Physical content of SAR data

Thuy Le Toan
Centre d'Etudes Spatiales de la Biosphère (CESBIO)
CNRS, CNES, IRD, Université Paul Sabatier
Toulouse, France

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Radar vs Optical remote sensing

Radar

1. Day and night operation (independence of sun illumination)
2. All weather capability (under clouds & rains)
3. No effects of atmospheric constituents (→multitemporal analysis)
4. Sensitivity to dielectric constant (water content, i.e. soil moisture, biomass)
5. Sensitivity to surface roughness (sea state, topography..)
6. Sensitivity to target structure (→ use of polarimetry)
7. Accurate measurement of distance (→ interferometry)
8. Subsurface penetration

Optical

1. Day operation (Vis bands)
2. Weather limitations (clouds, rain)
3. Effects of atmospheric constituents (→correction needed)
4. Sensitivity to chemical constituents (chlorophyl, soil..)
5. Low sensitivity to surface roughness (e.g. through shadow)
6. No use of polarimetry
7. No measurement of distance
8. No subsurface penetration

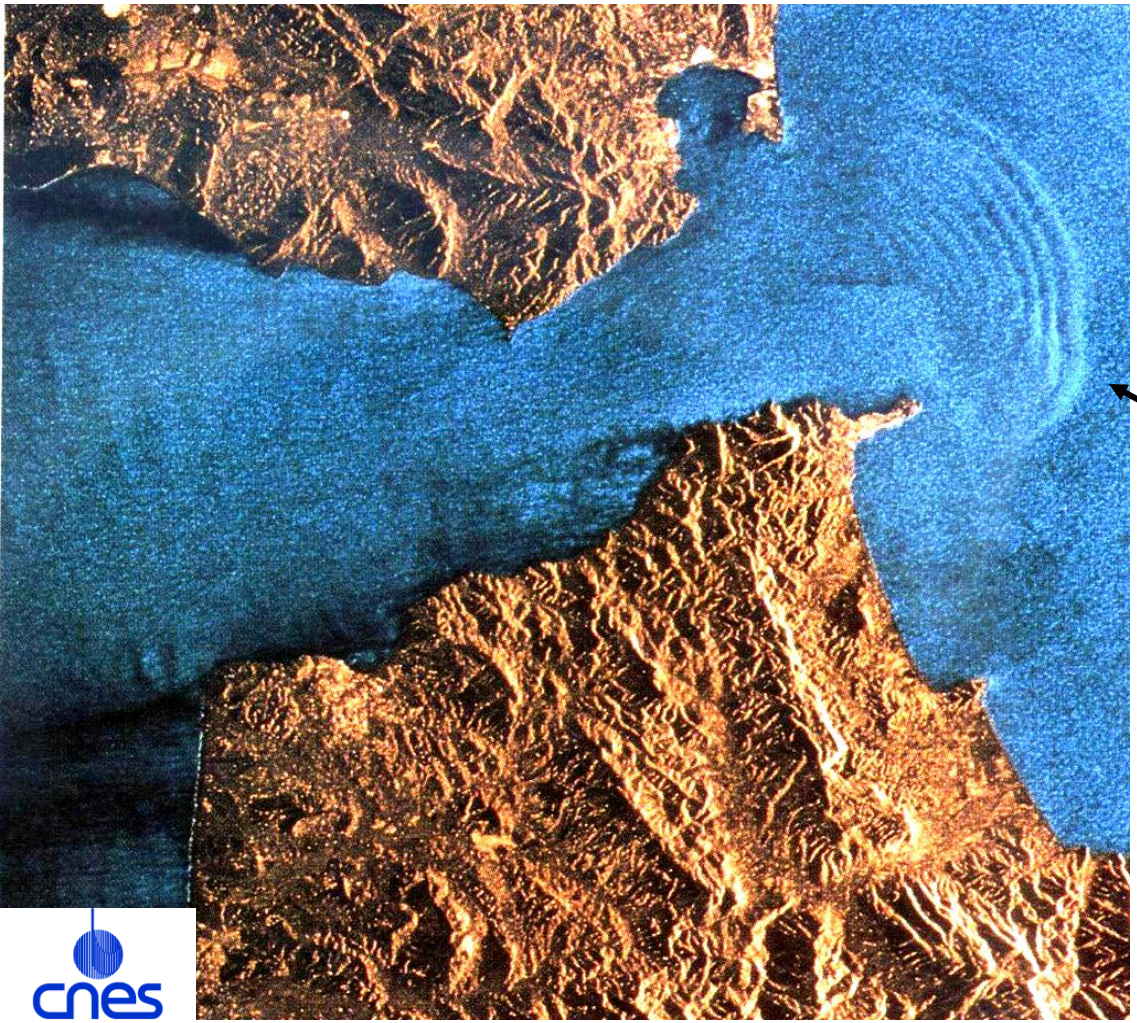
Radar remote sensing: main difficulties

1. Complex wave target interaction mechanisms
   (Difficulty in image understanding and visual interpretation)

2. Complex statistical properties of SAR images , e.g. speckle effects
   (Difficulty in image analysis and processing)

3. Topographic effects on both radiometric and geometric properties

Effect of surface roughness: waves



ERS Images (C band, 23°, VV)
in false colors

Gibraltar strait
Image : 90 km x 100 km

• **Internal waves** (l≈2 km)
Origin : difference of salinity between Atlantic Ocean and Mediterranean sea + tide effects

From 'ERS-1 : 500 days in orbit '. Published by the Europec Space Agency'

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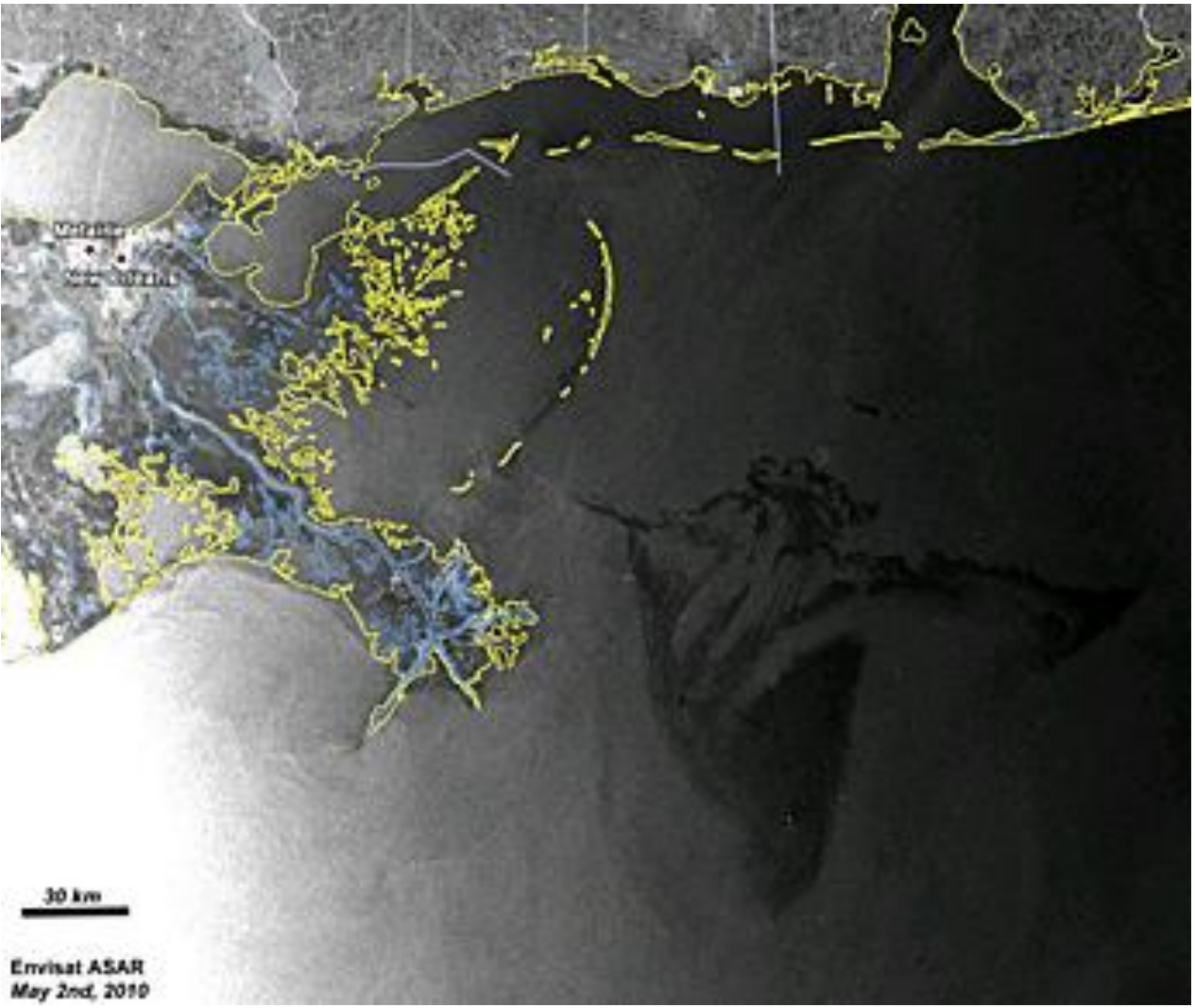
Effect of surface roughness: sea state

Micowave:
Sensitivity to
surface roughness
→ sea state

Optical:
sensitivity to clouds

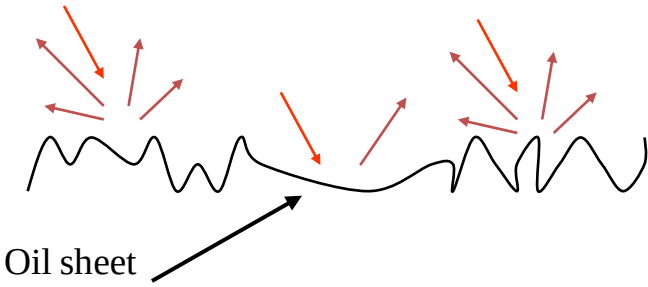
Matching images of the islands of Corsica and Sardinia, with the Italian coast in the upper right-hand corner, acquired 26 June 2002 using Enivsat ASAR (left), and MERIS (right).

Effect of surface roughness: oil spills



C-band ASAR data on 2 May 2010 03:45 UTC
The oil spill is visible in the Gulf of Mexico.

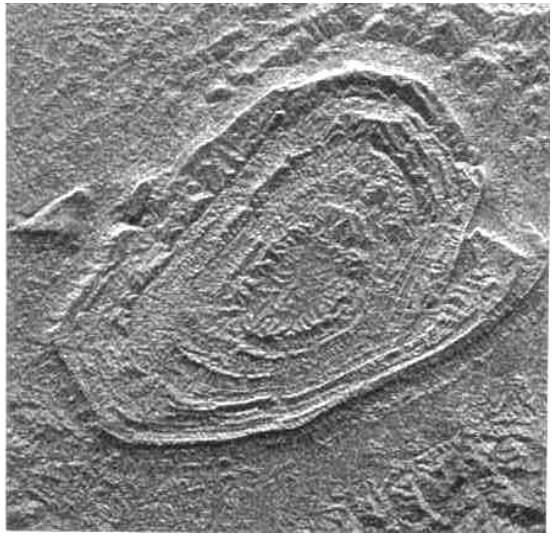
Decrease of local sea surface roughness due to oil spill



Effect of topography

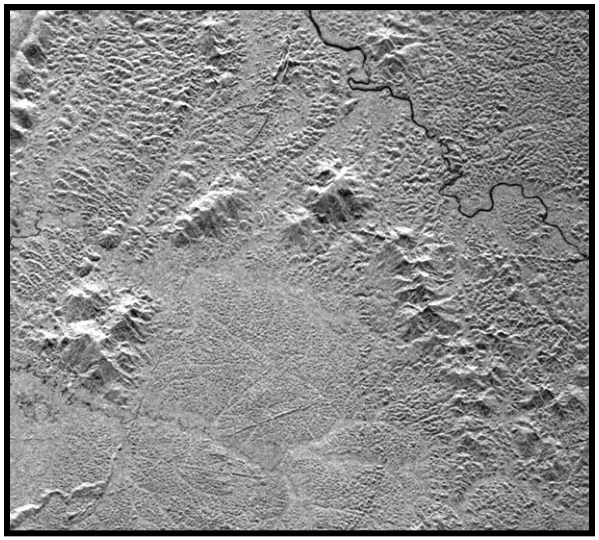
Richat, Mauritania

Cosmo Skymed
(X band, Strip mode)



Kalimantan, Indonesia
Sedimentary basin

RADARSAT F4 (C band, 45°, 8 m)

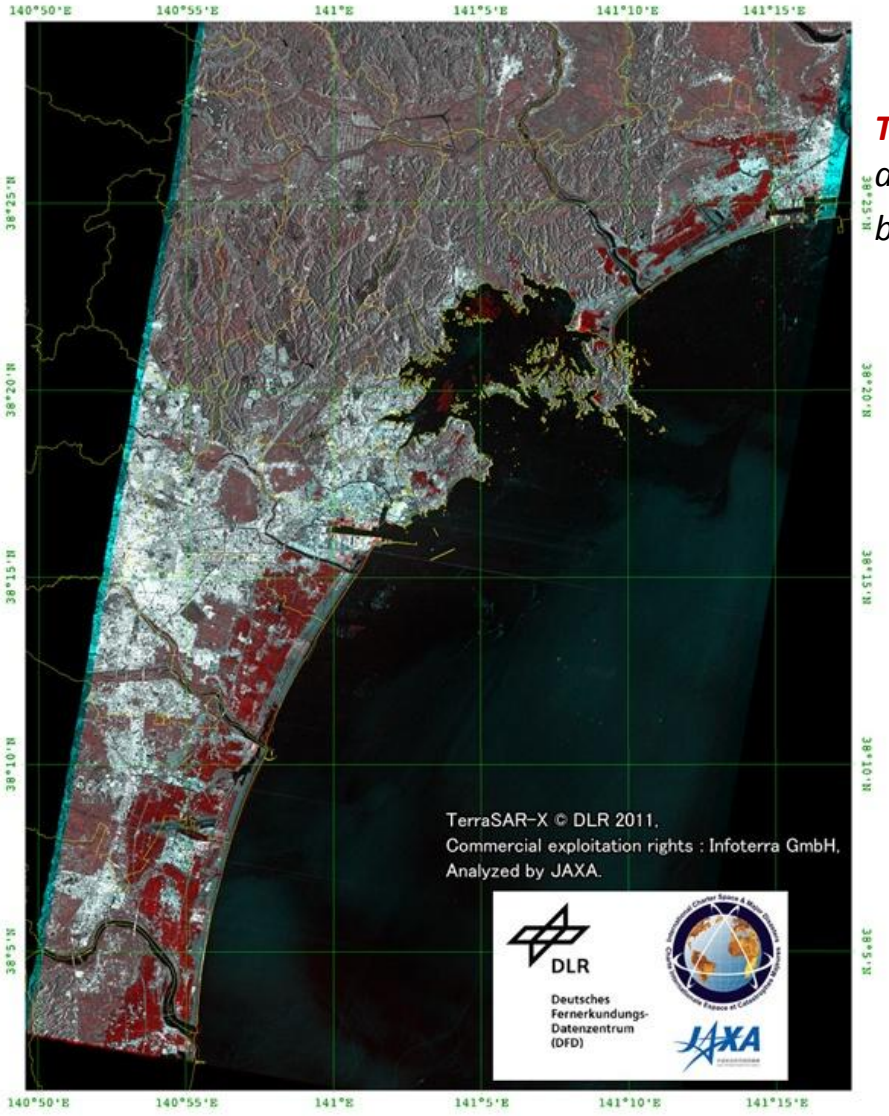


French Guiana
Tropical forest

ERS (C band, 23°, VV, 20 m)

The SAR backscatter signal is very sensitive to topography, even under tropical forests. This is due to the side looking observation and the angular behaviour of the backscattering signal.

Multitemporal observations

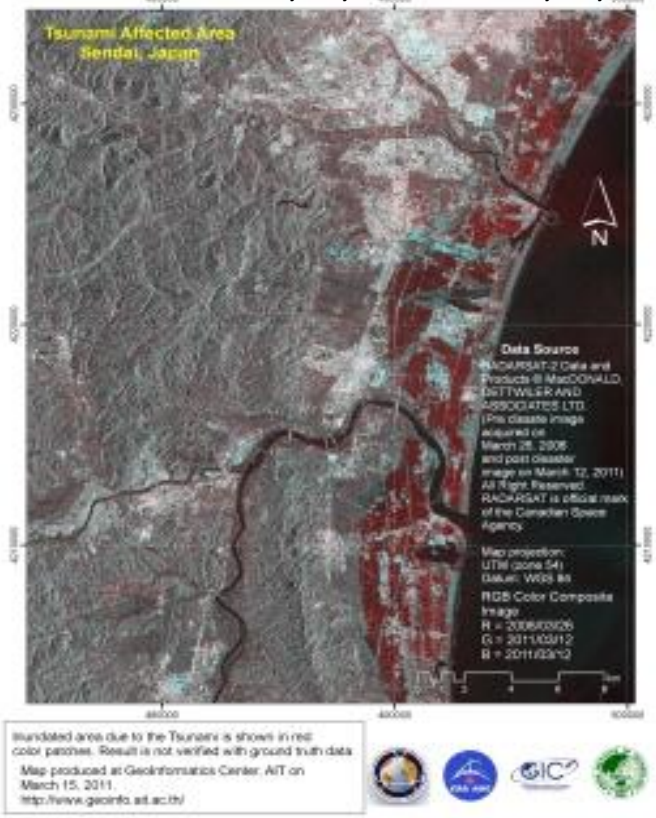


Change after the earthquake/tsunami In Sendai, Japan

TerraSAR-X

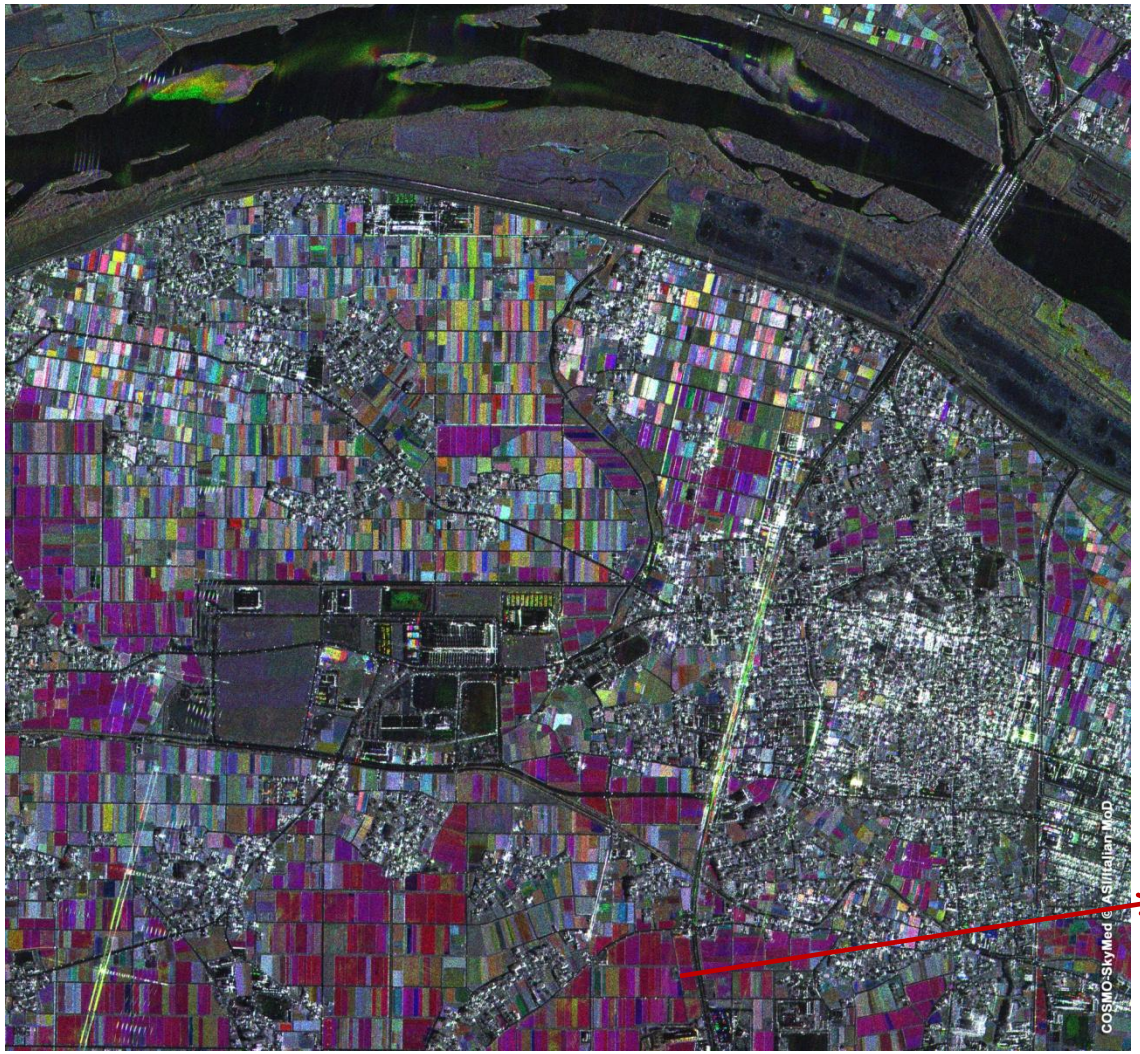
acquired before (red: 2010/10/21) and after (green and blue: 2011/03/12) the earthquake.

***RADARSAT2**: 2011/03/12 and 2006/03/26*



Multitemporal observations

Crop observation in Japan using CosmoSkymed



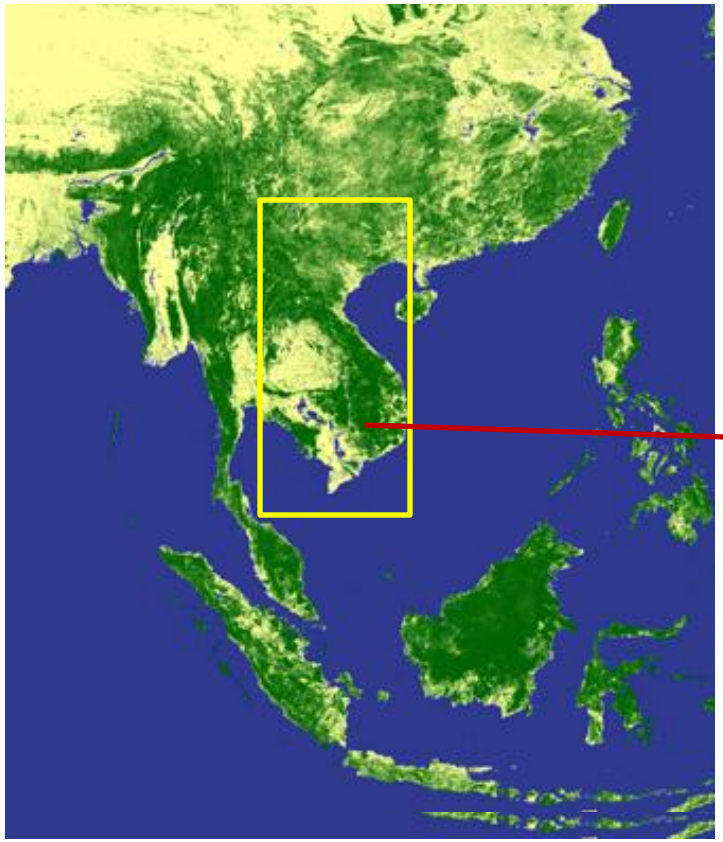
Kumagaya fields: COSMO-SkyMed © ASI/Italian MoD
Multitemporal image;

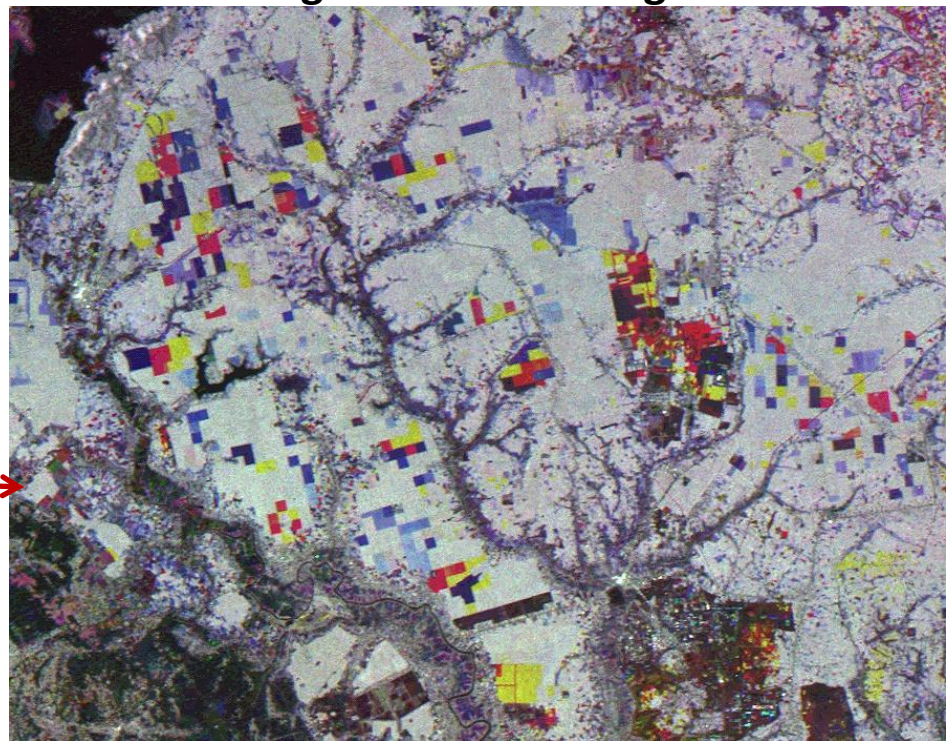
Red: 28/07/2008
Green: 26/06/2008
Blue: 25/05/2008

Rice: R & B colour
May: ploughed soil
June: water
July: small plant

Multitemporal observations: forest monitoring

Forest monitoring in Vietnam using PALSAR





Red: forest cleared 2007-2008 , Yellow: clearings between 2008-2009.
Blue: young growing rubber

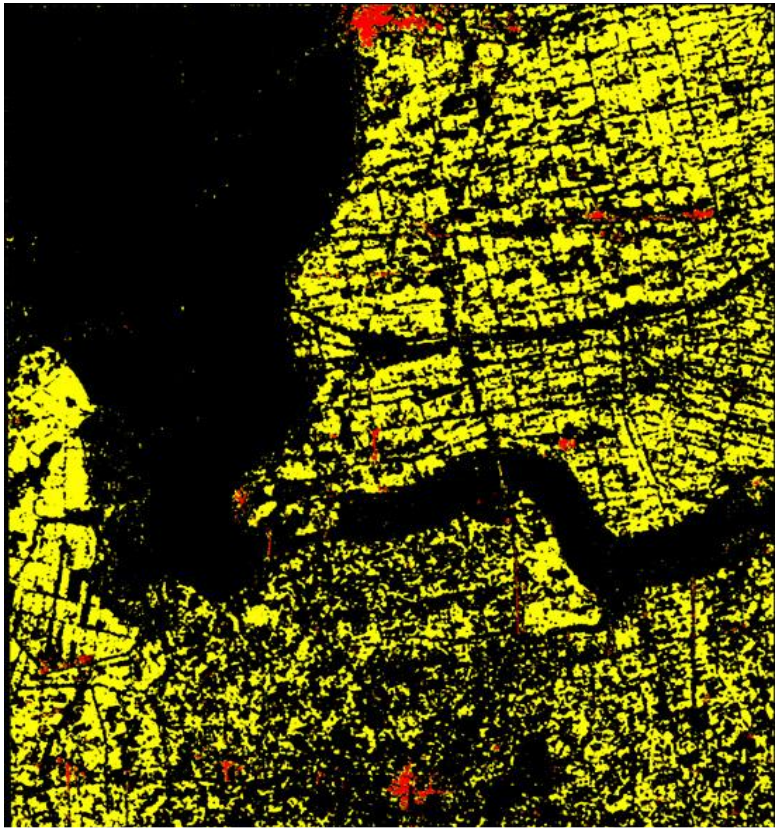
Multi-temporal PALSAR image over Dau Tieng, Vietnam (R: 2007; G: 2008; B: 2009).
The area is part of the extensive rubber plantation programme.

Polarimetric observations: rice mapping

Rice mapping in China ASAR HH/VV

September 6th, 2004 **Hongze area , China**

Magenta=HH, Green=VV

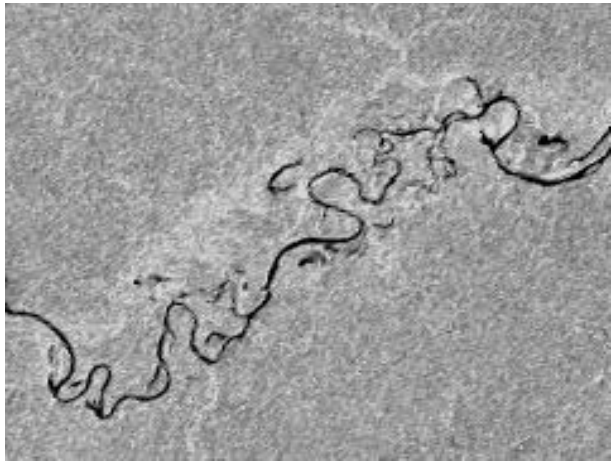


Yellow=rice, Red=urban, Black=othe

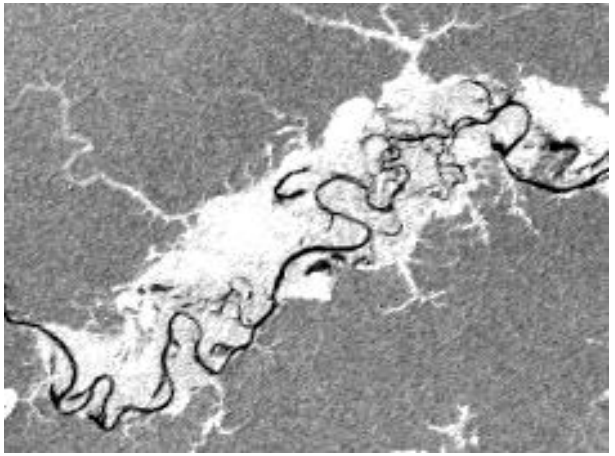
Sub-canopy observations

Varzea Dry Season

Varzea Wet Season



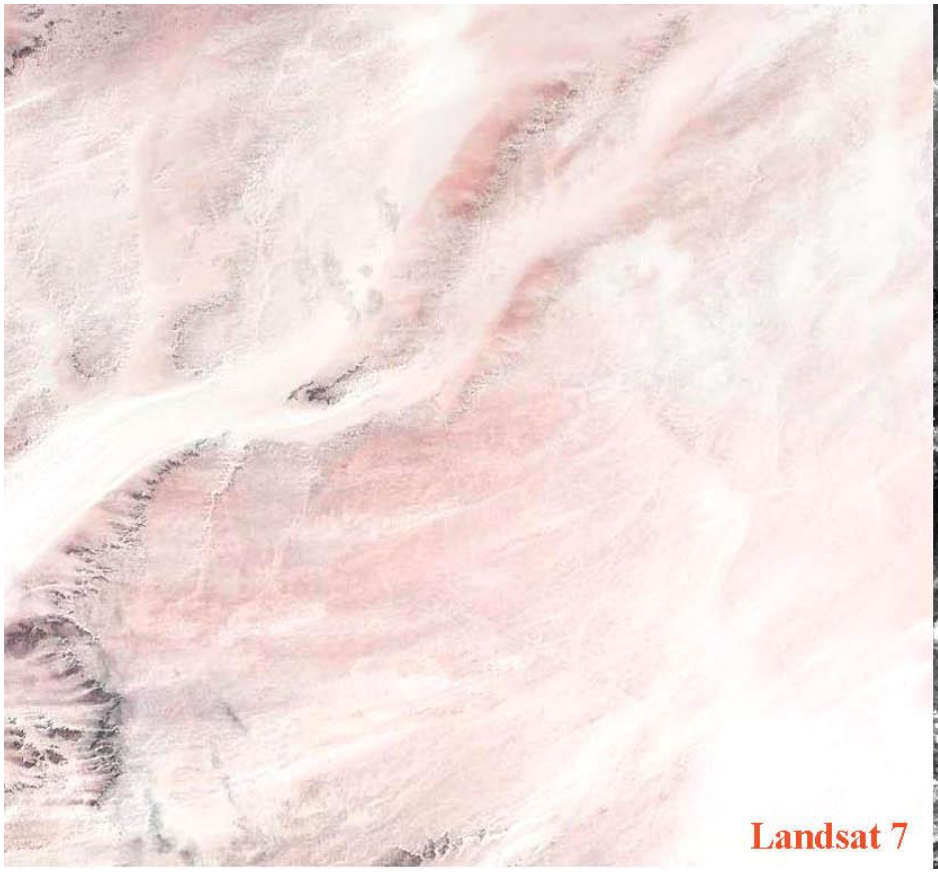
SAR image

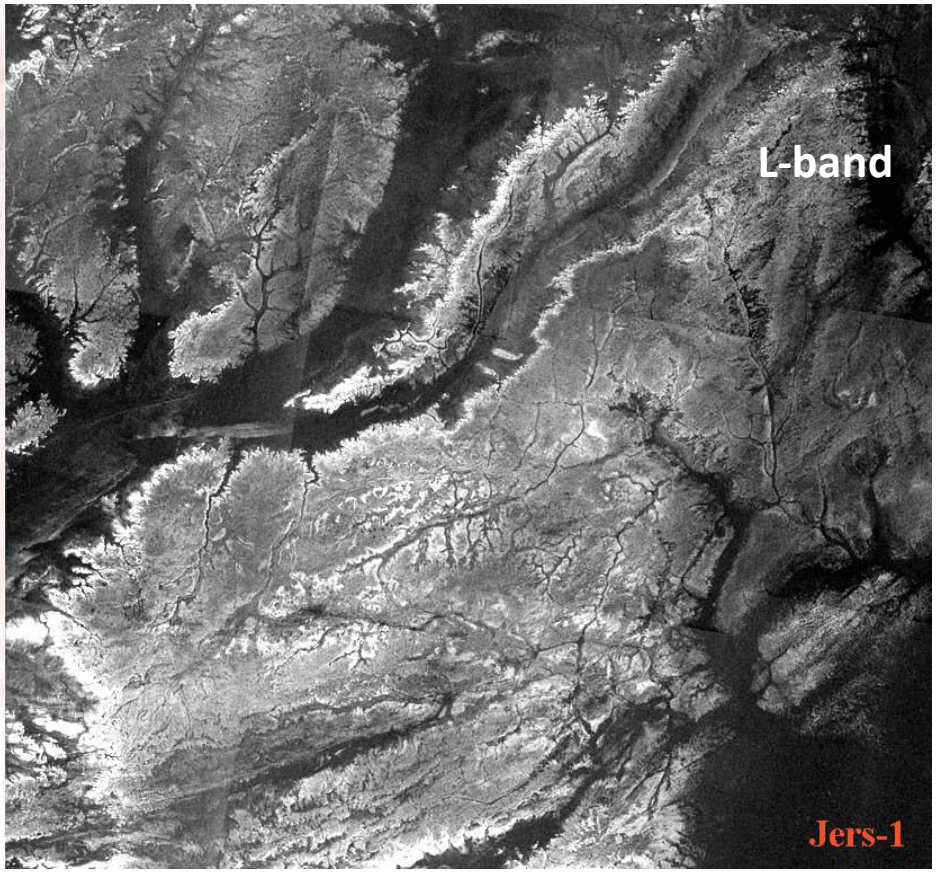


SAR image

Document S.Saatchi, JPL

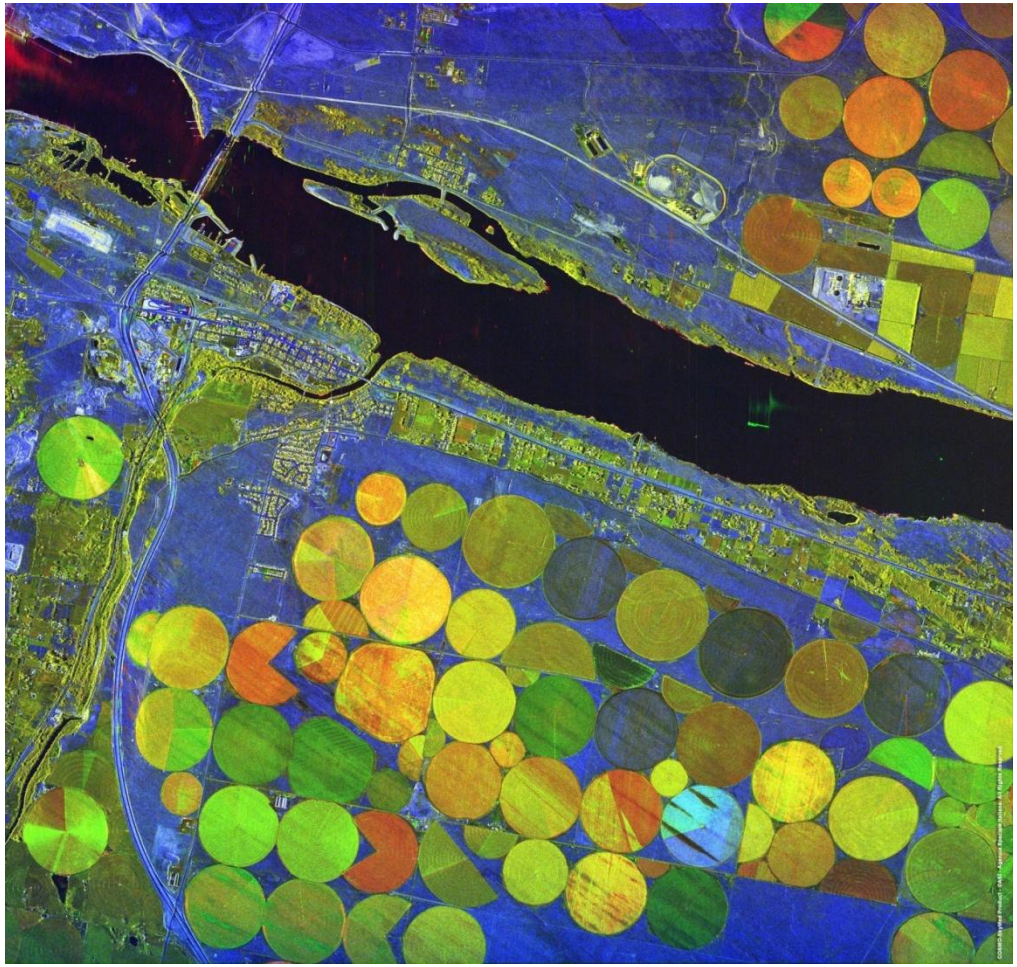
Subsurface penetration





Document P. Paillou

Interferometric –multi dates observations



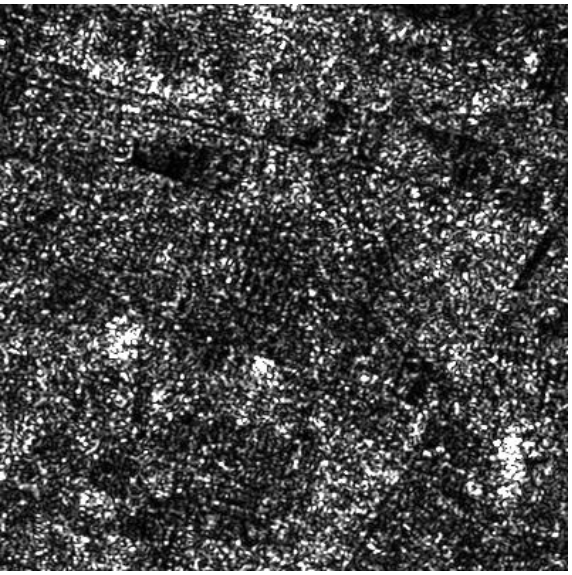
Pivot cultivation, Umatilla along theColumbia river, Oregon , US
COSMO-SkyMed © ASI/Italian MoD
Red: Amplitude 23/08/2008
Green: Amplitude 2/10/2008
Blue: Coherence

Agricultural activities are limited to the areas irrigated with “pivot” system. Different colours between red and green indicate the different timing in plant growth. The surrounding terrain remains very stable (bluish colour due to a high value of coherence)

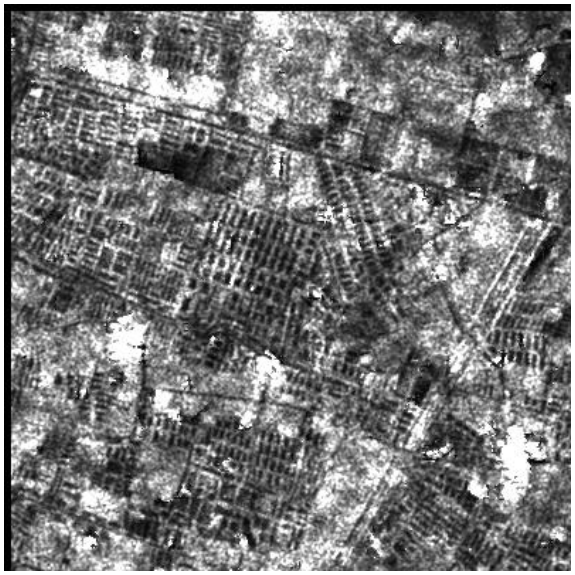
Physics of SAR data

What is a SAR image?

ASAR VV image



After speckle filtering



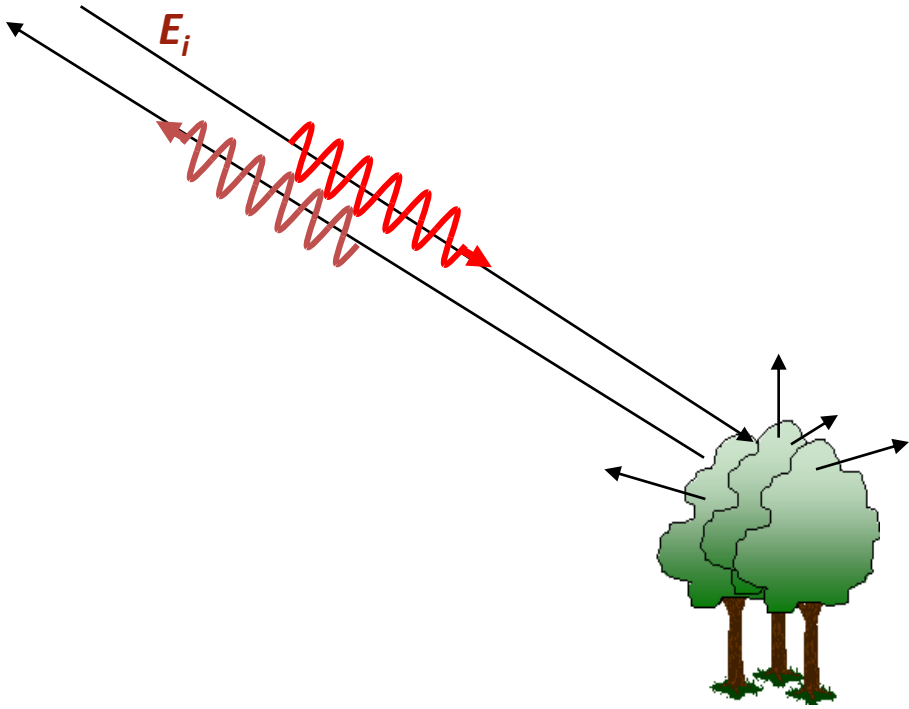
Combining filtered HH and VV images

- The image represents **physical processes**.
- Pixels are **measurements**.
- Image is interpretable based on understanding of the physical processes

The radar scattering

Backscattered electric field E_s

Incident electric field E_i



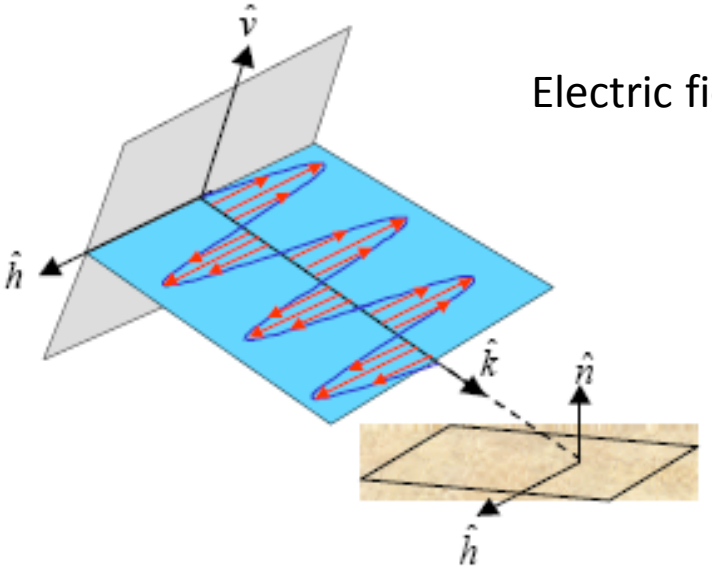
the amplitude, phase and polarisation of E_s are modified with respect to E_i

$$E_s = \frac{e^{ikr}}{r} S E_i$$

$$\begin{bmatrix} E_{sv} \\ E_{sh} \end{bmatrix} = \frac{e^{ikr}}{r} \begin{bmatrix} S_{vv} & S_{vh} \\ S_{hv} & S_{hh} \end{bmatrix} \begin{bmatrix} E_{iv} \\ E_{ih} \end{bmatrix}$$

$$S_{ij} = \left| S_{ij} \right| e^{i\phi_{ij}}$$

The scattering matrix contains information on the nature and characteristics of the observed media

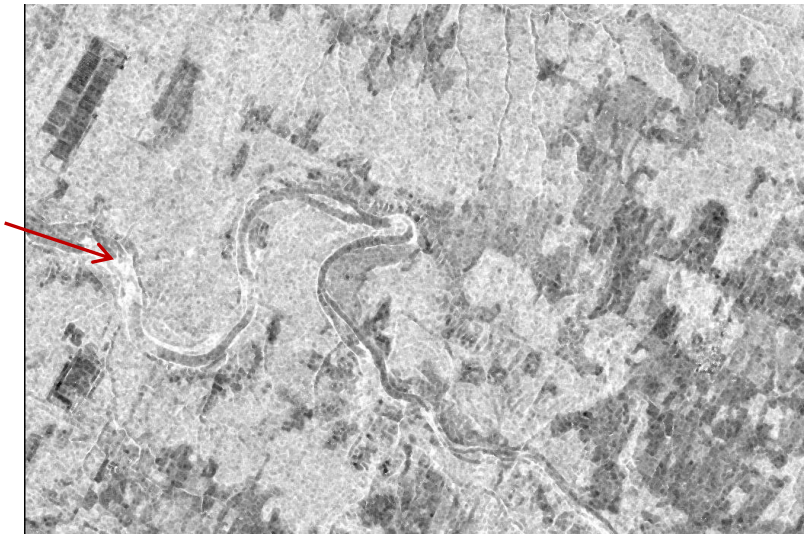


Horizontal polarisation

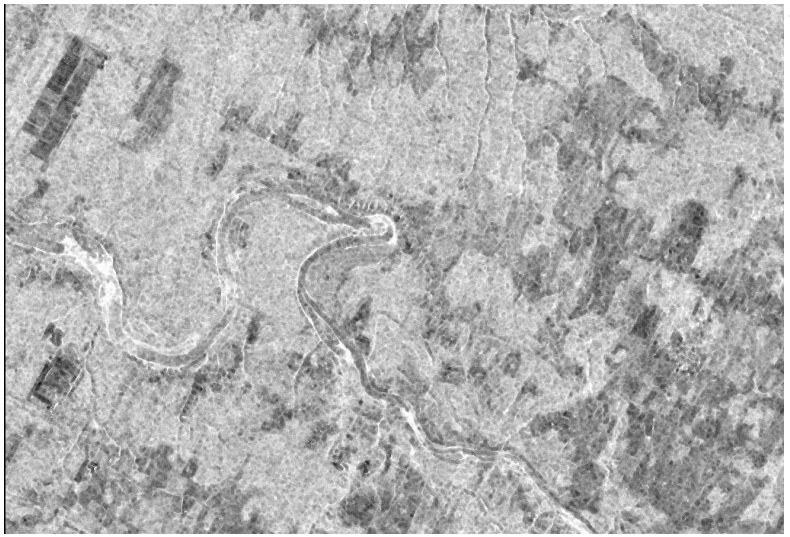
Vertical polarisation

HH

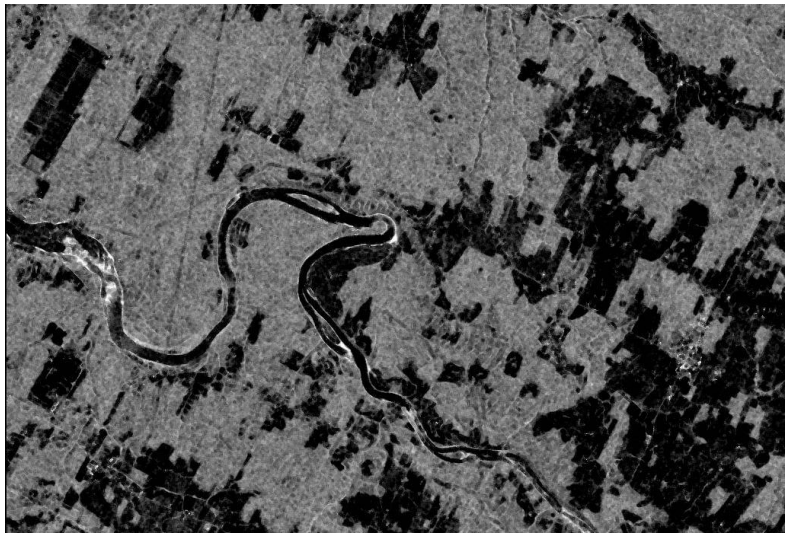
ice



VV



HV

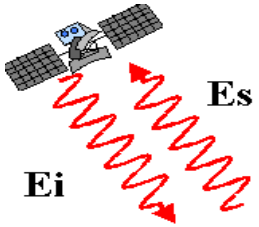


HH

VV

HV

Province of Quebec, Canada. RADARSAT2, 14 March 2009 (S. Mermoz)



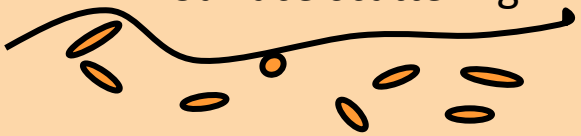
Scattering mechanisms

water

Surface scattering

soil, rock

Surface scattering



Volume scattering if penetration

vegetation

Volume scattering

Volume-surface scattering

Surface scattering

snow

Volume scattering

Surface scattering

Scattering mechanisms

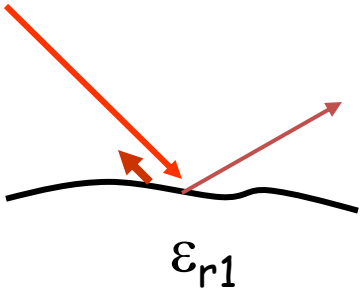
- The backscattered signal results from:
  - surface scattering
  - volume scattering
  - multiple volume-surface scattering

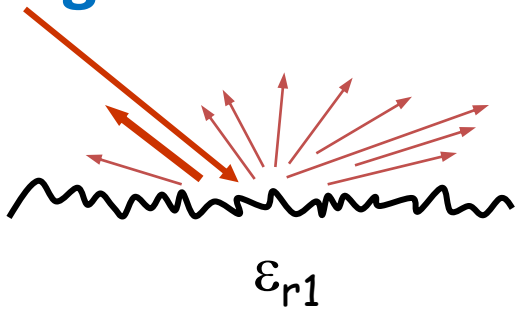
- The relative importance of these contributions depend on
  - surface roughness
  - dielectric properties of the medium

- All of these factors depend on
  - the radar frequency
  - the polarisation
  - the incidence angle

Surface scattering

Smooth surface



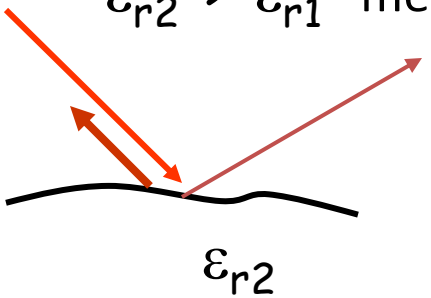


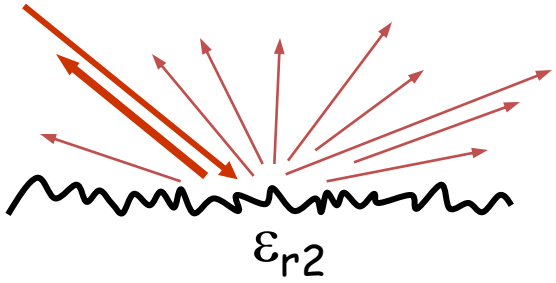
Rough surface

The roughness of the surface (wrt to the wavelength) governs the scattering pattern

$\varepsilon_{r2} > \varepsilon_{r1}$ medium 2 is wetter than medium 1

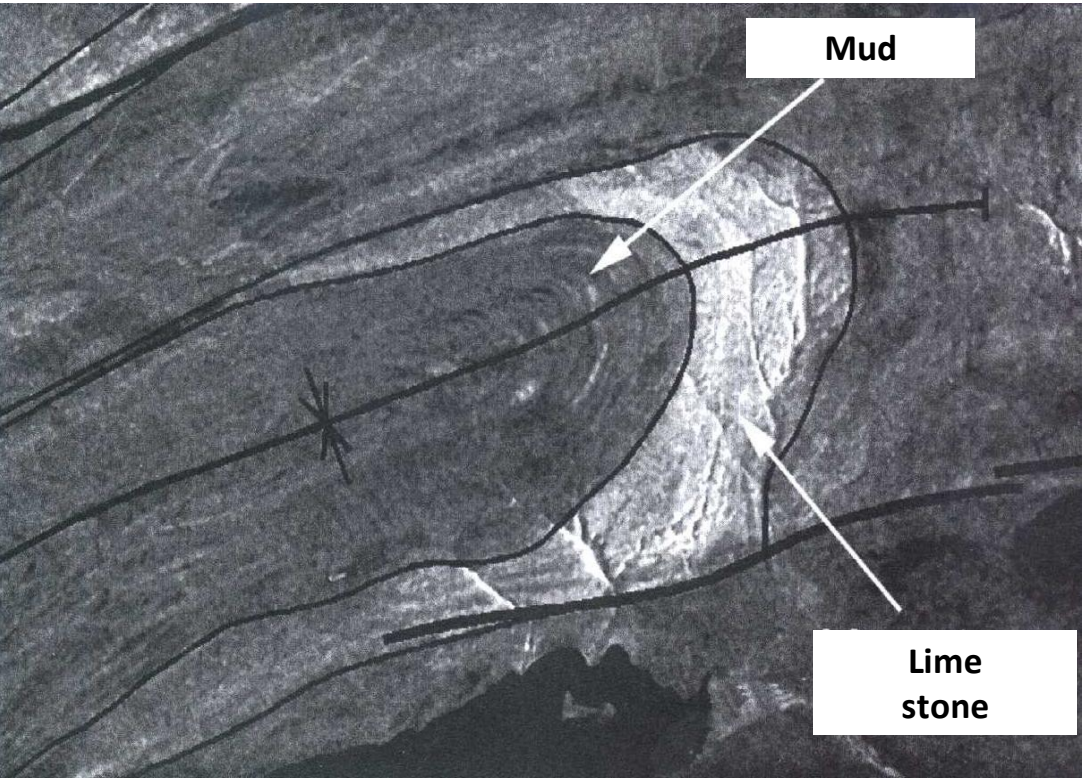
Wetter media





The dielectric constant (moisture content) of the medium governs the strength of the backscatter

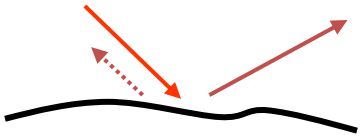
Surface scattering: effect of surface roughness



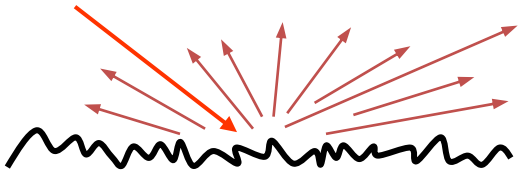
RADARSAT
(C band, HH, 45°)

Quaternary lithology:
Bathurst Island, Canada

From : RADARSAT Geology Handbook

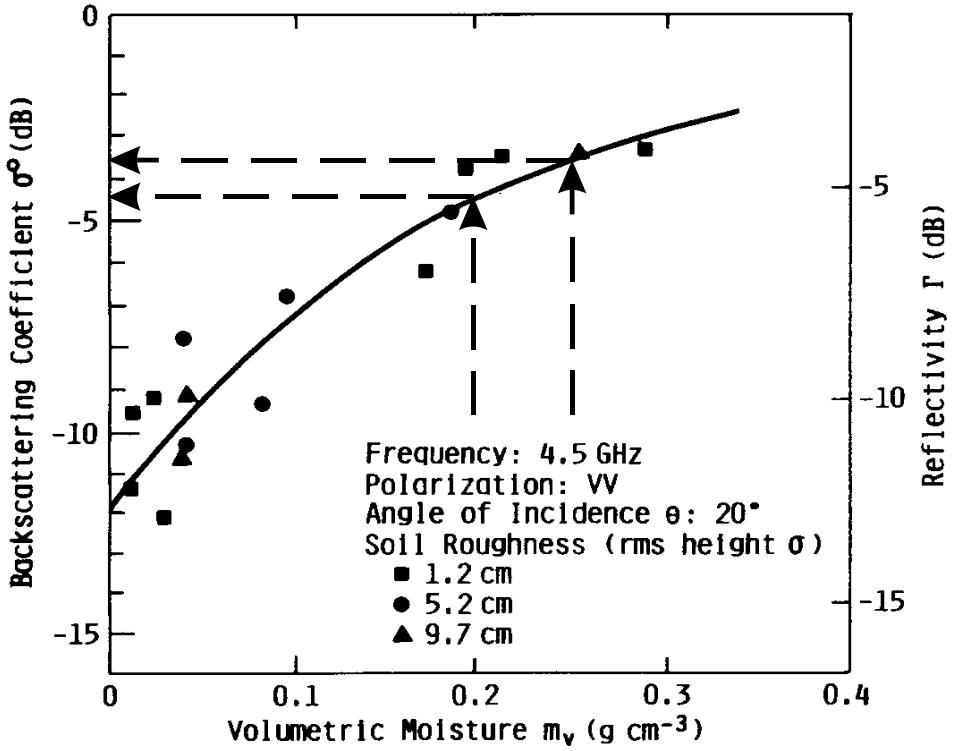


Mud fragments (smooth surface)
➡ **low** radar backscatter



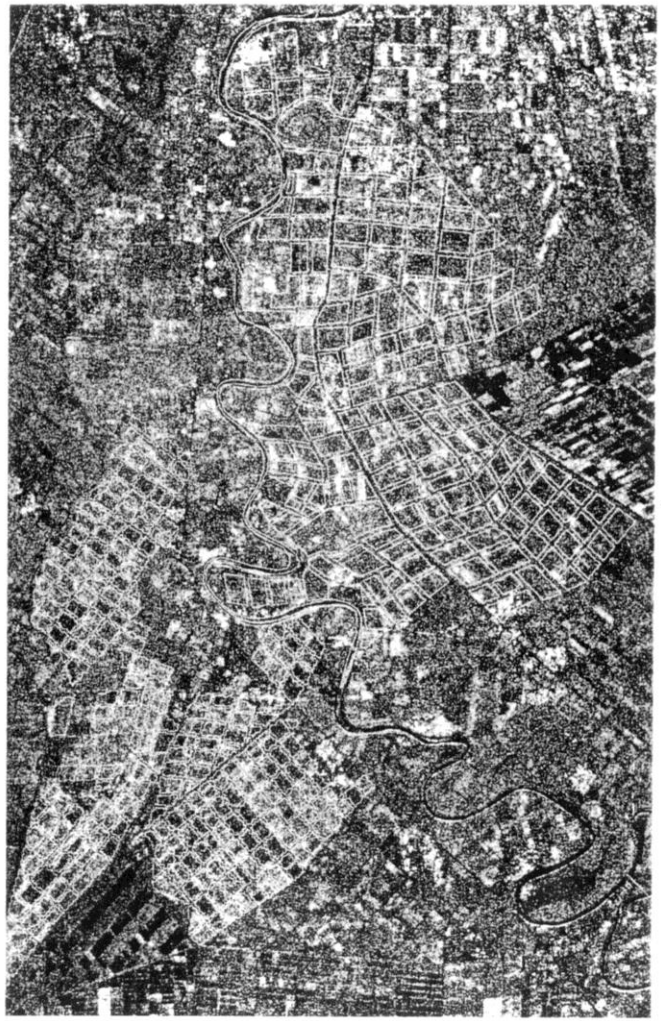
Limestone ➡ **Higher backscatter**
because of rougher surface

Surface scattering: effect of soil moisture



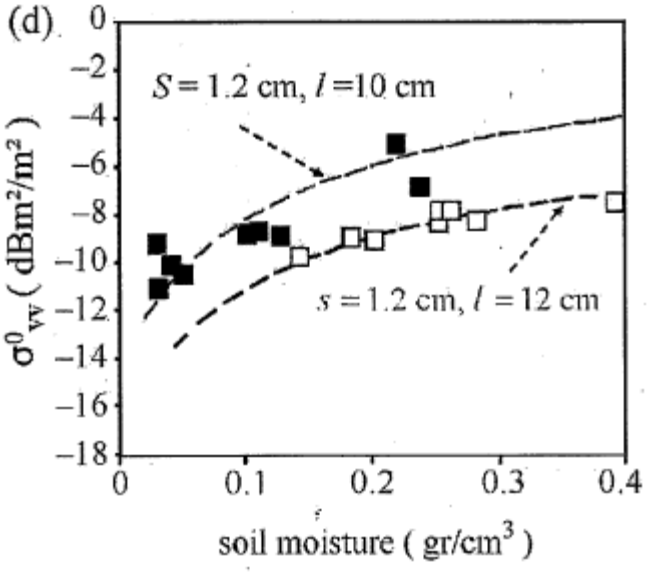
Experimental results using a ground based scatterometer

(adapted from Le Toan, T. , 1982)



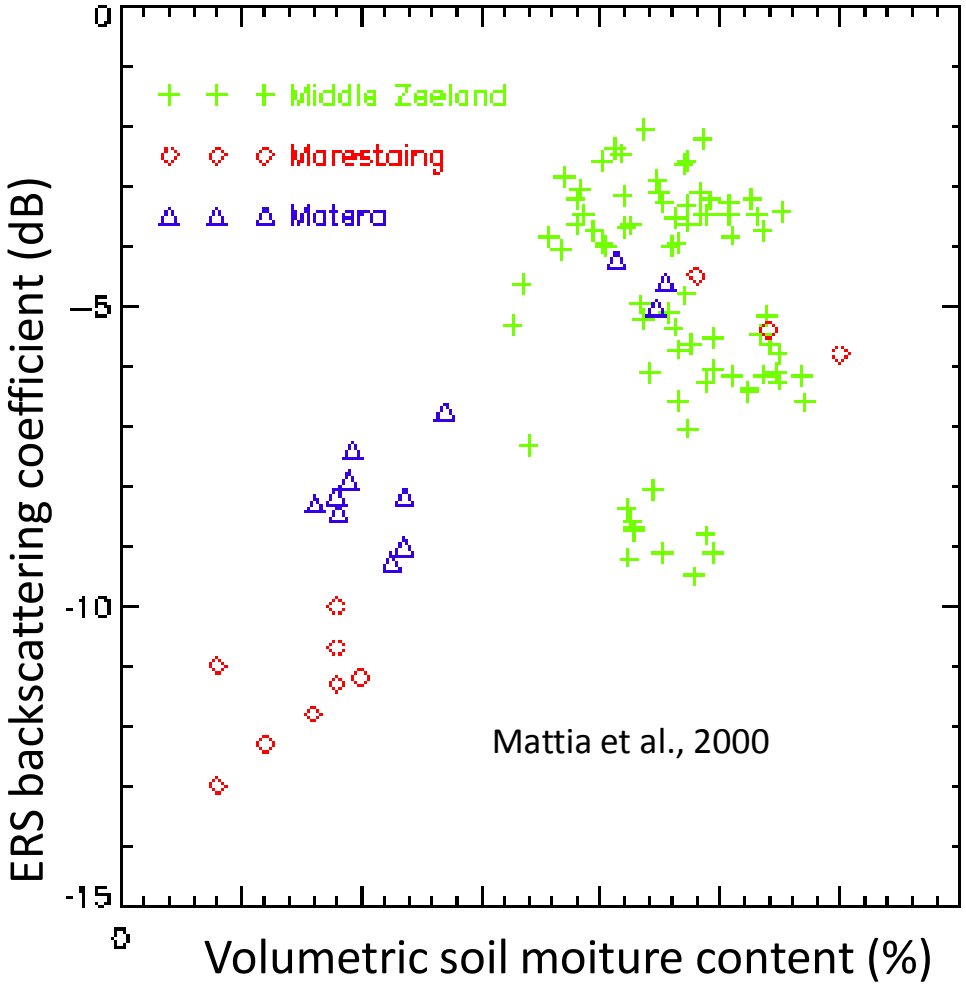
Our first experiment in 1992 on irrigated area in Gharb, Morocco

We mapped irrigated fields, but to retrieve soil moisture was found hard with a single ERS data!



Le Toan, T, J.C. Souyris and P. Macchia, 1993

Surface scattering: Effect of roughness and moiture



The relationship between radar backscatter at C band 23° VV and soil moisture is modulated by surface roughness

2438 IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 40, NO. 11, NOVEMBER 2002

2002

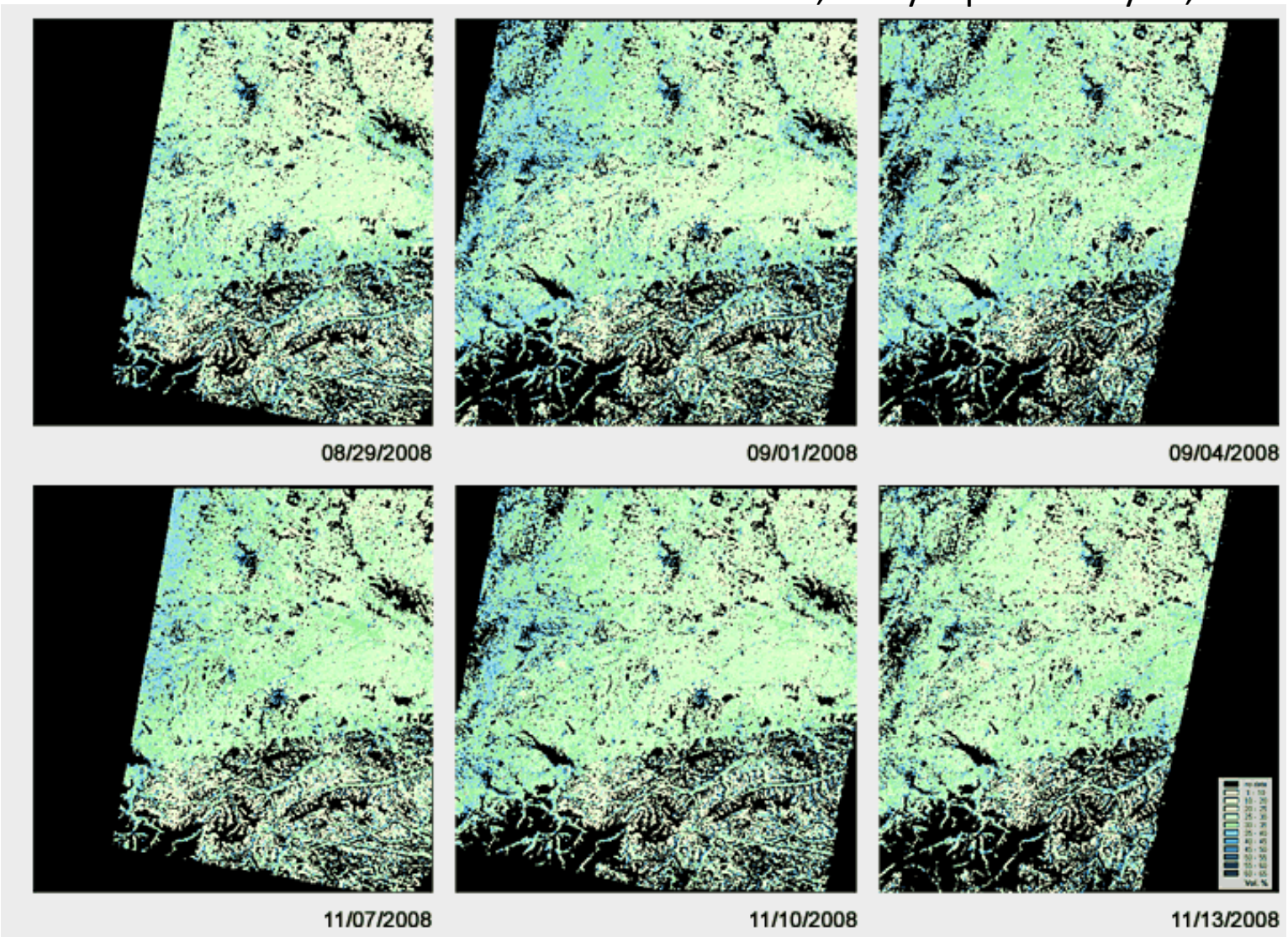
On Current Limits of Soil Moisture Retrieval From ERS-SAR Data

Giuseppe Satalino, Francesco Mattia, *Member, IEEE*, Malcolm W. J. Davidson, Thuy Le Toan, Guido Pasquariello, and Maurice Borgeaud, *Senior Member, IEEE*

…no more than 2 moisture classes can reliably retrieved from ERS.
Multiparameter ASAR is expected to improve the limits…

But over all, for soil moisture, high acquisition cycle is the most important requirement

This was later shown with ASAR Wide Swath, 3 day repetition cycle, at 1 km



: Temporal dynamic of the soil moisture, monitored by ENVISAT ASAR Wide-Swath-Mode. Catchments (here: Upper Danube
monitored in near-real-time, independent from clouds in an up to 3-day repetition cycle and a spatial resolution of 1 km.

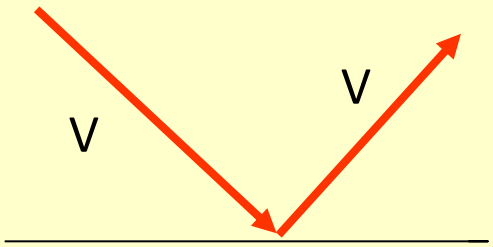
Soil moisture map 2008

From Heike Bach VISTA GmBH

This paved the way for Sentinel 1

Surface scattering: effect of polarisation

Smooth surface

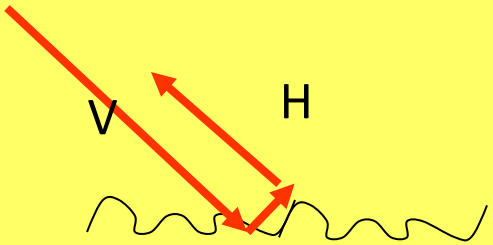


- no depolarisation

no HV or VH backscatter

- Fresnel Reflectivity $R_H > R_V$

Rough surface

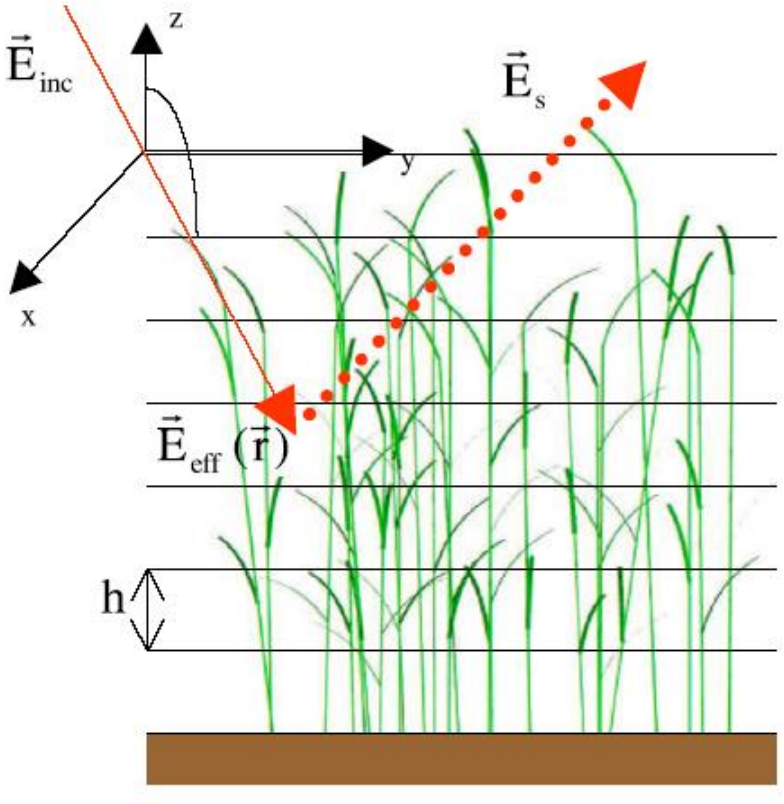


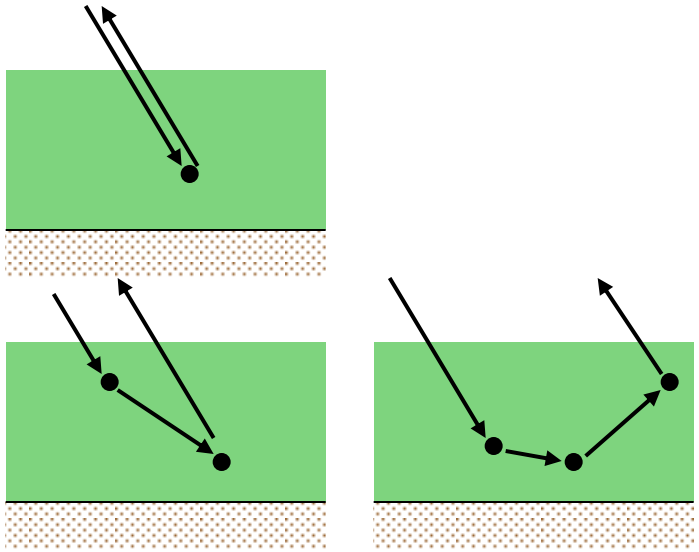
- some depolarisation

HV or VH backscatter > 0

- Fresnel Reflectivity $R_H = R_V$

Volume scattering

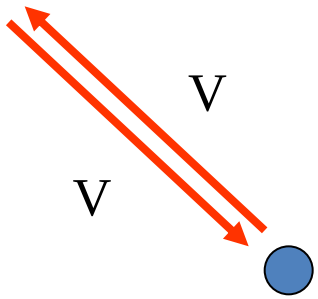




Single and multiple scattering

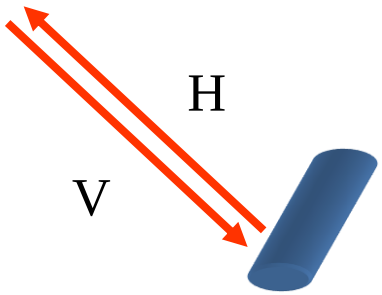
Polarisation in volume scattering

Point scatterer



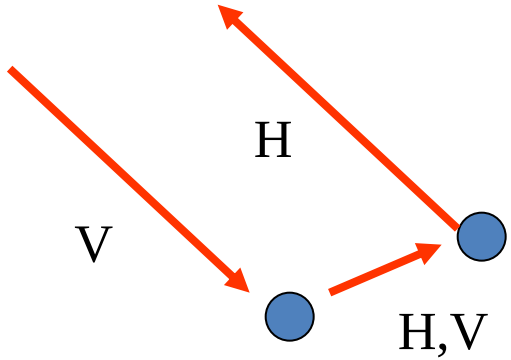
-> no depolarisation

Anisotropic scatterer



-> depolarisation

Multiple scattering



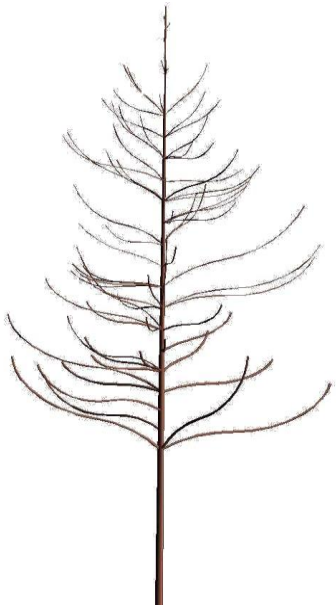
-> depolarisation

What are the scatterers in the volume scattering?

Austrian pine

X band
λ= 3 cm

L band
λ= 27 cm



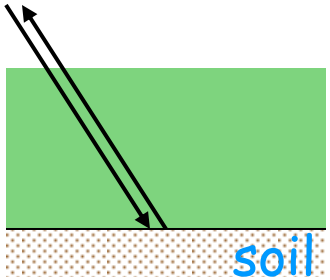
P band
λ= 70 cm

VHF
λ > 3 m

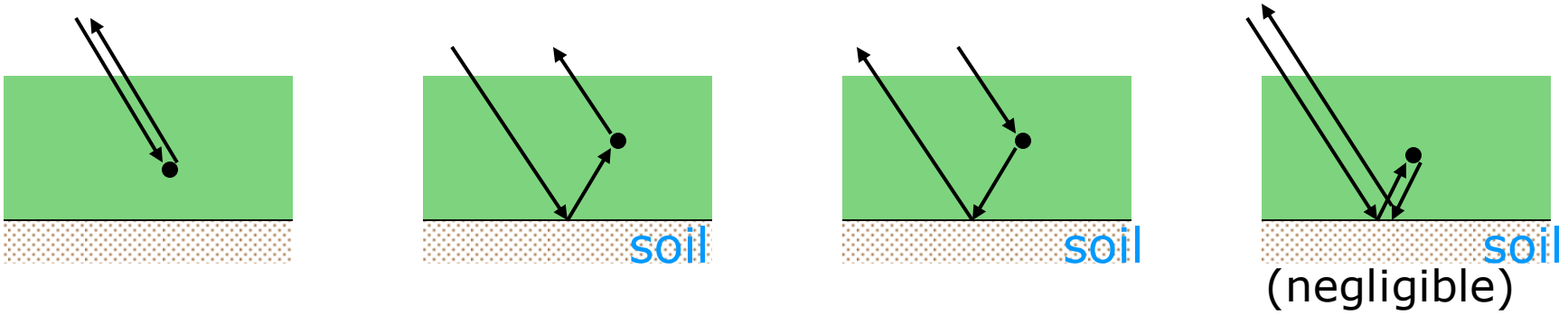
The main scatterers in a canopy are the elements having dimension of the order of the wavelength

Scattering from vegetation

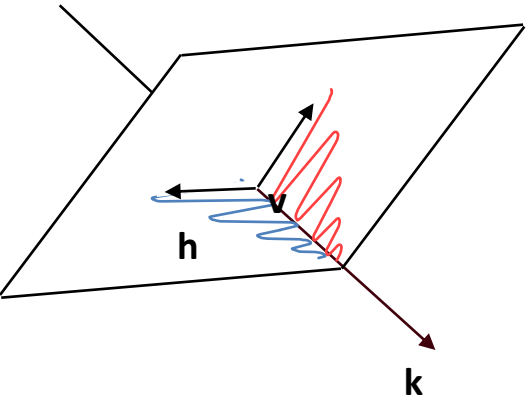
* Order 0



* Order 1: simple scattering

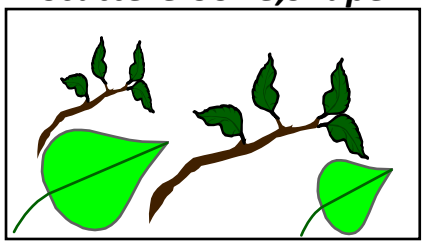


$$\sigma^0 = \sigma^0_{soil} + \sigma^0_{veg.} + \sigma^0_{soil-veg.}$$

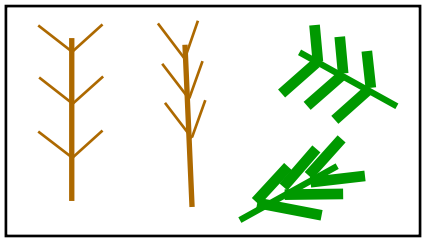


Geometric, structural properties

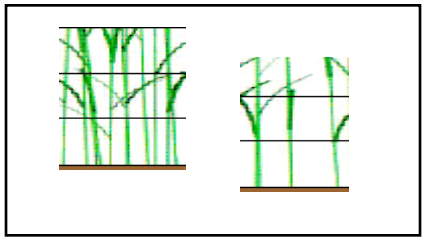
scatterers size,shape



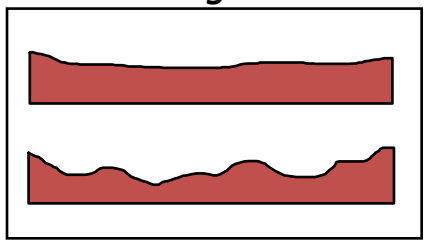
scatterers orientation



scatterers density

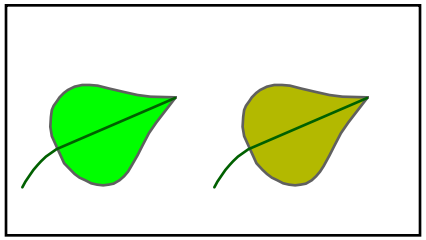


soil roughness

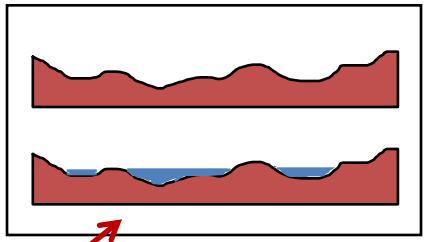


Dielectric properties

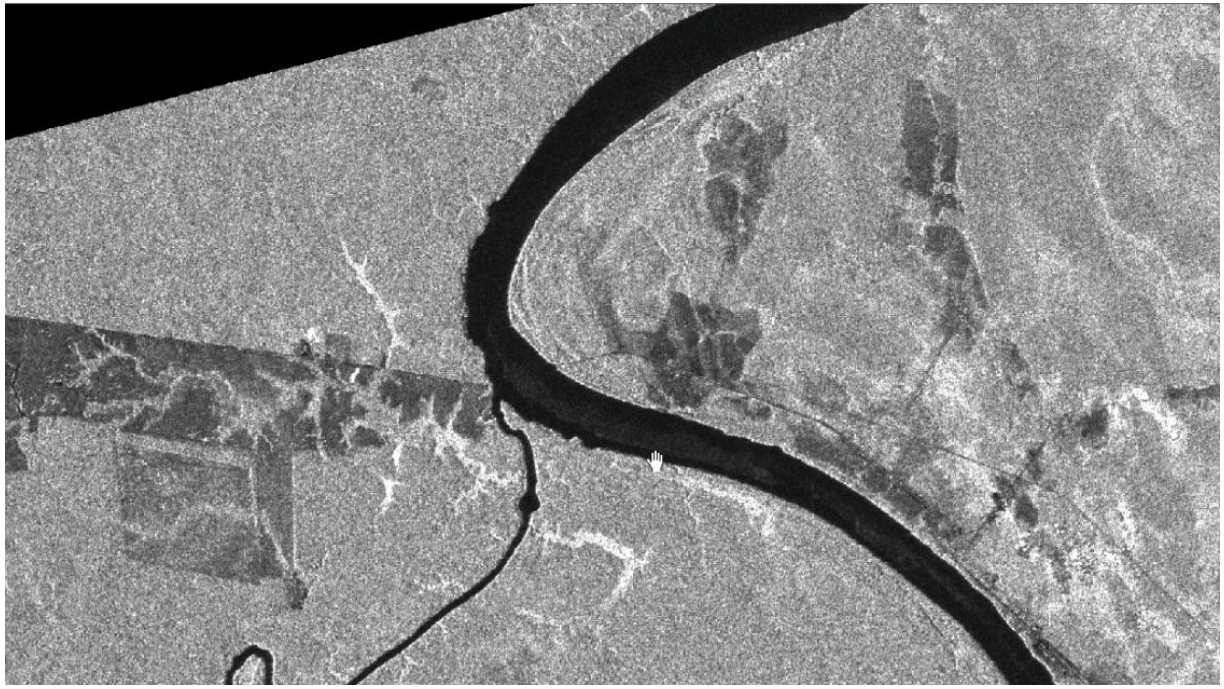
scatterers water content



soil moisture

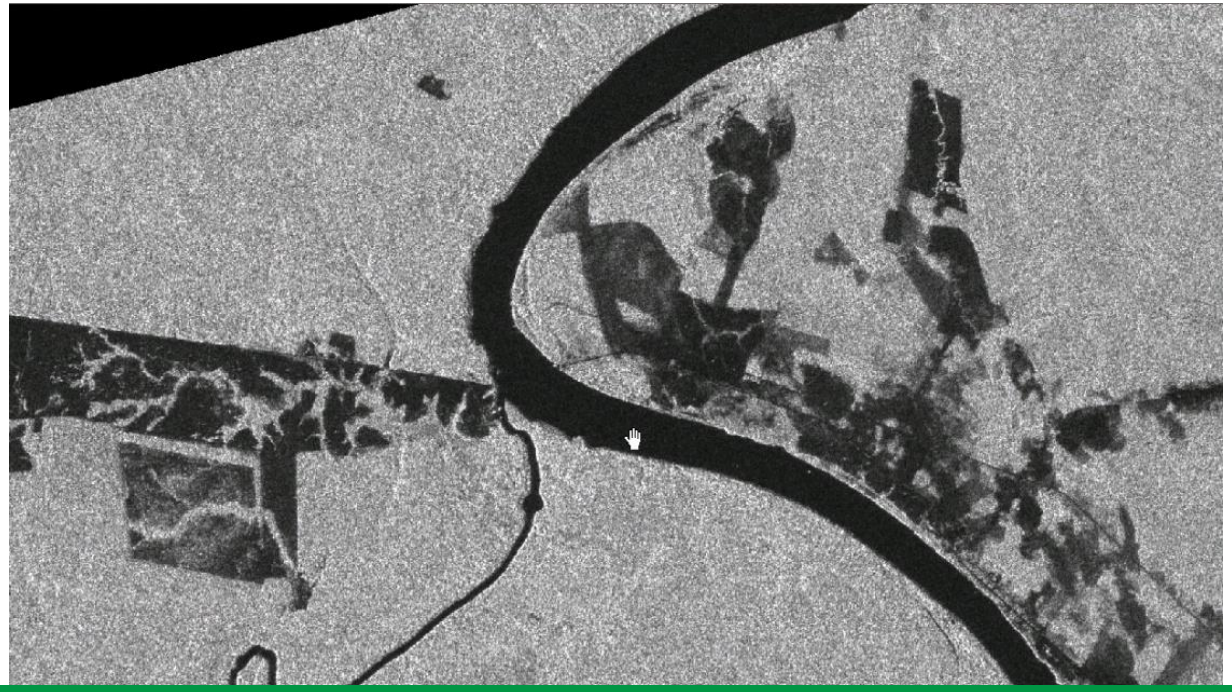


Surface scattering



HH

ALOS PALSAR
Amazon forest

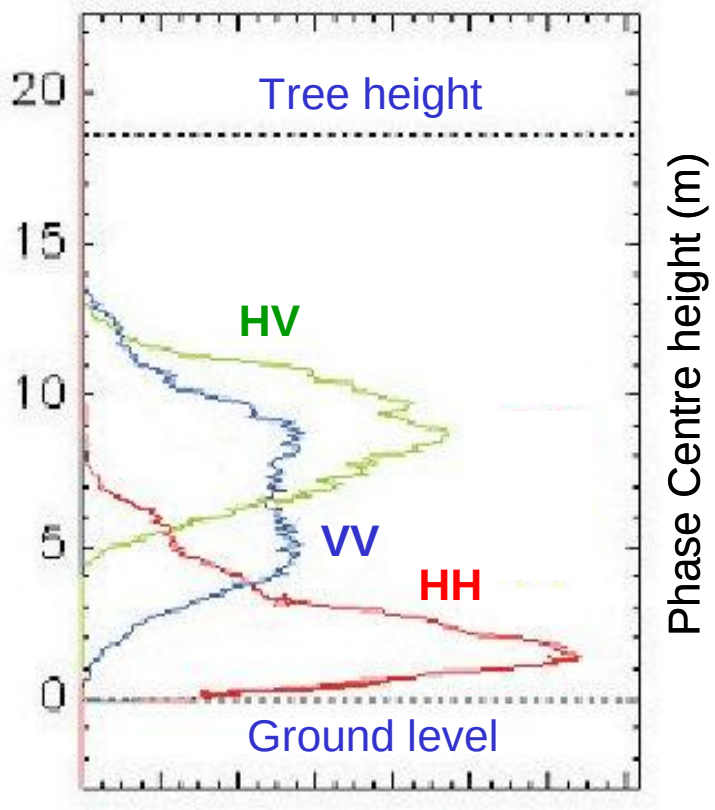


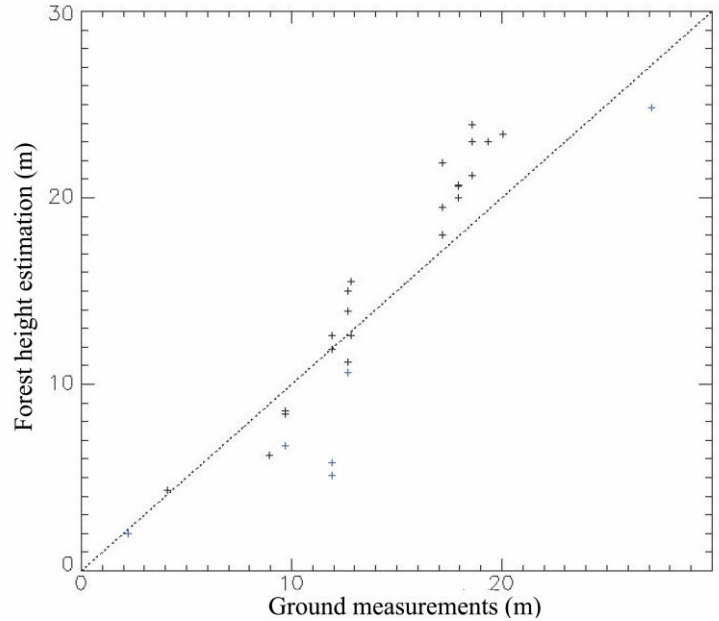
HV

J.M. Martinez, IRD

Polarimetric Interferometry (PolinSAR)

Tree height inversion

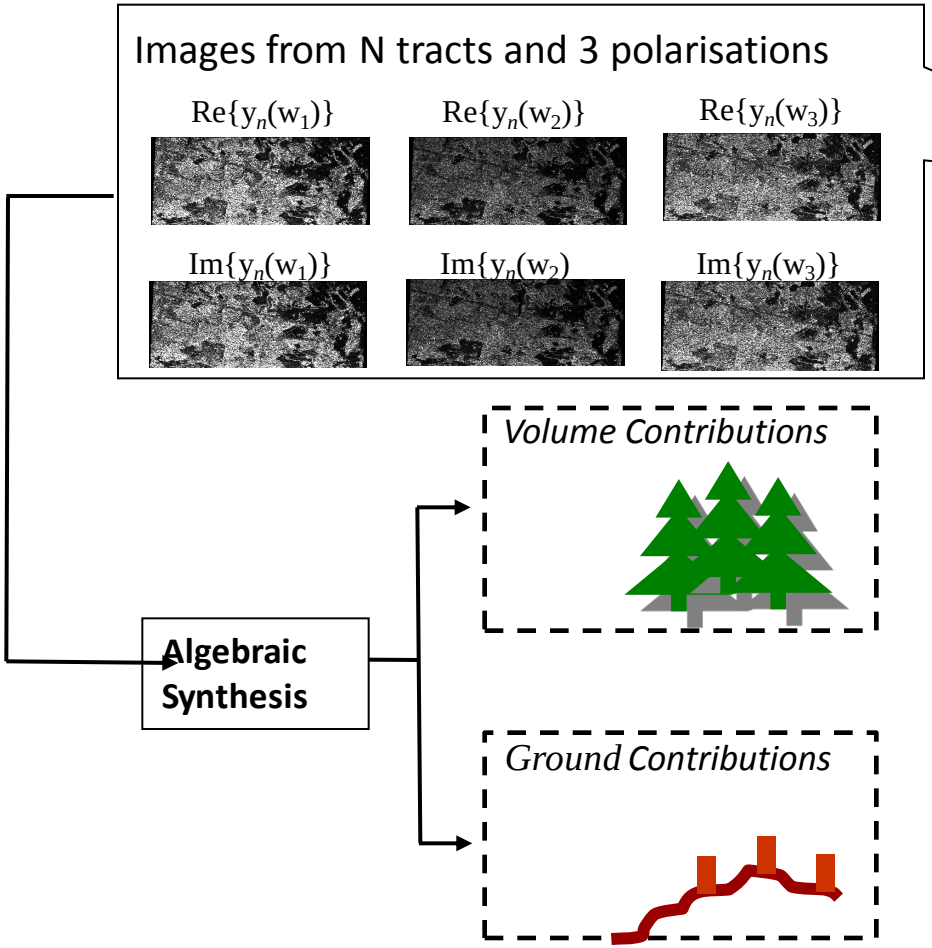


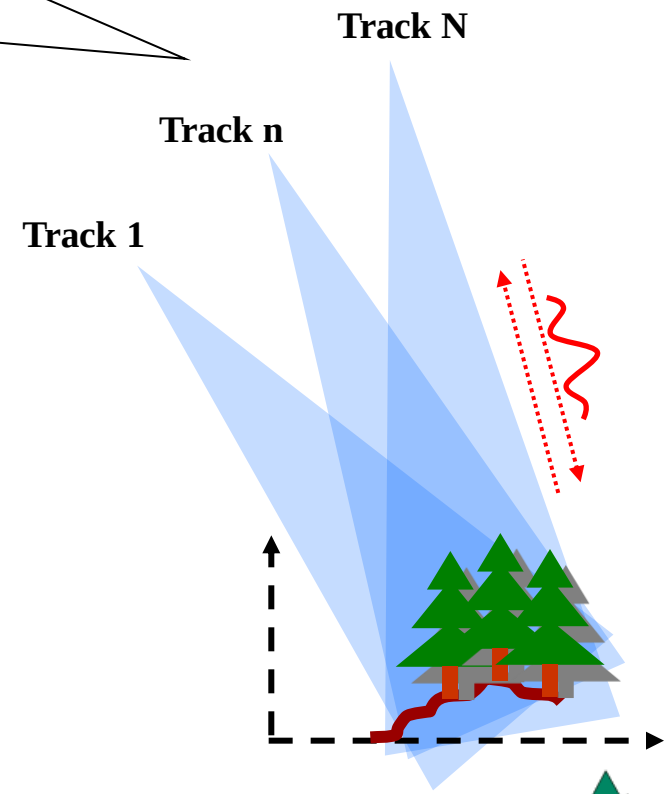


Garestier, 2006

SAR tomography

Decomposition of Ground and Volume scattering

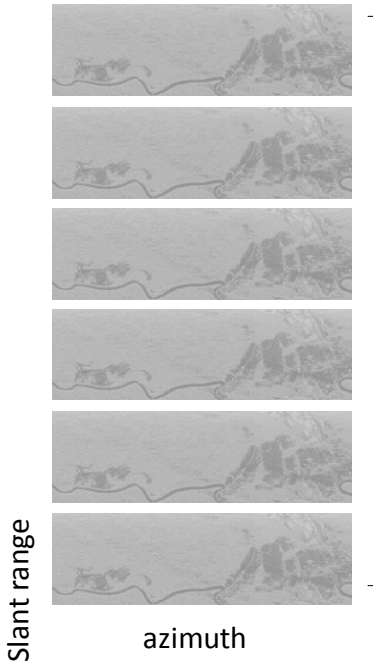




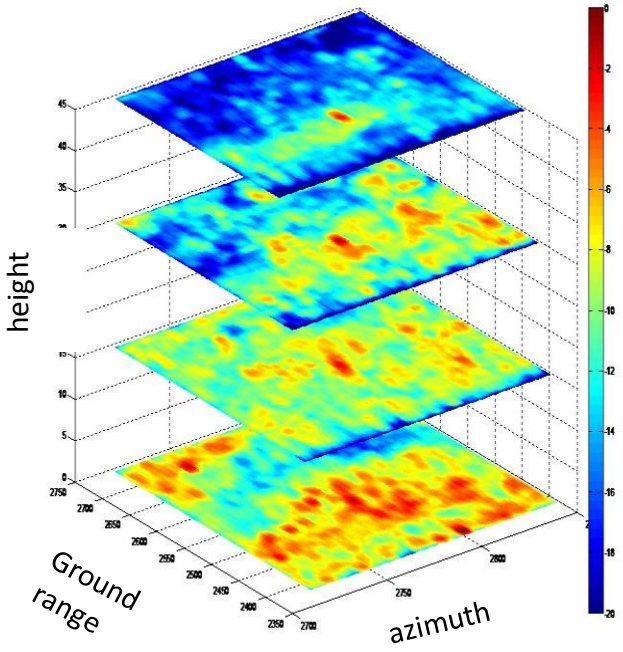
Tebaldini, 2010

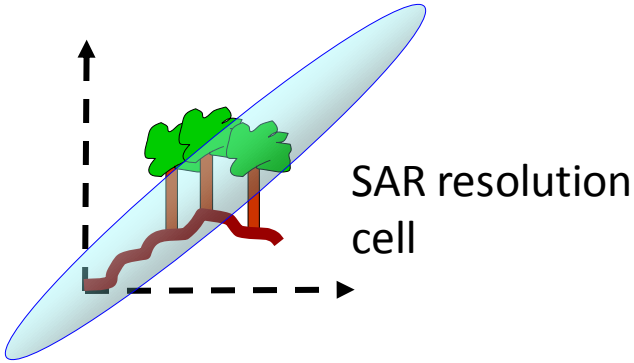
Tomographic processing of TropiSAR

Goal: generation of a stack of *multi-layer SLC* SAR images out of a stack of *multi-baseline SLC* SAR images

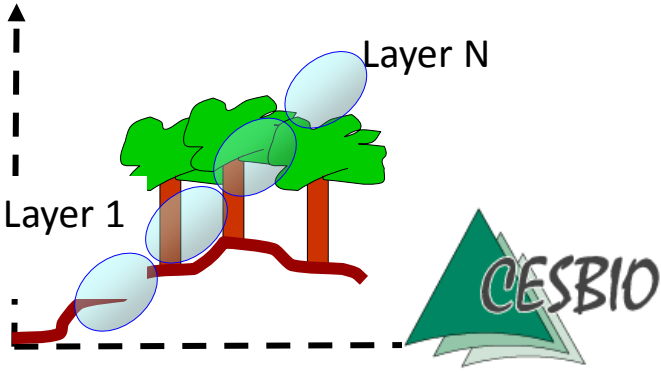


Tomographic Processor



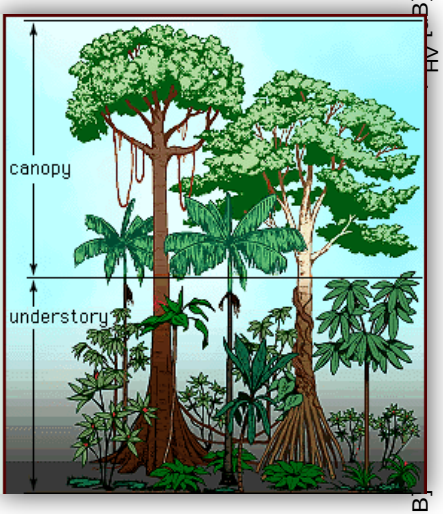


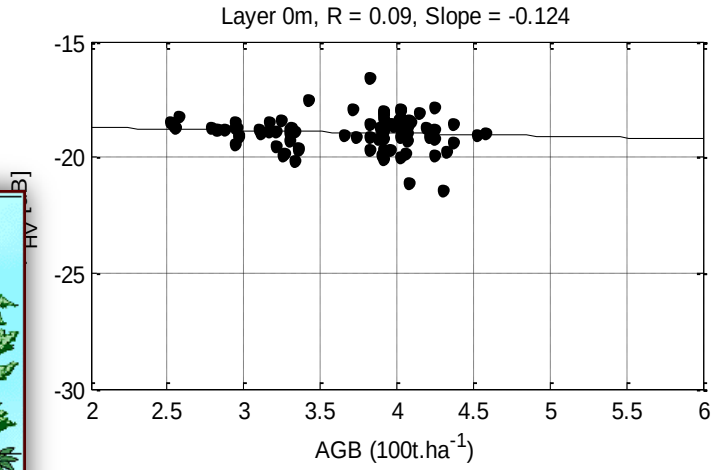
SAR Tomography resolution cell

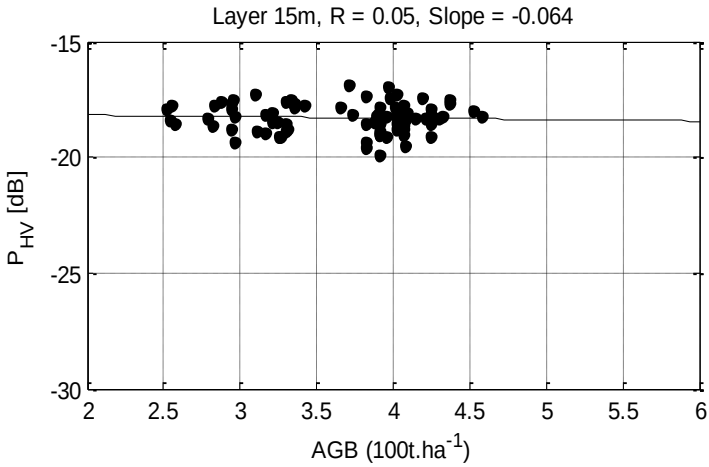


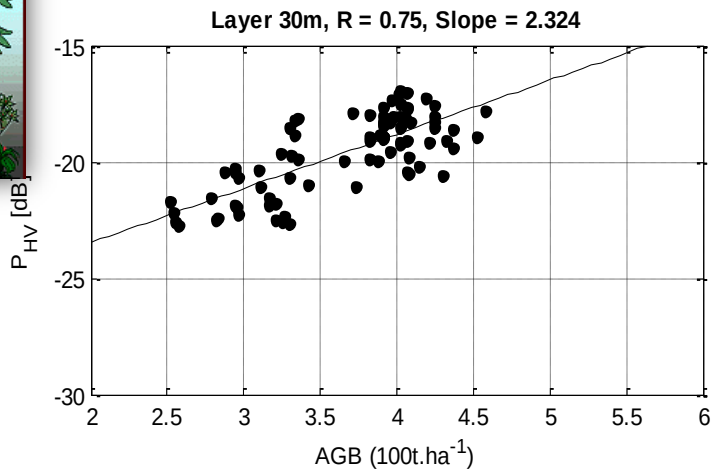
PoliMi, 2010

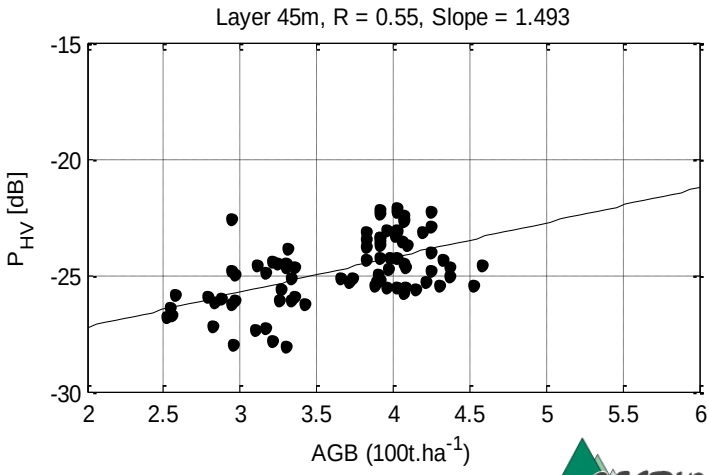
Relationship between power from different layers and biomass







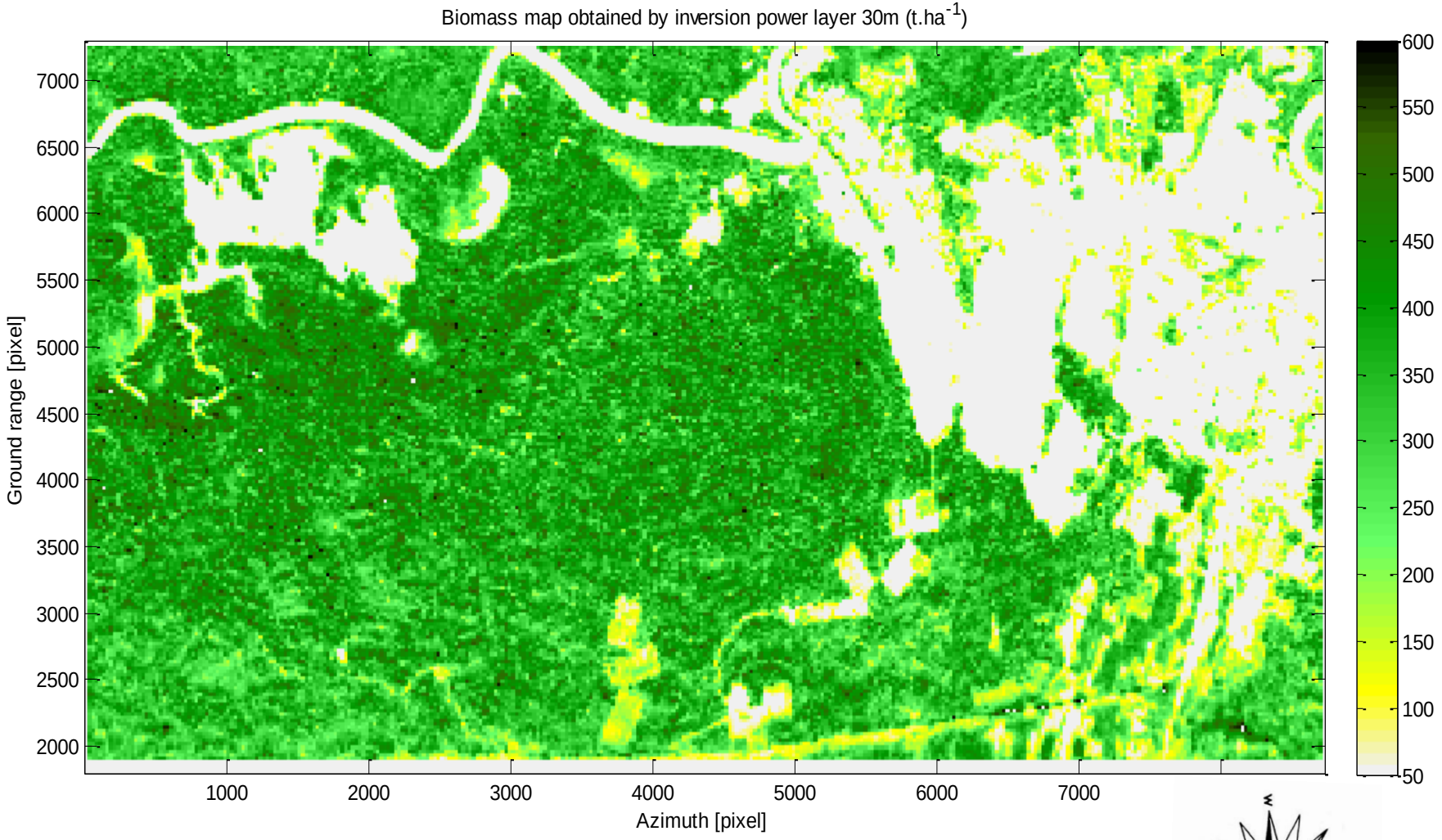




Polarization = HV, Spatial resolution = 125 m

PoliMi-CESBIO: Ho Tong Minh Dinh et al., 2011

Biomass mapping using P-band SAR tomography



PoliMi –CESBIO, 2011