THE INJUNE LANDCAPE COLLABORATIVE PROJECT: AN UPDATE ON RESEARCH ACTIVITIES

[1] Richard Lucas, [1] Peter Bunting, [2] John Armston, [3] Alex Lee and [4] Glenn Campbell

[1] Institute of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, Ceredigion,Wales, SY23 3DB, Wales, UK
Tel: +44 1970 622612, Fax: +44 1970 622659, Email: rml@aber.ac.uk

[2] Joint Remote Sensing Research Program, School of Geography, Planning and Environmental Management, The University of Queensland,
Remote Sensing Centre, Queensland Department of Environment and Resource Management, 80 Meiers Road, Indooroopilly, Queensland, Australia

[3] Defence Imagery and Geospatial Organisation, Russell Offices, Canberra, ACT 2600, Australia.

[4] Australian Centre for Sustainable Catchments, University of Southern Queensland, Toowoomba QLD 4350

Abstract

The Injune Landscape Collaborative Project (ILCP) was initiated in 1998 to evaluate the potential of airborne SAR, either singularly or in combination with optical data, for retrieving vegetation biomass and structure. With funding from the Australian Research Council (ARC) and government partners, and as part of the 2000 NASA Jet Propulsion Laboratory (JPL) PACRIM II Mission, AIRSAR C, L and P-band data were acquired over a 40 x 60 km subtropical savanna area near Injune in central southeast Queensland. Over the same period, discrete return LiDAR, hyperspectral Compact Airborne Spectrographic Imagery (CASI) and 1:4000 aerial photography were acquired over 150 500 x 150 m sampling units located within the imaged area. These data have been used subsequently to advance the development of algorithms for tree crown delineation, species differentiation and biomass estimation from finer (< 1 m) spatial resolution data, radar simulation modelling and empirical methods for retrieving structural attributes and biomass, and mapping of regrowth and forest structural types using combinations of SAR and Landsat sensor data.

In 2009, a second airborne campaign was undertaken to establish whether changes in the species composition, structure and biomass of forests occurring as a consequence of both natural and anthropogenic (including climate) change could be detected and quantified. Airborne datasets acquired included Riegl LMS-Q560 full waveform LiDAR, EAGLE hyperspectral and digital aerial photography. Terrestrial laser scanner and field data were obtained to provide ground truth. The ILCP has also been the focus of multiple acquisitions of Advanced Land Observing Satellite (ALOS) Phased Arrayed L-band SAR (PALSAR) and a NASA-funded project aimed at establishing the potential of the proposed DESDynI mission for retrieving biophysical attributes.

As a consequence of these activities, the ILCP is now associated with one of the most comprehensive time-series of airborne and spaceborne datasets available within Australia and indeed internationally. As such, the Injune area is a potential candidate for a long-term environmental research (LTER) site and the data, algorithms and outputs generated can play a key role in addressing a wide range of scientific questions relating to future sensors, carbon cycle science, land use/cover change and conservation of biological diversity.

1. Introduction

In 1998, the Australian Research Council (ARC) SPIRT grant with industry (government) partners funded a project to evaluate the potential of airborne SAR (AIRSAR) data, either singly or in combination with optical data, for quantifying the structure and above ground biomass (AGB) of forests and open woodlands. The research was undertaken in the knowledge that the Japanese Space Exploration Agency (JAXA) Advanced Land Observing Satellite (ALOS) Phased Arrayed L-band Synthetic Aperture Radar (SAR) was to be launched in the early 2000s and would be providing global coverage of polarimetric L-band data, with potential for retrieving the above ground biomass (AGB) and structure of vegetation and classifying forest growth stage and type.

The project focused on a 40 x 60 km mixed forest/agricultural landscape west of Injune in the central southeast Queensland Southern Brigalow Belt (Latitude 25°32'S, Longitude 147°32'E). Activities at this si te have been undertaken through what is now termed the Injune Landscape Collaborative Project (ILCP). Within this area, the natural vegetation consists predominantly of low open woodland, open woodland, woodland and open forest. Forests with *Eucalyptus* species dominate the more productive sandy and clay soils and *Callitris glaucophylla* occurs on the poorer sandy soils. On the clay soils, Brigalow is commonplace and within the open forests of the plateau, Iron barks (e.g., Silver-leaved ironbark or *Eucalyptus melanaphloia*) are frequent. Mean annual rainfall is approximately 635 mm year^{-1}, although is highly variable.

To support the interpretation of the AIRSAR data, through both empirical studies and SAR simulation modeling, airborne LiDAR and hyperspectral data and aerial photography were acquired over a similar time-frame (July – early September, 2000). Given the complexity of these datasets, significant research effort was directed towards retrieving detailed information on the species composition, structure and ABG of these forests at scales ranging from individual trees to stands and landscapes.

Additional campaigns within the Injune study area were undertaken in 2004 and 2006 to support the development and validation of biophysical retrieval algorithms. The field campaign in 2006 took place near the peak of an intense drought period and many of the trees observed as living in the airborne imagery acquired in 2000 had subsequently succumbed to the harsh conditions, with dieback of selected species observed. Significant losses of vegetation as a consequence of clearing and fire as well as recovery from previous events (e.g., through regrowth and thickening) were also noted in the intervening period. A second airborne campaign was undertaken in 2009, during which repeat coverage of airborne LiDAR, hyperspectral and digital aerial photography was obtained, to establish whether the type, magnitude and direction of change could be quantified through time-series comparisons of these data. The outcomes of this research were also anticipated to establish whether such changes could be quantified through time-series comparison of spaceborne optical and SAR data (primarily Landsat Thematic Mapper and ALOS PALSAR).

This paper provides a broad overview of the datasets and some key scientific outcomes resulting from the 2000 campaign as well as the associated follow-on field campaigns in 2004 and 2006. The benefits of the ILCP in the interpretation of spaceborne data, particularly in relation to retrieval of AGB, classification of vegetation community composition and mapping of regrowth forests, are also highlighted. The 2009 airborne campaign is described and preliminary results relating to the detection of growth, losses of trees through fire and natural dieback, and gains through regeneration are provided. Finally, the case is made for including the ILCP as a long term environmental research (LTER) site in Australia, particularly given the availability of baseline datasets and knowledge that can be used to increase understanding of how forests are responding to land management practices, natural events and processes, and climatic change.

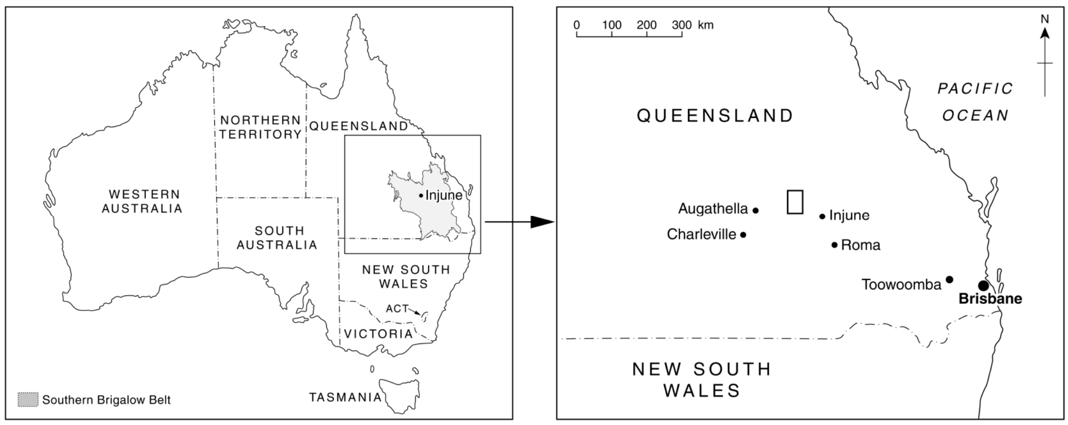
2. The 2000 campaign

The 40 x 60 km area west of the township of Injune (Figure 1a) was selected for the initial study as extensive tracts of vegetation were being cleared and the open forests and woodlands (wooded savannas) contained structural formations typical to large areas of Queensland. In 2000, and as part of the NASA Jet Propulsion Laboratory (JPL) PACRIM II mission to Australia, multi-frequency (C, L and P-band) polarimetric AIRSAR were acquired over the area.

To support the interpretation of these data, hyperspectral Compact Airborne Spectrographic Imager (CASI), discrete return LiDAR (OPTECH ALTM1020) and 1:4000 scale colour aerial photographs were also acquired over the same period across a sample grid (10 columns x 15 rows) of 150 500 x 150 m Primary Sampling Units (PSUs; Figure 1b). Forest inventory was undertaken within 34 field plots and trees of the species *Callitris glaucophylla*, *Eucalyptus melanaphloia* and *E. populnea* were destructively harvested to support the retrieval of AGB and structural attributes from these finer spatial resolution airborne datasets.

Using these data, algorithms have been progressively developed for delineating tree crowns (Bunting and Lucas, 2006), differentiating mapped crowns to a species or genus-type (Lucas *et al.*, 2008a) and retrieving biomass and structural attributes (crown cover, density, height) at both the tree (Lucas *et al.*, 2008b) and stand (Lee and Lucas, 2007, Lucas *et al.* 2008b) level from LiDAR and/or CASI data. These derived data have subsequently informed the interpretation of AIRSAR (Lucas *et al.*, 2004, 2006a), Landsat (Lucas *et al.*, 2006b) and, more recently, ALOS PALSAR data (e.g., Lucas *et al.*, 2010). The data have also been used to support parameterisation and validation of SAR simulation models (Lucas *et al.*, 2004; Liang *et al.*, 2005; Lucas *et al.*, 2006c), with a view to better understanding microwave interaction with different structural components and advancing inversion algorithms.

a)



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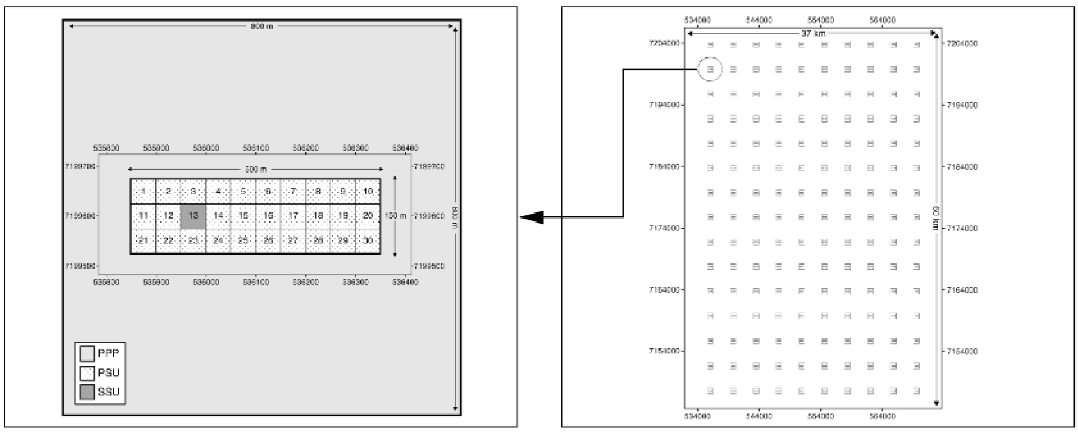

Figure 1. a) The location of the Injune study area and b) the layout of the sampling grid. Abbreviations used: PPP, primary photo plot; PSU, primary sampling unit; SSU, secondary sampling unit.

3. Observing change – the 2004 and 2006 campaigns

In 2004 and 2006, a field campaign to the Injune study area was conducted to a) support the retrieval of structural attributes and AGB from LiDAR and b) develop methods for discriminating tree species using spectra extracted from tree crowns delineated using hyperspectral CASI data. By 2004, a number of the 34 field plots had lost individual trees through natural processes whilst growth had continued in many. The 2006 campaign was conducted near the peak of an intense drought in Queensland and significant dieback of trees observed as living in the 2000 airborne datasets was noted (Figure 2). Within a number of PSUs, the response of different species to the drought was evident. For example, many mature rough barked apples (*A. floribunda*) had died but smooth barked apples (*A. leiocarpa*) were unaffected. The differential dieback of species during drought periods has been reported in a number of studies (e.g., Fensham and Holman, 1999). In other PSUs, changes in the structure, biomass and species composition were evident because of regrowth, both through succession and following recovery from fires and clearing. These observations highlighted the dynamic nature of the forests in response to a wide range of human-induced and natural events and processes.

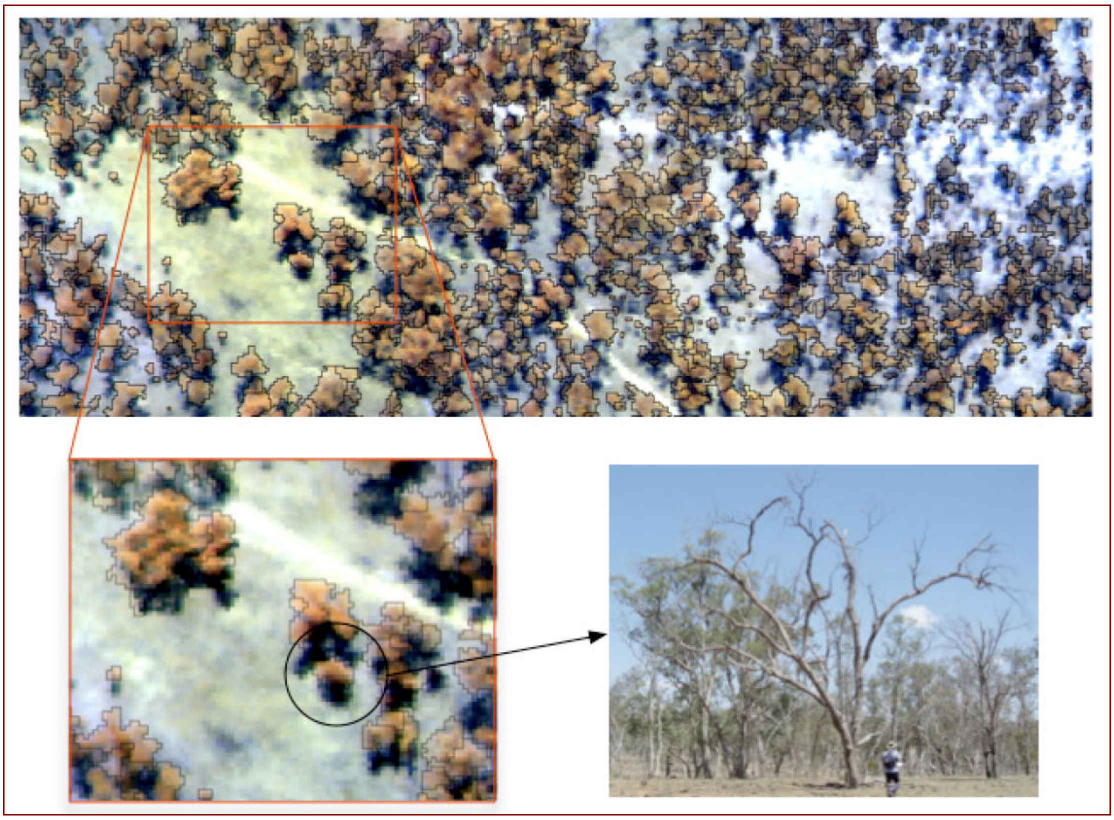

Figure 2. CASI image acquired in 2000. Delineated tree crowns were observed in full leaf in 2000 but many individuals of the species *A. floribunda* had experienced dieback in 2006 following the intense drought (bottom right).

4. Repeating the acquisitions – the 2009 campaign

An opportunity to reacquire airborne data was presented in 2009 through a campaign organised in conjunction with the Queensland Department of Environment and Resource Management (QDERM). In April, 2009, full waveform LiDAR (RIEGL LMS-Q560), hyperspectral EAGLE and digital aerial photography (< 1 m spatial resolution) were acquired across the entire PSU grid by Airborne Research Australia, Flinders University. Leica ScanStation-II Terrestrial Laser Scanner (TLS) and associated ground data were also obtained through a joint field campaign with the University of Southern Queensland and QDERM. The TLS data were acquired primarily to support the retrieval of structural attributes and AGB from the airborne LiDAR data and better parameterisation of SAR simulation models. Data were collected from six of the 34 field plots that were inventoried in 2000 and 2004 and from additional sites within selected PSUs.

5. Preliminary analysis

Initial investigations have indicated a close correspondence between the airborne LiDAR and TLS data (Figure 3), with differences attributed to the position of the sensor (above or below the canopy), the method of detecting returns, laser wavelength, and the range of scan angles. These data are being used to generated maps of individual tree locations, with these attributed with information from the field and TLS data including size, species type, and the density, size, orientation and biomass of components (leaves, branches and trunks) at both the individual tree and stand level. Such information will be used to support retrieval of similar attributes from the airborne LiDAR and also parameterisation of models that simulate microwave interaction with different components of the forest, thereby leading to a better understanding of how these might be retrieved from either airborne or spaceborne data.

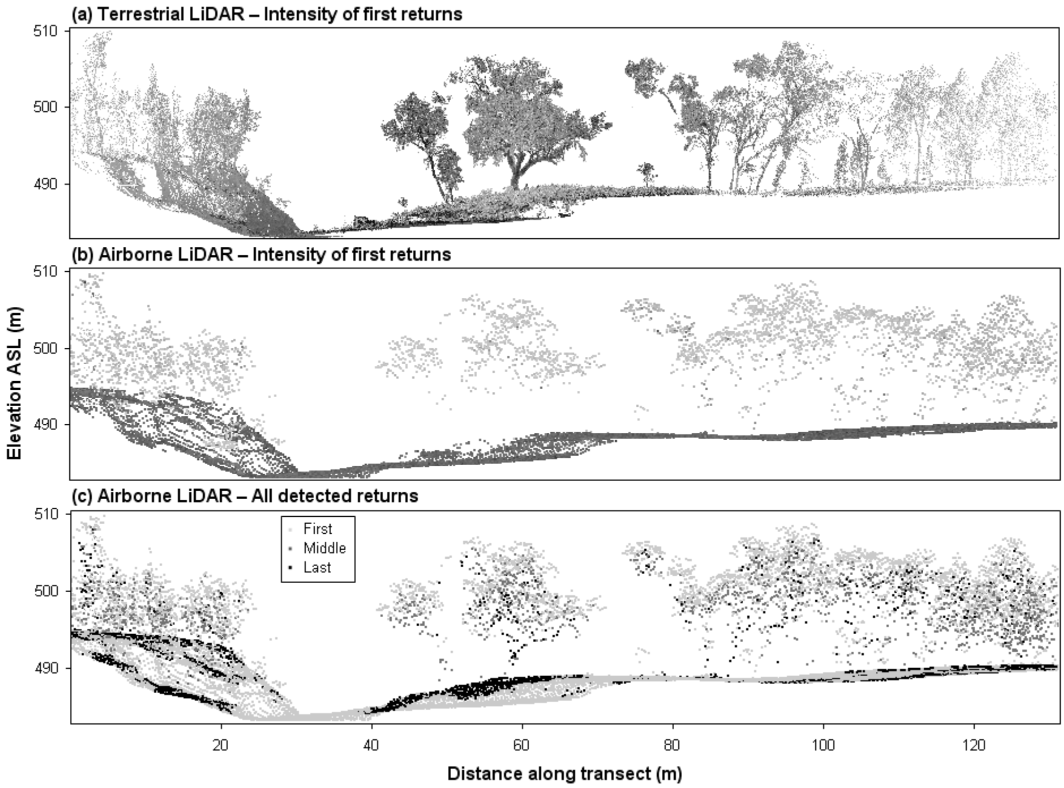

Figure 3. Comparisons between the TLS and airborne LiDAR point data acquired in 2009 (Lucas *et al*., 2010).

Comparison of the LIDAR data acquired in 2000 and 2009 has revealed significant changes throughout the PSU grid, with these relating primarily to regrowth following fire or clearance events or loss of individual trees. As an example, for areas of regrowth dominated by brigalow (*Acacia harpophylla*), an increase in canopy height of ~ 1 m was observed within a stand, with this confirmed through field observations conducted in 2000 and 2009 for the site (Figure 4). Brigalow regrowth is common to agricultural land and is characterized by a high density (often > 8000 ha^{-1}) of stems, with most being less than a few centimeters in diameter. As a consequence of this high density, these stands may remain structurally similar for several decades unless thinned (e.g., through active management; Dwyer *et al.*, 2010). Hence, the small difference in the canopy height model (CHM) between 2000 and 2009 was expected.

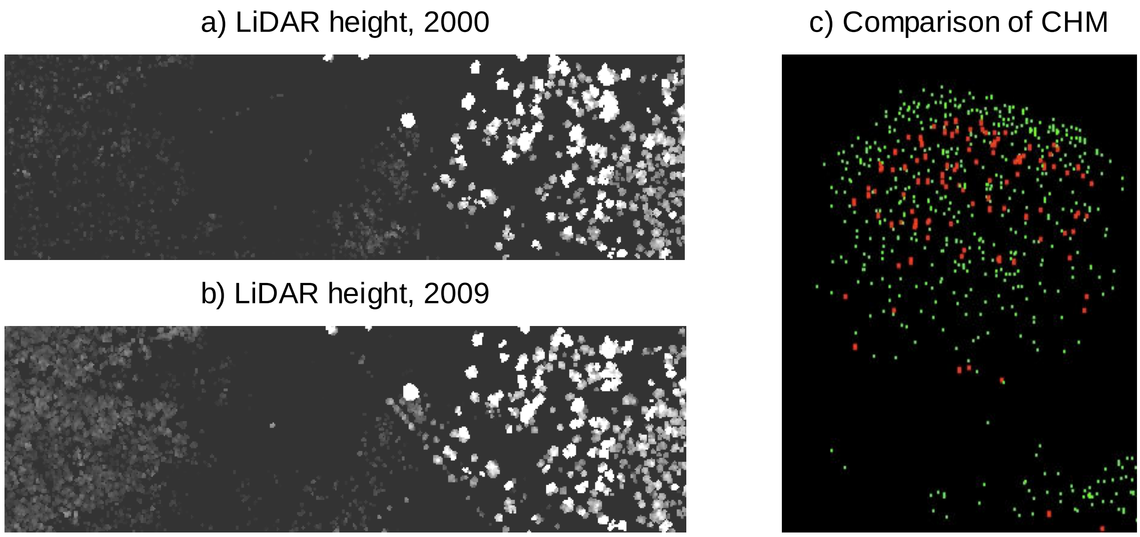

Figure 4. Comparison of Canopy Height Models (CHM) generated from LiDAR data acquired in a) 2000 and b) 2009 for PSU 131. A 1-2 m increase in the height of brigalow-dominated regrowth is observed towards the left of the image. Similarities in the distribution of trees between the two years are evident in the more mature stand towards the right. c) Growth of an individual tree in PSU 131, as manifested within time-series comparison of airborne LiDAR data from 2000 (red) and 2009 (green).

Within the intact forest, losses of trees between 2000 and 2009 are observed (Figure 5), with these often involving larger individuals. Information on the species type and also the loss of biomass or structural components (e.g., canopies or branches) can be quantified through reference to the aerial photography acquired in 2000 and 2009 and also the maps of tree species generated by classifying delineated tree crowns (Lucas *et al.*, 2008a). Similarly, the magnitude of tree growth can also be quantified. An example is provided in Figure 4c where an increase in height and crown volume is evident. Comparison of the LiDAR data from each of the 150 PSUs indicates some level of change and research is focusing on accounting for differences between sensors and quantifying such change across the PSU grid to establish the magnitude and direction of change in AGB (and hence carbon) and also the differential response of tree species to change.

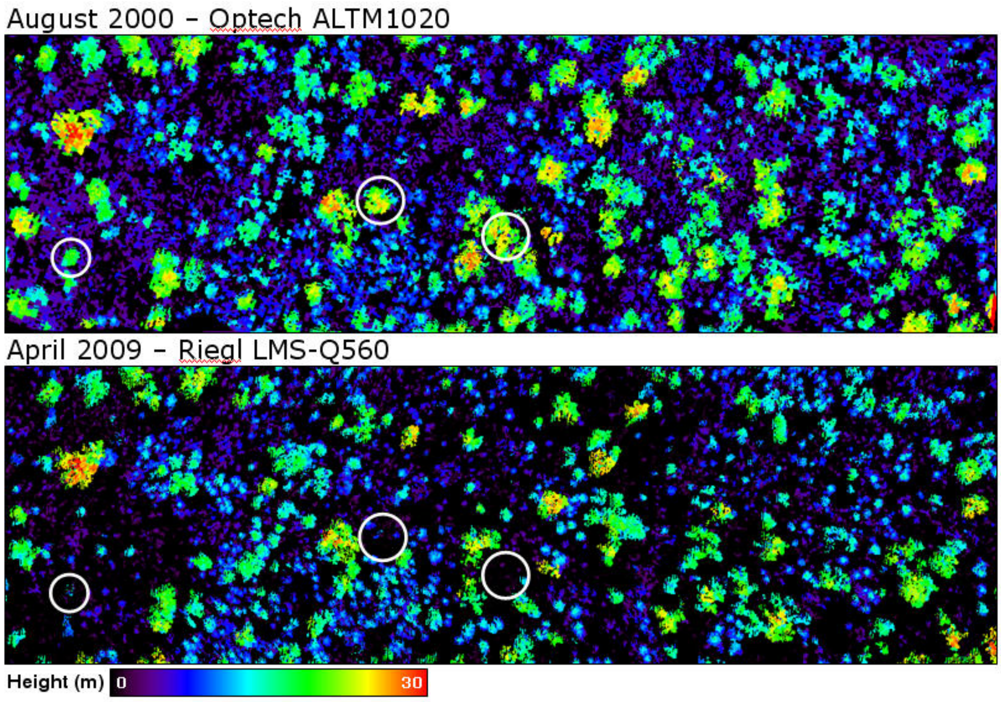

Figure 5. Height retrieved from discrete return and full waveform LiDAR acquired in 2000 and 2009 respectively for 1 of 150 PSUs highlighting the loss of trees (circled).

6. Change detection using spaceborne sensors.

The ILCP has demonstrated a capacity to detect change through time-series comparison of airborne LiDAR and hyperspectral data. These data and their fusion have allowed description of change through reference to information on species distributions and structure obtained from hyperspectral data and to attribute the cause of change to a specific event or process. This provides considerable opportunity to a) understand and quantify change across a landscape and b) develop methods for retrieval across larger areas through time-series comparison of spaceborne SAR and optical remote sensing data. A particular benefit of using these data is that the detection of changes occurring within the intact forest (e.g., degradation, regrowth) can be addressed whereas previously, detection has focused largely on more notable transitions (i.e., forest to non-forest and non-forest to regrowth).

An example of change detected through comparison of L-band HH data from the Japanese Earth Resources Satellite (JERS-1) SAR (mid 1990s) and the ALOS PALSAR 2007) is given in Figure 6. The images that are inset represent a composite of Landsat Foliage Projected Cover (FPC) and ALOS PALSAR and provide an indication of the type of change occurring. For example, areas of regrowth are typically manifested as supporting a high FPC (because of a high canopy cover), but a low L-band HH and HV backscattering coefficient because of the lack of stems of a size sufficient to evoke double bounce scattering. Dead standing timber typically exhibits a low FPC, because of lack of foliage, but a high L-band HH from double bounce interactions with the tree trunks. Cleared forests are associated with a low FPC and L-band HH and HV backscattering coefficient because of the lack of vegetation. On this basis, reductions in the L-band HH backscattering coefficient are observed as a consequence of clearing, fire damage and stem injection of trees. Gains are associated with regrowth following fire or clearing for agriculture. Some gains are also evident within the intact forest area and it is suggested that these are associated with tree growth and potentially woody thickening. However differences in ground moisture will also contribute. A further example of change observed from Landsat sensor data is illustrated in Figure 7 which reflects the reduction in vegetation productivity within the study area through the drought period of the mid 2000s.

Over the Injune study area, multiple-acquisitions of ALOS PALSAR data (fine beam single (FBS), dual (FBD) and polarimetric modes; multiple incidence angles) have been obtained through the JAXA PI programme and the Kyoto and Carbon (K&C) Initiative and an extensive time-series of Landsat sensor data are available through QDERM and the recently available USGS Landsat archive. The ILCP therefore provides a unique opportunity to establish whether comparison of these data in a time-series can allow various levels of forest degradation, regrowth and recovery to be quantified across larger areas.

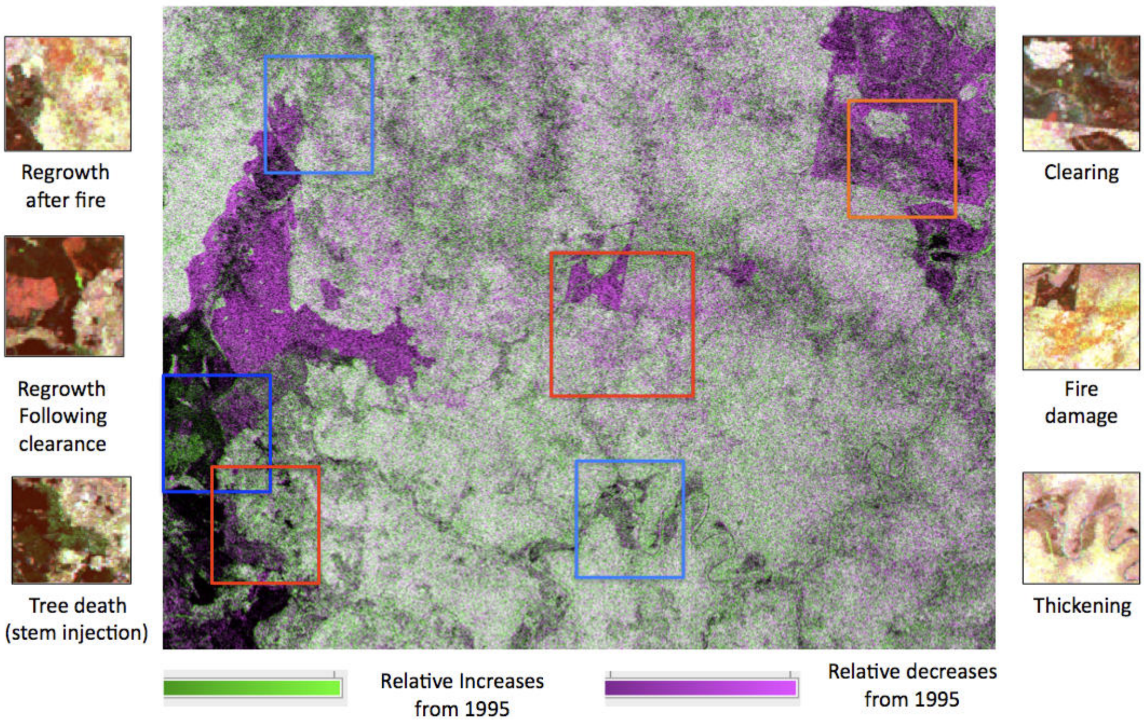

Figure 6. Changes detected between 1995 and 2009 by comparing time-series of JERS-1 SAR and ALOS PALSAR.

7. Discussion

7.1 Forest characteristion

During the course of the ILCP, a large number of algorithms have been developed on a common dataset, with the majority published and available for wider use. A list of publications is given at the end of this paper. A particularly benefit of multiple acquisitions over a specific site is that algorithms that integrate data from a range of sources can be advanced. Furthermore, repeat acquisitions of the same or similar datasets allow algorithms to be transferred or refined, thereby allowing better detection of change across a range of scales. The approach adopted by the ILCP may therefore represent a model which might be applied to other regions, both in Australia and overseas. Using the original 2000 datasets, algorithms continue to be developed (e.g., Bunting and Lucas, 2010) and the ILCP is also supporting a large number of research projects within the UK, Australia and the US (A list of Ph.D projects associated with the ILCP is given in Appendix I).

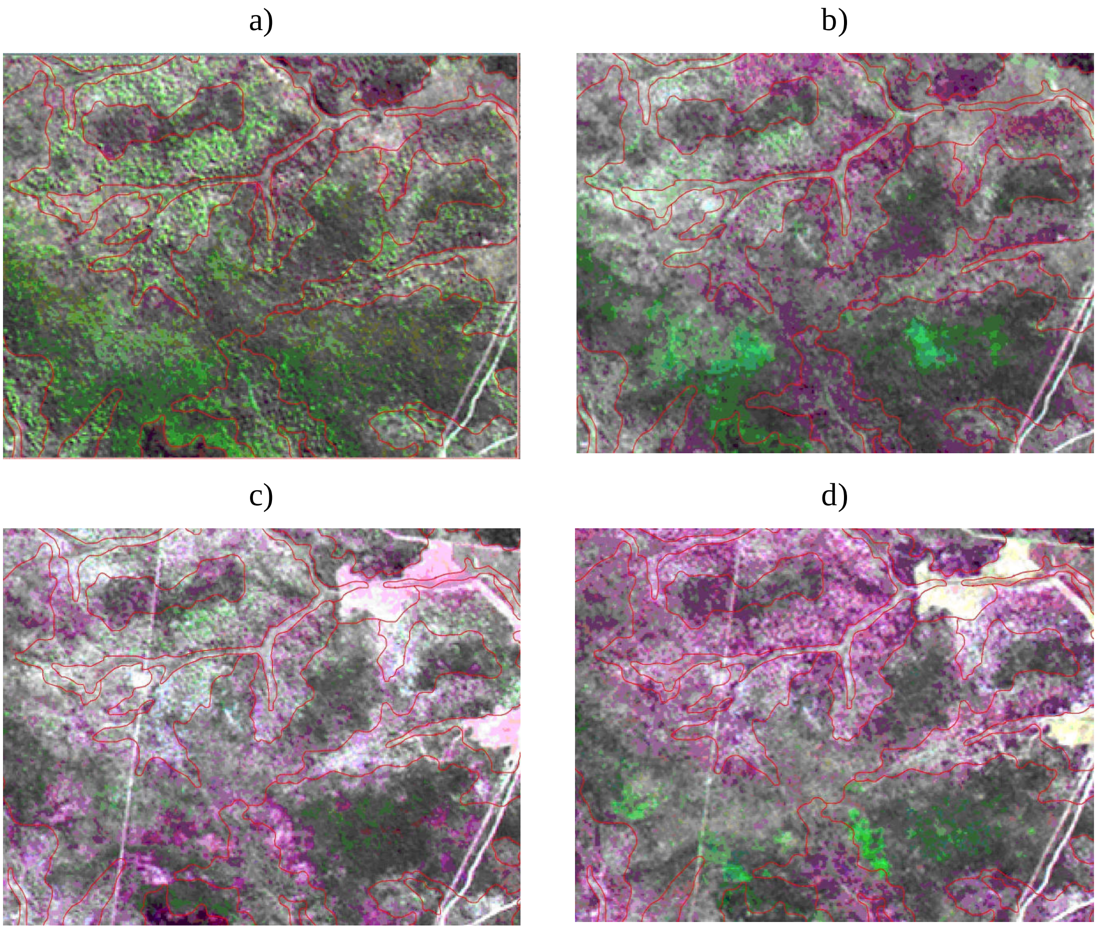

Figure 7. Landsat sensor data of forests observed in a) 1995, b) 2000, c) 2005 and d) 2008 (Source: A.B Pollock, Queensland Herbarium).

7.2 Detection of change

The ILCP has provided a unique opportunity to establish the extent to which multi-resolution airborne/spaceborne optical, LiDAR and SAR can detect changes within intact forests. From these data, the potential exists for identifying trends in the amount and distribution of species, structural attributes and biomass at the tree, stand and landscape level, at least for the period 2000 to 2009. At the tree level, loss or gains of species can be related to events (e.g., fire, selective removal) and processes (drought-induced mortality, regeneration or thickening). Where dieback of species is observed, the vulnerability to future land use and climate change can be assessed and, in particular, the impact of losing or gaining certain species on the overall structure and biomass of the forests quantified. Changes in AGB and carbon across the landscape are also able to be quantified. As the contribution of different species to the overall AGB can be established, the likely impacts of dieback, vegetation thickening, regrowth and fires on above ground carbon stocks can also be better estimated.

7.3 Injune as a long-term monitoring site

The field, airborne and spaceborne datasets acquired as part of the ILCP are unique and beneficial in that they provide a spatial and permanent baseline dataset of the broad species composition, structure and AGB of forests. A large number of algorithms have been developed for routinely retrieving information on the biophysical state of the forests. The provision of airborne data following the 2009 airborne campaign has given a unique temporal component to the project, allowing change associated with a range of causes and at scales ranging from within individual trees to the entire project area to be quantified. A large and diverse range of spaceborne remote sensing data have been acquired for the site and these are already being analysed to support related projects supported by the JAXA and NASA in relation to the use, or proposed use, of ALOS PALSAR and DESDynI. The outcomes of the ILCP are also addressing a wide range of issues relating to carbon cycle science, land management, conservation of biodiversity and algorithm development for existing and forthcoming sensors. Whilst significant change in the landscape has occurred between 2000 and 2009, change will continue to occur in the future and, as a very minimum, continued acquisition of airborne data in 2015 and every 5 years subsequent is recommended. Intra-annual ground-based sampling of key attributes is also required to understand the impact of seasonal variation in ground and canopy condition on the remotely sensed datasets (and hence change estimates) and to ensure the timing of degradation and recover events is captured. Therefore, the ILCP would also benefit from more long-term field based studies to complement and support the analysis of the airborne and spaceborne remote sensing data and the inclusion of the area for long-term monitoring of forests is recommended.

8. Conclusions

The ILCP has provided unique datasets and resulted in a suite of methods and algorithms for characterizing forests and detecting change across a range of spatial and temporal scales. Analysis of these data has also increased understanding of the dynamics of forests and their response to natural and anthropogenic causes of change (including climatic fluctuation). In particular, the preliminary time-series comparison of airborne datasets from 2000 and 2009 has highlighted significant change occurring as a function of tree death and plant growth and these data are expected to provide a unique insight into distributions of biodiversity, carbon dynamics and succession. Given the already substantial datasets and derived products which are being used to form a baseline of forest state and change, the Injune study area is well suited for inclusion as a long-term monitoring site for quantifying and understanding the dynamics of a widespread ecosystem.

Acknowledgements

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Appendix I

ILCP journal articles and book chapters

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ILCP Ph.D. students

Natasha Cronin (University of New South Wales, Australia)
Michelle Paterson (University of New South Wales, Australia)
Trevor Moffiet (Newcastle University)
Alexander Lee (Australian National University, Australia)
Peter Bunting (Aberystwyth University)
[1]Daniel Clewley (Aberystwyth University)
[1]John Armston (University of Queensland, Australia)
[1]Mariko Burgin (University of Michigan, US)
[1]Twi Barnardo (Aberystwyth University)

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