Comparison of low dimensional profile models for the characterization of tropical forests using SAR tomography

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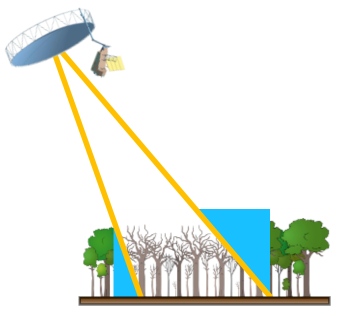
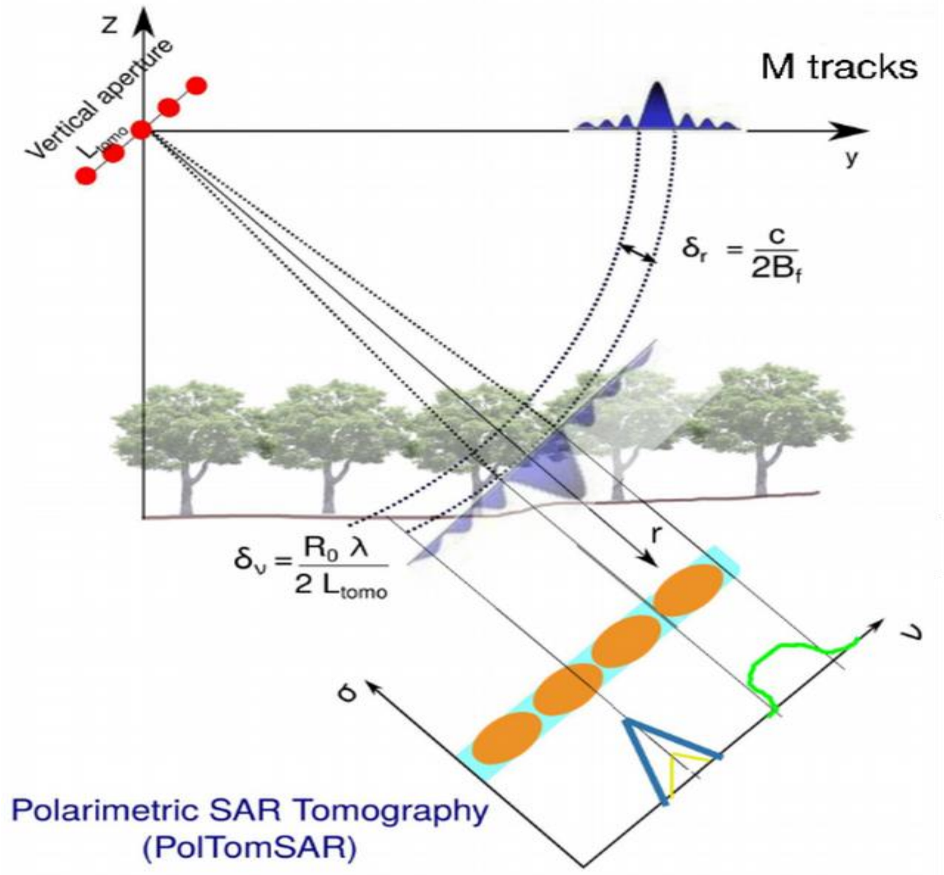
Context : Need for Parametric Tomography

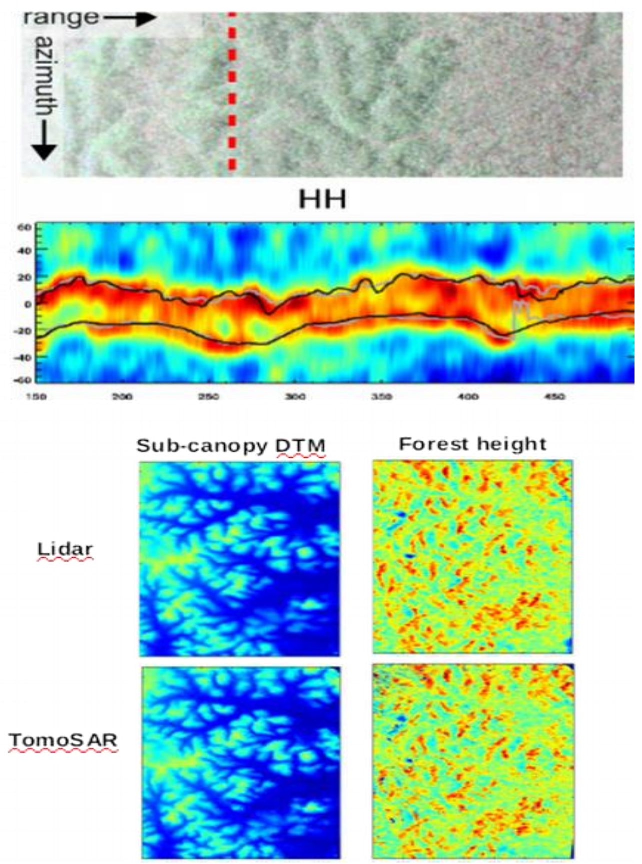
BIOMASS mission



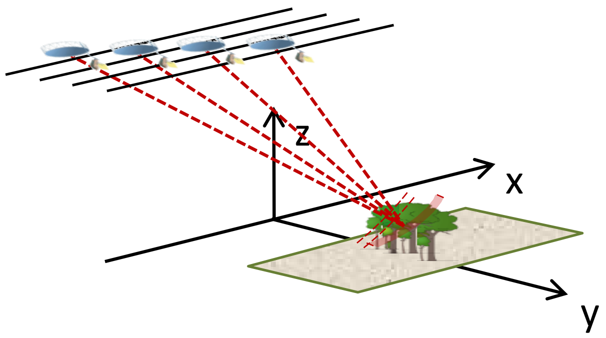
P-band radar



ONERA TropiSAR campaign



Parameter extraction in Tomography

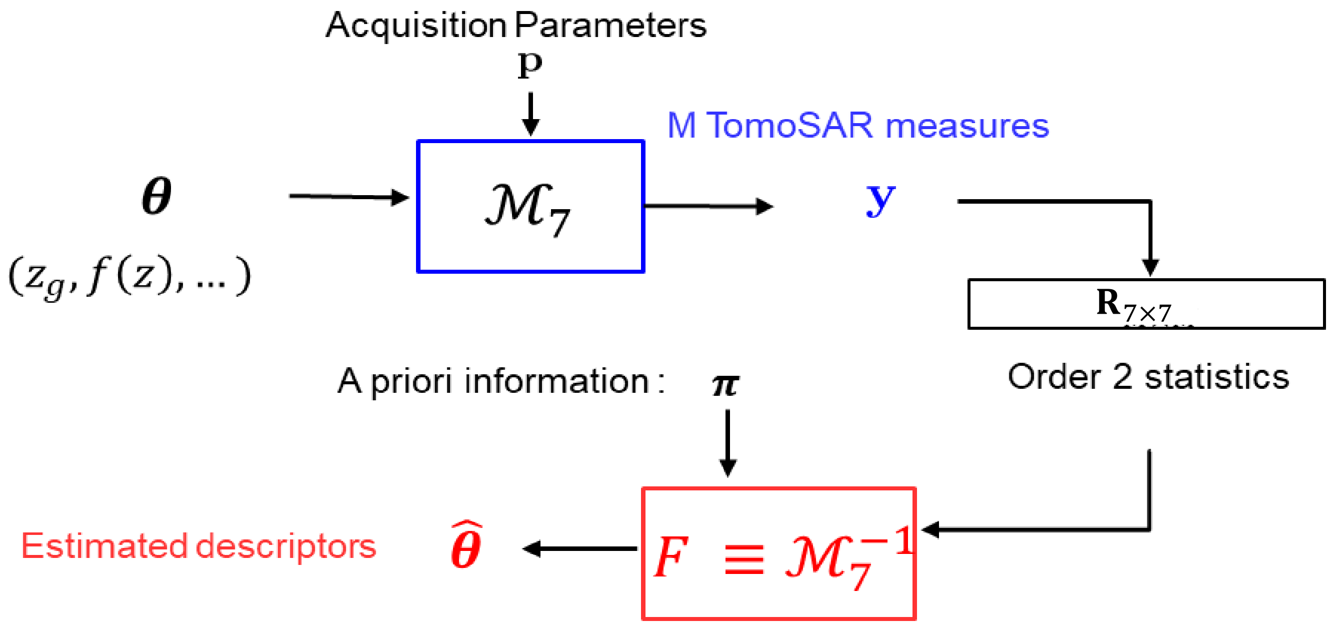


Tomographic phase

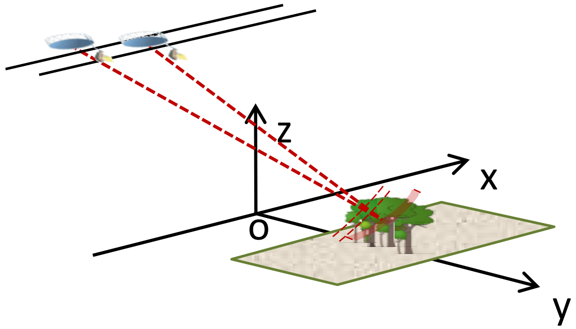
Global coverage : 16 months

M = 7 images (3 days REV)

→ High Resolution

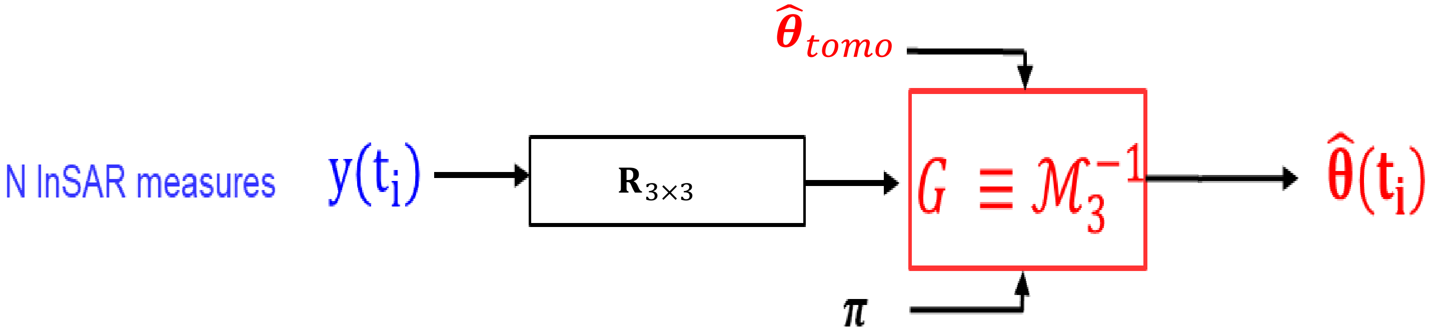


Parameter extraction by models with few parameters



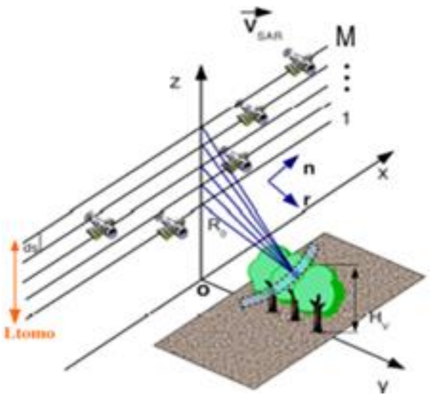
Interferometric cycles
Every 8 months
M = 3 images (3 days REV)

Low Resolution

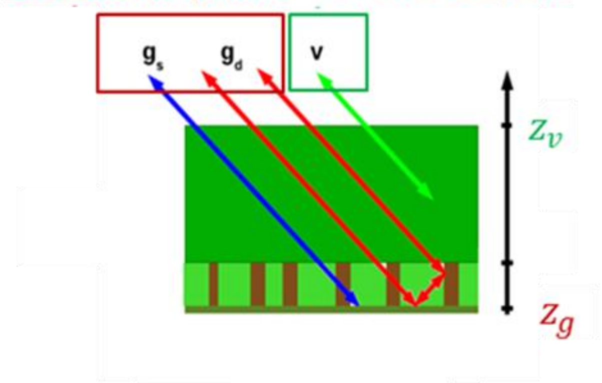


Objective : Choice of a low dimensionality model

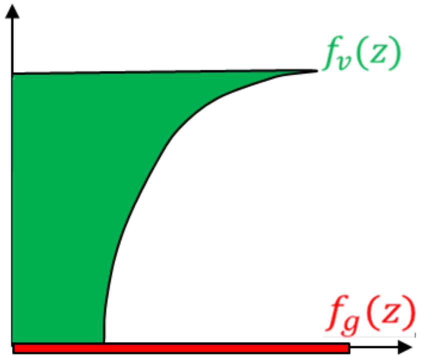
TomoSAR Forest Response Model



Scattering mechanisms :



Vertical reflectivity Profile



$$\mathbf{R}_{M\times M} = I \begin{bmatrix} 1 & \gamma_{12} & \cdots & \gamma_{1M} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{M1} & \cdots & \cdots & 1 \end{bmatrix} = \mathbf{R}_v + \mathbf{R}_g$$

$$\gamma\left(k_{z_{ij}}\right) = \frac{\int f_x(z) e^{jk_{z_{ij}}z} dz}{I}$$

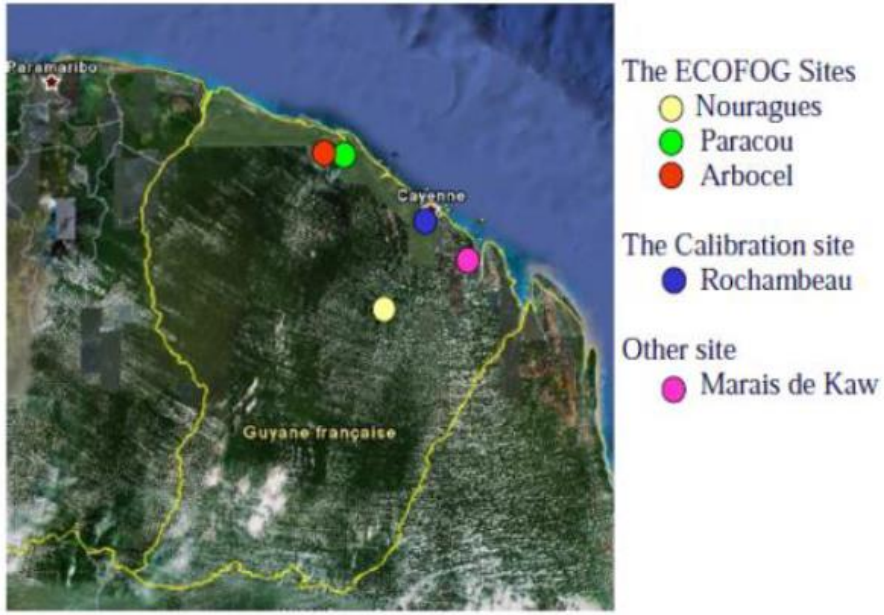
$$f_x(z) = \hat{f}_v(z) + \hat{f}_g(z)$$

Inverse Problem

Estimate $\hat{f}_v(z)$, $\hat{f}_g(z)$ using a low dimensional parametrization

Comparison of reflectivity profile basis

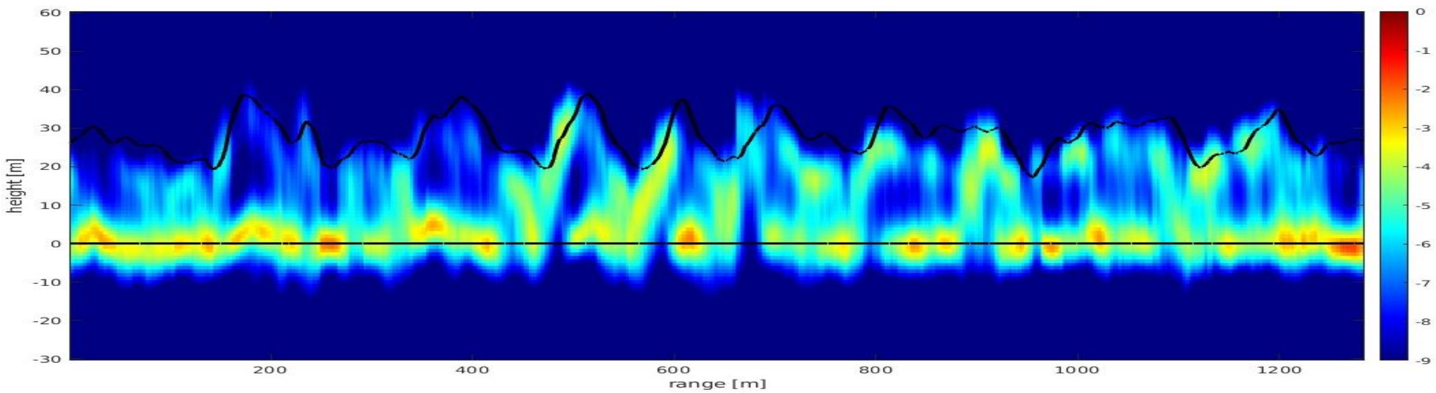
- TropiSAR Campaign, 2009
- ONERA SETHI
- P-band
- 6 pass
- $\delta_{az} = 1.245m$
- $\delta_{rg} = 1m$
- $\delta_z = 12.5m$



Courtesy ONERA

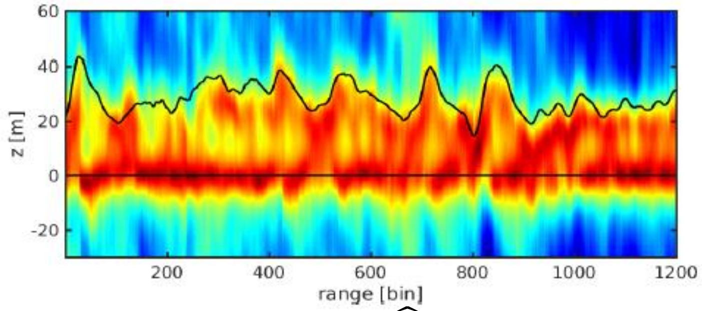
French Guyana test site

Capon Tomogram

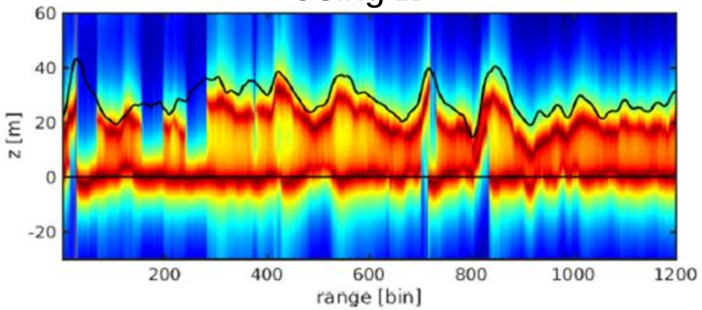


Estimation of the model order for single PolTomography

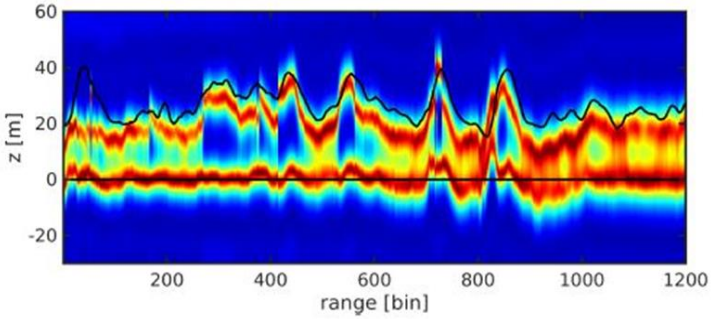
Capon Tomogram :



Using $\widehat{\mathbf{R}}$



Using an adaptive basis (wavelets)



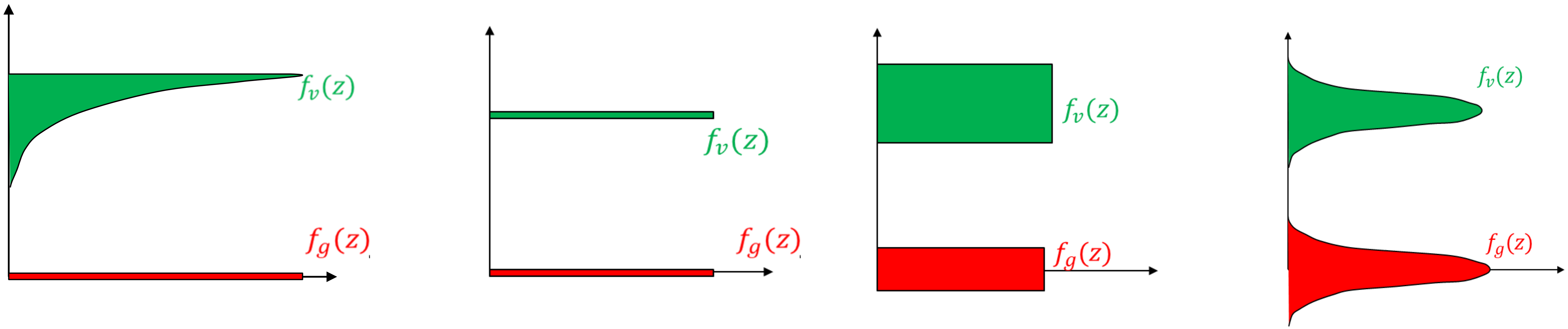
Using an exponential Profile

- Modelled with an adaptive basis & sparse signal estimation
  → 2 components
  "Forest structure characterization using SAR tomography and an adaptative estimation technique", EuSAR 2022
- Using a fixed basis : Exponential Volume + Ground
  → Similar Results
- Notice : the Volume component is always located **below** the LiDAR upper limit estimate

→ Fixed 2 components basis :

Parametric estimation of Volume & Ground

Proposed 2 components reflectivity models

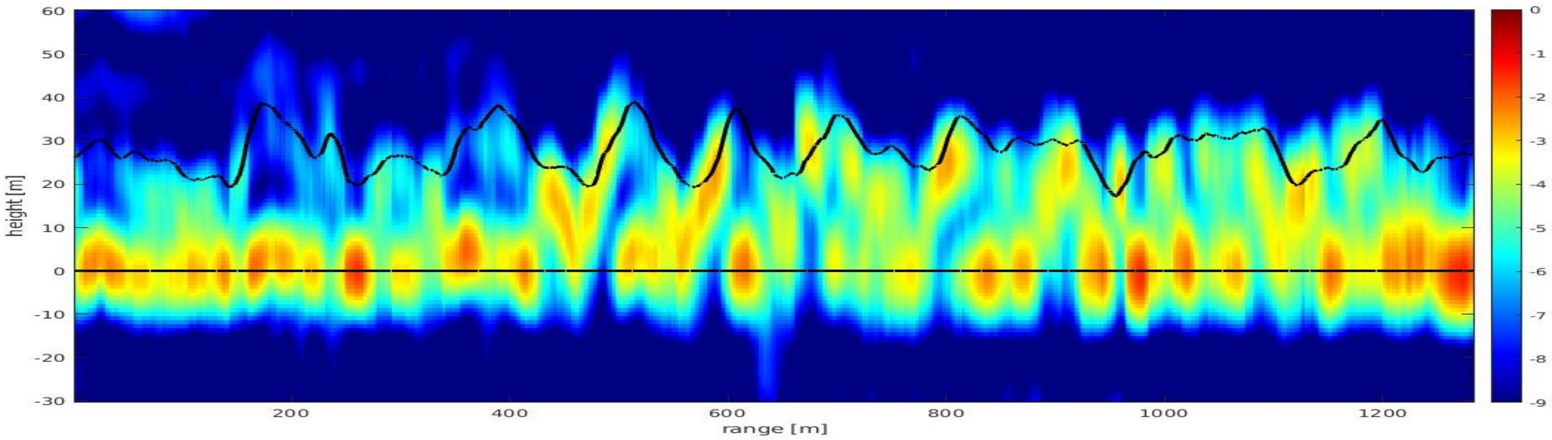


Exponential & Dirac | 2 Diracs | 2 Boxes | 2 Gaussian components

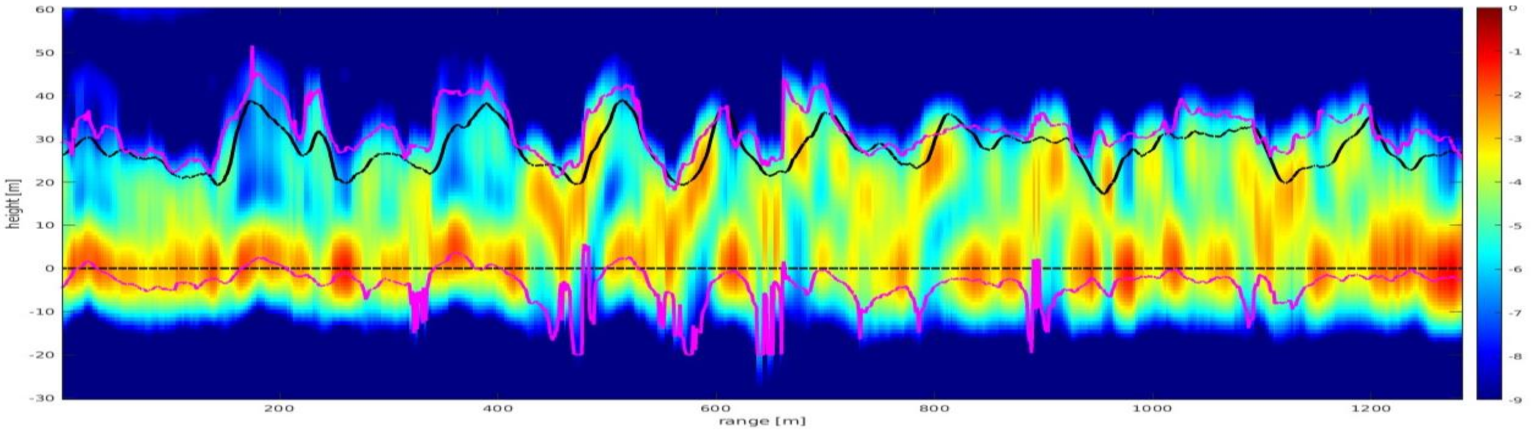
Retrieved z_g, z_v & reflectivity profile for a single polarization tomogram

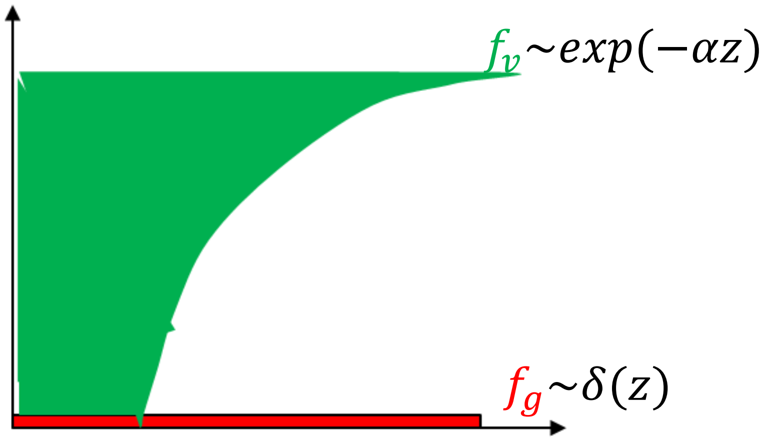
Exponential model

Original Tomogram



Reconstructed tomogram

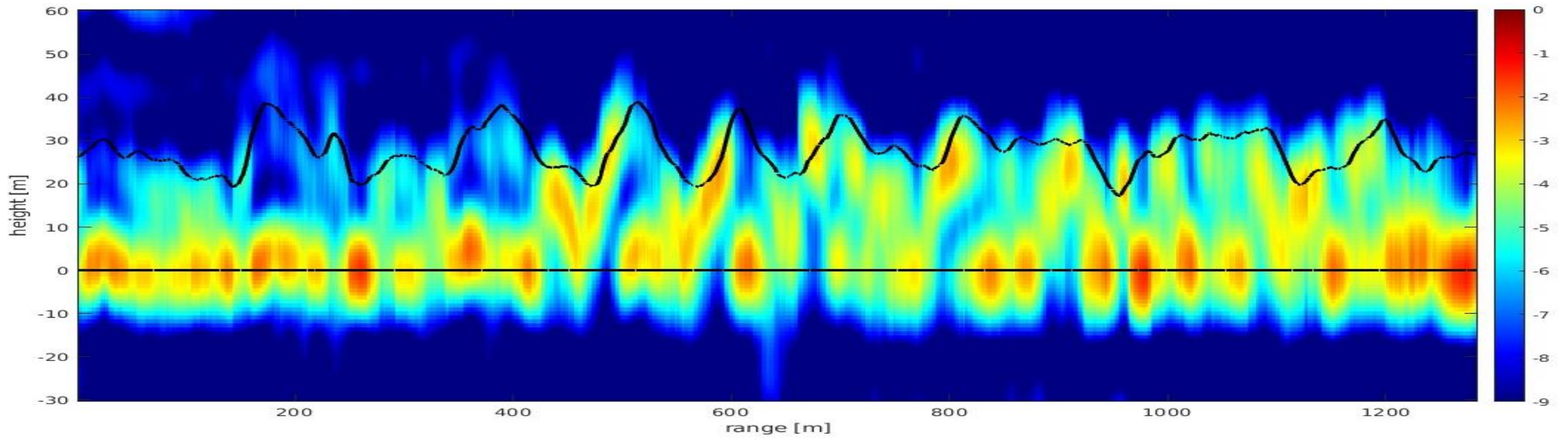




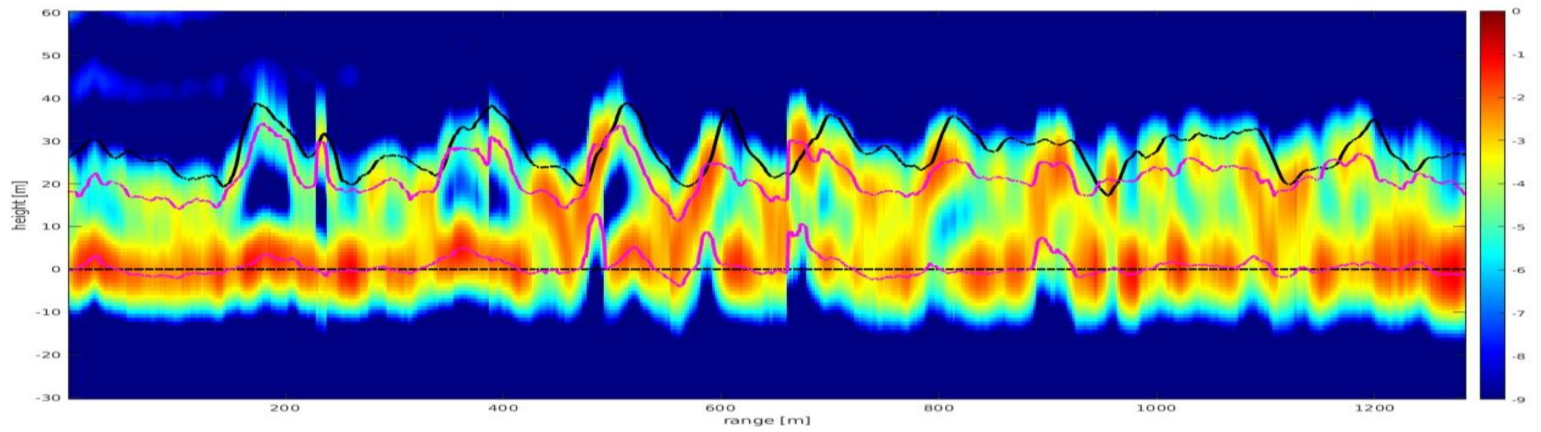
- Overestimated volume
- Underestimated ground

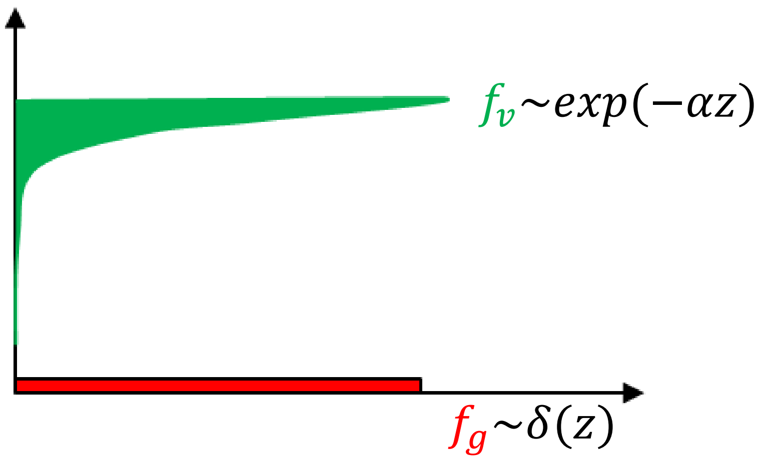
Exponential model

Original Tomogram



Constraint : large α values





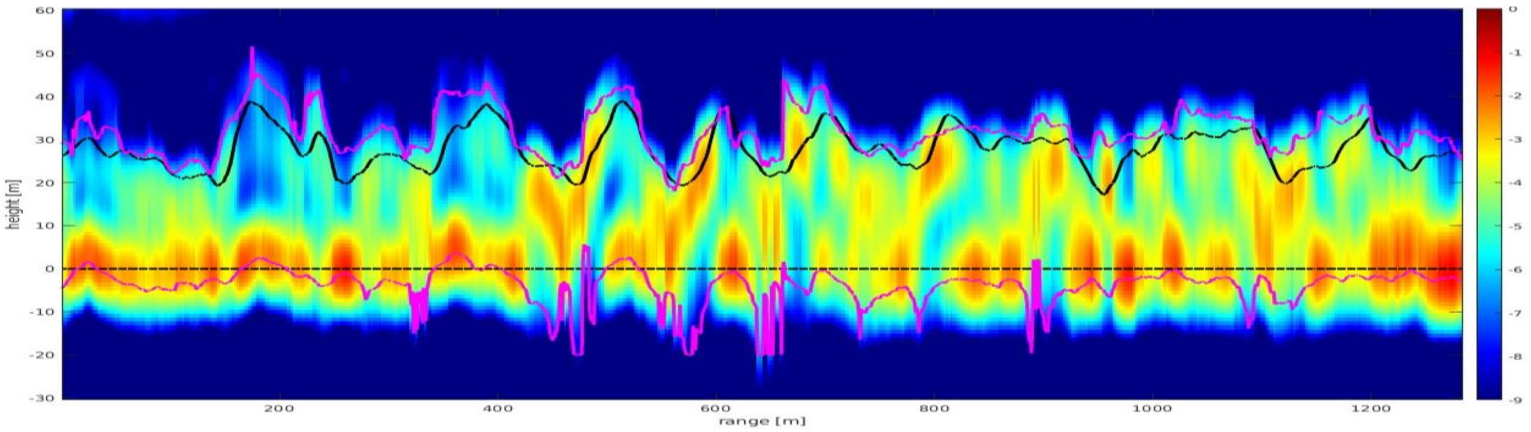
Constraint retrieval :

Correct z_g, z_v estimates

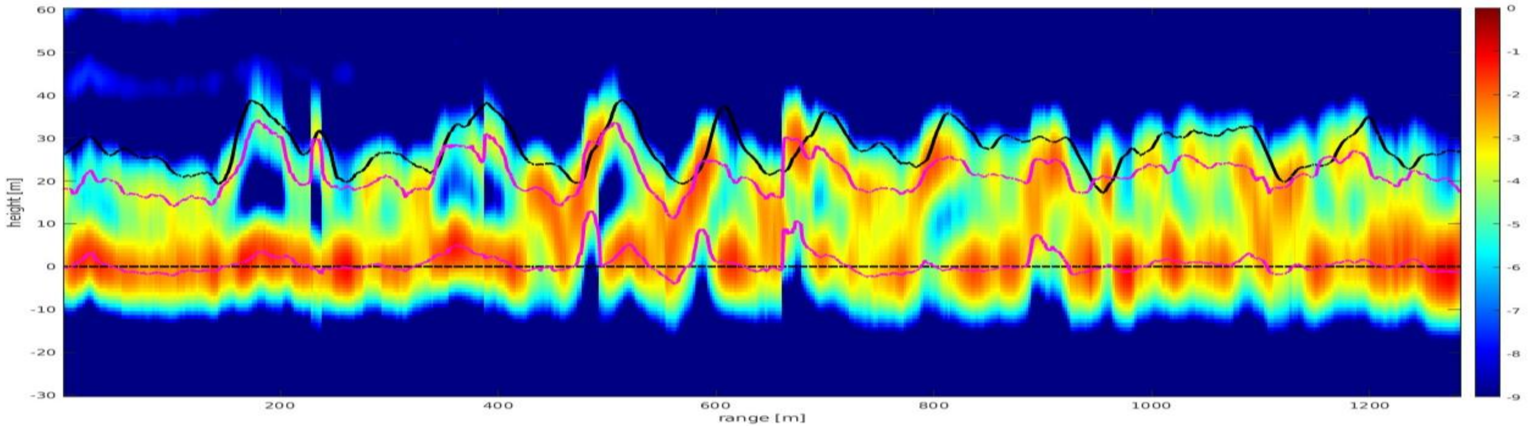
→ Restriction to narrow exponential profiles

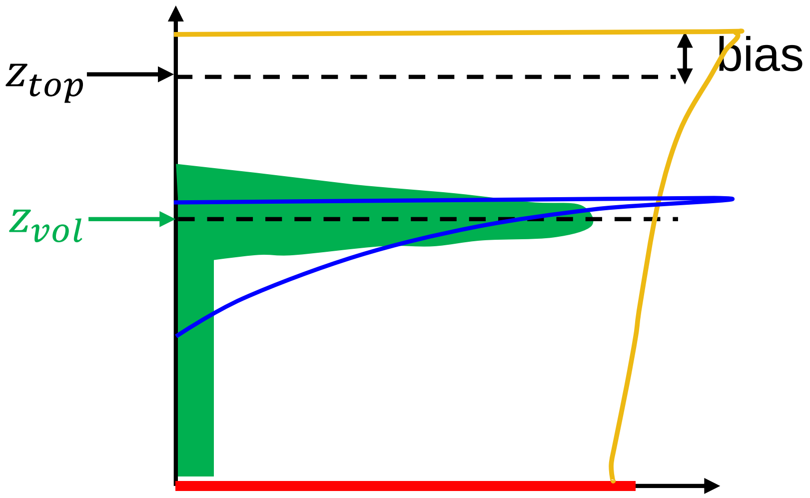
Exponential model : Interpretation

No Constraint



Constraint : large α

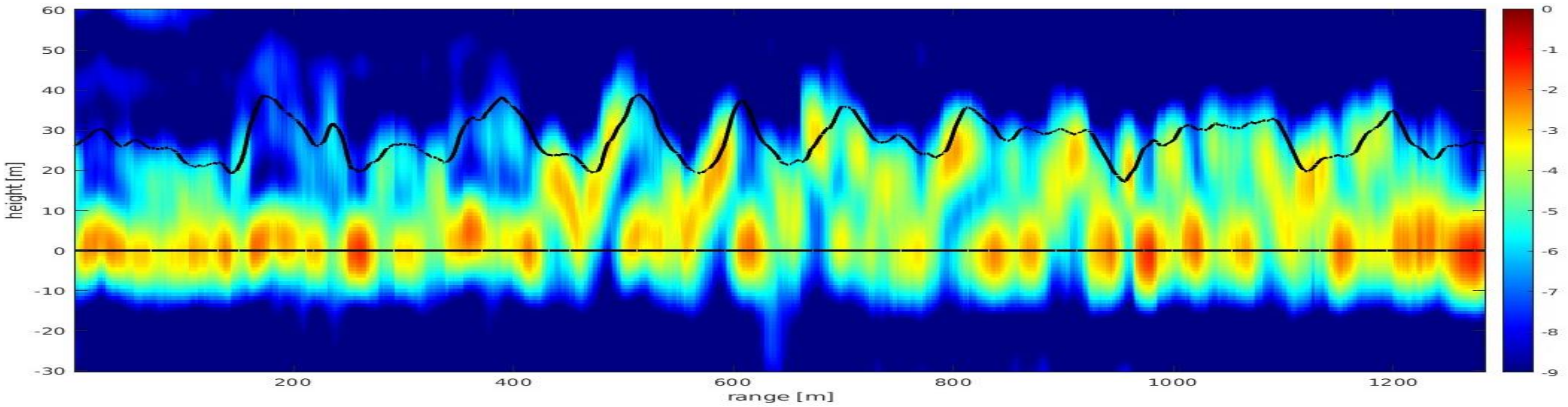




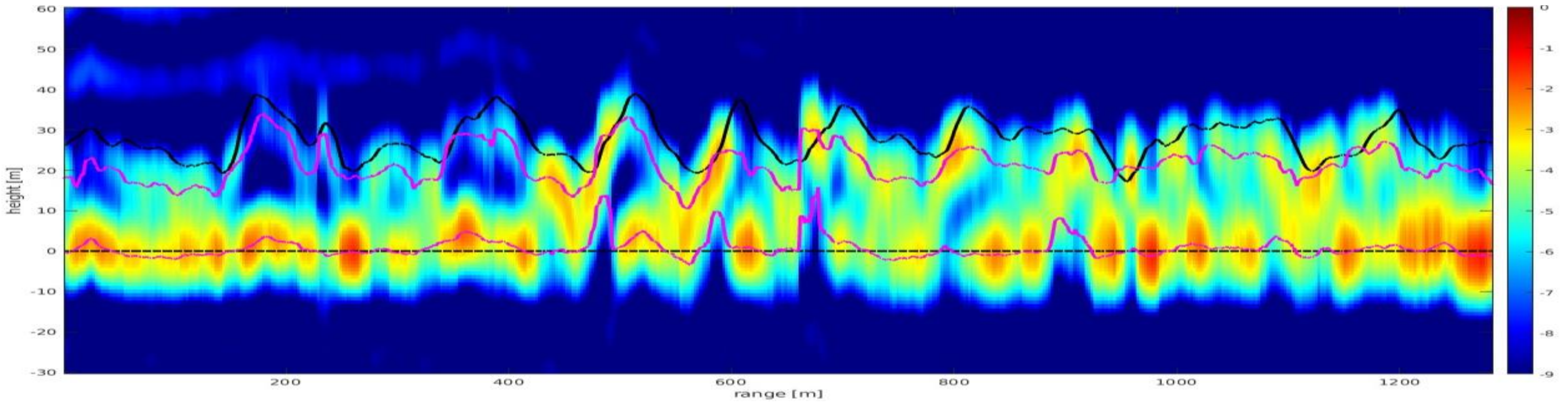
- Small α :
  - arbitrary bias
  - Ambiguous ground component estimate
- Large α : fit to z_{vol}
- Reflectivity fit could be improved

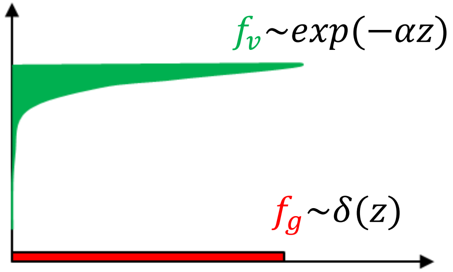
Exponential model with global decorrelation terms

Original Tomogram



Reconstructed tomogram with large α





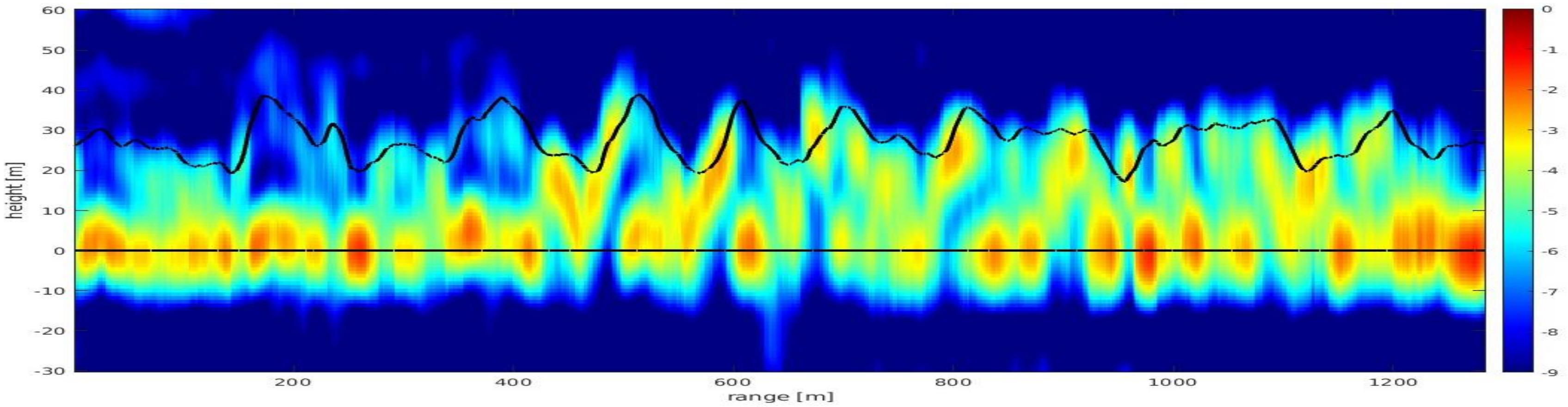
Inclusion of a global decorrelation term :

- SNR
- Spectral shift (range geometry)

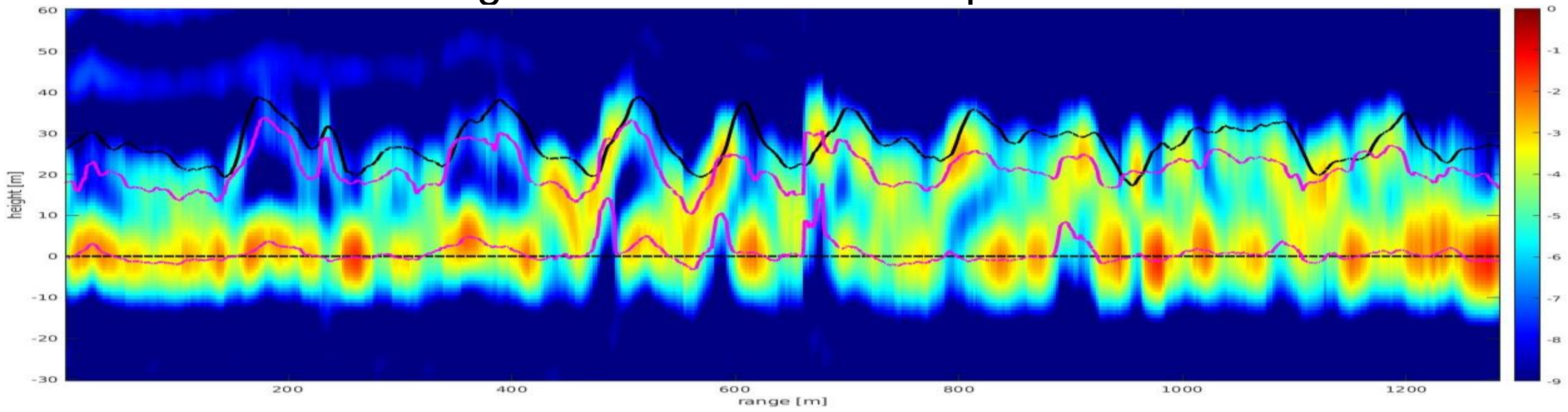
Very good Ground, Volume estimates & reflectivity fit

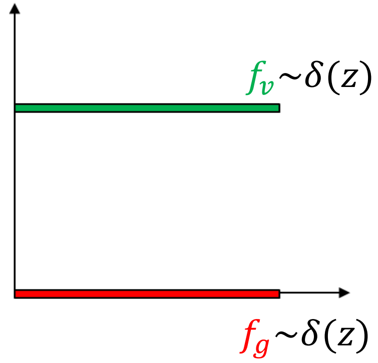
Model with two Diracs & decorrelation terms

Original Tomogram



Tomogram with 2 Diracs components

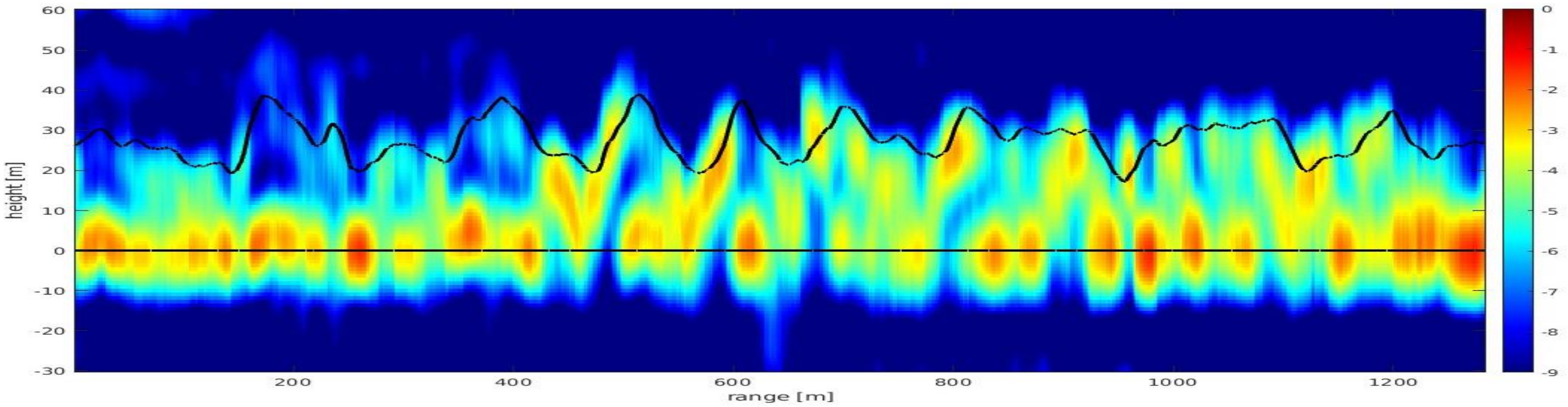




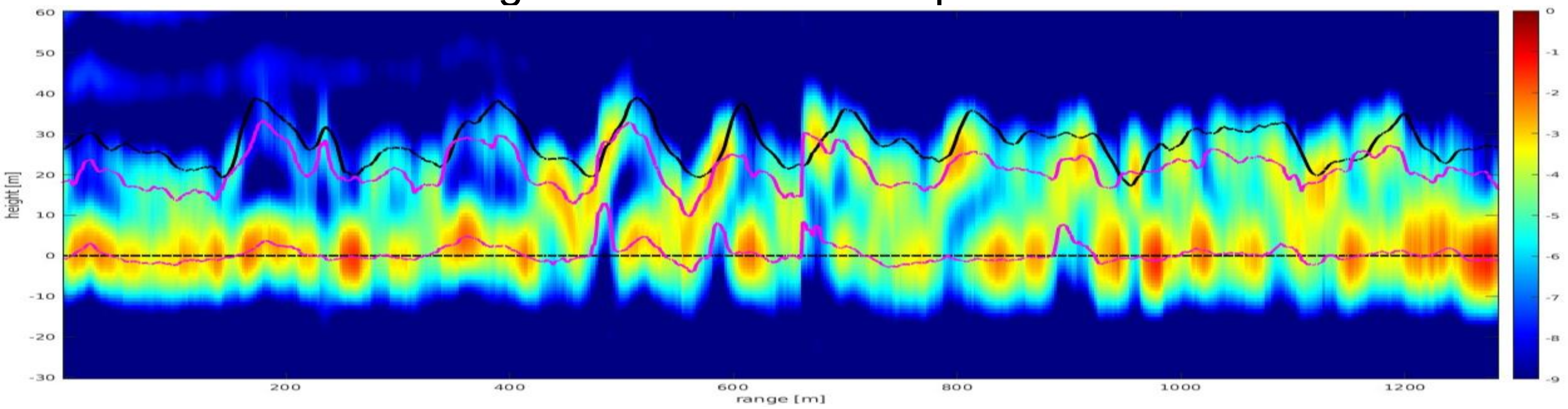
- Very good z_g , z_v fit & excellent reflectivity fit

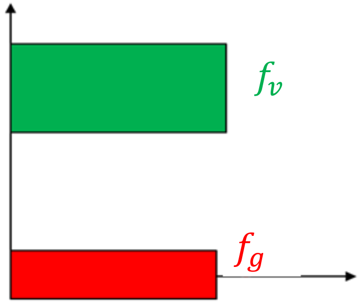
Box model for the volume, the ground & decorrelation terms

Original Tomogram



Tomogram with 2 Box components

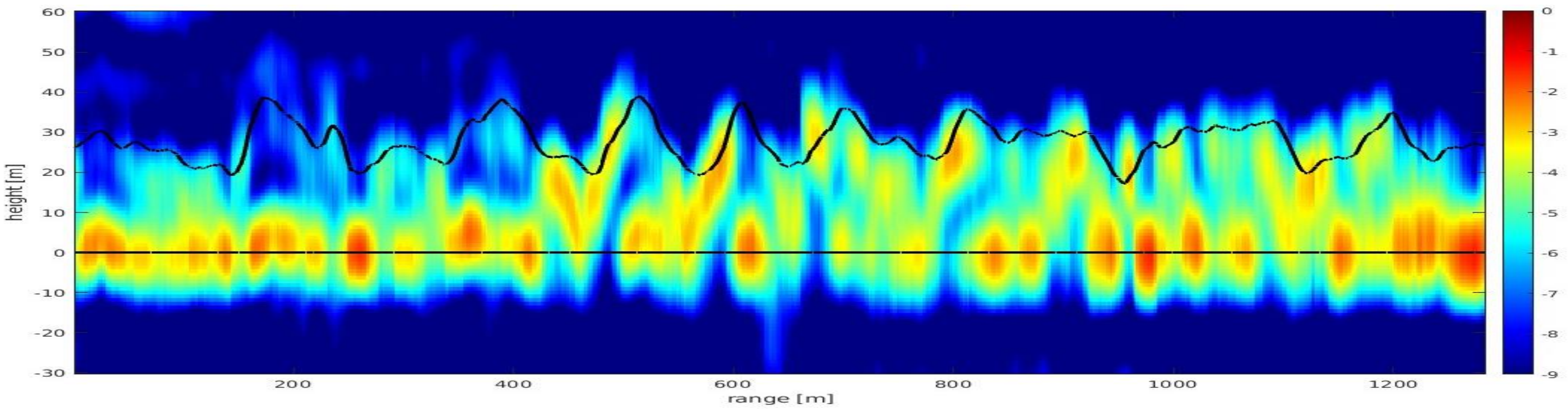




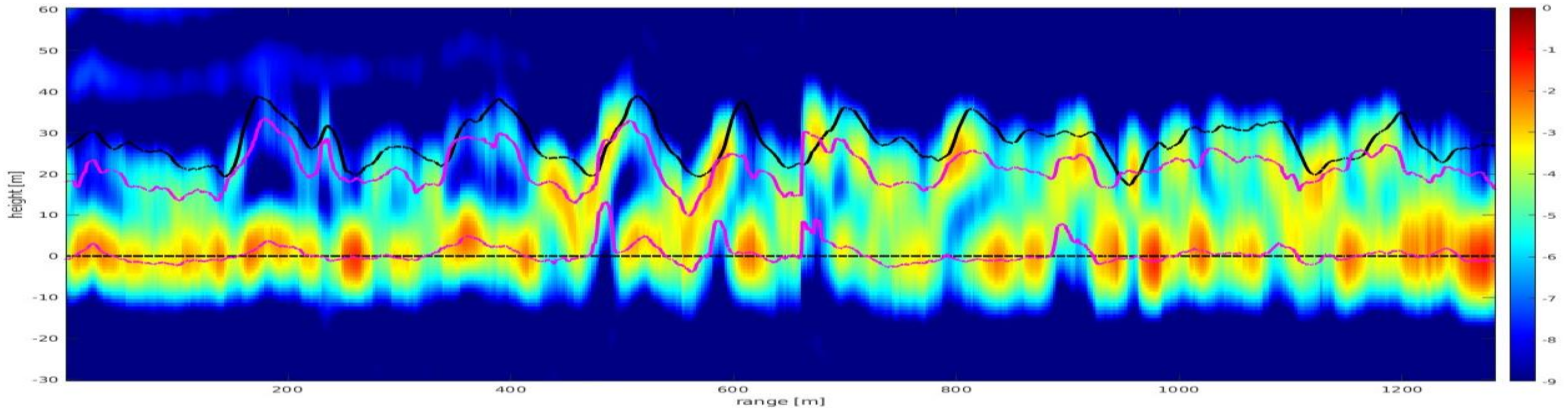
- Very good z_g , z_v fit & excellent reflectivity fit

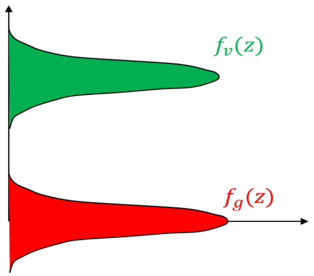
Gaussian model for the volume, the ground & decorrelation terms

Original Tomogram



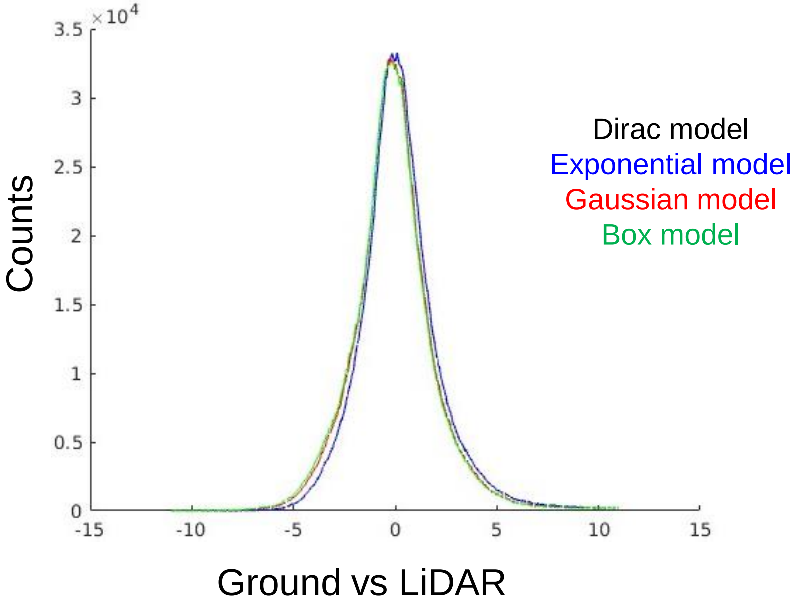
Tomogram with 2 Gaussian components

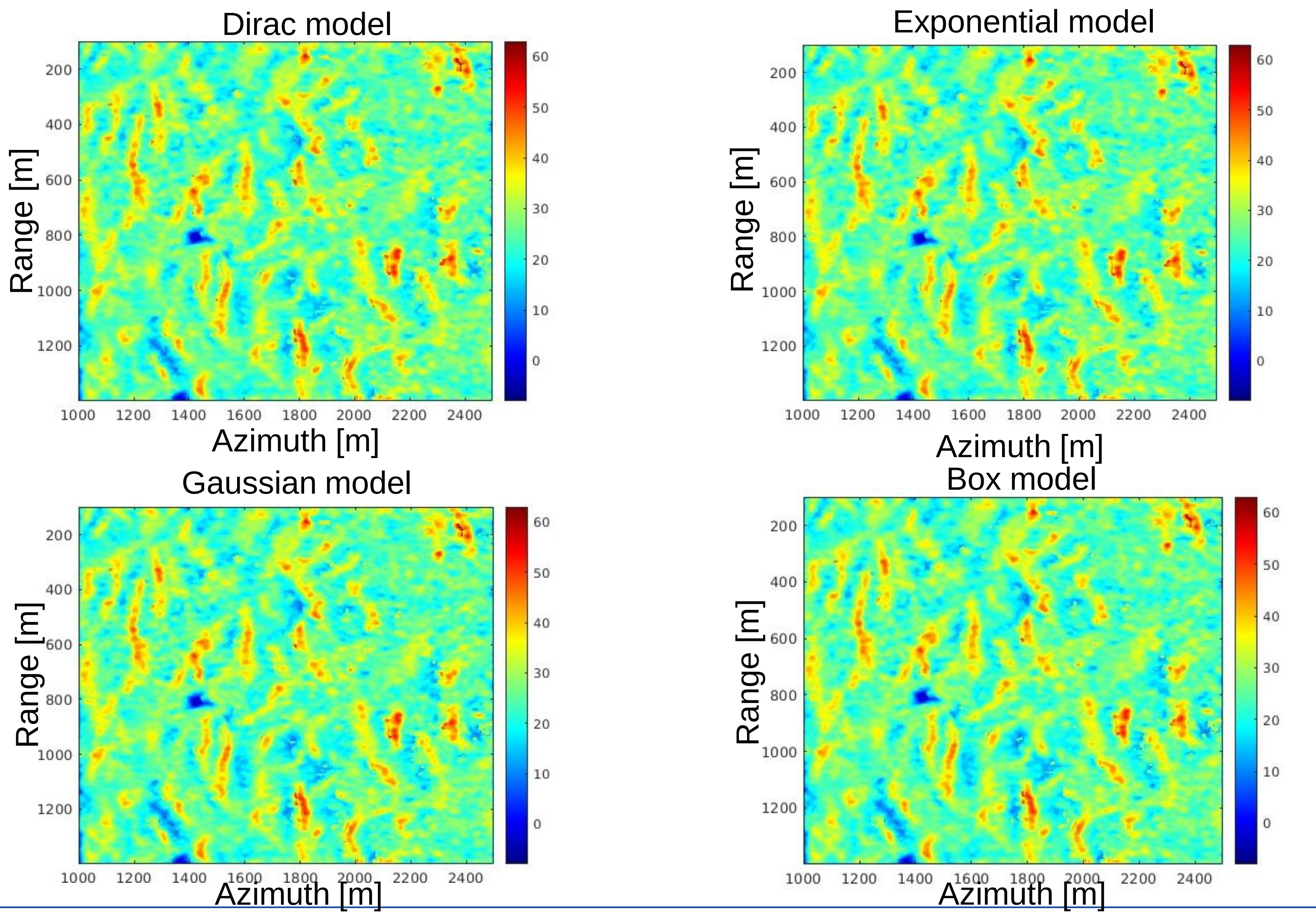




- Very good z_g , z_v fit & excellent reflectivity fit

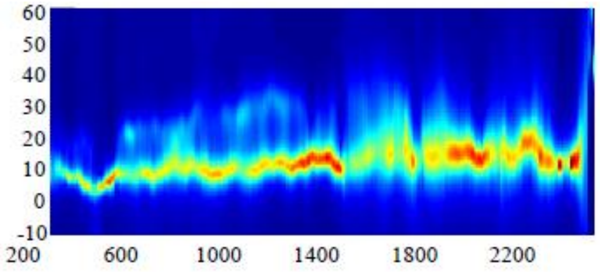
Comparison of the ground estimates

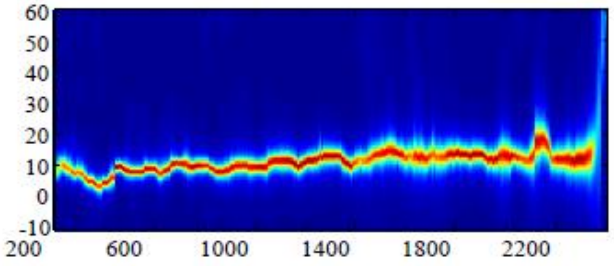


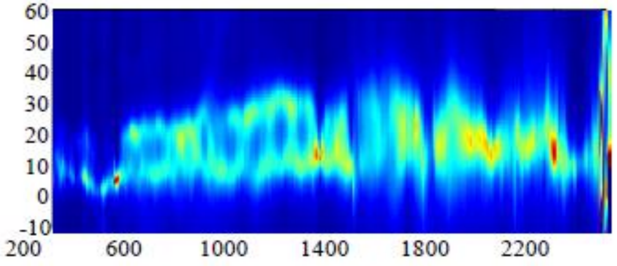


Validation of the parametric tomographic approach

- Polarimetric method : SKP decomposition

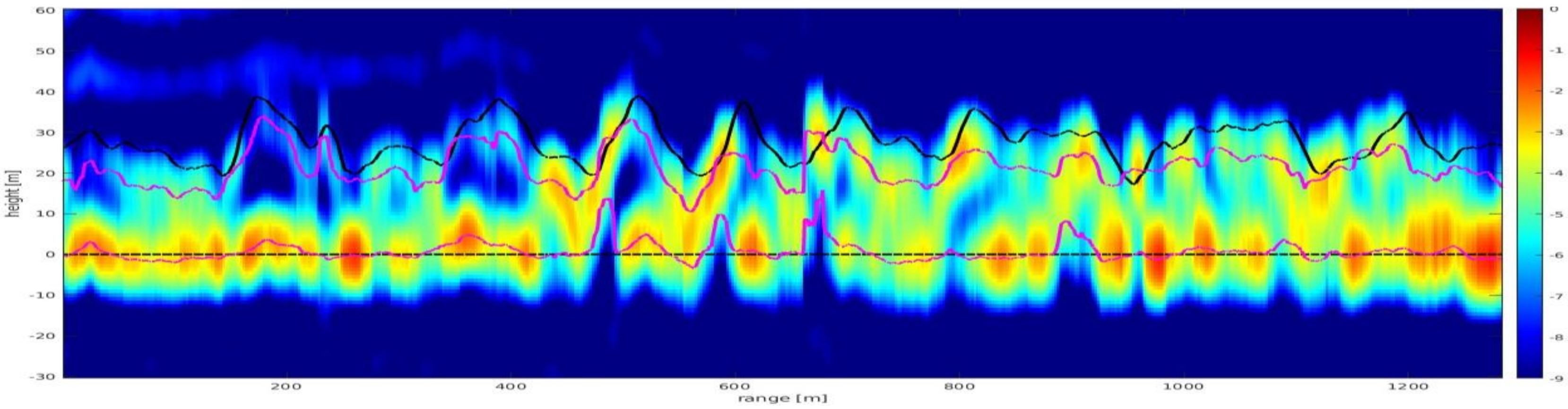






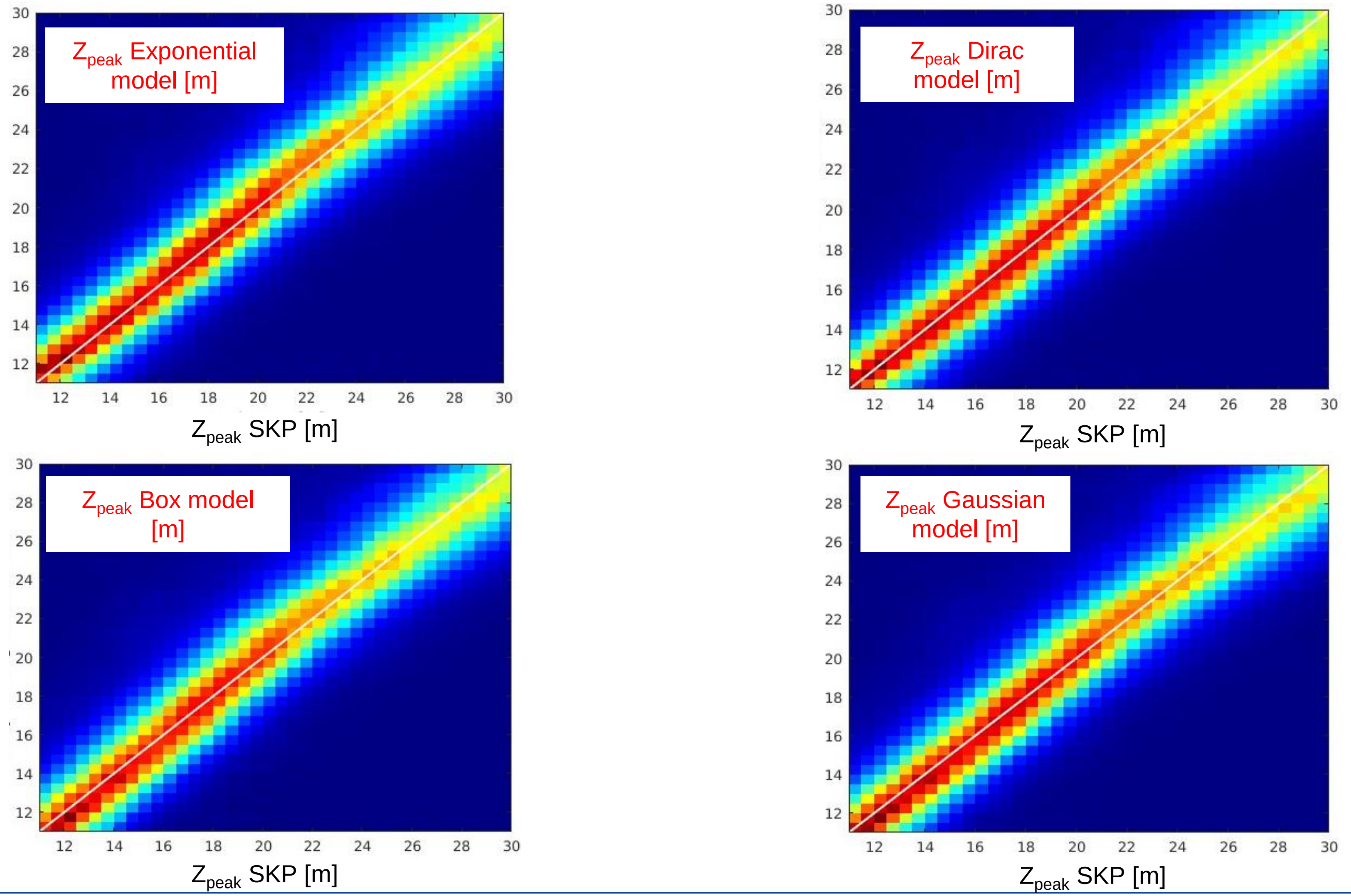
Total Tomogram = Ground + Volume

- Low rank model fit



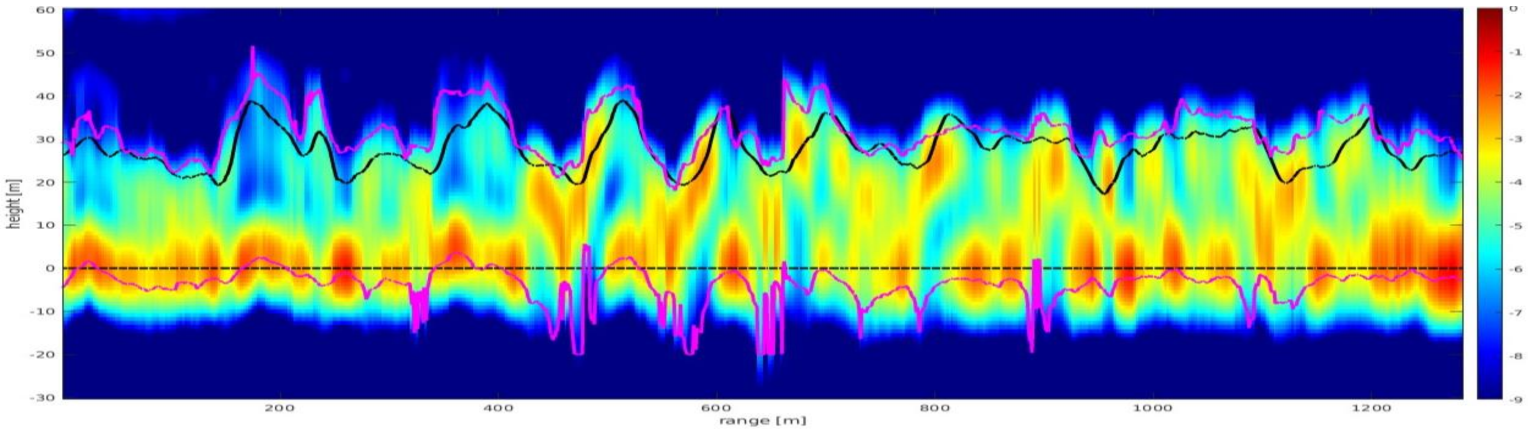
Relationship between z_{vol} fit & z_{vol} SKP

Validation of the parametric tomographic approach

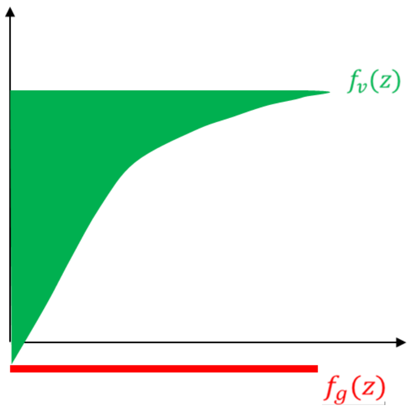


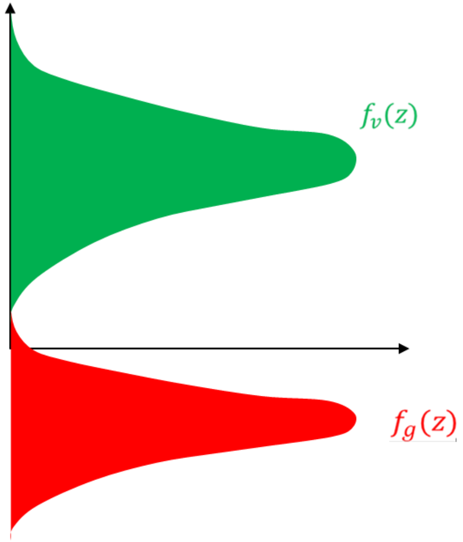
- $z_v \equiv z_{peak_{volSKP}}$
- Single Pol HH fit is equivalent to full Pol SKP approach

Conclusion :



- Overestimated z_{top}
- Underestimated z_{ground}

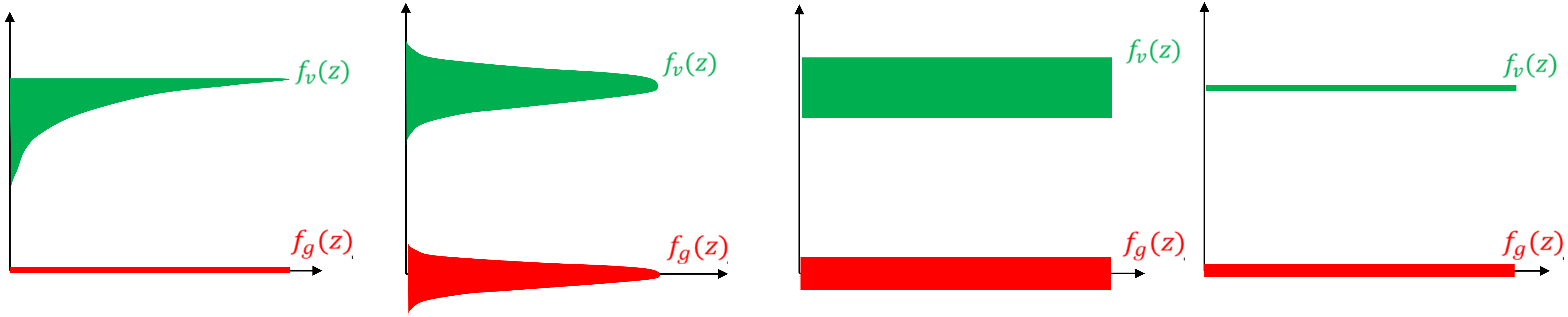




Wide volume shape

- exaggerated spread to account for decorrelation
- Ambiguous estimation of ground component

Conclusion :



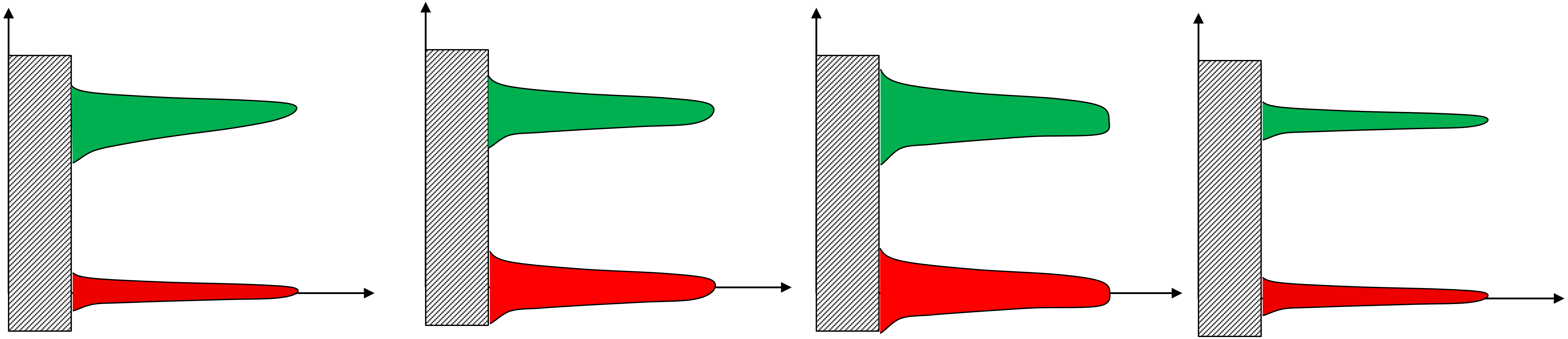
All **low rank** models lead to comparable estimates of ground & volume height

Accurate reflectivity modelling requires decorrelation terms

HH model fit estimates are similar to SKP ones

Conclusion :

Introduction of a decorrelation term to adjust the reconstruction & be similar to the original tomogram



After accounting for decorrelation terms all models converge to similar rounded narrow shape

Next step

- Application to BIOMASS like configuration with less resolution
- Synergy of BIOMASS acquisition modes