Adaptive cancellation of ground or overlying volume responses using multi-baseline InSAR acquisitions: first application to BIOMASS data

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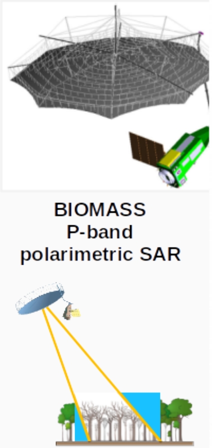
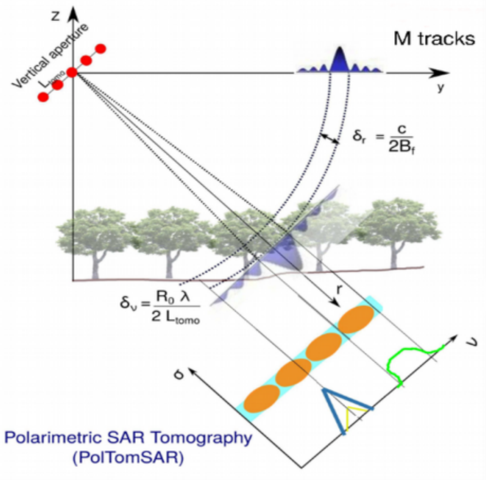
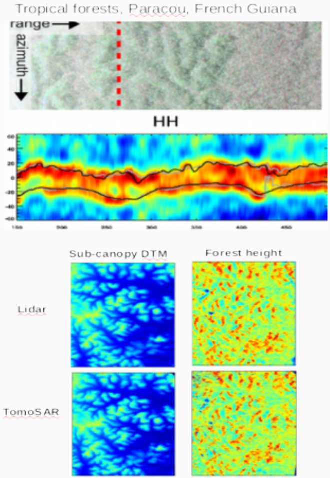
PolTomoSAR principle

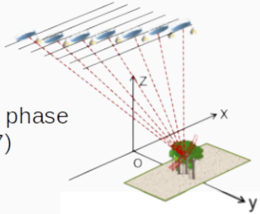


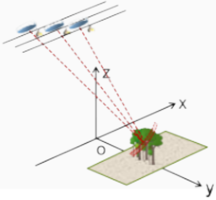




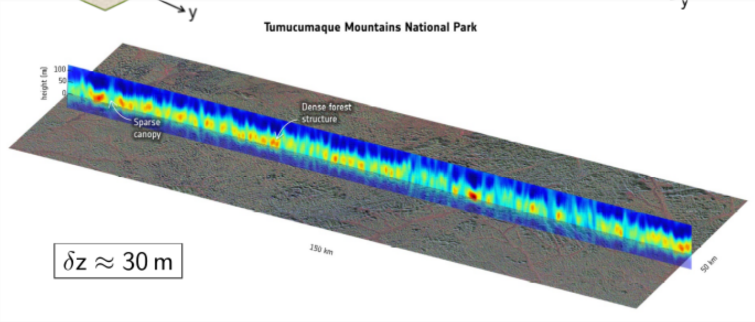
BIOMASS tomographic features

TomoSAR phase
(M=7)

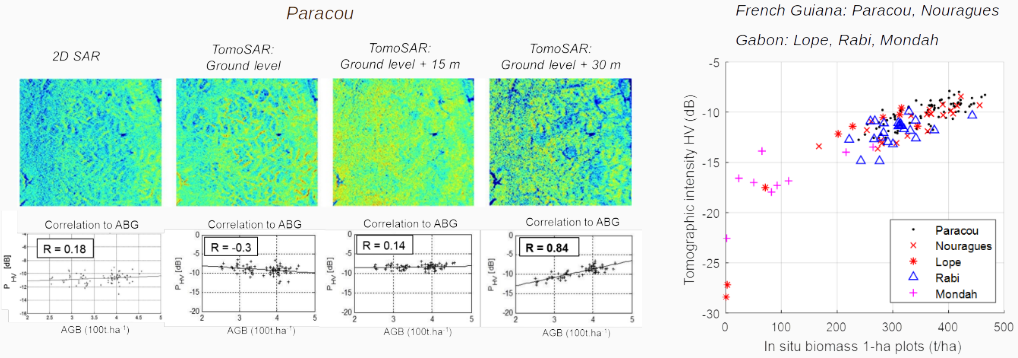




DB-InSAR phase
(M=3)



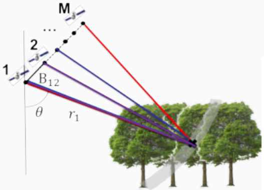
AGBD estimation using TomoSAR

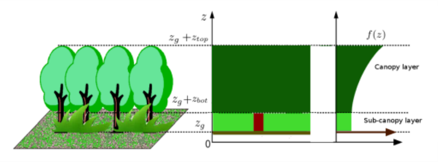


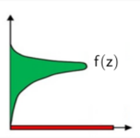
D. Ho Tong Minh et al., "Relating P-band SAR tomography to tropical forest biomass", TGRS, Feb. 2014.
Ride group, PoliMi, ESA study

- AGBD: well correlated with $I_{HV}(z = 30\ m)$
- Ground echo leakage mitigation $\Rightarrow$ Ground notching

Interferometric ground-notching



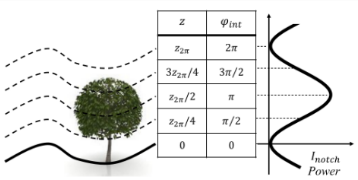


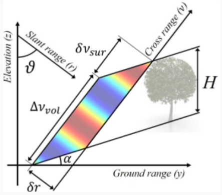


- Two-tap notching filter
- Filtered intensity

$$I_{GN-In} \simeq \int_{C(x_0, r_0)} f(z) \left| H_{GN-In}(z) \right|^2 dz$$

$$\left| H_{GN-In}(z) \right|^2 = \sin^2 \left(\frac{\Delta k_{z_{12}} (z - z_g)}{2} \right)$$

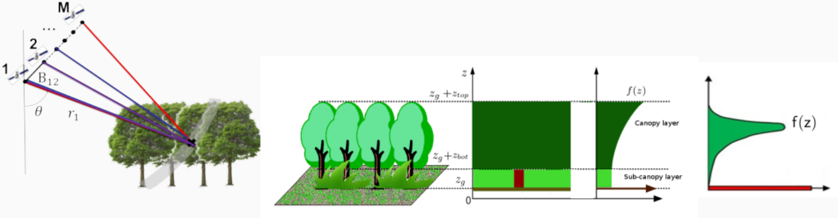




M. Mariotti d'Alessandro et al., TGRS, 2020

Idealy: $h_{amb} = 60\ m \Rightarrow \left| H_{GN-In}(30\ m) \right|^2 = 1$

Objective of SAR tomography



- Single-look complex MB-InSAR signal model

$$y_m \simeq \int_{C(x_0, r_0)} s(z) e^{jk_{z_m} z} dz + \epsilon_m \quad m = 1, \dots, M$$

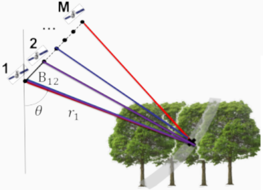
- Second-order statistics:

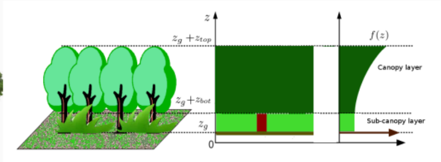
$$[\mathbf{R}]_{mn} = \mathrm{E}(y_m y_n^*) = \boxed{\rho(\Delta k_{z_{mn}}) \simeq \int_{C(x_0, r_0)} f(z) e^{j\Delta k_{z_{mn}} z} dz + \sigma_\epsilon^2 \delta_{m-n}}$$

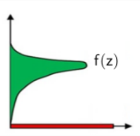
- Objective: estimate $f(z)$ from multiple acquisitions (spectral sampling)

$$\boxed{\{\rho(\Delta k_{z_{mn}})\}_{m,n=1}^{M} \longrightarrow \hat{f}(z)}$$

Non-parametric spectral estimation as a constrained optimization problem







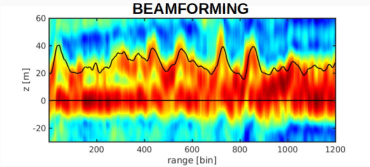
- Spectral estimation: linear filter $\mathbf{h} \in \mathbb{C}^M$

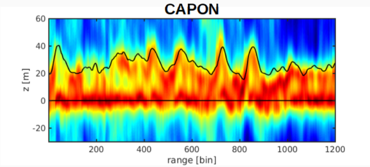
$$\hat{f}(z_0) = \mathbf{h}^H(z_0)\mathbf{R}\mathbf{h}(z_0)$$

- Power minimization with gain constraint

$$\mathbf{h}(z_0) = \arg\min_{\mathbf{h}} \left(\mathbf{h}^H\mathbf{M}\mathbf{h}\right) s.t.\, \mathbf{h}^H\mathbf{a}(z_0) = 1$$

- $\mathbf{M} \propto \mathbf{I} \Rightarrow$ Beamformer (DFT)
- $\mathbf{M} = \mathbf{R} \Rightarrow$ Capon's adaptive solution





- Transfer function

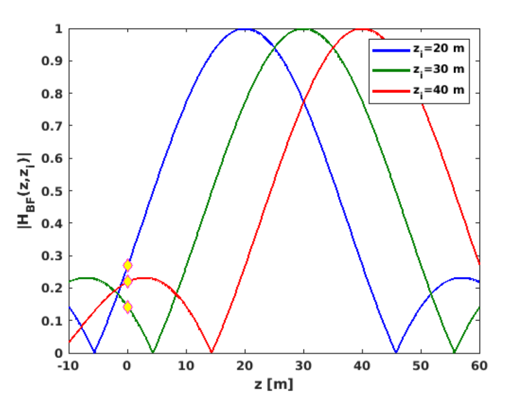
$$H(z, z_0) = DFT(h(z_0))$$

- Estimated (noise-free) reflectivity density

$$\hat{f}(z_0) = \int f(z)|H(z; z_0)|^2 dz$$

- Ground to Volume power Leakage

$$GVL(z_g, z_v) = \frac{|H(z_g; z_v)|^2}{|H(z_v; z_v)|^2}$$



A solution: Ground-Notched tomographic focusing

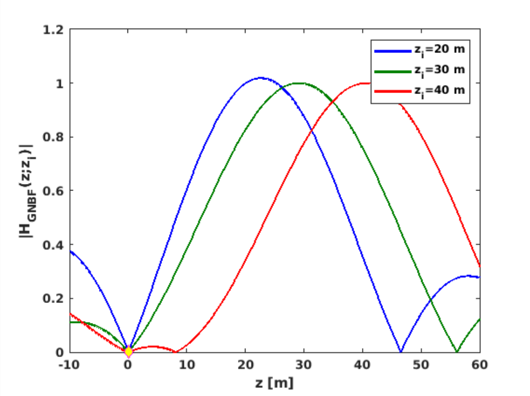
- Additional null-gain constraint

$$\mathbf{h}(z_0) = \arg\min_{\mathbf{h}} \left(\mathbf{h}^H \mathbf{M}\mathbf{h}\right)$$

$$s.t. \begin{cases} \mathbf{h}^H \mathbf{a}(z_0) = 1 \\ \mathbf{h}^H \mathbf{a}(z_g) = 0 \end{cases}$$

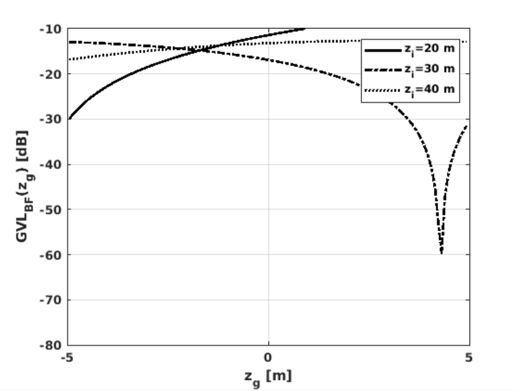
- Closed-form solutions (BF & CP)
  - $h_{GN-BF}(z) = g_c(z, z_g)\mathbf{\Pi}^{\perp}_{\mathbf{a}(z_g)}\mathbf{a}(z)$
  - $h_{GN-CP}(z) = \tilde{g}_c(z, z_g)\mathbf{\Pi}^{\perp}_{\widetilde{\mathbf{a}}(z_g)}\widetilde{\mathbf{a}}(z)$

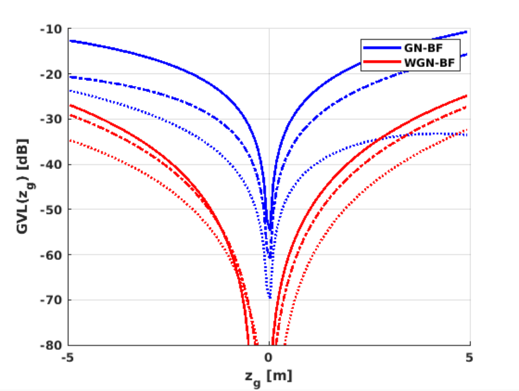
- No additional complexity



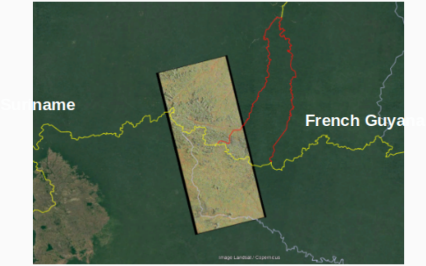
Tomographic imaging with a wide ground notch

- Adding notches or using a flatter notching function
  ⇒ requires additional DoFs, not adapted to small stack cases
- Spectral tapering and CP method
  ⇒ widened nulls & preserved selectivity

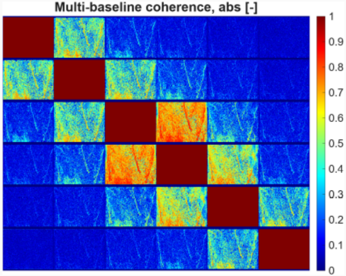


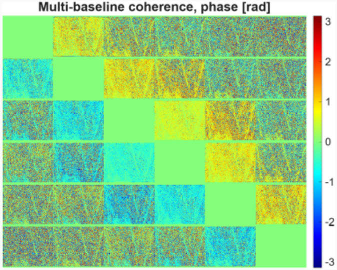


The Tumucumaque park test site

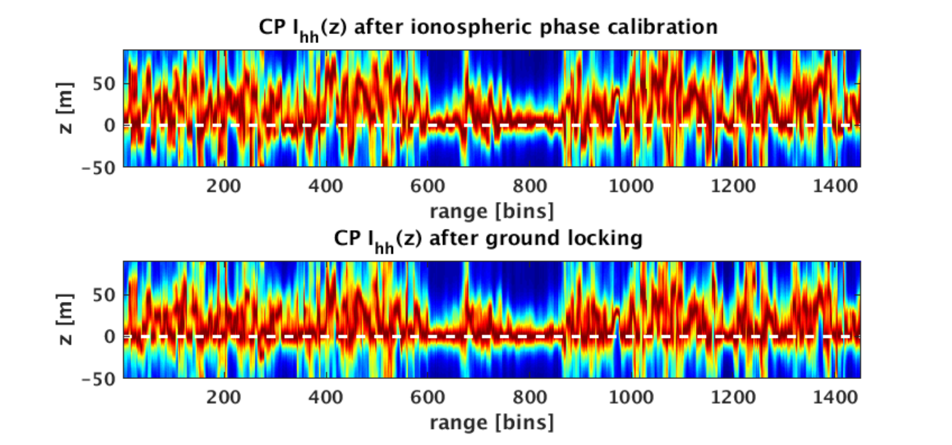


Coordinates: 2° 20' N, 54° 25' W



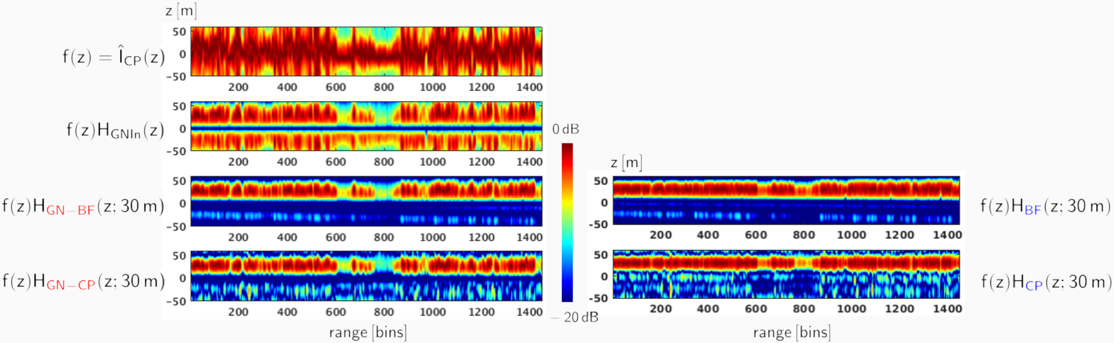


Ground locking



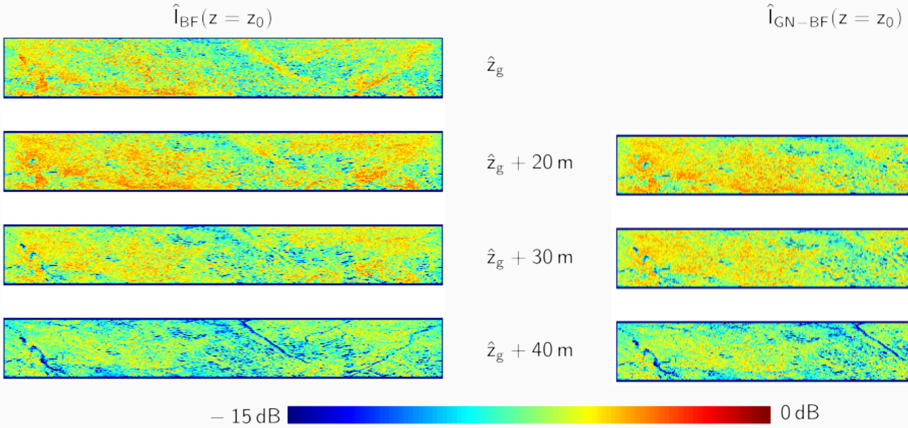
- Simple DTM-free ground locking technique (see presentation by F. Salvaterra):
- Critical step for Ground Notching !

Ground-Notched tomography (M=6): filtering features



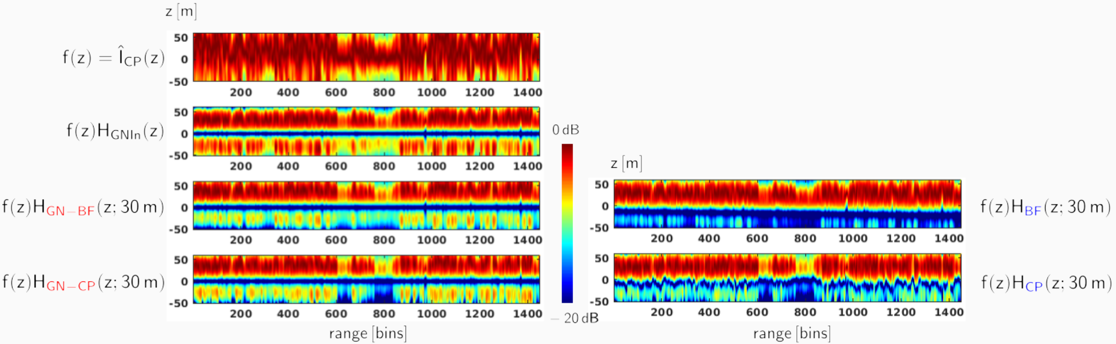
- Adaptive Ground-Notching improves
  - GVL
  - adaptivity in elevation

Ground-Notched tomography: spatial features



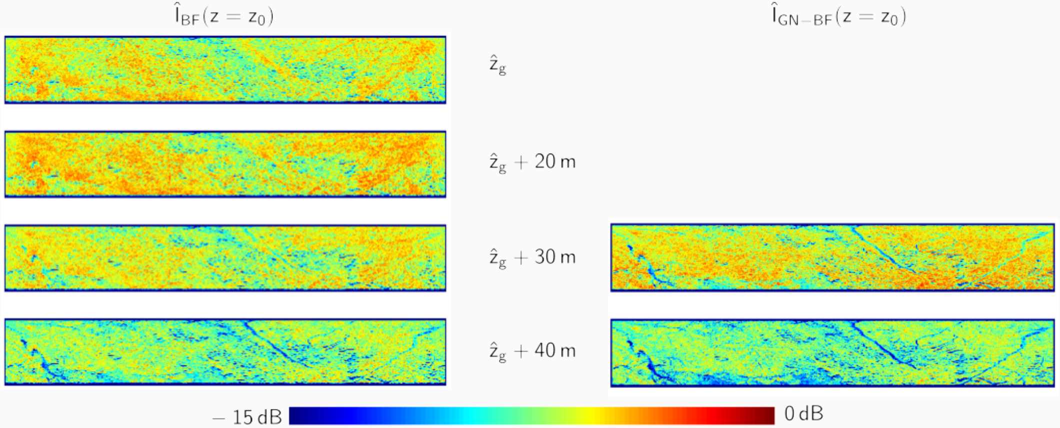
- Unbiased estimates with reduced GVL

Ground-Notched tomography for DB-InSAR configuration (M=3): filtering features



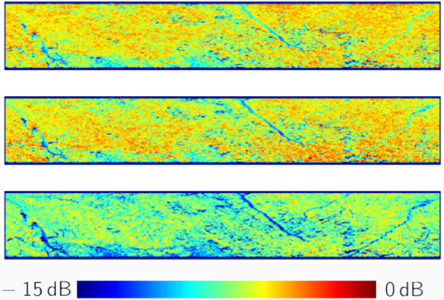
- Unconstrained TomoSAR → high GVL ($\delta z \approx 60\ m$)
- GN-BF (3 images) vs. GN-In (2 images) $\longrightarrow$ selectivity improvement ($\approx 6 - 8\ dB$)

Ground-Notched tomography for DB-InSAR configuration (M=3): spatial features



- 3-image Unconstrained tomography ⇒ unacceptable GVL
- Ground-notched tomography ⇒ GVL mitigation

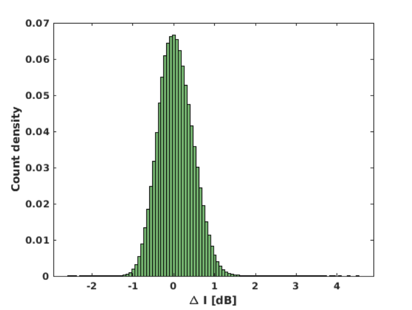
Ground-Notched tomography vs. Ground-Notched InSAR



$\hat{I}_{GN-In}$

$\hat{I}_{GN-BF}(\hat{z}_g + 30\,\mathrm{m})$

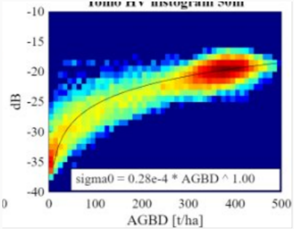
$\hat{I}_{GN-BF}(\hat{z}_g + 40\,\mathrm{m})$

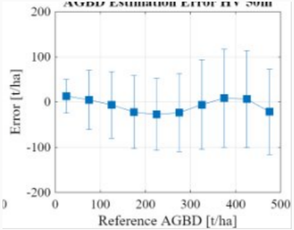


- 96% of estimates $\in [-1\,dB, +1\,dB]$ **@ GN-InSAR fixed elevation**
- Structured outliers: some local features may radically differ
- TomoSAR provides height adaptation: $\rightarrow$ application to various biomes (smaller trees . . .)

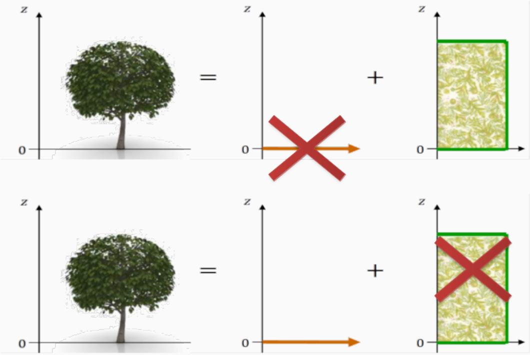
Some applications of tomographic notching

AGBD estimation in DB-InSAR mode





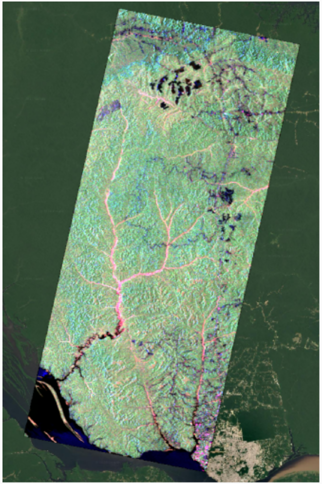
Ground vs. Canopy notching



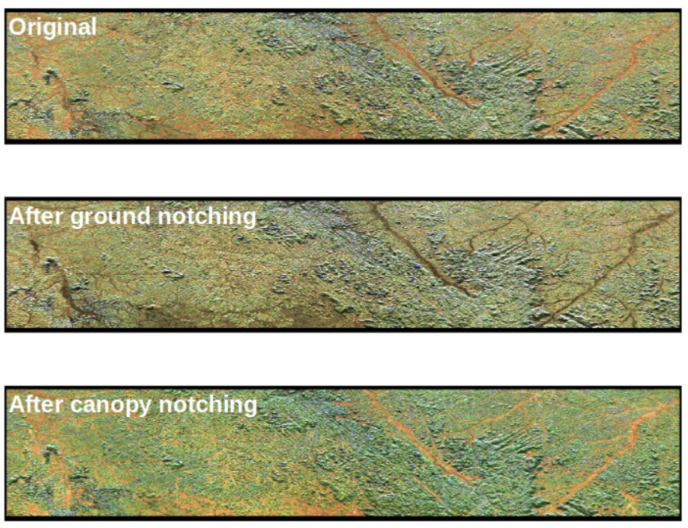
Polarimetric features of notched images

Tumucumaque national park, Amapá, Brazil

Manaus surroundings, Amazonas, Brazil

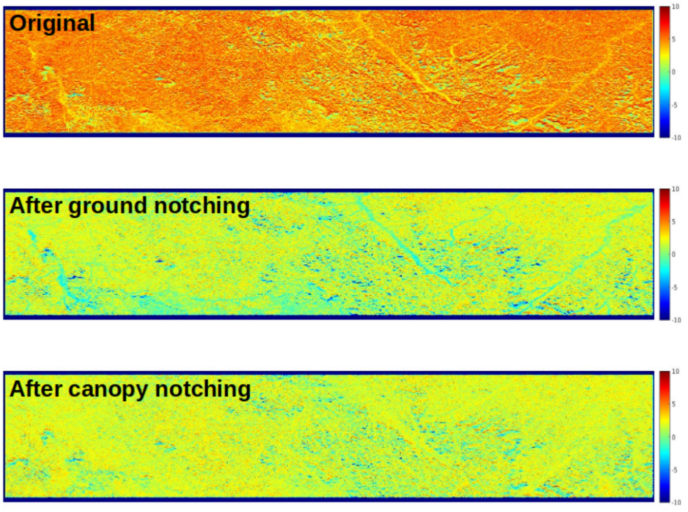


Tumucumaque: Pauli color-coded image



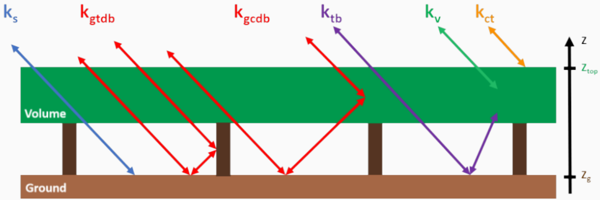
Ground Notching reveals hydrological network

Tumucumaque: Volume scattering (Arii's decomposition)

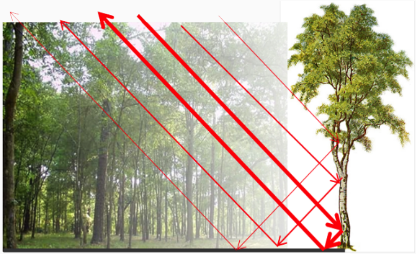


Significant volume reponse at ground level!

Ground-Canopy Volume-like DB scattering

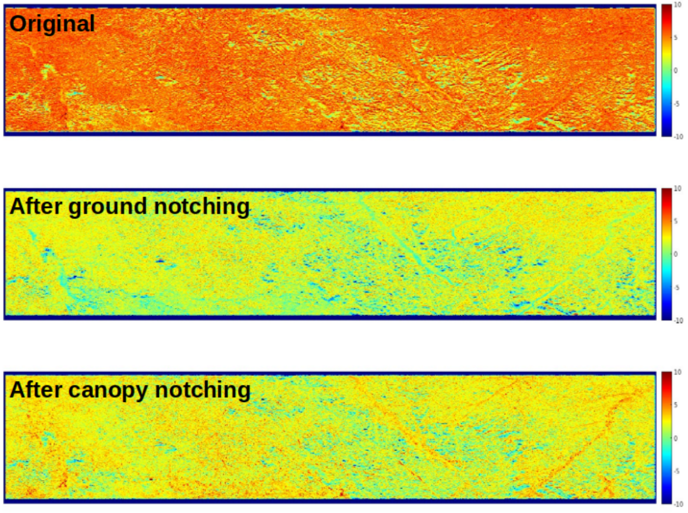


Abdo et al. RS, 2021


Mariotti d'Alessandro, TGRS, 2019

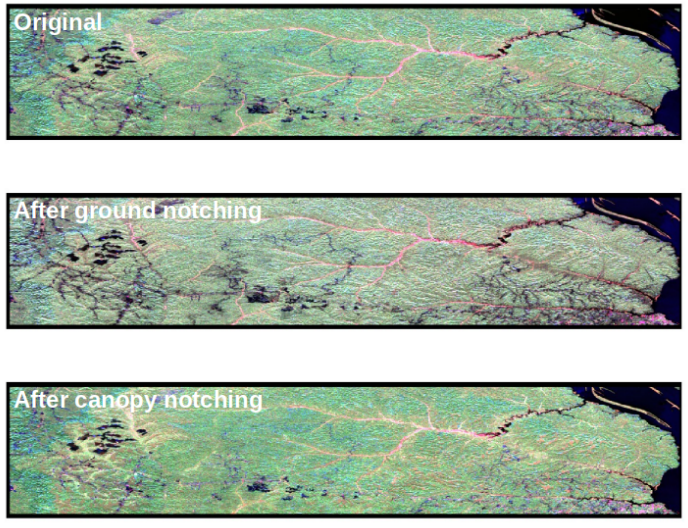
Volume component at ground level. Strong itensity in low density forest

Tumucumaque: Double-Bounce scattering (Arii's decomposition)



Canopy notching reveals ground DB features

Manaus: Pauli color-coded image



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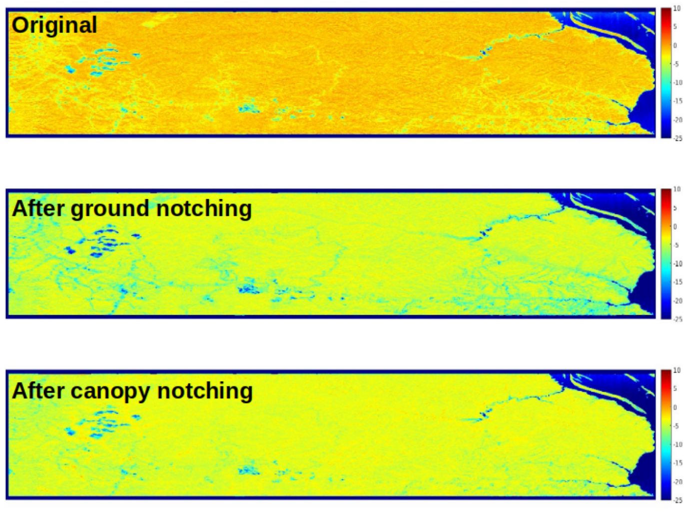

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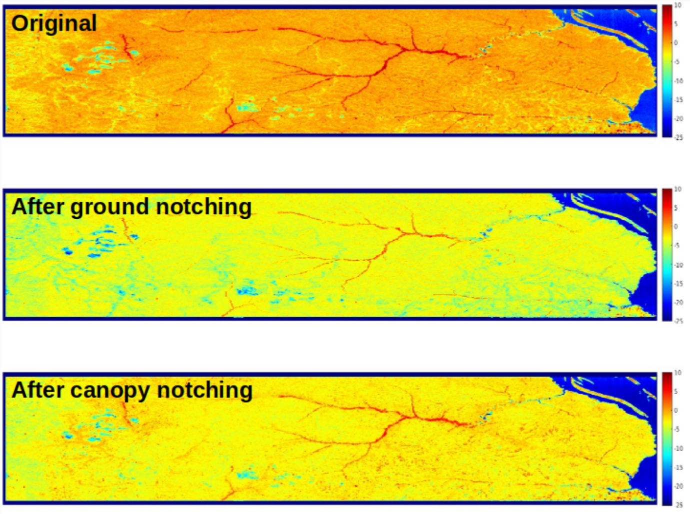
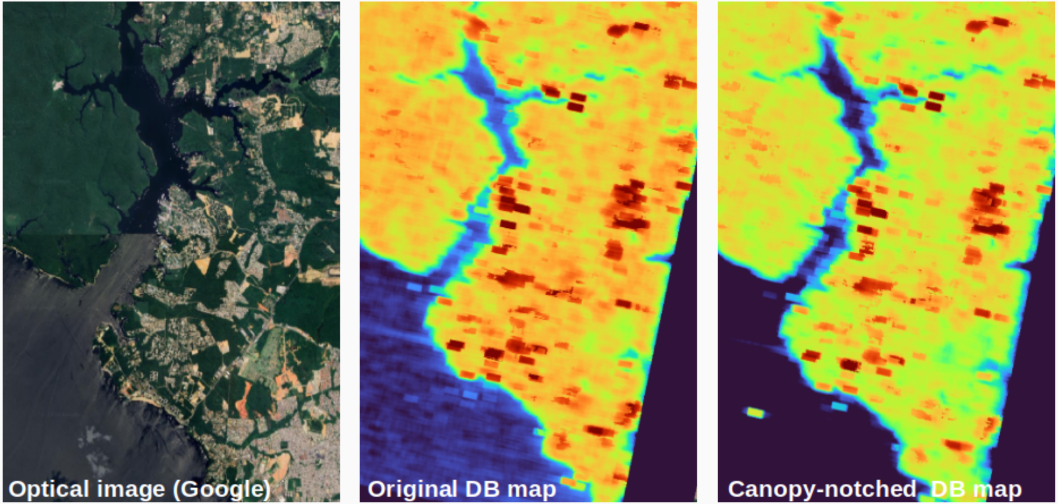


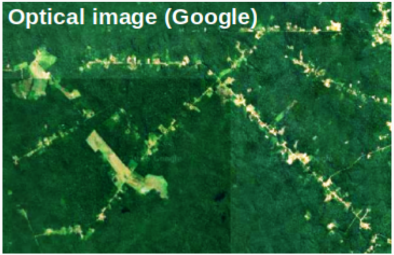
Canopy notching reveals ground DB features

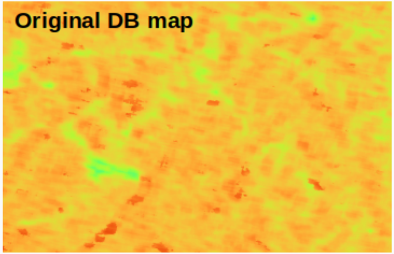
Looking below the forest cover using Canopy-notched PolTomo

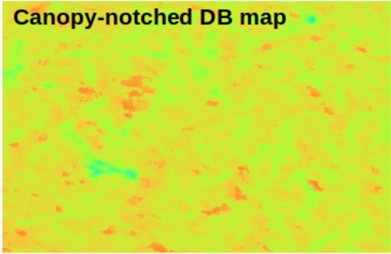


Canopy notching improves contrast

Looking below the forest cover using Canopy-notched PolTomo

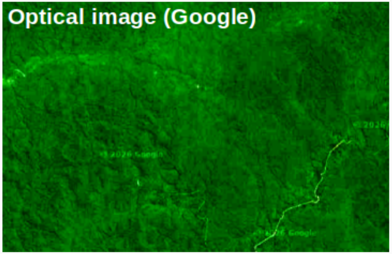


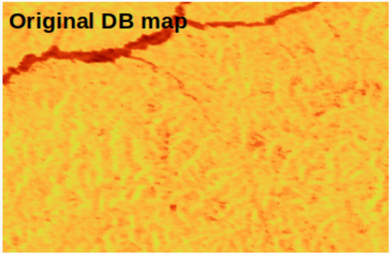


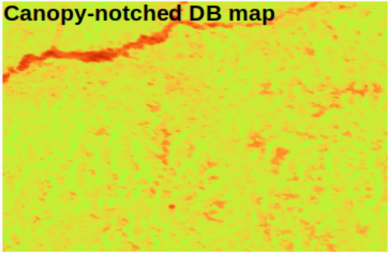


Canopy notching improves contrast ... and provides different DB features

Looking below the forest cover using Canopy-notched PolTomo







Canopy notching improves contrast ... and provides different DB features

Conclusions

- Ground-Notched InSAR generalized to Ground-Notched TomoSAR
  - isolation guaranteed by accurate ground locking
  - adaptive scanning in elevation
- Main application: AGBD etsimation in DB-InSAR mode
- Extension to canopy notching reveals
  - strong volume contribution at ground level
  - double-bounce PolSAR features at ground level:
    could be related to human activity or the presence of water (under investigation)