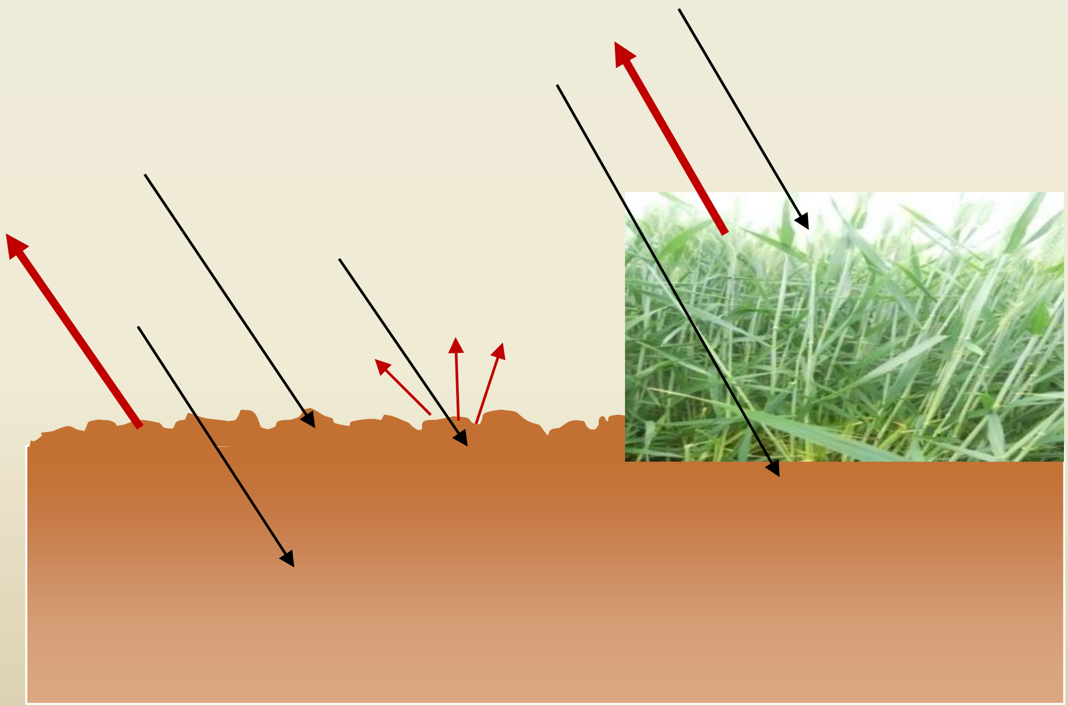
Effet de la rugosité des surfaces continentales sur la mesure radar

M. Zribi, N. Baghdadi

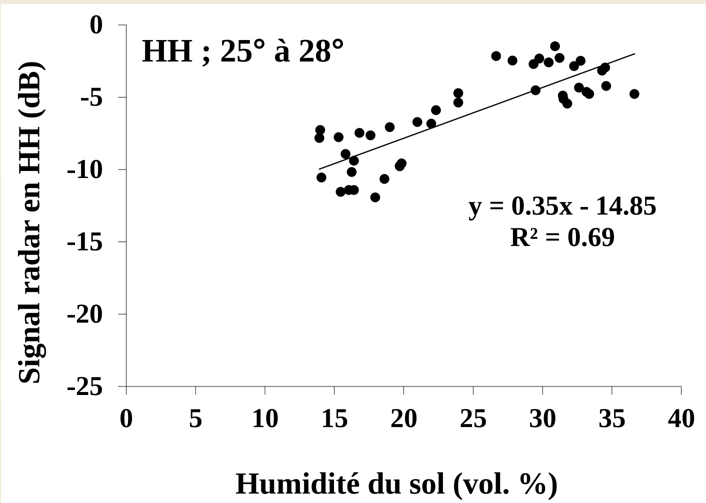
INTRODUCTION

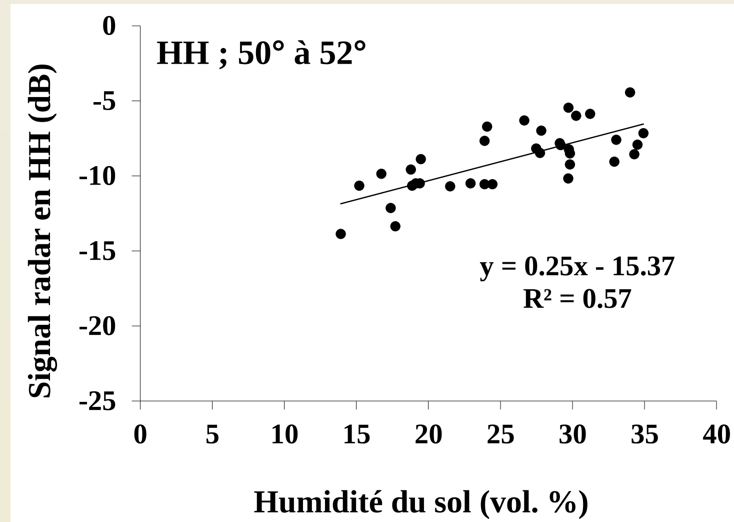
Soil parameters:
Roughness, **moisture**
vegetation

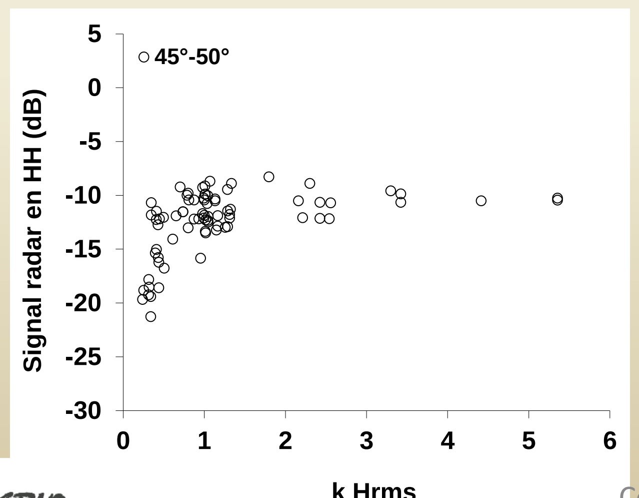
Backscattering coefficient

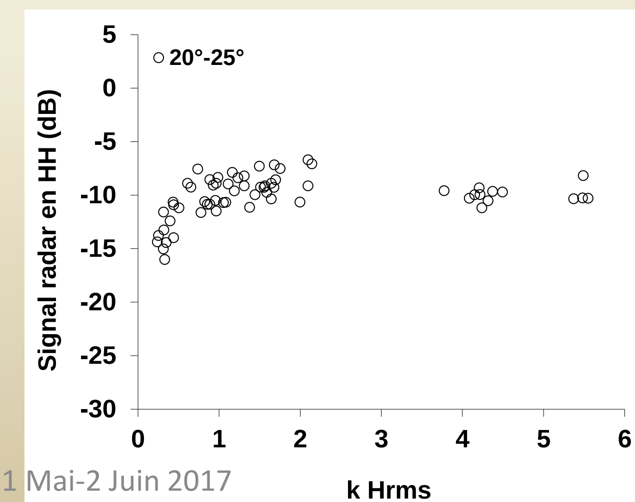


RADAR SIGNAL SENSITIVITY TO SURFACE PARAMETERS









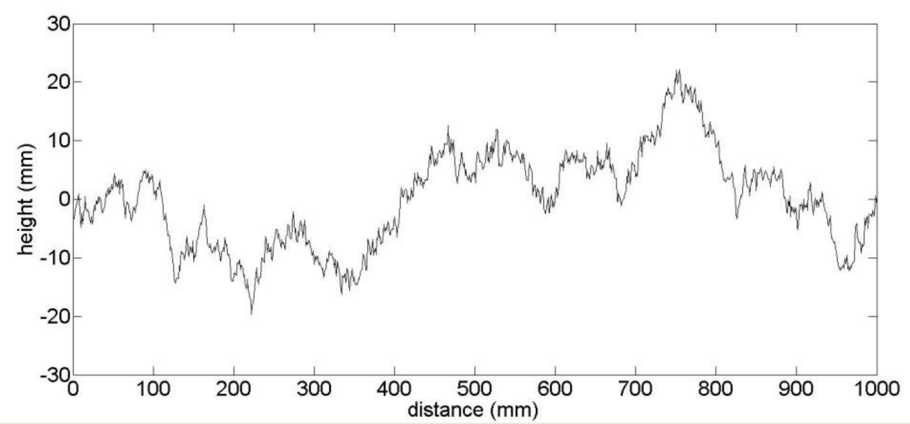
ROUGHNESS DESCRIPTION

$$\rho(x) = Hrms^2 \exp\left(-\left(\frac{x}{L}\right)^{\alpha}\right)$$

Hrms: Rms height

L: Correlation length

α: power of height correlation function



References	New descriptions or improvements
Shi et al., 1997	General power law Spectrum
Rouvier et al., 2000 **Zribi et al., 2000**	Fractal brownian approach, introduction of fractal dimension D
Mattia et al. 1997, Davidson et al. 2000, Oh et al., 1998	Statistics, length of the profile
Zribi et al., 2000	Introduction of fractal structures in correlation function shape
Li et al, 02, Fung, 1994, **Zribi et al., 2005**	Analysis of correlation function shape
Lievens et al., 2011	Effective roughness parameter
Baghdadi et al. 2006, 2011, 2012	Fitting parameter Lopt=f(Hrms)

OUTLINE

→ C and X bands

- Proposition of new Zg parameter
- Validation with experimental campaigns

→P band

- Roughness multi-scale analysis
- Validation with experimental campaigns

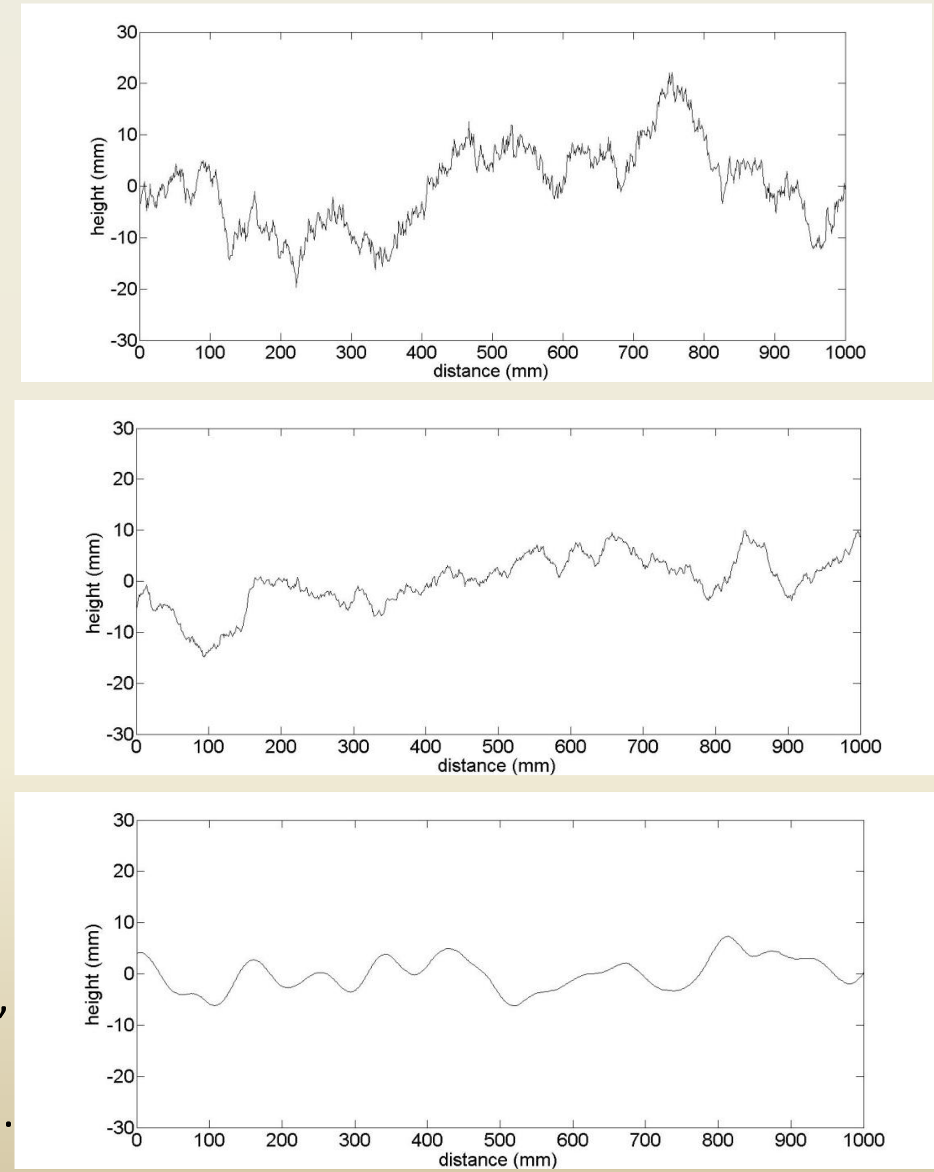
Numerical backscattering modelling: Surface profile generation

$$\rho(x) = s2\exp\left(-\left(\frac{x}{l}\right)^{\alpha}\right)$$

s: Rms height
l: Correlation length

$$h(k) = \sum_{i=-M}^{i=M} W(i)X(i+k)$$

$$W(i) = F^{-1}\left[\sqrt{F\left[C(i)\right]}\right]$$



Three synthetically generated surface profiles, with *rms* height=0.6 cm, correlation length=6 cm, and a) *a*=1, b) *a* =1.5 and c) *a* =2.

Numerical modelling: moment method

$$\begin{cases} \vec{n}\times\vec{E}^{i}(\bar{r}) = -\frac{1}{2}\vec{K} + \vec{n}\times\int_{c}\left[j\omega\mu_0 G_1\vec{J} - \vec{K}\times\nabla G_1 - \frac{\nabla'.\vec{J}}{j\omega\varepsilon_1}\nabla G_1 \right] dl' \\ \vec{n}\times\vec{H}^{i}(\bar{r}) = -\frac{1}{2}\vec{J} + \vec{n}\times\int_{c}\left[j\omega\varepsilon_1 G_1\vec{K} + \vec{J}\times\nabla G_1 - \frac{\nabla'.\vec{K}}{j\omega\mu_0}\nabla G_1 \right] dl' \\ 0 = -\frac{1}{2}\vec{K} - \vec{n}\times\int_{c}\left[j\omega\mu_0 G_2\vec{J} - \vec{K}\times\nabla G_2 - \frac{\nabla'.\vec{K}}{j\omega\varepsilon_2}\nabla G_2 \right] dl' \\ 0 = -\frac{1}{2}\vec{J} - \vec{n}\times\int_{c}\left[j\omega\varepsilon_0 G_2\vec{K} + \vec{J}\times\nabla G_2 - \frac{\nabla'.\vec{K}}{j\omega\varepsilon_2}\nabla G_2 \right] dl' \end{cases}$$

$$G_i = -\frac{j}{4}H_0^{(2)}\left(k_i\left|\vec{\rho}-\vec{\rho}'\right|\right), i = 1,2$$

Numerical modelling: moment method

$$\begin{cases} E_y^i(\vec{\rho}) = \frac{1}{2}E_y(\vec{\rho}) + \int_c \left[j\omega\mu_0 G_1 J_y + E_y(\vec{n}'.\nabla G_1) \right] dl' \\ 0 = \frac{1}{2}E_y(\vec{\rho}) - \int_c \left[j\omega\mu_0 G_2 J_y + E_y(\vec{n}'.\nabla G_2) \right] dl' \end{cases}$$

$$\begin{bmatrix} Q^{11} & Q^{12} \\ Q^{21} & Q^{22} \end{bmatrix} \begin{bmatrix} E_y \\ J_y \end{bmatrix} = \begin{bmatrix} E_y^i \\ 0 \end{bmatrix}$$

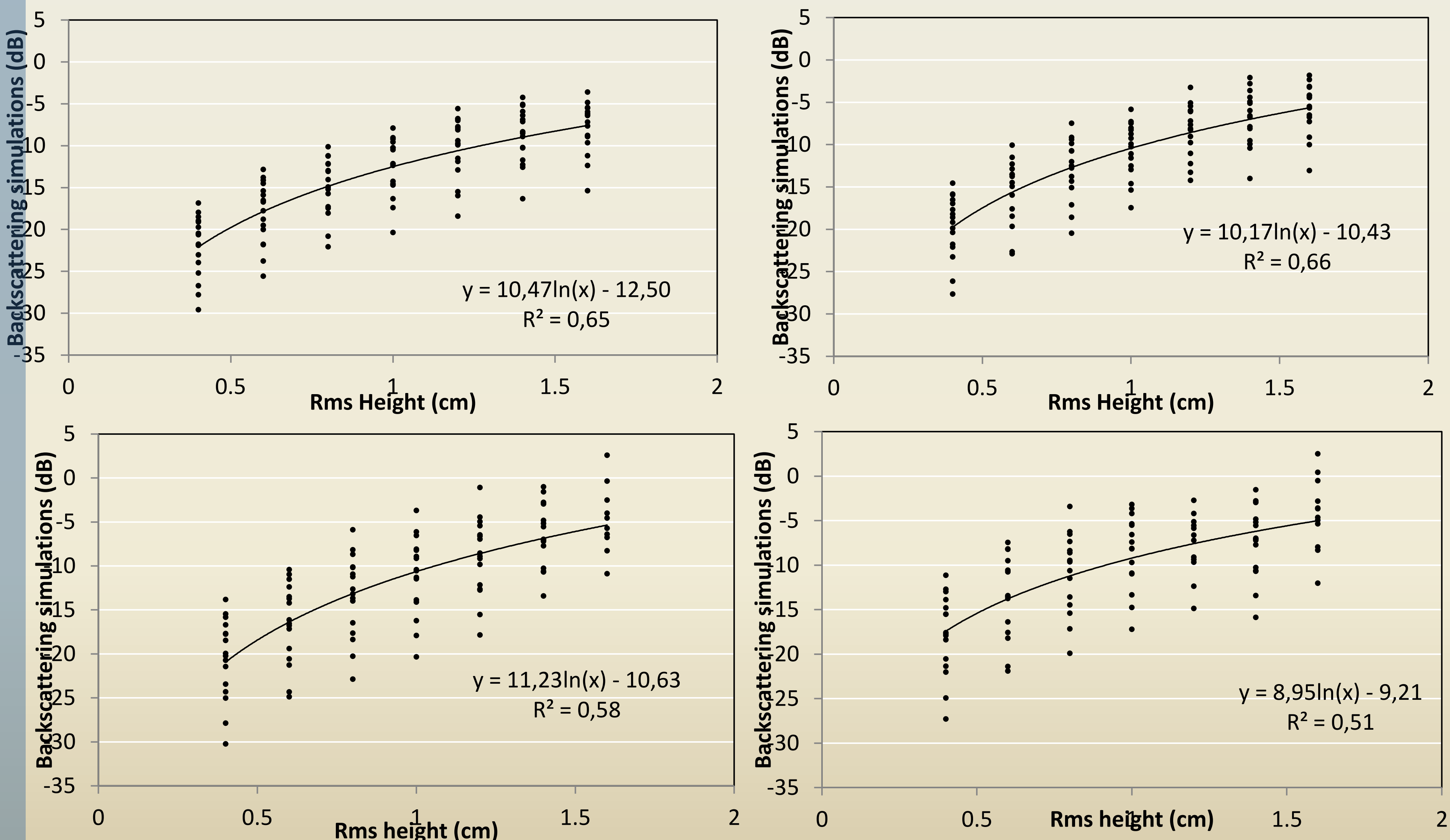
$$E_y^s = -\int_c \left[j\omega\,\mu_0 G_1 J_y + E_y(\vec{n}'.\nabla G_1) \right] \quad dl'$$

$$\sigma^0 = \frac{2\pi\rho}{PL_{eff}} \left[\sum_{j=1}^{P} \left| E_j^s \right|^2 - \frac{1}{P} \left| \sum_{j=1}^{P} E_j^s \right|^2 \right]$$

Simulations will be proposed for: rms heights *s*=0.4 cm, *s* =0.6 cm, *s* =0.8 cm, *s* =1 cm, *s* =1.2 cm, *s* =1.4 cm, *s* =1.6 cm; correlation lengths *l*=4 cm, *l* =6 cm, *l* =8 cm and *l* =10 cm; *a* parameter *a*=1, *a* =1.25, *a* =1.5 and *a* =1.75.

HH, VV polarisations, 20 and 40° incidence angles, Mv=10%, 20%, 30%

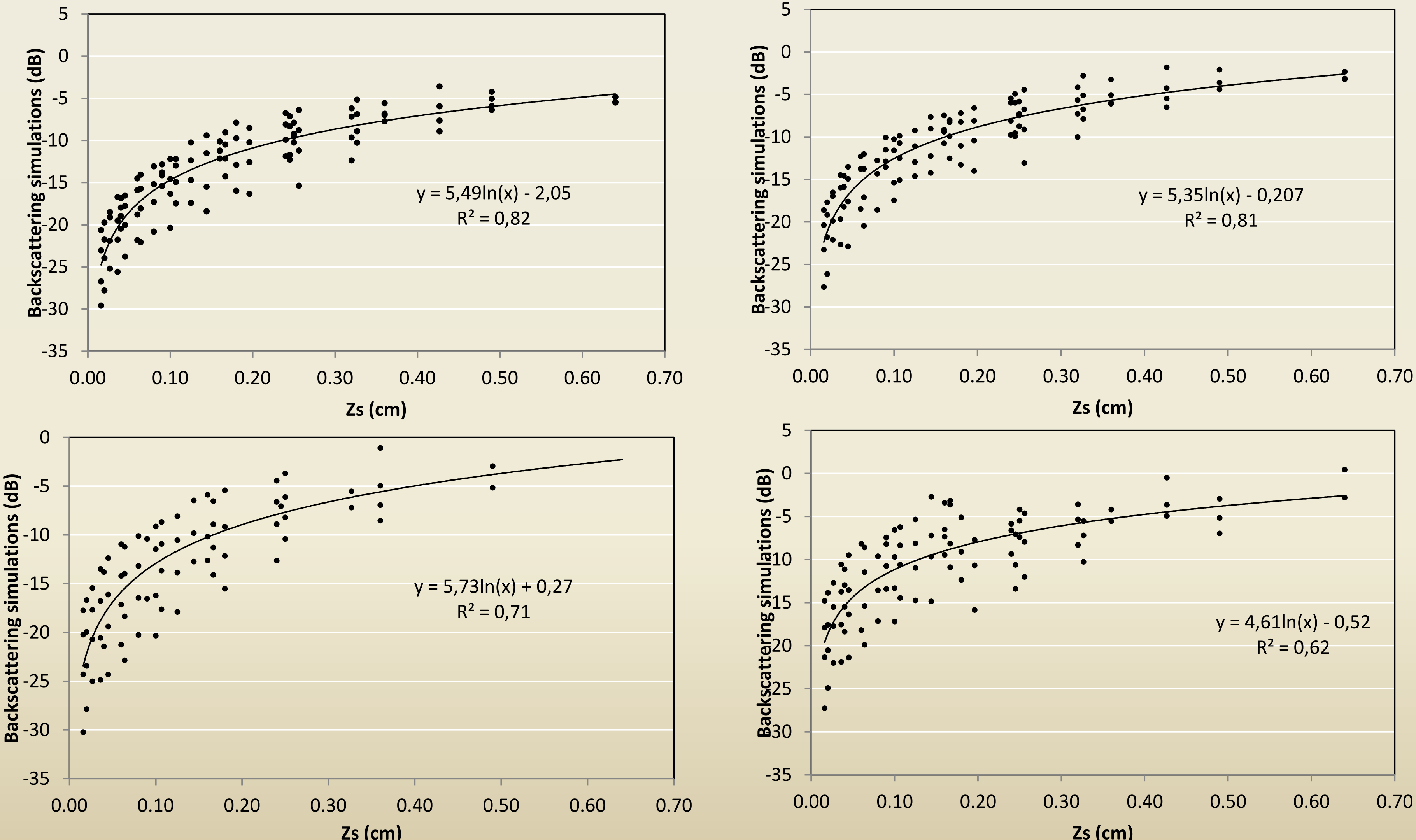
Relationships between rms height and backscattering simulations



Backscattering simulations in the *HH* polarisation at 40° incidence, as a function of the rms height: a) C band, *mv*=10%, b) C band, *mv*=30%, c) X band, *mv*=10%, d) X band, *mv*=30%

sigma=f(Zs)

$Zs=s^2/l=s.s/l$ (Zribi and Dechambre, 2003)



Backscattering simulations in the *HH* polarisation at 40° incidence, as a function of *Zs*. a) C band, *mv*=10%, b) C band, *mv*=30%, c) X band, *mv*=10%, d) X band, *mv*=30%

Zg introduction

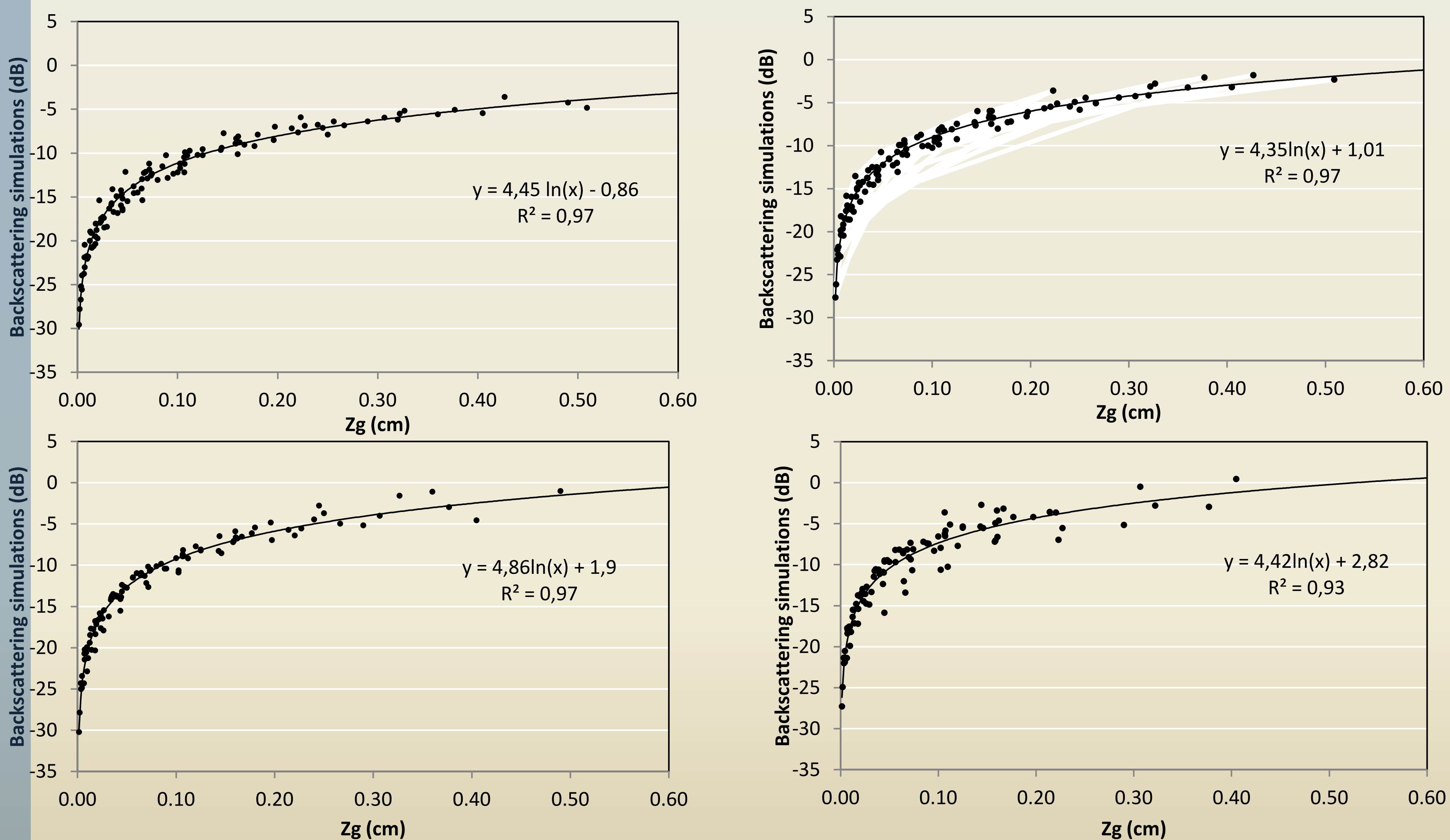
- The parameter *Zs* was initially proposed for use with an exponential correlation, and weaker correlations are observed between *Zs* and the simulated backscattering when other correlation function shapes are considered.
- Since the contribution of the ratio *s/l* must be different from one correlation shape to another, we propose to introduce a new parameter, which is a global representation of the *Zs* parameter, written as:

$$Zg = s \cdot \left(\frac{s}{l}\right)^{g(\alpha)}$$

The best correlation between the global roughness parameter *Zg* and the simulations was determined by least squares regression.

$$g(\alpha) \approx \alpha \quad \Rightarrow \quad Z_g = s\left(s/l\right)^{\alpha}$$

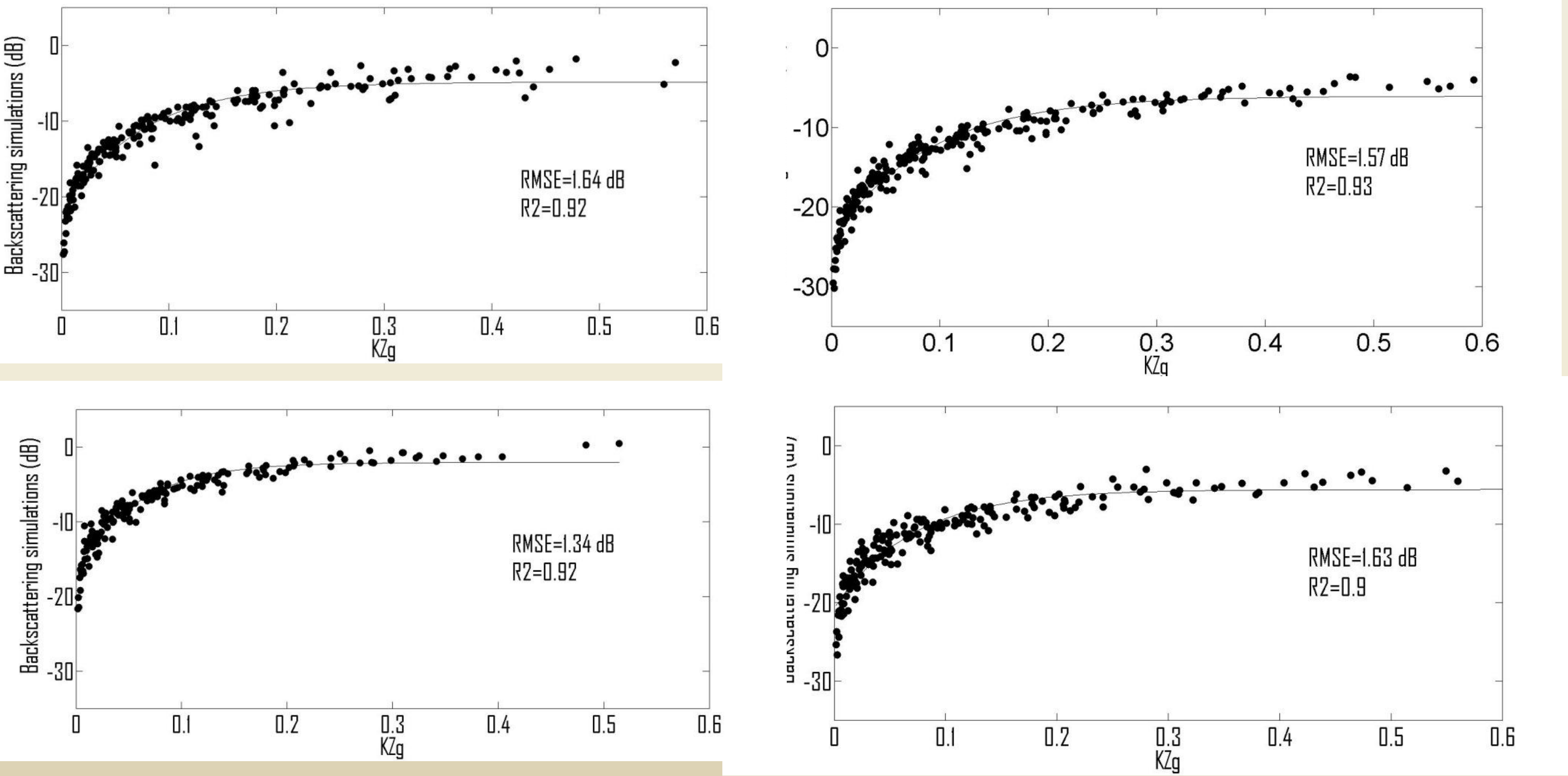
Relationships between Zg and backscattering simulations



Backscattering simulations in the *HH* polarisation at 40° incidence as a function of the parameter *Zg*, C band, *mv*=10%, b) C band, *mv*=30%, c) X band, *mv*=10%, d) X band, *mv*=30%

Relationships between K.Zg and backscattering simulations (C & X bands)

$$\sigma^0 = \alpha + \beta\left(1 - e^{-\mu\, k\, Zg}\right)$$



Backscattering simulations as a function of the parameter *kZg*, at 40°: a) *HH* pol, *mv*=10%, b) *HH* pol, *mv*=30%, c) *VV* pol, *mv*=10%, d) *VV* pol, *mv*=30%

Parameters and correlation coefficients for relationships between KZg and simulations

Configuration		α	β	μ	R^2	RMSE (dB)
Mv=10%	HH-20°	-16.14	12.34	23.71	**0.86**	**1.44**
	VV-20°	-15.11	10.21	38.31	**0.77**	**1.53**
	HH-40°	-24.19	18.13	11.27	**0.93**	**1.57**
	VV-40°	-20.71	15.10	14.02	**0.90**	**1.63**
Mv=20%	HH-20°	-14.15	12.11	22.81	**0.88**	**1.37**
	VV-20°	-12.54	10.68	33.41	**0.84**	**1.31**
	HH-40°	-22.57	17.87	11.28	**0.92**	**1.66**
	VV-40°	-21.04	15.46	15.48	**0.89**	**1.72**
Mv=30%	HH-20°	-13.05	12.01	22.95	**0.87**	**1.35**
	VV-20°	-11.09	10.86	32.26	**0.86**	**1.24**
	HH-40°	-22	-17.21	13.43	**0.92**	**1.64**
	VV-40°	-17.01	-14.92	17.65	**0.92**	**1.34**

Sites and data base

Campaign	Sensor	date	Configuration
Orgeval'94	SIRC	12/04/94 - 18/04/94	C band, HH, 44°
Pays de Caux'94	ERASME	February 1994	C and X bands, HH, VV 20°, 25°, 30°, 35°
Villamblain '03	ASAR/ENVISAT	October 2003	C band, HH, ~43°

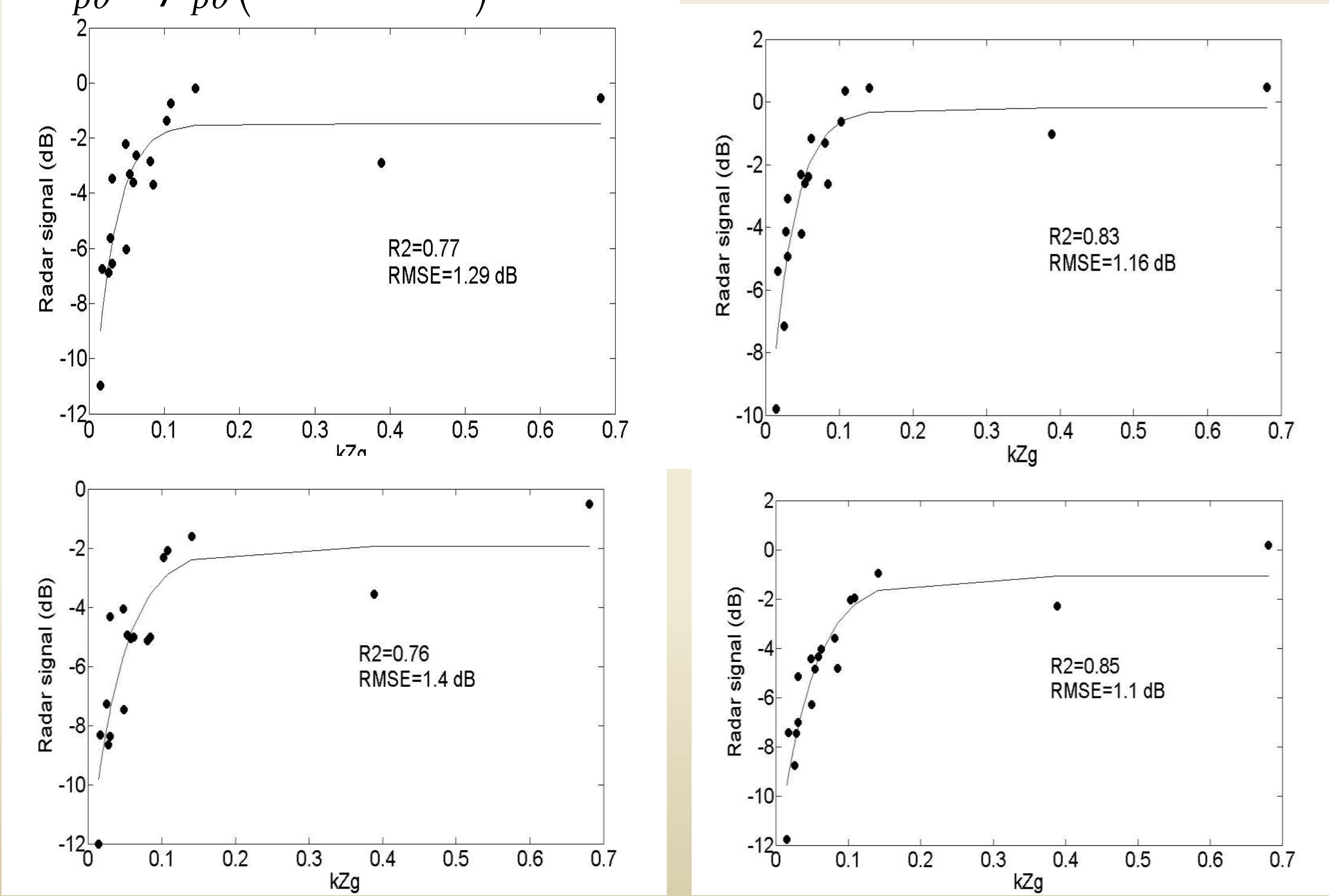
Ground measurements over test fieds:

•Roughness (pin-profiler)

•Moisture (gravimetric method or TDR probe)

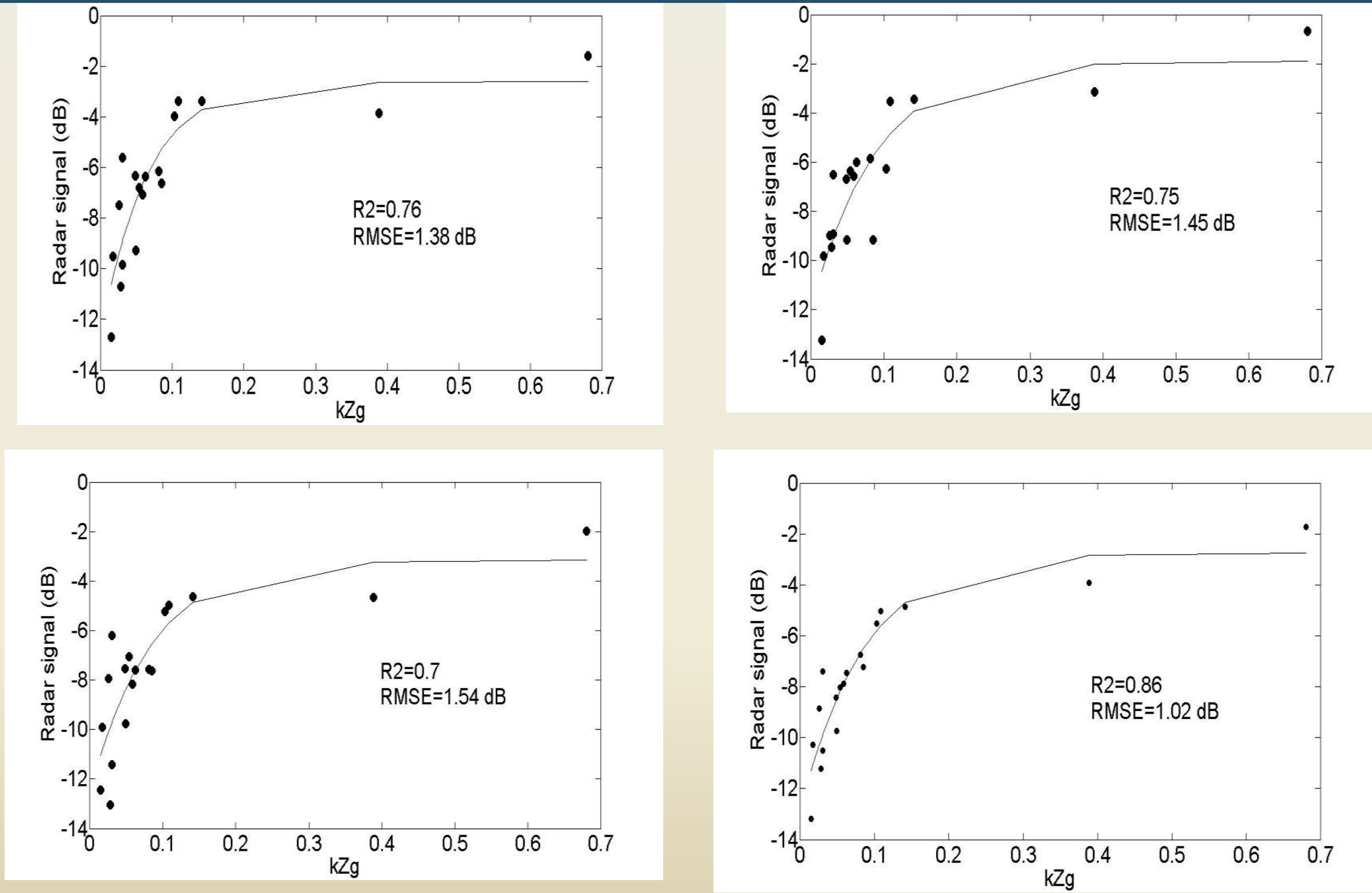
Relationships between KZg and measured radar data

$$\sigma^0_{p\theta} = \alpha_{p\theta} + \beta_{p\theta}\left(1 - e^{-\mu_{p\theta}\, k\, Zg}\right)$$



Relationship between *kZg* and measured radar signals, for: a) *HH* pol at 20°, b) *VV* pol at 20°, c) *HH* pol at 25°, d) *VV* pol at 25°

Relationships between KZg and measured radar data



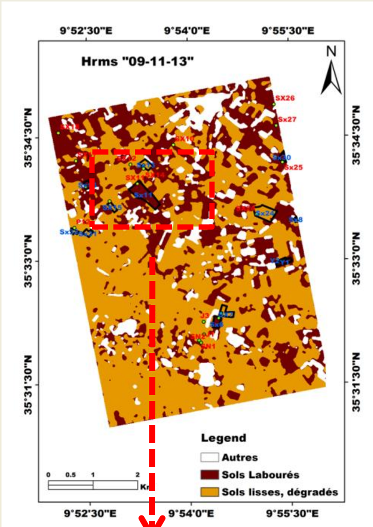
Relationship between *kZg* and measured radar signals, for: a) *HH* pol at 30°, b) *VV* pol at 30°, c) *HH* pol at 35°, d) *VV* pol at 35°

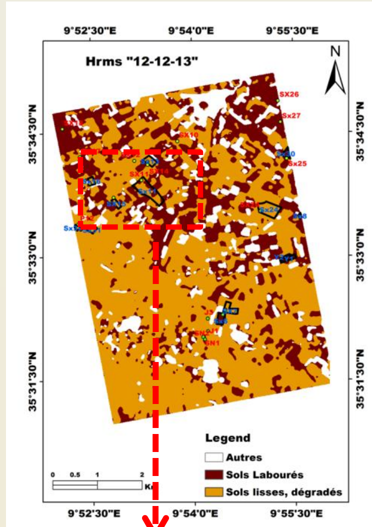
Zribi et al., RSE, 2014

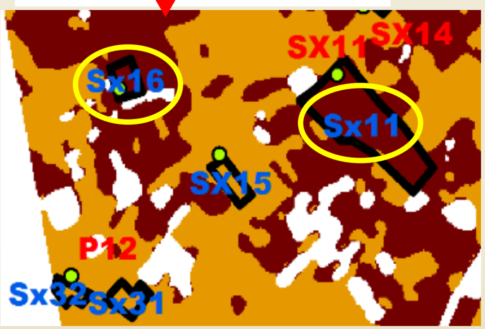
SOIL ROUGHNESS MAPPING

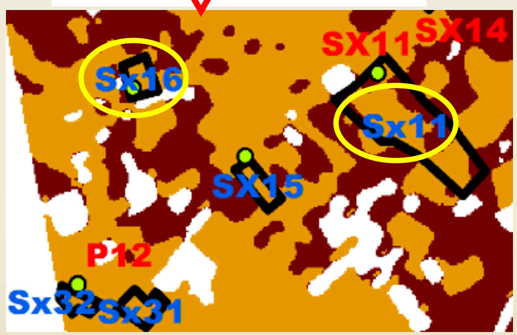
Gorrab et al., 2016

Soil roughness mapping (TERRASAR-X data









09/11/13

sx11

12/12/13

sx16

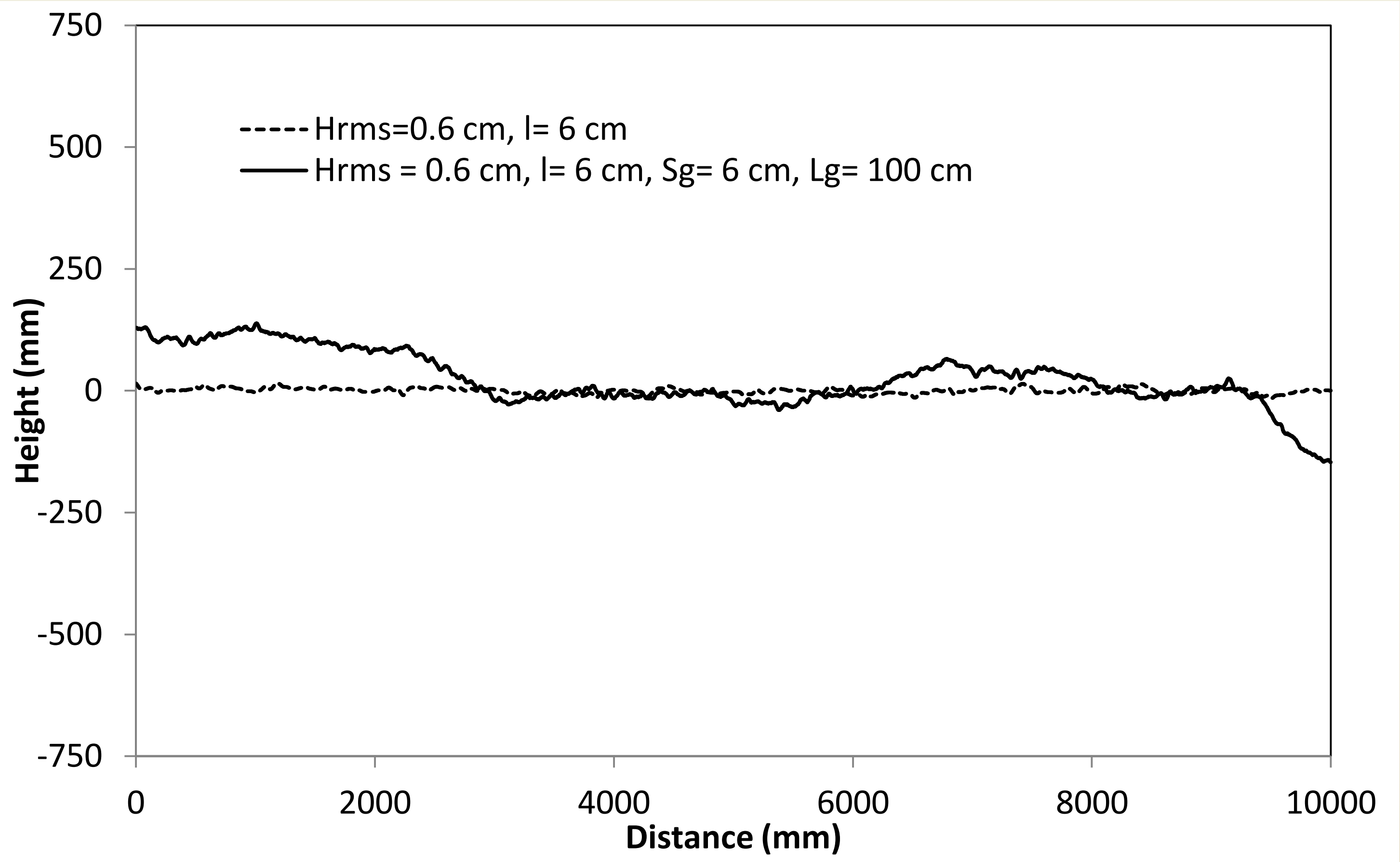
09/11/13

12/12/13

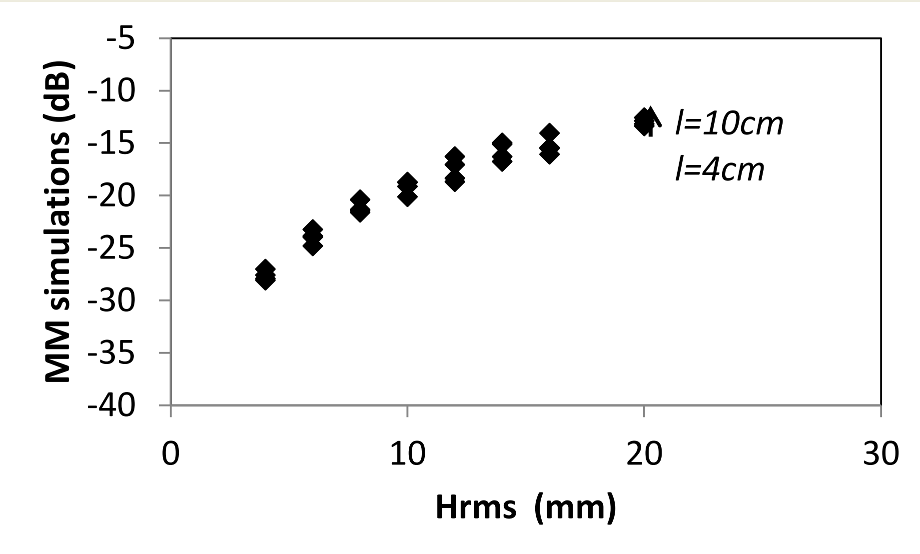
P band?

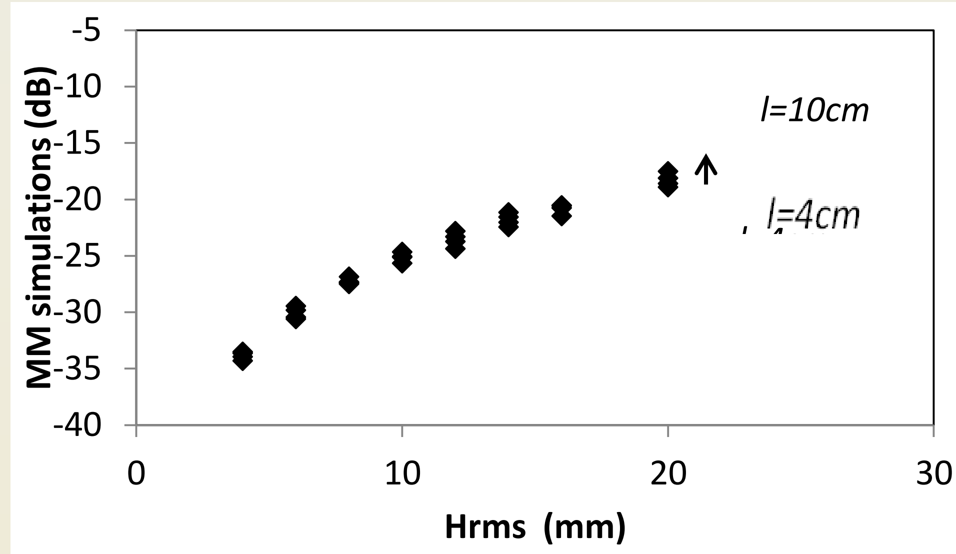
Multi-scale roughness

$$\rho(x) = Hrms^2 \exp\left(-\frac{x}{l}\right) + S_g{}^2 \exp\left(-\frac{x}{L_g}\right)$$



Small scale roughness

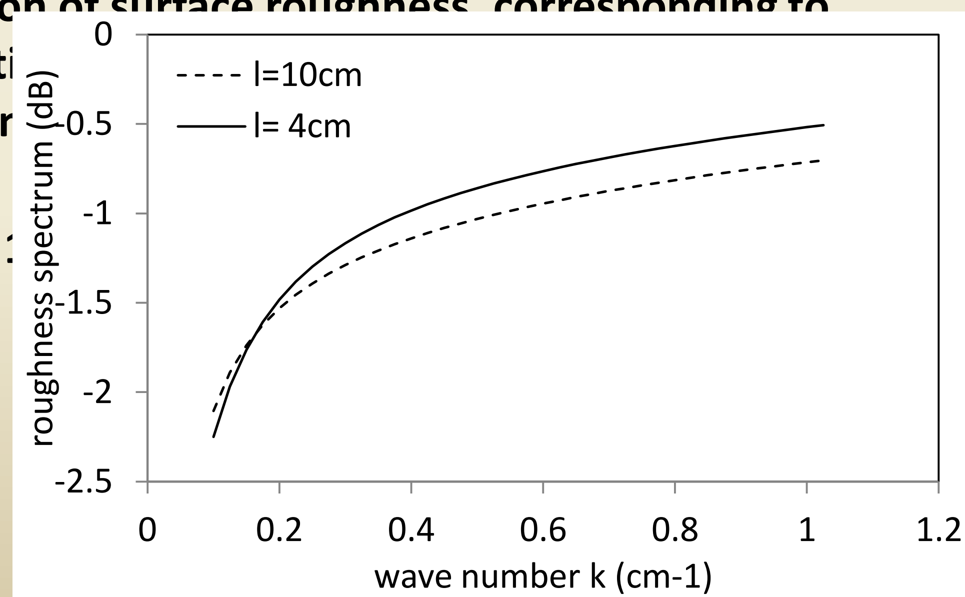




Backscattering simulations as a function of surface roughness, corresponding to microtopography (*Hrms)* with correlati ... lations are made at a 20° and 40° incidence ar

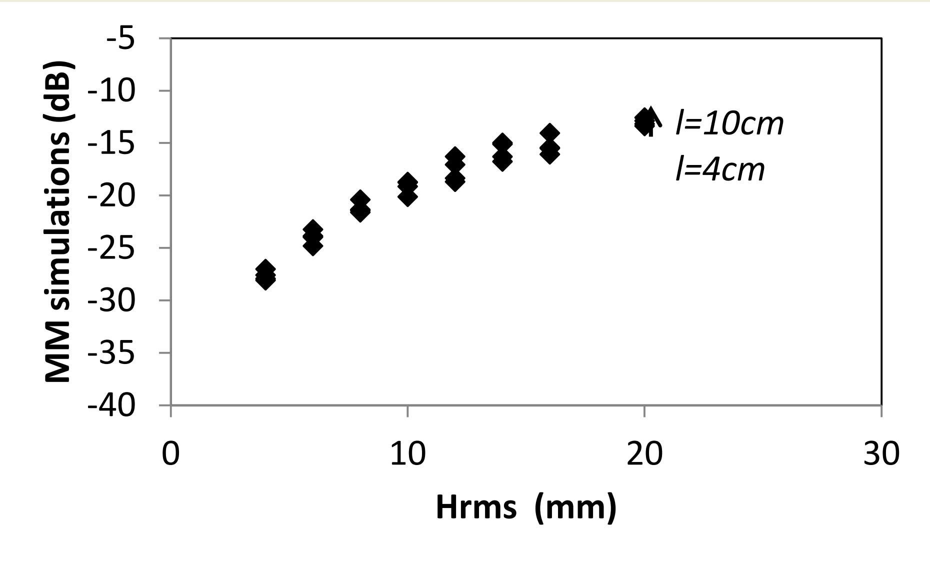
Hrms effect is dominant, less than 1

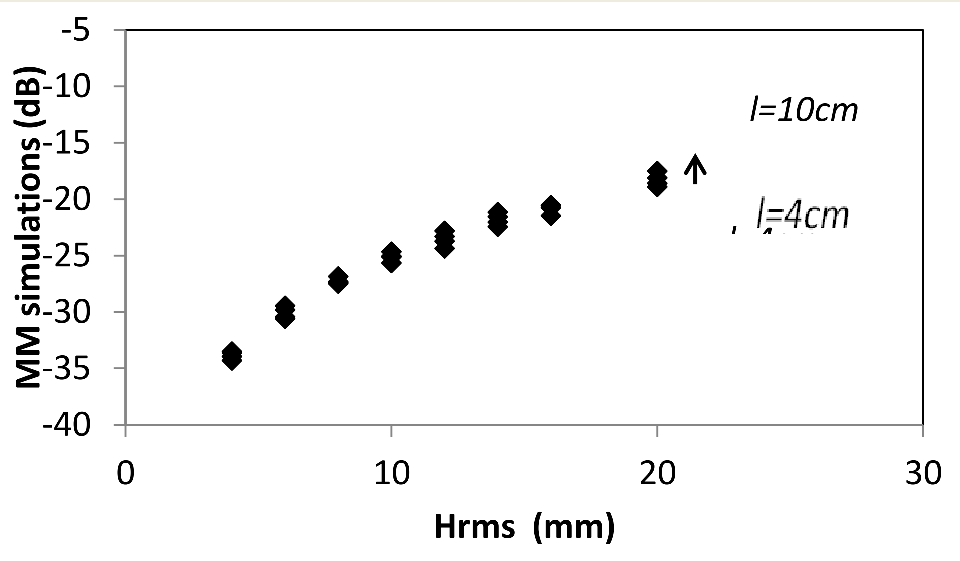
$$W = \frac{k^4 l^2 Hrms^2}{\left(1 + (2kl \sin\theta)^2\right)^{1.5}}$$



Exponential roughness spectrum as a function of wave number

Small scale roughness





Backscattering simulations as a function of surface roughness, corresponding to microtopography (*Hrms)* with correlati … lations are made at a 20° and 40° incidence ar …

Hrms effect is dominant, less than 1 …

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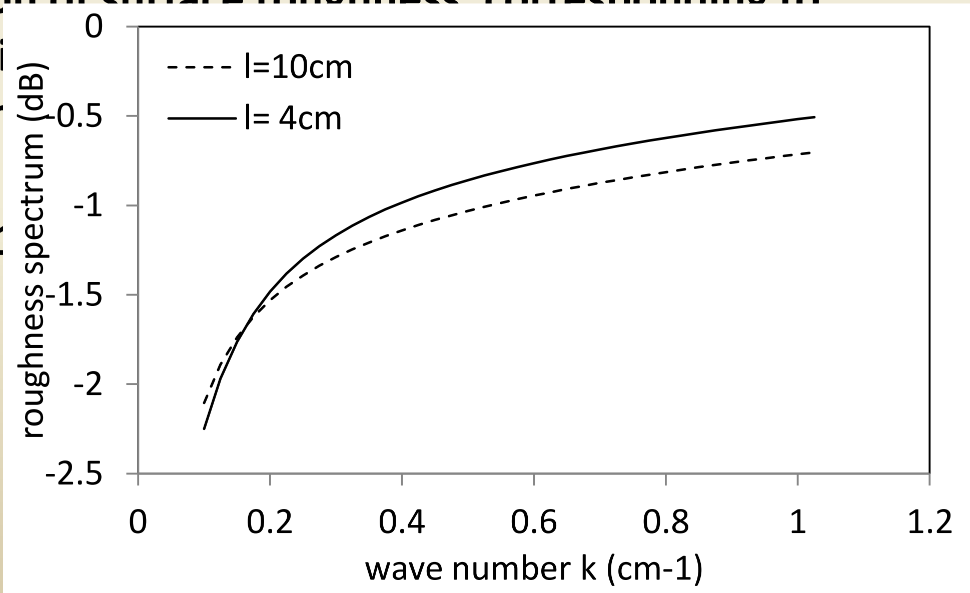
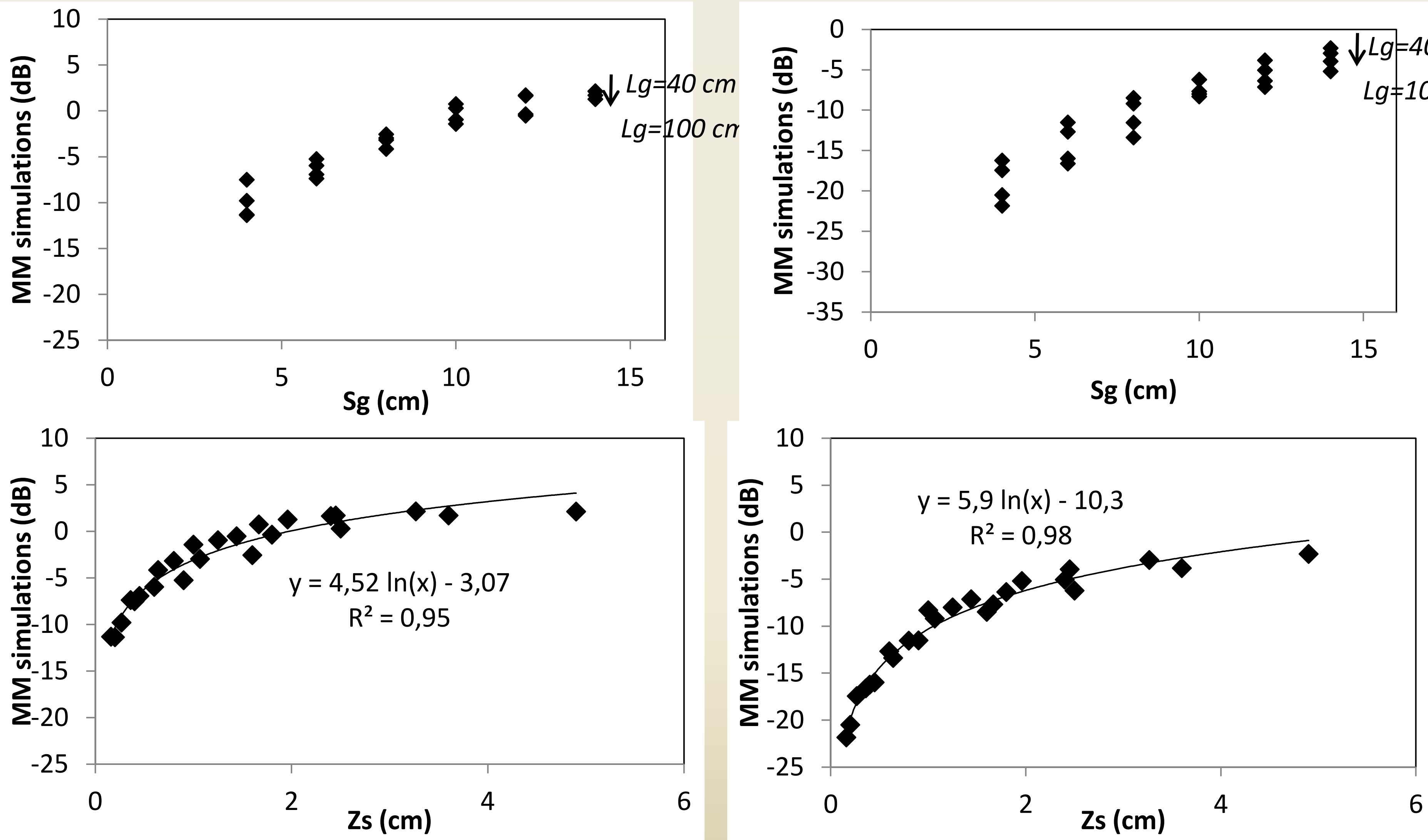


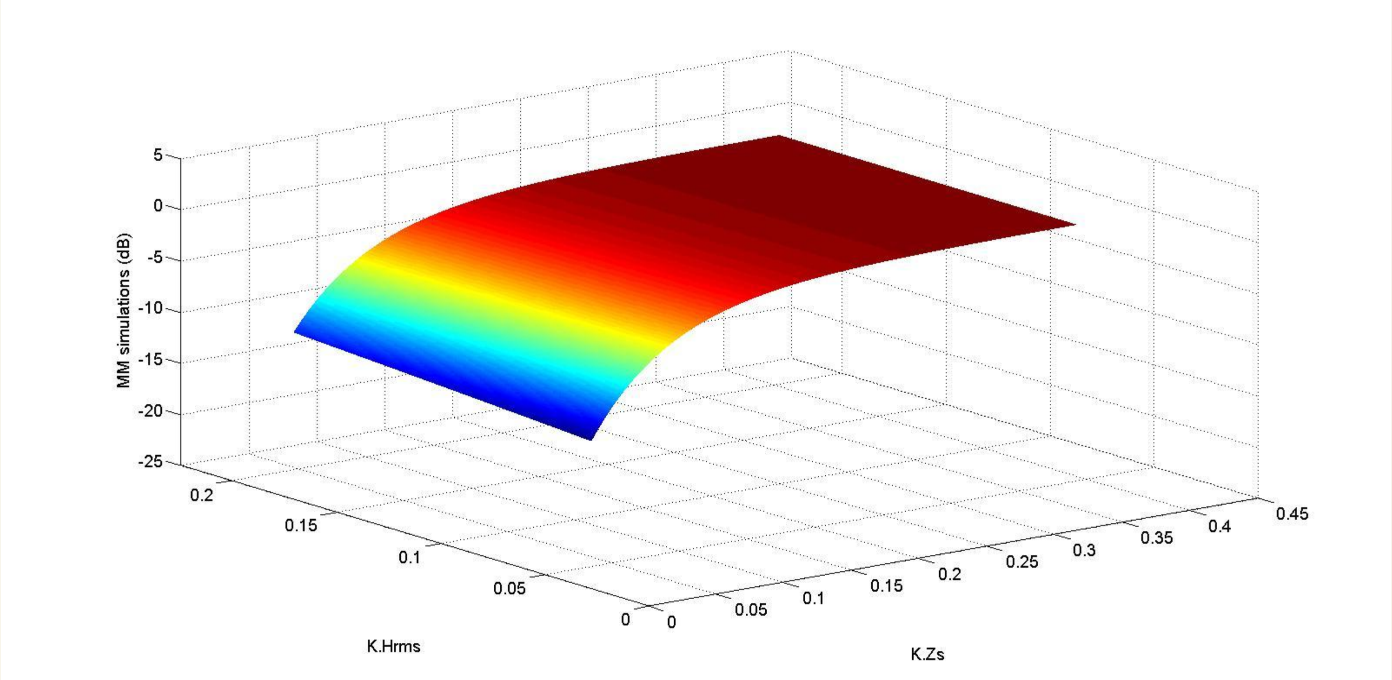
Exponential roughness spectrum as a function of wave number

Low roughness structures



Backscattering simulations as a function of surface roughness, corresponding in the case of a low spatial frequency rms height (Sg), with correlation lengths Lg equal to 40, 60, 80 and 100 cm. The simulations are made at a 20° and 40° incidence angles.

MM multiscale simulations



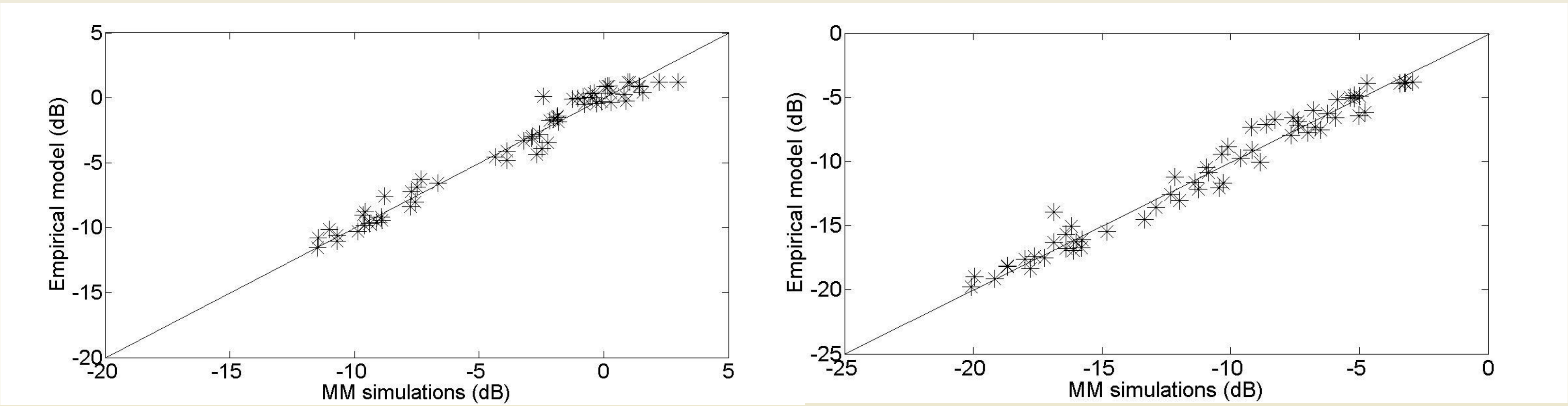
Limited effect of small roughness scale

Roughness spectrum is produced by the sum of two independent exponential spectra corresponding to the small, and to the low spatial frequency, roughness scales described above.

Comparison between MM and empirical simulations

Empirical relationship σ=f(Hrms, Zs)

$$\sigma^0 = \alpha_{\theta,p} + \beta_{\theta,p}\left(1 - e^{-\left(\mu_{\theta,p}\, k\, Zs + \gamma_{\theta,p} kHrms\right)}\right)$$



The empirical model is validated for all of the roughness conditions analyzed by the moment method simulations, in which K.Hrms ranges between 0.036 and 0.18, and K.Zs ranges between 0.015 and 0.45.

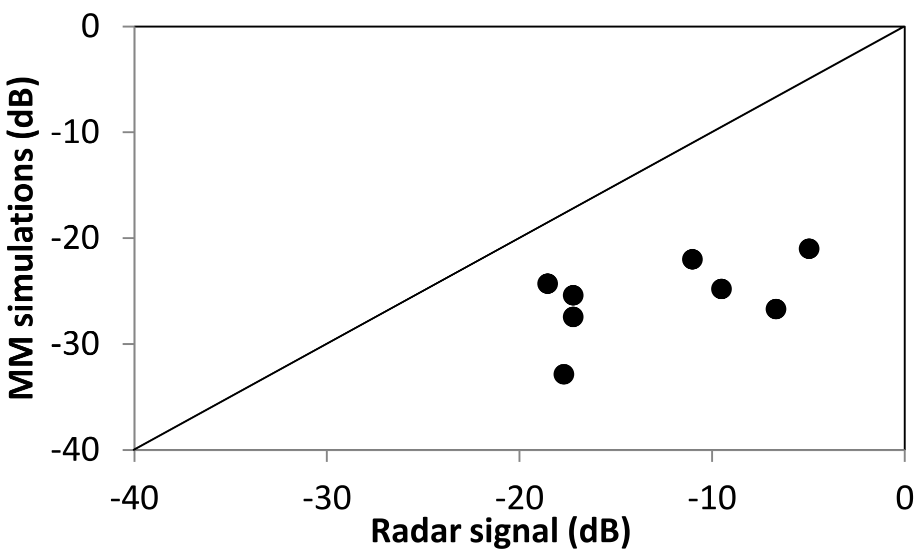
Analysis of real data over agricultural soils

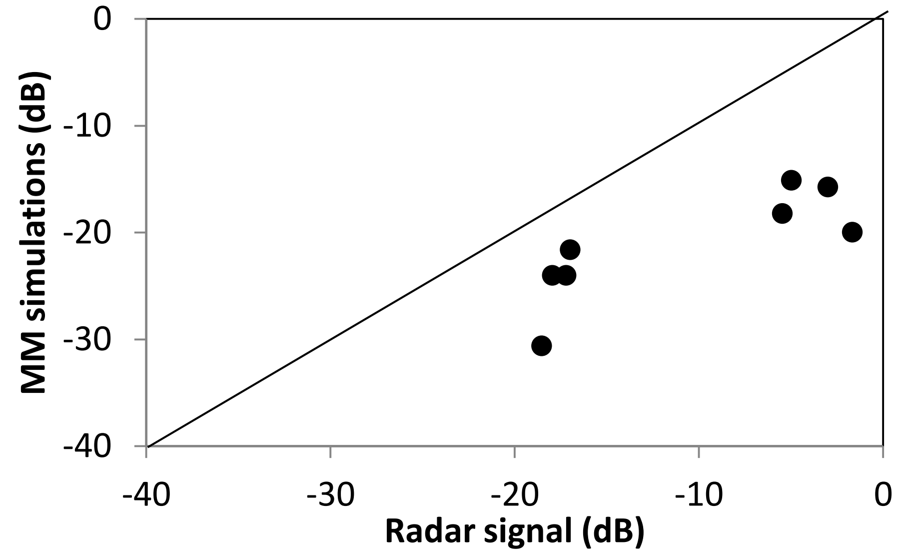
Bordeaux site: this site is located in the southwest of France. The soil is comprised of approximately 19% silt, 29% clay, and 51% sand. On January 21, 2004, fully polarimetric P-band radar data (435 MHz) was acquired by the airborne RAMSES SAR,

Garons site: this site is located near to Nîmes in the South of France. The soil is stony, and is comprised of 54% silt, 40% clay, and 6% sand. Fully polarimetric radar data were acquired in the UHF-band (360 MHz, spatial resolution approximately 0.75 m) on October 4th, 2011,

Study site	Plot number	θ (°)	m_v (vol%)	*Hrms* (cm)	*l (cm)*
Bordeaux	Bare soil (B1)	53°	26.9	1.89	4.33
	Bare soil (B2)	47°	46.9	0.88	3.22
	Bare soil (B3)	50°	32.9	1.31	3.95
	Bare soil (B4)	52°	39.4	1.69	4.30
Garons	Bare soil (G1)	43°	4	1.56	4.80
	Bare soil (G2)	45°	4.3	1.40	3.34
	Bare soil (G3)	34°	4.4	0.59	3.27
	Bare soil (G4)	46°	2.8	1.25	3.80

Comparison betwee real radar data and MM simulations



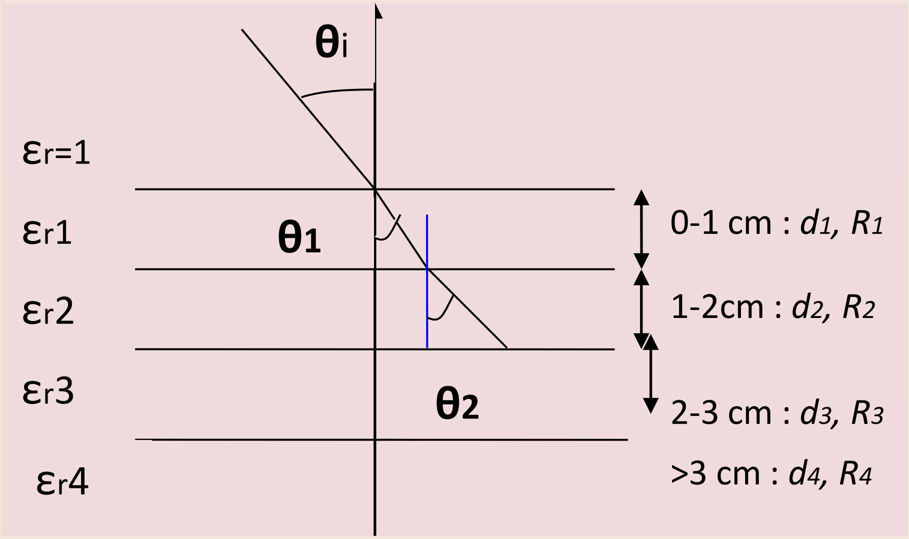


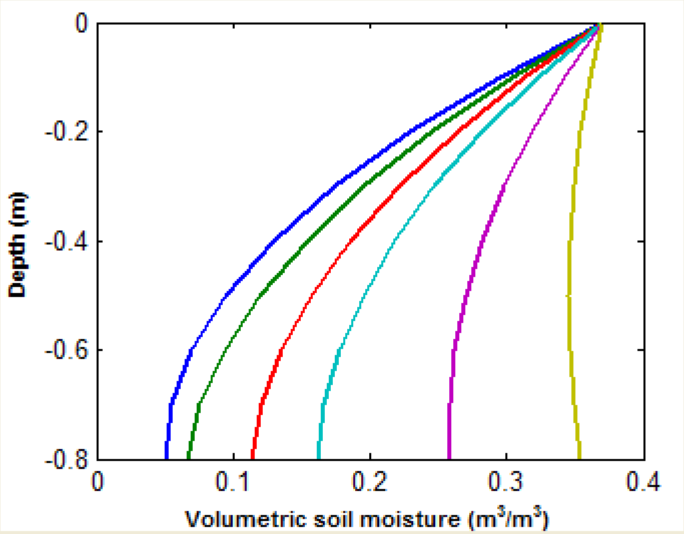
Simulated MM radar signals as a function of measured radar signals over agricultural fields, a) HH pol (b) VV pol

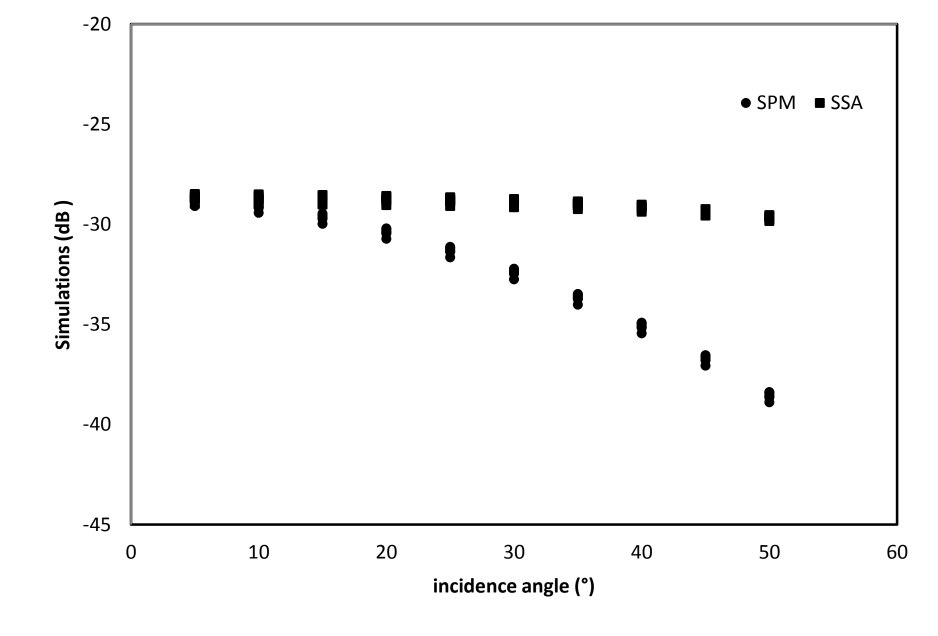
High discrepency between measurements and simulations

- Effect of low scale struture
- Effect of volume scattering
- Effect of vertical moisture heterogeinity

Results discussion, moisture heterogeneity



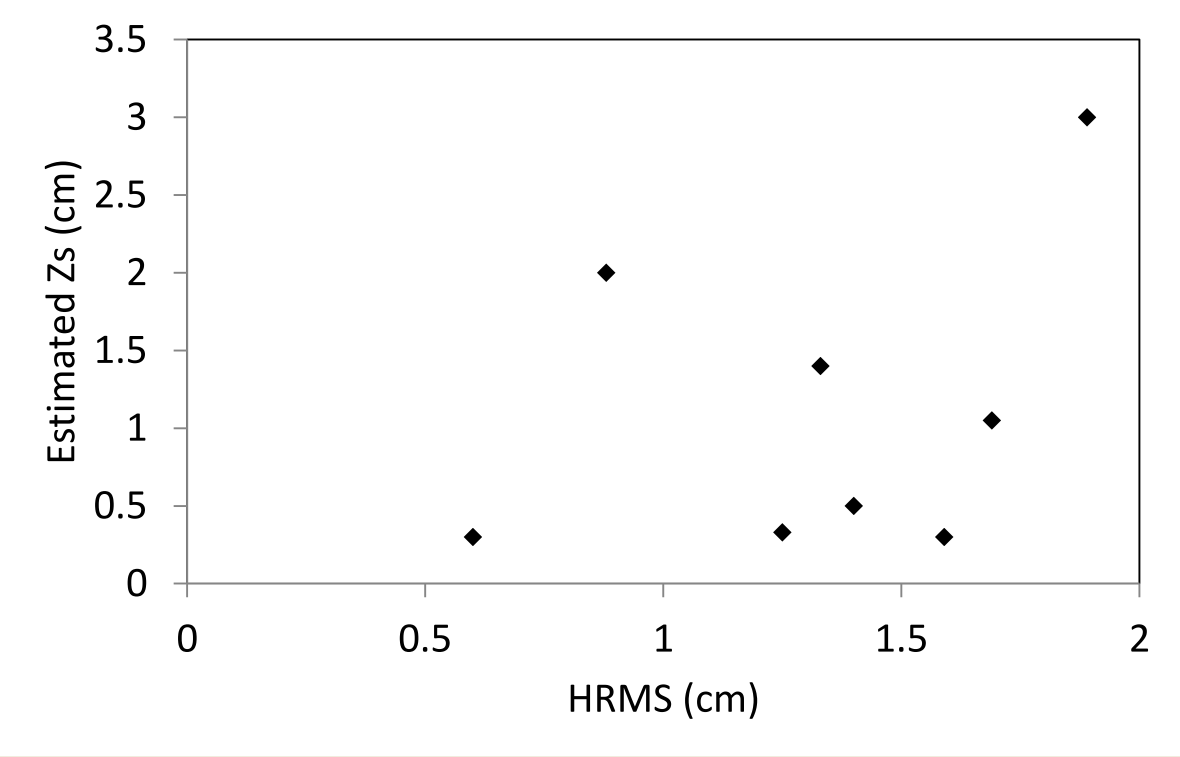




- **Limited effect, lower than 1.5 dB**

Retrieving of Zs low scale parameters for test fields

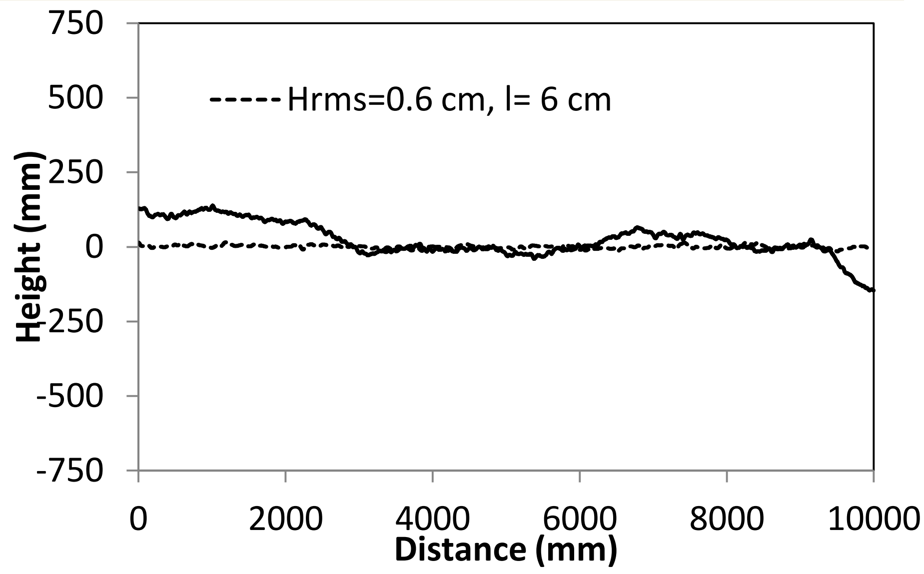
In the absence of ground truth measurements allowing the real value of low spatial frequency roughness to be determined, the proposed empirical model described before is used here, to retrieve the roughness parameter Zs corresponding to eight test fields.

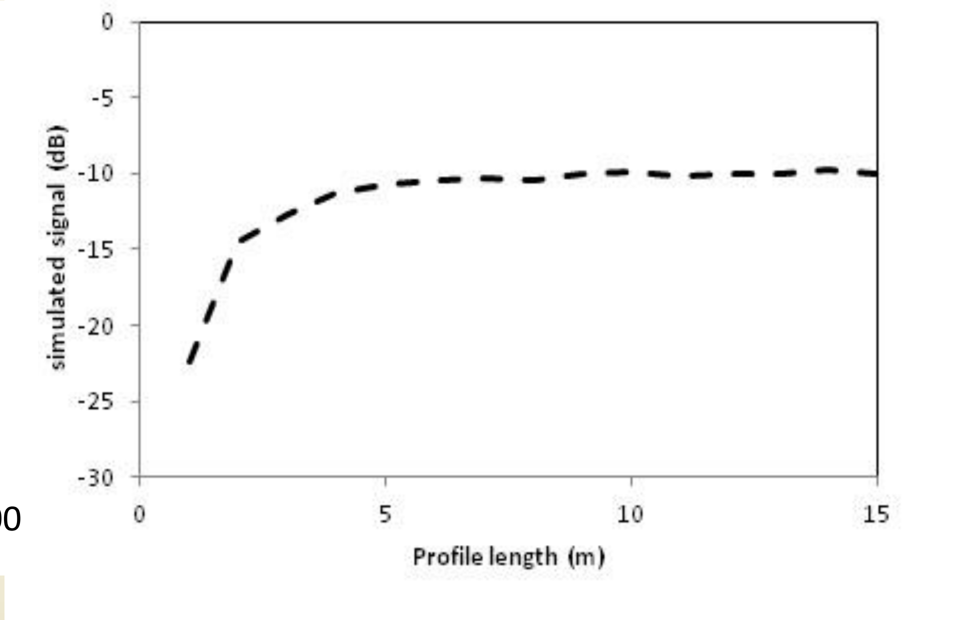


Estimated values of Zs, plotted as a function of the in situ values of Hrms measured on eight test fields

(Zribi et al., RSE, 2016)

Results discussion, errors due to profile length





- **Decreasing error with increasing of height profiles**

Conclusions

- Roughness is a key parameter in soil backscattering analysis
- Introduction of different parameters particularly useful for radar signal inversion (Zs, Zg etc)
- Principal roughness parameters to describe P-band radar signal over soil, Hrms for small scales and Zs for low frequency scale
- Limited effect of small scale compared to low scale

CESBIO

Thank you for your attention!