

(解析手法研究)

# SAR偏波利用の可能性と 電波科学の挑戦

東北大学 東北アジア研究センター  
佐藤 源之



[sato@cneas.tohoku.ac.jp](mailto:sato@cneas.tohoku.ac.jp)

SARが切り拓く地球人間圏科学の新展開へ向けて  
2013年8月22日 京都大学



# ポーラリメトリック・リモートセンシング

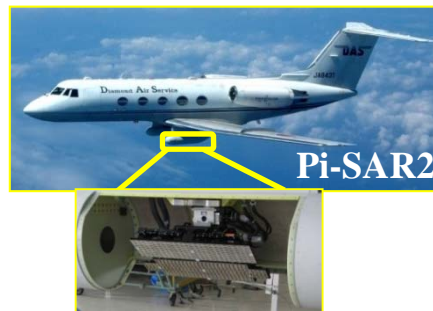
- Synthetic Aperture Radar (**SAR**)
  - Day and night, all-weather
- Polarimetric SAR (**PolSAR**)
  - Full polarimetric information
- Polarimetric SAR Interferometry (**PolInSAR**)

- ... ..

## - Ground-based



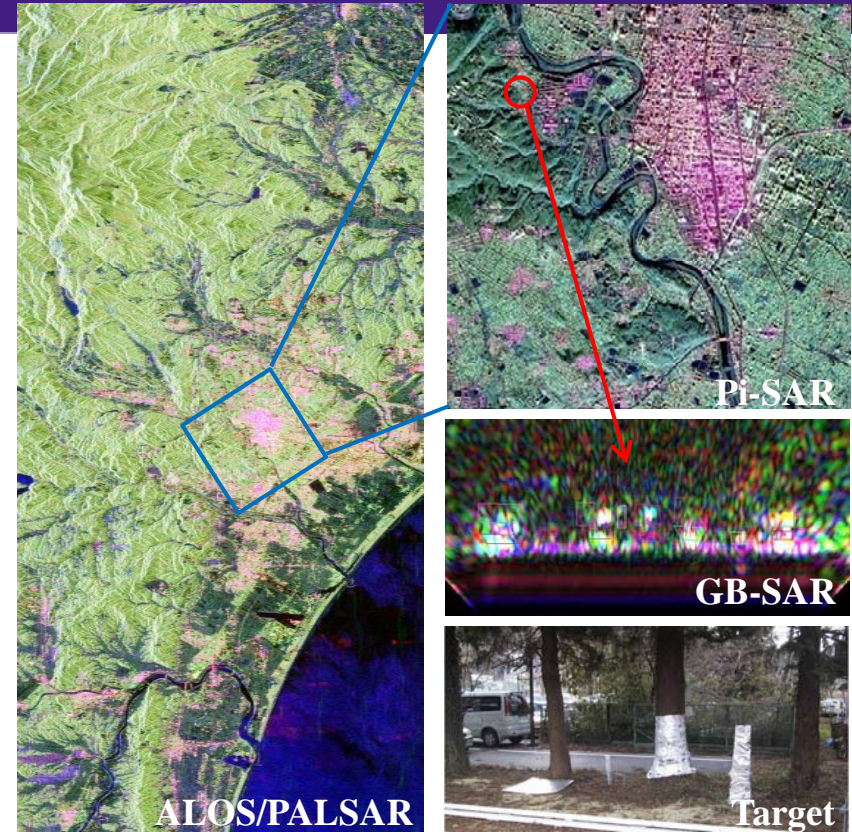
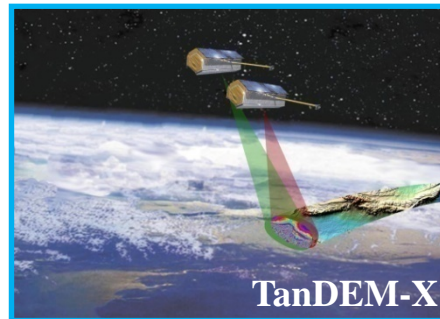
## - Airborne



## - Spaceborne



## - Satellite constellation



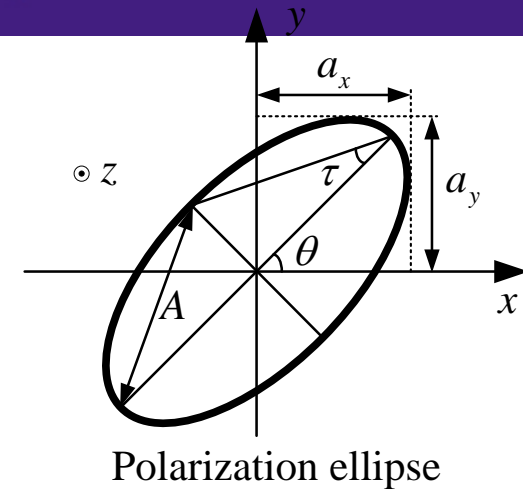
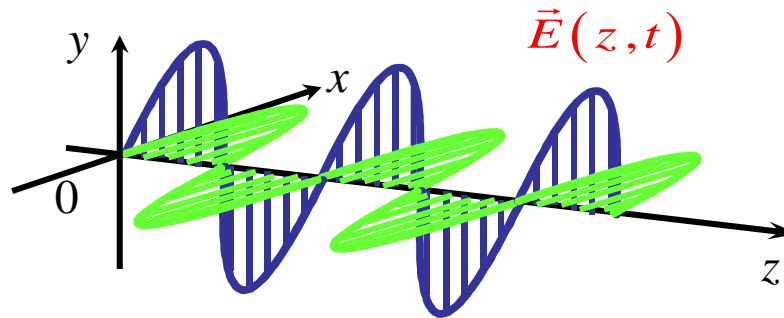
Golden Age



# レーダー・ポーラリメトリ

## ➤ Electromagnetic Wave Polarization

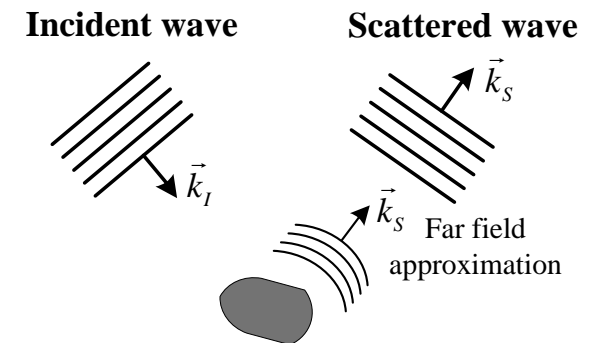
- Trajectory of the wave as time progresses
- Descriptors



## ➤ Electromagnetic Scattering Polarization

- Transform the incident into the scattered wave
- Modulated with target information...
- **Scattering matrix**

$$\underline{\underline{E}}_S = \frac{e^{-jkr}}{r} \underline{\underline{S}} \underline{\underline{E}}_I = \frac{e^{-jkr}}{r} \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \underline{\underline{E}}_I$$



(IGARSS tutorial)

Polarimetric Observations



Target Properties

# 電磁波伝搬と偏波・位相情報

- 電離層（ファラデー回転）
- 対流圏

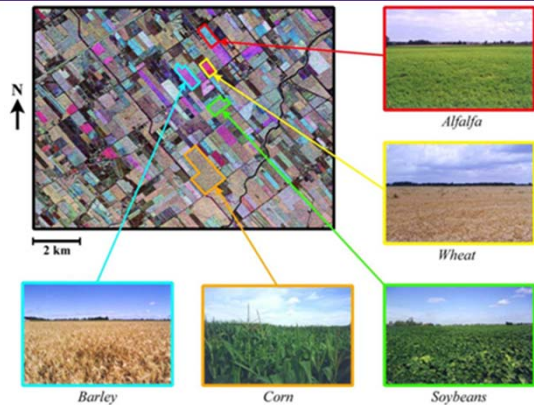
観測値からのモデル構築



SARデータからの物理量推定

# 偏波の応用

## – Agriculture

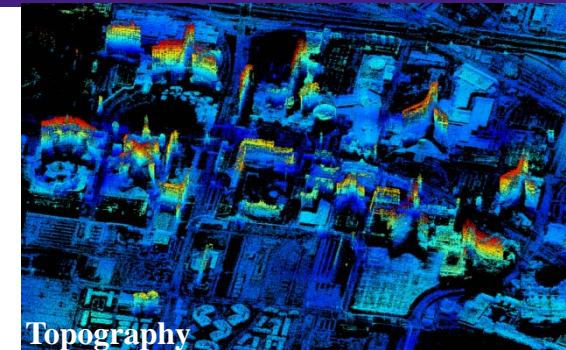


Classification

(IGARSS tutorial)

- Ecosystem change
- Carbon circle
- Water resources
- Hydrology ... ..

## – Urban area



(X. X. Zhu *et al.*, 2011)

## Polarimetric SAR Remote Sensing

Qualitative

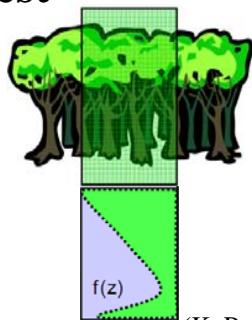


Quantitative

## – Natural disaster



## – Forest



Tree height  
Biomass

(K. Papathanassiou *et al.*)

Polarimetric  
Observations

Scattering mechanism

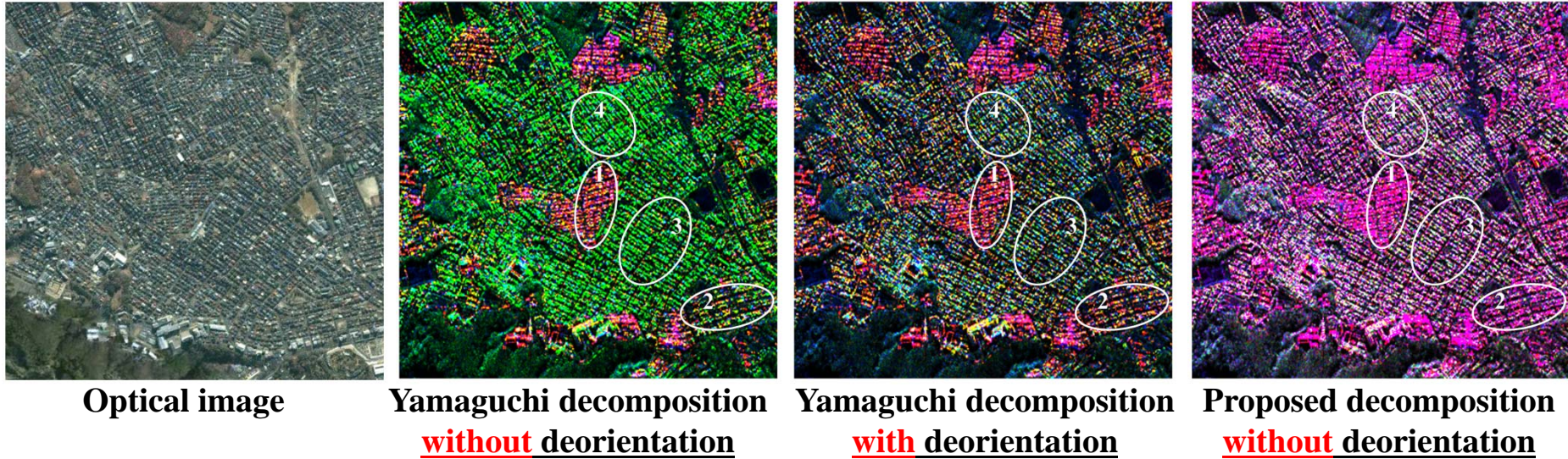


Characterization, interpretation

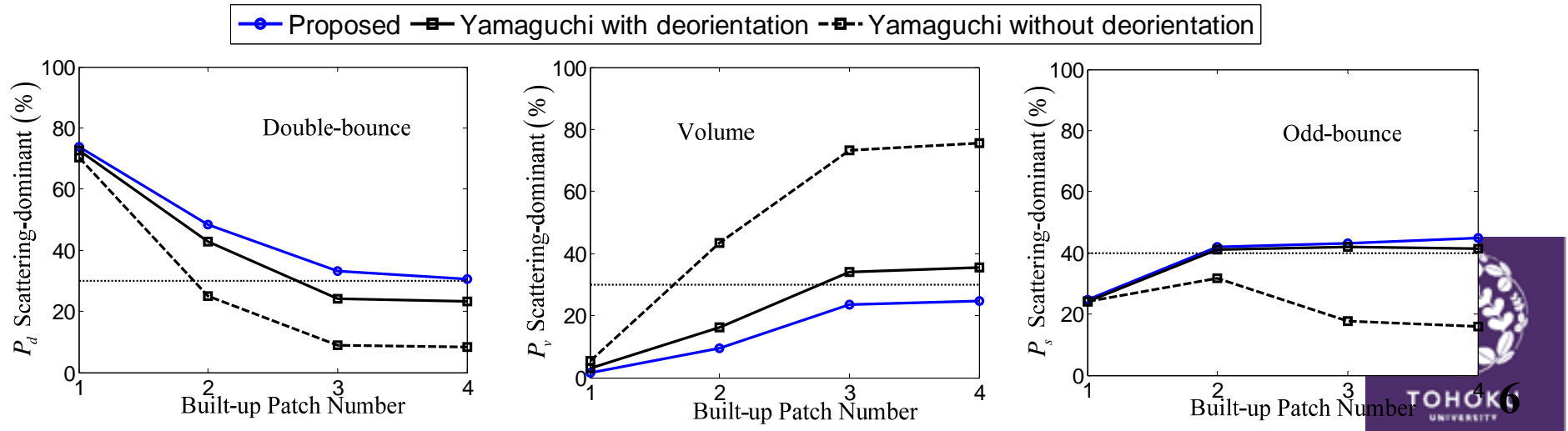
Physical Parameters  
Retrieval

# Comparison \_ Pi-SAR Data ROI

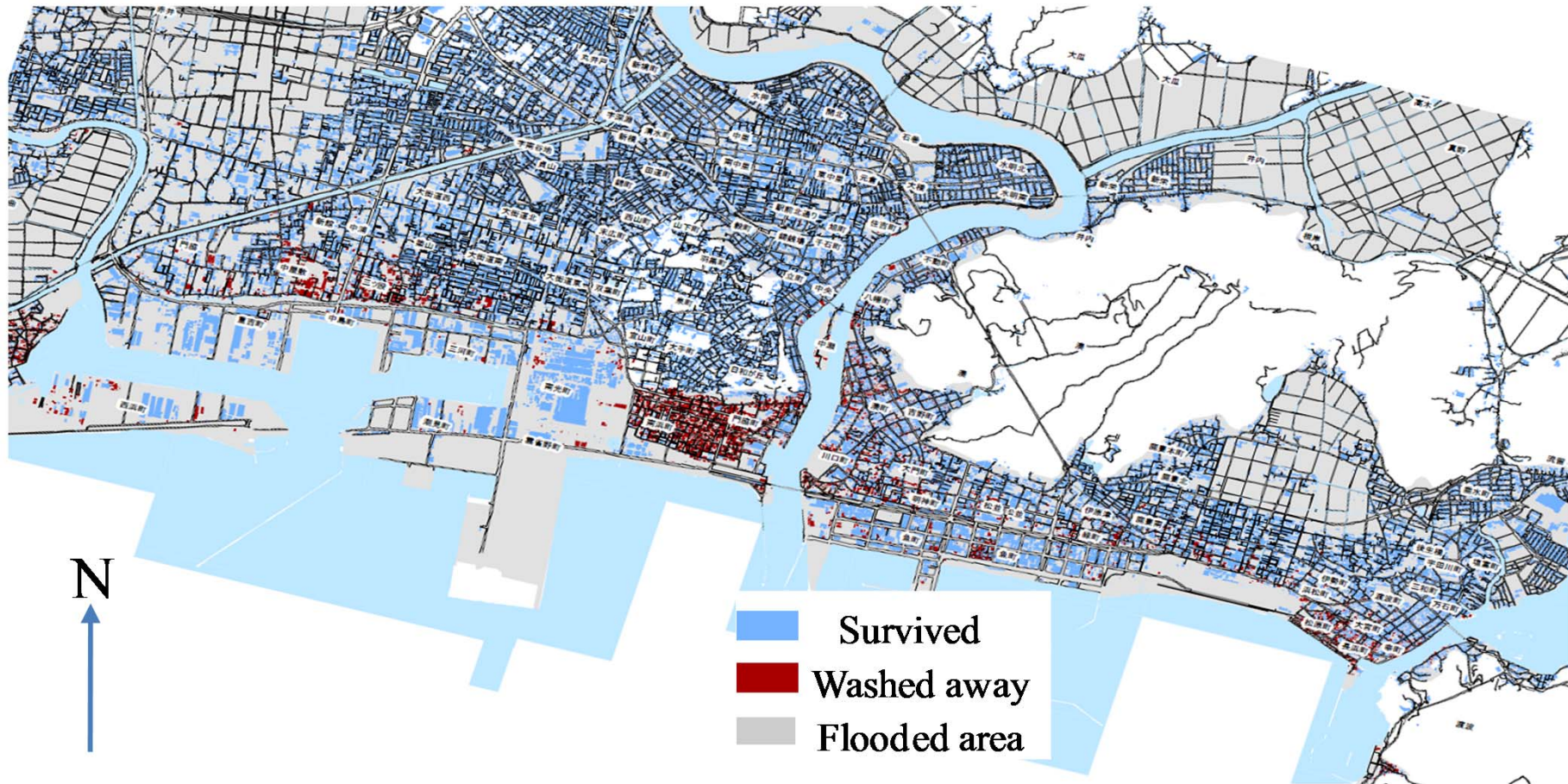
## ➤ Oriented Built-up Areas



## ➤ Quantitative Comparison

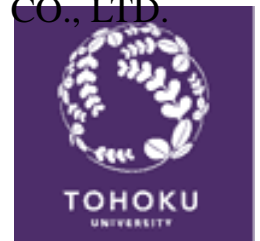


# Study Area\_ Ishinomaki City

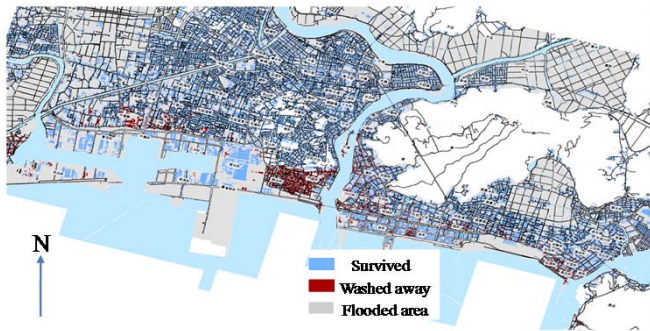


Copyright 2011 ZENRIN CO., LTD.

**Building Damage Map**



# ALOS Optical Images



Washed Away Ratio	Patch Number
80-100%	1
50-80%	2, 3
20-50%	4, 5, 6
0%	7, 8, 9





# Basic Scattering Mechanisms

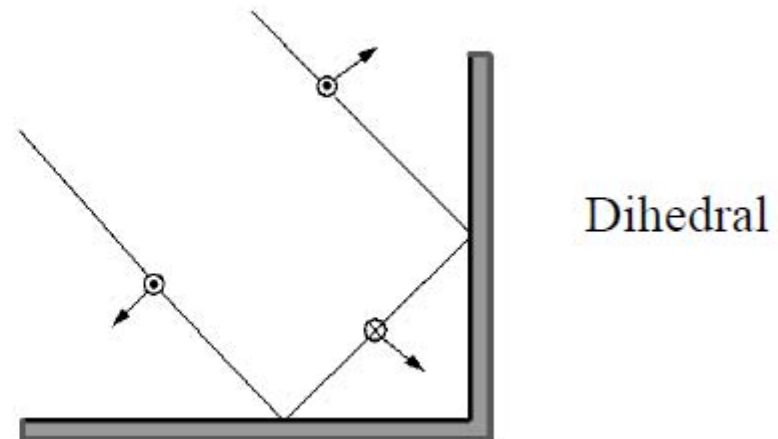
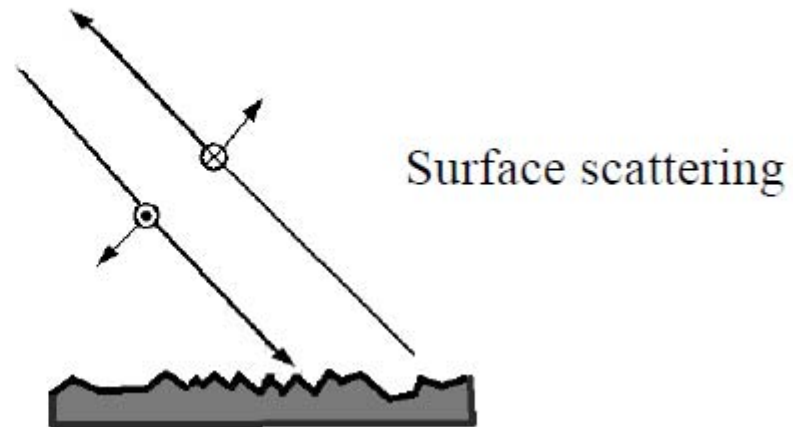
- Surface scattering (Bragg) :  $b > a$

$$\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} a & 0 \\ 0 & b \end{bmatrix}$$

- Dihedral - conducting

$$\begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = \begin{bmatrix} a & 0 \\ 0 & -a \end{bmatrix}$$

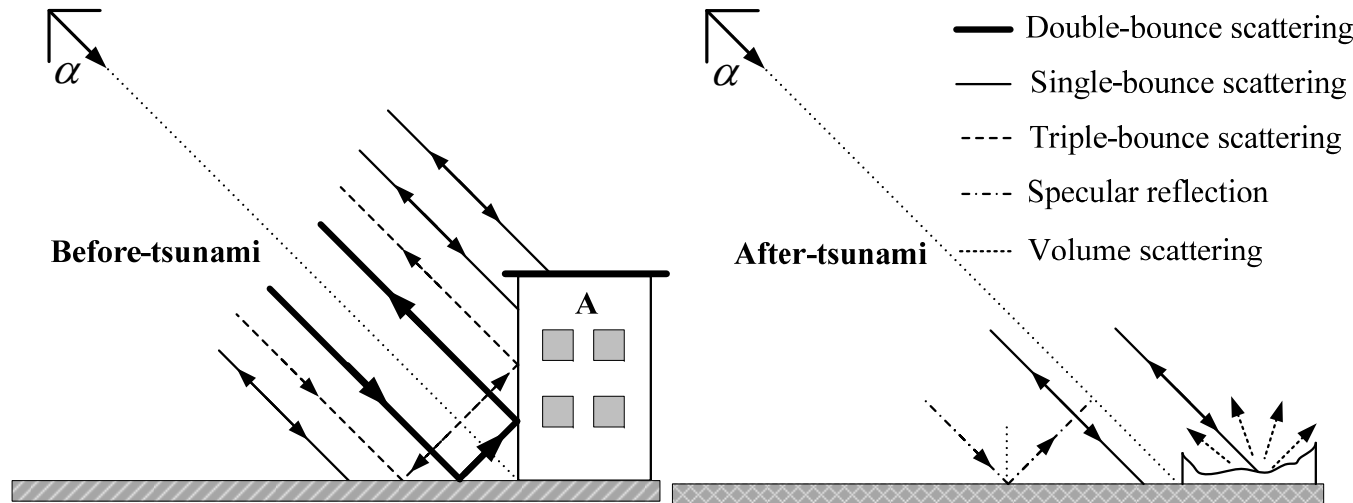
- HH and VV phase difference =  $180^\circ$ 
  - Non-conducting surface  $< 180^\circ$
- Round trip distance identical
- Strong return



(J.S. Lee, IGARSS 2006 tutorial)

# Scattering Mechanism Analysis \_ Built-up Area

## ➤ Polarimetric Scattering Mechanism Change



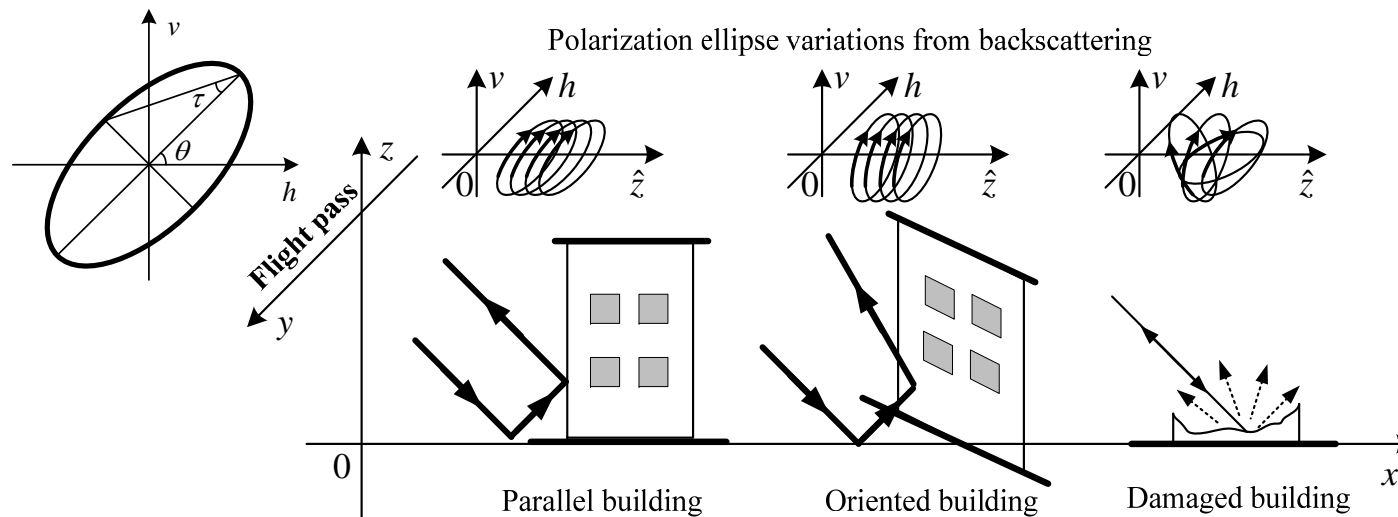
### Scattering Mechanism

**Double-bounce**



**Odd-bounce**

## ➤ Polarization Orientation (PO) Angle Shift



### PO Angle Distribution

**Deterministic**

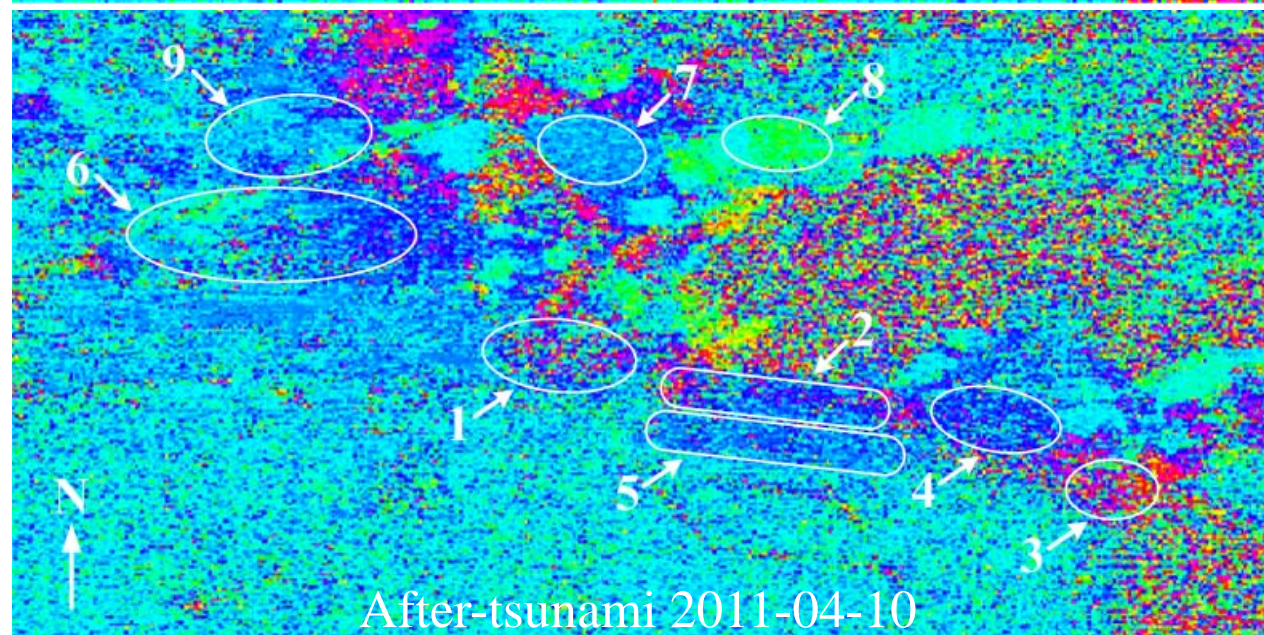
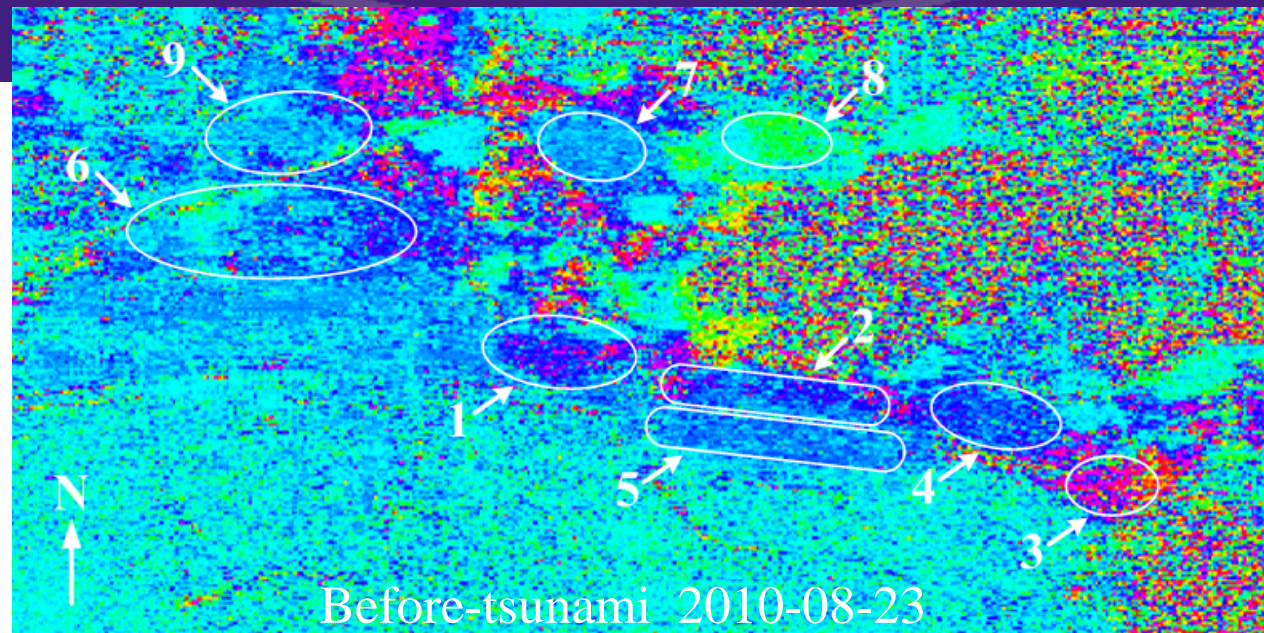


**Random**



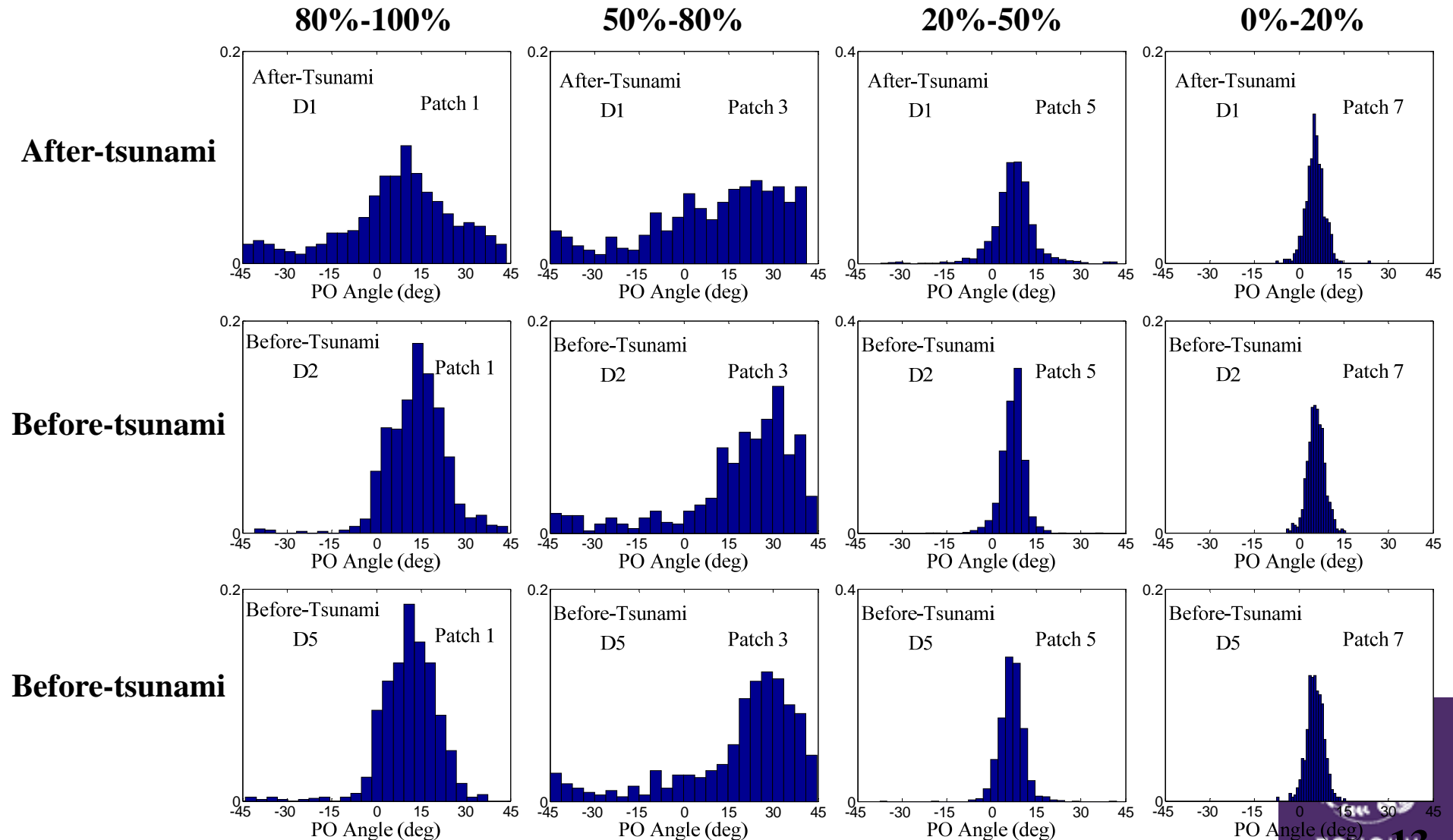
# Polarization Orientation Angle Map

Washed Away Ratio	Patch Number
80-100%	1
50-80%	2, 3
20-50%	4, 5, 6
0%	7, 8, 9



# PO (Polarization Orientation) Angle

## ➤ PO Angle Histograms



# ALOS/PALSAR\_ Model-based Decomposition

Temporal Baseline:

138 days

Spatial Baseline:

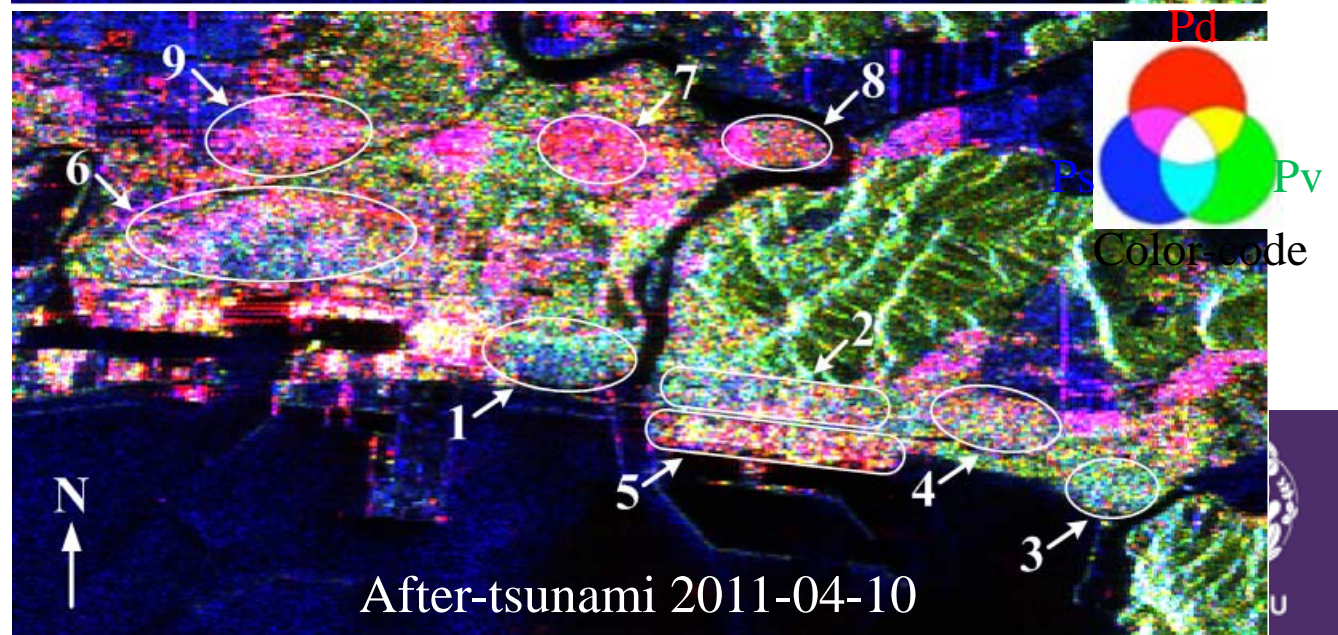
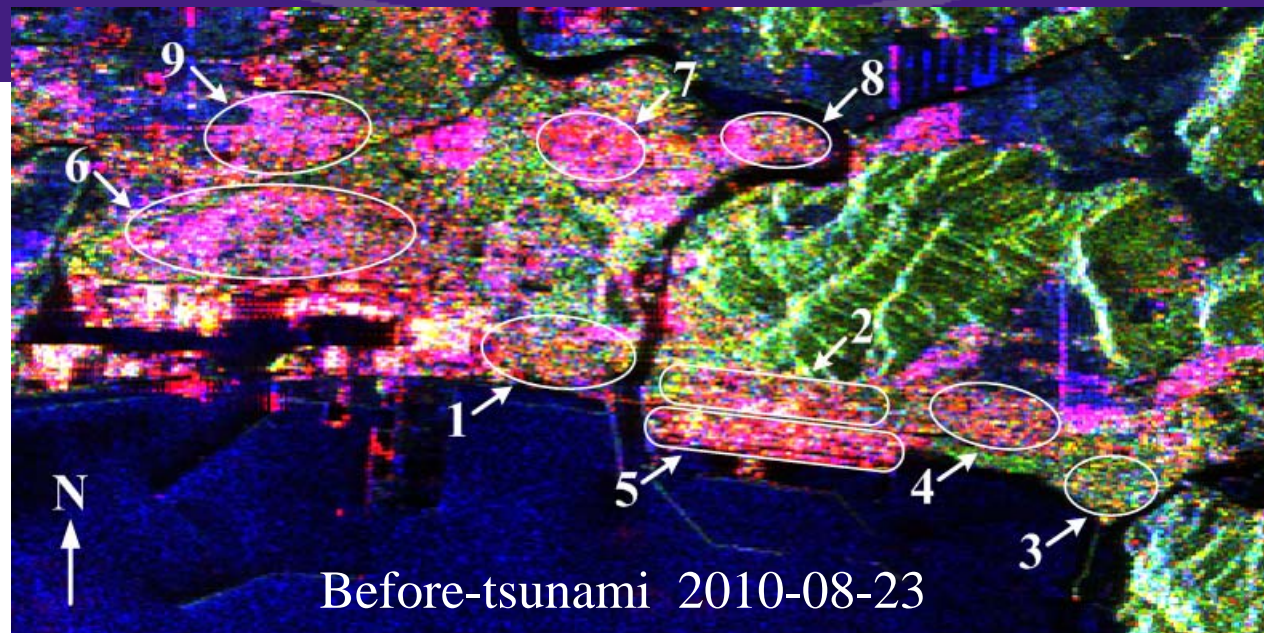
about 2 kilometers

Resolution:

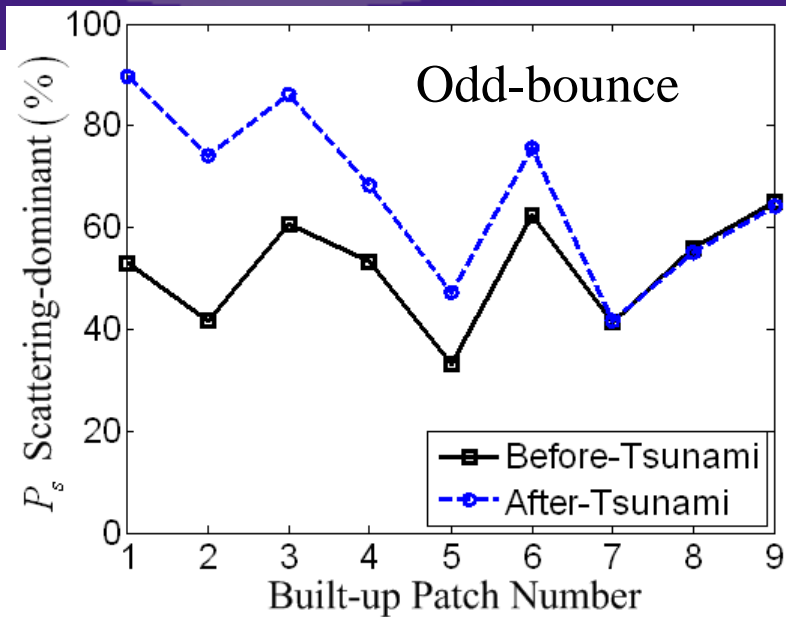
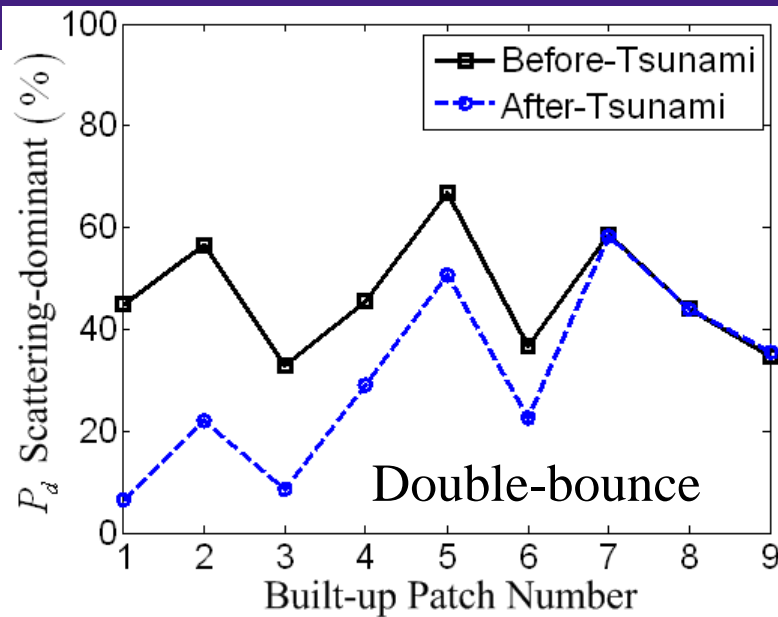
about  $20 \times 20$  meters

**Building Block Scale**

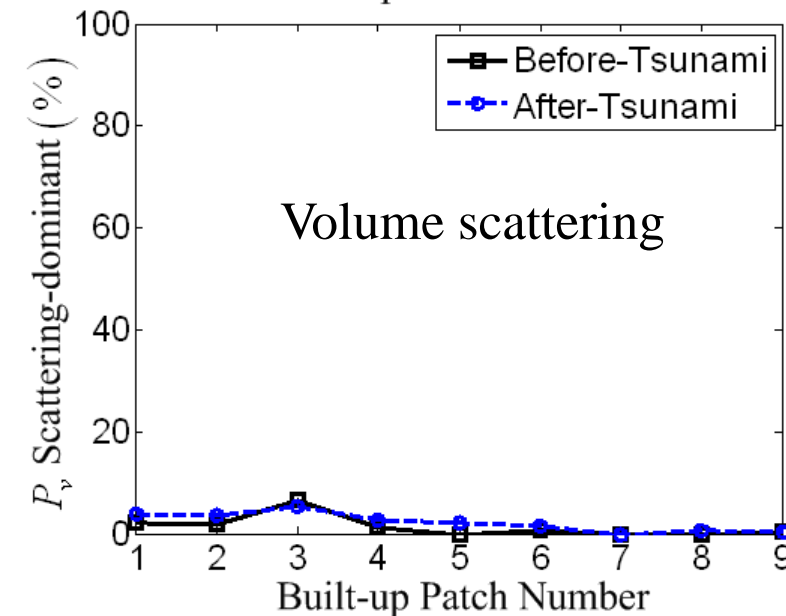
Washed Away Ratio	Patch Number
80-100%	1
50-80%	2, 3
20-50%	4, 5, 6
0%	7, 8, 9



# Decomposition Comparison \_ Built-up patch



Washed Away Ratio	Patch Number
80-100%	1
50-80%	2, 3
20-50%	4, 5, 6
0%	7, 8, 9



# SARデータの解析手法

- コヒーレンシー  
(散乱の空間分布)
- 偏波  
(固有値解析は空間分布情報が主)



# 現在の偏波情報利用

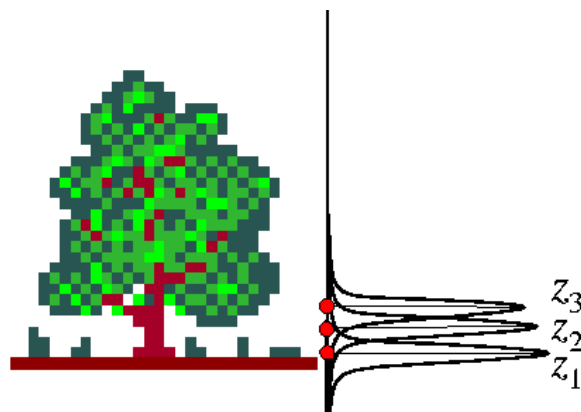
- 地表面分類  
固有値解析  
モデル分解
- Pol-IN-SAR  
樹高推定
- その次？

## Conditioning of the Inversion Problem

... or which polarisations lead to the best parameter estimates

### Senario 1

High Coherences  
Close phase centers



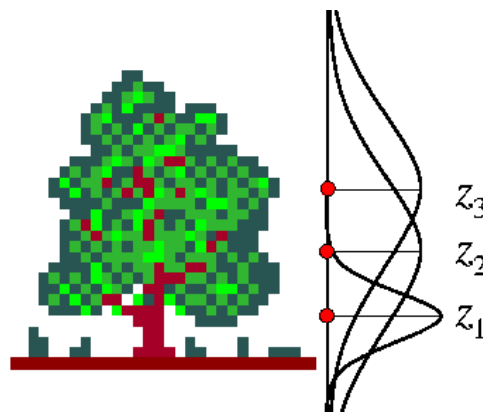
Insufficient Separability



Ill-Conditioned

### Senario 2

Low Coherences  
Separated phase centers



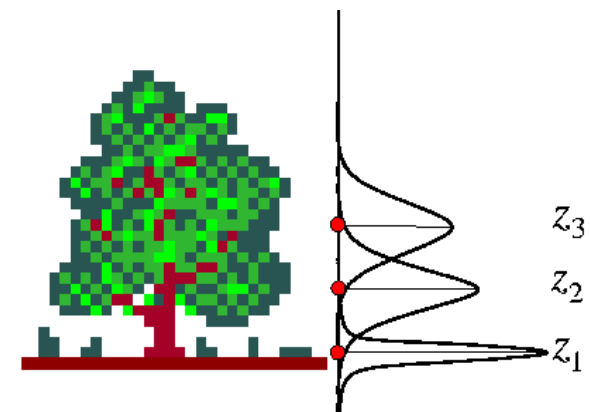
Insufficient Separability



Ill-conditioned

### Senario 3

Optimised Coherences  
Separated phase centers



Sufficient Separability

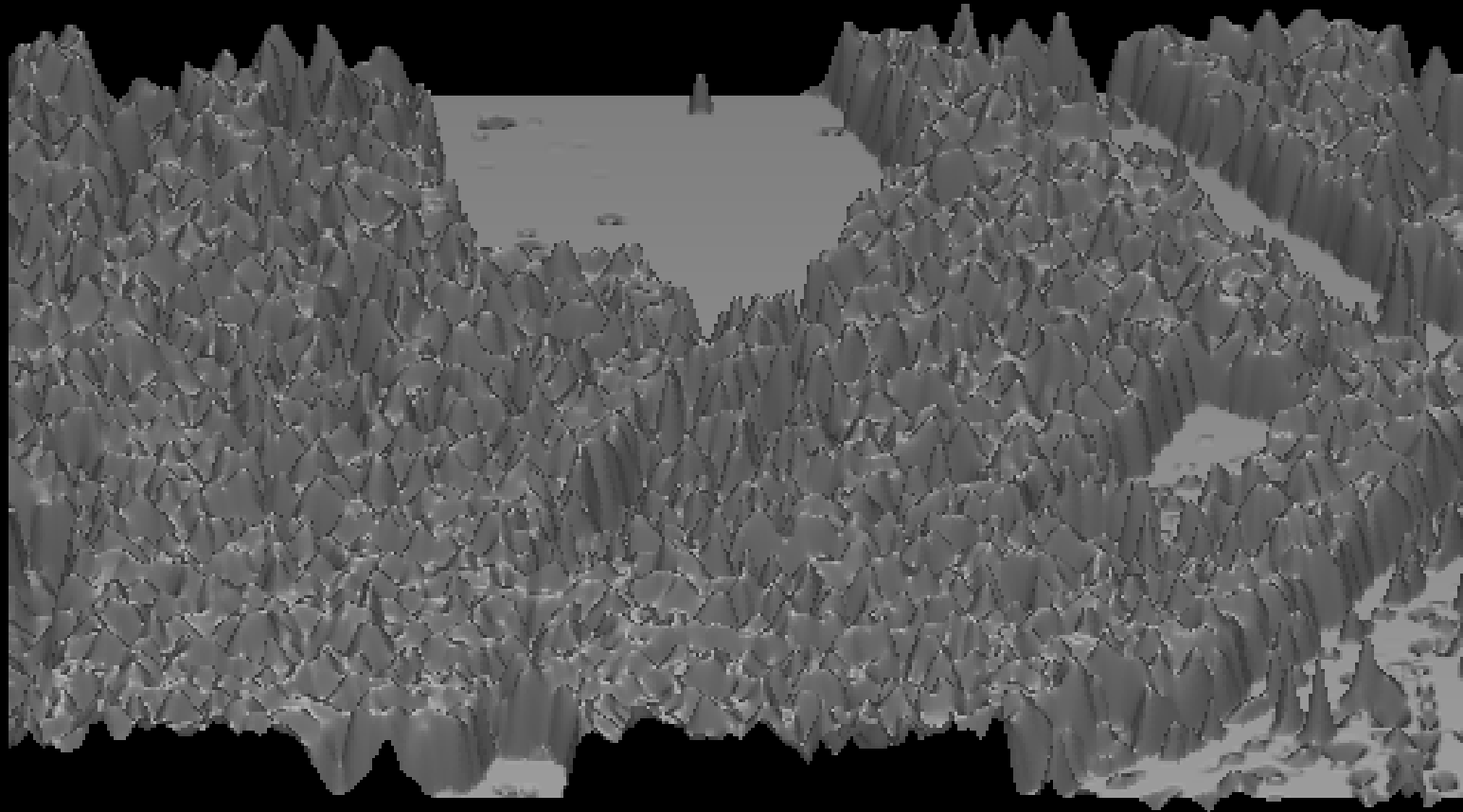


Well-conditioned



## 3-Dimensional Forest Height Representation

*E-SAR / Test Site: Oberpfafenhoffen*



# 逆問題としてのSAR

$y$ : 観測量    $x$ : 物理量    $K$ : 物理法則

$$Kx = y \quad \text{順問題}$$

$$x = K^{-1}y \quad \text{逆問題}$$

$K^{-1}$  が求まる例は少ない。  
SARプロセッシングはその例の一つ



# 逆問題としてのリモートセンシング

$$\mathbf{E}_{sca}(\mathbf{r}) = \int_V d\mathbf{r}' \bar{\mathbf{G}}(\mathbf{r}, \mathbf{r}', \varepsilon_b) \cdot \bar{\mathbf{G}}(\mathbf{r}', \mathbf{r}'', \varepsilon_b) \cdot \mathbf{a}(\mathbf{r}'') \left[ k^2(\mathbf{r}') - k_b^2 \right]$$

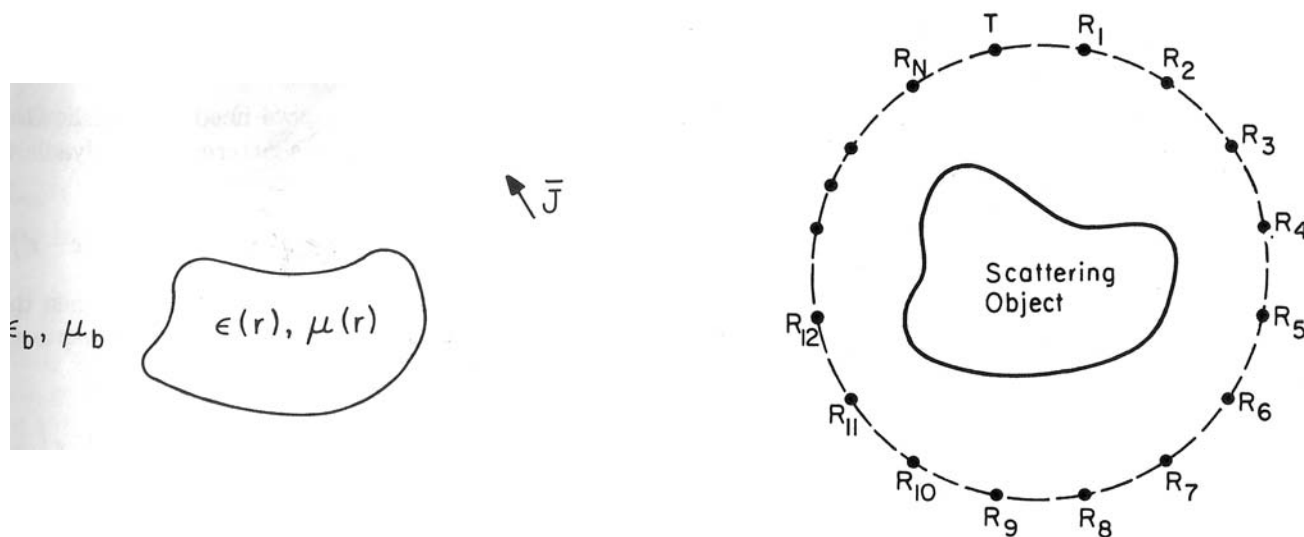


Figure 9.1.1 An example of an inverse scattering experiment.

# 物体からの電磁波散乱

- 周波数 -2, 3周波数△
- 偏波 -フルポーラリメトリ○
- 入射・散乱方向 -タンデム飛行△

- 限られた観測しかできない  
→ 逆問題における「不適切問題」

$$\underline{E}_S = \frac{e^{-jkr}}{r} S \underline{E}_I = \frac{e^{-jkr}}{r} \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \underline{E}_I$$



# 限られた観測での逆問題

未知数を限定することによる「不適切問題」の解消

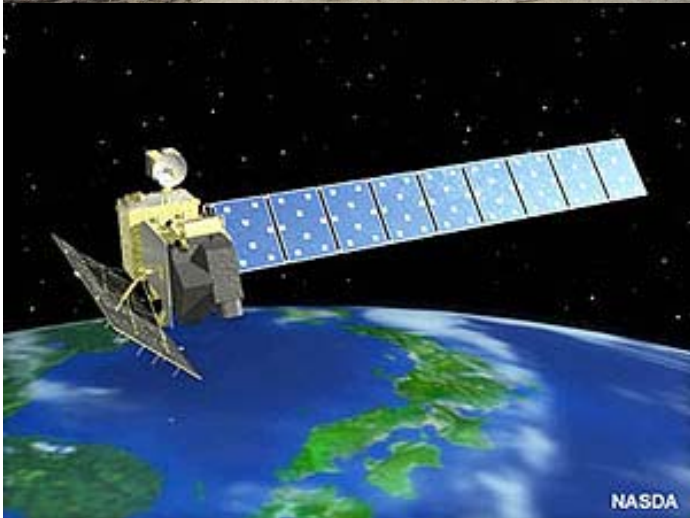
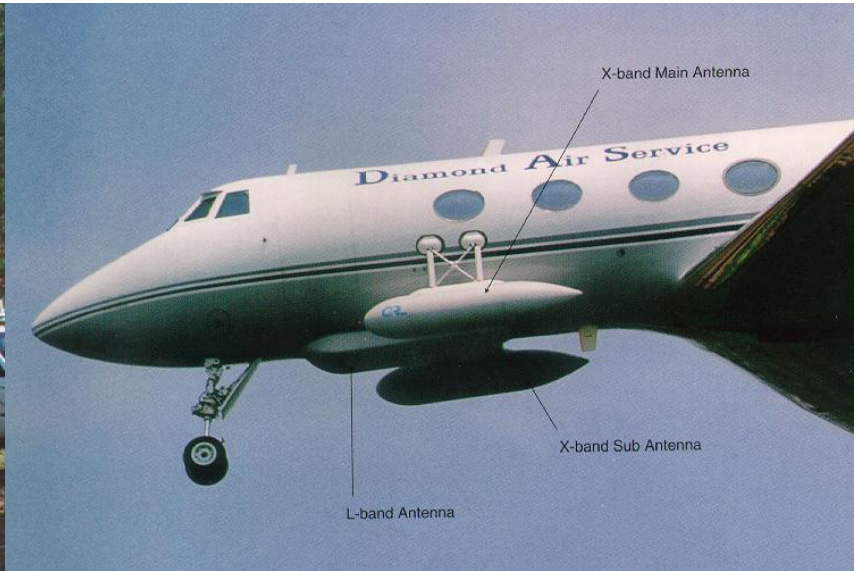
- 一層の散乱面を仮定し、位相変化と地表面変位
- 樹木の2層構造モデル化による樹高推定
- 有限個数の散乱モデルを仮定した地表面分類



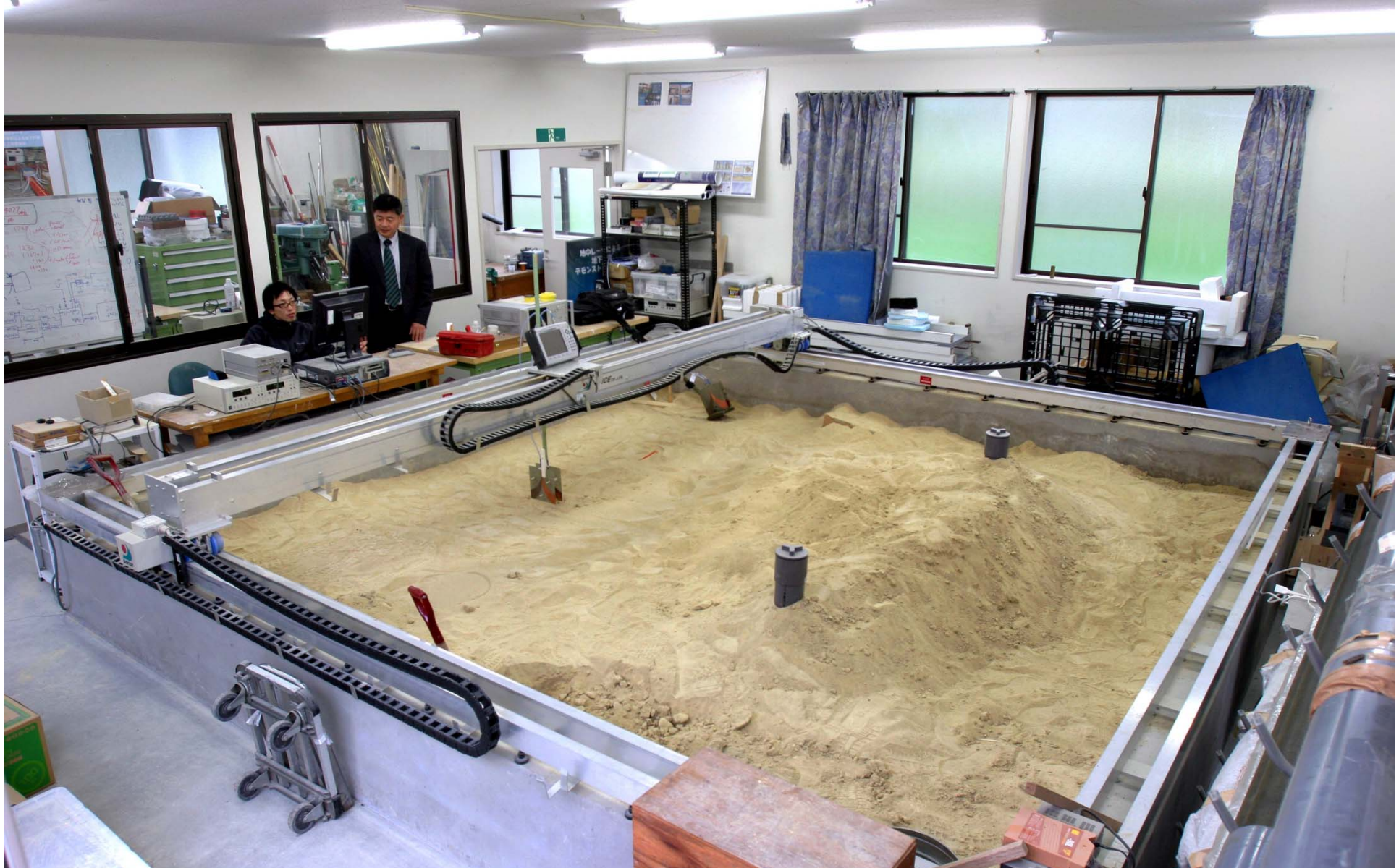
# より効率の良い推定

- 本質的な電磁波散乱特性の利用
- フーリエ変換に依らない像の再構成
  - MEM, CS...

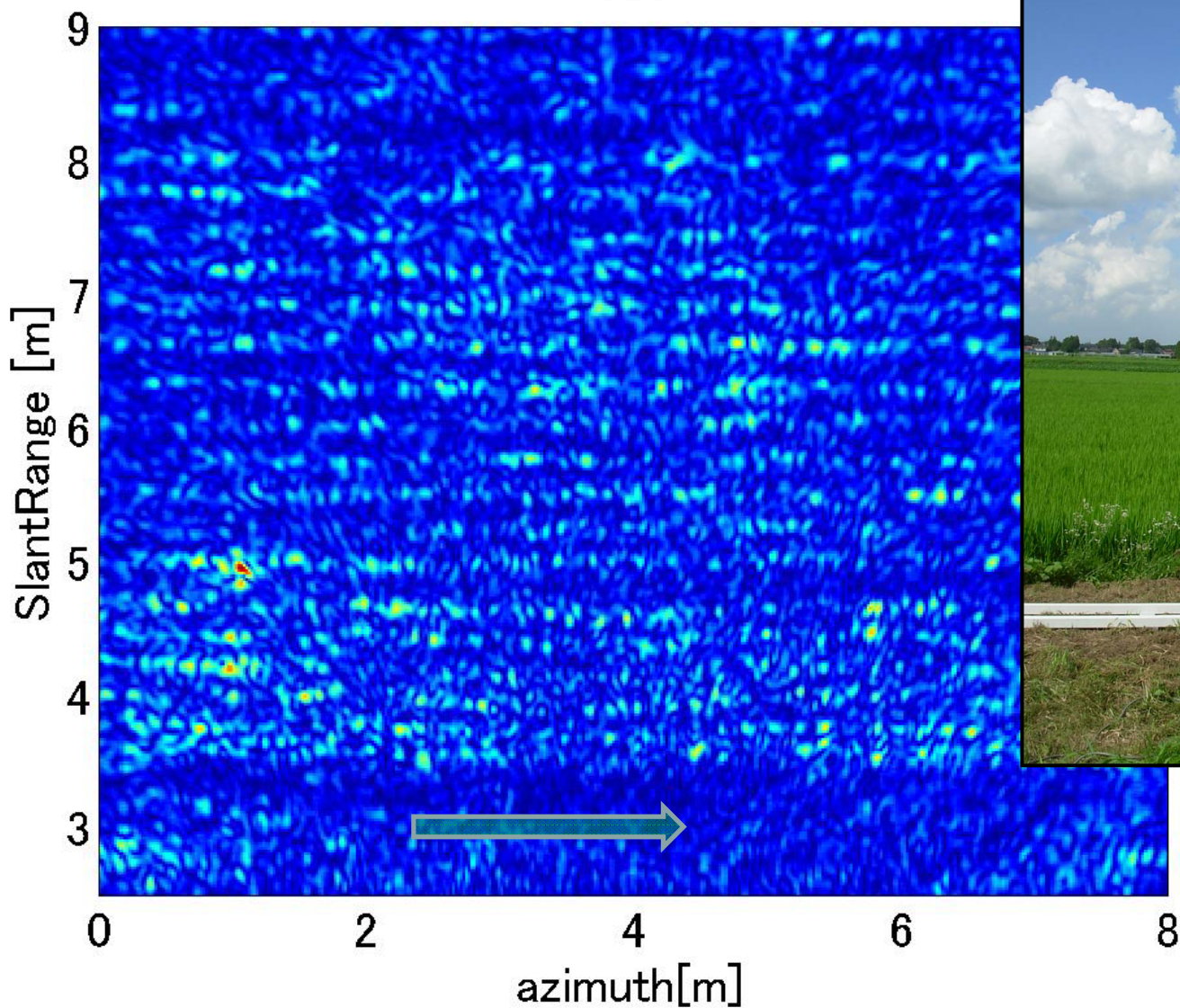




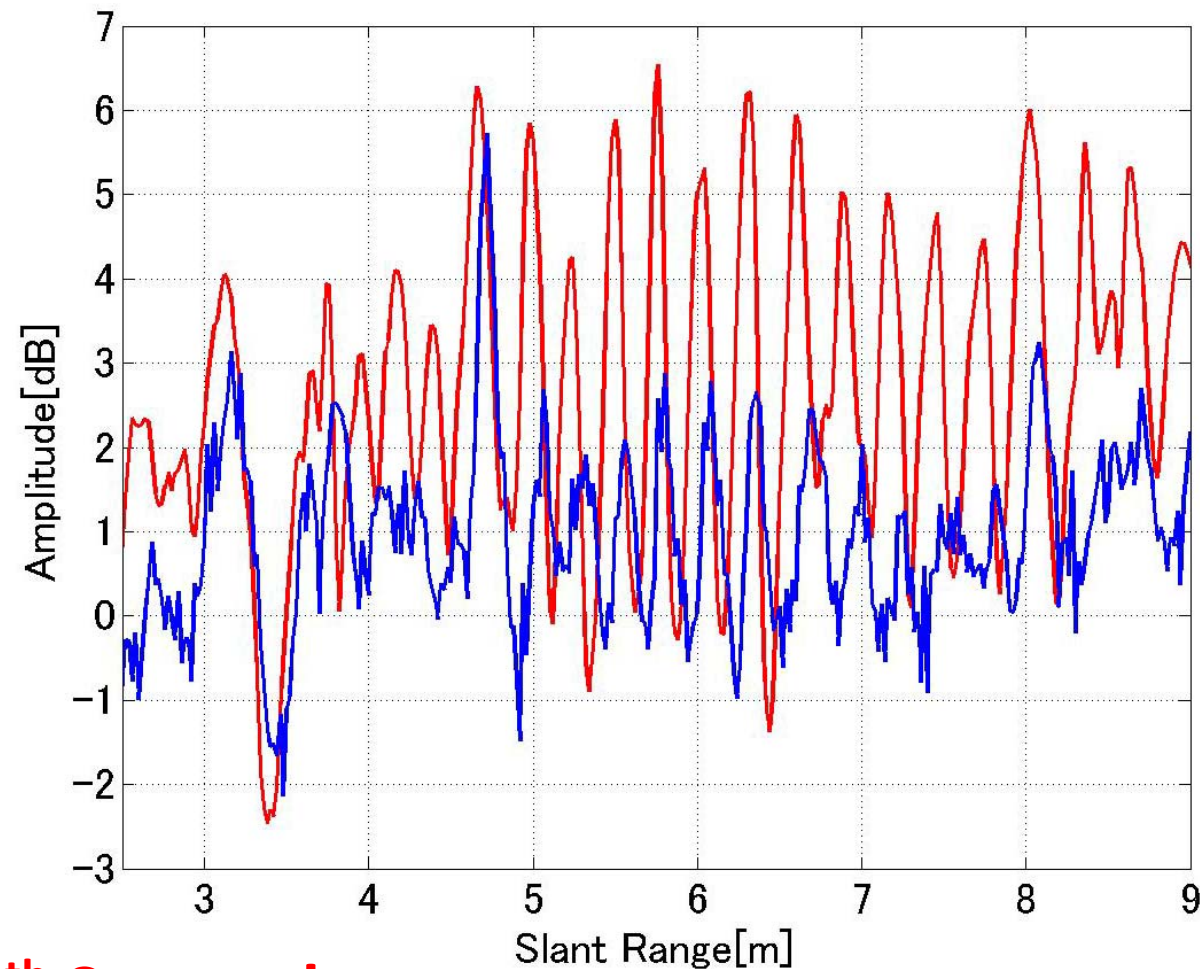
# GPR Test Facility for Humanitarian Demining



# GB-SAR image of rice field



# HH-component of GB-SAR



— :4<sup>th</sup> September  
— :19<sup>th</sup> September

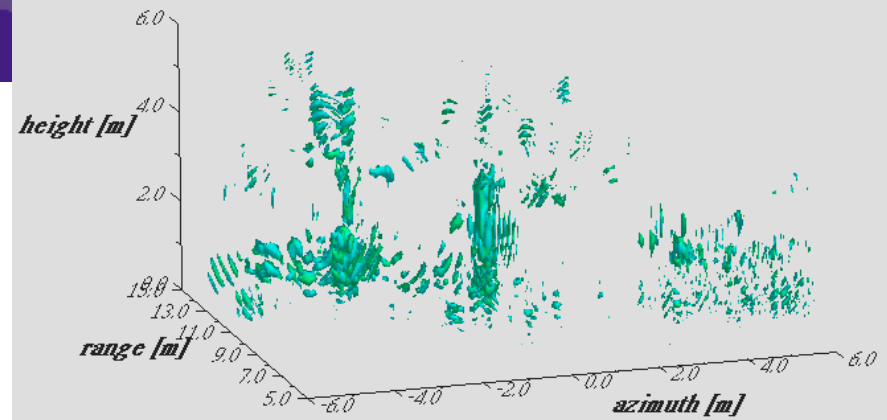
Normalized by the data on 3<sup>rd</sup> August

# 3D radar monitoring of a tree



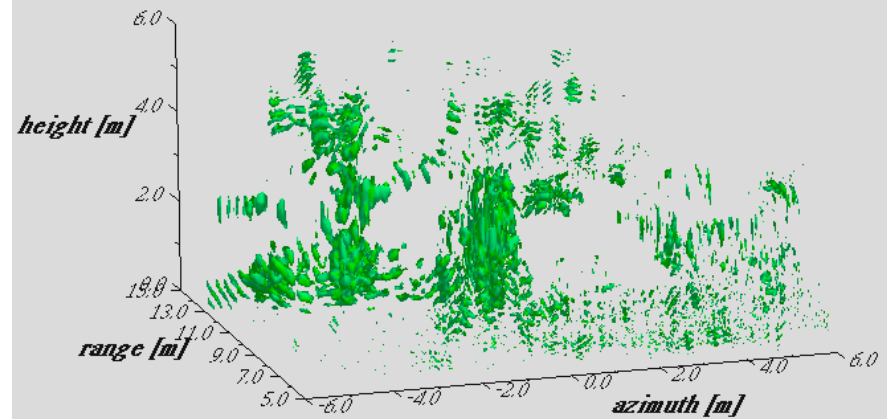
HH of exp#1

*on April 19, 2002*



HH of exp#2

*on May 28, 2002*



# GB-SAR 装置



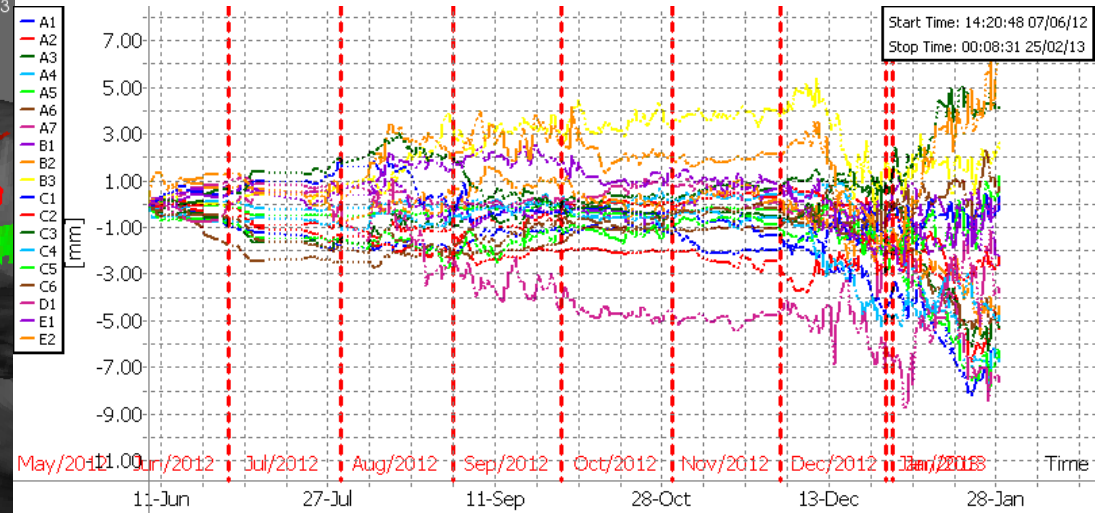
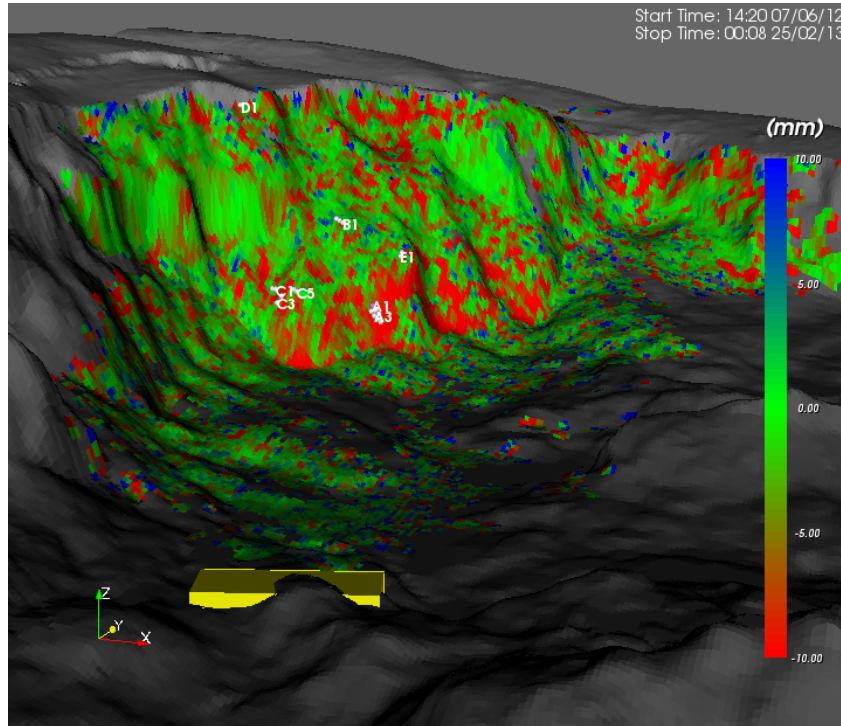
- Horn antennas
- Center frequency at 17.2 GHz (Ku-band)
- 150 MHz frequency bandwidth
- Scans 2 m in 2 min.
- Data acquisition at every 5 mm
- Real time SAR processing
- Detection of small displacements by radar interferometry (repeat-pass)

# 宮城県 栗原市 荒砥沢

- 2008年岩手・宮城内陸地震で発生した大規模地滑り
- 計測範囲 高さ100m, 幅 900 m
- 斜面の安定性モニタリング
- 2011年11月から試験、2102年6月より長期モニタリング
- 高品位ビデオカメラと併用



# 2012年6月7日 – 2013年2月25日 (13時間毎)



期間	6月7日－2月25日
データ間隔	156(約13時間毎)
Window	50
Image quality	Low



# 応用分野との連携

- 土木
- 農業
- 植生



# まとめ

- ポーラリメトリ・インターフェロメトリによる定量計測
  - 対象物形状: 災害
  - 土壌水分
  - 植生
  - 層構造の解析: 樹冠、雪、氷、土壌
- 地表同期実験
  - GB-SAR
  - GPR
- 電波科学
  - 大規模なデータに対応する実用的なアルゴリズム
- SAR学術コミュニティーの形成

