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MAPPING BUSHFIRE HAZARD AND IMPACTS

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The Elevator Pitch:

This project will bring the industry closer to an operational broad-scale, spatially explicit fuel data collection system relevant to Vesta or Overall Fuel Hazard Assessment (OFHA) that can be used in existing fire behaviour models. The work will also help end-users to understand what information is easily and reliably collected from remote systems as a precursor to developing a new fire behaviour model based on the remote data.

Introduction:

Government agencies, individuals and businesses need accurate spatial information on fire hazard to prevent, avoid and manage impacts. Bushfire hazard depends not only on weather but also on landscape conditions. For example, fire hazard monitoring in Australia involves fire danger indices that consider mainly meteorological conditions, although a simple algorithm is used in the McArthur Forest Fire Danger Index to calculate the 'Drought Factor Value' from antecedent weather data, intended as a rough estimate of litter moisture content (e.g. Finkele et al., 2006; Dowdy et al., 2009). To date, there has not been much emphasis on routinely providing and using spatial information on landscape-related hazard factors in determining fire risk. Partly, this is because of a lack of reliable, consistent, accurate and long-term information. This situation is changing, however. Several relevant satellite, airborne and mapping derived products and prediction models are now readily available to estimate important landscape variables that determine fire hazard. Their applicability, added value and any adaptations required need to be assessed with direct reference to the data currently required for fire risk calculations and fire behaviour models, and how these might change in the near future due to current or upcoming research on fuel and fire behaviour.

This project will develop methods to produce the spatial information on fire hazard needed by planners, land managers and emergency services. The relevance and added value represented by these new information sources will be compared to the practical feasibility and costs of its use. Together with the end users, we will develop worked case studies and guidelines to describe how each information source can be produced and/or used operationally and to determine research and development requirements and priorities to achieve that.

The Project:

The project is structured in two main activities

Activity 1. Fire hazard mapping and monitoring

Spatial information on fuel properties can improve fire preparedness through better fire danger rating and supporting logistics and resources planning by emergency services (Hines et al., 2010). It can also improve fire management by helping guide activities such as prescribed burning. Forest fire behaviour models (and bushfire event simulators based on them) also require specific information on fuel structure. For example, fire behaviour models for dry eucalypt forest recently published by CSIRO and collaborators (Cheney et al. 2012; McCaw et al., 2012) and the Phoenix fire event simulator (Tolhurst et al. 2008) both rely on fuel hazard scores that describe various aspects of fuel quantity and arrangement across a range of fuel strata (e.g., Hines et al., 2010). Based on literature review and discussion with end users, the following priorities were identified:

- Arguably the greatest and most urgent information gap is spatial knowledge of the load and attributes of *forest fuel*.
- As a proxy for *fuel moisture*, the drought factor value is usually calculated for climate stations with over-simplified assumptions about its value in between stations. Furthermore the index itself is an empirical and only very approximate one developed in a time when more accurate data were not available.

Currently, limited use is made of the considerable body of spatial data available on the above, and hence there are several opportunities for research to help improve fire hazard mapping, monitoring and prediction.

<u>Approach</u>**:** Initially, we will review and analyse the potential added value of new data sources relating to each of the above aspects. The utility and feasibility of using a new data source will depend on such factors as spatial resolution, accuracy, operational availability and the resources required for data acquisition, processing and interpretation.

Where possible, the spatial data derived will be evaluated against ground-based measurements of critical fuel hazard scores (e.g. surface and near surface fuel hazard and elevated fuel hazard scores for the mentioned fire models, the drought factor value, etc.). Where appropriate, the information will be developed to fit into the Fire Danger Rating system or fuel classification systems suitable for end users.

Data sources at this stage considered to have the greatest potential include:

[1] *Forest fuel load and structure at high resolution (<5 m).* For local fire management and preparedness large area data are likely to be inadequate. In these applications, other observation sources can be used, however. Full wave form airborne Light Detection And Ranging (LiDAR) data allows very detailed mapping of fuel in all vertical layers and even coarse woody debris at very high resolution (e.g., Riano et al., 2003; García et al., 2012; Skowronski et al., 2011), although data acquisition and processing can be costly. By linking to research conducted and data collected by the ACT and Victorian governments and the CSIRO, we will analyse the information content and accuracy of airborne LiDAR acquired for parts of the ACT and Victoria and determine opportunities to reduce the costs of data processing and improve the information derived from it.

[2] *Forest fuel load and structure and moisture content at moderate resolution (30-1000 m).* Where LiDAR is not an option, potentially valuable information of forest structure and moisture content may still be derived from satellite observations. For example, we developed a method to measure live fuel moisture content by optical remote sensing (Yebra et al., 2008, Jurdao et al., 2013) that has already been applied for fire hazard assessment across Spain (Chuvieco et al., 2011). The method can be applied using optical data freely available at 30-500 m resolution (e.g. Landsat, MODIS) and can also be used in newer generation fire behaviour models such as the Forest Flammability Model (Zylstra, 2011ab). This information can be expected to be particularly informative for predicting the behaviour of fire in shorter vegetation (e.g., heath and shrubland) as well as crown fires in forests with dynamic forest canopy moisture content.

[3] *Dead fuel moisture content at coarse resolution (>5 km)* is continuously observed over Australia by satellites using passive microwave (e.g., SMOS, AMSR2) and radar instruments (e.g., ASCAT) (Liu et al., 2011, 2012). They represent the moisture content of the top few cm of soil only and therefore are particularly relevant to litter moisture content. They also provide information on ground saturation that can help assess flood hazard. These data have not yet been used in fire risk assessment or forecasting. The main limitation is their relative coarse resolution but strengths are that they are freely available and can be operationally updated every 2-3 days. These properties may make them particularly suitable for regional rather than local management purposes (e.g. in fire danger rating systems). Analyses over Australia have shown that good quality observations are available even for relatively dense woodlands (but not wet forests; Liu et al., 2011, 2012). Top soil moisture content is also estimated daily across Australia by the AWRA model-data system that is used operationally in BoM for water resources assessment reporting and water accounting (Van Dijk et al., 2011) and can also assimilate satellite soil moisture observations (Renzullo et al., in prep.). We will analyse which of these data can be used to improve the McArthur FFD index and under what circumstances. We will do so through a statistical comparison and difference analysis with the current Drought Factor Value, as well as through direct comparison against simultaneous field-measured fuel and moisture content.

[4] *Live fuel load and moisture content at coarse resolution (>5 km).* Live standing biomass can also be derived directly from the same passive microwave remote sensing for all of Australia by making use of the influence of vegetation biomass water content on the satellite signal (Liu et al., 2011, 2012, 2013). These observations are available for any vegetation type and even for relatively dense forests. By automated interpretation of the biomass water content against preceding values, it is possible to estimate above ground biomass fuel load and moisture content separately. This application will be developed and combined with vegetation data at higher resolutions to test the possibility of down-scaling the passive microwave information.

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 and subsequently taken up again after burning. 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; Van Dijk & Keenan, 2007).

<u>Approach</u>**:** We will perform a spatial case study for one or more of ACT's water catchments recovering from the 2003 bushfires and nearby NSW forests. We will analyse airborne and remote sensing observations and using these observations to improve and set up a spatial forest growth, water use and carbon uptake model. In particular, will 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. The data used will include:

- spatial data on forest structure from airborne LiDAR (see Activity 1),

- existing and new targeted field observations on vegetation and fuel attributes made by ACT and ANU researchers, and
- Landsat-derived estimates of vegetation cover and canopy conductance (a critical input to water and carbon models) using the method published recently by Yebra et al. (2013).

The data will be used set up and evaluate the spatial vegetation growth, carbon uptake and water use model developed as part of the Australian Water Resources Assessment system (AWRA, Van Dijk, 2010). The model is currently used by the Bureau of Meteorology Climate and Water Division at 5 km resolution to produce the National Water Account and Australian Water Resource Assessment reports. We will use higher resolution climate and topography inputs (available from the TERN e-Mast project (Hutchinson et al., in prep.) and the SRTM elevation model, respectively) to produce spatially detailed estimates of biomass and litter dynamics and moisture, water use and carbon uptake, constrained by Landsat satellite observations available from GA. We will use model-data fusion and data assimilation techniques to integrate these data types.

The resulting estimates will be evaluated using field biomass and fuel measurements made by ACT agencies, vegetation, water and carbon measurements made by the CSIRO in nearby NSW (Tumbarumba; Van Gorsel et al., 2012, 2013), and new data on vegetation attributes collected in the field.

The resulting time series will be combined with mapping of past fire events and severity (produced by ACT and NSW agencies or derived from remote sensing burned area mapping, or both) to analyse the impact on water, carbon and fuel as a function of fire severity and time since burning.

Publications

Dr. Marta Yebra completed a paper with her previous PhD student "Laboratory Measurements of Plant Drying: Implications to Estimate Moisture Content from Radiative Transfer Models in Two Temperate Species" to be published in *Photogrammetric Engineering and Remote Sensing.* This paper is an output from a previous project but leads to new research opportunities in the current project

What's been happening:

- New recruitment: Dr Marta Yebra, an expert on remote sensing of vegetation biophysical properties, was appointed for the project at the Fenner School of Environment & Society (ANU)
- Project meetings:
    - An initial project planning meeting was held on the 25th September, 2013, at CSIRO. The meeting was attended by all project researchers (Albert Van Dijk, Marta Yebra and Geoff Cary) and some of the external collaborators (Alex Held and Jim Gould). The main outcome of the meeting was an agreement in data sharing (airborne and ground truth).
    - Dr. Marta Yebra and Dr. Geoff Cary attended the 18-20 March inaugural Bushfire and Natural Hazards CRC Research Advisory Forum in Adelaide. Marta and Geoff commenced discussions with end users about where we are all headed together over the next few years

- Project activities:
  - Literature review
  - Airborne LiDAR and hyperspectral (Hymap) data were successfully collected across several parts of the ACT in February-March.

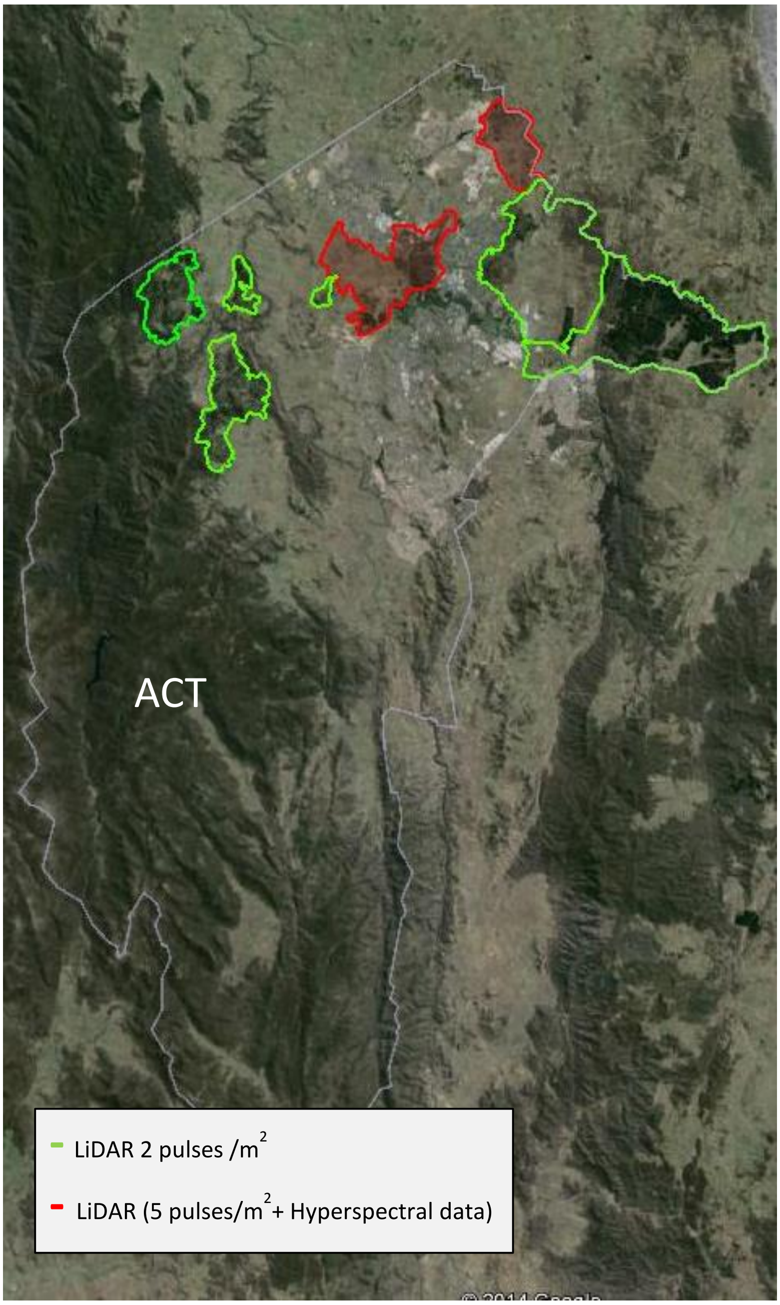

Figure 1. LiDAR and Hymap survey areas.

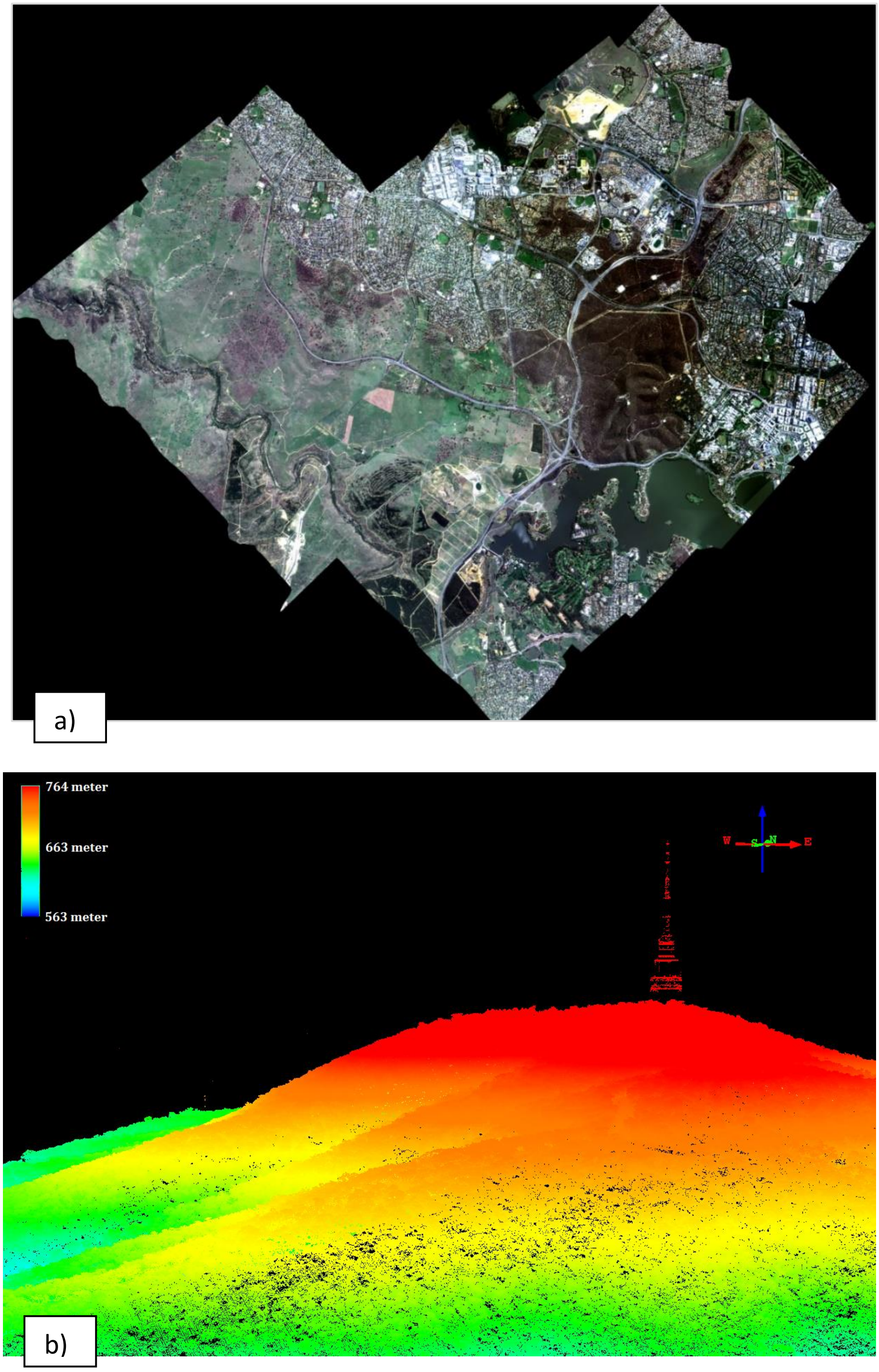

Figure 2. a) Nature colour composite of the Hymap data acquired over the Black Mountain Nature Reserve and Arboretum b) LiDAR image of the Black Mountain Nature Reserve.

Figure 3. Right, isolate tree in Mulligans flat left, LiDAR point cloud for the same tree.

- Fuel load and moisture measurements were made at 40 plots around the same time by project staff and 14 volunteers and will be used for data interpretation and validation. The measurements are currently being processed and analysed.

Figure 4. Grass biomass sampling.

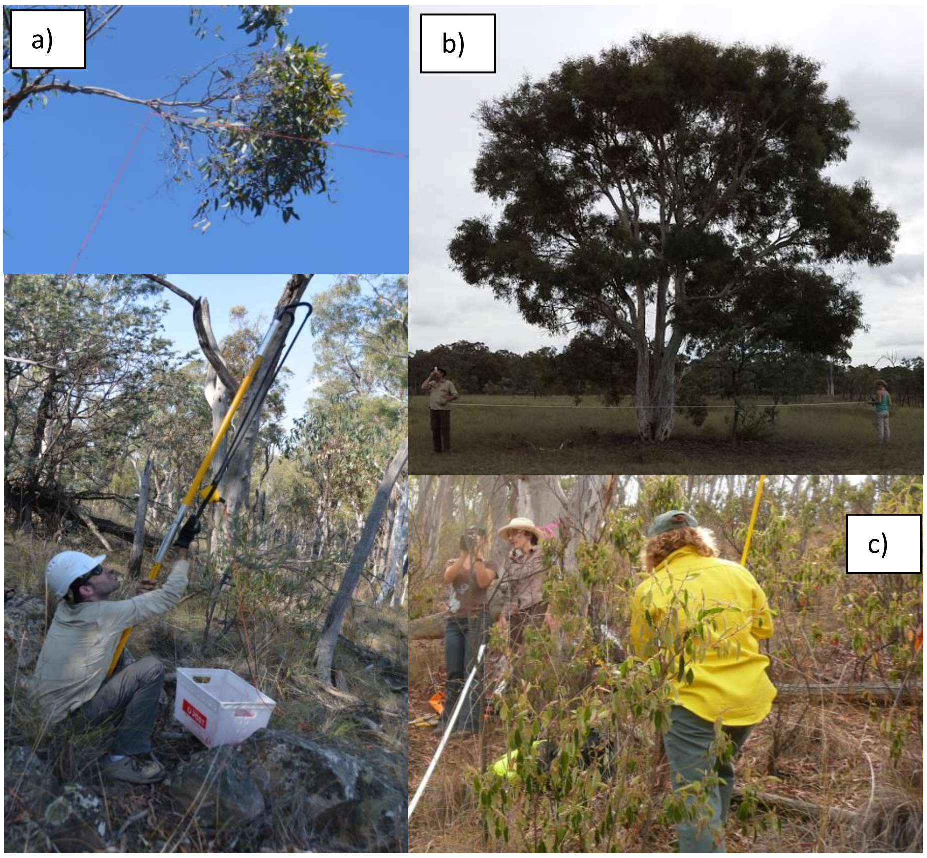

Figure 4. a) Sampling leaves from the canopy with an arborist throw line. B) Measuring crown dimensiong, c) Measuring tree hights with a laser ranger

- **Data collection, organization and processing.**
    - <u>Collecting data in the field</u> that complements the field campaign carried out during the previous period. This activity involved:
        - Extra measurements of trees structural parameters in Mulligans flat Nature Reserve.
        - Scanning the forest with a handheld laser scanner (Zebedee) which generates 3D maps (see section of emerging opportunities for further details).

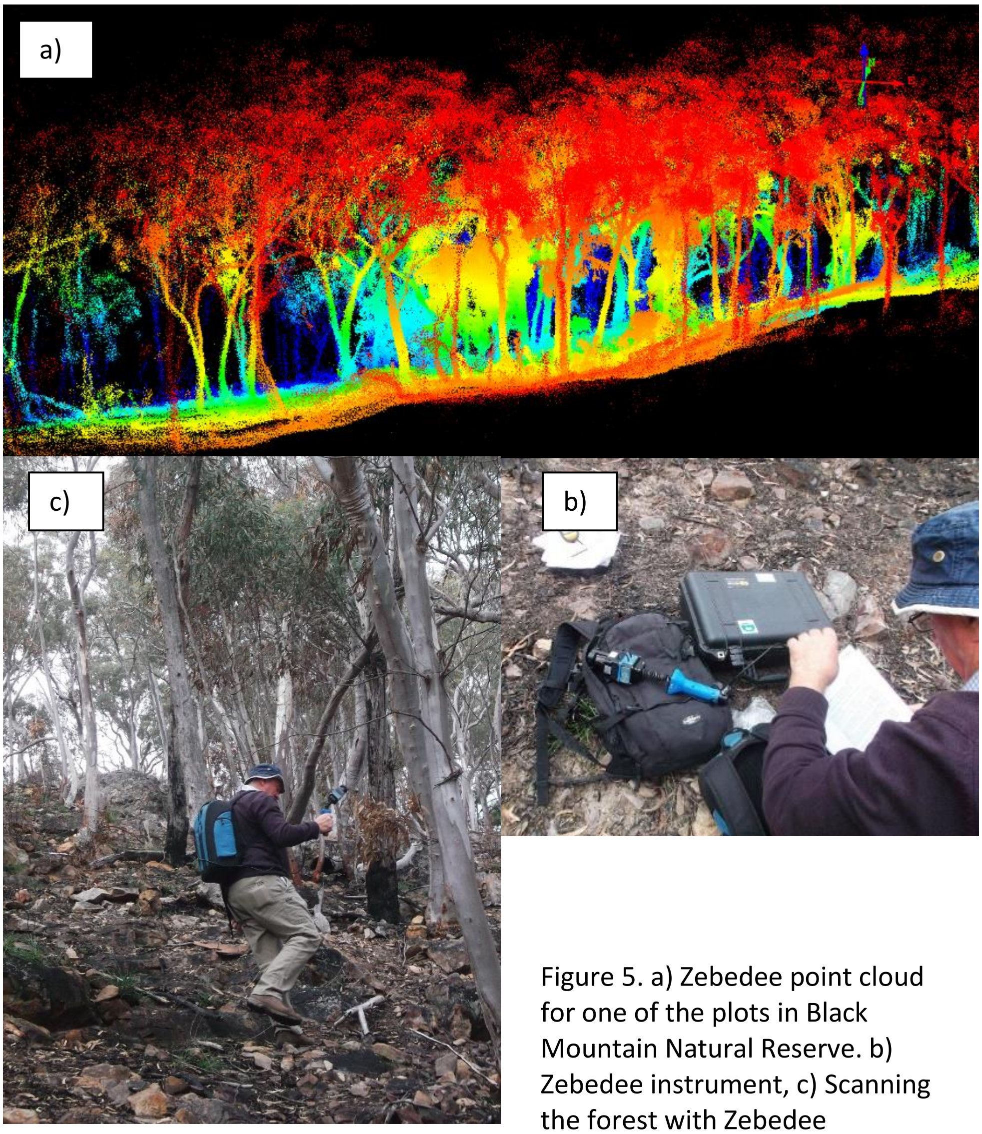

Figure 5. a) Zebedee point cloud for one of the plots in Black Mountain Natural Reserve. b) Zebedee instrument, c) Scanning the forest with Zebedee

- Organizing and processing of the Airborne Light Detecting and Ranging (LiDAR) and hyperspectral (Hymap) data collected across several parts of the ACT in February-March 2013. These activities involved:
  - Protecting the data with adequate storage and backup.
  - LiDAR: georeferencing and classification of the returns.
  - Hymap: georeferencing, atmospheric correction, conversion of spectral radiance to reflectance and mosaicking.
- Organizing and processing of the data collected on the field for ground truthing the remote sensing derived fuel properties (fuel load and moisture content). This activity involved
  - database entering
  - storing in standard formats

- computing of derived variables.

- Gaining data and knowledge from the end users. We have maintained an active collaboration with ACT Parks and Conservation in order to understand fire management work and the information they already have and can add value to our project. Adam Leavesley has provided us with the following data:
    - Fire history on the Black Mountain Nature Reserve.
    - Field measurements of Fuel Moisture Content in several locations within ACT.
    - Fuel assessment observations in several locations within ACT.
- Preliminary analysis

Six thematic maps for the Black Mountain and Mulligans Flat Nature Reserves (the two main research areas of this project) have been derived from LiDAR data: canopy height, canopy base height, understory height, canopy cover, fractional understory cover and vegetation layering (see an example in Figure 6). These maps are ready to be used for forest fuel assessments and flammability modelling. Their possibilities and limitations have been studied as well as the opportunities for future research. All these results will be presented in detail in the next quarterly report due by the 30th of September as agreed in our project plan.

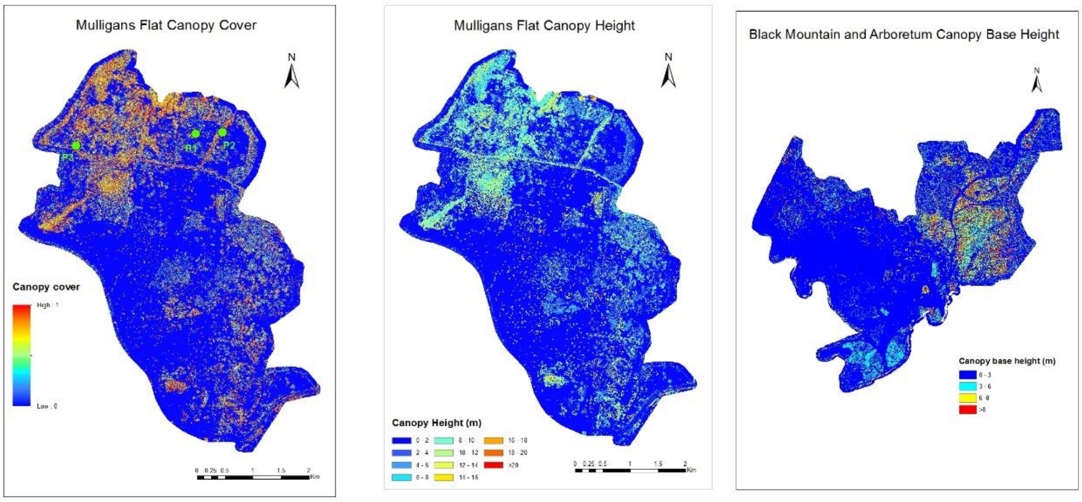

Figure 6. Some examples of maps derived from Airborne LiDAR

New project opportunities

- Suzanne Marselis, a MSc student from the University of Amsterdam successfully fulfilled her Maters project at the Fenner School of Environment and Society. Project title: "Comparing different types of remote sensing data for forest fuel mapping in the Australian Capital Territory region". Suzanne has been processing the LiDAR data and has produced results very relevant for the project.
- Suzanne Marselis gave a Fenner School public lecture (11th June 2014) about the work she did during her internship: "Vegetation structure mapping with airborne and ground-based laser scanning to advance forest fire research". An invitation to this seminar was extended to the end

users of this project. Adam Leavesley from ACT Parks and Conservation attended and we took the opportunity to meet afterwards to discuss how our preliminary results fits their management needs. Adam circulated a commentary on the seminar to a wide range of operational staff in ACT Parks and Conservation, and the seminar slides were circulated to all project End-users (http://www.slideshare.net/myebra12/marselis-2014-vegetation-structure-mapping-with-lidar-for-forest-fire-research, last accessed 16-06-2014)

- Mr. Wasin Chaivaranont Associated Student within the postgraduate scholarship program. The research question addressed in his proposal "passive microwave data to estimate fuel load and moisture content" is clearly aligned with this project.
- Collaboration with CSIRO Ecosystem Sciences to scan some of the project's field plots at Mulligans flats and Black Mountain with a handheld laser scanner (Zebedee). Airborne LiDAR data does not always provide all detailed information on understory and midstory that is needed in fire assessments and fire spread models. This collaboration brings a unique research opportunity to investigate the use of ground-based Zebedee LiDAR data for assessing fuel structure and compare the results with those obtained with airborne LiDAR.
- Collaboration with CSIRO-Centre of marine and atmospheric research to scan some of the project's field plots at Mulligans flats and Black Mountain with the DWEL (an innovative, ground-based scanning LiDAR instrument to characterise forest structure from a point on the forest floor). Similarly than the Zebedee measurements, DWEL will be used to assess the usefulness of the maps derived with airborne data as well as to fill in the gaps in forest fuel mapping derived from airborne LiDAR.
- Through a grant awarded by Actew AGL, we will be installing a cosmic ray sensor to investigate its use for on-ground fire and flood risk early warning in remote areas. A suitable location has been identified in Namadgi national Park in discussion with Actew AGL and ACT Parks & Conservation. Installation is planned for early July.

Publication list:

- Yebra, M, Marselis, S., Van Dijk, A., Jovanovic, T., Cary, G., Cabello-Leblic, A. Mapping Bushfire Hazard and impact. AFAC 2014. After Disaster strikes leaning from adversity. Wellington. September 2014. Poster.

List of current integrated project team members:

- Researchers
  - Marta Yebra
  - Albert van Dijk
  - Geoff Cary
- Students
  - Rachael Tarlinton
- End users.
  - John Bally, Regional Director Tasmania and Antarctica, Bureau of Meteorology.
  - Jeff Kingwell, Section Leader, Land and Water Monitoring, Geoscience Australia.

- Neil Cooper, Manager, Fire, Forest and Roads, ACT Parks and Conservation Service.
- Adam Leavesley, Fire Management Officer, ACT Parks and Conservation Service.
- Belinda Kenny, Fire Science Interpretation Officer, Office of Environment & Heritage, Department of Premier & Cabinet. New South Whales.
- Andrew Sturgess and Bruno Greimel of Queensland Fire and Emergency Services.
- Robert Preston, Public Safety Business Agency, Queensland.
- Simeon Telfer: Department of Environment, Water and Natural Resources. South Australia.