and presentations featuring the AFMS, recognised the value of the system to improve fire management in Australia (Figure 4). However, they also identified some significant barriers to adoption by the Australian bushfire sector. Firstly, neither FMC nor FI are presently used in any models or systems. This means that the sector needs to explore the information and develop work processes for using it. Another key barrier is the timeliness of the system. It presently takes 15 days to acquire the satellite data, process and publish. This delay is too long to allow practitioners to trial the system during operations.

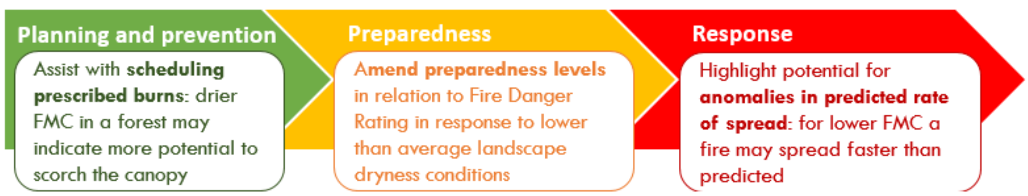


FIGURE 4. CURRENT AND POTENTIAL USES OF THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM IN FIRE MANAGEMENT

Future priorities for further development of the AFMS should focus on activities that will contribute to strengthening the usability of the AFMS and adoption (Table 1). As a first step, we need to invest more time working with end users to develop specific operational applications and integrate the information displayed in the AFMS into current decision processes and tools (e.g. the ACT Parks and Conservation Service's Prescribe Burn Decision Tool). Meanwhile, we also need to improve timeliness, robustness, visual presentation and explanation of the information displayed on the AFMS website to make it easier for users to extract the important details.

The implementation of the AFMS into daily fire management operations will take fire management in Australia to a new level.

TABLE 1. SUMMARIZES THE USER FEEDBACK AND PRIORITIES FOR FURTHER DEVELOPMENT

THEME	FEEDBACK	SOLUTION	STATUS
Web Service Enhancement	Pixels are not square	Change in the projection	Done
	The system needs to better represent the interaction between vegetation types with vastly different FMC dynamics and the scale of the coloured classification	Map the different fuels (grass, shrub and forest) separately Display decile maps in addition to absolute values	Utilisation Funding under request Utilisation Funding under request
	It is confusing to know what the FMC and FI products inform in a multilayer forest in relation to what the satellite senses	Make it easy to identify from what layer the FMC is being calculated by adding additional contextual or fire danger factor data layers that are already available online.	Utilisation Funding under request
	Data needs to be integrated into the users' GIS systems	Allowing direct data downloads for a region of interest as GeoTIFF	Utilisation Funding under request
	More regular updates of data displayed are needed	Automate this process	Utilisation Funding under request
Understanding and usability	Users want to make more use of the information displayed on the AFMS	Invest more time working with the end users and develop specific, operational applications and integrate the information displayed in the AFMS into current decision processes and tool.	Utilisation Funding under request
	Users want to learn more about integrating AFMS products into their current systems	Develop use examples or instruction videos for new website users that explain the strengths and limitations of the data (based on our conversation with end users)	
	Users would like to use FMC in the current grass fire spread model	Relate grass moisture content to curing	Utilisation Funding under request
Algorithm development	Explore other satellite data sources to allow finer spatial and temporal resolution.	Suitability study of different satellite data sources	Planned by June

Coupling Litter and soil moisture dynamics for dead fuel moisture content forecast (PhD project, Li Zhao)

Dead fuel moisture content (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 dead FMC forecast. 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 to estimate soil moisture, among others.

Preliminary results from a study case (Figure 5) show that;

- The coupling model reduced mean error (ME) in dead FMC but had little influence on other performance metrics (Table 2).
- Soil water content can influence dead FMC predictions, especially the profile FMC.

The comparison with field FMC was a preliminary test and only considered coupling of vapour fluxes. Future research will consider coupling through capillary flow.

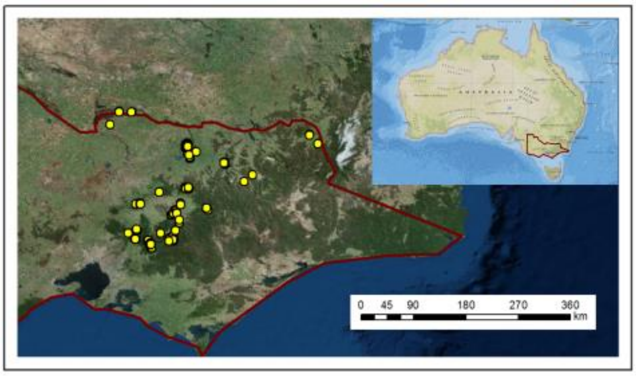


FIGURE 5. LOCATION OF THE CASE STUDY AND THE SAMPLING POINTS

TABLE 2. STATISTICAL ANALYSIS BEFORE AND AFTER COUPLING SOIL-LITTER VAPOR FLUX EXCHANGE COMPARED TO FMC MEASURED IN SURFACE LITTER LAYER (SURFACE FMC) AND BOTTOM LITTER LAYER (PROFILE FMC). ME, MEAN ERROR; MAE, MEAN ABSOLUTE ERROR; RMSE: ROOT MEAN SQUARE ERROR.

Soil-litter flux	FMC	Contingency Table				Statistics for Hit Only		
		Hit	Correct Rejection	Miss	False Alarm	ME	MAE	RMSE
No	Surface	92%	2%	2%	4%	-2.6	3.2	4.1
	Profile	66%	7%	6%	21%	-3.1	4.7	5.7
Yes	Surface	92%	2%	2%	4%	-1.6	3.2	4.1
	Profile	69%	7%	3%	21%	-1.1	4.2	5.3

Satellite monitoring of fire impact and recovery (PhD project, Andrea Massetti)

We propose an index (Vegetation Structure Perpendicular Index, VSPI) for continuous monitoring of forested areas. The index is based on the free of charge Landsat satellite imagery and allows the creation of fuel load maps and the reconstruction of post-fire fuel re-accumulation curves (Massetti *et al.* 2018).

We tested the index on Perth Hill fires (2005) (Figs. 6 and 7).

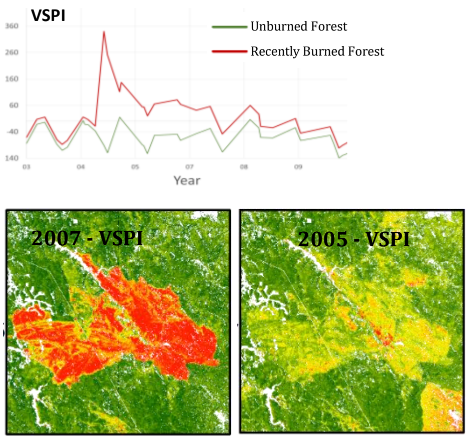


FIGURE 6 – VSPI RESPONSES ACROSS TIME FOR A RECETLY BURNED (RED) AND UNBURNT FOREST (GREEN). VSPI MAPS. FIRST DATE AVAILABLE AFTER THE PERTH HILLS WILDFIRE (LEFT) AND SAME AREA 23 MONTHS POST FIRE (RIGHT)

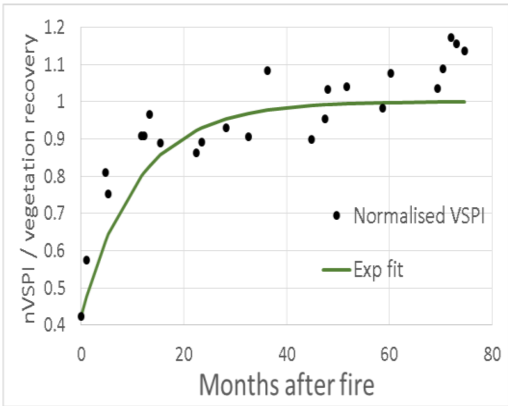


FIGURE 7 – THE VSPI SIGNAL CAN BE USED TO ASSESS THE VEGETATION RECOVERY STATUS AFTER A FIRE

Results show that the VSPI detected a disturbance in the burned vegetation for about 30 months (Figure 6) and could be used to reconstruct the forest fuel re-accumulation which followed an exponential decay curve (Fig. 7). These results have important implications for prescribed burns assessment, fire behaviour simulation, fire risk assessment.

MAJOR FIELD RESEARCH HIGHLIGHTS

The research team met Adam Leavesley, Brian Levine and Tony Scherl (ACT Parks and Conservation Service) and Matthew Hayne (Utilisation Manager BNHCRC) to discuss the usability of the Australian Flammability Monitoring System and other LiDAR-derived spatial maps of fuel loads to conduct their prescribed burning program. During the meeting, a media team from the Australian Academy of Science and the ANU filmed some scenes of the meeting as well as interviewed Marta Yebra and Adam. They produced two videos with the scenes of the day (Link 1, Link 2). Afterwards, Marta, Geoff Cary, Matt and Adam inspected one of the burns with the fuel maps on hand to understand if the fuel conditions contributed to the burn breaking the containment lines.

FIGURE 8. COLLABORATIVE WORK BETWEEN THE RESEARCH TEAM AND ACT PARKS AND CONSERVATION SERVICE TO ENHANCE THE USABILITY OF THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM AND OTHER LIDAR DERIVED SPATIAL MAPS OF FUEL LOADS TO CONDUCT THEIR PRESCRIBED BURNING PROGRAM. ©GEOFF CARY AND ©MARTA YEBRA.

UTILISATION OUTPUTS

COMMERCIALISATION/UTILISATION

The project team was granted support of utilisation funds from the BNHCRC to develop the AFMS, and the released the website version 1.0 in March 2018 as an experimental information service undergoing active research. The AFMS version 1.0 is a web-based spatial data explorer (Figure 9) 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 m^3 water per m^3 of soil volume).
- Soil moisture content in the shallow soil (10-35 cm), in the same units.

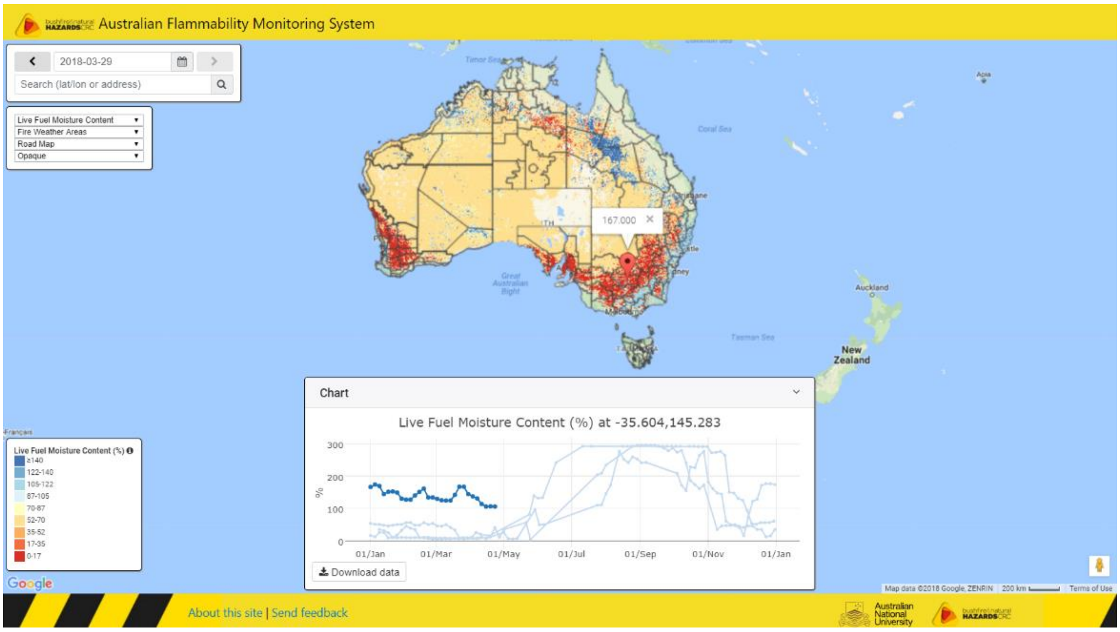


FIGURE 9. SCREEN CAPTURE OF THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM. HTTP://WENFO.ORG/AFMS/

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.

GIS 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.

Separately from the BNHCRC, but facilitated by our end users, we have been engaged by TERN AusCover to produce spatial data products for the ACT and nationally relating to vegetation structure and properties, derived from a combination of satellite and airborne data. Several fire scientists and practitioners have been consulted in the specification of the products, which will be valuable for fire risk assessment and were made available via the web portal (Figure 10).

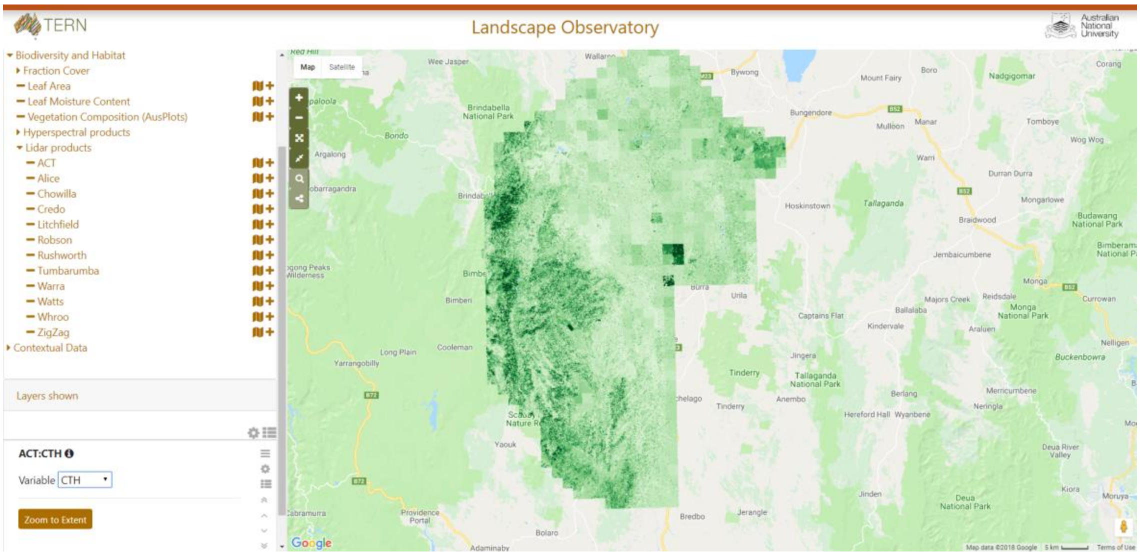


FIGURE 10. SCREEN CAPTURE OF THE TERN LANSCAPE OBSERVATORY

END USER ENGAGEMENT

The objective of our project engagement plan is to promote engagement, feedback as well as in-kind support and collaboration from the end-users and external collaborators on the research, e.g. the development and testing of algorithms and measuring or analysis techniques. Therefore, our plan will be focused on engaging our end users in our project team through participating in fieldwork campaigns, targeted meetings to brainstorm ideas, and discussions around the potential impact or change from using our research outputs in their organisation. Additionally, as engagement works in two directions, our plan is to become further involved in the end users operational activities so we can continue to better understand priority needs of end users.

Our utilisation engagement plan focuses on engagement to achieve understanding, credibility and acceptance of the AFMS by end users. To this end, we organised a targeted training workshop on the demonstration and use of our prototype-web data service to support. The workshop was sponsored by AFAC.

The project is linked to the AFAC Predictive Services Group and the New National Fire Danger Ratings (NFDR) working group (WG). During this financial year, we also participated in a AFAC Predictive Services Group Meeting. We presented progress on the Australian Flammability Monitoring System. The group was keen to see the system available and operational before the next fire season, which is an intended outcome.

The AFAC's Predictive Services Group also sponsored a webinar to demonstrate the Australian Flammability Monitoring System. Nineteen end users around Australia logged in to the webinar, which was recorded and can be accessed via this link.

OPPORTUNITIES

We will explore opportunities to bring the Australian Flammability Monitoring System into operations in the Bureau of Meteorology or Geoscience Australia, and therefore the project requires close collaborations with those organisations to promote a smooth transition.

PUBLICATIONS LIST (2017-2018)

JOURNAL MANUSCRIPTS

Under review

3. Masseti, A., Rudiger, C., Yebra, M., Hilton, J., M. The vegetation Structure Perpendicular Index (VSPI): a forest condition index for wildfire predictions. Accepted for publication with *Remote Sensing of Environment*.
4. Liu, L., Lim, S., Yebra, M. A multiscale morphological algorithm for canopy height model refinement. Submitted to the *Journal of Computers and Geosciences*.
5. Liu, L., Lim, S., Shen, X., Yebra, M. A hybrid method for segmentating individual trees from an airborne lidar data multiscale morphological algorithm for canopy height model refinement. Submitted to the *Forest Ecology and Management*.
6. Liao, Z. He, B., Quan, X., van Dijk, A., Yebra, M, Yin, C., and Qiua, S. Correcting local incidence angle effect for improving the sensitivity of P-band SAR backscatter to forest aboveground biomass. Submitted to *Int. J. Appl. Earth Observation & Geoinformation*.

Published

1. Yebra, M. Quan, X., Riano, D., van Dijk, A. Rozas, P., Cary, G. (2018)A fuel moisture content and flammability monitoring methodology for continental Australia based on optical remote sensing. *Remote Sensing of Environment*. 212, 260-272.
2. Chen, X., Liu, Y.Y., Evans, J.P., Parinussa, R.M., van Dijk, A., Yebra, M (2018). Estimating fire severity and carbon emissions over Australian tropical savannas based on satellite observations. Geophysical Research Letters. DOI: 10.1080/01431161.2018.1460507

DRAFT BOOK CHAPTER

1. Bradstock, R., Harrison, B. and Yebra, M. Volume 3: Applications. 3A-Terrestrial Vegetation. Observing Carbon Dynamics. Fire. In Earth Observation: Data, Processing and Applications. Publisher: CRCSI (2016). Editorial Panel: Barbara Harrison, Megan Lewis, Laurie Chisholm, Alfredo Huete.

CONFERENCE ABSTRACTS AND ARTICLES

1. Massetti, A., Hilton, J., Yebra, M., Rüdiger, C. The Vegetation Structure Perpendicular Index for wildfire severity and forest recovery estimation. International Geoscience and Remote Sensing Symposium, 2018, Valencia (Spain).

2. Quan, X, He, B., Yebra, M., Liu, X., Zhang, X. Retrieval of Fuel Moisture Content from Himawari-8 product: Towards real-time wildfire assessment. International Geoscience and Remote Sensing Symposium, 2018, Valencia (Spain).
3. Yebra, M, Quan, X, Riaño, D, Rozas Larraondo, P, van Dijk, Albert IJM and Cary, GJ. Mapping Live Fuel Moisture Content and flammability for Continental Australia using optical remote sensing. International Geoscience and Remote Sensing Symposium, 2018, Valencia (Spain).
4. Yebra, M., Van Dijk, A.I.J.M, Hatfield-Dodds, Z., Cary, G. Using multi-temporal and -spatial remote sensing imagery to monitor flammability in Australia. AFAC 2018, 4-7 September 2018, Perth.
5. Zhao, L., Yebra, M., Van Dijk, A.I.J.M, Cary, G. Coupling Litter and soil moisture dynamics for dead fuel moisture content forecast. AFAC 2018, 4-7 September 2018, Perth.
6. Massetti, A., Yebra, M., Hilton, J., Rüdiger G. Satellite monitoring of fire impact and recovery. AFAC 2018, 4-7 September 2018, Perth.
7. Leavesley, A., Van Dijk, A., Yebra, M, Levine, B. A LiDAR-derived fuel map for the whole ACT. AFAC 2018, 4-7 September 2018, Perth.
8. Vilar, L., Gallardo, J., Herrera, S., Bedia, J., Yebra, M., Echavarría, P., Martín, M.P. Wildfire occurrence estimation in Spanish regions based on Land Use-Land Cover interfaces and biophysical variables. VIII International Conference on Forest Fire Research. Coimbra, 2018.
9. Massetti, A., Yebra, M., Hilton, J., Rüdiger, C. Determining Spatio-Temporal Fuel Accumulation Using the Vegetation Structure Perpendicular Index from Optical Remote Sensing: Application to Dynamic Fire Spread Simulations. VIII International Conference on Forest Fire Research. Coimbra, 2018.
10. Massetti, A., Yebra, M., Rudiger, C., Hilton, J. A method for forest fuel assessment and recovery based on satellite remote sensing14th APRU Multi-Hazards Symposium Multihazards
11. Changming, Y., Bimbi, H., Yebra, M., Quan, X., Liu, X., Liao, Z. Burn severity estimation of North Australian Tropical Savannas using Radiative Transfer Models and Sentinel 2A MSI Data. Multihazard. 14th APRU Multi-Hazards Symposium Multihazards

REPORTS

1. Yebra, M. and Renzullo, L. Case study: Changes in FMC and flammability across defence lands. Bushfire and Natural Hazards CRC Milestone 1.2.2. 2018 Link.
2. Yebra, M., van Dijk, A., Cary, G. J. Australian Flammability Monitoring System version 1.0 – User feedback and priorities for further development. Bushfire and Natural Hazards CRC Milestone 1.3.1. 2018. Link.

TEAM MEMBERS

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

MARTA YEBRA

Senior Scientist at the Fenner School of Environment & Society (FSES-ANU) and project leader. Her 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 Fenner School of Environment & Society. He 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 Fenner School of Environment & Society (ANU). 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 Fenner School of Environment & Society (ANU) 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)
2. John Bally, Bureau of Meteorology
3. Adam Leavesley and Neil Cooper, ACT Parks and Conservation
4. Frederick Ford, Department of Defence
5. Stuart Matthews, NSW Rural Fire Service
6. Robert Preston, Public Safety Business Agency, QLD
7. Andrew Sturgess and Bruno Greimel, QLD Fire and Emergency
8. Andrew Grace, Attorney-General's Dept, ACT
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
12. Bruce Murrell and Michael Konig, Boeing Defence Space &Security
13. Frank Crisci and Ali Walsh, SA Power Networks
14. David Hudson and Maggie Tran, 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, has 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.
4. **Mr Wasin Chaivaranont**, a PhD candidate from the UNSW and BNHCRC Associated Student, is using passive microwave data to estimate fuel load and moisture content.

4\. **Dr David Riaño**, senior researcher at the University California Davis (California), received funding from the ANU Centre for European Studies and the UC-Davis Professional Development Award to intensify collaboration with Yebra on estimating live fuel moisture content from satellite data.

6\. **Dr Philip Zylstra** (University of Wollongong) is comparing the fire behaviour modelled from surveys vs LiDAR vs rapid assessment to evaluate to what extent the information we have derived from LiDAR can advance decision making from rapid assessments, and to determine where the priorities lie in further LiDAR work.

7. **Dr Samsung Lim** (UNSW), an expert on full-waveform LiDAR, is providing expert advice on the full-waveform LiDAR processing.
8. **Dr Sergi Costafreda-Aumedes** of University of Lleida (Spain) is applying for an Endeavour Research Fellowship at the ANU. If successful, he will research spatiotemporal patterns of fire occurrence in Australia.
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 Alcala, Spain) and **Prof Susan Ustin** (UC-Davis).
10. **Miss Shiyao Zhong** is a master student under the supervision of Marta Yebra that will investigate the use of the LiDAR-derived fuel maps to determine pasture biomass in reserves and rural lands in the ACT.

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