Joint GFOI / GOFC-GOLD / CONABIO / SilvaCarbon R&D Expert and Capacity Building workshop on:

Regional solutions to forest type stratification and characterising the forest state for national forest monitoring and carbon emissions reporting

LiDAR/SAR-based mapping of savannahs forests in Southern Africa

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“Forested” landscapes in South Africa

- Savannahs and woodlands: 35% (42M ha), cover ranging from 20-70%, biomass < 50T ha⁻¹
- Indigenous dense forests: 0.4% (0.5M ha) Commercial plantation: 1.0% (1.2M ha), mostly pine, eucalyptus, and acacia
- Albany thicket: 2.6% (3.2M ha), dense impenetrable vegetation with spiny, often succulent trees and shrubs, height < 5m

South Africa's nine biomes:
- Albany Thicket Biome
- Desert Biome
- Forests
- Fynbos Biome
- Grassland Biome
- Indian Ocean Coastal Belt
- Nama-Karoo Biome
- Savanna Biome
- Succulent Karoo Biome
Context: Some information needs

• Drastic vegetation changes: management needs
  – Bush encroachment affects 10-20 M ha in SA, 5-6% tree cover increase per decade → food security vs energy security
  – Woody alien invasive affects additional 10 M ha in SA & Lesotho → land productivity / water security
  – Carbon stock assessment, legal international reporting obligation (UNFCC) → Impact of bush encroachment? (1/3 of C sink in US, (Houghton et al. 1999)

• Lack of national spatial information to manage woody resources
  Medium Term Strategic Framework Outcome 10 led by Dept. Env. Affairs
  “Net deforestation to be maintained at no more than 5% woodlands by 2020
  Undertake provincial and national forest resource assessment programs

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.

Dept. Forestry has legally to report every three years on the status of woodlands to the minister.

“Professor, this is a very important topic, could you provide more details on the impact of bush encroachment?”

Houghton et al. 1999
Some information needs

- Drastic vegetation changes: management needs
  - Bush encroachment affects 10-20 M ha in SA, 5-6% tree cover increase per decade → food security vs energy security
  - Woody alien invasive affects additional 10 M ha in SA & Lesotho → land productivity / water security
  - Carbon stock assessment, legal international reporting obligation (UNFCC)
    → is the above increasing or decreasing ABG stocks?

- Focus on national mapping of continuous variables
  - Woody cover, height and biomass
  - Forest types largely (but not only) related to structure, cover / height
Geographical context

Aim to approaches scalable at national level

R&D pilot sites (GFOI)
1: Lowveld, KNP (Mpumalanga, Limpopo): plantation, mountain forests, savannas
2: Duku Duku area & iSimangaliso Wetland Park (KZN): plantation, coastal forests, savannas, mangrove
3: Addo Elephant Park area (Eastern Cape): thicket
4: Alguhlas Plains (Western Cape): alien woody vegetation, fynbos
General methods LiDAR/SAR for mapping structure

- SAR / optical data
  - Multi-frequency & multi-season
- Airborne LiDAR
  - AC Biomass
  - Tree fraction cover
- Applied a 75m cell size fixed grid with a 50m distance spacing between cells
- Extract mean values of SAR and LiDAR-based structural indicators

SAR + LiDAR integrated variable dataset (at 75 m)

Machine learning algorithms:
- Random Forest (in WEKA 3.6.9 & R rattle software)
- 1/3 calibration - 2/3 validation

Canopy cover and ABG maps

Predicted woody cover

- $R^2 = 0.76$
- RMSE = 6.95 t/ha
- SEP = 32.25%
Development of national / regional EO-based woody & forest products

JAXA ALOS PALSAR Forest >10% cover / Non Forest product
CSIR locally cal/val ALOS PALSAR >10% cover / Non Forest product

LiDAR indigenous forests
LiDAR savannas
LiDAR plantations

2007
2015
Extensive Calibration / Validation Airborne LiDAR Coverage

ALOS PALSAR HH+HV winter mosaic

R2=0.76
RMSE=11.7%
Biomass mapping in South Africa

2010 CSIR above ground biomass map in Lowveld (75m)
Method: integration of airborne LiDAR and ALOS PALSAR using machine learning algorithm (Random Forest)

Le Toan & team
2005/2010/2015 CESBIO-CSIR above ground biomass map in SA forest belt; method: semi empirical methods, use small number of cal plots, MIPERS SAR simulator (forest/env parameters), water cloud models & Bayesian inversion
Field sampling effort – above ground biomass

• 1 ha square plots (cal/val LiDAR & SAR)
  – Height & DBH
  – Species

• ~ 100 plots over various veg types

• Allometric equations
LiDAR cal/val & product development

Assessment of accuracy of LiDAR products, development and validation of above ground woody biomass products – SAR upscaling

LiDAR height
- Field woody height (single plants)

LiDAR cover
- Field cover (25x25m plots)

LiDAR biomass
- Field biomass (25x25m plots)

LiDAR-based biomass allometric equations

Biomass = 9.8 x Mean Woody Height x Canopy Cover + 32
National (and SADC) LiDAR database development

- LiDAR inventory, storage and processing
- 2006+
- Main stream discrete LiDAR instruments are available (Southern Mapping Company)
- Many datasets are collected in SA (and Namibia, Zambia)
  - Power utilities
  - Plantation company
  - National and provincial parks
  - Cities, mines
  - Etc.
Season: Winter >> summer > autumn, multi-season improves slightly the model

Polarization: HV (best)

Scale: optimum around 1ha (100m)

Polarimetric decomposition (Freeman, Van Zyl): volume component does not improve on co-pol HV

SAR better predict woody volume > cover

Mathieu et al. 2013, Remote Sensing of the Environment
Multi-temporal, polarimetric L-band PALSAR & woody cover in savannahs

Season: Winter >> summer > autumn
Polarization: HV & HH during dry season, HV during wet season
Scale: optimum around 0.25-1ha (50-100m)
Polarimetric decomposition (Freeman, Van Zyl): volume component does not improve on co-pol HV

Winter: tree leaf-off, dry grass
Summer: tree leaf-on, green grass
Autumn: tree leaf-on, dry grass

Urbazaev et al. 2015, Remote Sensing of the Environment
Multi-frequency SAR (X, C, L) modelling of woody cover, biomass, and volume in savannahs

Winter dual-pol datasets

Combined L&C&X-band > L-band (ALOS PALSAR) >> C-band (RADARSAT-2) >>> X-band (TerraSAR-X)

Random forest > ANN > Decision trees > linear reg

SAR better predict woody volume > cover = biomass

### Combined L-band SAR and optical Landsat datasets

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>$R^2$</th>
<th>RMSE (%)</th>
<th>SEP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn</td>
<td>0.46</td>
<td>12.82</td>
<td>52.44</td>
</tr>
<tr>
<td>Spring</td>
<td>0.40</td>
<td>13.51</td>
<td>55.27</td>
</tr>
<tr>
<td>Summer</td>
<td>0.53</td>
<td>11.99</td>
<td>49.05</td>
</tr>
<tr>
<td>Winter</td>
<td>0.38</td>
<td>13.78</td>
<td>56.39</td>
</tr>
<tr>
<td>All Four Seasons</td>
<td>0.66</td>
<td>10.33</td>
<td>42.24</td>
</tr>
<tr>
<td>L-band SAR only</td>
<td>0.80</td>
<td>7.87</td>
<td>32.21</td>
</tr>
<tr>
<td>L-band SAR and Summer</td>
<td>0.85</td>
<td>6.78</td>
<td>27.74</td>
</tr>
</tbody>
</table>

- **Green woody canopy, dry grass**
- **Green woody canopy, green grass**
- **Leaf-off woody canopy, dry grass**

#### Enhanced Vegetation Index (EVI)

- **Summer wet**
- **Winter dry**

*Naidoo et al, in Press, International Journal of Applied Earth Observation and Geoinformation*
Hypertemporal C-band time series

C-band ENVISAT-ASAR WS: 75 m, HH; preparation for Sentinel-1 (free, already large database)

Random Forest ± = linear regression; temporal filter improves modelling results

ASAR predicts woody volume > woody cover; dry > wet, but both improve modelling results

ASAR C-band HH produces similar results to ALOS L-band between 6-10 images (mostly acquired in winter)

Main et al 2014, IGARSS

Woody cover map ASAR C-band 20 winter summer images
System design & processing

System development, critical for large scale applications

- Large datasets (spatial & temporal), need maximize automation of processing
- Framework for testing methodological approach and developing research question (e.g. model, sample selection)

LiDAR data storage
1 folder / dataset
Naming convention? <date><centroid_latlong> link to QGIS database

Non processed LiDAR
- las file
Processed
- Classified las cloud point
- Canopy height model (tile, virtual raster)
- Digital elevation model (tile, virtual raster)
- VOXEL

Maps
- Water, Urban&settlement, Croplands

Optimal parameter for classification
Processing according to general landscape classes: Flat, hilly, mountain, urban

Standard projection
(Albers eq. area, WGS84)
1m resolution

Grid building

Calibration / validation sample
Criteria selection (e.g.):
1) > 90% area of grid include LiDAR
2) building area < 10%
3) date difference SAR - LiDAR

Model SAR + LIDAR
Model selection
Random forest

Envisat ASAR

Ancillary data (stratification)
Biome (veg map)
DEM (slope, aspect)
• 1 km of carbon stocks and flux modelled with uncertainty / GIS & remote sensing data
1. Satellite data requirements
   • Firstly L-band SAR, dual pol, single scene
   • Systematic acquisition of winter season
   • Complement with Landsat / Sentinel-2
   • Sentinel-1 time series

2. Operational status of the existing technology (R&D, pre-operational, operational)
   • Woody cover: pre-operational
   • Above ground biomass: R&D
   • Woody height: R&D

3. Are your IT/infrastructure needs met?
   • Combined commercial software (GAMMA), and developed script
   • High computing environment
1. Describe the obstacles to “operational use” (challenges)
   • Reduce errors in low biomass & cover environment
   • Mapping gradual change / uncertainty assessment (error propagation, field-to-satellite and changes)
   • Development (funding) of long-term calibration / validation infrastructure
   • Deal with variable phenological status
   • Species mapping
   • Last not least: institutional support
2. Indicate the nature of the R&D required to advance the methods to operational use
   • Interferometry – coherence analysis (height assessment and biomass)
   • LiDAR-based AGB modelling
3. What are the timelines for completing the R&D?
   • 3-5 years
4. Describe your satellite data needs for R&D
   1. Data for height estimates, interferometry?
   2. Long term access to L-band data
Invitation for special session on forest / carbon applications

Suggestion welcome

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