Hybrid- Versus Matched- Transmit-Receive Antenna Dual- and Fully Polarimetric SAR: Polarization Efficiency and Applications

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Acknowledgment

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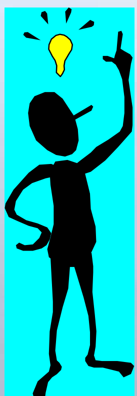
Background

- Compact& Hybrid:
  - Transmitted polarization: H+V (π/4) or CP (hybrid)
  - Received polarization: H and V
- Firstly introduced in 1965 (Long 1967, Green 1968)
- Resuscitated in 2005 (Souyris 2005, Raney 2007):



- Mis-leading message:
  - **“Cheap way to do polarimetry at double swath” !!!!**
  - **“The dual-polarization hybrid Compact data always approach - and occasionally are comparable to analyzes of quad-pol data”**
- Big **Confusion** => Full Polarimetry (FP) questioned with reference to the Hybrid (Double swath, Half data volume)

OUTLINE

☛SAR Architecture: Hybrid versus Matched Antennas

- Compact (Hybrid-) versus (Orthogonal-) Dual CP in terms of antenna polarization efficiency
- Optimum architecture for Fully Polarimetric (FP) SAR ☛ the Livingstone architecture => Convair 580

☛Applications: Dual-pol Hybrid (Compact) versus FP

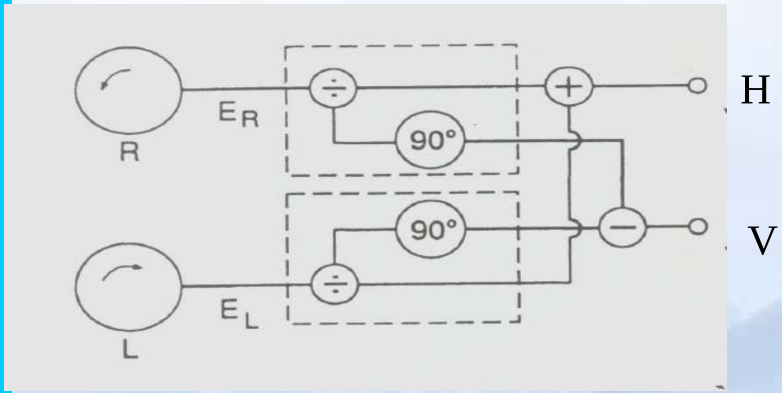
- Quantification of the Compact loss of information using **the degree of polarization** (DoP) excursion and signature
- **Reconstruction** of FP from the Compact (Souyris method) and demonstration of the loss of key polarimetric information for peatland subsurface water monitoring

Hybrid Dual- and Quad-Pol

- ☛ Transmit CP using H-V antenna
- ➢ Receive linear (H & V)
  - – RCP=> RH-RV (Compact)
  - – LCP=> LH-LV (Compact)
- ☛ Convenient way for the implementation of Dual-CP using H-V antenna

Alert:

- ✷ RH and RV not Matched antenna
  - ➩ 50% **efficiency** => 3 dB Loss
- ✷ Transmitted RCP Not **perfectly circular**
  - ➢ RCM, ALOS2, and RISAT

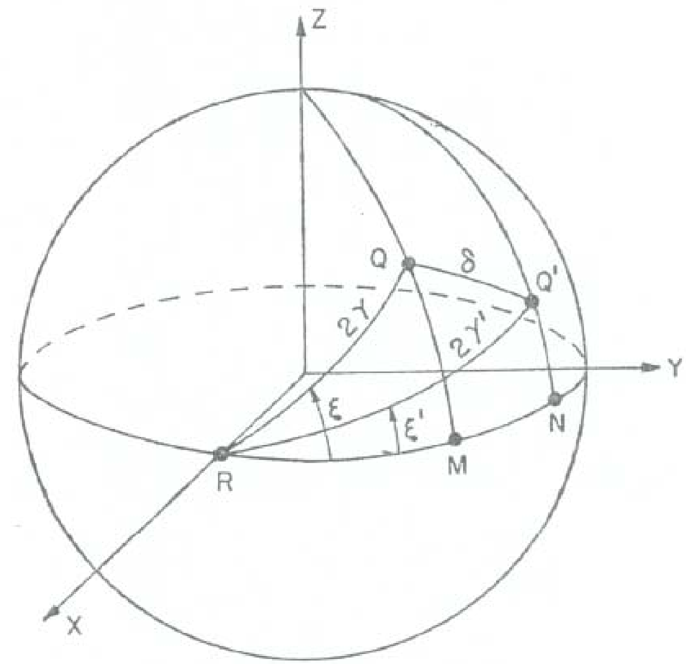


Generation of CP from an H-V Antenna (Stutzman1984)

Compact-Hybrid versus Dual CP Polarization Efficiency

- **Polarization Efficiency**: ratio of the power received by an antenna of a given polarization to the power that would be received from a plane wave of the same flux density and direction of propagation whose polarization state has been adjusted for maximum received power (*IRE* 1960)
- E=1 when the antenna polarization is **matched** with the incident wave polarization, and **all the energy** contained in the completely polarized wave is **absorbed** by the antenna

☛ **Ko 1962, Stutzman 1983**



δ: Angular distance between the antenna and the incident wave polarization states

Polarization efficiency variations as function of the antenna wave polarization mis-match angle and the DoP of the scattered wave (*Ko 1962, Stutzman 83*)

- δ=0º & E=1: Matched Antenna

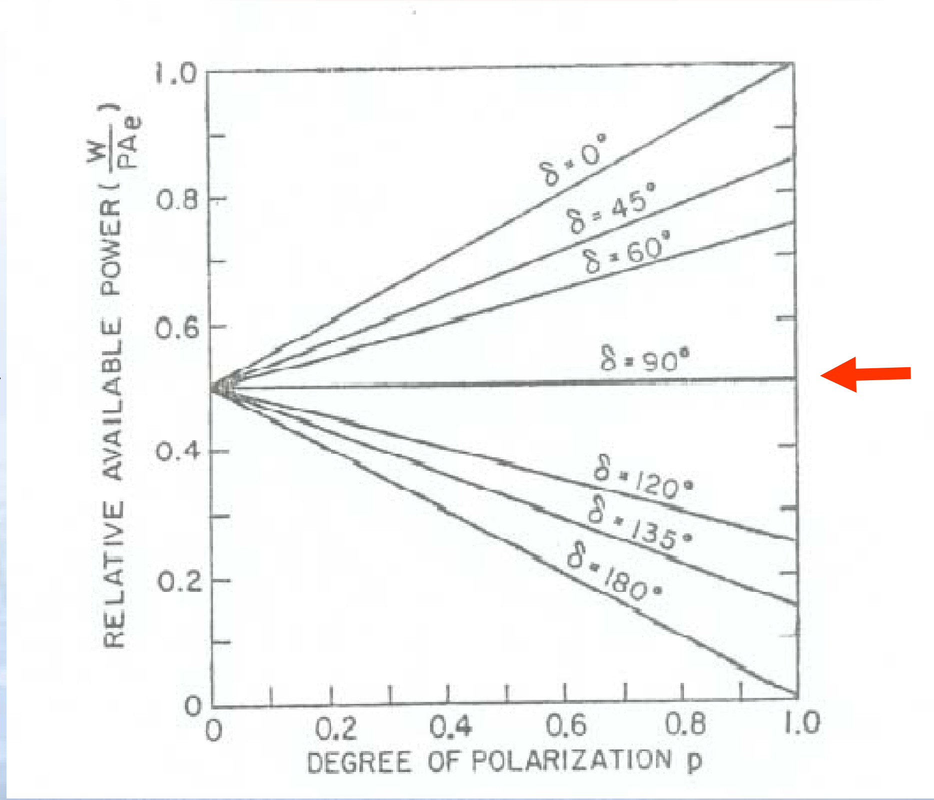
➪ Unpolarized wave: E=0.5

✶ **Hybrid**: δ=90° ➡ E=0.5

➪ Available power from the antenna **minimum** and independent of the DoP

✶ Hybrid (RH-RV): 3 dB **loss** with reference to **matched** CP: RR-RL

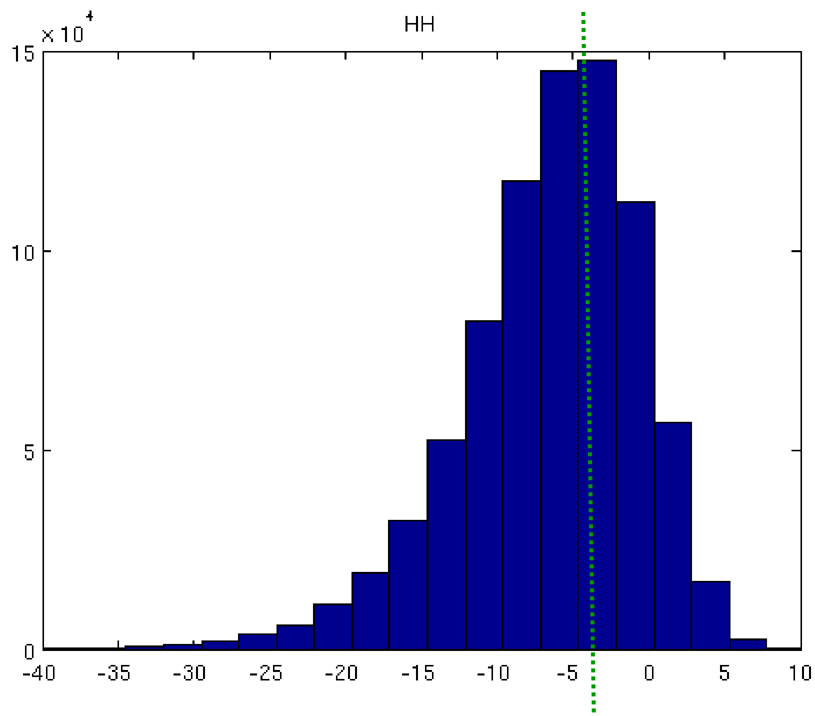
➪ **Less accurate** RL for signal of low S/N (with ref. to RR-RL)

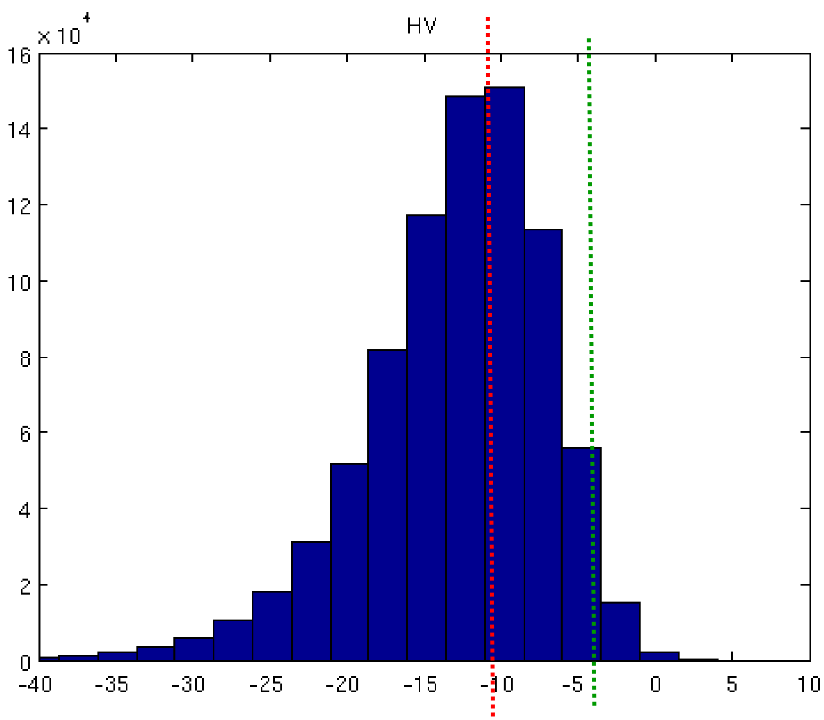


H.C. KO, IRE, 1962

Forest: HV backscattering 6 dB lower than HH and VV

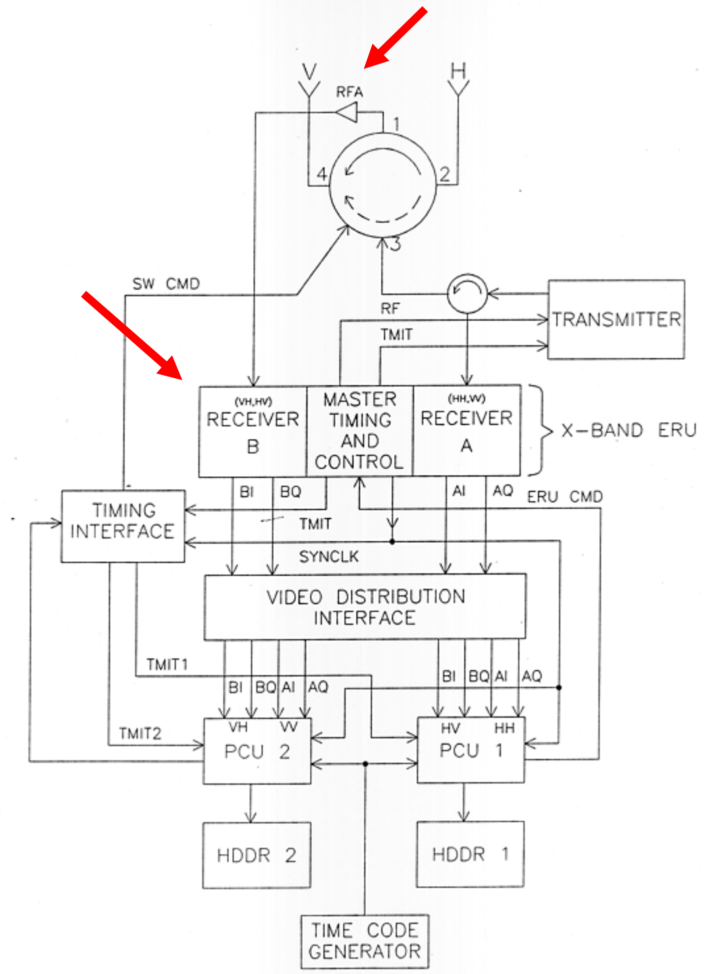
- HH: -4.86 dB HV: -11.26 dB (Amazonia, Radarsat2)
- **Variable Gain Amplifier** (VGA) or **Switched Attenuator** applied right after **LNA** to adjust the position of the receiver dynamic range to the expected range of backscattered power before **ADC**





Fully Polarimetric System Design
The Livingstone FP Architecture (1988)

- HV&VH and HH&VV **routed** to two **separate** receivers
  - LNA well beyond the receiver
  - (HV-VH)- S/N increased of **6 dB**
- Adapted by JAXA to Active Array PALSAR (Shimada 2009)
  - ⇨ HV **improved** of 9 dB in S/N



Convair-580 Polarimetric SAR

Hybrid versus Matched Transmit-Receive Antennas

Dual-Pol:

✷ RH and RV => Receiving Wave-Antenna **Not Matched**

- ➩ 50% **efficiency** => 3 dB Loss
- ➩ RL of low S/N affected

Quad-Pol:

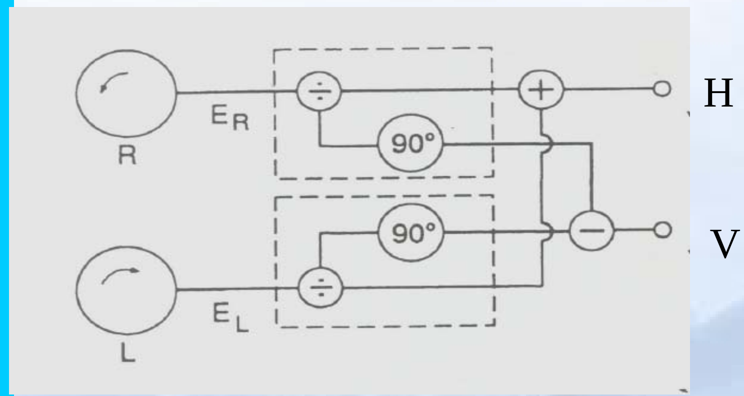
- ➩ 50% **efficiency** => 3 dB Loss
- ➩ X-Pol (RL and HV and ..) of low S/N affected

☛ **Ko 1962, Stutzman 1983, and … (1960)**

SAR requirements: S/N Not NESZ ????!!!!

Hybrid Calibration Requirements

- Transmitted RCP assumed **perfectly circular**
- **Not realistic**: Actual technology does **not permit** the generation of **perfect CP** (RCM, ALOS2, RISAT)
- RCM: 5° to 10° error in the ellipticity as a function of the Beam Scan Angle
- 2-3 dB error in RH and RV (300km)
- **Calibration Requirements**:
- RH and RV: within 0.5 dB in radiometry and 10° in phase
- **Synthesis** of RR, RL, Rπ/4, … etc



Generation of CP from H-V Antenna

Canada

Polarimetric Applications: Hybrid Versus FP

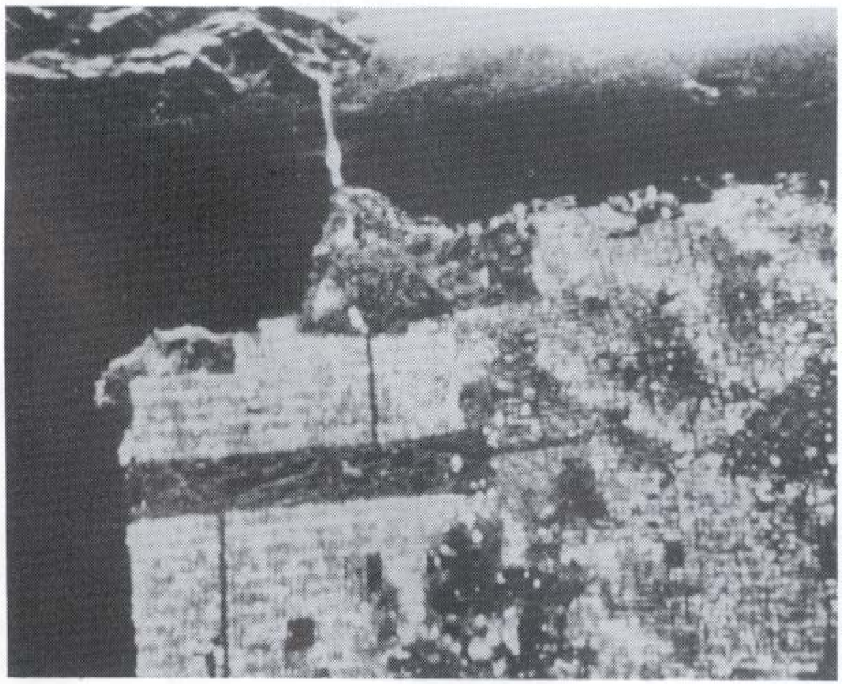
- Hybrid and FP ⇨ **Similar** target scattering **classification** (J.C. Souyris, K. Raney, P. Dubois, F. Charbonneau, … etc)
- Mis-leading message: **"Cheap way to do polarimetry at double swath and half data volume"** **!!!!**
- **Comparison** based on simple **Coarse** Scattering Classification: Surface scattering (**Single** Bounce)**-double-**bounce and **Volume** (**Random**) Scattering
- Polarimetry **EQ** Cloude-Pottier or Freeman Decomposition**??!!**
- Hybrid:
  - ⇨ Raney Hybrid **DoP-δ** decomposition
  - ⇨ Souyris Quad-pol **reconstruction** (from Hybrid)
- Polarization Synthesis ⇨ **abandoned** since Cloude-Pottier Decomposition 1996 and Freeman 1998

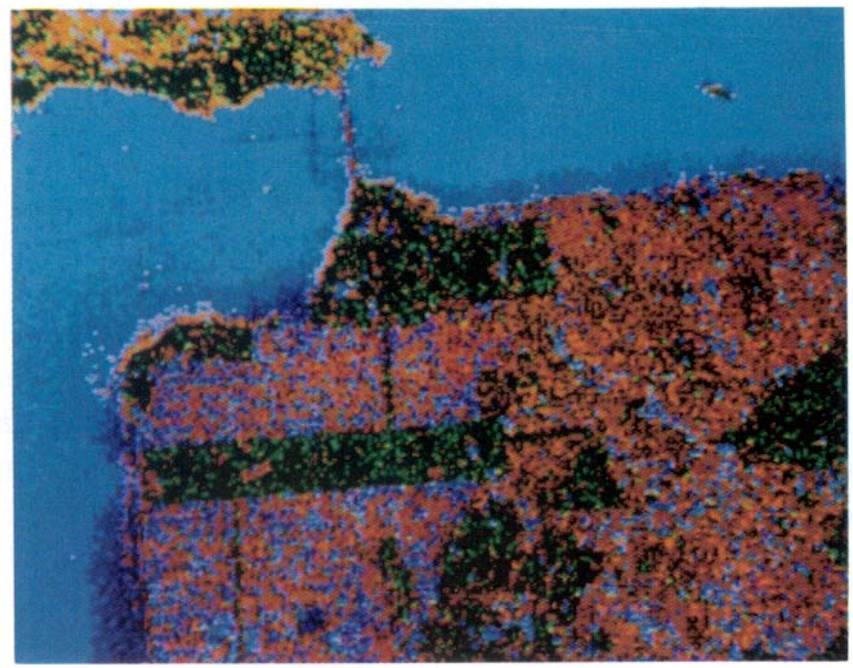
Hybrid Versus FP
Using DoP and Ro Excursion

- DoP **extrema** and **Excursion** (Δp) shown very **promising** for target scattering classification
- Scattered intensity R_0 extrema shown important
- Touzi R et al., “Polarimetric discriminators for SAR images” , *IEEE TGRS*., Vol.30, No. 5, Sep. 1992

- Assessment of the **Loss** of information related to the use of only **one** transmitted polarization (**CP or π/4**) among the 180 x 90 (ψ,χ) polarization possibilities using:
  - DoP **excursion:** Δp
  - DoP **signature** as a function of transmitted antenna polarization
  - R_0 **excursion** and **signature**

San-Francisco Segmentation using the maximum DoP and the DoP excursion Δp

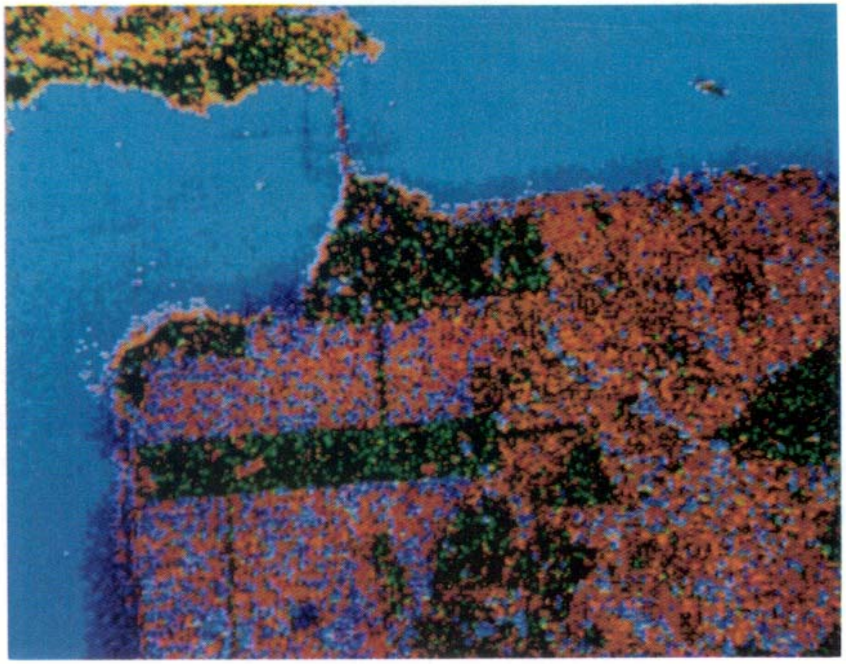




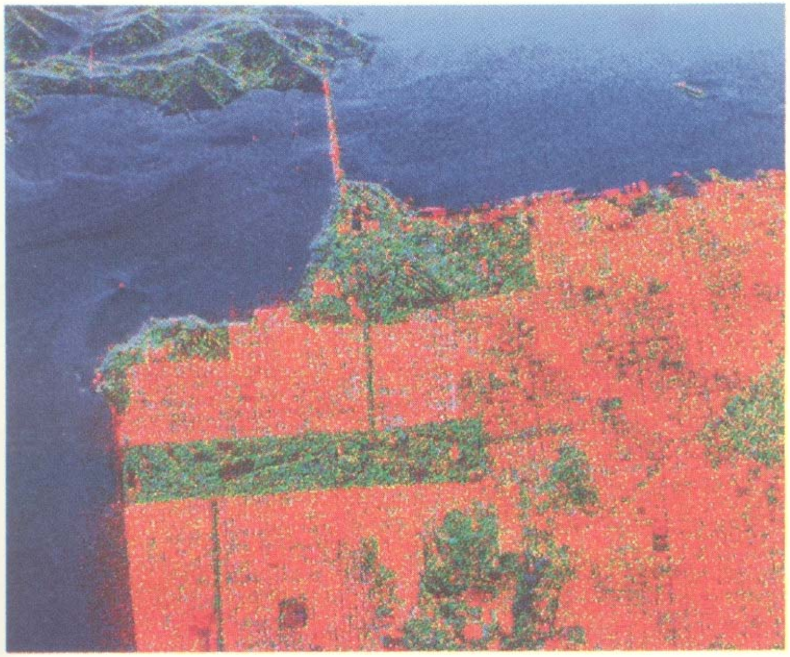
☛ **Touzi R et al., "Polarimetric discriminators for SAR images" ,**

***IEEE TGRS*., Vol.30, No. 5, pp 973-980, Sep. 1992**

Van Zyl Decomposition (1988)
Single-, Double-, and Volume scattering

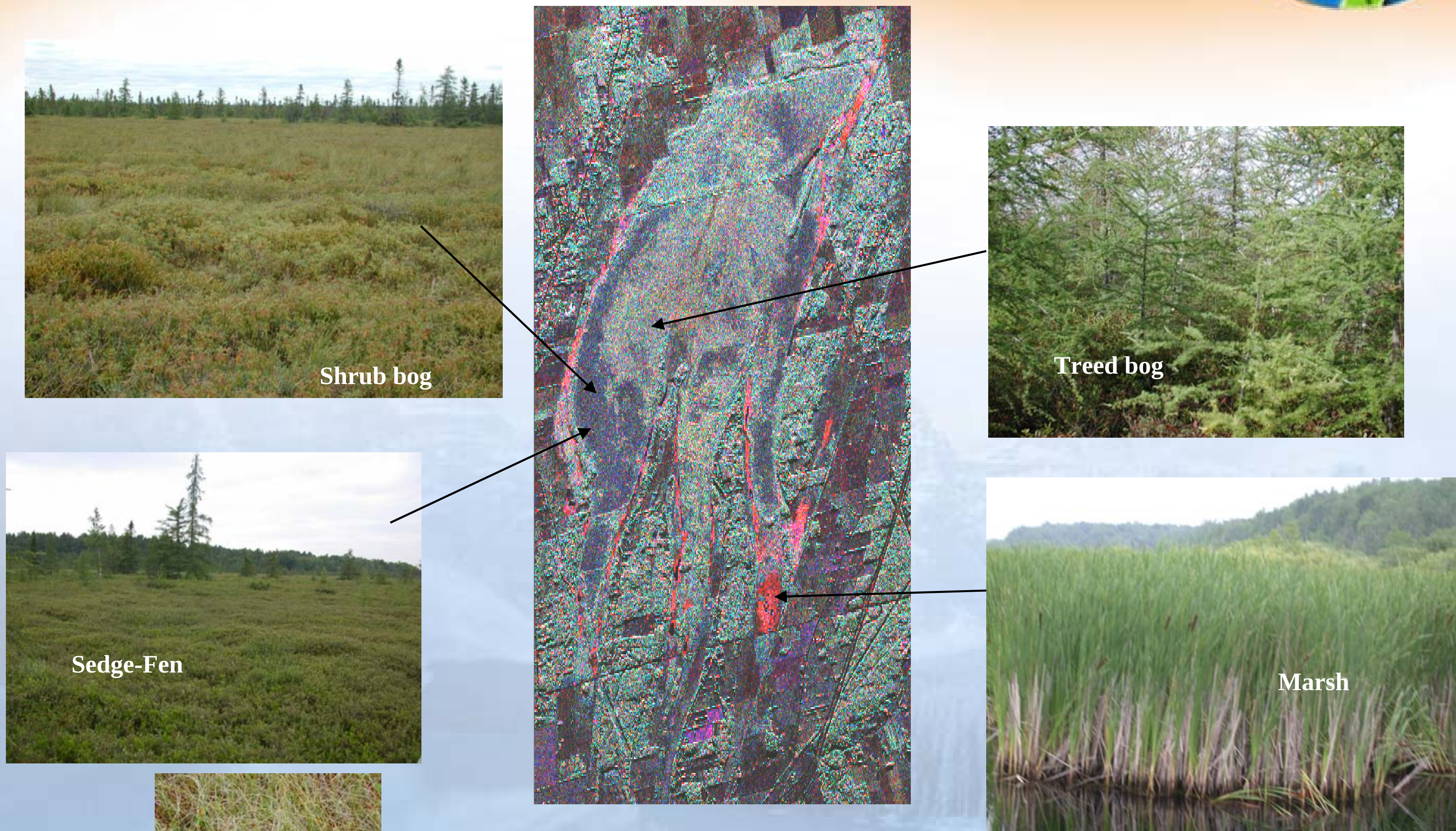


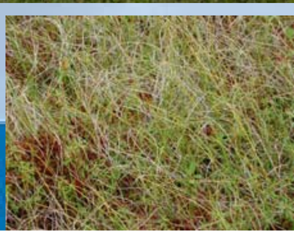
Touzi DoP Classification 1988



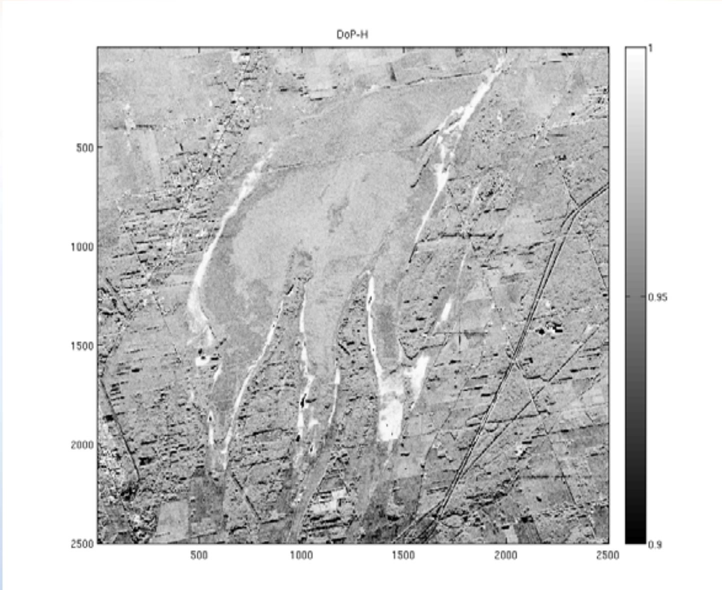
VanZyl Classification 1988

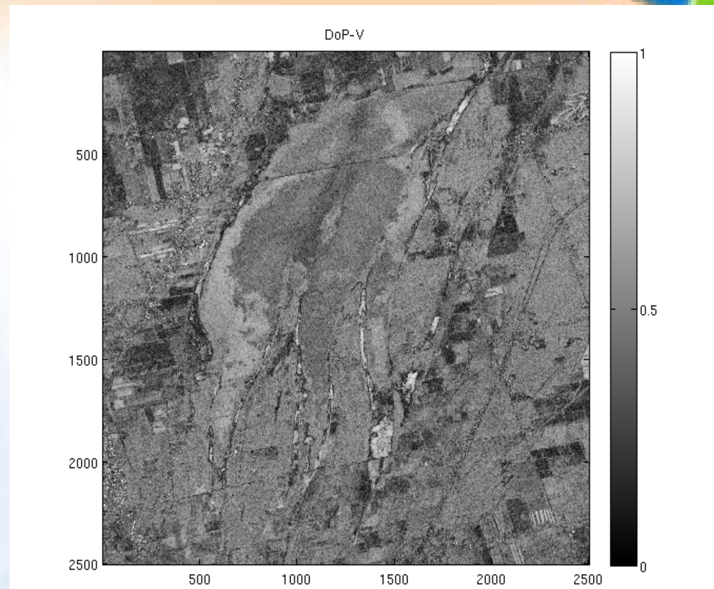
Study Site: Mer Bleue Wetland
Convair-580 SAR HH (red), HV (green), VV (bleue)

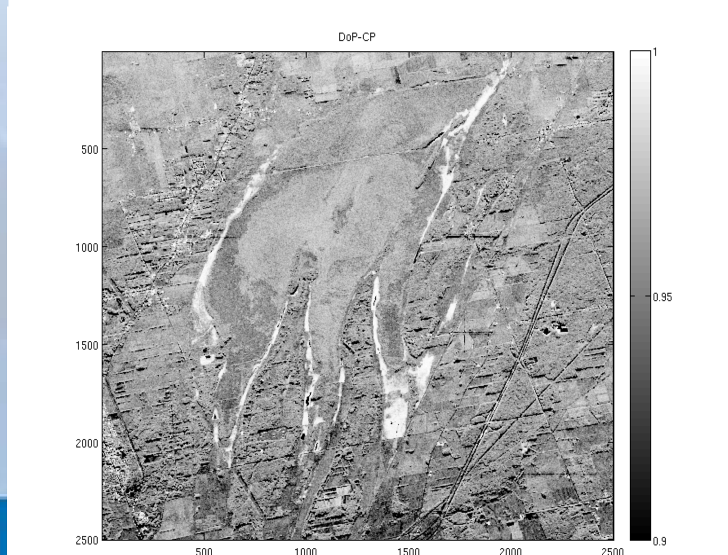


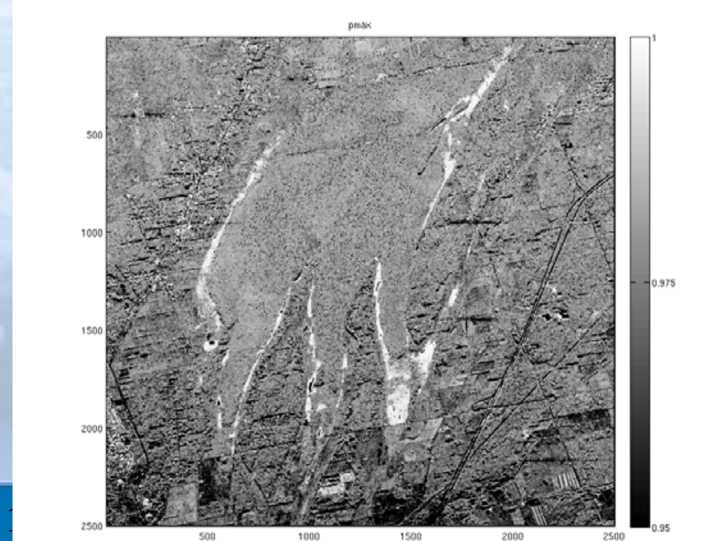


Maximum DoP and DoP for H, V, and CP Polarization

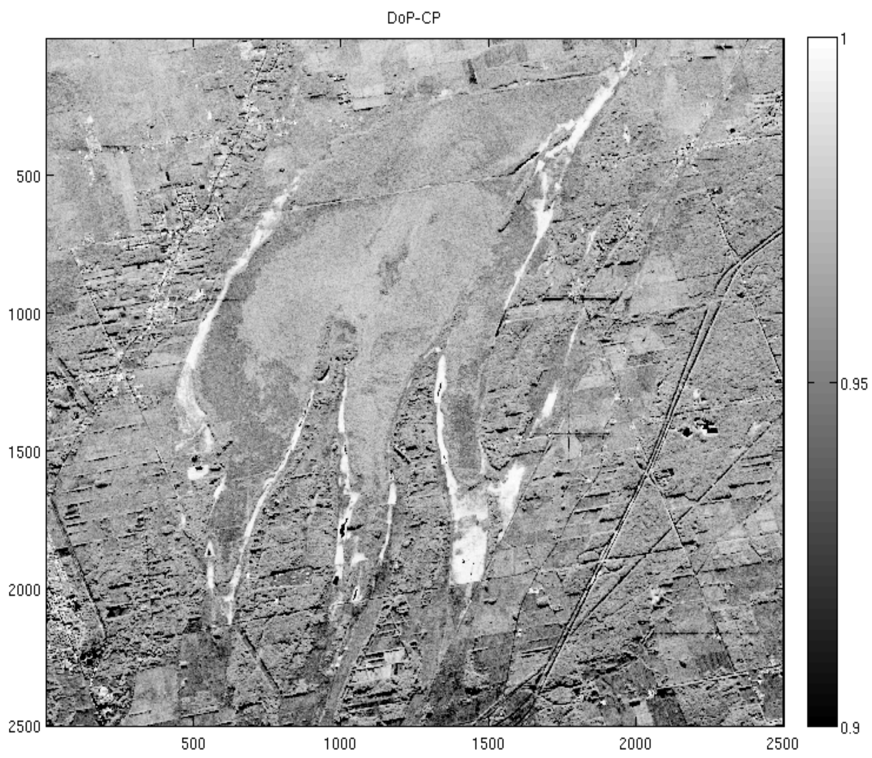




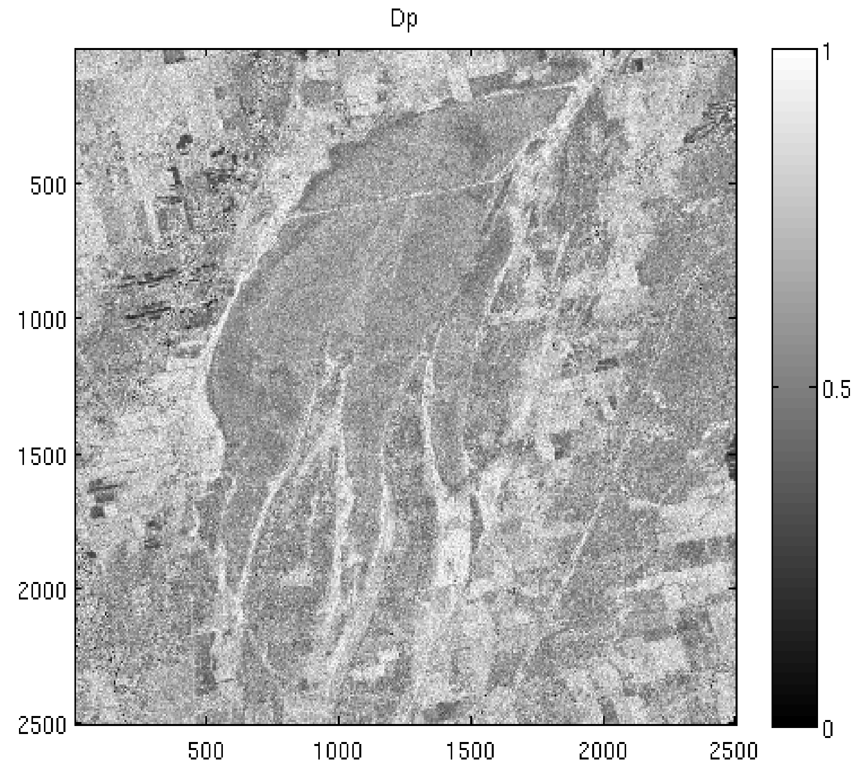




DoP Excursion ☛ Hybrid Information Loss

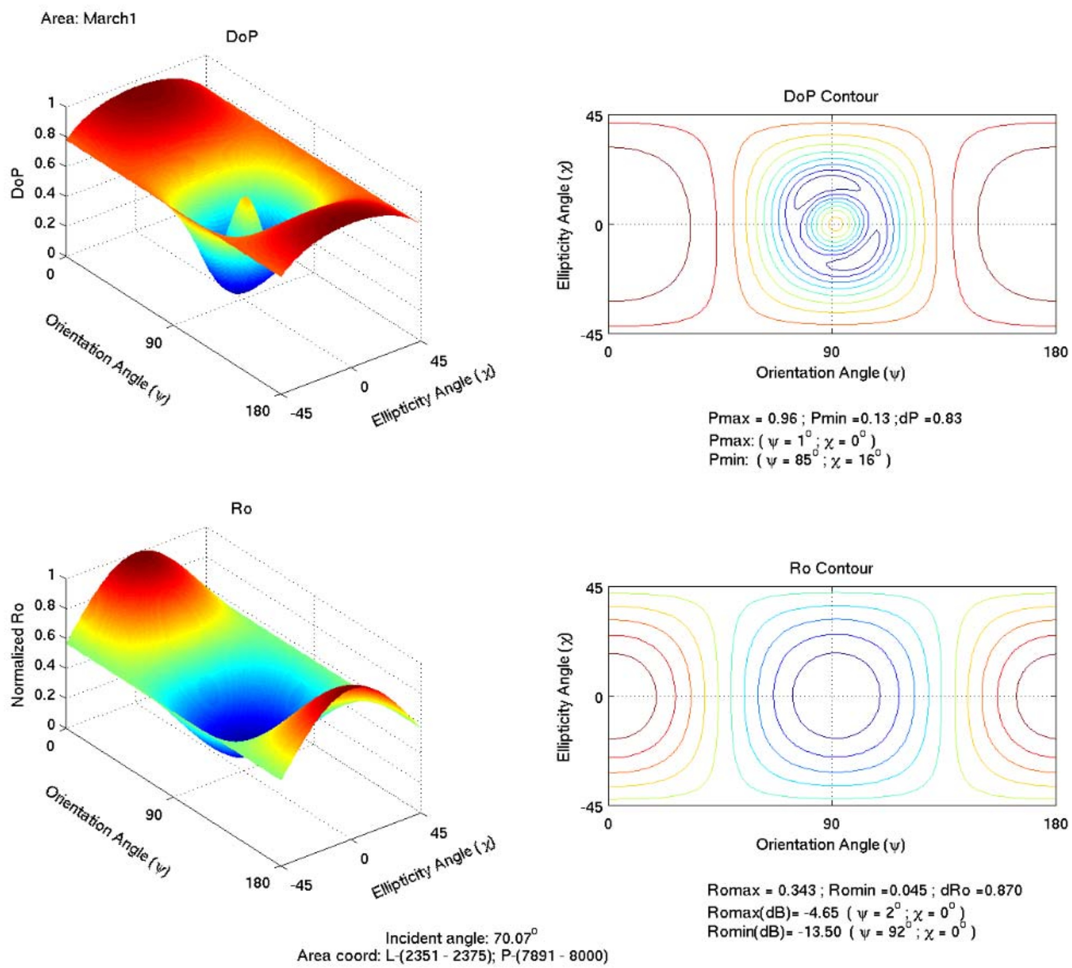


Hybrid DoP

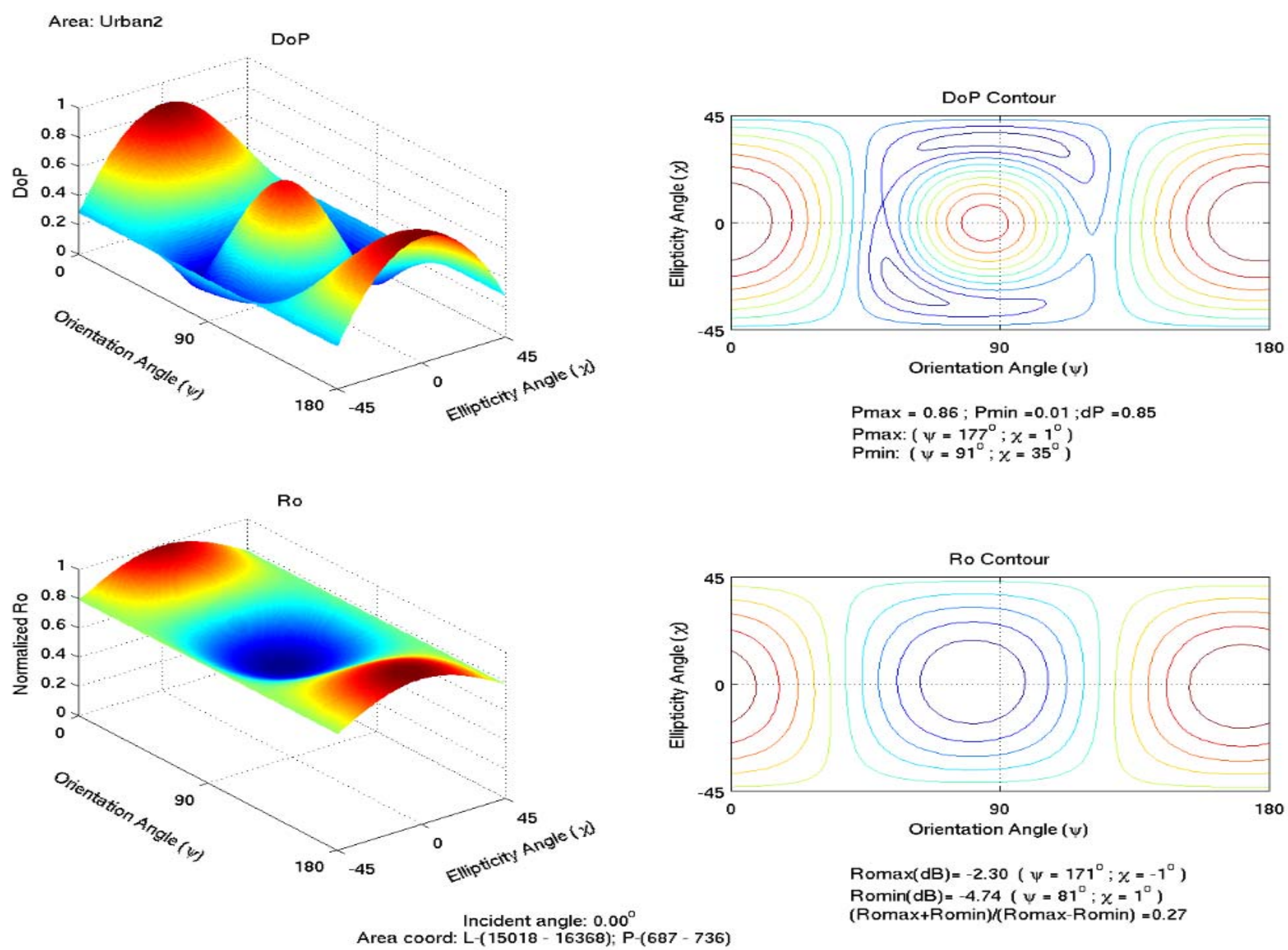


Δp

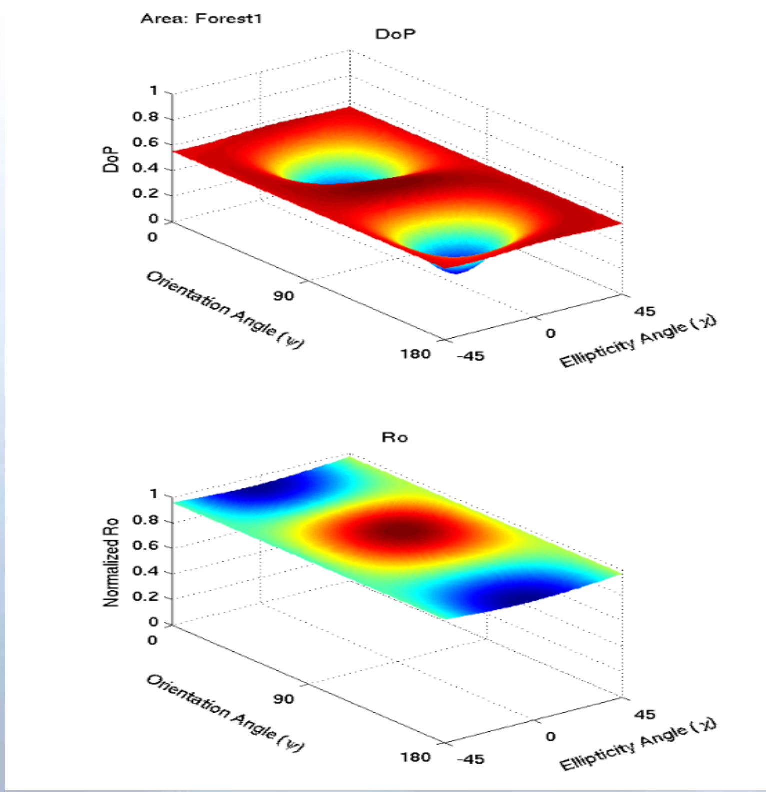
DoP and R_0 Signature as a function of transmitting antenna polarization Target: Marsh field



DoP and R_0 Signature
Urban Area

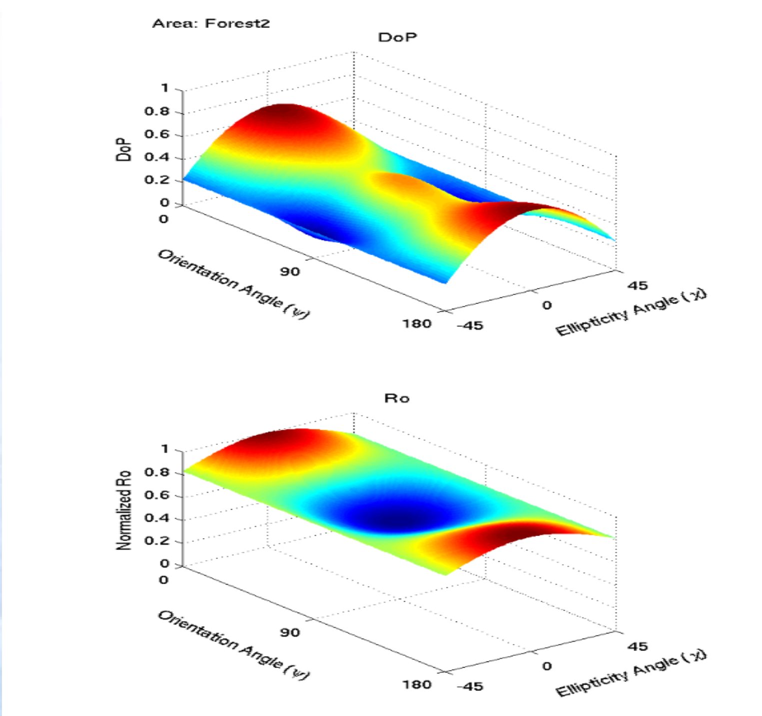


DoP and R0 Signature of a Forest C-band CV580 and L-band ALOS



Pmax = 0.60 ; Pmin =0.14 ;dP =0.46
Pmax: (ψ = 89^0 ; χ = -5^0)
Pmin: (ψ = 43^0 ; χ = 6^0)

Romax = 0.092 ; Romin =0.085 ; dRo =0.072
Romax(dB)= -10.36 (ψ = 88^0 ; χ = 3^0)
Romin(dB)= -10.69 (ψ = 178^0 ; χ = -3^0)



Orientation Angle (ψ)

Pmax = 0.69 ; Pmin =0.08 ;dP =0.62
Pmax: (ψ = 0^0 ; χ = 1^0)
Pmin: (ψ = 77^0 ; χ = -34^0)

Orientation Angle (ψ)

Romax(dB)= -2.90 (ψ = 175^0 ; χ = -2^0)
Romin(dB)= -4.82 (ψ = 85^0 ; χ = 2^0)
(Romax+Romin)/(Romax-Romin) =0.22

Compact Versus FP

HV reconstruction from Compact (Souyris 2005)

- Reflection symmetry: $\langle hh.hv^* \rangle = 0 = \langle vv.vh^* \rangle$
- $X = \langle |hv|^2 \rangle$, $H = \langle |hh|^2 \rangle$, $V = \langle |vv|^2 \rangle$, $P = \langle hh.vv^* \rangle$
- Iterative method to estimate $\langle |hv|^2 \rangle$ under the condition:

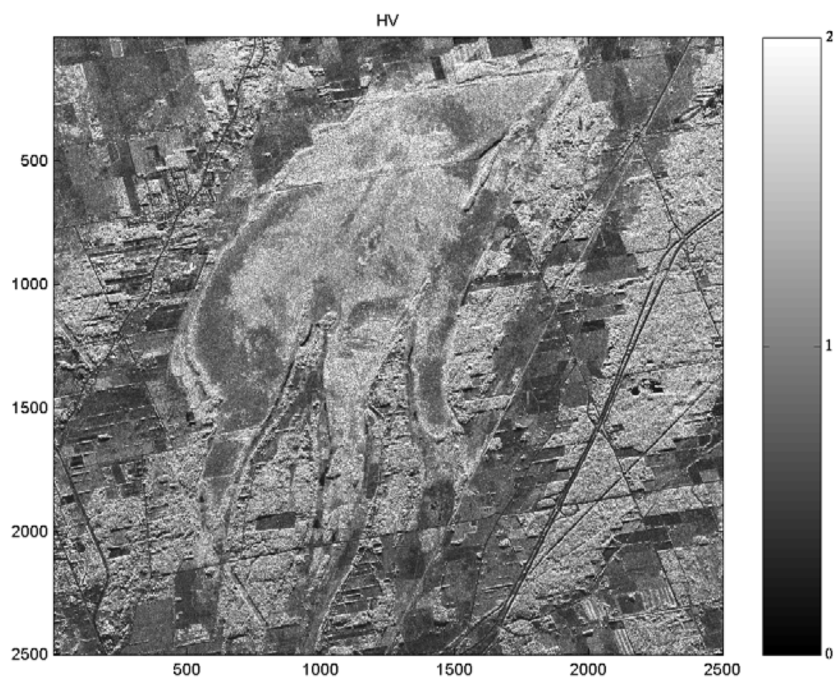
$$[J]_{\pi/4} \cong \begin{bmatrix} H+X & P+X \\ P^*+X & V+X \end{bmatrix}$$

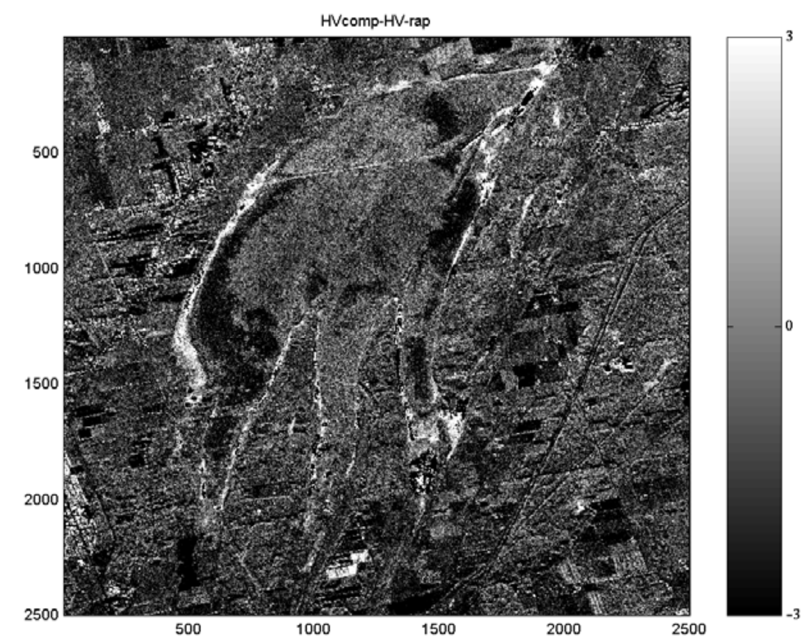
$$\frac{X}{H+V} \cong (1-\rho_{hhvv*})/4$$

➢ Estimate of FP covariance =>

$$[\hat{C}]_{FP} \cong \begin{bmatrix} j_{11}-X & 0 & j_{12}-X \\ 0 & 2X & 0 \\ j_{12}{}^*-X & 0 & j_{22}-X \end{bmatrix}$$

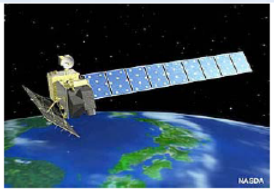
HV reconstruction from Compact 3-6 dB Error

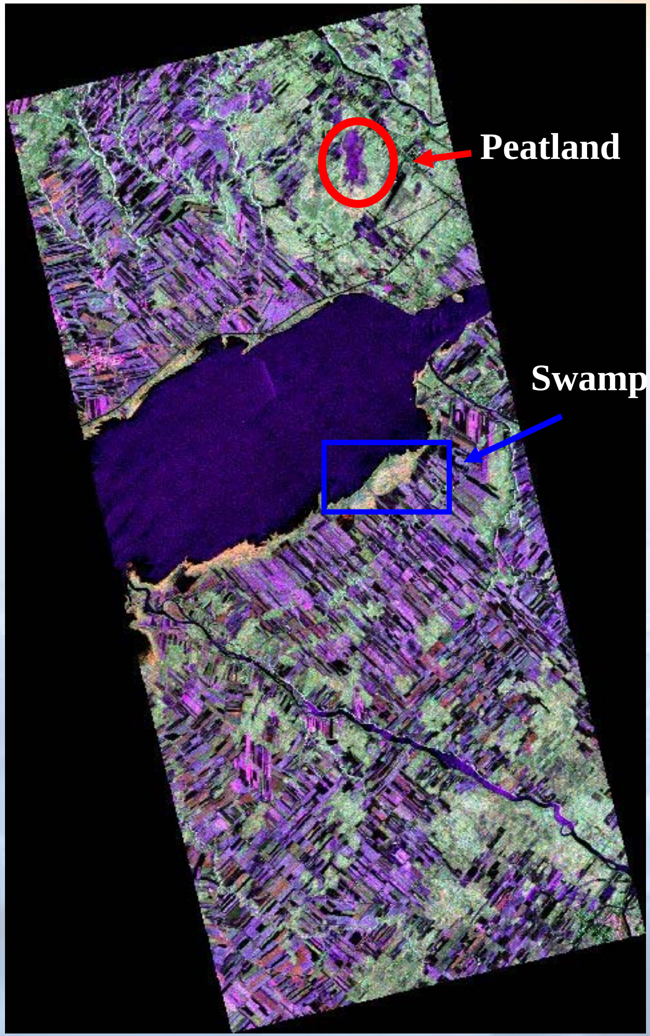




- Radiometric calibration error (3-6 dB)
- ➪ <|hv|^2> reconstructed **not reliable** (CEOS Requirement 0.5 dB)
  - Sedge Fen: 3 dB error
  - Treed Bog: 2dB
  - Marsh: more than 6 dB

Peatland subsurface water monitoring using L-Band PALSAR (Lac St Pierre)



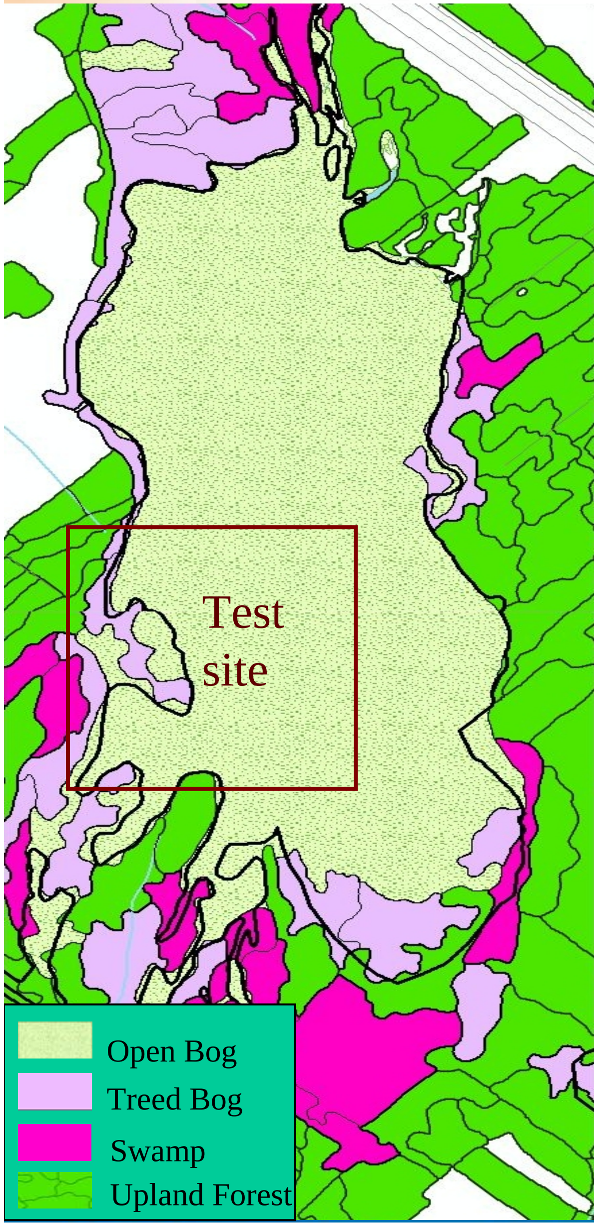


PALSAR, Nov. 10, 2007

PALSAR, May 13, 2007

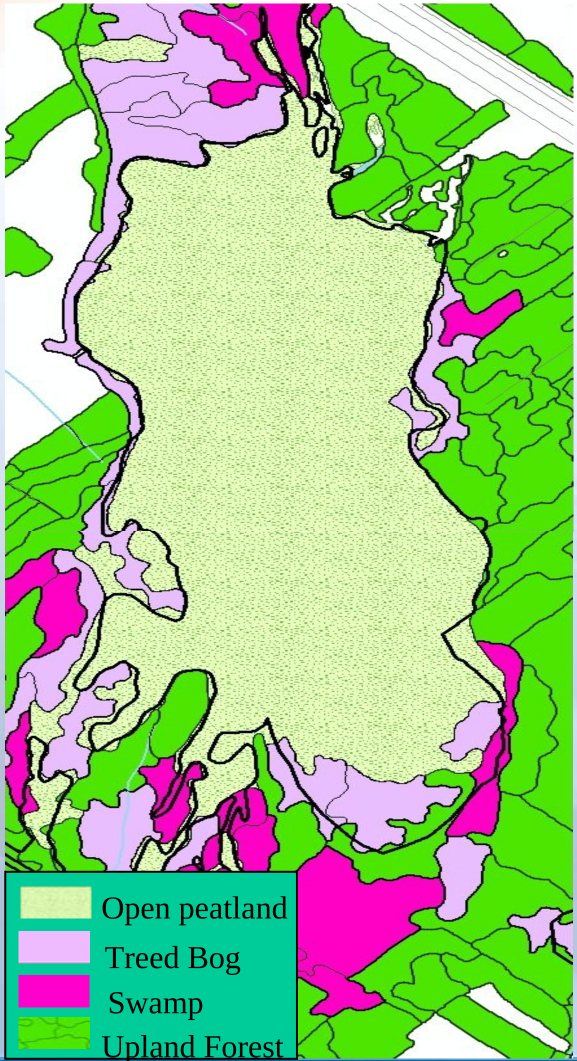
Peatland: Poor fen + Bog

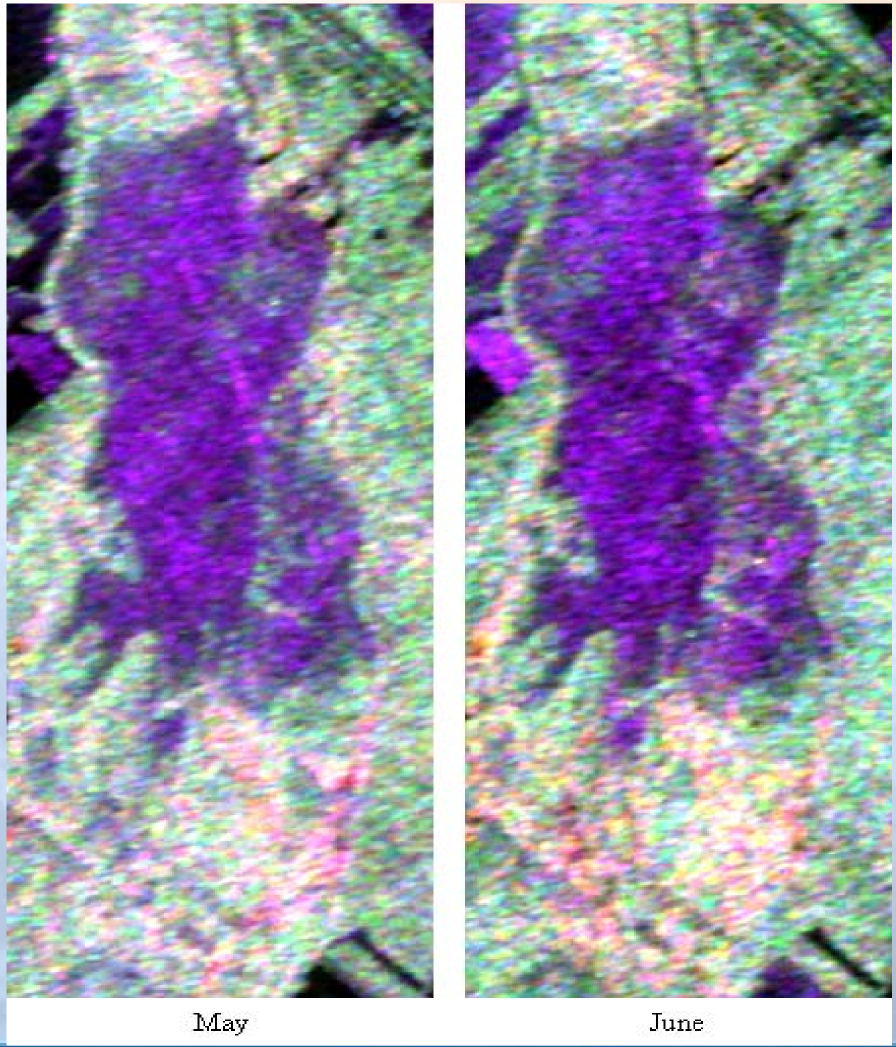
☛ Cannot be discriminated with Optic Sensors



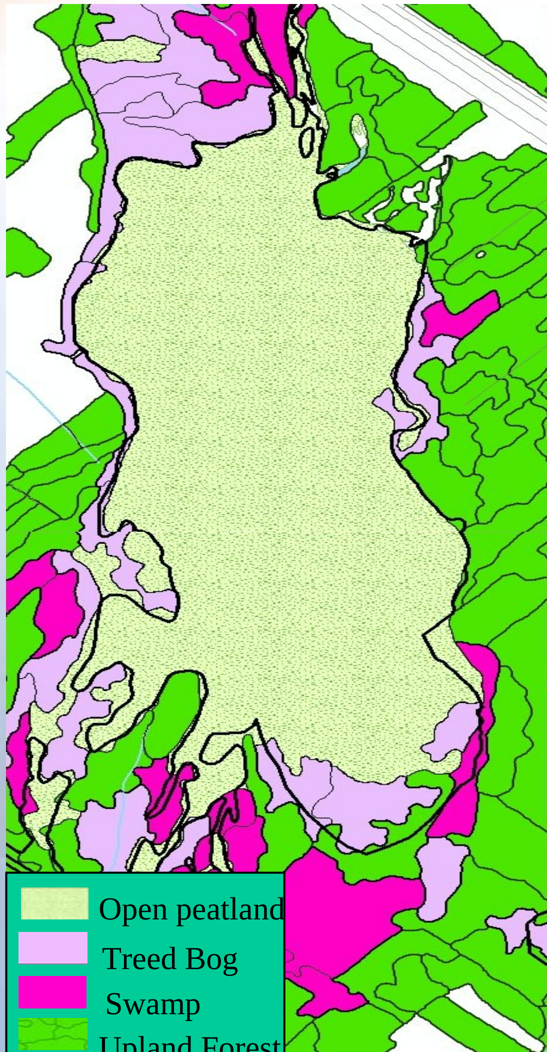
- **Bog**:
  - **Ombrotrophic**: . precipitations, fog and snow are the primary water sources
- **Poor Fen**:
  - **Minerotrophic**: fens are connected to small streams and may also receive water from surrounding uplands.
  - As such, poor fens of high water retention are **continuously irrigated** with subsurface water even under no rainy conditions.

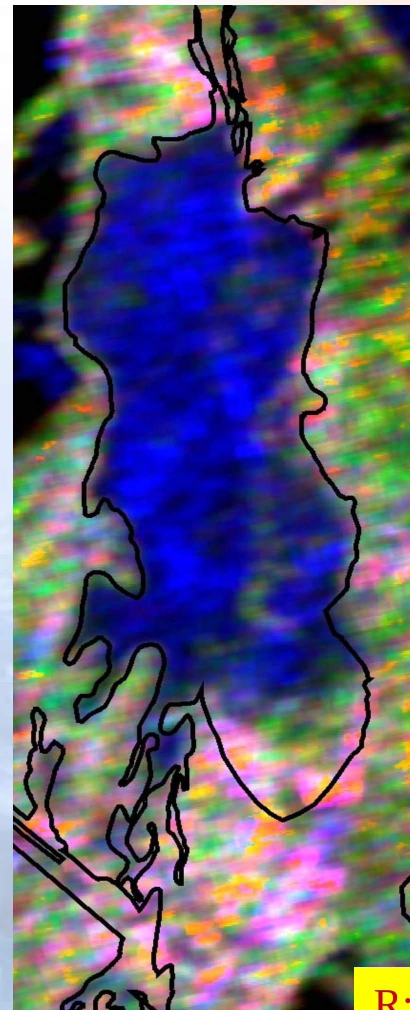
☛ HH-HV-VV not sensitive to water flow variations **beneath** the peat surface



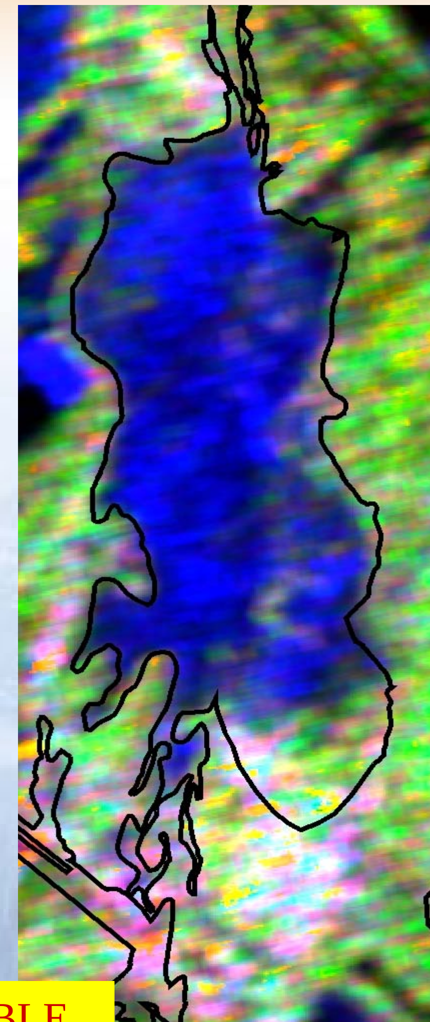


Freeman **Coarse** Scattering Classification **not sensitive** to water flow variations **beneath** the peat surface





Nov



May

R:DOUBLE
G:VOLUME
B:ODD

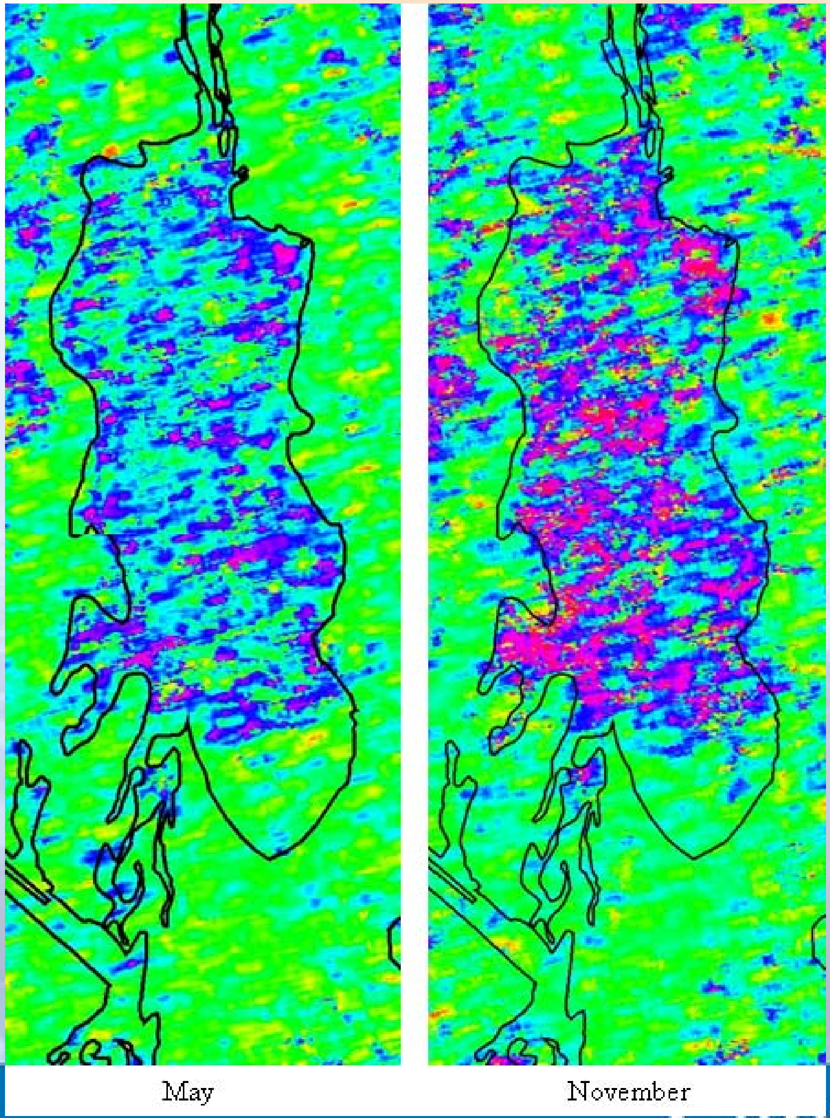
☛ Touzi phase $\phi_{\alpha s}$ generated from FP **detects** water flow variations **beneath** the peat surface

- **Pink** ➪ subsurface water (less then 20 cm)

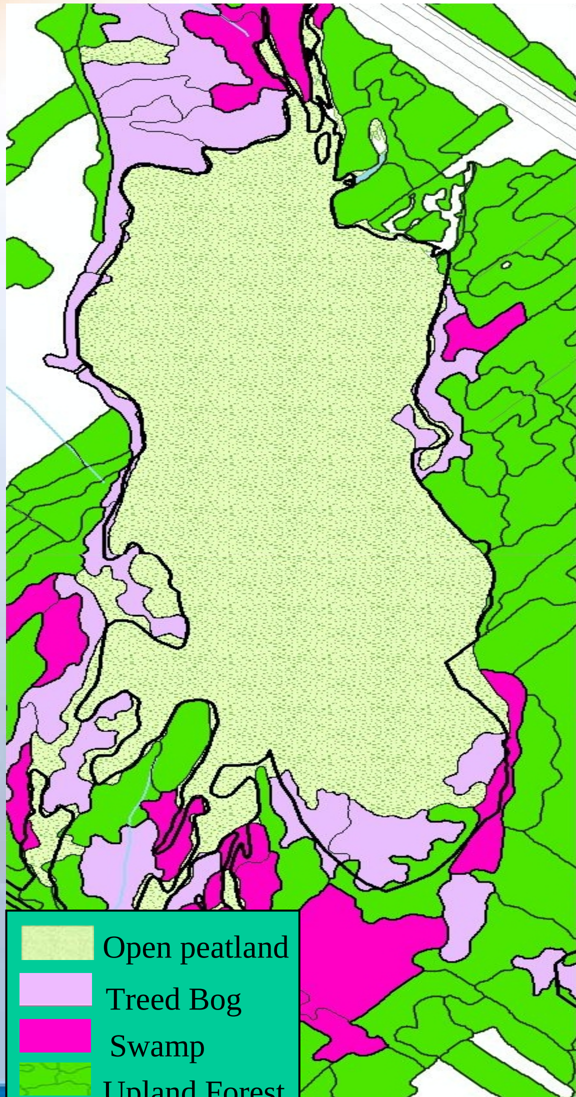
➪ Fen: subsurface run off water

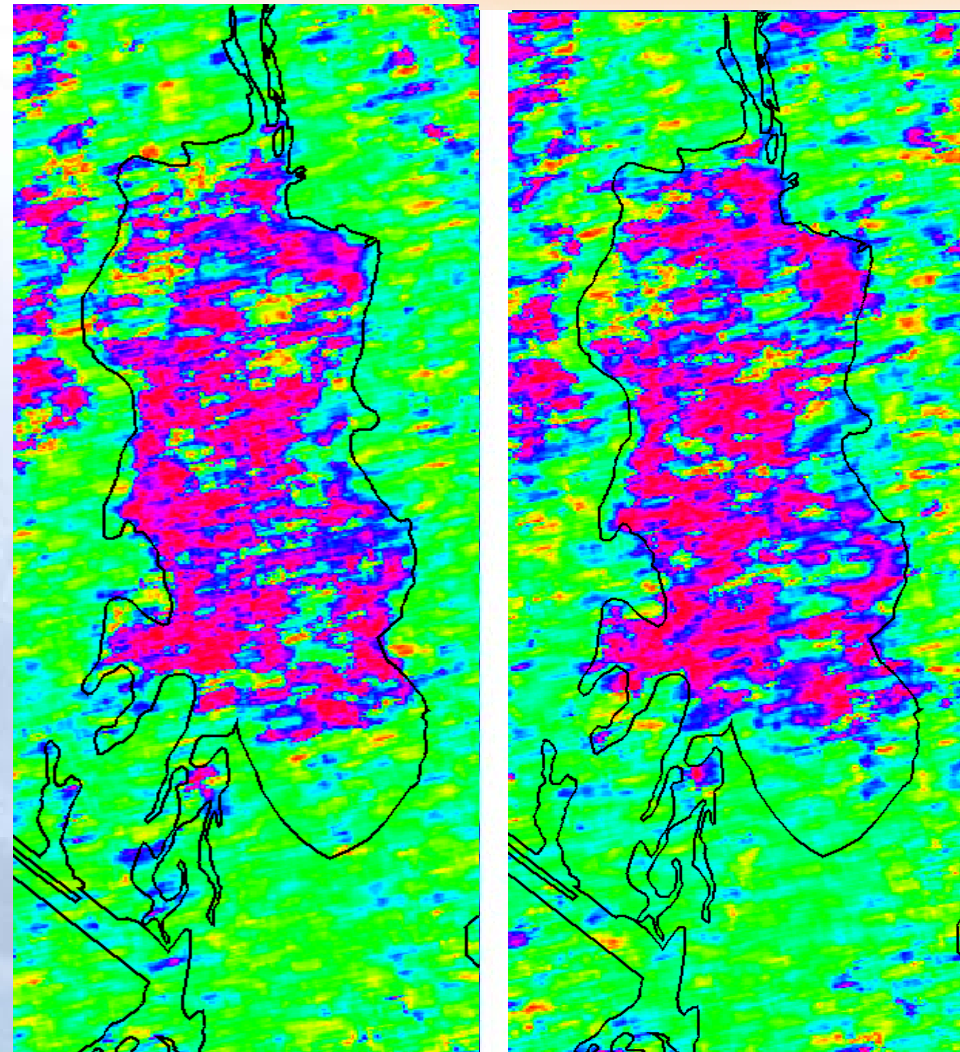
- **Bleue** ➪ deep underground water
- Bog: water level at the catotelm (40-50 cm)

☛ **Essential** information for monitoring Bog-Fen Transformations in the North due to climate change stress



Reconstructed Compact: $\phi_{\alpha s}$ <u>not sensitive</u> to water flow variations **beneath** the peat surface





May

November

Conclusions

- Hybrid **convenient** for generation of CP with H-V antennas
- **Not efficient** ➪ **Not** accurate RL (and HV) at **low S/N**
- Transmitted CP **not** perfectly **circular**
  - ➪ Calibration **requirements**: **0.5 dB** and **10º** will be a **Challenge**
  - ➪ Very hard to reach at **high Faraday** conditions and (-25dB) isolation
- CP antenna for Future **P-band** missions ➪ **Operational** use of single and dual-mode **radiometry not affected** by **Faraday** rotation

- Δp and DoP signature ➪ **Quantification** of Hybrid polarization information loss
  - **The one-** transmitted polarization (CP or π/4) Cannot provide the full polarimetric information provided by FP that exploits 180x90 (ψ,χ) transmitted polarization possibilities

Polarimetry NEQ Freeman & Cloude-Pottier Decomposition

- The **abandoned** polarization optimization theory provides **valuable** information (polarization synthesis, DoP excursion and signature, target contrast optimization, unpolarized component signature ...)**????!!!!!**