Comparison between the conformity coefficient and previous classification techniques for bare surface discrimination and application to compact polarimetry mode

My-Linh Truong-Loï, ONERA
Pascale Dubois-Fernandez, ONERA
Anthony Freeman, JPL
Eric Pottier, IETR-UMR CNRS 6164, Université Rennes 1

ONERA
THE FRENCH AEROSPACE LAB

retour sur innovation

JPL

UNIVERSITÉ DE RENNES 1

Overview

- Context
- The conformity coefficient, μ
  - Definition
  - Published classifications
  - Comparison between the conformity coefficient and previous classifications
    - Over Ramses data
    - Over PALSAR data
- Faraday rotation (FR) estimate
  - Freeman and Bickel&Bates methods, FR estimate from CP data
  - Over Ramses data
  - Over PALSAR data
- Application : soil moisture inversion

Context

- Compact polarimetry ($\pi/2$ mode) at low frequency (P-band)
  - Higher incidence angles
  - Larger swaths
  - Higher power of penetration in the canopy

- $\pi/2$ mode : An unique circular transmission and two independant receptions (linear H&V or circular R&L).
  - Here, we use a right circular transmission and two linear receptions

$$\begin{pmatrix} S_{RH} \\ S_{RV} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

$$\begin{pmatrix} M_{RH} \\ M_{RV} \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \begin{pmatrix} S_{HH} & S_{VH} \\ S_{HV} & S_{VV} \end{pmatrix} \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \begin{pmatrix} 1 \\ -j \end{pmatrix}$$

The conformity coefficient - Definition

Definition

$$\mu = \frac{2\,\mathrm{Im}\langle M_{RH} M_{RV}^{*}\rangle}{\langle M_{RH} M_{RH}^{*}\rangle + \langle M_{RV} M_{RV}^{*}\rangle}$$

FR independent

$$\mu = \frac{2\,\mathrm{Im}\langle S_{RH} S_{RV}^{*}\rangle}{\langle S_{RH} S_{RH}^{*}\rangle + \langle S_{RV} S_{RV}^{*}\rangle} = \frac{2\,\mathrm{Im}\langle M_{RH} M_{RV}^{*}\rangle}{\langle M_{RH} M_{RH}^{*}\rangle + \langle M_{RV} M_{RV}^{*}\rangle}$$

Over natural targets with reflection symmetry hypothesis

$$\mu = \frac{2\,\mathrm{Im}\langle M_{RH} M_{RV}^{*}\rangle}{\langle M_{RH} M_{RH}^{*}\rangle + \langle M_{RV} M_{RV}^{*}\rangle} \approx \frac{\mathrm{Re}(S_{HH} S_{VV}^{*}) - |S_{HV}|^{2}}{\left(|S_{HH}|^{2} + 2|S_{HV}|^{2} + |S_{VV}|^{2}\right)}$$

The conformity coefficient

$$\mu = \frac{2\,\mathrm{Im}\langle M_{RH} M_{RV}^{*}\rangle}{\langle M_{RH} M_{RH}^{*}\rangle + \langle M_{RV} M_{RV}^{*}\rangle} \approx \frac{\mathrm{Re}(S_{HH} S_{VV}^{*}) - |S_{HV}|^{2}}{\left(|S_{HH}|^{2} + 2|S_{HV}|^{2} + |S_{VV}|^{2}\right)}$$

Double-bounce	**Volume**	**Surface**
$S_{HV} \sim 0$	$S_{HV} >> 1$	$S_{HV} \sim 0$
S_{HH}, S_{VV} correlated	S_{HH}, S_{VV} less correlated	S_{HH}, S_{VV} correlated
$\mathrm{Arg}\langle S_{HH}S_{VV}^{*}\rangle \approx 180°$		$\mathrm{Arg}\langle S_{HH}S_{VV}^{*}\rangle \approx 0$
$-1 < \mu < t_2$	$t_2 < \mu < t_1$	$t_1 < \mu < 1$

- This coefficient
  - Is FR independent
  - Can be used with CP data as well as FP data
  - Allows distinguishing 3 different types of scattering

Published classifications

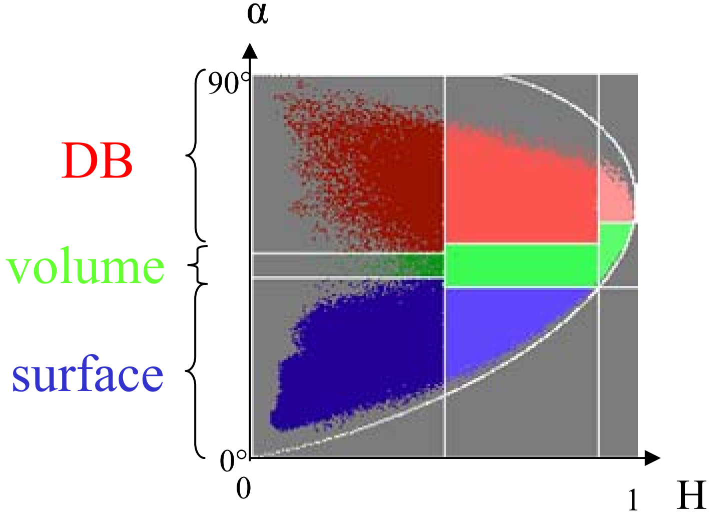
- Freeman-Durden Model[1]

$$\langle |S_{hh}|^2 \rangle = f_s|\beta|^2 + f_d|\alpha|^2 + f_v$$
$$\langle |S_{vv}|^2 \rangle = f_s + f_d + f_v$$
$$\langle S_{hh}S_{vv}^* \rangle = f_s\beta + f_d\alpha + f_v/3$$
$$\langle |S_{hv}|^2 \rangle = f_v/3$$

- Cloude and Pottier[2] classification

$$H = \sum_{i=1}^{n} -P_i \log_n P_i \qquad P_i = \frac{\lambda_i}{\sum_{j=1}^{n} \lambda_j}$$

$$\alpha = \sum_{k=1}^{3} P_k \alpha_k \qquad \alpha_k = \arccos|v_{k_1}|$$

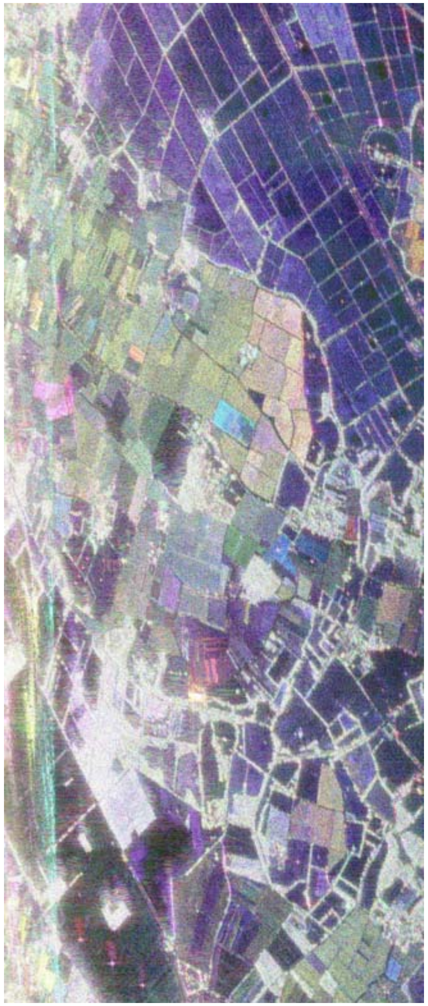


[1] "A Three-Component Scattering Model for Polarimetric SAR Data", A. Freeman, IEEE TGRS, vol. 36, no. 3, May 1998

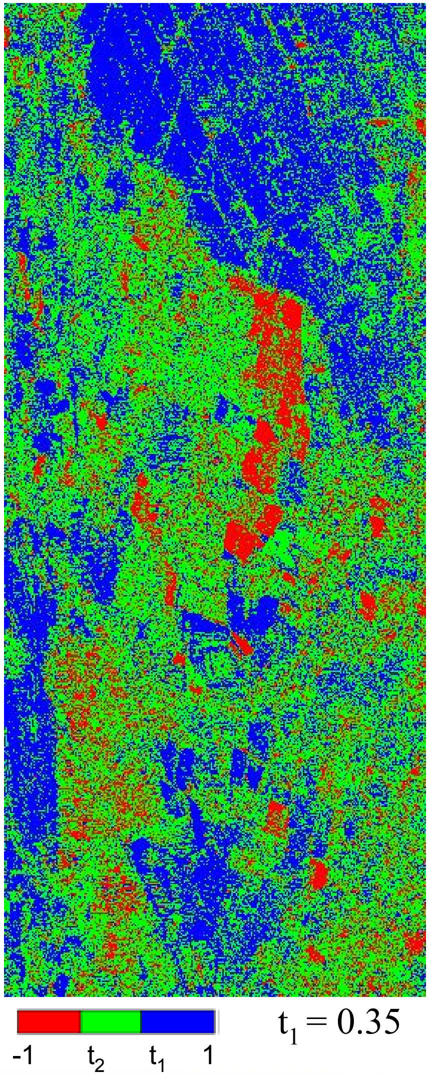
[2] "An Entropy Based Classification Scheme for Land Applications of Polarimetric SAR", S.R. Cloude and E. Pottier, *IEEE TGRS*, vol. 35, no. 1, pp. 68-78, January 1997.

Conformity coefficient vs Cloude-Pottier (H/α) classification over Ramses data

{R;G;B}={Hh;Hv;Vv}



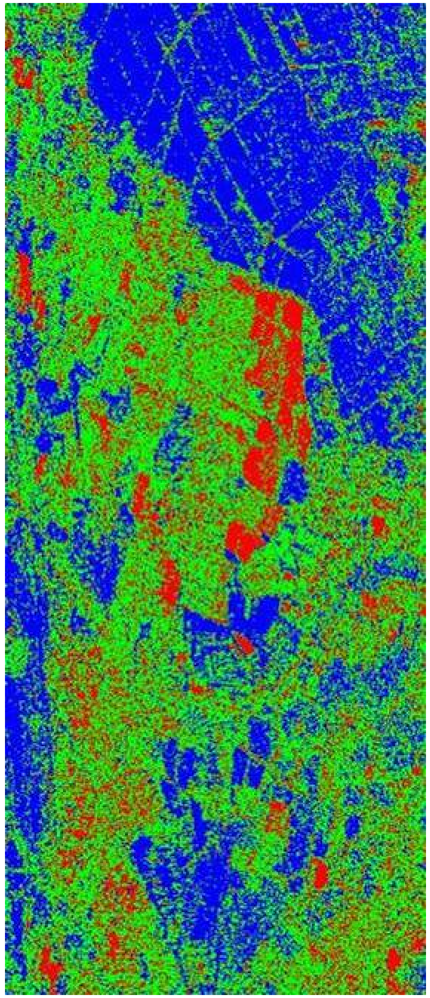
Conformity coefficient



$t_1 = 0.35$

$t_2 = -0.2$

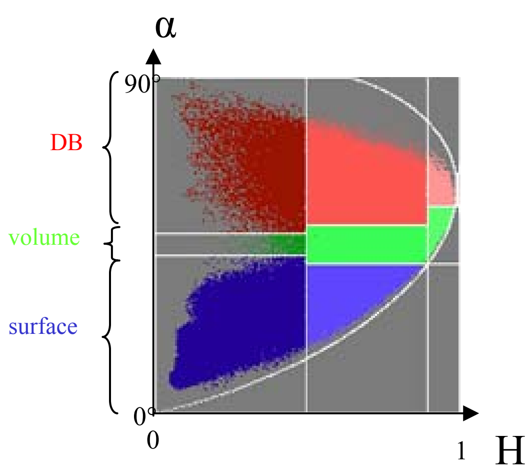
Cloude-Pottier classification



$$\begin{bmatrix} (S1\&S2)\% & (S1\&X2)\% \\ (X1\&S2)\% & (X1\&X2)\% \end{bmatrix}$$

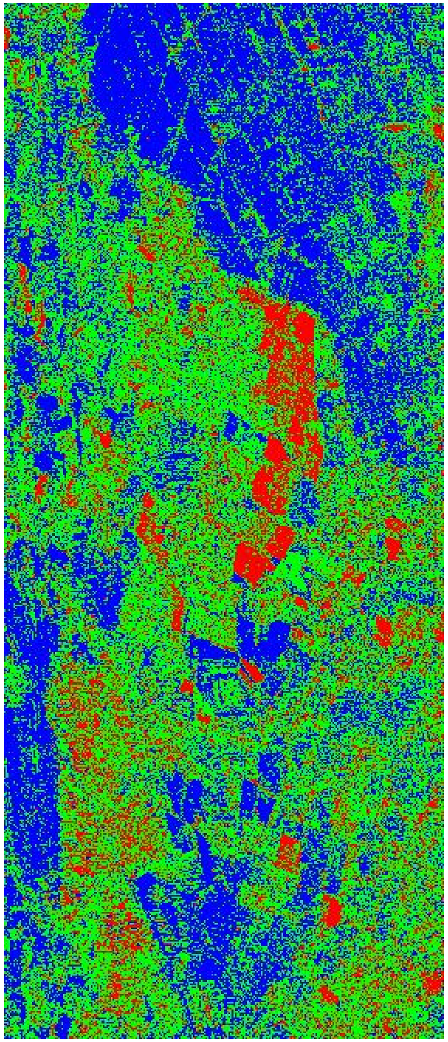
$$\mu$$

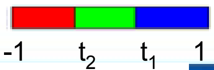
$$H/\alpha \begin{bmatrix} 30.05\% & 5.50\% \\ 6.93\% & 57.52\% \end{bmatrix}$$



Conformity coefficient vs Freeman-Durden classification over Ramses data

Conformity coefficient

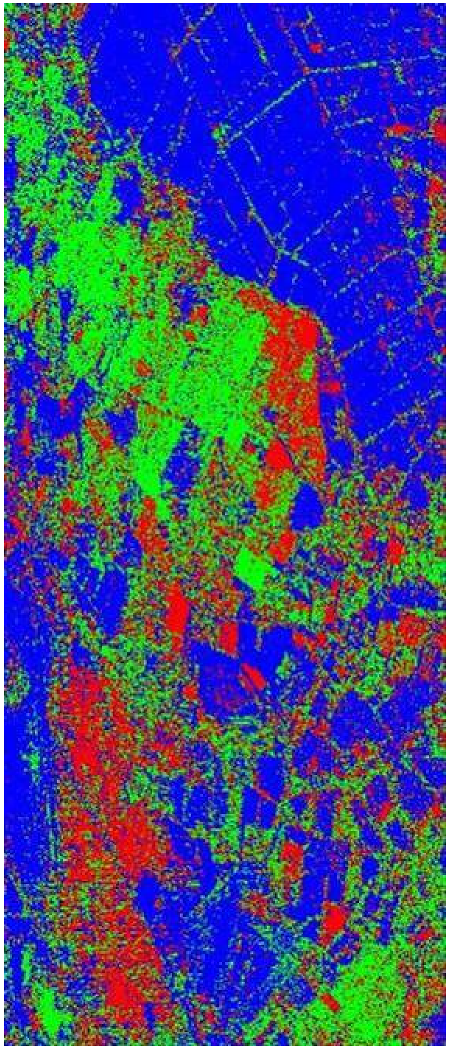




t_1=0.35

t_2=-0.2

Freeman-Durden classification



$$\mu$$

$$FD \begin{bmatrix} 35.38\% & 14.12\% \\ 7.12\% & 43.40\% \end{bmatrix}$$

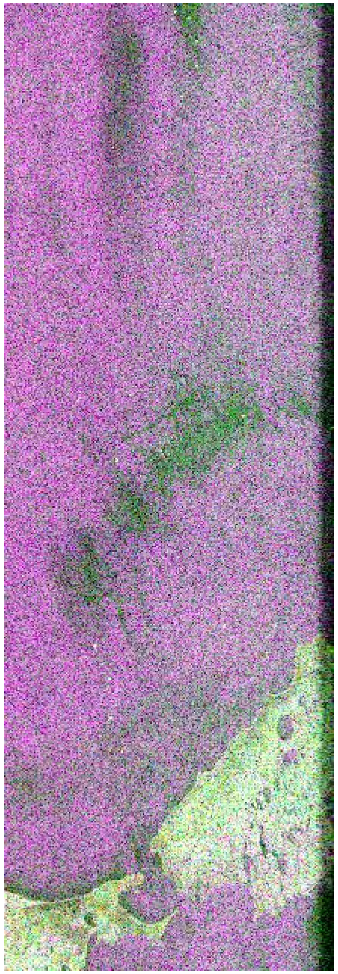
$P_s > P_d$ & $P_s > P_v$ ➔ surface

$P_d > P_s$ & $P_d > P_v$ ➔ Double-Bounce

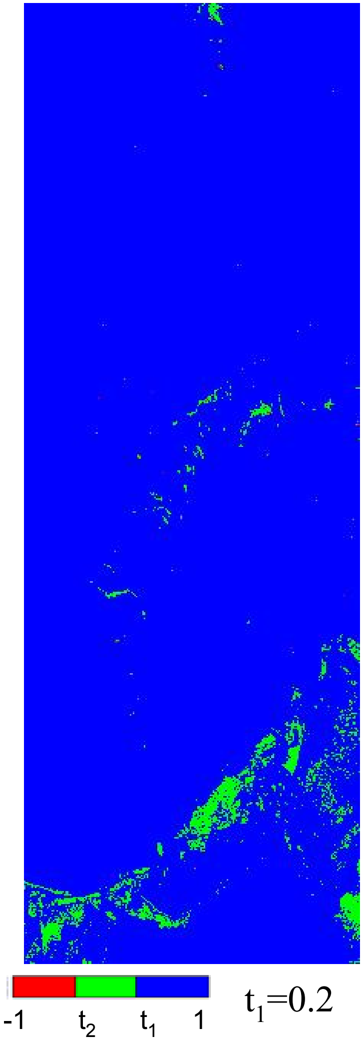
$P_v > P_d$ & $P_v > P_s$ ➔ volume

Conformity coefficient vs Freeman-Durden classification over PALSAR data

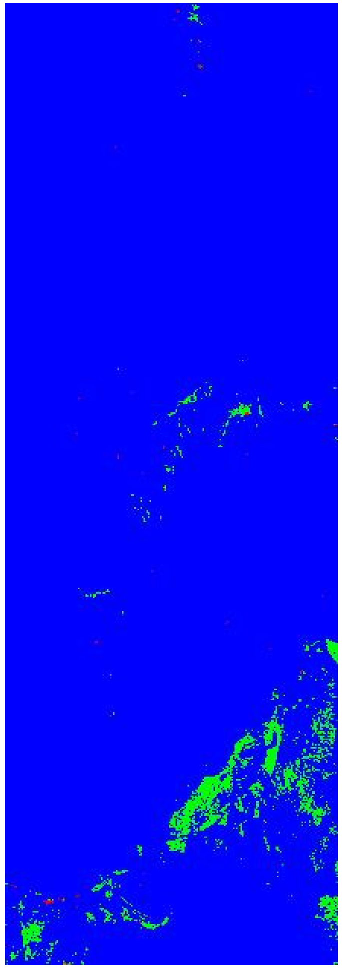
{R;G;B}={Hh;Hv;Vv}



Conformity coefficient



Freeman-Durden classification



$t_1=0.2$

$t_2=-0.25$

$$\begin{array}{cc} & \mu \\ FD & \begin{bmatrix} 96.66\% & 0.88\% \\ 0.67\% & 1.79\% \end{bmatrix} \end{array}$$

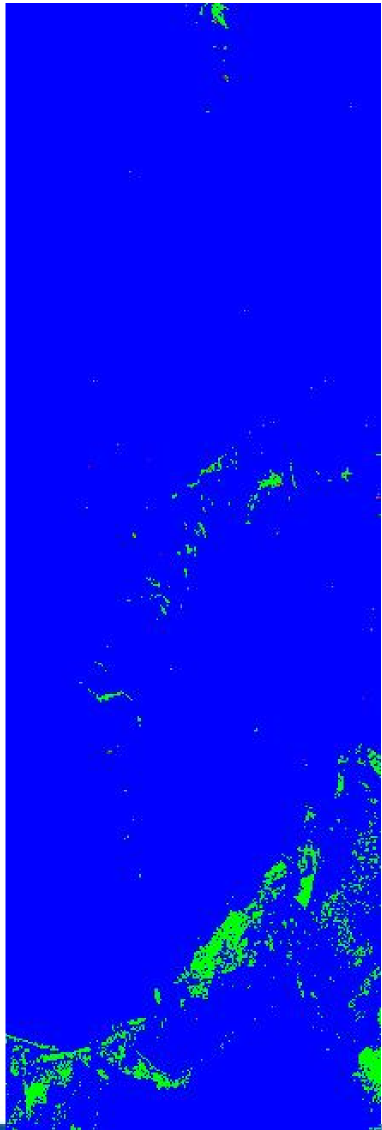
$P_s>P_d$ & $P_s>P_v$ ➔ surface

$P_d>P_s$ & $P_d>P_v$ ➔ Double-Bounce

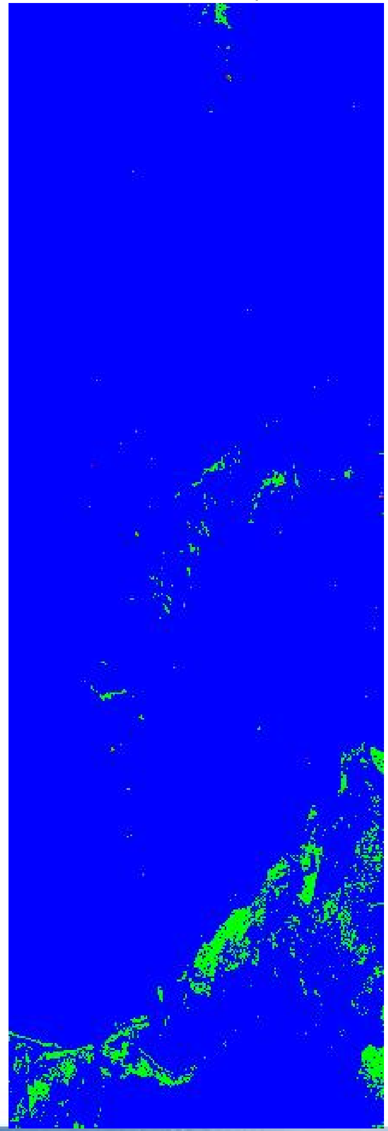
$P_v>P_d$ & $P_v>P_s$ ➔ volume

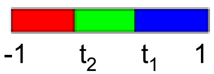
Conformity coefficient vs H/α classification over PALSAR data

Conformity coefficient



Cloude-Pottier classification

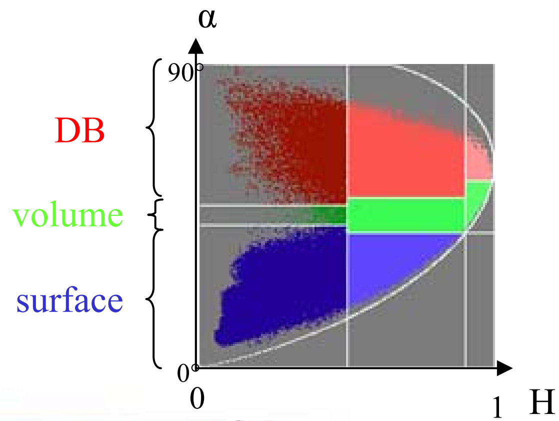




t_1=0.2

t_2=-0.25

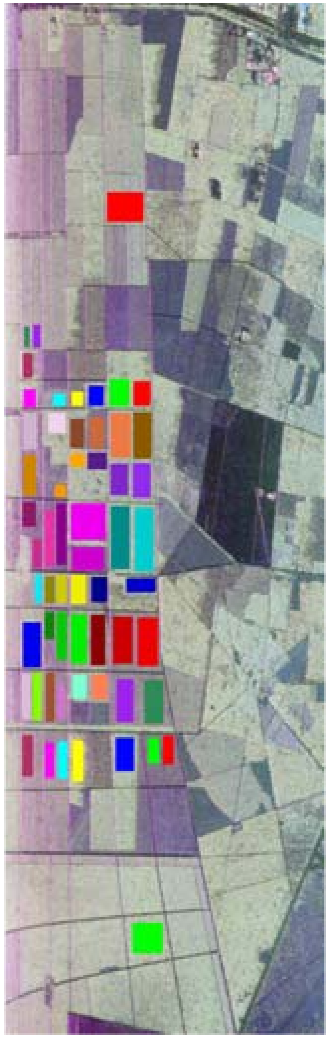
$$\mu \quad H/\alpha \begin{bmatrix} 96.94\% & 0.41\% \\ 0.39\% & 2.26\% \end{bmatrix}$$



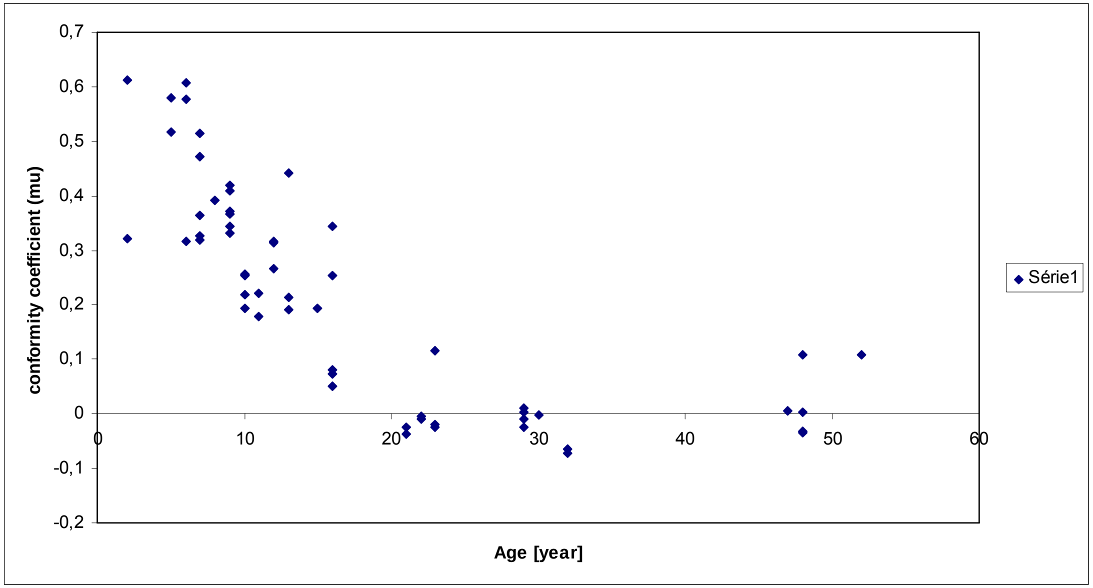
Images courtesy of Alaska Satellite Facility and JAXA

Behavior of μ with parcels ages

RAMSES data, Pyla, 2001, P-band



{R;G;B}={Hh;Hv;Vv}



-young parcels (<20 years), 0,2 < μ <1

-old parcels, μ ~ 0

Faraday rotation (FR) estimate

- Using FP data
  - Freeman method (2004,FP data) $\Omega = \pm\frac{1}{2}\tan^{-1}\sqrt{\frac{4\langle Z_{hv}Z_{hv}^{*}\rangle}{\langle M_{hh}M_{hh}^{*}\rangle + \langle M_{vv}M_{vv}^{*}\rangle + 2\,\mathrm{Re}\langle M_{hh}M_{vv}^{*}\rangle}} \pm \frac{\pi}{4}$
    with $Z_{hv}=0.5(M_{vh}-M_{hv})$
  - Bickel and Bates (FP linear data transformed in circular basis)

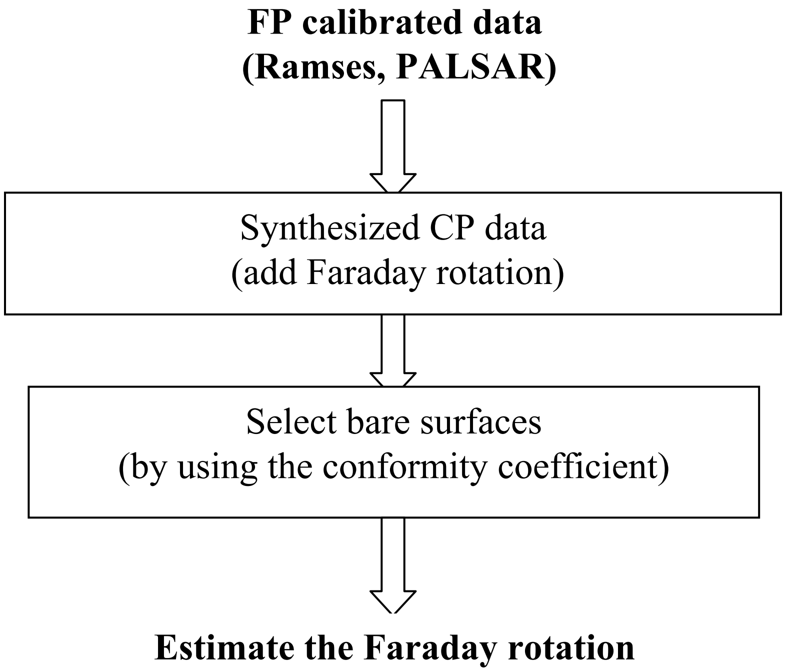
$$\Omega = \frac{1}{4}\arg\langle M_{RL}M_{LR}^{*}\rangle \pm \frac{\pi}{4}$$

- Using CP data
  - By correcting the data, then estimating $Arg\langle \tilde{S}_{Rh}\tilde{S}_{Rv}^{*}\rangle$ until it reaches the value of 90°±n180°
  - Linear receptions (H & V) $\Omega = \frac{1}{2} Arc\tan\left(2\frac{\mathrm{Re}\left(M_{RH}M_{RV}^{*}\right)}{\left(\langle M_{RV}M_{RV}^{*}\rangle - \langle M_{RH}M_{RH}^{*}\rangle\right)}\right) \pm \frac{\pi}{4}$
  - Circular receptions (L & C) $\Omega = \frac{1}{2} Arg < M_{RR}M_{RL}^{*} > \pm n\frac{\pi}{2}$

With assumptions: $\langle S_{HH}S_{HV}^{*}\rangle \approx \langle S_{VV}S_{HV}^{*}\rangle \approx 0$ *and* $Arg\langle S_{HH}S_{VV}^{*}\rangle \approx 0$

Process

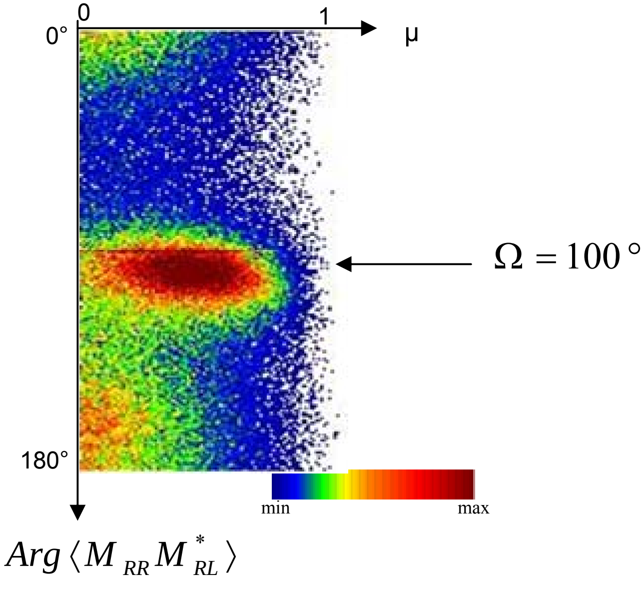
- Flow diagram of the process

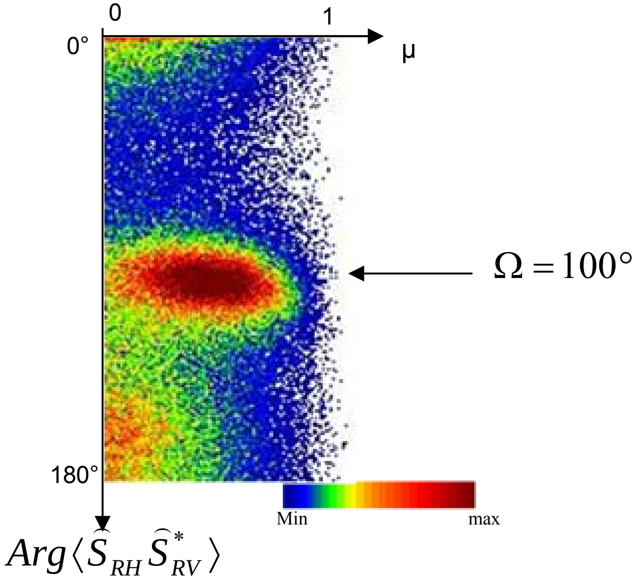


FR estimate vs conformity coefficient

$$\Omega = \frac{1}{2} Arg < M_{RR} M_{RL}^{*} > \pm n \frac{\pi}{2}$$

$$Arg \left\langle \widetilde{S}_{Rh} \widetilde{S}_{Rv}^{*} \right\rangle = 90° \pm 180°$$





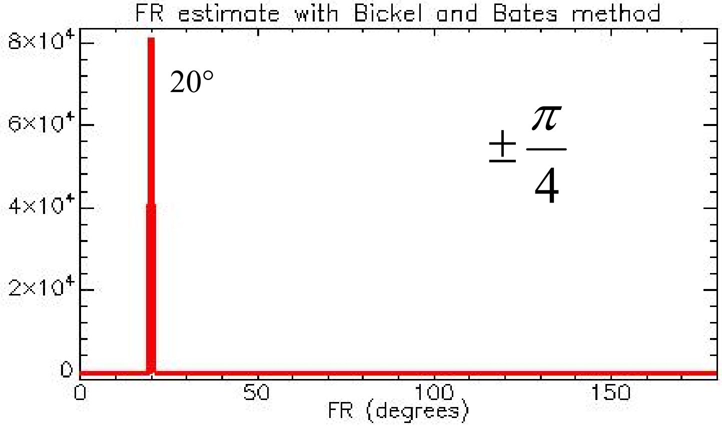
μ identifies the bare surfaces in CP

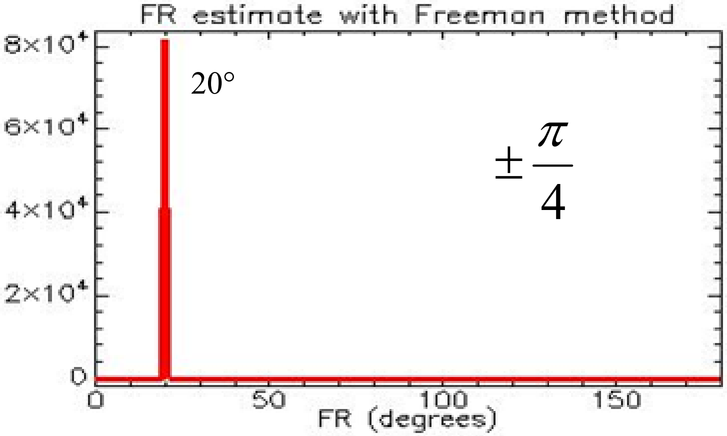
is FR independent

provides a robust estimate of FR

FR estimate over Ramses data (110° FR has been introduced)

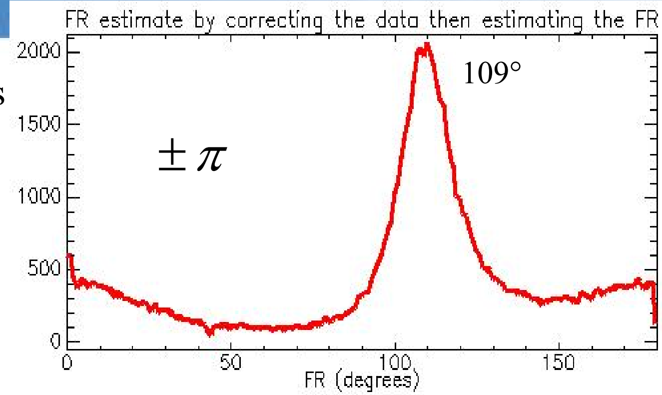
Over the full scene

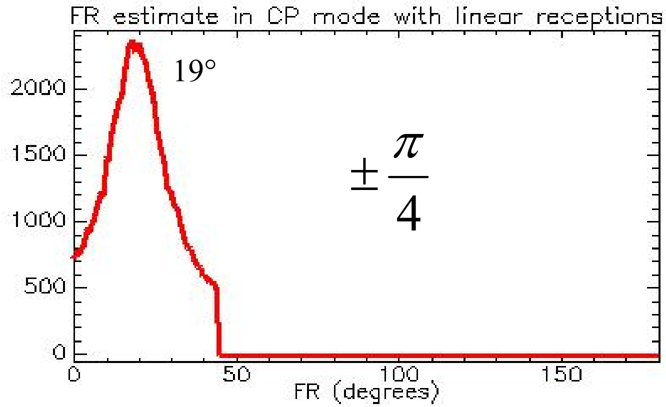


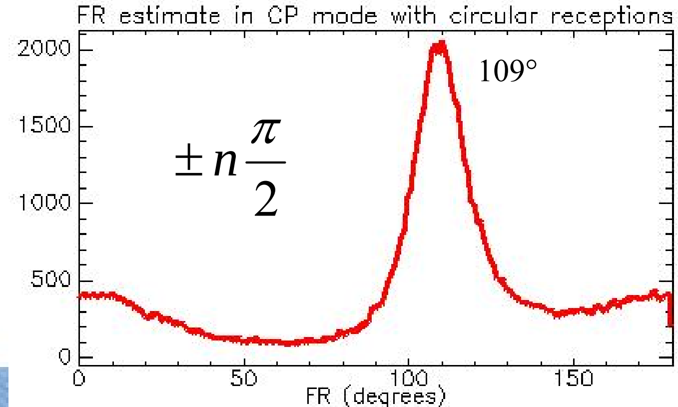


Over bare surfaces

μ>0.35

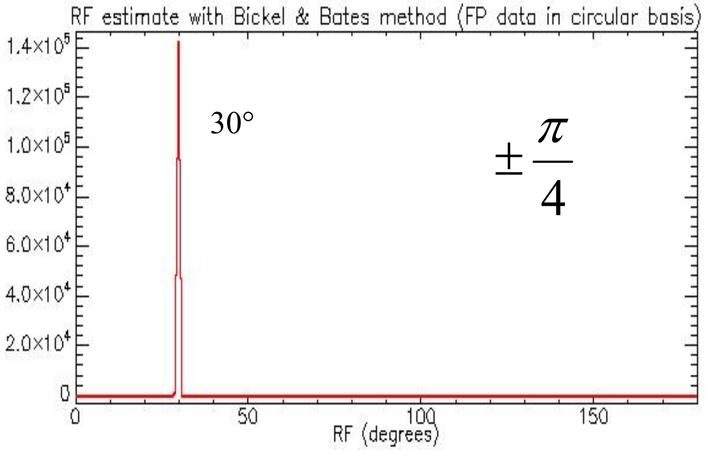


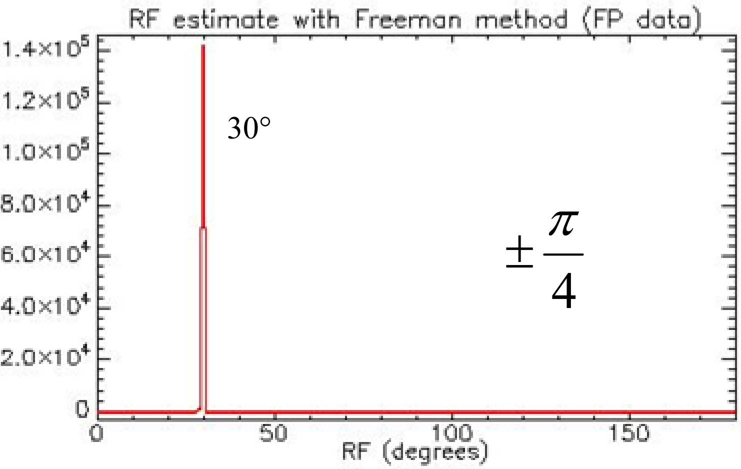




FR estimate over PALSAR data (30° FR has been introduced)

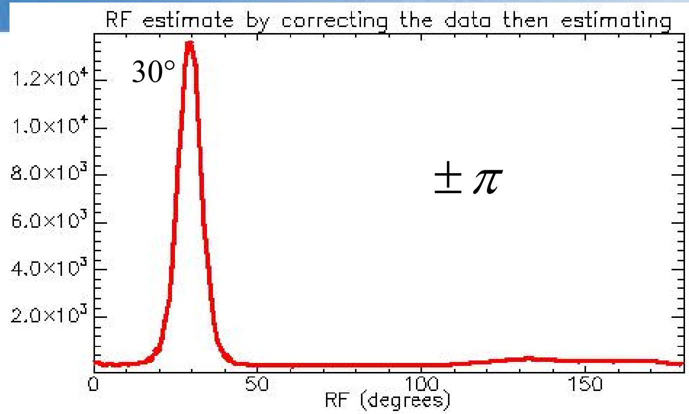
Over the full scene

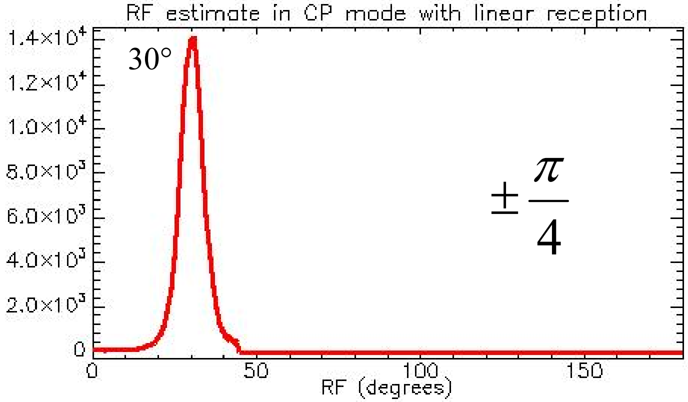


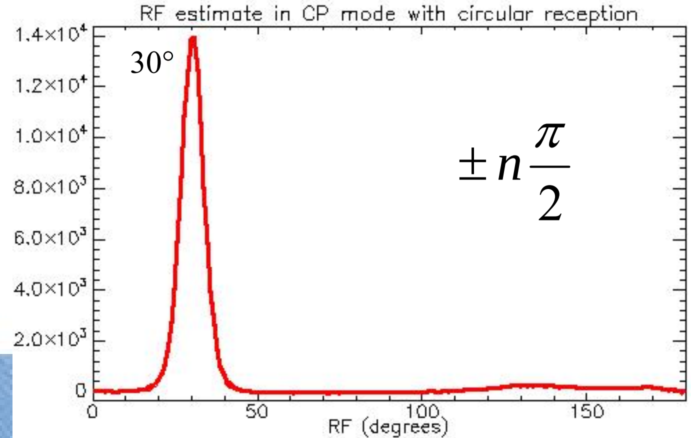


Over bare surfaces

μ>0.2

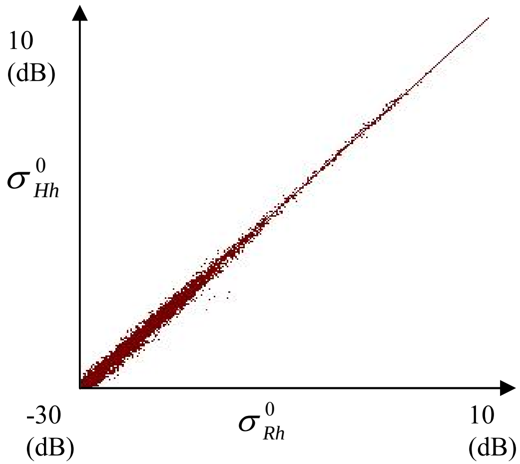


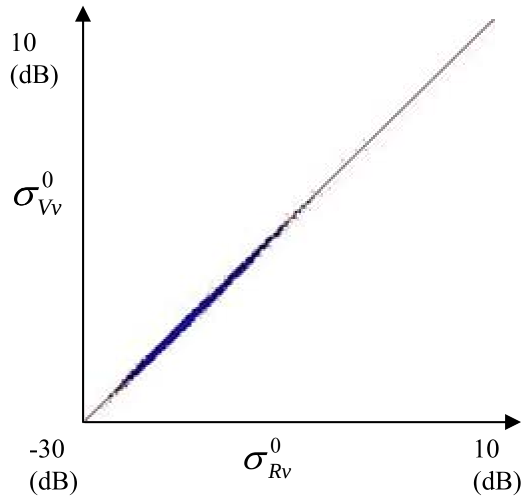




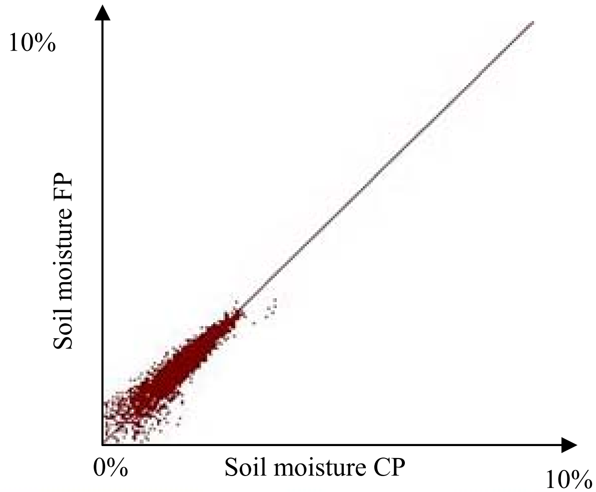
CP vs FP signatures and applying the Dubois et al. (1995*) algorithm to Ramses CP data

- Over bare surfaces $\begin{pmatrix}\tilde{S}_{RH} \\ \tilde{S}_{RV}\end{pmatrix} \cong \begin{pmatrix} S_{HH} - jS_{HV} \\ S_{VH} - jS_{VV}\end{pmatrix}$





WS : 7x7, RMS deviation less than 1dB



WS : 7x7, RMS deviation less than 2%

P. Dubois, J. van Zyl and T. Engman, "Measuring Soil Moisture with Imaging Radars", *IEEE Trans. Geosci. Remote Sens.*, vol. 33, no. 4, pp. 915-926, July 1995

Summary

- Compared conformity coefficient, μ, which is FR-invariant and can separate scattering types with
  - Freeman-Durden classification
  - Cloude-Pottier classification
  - Assess μ over Ramses and PALSAR data

- Used μ to screen for surface scatterers ➔ estimate of FR
  - Assess FR estimates using CP data with FP methods (Freeman and Bickel&Bates)
  - Compute FR over Ramses and PALSAR data

- For the same bare surfaces, shown that soil moisture can be estimated from CP data with an equivalent accuracy than with FP data.