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

Pascale Dubois-Fernandez, Isabelle Champion, Franck Garestier, Xavier Dupuis

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FOREST PARAMETER RETRIEVAL FROM P BAND DATA:

Polarimetry and Polarimetric interferometry

Pascale Dubois-Fernandez

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

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- 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

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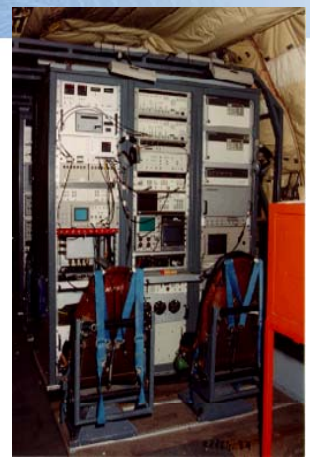
RAMSES



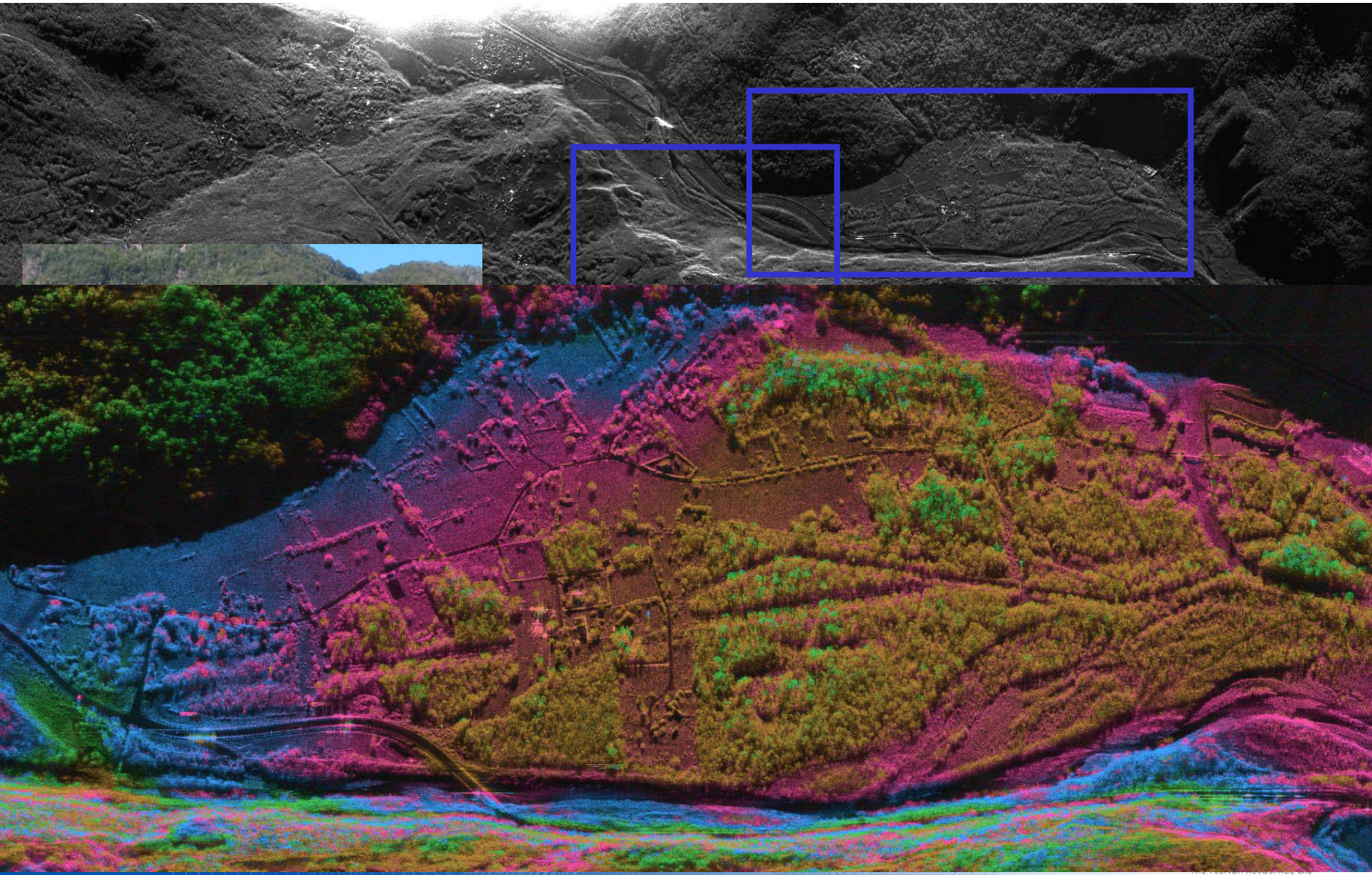
Band	P*	L*	S	C	X*	Ku*	Ka*	W
Center Frequency	0,43 GHz	1,3 GHz	3,2 GHz	5,3 GHz	9,6 GHz	14,3 GHz	35 GHz	95 GHz
Bandwidth	70 MHz	200 MHz	300 MHz	300 MHz	1200 MHz	1200 MHz	1200 MHz	500 MHz
Transmit Polarization	V / H	V / H	V / H	V / H	V / H	V / H	V or H	L or R
Receive Polarization	V and H	V and H	V and H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

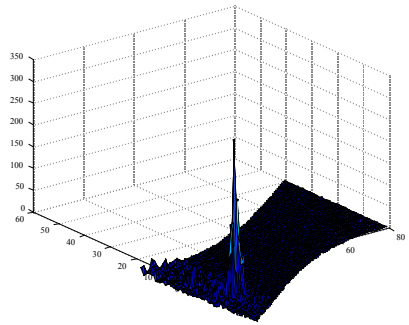
X-Band: examples



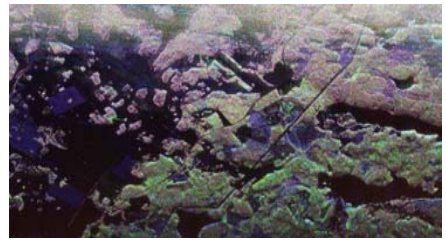
SAR Techniques

Polarimetry

GMTI / STAP

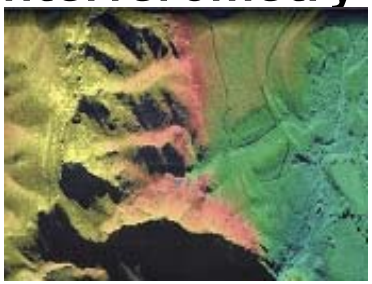


Low frequency



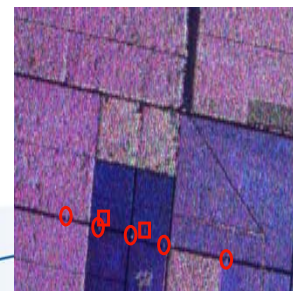
Very High Resoluti

Interferometry



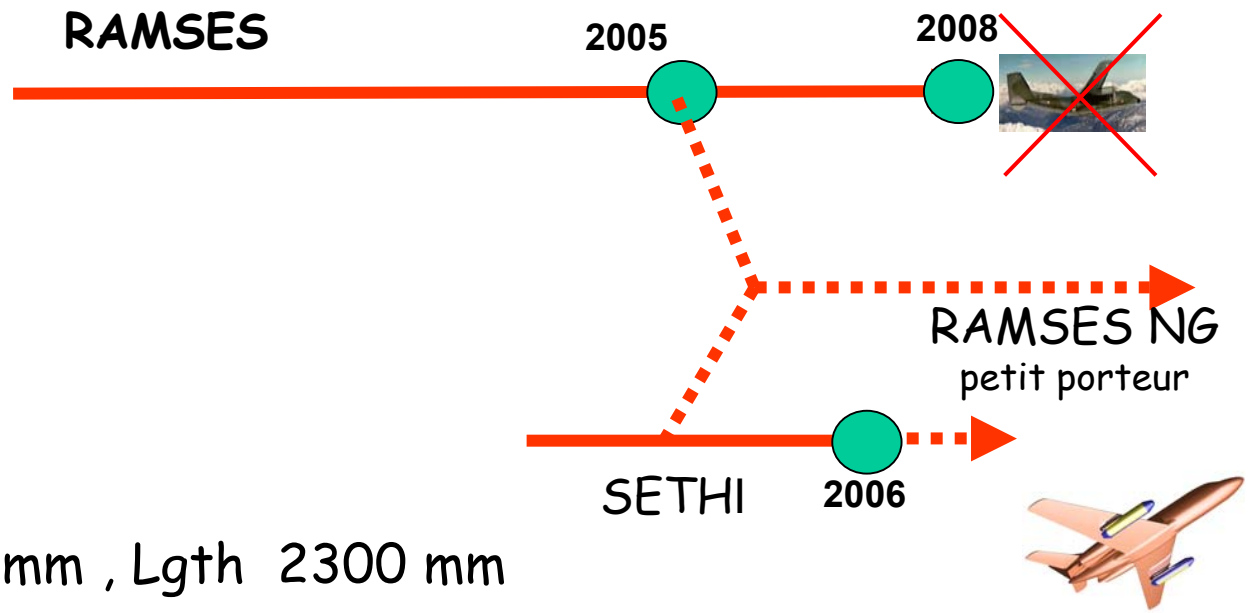
Bi-static

FOPEN



PolInSar

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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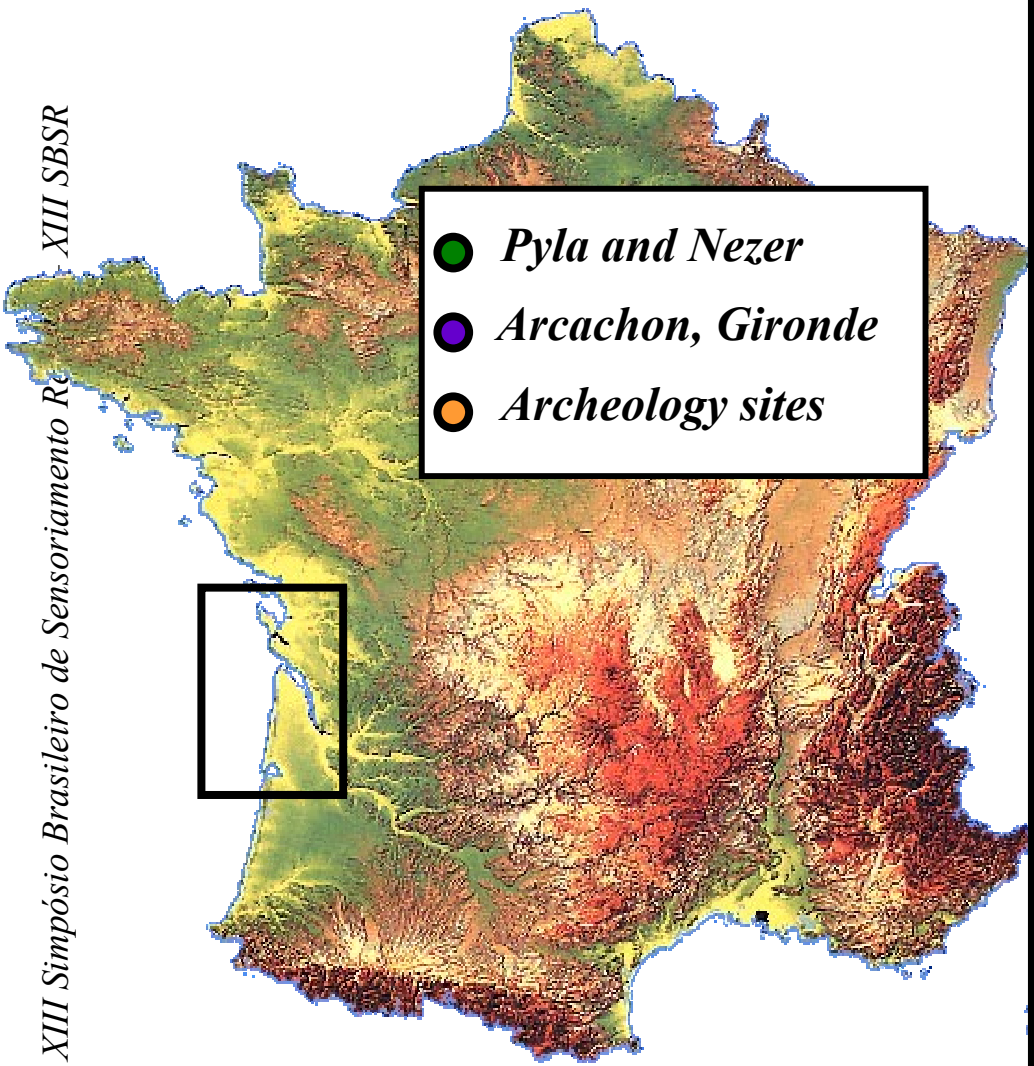
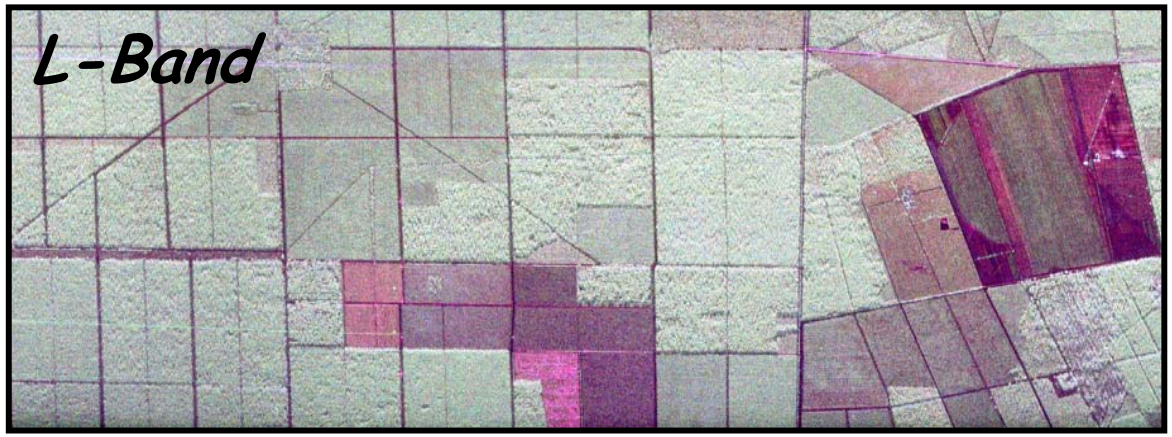
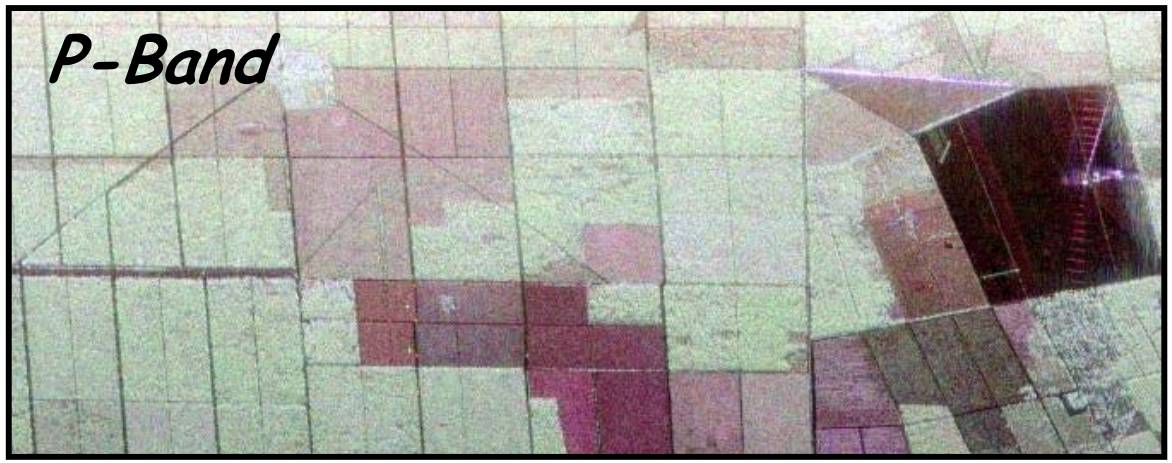
Pyla2004 campaign: January 2004



Nezer Forest





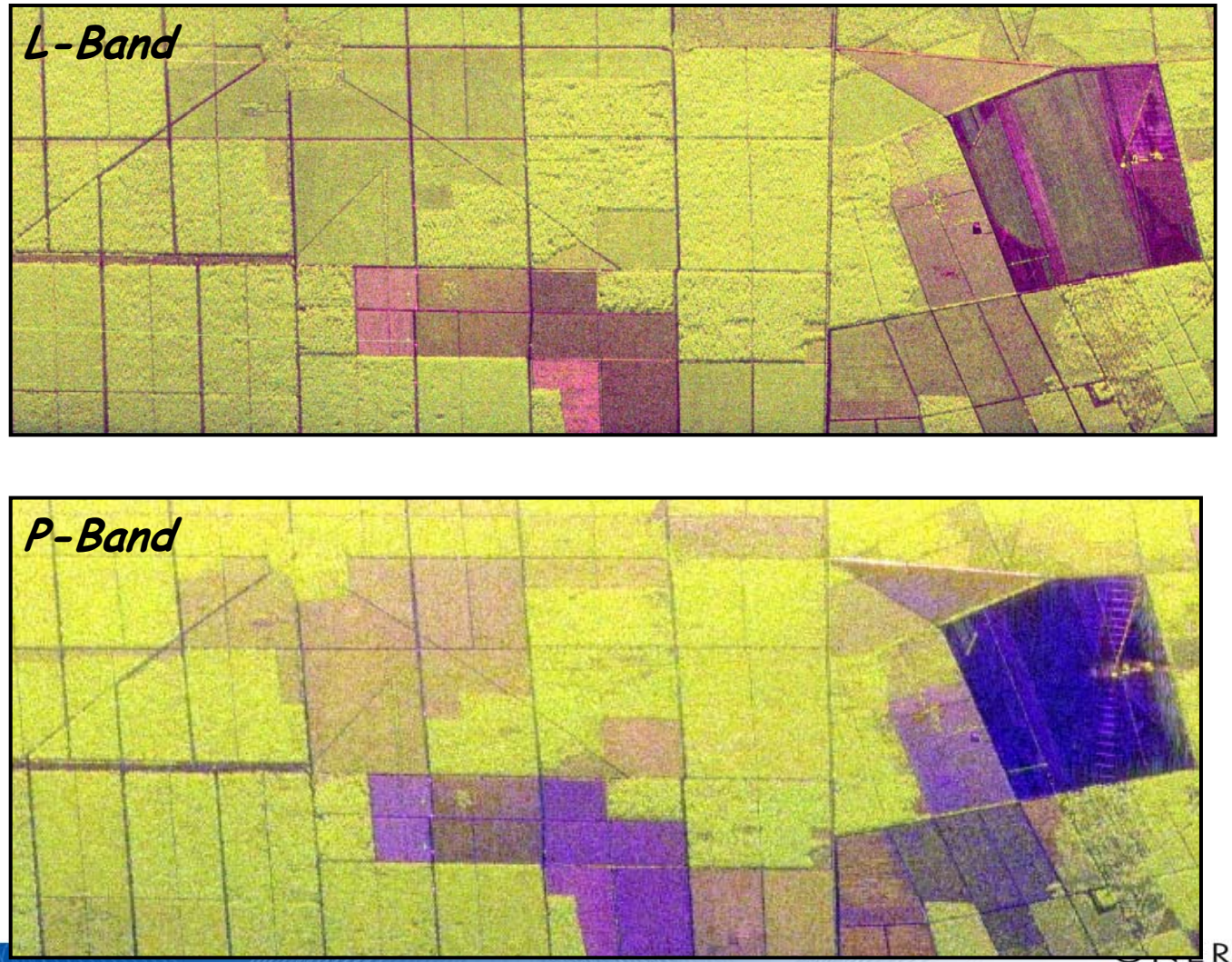
HH+VV HV HH-VV

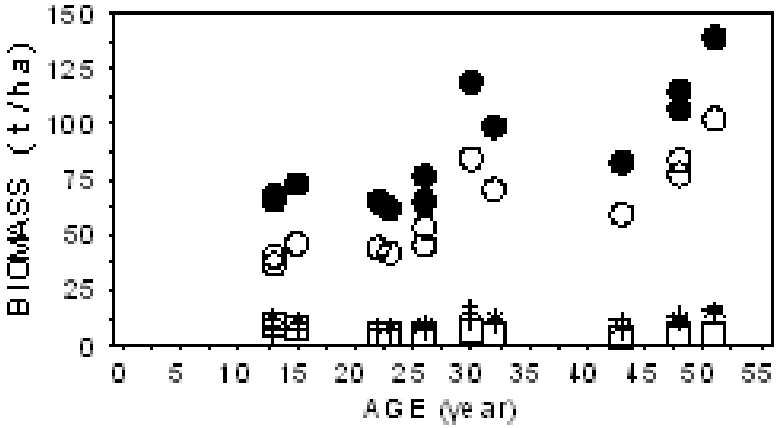
Nezer Forest

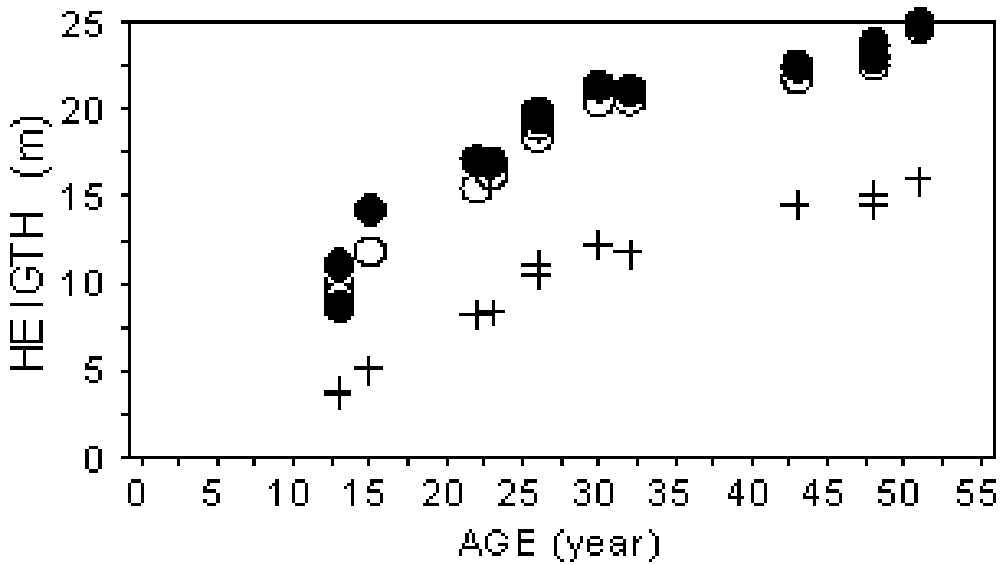
HH+VV

HV

γ_{HHVV}^{*}




BIOMASS (t/ha)
150
125
100
75
50
25
0
0 5 10 15 20 25 30 35 40 45 50 55
AGE (year)


HEIGTH (m)
25
20
15
10
5
0
0 5 10 15 20 25 30 35 40 45 50 55
AGE (year)

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

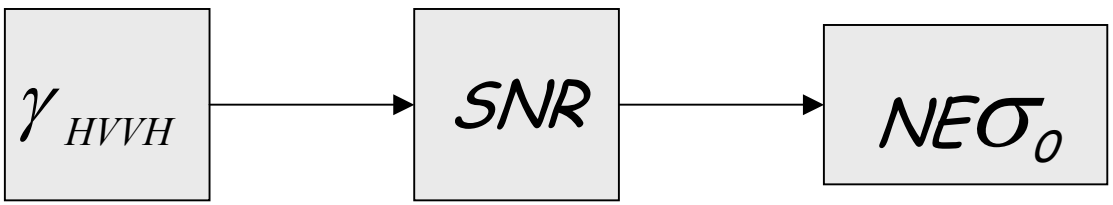
Dièdre de profil avec angle de dépolarisation de 22,5°

Dièdre de face avec angle de dépolarisation de 22,5°

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

$$\gamma_{HVVH} = \frac{\langle HVVH^{*} \rangle}{\sqrt{HVHV*}\sqrt{VHVH*}} = \frac{P_S}{P_S + N} = \left(1 + 1/SNR\right)^{-1}$$



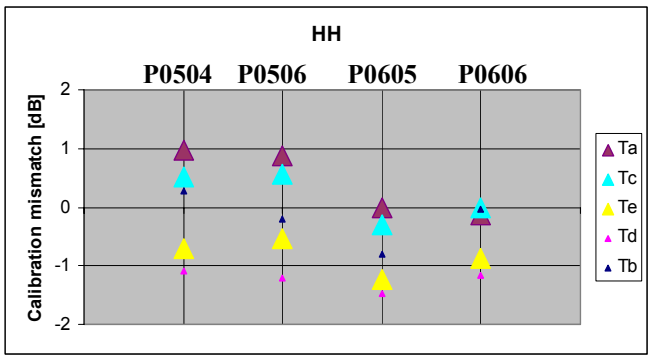
P Band calibration results

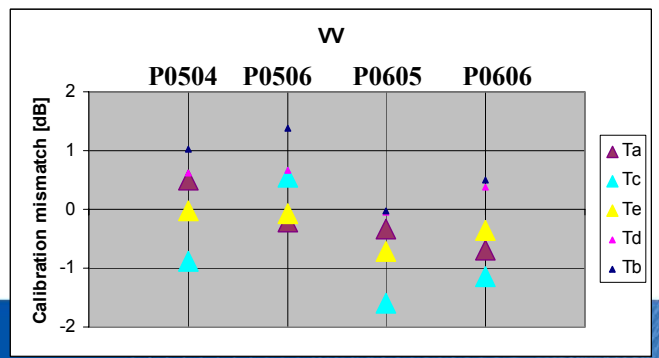
NESigma0 : better than -34 dB for co-polar channels

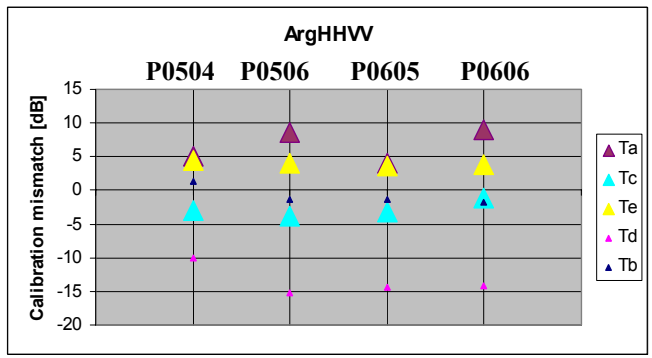
NESigma0 : better than -39 dB for crosspolar channels

HH et VV: ± 0.7 dB Copolar phase: ± 4°

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







The radiometric analysis

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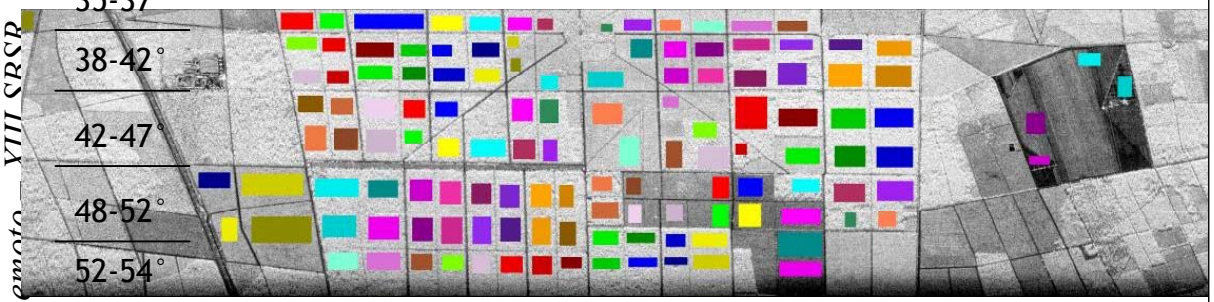
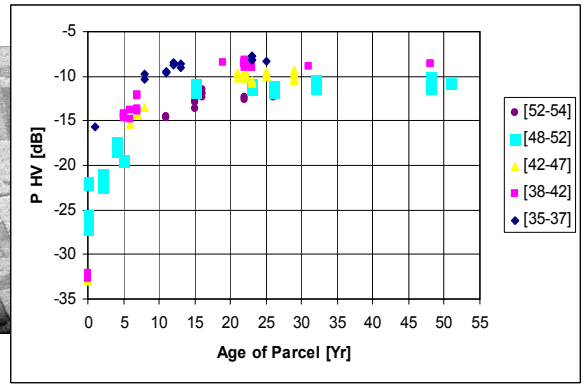
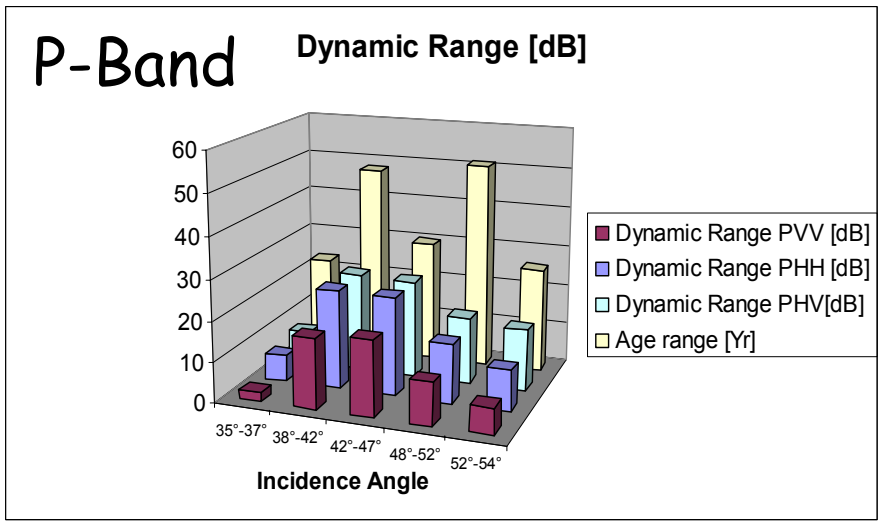
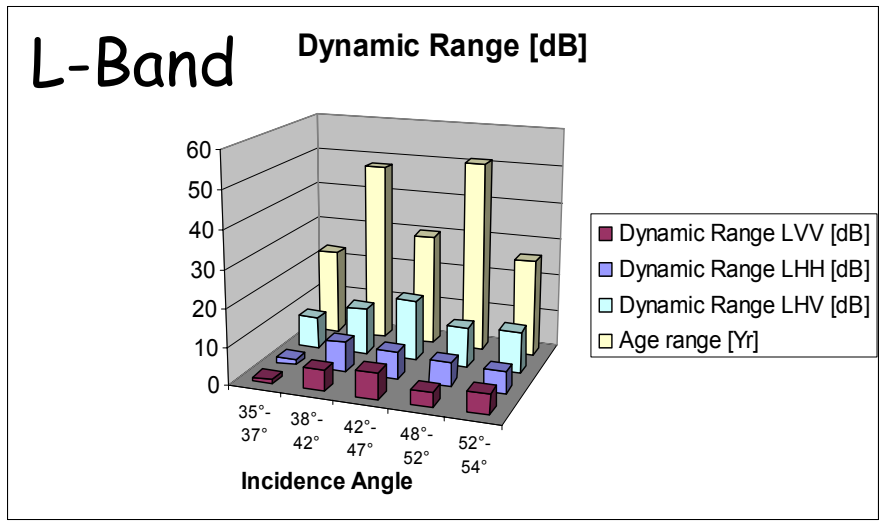
Radiometric analysis









Polarimetric analysis

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Background in polarimetry

$$[T_3] = \begin{bmatrix} \langle |(S_{hh}+S_{vv})|^2 \rangle & \langle (S_{hh}+S_{vv})(S_{hh}-S_{vv})^* \rangle & 2\langle (S_{hh}+S_{vv})S_{hv}^* \rangle \\ \langle (S_{hh}-S_{vv})(S_{hh}+S_{vv})^* \rangle & \langle |(S_{hh}-S_{vv})|^2 \rangle & 2\langle (S_{hh}-S_{vv})S_{hv}^* \rangle \\ 2\langle S_{hv}(S_{hh}+S_{vv})^* \rangle & 2\langle S_{hv}(S_{hh}-S_{vv})^* \rangle & 4\langle |S_{hv}|^2 \rangle \end{bmatrix}$$

3 eigenvectors

3 eigenvalues

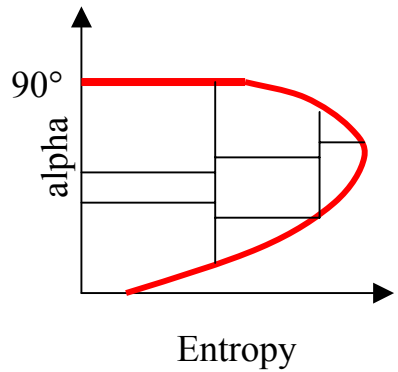
$\vec{e}_1 \quad \lambda_1$

$\vec{e}_2 \quad \lambda_2$

$\vec{e}_3 \quad \lambda_3$

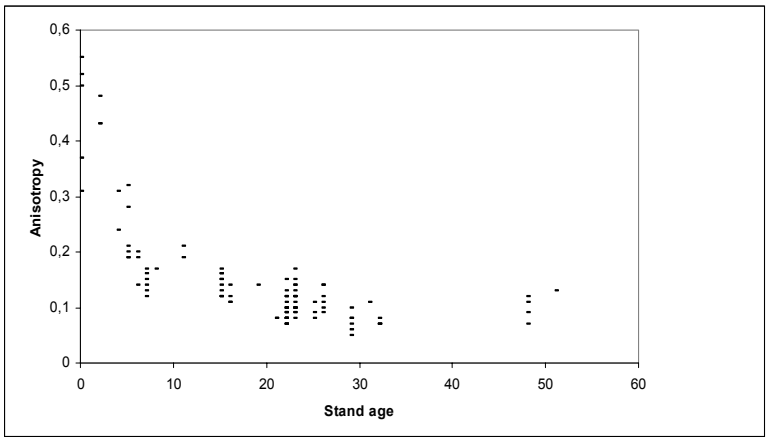
Alpha angle $$\alpha = \sum_{i=1}^{3} \frac{\lambda_i}{\lambda_1 + \lambda_2 + \lambda_3} \cos^{-1}(|e_{i_1}|)$$

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

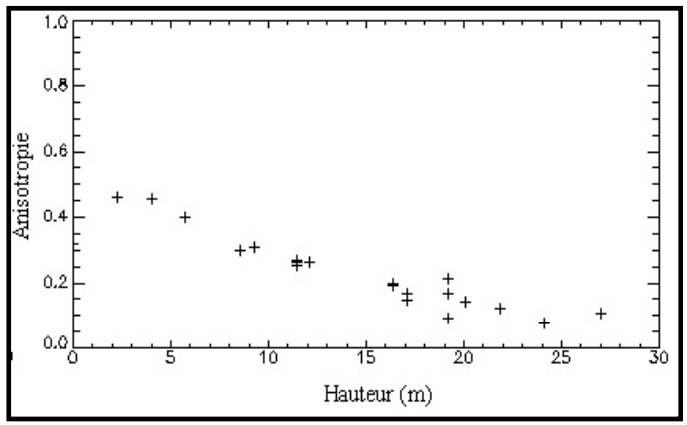


Anisotropy $$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}$$

Polarimetric analysis

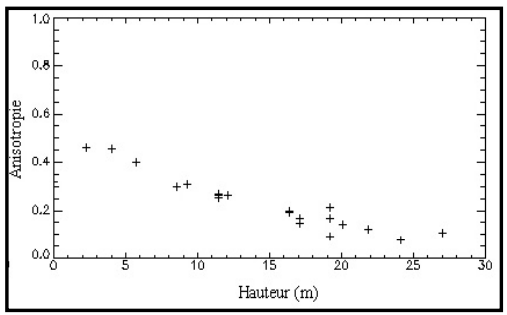


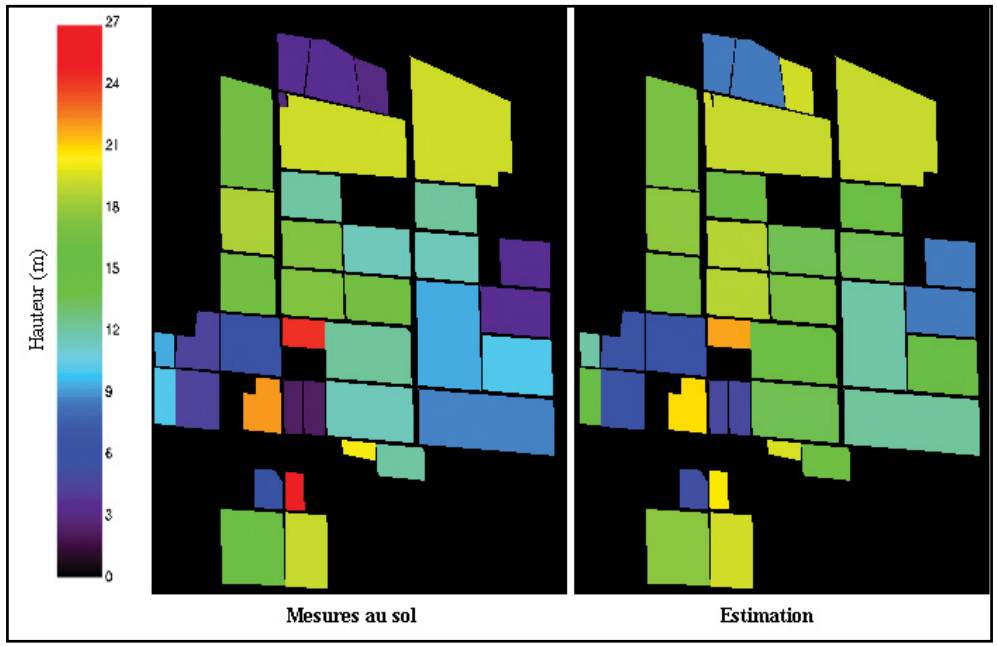
Anisotropy at L band



Anisotropy at P band

Inversion based on anisotropy





RMS error = 2m

Garestier: Thesis manuscript

PolInSAR Analysis

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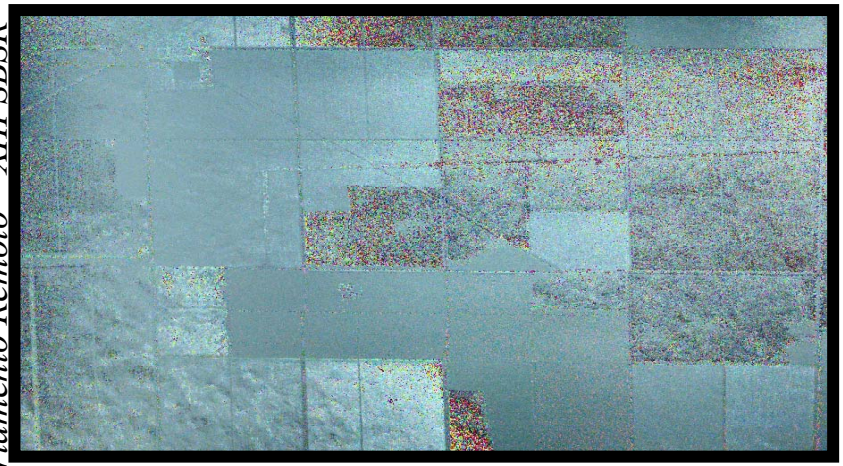
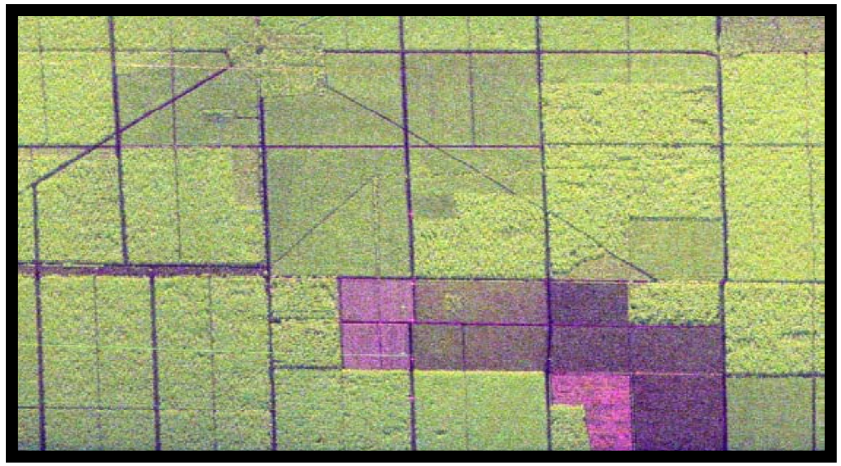
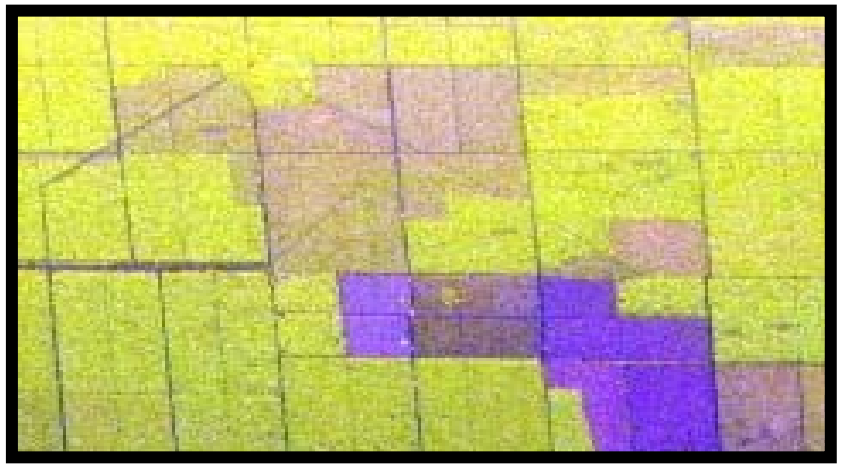
PolinSAR data: Nezer L P

L

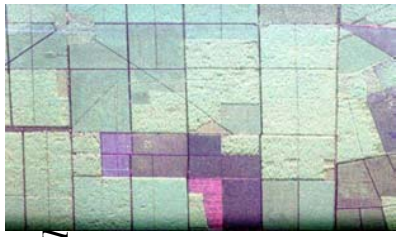


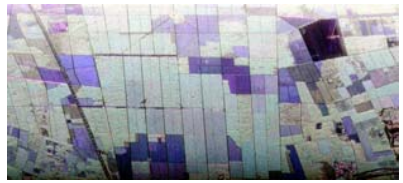


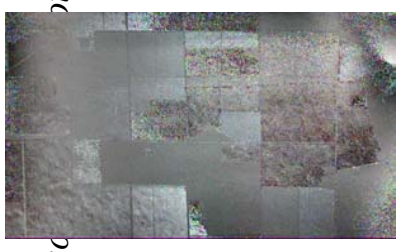
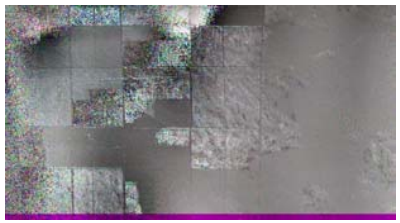
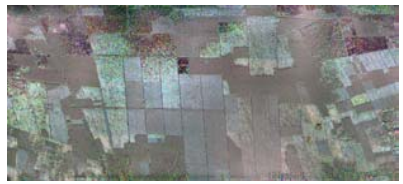
P

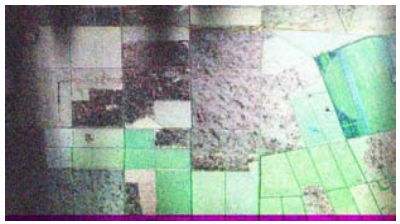
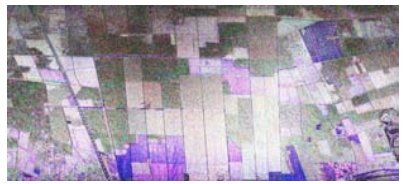
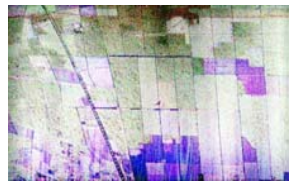
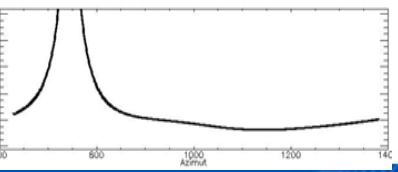
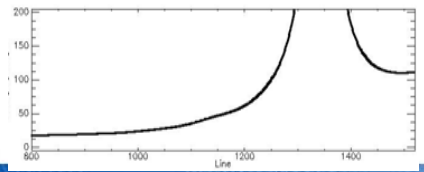
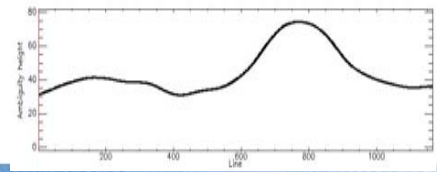
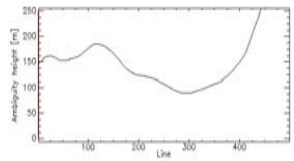


PolInSAR dataset





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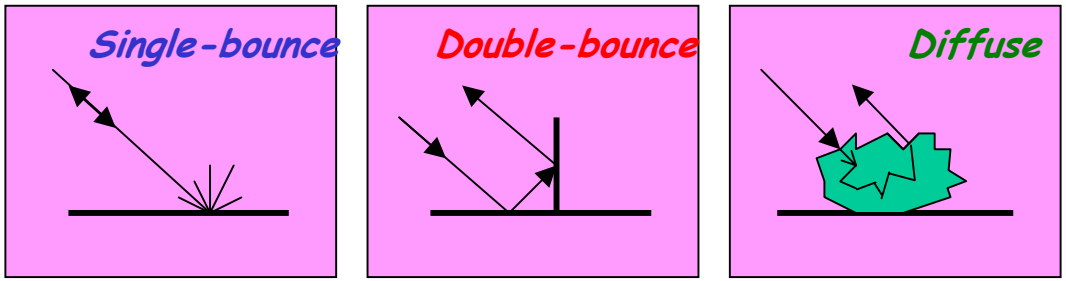
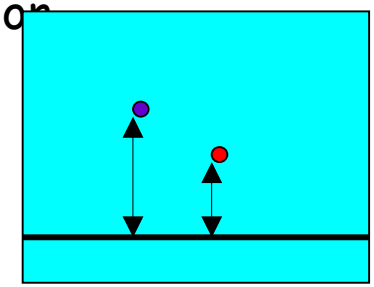
PolInSar data for biomass

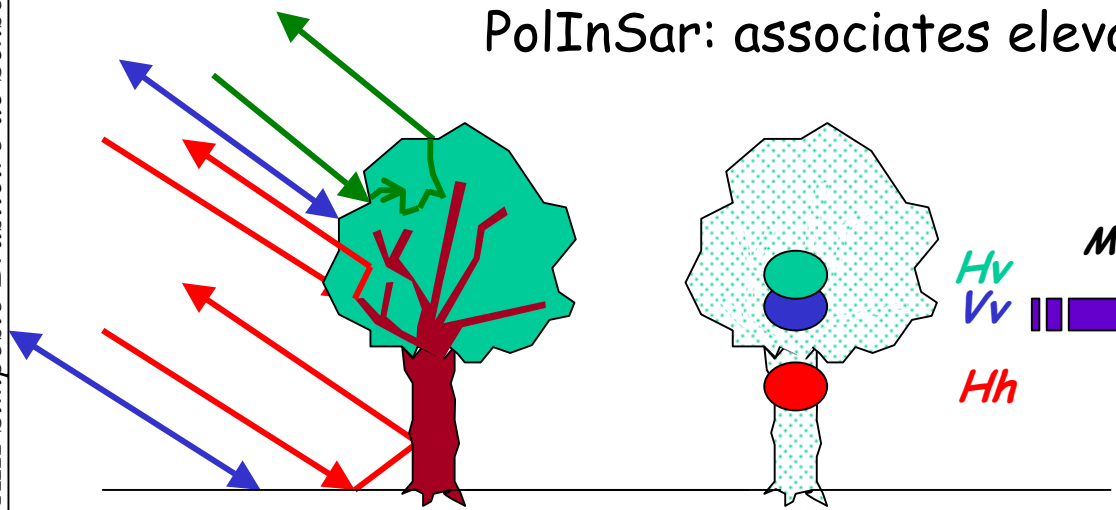
Polarimetry: identifies the scattering type



Interferometry: elevation



PolInSar: associates elevation to scattering type

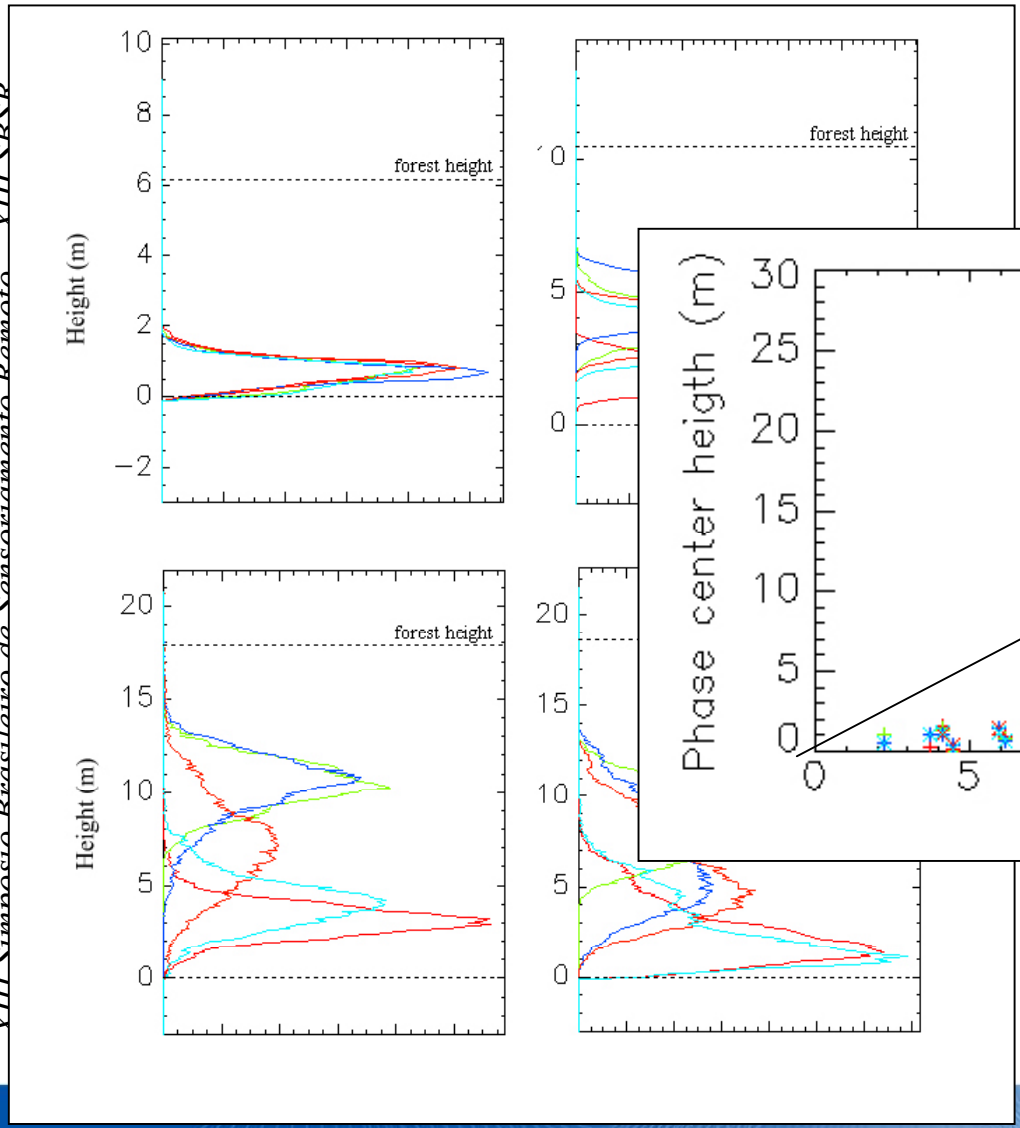


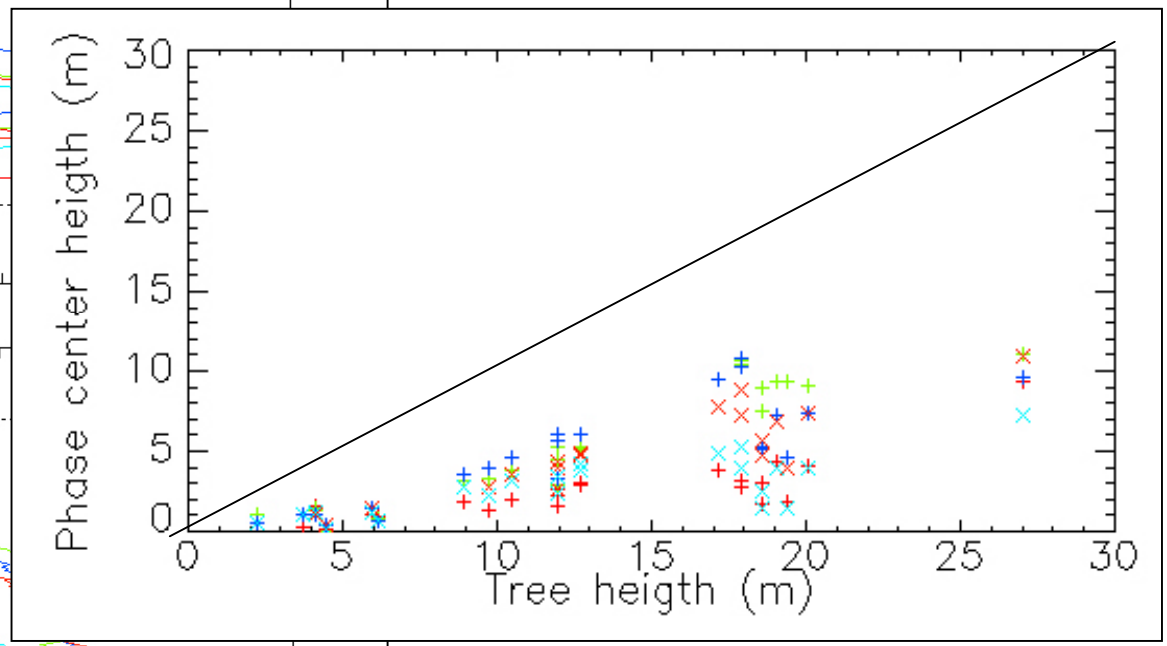
Hv
Vv
Hh

Model

Biophysical parameters
- *tree height*
- *tree biomass*
- *attenuation*
- *…*

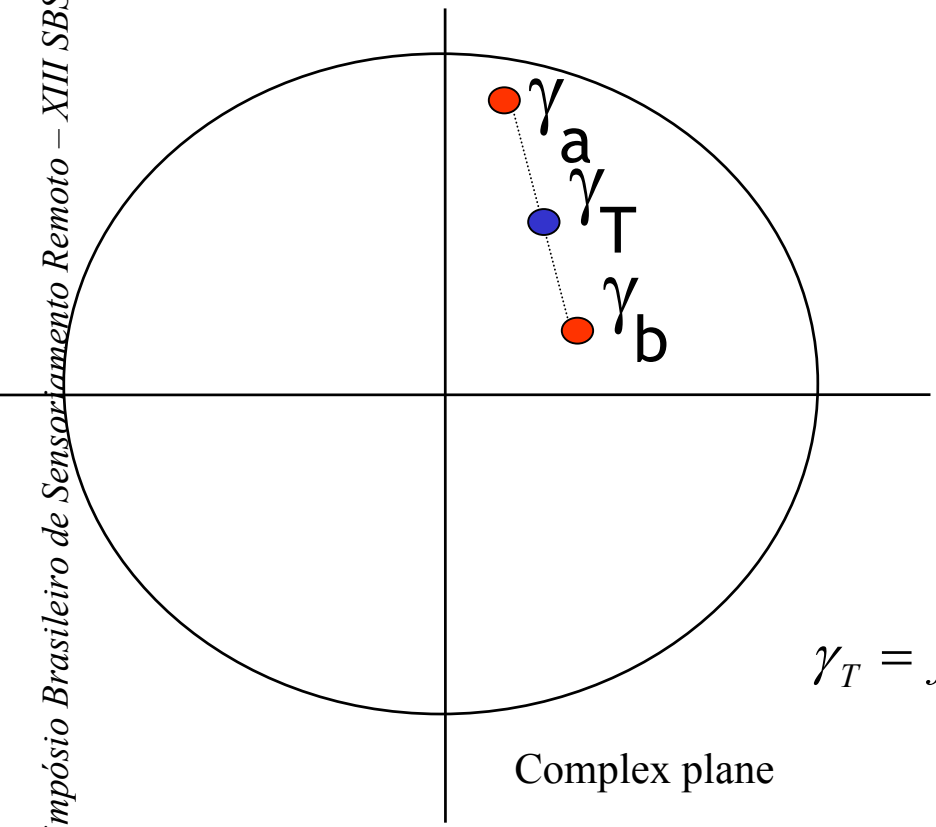
Polinsar analysis





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

Combining independant scatterers



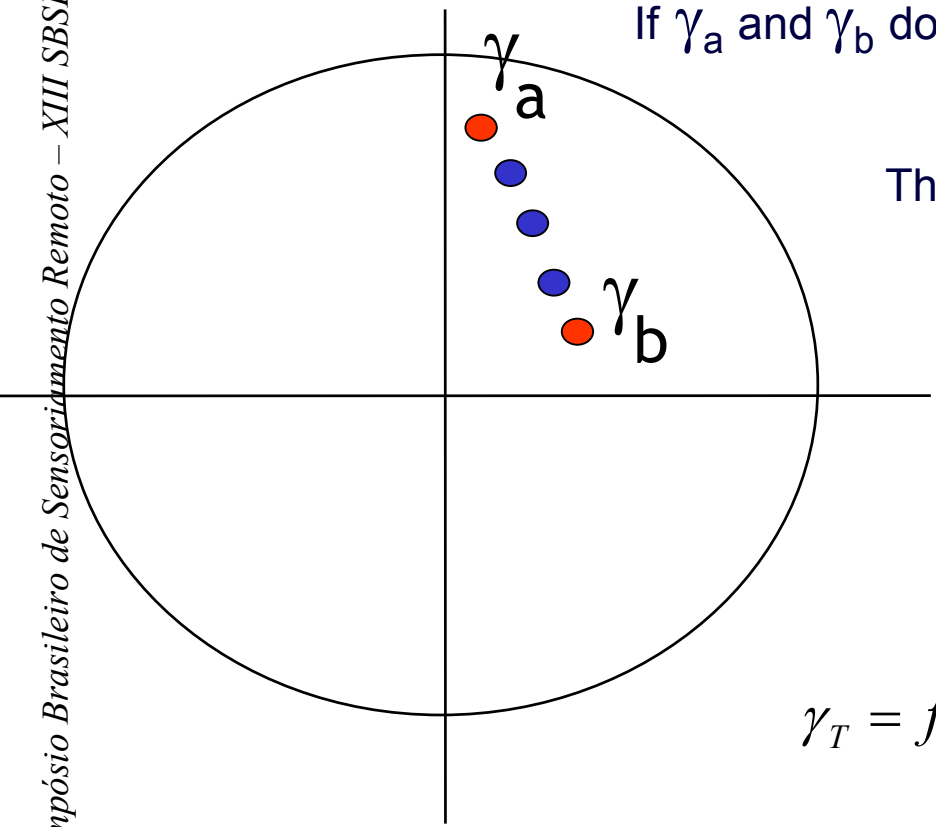
Complex plane

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

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

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

Adding polarimetry…



Complex plane

If γ_a and γ_b do not vary with polarimetry

Then γ_T varies along a line

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

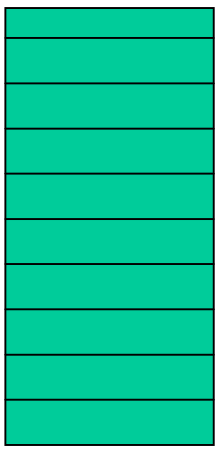
Looking for Stable PolInSAR Scatterers

- 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.



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

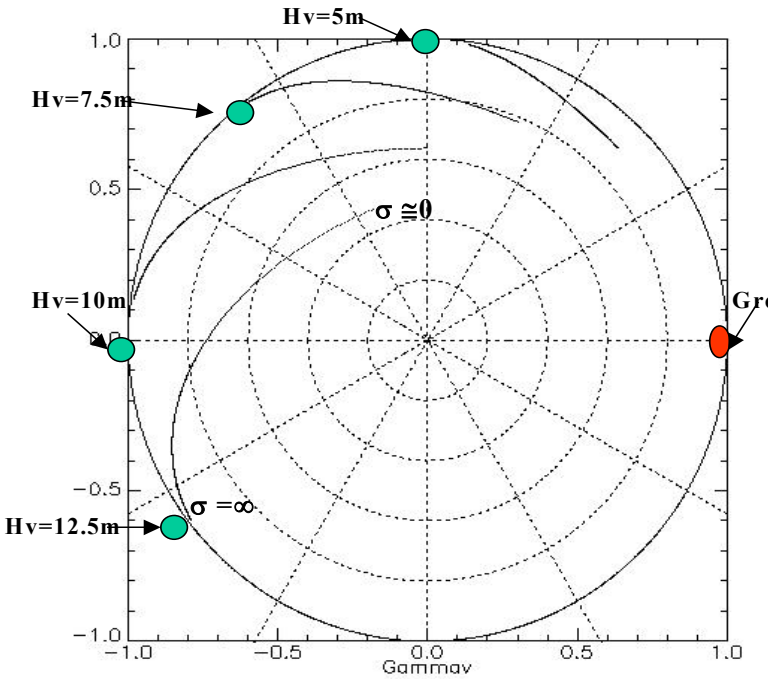
σ_x: extinction coefficient

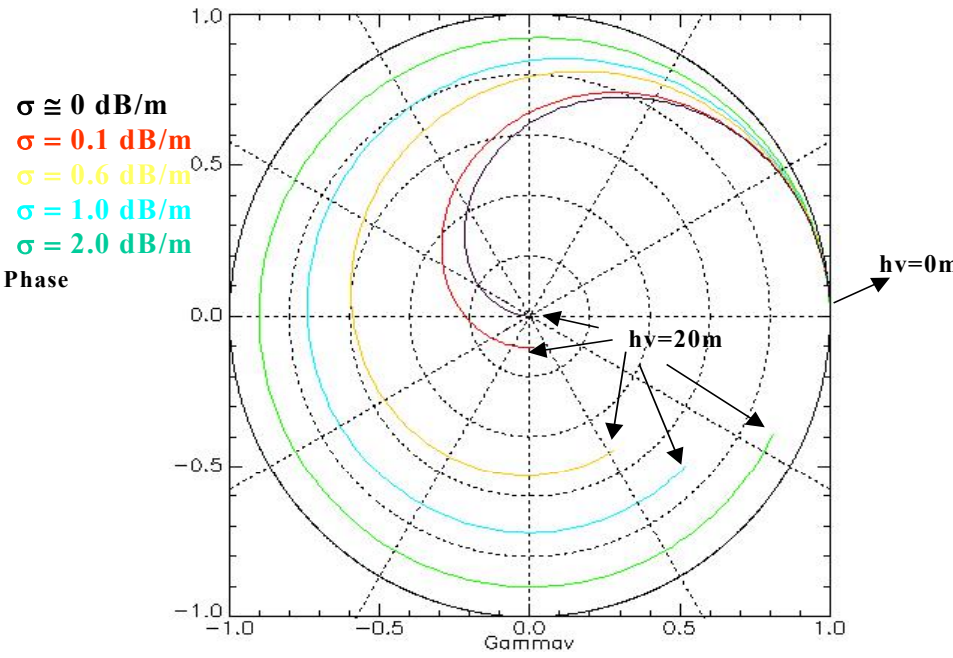
h : height of volume

θ: incidence angle

k_z :geometric charact.

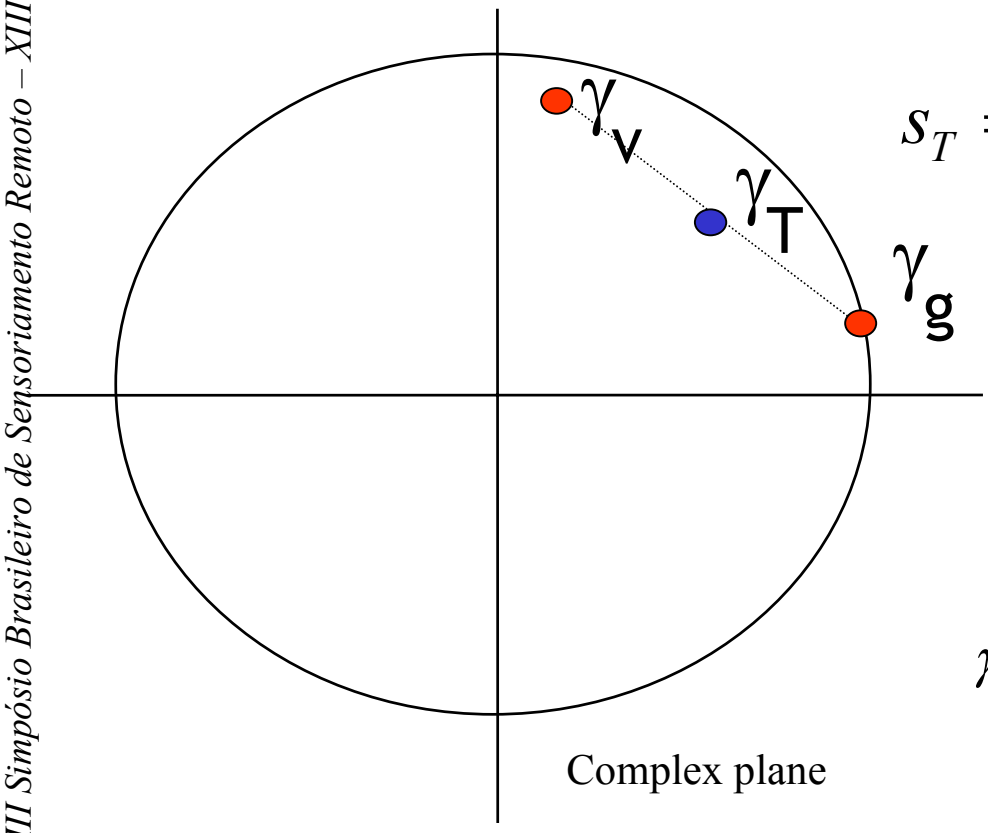
Random volume coherence



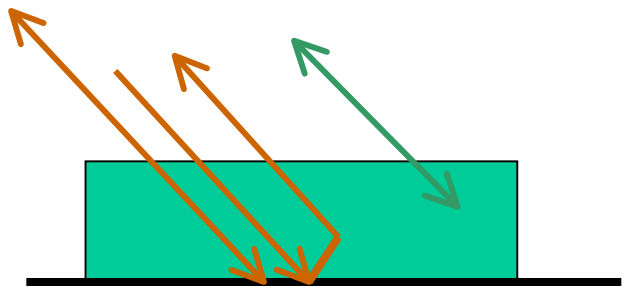


Therefore, given a "volume only" coherence,
one can invert the height and the extinction coefficient

Random Volume Over Ground Model *



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



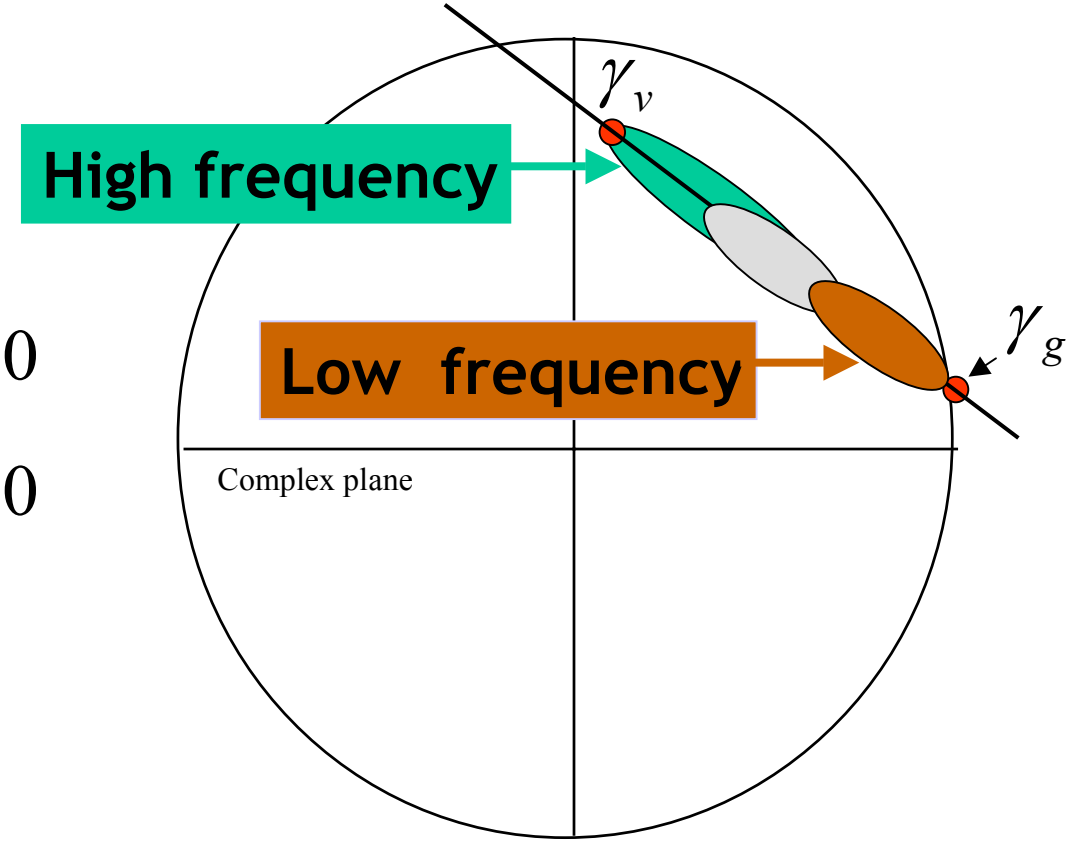
$$\gamma_T = f(\gamma_g, \gamma_v) = \frac{P_g}{P_g + P_v}\gamma_g + \frac{P_v}{P_g + P_v}\gamma_v$$

* Cloude and Papathanassiou

Random Volume over Ground model

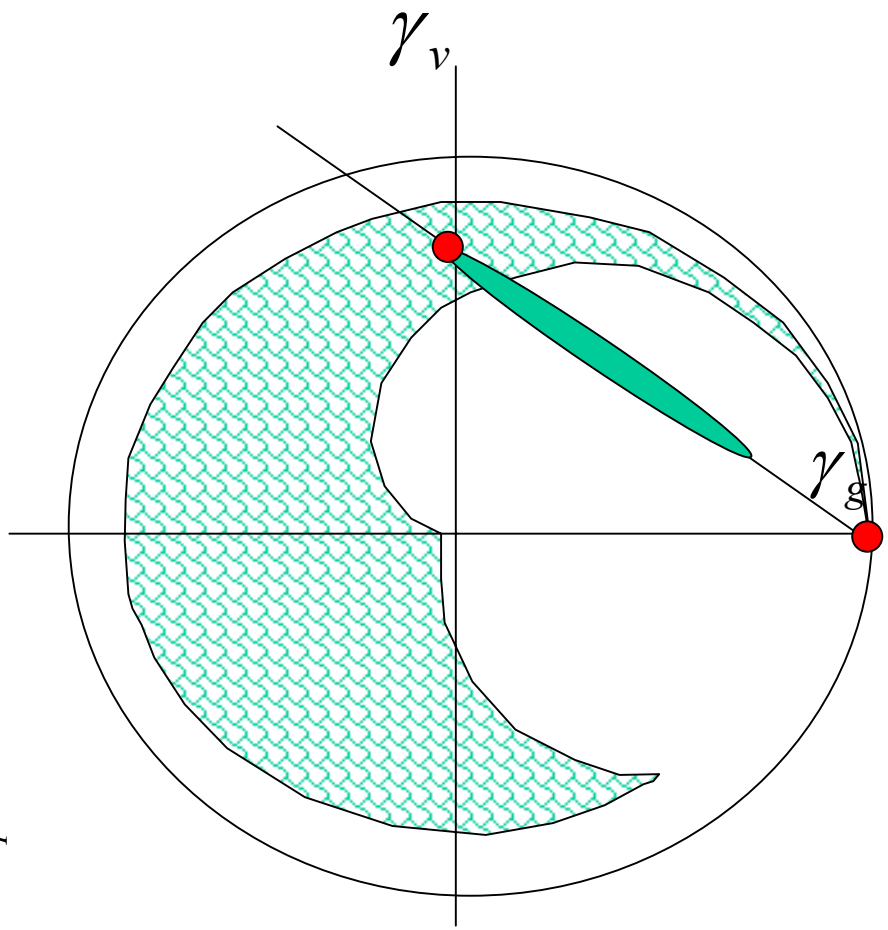
$$\exists w_0 \text{ such that } P_g(w_0) = 0$$

$$\exists w_0 \text{ such that } P_g(w_0) = 0$$



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

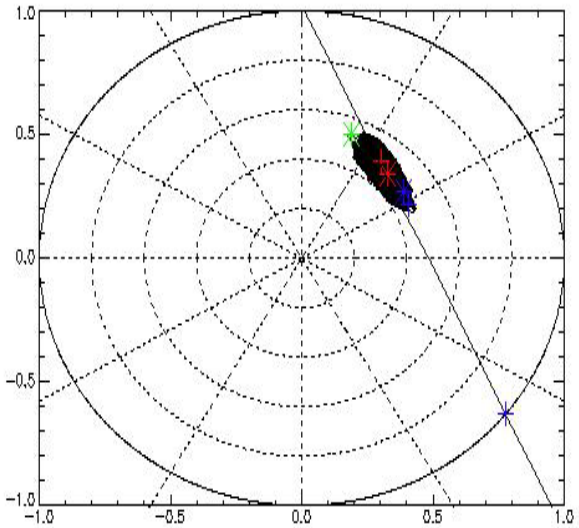
Standard RVoG inversion

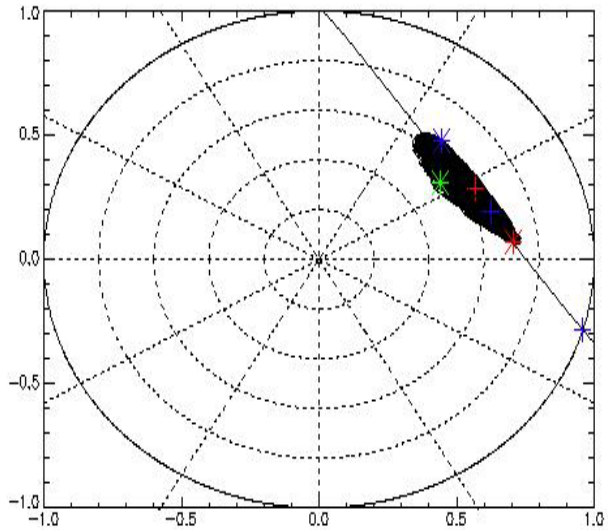


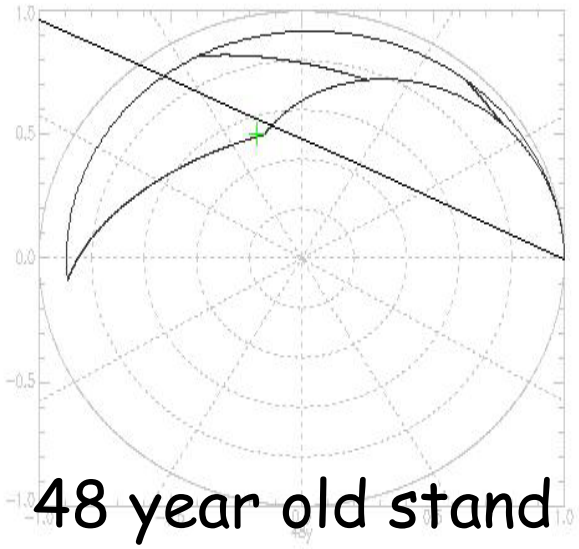
$$\gamma_V = e^{i\varphi_0} \frac{\int_0^{h_v} e^{2\frac{\sigma_x z}{\cos\theta}} e^{ik_z z} dz}{\int_0^{h_v} e^{2\frac{\sigma_x z}{\cos\theta}} dz}$$

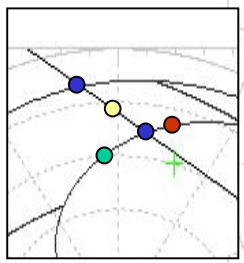
$h\ \sigma_x$

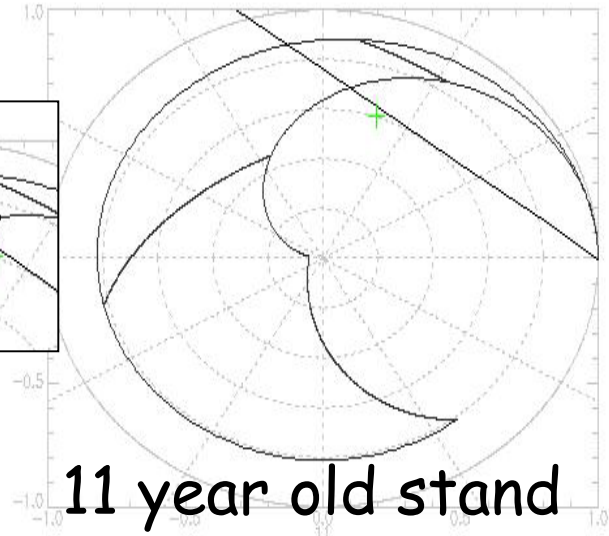
Inversion at P band











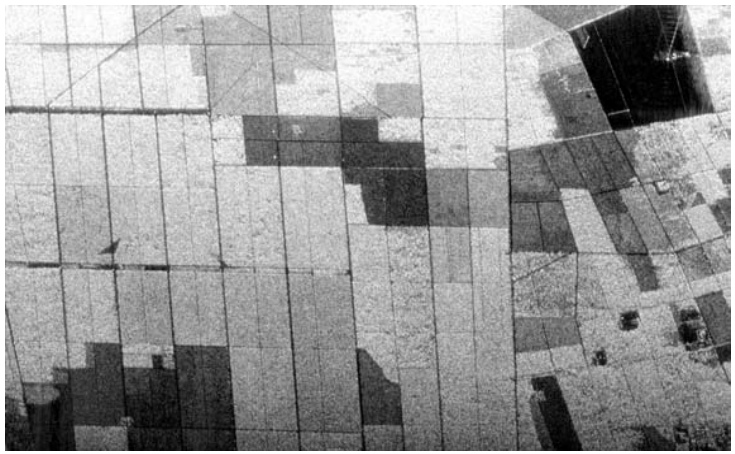
48 year old stand

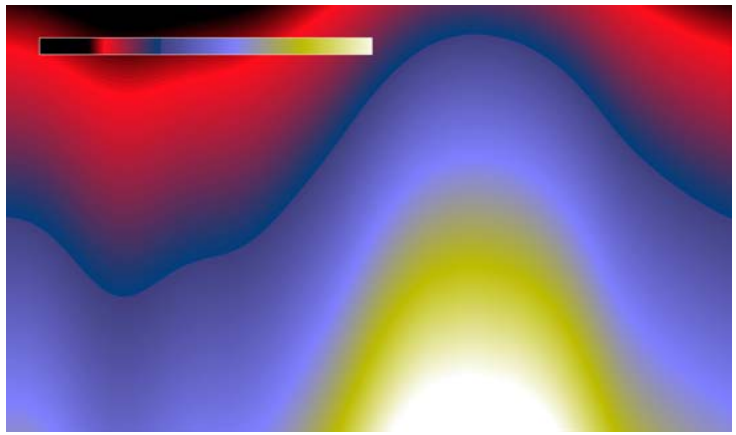
11 year old stand

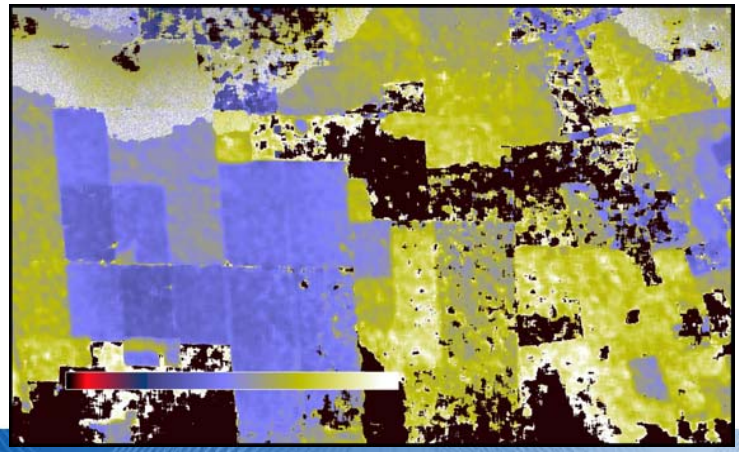
Inversion PolInSAR

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

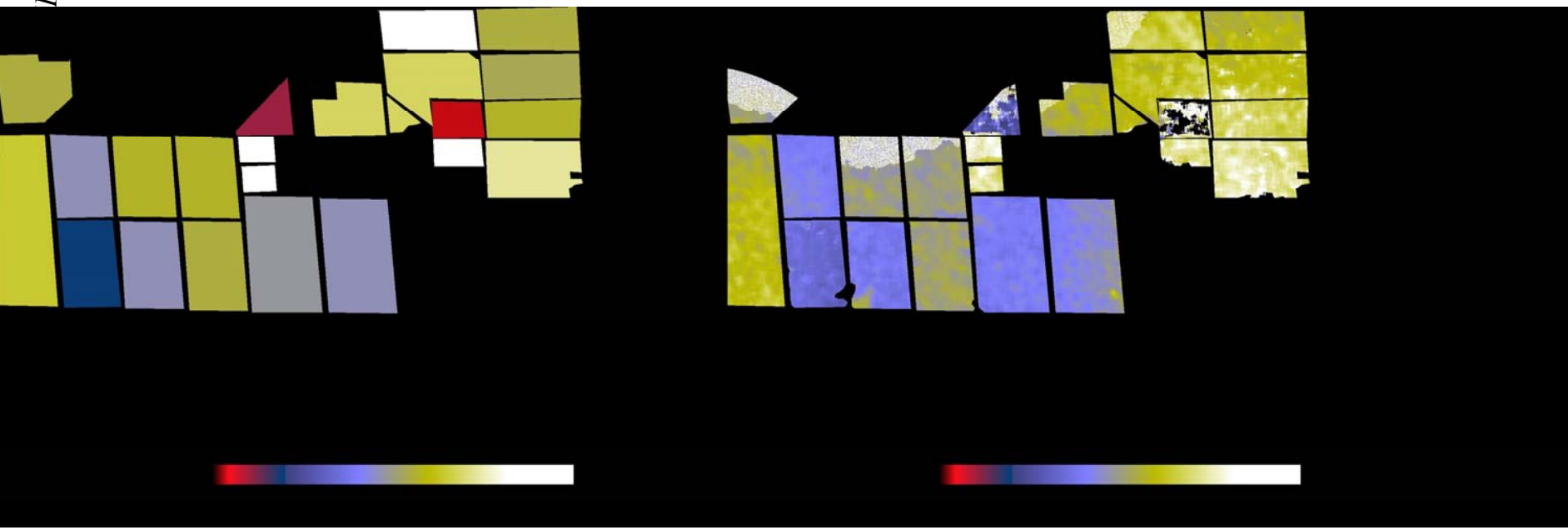
PolInSAR results at P band



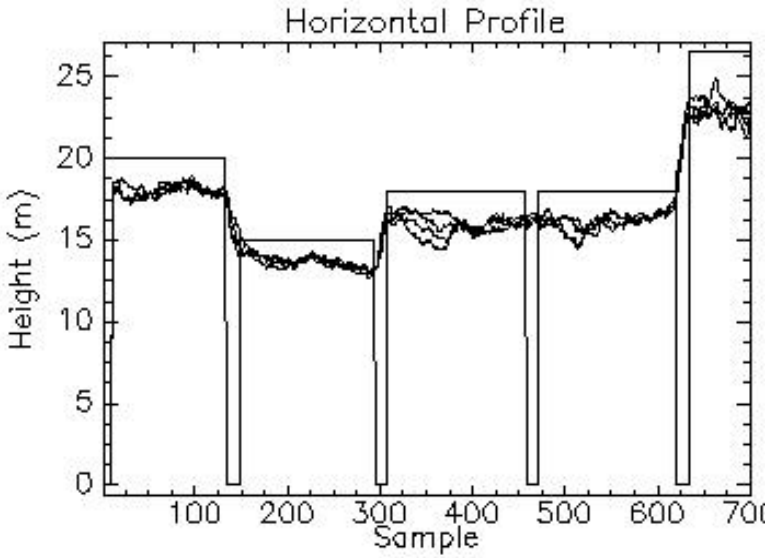


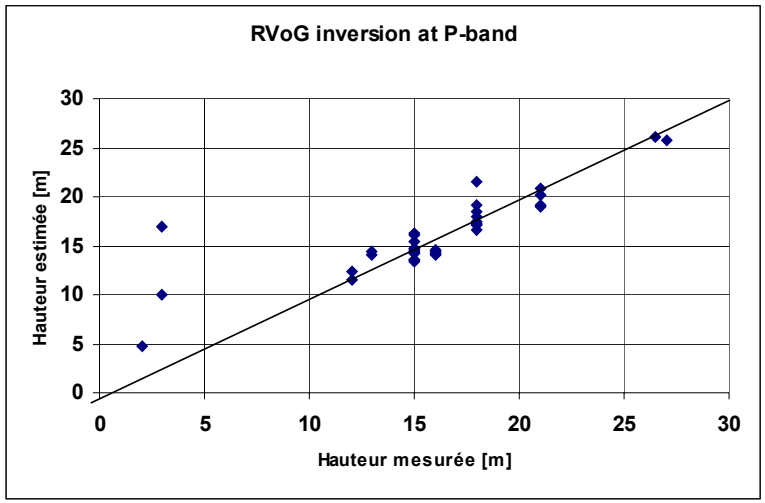


PolInSAR results at P band



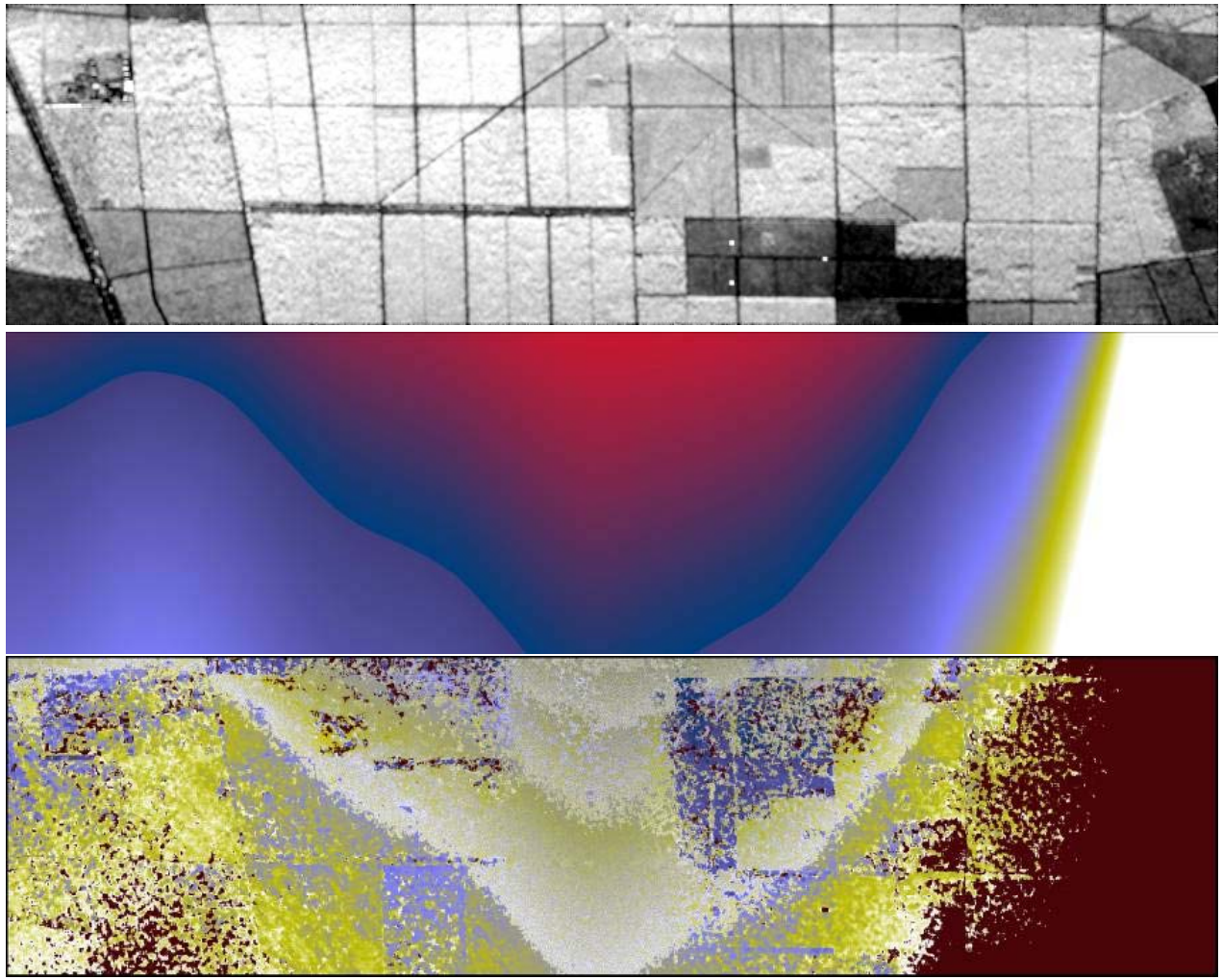
PolInSAR results at P band



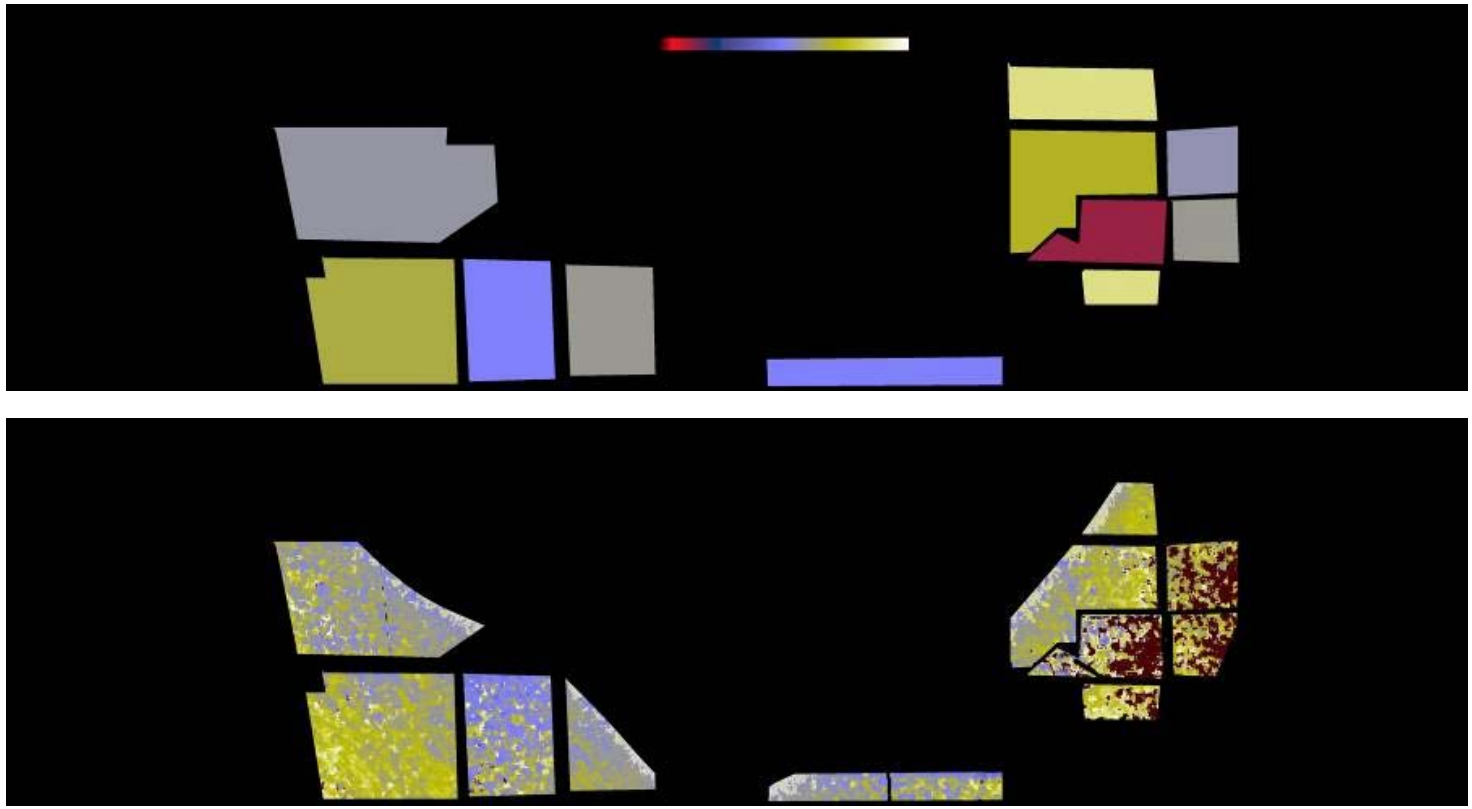


RMS error= 1.2m

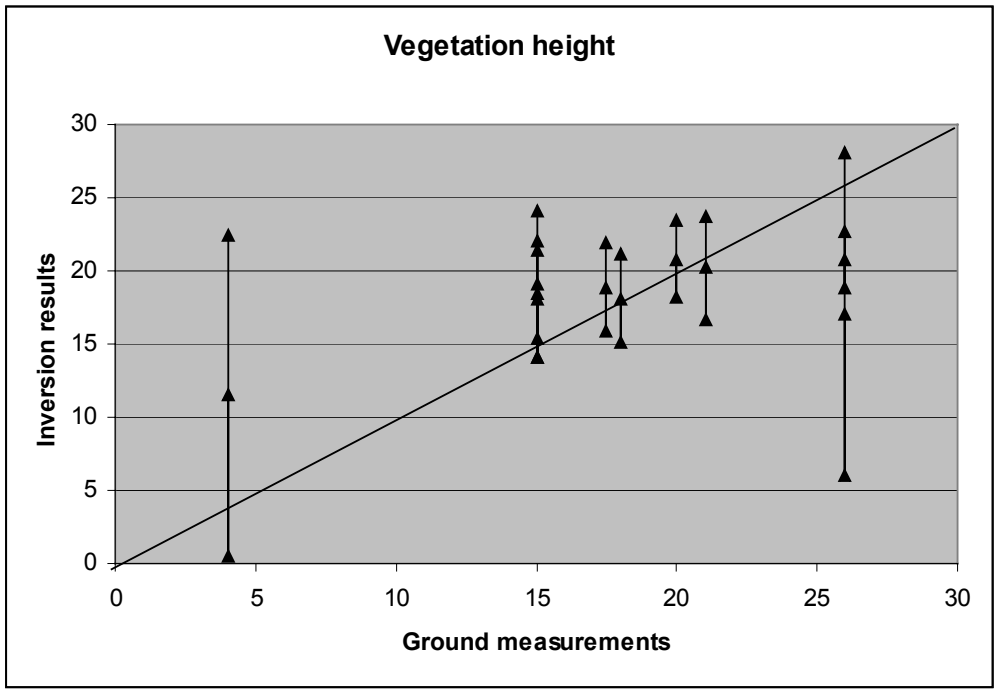
PolInSAR at L band



PolInSAR at L band

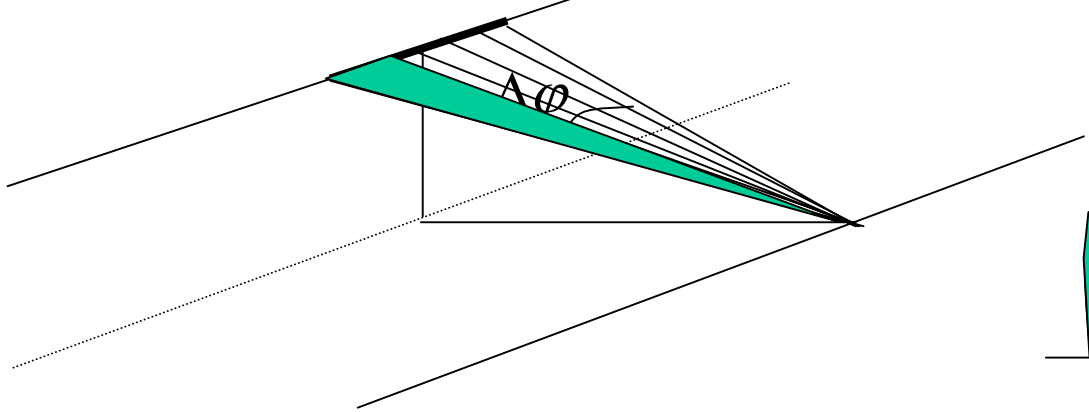


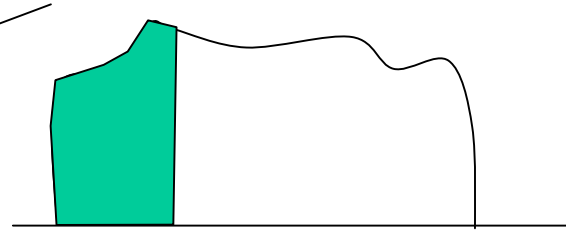
PolInSAR at L band



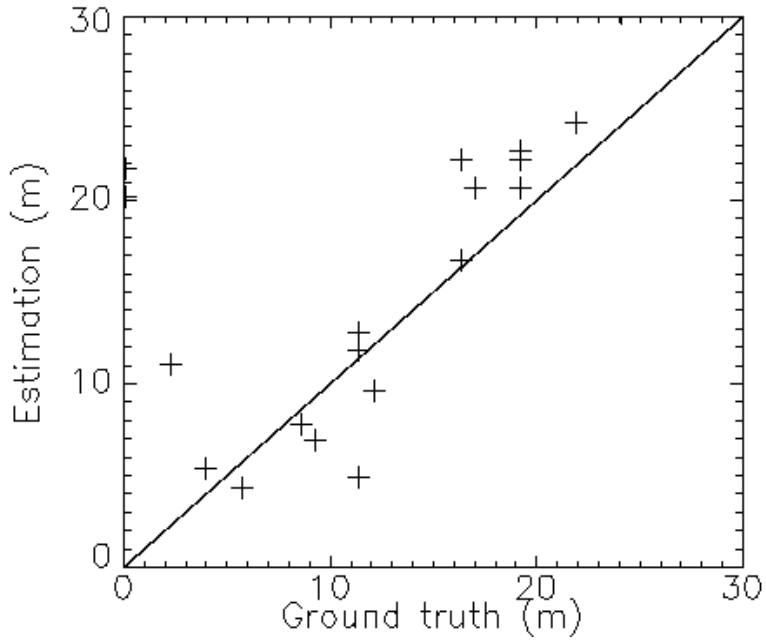
Time Frequency Optimization
P-Band

$$\delta_a = \frac{\lambda}{2\Delta\varphi}$$





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