

Hierarchical Unsupervised Nonparametric Classification of Polarimetric SAR Time Series Data

Ashlin Richardson¹, David G. Goodenough^{1,2}, Hao Chen²

¹*Department of Computer Science, University of Victoria*

²*Pacific Forestry Centre, Natural Resources Canada*

ECS Rm. 504, 3800 Finnerty Road, Victoria, Canada, V8W 2Y2
ashy@uvic.ca

**International Geoscience and Remote Sensing Symposium
(IGARSS 2014) and 35th Canadian Symposium on Remote Sensing**
Québec City, Québec, Canada
July 13th-19th, 2014



Natural Resources
Canada



University
of Victoria

Canada



Why Polarimetric SAR For Forestry?

- All weather
- ***Forest biomass estimation***
- ***Forest land-cover type discrimination***
- Have shown we can ***detect historical fire scars in Canada's western forests (CJRS 2011, IGARSS 2010)***
- Canada is heavily invested in satellite radar

- For Quad-Pol SAR, information is hiding in the interplay between the intensities and phases!
- **More accurate forest information can be retrieved if exploited fully!**
 - **The future:** high resolution multi-frequency multi-temporal tomography: **Reconstruction in time and space**



Natural Resources
Canada

Ressources naturelles
Canada

Canada



Quad-Pol Analysis for Forestry

- Quad-Pol analysis.. **Several ongoing challenges:**
 - Need a physically meaningful understanding of decomposition parameters.
 - Need to visualize high dimensional data, and **classify it effectively**
- Present work by University of Victoria (UVic) and Canadian Forest Service (CFS, NRCAN) seeks to address these issues through new algorithms R&D:
 - ***Real-time interactive data visualization***
 - ***Data Driven Classification***



Natural Resources
Canada

Ressources naturelles
Canada

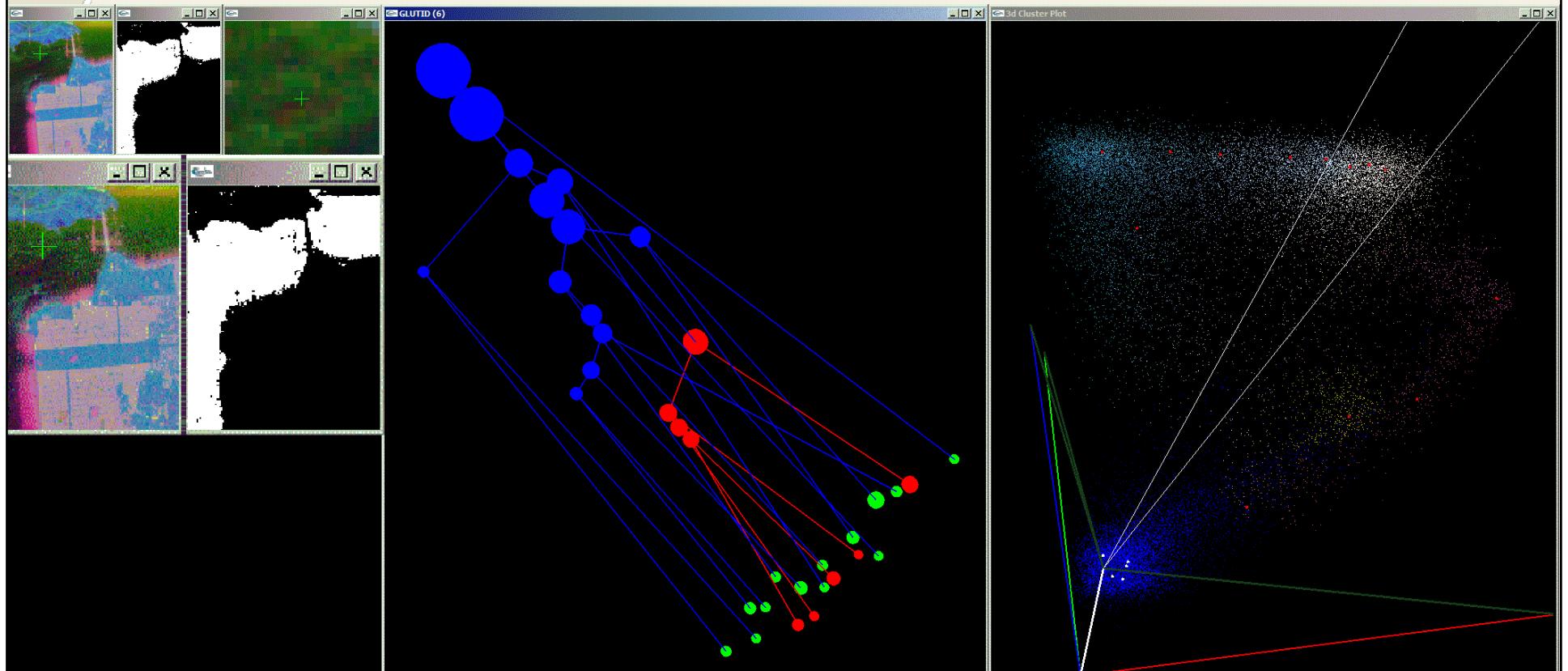
Canada



Rapid visual data exploration

Essential for data understanding.. Explore discrimination potential of the data!!!

- Interactive image, dendrogram, and 3-d scatter displays.
- **Change parameters “on the fly”: see resulting clusters immediately.**
- Explore the hierarchy of clusters by clicking on 1) the image 2) the tree (middle), or 3) cluster centers in **the feature space** (right).

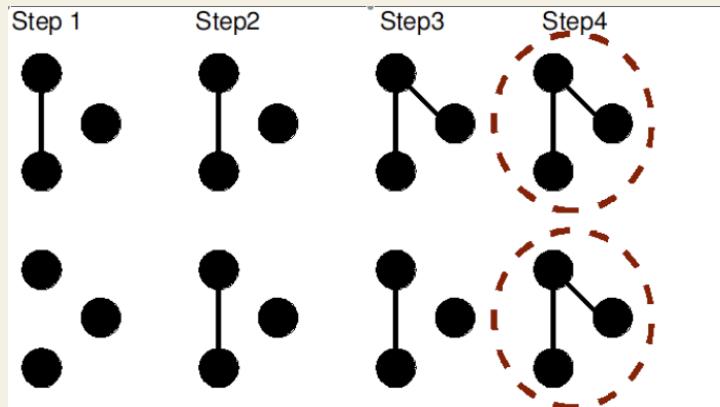




Land Cover Discrimination – why use geometry based methods?

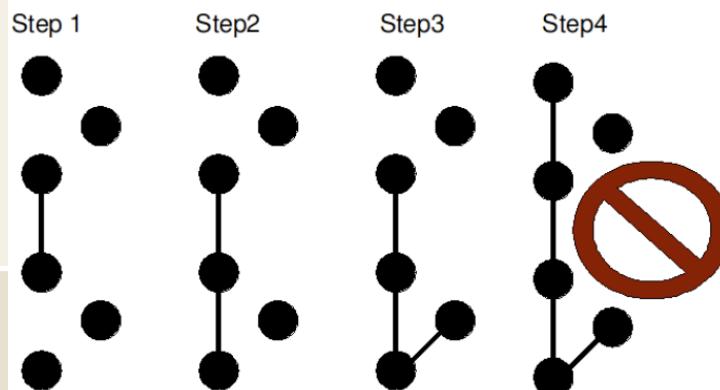
- Classical agglomeration algorithms sensitive to initialization.
- **Poorly separated clusters** reveal mutual inconsistencies between: merging procedure, cluster shapes, & distance function. Also: **want to know how clusters connect!!!**

Initialization #1



$$d(X, Y) = \frac{1}{|X||Y|} \sum_{x \in X} \sum_{y \in Y} d(x, y)$$

Initialization #2



Natural Resources
Canada

Canada



Classification – why use non-parametric methods?

- **Data is NOT GAUSSIAN.**
- Textbook assumption: Quad-pol data Wishart/modified-Wishart distributed.. Cluster is described by a single representative
- Wishart assumption implies “round” shaped clusters.. For “non-round” clusters, merging is problematic
- **Cluster description may require multiple elements.**
- **More general approaches e.g. geometry/point-clouds, may give improved results.**

Notes:

- **Want to avoid explicitly setting the number of clusters.**
- Not all clusters may be meaningful (on the ground).



Natural Resources
Canada

Ressources naturelles
Canada

Canada



Q: What is mapping?????

Multi-scale

Multi-scale

Multi-scale

Multi-scale

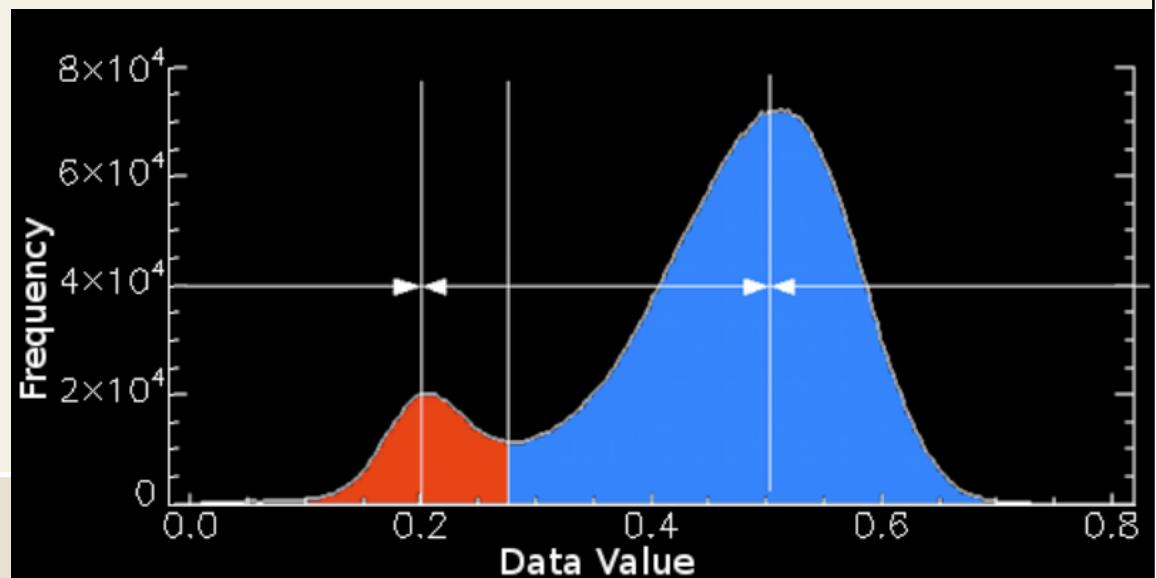


Possible Answer: Modes (Peaks) And Interconnectivities

- Wishart (1969): **clusters are the modes (hilltops) of a density.**
- **A peak (an attractive center) is deemed to represent a cluster..**
- All points attracted to the peak belong to that cluster
- **Method: Climb to the top!!!!**

Histograms represent estimated density functions - ***one dimensional motivational example:***

Shown: two peaks and associated domains of attraction (red & blue).





Geometry-based approach: KNN Graph Clustering (KGC)

IGARSS 2010 (KGC-1)

- Inspired by Wishart's **Mode Analysis**.
- **Data driven**; only one parameter (K).
- **Finds clusters of arbitrary shape** by considering the K-Nearest Neighbors about each point, and their interrelations
- No direct assumption about cluster number, or underlying parameterized distribution (e.g. Wishart).
- Stable in terms of both the number of clusters, and the cluster shapes (with respect to the parameter K).



Natural Resources
Canada

Ressources naturelles
Canada

Canada



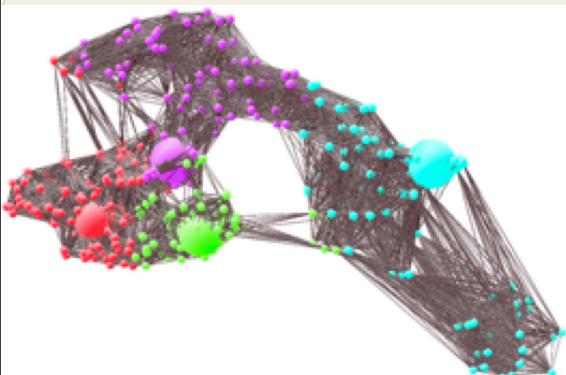
KGC-1 method: description

- 1) Construct the K-NN graph.. Compare everything to everything else!! AKA **compute the distance matrix.**
- 2) Estimate density at each data point.

$$\rho(x) = \frac{1}{\frac{1}{K} \sum_{n \in N} d(x, n)}$$

- x is a data point, K is the number of nearest neighbors of x , and N is the set of nearest neighbors of x
- Density taken as reciprocal of average neighbour-distance

- 3) Mode seeking on the K-NN graph.. find the peaks!



- Method: “If my density is higher than my neighbours’, I’m a peak! Otherwise, climb up! (traverse to my highest-density neighbour)”
- Associate peak with a basin of attraction: A peak and the data points which “climb up” to that peak.. are given the same color (class label).
- Left: example with 4 classes! (K-NN graph in 3-d..K=40) PALSAR data sub-area
- Data points: small spheres. Peaks: large spheres.



Natural Resources
Canada

Ressources naturelles
Canada

Canada



Geometry-based approach: KNN Graph Clustering (KGC)

CSRS 2013 (h-KGC)

- **Full Hierarchical operation**: Cluster merging consistent with density observations. **Estimation of cluster tree of density!**
- **Interactive pixel & cluster selection, hierarchy traversal.**
- **Application to large data sets (exploiting multi-core architecture) → offload computationally intensive neighbor calculations.**
- All data points are used (IGARSS 2010 used a sampling approach). **→ More accurate representation of low-density clusters. Warning: still computationally intensive.**



Natural Resources
Canada

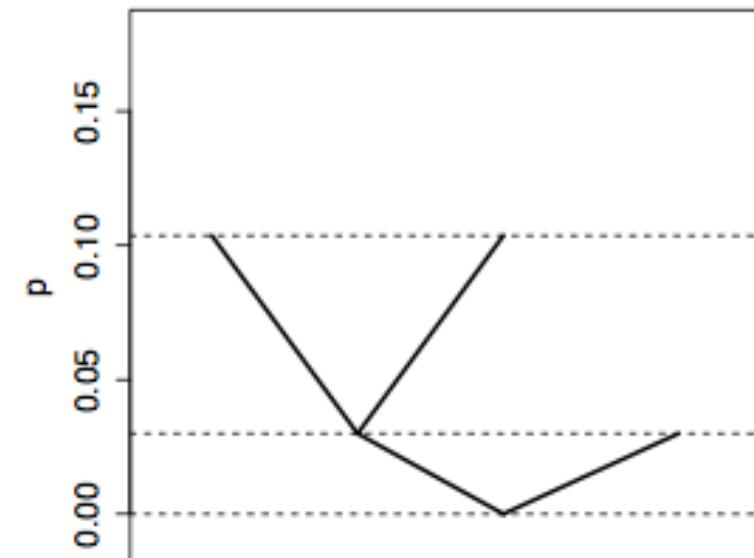
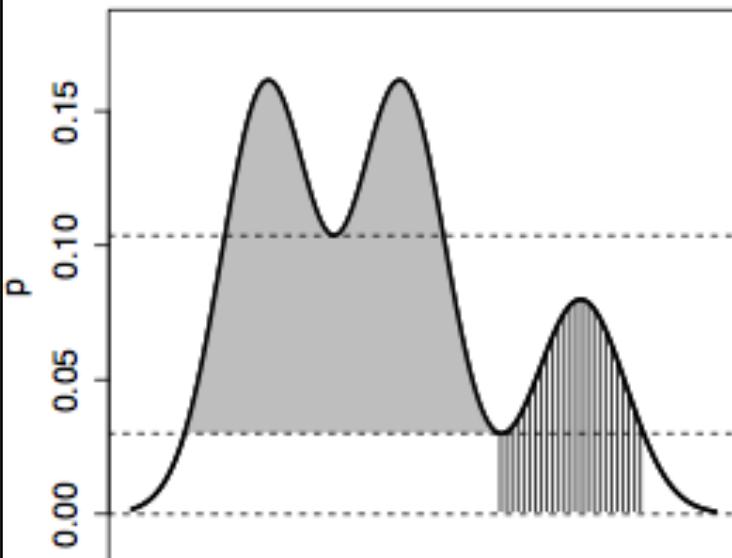
Ressources naturelles
Canada

Canada



h-KGC method: Description

- *****Fully Hierarchical***** operation:
Estimate Cluster Tree (*****DENDROGRAM*****) from density estimate!!!
 - (a) Find modes associated with Density estimate
 - (b) Estimate the Cluster Tree (math: “persistence of connected components of upper-level sets” $L(\lambda; \rho) = \{x | \rho(x) > \lambda\}$)
- The splitting ordered in terms of the density → interpretation in terms of statistical significance. Model-based splitting may not fit the data, and may not have a probability interpretation.





h-KGC method: Description

- Hierarchical operation: Estimation of the cluster tree (yes, a Binary Partition Tree (BPT))

Interfaces between modes

Suppose modes M_i, M_j share an interface:

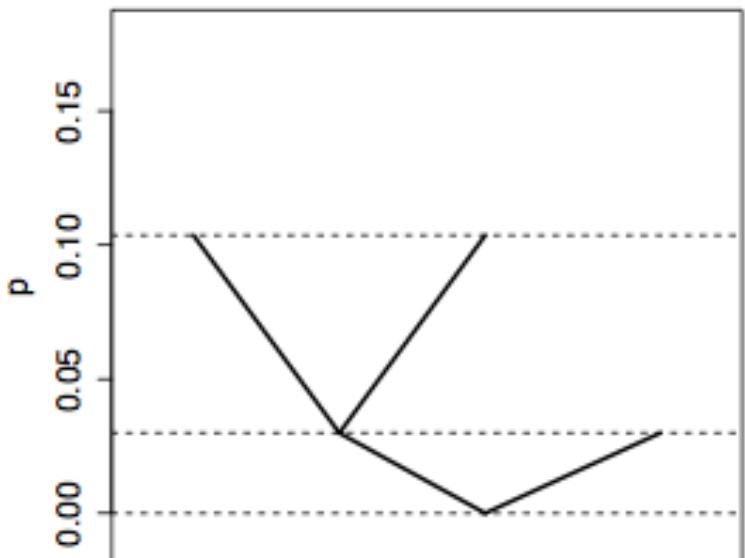
$$\begin{aligned} I_{i,j} &= I_{M_i, M_j} = I_{M_j, M_i} \\ &= (N(M_i) \cap M_j) \cup (N(M_j) \cap M_i) \end{aligned}$$

Waterfall Algorithm:

- 1) Find interfaces (bridges between peaks)
- 2) Perform merging (in order of highest interface density, to lowest)

Data structure: disjoint set-forest with path-flattening!

Left: dotted lines → interfaces!!



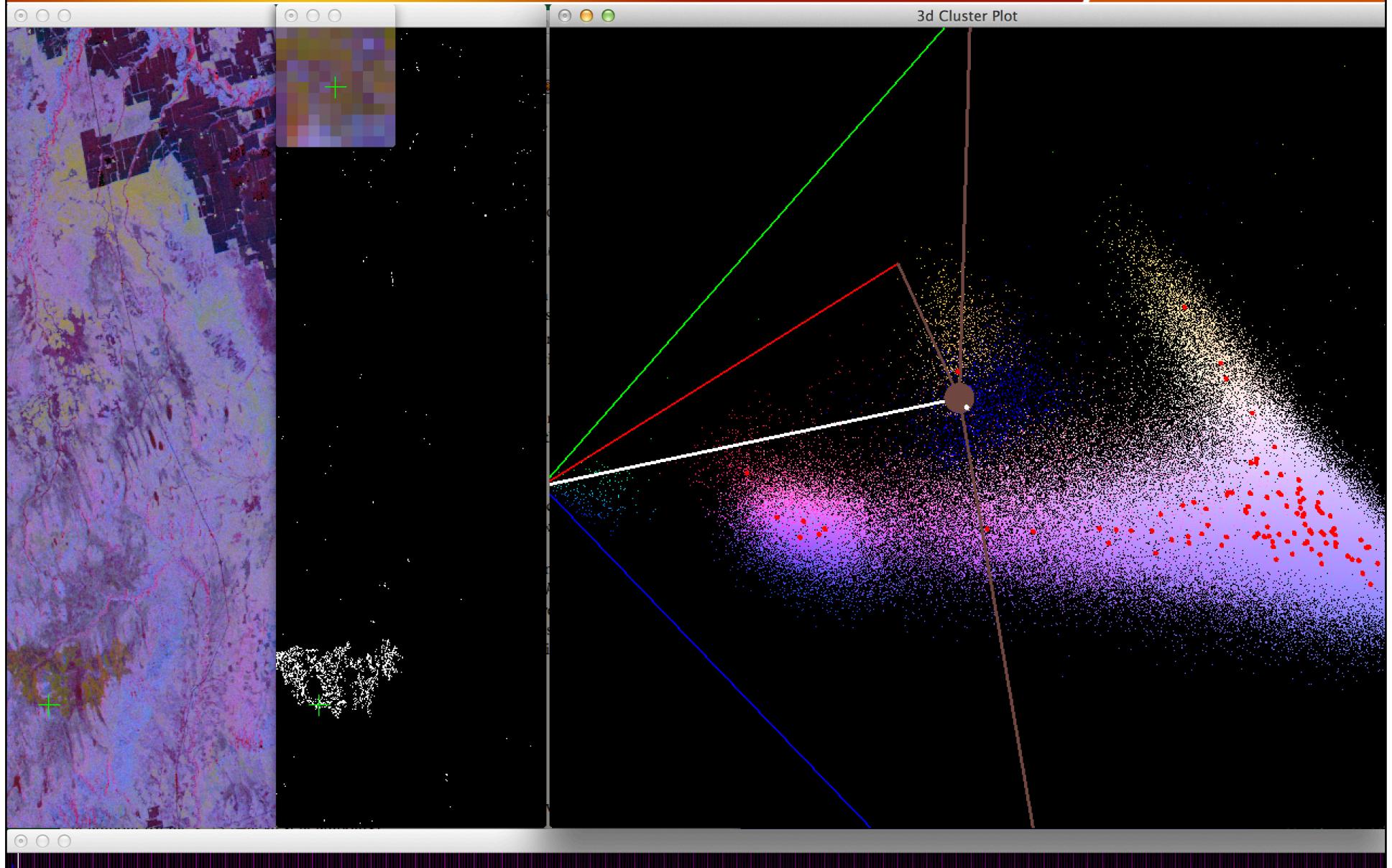
(b)

Canada



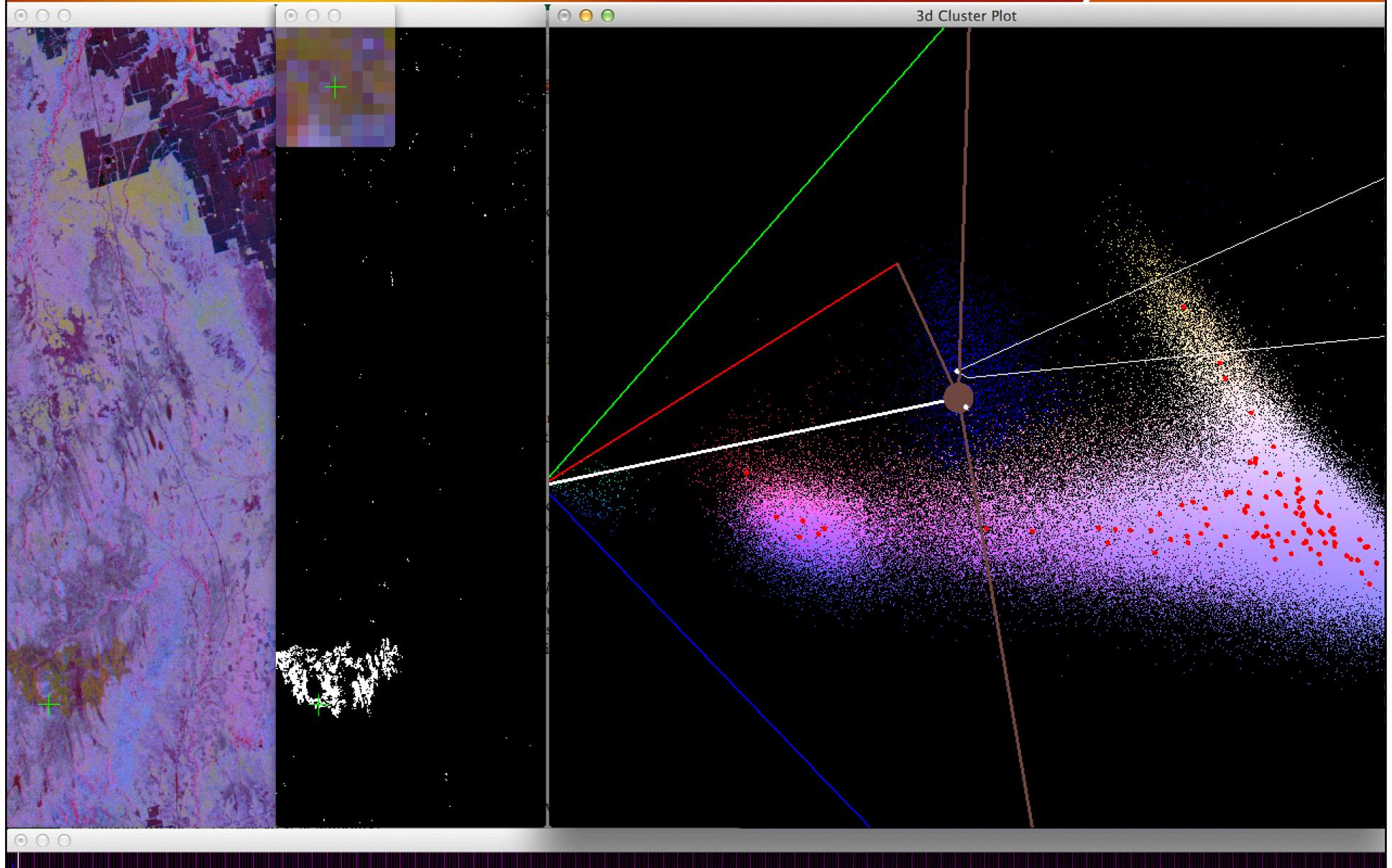
Interactive Node Selection

L-band ALOS near Keg River





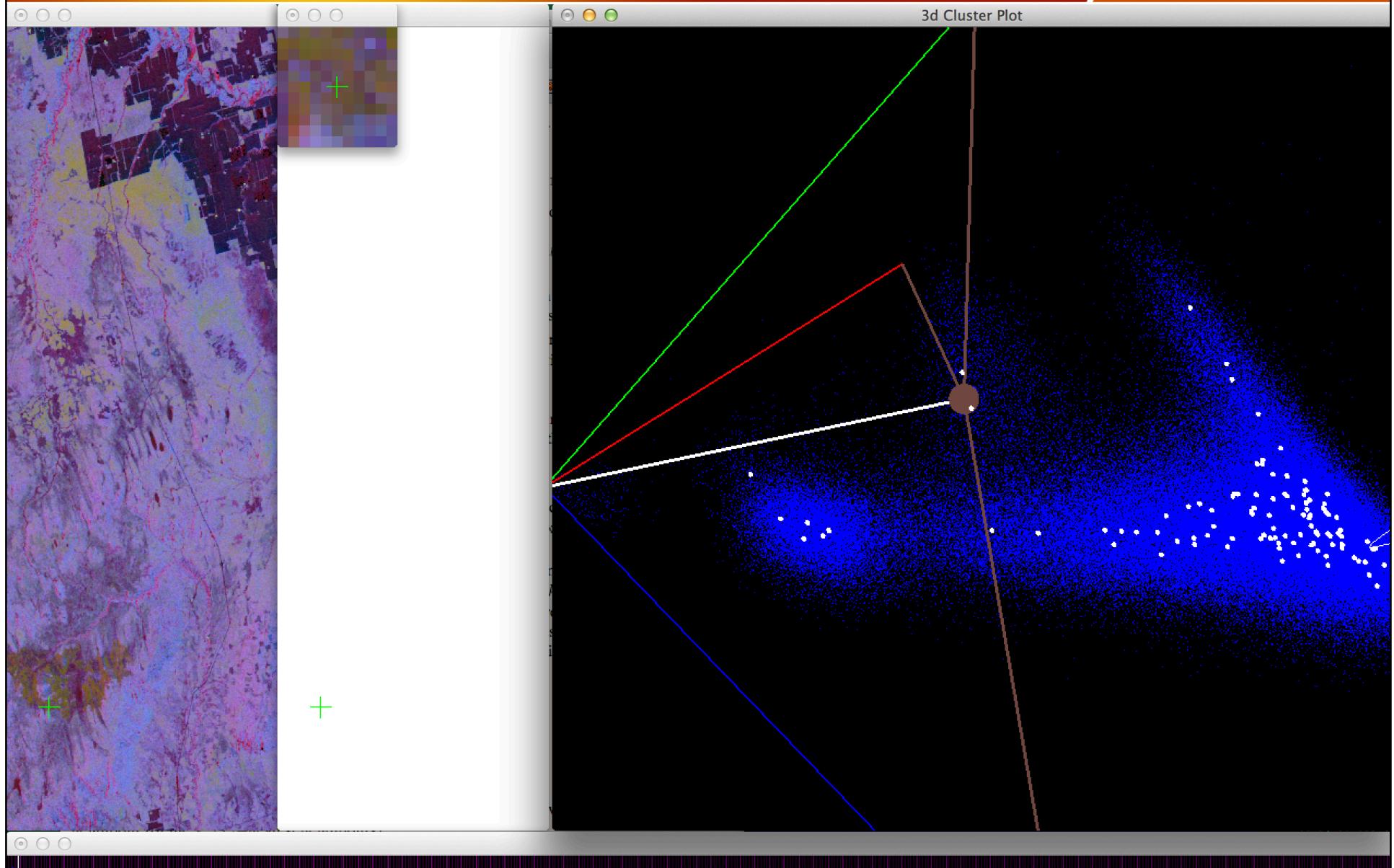
Interactive Node Selection L-band ALOS near Keg River





Interactive Node Selection

L-band ALOS near Keg River





KGC-3 method: description

(1/3)

1) Perform nonparametric (local) segmentation

~~Classical solution: waterfall algorithm on image intensity (← bad.. ignores multivariate interrelationships).~~

Generic method: given an *image metric*,

$$\text{e.g., } d(x,y) = |x-y|^2$$

augment that metric with spatial information

$$\text{e.g., } d(x,y) = |x-y|^2 + |i_x - i_y|^2 + |j_x - j_y|^2$$

And perform 1) Distance matrix calculation

2) Density estimation

3) Hill climbing

$$\rho(x) = \frac{1}{\frac{1}{K} \sum_{n \in N} d(x, n)}$$

Advantage: fast!!! Consider only neighbors in a small window

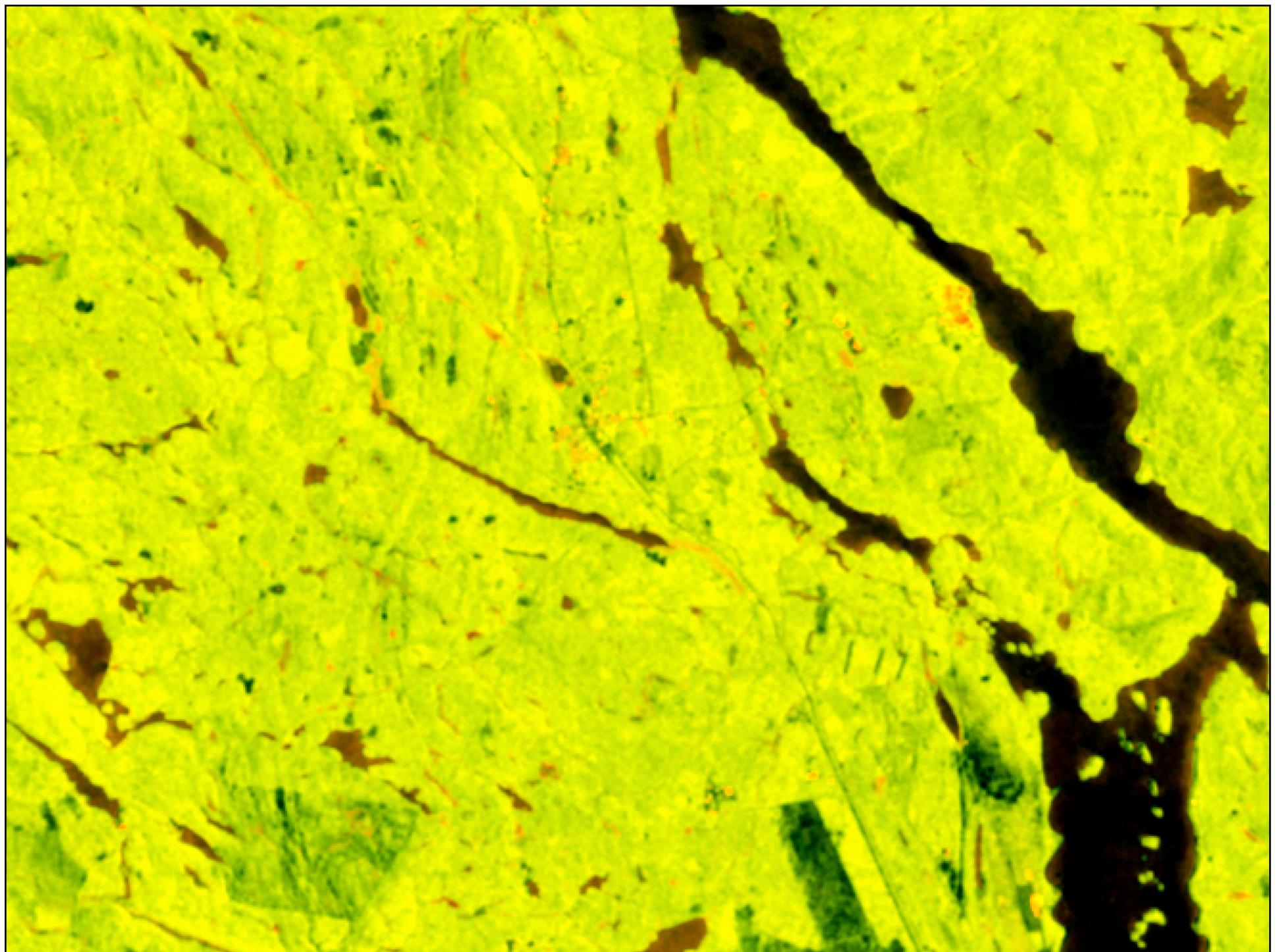
Result: small patches. Next slide..Example (3x3 window).

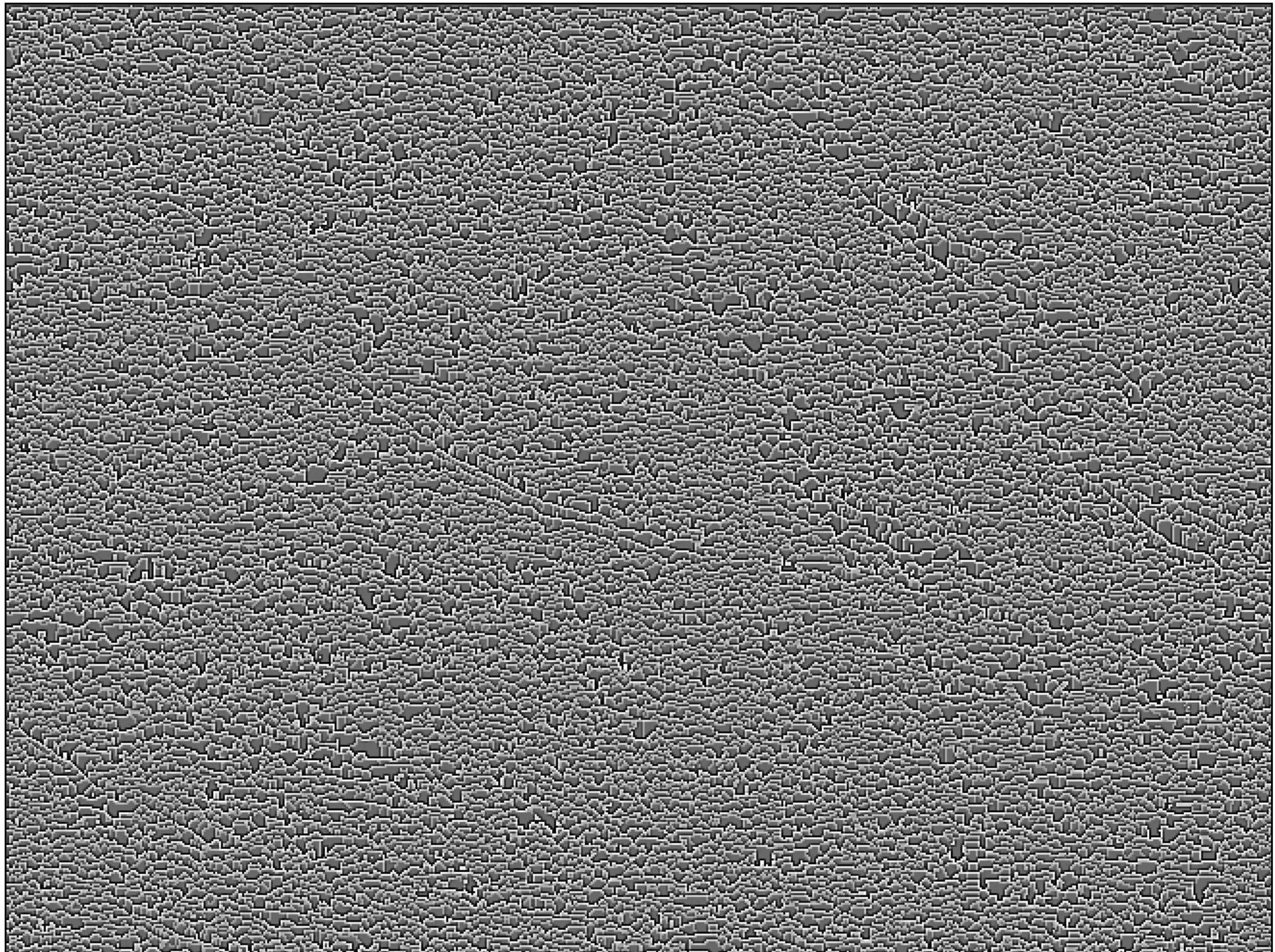


Natural Resources
Canada

Ressources naturelles
Canada

Canada







KGC-3 method: description

(1/2)

2) Next, on the segments perform:

- 1) Distance matrix calculation**
- 2) Density estimation**
- 3) Hill climbing**

We used:

- $d(x,y)=|x-y|^2$ with x and y mean vectors for a pair of patches (segments).
- Same rudimentary (effective) density estimate.

3) Perform the merging. Result: a tree!

*Next slide.. Visualizing the result for R2 FQ9 stack
(averaged) parameters (water class selected..)*



Natural Resources
Canada

Ressources naturelles
Canada

Canada



Results: Data and Comparison

Processing

RS2 FQ9	Date
	20081231
	20090124
	20090217
	20090711
	20090804
	20090828
	20090921
	20091015
	20091108
	20091202
	20100212
	20100823
	20101010
	20101103
	20101127
	20101221
	20111122

- 1) Multilook 4x2**
- 2) Boxcar 5x5**
- 3) Coregistration**
- 4) Boxcar 3x3**
- 5) Multilook 2x2**
- 6) TS averaging**

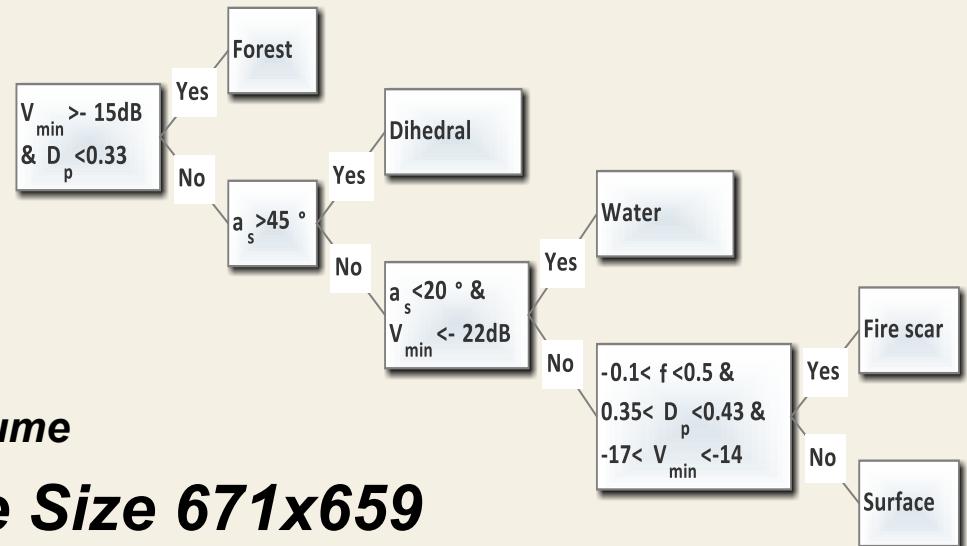
7 Parameters:

**Alpha, Entropy, Anisotropy,
Shannon Entropy,
RVOG: Biomass, surface, volume**

After trimming: Image Size 671x659

**Comparison with rule based classifier:
Simulated Compact-pol parameters**

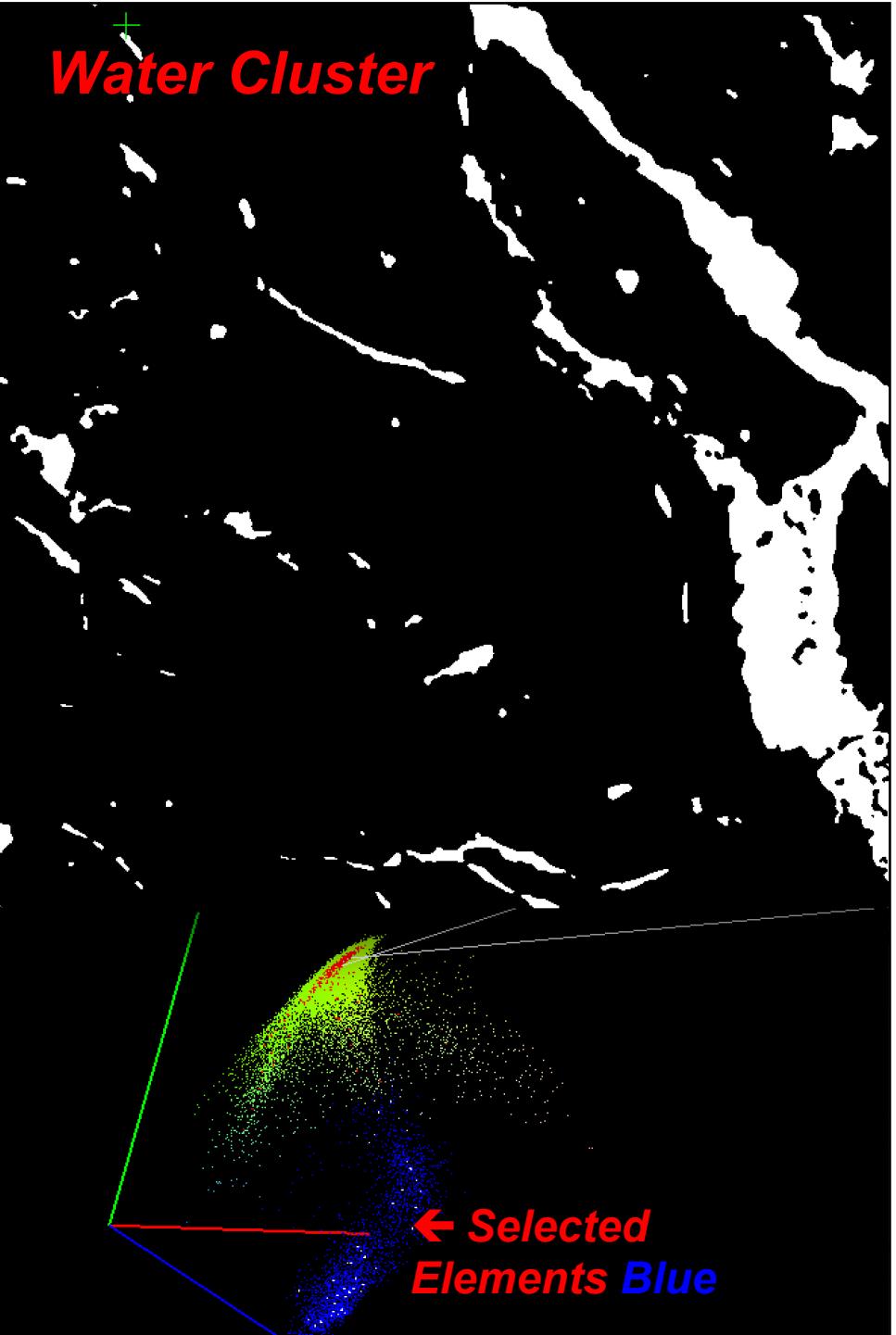
**IGARSS 2014: Mapping Forest Fire Scars
with Simulated RCM Compact-pol Data**
Hao Chen, David G. Goodenough, Shane
Cloude, Philip Snead



Natural Resources
Canada

Ressources naturelles
Canada

Canada

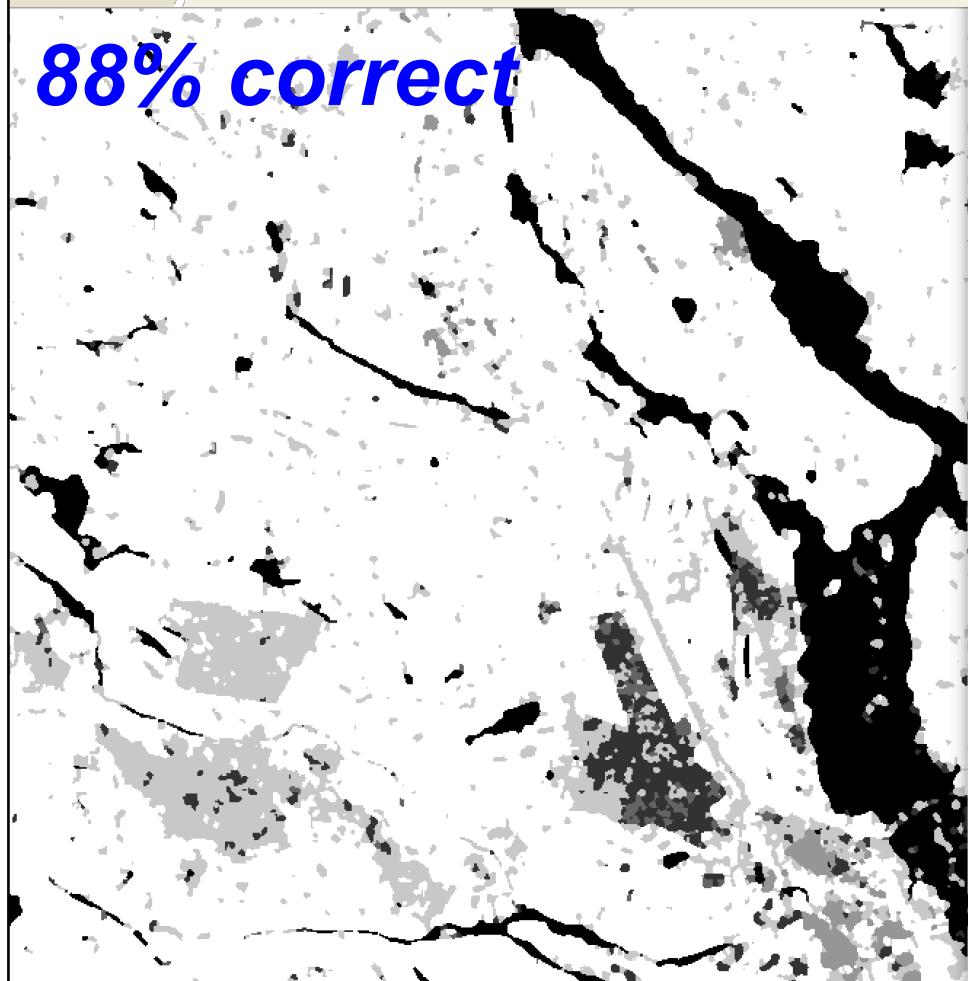




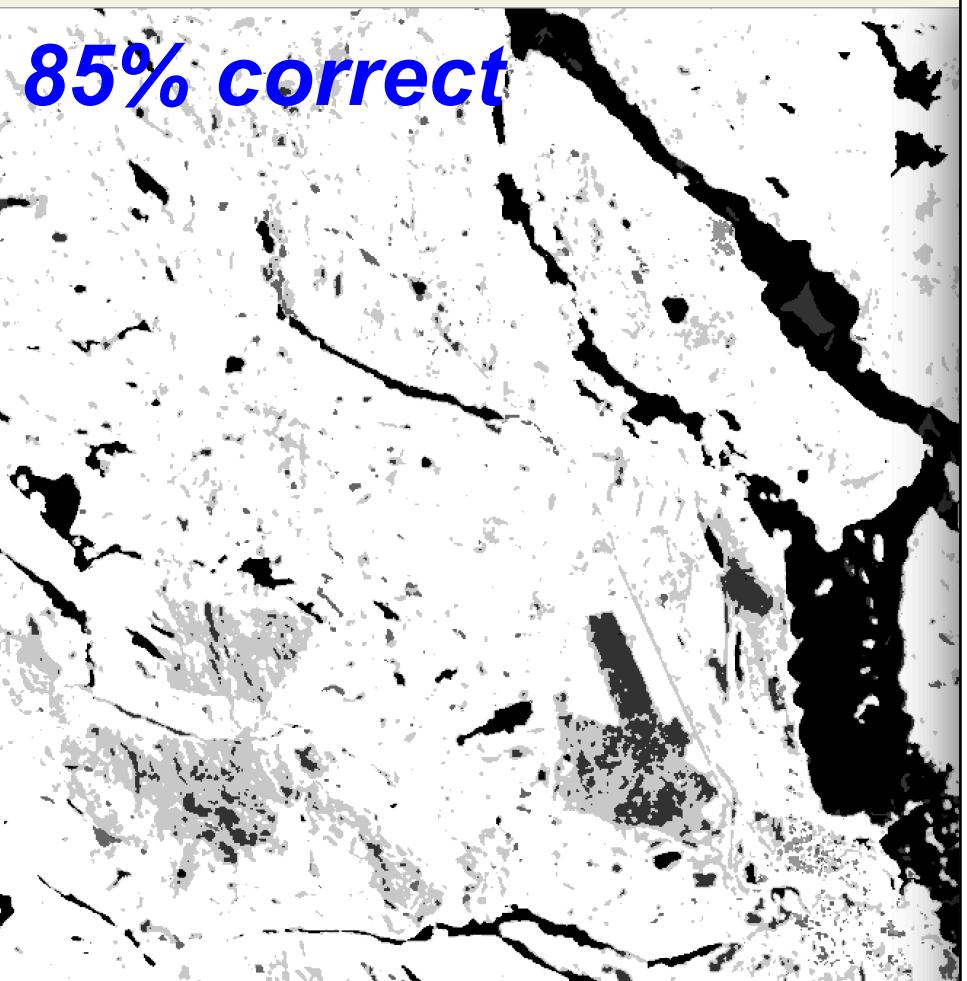
Classification maps:

- Left) KGC-3 unsupervised method (with manual cluster assignment)
- Right) rule-based classifier on simulated compact parameters

88% correct



85% correct

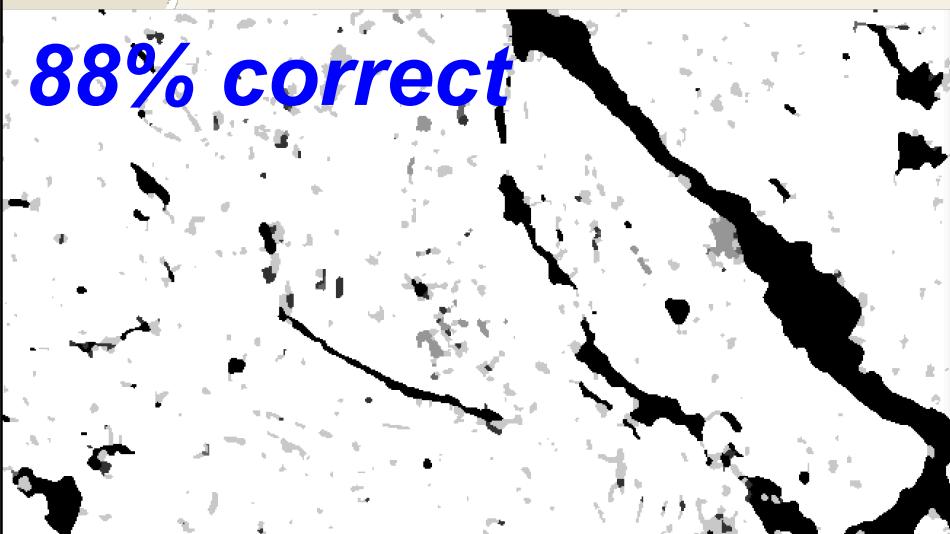




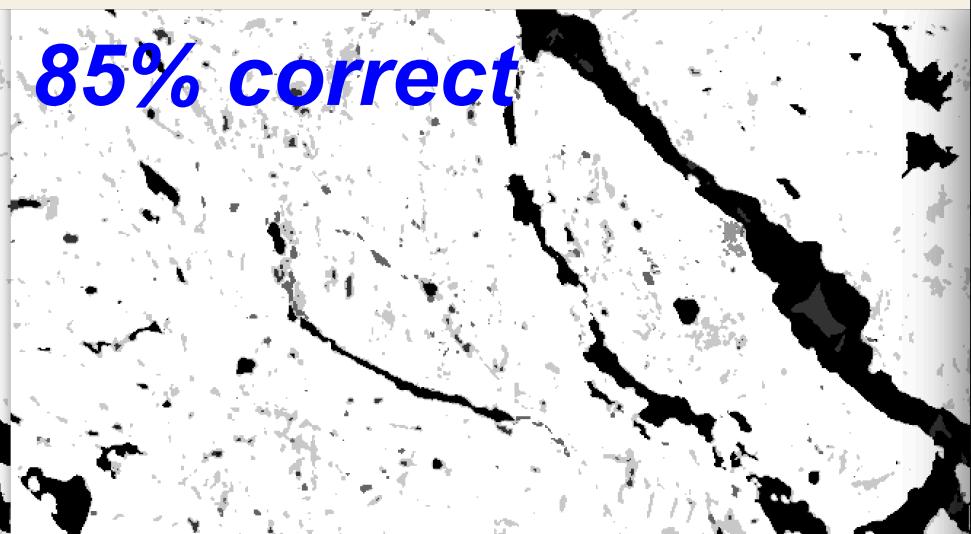
Classification maps:

- *Left) KGC-3 unsupervised method (with manual cluster assignment)*
- *Right) rule-based classifier on simulated compact parameters*

88% correct



85% correct



Water	Bare	Grass	Urban	Veg	Forest		Water	Bare	Grass	Urban	Veg	Forest	
4068	0	0	0	0	0	100%	4068	0	0	0	0	0	100%
0	50	31	0	74	9	30%	0	41	0	0	109	14	25%
0	272	169	2	391	247	16%	0	0	58	286	10	109	13%
0	0	0	419	26	18	90%	0	0	58	286	10	109	62%
0	376	146	0	1179	617	51%	0	565	0	0	972	781	41%
0	0	10	1	311	13366	98%	0	21	71	0	434	13162	96%



Advantages: KGC classification

- **Data driven:** KGC finds unusually shaped, poorly separated clusters that are difficult to find by existing approaches!!
- **Nonparametric technique:** Avoid pitfalls of K-means & agglomeration (respectively assuming “roughly spherical” & “well-separated” clusters). For radar these may fail, especially when using decomposition parameters (**clusters behave strangely in decomposition parameter space..**)
- **Hierarchical information:** geometry approach: **merging reflects connections between clusters!** Merge order has statistics interpretation (significance).
- **More important features pop out first!!!!**
- **KGC:** New nonparametric (local) segmentation step, reduces data volume, utilizes spatial information, and takes a stab at the filtering problem (less filtering required).



Natural Resources
Canada

Ressources naturelles
Canada

Canada



Summary

- **KGC-3 – new hierarchical data driven method for unsupervised detection of arbitrarily shaped clusters** implemented and applied to Radarsat-2 time series data.
- Studies 2010-present → consistent delineation of historical Fire Scars using Radarsat-2, ALOS-1 PALSAR, and other sensors
- Results show **effectiveness for forest applications, esp.. Fire Scar detection.**
- **Next steps:**
 - **Data fusion:** optical, radar combination
 - **Perform KGC-3 generic (metrical) clustering directly on time-series signatures**



Natural Resources
Canada

Ressources naturelles
Canada

Canada



Acknowledgements



Thanks for Financial support from:

- The Canadian Space Agency (CSA).
- Natural Resources Canada (NRCan).
- The Department of Computer Science (Uvic).

Thanks for your attention.



Natural Resources
Canada

Ressources naturelles
Canada

Canada

