A Dual-frequency Approach to Detect Forest Height and Structure Using PolInSAR Technique

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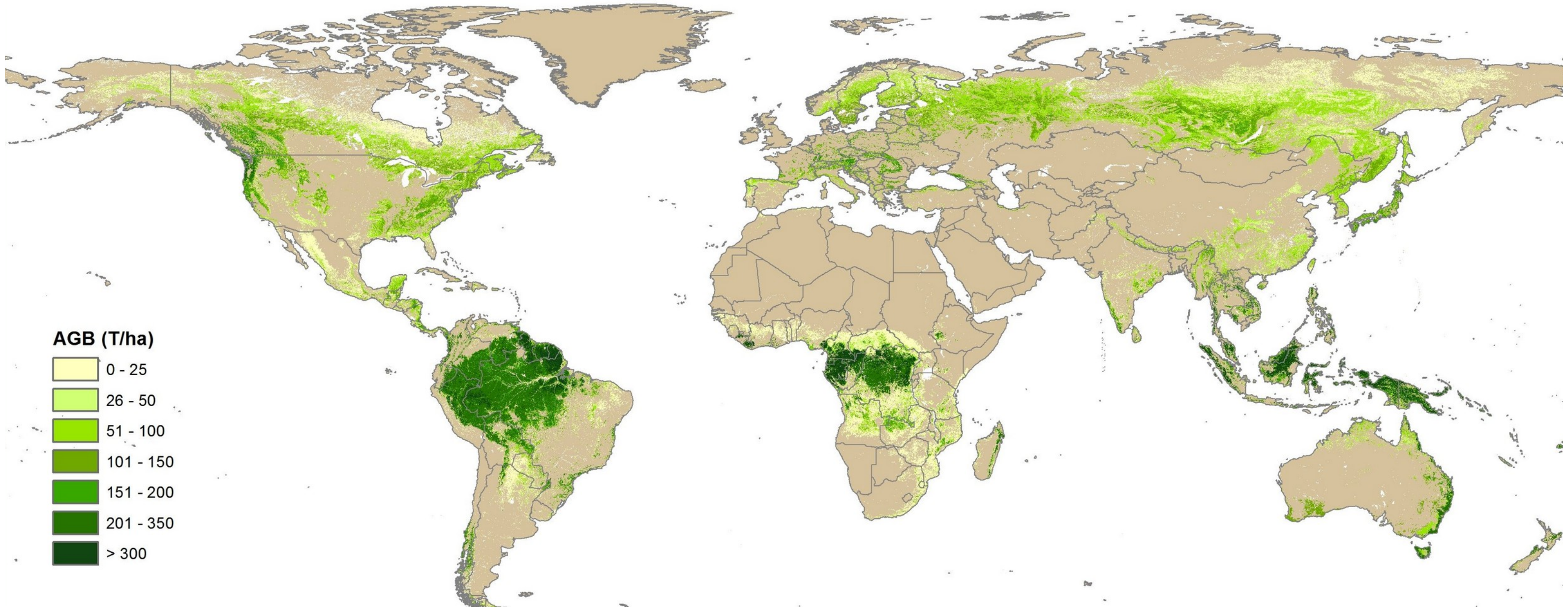
Problematic

Boreal forests constitute 1/3 of the world forest biomass

15% of the Earth's land surface

low biodiversity

sink-source distribution little-known

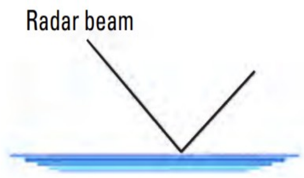


➜ Pol-InSAR remote sensing for global carbon cycle

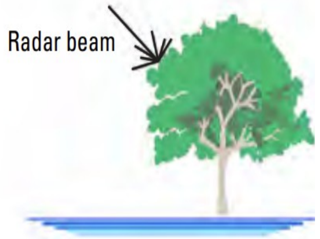
Technique

polarimetry

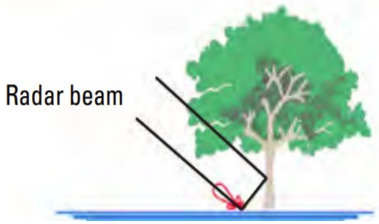
Specular reflection



Volume Diffusion



Double bounce



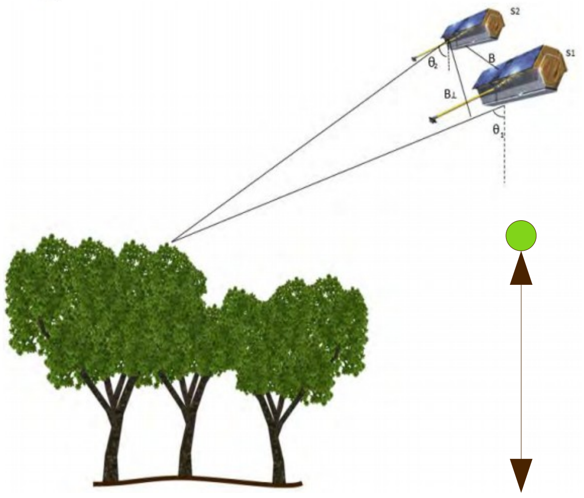
$$\mu = \omega^{+} k$$

$$\omega^{+} k k^{+} \omega$$

$$\mu \mu^{+} = \omega^{+} T \omega$$

interferometry

$$\gamma = \frac{\langle S_1 S_2^{+} \rangle}{\sqrt{\langle |S_1|^2 \rangle \langle |S_2|^2 \rangle}}$$



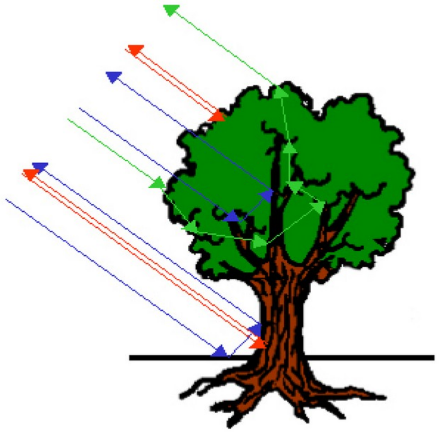
Vertical positioning of the target

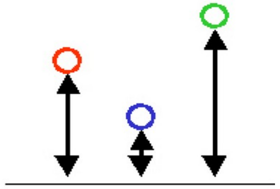
Polarimetric interferometry

$$\mu_1 = \omega_1^{+} k_1$$

$$\mu_2 = \omega_2^{+} k_2$$

$$\gamma = \mu_1 \mu_2^{+} = \frac{\omega_1^{+} \Omega_{12} \omega_2}{\sqrt{\omega_1^{+} T_{11} \omega_1 \omega_2^{+} T_{22} \omega_2}}$$





Vertical positioning of polarimetric phase centers

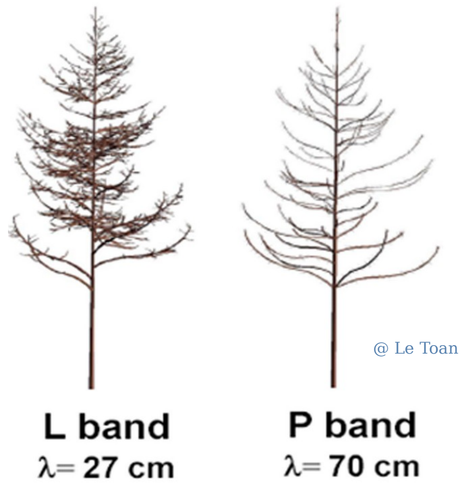
function of the frequency

Objectives

Dual frequency approach

exploiting different interactions with forest:

penetration + scatterers



Forest heterogeneity in models

vertical structure detection:

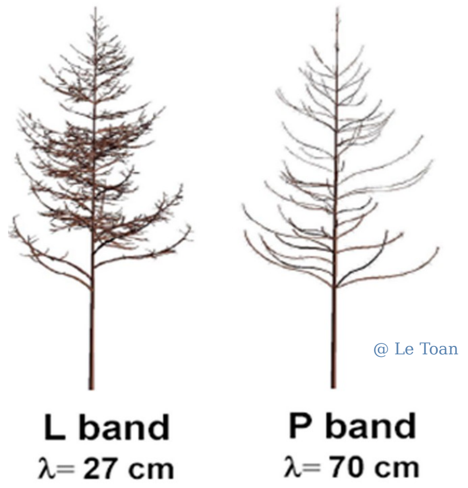
AGB = height + structure

Objectives

Dual frequency approach

exploiting different interactions with forest:

penetration + scatterers



Forest heterogeneity in models

vertical structure detection:

AGB = height + structure

Outline

I Data

II Forest structure inversion using GVB

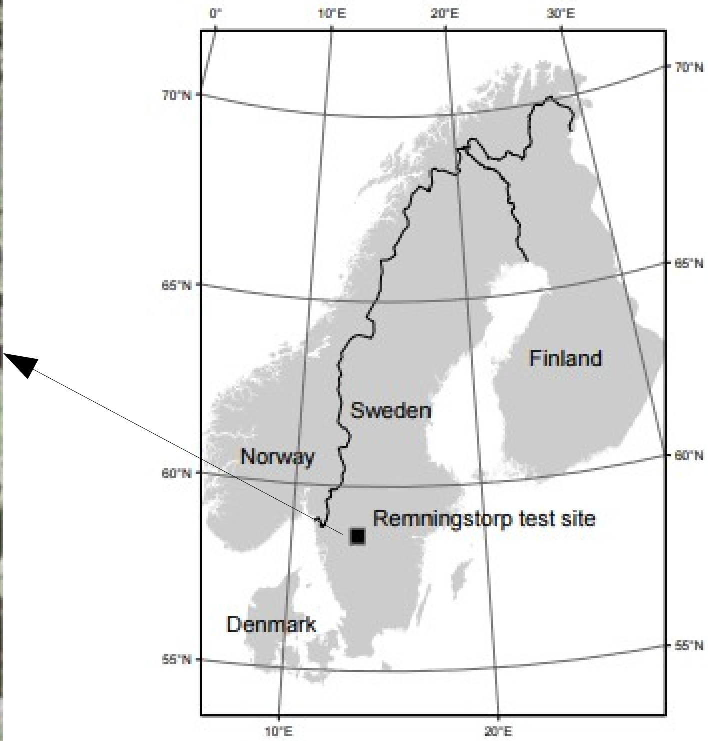
III Results at L- and P-bands

IV AGB inversion strategy

V conclusion & perspectives

Data: BIOSAR

Remingstorp hemi-boreal forest



L- & -P band acquisition

Choice of the data

- min temporal decorrelation
- appropriate kz range

Different species

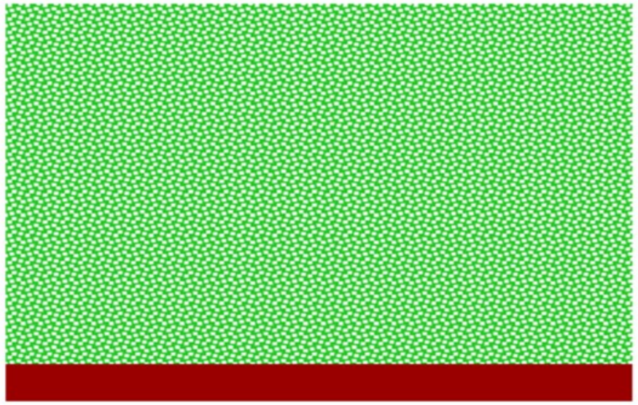
birches / pines / spruces etc.

DTM+DSM+ground measurements

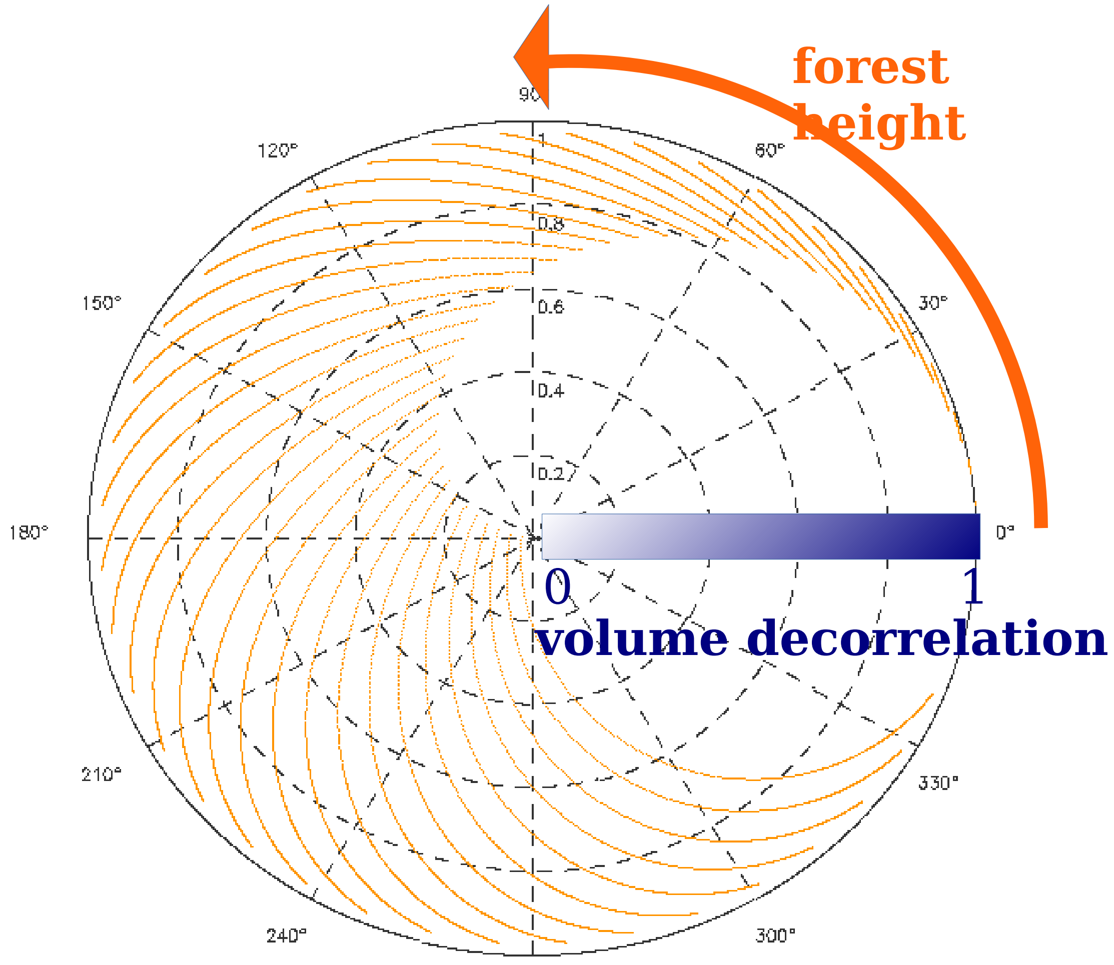
Forest structure inversion using GVB

Classical 2 layer forest represention

random volume + ground



$$\gamma_\upsilon(h_v,\sigma_z)=\frac{\int_0^{h_v} e^{\frac{2\sigma_z}{\cos\theta}} e^{jk_z z}\,dz}{\int_0^{h_v} e^{\frac{2\sigma_z}{\cos\theta}}\,dz}=\frac{1}{1+\frac{jk_z\cos\theta}{2\sigma_z}}\;\frac{e^{\left(\frac{2\sigma_z}{\cos\theta}+jk_z\right)h_\upsilon}-1}{e^{\frac{2\sigma_z h_\upsilon}{\cos\theta}}-1}$$

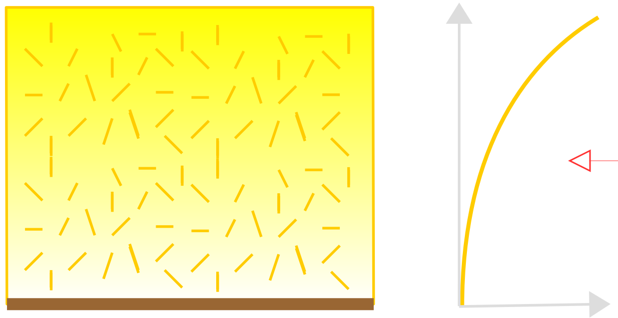


Interferometric coherence of the volume

height: 0-40 m
extinction: 0-2 dB/m

Forest structure inversion using GVB

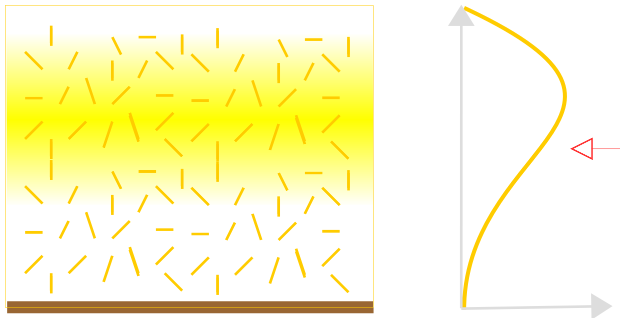
Random volume + ground = RVoG



exponential backscatter

$$\gamma_\upsilon(h_v,\sigma_z)=\frac{\int_0^{h_v} e^{\frac{2\sigma_z}{\cos\theta}} e^{jk_z z}\,dz}{\int_0^{h_v} e^{\frac{2\sigma_z}{\cos\theta}}\,dz}=\frac{1}{1+\frac{jk_z\cos\theta}{2\sigma_z}}\;\frac{e^{\left(\frac{2\sigma_z}{\cos\theta}+jk_z\right)h_\upsilon}-1}{e^{\frac{2\sigma_z h_\upsilon}{\cos\theta}}-1}$$

Gaussian vertical backscatter + ground = GVBoG

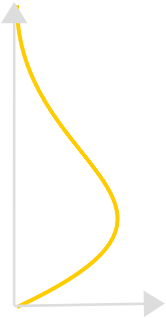


Gaussian backscatter

$$\gamma_v(h_v,\delta,\chi)=\frac{\int_0^{h_v} e^{-\frac{(z-\sigma)^2}{2\chi^2}+jk_z z}\,dz}{\int_0^{h_v} e^{-\frac{(z-\sigma)^2}{2\chi^2}}\,dz}=e^{\frac{-\chi^2 k_z^2}{2}+j\delta k_z}\;\frac{erf\left(\frac{1}{\sqrt{2}}\left(j\chi k_z+\frac{\delta}{\chi}\right)\right)-erf\left(\frac{1}{\sqrt{2}}\left(j\chi k_z+\frac{\delta-h_v}{\chi}\right)\right)}{erf\left(\frac{h_v-\delta}{\sqrt{2}\chi}\right)+erf\left(\frac{\delta}{\sqrt{2}\chi}\right)}$$

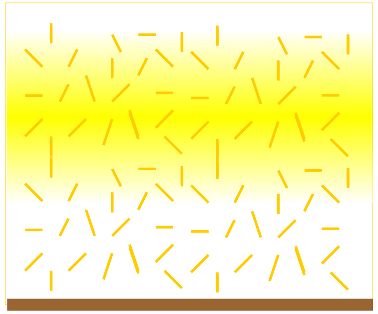
Forest structure inversion using GVB

Gaussian vertical backscatter + ground = GVBoG


can distinguish
very different structure

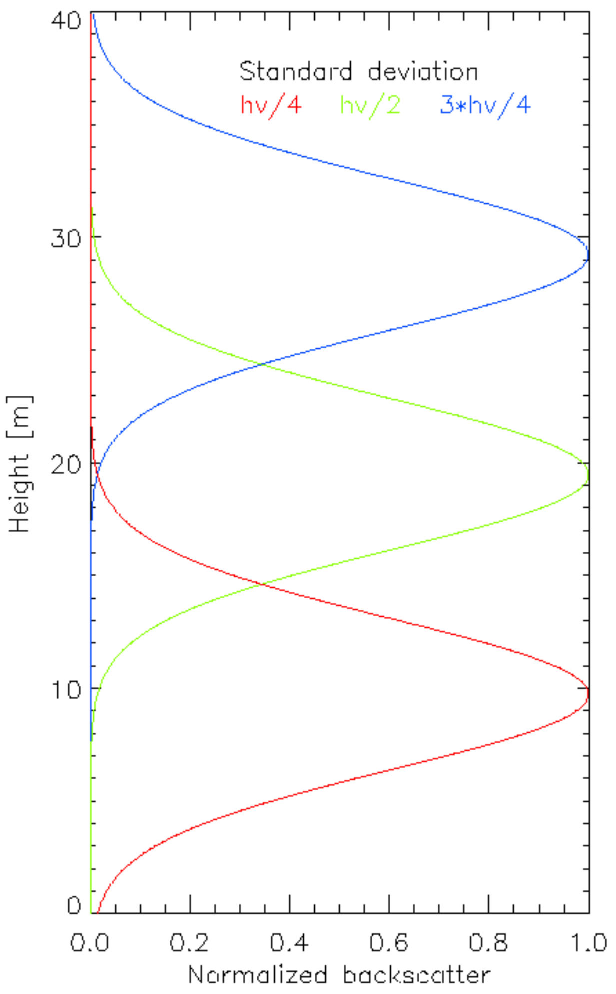
↓

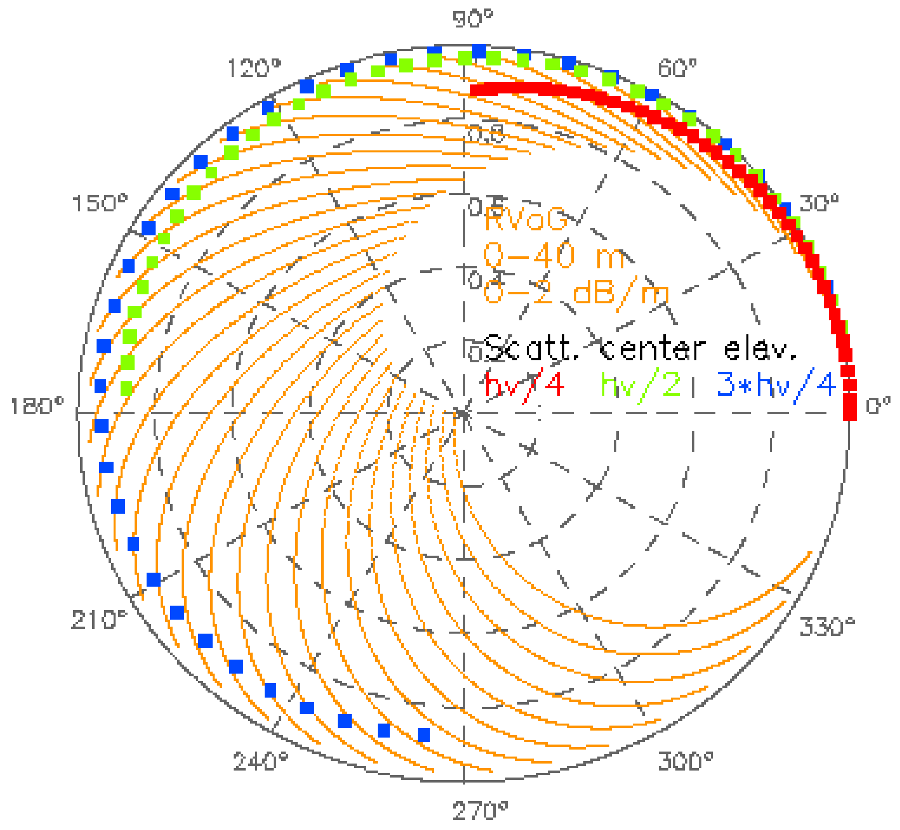


**specie "rough"
discrimination**

Forest structure inversion using GVB

only relative elevation varies



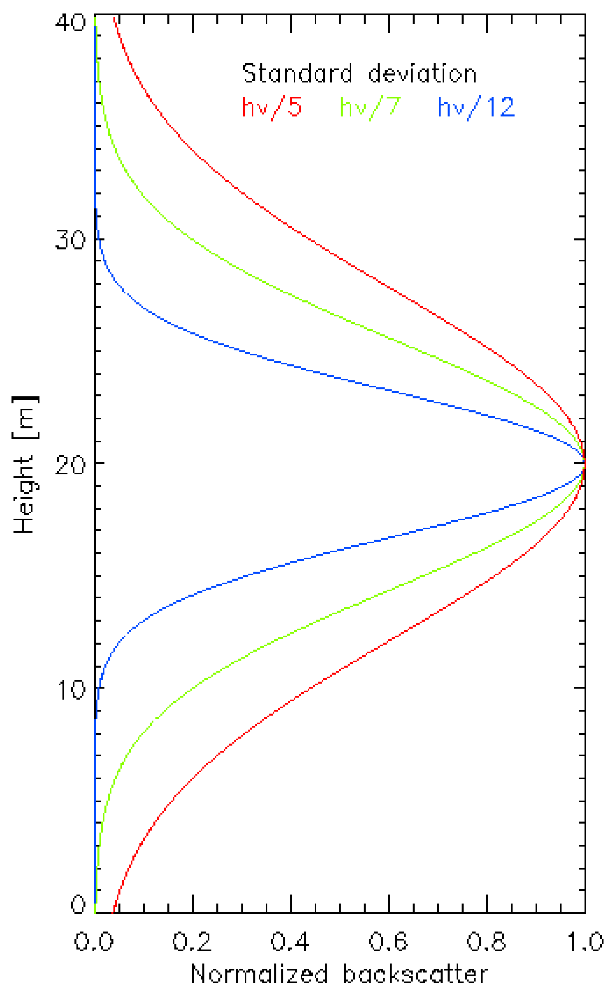


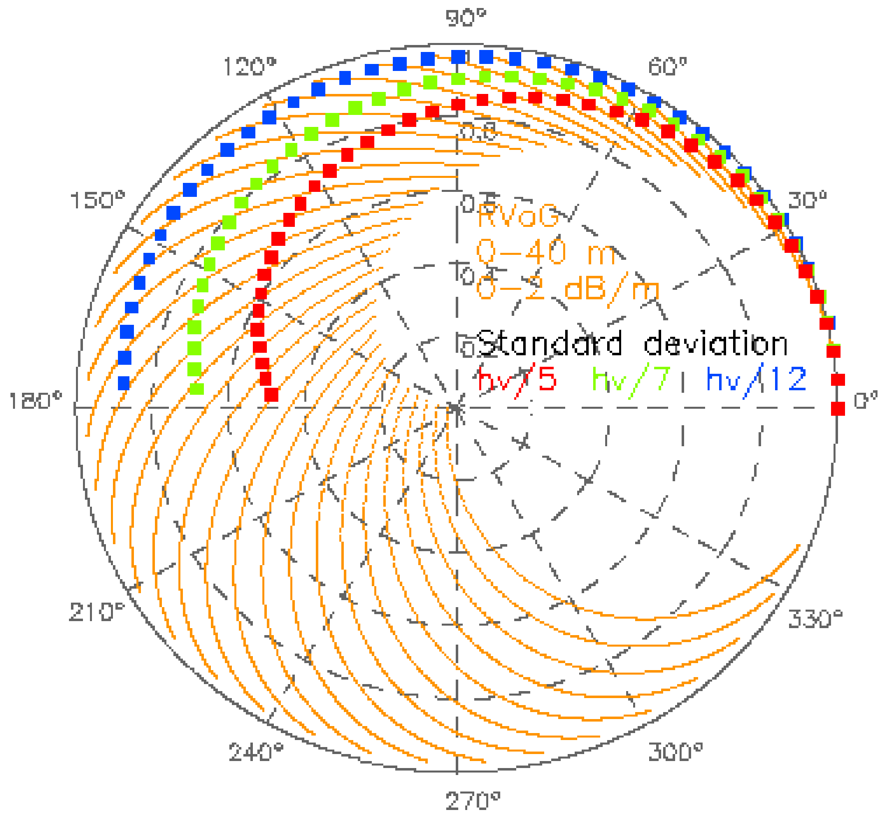
different position of backscatter peak in the forest

➔ rotation in the complex plane

Forest structure inversion using GVB

only the relative standard deviation varies

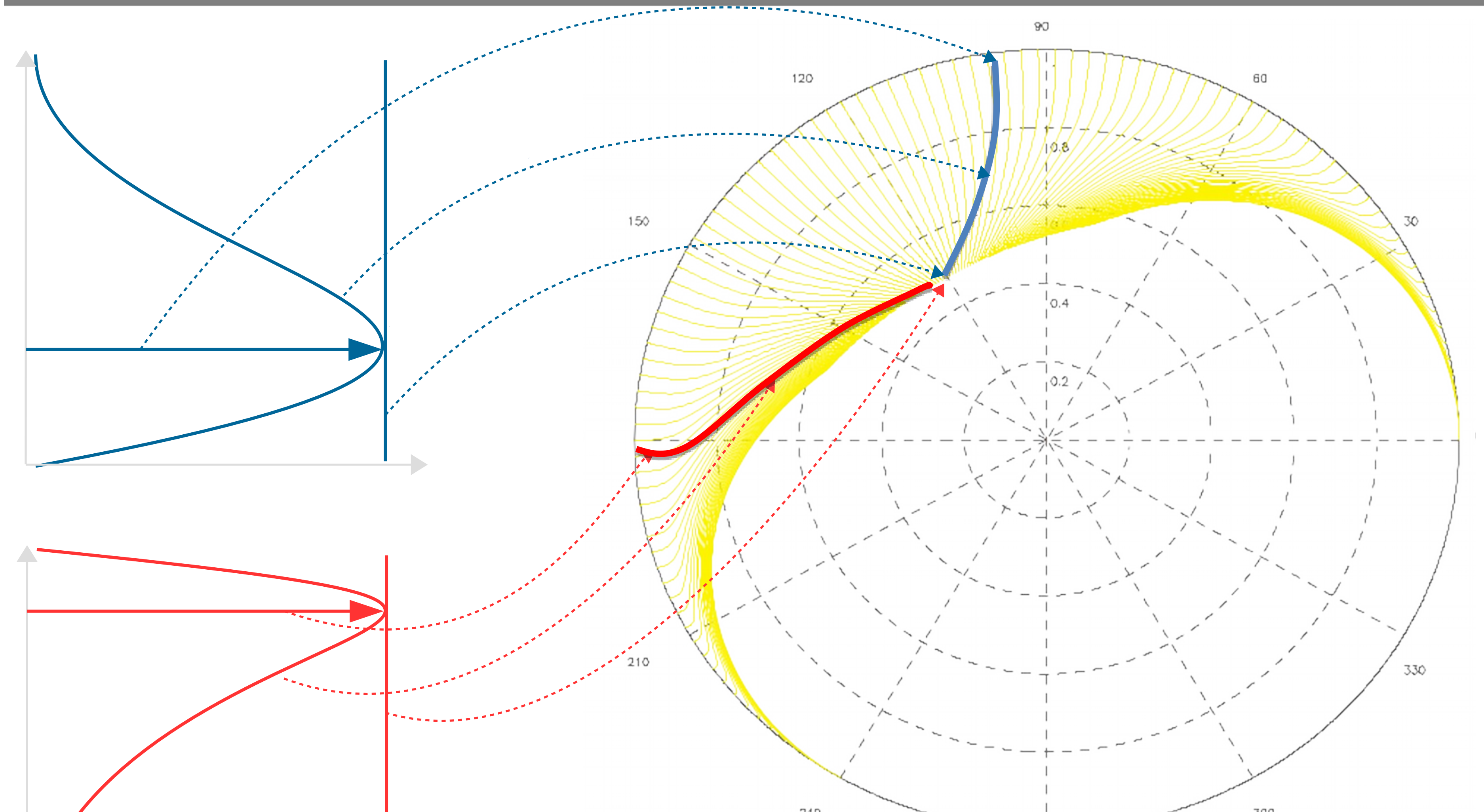




variation of the vertical interval of contributions

➔ radial migration in the complex plane (volume decorrelation)

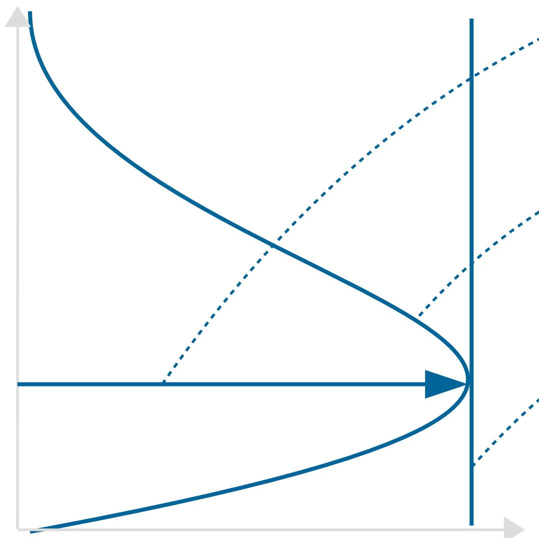
Forest structure inversion using GVB

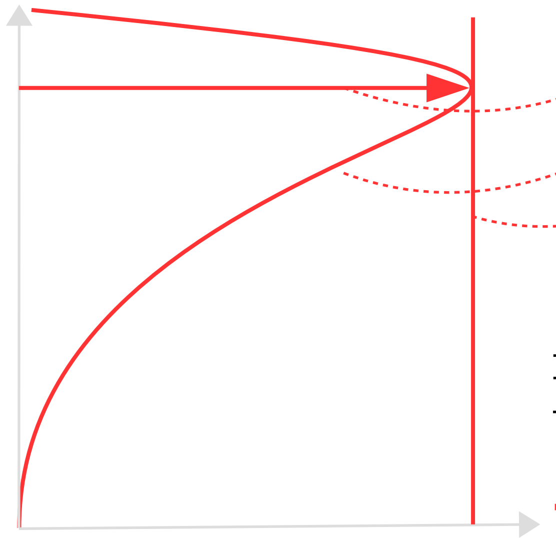


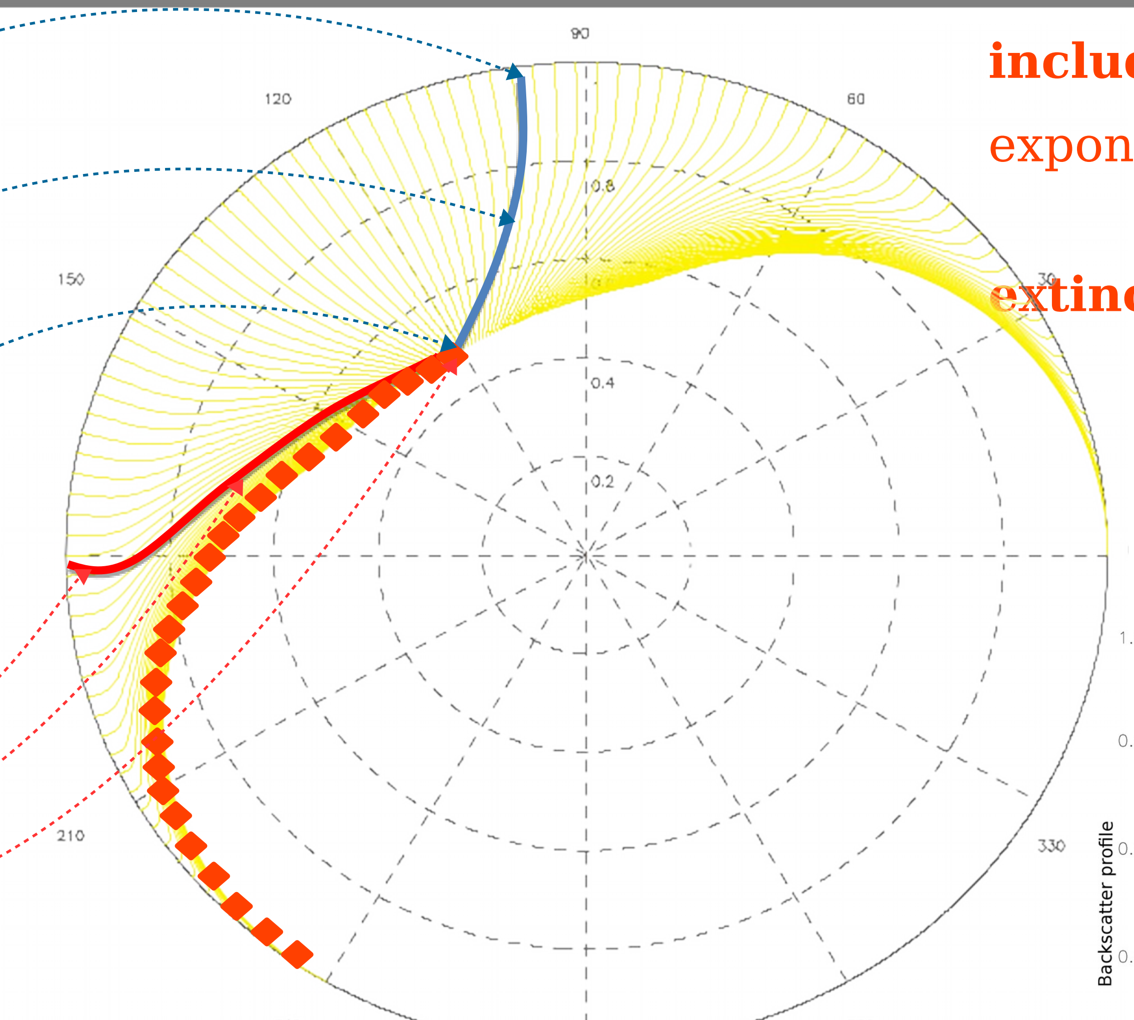
from **Delta** function to **uniform** profile
through any truncated **Gaussian** shape

→ representation of all possible structures

Forest structure inversion using GVB





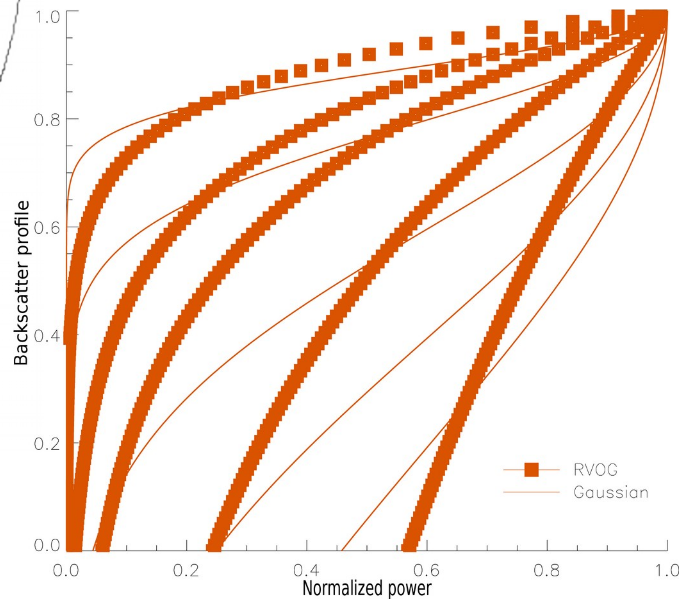


includes RVoG representation

exponential≃ half Gaussian

↓

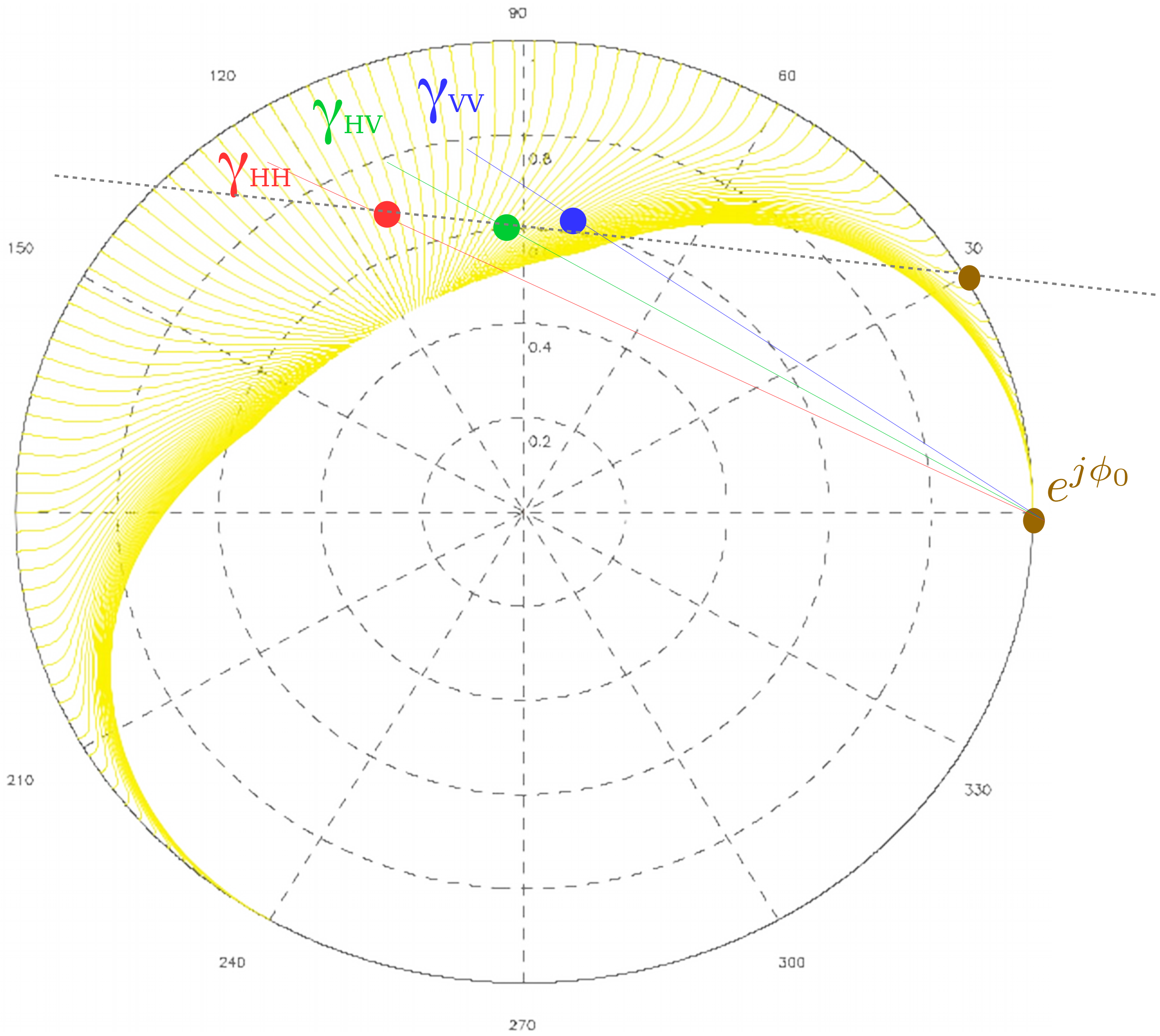
extinction without structure



from **Delta** function to **uniform** profile through any truncated **Gaussian** shape

→ representation of all possible structures

Forest structure inversion using GVB



Usually, **structure** seen by SAR

varies with polarization

↓

interferometric coherences

not exactly on the same line

underlying ground phase estimated

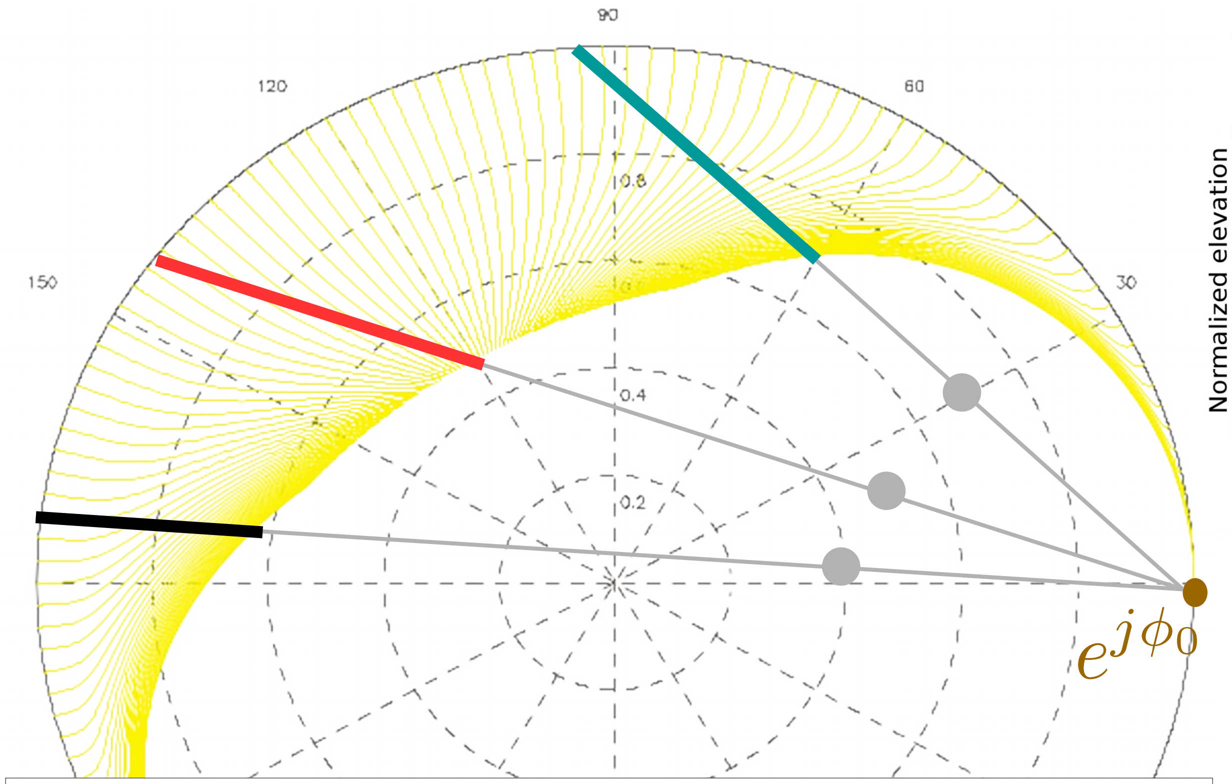
from LiDAR over bare surfaces

↓

no bias in the structure estimation

for each polarization

Forest structure inversion using GVB

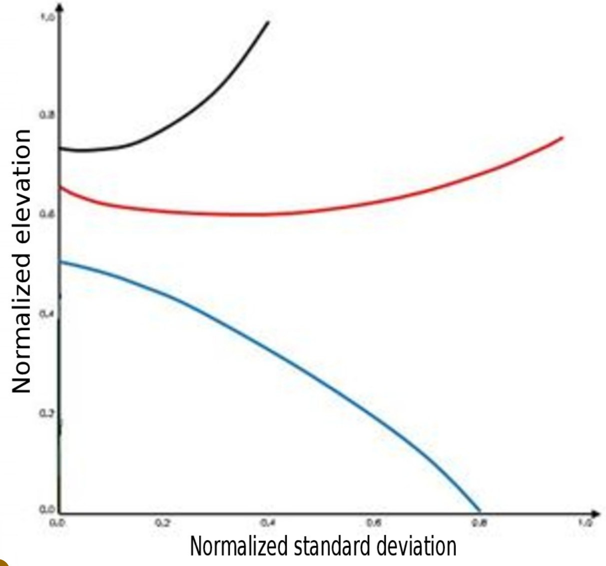


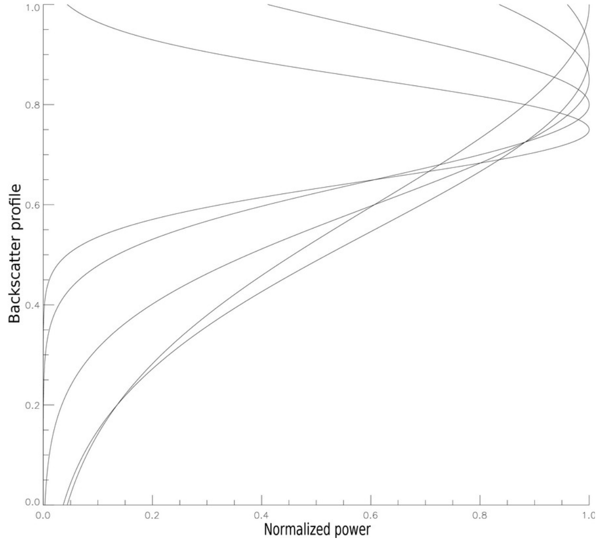
structure inversion = intersection line/GVB

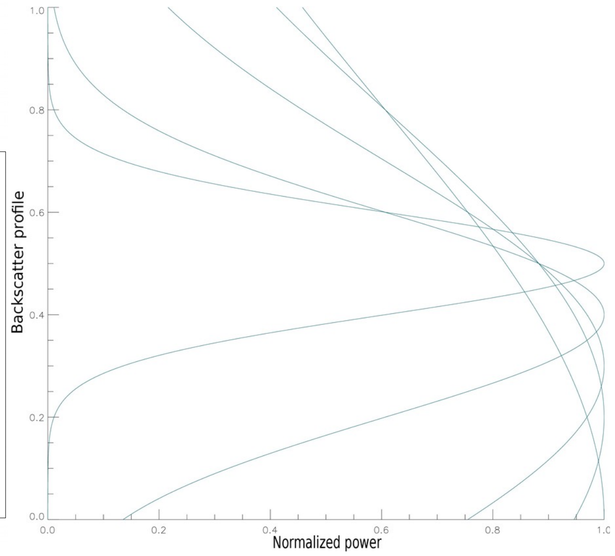
➜ 2D δ-χ ensemble of solution

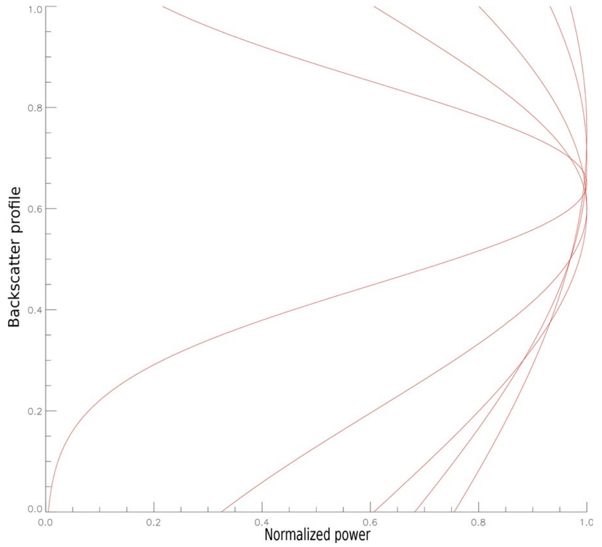
➜ structure indicator

270







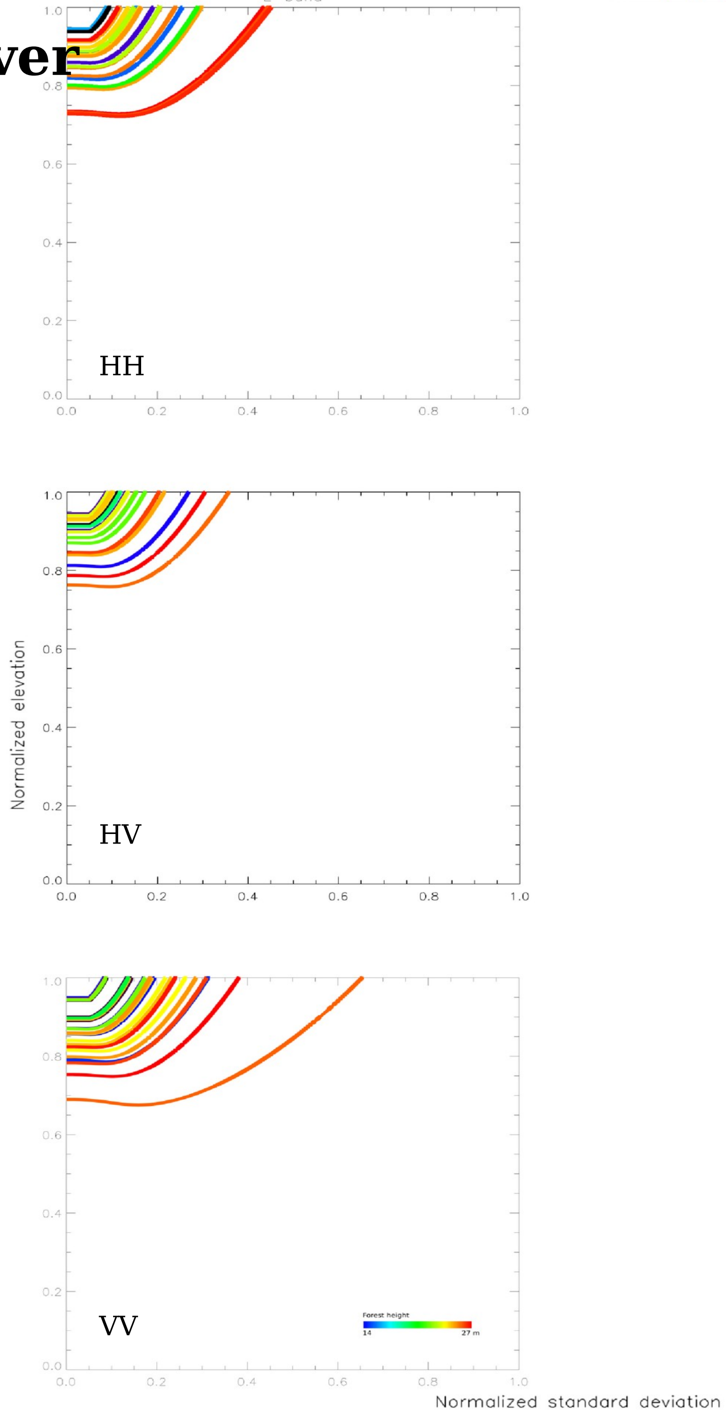


Structure estimation over all the forest stands

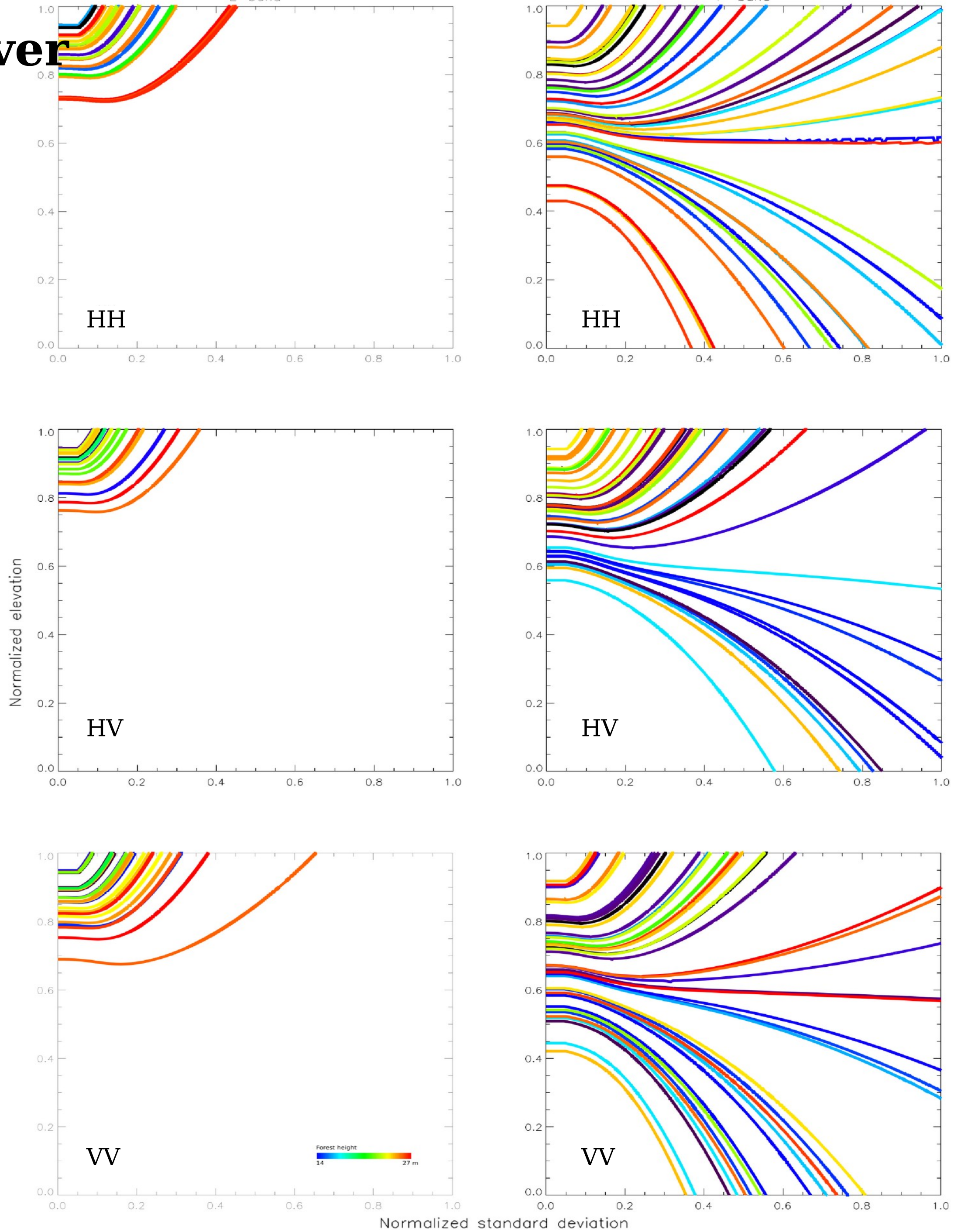
L-band

low sensitivity to **forest structure**

structure seen **similarly** for **each polarization**



Structure estimation over all the forest stands



L-band

low sensitivity
to **forest structure**

structure seen **similarly**
for **each polarization**

P-band

important sensitivity
to **forest structure**

structure seen **differently**
for **each polarization**

↓

best for estimating structure

Structure estimation at P-band

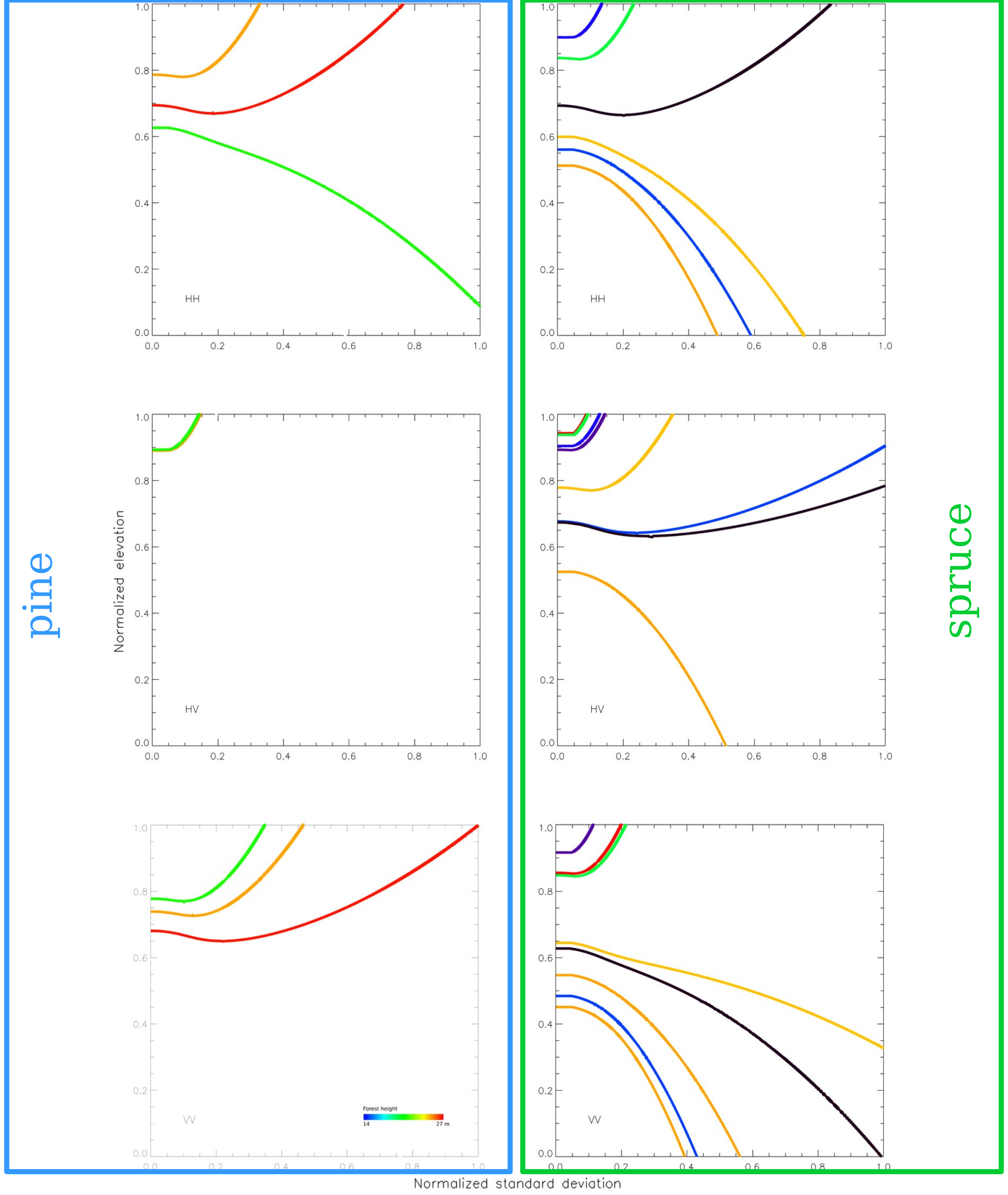
over the stands of accurate ground measurements
(specie inventory by foresters)

Different signatures of the species

pine: backscatter from the top of the canopy

spruce: backscatter from the whole canopy

➜ discrimination of the two main species

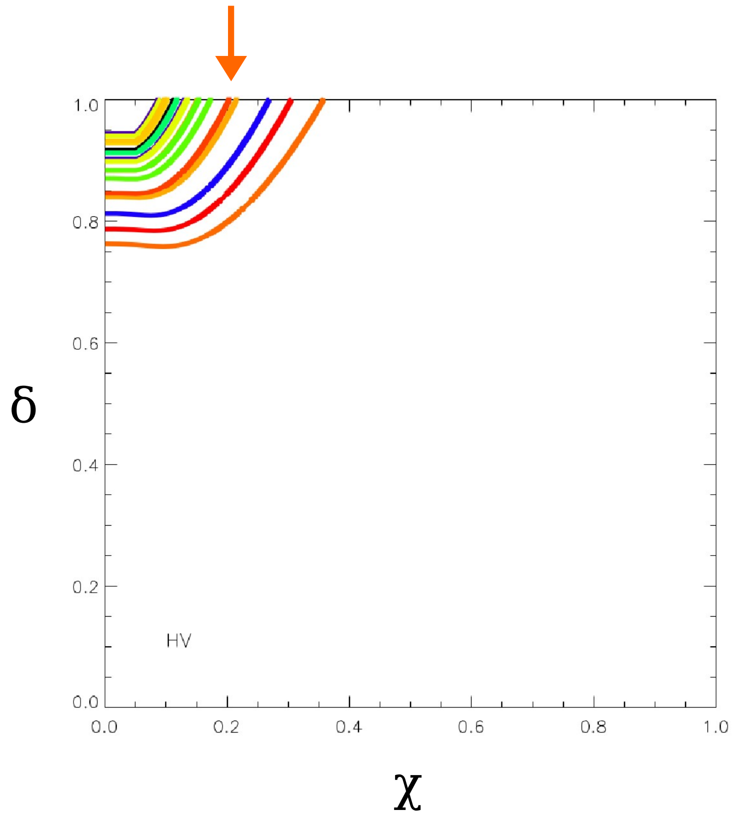


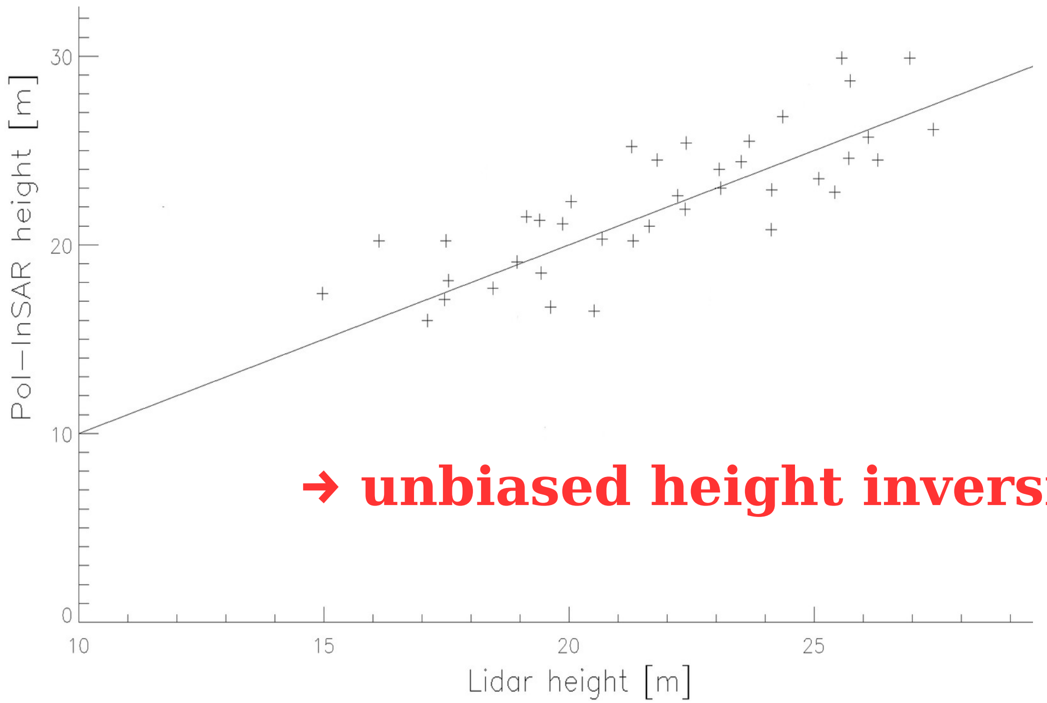
Results : forest height estimation at L-band

Low sensitivity to forest structure at L-band → secure height inversion

mean curve of HV channel = mean structure

$\delta = 0.86 + 0.16\chi - 10.21\chi^{2} + 166.17\chi^{3} - 694.63\chi^{4} + 1097\chi^{5}$ → injected in GVB for unique solution

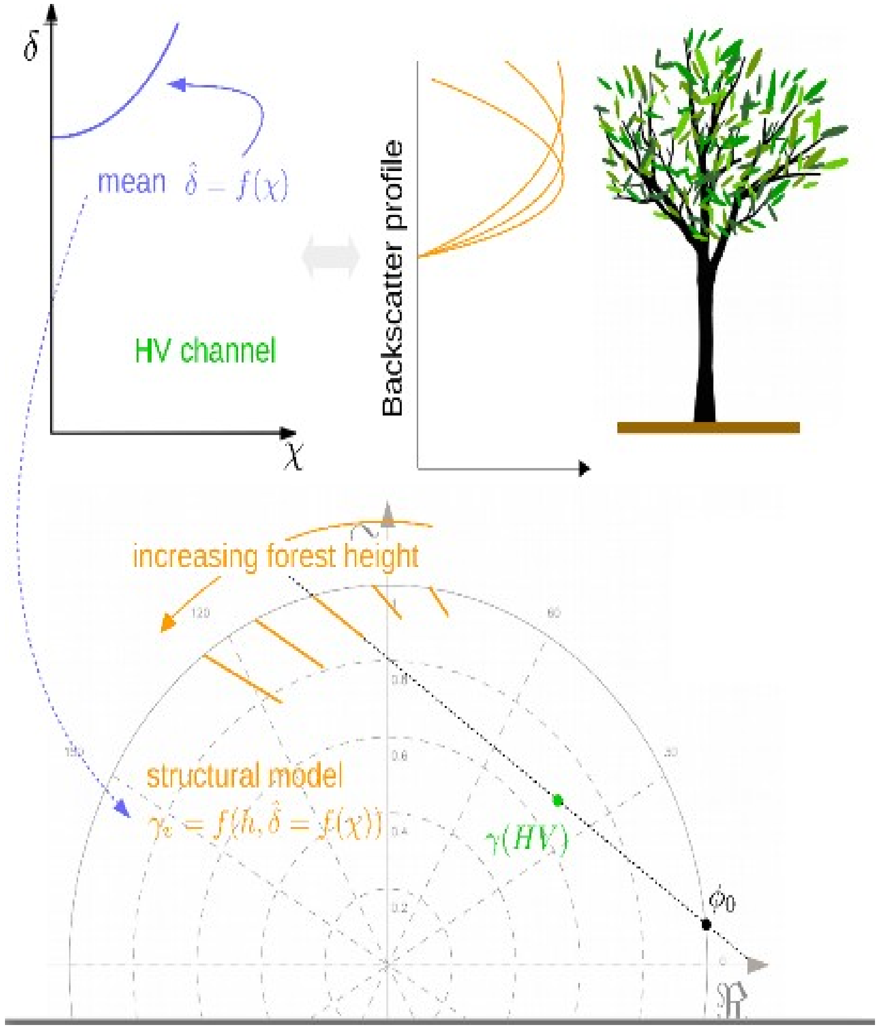




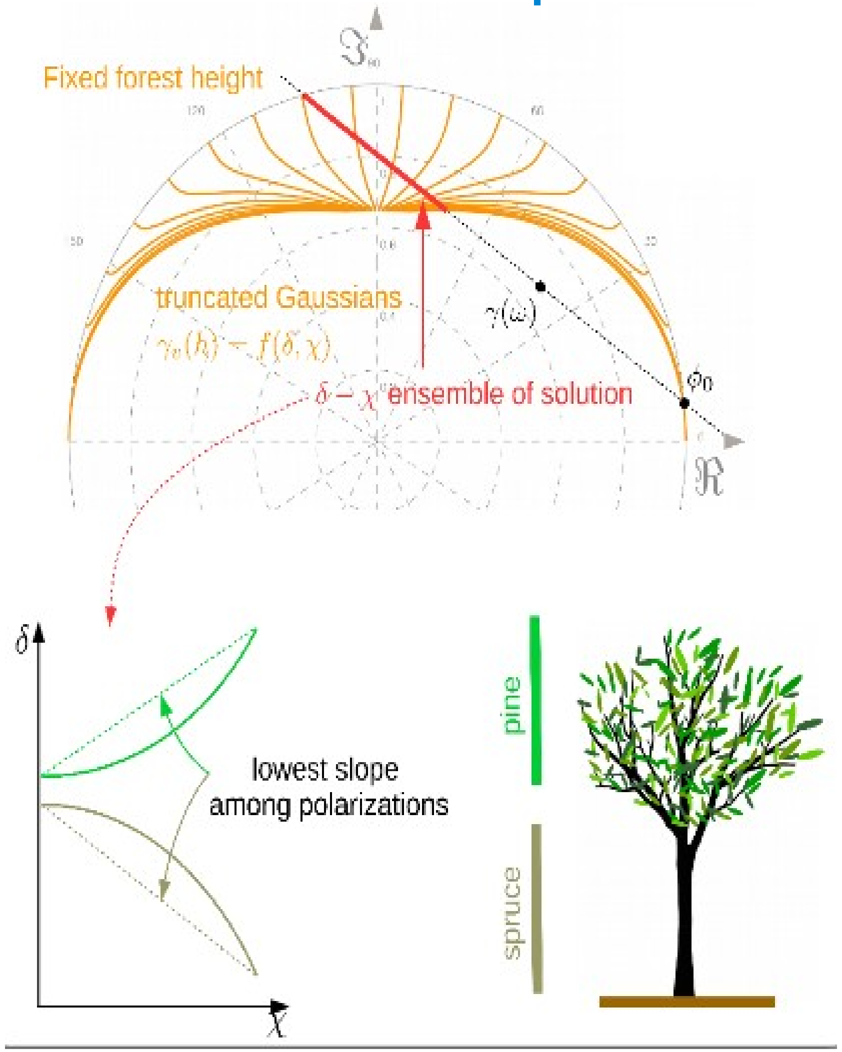
→ **unbiased height inversion**

Conclusion

Estimation of forest height at L band



Determination of forest species at P band



Above Ground Biomass = height (L-band) + structure (P-band)

Perspectives

Using actual/near future **spaceborne** sensors (BIOMASS)

1/ evaluation of GVB for different forest types & conditions

2/ temporal behaviour of the inversion for better constraining the structure

3/ complementarity of higher frequencies (tandem X)

Thank you for your attention!

AGB inversion strategy

Initial goal of Pol-InSAR over forests

➜ estimation of both **forest height** and **structure** for **above ground biomass** assessment

Over the boreal forests (1/3 of the world forest biomass) ➜ **polarimetric Dual-frequency approach**

P-band

ground phase estimation using dual-pol HH-HV space

L-band

forest height estimation using GVB constrained by δ-χ empirical model

P-band

forest structure discrimination from derivative in δ-χ space

spaceborne missions upcoming soon

P-band: BIOMASS (low frequency-short revisit)
L-band: TanDEM-L (no temporal decorrelation)

➜ **biomass from height specie allometric relations**

Results : Physical

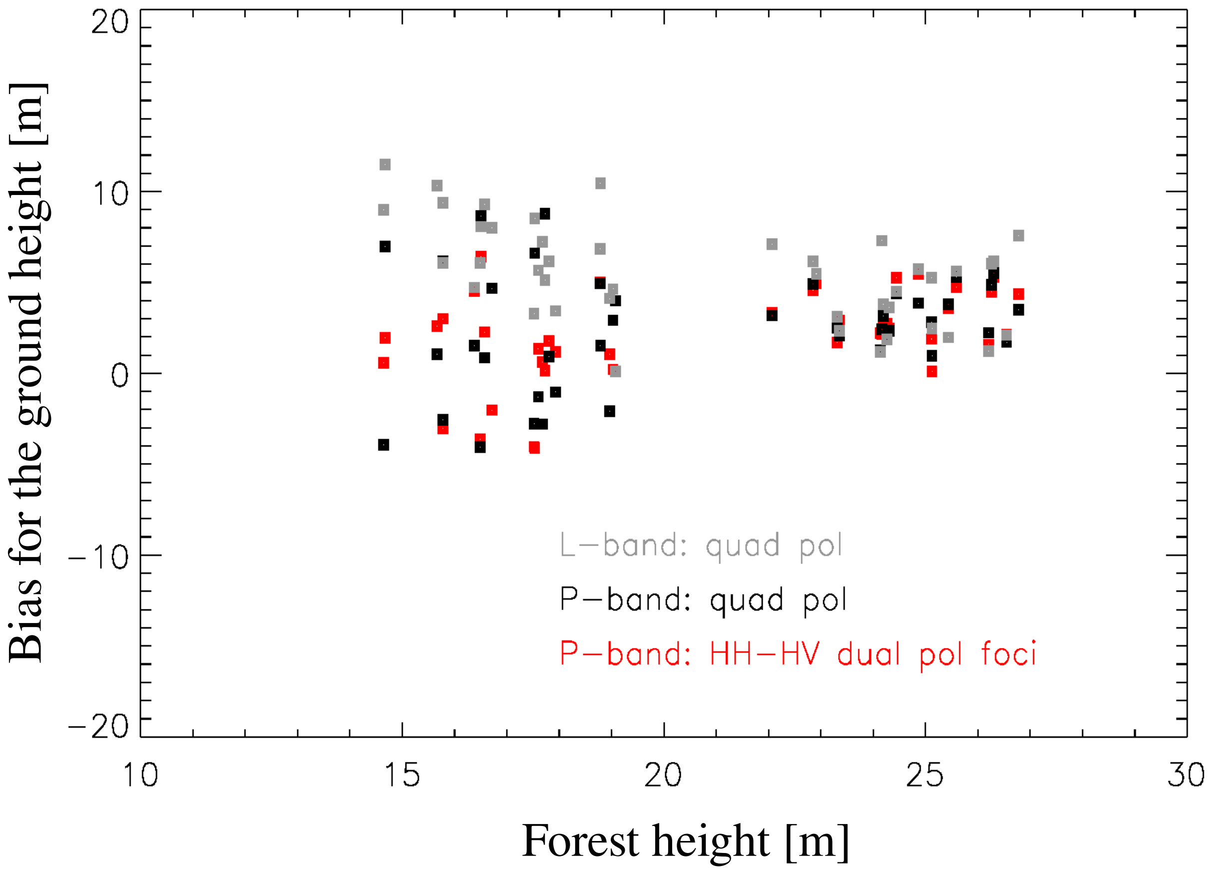
The ground bias is

1/ lower at P-band than at L-band

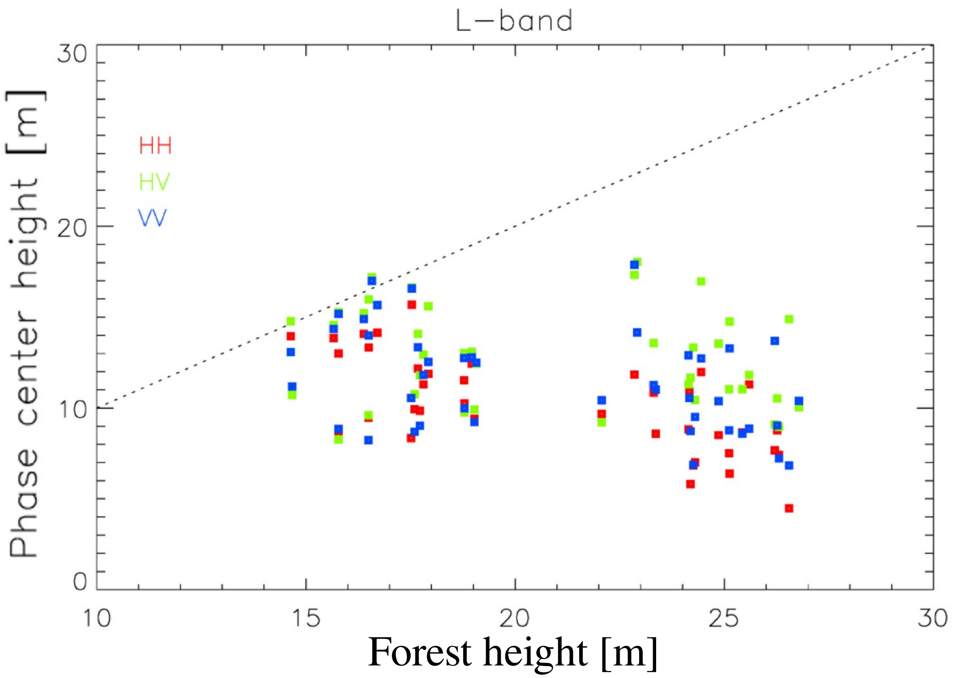
2/ is minimum in HH-HV dual pol space

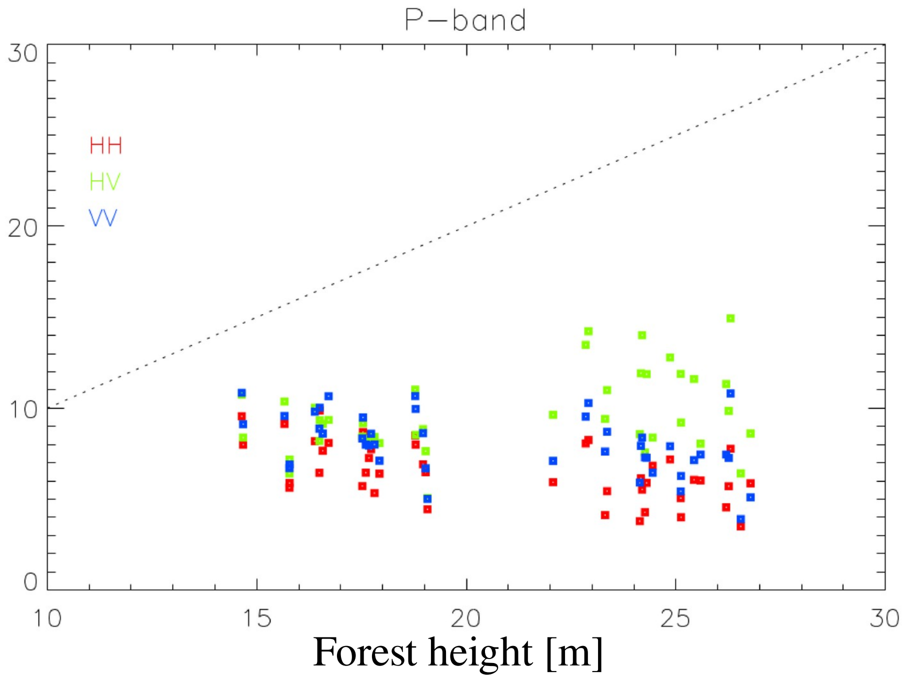
As ground phase estimation is independent of weather-phenology-temporal decorrelation

multi-baseline → increase of accuracy



Results : phase center vertical distribution





lower penetration

random vertical sorting

higher penetration

deterministic vertical sorting