→ POLINSAR 2013
The 6th International Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry

Polarimetric decomposition analysis of Sea Ice data

M.-A. Moen[1], L. Ferro-Famil[4,1], A. P. Doulgeris[1], S. N. Anfinsen[1], S. Gerland[3], T. Eltoft[1,2]

[1]University of Tromsø, Norway, [2]Norut Tromsø, Norway, [3]Norwegian Polar Institute, Norway, [4]University of Rennes 2, France

Outline

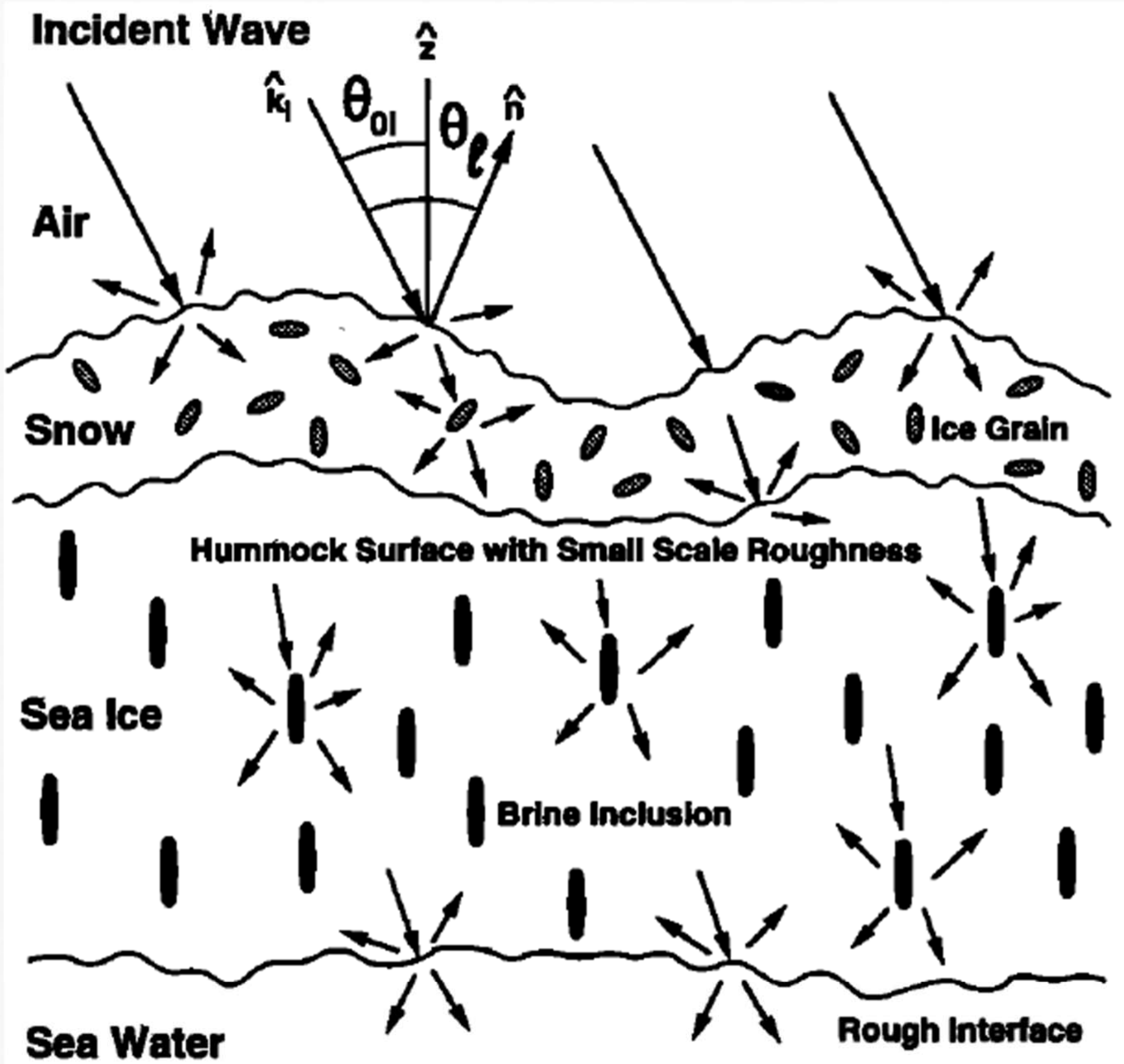
- Objectives
- Preliminaries
- PolSAR image segmentation
- Polarimetric analysis
- Summary and future work

Research goal

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*

EM scattering from sea ie



Wave scattering from sea ice (from Nghiem et al., (1995)).

Sea ice physical structure

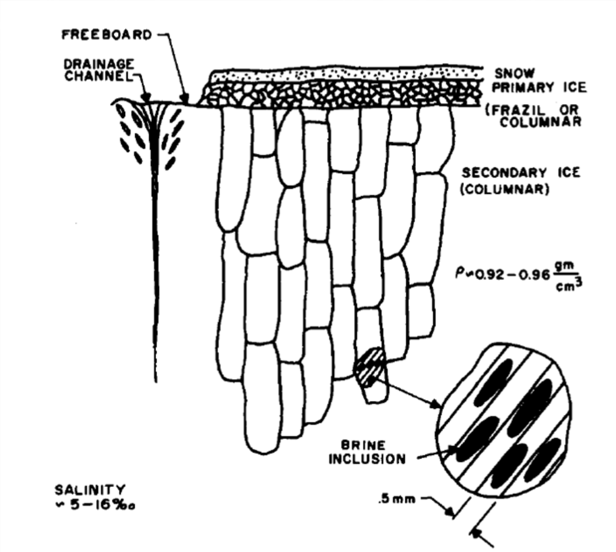


FIG. 1. Simplified geometry of first-year sea ice.

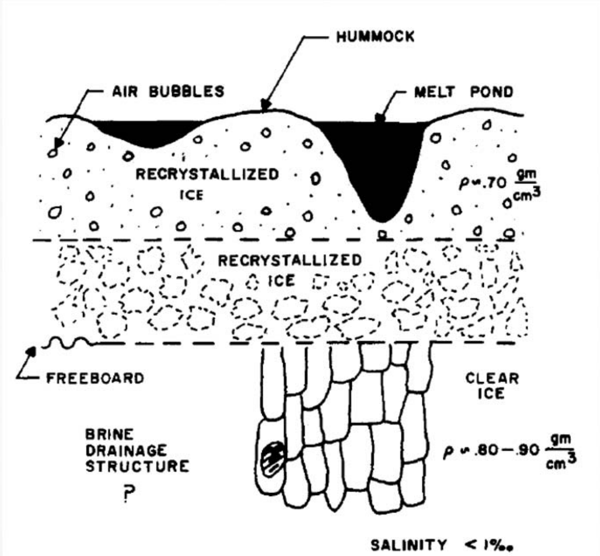
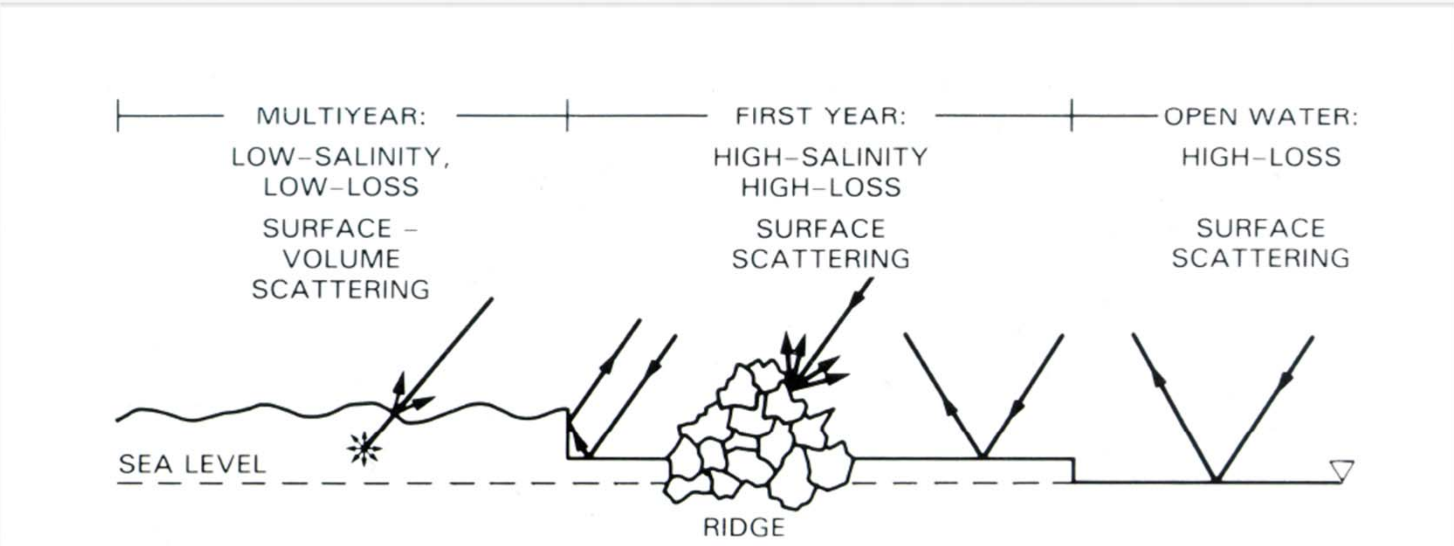


FIG. 2. Simplified geometry of multiyear sea ice.



Work flow

Image segmentation
from statistical modelling

↓

Scattering properties
from PolSAR analysis

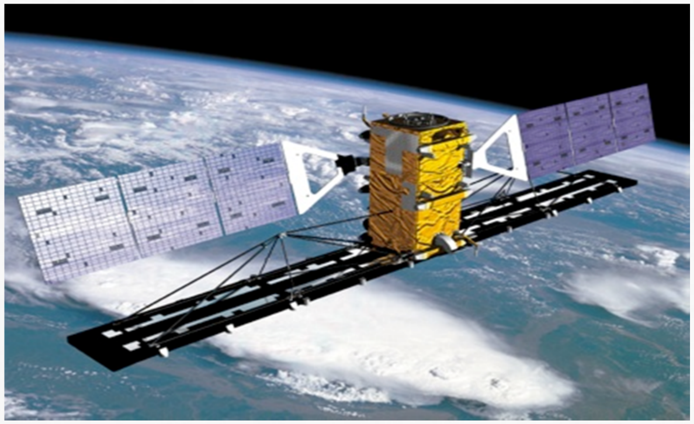
↓

Classification into
sea ice types

↓

Estimation of
geophysical parameters

Validation measurements



Satellite data

Drillings

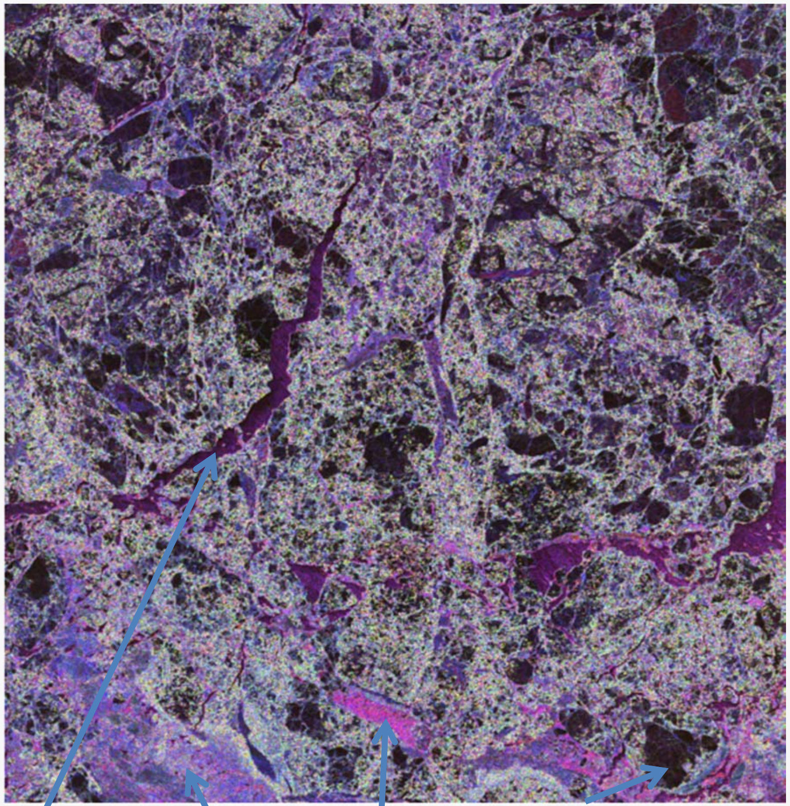
Helicopter EM

- 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

Study area

RS2: Pauli image

RS2 image: Drift ice North of Svalbard, April 2011



Thin smooth ice

Nilas

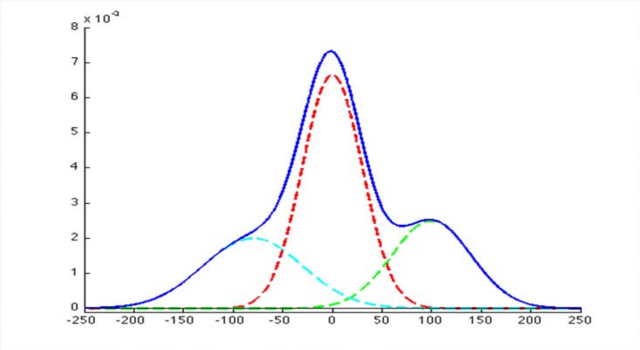
Nilas with frost flower

Refrozen lead

Segmentation

Mixture of Gaussian modelling on selected features

$$p(\mathbf{x};\mathbf{q}) = \sum_{i=1}^{K} \mu_i p_i(\mathbf{x};\mathbf{q}_i)$$



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

$$\mathrm{RK} = \frac{1}{Nd(d+1)} \sum_{i=1}^{N} [\mathbf{s}_i^H \mathbf{C}^{-1} \mathbf{s}_i]^2$$

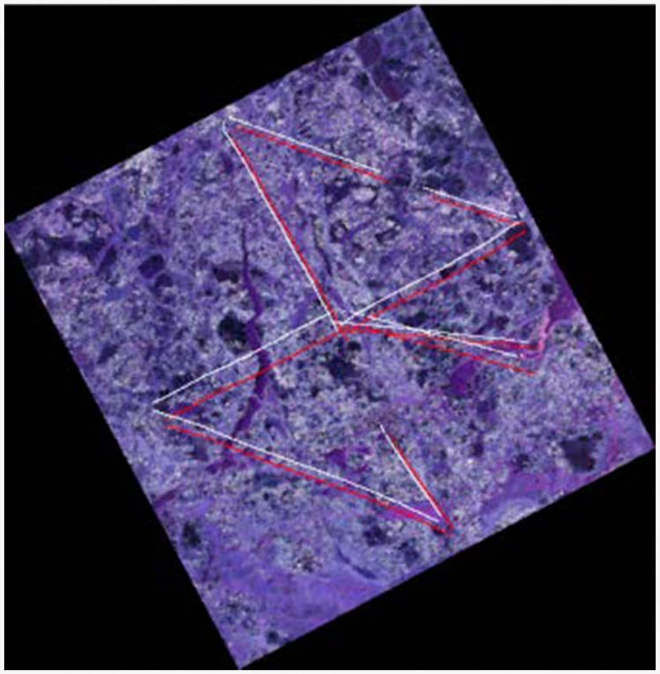
2. An absolute backscatter value: $\mathrm{MRCS} = \sqrt[d]{\det(\mathbf{C})}$
3. A cross-polarisation fraction or ratio: $R_{\mathrm{cr}} = \mathbf{C}_{hvhv}/\mathrm{MRCS}$
4. A co-polarisation ratio: $R_{\mathrm{co}} = \mathbf{C}_{vvvv}/\mathbf{C}_{hhhh}$
5. The co-polarisation correlation magnitude: $|\rho|$

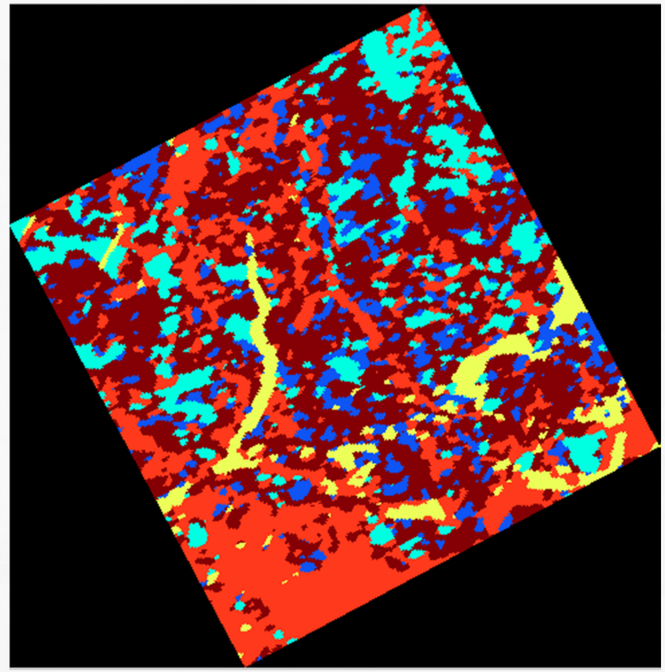
$$\rho = \mathbf{C}_{hhvv}/\sqrt{(|\mathbf{C}_{hhhh}|\ |\mathbf{C}_{vvvv}|)}$$

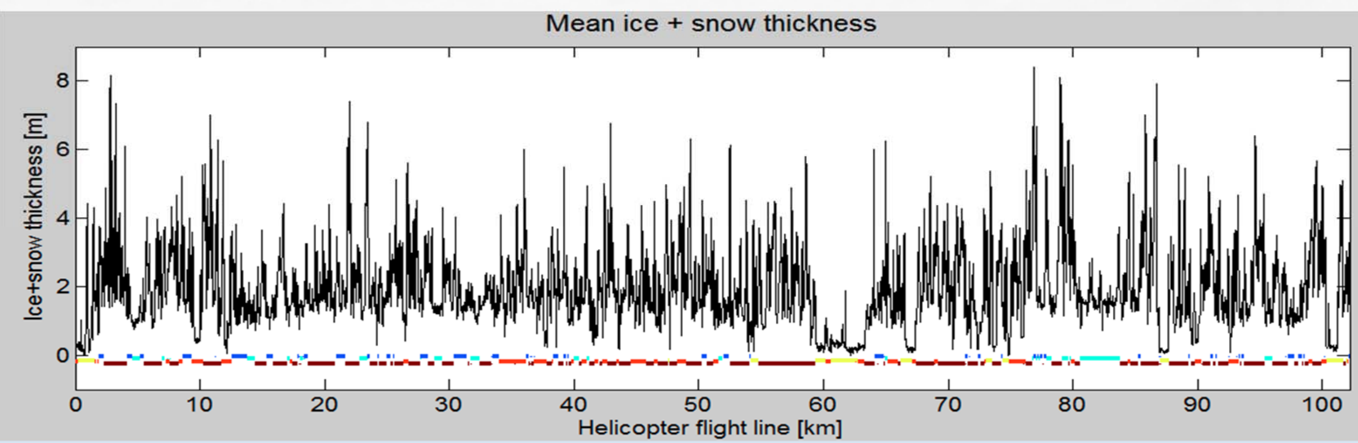
6. The co-polarisation correlation angle: $\angle\rho = < \phi_{hh} - \phi_{vv} >$

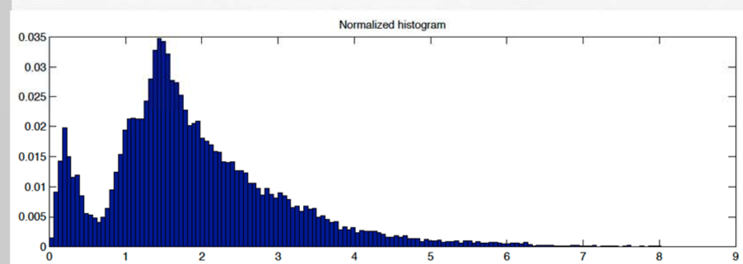
Note: All features are texture model independent.

Sea Ice: class vs. thickness





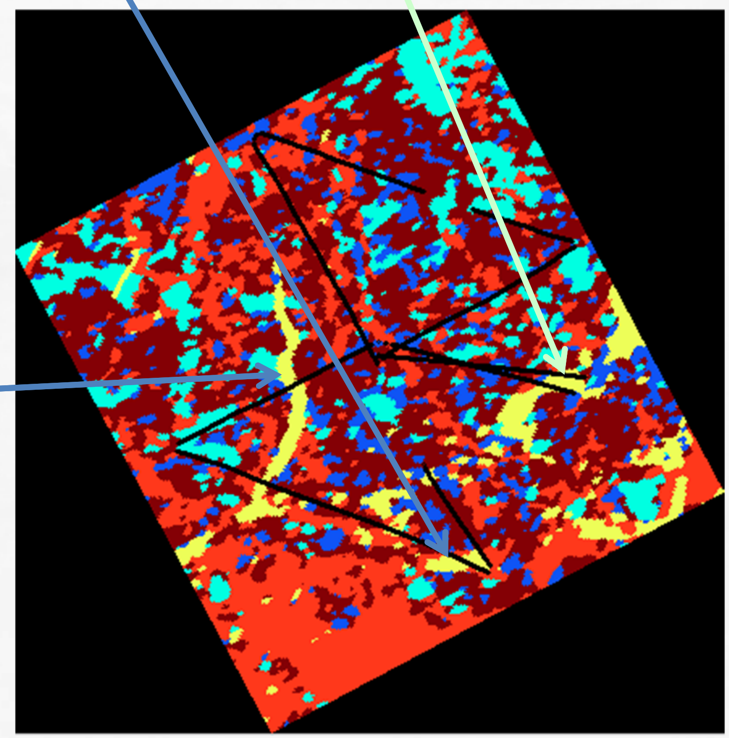




Sea Ice: Yellow class

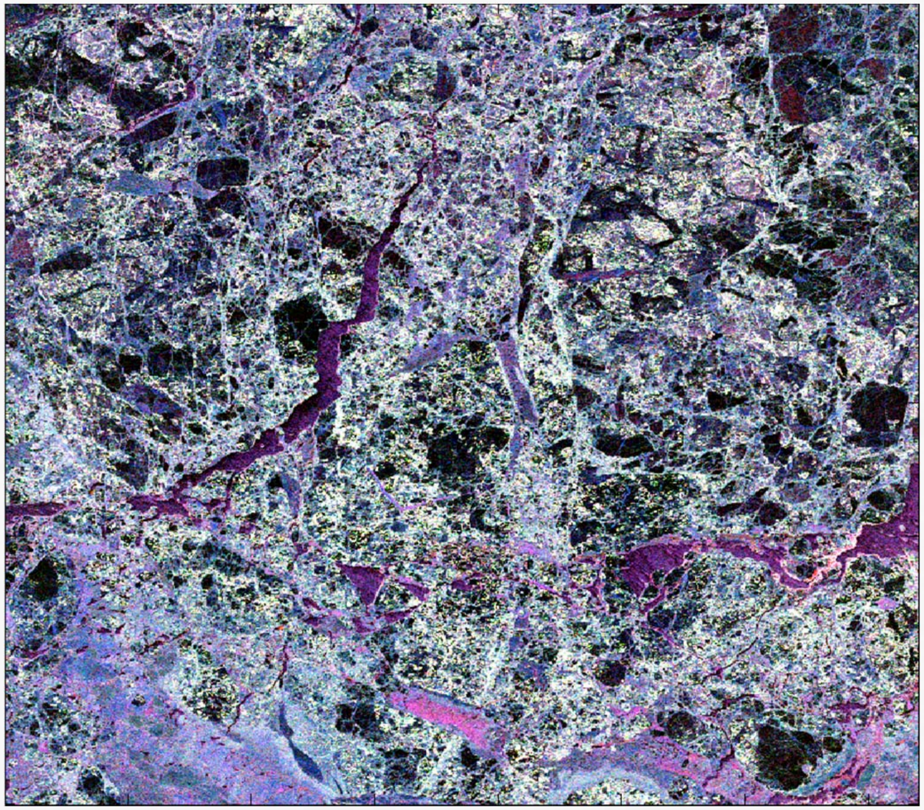
Yellow area

- Thin ice
- Open water
- New ice
- Nilas
- Gray ice

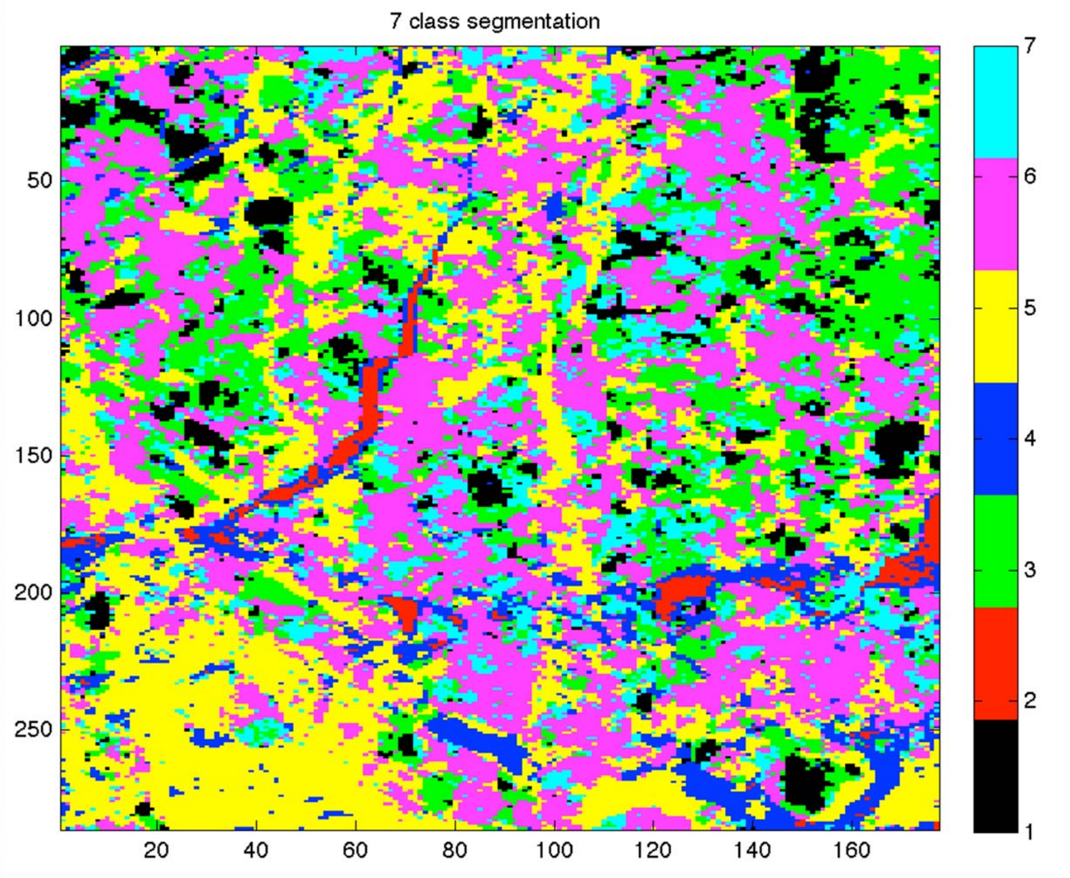


7 class segmentation

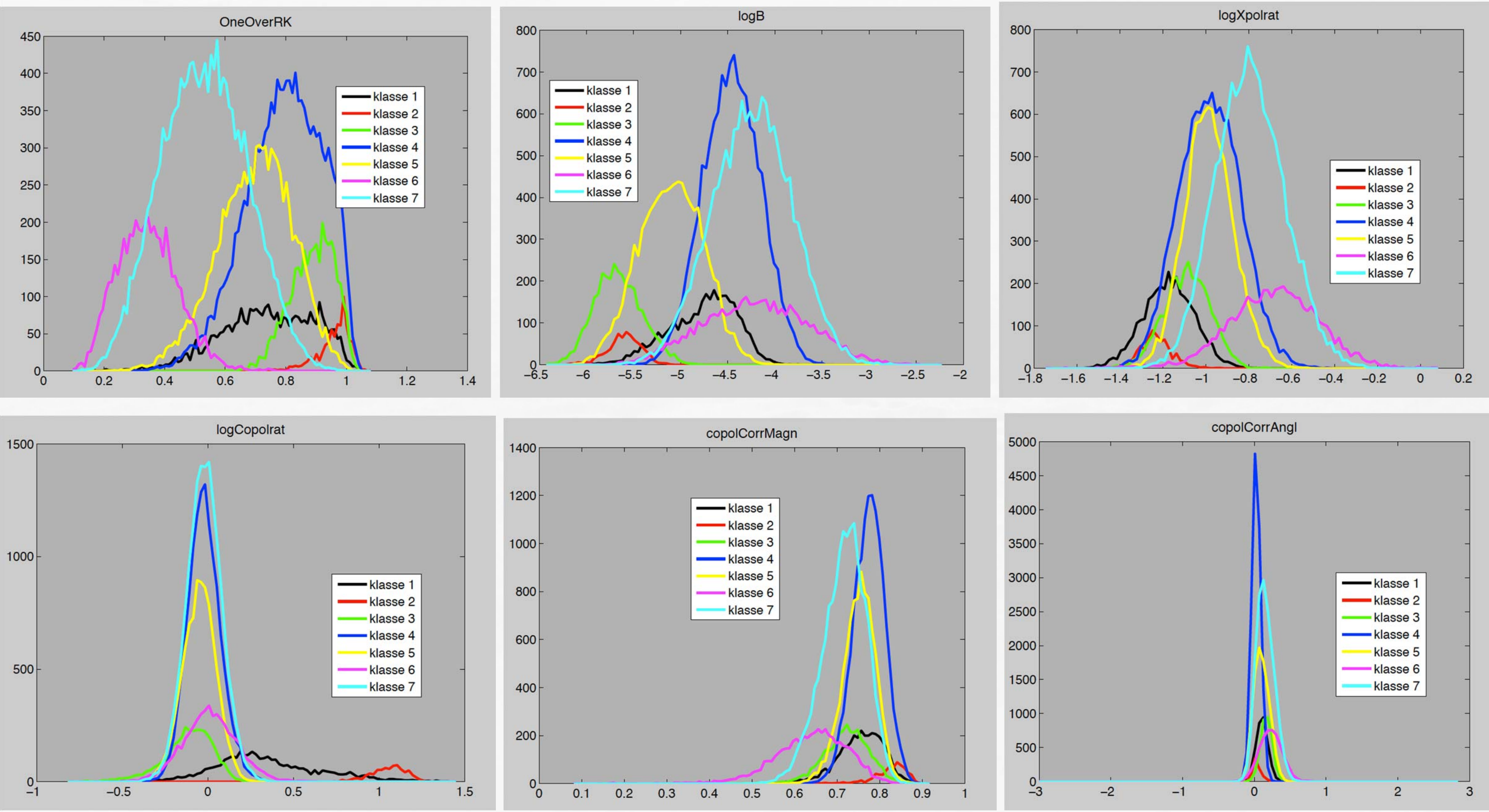
Pauli image



7 classes segmented image



Feature histograms



NNED FD Decomposition

$$T = P_s T_s + P_d T_d + P_v T_v$$

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

$T_g = T - aT_v$ where $a =$ *minimum eigenvalue of* $\{ T_v^{-1} T \}$

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

NNED Freeman Durden

$$\begin{bmatrix} T_{g,11} & T_{g,12} & \\ T^*_{g,12} & T_{g,22} & \\ & & T_{g,33} \end{bmatrix}$$

$$P_v = a = 4T_{g,33}$$

$$T_{g,11} > T_{g,22}$$

yes

$$\alpha = 0,\ \beta = T_{g,12} / T_{g,11}$$

$$P_s = T_{g,11} + |T_{g,12}|^2 \big/ T_{g,11}$$

$$P_d = T_{g,22} - |T_{g,12}|^2 \big/ T_{g,11}$$

no

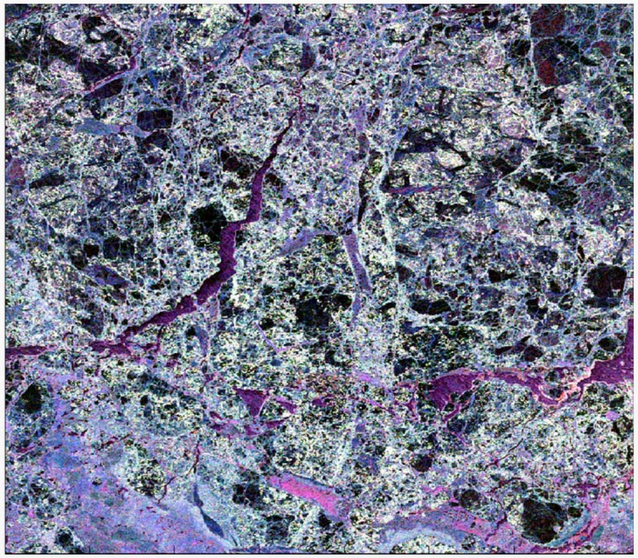
$$\beta = 0,\ \alpha = T_{g,12} / T_{g,22}$$

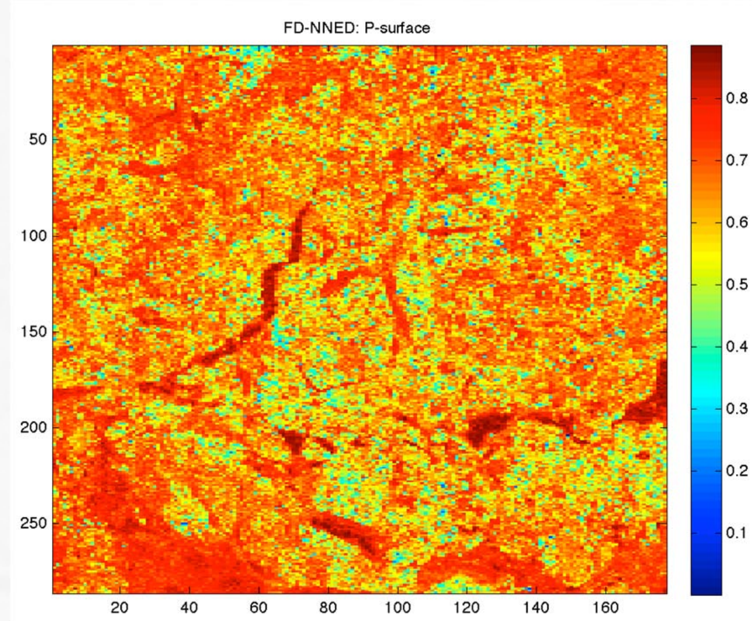
$$P_s = T_{g,11} - |T_{g,12}|^2 \big/ T_{g,22}$$

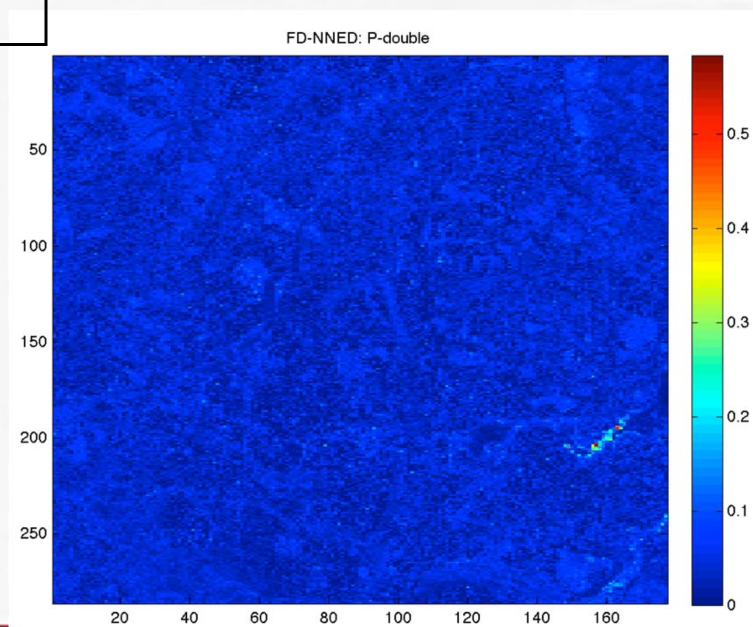
$$P_d = T_{g,22} + |T_{g,12}|^2 \big/ T_{g,22}$$

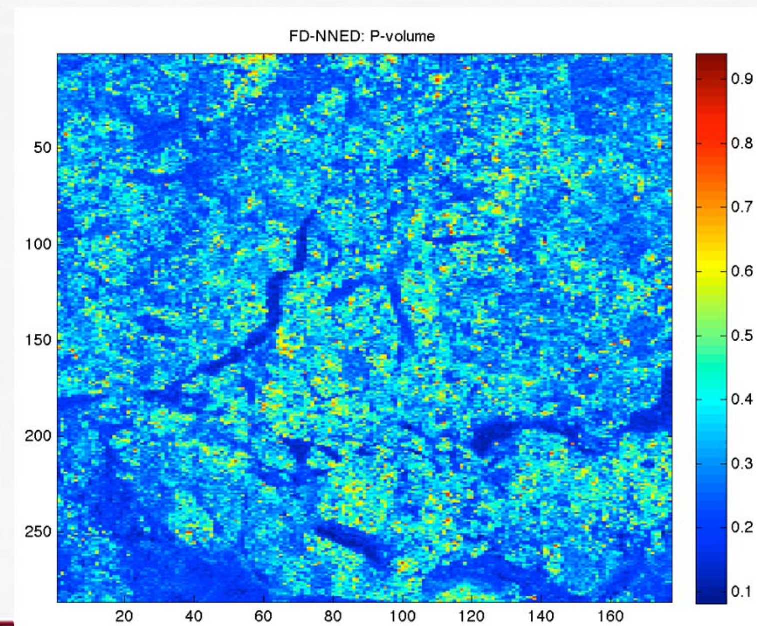
NNED- Freeman Durden

Pauli image	Surface
Double	Volume

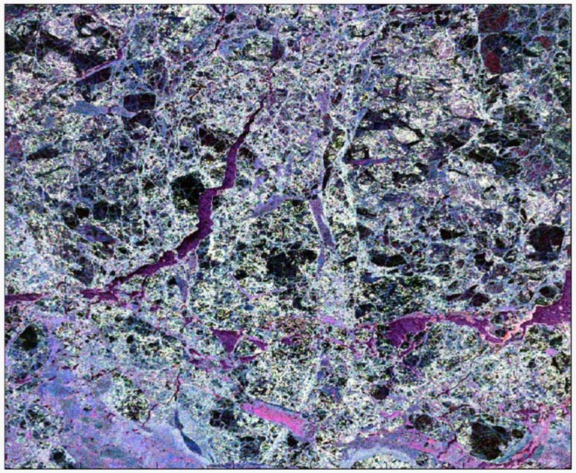


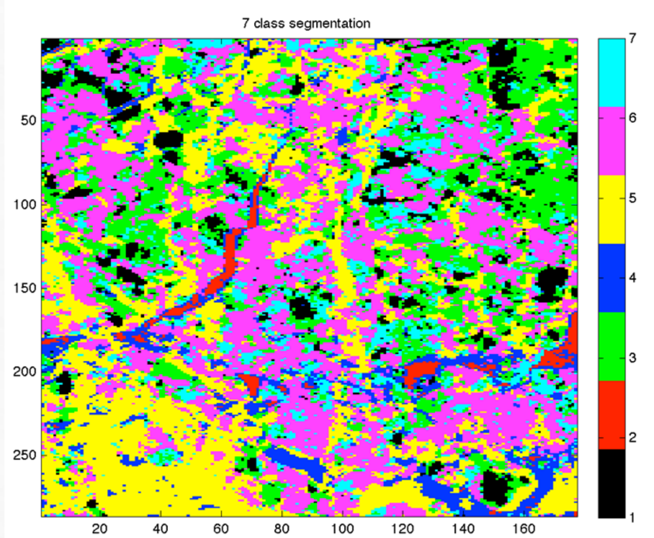


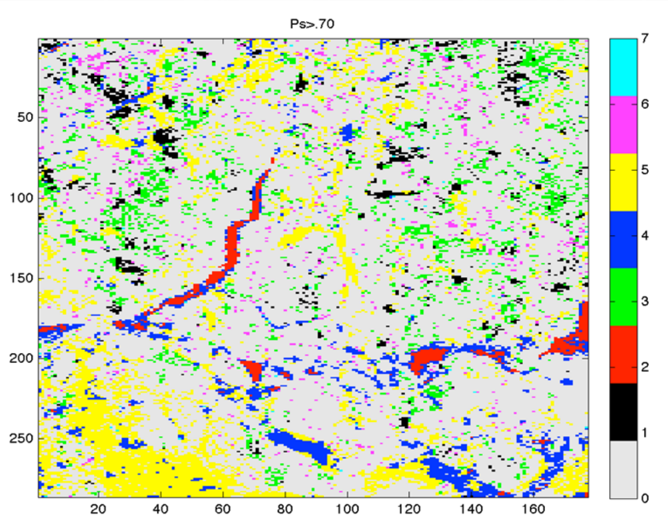




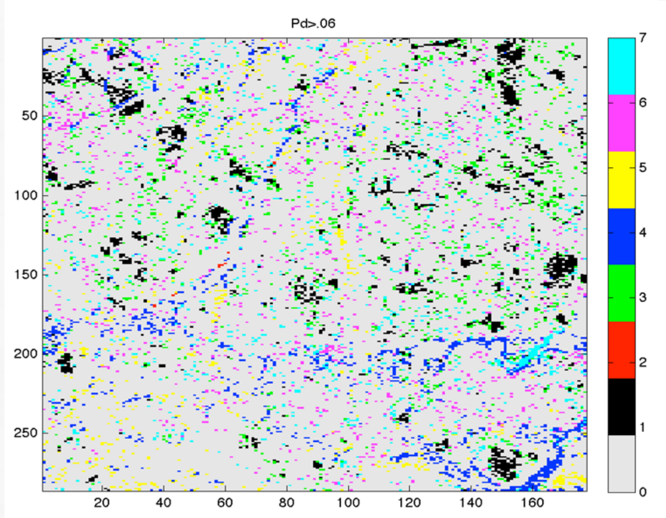
Scattering mechanisms vs. classes

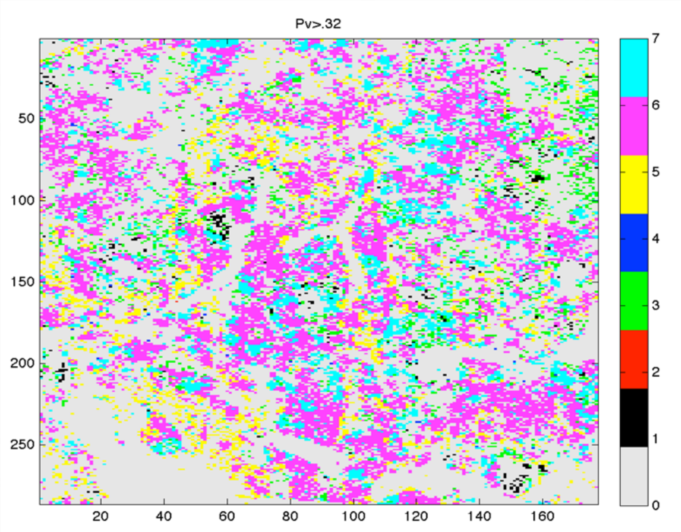






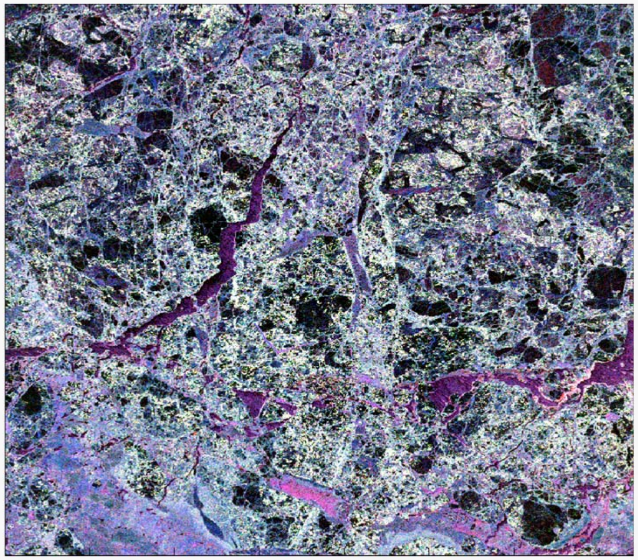
Pauli image	Segmented image	$P_s / SPAN \geq .7$
	$P_d / SPAN \geq .06$	$P_v / SPAN \geq .32$

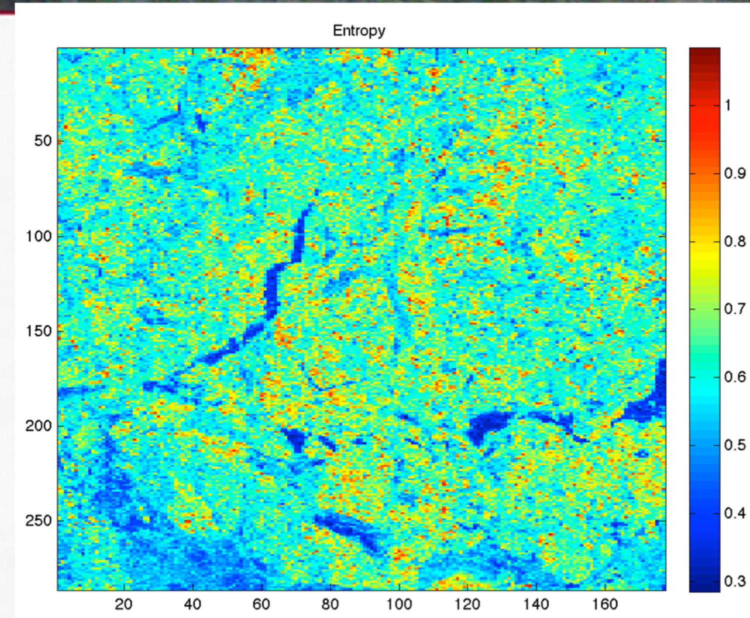


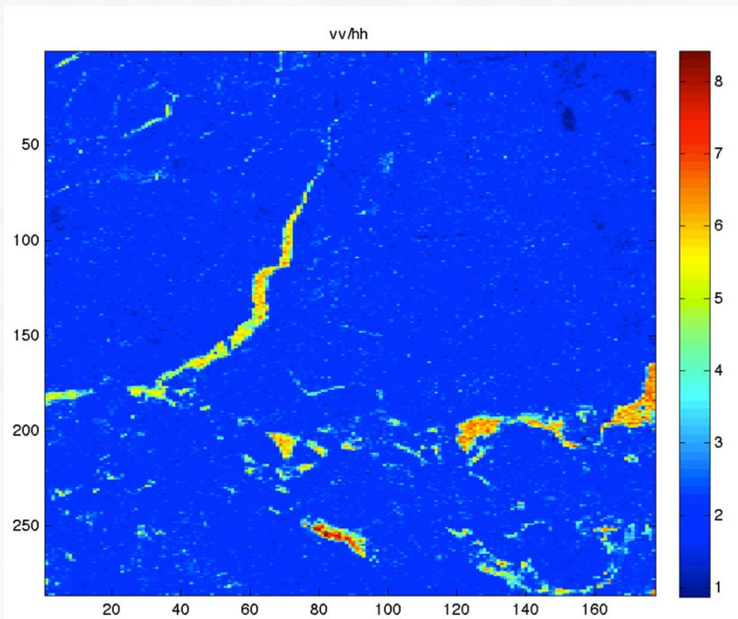


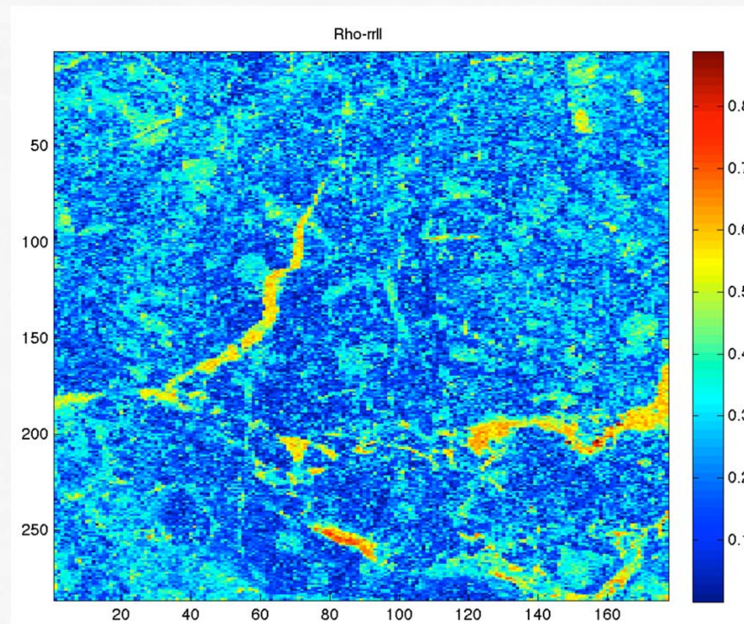
Some other polarimetric features

Pauli image	Entropy
HH/VV ratio	RR-LL Coherence









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