

Tropical Forest Parameter Estimation Using P-band SAR Tomography In Both Airborne And Simulated BIOMASS Configurations

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PollnSAR 2023, Toulouse, France

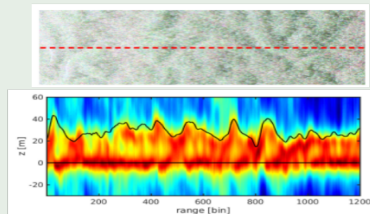
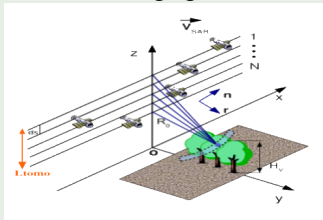
Background: BIOMASS mission

Objectives: estimate L2 products (forest height and DTM)

- High-resolution airborne data
- Simulated BIOMASS low-resolution configuration

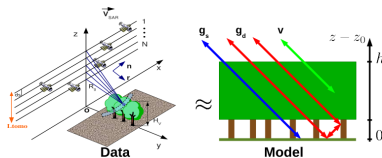
Techniques: PolTomoSAR (SKP vs single-pol low-rank model estimation)

- 3-D forest imaging

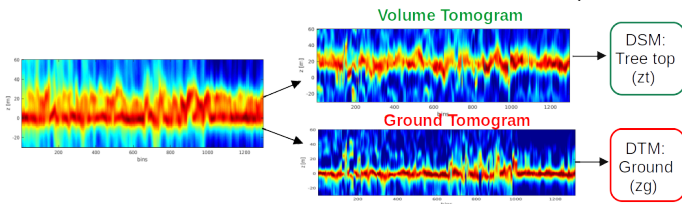


- Forest parameter estimation
- Separation of volume and ground contributions

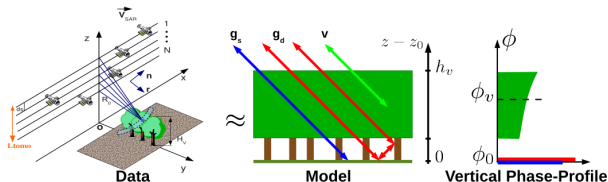
Ground-Volume Separation using PolTomoSAR



- VOG-like response: $\mathbf{y}(l) = \mathbf{y}_g(l) + \mathbf{y}_v(l)$
- SKP-2 PolTomoSAR modeling: $\mathbf{R} = E(\mathbf{y}\mathbf{y}^H) = \mathbf{C}_g \otimes \mathbf{R}_g + \mathbf{C}_v \otimes \mathbf{R}_v$
- Volume-ground separation using SKP-2 decomposition (Tebaldini 2009)



Single polarization low-rank model-based tomography



- MB-InSAR coherence:

$$\mathbf{R}_{i,j} = \gamma(k_{z_{i,j}}) = \frac{\int f(z) \exp^{jk_{z_{i,j}}z} dz}{\int f(z) dz}$$

- Low-rank modeling: $f(z) = f_g(z) + f_v(z)$
 - $f_g(z)$: Dirac pulse
 - $f_v(z)$: Narrow exponential shape
- Covariance matrix fitting

$$\begin{aligned} \hat{\boldsymbol{\theta}} &= \arg \min \|\hat{\mathbf{R}} - \mathbf{R}\|_W^2 \\ \hat{\boldsymbol{\theta}} &\rightarrow \hat{z}_t, \hat{z}_g, \hat{h}_v \end{aligned}$$

TropiSAR Campaign, 2009

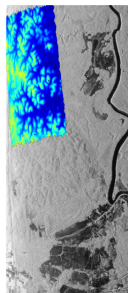
- Paracou site, French Guiana
- ONERA SETHI
- 6 fully pol images
- $\delta_{az} = 1.5\text{m}$, $\delta_{rg} = 1.2\text{m}$, $\delta_z = 12.5\text{m}$
- Validation data: Lidar (ALS)
- Processing: 200 looks
- Error statistics: refer to ALS



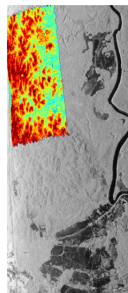
(a) Optical Image



(b) SAR Image

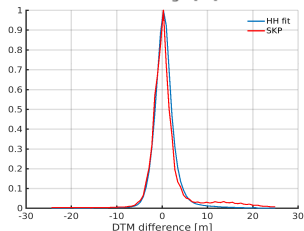
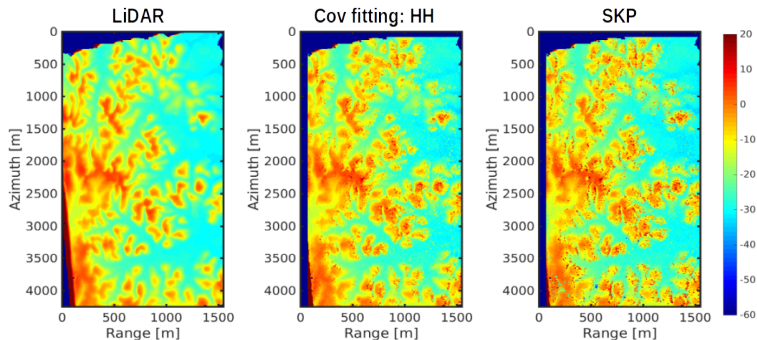


(c) Lidar DTM



(d) Lidar DSM

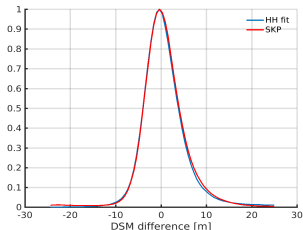
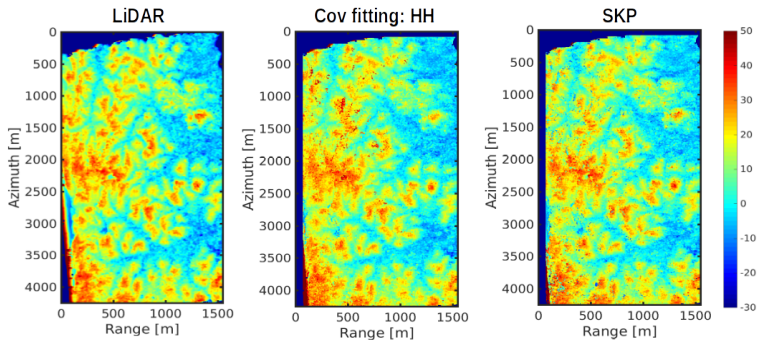
DTM (terrain elevation) estimation using airborne data



| Tomo - Lidar | bias | sdev |
|--------------|--------|--------|
| Cov fit | 0.10 m | 1.26 m |
| SKP | 0 m | 1.67 m |

- Similar good performance
- SKP: potential instability, a few large errors

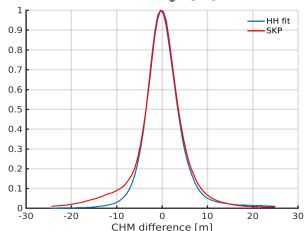
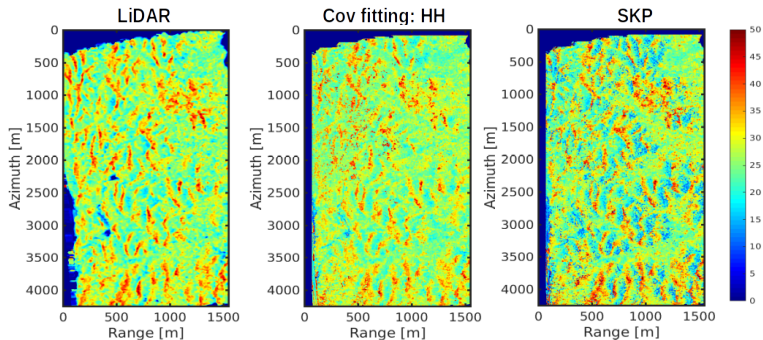
DSM (tree top) estimation using airborne data



| Tomo - Lidar | bias | sdev |
|--------------|---------|--------|
| Cov fit | -0.08 m | 2.64 m |
| SKP | -0.02 m | 2.67 m |

- SKP & cov fitting: perform in a similar way

CHM (tree height) estimation using airborne data



| Tomo - Lidar | bias | sdev |
|--------------|---------|--------|
| Cov fit | -0.18 m | 2.40 m |
| SKP | -0.02 m | 2.83 m |

■ SKP: less stable

- Bandwidth:

Airborne $B = 70\text{MHz} \Rightarrow$ BIOMASS $B = 6\text{MHz}$

- Rg-Az resolution:

Airborne $1.5\text{m} \times 1.2\text{m} \Rightarrow$ BIOMASS $25\text{m} \times 12.5\text{m}$

- Covariance matrix estimation:

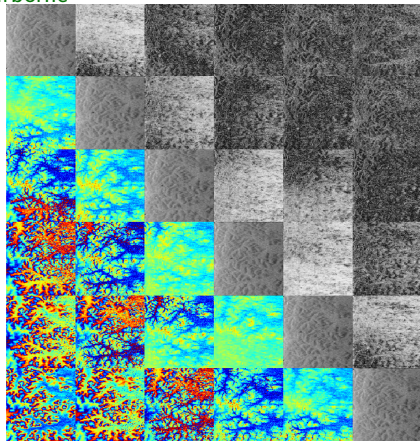
4×16 looks $\Rightarrow 200\text{m} \times 200\text{m}$ in ground

Expected impacts

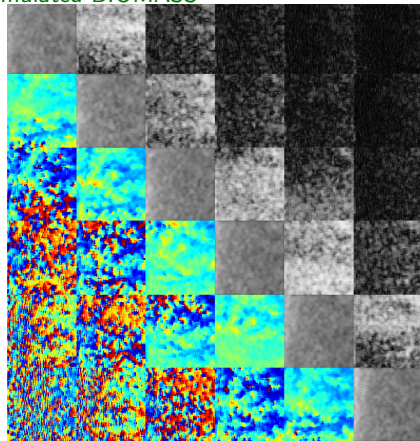
- Loss of high-resolution details ($200\text{m} \times 200\text{m}$)
- Range decorrelation: degraded vertical resolution

Interferometric phase and coherence

Airborne



Simulated BIOMASS



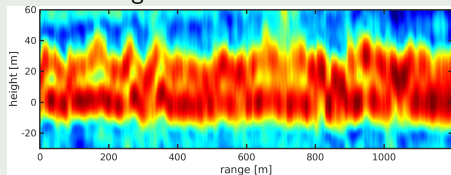
Simulated BIOMASS data:

- Reduced coherence
- Interferometric phase fluctuations & artefacts

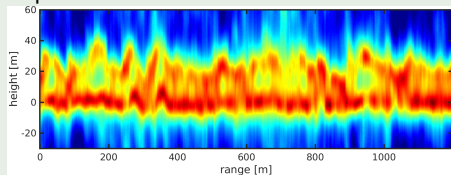
Airborne vs simulated BIOMASS tomographic focusing

Airborne

Beamforming

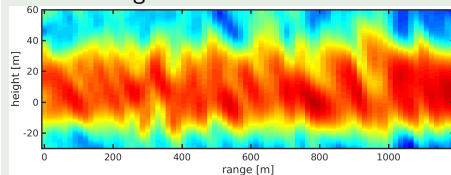


Capon

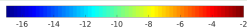
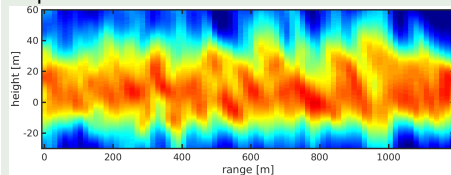


Simulated BIOMASS

Beamforming

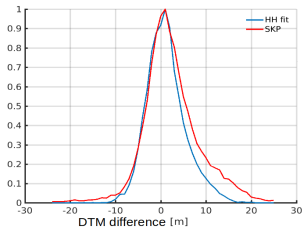
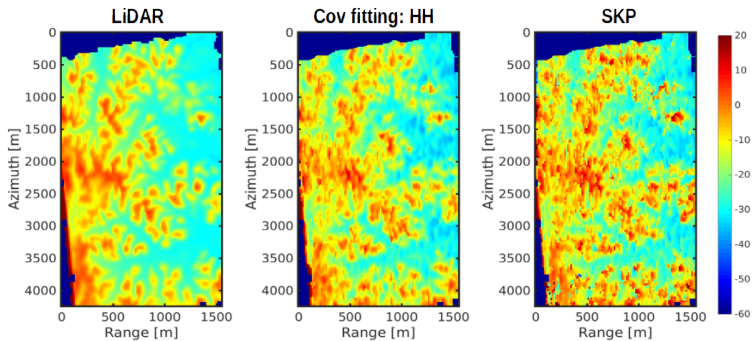


Capon



- Simulated BIOMASS: deteriorated resolution but preserved structural information

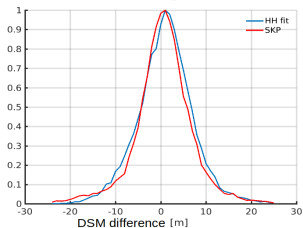
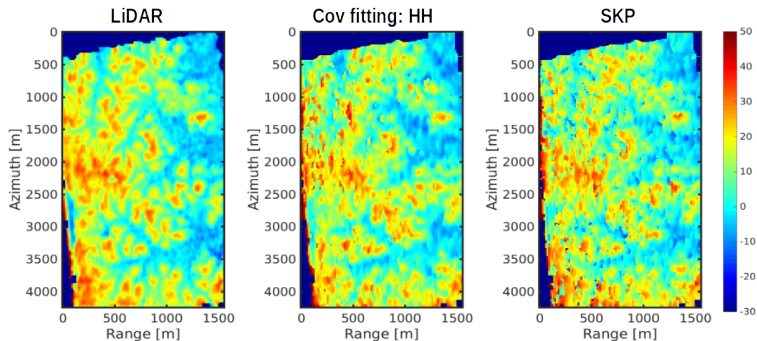
DTM (terrain elevation) estimation using simulated BIOMASS data



| Tomo - Lidar | bias | sdev |
|--------------|---------------|--------|
| Cov fit | 0.33 m | 2.67 m |
| SKP | 1.10 m | 3.63 m |

- SKP: overestimate ground elevation, some systematic large errors

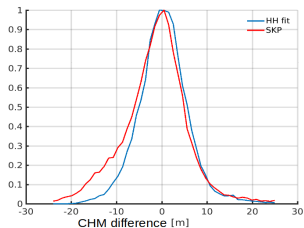
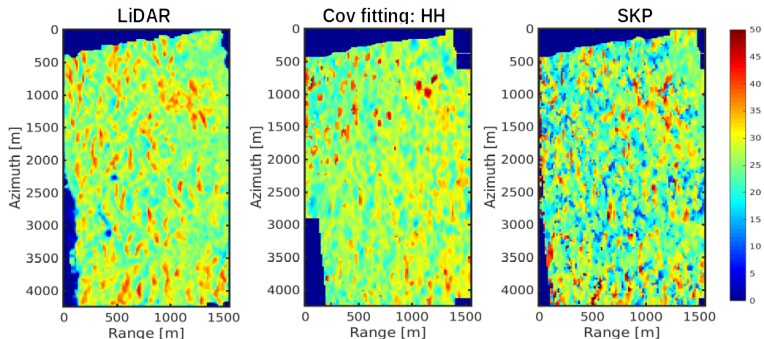
DSM (tree top) estimation using simulated BIOMASS data



| Tomo - Lidar | bias | sdev |
|--------------|--------|--------|
| Cov fit | 0.32 m | 3.73 m |
| SKP | 0.21 m | 3.51 m |

■ Similar performance

CHM estimation using simulated BIOMASS data

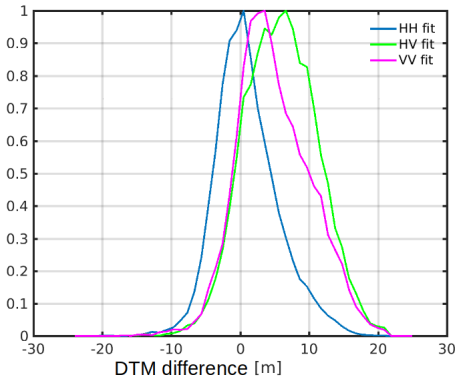


| Tomo - Lidar | bias | sdev |
|--------------|---------|--------|
| Cov fit | -0.20 m | 3.31 m |
| SKP | -1.42 m | 4.21 m |

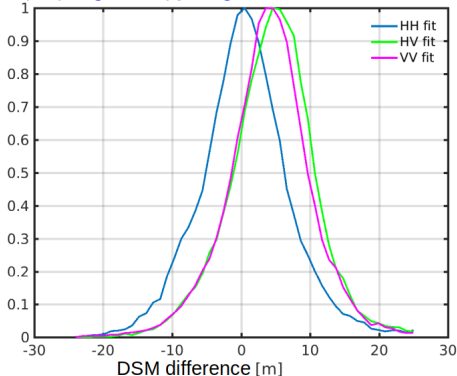
- SKP: underestimate CHM with larger errors
- Cov-fitting: overall smaller errors & uncertainty

Cov-fitting estimation errors for different polarizations

Tomo DTM- Lidar DTM



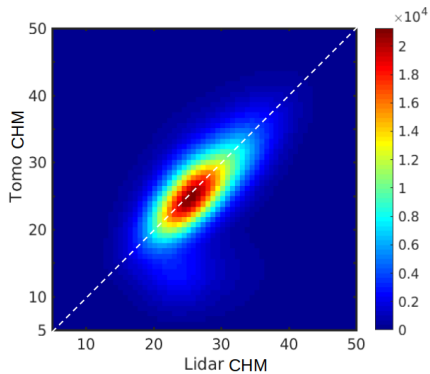
Tomo DSM- Lidar DSM



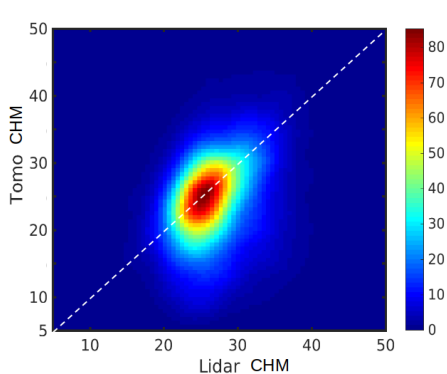
- Over all lexicographic polarimetric channels, HH provides the best estimates, quasi-null bias
- HH is able to catch both ground response (SB, DB) & canopy response (volume diffusion)

2D CHM estimation histograms

Airborne data



Simulated BIOMASS data



P-band SAR tomography over Temperate forests

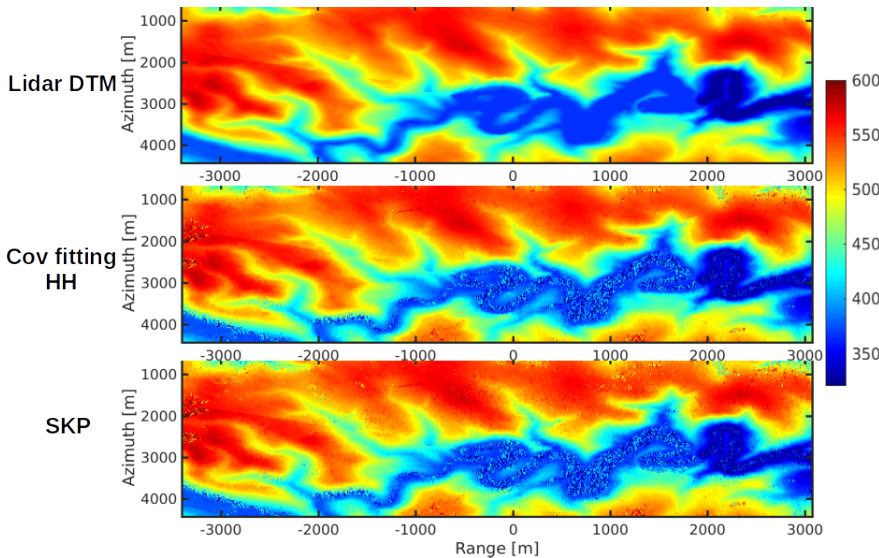
TomoSens Campaign, 2020

- Kermeter site, Germany
- MetaSensing
- Full-pol 28 images
- 6 images selected for tomo processing
- $\delta_{az} = 0.5\text{m}$, $\delta_{rg} = 1.5\text{m}$, $\delta_z = 16\text{m}$
- Validation data: Lidar

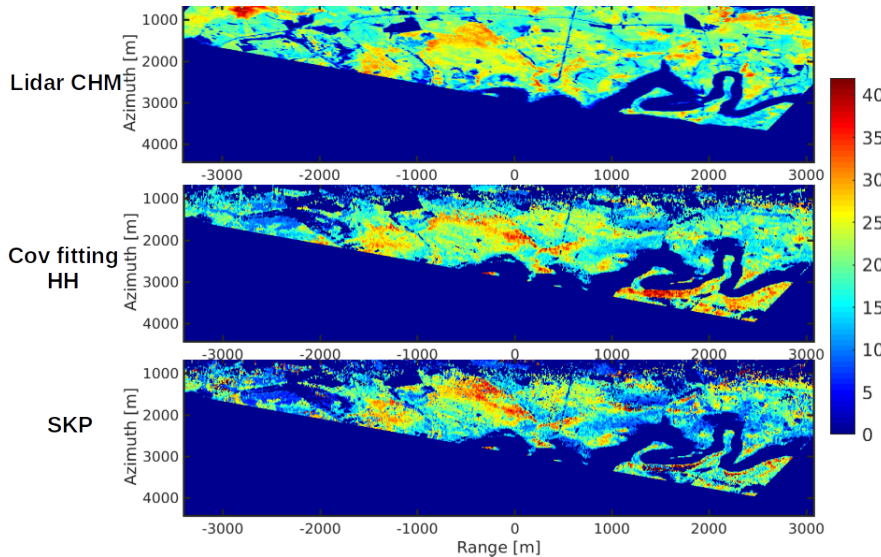


Courtesy: Tebaldini IGARSS 2021

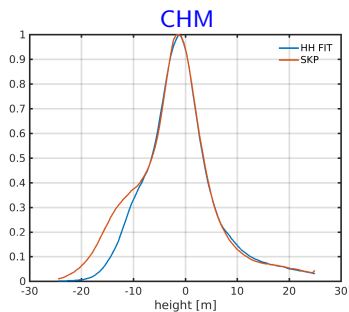
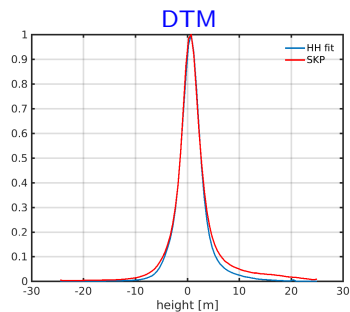
DTM (terrain elevation) estimation



CHM (tree height) estimation



Estimation errors



| Tomo - Lidar | bias | sdev |
|--------------|--------|--------|
| Cov fit | 0.41 m | 1.50 m |
| SKP | 0.5 m | 1.99 m |

| Tomo - Lidar | bias | sdev |
|--------------|---------|--------|
| Cov fit | -1.40 m | 4.20 m |
| SKP | -2.03 m | 4.99 m |

- Over temperate forests: excellent DTM, some uncertainty for CHM
- Cov-fitting: never worse and sometimes better than SKP.

Single-polarization covariance fitting approach

- Airborne HR data: equivalent to SKP
- Simulated BIOMASS data: better than SKP

Future work

- Model-based approach with some improved vertical structure model, e.g. by incorporating decorrelation effects
- Simulation of BIOMASS-like data over other tropical sites, and application of DTM and CHM estimation

Thank you for your attention!