Land Retrieval from PolSAR

Eric POTTIER

20 / 11 / 2019

ESA–MOST China Dragon 4 Cooperation

2019 ADVANCED INTERNATIONAL TRAINING COURSE IN LAND REMOTE SENSING

中欧科技合作“龙计划”第四期 2019年陆地遥感高级培训班

18 to 23 November 2019 | Chongqing University, P.R. China

培训时间:2019年11月18日-23日 主办方:重庆大学

Eric POTTIER

eric.pottier@univ-rennes1.fr

INSTITUT D'ÉLECTRONIQUE ET DE TÉLÉCOMMUNICATIONS DE RENNES

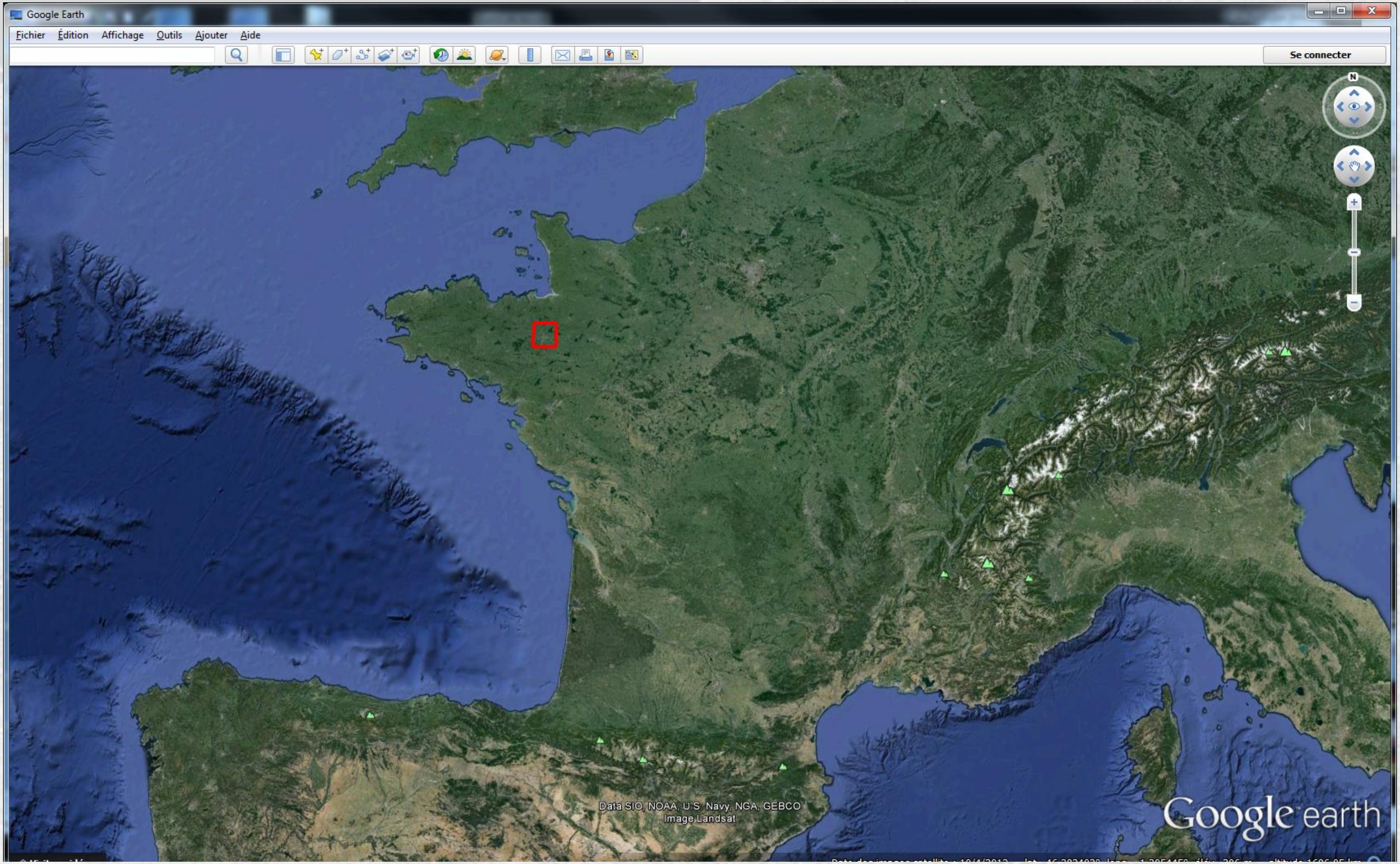
I.E.T.R. - UMR CNRS 6164
Université de Rennes I - Campus de Beaulieu
Pôle Micro Ondes Radar - Bat 11D
263 Avenue Général Leclerc
CS 74205 - 35042 Rennes Cedex – France

SHINE

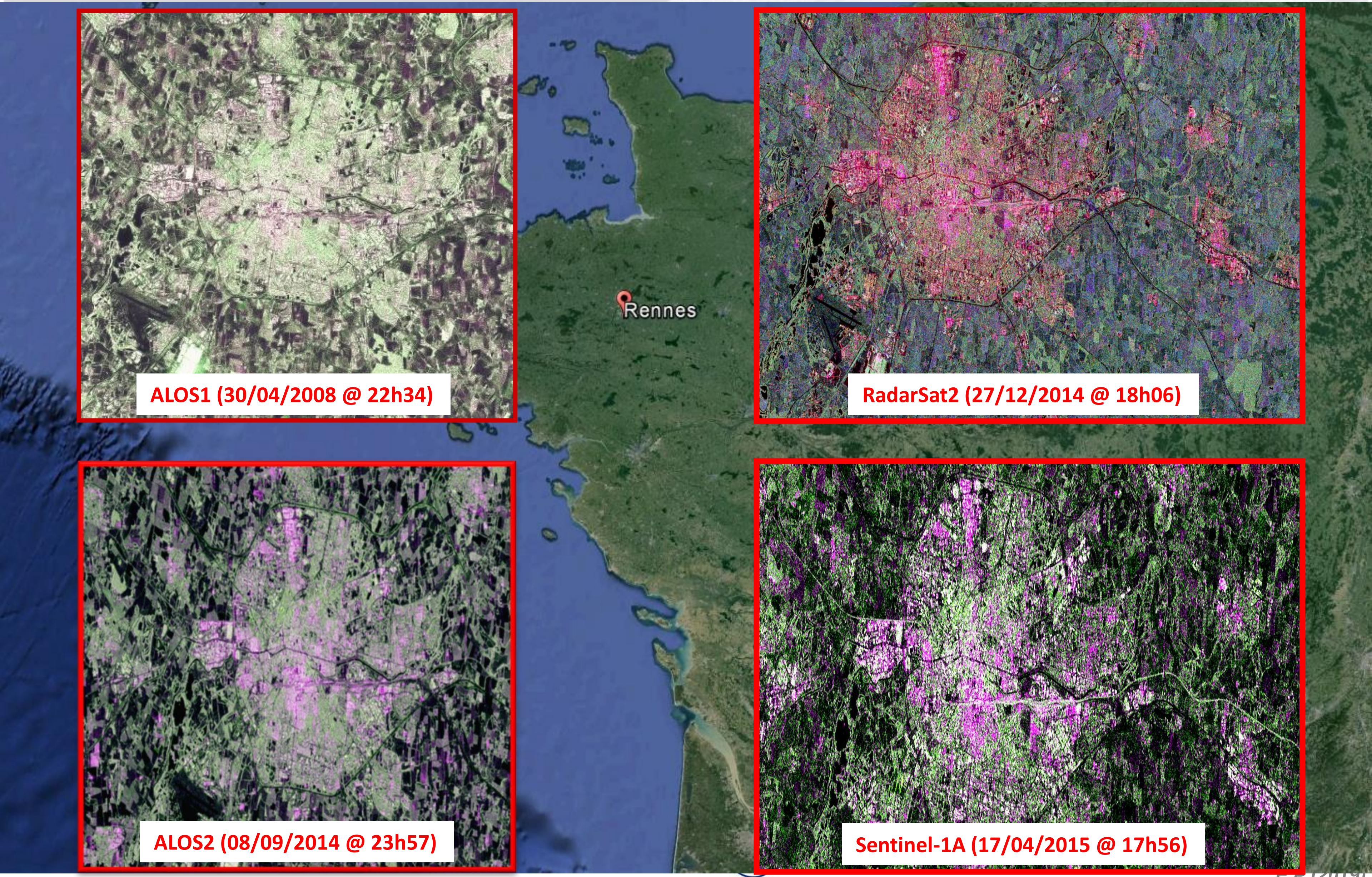
SAR & Hyperspectral multi-modal Imaging and sigNal processing, Electromagnetic modeling

UNIVERSITÉ DE RENNES 1

RENNES - BRITANNY - FRANCE

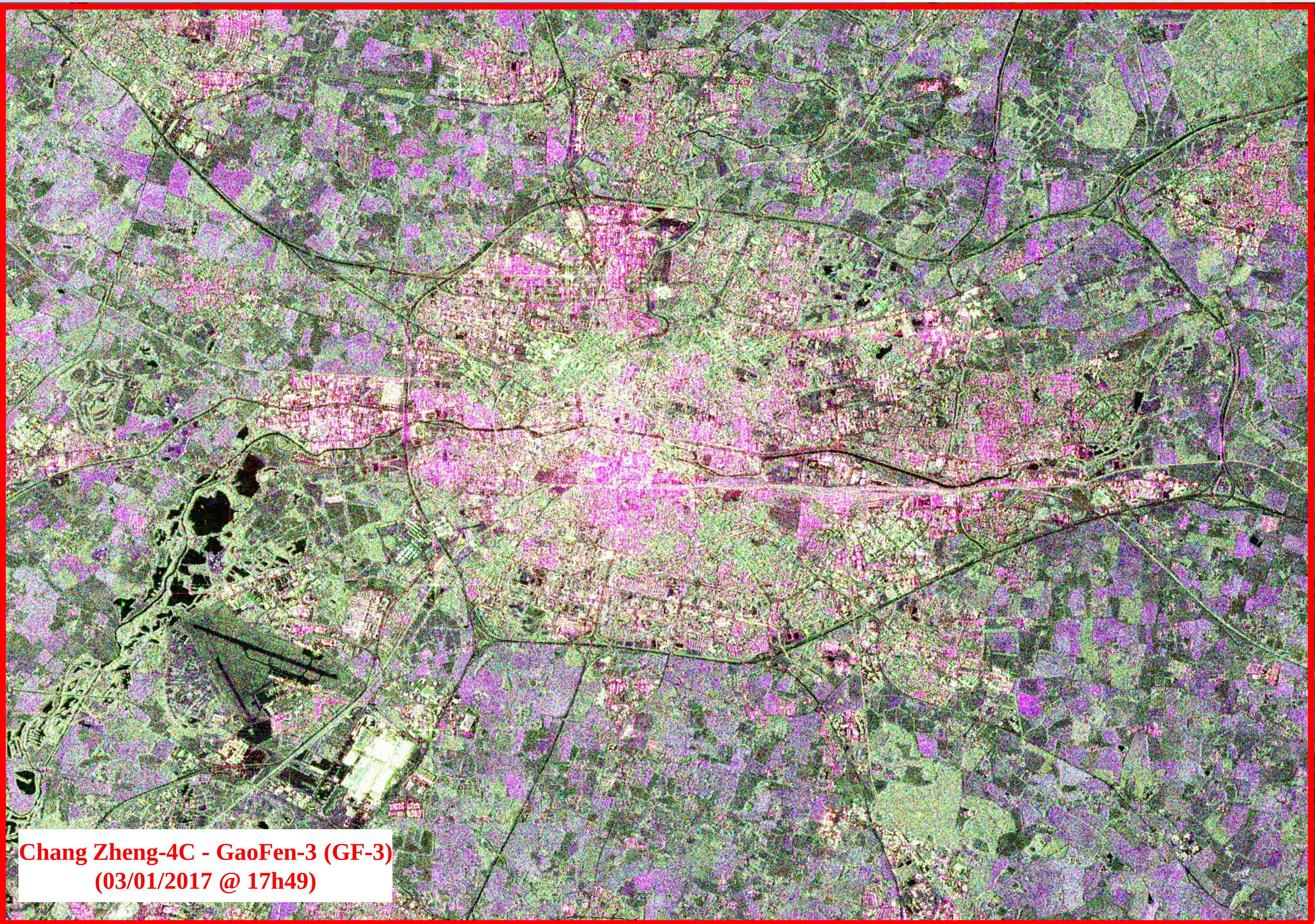


RENNES - BRITANNY - FRANCE



E.P (2019)

RENNES - BRITANNY - FRANCE



Objective

To provide

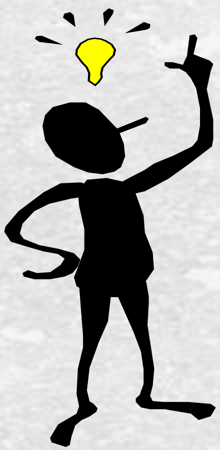
the minimum, but necessary,

amount of knowledge required

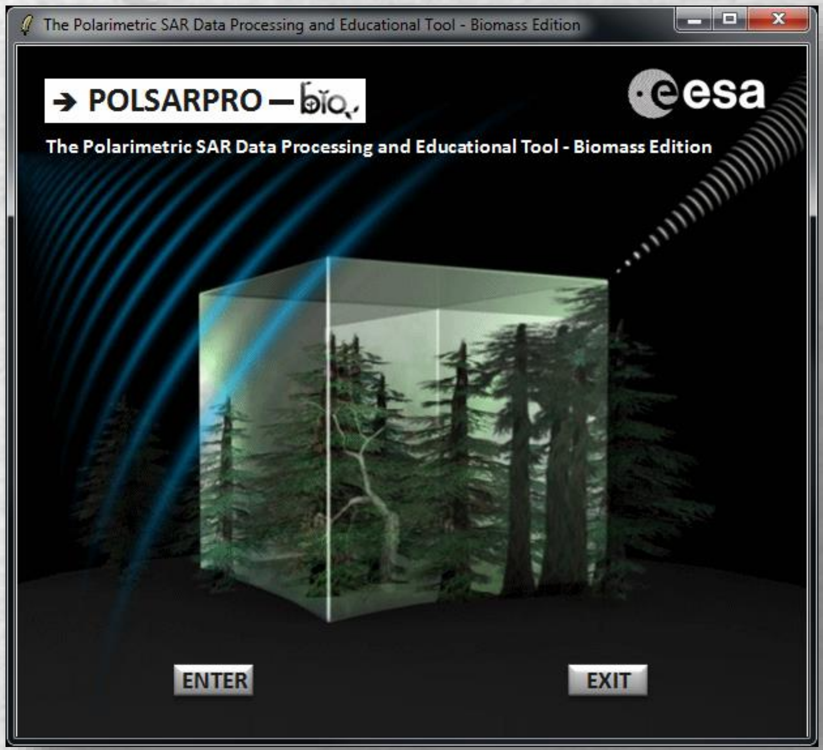
to understand

scientific works on

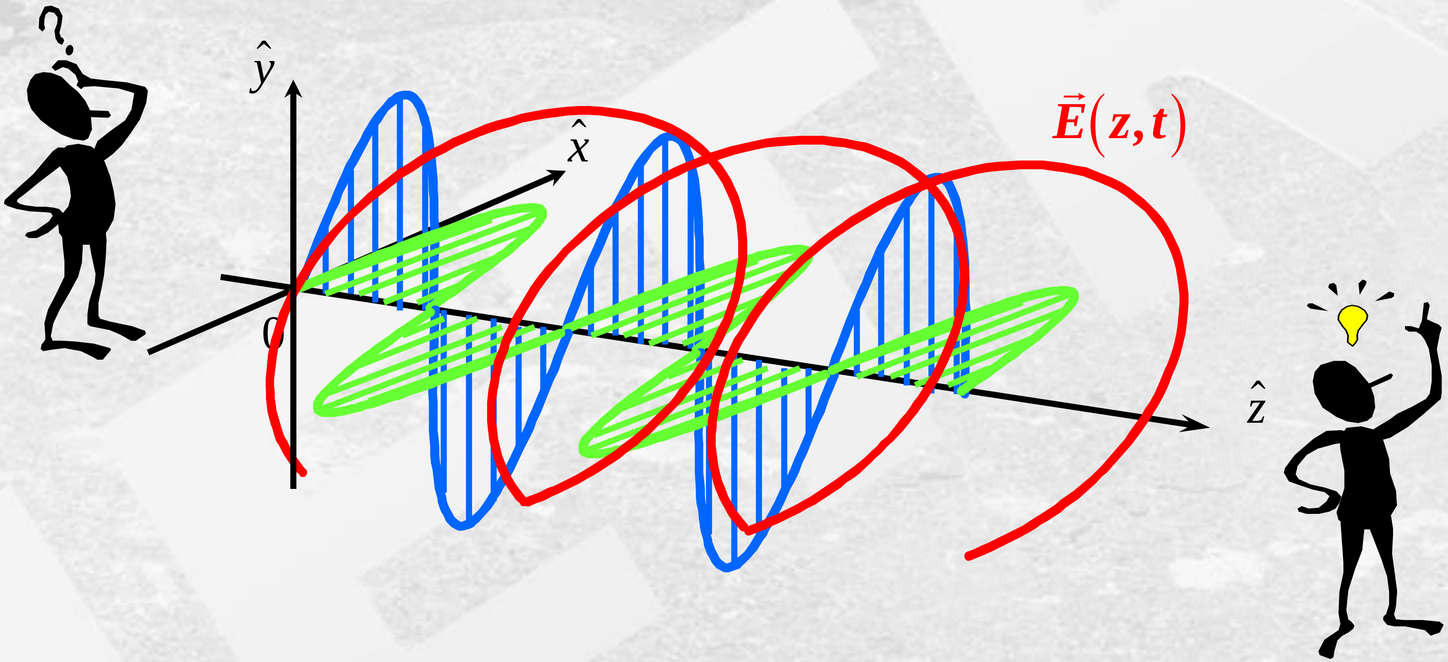
Radar Polarimetry



Practicals


The Polarimetric SAR Data Processing and Educational Tool - Biomass Edition
POLSARPRO — bio
esa
The Polarimetric SAR Data Processing and Educational Tool - Biomass Edition
ENTER
EXIT


esa
POLSARPRO bio
The Polarimetric SAR Data Processing and Educational Tool
http://earth.esa.int/polsarpro
www.esa.int
European Space Agency



DATASETS

AIRSAR

DC8

P, L, C-Band (Quad)

© Google Earth

SAN FRANCISCO BAY

NRSCC esa

© Google Earth

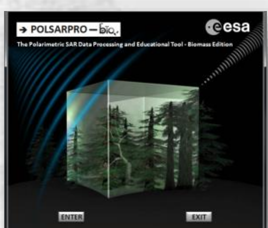
|HH+VV| $T_{11}=2A_0$

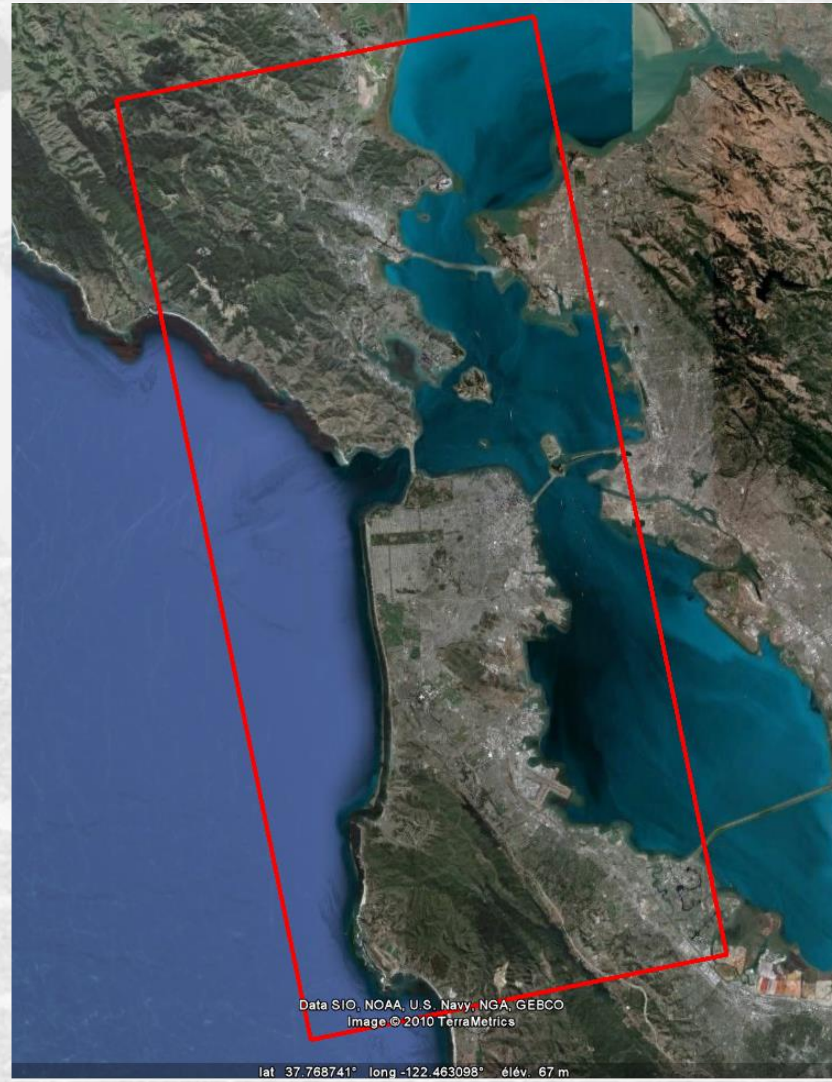
|HV| $T_{33}=B_0-B$

|HH-VV| $T_{22}=B_0+B$

ALOS - PALSAR

L-Band (Quad)





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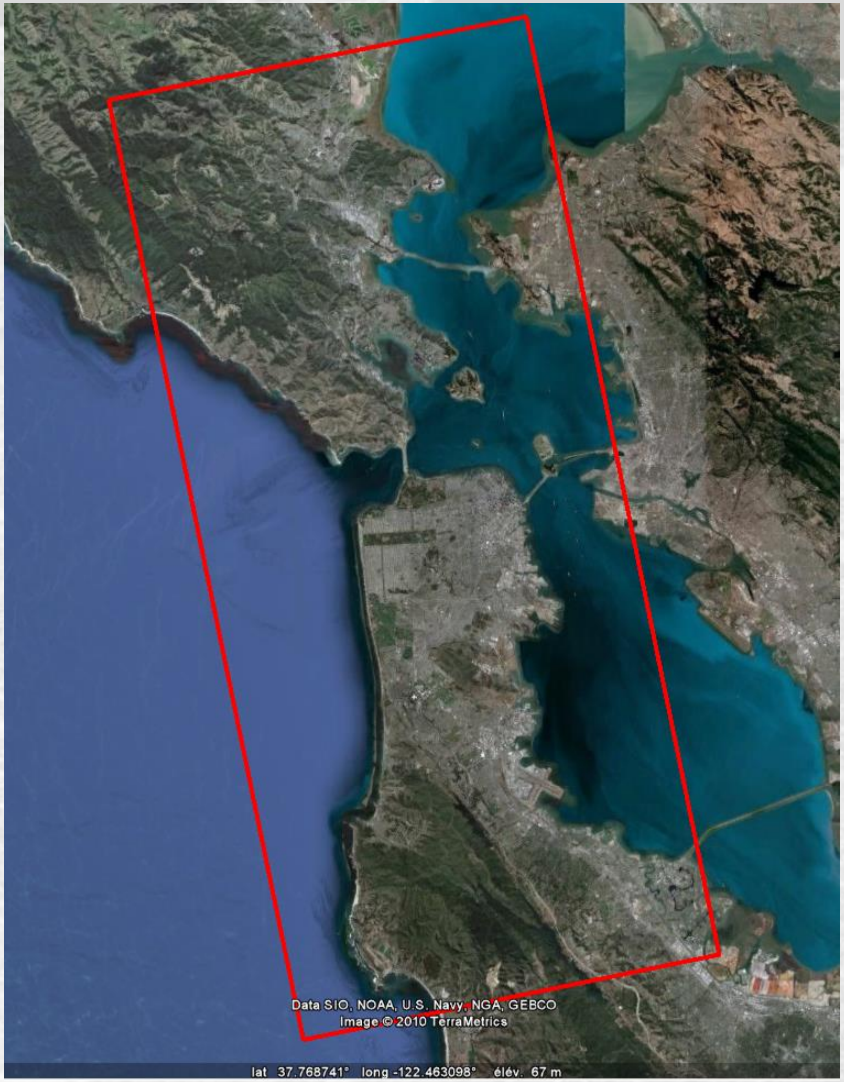
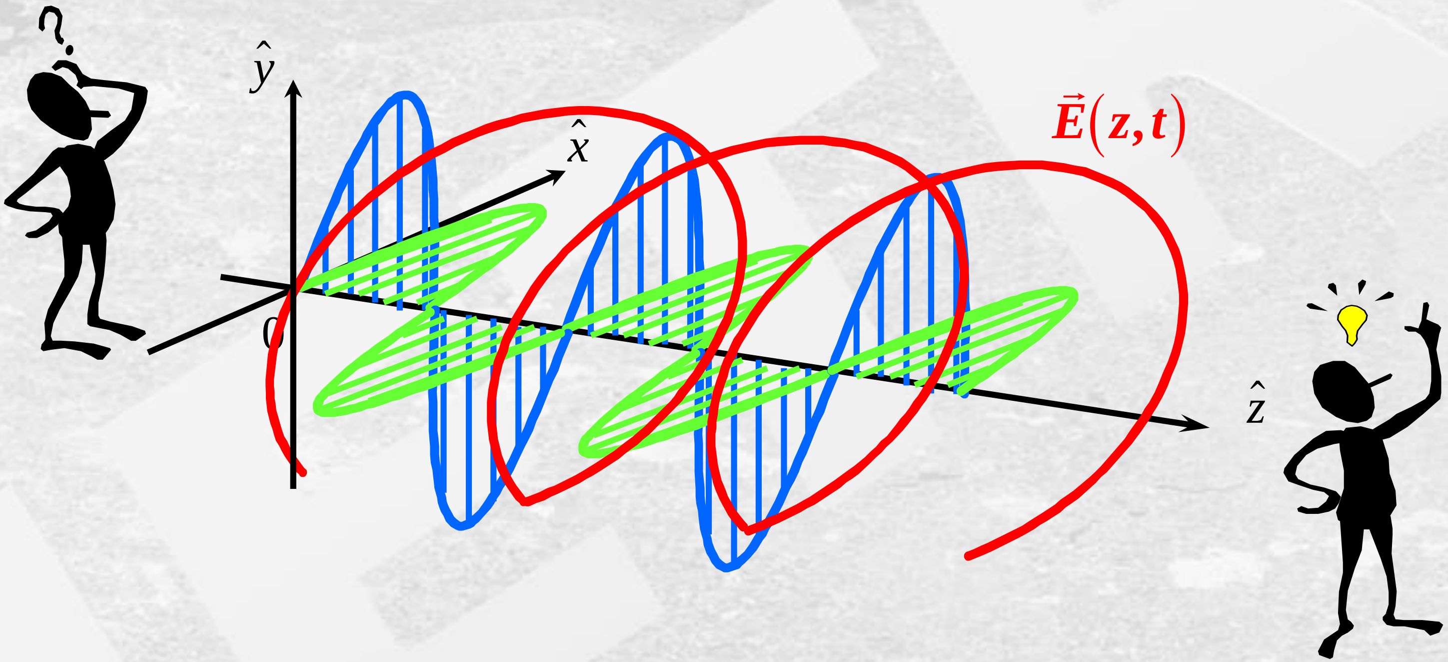
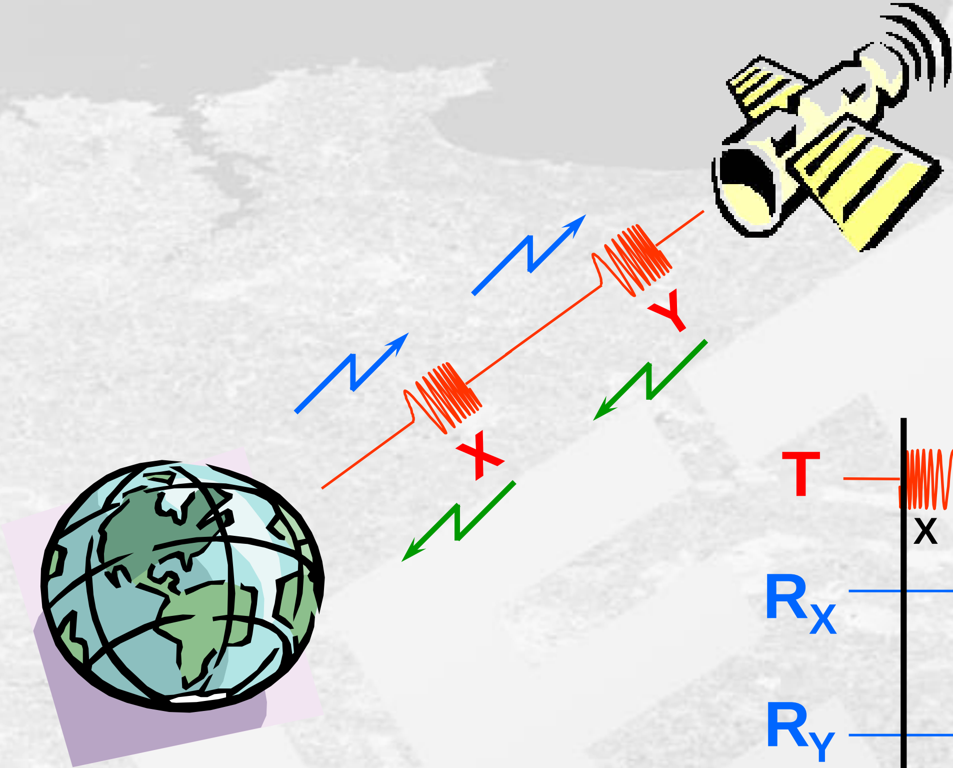
SAN FRANCISCO BAY

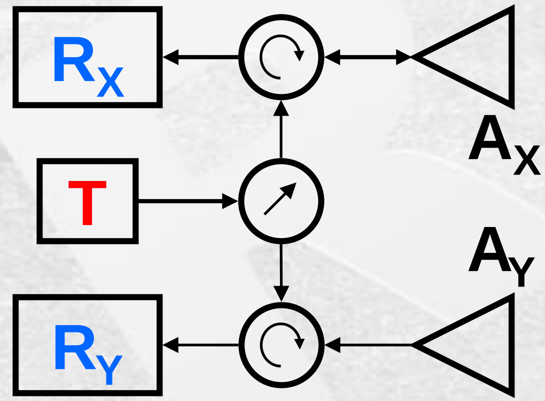


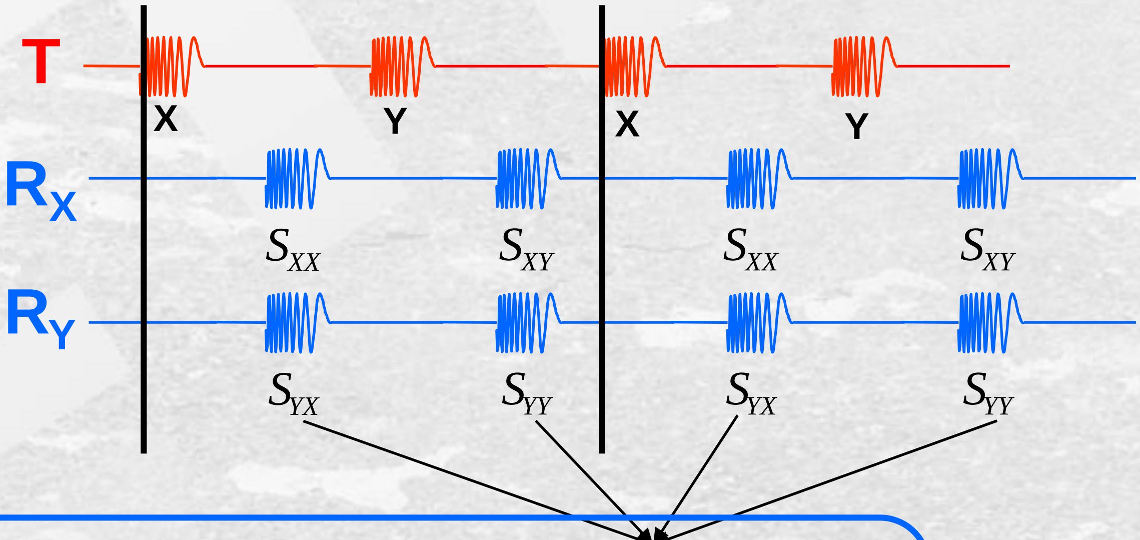
Courtesy of Dr Don Artwood (ASF)



SUMMARY







TRANSMITTER: X & Y

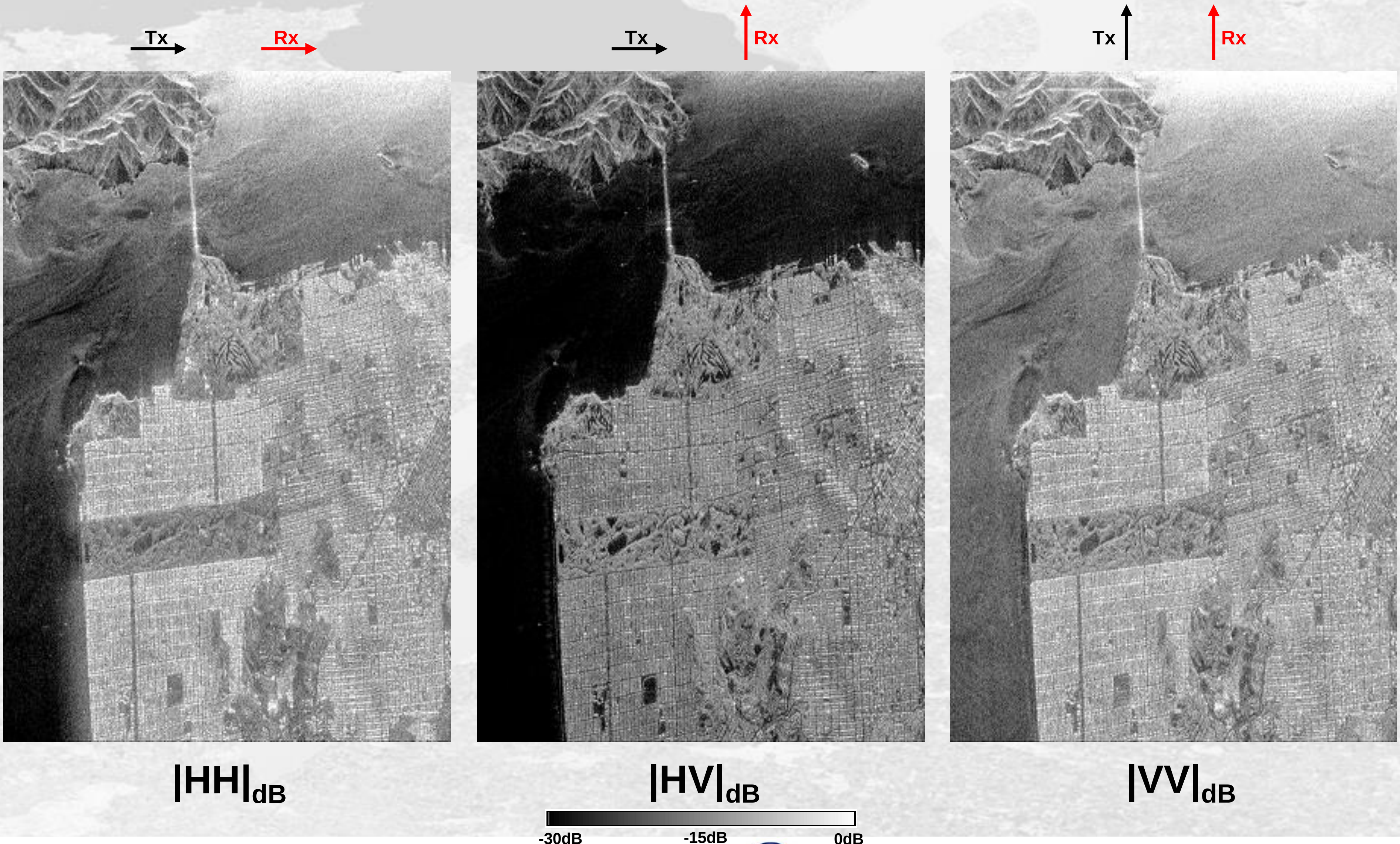
RECEIVERS: X & Y

SINCLAIR MATRICES

$$\left\{ [S] = \begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix} \right\}$$

SCATTERING POLARIMETRY

SCATTERING POLARIMETRY



SCATTERING POLARIMETRY

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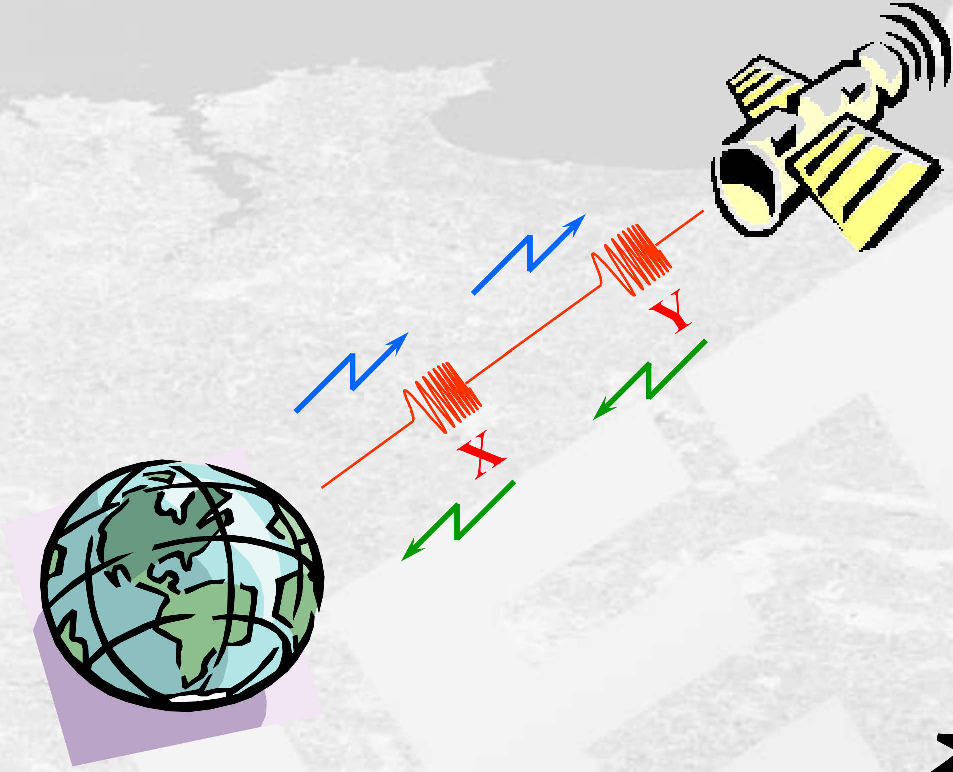
Sinclair Color Coding

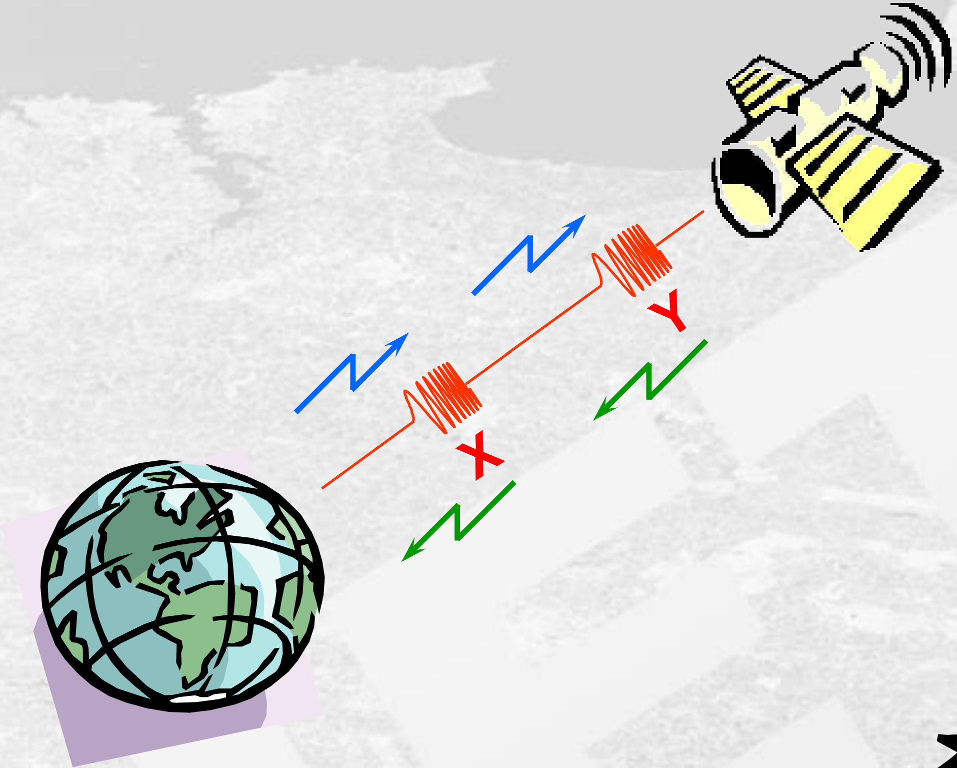
|HH| |HV| |VV|



TRANSMITTER: X & Y
RECEIVERS: X & Y

THE DIFFERENT TARGET POLARIMETRIC DESCRIPTORS

[S]	SINCLAIR Matrix
k, Ω	Target Vectors
[K]	KENNAUGH Matrix
[T]	Coherency Matrix
[C]	Covariance Matrix



TRANSMITTER: X & Y
RECEIVERS: X & Y

THE DIFFERENT TARGET POLARIMETRIC DESCRIPTORS

[S] SINCLAIR Matrix
[K] KENNAUGH Matrix
k, Ω Target Vectors
[T] Coherency Matrix
[C] Covariance Matrix

STATISTICAL DESCRIPTION

PARTIAL SCATTERING POLARIMETRY

MONOSTATIC CASE

PAULI SCATTERING VECTOR $\underline{k}$

$$\underline{k} = \frac{1}{\sqrt{2}}\left[S_{XX} + S_{YY} \quad S_{XX} - S_{YY} \quad 2S_{XY}\right]^T$$

$$\Downarrow$$

COHERENCY MATRIX $[T]$

$$[T] = \underline{k} \cdot \underline{k}^{*T} = \begin{bmatrix} 2A_0 & C - jD & H + jG \\ C + jD & B_0 + B & E + jF \\ H - jG & E - jF & B_0 - B \end{bmatrix}$$

HERMITIAN POSITIVE SEMI-DEFINITE MATRIX - RANK 1

HUYNEN TARGET GENERATORS

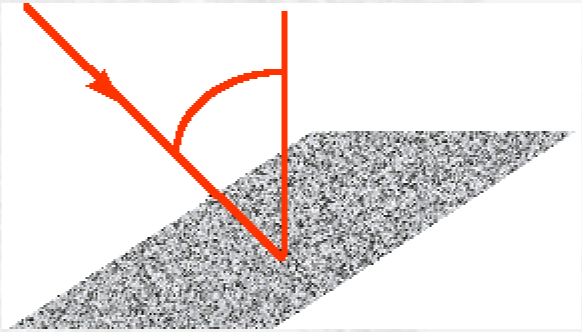
$$T_{11} = 2A_0 = |S_{XX} + S_{YY}|^2 \qquad T_{22} = B_0 + B = |S_{XX} - S_{YY}|^2$$

$$T_{33} = B_0 - B = 2|S_{XY}|^2$$

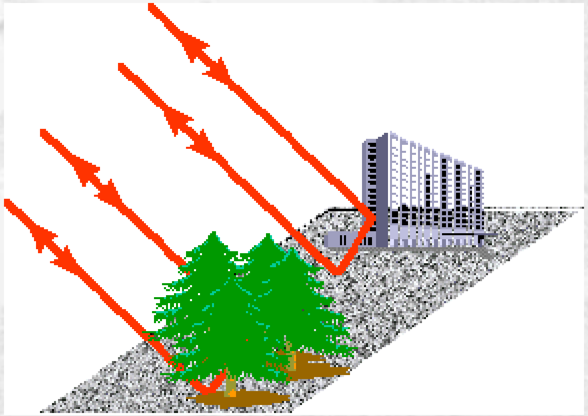
TARGET GENERATORS

PHYSICAL INTERPRETATION

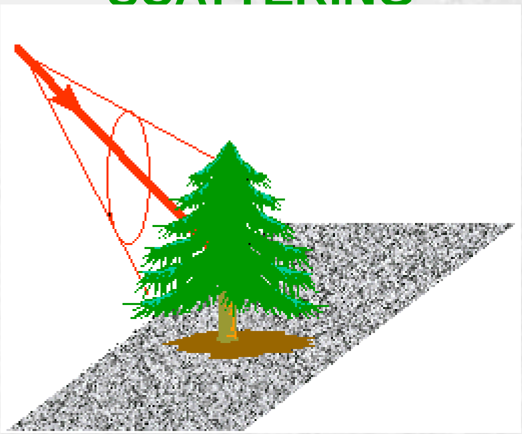
SINGLE BOUNCE SCATTERING (ROUGH SURFACE)



DOUBLE BOUNCE SCATTERING



VOLUME SCATTERING

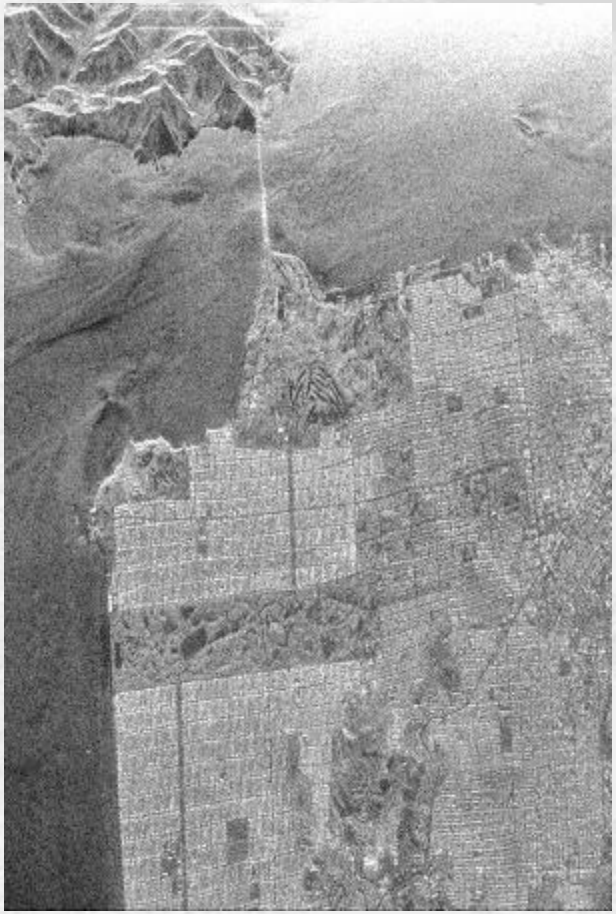


$$T_{11} = 2A_0 = |S_{XX} + S_{YY}|^2$$

$$T_{33} = B_0 - B = 2|S_{XY}|^2$$

$$T_{22} = B_0 + B = |S_{XX} - S_{YY}|^2$$

TARGET GENERATORS



$|HH+VV|_{dB}$

$|HV|_{dB}$

$|HH-VV|_{dB}$

TARGET GENERATORS

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(H,V) POLARISATION BASIS

|HH+VV| |HV | |HH-VV|

SINCLAIR MATRIX

$$[S] = \begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix}$$

SCATTERING VECTOR $\underline{k}$

$$\underline{k} = \frac{1}{\sqrt{2}} \left[S_{XX} + S_{YY} \quad S_{XX} - S_{YY} \quad 2S_{XY} \right]^T$$

COHERENCY MATRIX $[T]$

$$[T] = \underline{k} \cdot \underline{k}^{*T}$$

SINCLAIR MATRIX

$$\left[S_{(B,B_\perp)}\right]=\left[U_{(A,A_\perp)\mapsto(B,B_\perp)}\right]^T\left[S_{(A,A_\perp)}\right]\left[U_{(A,A_\perp)\mapsto(B,B_\perp)}\right]$$

CON-SIMILARITY TRANSFORMATION

$$\left[U_{3(A,A_\perp)\mapsto(B,B_\perp)}\right]$$

U(3) SPECIAL UNITARY ELLIPTICAL BASIS TRANSFORMATION MATRIX

COHERENCY MATRIX

$$\left[T_{(B,B_\perp)}\right]=\left[U_{3(A,A_\perp)\mapsto(B,B_\perp)}\right]\left[T_{(A,A_\perp)}\right]\left[U_{3(A,A_\perp)\mapsto(B,B_\perp)}\right]^{-1}$$

SIMILARITY TRANSFORMATION

ELLIPTICAL BASIS TRANSFORMATION

SPECIAL UNITARY SU(2) GROUP

$$[U_2] = \begin{bmatrix} \cos(\phi) & -\sin(\phi) \\ \sin(\phi) & \cos(\phi) \end{bmatrix} \begin{bmatrix} \cos(\tau) & j\sin(\tau) \\ j\sin(\tau) & \cos(\tau) \end{bmatrix} \begin{bmatrix} e^{-j\alpha} & 0 \\ 0 & e^{j\alpha} \end{bmatrix}$$

$$[U_2(\phi)] \qquad [U_2(\tau)] \qquad [U_2(\alpha)]$$

SPECIAL UNITARY SU(3) GROUP

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(2\phi) & \sin(2\phi) \\ 0 & -\sin(2\phi) & \cos(2\phi) \end{bmatrix} \begin{bmatrix} \cos(2\tau) & 0 & j\sin(2\tau) \\ 0 & 1 & 0 \\ j\sin(2\tau) & 0 & \cos(2\tau) \end{bmatrix} \begin{bmatrix} \cos(2\alpha) & -j\sin(2\alpha) & 0 \\ -j\sin(2\alpha) & \cos(2\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$[U_3(2\phi)] \qquad [U_3(2\tau)] \qquad [U_3(2\alpha)]$$

ELLIPTICAL BASIS TRANSFORMATION

© Google Earth

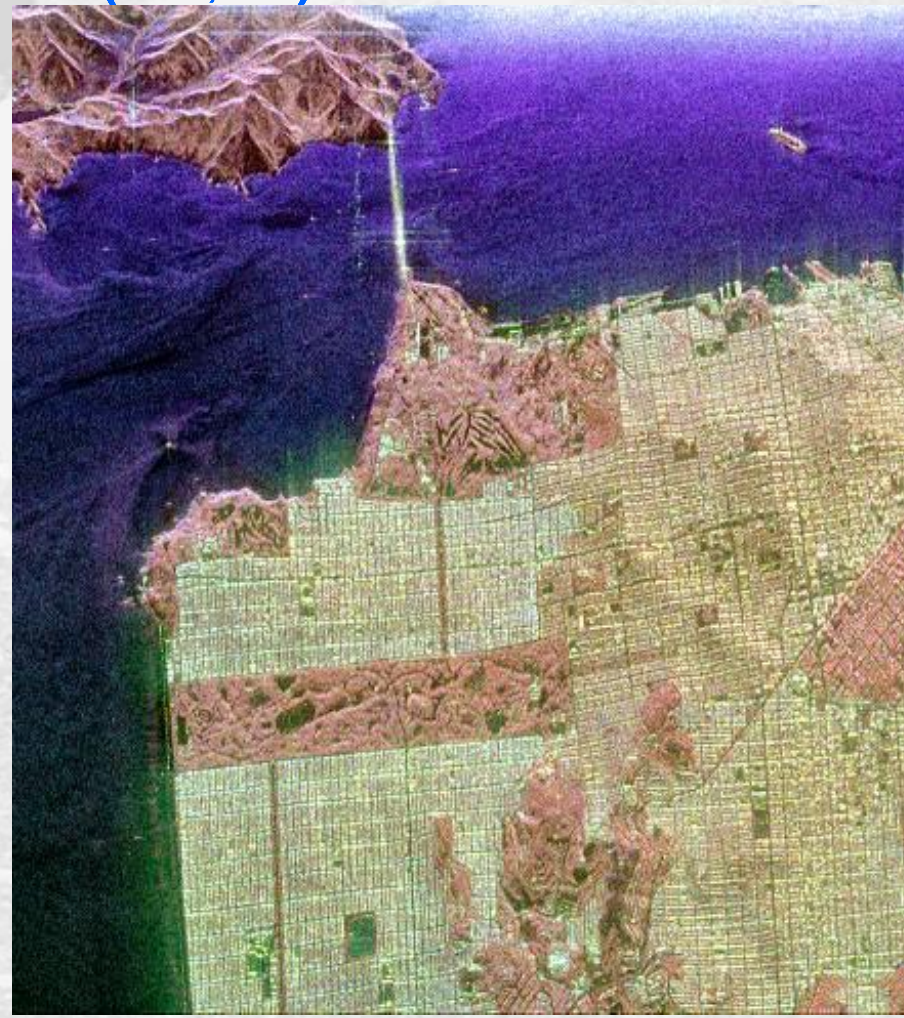
(H,V) POLARISATION BASIS

|HH+VV| |HV | |HH-VV|

ELLIPTICAL BASIS TRANSFORMATION

© Google Earth

(+45°,-45°) POLARISATION BASIS



|AA+BB| |AB | |AA-BB|

With: A=Linear +45°, B=Linear –45°

ELLIPTICAL BASIS TRANSFORMATION

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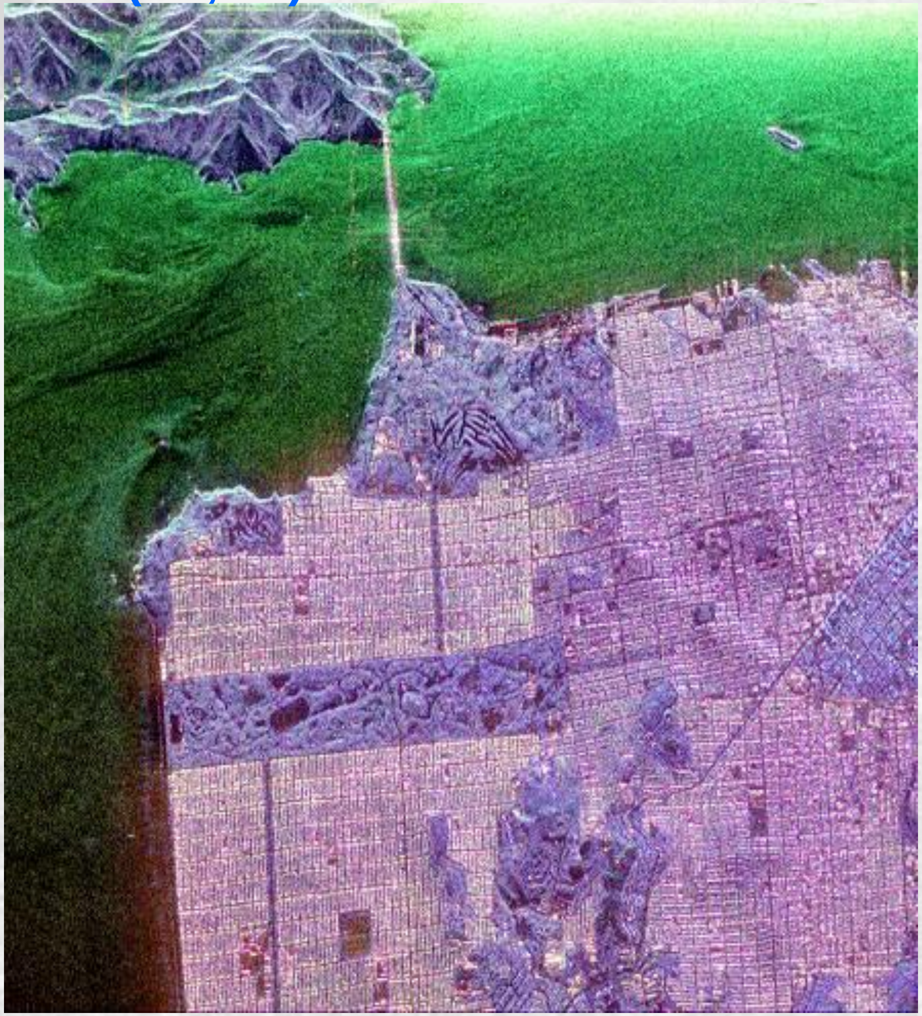
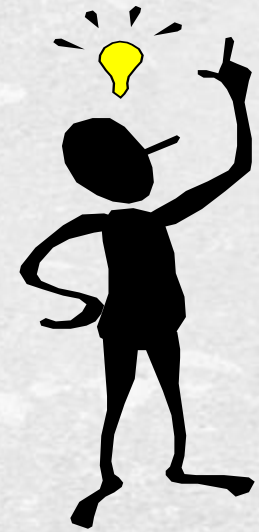
(LC,RC) POLARISATION BASIS



|LL+RR| |LR | |LL-RR|



POLARIMETRIC GOLDEN NUMBER

POLARIMETRIC TARGET DIMENSION

TARGET EQUATIONS

$$[S] = \begin{bmatrix} S_{XX} & S_{XY} \\ S_{YX} & S_{YY} \end{bmatrix}$$

5 DEGREES OF FREEDOM

$$|S_{XX}|, |S_{XY}|, |S_{YY}|$$

$$\phi_{XY-XX}, \phi_{YY-XX}$$

COHERENCY MATRIX $[T]$

9 HUYNEN REAL PARAMETERS

(*A0, B0, B, C, D, E, F, G, H*)

TARGET MONOSTATIC POLARIMETRIC « *DIMENSION* »

=

5

9 - 5 = 4 TARGET EQUATIONS

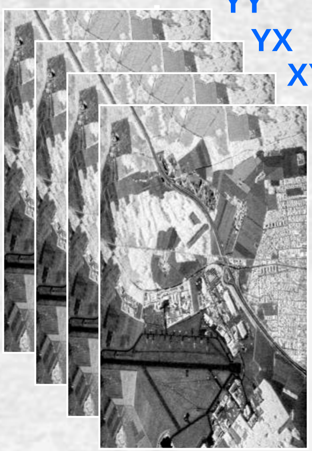
$$2A_0(B_0 + B) = C^2 + D^2$$

$$2A_0(B_0 - B) = G^2 + H^2$$

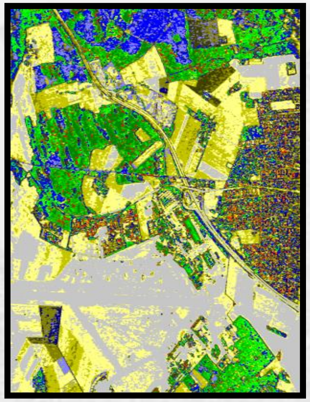
$$2A_0 E = CH - DG$$

$$2A_0 F = CG + DH$$

POL-SAR PROCESSING
PHENOMENOLOGIC
QUALITATIVE ANALYSIS



YY
YX
XY
XX



POLARIMETRIC SPECKLE FILTERING

POLARIMETRIC TARGET DECOMPOSITION

POLARIMETRIC CLASSIFICATION
MONO/DUAL CHANNELS

POLARIMETRIC SPECKLE FILTERING IS NOT AN EXACT SCIENCE
SUBJECTIVE, IMAGE DEPENDENT

Quantitative Criteria (J.S. Lee - IGARSS 98)

- Speckle Reduction (E.N.L)
- Edge Sharpness Preservation
- Line and Point Target Contrast Preservation
- Retention of Mean Values in Homogeneous Regions
- Retention of Texture Information
- Retention of Polarimetric Information (co, cross-correlations)
- Computational Efficiency
- Implementation Complexity

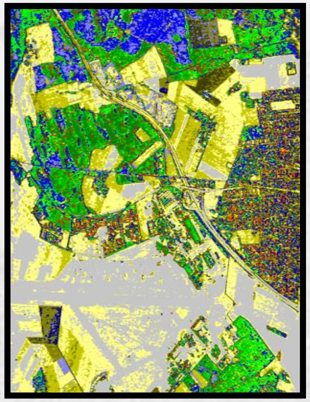
$$[\hat{T}] = E([T]) - k[E([T]) - [T]]$$

THE POLARIMETRIC SPECKLE LEE FILTER
IS TODAY A GOOD COMPROMISE

POL-SAR PROCESSING

PHENOMENOLOGIC

QUALITATIVE ANALYSIS



POLARIMETRIC SPECKLE FILTERING

POLARIMETRIC TARGET DECOMPOSITION

POLARIMETRIC CLASSIFICATION
MONO/DUAL CHANNELS

SPECKLE FILTERING

$$[T] = \underline{k}\,\underline{k}^{*T}$$

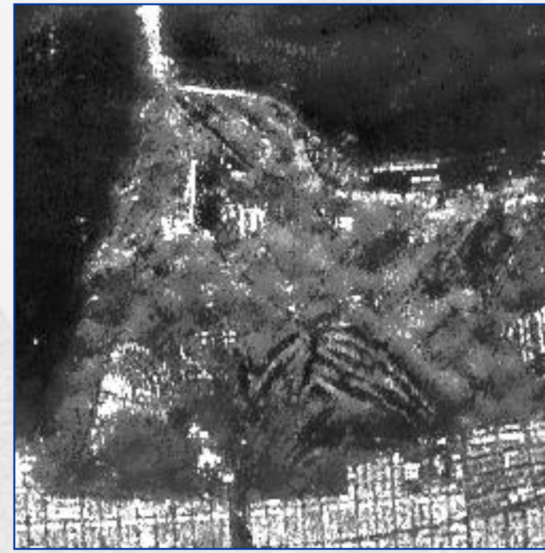
SPECKLE FILTER

AVERAGING DATA

SECOND ORDER STATISTICS

COHERENCY MATRICES

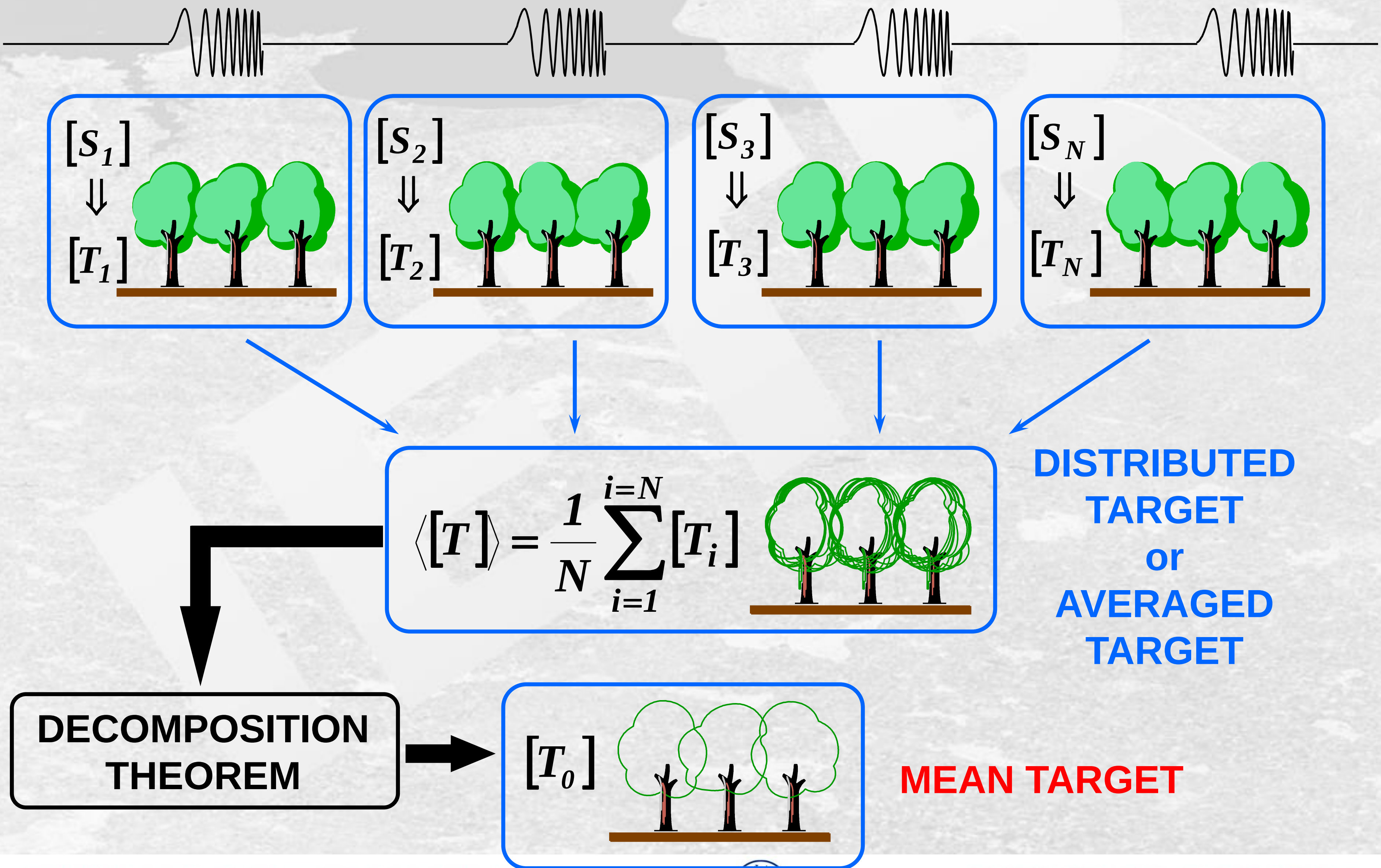
SMOOTHING AVERAGING



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

CONCEPT OF THE DISTRIBUTED TARGET

TARGET DECOMPOSITIONS



TARGET DECOMPOSITIONS

[*S*]

COHERENT DECOMPOSITION

- E. KROGAGER (1990)
- W.L. CAMERON (1990)

[*K*]

TARGET DICHOTOMY

- J.R. HUYNEN (1970)
- R.M. BARNES (1988)

[*T*] [*C*]

AZIMUTHAL SYMMETRY

EIGENVECTORS BASED DECOMPOSITION

- S.R. CLOUDE (1985)
- W.A. HOLM (1988)

MODEL BASED DECOMPOSITION

- A.J. FREEMAN – S.L. DURDEN (1992)
- Y. YAMAGUSHI (2005 - 2012), AN (2010)

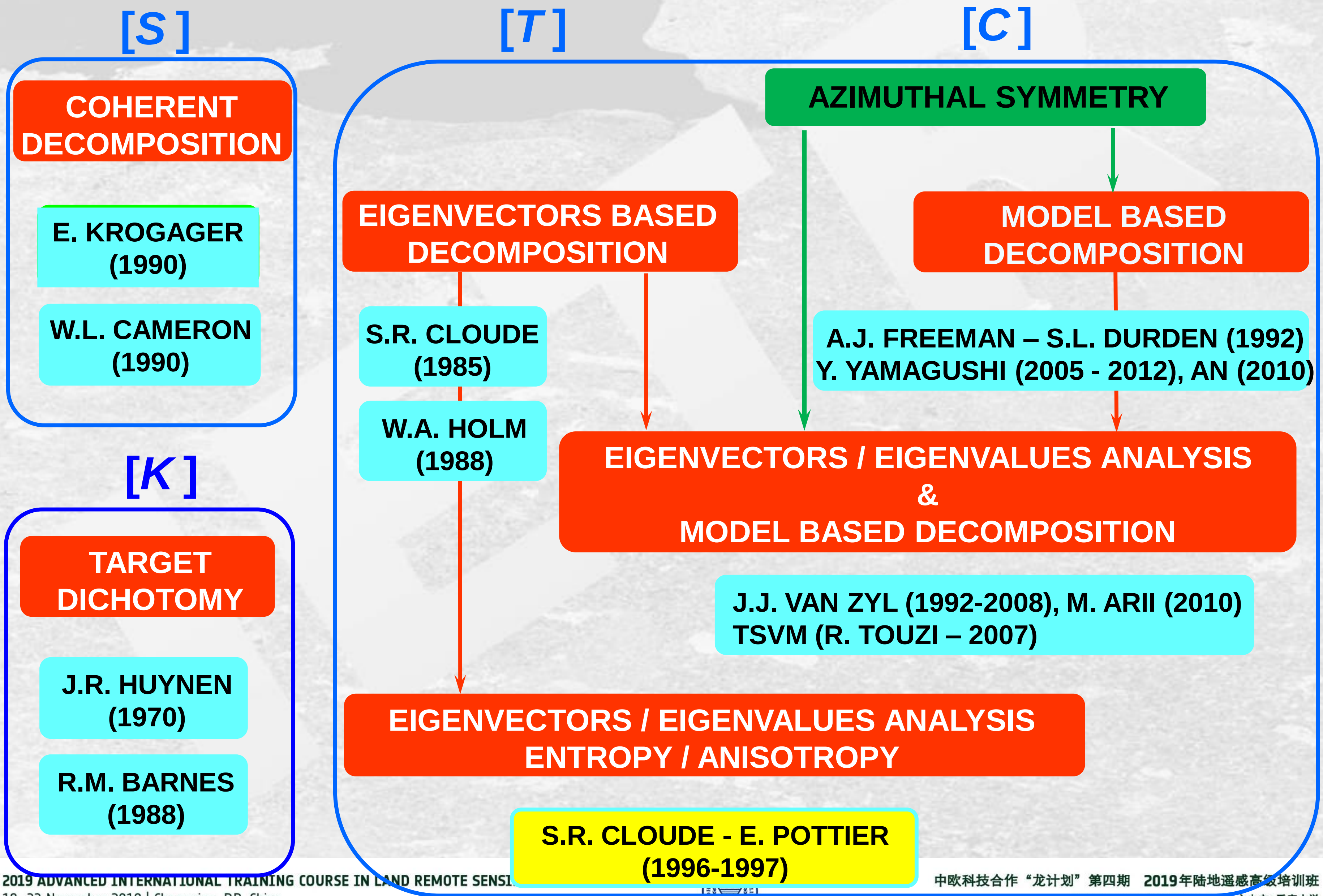
EIGENVECTORS / EIGENVALUES ANALYSIS & MODEL BASED DECOMPOSITION

- J.J. VAN ZYL (1992-2008), M. ARII (2010)
- TSVM (R. TOUZI – 2007)

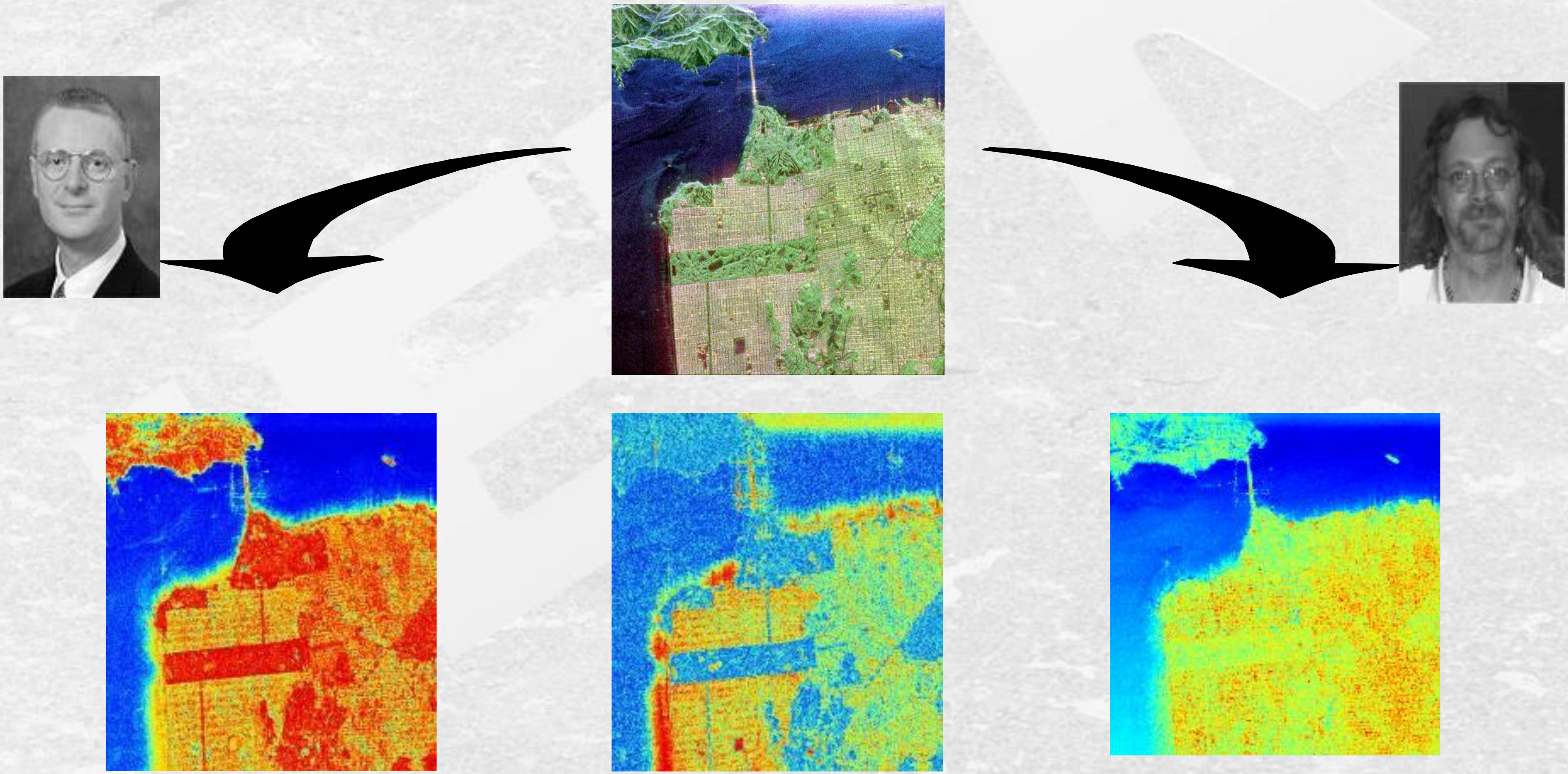
EIGENVECTORS / EIGENVALUES ANALYSIS ENTROPY / ANISOTROPY

- S.R. CLOUDE - E. POTTIER (1996-1997)

TARGET DECOMPOSITIONS



THE H / A / $\underline{\alpha}$ POLARIMETRIC TARGET DECOMPOSITION THEOREM



S.R. CLOUDE - E. POTTIER (1995 - 1996)

TARGET VECTOR

$$\underline{k} = \frac{1}{\sqrt{2}}\left[S_{XX} + S_{YY} \quad S_{XX} - S_{YY} \quad 2S_{XY}\right]^T$$

LOCAL ESTIMATE OF THE COHERENCY MATRIX

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

EIGENVECTORS / EIGENVALUES ANALYSIS

$$\langle [T] \rangle = [U_3][\Sigma][U_3]^{-1} = \begin{bmatrix} \underline{u}_1 & \underline{u}_2 & \underline{u}_3 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} \underline{u}_1 & \underline{u}_2 & \underline{u}_3 \end{bmatrix}^{*T}$$

ORTHOGONAL EIGENVECTORS

REAL EIGENVALUES $\lambda_1 > \lambda_2 > \lambda_3$

$$P_i = \frac{\lambda_i}{\sum_{k=1}^{3} \lambda_k}$$

$$\langle[T]\rangle = [U_3][\Sigma][U_3]^{-1} = \begin{bmatrix} \underline{u}_1 & \underline{u}_2 & \underline{u}_3 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} \underline{u}_1 & \underline{u}_2 & \underline{u}_3 \end{bmatrix}^{*T}$$

ORTHOGONAL EIGENVECTORS

REAL EIGENVALUES $\lambda_1 > \lambda_2 > \lambda_3$

PARAMETERISATION OF THE SU(3) UNITARY MATRIX

$$[U_3] = \begin{bmatrix} \cos\alpha_1 e^{j\phi_1} & \cos\alpha_2 e^{j\phi_2} & \cos\alpha_3 e^{j\phi_3} \\ \sin\alpha_1 \cos\beta_1 e^{j\phi_1} e^{j\delta_1} & \sin\alpha_2 \cos\beta_2 e^{j\phi_2} e^{j\delta_2} & \sin\alpha_3 \cos\beta_3 e^{j\phi_3} e^{j\delta_3} \\ \sin\alpha_1 \sin\beta_1 e^{j\phi_1} e^{j\gamma_1} & \sin\alpha_2 \sin\beta_2 e^{j\phi_2} e^{j\gamma_2} & \sin\alpha_3 \sin\beta_3 e^{j\phi_3} e^{j\gamma_3} \end{bmatrix}$$

TARGET 1 TARGET 2 TARGET 3

PROBABILITIES

$$P_i = \frac{\lambda_i}{\sum_{k=1}^{3} \lambda_k}$$

AVERAGED PARAMETERS

$$\underline{\alpha} = P_1\alpha_1 + P_2\alpha_2 + P_3\alpha_3 \qquad \underline{\beta} = P_1\beta_1 + P_2\beta_2 + P_3\beta_3$$

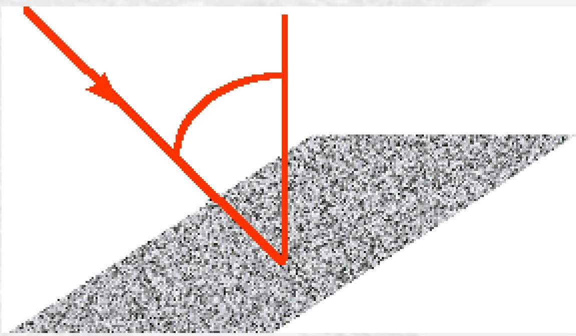
$$\underline{\gamma} = P_1\gamma_1 + P_2\gamma_2 + P_3\gamma_3 \qquad \underline{\delta} = P_1\delta_1 + P_2\delta_2 + P_3\delta_3$$

UNITARY TARGET VECTOR ($\underline{u}_0$) OF THE MEAN DOMINANT MECHANISM

$$\underline{u}_0 = \begin{bmatrix} \cos(\underline{\alpha}) & \sin(\underline{\alpha})\cos(\underline{\beta})\, e^{j\underline{\delta}} & \sin(\underline{\alpha})\sin(\underline{\beta})\, e^{j\underline{\gamma}} \end{bmatrix}^T$$

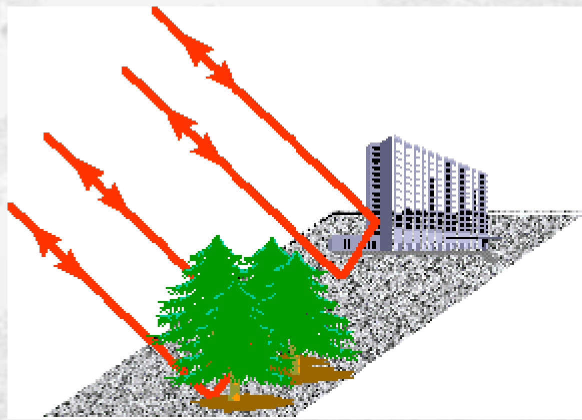
$\underline{\alpha}$ PHYSICAL INTERPRETATION

SINGLE BOUNCE SCATTERING (ROUGH SURFACE)



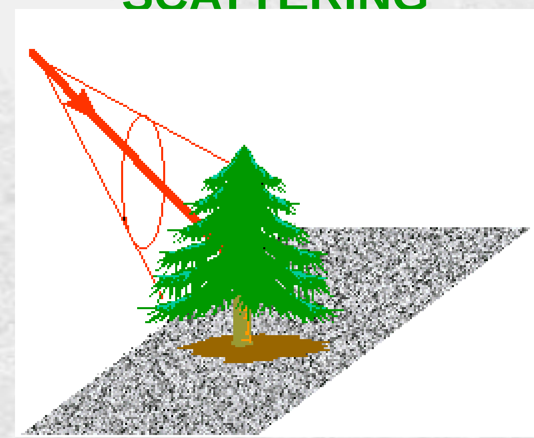
$$a \mapsto b \Rightarrow \nu \mapsto 0$$
$$\Downarrow$$
$$\underline{\alpha} \mapsto 0$$

DOUBLE BOUNCE SCATTERING



$$a \mapsto -b \Rightarrow \varepsilon \mapsto 0$$
$$\Downarrow$$
$$\underline{\alpha} \mapsto \frac{\pi}{2}$$

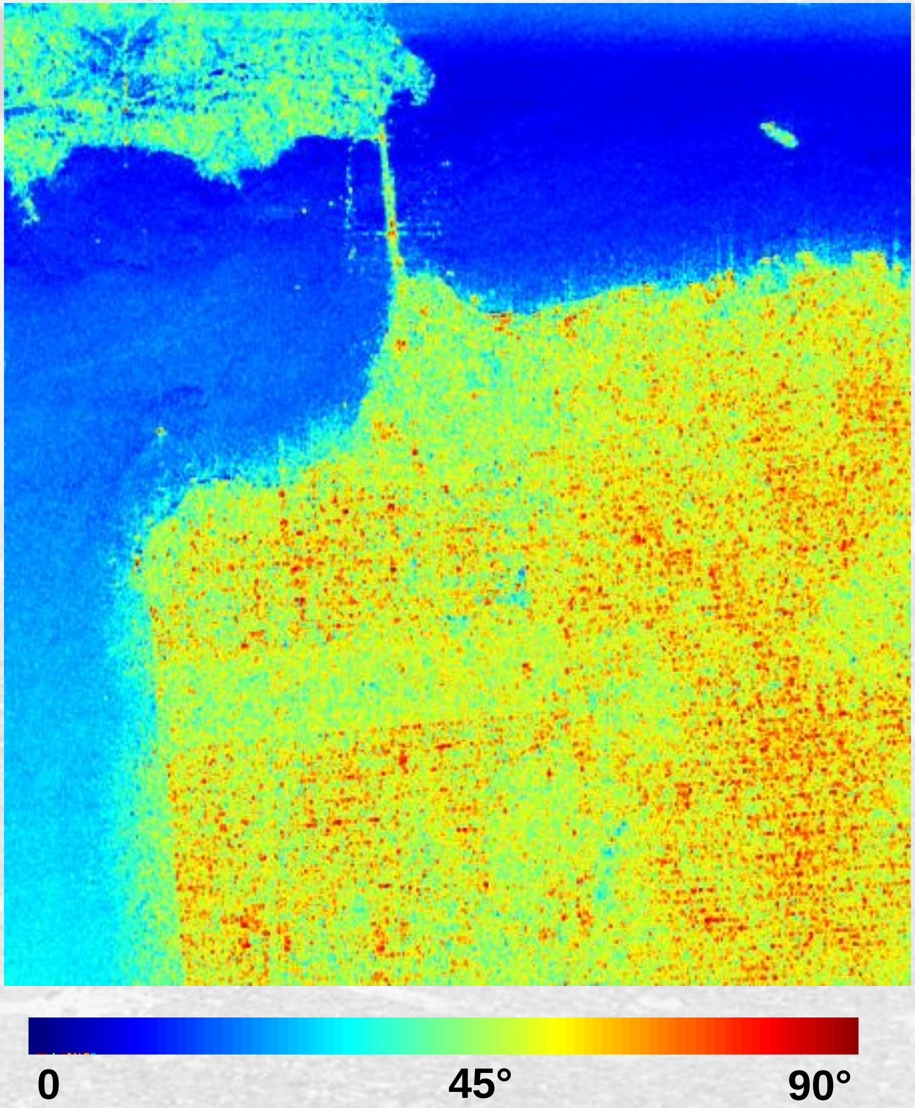
VOLUME SCATTERING



$$a >> b \Rightarrow \varepsilon \approx \nu$$
$$\Downarrow$$
$$\underline{\alpha} \mapsto \frac{\pi}{4}$$

H / A / $\underline{\alpha}$ DECOMPOSITION

$2A_0$ $B_0 + B$ $B_0 - B$



$\underline{\alpha}$ PARAMETER

E.P (2019)

EIGENVALUES λ_1 λ_2 λ_3 : ROLL INVARIANT

PROBABILITIES P_1 P_2 P_3 : ROLL INVARIANT

↓

ENTROPY

(DEGREE OF RANDOMNESS
STATISTICAL DISORDER)

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

PURE TARGET

$\lambda_1 = SPAN \quad \lambda_2 = 0 \quad \lambda_3 = 0$

$H = 0$

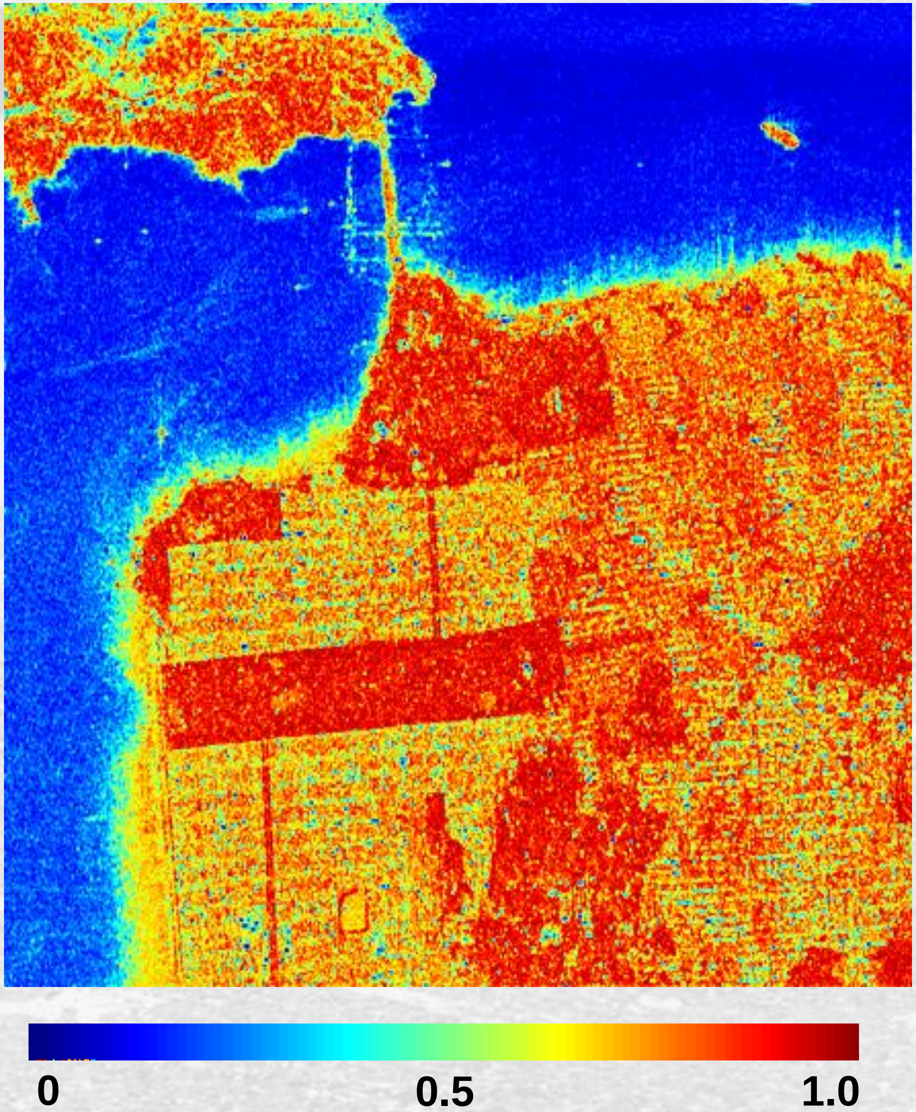
DISTRIBUTED TARGET

$\lambda_1 = \lambda_2 = \lambda_3 = SPAN / 3$

$H = 1$

H / A / α DECOMPOSITION

$2A_0$ $\quad$ $B_0 + B$ $\quad$ $B_0 - B$



ENTROPY (H)

E.P (2019)

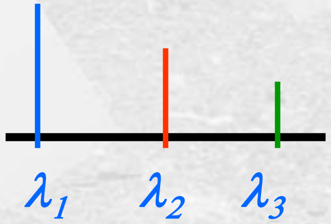
H / A / α DECOMPOSITION

DIFFICULT MECHANISM DISCRIMINATION WHEN : H > 0.7

ANISOTROPY

(EIGENVALUES SPECTRUM)

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

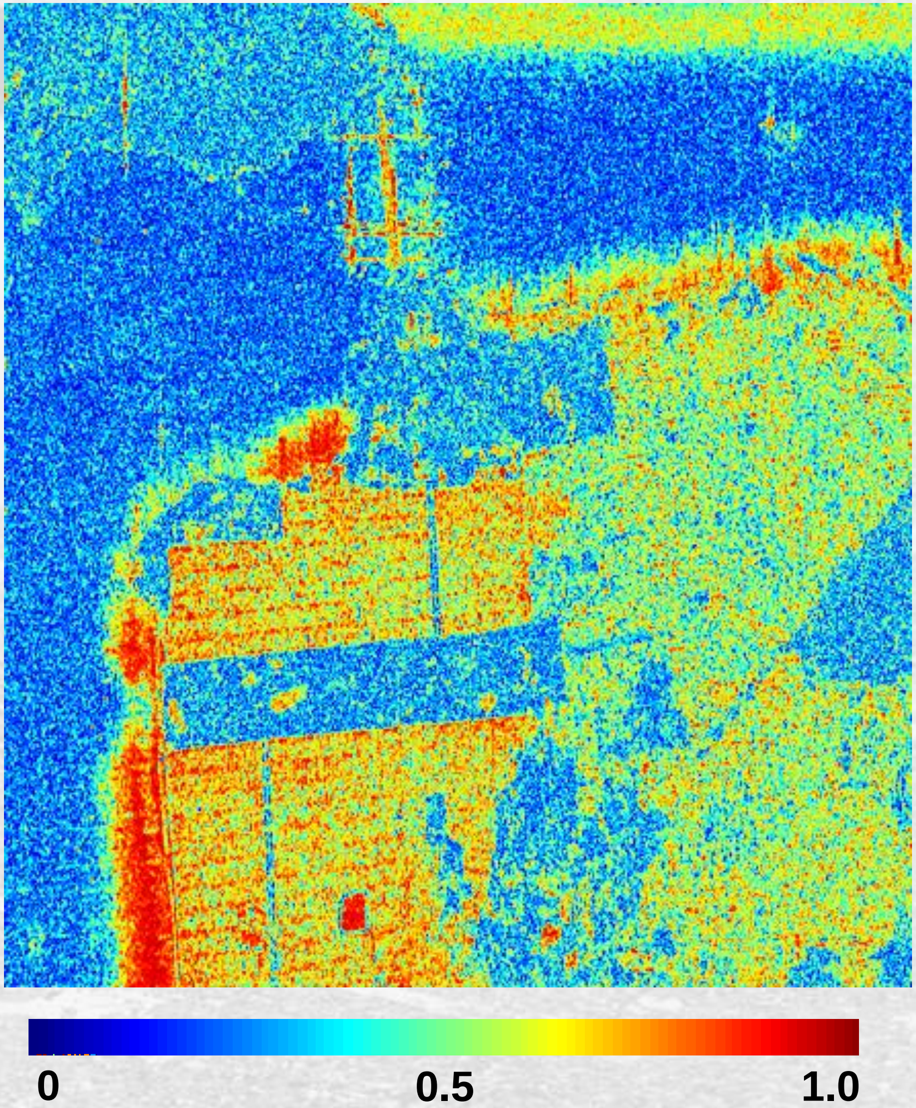


- **COMPLEMENTARY TO ENTROPY**
- **DISCRIMINATION WHEN H > 0.7**
- **ROLL INVARIANT**

H / A / α DECOMPOSITION

NRSCC esa

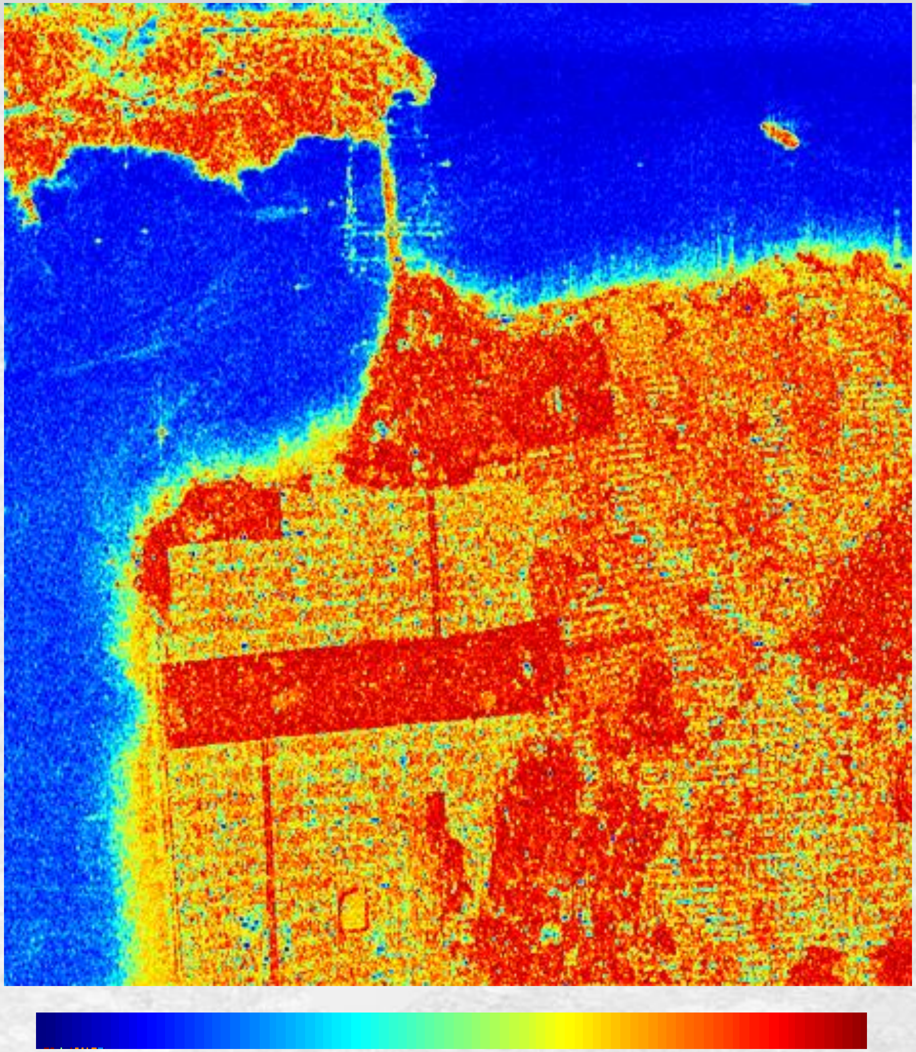
$2A_0$ $B_0 + B$ $B_0 - B$



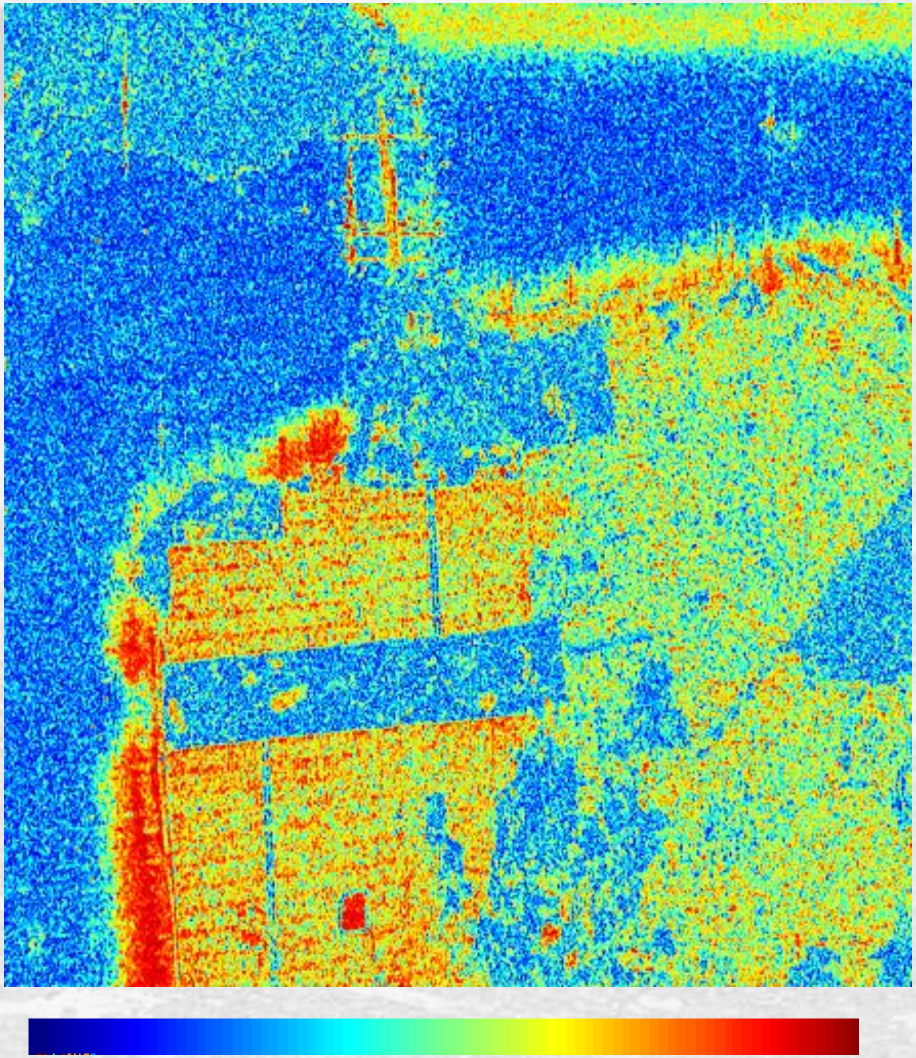
ANISOTROPY (A)

E.P (2019)

H / A / α DECOMPOSITION



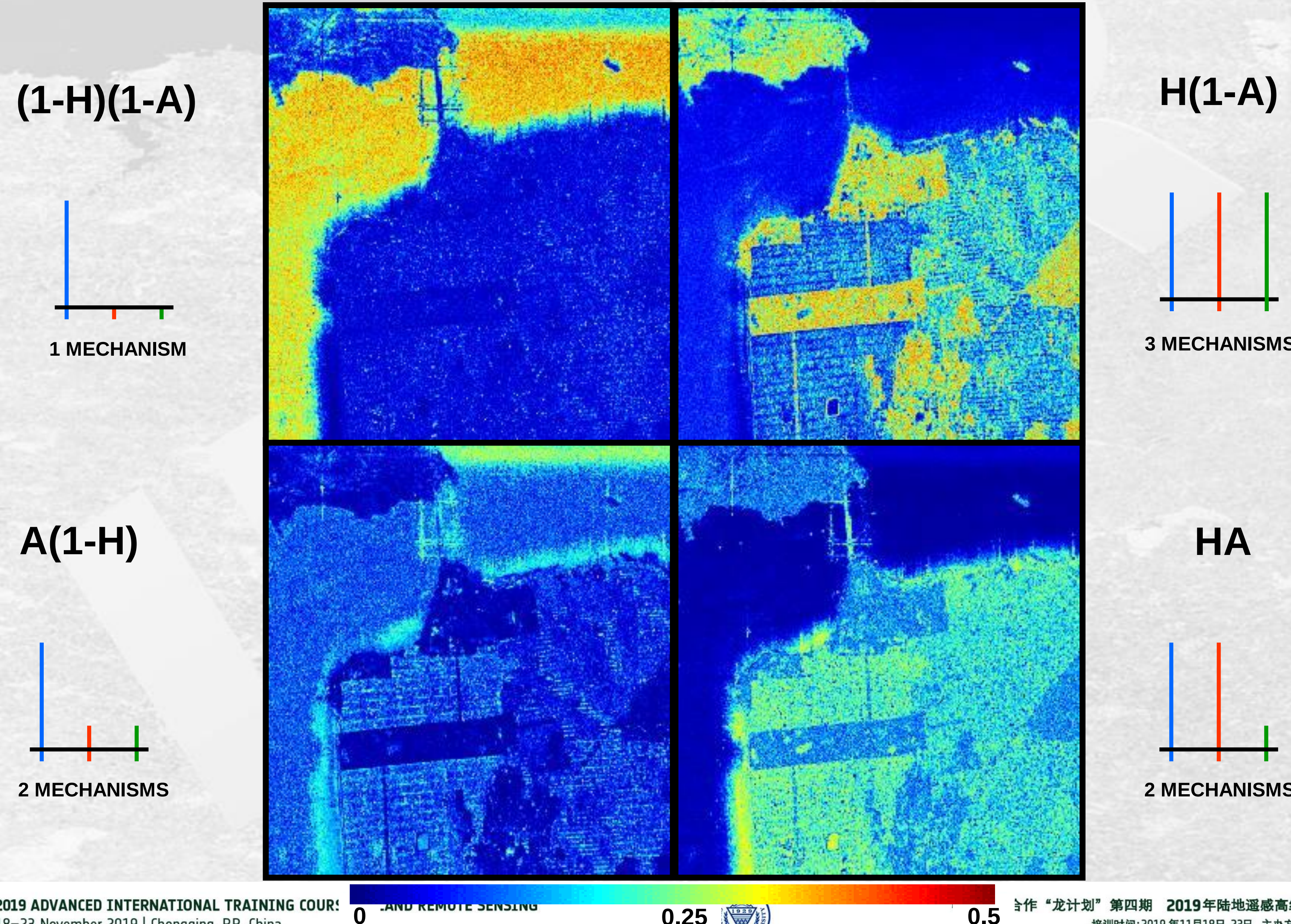
ENTROPY (H)



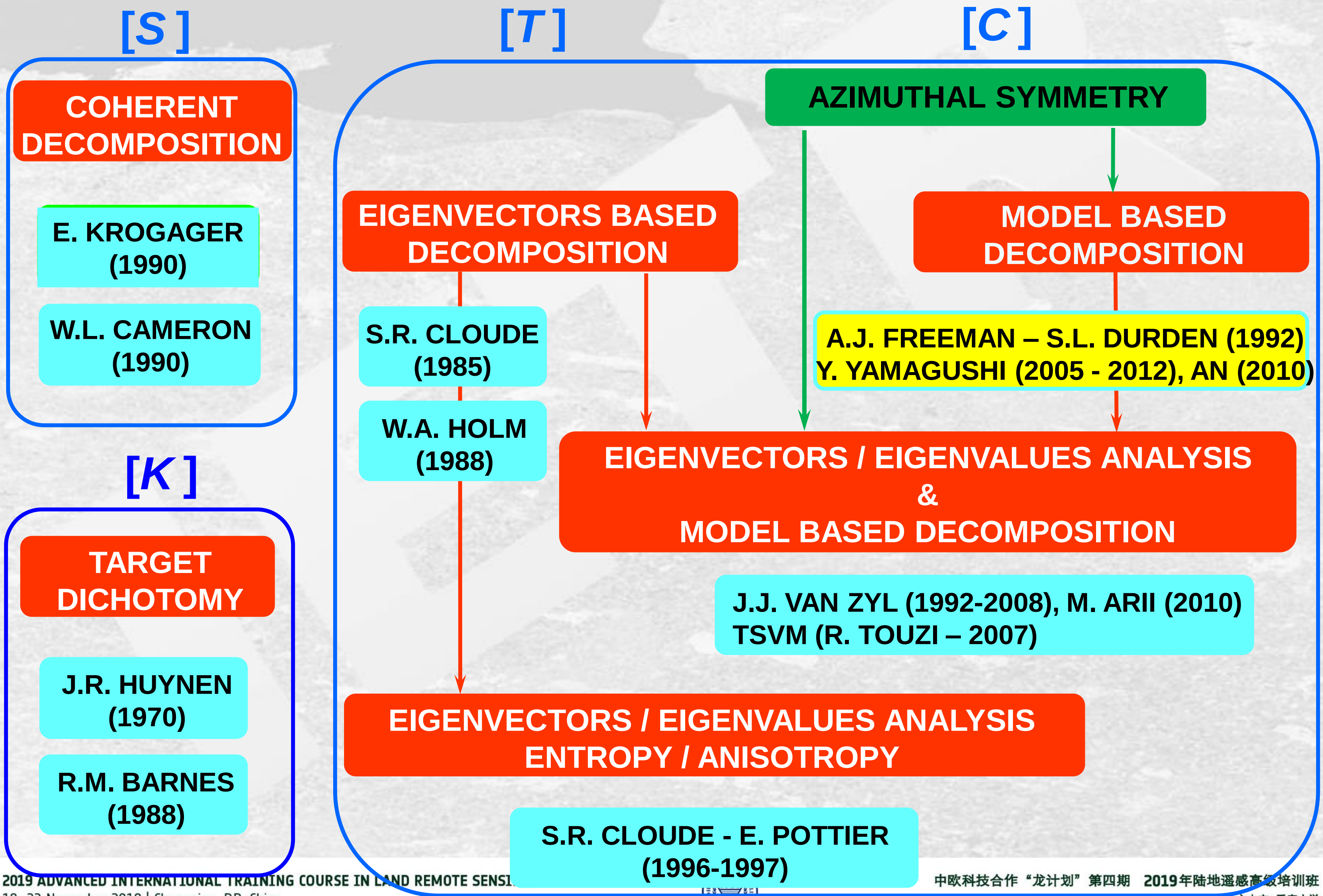
ANISOTROPY (A)

E.P (2019)

H / A / $\underline{\alpha}$ DECOMPOSITION



TARGET DECOMPOSITIONS

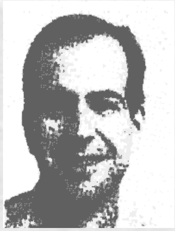


MODEL BASED

DECOMPOSITIONS

➡ **A. FREEMAN – S. DURDEN**

(1992)



➡ **Y. YAMAGUCHI – S. SINGH**

(2005 - 2018)

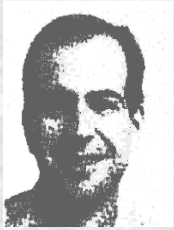
➡ **And others …**

(2015 - 2017)

TARGET DECOMPOSITION FOR TARGETS WITH REFLECTION SYMMETRY

MODEL BASED DECOMPOSITION

A. FREEMAN – S. DURDEN (1992)



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

3 COMPONENTS SCATTERING MECHANISM MODEL

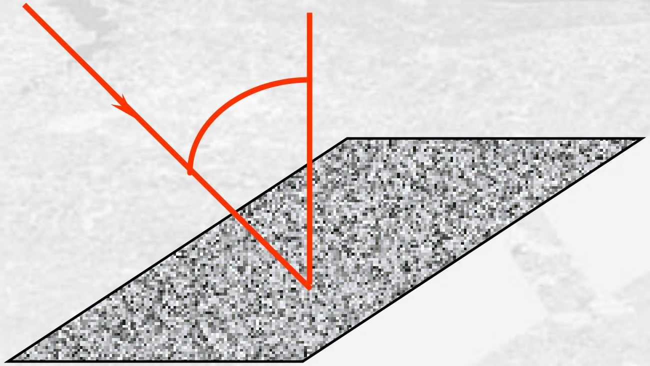
$$\langle [T] \rangle = [T_S] + [T_D] + [T_V]$$

SINGLE SCATTERING

DOUBLE SCATTERING

VOLUME SCATTERING

SINGLE SCATTERING
(ROUGH SURFACE)



MECHANISM

$$[S_S] = \begin{bmatrix} R_H & 0 \\ 0 & R_V \end{bmatrix} \Rightarrow \underline{k}_S = \begin{bmatrix} R_H + R_V \\ R_H - R_V \\ 0 \end{bmatrix}$$

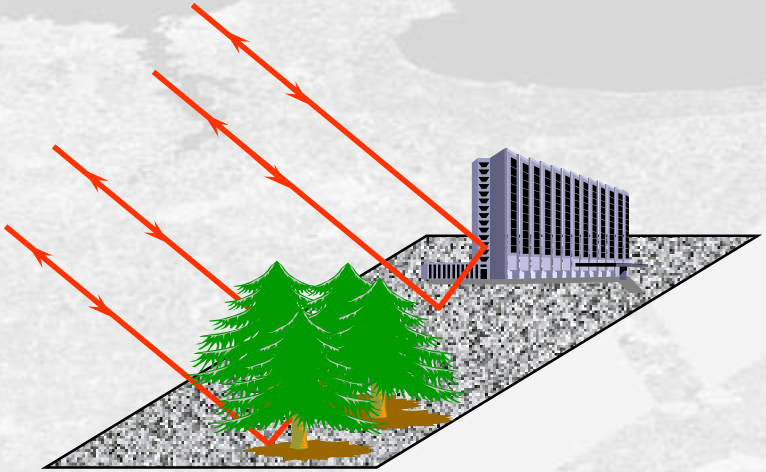
COHERENCY MATRIX

$$[T_S] = f_S \begin{bmatrix} |\beta+1|^2 & (\beta+1)(\beta-1)^* & 0 \\ (\beta+1)^*(\beta-1) & |\beta-1|^2 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$f_S = |R_V|^2$$

$$\beta = \frac{R_H}{R_V}$$

DOUBLE SCATTERING MECHANISM



$$[S_D] = \begin{bmatrix} R_{GH}R_{TH} & 0 \\ 0 & -R_{GV}R_{TV} \end{bmatrix}$$

$$\Rightarrow \underline{k}_D = \begin{bmatrix} R_{GH}R_{TH} - R_{GV}R_{TV} \\ R_{GH}R_{TH} + R_{GV}R_{TV} \\ 0 \end{bmatrix}$$

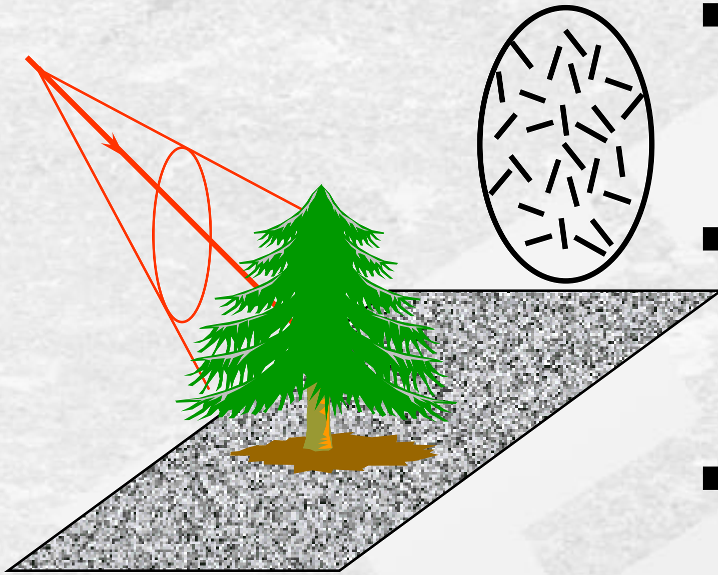
COHERENCY MATRIX

$$[T_D] = f_D \begin{bmatrix} |\alpha-1|^2 & (\alpha-1)(\alpha+1)^* & 0 \\ (\alpha-1)^*(\alpha+1) & |\alpha+1|^2 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$f_D = |R_{GV}R_{TV}|^2$$

$$\alpha = \frac{R_{GH}R_{TH}}{R_{GV}R_{TV}}$$

VOLUME SCATTERING
(RANDOMLY ORIENTED VERY THIN CYLINDER-LIKE SCATTERERS)



MECHANISM (CYLINDER)

$$[S]=\begin{bmatrix} a & 0 \\ 0 & b \end{bmatrix}$$

ORIENTED MECHANISM

$$[S_\theta]=[U_2(\theta)]^T[S][U_2(\theta)]$$

UNIFORM ORIENTATION

$$P(\theta)=\frac{1}{2\pi}$$

SECOND-ORDER STATISTICS

$$[T_V]=\langle[T_\theta]\rangle=\int_0^{2\pi}[T_V]P(\theta)d\theta$$

COVARIANCE MATRIX

(THIN CYLINDERS)

$\mathbf{a} \mapsto 1 \quad \mathbf{b} \mapsto 0$

$$[T_V]=\frac{f_V}{3}\begin{bmatrix} 4 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 2 \end{bmatrix}$$

3 COMPONENTS SCATTERING MECHANISM MODEL

$$\langle [T] \rangle = [T_S] + [T_D] + [T_V]$$

SINGLE SCATTERING — DOUBLE SCATTERING — VOLUME SCATTERING

$$T_{11} = f_S |\beta + 1|^2 + f_D |\alpha - 1|^2 + \frac{4 f_V}{3}$$

$$T_{12} = f_S (\beta + 1)(\beta - 1)^* + f_D (\alpha - 1)(\alpha + 1)^*$$

$$T_{22} = f_S |\beta - 1|^2 + f_D |\alpha + 1|^2 + \frac{2 f_V}{3}$$

$$T_{33} = \frac{2 f_V}{3}$$

→ 5 UNKNOWN REAL COEFFICIENTS

→ 4 OBSERVED EQUATIONS

$$if\ \Re\left(\langle S_{XX}S_{YY}^{*}\rangle - \frac{f_V}{3}\right) \geq 0 \quad \Rightarrow \quad \alpha = +1$$

$$if\ \Re\left(\langle S_{XX}S_{YY}^{*}\rangle - \frac{f_V}{3}\right) \leq 0 \quad \Rightarrow \quad \beta = +1$$

$$\{f_S, |\beta|, f_D, |\alpha|, f_V\}$$

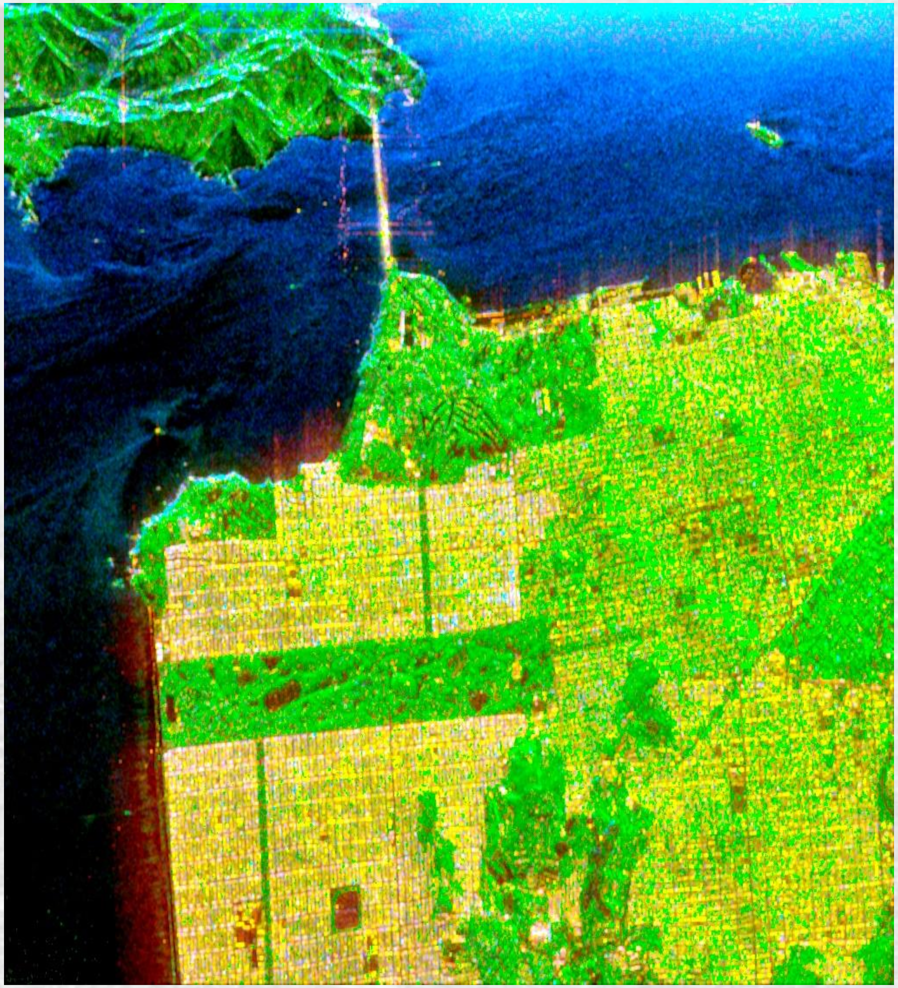
$$span = \langle T_{11}\rangle + \langle T_{22}\rangle + \langle T_{33}\rangle = f_S\left(1+\beta^2\right) + f_D\left(1+|\alpha|^2\right) + \frac{2}{3}f_V$$

SINGLE BOUNCE SCATTERING (ODD)

DOUBLE DOUBLE SCATTERING (DBL)

VOLUME SCATTERING (VOL)

MODEL BASED DECOMPOSITION



$2A_0$ $\quad B_0 + B$ $\quad B_0 - B$

$$ODD = f_S\left(1+\beta^2\right)$$

$$DBL = f_D\left(1+\alpha^2\right)$$

$$VOL = \frac{2f_V}{3}$$

TARGET DECOMPOSITION FOR TARGETS WITHOUT REFLECTION SYMMETRY

MODEL BASED - 4 COMPONENTS DECOMPOSITION

Y. YAMAGUCHI et al. (2005 - 2013)

MEDIUM WITHOUT ANY REFLECTION SYMMETRY

4 COMPONENTS SCATTERING MECHANISM MODEL

$$\langle [T] \rangle = [T_S] + [T_D] + [T_V] + [T_H]$$

SINGLE SCATTERING | DOUBLE SCATTERING | VOLUME SCATTERING | HELIX SCATTERING

$$[S]_{\pm Helix} = \frac{1}{2}\begin{bmatrix} 1 & \pm j \\ \pm j & -1 \end{bmatrix} \qquad \langle [T] \rangle_{Helix} = \frac{1}{2}\left\langle \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & \pm j \\ 0 & \mp j & 1 \end{bmatrix} \right\rangle$$

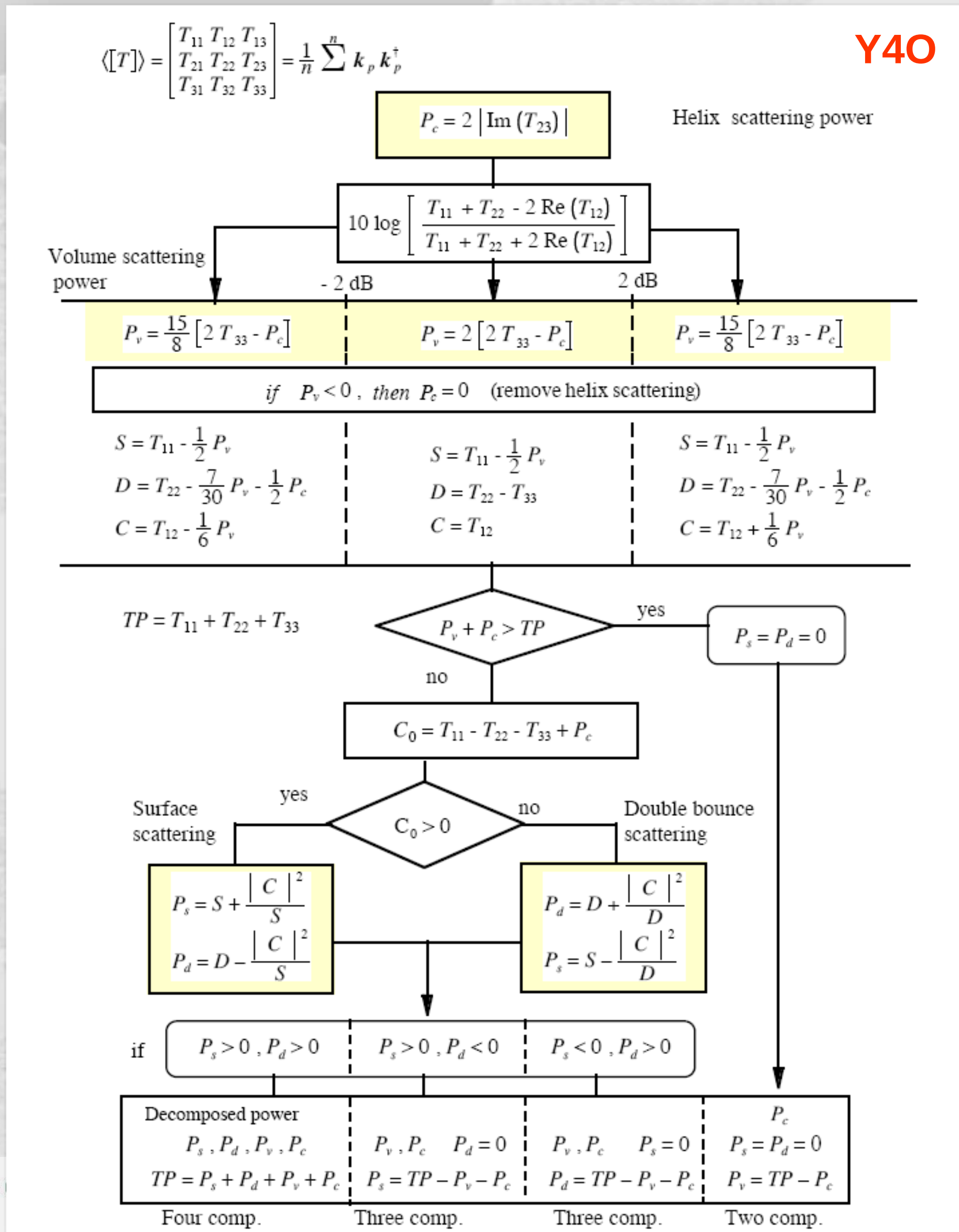
Non reflection Symmetric cases

Yamaguchi Y., Moriyama T., Ishido M. and Yamada H., "*Four-Component Scattering Model for Polarimetric SAR Image Decomposition*", IEEE Trans. Geos. Remote Sens., vol. 43, no. 8, August 2005.

Yamaguchi Y., Yajima Y. and Yamada H., "A Four-Component Decomposition of POLSAR Images Based on the Coherency Matrix", IEEE Geos. Rem. Sens. Letters, vol. 3, no. 3, July 2006.

2005 - 2006

MODEL BASED DECOMPOSITION



MODEL BASED DECOMPOSITION

$2A_0$ $\quad B_0 + B$ $\quad B_0 - B$

$$ODD = f_S\left(1+\beta^2\right)$$

$$DBL = f_D\left(1+\alpha^2\right)$$

$$VOL = \frac{2f_V}{3}$$

E.P (2019)

MODEL BASED DECOMPOSITION

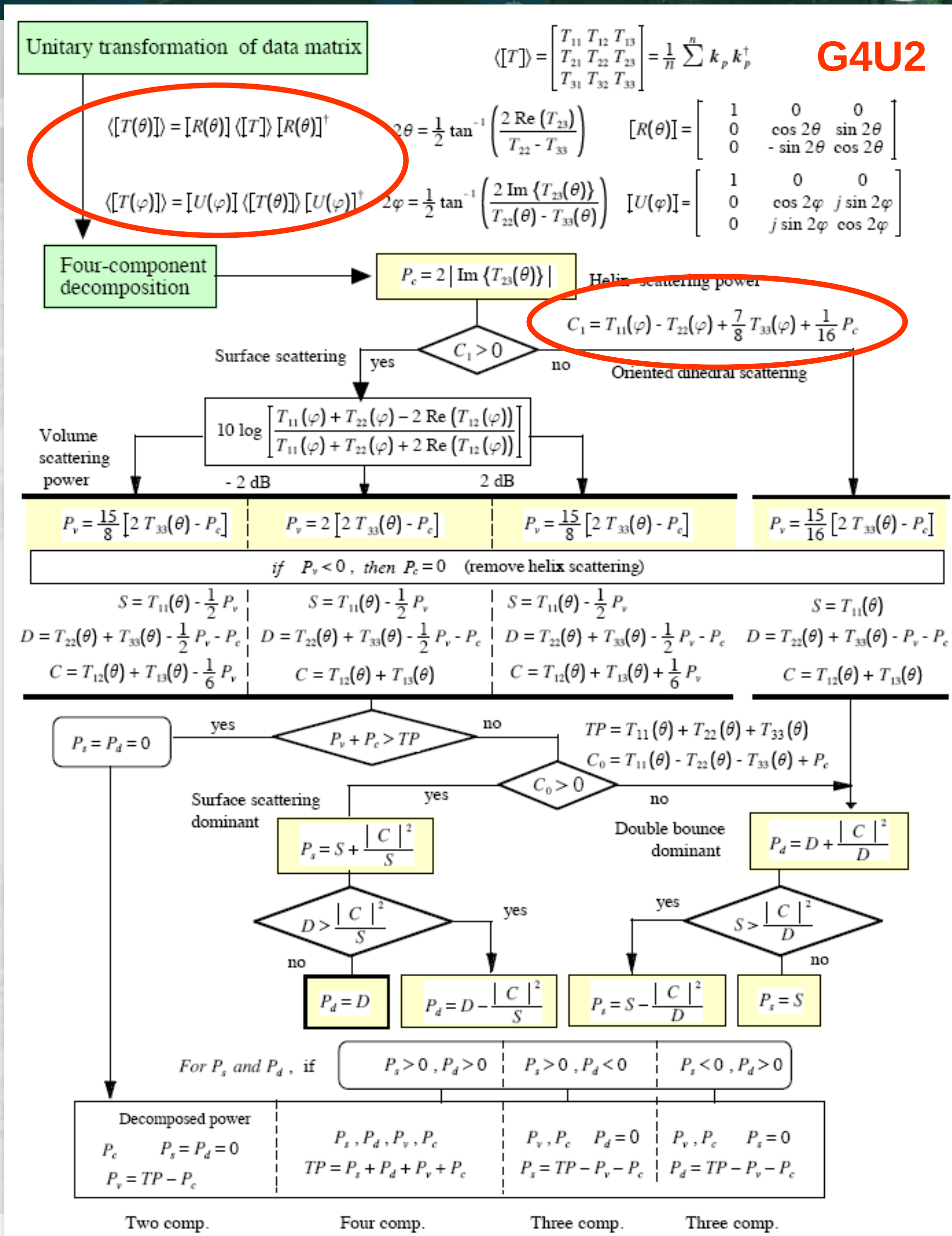
Y. Yamaguchi, A. Sato, W.M. Boerner, R. Sato, H. Yamada, "*4-component scattering power decomposition with rotation of coherency matrix*", IEEE TGRS vol. 49, no. 6, June 2011.

A. Sato, Y. Yamaguchi, G. Singh, and S.-E. Park, "*4-component scattering power decomposition with extended volume scattering model*", IEEE GRS Letters, vol. 9, no. 2, pp. 166–170, March 2012.

G. Singh, Y. Yamaguchi, S.E. Park, *Y. Cui, H. Kobayashi, « Hybrid Freeman/Eigenvalue Decomposition Method With Extended Volume Scattering Model »* IEEE GRS Letters, vol. 10, no. 1, January 2013.

G. Singh, Y. Yamaguchi, S.E. Park, *« General Four-Component Scattering Power Decomposition With Unitary Transformation of Coherency Matrix »* IEEE TGRS vol. 51, no. 5, May 2013.

MODEL BASED DECOMPOSITION



MODEL BASED DECOMPOSITION

$2A_0$ $B_0 + B$ $B_0 - B$

ODD *DBL* *VOL*

E.P (2019)

TARGET DECOMPOSITION FOR TARGETS WITHOUT REFLECTION SYMMETRY

MODEL BASED - 4 / 5 / 6 COMPONENTS DECOMPOSITION

(2015 - 2017)

MODEL BASED DECOMPOSITION

A. BHATTACHARYA, A. FRERY, "*Modifying the Yamaguchi 4-component decomposition scattering powers using a stochastic distance*", IEEE JSTARS, vol. 8, pp 3497-3506, July 2015.

F. XU, Y.Q. JIN, "*Deorientation theory of Polarimetric scattering targets and application to terrain surface classification*", IEEE TGRS Vol 43, n° 10, October 2015.

B. ZOU, D. LU, L. ZHANG, W.M. Moon, « *Eigen-decomposition-based Four Component Decomposition for PoSAR Data"*. IEEE JSTARS, vol. 9, pp 1286-1296, March 2016.

H. AGHABABAEE, M. Reza SAHEBI, *"Incoherent Target Scattering Decomposition of Polarimetric SAR Data Based on Vector Model Roll-Invariant Parameters"*. IEEE TGRS, vol. 54, no 8, August 2016.

G. SINGH, Y. YAMAGUCHI, "*Model-based Six-Component Scattering Matrix Power Decomposition*", IEEE TGRS Vol 56, n° 10, October 2018.

MODEL BASED DECOMPOSITION

$2A_0$ $B_0 + B$ $B_0 - B$

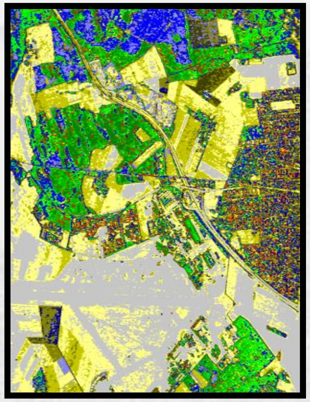
ODD *DBL* *VOL*

Singh decomposition – 6 components

POL-SAR PROCESSING

PHENOMENOLOGIC

QUALITATIVE ANALYSIS

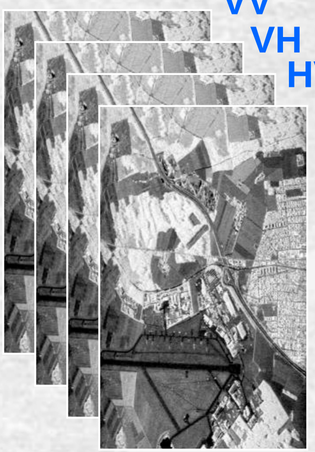


POLARIMETRIC SPECKLE FILTERING

POLARIMETRIC TARGET DECOMPOSITION

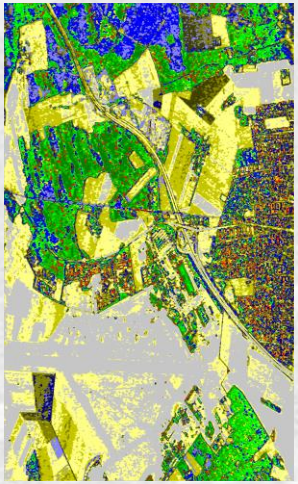
POLARIMETRIC CLASSIFICATION

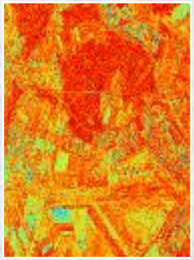
MONO/DUAL CHANNELS



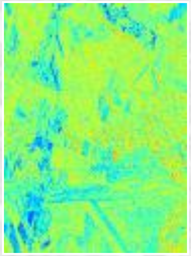
UNSUPERVISED POLSAR CLASSIFICATION

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





H



α

H / α DECOMPOSITION THEOREM

ENTROPY

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

$\underline{\alpha}$ PARAMETER

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

ANISOTROPY

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

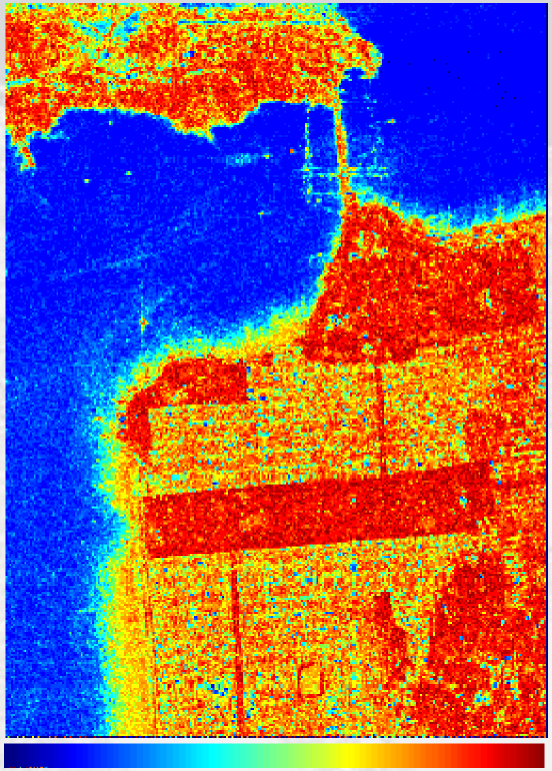
3 ROLL INVARIANT PARAMETERS

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

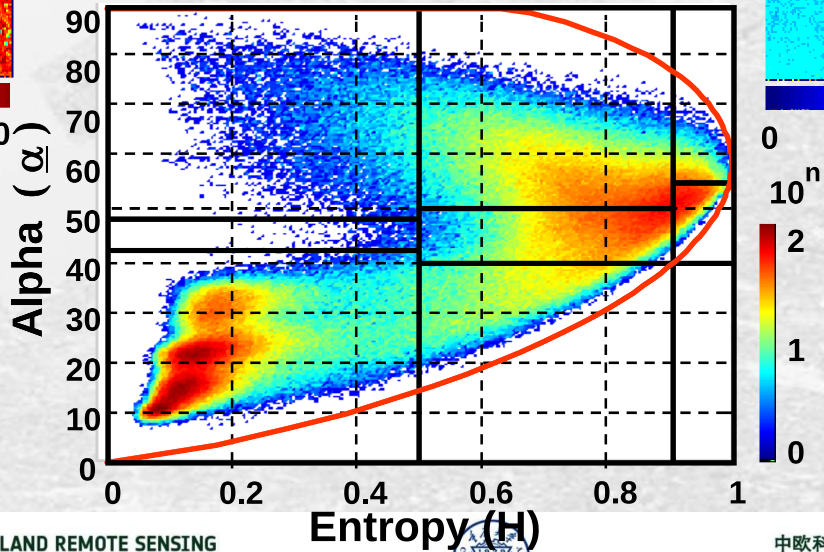
→ PHYSICAL SCATTERING MECHANISM

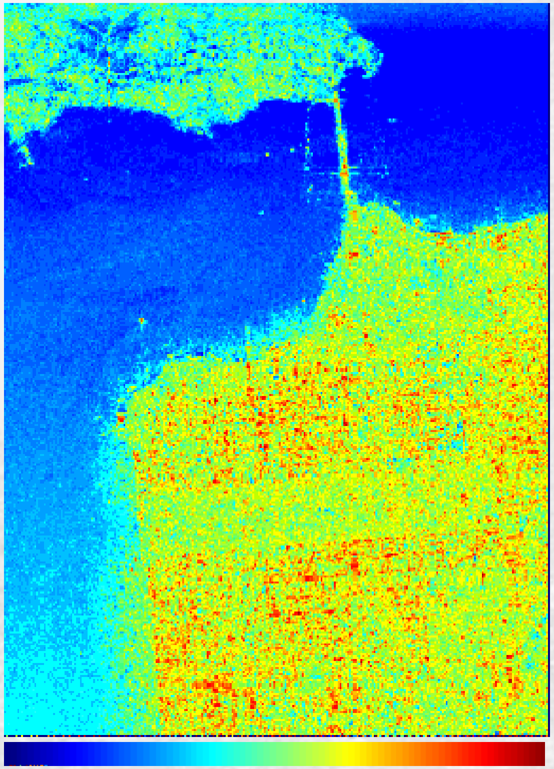
→ TYPE OF SCATTERING PROCESS

SEGMENTATION / CLASSIFICATION



POLSAR DATA DISTRIBUTION IN THE H / α PLANE

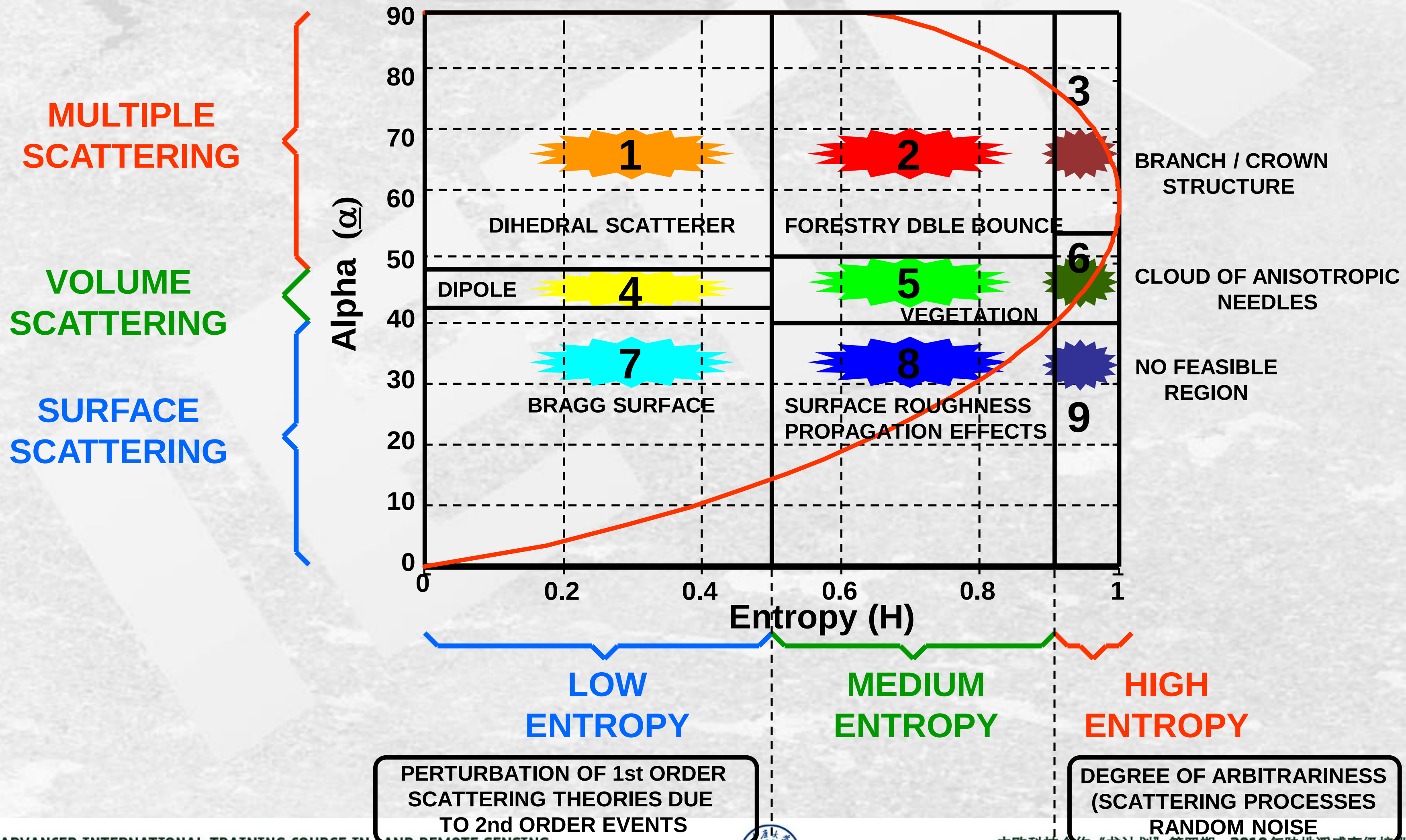




H / $\underline{\alpha}$ CLASSIFICATION

NRSCC esa

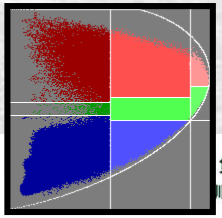
SEGMENTATION OF THE H / $\underline{\alpha}$ SPACE



H / α CLASSIFICATION

$2A_0$ $B_0 + B$ $B_0 - B$

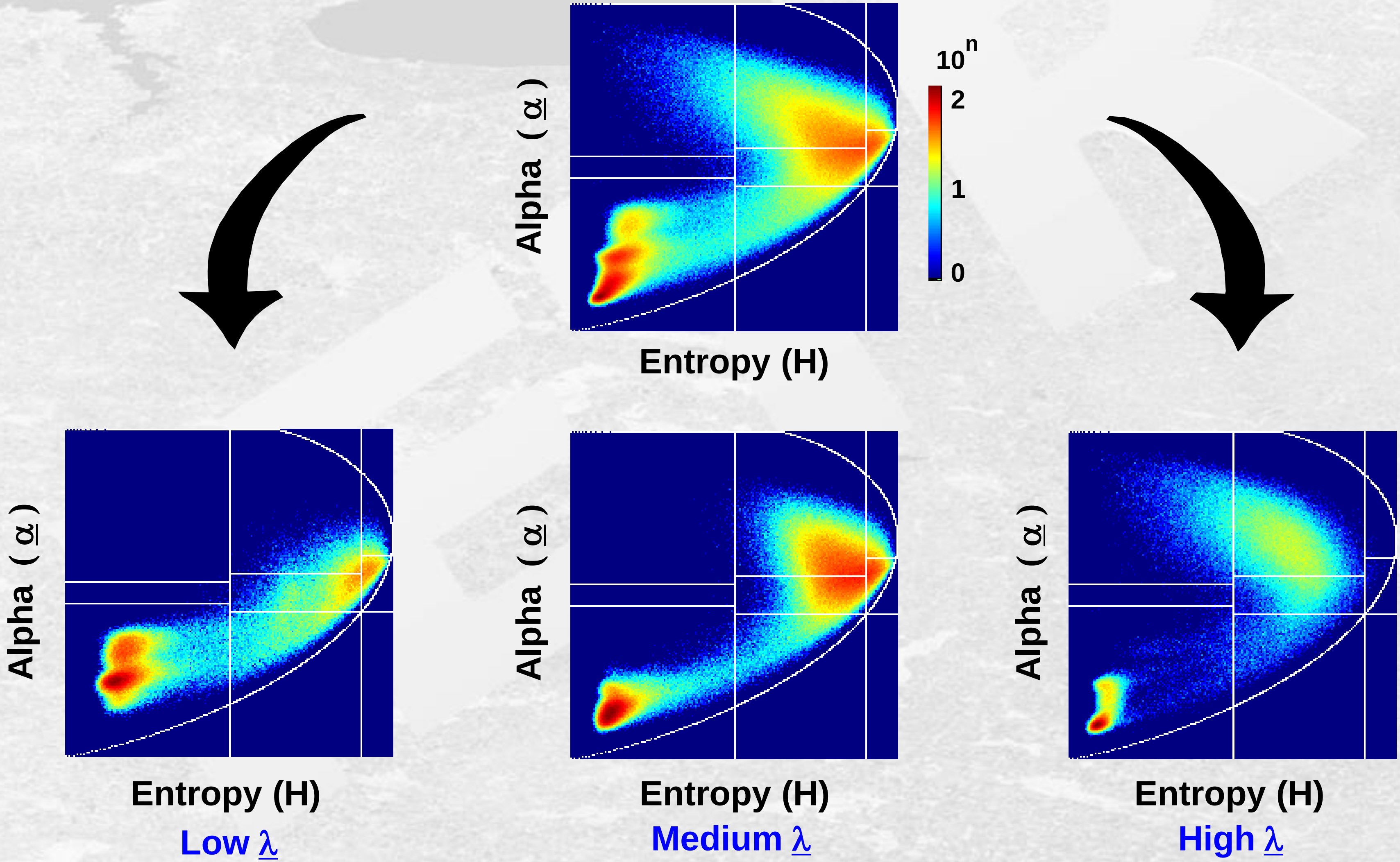
H - α classification



E.P (2019)

H / α / span CLASSIFICATION

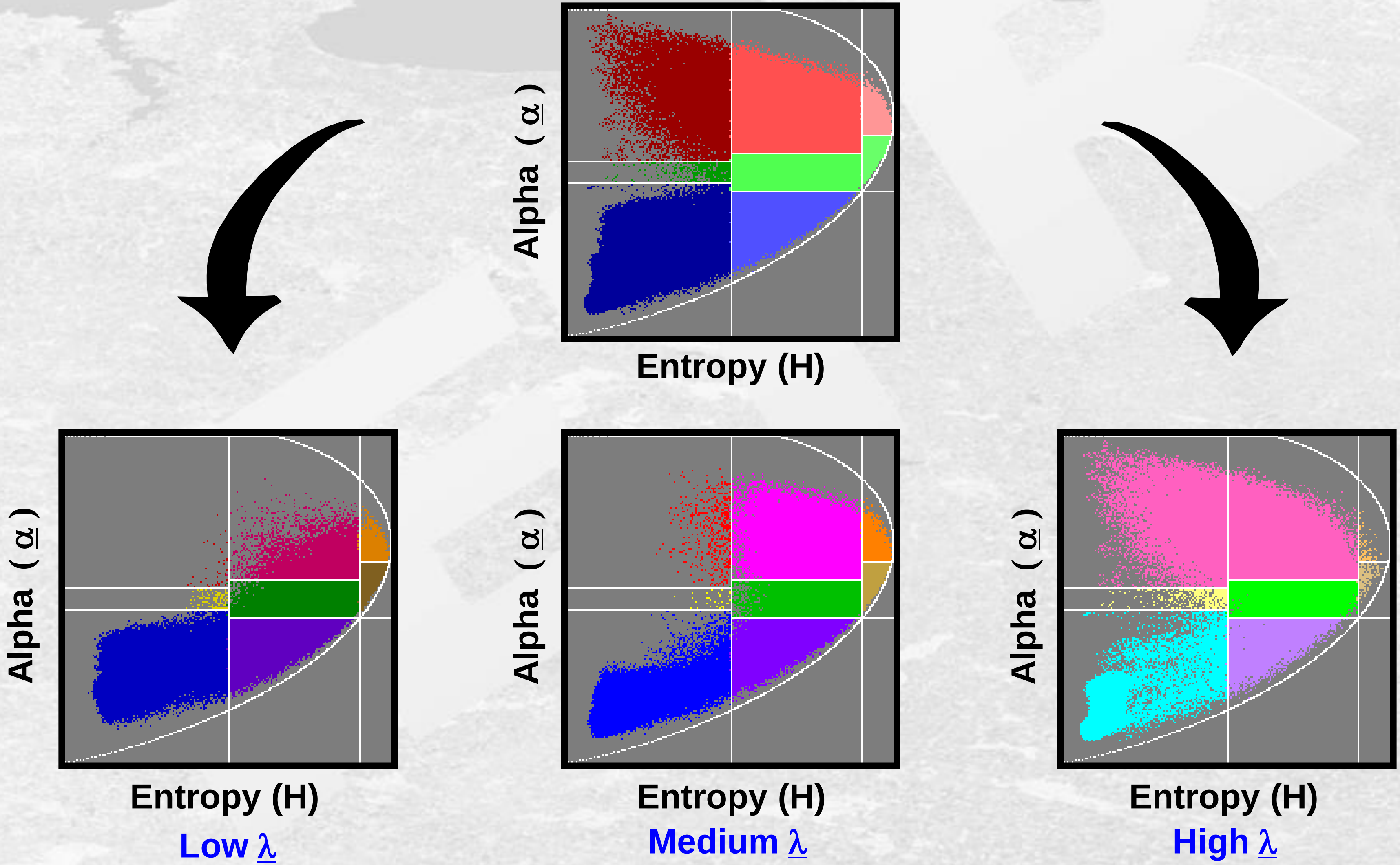
POLSAR DATA DISTRIBUTION IN THE H / α PLANE



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

H / α / span CLASSIFICATION

POLSAR DATA DISTRIBUTION IN THE H / α PLANE

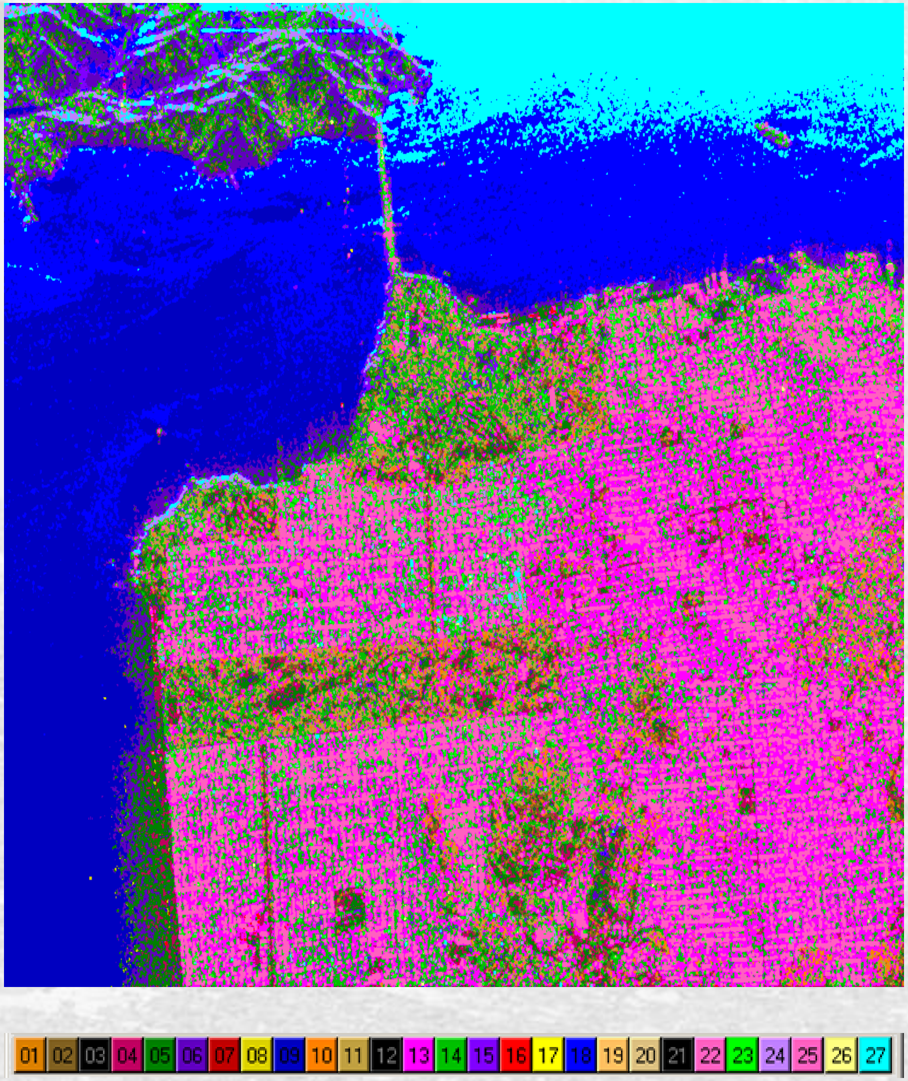


Cao Fang, Hong Wen *A New Classification Method Based on Cloude-Pottier Eigenvalue / Eigenvector Decomposition,* IGARSS 05, Seoul, Korea

H / $\underline{\alpha}$ / span CLASSIFICATION

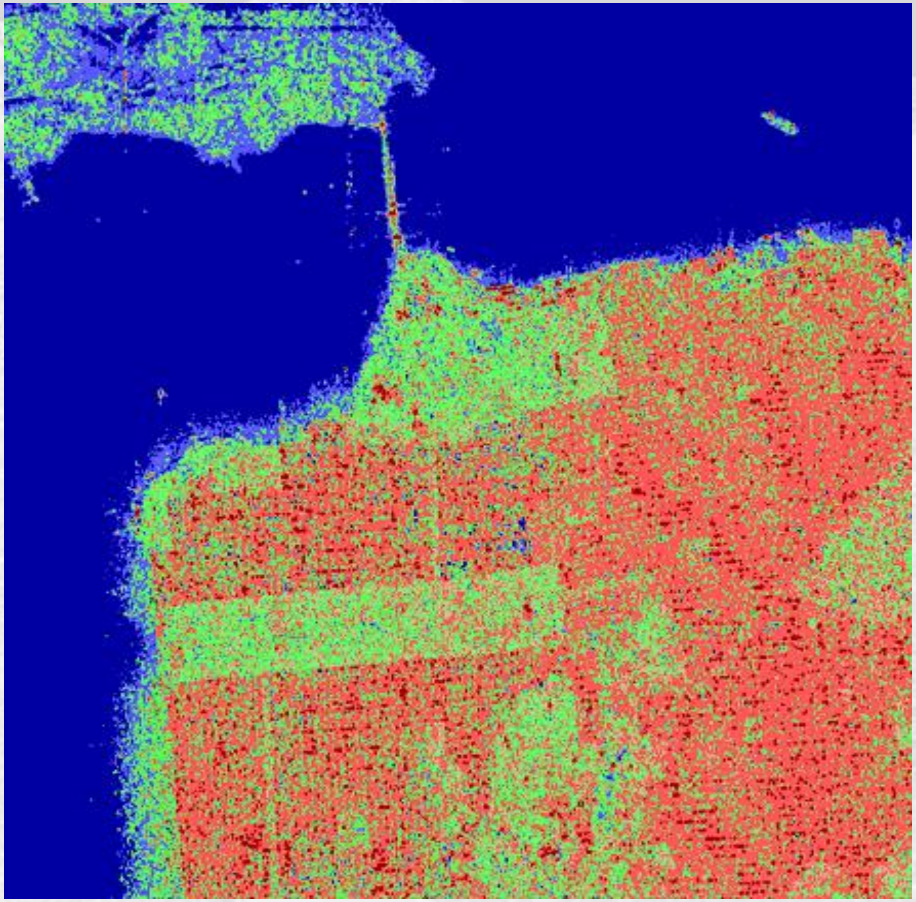
H – $\underline{\alpha}$ ($\underline{\lambda}$) classification

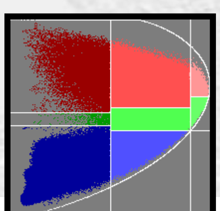
$2A_0$ $B_0 + B$ $B_0 - B$



H / α CLASSIFICATION

H-α classification





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

↓

Location of the boundaries is arbitrary and generically

Degree of arbitrariness on the setting of these boundaries

↓

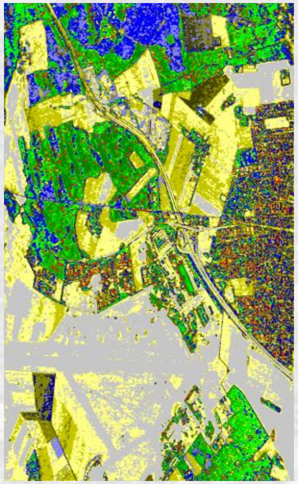
Segmentation is offered merely to illustrate the unsupervised classification strategy and to emphasize the geometrical segmentation of physical scattering processes

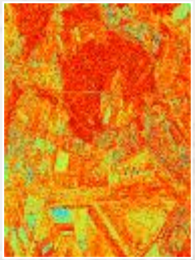
WISHART PDF

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

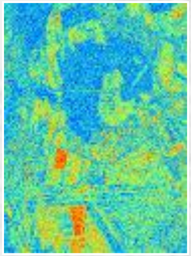
UNSUPERVISED POLSAR CLASSIFICATION

E.POTTIER, J.S LEE (2000)

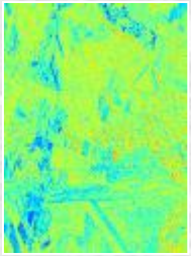




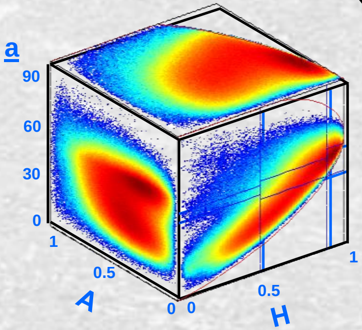
H



A



α



H / A / α DECOMPOSITION THEOREM

PolSAR 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 / $\underline{\alpha}$ » 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

Target Vector

$$\underline{X} = \left[S_{HH} \quad \sqrt{2} S_{HV} \quad S_{VV} \right]^T \qquad P(\underline{X}) = \frac{1}{\pi^3 |[C]|} e^{-\underline{X}^{*T} [C]^{-1} \underline{X}}$$

$$\underline{k} = \frac{1}{\sqrt{2}} \left[S_{HH} + S_{VV} \quad S_{HH} - S_{VV} \quad 2S_{HV} \right]^T \qquad P(\underline{k}) = \frac{1}{\pi^3 |[T]|} e^{-\underline{k}^{*T} [T]^{-1} \underline{k}}$$

Coherency Matrix

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

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

COMPLEX WISHART DISTRIBUTION

L: Number of Look p: Polarimetric Dimension

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

BAYES MAXIMUM LIKELIHOOD CLASSIFICATION PROCEDURE

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

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

It follows

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

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

WISHART CLASSIFIER

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

BAYES MAXIMUM LIKELIHOOD CLASSIFICATION PROCEDURE

$$\langle [T] \rangle \in [T_m] \quad if \quad d_m\left(\langle [T] \rangle\right) < d_j\left(\langle [T] \rangle\right) \quad \forall\, j \neq m$$

with

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

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

ROBUSTENESS OF WISHART CLASSIFIER

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

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

H / $\underline{\alpha}$ - WISHART CLASSIFIER

k - mean CLASSIFICATION PROCEDURE

PROVIDE INITIAL $[T_m]^{(0)}$ FOR EACH CLASS

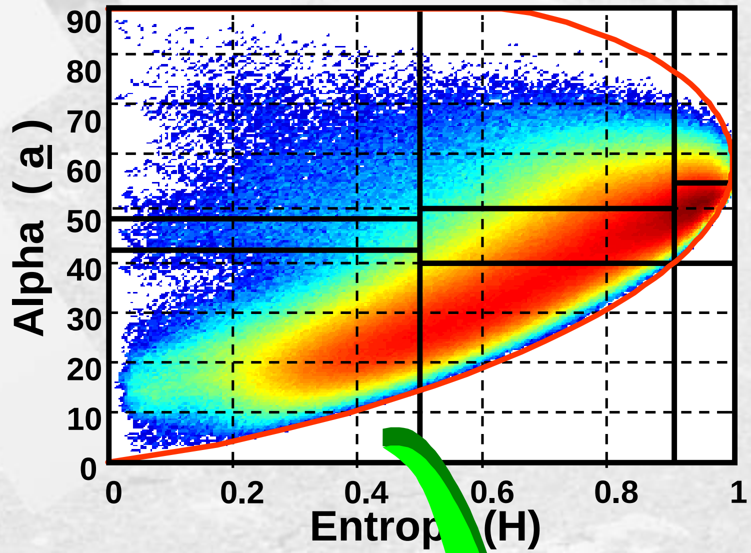
CLASSIFY THE WHOLE IMAGE WITH THE DISTANCE PROCEDURE

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

COMPUTE $[T_m]^{(k+1)}$ FOR EACH CLASS USING THE CLASSIFIED PIXELS OF STEP 2

$$[T_m]^{(k+1)} = \frac{1}{N_m} \sum_{j=1}^{j=N_m} \langle [T] \rangle_j$$

TERMINAISON CRITERION ?



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

Cluster Center of the class *m* (Lee 1998)

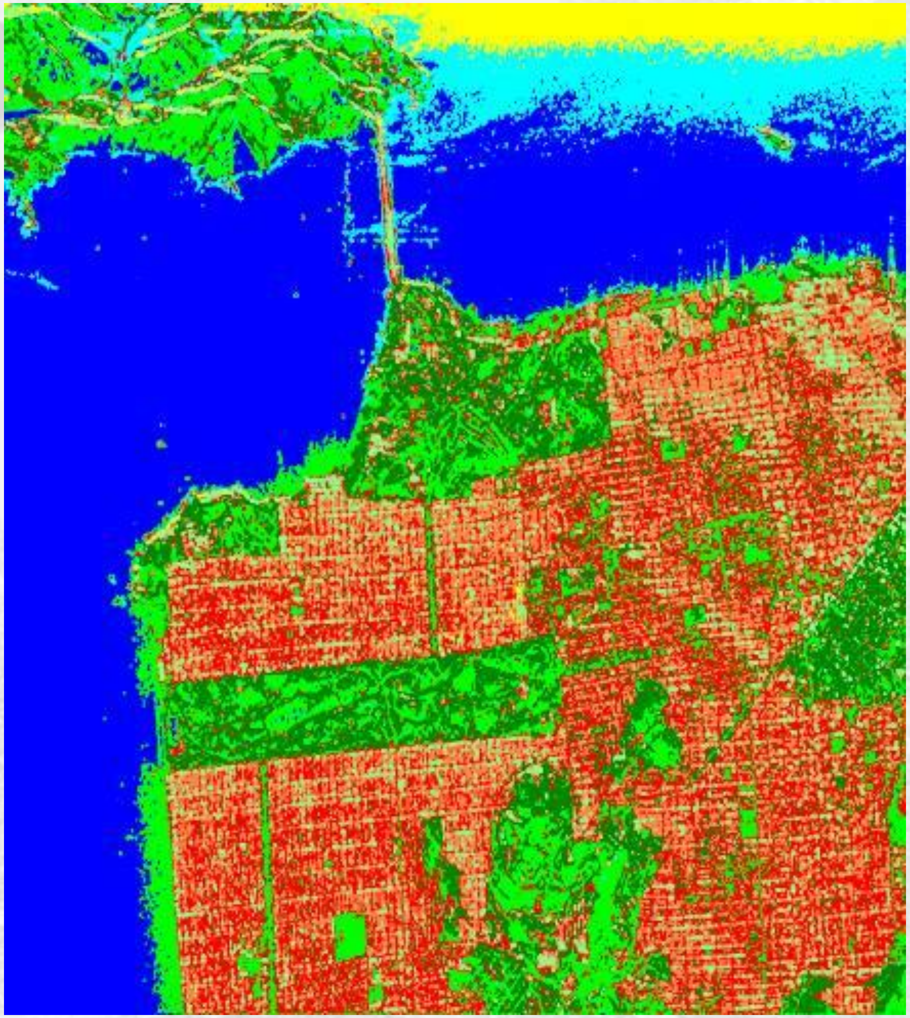
H / α - WISHART CLASSIFIER

NRSCC esa

SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

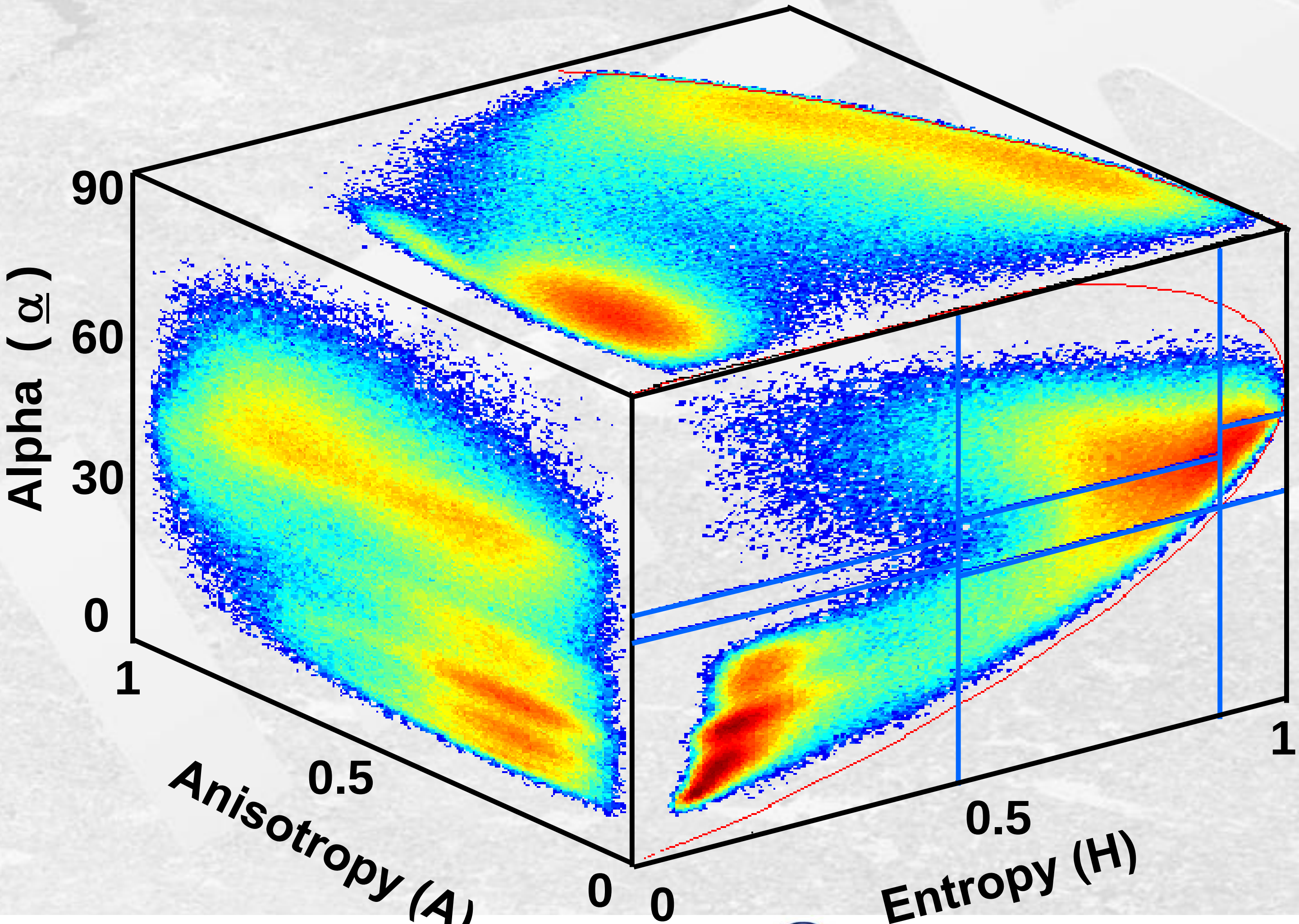
$2A_0$ $B_0 + B$ $B_0 - B$

4th ITERATION

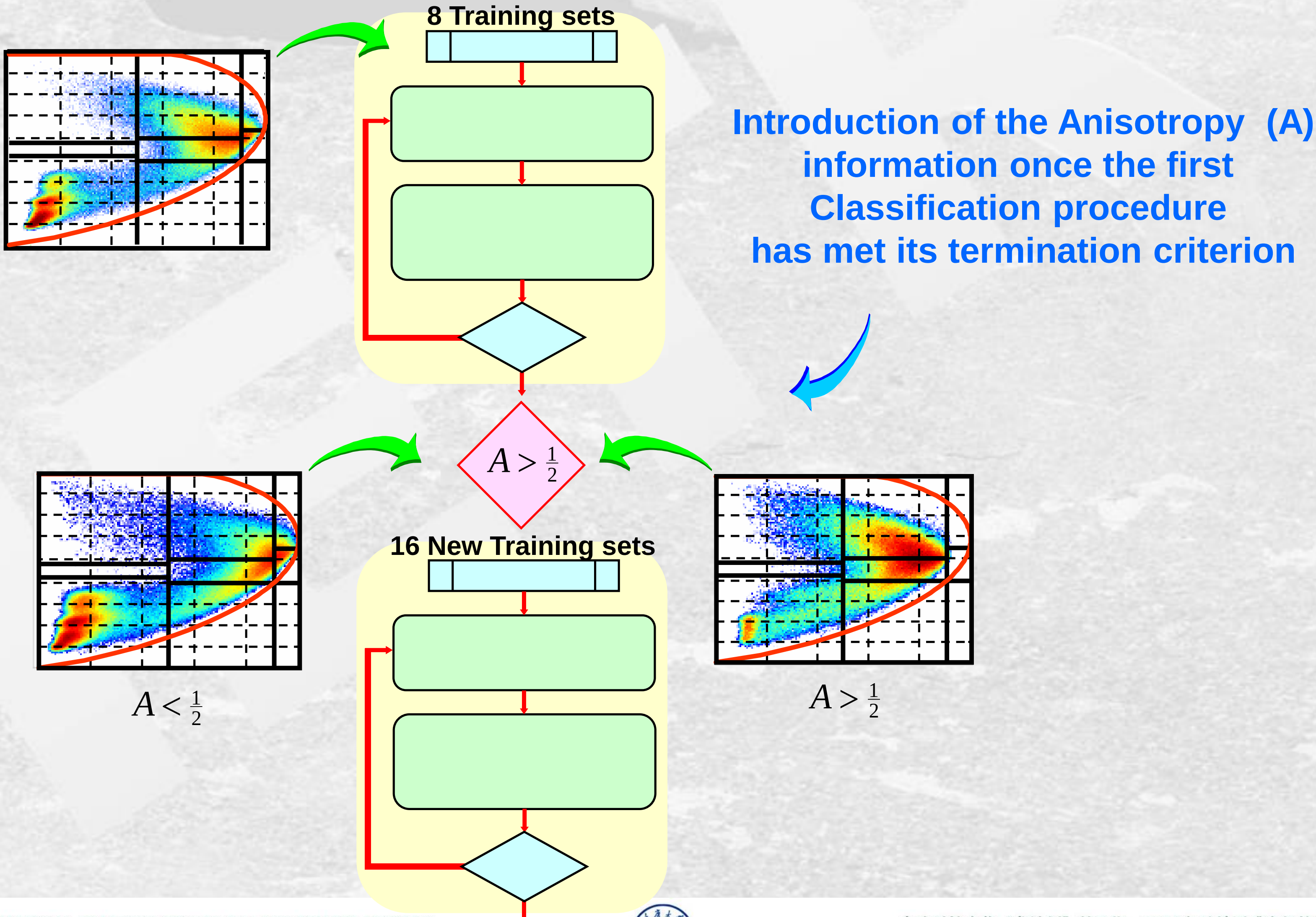


C1 C2 C3 C4 C5 C6 C7 C8

POLSAR DATA DISTRIBUTION IN THE H / A / $\underline{\alpha}$ SPACE



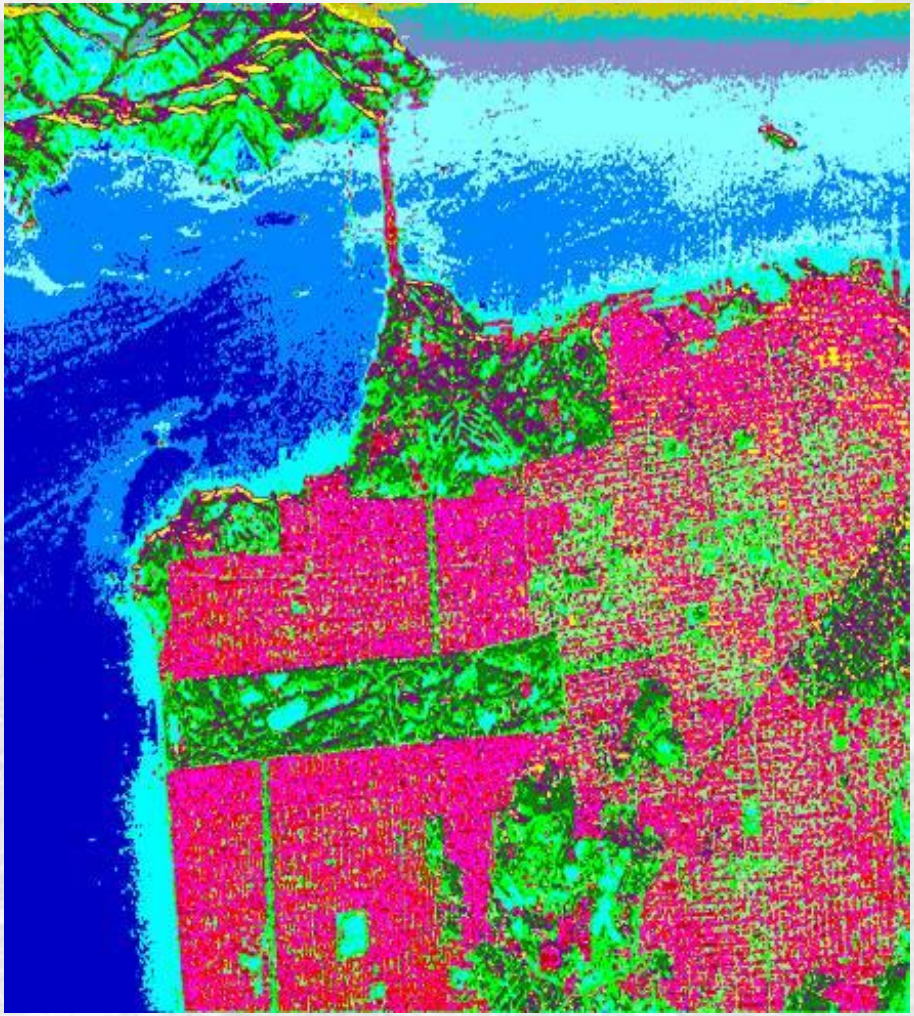
2 Successive k - mean Classification procedures



SAN FRANCISCO BAY JPL - AIRSAR L-band 1988

$2A_0$ $B_0 + B$ $B_0 - B$

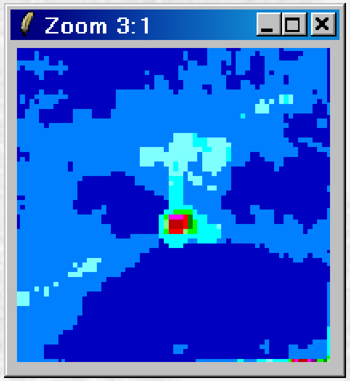
4th ITERATION

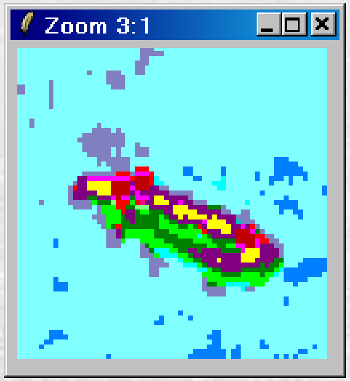


C1	C2	C3	C4	C5	C6	C7	C8
C9	C10	C11	C12	C13	C14	C15	C16

H / A / α - WISHART CLASSIFIER

SAN FRANCISCO BAY JPL - AIRSAR L-band 1988



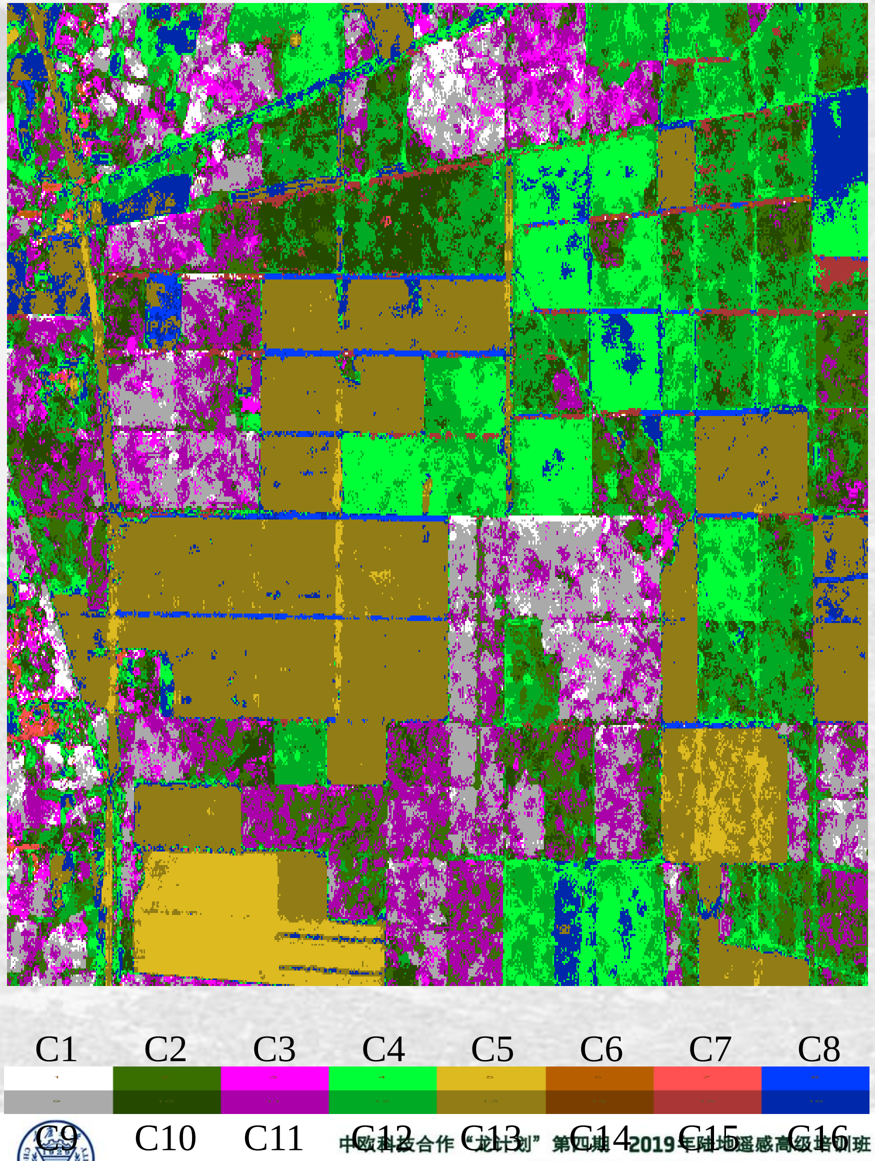


$2A_0$ $B_0 + B$ $B_0 - B$

H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

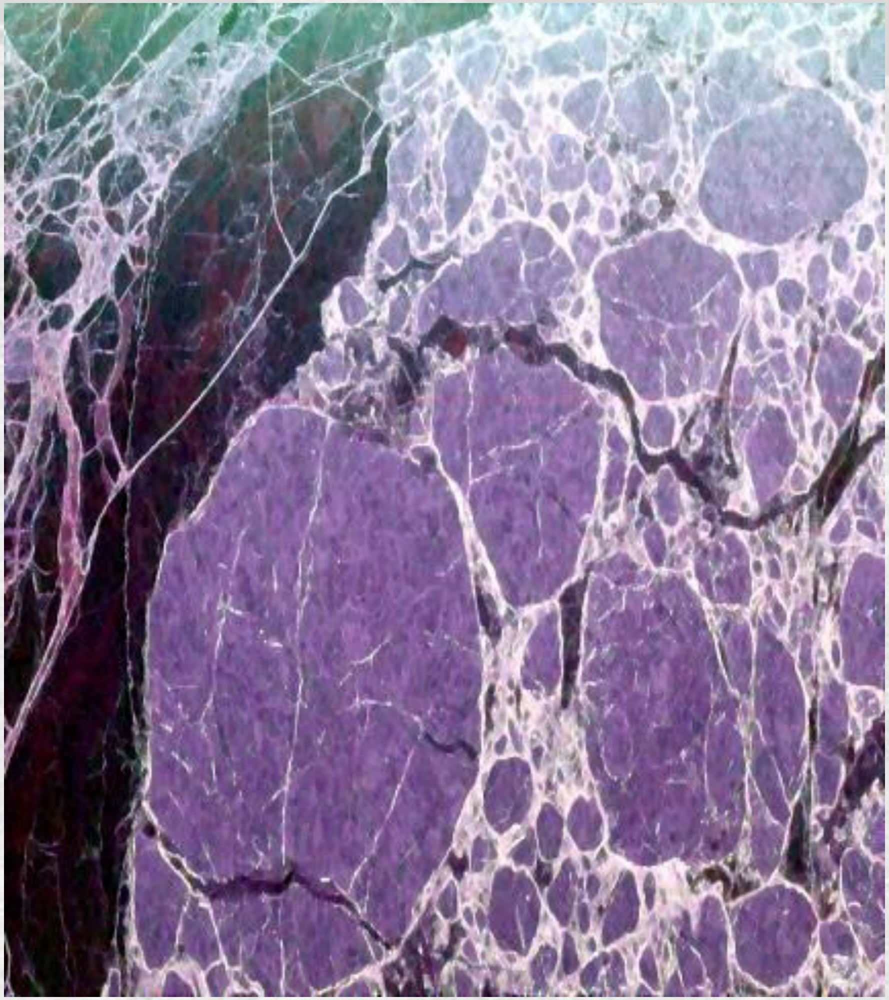
NEZER FOREST JPL - AIRSAR L-band

$2A_0$ $\quad B_0 + B$ $\quad B_0 - B$

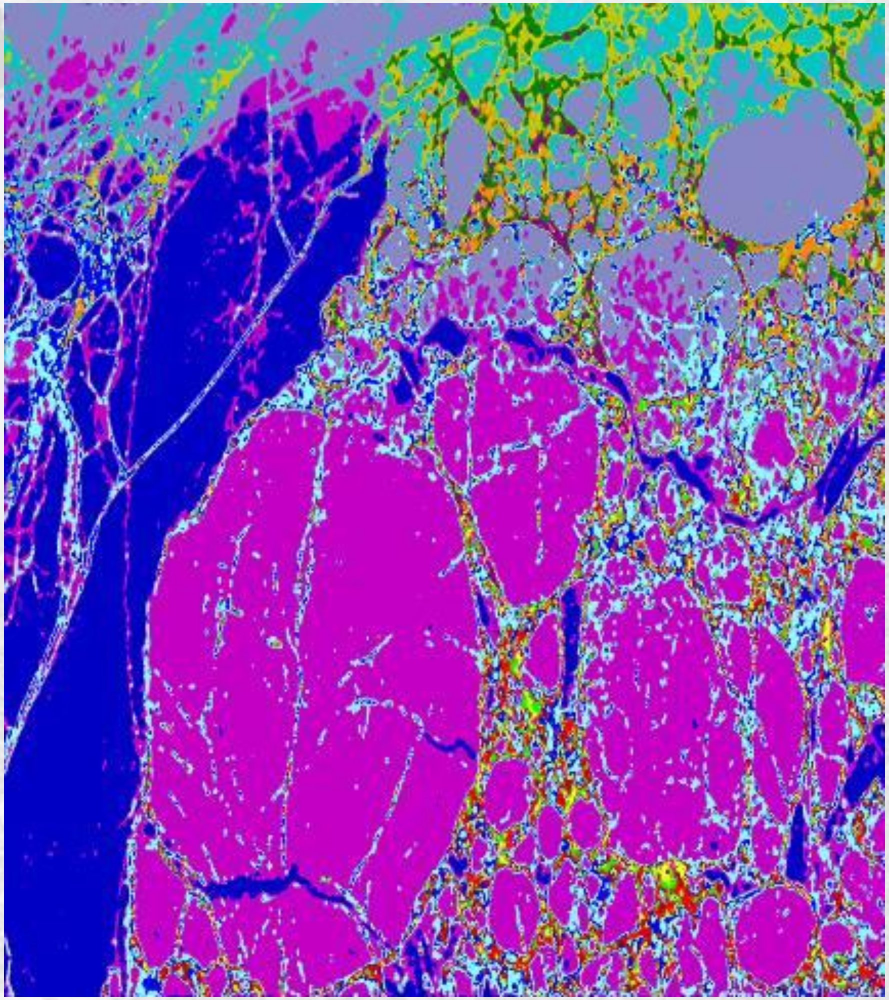


H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

ICE AREA JPL - AIRSAR L-band



$2A_0$ $B_0 + B$ $B_0 - B$

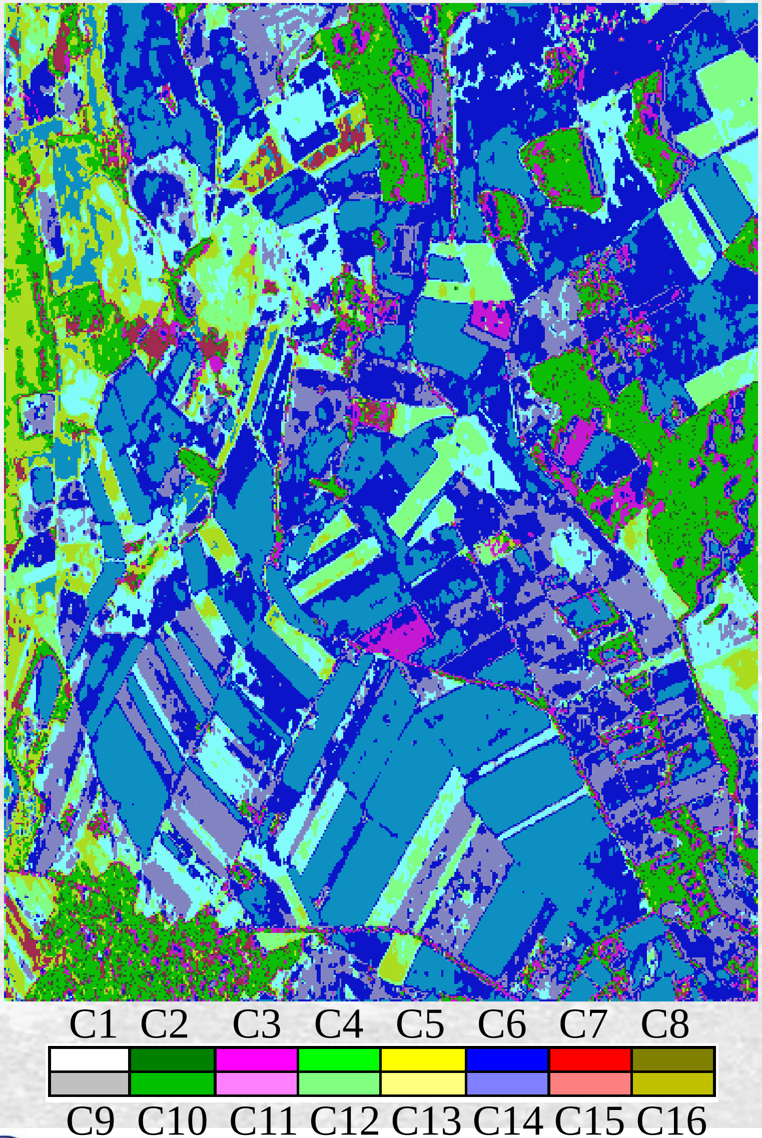


H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

ALLING - ESAR L-band

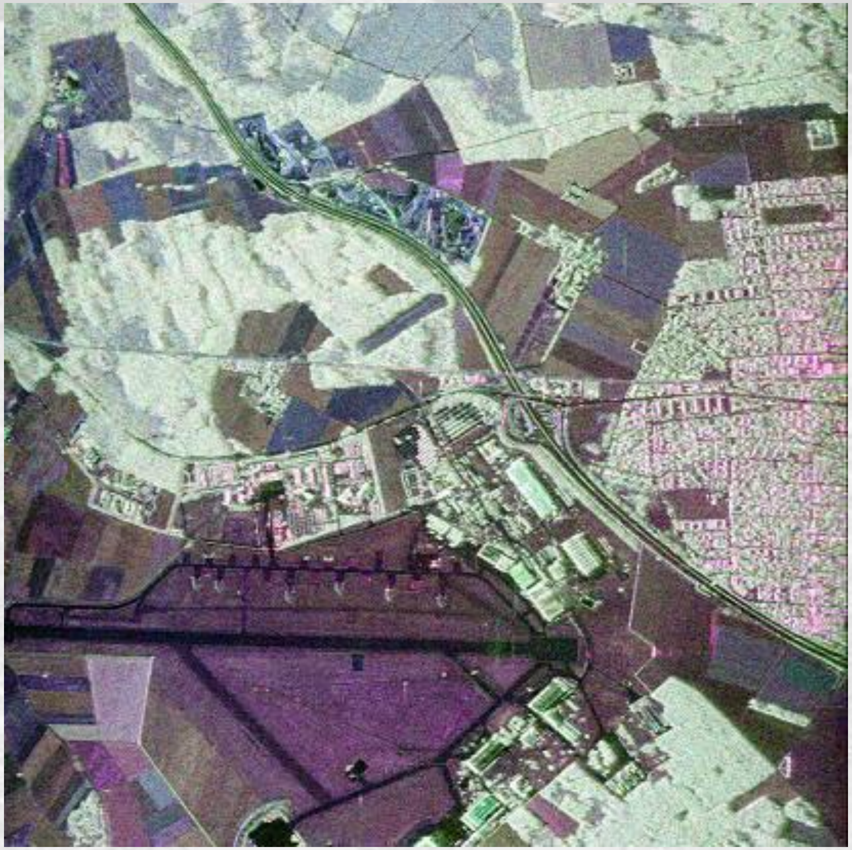
$2A_0$ $\quad$ $B_0 + B$ $\quad$ $B_0 - B$

H / A / $\underline{\alpha}$ and WISHART CLASSIFIER



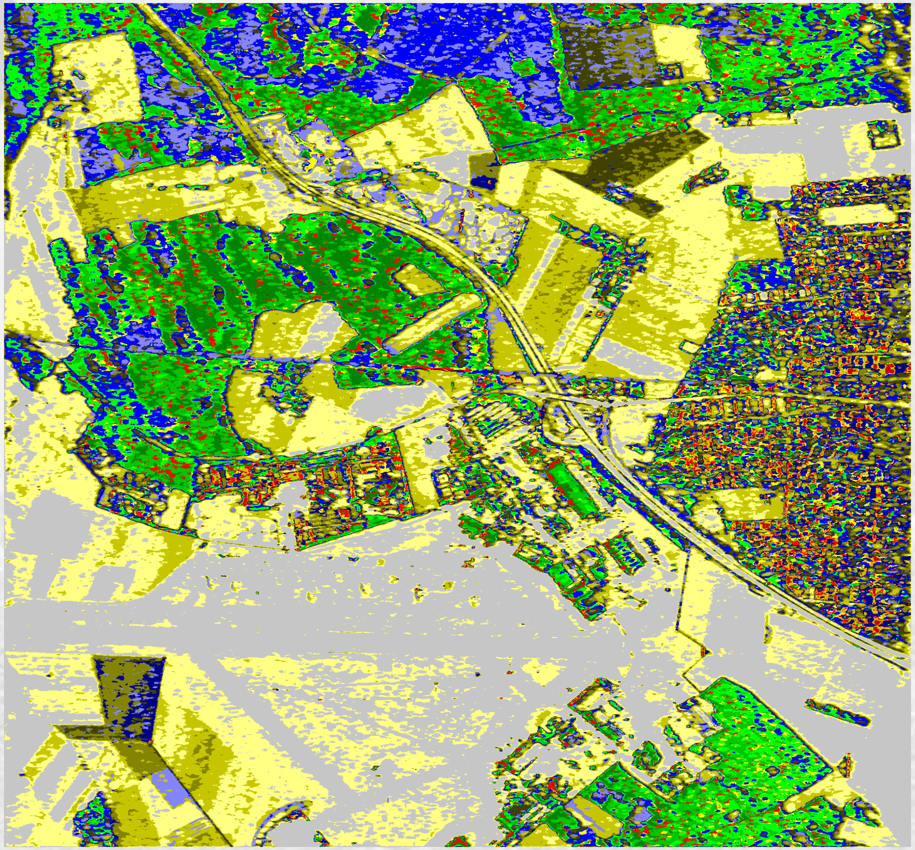
H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

OBERPFAFFENHOFEN - ESAR L-band



$2A_0$ $B_0 + B$ $B_0 - B$

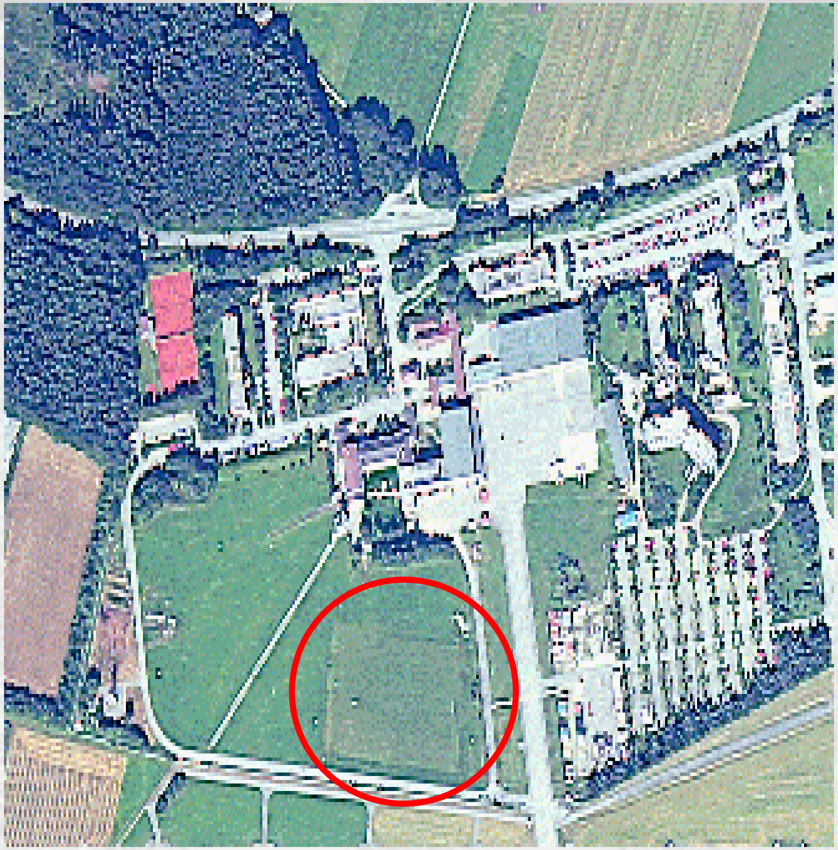
H / A / $\underline{\alpha}$ and WISHART CLASSIFIER



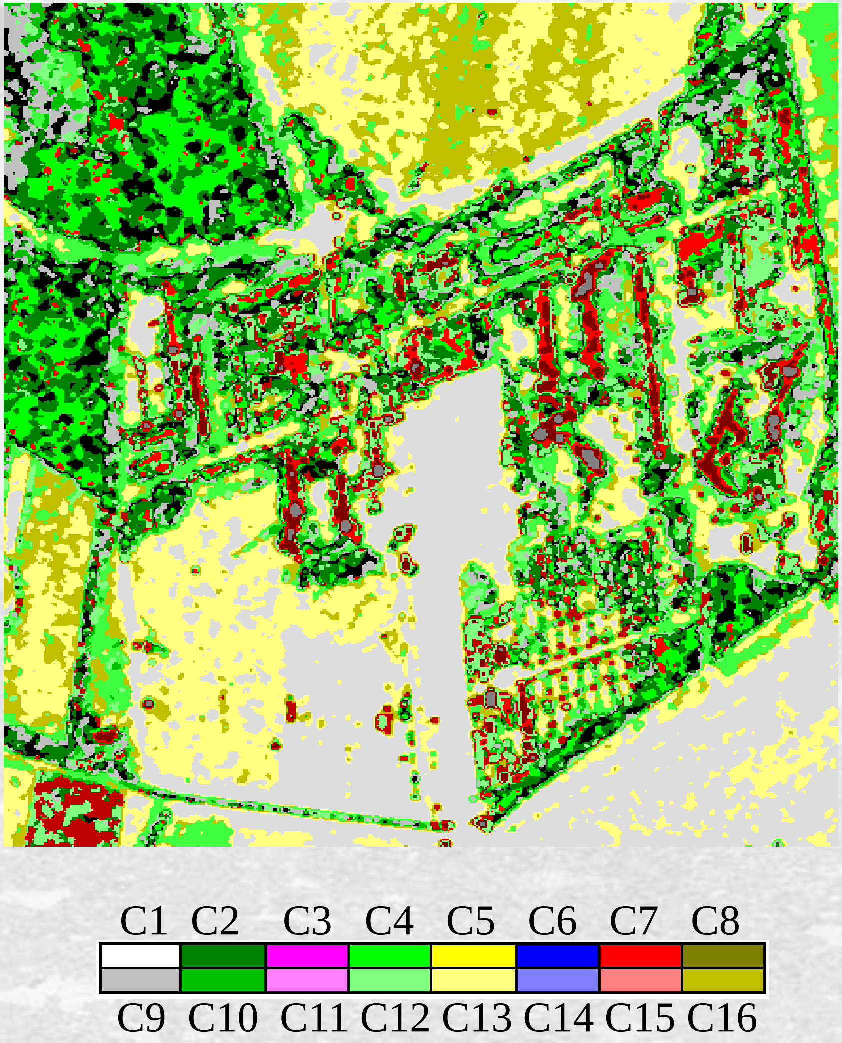
C1	C2	C3	C4	C5	C6	C7	C8
C9	C10	C11	C12	C13	C14	C15	C16

H / A / $\underline{\alpha}$ - WISHART CLASSIFIER

OBERPFAFFENHOFEN - ESAR L-band



H / A / $\underline{\alpha}$ and WISHART CLASSIFIER

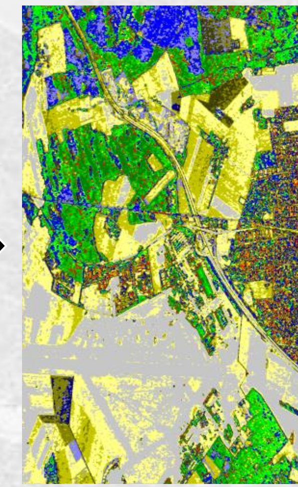


WISHART PDF

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

UNSUPERVISED POLSAR CLASSIFICATION

J.S LEE et al. (2002)



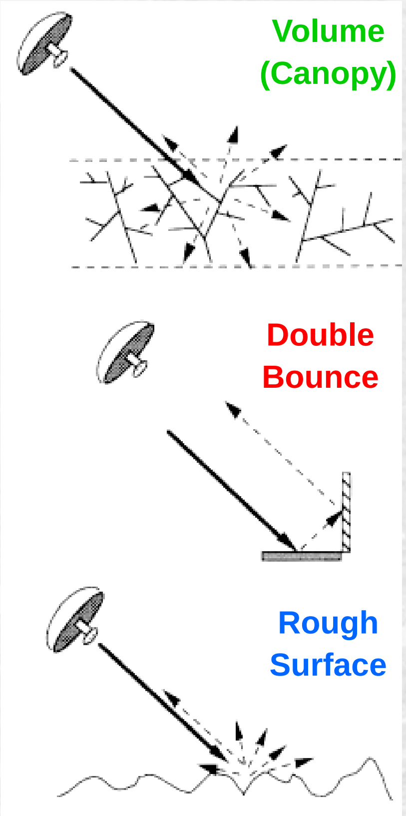
Unsupervised Classification Preserving Scattering Mechanisms

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

Courtesy of Dr J.S Lee

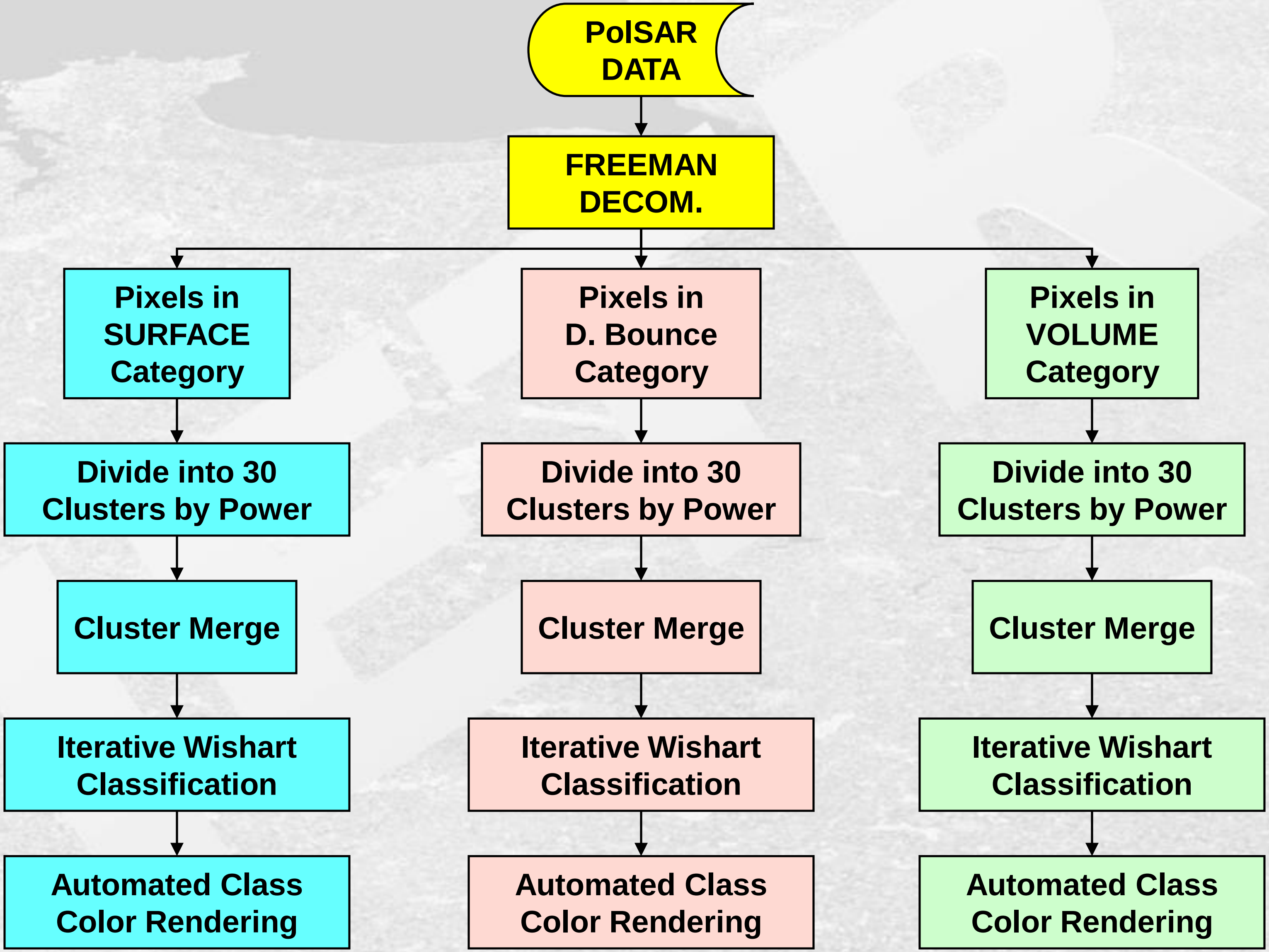
|HH-VV|, |HV|, |HH+VV|

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

PROCEDURE – FLOW CHART



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

Wishart Iteration – After Class Merge

Classification Maps


First Iteration


Second Iteration

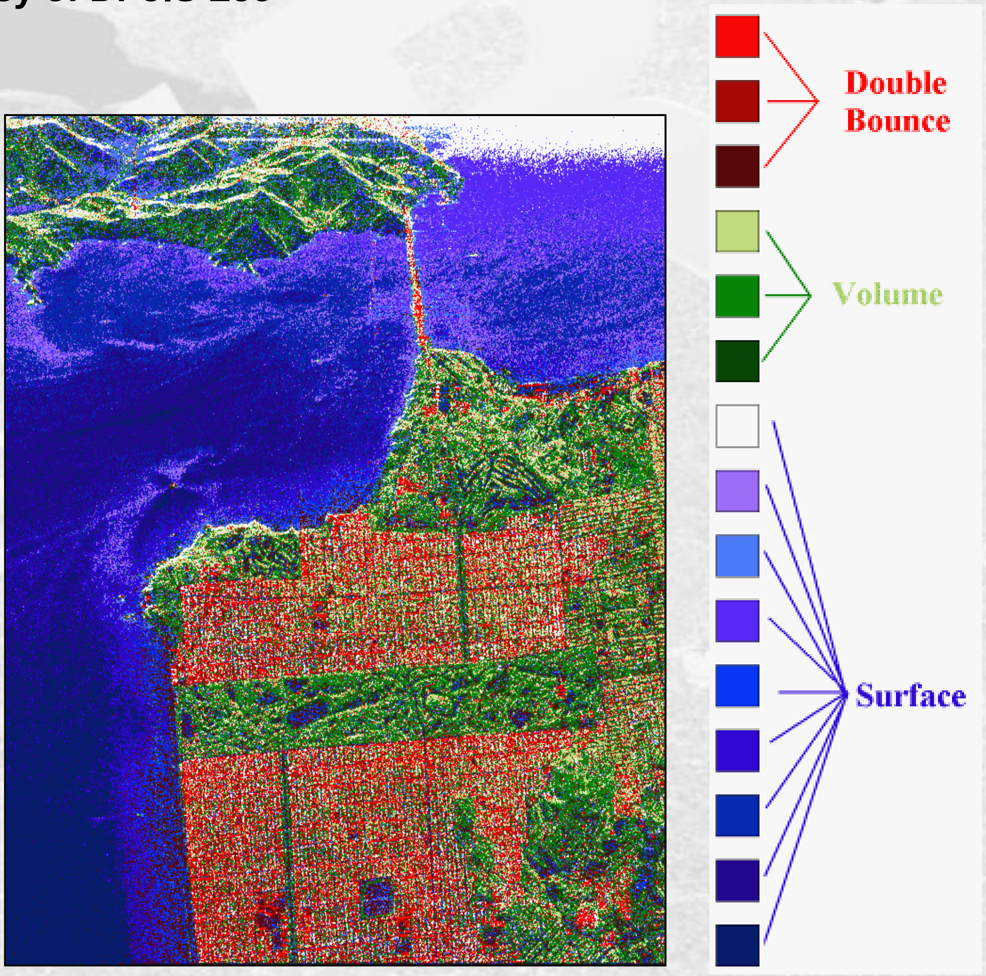

Third Iteration

Note: Stability insures good convergence

FREEMAN - WISHART CLASSIFIER

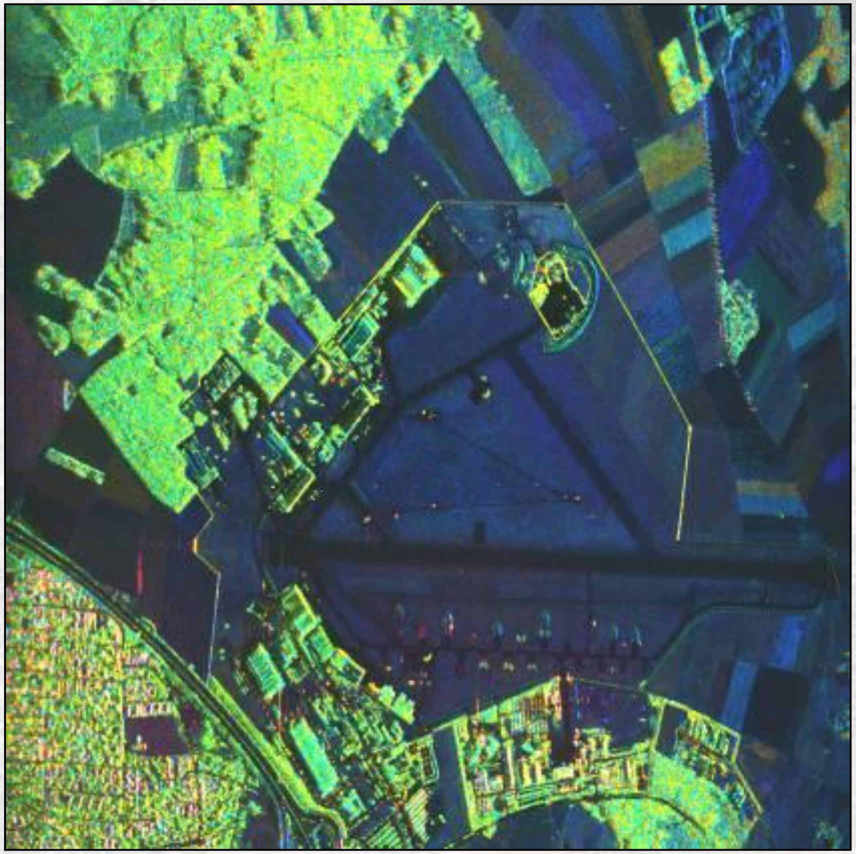
Courtesy of Dr J.S Lee

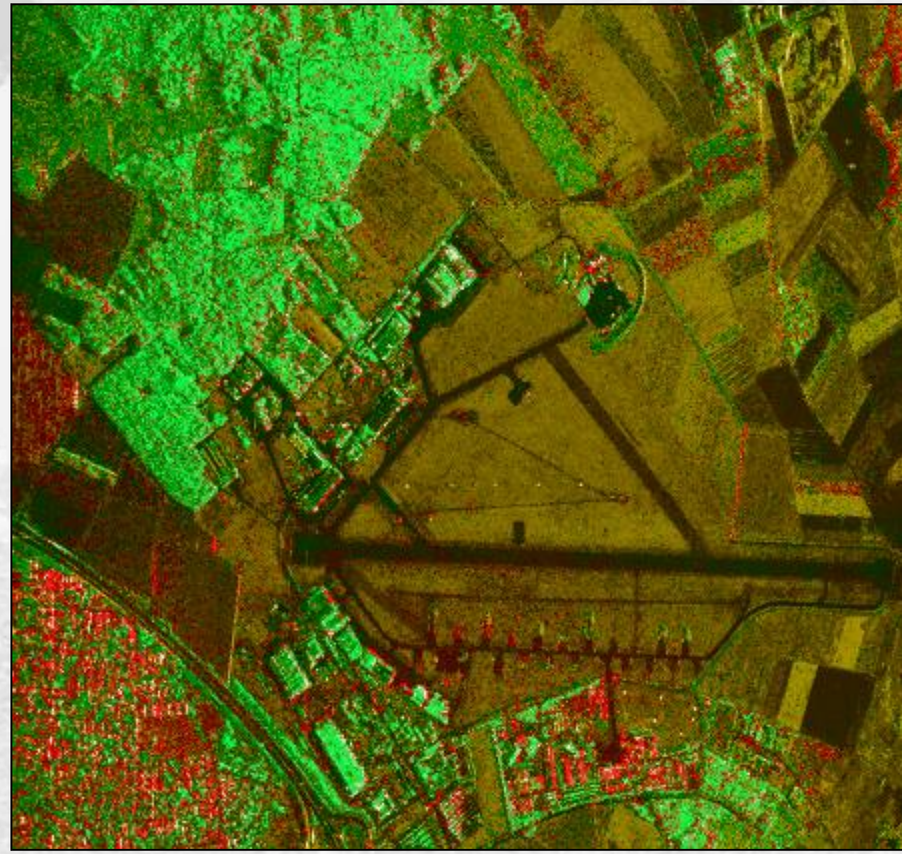
|HH-VV|, |HV|, |HH+VV|



4^{th} Iteration (15 classes)

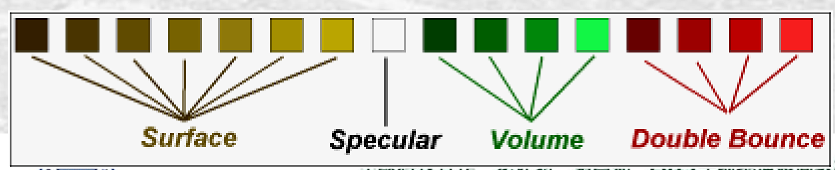
Courtesy of Dr J.S Lee





$2A_0$ $B_0 + B$ $B_0 - B$

4th Iteration (15 classes)

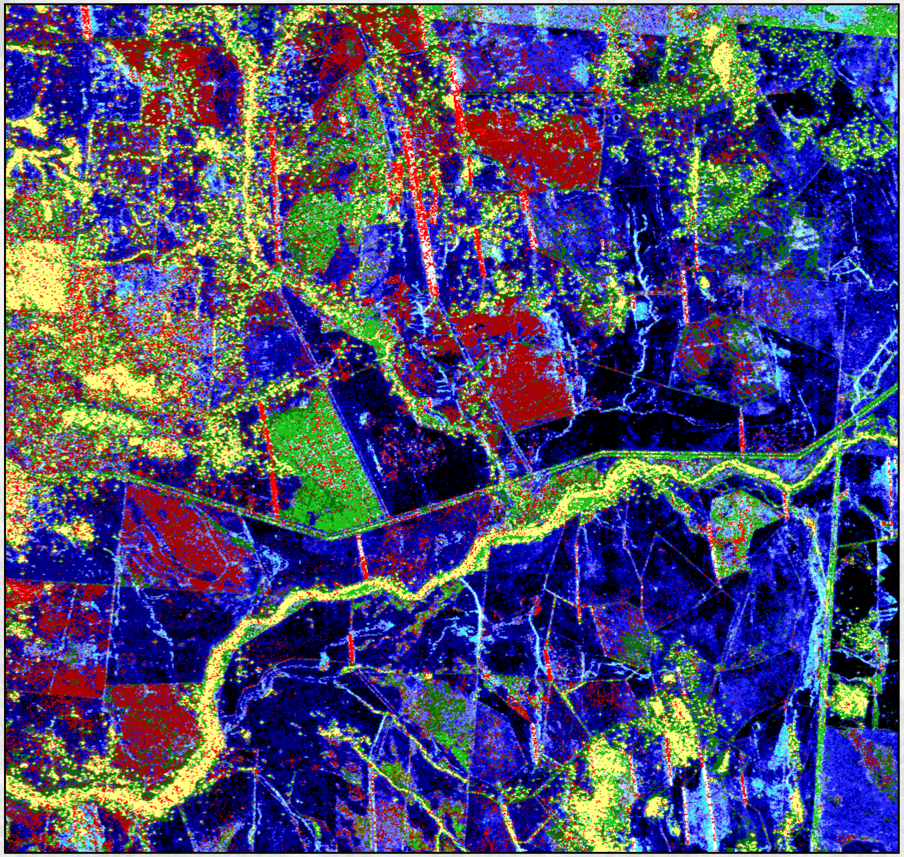


FREEMAN - WISHART CLASSIFIER

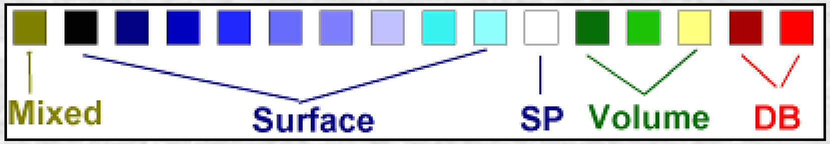
Courtesy of Dr J.S Lee

$2A_0$ $B_0 + B$ $B_0 - B$

Australian Pasture

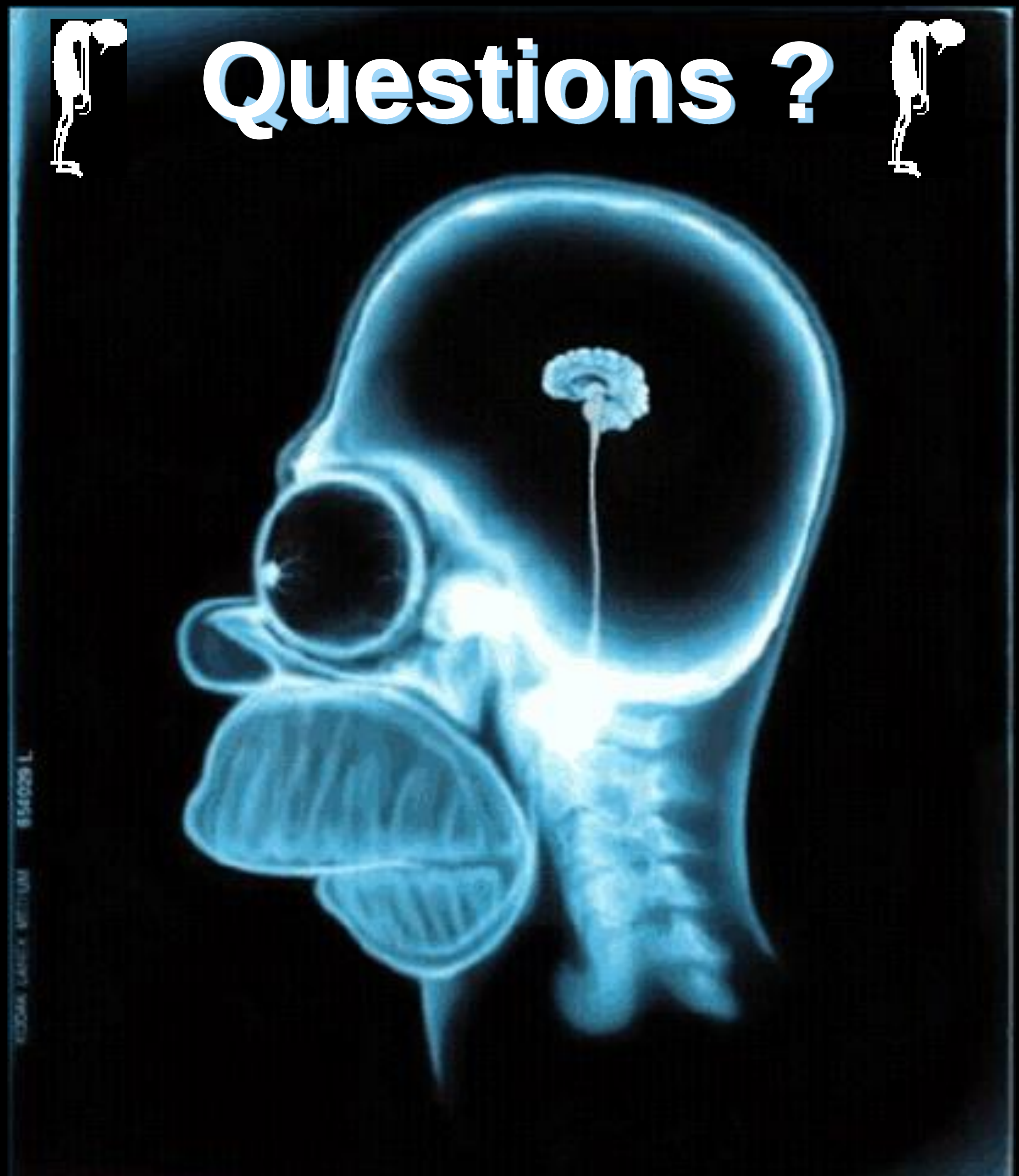


4th Iteration (15 classes)



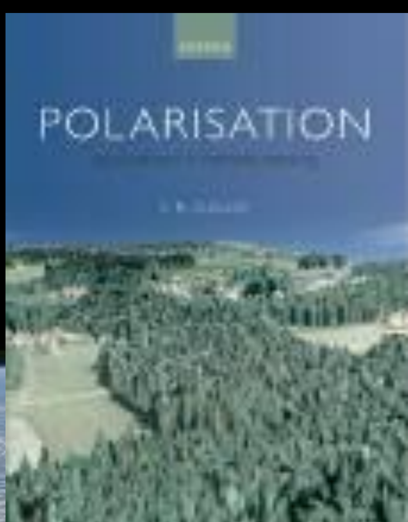
L-Band Volume Dominated

Questions ?



Books On Polarimetric Radar
SAR, Polarimetric Interferometry

Polarimetric Radar Imaging: From basics to applications
Jong-Sen LEE – Eric POTTIER
CRC Press; 1st ed., February 2009, pp 422
ISBN: 978-1420054972



Polarisation: Applications in Remote Sensing
Shane R. CLOUDE
Oxford University Press, October 2009, pp 352
ISBN: 978-0199569731

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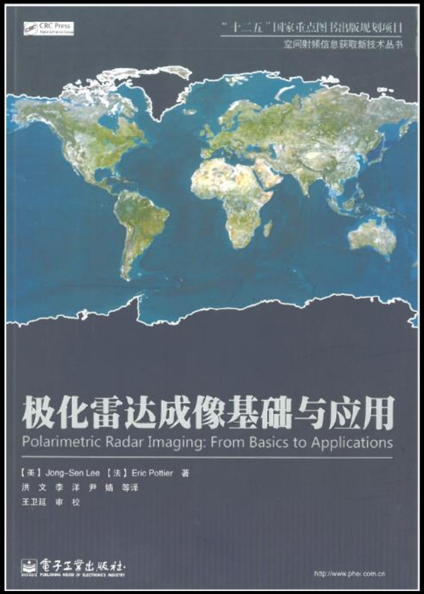

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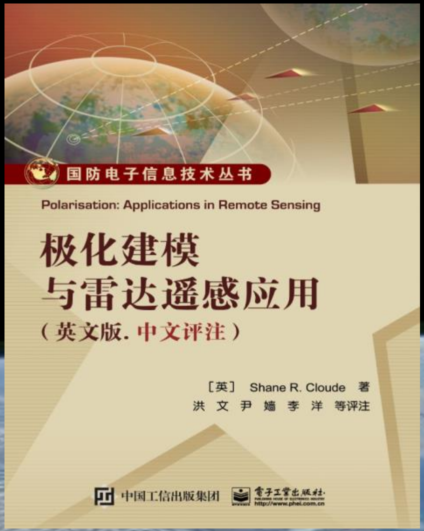
Prof. Wen HONG, Dr. Qiang YIN et al.



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