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Classification and Segmentation of Radar Polarimetric Images

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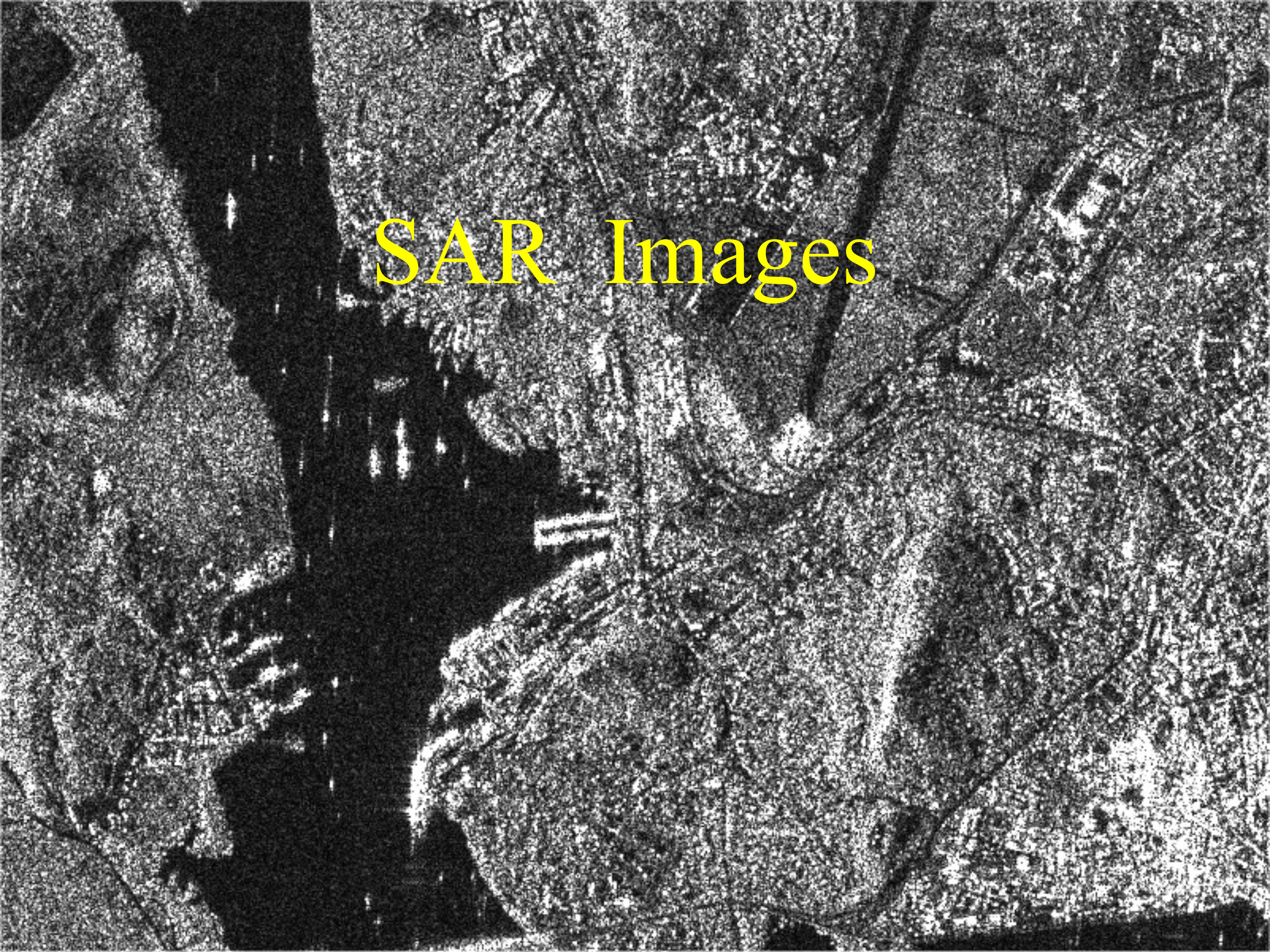
Classification and Segmentation of Radar Polarimetric Images

- SAR (Synthetic Aperture Radar) images
- Polarimetric SAR images
- Hierarchical Image Segmentation
  → maximum likelihood approximation
- Segmentation of polarimetric images


SAR Images

SAR (Synthetic Aperture Radar) IMAGE

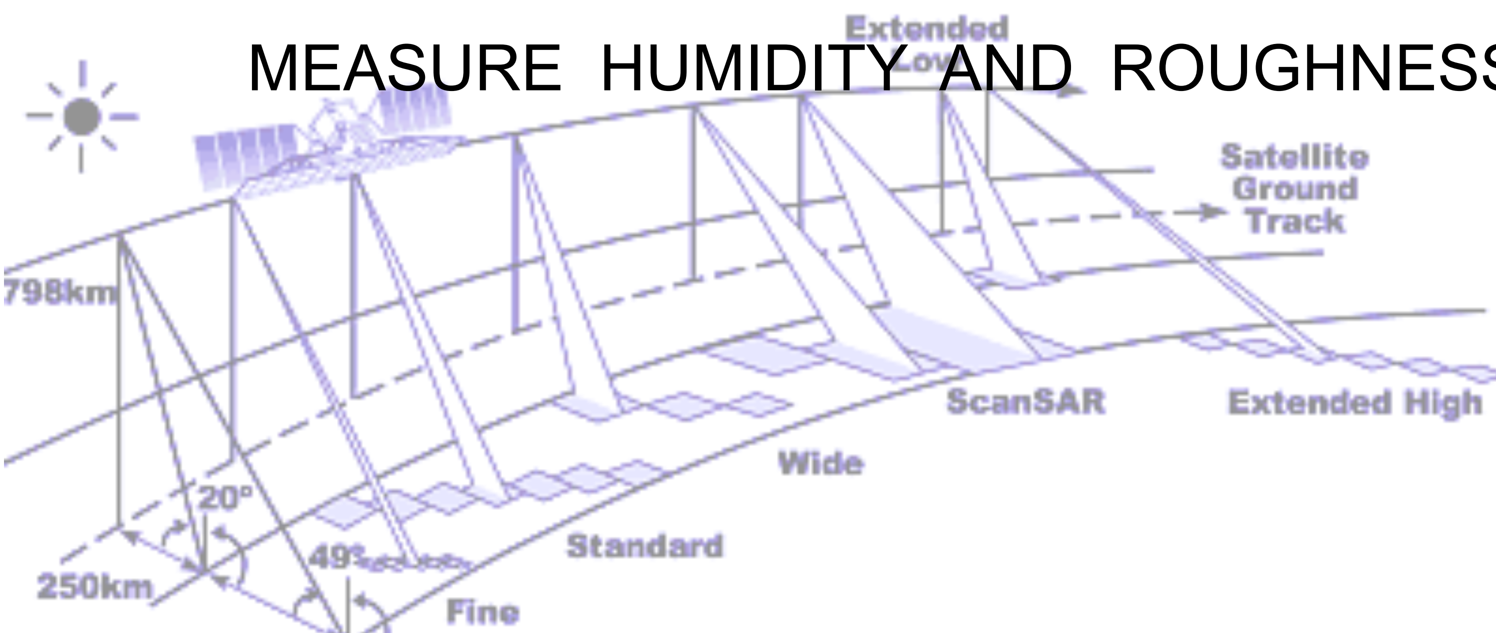
ACTIVE SENSOR → SEND A COHERENT SIGNAL

ONE CHANNEL → GREY SCALE IMAGE

LONG WAVELENGTH → 0.1 TO 1 METER

PASS THROUGH CLOUDS

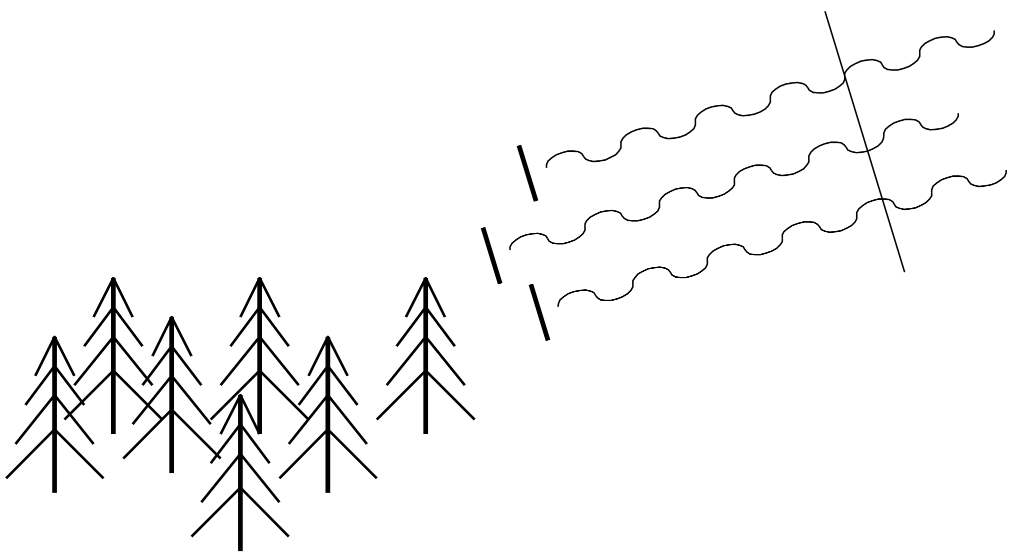
MEASURE HUMIDITY AND ROUGHNESS



SAR (Synthetic Aperture Radar) IMAGE

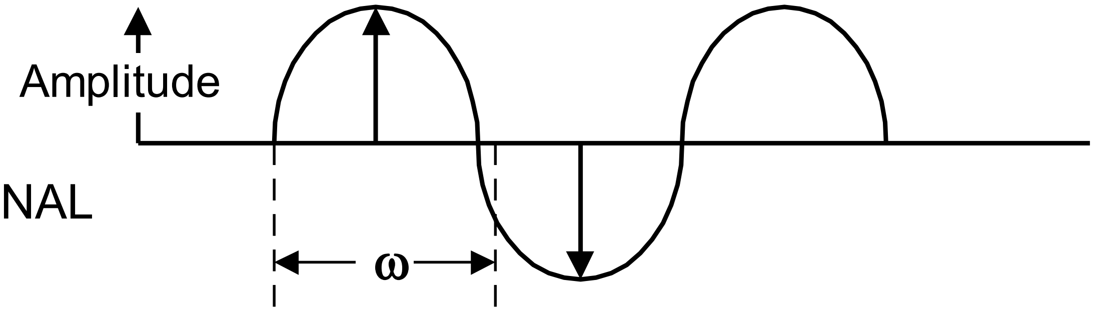
SAR IMAGE → COHERENT SIGNAL (RADAR)

→ INTERFERENCE PATTERN



RETURNED SIGNAL HAS **AMPLITUDE** AND **PHASE**

THE NOISE IS PROPORTIONAL TO THE AMPLITUDE



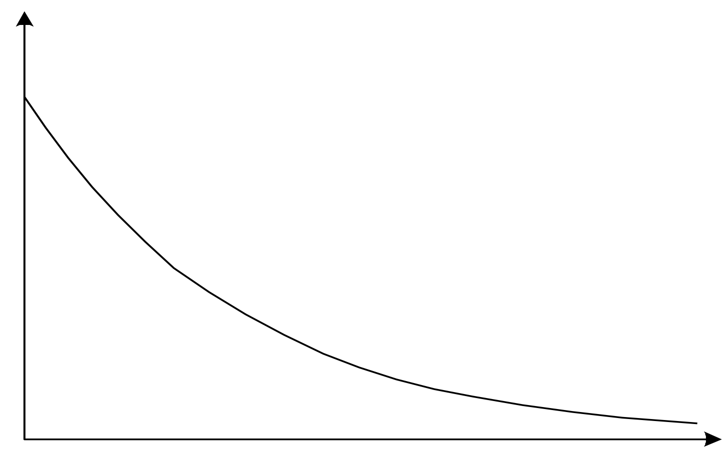
SIGNAL DISTRIBUTION

POWER OR **INTENSITY**

EXPONENTIAL DISTRIBUTION

$$p(I) = \frac{1}{\lambda}\ Exp\left\{\frac{-I}{\lambda}\right\}$$

$$where\ \ \sigma_I = E(I) = \lambda$$



<u>MULTI-LOOK IMAGE</u>

L = NUMBER OF LOOKS

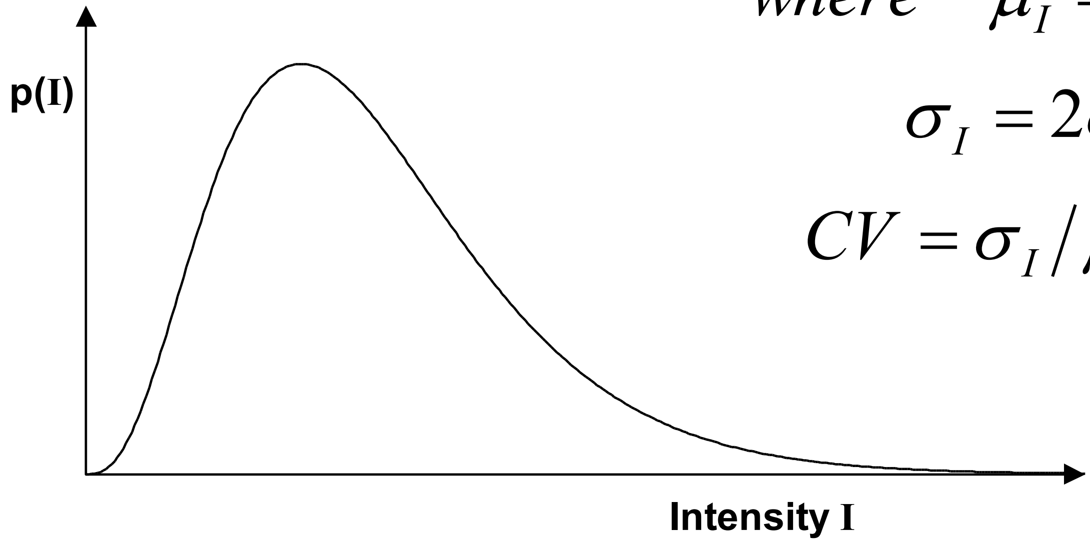
INTENSITY FOLLOWS A **GAMMA** DISTRIBUTION

$$p(I) \quad = \quad \left(\frac{L}{2\sigma^2}\right)^L \frac{I^{L-1}}{\Gamma(L)} Exp\left\{\frac{-L\,I}{2\sigma^2}\right\}$$

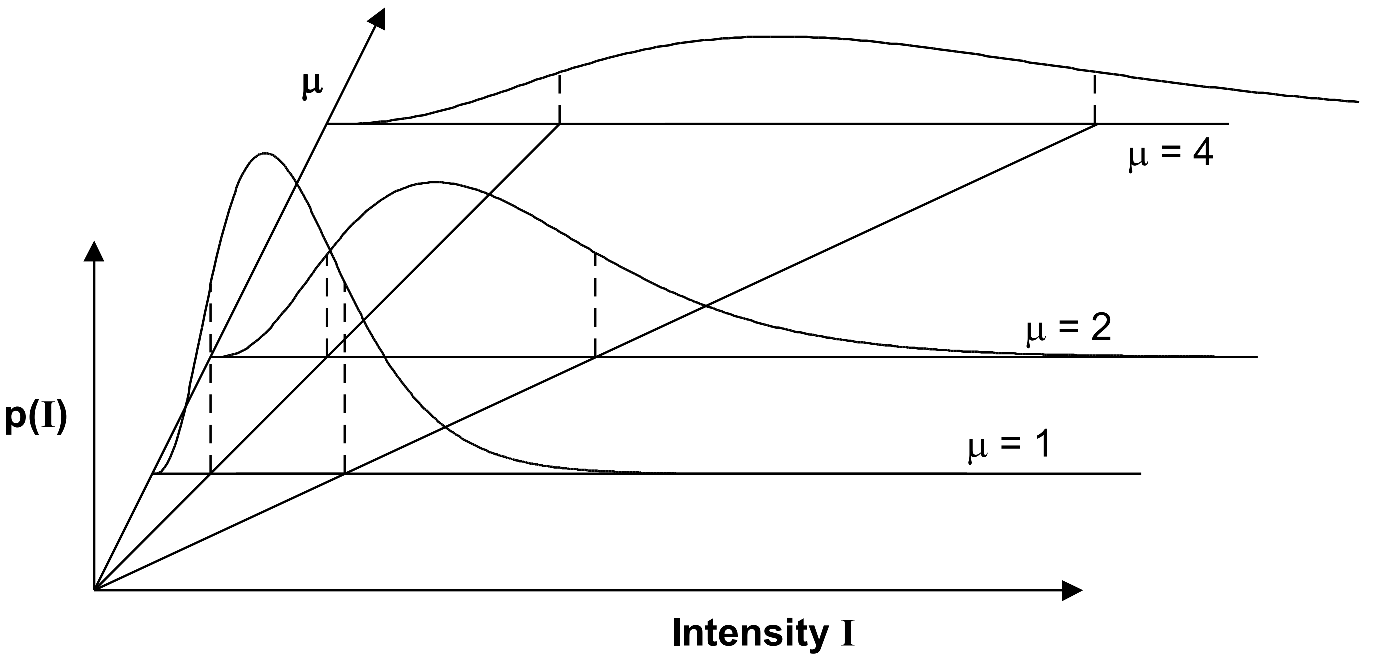
$$where \quad \mu_I = E(I) = 2\sigma^2$$

$$\sigma_I = 2\sigma^2 / \sqrt{L}$$

$$CV = \sigma_I / \mu_I = 1/\sqrt{L}$$



MULTIPLICATIVE NOISE

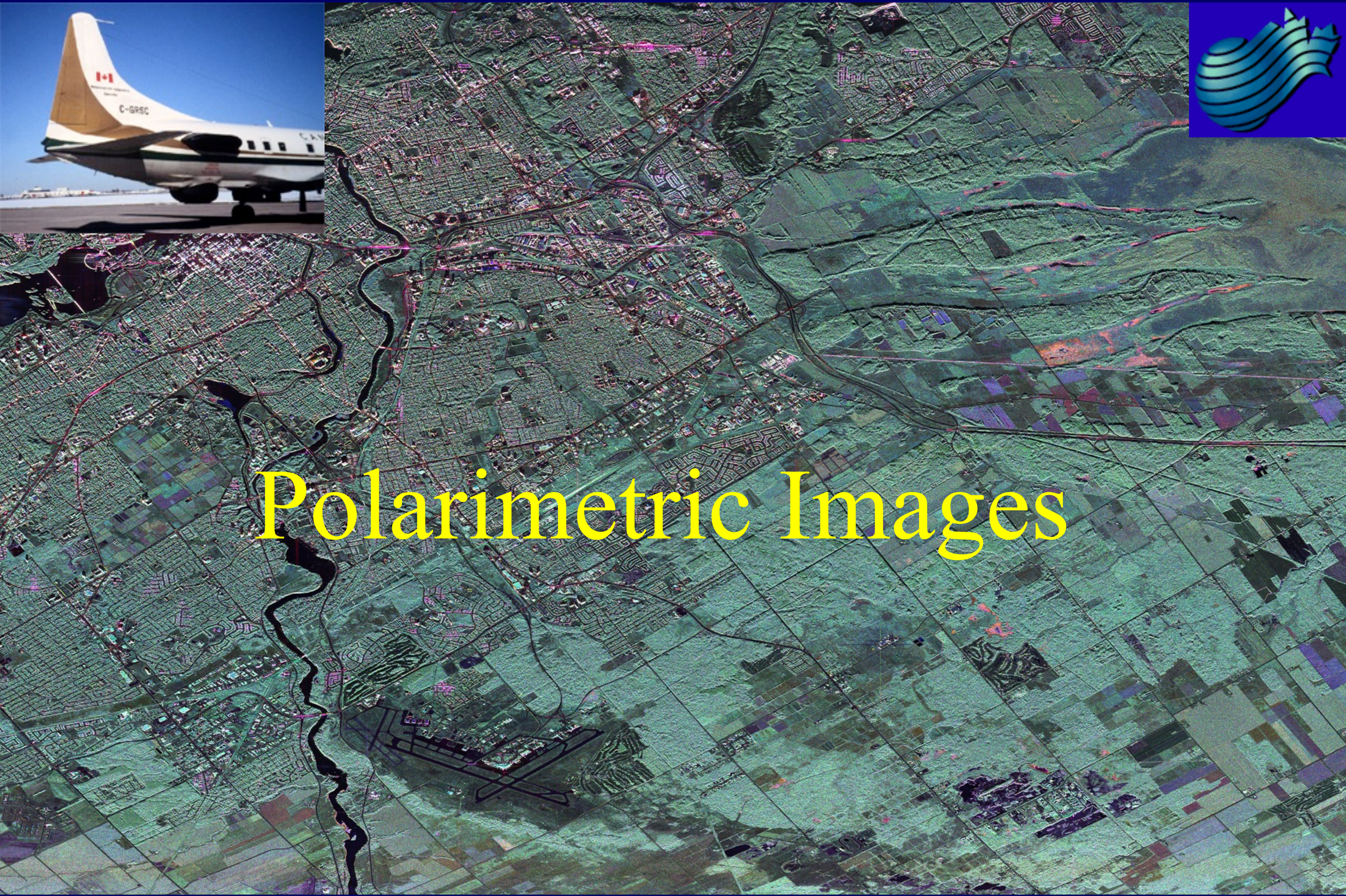


NOISE IS PROPORTIONAL TO INTENSITY

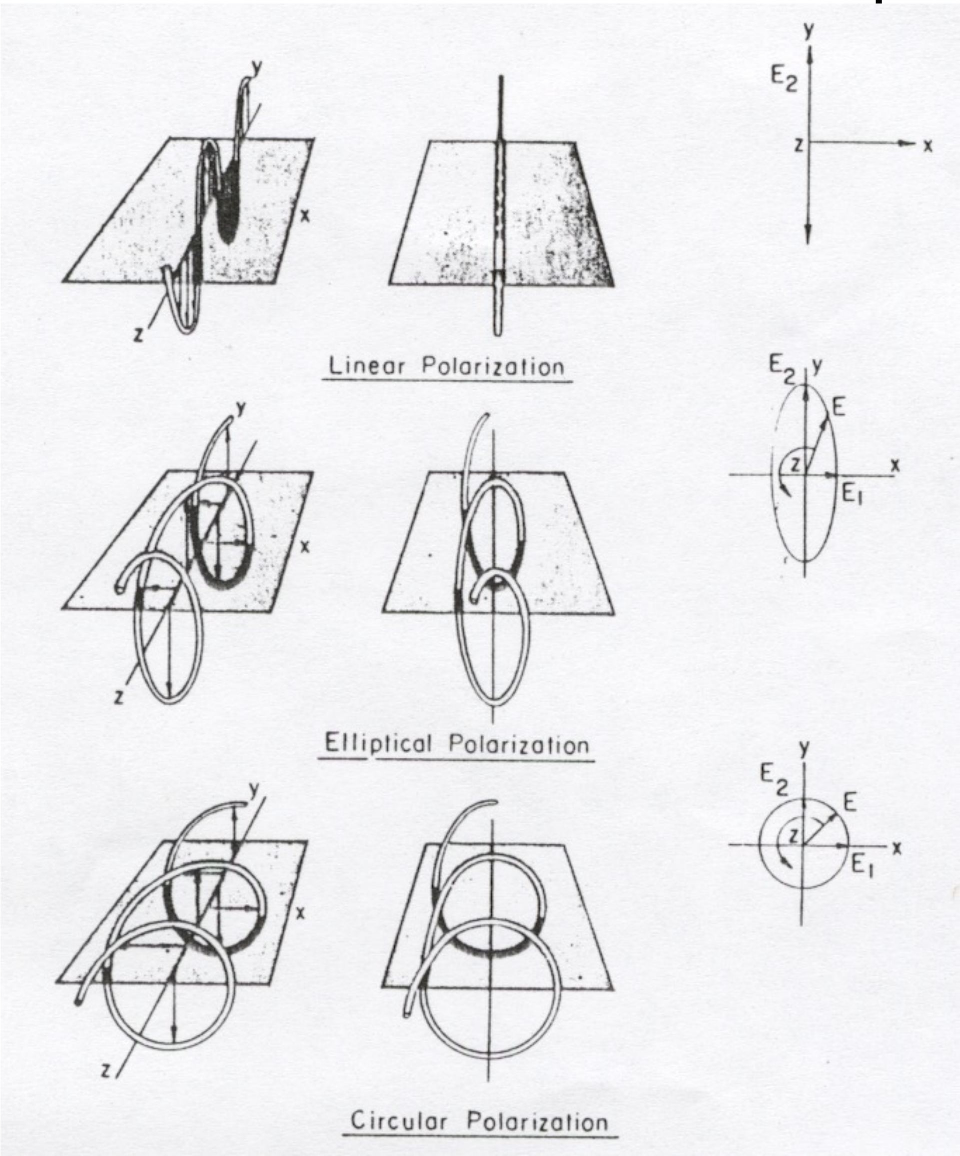
1000x1000 SAR image


SAR image

Polarimetric Images

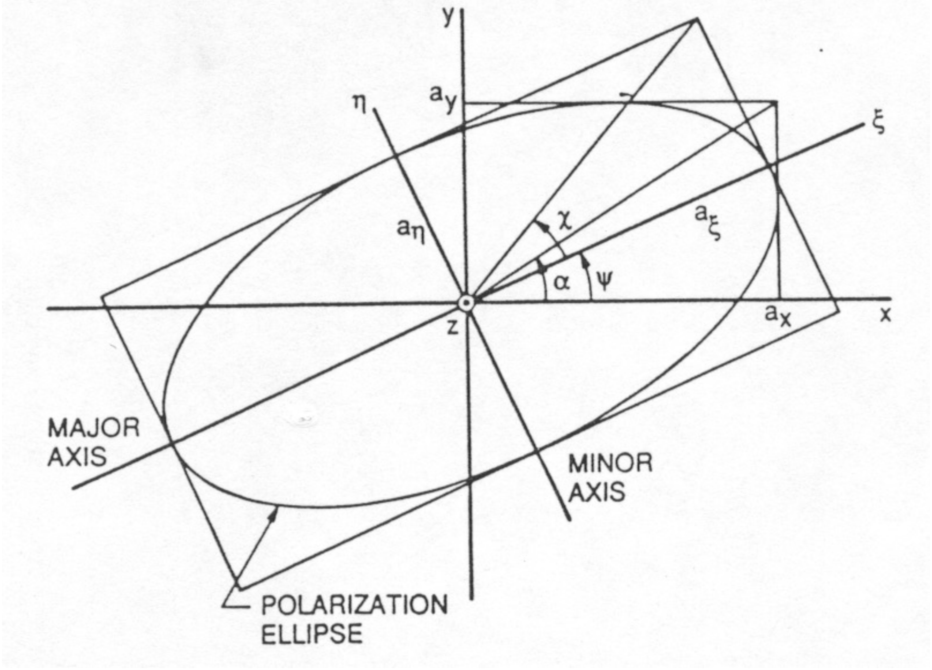


Polarization of an e.m. monochromatric plane wave



Polarization of an e.m. monochromatric plane wave

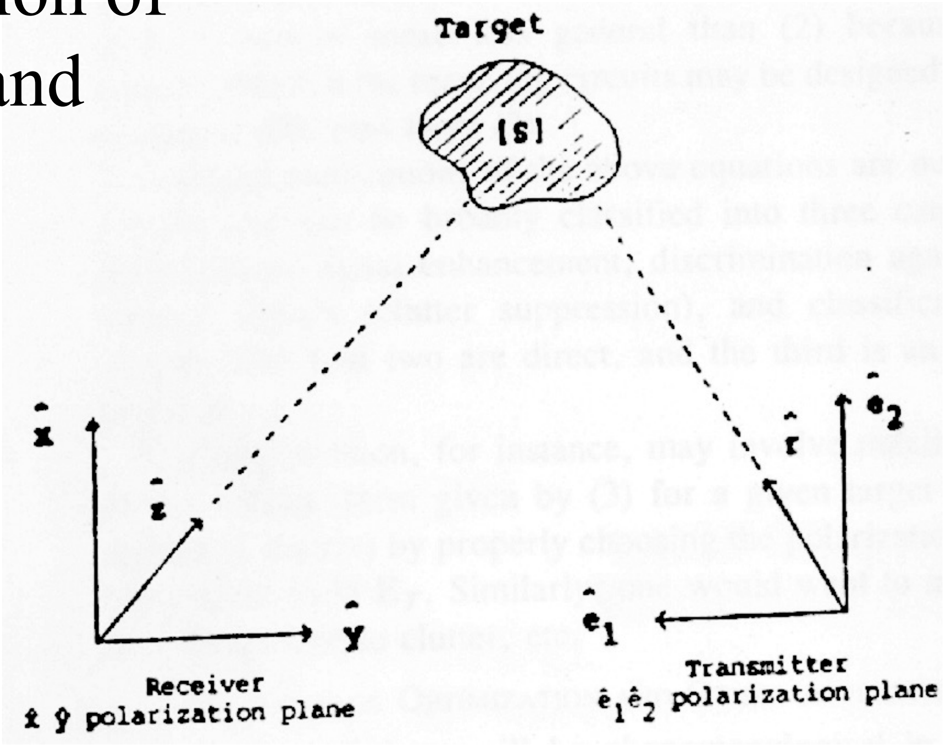
- The polarisation is a combination of the horizontal and vertical fields and could be represented by an ellipse (locus of the end point of the electric field)



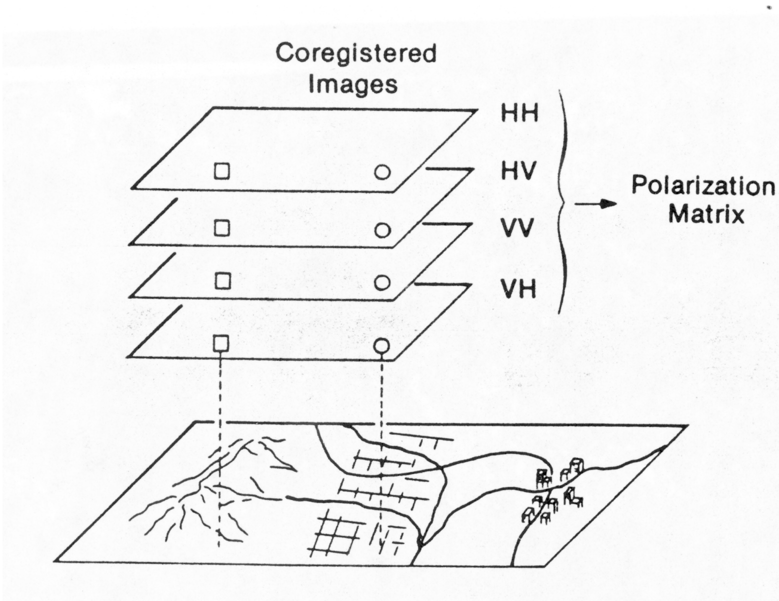
Imaging system

Consider the polarization of
the transmitter and
the receiver

	receiver h	receiver v
transmitter h	hh	hv
transmitter v	vh	vv



Polarization Synthesis

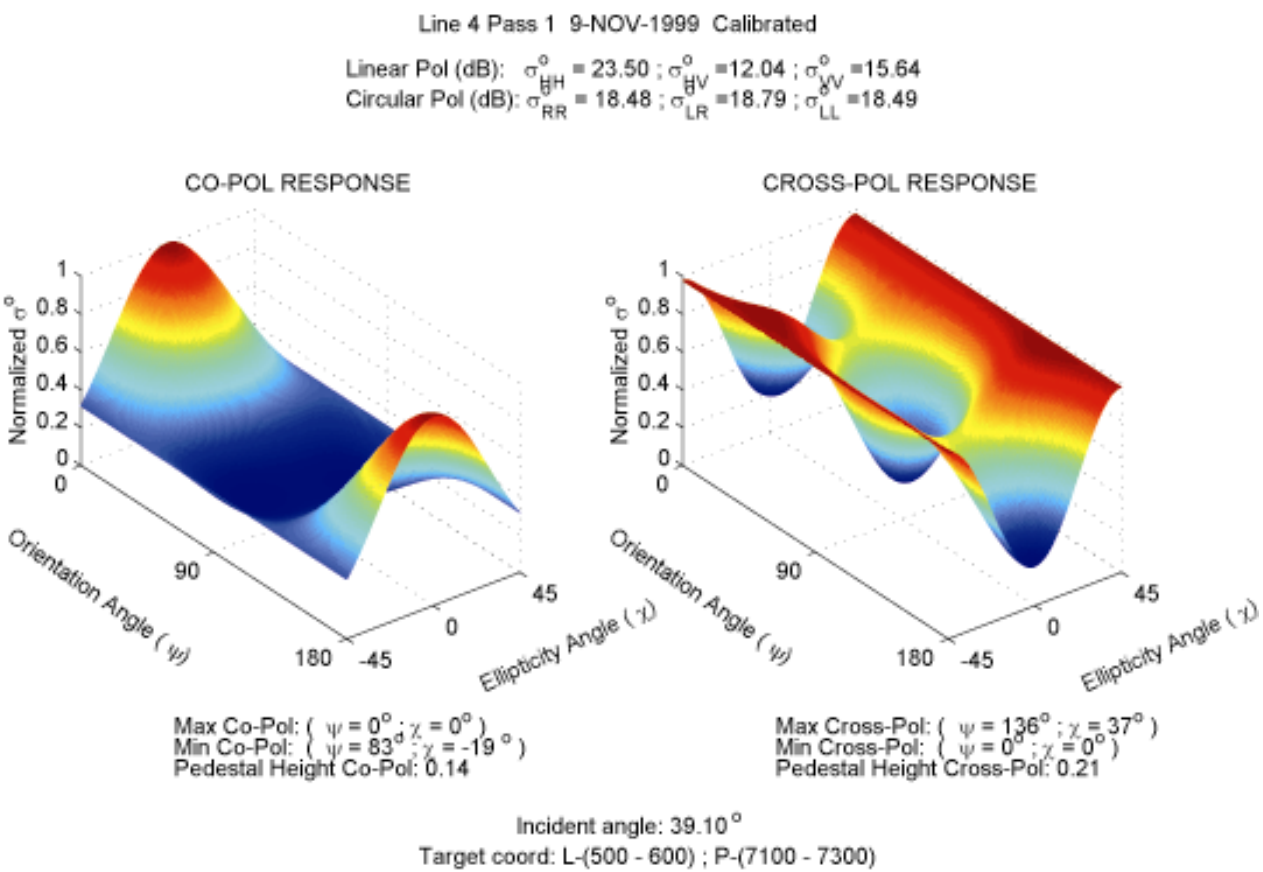


Polarization Synthesis

Grey level image

Chouse transmit and receive polarizations
→ produce one grey level image

Polarization signatures of a forest area in Shirley Bay



POLARIMETRIC SAR IMAGE

Multi-channel image – 3 complex elements

$$x = \begin{bmatrix} hh \\ hv \\ vv \end{bmatrix}$$

each element has
a zero mean circular
gaussian distribution

Complex gaussian pdf (**Σ** is the covariance matrix)

$$p(x \mid \Sigma) = \frac{1}{\pi^3 |\Sigma|} \exp\left(-x^* \Sigma^{-1} x\right)$$

x^* is the complex conjugate transpose of x

Multi-look images
Use the covariance matrix

$$\hat{\Sigma} = C = \frac{1}{n_s} \sum_{x \in s} x\, x^*$$

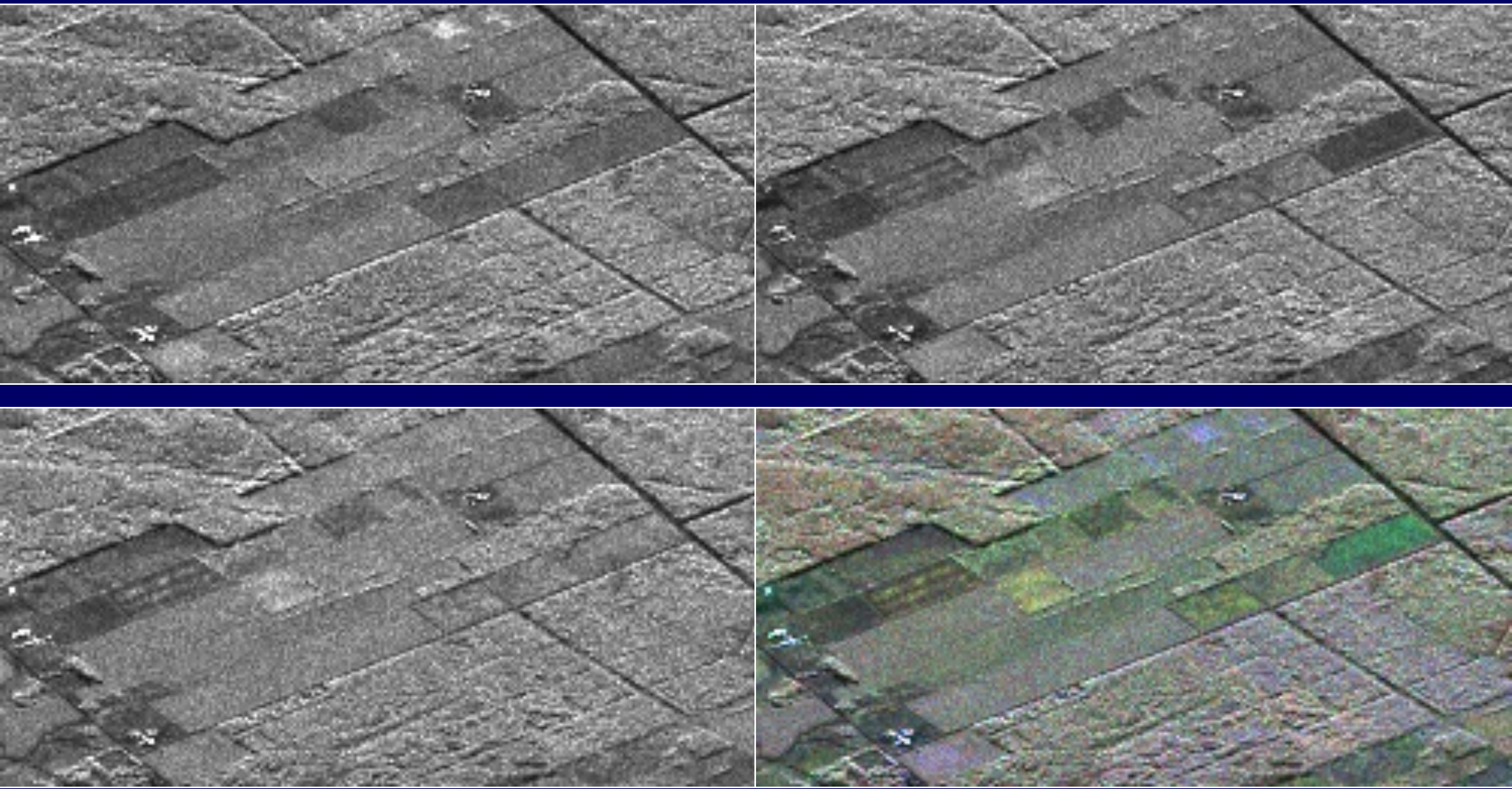
n_s is the number of pixels in segment s

$$\boldsymbol{C} = \frac{1}{n} \begin{bmatrix} \sum hh\, hh^* & \sum hh\, hv^* & \sum hh\, vv^* \\ \sum hv\, hh^* & \sum hv\, hv^* & \sum hv\, vv^* \\ \sum vv\, hh^* & \sum vv\, hv^* & \sum vv\, vv^* \end{bmatrix}$$

Follows a complex Wishart distribution

Amplitude values

|hh| |hv|

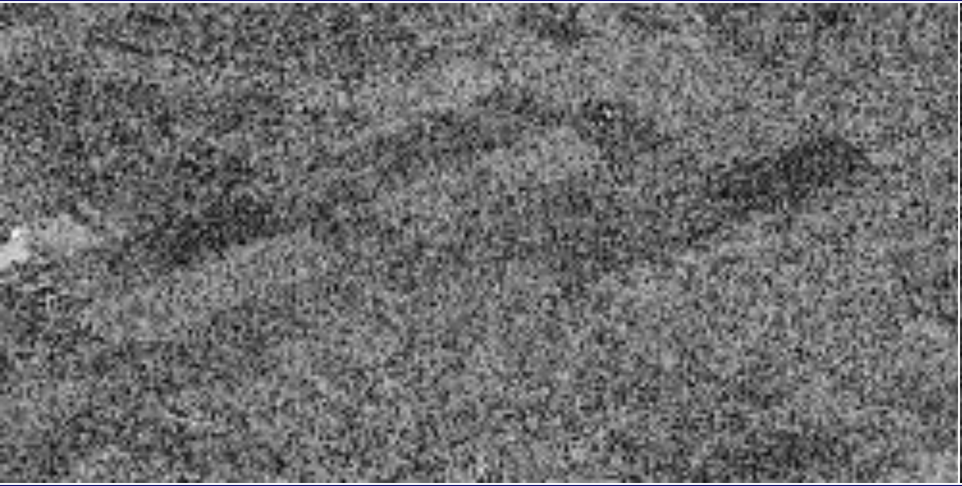


|vv| |hh| / |hv| / |vv|

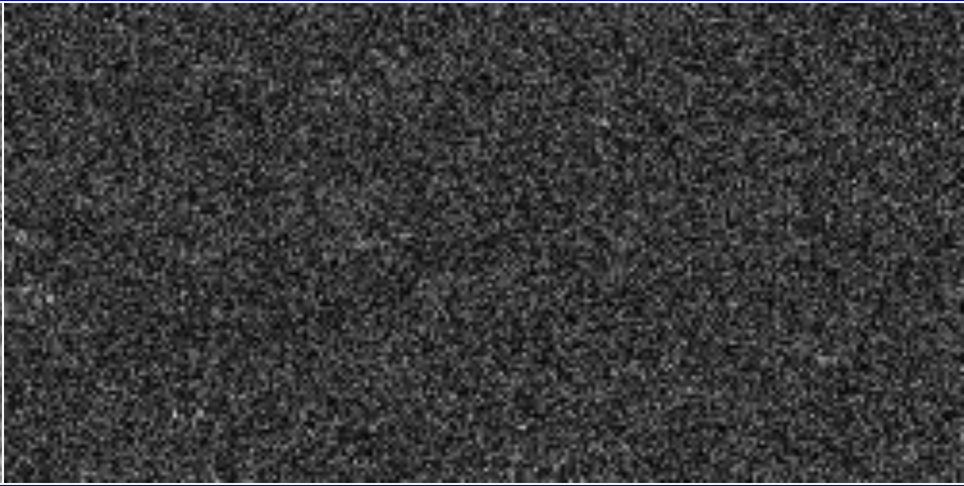
80 pixels / cell

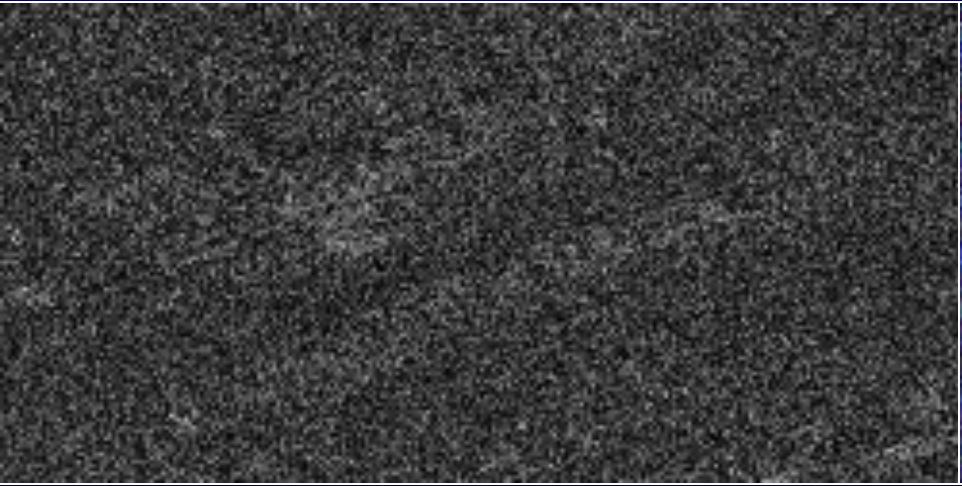
Correlation – module   (0 – 1)

hh vv*

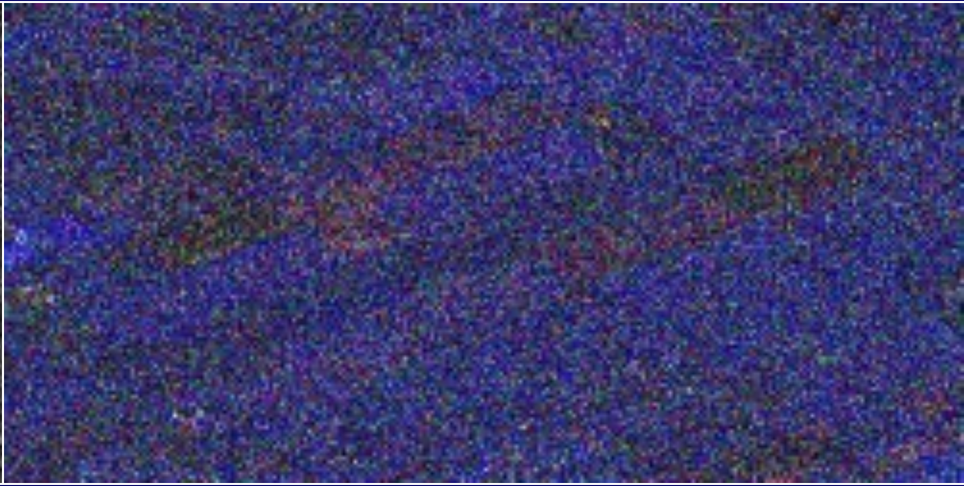


hh hv*





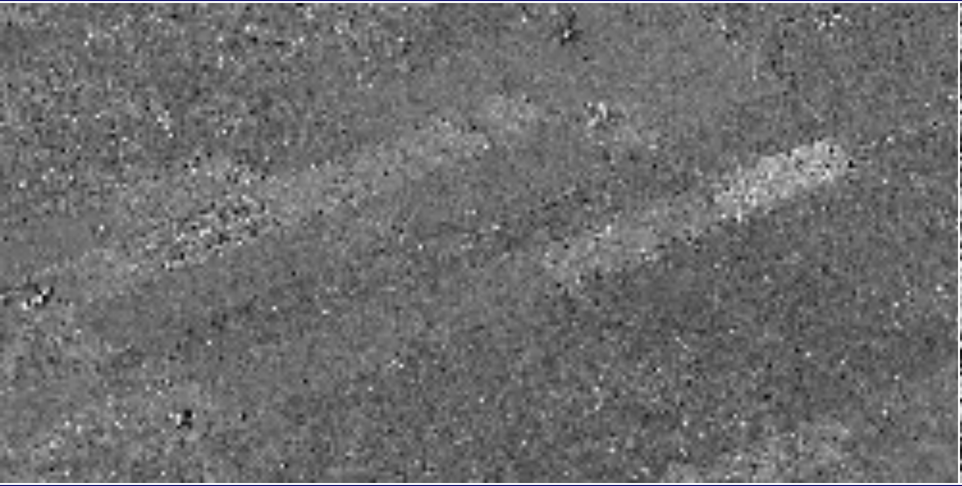
vv hv*



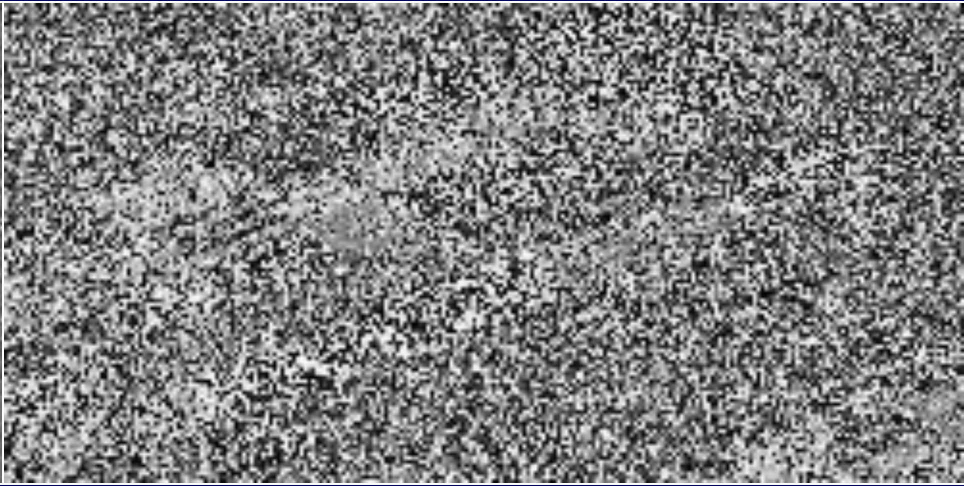
hh vv*/ hh hv*/ vv hv*

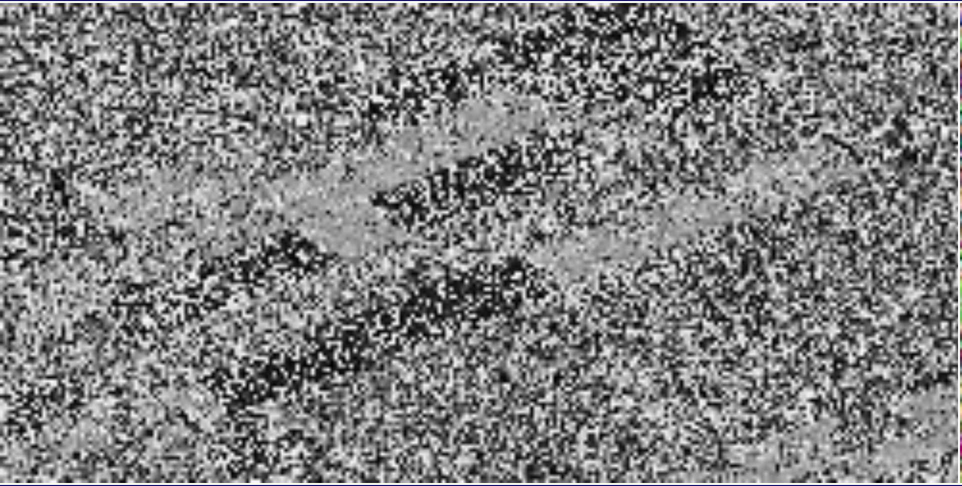
Correlation – phase (-180^{o} – 180^{o})

hh vv*

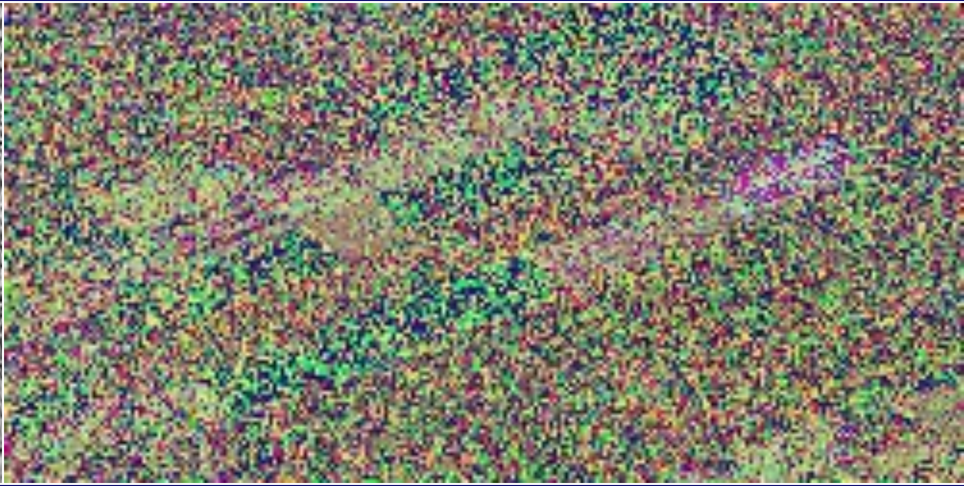


hh hv*

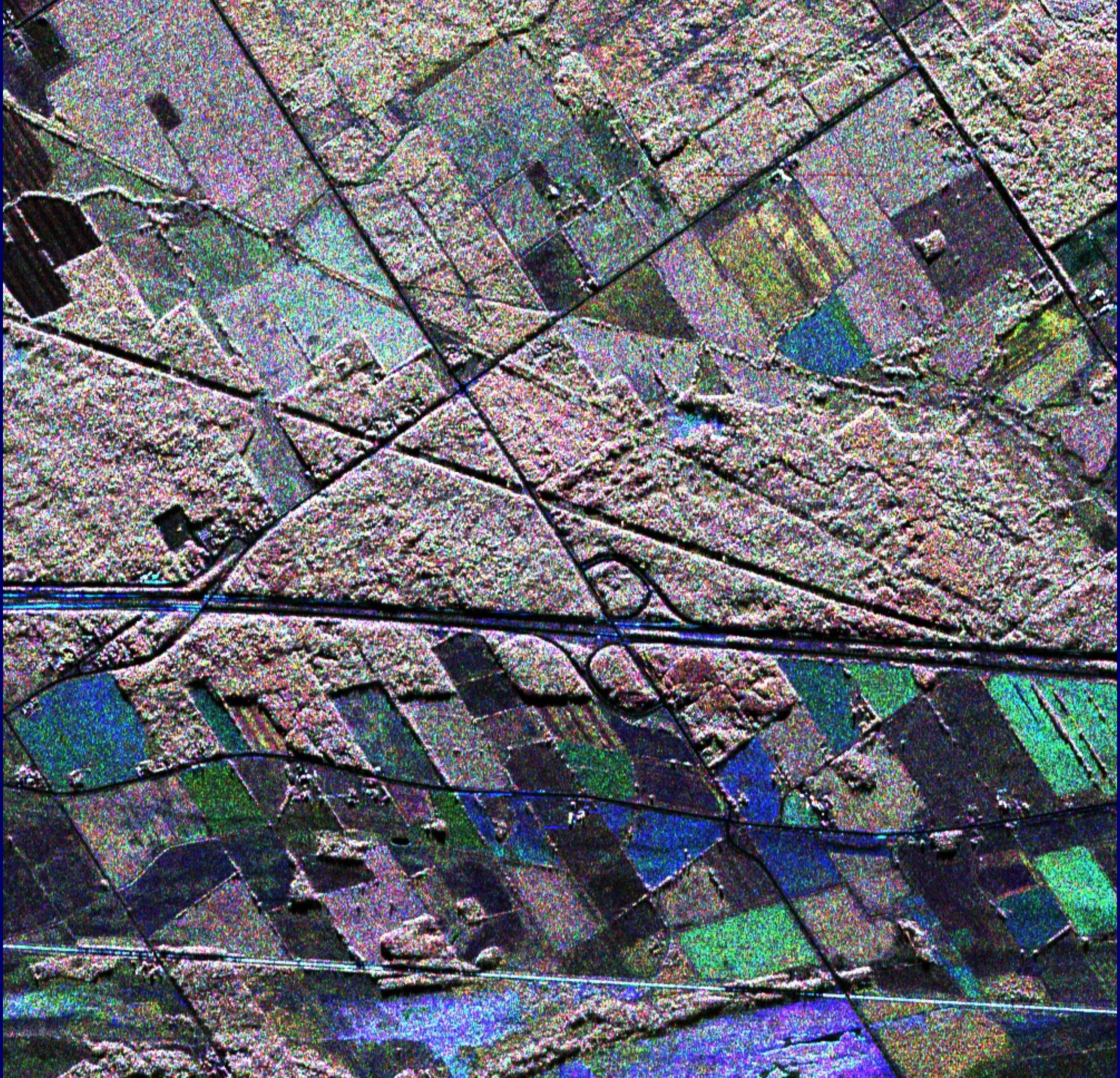




vv hv*



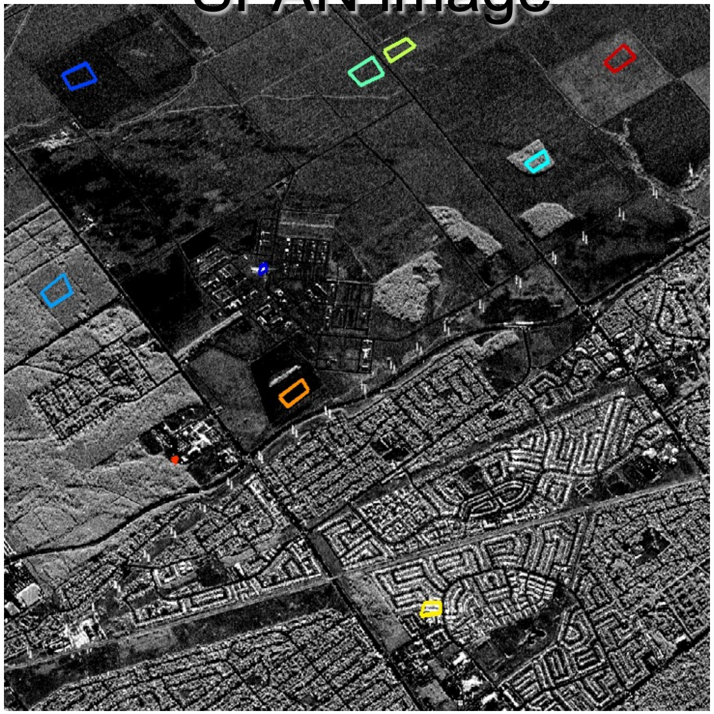
hh vv*/ hh hv*/ vv hv*



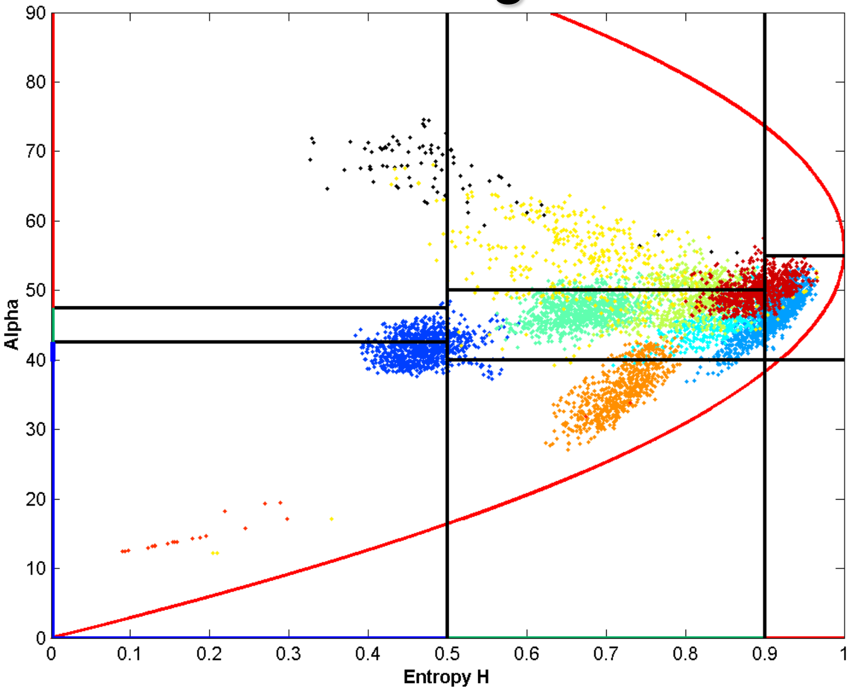
Amplitude image

Cloude Decomposition

SPAN image

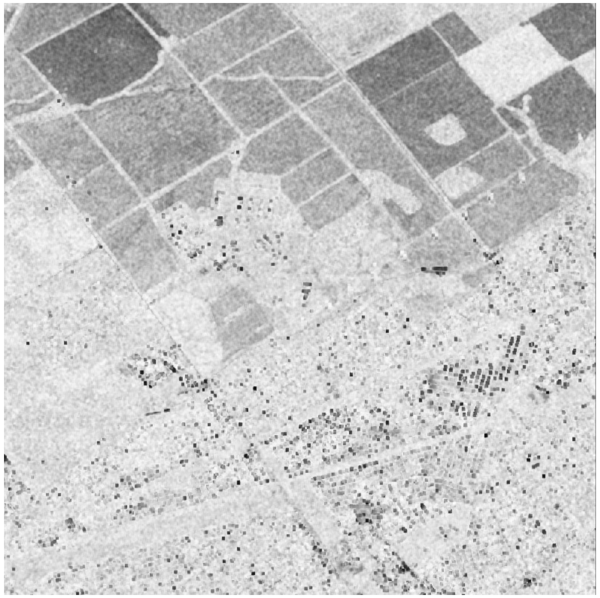


H / α diagram

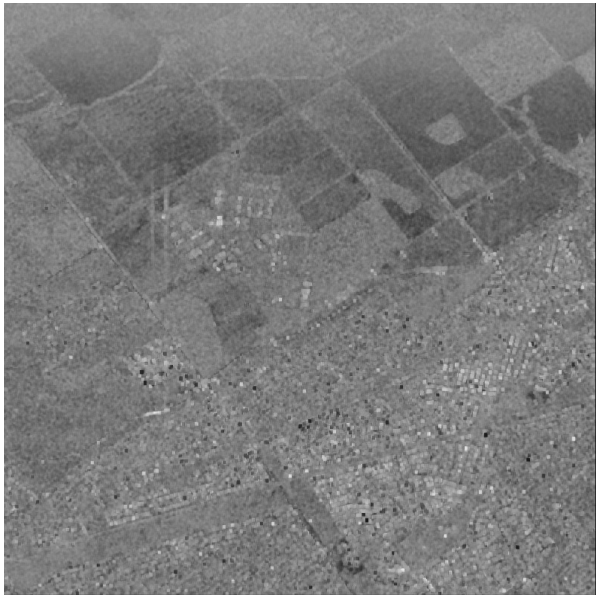


Cloude decomposition …

Entropy



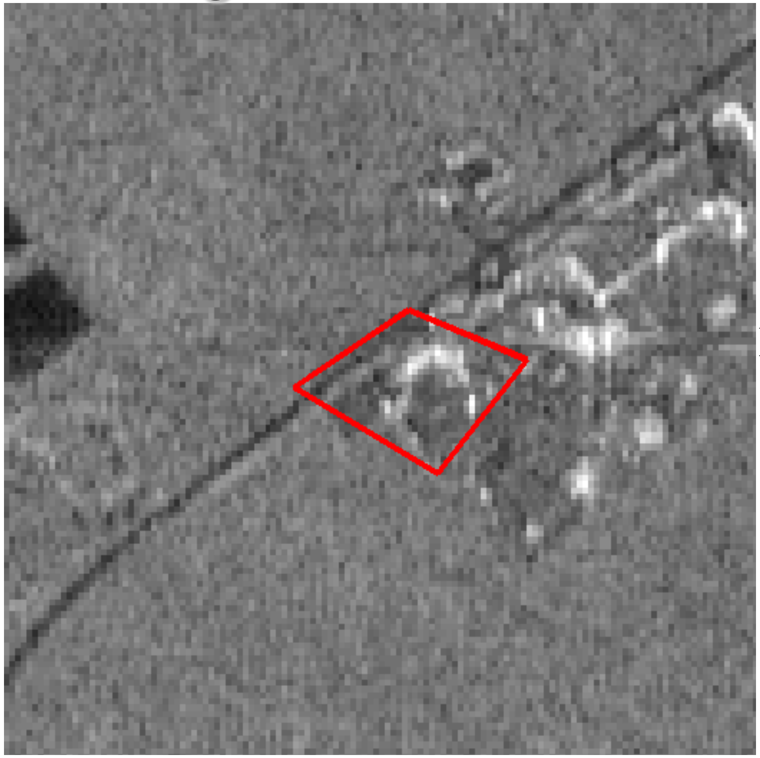
α



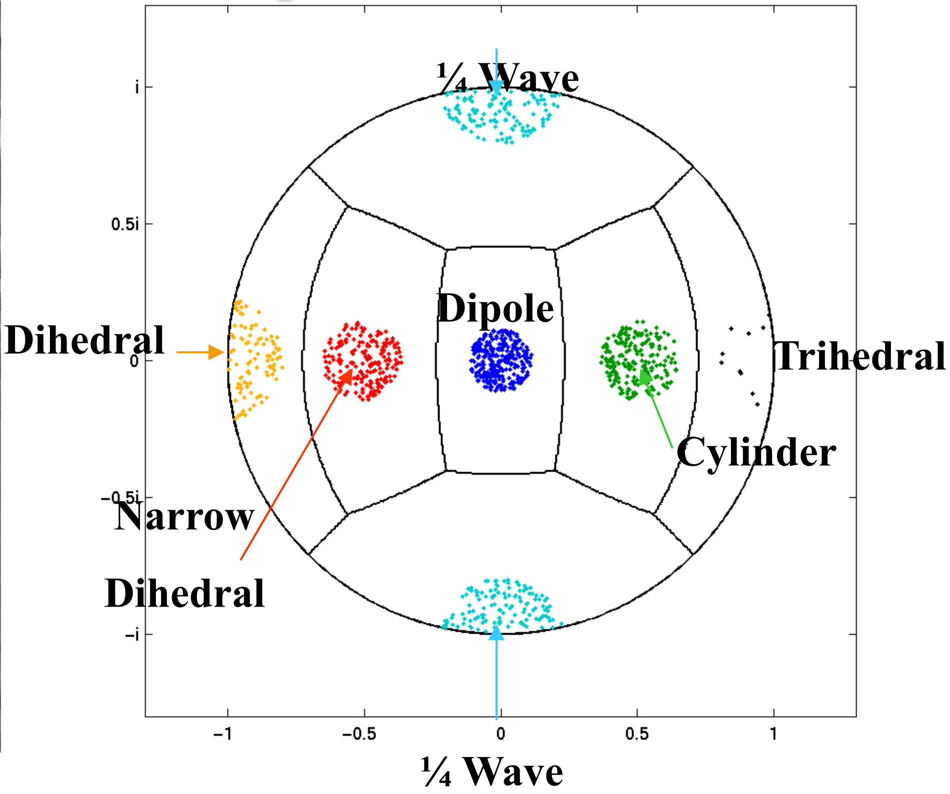
Anisotropy

Cameron Decomposition

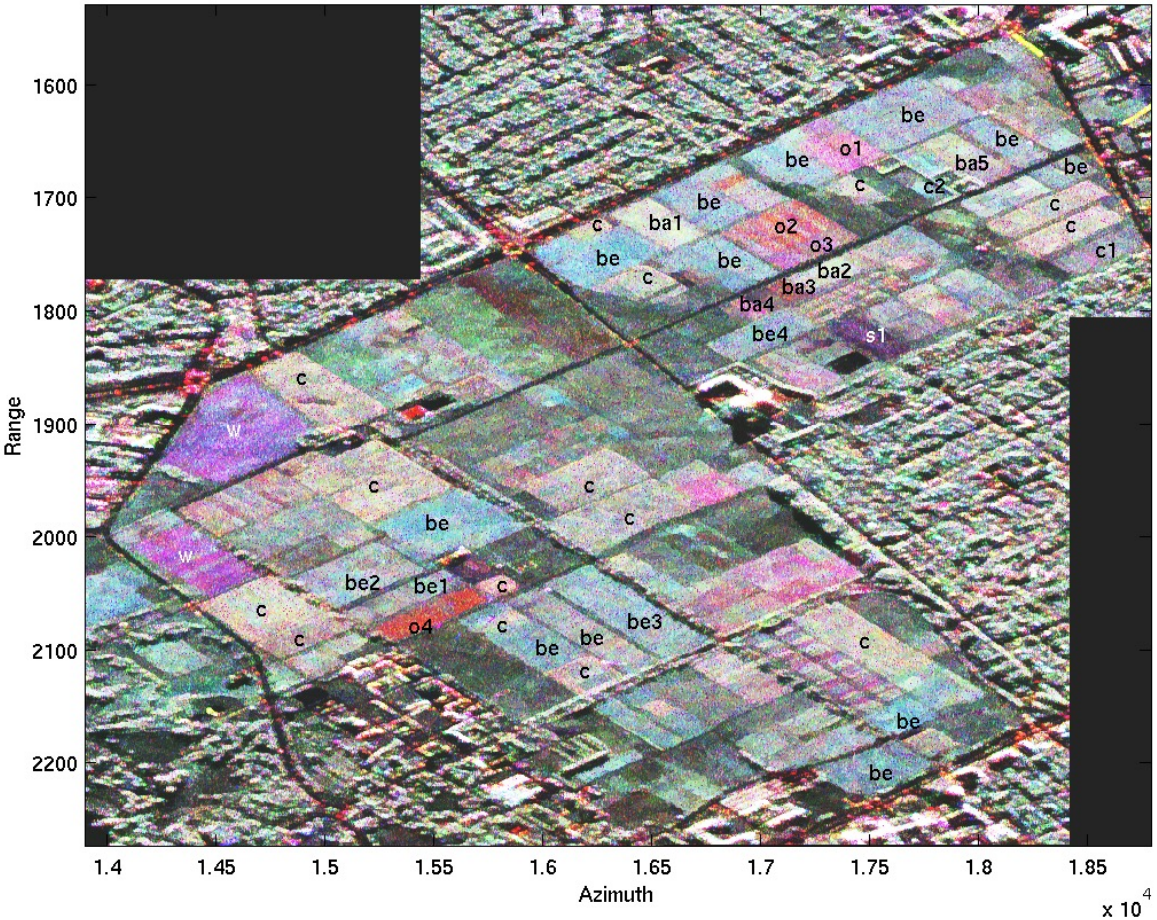
Region of Interest



Z Diagram Threshold 2dB



Classification of Distributed Target



w : wheat

c : corn

be: beans

o : oats

ba: barley

s : bare soil

…………………………………………………

o1: rows of 90cm oats (4m) & soil (1.5m)

o2: rows of cut (10m) & 90cm (28m) oats

o3: rows of 90cm oats (1m) & grass (3m)

o4: oats, uniform, ripe (90cm)

c1: corn, young leaves only

c2: corn, unhealthy, sparse, grass

ba1: barley, ripe

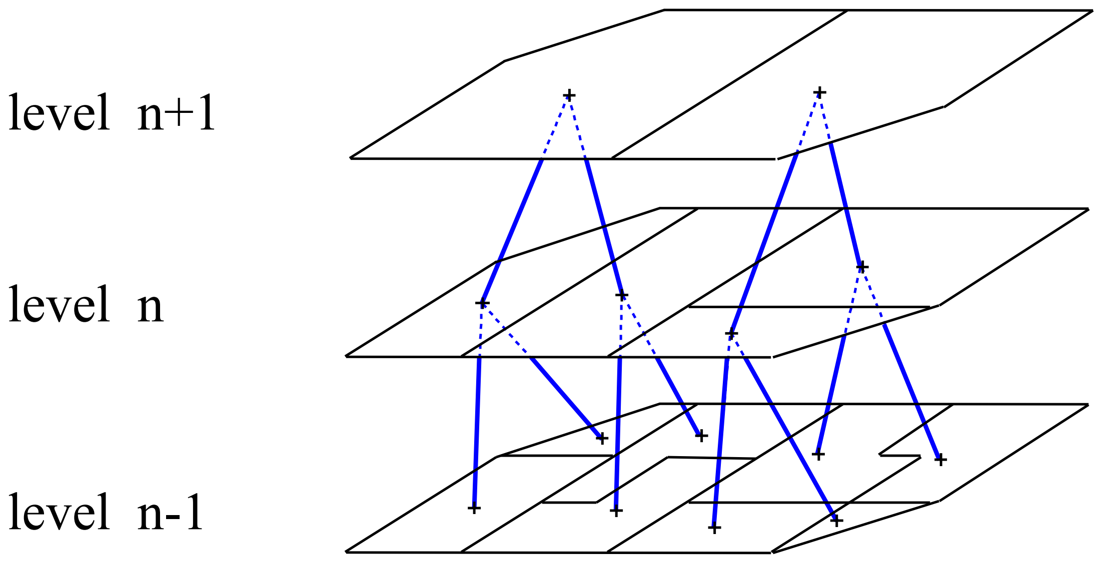
ba2: barley, young & green

…………………………………………………

polarimetric filter : Lee phase preserving

HIERARCHICAL SEGMENTATION BY STEP-WISE OPTIMISATION

A hierarchical segmentation begins with an initial partition P^0 (with N segments) and then sequentially merges these segments.

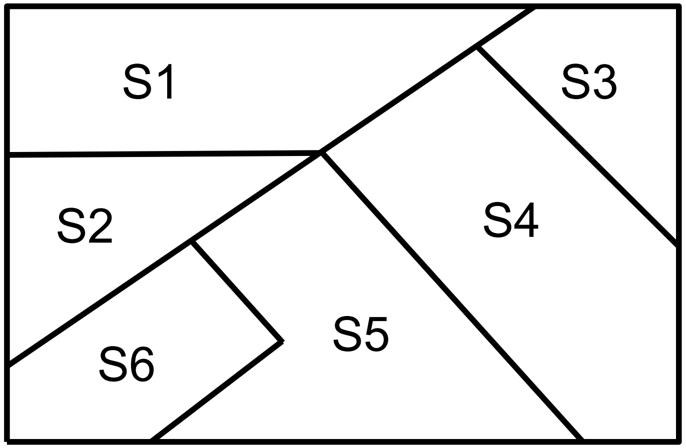


Segment tree

SEGMENTATION AS MAXIMUM LIKELIHOOD APPROXIMATION

1) need a partition of the image

$$P = \{s_k\}, \quad s_k = \{i\} \subset I$$



2) need statistical parameters

$$\theta = \{\theta_s\}, \quad s \in P$$

3) need an image probability model

$$p(x_i \mid \theta_s)$$

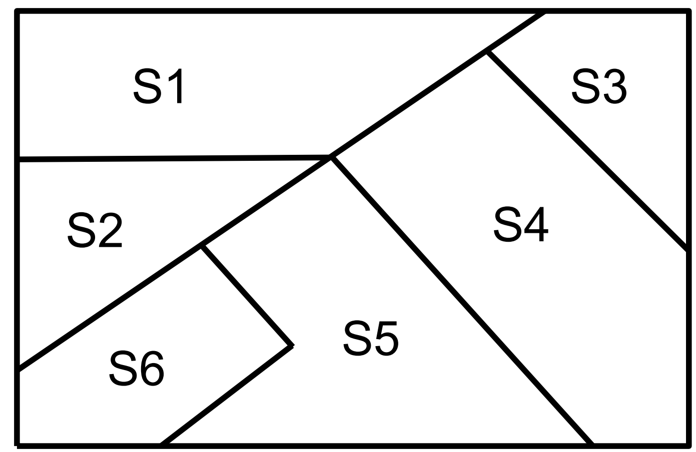
x_i are conditionally independent

Given an image $X = \{x_i\}, \quad i \in I$

the likelihood of $\theta = \{\theta_s\}, \quad P$

is $L(\theta, P \mid X) = p(X \mid \theta, P)$

$$L(\theta, P \mid X) = \prod_{i \in I} p(x_i \mid \theta_{s(i)})\Big|_P$$

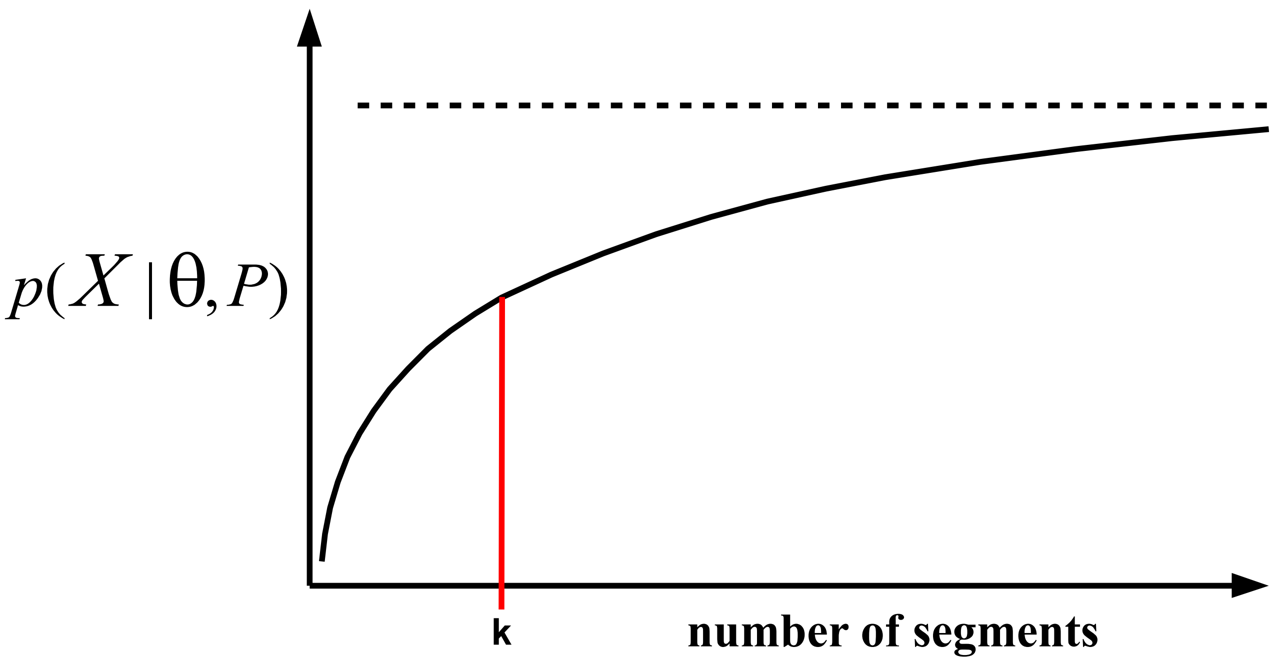


The segmentation problem is to find the partition that maximizes the likelihood.

Global search – too many possible partitions.

θ_s **is derived from statistics calculated over a segment *s*.**

The maximum likelihood increases with the number of segments

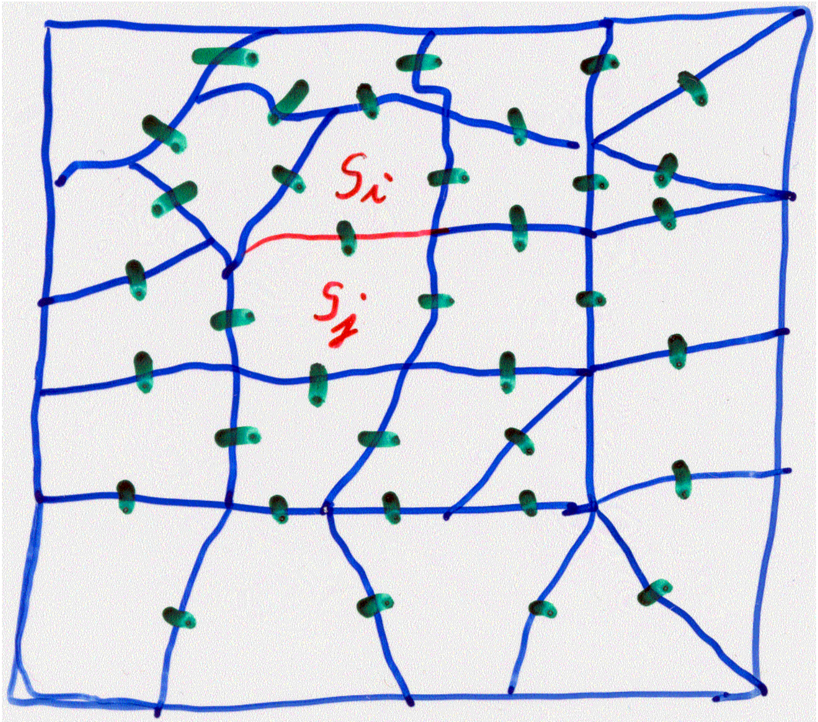


Can't find the optimum partition with k segments, P_k
Too many, except for P_1 and P_{nxn}.

Hierarchical segmentation
→ get P_k from P_{k+1} by merging 2 segments.

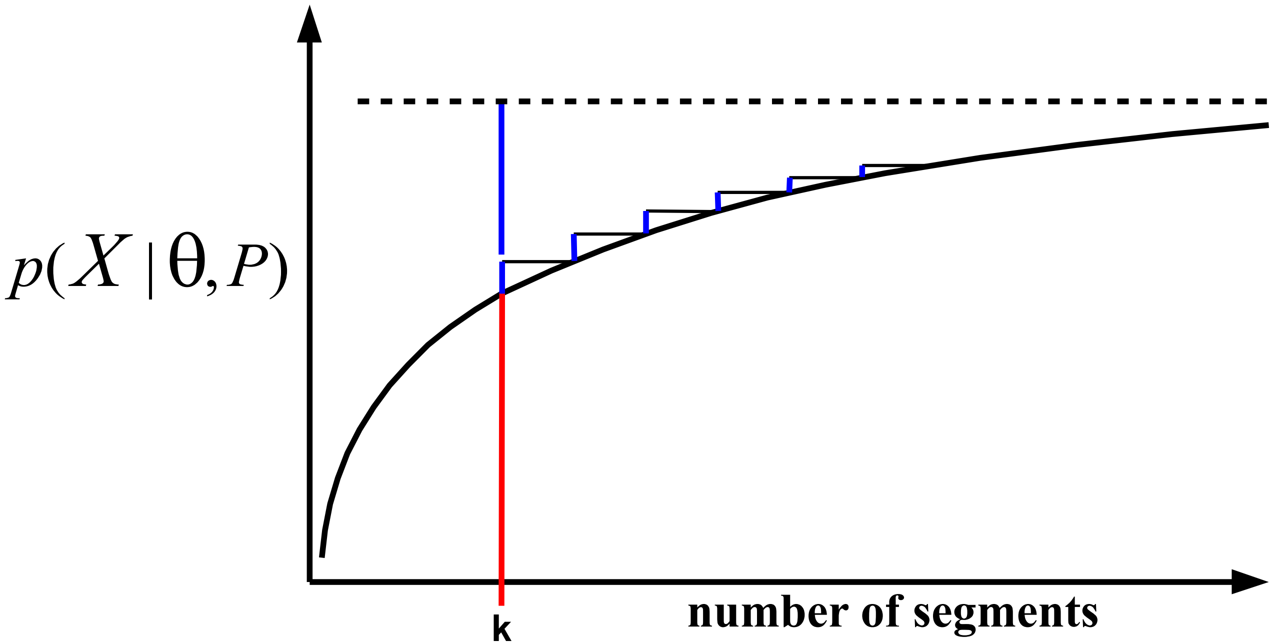
Stepwise optimization

- examine each adjacent segment pair
- merge the pair that minimizes the criterion



Merging criterion:

merge the 2 segments producing the smallest decrease of the maximum likelihood (stepwise optimization)



Sub-optimum within hierarchical merging framework.

Log likelihood form

$$\ln\left(L(\theta, P \mid X)\right) = \ln\left(\prod_{i \in I} p(x_i \mid \theta_{s(i)})\right) = \sum_{i \in I} \ln\left(p(x_i \mid \theta_{s(i)})\right)$$

Summation inside region

$$\sum_{s \in P} \sum_{i \in s} \ln\left(p(x_i \mid \theta_s)\right) = \sum_{s \in P} LML(s)$$

Criterion → cost of merging 2 segments

$$\Delta = LML(s_i) + LML(s_j) - LML(s_i \cup s_j)$$

$$\Delta = \sum_{x \in s_i} \ln\left(p(x \mid \theta_{s_i})\right) + \sum_{x \in s_j} \ln\left(p(x \mid \theta_{s_j})\right) - \sum_{x \in s_i \cup s_j} \ln\left(p(x \mid \theta_{s_i \cup s_j})\right)$$

minimize $|\Delta|$

POLARIMETRIC SAR IMAGE

Multi-channel image – 3 complex elements

$$x = \begin{bmatrix} hh \\ hv \\ vv \end{bmatrix}$$

each element has
a zero mean circular
gaussian distribution

Complex gaussian pdf (Σ is the covariance matrix)

$$p(x \mid \Sigma) = \frac{1}{\pi^3 |\Sigma|} \exp\left(-x^* \Sigma^{-1} x\right)$$

x^* is the complex conjugate transpose of x

The best maximum likelihood estimate of Σ is the covariance calculated over the region (segment)

$$\hat{\Sigma} = C = \frac{1}{n_s} \sum_{x \in s} x\, x^*$$

n_s is the number of pixels in segment s

$$\boldsymbol{C} = \frac{1}{n} \begin{bmatrix} \sum hh\, hh^* & \sum hh\, hv^* & \sum hh\, vv^* \\ \sum hv\, hh^* & \sum hv\, hv^* & \sum hv\, vv^* \\ \sum vv\, hh^* & \sum vv\, hv^* & \sum vv\, vv^* \end{bmatrix}$$

***LML* for a region *s* is**

$$LML(s) = \sum_{x \in s} \ln\left(p(x \mid C_s)\right) = \sum_{x \in s} \ln\left(\frac{1}{\pi^3 |C_s|} \exp\left(-x^* C_s^{-1} x\right)\right)$$

$$= \sum_{x \in s} \left[-\ln \pi^3 - \ln|C_s| - x^* C_s^{-1} x\right]$$

$$= -n_s \ln \pi^3 - n_s \ln|C_s| - \sum_{x \in s} x^* C_s^{-1} x$$

$$= -n_s \ln|C_s| - n_s \ln \pi^3 - 3n_s$$

constant term for the whole image

The variation produced by merging 2 segments is

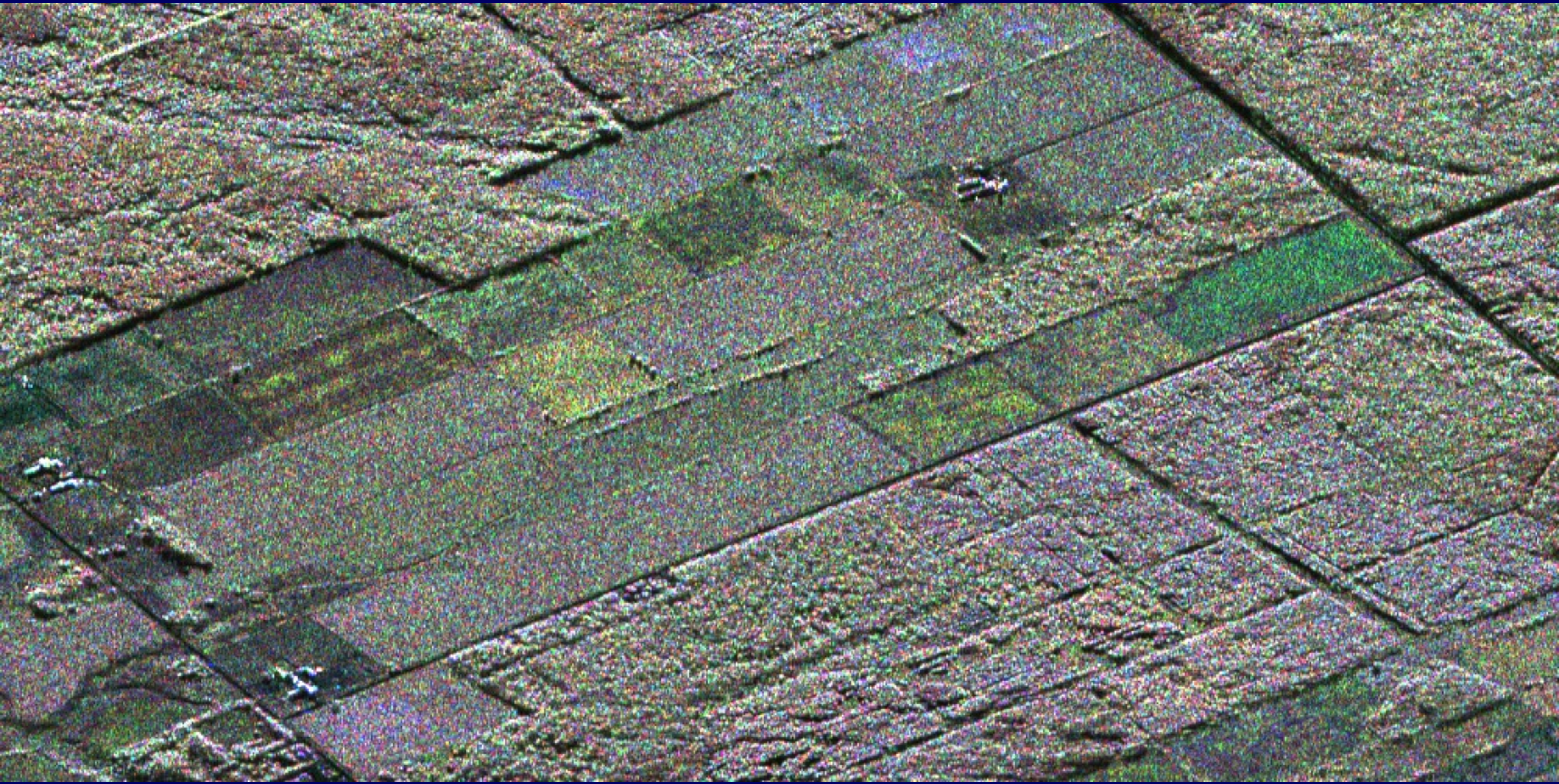
$$\Delta = LML(s_i) + LML(s_j) - LML(s_i \cup s_j)$$
$$= -n_{si} \ln\left|C_{si}\right| - n_{sj} \ln\left|C_{sj}\right| + (n_{si} + n_{sj}) \ln\left|C_{si \cup sj}\right|$$

Hierarchical segmentation:

at each iteration, merge the 2 segments that minimize the stepwise criterion $C_{\mathbf{i,j}}$

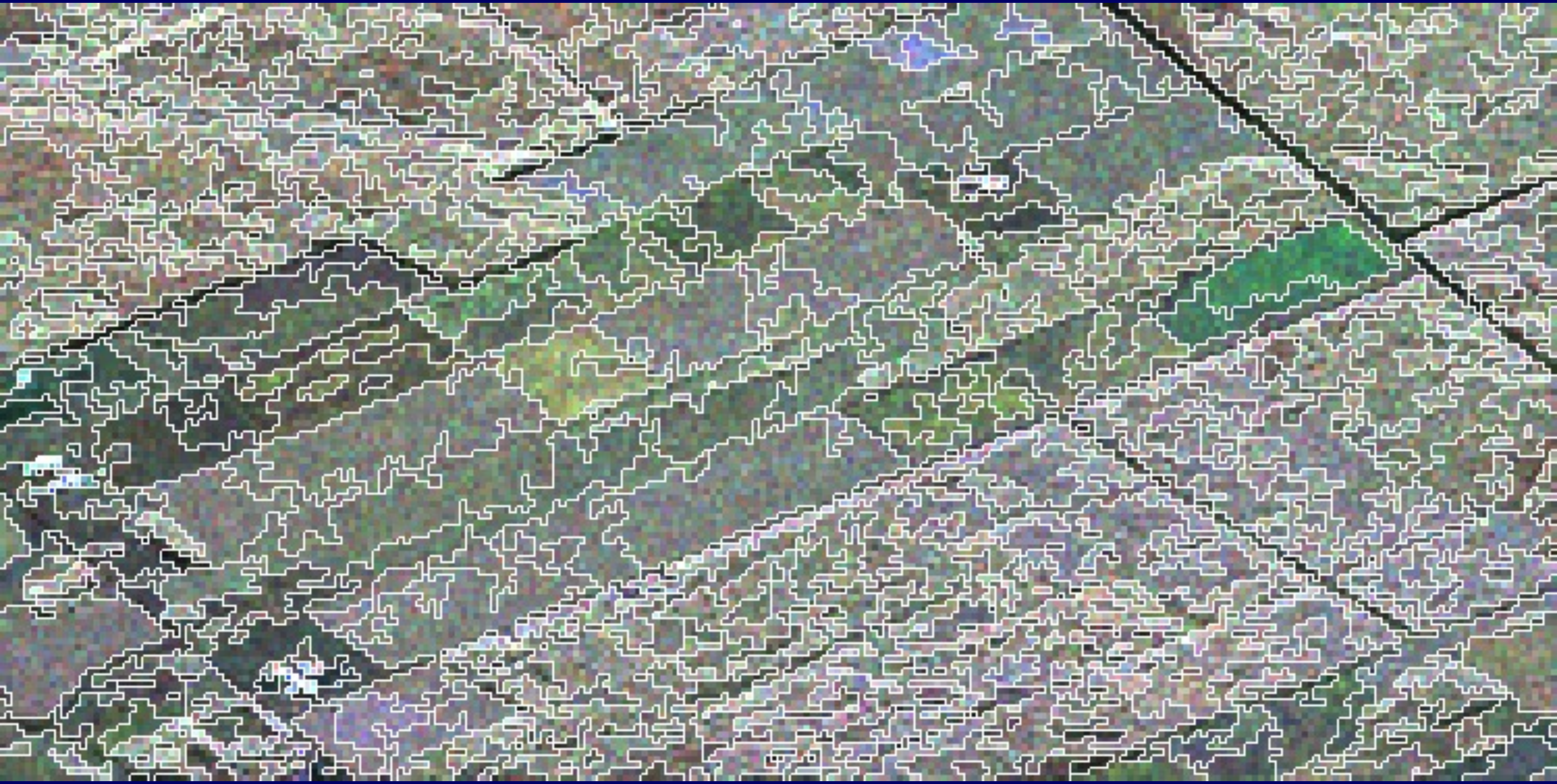
$$C_{i,j} = (n_{si} + n_{sj}) \ln\left|C_{si \cup sj}\right| - n_{si} \ln\left|C_{si}\right| - n_{sj} \ln\left|C_{sj}\right|$$

Amplitude image

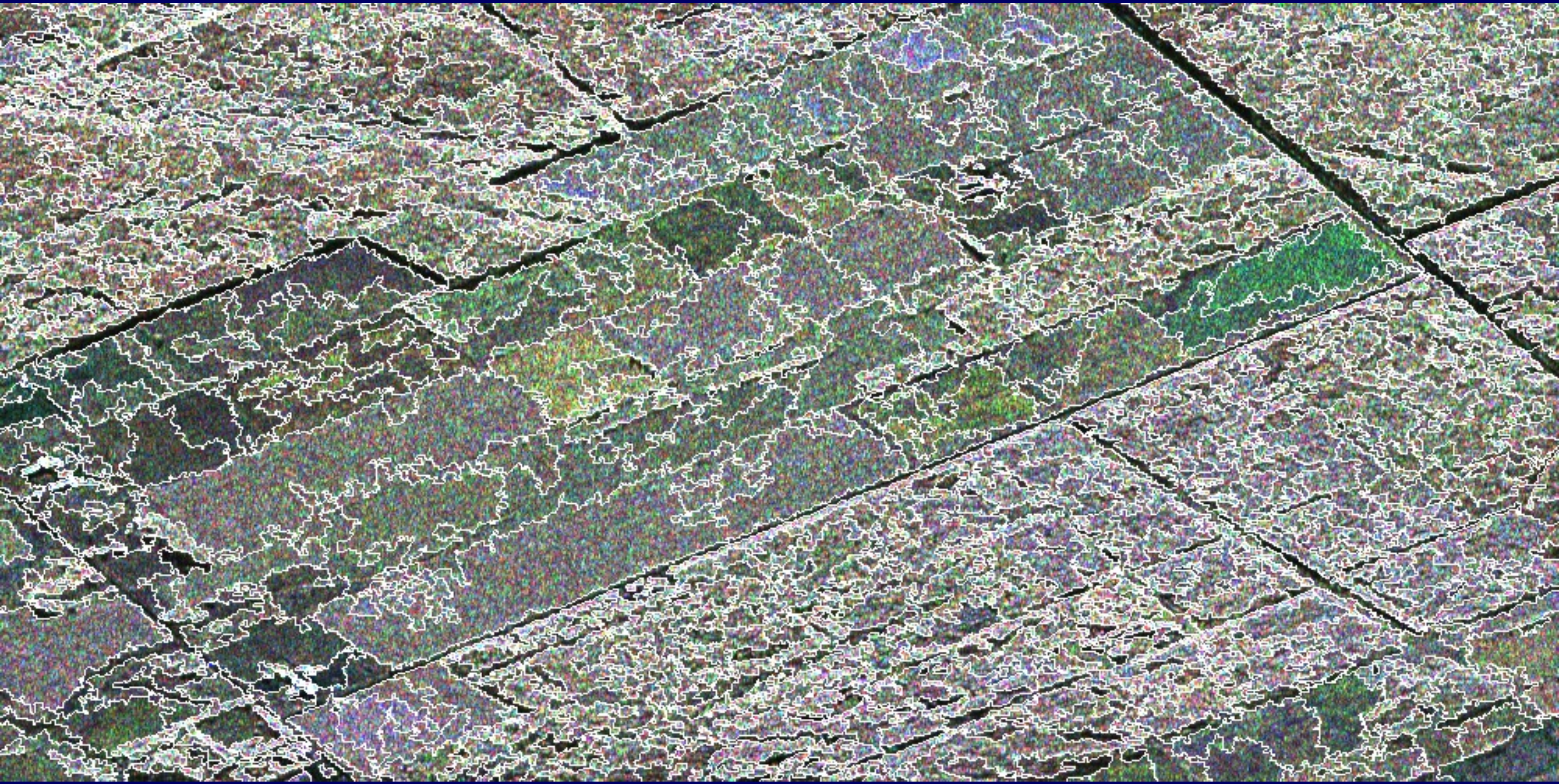


5 pixels / cell

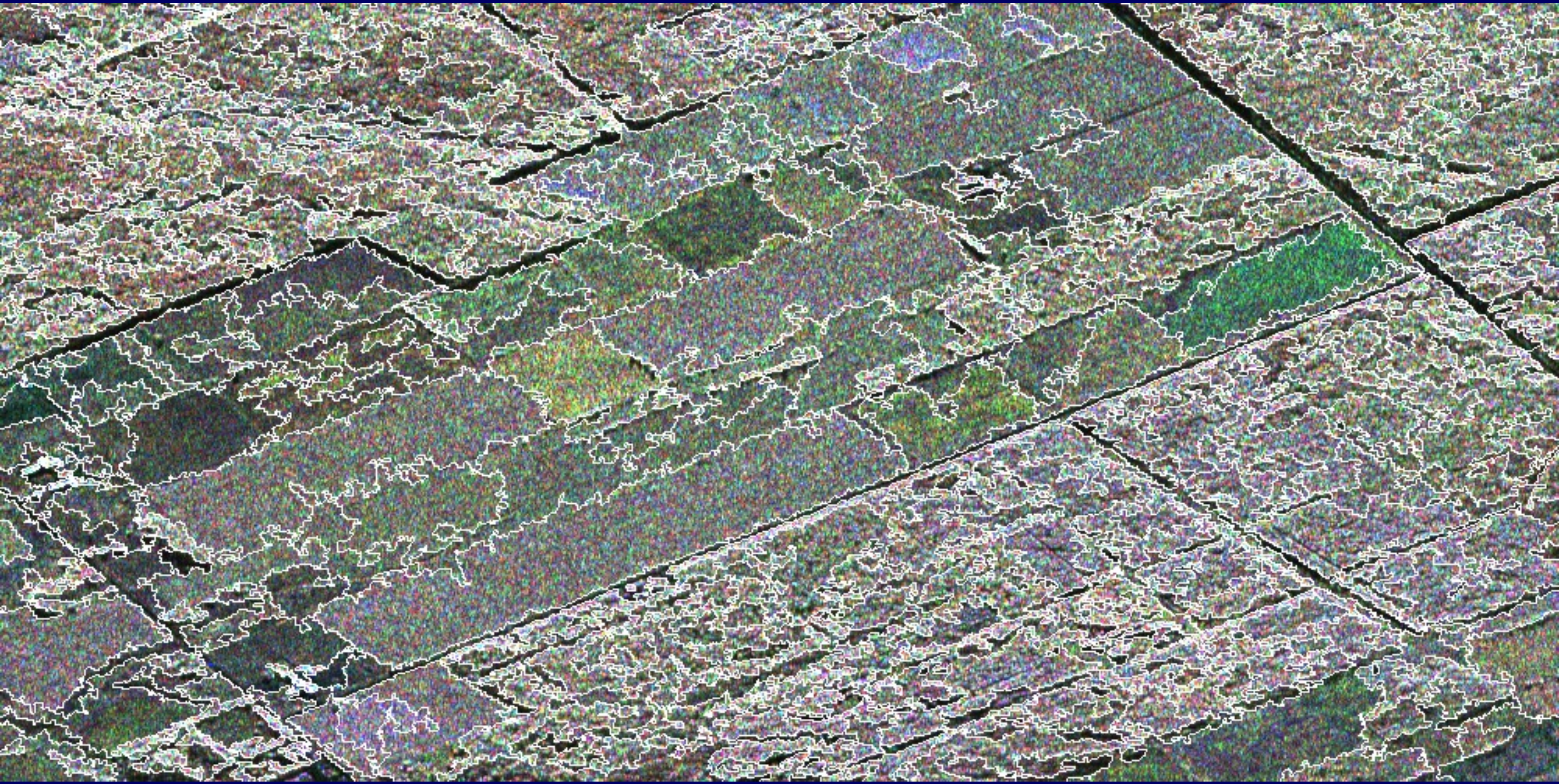
1000 segments – low resolution



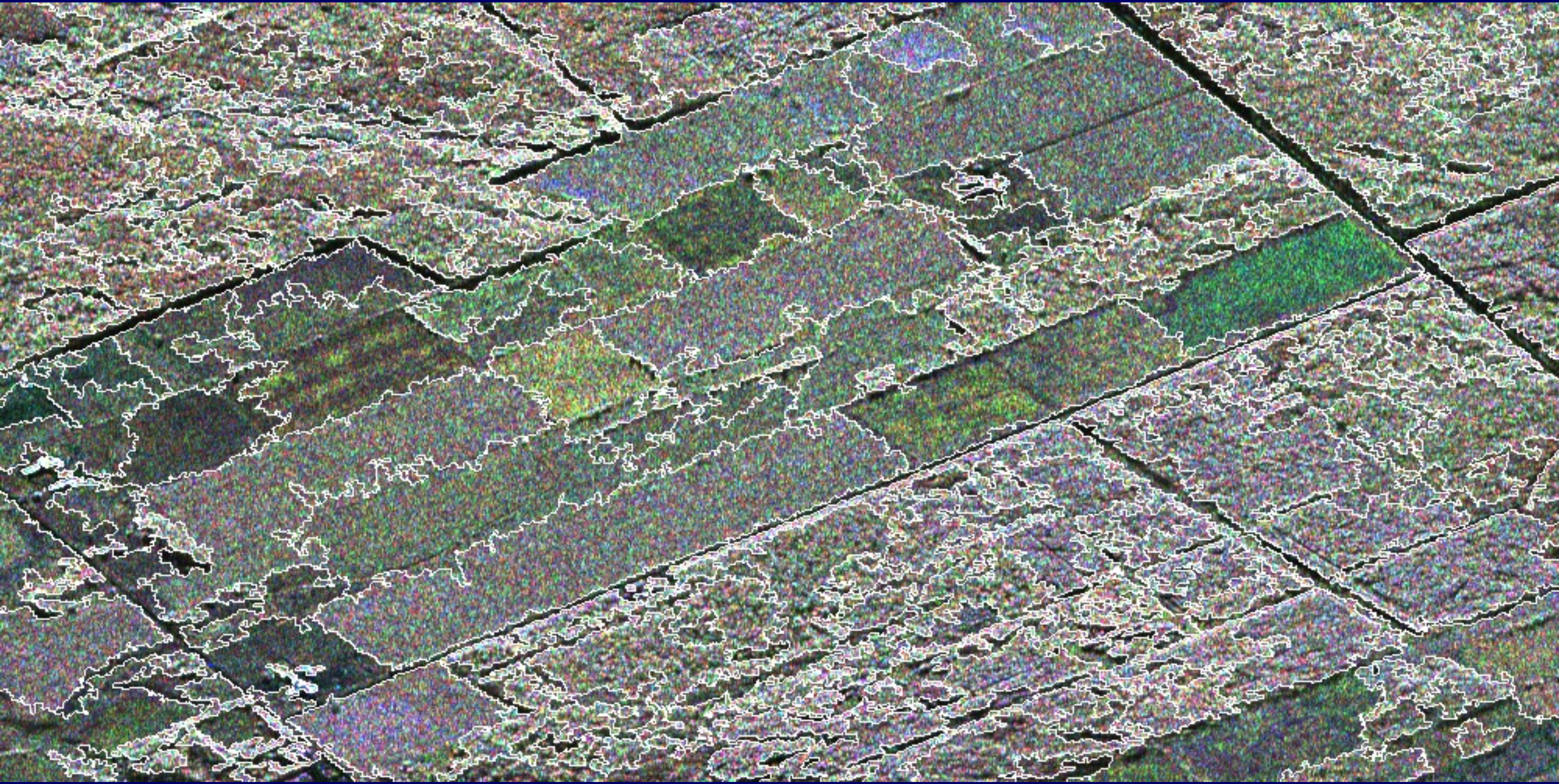
1000 segments



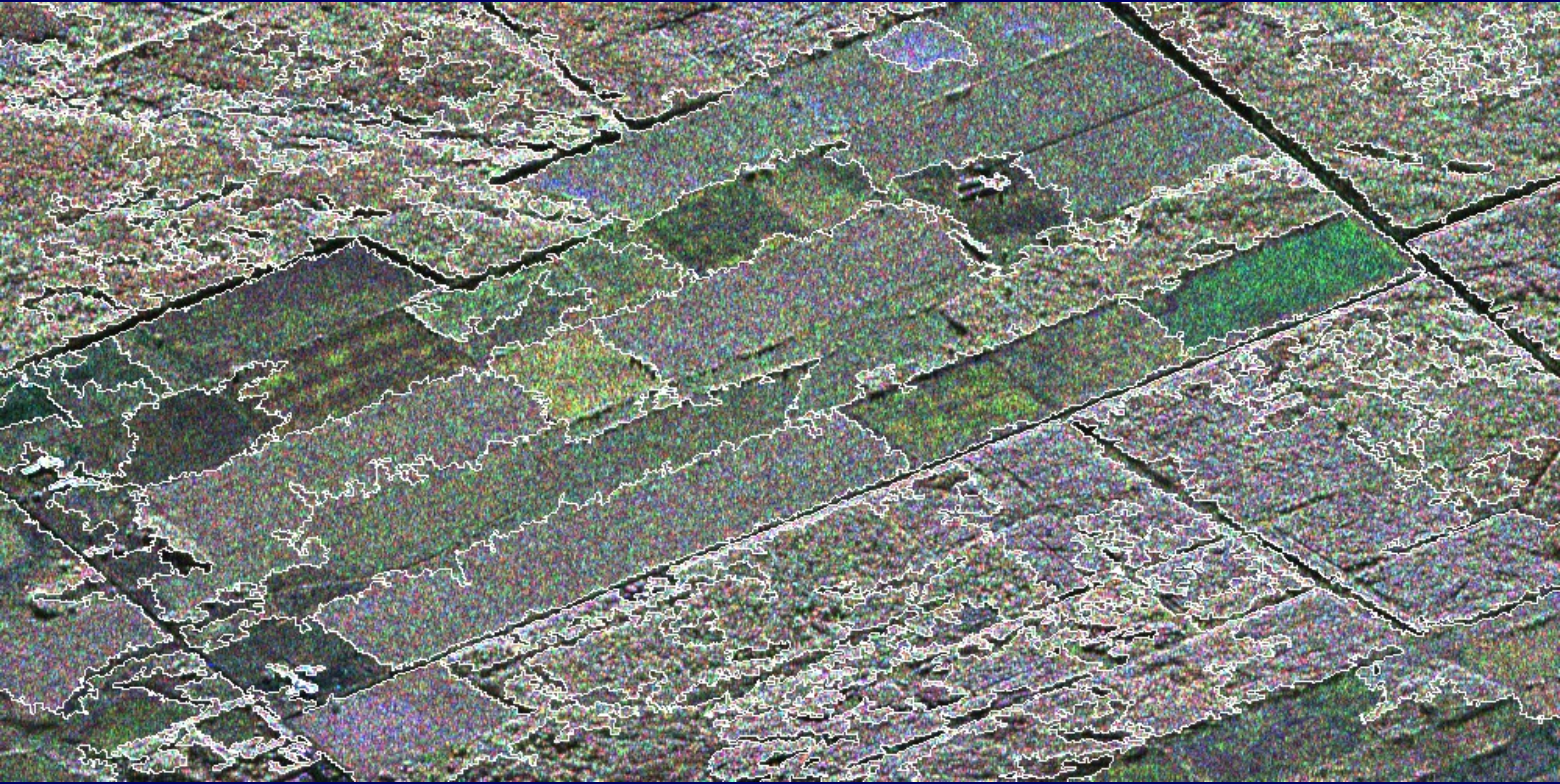
500 segments



200 segments



100 segments



CONCLUSION

•Hierarchical segmentation produces good results

•Criterion should be adapted to the application

•Good polarimetic criterion

•The first merges should be done correctly

CRITERION FOR SMALL SEGMENTS

The determinant |C| is null for small segments

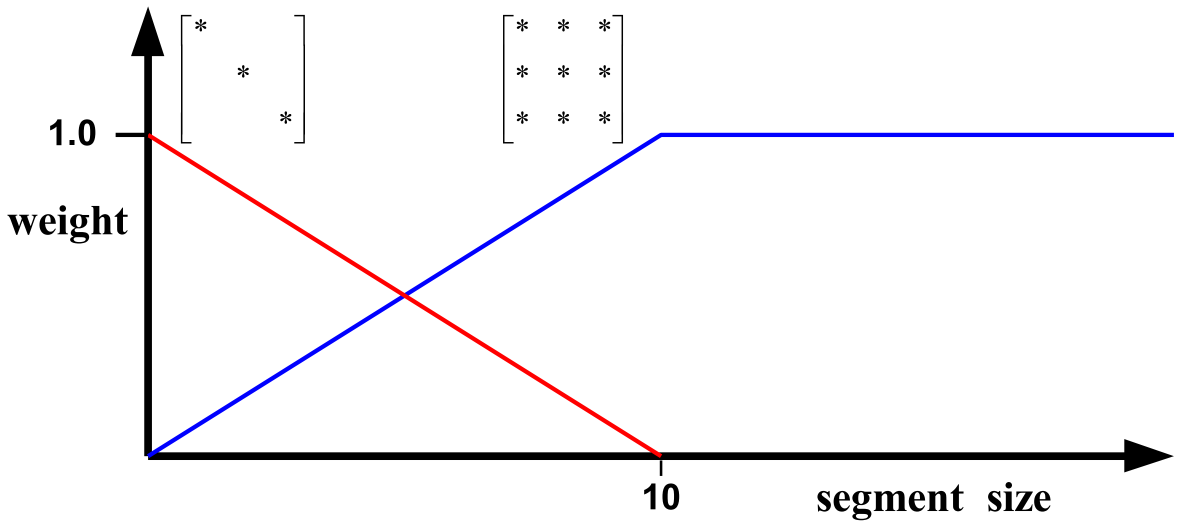
$$\boldsymbol{C} = \frac{1}{n}\begin{bmatrix} \sum hh\, hh^* & \sum hh\, hv^* & \sum hh\, vv^* \\ \sum hv\, hh^* & \sum hv\, hv^* & \sum hv\, vv^* \\ \sum vv\, hh^* & \sum vv\, hv^* & \sum vv\, vv^* \end{bmatrix}$$

Reduce covariance matrix model for small segments

$$\frac{1}{n}\begin{bmatrix} \sum hh\, hh^* & 0 & \sum hh\, vv^* \\ 0 & \sum hv\, hv^* & 0 \\ \sum vv\, hh^* & 0 & \sum vv\, vv^* \end{bmatrix}$$

$$\frac{1}{n}\begin{bmatrix} \sum hh\, hh^* & 0 & 0 \\ 0 & \sum hv\, hv^* & 0 \\ 0 & 0 & \sum vv\, vv^* \end{bmatrix}$$

Gradual transition between models



SEGMENT SHAPE CRITERIA

High speckle noise

→ first merges produce ill formed segments

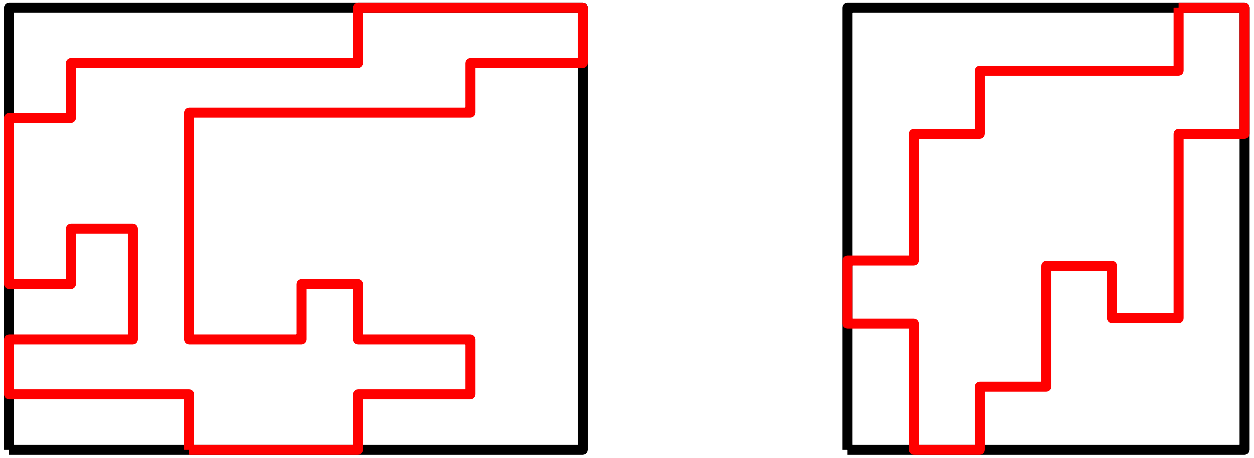
•Bonding box – perimeter	Cp
•Bonding box – area	Ca
•Contour length	Cl

New criteria

$$\mathrm{C}_{\mathrm{i,j}}^{contour} = \mathrm{C}_{\mathrm{i,j}}^{polar} \times Cp^2 \times Ca \times Cl$$

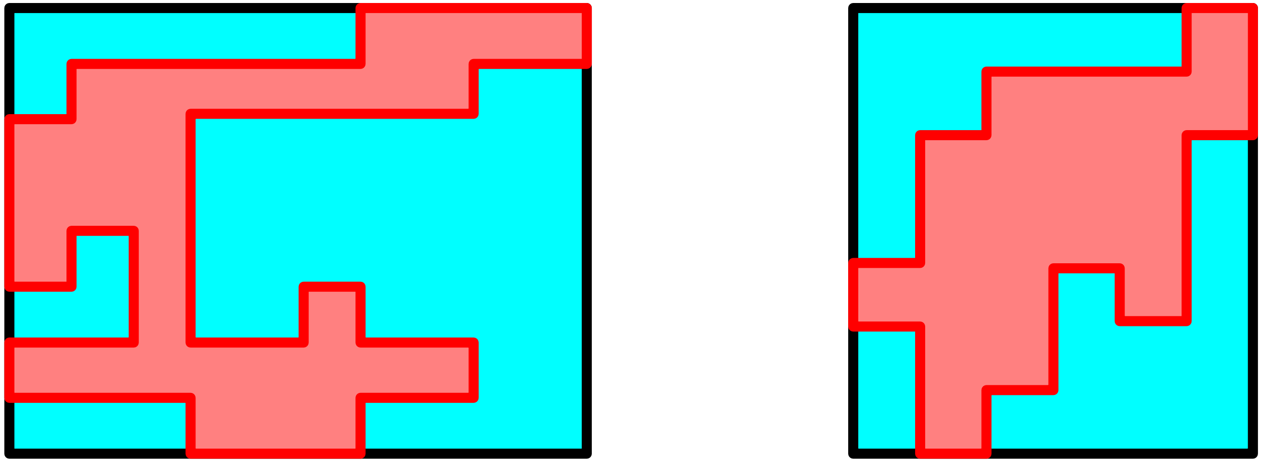
Bonding box – perimeter

$$Cp = \frac{perimeter\ of\ S_i \cup S_j}{perimeter\ of\ bonding\ box}$$



Bonding box – area

$$Ca = \frac{area\ of\ bonding\ box}{area\ of\ S_i \cup S_j}$$

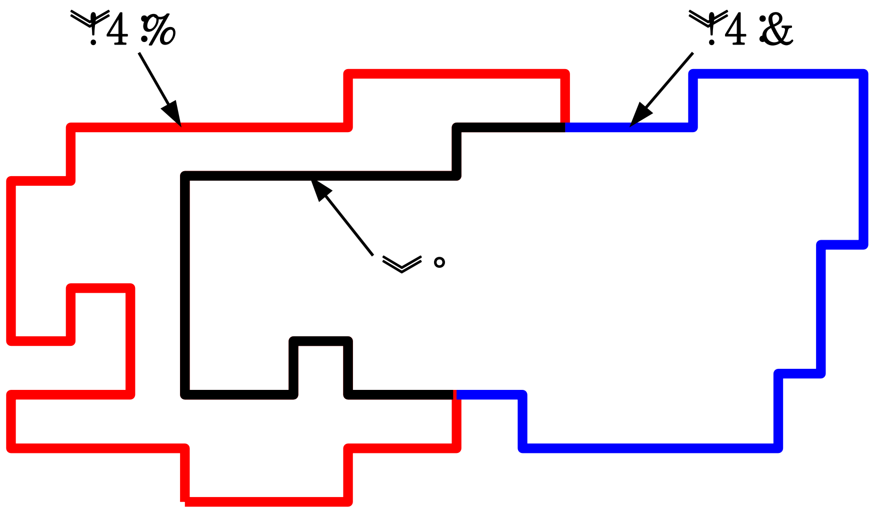


Contour length

$$Lc = \text{length of common part of contours}$$

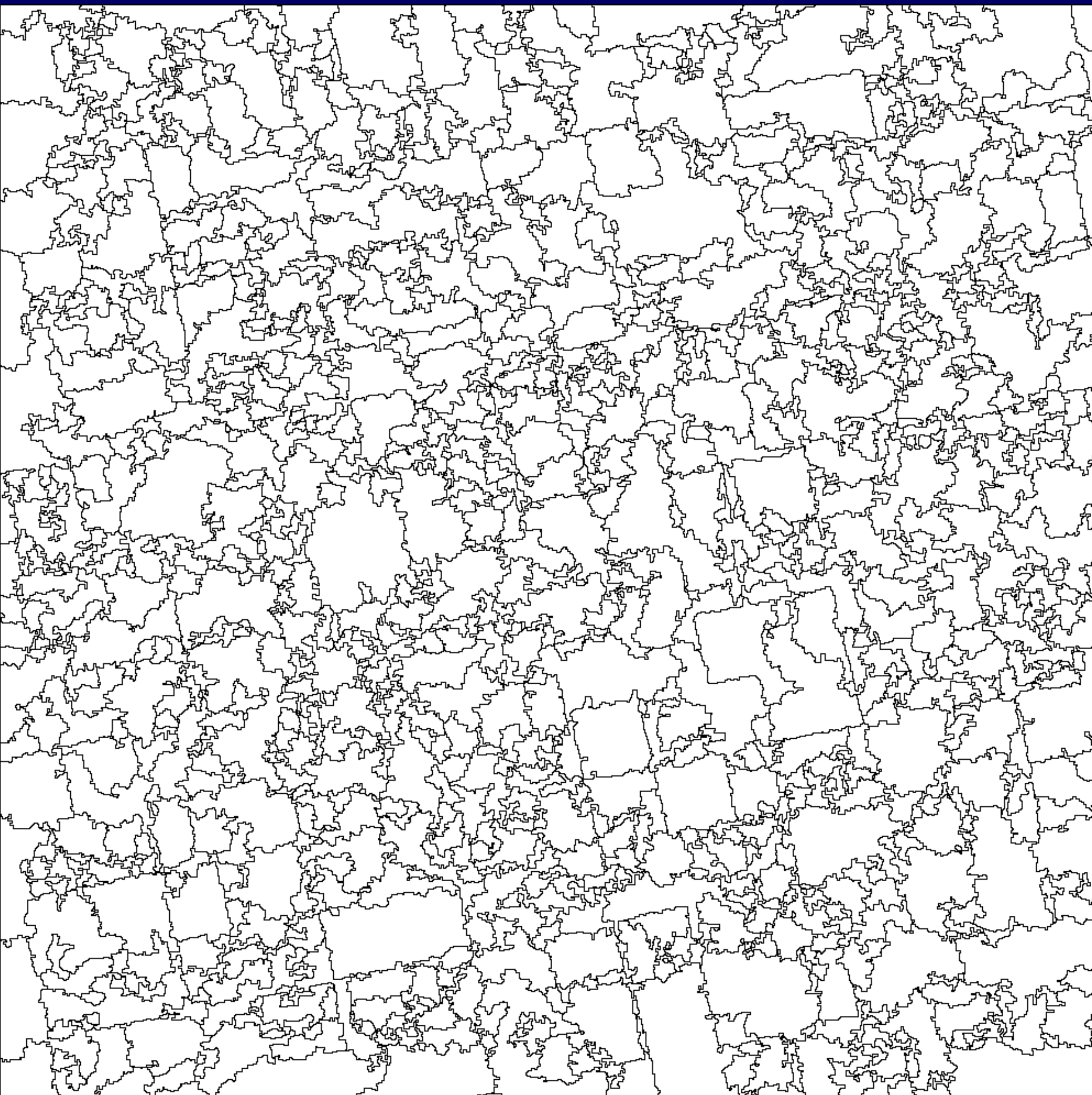
$$Lex\,i = \text{length of exclusive part for } S_i$$

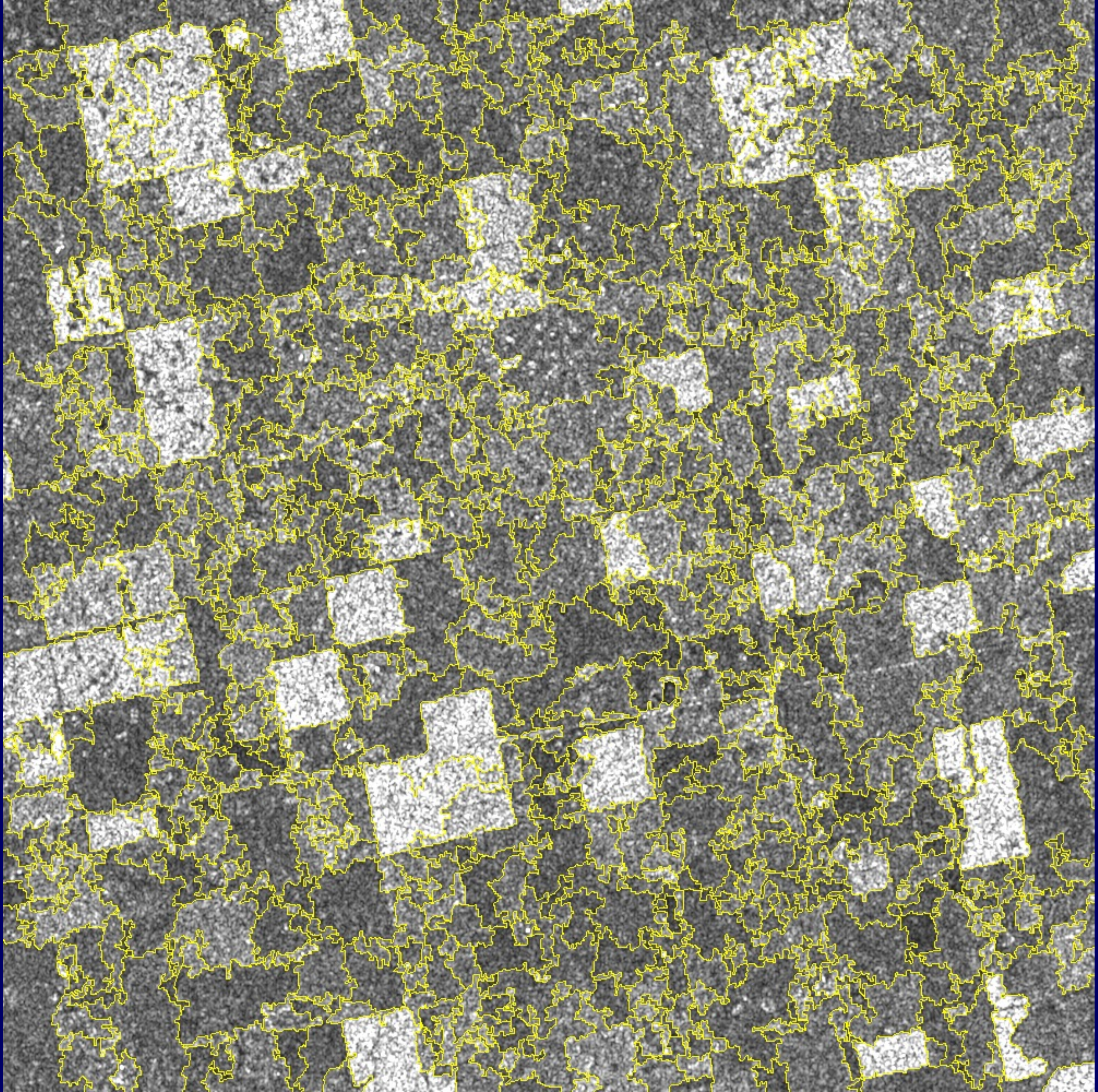
$$Cl = Min\left\{ \frac{Lex\,i}{Lc}, \frac{Lex\,j}{Lc} \right\}$$



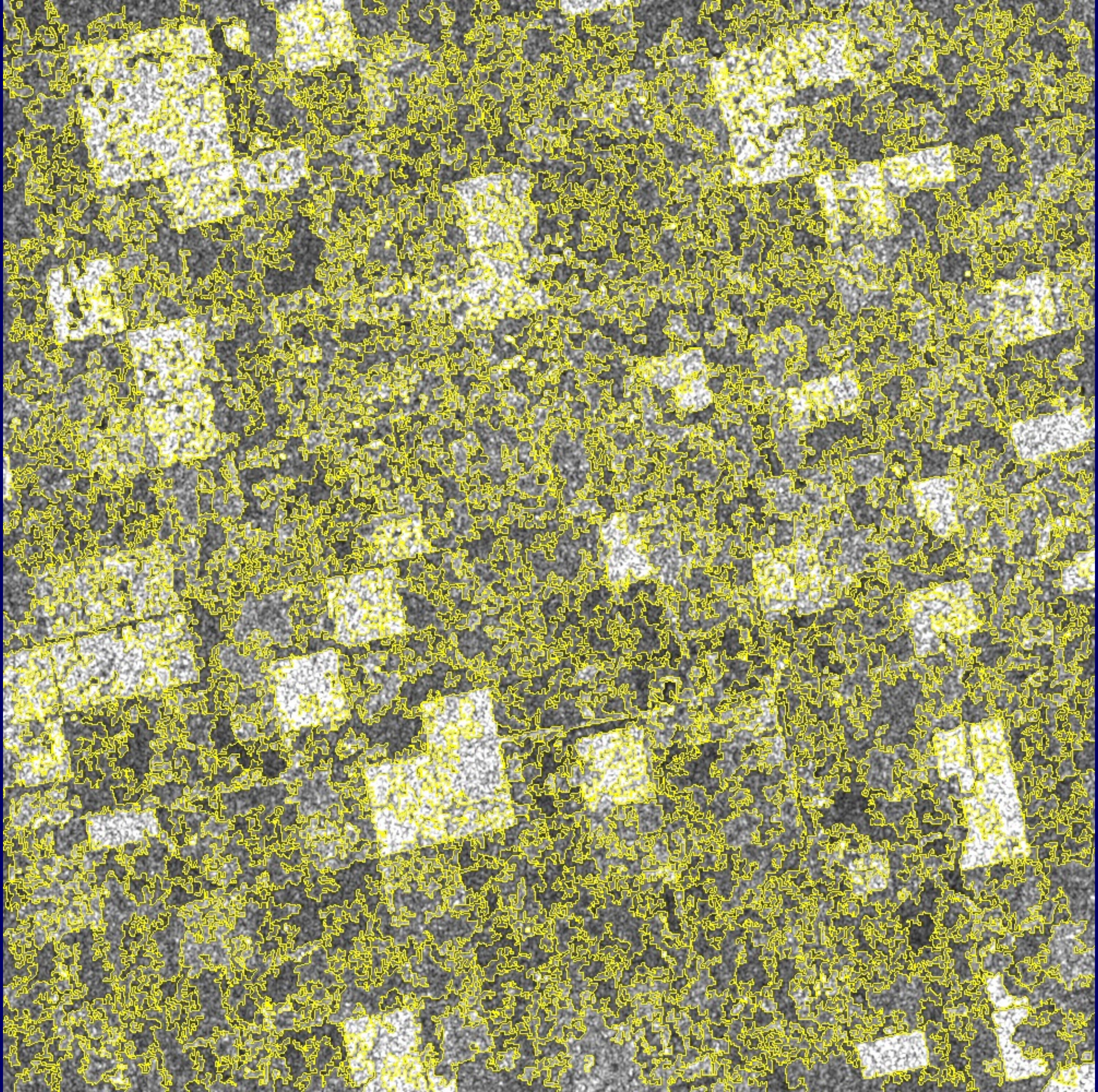
1000x1000 SAR image

1000 segments

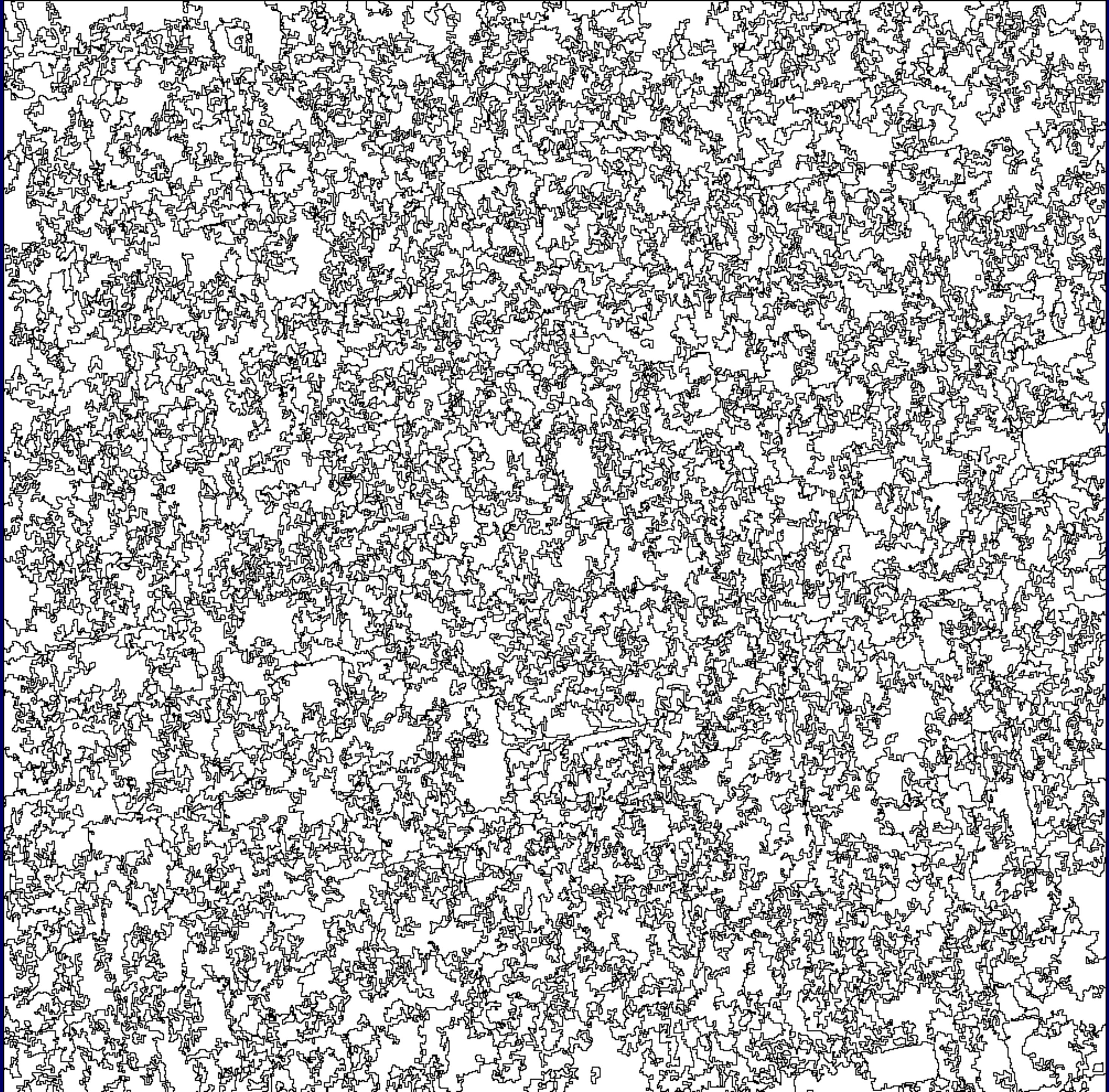




1000 segments



1000 segments



1000 segments