# Key outcomes of the Tasmania ‘National Demonstrator’: A project for the GEO Forest Carbon tracking task

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**Abstract – Global forest information monitoring demands consistent, wall-to-wall, time-series measurements of forest and land cover change. To be of value to the scientific community and to support countries' Monitoring, Reporting and Verification (MRV) systems, robust and repeatable methods of generating forest change estimates from remote sensing data are required. In this paper, we demonstrate an approach to mapping the changing extent of forest and land cover in Tasmania using data acquired by the ALOS PALSAR. Land cover and forest/non-forest mosaics were produced for the years 2007 – 2009. Change maps were produced that identified areas of deforestation and regeneration between years. The accuracy of forest information products will be assessed using available state-wide vegetation mapping, field inventory and optical data. The methodologies presented are applicable to regional scale forest monitoring and the products developed are of sufficient accuracy to be included in modelling scenarios for the estimation of carbon stocks.**

**Key words**: land cover, mapping, vegetation, environment, forestry, carbon

## 1. INTRODUCTION

Consistent estimation of carbon stocks at national scale requires the integration of multi-temporal, wall-to-wall satellite measurements of forest extent, land cover and change. To alleviate current uncertainty in forest change estimates, standardised methods of linking remote sensing data and forest inventory, extracting forest cover information and evaluating accuracy are required (Achard et al., 2007). More reliable forest information will facilitate more accurate determination of emissions from forest and land cover change and so contribute to individual countries' Measurement, Reporting and Verification (MRV) systems and international reporting requirements (Herold and Johns, 2007).

Australia's National Carbon Accounting System (NCAS) relies on time-series Landsat measurements to extract forest cover information (AGO, 2002). One of the goals of the Group on Earth Observations (GEO) Forest Carbon Task (FCT) is to demonstrate the capabilities of Synthetic Aperture Radar (SAR) data for forest information monitoring. SAR is of interest because of its cloud penetrating capability and ongoing data continuity. Radar data will be analysed as an independent source of forest information, and its interoperability with optical data will also be investigated.

In this paper, we address the fundamental requirement of spatially and temporally consistent, wall-to-wall radar mosaics for the generation of forest information products and how a time series of mosaics can investigate forest change. The potential of satellite based operational forest monitoring for national carbon accounting is also discussed.

## 2. TASMANIA: VEGETATION AND LAND USE

Tasmania is Australia’s only island state, covering an area of approximately 6.7 million ha. The combination of mountainous terrain, geology and temperate climate has yielded a diversity of vegetation types (Figure 1). The majority of forested landscapes in Tasmania are covered with Eucalyptus species (Harris and Kitchener, 2005). Dry Eucalypt forest tends to grow on the east coast, central highlands and north east, wet eucalypt forest is found in the south, west and north west, and rainforest occurs extensively in the north west. Highland treeless vegetation inhabits the alpine and subalpine regions. Buttongrass moorland and sedgeland dominates the western part of the State, while scrub, heathland and coastal complexes are more scattered. Agriculture predominates in the north east.

Land use in Tasmania is dominated by commercial forestry and agriculture (Australian Natural Resources Atlas, 2009). Commercial plantations consist mainly of native hardwood (eucalypt) species, with some large areas of softwood plantation (e.g., pine). Conservation within parks and reserves is extensive, especially in the north west, and is mostly remnant native vegetation. Agriculture is diverse with livestock and cropping being the major contributors.

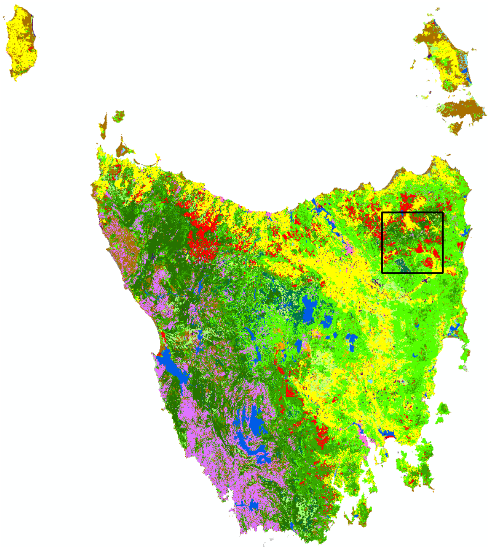

Figure 1. State-wide vegetation communities (TASVEG). Mathinna calibration site in the NE is indicated in black.

## 3. RADAR DATA AND PROCESSING

141 Fine Beam Dual (FBD) polarisation (L-band HH+HV) ALOS PALSAR images were acquired over Tasmania during an August to October timeframe for the years 2007 – 2009. Data were acquired in ascending mode at an incidence angle of 34.3°. Annual wall-to-wall mosaics were generated by applying the processing sequence illustrated in Figure 2.

Single Look Complex (SLC) FBD data were supplied by the Japanese Space Agency (JAXA). Using ENVI SARscape software, data were multi-looked using 4 looks in azimuth and 1 look in range to produce quasi-square pixels approximating 12.5 m. Multi-date slant range images over the same area were automatically co-registered and standard Lee filtering was applied to reduce speckle.

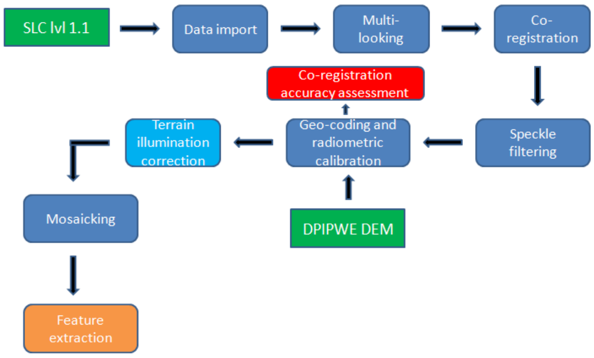

Figure 2. Flowchart illustrating the processing sequence applied to generate the annual, wall-to-wall radar mosaics.

A 25 m resolution Digital Elevation Model (DEM), available through the Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE) was used to ortho-rectify the radar imagery. The process corrects for distortion resulting from the side viewing geometry of SAR and topography. Data were radiometrically calibrated and normalised to account for brightness differences from near to far range. Standard radar equations using pre- and post-2009 calibration factors were applied, and data were converted to sigma0 (dB). Pixel-to-pixel co-registration accuracy between multi-date radar images was achieved.

Ortho-rectified images were corrected for terrain induced artefacts using a procedure developed by Zhou et al. (2011). Terrain Illumination Correction (TIC) is applied prior to mosaicking to ensure consistency in illumination within and between images; essential for subsequent discrimination of surface cover. TIC images were first mosaicked along the path. The path mosaics were then mosaicked from east to west to produce the final, wall-to-wall coverage. The same processing sequence was applied to generate all 3 annual, ortho-rectified, terrain and illumination corrected, radiometrically calibrated, seamless, wall-to-wall mosaics.

## 4. BASELINE LAND COVER MAPPING

A baseline land cover and forest/non-forest map was produced from the 2007 ortho-rectified PALSAR mosaic. Urban and water polygons were extracted from the TASVEG dataset and used to mask the mosaic. An object-based approach to classification was then implemented using eCognition Developer software. Segmentation of SAR data is a popular approach to enhancing information extraction, and the results will be used for subsequent studies on the comparison of alternative classifiers and methods. The size of the mosaic and desired level of segmentation exceeded the computing capability within the Developer environment, so a chessboard segmentation was first applied to sub-divide the full mosaic into 34 square tiles. Each tile was identified in turn and a 2-step fine chessboard and multi-resolution segmentation was applied. Chessboard segmentation divided the tile into objects of 1 pixel in size. Multi-resolution segmentation then iteratively merged those pixels into objects of maximum homogeneity. Polygon variables were defined along tile borders and the area re-segmented to ensure a seamless connection between the segments of adjacent tiles.

Cover classes were identified using field knowledge at 3 calibration sites and TASVEG mapping as reference. Rule sets were established for each tile and each class using membership (fuzzy logic) functions and/or thresholds relying on spatial (context) and spectral features. Region growing was often applied, where strict thresholds are first used to classify segments of definite class membership. The process then runs in a loop, iteratively classifying neighbouring segments that satisfy a given criterion.

The complexity of the rule sets increased with increasing number and spectral overlap of cover types. Differences in backscatter resulting from soil or canopy moisture, or on-ground change due to timing of image acquisition, also meant that the classification rules were adjusted for like classes in different tiles. Texture measures extracted from segmented data did not contribute greatly to class separation. Where height ranges extracted from the DEM were used to define class membership, these varied with location.

Simple backscatter thresholds were used to separate agricultural land from other classes. The ease of separation was primarily due to paddocks being the darkest feature (i.e., lowest backscatter response) on the L-band imagery, with the exception of areas of growing crop. Alpine heath and sedgeland was discriminated on the basis of elevation. As an example, alpine heathland in Mathinna was the only vegetation community present above 1200 m. Buttongrass moorland was discriminated reasonably well, given its distinct appearance on PALSAR imagery and low HV backscatter. Most difficult was the separation between buttongrass and scrub communities, with similar backscatter response observed over dense growth.

In comparison to natural forest, pine plantation was characterised by a smoother texture, and higher HH and HV backscatter within a fairly narrow defined range. There was clear visual separation of eucalypt plantation from forest and pine plantation, particularly at HV. However, there was confusion in the classification where mature plantation approached near structural similarity with forest, due largely to increasing canopy closure and the impact on ground and volume scattering.

Minor vegetation communities including grassland, wetland, lichen, and urban and exotic vegetation were, for the most part, manually identified on the imagery. Rule sets for minor cover types included the location of clusters of segments, together with spectral and spatial features (e.g., size and shape of segments). Context was often useful, for example, wetland and saltmarsh communities were located within a certain distance of a water body or other vegetation class.

Following generation of the land cover map, the classes 'forest', 'pine plantation' and 'eucalypt plantation' were merged into a 'forest' super class, and all other classes were merged into 'non-forest'. Figure 3 illustrates the PALSAR data over the Mathinna calibration site and the derived land cover and forest/non-forest maps. Mapping accuracy of the 2007 baseline will be assessed using available field data, TASVEG and Landsat data.

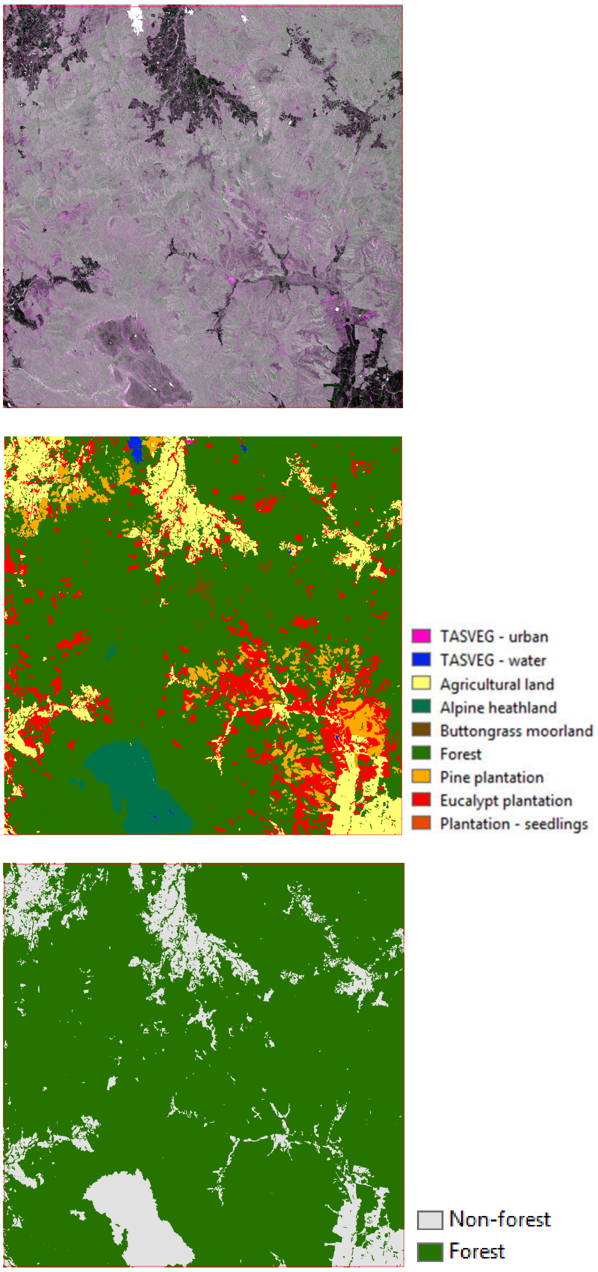

Figure 3. ALOS PALSAR 2007 data (HH:HV:HH in RGB) over Mathinna calibration site (top), derived land cover classification (middle) and forest/non-forest map (bottom).

The method is not yet operational in the sense of a trade-off between mapping accuracy and process efficiency. Ideally, one rule set per cover class would be established and applied to each tile of the mosaic, similar in approach to extracting samples from data to train a classifier; the trade-off being an anticipated reduction in overall accuracy. Experience in processing this dataset suggests that both approaches would achieve acceptable levels of accuracy for the purposes of mapping forest cover and identifying change at the relevant scale. Use of eCognition server and parallel processors would also streamline the processing, and facilitate more rapid quality control during classification.

## 5. FOREST INFORMATION PRODUCTS

Land cover maps for subsequent years were generated using the 2007 baseline land cover and change detection results. The change images (e.g., Figure 4) are used to identify where change has occurred between dates, which, in some instances, can be related to a change in land cover. A positive change or increase in brightness between dates can indicate regrowth or vigorous vegetation activity. A negative change or decrease in brightness can indicate clearing or a change in cover (e..g, clear felling forest for plantation). A change in soil and/or canopy moisture due to rainfall can also induce a change in backscatter however, and must be considered when interpreting the change results.

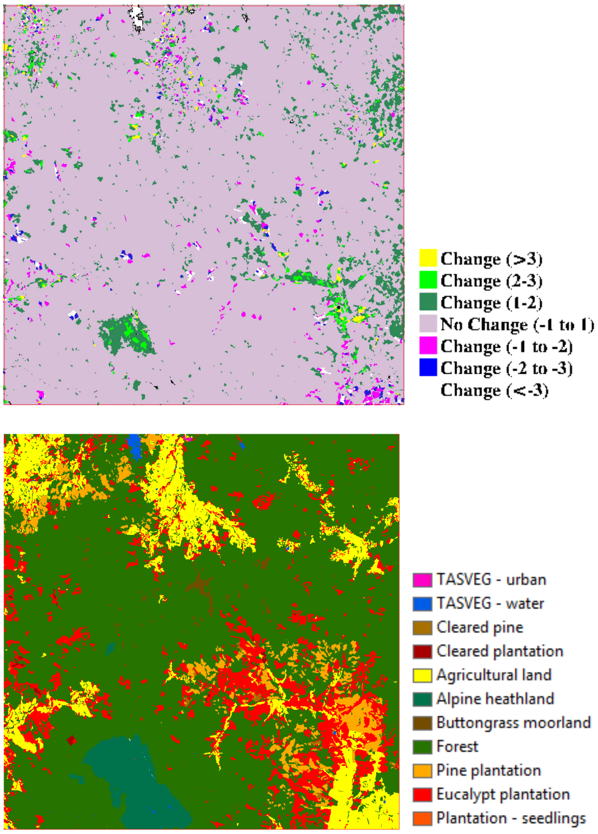

Figure 4. PALSAR change analysis (in dB): 2007 to 2008 (top) and derived land cover classification for 2008 (bottom).

HV backscatter provided the best discrimination between cover types and so mean HV segmented data were used in the change detection. Change mosaics were produced for 2007 - 2008 and 2008 - 2009, wherein change was indicated in 1 dB increments. Focussing on negative change, masks were generated that showed instances of where change had occurred in a particular cover class. The relevance of the change, i.e., a decrease in backscatter due to clearing of forest, rather than a change in moisture or other anomaly, was confirmed by simultaneous observation of the two dates of PALSAR imagery and/or knowledge of on-ground practices. Similarly, masks were generated for areas exhibiting positive change, and related to processes of regeneration following clearing, but separated from normal vegetation growth. Figure 4 shows the 2007 - 2008 radar change map and derived 2008 land cover classification for Mathinna.

The process was repeated for 2009 using the 2008 classification as the base and the change map for 2008 - 2009. The process effectively identified both positive and negative changes as related to regeneration or deforestation, while maintaining the integrity of unchanged classes. Forest/non-forest maps were then produced as for 2007 above. Mapping accuracy will be assessed following collation of suitable temporal field and satellite data.

## 6. LAND USE/COVER CHANGE MAPPING

Land use/cover change maps, such as those presented in Figure 5, can be produced for the purposes of reporting and also simplifying the forest information. The change maps summarise the spatial extent and location of deforestation, regeneration and no change. They were produced by re-classifying the land cover maps for 2008 and 2009 into 4 categories. Deforestation was more evident between 2007 to 2008, with only limited regeneration occurring in the 3 year timeframe (Figure 5).

Forest/non-forest and land cover change estimates for the Mathinna site are provided in Table A. The mapped extent of forest cover in Mathinna did not vary significantly between years. A net deforestation of 2,596 ha was estimated over 2007 to 2008, and 1,176 ha for 2008 to 2009.

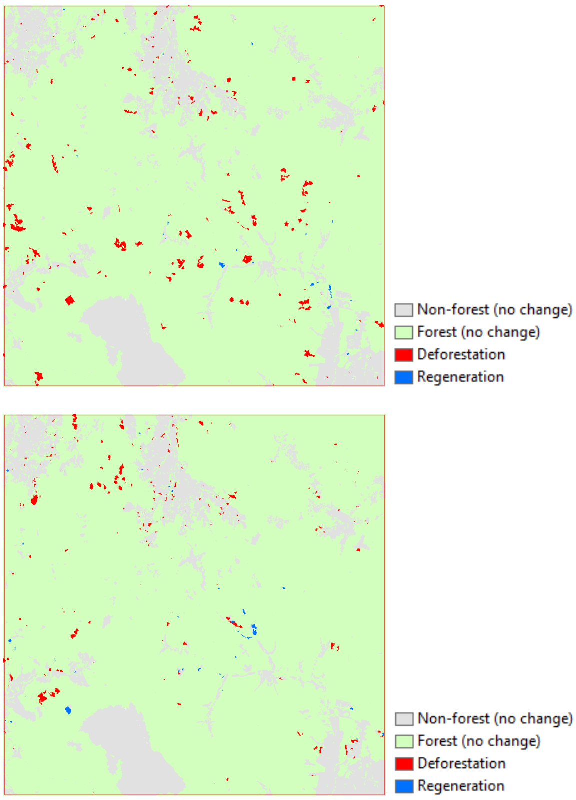

Figure 5. Annual land use change maps for Mathinna derived from PALSAR classifications: 2007 to 2008 (top) and 2008 to 2009 (bottom).

Table A. Forest/non-forest and change estimates for Mathinna.

| **Single date** | **Forest (ha)** | **Non-forest (ha)** |
|---|---|---|
| 2007 | 212,781 | 37,210 |
| 2008 | 212,157 | 37,834 |
| 2009 | 211,633 | 38,359 |
| **Change** | **2007 to 2008 (ha)** | **2008 to 2009 (ha)** |
| Deforestation | 2,734 | 1,430 |
| No change | 247,120 | 248,308 |
| Regeneration | 138 | 254 |

## 7. CONCLUDING SUMMARY

The extensive and ongoing acquisition of SAR imagery presents a unique opportunity to contribute to global scale studies of the world's forested ecosystems. Radar's cloud penetrating and all-weather capability is invaluable when acquiring data in tropical to sub-tropical regions. Data acquired by the ALOS PALSAR provides an opportunity to extend the optical time-series (e.g., Landsat) or historic JERS-1 data for continuous forest monitoring and assessment of change on decadal and longer timeframes.

A strategy for the generation of baseline, wall-to-wall ALOS PALSAR mosaics was described in this paper. The subsequent generation of annual, wall-to-wall mosaics of forest extent, land cover and change was also presented. Successful validation of these products will rely on the availability of temporal data on forest cover, land use and change. The methodologies developed are applicable to regional scale forest monitoring for the purposes of MRV and ultimately national carbon accounting.

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