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MAPPING BUSHFIRE HAZARD AND IMPACTS

Annual project report 2015-2016

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Bushfire and Natural Hazards CRC

Version	Release history	Date
1.0	Initial release of document	26/09//2016

Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Programme

Publisher:
Bushfire and Natural Hazards CRC

September 2016

Citation: M Yebra, A van Dijk, G Cary (2016) Mapping bushfire hazard and impacts: Annual project report 2015-2016, Bushfire and Natural Hazards CRC

Cover: Prescribe burns at the ACT. Photo by Marta Yebra

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EXECUTIVE SUMMARY

This annual report is an output from the Bushfire and National Hazards CRC, Project '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 2015/2016**.

The project team has made considerable progress this financial year and has generated a number of nationwide products. More specifically this financial year we have:

1) developed and tested the "Bushfire Information System" with potential for operational prediction of live fuel moisture content and fire occurrence in Australia;
2) analysed the suitability of near-surface soil moisture data to improve the McArthur forest fire danger index;
3) tested a forest carbon uptake estimation model constrained with remote sensing data at 25 m to 5 km resolution and evaluated against field data; and
4) Developed a predictive model for estimating forest surface fuel load with LiDAR data.

We have also completed some activities initialised during the previous financial year including:

1) the development and testing of a new software tool to automatically derive detailed vegetation structure information from ground-based LiDAR; and
2) testing an on-ground network of curing/FMC sensors.

We have maintained an effective and engaging relationship with project end users. The most intensive interactions have been with ACT Parks and Conservation, with whom the team collaborates closely, including in an operational setting. However, now that we have generated a number of nationwide products, more end users are identifying how they can practically engage in the research. This has led to a large number of follow-up projects that have been requested and will be addressed as much as possible over the next years, contingent on future project funding.

Additionally we:

1) published 1 journal manuscript with another 6 currently in review and one invited book chapter in preparation, 10 conference abstracts, one conference paper and 3 milestone reports;
2) hosted three international exchange visits and were approached by more than 15 domestic and international applicants for a PhD scholarship or postdoc position in bushfire research; and

3) in consultation with the end users, 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.

END USER STATEMENT

John Bally, *Tasmanian Regional Office, Bureau of Meteorology*

"This project has are large number of identified end users who are generally very enthusiastic supporters of the research work. There has also been some very good local engagement, especially in the ACT, but less in other parts of the country. The project has developed some candidate systems that show various levels of operational potential.

One example is the demonstration national Satellite fuel moisture (FMC) assessment that has been validated against in-situ measurements but not yet compared with other FMC systems like the aging SDI/KBDI/DF which are the current operational standard. The project plans to work with fire agencies towards trialing the FMC product for estimating fire risk.

Another example is the LIDAR based Fuel Classification Structure software system that has not yet been linked with the AFAC sponsored National Fuel Classification work. The project will look for linkages with this work in the next year to explore ways that the LIDAR system can be used for point validation and possibly for training people who perform manual assessments to better calibrate subjective assessments.

The CFA sponsored (national) curing project and new National Fire Danger Ratings project both present opportunities for operationalising components of this research work."

INTRODUCTION

Understanding and predicting fire behavior 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 behavior 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 this understanding will be enhanced by remote sensing data. 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 project is structured into two main activities.

ACTIVITY 1. FIRE HAZARD MAPPING AND MONITORING

Spatial information on fuel load, structure and moisture properties can inform fire preparedness through better fire danger rating and fire behavior prediction, thereby supporting logistics and resources planning by emergency services. It can also improve fire management by helping guide activities such as scheduling and implementing prescribed burning. Insights from discussion with end users indicates that the greatest and most urgent information gap is **spatial information on forest fuel load, structure and moisture**.

Approach: We review and analyse the potential added value of new data sources relating to the load and attributes of forest fuel. The utility and feasibility of using a new data source depends on such factors as spatial resolution, accuracy, operational availability and the resources required for data acquisition, processing and interpretation. Where possible, the derived spatial data are evaluated against ground-based measurements of relevant fuel hazard scores and fuel moisture content. Where appropriate, the information is developed to fit into the Fire Danger Rating system or fuel classification systems suitable for end users.

ACTIVITY 2. FIRE IMPACTS ON LANDSCAPE VALUES

In addition to information on fire hazard, land managers also need spatial information on the **expected fire impacts on landscape values, such as water resources, carbon storage, habitat and remaining fuel load**. Relevant issues include the impact of unplanned or prescribed fires and subsequent recovery on catchment water yield and the carbon lost due to fire and then subsequently taken up during regeneration. Current prediction methods are crude and make bold assumptions (for example, about the similarity of the water use patterns between (well-studied) recovering mountain ash forests and (unstudied) other forest types.

Approach: We analyse airborne and remote sensing observations and use insights from these to improve and set up a spatial forest growth, water use and carbon uptake model. In particular, we test assumptions that are commonly being made about fire impacts on water and carbon, use the observations to improve predictions and understanding of the uncertainty, and produce spatial information that can guide land management actions such as prescribed burning.

WHAT THE PROJECT HAS BEEN UP TO

SUMMARY OF MAIN RESULTS

Activity 1. Fire hazard mapping and monitoring

Bushfire Information System

Live fuel moisture content (FMC) is one of the primary variables affecting bushfire ignition. We have developed the Bushfire Information System which is the first Australia-wide system with potential for operational prediction of live fuel moisture content (LFMC, Figure 1) and ignition probability (IP, Figure 2) using satellite data. 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 an historic data archive from 2000 onwards.

LFMC 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. 2016b).

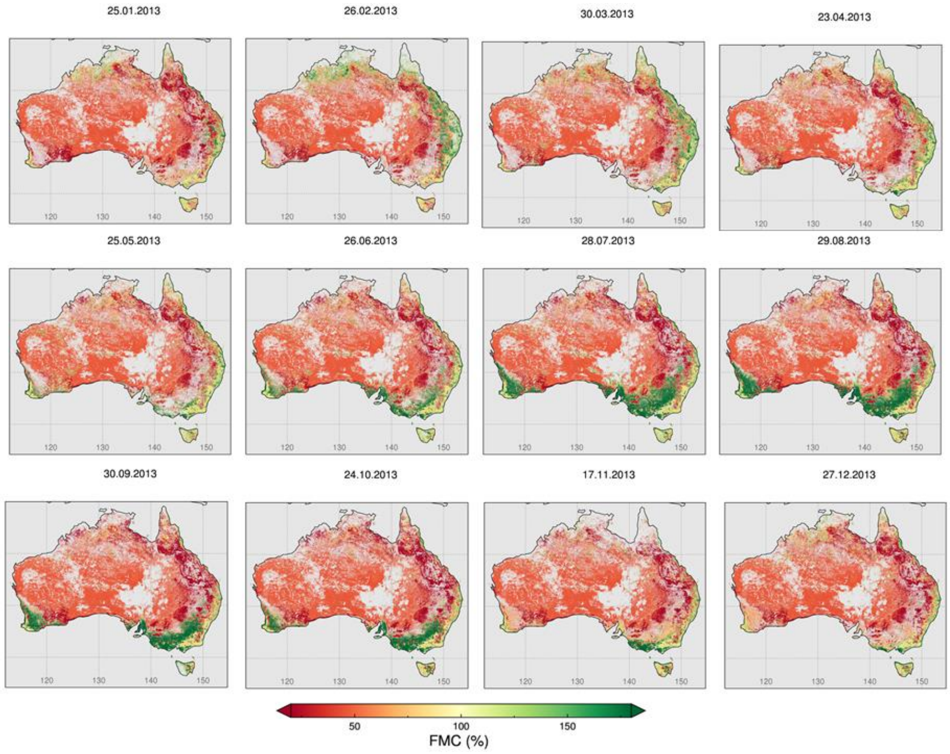

FIGURE 1. MULTI-TEMPORAL CHANGE IN LIVE FUEL MOISTURE CONTENT (LFMC) FOR 2013 FOR AUSTRALIA. IN JANUARY 2013, THERE WERE LOW VALUES OF LFMC IN MOST OF THE TEMPERATE ZONES OF AUSTRALIA. THE LFMC VALUES IN THESE AREAS GRADUALLY INCREASE UNTIL REACHING THEIR MAXIMUM AT THE END OF WINTER OR BEGINNING OF 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). SOUCE: (YEBRA ET AL. 2016).

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. 2016b). Although considerable further large reductions of error in the absolute values of FMC estimates is still expected as a result from ongoing research, the current maps are already useful for fire managers to monitor spatial and temporal dynamics in fuel moisture, thus providing insights into risk of unplanned fire (Figure 3) and optimal scheduling of prescribed burning.

The methodology used to map Ignition Probability 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 LFMC product previously presented.

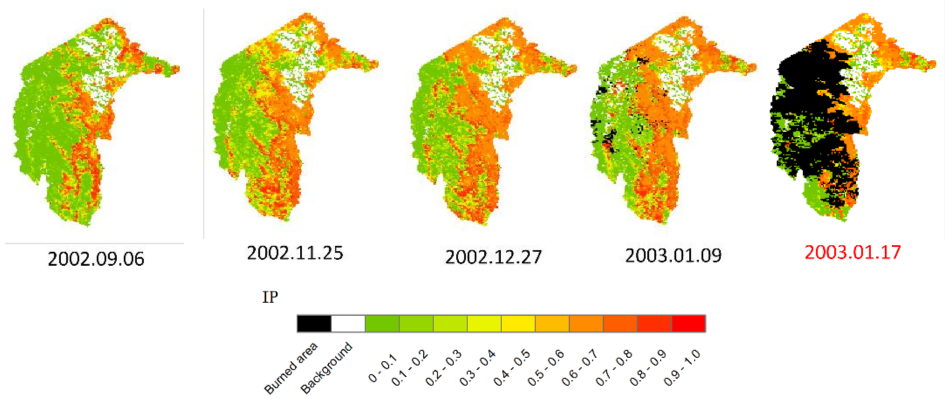

FIGURE 2. EXAMPLE OF THE NATIONAL-WIDE PRODUCT OF IGNITION PROBABILITY (IP). MULTI-TEMPORAL CHANGE IN IP BEFORE AND AFTER THE CANBERRA REGION BUSHFIRES THAT IGNITED ON THE 8TH JANUARY, 2003, AND BURNED FOR AROUND TWO WEEKS, WITH PEAK AREA BURNED OCCURRING ON THE 17TH AND 18TH OF JANUARY, 2003. WHITE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

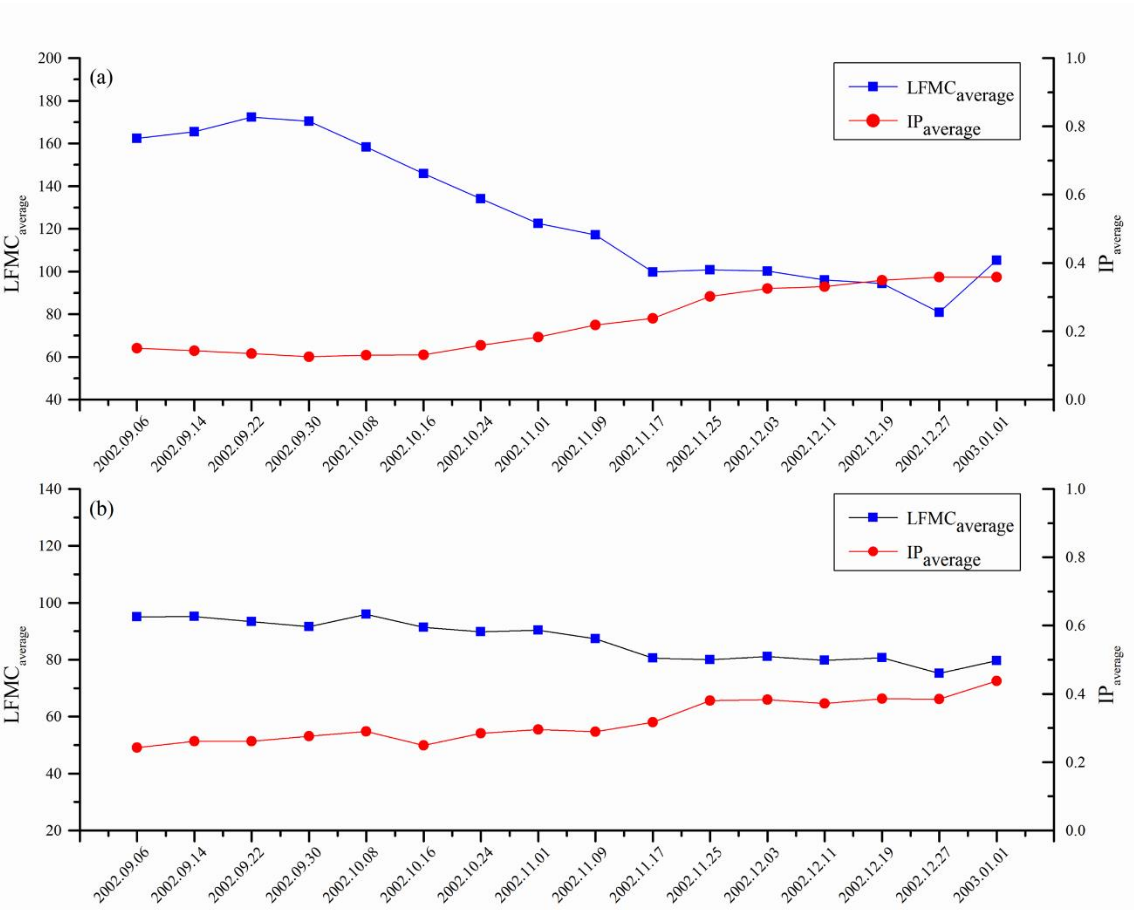

FIGURE 3. TEMPORAL EVOLUTION OF LIVE FUEL MOISTURE CONTENT (LFMC) AND IGNITION PROBABILITY (IP) OF GRASSLAND (A) AND FOREST (B) AREAS THAT WERE BURNED DURING THE CANBERRA REGION BUSHFIRES THAT IGNITED ON THE 8TH JANUARY, 2003. IT CAN BE SHOWN HOW LFMC

PROGRESSIVELY DECREASED AND IP INCREASED TOWARDS THE DAYS PRIOR THE FIRE EVENT.

Our future plans for this specific activity are to assimilate the satellite derived estimates of LFMC and IP in the High-resolution Fire Risk and Impact (HiFRI) model-data fusion software (Van Dijk et al. 2015) to forecasts FMC and flammability over the following weeks and months at a resolution that can be varied between 25 and 5000 m, depending on management requirements.

These tools can support the development of the new NFDRS and, with further development, be made available as software tools for fire managers.

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 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., in preparation, Holgate et al. 2015):

(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 time 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 3, 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.

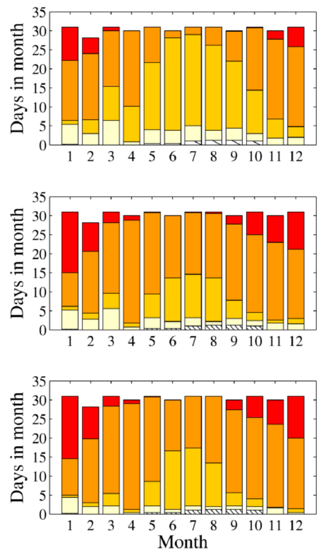

FIGURE 3. FFDI FREQUENCY BASED ON SMOS_L3 AT YANCO AGRICULTURAL INSTITUTE SITE NSW-01USING KBDI (TOP), API (MIDDLE) AND SMOS_L3 (BOTTON) (C). SOURCE: (HOLGATE ET AL., IN PREPARATION)

Fuel Classification and Structure Software

We developed, tested and published software to classify a dense point cloud derived from a mobile laser scanner (Zebedee) into different vegetation components: ground returns, near-surface vegetation, elevated understory vegetation (shrubs), tree trunks and tree canopy (Figure 4) (Marselis et al. 2016). The resulting classified point cloud is used to automatically derive information on the different fuel components that are important for fire hazard assessment such as total biomass, fractional cover and height. These results open a promising pathway of automatically deriving detailed vegetation structure information from ground-based LiDAR. These vegetation data can be valuable for local fire management and preparedness, including evaluating the success of fuel reduction activities such as prescribed burning or mechanical fuel treatment.

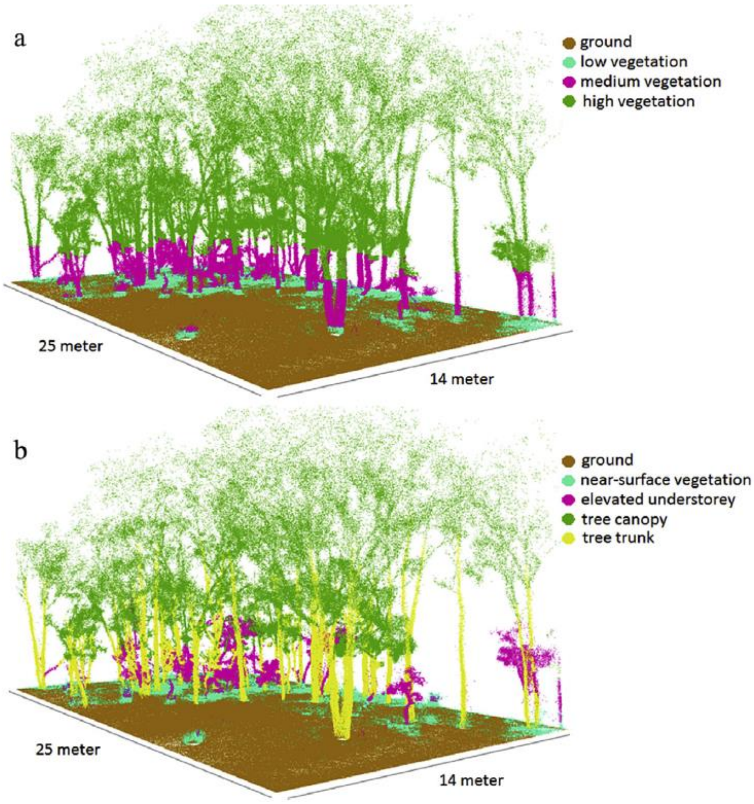

FIGURE 4. CONVENTIONAL CLASSIFICATION BASED ON HEIGHT THRESHOLDS (A) AND THE ZEBEDEE CLASSIFICATION (B). SOURCE: (MARSELIS ET AL. 2016)

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

We developed a predictive model that efficiently and accurately predicts quantities and spatial patterns in surface fuel load from surface litter fuel depth, forest type, fuel characteristics, topography and previous fire disturbance, through statistical analysis of LiDAR data (Figure 5). The model can predict surface fuel load with a prediction error of 0.08 (kg/m^2) and with further work may be used as an efficient approach to assist in forest fuel management and fire related operational activities.

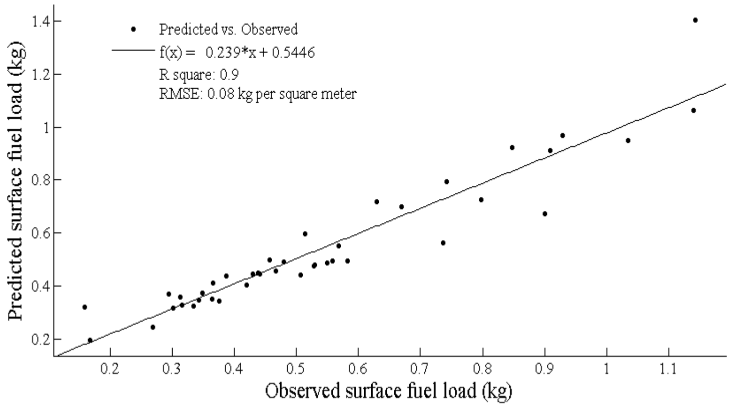

FIGURE 5. PREDICTED VS OBSERVED SRFACE FUEL LOAD IN THE UPPER YARRA RESERVOIR PARK. SOURCE: CHEN ET AL, SUBMITTED.

Activity 2. Fire impacts on landscape values

Forest growth-water-carbon estimation model constrained with remote sensing data and evaluated against field data

We developed a model to provide best possible estimates on forest fuel load and moisture content and fire impacts on landscape values such as water resource generation, carbon storage and habitat (Figure 6) (Van Dijk et al. 2015) (Yebra et al. 2015)

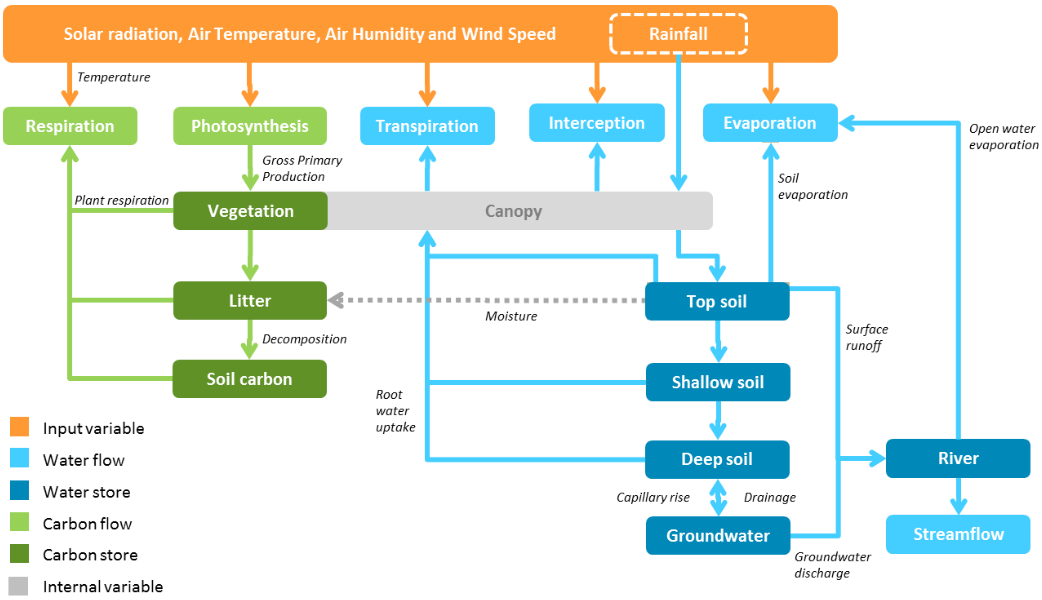

FIGURE 6. ILLUSTRATION OF THE SPATIAL FOREST GROWTH, WATER USE AND CARBON UPTAKE MODEL. SOUCE: (VAN DIJK ET AL. 2015).

During the 2015-16 financial year we have evaluated the performance of the model in estimating carbon uptake (a precursor of fuel accumulation) using estimates of Gross Primary Production (GPP) measured at 15 eddy covariance flux towers in the OzFlux network (http://www.ozflux.org.au/). The original model evaluated was calibrated using 16 towers across several biomes worldwide. For Australia, this model version accurately estimated the temporal evolution of GPP but underestimated the observed GPP (Figure 7).

The model was recalibrated using the data from the Australian flux towers, producing very accurate results (Figure 8).

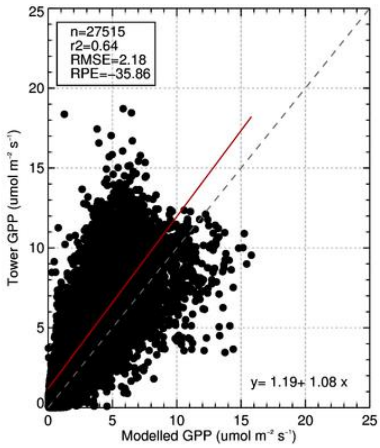

FIGURE 7. MODELLED GPP PLOTTED AGAINST FLUX TOWER GPP USING YEBRA ET AL. 2015 MODEL. ALSO SHOWN ARE STATISTICS FOR MODEL PERFORMANCE: N, NUMBER OF CASES; RMSE, ROOT MEAN SQUARE ERROR; RPE, RELATIVE PREDICTIVE ERROR AND R^2, COEFFICIENT OF DETERMINATION. SOURCE: YEBRA ET AL., IN

Water use estimates from the model are currently being evaluated using the same flux towers.

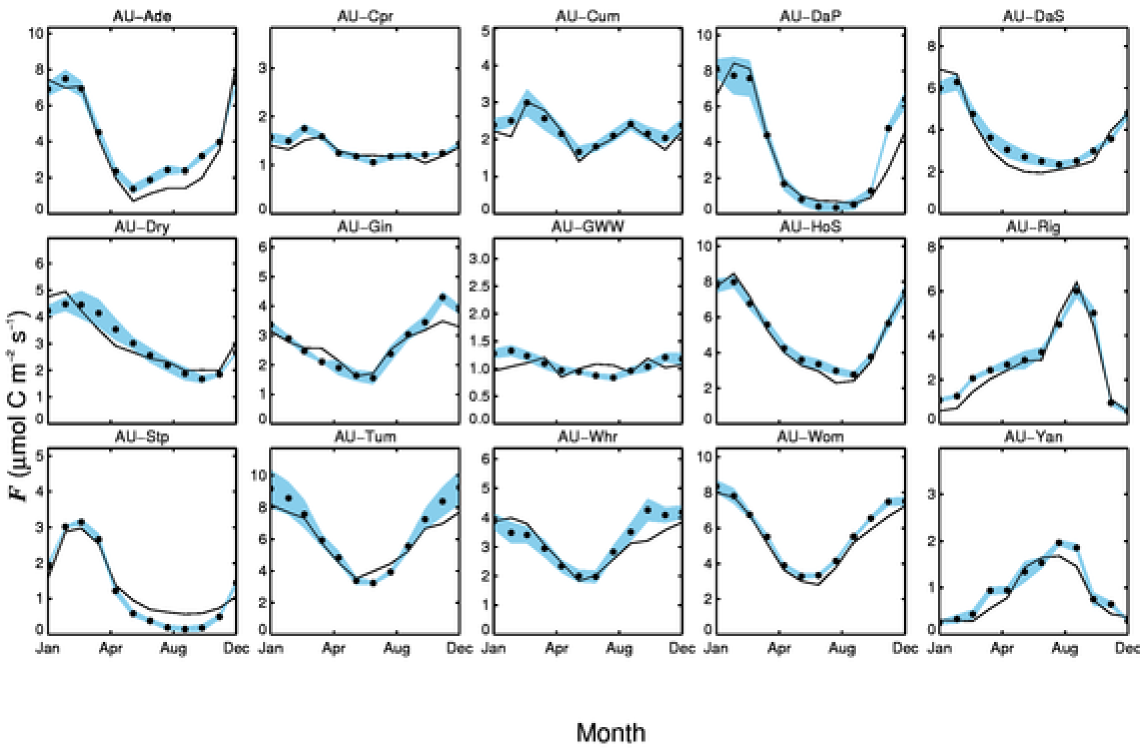

FIGURE 8. COMPARISON OF YEBRA ET AL., 2015 (SOLID LINES) MULTIYEAR MEAN MONTHLY GPP WITH FLUXNET OBSERVATIONS (DOTS). BLUE AREA REPRESENT THE STANDARD DEVIATION OF THE TOWER DERIVED GPP VALUES DERIVED USING FOUR DIFFERENT METHODS. MODEL PARAMETERS WERE OPTIMIZED FOR EACH SITE. SOURCE: YEBRA ET AL., IN PREPARATION.

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 9). The objective of this field work is to validate the satellite-based fuel moisture model for south-east Australian forests. In addition, 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).

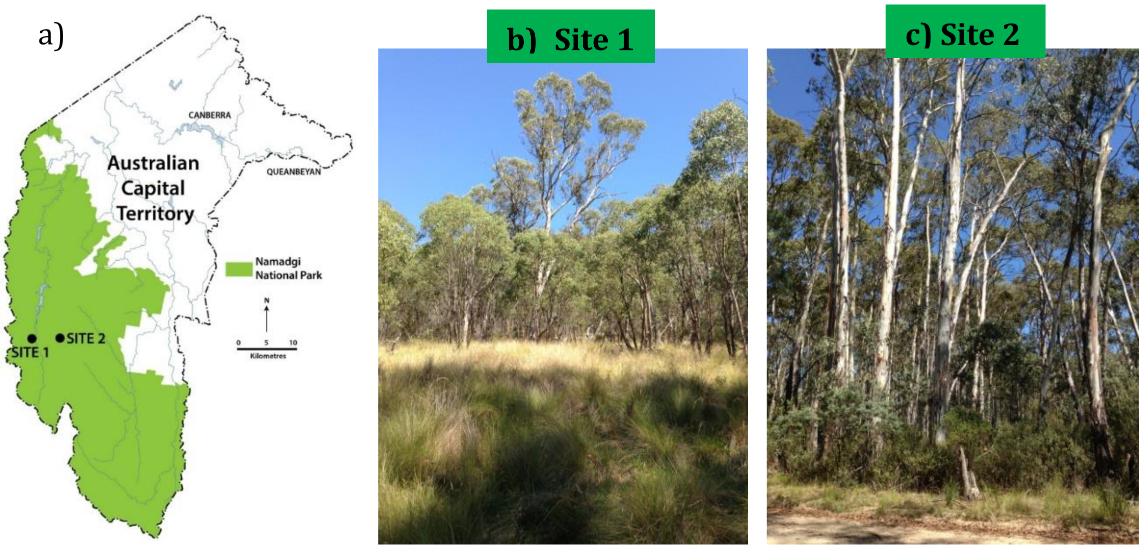

FIGURE 9. (A) LOCATION OF THE NAMADGI COSMOZ STATION AND OVERVIEW OF SITE 1 (B) AND 2 (C). SOURCE: (PADGHAM ET AL. 2016)

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 9), 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 9. ACT PARKS & CONSERVATION STAFF MEMBER AND ANU RESEARCHER COLLECTING LEAVES AND SOIL SAMPLES AT NAMADGI NATIONAL PARK.

Braidwood Burns

The team also participated in experimental burns organised by CSIRO and CFA near Braidwood (NSW) to better characterise the spectral signature of grassland curing and study the heterogeneity of curing levels in the different experimental block.

To this end we measured the sunlight reflectance spectra of 10 experimental plots with different curing levels using a spectroradiometer (Figure 10).

FIGURE 10. (UPPER) MARTA YEBRA MEASURING THE SPECTRAL RESPONSE OF THE GRASSLAND IN ONE OF THE EXPERIMENTAL BURN SITES. (LOWER) MARTA YEBRA AND VISITING STUDENT FROM BRAZIL CAROLINE LUIZ MEASURING THE SPECTRAL RESPONSE (USING AN ASD) AND THE NDVI (USING THE GREENSEEKER) OVER A TRANSECT IN ONE OF THE EXPERIMENTAL PLOTS.

Grassland curing and fuel moisture content

During the previous financial year 2014-2015 we installed 5 reflectance sensors in a grassland in the ACT (E 149 3' 26.509", S 35 16' 55.778") to test their suitability to monitor grassland curing and moisture content (Figure 11), with funding from TERN. The sensors measure reflectance in four bands (Blue, Green, Red and Near-Infrared), are solar-powered and transmit the data wirelessly to a base station every 2 minutes. The base station has a meteorological station, a small computer, a modem and an integrated 'Megapixel' camera trained on the measurement locations.

The 2014-2015 results demonstrated very close agreement between visually assessed curing and the sensor measurements (Wall 2015), suggesting that the sensor can be used successfully where regular visual assessment is not feasible. However, de Waal (2015) recommended changing the experimental design and taking further measurements without disturbance by cattle, which confounded the analysis.

Ahead of the 2015-2016 season, staff from ACT Parks and Conservation fenced the sensors off. Together with and visiting student Xingwen Quan from the University of Technology of China, they carried out visual assessment of curing and collected grass samples for fuel moisture content measurement each week during the fire season 2015-2016 in order to explore the relationships between visual and destructive FMC measurements and sensor measurements.

FIGURE 11. IN-SITU SENSORS FOR MONITORING GRASS CURING AND FUEL MOISTURE CONTENT. (TOP LEFT) METEOROLOGICAL STATION; (TOP RIGHT) ONE OF THE 5 SENSOR LOCATED ON THE SITE AND (BOTTOM) VIEW FROM THE RASBERRY PI CAMARA.

AIRBORNE DATA COLLECTION

LiDAR and imagery data capture across the whole ACT was commissioned by ACT government and completed earlier this year. We successfully applied to TERN-AusCover for additional funding ($25k) that allowed the ACT Government LiDAR data capture to be complemented with full-waveform LiDAR over the Black Mountain Reserve. These data will support research on the optimal approach to collect fuel load and structure information and compare the performance of different LiDAR configurations and systems. The data was delivered in May 2016 and PhD student Narsimha Garlapati is evaluating the quality of the data and extracting forest fuel load information.

MEETINGS

During this financial year we had a series of work meetings with end users and weekly meeting with our local ACT end users (ACT Parks and Conservation Service). These meetings have helped us to develop worked case studies and guidelines to describe how each satellite information source might be useful for bushfire management, and its application to operational activities. The meetings were important for determining research and development requirements and priorities to achieve specific objectives, as well as establishing and coordinating in-kind contributions by end users to the project.

A key meeting was the Research Advisory Forum in Brisbane (17-18 November 2015). There we presented progress on different parallel developments in our project and highlighted the need to narrow down objectives: until that stage different developments in the project took place without substantial trade-offs, but into the future there needed to be decisions about what aspects of research the project would focus on, so that discretionary resources could be directed as effectively as possible and achieve the most rapid progress. To guide the contraction of R&D topics, a survey was circulated and subsequent discussions took place over the two days, some casual and some facilitated and structured. Generally, end users expressed greater interest in information derived from freely available satellite data rather than the in-field and airborne methods. In-field methods raised concerns about the cost and the representativeness of the sample locations. However some end users did see the opportunity to include sensors such as NDVI sensors as part of the validation or calibration of broad scale methods. The survey results will be discussed in more detail in an upcoming milestone report.

CONFERENCES, FORUMS AND SEMINARS

During this financial year we have been invited to present in two occasions:

- M. Yebra: A very sensory environment: new views and capacities, Fenner School Forum, ANU (August 2016, Canberra)
- M. Yebra: Spatial data of the water cost of carbon capture and the environmental impacts of fire. Remote Sensing of Water Systems colloquium (October 2015, University of Zurich).

PUBLICATIONS LIST

JOURNAL MANUSCRIPTS

1) Marselis, S., Yebra, M., Jovanovic, T., van Dijk, A. 2016. Automated classification of mobile laser scanning observations to automatically derive information on forest structure and biomass. Environmental Modelling & Software. vol. 82, pp. 142-151, 8.

2) Chen, Y., Zhu, X., Yebra, M., Harris, S., Tapper, N. Strata-based forest fuel classification for wildfire hazard assessment using terrestrial LiDAR data. Submitted to International Journal of Wildland Fire.

3) Chen, Y., Zhu, X., Yebra, M., Harris, S., Tapper, N. Development of a predictive model for estimating forest surface fuel load with LiDAR data. Submitted to International Journal of Wildland Fire.

4) 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.

5) Quan, X., He, B., Yebra, M., Yin, C., Liao, Z., Li, X. Retrieval of live fuel moisture content of a two-layered forest using a coupled radiative transfer model. Submitted to Selected Topics in Applied Earth Observations and Remote Sensing.

6) Quan, X., He, B., Yebra, M., Yin, C., Liao, Z., Xueting, Z. Estimating Grassland Aboveground Biomass Using Radiative Transfer Model. Submitted to IEEE International Journal of Applied Earth Observation and Geoinformation.

7) 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.

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) 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.
2) 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.
3) Zylstra, P., Marselis, S., Horsey, B., Yebra, M. LiDAR improves fire behavior predictions using a biophysical, mechanistic model. EGU General Assembly 2016. Vienna. Austria. Poster.

4) Chen, Y., Zhu, X., Yebra, M., Harris, S., Tapper, N. Surface fuel load modelling with LiDAR data: A case study of upper Yarra reservoir area. Proceedings for the 5th International Fire Behaviour and Fuels Conference. April 11-15, 2016, Melbourne, Australia. Published by the International Association of Wildland Fire, Missoula, Montana, USA.
5) Yebra, M., Quan, X., van Dijk, A., Cary, G. Monitoring and forecasting fuel moisture content for Australia using a combination of remote sensing and modelling. Proceedings for the 5th International Fire Behaviour and Fuels Conference. April 11-15, 2016, Melbourne, Australia. Published by the International Association of Wildland Fire, Missoula, Montana, USA.
6) Yebra, M., Jurdao, S., Chuvieco, E., San-Miguel, J. Mapping Life Fuel Moisture Content for Europe using MODIS imagery. 10th EARSeL Forest Fire Special Interest Group Workshop - Limassol, Cyprus, Nov 2-5th. Oral presentation.
7) Gale, M.J., Yebra, M., Martin, D., Culvenor, D., Leavesley, A., Gill, A.M., Cary, G.J., De Waal, L., Farquhar, S. (2015) Understanding Grassland Curing for Fire and Land Management Operations in the Australian Capital Territory. Poster presented at the AFAC/BFNHCRC Conference, Adelaide, September, 2015.
8) Yebra, M., van Dijk, A., Cary, G., Marselis, S., Jovanovic, T., Gale, M., de Waal, L., Leavesley, A., Culvenor, D., Garlapati, N. and Chen, Y. Mapping bushfire hazard and impact. Poster presented at the AFAC/BFNHCRC Conference, Adelaide, September, 2015.
9) Garlapati, N., van Dijk, A., Yebra, M. and Cary, G. Mapping forest fuel load and structure from airborne LiDAR data. Poster presented at the AFAC/BFNHCRC Conference, Adelaide, September, 2015.
10) Chen, Y., Zhu, X., Yebra, M., Tapper, N. and Harris, S. Modelling forest fuel hazard change over time using LiDAR technology. Poster presented at the AFAC/BFNHCRC Conference, Adelaide, September, 2015.

MILESTONE REPORT

1) Holgate, C., van Dijk, A., Cary, G., Yebra, M. Analysis of the suitability of operational coarse resolution near-surface soil moisture data to improve the MacArthur forest fire danger index. (Bushfire and Natural Hazards CRC, 2015).
2) Yebra, M., Quan, X., van Dijk, A., Cary, G. Feasibility of satellite-based live fuel moisture content estimation across Australia (Bushfire and Natural Hazards CRC, 2016).
3) Yebra, M., Quan, X., van Dijk, A., Cary, G. Mapping fire ignition probability for Australia from satellite estimates of live fuel moisture content (Bushfire and Natural Hazards CRC, 2016).

OTHER PUBLICATIONS

- A post was published in the ANU newsletter about our recent collaboration with the NCI to produce the national live fuel moisture content product.
- The BNHCRC project research featured in a booklet of ANU Fenner School of Environment & Society research highlights.

CURRENT TEAM MEMBERS

The official project team is composed of three principal researchers and two PhDs students awarded a BHNCRC top-up scholarship.

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, who is currently modelling forest fuel hazard change over time using terrestrial LiDAR data. The technique she is developing will be tested at sites of different vegetation ages (time since fire) in southeastern Australia and the ACT.

NARSIMHA GARLAPATI

PhD candidate from ANU, who is interested in mapping forest fuel load and structure from airborne LiDAR data. He aims to produce spatially explicit information on fuel load and structure to develop a fire danger index that can be potentially integrated in the National Exposure Information System (NEXIS). He will also assess the accuracy of the LiDAR classification and the derived products based on standard product specifications.

LIST OF OFFICIAL PROJECT END USERS

1. John Bally, Bureau of Meteorology - lead end user
2. Adam Leavesley and Neil Cooper, ACT Parks and Conservation
3. Robert Preston, Public Safety Business Agency, QLD
4. Andrew Sturgess and Bruno Greimel, QLD Fire and Emergency
5. Laurance McCoy and Stuart Matthews, NSW Rural Fire Service
6. Andrew Grace, Attorney-General's Department, ACT
7. Richard Wald, SA Country Fire Service
8. Simeon Telfer, Department of Environment, Water and Natural Resources SA
9. Belinda Kenny, Office of Environment & Heritage, NSW
10. David Taylor, Tasmania Parks and Wildlife Service
11. Bruce Murrell and Michael Konig, Boeing Defence Space &Security
12. Frank Crisci and Ali Walsh, SA Power Networks
13. David Hudson, Geoscience Australia

OTHER CONTRIBUTING STUDENTS AND COLLABORATORS

1. **Dr. David Riaño**, senior researcher from 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.
2. **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.
3. **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.
4. **Mr. Xingwen Quan**, PhD candidate from the University of Electronic Science and Technology of China, received a scholarship from the China Research Council for an a occupational traineeship at the Fenner School, ANU, for the period 1 Sept 2015-1 Sep 2016 under the supervision of Yebra. He is supporting the development of the Forest Fire Information System.
5. **Ms. Suzanne Marselis**, MSc student from the University of Amsterdam, Netherlands, spent 6 months with the team to develop and test the Fuel Classification and Structure Software.
6. **Ms. Caroline Luiz**, an undergraduate student at ANU, was sponsored by the Brazil government to participate in the experiment at Braidwood (NSW).
7. **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.
8. **Dr. Samsung Lim** (UNSW), an expert on full-waveform LiDAR, is providing expert advice on the full-wave form LiDAR processing and is an associated supervisor for Narsimha Garlapati.
9. **Dr. Eva van Gorsel** (CSIRO), **Dr Peter Isaac** and **Dr. Jason Beringer** (University of Western Australia) collaborate closely on the evaluation of our forest-growth-carbon water estimation model.
10. **Dr. David McJannet** (CSIRO) leads the CosmOz network and collaborates closely on testing the cosmic ray sensor installed in Namadgi National Park to investigate its use for on-ground fire risk early warning in remote areas.

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