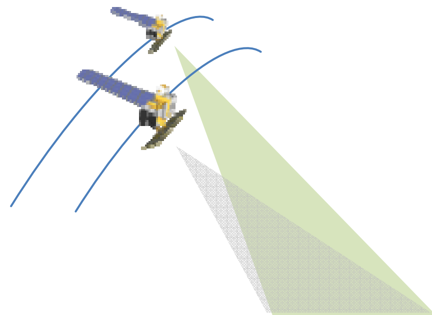

Theory and PALSAR Observations of the PolInSAR $\pi / 4$ mode

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ALOS PI Symposium 3-7 November 2008

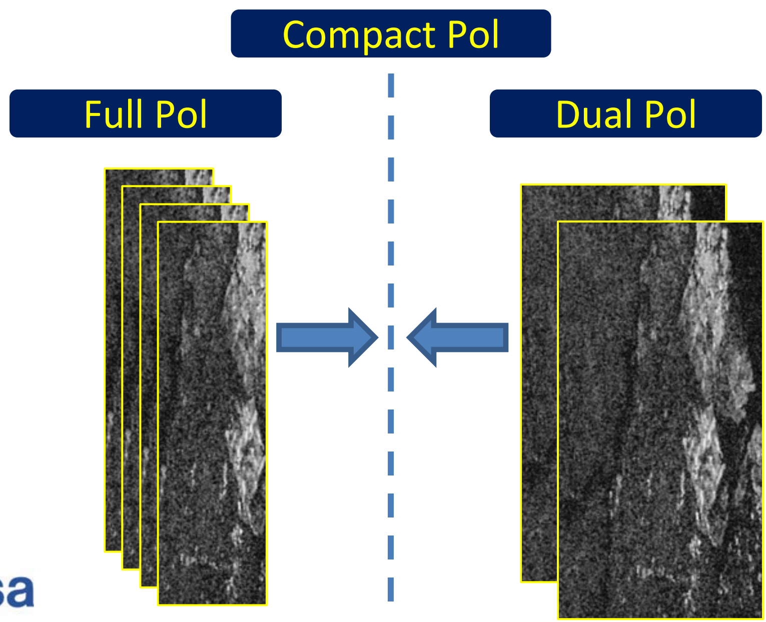
Outline

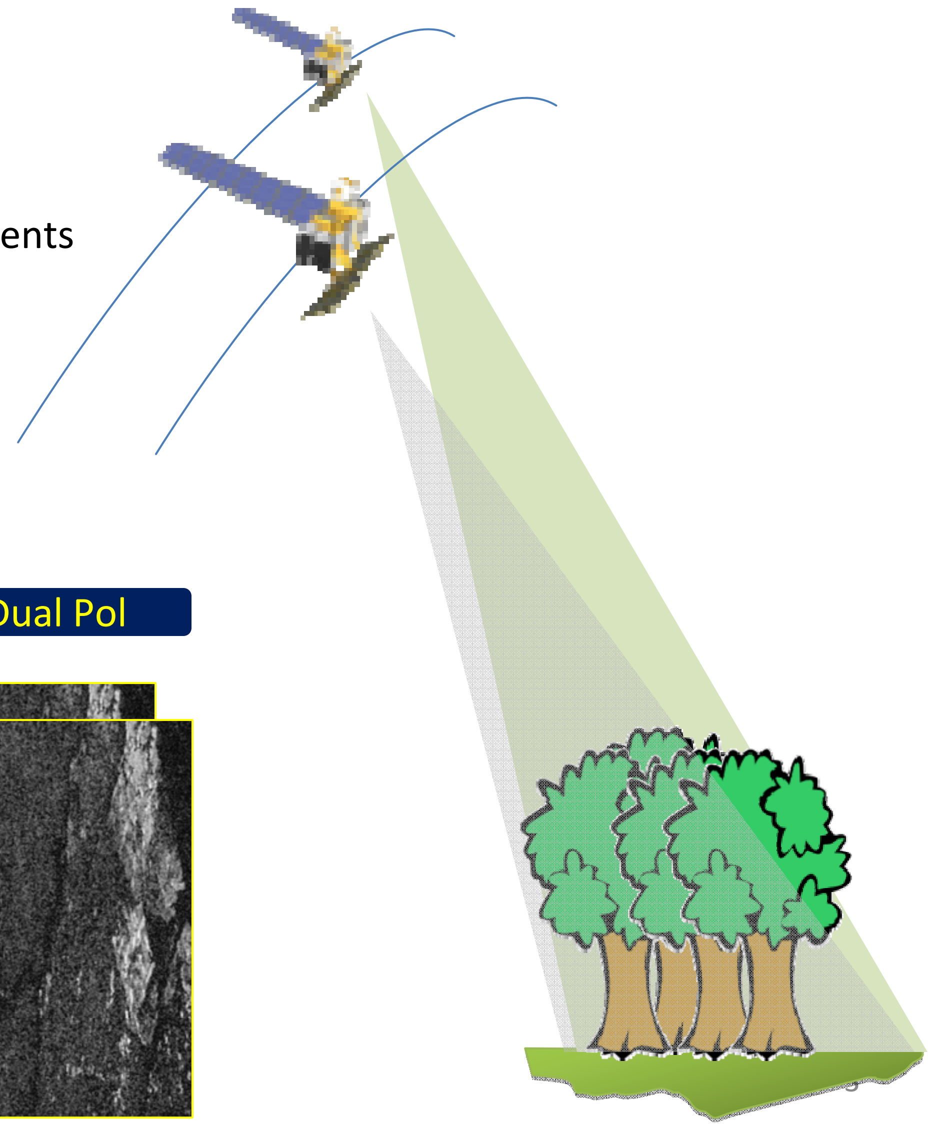
- Introduction
- *Compact* Polarimetric SAR Interferometry
- New approach for forest height estimation
- Results: PALSAR data
  - Full PolInSAR
  - Compact PolInSAR
- Conclusions

Introduction

Polarimetric SAR Interferometry: ALOS-PALSAR

- → PolInSAR basic idea:
  - → InSAR coherence has different sensitivity according to polarization
  - → To discriminate among different components of the vertical structure of vegetation
- → ALOS PALSAR
  - → L-band
  - → 46 days revisit time

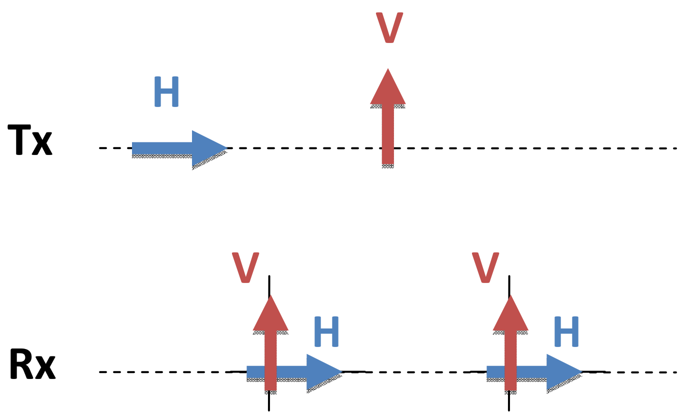




Introduction

Compact Polarimetry VS Full Polarimetry

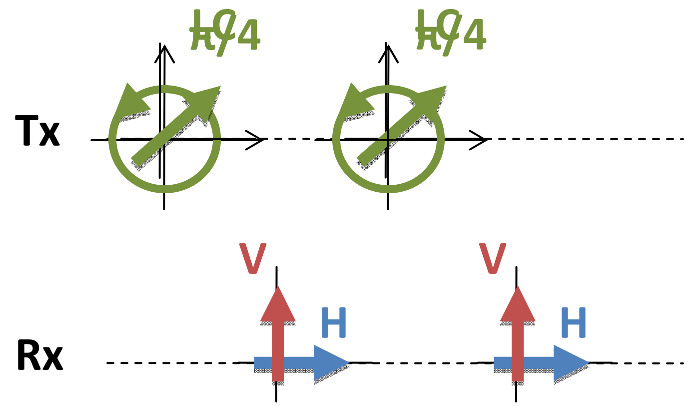
Full Polarimetry (FP)



$$S = \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \rightarrow k_L = \begin{pmatrix} S_{HH} \\ \sqrt{2}S_{HV} \\ S_{VV} \end{pmatrix}$$

Compact Polarimetry (CP)

e.g. π/4 mode

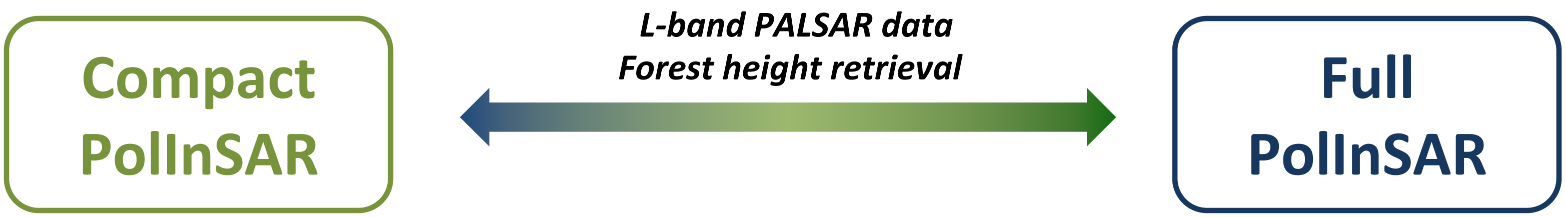


$$k_{circ} = \begin{pmatrix} \mathbf{S}_{H(circ)} \\ \mathbf{S}_{V(circ)} \end{pmatrix} = \begin{pmatrix} S_{HH} \pm jS_{HV} \\ jS_{VV} \pm S_{HV} \end{pmatrix}$$

CP relaxes system constraints (antenna, downloading rate, swath, power consumption) but requires the reconstruction of the full polarimetric information to exploit PolSAR algorithms.

Objective of the work

To compare the PolInSAR performance of Compact-Pol with Full-Pol using L-band PALSAR data and forest height estimation



We will show:

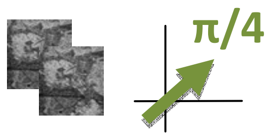
1) **A reconstruction algorithm of the Full PolInSAR information**
2) **A new approach for the forest height estimation**

Reconstruction algorithm

C-PolInSAR → F-PolInSAR

Compact Polarimetry

Reconstruction of full polarimetric information



CP (π/4 mode)

CP scattering vector

$$k_{\pi/4}$$

2×2 CP covariance matrix

$$J_2 = \left\langle k_{\pi/4}\, k_{\pi/4}^{*T} \right\rangle$$

Reconstruction of FP

3×3 reconstructed FP coherency matrix

$$T_3$$

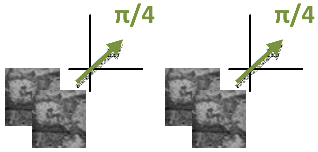
PolSAR algorithms

→ Reconstruction based on symmetry properties of geophysical media

→ Performance of CP (π/4 mode) evaluated on PolSAR classification results (Souyris, 2005)

Compact PolInSAR

Reconstruction of full PolInSAR information



C-PolInSAR(π/4 mode)

2 CP scattering vectors

$$k_{(\pi/4)_1}$$
$$k_{(\pi/4)_2}$$

→

4×4 CP covariance matrix

$$J_4$$

→

Reconstruction of F-PolInSAR

↓

6×6 reconstructed F-PolInSAR coherency matrix

$$T_6 = \begin{bmatrix} T_{11} & \Omega_{12} \\ \Omega_{12}^{*T} & T_{22} \end{bmatrix}$$

↓

PolInSAR algorithms

Compact PolInSAR

Reconstruction of Full PolInSAR information

CP scattering vectors

$$k_{(\pi/4)_1} = \begin{pmatrix} S_{HH_1} + S_{HV_1} \\ S_{VV_1} + S_{HV_1} \end{pmatrix}$$

$$k_{(\pi/4)_2} = \begin{pmatrix} S_{HH_2} + S_{HV_2} \\ S_{VV_2} + S_{HV_2} \end{pmatrix}$$

4×4 C-PolInSAR covariance matrix

$$J_4 = \left\langle \begin{bmatrix} k_{(\pi/4)_1} \\ k_{(\pi/4)_2} \end{bmatrix} \begin{bmatrix} k_{(\pi/4)_1} \\ k_{(\pi/4)_2} \end{bmatrix}^{*T} \right\rangle = \begin{bmatrix} J_{11} & J_{12} \\ J_{12}^{*T} & J_{22} \end{bmatrix}$$

$$J_{12} = \begin{bmatrix} j_{11} & j_{12} \\ j_{21} & j_{22} \end{bmatrix}$$

$$\begin{cases} j_{11} = S_{HH_1}S^*_{HH_2} + S_{HH_1}S^*_{HV_2} + S_{HV_1}S^*_{HH_2} + S_{HV_1}S^*_{HV_2} \\ j_{12} = S_{HH_1}S^*_{VV_2} + S_{HH_1}S^*_{HV_2} + S_{HV_1}S^*_{VV_2} + S_{HV_1}S^*_{HV_2} \\ j_{21} = S_{VV_1}S^*_{HH_2} + S_{VV_1}S^*_{HV_2} + S_{HV_1}S^*_{HH_2} + S_{HV_1}S^*_{HV_2} \\ j_{22} = S_{VV_1}S^*_{VV_2} + S_{VV_1}S^*_{HV_2} + S_{HV_1}S^*_{VV_2} + S_{HV_1}S^*_{HV_2} \end{cases}$$

8 observables < 18 unknowns !

Compact PolInSAR

Reconstruction of Full PolInSAR information

→Additional equations from symmetry properties (Nghiem, 1992)

→Two approaches:

- rotation symmetry
- reflection symmetry

C-PolInSAR observables
+
Reflection symmetry
+
rotation invariance of x-pol terms

→

6×6 reconstructed
F-PolInSAR coherency matrix

$$T_6^{\text{ref}}$$

Cross-coherency matrix:

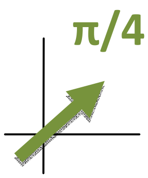
$$\Omega_{12} = \frac{1}{4} \begin{pmatrix} j_{11} + j_{12} + j_{22} + 5j_{21} & 2(j_{11} - j_{22}) & 0 \\ 2(j_{11} - j_{22}) & 2(j_{11} + j_{22}) - 4j_{21} & 0 \\ 0 & 0 & j_{11} + j_{22} - j_{21} - j_{12} \end{pmatrix}$$

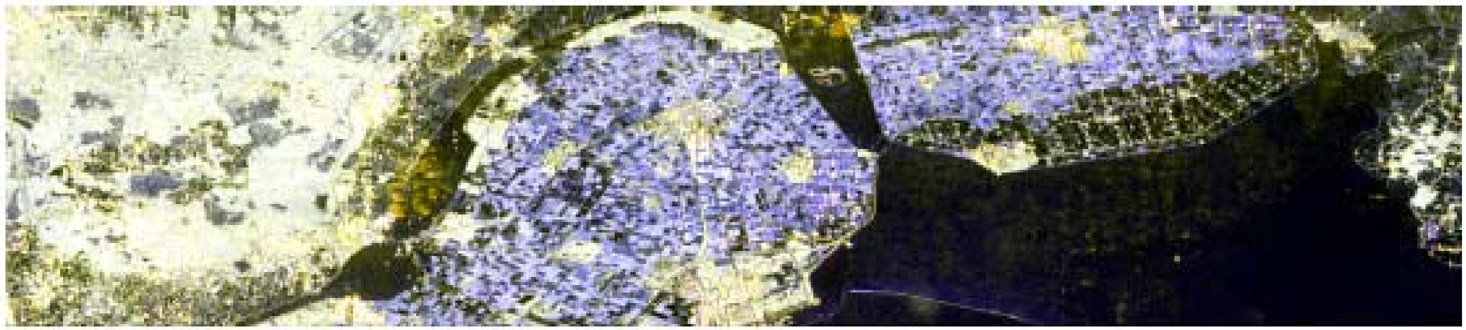
Reconstructed FP information

PALSAR example (Flevoland)

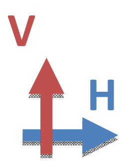
→ Pauli Decomposition: **HH+VV**, **HH-VV**, **HV**

Compact-Pol



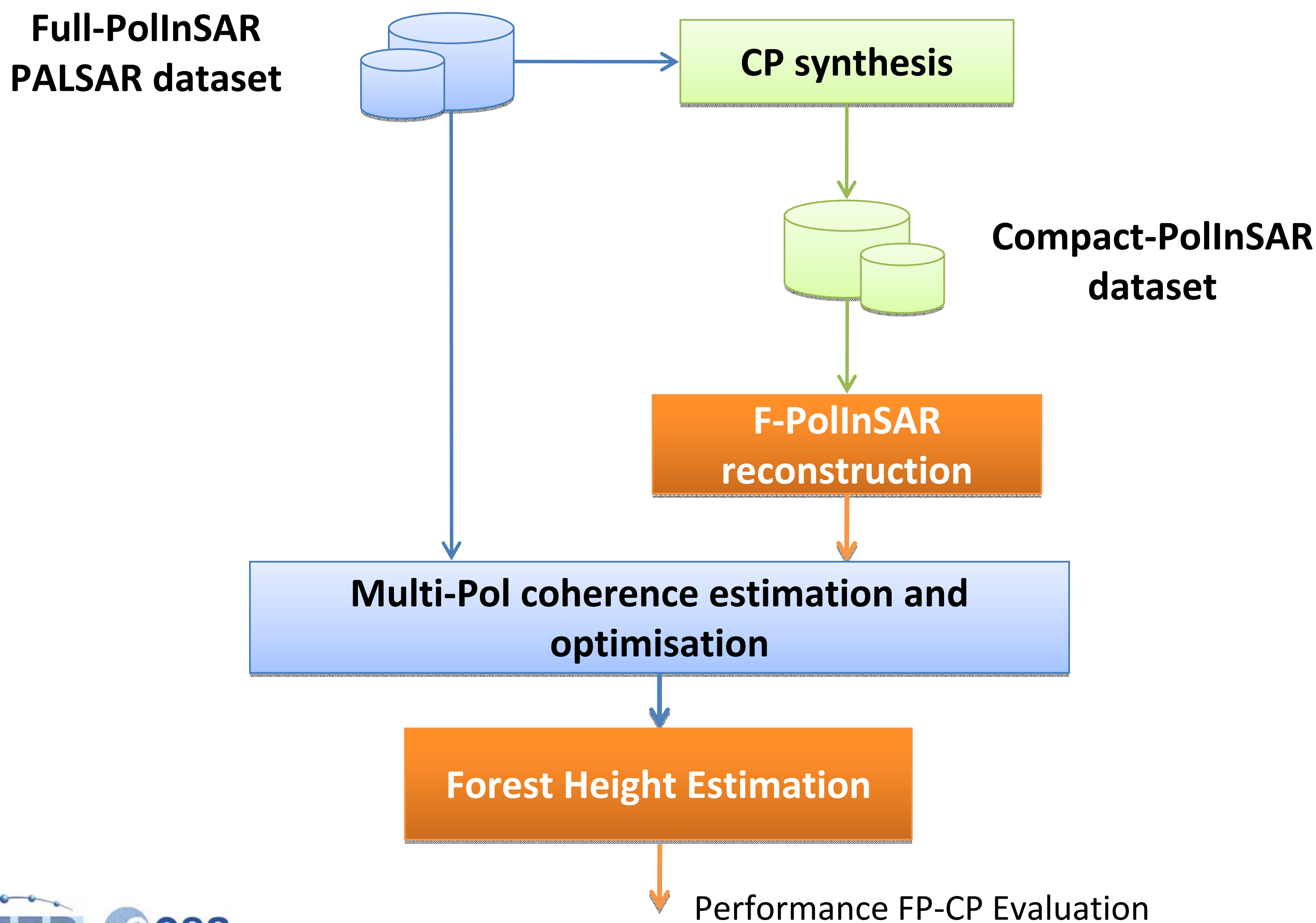


Full-Pol



Compact PolInSAR

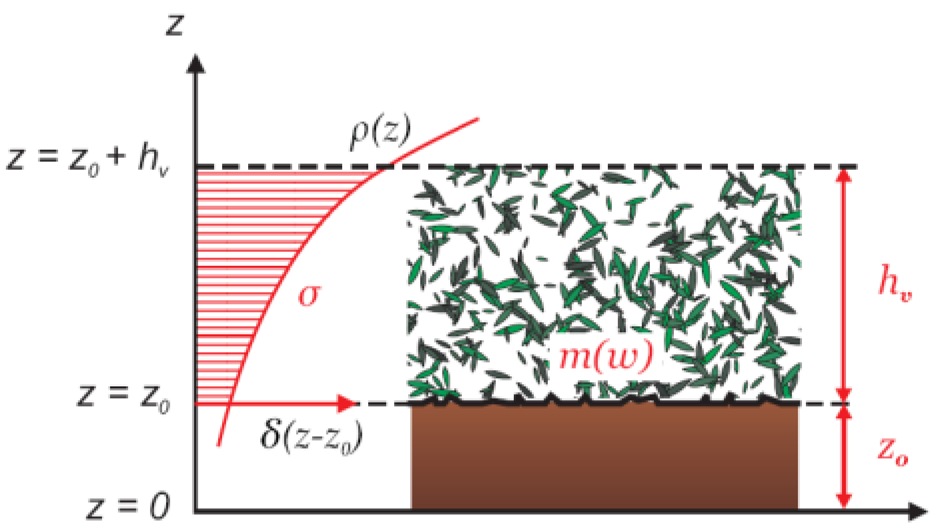
Performance Evaluation Scheme



New approach for forest height estimation

Random Volume over Ground Model

Previous approach (Papathanassiou, 2001)



Volume coherence:

$$\tilde{\gamma}_v = e^{jk_z z_0} \frac{\int_0^{h_v} \rho(z) e^{jk_z z} dz}{\int_0^{h_v} \rho(z) dz}$$

RVoG coherence:

$$\tilde{\gamma}_{RVoG} = e^{jk_z z_0} \left[\tilde{\gamma}_v + \frac{m(\vec{w})}{1 + m(\vec{w})} (1 - \tilde{\gamma}_v) \right]$$

Total Coherence:

$$\tilde{\gamma}_{tot} = \tilde{\gamma}_{temp} \, \tilde{\gamma}_{RVoG} \, \gamma_{SNR}$$

Vegetation height h_v

Vertical reflectivity function $\rho(z)$

Gound/Volume Ratio: $m(\vec{w})$

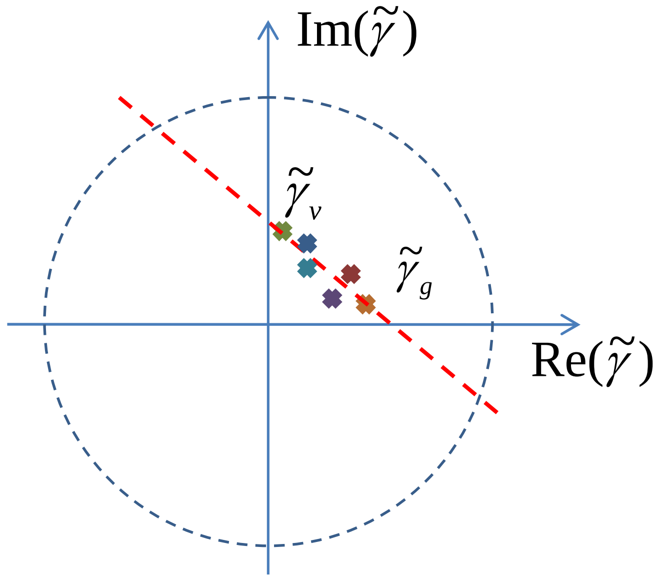
$\rightarrow \tilde{\gamma}$

Random Volume over Ground Model

Inversion using PALSAR data

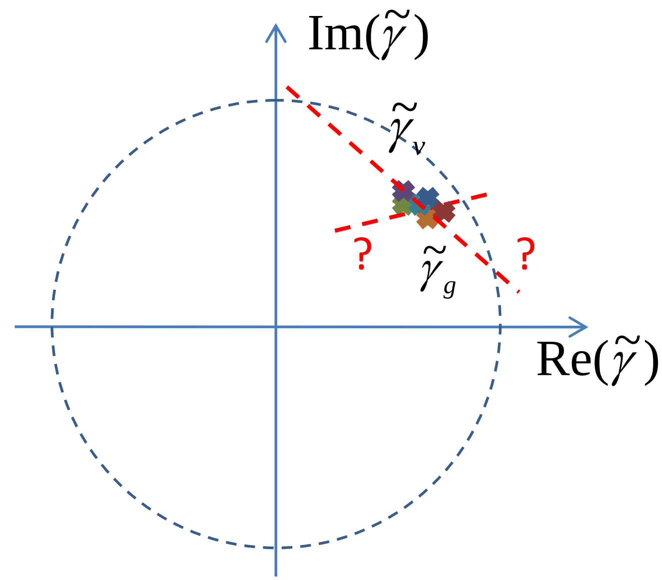
LARGE BASELINE
(>600m)

High decorelation



SMALL BASELINE
(<300m)

Line fitting fails



PolInSAR Scattering Model

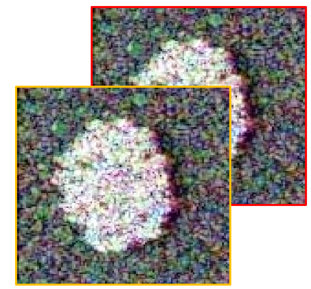
Extensive parametric analysis

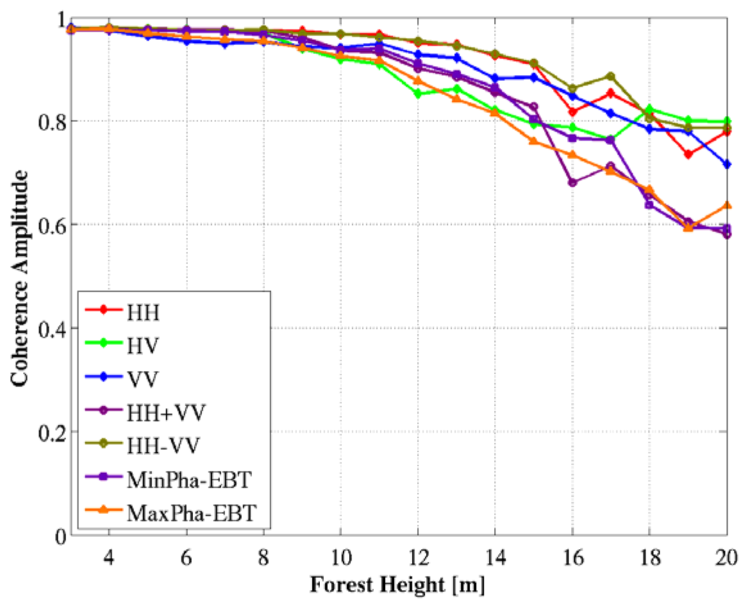
→PolSARProSIM:

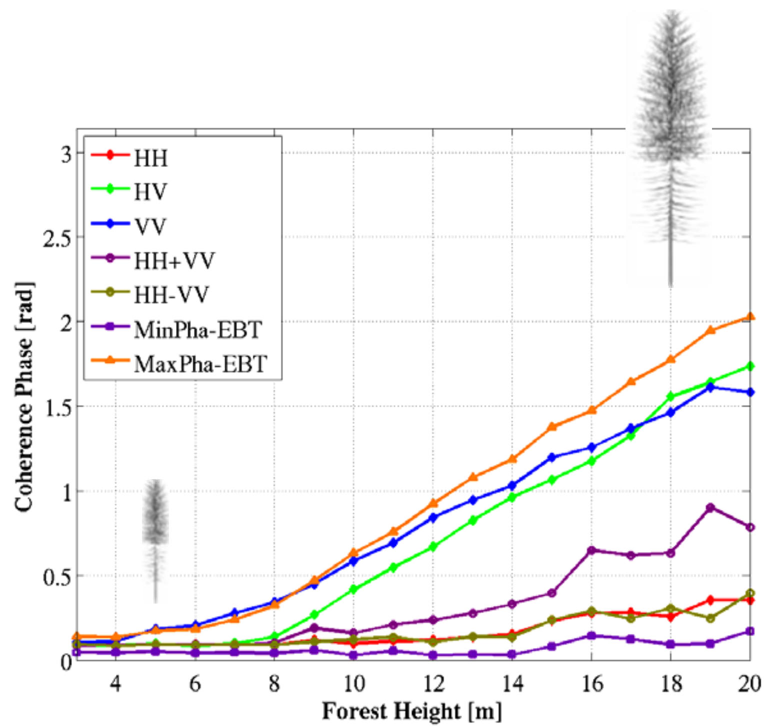
- PolInSAR scattering model (Williams, 2006)
- Fully coherent SAR simulation

→ Input Parameters:

- Acquisition Geometry (altitude, baseline, inc. angle)
- Forest (height, density, tree type)
- Soil (roughness, moisture, slope)







PolSARproSIM

Extensive parametric analysis

→ **Bio-physical parameters that impact on the PolInSAR coherence**

1. **Tree height**
2. **Azimuth terrain slope**
3. **Forest density**

→

PolInSAR coherence

$$\tilde{\gamma}$$

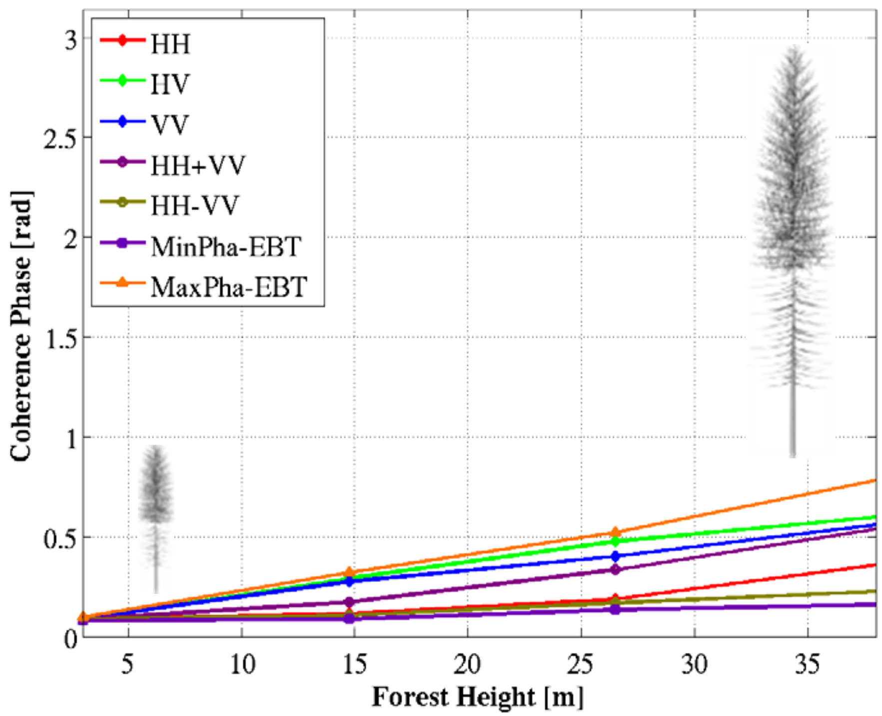
→ **Baseline and incident angle known from the acquisition information**

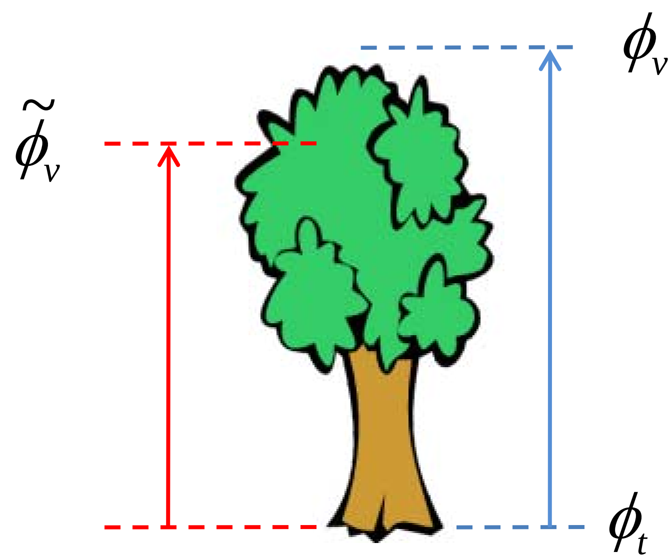
Model Analysis

Coherence vs Vegetation Height

→ Simulated scenario:

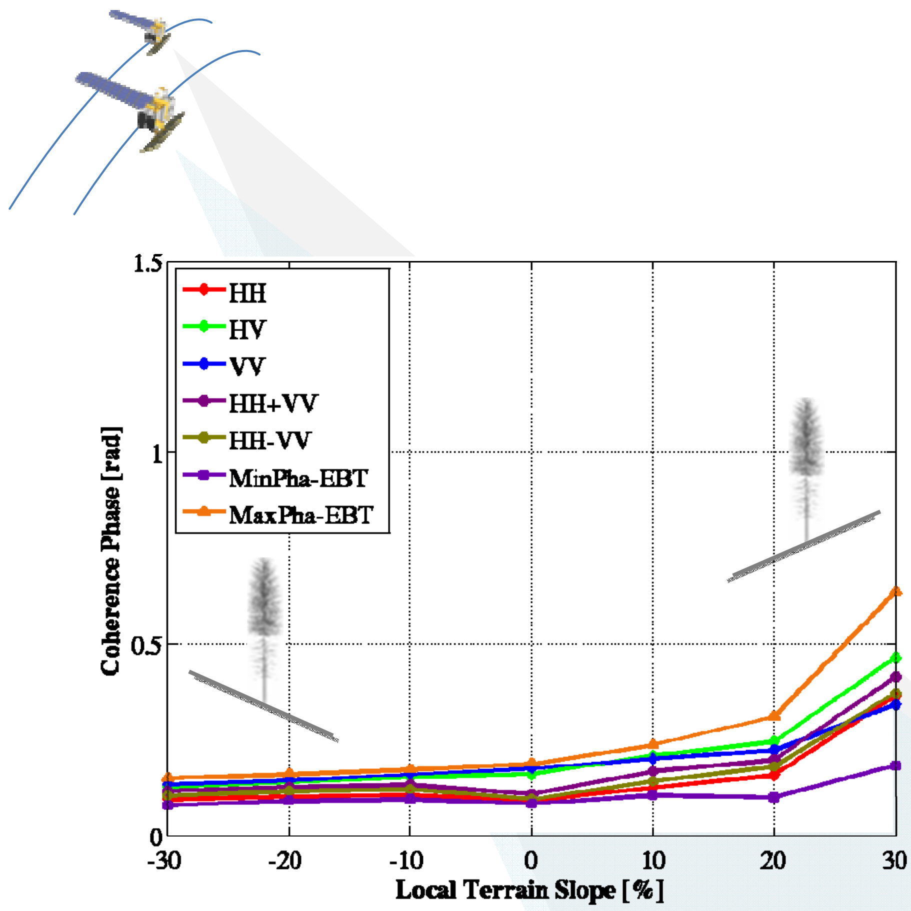
- ALOS/PALSAR
- Baseline 100 m

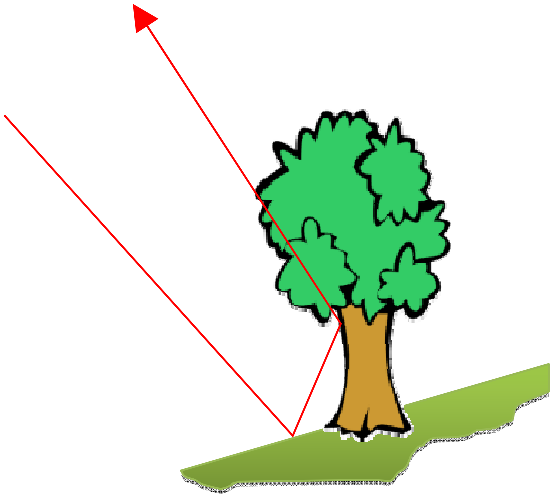


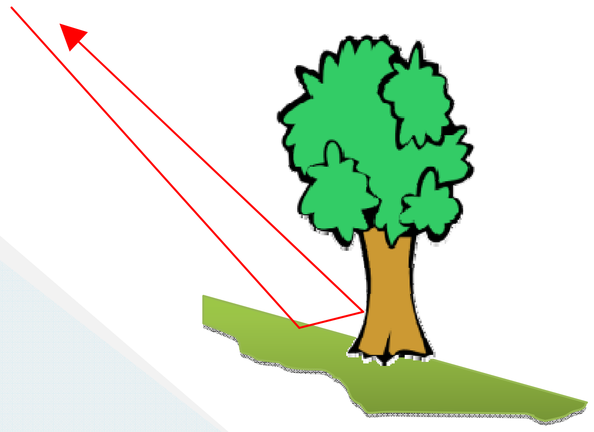


Model Analysis

Coherence vs Local Terrain Slope

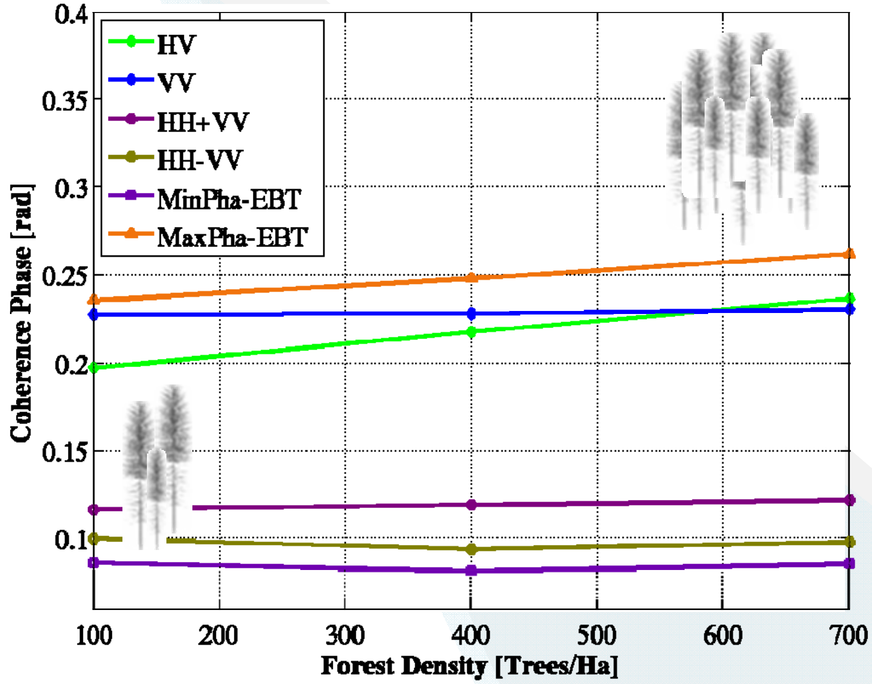


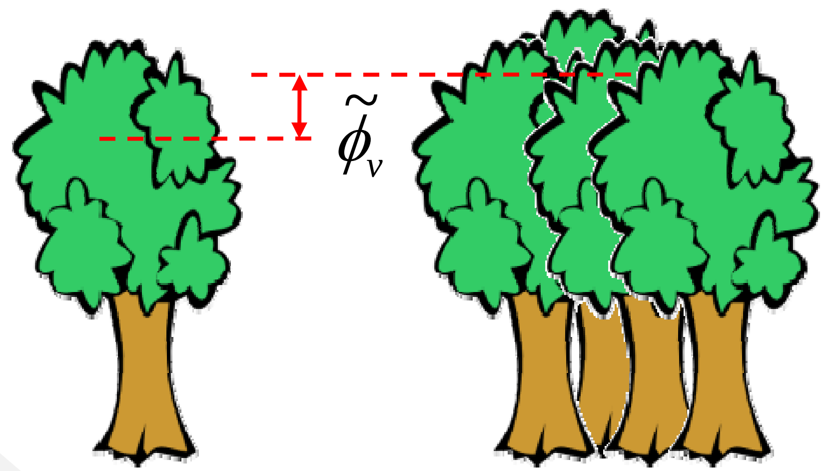




Model Analysis

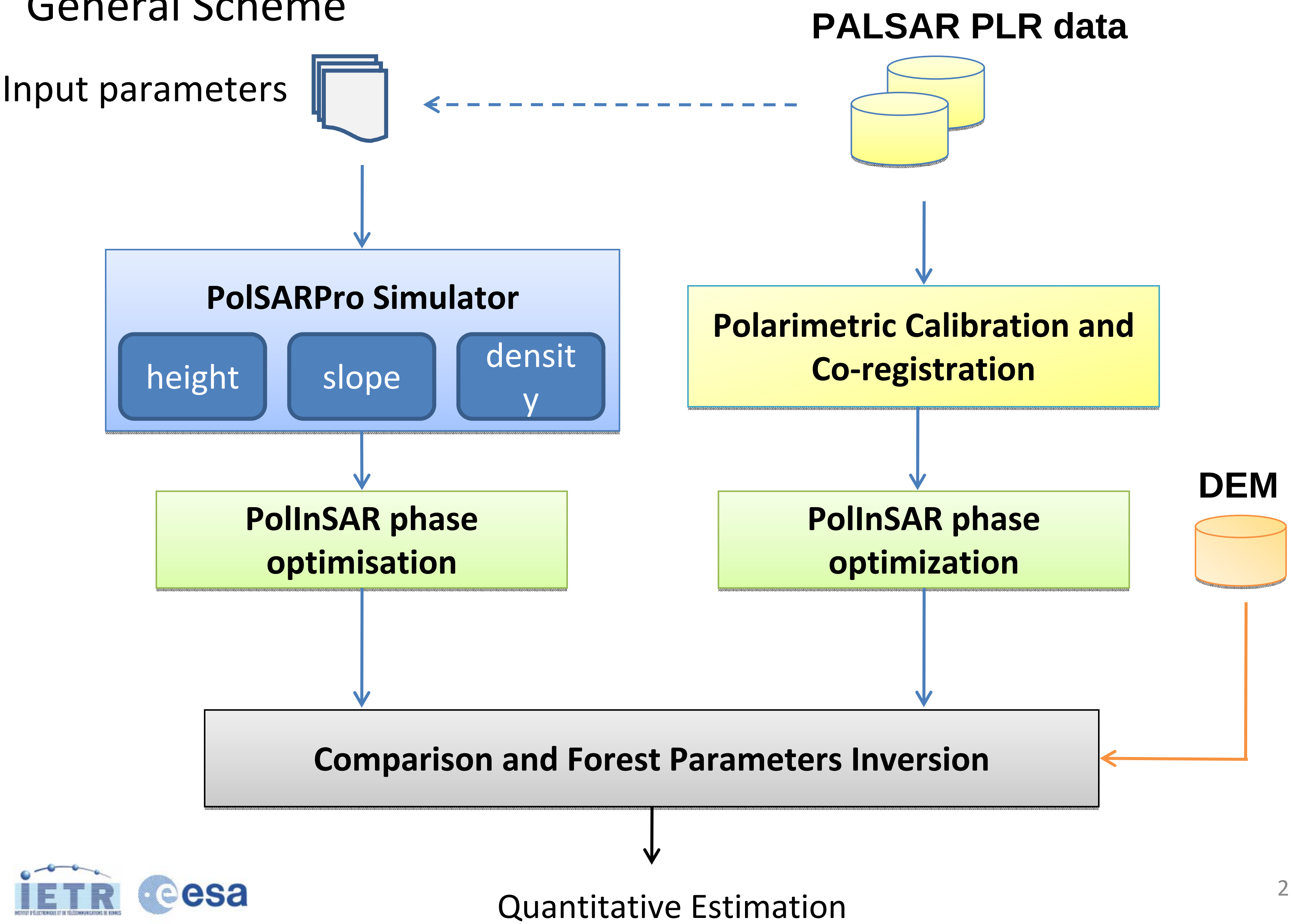
Coherence vs Forest Density





Proposed Methodology

General Scheme



Proposed approach VS RVoG

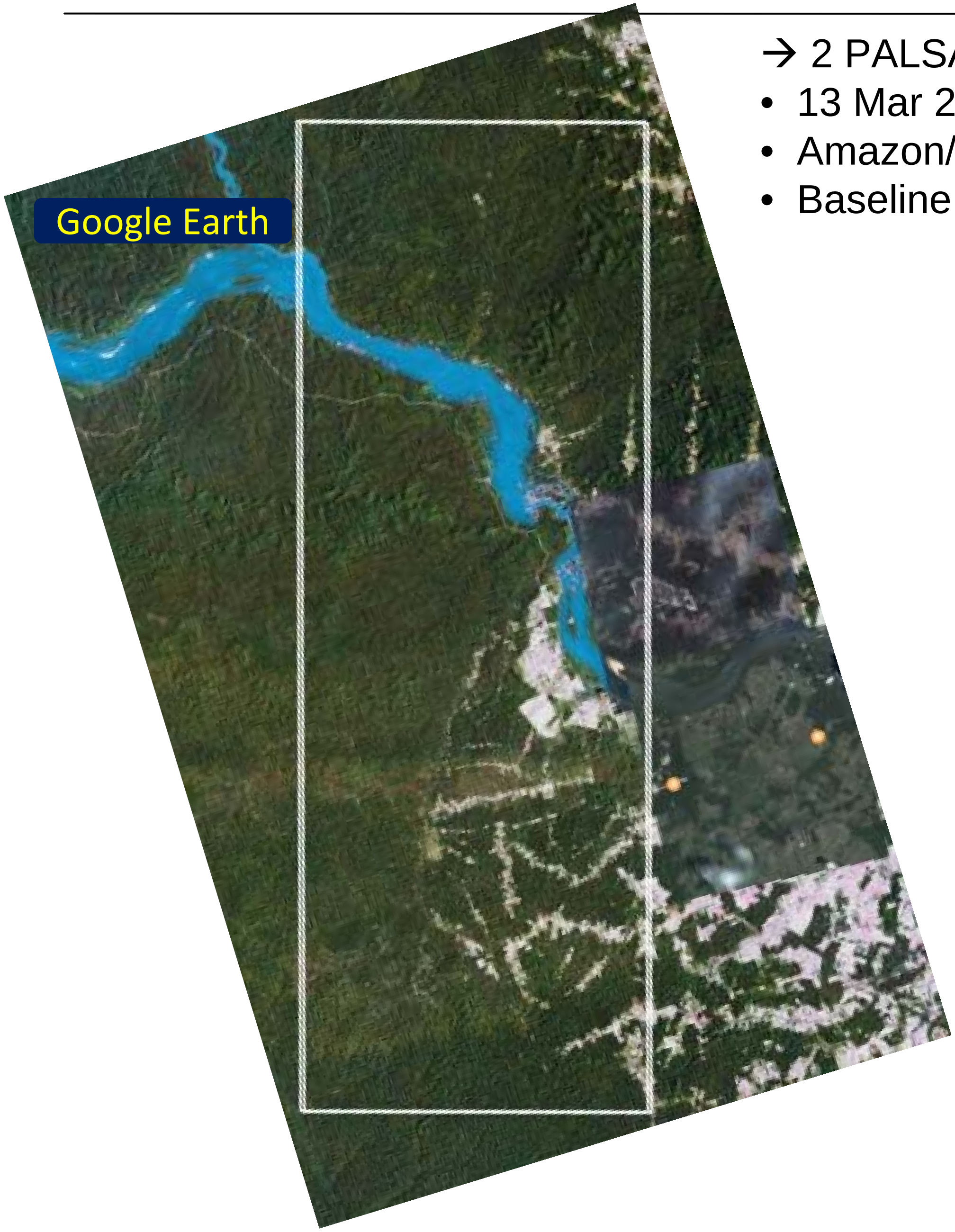
Forest height estimation

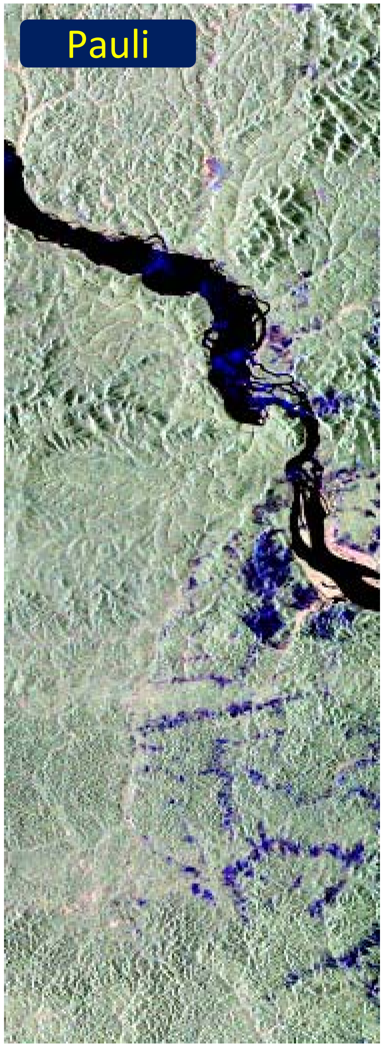
Our approach	RVoG inversion
Coherent scattering model	Not coherent scattering model
Slow in computing the model output	Fast implementation and inversion
Model inputs are trees height, azimuth terrain slope and forest density	Model inputs are trees height, ground-to-volume ratio, canopy extinction
Inversion uses the slope information from external DEM	Fitting of the line can fail for small baseline dataset
Require the generation of LUT that depends on the baseline	Fully automatic

Results on ALOS PALSAR

→ 2 PALSAR PolInSAR acquisitions:

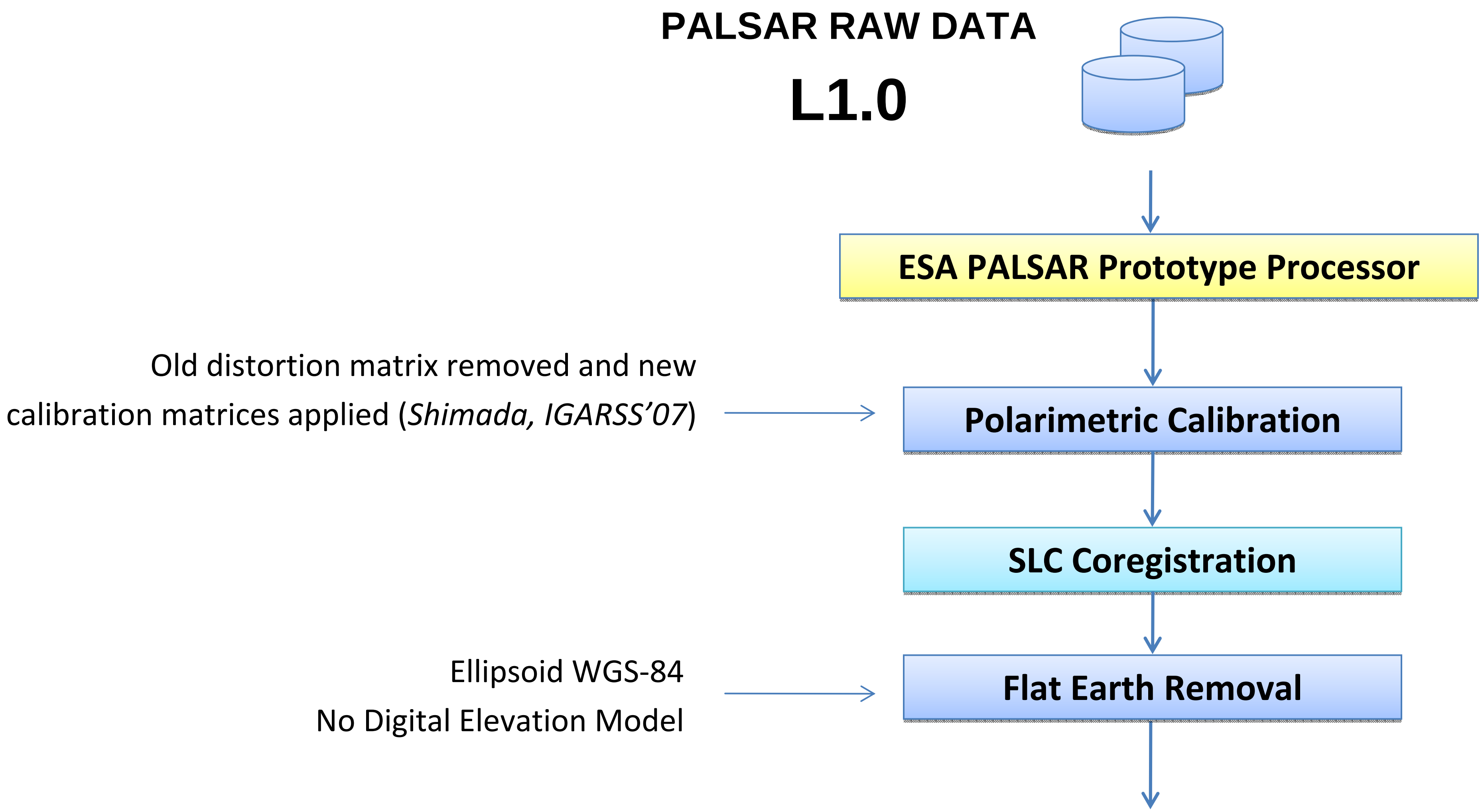
- 13 Mar 2007 and 28 Apr 2007
- Amazon/Belize (lat. -4.3°, lon. -56.3°)
- Baseline 100 m





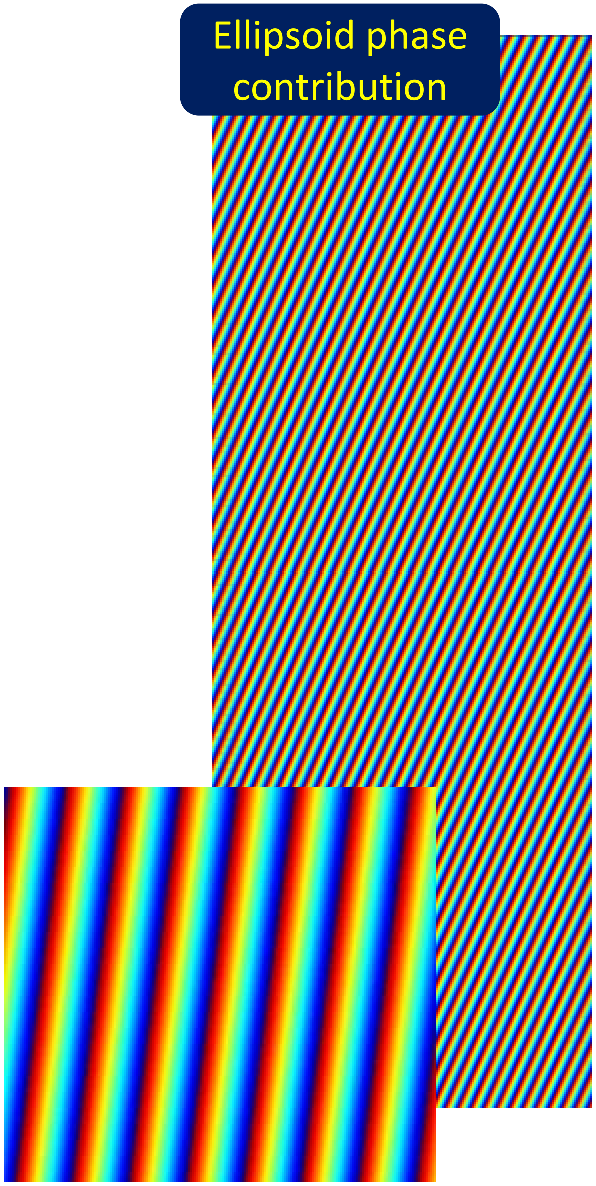
Results on ALOS PALSAR

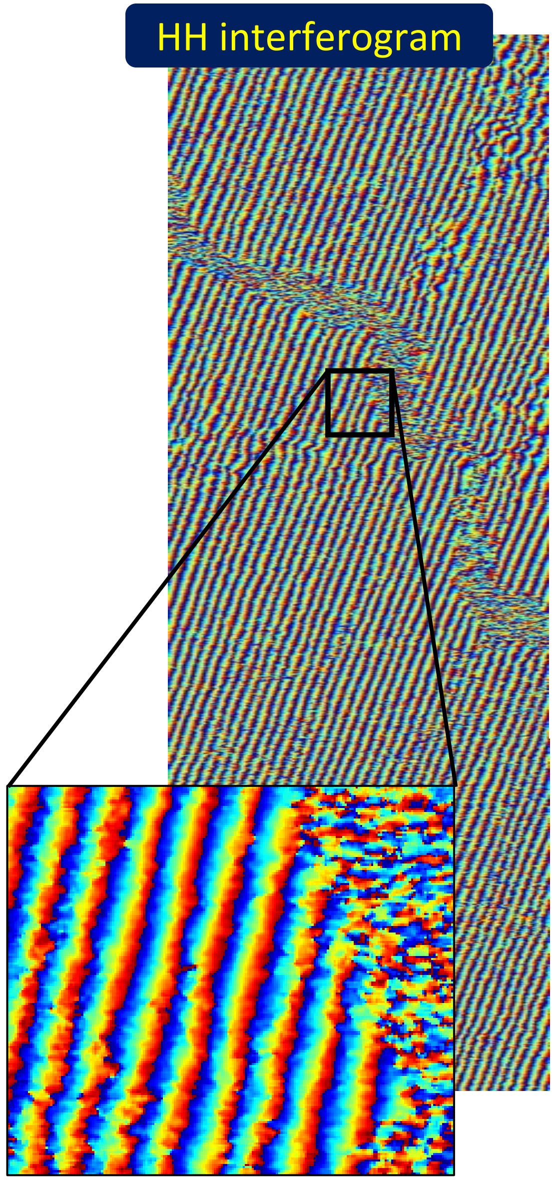
Amazon Forest



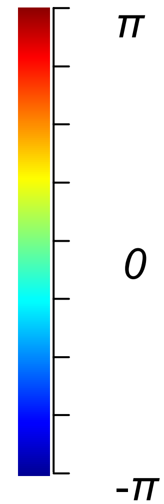
Results on ALOS PALSAR

Amazon Forest



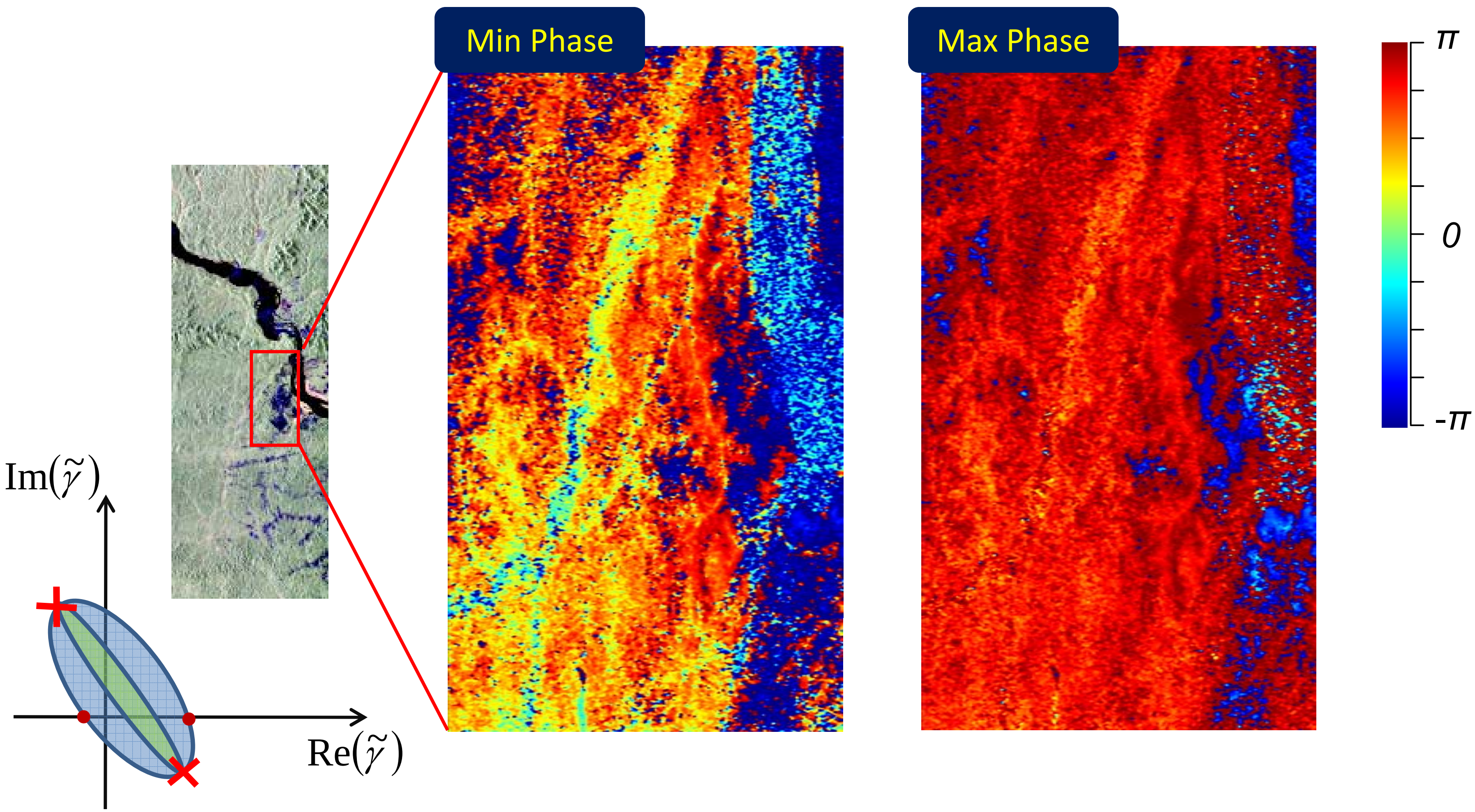


HH flattened interferogram



Results on ALOS PALSAR

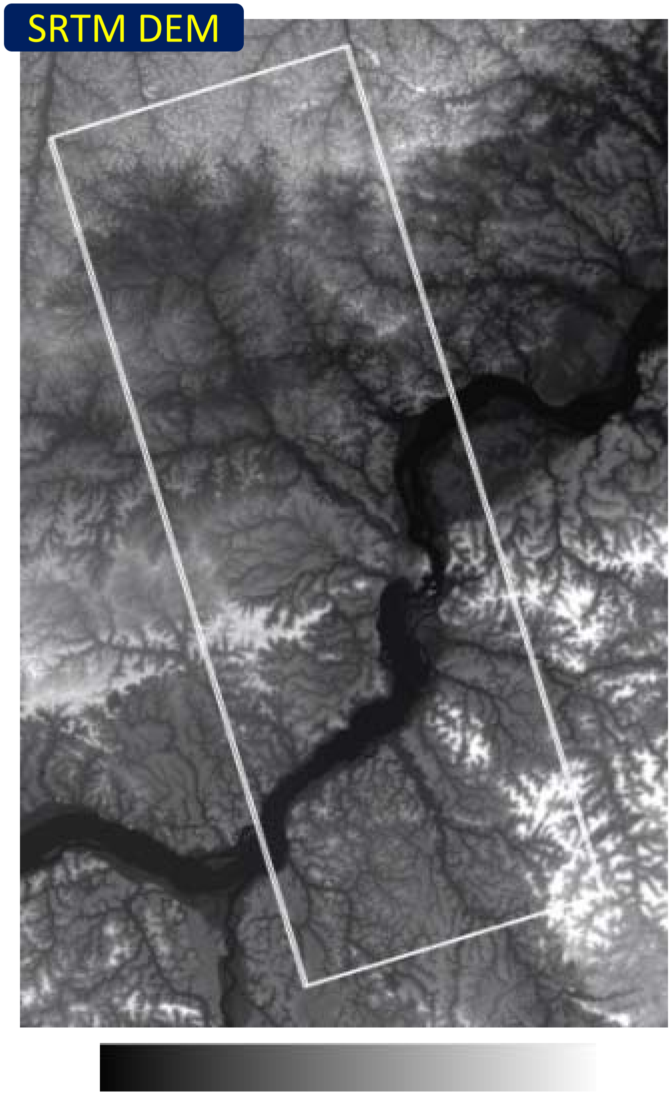
Best phase selection



Results on ALOS PALSAR

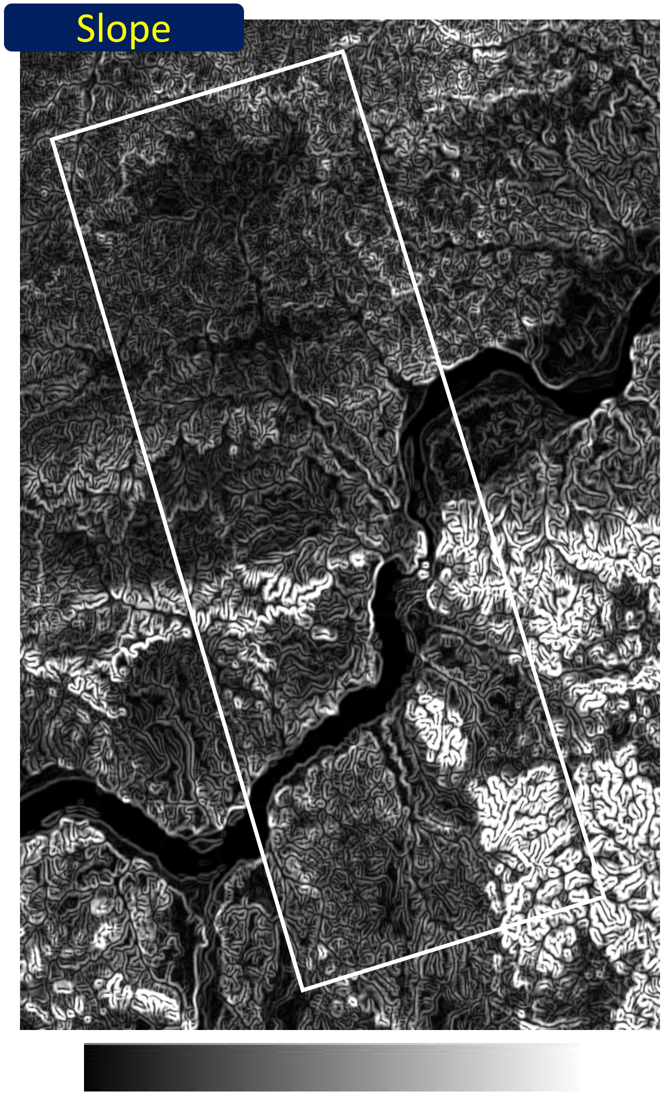
Amazon Forest

SRTM DEM

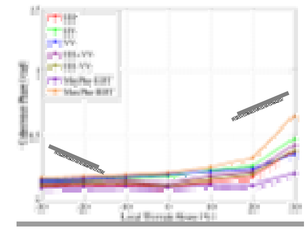


0 m 340 m

Slope



0% 30%



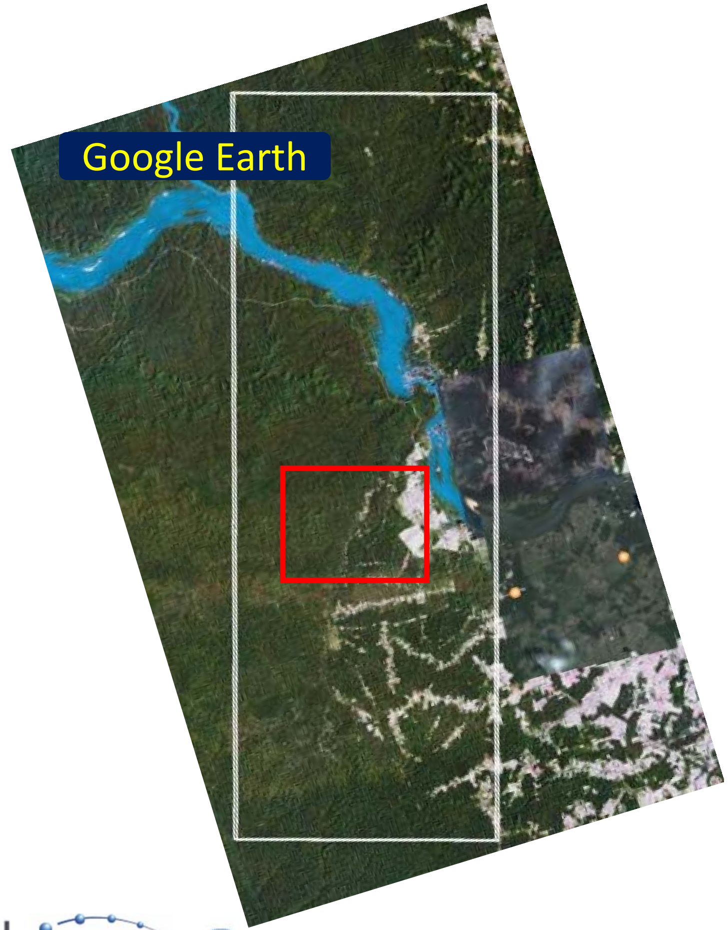
Max phase difference due to topography = 0.45 rad

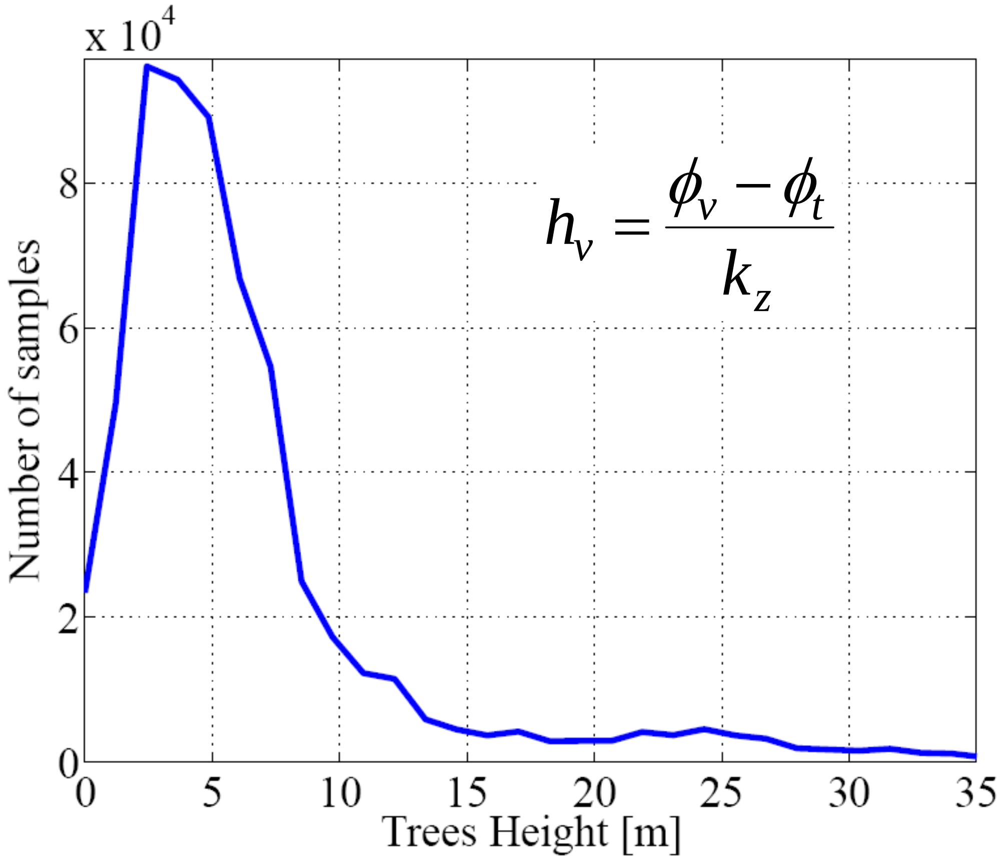
Max Error 20%

Results on ALOS PALSAR

Preliminary Inversion Example

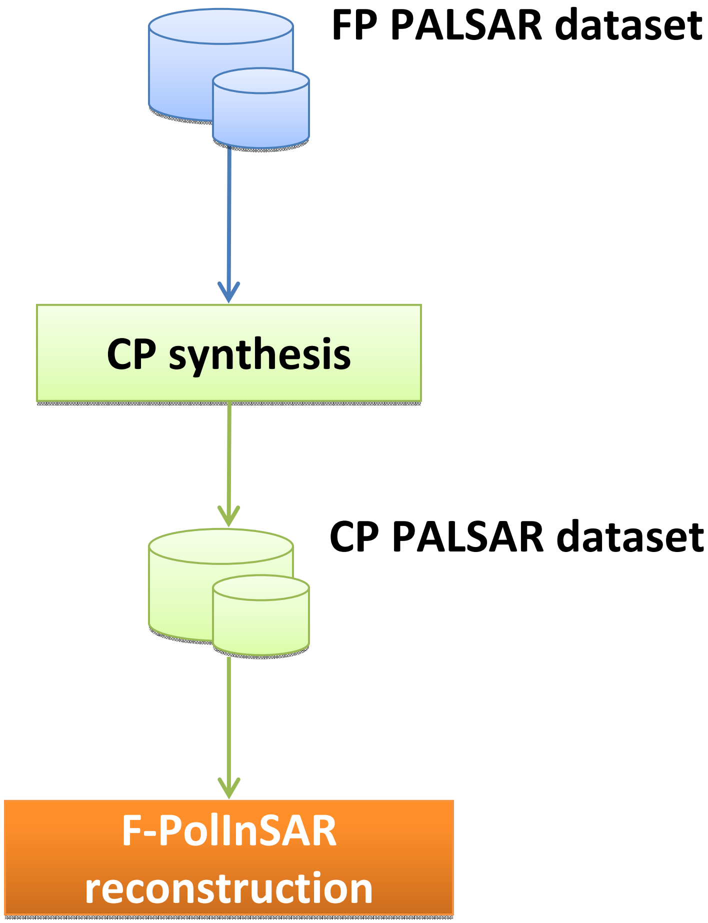
→ Vegetation height estimated from a vegetated area of the Amazon PALSAR dataset

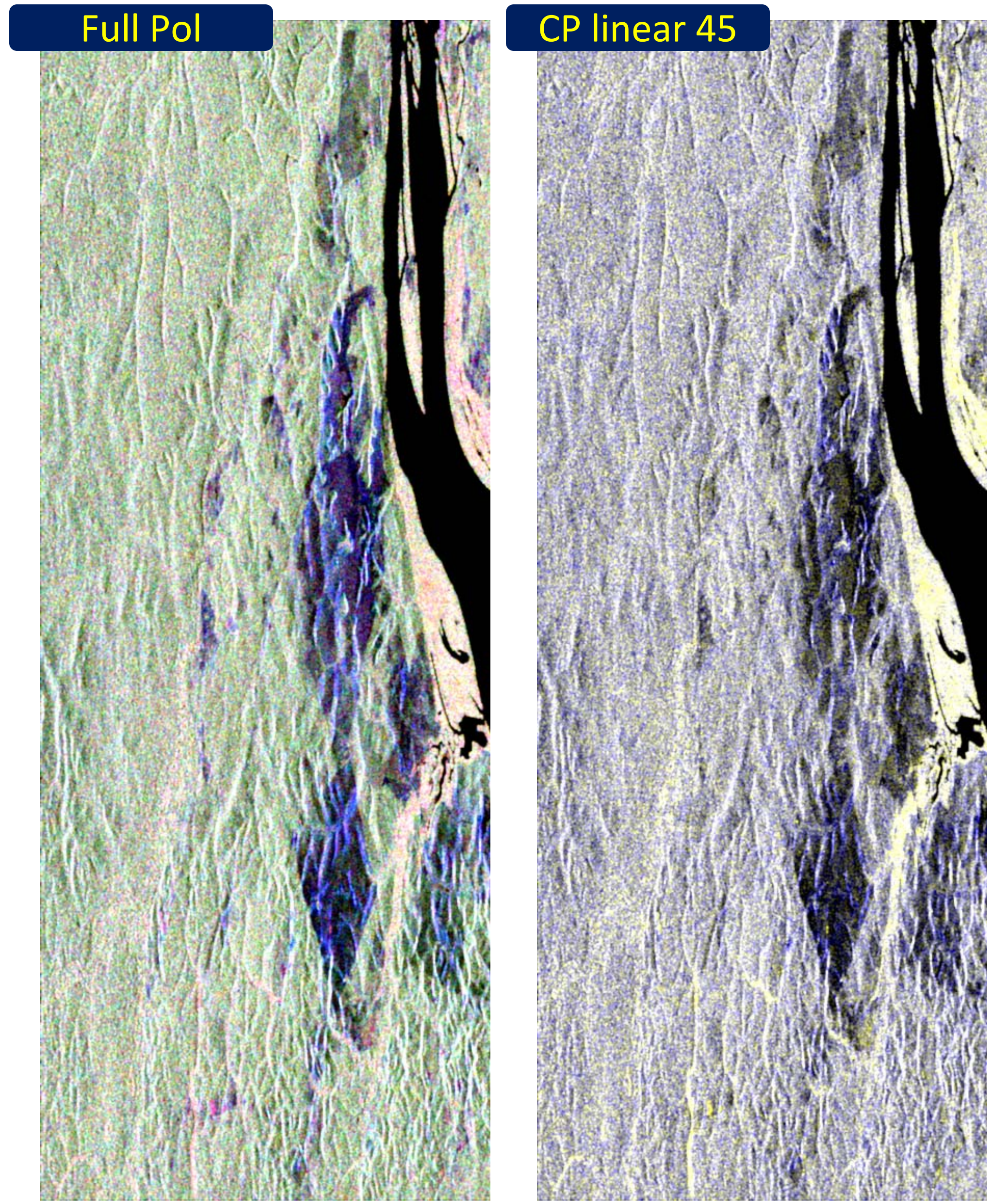




Comparison with *Compact* Polarimetric SAR Interferometry

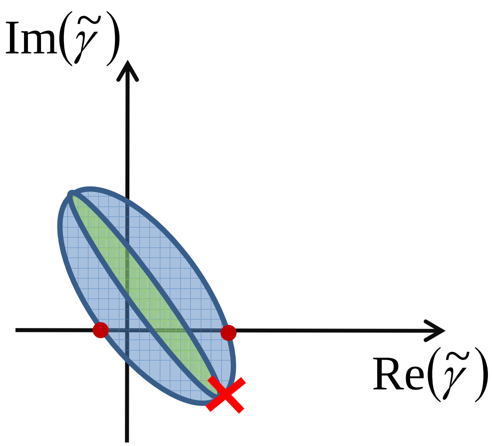
Results: Compact PolInSAR

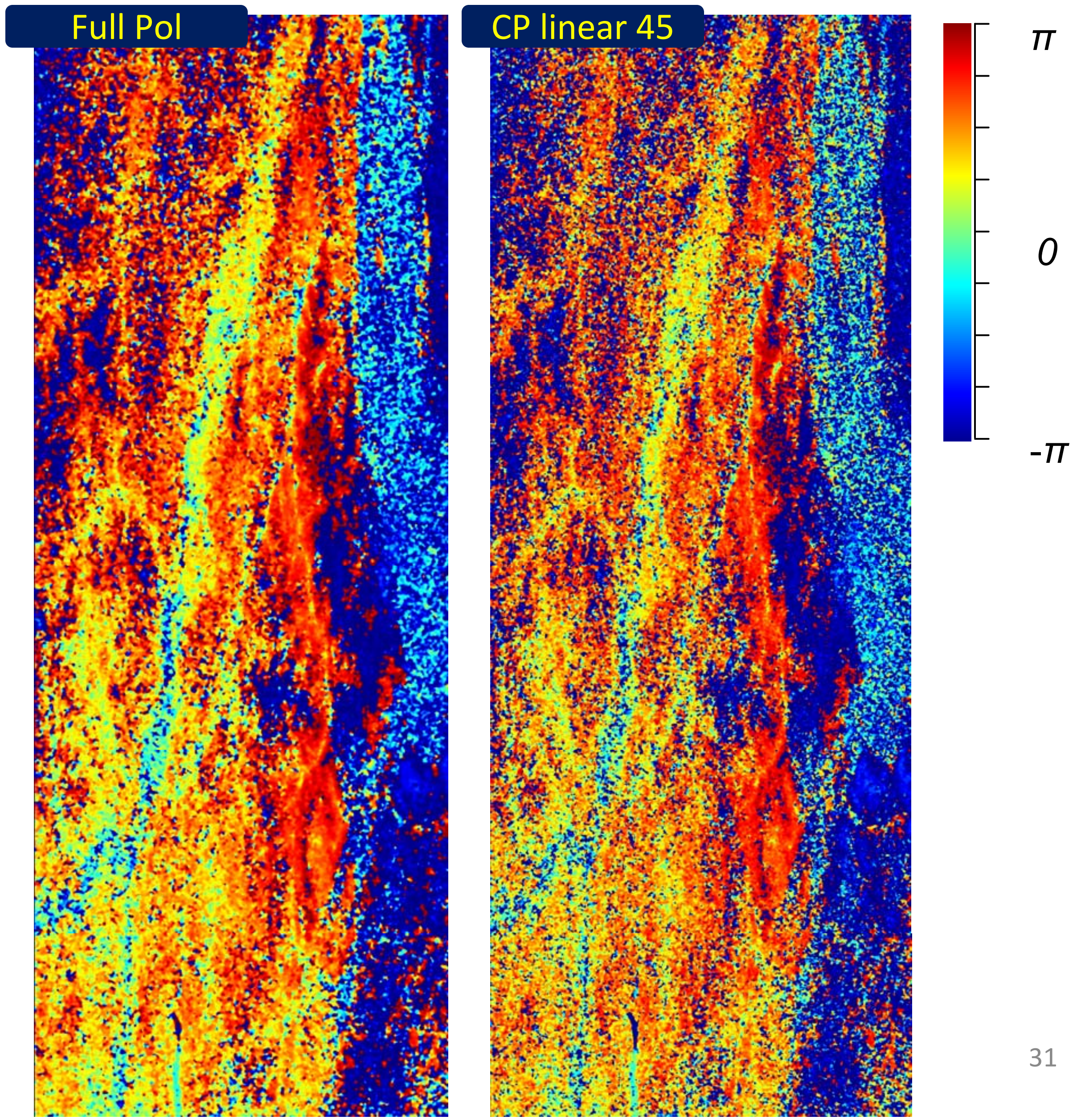




Results: Compact PolInSAR

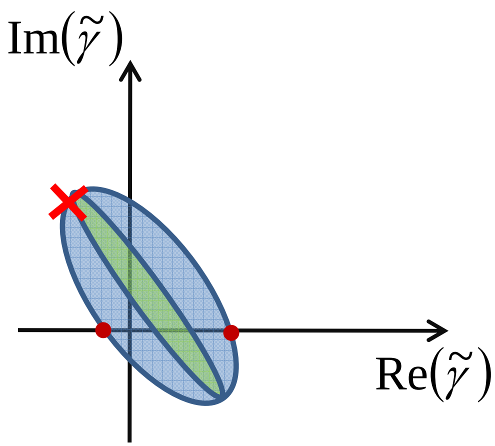
Min Phase

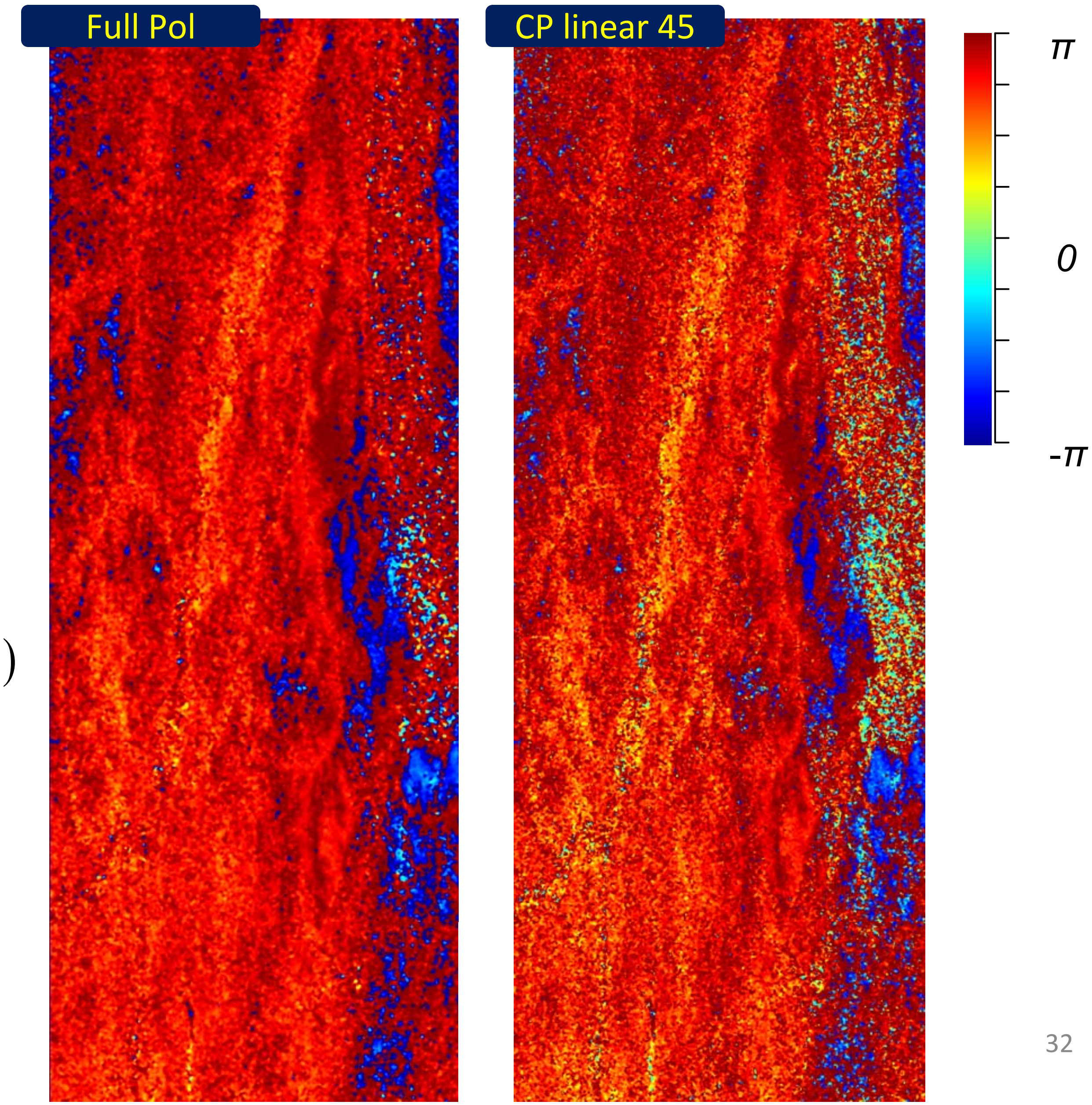




Results: Compact PolInSAR

Max Phase

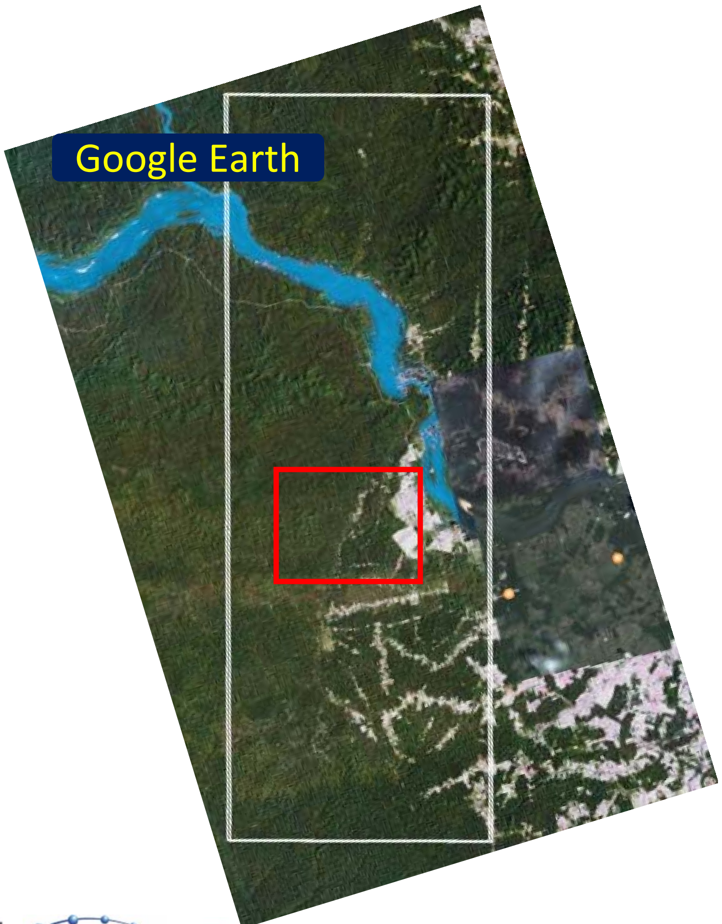


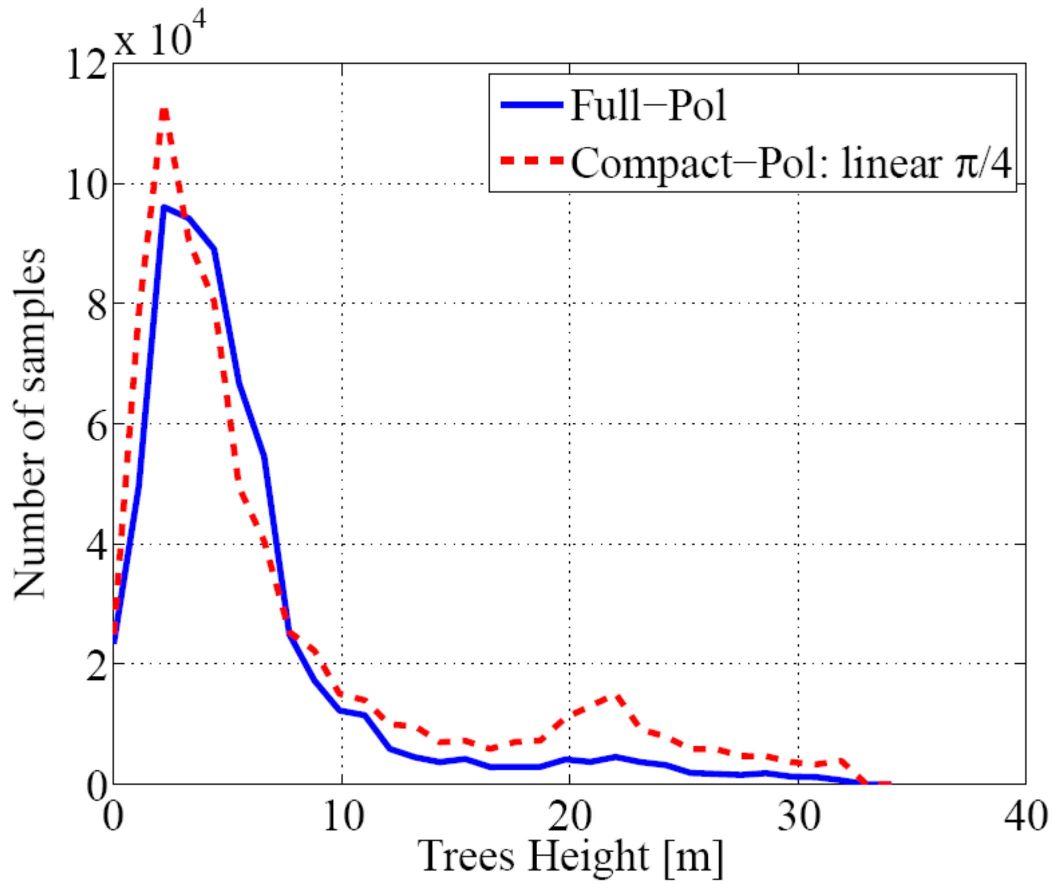


Results on ALOS PALSAR

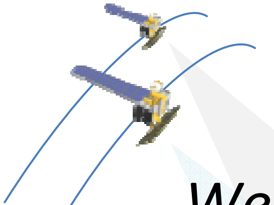
Preliminary Inversion Example

→ Vegetation height estimated from a vegetated area of the Amazon PALSAR dataset





Conclusions



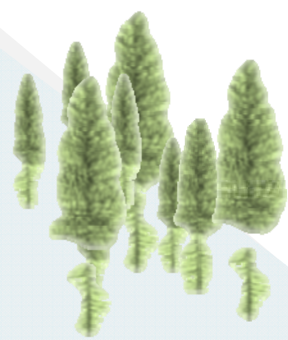
We have shown the performance of Compact PolInSAR using a new forest height estimation approach suitable for PALSAR data

→ Forest height estimation

- Based on tree height, terrain slope and forest density.
- Suitable for small baseline dataset (less decorelation impact)
- Require the generation of data-dependent LUT using PolSARProSIM

→ Compact PolInSAR

- CP linear is feasible for forest height estimation
- CP circular still not investigated

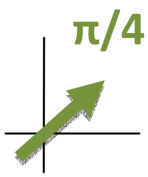


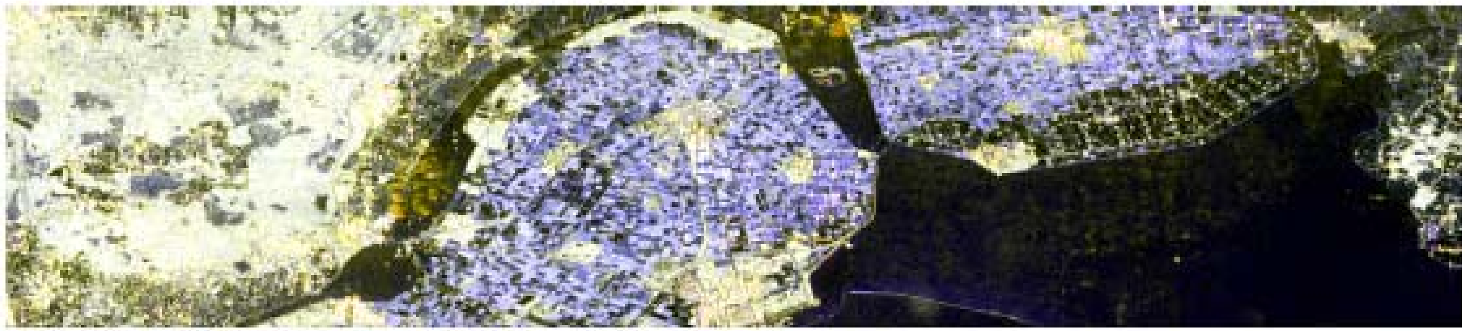
Reconstructed FP information

PALSAR example (Flevoland)

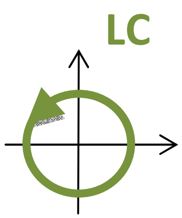
→ Pauli Decomposition: **HH+VV**, **HH-VV**, **HV**

Compact-Pol





Compact-Pol



Full-Pol