POLInSAR Forestry products from Tandem-X: An assessment

by

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Outline

Introduction : X-band POLInSAR and Phase Tubes

New POLInSAR Performance Analysis Tools:

1. Speckle region-width model
2. High Frequency Mu spectrum Estimation

Terrasar-X and ALOS-PALSAR Data Analysis:

1. Glen Affric, Scotland : Pine Forests
2. Tai’an City, China : Mountain Forests
3. Kalimantan, Borneo : Tropical Forest

Conclusions : Quad or Dualpol Modes?

Acknowledgement : All Terrasar-X data provided courtesy of DLR under Research Contracts LAN 0638 and LAN 0943
Tandem-X: A Space-borne single pass Polarimetric Interferometer

2 satellites in close formation orbit..
250 - 500m separation...

... launched June 21st 2010...

..two potential POLInSAR modes
- Dual Polarization (inc. HH/VV)
- Quad Polarization (experimental)
..narrow steep tubes are required, but 2 key features missing:

1. Fuzziness can be due to ‘coherence region’ speckle width in optimization processing
2. The mu-spectrum is key...even for short-steep tubes can lead to poor performance

Speckle Region Width Model

Vertical structure function

\[ f(z) = f_v(z) + m_1(w) \delta(z-z_0) \]

Top of layer

Surface scattering

...key RVOG idea is that when surface = 0, volume only response has a point coherence loci

..BUT, for L looks, speckle will yield a finite region

\[ [\Lambda_8] = \begin{bmatrix} T_3 & \tilde{\gamma}_v T_3 \\ \tilde{\gamma}_v T_3 & T_3 \end{bmatrix} \rightarrow [T_3] = \begin{bmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \]

\[ [\Lambda_8] = \begin{bmatrix} T_2 & \tilde{\gamma}_v T_2 \\ \tilde{\gamma}_v T_2 & T_2 \end{bmatrix} \rightarrow [T_2] = \begin{bmatrix} 2 & 0 \\ 0 & 1 \end{bmatrix} \]

\[ u = [U_N][E] = \begin{bmatrix} e_1 & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & e_N \end{bmatrix} \]

\[ e_i = \sqrt{\frac{\lambda}{2}} \{ G_u(0,0) + i G_u(0,1) \} \]

\[ [\hat{\Lambda}_N] = \sum_{i=1}^{L} uu^T \xrightarrow{L \to \infty} [\Lambda_N] \]
Speckle Curves (for ENL = 100)

Operating point... but how to calculate
The 2 parameters $\Delta$ and $\gamma_{\text{min}}$?

Mean width
Stage 1: Decomposition Theory

\[ T = R(T_s + T_{vs})R^{-1} + T_{vf} \]

Stage 2: RVOG Depolarization by Surface and Volume

\[
T_V = T_{vf} + T_{vs} = m_{vf} \begin{bmatrix} F_{pv} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} + m_{vs} \begin{bmatrix} F_{ps} & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}
\]

Stage 3: Mu spectrum of pixel with matrix T is then given by max.min eigenvalues of

\[
\mu_{1,2,3} = eig(T_{vf}^{-1}T - I) = eig(\frac{1}{m_{vf}} \begin{bmatrix} t_{11} - m_{vf} & t_{12} & 0 \\ t_{12} & t_{22} - m_{vf} & 0 \\ 0 & 0 & t_{33} - m_{vf} \end{bmatrix})
\]

.. Need to estimate 2 parameters for a solution... \( m_{vf} \) and \( F_p \)

\[ f(z) = f_v(z) + m_1(\mathbf{w})\delta(z-z_0) \]
...estimating $m_{vf}$ need to estimate a ratio $Y$ and $F_p$

$$X = \frac{m_s}{m_v} = \frac{am_{so}}{m_{vf} + am_{viso}} \quad \left\{ \begin{array}{c}
Y = \frac{m_{so}}{m_{viso}} \Rightarrow m_{vf} = \frac{Y - X}{Y} t_{33} \\
\end{array} \right.$$
...and SNR Decorrelation

HV/VH Coherence

Terrasar-X

ALOS-PALSAR

Terrasar-X

HH and VV SNR Decorrelation

..suggests using HH/VV dualpol is better than quad!!
..but crucially depends on mu-spectrum for quad vs. dual
Unfiltered C4 Matrix : Terrasar-X Quadpol data
Rank-3 Noise filtered C4 Matrix : Terrasar-X Quadpol data

...‘Noise Free’ Entropy/Alpha/Span HSV Images...looking for good contrast between forest/non-forest
Mu-spectrum...estimating \( Y \)

...forest/non-forest classification and then decomposition over non-forest regions only

\[
Y = \frac{m_{so}}{m_{vso}}
\]

Glen Moriston, Scotland

L-band \( Y = 5.6 \)          X-band \( Y = 1 \)
N.B. We have assumed $k_v = 1$ and 100 looks in the processing...

Glem Moriston, Scotland
...suitable performance measure is ratio of region width to speckle width...should be > 1

..histograms over all forest pixels..X-band
We have developed a new methodology for assessing POLInSAR forest product quality:

..modifies the phase tube concept in 2 ways:
• Speckle region width statistics
• Mu-spectrum estimation from POLSAR data (dual HH/VV or quad)

We have applied this methodology to Tandem-X by using Terrasar-X data archive

..our main conclusion is that dualpol HH/VV mode is the best to use for POLInSAR
..mainly because quadpol employing HV or VH has large SNR decorrelation
..but what about the HH/VV mu-spectrum?

Three sites have been investigated so far:

GLEN AFFRIC, SCOTLAND : wider variance than quad but useful over many areas
TAIAN CITY, CHINA : mu-spectrum is here worse (lower mean) than for Glen Affric
KALIMANTAN, INDONESIA : good HH/VV mu-spectrum compared to quadpol