Time Series Decomposition Analysis for Compact Polarimetry

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RCM: Radar for Forestry

- 3 satellite constellation
- Launch 2015-2017
- C-Band Imaging Radar

Ecosystem Monitoring

<table>
<thead>
<tr>
<th>User Requirements</th>
<th>Expected Results and Benefits</th>
<th>SAR Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forestry</td>
<td></td>
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<tr>
<td>• Clearcut harvest with partial cut detection.</td>
<td>• Better assessment of forestry parameters.</td>
<td>Monitoring riparian leave strips in forest clearcuts with multi-temporal RADARSAT Fine 2 mode image data.</td>
</tr>
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<td>• Forest typing.</td>
<td>• Improved forestry management.</td>
<td></td>
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<tr>
<td>• Biomass estimation.</td>
<td>• Better production capacity of forest lands.</td>
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<tr>
<td>• Disturbance detection.</td>
<td>• Canadian international leadership in forest management and monitoring.</td>
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</table>

• Maritime Surveillance
• Disaster Monitoring
• Eco-system Monitoring

...potentially using compact polarimetry: RHC transmit.. H&V receive...
### m-alpha Decomposition

**2-layer Vegetation Model**

Our approach...

Compact Decomposition

\[
g = 2m_v \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} + \frac{m_s}{2} \begin{bmatrix} 1 \\ \sin 2\alpha_s \cos \phi \\ \sin 2\alpha_s \sin \phi \\ \cos 2\alpha_s \end{bmatrix}_{RHC}
\]

\[
\begin{align*}
    m_v &= \frac{1}{2} g_0 (1 - D_p) \\
    m_s &= 2 g_0 D_p \\
    \alpha_s &= \frac{1}{2} \tan^{-1}\left(\frac{\sqrt{g_1^2 + g_2^2}}{g_3}\right) \\
    \phi &= \arg(g_1 + ig_2)
\end{align*}
\]

Random Volume RV  \quad  Rank-1  \quad  Fully invertible model

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...but
HV is not directly measured in Compact...but it can be estimated from a model e.g.

\[ t_{33} = 4 \sigma_{HV} = \frac{1}{2} g_0 (1 - D_p) \Rightarrow \sigma_{HV} = \frac{1}{8} g_0 (1 - D_p) \]

Compact Crosspol estimation

Notes:

- HV estimate corresponds to volume scattering in Freeman-Durden* decomposition
- Dp is the degree of polarization (a coherence)
- VEGETATION MONITORING LEADS TO LOW COHERENCE STATISTICS
- FILTERING AND ESTIMATION NON-TRIVIAL….space-time filtering considered

## RADARSAT-2 TIME SERIES

### HINTON, ALBERTA, 15 consecutive FQW datasets

### PETAWAWA, ONTARIO, 16 interrupted data sets

<table>
<thead>
<tr>
<th>Track</th>
<th>Petawawa FQ9 (A01-28') A, 22:35 UTC</th>
<th>Petawawa FQ10W (A01-30') D, 14:12 UTC</th>
<th>Hinton Tmax/min (°C)</th>
</tr>
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<tbody>
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<td>30.4/1.1</td>
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<tr>
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<td>26/12/09 0.3/-2.5 06/05/12</td>
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<td>23/08/10 25.8/16.8 23/06/12</td>
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<td>15</td>
<td>03/11/10 8.7/-6.1 10/08/12</td>
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<td>16</td>
<td>27/11/10 -1.6/-10.8</td>
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Space vs. Time Filtering of Compact Dp

- Space only
- Time average
- Combined time space average

Degree of polarization

Time
\[ c = \begin{bmatrix} a_1 & a_2 & d_1 & d_2 & d_3 & v_1 & v_2 & s_1 \end{bmatrix} \]

8 thresholds values set using physics of decomposition.
Rule Based Land-Use Classifier

Spatial averaging: 2 cases:
1. multilook (ML)
2. ML+ 5x5 boxcar

Products used:
- $2g_0$
- $\alpha$
- $Dp$
- $Vol_{min}$

$c = [20 \ 60 \ 0.25 \ 0.33 \ 0.5 \ -16 \ -22 \ -16]$
Petawawa C-Band Radar Classification
Hinton Optical Image
Hinton C-Band Radar Classification

Good general performance but poor biomass discrimination..

..augment C-band with X-band data..
POLInSAR Forest Height product: Tandem-X

good for forest height...poor for other land-use types
3-level Forest Height Classifier: Tandem-X only
Merged C-Band Compact + Tandem-X Height
Conclusions

• Compact Mode leads to low coherence estimation for vegetation monitoring requires combined space-time filtering...
  ..we found time filtering to be useful, even over long periods..

• Good Filtering leads to design of robust rule-based classifier
  we used one test site (Petawawa) to train and then
  another (Hinton) for validation

• Found good general performance but poor discrimination of forest biomass
  so augmented by Tandem-X POLInSAR height estimate..
  3-level high biomass classes

• Merged products into consistent classifier X-Band POLInSAR + C-band compact

• Could be used to augment forest coverage of other sensors e.g. ESA-BIOMASS
Acknowledgements:

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