



Forest parameter retrieval from P band data: polarimetry and polarimetric interferometry

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Dupuis

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$\partial_t \psi + \frac{M}{\epsilon} |\nabla \psi|^2 - \nu \Delta \psi + \nabla p = 0, \quad \nabla \psi = 0, \quad \psi(x, 0) = \psi_0(x), \quad \psi(x, t) \in e$

$\frac{1}{\rho} \frac{\partial^2 \rho}{\partial z^2} = \frac{1}{\rho} \frac{\partial^2 \rho}{\partial z^2}$

ONERA

THE FRENCH AEROSPACE LAB

r e t o u r s u r i n n o v a t i o n

www.onera.fr



FOREST PARAMETER RETRIEVAL FROM P BAND DATA:

Polarimetry and Polarimetric interferometry

Pascale Dubois-Fernandez

*Isabelle Champion (INRA)
Franck Garestier (CESBIO)
Xavier Dupuis (ONERA)*



retour sur innovation

- The ONERA instrument: RAMSES
- The campaign over les Landes
- The calibration procedure
- The radiometric analysis
- The polarimetric analysis
- The Polarimetric interferometry analysis
- Conclusions

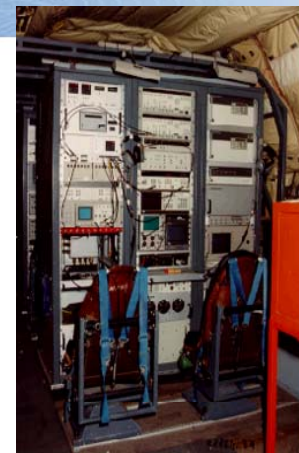


RAMSES, the ONERA System



retour sur innovation

RAMSES



Band	P*	L*	S	C	X*	Ku*	Ka*	W
Center Frequency	0,43 GHz	1,3 GHz	3,2 GHz	5,3 GHz	9,6 GHz	14,3 GHz	35 GHz	95 GHz
Bandwidth	70 MHz	200 MHz	300 MHz	300 MHz	1200 MHz	1200 MHz	1200 MHz	500 MHz
Transmit Polarization	V / H	V / H	V / H	V / H	V / H	V / H	V or H	L or R
Receive Polarization	V and H	V and H	V and H	V and H	V and H	V and H	V and H	L and R



* P, L, X, Ku : GMTI capability

X, Ku, Ka : Interferometry capability

X-Band Examples

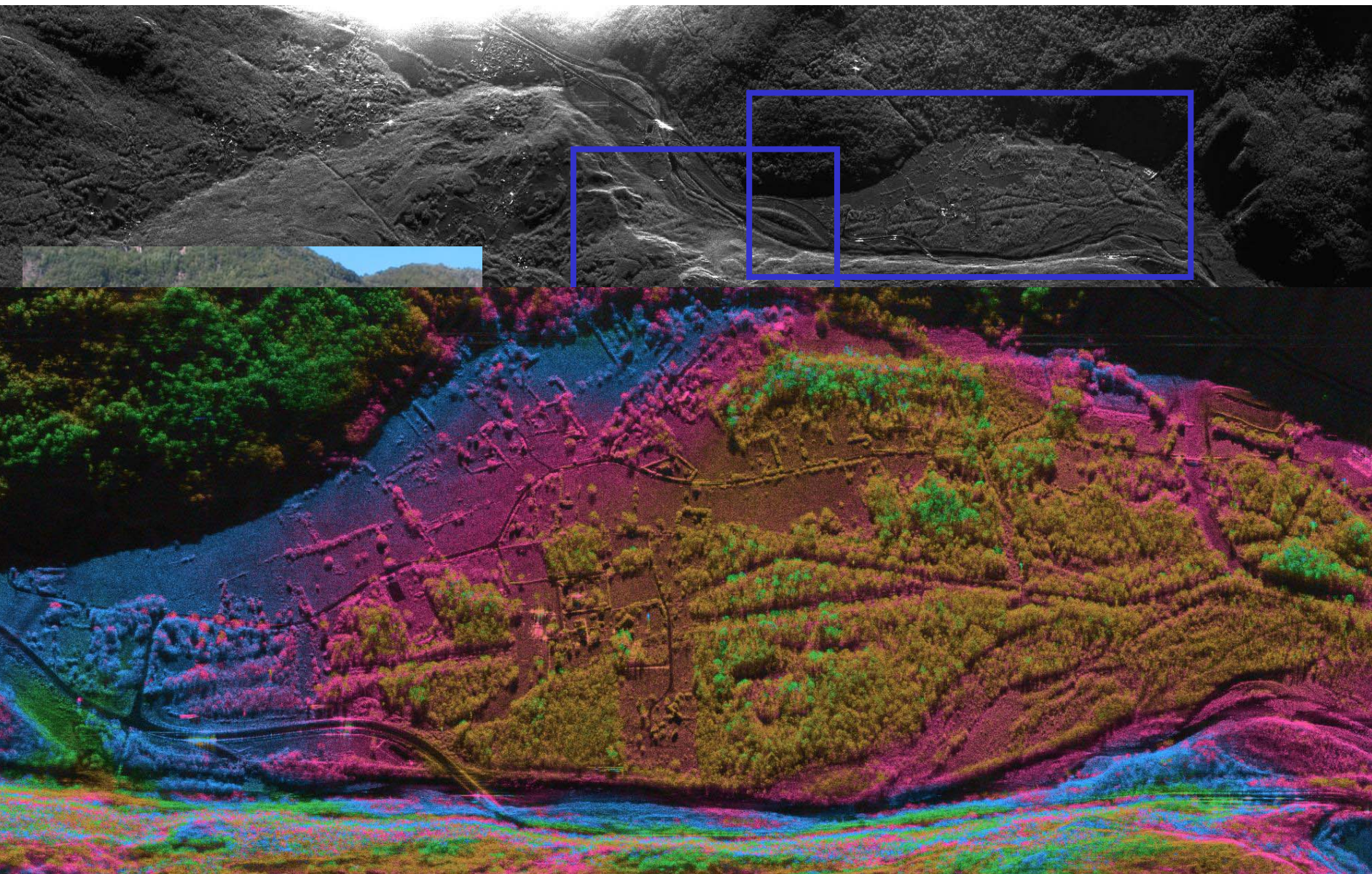


HH+VV

HV

HH-VV

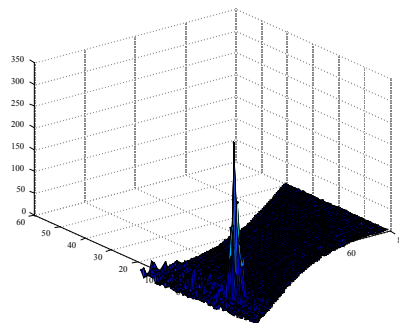
X-Band: examples



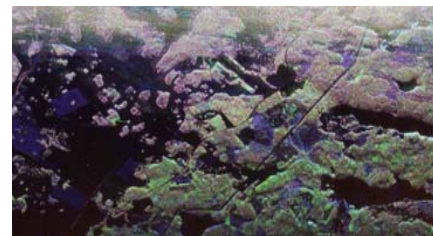
Polarimetry



GMTI / STAP



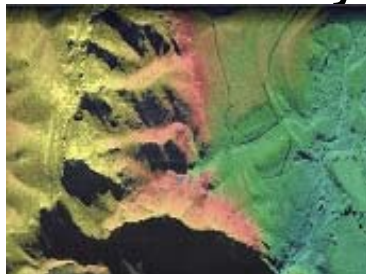
Low frequency



Very High Resolution



Interferometry



SAR Techniques

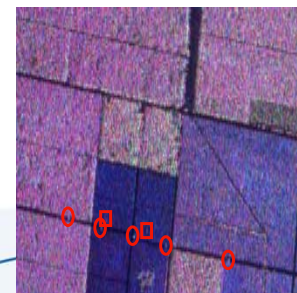
Bi-static



PollnSar



FOPEN



Planned Evolutions

SETHI

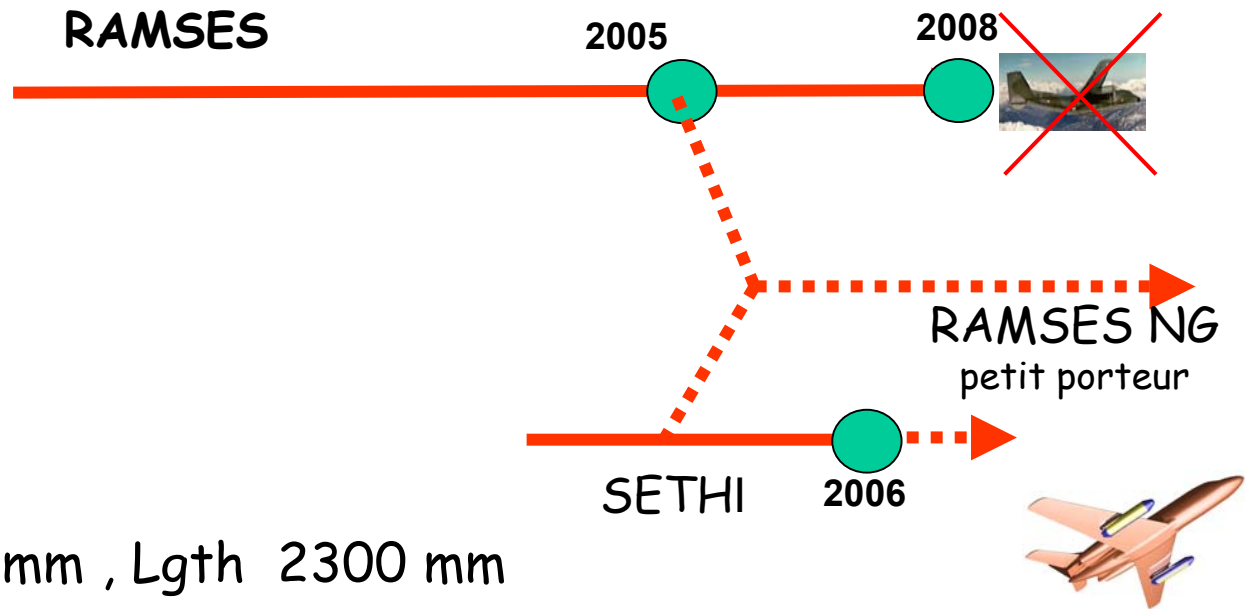
- 2 pods diam 530 mm , Lgth 2300 mm
- 3 band simul P,L,X, interfero, full polar

Motorized elevation

Max Altitude 30 000 feet (1 pod)

Min Altitude 300 feet

Optical POD under study

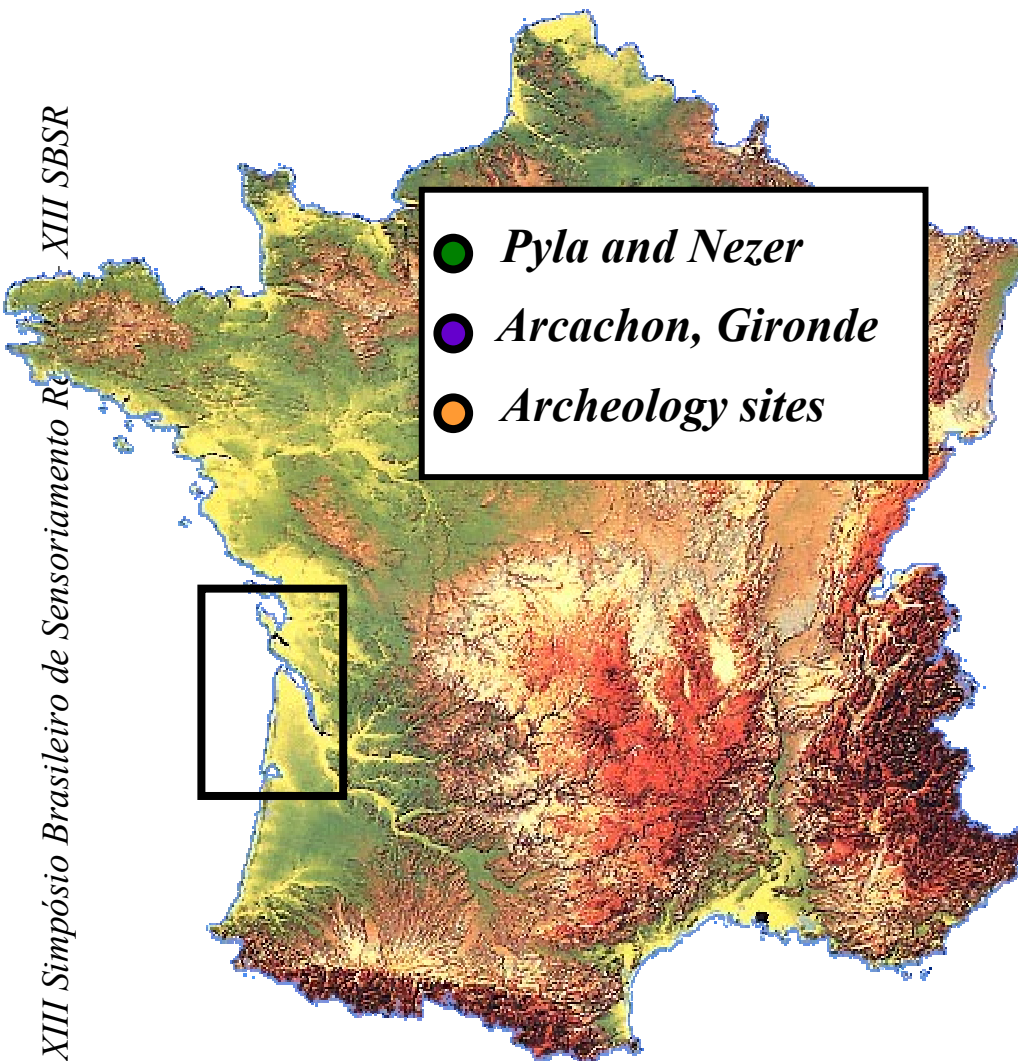


The campaign, the site, the calibration

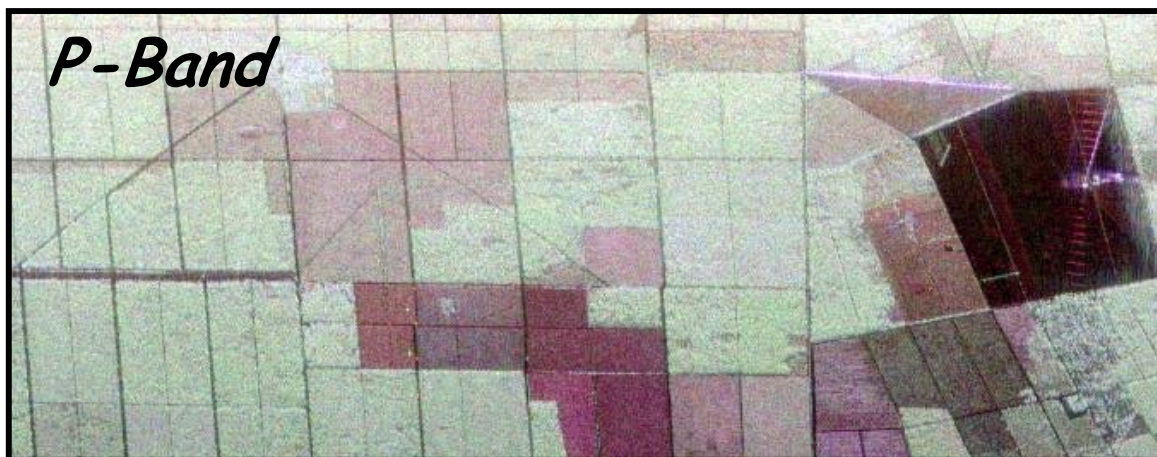
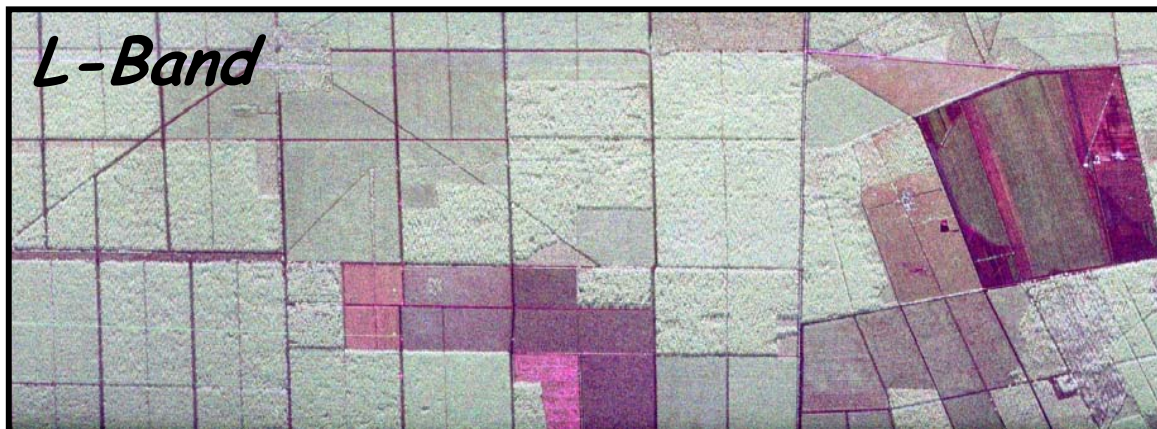


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Pyla2004 campaign: January 2004



Nezer Forest



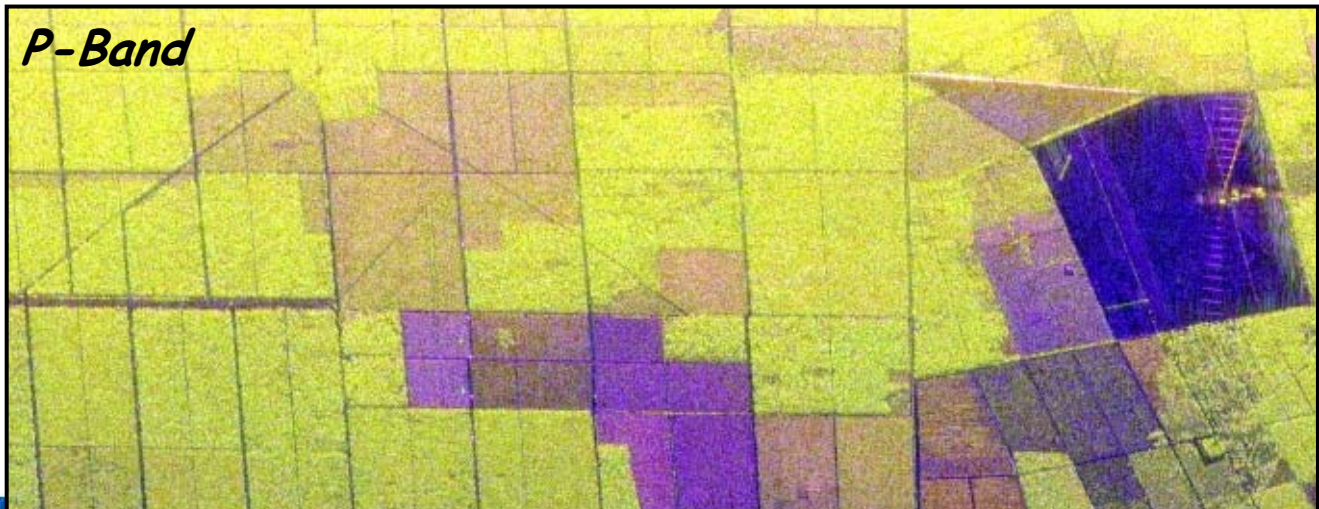
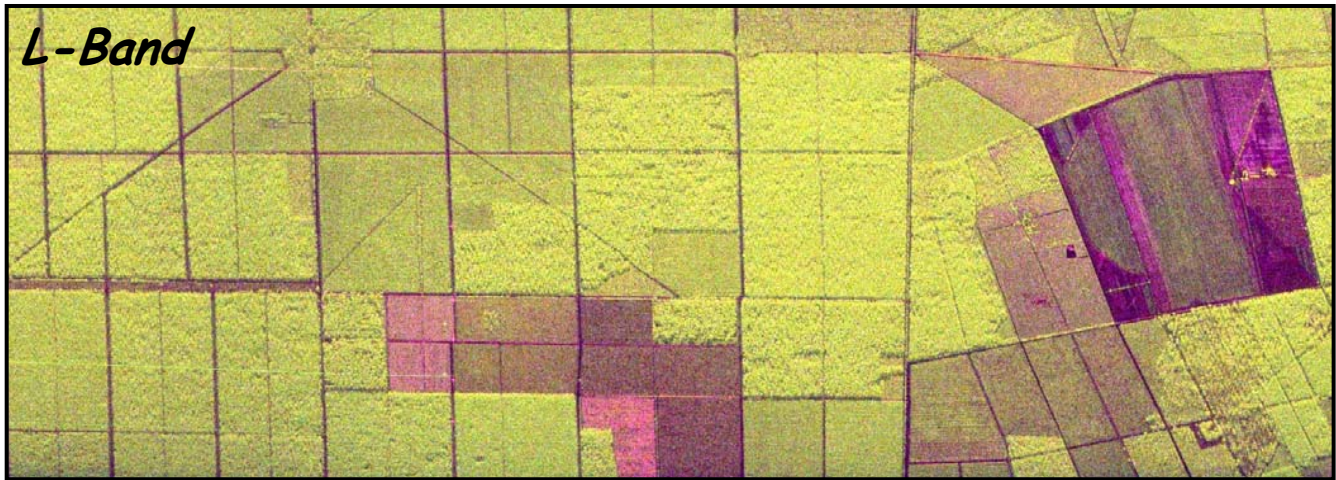
HH+VV HV HH-VV

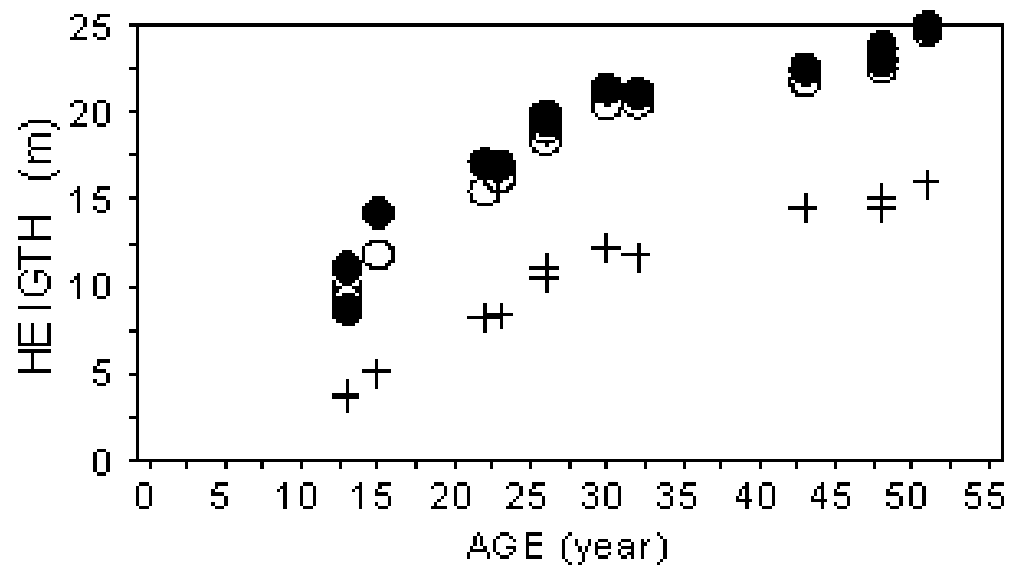
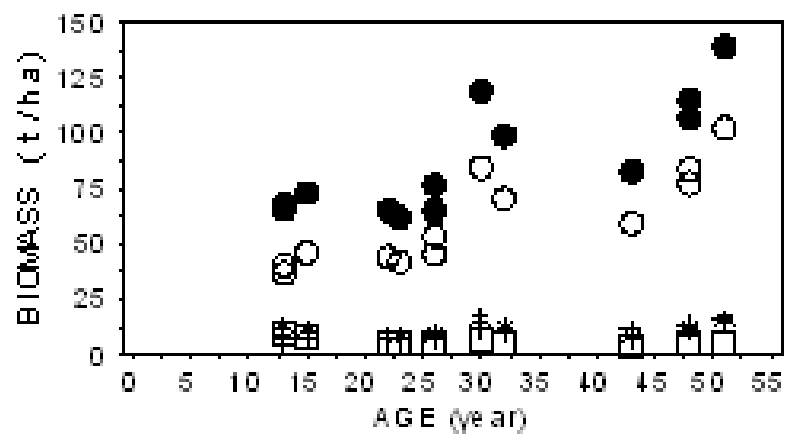
Nezer Forest

HH+VV

HV

γ_{HHVV}^*





SAR Acquisitions

- Two days, 12 acquisitions/day
- Waveforms:
 - P+L simultaneous
 - Range resolution: P band 2.5m ; L band 1.3m
 - Incidence angle varying from 10° to 55°
- Multipass
 - 4 tracks for PolinSAR processing
 - 2 tracks for high incidence angle analysis

Trièdre 2m275 de profil



Trièdre 2m275 de face



Dièdre de profil avec angle de dépolariation de $22,5^\circ$



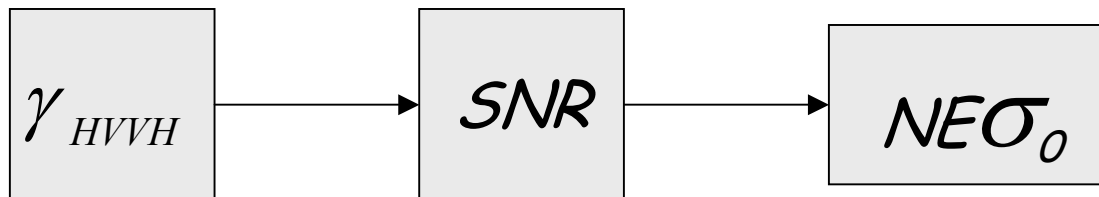
Dièdre de face avec angle de dépolariation de $22,5^\circ$



Evaluation of the NEsigma0

- In dark areas
- In the cross-pol channels by assuming the loss of coherence between HV and VH is due to noise

$$\gamma_{HV VH} = \frac{\langle HV VH^* \rangle}{\sqrt{HV HV^*} \sqrt{VH VH^*}} = \frac{P_s}{P_s + N} = (1 + 1 / SNR)^{-1}$$



P Band calibration results

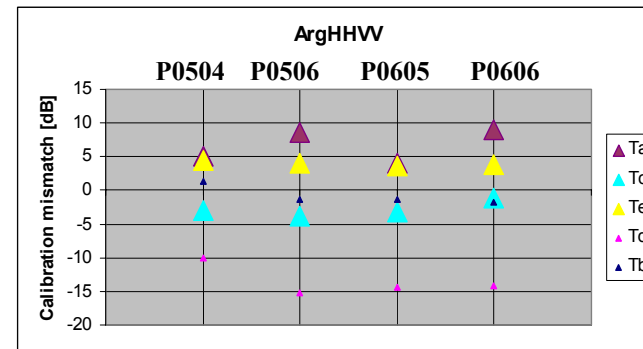
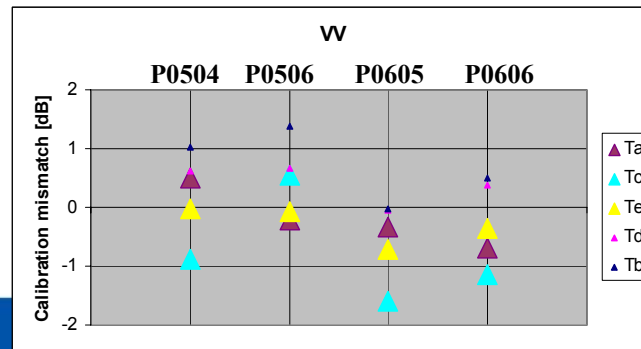
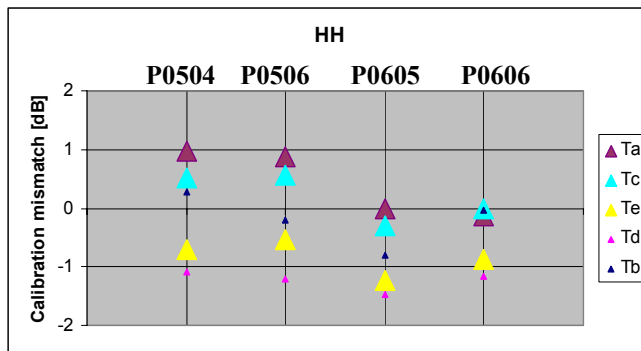
NESigma0 : better than -34 dB for co-polar channels

NESigma0 : better than -39 dB for crosspolar channels

HH et VV: ± 0.7 dB

Copolar phase: $\pm 4^\circ$

to be compared to the expected 0.75dB, 3° phase error for 1° misorientation





The radiometric analysis



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Radiometric analysis

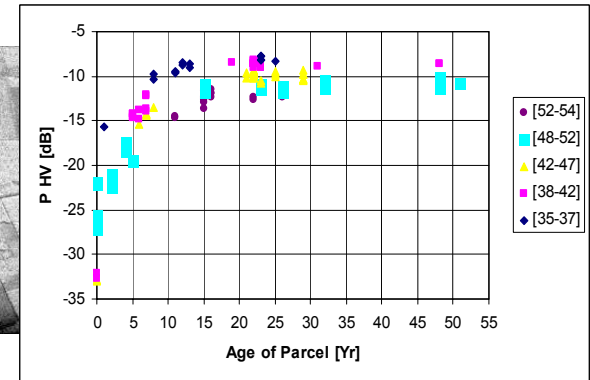
35-37°

38-42°

42-47°

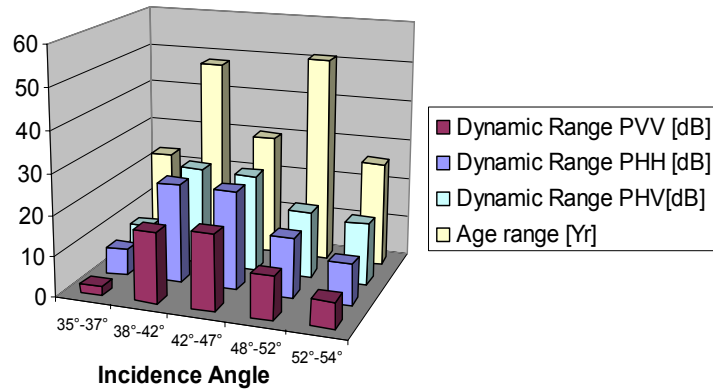
48-52°

52-54°



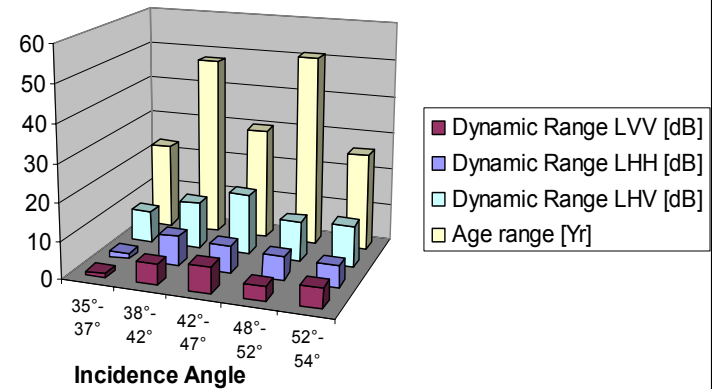
P-Band

Dynamic Range [dB]



L-Band

Dynamic Range [dB]





Polarimetric analysis



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Background in polarimetry

$$T_{33} = \begin{bmatrix} \langle |S_{hh} + S_{vv}|^2 \rangle & \langle (S_{hh} + S_{vv})(S_{hh} - S_{vv})^* \rangle & 2\langle (S_{hh} + S_{vv})S_{hv}^* \rangle \\ \langle (S_{hh} - S_{vv})(S_{hh} + S_{vv})^* \rangle & \langle |S_{hh} - S_{vv}|^2 \rangle & 2\langle (S_{hh} - S_{vv})S_{hv}^* \rangle \\ 2\langle S_{hv}(S_{hh} + S_{vv})^* \rangle & 2\langle S_{hv}(S_{hh} - S_{vv})^* \rangle & 4\langle |S_{hv}|^2 \rangle \end{bmatrix}$$

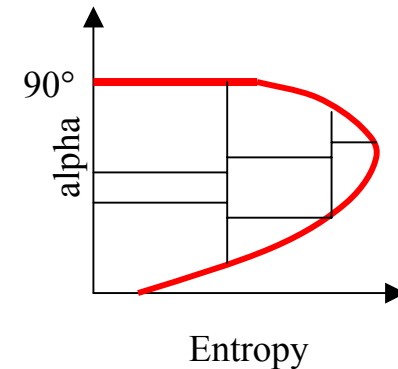
3 eigenvectors
3 eigenvalues

$$\begin{matrix} \vec{e}_1 & \lambda_1 \\ \vec{e}_2 & \lambda_2 \\ \vec{e}_3 & \lambda_3 \end{matrix}$$

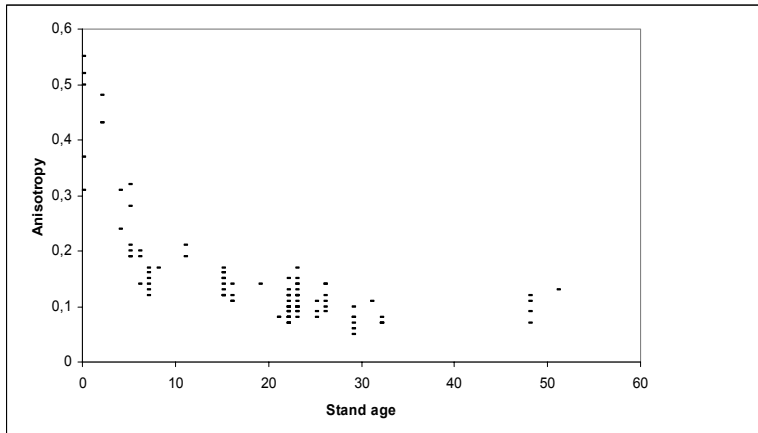
Alpha angle $\alpha = \sum_{i=1}^3 \frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3} \cos^{-1}(|e_{i1}|)$

Entropy $H = \sum_{i=1}^3 - \frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3} \log_3 \frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3}$

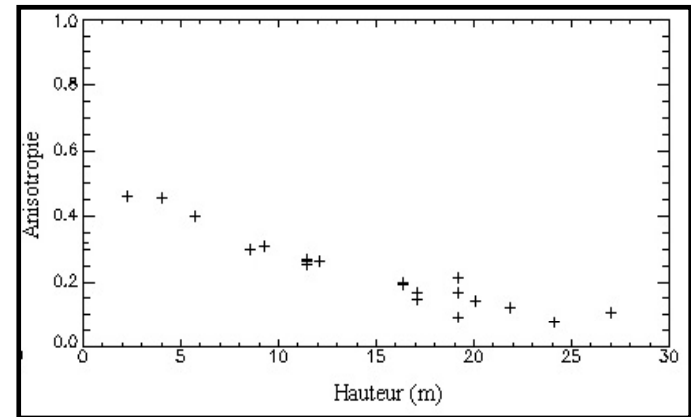
Anisotropy $A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}$



Polarimetric analysis

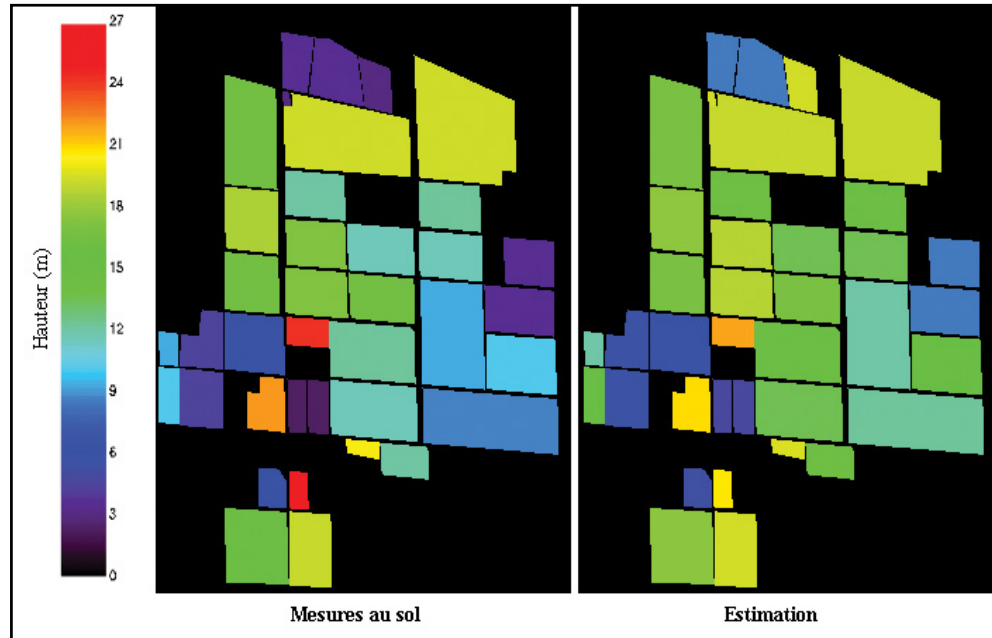
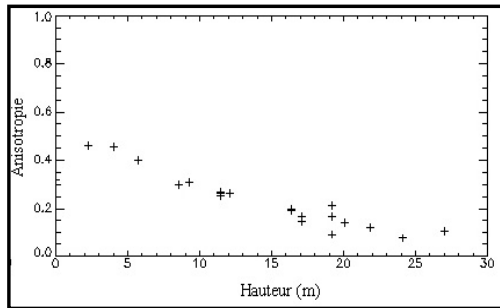


Anisotropy at L band



Anisotropy at P band

Inversion based on anisotropy



RMS error = 2m



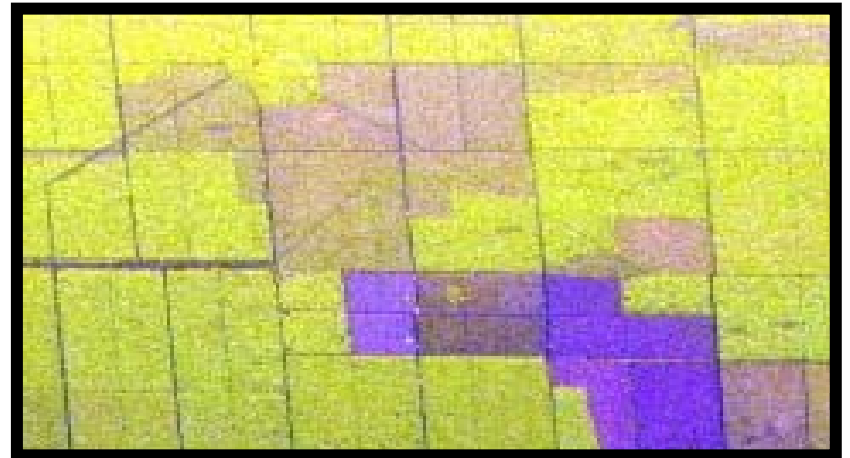
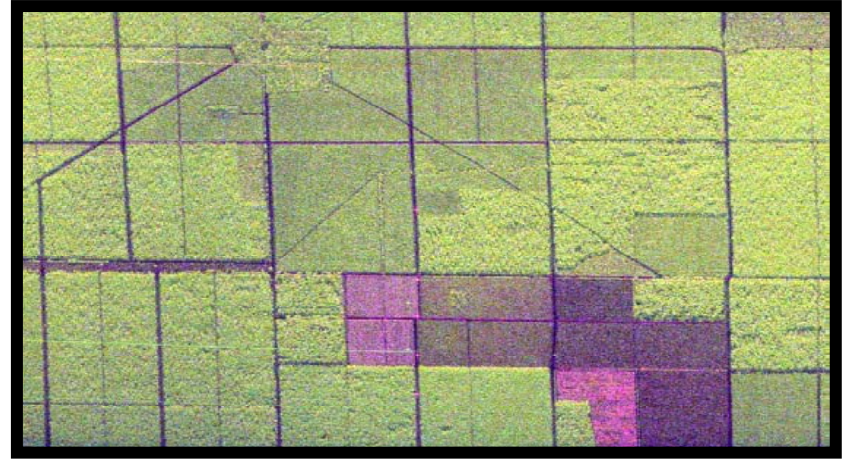
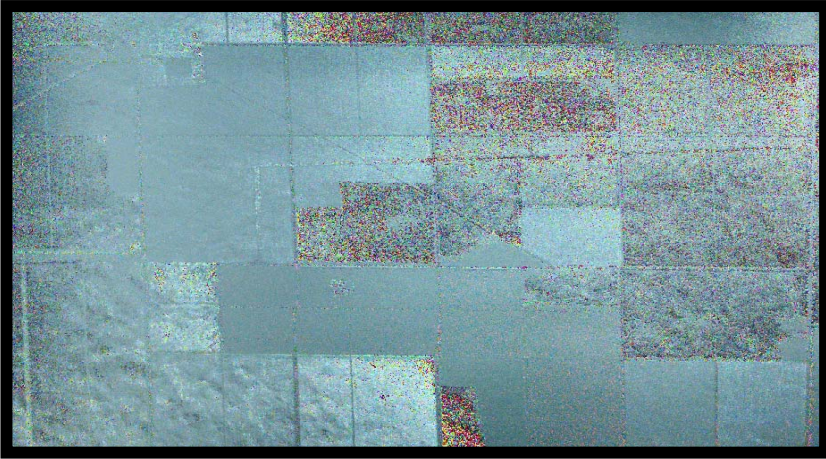
PolInSAR Analysis



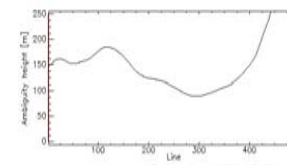
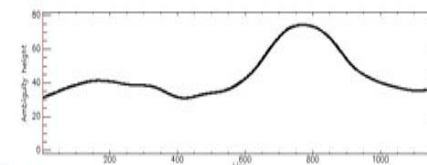
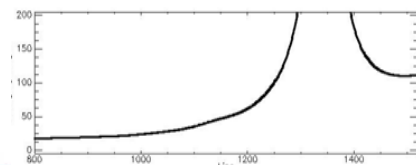
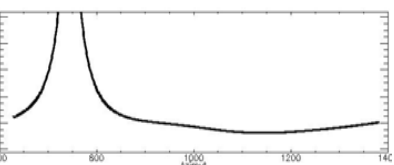
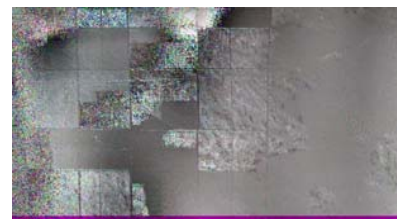
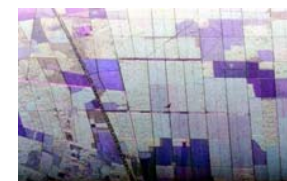
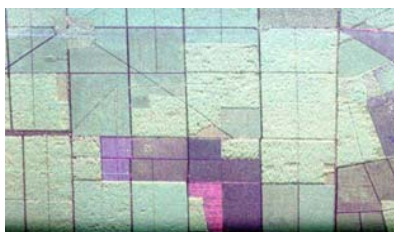
retour sur innovation

PolinSAR data: Nezer L P

L
P
VIII Simulazione del Consorzio Remoto - XIII SBSR

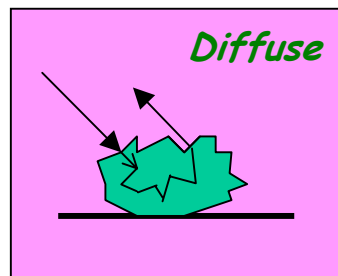
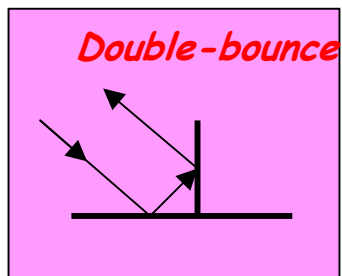
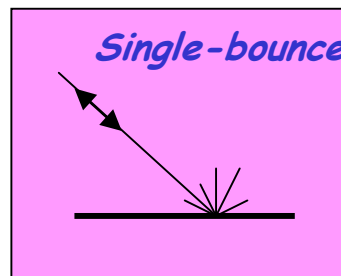


PolInSAR dataset

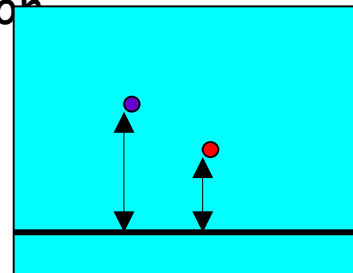


PolInSar data for biomass

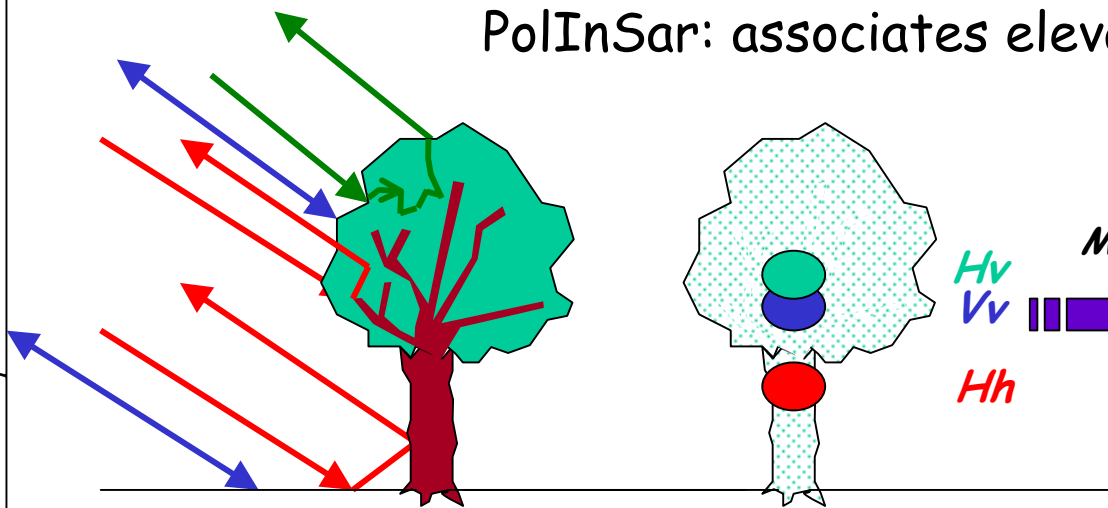
Polarimetry: identifies the scattering type



Interferometry: elevation



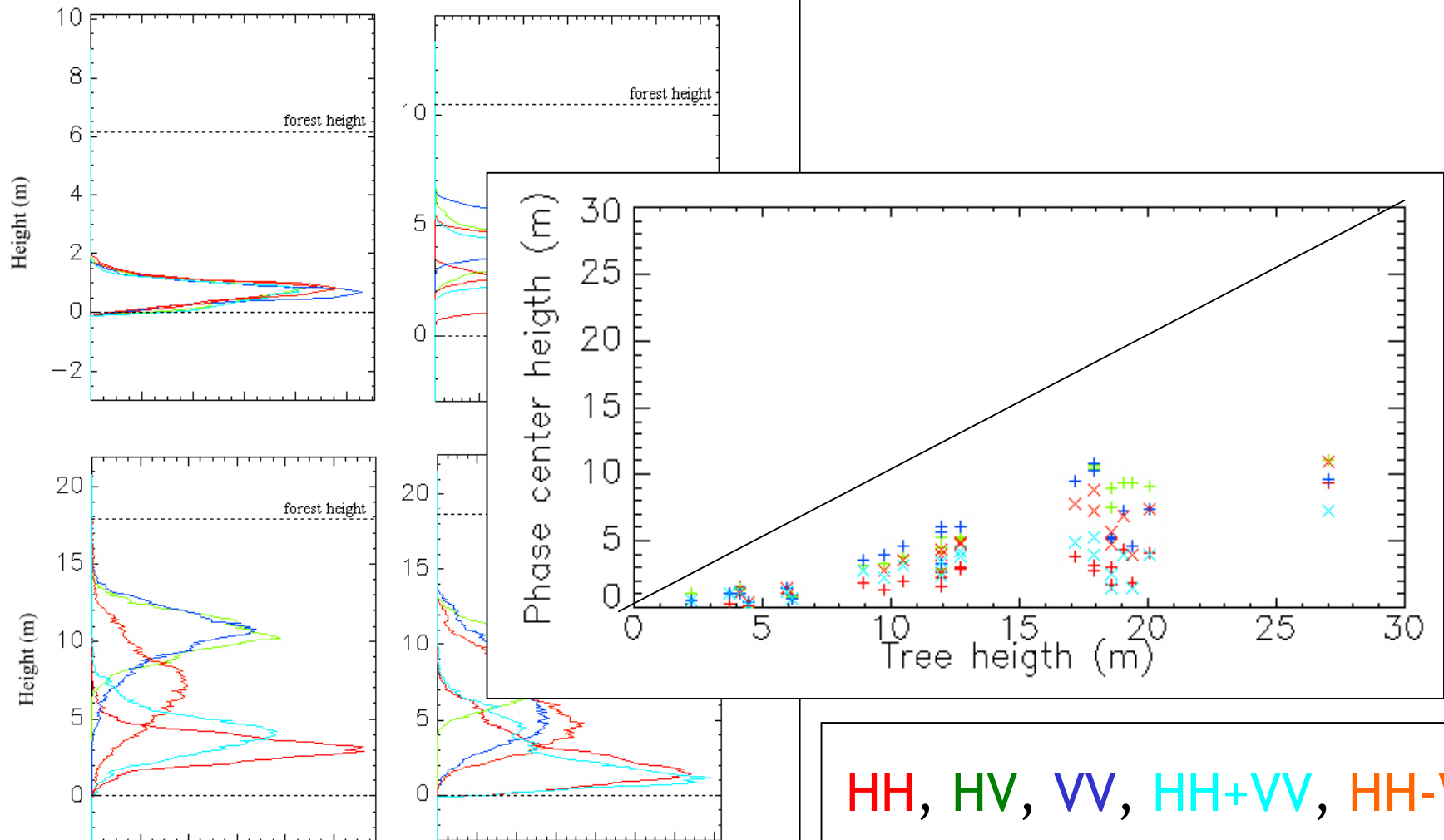
PolInSar: associates elevation to scattering type



Biophysical parameters

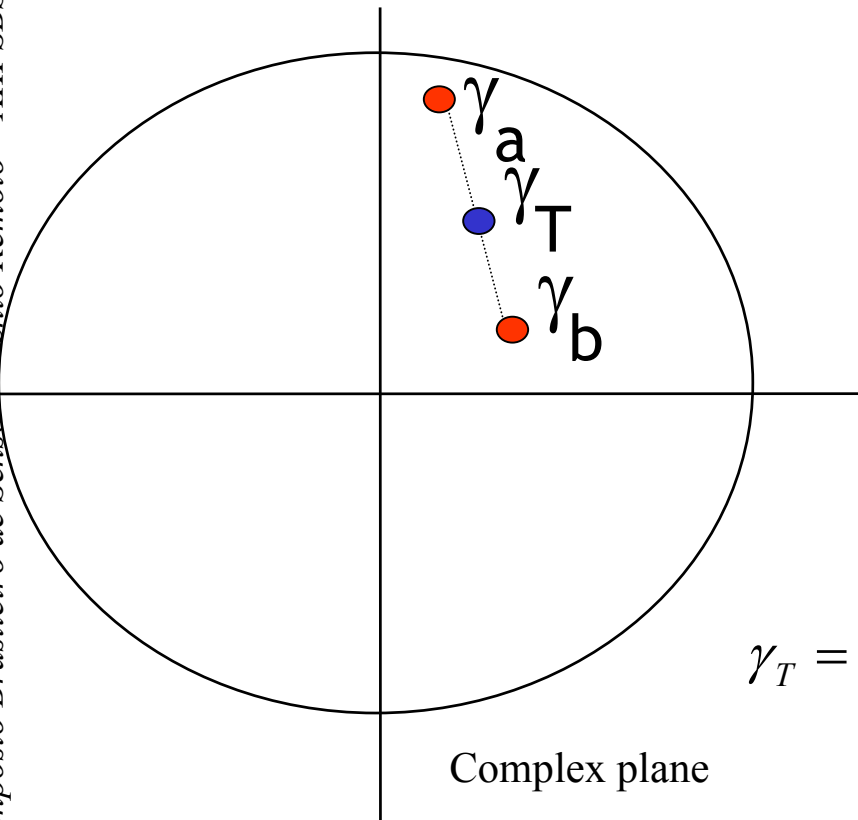
- tree height
- tree biomass
- attenuation
- ...

Polinsar analysis



HH, HV, VV, HH+VV, HH-VV

Combining independant scatterers



$$\gamma_T = \frac{\langle s_{1T} s_{2T}^* \rangle}{\sqrt{\langle s_{1T} s_{1T}^* \rangle \langle s_{2T} s_{2T}^* \rangle}}$$

$$s_T = s_a + s_b \quad \text{with} \quad \langle s_a s_b^* \rangle = 0$$

$$\gamma_T = f(\gamma_a, \gamma_b) = \frac{P_a}{P_a + P_b} \gamma_a + \frac{P_b}{P_a + P_b} \gamma_b$$

Adding polarimetry...

If γ_a and γ_b do not vary with polarimetry

Then γ_T varies along a line

Complex plane

$$\gamma_T = f(\gamma_a, \gamma_b) = \frac{P_a}{P_a + P_b} \gamma_a + \frac{P_b}{P_a + P_b} \gamma_b$$

Looking for Stable PolInSAR Scatterers

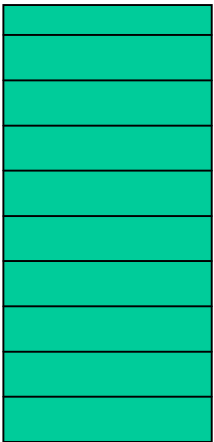
- SPS: Coherence independant of polarisation

- *Surface*

- Coherence phase from elevation
- Unity coherence

Looking for Stable PolInSAR Scatterers

- *Random Volume*
 - Treuhaft model
 - Identical layers with constant extinction coeff.



$$\gamma_V = \frac{\int_0^{h_v} e^{2\frac{\sigma_x z}{\cos \theta}} e^{ik_z z} dz}{\int_0^{h_v} e^{2\frac{\sigma_x z}{\cos \theta}} dz}$$

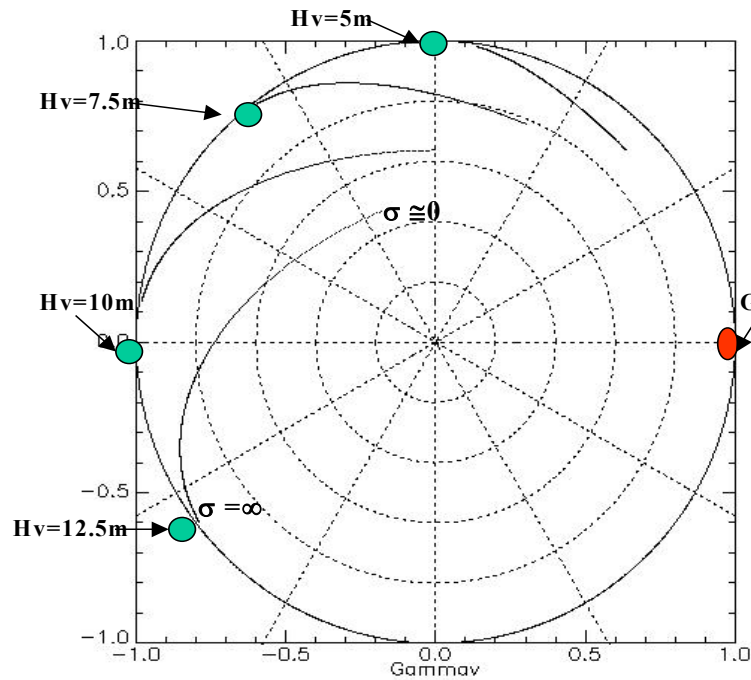
σ_x : extinction coefficient

h : height of volume

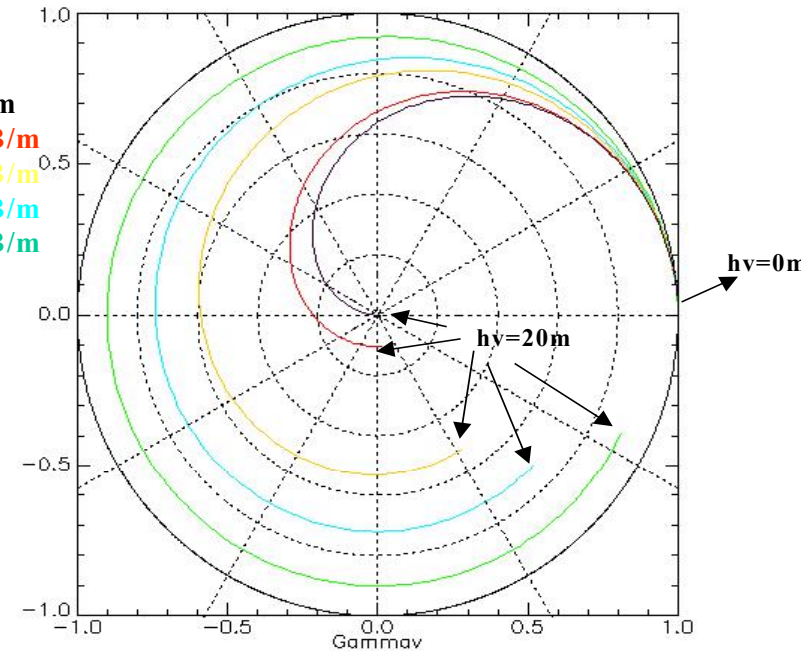
θ : incidence angle

k_z :geometric charact.

Random volume coherence

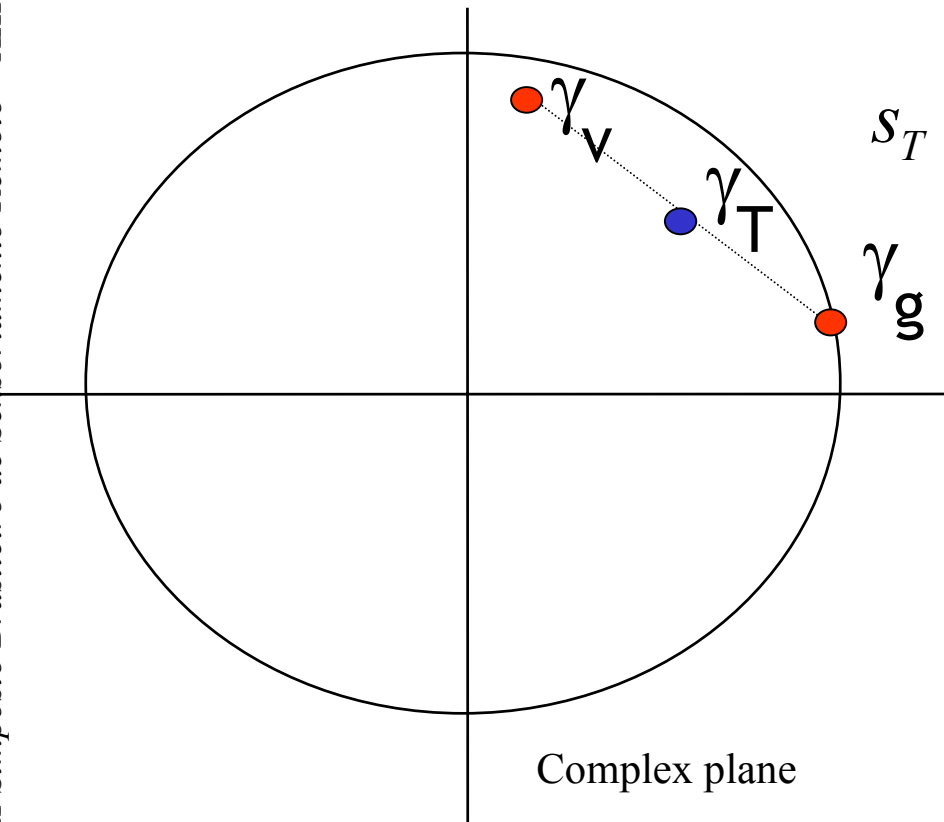


$\sigma \approx 0$ dB/m
 $\sigma = 0.1$ dB/m
 $\sigma = 0.6$ dB/m
 $\sigma = 1.0$ dB/m
 $\sigma = 2.0$ dB/m

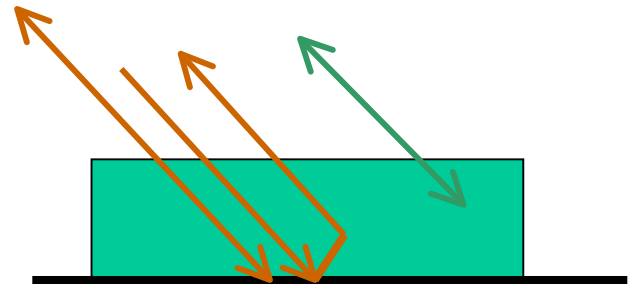


*Therefore, given a "volume only" coherence,
one can invert the height and the extinction coefficient*

Random Volume Over Ground Model *



$$s_T = s_g + s_v \quad \text{with} \quad \langle s_g s_v^* \rangle = 0$$



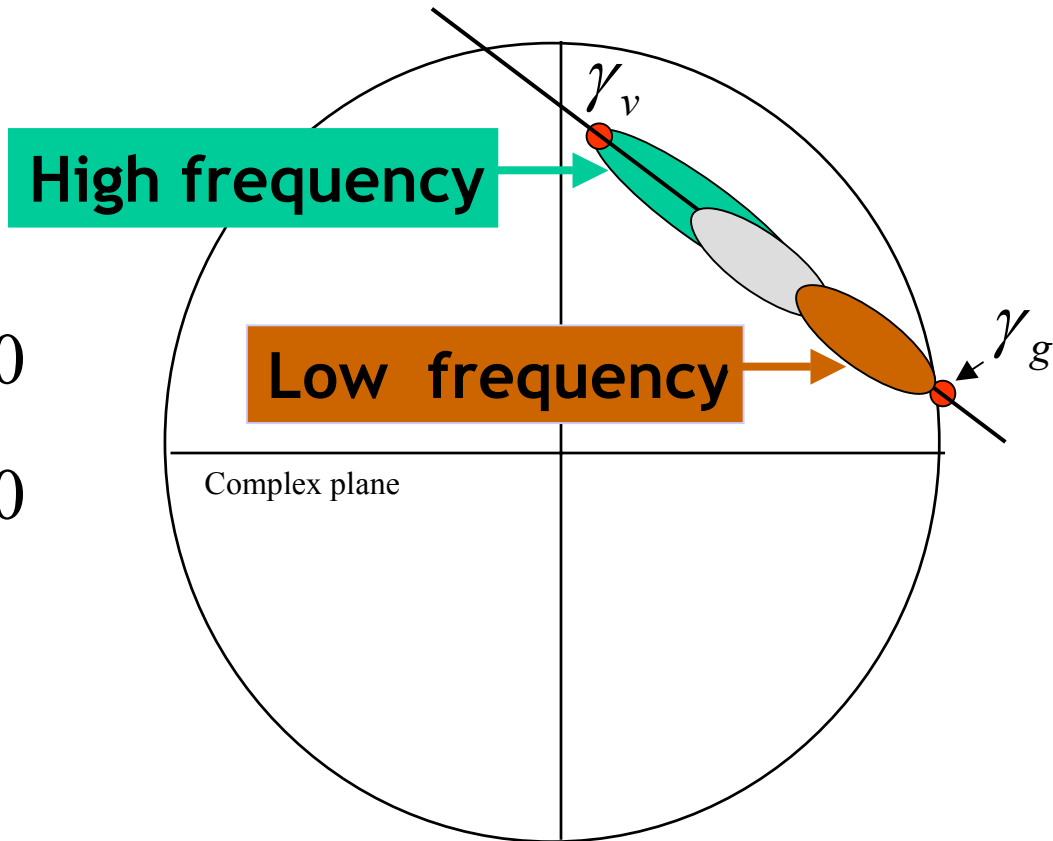
$$\gamma_T = f(\gamma_g, \gamma_v) = \frac{P_g}{P_g + P_v} \gamma_g + \frac{P_v}{P_g + P_v} \gamma_v$$

* Cloude and Papathanassiou

Random Volume over Ground model

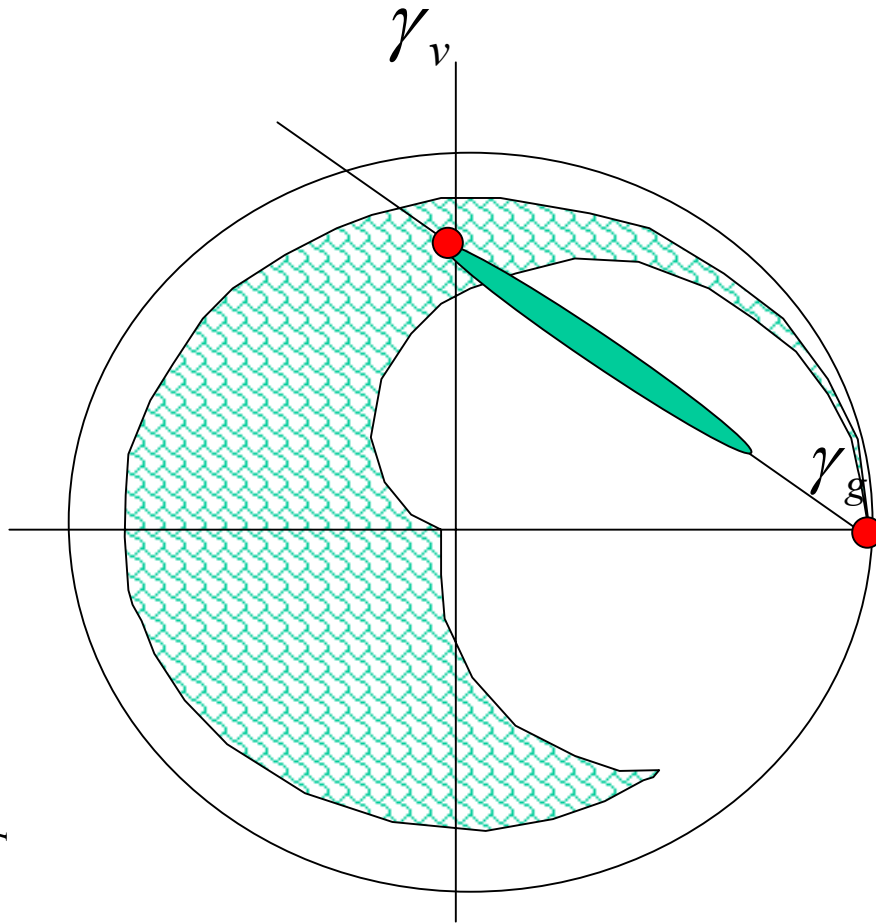
$\exists w_0$ such that $P_g(w_0) = 0$

$\exists w_0$ such that $P_g(w_0) = 0$



$$\gamma_T(w) = \frac{P_g(w)}{P_g(w) + P_v(w)} \gamma_g + \frac{P_v(w)}{P_g(w) + P_v(w)} \gamma_v$$

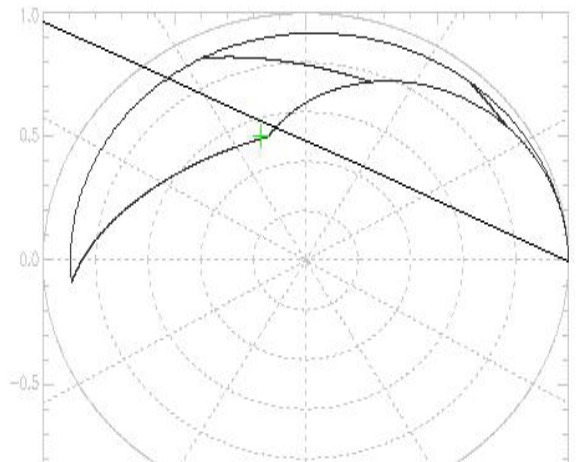
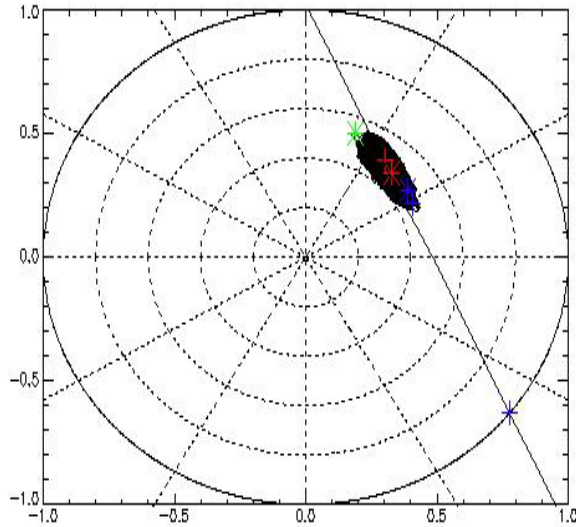
Standard RVoG inversion



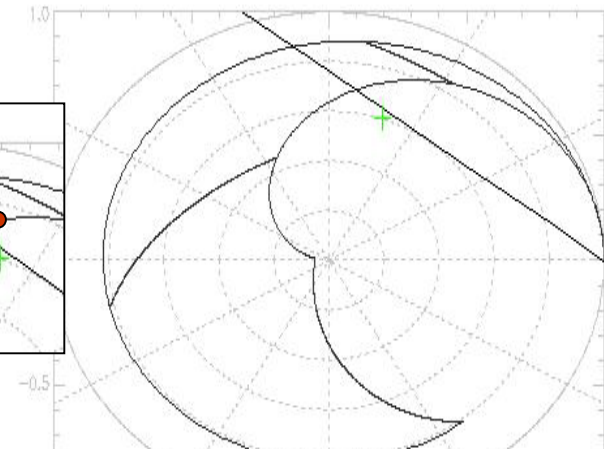
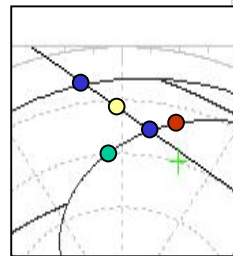
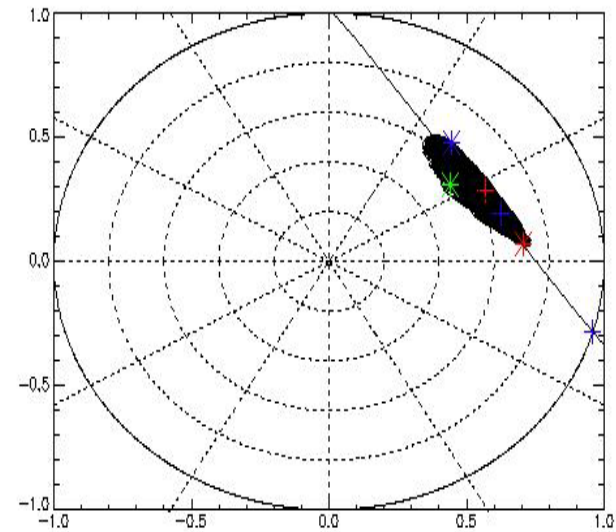
$$\gamma_V = e^{i\varphi_0} \frac{\int_0^{h_v} e^{2\frac{\sigma_x z}{\cos\theta}} e^{ik_z z} dz}{\int_0^{h_v} e^{2\frac{\sigma_x z}{\cos\theta}} dz}$$

$$h \quad \sigma_x$$

Inversion at P band



48 year old stand

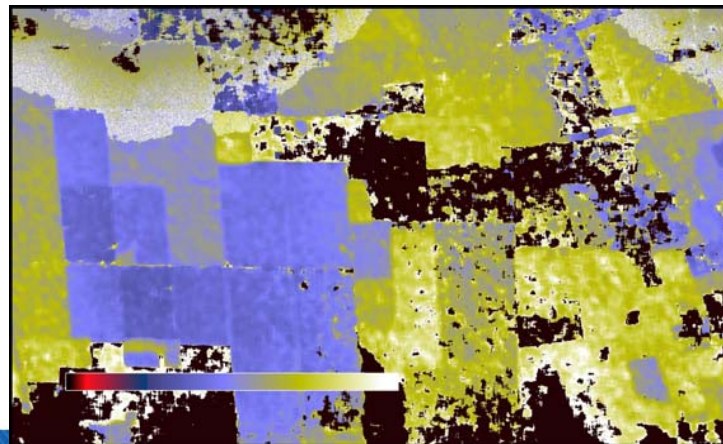
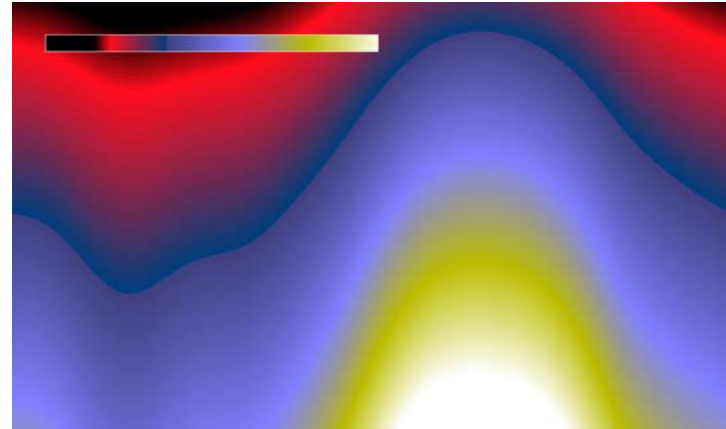


11 year old stand

Inversion PolInSAR

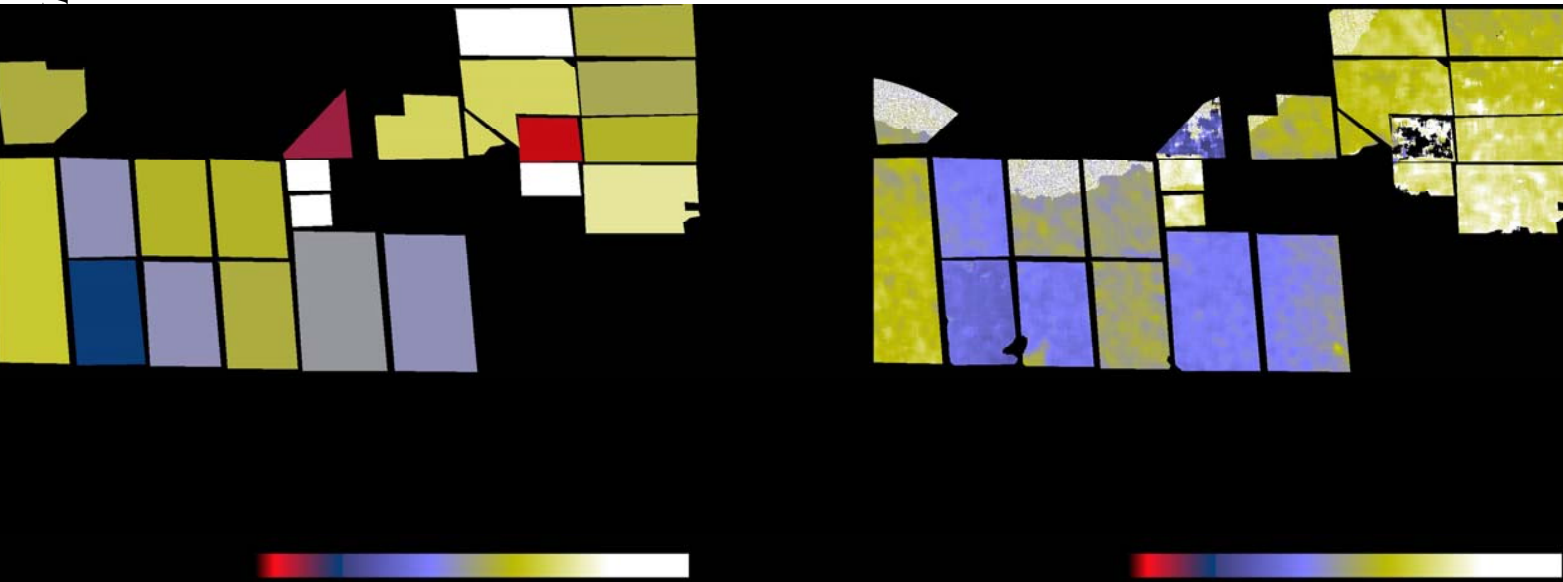
- Standard Inversion RVoG
- Adapted to P-Band
 - Known attenuation
 - Time-frequency analysis

PolInSAR results at P band



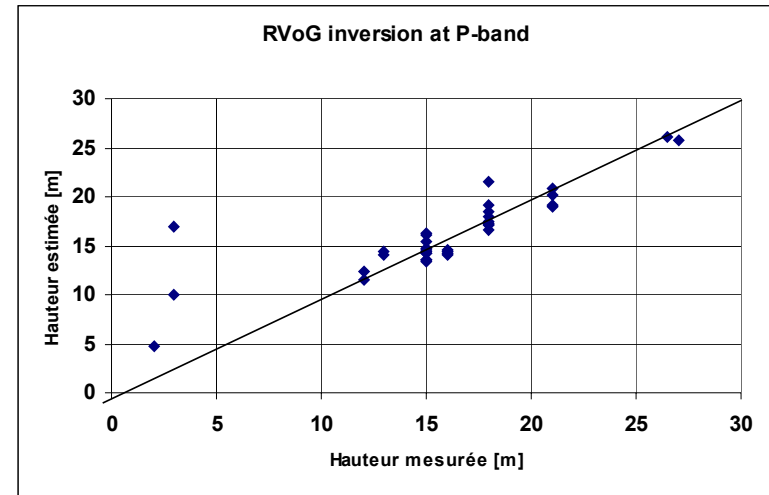
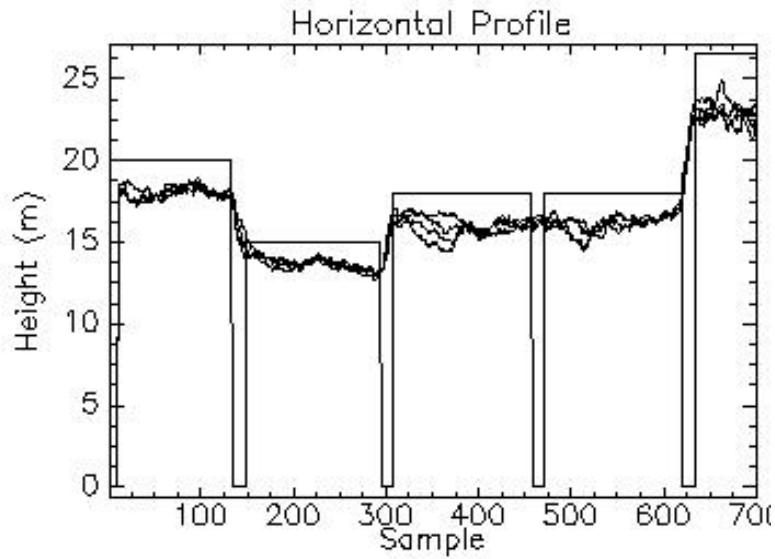
PolInSAR results at P band

II SBSR



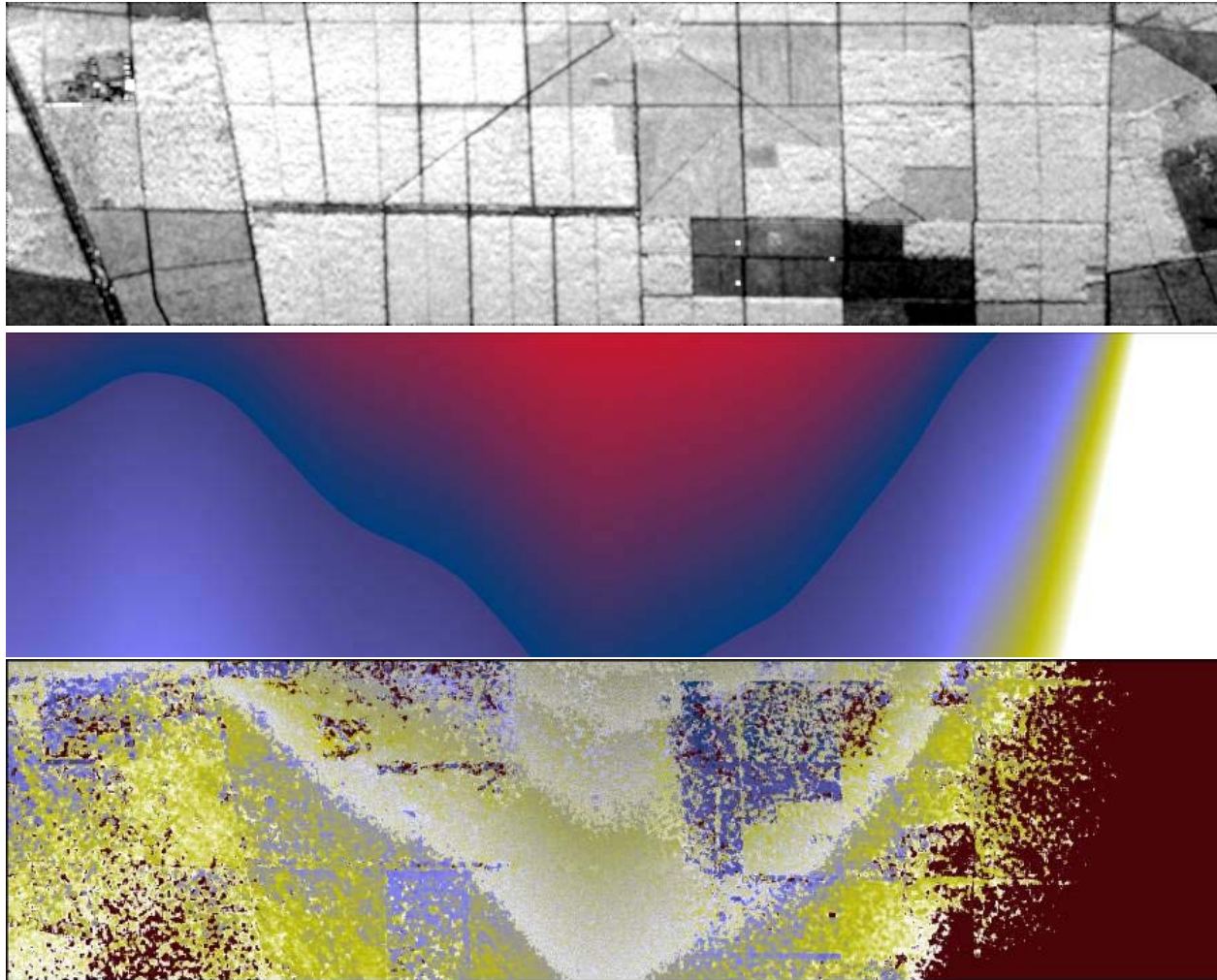
XIII Simpósio

PolInSAR results at P band

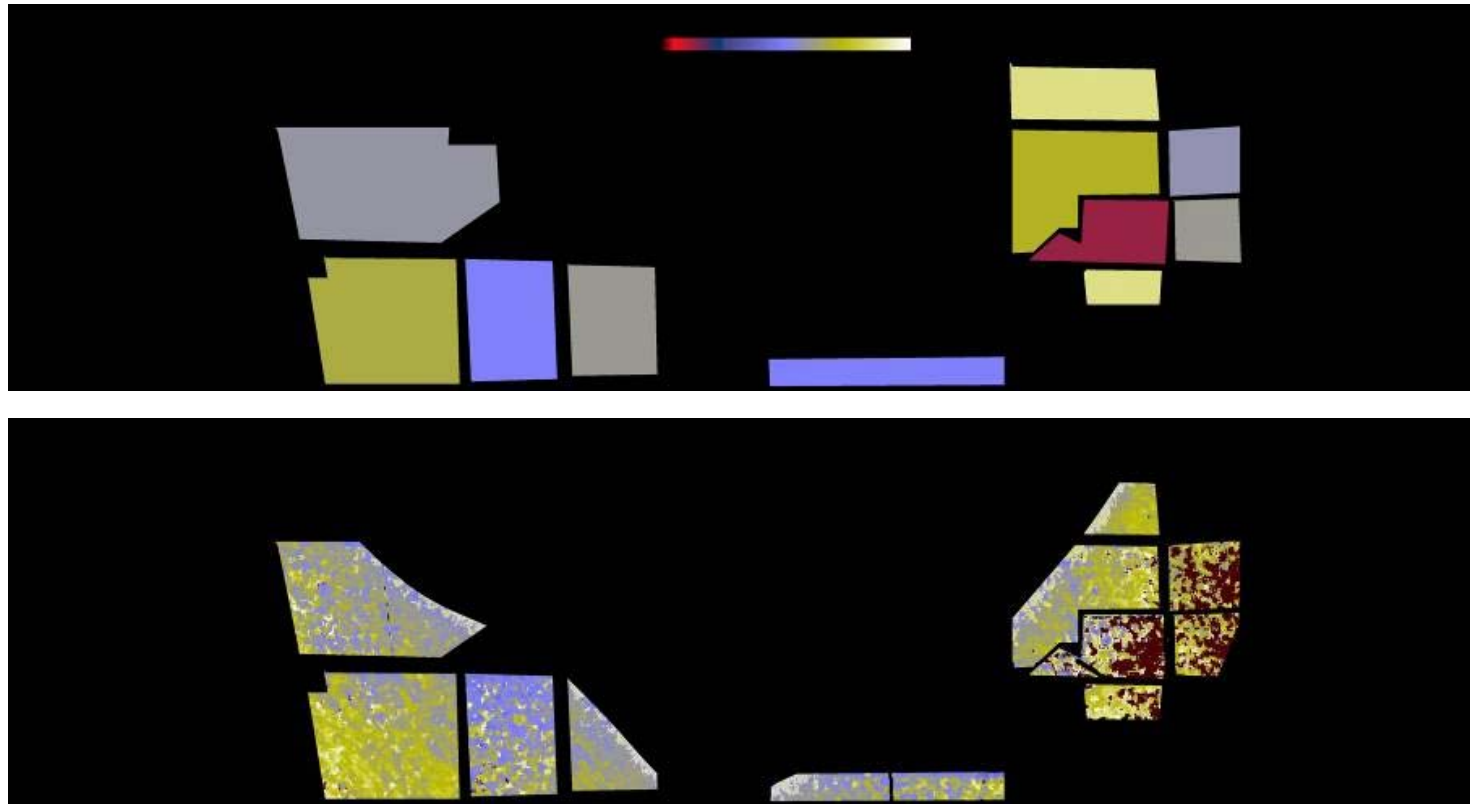


RMS error= 1.2m

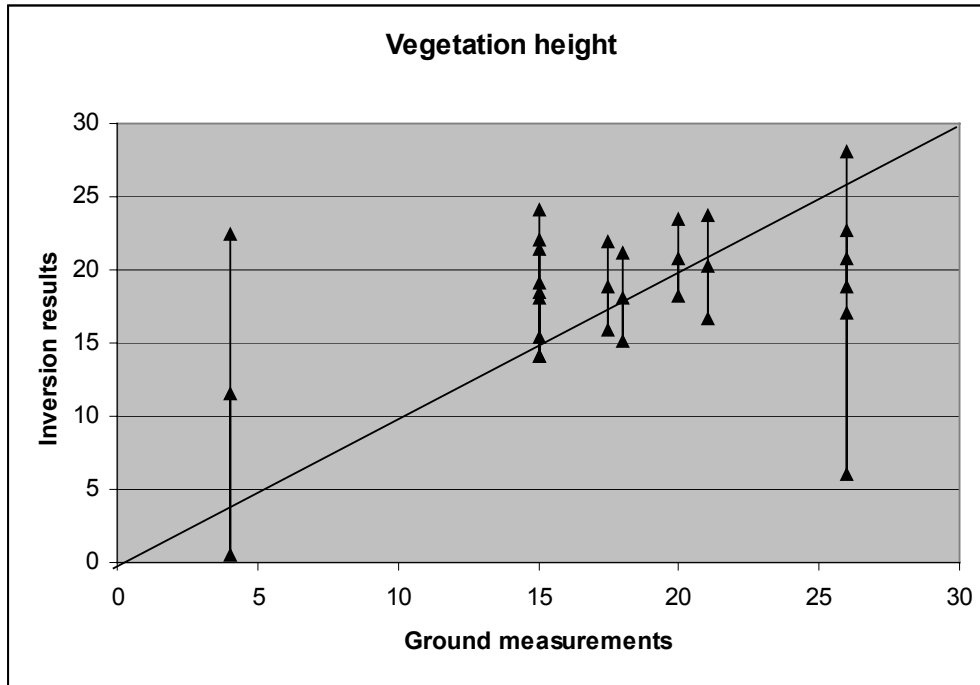
PolInSAR at L band



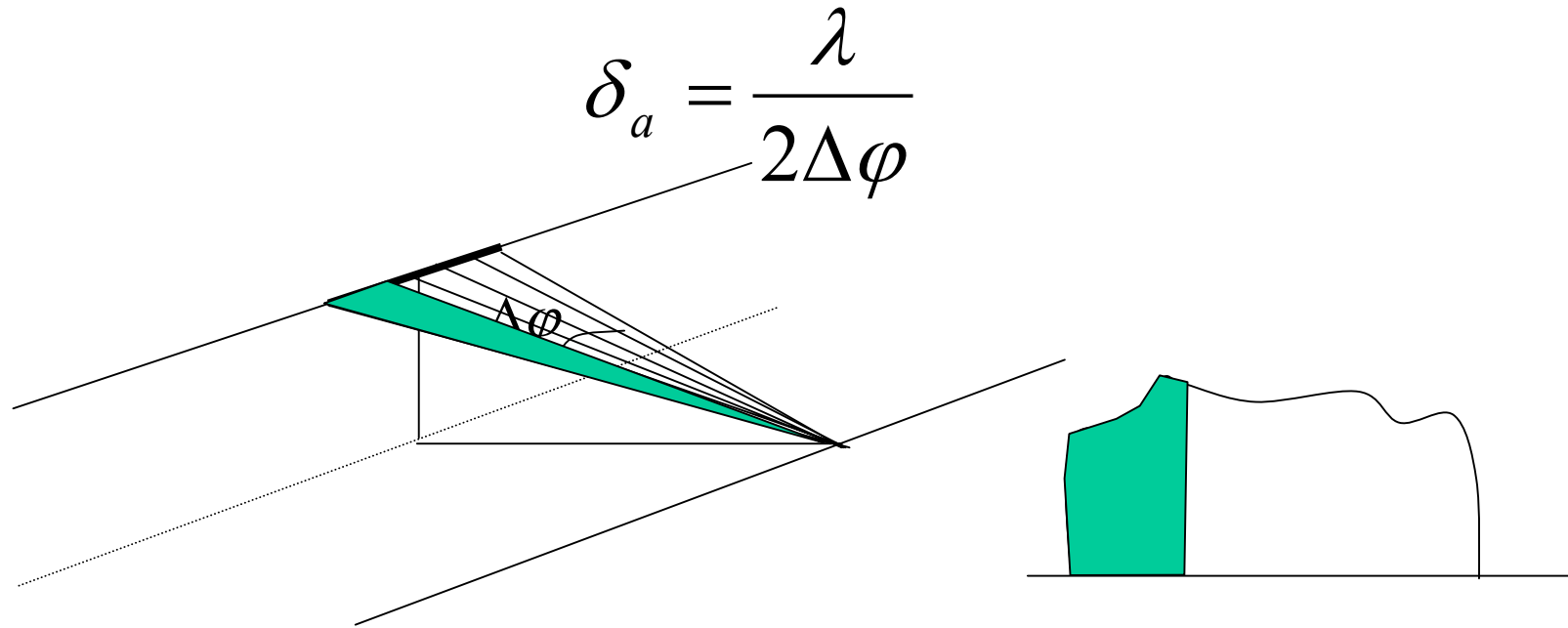
PolInSAR at L band



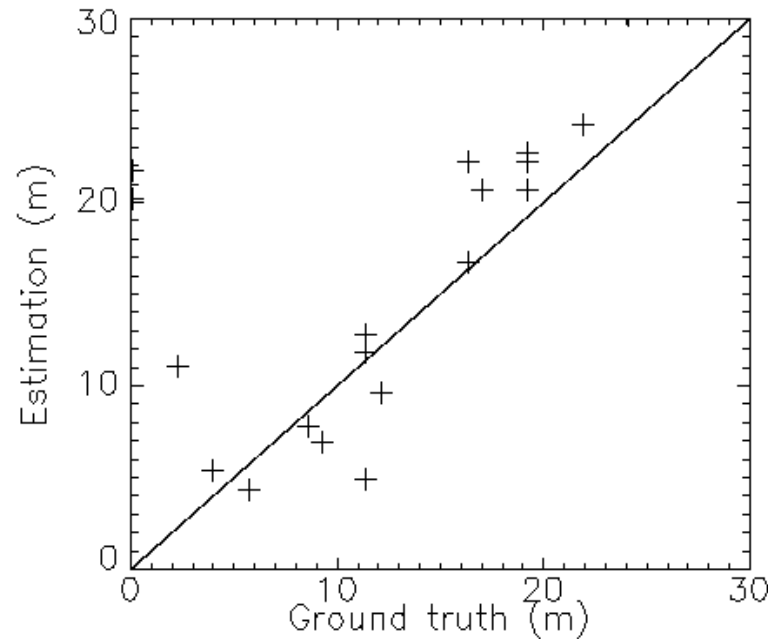
PolInSAR at L band



Time Frequency Optimization P-Band



Time-frequency optimization P band



RMS=2.3m

Conclusion (1/3)

- Calibration and evaluation procedure
- Radiometric analysis:
 - Better dynamic range at P band
 - Better dynamic range for HV
- Polarimetry
 - Good correlation between anisotropy and height for P band
 - to be confirmed on other type of forests
 - Combine P and L bands

Conclusion (2/3)

- PolInSAR
 - Good results at P band (1.2m rms)
 - Equivalent inversion results based on P-HH and P-VV
 - High sensitivity to altitude of ambiguity
 - Time frequency analysis: attractive concept

Conclusion (3/3)

- Radiometric inversion
- Polarimetric inversion
- PolInSAR inversion

- 3 independent techniques
 - could be combined