Regional Mapping of Forest Growth Stage, Queensland, Australia, through Integration of ALOS PALSAR and Landsat Foliage Projected Cover.

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***Abstract*—Focusing on northern Australia and specifically the State of Queensland, ALOS PALSAR and Landsat-derived Foliage Projected Cover (FPC) 50 m strip mosaics were investigated for their potential for regional mapping of regrowth (non-remnant areas only) and above ground biomass (as a surrogate for growth stage) and for detecting dead standing timber, either induced naturally or through anthropogenic activities. Whilst approaches to mapping were developed and implemented at a regional level, the accuracy of the estimates was compromised by the variability in backscatter across and between strips. Current research is focusing on correction of mosaics and the collection and collation of new field and airborne datasets to support the regional mapping of growth stages, primarily between 2007 and 2011. Comparisons with historical JERS-1 SAR are also being undertaken.**

***Index Terms*—ALOS PALSAR, K&C Initiative, Forest Theme, forest growth stage, Queensland, Australia.**

I. INTRODUCTION

A. *Defining forest growth stage*

All forests can be associated with a growth stage but the spatial extent and size class distribution of trees at different stages of growth varies. Where plantations occur or forests are re-establishing on previously cleared land, relatively homogenous even-aged stands of forests occur. However, heterogeneity in the growth stage is introduced through competition and also where forests have experienced interrupted succession through processes that are natural, such as fires or drought, associated with human activities, such as grazing and selective thinning. Variability in the structure of forests at different stages of growth is also introduced at various scales through differences in physical environment and climate. Quantifying forest growth stage, particularly at regional levels, is therefore complex.

In all its forms, knowledge of the forest growth is fundamental for a number of reasons. In particular, regional estimation of growth stage can inform on the capacity of forests to recover carbon and biodiversity lost previously through deforestation and degradation activities. By understanding the impact of past land use and type as well as natural processes and events on the regrowth capacity of forests, options for greater sustainability of the land can also be developed.

B. *Remote sensing of growth stage*

Forest growth is a continuum but stages of growth are often described to more simply convey the state of the forest and methods, particularly those based on remote sensing data, vary. The scale at which forests are observed also impacts on the methods used for the description and quantification of growth stage using remote sensing data.

Detailed, albeit spatially limited, observations of individual trees and stands (e.g., in terms of height and size class distributions) can be undertaken using, for example, fine (< 1 m) spatial resolution data such as Light Detection and Ranging (LiDAR), aerial photography and/or multi/hyperspectral data (e.g., Ikonos, Quickbird, CASI [1]). More commonly, however, growth stage is defined using coarser spatial resolution optical and/or radar remote sensing data because of the requirement for characterisation and mapping across more extensive areas (e.g., for commercial forest inventory).

Many studies focusing on forest growth stage mapping have utilised optical remote sensing data, largely because of the availability of time-series, which can extend back to the early 1970s (in the case of Landsat). Using these data, the stage of growth is often defined on the basis of forest age, as estimated by comparing time-series classifications of land cover, or by establishing relationships with biophysical properties (e.g., height, density, or crown cover) that vary over the growth period. Spectral differences in reflectance may also indicate the growth stage as a function of the species composition, which may change rapidly as the forest regenerates, particularly in tropical environments [2]. Actual and relative biomass is also commonly used to indicate growth stage, although measures need ideally to be relative to the potential maximum biomass for a particular biome and environmental envelope.

With the increased availability of Synthetic Aperture Radar (SAR) data from spaceborne sensors, approaches to growth stage mapping have varied. The majority have indirectly quantified growth stage by utilising the recognised relationship between SAR backscatter and biomass or have established relationships with other structural attributes (e.g., stem number density, volume; (e.g. [3]), which vary as the forests regenerate. Time-series of SAR data have also been exploited to track the structural development of forests. Options for integrating SAR and optical data for mapping regeneration stage have also been considered. As an example, [4] combined NASA Jet Propulsion Laboratory (JPL) AIRSAR L-band HH SAR backscatter data and Landsat-derived Foliage Projected Cover (FPC) to map the extent of regrowth dominated *by Acacia harpophylla* (Brigalow) in south central Queensland, Australia. Based on the known relationship between L-band HV backscatter and biomass, several stages of regeneration were mapped.

C. Project objectives

The overall objective of the project is to investigate and demonstrate the potential of the Japanese Space Exploration Agency's (JAXA) Advanced Land Observing Satellite (ALOS) Phased Array L-band SAR (PALSAR), either singularly or in combination with optical data, for quantifying forest growth stage in northern Australia, focusing primarily on the State of Queensland and regenerating forests in particular. The study also sought to establish whether measures of growth stage might also be extracted from these data, including above ground biomass (relative to potential) or the extent of dead standing timber.

II. Background

A. Vegetation mapping in Queensland

The survey and mapping of Queensland's vegetation is a major program of the State's Environmental Protection Agency (EPA). The mapping program provides detailed information on regional ecosystems in terms of their distribution, rate of clearing and conservation status. The majority of regional ecosystem information has been produced at a scale of 1:100 000 although some coastal areas are mapped at a larger (1:50,0000) scale, including parts of Southeast Queensland and the Wet Tropics bioregions. Areas of non-remnant with vegetation (e.g., young regrowth or heavily disturbed vegetation) are not included [6]. For woody vegetation to be mapped as remnant, the dominant canopy must have > 70% of the height and > 50% of the cover relative to the undisturbed height and cover of that stratum and be dominated by species characteristic of the vegetation's undisturbed canopy. [20] provides further details on these definitions and the methodology used to survey and map vegetation in Queensland.

B. Forest growth stages in Queensland

Prior to European settlement, over 80 % of Queensland supported woody vegetation, including a diversity of forests, shrubs and heaths [5], with these ranging from tropical rainforest to low open mallee. Much of this vegetation, particularly in the northern regions, is still regarded as remnant although nevertheless suffers disturbance from natural processes (e.g., drought) or events (e.g., fire). In these areas, growth stage is more difficult to define because of the complexity of regeneration patterns associated with the differential response of species to adverse conditions and their capacity to recover, and limited knowledge of the characteristics of the mature state. A number of studies have, nevertheless, attempted to establish what is the biomass potential of these areas based on both pre-European and present-day distributions of ecosystems [6]. Differences between these two datasets may therefore provide some indication of the growth stage of forests, although factors such as fire extent, frequency and intensity are not easily accounted for.

Whilst much of Queensland is still regarded as remnant, significant clearing of vegetation has historically occurred in the south central and south-eastern regions. The Brigalow Bioregion, for example, has experienced some of the highest clearance rates with less than 15 % of forests with brigalow of gidgee (*Acacia cambagei*) as a major component occurring [7]. Other forest types that are disproportionately affected by clearing include flood and other depositional plains, which are typically dominated by *Eucalpytus* species. Within these regions, methods of clearing, and hence the subsequent regrowth of woody vegetation, vary. Where clearing occurs at the same time and over large areas, subsequent regrowth is often relatively even-aged. However, where processes such as ring-barking or stem injection occur [8], the regeneration is more piecemeal. The species composition and structure (e.g., density, canopy cover) of regenerating vegetation vary depending upon biogeographic distributions as well as the use and management of the land prior to abandonment (e.g., burning and reclearance frequency). Variations in topography, soils, geology, hydrology and climate also impact upon regrowth rates.

C. Current approaches to mapping growth stage

Within Australia, mapping of growth stage has commonly been undertaken using aerial photography, with young, early mature, mature, late mature and over-mature stages often defined. [9] suggested seven classes, with these depending largely upon the size, shape and condition of crowns. However, the mapping of equivalent classes using spaceborne sensors is more difficult and alternative approaches are needed.

For mapping the extent of early regrowth in areas where *Acacia* dominated, the method developed in [4] was based on the premise that whilst such forests typically support an FPC equivalent to forests, as defined by the Queensland Department of Natural Resources and Water (QDNRW), the size and density of stems has to be of sufficient magnitude to evoke a response at L-band and particularly at the HH polarisation where double bounce scattering between stems and the ground surface is prominent. Therefore, the extent of woody regrowth was associated with areas supporting an FPC > 12 % (approximately equivalent to 20 % canopy cover) but with an L-band HH backscatter equivalent to that of non-forest. The accuracy of classification for the Injune study area in central south east Queensland, as assessed against hyperspectral Hymap data, exceeded 80 %.

L-band SAR data also showed potential for discriminating stages of growth within the mapped area of regrowth. Modelling of L-band SAR backscatter from stands dominated by *A. harpophylla* at various stages of growth suggested that stems (which occur in clusters) individually have to be at least 2.5 m in height (which equates to about 2 - 5 cm in diameter) for the L-band backscatter to exceed that of non-forested areas. The model also indicated that volume scattering at L-band HV started to increase where trees were approaching 4 m in height, which was attributable to the increase in the size of branches within the canopy. The L-band HV backscatter was also shown by [10] to be more sensitive to increases in above ground biomass compared to L-band HH and provided an avenue for quantifying regrowth stage (i.e., by binning biomass classes). An alternative approach to tracking the development of forests is to utilise time-series of FPC on the assumption that increases and changes in spatial distribution of FPC occur as the canopy expands, particularly in open forest systems.

III. Study Area

Within Queensland, the extent of vegetation has been mapped using a combination of historical aerial photography and satellite sensor data [11] by the Queensland Herbarium of the Environmental Protection Agency (EPA; Figure 1). Areas of vegetation clearance over the period 1988 to 2009 have also been mapped on an annual basis by QDNRW. By linking clearance data with the distributions of mapped ecosystems, losses of vegetation by forest type are determined and areas regarded as remnant or non-remnant defined.

Within this region, the study focused initially on the Injune Landscape Collaborative Project study area ([12,13]; Figure 2), which is located within the Southern Brigalow Belt. In the late 1990s and early 2000s, extensive clearance of forests within and below the southern section of the Injune study area occurred. However, the areas cleared were difficult to maintain as active pasture and extensive tracts of regrowth, dominated primarily by brigalow, but also other species such as Poplar Box (*E. populnea*) and Silver-leaved ironbark *(E. melanaphloia*) regenerated. Other areas of regrowth distributed throughout Queensland and for which plot-based data had been collected, were also identified, with these being associated with *Acacia*-dominated forests but also a range of other forest types.

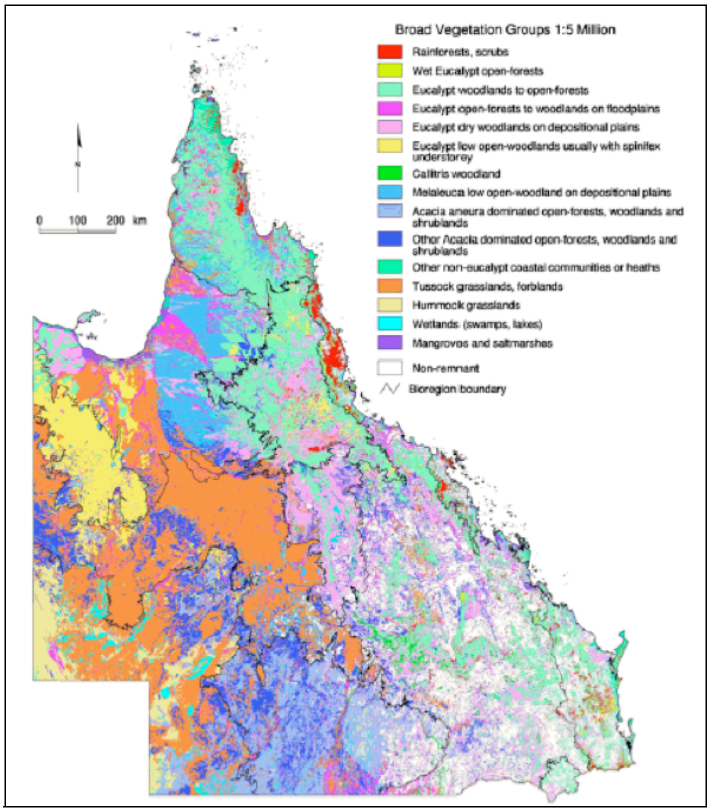

Figure 1). Mapped distribution of major forest types in Queensland, Australia [6]

IV. Available Data

A. *Satellite sensor data.*

For northern Australia, ALOS PALSAR fine beam dual (FBD) strip data were provided by the JAXA Kyoto and Carbon (K&C) Initiative for both 2007 and 2008. These data were provided at 50 m spatial resolution, in slant-range geometry, amplitude format, and 64 looks (4 in range and 16 in azimuth), with a swath width approximating 70 km.

Figure 2). The location of the Injune Landscape Collaborative Project and other regrowth sites in the IBRA bioregion of Brigalow Belt South, Queensland.

A regional mosaic of Landsat FPC data was also generated for 2006 by the Queensland Department of Natural Resources and Water (QDNRW) and the analysis focused on only those areas associated with non-remnant vegetation. To support the mapping of forest growth stages, a number of additional datasets were collated or collected including:

a) Compact Airborne Spectrographic Imager (CASI) and hyperspectral HyMap data, for extensive areas of regrowth within the Injune study area.
b) Plot-based measurements, including forest inventory from the Injune site [13], other regrowth sites 14], and through the TRAPS network of permanent plots [15].

These data were used to inform on the location of areas of regrowth. Additional datasets are currently in the process of being acquired.

V. METHODS

A. Pre-processing of satellite sensor data.

The ALOS PALSAR strip data were provided in slant range geometry, amplitude format, and were converted to intensity and calibrated (absolute calibration) using Gamma SAR processing software [16]. Geocoding of the strip data was undertaken with the Gamma Differential Interferometry and Geocoding (DIFF and GEO) suite. Initially, the geometric transformation from image to reference coordinates was undertaken by first using orbital state vectors and SRTM-derived DEM to approximate the position of each image strip and, second, establishing offsets between the ALOS PALSAR data and a SAR image simulated using the same SRTM-derived DEM to refine the registration. In this process, correlations were established between a large number of *n* x *n* windows passed over both images, with those with greatest correlation retained. However, as much of the northern Australia has very little significant relief, the refinement of the geometric transformation was undertaken (for Queensland only) by using Landsat Enhanced Thematic Mapper (ETM+) panchromatic mosaics for zones 54 to 56 and the same automated cross-correlation procedure. Each strip was then resampled using the resulting transformation. Geocoding errors were typically less than < 50 m. Across track correction and mosaicing was undertaken using Gamma and procedures developed by the European Commission's Joint Research Centre (JRC).

The Landsat FPC mosaic was generated using procedures outlined in [4,19]. As these were generated using the same Landsat sensor data associated with the panchromatic bands, the Landsat FPC and other State-wide datasets (e.g., land use change, vegetation mapping; several of which were obtained using the Landsat sensor data themselves), were also well registered and able to be integrated into subsequent analyses.

B. Mapping regrowth and dead standing timber (non-remnant areas)

Within the Brigalow Bioregion, and as observed using airborne SAR data, areas of regrowth dominated primarily by *A. harpophylla*, exhibited an FPC equivalent to that of forests and an ALOS PALSAR L-band HH backscatter equivalent to non-forest. To map the extent of regrowth, a rule-based classification was undertaken within Definiens Developer image segmentation and classification software, whereby areas defined as forest (FPC threshold > 12 %; equating to a canopy cover of ~ 20 %) and with a low (< ~ -14 dB) L-band HH backscatter were mapped as regrowth. Within this mapped area, relative stages of regrowth were defined by binning biomass values obtained using a relationship established with L-band HV backscatter (for low biomass forests). The same approach for mapping regrowth was applied to other sites and also to the strip mosaic of Queensland (non-remnant areas only).

Based on previous analysis of airborne data [8], areas of dead standing timber were identified as having an FPC typical of non-forest (< 12 % FPC) and an L-band HH typical of forests (e.g., > -14 dB), with this combination indicating the presence of woody material but no leaves.

C. Biomass estimation

For the local study areas and also for the full mosaic, above ground biomass (B) was estimated using a modification of the algorithm of [18], which included only the L-band HH and HV backscattering coefficient (σ^o) such that:

$$\mathrm{Ln}\,(B) = a_0 + a_1\sigma^o\mathrm{HH} + a_2\sigma^o(\mathrm{HV})^2 + a_3\sigma^o\mathrm{HV} + a_4\sigma^o(\mathrm{HV})^2 \quad (1)$$

where a_0 to a_4 represent equation coefficients and σ^o represents the backscatter coefficient (dB). The algorithm was re-parameterized by including measures of biomass collected for regrowth and intact forest sites (e.g., the permanent plot data acquired as part of the TRAPS network).

VI. RESULTS

A. Regional mosaics of ALOS PALSAR and Landat FPC

For Queensland, combined mosaics of Landsat-derived FPC and ALOS PALSAR HH and HV data were generated using both the 2007 and 2008 (Figure 3) acquisitions. Whilst at a regional level, the mosaic evidently suffers from the across track variability and the between-image differences (including, although to a far lesser degree, that associated with the Landsat FPC), unique information on vegetation and other surface structures is apparent within subsets of the mosaic (see example in Figure 4). Refinement of the strip correction and mosaicking process is ongoing with a view to generating a more seamless mosaic with standardized backscatter values.

Based on SAR simulation [13], L-band microwave interactions associated with the HH and HV data are primarily the result of double bounce scattering with the trunks and volume scattering from larger branches, respectively. By contrast, FPC is directly retrieved from Landsat sensor and ancillary (e.g., climate data; [19]) data and provides a quantitative a measure of foliage cover. The combination of these within the mosaic therefore provides a new regional data layer which can assist characterization and mapping of a range of forest structural types, including growth stage (particularly regeneration stage and standing dead or senescent timber). Unique information on the distribution and characteristics of wetlands (including mangroves) is also provided.

a)

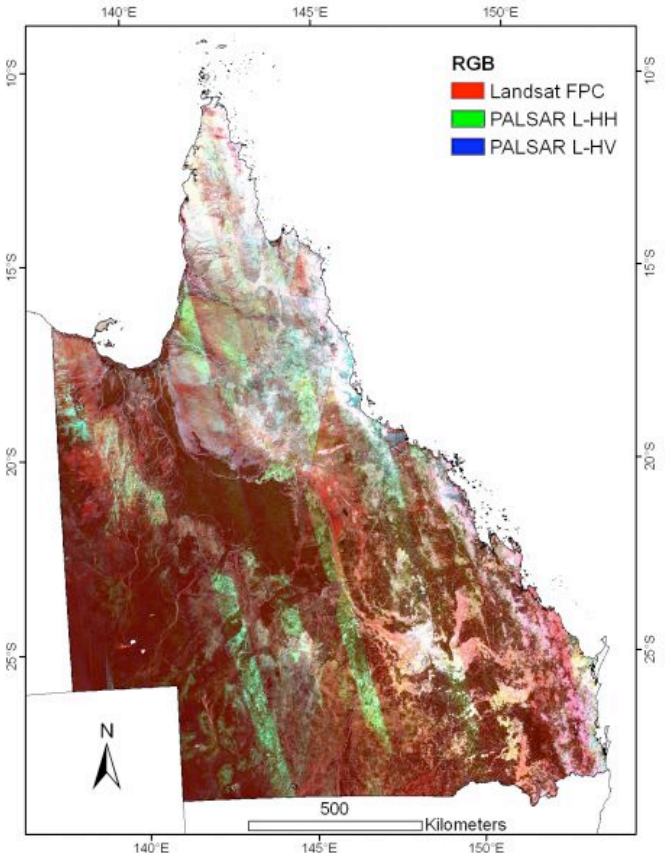

Figure 3) Landsat FPC and ALOS PALSAR L-band HH and HV mosaic of Queensland and b) a forested area in southern Queensland showing areas of closed tropical forest (pink), coastal mangrove (orange) and wooded savanna (shades of red and green)

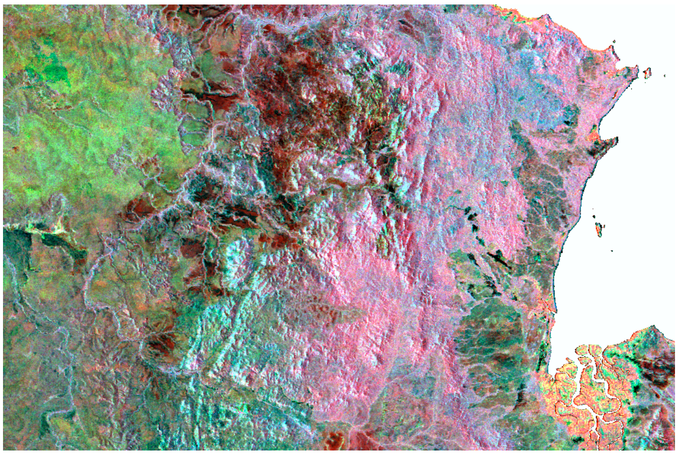

Figure 4) Landsat FPC and ALOS PALSAR L-band HH and HV mosaic of a forested area in north east Cape York Bioregion, Queensland, showing areas of closed tropical forest (pink), coastal mangrove (orange) and wooded savanna (shades of red and green)

B. Regrowth extent and growth stage, Injune

For the Injune study area, composites of Landsat FPC and L-band HH and HV data (in RGB respectively) were generated (Figure 5) which highlighted areas associated with regrowth (red).

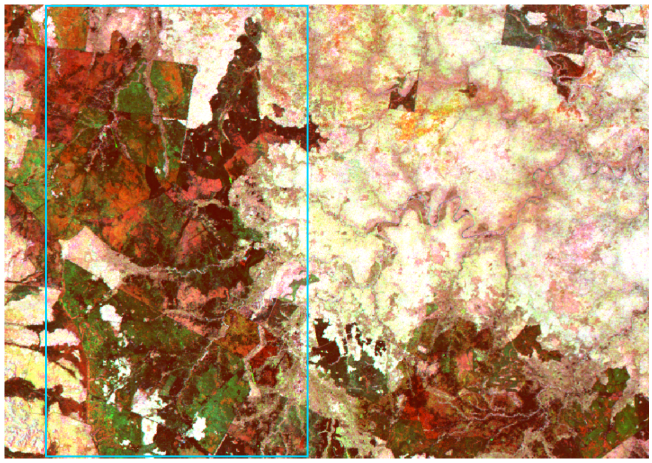

Figure 5). Subset of Landsat-derived FPC mosaic and ALOS HH and HV mosaics in RGB showing areas occupied by dead standing timber (green). Remnant vegetation supports higher FPC and HH and HV returns (shades of white).

For non-remnant forests, a diversity of information on the structure of forests within these three data layers was particularly evident. The map of regrowth extent and classification of two growth stages (Figure 6) within areas defined as non-remnant vegetation showed a close correspondence with the distribution observed within the composite image. The distribution was also similar to that mapped previously using a combination of AIRSAR L-band data and Landsat FPC over the study area.

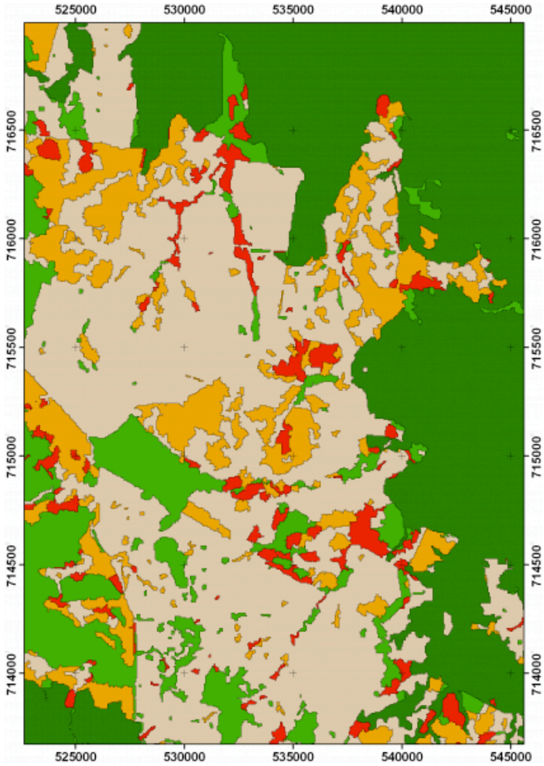

Figure 6). Classification of remnant forest (dark green), non-remnant forest (light green), early regrowth (orange) and late regrowth (red; see inset in Figure 5)

Preliminary regrowth maps have also been generated for areas regarded as non-remnant (i.e., previously cleared) in Queensland. Whilst a general correspondence between the mapped distributions of regrowth with field data and observations was noted, some discrepancies were observed. In particular, confusion between the early stages of regrowth and other vegetation types, including understorey vegetation, sand dune vegetation, heathlands and low mangroves led to the overestimation of regrowth extent. Older stages of regrowth or those occurring within areas with older remnant trees were also less well mapped. The variability in overall forest structure, which is largely associated with different species dominating regrowth and the spatial patterns of regeneration, was also considered responsible for the inconsistencies in classification, which are currently being investigated.

C. Dead standing timber

Preliminary assessments of the distribution of dead standing timber were undertaken for selected areas with ground information with a view to extrapolating to the wider area following correction of the ALOS PALSAR mosaics. Areas of of dead standing timber are noticeable in Figure 5 (dark green). Additional areas are being investigated with a view to regional mapping in Phase 2.

D. Biomass estimation

Using 10-fold cross validation, the model for retrieving biomass yielded a root mean square error of 28.5 Mg ha^{-1} and a coefficient of determination between observed and predicted of 0.48. Errors in the model were associated with discrepancies in the timing of the acquisitions of ALOS PALSAR and field data and also to within (across track) and between differences in the image data. Such issues are currently being addressed in Phase 2.

This model was nevertheless applied to the ALOS PALSAR 2007 and 2008 mosaics of Queensland to generate a preliminary map of biomass (Figure 6). The mapping largely reflected the known distribution of biomass within the region, with greater amounts associated with forests on the coastal regions towards the north and west of Australia. However, the biomass of many of the subtropical and tropical forests was under-estimated and this was attributed to the algorithm being developed primarily using data obtained for wooded savannas. The upper range of biomass (approximated here at 150 Mg $^{ha-1}$) is uncertain because of saturation of L-band SAR. Discrepancies are clearly associated with variation within and between strips.

Our studies using airborne data have suggested that different algorithms need to be developed and applied as a function of the structure of the forest (and particularly in relation to canopy closure). For this reason, revisions of the algorithm are being undertaken in Phase 2 using new collations of existing field data acquired over periods corresponding to past and future ALOS PALSAR acquisitions. New field and airborne (e.g., LiDAR) data acquisitions are also being conducted in 2009 to support this analysis.

VII. Discussion

A. Overview

Consideration of the differential interaction of microwaves with different components of the forest volume is important in understanding how and why different forest growth stages may be differentiated and mapped using SAR data. The following provides an overview of observations using airborne multi-frequency polarimetric SAR data and then discusses these in the context of mapping biomass, regrowth, dead standing timber from ALOS PALSAR data.

B. Microwave interactions

For most forests with a full canopy, a high C-band backscatter is typically observed, primarily because of volume scattering from the leaves and small branches [13]. In many ways, these data provide similar information as the Landsat FPC. However, for forests to be observed within lower frequency L- and P-band data, the size (diameter and also length) and density of stems have to be sufficient to evoke a response. This is highlighted below using two examples from woody savannas (Lucas *et al*., 2006b).

In the first example, areas of regrowth and more mature forest are not distinguishable at C-band (and also within Landsat FPC data) because the amount of foliage and small branches in the canopy is similar. However, the L- and particularly the P-band backscatter from the younger regrowth forests is lower compared to the mature forest because there is an insufficient amount of woody material for double bounce or volume scattering mechanisms to fully operate. In the second example, medium size (e.g., 5 - 10 cm diameter) trees (as delineated within hyperspectral data) are observed at L-band but not at P-band, suggesting that even less and perhaps a significant proportion of the woody material remain undetected.

This knowledge can assist with interpretation of relationship between backscatter and biomass. In closed forests, for example, saturation occurs above a certain level of biomass density as no increase in backscatter with biomass is observed. In more open forest, however, the same magnitude of backscatter may not be attained because of the lack of interaction with woody material below a certain size and density. At P-band HV, for example, ‘saturation’ within wooded savannas is observed at about 65 Mg ha^{-1} [10], which is lower than that typically observed for closed forests (100-150 Mg ha^{-1}) simply because the P-band is only showing sensitivity to the larger woody components and many of the smaller trees and components are simply not observed. The relatively wide spacing of trees may also reduce the overall backscatter as greater interactions with the ground surface occur.

Other factors also complicate interpretation. For example, as a greater amount of backscatter returns from ground interactions occurs in more open forests, rainfall and associated increases in soil moisture can also increase backscatter and give a false impression of increased biomass. Backscatter also increases with surface roughness and, particularly in areas of rocky terrain, can lead to inaccuracies in biomass retrieval.

C. Biomass estimation

For wooded savannas of relatively low biomass, and depending on their structure, L-band microwaves are well suited for estimating biomass because of greater interaction with a wider range of size classes (i.e., of woody branches and trunks). Differences in the biomass-backscatter relationships as a function of canopy closure are currently being evaluated but indicate that different algorithms are required for estimating the biomass of open and closed forests. This is partly evident from Figure 8 where many of the higher biomass tropical and subtropical rainforests on the east coast are (incorrectly) not associated with a high biomass value. However, wooded savannas known to support higher biomass values (e.g., the west coast of Cape York) have been identified.

Whilst the current algorithm has been developed for retrieval of biomass without consideration of forest type, the formulation of separate algorithms for open and closed forests is anticipated. However, the following needs to be undertaken:

a)

b)

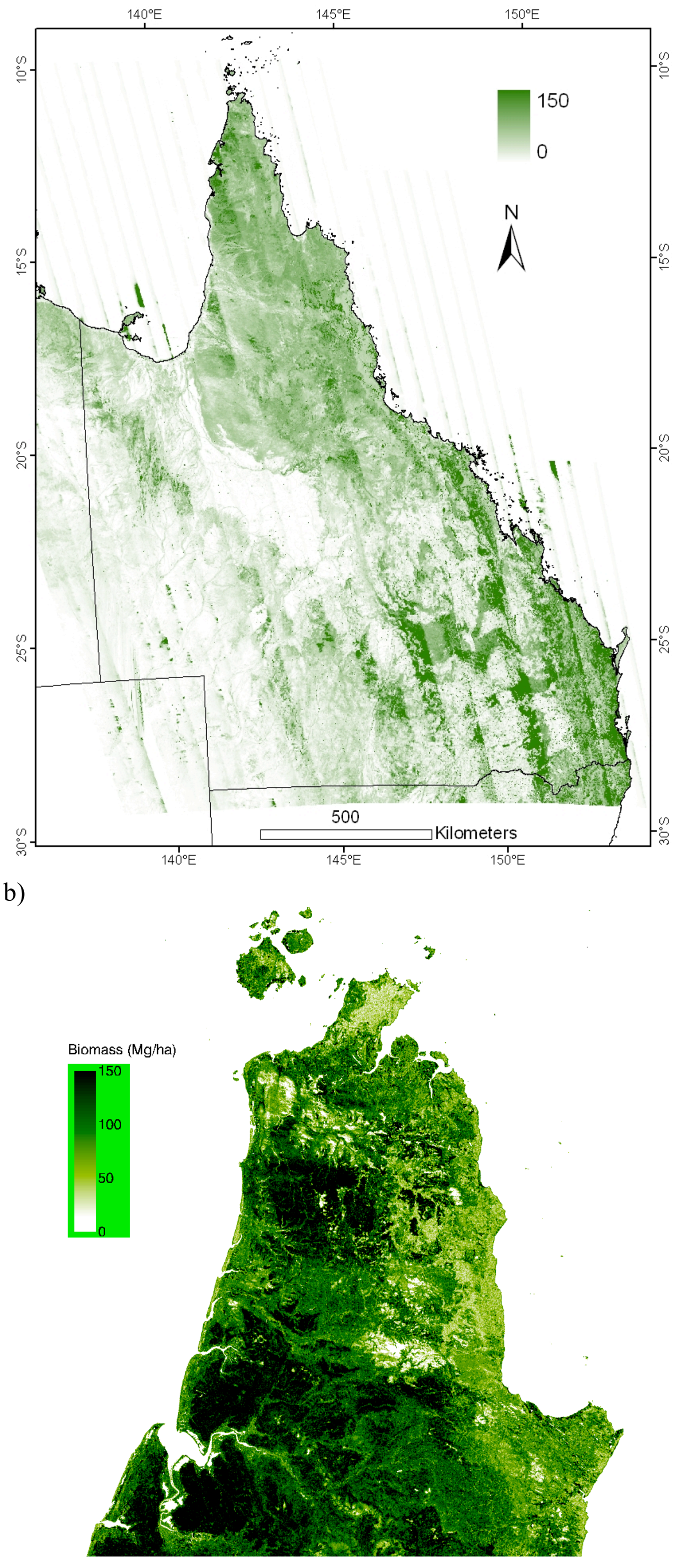

Figure 8. Preliminary estimates of biomass for top) Queensland and bottom) north Cape York based on ALOS PALSAR data acquired in 2008

a) A range of field-based biomass data needs to be collated and collected for both open and closed forests. This is currently being undertaken with focus on data acquired during the period of the ALOS operation. A proportion of the available field data was acquired prior to this period, which has led to inaccuracies in parameterization of the algorithm. This is particularly an issue in northern Australia where forests are dynamic and responding differently to processes such as drought, flooding, fires and anthropogenic disturbance.

b) Scatter in the relationships between L-band data and biomass attributed to variations within (due to cross track effects) and between the ALOS PALSAR images/strips needs to be reduced through better correction of the data.

D. Regeneration stage

The combination of L-band HH and Landsat FPC is a simple approach to the mapping of regrowth that can be applied using image pairs acquired on proximal dates. The main limitation is the inconsistency of the approach between regions. Whilst the approach provides good estimates where a relatively closed canopy, such as that typified by brigalow occurs, regrowth with sparser canopies or older regrowth is more difficult to detect. The approach to mapping is therefore being evaluated for a wider range of regrowth types and across bioregions.

E. Dead standing timber

The combination of Landsat-derived FPC and L-band HH data allowed known areas of dead standing timber to be mapped. Typically, identified areas were associated with clearance for agriculture (particularly grazing) as many trees are killed but left standing and a grass layer maintained beneath. However, where tree death occurs through natural causes such as fire, flooding or drought, regeneration often occurs either from the understorey or through epicormal growth. FPC may therefore return to levels associated with forest cover after several years of growth. Confusion with woody debris and also rocky outcrops or surfaces also occurred, although the ratio of L-band HH and HV assisted in discrimination.

Whilst in theory, the approach to classification should provide relatively consistent mapping, the high level of variability in the structure of dead standing timber (e.g., in terms of size class distributions), the causes of tree death and the nature of recovery requires adaption of algorithms which is an ongoing process. Nevertheless, the potential exists for the regional mapping of dead standing timber over time which, if combined with Landsat FPC and climate data, may provide unique insights into the longer-term response of forests to natural and human-induced (including climate) change.

VIII. CONCLUSIONS

The research has provided a first evaluation of the use of the ALOS PALSAR and Landsat-derived FPC mosaics for regional mapping of forest growth stage in Queensland, Australia. Options for quantifying the regional extent of different stages of early regrowth and standing dead or senescent timber have been presented. An algorithm for the estimation of above ground biomass has been formulated and applied regionally. Key highlights of the work are as follows:

a) The Landsat FPC and ALOS PALSAR HH and HV mosaics have provided unique regional datasets that give information on different structural attributes of woody vegetation (leaves, branches, trunks). Given the diversity of structural formations across Queensland and northern Australia in general, which are largely attributable to environmental (e.g., climate) gradients, the interpretation of these mosaics is complex. Nevertheless, our studies have shown that an enormous amount of information on vegetation and particularly growth stage and also structural type, can be extracted.

b) Options for mapping regrowth and dead standing timber in non-remnant areas have been provided. Information on the extent of regenerating forests on land cleared of vegetation since European settlement (defined as non-remnant) is required to better understand the recovery of forests following clearance and also to determine their relative biomass and contribution to regional carbon budgets. Whilst discrepancies in the extent of regrowth were observed, options exist for resolving these issues. The extent of dead standing timber, particularly over time, is important for understanding ecosystem response to climatic variation (e.g., drought cycles), particularly if integrated with time-series of JERS-1 SAR data. Detection of dead standing timber associated with human activities rather than natural events and processes appears to be more successful, although options for mapping the latter are being considered.

c) The estimation of biomass from ALOS PALSAR dual polarimetric data is feasible although better parameterisation of the model is required through use of field and airborne-derived estimates acquired over similar time-periods. Different biomass retrieval algorithms are therefore being developed, at least for closed and open forests.

Despite these advances, the provision of the regional mosaics has raised particular issues in relation to correction of the strip data and the availability of appropriate and timely ground truth data, particularly given the dynamic nature of the Australian forests. For these reasons, current research is focusing on better correction of the strip mosaic data and collection of field and airborne data in late 2008/early 2009 such that more appropriate datasets are used to support the development of mapping algorithms. Such activities include:

a) Reprocessing of the ALOS PALSAR data to reduce within (across track) and between strip variation and gaining a better understanding of the reasons for such variation through reference to meteorological and vegetation datasets.

b) Acquisition of full waveform LiDAR for 20 sites covering a range of forest structural types (from sparse open woodland to closed subtropical forests) and associated collection of ground truth (including terrestrial laser scanner data). Data have already been acquired for 19 sites and LiDAR are to be acquired for Injune (Site 20) in April, 2009 (9 years following the previous acquisition in 2000). Such data will also then be used to establish whether change can be detected (e.g., regrowth, tree mortality, woody thickening) through time-series comparison of SAR data, and in combination with the Landsat time-series.

c) Focused studies on areas in Queensland associated with change. Examples include the Bunya Mountains where woody thickening and rainforest encroachment has occurred in recent decades.

d) The advancement of algorithms for retrieving the above ground biomass of forests with modifications for closed and open forests.

These activities are being conducted currently and will also feed into the interpretation of the 2010 and 2011 ALOS PALSAR mosaics to be provided under the K&C Initiative in Phase 2.

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