

→ **POLSARPROF**



PRESENTS

POLARIMETRIC SUPERVISED AND UNSUPERVISED CLASSIFICATIONS

OBJECTIVES

- **WISHART CLASSIFIER**
- **SUPERVISED CLASSIFICATION**
- **UNSUPERVISED H / α CLASSIFICATION**
- **UNSUPERVISED WISHART – H / α CLASSIFICATION**
- **UNSUPERVISED WISHART – FREEMAN CLASSIFICATION**

Target Vector

$$\underline{X} = \begin{bmatrix} S_{HH} & \sqrt{2}S_{HV} & S_{VV} \end{bmatrix}^T$$

$$P(\underline{X}) = \frac{1}{\pi^3 |C|} e^{-\underline{X}^{*T} [C]^{-1} \underline{X}}$$

$$\underline{k} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} & S_{HH} - S_{VV} & 2S_{HV} \end{bmatrix}^T$$

$$P(\underline{k}) = \frac{1}{\pi^3 |T|} e^{-\underline{k}^{*T} [T]^{-1} \underline{k}}$$

Coherency Matrix

$$\langle [T] \rangle = \frac{1}{N} \sum_{i=1}^N \underline{k}_i \cdot \underline{k}_i^{*T} = \frac{1}{N} \sum_{i=1}^N [T_i]$$

$$P(\langle [T] \rangle / [T_m]) = \frac{L^{Lp} |\langle [T] \rangle|^{L-p} e^{-L \text{Tr}([T_m]^{-1} \langle [T] \rangle)}}{\pi^{\frac{p(p-1)}{2}} \Gamma(L) \dots \Gamma(L-p+1) [T_m]^L}$$

COMPLEX WISHART DISTRIBUTION

L: Number of Look p: Polarimetric Dimension

$$P(\langle [T] \rangle / [T_m]) = \frac{L^{Lp} \|[[T]]\|^{L-p} e^{-L \text{Tr}([T_m]^{-1} \langle [T] \rangle)}}{\pi^{\frac{p(p-1)}{2}} \Gamma(L) \dots \Gamma(L-p+1) [T_m]^L}$$



BAYES MAXIMUM LIKELIHOOD CLASSIFICATION PROCEDURE

$$\langle [T] \rangle \in [T_m] \quad \text{if} \quad P([T_m] / \langle [T] \rangle) \geq P([T_j] / \langle [T] \rangle) \quad \forall j \neq m$$

Applying Bayes rule
$$P([T_m] / \langle [T] \rangle) = \frac{P(\langle [T] \rangle / [T_m])}{P(\langle [T] \rangle)} P([T_m])$$

It follows

$$\langle [T] \rangle \in [T_m] \quad \text{if} \quad P(\langle [T] \rangle / [T_m]) P([T_m]) \geq P(\langle [T] \rangle / [T_j]) P([T_j]) \quad \forall j \neq m$$

$[T_m]$: Cluster Center of the class m

$$P(\langle [T] \rangle / [T_m]) = \frac{L^{Lp} \|\langle [T] \rangle\|^{L-p} e^{-LTr([T_m]^{-1} \langle [T] \rangle)}}{\pi^{\frac{p(p-1)}{2}} \Gamma(L) \dots \Gamma(L-p+1) [T_m]^L}$$



BAYES MAXIMUM LIKELIHOOD CLASSIFICATION PROCEDURE

$$\langle [T] \rangle \in [T_m] \quad \text{if} \quad d_m(\langle [T] \rangle) < d_j(\langle [T] \rangle) \quad \forall j \neq m$$

with

$$d_m(\langle [T] \rangle) = LTr([T_m]^{-1} \langle [T] \rangle) + L \ln([T_m]) - \ln(P([T_m])) + K$$

$[T_m]$: Cluster Center of the class m

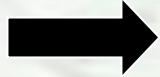
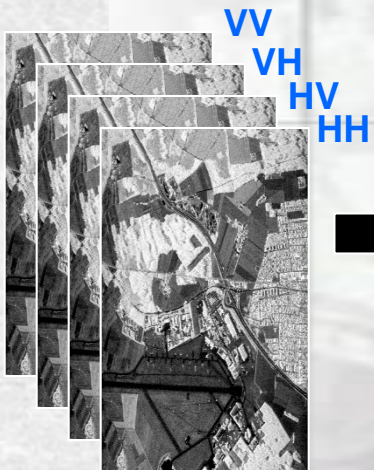
ROBUSTENESS OF WISHART CLASSIFIER

$$d_m(\langle [T] \rangle) = L \text{Tr}([T_m]^{-1} \langle [T] \rangle) + L \ln([T_m]) - \ln(P([T_m])) + K$$

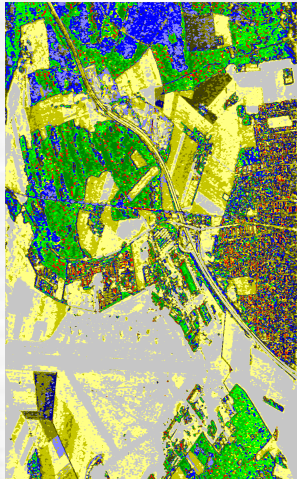
- INDEPENDENT OF # OF LOOKS
- INDEPENDENT OF POLARIZATION BASIS
- $[T]$ or $[C]$ IDENTICAL CLASSIFICATION RESULTS
- FOR Dual-Pol ($p=2$), PolSAR ($p=3$), Pol-InSAR ($p=6$)

J.S. Lee, E. Pottier, *Polarimetric Radar Imaging: From Basics to Applications*, Taylor & Francis/CRC, 2009

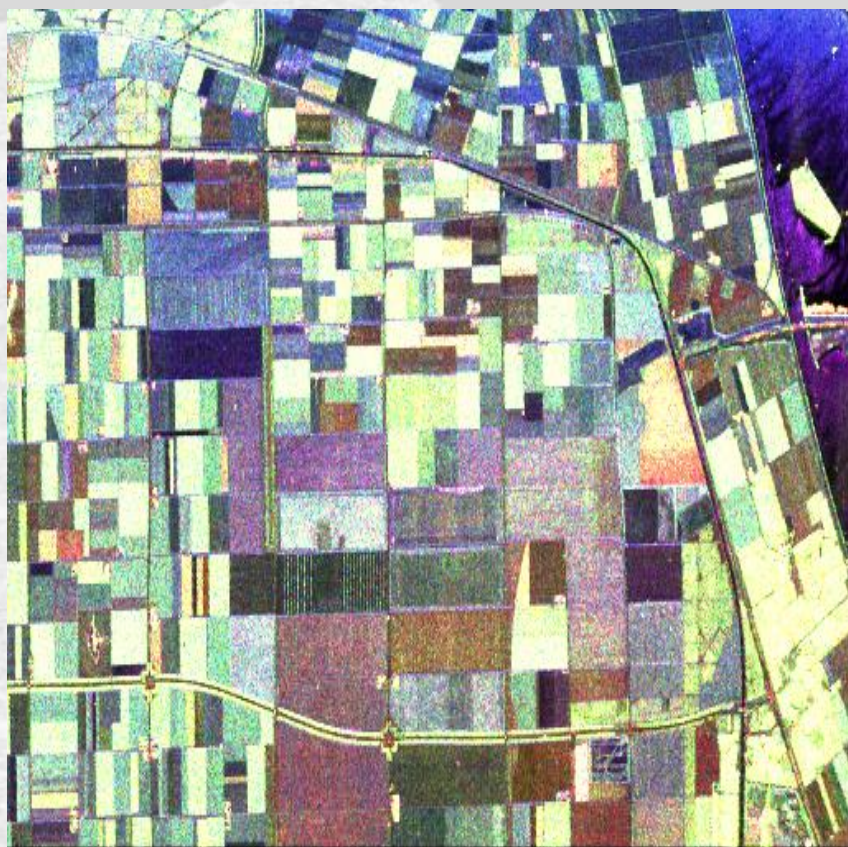
WISHART PDF $P(\langle [T] \rangle / [T_m]) = \frac{L^p \langle [T] \rangle^{L-p} e^{-LT_r([T_m]^{-1} \langle [T] \rangle)}}{\pi^{\frac{p(p-1)}{2}} \Gamma(L) \dots \Gamma(L-p+1) [T_m]^L}$



**SUPERVISED
 POLSAR
 CLASSIFICATION**
 J.S LEE, M.R GRUNES, E.POTTIER (2002)



Courtesy of Dr J.S Lee

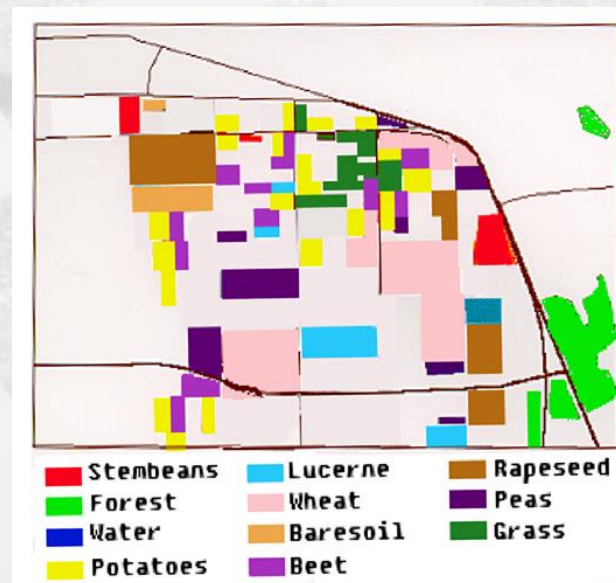


$2A_0$

$B_0 + B$

$B_0 - B$

JPL AIRSAR
 P-L-C Band Flevoland Data

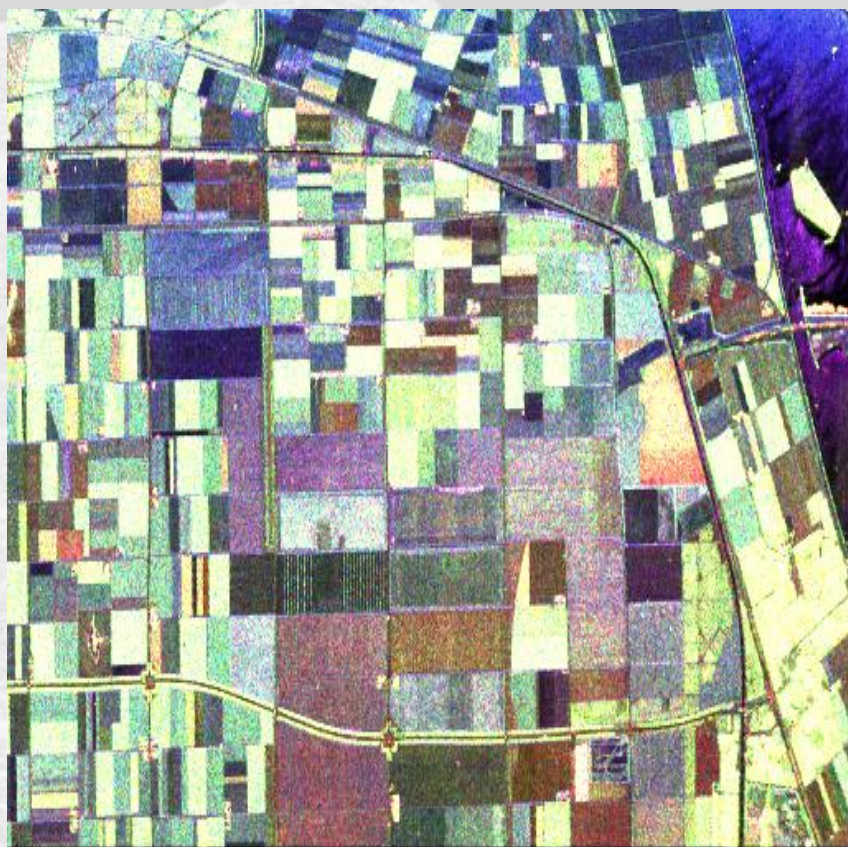


Original Ground- Truth



Training Sets / Reference map

Courtesy of Dr J.S Lee



$2A_0$

$B_0 + B$

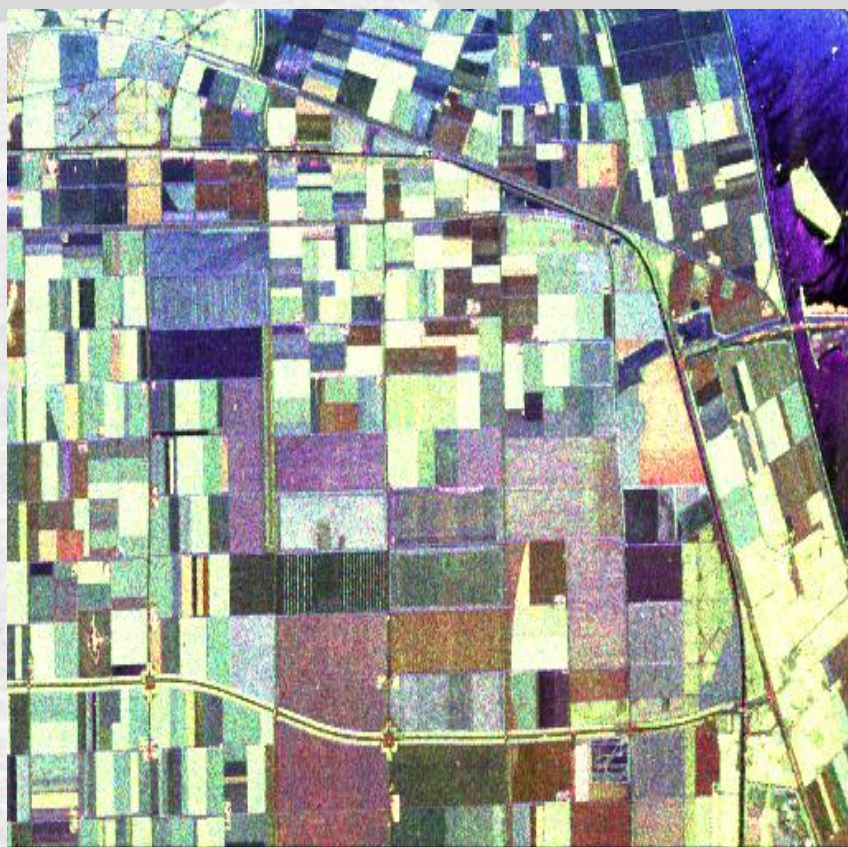
$B_0 - B$

JPL AIRSAR
 L-Band Flevoland Data



C-band (66.53%)

Courtesy of Dr J.S Lee

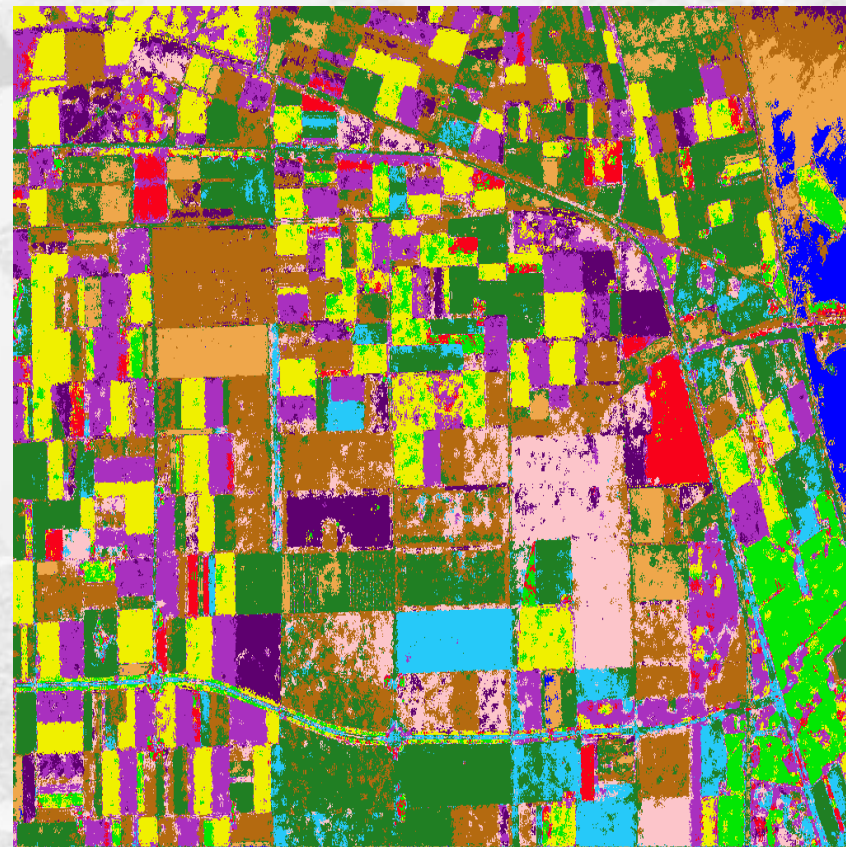


$2A_0$

$B_0 + B$

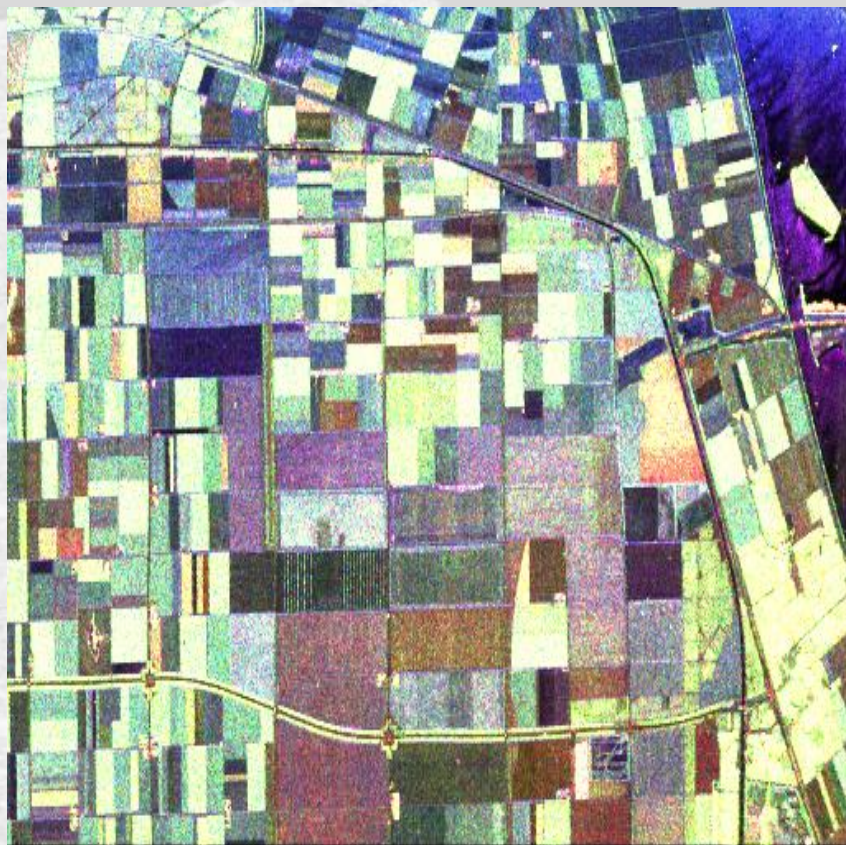
$B_0 - B$

JPL AIRSAR
 L-Band Flevoland Data



L-band (81.63%)

Courtesy of Dr J.S Lee

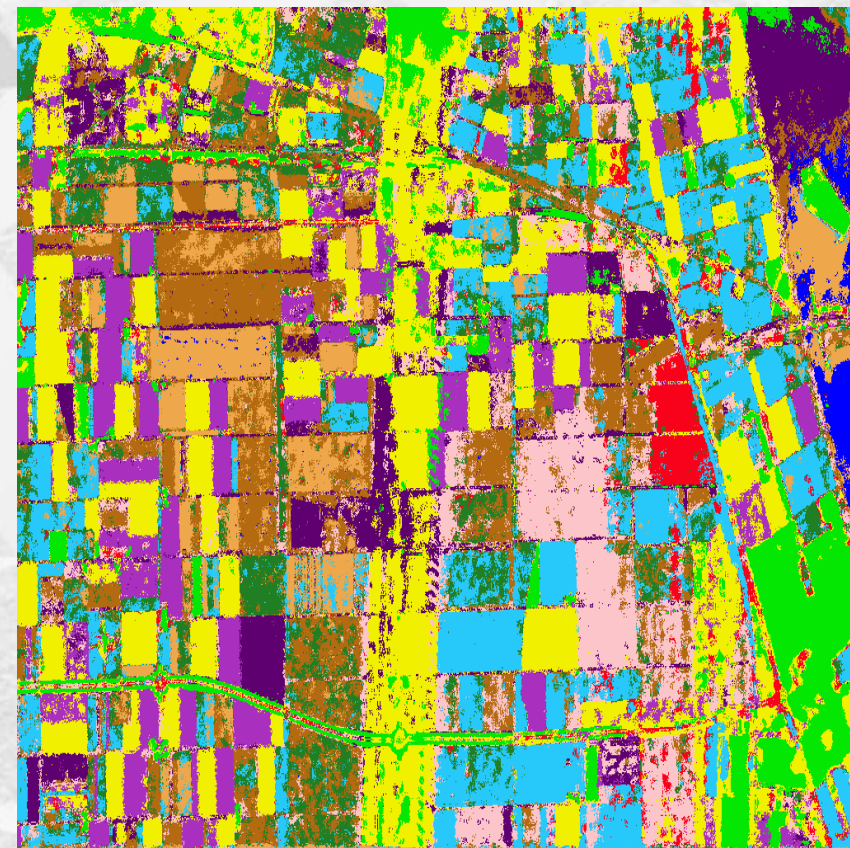


$2A_0$

$B_0 + B$

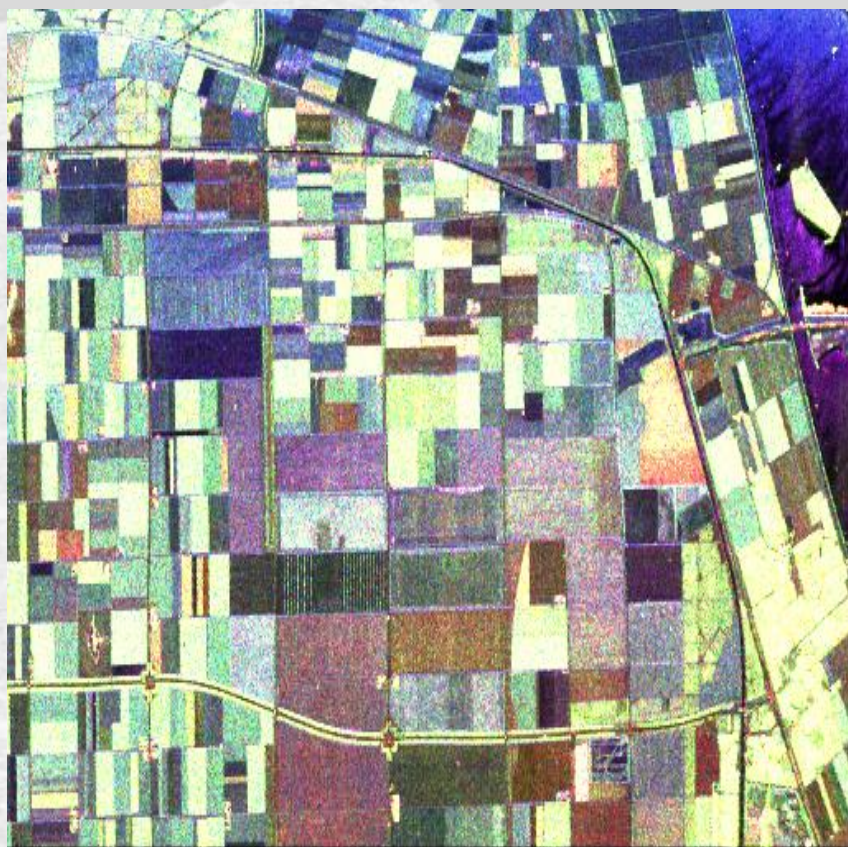
$B_0 - B$

JPL AIRSAR
 L-Band Flevoland Data



P-band (71.37%)

Courtesy of Dr J.S Lee

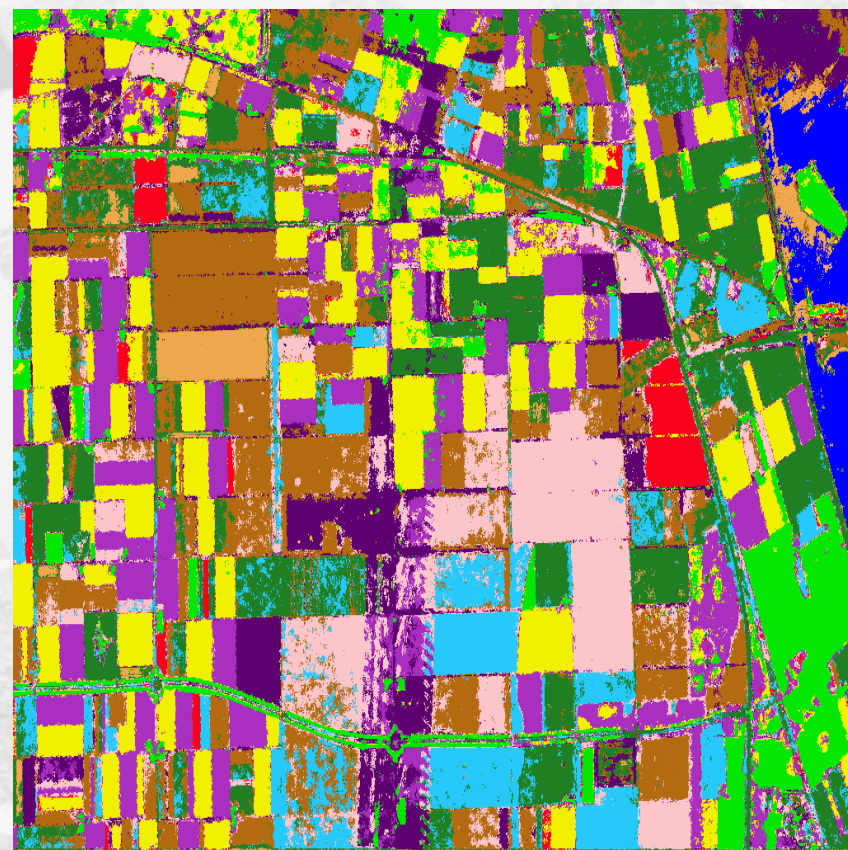


$2A_0$

$B_0 + B$

$B_0 - B$

JPL AIRSAR
 L-Band Flevoland Data



P-L-C band (91.21%)

Courtesy of Dr J.S Lee

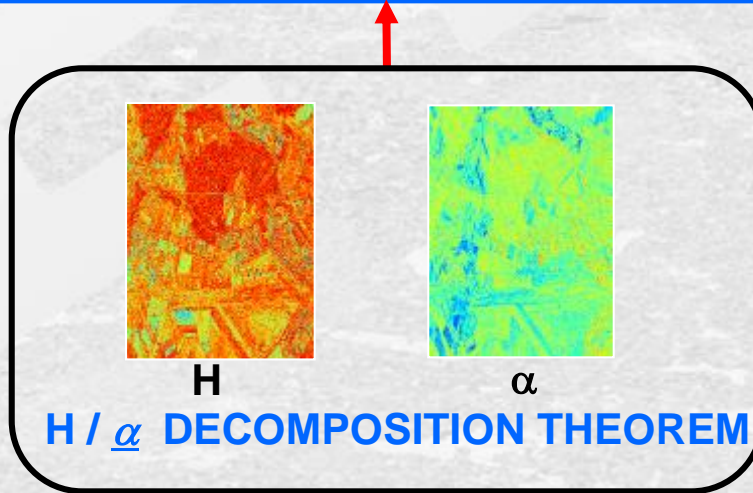
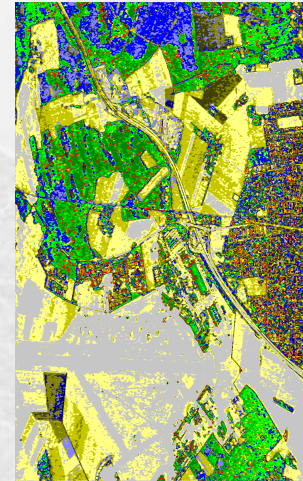
	Fully Polarimetric	Complex HH, HV	Intensity HH, HV	Complex HH, VV	Intensity HH, VV	Complex VV, HV	Intensity VV, HV
Stem Bean	95.32	51.16	63.27	90.64	61.73	35.97	31.29
Forest	81.07	66.73	68.39	75.75	33.83	60.05	60.91
Potatoes	82.89	67.53	66.36	81.52	49.35	54.40	59.15
Lucerne	97.91	39.29	38.23	99.26	65.15	67.49	65.30
Wheat	64.80	49.77	44.27	68.02	53.72	49.43	41.65
Bare Soil	99.36	90.04	82.86	98.42	93.15	90.93	63.74
Beet	89.26	68.80	66.36	86.22	81.98	75.94	74.77
Rape Seed	89.05	55.01	53.23	87.18	49.85	82.31	77.12
Peas	86.47	50.77	39.25	84.59	65.21	81.82	79.59
Grass	91.05	66.44	65.06	90.13	71.08	75.36	75.19
Water	100	90.39	87.33	100	99.86	96.30	70.53
TOTAL	81.63	59.16	55.38	80.91	56.35	64.72	60.12

L-Band Crop Classification Results



UNSUPERVISED POLARSAR CLASSIFICATION

S.R. CLOUDE, E.POTTIER (1996)



ENTROPY

$$H = -\sum_{i=1}^3 P_i \log_3(P_i)$$

α PARAMETER

$$\underline{\alpha} = P_1 \alpha_1 + P_2 \alpha_2 + P_3 \alpha_3$$

ANISOTROPY

$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}$$



3 ROLL INVARIANT PARAMETERS

$$\underline{I} = \begin{bmatrix} \underline{\alpha} \\ HA \\ H(1-A) \\ (1-H)A \\ (1-H)(1-A) \end{bmatrix}$$

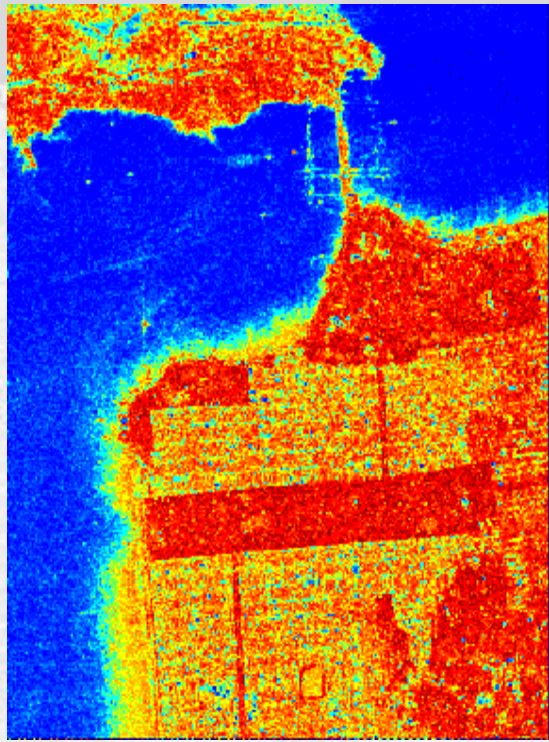


PHYSICAL SCATTERING MECHANISM



TYPE OF SCATTERING PROCESS

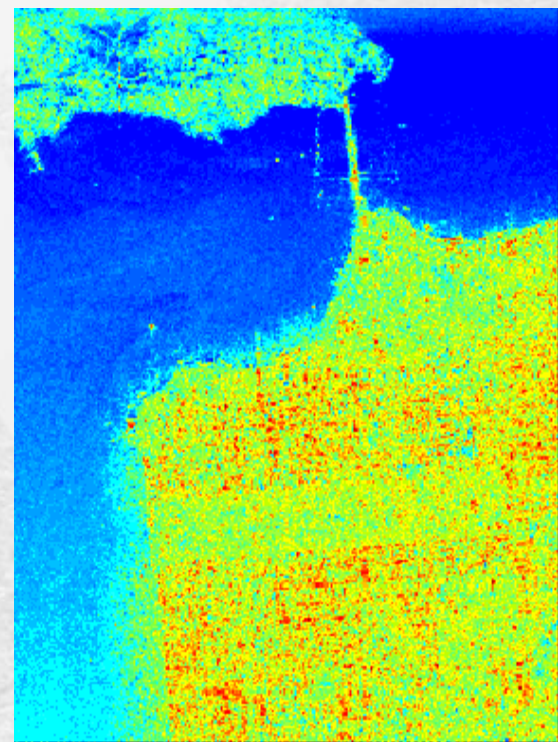
SEGMENTATION / CLASSIFICATION



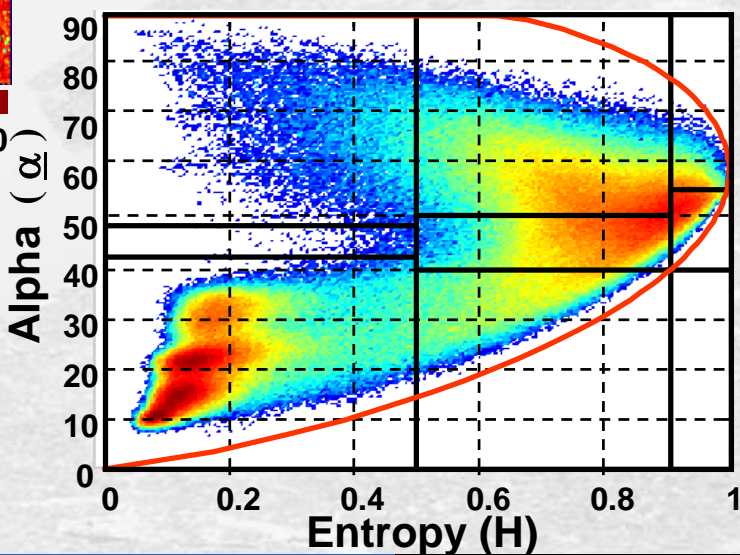
0 0.5 1.0
H



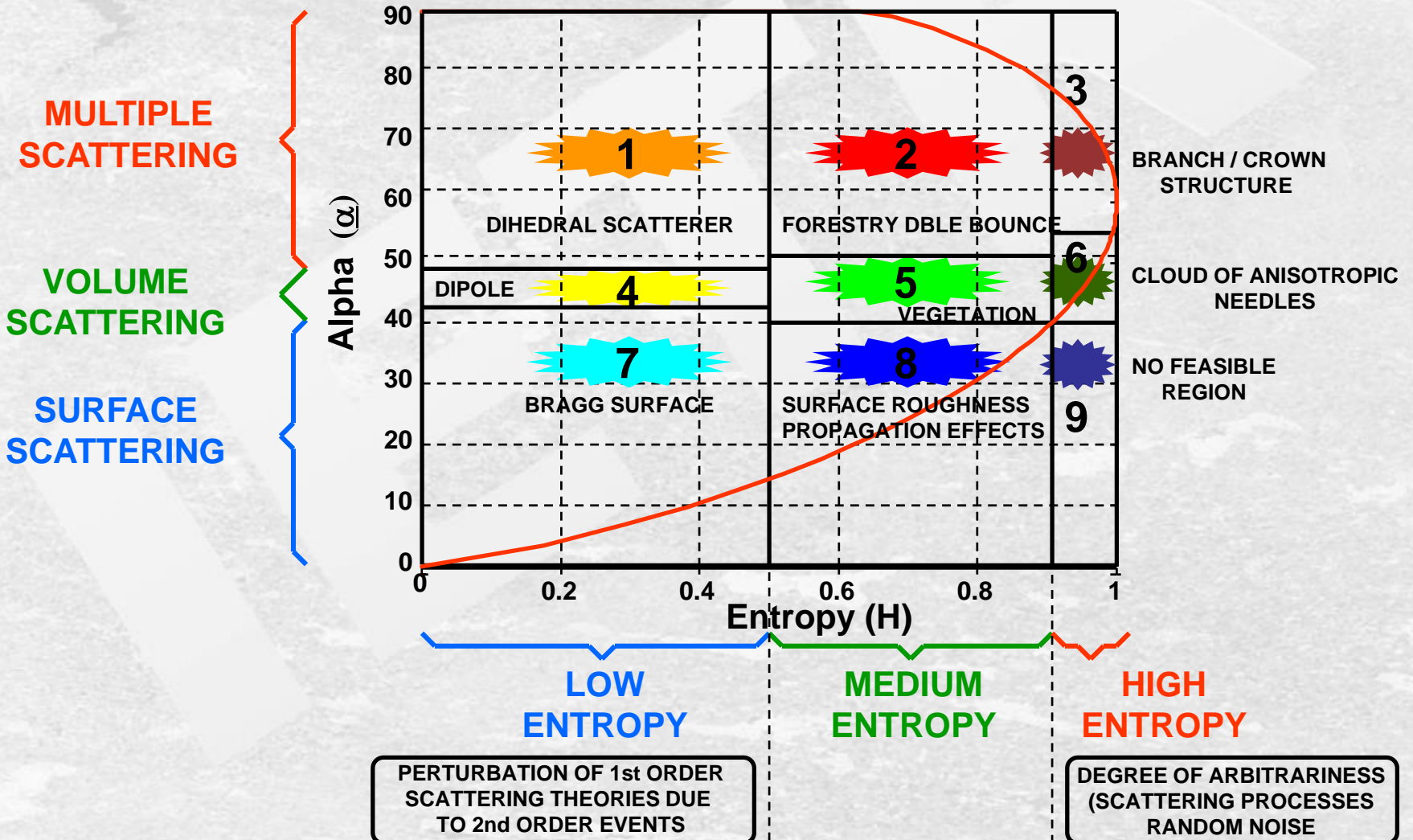
POLSAR DATA DISTRIBUTION IN THE H/α PLANE



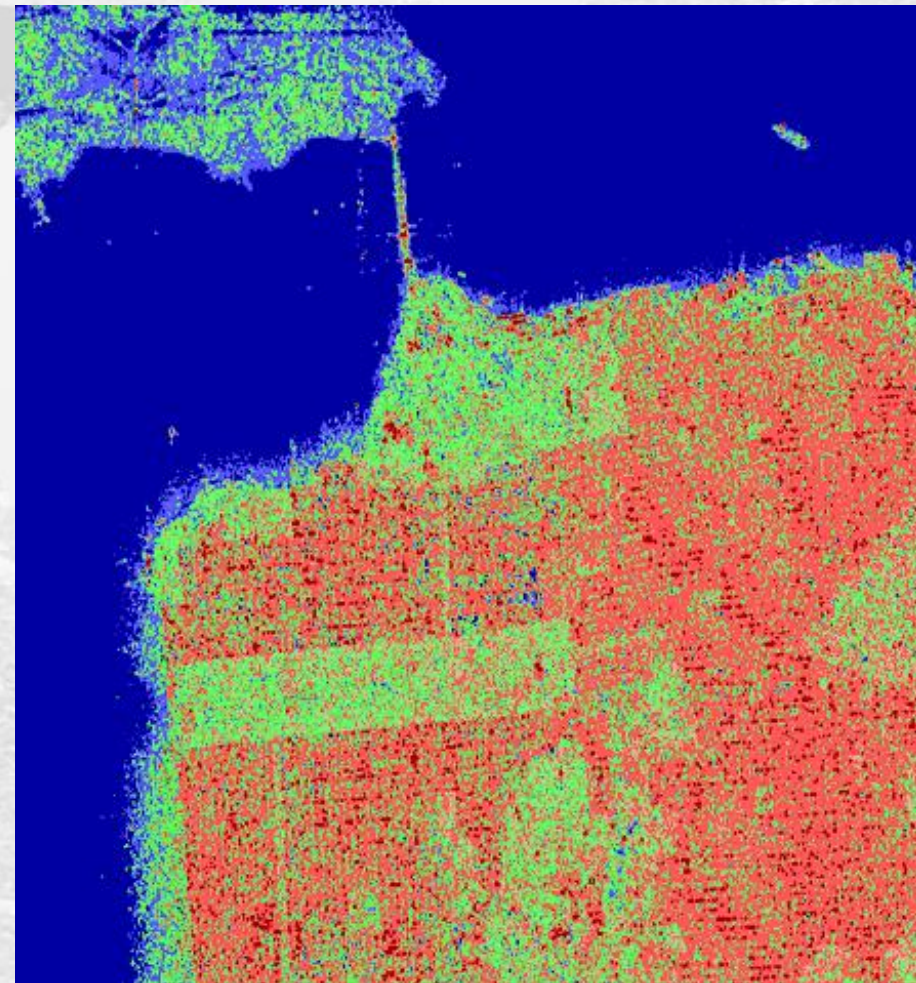
0 45° 90°
 α



SEGMENTATION OF THE H / α SPACE



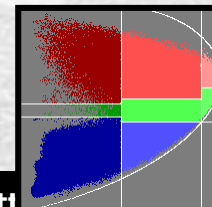
H - α classification



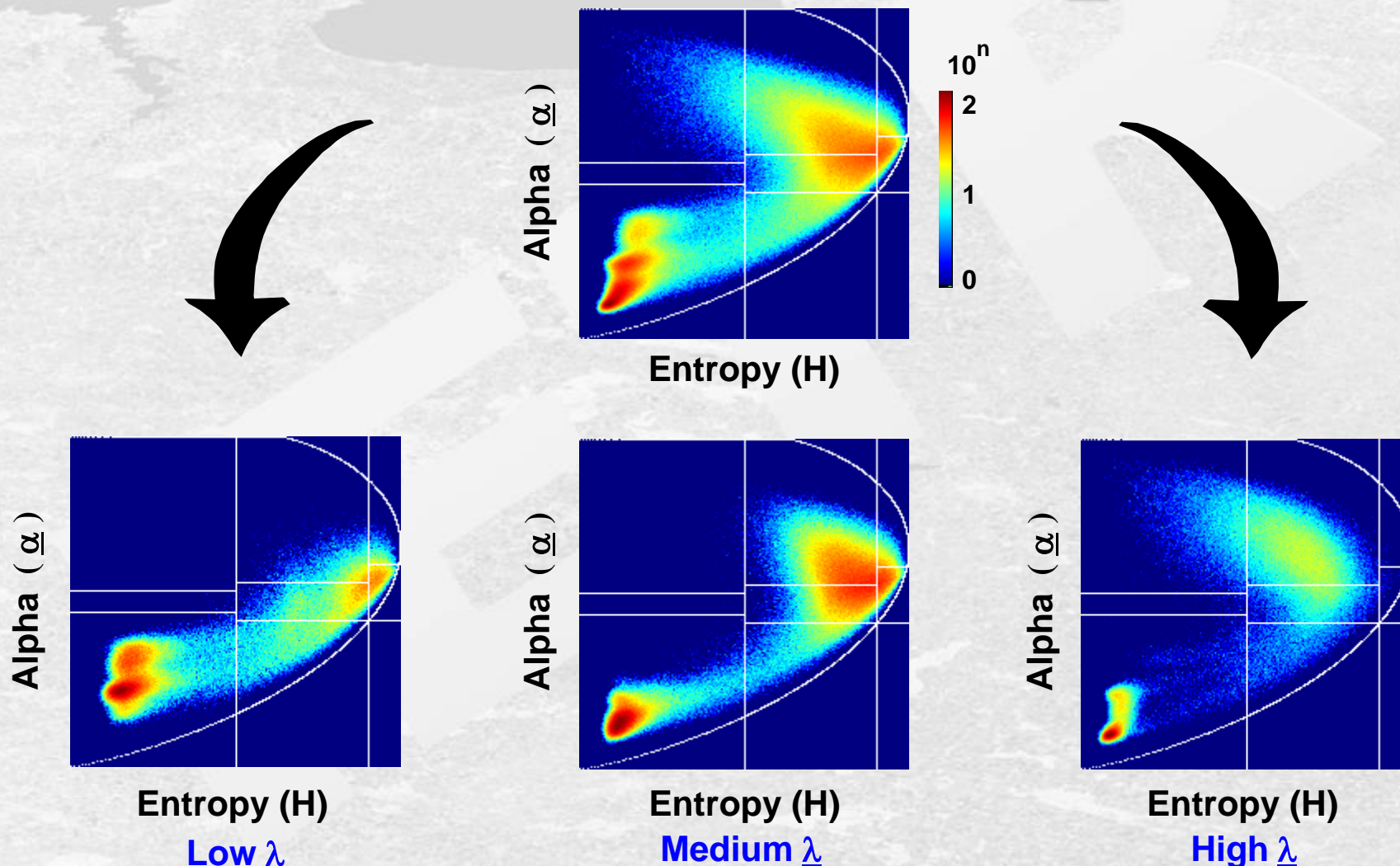
$2A_0$

$B_0 + B$

$B_0 - B$

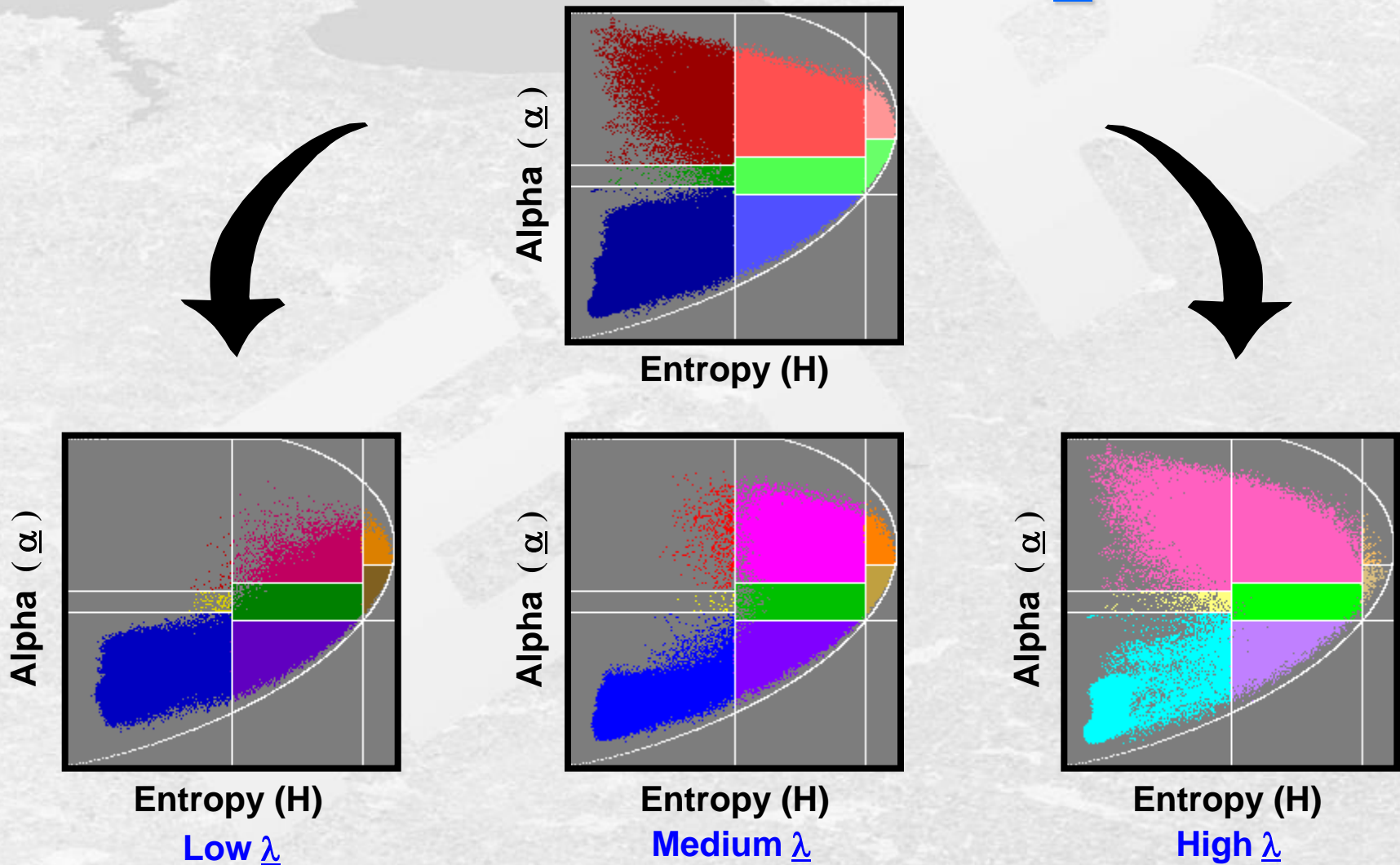


POLSAR DATA DISTRIBUTION IN THE H / α PLANE



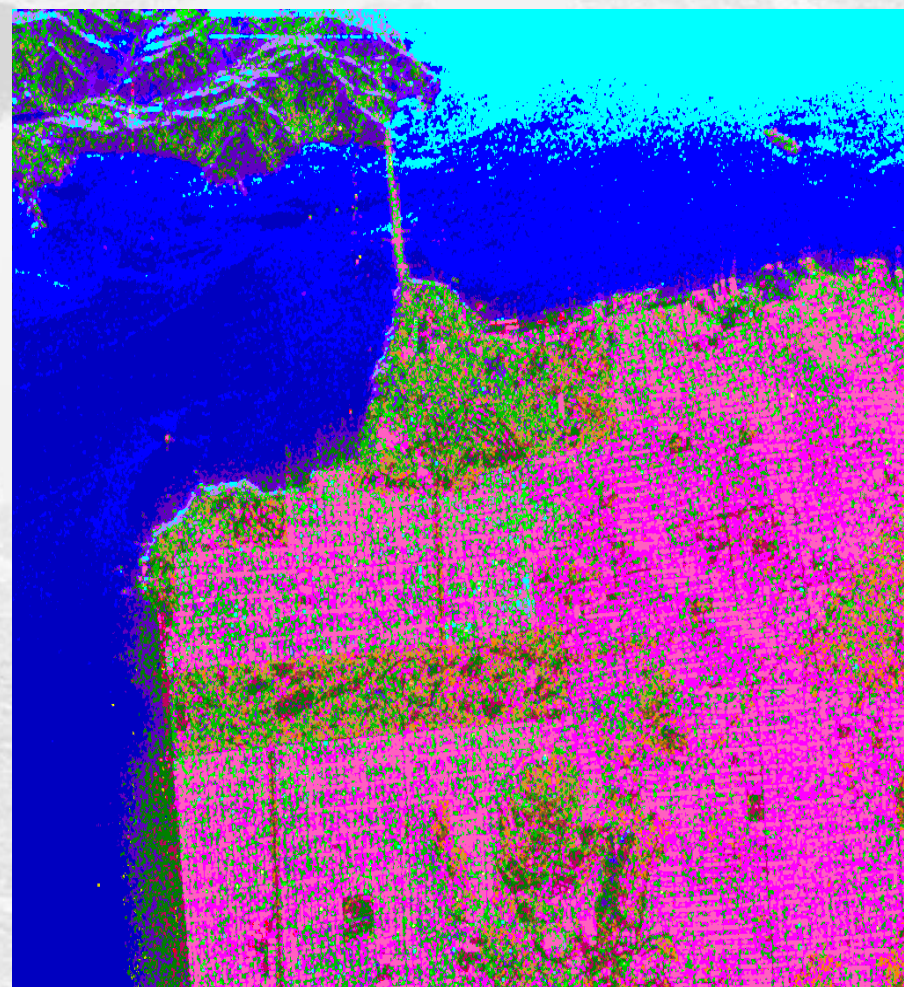
Cao Fang, Hong Wen A New Classification Method Based on Cloude-Pottier Eigenvalue / Eigenvector Decomposition, IGARSS 05, Seoul, Korea

POLSAR DATA DISTRIBUTION IN THE H / α PLANE



Cao Fang, Hong Wen A New Classification Method Based on Cloude-Pottier Eigenvalue / Eigenvector Decomposition, IGARSS 05, Seoul, Korea

H - α (λ) classification



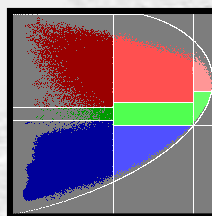
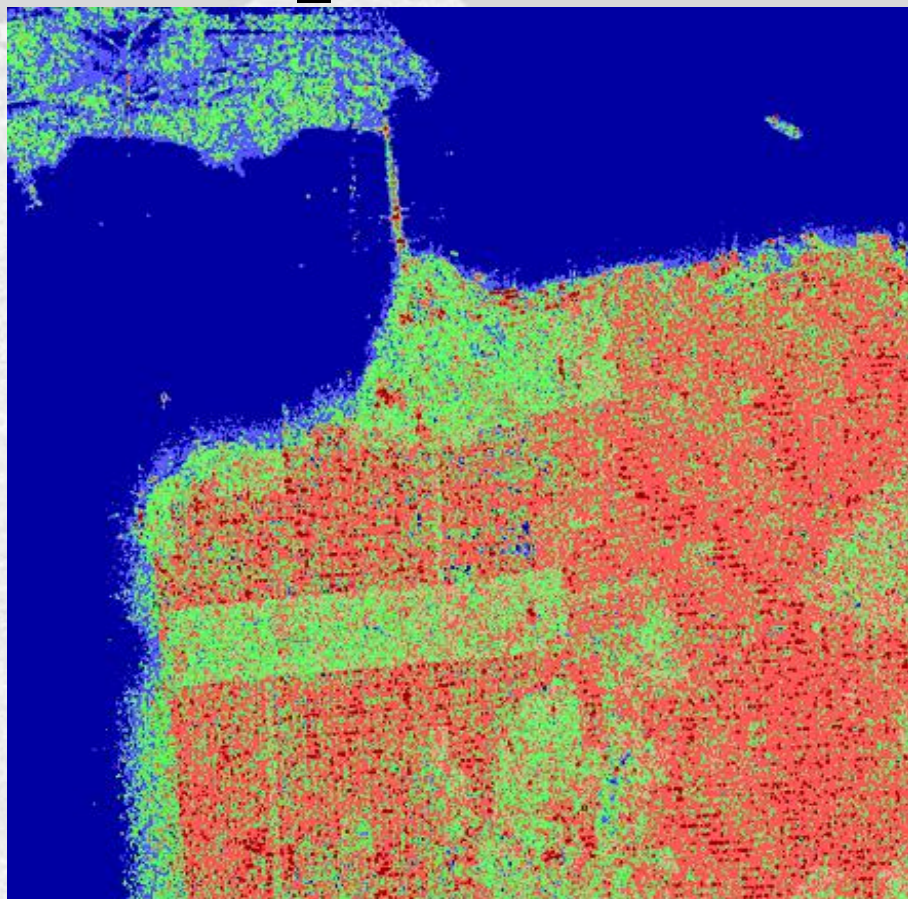
$2A_0$

$B_0 + B$

$B_0 - B$



H- α classification



H / α Classification Space
Sub-divided into 9 basic zones



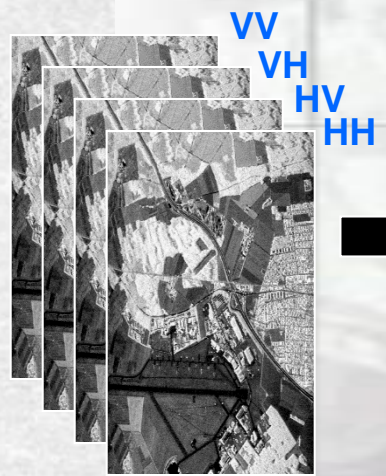
Location of the boundaries
is arbitrary and generically

Degree of arbitrariness on the
setting of these boundaries

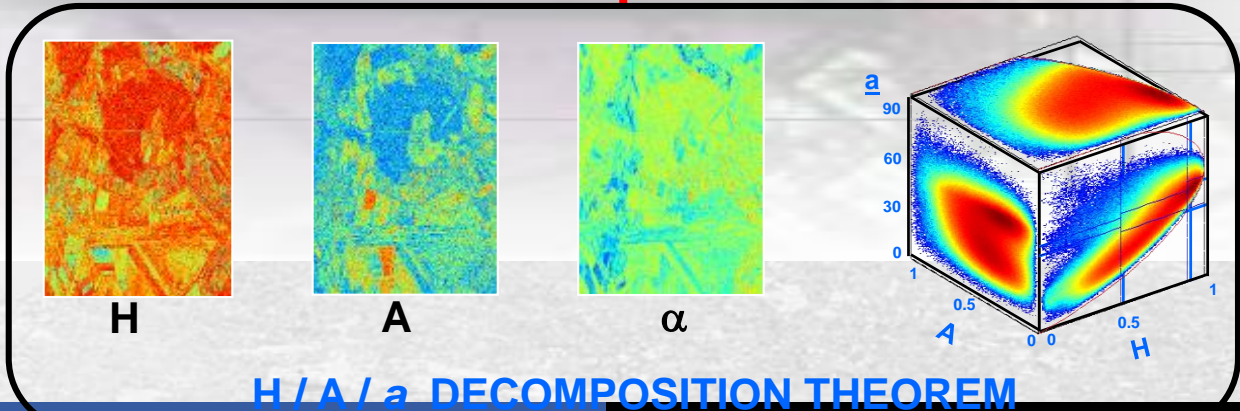
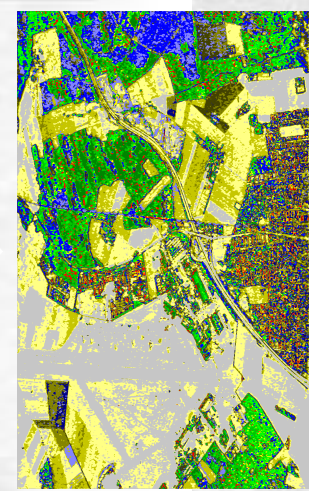


Segmentation is offered merely
to illustrate the unsupervised
classification strategy and to
emphasize the geometrical
segmentation of physical scattering
processes

WISHART PDF $P([T]/[T_m]) = \frac{L^p \|[T]\|^{L-p} e^{-LTr([T_m]^{-1}[T])}}{\pi^{\frac{p(p-1)}{2}} \Gamma(L) \dots \Gamma(L-p+1) [T_m]^L}$



**UNSUPERVISED
POLARSAR
CLASSIFICATION**
E.POTTIER, J.S LEE (2000)

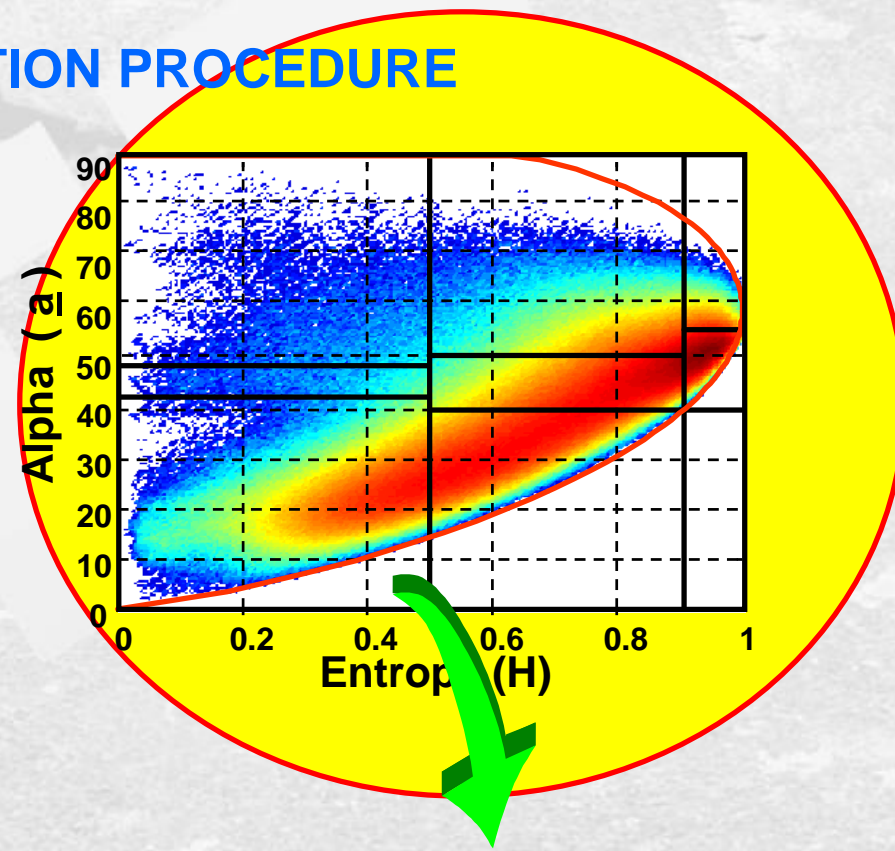
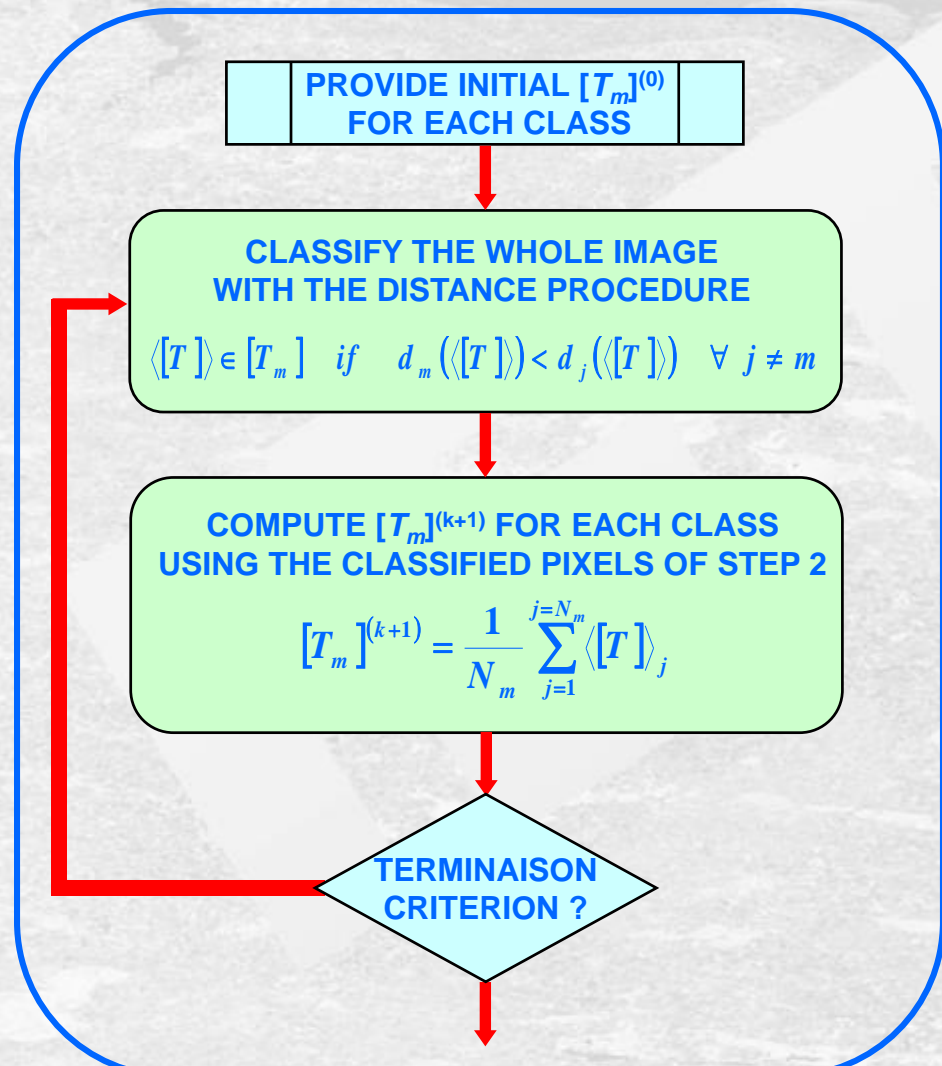




Dr J.S. LEE
N.R. L US -NAVY

- 1994** *LEE et al.* PROPOSED A SUPERVISED ALGORITHM BASED ON THE COMPLEX WISHART DISTRIBUTION FOR THE COMPLEX COVARIANCE / COHERENCY MATRIX.
- 1998** *LEE et al.* DEVELOPED A COMBINED UNSUPERVISED CLASSIFICATION METHOD THAT USES THE H / α PLANE WHICH INITIALLY CLASSIFIES THE POLSAR IMAGE. THIS SEGMENTED IMAGE IS THEN USED AS TRAINING SETS FOR THE INITIALIZATION OF THE SUPERVISED WISHART CLASSIFIER.
- 1999** INTRODUCTION OF THE ANISOTROPY (*E. POTTIER - J.S.LEE*) IMPROVEMENT OF THE CAPABILITY TO DISTINGUISH BETWEEN DIFFERENT CLASSES WHOS CENTERS END IN THE SAME ENTROPY (H) AND ALPHA (α) ZONE.

k - mean CLASSIFICATION PROCEDURE



$$[T_m]^{(0)} = \frac{1}{N_m} \sum_{k=1}^{k=N_m} \langle [T] \rangle_k$$

Cluster Center of the class m
 (Lee 1998)

SAN FRANCISCO BAY JPL - AIRSAR L-band 1988



4th ITERATION



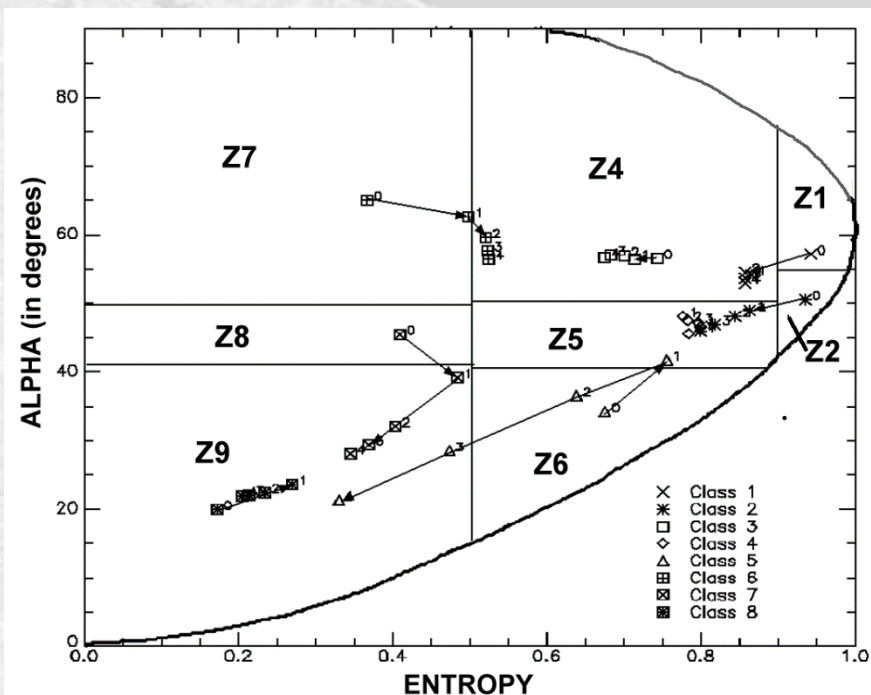
$2A_0$

$B_0 + B$

$B_0 - B$



4th ITERATION



Cluster centers shifting after each iteration



During the classification, the cluster centers can move out their zones or several clusters may end in the same zone



Identification of the terrain type may cause some confusion due to the color scheme



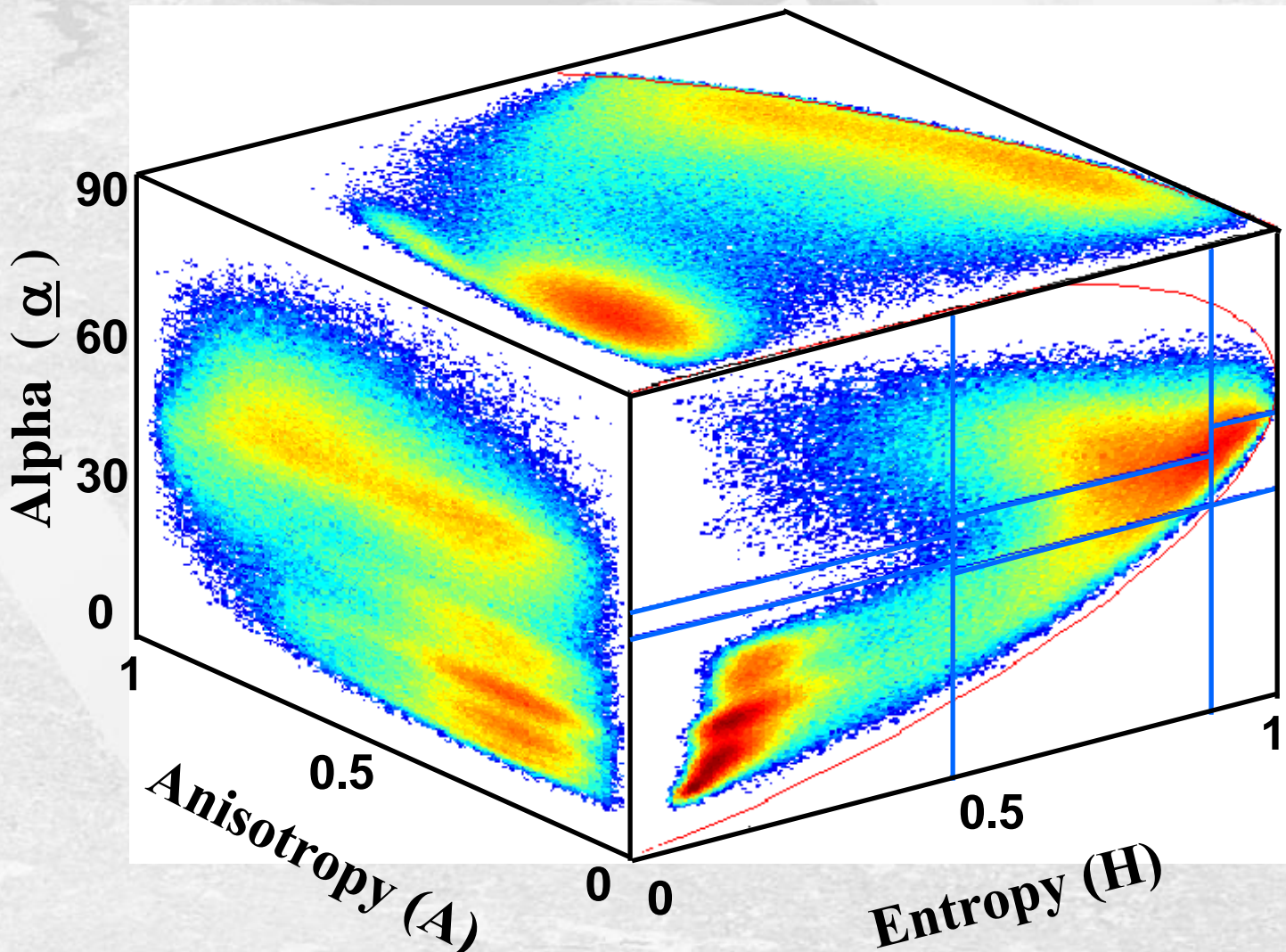
The combined Wishart classifier is extended and complemented with the introduction of the Anisotropy (A)

4th ITERATION

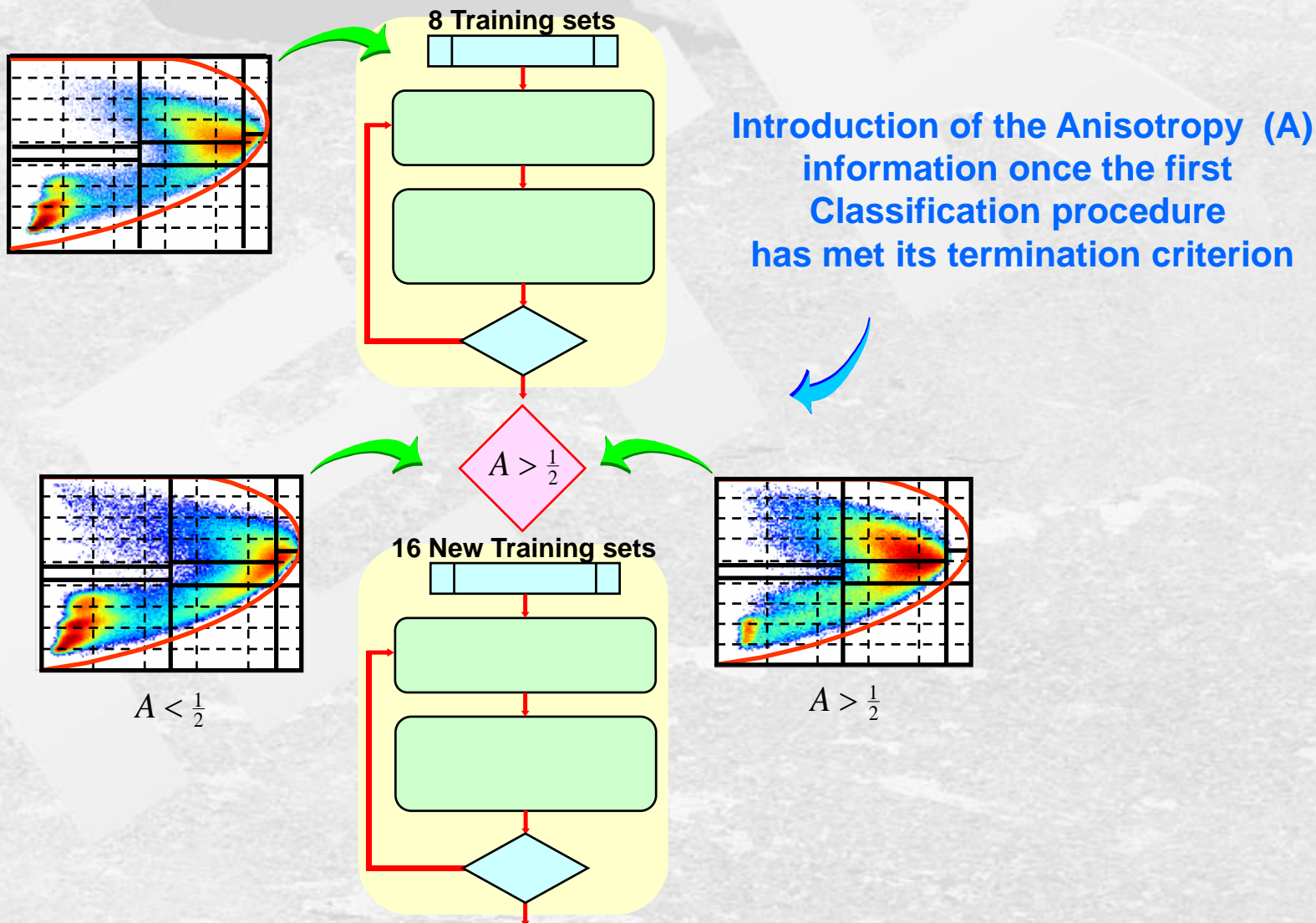


C1 C2 C3 C4 C5 C6 C7 C8

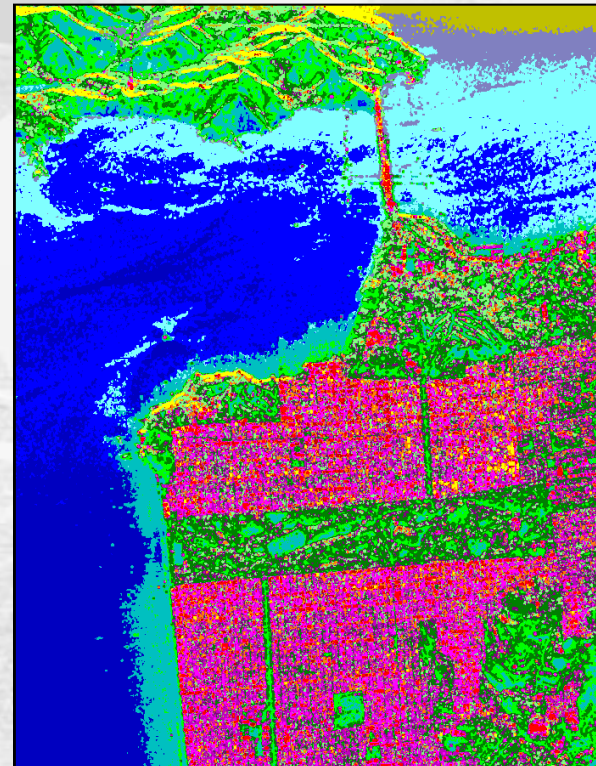
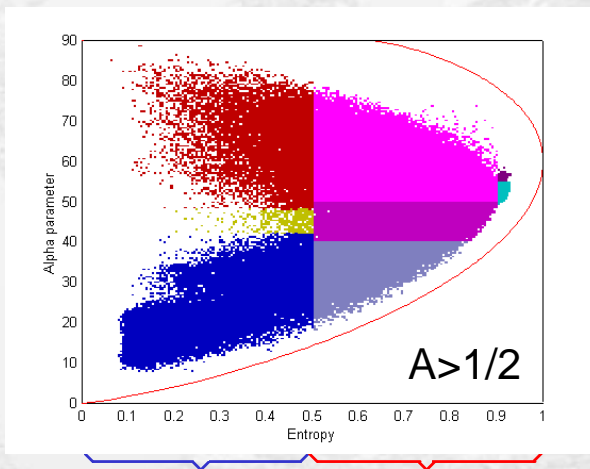
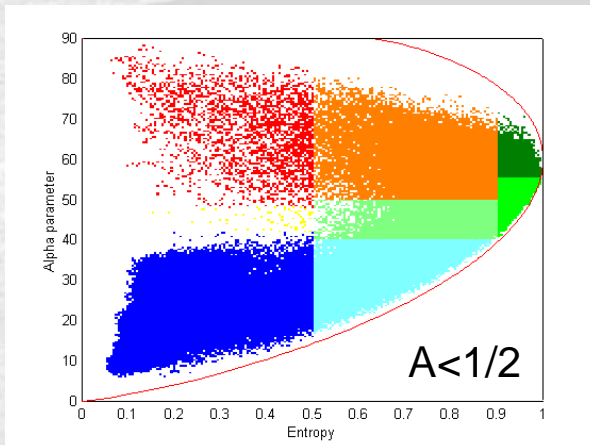
POLSAR DATA DISTRIBUTION IN THE H / A / α SPACE



2 Successive k - mean Classification procedures



Using Anisotropy to divide entropy-alpha into 16 classes



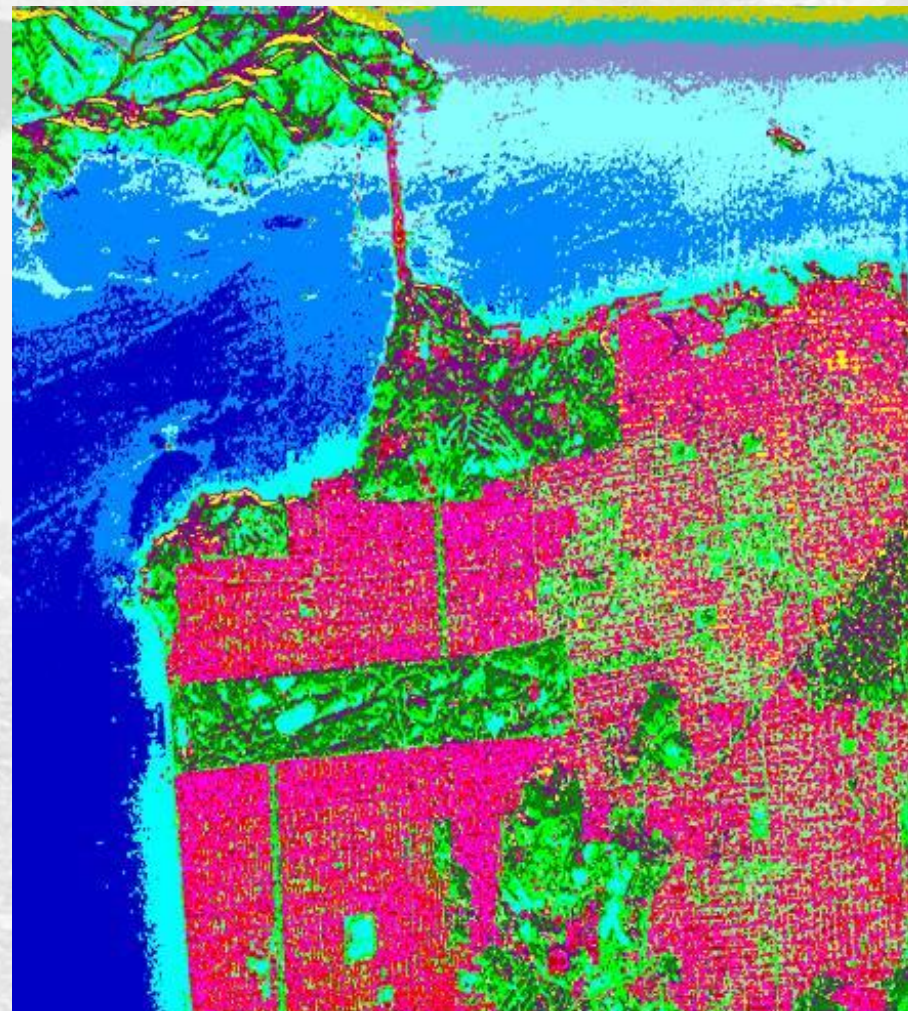
Results after 4 additional iterations – 16 classes

E. Pottier and J.S. Lee, “Application of the « H / A / α » polarimetric decomposition theorem for unsupervised classification of fully polarimetric SAR data based on the Wishart distribution” Proceedings of EUSAR2000

SAN FRANCISCO BAY JPL - AIRSAR L-band 1988



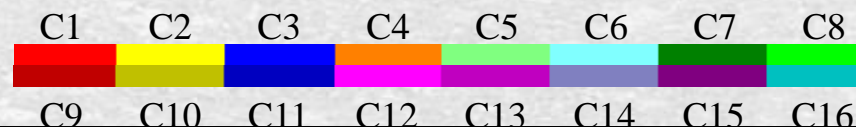
4th ITERATION



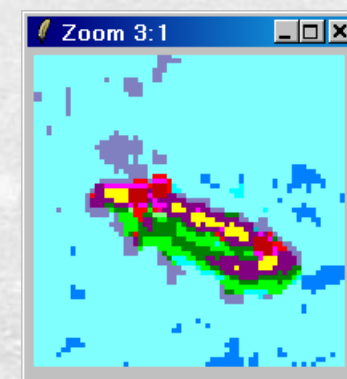
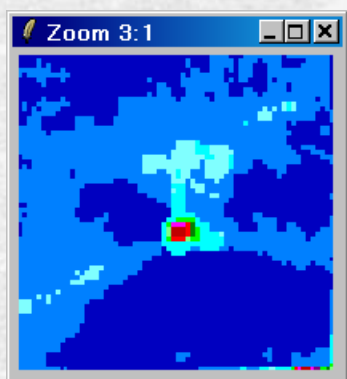
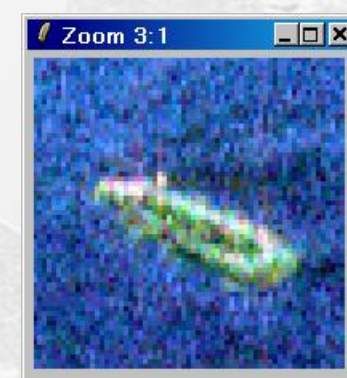
$2A_0$

$B_0 + B$

$B_0 - B$



SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

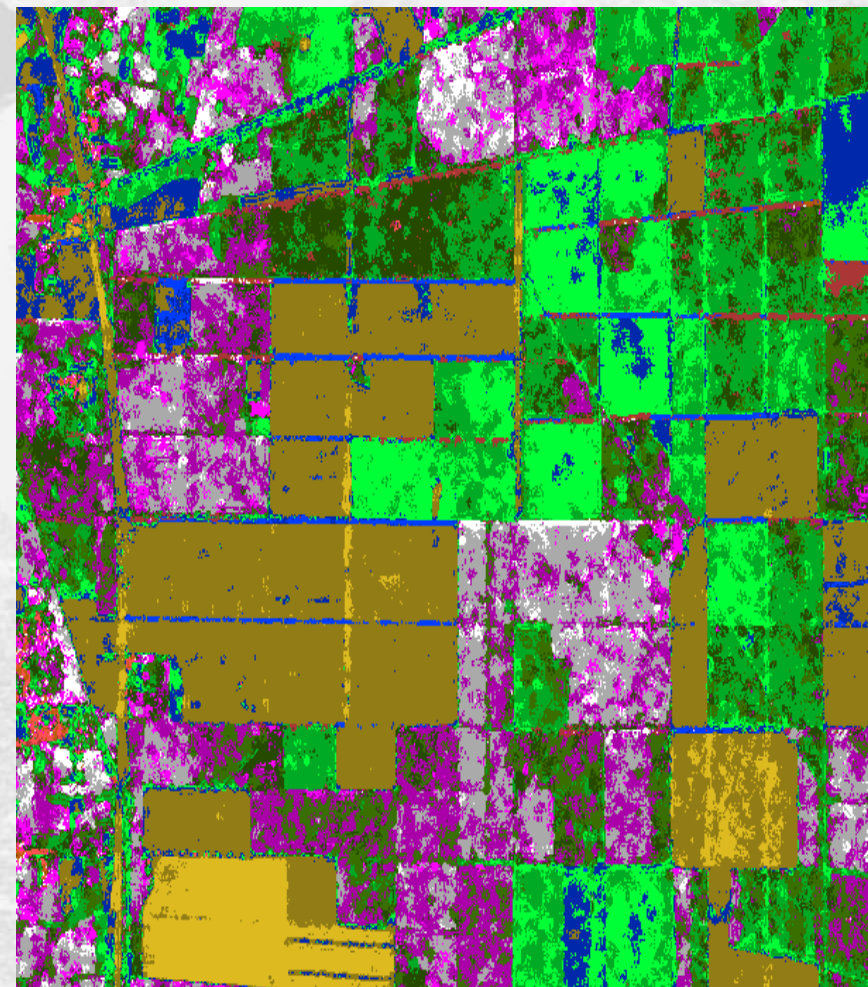
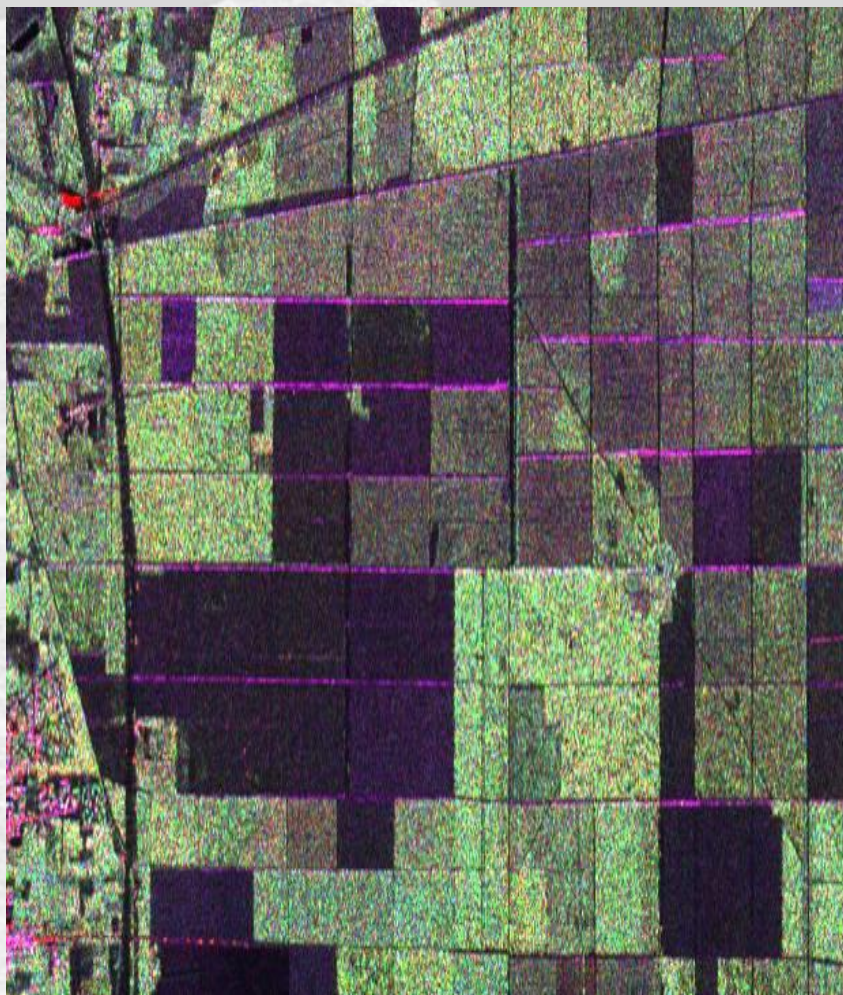


$$2A_0$$

$$B_0 + B$$

$$B_0 - B$$

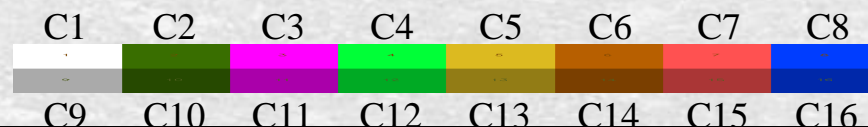
NEZER FOREST JPL - AIRSAR L-band



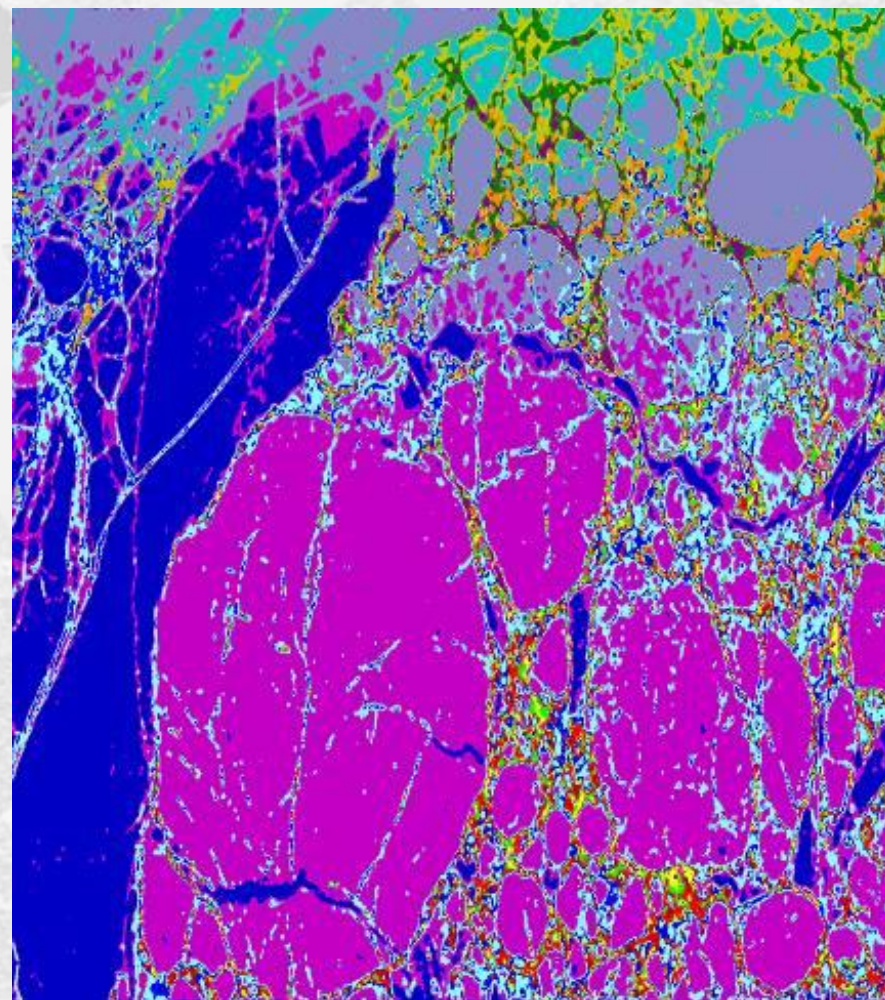
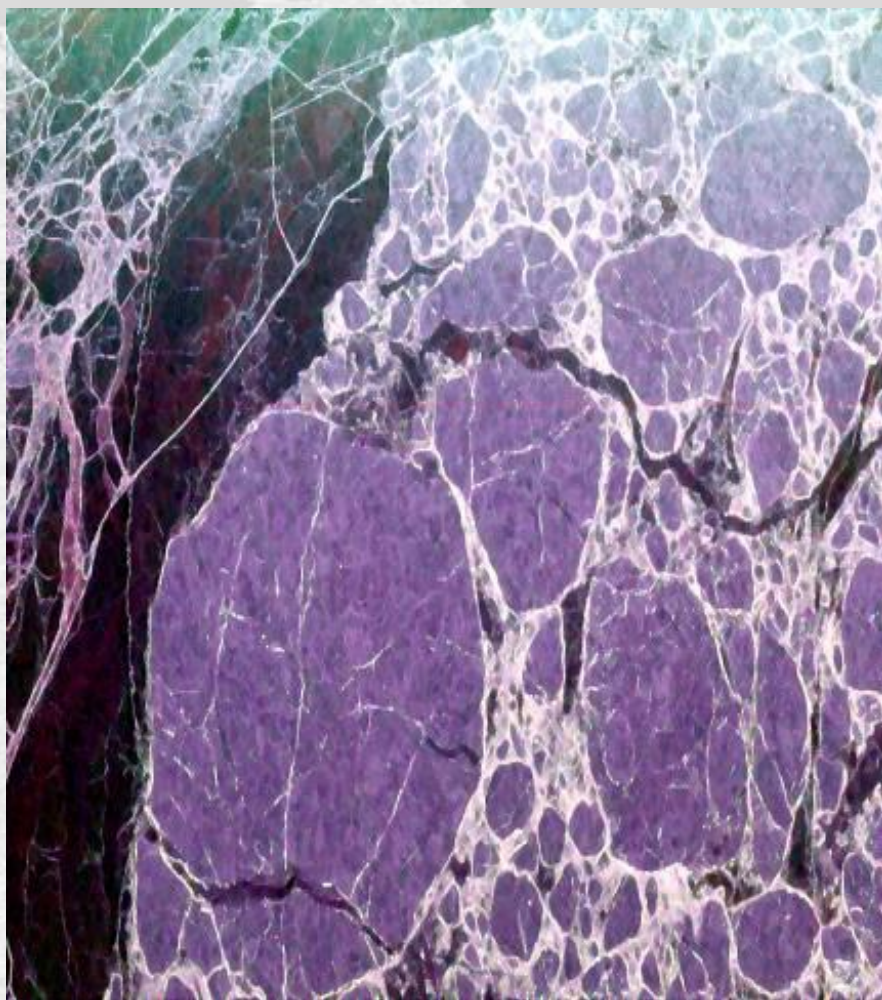
$2A_0$

$B_0 + B$

$B_0 - B$



ICE AREA JPL - AIRSAR L-band



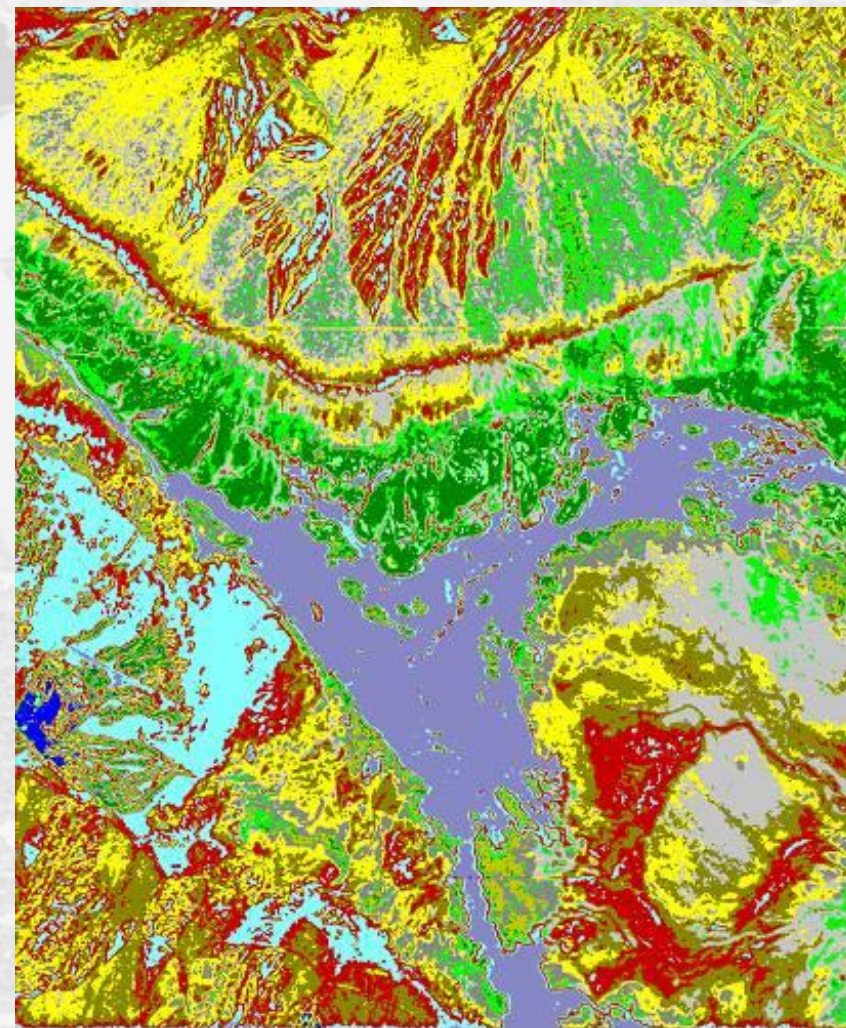
$2A_0$

$B_0 + B$

$B_0 - B$



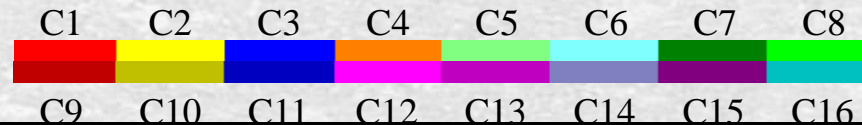
DEATH VALLEY JPL - AIRSAR L-band



$2A_0$

$B_0 + B$

$B_0 - B$



ALLING - ESAR L-band

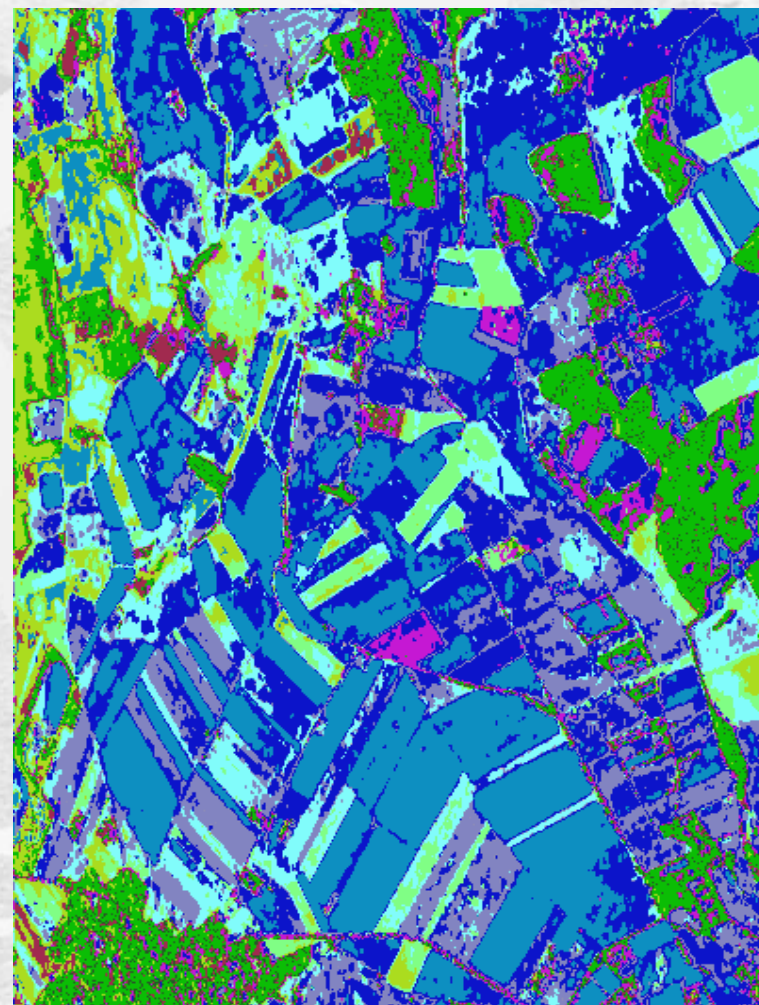


$2A_0$

$B_0 + B$

$B_0 - B$

H / A / α and WISHART CLASSIFIER

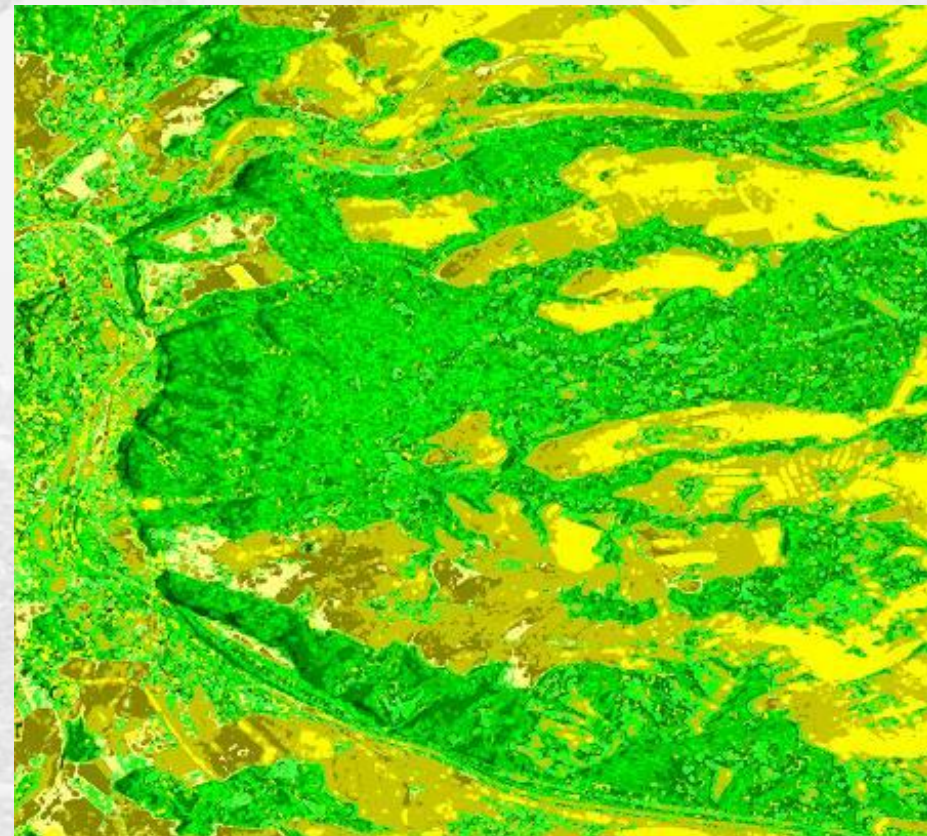
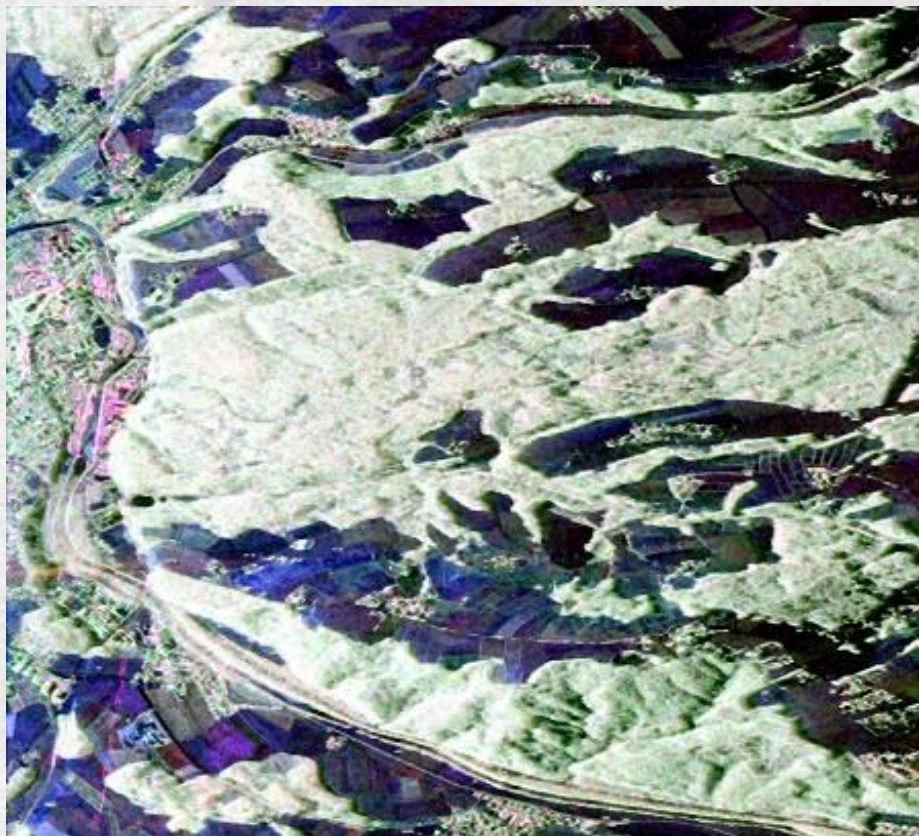


C1	C2	C3	C4	C5	C6	C7	C8
C9	C10	C11	C12	C13	C14	C15	C16

POLinSAR Project

TRAUNSTEIN - ESAR L-band

H / A / α and WISHART CLASSIFIER



$2A_0$

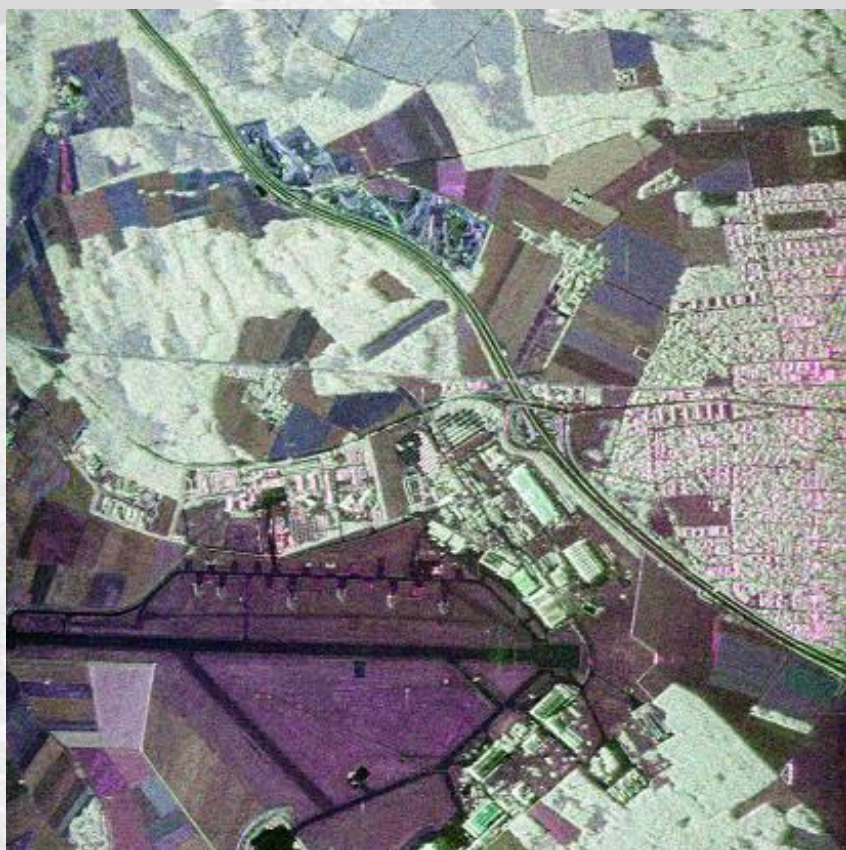
$B_0 + B$

$B_0 - B$

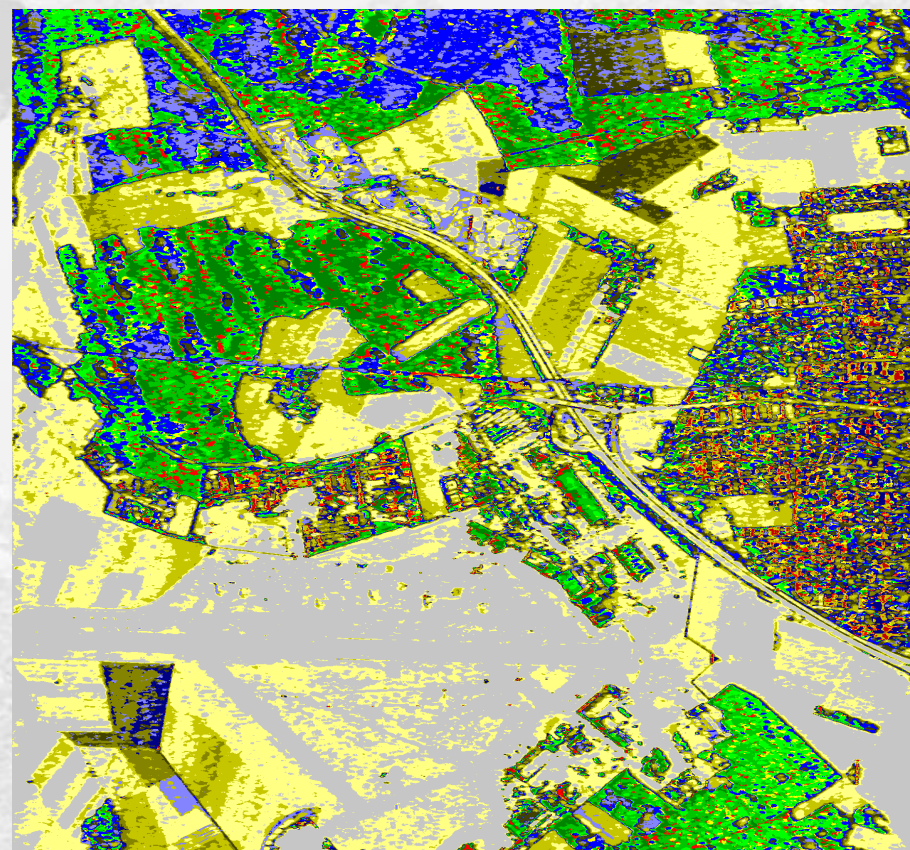


C1	C2	C3	C4	C5	C6	C7	C8
C9	C10	C11	C12	C13	C14	C15	C16

OBERPFAFFENHOFEN - ESAR L-band



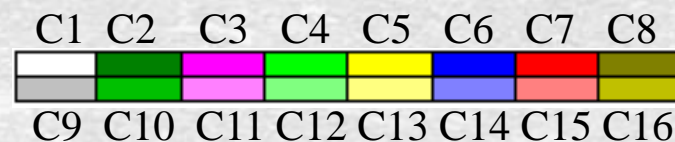
H / A / α and WISHART CLASSIFIER



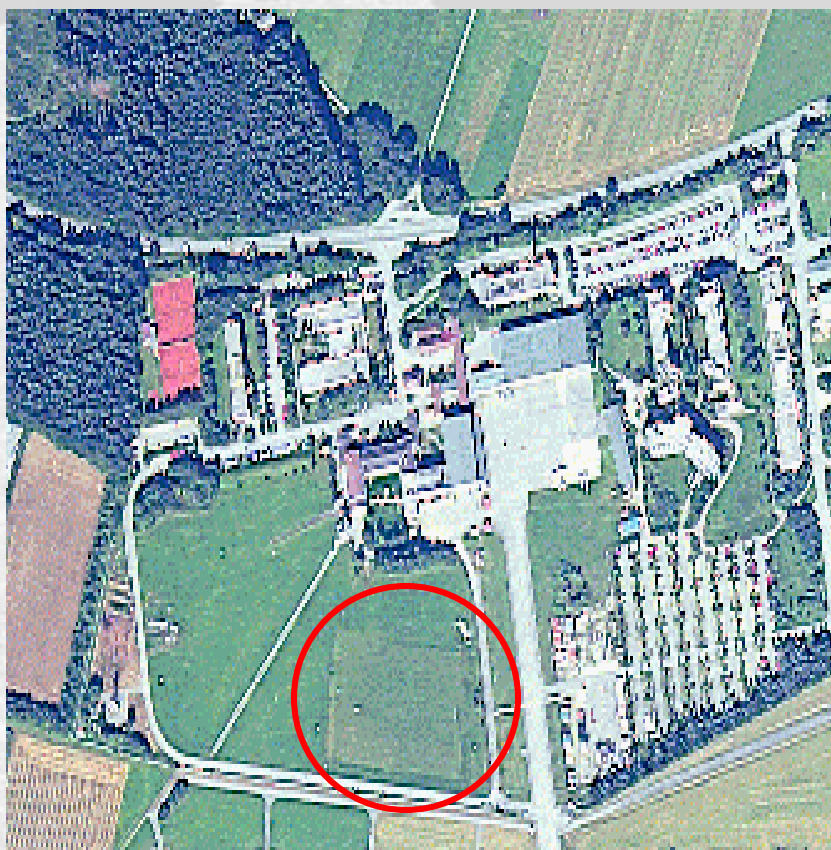
$2A_0$

$B_0 + B$

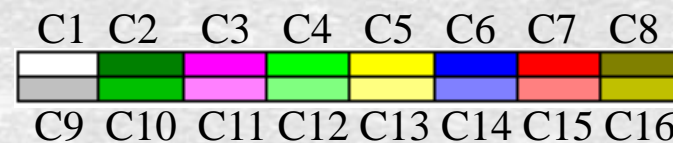
$B_0 - B$



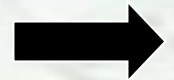
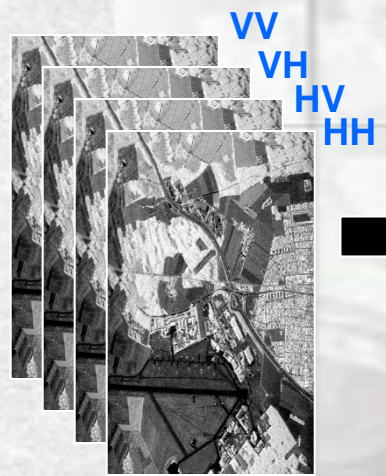
OBERPFAFFENHOFEN - ESAR L-band



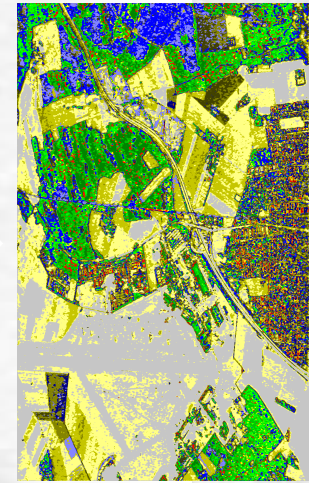
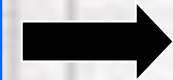
H / A / α and WISHART CLASSIFIER



WISHART PDF $P(\langle [T] \rangle / [T_m]) = \frac{L^L p \langle [T] \rangle^{L-p} e^{-LTr([T_m]^{-1} \langle [T] \rangle)}}{\pi^{\frac{p(p-1)}{2}} \Gamma(L) \dots \Gamma(L-p+1) [T_m]^L}$



**UNSUPERVISED
 POLSAR
 CLASSIFICATION**
 E.POTTIER, J.S LEE (2000)



Unsupervised Classification Preserving Scattering Mechanisms

J.S. Lee, M.R. Grunes, E. Pottier and L. Ferro-Famil, "Segmentation of polarimetric SAR images that preserves scattering mechanisms" Proceedings of EUSAR2002

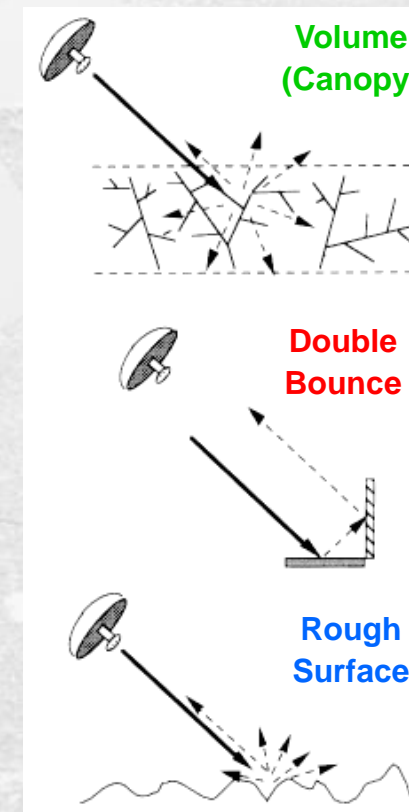
– Polarimetric SAR (POLSAR) classification

- Complex Wishart distribution (Lee et al., 1994)
- Wishart + Entropy/Alpha (Lee et al., 1999)
- Wishart + Entropy/Alpha/Anisotropy (Pottier and Lee, 2000)
- Deficiency: Wishart classifier is a statistic operator. Pixels in a class can be mixed in scattering mechanisms

– A new approach

- Preserving scattering property of each pixel based on Freeman and Durden decomposition:
 - Double bounce
 - Surface
 - Volume (Canopy)
- Better stability in convergence
- Automated color rendering

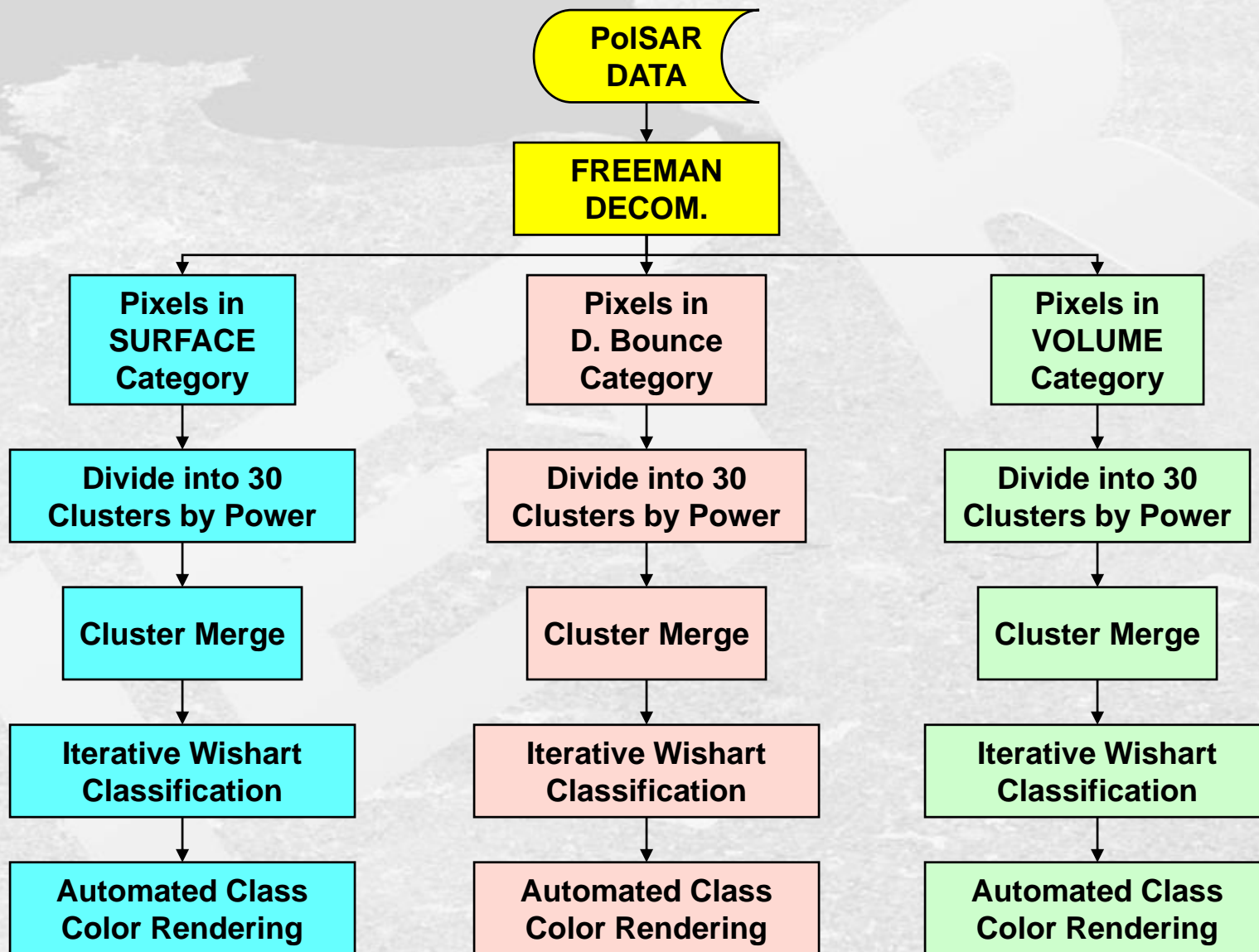
Courtesy of Dr J.S Lee



$|HH-VV|$, $|HV|$, $|HH+VV|$

Freeman and Durden

A. Freeman and S.L. Durden, "A Three-Component Scattering Model for Polarimetric SAR Data" IEEE TGRS, vol. 36, no. 3, May 1998



Cluster Merging
$$D_{ij} = \frac{1}{2} \{ \ln(|V_i|) + \ln(|V_j|) + \text{Tr}(V_i^{-1}V_j + V_j^{-1}V_i) \}$$

Wishart Iteration – After Class Merge

Classification Maps



First Iteration



Second Iteration



Third Iteration

Note: Stability insures good convergence

Courtesy of Dr J.S Lee



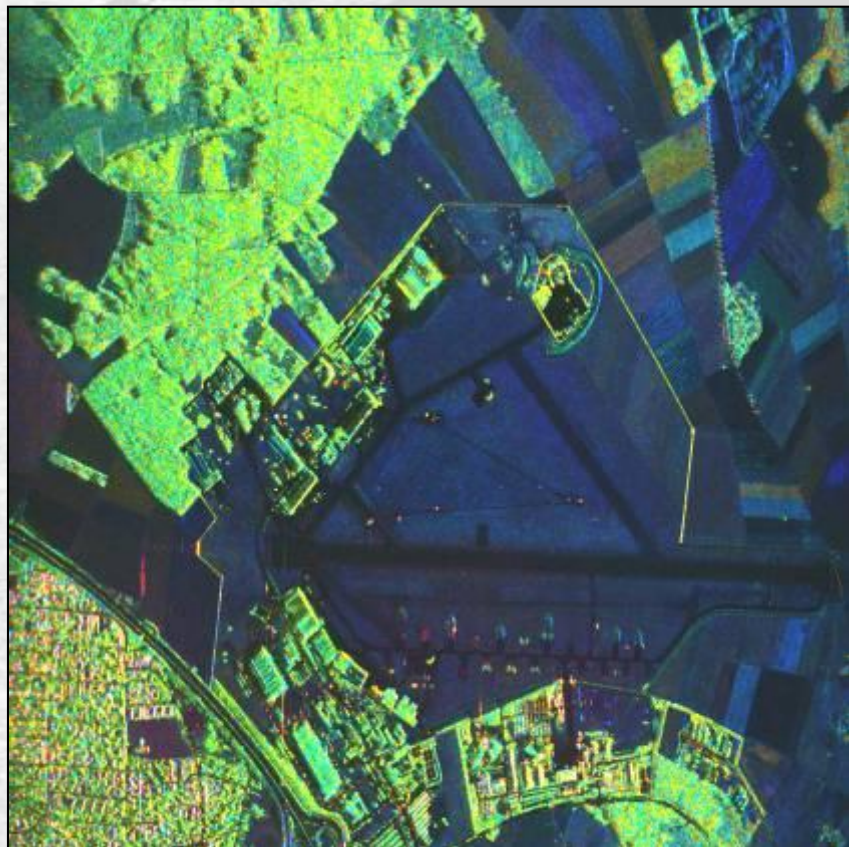
$|HH-VV|$, $|HV|$, $|HH+VV|$



4th Iteration (15 classes)



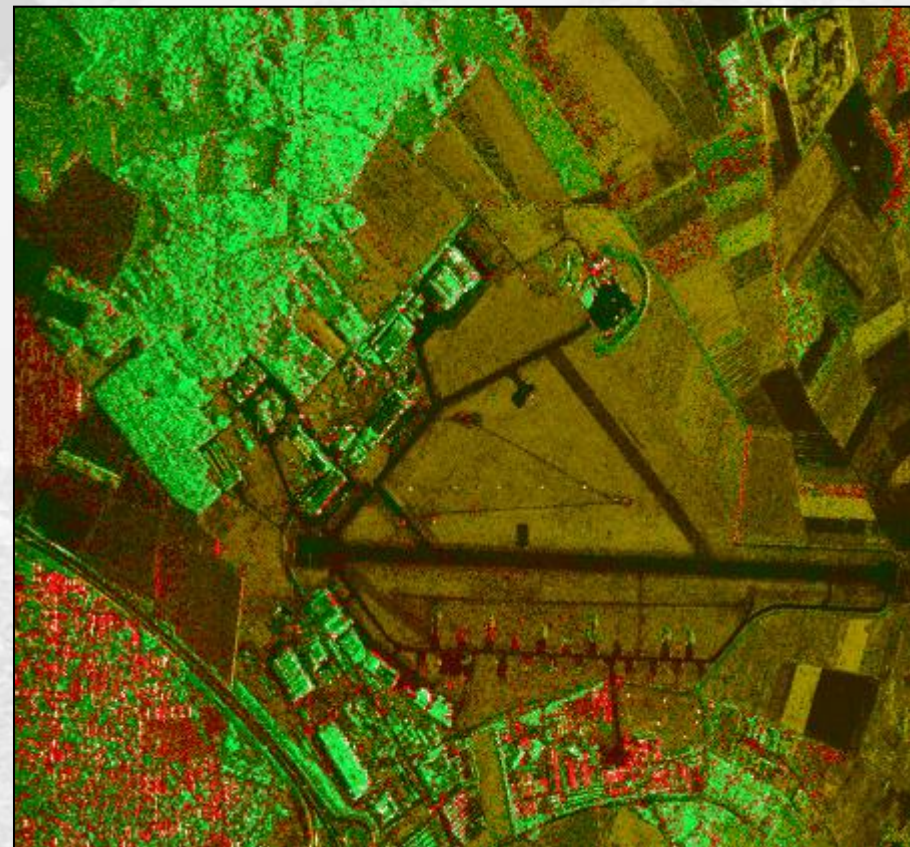
Courtesy of Dr J.S Lee



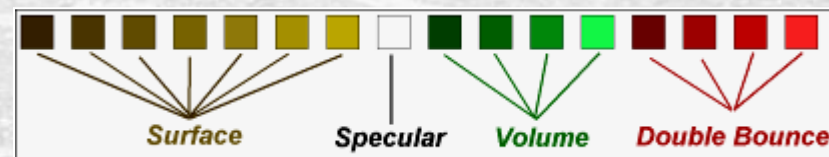
$2A_0$

$B_0 + B$

$B_0 - B$



4th Iteration (15 classes)



Courtesy of Dr J.S Lee

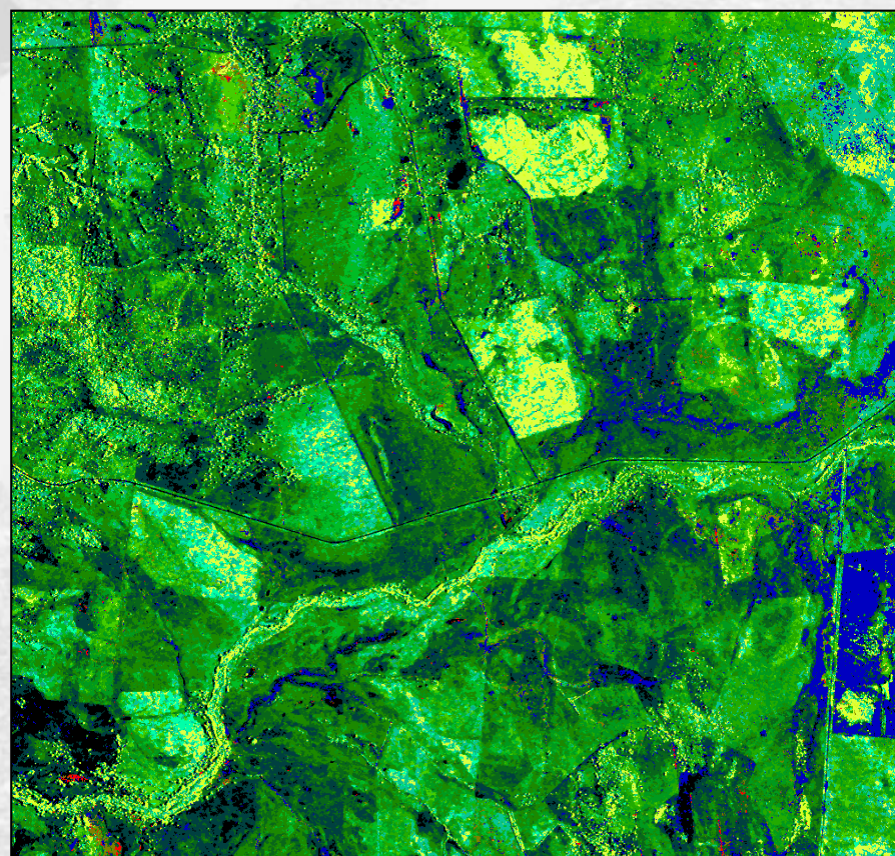


$2A_0$

$B_0 + B$

$B_0 - B$

Australian Pasture



4th Iteration (15 classes)



C-Band Volume Dominated

Courtesy of Dr J.S Lee

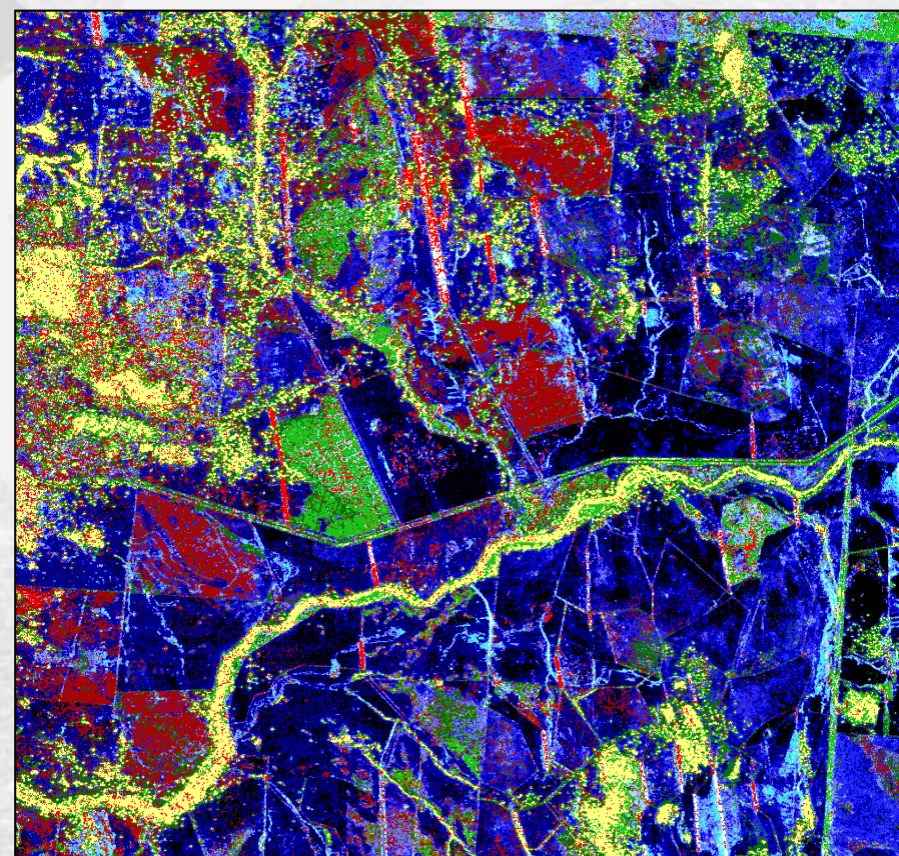


$2A_0$

$B_0 + B$

$B_0 - B$

Australian Pasture



4th Iteration (15 classes)



L-Band Volume Dominated

PoISAR TERRAIN and LAND-USE CLASSIFICATION

J.S. Lee, M.R. Grunes, E. Pottier, L. Ferro-Famil, "Unsupervised terrain classification preserving scattering characteristics," IEEE Transactions on Geoscience and Remote Sensing, vol. 42, no.4, pp. 722-731, April, 2004.

J.S. Lee, M. R. Grunes and E. Pottier, "Quantitative Comparison of Classification Capability: Fully polarimetric versus Dual- and Single polarization SAR," IEEE TGRS, November 2002

E. Pottier and J.S. Lee, "Application of the « $H / A / \alpha$ » polarimetric decomposition theorem for unsupervised classification of fully polarimetric SAR data based on the Wishart distribution" Proceedings of EUSAR2000

J.S. Lee, M.R. Grunes, T.L. Ainsworth, L. Du, D.L. Schuler, and S.R. Cloude, " Unsupervised Classification of Polarimetric SAR Imagery Based on Target Decomposition and Wishart Distribution," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 37, no. 5, 2249-2258, September 1999.

J.S. Lee, M. R. Grunes and R. Kwok," Classification of Polarimetric SAR Images Based on the Complex Wishart Distribution," *Int. J. Remote Sensing*, vol.32, No. 5, Sept. 1994.

J.S. Lee, E. Pottier, *Polarimetric Radar Imaging: From Basics to Applications*, Taylor & Francis/CRC, 2009



Questions ?

