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MAPPING BUSHFIRE HAZARD AND IMPACT

Developing spatial information on fire hazard for planners,
land managers and emergency services

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An Australian Government Initiative



Australian
National
University

PROJECT END-USERS

- John Bally, Bureau of Meteorology (Lead-end-user)
- Adam Leavesley and Neil Cooper, ACT Parks and Conservation.
- Robert Preston, Public Safety Business Agency (QLD).
- Andrew Sturgess and Bruno Greimel, QLD Fire and Emergency
- Laurance McCoy and Stuart Matthews, NSW Rural Fire Service
- Andrew Grace, Attorney-General's Dept, ACT
- Richard Wald, SA Country Fire Service
- Simeon Telfer, Department of Environment, Water and Natural Resources. SA
- Belinda Kenny, Office of Environment & Heritage, NSW
- David Taylor, Tasmania Parks and Wildlife Service.

New end-users: Bruce Murrell and Michael Konig (Boeing Defence Space & Security)

PROJECT EXTERNAL COLLABORATORS

- Darius Culvenor (Sensing Systems)
- Jim Gould (CSIRO)
- Tom Jovanovic (ANU)
- Alex Held, Arantxa Cabello and Michael Schaefer (CSIRO/ TERN-AUSCOVER)
- Emilio Chuvieco (University of Alcala, Spain)
- Philip Zylstra (UOW)
- Samsung Lim (UNSW)

PROJECT STUDENTS

PhD students on “Mapping forest fuel load and structure from LiDAR”.

- **Narshima Garlapati** (ANU-APA+ BNHCRC top-up scholarship)
- **Yang Chen** (University of Monash-APA + BNHCRC top-up scholarship)

Undergraduate students

- **Lois Padgham** (ANU-Independent Research Project, ACT Parks).
Topic: Cosmic ray soil moisture probe for fuel monitoring
- **Lauren de Waal** (Engineering Honours student at ANU)
Topic: “Grassland curing and moisture content monitoring with automated sensing systems for bushfire prediction”

Academic study visitors

- **Susanne Marselis** (Graduated Msc Earth Sciences, University of Amsterdam)- (February-April 2015).
Topic: Terrestrial LiDAR and fuel structure.
- **Xingwen Quan** (PhD student, University of Electronic Science and Technology of China, Chengdu) (October 2015-October 2016)
Topic: Remote Sensing of Fuel Moisture Content

GOAL

- Produce reliable and operationally useful **spatial information on critical aspects of bushfire hazard** (fuel structure, load and flammability)
- Determine the **impact of unplanned and prescribed burning** on fuel accumulation as well as landscape values (habitat, water resources and carbon storage) over time, in support of fire management.

TWO DIFFERENT SET OF TRACKING METHODS

1) IN-FIELD methods

- a) Local scale
- b) End-user may need to collect and post-process the data using standardized protocols
- c) Provide objective, detailed and consistent observations at real time

2) Spatial information at national scale

- a) National scale
- b) Freely available and in most cases at near real-time

DISPLAY SCREEN




RECHARGEABLE BATTERY



IN-FIELD METHODS

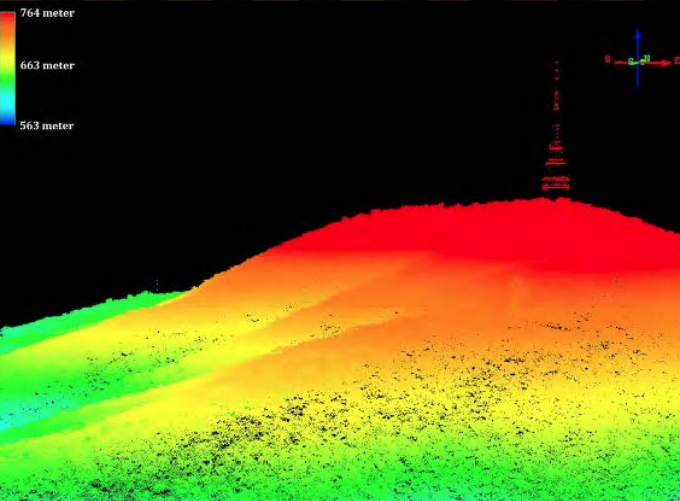
AUTOMATED AIRBORNE LIDAR FUEL STRUCTURE

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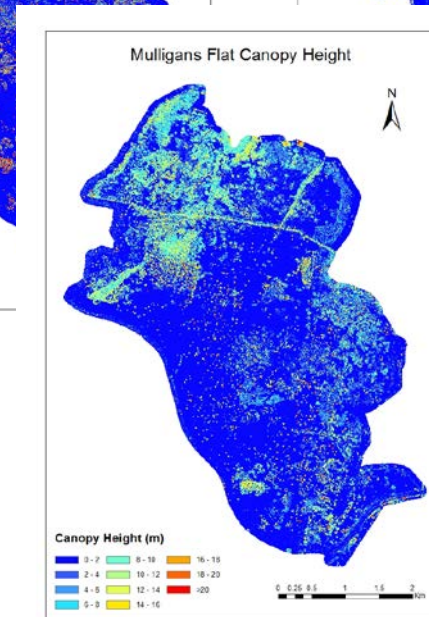
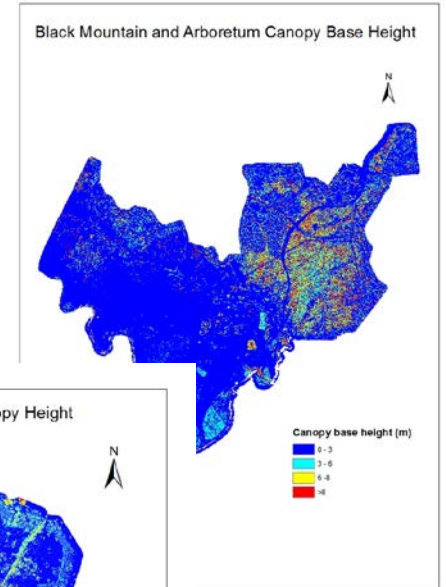
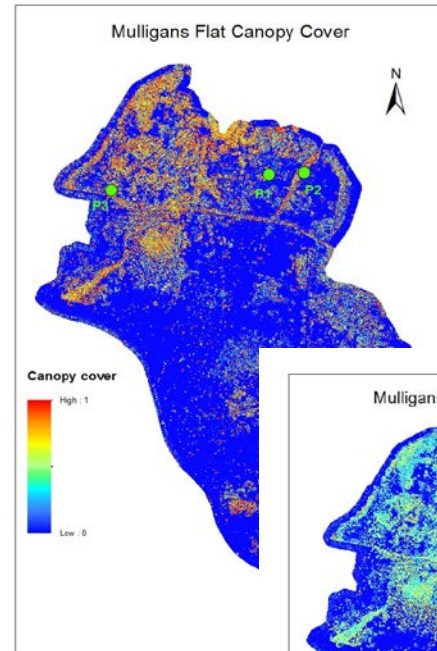


USING LIDAR FOR FOREST AND FUEL STRUCTURE MAPPING: OPTIONS, BENEFITS, REQUIREMENTS AND COSTS

Yebra, M,^{1,4} Marselis, S,^{3,1} van Dijk, A,^{1,4} Cary, G,^{1,4} and Chen, Y,^{2,4}
¹Australian National University
²Monash University
³University of Amsterdam
⁴Bushfire and Natural Hazards CRC



764 meter
663 meter
563 meter



AIRBORNE LIDAR FOR FUEL STRUCTURE MAPPING

Mapping forest fuel load and structure from airborne LIDAR data



Narsimha Garlapati^{1,2}, Albert Van Dijk^{1,2}, Marta Yebra^{1,2}, Geoffrey Cary^{1,2}

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Research Cluster: Monitoring and prediction, Project: Mapping bushfire hazard and impacts

AUSTRALIA IS A DRY CONTINENT, WITH HIGH CLIMATE VARIABILITY, AND IS CONTINUALLY VULNERABLE TO NATURAL HAZARDS LIKE BUSHFIRES. IN ORDER TO BETTER EVALUATE & REDUCE THE RISK OF BUSHFIRES, FIRE MANAGEMENT AGENCIES AND LAND MANAGERS NEED TIMELY, ACCURATE AND SPATIALLY EXPLICIT UNDERSTOREY FUEL METRICS ALONG WITH CLIMATIC AND OTHER SPATIAL TOPOGRAPHICAL INFORMATION. THE LIGHT DETECTION AND RANGING (LIDAR) DATA AND TECHNOLOGY IS A PROVEN ALTERNATIVE TO TRADITIONALLY TIME CONSUMING AND LABOUR INTENSIVE FUEL ASSESSMENT METHODS.

INTRODUCTION

- LIDAR technology and full-waveform form data has wide potential in forestry fuel mapping. This is because of increased capabilities in capturing the understorey and near surface fuel loads and other structural information with highest precision in a reasonable time.
- Now bushfire research must overcome many challenges (time & spatial accuracies) with the utilisation of the advanced ALS-FWL technologies to develop more accurate fuel data bases which are crucial for fire risk assessments.



Figure 1: Field survey plots (Photo credit: PhD student, UNW)

- EARLIER** fire management was making reliable estimates about the fuels with the combination of extensive ground survey data along with other remote sensing data (Figure 1).

- Even after the evolution of LIDAR, the remote identification and assessment of the elevated and near surface fuel (HSP) under denser canopies was challenging (Parsons et al., 2015). This is because discrete pulses cannot detect the understorey fuel/other structures due to weakening of pulses which were unable to reflect back to the sensor from the ground (Figure 2).

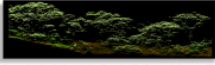


Figure 2: Black Mountain discrete LIDAR vegetation profile

Did you know?

Today airborne LIDAR systems (ALS) and technology with full-waveform LIDAR data (FWL) capability, has become a very accurate and affordable solution for forestry mapping covering larger areas in shorter timescales (Wagner et al., 2008)

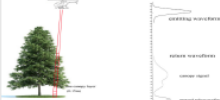


Figure 3: Full-waveform signal response on vegetation (Ho et al., 2018)

WHY FULL-WAVE LIDAR?
 FWL Laser pulses can penetrate through the dense canopies and are able to detect the understorey fuels over large areas with high spatial and volumetric accuracies. (Figure 3)

HOW MIGHT IT WORK?

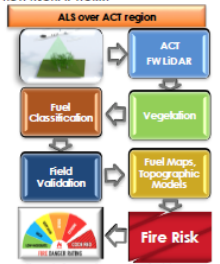


Figure 4: Proposed research methodology

ACKNOWLEDGEMENTS
 1. ACT Government Environment & Planning, Parks & Conservation for the FW LIDAR.
 2. BNHCRC for top-up scholarship and project support.
 3. CSIRO for the provision of discrete LIDAR and TERN for co-funding the FW acquisitions.

THIS PhD RESEARCH

- Investigates and utilises cutting-edge active remote sensing technologies like LIDAR to advance Australian bushfire research and utilise the next generation spatial information.
- Assesses the competence of full-waveform LIDAR to map the understorey forest fuels and structures for the whole of the ACT.
- Identify and develop high resolution spatial products which are of particular interest to bushfire and emergency management.
- Will develop an accurate fire risk index and add value to existing spatial data, to make informed decisions in critical times.

RESEARCH QUESTIONS

- Is FW LIDAR any better than the discrete form?
- How and to what extent the can FW-LIDAR data can be used in mapping bushfire hazards and impacts?
- Is the available LIDAR data complying with the national Fuel Classification system and the fuel hazard assessments based on the LIDAR derived fuel metrics?

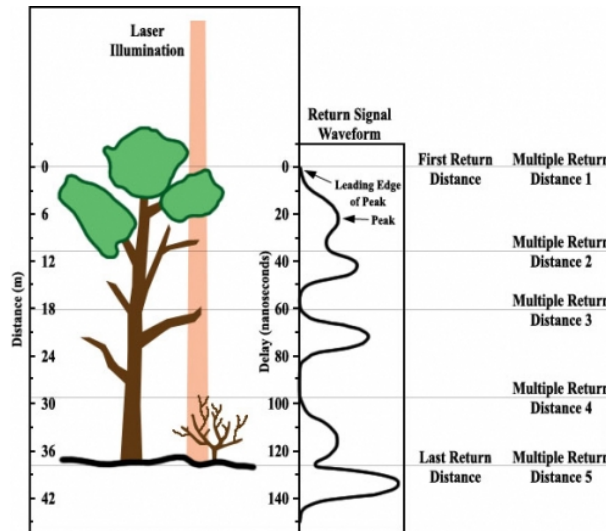
1. Mu, H., Song, J. and Wang, J., 2015. Forest Canopy LAI and Vertical Fuel Profile Inversion from Airborne Full-Waveform LIDAR Data Based on a Scatter Transfer Model. Remote Sensing, 7(2): 1887-1916.
 2. Wagner, W. et al. (2008). "3D vegetation mapping using small-footprint full-waveform airborne laser scanners."
 3. Parsons, M. W. et al. (2015). "Testing forest structure as a tropical forest using field measurements, a synthetic model and discrete return laser data." Photos from midg, carbonmap, black mountain field work

END-USER STATEMENT

This PhD research is well aligned with the BNHCRC's priorities and also with the stakeholders strategic objectives.
 Andrieta Siqueira, Geoscientist, ANHCRC

New Airborne **Full-wave** LiDAR collected across ACT July 2015 (funding from ACT Government and TERN)

Narsimha Garlapati PhD project



AUTOMATED GROUND-BASED LIDAR FUEL STRUCTURE CLASSIFICATION

MODELLING FOREST FUEL CHANGE OVER TIME USING LIDAR TECHNOLOGIES



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LIDAR based technology is proposed as a means to measure landscape-scale forest fuels in order to generate a fine effective, cheap and objective method for forest fuel hazard assessment. The technique was tested at sites of different vegetation ages in southeastern Australia to extract accurate information about forest fuel structure and assess forest fuel hazards. It will also assess how the other environmental factors impact on the hazards.

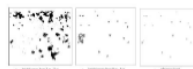


Fig. 1. Reference trunk identification.
 ▶ Tree trunks assignment
 ▶ Elevated shrubs reassignment
 ▶ Branches and Leaves assignment

A GIS TOOL DEVELOPMENT
 This study developed a GIS-based method for forest fuel strata classification. It can be applied to efficiently and objectively assess forest fuel characteristics in dense eucalypt forests as well as to estimate inventory parameters for forest fuel management using various laser scanning systems (e.g. tripod-mounted devices and portable devices).

The GIS tool supports a five-stage process for the automatic forest fuel layers classification and forest inventory and fuel hazard estimates: raw data extraction, Z to H conversion, fuel structure classification, fuel hazard assessment, and inventory estimates.

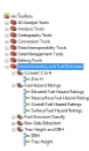


Fig. 2. A GIS tool for forest inventory and fuel estimates.

Fuel characteristics
 After the fuel structure classification, forest fuel characteristics can be more accurately and efficiently determined by terrestrial laser points, including fuel depth and horizontal continuity (Fig. 4).

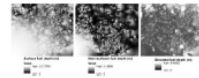


Fig. 4. LIDAR representation of fuel depth.

Inventory estimates
 Tree heights can be estimated by searching for the highest points within a distance of a threshold to the individual tree trunks, where the threshold refers to the maximum radius of crowns. The DBH is the diameter at breast height (1.3 m above the terrain) that can be estimated by a Hough circle fitting algorithm. The detected circles can be seen in Fig. 5. Basal area (BA) is the cross-sectional area of tree trunks which can be estimated based on the calculated DBHs.

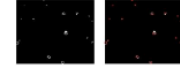


Fig. 5. Circle fitting application in detecting tree trunks.

Accuracy assessment
 Table 1. Accuracy assessment of terrestrial Lidar derived fuel depth (cm) and percentage cover (%) of different fuel layers.

Fuel Layer	Reference fuel depth (cm)	Reference fuel percentage cover (%)	Terrestrial Lidar derived fuel depth (cm)	Terrestrial Lidar derived fuel percentage cover (%)
Surface	1000	10.00	1000	10.00
Shrub	1500	15.00	1500	15.00
Tree	2000	20.00	2000	20.00

LIDAR has the great potential to efficiently and objectively preform strata-based forest fuel characteristics

END USERS STATEMENT

CURRENT FINDING

CONVENTIONAL FUEL LAYER CLASSIFICATION

Fuel layer classification aims to vertically classify fuels into groups including surface and near-surface fuels, elevated shrub fuels, and overstory fuels according to vertical height ranges. However, directly applying the conventional manner to the LIDAR point may lead to the following mis-classification: tall shrubs above 2 m are mis-assigned as overstory fuels; shrub fuels below 0.5 m are mis-classified as near surface fuels; trunks cannot be separated. These mis-classified points need to be reassigned according to the special relationship.

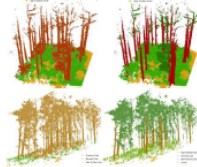


Fig. 3. The fuel strata classification comparison between the conventional manner (left) and the GIS-based method (right) using Zbedded (Za) and H(ei)g (height) (height).

LIDAR BASED FUEL STRUCTURE CLASSIFICATION

LIDAR derived fuel structure classification involves the following procedures:

- ▶ Horizontal slicing aims to separate laser points into groups based on the height interval.
- ▶ Reference tree trunks identification (Fig. 1.)

Marselis, S., Yebrá, M., Jovanovic, T., van Dijk, A. Automated classification of mobile laser scanning observations to automatically derive information on forest structure and biomass. Submitted to *Environmental Modelling and Software*. Under review.

Chen, Y., Zhu, X., Yebrá, M., Harris, S., Tapper, N. Strata-based forest fuel classification for wild fire hazard assessment using terrestrial LiDAR data. Submitted to *ISPRS Journal of Photogrammetry and Remote Sensing*. Under review.

MOVING TOWARDS A MORE OBJECTIVE FUEL ASSESSMENT

Traditional visual assessment

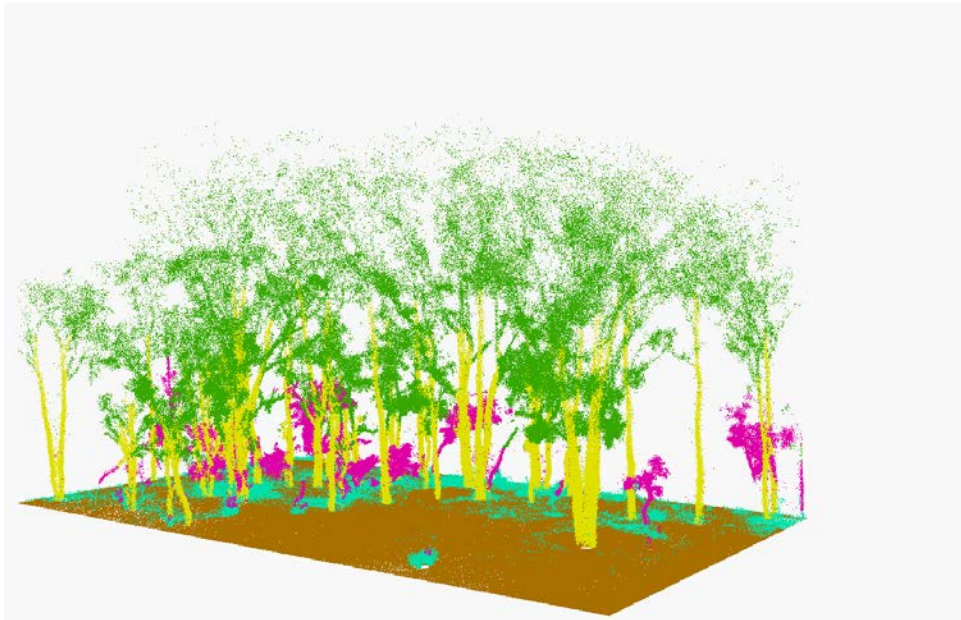


Terrestrial LiDAR (Zebedee)



CLASSIFIED POINT CLOUD

The classification algorithm is able to **automatically recognise 98% of the trees** in the study site and **80% of the elevated vegetation** components with an **error of commission of 20%**.

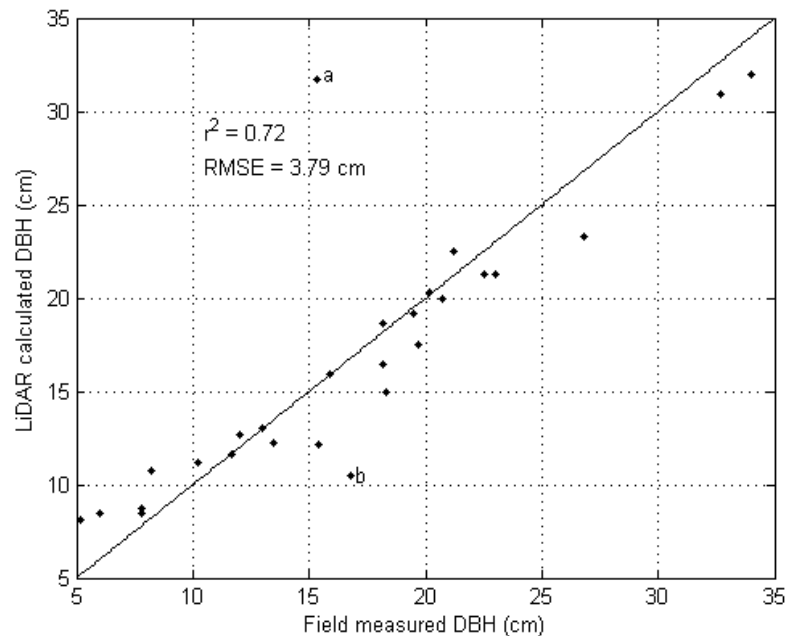


LiDAR classification	Field observed			Total
	Tree	Elevated	Not observed	
Tree	49	1	2	52
Elevated	0	12	1	13
Undetected	1	2	0	3
Total	50	15	3	68

Marselis, S *et al.* (2015, Submitted to *EMS*)

AUTOMATICALLY DERIVED INFORMATION ON FUEL STRUCTURE

- 1) Fractional cover and depth of near surface, elevated and canopy fuels
- 2) Diameter at breast height

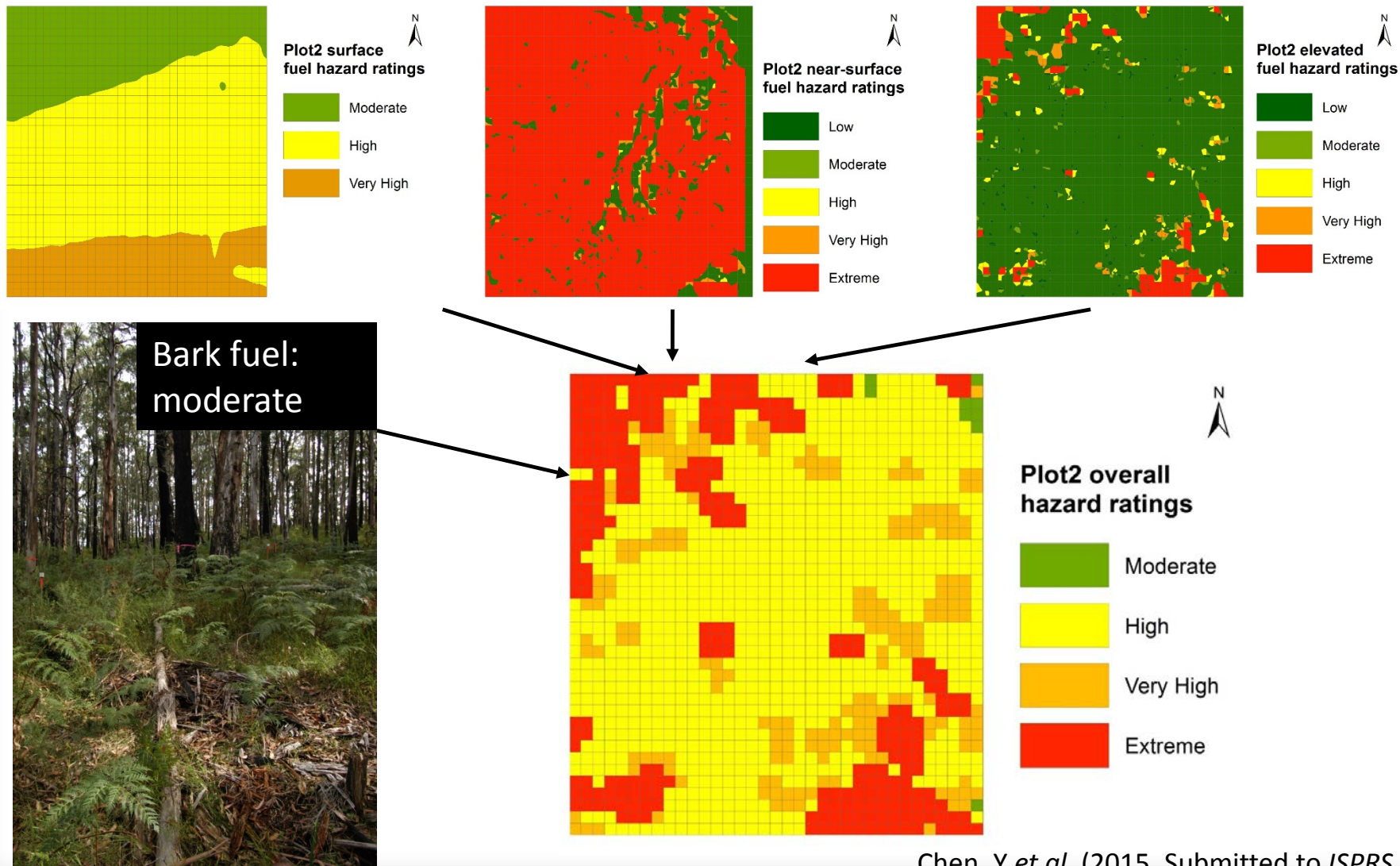


Marselis, S *et al.* (2015, Submitted to *EMS*)

Fuel Property	R ²	RMSE
Litter-bed depth	0.87	10.97mm
Litter cover	0.8	5.38 %
NS cover	0.94	6.9%
Elevate cover	0.87	9.86%

Chen, Y *et al.* (2015, Submitted to *ISPRS JPRS*)

LIDAR DERIVED OVERALL FUEL HAZARD RATINGS



SUMMARIZING

- 1) An algorithm has been developed to **automatically derived forest fuel structure and OFHA** from Zebedee LiDAR
- 2) This does not obviate field assessment but it will provide **more objective and consistent** way to assess the fuels in comparison to traditional visual assessments

INTEGRATED SENSOR SYSTEM FOR GRASSLAND CURING AND FMC

Understanding Grassland Curing for Fire and Land Management Operations in the Australian Capital Territory

Gale, M.J.^{1,2} Yebra, M.^{2,3} Martin, D.⁴ Culvenor, D.⁵ Leavesley, A.J.^{1,2} Gill, A.M.^{2,3} Cary, G.J.^{2,3} De Waal, L.³ Farquhar, S.^{1,2}

1. ACT Parks and Conservation Service
2. Bushfire and Natural Hazard: Cooperative Research Centre
3. Fenner School of Environment and Society, Australian National University
4. Victorian Country Fire Authority
5. Environmental Sensing Systems



One of the 5 sensors located at the array site

Understanding Grassland Curing

ACT Parks and Conservation Service is hosting a collaborative methodological study comparing the outputs from different grassland curing methods: the CFA satellite-based grass curing model; a ground-based array of Normalised Difference Vegetation Index (NDVI) sensors; the "Green Seeker®" (handheld NDVI sensor); and human field observations. A trial since September 2014 in the ACT has been undertaken which routinely collects visual curing levels using the CFA Grassland Curing Guide.

Grass curing is a key consideration for bushfire planning and operations. Accurate determination of the degree of grass curing is required for four public policy objectives: public warnings; fire response readiness level; fire behaviour predictions and fuel management activities such as slashing and grazing.

These images illustrate the change in Grass Curing over the summer period. The observed grass curing using the CFA Grassland Curing guide was inversely related to the NDVI measured at the array (Figure 1a). The Fuel Moisture Content (percentage of oven dried weight) of the grass samples was directly related to the NDVI measurements from the handheld Green Seeker® (Figure 1b).

Objective

The objective of the study was to compare the different grass curing estimation methods and to increase understanding of the interactions between grass curing, NDVI and FMC.

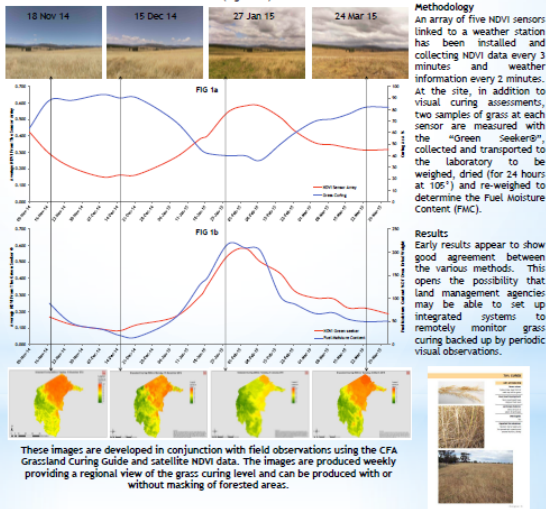


The meteorological station at the array site



Conclusion

The advantages of such systems would be a reduction in the reliance on staff and volunteers for checking satellite data and reduced exposure to human subjectivity.



Methodology
An array of five NDVI sensors linked to a weather station has been installed and collecting NDVI data every 3 minutes and weather information every 2 minutes. At the site, in addition to visual curing assessments, two samples of grass at each sensor are measured with the "Green Seeker®", collected and transported to the laboratory to be weighed, dried (for 24 hours at 105°) and re-weighed to determine the Fuel Moisture Content (FMC).

Results
Early results appear to show good agreement between the various methods. This opens the possibility that land management agencies may be able to set up integrated systems to remotely monitor grass curing backed up by periodic visual observations.

These images are developed in conjunction with field observations using the CFA Grassland Curing guide and satellite NDVI data. The images are produced weekly providing a regional view of the grass curing level and can be produced with or without masking of forested areas.

GRASSLAND CURING AND MOISTURE CONTENT MONITORING WITH AUTOMATED SENSING SYSTEMS FOR BUSHFIRE PREDICTION



Lauren de Waal

Supervised by Maria Yebra & Geoff Cary

Fenner School of Environment & Society, ANU College of Medicine, Biology & Environment
Research School of Engineering, ANU College of Engineering & Computer Science

1. BACKGROUND

- Australia has a hot and dry climate, prone to bushfire events
- Remote locations present monitoring issues for agencies as they are difficult to access and require expensive manpower
- Environmental Sensing Systems, alongside the CSIRO and ANU, are testing a set of stationary spectral sensors (Alexander et al. 2014). These sensors are deployable in remote areas as they measure Normalised Difference Vegetation Index (NDVI) and transmit results to a base station for online upload



2. GOALS

This research had two main purposes:

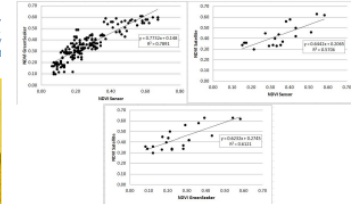
- To act as an expanded trial, testing spectral sensor NDVI estimates in a different geographic location, initial sensors tests were conducted in Victoria, 2014 (Alexander et al. 2014)
- To increase understanding of interactions between visual curing percentage, NDVI, Fuel Moisture Content (FMC) and meteorological effects

3. METHOD

- A grassland on Coppins Crossing Road in the Australian Capital Territory (ACT) was used for weekly data collection
- Five sets of spectral sensors were used on site, spaced along a transect of approximately 700m. The sensors measured NDVI every three minutes and transmitted this information. A base station gathered weather data and took photos of the grassland curing process, uploading all information to an online repository
- Weekly field site sampling included five visual curing percentage estimates, ten handheld "GreenSeeker" device measurements and ten FMC samples collected for further laboratory processing
- Satellite products were used to derive another value of NDVI over the sampling time period, for further comparison of spectral sensor results

4. RESULTS

- While the spectral sensors, GreenSeeker and satellite followed the same greening trends over the summer period, the methods predicted significantly different values of NDVI



An ANOVA further confirmed differences between methods

	Difference between Mean Values	F Value	Significant
GS v S	0.0005	0.0002	No
GS v SAT	0.0003	0.0002	Yes
S v SAT	0.0027	0.0448	Yes

- Two regression analyses were used to determine the best subsets for explaining variation in visual curing and FMC results

	Adjusted (R)	ACC	NDVI GS	NDVI S	NDVI SAT	FMC
Visual Curing	0.37	23.01	<0.001	-	0.002	-
FMC	0.59	18.06	0.001	-	0.007	-

- It was found the best possible combination when predicting curing and FMC was using the GreenSeeker and satellite products, without inclusion of spectral sensor results

5. CONCLUSIONS

The spectral sensors should be further considered for bushfire monitoring purposes, undergoing additional testing in different locations and within varied vegetation types to extend range of employment. As the trial restarts in the 2015-16 summer season, it is recommended that method changes include GreenSeeker measurements directly underneath spectral sensor locations and the formation of a grid system for strategic FMC sampling. This would ensure better practice data collection and monitoring. Ultimately, the measurement technique chosen for monitoring depends on fire authority operational plans, access to technologies and budget constraints. Utilising a combination of methods presented would allow management agencies to establish integrated systems for improved remote monitoring of grasslands, using only intermittent visual assessments.

REFERENCES

Alexander, L., Culvenor, D., Westburn, G., Martin, G., Beesley, R., Nelson, G., Wilson, S. & Cary, A. (2014). Automated sensing system for grassland/curing monitoring of grassland curing. Country Fire Authority Victoria, Australia.

Culvenor, D. (2014). ACT Grass Curing Trial Methodology Report. Spectral Sensor Image.

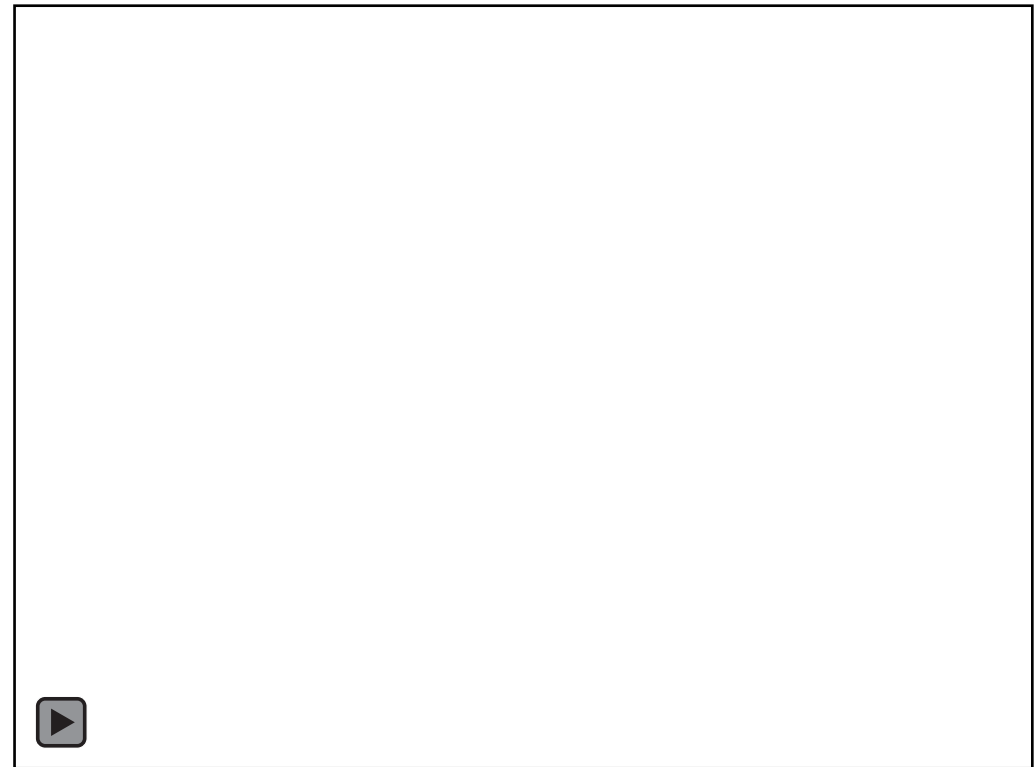
2nd Conference on Engineering Students Individual Projects
CSIU
October 2015
Contact: lauren.dewaal@anu.edu.au

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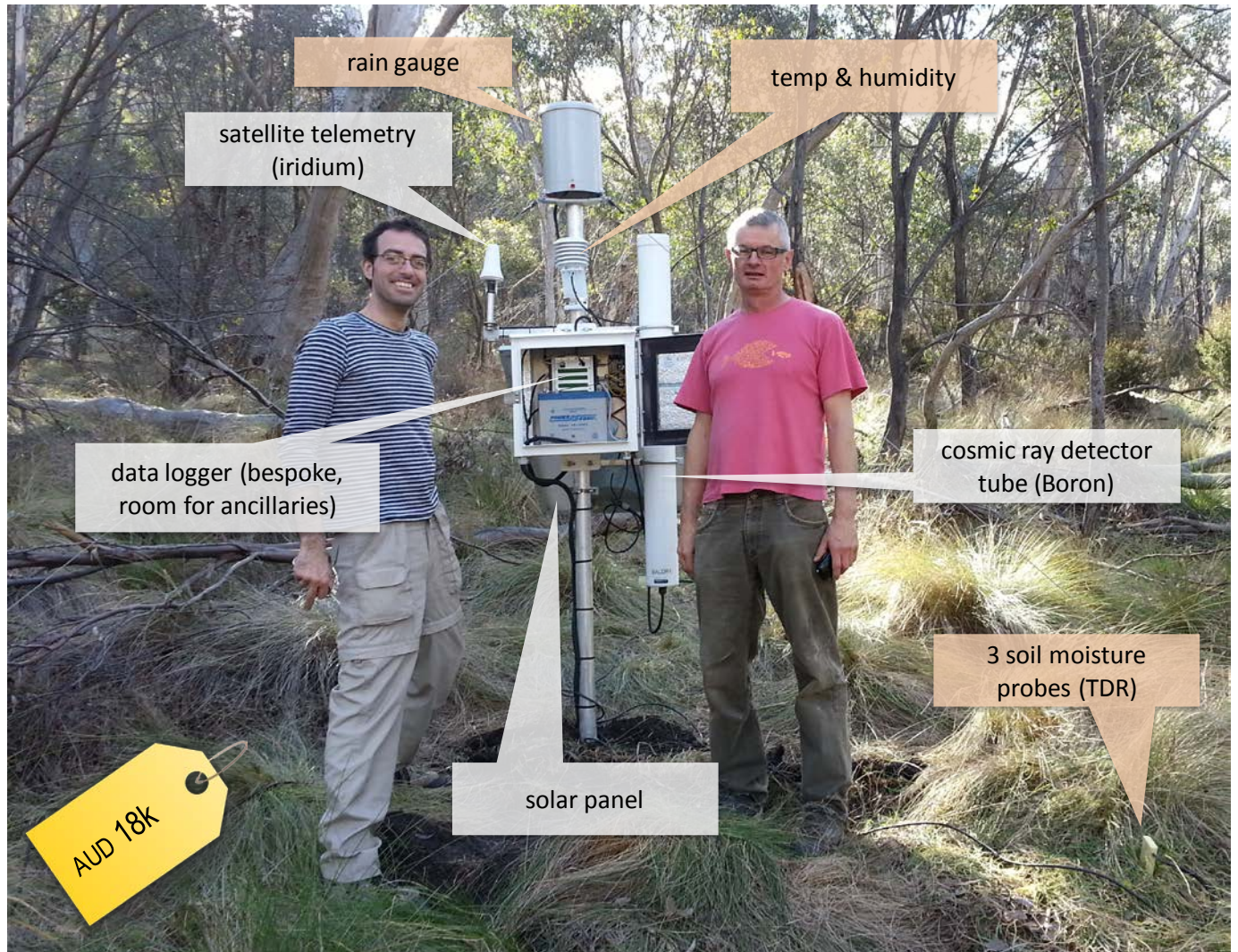
INTEGRATED SENSOR SYSTEM FOR GRASSLAND CURING AND FMC

Trial with in-situ sensors for monitoring grass curing and FMC

- Detailed and consistent observations
- Useful for models evaluation



COSMIC RAYS FOR FIRE RISK WARNING



AUD 18k

Funding: Actew/ActewAGL

FIELD WORK IN NAMADGI NATIONAL PARK





SPATIAL INFORMATION

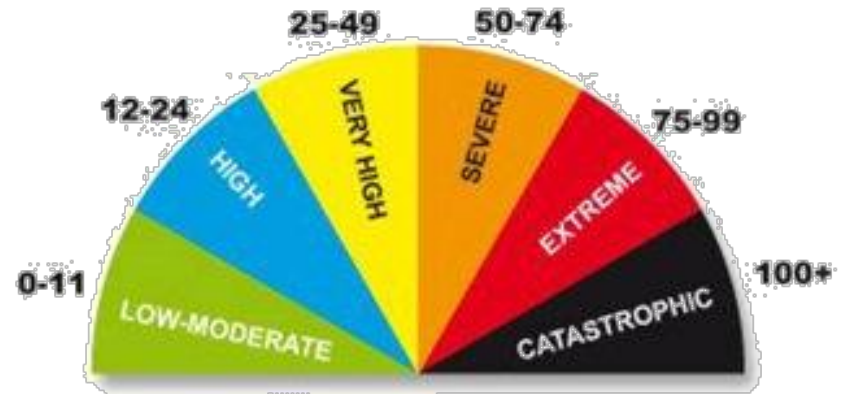

SOIL MOISTURE DATA TO IMPROVE FFDI

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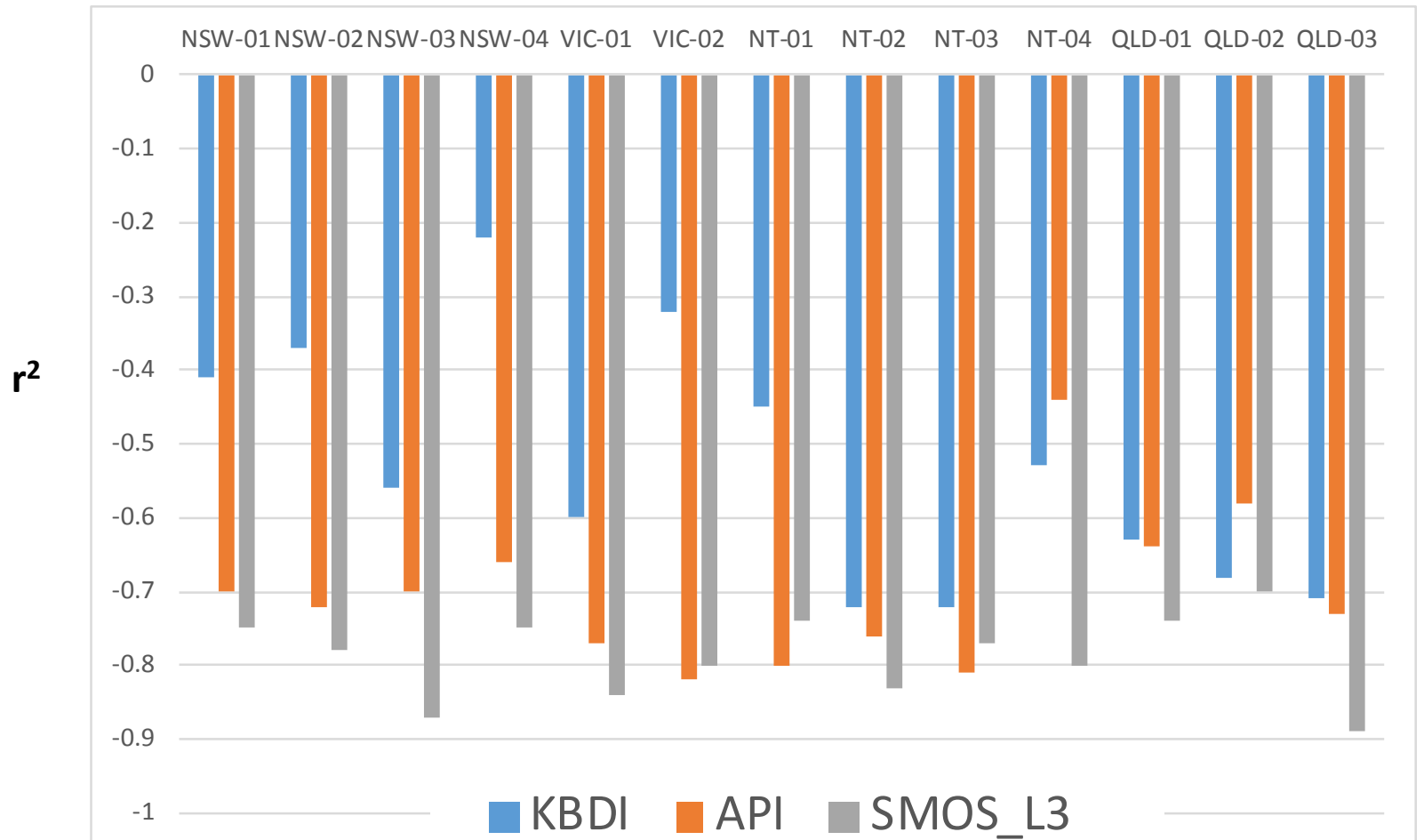
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ANALYSIS OF THE SUITABILITY OF OPERATIONAL COARSE RESOLUTION NEAR-SURFACE SOIL MOISTURE DATA TO IMPROVE THE MCARTHUR FOREST FIRE DANGER INDEX

Chiara Holgate, Albert van Dijk, Geoff Cary and Marta Yebra
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KBDI IS A RELATIVELY POOR PREDICTOR OF SOIL MOISTURE CONTENT



(2010-2013)

SUMMARIZING

- 1) **Better soil moisture estimates than KBDI** are freely and readily available, both from models and satellite products.
- 2) Replacing the KBDI with more accurate soil moisture estimates is not straightforward, as it requires **scaling of the soil moisture units**.
- 3) This highlights the **lack of physical basis** and interpretation for the McArthur FFDI

FUEL MOISTURE CONTENT DERIVED FROM MODIS



FUEL MOISTURE CONTENT DERIVED FROM MODIS

Model

Fuel Moisture Content based on the inversion of Radiative Transfer Models using MODIS data (Yebara et al 2008, 2009; Jurdao et al 2013a,b,c)

Basic data

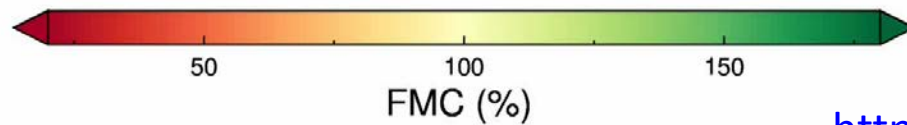
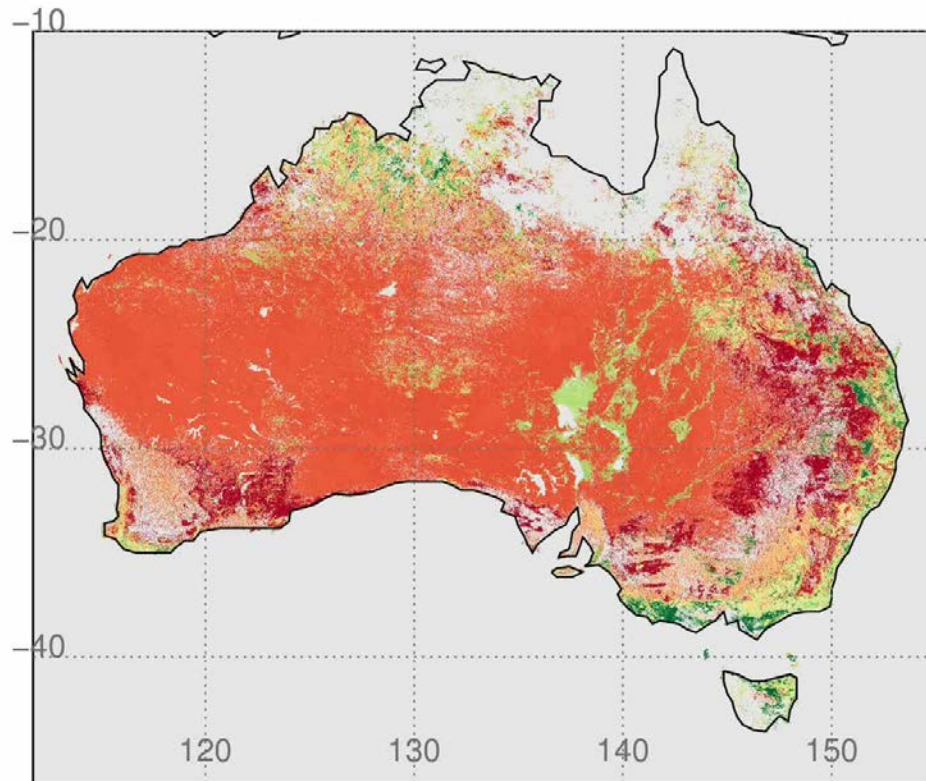
- 500 m MODIS reflectance, 8 days (daily)
- 250 m Dynamic Land Cover map (GA)
- Look up table

Data for **validation**:

- Grassland (Coppins Crossing+Braidwood) and woodlands (Namadgi) (2014-2015)- in collaboration with ACT Parks
- 79 sites located in NSW, ACT, VIC, QLD, WA, TAS (2006-2015) thanks to Glenn Newman, Gabrielle Caccamo, Brendan Phippen, Ross Bradstock.
- Data for the NT requested to Andrew Edwards.
- SA?

13 YEARS OF FUEL MOISTURE CONTENT

01.01.2002




<https://youtu.be/OacMUz048il>

SUMARIZING

- 1) The first prototype of a **satellite-based Fuel Moisture Content** product for Australia at 500m resolution has been produced at 8-day intervals
- 2) Potential to apply it to Landsat (30m) but loosing temporal resolution (ca. 16 days at best)
- 3) What is more useful from an operational point of view?
 - a) Absolute values
 - b) Anomalies
 - c) Probability of ignition (Moisture of Extinction (Chuvieco et al 2004) or logistic models (Jurdao et al 2012))
 - d) Integrated in the new National FD RS based on physical parameters.

HIGH-RESOLUTION FIRE RISK AND IMPACT (HIFRI) FRAMEWORK

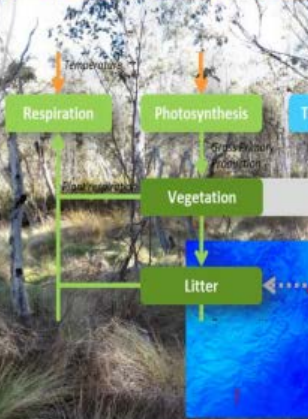
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A MODEL-DATA FUSION FRAMEWORK FOR ESTIMATING FUEL PROPERTIES, VEGETATION GROWTH, CARBON STORAGE AND THE WATER BALANCE AT HILLSLOPE SCALE

FEASIBILITY STUDY IN NAMADGI NATIONAL PARK, ACT

Albert van Dijk, Marta Yebra, Geoff Cary
Fenner School of Environment & Society
The Australian National University



Questions:

- What is the impact of planned or unplanned burning on water, carbon, habitat?
- How does it vary in space over 10-100 m scale?
- Can that knowledge help management, e.g. prescribed burning?

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Global vegetation gross primary production estimation using satellite-derived light-use efficiency and canopy conductance

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Abstract:
Climate and physiological controls of vegetation gross primary production (GPP) vary in space and time. In many ecosystems, GPP is primarily limited by absorbed photosynthetically-active radiation; in others by canopy conductance. These controls further vary in importance over daily to seasonal time scales. We propose a simple but effective conceptual model that estimates GPP as the lesser of a conductance-limited (F_c) and radiation-limited (F_r) assimilation rate. F_c is estimated from canopy conductance while F_r is estimated using a light use efficiency model. Both can be related to vegetation properties observed by optical remote sensing. The model has only two fitting parameters: maximum light use efficiency, and the minimum achieved ratio of internal to external CO_2 concentration. The two parameters were estimated using data from 16 eddy covariance flux towers in major biomes including both energy- and water-limited ecosystems. Evaluation of model estimates with lower derived GPP compared favourably to that of more complex models, for fluxes averaged; per day ($r^2 = 0.72$, root mean square error, RMSE = $2.48 \mu\text{mol C m}^{-2} \text{s}^{-1}$, relative percentage error, RPE = -1.1%), over 8-day periods ($r^2 = 0.78$, RMSE = $2.05 \mu\text{mol C m}^{-2} \text{s}^{-1}$, RPE = -1.0%), over months ($r^2 = 0.79$, RMSE = $1.93 \mu\text{mol C m}^{-2} \text{s}^{-1}$, RPE = -0.8%) and over years ($r^2 = 0.54$, RMSE = $1.62 \mu\text{mol C m}^{-2} \text{s}^{-1}$, RPE = -0.9%). Using the model we estimated global GPP of $1.07 \text{ Pg C yr}^{-1}$ for 2000–2011. This value is within the range reported by other GPP models and the spatial and inter-annual patterns compared favourably. The main advantages of the proposed model are its simplicity, avoiding the use of uncertain biome- or land-cover class mapping, and inclusion of explicit coupling between GPP and plant transpiration.

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1. Introduction

Plant physiological control of these opposing fluxes is exerted by stomata and the degree of control is quantified in terms of leaf stomatal conductance. At the ecosystem level, canopy conductance for water vapour ($G_{w,c}$) and CO_2 ($G_{c,c}$) provide links between transpiration and photosynthesis, respectively. Estimates of canopy conductance can be obtained by upscaling stomatal conductances for all leaves in the canopy (e.g. Reich, 2000; Reich, 2000; Reich, 2000), or be inferred from measurements of exchanges of water vapour and CO_2 (e.g. Leuning, 1995). Both approaches have been shown to be suitable for application at canopy or local scales (<1–2 km) but to derive regional or global estimates of canopy conductance, satellite remote sensing

In a previous study, Yebra, Van Dijk, Leuning, Huete, and Guerschman (2013) used eddy covariance measurements of water vapour fluxes at 16 sites distributed globally to establish relationships between $G_{w,c}$ and Moderate Resolution Imaging Spectroradiometer (MODIS) reflectance observations. When the derived estimates of $G_{w,c}$ were combined with net radiation, wind speed and humidity deficit data, the resulting estimates of evapotranspiration (ET) were compared favourably with those from alternative approaches. Moreover, the method allowed a single parameterisation for all land cover types, which avoids artefacts resulting from errors in vegetation classification. In principle, the same satellite-derived $G_{w,c}$ values can be used within a process-based model for Gross Primary Production (GPP) while providing a direct link to the coupled energy and water balance of plant canopies.

In many ecosystems, GPP is limited by the amount of absorbed photosynthetically-active radiation (APAR), rather than by canopy conductance. The simplest approach to estimating GPP for these conditions is to multiply APAR by a light-use efficiency term (LUE for $\mu\text{mol C mol}^{-1}$ APAR) representing the plant's capacity to convert light into fixed carbon (Running, Nemani, Glassy, & Thornton, 1999; Sims et al., 2008; Sjöström et al., 2011). This approach requires maximum LUE to be

HIGH-RESOLUTION FIRE RISK AND IMPACT (HIFRI) FRAMEWORK

Model

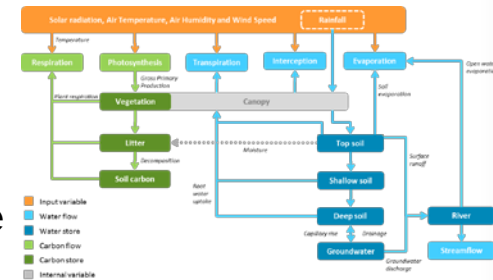
Spatial forest growth, water use and carbon uptake model based on the BoM AWRA model.

Basic data

- 30m Data Cube Landsat data (vegetation)
- 1km TERN e-Mast daily precipitation and temperature
- 5km BAWAP/SILO daily short-wave radiation
- 30m relief and landscape morphology (TERN, GA)

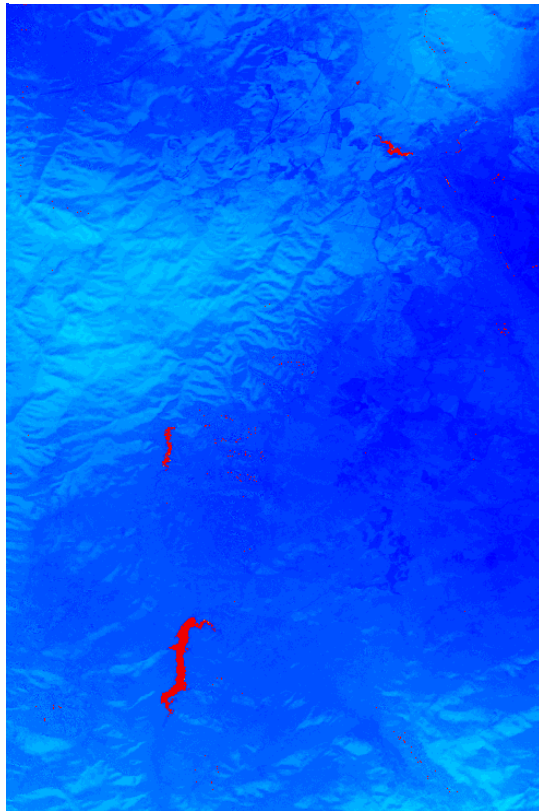
Data for **validation** and investigation of **added value**:

- airborne LiDAR (forest structure)
- airborne hyperspectral data (canopy density, moisture)
- field measurements (vegetation and fuel attributes)
- TERN OzFlux site data @ Tumbarumba (water and carbon fluxes, vegetation structure)
- CosmOz cosmic ray sensor @ Corin Dam (large area soil moisture, micro-climate)

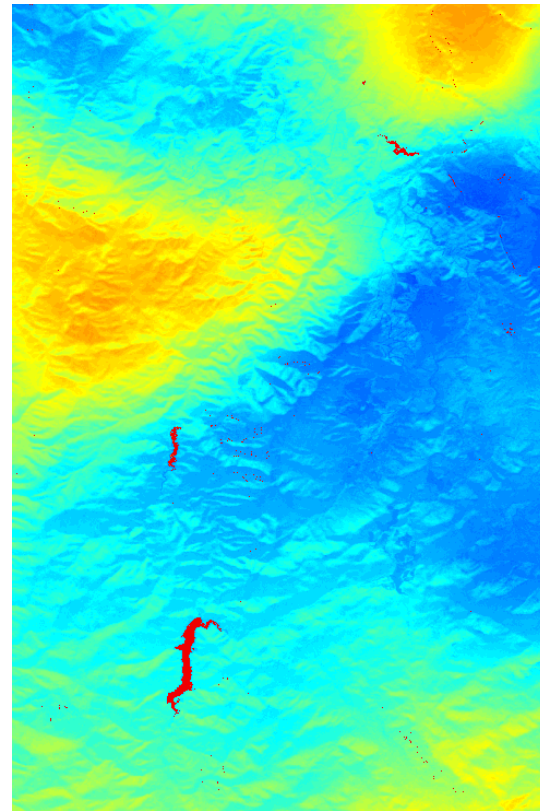


OUTPUT: SOIL MOISTURE PATTERNS

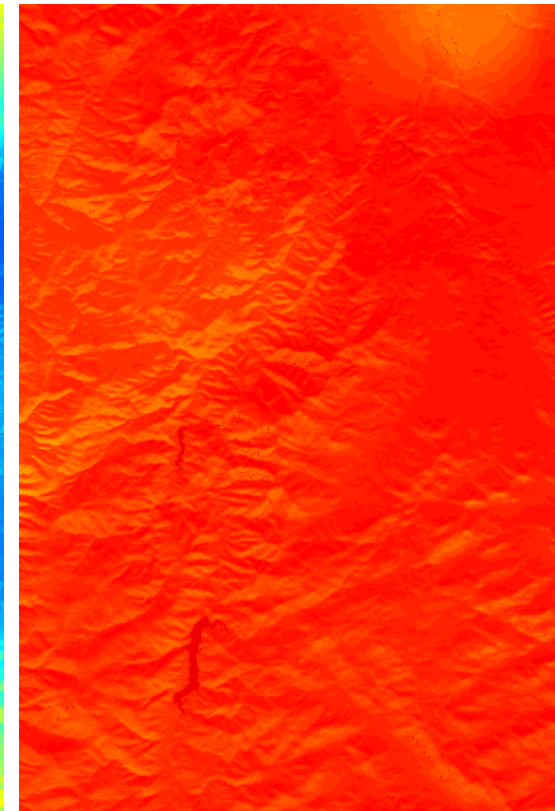
estimated moisture vol.% in top 10 cm mineral soil



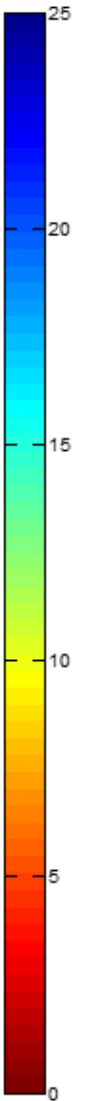
6 August 2002



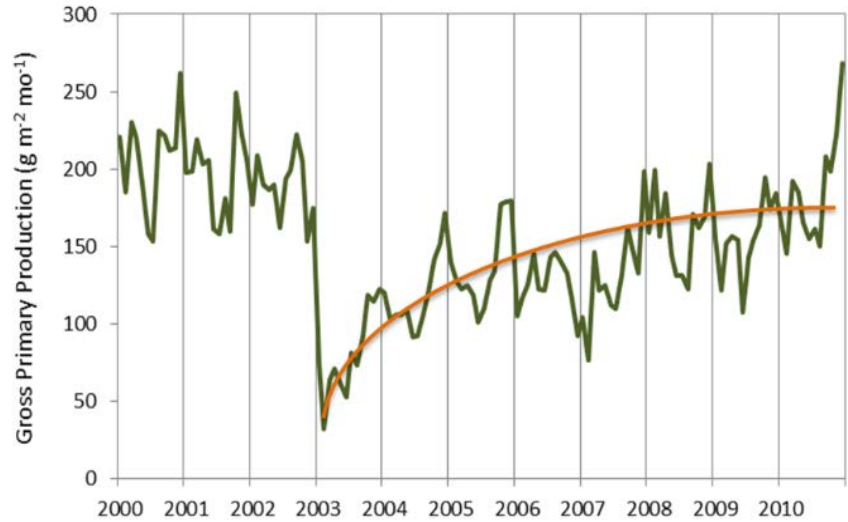
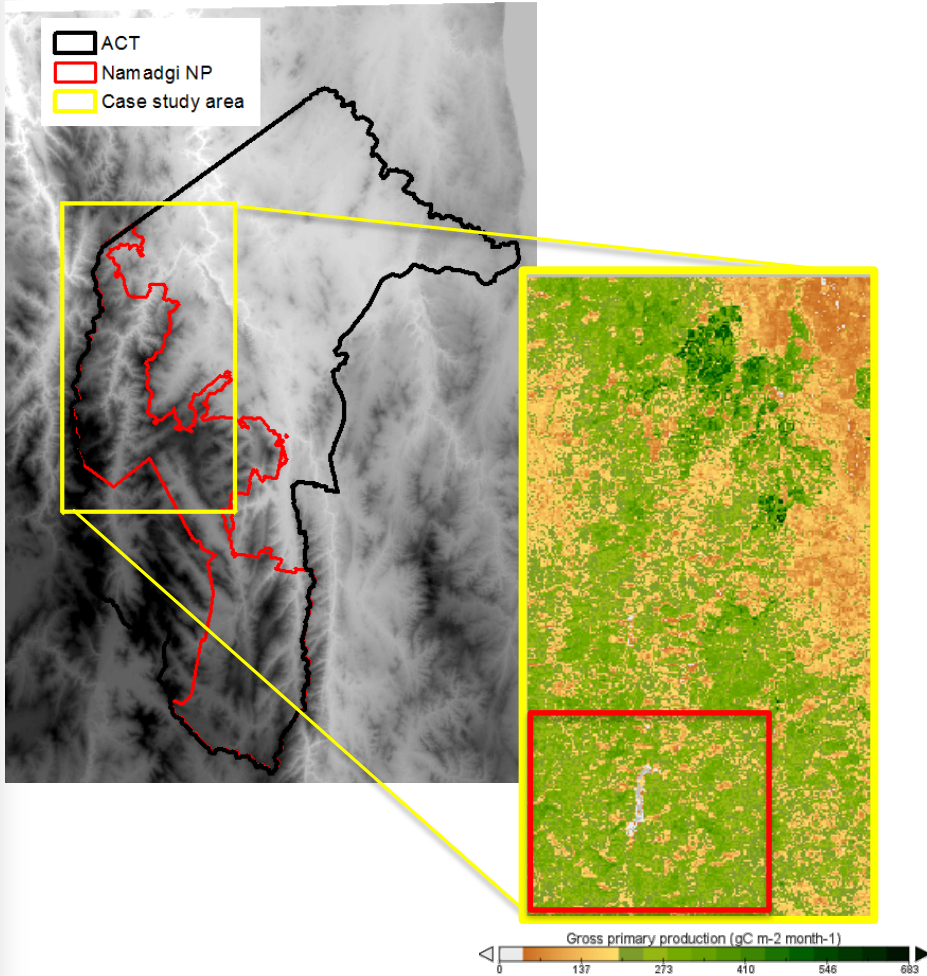
16 October 2002



29 December 2003



CASE STUDY: CORIN DAM CATCHMENT



SUMMARISING

- Spatial estimates of various aspects of vegetation (fuel/carbon/biomass) and water can be generated
 - anywhere in Australia
 - at 30 m detail
 - daily time step
- What are the most useful applications? *What mapping products could you potentially see an application for?*
- Although driven by observations, it is still essentially a model, and so prediction **quality assessment** is paramount to gain confidence in the predictions.
- This can be achieved using a comprehensive range of observations :
 - vegetation, weather, water or soil
 - point-based or airborne

TAKE HOME MESSAGE

- 1) An algorithm has been developed to **automatically derived forest fuel structure and OFHA** from Zebedee LiDAR
- 2) We are testing two **integrated sensor systems** (curing sensors-COSMOS) for fire risk warning
- 3) Much **better soil moisture estimates than KBDI** are freely and readily available. However replacing the KBDI with more accurate soil moisture estimates is not straight forward.
- 4) A **satellite-based Fuel Moisture Content** product for Australia 500m resolution has been produced and can be converted into probability of ignition or integrated in the new National FD RS based on physical parameters.
- 5) HiFRI provides **estimates on forest fuel load and moisture content and fire impacts on landscape values** such as water resource generation and carbon storage by integrating satellite observations into an environmental model.

CURRENT PRIORITIES FOR FUTURE WORK

- 1) Complete documentation of outputs
- 2) Decide on next priorities based on end-user feedback

THANK YOU!

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