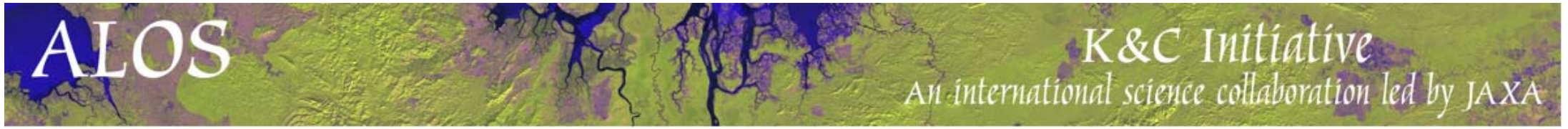



# K&C Phase 3 – Brief project essentials

*Assessing woody structural properties of semi-arid African savannahs from multi-frequency SAR data*

Renaud Mathieu, Laven Naidoo, Konrad Wessels, Greg Asner, Mikhail Urbazaev, Christiane Schmullius

Council for Scientific and Industrial Research, South Africa
Carnegie Institute for Science, USA
Friedrich-Schiller-University Jena, Germany

AGRICAB

CSIR
our future through science

CAO
Carnegie Airborne Observatory

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

science and technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

CARNEGIE INSTITUTION FOR SCIENCE

## Context

- Savannahs (94% of forests): mixed grass / woody layer
- Woody component essential in region
  - Food / energy security → poor communities
  - Biodiversity
  - Carbon accounting (REDD+), 1/6 of land surface; 3rd carbon pool after tropical and temperate forest
  - Climate modeling (grass vs. woody dynamic)
- Limited "validated" spatial data in Southern Africa
- Research programme aims to:
  - Assess a range of remote sensing techniques to quantify woody structure parameters
  - Develop national/regional calibrated & validated woody structure products
  - Develop the technology base (and human capacity) for developing remote sensing products for SA environments

# Context

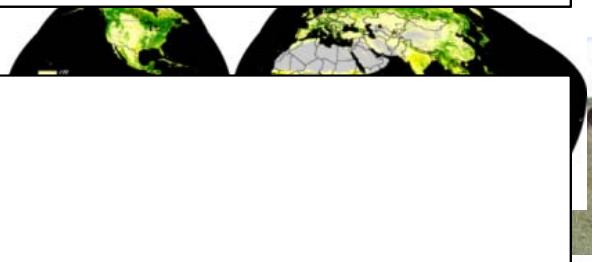
Policy on Woodlands

*National Forests Act (84 of 1998) caters for woodlands* and recognizes them explicitly as renewable energy source. The Act makes provision for research, monitoring, dissemination of information and reporting. *DAFF has legally to report every three years on the status of woodlands to the minister*.

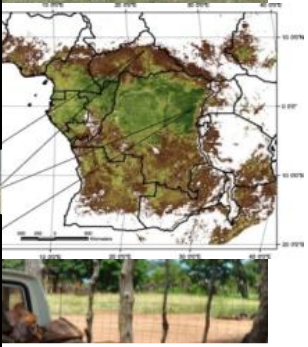
- Carbon accounting (REDD+), 1/6 of land surface;

ALOS PalSAR 10 m Global forest map

nuous Field



*% tree cover, herbaceous, and bare, annual product, 500 m*





t Global Tree Height Map


Policy on Woodlands

Medium Term Strategic Framework Outcome 10 led by DEA
"*Net deforestation to be maintained at no more than 5% woodlands by 2020*"
"*Undertake provincial and national forest resource assessment programs*"

Assess a range of remote sensing techniques to quantify woody structure parameters

Green economy

Nationally households use 4.5-6.7 million T / yr of wood for energy to a value of R3 billion.
Savings on new electricity generation between USD14.6-77.4 million per yr

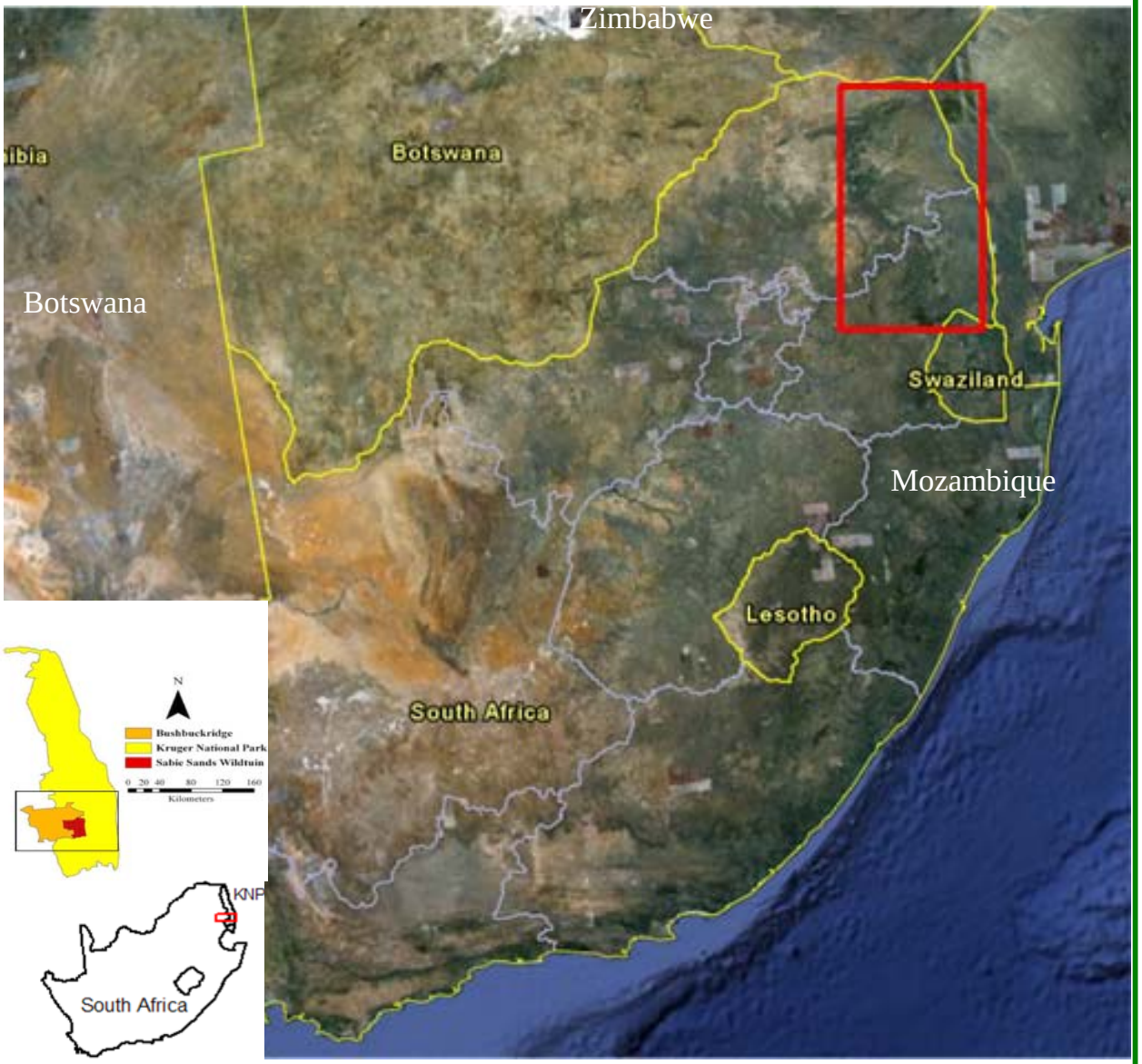
for SA environments

# Savannahs & woodlands in southern Africa

- Arid / semi-arid: 10-50% woody cover, < 60 woody T/ha ABG
- Mostly gradual changes: logging, encroachment
- Fine scale heterogeneity = remote sensing challenge
  - Woody plant size & cover (3-6 m, 10-40%)
  - Soil properties & water availability
  - Disturbance factors: fire, herbivore, human
- Woody plant: multi-stemmed clumps, high biomass in branches rather than in main stem

# Project area: Greater Kruger National Park, South Africa

- Dominant landscape = woodlands and savannahs, with plantations and remnants of indigenous forest
- Generally flat or gently undulated
- Ca. 60000 km2
- Dominant land uses: commercial plantations, private & public conservation areas, private rangelands (beef production), communal rangelands (subsistence use)
- Issues: biodiversity conservation, energy security (woodland thinning), bush encroachment



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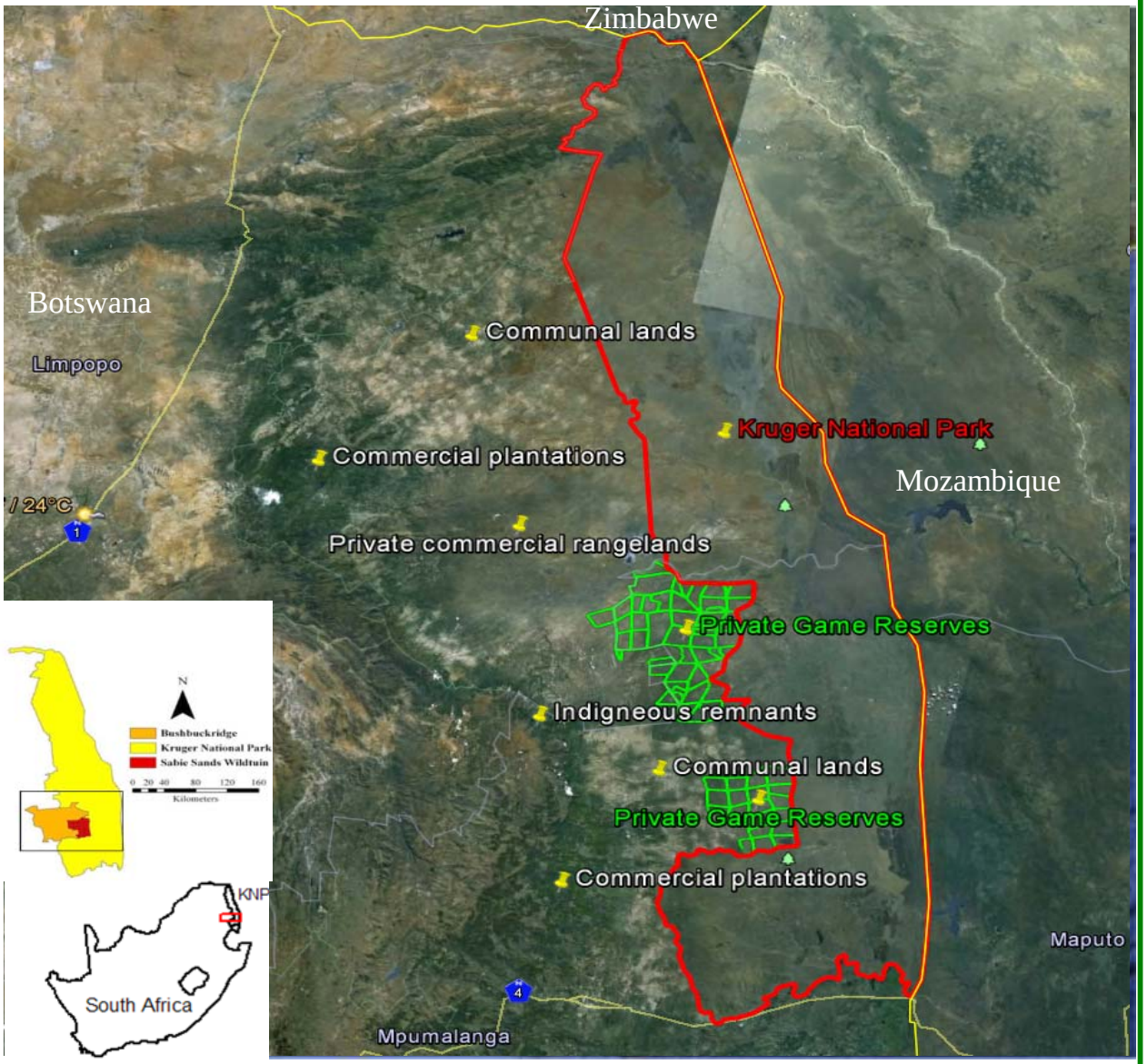

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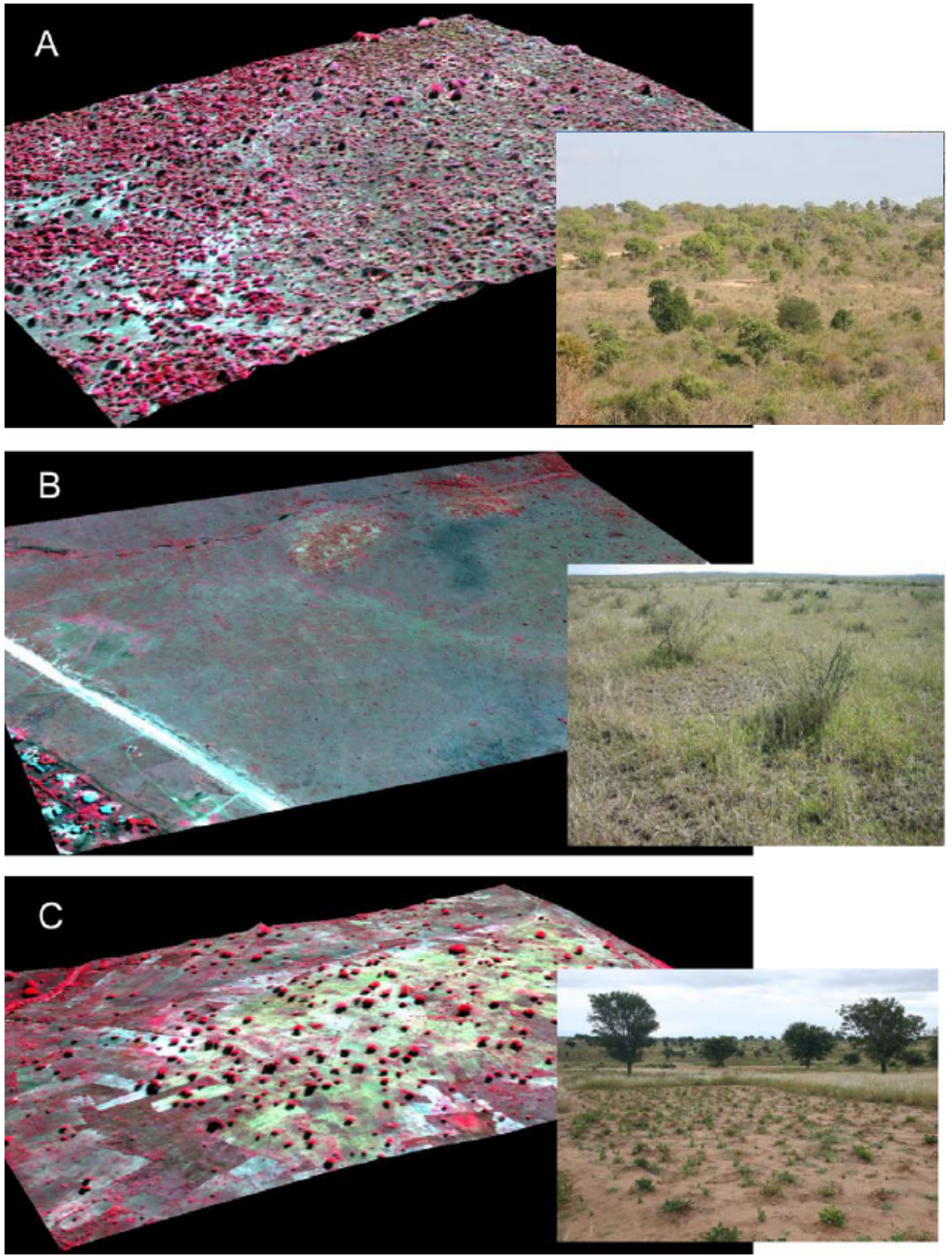
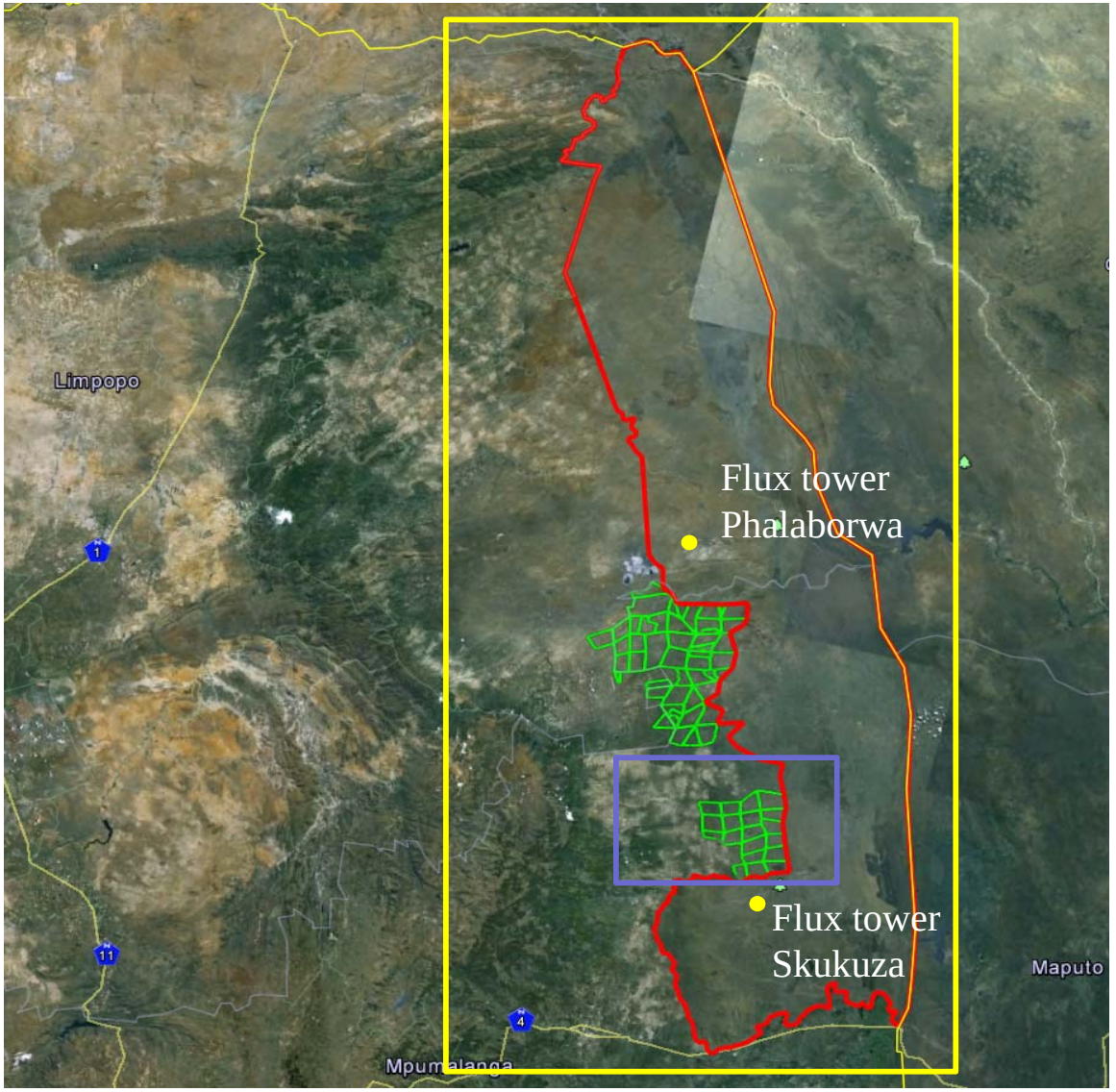


## Data currently available

- Ground
  - Woody cover (N= 37) and biomass plots (N= 152)
- Airborne
  - LiDAR 2008, 10 & 12 (Carnegie Airborne Observatory) – end wet season
- Satellite
  - SAR: Radarsat-2 (C-band), ALOS-1 PALSAR (L-band), TerraSAR-X (X-band)




High res SAR biomass / cover mapping

Medium res SAR biomass / cover mapping

## Data currently available

- Ground
  - Woody cover (N= 37) and biomass plots (N= 152)
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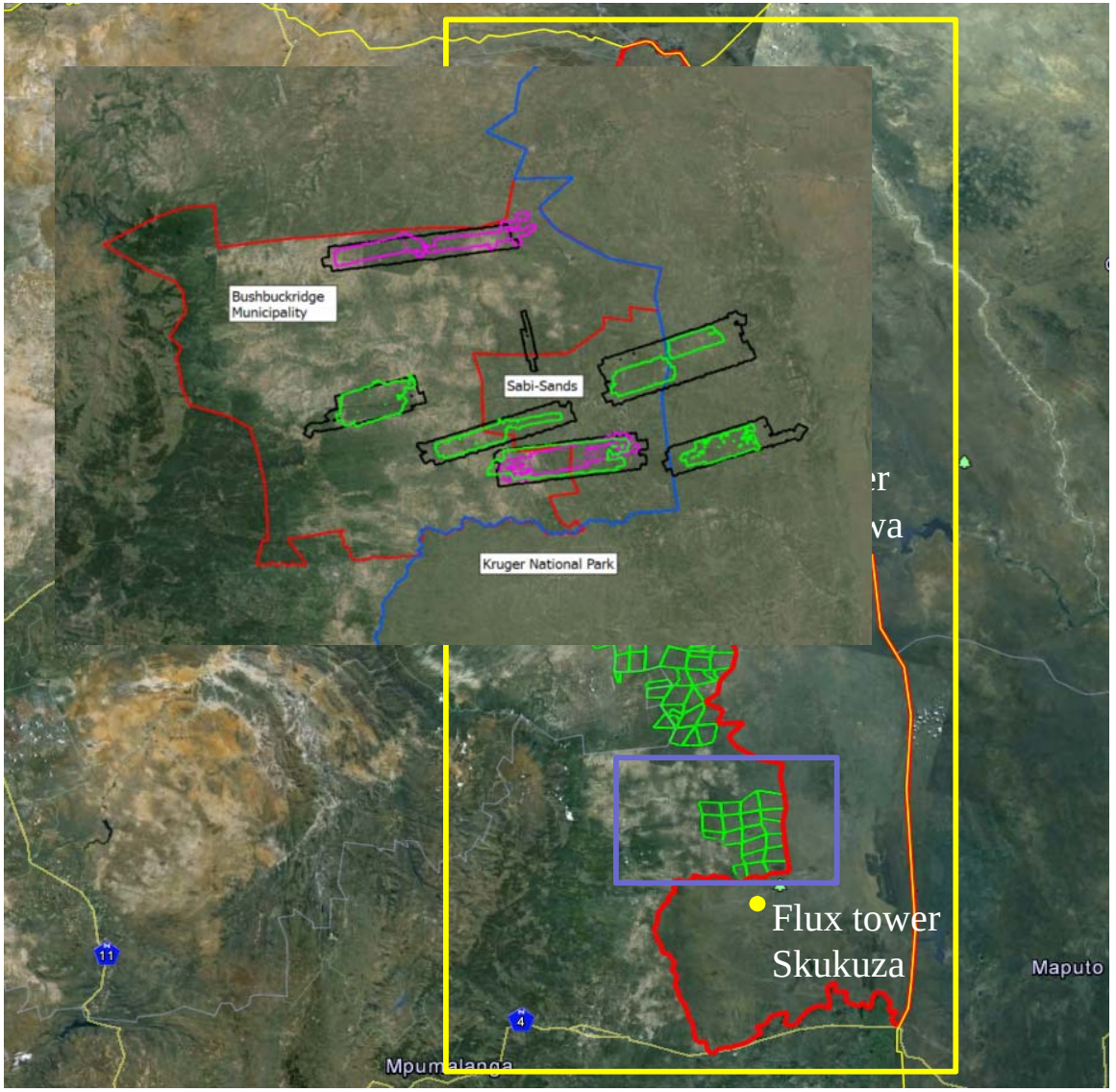



High res SAR biomass / cover mapping

Medium res SAR biomass / cover mapping

# Project objectives and schedule

- General objective: assess and develop “affordable” methods to predict woody cover and biomass in southern African woodlands and savannahs using SAR imagery
- Secondary objectives:
  - Investigate the potential of combining multiple SAR frequencies (L-band ALOS PalSAR, C-band Radarsat-2, X-band TerraSAR-X)
  - Optical / SAR “fusion”
  - Investigate full polarimetric ALOS PalSAR / RADARSAT-2 imagery and polarimetric decompositions
  - Change detection of woody cover for complete Kruger National Park using ALOS PalSAR (2008-2010) and JERS-1 / Landsat (2000)

# Project objectives and schedule (cont)

- List the project milestones
  - Milestone 1 (11/2012): field & airborne LiDAR campaign
  - Milestone 2 (12/2012): LiDAR data processing
  - Milestone 3 (04/2013): SAR data acquisition, and SAR processing chains (including training and script development, i.e GAMMA)
  - Milestone 4 (09/2013): Assessment of multifrequency SAR for woody and biomass prediction
  - Milestone 5 (12/2013): Assessment of dual and full polarimetric ALOS PalSAR for woody and biomass prediction
  - Milestone 6 (02/2014): 2000 – 2010 change analysis over Kruger National Park

ALOS

K&C Initiative

An international science collaboration led by JAXA

Polarization and polarimetric decomposition

TerraSAR-X X-band (Winter 2012), RADARSAT-2 C-band (Winter 2009) & ALOS PALSAR L-band (Winter 2010)

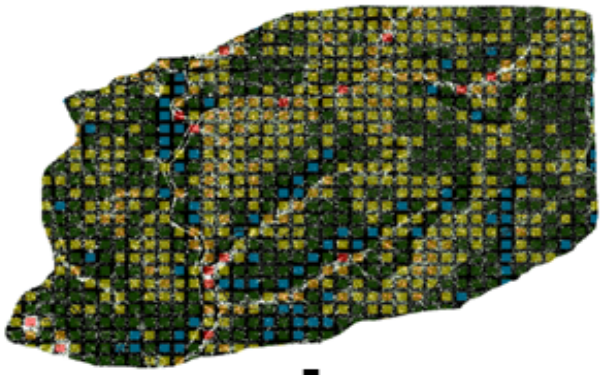
+

LiDAR (2012)

- Cover
- Canopy volume
- AG biomass

Field Cal/VAL

Access best scale for data integration



Extract mean values from 105m grid cells

TerraSAR-X + RADARSAT + ALOS PALSAR + LiDAR integrated variable dataset (at 105m cell size)

Independent variables

**Scenario**
Polarization
Season
Frequency

Applied to Data mining, regression and machine learning algorithms (in WEKA 3.6.9 & R rattle software)

Dependent variable

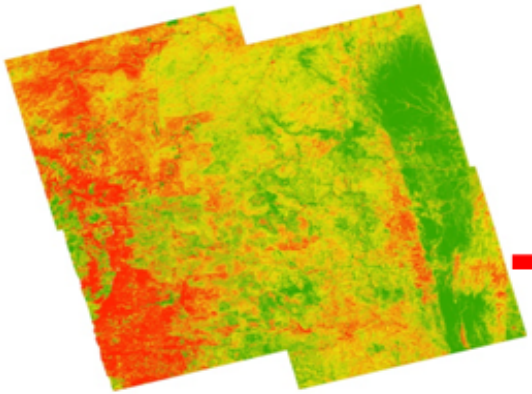
- Cover
- Canopy volume
- AG biomass

R2

RMSE

SAR woody structural parameter maps

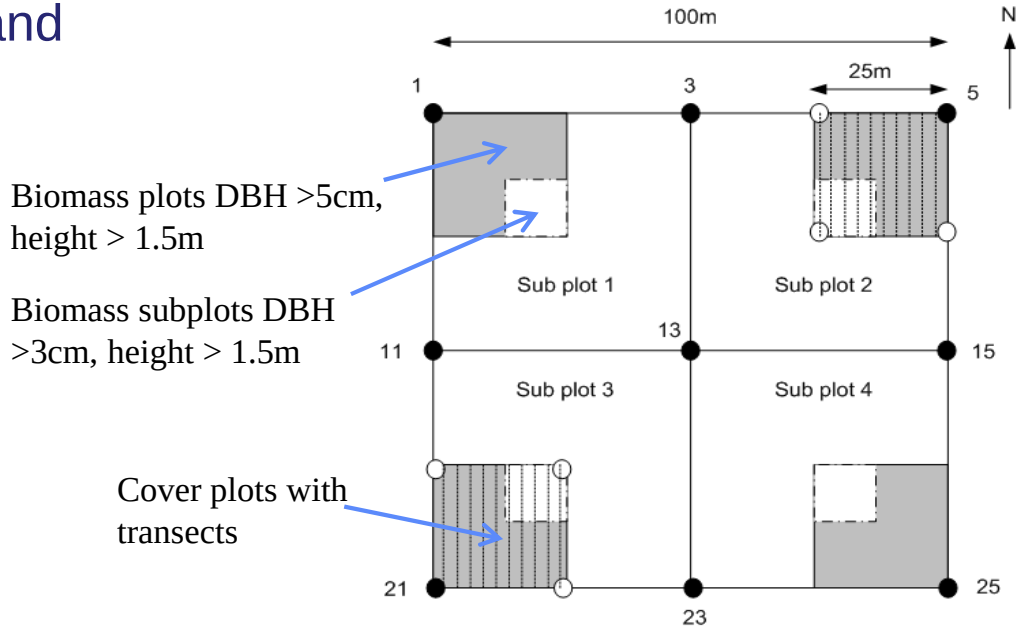
- Combined model
- X-band model
- C-band model
- L-band model



LiDAR – SAR Error Assessment (stats + spatial)

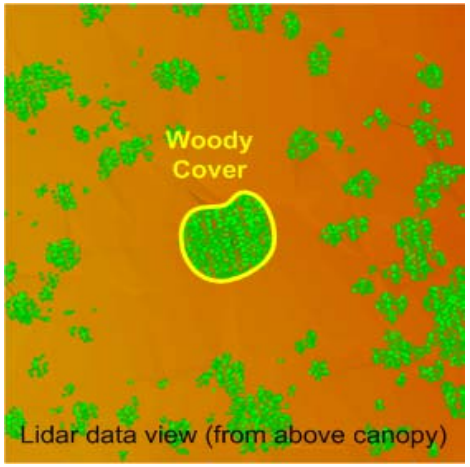
# Field data collection

- Field data
  - 37 sites with clustered plots (min 50m apart, autocorrelation determined via geostatistics on LiDAR)
  - Biomass
    - DBH, height, species
  - Woody cover using transect and point intercept methods

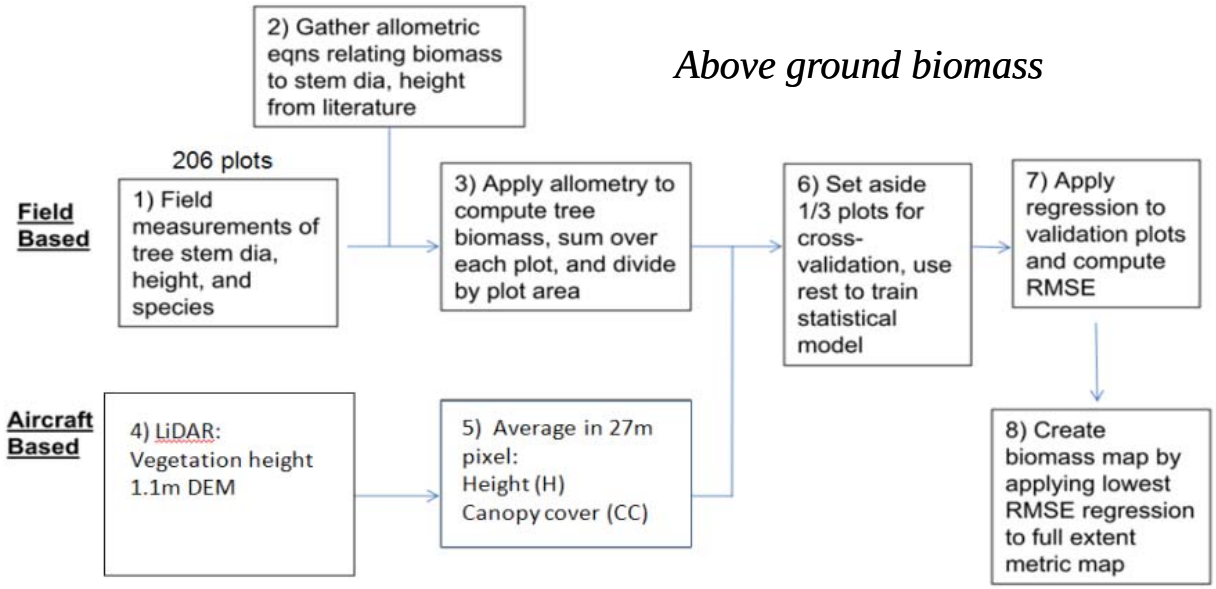



# LiDAR-based structural variables

- Woody cover: area vertically projected on a horizontal plane (%)
- Canopy volume: approximated from integration of vertical profile of laser hits
- Biomass: Linear model between field AGB and LiDAR woody cover and height metrics

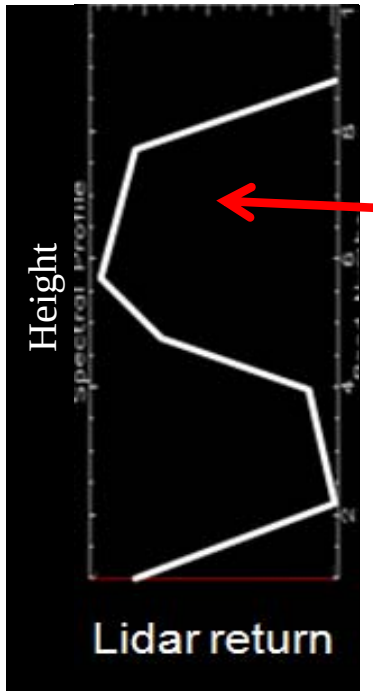


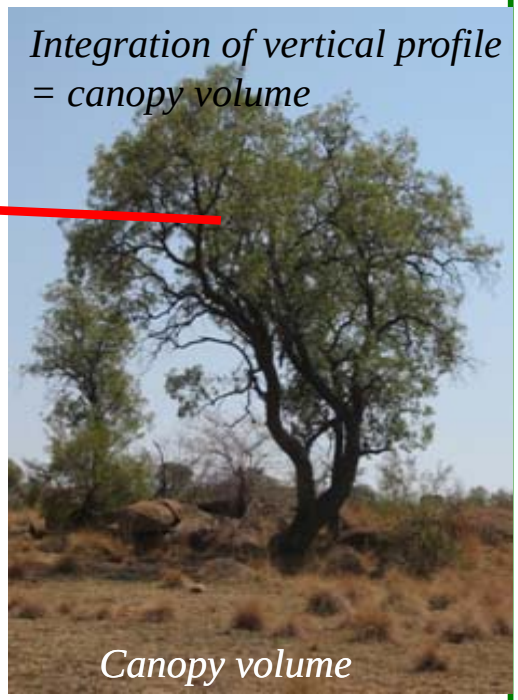

*Woody cover*




*Above ground biomass*

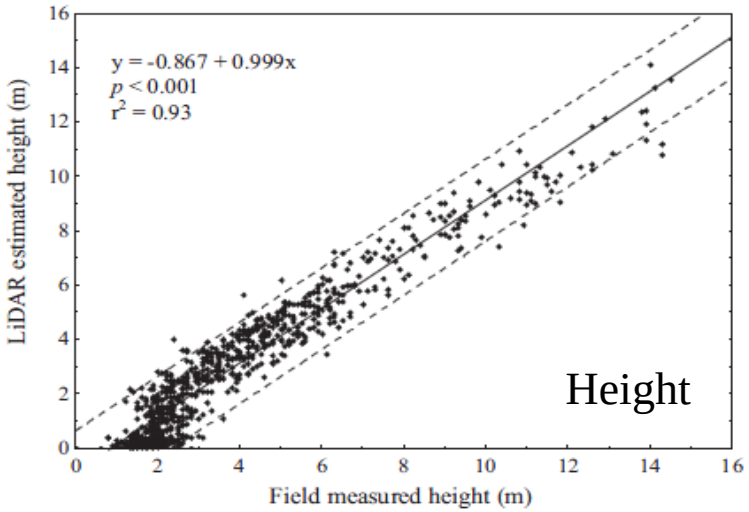
*Methods after Colgan et al, 2012, Biogeosci. Disc*

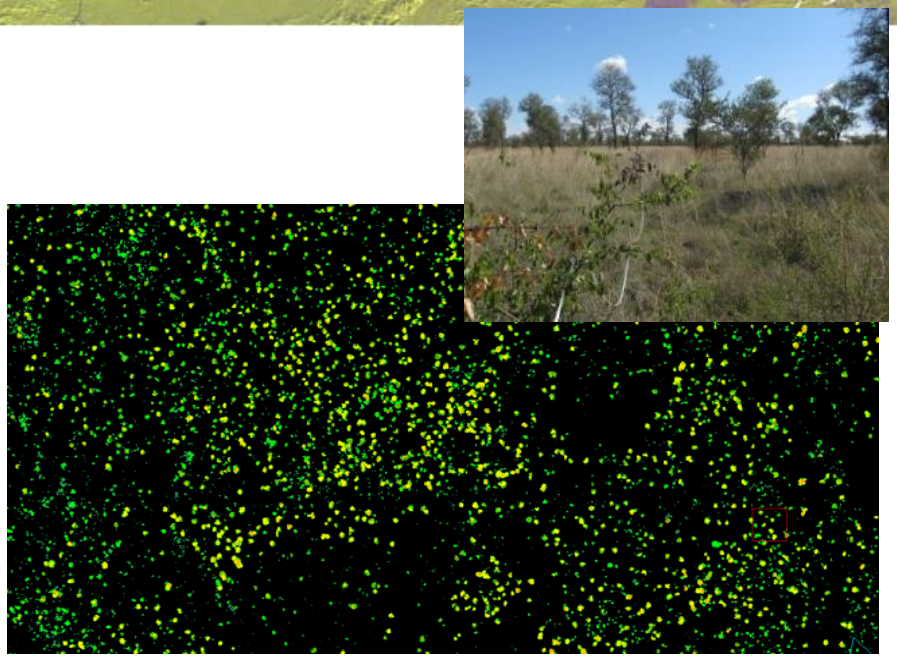


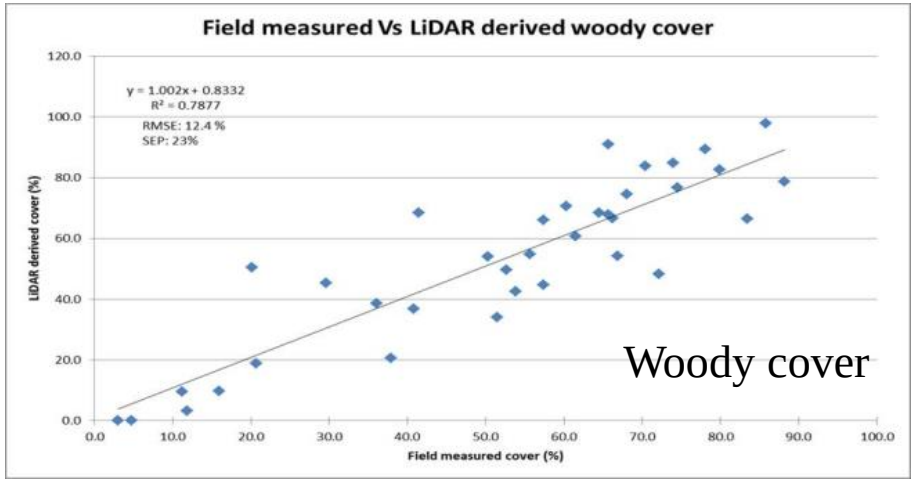



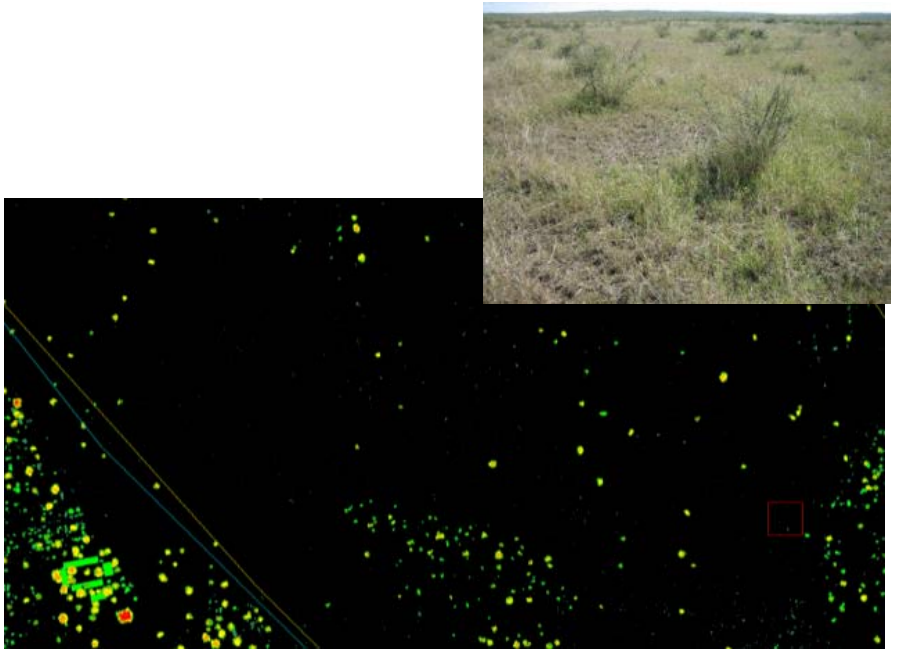
# LiDAR-based cal/cal: height and cover

LiDAR metric



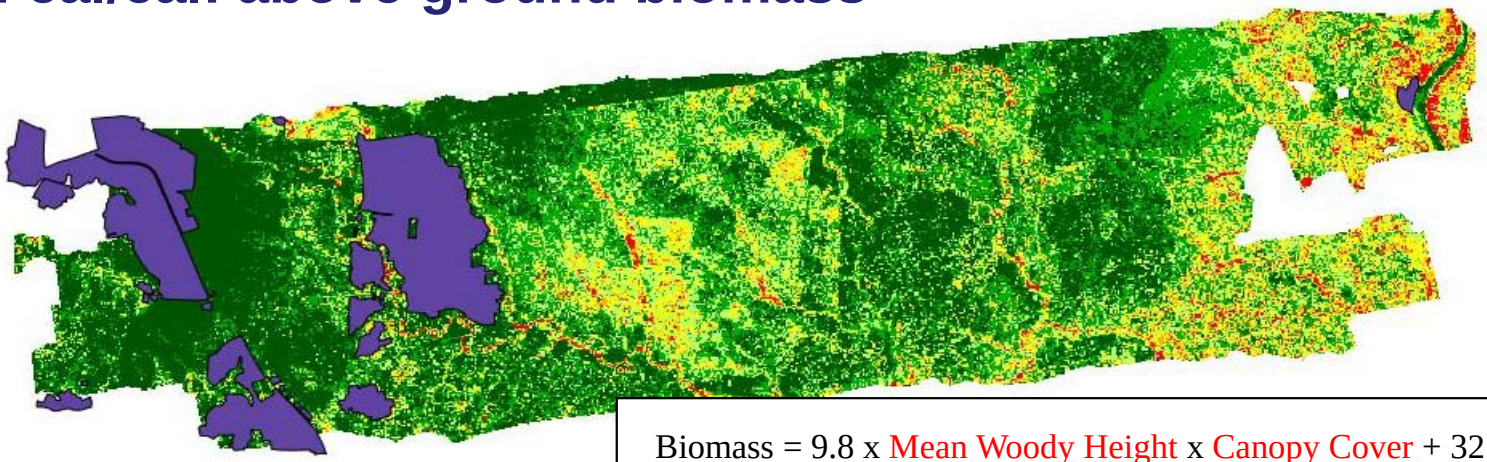





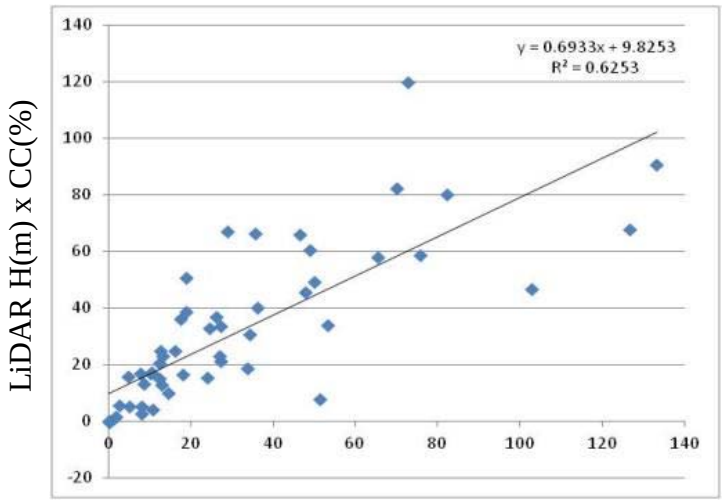



Field metric

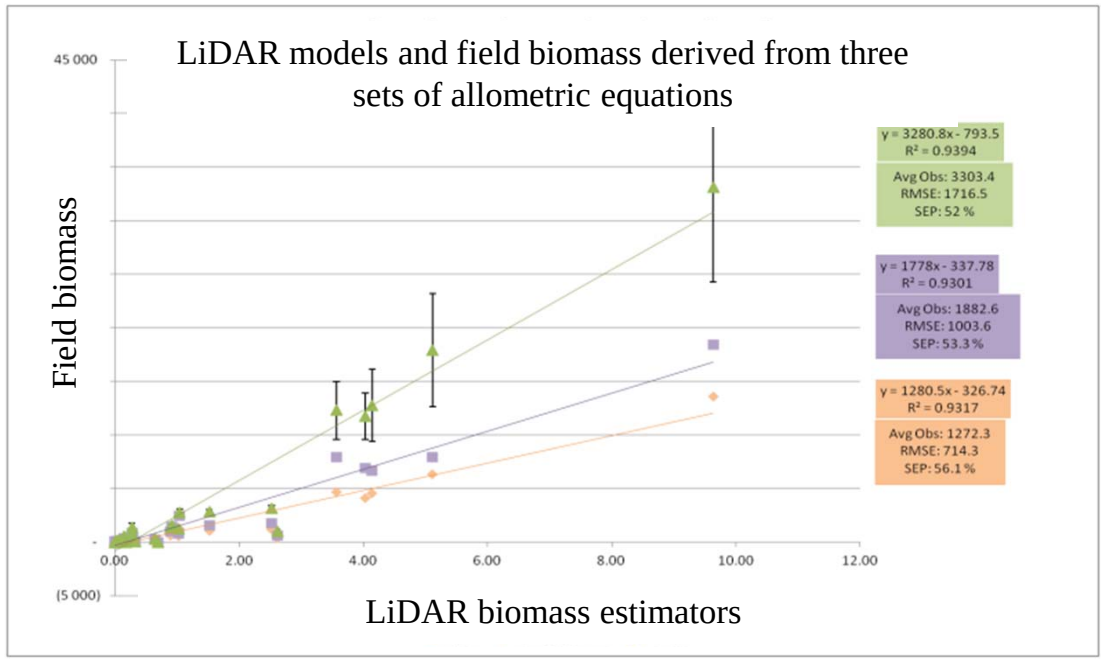
# LiDAR-based cal/cal: above ground biomass

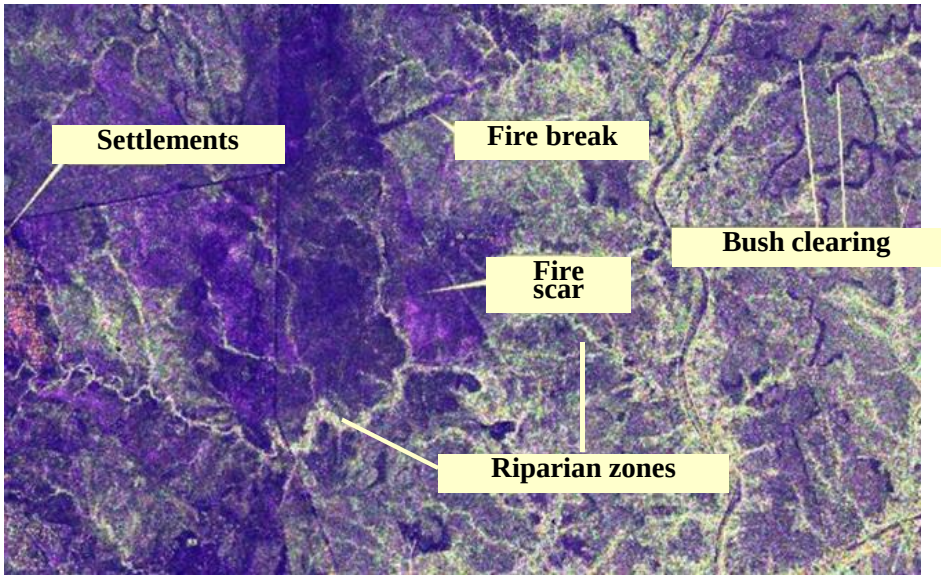
Biomass = 9.8 x Mean Woody Height x Canopy Cover + 32



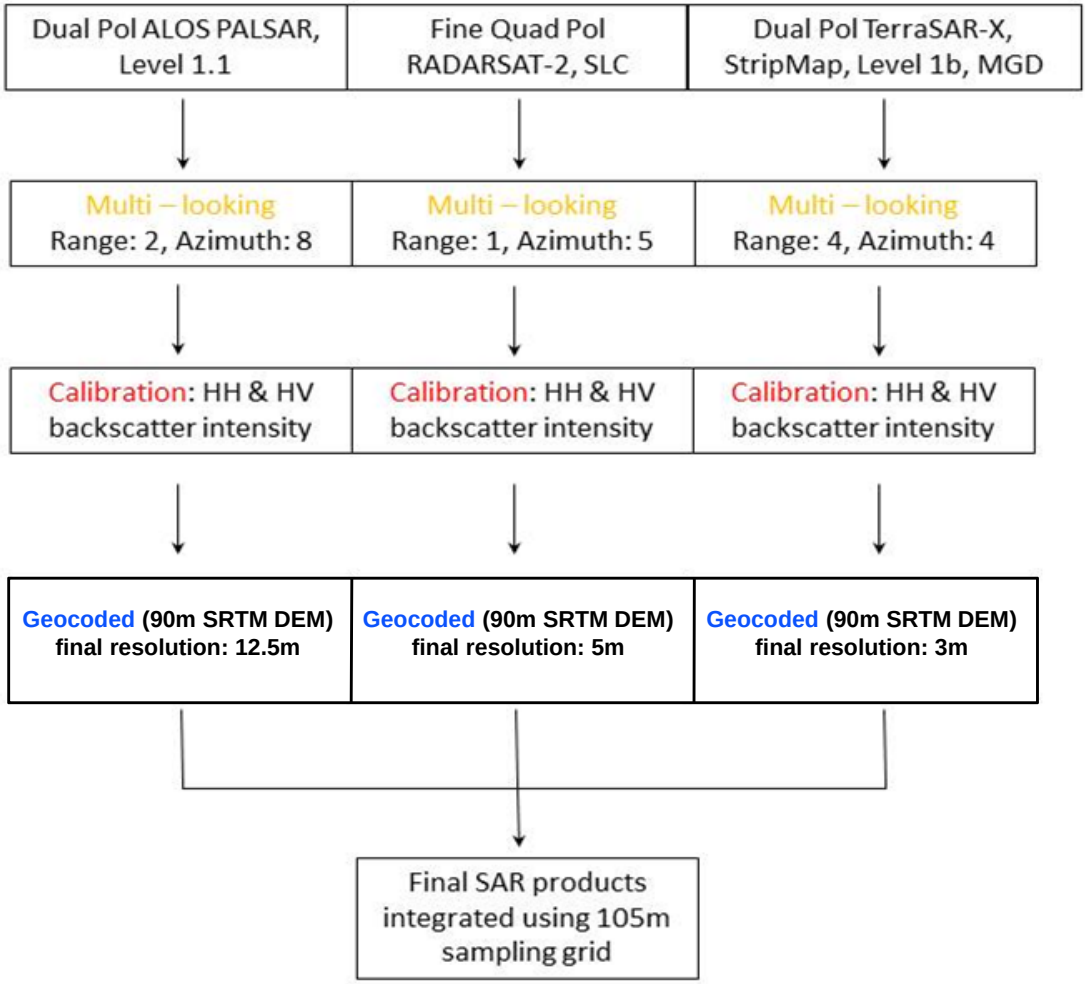

Field biomass (25x25m plots)



# SAR processing




Radarsat-2 image , dry season



ALOS

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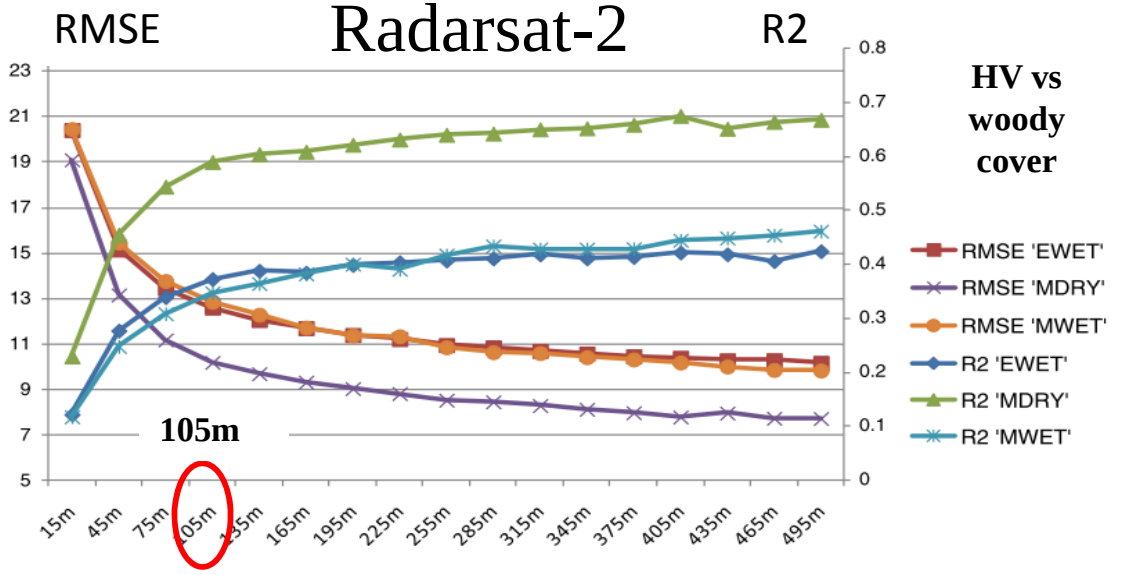
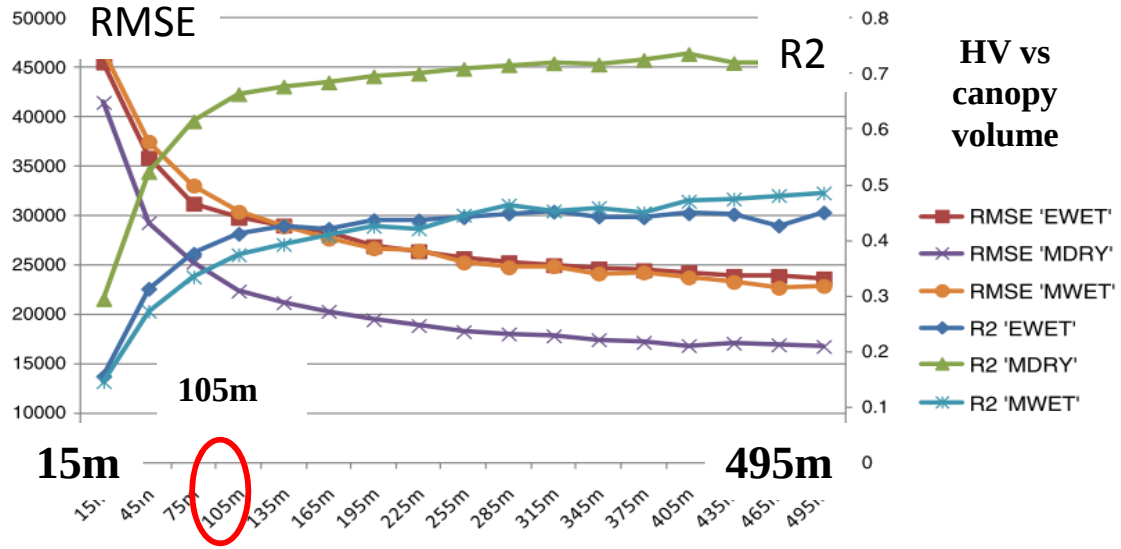
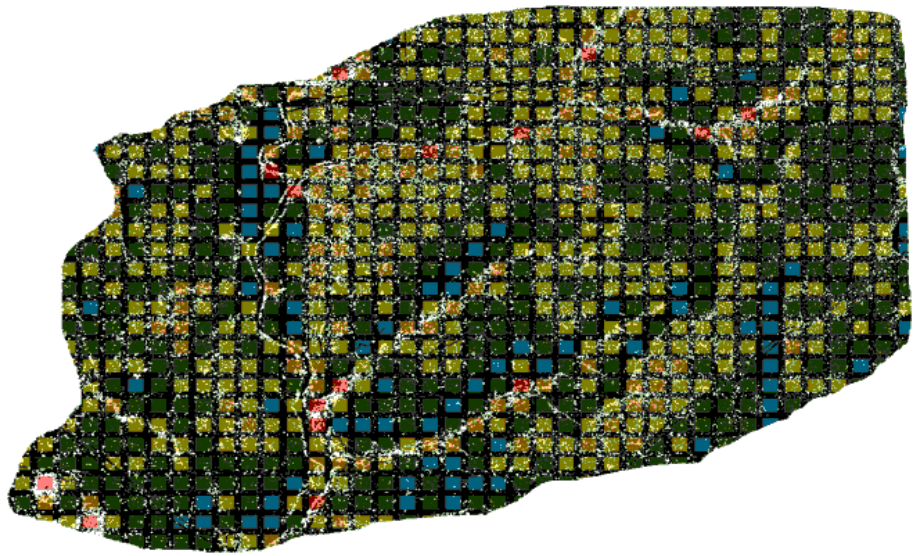


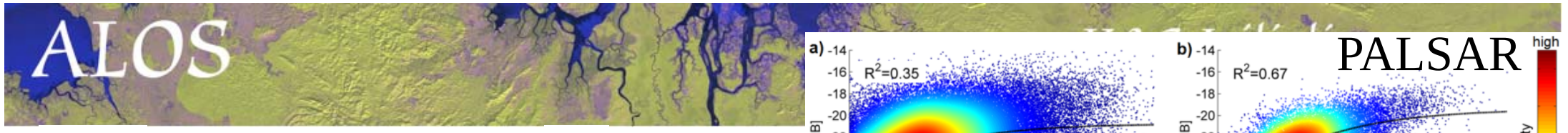

**Effect of size of sampling blocks on relationships between LiDAR metrics cover and Radarsat-2 C-HV bands**

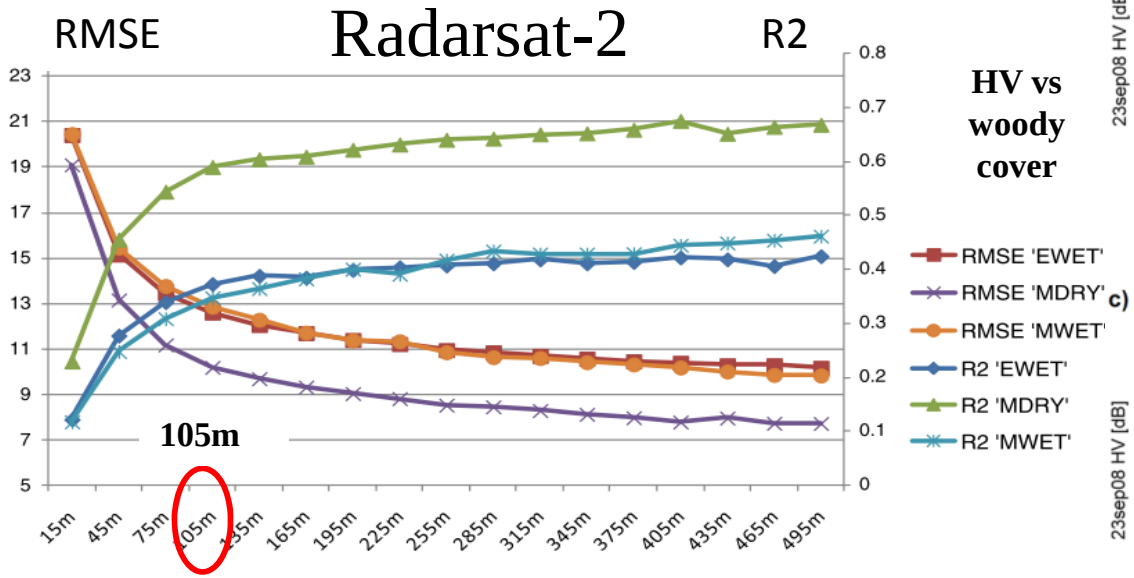


Sampling blocks overlaid on the LiDAR canopy height model, blue to red, increasing woody canopy cover

## Scale of SAR / LiDAR integration

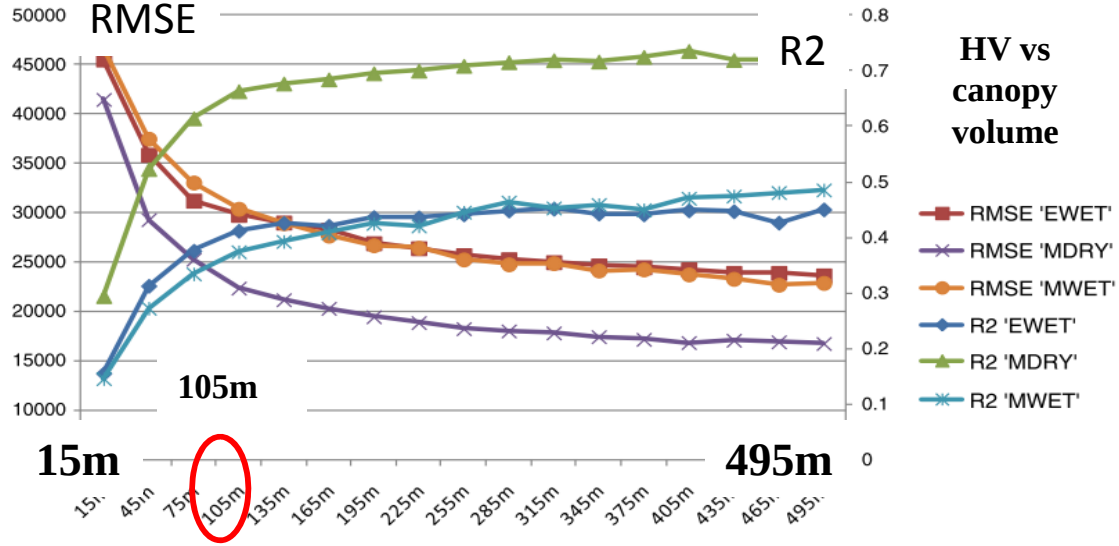
- Inherent SAR noise: speckle
- Savannah heterogeneity
- Geolocation issues
- Best trade-off mapping details, model performance around 100 m, average size on landscape units along catena




**HV vs woody cover**

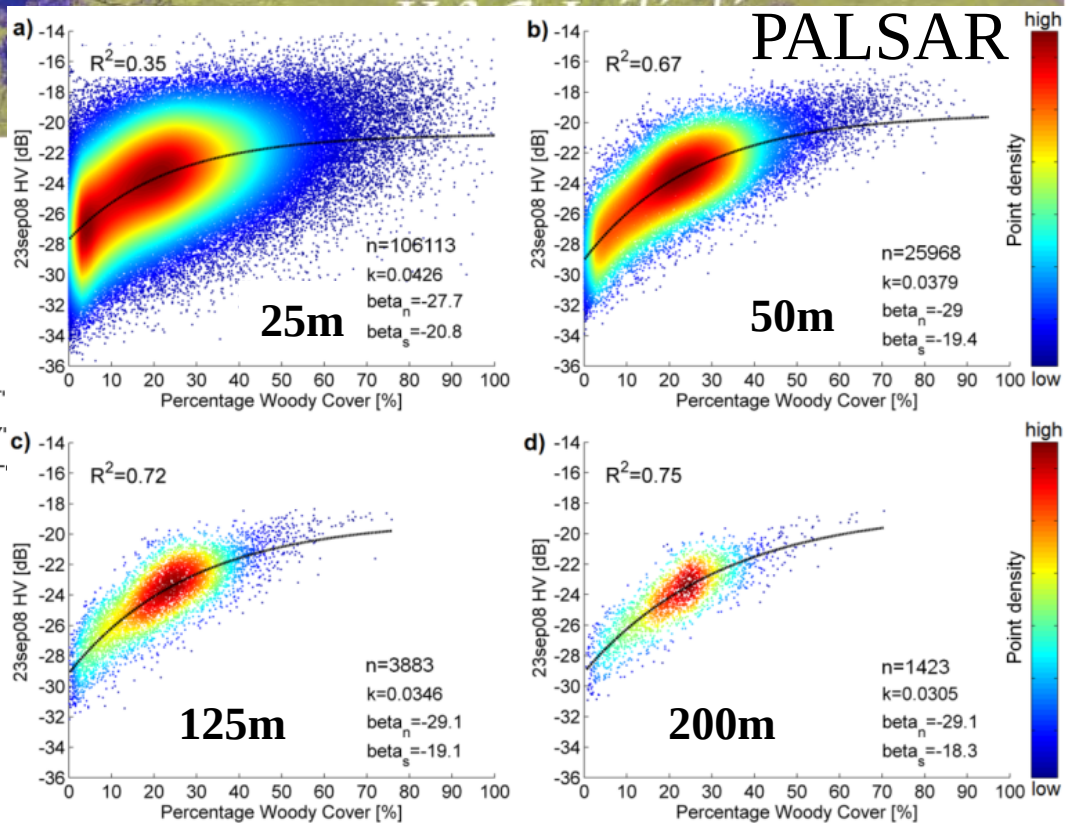
RMSE 'EWET'
RMSE 'MDRY'
RMSE 'MWET'
R2 'EWET'
R2 'MDRY'
R2 'MWET'




**HV vs canopy volume**

RMSE 'EWET'
RMSE 'MDRY'
RMSE 'MWET'
R2 'EWET'
R2 'MDRY'
R2 'MWET'

**Effect of size of sampling blocks on relationships between LiDAR metrics cover and Radarsat-2 C-HV bands**

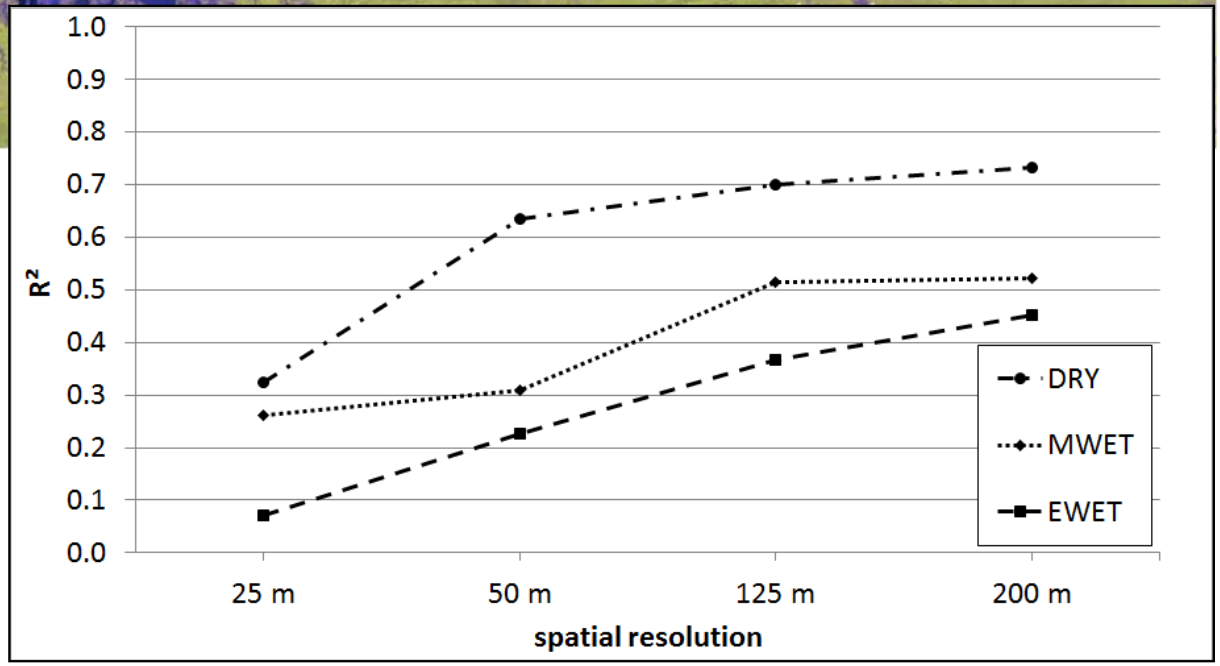



## Scale of SAR / LiDAR integration

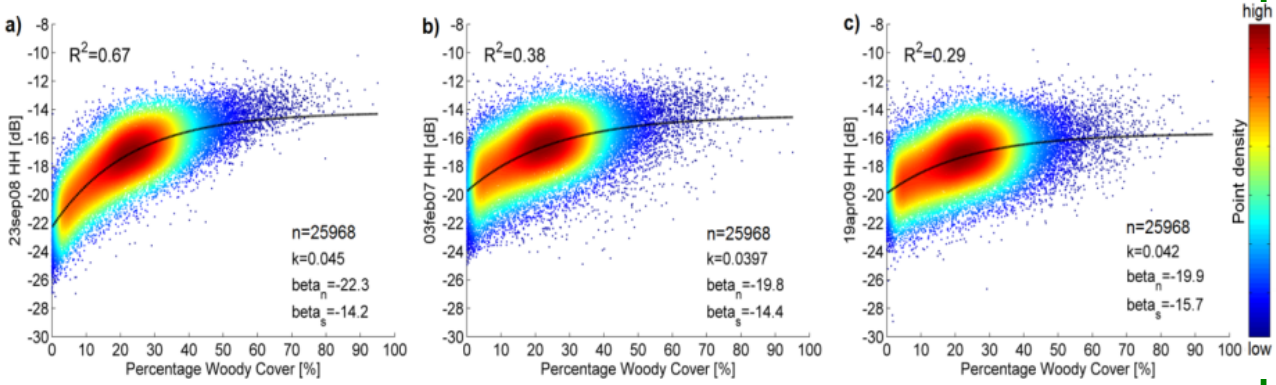
- Inherent SAR noise: speckle
- Savannah heterogeneity
- Geolocation issues
- Best trade-off mapping details, model performance around 100 m, average size on landscape units along catena

## Season

- Strong change of vegetation condition – water balance with season and phenology
  - Middle Wet (Summer) – grass green and woody leaf-on
  - End of Wet (Autumn) – grass dry and woody leaf-on
  - Dry (Winter) – grass dry and woody leaf-off
  - Early Wet (Spring) – grass dry and woody leaf-on
- Best is dry season, than middle wet, and end of wet (early wet?)
  - Low moisture effect, higher penetration (high frequency)
- Similar pattern for L- and C-band




Mean $R^2$ between PALSAR HH backscatter intensity and LiDAR-based woody cover at four aggregation levels (DRY dry season; EWET end of wet season; MWET middle of wet season)




DRY MWET EWET

## Polarization

- HV > HH >>> VV
- HV and HH similar with leaf off (dry season)
- Polarimetric decomposition: Freeman-Durden, Van Zyl (double bounce, single bounce, volume) Cloude-Pottier (entropy H, anisotropy A, alpha angle $\alpha$)
- Volume = or < to HV
- Similar pattern for L- and C-band

| | | 25 m | 50 m | 125 m | 200 m |
|---|---|---|---|---|---|
| DRY | Mean (HH DRY) | 0.32 | 0.63 | 0.69 | 0.73 |
| | Mean (HV DRY) | 0.34 | 0.64 | 0.69 | 0.72 |
| | | | | | |
| MWET | Mean (HH MWET) | 0.26 | 0.30 | 0.51 | 0.52 |
| | | | | | |
| EWET | Mean (HH EWET) | 0.07 | 0.22 | 0.36 | 0.45 |
| | Mean (VV EWET) | 0.04 | 0.14 | 0.27 | 0.35 |
| | Mean (HV EWET) | 0.12 | 0.34 | 0.51 | 0.60 |
| | Mean (VH EWET) | 0.10 | 0.30 | 0.47 | 0.57 |
| | | | | | |
| EWET | Mean (Freeman Vol) | 0.21 | 0.42 | 0.52 | 0.61 |
| | Mean (VanZyl Vol) | 0.21 | 0.42 | 0.52 | 0.61 |

# Model assessment

| Algorithm | Algorithm type | Algorithm Description |
|---|---|---|
| **Linear Regression** | Parametric & linear | Utilises linear regression for prediction. and is able to deal with weighted instances. |
| **SMO Regression** | Non-parametric & non-linear | Implements a support vector machine for regression. |
| **Decision Tree** | Non-parametric & non-linear | Uses a recursive partitioning approach to split data into 'branches' of common parameter attributes |
| **Artificial Neural Network** | Non-parametric & non-linear | Utilises multiple layers of neurons connected to each other which feed the data through the network |
| **Random Forest** | Non-parametric & non-linear | Utilises an ensemble of un-pruned decision trees which votes on the best decision tree design based on plurality |

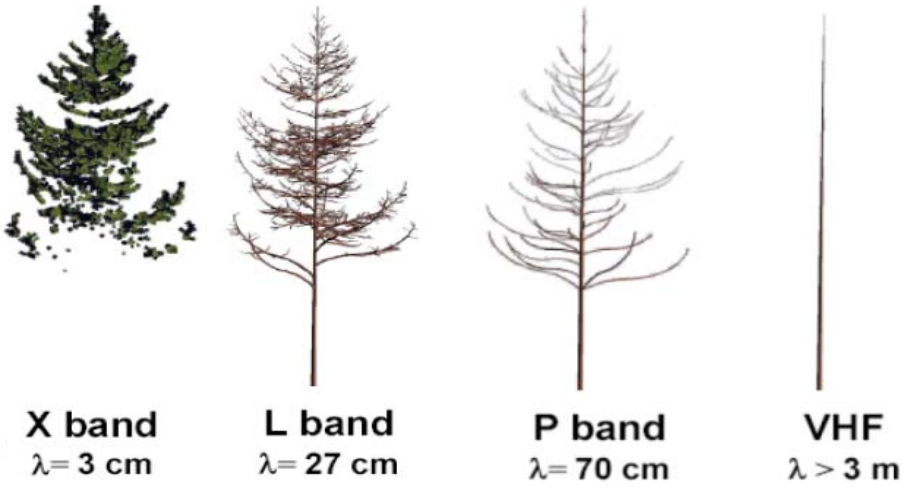
Tested on C-, and L-band and combination

RF generally the best, but not a huge improvement

C-, L- and C+L Band TCC (%) Modelling Results *[35% Training; 65% Validation]*

| Algorithm | Algorithm type | C-band only | | L-band only | | C+L band | |
|---|---|---|---|---|---|---|---|
| | | $R^2$ | RMSE | $R^2$ | RMSE | $R^2$ | RMSE |
| Linear Regression | Parametric & linear | 0.72 | 12.42 | 0.81 | 10.36 | 0.83 | 9.91 |
| SMO Regression | Non-parametric & non-linear | 0.72 | 12.61 | 0.82 | 10.61 | 0.83 | 10.05 |
| Decision Tree | Non-parametric & non-linear | 0.73 | 12.09 | 0.82 | 10.18 | 0.83 | 10 |
| ANN | Non-parametric & non-linear | 0.76 | 11.55 | 0.83 | 9.96 | 0.83 | 9.91 |
| Random Forest | Non-parametric & non-linear | 0.75 | 11.82 | 0.83 | 9.89 | 0.86 | 8.96 |

- Multi-frequency: hypothesis long vs. shorther SAR wavelenghts
  - C-band saturation occurs at higher biomass level in savannas (Lucas et al. 2006)
  - Savannas woody structure (low density) favours increased wave penetration, better for C-band?
  - Expected free C-band access with Sentinel-1



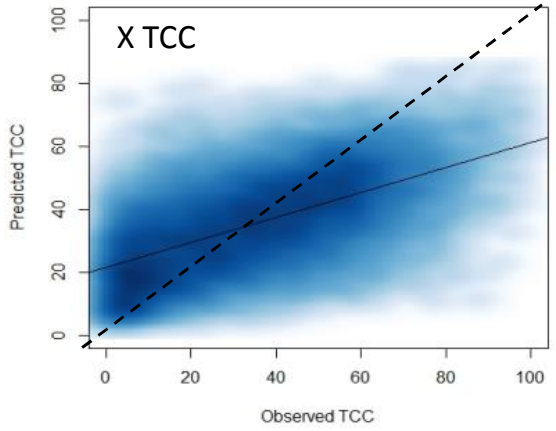
# Multi-frequency assessment

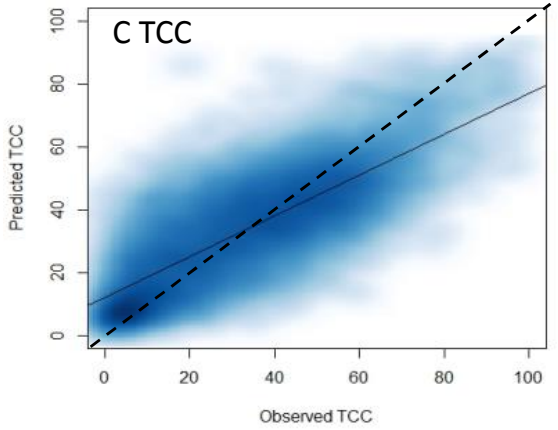
- Assess various scenario with winter HH/HV polarization, RF model
  - Single frequency (e.g. C band)
  - Dual frequency (e.g. C and L bands)
  - Tri frequency (X, C, and L bands
- Best single L>>C>>>X, X gave poor results
- X, C, L combination gave systematically best result
- Improvement needs to consider costs of multiple datasets
- Structural metric canopy volume>biomass>woody cover

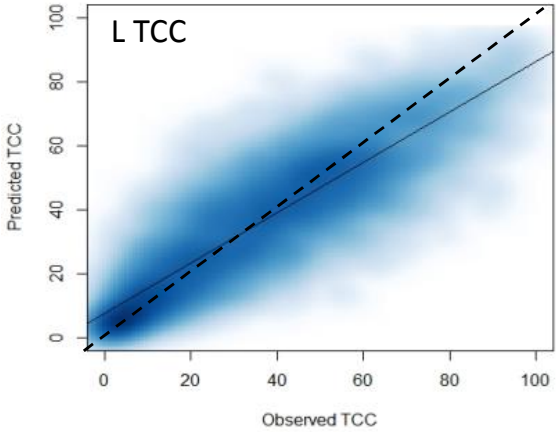
| CC Model Validation Results *[split into 35% Training & 65% Validation]; Units = %* | | | | | |
|---|---|---|---|---|---|
| **X-band only** | | **C-band only** | | **L-band only** | |
| **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** |
| 0.34 | 18.12 (50.87%) | 0.61 | 13.20 (38.50%) | 0.77 | 10.59 (29.64%) |
| **X+C band** | | **X+L band** | | **C+L band** | |
| **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** |
| 0.69 | 11.71 (33.94%) | 0.80 | 9.90 (27.78%) | 0.81 | 9.23 (26.94%) |
| | | **X+C+L band** | | | |
| | | **$R^2$** | **RMSE (SEP)** | | |
| | | 0.83 | 8.76 (25.40%) | | |

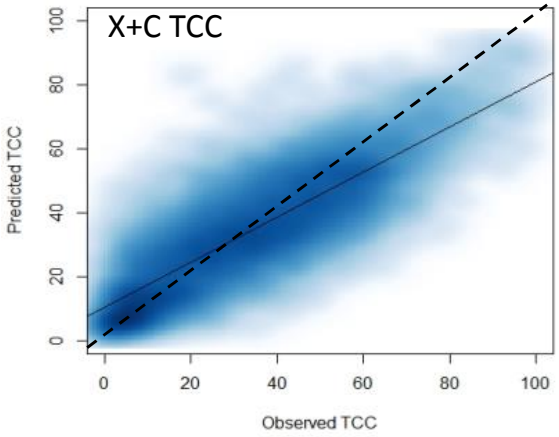
| TCV Model Validation Results *[split into 35% Training & 65% Validation]; Units = unitless per hectare* | | | | | |
|---|---|---|---|---|---|
| **X-band only** | | **C-band only** | | **L-band only** | |
| **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** |
| 0.35 | 35534.50 (33.79%) | 0.66 | 24731.06 (24.07%) | 0.79 | 19902.79 (18.88%) |
| **X+C band** | | **X+L band** | | **C+L band** | |
| **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** |
| 0.72 | 22243.64 (21.59%) | 0.82 | 18609.04 (17.70%) | 0.83 | 17236.50 (16.77%) |
| | | **X+C+L band** | | | |
| | | **$R^2$** | **RMSE (SEP)** | | |
| | | 0.85 | 16443.57 (15.96%) | | |

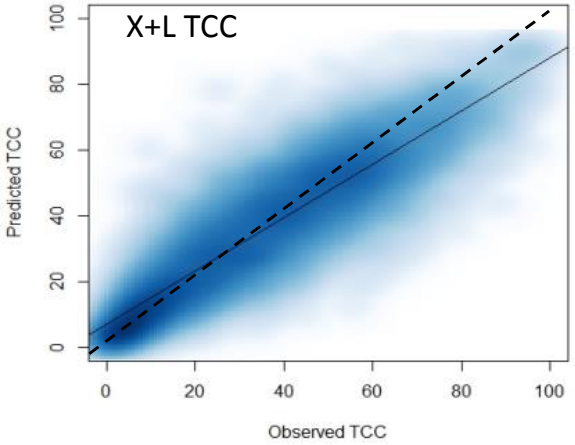
| AGB Model Validation Results *[split into 35% Training & 65% Validation]; Units = tonnes/ha* | | | | | |
|---|---|---|---|---|---|
| **X-band only** | | **C-band only** | | **L-band only** | |
| **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** |
| 0.32 | 10.88 (59.82%) | 0.60 | 7.81 (43.66%) | 0.78 | 6.05 (32.90%) |
| **X+C band** | | **X+L band** | | **C+L band** | |
| **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** | **$R^2$** | **RMSE (SEP)** |
| 0.67 | 7.19 (40.33%) | 0.81 | 5.70 (31.35%) | 0.81 | 5.45 (30.44%) |
| | | **X+C+L band** | | | |
| | | **$R^2$** | **RMSE (SEP)** | | |
| | | 0.83 | 5.20 (29.18%) | | |

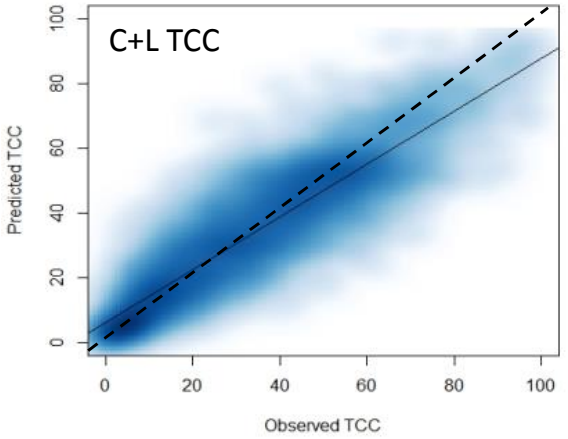


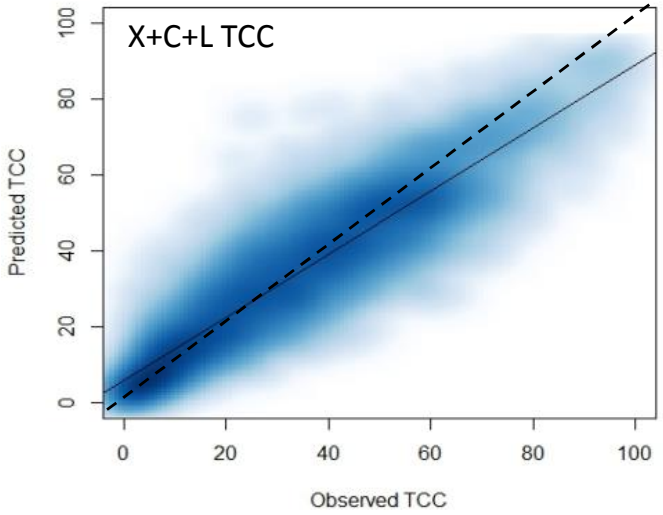



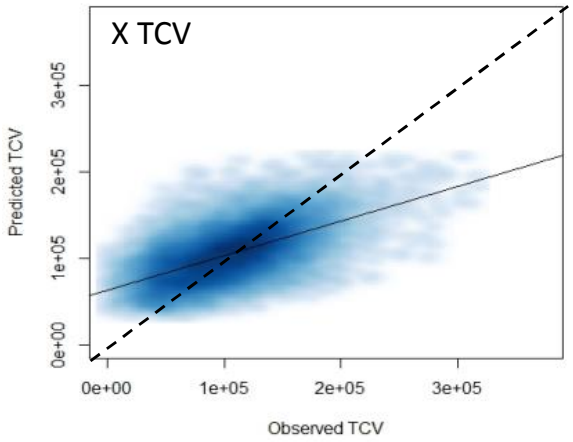



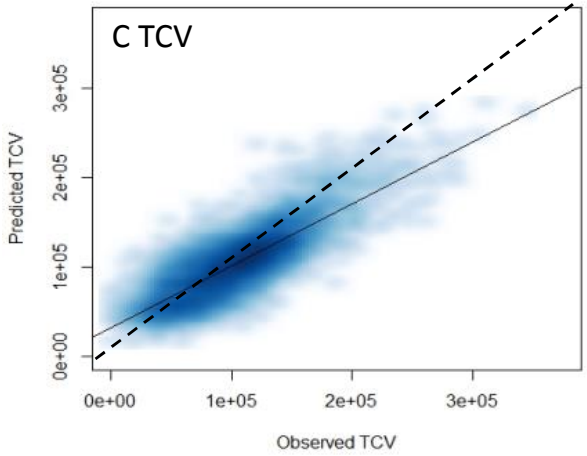



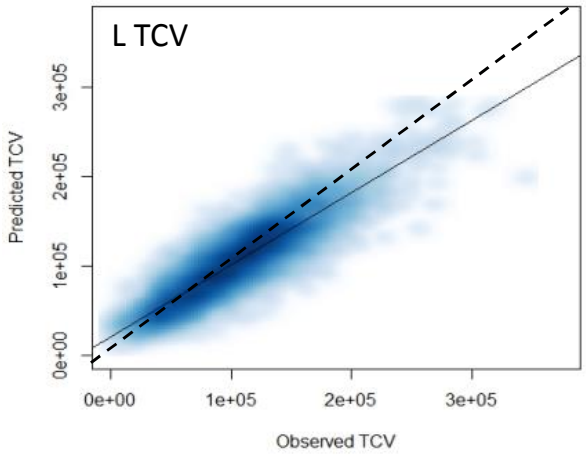

Validation of woody cover model

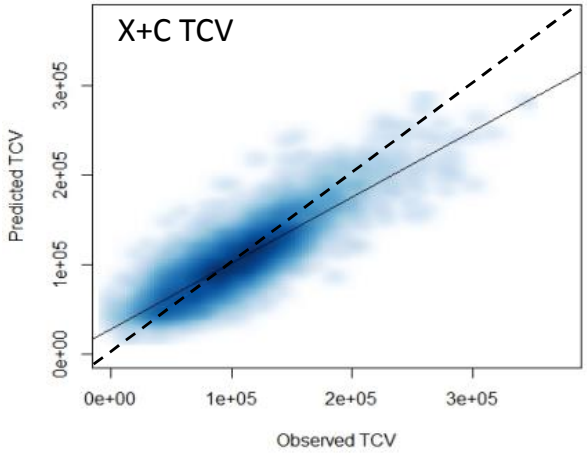
From short to longest wavelength and addition of bands tend to decrease over estimation and underestimation at low and high density

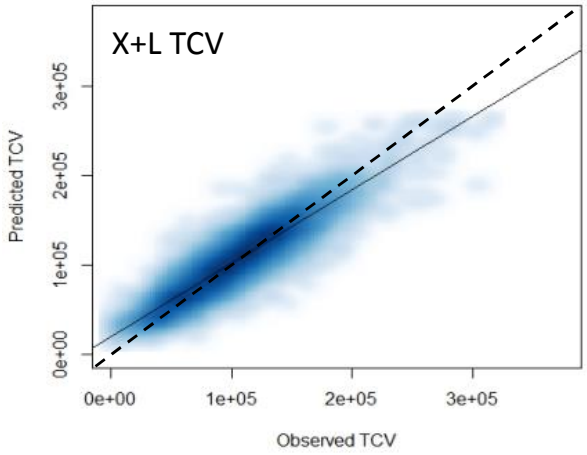
Validation of canopy volume model

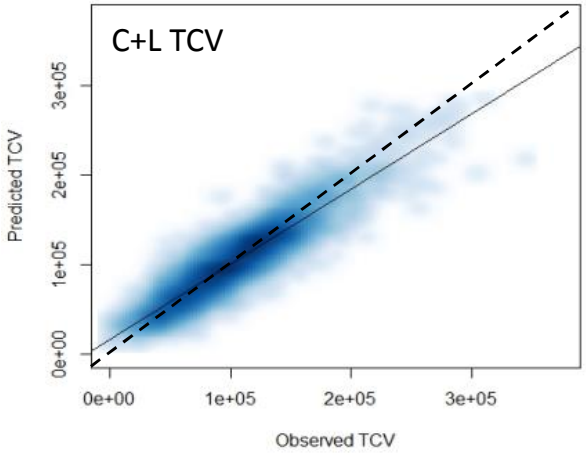


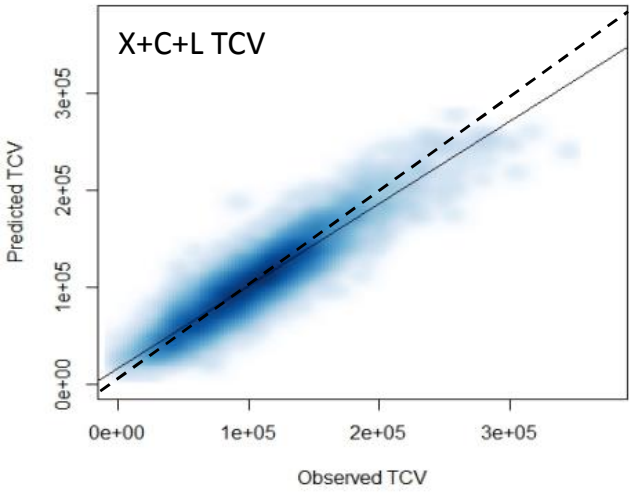



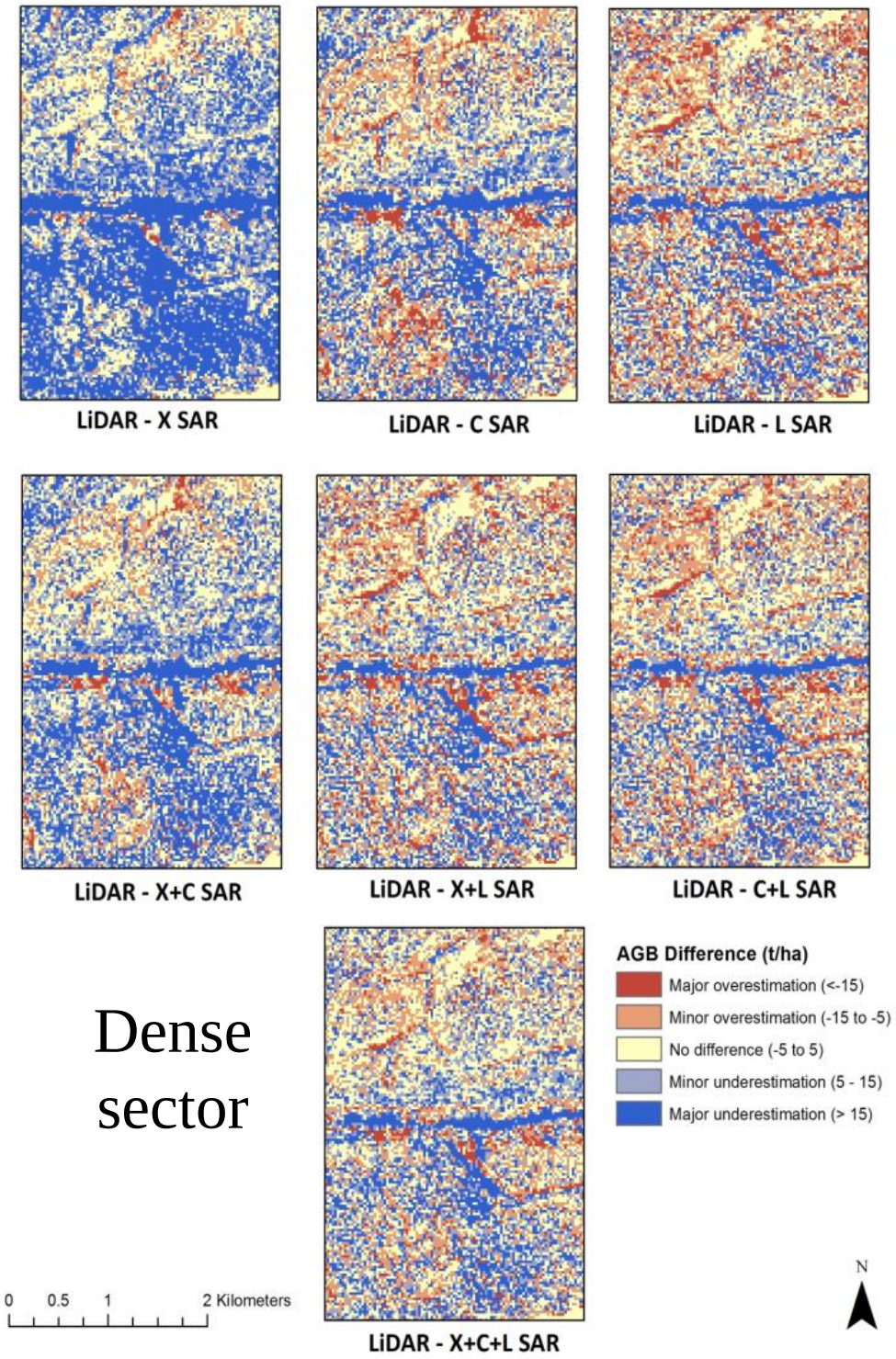



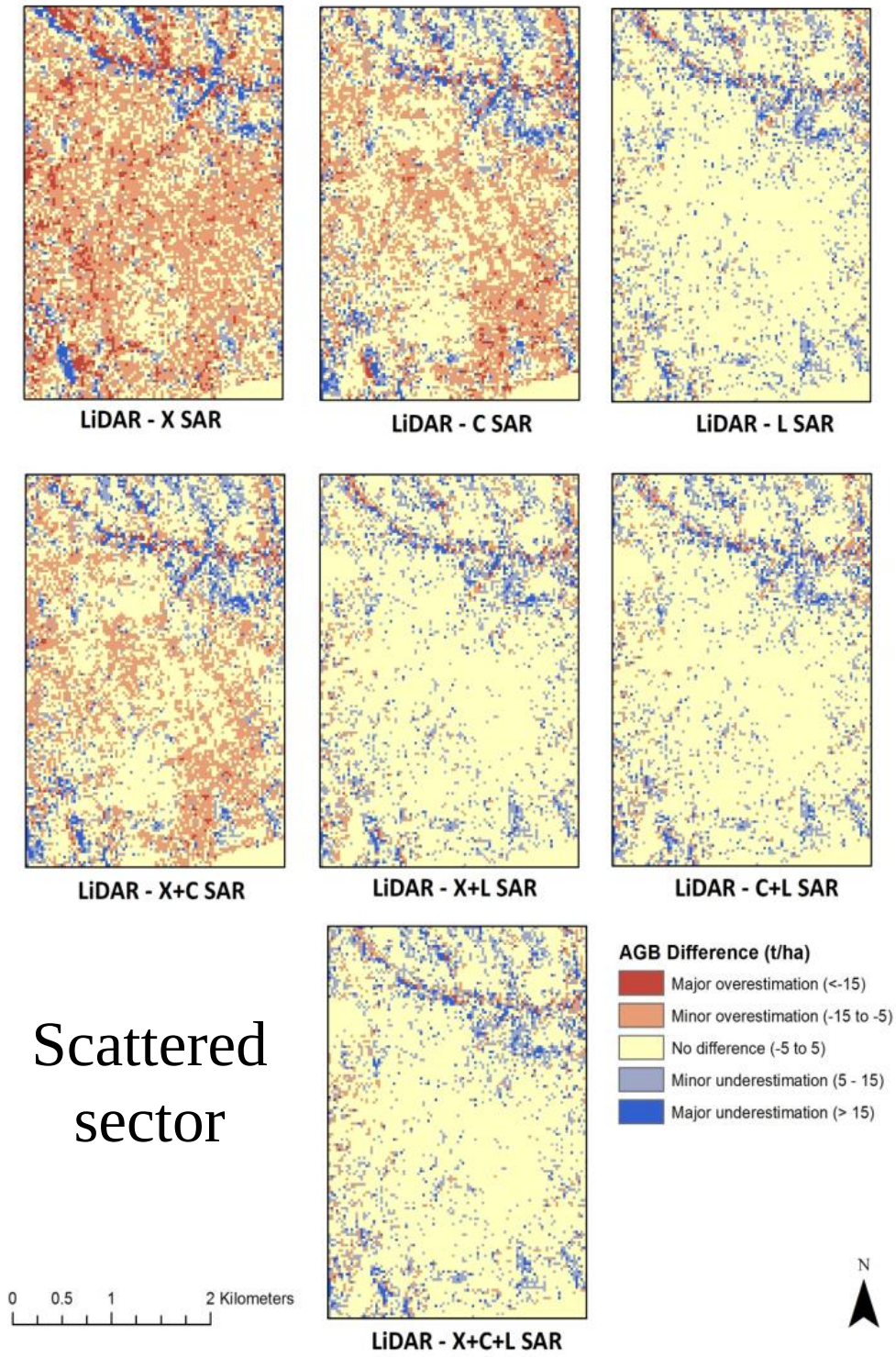



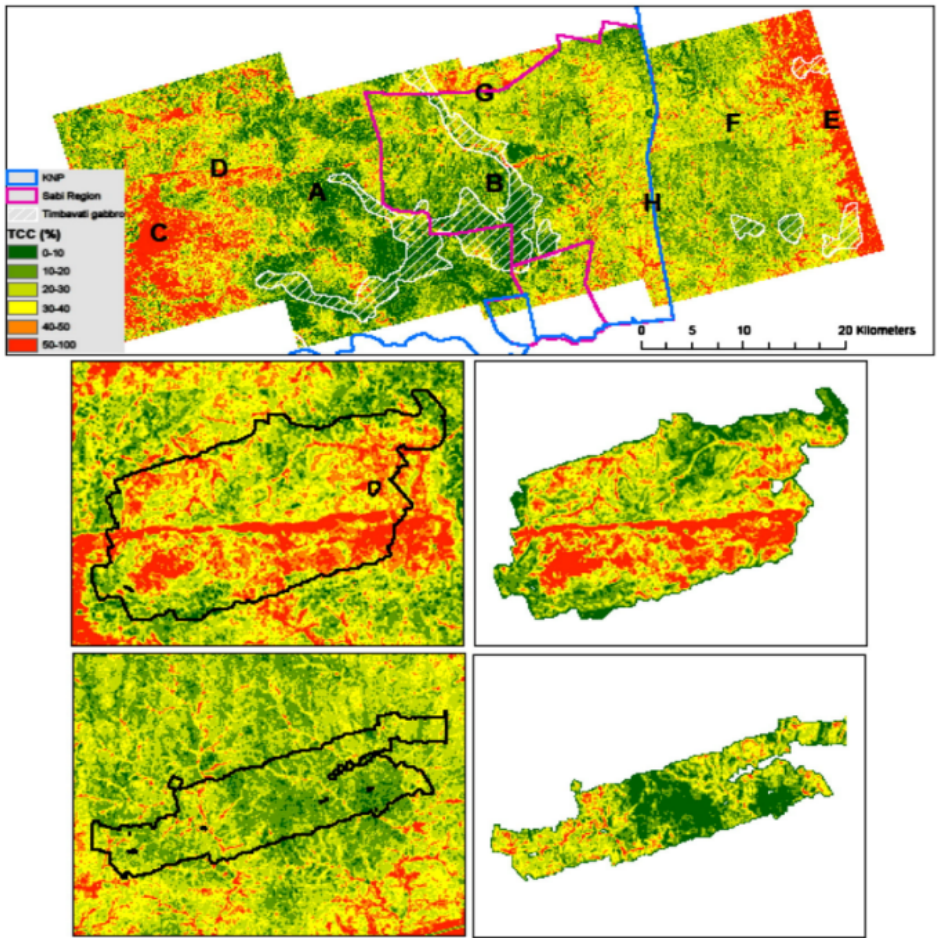




LiDAR - X SAR
LiDAR - C SAR
LiDAR - L SAR
LiDAR - X+C SAR
LiDAR - X+L SAR
LiDAR - C+L SAR
LiDAR - X+C+L SAR
Dense sector
AGB Difference (t/ha)
Major overestimation (<-15)
Minor overestimation (-15 to -5)
No difference (-5 to 5)
Minor underestimation (5 - 15)
Major underestimation (> 15)
0 0.5 1 2 Kilometers
N


LiDAR - X SAR
LiDAR - C SAR
LiDAR - L SAR
LiDAR - X+C SAR
LiDAR - X+L SAR
LiDAR - C+L SAR
LiDAR - X+C+L SAR
Scattered sector
AGB Difference (t/ha)
Major overestimation (<-15)
Minor overestimation (-15 to -5)
No difference (-5 to 5)
Minor underestimation (5 - 15)
Major underestimation (> 15)
0 0.5 1 2 Kilometers
N

## *Woody cover mapping*

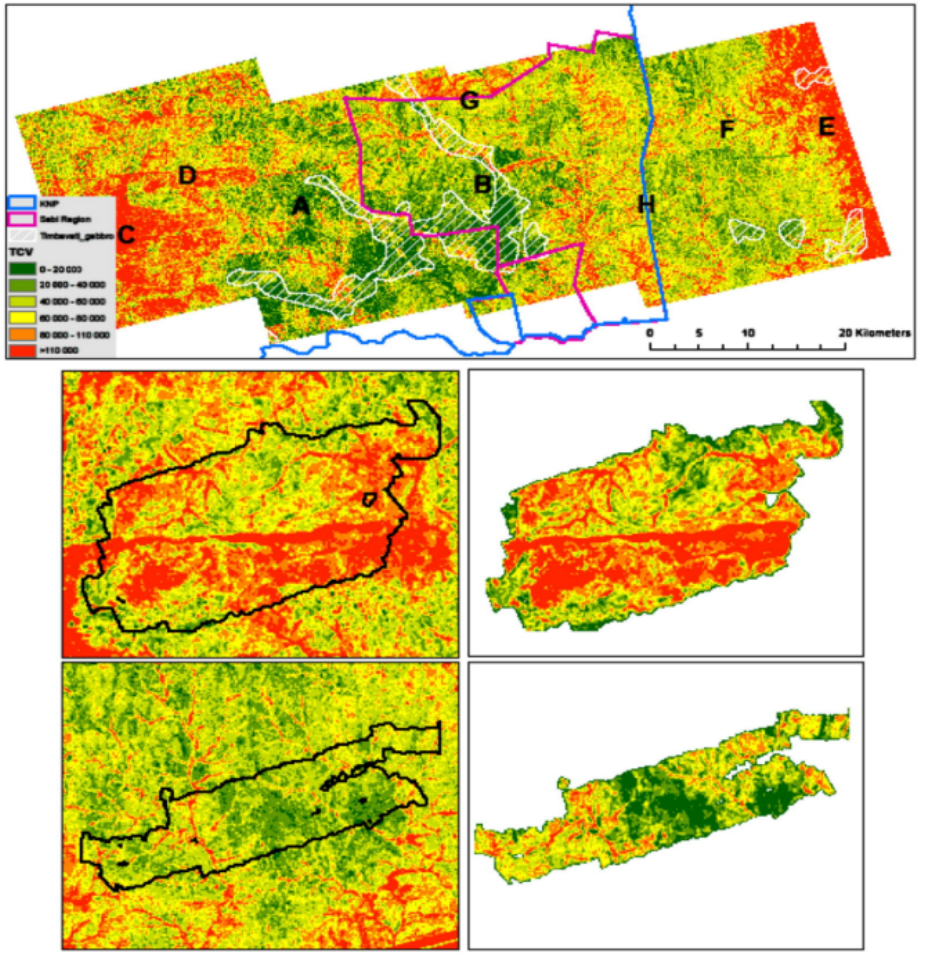



$R^2$ = 0.71, RMSE = 8.1% (38%)

Multi-season C-band prediction

LiDAR observation

## *Canopy volume*




$R^2$ = 0.75, RMSE = 17200 (34%)

Multi-season C-band prediction

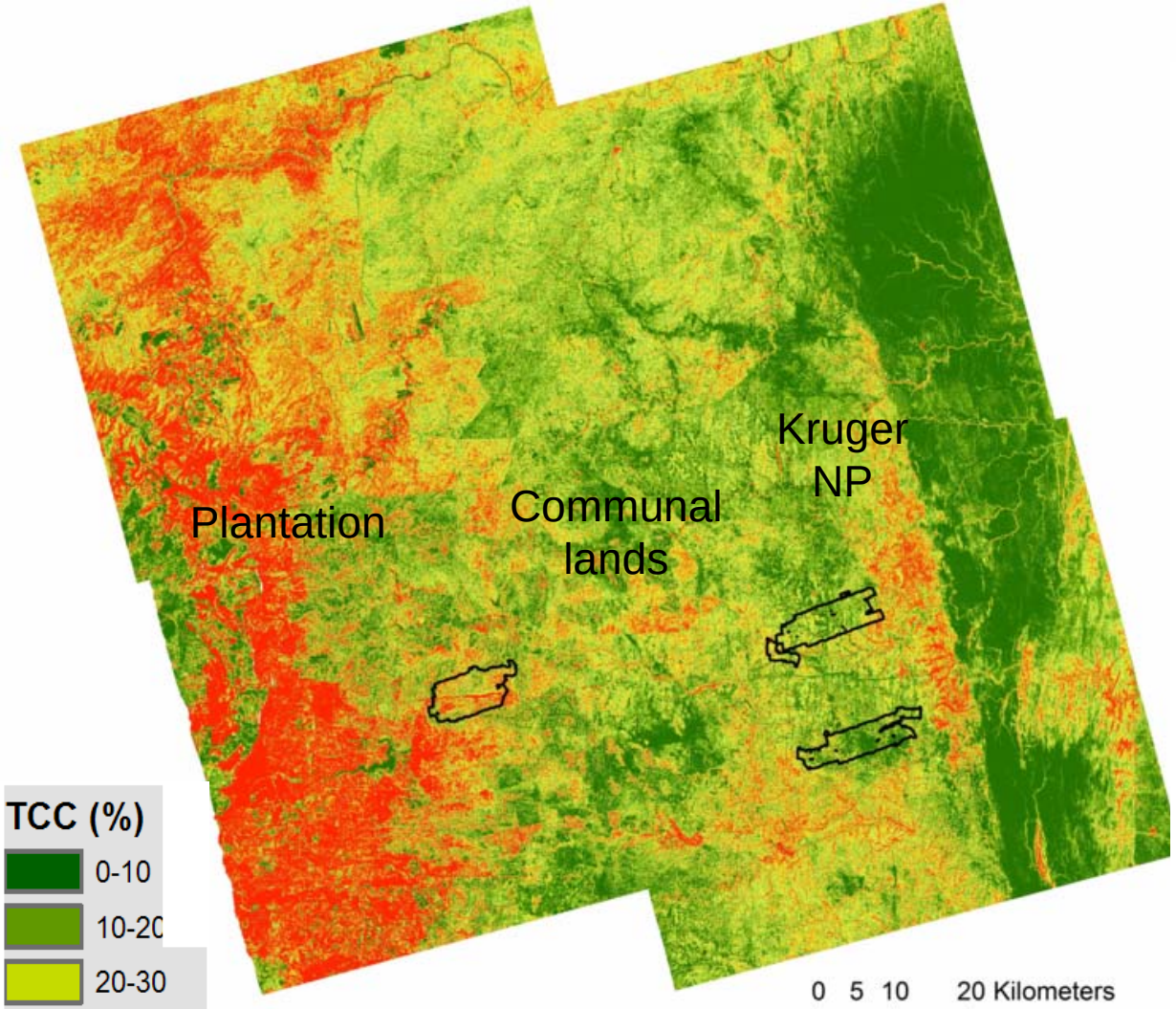
LiDAR observation

Mathieu et al., RSE, 2013

ALOS

K&C Initiative

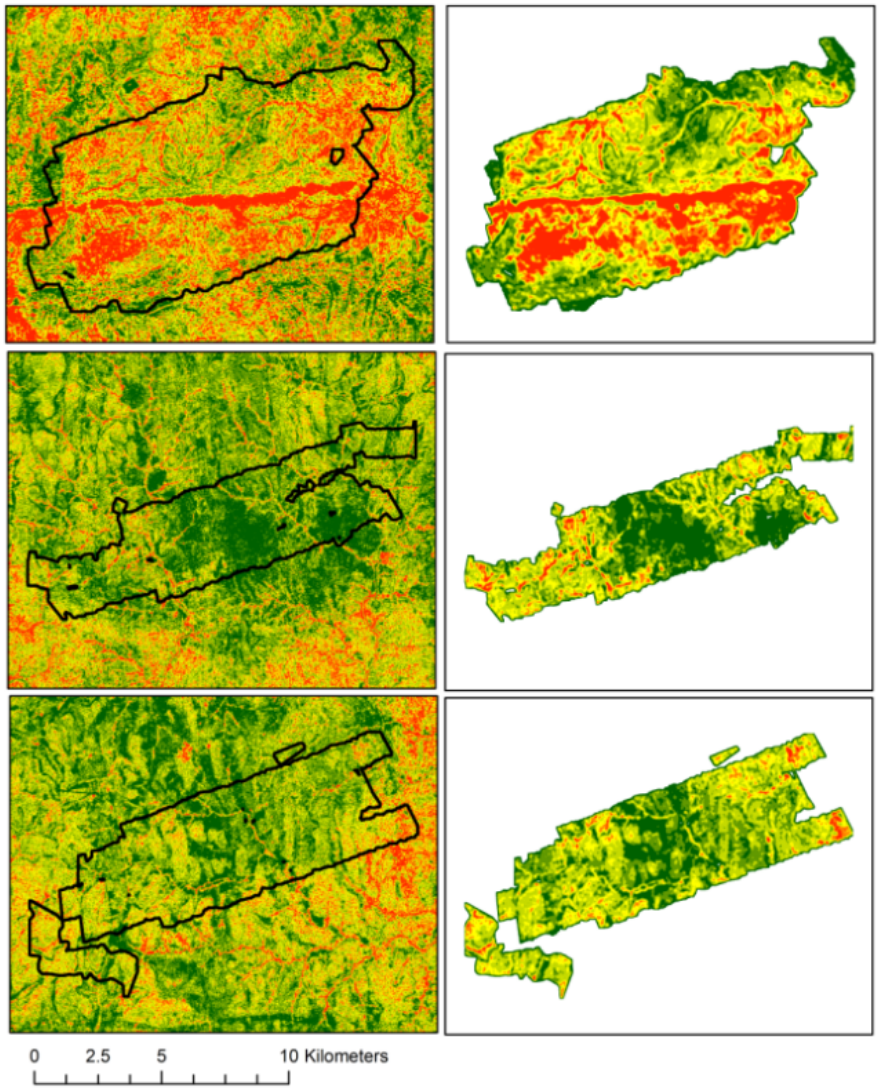
An international science collaboration led by JAXA



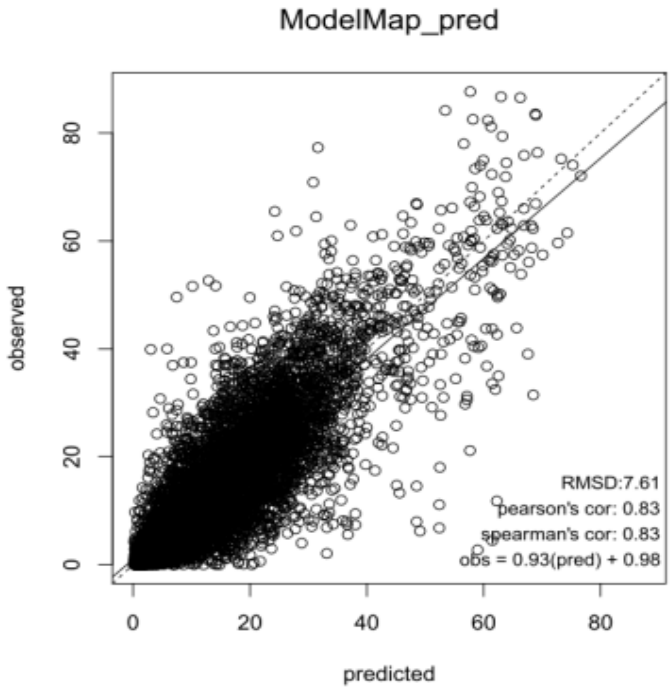

TCC (%)
- 0-10
- 10-20
- 20-30
- 30-40
- 40-50
- 50-100

L-band prediction

LiDAR observation

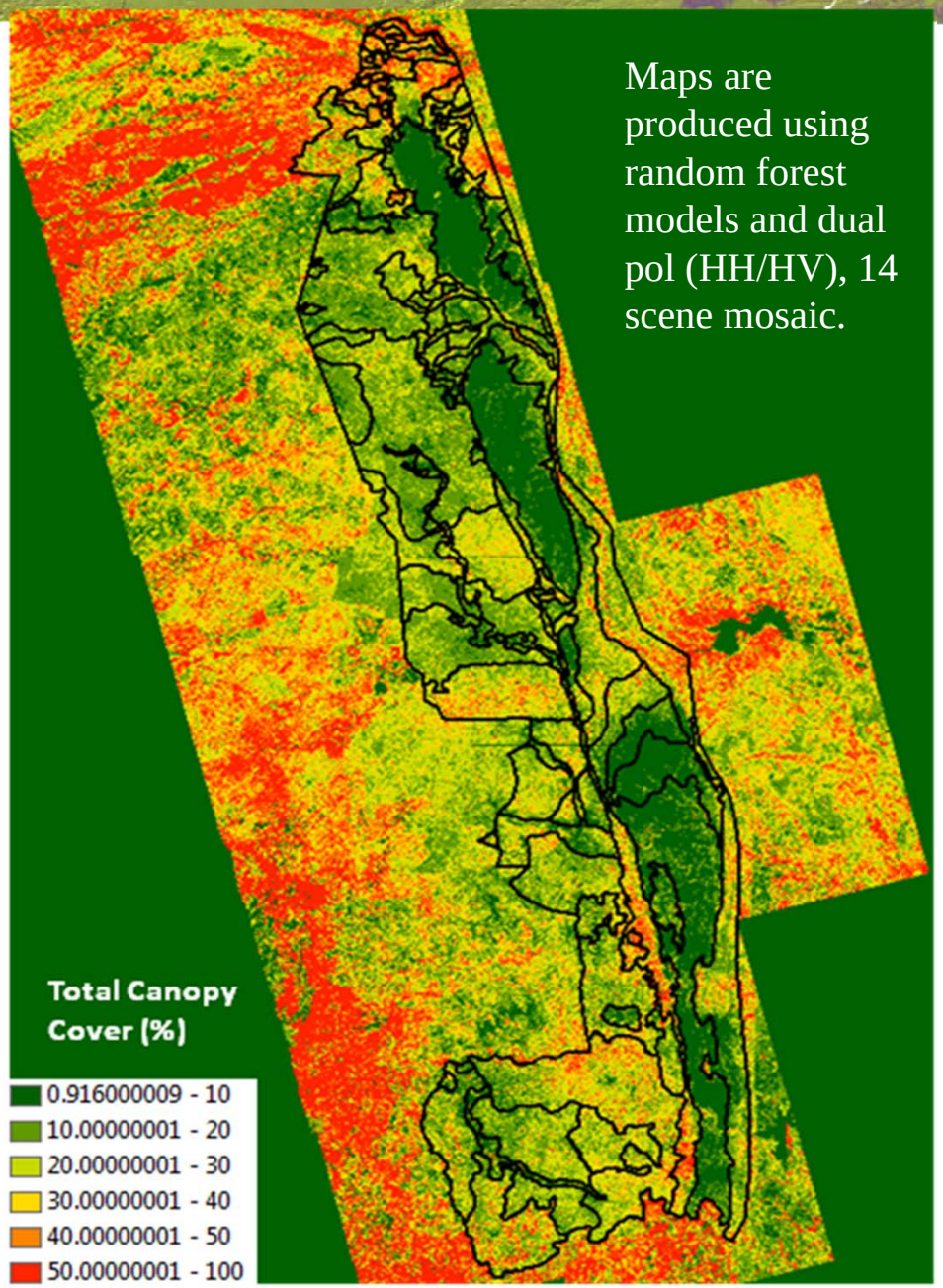


## Provincial up scaling




Total canopy cover maps from ALOS PalSAR L-band in the South African Loweld.

Need more extended cal/val



# Final comments

- ALOS PALSAR: high potential for mapping woody structure
  - C-band also potential → free SAR upcoming satellite (Sentinel-1)
- Future steps
  - "Fusion" with freely available Landsat product (L8)
  - Compare 2008-2010 PALSAR to earlier map (2000, JERS-1 / Landsat), and PALSAR-2
  - Assess multi-temporal (backscatter / coherence) and fully polarimetric ALOS-PALSAR-2
- Coupled LiDAR - SAR
  - Good trade off between area covered (large track, landscape scale) and details (patchy environment) between point sampling and wall-to-wall mapping
  - Understanding long term dynamics and effects of drivers (human, fire, herbivory)
  - Wall-to-wall up-scaling, calibration/validation of satellite imagery (e.g. SAR models with LiDAR), error propagation needs too be documented (biomass)
- Establish network of regional long-term pilot sites (ground, airborne, and satellite data): e.g. structure (3-5 yr, LiDAR), species (> 5 yr, WV-2)
- Opportunity to develop within region monitoring tools and EO products (GMES) answering to local needs and suited to local ecosystems

# Final comments

- ALOS PALSAR: high potential for mapping woody structure
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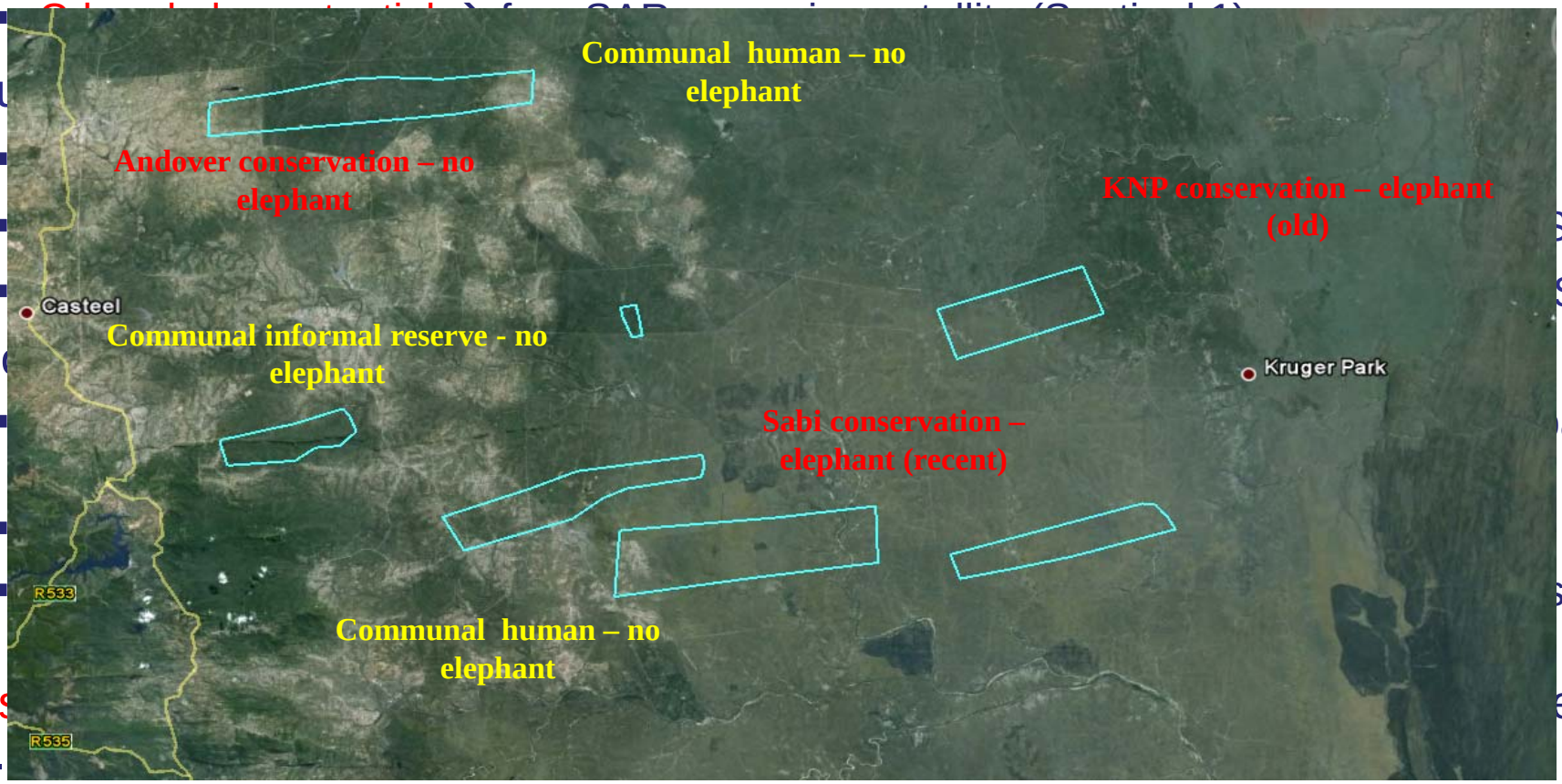


SAR-2

SAR-2

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- Opportunity to develop within region monitoring tools and EO products (GMES) answering to local needs and suited to local ecosystems

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**Thank you!**

**Acknowledgement:**
**Carnegie Institute of Science, JAXA, DLR**
**EU FP7 AGRICAB, SA Department of Science and Technology**