Structure

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As part of the BRIX exercise, a large amount of data acquired at various ESA’s campaigns was provided.

The focus of this research is on the AfriSAR Campaign which was one of the most recent ESA’s campaigns.

This campaign was a joint collaboration between ESA, NASA, DLR, ONERA, CESBIO and UCL. SAR P and L band were collected by NASA, DLR and ONERA over different test sites (Mondah, Lope, Mabounie and Rabi). LiDAR data was collected by NASA, and field measurement was carried out by CESBIO and UCL.

Team Leicester focused on:

- **SAR P Band data acquired by DLR’s F-SAR instrument**
- **Lope test site**: Lope was considered as supersite due to being so diverse and covering different vegetation types within one area and this makes the observation of such a site challenging.
Study Site

- The test site is within the northeastern part of Lope National Park in Gabon, Africa (Figure 1)

- Figure 2 is an above ground biomass map of the test site, generated based on SAR backscatter.

- It indicates that the area contains different vegetation types, surrounded by closed-canopy tropical rainforest typical of the Congo Basin, the middle of the site is characterized by savannah and a mosaic of low-biomass forest types.
Data Available for the exercise

- Data collected by DLR’s F-SAR instrument. The F-SAR is a fully polarimetric single-look-complex (SLC) operated with a carrier frequency of 435MHZ with range and azimuth resolutions of 3.9 x 2 m.

- The datasets provided in different acquisition modes. We used the data from Heading 2 for running the experiment, and validated the algorithm using the data from Heading 3. The images from these two headings, cover slightly similar areas but with different incidence angle. This made possible to investigate the impact of incidence angle on the algorithm performance.

- Each heading included a master image and two slaves with interferometric baselines (10 and 30 meter)
LiDAR measurements were collected by Dr. Saatchi. Data products include: Canopy Height Model (CHM) at 1 m spatial resolution, and LiDAR-derived AGB map at 50 m resolution based on a single AGB-mean canopy height (MCH) power law model. (These data products were used for validation purposes)

These data were collected by UCL and CESBIO with the purpose of providing estimates from different AGB ranges: from savannas to old growth forest. A total of 12 plots 50x50 m (33 subplots 25x25 m) were measured. (These data products were used for calibration/validation purposes)
We processed **SAR P band data**, and generated the following parameters:

- **Backscatter Intensity** ($\sigma_0$): $\sigma_0 \text{ (dB)} = 20\log_{10}(|\text{backscatter}|)$
- **H/A/Alpha Decompositions Components** (entropy, anisotropy, alpha)
- **Polarimetric Radar Interferometry** (PolInSAR) Height
Methods

- **Step 1**: Correlation Analysis
- **Step 2**: Non-linear regression model
- **Step 3**: AGB calculation for each polarization
Step 1: We carried out a correlation analysis to understand the degree of correlation between each SAR derived parameters and LiDAR AGB (Figuer 3):

Parameters includes:

- mean alpha
- mean anisotropy
- mean entropy
- angle
- mean backscatter (HH, HV, and VV)
- mean heights

Backscatter intensity indicated the highest correlation in compare to the other variables.
Nonlinear Regression Model

Eq (1): \[
AGB = \frac{1}{U + (a \cdot b \cdot y_i)}
\]

- where AGB is the above ground biomass
- \(U\) is the upper limit of the logistic model (Greene, 2000). The upper limit was assumed as 600 t ha\(^{-1}\) which is the 98 percentile of the AGB found in the ground dataset plus one standard deviation.
- \(y_i\) is the backscatter of polarization \(i\) (HV, HH, or VV)
- \(a\) and \(b\) are the model coefficients their computation will be explained in Step 2.

Step 2: There were 33 plots (0.25 ha) available. Due to the small number of samples, the calibration and validation were performed following a k-fold approach (k =11) as follows:

- The original dataset (33 plots) was stratified by AGB range in low, medium and high
- Each sample of the each stratum was randomly assigned to one fold \(k\) (1 to 11). Therefore each fold had 3 plots, each at a different AGB range.
- Of the \(k\) folds, a single fold was retained for testing the model, and the remaining \(k-1\) folds (split) were used to calibrate a model
- The cross-validation process was then repeated \(k\) times (splits), with each of the \(k\) folds used exactly once as validation data
- All observations were used for both training and validation, and each observation was used for validation exactly once
- The model coefficients for each polarisation were computed based on the median of the \(k\) models.

Step 3: Using Eq(1), we calculated the AGB for all the polarisation HH, HV and VV.
Investigating the Effects of Incidence Angle

- The model was applied to data from Heading-2 including (H2-0, H2-1 and H2-2) as well as the images corresponding to Heading-3 (H3-0, H3-1, H3-2).
- Kruskal-Wallis test was applied to test for the null hypothesis that the data are coming from the same distribution.
- To test for the statistical significance of the differences for the estimates obtained for each incidence angle, a two-sided Wilcoxon signed rank test was performed. This test examines the null hypothesis that the median difference between the two samples is zero, against the alternative hypothesis that it is not.
Calibration and Model Coefficients Estimation

- Using Eq(1), we estimated the model coefficients for all the backscatter at different polarisations HH, HV and VV, which can be seen in Table I.

### Table I: Estimated model coefficients using k-fold approach

<table>
<thead>
<tr>
<th>Model</th>
<th>$a$</th>
<th>SD ($a$)</th>
<th>$b$</th>
<th>SD ($b$)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV</td>
<td>0.000027</td>
<td>$\pm0.000004268$</td>
<td>0.762660</td>
<td>$\pm0.006852300$</td>
<td>0.80</td>
</tr>
<tr>
<td>HH</td>
<td>0.000165</td>
<td>$\pm0.000016759$</td>
<td>0.779614</td>
<td>$\pm0.006591693$</td>
<td>0.73</td>
</tr>
<tr>
<td>VV</td>
<td>0.000056</td>
<td>$\pm6.690563232$</td>
<td>0.728322</td>
<td>$\pm0.007158373$</td>
<td>0.80</td>
</tr>
</tbody>
</table>
Results & Validation

The single AGB polarization models as well as the AGB median estimate were validated against the field data (Table II & Figure 4).

Table II: Validation of estimated AGB at individual polarisation and median versus field measured AGB

<table>
<thead>
<tr>
<th>Model</th>
<th>$R^2$</th>
<th>RMSE (t ha$^{-1}$)</th>
<th>CV(RMSE)</th>
<th>Bias (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGB$_{HV}$</td>
<td>0.78</td>
<td>69.1</td>
<td>30%</td>
<td>6.5</td>
</tr>
<tr>
<td>AGB$_{HH}$</td>
<td>0.70</td>
<td>80.4</td>
<td>35%</td>
<td>7.8</td>
</tr>
<tr>
<td>AGB$_{VV}$</td>
<td>0.79</td>
<td>67.8</td>
<td>30%</td>
<td>6.3</td>
</tr>
<tr>
<td>AGB$_{median}$</td>
<td>0.78</td>
<td>69.7</td>
<td>30%</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Figure 4: validation of estimated AGB at individual polarisation and median versus field measured AGB

5. Results
Validation by AGB Range

Table III: Validation of estimated AGB based on different AGB ranges vs ground measured AGB

<table>
<thead>
<tr>
<th>AGB range (t ha⁻¹)</th>
<th>Nr plots</th>
<th>RMSE (t ha⁻¹)</th>
<th>Rel. RMSE</th>
<th>SD (t ha⁻¹)</th>
<th>Bias (t ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 100</td>
<td>9</td>
<td>46.0</td>
<td>2.57</td>
<td>21.8</td>
<td>40.5</td>
</tr>
<tr>
<td>100-200</td>
<td>3</td>
<td>96.8</td>
<td>0.60</td>
<td>39.1</td>
<td>88.6</td>
</tr>
<tr>
<td>200-300</td>
<td>11</td>
<td>59.7</td>
<td>0.21</td>
<td>58.6</td>
<td>-11.3</td>
</tr>
<tr>
<td>300-400</td>
<td>7</td>
<td>79.8</td>
<td>0.23</td>
<td>78.9</td>
<td>-12.0</td>
</tr>
<tr>
<td>&gt; 400</td>
<td>3</td>
<td>99.4</td>
<td>0.22</td>
<td>54.9</td>
<td>-82.8</td>
</tr>
<tr>
<td>Overall</td>
<td>33</td>
<td>69.8</td>
<td>0.31</td>
<td>69.6</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Figure 5: Validation of estimated AGB based on different AGB ranges vs ground measured AGB

5. Results
Results & Validation

We also validated the median AGB versus LiDAR-derived AGB which shows a moderate agreement (Figures 6 and 7).

Figure 6. Agreement between the AGB P-band estimates vs AGB LiDAR estimates. Solid line ($y=x$)

Figure 7. Histograms showing the AGB distribution estimated using the P-band and the airborne LiDAR data. The dashed line represents the AGB distribution for field measurements.
Output Product

- The map of AGB for the median values is reported in (Figure 8)

![Figure 8: A map of AGB median estimate](image-url)
Effects of Incidence Angle

- Kruskal-Wallis test showed that there were no significant differences (p-value > 0.1); therefore, we can assume the data are coming from the same distribution.

- The two-sided Wilcoxon signed rank test showed different results for each band:
  - HH band: differences were significant but for the slave images with B=30m.
  - HV band: differences were significant but for the slave images with B=30m.
  - VV band: all images showed statistical significant differences (p-value<0.001).

- Differences represented up to 11.5% of the mean AGB for HH, 8.5% for HV and 12% for VV, respectively.
Discussion

- For this experiment we used data from headings 2 and 3, as they cover slightly similar test site but with different incidence angle.
- We developed our model for heading 2 datasets, and tried investigating the impact of incidence angle using heading 3 data.
- Multiple parameters were extracted from SAR datasets including components of H/A/Alpha decomposition (alpha, entropy and anisotropy), backscatter intensity ($\sigma_0$) for all polarisation channels, and PolInASR height.
- We carried out a correlation analysis to understand the degree of correlation between individual variables and LiDAR-derived AGB: backscatter intensity showed the highest correlation.
- Finally the model trained using backscatter intensity only, due to high correlation.
- We validated the estimated AGB at individual polarisation and AGB median, versus field measured AGB, and the results are promising.
- We validated the median AGB (which was generated based on individual estimated AGB of each polarisation HH, HV and VV) versus LiDAR-derived AGB, and it showed a good agreement with $r^2 = 0.57$.
- Incidence angle has a significant impact on the estimated results. The effects are more obvious at VV-backscatter-derived AGB with the mean difference of 12%.
Limitations

- PollInSAR estimated height did not show a sufficient correlation due to following limitation:
  a) There were only two vertical interferometric baseline available (10 & 30m). Normally using a short baseline limits the height estimation performance due to insufficient values of vertical wavenumber (kz) leading to over-estimation of the height.
  b) The kz values provided was not topography corrected, and the off-nadir file was not available to correct this.
  c) The Flat-Earth file was not provided and the Tandem-X DEM was used to correct this effect, while Tandem-X DEM is not appropriate for removing the Flat-Earth effect inside a SAR P Band data over tropics.
  d) The use of LiDAR measured height was another problem. As per BRIX outline, LiDAR should not be used at any stage of algorithm development except for final validation. Whereas, if we could have used LiDAR, to correct the PollInSAR estimated height and improve the estimation accuracy.

- Small sample size: The model calibrations were carried out using a small number of field plots
- We used subplots (1 ha plot divided into 4 subplots) → autocorrelation effects
- We were not able to assess the utility of the tomoSAR data, as tools for georeferencing these datasets were not available.
- The field data was not available for the other test sites (Mondah, Mabounie and Rabi), therefore we used the same model coefficient estimated for Lope test site for the other test sites to assess the validity of the model.
Conclusion

After the analyses carried out, the following conclusions can be drawn:

● Between the group of SAR-derived variables analysed in this study, the backscatter intensities at different polarizations (HH, HV and VV) showed the highest correlation to AGB.
● The relationship between backscatter and AGB was fitted using a non-linear regression model which was based on a priori knowledge of AGB values in the study area.
● The algorithm showed a good performance when validated against field data using the k-fold cross validation.
● The estimated AGB was compared to the LiDAR-derived AGB, showing a relative good agreement. The LiDAR-derived AGB contains different errors which might be propagated through the LiDAR product, and this should be taken into account when comparing the two products.
● For a more robust model, it would be necessary to have access to more field samples for calibration and validation of the model.
● Incidence angle had a significant impact on the estimates, which ranges between 8% -12% depending on the polarization.
Acknowledgment

- We acknowledge ESA and all the other collaborators for their efforts in conducting the AfriSAR campaign.
- F-SAR data pre-processing carried out by the German Space Agency (DLR). LiDAR datasets were collected by Dr Saatchi from the NASA Jet Propulsion (JPL). Ground measurements were conducted by teams from University College London (UCL) and Centre d'Etudes Spatiales de la BIOsphère (CESBIO).
- We express gratitude to Dr Klaus Scipal, and Dr Clément Albinet from ESA for conducting the BRIX exercise, and for their continuous support during the project.
Thanks for Listening!

Any questions?