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MAPPING BUSHFIRE HAZARD AND IMPACTS

Annual project report 2016-2017

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Cover: Prescribed burn in the ACT. Photo by Marta Yebra

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EXECUTIVE SUMMARY

This annual report is output from the Bushfire and National Hazards CRC, '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 2016/2017**.

In consultation with the end users we have identified a subset of key outputs that have the highest utilisation potential, and that will be the focus of our work program in the future.

On those lines, the project team has made considerable progress this financial year towards the validation and increased accessibility to the "Australian Flammability Monitoring System" for operational prediction of live fuel moisture content (FMC) and flammability in Australia. In this regard, we have created a prototype web service to make spatial information on FMC and flammability easier and faster to access.

Additionally we have:

1) Evaluated the suitability of coarse resolution near-surface soil moisture data to improve the McArthur forest fire danger index
2) Undertaken development of a predictive model for estimating forest surface fuel load with LiDAR data
3) Developed a satellite-based method for the estimation of grassland aboveground biomass
4) Published four journal manuscript with another three currently in review and one invited book chapter in preparation, ten conference abstracts and two milestone reports;
5) 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

Over the next three years (2017-2020), this research project will focus on increasing the understanding, reliability and long-term continuity of the AFMS, and through this, its acceptance and adoption. 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 STATEMENTS

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 an 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'.

PRODUCT USER TESTIMONIALS

The prototype web service of the Australian Flammability Monitoring System (AFMS) is still under development, and it will be tested during the 2017-2018 fire season in collaboration with Stuart Matthews and under the frame of the National Fire Danger Rating Project. More specifically, our AFMS-FMC product will be used to estimate Spinifex fuels FMC since the rate of spread model for this fuel type requires FMC but doesn't provide a way to calculate it. Consequently, we hope to get user testimonials during and after the above-mentioned fire season.

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 processes, 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 cutting edge technology and imagery 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.

PROJECT BACKGROUND

The Bushfire & Natural Hazards CRC project 'Mapping Bushfire Hazards and Impacts' uses cutting-edge technology to produce spatial information on fuel condition, fire hazard and impact. This information can support a wide range of fire risk management and response activities such as hazard reduction burning and pre-positioning firefighting resources and, in the longer term, the new National Fire Danger Rating System (NFDRS).

The first phase of this project (2014-2017) involved the parallel investigation of some promising data sources and methods that can be categorised as either 'in-field' or 'national-scale' methods. In-field methods provide detailed information at the plot scale of metres to hectares. They provide more accurate and spatially concentrated measurements but can also be relatively costly - examples investigated previously in this project include on-ground networks of field sensors measuring grass curing or fuel moisture content (FMC) and automated ground-based LiDAR laser scanning for fuel characterization. National-scale methods are generally derived from already available satellite imagery and other spatial data. Two such methods were successfully developed in this project: the Australian Flammability Monitoring System (AFMS), and the High-resolution Fire Risk and Impact (HiFRI) model-data fusion framework. The former was implemented at national-scale, whereas the latter was tested for a smaller region but can be applied anywhere in Australia.

Information derived from the national-scale methods appeared to represent better return on investment and generated greater interest among end users (Yebra et al. 2016b). They, therefore, appear to have greater utilisation potential than in-field methods, which require careful consideration of the cost and the representativeness of the sample locations. However, end users did recognise the importance of in-field methods as part of the verification, acceptance and tuning of large-scale methods. Moreover, adoption of some in-field technologies was considered more likely to occur once data acquisition and analysis technologies become cheaper.

RESEARCH APPROACH

SUMMARY OF MAIN RESULTS

Activity 1. Fire hazard mapping and monitoring

The Australian Flammability Monitoring System

Live fuel moisture content (FMC) is one of the primary variables affecting bushfire ignition. We have developed the Australian Flammability Monitoring System which is the first Australia-wide system for operational prediction of live fuel moisture content (FMC, Figure 1) and associated flammability using satellite data (Yebra et al. 2016c)(Yebra et al., in preparation). This work has been undertaken in collaboration with staff from the National Computing Infrastructure (NCI) that provided advice and assistance with high-performance computing to rapidly create a historic data archive from 2000 onwards.

FMC estimates are physically-based given the algorithm uses reflectance data from MODIS (Moderate Resolution Imaging Spectrometer) satellite and radiative transfer modelling inversion approaches (Yebra et al. 2016c).

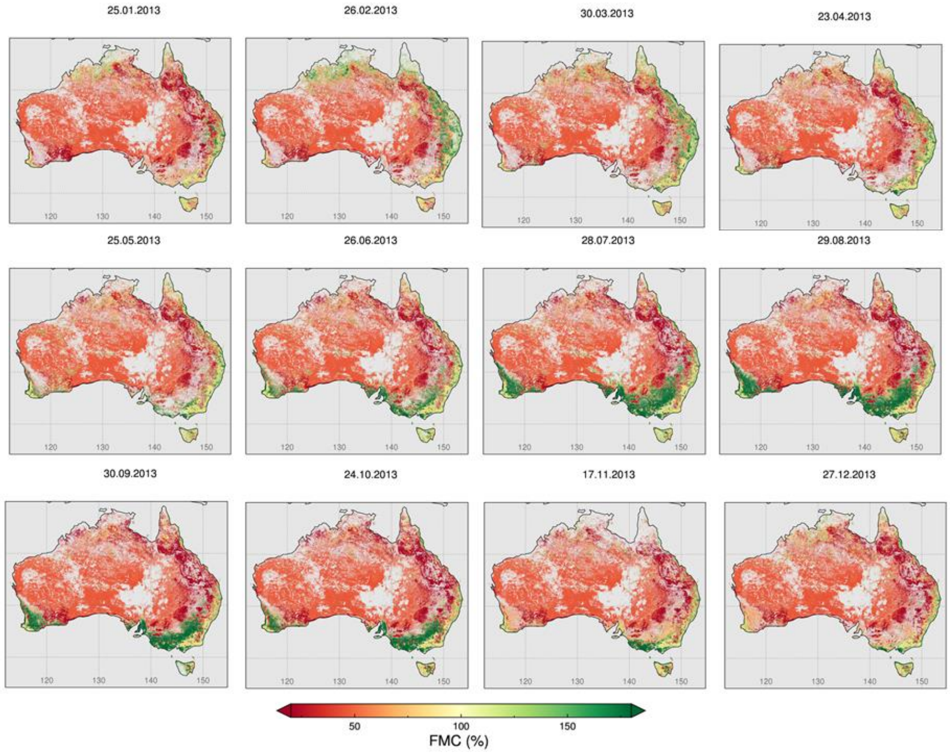

FIGURE 1. MULTI-TEMPORAL CHANGE IN LIVE FUEL MOISTURE CONTENT (FMC) FOR 2013 FOR AUSTRALIA. IN JANUARY 2013, THERE WERE LOW VALUES OF LFMC IN MOST OF THE TEMPERATE ZONES OF AUSTRALIA. THE LFMC VALUES IN THESE AREAS GRADUALLY INCREASE UNTIL REACHING THEIR MAXIMUM AT THE END OF WINTER OR BEGINNING OF SPRING. AFTERWARDS, LFMC START TO DECREASE UNTIL THE END OF THE SUMMER WHEN VALUES ARE THE LOWEST. IN THE TROPICAL REGIONS IN THE NORTH OF THE COUNTRY, THE TENDENCY IS THE OPPOSITE; HIGHER VALUES DURING THE NORTHERN WET SEASON (DEC-MARCH) AND LOWER DURING THE DRY SEASON (APRIL-OCTOBER) LFMC VALUES ARE ALWAYS LOW IN DESERT AREAS. (THE WHITE AREAS SHOW MISSING DATA DUE TO CLOUD CONTAMINATION) SOURCE: (YEBRA ET AL. IN PREPARATION).

The accuracy of the product was evaluated using existing field measurements of FMC across Australia provided by several research groups (Details can be found in Yebra et al. 2016c). Although considerable further large reductions of error in the absolute values of FMC estimates is still expected as a result of ongoing research, the current maps are already useful for fire managers to monitor spatial and temporal dynamics in fuel moisture, thus providing insights into the risk of unplanned fire and optimal scheduling of prescribed burning.

The methodology used to map flammability across Australia is based on logistic regression models between fire occurrence, estimated from the burned area product developed by Giglio et al. (2009), and several explanatory variables derived from the FMC product previously presented (Figure 2 and 3).

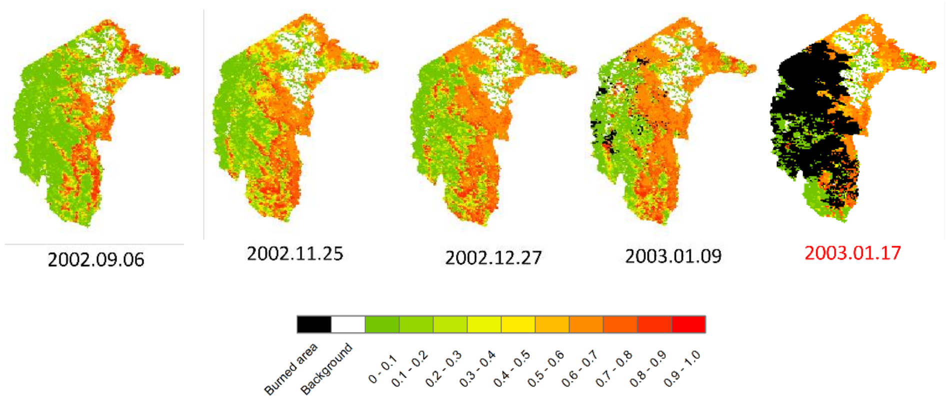

FIGURE 2. EXAMPLE OF THE NATIONAL-WIDE PRODUCT OF FLAMMABILITY (FI). MULTI-TEMPORAL CHANGE IN IP BEFORE AND AFTER THE CANBERRA REGION BUSHFIRES THAT IGNITED ON THE 8TH JANUARY, 2003, AND BURNED FOR AROUND TWO WEEKS, WITH PEAK AREA BURNED OCCURRING ON THE 17TH AND 18TH OF JANUARY, 2003. WHITE PIXELS CORRESPOND TO URBAN AREA WHILE BLACK PIXELS CORRESPOND TO THE BURNED AREA. SOURCE: (YEBRA ET AL. 2016A).

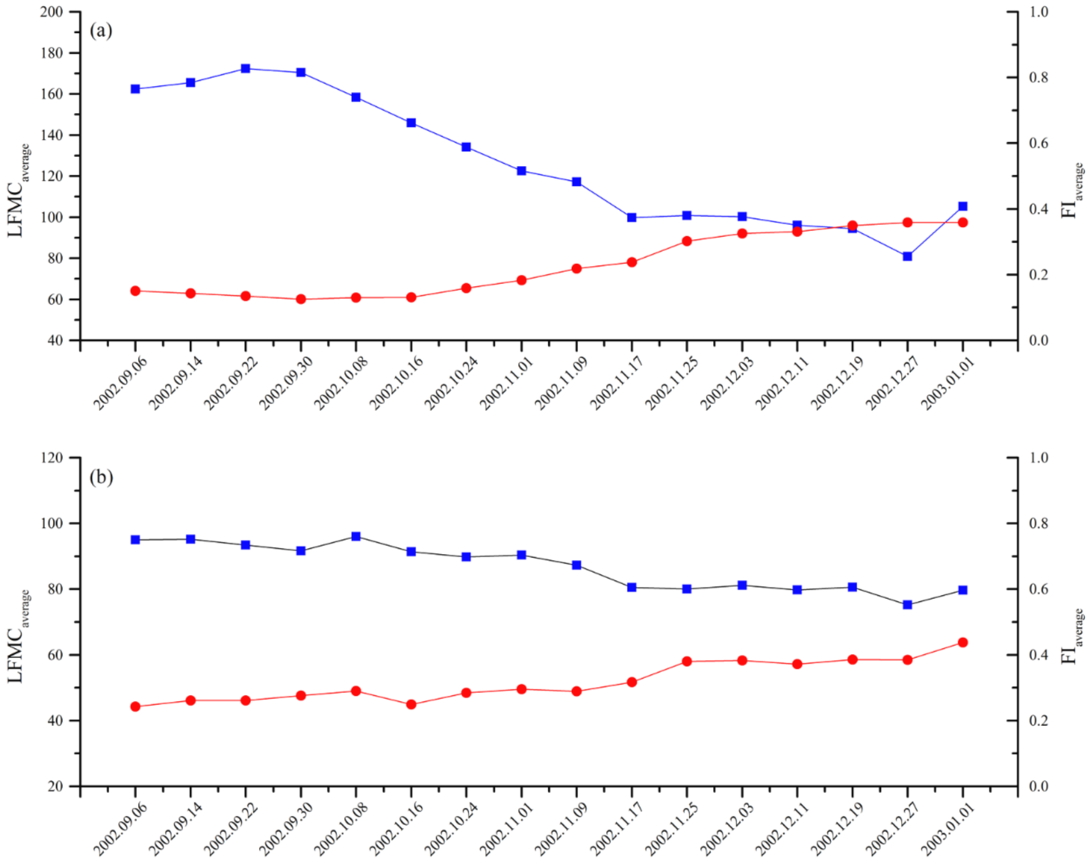

FIGURE 3. TEMPORAL EVOLUTION OF LIVE FUEL MOISTURE CONTENT (LFMC, BLUE) AND FLAMMABILITY INDEX (RED) OF GRASSLAND (A) AND FOREST (B) AREAS THAT WERE BURNED DURING THE CANBERRA REGION BUSHFIRES THAT IGNITED ON THE 8TH JANUARY, 2003. IT CAN BE SHOWN HOW LFMC PROGRESSIVELY DECREASED AND IP INCREASED TOWARDS THE DAYS PRIOR THE FIRE EVENT.

These tools can support the development of the new NFDRS and, with further development, be made available as software tools for fire managers (see utilisation outcomes section).

We are now testing the developed algorithms at a global scale and compare the results to other empirical models published in the literature (Yebra et al. 2017). A network of over 200 FMC field sampling sites in Argentina, Australia, China, France, Spain, South Africa, Italy and USA provided a validation data set for these models.

We have recently proposed and improved version of the FMC for a multilayered forest in China (Quan et al. 2017a), and it will be implemented and tested in Australia.

A radiative transfer model-based method for the estimation of grassland aboveground biomass

We developed a novel method to derive grassland aboveground biomass (AGB) based on radiative transfer model (RTM) inversion techniques. A case study of the presented method was applied to a plateau grassland in China to estimate its AGB offering good accuracies (R^2 = 0.64 and RMSE = 42.67 gm^{-2}). The methodology allows to estimate grassland AGB at large scale without the need to collect field measurements, and it will also be tested in Australia. If successful, resulting maps of grassland aboveground biomass will be incorporated in the Australian Flammability Monitoring System web explorer.

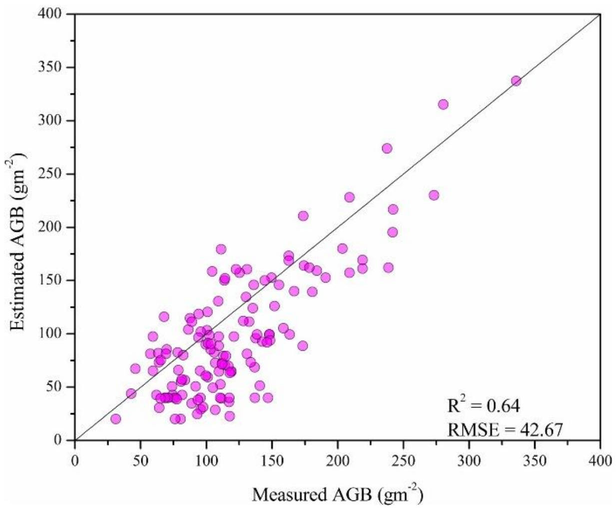

FIGURE 4. RESULT OF ESTIMATED GRASSLAND AGB USING THE RTM-BASED METHOD. SOURCE; (QUAN ET AL. 2017B)

Suitability of coarse resolution near-surface soil moisture data to improve the McArthur forest fire danger index

We explored different opportunities to better inform the Forest Fire Danger Index (FFDI) through the consideration of two alternative soil moisture data sources, chosen because the both were demonstrated to agree best to soil moisture observed at stations across Australia (Holgate et al. 2015; Holgate et al. 2017):

(1) the model-based Antecedent Precipitation Index (API); and

(2) the official Soil Moisture Ocean Salinity (SMOS) satellite mission soil moisture estimates.

We used these two alternative data sources to calculate the Drought Factor and subsequently the FFDI over a sample period of four years (2010-2013) covering the overlapping period for which both products were available, and compared the results to the currently used the Keetch-Bryam Drought Index (KBDI) data set.

The results show that the KBDI is a relatively poor predictor of soil moisture content, and much better estimates can be obtained from the model (API), the satellite (SMOS), or both. However, replacing the KBDI with more accurate soil moisture estimates is not straightforward, as it requires scaling of the soil moisture units. The conceptually most simple and logical scaling approach shown that the choice of soil moisture input into the FFDI affects the magnitude of the estimated bushfire danger level, but has little effect on the timing throughout the year, at the locations considered (Fig 5, calculated using standardised fire weather conditions). This highlights the lack of physical basis of the McArthur FFDI approach, which will likely need to be addressed before improved estimates of soil moisture (and fuel moisture) can be used productively to improve fire danger assessment.

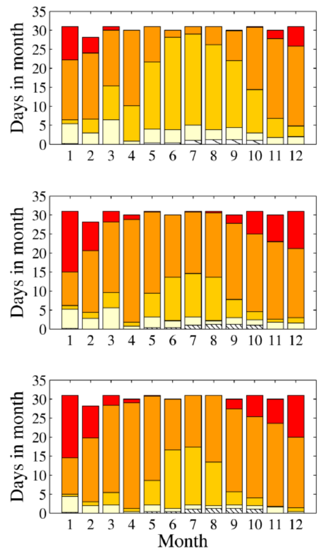

FIGURE 5. FFDI FREQUENCY BASED ON SMOS_L3 AT YANCO AGRICULTURAL INSTITUTE SITE NSW-01USING KBDI (TOP), API (MIDDLE) AND SMOS_L3 (BOTTON) (C). SOURCE: (HOLGATE ET AL. 2017)

Development of a predictive model for estimating forest surface fuel load with LiDAR data

Quantifying surface fuel load is still an ongoing requirement for fire authorities and fire management agencies, due to its importance in predicting fire behaviour and assessing potential fire risks. We have integrated multiple regression analysis and LiDAR-derived metrics to propose a new relationship between quantity of forest surface fuel, fuel depth and years since last fire, and found that the spatial variation in surface litter fuel load also highly relates to canopy density, elevation, and fuel type across the study area (Upper Yarra Reservoir area). We used LiDAR data as an effective means to provide spatial continuity in fuel depth and topography estimates with high spatial accuracy (Figure 6). The predictive models we developed provide a better prediction of spatial variations in surface fuel load over compared to currently used models in the Upper Yarra Reservoir area. This novel approach to develop forest surface fuel load models, therefore, assists forest fuel management and assists assessment of suppression difficulties and potential fire hazards in Australian southeast eucalypt forests.

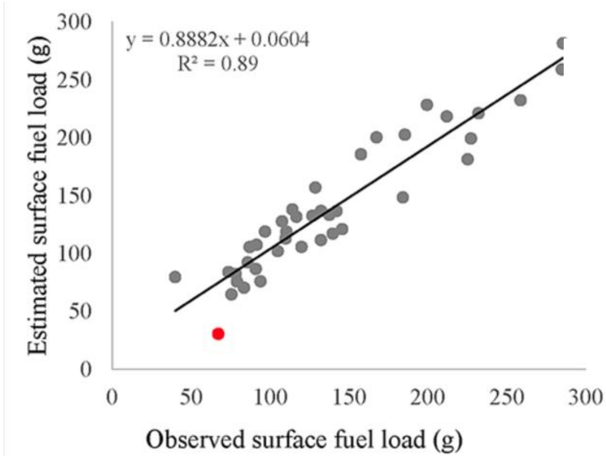

FIGURE 6. PREDICTED VS OBSERVED SURFACE FUEL LOAD IN THE UPPER YARRA RESERVOIR PARK. THE RED DOT REPRESENTS AN OUTLIER IN THE MODEL DEVELOPMENT. SOURCE: (CHEN ET AL. 2017)

MAJOR FIELD RESEARCH HIGHLIGHTS

Field work at Namadgi National Park

ACT Parks has collaborated on the collection of weekly measurement of vertical distribution of FMC in two Forest sites at Namadgi National Park (ACT, lat.: 35°37'55.80''S Lon.: 148°53'18.83''E, Figure 7). The objective of this field work is to validate the satellite-based fuel moisture model for south-east Australian forests. Also, a cosmic ray soil moisture probe that is part of the CosmOz network is being used to monitor biomass moisture content (see data on http://cosmoz.csiro.au/sensor-information/?SiteNo=12).

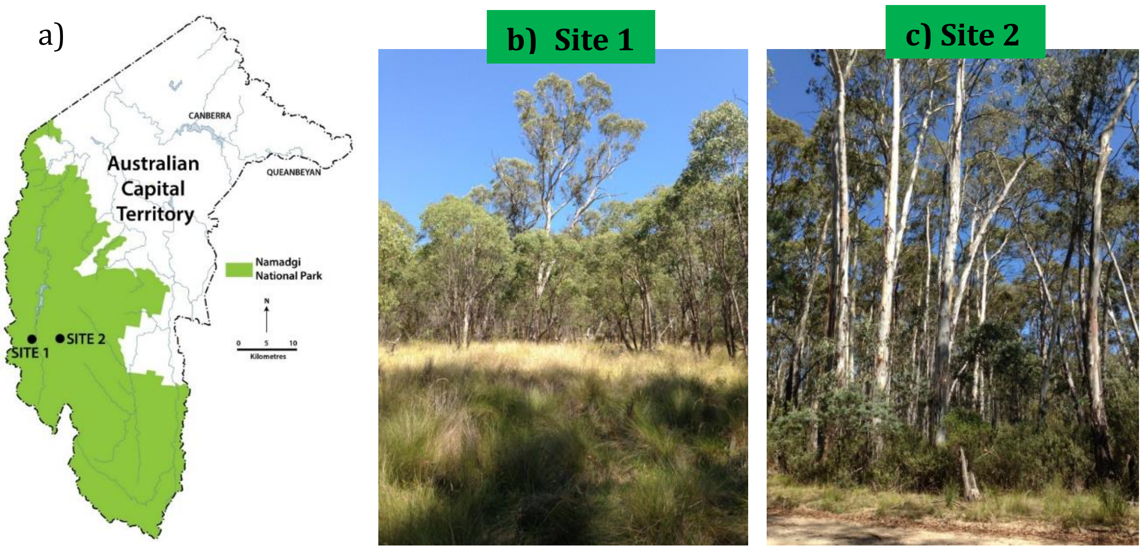

FIGURE 7. (A) LOCATION OF THE NAMADGI COSMOZ STATION AND OVERVIEW OF SITE 1 (B) AND 2 (C). SOURCE: (PADGHAM ET AL. 2016)

To this end, four live fuels samples were taken each week during the ACT's 2015-16 bushfire season, from all the forest strata including canopy (using a sling shot,

Figure 8), shrub layer and grass layer. Samples were transported to the laboratory and oven dried for 24 hrs. at 105° C to determine FMC (Mathews, 2010) by weight difference. Site 1 was co-located with a CosmOz soil moisture probe which measures a weighted combination of soil and vegetation water content.

FIGURE 8. ACT PARKS & CONSERVATION STAFF MEMBER AND ANU RESEARCHER COLLECTING LEAVES AND SOIL SAMPLES AT NAMADGI NATIONAL PARK.

UTILISATION OUTPUTS

Commercialisation/Utilisation

We have developed a pre-operational near-real time flammability data service (The Australian Flammability Monitoring System, AFMS, http://wenfo.org/afms/, Figure 9) in support of a wide range of fire risk management and response activities such as hazard reduction burning and pre-positioning firefighting resources and, in the long term, the new National Fire Danger Rating System. The AFMS will also provide general knowledge and better understanding of the relationships between FMC and fire occurrence. The prototype service is built in consultation with end-users to make sure the system is adapted to their needs in terms for example of data content and formats.

The AFMS currently provides information on fuel condition and flammability across Australia at 500m. It offers the flexibility to incorporate other relevant spatial information that is or will be available, e.g. fire weather, grassland curing, information on past fires (occurrence, intensity and burn extent), near surface fuel moisture content. The AFMS offers advanced functions for professional users to interrogate the data and download options.

The AFMS will be piloted through a pre-operational system to be hosted by ANU in the first instance. The intention of this system is to tune to user information requirements, evaluate detailed requirements for fully operational deployment, and to iron out any data and IT challenges. This requires an adaptive research environment so a stable well-designed system can be developed before migrating to a fully operational system in an operational agency or other organisation. The pre-operational system will be made available to end-users in different jurisdictions to first pilot the system during the 2017-2018 fire season, to be followed by further trials and subsequent years. The system will also be available to interested industries such as insurance, agricultural sector and electricity and water suppliers.

Please browse the explorer and send us your feedback.

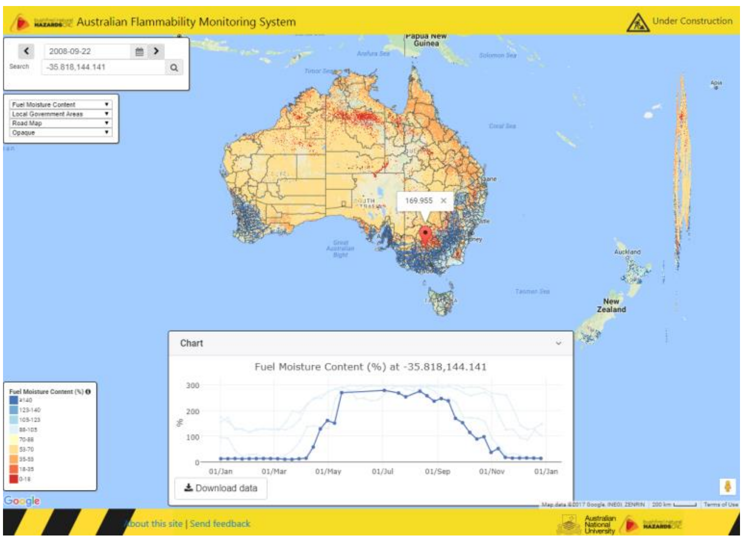

FIGURE 9. SCREEN CAPTURE OF THE AUSTRALIAN FLAMMABILITY MONITORING SYSTEM. HTTP://WENFO.ORG/AFMS/

End User Engagement

The objective of our project engagement plan is to gain 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 having our end users involved in our project team through participating in field work 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 get involved in the end user's professional activities, so we can get a better understanding of their real needs.

Our utilisation engagement plan focuses on engagement to achieve understanding, credibility and acceptance of the AFMS by end users. To this end, we are also planning to organise a targeted training workshop on the demonstration and use of our prototype-web data service to support end user on the trial of our system during the 2017-2018 fire season, and subsequent seasons. Likewise, we will organise post-trial workshops to obtain innovative and high-quality end-user feedback for the future development of the system.

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 attended the National Fire Danger Rating Project Workshop. The participants of the workshop were able to identify a direct application for our AFMS-FMC product to Spinifex fuels: the rate of spread model for this fuel type requires FMC but doesn't provide a way to calculate it. We followed up with Stuart Matthews and agreed on making the FMC product available for the coming fire season as well as historical FMC data for their models calibration. We received FMC field observations from Niels Burrows (Department of Biodiversity Conservation and Attractions, WA) to validate our FMC estimates in spinifex (work in progress). We also participated in the 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. This is intended.

Opportunities

We will explore opportunities to bring the Australian Flammability Monitoring System into operations in BoM or GA, and therefore the project will need to have close collaborations with those organisations to make the transition smooth.

Marta Yebra is involved in a Canberra Innovation funded monitoring project "From Sensors to Solutions" to develop applications for AIRBUS SPOT satellite data (1.5 m spatial resolution). Marta will apply the Australian Flammability Monitoring System (AFMS) to SPOT imagery over the next six months. This project brings the opportunity of having information on FMC and Flammability at higher spatial resolution what can highly benefit prescribe burning planning and fire risk analysis in the wildland-urban interface. Nevertheless is it still unknown how this can further progress as SPOT imagery is commercialized via AIRBUS. A workshop will be organised in September to discuss this aspect further.

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 developed in the specification of the products, which will be valuable for fire risk assessment and made available around October 2017. The new collaboration with TERN AusCover provides a new mechanism for collaboration with satellite and airborne data scientists across Australia, and some products are being developed and made available that can benefit fire research and management.

WHERE TO FROM HERE

Over the next three years (2017-2020), this research project will focus on increasing the understanding, reliability and long-term continuity of the AFMS, and through this, its acceptance and adoption. Also, a small number of promising, low-cost in-field techniques will continue to be investigated to improve their cost/benefit ratio and utility.

I. AFMS understanding and reliability.

The algorithm we have developed to map FMC for Australia is physically-based using reflectance data from MODIS satellite and radiative transfer models (RTM) Lookup Table inversion techniques. The evaluation of the algorithm for different vegetation types in Australia (Yebra et al. 2016a) has shown that better description of the links between vegetation biophysical and structural properties and leaf reflectance is a critical need, especially for sclerophyll forests. This is because existing RTMs that describe vegetation chemical, structural and optical properties are mainly derived for European vegetation types. Further advancement towards physically-based satellite FMC monitoring methods can be realised through the development of RTMs suited for Australian temperate sclerophyll forest. Field measurement of leaf spectra and corresponding leaf biochemical traits of key species will be essential to that end and will be undertaken as part of the project.

II. AFMS long-term continuity

The current AFMS relies on MODIS instruments on board the Terra and Aqua satellites. However, the expected lifetime of the Terra and Aqua satellites has already been exceeded, and at some point, in the not-too-distant future, they will become inoperative. To support an AFMS continuity strategy, we will evaluate the feasibility and relative benefits of using alternative satellites, in collaboration with Geoscience Australia and Bureau of Meteorology. The most promising candidate data sources are the geostationary Japanese Himawari-8 satellite, the European Sentinel-2 and the Landsat and VIIRS satellites.

Apart from ensuring data continuity and redundancy, the use of these satellites may also create the opportunity to increase the temporal or spatial resolution or both of the AFMS. The benefits of this will also be investigated.

III. Towards a comprehensive characterization of flammability.

The AFMS provides the first Australia-wide product of flammability from satellite estimates of live FMC (Yebra et al. 2016b). The flammability index was adjusted using a continuous logistic probability model between fire occurrence and live FMC. 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. For example, weather observations and forecasts are available from Bureau of Meteorology, the method of Matthews et al. (2006) can be used to predict dead FMC and Quan et al. (2016) to estimate grassland aboveground biomass. We will quantitatively integrate these additional factors by including them in probabilistic prediction framework. Such an approach will provide a more observation-based and comprehensive assessment of flammability, where current national approaches (e.g. the MacArthur-type methods) are conceptual and focused on meteorological variables.

IV. Low-cost technology to monitor fuel condition on Defence Lands.

As this project has already demonstrated, remote sensing techniques for fire risk assessment have progressed rapidly in recent years. These offer the potential for land managers, like the Department of Defence, to access broad-area information that underpins key decisions for fuel management and conduct of training activities with the potential to start bushfires. This approach is particularly useful for remote areas and restricted access areas used by Defence. However, satellite data may not provide Defence managers with ready access to all necessary up to date data or the necessary spatial or temporal resolution, and field assessment is still needed to build understanding and confidence in the satellite-derived information. To that end, low-cost ground-based techniques such as fuel depth gauges or automatic cameras may provide a more immediate method for managers to assess fuel condition (e.g. FMC, fuel structure and fuel load). Consequently, there is a need to assess the real and ongoing cost of providing fuel-related fire risk information using both satellite and field techniques against the suitability of the data for Defence and other lands and its potential common good value. It is anticipated that the most powerful and robust flammability assessment system will include a combination of both (spatial) satellite and (in situ) field monitoring methods.

PUBLICATIONS LIST (2016-2017)

JOURNAL MANUSCRIPTS

Under review

1) Chen, Y., Zhu, X., Yebra, M., Harris, S., Tapper, N. Estimation of Forest Litter-bed Fuel Load using Airborne LiDAR Data. Submitted to Environmental Modelling & Software.

2) Zhanmang Liaoa, Binbin He, Xingwen Quan, Albert van Dijk, Marta Yebra, Changming Yina, and Shi Qiua. Correcting local incidence angle effect for improving the sensitivity of P-band SAR backscatter to forest aboveground biomass. Submitted to Remote Sensing of Environment.

3) Chen, X., Liu, Y.Y., Evans, J.P., Parinussa, R.M., van Dijk, A., Yebra, M. Estimating fire severity and carbon emissions over Australian tropical savannas based on satellite observations. Submitted to Geophysical Research Letters.

Published

4) Holgate, C.M., van Dijk, A.I.J.M, Cary, G.J., Yebra, M., Influence of using alternative soil moisture estimates in the McArthur Forest Fire Danger Index. Accepted for publication at International Journal of Wildland Fire. WF16217

5) Chen, Y., Zhu, X., Yebra, M., Harris, S., Tapper, N. 2017. Development of a Predictive Model for Estimating Forest Surface Fuel Load in Australian Eucalypt forests with LiDAR Data. Environmental Modelling and Software. 97, 61-71, 2017.

6) Quan., X, Hea, B., Yebra, M. Yina, C., Liaoa, .and Xing L. 2017. Retrieval of forest fuel moisture content using a coupled radiative transfer model. Environmental Modelling & Software. 95, 290-302.

7) Quan, X., He, B., Yebra, M., Yin, C., Liao, Z., Xueting, Z. Estimating Grassland Aboveground Biomass Using Radiative Transfer Model. IEEE International Journal of Applied Earth Observation and Geoinformation. 54, 159-168.

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) Yebra, M., Van Dijk, A.I.J.M, Hatfield-Dodds, Z., Cary, G. The Australian Flammability Monitoring System. AFAC 2017, 4-7 September 2017, Sydney.

2) Massetti, A., Yebra, M., Hilton, J., Rüdiger, C. A novel vegetation structure perpendicular index (VSPI). Theoretical background and firts applications. 5th International Symposium on Recent Advances in Quantitative Remote Sensing: RAQRS'V, 18-22th September 2017

3) Marta Yebra, David Riaño, Xingwen Quan, Florent Mouillot, Eugenia Paget, Carlos M. Di Bella, Mariano Garcia, Pilar Martín, Philip Frost, Greg Forsyth, Albert van Dijk, Geoff Cary, Emilio Chuviec , Susan Ustin. Global validation of Live Fuel Moisture Content products from satellite MODIS. 5th International Symposium on Recent Advances in Quantitative Remote Sensing: RAQRS'V, 18-22th September 2017
4) Yebra, M., Quan, X., van Dijk, A., Cary, G. The Australian flammability system. AFAC/BFNHCRC Conference, Brisbane, September, 2016.
5) Garlapati, N., van Dijk, A., Yebra, M., Cary, G., Lim, S. Mapping and validating forest structures from airborne LiDAR data. AFAC/BFNHCRC Conference, Brisbane, September, 2016.
6) Chen, Y., Zhu, X., Yebra, M., Harris, S., Tapper, N. Estimation of Forest Litter-bed Fuel Load using Airborne LiDAR Data. AFAC/BFNHCRC Conference, Brisbane, September, 2016.
7) Padgham, L., Quan, X., Yebra, M., Leavesley, A., Dunne, B., Van Dijk, A., Cooper, N. Determination of live fuel moisture content in complex forest stands using remote-sensing. AFAC/BFNHCRC Conference, Brisbane, September, 2016.
8) Chen, Y., Zhu, X., Yebra, M., Harris, S., Tapper, N. Estimation of Forest Litter-bed Fuel Load using Airborne LiDAR Data. Proceedings for the 24th International Conference on Geoinformatics. August 14-20, 2016, Galway, Irelan
9) Padgham, L., Quan, X., Yebra, M., Leavesley, A., Dunne, B., Van Dijk, A., Cooper, N. Determination of live fuel moisture content in complex forest stands using remote-sensing. AFAC/BFNHCRC Conference, Adelaide, September, 2016.
10) Chen, Y., Zhu, X., Yebra, M., Harris, S., Tapper, N. Estimation of Forest Litter-bed Fuel Load using Airborne LiDAR Data. Proceedings for the 24th International Conference on Geoinformatics. August 14-20, 2016, Galway, Ireland.

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11) Yebra, M., Isaac, P., van Dijk, A. 2016. Forest growth-water-carbon estimation model constrained with remote sensing data and evaluated against field data.
12) Yebra, M., van Dijk, A., Cary, G. J. 2016. Assessment of the utilization potential of new technologies to map bushfire hazard and impacts.

TEAM MEMBERS

The official project team is composed of three principal researchers.

MARTA YEBRA

Research Fellow at the Fenner School of Environment & Society (ANU) and project leader. Her main background is in remote sensing of vegetation biophysical properties, such as fuel load and moisture content for spatial fire risk analysis, and canopy conductance for carbon sequestration and water balance studies.

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.

YANG CHEN

PhD candidate from Monash University completed her thesis on "Modelling forest fuel hazard change over time using LiDAR technology". She has since secured a postdoctoral research position at CSIRO Perth.

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. **Li Zhao** is a new PhD student at ANU under the supervision of Marta Yebra, Albert van Dijk and Geoff Cary that has just started her studies on the estimation and forecasting of dead FMC. She will be officially affiliated with the project.
2. **Wasin Chaivaranont**, a PhD candidate from the UNSW and BNHCRC Associated Student, is using passive microwave data to estimate fuel load and moisture content.
3. **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.
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.
5. **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 at a global scale.
6. **Dr Philip Zylstra** (University of Wollongong) is comparing the fire behaviour modelled from surveys vs. LiDAR vs. rapid assessment to see 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-wave form 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. **Lois Padgham** is an undergraduate student at ANU as well as operational bushfire firefighter of ACT Parks and Conservation Service, and she has undertaken a special topic project under Dr Marta Yebra's supervision to validate satellite-based fuel moisture estimates for the forest in Namadgi NP as well as observations from the CosmOz sensor to monitor fuel moisture content.
11. **Nicola McPherson** is an Engineering Honours student at ANU that carried out a project entitled "Grassland curing and moisture content monitoring with passive microwave remote sensing".
12. **Honghao Zeng** is a master student enrolled in the Fenner School of Environment and Society (ANU) who is carrying out a multivariable analysis of fire occurrence in Australia under the supervision of Marta Yebra
13. **Zhaoyu Zhang** is an undergraduate student that carried out an independent research project on characterising and assessing the spectral signature of grasslands with different degree of curing.

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