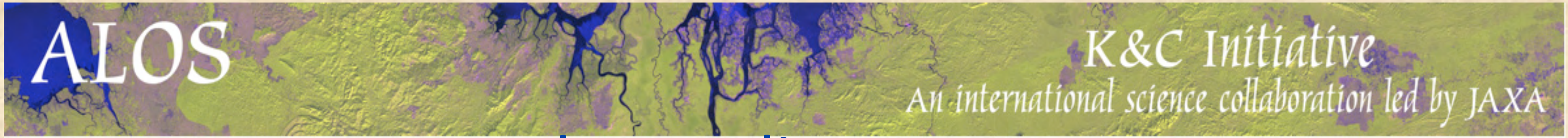

Product Delivery Report for K&C Phase 2= PI: Richard Lucas1

J. Armston[2], D.C. Clewley[1], R. Fairfax[3], R. Fensham[3], A. Accad[3], J.C. Carreiras[4] and Peter Bunting [1]

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Science Team meeting #15
JAXA TKSC/RESTEC HQ, Tsukuba/Tokyo, January 24-28, 2011

K&C deliverables

Papers and Reports

1. Published (Journals/books)

- K&C Phase-1 and Phase 2 reports
- K&C Booklet (biomass and regrowth stage)
- De Grandi, F., Lucas, R.M. and J. Kropacek (2009). Analysis by wavelet frames of spatial statistics in SAR data for characterizing structural properties of forests. *IEEE Transactions Geoscience and Remote Sensing*, 7, 2, 9-507.
- Lucas, R.M., Armston, A., Accad, A., Carreiras, J., Bunting, P., Clewley, D. et al. (2010). An evaluation of the ALOS PALSAR L-band backscatter-above ground biomass relationships over Queensland, Australia, IEEE JSTARS K&C Special Issue, 3(4), 576-593.
- Lucas, R.M. et al. (2010). Quantifying Carbon in Wooded Savannas: The Role of Active Sensors in Measurements of Structure and Biomass. In: Ecosystem Function in Savannas: Measurement and Modelling at Landscape to Global Scales, Eds. M.J. Hill and N.P. Hanan, Taylor and Francis.

2. Submitted

- De Grandi, G., Bouvet, A., Lucas, R., Shimada, M., Monaco, S. and Rosenqvist, A. (2011). The K&C PALSAR mosaic of the African Continent: Processing Issues and First Thematic Results. IEEE Transactions Geoscience and Remote Sensing, submitted.
- Buergin, M., Clewley, D., Moghaddam, M. and Lucas, R.M. (2010). A generalised radar scattering model based on wave theory for multi-layer multi-species vegetation. IEEE Transactions Geoscience and Remote Sensing and Remote Sensing, submitted.

K&C deliverables

Papers and Reports

1. Published (Journals/books)

- Luas,

2. Submitted

- De Grandi, G., Bouvet, A., Lucas, R., Shimada, M., Monaco, S. and Rosenqvist, A. (2011). The K&C PALSAR mosaic of the African Continent: Processing Issues and First Thematic Results. IEEE Transactions Geoscience and Remote Sensing, submitted.
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K&C deliverables

Papers and Reports

1. Published

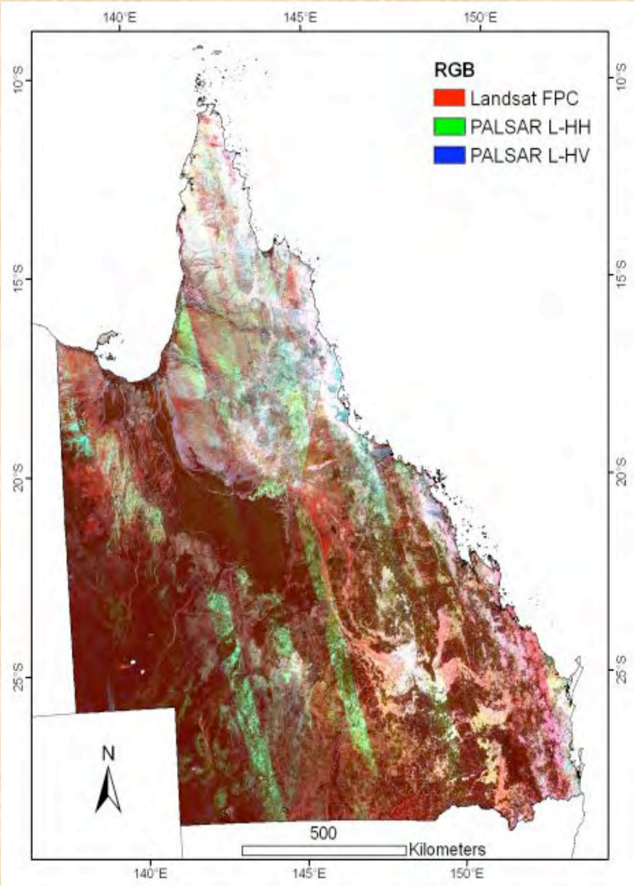
- Special Session; Australian Remote Sensing and Photogrammetry Conference, Alice Springs, Australia, 2010.
  - 10 presentations
  - 4 papers
- IGARSS, Hawaii
  - 2 presentations/papers

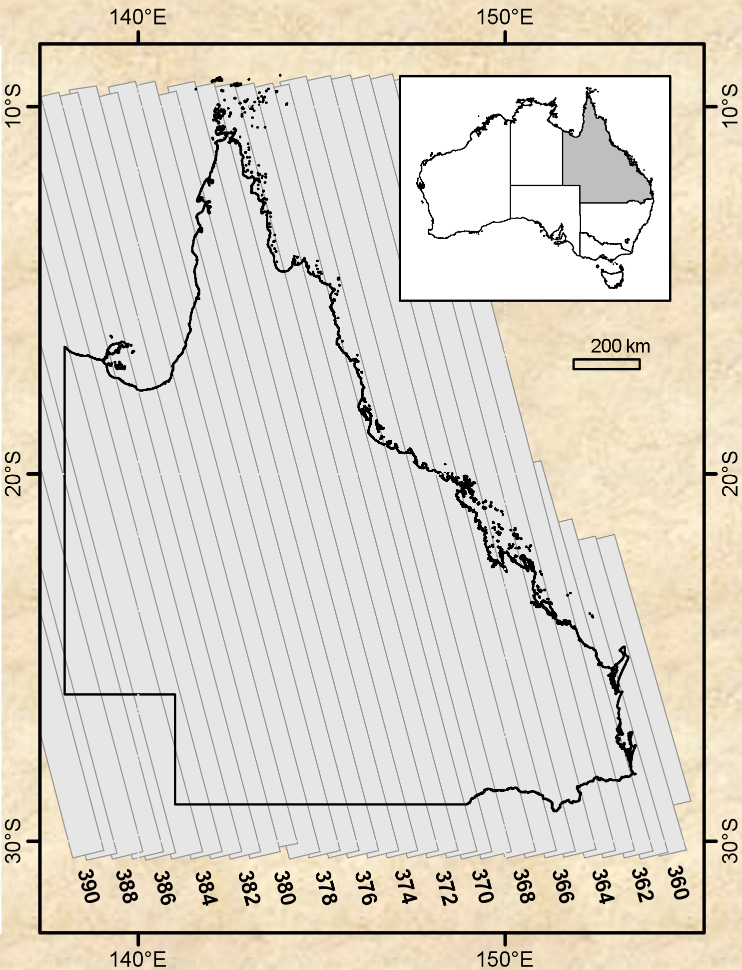
2. In preparation

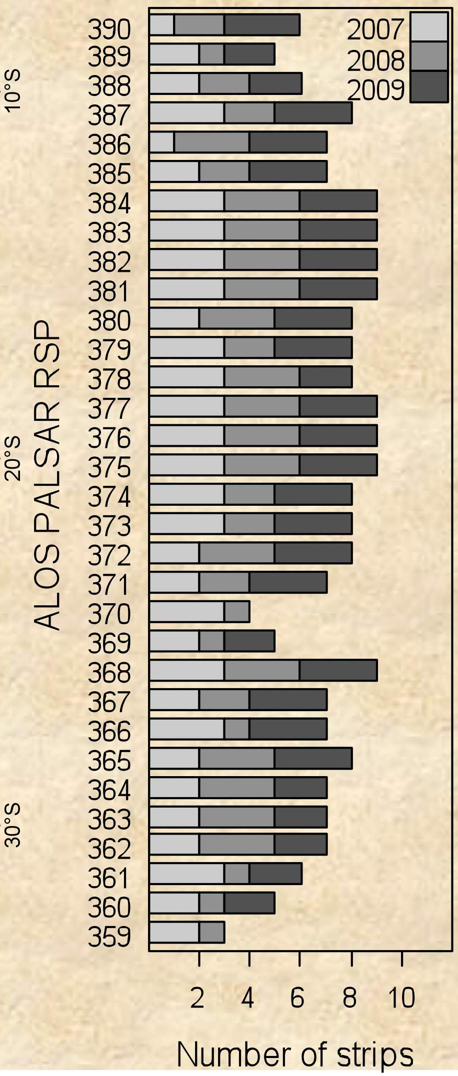
- Lucas et al. Role of ALOS PALSAR for assessing the potential for recovery of carbon stocks and biodiversity in the Brigalow Belt Bioregion, Queensland, Australia, RSE.
- Armston, Lucas & Carreiras: Influence of surface moisture conditions on forest parameter retrieval from ALOS PALSAR mosaics, Queensland, Australia, RSE
- Nugroho, Lucas, de Grandi & Isoguchi: Retrieval of forest biomass and detection of degradation from logging in Indonesia using ALOS PALSAR, RSE

Objectives

- To generate maps of forest growth stage/biomass for northern Australia, with focus on Queensland.

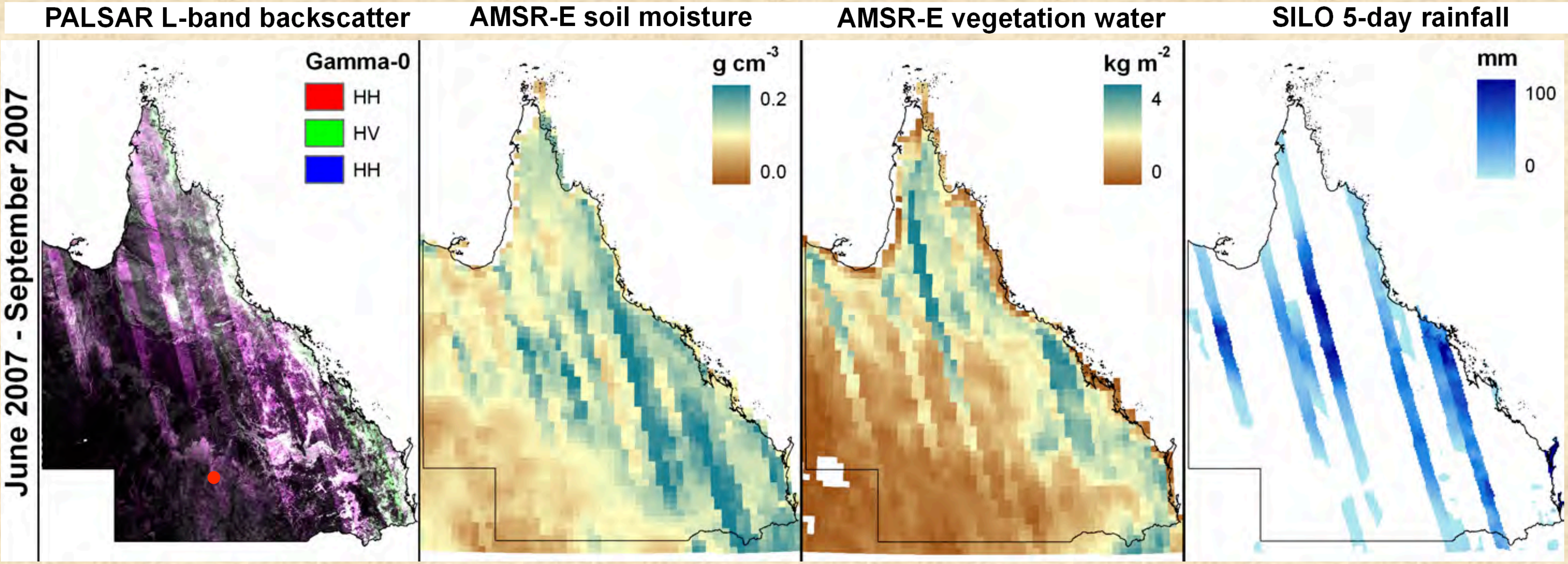


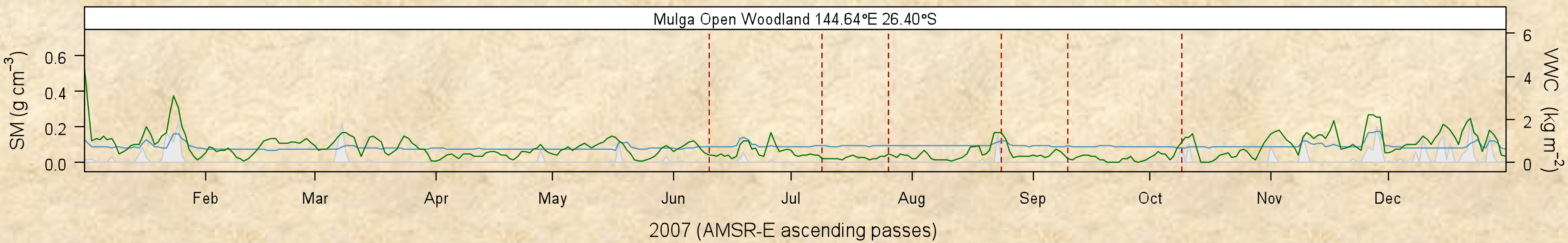




Kyoto & Carbon strip data

- Independent comparison with surface moisture and rainfall datasets
  → Environmental conditions are important





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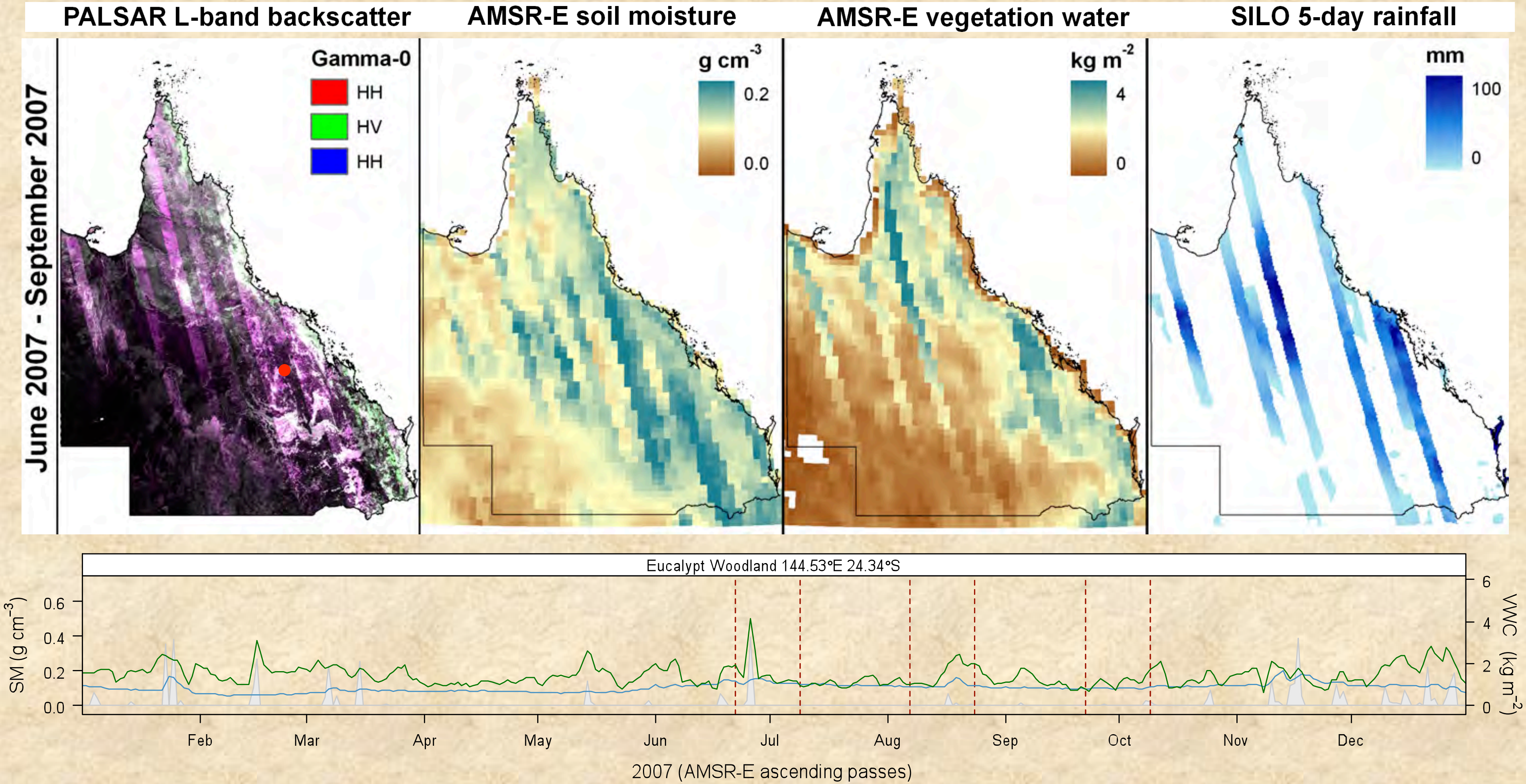

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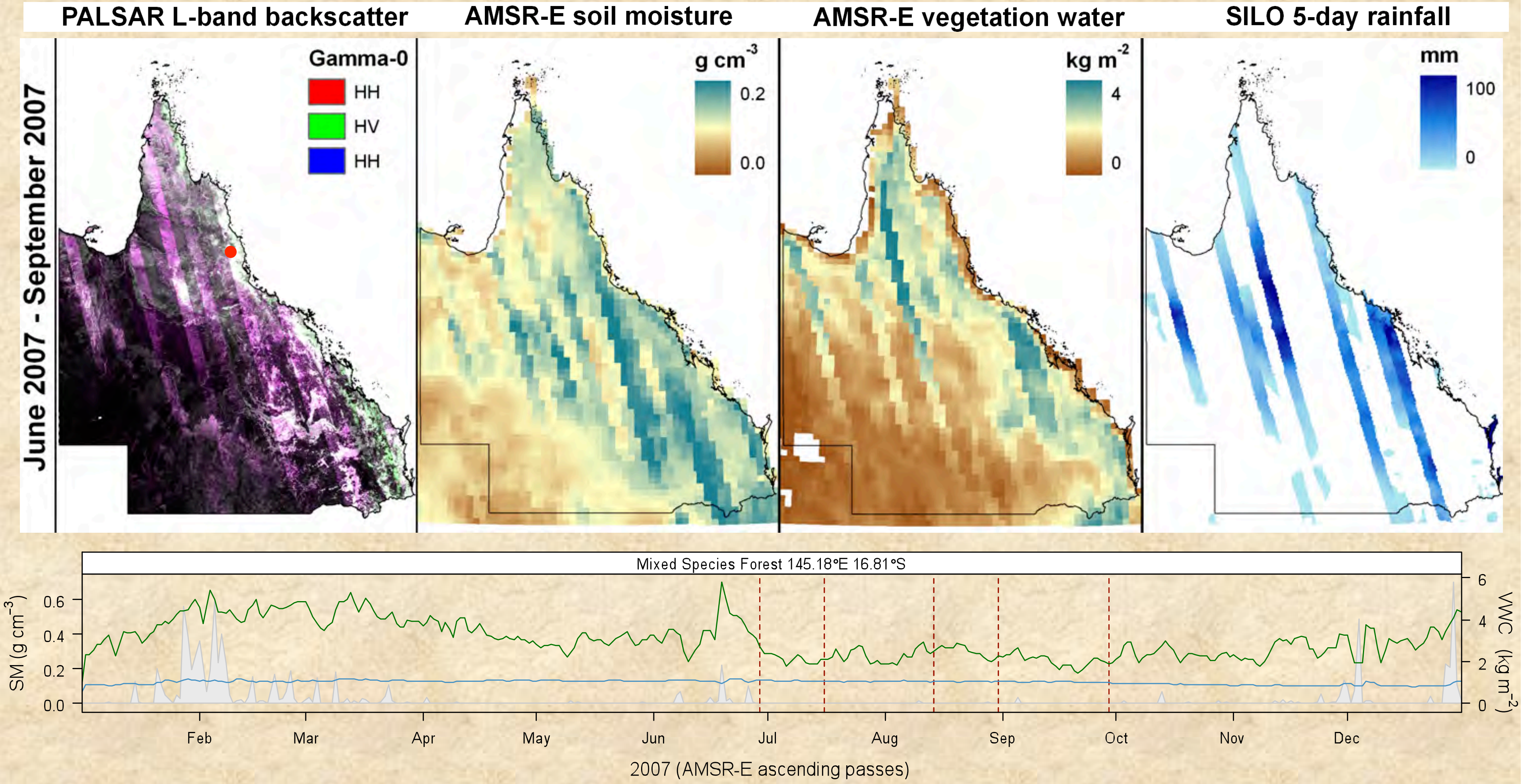
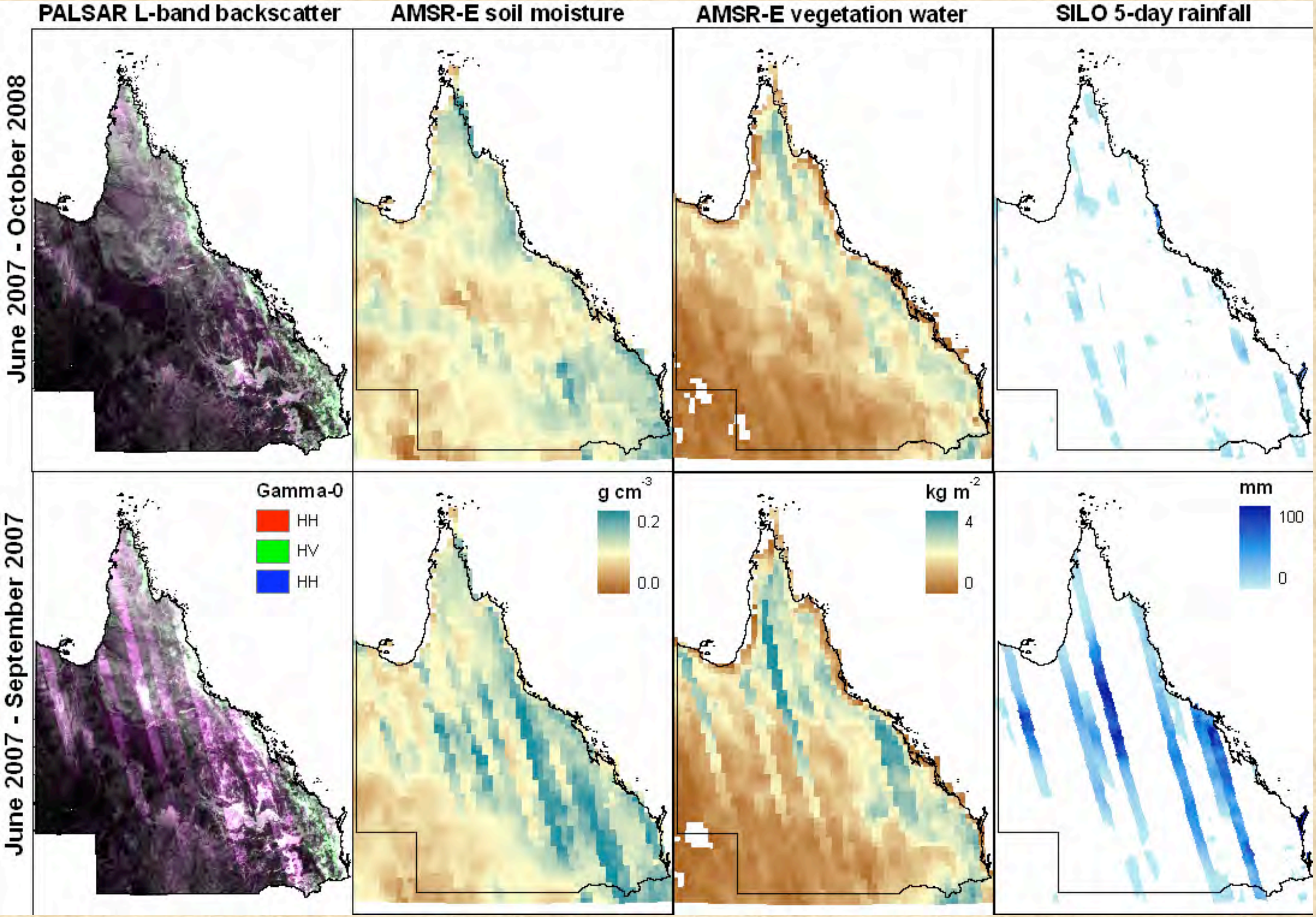
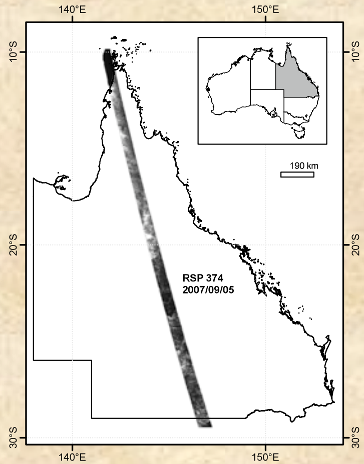


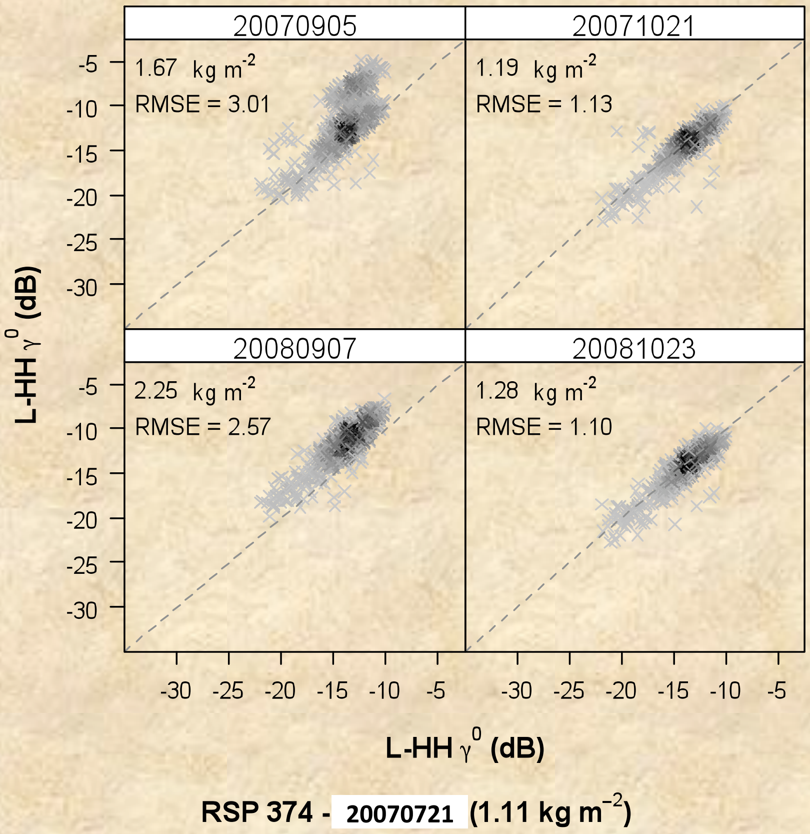
Generation of Regional Mosaics

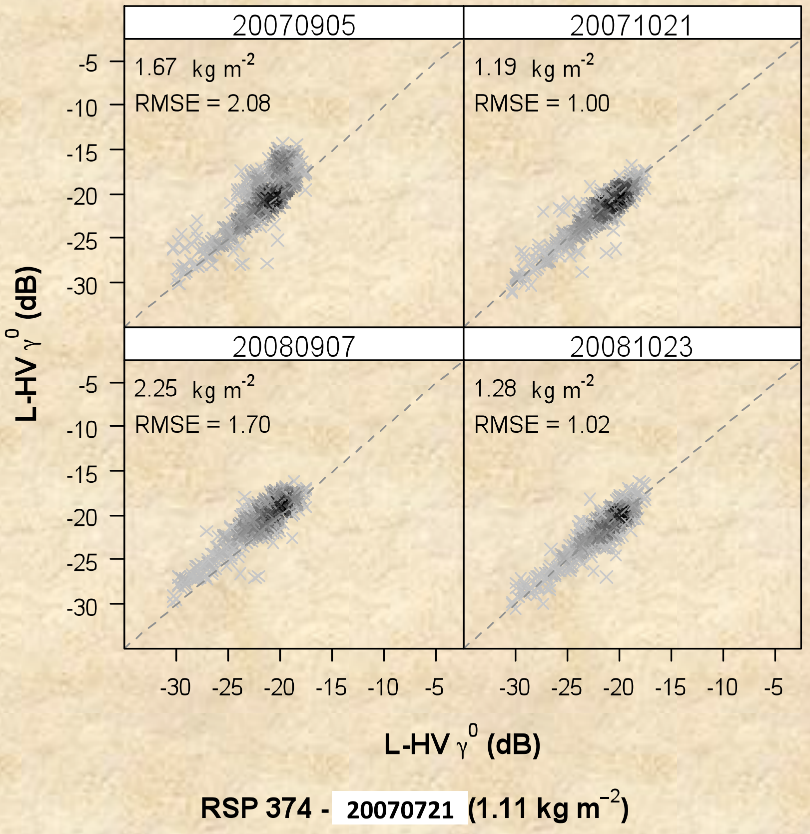


Evaluation of mosaics

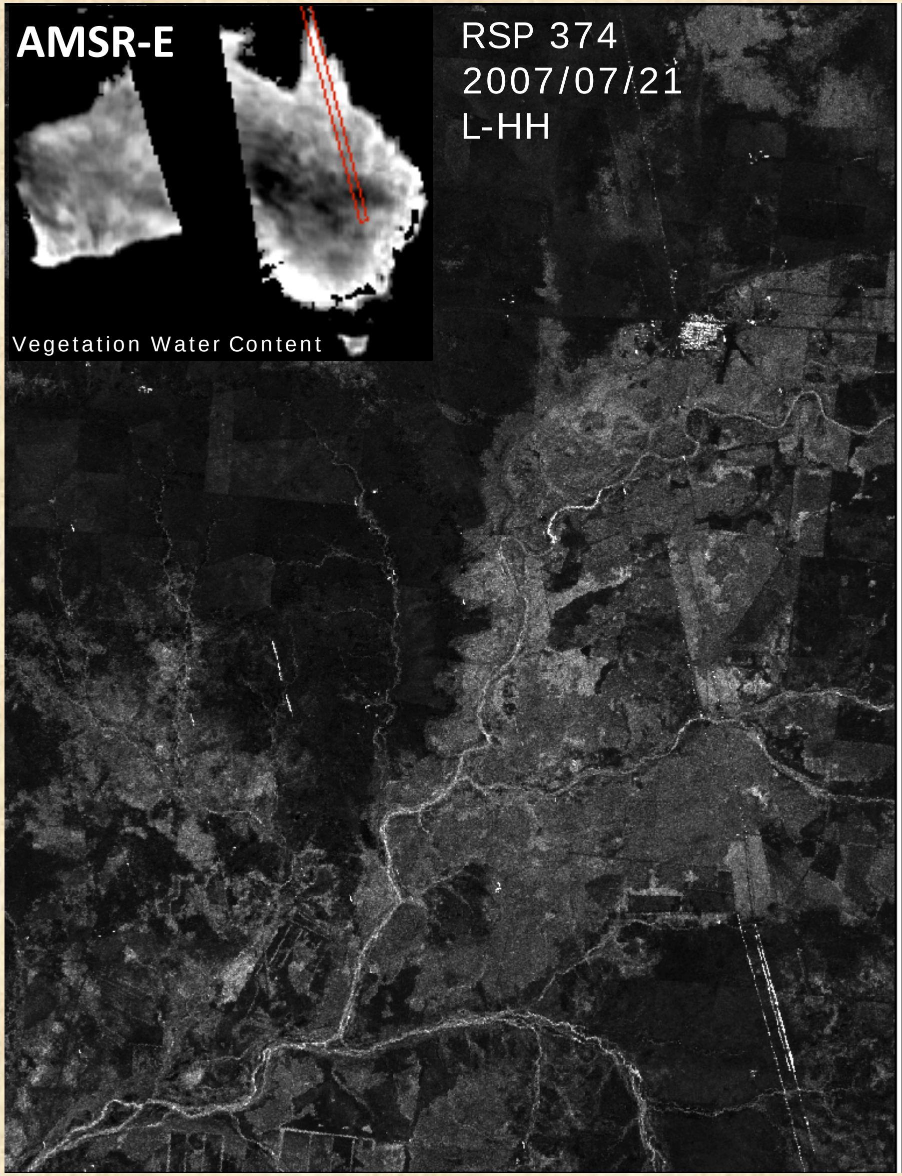
- **Impact of surface moisture**
  - Effect greater for L-HH compared to L-HV
  - Greater than 3 dB upward bias observed

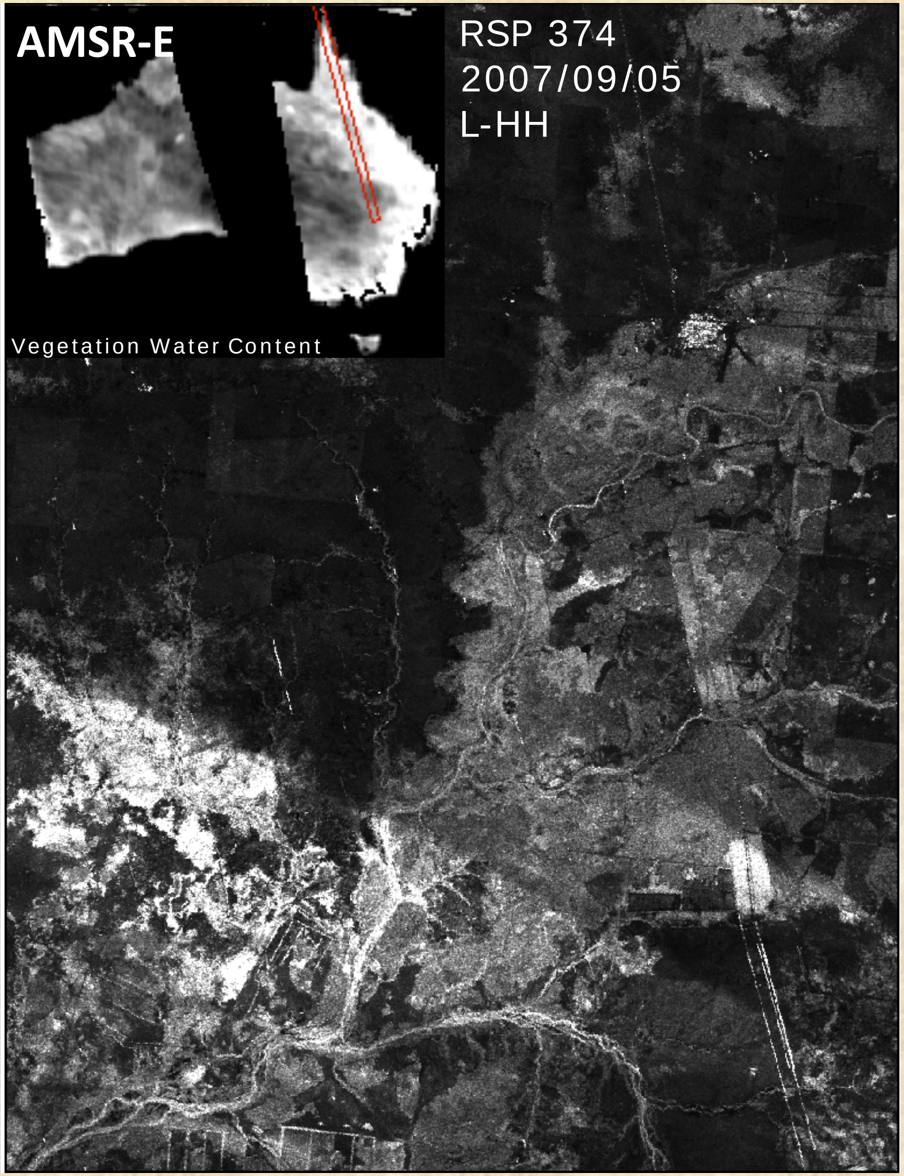






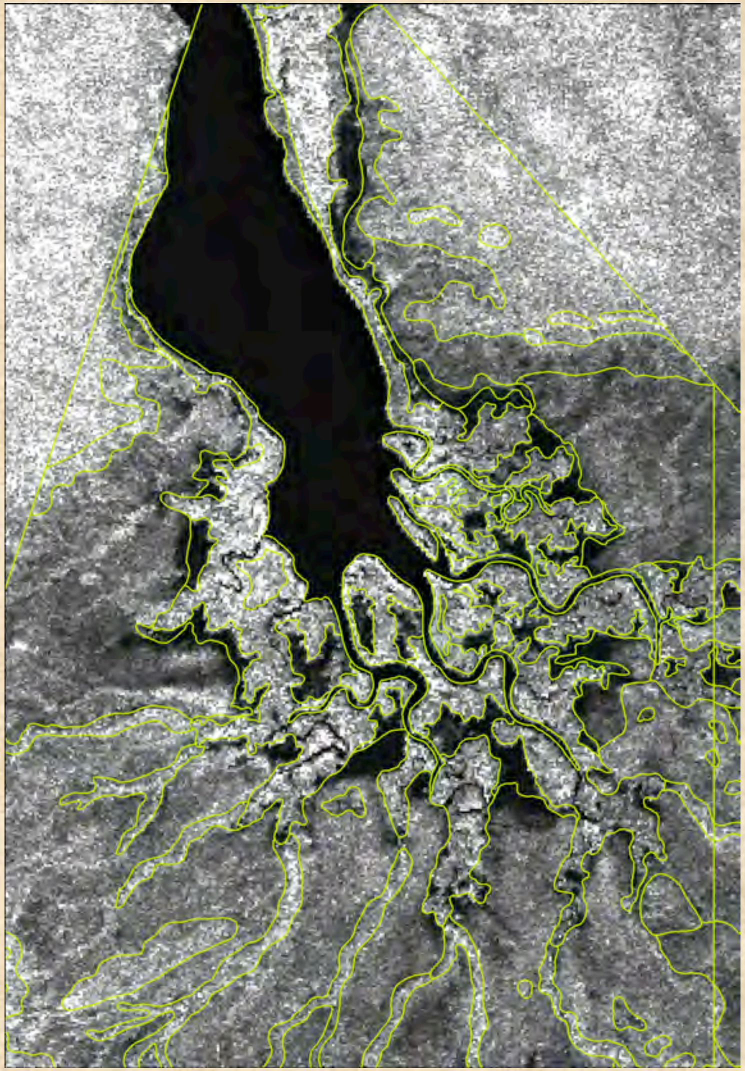
Impact of Surface Moisture

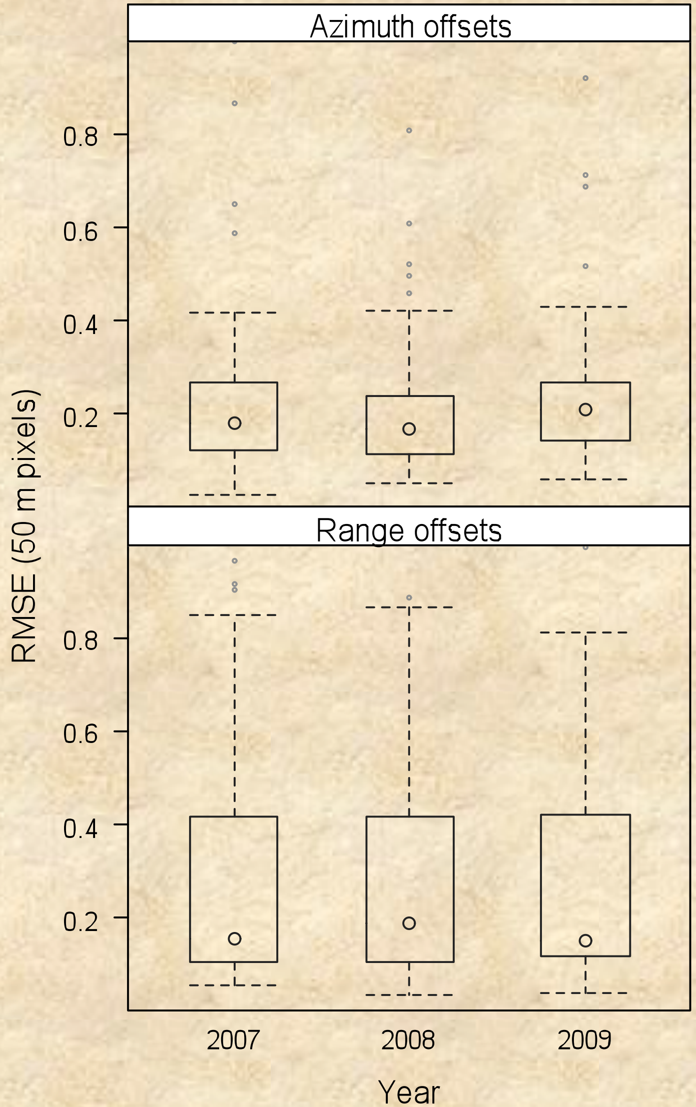




Evaluation of mosaics

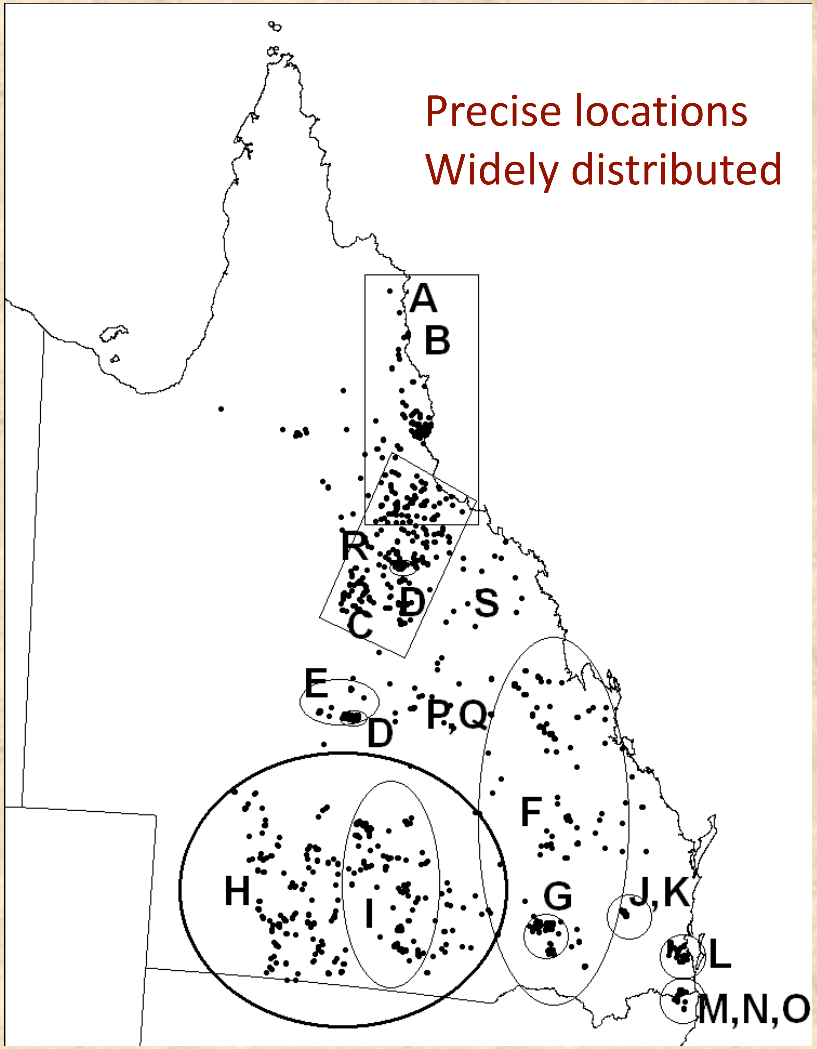
- Geometric accuracy



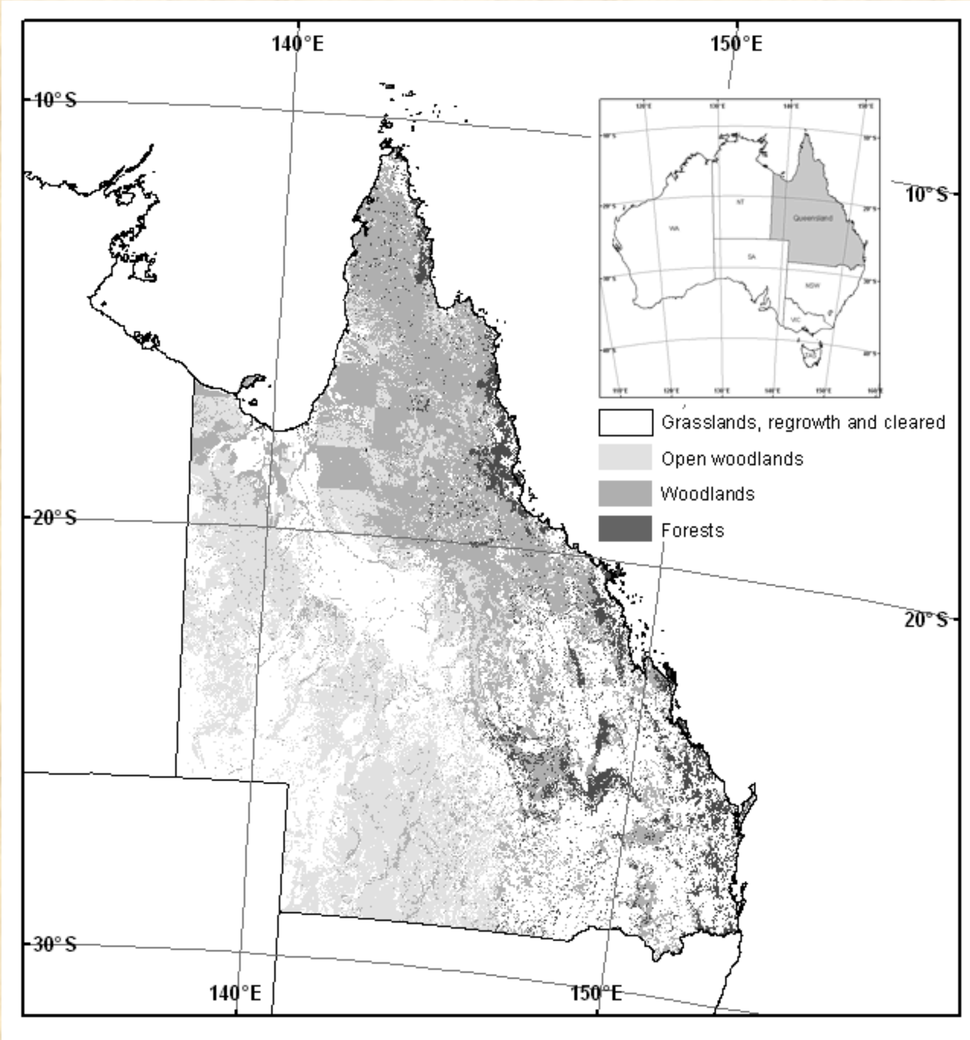


Linking with Statewide datasets

Generation of Biomass Library (Queensland Herbarium)



Location of inventory plots
Queensland, Australia



Mapped distribution of
broad structural types

Field data and allometric equations

Study (see Fig. 2)	No. plots	No. transects	Typical plot size (m)	Date	Description	Reference
A	1	1	100 x 95 m	2005	Forest	[37]
B	99	99	50 x 20m	2005-8	Rainforest, some Eucalyptus forest	[38]
C	199	199	100 x 20 m	1997	Eucalyptus woodland Some Acacia open forest	[39, 40]
D	95	760	Eight 50 x 8 m	2004	Acacia and eucalyptus dominated	[41]
E	45	45	50 x 20 m	2007	*Acacia cambegei* woodlands/forest and grasslands	[42,43]
F	42	270	Four 50 x 4 m	2007	*Acacia harpophylla* regrowth and remnant woodlands and forests	[44]
G	82	164	Two 2 x 50 m	2005-6	*Acacia harpophylla* forests	[45]
H	190	760	Four 25 x 50 m	2008-9	Acacia and eucalyptus woodlands	[46]
I	87	87	50 x 100 m	2008-9	Acacia and eucalyptus woodlands regrowth and remnant	[47]
J	4	4	100 x 100 m	2003	rainforest	[48]
K	39	39	50 x 10 m	200	Closed forest and grassland	[49]
L	31	128	Four 40 x 50 m	2009	Eucalyptus forests	[50]
M	1	1	100 x 100m	2006	Rainforest	[51]
N	20	20	20 x 20 m	2005	Rainforest	[52]
O	29	29	20 x 20 m	2003-4	Rainforest	[53]
P	3	3	100 x 100 m	2004	Eucalyptus open woodland	[54]
Q	3	3	100 x 100 m	2008	Eucalyptus open woodland	[54]
R	1	1	300 x 52 m	2004	Eucalyptus open woodland	[55]
S	164	164	Five 50-100 x 2 m	2005-8	Eucalyptus open woodland	[56]

Data are current

Allometric equation	Application	Source
Acacia harpophylla	*Acacia harpophylla*, *A. cambagei*, *A. tephrina* and allies	[58]
Eremophila mitchellii	Semi-arid small trees (high dbh to height ratio) includes umbragenous *Acacia* and other *Eremophila*, *Petalostigma*, *Eythroxylom*, *Carisssa*, *Senna* and *Bursaria* spp. *Maytenus cunninghamii*	[59]
Xanthorrhoea spp.	*Xanthorrhoea* spp., cycads	[60]
Rainforest	All rainforest, including mesophyllic semi-arid species (e.g., *Flindersia*, conifers including *Callitris* spp.	[25]
Banksia aemula	Coastal sclerophyll small trees (high dbh to height ratio)	[61]
Forest-woodland	*Eucalyptus*, *Corymbia*, *Angophora*, *Lophostemon*, *Syncarpia*, other *Acacia*, *Casuarina* and *Melaleuca*, *Grevillea* and *Hakea* spp.	[62]
Acacia aneura	*Acacia aneura* and allies	[63]
Palms	palms	[64]

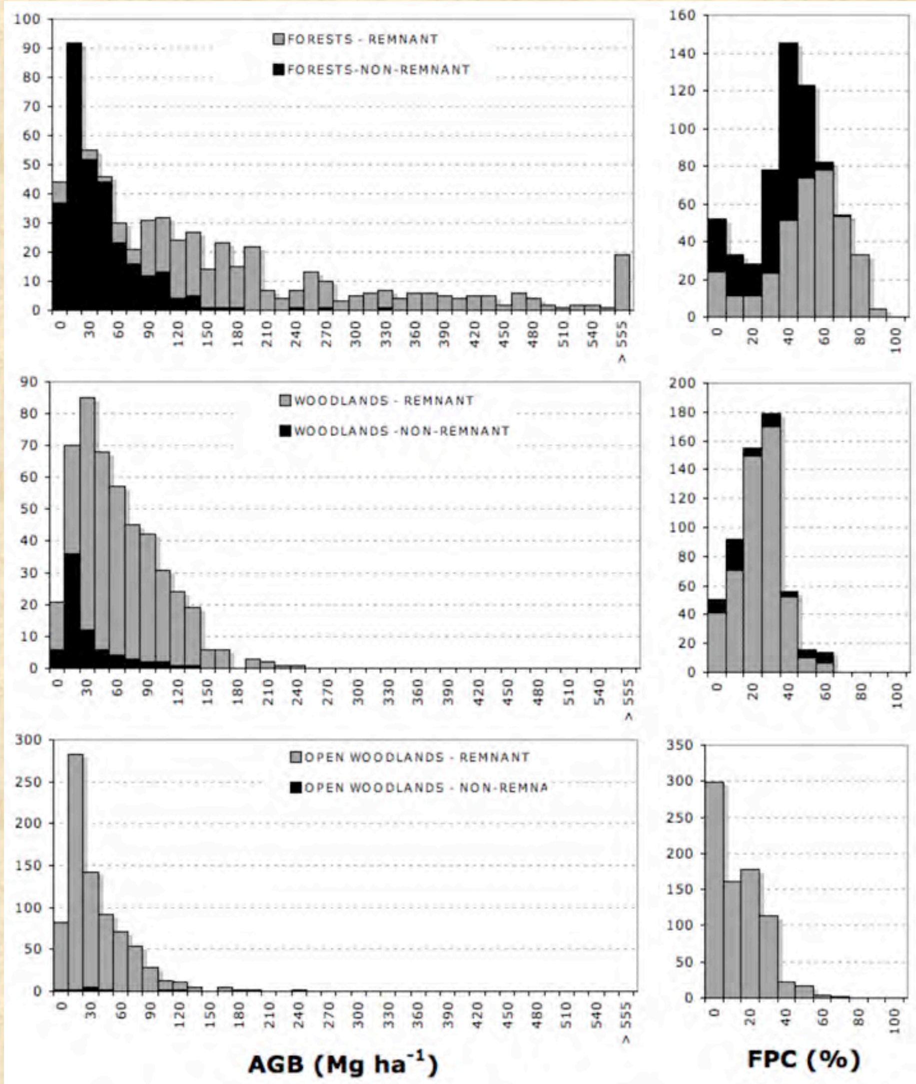
Appropriate use of allometric equations

Category	Description	Correction factor for biomass (%)
0	Live (could include major damage to branches)	100
1	Barely alive (epicormic growth or almost all crown dead)	95
2	Recently dead (Bark still hugging trunk)	90
3	Long dead (Bark present but not hugging trunk)	90
4	Old dead (Standing but bark absent)	55

Consideration of live and dead trees

Distribution of AGB by structural formation

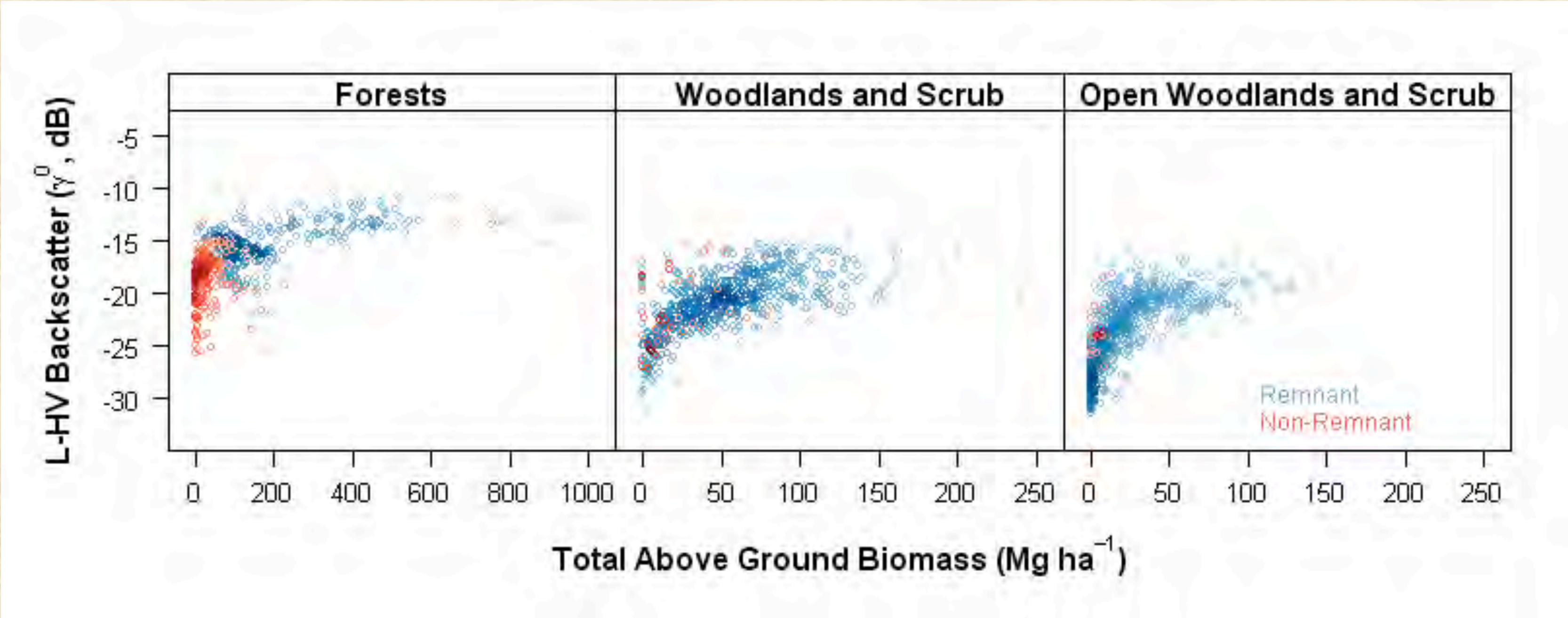
- Highest levels of AGB within forests
  - Over 500 Mg ha^{-1}
  - Lower levels (< 150 Mg ha^{-1}) within non-remnant (secondary) forests
- Lowest AGB levels within open woodlands
  - Naturally low biomass
    - Typically < 100 Mg ha^{-1}).
  - Fewer non-remnant stands considered



Relationships with AGB

- L-band HH and HV data extracted from:
  - Relatively dry strips
  - Relatively wet strips
- Differences between forest structural types
  - Forests
  - Woodlands
  - Open woodlands
- Differences in growth state
  - Remnant
  - Non-remnant

ALOS PALSAR/Biomass: Wet conditions

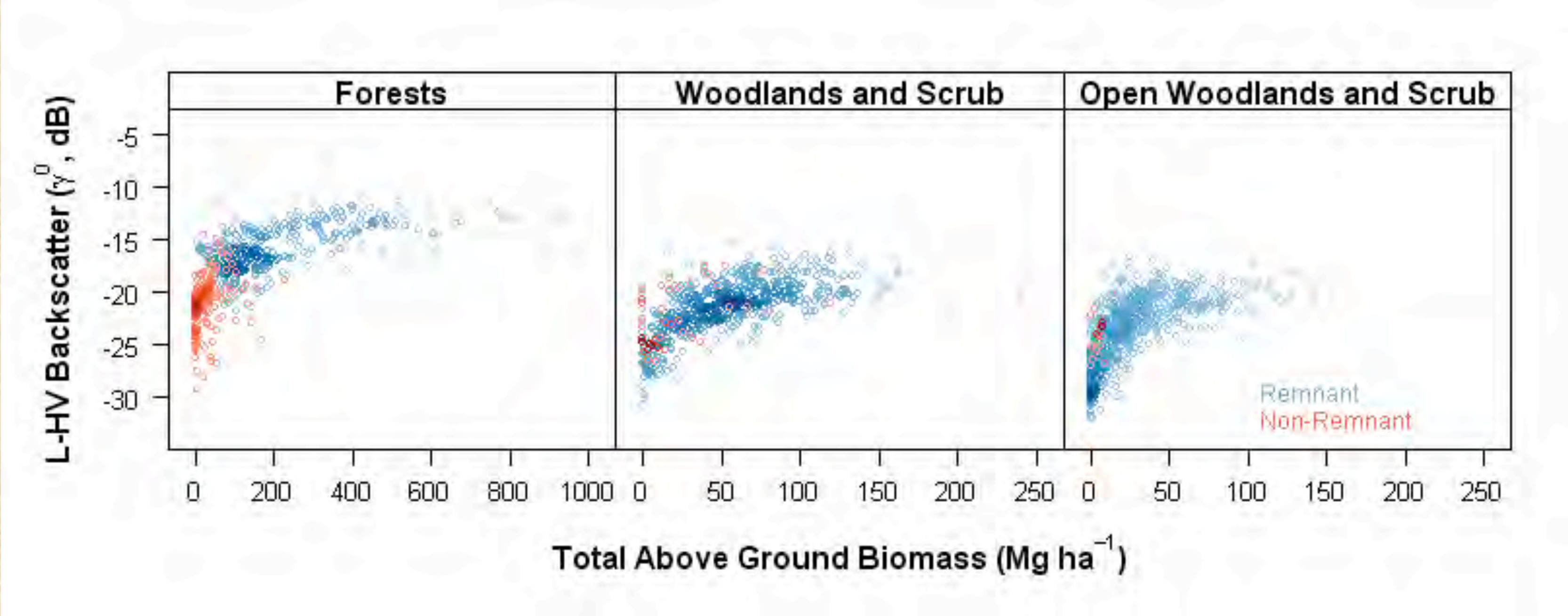


Closed forest

Woodland

Open Woodland

ALOS PALSAR/Biomass: Dry conditions

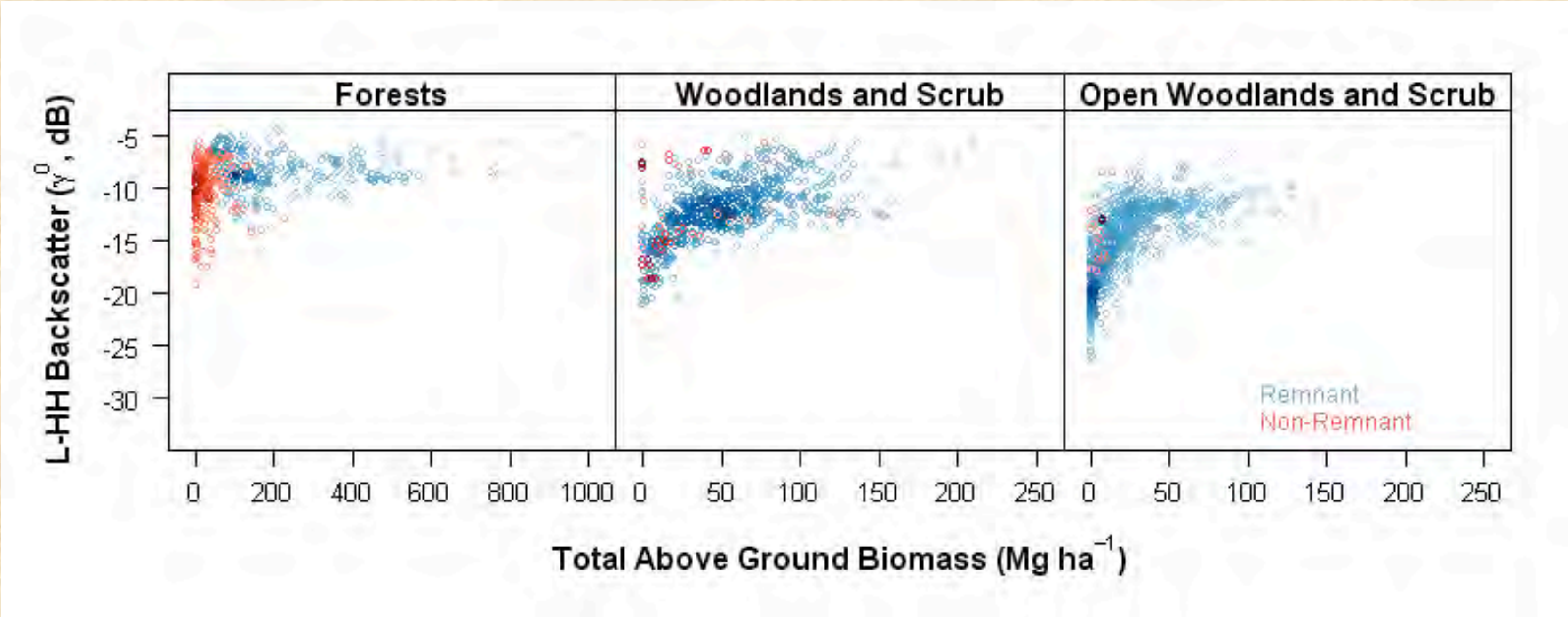


Closed forest

Woodland

Open Woodland

ALOS PALSAR/Biomass: Wet conditions

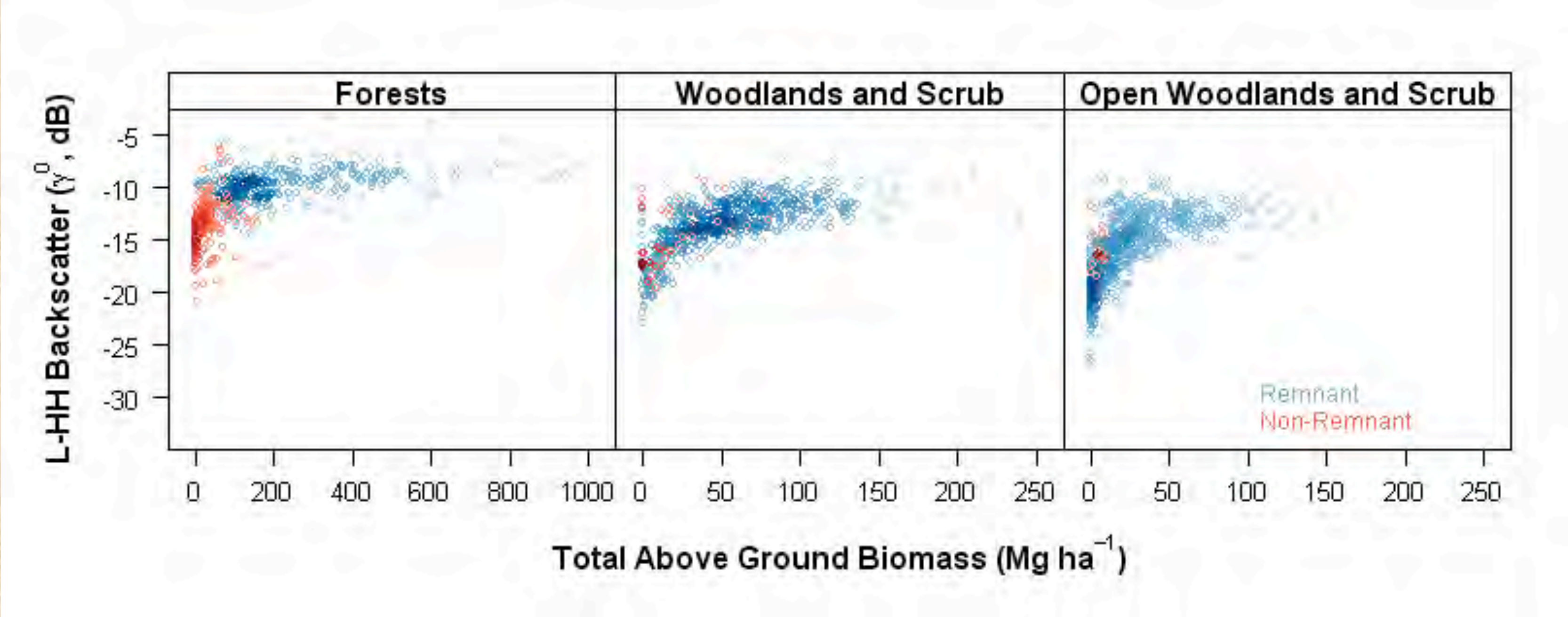


Closed forest

Woodland

Open Woodland

ALOS PALSAR/Biomass: Wet conditions

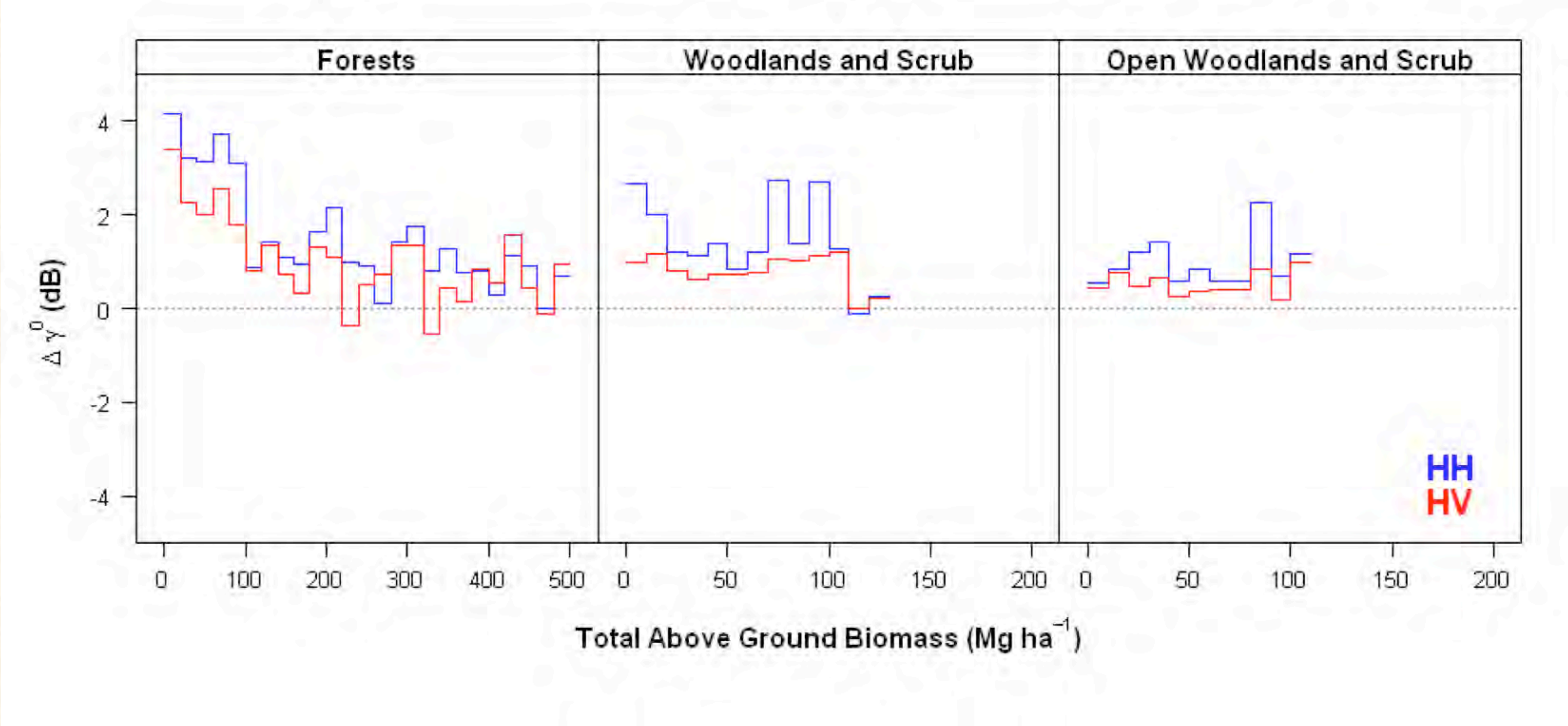


Closed forest

Woodland

Open Woodland

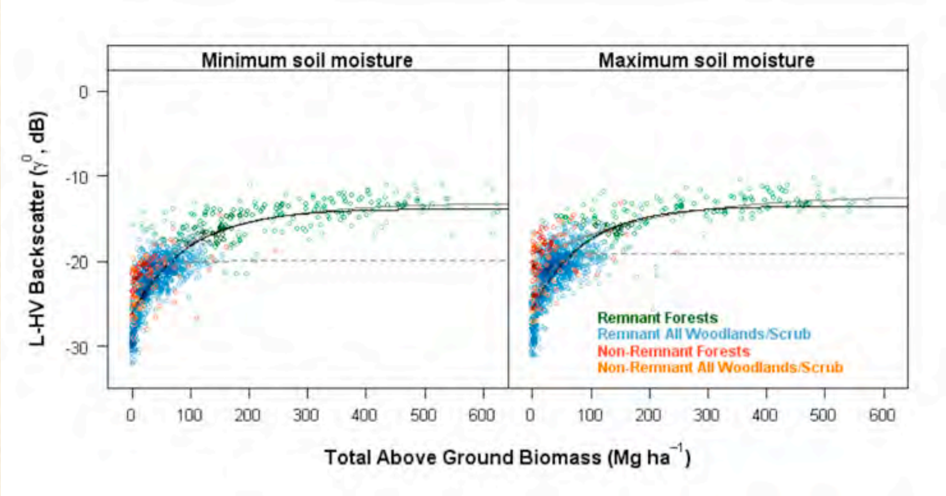
Impact of surface/sub-surface moisture

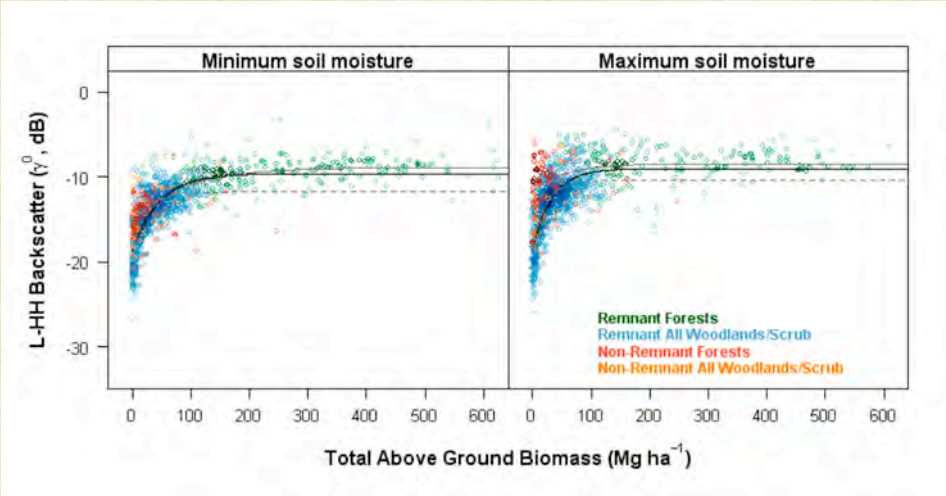


- Differential response at L-band HH and HV to moisture
- Limits use of algorithms combining both HH and HV
- Recommended to use single channel unless consideration is given to environmental conditions

Establishing Relationships

- Based on forest type
  - Forests
  - Woodlands
  - Open woodlands
  - Combined
- Based on growth state
  - Remnant
  - Non-remnant
- Need to consider and understand the reasons for variability
  - Moisture content
  - Density
  - Size class distribution
- 'Saturation' level based on retrieval differs from that based on the asymptote.



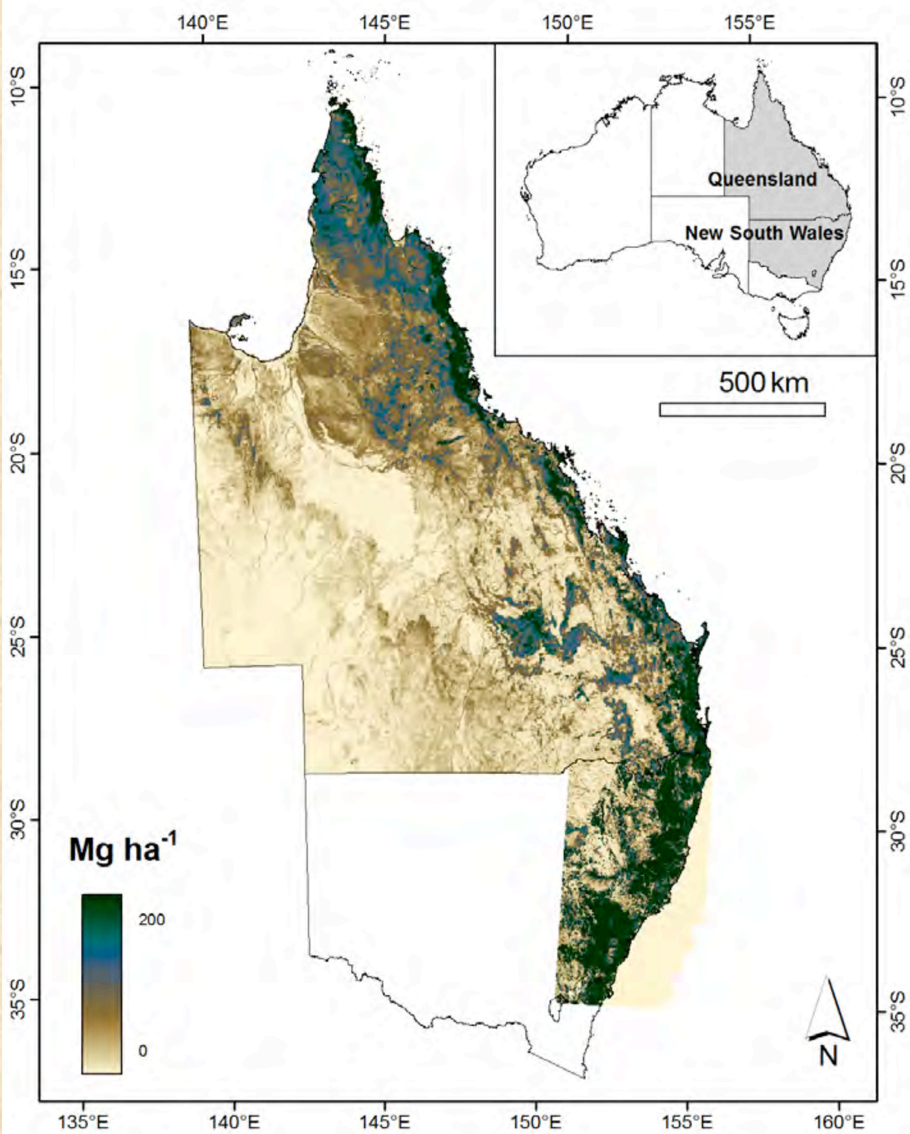


Map of Above Ground Biomass, Queensland

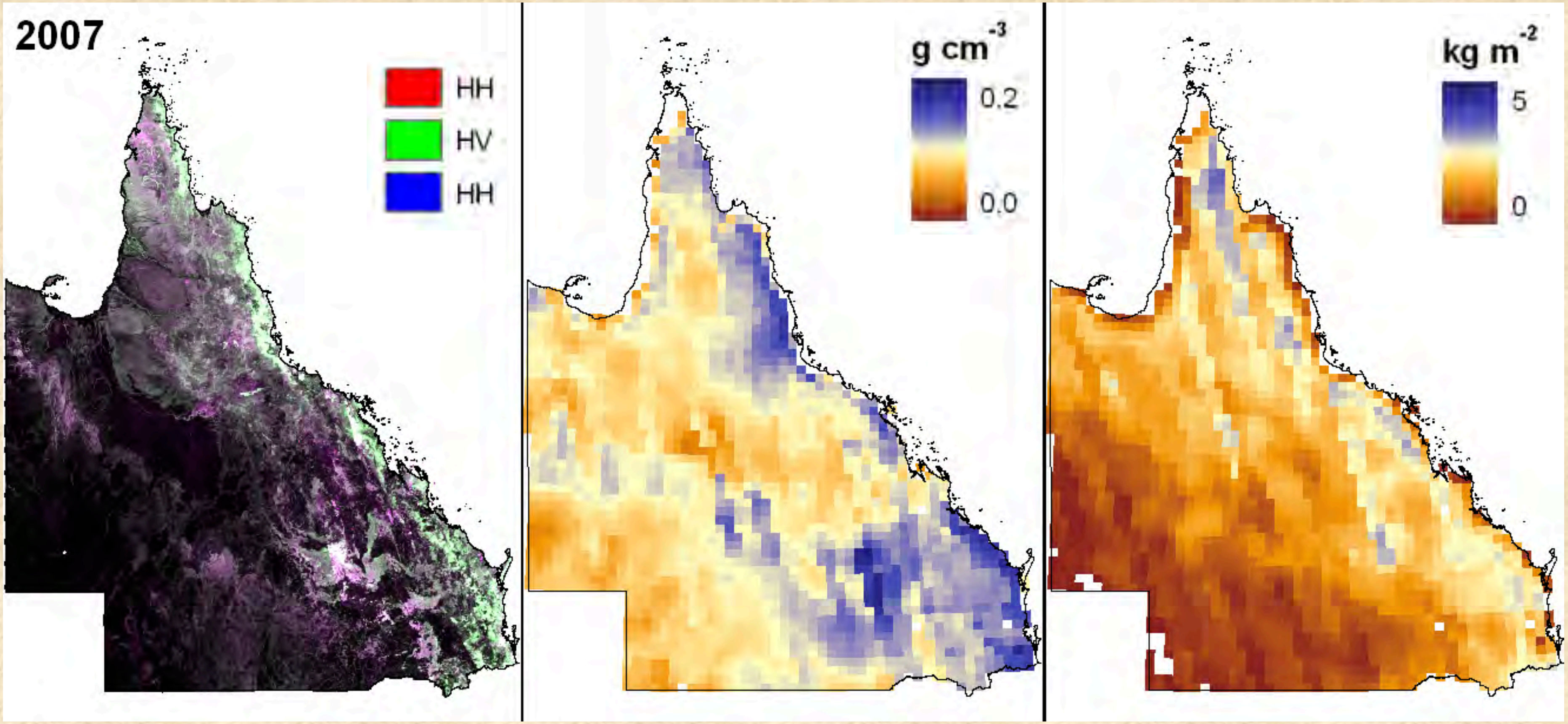
- Biomass estimated using relationship established with ALOS PALSAR L-band HV (50 m spatial resolution)

- Limitations associated with
  - Asymptotic relationship
  - Variations as a function of structural formation
  - Anomalies
    - Geology
    - Flooded forest
    - Mangroves

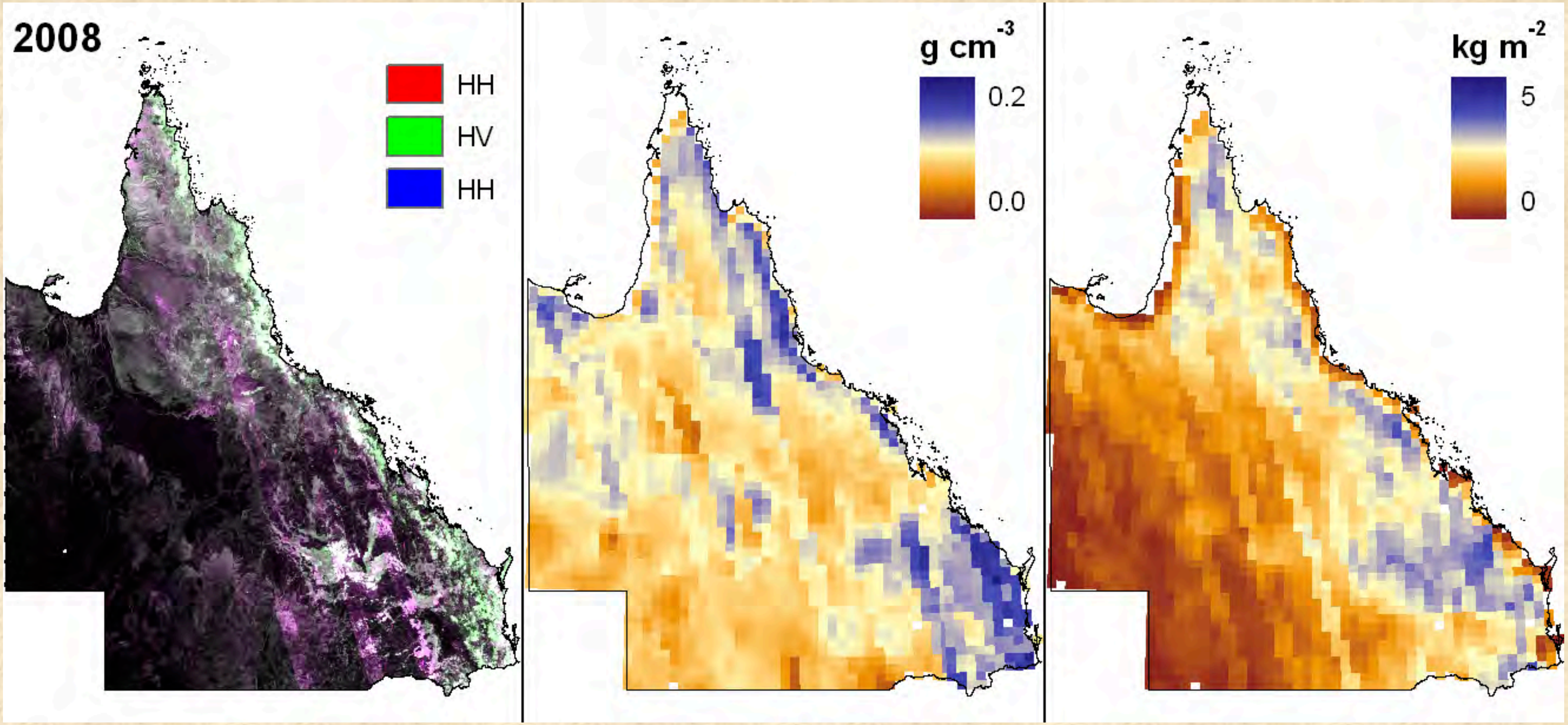
- Mapping being revised through consideration of other datasets



Evaluation of mosaics for AGB estimation and change detection



Evaluation of mosaics for AGB estimation and change detection



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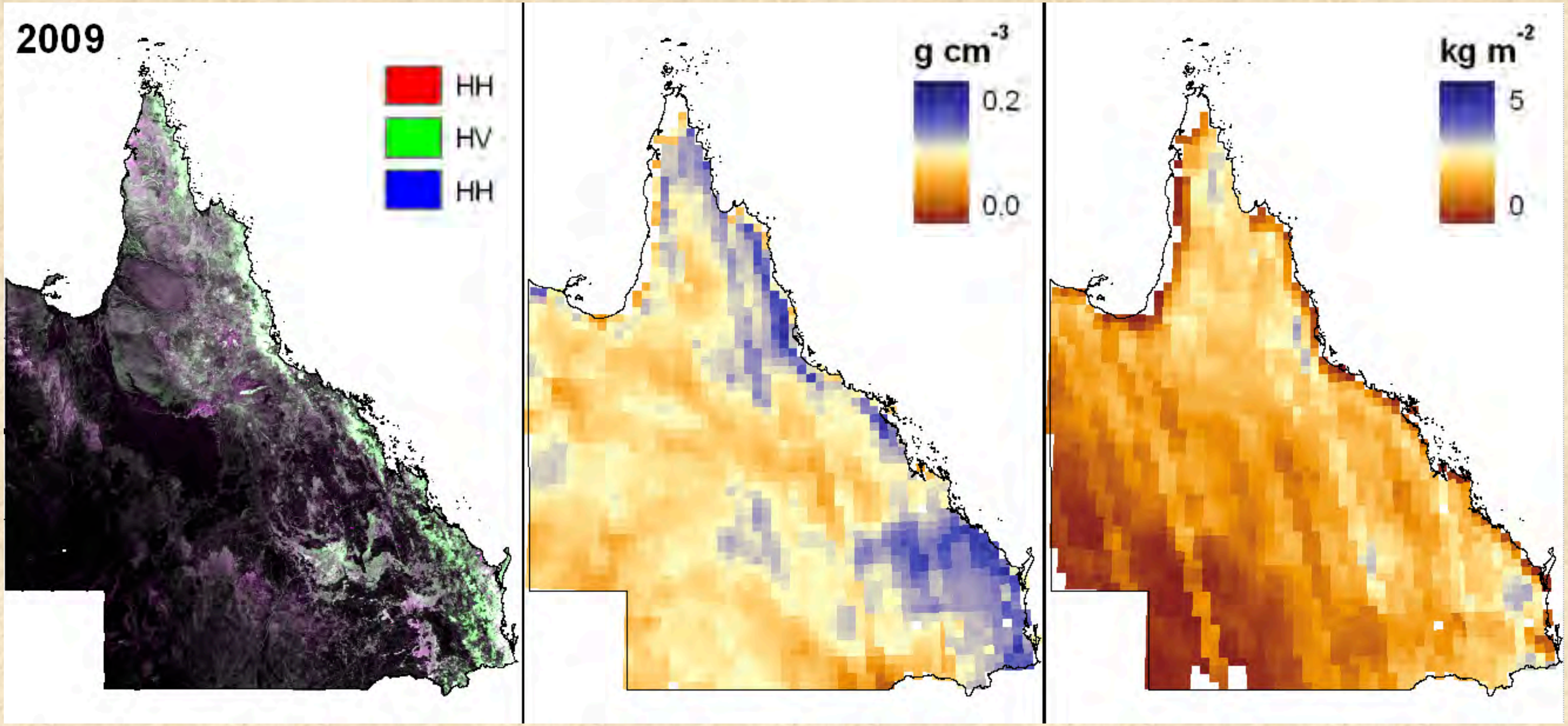
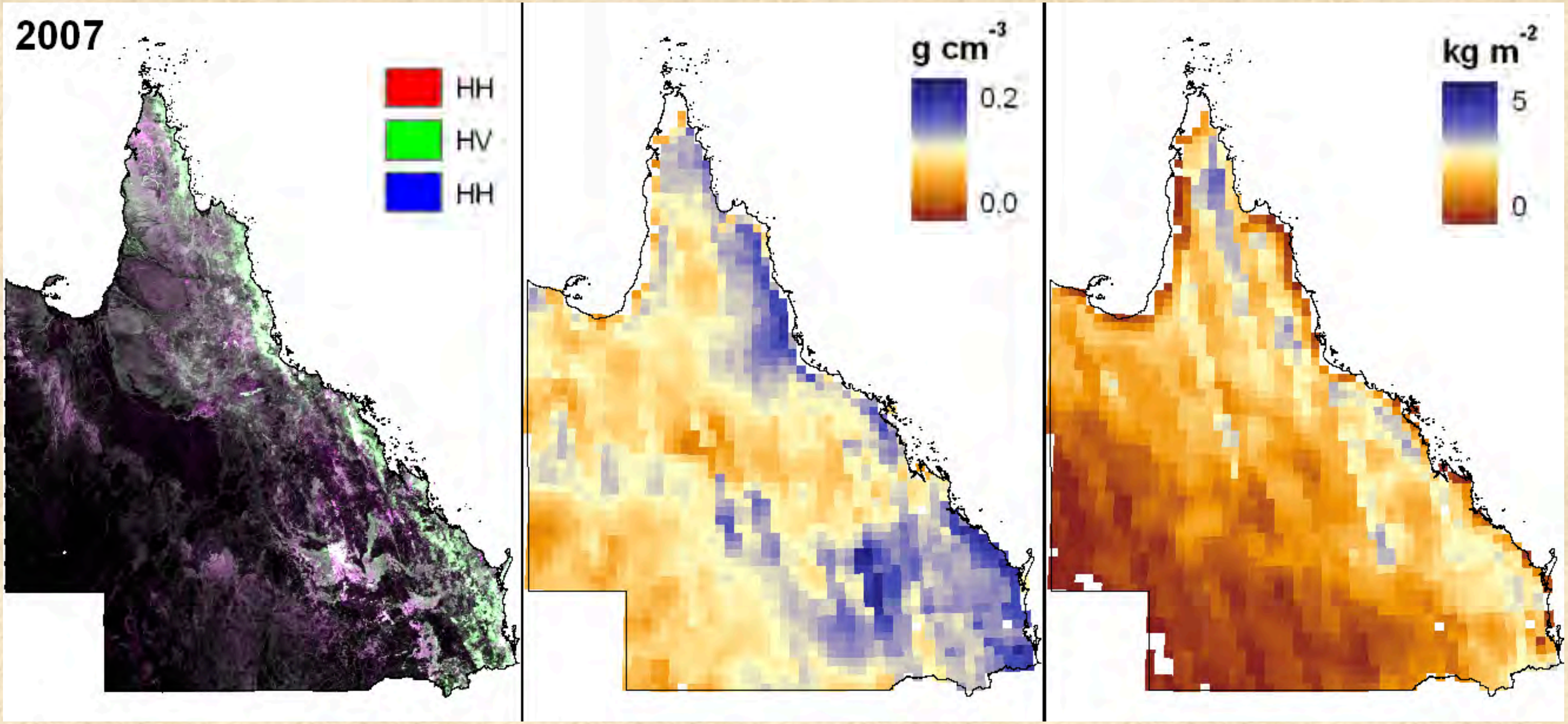


Evaluation of mosaics for AGB estimation and change detection

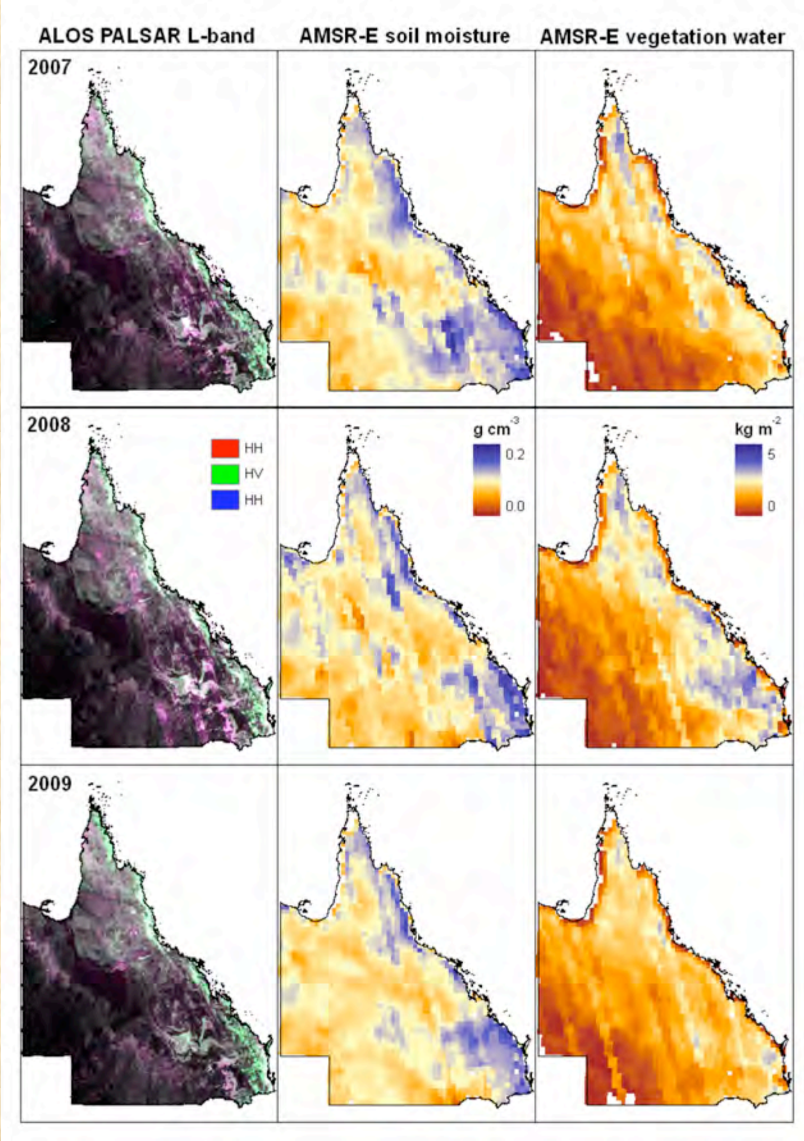


Improving Biomass Estimates: Consideration of moisture conditions and structure

- Reference meteorological (e.g., rainfall) and spaceborne sensors (e.g., AMSR-E, SMOS) to identify areas where soil and vegetation moisture influences on L-band data are minimal.
  - 2009 mosaic may be optimal

- Develop further understanding of the impacts of vegetation structure on L-band backscatter
  - SAR simulation modeling
  - Further observational data

- Use of multi-temporal data
  - Minimum L-band HV values from a multi-year time-series
  - Compromises ability to detect change

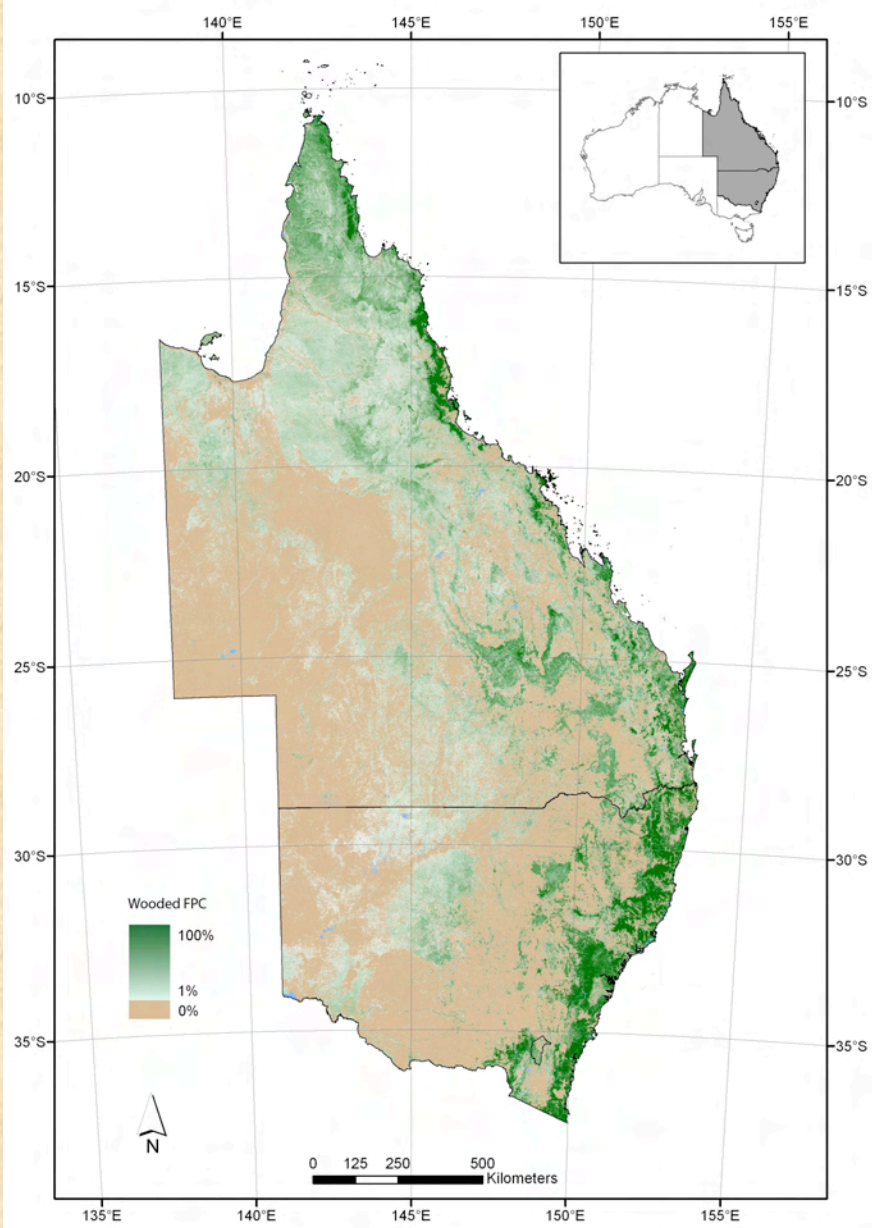


Inclusion of Landsat FPC

- Foliage Projected Cover (FPC) estimates from Landsat are derived, in part, from a relationship between FPC and basal area.

- Statewide estimates of biomass generated previously by Henry *et al*. (2002)

- Best used initially within multiple regression algorithm



Inclusion of ICESAT

- Scarth *et al*. (2010) demonstrated the use of IceSAT data for retrieving fractional cover and vegetation height.

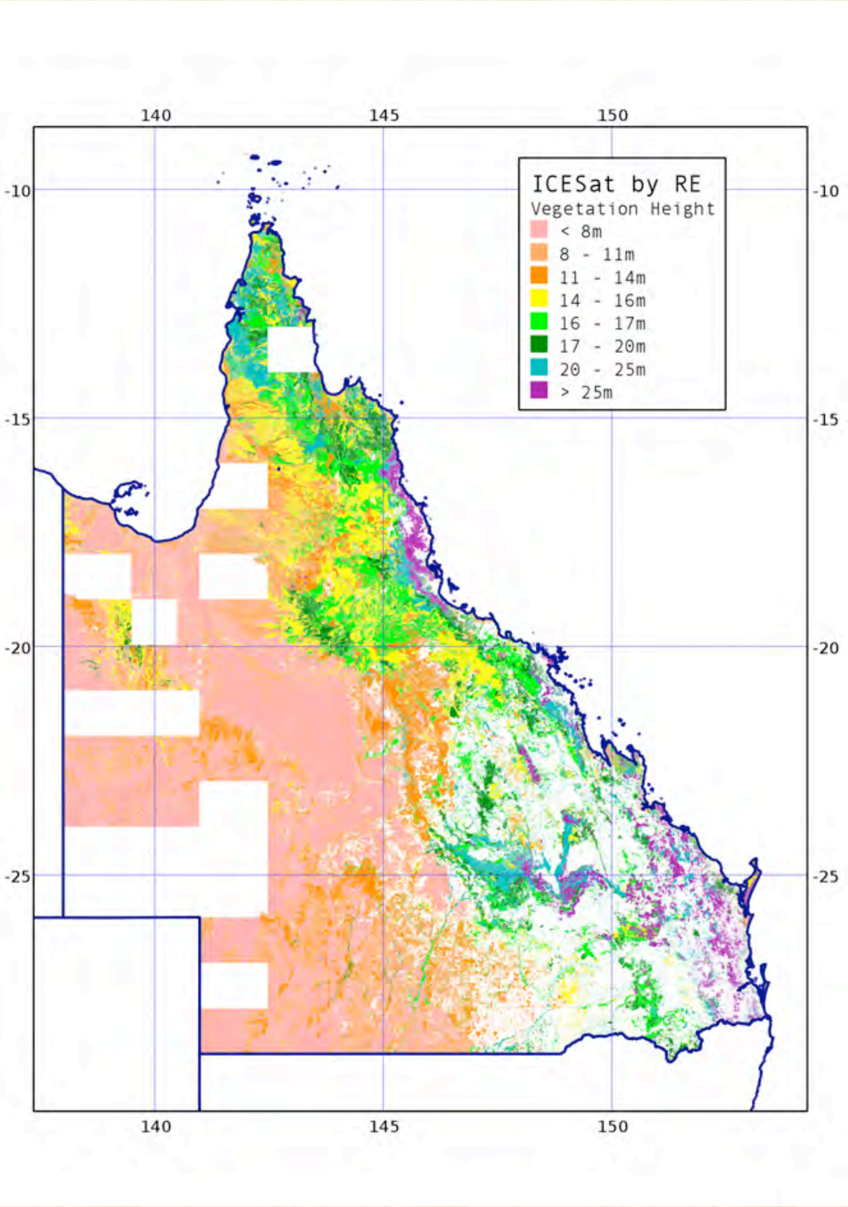
- IceSAT waveforms summarised by Queensland Regional Ecosystem (RE) data.

  – (r^2 = 0.73 when validated against airborne LiDAR of height)

- Not pixel-based nor spatially explicit within mapped polygons

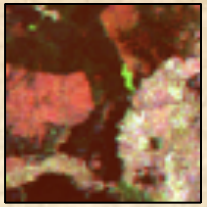
- Best used to constrain estimates of AGB generated through integration of ALOS PALSAR and/or Landsat FPC

- Could help saturation issue in higher biomass forests



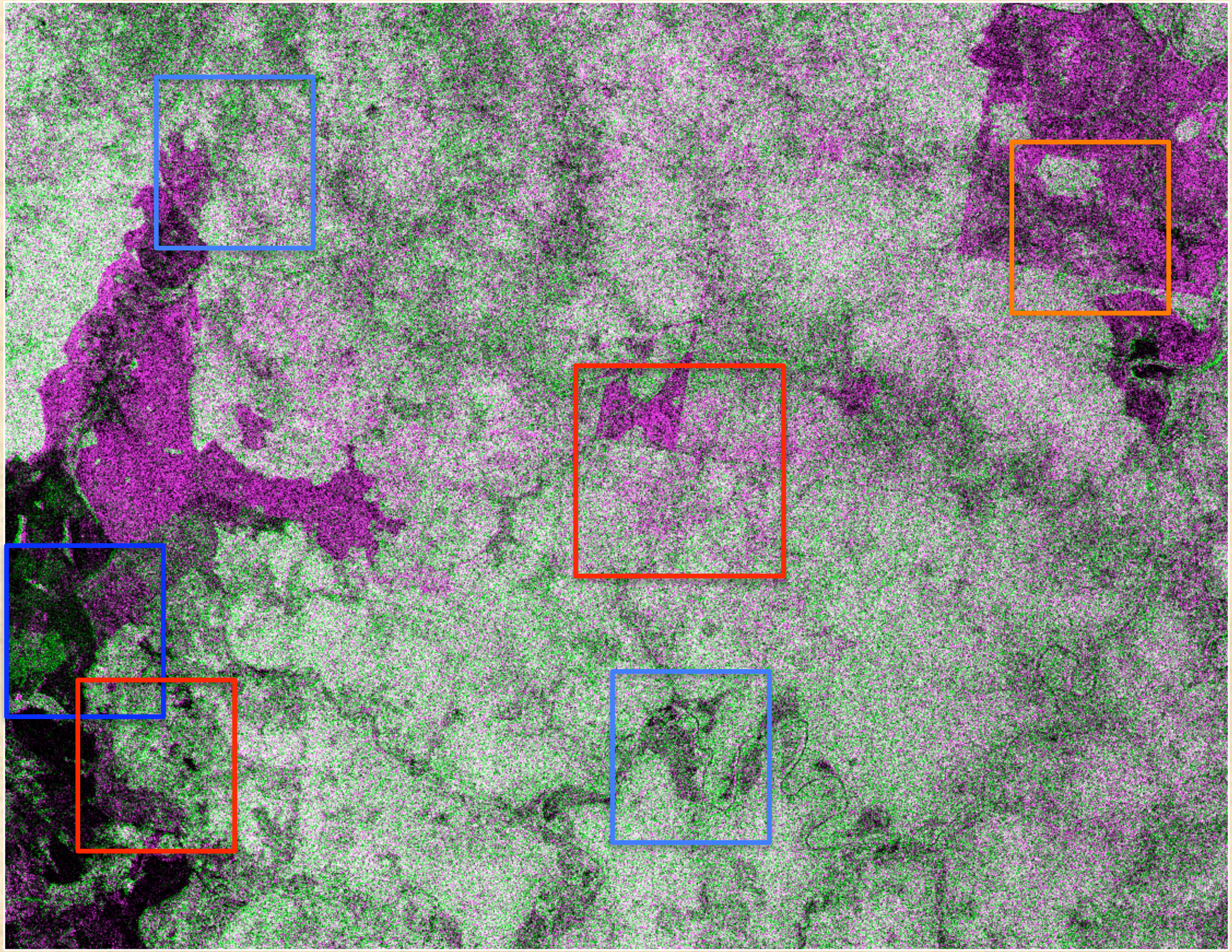
Quantifying Changes in AGB through time-series comparison of L-band SAR data

Regrowth after fire



Regrowth Following clearance

Tree death (stem injection)



Clearing

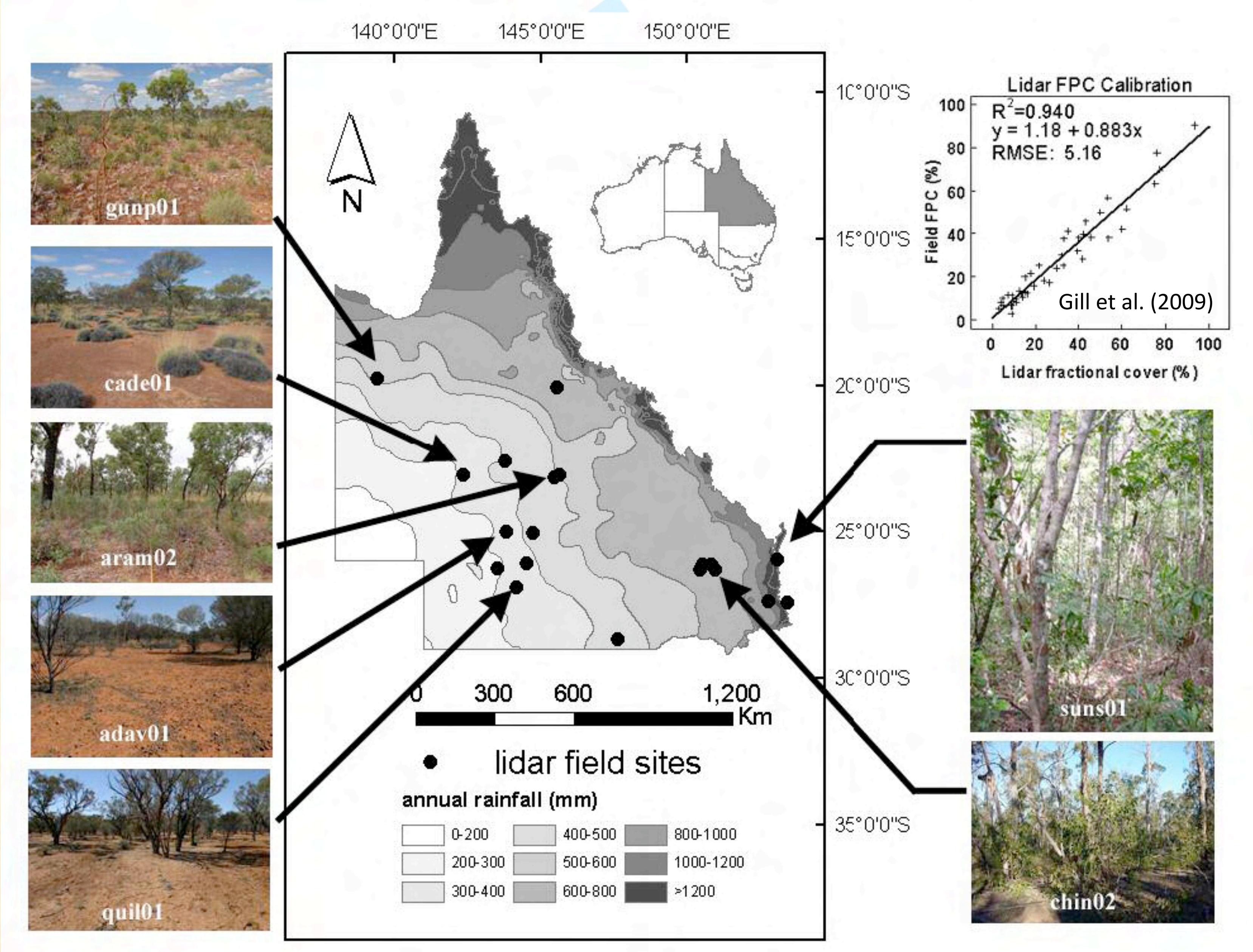
Fire damage

Thickening?

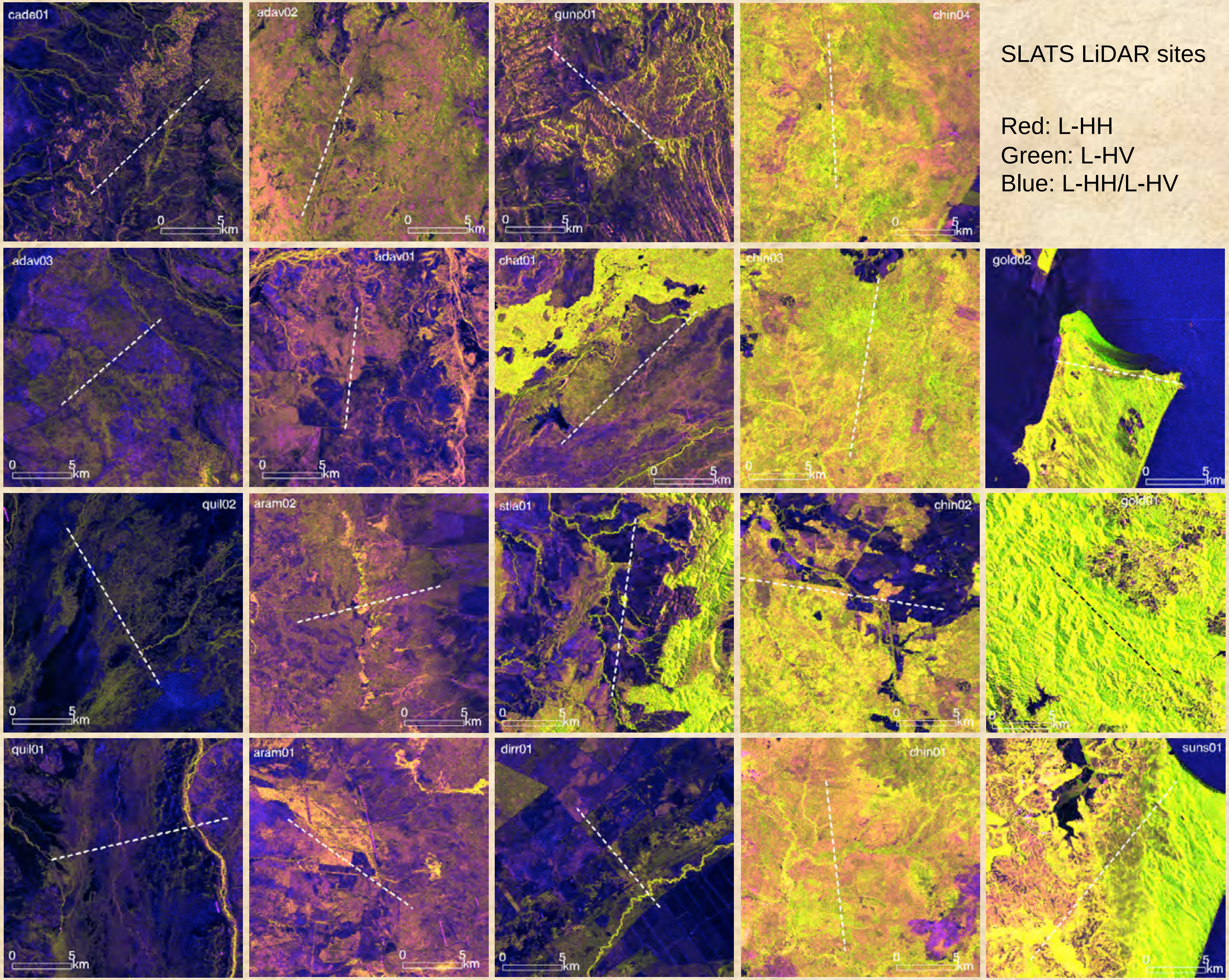
Relative Increases from 1995

Relative decreases from 1995

Scaling from LiDAR to SAR



ALOS PALSAR with LiDAR overflights, Queensland Australia

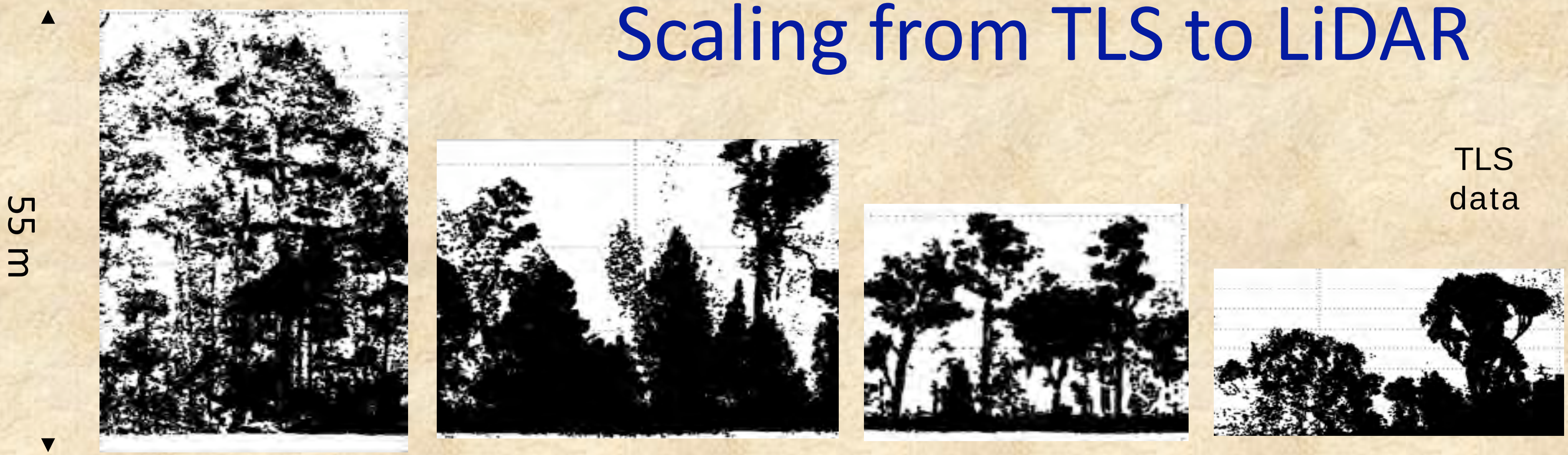


SLATS LiDAR sites

Red: L-HH
Green: L-HV
Blue: L-HH/L-HV

Scaling from TLS to LiDAR

TLS data

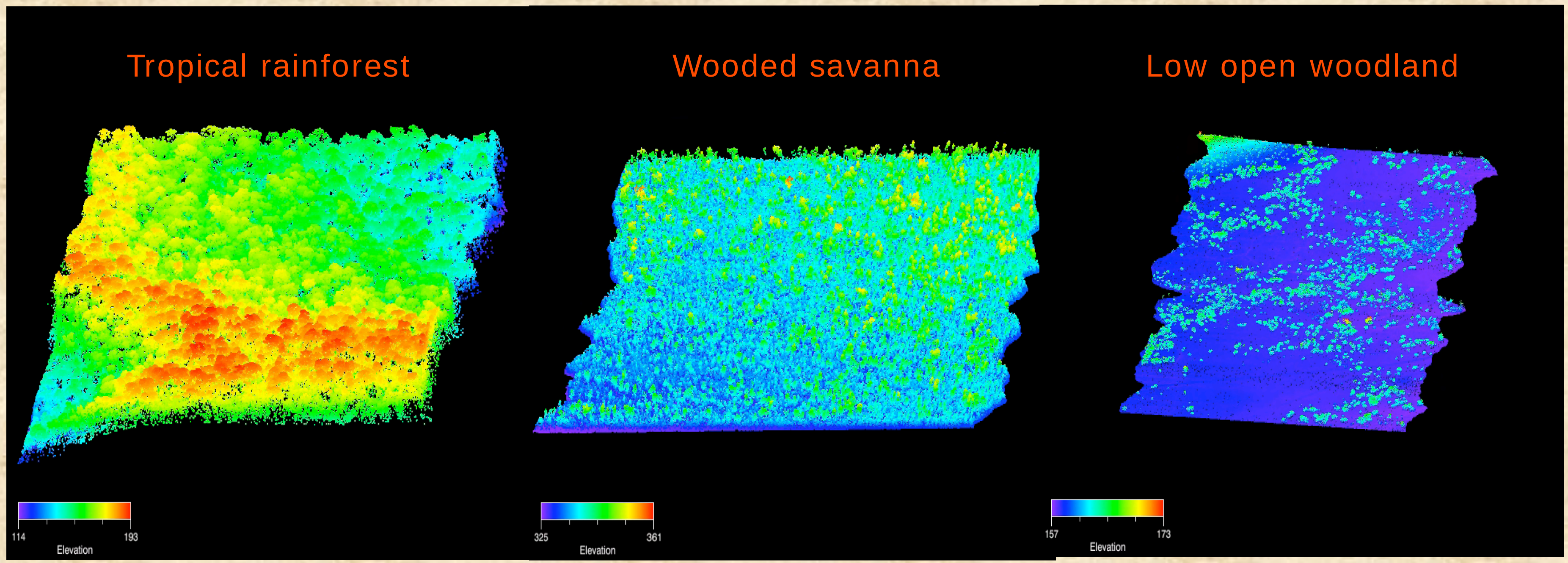


Subtropical rainforest

Closed savanna woodland

Open savanna woodland

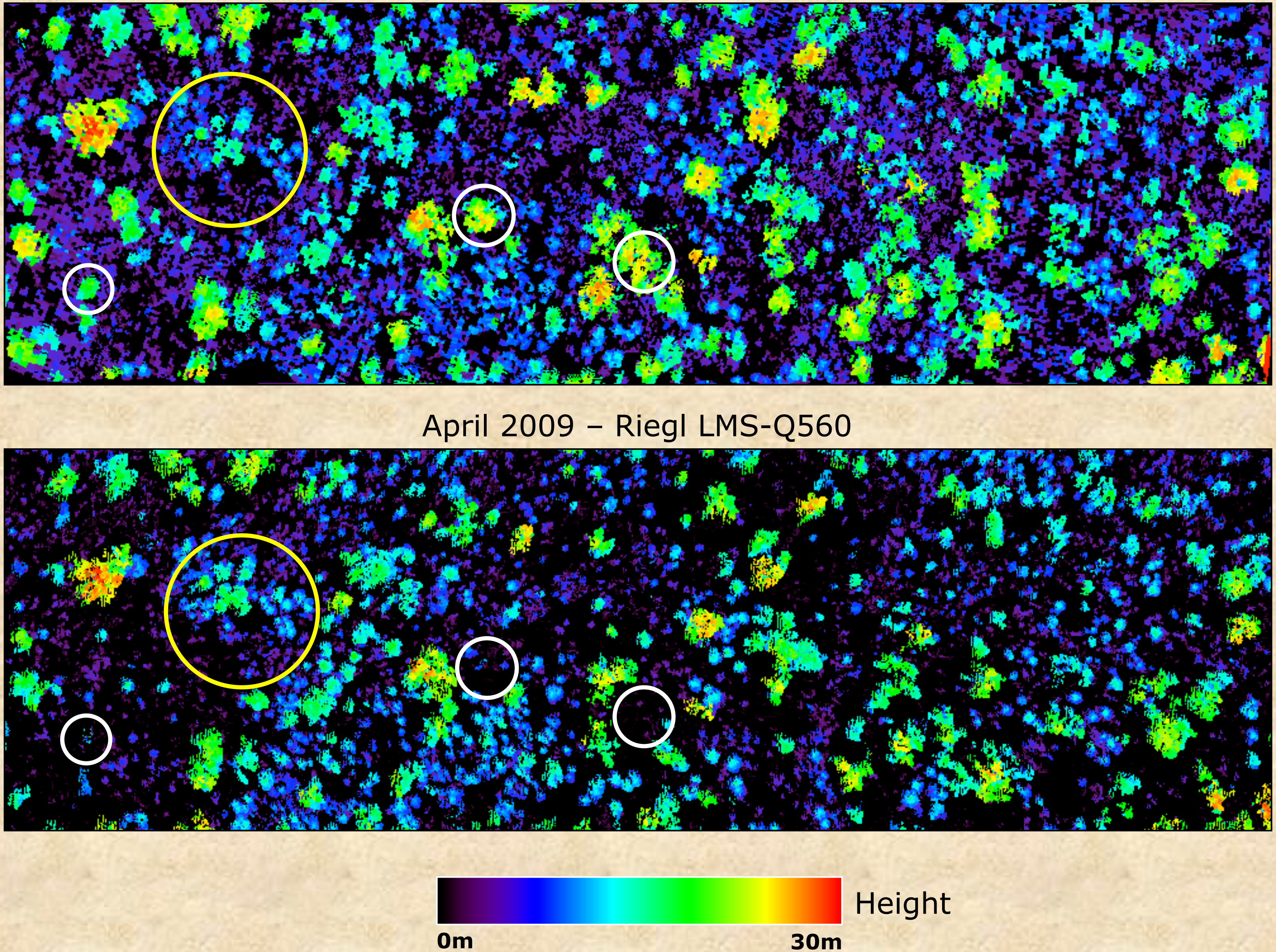
Coastal scrub



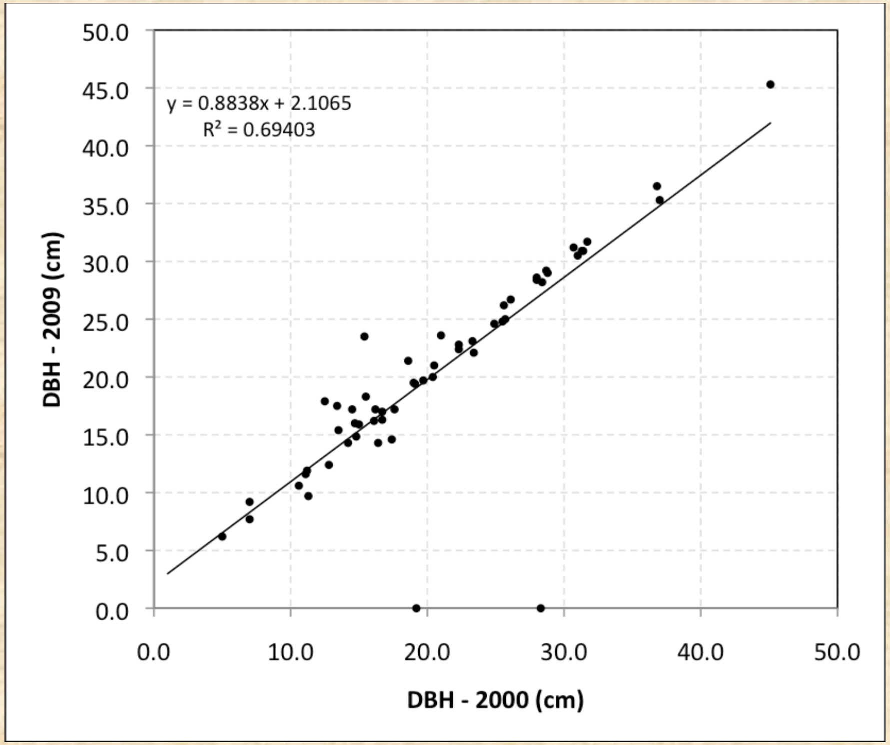
Tree mortality: Comparison of 2000 and 2009 LiDAR

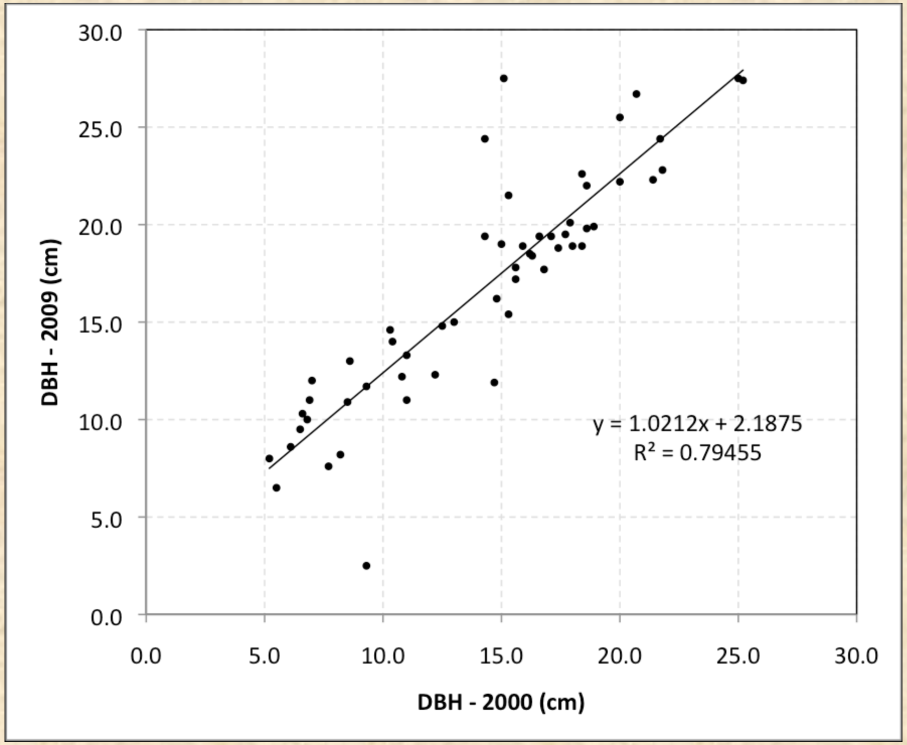
August 2000 – Optech ALTM1020

April 2009 – Riegl LMS-Q560



Forest growth: Comparison of 2000 and 2009 LiDAR



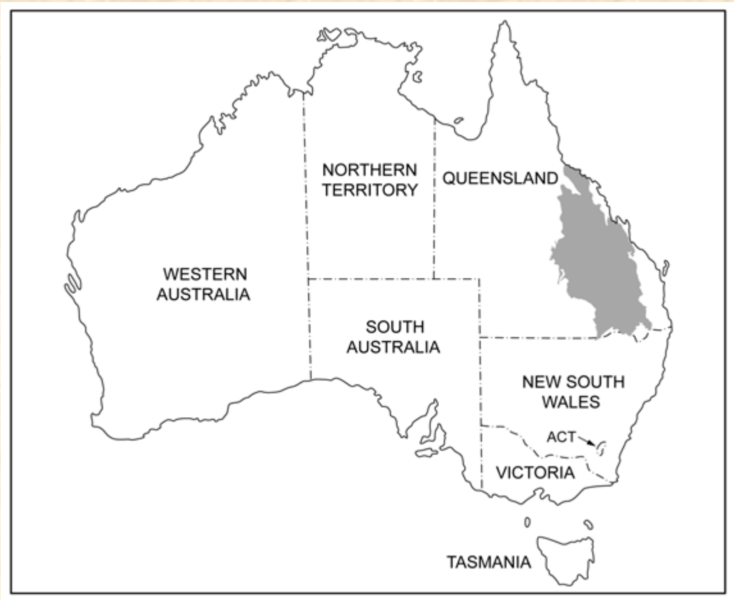


- 111: Increase of approximately 2 cm DBH; loss of two trees
- 142: Overall increase but variable gains and losses

Growth Stage Mapping: Brigalow Belt Bioregion

- The BBB extends across the temperate, semi-arid tropical and subtropical regions of eastern Australia and occupies an area of approximately 36.5 million ha

- The bioregion includes 169 different Regional Ecosystems (REs; REDD, 2010) and 41.9% of all ecosystems occurring prior to clearing are still considered to be remnant (Accad *et al*., 2008).



Brigalow Communities

- ❑ Since European settlement, and particularly the 1950s, extensive clearance of woody vegetation has taken place in Queensland, Australia (Johnson, 1964).

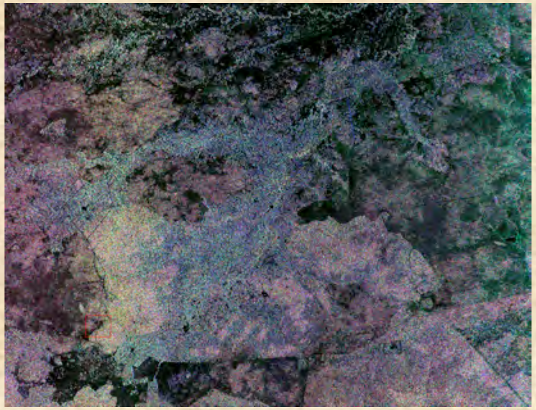
- ❑ Regional Ecosystems with brigalow (*Acacia harpophylla*) in majority have less than 10% remaining

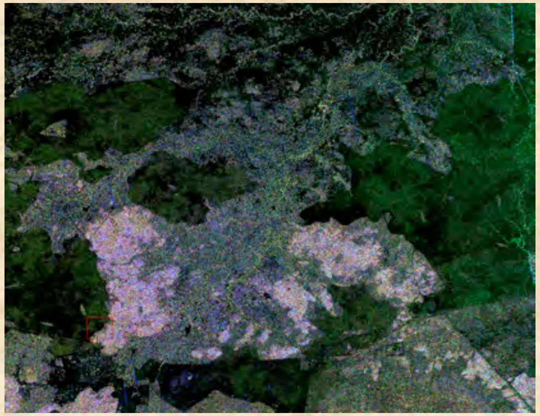
Brigalow communities remnant extent (Accad et al. 2008)

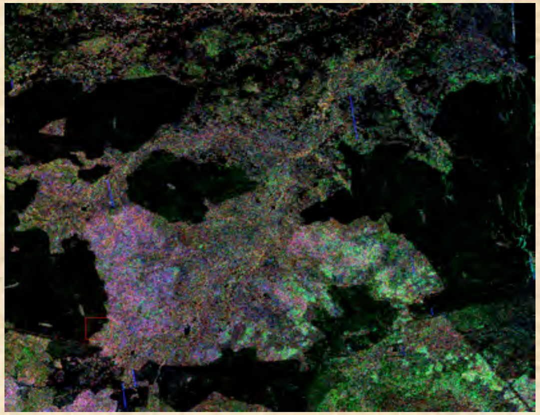
RE	Pre-clear	Remnant 2005	% of Pre-clear
06.04.02	264,564	17,970	6.80%
11.03.01	749,091	80,679	10.80%
11.04.03	1,591,360	77,389	4.90%
11.04.07	210,249	20,886	9.90%
11.04.08	722,604	71,909	10.00%
11.04.09	1,006,581	96,425	9.60%
11.04.10	63,120	6,307	10.00%
11.05.16	13,213	3,027	22.90%
11.09.01	567,819	55,195	9.70%
11.09.05	2,272,573	168,841	7.40%
11.09.06	15,317	371	2.40%
11.11.14	39,803	4,693	11.80%
11.12.21	72,691	6,634	9.10%
12.08.23	7,949	516	6.50%
12.09-10.06	33,624	916	2.70%
12.12.26	9,094	1,168	12.80%
Total	**7,639,652**	**612,926**	**8.00%**

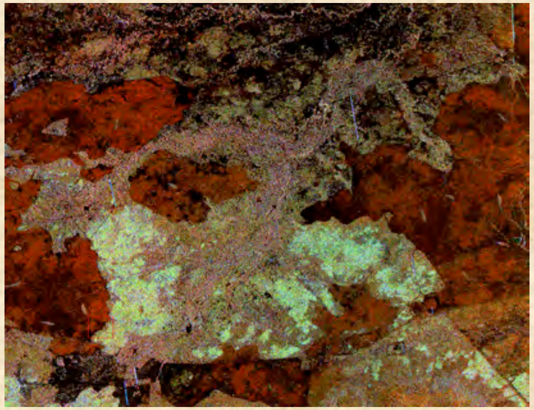
AIRSAR Observations of brigalow regrowth

C-band (λ ~6 cm) L-band (λ ~24 cm) P-band (λ ~68 cm)









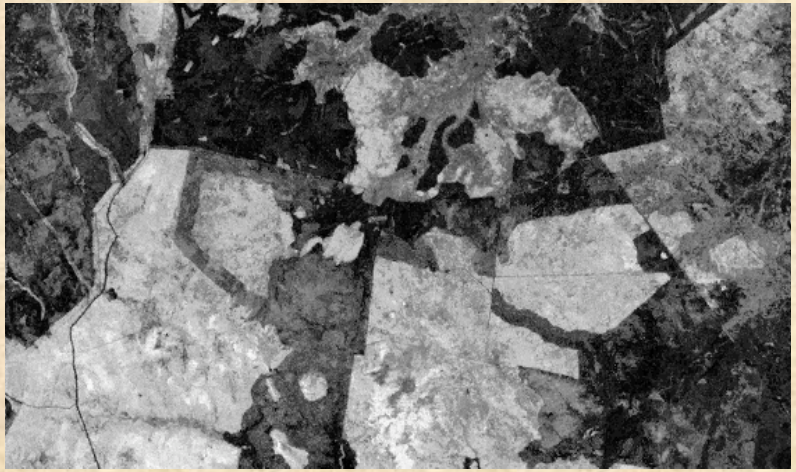
Total Power

Reduced return from *Acacia*-dominated regrowth with increasing wavelength (λ)

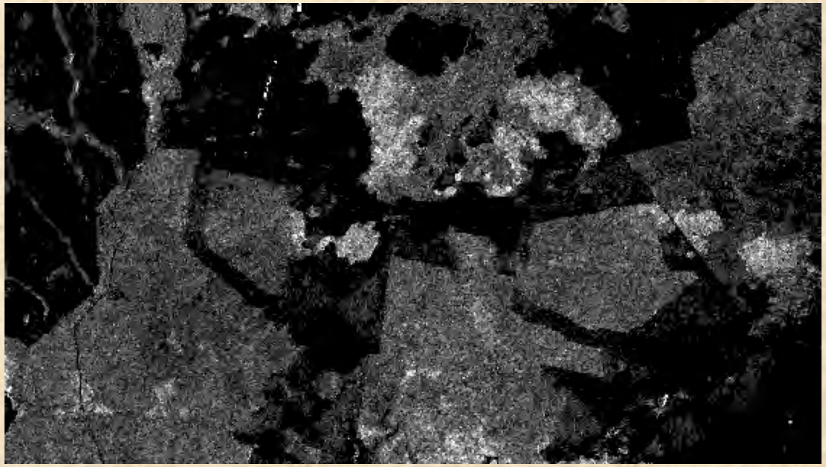
Areas of *Acacia* regrowth particularly prominent (red) in total power image (C-band in red); (Lucas et al., 2006)

Integration of ALOS PALSAR and Landsat-derived FPC New perspectives on landscape dynamics

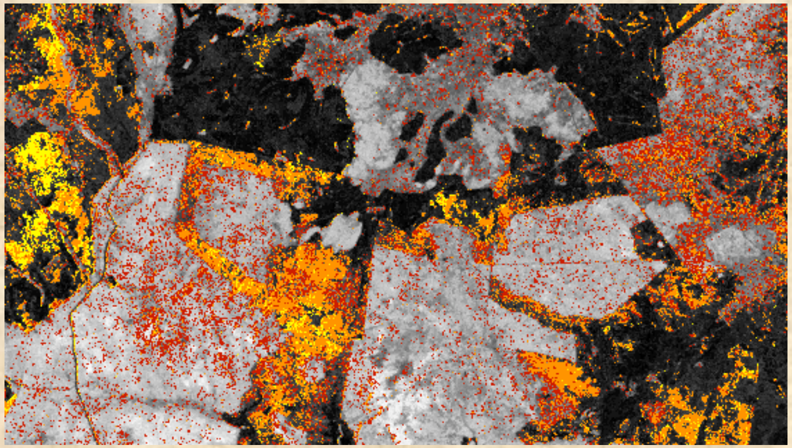
ALOS PALSAR/Landsat FPC Observations of brigalow regrowth



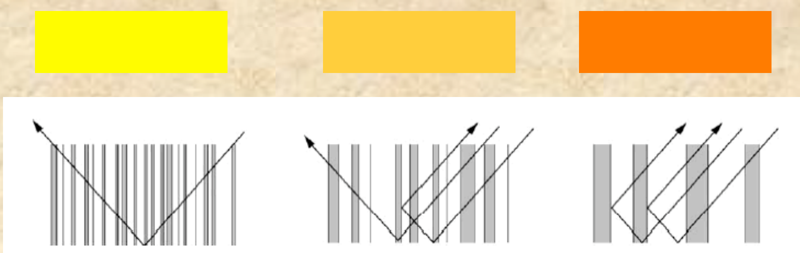
Landsat Foliage Projected Cover
(Woody vegetation defined as > 12 % FPC)



ALOS PALSAR L-band HH



Stages of structural development



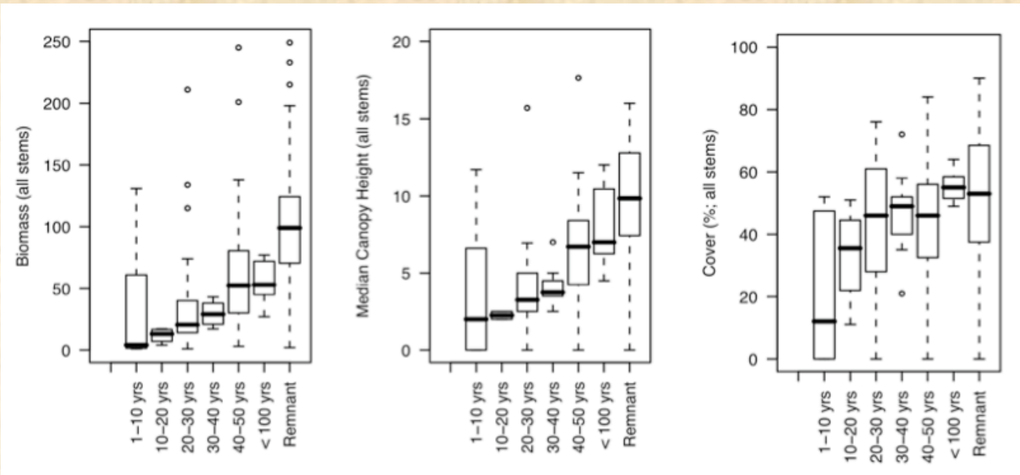
Regrowth dynamics; open forests of the Brigalow Belt Bioregion, SE Queensland, Australia

5 years

27 years

40 years

Remnant

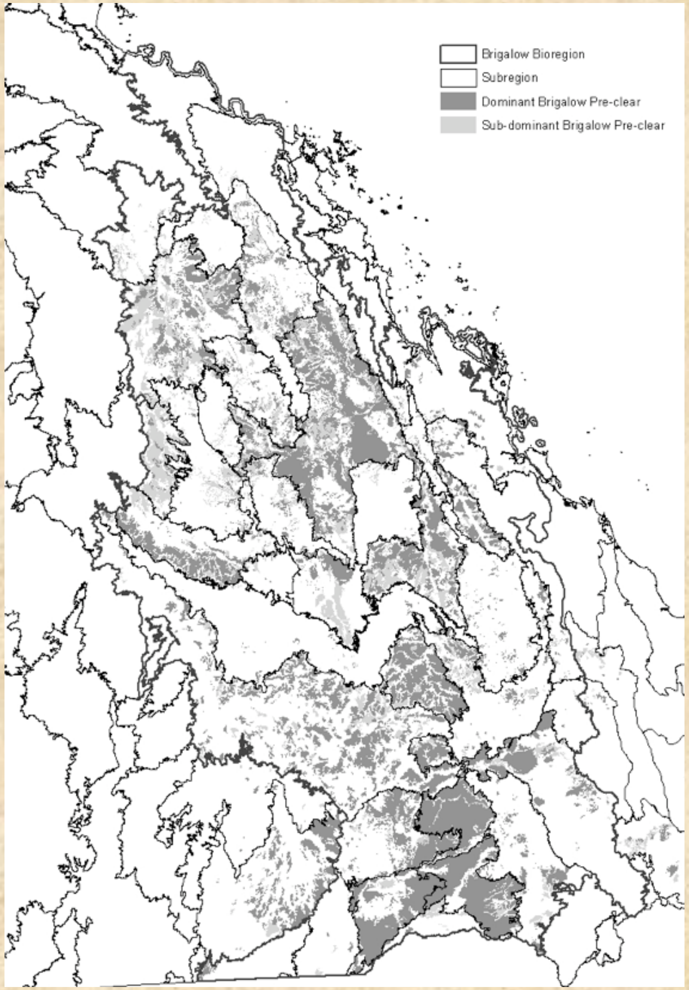


- Extensive clearing of woody vegetation in late 1990s/early 2000s
- Regrowth extensive following restrictions on clearing
- Varying pathways to recovery
- Implications for carbon and biodiversity

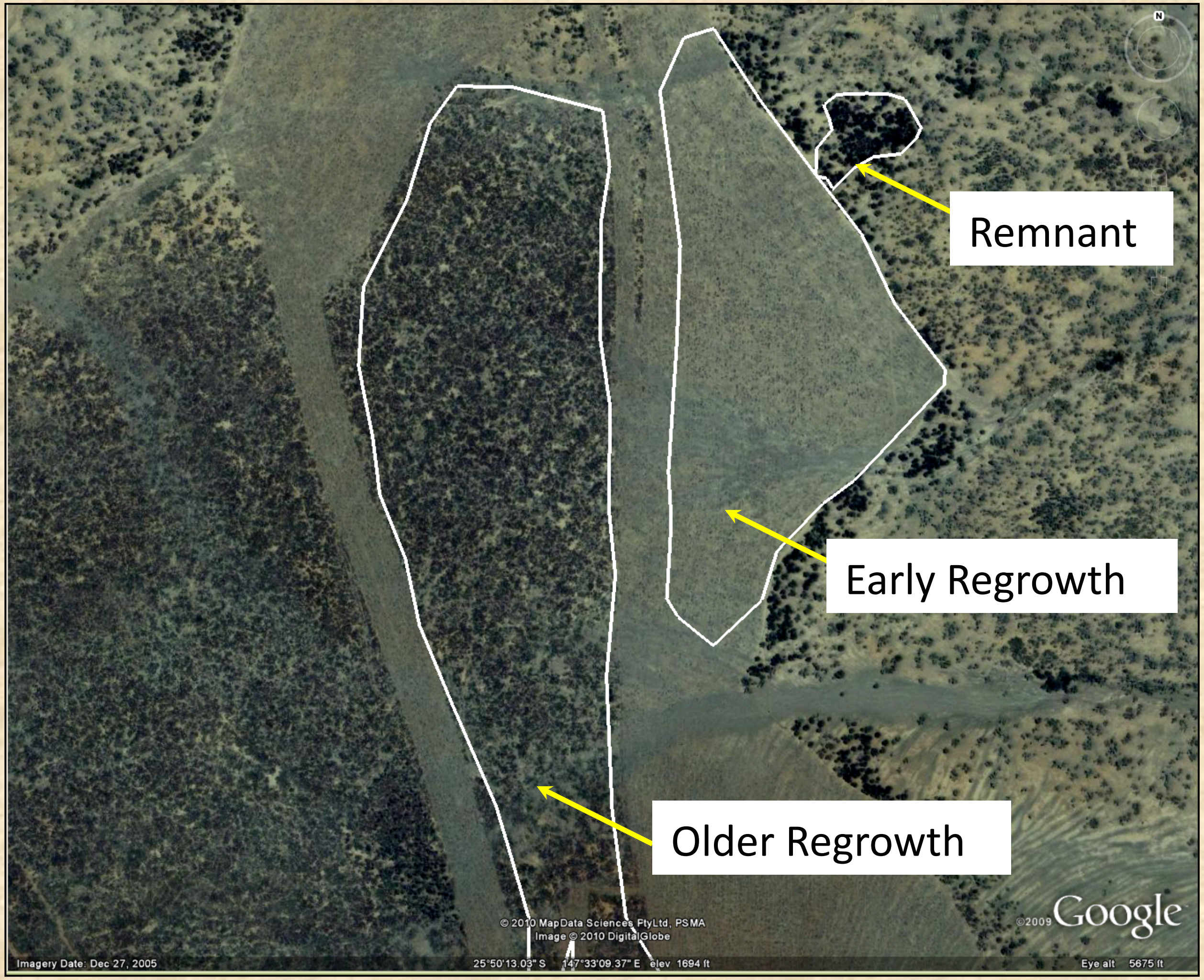
Brigalow Community Growth Stages

- ❑ **Early Regrowth***
- ❑ **Remnant** vegetation
  - ❑ Supports> 70% of the height and > 50% of the cover relative to the height and cover of that stratum undisturbed canopy and contains species characteristic of the vegetation (Neldner *et al.*, 2005).
- ❑ **Older Regrowth***

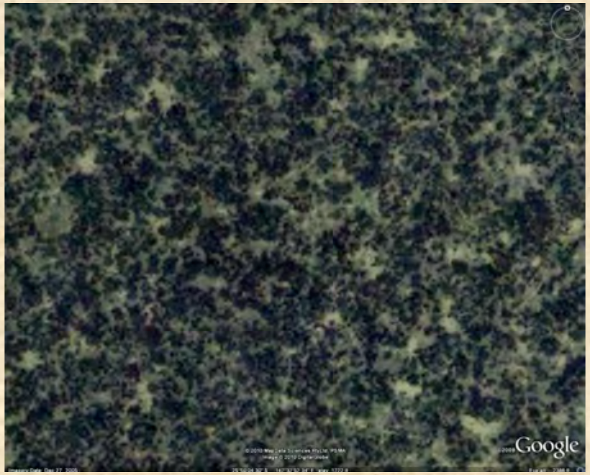
* Brigalow regrowth is considered to only occur in areas where the pre-clearing mapping (Herbarium 2009a) showed a brigalow community as a dominant, co-dominant or sub-dominant

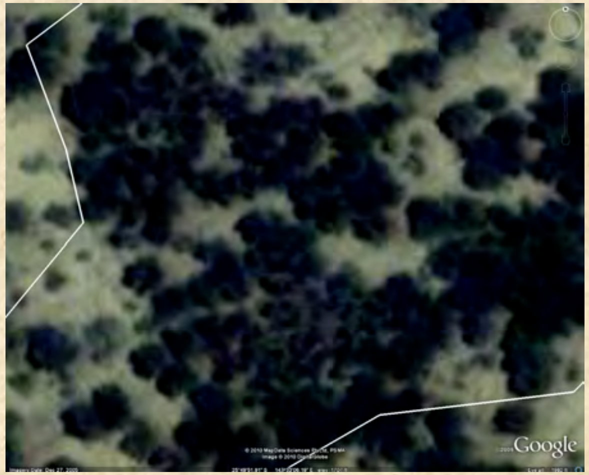


Brigalow Growth Stages (11.9.5)



Brigalow Growth Stages(11.9.5)





Early regrowth

Older regrowth

Remnant

The distribution of the field plots

- For the study, the field plots of Bowen (2009) and Dwyer (2009) were standardized and combined
- Bowen (2009) measured 82 (77 used) stands associated with brigalow and *Casuarina* species in the Tara Downs region within RE 11.4.3.
- Dwyer (2010) collected data from 70 sites where brigalow was dominant or co-dominant within the regenerating forest community. Plots were more widely distributed between the REs
- The eight out of 12 brigalow REs in BBB represented 93.8% of the pre-clearing extent of brigalow communities

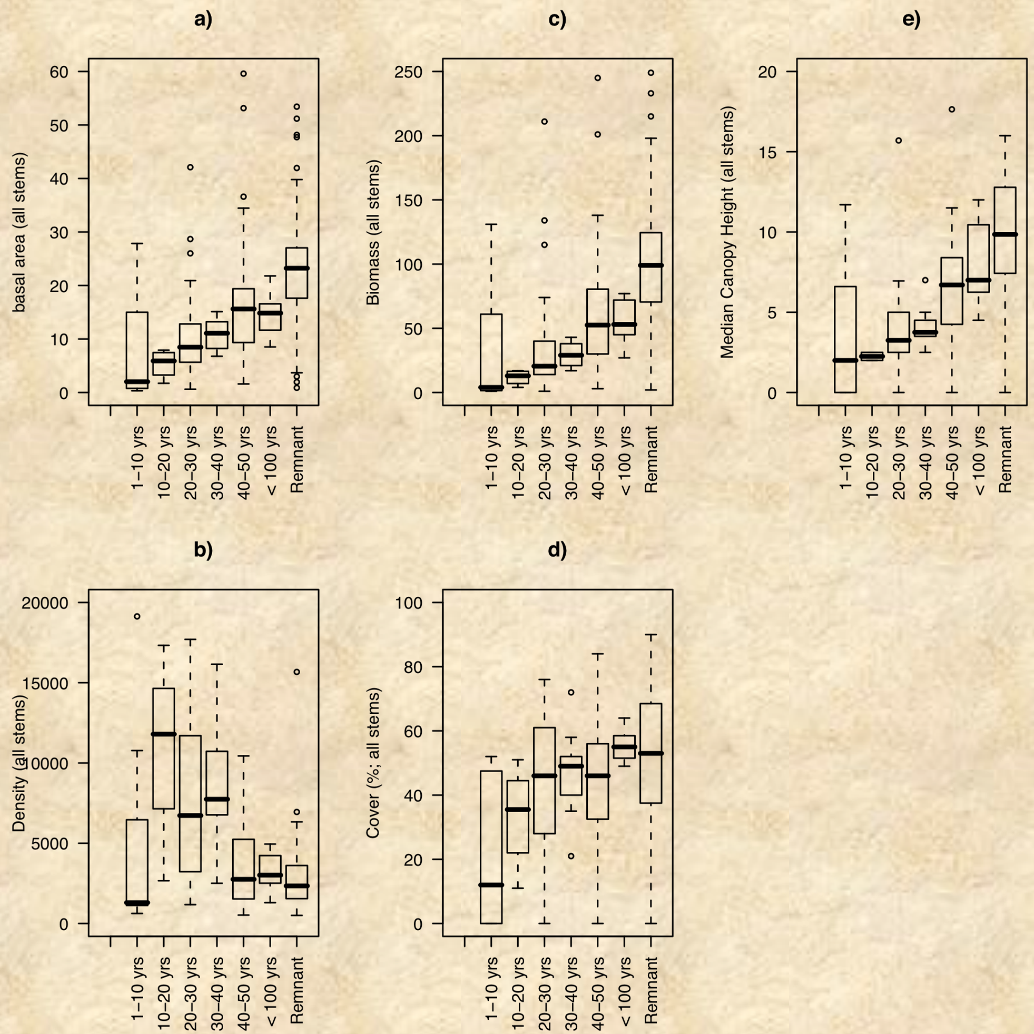
RE Code	Area[1] %	No.	Brigalow Belt (Tara Downs)		Brigalow Belt (Other)	
			Regrowth	Remnant	Regrowth	Remnant
11.3.1	10.0	2			1	1
11.4.3	21.2	94	27	50	12	5
11.4.8	9.6	3			3	0
11.4.9	13.4	14			13	1
11.4.10	0.8	1			0	1
11.9.1	7.6	6			5	1
11.9.5	30.2	26			21	5
11.12.21	1.0	1			1	0
TOTAL	93.8	147	27	50	56	14

Field measurements as function of age

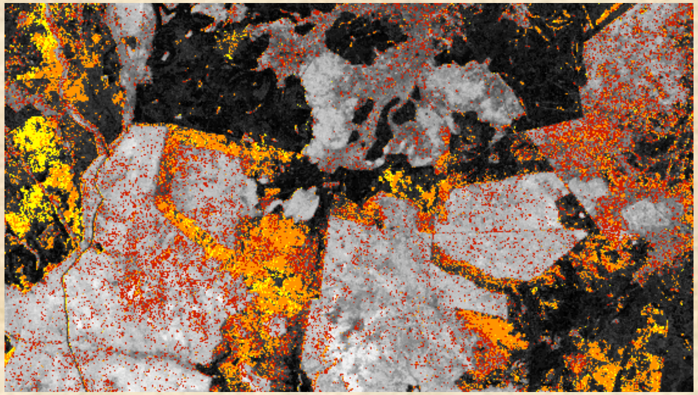
Variations in:
a) basal area,
b) stem density,
c) biomass,
d) canopy cover, and
e) median canopy height,

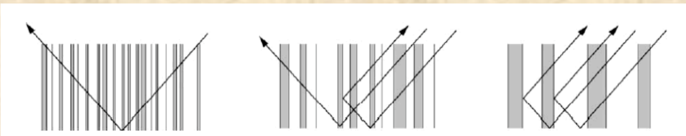
as a function of age.

* The age of the forests was estimated with reference to time-series of aerial photography and SPOT HRG imagery (Bowen, 2009) and farmer interviews (Dwyer, 2010).

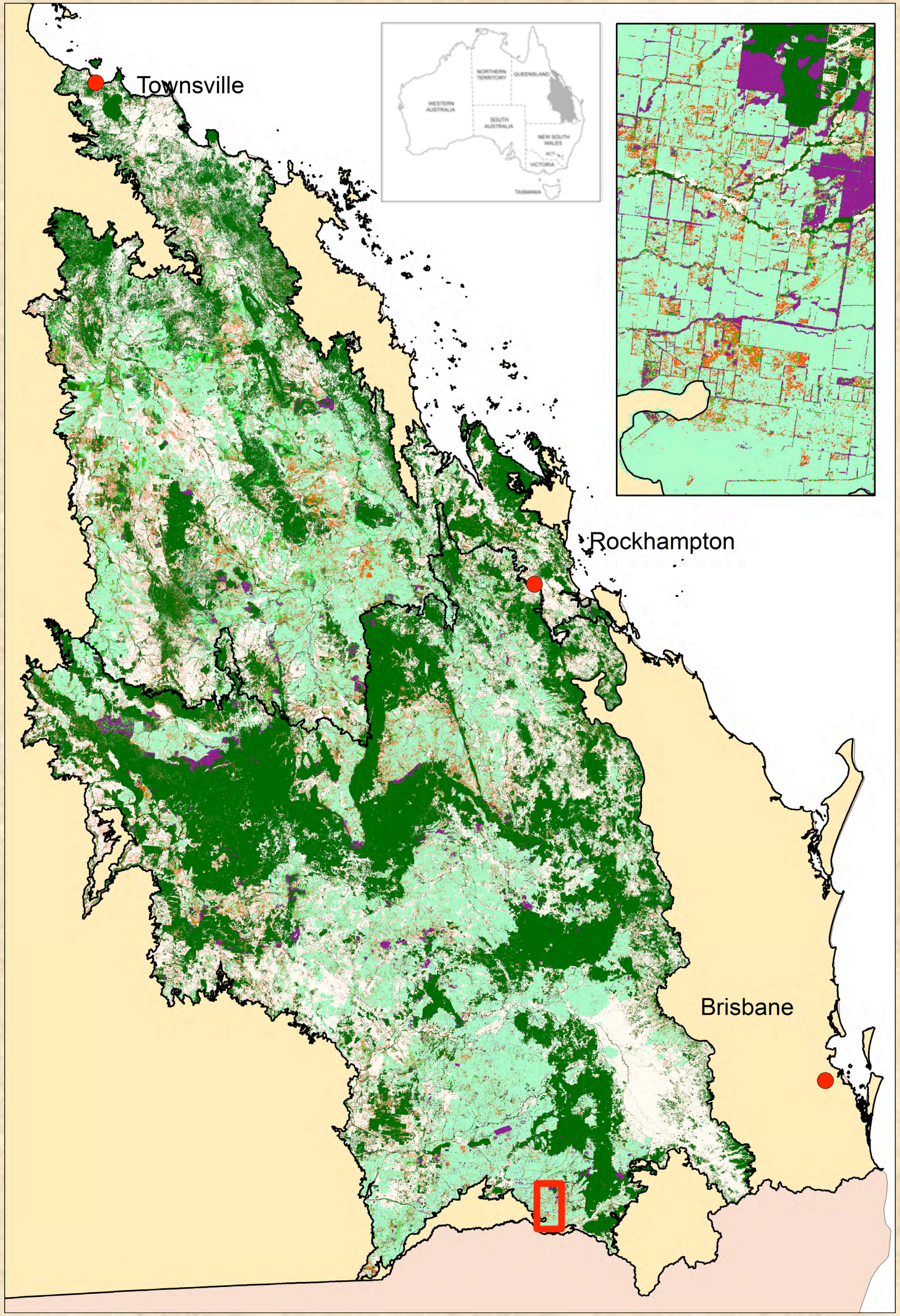


Integration of ALOS PALSAR & Landsat FPC for regional growth stage mapping





- Early regrowth
- Older regrowth
- Remnant



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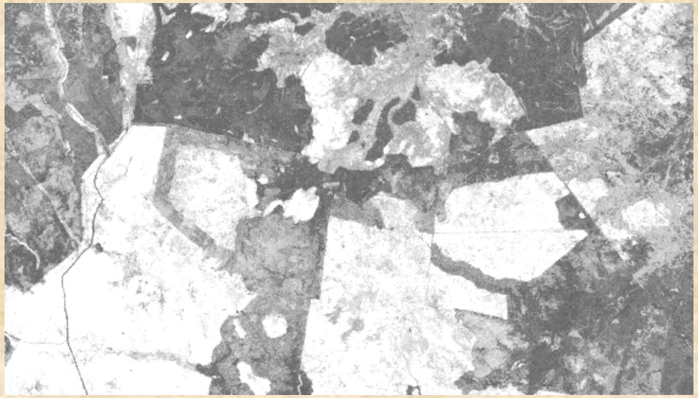
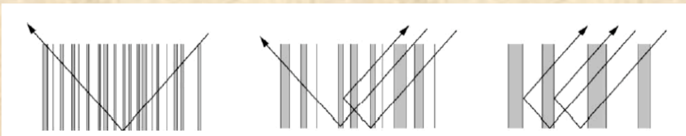
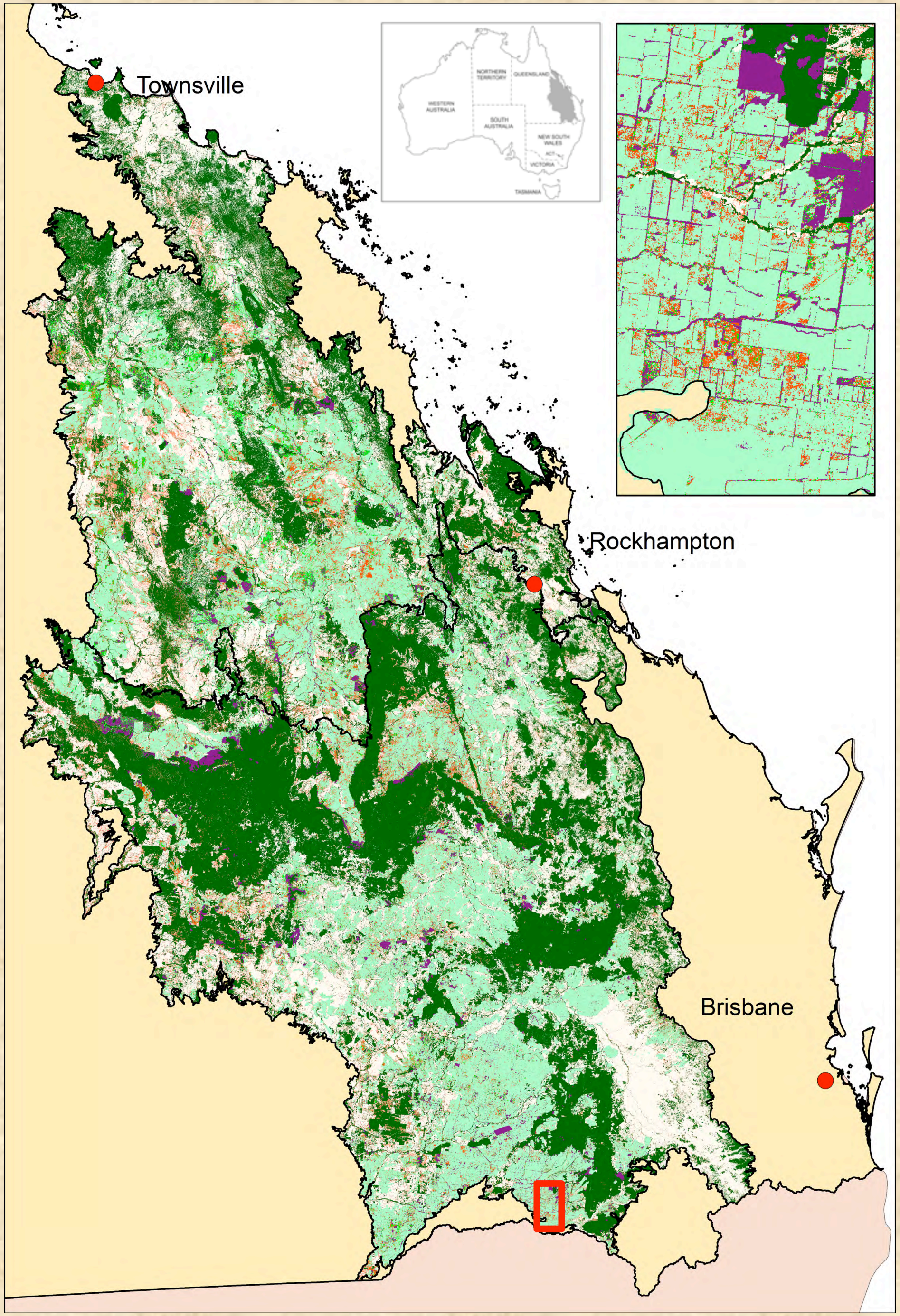




- Early regrowth
- Older regrowth
- Remnant



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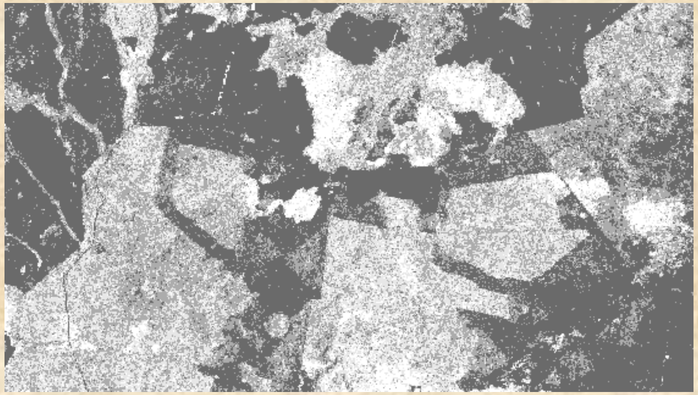
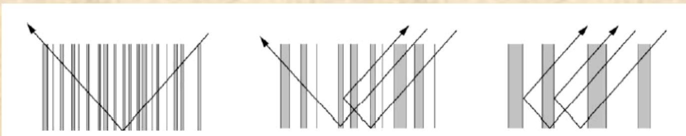
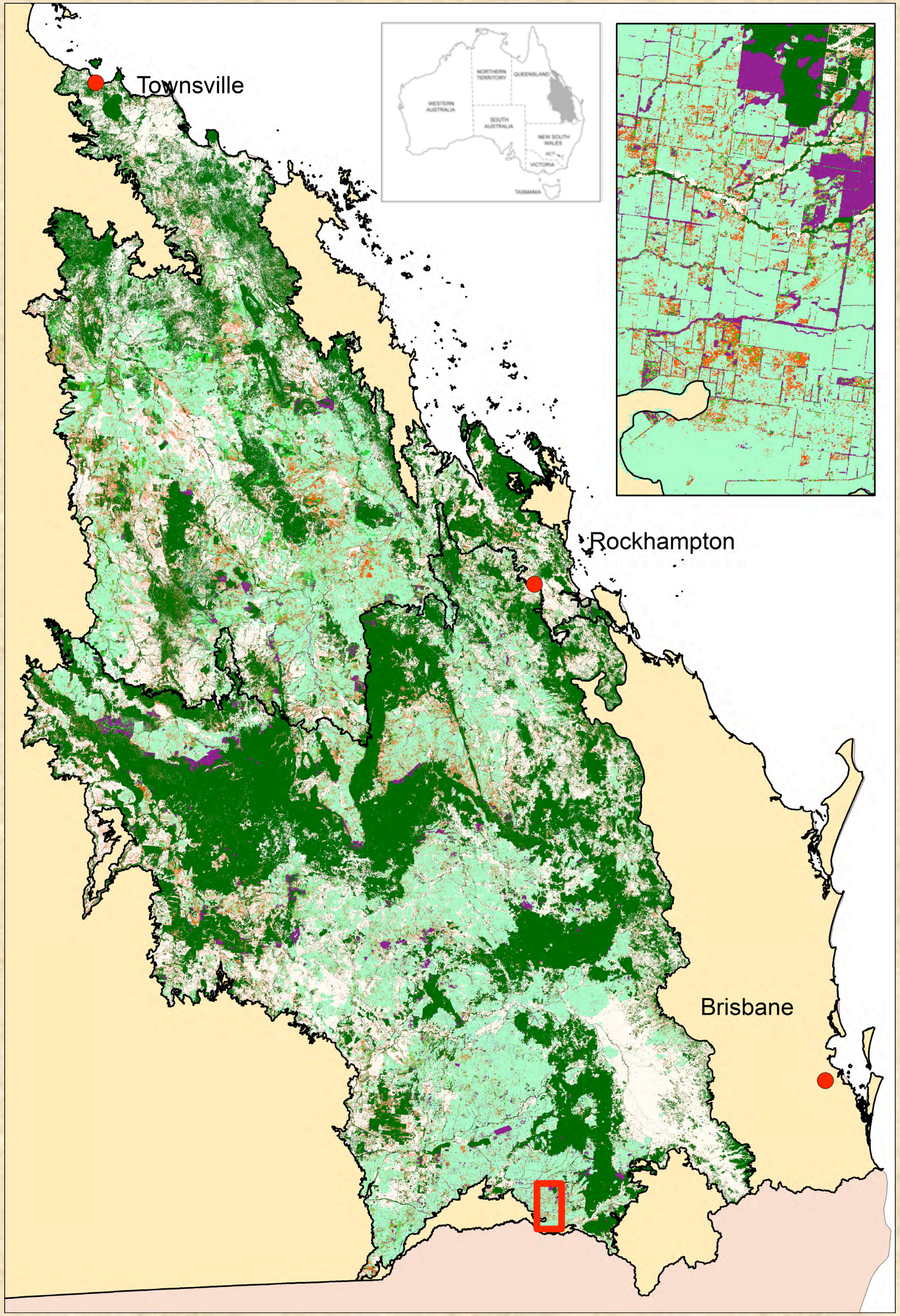




- Early regrowth
- Older regrowth
- Remnant



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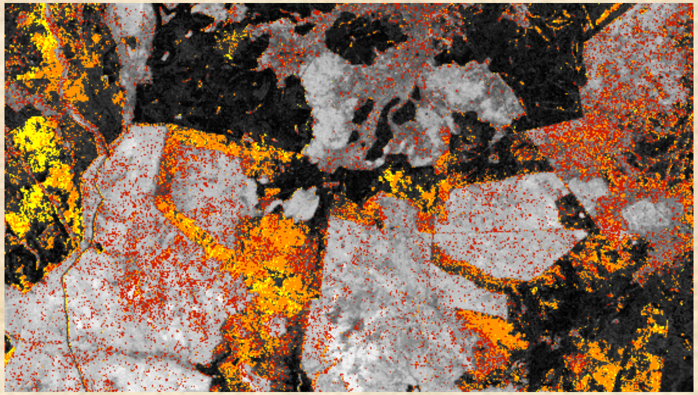
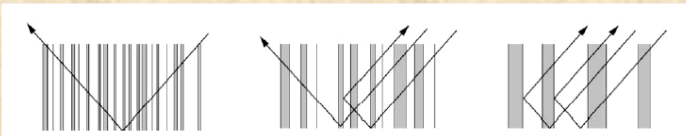
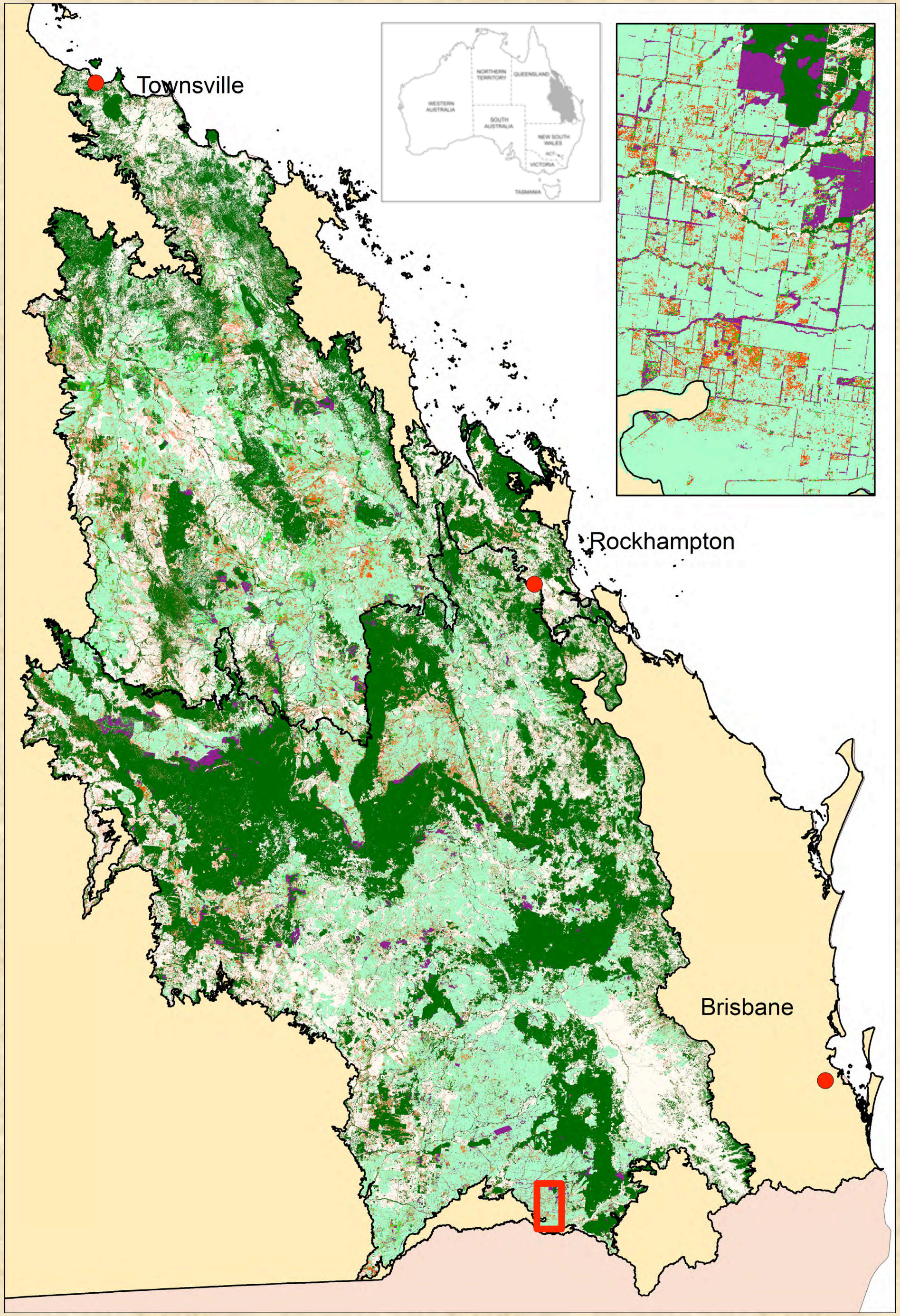




- Early regrowth
- Older regrowth
- Remnant

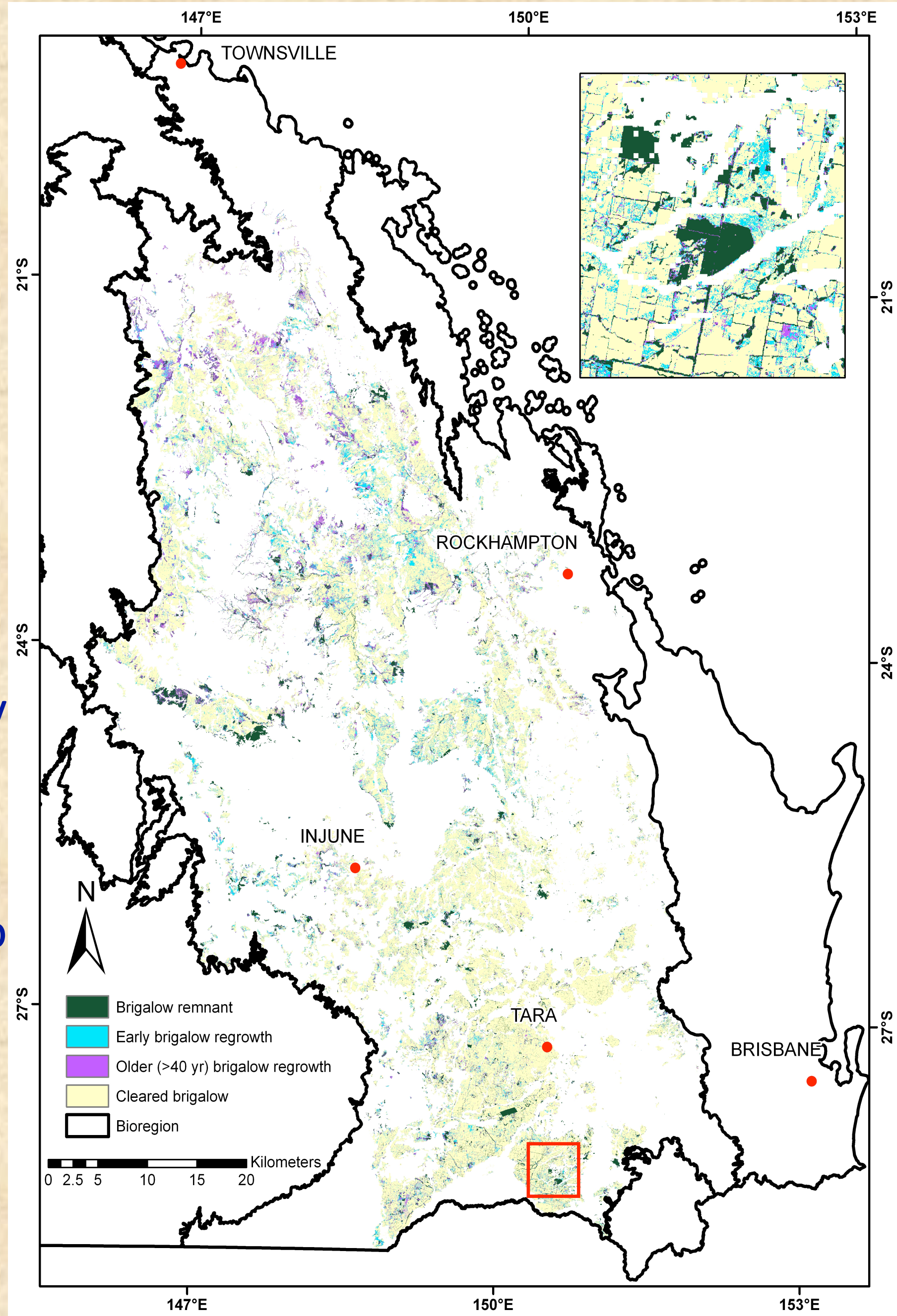


Approach to mapping

The mapping of all growth stages was undertaken within eCognition (Definiens AG) by initially segmenting the Landsat FPC mosaic into objects of few pixels

Then, within the area associated with the pre-clearing extent of forests with brigalow as a component, the thresholds (previous slide) were applied progressively to distinguish early regrowth, remnant forest and finally older regrowth.

The resulting objects were then merged to generate the brigalow communities growth stage map.

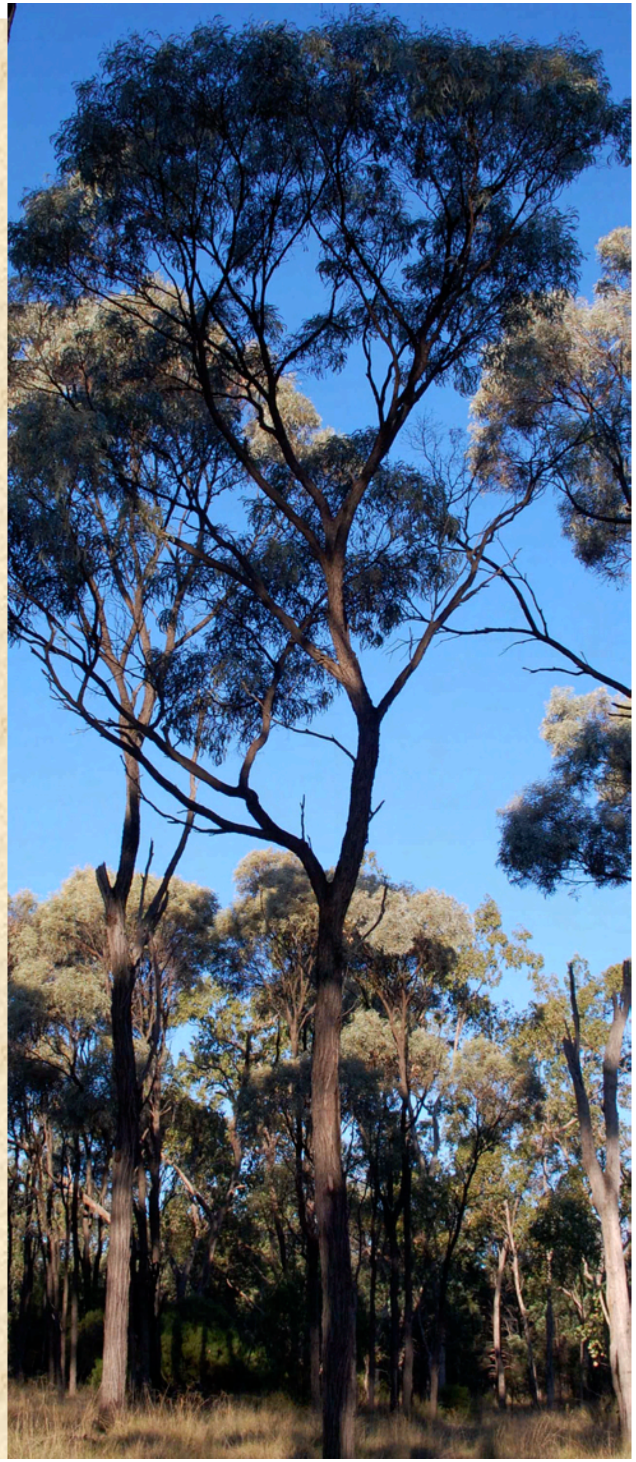


Accuracy Assessment

- An objective assessment approach was developed using a total of 190 randomly generated locations in three separate areas located within the BBB.

- Random points were classified (eCognition) by the three stages of growth (early regrowth, older regrowth and remnant).

- Independent allocation of the points to a reference growth stage was undertaken using a combination of field knowledge and historical aerial photography and imagery



Accuracy Assessment Results

- The independent assessment of the classification described in the methods resulted in high levels of accuracy in the delineation between **regrowth and remnant brigalow** with overall accuracy of 87.4% with remnant reaching as high as 90%.

- Further assessment of the accuracy of **brigalow regrowth early and older stages** has resulted with an overall accuracy of 73%.

- This lower accuracy mainly due to the variability in structure within **the older regrowth stage** in the different brigalow REs.

	Classification	
Assesment	Regrowth	Remnant
Cleared	14	0
Regrowth	121	5
Remnant	5	45
	86.4%	**90.0%**
Overall:	**87.4%**	

	Classification			
Assesment	Early Regrowth	Older Regrowth	Remnant	
Cleared	9	5		14
Early Regrowth	59	20	4	83
Older Regrowth	8	34	1	43
Remnant	2	3	45	50
	75.6%	54.8%	90.0%	**73%**

Summary and Conclusions

- At a regional level, retrieval of AGB from ALOS PALSAR L-band data (based on empirical relationships) requires:
  - The generation of mosaics from data acquired during periods where vegetation and soil moisture are relatively minimal.
  - Consideration of differences in L-band backscattering coefficient as a function of structural formations
    - Forest type
    - Growth stage
- Retrieval is limited by saturation of the relationship between AGB and L-band HV data. Therefore, to increase robustness of retrieval need to consider:
  - Additional datasets (e.g., Landsat FPC, IceSAT)
  - Alternative algorithms (non-linear estimation)
  - A stratified approach (consideration of regrowth, flooded forest, mangroves)
  - Extension of the biomass library to support calibration/validation
- Whilst retrieval may be improved by combining multi-year data, the detection of change is compromised; retrieval from single year imagery recommended
- For Australia-wide application, consistency in datasets, validation/ calibration data and retrieval algorithms is desirable.

Conclusions

- Technique for mapping ***early regrowth*** based on **airborne SAR (AIRSAR)** and Landsat FPC (Lucas et al., 2006) can be applied at a regional level using **ALOS PALSAR**.
- In addition, ***remnant forests*** can be discriminated using ALOS PALSAR and Landsat FPC; all remaining areas are assigned to ***older regrowth*.**
- Using **single date FPC data alone**, differentiation of remnant from regrowth forests was not possible because of similarities in canopy cover
- Estimates of regrowth and remnant forest extent are in line with previous mapping based on **multi-date FPC**
- However, the major advantage of using the combination of ALOS PALSAR (with Landsat FPC) is that only one acquisition date is needed. The caveat is that the ALOS PALSAR data acquired during periods of **minimal moisture** should be used.
- Whilst it is recognised that **thresholds might vary as a function of RE** and environmental conditions, these were considered appropriate at a regional level.
- A **more specific thresholds for each RE** is investigated which may improve the overall accuracy.
- The maps generated from this research can be used to **support restoration of brigalow ecosystems to maximise carbon sequestration and conservation of biodiversity.**

K&C deliverables

Data sets and Thematic products
(mosaics, classification maps etc.)

1. Completed and Delivered to JAXA

- *Biomass map (above ground), Queensland, Australia*
- *Regrowth stage map, Brigalow Belt Bioregion, Queensland, Australia.*

Acknowledgements

Richard Lucas[1], John Armston[2,6], Russell Fairfax[2], Rod Fensham[2], Arnon Accad[2], Joao Carreiras[3], Jack Kelly[2], Peter Bunting[1], Dan Clewley[1], Steven Bray[4], Dan Metcalfe[5], John Dwyer[6], Michiala Bowen[6], Teresa Eyre[2] and Melinda Laidlaw[7].

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[5]*CSIRO, Atherton, Queensland, Austrália.*
[6]*University of Queensland, St. Lucia Campus, Brisbane, Queensland, Austrália.*
[7]*Griffith University, Brisbane, Queensland, Austrália.*

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