Soil moisture retrieval over periodic surfaces using PolSAR data

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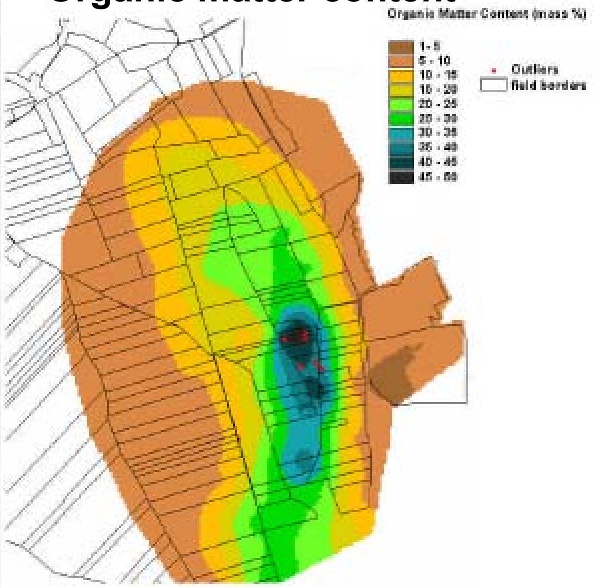
Contents

- Soil moisture retrieval over plowed fields: classical methods
- Time-Frequency analysis
- Polarimetric analysis
- Rough periodic surface scattering model
- Soil moisture retrieval

Test site

Organic matter content



RGB

Ikonos image

L band Quad pol data set

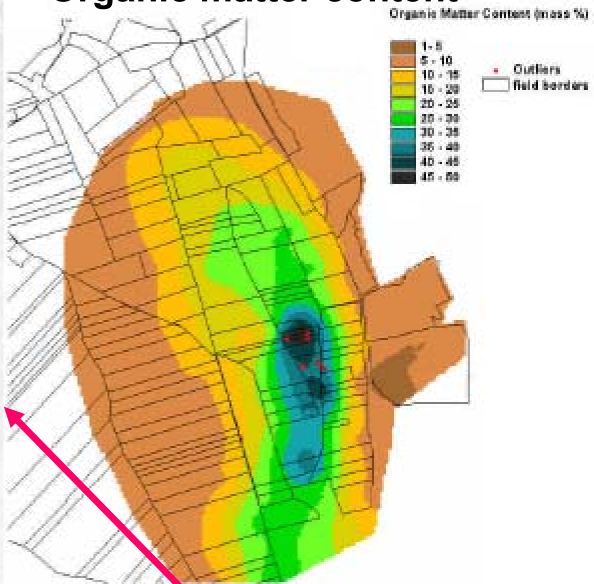
DLR E-SAR sensor

March 2000, Alling, Germany

Herold M. et al., "Acquisition and evaluation of field measurements from the Alling-SAR 2000 campaigns", 2001.

Test site

Organic matter content



RGB

Ikonos image

Slightly wet area

- Mainly rough and flat fields
- Some are plowed

Herold M. et al., "Acquisition and evaluation of field measurements from the Alling-SAR 2000 campaigns", 2001.

Classical retrieval methods

Objective

- Estimate soil moisture over all unvegetated agricultural fields

⇨ FLAT and PLOWED fields

Classical soil moisture retrieval schemes

- Oh's method → Co and Cross polar ratio analysis

$$p = \frac{\sigma_{HH}}{\sigma_{VV}} \qquad q = \frac{\sigma_{HV}}{\sigma_{VV}}$$

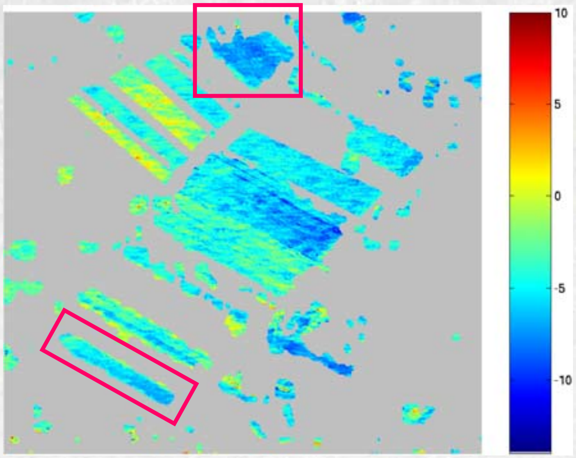
- H/α method → Entropy and α angle analysis

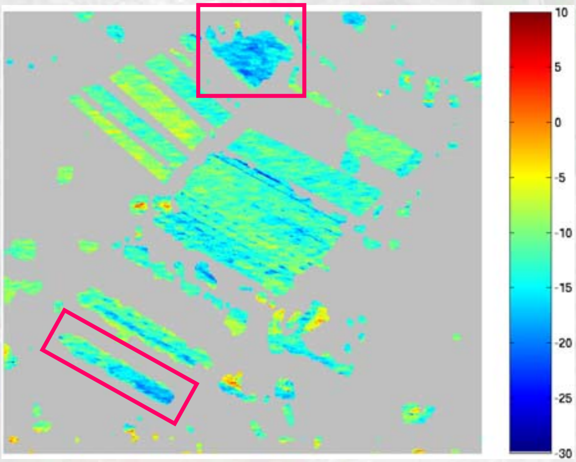
Polarimetric degree of randomness

Nature of scattering mechanisms

Oh's method

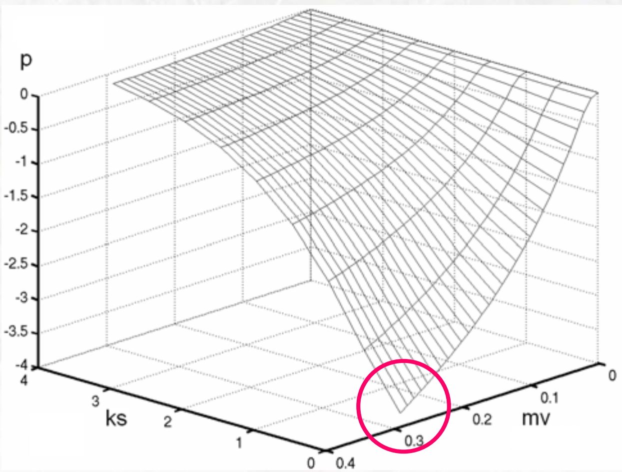
Plowed fields

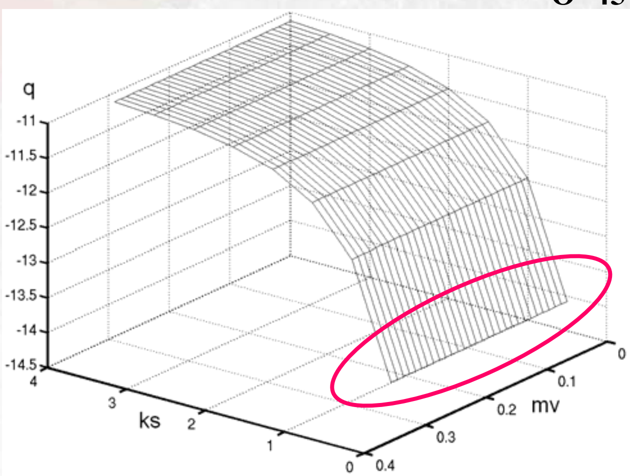




Oh's model co- and cross-polar ratios

Θ=45°





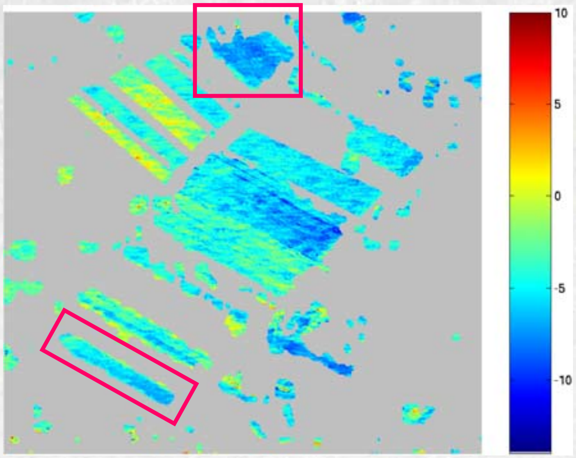
ks: roughness

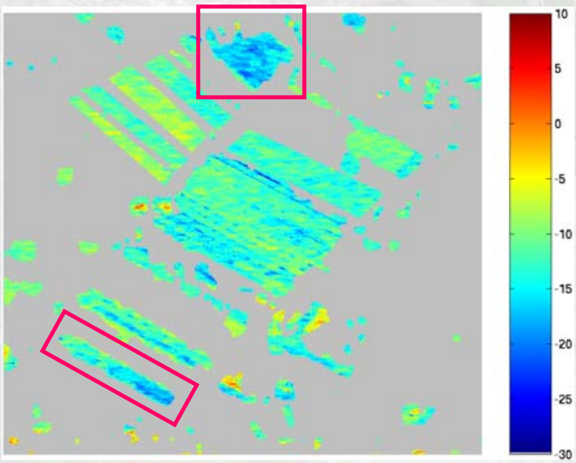
mv: moisture content

Oh Y., "Quantitative Retrieval of Soil moisture Content and Surface Roughness From Multipolarized Radar Observations of Bare Soil Surfaces",2004.

Oh's method

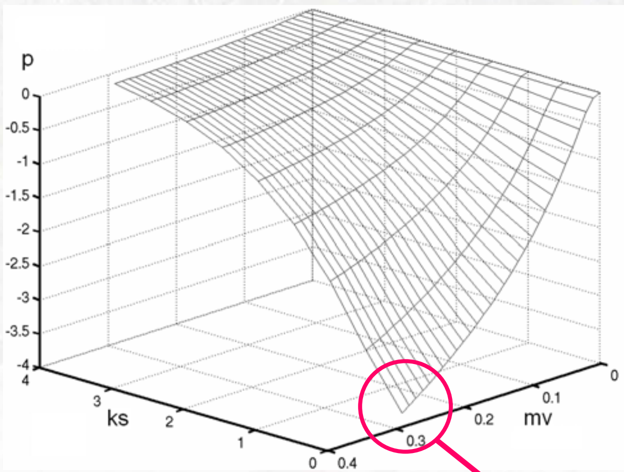
Plowed fields

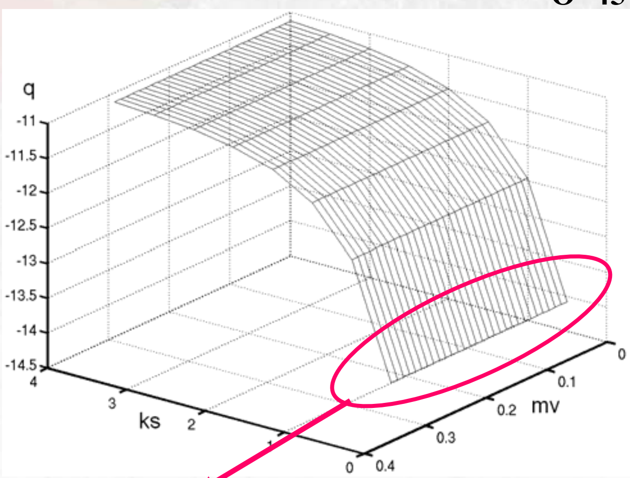




Oh's model co- and cross-polar ratios

$\Theta=45°$

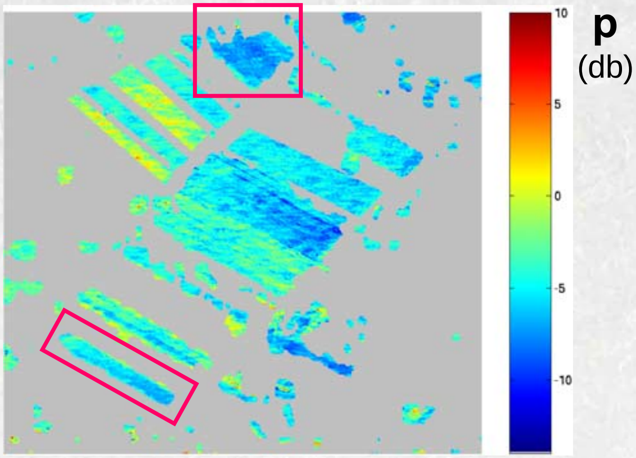


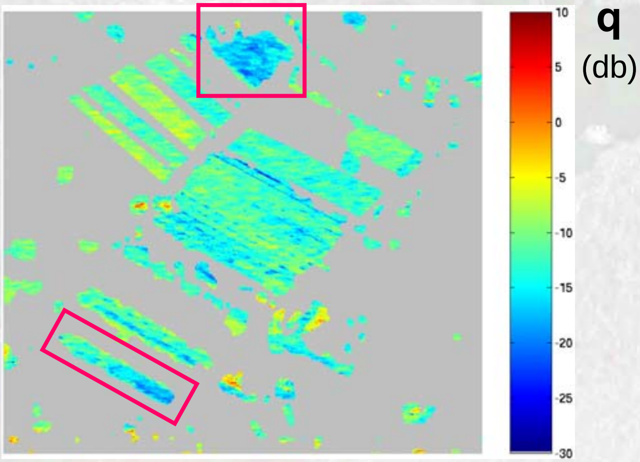


Soil estimation: very smooth and very wet

Oh's method

Plowed fields





Oh's model co- and cross-polar ratios

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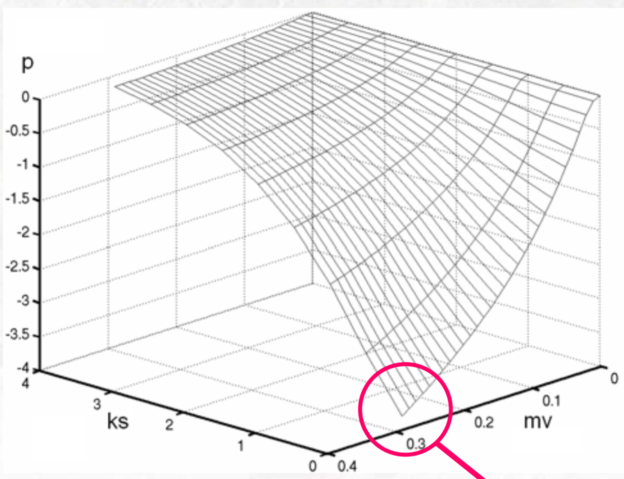
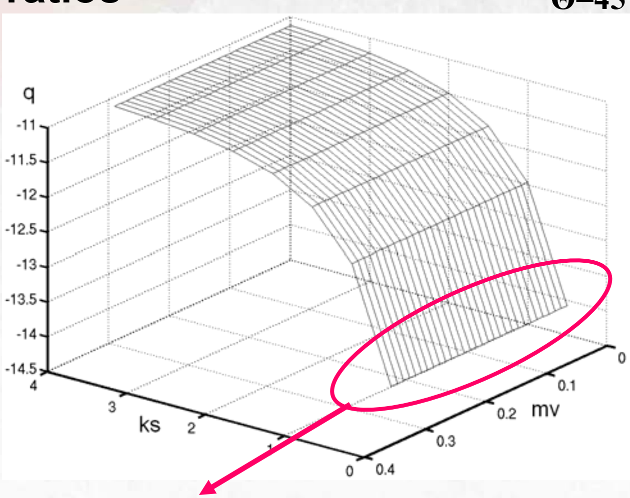


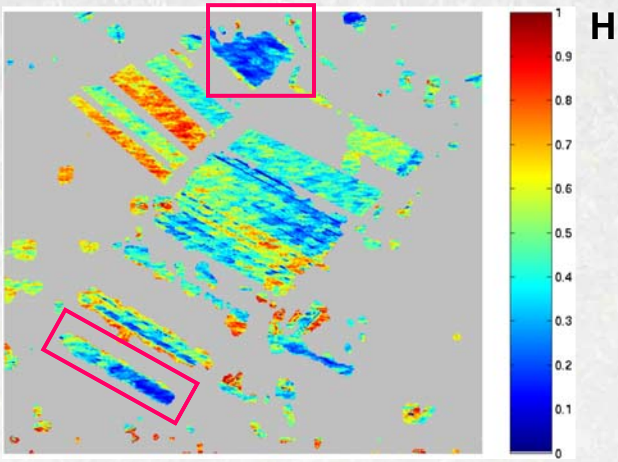


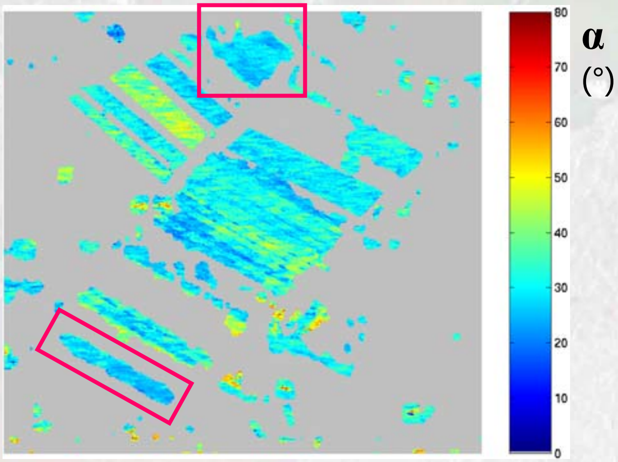
Soil estimation: ~~very smooth and very wet~~

Ground truth: plowed fields and slightly wet

H/α method

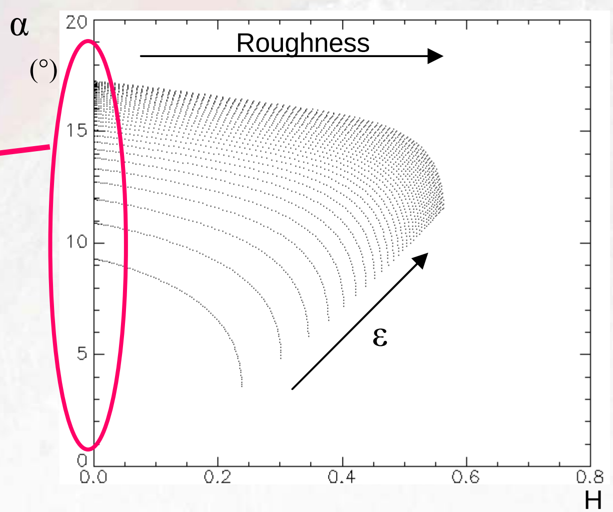
Plowed fields





Θ=45°

Soil estimation: very smooth and very wet

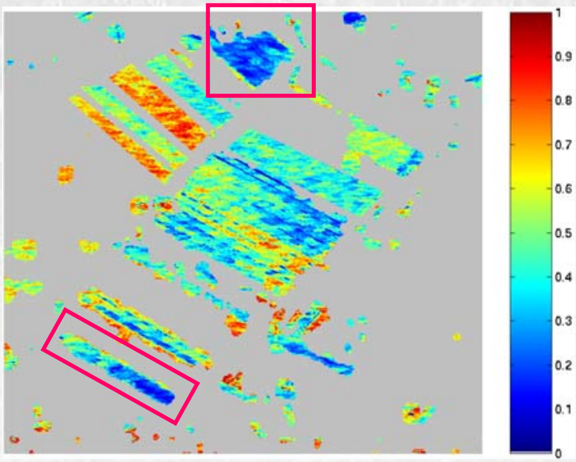


Hajnsek I., Pottier E., Cloude S.R., "Inversion of surface parameters from polarimetric SAR", 2003.

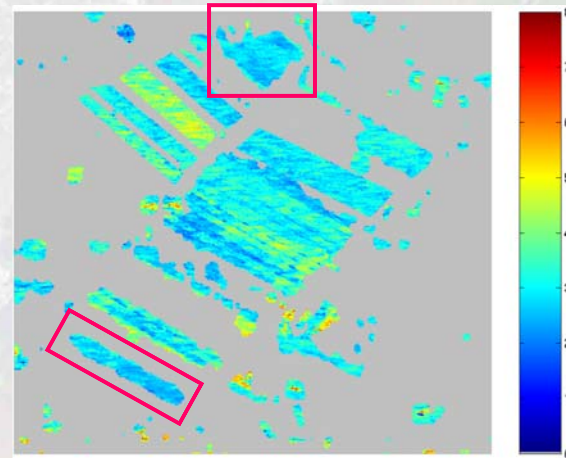
H/α method

esa

Plowed fields

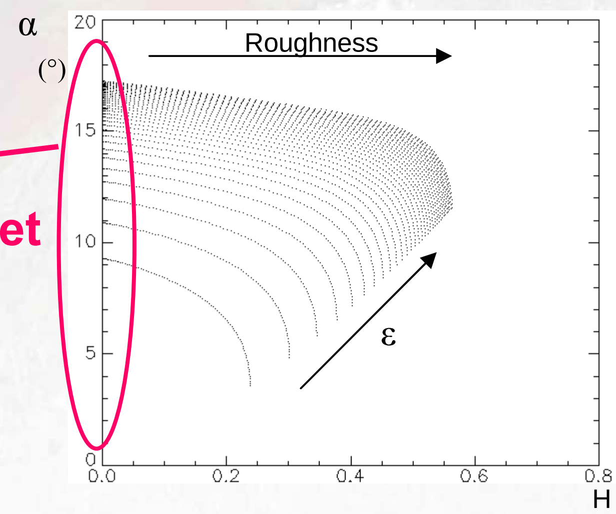


H



α (°)

Θ=45°



Soil estimation: ~~very smooth and very wet~~

Ground truth: plowed fields and slightly wet

Classical retrieval methods

Erroneous estimates over some plowed fields

↓

Classical methods are not adapted

Low values of entropy and α angle may be observed over anisotropic fields*

↓

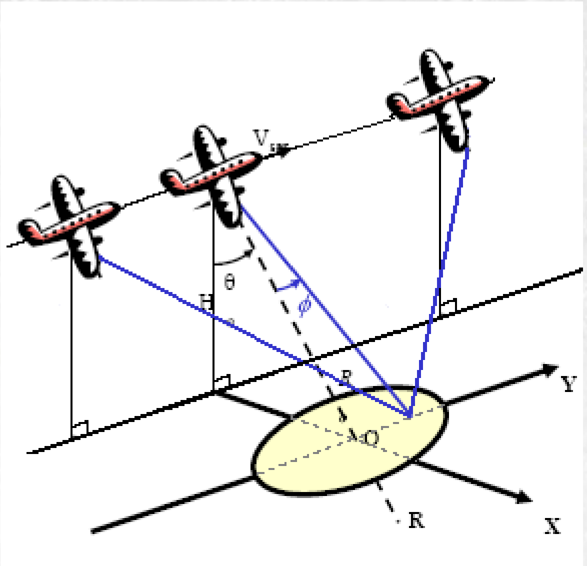
Non-stationary scattering pattern investigation

↓

Time-frequency analysis

Ferro-Famil L et al., "Nonstationary natural media analysis from polarimetric SAR data using a two-dimensional time-frequency decomposition approach", 2005.

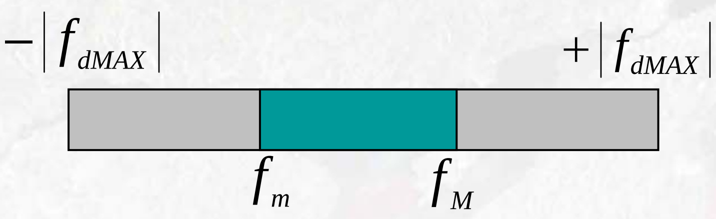
Principle of SAR



One scene is observed under different azimuth look angles

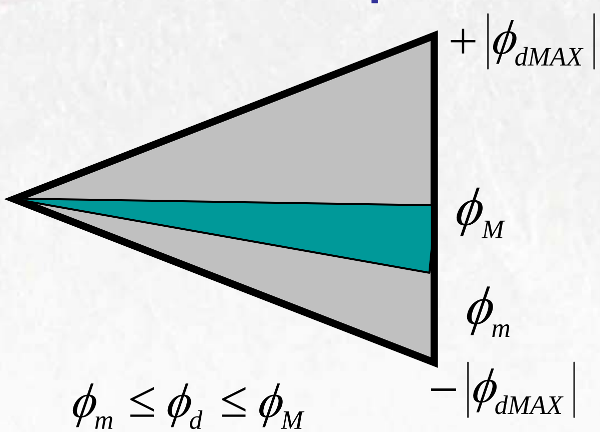
$$f_{az} = 2 f_c \frac{V_{SAR}}{c} \sin \phi_o$$

Doppler spectrum



$$f_m \leq f_d \leq f_M$$

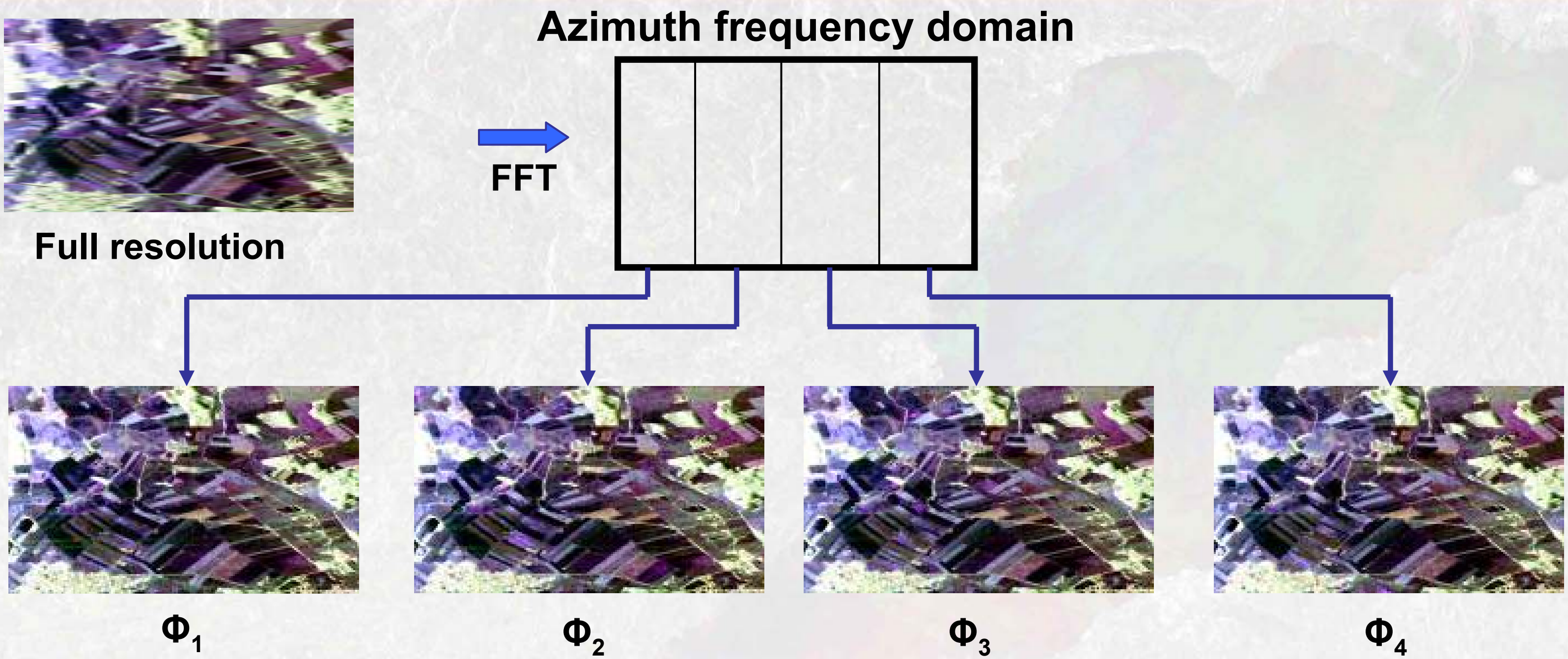
Antenna azimuth aperture



$$\phi_m \leq \phi_d \leq \phi_M$$

Ferro-Famil L et al., “Scene Characterization Using Subaperture Polarimetric SAR data”, 2003.

Time-Frequency analysis



Ferro-Famil L et al., "Scene Characterization Using Subaperture Polarimetric SAR data", 2003.

Time-Frequency analysis

Full resolution

FFT →

Azimuth frequency domain

Φ_1	Φ_2	Φ_3	Φ_4

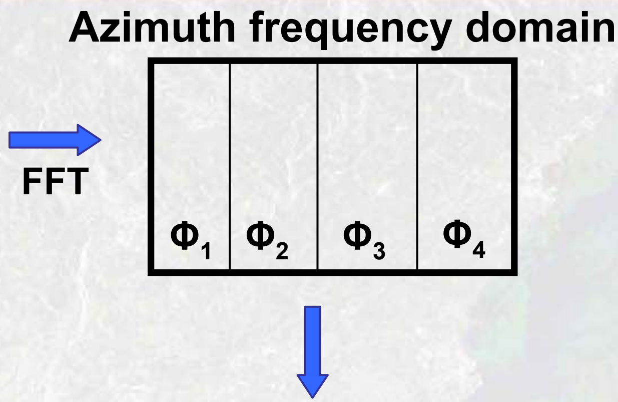
↓

Bragg resonance

Ferro-Famil L et al., "Scene Characterization Using Subaperture Polarimetric SAR data", 2003.

Time-Frequency analysis

Full resolution



Nonstationary field detection

- **Polarimetric representations statistics**

Over homogeneous areas $\mathbf{S}(\phi_i) \sim N_C(0, \boldsymbol{\Sigma}_i)$

⇨ n-look sampled matrix $\mathbf{T}(\phi_i) \sim W_C(n, \boldsymbol{\Sigma}_i)$

- **Maximum-likelihood detection**

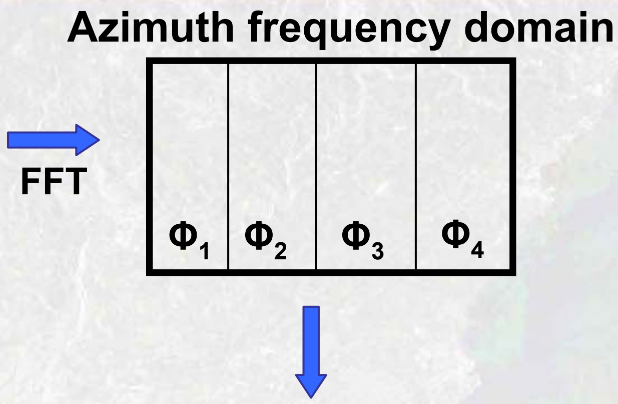
Hypothesis: $\mathbf{T}(\phi_1), \ldots, \mathbf{T}(\phi_R)$ follow the same distribution, i.e. $\boldsymbol{\Sigma}_1 = \ldots = \boldsymbol{\Sigma}_R$

⇨ ML ratio test: $\Lambda = \dfrac{\prod_{i=1}^{R} \left|\mathbf{T}(\phi_i)\right|^{n_i}}{\left|\mathbf{T}_t\right|^{n_t}}$ with $n_t = \sum_{i=1}^{R} n_i$ and $\mathbf{T}_t = \dfrac{\sum_{i=1}^{R} n_i \mathbf{T}(\phi_i)}{n_t}$

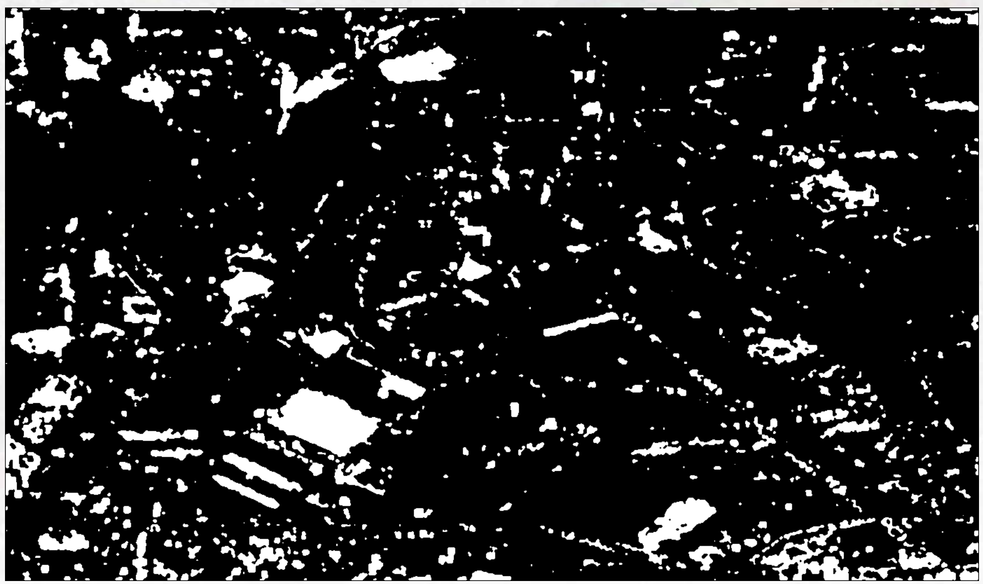
Ferro-Famil L et al., "Nonstationary natural media analysis from polarimetric SAR data using a two-dimensional time-frequency decomposition approach", 2005.

Time-Frequency analysis

Full resolution



Nonstationary field detection



Ferro-Famil L et al., "Scene Characterization Using Subaperture Polarimetric SAR data", 2003.

Time-Frequency analysis

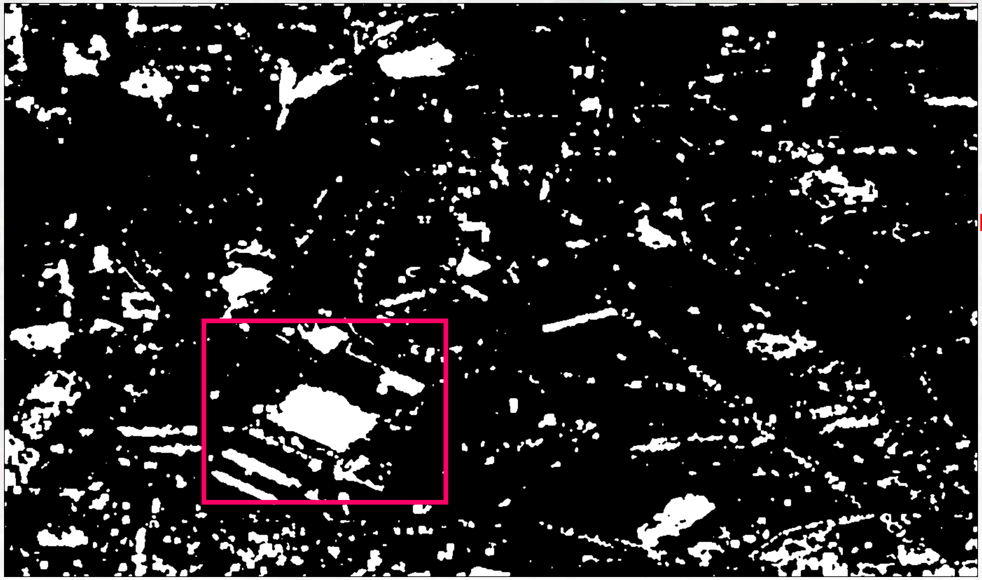
Full resolution

FFT

Azimuth frequency domain

Φ_1	Φ_2	Φ_3	Φ_4

Nonstationary field detection



Polarimetric analysis

Ferro-Famil L et al., "Scene Characterization Using Subaperture Polarimetric SAR data", 2003.

Polarimetric Analysis

Nonstationary fields

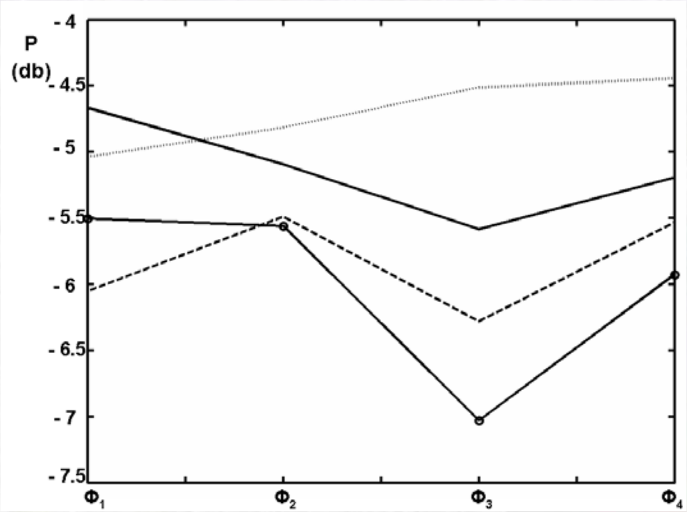
Z_1

Z_2

Stationary fields

Z_3

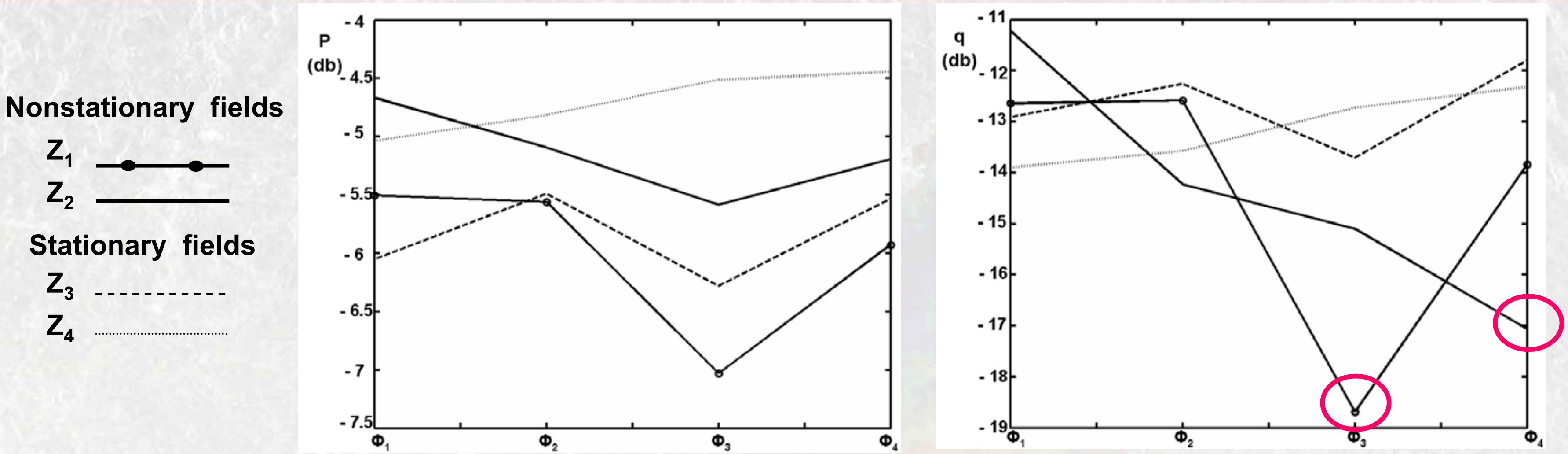
Z_4



Co-polar ratio

- low variations between sub-images (±1.5db)
- may be used for soil moisture retrieval

Polarimetric Analysis



Cross-polar ratio

- **strong variations between sub-images (±6db)**
- **lower depolarization in presence of Bragg resonance**

Polarimetric Analysis

Nonstationary fields

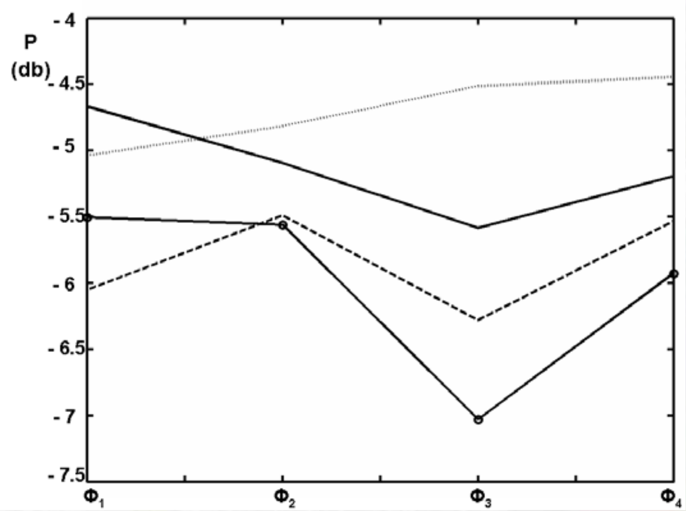
Z_1

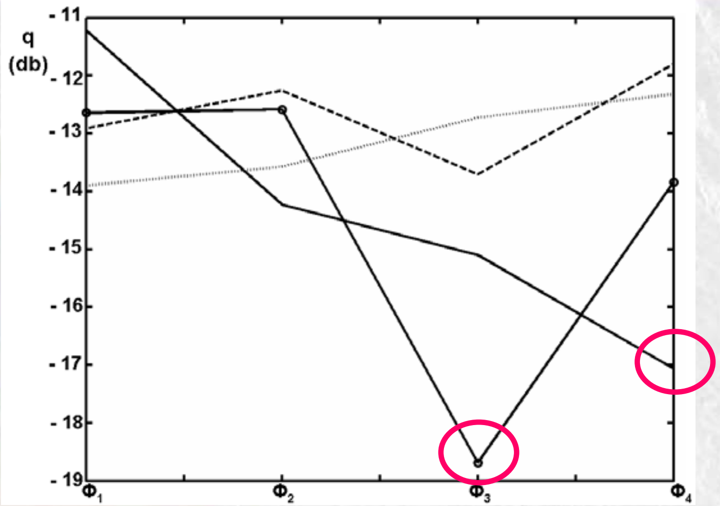
Z_2

Stationary fields

Z_3

Z_4

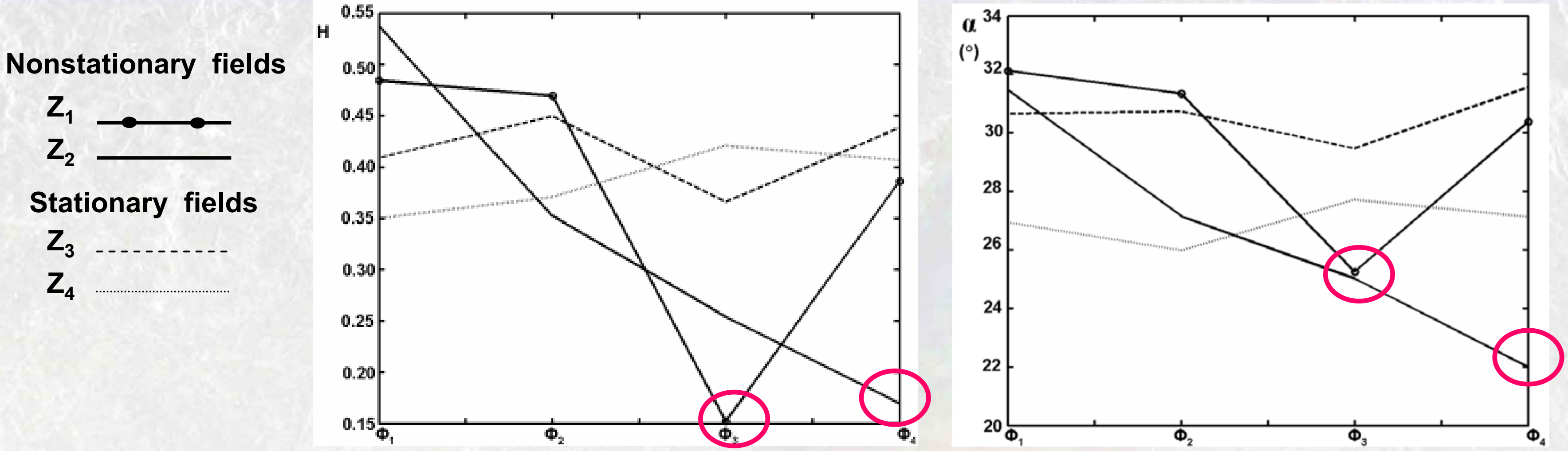




Co and Cross-polar ratios

Not adapted for soil moisture retrieval over nonstationary fields

Polarimetric Analysis



Entropy / α

- strong variation between sub-images (±0.4 for H and ±10° for α)
- one main scattering mechanism in presence of Bragg resonance

⬇

Not adapted for soil moisture retrieval over nonstationary fields

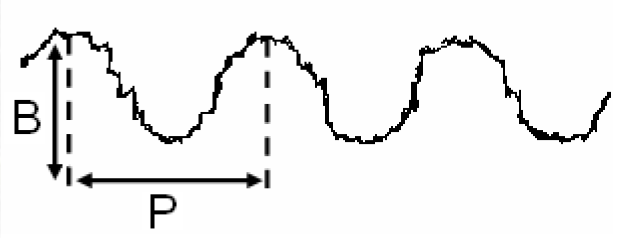
⬇

New inversion parameters are needed:

⇨ development of a new rough periodic surface scattering model

Rough periodic surface scattering Model

Surface characterization



$$f(x,y) = B\cos\frac{2\pi x}{P} + \xi(x,y)$$

periodic component

random component

Agricultural field

New rough periodic surface scattering model

- based on the Kirchhoff model with scalar approximation
- adapted to rough periodic surfaces

Yueh H. A. et al., "Scattering from randomly perturbed periodic and quasi-periodic surfaces", 1988

Rough periodic surface scattering Model

Backscattering coefficients

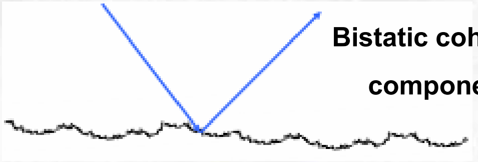
$$\sigma_{pq} = \sigma_{pq_c} + \sigma_{pq_n} + \sigma_{pq_s}$$

Coherent component

Incoherent component

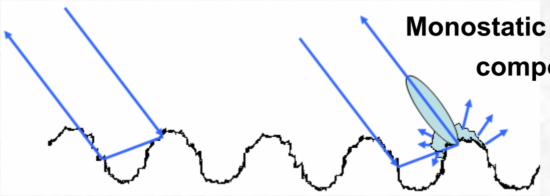
Slopes components
negligible

Rough Surface



No coherent part in monostatic

Rough periodic Surface

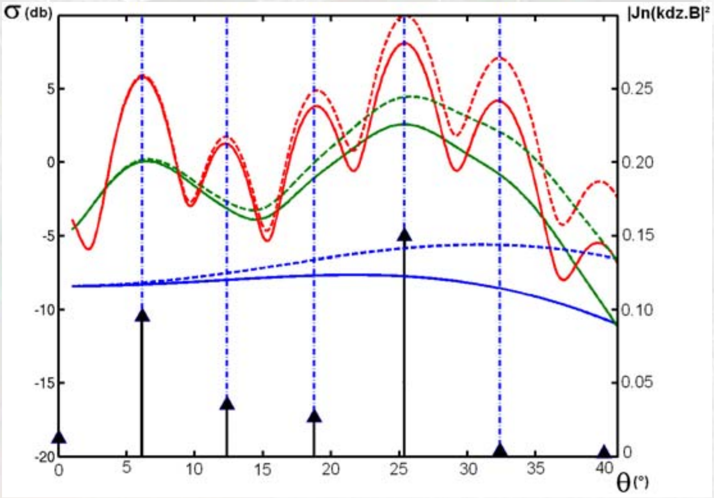


Rough periodic surface scattering Model

Incoherent backscattering coefficients

— HH polarization
- - - VV polarization

red: l = 100cm
green: l = 50cm
blue: l = 10cm
} Correlation lengths



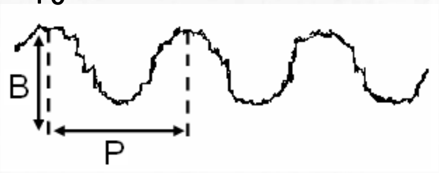
- Rough surface behavior

$$\sigma_{VV} > \sigma_{HH}$$

- *l* influences the coefficient shapes which depend on the Floquet modes

Surface characteristics:

- P = 100cm
- B = 10cm
- rms height = 1cm
- ε = 6
- F = 1.3GHz
- ϕ_o = 0°



Floquet modes

From Bragg resonance condition

$$\sin\theta\cos\phi_o = \mathrm{n}\frac{\lambda}{2\mathrm{P}}$$

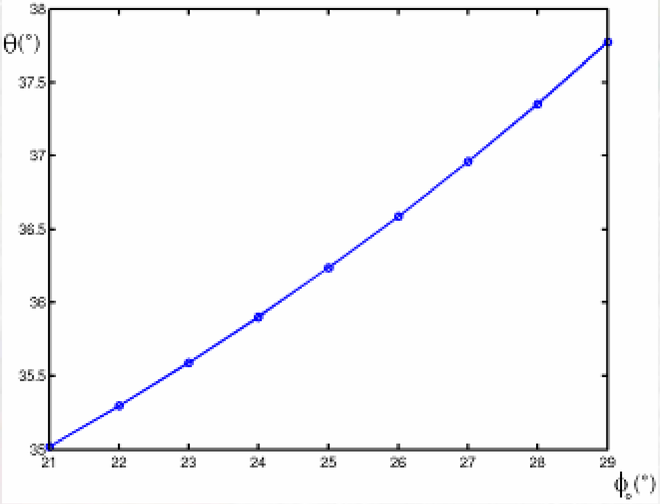
Rough periodic surface scattering Model

Bragg resonance conditions

$$\sin\theta\cos\phi_o = n\frac{\lambda}{2P}$$

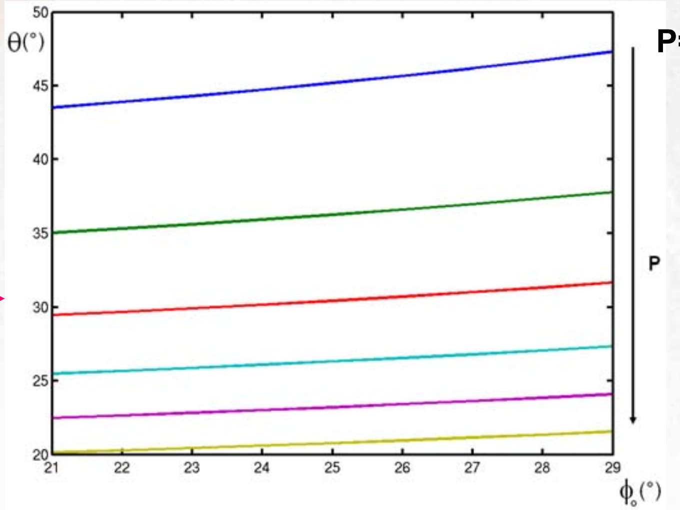
depends on

- incidence angle: θ
- azimuth look angle: Φ_0
- Floquet mode: n
- period: P



P=0,6 m

n=3



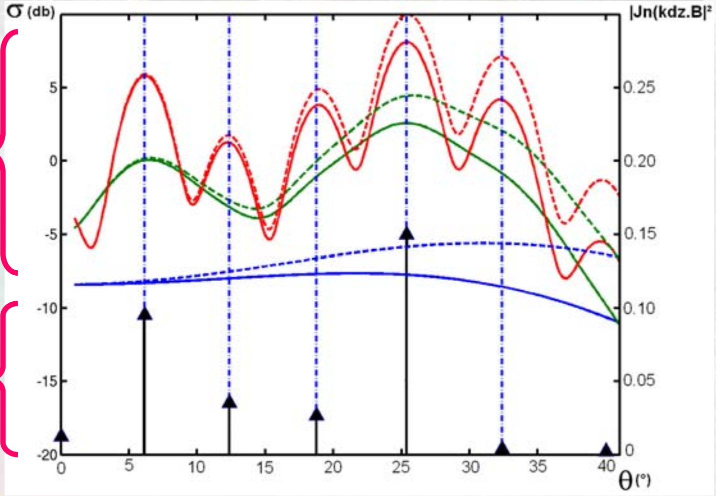
P=0,5 m to 1 m

n=3

Rough periodic surface scattering Model

Incoherent backscattering coefficients

- HH polarization (solid line)
- VV polarization (dashed line)
- l = 100cm (red), l = 50cm (green), l = 10cm (blue) — Correlation lengths



Floquet modes

From Bragg resonance condition

$$\sin\theta\cos\phi_o = n\frac{\lambda}{2P}$$

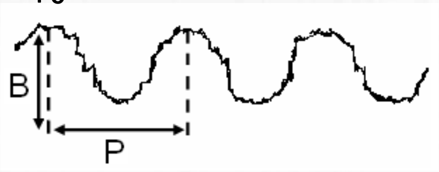
$$\theta = \mathrm{asin}\left(\frac{n\pi}{Pk\cos(\phi_o)}\right)$$

Locations and amplitudes of the Floquet modes:

$$|Jn(kdz.B)|^2 = f(\theta,\phi_o,P,B,k)$$

Surface characteristics:

- P = 100cm
- B = 10cm
- rms height = 1cm
- ε = 6
- F = 1.3GHz
- ϕ_o = 0°



Chuang S.L et al., "Scattering of waves from periodic surfaces", 1981.

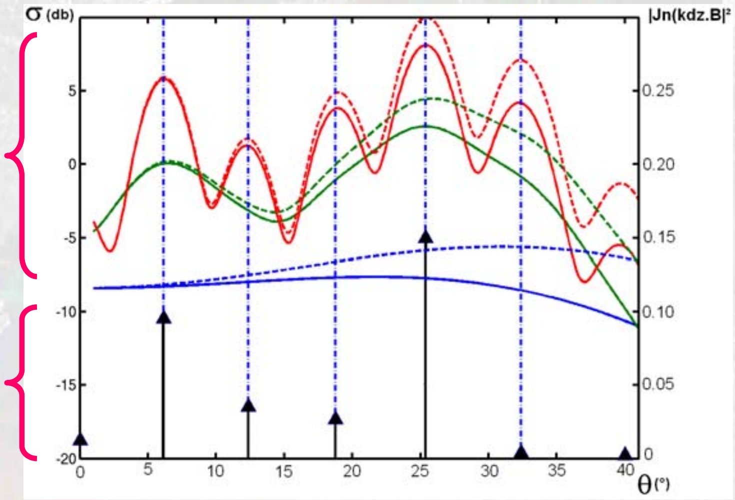
Rough periodic surface scattering Model

Incoherent backscattering coefficients

HH polarization (solid black line)

VV polarization (dashed black line)

Correlation lengths:
- l = 100cm (red)
- l = 50cm (green)
- l = 10cm (blue)



Floquet modes

From Bragg resonance condition

$$\sin\theta\cos\phi_o = n\frac{\lambda}{2P}$$

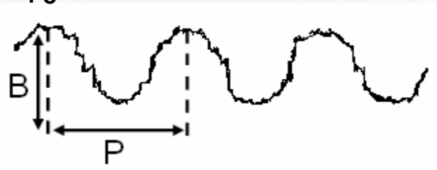
$$\theta = \text{asin}\left(\frac{n\pi}{Pk\cos(\phi_o)}\right)$$

↓

Polarimetric analysis

Surface characteristics:

- P = 100cm
- B = 10cm
- rms height = 1cm
- $\varepsilon = 6$
- F = 1.3GHz
- $\phi_o = 0°$



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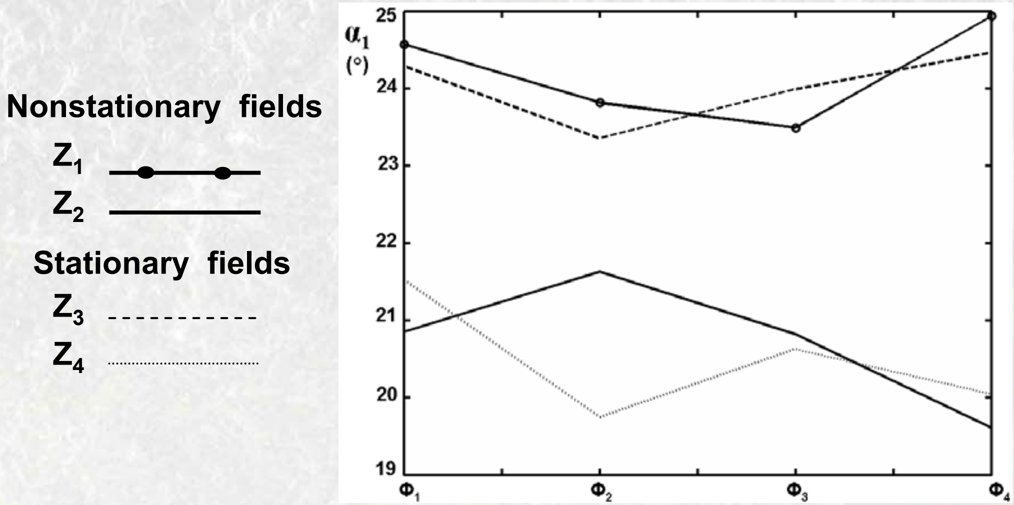
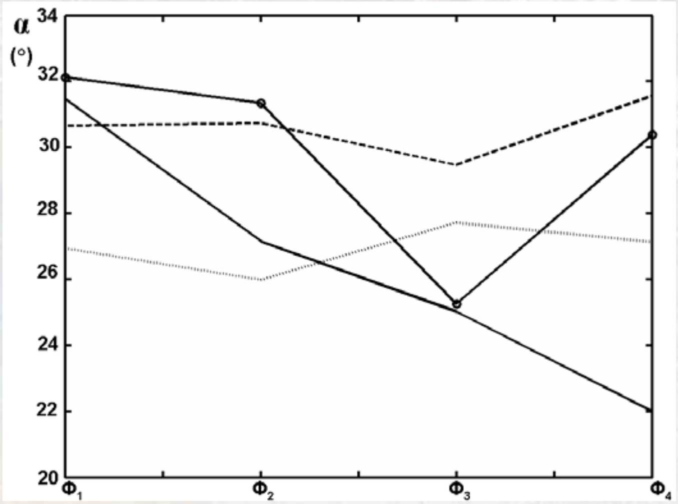
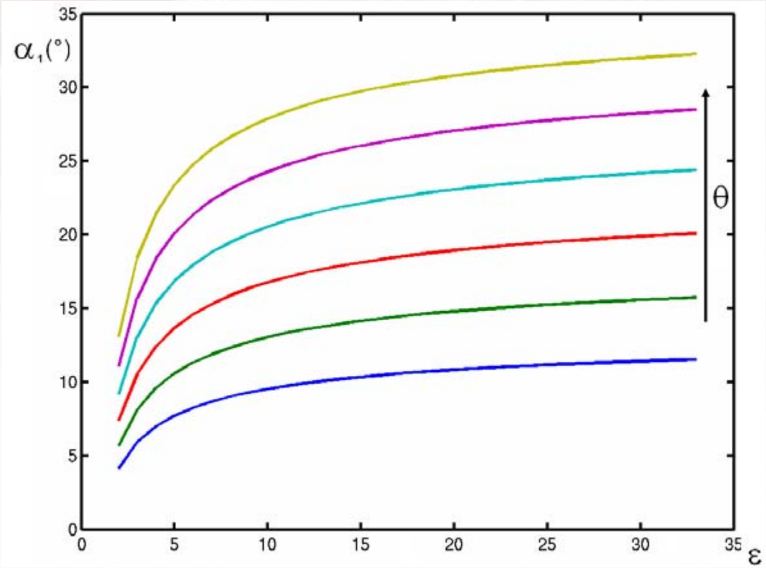
α_1 angle Analysis





α_1 angle:

- low variation between sub-images (±2°)
- depends on soil moisture and incidence angle



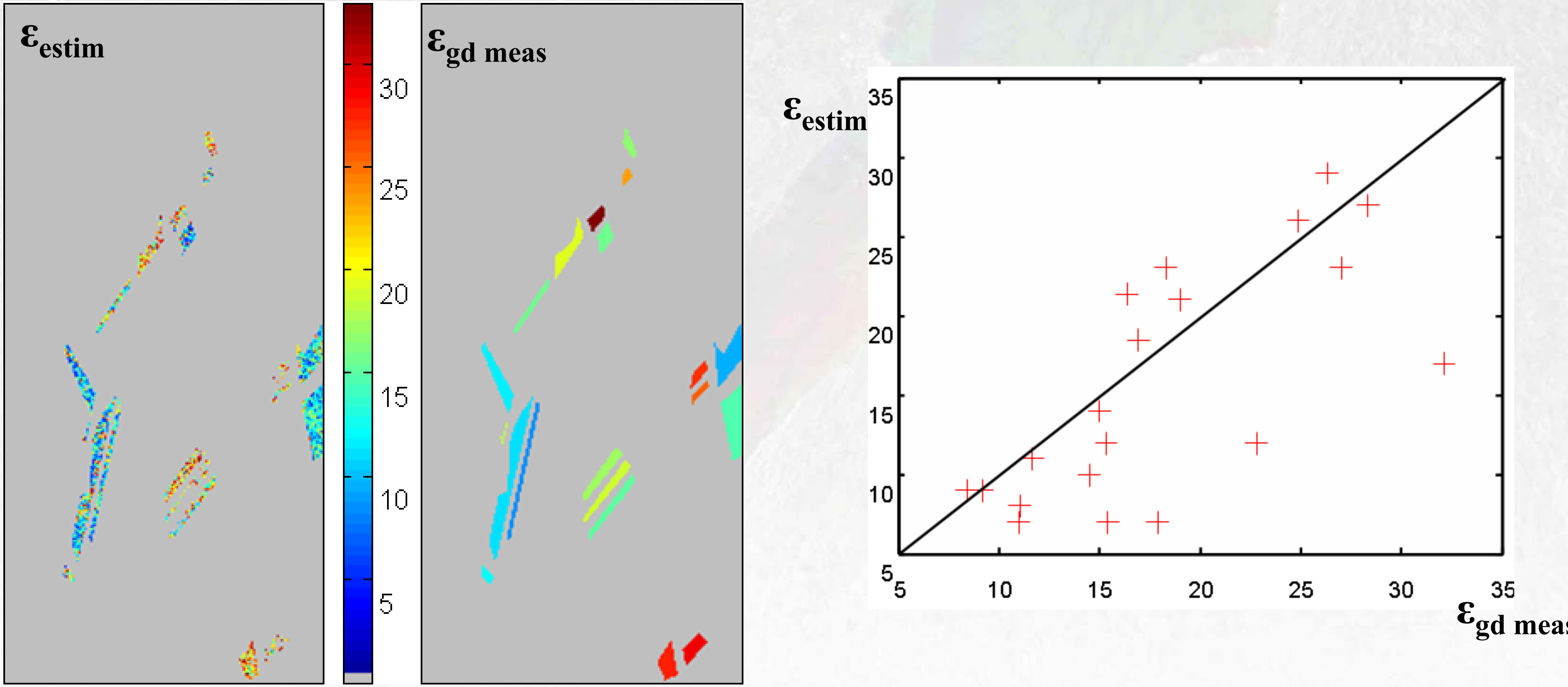
May be used for soil moisture retrieval even over nonstationary fields

Soil moisture retrieval

α_1 inversion method

$$\alpha_{1_{corrected}} = \alpha_{1_{iem}} \frac{mean(\alpha_{1_{data/surface}})}{mean(\alpha_{1_{iem}})}$$

adapted for each θ



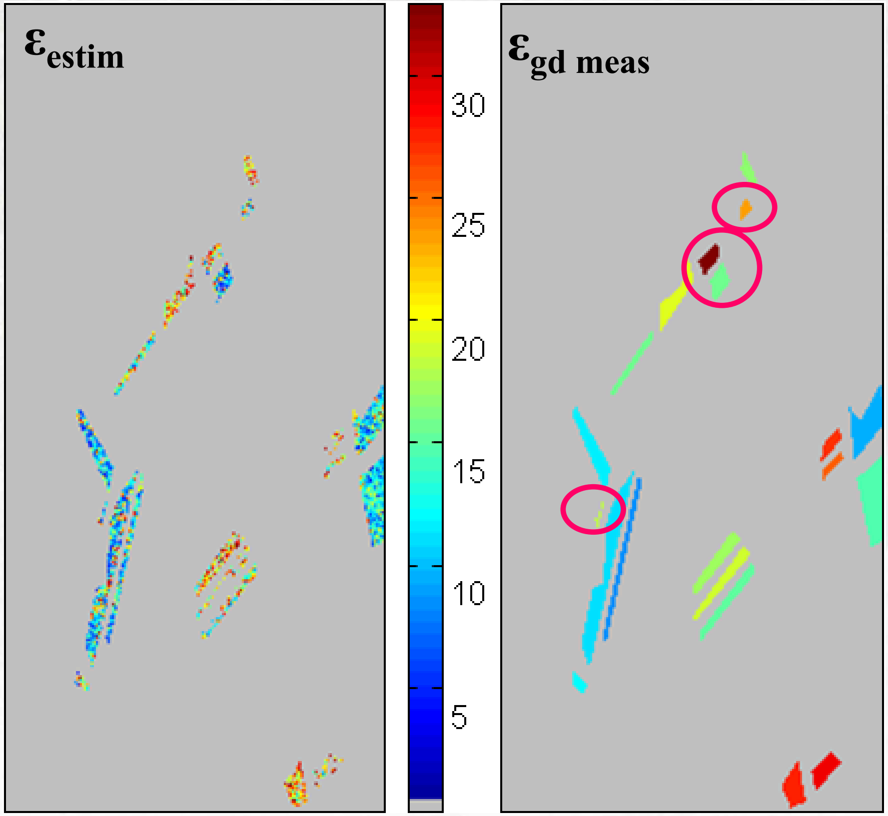
Allain S. et al, "Two novel surface model based inversion algorithms using multi-frequency polSAR data", 2004.

Soil moisture retrieval

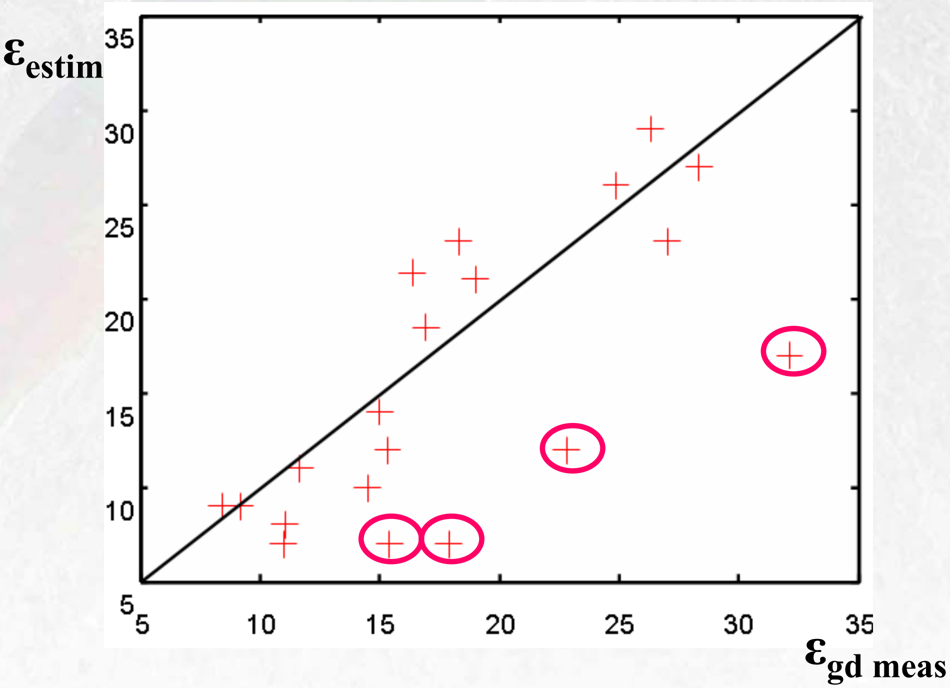
α_1 inversion method

$$\alpha_{1_{corrected}} = \alpha_{1_{iem}} \frac{mean(\alpha_{1_{data/surface}})}{mean(\alpha_{1_{iem}})}$$

adapted for each θ



mean error(ε)= 13%



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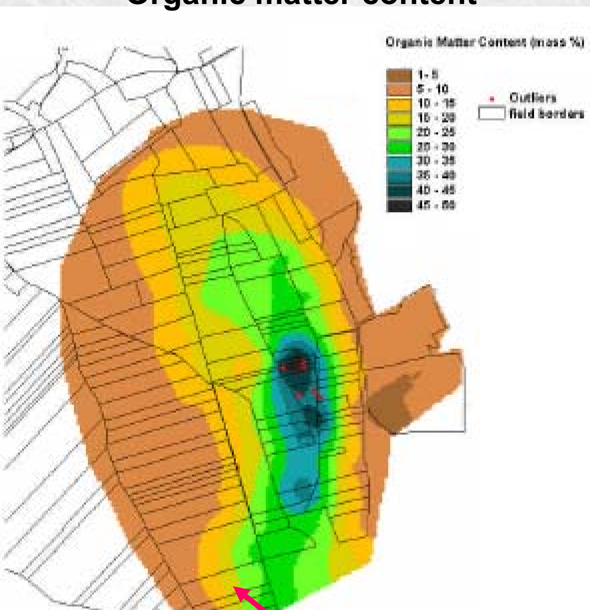
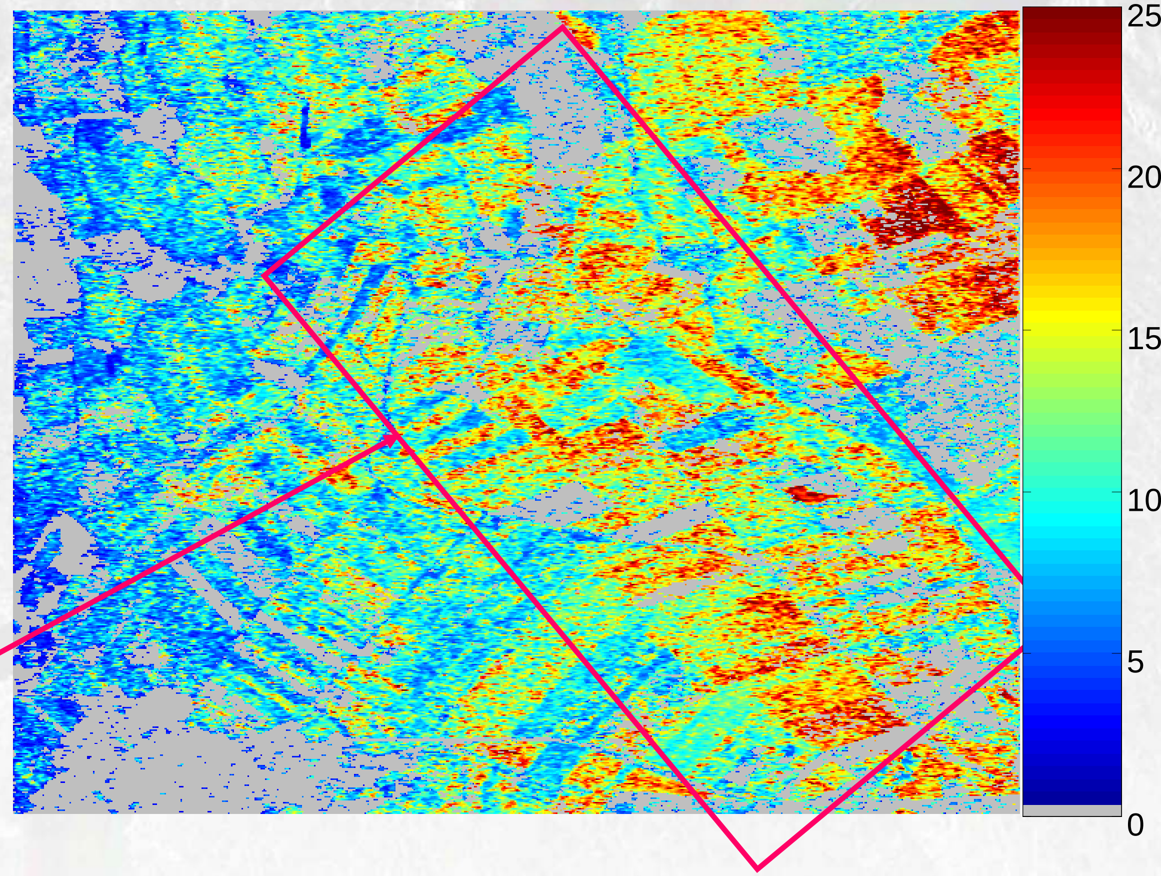
Soil moisture retrieval

Organic matter content



Dielectric constant retrieval

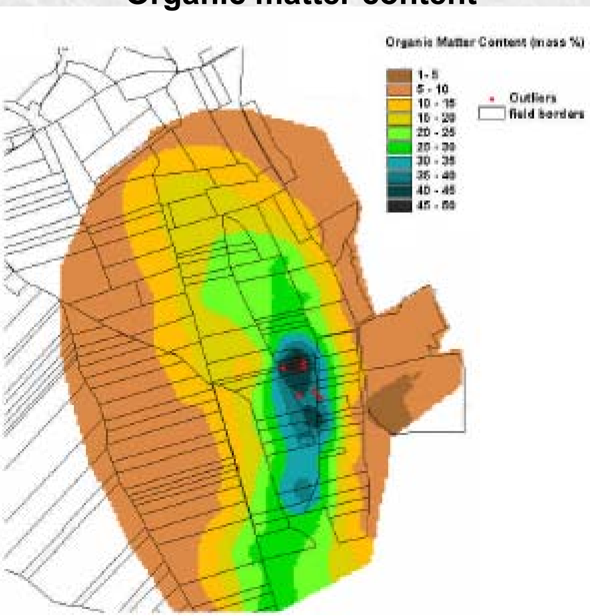


Very wet area

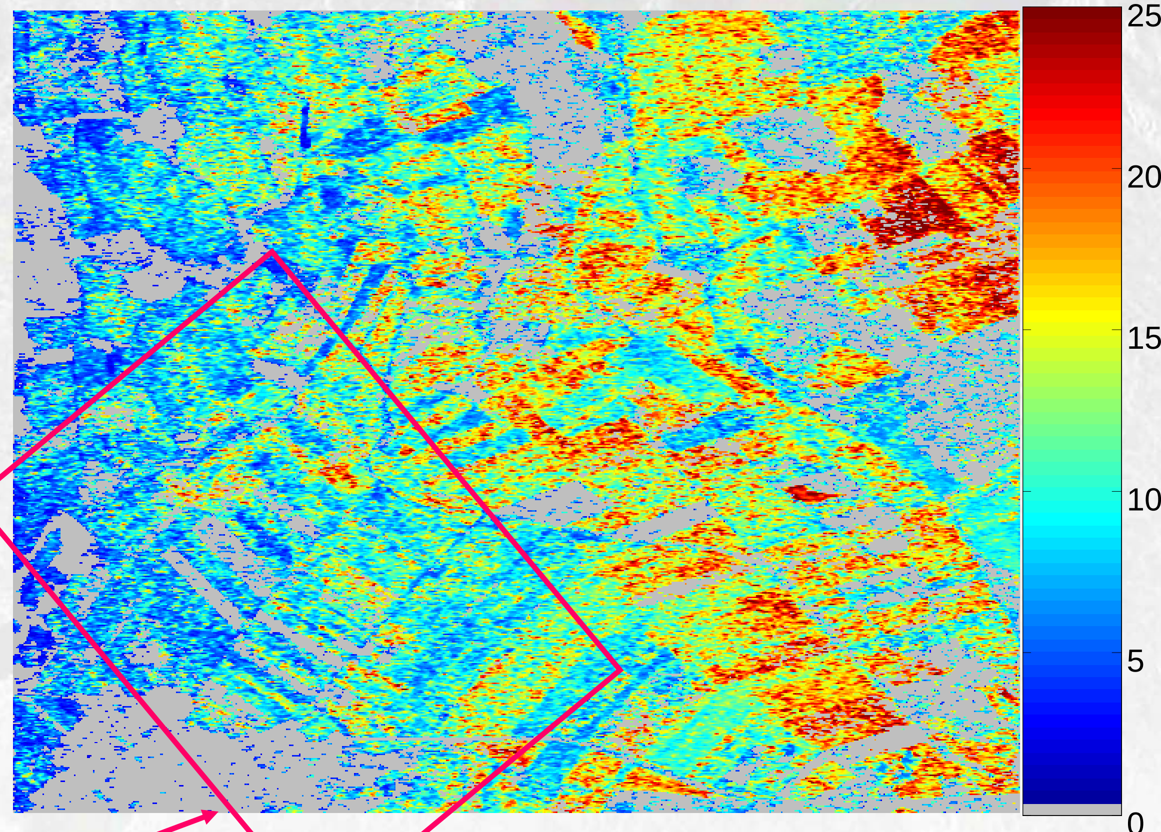
Soil moisture retrieval

esa

Organic matter content



Dielectric constant retrieval

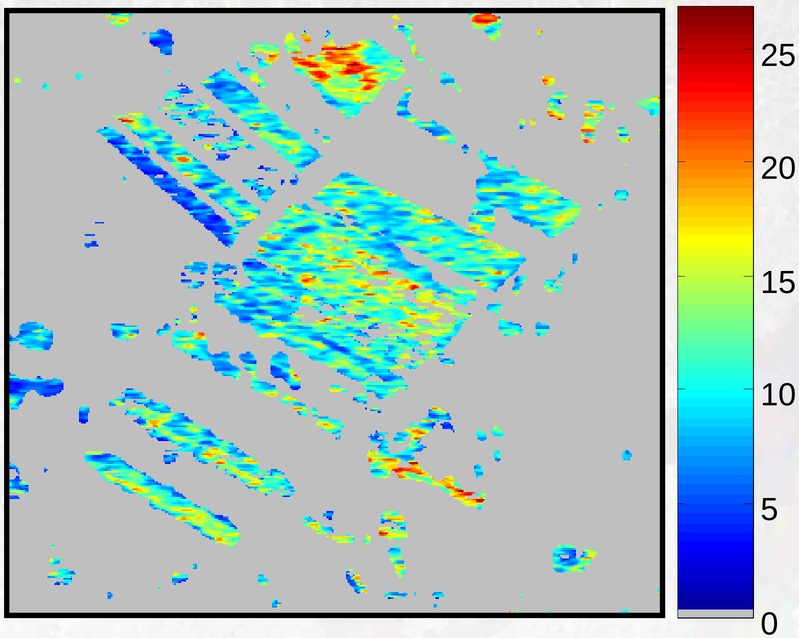


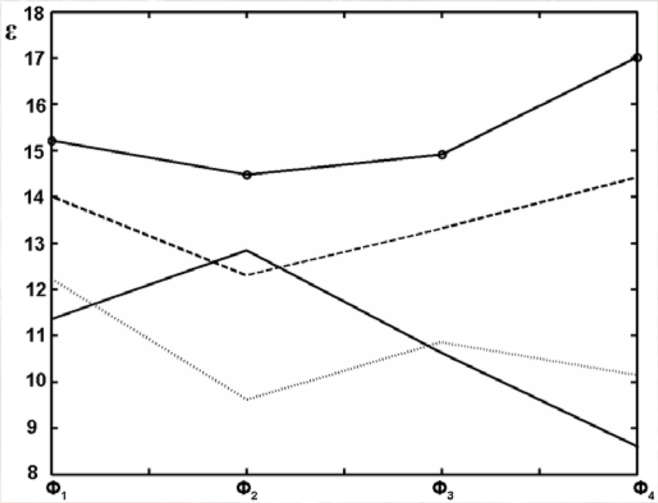
Slightly wet area

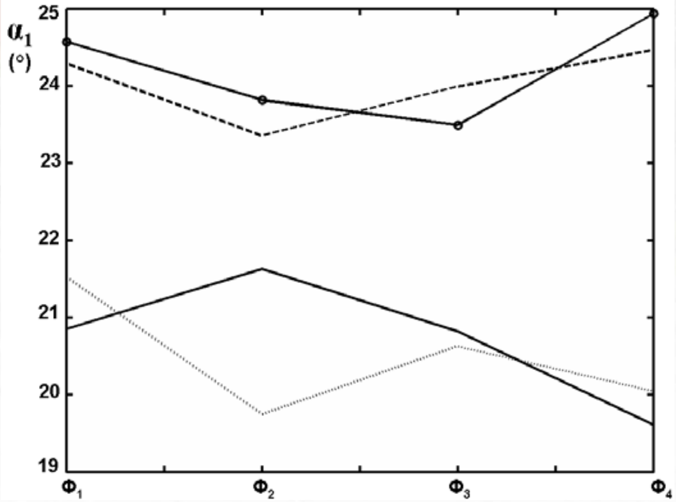
Soil moisture retrieval

Azimuthal look angle variations

Dielectric constant retrieval







Conclusions

- Classical retrieval methods

→ anomalous behaviors may appear over periodic surfaces

- Time-Frequency analysis

→ identify nonstationary fields

→ confirms the dependence on the azimuth look angle

- New rough periodic surface scattering model

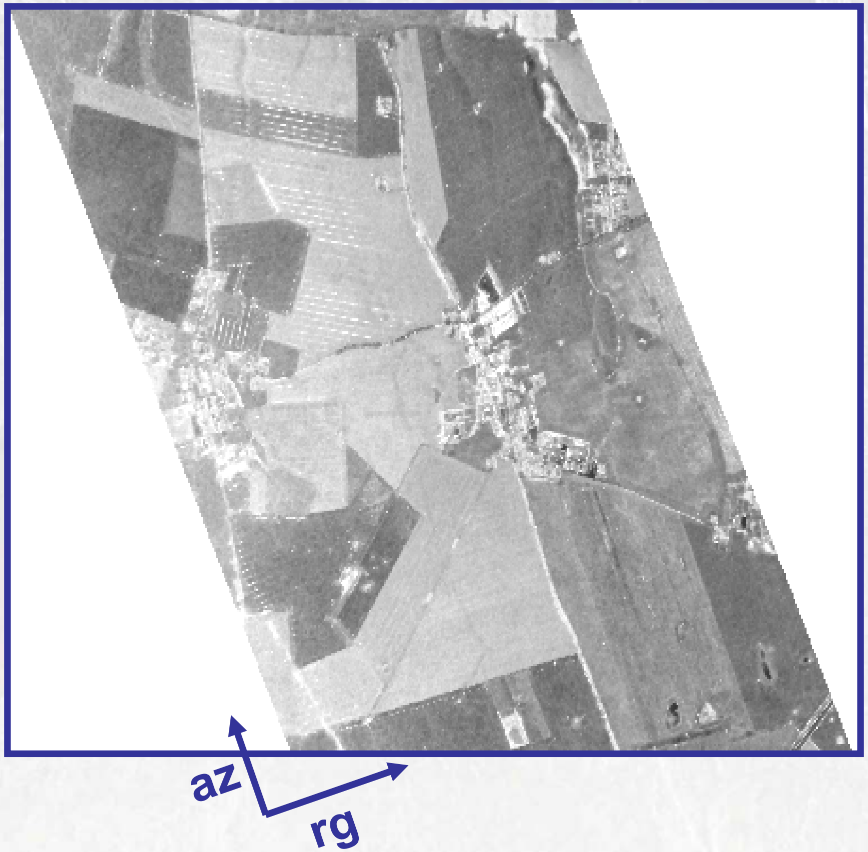
α_1 parameter:

→ remains constant in presence of resonance phenomena

→ highly sensitive to soil moisture

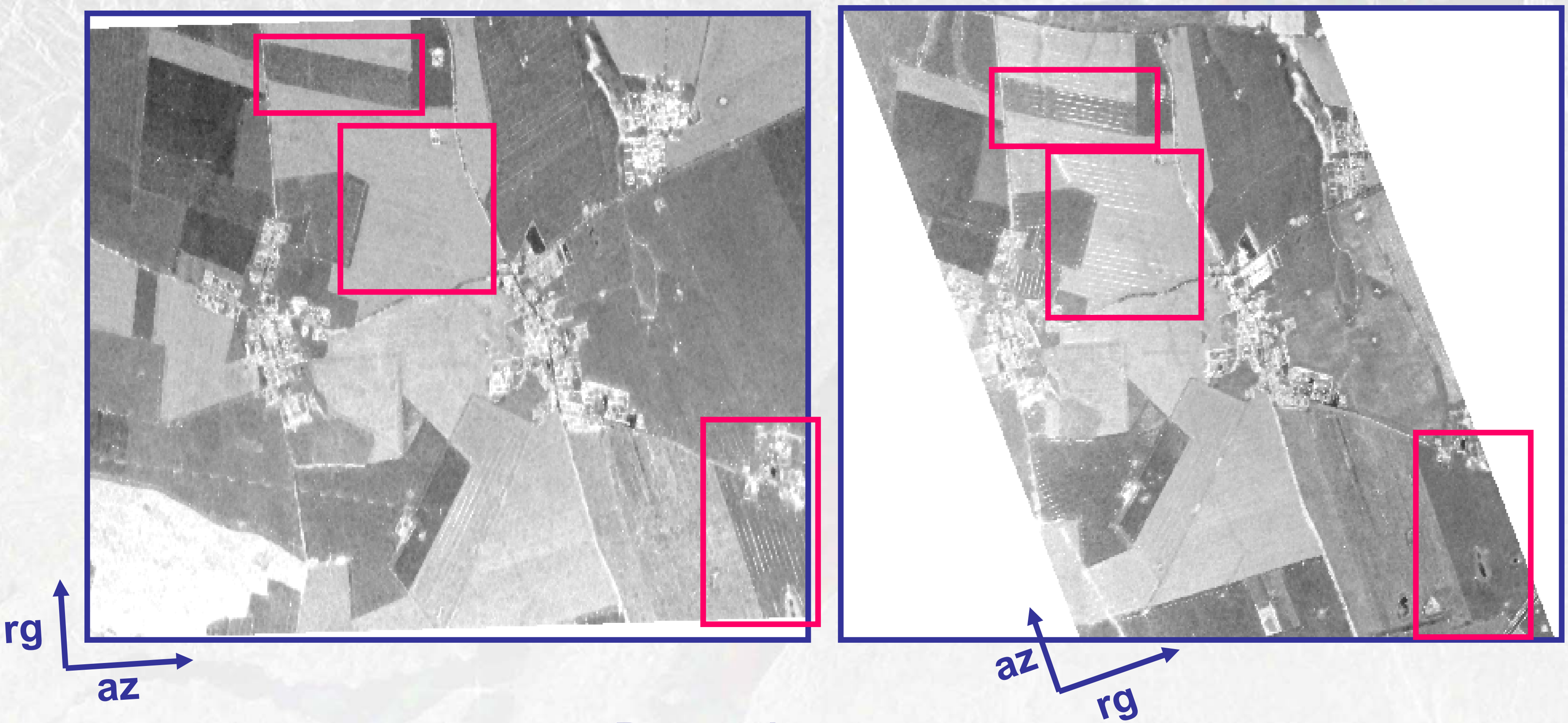
- Application over real SAR data acquired at L band

Outlook



<u>AGRISAR 2006</u>
L band Quad pol data set
DLR E-SAR sensor

Outlook



Bragg phenomenon

Grazie