Polarimetric PALSAR System
Model Assessment and Calibration

R. Touzi
Canada Centre for Remote Sensing
Natural Resource of Canada

M. Shimada (JAXA)
S. Nedelcu (CCRS)
R.K. Hawkins (CCRS)

Acknowledgement (DATA)
K. Paphathanassiou, DLR

Acknowledgement (DATA)
G. SANDBERG, L.E.B. ERIKSSON
Chalmers University of Technology
Background

- There has been a big **confusion** to interpret the presence of a significant CR response at the cross-pol HV and VH

  ➢ Pol-In SAR’07 (Jan. 07): PALSAR of **significant** antenna isolation (-25 dB)

  ✡ Cal-VAL meetings CVST5 and CVT6

  ➢ Cal-Val workshop CVST6 (March. 07): **No Consensus**
    ➢ Antenna highly isolated (better than -30 dB) with significant Faraday rotation?
    ➢ Low Faraday rotation and PALSAR of bad isolation (-18, -25 dB)?

- Action: JAXA provided test data sets to Cal-Val members:
  • Amazonia
  • Sweeden (Merci Leif Eriksson and G. Sandberg)
  • DLR calibration site (Merci K. Papathanassiou)
OUTLINE

I SAR System model assessment using Amazonian data (zero Faraday rotation)
   - Improvement of the Freeman-VanZyl calibration method
   - Application on the Amazonian data sets for PALSAR parameters measurement
     ➢ Antenna cross-talk better than -35dB

➢ Validation of the PALSAR system model using the Sweeden, DLR, and Ottawa data sets

➢ Corner reflector with significant cross-polarization return: Low Faraday rotation or antenna cross talk?
PALSAR Characteristics

- Active antenna with 80 T/R elements
  - Channel imbalance stability Ũ Shimada (IGARSS’08)

- Subaperture antenna: H/V isolation less than -25 dB??
  Ũ Significant cross-talk
  - Cross-talk variation with incidence angle Ũ DEM
  - Measurement of cross-talk variations within a large interval of incidence angles

- L-band Ũ sensitivity to Faraday rotation
SAR Processing Schemas (Shimada CVST4)

➢ “uncalibrated”: Corrected for antenna gain and range

➢ “Calibrated”: Corrected for antenna cross-talk and channel imbalance
JAXA “Calibrated” data

1. Amazonian forest stable with polarization
   - Antenna gain pattern variations with incidence angle
   - Antenna cross-talk variations with incidence angle

2. After antenna gain and cross-talk removal + correction for range variations

\[
\begin{bmatrix}
M_{hh} & M_{vh} \\
M_{hv} & M_{vv}
\end{bmatrix} =
\begin{bmatrix}
1 & 0 \\
0 & f_2
\end{bmatrix}
\begin{bmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{bmatrix}
\begin{bmatrix}
S_{hh} & S_{vh} \\
S_{hv} & S_{vv}
\end{bmatrix}
\begin{bmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{bmatrix}
\begin{bmatrix}
1 & 0 \\
0 & f_1
\end{bmatrix}
\]

3. Faraday rotation

4. Channel imbalance $f_1$ and $f_2$
Predictions of one way FR under high sunspot activity for 12:00 GMT, April and 35 degree incidence angle

- Typical values of absolute two-way FR (at L-band) in most of the Amazon between 0-10°
PALSAR System Model using the Amazonian data
(Faraday rotation close to Zero)

- Freeman-VanZyl Calibration method used for SIR-C:
  - Freeman’s Symmetrization
  - VanZyl iterative method for measurement of antenna cross talks using azimuthally symmetric targets
  - Channel imbalance measurement using a CR

Problem with VanZyl algorithm: biased cross-talk estimates with reference azimuthally targets of $|HV|^2$ much lower than $|HH|^2$, $|VV|^2$ and $|<HH*VV>|$

Same problem with the Quegan calibration method

Improvement of VanZyl algorithm
Freeman’s System Symmetrization

- Non symmetric

\[
\begin{bmatrix}
V_{hh} & V_{vh} \\
V_{hv} & V_{vv}
\end{bmatrix}
= Ae^{j\phi}
\begin{bmatrix}
1 & \delta_3 \\
\delta_4 & f_2
\end{bmatrix}^T
\begin{bmatrix}
S_{hh} & S_{vh} \\
S_{hv} & S_{vv}
\end{bmatrix}
\begin{bmatrix}
1 & \delta_1 \\
\delta_2 & f_1
\end{bmatrix}
\]

- Symmetric system:

\[
\begin{bmatrix}
V_{hh} & V_{vh} \\
V_{hv} & V_{vv}
\end{bmatrix}
= Ae^{j\phi}
\begin{bmatrix}
1 & \Delta_3 \\
\Delta_4 & f_1
\end{bmatrix}^T
\begin{bmatrix}
S_{hh} & S_{vh} \\
S_{hv} & S_{vv}
\end{bmatrix}
\begin{bmatrix}
1 & \Delta_3 \\
\Delta_4 & f_2
\end{bmatrix}
\]

\[
\Delta_3 = \left| \frac{f_2}{f_1} \right| e^{-j\phi} (\delta_1 + \delta_3 f_1/f_2)/2
\]

\[\Delta_4 = (\delta_2 + \delta_4)/2\]

Van Zyl Calibration Method

• Reciprocal system (after symmetrization): \([R]=[T]\)

\[
\begin{bmatrix}
V_{hh} & V_{vh} \\
V_{hv} & V_{vv}
\end{bmatrix} = A e^{j\phi} \begin{bmatrix}
1 & \Delta_3 \\
\Delta_4 & f_1
\end{bmatrix}^T \begin{bmatrix}
S_{hh} & S_{vh} \\
S_{hv} & S_{vv}
\end{bmatrix} \begin{bmatrix}
1 & \Delta_3 \\
\Delta_4 & f_2
\end{bmatrix}
\]

• \(\Delta\): cross-talk  \(f\): channel imbalance
• Azimuthally symmetric target (Borgeaud 1987):

\[<S_{HH} S_{HV}^*> = <S_{VV} S_{VH}^*> \approx 0\]

• \([V]\) autocorrelation expressed in terms of \([S]\) autocorrelation

\(\hat{A}\) Iterative method \(\Delta_3\) and \(\Delta_4/f\) for each incidence angle
• Corner reflector \(\hat{A}\) \(f\) and \(A\)
Calibration unknowns determined using an equation of 1st degree

Optimum azimuthally symmetric Reference target

- Approximations not valid for target of $|HV|^2$ much lower than $|HH|^2$, $|VV|^2$ and $|<HH*VV>|$

$$RR = \frac{|a_{21}|^2}{|a_{11}|^2} \frac{\langle |V_{HH}|^2 \rangle}{\langle |V_{HH}|^2 \rangle} + \frac{|a_{33}|^2}{|a_{11}|^2} \frac{\langle |V_{VV}|^2 \rangle}{\langle |V_{HV}|^2 \rangle} + 2Re \left( \frac{a_{21}a_{23}^*}{a_{11}a_{33}^*} \frac{\langle V_{HH} V_{VV}^* \rangle}{\langle |V_{HV}|^2 \rangle} \right)$$

- Excellent results for $RR$ of low values
- Problem with $RR$ of large value
  - Iteration converges \( \text{biased} \) cross-talk estimates
  - An additional equation is used
  - Iterative process stopped before reaching the noise floor

$$\langle V_{HV} V_{HV}^* \rangle = \frac{a_{21}}{a_{11}} \langle |V_{HH}|^2 \rangle + \frac{a_{23}}{a_{33}} \langle V_{VH} V_{HV}^* \rangle + \frac{a_{32}^*}{a_{22}} \langle |V_{HV}|^2 \rangle (1 - RR) \quad (24)$$

$$\langle V_{HV} V_{VH}^* \rangle = \frac{a_{21}}{a_{11}} \langle |V_{VH}|^2 \rangle + \frac{a_{23}}{a_{33}} \langle |V_{VH}|^2 \rangle + \frac{a_{32}^*}{a_{22}} \langle |V_{HV}|^2 \rangle (1 - RR) \quad (25)$$
SAR System model assessment using Amazonian data
(20July Asc and 21 July Desc)
Cross-talk estimation using the Ascending Mode (20 July Asc)

- 1st order equation: problems with RR of high value

\ Problem solved with the equation of 2nd degree

- Cross-talks $\delta_3$ and $\delta_4$ better than -33 dB
System parameters using the Amazonian uncalibrated data

- **Asc:**
  - $|\Delta_3| = -39.26$ dB, $|\Delta_4| = -38.63$ dB, and
  - $|f_1| = 1.02$, $|f_2| = 0.723$, $|f_2/f_1| = 0.709$

- **Desc:**
  - $|\Delta_3| = -36.56$ dB, $|\Delta_4| = -41.66$ dB, and
  - $|f_1| = 1.025$, $|f_2| = 0.745$, $|f_2/f_1| = 0.726$
System parameters in agreements with Moriyama’s results

- **Asc:**
  \[ |\Delta_3| = -39.26 \text{ dB}, \quad |\Delta_4| = -38.63 \text{ dB}, \quad |f_1| = 1.02 \quad |f_2| = 0.723 \quad |f_2/f_1| = 0.709 \]

- **Desc:**
  \[ |\Delta_3| = -36.56 \text{ dB}, \quad |\Delta_4| = -41.66 \text{ dB}, \quad |f_1| = 1.025 \quad |f_2| = 0.745 \quad |f_2/f_1| = 0.726 \]

- Moriyama: Quegan method used
- At the CR location, RR very low 
  - 1st degree polynom solution equivalent to the Quegan method

- Action from CVST5: Amazonian Distortion matrix with cross-talk better than -37 dB is used for calibration

Antenna cross-talk can be **ignored**

**Diagonal distortion matrix??**

Amazon data sets (7/20, 7/21, 9/4, 9/5)

- **Transmit:**
  - 1.000000e+00
  - 0.000000e+00
  - Real\_transmit\_dist\_12: 2.427029e-03
  - Imag\_transmit\_dist\_12: 1.293019e-02
  - \( \delta_1 = 2.427029e-03 + j1.293019e-02 \)
  - \( \delta_2 = -37\text{dB} \)
  - Real\_transmit\_dist\_21: -1.147240e-02
  - Imag\_transmit\_dist\_21: -6.228230e-03

- **Receive:**
  - 1.000000e+00
  - 0.000000e+00
  - Real\_recep\_dist\_12: -6.263392e-03
  - Imag\_recep\_dist\_12: 7.082863e-03
  - \( \delta_3 = -40\text{dB} \)
  - Real\_recep\_dist\_21: -6.297074e-03
  - Imag\_recep\_dist\_21: 8.026685e-03
  - \( \delta_4 = -39.8\text{dB} \)
  - Real\_recep\_dist\_22: 7.217117e-01
  - Imag\_recep\_dist\_22: -2.367683e-02
Amazonie-Ottawa Distortion matrix with significant cross-talks Â· mis-leading results

- Distortion matrix estimated on the Tomakomai site in non-zero Faraday conditions using the Quegan Method: **Cross talk about -28 dB**

<table>
<thead>
<tr>
<th>Ottawa: May 20, July5, Aug.20, Oct 5 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>wavelength</td>
</tr>
<tr>
<td>calibration_factor</td>
</tr>
<tr>
<td>Real_transmit_dist_11</td>
</tr>
<tr>
<td>Imag_transmit_dist_11</td>
</tr>
<tr>
<td>Real_transmit_dist_12</td>
</tr>
<tr>
<td>Imag_transmit_dist_12</td>
</tr>
<tr>
<td>δ1=0.028047-j0.002933 = -31dB</td>
</tr>
<tr>
<td>Real_transmit_dist_21</td>
</tr>
<tr>
<td>Imag_transmit_dist_21</td>
</tr>
<tr>
<td>δ2=-0.031640-j0.010382 = -29.55dB</td>
</tr>
<tr>
<td>Real_transmit_dist_22</td>
</tr>
<tr>
<td>Imag_transmit_dist_22</td>
</tr>
<tr>
<td>F1=0.935235+j0.935235</td>
</tr>
<tr>
<td>Real_recep_dist_11</td>
</tr>
<tr>
<td>Imag_recep_dist_11</td>
</tr>
<tr>
<td>Real_recep_dist_12</td>
</tr>
<tr>
<td>Imag_recep_dist_12</td>
</tr>
<tr>
<td>δ3=-0.03699+0.000845 = -28.6 dB</td>
</tr>
<tr>
<td>Real_recep_dist_21</td>
</tr>
<tr>
<td>Imag_recep_dist_21</td>
</tr>
<tr>
<td>δ4=-0.021159+0.005648 = -33.1 dB</td>
</tr>
<tr>
<td>Real_recep_dist_22</td>
</tr>
<tr>
<td>Imag_recep_dist_22</td>
</tr>
</tbody>
</table>

Amazon_July21_Desc

| wavelength | 0.236057 |
| calibration_factor | -83.000000 |
| Real_transmit_dist_11 | 1.000000 |
| Imag_transmit_dist_11 | 0.000000 |
| Real_transmit_dist_12 | -0.028047 |
| Imag_transmit_dist_12 | -0.002933 |
| δ1=-0.028047-j0.002933 = -31dB |
| Real_transmit_dist_21 | 0.031640 |
| Imag_transmit_dist_21 | -0.010382 |
| δ2=-0.031640-j0.010382 = -29.55dB |
| Real_transmit_dist_22 | 0.935235 |
| Imag_transmit_dist_22 | 0.935235 |
| F1=0.935235+j0.935235 |
| Real_recep_dist_11 | 1.000000 |
| Imag_recep_dist_11 | 0.000000 |
| Real_recep_dist_12 | -0.036990 |
| Imag_recep_dist_12 | 0.000845 |
| δ3=-0.03699+0.000845 = -28.6 dB |
| Real_recep_dist_21 | 0.021159 |
| Imag_recep_dist_21 | 0.005648 |
| δ4=-0.021159+0.005648 = -33.1 dB |
| Real_recep_dist_22 | 0.725000 |
| Imag_recep_dist_22 | 0.000554 |
Uncalibrated CR Impulse Response HH-VV
Amazonia 20 July Asc
Calibrated versus UnCalibrated HV
Amazonia 20 July Asc
Uncalibrated CR Impulse Response HH-VV
Amazonia 21 July Desc

R. Touzi, CCRS, Pol-InSAR’09, Frascatti, Jan. 2009
Calibrated versus UnCalibrated HV
Amazonia 21 July Desc
Calibrated versus Uncalibrated VH
(21 July, Desc)
ALOS / PALSAR
OTTAWA - CANADA AREA
CHANNELS: HH, HV, VV (R G B)
\[ \theta_b = 37.0^\circ \]
\[ \theta_{inc} = 17.7^\circ \]
\[ \phi_s = 256^\circ \]
\[ \phi_d = 13.9^\circ \]
\[ \ell = 3.40 \text{ m} \]
\[ \sigma = 34.2 \text{ dBm}^2 \]
\[ \theta_{lat} = 45^\circ 18' 15.5'' \]
\[ \phi_{long} = -75^\circ 46' 8.9'' \]
\[ H_{ellip} = 61.94 \text{ m} \]
Calibrated versus uncalibrated HV
Ottawa 5 October 2006

R. Touzi, CCRS, Pol-InSAR’09, Frascati, Jan. 2009
Ottawa Acquisition

5 Oct. 06:

- No return in HV and VH δ zero Faraday rotation

- PALSAR parameter measurements:
  - \(|\Delta_3| = -34.56 \text{ dB}, \ |\Delta_4| = -35.66 \text{ dB}\)
  - \(|f_1| = 0.703, \ |f_2| = 0.99, \ |f_2/f_1| = 0.712,\)
Validation using the Sweden data set

• 5m-height trihedral with a cross section of 47.2 dBm.
• Acknowledgment: Leif Eriksson and G. Sabdberg, Chalmers University of Technology
Night acquisition (19 Oct. 06)

HH and VV
Night acquisition (19 Oct. 06)  
HV and VH

R. Touzi, CCRS, Pol-InSAR’09, Frascatti, Jan. 2009
Calibration parameters

- Uncalibrated data:
  \[ |\Delta_3| = -43 \text{ dB}, \quad |\Delta_4| = -42 \text{ dB} \]
  \[ |f_2/f_1| = 0.703, \quad |f_1| = 0.715, \quad |f_2| = 1.016 \]
  \[ \Omega = 0.22^\circ \]

- Calibrated data using the Amazonian distortion matrix:
  \[ |\Delta_3| = -37.98 \text{ dB}, \quad |\Delta_4| = -42.60 \text{ dB} \]
  \[ |f_2/f_1| = 1.004, \quad |f_1| = 0.99, \quad |f_2| = 0.985 \]
  \[ \Omega = 0.42^\circ \]

Antenna cross-talk can be ignored in a diagonal distortion matrix.
Day acquisition (5 Oct. 06)
HH and VV
Day acquisition (5 Oct. 06)

HV and VH

R. Touzi, CCRS, Pol-InSAR’09, Frascati, Jan. 2009
Faraday rotation or Antenna Cross Talk??!!

- Channel imbalance ratio stable

- After JAXA calibration:

\[
M_{hh} = S_{hh} \cos^2 \Omega - S_{vv} \sin^2 \Omega \\
M_{hv} = f_1 [S_{hv} + (S_{hh} + S_{vv}) \sin \Omega \cos \Omega] \\
M_{vh} = f_1 [S_{hv} - (S_{hh} + S_{vv}) \sin \Omega \cos \Omega] \\
M_{vv} = f_1^2 [S_{vv} \cos^2 \Omega - S_{hh} \sin^2 \Omega]
\]

\(\hat{\odot}\) HV+VH=0 for a corner reflector
Channel imbalance stability

- Amazonia 20 July, Asc:
  - $|f_2/f_1|=0.709$, $|f_1|=1.50$, $|f_2|=1.05$

- Amazonia 21 July, Desc:
  - $|f_2/f_1|=0.726$, $|f_1|=1.22$, $|f_2|=0.88$

- Japan 19 May, Asc:
  - $|f_2/f_1|=0.712$, $|f_1|=1.39$, $|f_2|=0.98$

- Ottawa 5 Oct., Asc:
  - $|f_2/f_1|=0.712$, $|f_1|=0.703$, $|f_2|=0.99$

- Sweden 19 Oct., Asc:
  - $|f_2/f_1|=0.703$, $|f_1|=0.715$, $|f_2|=1.016$
Sweeden Calibrated Data HV + VH
Day acquisition (5 Oct. 06)

**HV**

**HV+VH**

PEAK STATISTICS

INPUT DATA: (Complex)
Peak value = 117.456 dB (542, 7347)
Peak value = 117.509 dB (542, 7347, 000)
Phase of Peak = 28.02°
Complex integrated/Phase = 24.83
Bandwidth integrated = 10.42 dB
Integration Area = 63.86 sq. samples
Peak-to-Cutter Ratio = 19.32 dB
Average clutter level = 58.16 dB
Clutter standard deviation = 10.41 dB
Independent clutter pixels: 9.31
Error: ± 5.254 dB
Caption: OP-4
Faraday rotation Measurement

- Sweden site Oct 5, Significant Faraday rotation:
  \[ HV + VH = 2S_{HV} \approx 0 \]
  \[ \Omega = 2.17^\circ \text{ but radiometry not affected } (\text{within 0.3 dB}) \]

- DLR site Sep. 30, Significant Faraday rotation:
  \[ HV + VH = 2S_{HV} \approx 0 \]
  \[ \Omega = 2.71^\circ \text{ but radiometry not affected } (\text{within 0.3 dB}) \]
DLR Site 30 Sep. 2006
CR-Gitching HH and VV

Aknowledgment: K. Papathanassiou and DLR

R. Touzi, CCRS, Pol-InSAR’09, Frascatti, Jan. 2009
DLR Site 30 Sep. 2006
CR-Gitching HV and VH
DLR Site 30 Sep. 2006
CR-Gitching

HV

HV+VH

R. Touzi, CCRS, Pol-InSAR’09, Frascatti, Jan. 2009
Calibration of a “local data” set using the JAXA “Calibrated” data

I JAXA calibration:
- Antenna cross-talk can be ignored (Diagonal distortion matrix)
- Antenna gain pattern variations with incidence angle removed

II Model for calibration of JAXA distributed data

\[
\begin{bmatrix}
M_{hh} & M_{vh} \\
M_{hv} & M_{vv}
\end{bmatrix} = \begin{bmatrix}
1 & 0 \\
0 & f_2
\end{bmatrix} \begin{bmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{bmatrix} \begin{bmatrix}
S_{hh} & S_{vh} \\
S_{hv} & S_{vv}
\end{bmatrix} \begin{bmatrix}
\cos \Omega & \sin \Omega \\
-\sin \Omega & \cos \Omega
\end{bmatrix} \begin{bmatrix}
1 & 0 \\
0 & f_1
\end{bmatrix}
\]

- Faraday rotation: estimated using natural target (HV-VH)
- Channel imbalance: \( f_1 \) (or \( f_2 \)) estimated using natural target under the assumption of channel imbalance ratio stability \( f_2 / f_1 \approx 0.72 \)
Conclusions

- PALSAR Antenna is highly isolated (better than -35 dB)
  - Make possible the calibration of areas with significant topographic relief without DEM
  - Cross-talk can be ignored
  - Antenna Distortion matrix diagonal

JAXA provides data corrected for antenna gain and range variations
User would have to calibrate for Faraday rotation and Channel imbalance $f_1$

Investigation of the Touzi decomposition for calibration using point and extended targets of significant symmetric scattering