Biomass Estimation by means of Interferometric Ground Suppression in SAR Data

Mariotti M., Tebaldini S., Quegan S., Soja M., Ulander L. M. H.

30/01/2019
Outline

A. SAR Tomography on forests
   1. Overview
   2. Correlation with AGB on tropical forests

B. Why 30m backscatter works in estimating AGB on tropical forests?
   1. Biophysical explanation: 30m as key elevation
   2. Tomographic explanation: ground rejection

C. Ground notching
   1. Theory
   2. Robustness to DTM errors and geometry variation
   3. Preliminary achievements

D. Conclusions
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SAR systems employ a RADAR sensor flown onboard a moving platform to synthesize an antenna aperture as long as several kilometers.

⇒ Two-dimensional map of Radar intensity at a given wavelength.
SAR tomography

SAR produces pixels → TomoSAR produces voxels!

Track $n$
Track 2
Track 1

Cross range (≈ elevation)

$\theta$
Slant range

height

azimuth

ground range

Ground level + 30 m
Ground level + 20 m
Ground level + 10 m
Ground level

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## Guyaflux tower through SAR tomography

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### 3D Imaging of the Guyaflux Tower

- **Scene**: Tropical forest ~150 species per hectare
- **Sites**: Paracou & Nourages, French Guyana
- **Carrier frequency**: P-Band
- **Horizontal resolution**: ~1m
- **Vertical resolution**: ~15m
AfriSAR 2016 – La Lopé (Gabon)

Multi-look beamforming (no topography)

Single-look back-projection:

Back-projection (Vv), Az 4921

TanDEM-X

Tomo DTM
Correlation with biomass (TropiSAR Paracou)

- TomoSAR focusing @30m provides 2 dB per 100 T/Ha AGB
- Very high correlation: 0.97

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The canopy layer:
- containing a major part of the leaves that convert sunlight to energy through photosynthesis,
- being a principal site for the interchange of heat, water vapor, and atmospheric gases
- contains a large proportion of the woody elements, including trunks and most of the branches (primary, secondary, and higher order) that contribute to the total AGB
30m layer as a proxy for total biomass

- Why is the best correlation observed at 30 m?
- How the biomass in this layer is related to AGB?
- Is 30 m a general feature of tropical forests?

Assessment using the TROLL model

- The biomass contained in the 20-40m layer vs the total AGB, both derived using the TROLL model.
- The biomass proportion is about 33%.
- A linear fit to the relationship gives a correlation coefficient of 0.92.
- An interesting feature is that it implies that this relation holds independent of biomass, from 250 to 700 t/ha, including the highest AGB plots with emergent trees.

30m layer as a proxy for total biomass

Assessment by LIDAR metrics

- The specific feature of the 30 m layer in tropical rainforests has also been noticed in a recent study of 9 tropical rainforest in South America by Meyer et al.
- Correlation between AGB and the area occupied at different heights by large trees (as derived from Lidar)
- Correlation ($R^2$) has been found to be maximum at height of 27-30 m, irrespectively of the 9 study sites.

‘De la canopée à la biomasse’ thèse de l’Université Paul Sabatier http://thesesups.ups-tlse.fr/3515/
Scattering mechanisms

\[ \sigma_{PQ}^0 = S_{PQ}(\theta_i, \varepsilon, k, s) \exp\left( -\frac{B_{PQ} W_{\beta PQ}}{\cos \theta_i} \right) + C_{PQ} W_{\delta PQ} \Gamma_{PQ}(\theta_i, \varepsilon, k, s) \sin \theta_i \exp\left( -\frac{B_{PQ} W_{\beta PQ}}{\cos \theta_i} \right) + A_{PQ} W_{\alpha PQ} \cos \theta_i \left[ 1 - \exp\left( -\frac{B_{PQ} W_{\beta PQ}}{\cos \theta_i} \right) \right] \]

**Ground echo**
- more AGB more strength but...
- ...more extinction so less strength
- surface bounce unrelated to AGB

**Double bounce**
- decreasing with AGB
- dependent on ground roughness, dielectric constant, slope, etc..

**Canopy echo**
- more AGB more strength but...
- ...more extinction so less strength
- surface bounce unrelated to AGB
Scattering mechanisms after tomographic focusing

\[
\sigma_{PQ}^0 = S_{PQ}(\theta_i, \varepsilon, k, s) \exp \left( - \frac{B_{PQ} W_{\beta PQ}}{\cos \theta_i} \right) + C_{PQ} W_{\delta PQ} \Gamma_{PQ}(\theta_i, \varepsilon, k, s) \sin \theta_i \exp \left( - \frac{B_{PQ} W_{\beta PQ}}{\cos \theta_i} \right) + A_{PQ} W^{\alpha PQ} \cos \theta_i \left[ 1 - \exp \left( - \frac{B_{PQ} W_{\beta PQ}}{\cos \theta_i} \right) \right]
\]

- **Ground echo**
  - \( \times \)
  - decreasing with AGB
  - dependent on ground roughness, dielectric constant, slope, etc..

- **Double bounce**
  - \( \times \)
  - more AGB more strength but...
  - ...more extinction so less strength
  - surface bounce unrelated to AGB

- **Canopy echo**
  - \( \times \)
  - \( \times \)
  - decreasing with AGB
  - \( \times \)
  - dependent on ground roughness, dielectric constant, slope, etc..

\[ \text{Power} \]

\[ \text{Tomo filter} \]
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SAR interferometry – interferometric fringes

\[ \Delta \varphi \triangleq \varphi_1 - \varphi_2 = \frac{4\pi}{\lambda} (r_1 - r_2) \]

Interferometric phase (\(\Delta \varphi\))
SAR interferometry - Phase flattening

\[ \Delta \varphi \triangleq \varphi_1 - \varphi_2 = \frac{4\pi}{\lambda} (r_1 - r_2) - \frac{4\pi}{\lambda} (r_{flat,1} - r_{flat,2}) \]
SAR interferometry – DEM compensation

\[ \Delta \varphi \triangleq \varphi_1 - \varphi_2 = \frac{4\pi}{\lambda} (r_1 - r_2) - \frac{4\pi}{\lambda} (r_{DEM,1} - r_{DEM,2}) \]

Interferometric phase (\( \Delta \varphi \))

---

Interferometric phase

Slant range

Azimuth
SAR interferometry – DTM compensation

\[ \Delta \varphi = \varphi_1 - \varphi_2 = \frac{4\pi}{\lambda} (r_1 - r_2) - \frac{4\pi}{\lambda} (r_{DTM,1} - r_{DTM,2}) \]

“Ground steered” images
zero interferometric phase
at the ground level

Interferometric phase (\(\Delta \varphi\))

Slant range
Azimuth

True topography
Removed topography
Ground steered images

Zero interferometric phase $\rightarrow$ same phase value in $I_1$ and $I_2$
Interferometric ground notching

Zero interferometric phase → same phase value in $I_1$ and $I_2$

$$I_{notch} = I_1 - I_2$$

- cancels out echoes coming from 0m
- emphasizes echoes coming from half of the ambiguity height

Elevation above the ground
Sensitivity to above ground features

- Weak correlation between SLC power and canopy height
- Stronger correlation between notch power and canopy height
- Data from AfriSAR Mondah
Ground features rejection

Data from TropiSAR Paracou

- A ground notched image can be computed for each polarization
- Double bounce revealed by a copolar phase value close to \( \pm 180^\circ \)
- Almost zero copolar phase after ground notching

Copolar phase (0m tomo)

Double bounce

Copolar phase (ground notch)

Surface backscattering or volumetric scattering

Double bounce
Sensitivity to AGB of ground notched images

- Sensitivity to ground truth AGB of the interferometric notch power is comparable to the TomoSAR 30m power: about 2 dB per 100 T/Ha AGB
- Correlation is 0.74 vs 0.97
- Sensitivity to LiDAR derived AGB is increased w.r.t. SLC power
Rejecting the ground is enough for AGB to emerge?

Short baseline notch

Long baseline notch

$\rho_p = 0.74359$, slope = 1.92

$\rho_p = 0.29635$, slope = 0.18

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Notch effect varying baseline

Normal baseline: $B_\perp$, $1.5 \cdot B_\perp$, $2 \cdot B_\perp$, …

$|I_{notch}|^2$

$z_{2\pi}$

$z_{2\pi} \over 2$

$z_{2\pi} \over 2$

$z_{2\pi} \over 2$

$z_{2\pi} \over 2$

$z_{2\pi} \over 2$
Space-varying vertical emphasis

- Airborne surveys are characterized by space-varying normal baseline
- The difference between two ground steered images leads to ground suppression
- The part of the tree that gets emphasized depends on the range azimuth coordinate
- Is it possible to mitigate this variation?
Baseline interpolation

Many interferometric images enable to select the desired $k_z$ by interpolation:
- Data must be baseband (in the $z$ domain)
- Extrapolation should be avoided
- Different interpolator kernels give different results
Space-varying vertical emphasis (airborne)

\[ \left| I_{\text{notch},hv} \right|^2 (\sin(\theta - \alpha) \text{ topo compensation}) \]

Airborne notch images
- Normal baseline is strongly space-varying
  - Due to deviation from the nominal trajectories
  - Due to the different geometry from near-range to far-range
- Baseline variations drive notch power fluctuations
Multi-baseline equalization

$|I_{notch, hv}|^2 (\sin(\theta - \alpha) \text{ topo compensation})$

Height of ambiguity [m]

Equalized notch
- The height of ambiguity is fixed for the whole image
- More than a slc pair is needed
- Likely not needed for spaceborne data
Conclusions

A. Motivation
   1. SAR Tomography provided the backscattered power in the surrounding of 30m above the ground
   2. 30m TomoSAR power exhibits an excellent correlation with AGB
   3. Such an high correlation can be due to ground rejection

B. Interferometric ground notching
   1. Requires two InSAR images and a good DTM
   2. Ground level is notched out
   3. Power coming from a certain elevation is emphasized (depends on the normal baseline)
   4. Power of the ground notched image with emphasis around 30m above the ground exhibits a good sensitivity and correlation to AGB

C. Airborne ground notching
   1. Baseline variations lead to space varying performances
   2. Notch filter can be stabilized if more than two SLCs are available

D. Ongoing work
   1. Analyses on temporal decorrelation
   2. Single baseline equalization
   3. Topographic compensation
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Thanks for your attention!