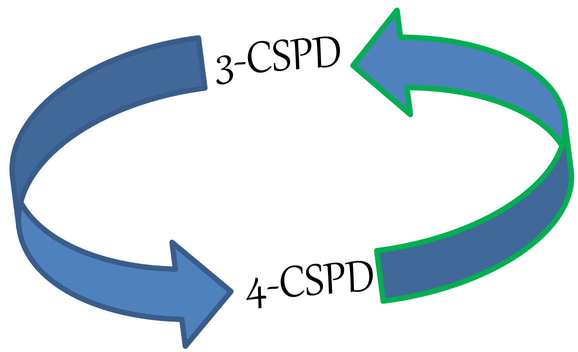
4-Component Scattering Power Decomposition with Phase Rotation of Coherency Matrix



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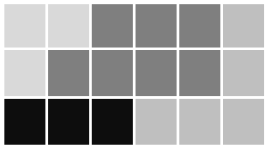
Outline

- Introduction: Scattering Power Decompositions and their problems
- Phase Rotation: **C**omplex **U**nitary **T**ransformation (CUT)
  - Conversion of 4- to 3-Component Scattering Power Decomposition
- Results
- Summary and Conclusions

Purpose: To decompose different scattering contributions



Introduction (1/6)

Applications: POLSAR image interpretation, classification and segmentation, and scattering parameter inversion .

POLSAR Data

$$S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{HV} & S_{VV} \end{bmatrix}$$

Scattering Matrix

$S_{HV}=S_{VH}$

$$\boldsymbol{k} = (1/2)\ \text{Trace}\ \{S[\psi]\}$$

Scattering Vector

$$\Psi = \left\{ \sqrt{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \sqrt{2}\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}, \sqrt{2}\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \right\}$$

Pauli Matrices Group

$$\boldsymbol{k_p} = (1/\sqrt{2})\ [S_{HH} + S_{VV}, S_{HH} - S_{VV}, 2S_{HV}]^t$$

Pauli Scattering Vector

$$[\boldsymbol{T}] = \begin{bmatrix} \boldsymbol{T}_{11} & \boldsymbol{T}_{12} & \boldsymbol{T}_{13} \\ \boldsymbol{T}_{21} & \boldsymbol{T}_{22} & \boldsymbol{T}_{23} \\ \boldsymbol{T}_{31} & \boldsymbol{T}_{32} & \boldsymbol{T}_{33} \end{bmatrix}$$

$$[\boldsymbol{T}] = \frac{1}{\boldsymbol{MN}} \sum_{\boldsymbol{i}=1}^{\boldsymbol{M}} \sum_{\boldsymbol{j}=1}^{\boldsymbol{N}} \boldsymbol{k}_{\boldsymbol{p}} \boldsymbol{k}_{\boldsymbol{p}}^{\dagger}$$

Multi-looked Coherency Matrix

Scattering Power Decompositions (natural/distributed targets)

Introduction (2/6)

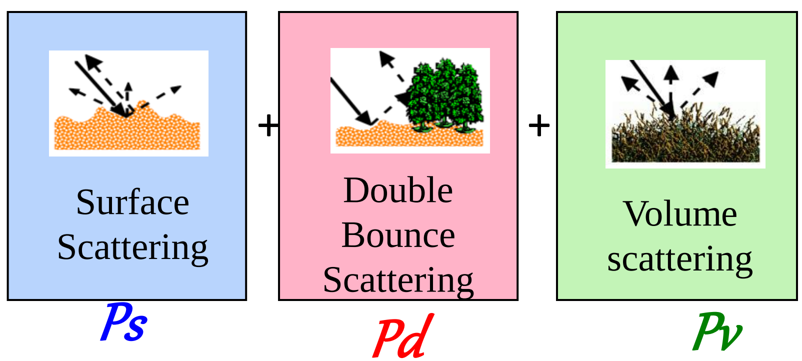
Freeman and Durden 3-Component Scattering Power Decomposition (3-CSPD) [1]

$$[T] = f_s[T_s] + f_d[T_d] + f_v[T_v]$$

$$[T] = f_s \begin{bmatrix} 1 & \beta^* & 0 \\ \beta & |\beta|^2 & 0 \\ 0 & 0 & 0 \end{bmatrix} + f_d \begin{bmatrix} |\alpha|^2 & \alpha & 0 \\ \alpha^* & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + f_v \cdot \frac{1}{4} \begin{bmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

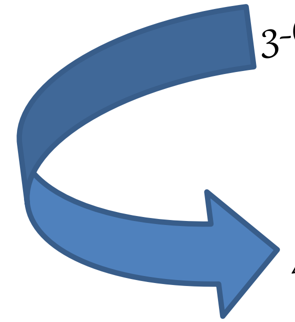
with reflection symmetry $\langle S_{HH} S_{HV}^* \rangle \approx 0, \ \langle S_{VV} S_{HV}^* \rangle \approx 0$ **for natural distributed targets**

Total Power (TP)=



[1] A. Freeman and S. L. Durden, ``A Three-component scattering model for polarimetric SAR data,`` IEEE TGRS, Vol.36, No. 3, pp. 963-973, May 1998.

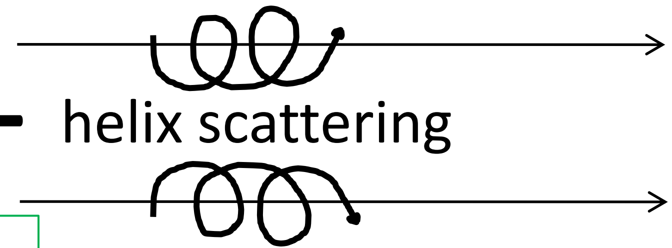
Introduction (3/6)



4-Component Scattering power decomposition [2]-[3]

$$[T] = f_s[T_s] + f_d[T_d] + f_v[T_v] + f_c[T_c]$$ **(Y4-0)**

4-CSPD = 3-CSPD + helix scattering



$$\frac{1}{2}\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & \pm j \\ 0 & \mp j & 1 \end{bmatrix}$$

by proposing new matrices for volume scattering

under with non-reflection symmetry

$$\langle S_{HH} S_{HV}^{*} \rangle \neq 0, \ \langle S_{VV} S_{HV}^{*} \rangle \neq 0$$

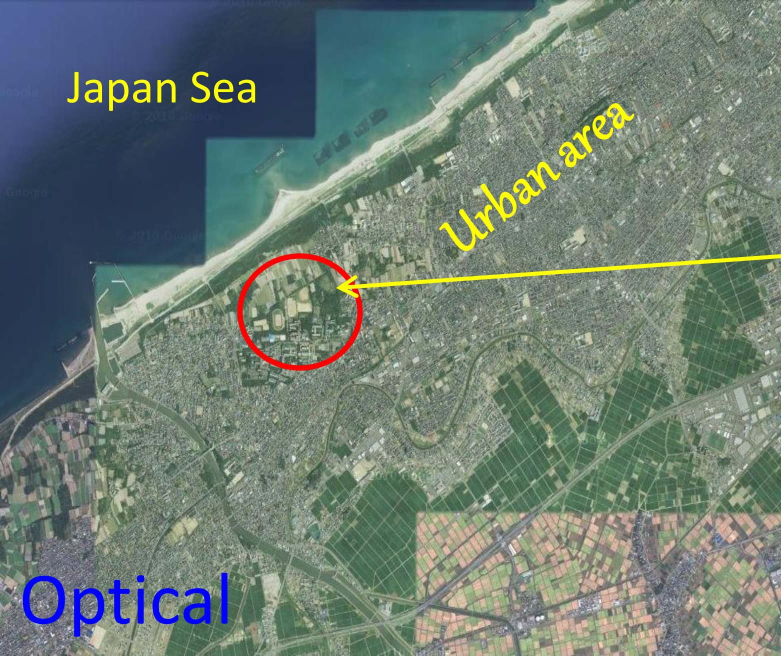
$\frac{1}{30}\begin{bmatrix} 15 & -5 & 0 \\ -5 & 7 & 0 \\ 0 & 0 & 8 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\frac{1}{30}\begin{bmatrix} 15 & 5 & 0 \\ 5 & 7 & 0 \\ 0 & 0 & 8 \end{bmatrix}$
$p(\theta) = \frac{1}{2}\cos\theta$	$p(\theta) = \frac{1}{2\pi}$	$p(\theta) = \frac{1}{2}\sin\theta$

$$TP = P_s + P_d + P_v + P_c$$

$$[T_v] = \int [T(\theta)]\, p(\theta)\, d\theta$$

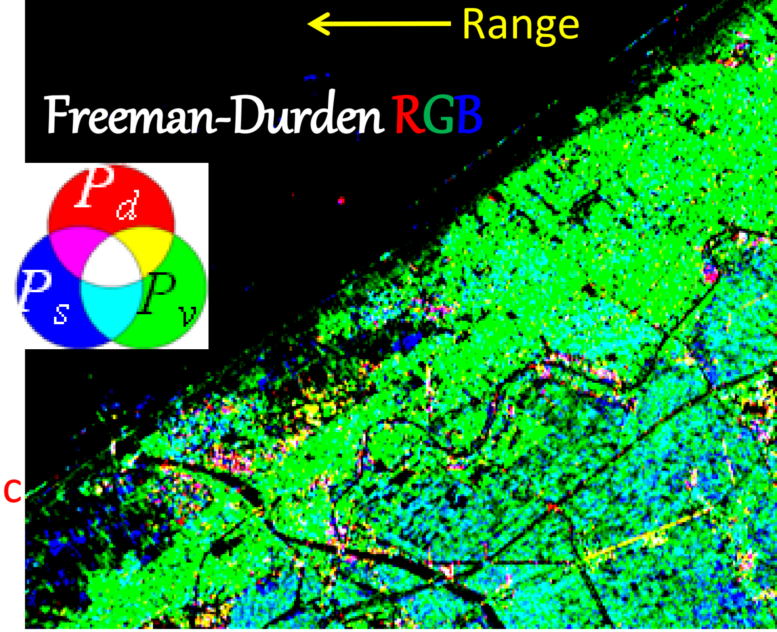
[2] Y. Yamaguchi, T. Moriyama, M. Ishido and H. Yamada, ``Four-Component Scattering Model for Polarimetric SAR Image Decomposition,`` IEEE TGRS, Vol.43, No.8, pp.1699-1706, Aug. 2005.

[3] Y. Yajima, Y. Yamaguchi, R. Sato and H. Yamada, ``POLSAR image analysis of wetlands using a modified four-component scattering power decomposition,`` IEEE TGRS, Vol.46, No.6, pp.1667-1673, June 2008.

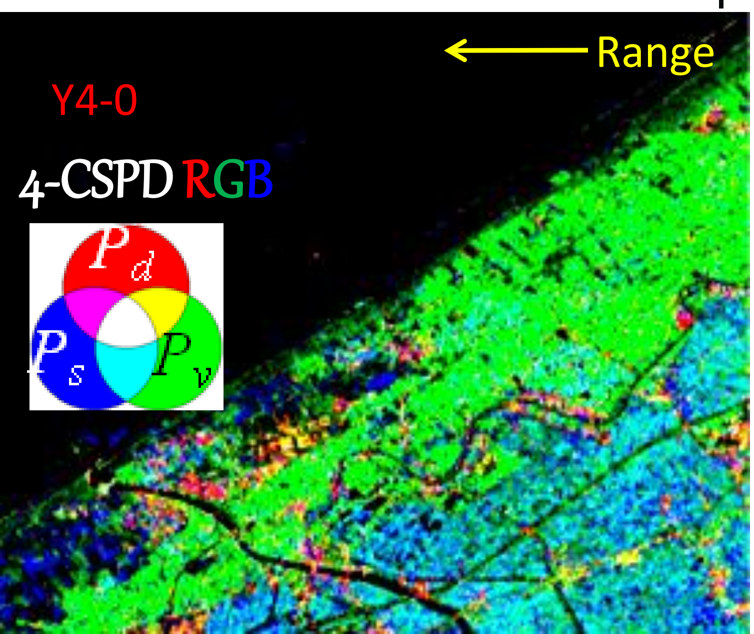


(4/6)

Fully polarimetric TerraSAR-X data
April 21, 2010



$P_v = \frac{15}{4} T_{33} - \frac{15}{8} P_c$	$P_v = 4\, T_{33} - 2\, P_c$	$P_v = \frac{15}{4} T_{33} - \frac{15}{8} P_c$ [5]



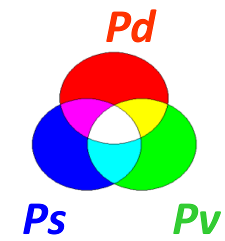
Strong volume scattering [4]-[5]

Misclassification of man-made targets

[4] J. S. Lee and T. L. Ainsworth, "The effect of orientation angle compensation on coherency matrix and polarimetric target decompositions," IEEE TGRS, vol. 49, no.1, pp.53-64, 2011.

[5] Y. Yamaguchi, A. Sato, W.-M. Boerner, R. Sato, and H. Yamada, "Four-component scattering power decomposition with rotation of coherency matrix," IEEE TGRS., vol. 49, no. 7, July 2011.

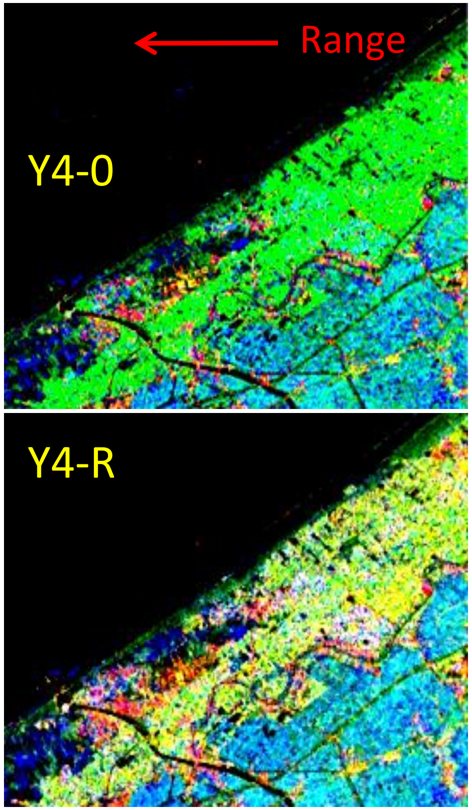
Introduction (5/6)



Rotation of [T] about line of sight [4]-[5]

$$[T'] = \begin{bmatrix} T'_{11} & T'_{12} & T'_{13} \\ T'_{21} & T'_{22} & T'_{23} \\ T'_{31} & T'_{32} & T'_{33} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix} [T] \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & -\sin 2\theta \\ 0 & \sin 2\theta & \cos 2\theta \end{bmatrix}$$

Rotation Matrix : Real Unitary Transformation



Determination of the rotation angle

$$\frac{dT'_{33}}{d\theta} = 0 \qquad \theta = \frac{1}{4} \tan^{-1}\left(\frac{2\,\mathrm{Re}\,(T_{23})}{T_{22} - T_{33}} \right)$$

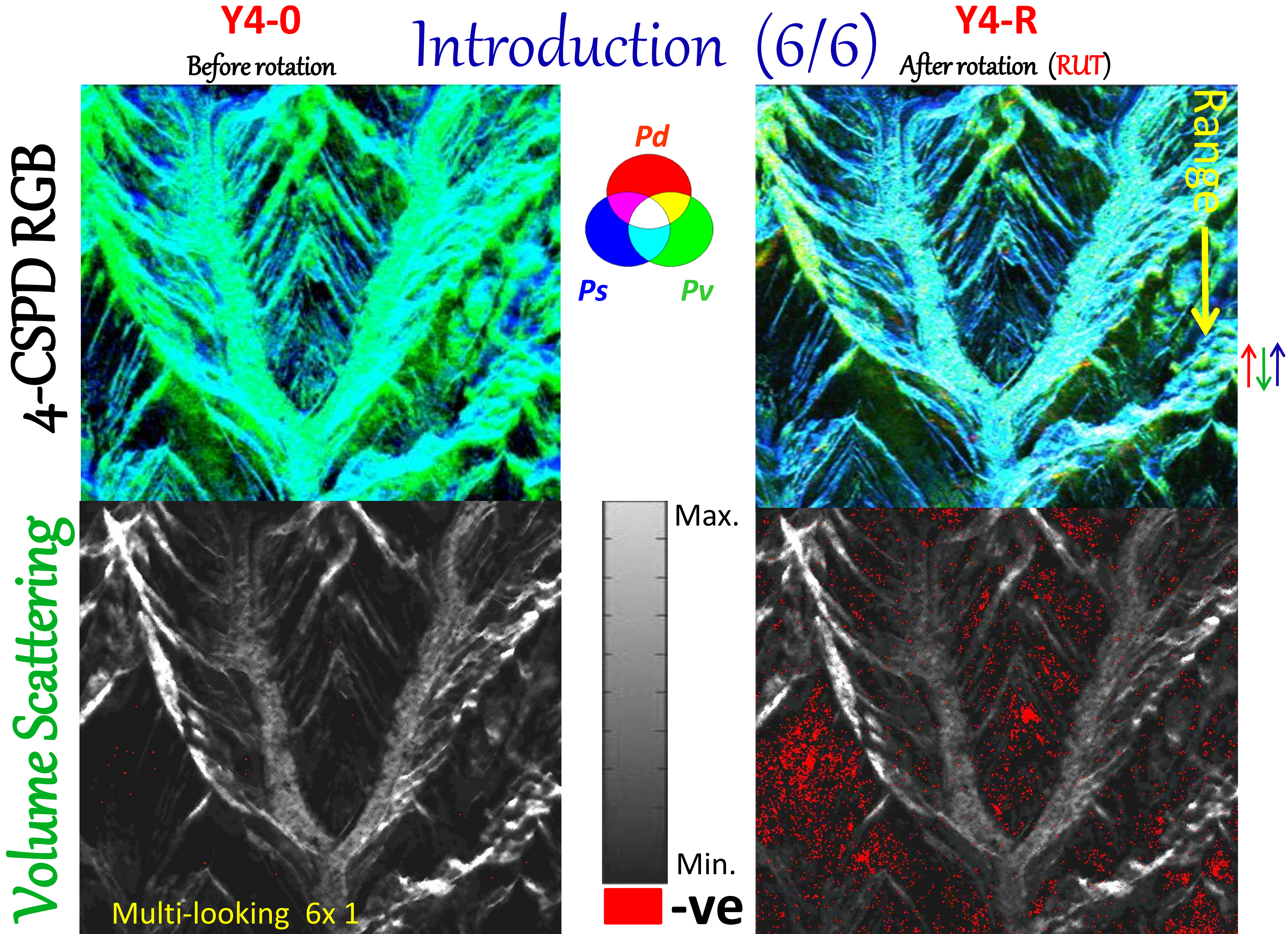
4-CSPD for the rotated matrix $[T']$ (Y4-R)

$$[T'] = f_s[T_s] + f_d[T_d] + f_v[T_v] + f_c[T_c]$$

[4] J. S. Lee and T. L. Ainsworth, "The effect of orientation angle compensation on coherency matrix and polarimetric target decompositions," IEEE TGRS, vol. 49, no.1, pp.53-64, 2011.

[5] Y. Yamaguchi, A. Sato, W.-M. Boerner, R. Sato, and H. Yamada, "Four-component scattering power decomposition with rotation of coherency matrix," IEEE TGRS, vol. 49, no. 7, July 2011.

Introduction (6/6)

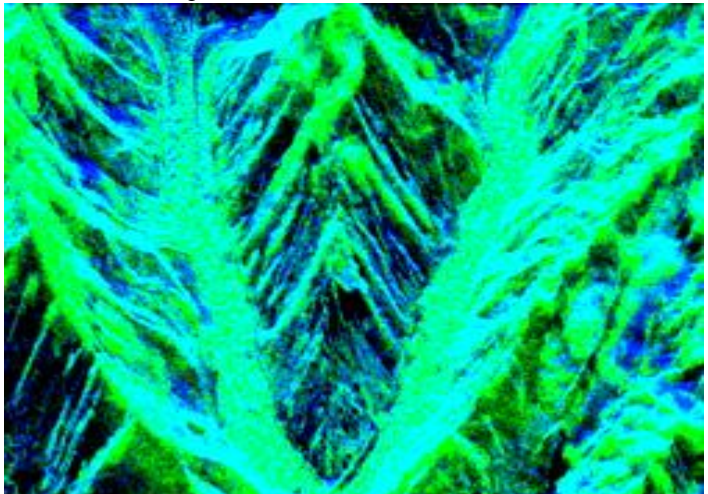


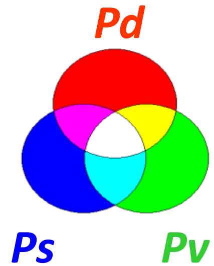
Introduction (6/6)

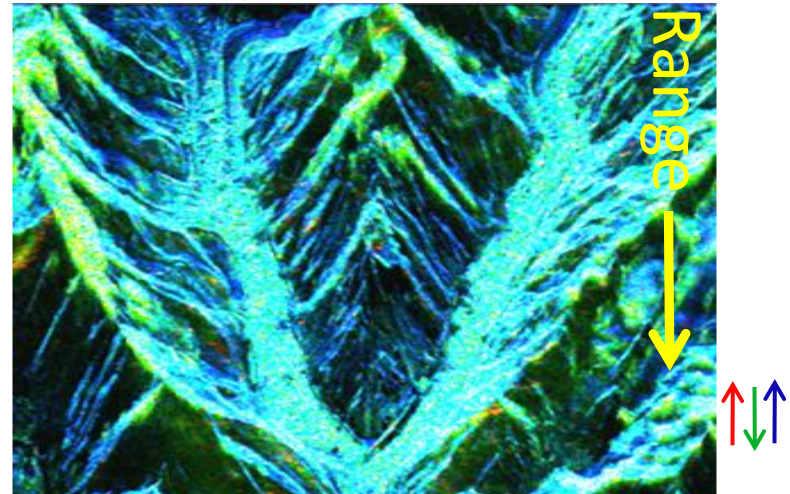
Y4-0
Before rotation

Y4-R
After rotation (RUT)

4-CSPD RGB







$$P_v = \frac{15}{4} T_{33} - \frac{15}{8} P_c$$

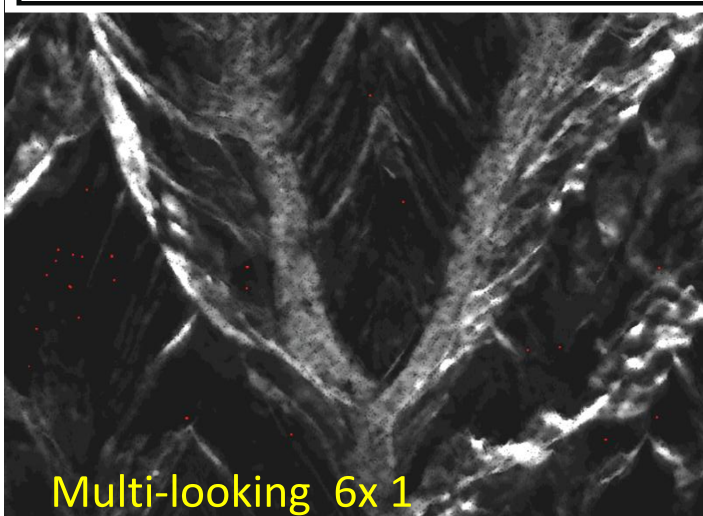
$$P_v = 4\, T_{33} - 2\, P_c$$

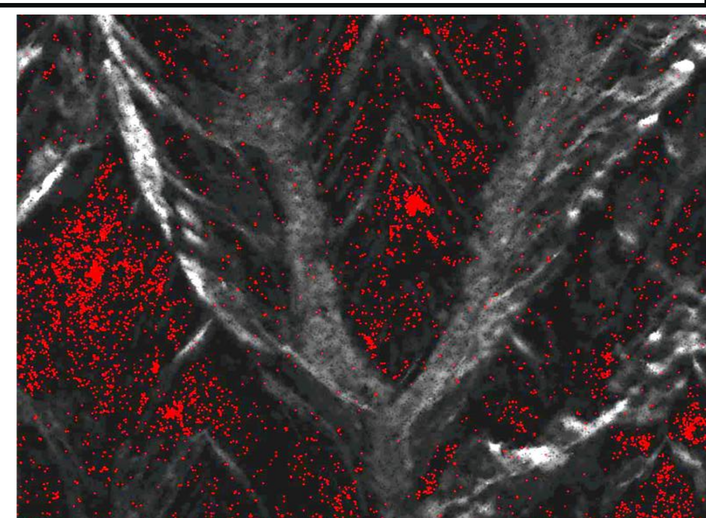
$$P_v = \frac{15}{4} T_{33} - \frac{15}{8} P_c$$

[5]

if $P_v < 0$, *then* $P_c = 0$ (remove helix scattering) $\Rightarrow$ 3 comp. (P_s, P_d, P_v) decomposition

Volume Scattering





Phase Rotation: Complex Unitary Transformation (1/3)

$$[T(\phi)] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\phi & j\sin 2\phi \\ 0 & j\sin 2\phi & \cos 2\phi \end{bmatrix} [T] \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\phi & -j\sin 2\phi \\ 0 & -j\sin 2\phi & \cos 2\phi \end{bmatrix}$$

$$[T] = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{bmatrix}, [T(\phi)] = \begin{bmatrix} T_{11}(\phi) & T_{12}(\phi) & T_{13}(\phi) \\ T_{21}(\phi) & T_{22}(\phi) & T_{23}(\phi) \\ T_{31}(\phi) & T_{32}(\phi) & T_{33}(\phi) \end{bmatrix}$$

$$\frac{dT_{33}(\phi)}{d\phi} = 2(T_{22} - T_{33}) \sin 4\phi - 4\,\mathrm{Im}(T_{23}) \cos 4\phi$$

$$\frac{dT_{33}(\phi)}{d\phi} = 0 \text{ , leads to } \quad \tan 4\phi = \frac{2\,\mathrm{Im}(T_{23})}{T_{22} - T_{33}}$$

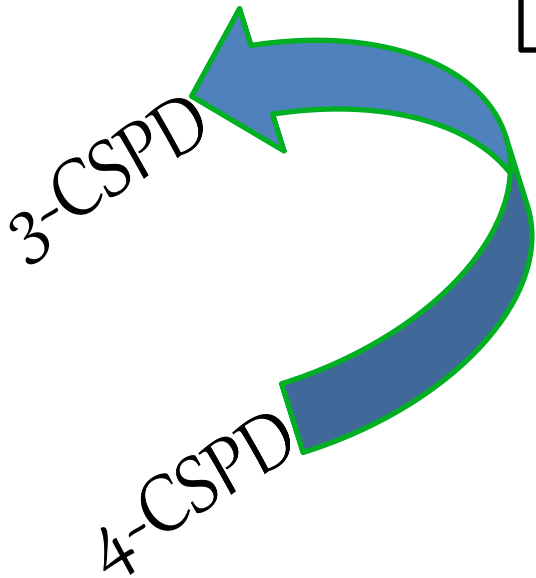
$$2\phi = \frac{1}{2} \tan^{-1} \frac{2\,\mathrm{Im}(T_{23})}{T_{22} - T_{33}}$$

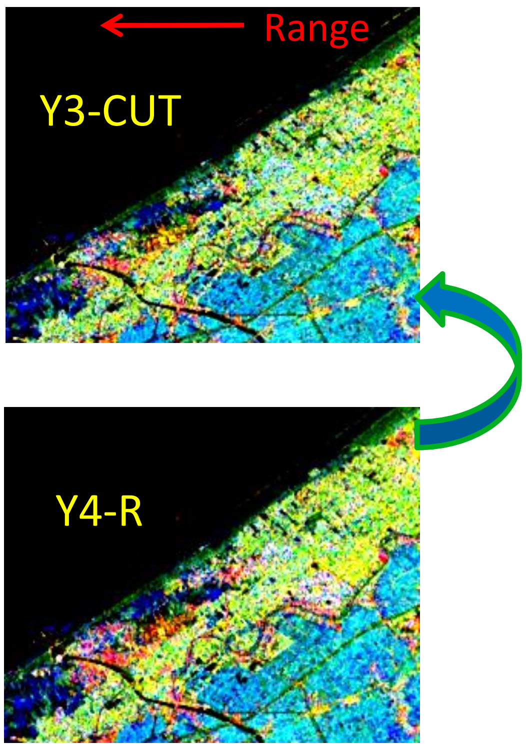
CUT(2/3)

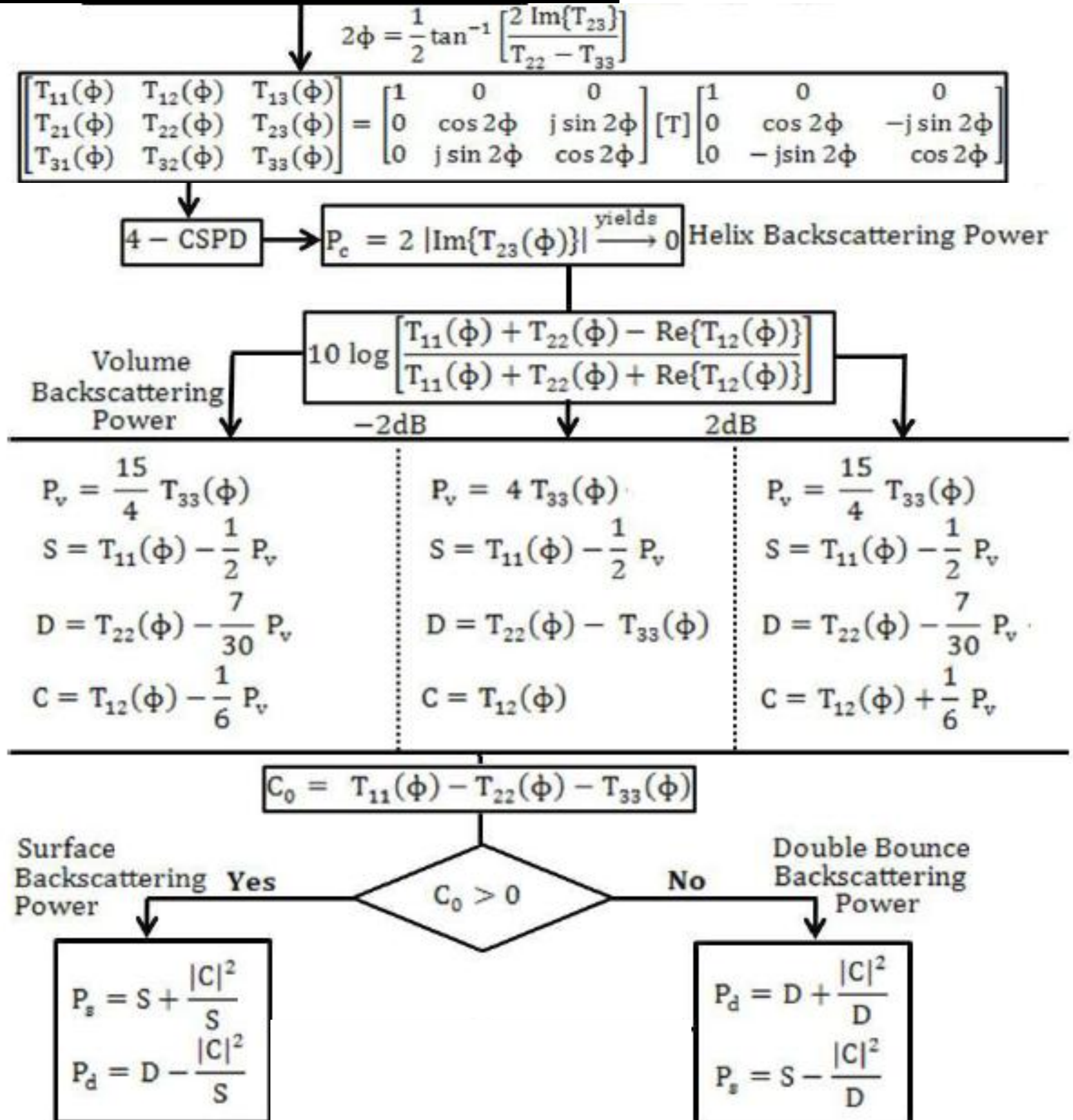
$$T_{11}(\phi) = T_{11}$$
$$T_{12}(\phi) = T_{12}\cos 2\phi - j\,T_{13}\sin 2\phi$$
$$T_{13}(\phi) = T_{13}\cos 2\phi - j\,T_{12}\sin 2\phi$$
$$T_{21}(\phi) = T_{12}(\phi)^{*}$$
$$T_{22}(\phi) = T_{22}\cos^2 2\phi + T_{33}\sin^2 2\phi + \mathrm{Im}\{T_{23}\}\sin 4\phi$$
$$T_{23}(\phi) = \mathrm{Re}\{T_{23}\}$$
$$T_{31}(\phi) = T_{13}^{*}(\phi)$$
$$T_{32}(\phi) = T_{23}^{*}(\phi)$$
$$T_{33}(\phi) = T_{33}\cos^2 2\phi + T_{22}\sin^2 2\phi - \mathrm{Im}\{T_{23}\}\sin 4\phi$$

$T_{23}(\phi)$ *has no imaginary part. This means no helix power in the 4-CSPD model.*

Phase Rotation of [T] : CUT (3/3)

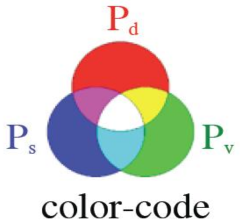






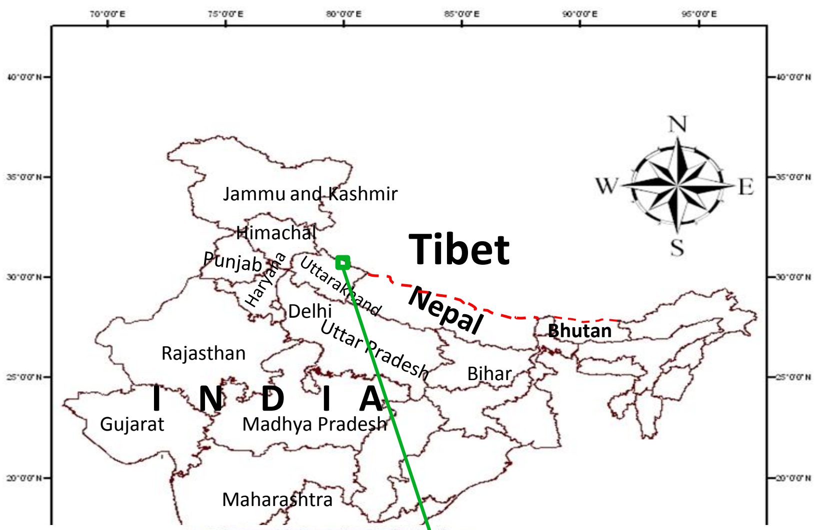
Y3-CUT

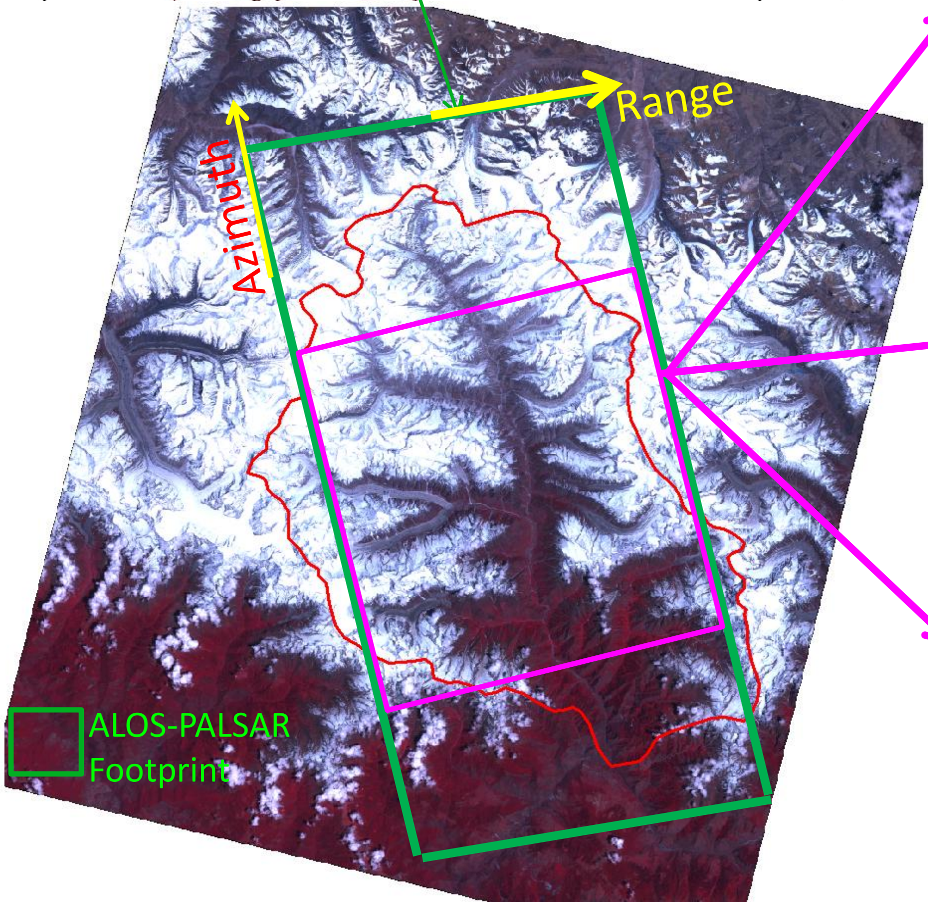
Results (1/4)

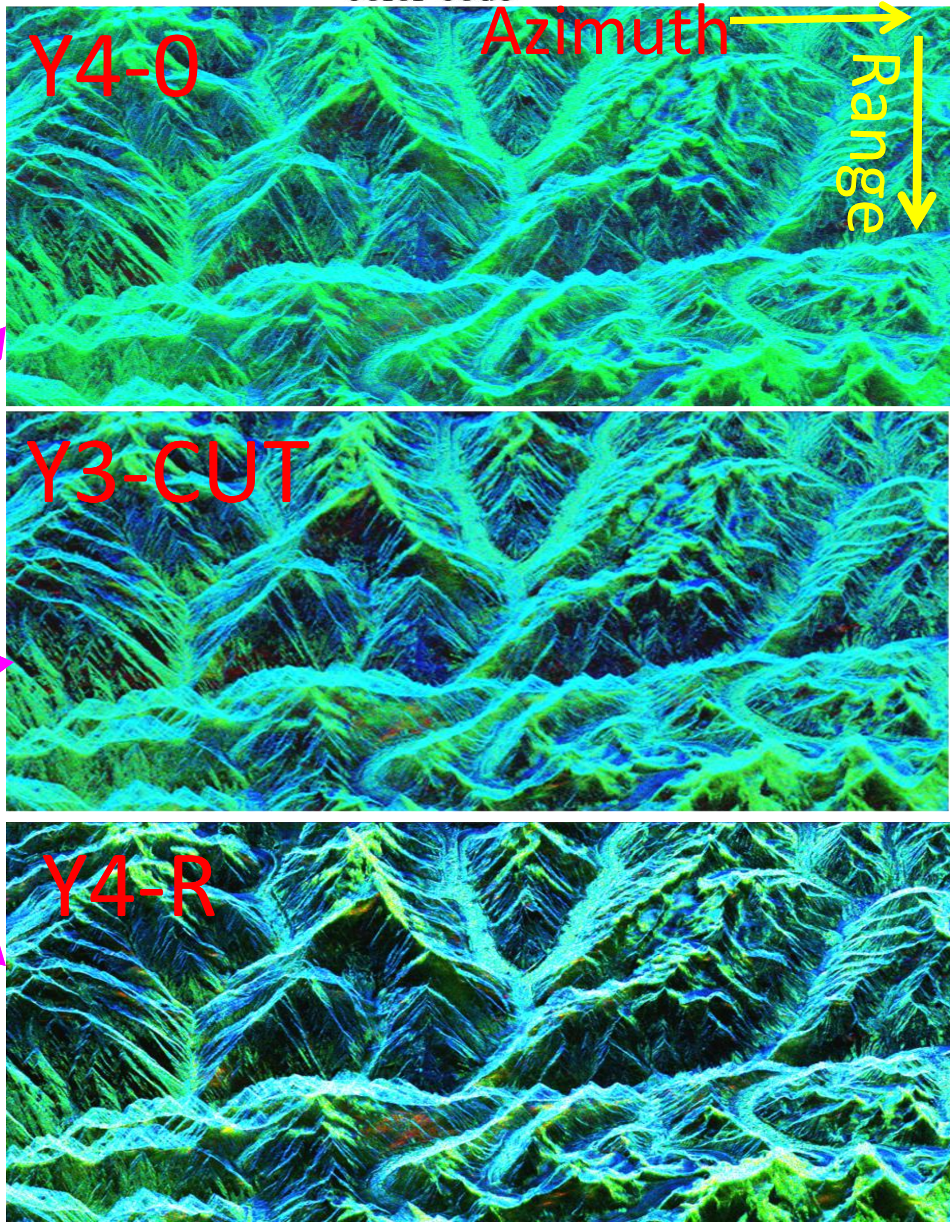


ALOS- PALSAR SLC

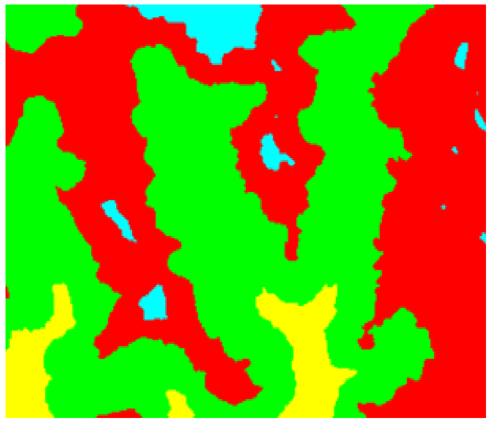
May 12, 2007





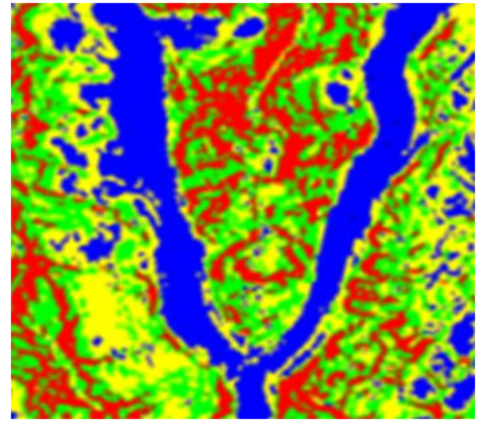


Results : Effect of steep slope (2/4)



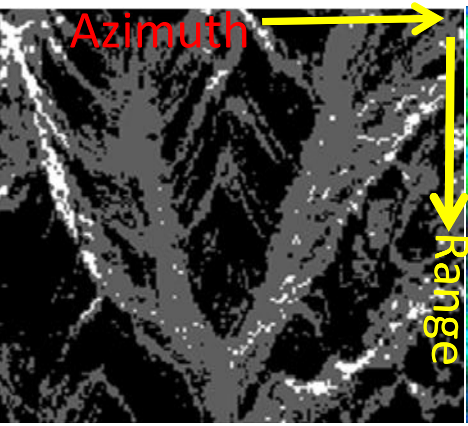
3-4 4-5 5-6 6-7

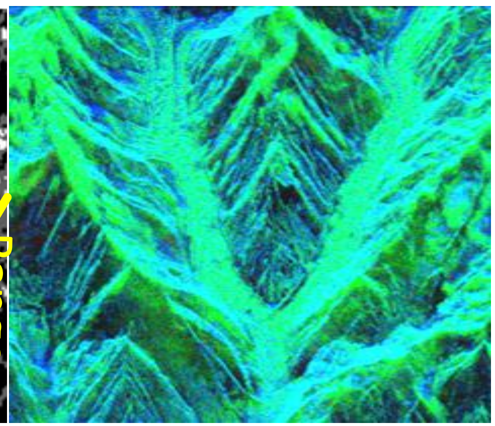
Elevation Range (Km):

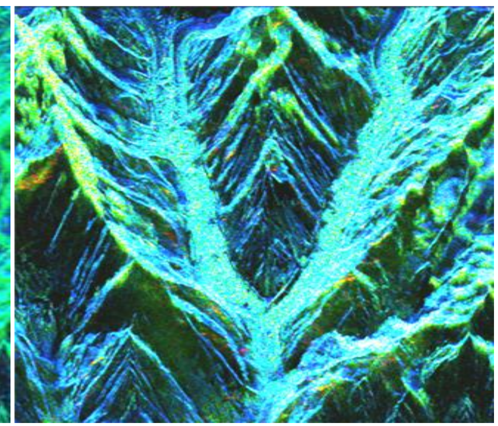


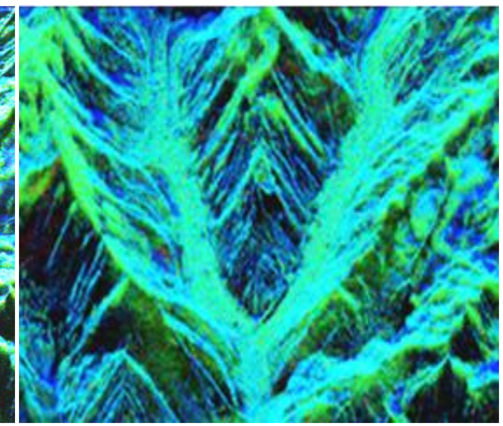
<15⁰ 15⁰-30⁰ 30⁰-45⁰ 45⁰-89⁰

Slope







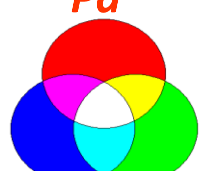


Pc in Y4-0 & Y4-R

< -20 dB   -20 dB to -10 dB

> -10 dB

Y4-0



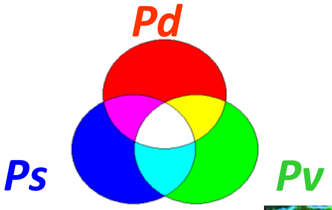
Y4-R

Y3-CUT

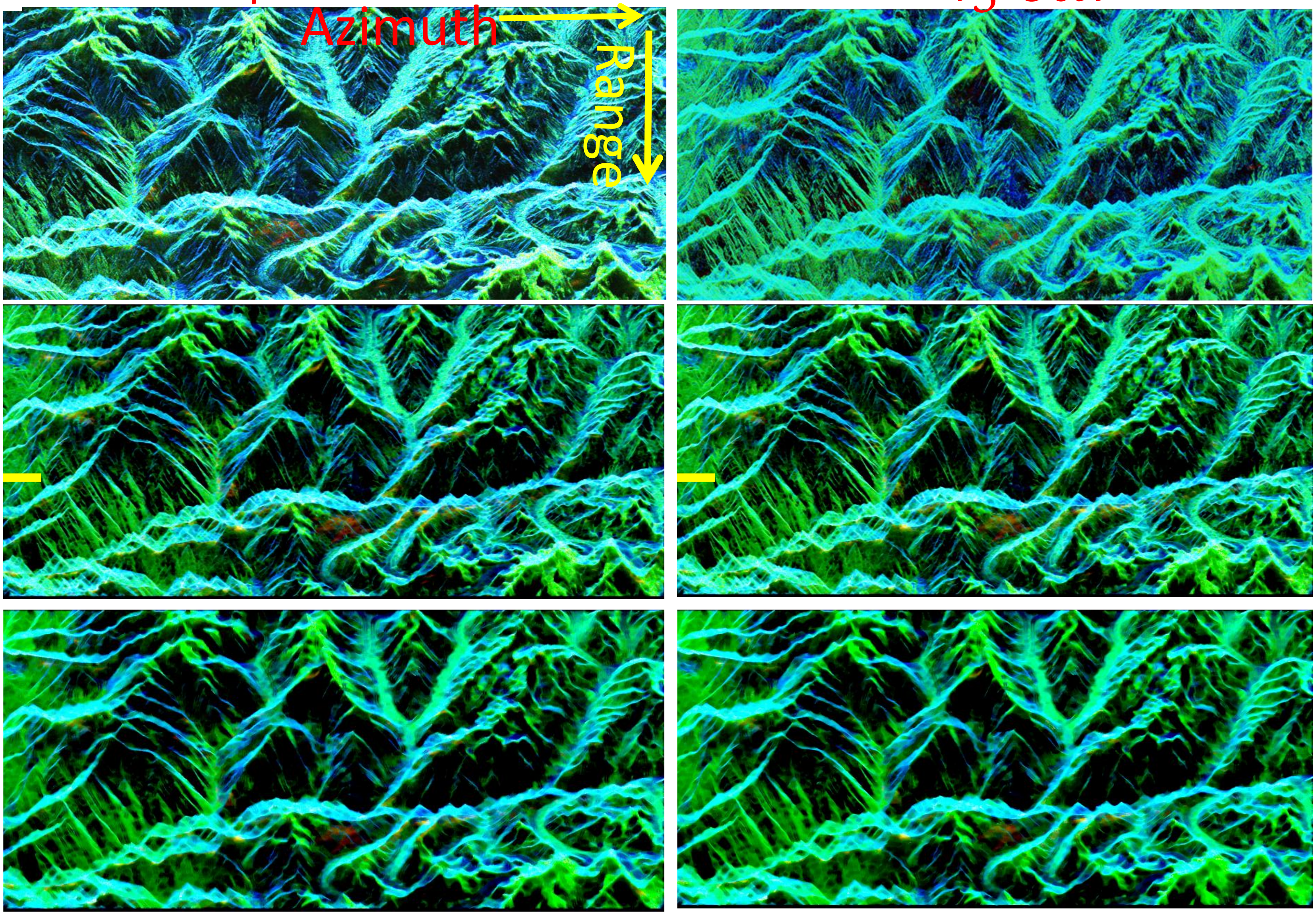
Multi-Looked factor: 6 x 1

(3/4)

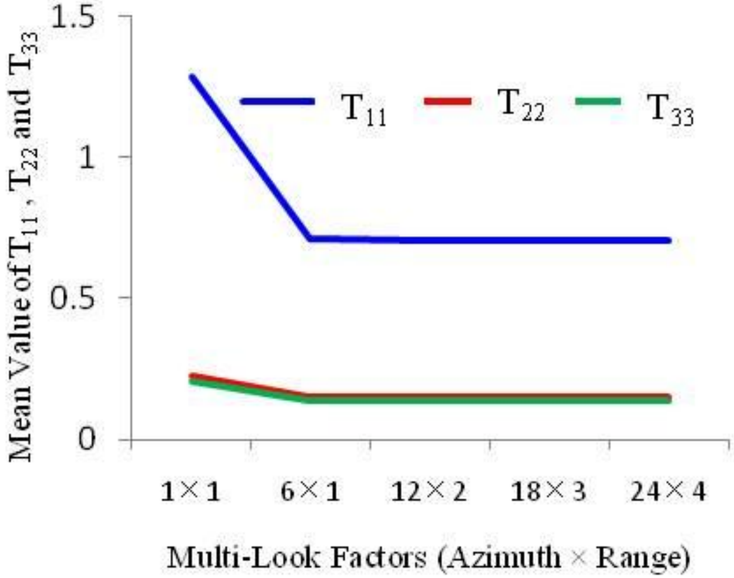
Results : Effect of multi-looking and Filtering

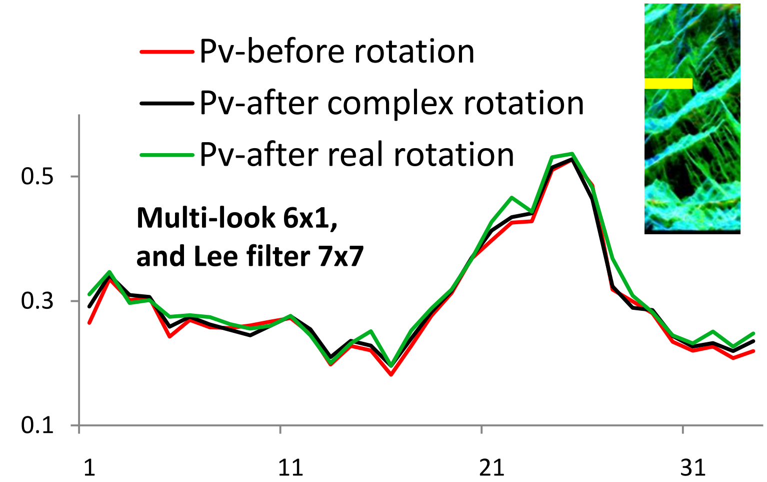


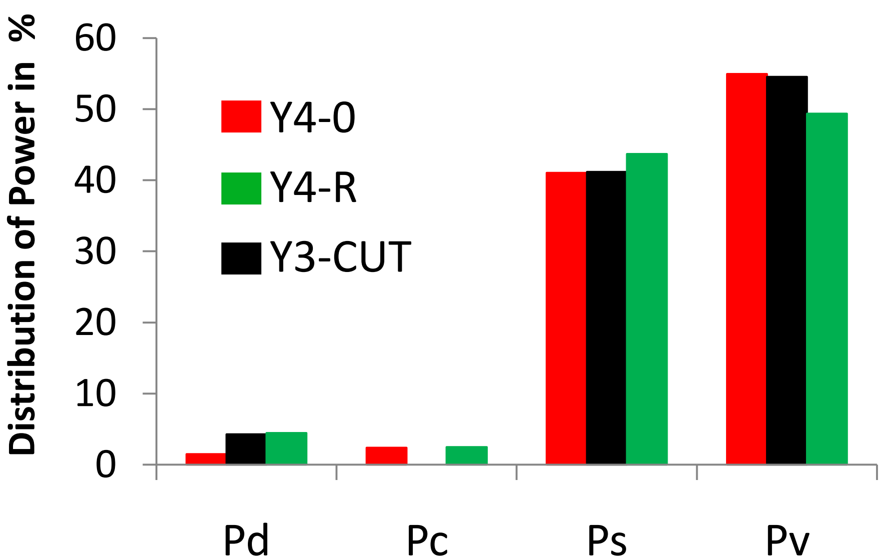
	Y_4-R	Y_3-CUT
Multi-look 6x1		
Multi-look 6x1; and Lee filter 7x7		
Multi-look 12x2; and Lee filter 7x7		
	Involved [T’] elements: 6/8 and θ	Involved [T(ϕ)] elements: 5/8 and ϕ



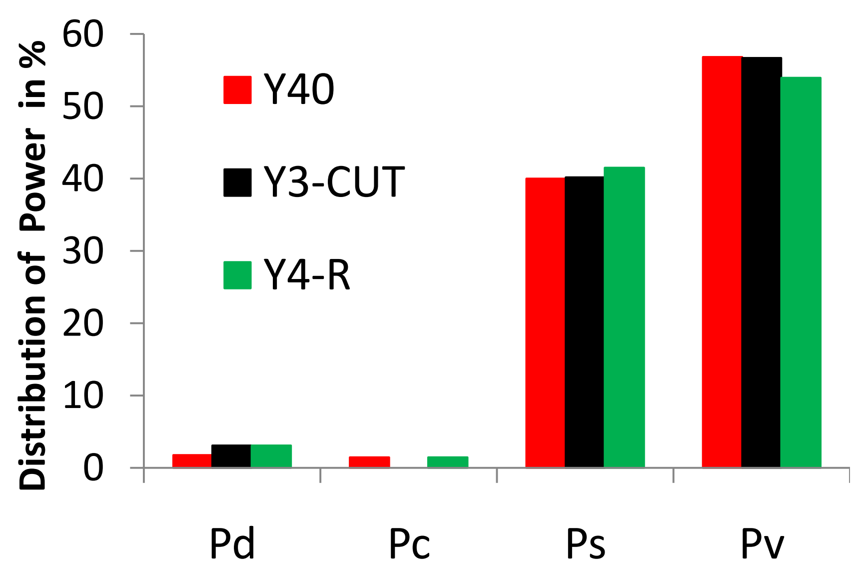
Results (4/4)







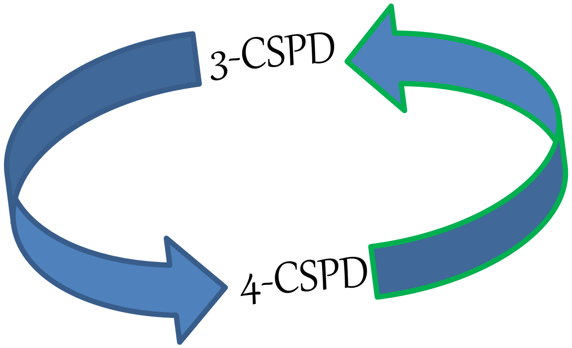
Multi-look 6x1; and Lee filter 7x7



Multi-look 12x2; and Lee filter 7x7

Summary and Conclusions (1/1)

1.



A mathematical approach for conversion of 4- to 3- Components.

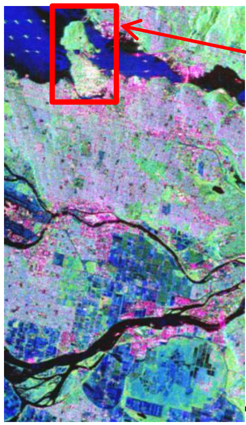
2.

% of negative values in Pv	Y4-o	Y4-R	Y3-CUT
Multi-look 6x1	0.02 **(767/ 3833856)**	1.65 **(63259/3833856)**	0
Multi-look 6x1; and Lee filter 7x7	≈0 **(73/ 3833856)**	≈ 0 **(223/3833856)**	0
Multi-look 12x2; and Lee filter 7x7	≈0 **(4/ 3833856)**	≈ 0 **(9/ 3833856)**	0

* multi-looking factors and filtering window size should be appropriate .

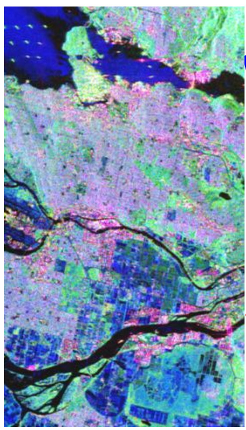
3. There is need to validate scattering decomposition scheme results for highly rugged terrain.

-:validity of **surface** and **volume** scattering models ??:-

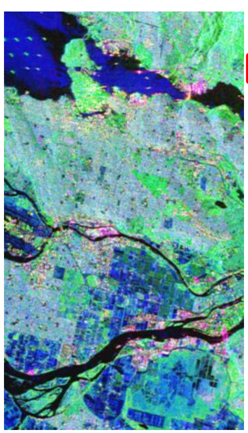


Y3-RUT-CUT

Range →



Y4-R



Y4-O

PALSAR

2011/04/08

[T']= RUT of [T]

$$[T(\phi)]=\text{CUT of } [T'] \rightarrow \begin{bmatrix} T_{11}(\phi) & T_{12}(\phi) & T_{13}(\phi) \\ T_{21}(\phi) & T_{22}(\phi) & 0 \\ T_{31}(\phi) & 0 & T_{33}(\phi) \end{bmatrix}$$

(1/1)

Scope

3-CSPD

4-CSPD

3CSPD

(5/7+θ+ϕ)

$$10\log\left[\frac{T_{11}(\phi)+T_{22}(\phi)-\mathrm{Re}\{T_{12}(\phi)\}}{T_{11}(\phi)+T_{22}(\phi)+\mathrm{Re}\{T_{12}(\phi)\}}\right]$$

Volume Backscattering Power

< −2dB	−2dB to 2dB	> 2dB
$P_v = \frac{15}{4}T_{33}(\phi)$	$P_v = 4T_{33}(\phi)$	$P_v = \frac{15}{4}T_{33}(\phi)$
$S = T_{11}(\phi) - \frac{1}{2}P_v$	$S = T_{11}(\phi) - \frac{1}{2}P_v$	$S = T_{11}(\phi) - \frac{1}{2}P_v$
$D = T_{22}(\phi) - \frac{7}{30}P_v$	$D = T_{22}(\phi) - T_{33}(\phi)$	$D = T_{22}(\phi) - \frac{7}{30}P_v$
$C = T_{12}(\phi) - \frac{1}{6}P_v$	$C = T_{12}(\phi)$	$C = T_{12}(\phi) + \frac{1}{6}P_v$

$$C_0 = T_{11}(\phi) - T_{22}(\phi) - T_{33}(\phi)$$

$C_0 > 0$

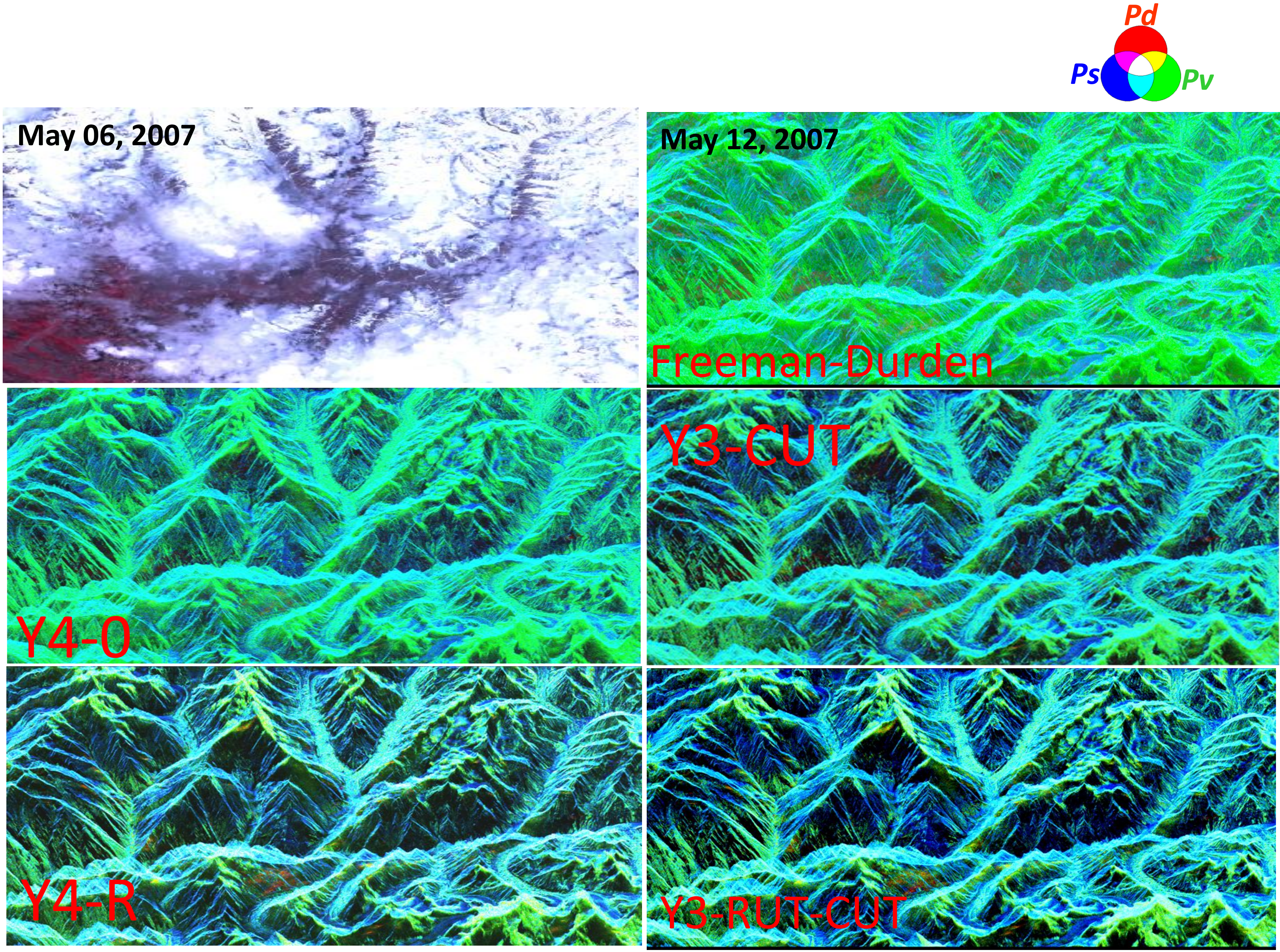
Surface Backscattering Power — **Yes**:

$$P_s = S + \frac{|C|^2}{S}$$
$$P_d = D - \frac{|C|^2}{S}$$

Double Bounce Backscattering Power — **No**:

$$P_d = D + \frac{|C|^2}{D}$$
$$P_s = S - \frac{|C|^2}{D}$$

Y3-RUT-CUT.


Pd
Ps
Pv
May 06, 2007
May 12, 2007
Freeman-Durden
Y4-O
Y3-CUT
Y4-R
Y3-RUT-CUT