Compact Polarimetric SAR Interferometry: observations and reconstruction algorithms

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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

<table>
<thead>
<tr>
<th></th>
<th>Full-pol</th>
<th>Compact-pol</th>
<th>Dual -pol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swath width</td>
<td>half</td>
<td>double</td>
<td>double</td>
</tr>
<tr>
<td>Data volume</td>
<td>double</td>
<td>half (?)</td>
<td>half</td>
</tr>
<tr>
<td>Information</td>
<td>double</td>
<td>hybrid</td>
<td>half</td>
</tr>
</tbody>
</table>

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

**Full Polarimetry (FP)**

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

**Compact Polarimetry (CP)**

\[
\mathcal{H}_{\pi/4} = \begin{pmatrix}
S_{H(\pi/4)} \\
S_{V(\pi/4)}
\end{pmatrix} = \begin{pmatrix}
S_{HH}^2 \pm jS_{HV} \\
jS_{VV} \pm S_{HV}
\end{pmatrix}
\]

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

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

$\pi/4$ CP (π/4 mode)

CP scattering vector

$J_2 = \begin{pmatrix} k_{\pi/4} & k_{\pi/4}^* \end{pmatrix}$

Reconstruction of FP

$3 \times 3$ 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

$\begin{bmatrix} k(\pi/4)_1 \\ k(\pi/4)_2 \end{bmatrix}$

4×4 CP covariance matrix

$J_4$

Reconstruction of F-PolInSAR

6×6 reconstructed F-PolInSAR coherency matrix

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

PolInSAR algorithms
Compact PolInSAR

Reconstruction of Full PolInSAR information

CP scattering vectors

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

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

4x4 C-PolInSAR covariance matrix

\[ J_4 = \begin{pmatrix} k_{(\pi/4)_1} & k_{(\pi/4)_1}^T \\ J_{12} & J_{12}^T \end{pmatrix} \]

where

\[ J_{12} = \begin{pmatrix} j_{11} \\ j_{21} \\ j_{12} \\ j_{22} \end{pmatrix} \]

\[ j_{11} = S_{HH_1}^* S_{HH_2} + S_{HH_1}^* S_{HV_2} + S_{HV_1}^* S_{HH_2} + S_{HV_1}^* S_{HV_2} \]

\[ j_{12} = S_{HH_1}^* S_{VV_2} + S_{HH_1}^* S_{HV_2} + S_{HV_1}^* S_{VV_2} + S_{HV_1}^* S_{HV_2} \]

\[ j_{21} = S_{VV_1}^* S_{HH_2} + S_{VV_1}^* S_{HV_2} + S_{HV_1}^* S_{HH_2} + S_{HV_1}^* S_{HV_2} \]

\[ j_{22} = S_{VV_1}^* S_{VV_2} + S_{VV_1}^* S_{HV_2} + S_{HV_1}^* S_{VV_2} + S_{HV_1}^* S_{HV_2} \]

8 observables < 18 unknowns
Compact PolInSAR
Reconstruction of Full PolInSAR information

Additional equations from symmetry properties (Nghiem, 1992)

Two approaches:
• rotation symmetry
• reflection symmetry

\[
\begin{align*}
\text{C-PolInSAR observables} & + \\
\text{Reflection symmetry} & + \\
\text{rotation invariance of x-pol terms}
\end{align*}
\]

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

Cross-coherency matrix:

\[
T_{6}^{\text{ref}}
\]
Compact PolInSAR
Performance Evaluation Scheme

Full-PolInSAR SLC dataset → CP synthesis → Compact-PolInSAR dataset → F-PolInSAR reconstruction → Multi-Pol coherence estimation and optimisation → Forest Height Estimation → Performance FP-CP Evaluation
Reconstructed FP information
Airborne E-SAR data (Traunstein, Germany)
Reconstructed PolInSAR information

Coherence magnitude (HH)

- Full pol
- CP linear 45
- CP circular
Reconstructed PolInSAR information

Coherence phase (HH)
Reconstructed PolInSAR information

Row profiles
Reconstructed PolInSAR information

Row profiles

PollnSAR coherence HV
Reconstructed PolInSAR information

Row profiles

PolInSAR coherence VV

![Graphs showing PolInSAR coherence VV](image)
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

\[ \text{Im}(\tilde{\gamma}) \]

\[ \text{Re}(\tilde{\gamma}) \]
Results: Compact PolInSAR

Max Phase

$\text{Im}(\tilde{\gamma})$  $\text{Re}(\tilde{\gamma})$
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)

Compact-Pol

\[ \frac{\pi}{4} \]

Compact-Pol

\[ \text{LC} \]

Full-Pol

\[ V \quad \text{H} \]

\[ |HH+VV|, |HH-VV|, |HV| \]
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
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

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)

SAR ANTENNA

LNA → INPUT FILTER → GAIN 1 → MIXER → FILTER BANK

GAIN 2 → ATTENUATORS → A/D CONVERTER

Co-polar (HH/VV) → 21 dB
X-polar (HV/VH) → 30 dB
Effects of the SAR receiver

\[ N(0, \sigma^2_{CO}) \rightarrow \text{ATTENUATOR} \rightarrow N\left(0, \frac{\sigma^2_{CO}}{A_{CO}}\right) \]

\[ N(0, \sigma^2_{X}) \rightarrow \text{ATTENUATOR} \rightarrow N\left(0, \frac{\sigma^2_{X}}{A_{X}}\right) \]

\[ A_{CO} = 21 \, dB \]

\[ A_{X} = 30 \, dB \]

\[ A/D \rightarrow \text{CP SYNTHESIS} \]

\[ N\left(0, \frac{\sigma^2_{CO}}{A_{CO}} + \frac{\sigma^2_{X}}{A_{X}}\right) \]
Effects of the SAR receiver

\[ N(0, \sigma_{\text{CO}}^2) \]

\[ \sigma_X^2 \]

\[ HH+HV \]

\[ VV+VH \]

**ATTENUATOR**

\[ A_{\text{CO}} = 21 dB \]

\[ A_X = 30 dB \]

\[ A_X = A_{\text{CO}} \]

**CONVERTER**

\[ N\left(0, \frac{\sigma_{\text{CO}}^2 + \sigma_X^2}{2A_{\text{CO}}} \right) \]

\[ \frac{\sigma_{\text{CO}}^2 + \sigma_X^2}{2A_{\text{CO}}} \]

**quantization noise**
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

\[ SQNR = 3 + 6n \text{ dB} \]

\[ \text{HV has 6 dB less than HH} \]

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