Use of ALOS PALSAR data for Quantifying the Biomass and Structure of Wooded Savannas, Queensland, Australia.

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***Abstract*—**The PI research has focused primarily on an area of wooded savanna in the Injune Landscape Collaborative Project (ILCP) area in central Queensland, Australia, for which a substantial amount of supportive airborne and field data had been collected in 2000 and 2004. In April, 2009, a second airborne campaign to the Injune area was also conducted during which airborne LiDAR, terrestrial laser scanning and field data were acquired. From these two LiDAR datasets (i.e., 2000 and 2009), retrieved estimates relating to the structure and species composition of the forests are being compared to quantify changes occurring as a result of natural and human-induced events and processes. These datasets have subsequently been used to interpret changes observed through time-series comparison of JERS-1 SAR, ALOS PALSAR and also Landsat sensor data. However, the study has also identified complications associated with variations in backscatter as a function of surface moisture conditions. The ILCP has provided a unique opportunity to understand the information content of the ALOS PALSAR data and is anticipated to be a valuable resource for the forthcoming ALOS-2 SAR mission.

***Index Terms*—ALOS PALSAR, airborne sensors, wooded savannas, Queensland, Australia.**

I. INTRODUCTION

The Injune Landscape Collaborative Project (ILCP) was initiated in 1998 to evaluate the potential of airborne SAR (AIRSAR), either singularly or in combination with optical data, for retrieving vegetation biomass and structure. 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 mixed forest/agricultural landscape west of Injune in the central southeast Queensland Southern Brigalow Belt.

AIRSAR data were acquired over the ILCP in 2000 by NASA Jet Propulsion Laboratory (JPL). To support the interpretation of the AIRSAR data, through both empirical studies and SAR simulation modelling, airborne LiDAR and hyperspectral data and aerial photography were acquired over a similar time-frame. 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 field campaigns within the ILCP 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 acquired, to establish whether the type, magnitude and direction of change could be quantified through time-series comparisons of these data. The research sought to establish whether such changes could be quantified through time-series comparison of spaceborne Landsat and ALOS PALSAR data.

This report provides an overview of the datasets and scientific outcomes resulting from the 2000 campaign as well as the associated follow on field campaigns in 2004 and 2006. The benefits of the ICLP 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 results relating to the detection of growth, losses of trees through fire and natural dieback, and gains through regeneration are provided. The role of the ALOS PALSAR and other spaceborne data in understanding the dynamics of these forests is then outlined.

II. 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 many occurring in 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.

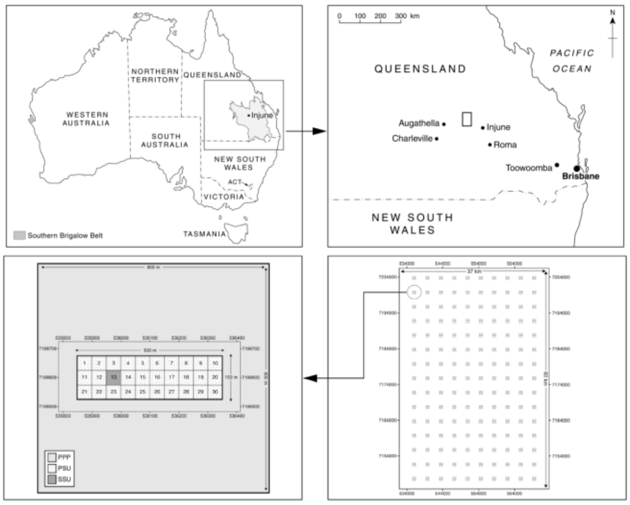

Figure 1. a) The location of the Injune study area and b) the layout of the sampling grid. Abbreviations used: PPP, primary photoplot; PSU primary sampling unit; SSU secondary sampling unit

Using these data, algorithms have been progressively developed for delineating tree crowns [1], differentiating mapped crowns to a species or genus-type [2] and retrieving biomass and structural attributes (crown cover, density, height) at both the tree [3] and stand [4,2] level from LiDAR and/or CASI data. These derived data have subsequently informed the interpretation of AIRSAR [5,6] Landsat [7], Terra MISR [8] and, more recently, ALOS PALSAR data (e.g., [9]). The data have also been used to support parameterisation and validation of SAR simulation models ([5],[10],[11]), with a view to better understanding microwave interaction with different structural components and advancing inversion algorithms.

III. 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, many of the 34 field plots had lost a number of individuals through natural processes whilst the growth of others had continued. 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. 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. In other PSUs, changes in the structure, AGB 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.

IV. REPEATING THE ACQUISITION: THE 2009 CAMPAIGN

A. *Generation of a biomass library*

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.

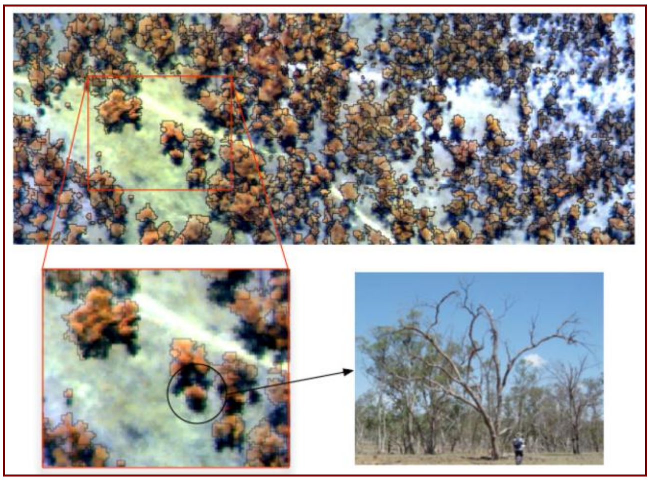

Figure 2. CASI image acquired in 2000. Delineated tree crowns were observed in full leaf in 2000 but many individuals of the species A. floribunda had experienced dieback in 2006 following the intense drought (bottom right).

V. Observing forest dynamics from airborne data

A. Regrowth

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, areas of regrowth dominated by brigalow (*Acacia harpophylla*) showed increases in height of ~ 1-2 m, with this confirmed through field observations conducted in 2000 and 2009 for the site (Figure 3).

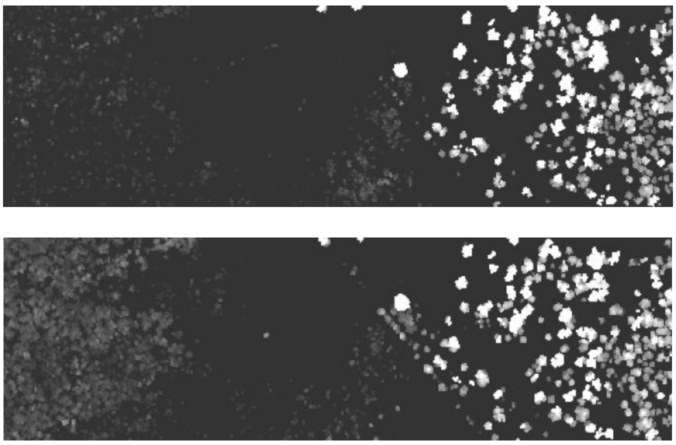

Figure 3. Comparison of Canopy Height Models (CHM) generated from LiDAR data acquired in a) 2000 and b) 2009 for PSU 131. A 1-2 m increase in the height of brigalow-dominated regrowth is observed towards the left of the image. Similarities in the distribution of trees between the two years are evident in the more mature stand towards the right.

Brigalow regrowth is common to agricultural land that has been neglected and is characterized by a high density (often > 8000 ha^{-1}) of stems, with most being less than a few centimetres 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) and hence the small differences in height observed between 2000 and 2009 are typical.

B. Forest growth and degradation

Within the intact forest, gains and losses of trees between 2000 and 2009 were observed (e.g., Figure 4), with the latter often involving larger individuals. Information on the species type and also the loss of AGB or structural components (e.g., canopies or branches) have been 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 [2]. Similarly, the magnitude of tree growth can also be quantified.

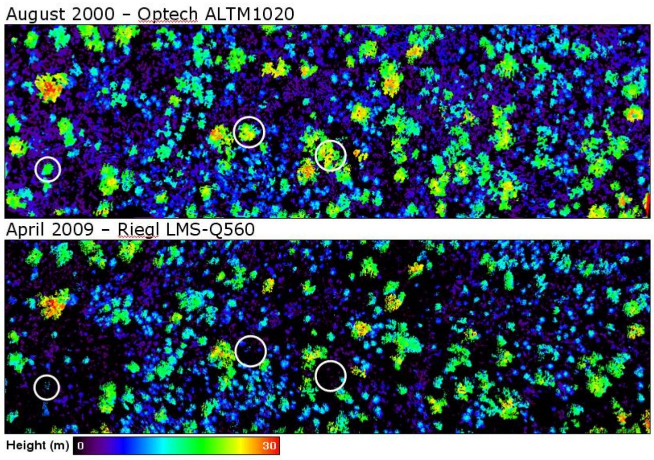

Figure 4. Height retrieved from discrete return and full waveform LiDAR acquired in 2000 and 2009 respectively for 1 of 150 PSUs highlighting the loss of trees (circled).

Comparison of the LiDAR data from each of the 150 PSUs has indicated different levels of change throughout the ILCP. Research continues to focus 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 natural and human-induced events and processes.

VI. Observing forest dynamics from spaceborne data

A. Time-series comparisons of SAR data

The demonstrated capacity to detect change through time-series comparison of airborne LiDAR data, describe 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 provided 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) could 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 [12]. Such changes have been supported through time-series observations using airborne datasets.

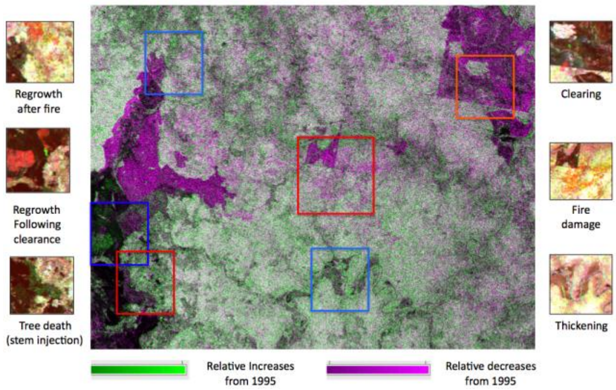

Figure 5. Changes detected between 1995 and 2009 by comparing time-series of JERS-1 SAR and ALOS PALSAR

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. In particular:

a) Areas of regrowth (following fire or clearance) 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.

b) 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.

c) Cleared forests are associated with a low FPC and L-band HH and HV backscattering coefficient because of the lack of vegetation.

d) Thickening is difficult to detect from the optical data but some differences are evident within the JERS-1 SAR/ALOS PALSAR comparison.

Reductions in the L-band HH backscattering coefficient were observed as a consequence of clearing, fire damage, selective logging and stem injection of trees. Gains were associated with regrowth following fire or clearing for agriculture. Some gains were also evident within the intact forest area with these associated with tree growth and potentially woody thickening. A further example of change observed from Landsat sensor data is illustrated in Figure 7, which reflects the reduction in vegetation productivity through the drought period of the mid 2000s.

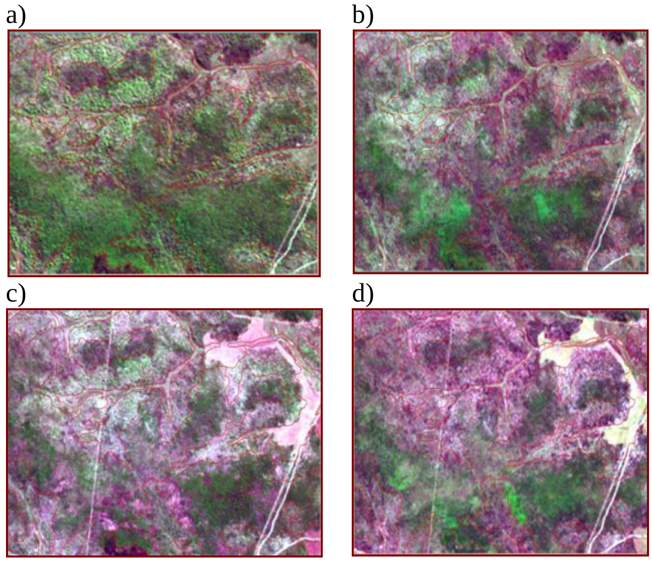

Figure 6. Landsat sensor data of forests observed in a) 1995, b) 2000, c) 2005 and d) 2008 (Source: A.B Pollock, Queensland Herbarium).

Comparison of regional ALOS PALSAR mosaics for 2007, 2008 and 2009 highlighted the impacts of ground moisture on the L-band HH and, to a lesser extent, HV backscattering coefficient and the increasing saturation with AGB. Whilst the time-series of ALOS PALSAR and also JERS-1 SAR data indicated that changes in the woody components of vegetation could be detected over decadal periods, distinguishing those attributed to growth of loss of woody vegetation rather than ground moisture differences was more difficult. Even within the same year, differences of up to ~ 4 dB and ~ 2 dB were observed within L-band HH and HV data respectively for the ILCP area. Research is continuing to focus on the use of the time-series of airborne LiDAR and multi/hyperspectral datasets for better understanding and validating how change is manifested within multi-temporal ALOS data and better establishing the influence of soil and vegetation water content on ALOS PALSAR backscatter data.

VII. CONCLUSIONS

The field, airborne and spaceborne datasets acquired as part of the ILCP are unique and beneficial in that they have provided 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.

The ILCP has provided a unique opportunity to better understand how structural attributes and changes in these can be detected using time-series of JERS-1 SAR and ALOS PALSAR data. Its role will continue into the future, with acquisitions from a range of spaceborne sensor data continuing including Worldview-2 and Tandem X. The outcomes of the ICLP 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, changes are also likely to occur in the future and, as a very minimum, continued acquisition of airborne data in 2015 and every 5 years subsequent is being promoted.

ACKNOWLEDGEMENTS AND IMAGE COPYRIGHTS

The work has been undertaken in conjunction with the Queensland Department of Natural Resources and Water (QDNRW) and the Queensland Herbarium and has been undertaken within the framework of the JAXA Kyoto & Carbon Initiative. ALOS PALSAR data have been provided by JAXA EORC." All illustrations are copyright of the ALOS K&C © *JAXA/METI, QDNRW and Queensland Herbarium EPA*.

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