Application of remote sensing for mapping and monitoring rangeland condition

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Abstract

Since 2007, state agencies on the east coast of Australia and the University of Queensland have been collaborating through the Joint Remote Sensing Research Program (JRSRP). This has resulted in a significant acceleration in the development and successful operational application of remote sensing methods for the JRSRP members and the various state and national programs and policies which they support. More recently this collaboration has included the Northern Territory's Department of Land Resource Management with a focus on rangeland monitoring. The JRSRP provides an open and collaborative mechanism and governance structure to successfully bring together a unique combination of expertise in image processing, field data collection, and data integration approaches to deliver accurate, repeatable and robust methods for mapping and monitoring Australia's unique ecosystems.

Remote sensing provides spatially- and temporally-comprehensive information about land cover features at a range of scales and often for minimal cost compared to traditional mapping and monitoring approaches. This makes remote sensing a very useful operational mapping and monitoring tool for land managers, particularly in the vast rangelands of Australia. This poster presentation outlines the current remote sensing and modelling products which are being used operationally by JRSRP members and collaborators for monitoring past, present and future changes in land condition, informed by extensive field-based baseline measures. Ongoing research and development is underway to integrate the remote sensing and modelling products to improve indicators of land condition state and change and to identify and target potential land condition issues in near real time.

Introduction

In recent years, those tasked with the management and stewardship of Australian rangelands have been increasingly looking to remote sensing and modelling approaches for monitoring changes in land condition to inform decision-making. This has been driven by advances in technology, legislation and reporting requirements, increasing business costs and time constraints, and a range of open data and infrastructure strategies by governments around the world.

An advantage of remote sensing for assessment and monitoring land condition is that objective, repeatable information may be acquired at a range of spatial scales over large areas and at regular intervals, often for minimal cost. In some cases (e.g. the Landsat program), continuous earth observation information is available over time periods that are seldom achieved by traditional monitoring approaches, thus providing a wealth of historical information. However, in order to cover large areas regularly, compromises are often required to be made on the spectral, spatial and/or temporal scale of the information, meaning not all desired features may be directly measured or monitored reliably. Land condition can change on a range of temporal scales. A management practice may take years to decades to express as a change in any condition indicators.

In 2007, the Joint Remote Sensing Research Program (JRSRP) (http://www.gpem.uq.edu.au/jrsrp) formed to undertake research and to improve operational monitoring of land cover and land condition attributes, particularly in rangeland environments. This is achieved through research and development of methods which use passive and active remote sensing technologies, field data, process-based modelling, and innovative image processing using open source software and high performance computing facilities. More recently, the partnership has been enhanced through initiatives such as the Terrestrial Ecosystem Research Network's Auscover facility and a collaborative research partnership with the Northern Territory government.

Mapping and monitoring land condition in Australia using remote sensing

There is a common misconception that because of the advantages of remote sensing for monitoring and mapping, it is a panacea for land condition assessment. Ludwig et al. (2007) discussed the relative merits of remote sensing information for assessment of 'landscape health'. They described examples of scenarios where remote sensing was solely adequate for the application, and others where remote sensing alone was not adequate for the required outcome. For example, the studies of Karfs et al. (2009) and Bastin et al. (2012), aimed to undertake relatively broad-scale, whole-of-landscape assessment of grazing lands, and as such indicators of land condition derived from medium-resolution Landsat satellite imagery were generally considered adequate for their purpose. Ludwig et al. (2007) proposed a five step procedure based on scaling to determine the appropriateness of multiple scales of remote sensing data to provide for the information needs of land managers. The JRSRP also recommend a similar procedure although additional factors to scale need to be considered, particularly in the context of the use of remote sensing for policy application. These factors include: the 'focal scale' of the information required; the physical and temporal characteristics of the features of interest; the environment, climate and land management activities which influence the features of interest; the cost of data and information acquisition and production; the time, capacity and skills required to produce the information; the accuracy, reliability and defensibility of the information produced; and, the level of knowledge/understanding and capacity of the users of the information, including the systems and mechanisms available to access the information.

Using the above principles, the JRSRP has undertaken research and development for a number of field data collection and land cover monitoring applications in the rangelands to support government programs. This includes the development of standardised and automated processing systems, standard field measurement approaches, testing and developing new field methods with new technologies, and developing a number of land cover and biomass products and derived metrics. This paper presents a brief overview of the current JRSRP activities which are enhancing Australia's capacity to use remote sensing and process modelling to improve land condition monitoring and land management in the vast rangelands of Australia, and the world.

Joint Remote Sensing Research Program activities in Australia's rangelands

Processing systems and data management

The JRSRP is supported by high performance computing infrastructure in both Queensland and New South Wales state governments, and also by national infrastructure provided by the Terrestrial Ecosystem Research Network (TERN) (http://www.tern.org.au/). These systems implement automated processing streams for storing and managing extensive archives of field data, satellite, aerial and ground-based imagery including optical, radar and LiDAR data. The image archives include tens of thousands of Landsat images for many parts of Australia, sourced from Geoscience Australia's National Earth Observation Group (NEOG) and, more recently, from the United States Geological Survey (USGS). Other imagery in the archive includes imagery from SPOT 4 and 5 (extensive coverage in NSW and Queensland), MODIS, IKONOS, Quickbird, LiDAR, ALOS PALSAR, IceSAT, and aerial photography. Data processing is undertaken using programs developed in-house in a range of programming languages including python (https://www.python.org/) and based on open source tools such as GDAL (http://www.gdal.org/), PostGRES/PostGIS (http://www.postgresql.org/) and the R statistical package (http://www.r-project.org/).

A critical precursor to accurate and repeatable land condition monitoring using remote sensing is ensuring imagery is appropriately corrected and geo-registered to account for atmospheric, reflectance, topographic and satellite sensor effects. In addition, undesirable elements such as cloud, cloud shadow and inundation are required to be classified and masked from imagery. This ensures comparisons over space and time are consistent and repeatable and any changes detected are representative of true change and not due to artefacts or spurious measurements in the imagery. The JRSRP invests significant time and resources into developing appropriate corrections and calibration for imagery and have implemented a range of approaches to account for these effects (e.g. Flood et al., 2013; Goodwin et al., 2013; Zhu and Woodcock, 2012; Danaher and Collett, 2006; Bunting et al., 2013).

A significant recent development has been the development of a seasonal data processing system which implements the seasonal compositing methods described by Flood, 2013. The seasonal system automatically generates, at the conclusion of a 3-month 'calendar' season, a composite image of surface reflectance (Figure 1) and derived image products based on all of the imagery acquired during the season. These image products have the benefit of minimising the influence of spurious measurements and outliers and they have a regular temporal sequence, which is well-suited to time-series analysis applications.

Field monitoring activities

The JRSRP undertakes a range of field data collection activities for calibration and validation of satellite imagery and for other monitoring purposes. Land cover sampling follows Muir et al. (2011) and supports the Ground Cover Monitoring for Australia project and TERN's Auscover facility in addition to JRSRP partner's requirements. To date, in excess of 1500 sites have now been captured across Australia in a range of landscapes (Figure 2).

Other field sampling activities include the use and development of ground-based sensor and optical technologies such as terrestrial laser scanning (TLS) and hemispherical photography. These technologies have the potential to capture range, cover, volume and elevation information, in some cases in extremely high detail and accuracy, for land surface and vegetation attributes (Figure 3). For TLS development, the JRSRP has partnered with world experts through the Terrestrial Laser Scanning International Interest Group (TLSIIG) (http://tlsiig.bu.edu/) to advance developments in the use of TLS, particularly for vegetation biomass monitoring. These products have great potential for monitoring and informing erosion estimates and for quantifying above-ground biomass for production, biodiversity and land accounting.

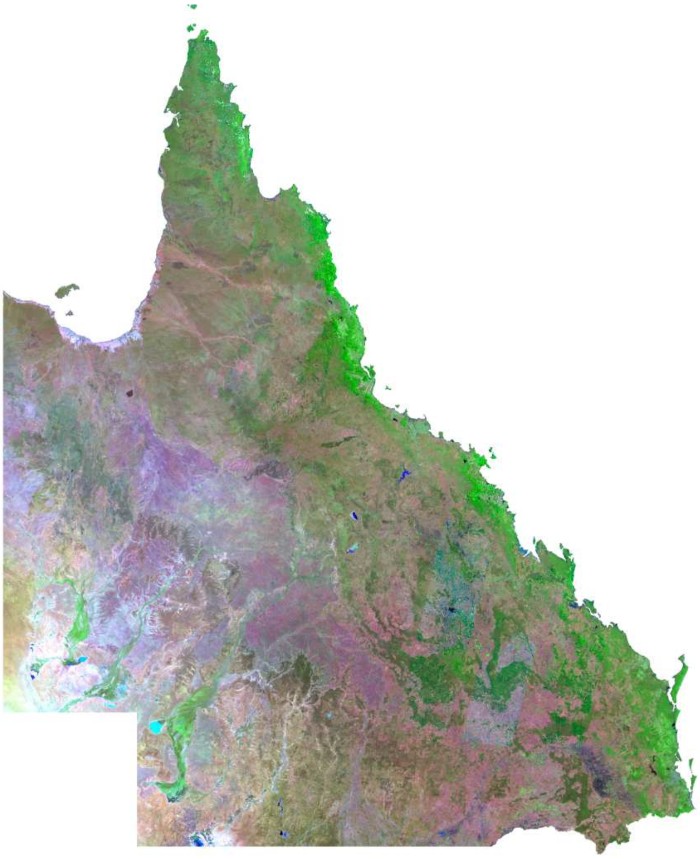

Figure 1. Seasonal surface reflectance composite of Landsat imagery for Queensland generated from the automated processing streams developed by the JRSRP. The seasonal composites minimise data loss from cloud and cloud shadow and scene to scene reflectance differences making them very useful for comparative analyses over large areas and over time.

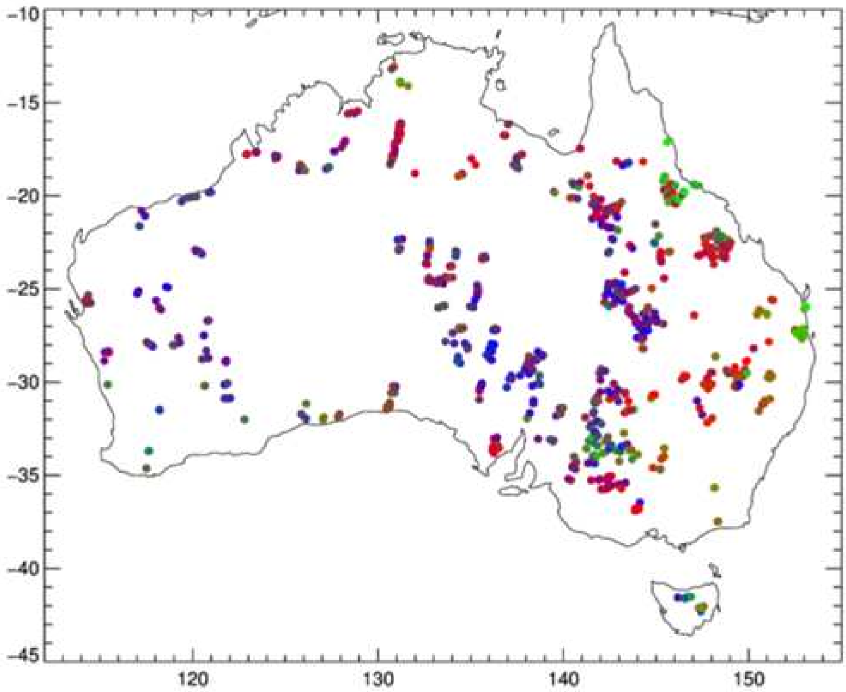

Figure 2. Location of field calibration and validation sites which are used by the JRSRP to develop land cover products. Many of these sites were collected by the Ground Cover Monitoring Project for Australia in partnership with state agencies and TERN's Auscover facility.

Figure 3. Example of terrestrial laser scanning of a woodland community in Queensland. The information collected is a point cloud of x, y, z coordinates enabling detailed and accurate reconstruction of the three-dimensional structure of the vegetation. The JRSRP is developing approaches with the TLSIIG to derive structural metrics from these data for monitoring and accounting activities and calibration and validation of satellite-derived products.

Woody vegetation mapping and monitoring

Mapping and monitoring extent and change in woody vegetation is a core requirement of JRSRP partners to meet respective jurisdictions legislative requirements and to service a range of monitoring and reporting initiatives at local, state, national and global scales. Foliage Projective Cover (FPC) data and land cover change estimates (Danaher et al., 2010) have been produced annually for a number of years based on Landsat imagery (Armston et al., 2009). In recent years, the NSW partners of the JRSRP have also developed an FPC and land cover change approach for that state using the higher resolution SPOT imagery. Access to the Landsat archive in recent years has also facilitated the research and development of time-series approaches for mapping of woody vegetation cover and also for monitoring of trends. Scarth et al. (2010) used the >1500 land cover sites from across the country and Landsat reflectance data to develop a linear spectral unmixing model which discriminates green and non-green vegetation cover and bare ground on a per pixel basis. The resulting product, termed *fractional cover*, is being produced and used operationally for a range of applications (Figure 4).

JRSRP researchers have been analysing the trends in the green cover fraction to: (i) identify the persistent green signal in the time-series – this is assumed to represent woody vegetation (Figure 5) and, (ii) analyse the trends in the persistent green signal over time to monitor subtle, longer term changes in woody vegetation which may be due to factors such as climate variability, land management, altered fire regimes, increased atmospheric CO_2 or woody weed encroachment (Figure 6) (see also Gibson et al. this conference).

The JRSRP is also significantly enhancing its capability and contributions to research and development of active imaging systems such as radar and LiDAR for rangeland monitoring. Through a collaborative arrangement with the Japanese Aerospace Exploration Agency's Kyoto and Carbon Initiative and TERN Auscover, the JRSRP have developed products which integrate field measurements, radar backscatter coefficients from ALOS PALSAR data, airborne and space-borne LiDAR and Landsat-based persistent green products which improve vegetation structural information and above-ground woody biomass estimates for Australia (Figure 7).

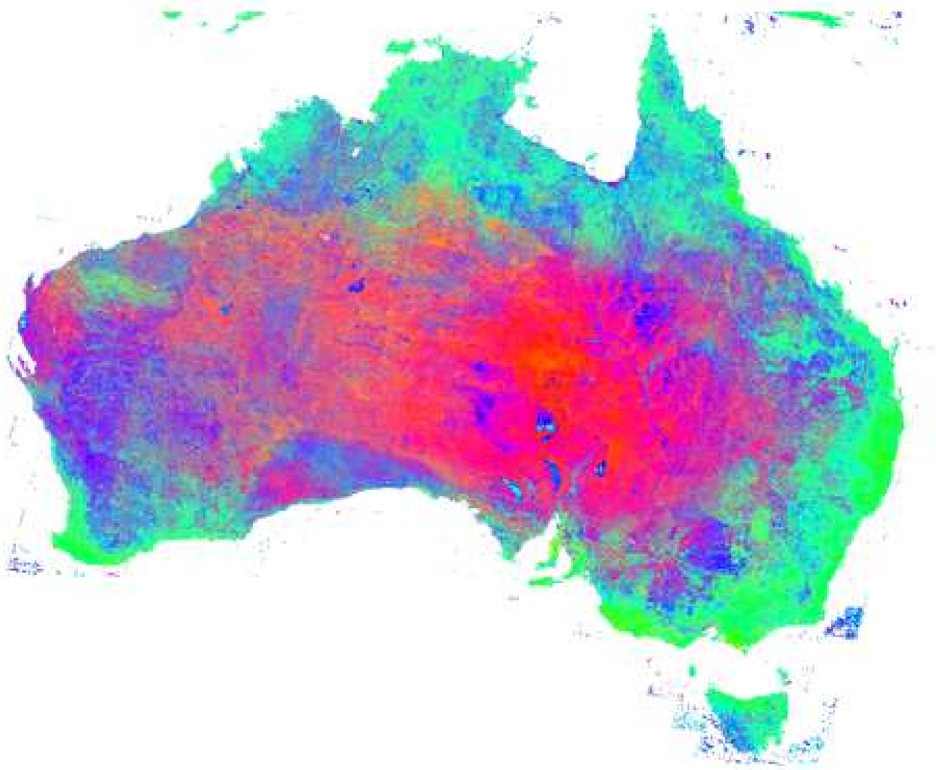

Figure 4. Example of a Landsat fractional cover mosaic for Australia. Green vegetation is shown in green, non-green cover is blue and bare ground is red. These data are publicly available from TERN's Auscover facility (http://www.auscover.org.au/xwiki/bin/view/Product+pages/Landsat+Fractional+Cover)

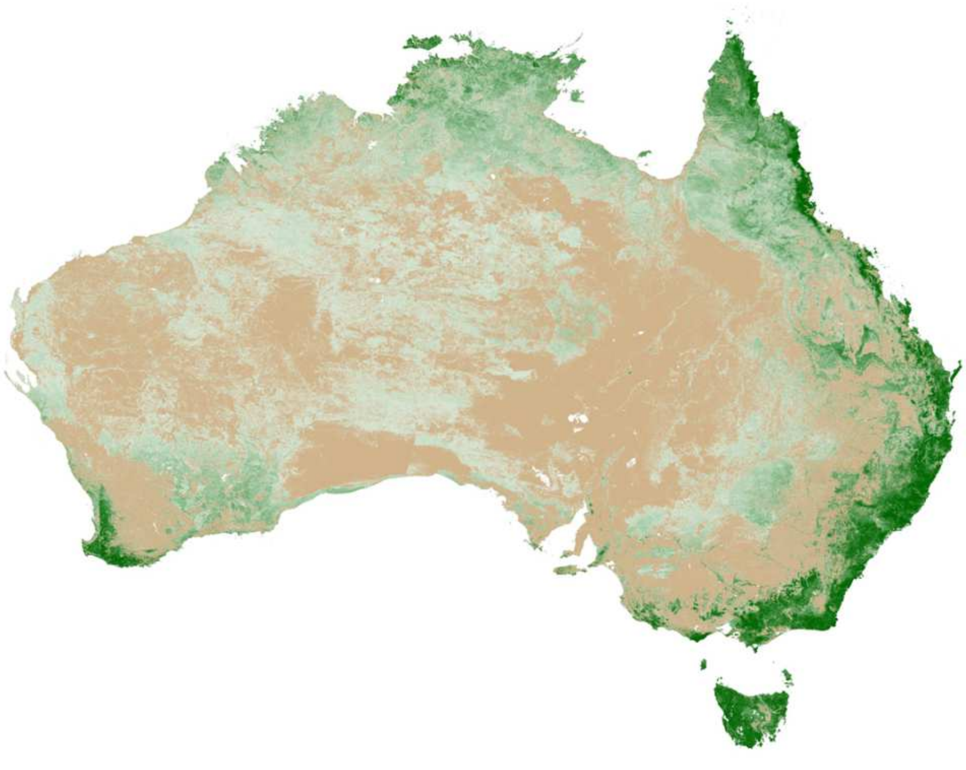

Figure 5. Persistent green vegetation cover for Australia derived from time-series analysis of Landsat fractional cover imagery.

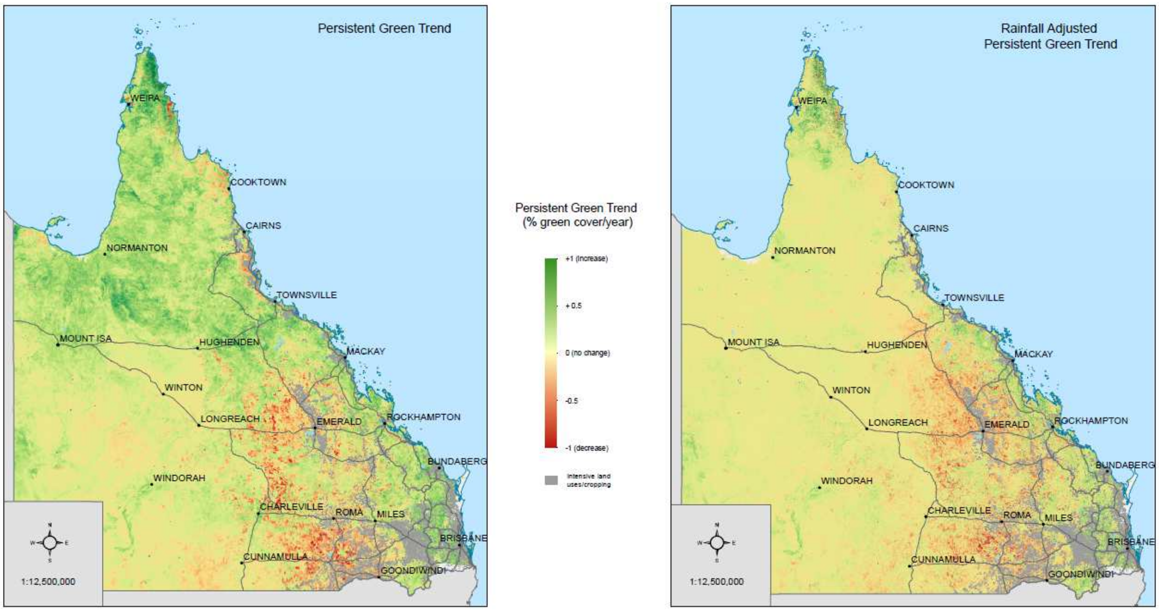

Figure 6. Persistent green trends in Queensland. The map on the left shows the trend in persistent green vegetation over the Landsat time-series (~28 years). Green areas show a slight increase in persistent green vegetation, red areas slight decreases in persistent green vegetation. The map on the right shows the persistent green trend adjusted for rainfall. This map suggests that rainfall accounts for a large proportion of the increases seen in persistent green vegetation in the map on the left. The decreases are still evident and indicative of land cover changes and vegetation clearing associated with development in the 1990's. These products are also being generated by the JRSRP for NSW and the Northern Territory.

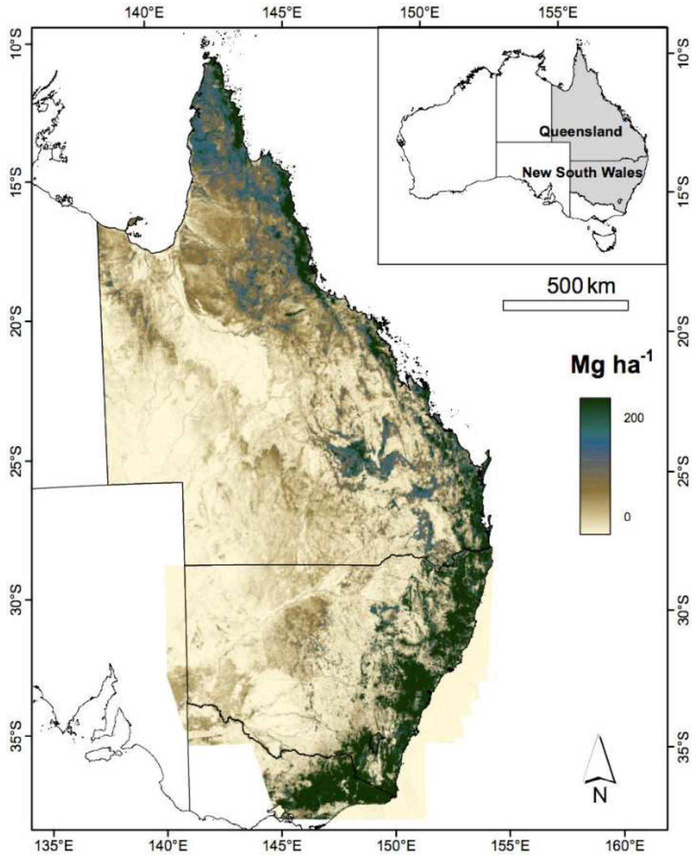

Figure 7. Demonstration map of above-ground biomass for eastern Australia produced by JRSRP partners and derived from ALOS PALSAR satellite imagery and allometrics developed using a national biomass library, compiled by the JRSRP from a range of sources.

Ground cover and pasture biomass mapping and monitoring

Ground cover and pasture biomass monitoring are critical to understanding land condition and production capacity and sustainability in the rangelands. For some time now, the JRSRP have been producing estimates of ground cover and bare ground from Landsat satellite imagery and daily modelled estimates and three-monthly forecasts of pasture biomass through AussieGRASS (www.longpaddock.qld.gov.au/about/researchprojects/aussiegrass/). In recent years, the fractional cover data has been used to improve ground cover and bare ground estimation and current research is developing methods to estimate cover in areas of higher tree cover to improve understanding of seasonal and spatial dynamics of ground cover, particularly in savannah woodlands. The approach uses field data estimates to calibrate and validate estimates of persistent green and non-green vegetation in the upper- and mid-stratum to adjust for the amount of cover expected on the ground (Figure 8). These data are forming the basis for ongoing development of ground cover products which support land condition monitoring and reporting. This includes programs such as Reef Plan (http://www.reefplan.qld.gov.au/) and drought management, development of metrics for de-coupling climate and management effects (e.g. Bastin et al. (2012, 2014, this conference), and providing data and metrics for delivery mechanisms such as VegCover (http://vegcover.com/), VegMachine (Beutel et al., this conference), , FORAGE (https://www.longpaddock.qld.gov.au/forage/) and the NRM Spatial Hub (http://www.crcsi.com.au/research/commissioned-research/nrm-spatial-information-hub/). Future developments to ground cover data include linking satellite-derived cover with modelled biomass to improve biomass predictions and working with partners in TERN Auscover to produce ground cover estimates from MODIS imagery, increasing the temporal frequency of the data to support more timely decision-making at the regional scale.

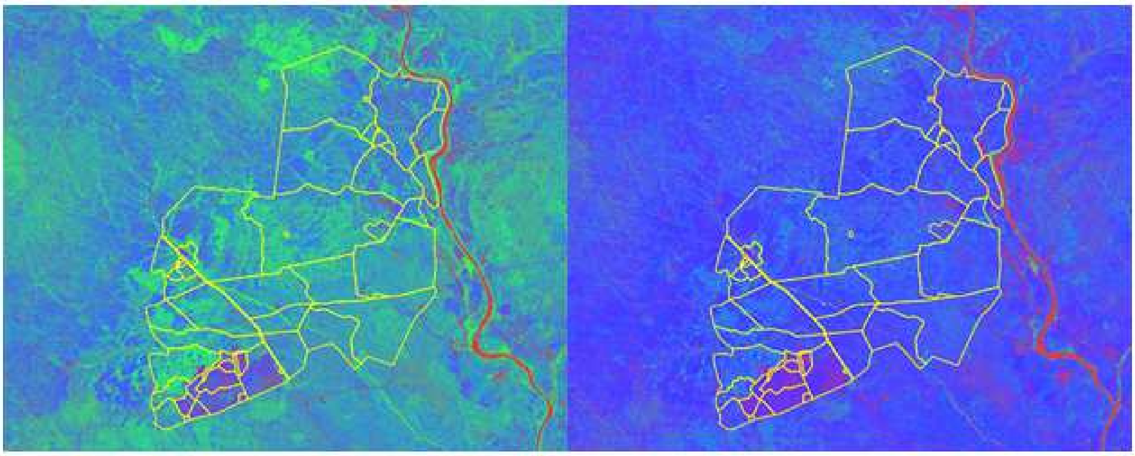

Figure 8 Ground cover data example. The left image shows fractional cover for an area in northern Queensland for a date in the late dry season. The right image shows the fractional *ground* cover for the same date and location. The effects of the trees and shrubs have been adjusted to provide estimates of the actual ground cover. The adjustment reveals that there is a significant amount of non-green vegetation on the ground surface beneath the tree and shrub canopies as indicated by the significant increase in blue in the image on the right.

Landsat-based fire scar mapping

The JRSRP has developed a method for automated detection and mapping of fire scars. The method, described in detail in Goodwin and Collett (2014) uses the dense time-series of Landsat, multi-date change detection and thermal data to discriminate fire scars in the landscape from the nearly 30 year archive of imagery. These data complement existing fire scar mapping systems based on MODIS and NOAA-AVHRR by providing higher resolution data where fire scars are able to be detected, and a greater historical perspective on burning regimes in the rangelands. To date, data has been produced state-wide for Queensland (Figure 9) and trials are currently underway in other states to evaluate the method for different environments across the country.

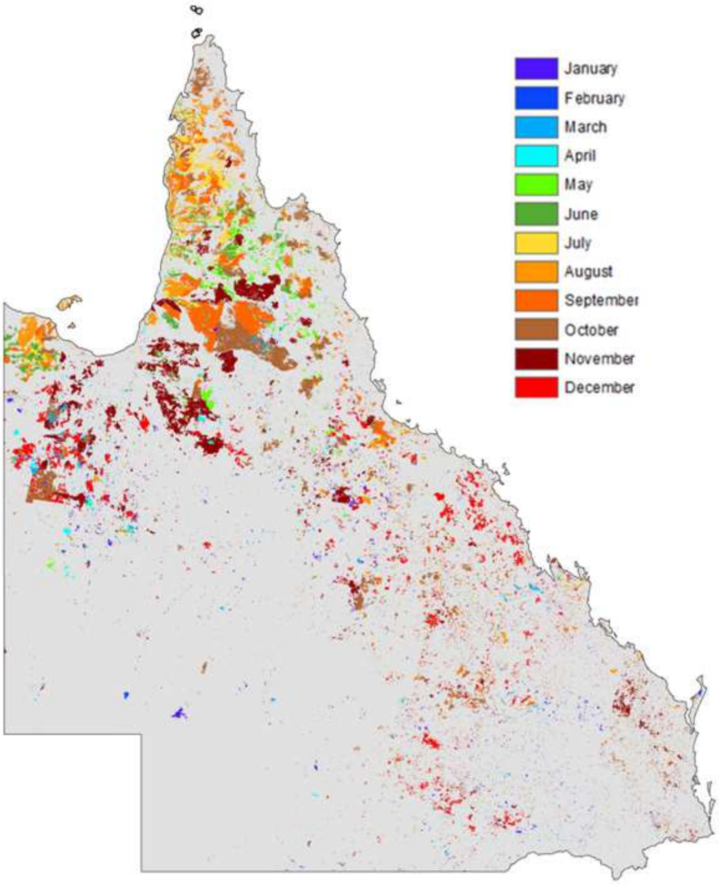

Figure 9. Example of Landsat fire scar mapping in Queensland. This example shows all fire scars mapped for the year 2001. The methods developed have been applied to the enture Landsat time-series in Queensland are currently being trialled in Northern Territory, New South Wales, Victoria, Western Australia and South Africa

The future of remote sensing in the rangelands

The JRSRP has demonstrated the benefits of collaborative and open sharing of knowledge, resources and skills for developing rangeland monitoring and mapping applications which support a range of end user requirements. This partnership and initiatives such as TERN are critical to the ongoing requirement to develop remote sensing capability in Australia. A number of earth observation satellite missions are planned for the near future, none of which Australia are investors in, despite our increasing reliance on these data to support our rangeland management programs and other environmental monitoring applications. In the absence of this direct investment, Australia does have significant international engagement and leverage capacity as a result of its investment in skills, method development, delivery systems and partnerships such as the JRSRP to assure Australia's to access imagery for rangeland monitoring in the future.

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