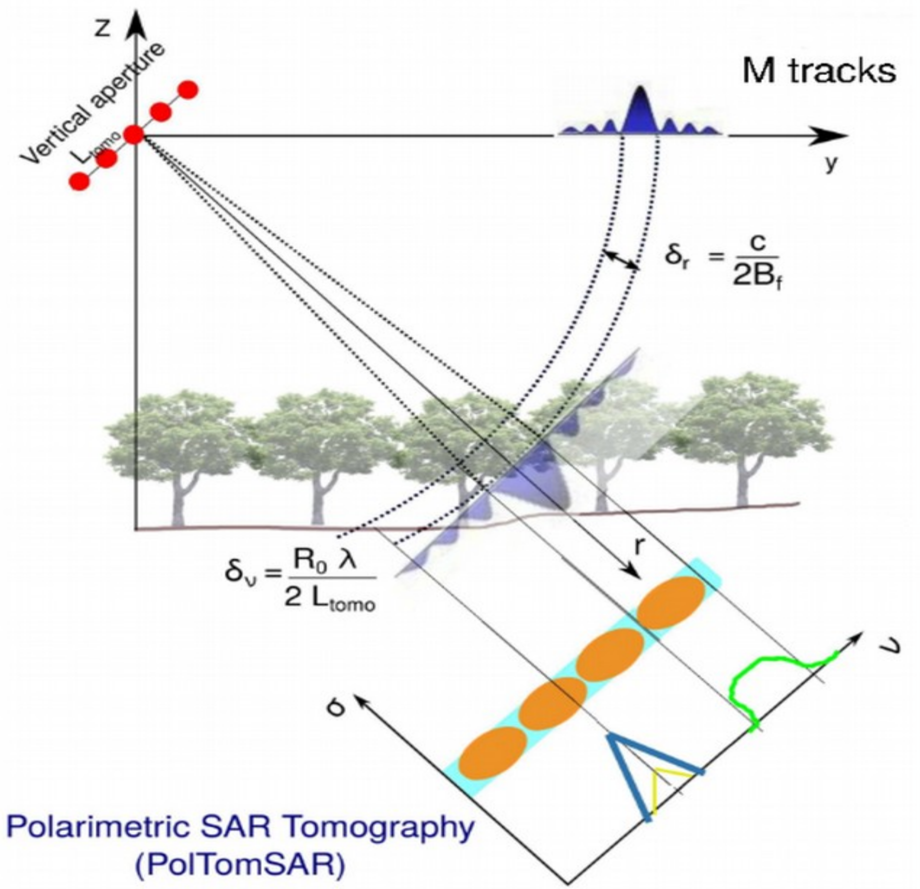
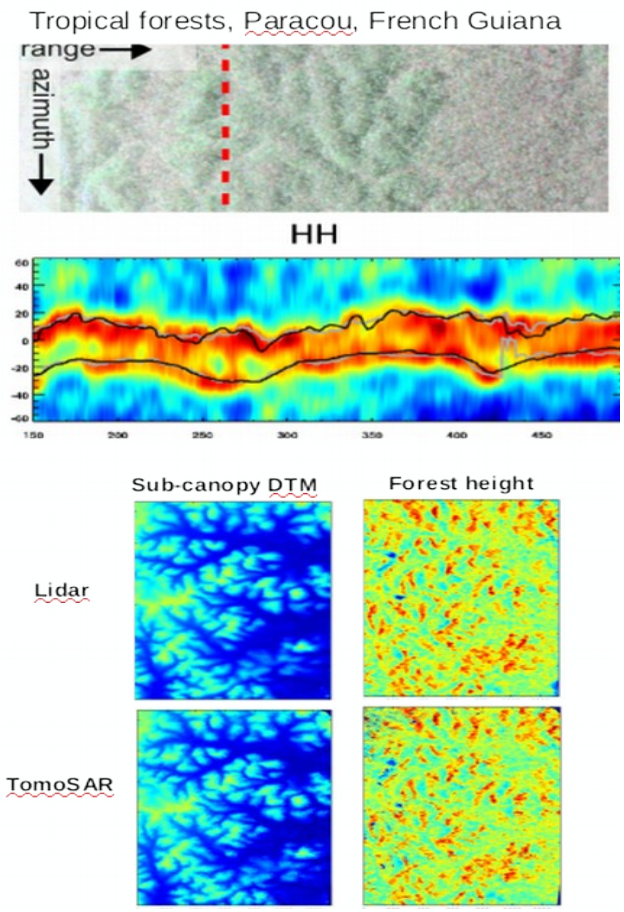
Performance limits of SAR Tomography for the characterization of of tropical forests measured in the BIOMASS configuration

L. Ferro-Famil[1,2], Y. Huang[2,3], P.A. Bou[2,4], S. Tebaldini[5], L. Villard[2], T. Koleck[2], T. Le Toan[2]

[1] ISAE-SUPAERO, University of Toulouse, France
[2] CESBIO, University of Toulouse, France
[3] IETR, University of Rennes, France
[4] ONERA, France
[5] DEIB, Politecnico di Milano, France

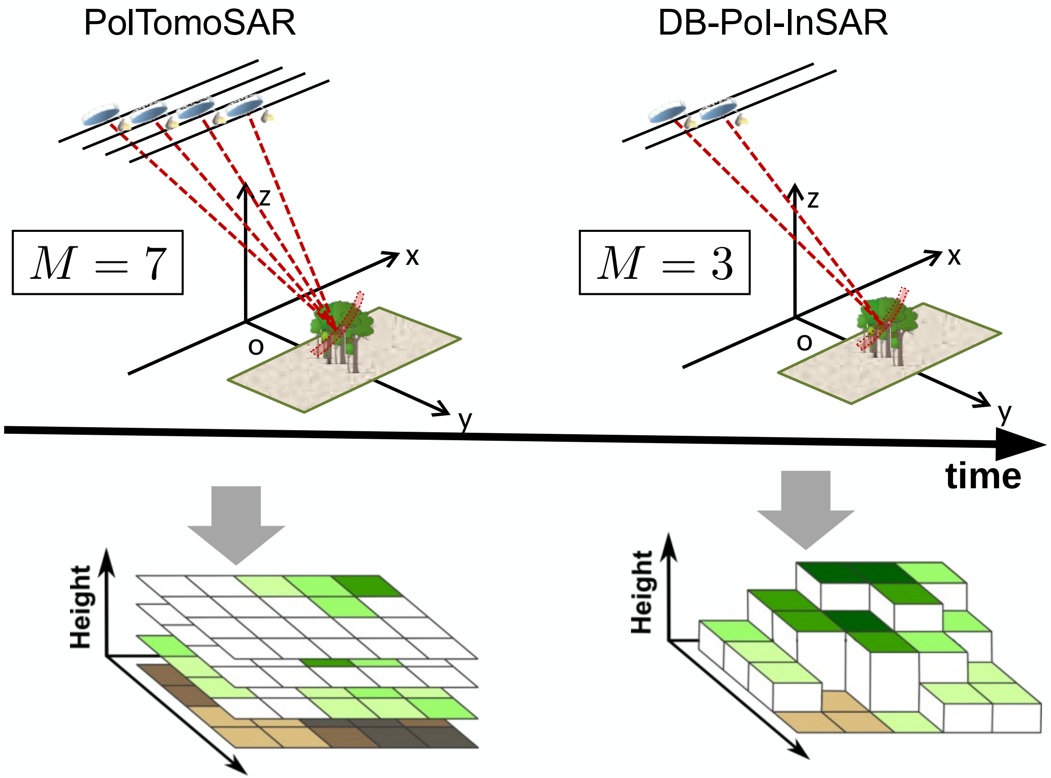
$$\delta z \propto \frac{1}{L_{tomo}} \approx \frac{z_{amb}}{M}$$





Tomographic Phase:
7 x 3-day repeat
15 months for global coverage

Interferometric Phase:
3 x 3-day repeat; 7 months for global coverage
≈ 4 years time series

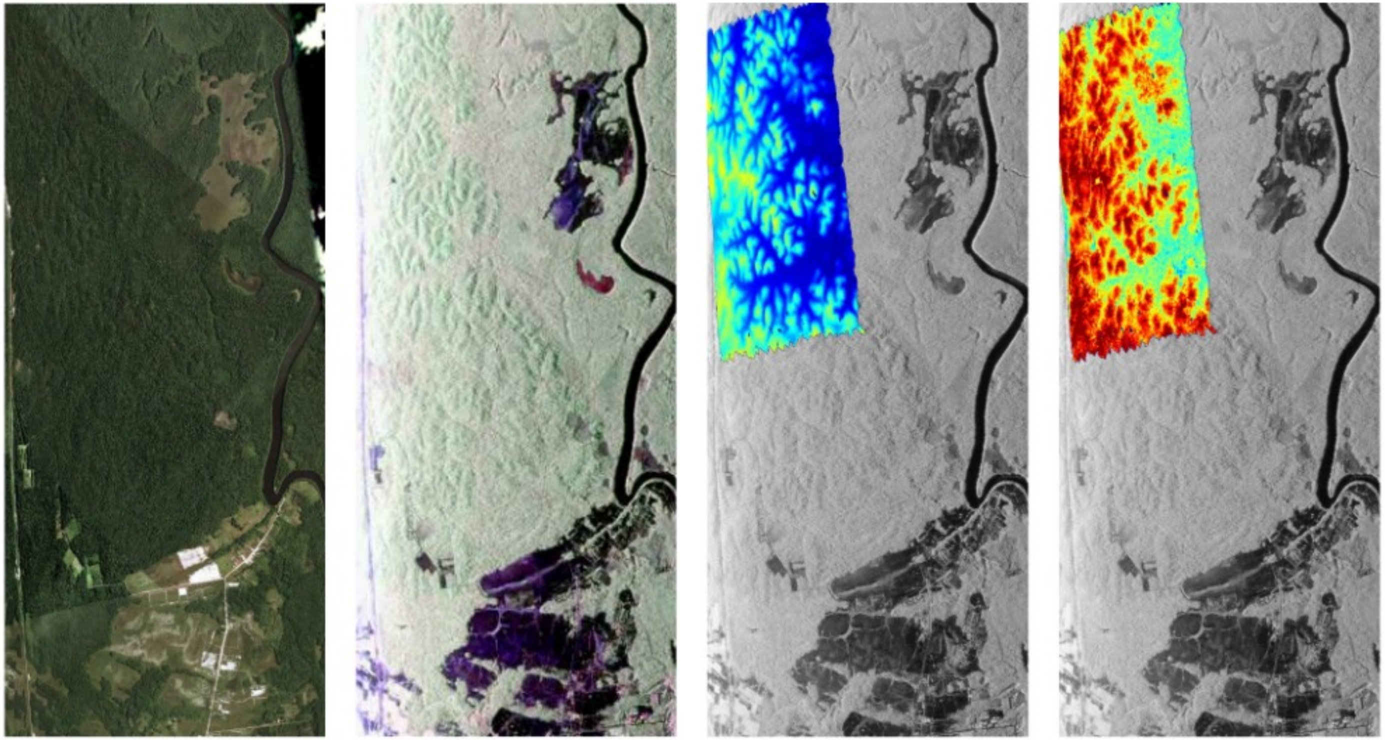


Objectives

- **Performance quantification tool**
  → Minimal achievable estimation uncertainty
- **Key forest parameters**
  → DTM, FH, (AGB proxy)
- **Assess simulated BIOMASS configuration**
  → Airborne vs BIOMASS resolutions
- **Synergistic use of BIOMASS modes**
  → Performance improvement using priors

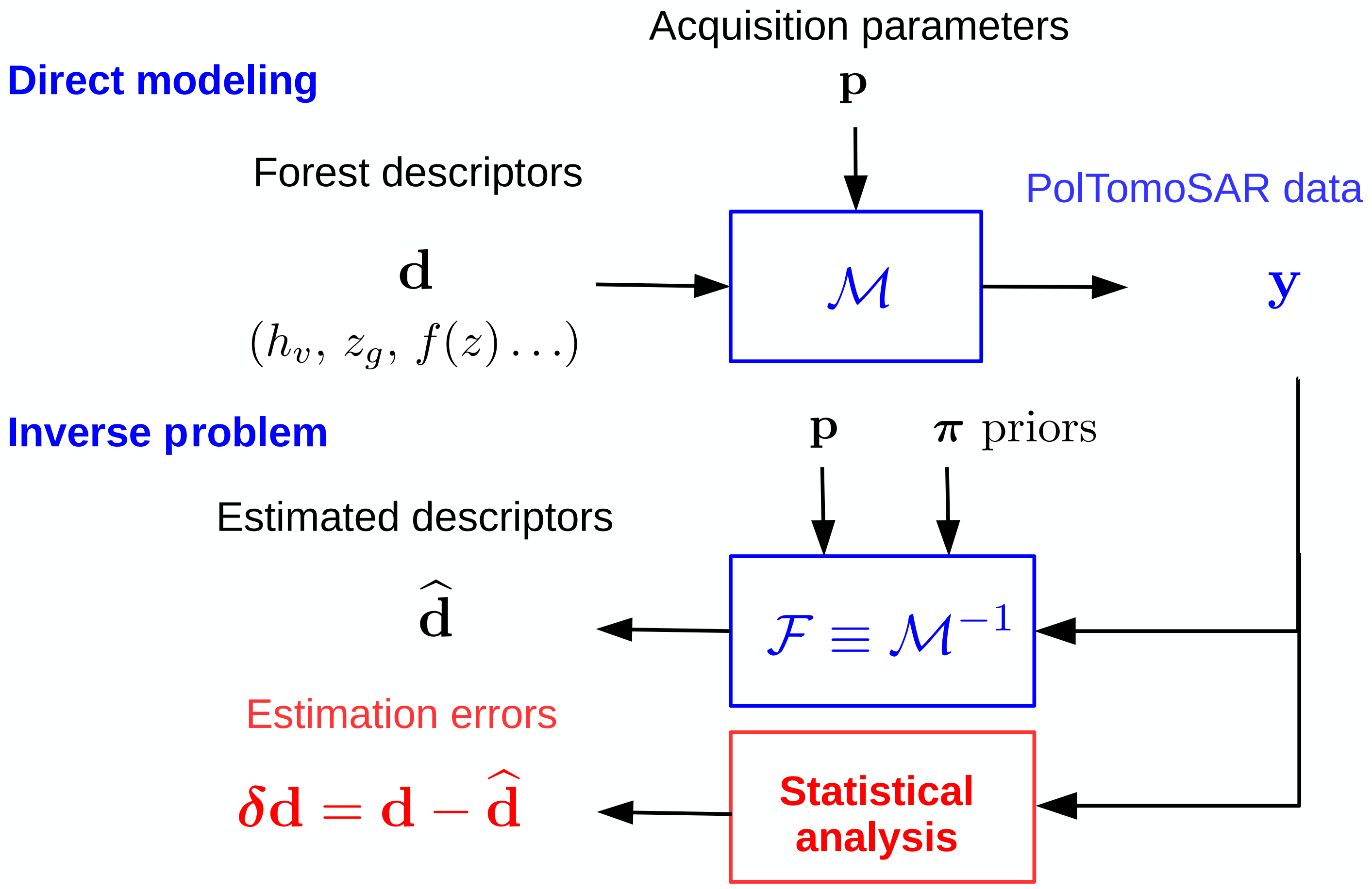
Evaluation data set

- TropiSAR Campaign, 2009
- ONERA SETHI
- P-Band
- 6 tracks
- $\delta_{az} = 1.245m$
  $\delta_{rg} = 1m$
- $\delta_z = 12.5m$
- Ground truth
  - LiDAR data
  - Biomass measurements for 16 ROIs



(a) Optical Image (b) SAR Image (c) Lidar DTM (d) Lidar DSM

Simulation of BIOMASS data



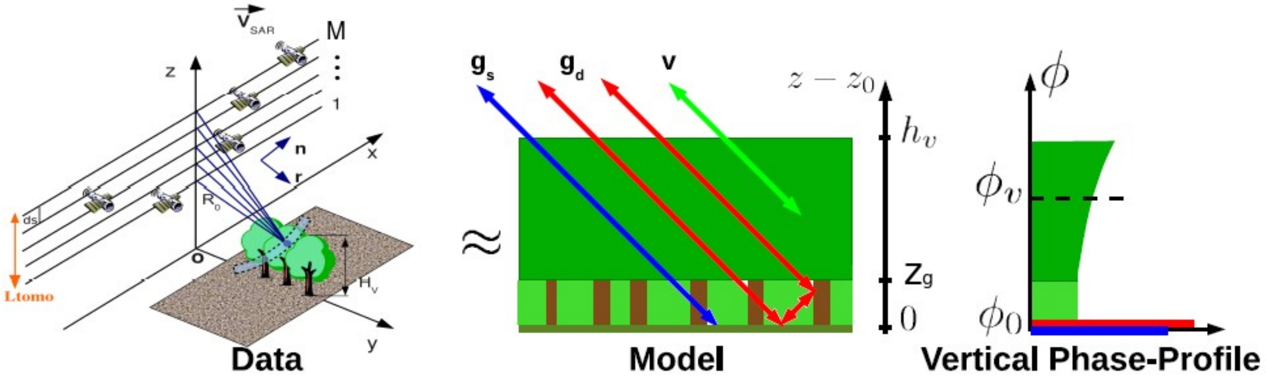
What is needed

- Valid direct model
- Forest configuration & acquisition conditions
- Potential priors
- Theoretical statistical analysis

↓

minimal achievable uncertainty of parameter estimates

Direct Model: Random Volume over Ground



- Vertical structure: $f(z) = f_g(z) + f_v(z)$

- Independent scattering mechanisms: $I = \int f(z)\mathrm{d}z = I_g + I_v$

- Interferometric coherence:

$$\gamma = \frac{\int f(z) e^{jk_z z}\mathrm{d}z}{I} = L\,\gamma_v + (1-L)\,\gamma_g, \qquad L = \frac{I_v}{I_v + I_g}$$

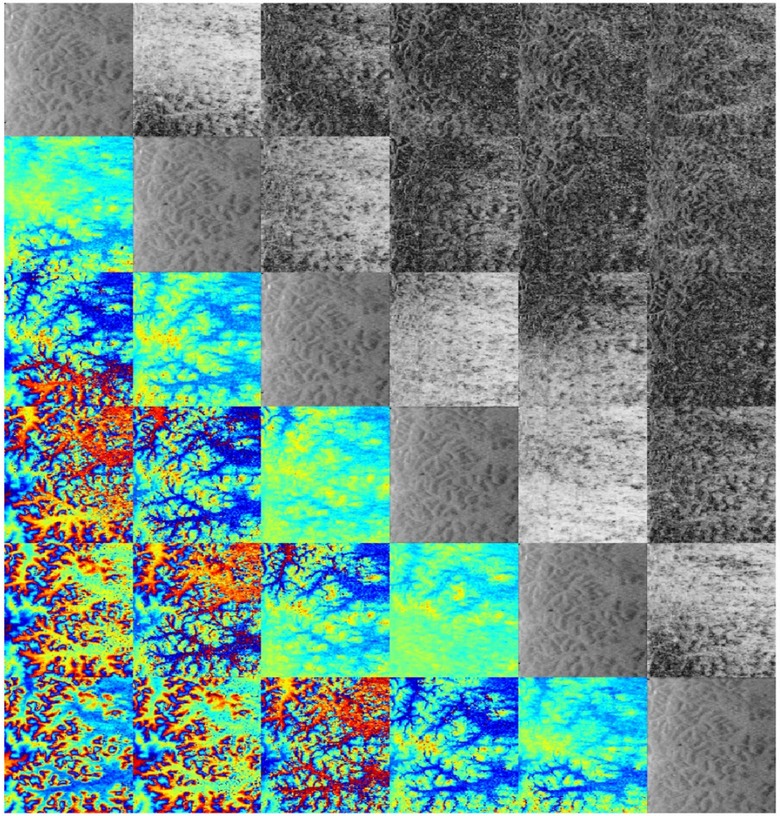
- Sensitivity to polarization

$$\gamma(\boldsymbol{\omega}) = L(\boldsymbol{\omega})\,\gamma_v + (1 - L(\boldsymbol{\omega}))\,\gamma_g \longrightarrow \boxed{\mathbf{R}_{P-S} = \mathbf{C_g} \otimes \mathbf{R_g} + \mathbf{C_v} \otimes \mathbf{R_v}} \in \mathbb{C}^{3M \times 3M}$$

Airborne vs simulated BIOMASS coherence maps

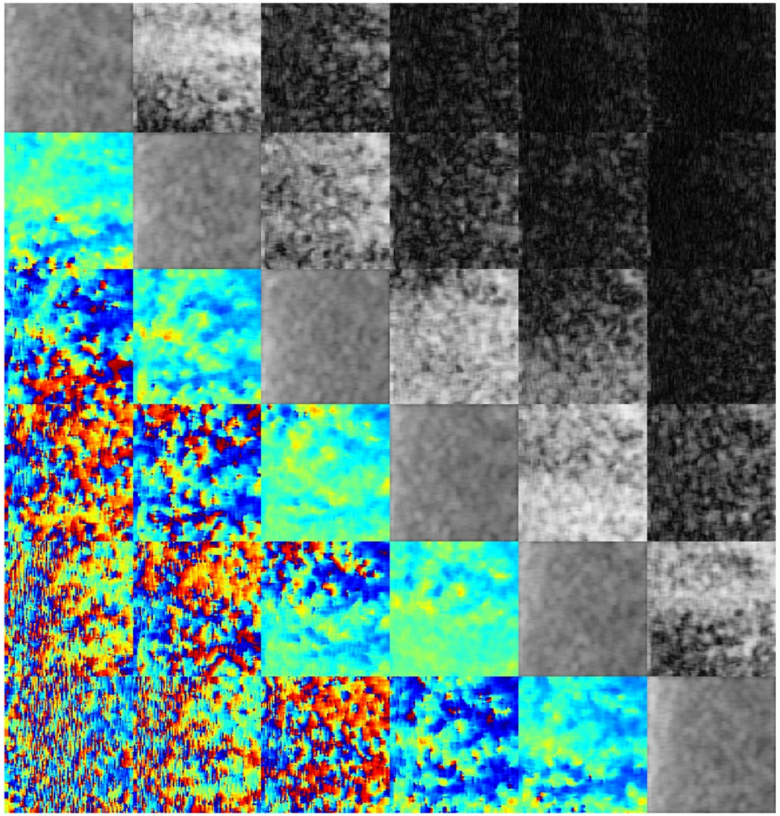
Airborne data

$\delta_{az} \approx 1\,m \quad \delta_{rg} \approx 1\,m$



Simulated BIOMASS data

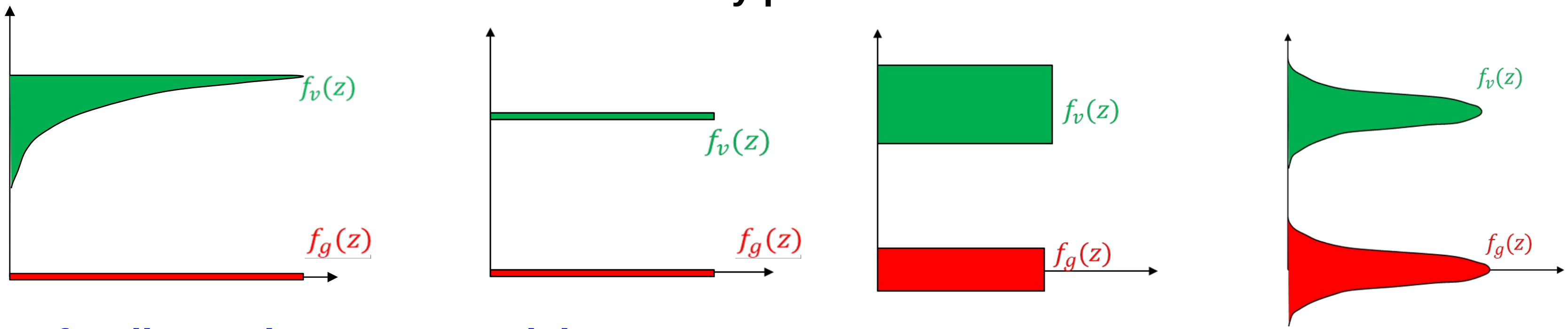
$\delta_{az} = 12.5\,m \quad \delta_{rg} = 25\,m$



- Important loss of spatial resolution
- Range decorrelation

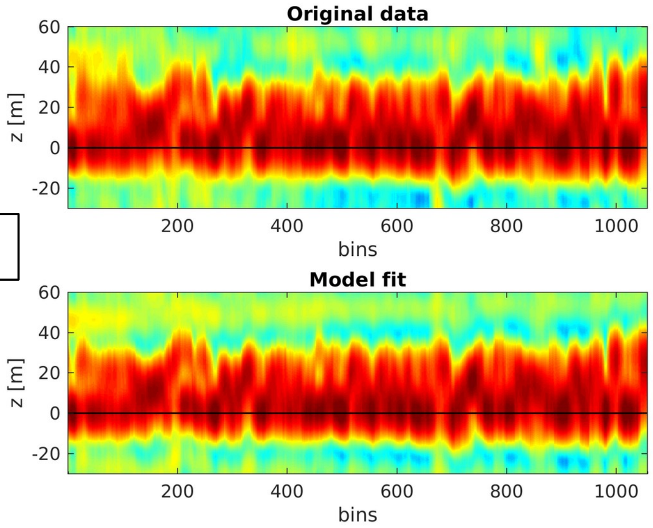
Model selection (see presentation by P.A. Bou)

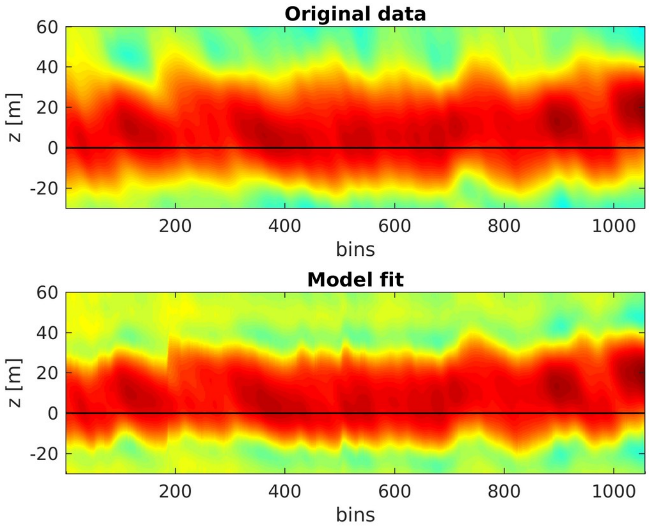
Low rank reflectivity profile + decorrelation terms



Validation of radiometric representativity

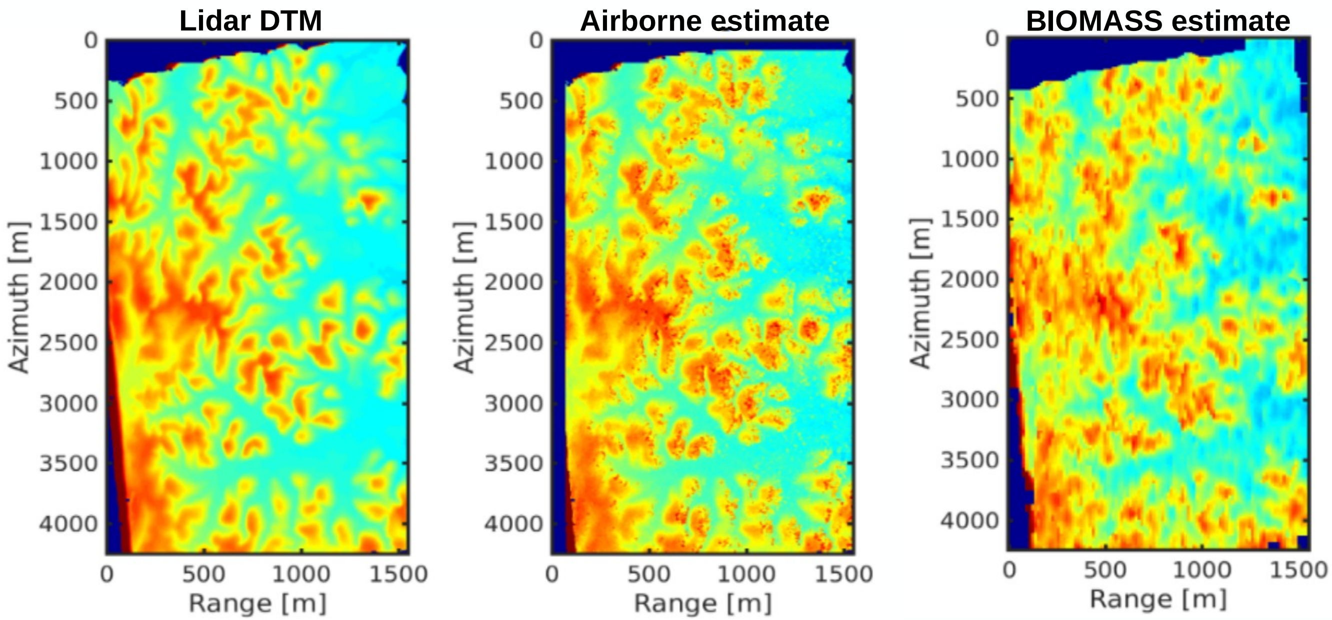
Airborne data





Simulated BIOMASS data

Validation of geometric representativity (see presentation by Y. Huang)



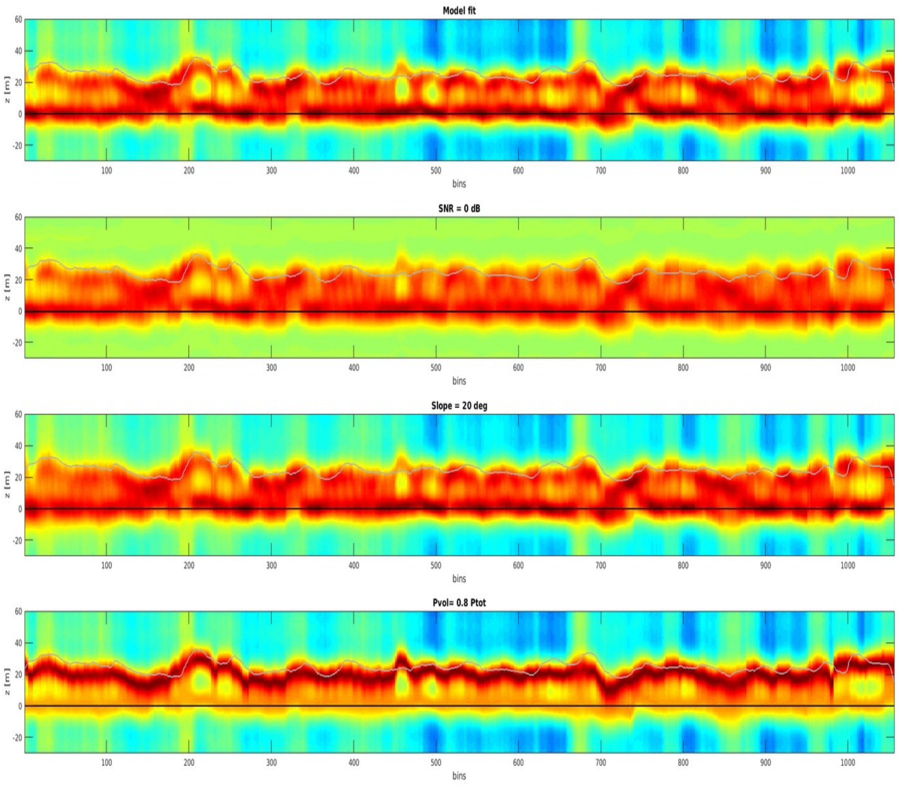
Airborne estimation performance

$$\sigma_{\hat{z}_g} = 1.26\,m \quad \sigma_{\hat{h}_v} = 2.40\,m$$

BIOMASS estimation performance

$$\sigma_{\hat{z}_g} = 2.67\,m \quad \sigma_{\hat{h}_v} = 3.76\,m$$

Influence of model parameters on tomographic features

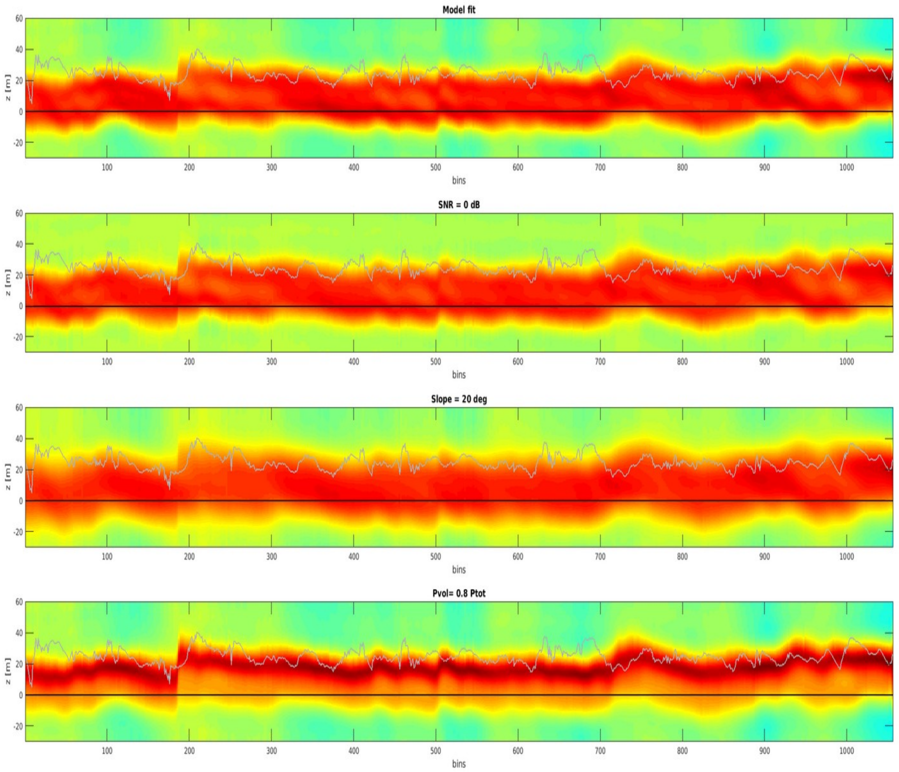


Original

SNR = 0 dB

Slope = 20 deg

$P_{vol} = 0.8\ P_{tot}$



The influence of parameters cannot be well appreciated from tomograms

→ a more quantitative approach is needed

Quantitative minimal achievable uncertainty computation

Principle

$\mathcal{M}(\mathbf{d})$

Data statistics

Information Theory

minimal achievable uncertainty

$u_{opt}(\mathbf{d})$

- **Does not require to invert the model!**
- Assumes a well chose model: <u>null or compensated bias</u>
- May be used to assess the representativity of actually retrieved results

Investigated forest descriptors

- Model: ground + narrow volume + decorrelation

Descriptors $\mathbf{d}$

$$z_g, h_v, w, L = \frac{I_v}{I_g + I_v}, SNR$$

Parameters

$$\{k_{z_m}\}_{m=1}^{M}, k_{z_{crit}}$$

- Advanced descriptors, e.g $AGB_{proxi} = f(P_{30m} = g(\mathbf{d})$

→ not presented today

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Typical configuration (valid unless otherwise specified)

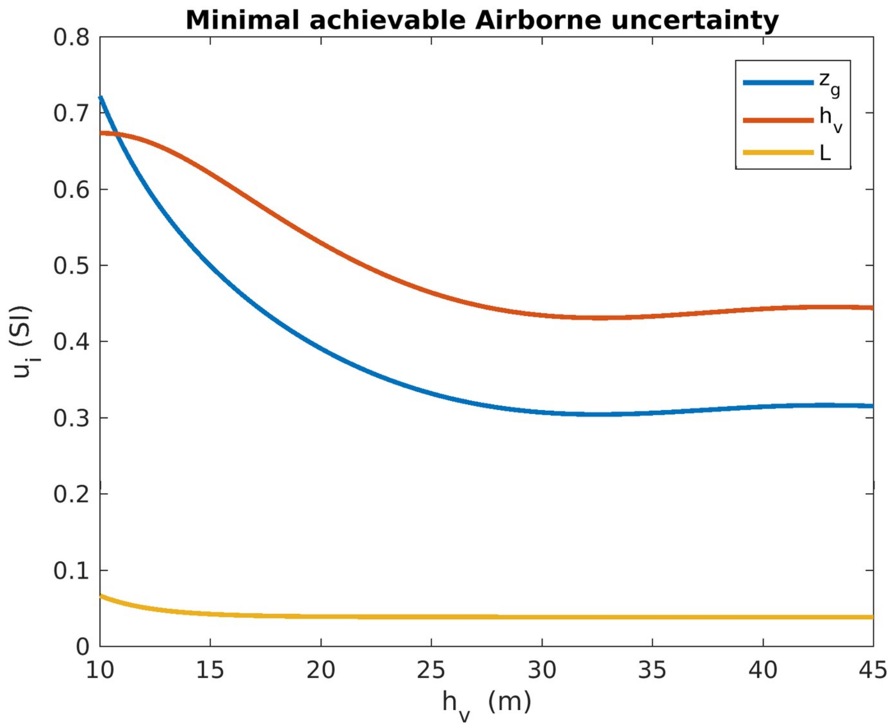
- descriptors

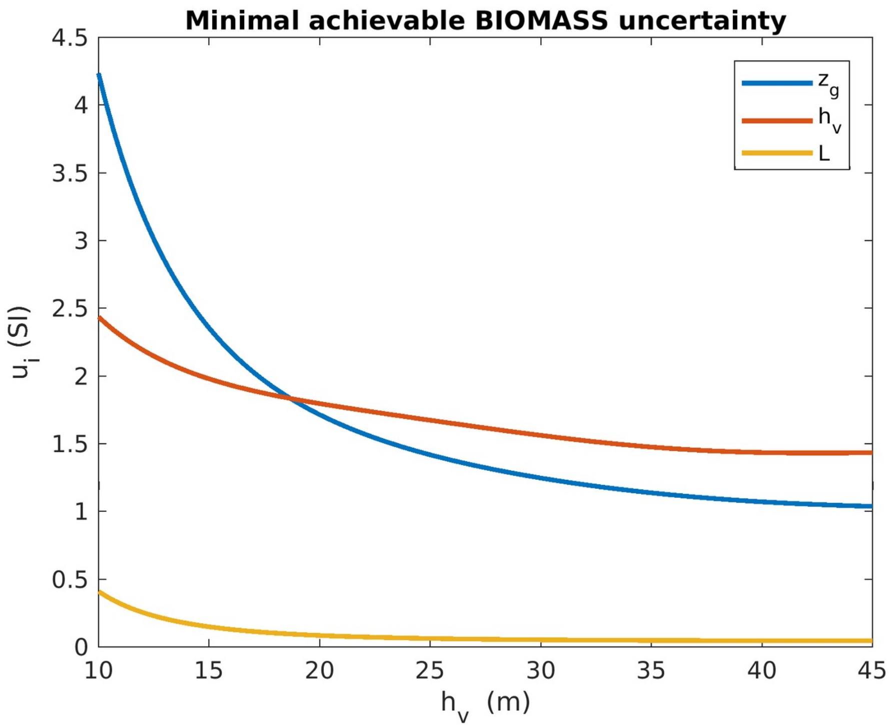
$$h_v = 30\,m, w \text{ "small"}, L = 0.5, SNR \approx 5\,dB$$

- baselines from TropiSAR data set

- horizontal terrain

Minimal achievable uncertainty: sensitivity to tree height



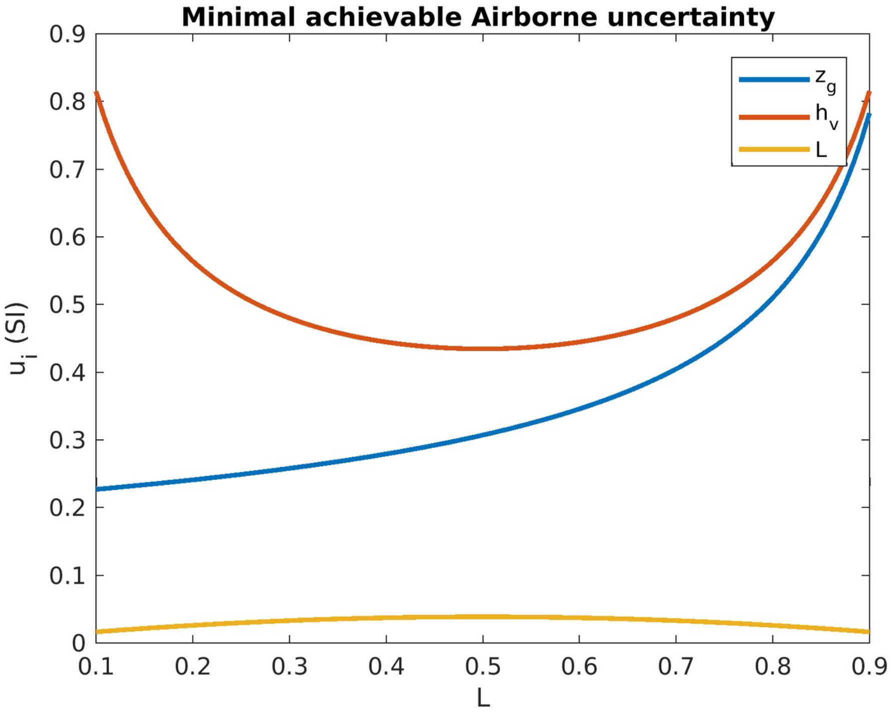


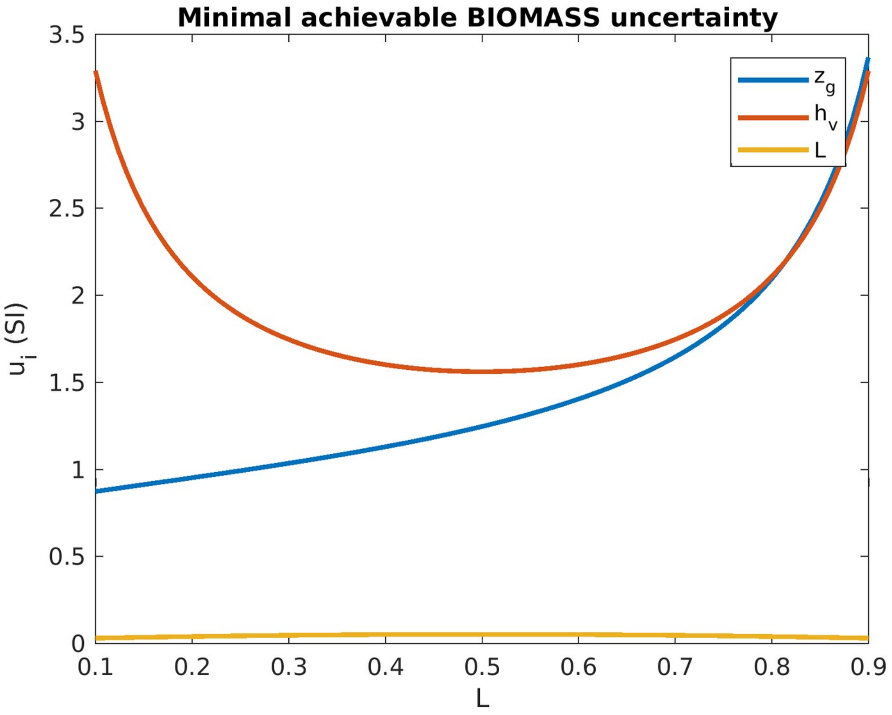
- Forest height uncertainty larger than geound elevation’s one

- Ground topography and tree height are more uncertain for small trees (vertical resolution limitation)

- Approx. 1m performance gap between Airborne and BIOMASS data

Minimal achievable uncertainty: sensitivity to GVR

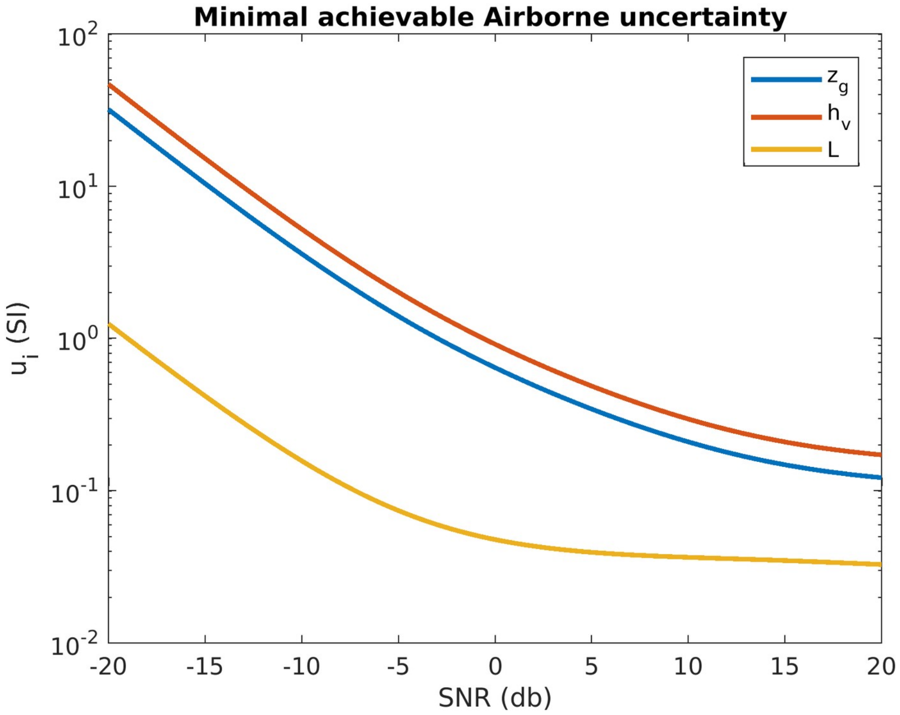


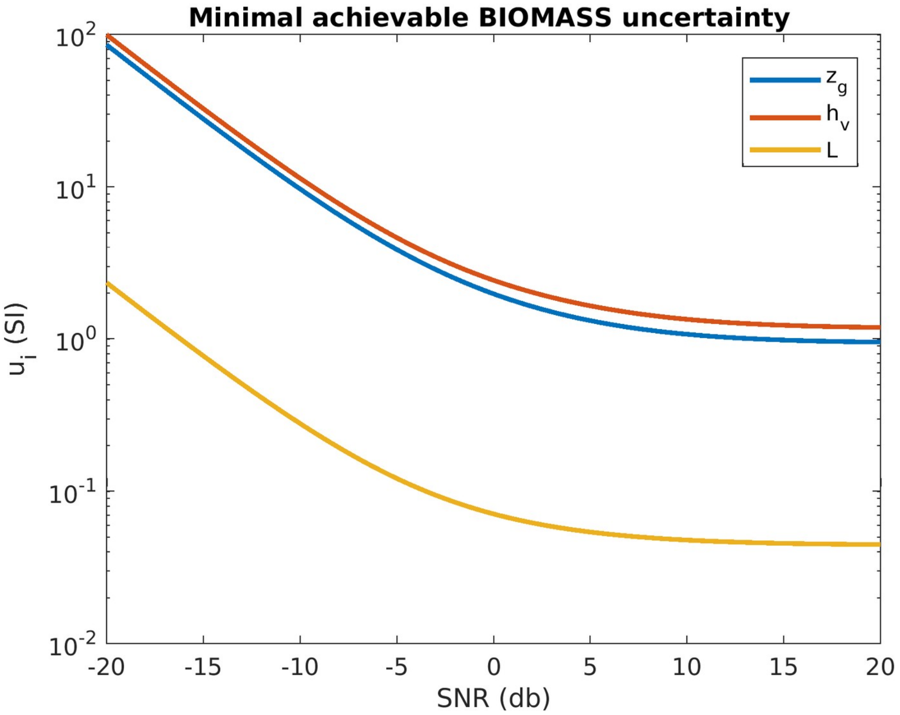


- Best ground topography uncertainty for $L \rightarrow 0$

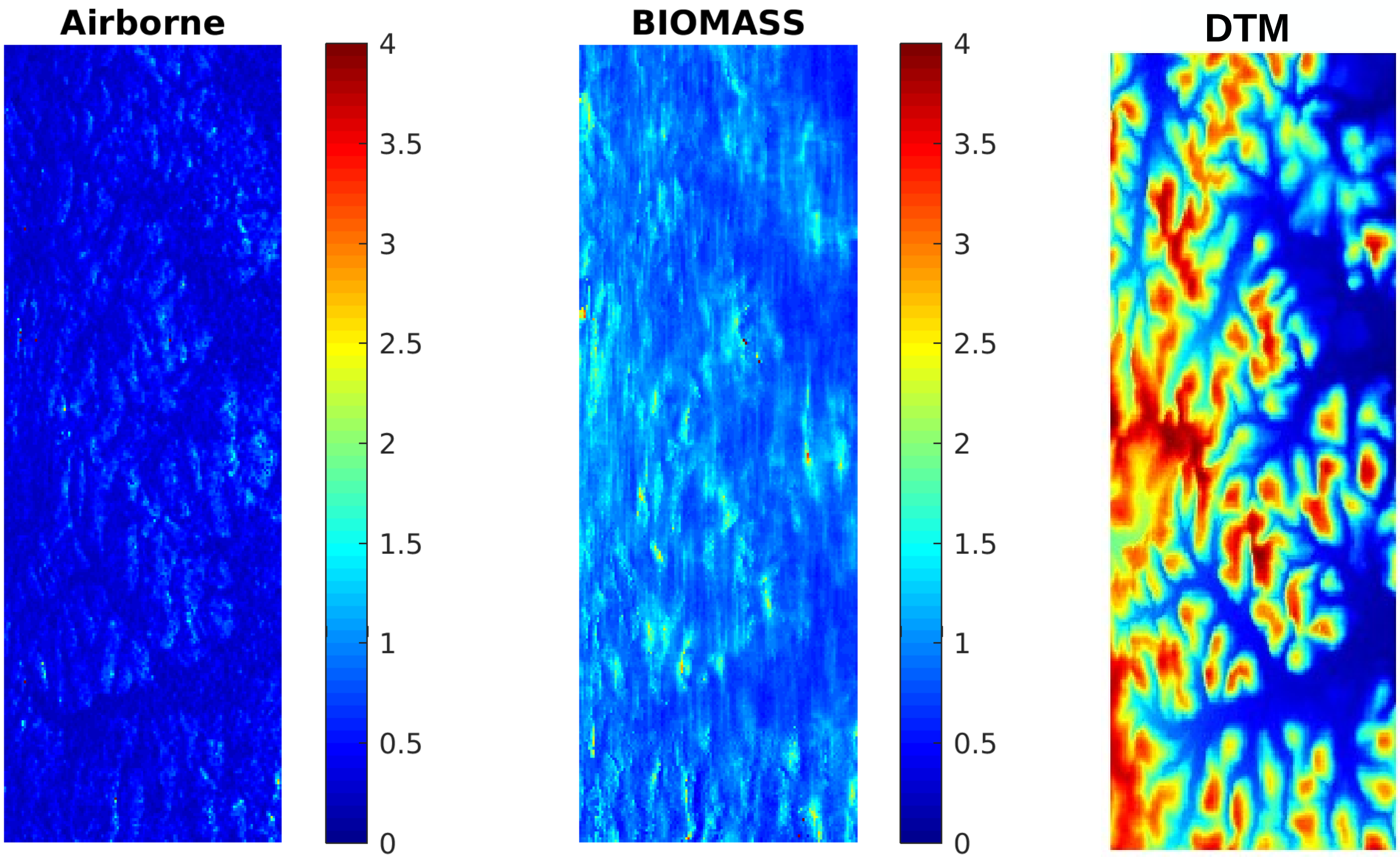
- Best tree height est. performance for $L \rightarrow 0.5$

Minimal achievable uncertainty: sensitivity to SNR





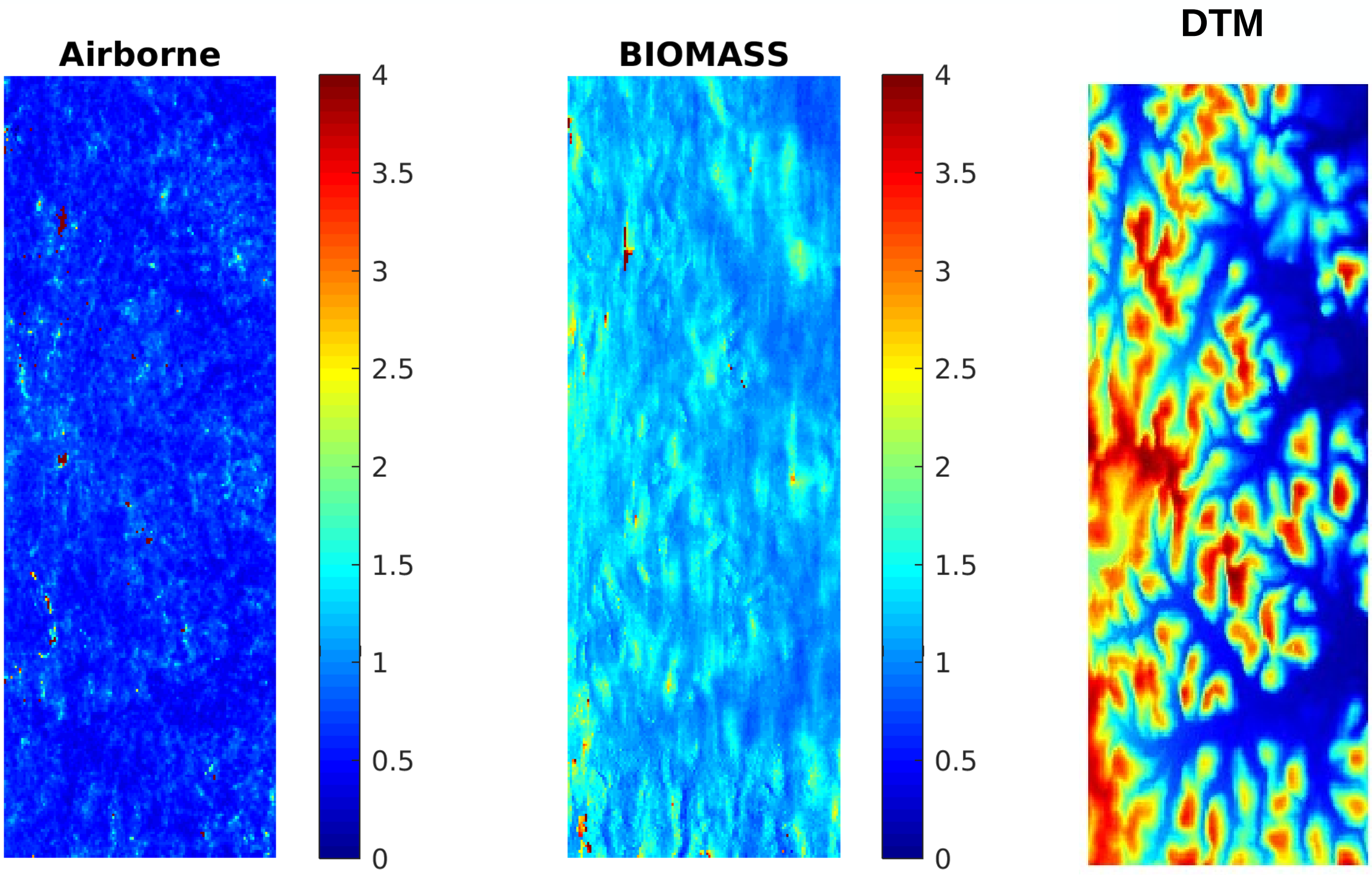
Ground topography



DTM uncertainty sensitivity to range slope well assessed by this method

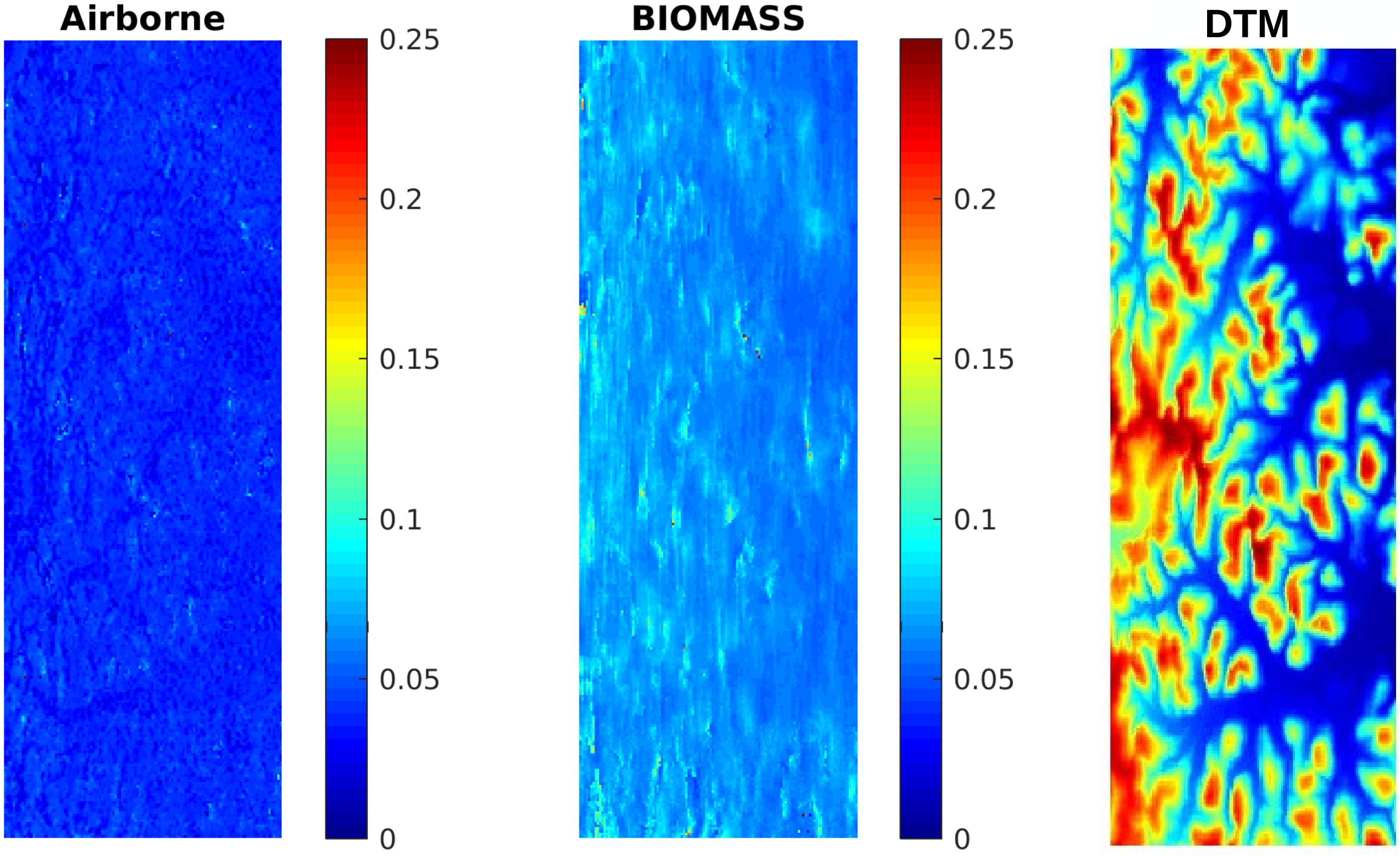
Minimal achievable uncertainty: application to real data

Tree height



Minimal achievable uncertainty: application to real data

GVR $$L = \frac{I_v}{I_g + I_v}$$



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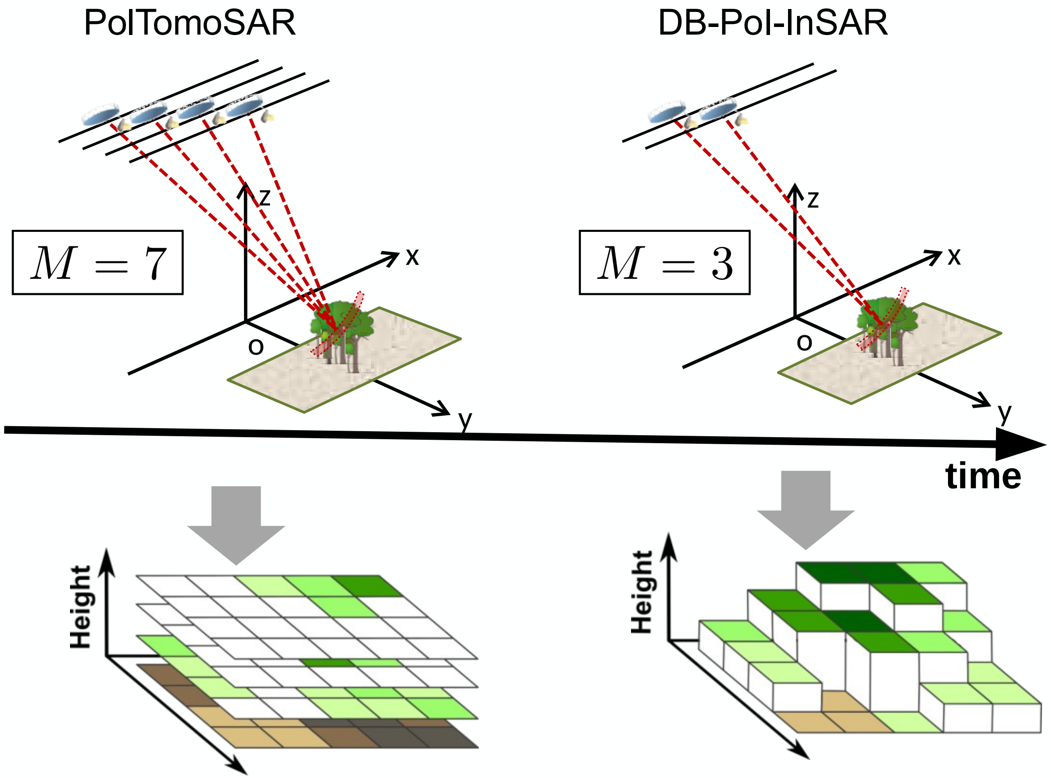


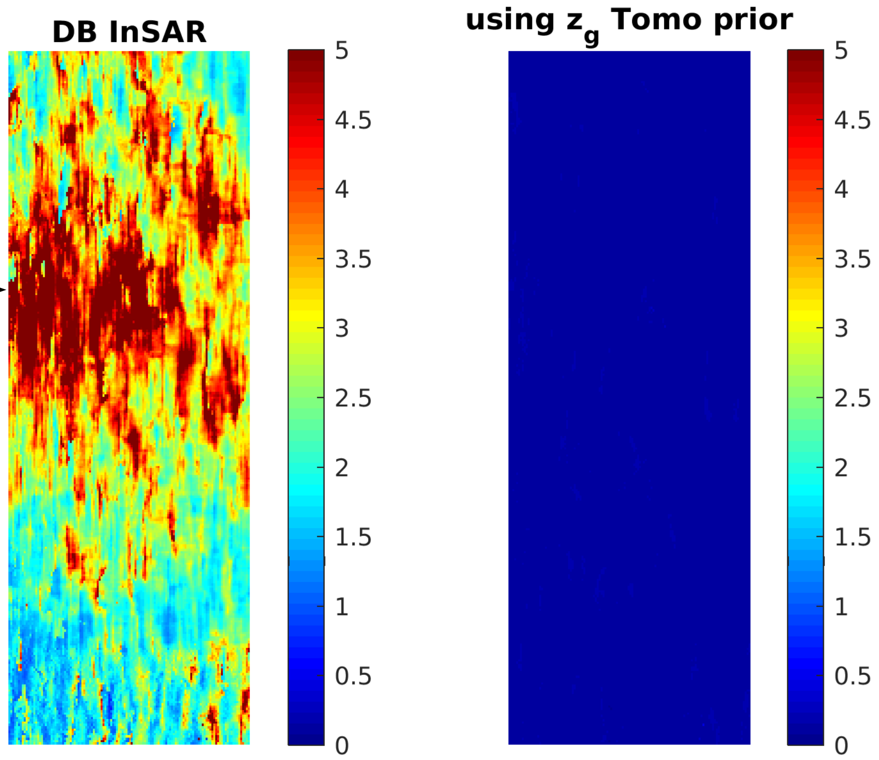
Synergistic use of priors

Inject Tomo DTM **estimate prior**

...to improve Dual Baseline Performance

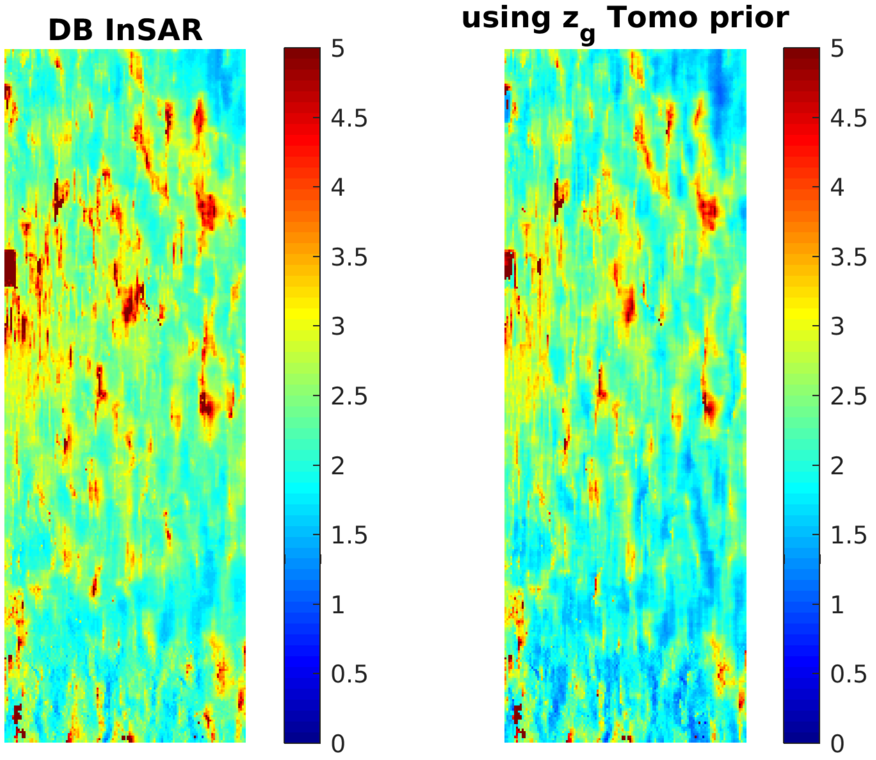
Ground topography

Local low resolution region



Highly informative prior → drastic reduction of uncertainty of the concerned parameter

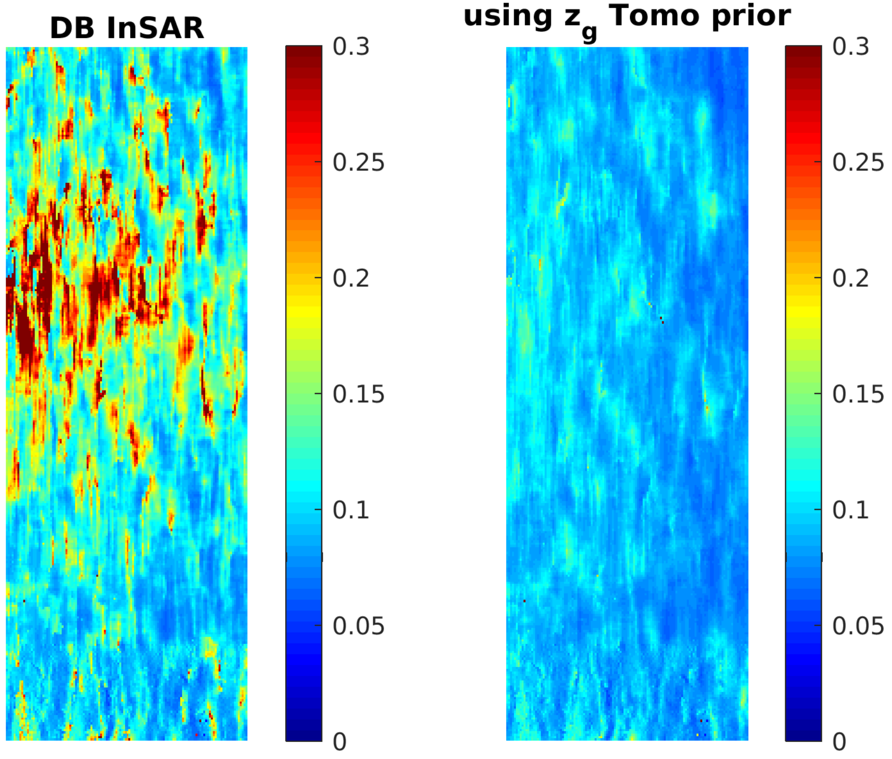
Tree height



DTM prior → moderate improvement of tree height uncertainty

Direct Model: Random Volume over Ground

GVR $$L = \frac{I_v}{I_g + I_v}$$



DTM prior → strong improvement of GVR uncertainty

Important for ground and forest volume characterization

Conclusion

- Statistical tool for assessing the performance of Forest parameter estimation

- Supports multi-modes

- Account for priors and auxiliary information

- Permits to estimate the synergistic use of BIOMASS operation sequence

- Ongoing work ...