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# SAR偏波データの計測技術とデータ解析

森山 敏文(長崎大学)



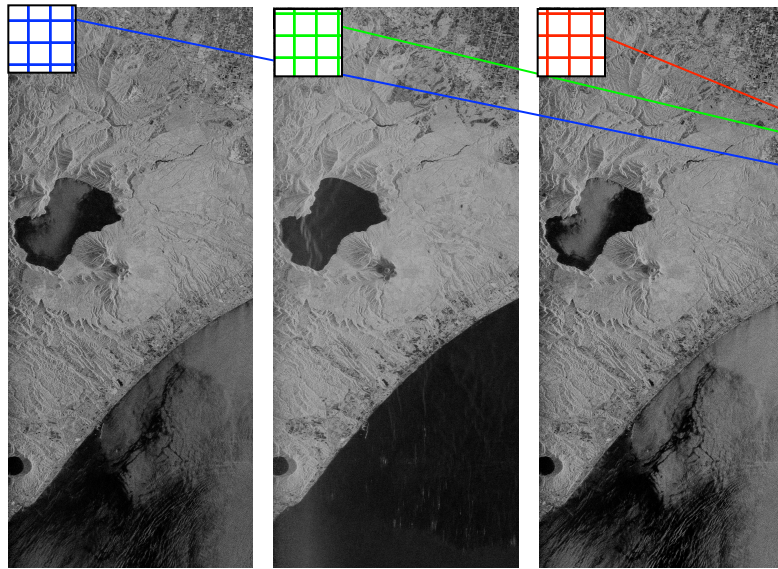
# 発表内容

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- 研究背景
- SAR偏波校正について
- SAR偏波データによる地形情報のデータ解析
- SAR偏波データによる地上情報のデータ解析
- まとめ



# 研究背景

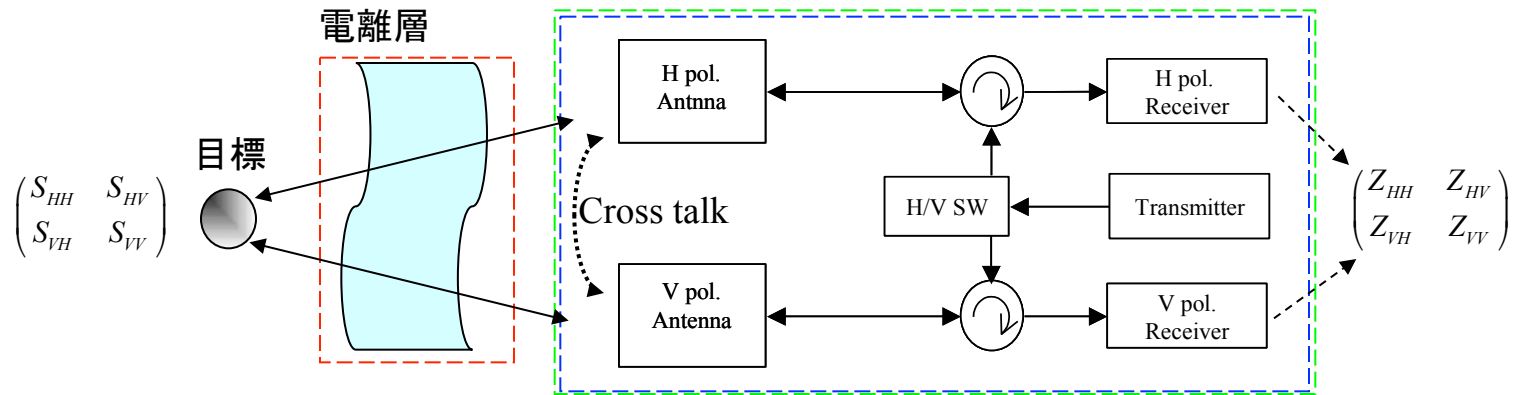


散乱行列

$$[S(HV)] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

HH HV=VH VV  
ALOS/PALSAR polarimetric images

衛星搭載SAR  
の場合



# 研究背景(続き)

## 偏波解析

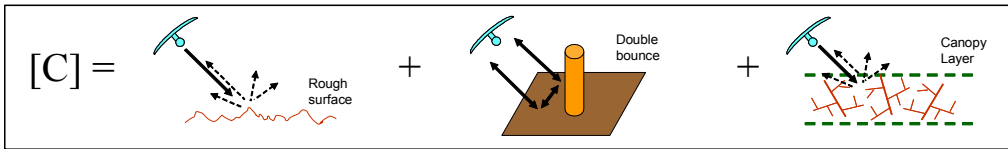
散乱行列  $[S(HV)] = \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix}$

例: 後方散乱係数:  $\sigma_{HH}, \sigma_{HV}, \sigma_{VV}$   
偏波間相関係数:  $Cor(HH, HV)$

Covariance行列

例: 三成分散乱モデル分解法  
(Three-component scattering model, A. Freeman, et al)

$$\mathbf{k} = \begin{bmatrix} S_{HH} \\ \sqrt{2}S_{HV} \\ S_{VV} \end{bmatrix}$$



$$[C(HV)] = \langle \mathbf{k} \cdot \mathbf{k}^{*T} \rangle$$

Coherency行列

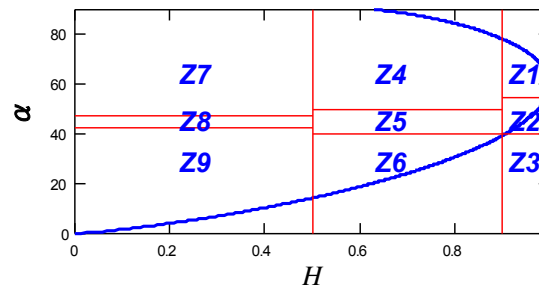
例: ポーラリメトリックエントロピー・アルファ  
(Polarimetric Entropy /alpha, S. Cloud, et al)

$$\mathbf{k}_p = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix}$$

$$[T(HV)] = \langle \mathbf{k}_p \cdot \mathbf{k}_p^{*T} \rangle$$

その他

H- $\alpha$  plane



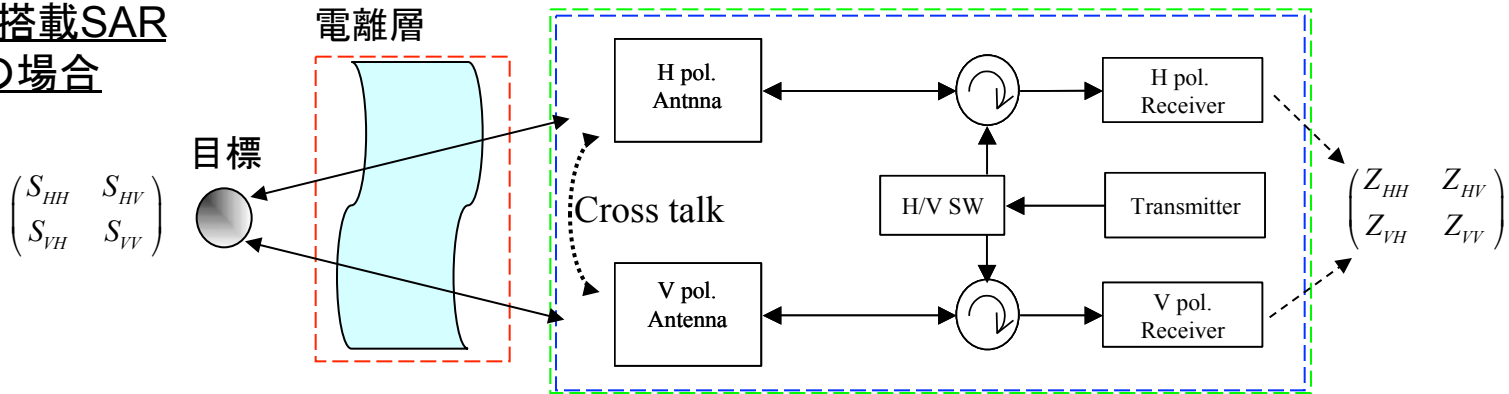
Zone3,6,9 : Surface scattering  
Zone2,5,8 : Dipole (Vegetation) scattering  
Zone1,4,7 : Multiple scattering

例: Polarization orientation angle/shift(地形の起伏情報)  
(Polarimetric signature, circular polarization, coherency matrix)

# SAR偏波校正について

- 偏波校正 : 測定した散乱行列から、レーダハードウェアや電波伝搬による偏波間の歪みを除去すること

## 衛星搭載SARの場合



$$\mathbf{Z} = A \frac{1}{r} e^{-j \frac{4\pi r}{\lambda}} \mathbf{R} \mathbf{F} \mathbf{S} \mathbf{F} \mathbf{T} + \mathbf{N}$$

$$\begin{pmatrix} Z_{HH} & Z_{HV} \\ Z_{VH} & Z_{VV} \end{pmatrix} = A \frac{1}{r} e^{-j \frac{4\pi r}{\lambda}} \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix} + \begin{pmatrix} N_{HH} & N_{HV} \\ N_{VH} & N_{VV} \end{pmatrix}$$

**Z**: 測定散乱行列  
**S**: 散乱行列  
**R, T**: 受信, 送信の誤差マトリクス  
**N**: システムノイズ

**F**: ファラデー回転( $\Omega$ : 回転角度)  
 $f_1, f_2$ : H/V間チャンネルインバランス  
 $\delta$ : クロストーク  
**A**: ラジオメトリック校正パラメータ

# SAR偏波校正について

## ファラデー回転角度:

$$\Omega = \frac{k}{f^2} \times B \cos \psi \sec \theta_0 \times TEC \quad [\text{radians}]$$

$k$ : Constant of value ( $2.365 \times 10^4$ )

$B$ : Magnetic flux density

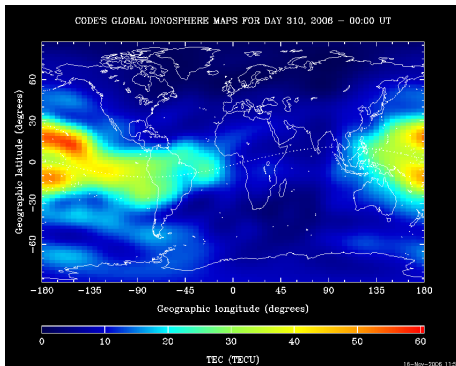
$f$ : Frequency

$\psi$ : Angle between earth's magnetic field and radar wave

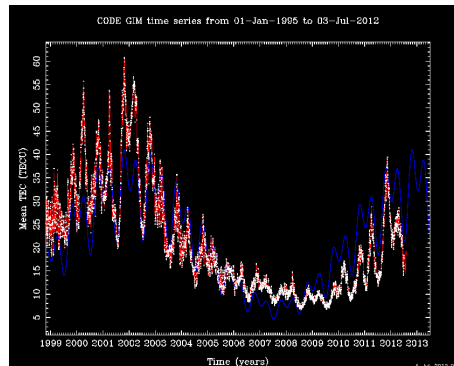
$\theta_0$ : Incident angle

$TEC$ : Total electron content

## ■ 全電子数(TEC)の例 ・時間変化

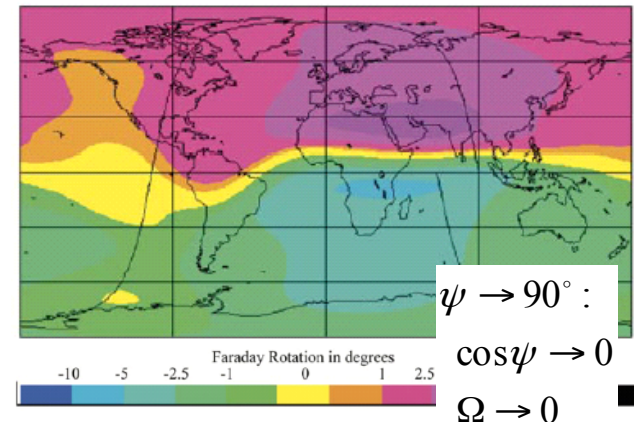


## ・年変化



<http://www.aiub.unibe.ch/ionosphere/>

## ■ ファラデー回転角の分布例

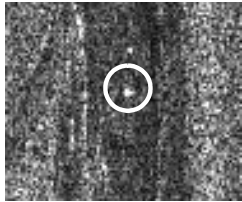


Wright, et al., "Faraday rotation effects on L-band spaceborne SAR data," IEEE TGRS, vol.41, no.12, December 2003.

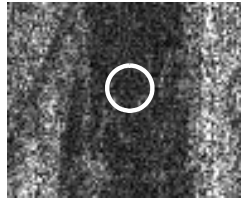


# SAR偏波校正について

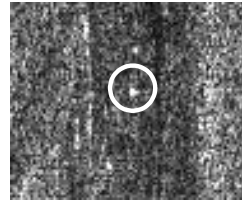
・CRの利用:  $S^{Tri} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$



(a) HH

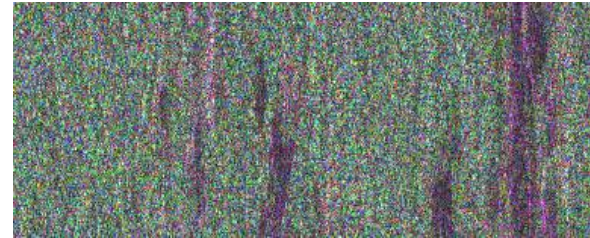


(b) HV or VH



(c) VV

・自然地形の利用:  $\langle S_{HH} S_{HV}^* \rangle, \langle S_{VV} S_{HV}^* \rangle \approx 0$



## ■ 偏波校正方法

・Quegan method ( $\Omega=0$ ):

$$\begin{pmatrix} Z_{HH} & Z_{HV} \\ Z_{VH} & Z_{VV} \end{pmatrix} = \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix}$$

・CRから:

$$f_1 f_2 = Z_{VV} / Z_{HH}$$

・自然地形から:

$$\alpha = f_1 / f_2, \delta_1, \delta_2, \delta_3, \delta_4$$

・Freeman method ( $\delta=0$ ):

$$\begin{pmatrix} Z_{HH} & Z_{HV} \\ Z_{VH} & Z_{VV} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & f_1 \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & f_2 \end{pmatrix}$$

任意の  
 $\Omega$ に  
ついて

・CRから:

$$f_1 f_2 = Z_{VV} / Z_{HH}$$

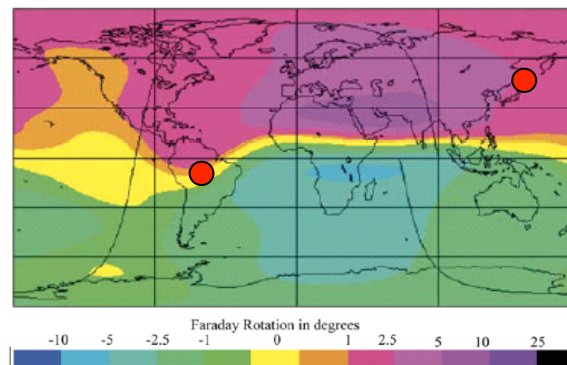
・自然地形から:

$$\alpha = f_1 / f_2$$

	Channel imbalance	Cross-talk	Faraday rotation
Quegan method	○	○	—
Freeman method	○	—	○

# SAR偏波校正について

- Rio branco (ブラジル) :  $\psi \doteq 90$  [deg.]  
 $\rightarrow \Omega \doteq 0$  [deg.]

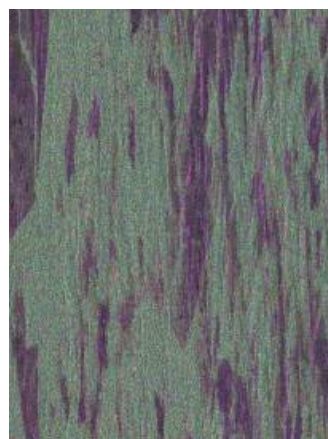


$$\Omega = \frac{k}{f^2} \times B \cos \psi \sec \theta_0 \times TEC$$

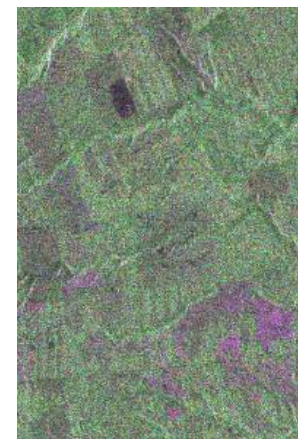
No.	Obs. date	Path (D/A)	Off-nadir angle[deg.]
1	7/ 20, 2006	A	21.5
2	7/ 21, 2006	D	21.5
3	9/ 4, 2006	A	21.5
4	9/ 5, 2006	D	21.5
5	10/20, 2006	A	21.5
6	10/21, 2006	D	21.5

- 苫小牧 (日本)

No.	Obs. date	Path (D/A)	Off-nadir angle[deg.]
1	5/19, 2006	D	21.5
2	7/7, 2006	A	23.1
3	8/ 19, 2006	D	23.1
4	8/22, 2006	A	23.1
5	10/4, 2006	D	23.1
6	10/7, 2006	A	23.1



Rio branco



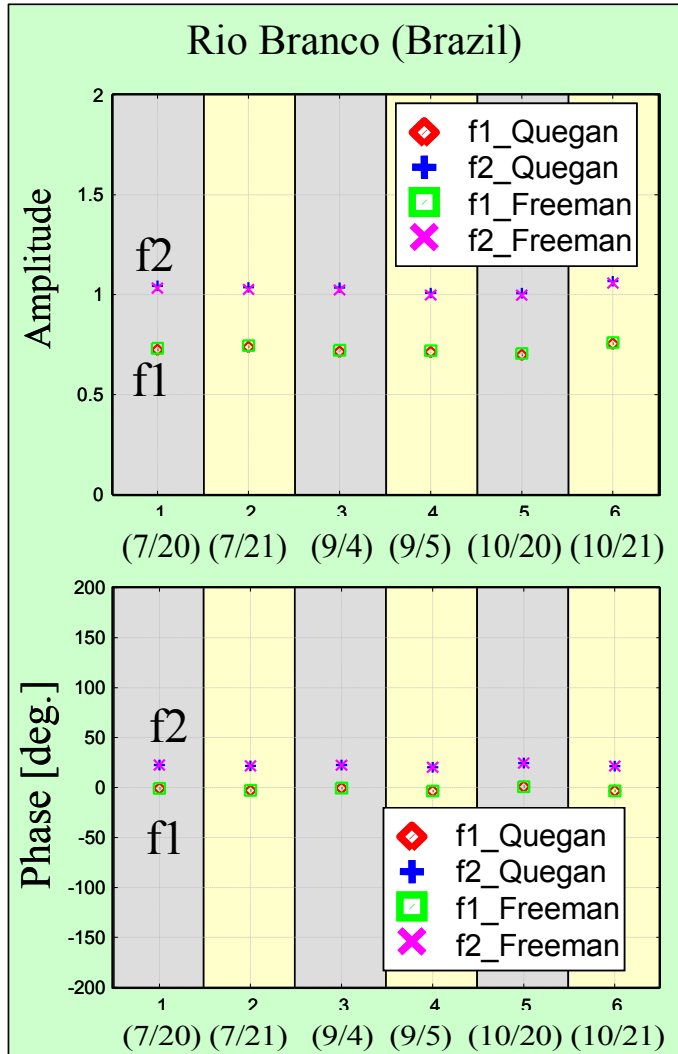
苫小牧

アマゾンの校正データとQueganの方法を用いてPALSARの偏波校正係数を算出

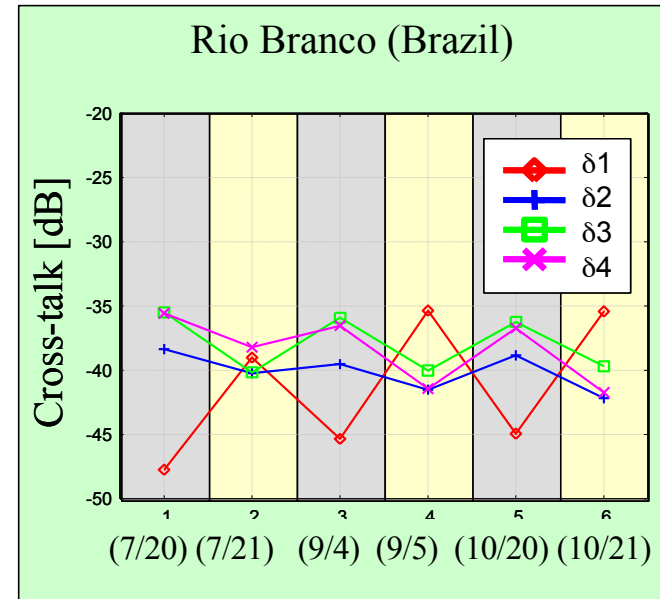


# SAR偏波校正について

## ■ チャンネルインバランス



## ■ クロストーク (Quegan methodから)



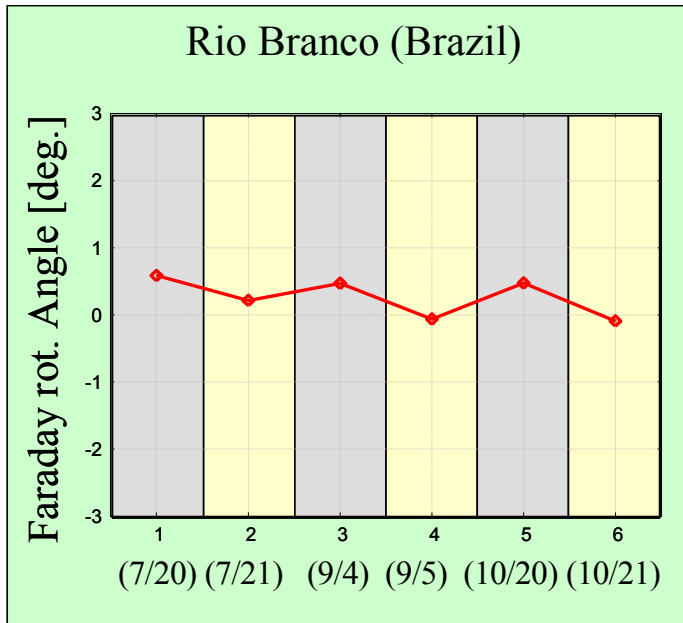
Descending  
(昼間観測)

Ascending  
(夜間観測)



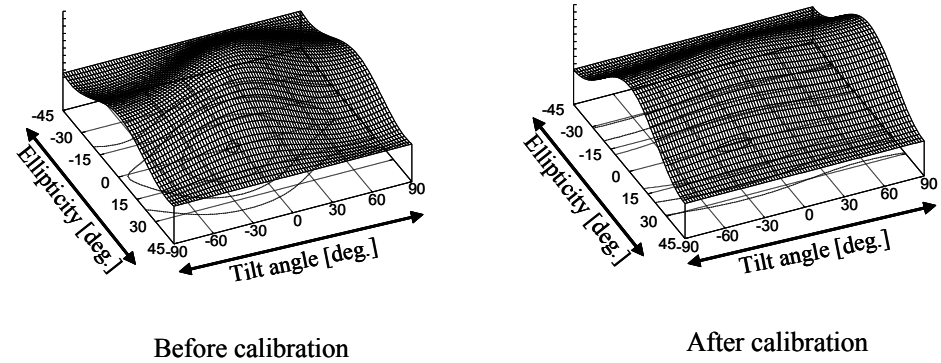
# SAR偏波校正について

## ■ ファラデー回転角 (Freeman methodから)



 Descending  
(昼間観測)

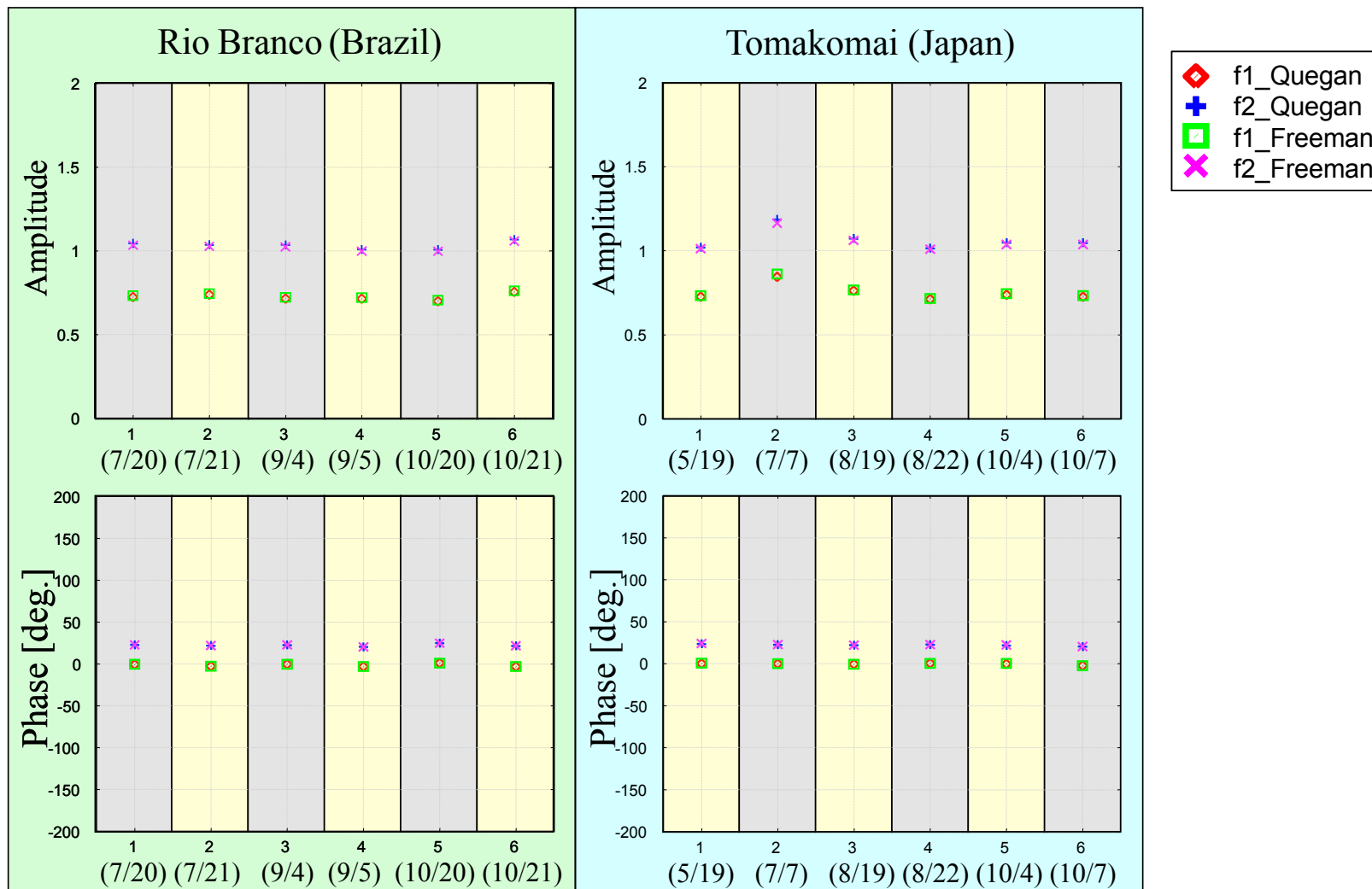
 Ascending  
(夜間観測)



PALSARの偏波校正係数(7/20,21 と 9/4,5の平均)

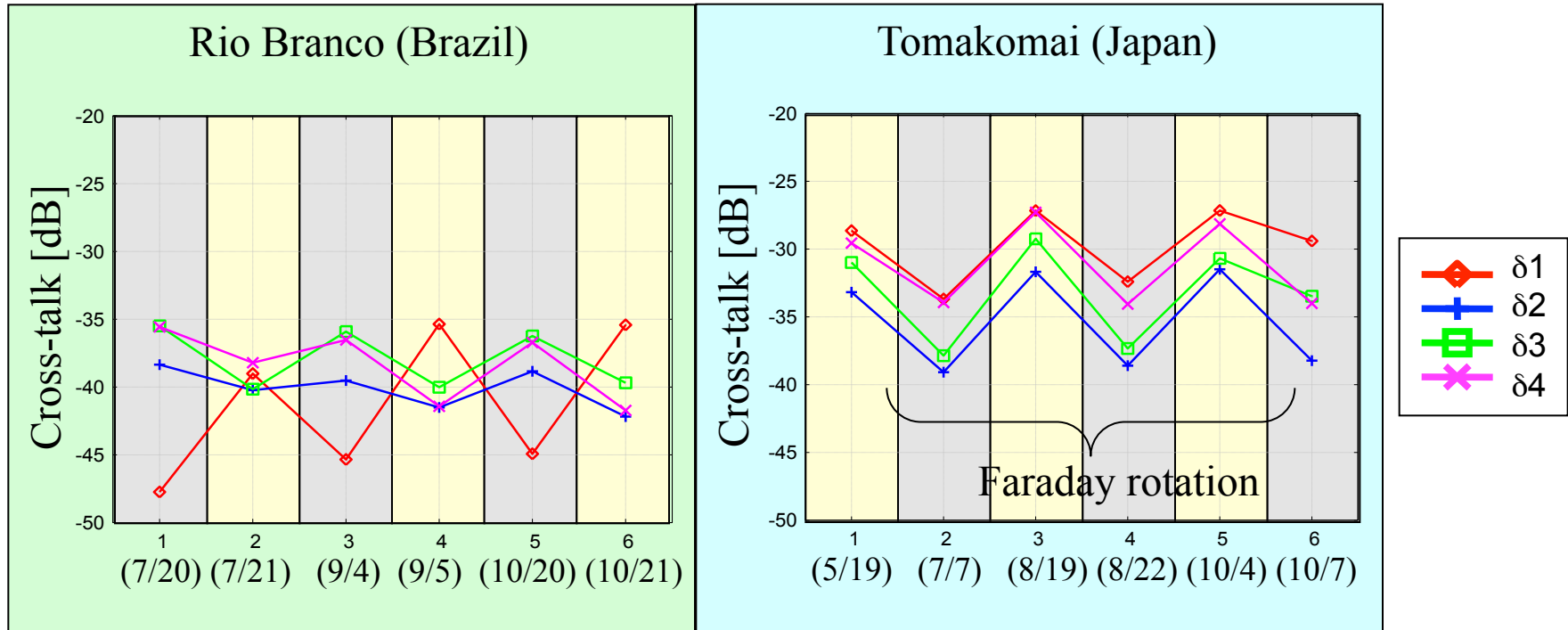
$$\begin{cases}
 F_1 = 0.957217 + j0.382956 = 1.03 \angle 21.81^\circ \\
 F_2 = 0.721712 - j0.023677 = 0.722 \angle 1.88^\circ \\
 \Delta_1 = 0.002427 + j0.012930 = 0.013 \angle 79.37^\circ \\
 \Delta_2 = -0.011472 - j0.006228 = 0.013 \angle -151.50^\circ \\
 \Delta_3 = -0.006263 + j0.007083 = 0.010 \angle 131.48^\circ \\
 \Delta_4 = -0.006297 + j0.008027 = 0.010 \angle 128.11^\circ
 \end{cases}$$

# SAR偏波校正について



# SAR偏波校正について

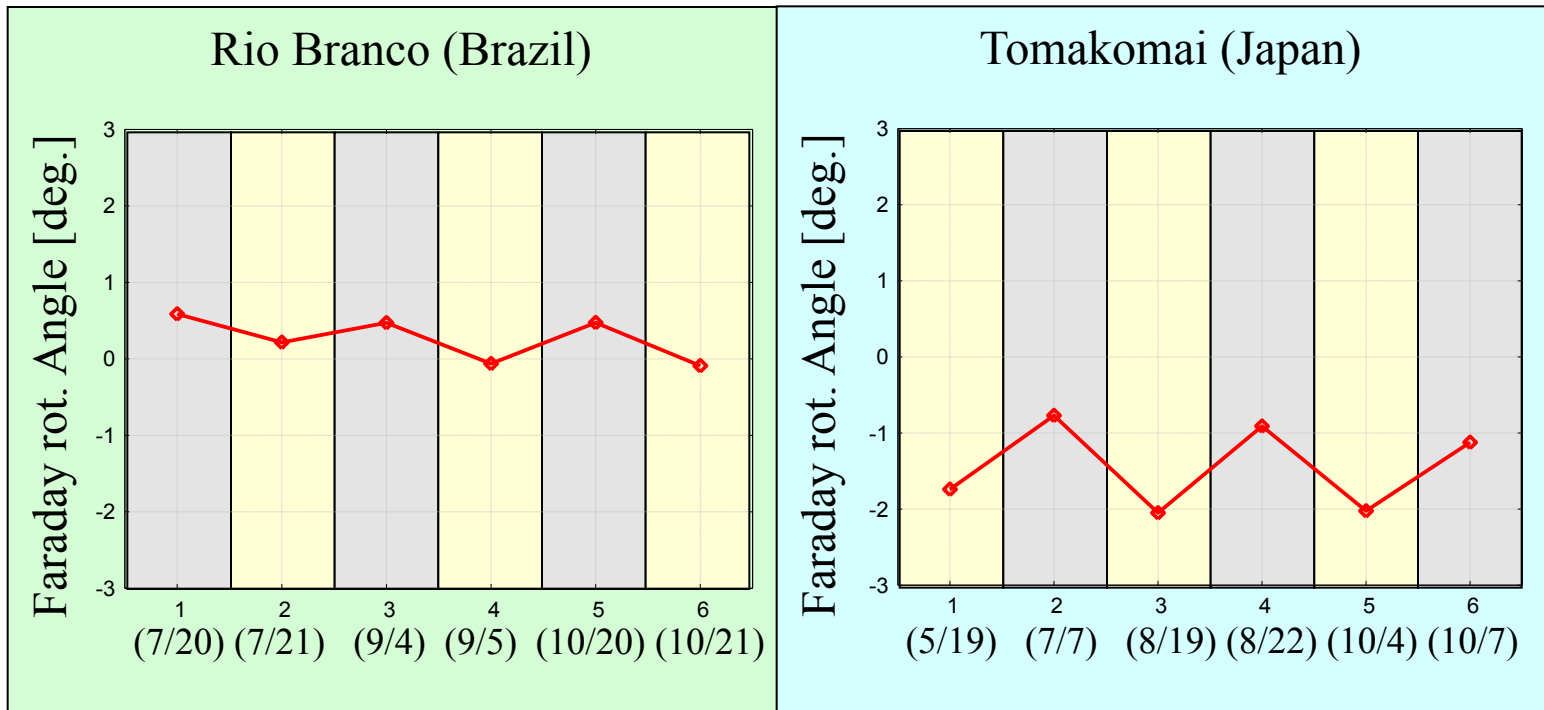
## ・クロストーク



Descending (昼間観測)
  Ascending (夜間観測)



# SAR偏波校正について



Descending (昼間観測)      Ascending (夜間観測)



# SAR偏波校正について

## TEC(全電子数)情報:

TECデータ: <http://modelweb.gsfc.nasa.gov/models/iri.html>

Rio brancoの緯度経度: (lat., lon.)=(-9.922°, -68.013°)

苫小牧の緯度経度: (lat., lon.)=(42.745°, 141.471°)

## ファラデー回転角:

Wright, et al., "Faraday rotation effects on L-band spaceborne SAR data," IEEE TGRS, vol.41, no.12, December 2003.

$$\Omega \approx 0.299 \times \frac{TECU}{f_{GHz}^2} \times \left\{ 2 \left[ \sin \theta_m \sin \theta \cos(\phi_m - \phi) + \cos \theta_m \cos \theta \right] \right. \\ \left. \pm \tan \theta_0 \left[ \sin \theta_m \sin \lambda \sin(\phi_0 - \phi_m) \pm \cos \theta_m \cos \lambda \right] \right\} \text{ [degree]}$$

at ALOS height=691.65 [km]

$(\phi_m, \theta_m)$  : 磁北極の座標

$(\phi, \theta)$  : 衛星の座標

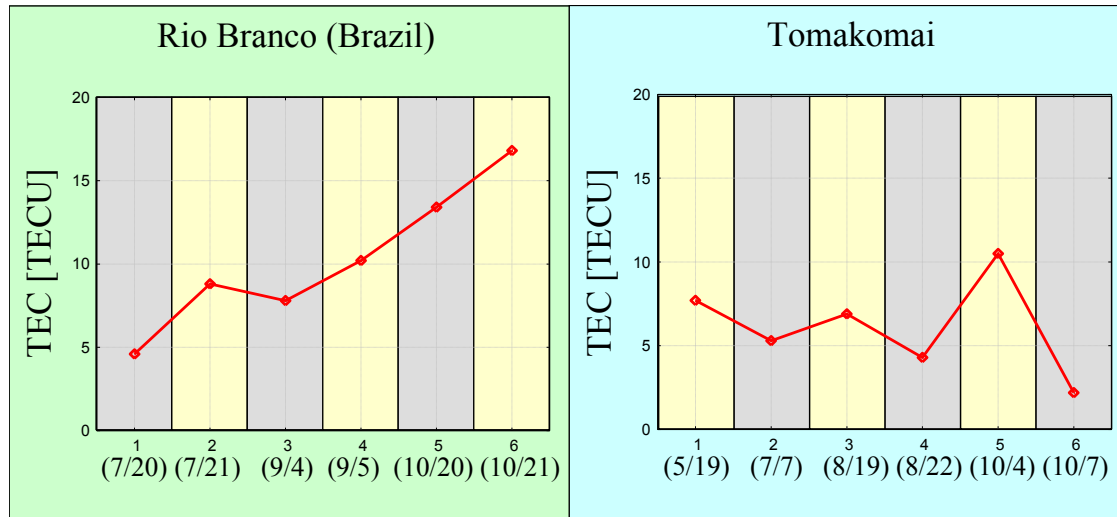
$\lambda$  : 衛星の軌道傾斜角

$\phi_0$  : 昇交点赤経

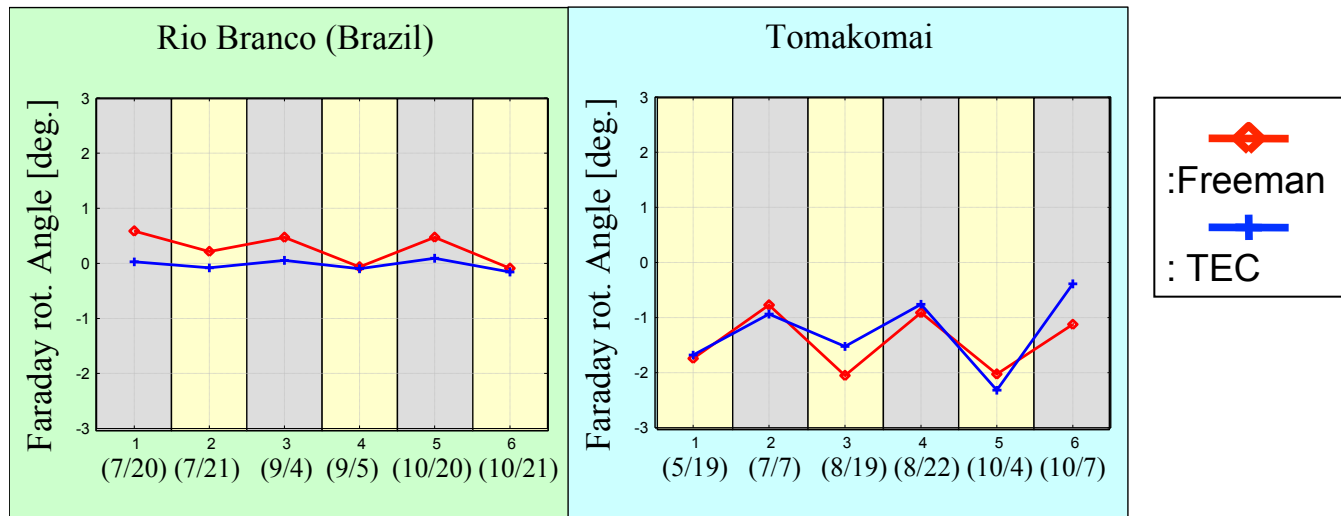


# SAR偏波校正について

・TEC  
(全電子数)



・ファラデー  
回転角



# SAR偏波校正について

$$\begin{pmatrix} Z_{HH} & Z_{HV} \\ Z_{VH} & Z_{VV} \end{pmatrix} = \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix}$$

$$\left\{ \begin{array}{l} f_1 = 0.957217 + j0.382956 = 1.03 \angle 21.81^\circ \\ f_2 = 0.721712 - j0.023677 = 0.722 \angle 1.88^\circ \\ \delta_1 = 0.002427 + j0.012930 = 0.013 \angle 79.37^\circ \\ \delta_2 = -0.011472 - j0.006228 = 0.013 \angle -151.50^\circ \\ \delta_3 = -0.006263 + j0.007083 = 0.010 \angle 131.48^\circ \\ \delta_4 = -0.006297 + j0.008027 = 0.010 \angle 128.11^\circ \end{array} \right.$$

$$\begin{pmatrix} Z'_{HH} & Z'_{HV} \\ Z'_{VH} & Z'_{VV} \end{pmatrix} = \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix}^{-1} \begin{pmatrix} Z_{HH} & Z_{HV} \\ Z_{VH} & Z_{VV} \end{pmatrix} \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix}^{-1} = \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix}$$



$$\begin{pmatrix} S_{LL} & S_{LR} \\ S_{RL} & S_{RR} \end{pmatrix} = \frac{1}{2} \begin{pmatrix} 1 & j \\ j & 1 \end{pmatrix} \begin{pmatrix} Z'_{HH} & Z'_{HV} \\ Z'_{VH} & Z'_{VV} \end{pmatrix} \begin{pmatrix} 1 & j \\ j & 1 \end{pmatrix}$$

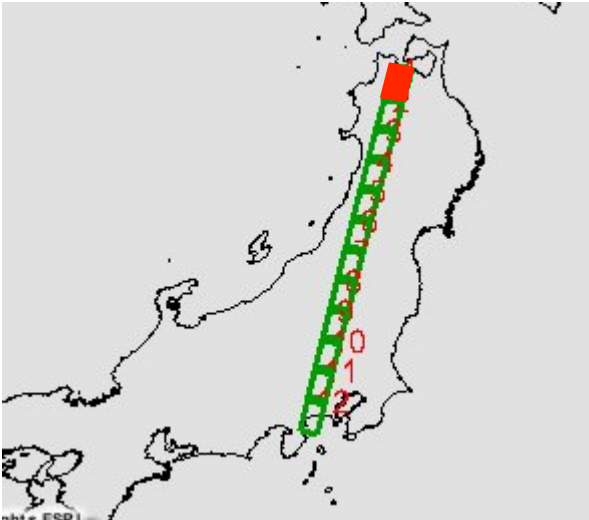


$$\Omega = -\frac{1}{4} \text{Arg}(\langle S_{LR} S_{RL}^* \rangle)$$





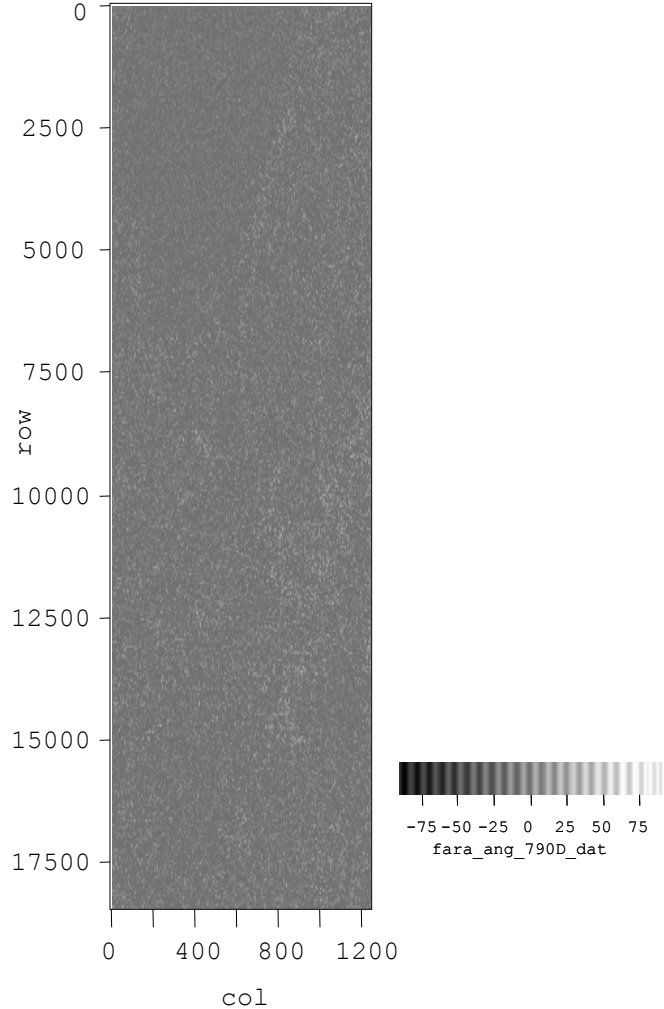
# SAR偏波校正について



ファラデー回転の解析エリア(2006,7/21)



青森(HH,HV,VV)

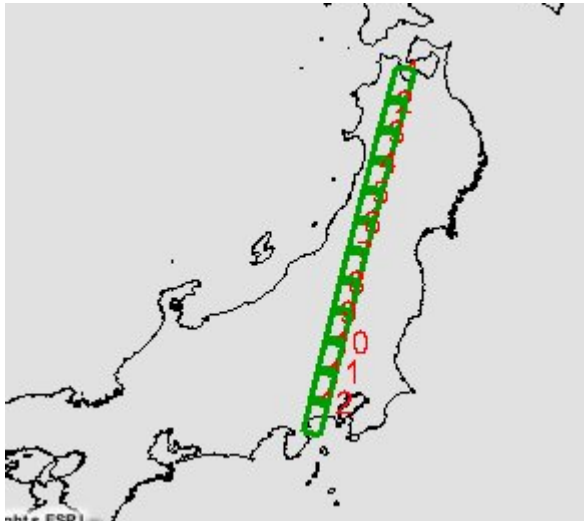


ファラデー回転の分布図



# SAR偏波校正について

## ファラデー回転の推定



ファラデー回転の解析エリア(2006,7/21)

No.	Latitude/Longitude [deg.]	FR angle (PALSAR) [deg.]	FR angle (IRI2001) [deg.]
1	40.738 / 140.666	-2.00	-2.14
2	40.244 / 140.533	-1.94	-2.17
3	39.751 / 140.399	-1.93	-2.18
4	39.257 / 140.27	-1.95	-2.19
5	38.763 / 140.141	-1.98	-2.22
6	38.269 / 140.012	-1.96	-2.23
7	37.775 / 139.887	-2.02	-2.25
8	37.281 / 139.763	-2.01	-2.27
9	36.786 / 139.637	-1.93	-2.29
10	36.292 / 139.511	-1.94	-2.31
11	35.798 / 139.387	-1.93	-2.33
12	35.303 / 139.267	-1.91	-2.34

# SAR偏波校正について

## 偏波解析

散乱行列

$$[S(HV)] = \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix}$$



例: 後方散乱係数:  $\sigma_{HH}$ ,  $\sigma_{HV}$ ,  $\sigma_{VV}$   
偏波間相関係数:  $\text{Cor}(HH, HV)$

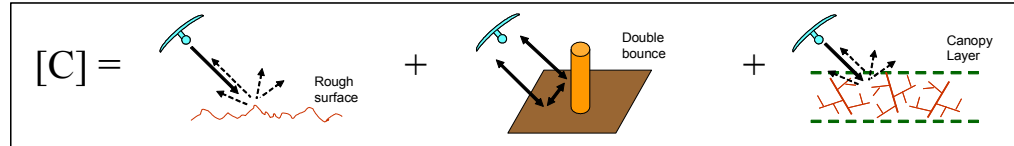
Covariance行列



例: 三成分散乱モデル分解法  
(Three-component scattering model, A. Freeman, et al)

$$\mathbf{k} = \begin{bmatrix} S_{HH} \\ \sqrt{2}S_{HV} \\ S_{VV} \end{bmatrix}$$

$$[C(HV)] = \langle \mathbf{k} \cdot \mathbf{k}^{*T} \rangle$$



Coherency行列

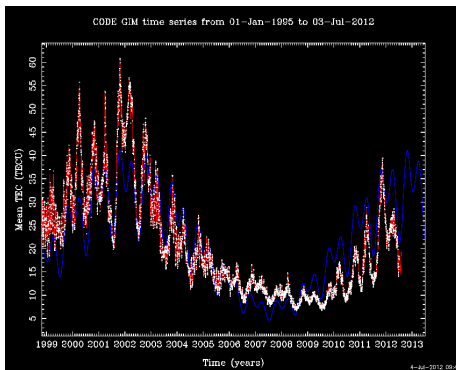


例: ポーラリメトリックエントロピー・アルファ  
(Polarimetric Entropy /alpha, S. Cloud, et al)

$$\mathbf{k} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ S_{HV} + S_{VH} \end{bmatrix}$$

H- $\alpha$  plane

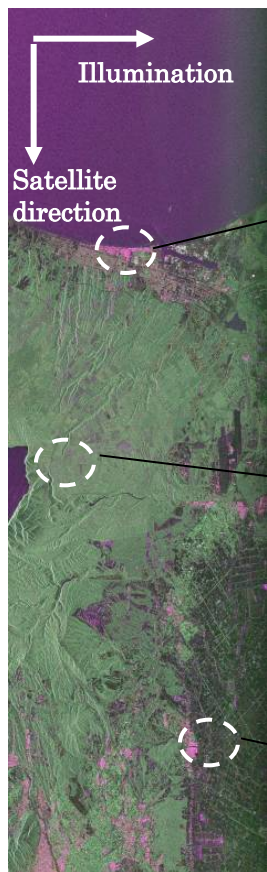
ファラデー回転の影響(今後TECが上昇していくことが予想される):



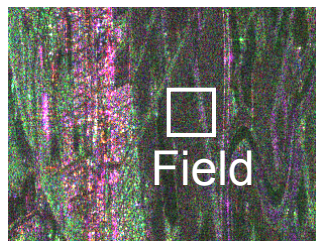
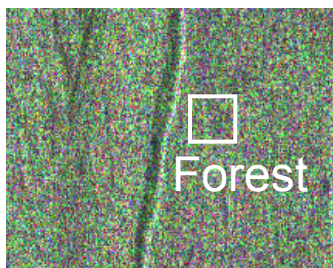
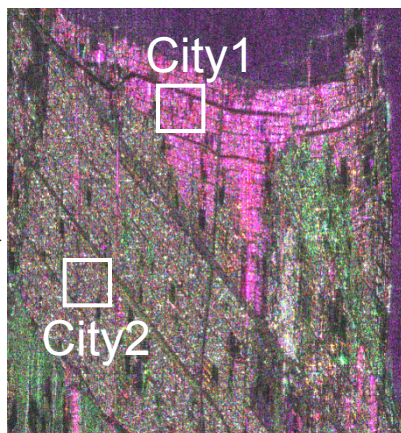
$$\begin{pmatrix} Z_{HH} & Z_{HV} \\ Z_{VH} & Z_{VV} \end{pmatrix} = \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix} \begin{pmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{pmatrix} \begin{pmatrix} \cos \Omega & \sin \Omega \\ -\sin \Omega & \cos \Omega \end{pmatrix}$$

# SAR偏波校正について

## ■ 解析データ



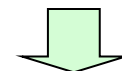
解析領域  
(50x50  
ピクセル)



苫小牧(HH,HV,VV)  
観測日:2007 05/25  
(Ascending)

## ■ 後方散乱係数 VS. Faraday回転

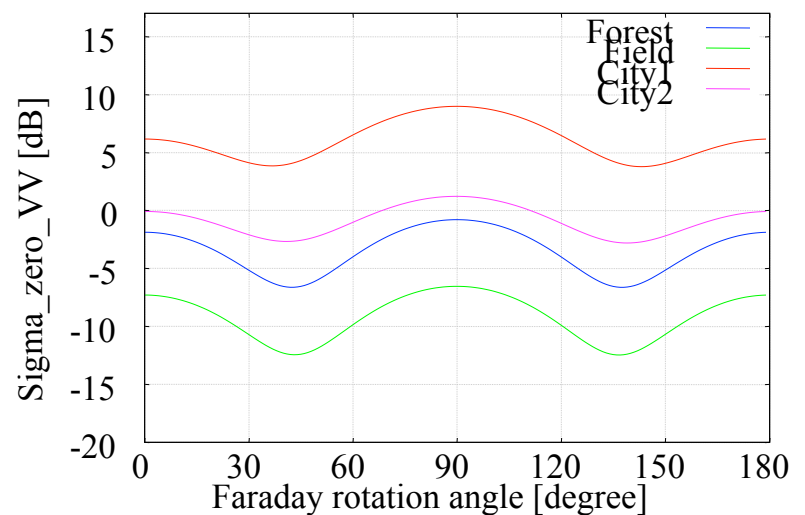
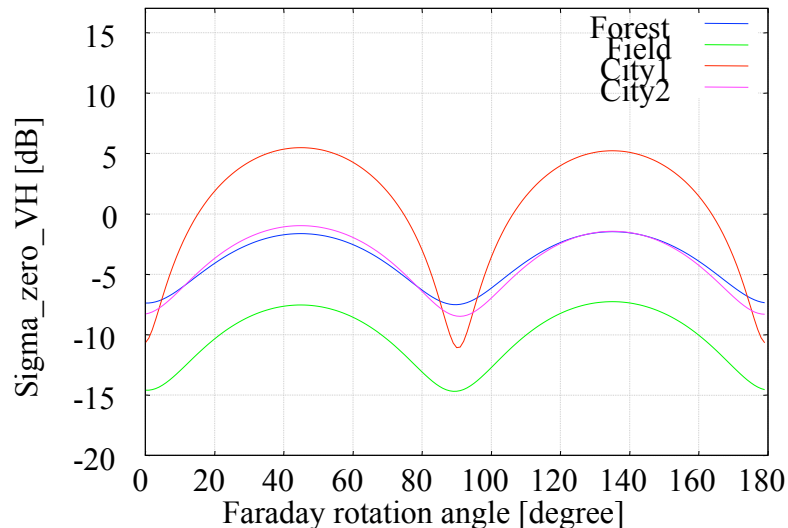
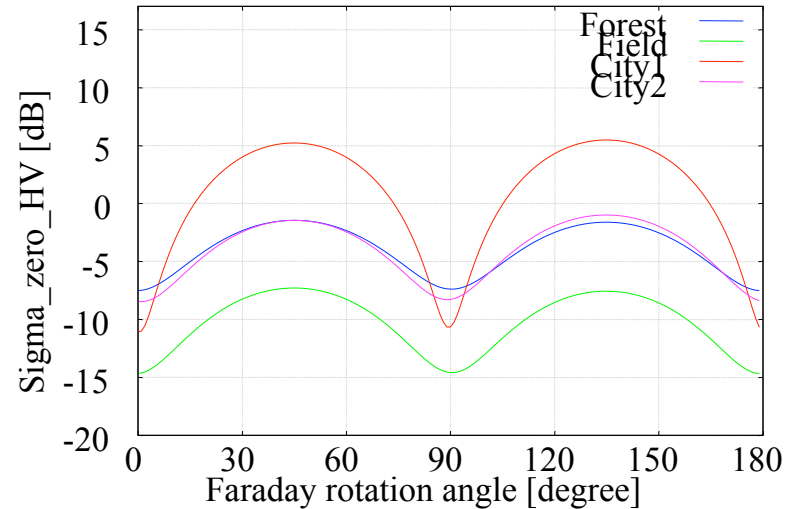
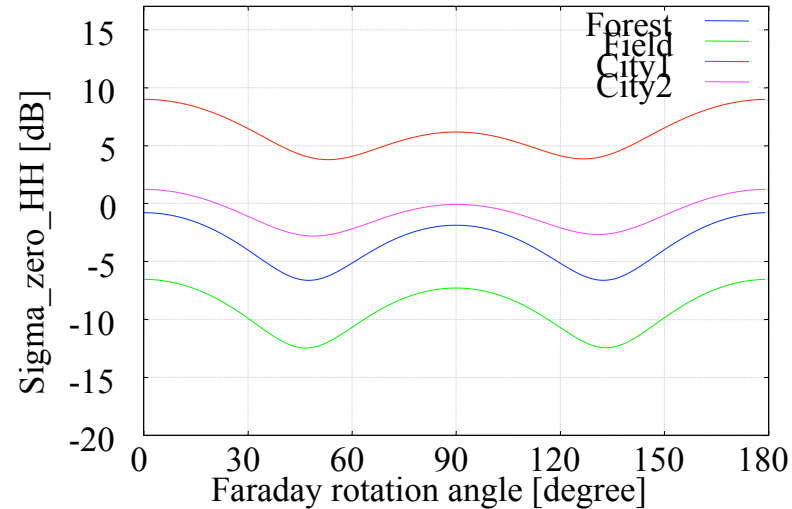
$$\begin{aligned}Z_{HH} &= S_{HH} \cos^2 \Omega - S_{VV} \sin^2 \Omega \\Z_{HV} &= S_{HV} + (S_{HH} + S_{VV}) \sin \Omega \cos \Omega \\Z_{VH} &= S_{HV} - (S_{HH} + S_{VV}) \sin \Omega \cos \Omega \\Z_{VV} &= S_{VV} \cos^2 \Omega - S_{HH} \sin^2 \Omega\end{aligned}$$



$$\begin{aligned}\sigma_{0,HH} &= 10.0 * \log_{10} \langle Z_{HH} Z_{HH}^* \rangle - 115.0 \\ \sigma_{0,HV} &= 10.0 * \log_{10} \langle Z_{HV} Z_{HV}^* \rangle - 115.0 \\ \sigma_{0,VH} &= 10.0 * \log_{10} \langle Z_{VH} Z_{VH}^* \rangle - 115.0 \\ \sigma_{0,VV} &= 10.0 * \log_{10} \langle Z_{VV} Z_{VV}^* \rangle - 115.0\end{aligned}$$

# SAR偏波校正について

## ■ 後方散乱係数 VS. Faraday回転 : 50 x 50ピクセルの平均値



# SAR偏波校正について

## ■ エントロピー・アルファ解析 VS. Faraday回転

- ・ Coherency行列[T]の固有値展開

$$[T] = \langle k \cdot k^T \rangle = [U_3] \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} [U_3^{*T}] = \lambda_1 \mathbf{e}_1 \mathbf{e}_1^{*T} + \lambda_2 \mathbf{e}_2 \mathbf{e}_2^{*T} + \lambda_3 \mathbf{e}_3 \mathbf{e}_3^{*T}$$

$$\text{ターゲットベクトル: } \mathbf{k} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} & S_{HH} - S_{VV} & 2S_{HV} \end{bmatrix}^T$$

$$\text{ユニタリ行列: } [U_3] = [\mathbf{e}_1 \quad \mathbf{e}_2 \quad \mathbf{e}_3], \quad \mathbf{e}_i = \begin{bmatrix} \cos \alpha_i & \sin \alpha_i \cos \beta_i e^{j\delta_i} & \sin \alpha_i \sin \beta_i e^{j\delta_i} \end{bmatrix}^T$$

H-Alpha Classification

- ・ 固有値の割合から各要素の発生確率

$$\text{確率: } P_i = \lambda_i / \sum_{i=1}^3 \lambda_i$$

エントロピー:

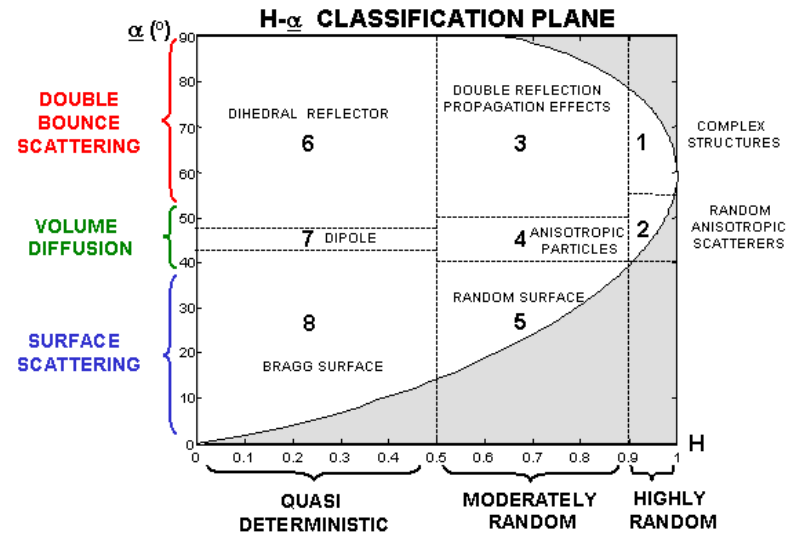
$$H = -P_1 \log_3 P_1 - P_2 \log_3 P_2 - P_3 \log_3 P_3$$

$$(0 \leq H \leq 1)$$

アルファ:

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

$$(0 \leq \bar{\alpha} \leq 90[\text{deg.}])$$



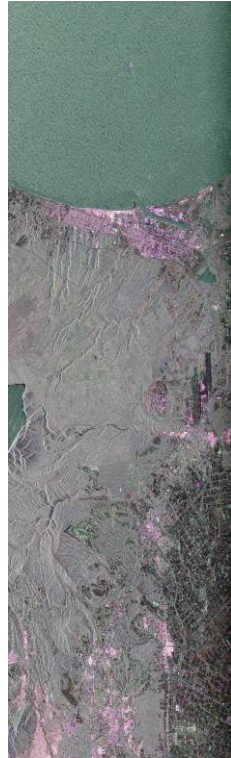
# SAR偏波校正について

- エントロピー・アルファ解析 VS. Faraday回転 : 4 x 16ピクセルから計算

H-Alpha Classification

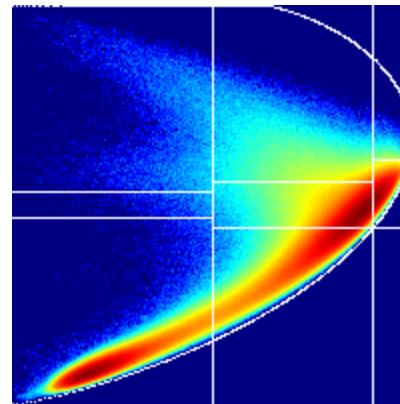
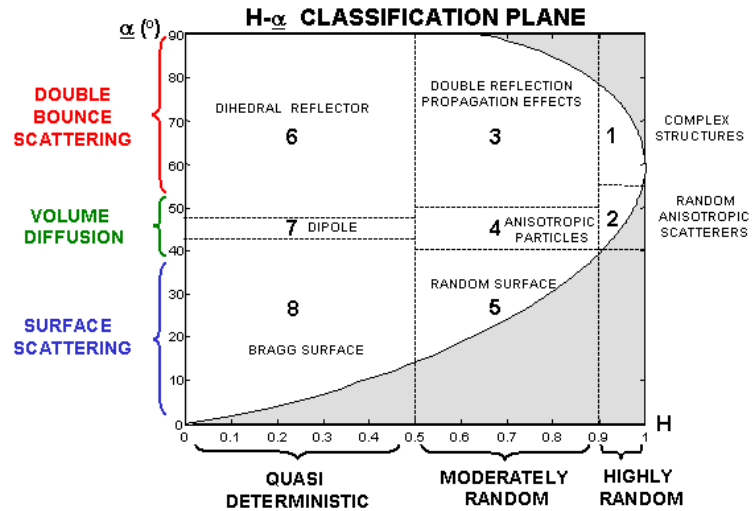


$\Omega = 0^\circ$

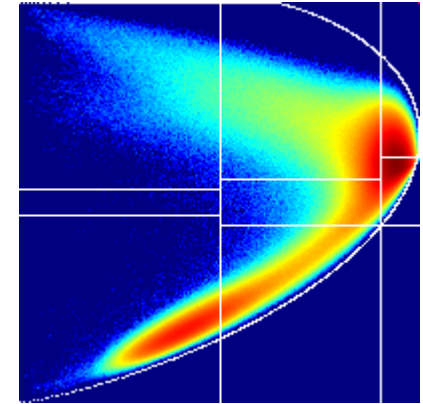


$\Omega = 30^\circ$

苫小牧(HH, HV, VV)

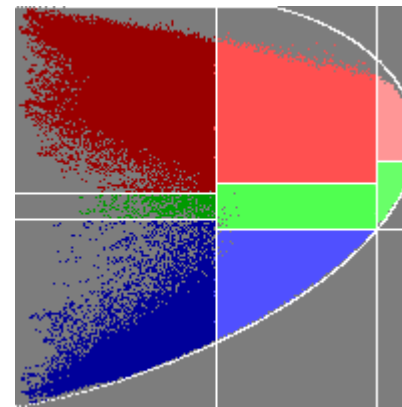
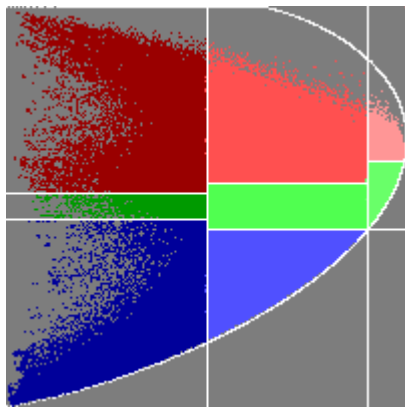
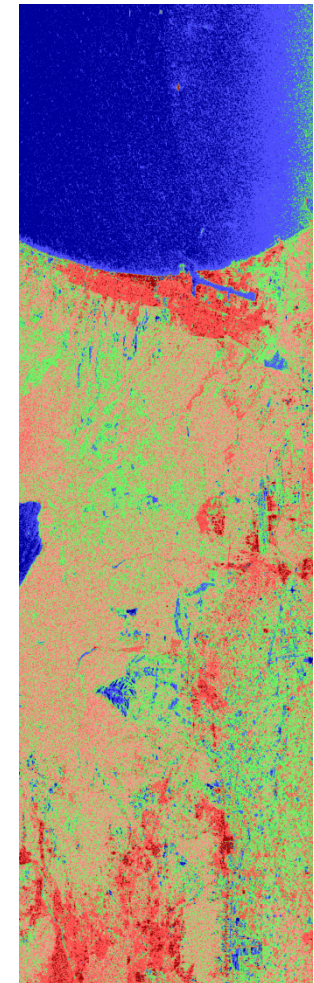
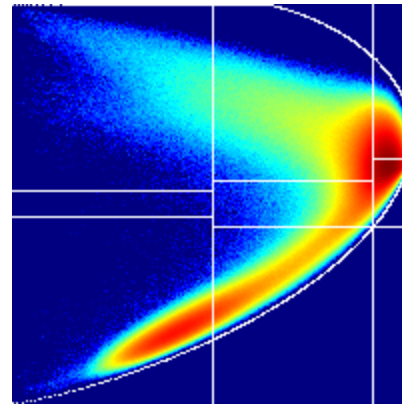
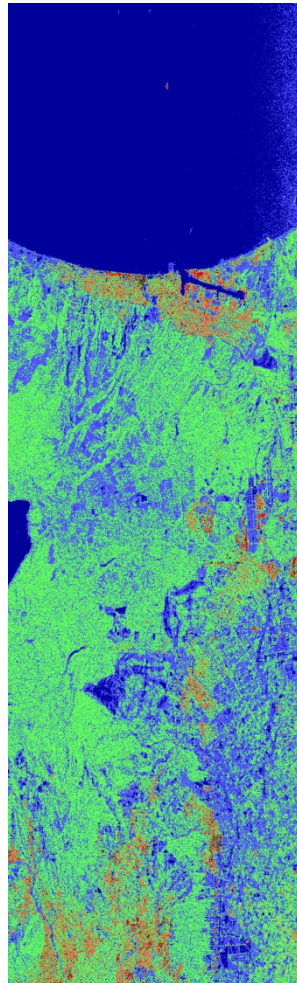
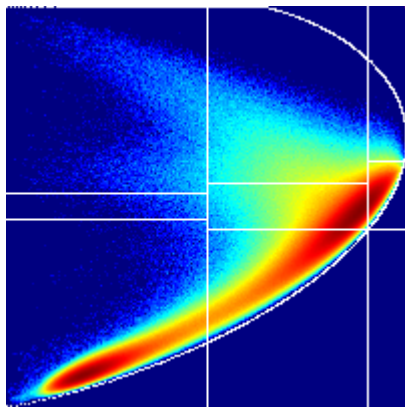


$\Omega = 0^\circ$



$\Omega = 30^\circ$

# SAR偏波校正について



$\Omega=0^\circ$

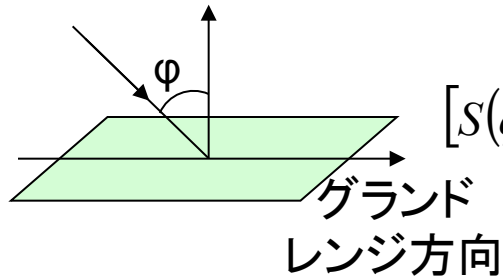
$\Omega=30^\circ$



# SAR偏波データによる地形情報のデータ解析

・地表散乱モデル(規範問題): The Small-Perturbation Model

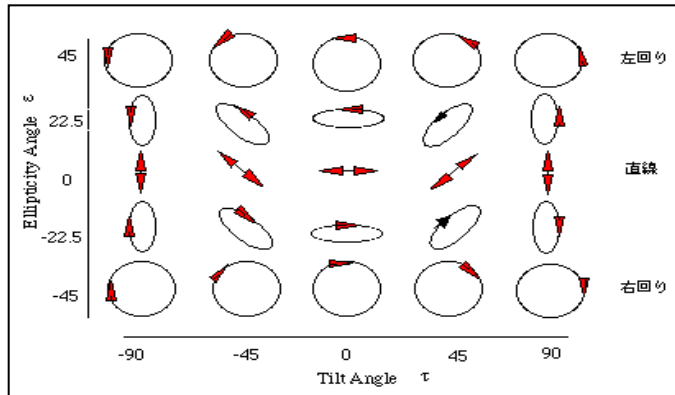
⇒ 入射角 $\phi$ の関数



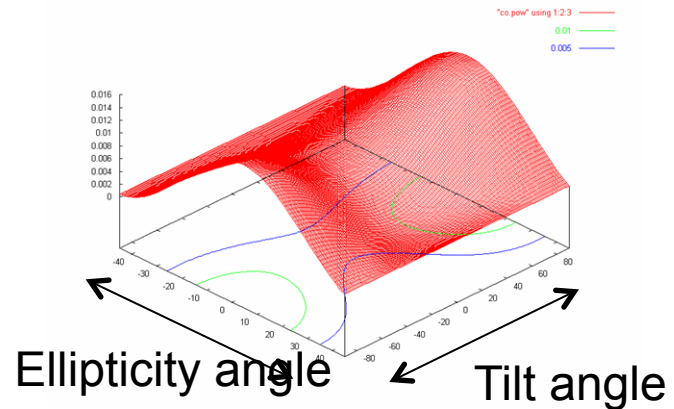
$$[S(\phi)] = \sqrt{\sigma} \begin{bmatrix} \alpha_h(\phi) & 0 \\ 0 & \alpha_v(\phi) \end{bmatrix}$$

$$\left\{ \begin{array}{l} \alpha_h = \frac{\cos \phi - \sqrt{\epsilon_r - \sin^2 \phi}}{\cos \phi + \sqrt{\epsilon_r - \sin^2 \phi}} \\ \alpha_v = \frac{(\epsilon_r - 1) [\sin^2 \phi - \epsilon_r (1 + \sin^2 \phi)]}{(\epsilon_r \cos \phi + \sqrt{\epsilon_r - \sin^2 \phi})^2} \\ \sigma = 8k^4 h^2 \cos^4 \phi W(2k \sin \phi) \end{array} \right.$$

・偏波情報の評価方法: 偏波シグネチャー



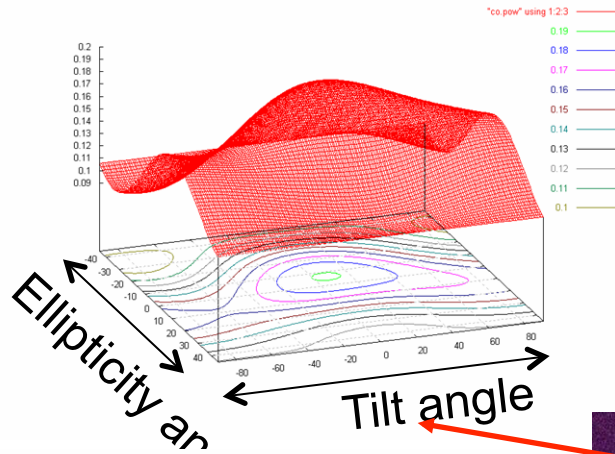
偏波シグネチャー(Polarimetric signature)



偏波シグネチャーの実例

(Co-pol. channel, L-band, 海)

# SAR偏波データによる地形情報のデータ解析



$$[S] = \sqrt{\sigma} \begin{bmatrix} \alpha_h & 0 \\ 0 & \alpha_v \end{bmatrix}$$

Azimuth  
Slope  $\omega$ により

$$[S'] = \sqrt{\sigma} \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

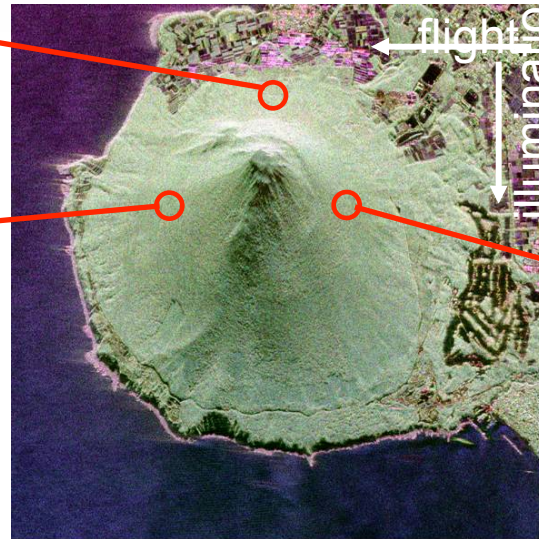
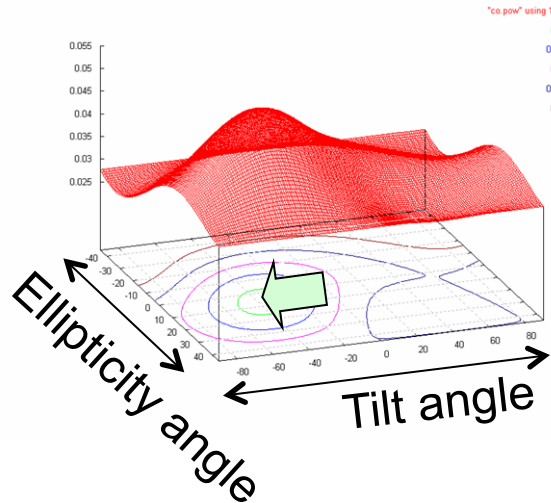
φ

ω

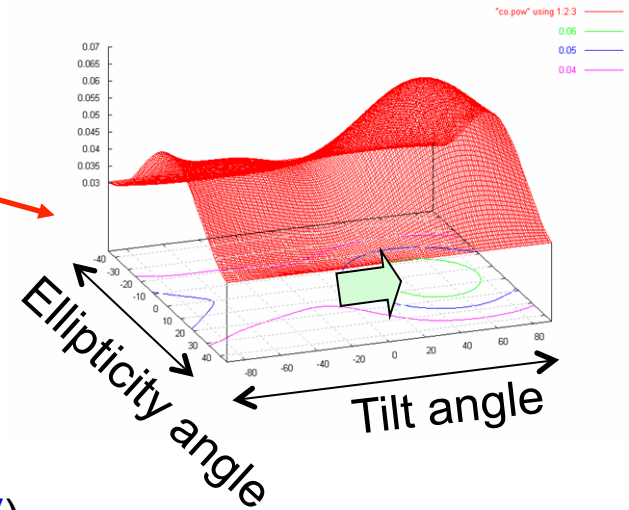
レンジ方向

アジマス方向

- ・HHとVV偏波のバランス変化
- ・クロス偏波の発生



L-band (HH, HV, VV)



# SAR偏波データによる地形情報のデータ解析

## ■ D.L. Schuler, J.S. Leeらのモデル

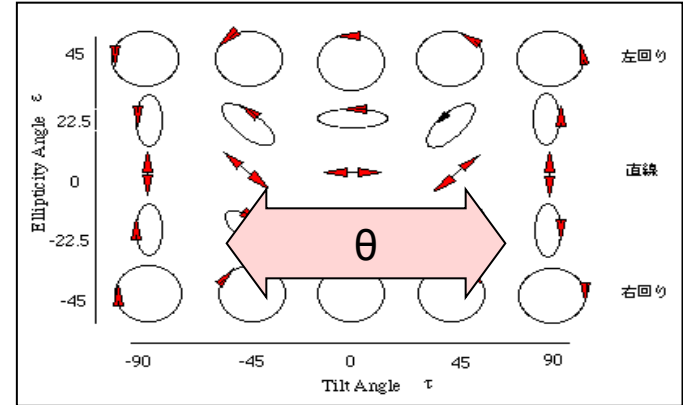
$$\tan \theta = \frac{\tan \omega}{-\tan \gamma \cos \phi + \sin \phi}$$

$\theta$ : orientation (tilt) angle shift

**$\tan \omega$ : azimuth slope**

$\tan \gamma$ : slope in the ground range direction

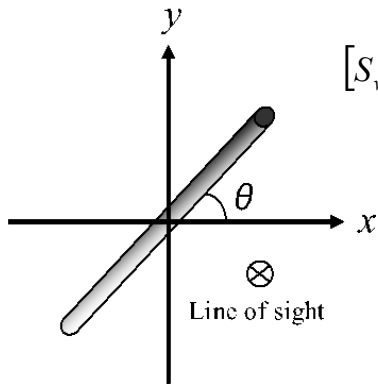
$\phi$ : radar look angle



Co pol. maxの偏波状態のTilt角が移動

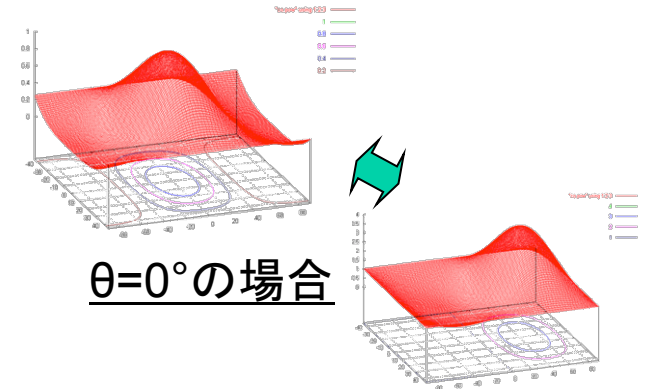
Azimuth方向の傾斜推定が可能(直交パスが必要)

## ・ワイヤーの散乱マトリクスとAzimuth Slope補正



$$[S_{wire}(\theta)] = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix}$$

$$= \begin{bmatrix} \cos^2 \theta & \frac{1}{2} \sin 2\theta \\ \frac{1}{2} \sin 2\theta & \cos^2 \theta \end{bmatrix}$$

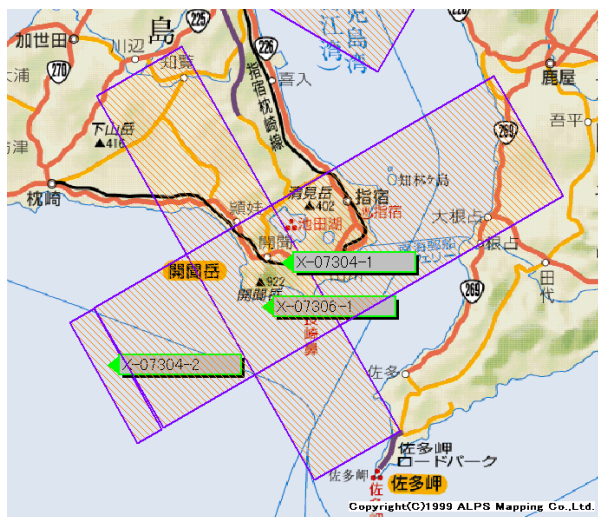


上式の逆変換を基にAzimuth slopeの影響を補正

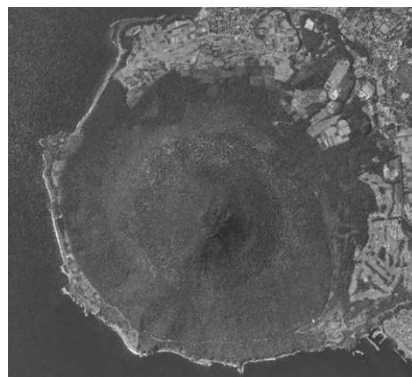
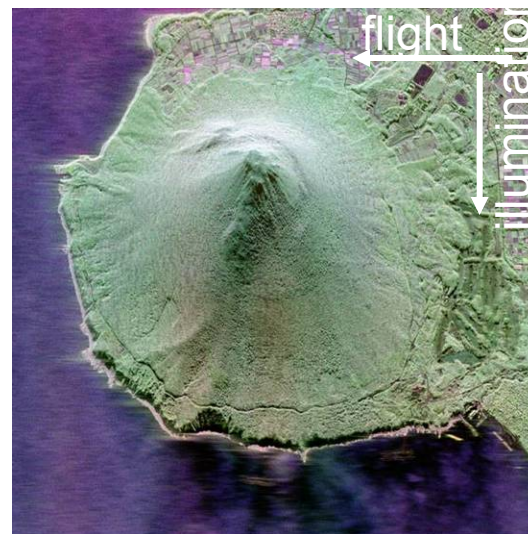
$\theta=45^\circ$ の場合

# SAR偏波データによる地形情報のデータ解析

## ■ 使用データ(2004 2/7観測, 9999データ)

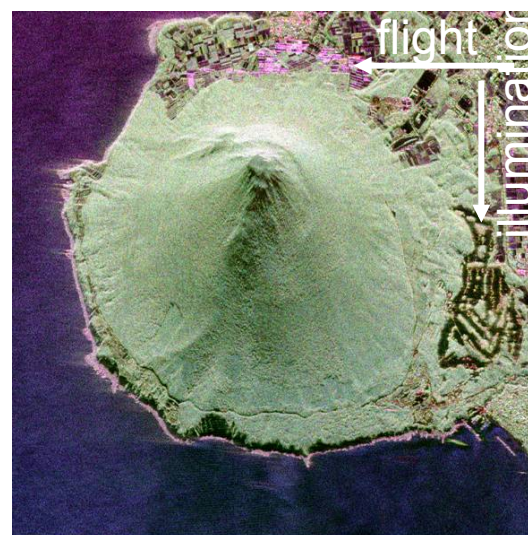


X-band  
(7304)



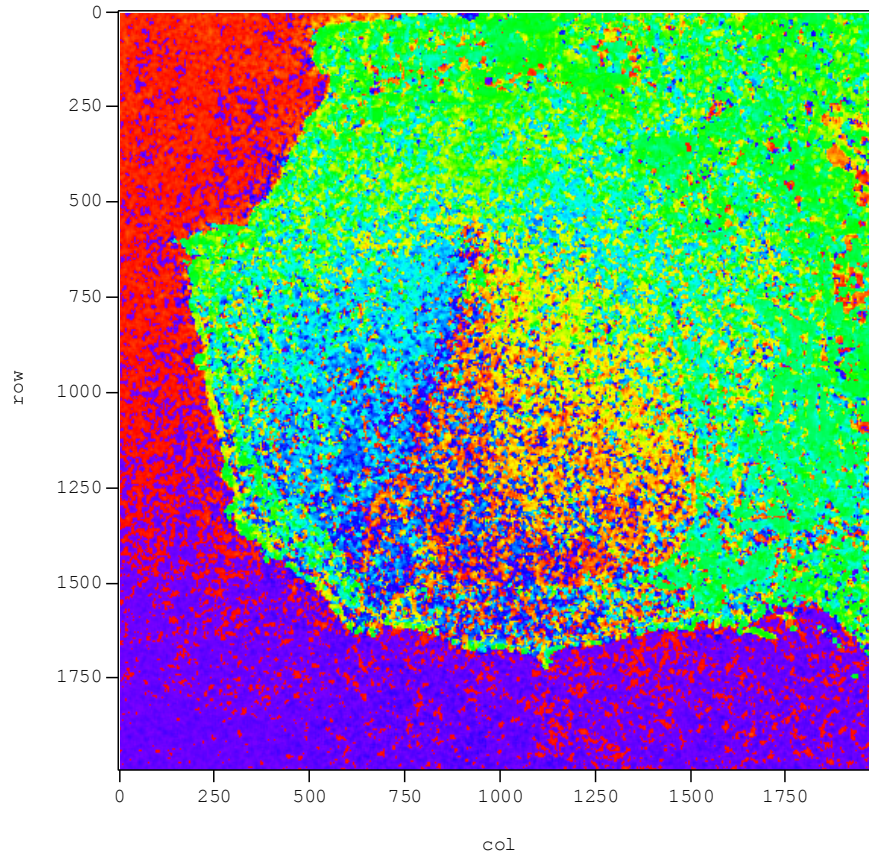
L-band  
(7304)

航空写真(2000,5/12  
国土地理院Webから)



# SAR偏波データによる地形情報のデータ解析

## ■ Co-pol. maxのtilt角分布図(L- band)



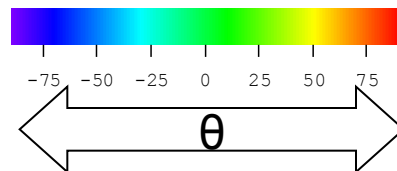
$$\tan(\theta) = \frac{\tan \omega}{-\tan \gamma \cos \phi + \sin \phi}$$

$\theta$ : orientation angle shift

$\tan \omega$ : azimuth slope

$\tan \gamma$ : slope in the ground range direction

$\phi$ : radar look angle



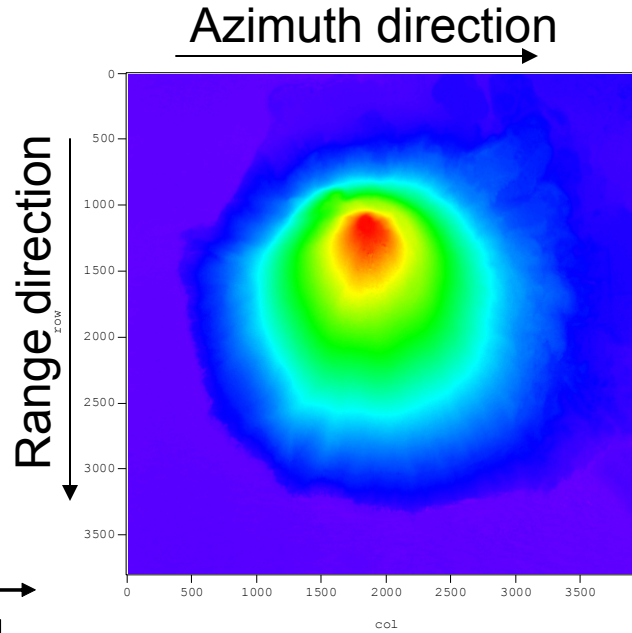
# SAR偏波データによる地形情報のデータ解析

## ■ インターフェロメトリデータとの比較 -1-

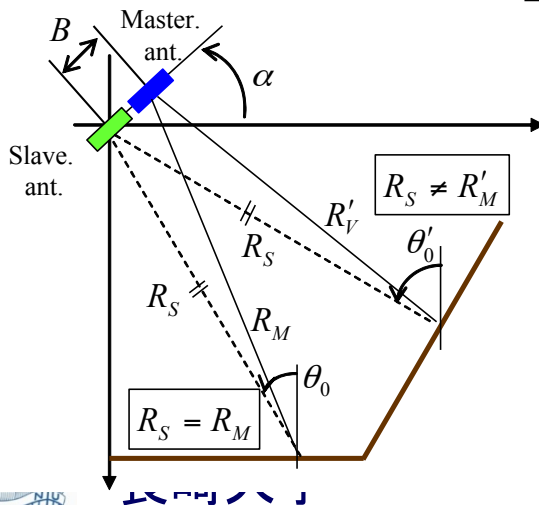
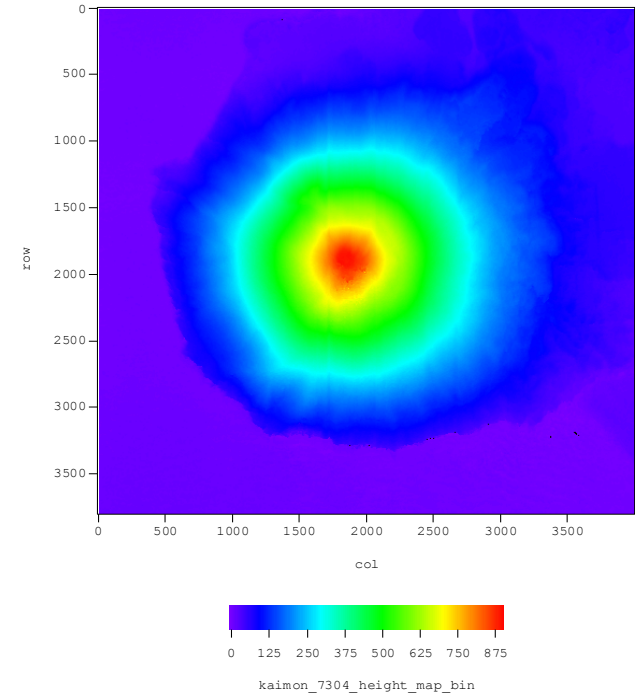
航空写真  
(国土地理院Webから)



高度補正前の  
地表高プロファイル(X-band)



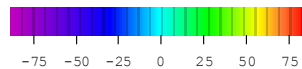
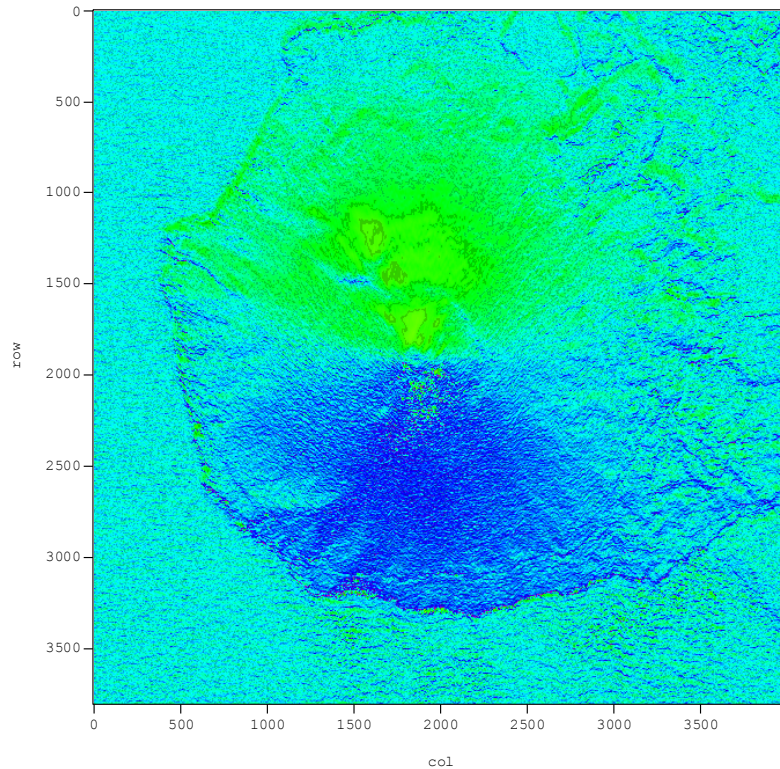
高度補正を行った  
地表高プロファイル(X-band)  
⇒ 航空写真に対応



# SAR偏波データによる地形情報のデータ解析

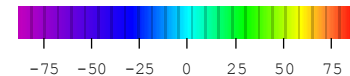
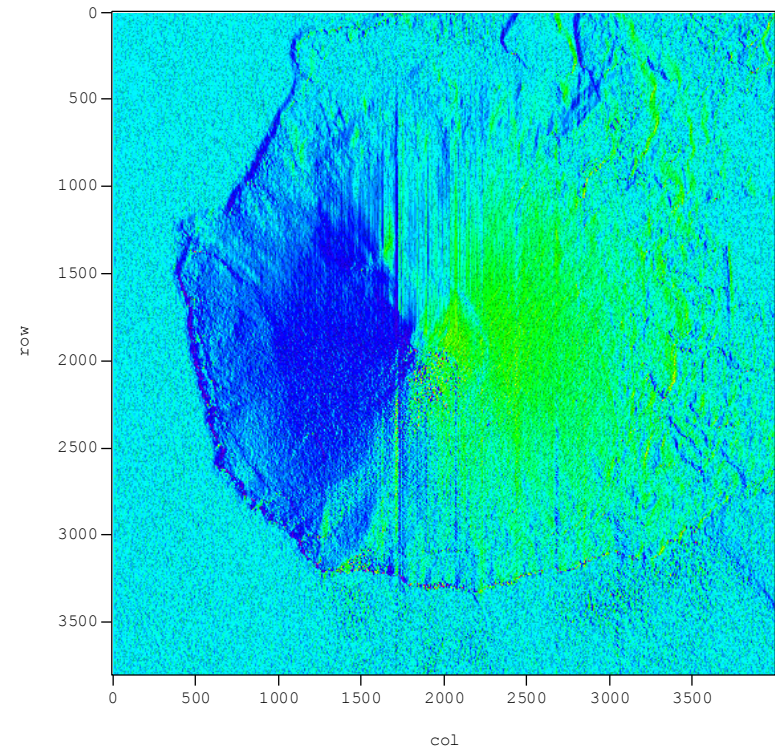
## ■ インターフェロメトリデータとの比較 -2-

地表高プロファイルから算出した  
Range slope



\_7304\_gslope\_dat\_

地表高プロファイルから算出した  
Azimuth slope



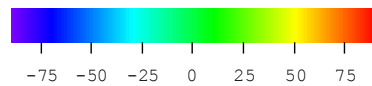
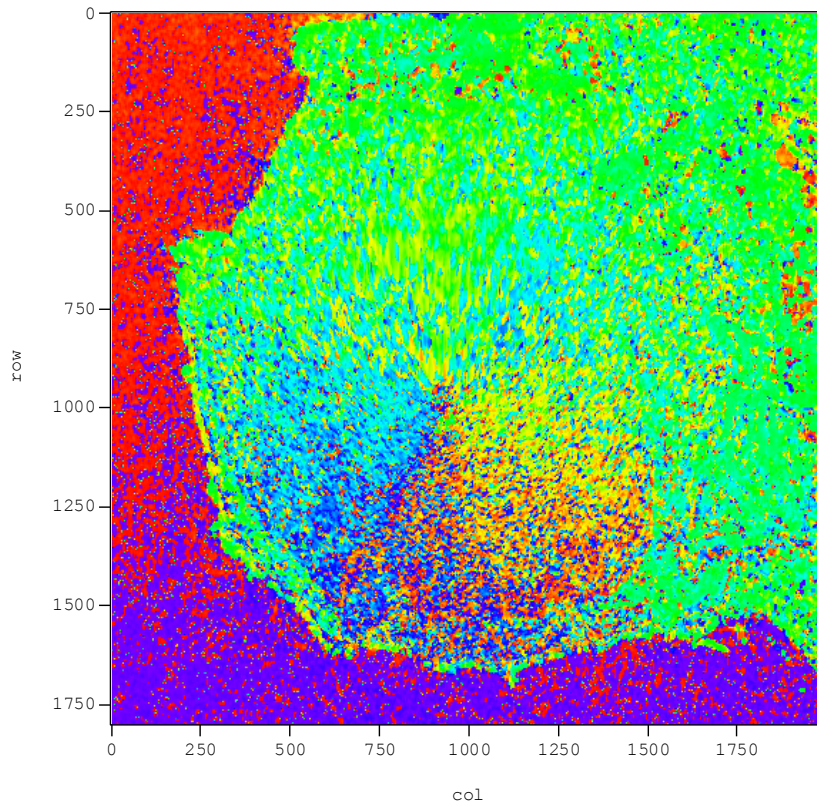
\_7304\_aslope\_dat\_



# SAR偏波データによる地形情報のデータ解析

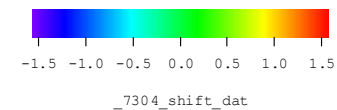
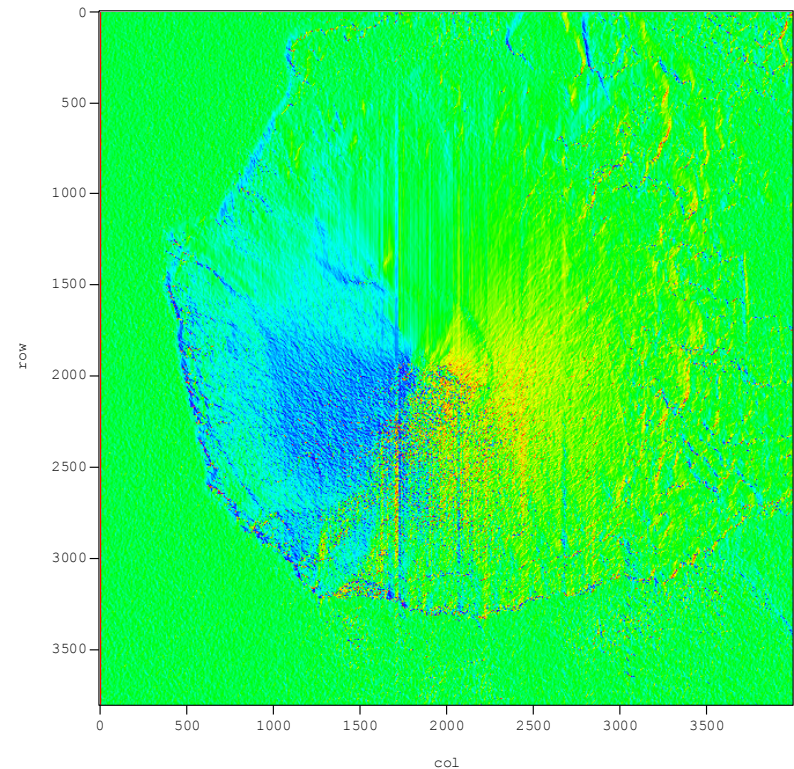
## ■ インターフェロメトリデータとの比較 -3-

### Co-pol. maxのtilt角分布(L-band)



kaimon\_L7304\_aslope\_map\_bin

### DEMから推定したtilt角分布図



\_7304\_shift\_dat

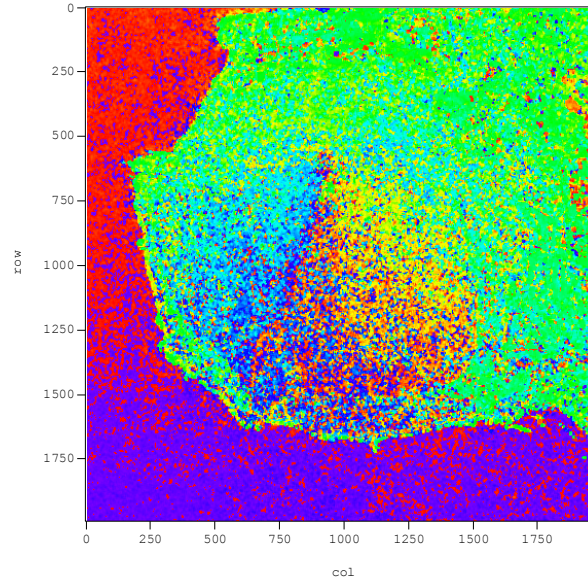




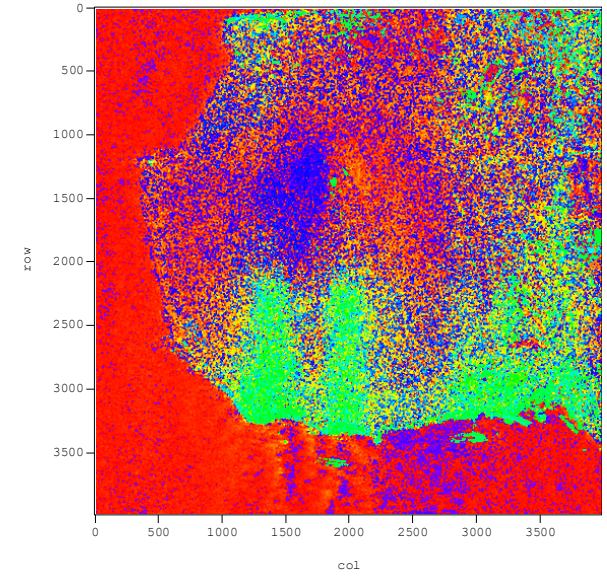
# SAR偏波データによる地形情報のデータ解析

## ■ L-bandとX-bandの比較

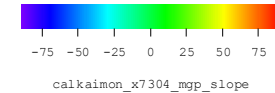
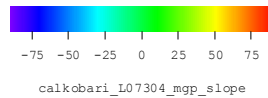
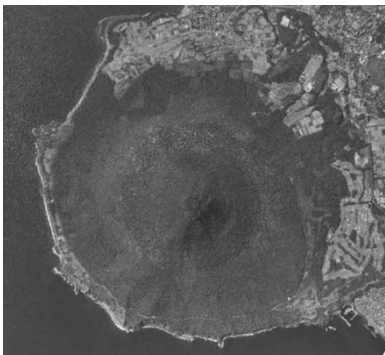
Co-pol. maxのtilt角分布(L-band)



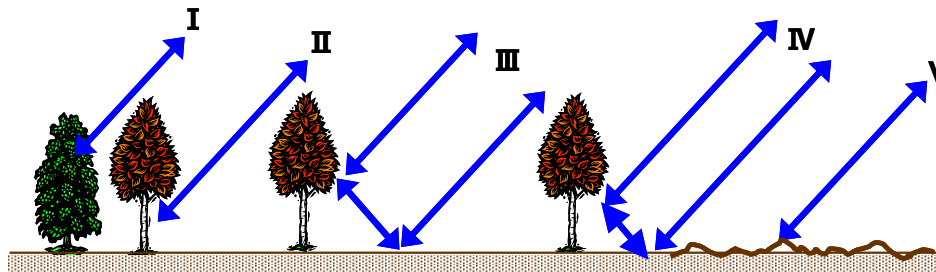
Co-pol. maxのtilt角分布(X-band)



航空写真  
(国土地理院Webから)



## ■ 自然地形の散乱



I : 葉冠からの後方散乱

II : 樹幹からの散乱

III : 地表と葉冠の2回反射後方散乱

IV : 地表と樹幹の2回反射後方散乱

V : 地表から後方散乱

X-band

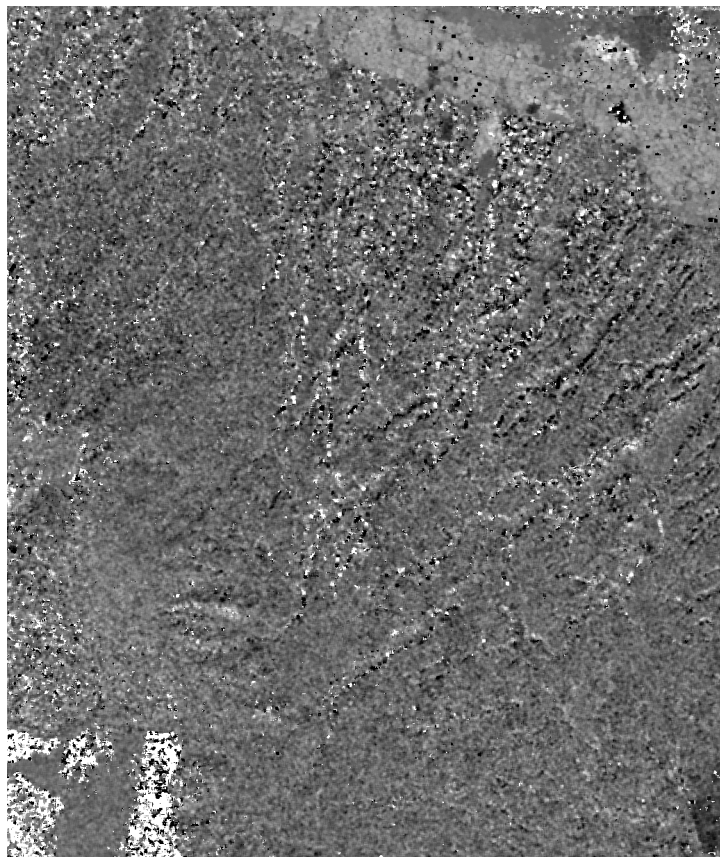
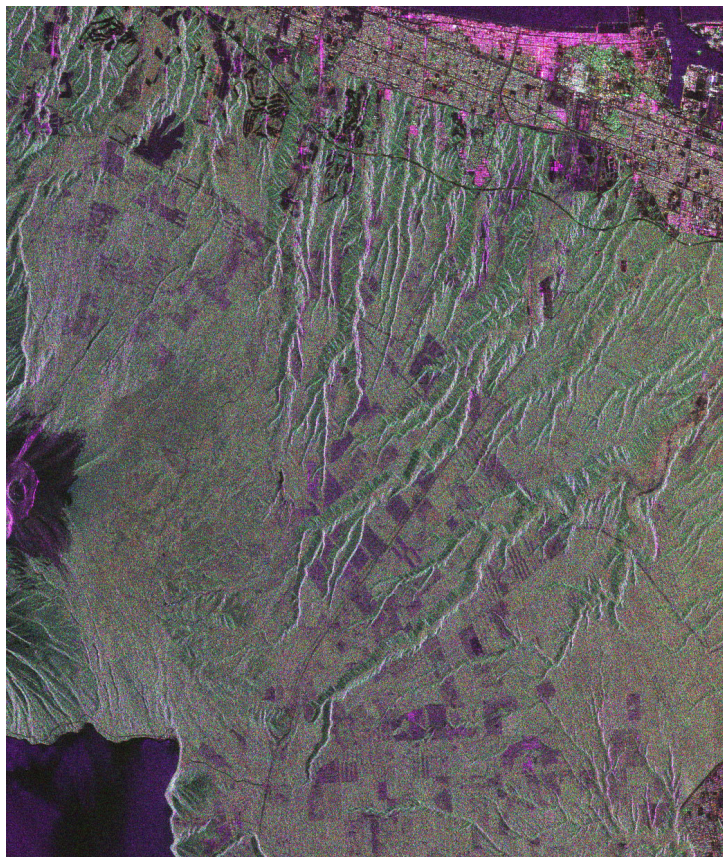
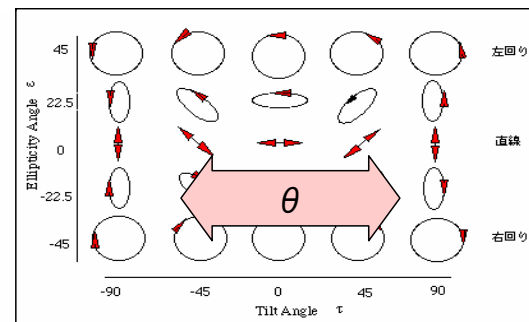
L-band

# SAR偏波データによる地形情報のデータ解析

## ■Polarization orientation angleの評価 (ALOS/PALSAR)

$$\tan \theta = \frac{\tan \omega}{-\tan \gamma \cos \phi + \sin \phi}$$

$\theta$ : orientation (tilt) angle shift  
 **$\tan \omega$ : azimuth slope**  
 $\tan \gamma$ : slope in the ground range direction  
 $\phi$ : radar look angle



# SAR偏波データによる地上情報のデータ解析

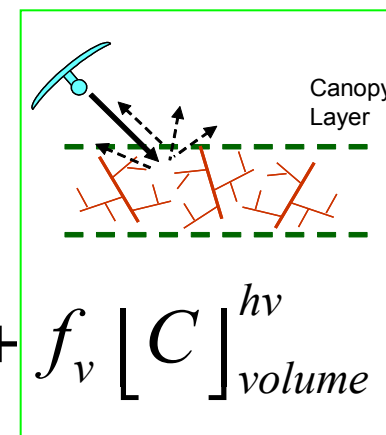
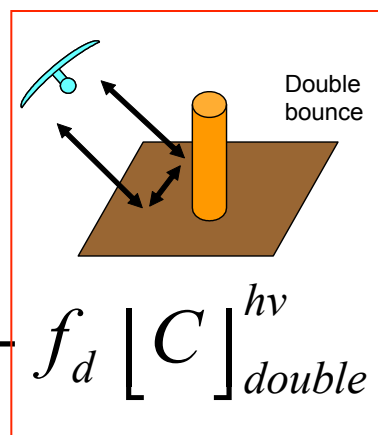
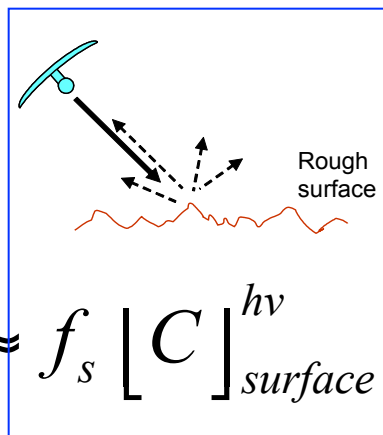
Freeman and Durdenによる三成分分解(モデル分解)

Surface scattering

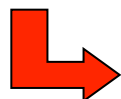
Double bounce

Volume scattering

Observation quantity



$$\langle [C(HV)] \rangle \approx f_s [C]_{surface}^{hv} + f_d [C]_{double}^{hv} + f_v [C]_{volume}^{hv}$$



$(f_s, f_d, f_v)$  : Features in interested area

Estimation of measured

covariance matrix [C] :

$$\langle S_{HH} S_{HH}^* \rangle = f_s |\beta|^2 + f_d |\alpha|^2 + f_v, \quad \langle S_{VV} S_{VV}^* \rangle = f_s + f_d + f_v$$

$$\langle S_{HH} S_{VV}^* \rangle = f_s \beta + f_d \alpha + f_v / 3,$$

$$\langle S_{HV} S_{HV}^* \rangle = 2f_v / 3$$

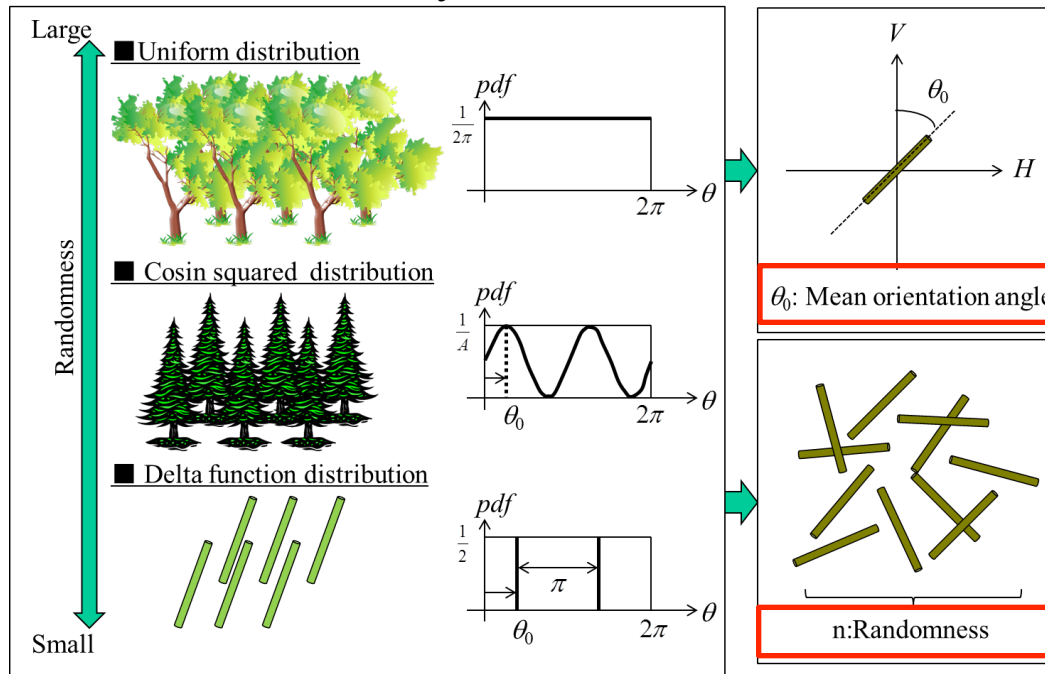
$$\langle S_{HH} S_{HV}^* \rangle = \langle S_{HV} S_{VV}^* \rangle = 0$$



Unknowns are calculated by deterministic method

# SAR偏波データによる地上情報のデータ解析

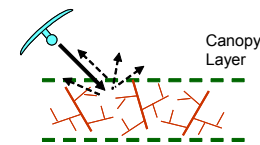
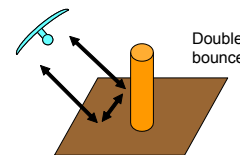
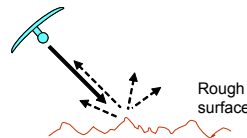
Dr. M. Arii, Dr. J. J. van Zyl and Dr Y. Kimらによるモデル分解法の拡張



## Freeman and Durdenの問題

Negative power  
can be reduced.

Overestimation of  
volume scattering



$$\langle [C(HV)] \rangle \approx f_s [C]_{surface}^{hv} + f_d [C]_{double}^{hv} + f_v(n, \theta_0) [C]_{volume}^{hv}$$

$(f_s, f_d, f_v, n, \theta_0)$  : Features in interested area

# SAR偏波データによる地上情報のデータ解析

Radar polarization orientation shift/angle affects the scattering matrix.  
 ⇒ The cross-polarization (HV) component increases.

## : Overestimation of volume scattering

### ■ Double bounce model:

$$[S_{cross}] = \sqrt{f_{cross}} \begin{bmatrix} 1 & \rho \\ \rho & \alpha \end{bmatrix} \quad \leftarrow$$

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

### ■ Surface (Bragg) scattering model:

$$[S_{bragg}^{HV}] = \begin{bmatrix} \cos \phi & \sin \phi \\ -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} \beta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \phi & -\sin \phi \\ \sin \phi & \cos \phi \end{bmatrix} \quad \leftarrow$$

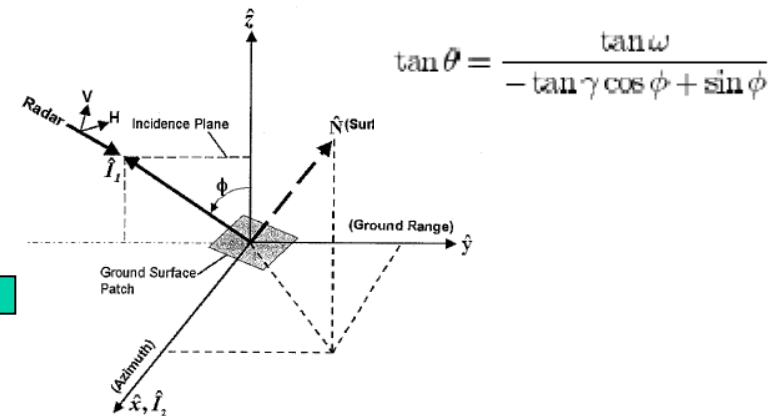
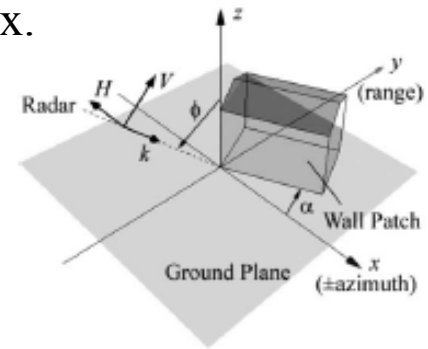
$$= \begin{bmatrix} \beta \cos^2 \phi + \sin^2 \phi & (1-\beta) \cos \phi \sin \phi \\ (1-\beta) \cos \phi \sin \phi & \cos^2 \phi + \beta \sin^2 \phi \end{bmatrix}$$

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

$$\tan \theta = \frac{-\tan \alpha}{\cos \phi}$$

### Radar polarization orientation shift

(H. Kimura, "Radar Polarization Orientation Shifts in Built-Up Areas", IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 5, NO. 2, APRIL 2008)



$$\tan \theta = \frac{\tan \omega}{-\tan \gamma \cos \phi + \sin \phi}$$

### Polarization orientation angle

(J.S. Lee, D.L. Schuler, etc)



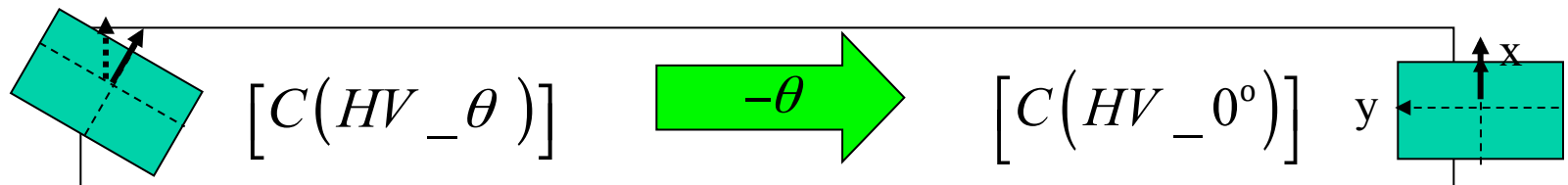
# SAR偏波データによる地上情報のデータ解析

If azimuth rotation angle of the covariance matrix is known, its inverse rotation ( $-\theta$ ) can be done.

## ■ Rotation of covariance matrix

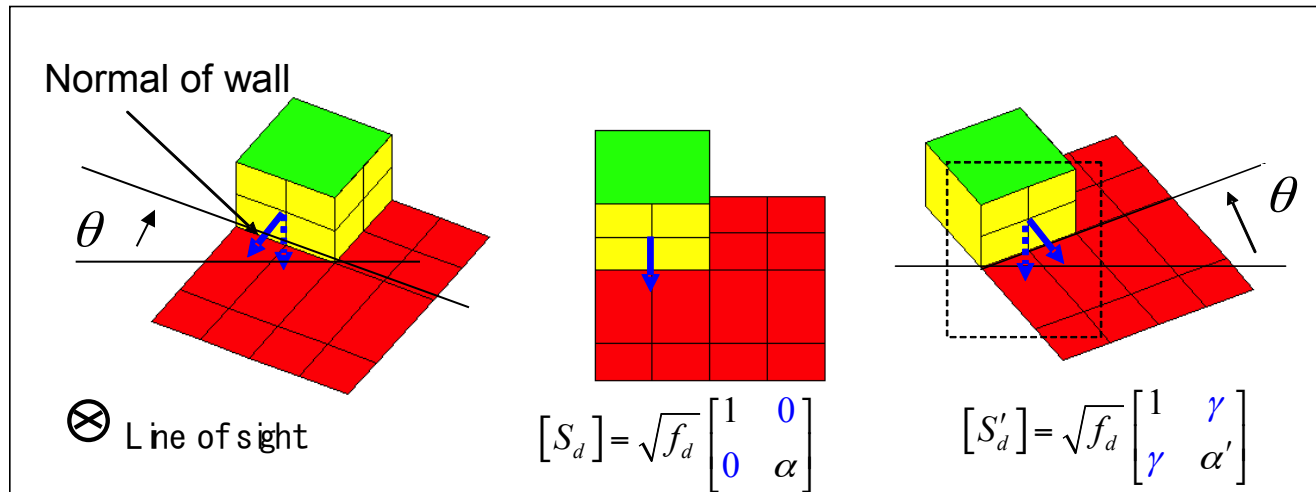
$$[C(HV_{-0^\circ})] = [U_\theta(-\theta)] [C(HV_{-\theta})] [U_\theta(-\theta)]^{*T}$$

$$[U_\theta] = \begin{bmatrix} \cos^2 \theta & \sqrt{2} \sin \theta \cos \theta & \sin^2 \theta \\ -\sqrt{2} \sin \theta \cos \theta & \cos 2\theta & \sqrt{2} \sin \theta \cos \theta \\ \sin^2 \theta & -\sqrt{2} \sin \theta \cos \theta & \cos^2 \theta \end{bmatrix}$$



The measured cross-polarization (HV) component can be decreased by phase rotation compensation.

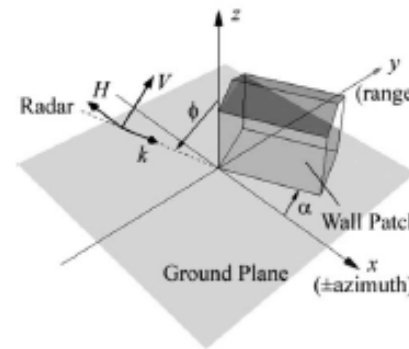
# SAR偏波データによる地上情報のデータ解析



Double bounce model:

$$[S_{cross}] = \sqrt{f_{cross}} \begin{bmatrix} 1 & \rho \\ \rho & \alpha \end{bmatrix}$$

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



$$\tan \theta = \frac{-\tan \alpha}{\cos \phi}$$

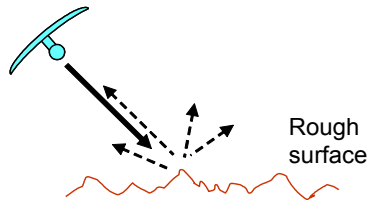
## Radar polarization orientation shift

(H. Kimura, "Radar Polarization Orientation, Shifts in Built-Up Areas", IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 5, NO. 2, APRIL 2008)



# SAR偏波データによる地上情報のデータ解析

## ■ Bragg scattering



### • Flat ground

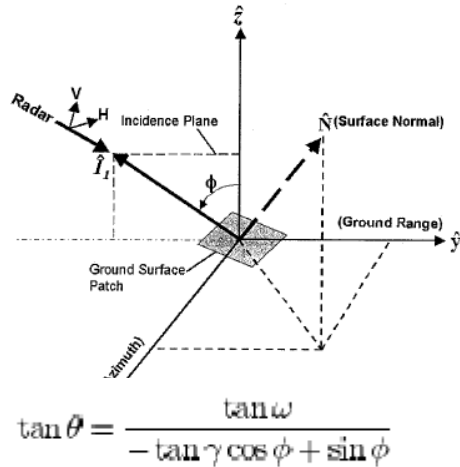
$$[S^{Bragg} (HV)] = \begin{bmatrix} \beta & 0 \\ 0 & 1 \end{bmatrix}$$

$$\beta = \frac{S_{HH}}{S_{VV}}$$

$$S_{HH} = \frac{\cos \theta_i - \sqrt{\epsilon_r - \sin^2 \theta_i}}{\cos \theta_i + \sqrt{\epsilon_r - \sin^2 \theta_i}}$$

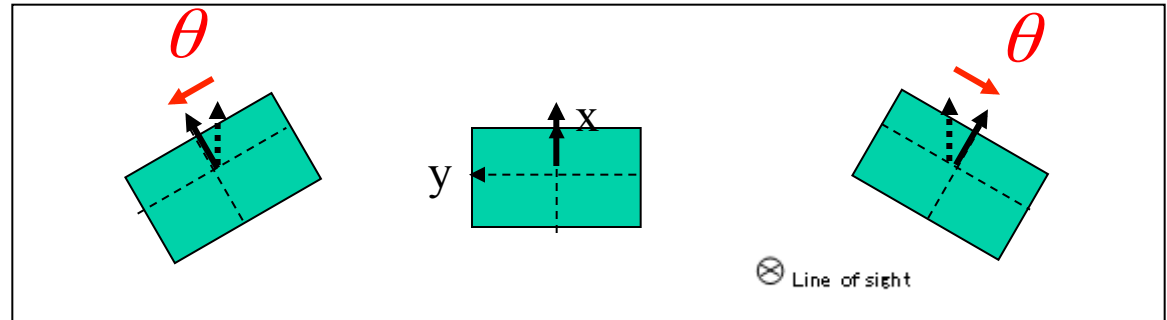
$$S_{VV} = \frac{(\epsilon_r - 1)(\sin^2 \theta_i - \epsilon_r(1 + \sin^2 \theta_i))}{(\epsilon_r \cos \theta_i + \sqrt{\epsilon_r - \sin^2 \theta_i})^2}$$

### • Sloping ground in azimuth direction



$$[S^{Bragg} (HV)] = \begin{bmatrix} \cos \phi & \sin \phi \\ -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} \beta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \phi & -\sin \phi \\ \sin \phi & \cos \phi \end{bmatrix}$$

$$= \begin{bmatrix} \beta \cos^2 \phi + \sin^2 \phi & (1 - \beta) \cos \phi \sin \phi \\ (1 - \beta) \cos \phi \sin \phi & \cos^2 \phi + \beta \sin^2 \phi \end{bmatrix}$$

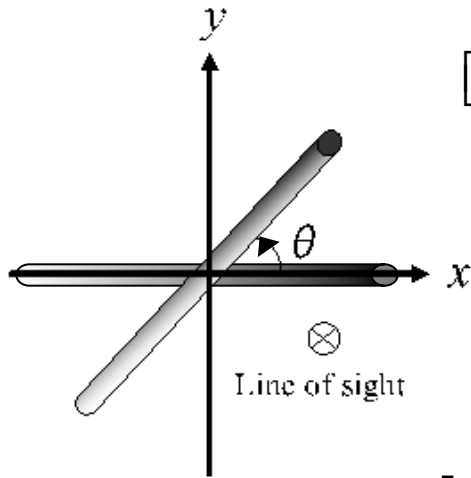


Polarization orientation angle  
(J.S. Lee, D.L. Schuler, etc)



# SAR偏波データによる地上情報のデータ解析

## ■ Estimation of azimuth rotation angle



$$\begin{aligned} [S_{-HV}(\theta)] &= \begin{bmatrix} S_{HH} & S_{HV} \\ S_{HV} & S_{VV} \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \alpha \end{bmatrix} \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \\ &= \begin{bmatrix} \cos^2 \theta + \alpha \sin^2 \theta & -\frac{1}{2}(1-\alpha)\sin 2\theta \\ -\frac{1}{2}(1-\alpha)\sin 2\theta & \sin^2 \theta + \alpha \cos^2 \theta \end{bmatrix} \end{aligned}$$

$$[S_{-LR}] = \begin{bmatrix} S_{LL} & S_{LR} \\ S_{LR} & S_{RR} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} S_{HH} - S_{VV} + j2S_{HV} & j\sqrt{2}(S_{HH} + S_{VV}) \\ j\sqrt{2}(S_{HH} + S_{VV}) & S_{VV} - S_{HH} + j2S_{HV} \end{bmatrix}$$

$$S_{LL}S_{RR}^* = -\frac{1}{4} \left\{ |1|^2 + |\alpha|^2 - 2\operatorname{Re}(\alpha^*) \right\} \exp(-j4\theta)$$

$$\operatorname{Arg}(-S_{LL}S_{RR}^*) = -4\theta \quad \Rightarrow \quad \theta = -\frac{1}{4} \operatorname{Arg}(-S_{LL}S_{RR}^*)$$

# SAR偏波データによる地上情報のデータ解析

## ■ PALSAR data (L-band)

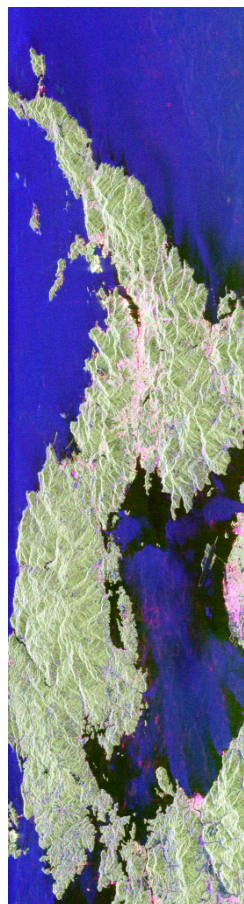
- Obs. date: 2007/12/23 PM10:49(JST)
- Scene ID: ALPSRP101890650
- Off-nadir angle: 23.1 [deg.]
- A/D: Ascending
- Processing level: L1.1
- Site: Nagasaki, Japan

## ■ RADARSAT 2 data (C-band)

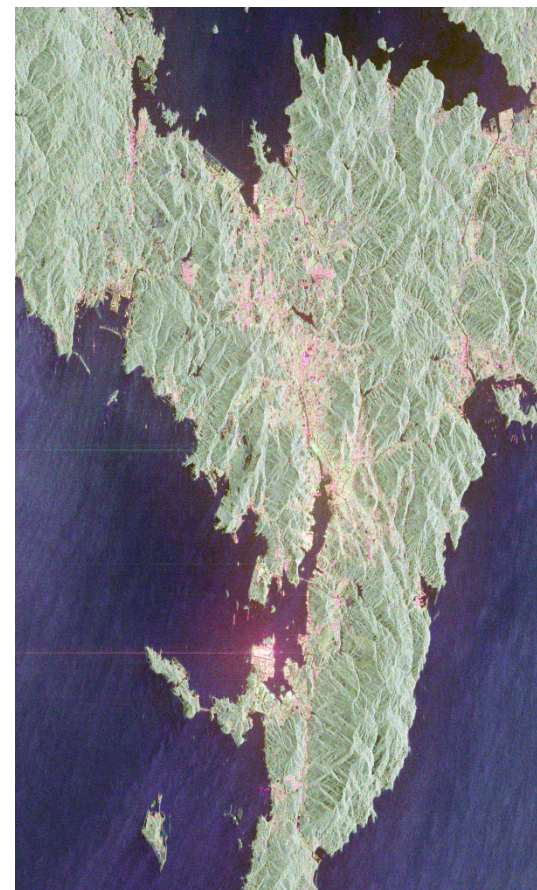
- Obs. date: 2010/10/22 AM6:22(JST)
- ImageID: 104029
- Incidence angle(center): 36.3 [deg.]
- A/D: Descending
- Processing level: SLC
- Site: Nagasaki, Japan

## ■ PSO

Number of particles: 20



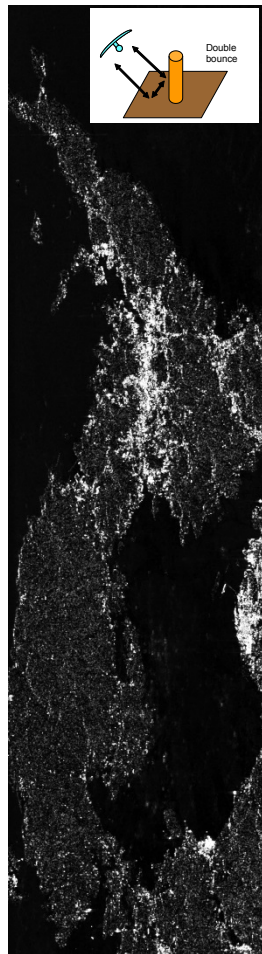
PALSAR image



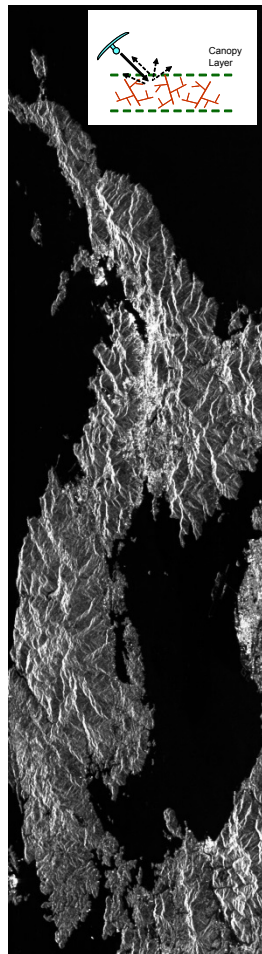
RADARSAT 2 image

HH-VV (red) VVHH+VV (blue) VVHH (green) (Pauli image)

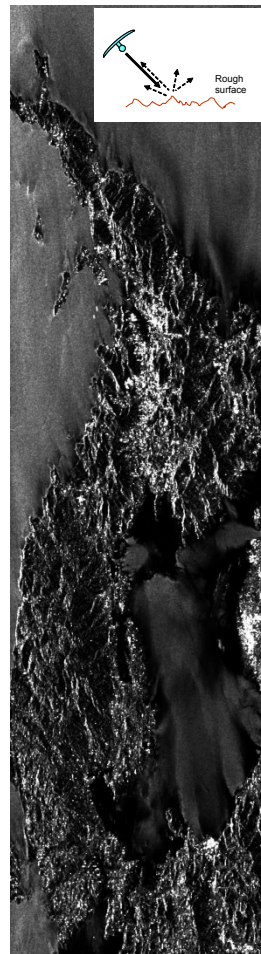
# 偏波観測データによる地上情報の計測



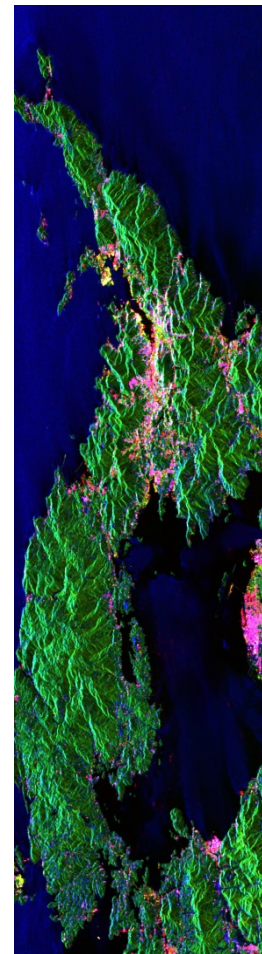
Double



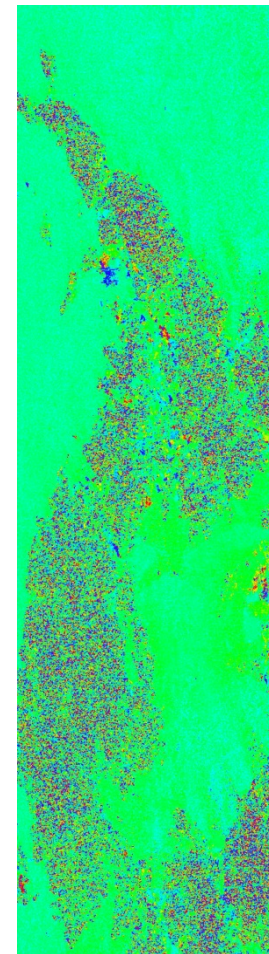
Volume



Surface



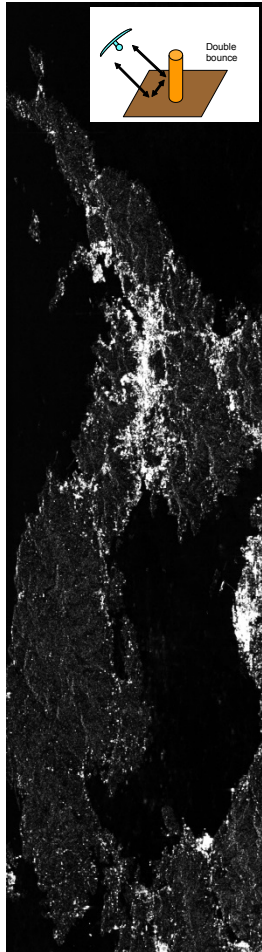
Double/Volume/Surface



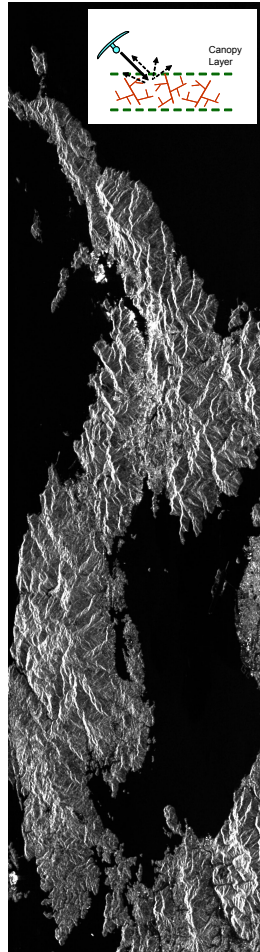
Polarization  
orientation angle

Adaptive nonnegative eigenvalue decomposition(ANNED)

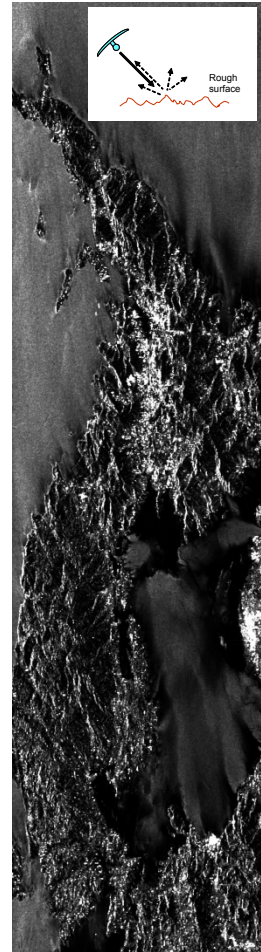
# SAR偏波データによる地上情報のデータ解析



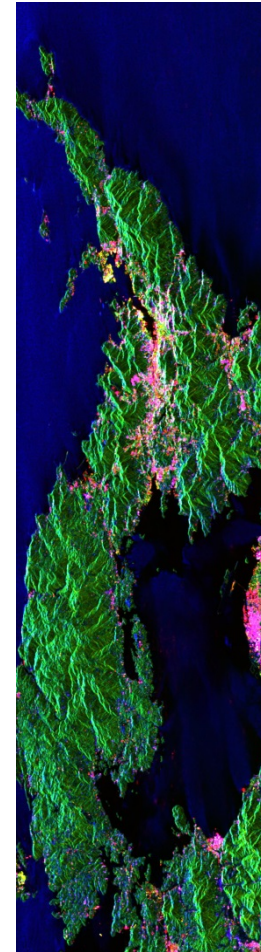
Double



Volume



Surface

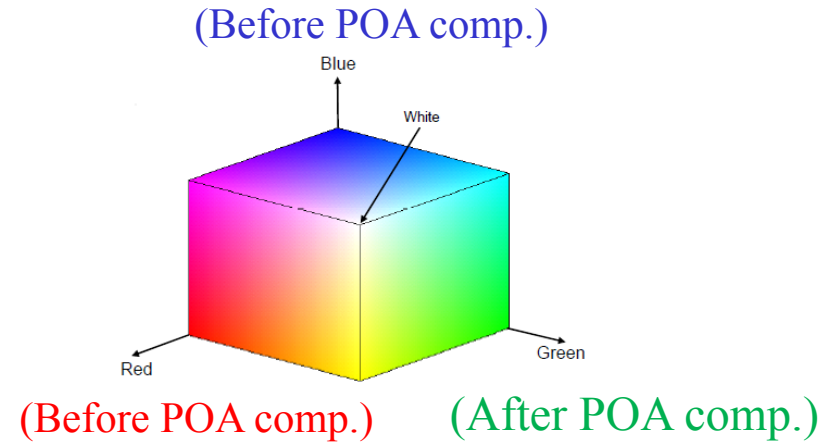
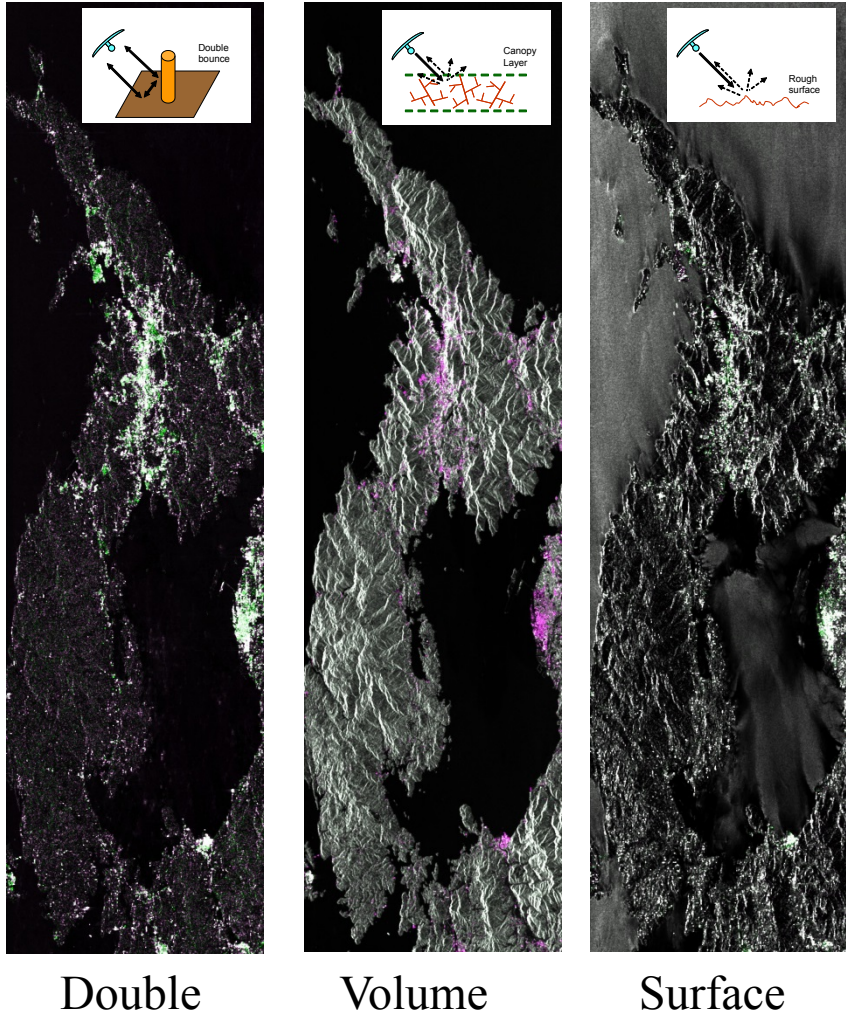


Double/Volume/Surface

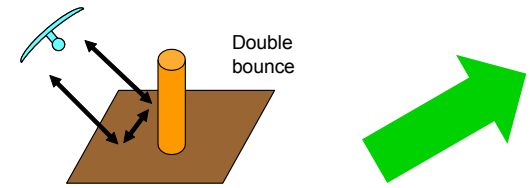
Adaptive nonnegative eigenvalue decomposition(ANNED) with POA

# SAR偏波データによる地上情報のデータ解析

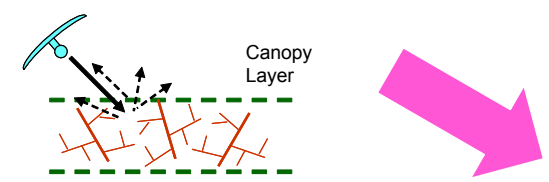
## Comparison before and after POA compensation



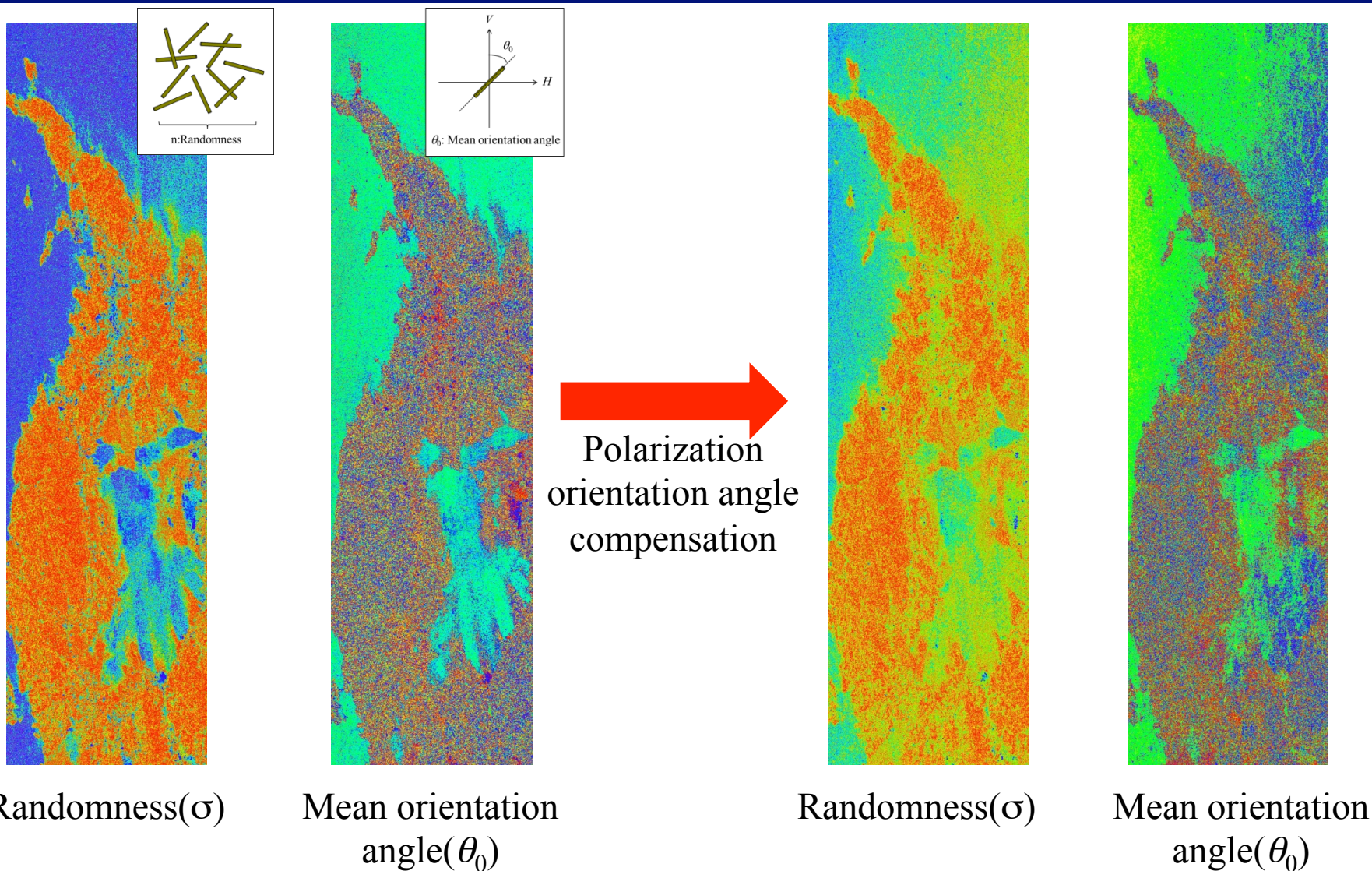
## Double bounce component after POA comp.



## Volume scattering component after POA comp.

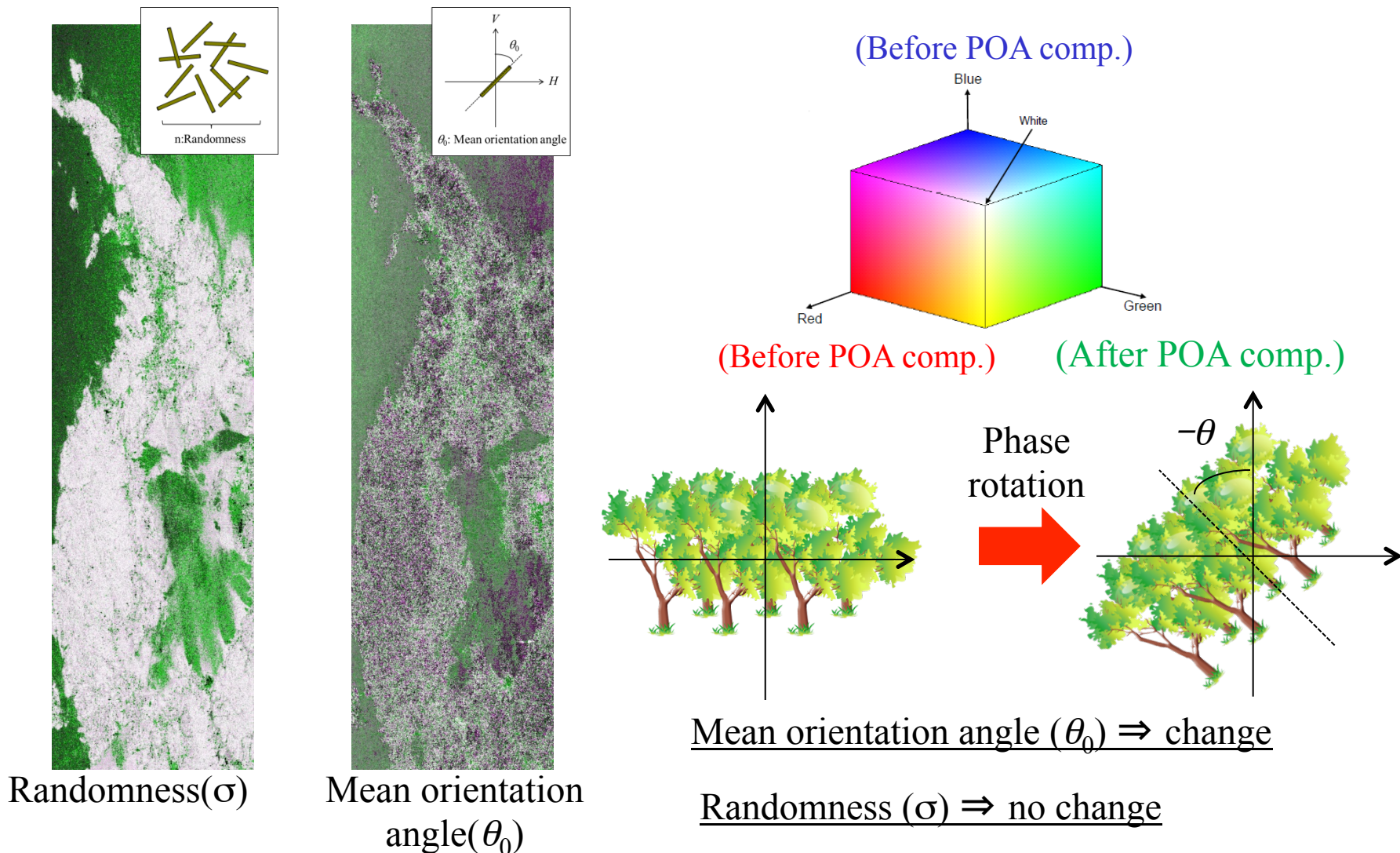


# SAR偏波データによる地上情報のデータ解析

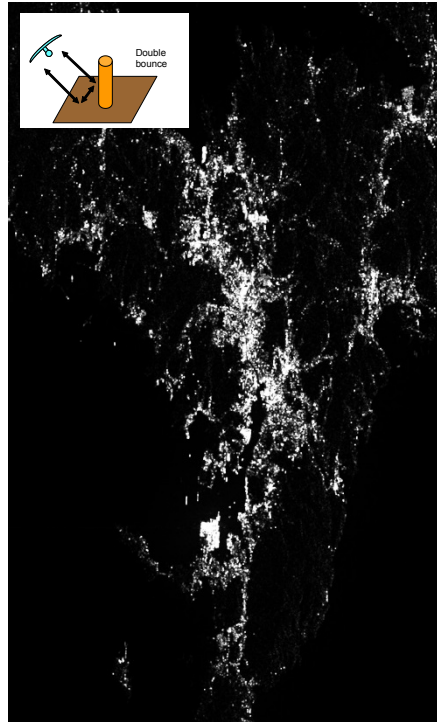


# SAR偏波データによる地上情報のデータ解析

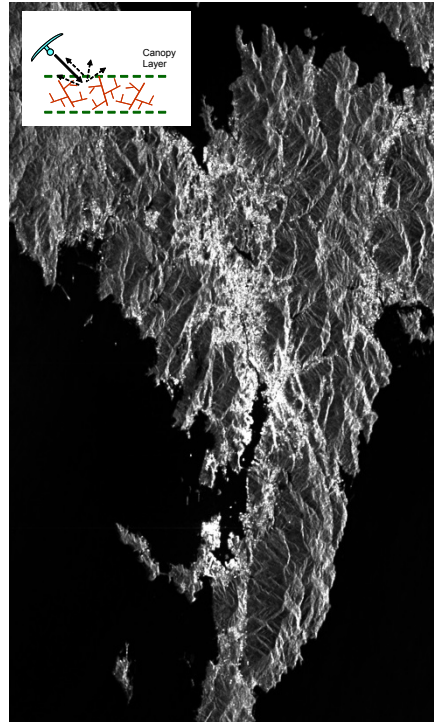
## Comparison before and after POA compensation



# SAR偏波データによる地上情報のデータ解析



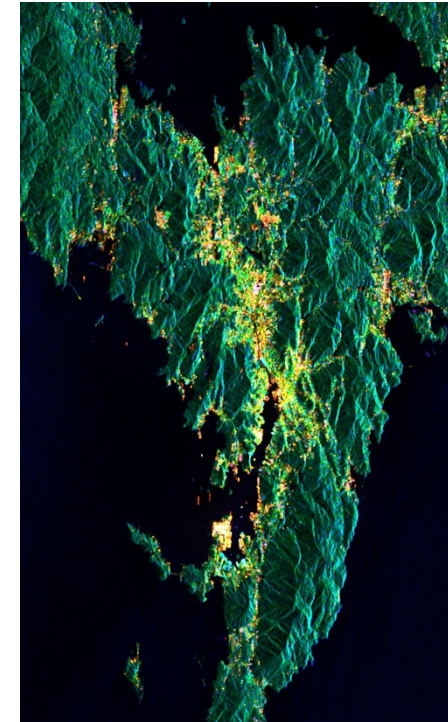
Double



Volume



Surface

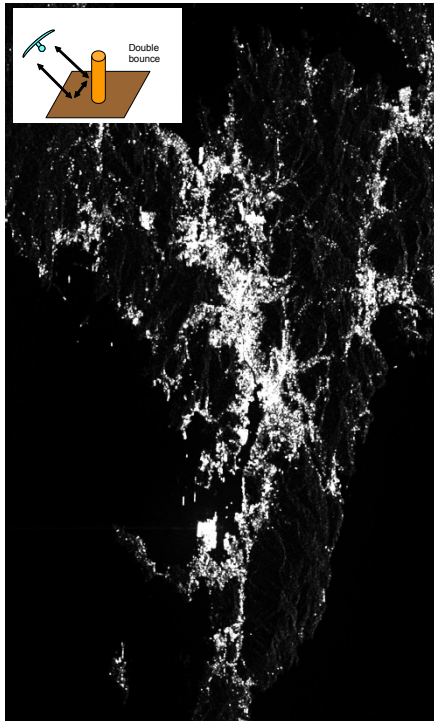


Double/Volume/Surface

Adaptive nonnegative eigenvalue decomposition(ANNED)



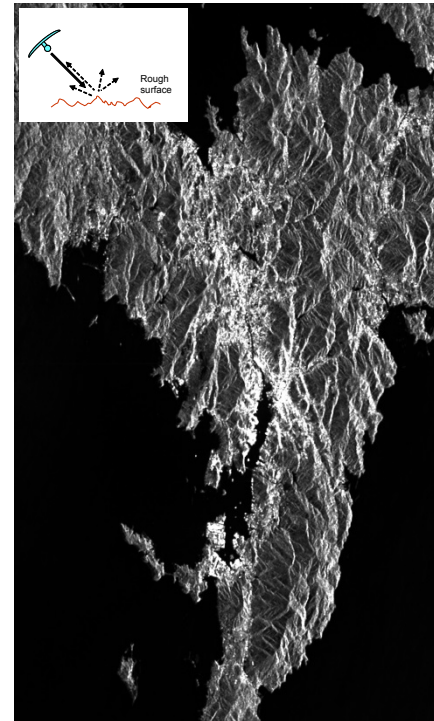
# SAR偏波データによる地上情報のデータ解析



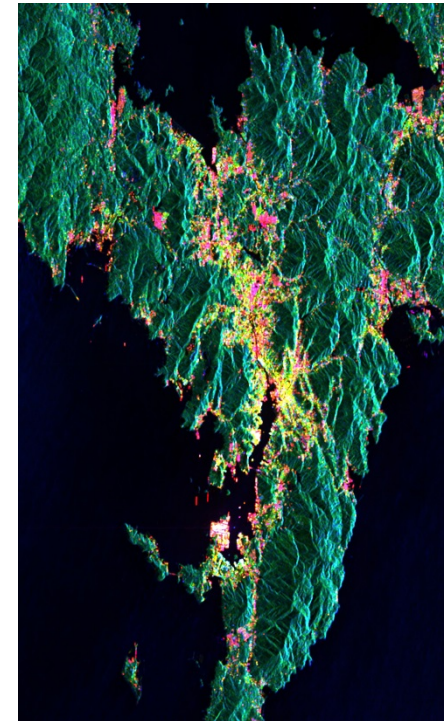
Double



Volume



Surface

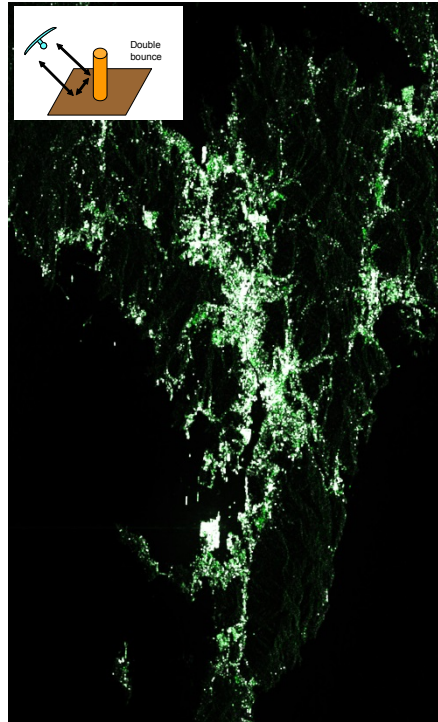


Double/Volume/Surface

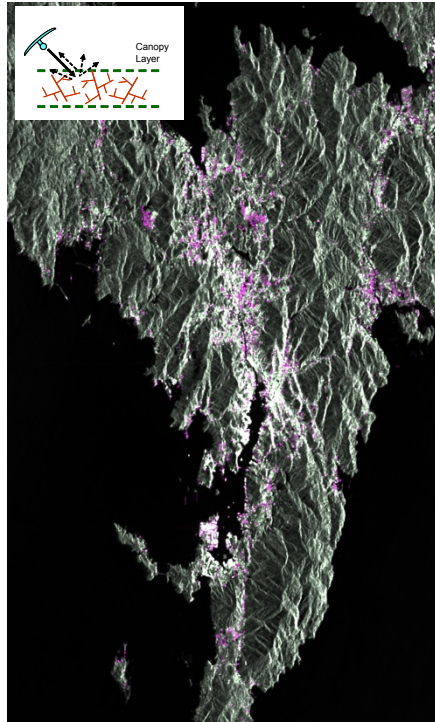
Adaptive nonnegative eigenvalue decomposition(ANNED) with POA

# SAR偏波データによる地上情報のデータ解析

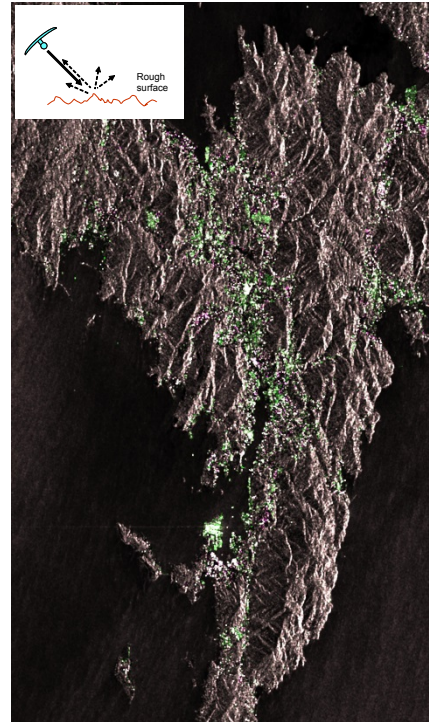
## Comparison before and after POA compensation



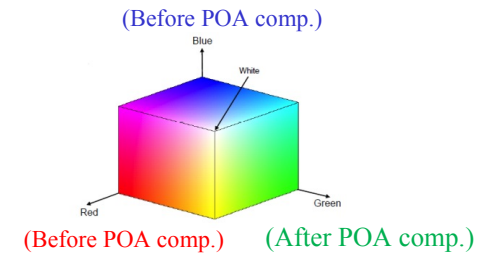
Double



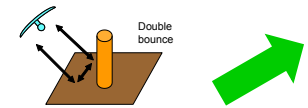
Volume



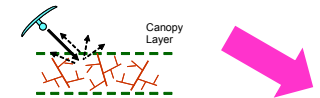
Surface



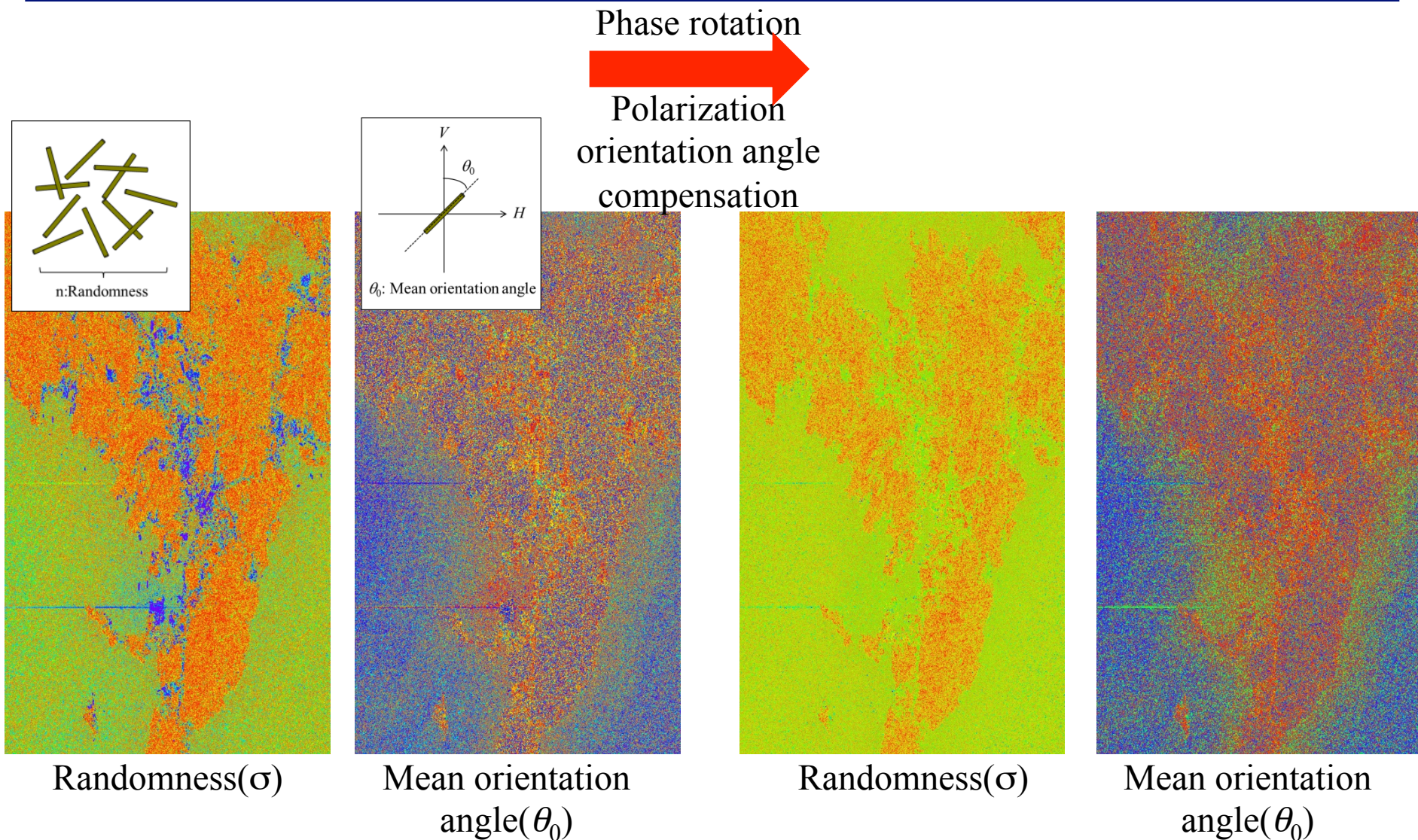
Double bounce component after POA comp.



Volume scattering component after POA comp.

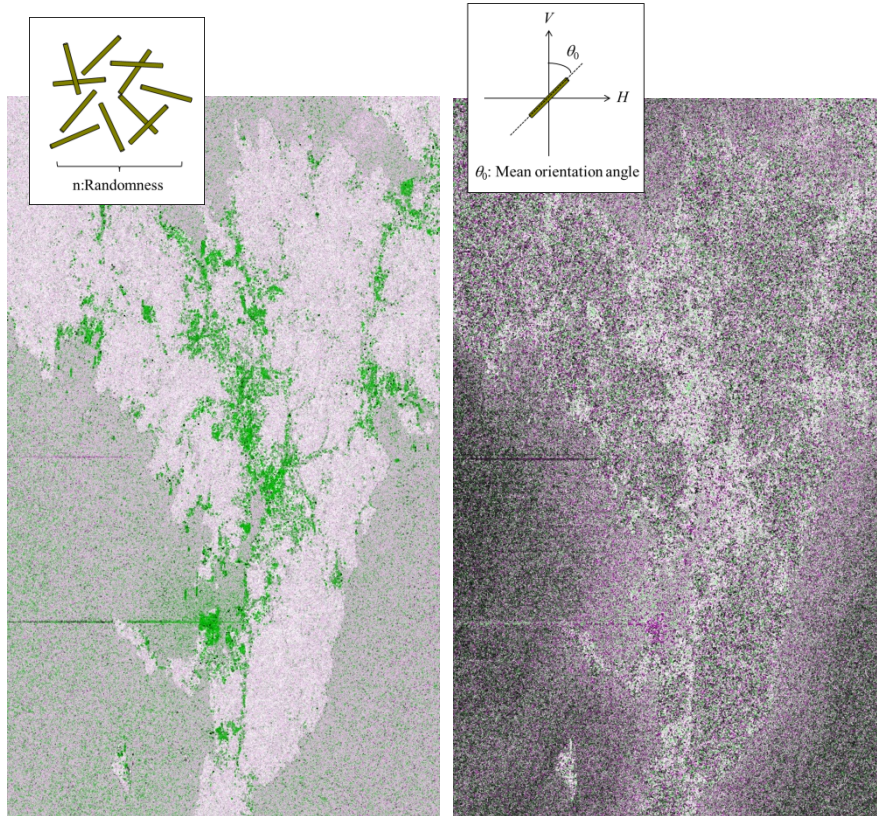


# SAR偏波データによる地上情報のデータ解析



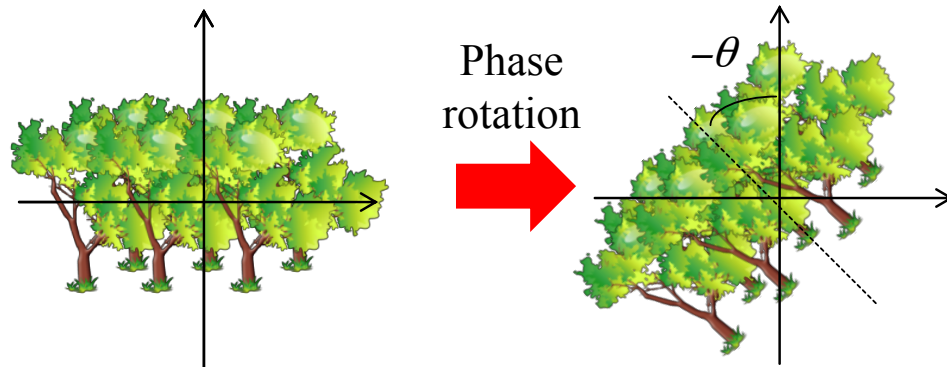
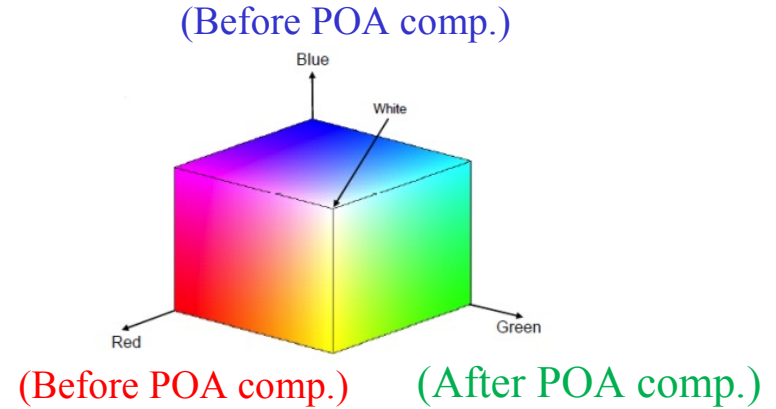
# SAR偏波データによる地上情報のデータ解析

## Comparison before and after POA compensation



Randomness( $\sigma$ )

Mean orientation  
angle( $\theta_0$ )



Mean orientation angle ( $\theta_0$ )  $\Rightarrow$  change

Randomness ( $\sigma$ )  $\Rightarrow$  no change

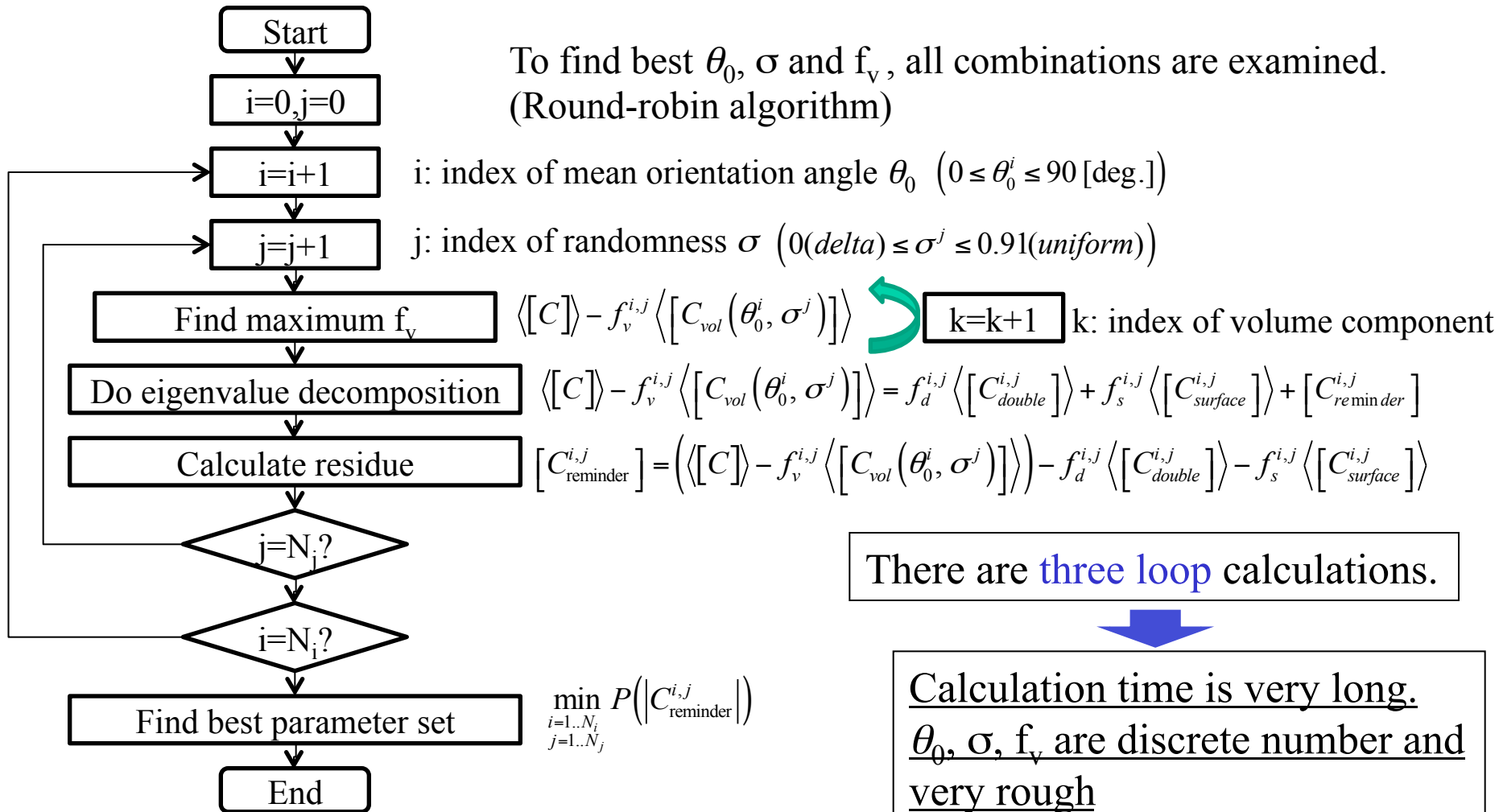
# まとめ

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- SAR偏波校正について  
=>ALOS2では，電離層の影響が懸念される．偏波データ解析のために，偏波と電離層の影響を詳しく調べていく必要がある．
- SAR偏波データによる地形情報のデータ解析  
=>単パスの偏波データから地形情報が抽出可能．物理量としての利用法の検討が必要．
- SAR偏波データによる地上情報のデータ解析  
=>モデルにより新たな物理量の評価が可能になってきており，応用の検討が必要．

# SAR偏波データによる地上情報のデータ解析

## Adaptive nonnegative eigenvalue decomposition(ANNED) of POLSAR data



# SAR偏波データによる地上情報のデータ解析

## Adaptive nonnegative eigenvalue decomposition(ANNED) of POLSAR data

