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A simple and extendable segmentation method for multi-polarisation SAR images

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A simple and extendable segmentation method for multi-polarisation SAR images

- Unsupervised segmentation of multi-channel SAR imagery

Main concepts:

- Feature extraction method for textured PolSAR data under the product model
  - Polarimetric features of ratios, magnitudes and phases from the covariance matrix
  - Extended to include radar texture (non-Gaussianity)
- Extendable with other features - data fusion
- Simple image segmentation method suffices
- Fast results

Basic Approach

PolSAR Data	4-D complex data, SLC
↓	
Feature Extraction	local neighbourhoods
↓	
Feature Transformation	6-D real data
↓	
Sub-sampling	[optional speed-up]
↓	
MoG Segmentation	choose number of classes
↓	
Expand to Whole Image	[optional]
↓	
MRF Contextual Smoothing	[optional]
↓	
Segmented Image	label image

PolSAR Image Data

SLC vector data: $\mathbf{s} = [S_{hh}, S_{hv}, S_{vh}, S_{vv}]^T$

MLC matrix data: $\mathbf{C} = \frac{1}{L}\sum_{i=1}^{L} \mathbf{s}_i\mathbf{s}_i^H$

Texture and the Product Model

$$\textit{texture} \times \textit{speckle} : \quad \mathbf{s} = \sqrt{\tau}\mathbf{g} \quad , \quad \mathbf{C} = \tau\mathbf{W}$$

where $\mathbf{g}$ multivariate complex Gaussian distributed

$\mathbf{W}$ matrix-variate complex Wishart distributed

τ texture random variable with its own distribution

Extended Polarimetric Feature Space (EPFS)

Basic Six Real Features:

1. A non-Gaussianity measure: relative kurtosis RK

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

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

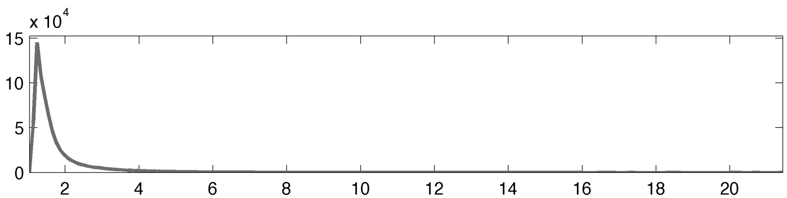
$$\rho = \mathbf{C}_{hhvv}/\sqrt{(|\mathbf{C}_{hhhh}|\,|\mathbf{C}_{vvvv}|)}$$

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

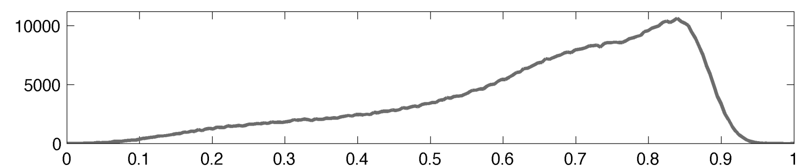
Note: All features are texture model independent.

Feature transforms and histograms

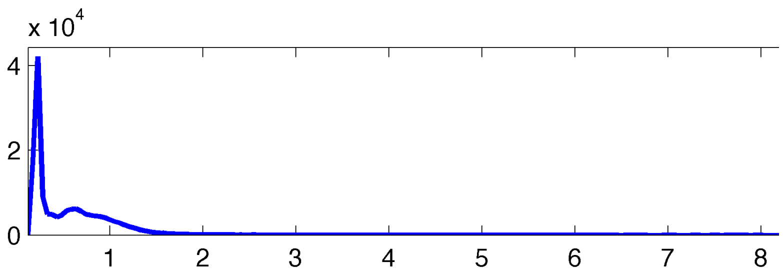
- Transform to reduce non-linearity in data space
  - often with logarithm
- Easier to visualise groupings/peaks
- Permits use of simple segmentation methods



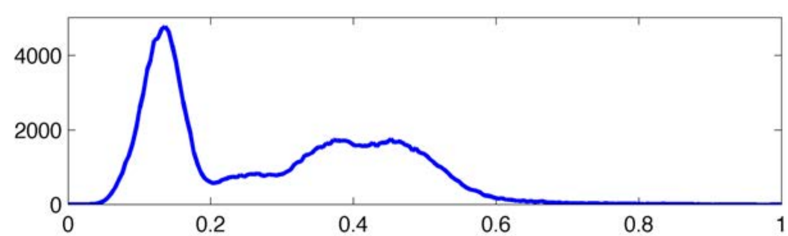
Raw RK



Transformed by inverse

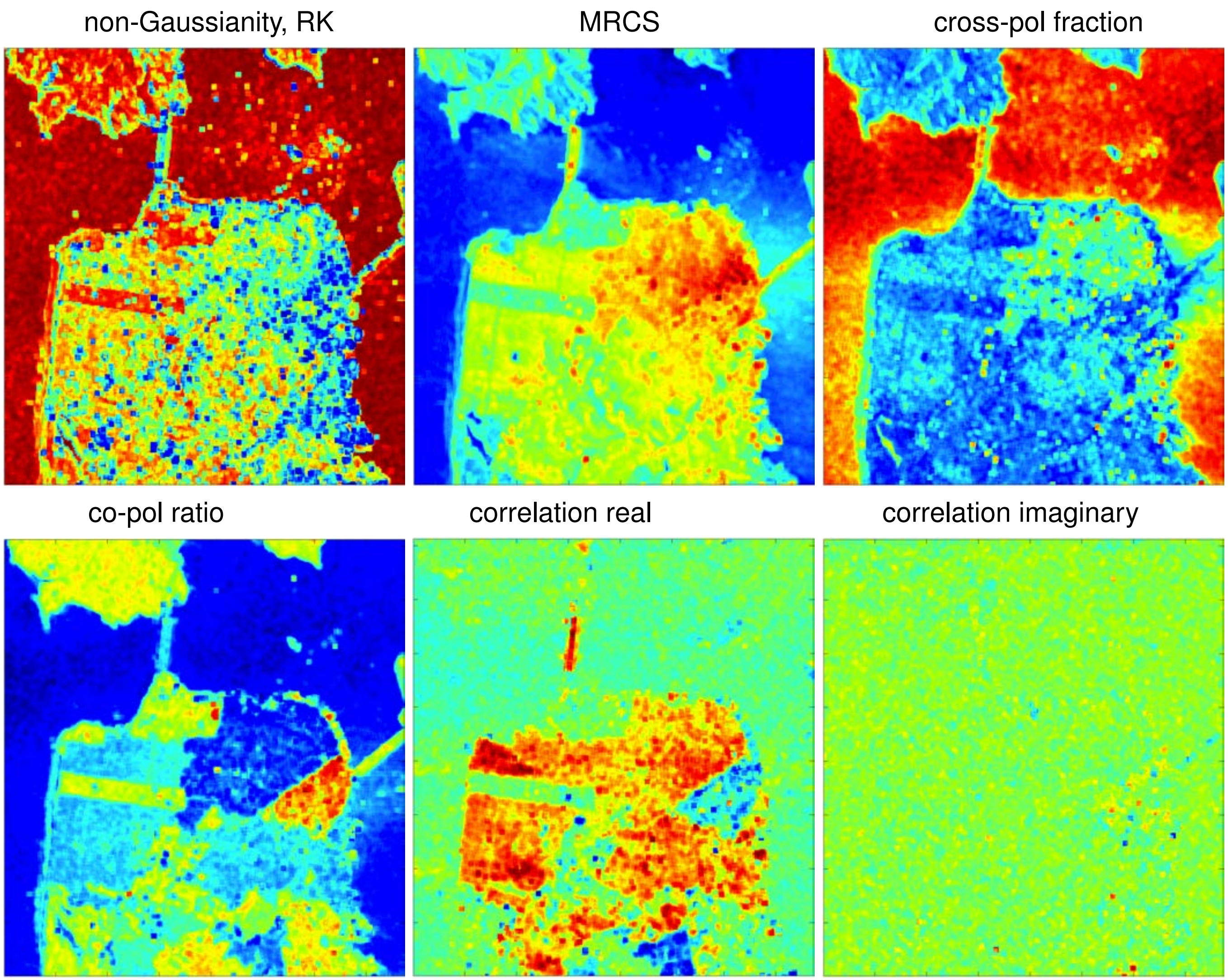


Raw Cross-pol ratio R_{cr}



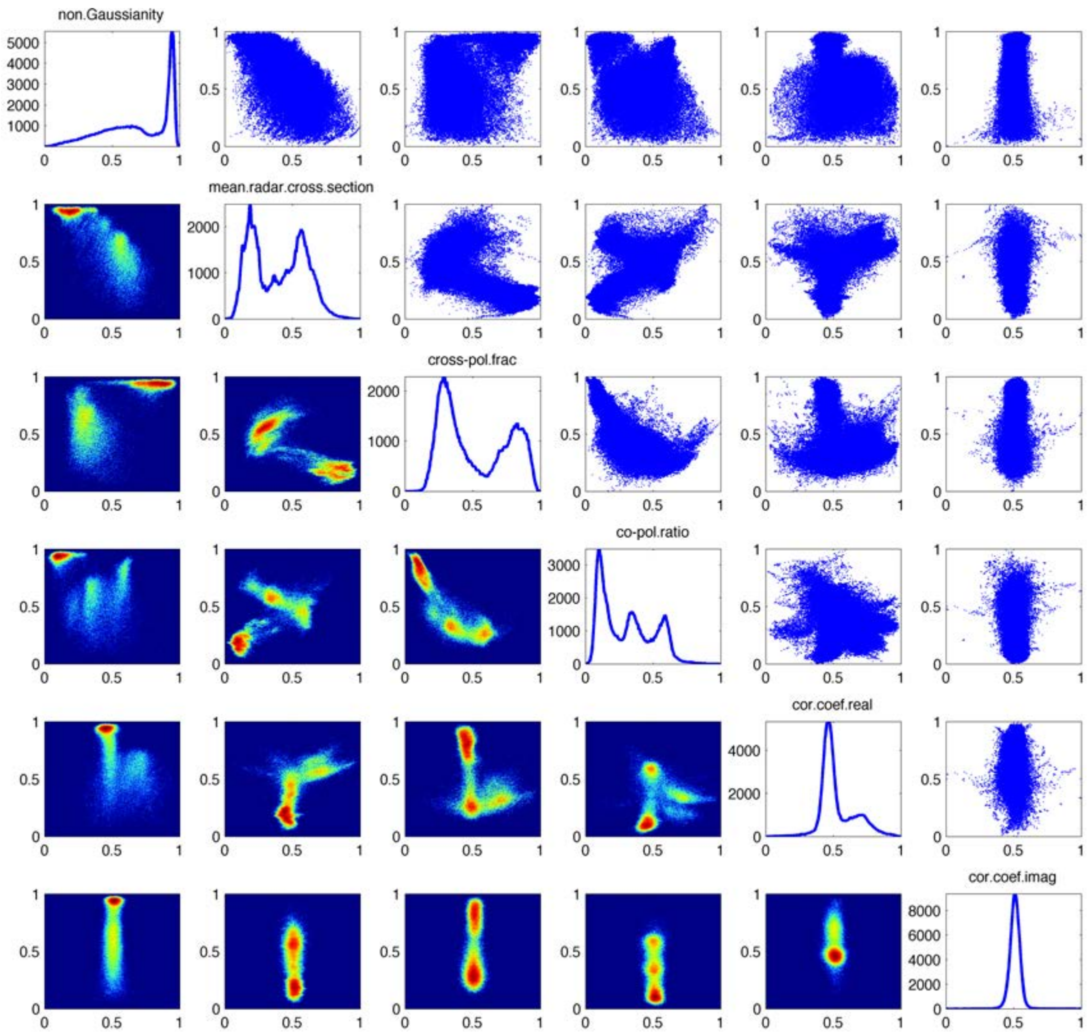
Transformed by logarithm

Example Feature Images - San Francisco

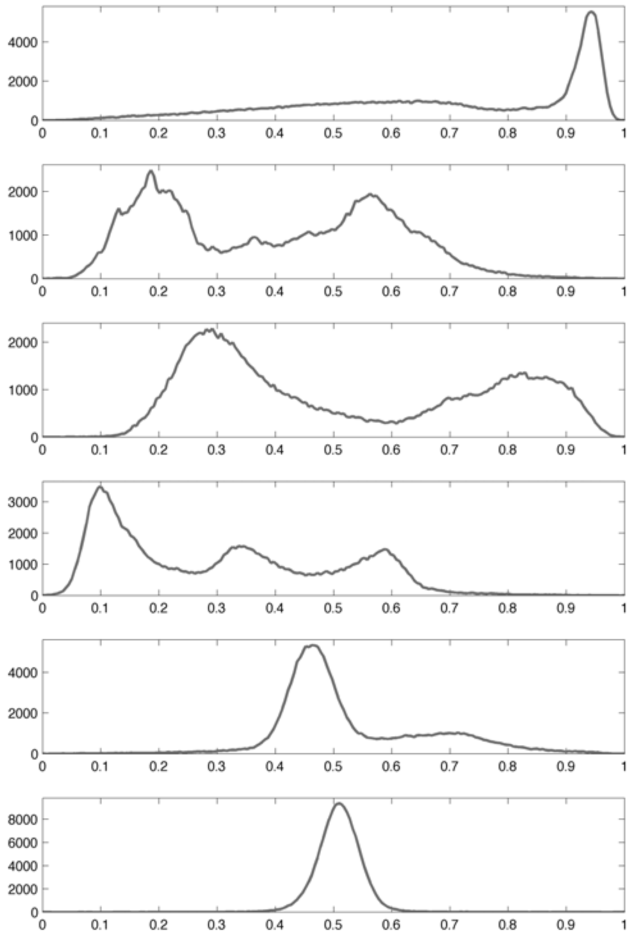


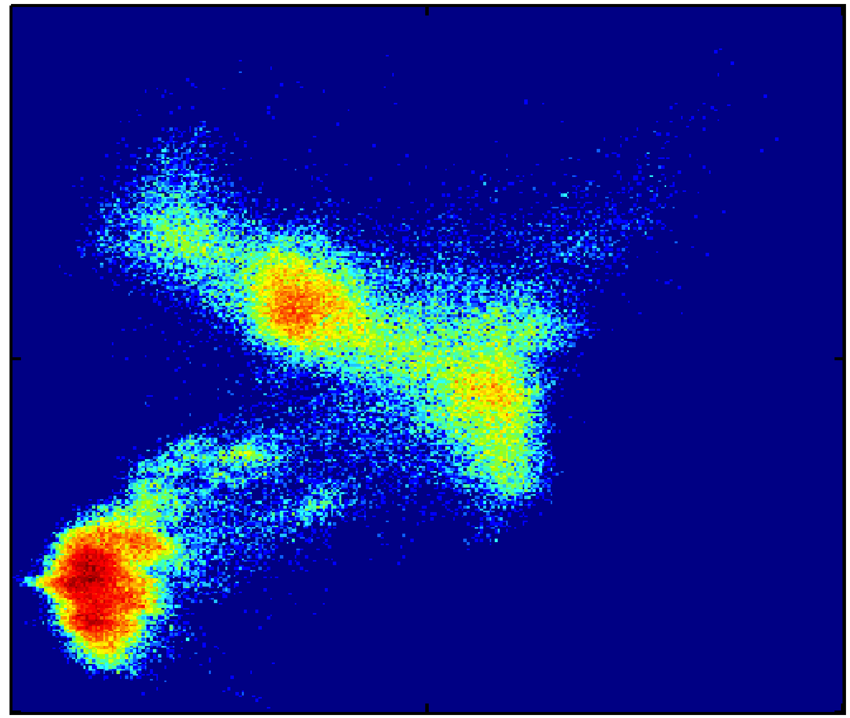
Example Pair-wise Scatter Plots

San Francisco City, Radarsat-2, window 8×4



Simplified Feature Space





Example 2-D scatter plot
MRCS vs. co-pol ratio.
(Radarsat-2, San Fancisco, 2008)

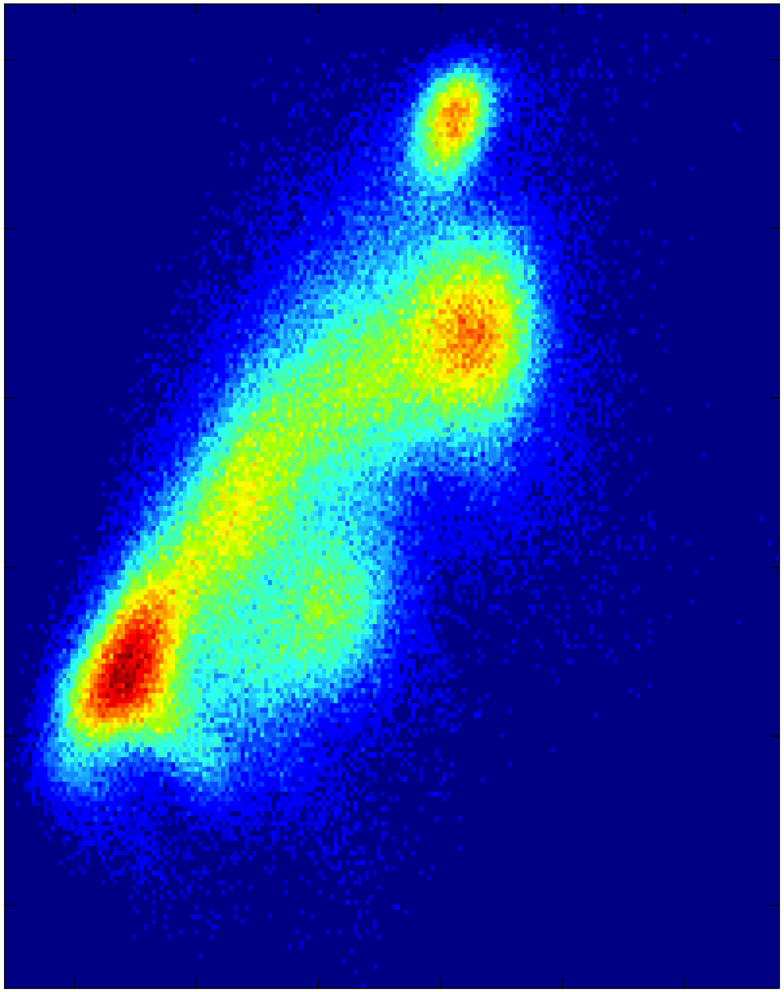
Real Feature Histograms
(Radarsat-2, San Fancisco, 2008)

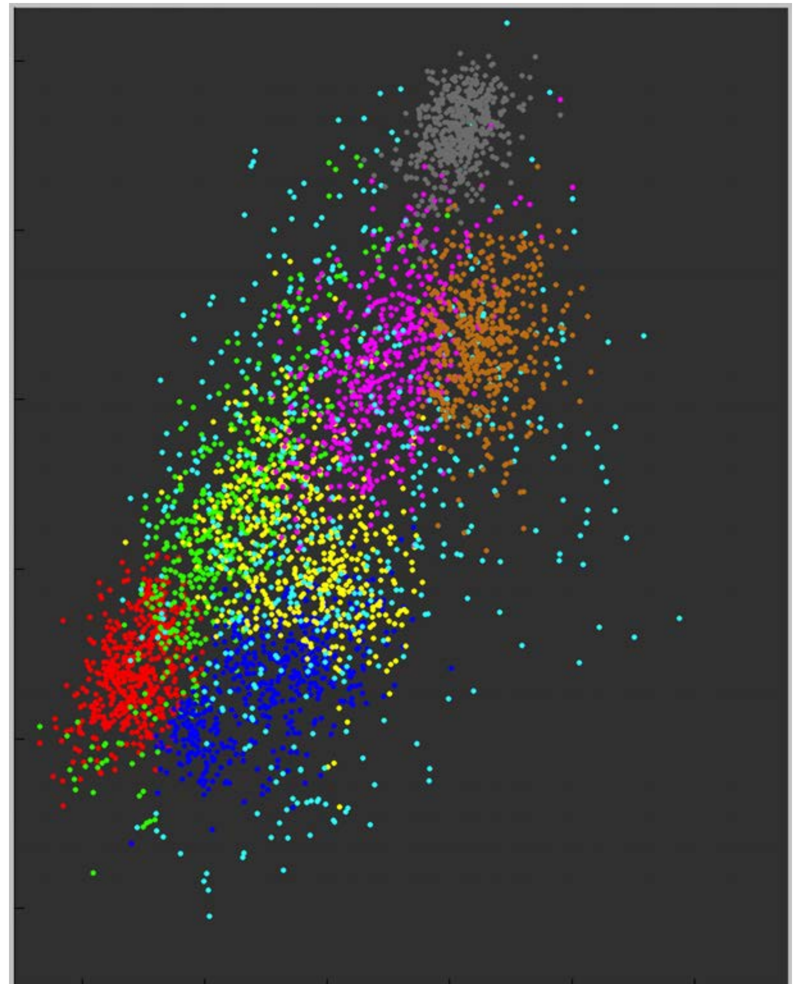
Simple Mixture of Gaussian Segmentation

- Simple globular clusters influenced choice of segmentation method
  $\longrightarrow$ Mixture of Gaussian clustering
- Fast - full scene results in only minutes or seconds.
- Could use k-means or any other unsupervised clustering method, or fully supervised with ground truth data
- Not precisely Gaussian nor symmetric, but at a coarse level (with sub-sampling) it works well
- Will try non-Gaussian or kernel methods in future

Feature Space Clusters

ALOS PALSAR, 2010, Sea Ice around Svalbard.

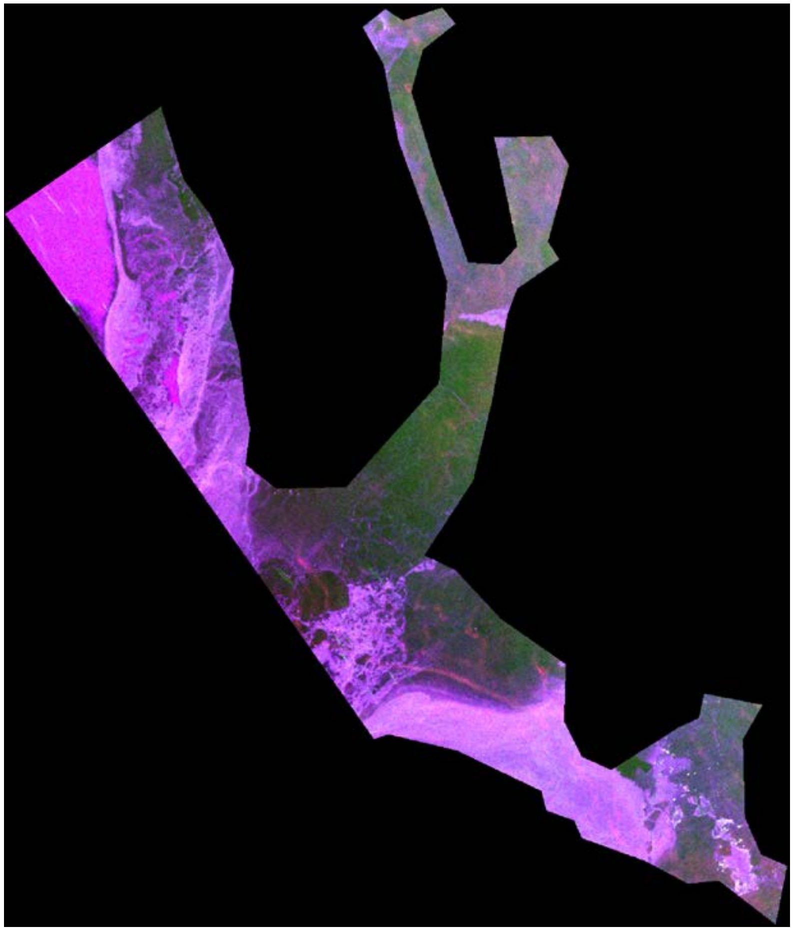




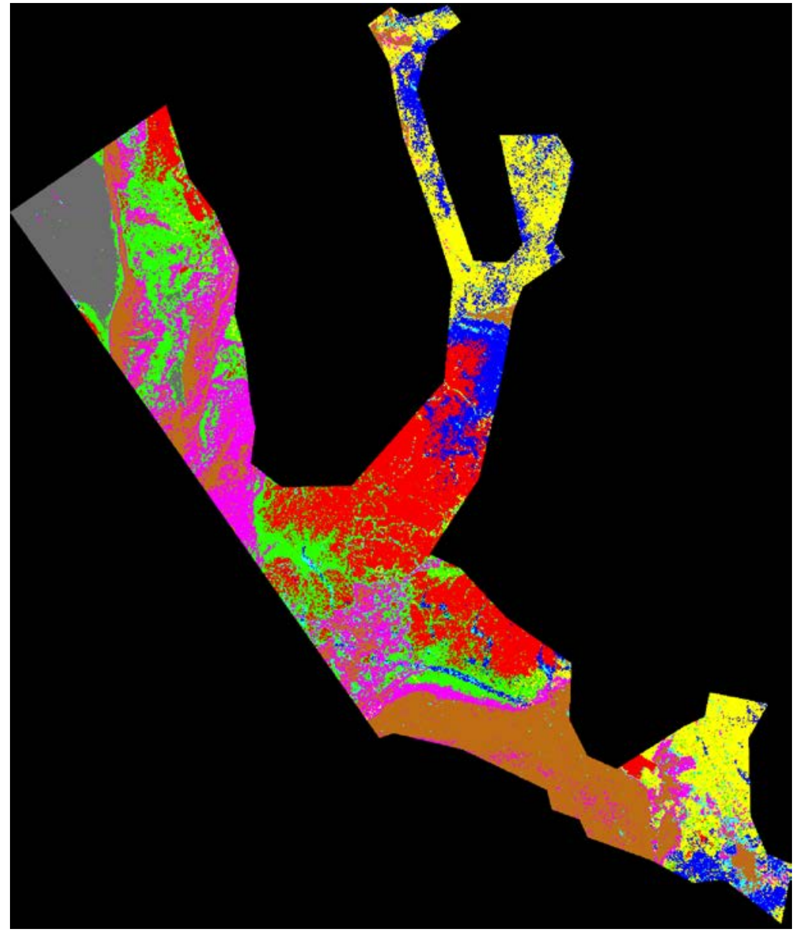
Remember that the segmentation worked on all six features, but only two are shown.

Image Space Clusters

ALOS PALSAR, 2010, Sea Ice around Svalbard.



Pauli RGB

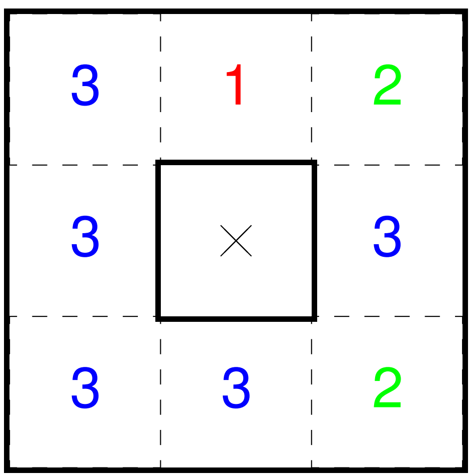


Unsupervised label image

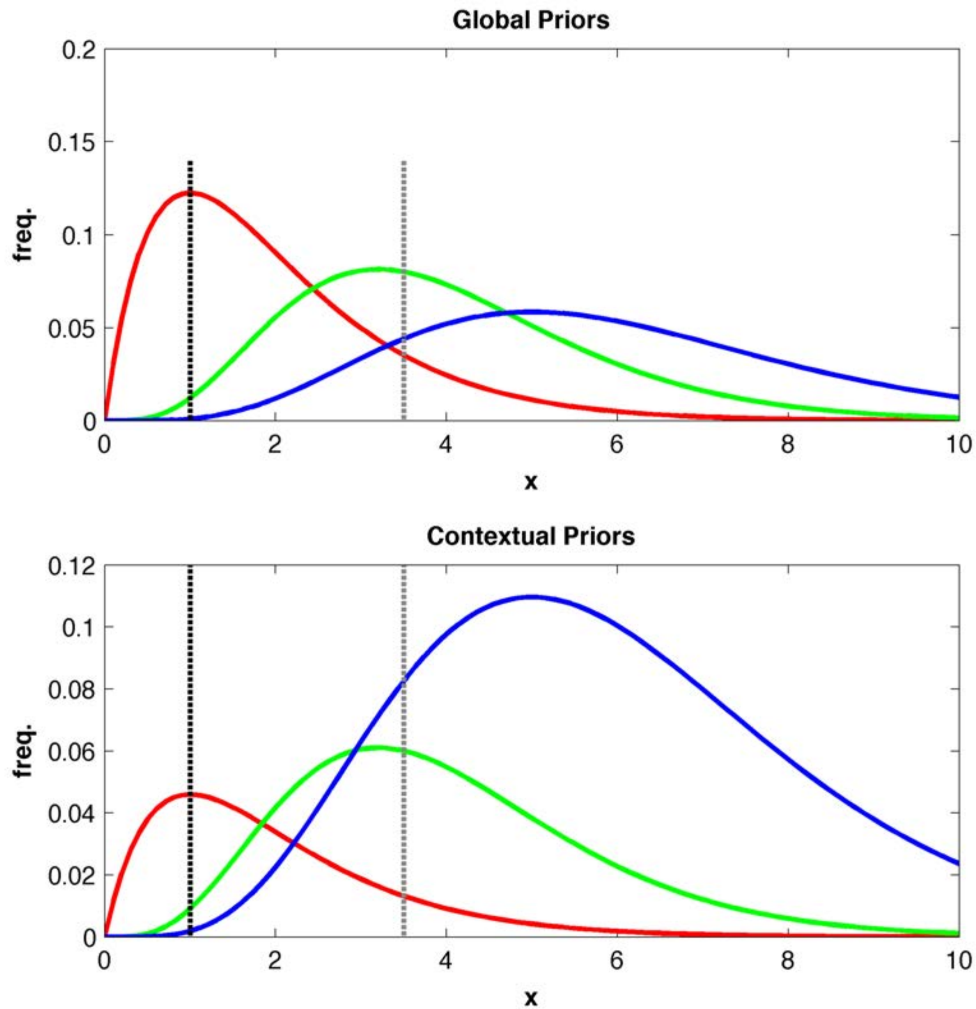
Contextual Smoothing - MRFs

- Local priors from contextual information

$$\pi_j \rightarrow \pi_j^{(i)}(\beta, \mathcal{L})$$

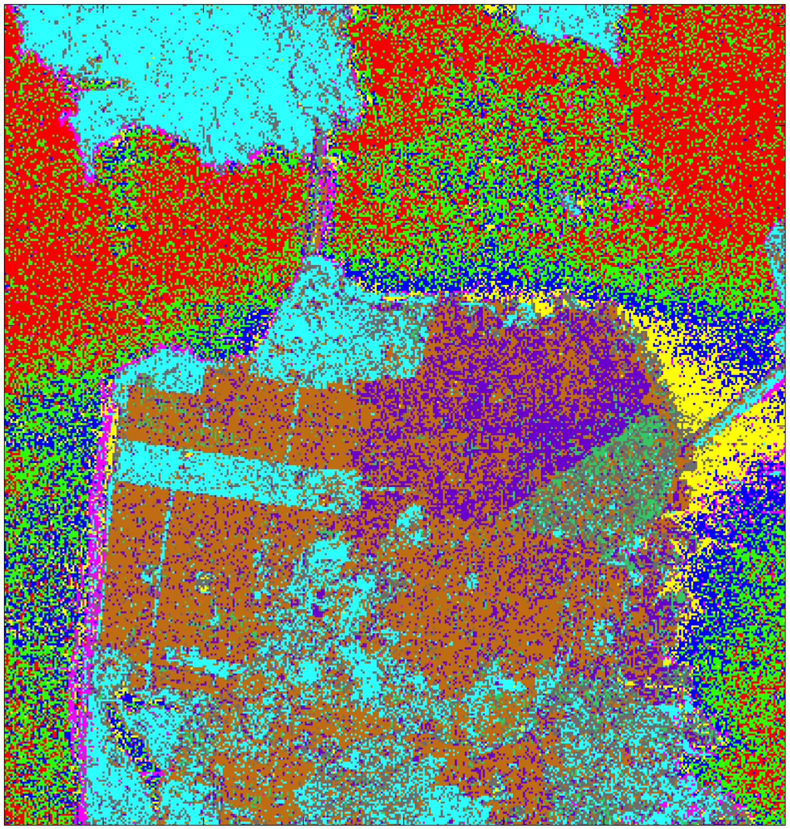


8 neighbours around central pixel

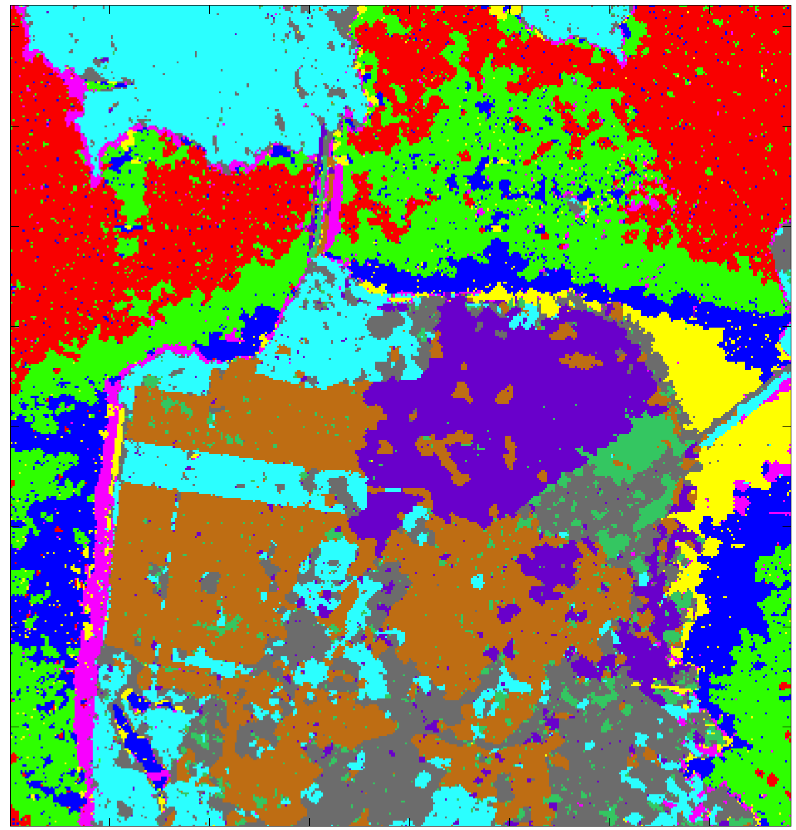


Contextual Smoothing Example

Radarsat-2, 2008, San Francisco, window 8 $\times$ 4, 10 classes.



After ML clustering

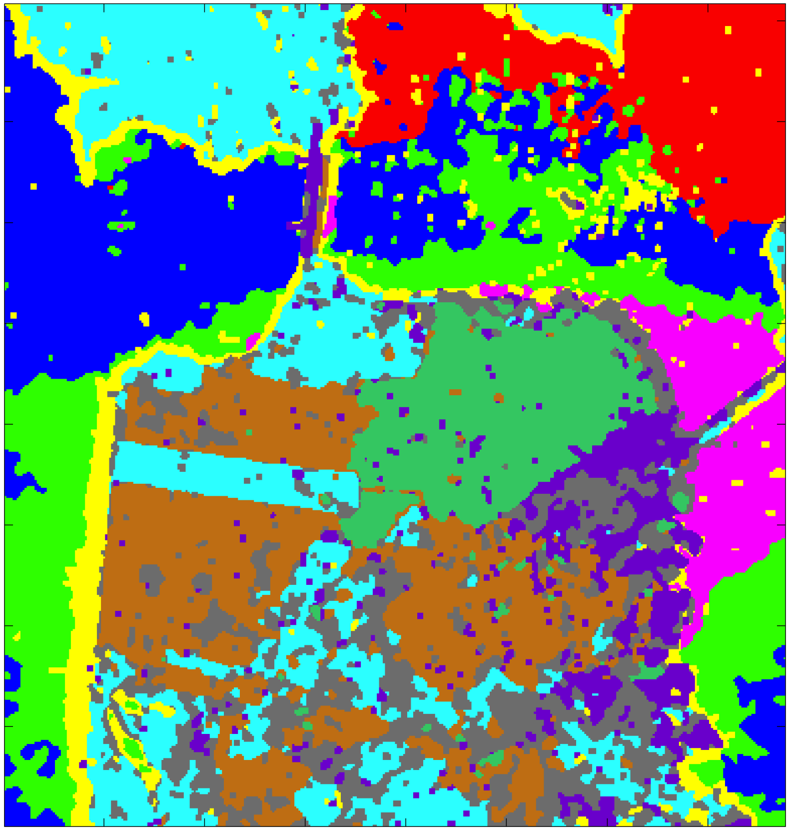


With MRF Smoothing

Further Examples

Radarsat-2, 2008, San Francisco, window 24 $\times$ 12.

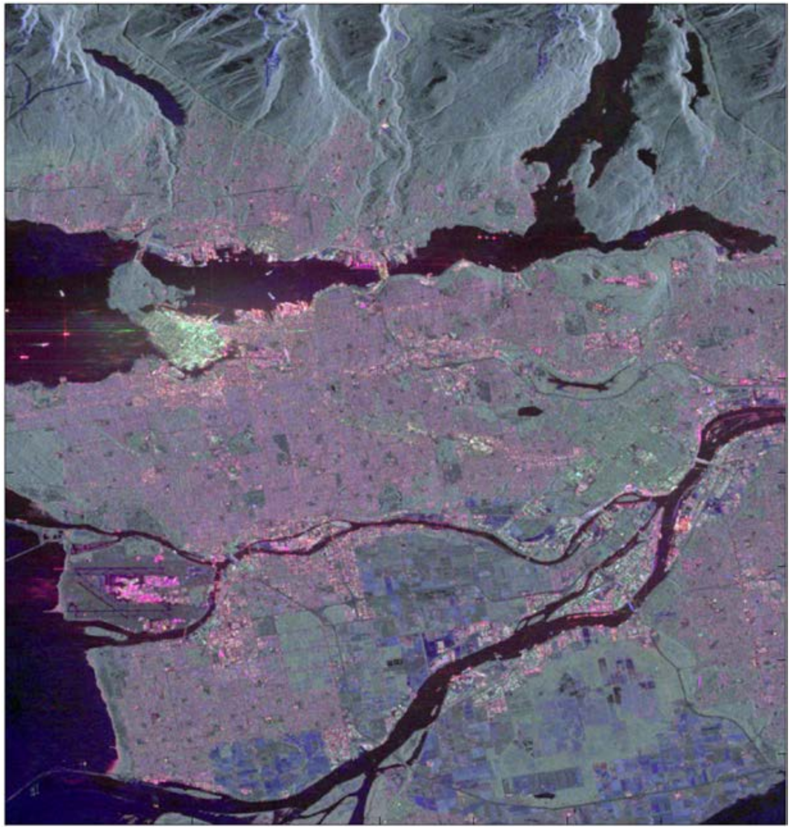
Pauli RGB



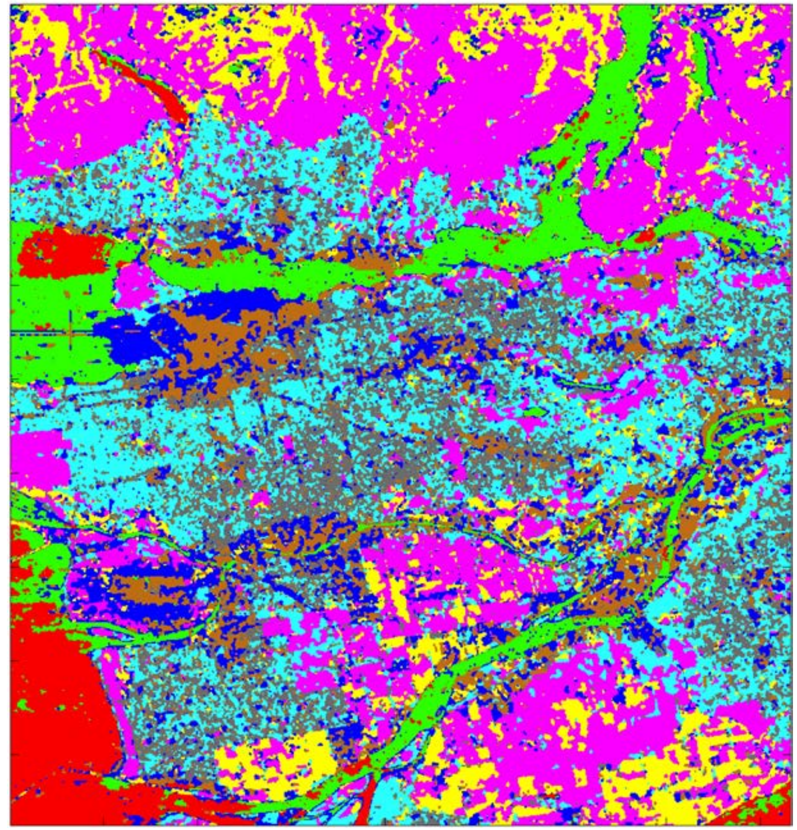
10 class Segmentation

Further Examples

Radarsat-2, 2008, Vancouver, window 16 $\times$ 8.



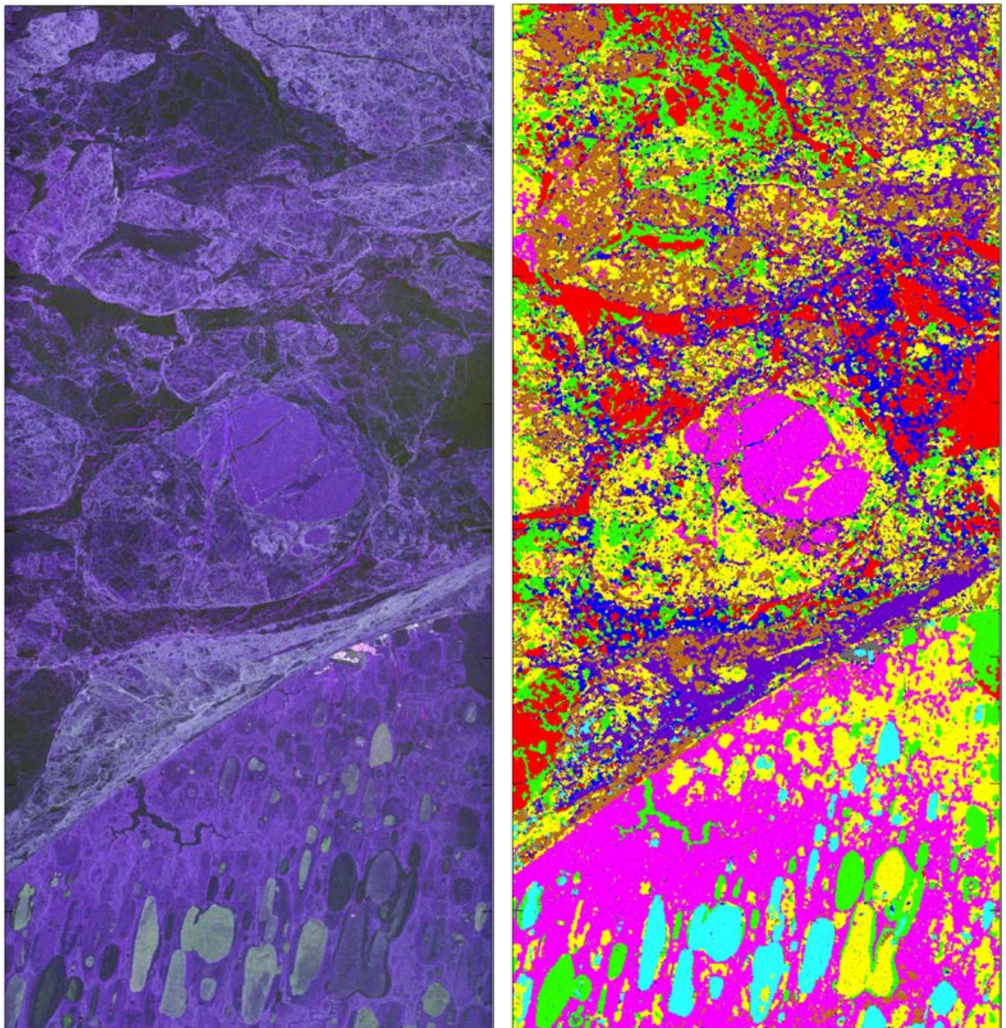
Pauli RGB



8 class Segmentation

Further Examples

ALOS PALSAR, 2009, Barrow, Alaska, window 16 $\times$ 2, 9 classes.



Generic Approach

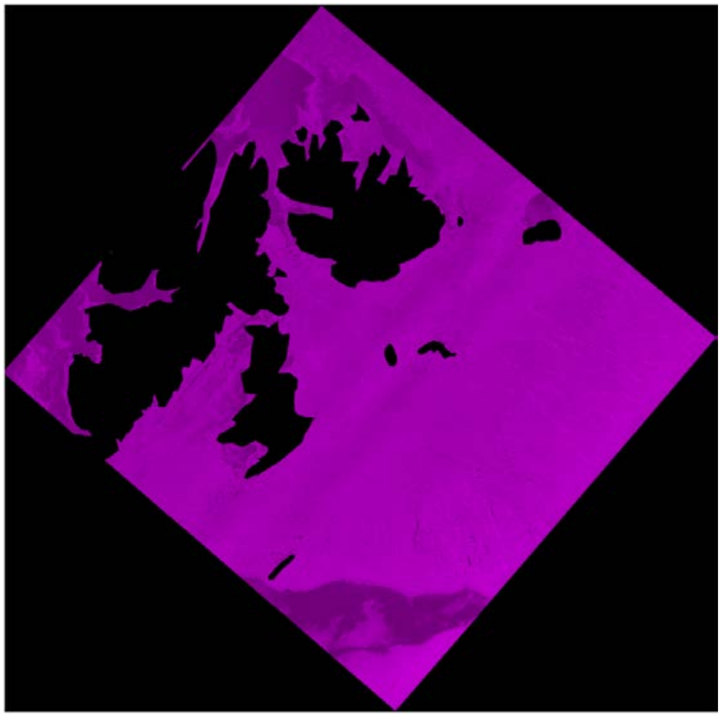
- Independent of the specific texture distribution or model
- 5 generic features from polarisation matrix given basic symmetries
- Applies to quad, dual or mono-pol data (reduced features)

	Quad	dual-co/cross	dual-co/co	mono
1. RK	+	+	+	+
2. MRCS	+	+	+	+
3. R_{cr}	+	+	-	-
4. R_{co}	+	-	+	-
5. $\lvert\rho\rvert$	+	-	+	-
6. $\angle\rho$	+	-	+	-

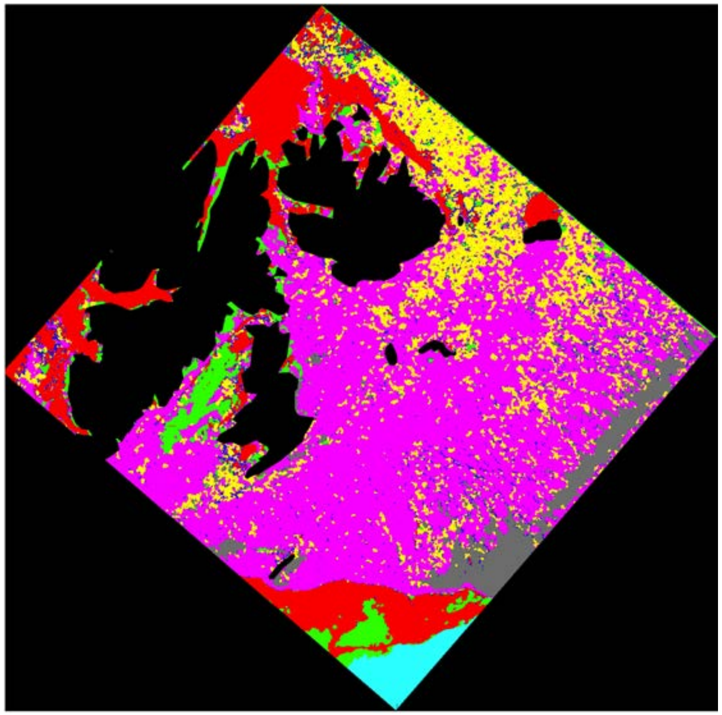
- Consistent approach no matter which features are used
  - the basic 6 or specialised to application task

Dual-pol HH-HV Sigma-nought Example

Radarsat-2, wide-swath, 2012, window 5×5, 7 classes.



Pauli RGB



Unsupervised label image

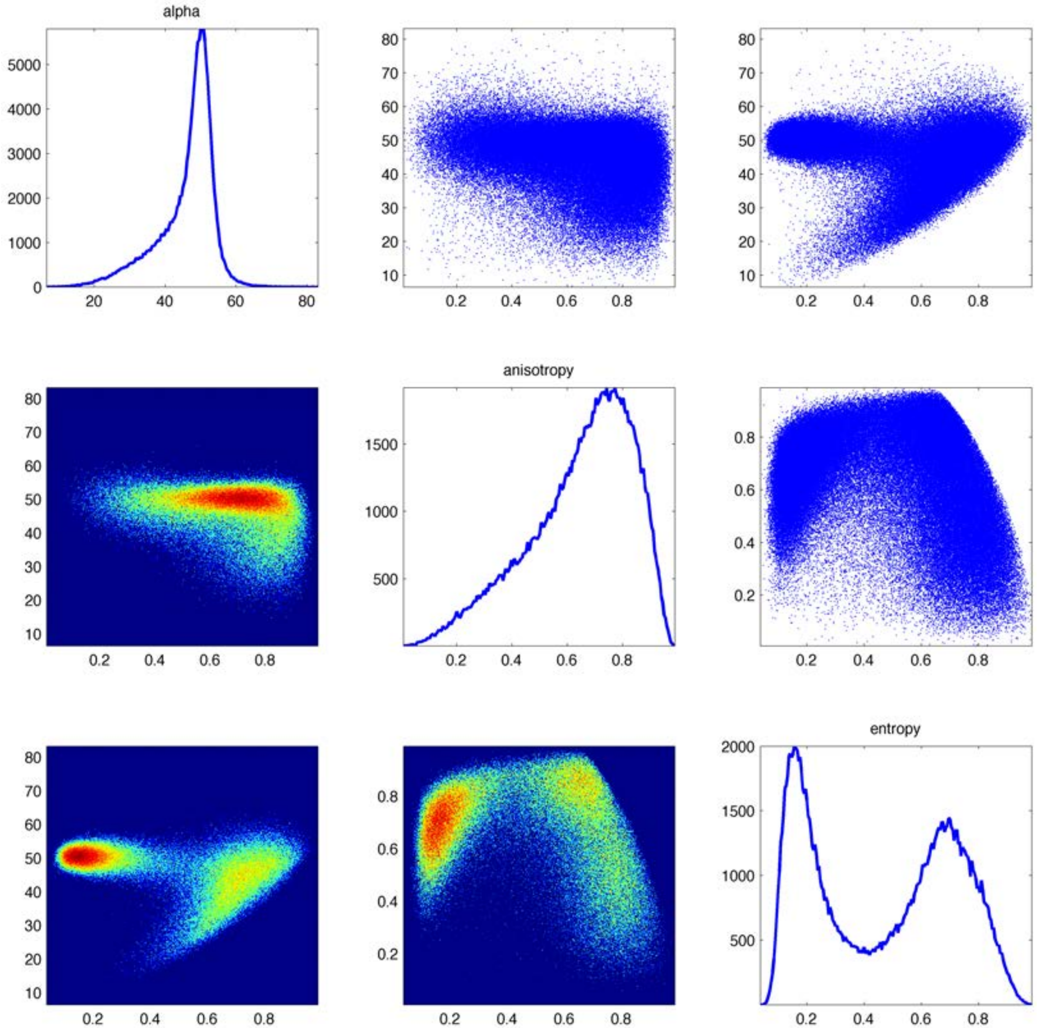
Extendable to Data Fusion

Can use any suitably transformed real valued features

- Log-cumulants κ_2, κ_3 for texture
- Optical data (e.g., Intensity, NDVI)
- Directional / image texture
- Multi-scale / wavelet measures
- Polarimetric decomposition parameters
- Model based decompositions (e.g., RVOG)

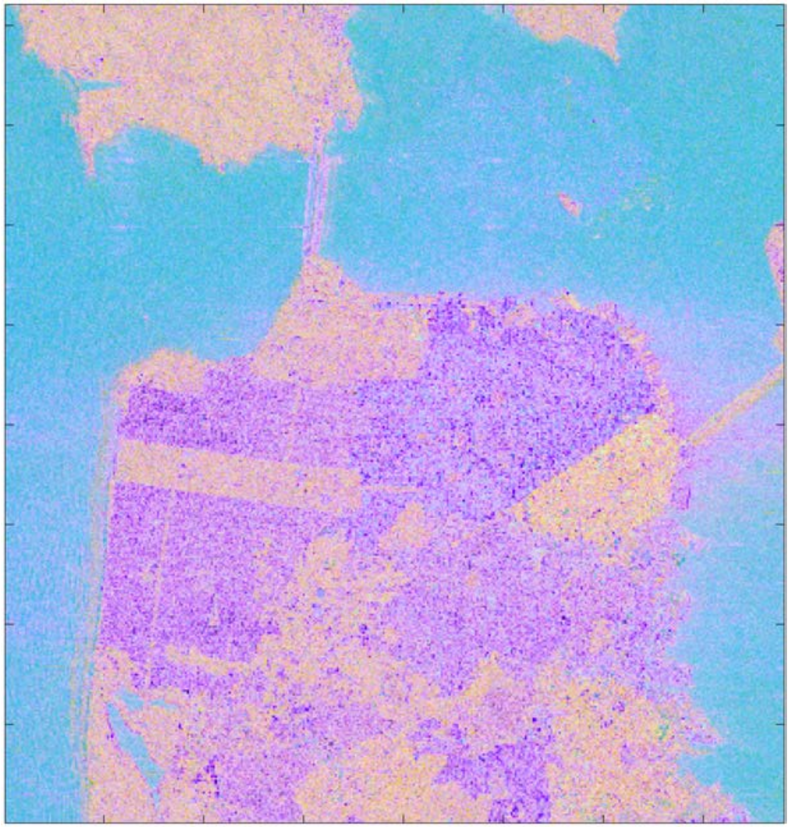
Example: Entropy-Alpha-Anisotropy

San Francisco City, Radarsat-2, window 8 $\times$ 4

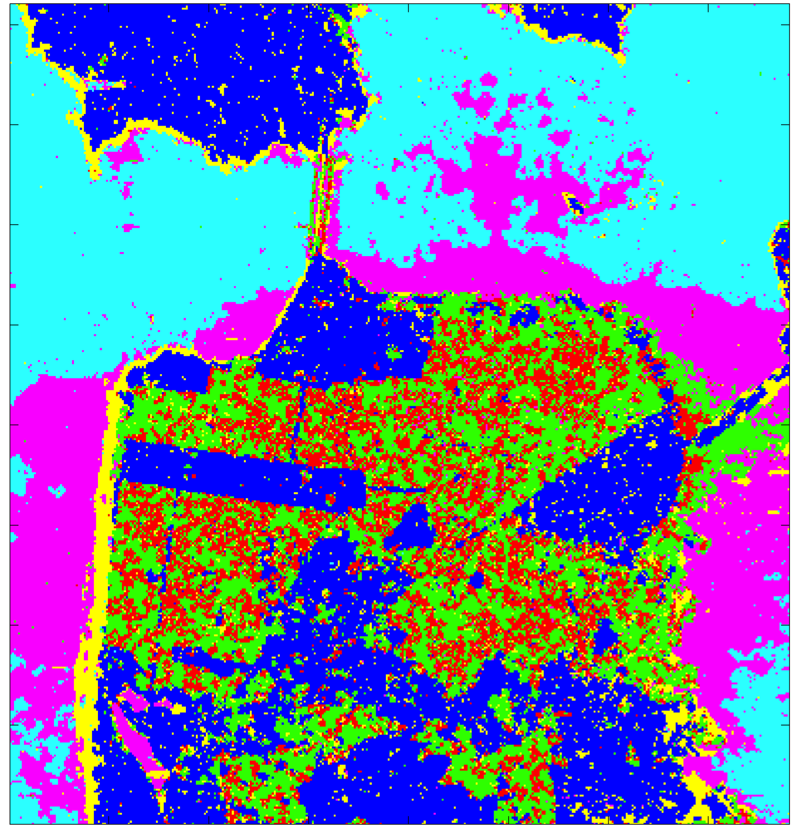


Entropy-Alpha-Anisotropy Examples

Radarsat-2, 2008, Vancouver, window 16 $\times$ 8, H-A-α only.



H-A-α RGB



6 class Segmentation

Conclusions

Good segmentation results on real images:

- Fast local window method, “near real-time”
- Simple segmentation with MoG
- Solid regions due to MRF contextual smoothing
- Texture aware with non-Gaussianity
- Extendable with new features
- Interpretable Polarimetric features
- Choice of window size, sub-sampling, and number of classes

Conclusions and future plans

Good segmentation results on real images:

- Fast local window method, “near real-time”
- Simple segmentation with MoG - improve clustering
- Solid regions due to MRF contextual smoothing
- Texture aware with non-Gaussianity
- Extendable with new features - evaluate other features
- Interpretable Polarimetric features
- Choice of window size, sub-sampling, and number of classes