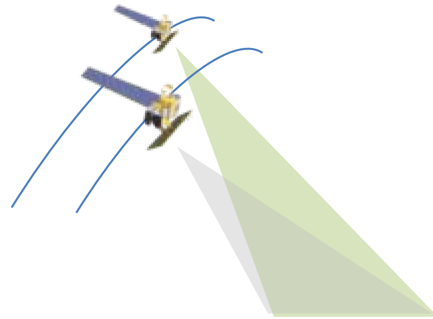

Compact Polarimetric SAR Interferometry: observations and reconstruction algorithms

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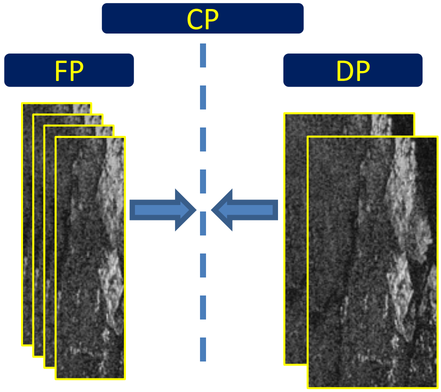
PolInSAR Workshop 26-31 Jan 2008

Outline

- Introduction
- *Compact* polarimetric SAR interferometry
- Results of the PolInSAR reconstruction
  - ESAR airborne data
  - PALSAR space borne data
- Synthesis of compact-pol data
  - Effects of the SAR processor
  - Effects of the SAR receiver
- Conclusions

Introduction

Compact Polarimetry

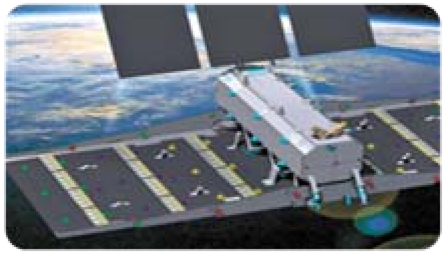


- → Compact polarimetry
  - → Compromise between full-pol and dual-pol
  - → Trasmits the same polarization (not H or V) at each PRF

- → Main characteristics

	Full-pol	Compact-pol	Dual -pol
Swath width	half	double	double
Data volume	double	half (?)	half
Information	double	hybrid	half

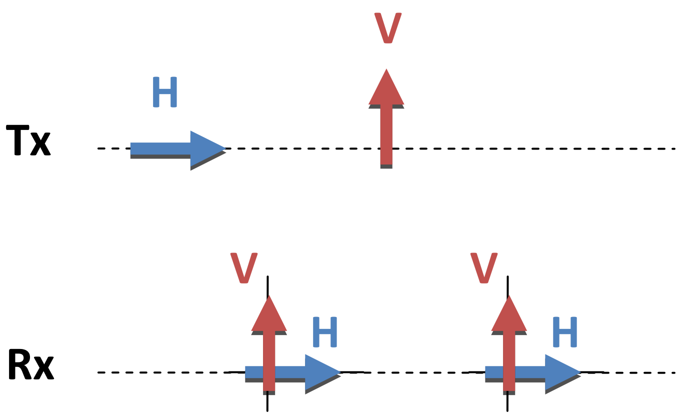
- → Compact SAR
  - → No airborne campaign or space borne missions
  - → Future Argentinean satellite SAOCOM
  - → ALOS-2?



Introduction

Compact Polarimetry VS Full Polarimetry

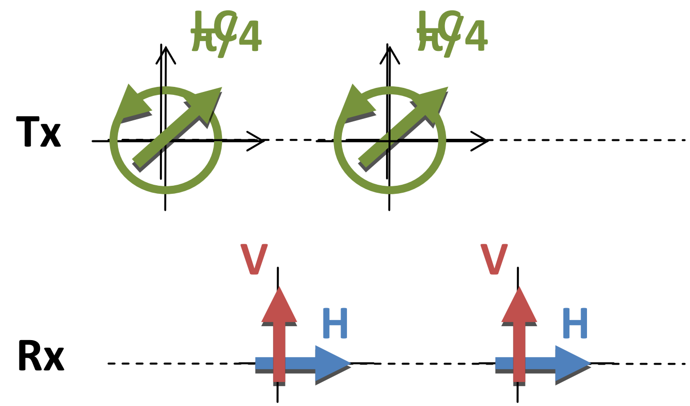
Full Polarimetry (FP)



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

Compact Polarimetry (CP)

e.g. π/4 mode



$$k_{\pi/4} = \begin{pmatrix} \mathbf{S}_{H(\pi/4)} \\ \mathbf{S}_{V(\pi/4)} \end{pmatrix} = \begin{pmatrix} S_{HH} + \mathbf{S}_{HV} \\ \mathbf{S}_{VV} + \mathbf{S}_{HV} \end{pmatrix}$$

A compact-pol dataset can be easily simulated from a full-pol dataset

Objective of the work

To compare the PolInSAR performance of Compact-Pol with Full-Pol using L-band data

Compact PolSAR/PolInSAR

L-band data
Forest height retrieval

Full PolSAR/PolInSAR

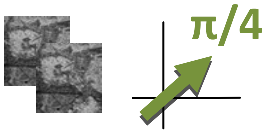
How

Reconstruction of the pseudo full PolInSAR information aims

- to extract the HH-HV-VV channels from compact-pol data
- to easily compare them with the full-pol channels

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

$$T_3$$

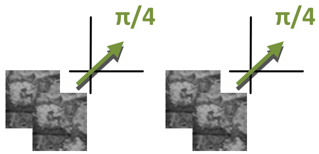
PolSAR algorithms

→ 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

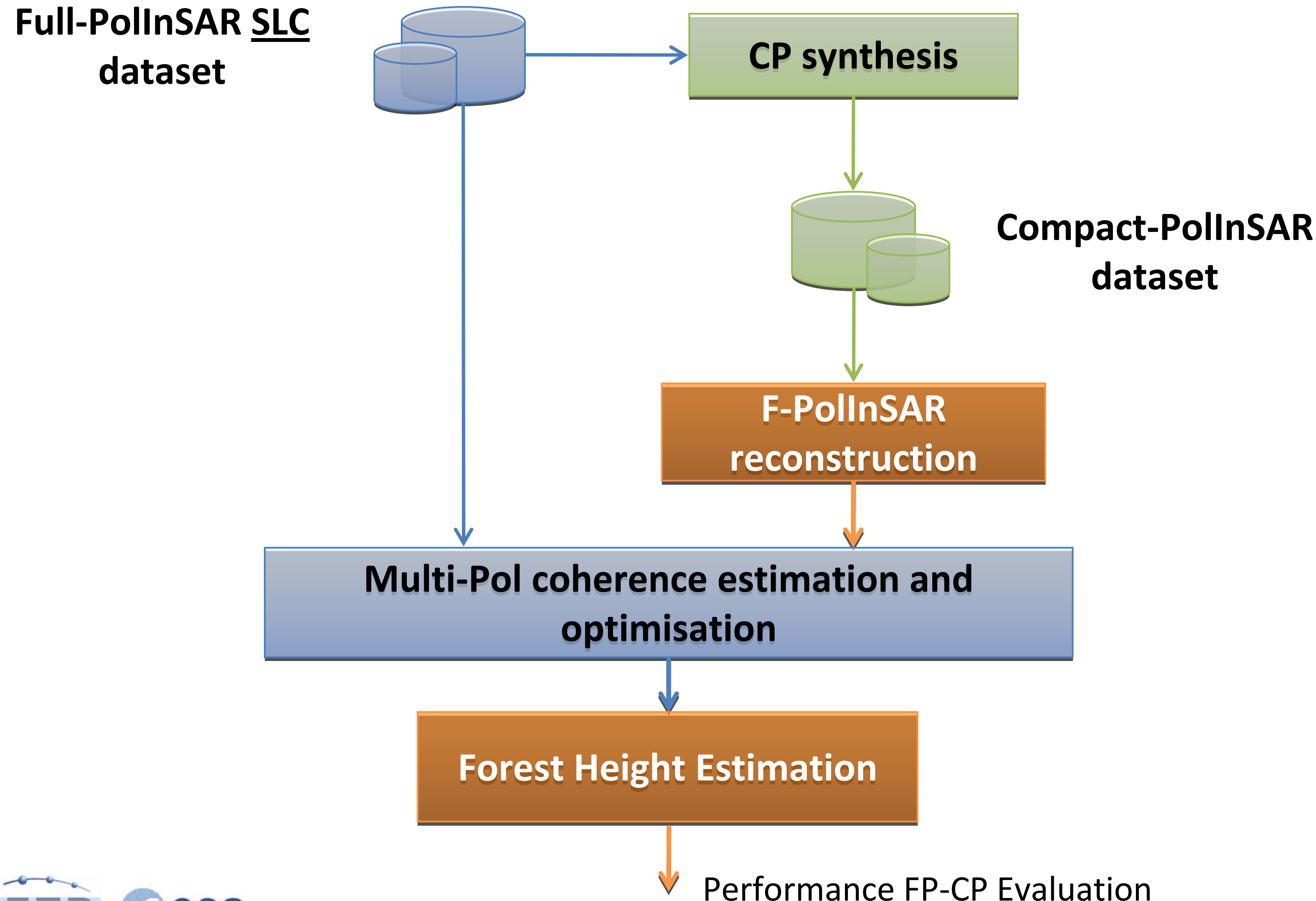
$$T_6^{\text{ref}}$$

Cross-coherency matrix:

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

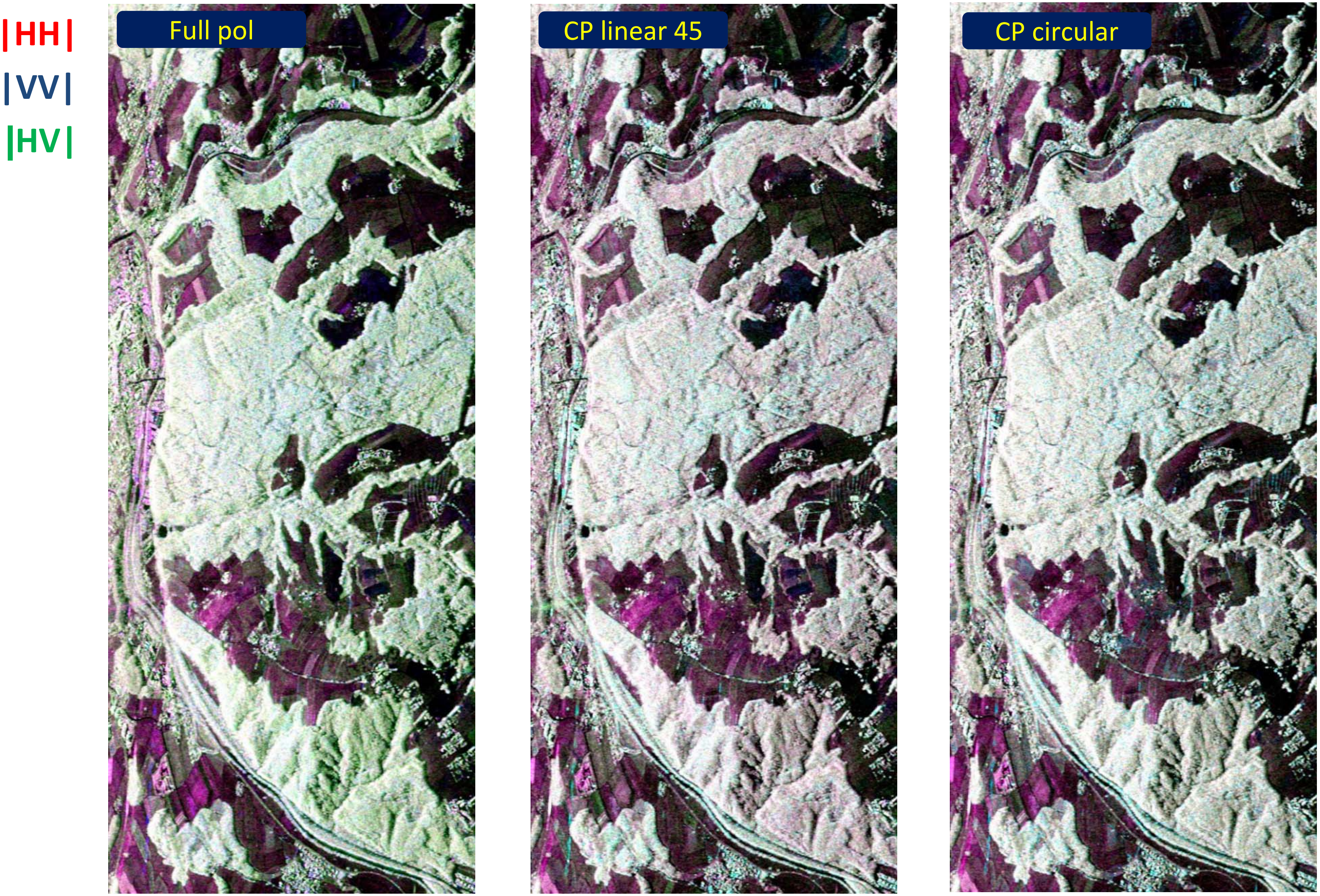
Compact PolInSAR

Performance Evaluation Scheme



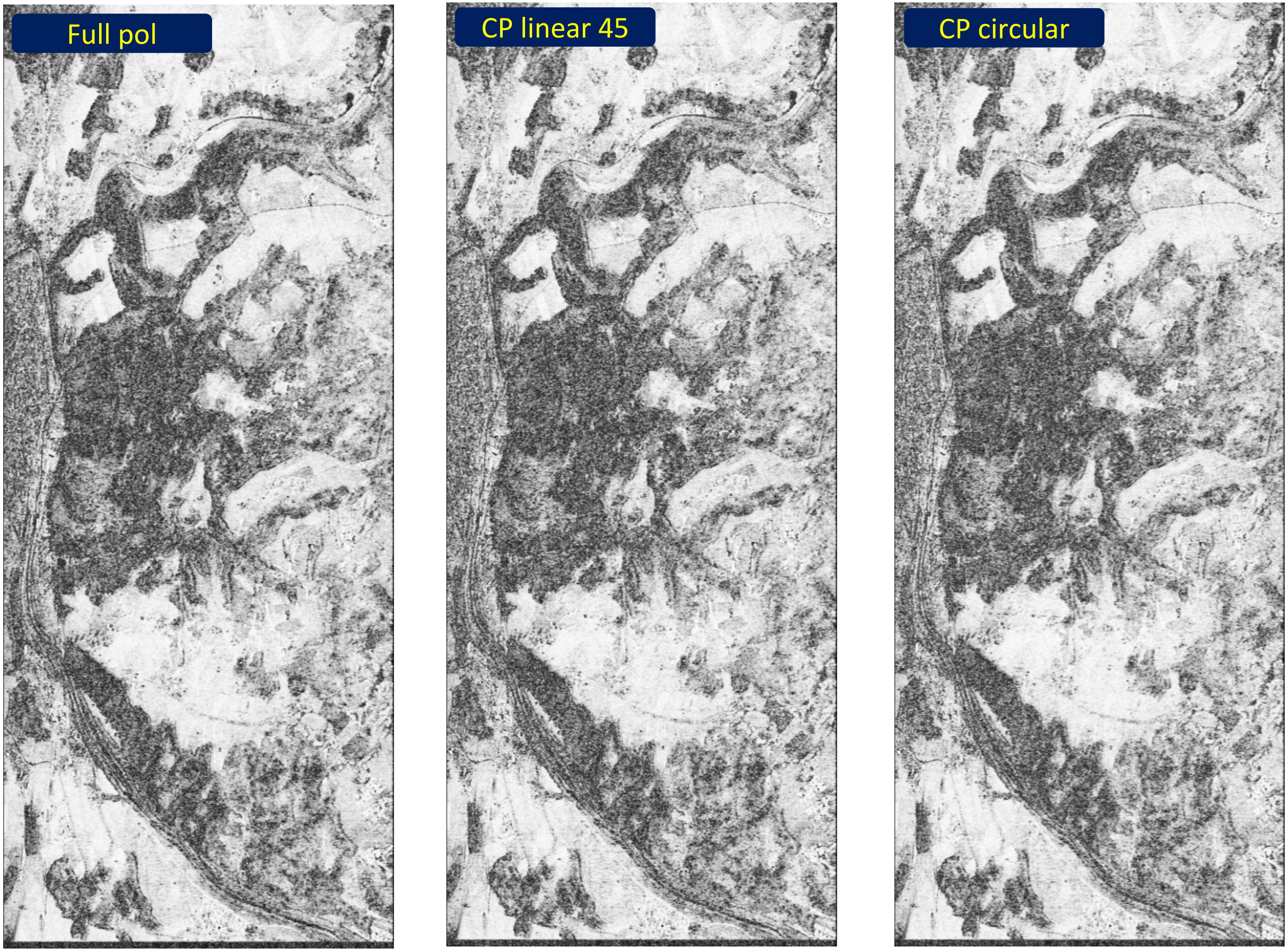
Reconstructed FP information

Airborne E-SAR data (Traunstein, Germany)



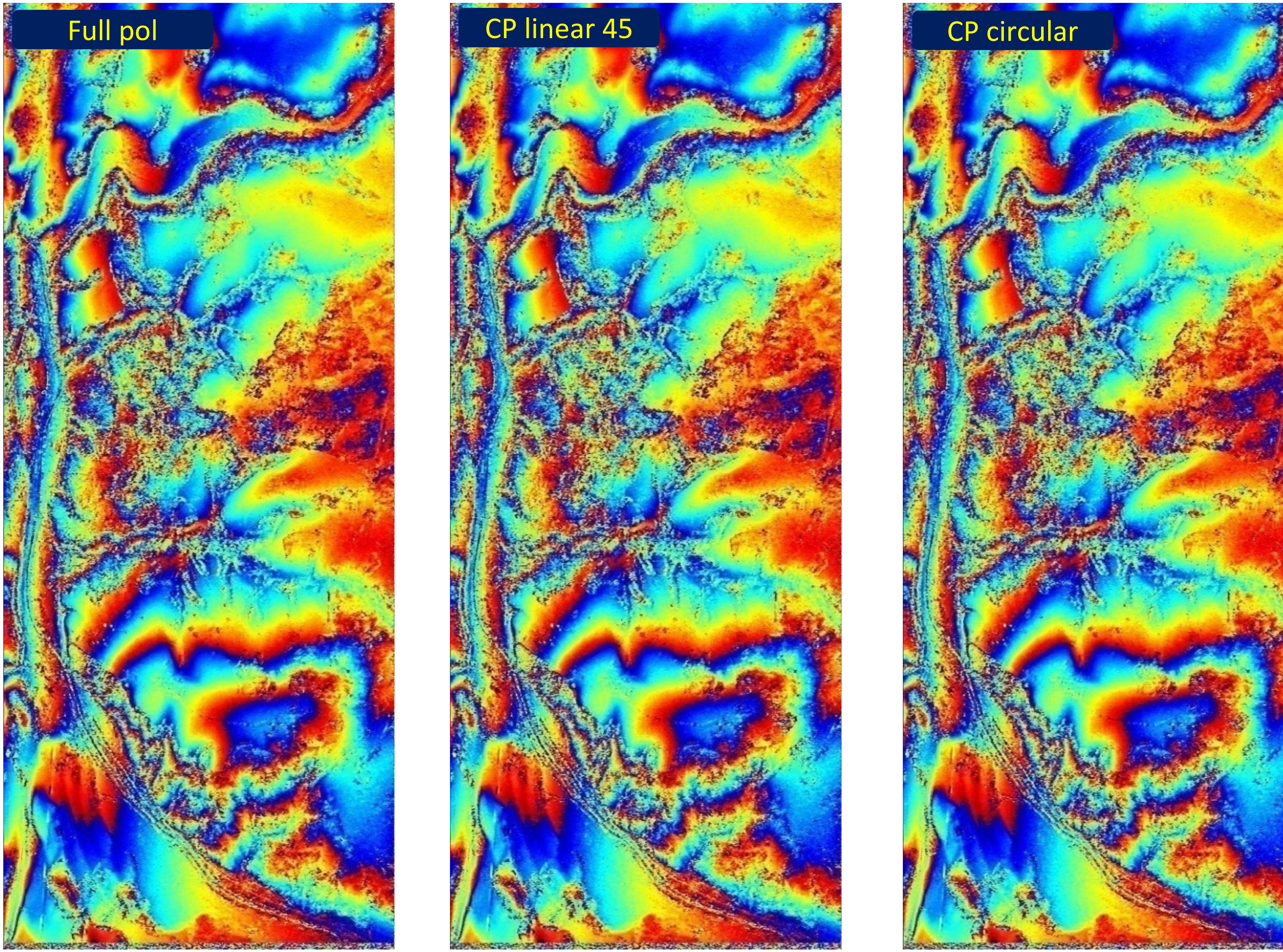
Reconstructed PolInSAR information

Coherence magnitude (HH)



Reconstructed PolInSAR information

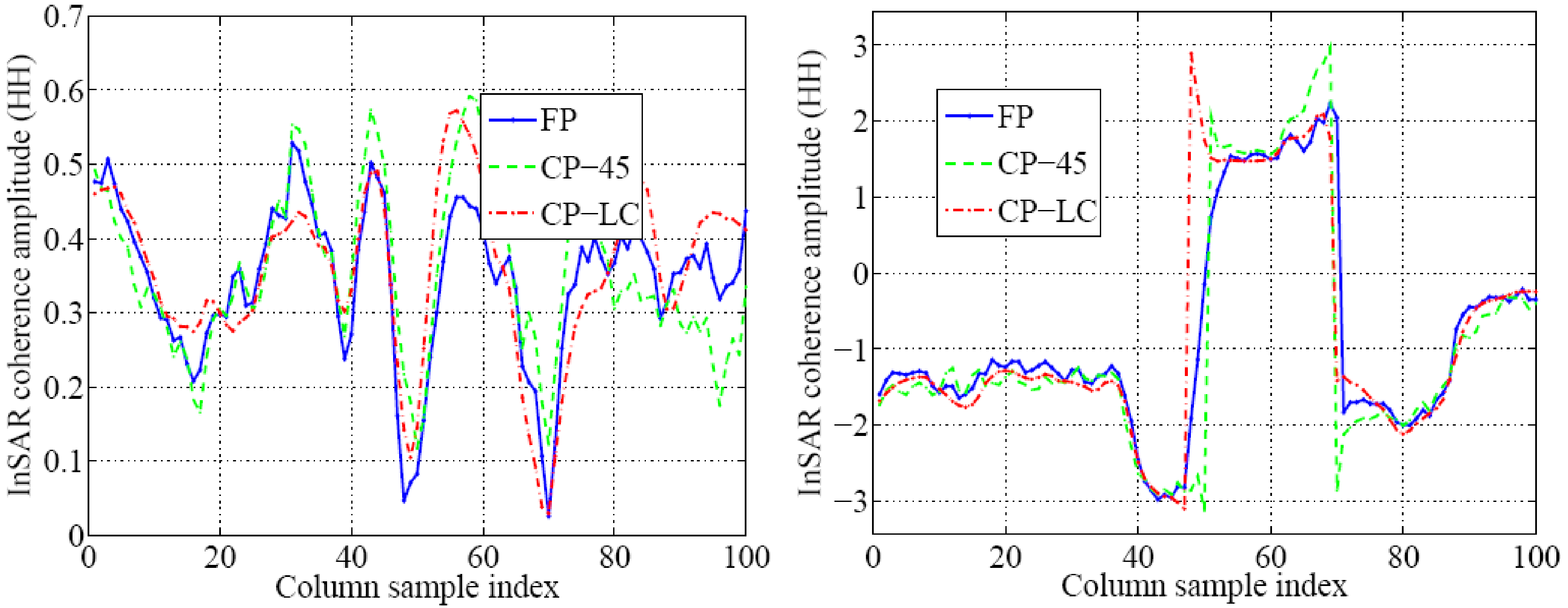
Coherence phase (HH)



Reconstructed PolInSAR information

Row profiles

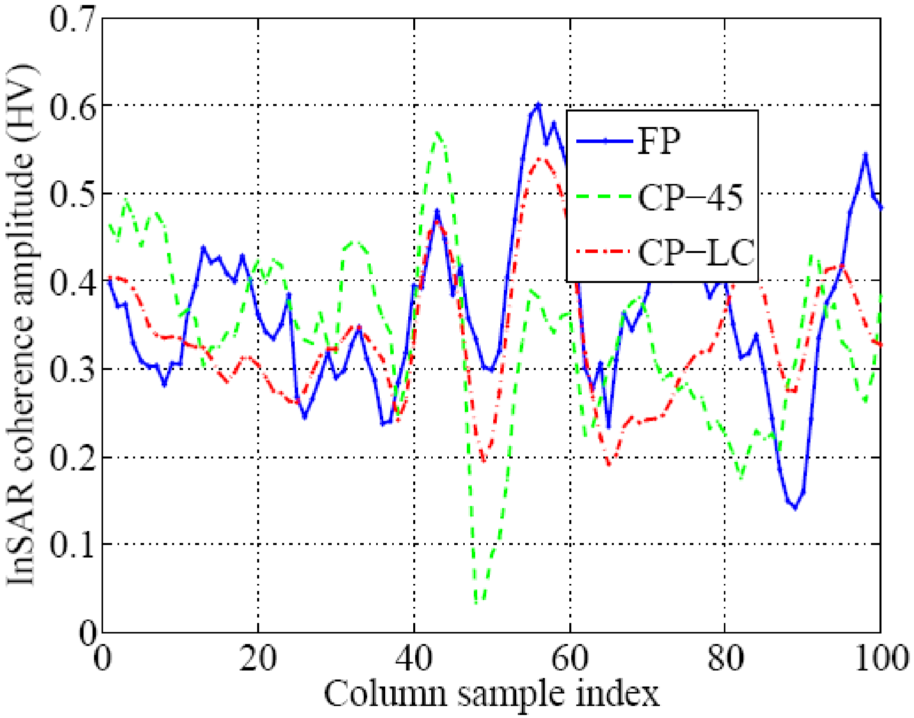
PolInSAR coherence HH

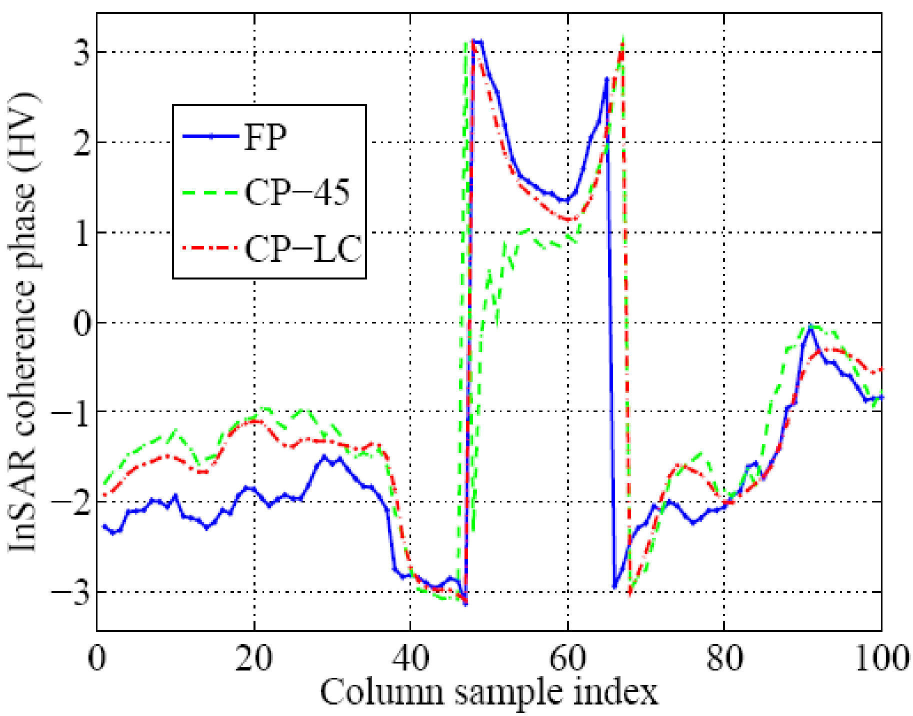


Reconstructed PolInSAR information

Row profiles

PolInSAR coherence HV

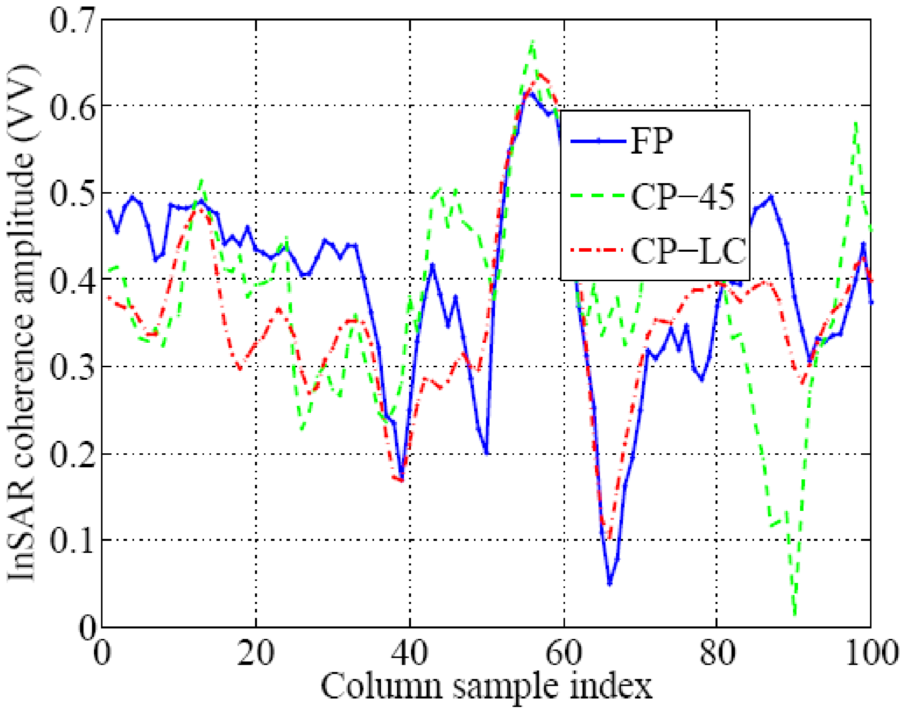


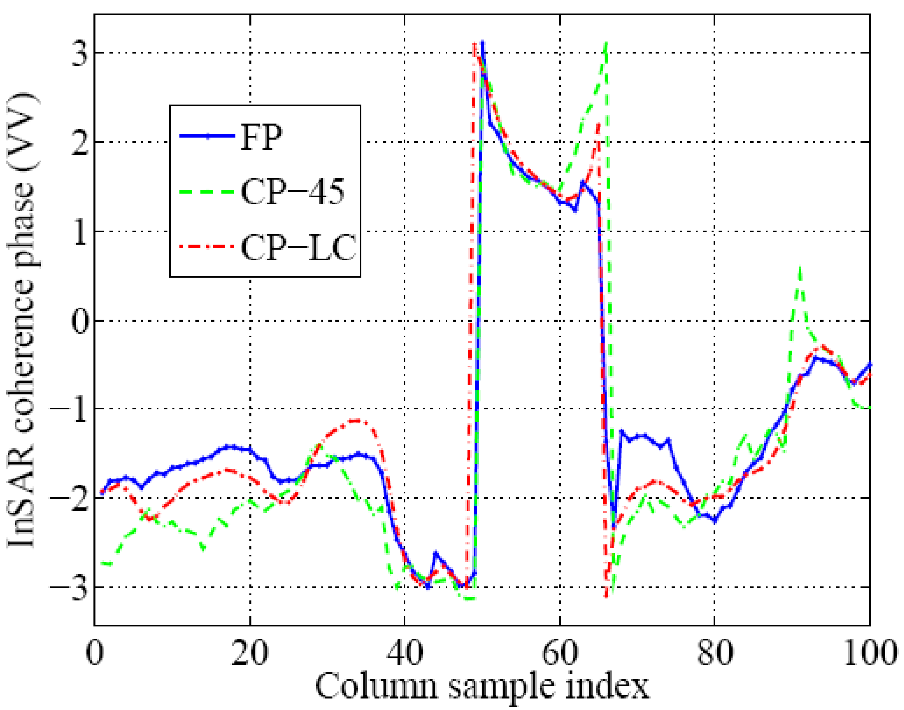


Reconstructed PolInSAR information

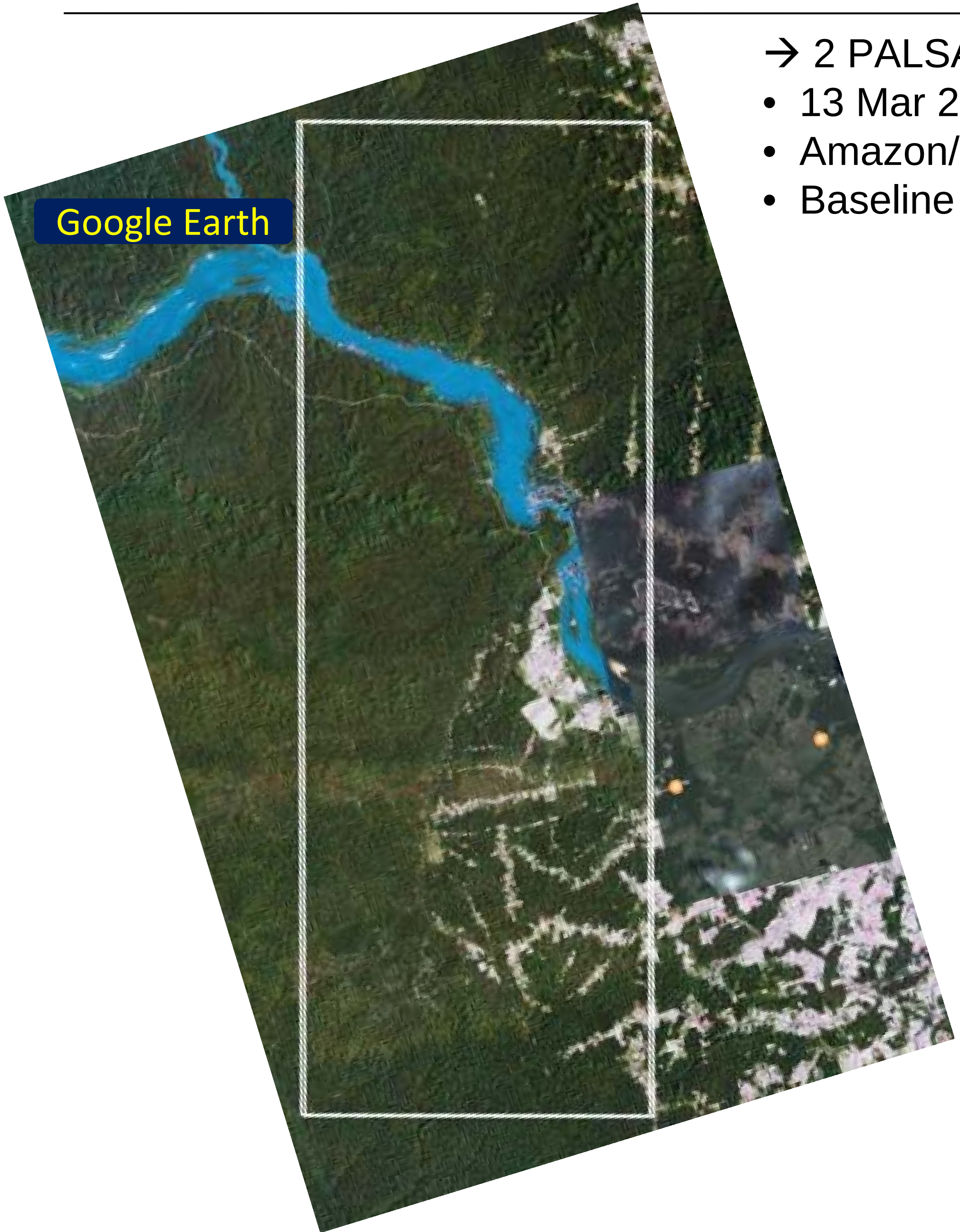
Row profiles

PolInSAR coherence VV

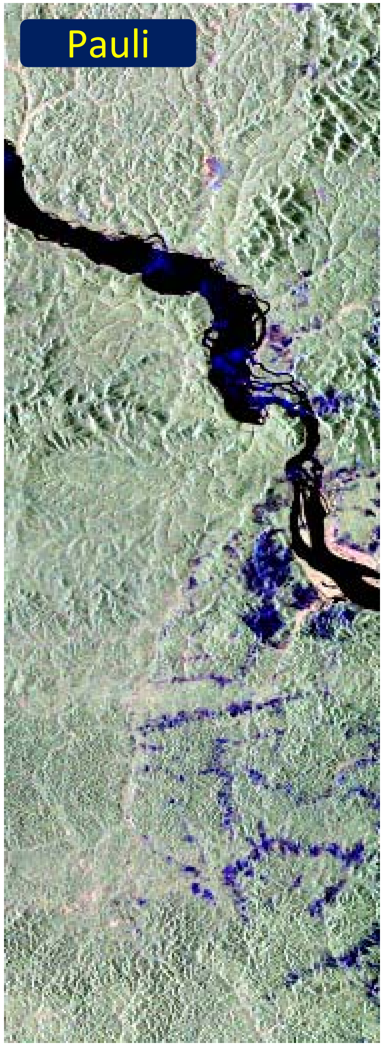




Results on ALOS PALSAR

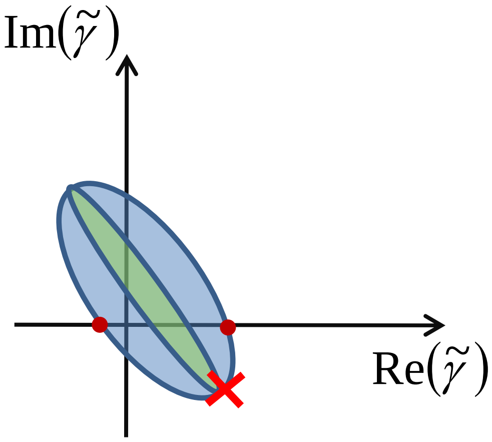


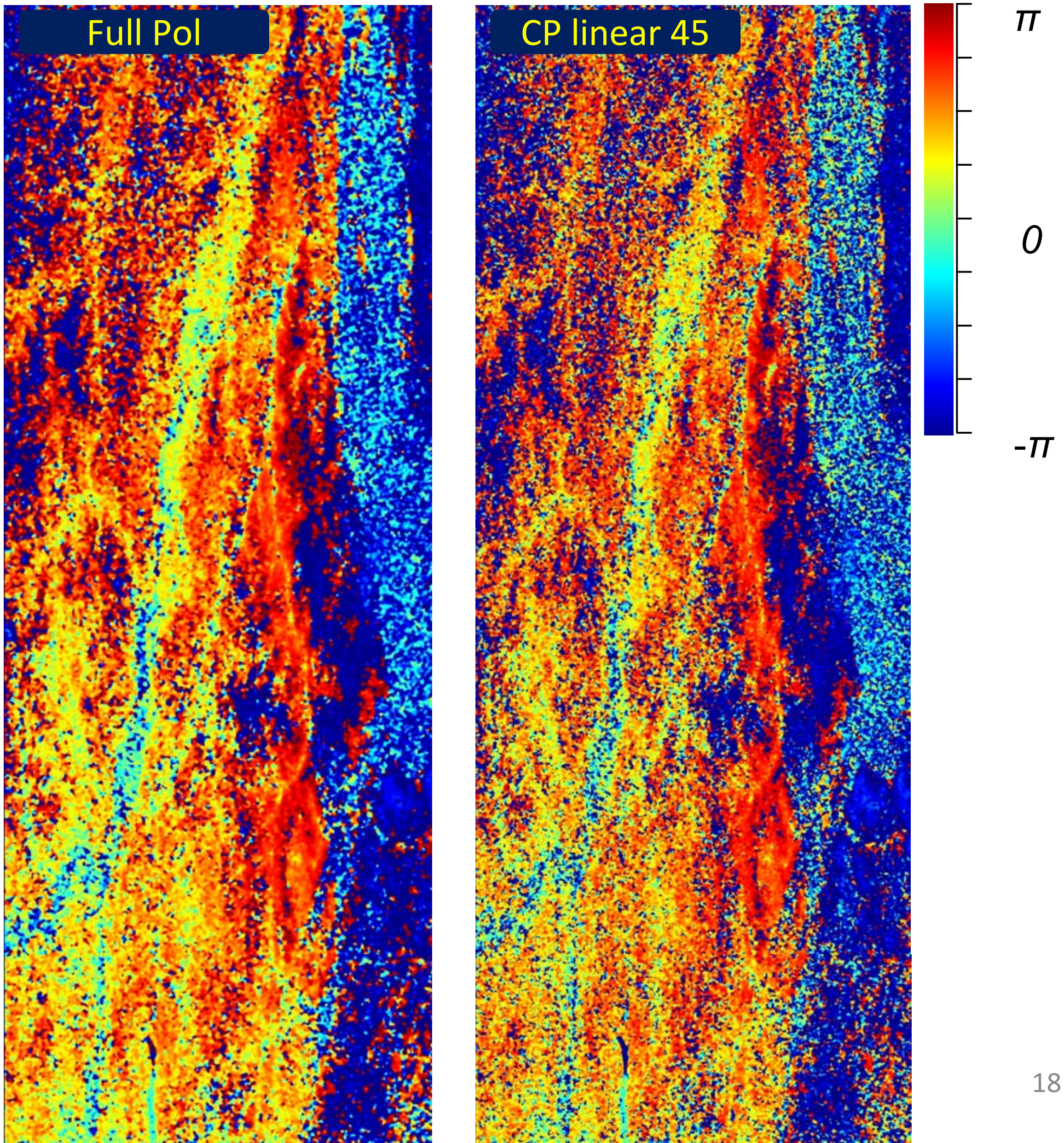
→ 2 PALSAR PolInSAR acquisitions:
- 13 Mar 2007 and 28 Apr 2007
- Amazon/Brasil (lat. -4.3°, lon. -56.3°)
- Baseline 100 m



Results: Compact PolInSAR

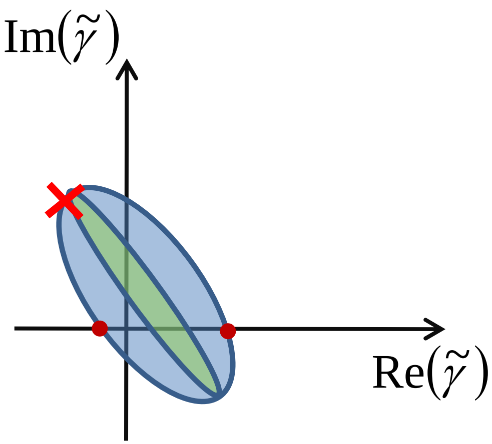
Min Phase

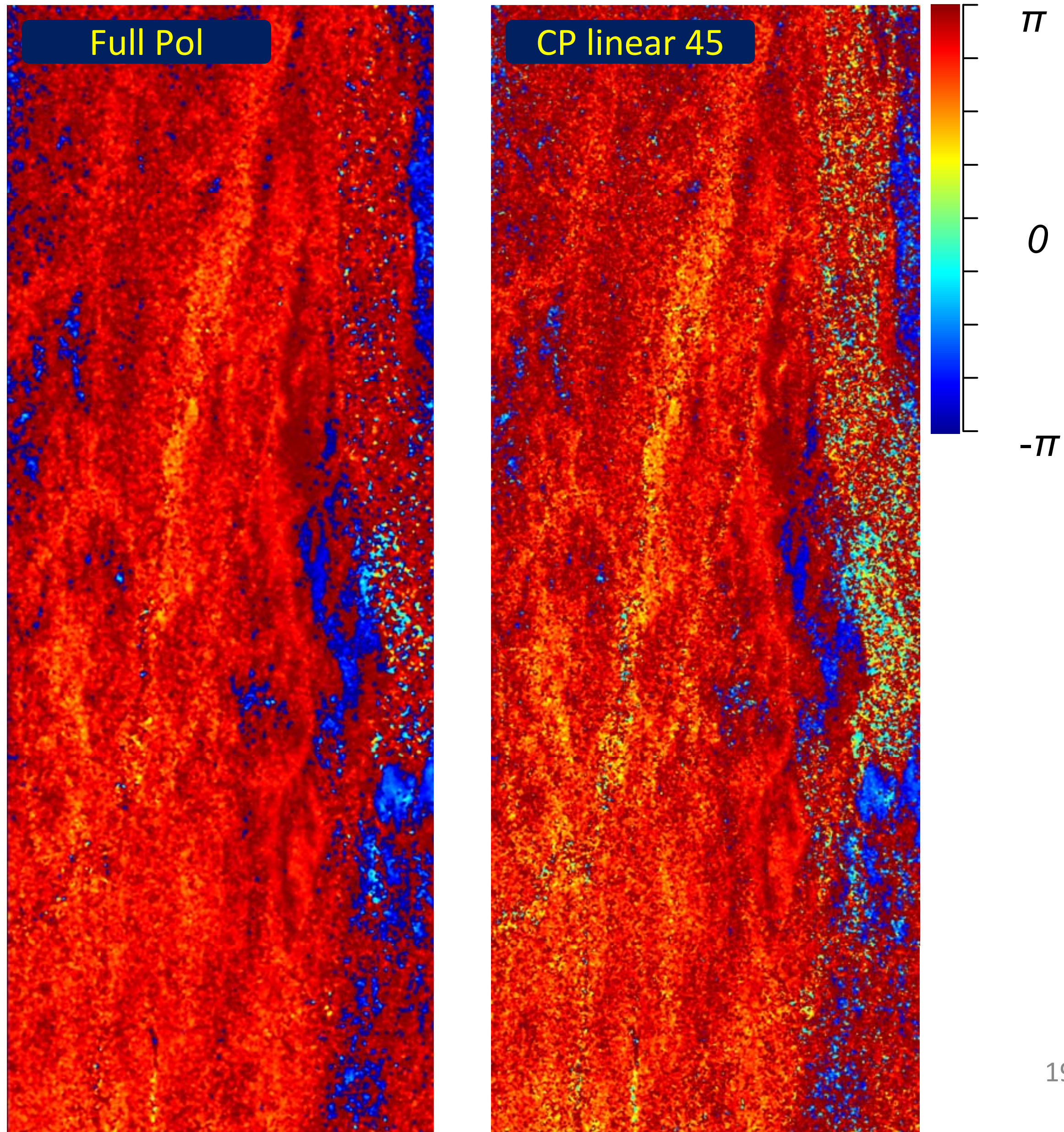




Results: Compact PolInSAR

Max Phase

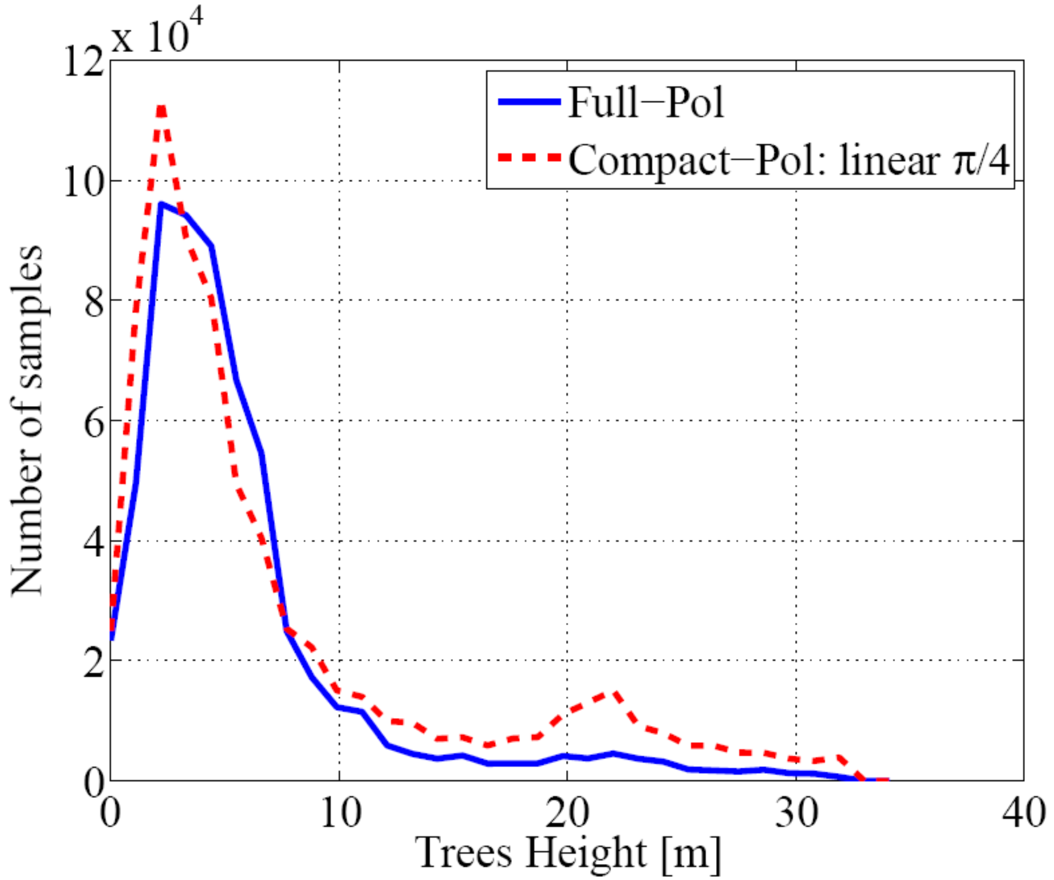




Results on ALOS PALSAR

Preliminary inversion example

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



Effects of the SAR processor and receiver

Synthesis of Compact-pol data

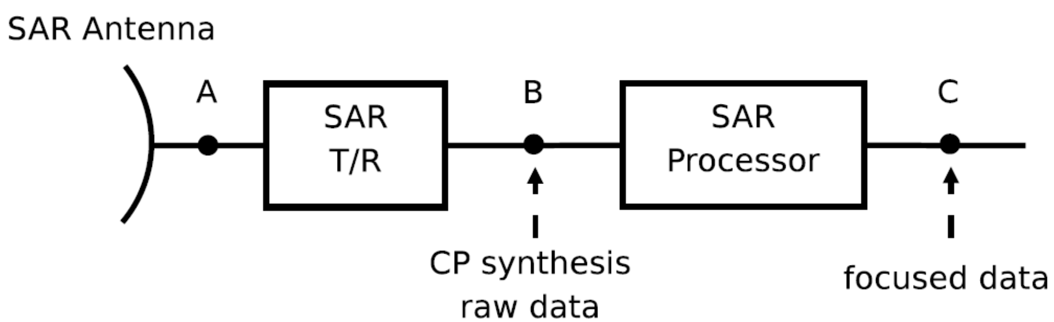
Effects of the SAR processor and receiver

→ Compact-pol data are usually synthesized from full-pol SLC data (C)

→ Synthesis of compact-pol data more close to the reality

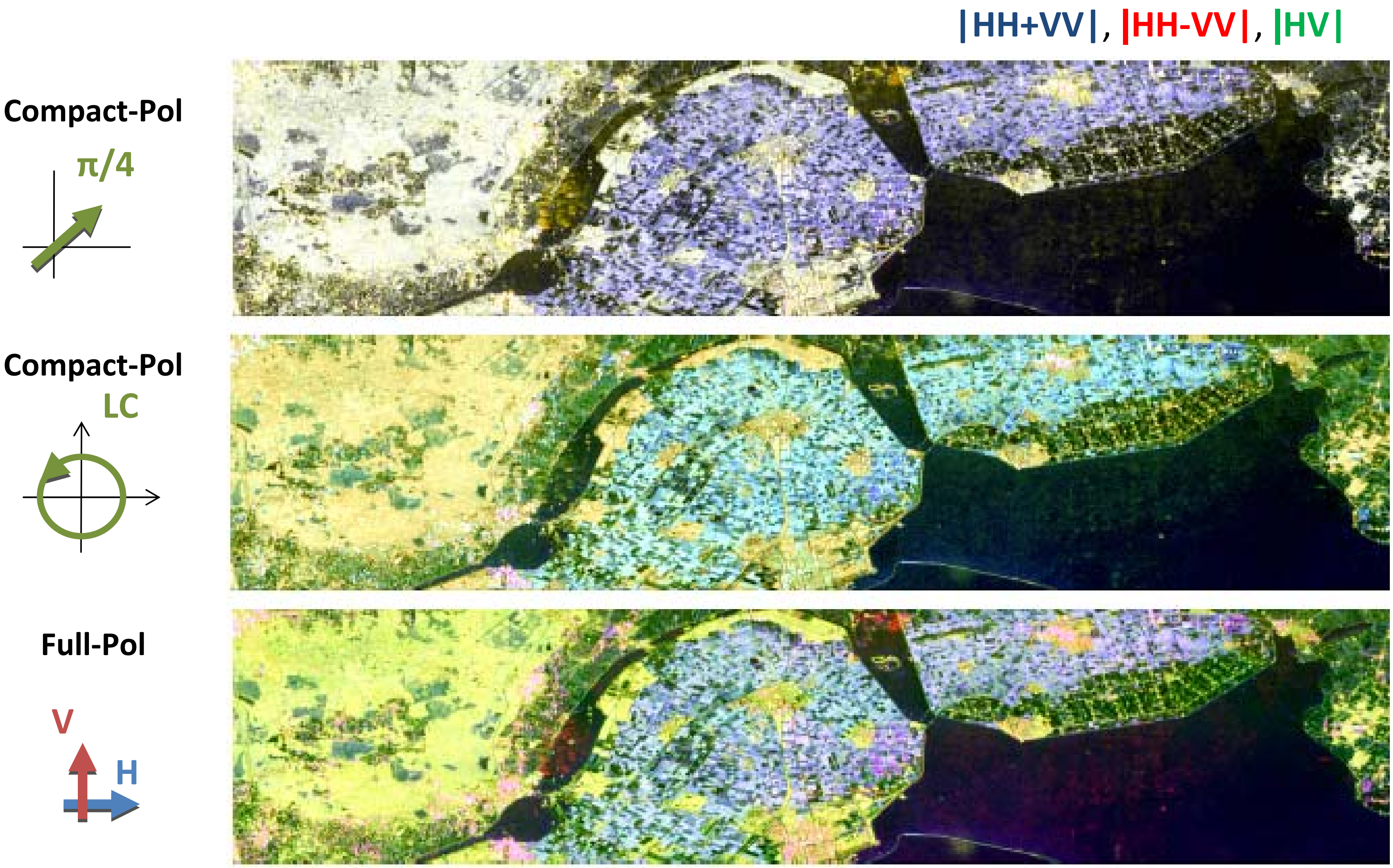
  → on raw data, before the SAR processor (B)

  → on received signal, before the SAR receiver (A)



Effects of the SAR processor

PALSAR example (Flevoland)



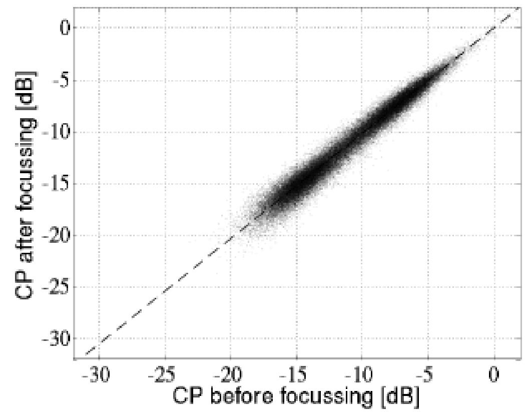
Effects of the SAR processor

PALSAR example (Flevoland)

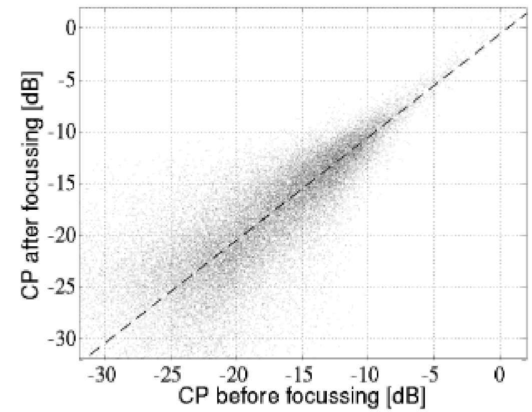
- → Comparison CP synthesis before/after focusing
- → Scatter plots of Stokes elements
- → No reconstruction

SAR processor does not introduce particular effects

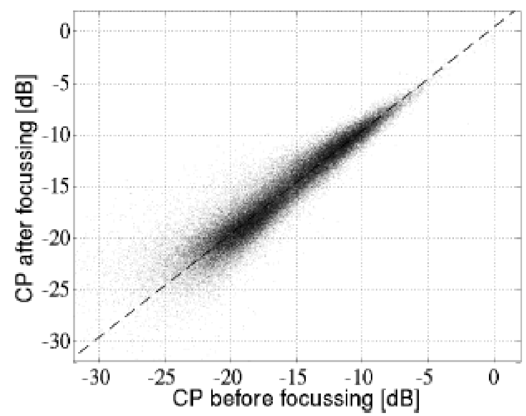
same processor for full-pol and compact-pol data



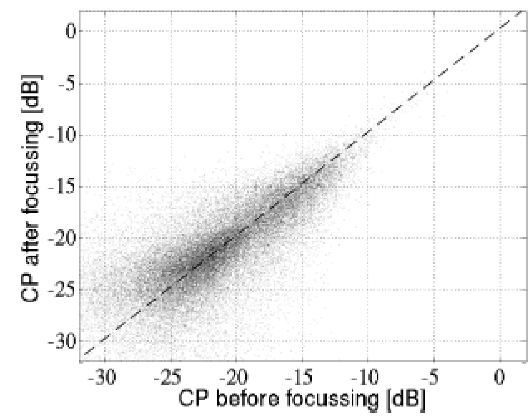
(a) Stokes element g_0



(b) Stokes element g_1



(c) Stokes element g_2

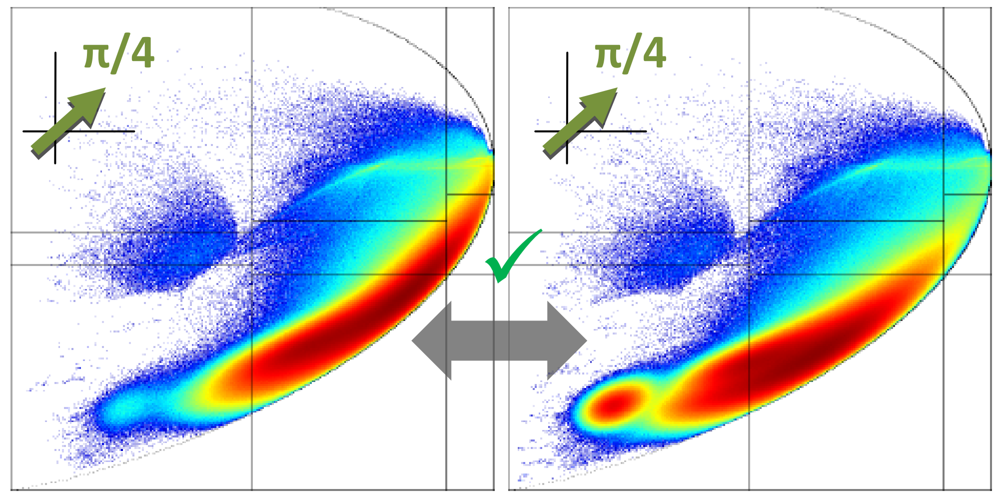


(d) Stokes element g_3

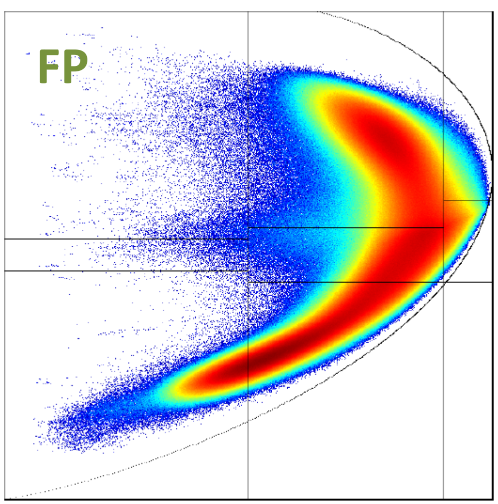
Effects of the SAR processor

PALSAR example (Flevoland)

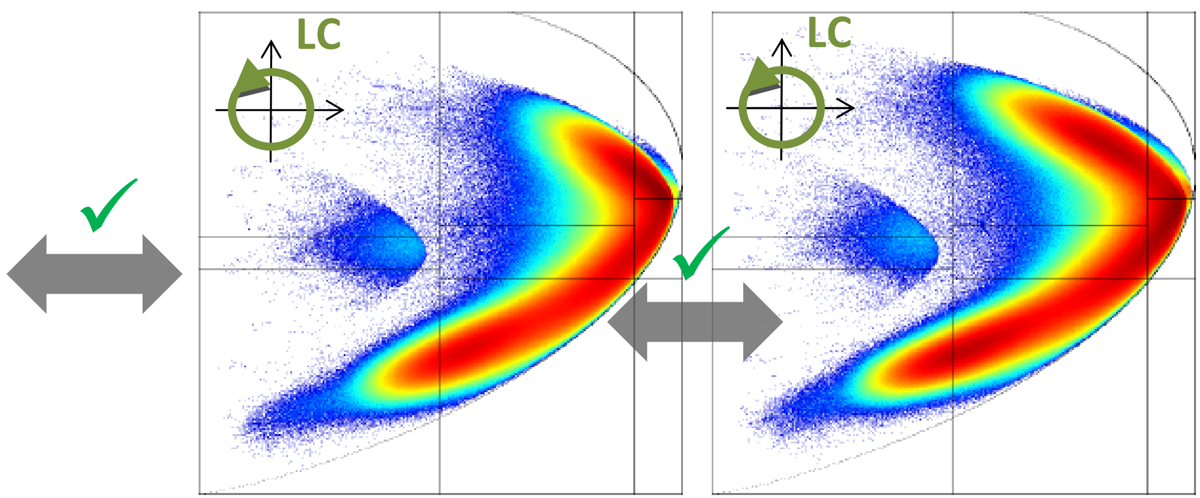
- → Comparison CP synthesis before/after focusing
- → H/α plane
- → Reconstructed pseudo full-pol information



(a) $\pi/4$: synthesis before focusing (b) $\pi/4$: synthesis after focusing



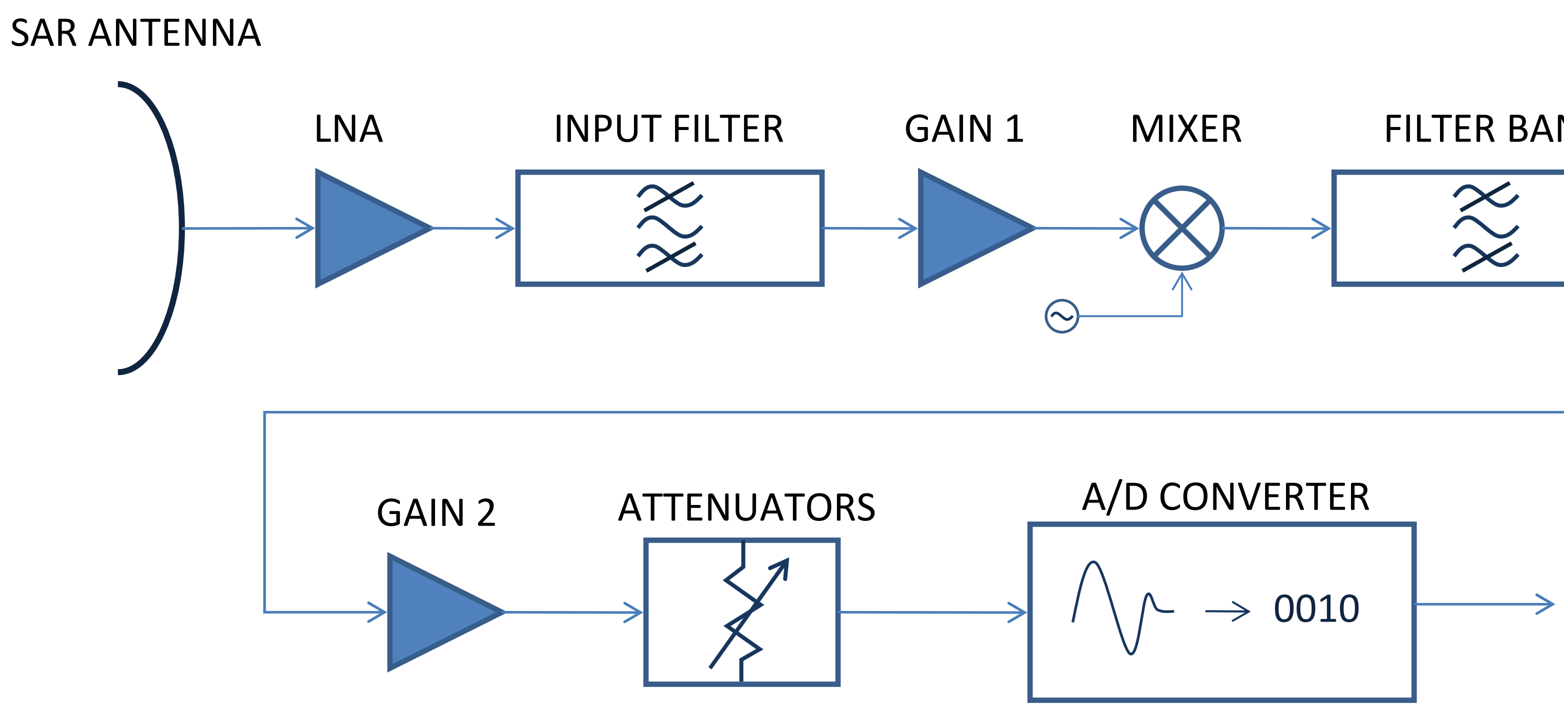
(e) Full Polarimetry



(c) $\pi/2$: synthesis before focusing (d) $\pi/2$: synthesis after focusing

Effects of the SAR receiver

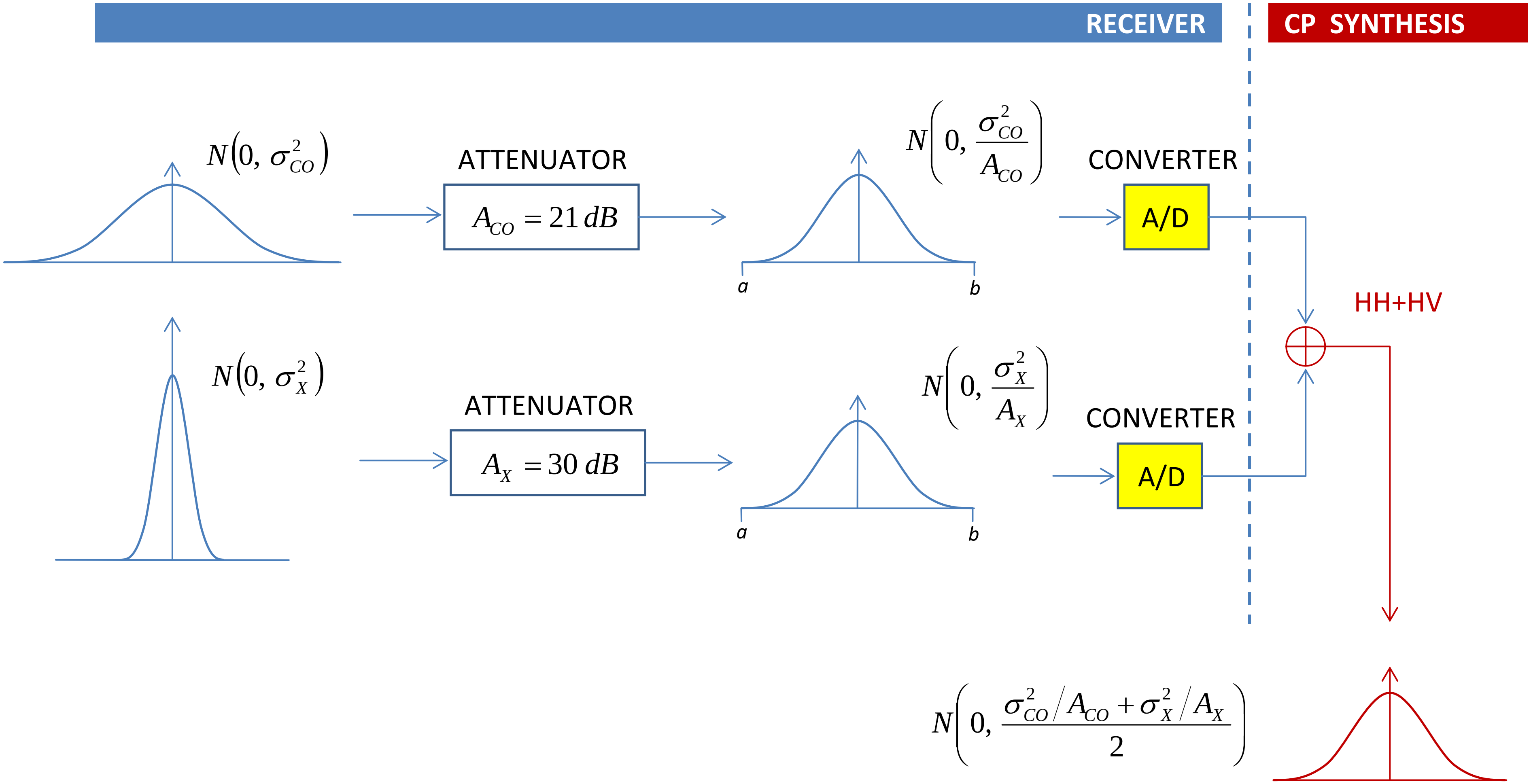
→ Simplified receiver chain of a quad-pol SAR (attenuator values from PALSAR receiver)



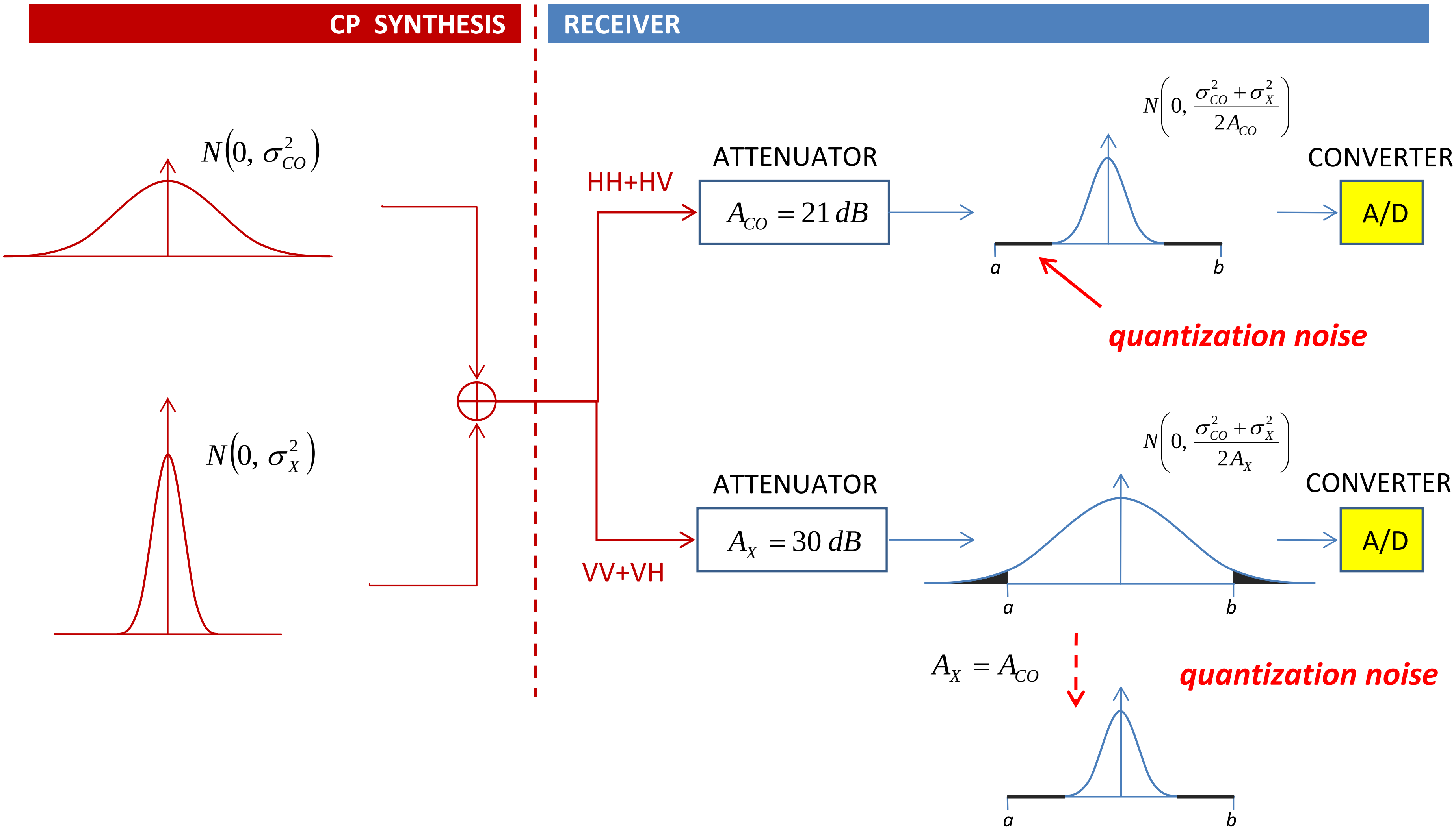
Co-polar (HH/VV) → 21 dB

X-polar (HV/VH) → 30 dB

Effects of the SAR receiver

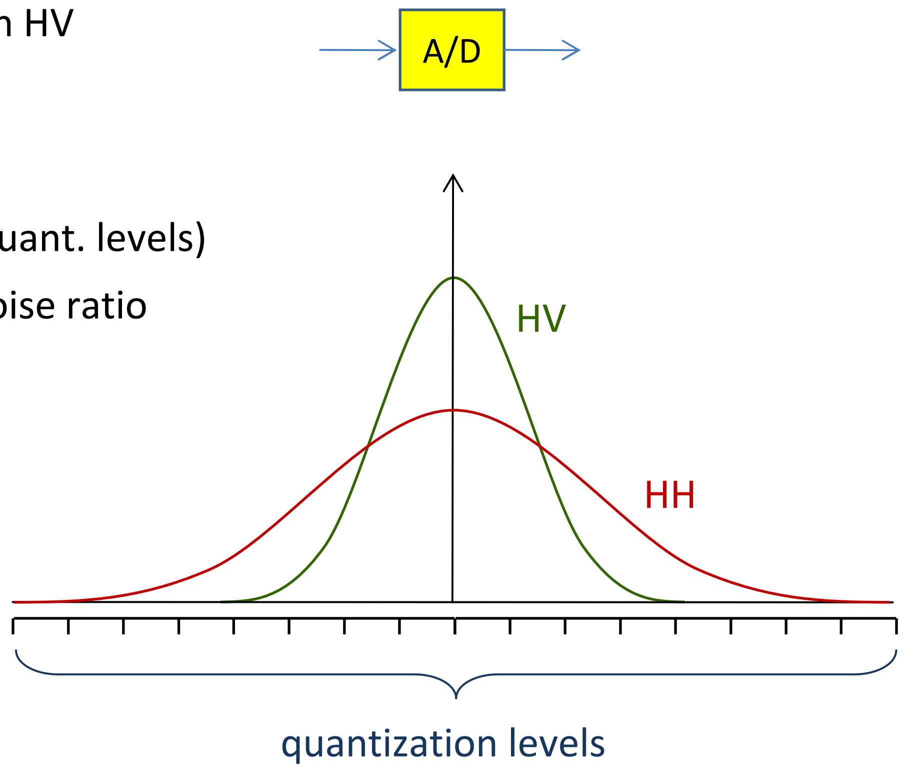


Effects of the SAR receiver



Effects of the SAR receiver

- Effects of the analogic/digital converter
  - HV has a shorter dynamic range compared to HH
  - CP return is a mixing of HH and HV return
  - A/D introduces more quantization noise on HV



- Example
  - HV has half dynamic range than HH (half quant. levels)
  - Simple model for signal-to-quantization-noise ratio

$$SQNR = 3 + 6n \ dB$$

HV has 6 dB less than HH

Impact on the reconstruction algorithms?

Conclusions

→ Compact PolSAR/PolInSAR

- Reconstruction algorithms useful to compare CP with FP
- Good performance for PolSAR and PolInSAR case
- HH/HV/VV coherence trend preserved between CP and FP
- Forest Height inversion still possible using CP data

→ Effects of the SAR processor and receiver

- SAR processor does not introduce distortions
- A/D converter in SAR receiver increases the signal-to-quantization-noise on HV/VH signals (about 6 dB)
- Assessment of the effects of the quantization noise in progress