Polarimetric decomposition analysis of Sea Ice data

M.-A. Moen¹, L. Ferro-Famil⁴,¹, A. P. Doulgeris¹, S. N. Anfinsen¹, S. Gerland³, T. Eltoft¹,²

¹University of Tromsø, Norway, ²Norut Tromsø, Norway, ³Norwegian Polar Institute, Norway, ⁴University of Rennes 2, France
Outline:

- Objectives
- Preliminaries
- PolSAR image segmentation
- Polarimetric analysis
- Summary and future work
Our objective is

• Combine in-situ and satellite observations to develop methodologies for analysis of polarimetric SAR data of sea ice

• to improve physical understanding of the interaction EM waves and sea ice, and the interpretation of polarimetric sea ice features
Wave scattering from sea ice (from Nghiem et al., (1995)).
Sea ice physical structure

FIG. 1. Simplified geometry of first-year sea ice.

FIG. 2. Simplified geometry of multiyear sea ice.
Work flow

1. Image segmentation from statistical modelling
2. Scattering properties from PolSAR analysis
3. Classification into sea ice types
4. Estimation of geophysical parameters
Validation measurements

- Quad pol RS2, Dual pol TSX data
- Ground Electromagnetics (Geonics EM31) and snow depth measurements
- Airborne EM profiling (AWI-EM Bird)
- Calibration and Validation Drillings

Satellite data

Drillings

Helicopter EM
Study area
RS2 image: Drift ice North of Svalbard, April 2011

- Refrozen lead
- Nilas
- Nilas with frost flower
- Thin smooth ice
Segmentation

Mixture of Gaussian modelling on selected features

\[ p(x; q) = \sum_{i=1}^{K} \mu_i p_i(x; q_i) \]

Segmentation: Recover mixture components using the EM algorithm

- Set number of classes
- Iterative algorithm:
  - Assigns pixels to clusters according to a Bayesian rule
  - Re-estimate mixture parameters
- Spatial context using a Markov Random Field model
Extended Polarimetric Feature Space (EPFS)

Basic Six Real Features:

1. A non-Gaussianity measure: relative kurtosis RK

\[
RK = \frac{1}{N d(d + 1)} \sum_{i=1}^{N} [s_i^H C^{-1} s_i]^2
\]

2. An absolute backscatter value: MRCS = \(d \sqrt{\text{det}(C)}\)

3. A cross-polarisation fraction or ratio: \(R_{cr} = C_{hvhv}/\text{MRCS}\)

4. A co-polarisation ratio: \(R_{co} = C_{vvvv}/C_{hhhh}\)

5. The co-polarisation correlation magnitude: \(|\rho|\)

\[
\rho = C_{hhvv}/\sqrt{(|C_{hhhh}| |C_{vvvv}|)}
\]

6. The co-polarisation correlation angle: \(\angle \rho = < \phi_{hh} - \phi_{vv} >\)

Note: All features are texture model independent.
Sea Ice: class vs. thickness
Sea Ice: Yellow class

Yellow area
- Thin ice
- Open water
- New ice
- Nilas
- Gray ice
7 class segmentation

Pauli image

7 classes segmented image
Feature histograms
NNED FD Decomposition

\[ T = P_s T_s + P_d T_d + P_v T_v \]

\[
T_s = \frac{1}{1 + |\beta|^2} \begin{bmatrix} 1 & \beta & 0 \\ \beta^* & |\beta|^2 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad T_d = \frac{1}{1 + |\alpha|^2} \begin{bmatrix} |\alpha|^2 & \alpha & 0 \\ \alpha^* & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad T_v = \frac{1}{4} \begin{bmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}
\]

\[ T_g = T - \alpha T_v \quad \text{where} \quad \alpha = \text{minimum eigenvalue of} \{ T_v^{-1} T \} \]

\[
\begin{bmatrix} T_{g,11} & T_{g,12} \\ T_{g,12}^* & T_{g,22} \\ T_{g,33} \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{12}^* & T_{22} \end{bmatrix} - \frac{\alpha}{4} \begin{bmatrix} 2 & 1 \\ 1 & 1 \end{bmatrix}
\]
\[
\begin{bmatrix}
T_{g,11} & T_{g,12} \\
T_{g,12} & T_{g,22}
\end{bmatrix}
\]

\[
P_v = a = 4T_{g,33}
\]

\[
\begin{align*}
P_s &= T_{g,11} + \left| T_{g,12} \right|^2 / T_{g,11} \\
P_d &= T_{g,22} - \left| T_{g,12} \right|^2 / T_{g,11}
\end{align*}
\]

\[
\begin{align*}
P_s &= T_{g,11} - \left| T_{g,12} \right|^2 / T_{g,22} \\
P_d &= T_{g,22} + \left| T_{g,12} \right|^2 / T_{g,22}
\end{align*}
\]

\[
\begin{align*}
T^*_{g,12} &> T_{g,22} \\
\alpha &= 0, \quad \beta = T_{g,12} / T_{g,11} \\
\beta &= 0, \quad \alpha = T_{g,12} / T_{g,22}
\end{align*}
\]
Scattering mechanisms vs. classes

<table>
<thead>
<tr>
<th>Pauli image</th>
<th>Segmented image</th>
<th>$P_d/SPAN \geq 0.06$</th>
<th>$P_i/SPAN \geq 0.32$</th>
<th>$P_d/SPAN \geq 0.06$</th>
<th>$P_i/SPAN \geq 0.32$</th>
<th>$P_d/SPAN \geq 0.06$</th>
<th>$P_i/SPAN \geq 0.32$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_i/SPAN \geq 0.7$</td>
<td>$P_i/SPAN \geq 0.32$</td>
<td>$P_i/SPAN \geq 0.32$</td>
<td>$P_i/SPAN \geq 0.32$</td>
<td>$P_i/SPAN \geq 0.32$</td>
<td>$P_i/SPAN \geq 0.32$</td>
<td>$P_i/SPAN \geq 0.32$</td>
<td>$P_i/SPAN \geq 0.32$</td>
</tr>
</tbody>
</table>
Some other polarimetric features

<table>
<thead>
<tr>
<th>Pauli image</th>
<th>Entropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH/VV ratio</td>
<td>RR-LL Coherence</td>
</tr>
</tbody>
</table>
Summary

• In-situ data confirm the validity of the statistical image segmentation
• Thin ice and open water are distinctively detected
• The model-based decomposition shows predominantly surface scattering. Volume scattering is also significant in some areas.
• Some of the segments are clearly dominated by certain types of scattering. This may help labeling classes.
• The polarimetric features allow identification of smooth areas and areas of deformation.
Further research

- Add automatic class determination
- Investigate other models for the volume component
- Further validation using other scenes from the area
- Compare TSX and RS2 observations.
- Examining decomposition based on only co-pol observations