Dependence of Polarimetric Surface Scattering on Spatial Resolution

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INTRODUCTION

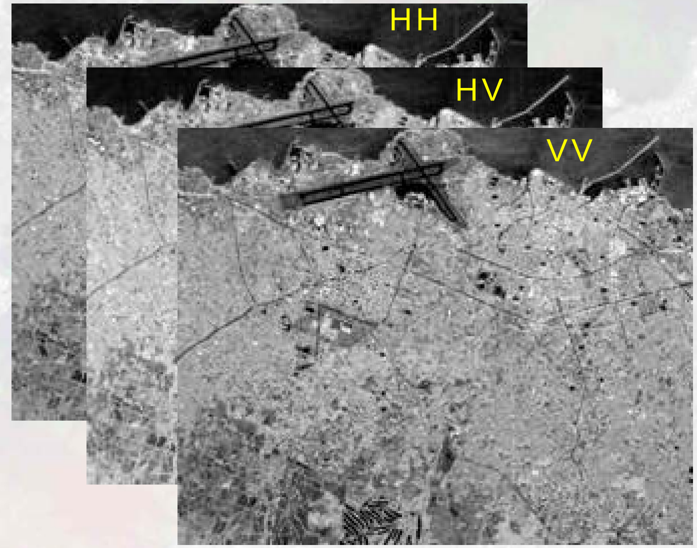
Geophysical Parameters

- **Surface Roughness**
- **Soil Moisture**

Forward Model F

Inverse Model F^{-1}

Polarimetric SAR Data



$$\Theta = \{ \text{Dielectric constant, Height distribution, Autocorrlation} \}$$

- **Nonlinear Forward Mapping** $F(\Theta) \rightarrow \Omega$

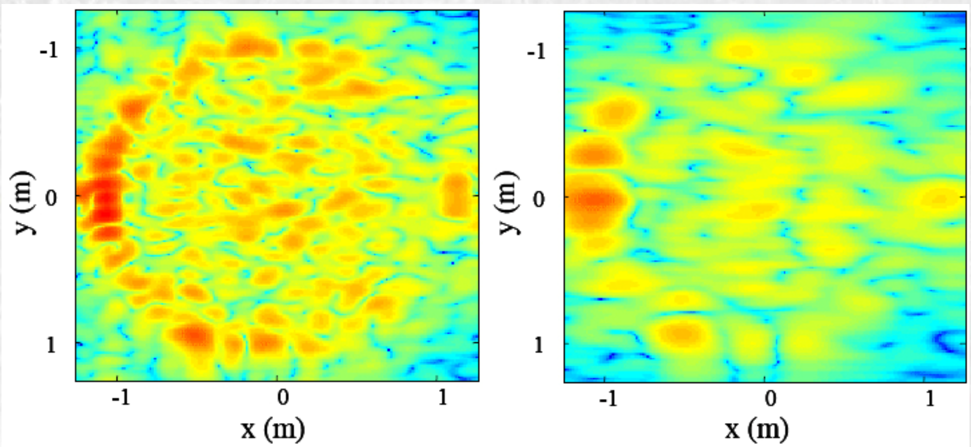
$$\Omega = \{ \text{Independent combination of polarization measurements} \}$$

→ **Finding the set of unknown surface parameters from polarization measurement**

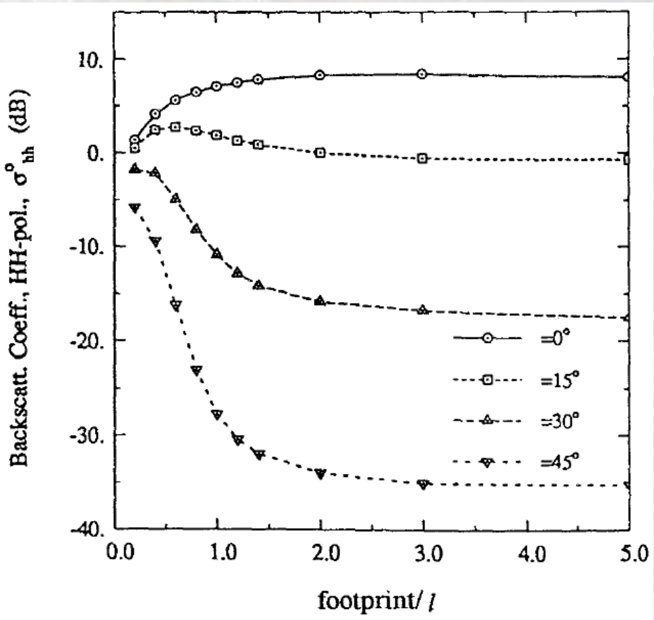
$$\overline{\Theta} = F^{-1}(\Omega)$$

INTRODUCTION

[Nesti et al., 1996; Allain et al. 2003]



[Sarabandi and Oh, 1995]



■ Aims of the study

Understanding the effects of the spatial resolution of the radar sensor on
1) the statistical description of surface roughness properties
2) the surface backscattering characteristics
particularly for the high resolution polarimetric radar systems.

Random Surface Parameters

Height Probability Distribution	Autocovariance (Autocorrelation)
Zero mean Gaussian characterized by its RMS height $\sigma = \sqrt{\langle z(x)^2 \rangle - \langle z(x) \rangle}$	$R(l) = \langle z(x) z(x+l) \rangle - \langle z(x) \rangle$ $R_N(l) = R(l)/R(0) = R(l)/\sigma^2$ $R_N(l_C) = 1/e$

✓**Essential to** define an appropriate **mathematical function for the autocovariance**

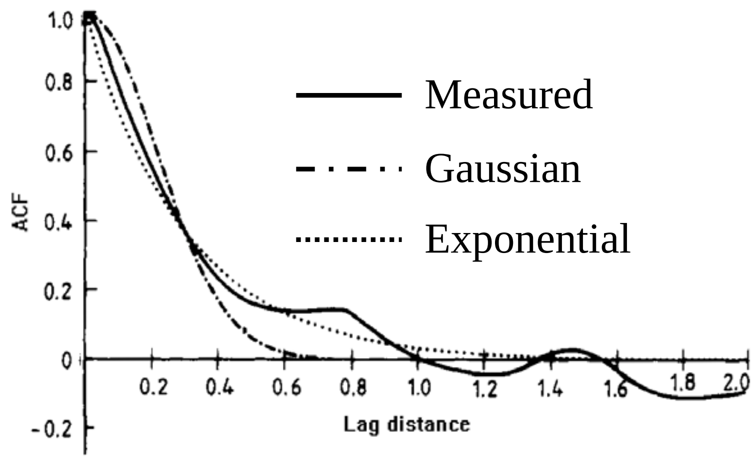
- The commonly used Autocovariance Functions (ACVF) are Gaussian and Exponential

$$\begin{cases} R(l)_G = \sigma^2 \exp[-l^2 / l_C^2] \\ R(l)_E = \sigma^2 \exp[-|l|/l_C] \end{cases}$$

Correlation length does not define the types of ACF

- Roughness Power Spectral Density (PSD)

$$\begin{cases} W(K)_G = FT\{R(\tau)_G\} = \sigma^2 \sqrt{\pi} l_C \exp[-l_C^2 K^2 / 4] \\ W(K)_E = FT\{R(\tau)_E\} = \sigma^2 2 l_C [1 + l_C^2 K^2]^{-1} \end{cases}$$



Roughness for Truncated Surface

✓ Statistical properties of random rough surfaces are affected by the spatial resolution of the radar sensor.

- Autocovariance of the infinite surface

$$R(l) = \langle [z(x)-\mu][z(x+l)-\mu] \rangle = \left\langle \lim_{L_x \to \infty} \frac{1}{L_x} \int [z(x)-\mu][z(x+l)-\mu] dx \right\rangle$$

- **Autocovariance defined in a range L_x**

$$\rho(l) = \left\langle \frac{1}{L_x} \int [z(x)-\bar{z}][z(x+l)-\bar{z}] dx \right\rangle$$

$$= (1-|l|/L_x) R(l) - (1-|l|/L_x) \mathrm{var}(\bar{z})$$

$$\mathrm{var}(\bar{z}) = \langle (\mu-\bar{z})^2 \rangle = \frac{2}{L_x} \int_0^{L_x} (1-|t|/L_x) R(t) dt$$

Roughness for Truncated Surface

Autocovariance Function of Truncated Surface (ACVFT)

$$\rho(l) = \left(1 - |l|/L_x\right)\left\{R(l) - \mathrm{var}(\bar{z})\right\}$$

Gaussian ACVFT

$$\rho(l)_G = \left(1 - \frac{|l|}{L_x}\right)\left\{\sigma^2 \exp\left[-\frac{l^2}{l_C^2}\right] - G\right\}$$

$$G = \sigma^2\left\{\alpha^2\left(\exp[\alpha^{-2}] - 1\right) + \alpha\sqrt{\pi}\,\mathrm{Erf}\left[\alpha^{-1}\right]\right\}$$
$$\alpha = l_C / L_x$$

Gaussian PSDT

$$S(K)_G = W(K)_G \otimes L_x \mathrm{sinc}^2(L_x K) - L_x G\,\mathrm{sinc}^2(L_x K)$$

Exponential ACVFT

$$\rho(l)_E = \left(1 - \frac{|l|}{L_x}\right)\left\{\sigma^2 \exp\left[-\frac{|l|}{l_C}\right] - H\right\}$$

$$H = 2\sigma^2\left\{\alpha^2\left(\exp[\alpha^{-1}] - 1\right) + \alpha\right\}$$
$$\alpha = l_C / L_x$$

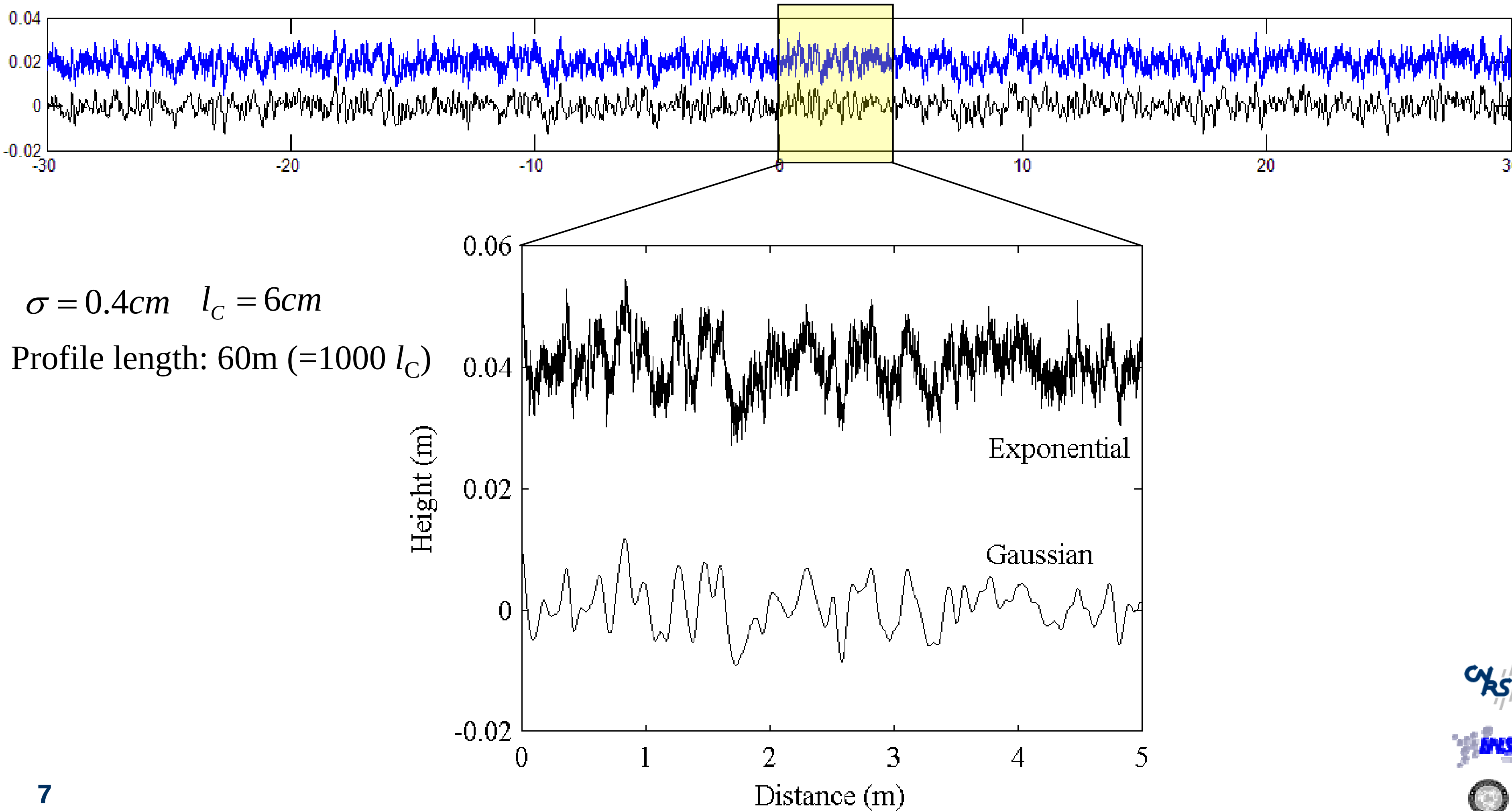
Exponential PSDT

$$S(K)_E = W(K)_E \otimes L_x \mathrm{sinc}^2(L_x K) - L_x H\,\mathrm{sinc}^2(L_x K)$$

Gaussian and Exponential ACVFT

- Numerical Generation

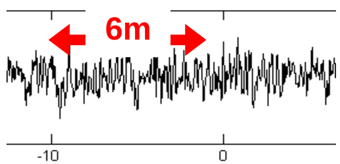
→ Gaussian and Exponentially Correlated Rough Surface

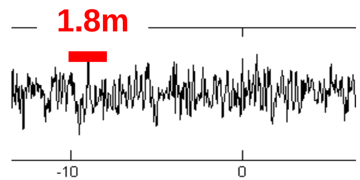


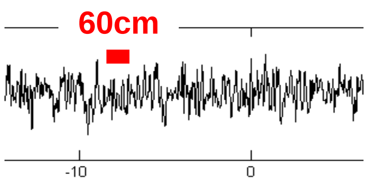
$\sigma = 0.4cm \quad l_C = 6cm$

Profile length: 60m (=1000 l_C)

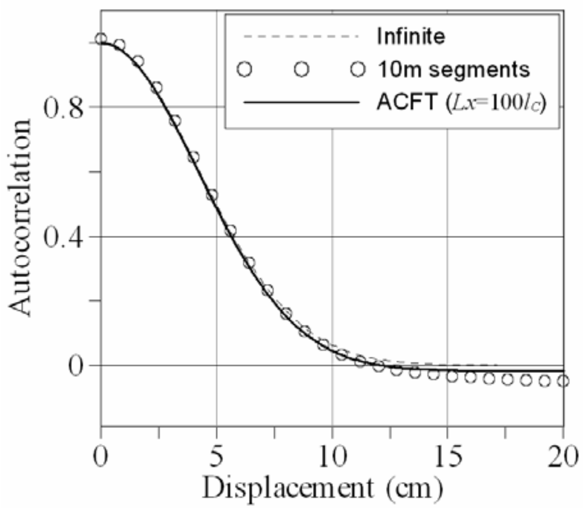
ACFT of Simulated Surface

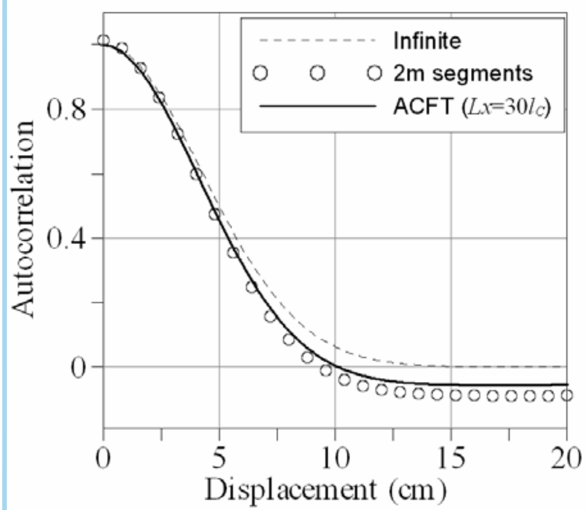


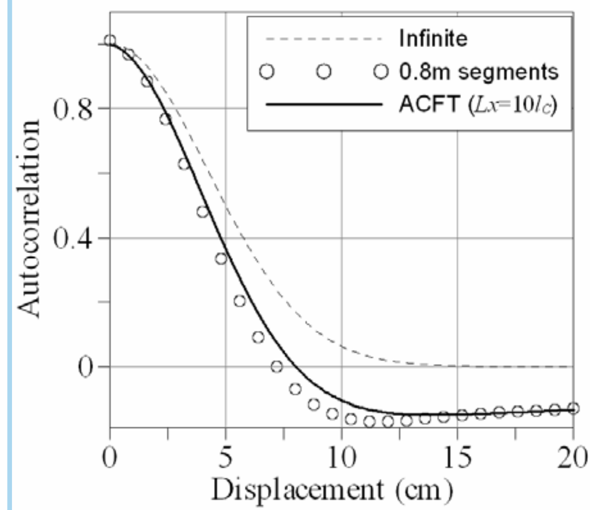




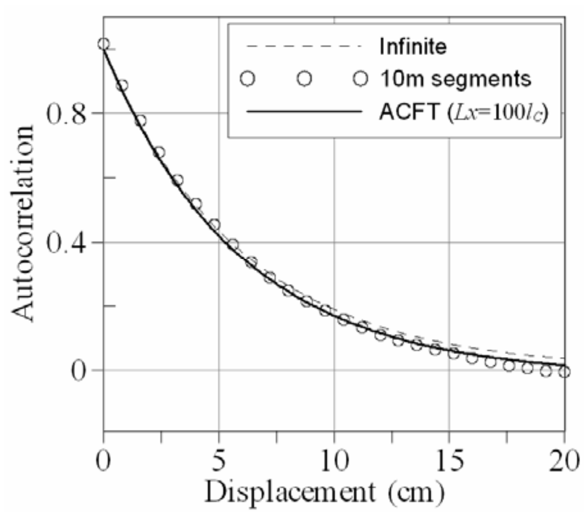
Gaussian

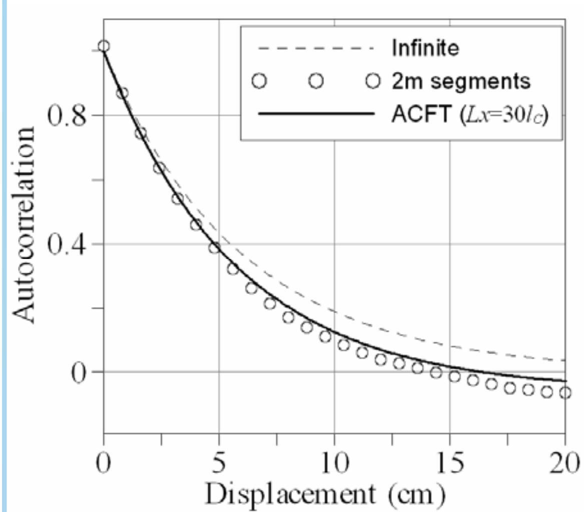


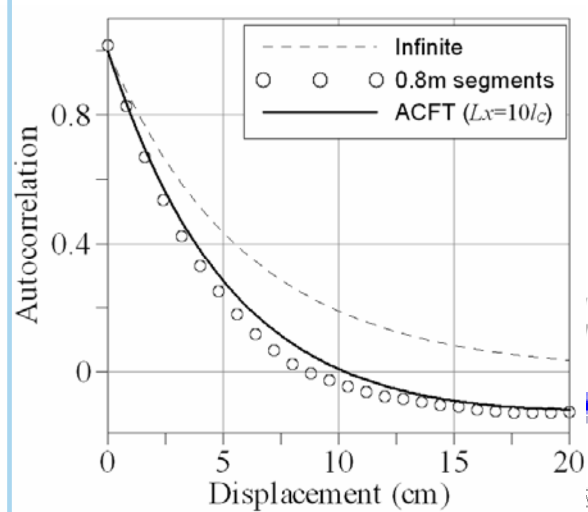




Exponential

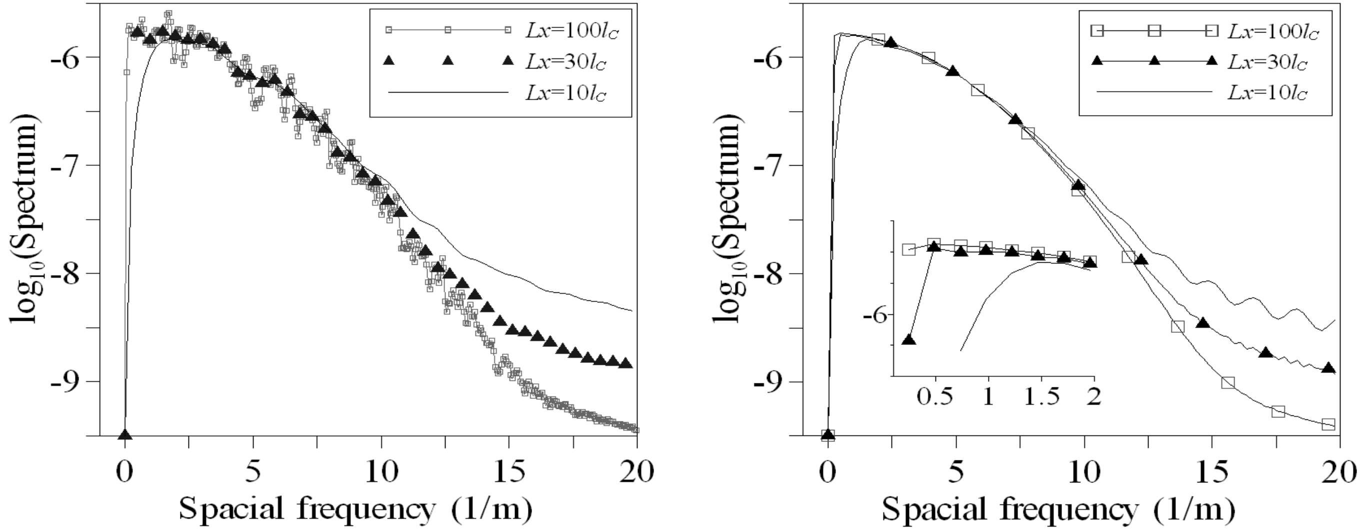




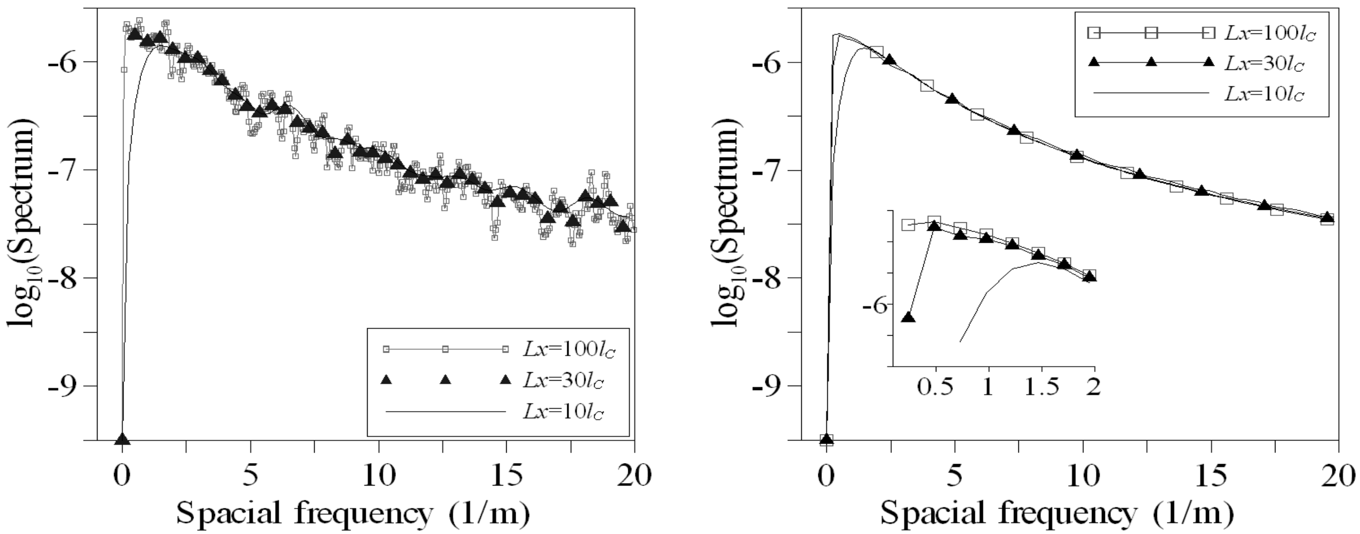


PSDT of Simulated Surface

Gaussian



Exponential



- The roughness power spectrum is band limited by a size of the resolution cell

$$f_c = \frac{1}{L_x}$$

SAPHIR

➢ Integral Equation Method

[Fung, 1992; 1994; Wu et al., 2001]

$$S(K) = W(K) \otimes L_x \mathrm{sinc}^2(L_x K) - L_x G\, \mathrm{sinc}^2(L_x K)$$

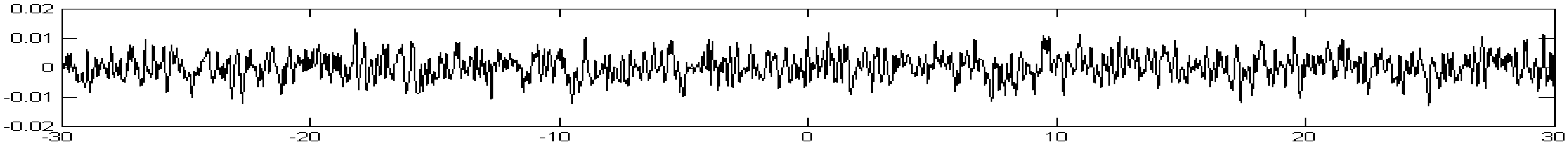
$$\sigma_{pq}^0 = \frac{k^2}{2} \exp\left[-2(kh\cos\theta)^2\right] \sum_{n=1}^{\infty} \left|I_{pq}^n\right|^2 \frac{S^{(n)}(-2k\sin\theta)}{n!}$$

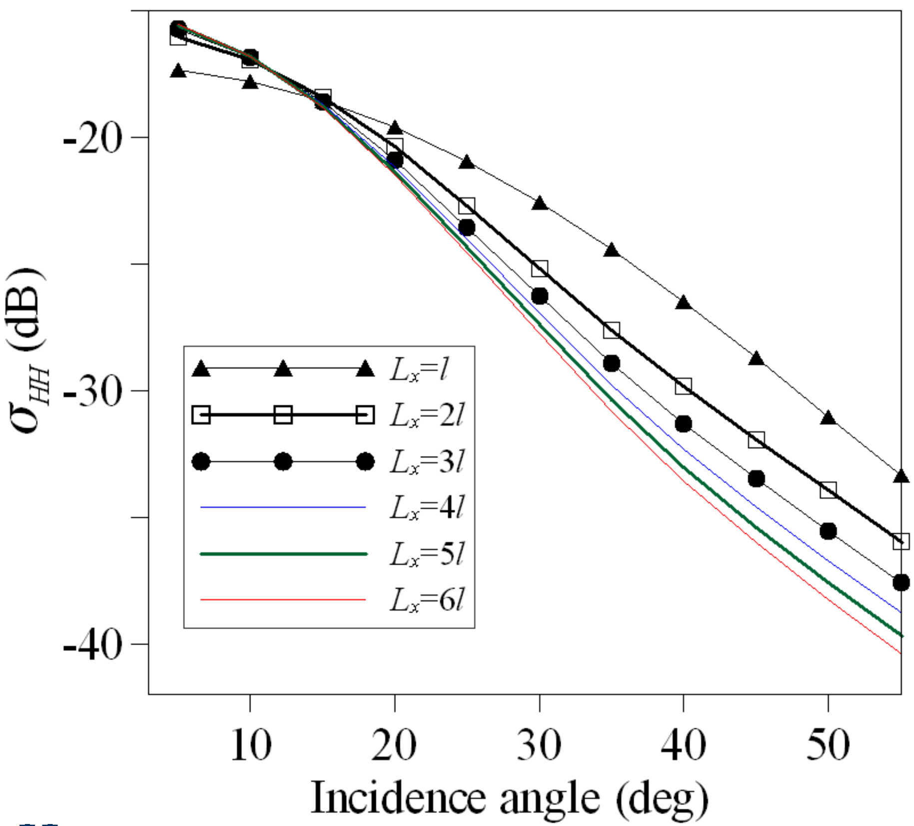
$$h = \sqrt{\sigma^2 - G(\alpha)}$$

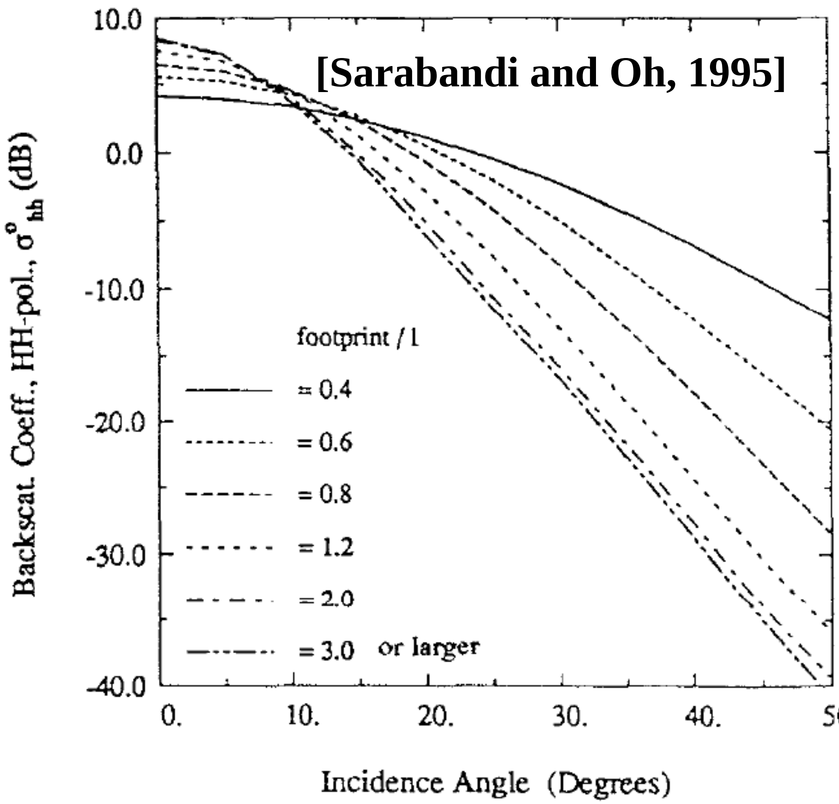
$$f\,(\mathit{Fresnel\ reflectivity})$$

Backscattering Simulations

- Dependence of backscattering coefficients on the spatial resolution for the generated rough surface $\sigma = 0.4cm,\ l = 6cm$



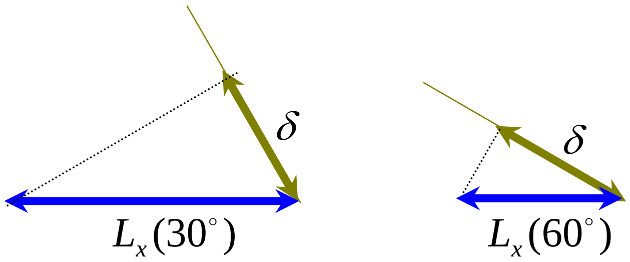


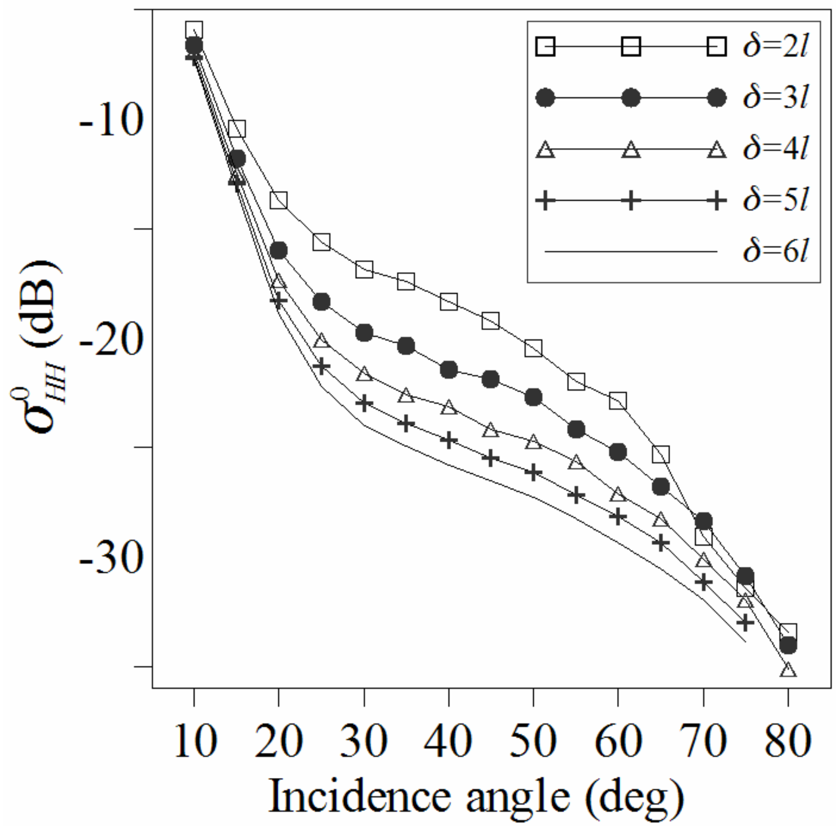


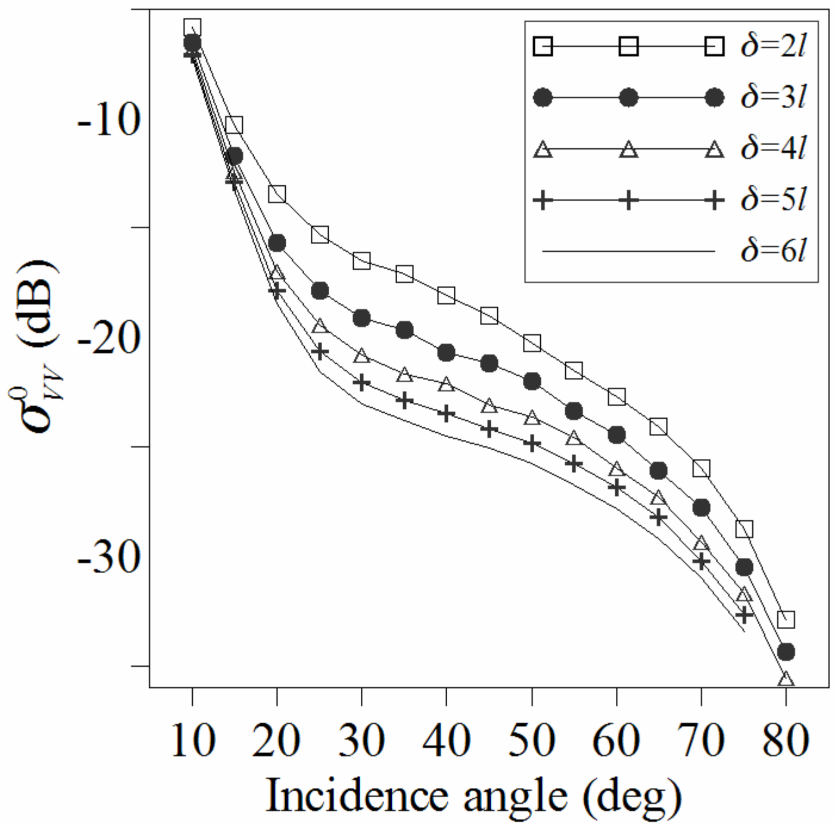
Backscattering Simulations

✓ Spatial resolution on the Earth's surface

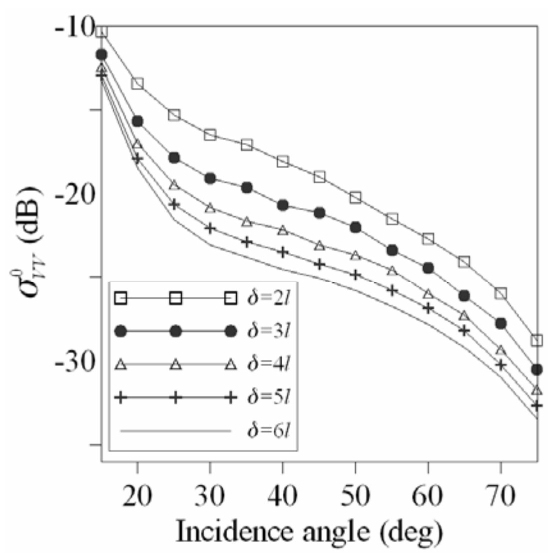
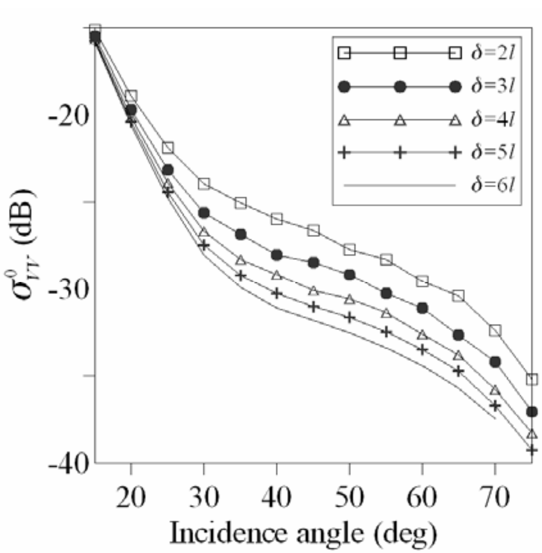
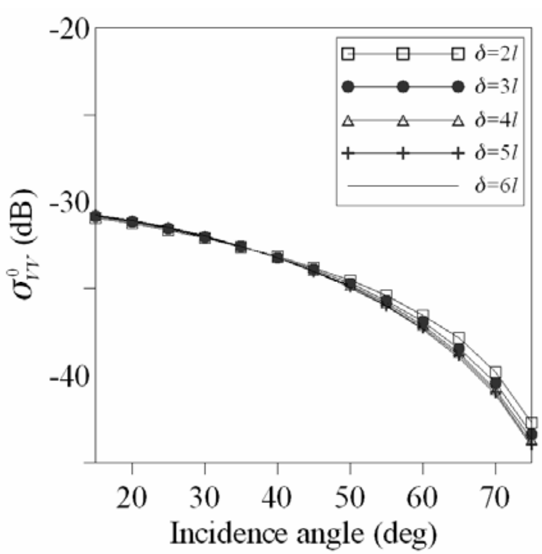
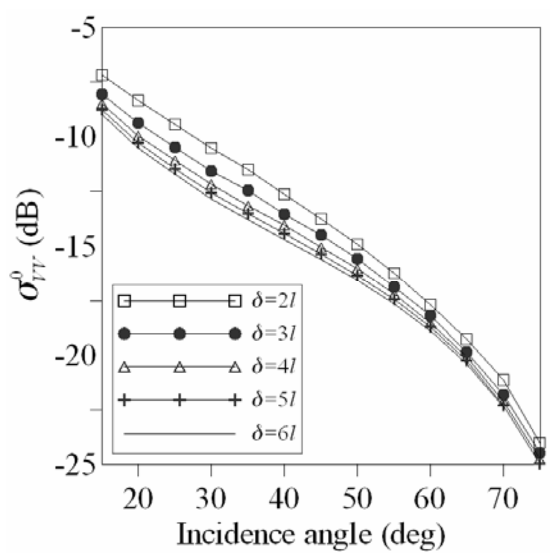
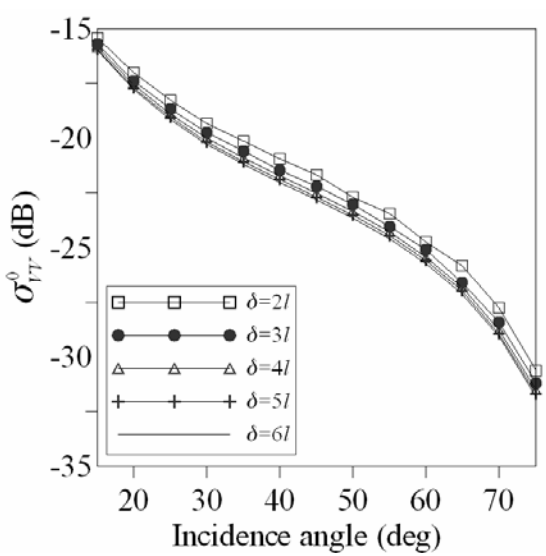
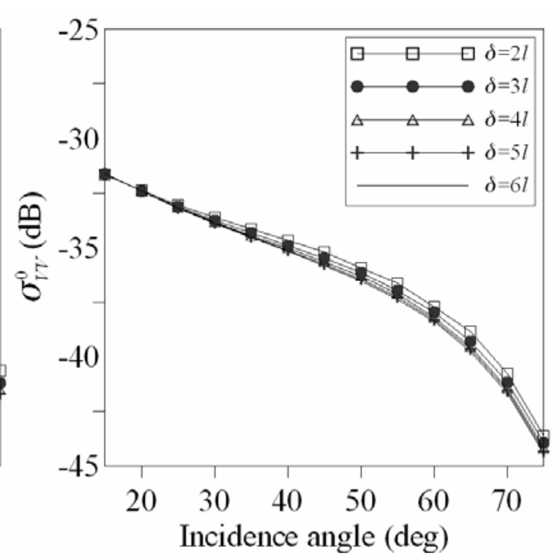
$$L_x = \frac{\delta}{\sin\theta} = \frac{c}{2B\sin\theta}$$







Backscattering Simulations

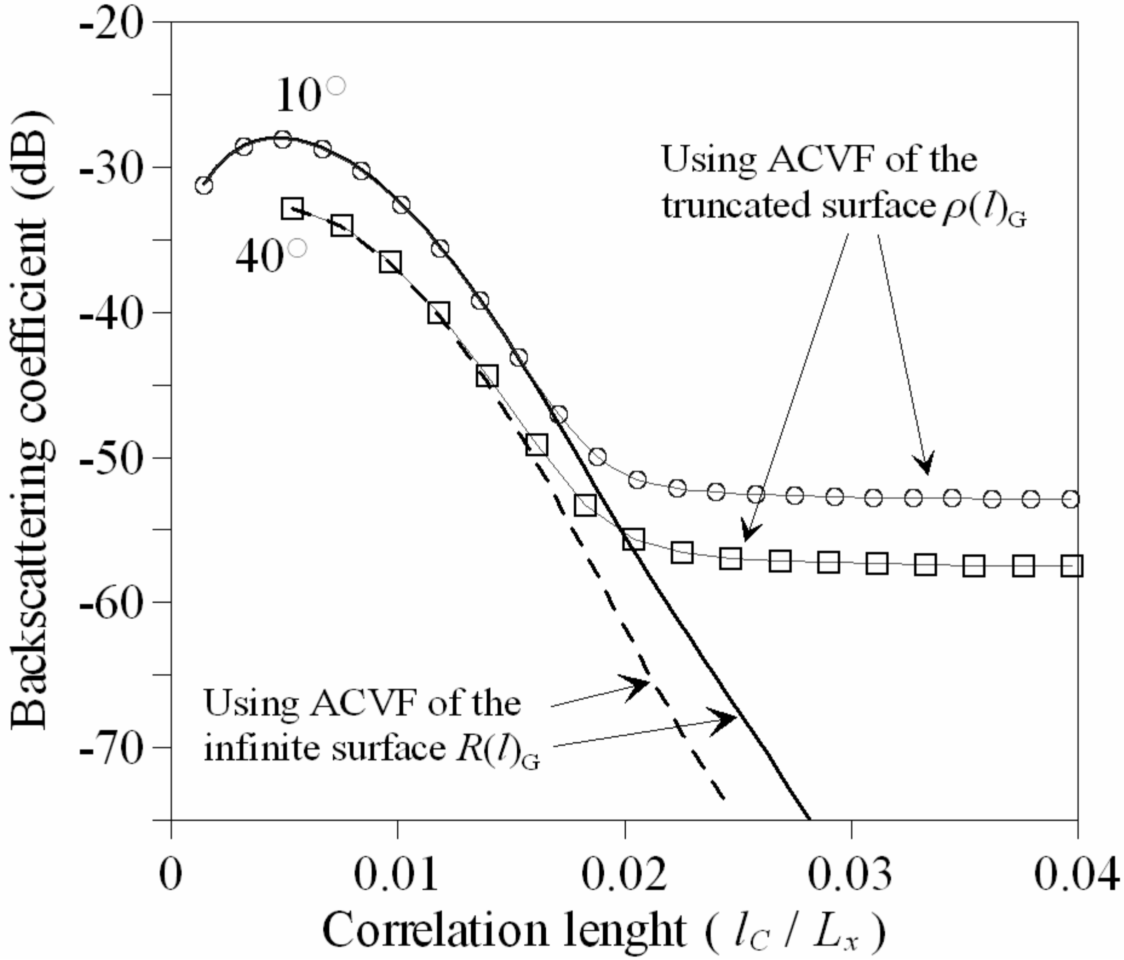
	X-band	C-band	L-band
Gaussian			
Exponential			

Backscattering Simulations

❑ ACVFT or PSDT depends on

•spatial resolution, and
•correlation length

The correlation length may affect an analysis of radar backscattering coefficient



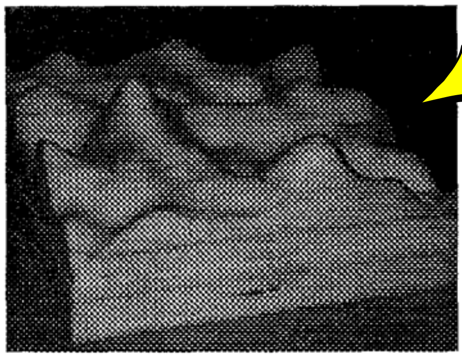
Experimental Measurements

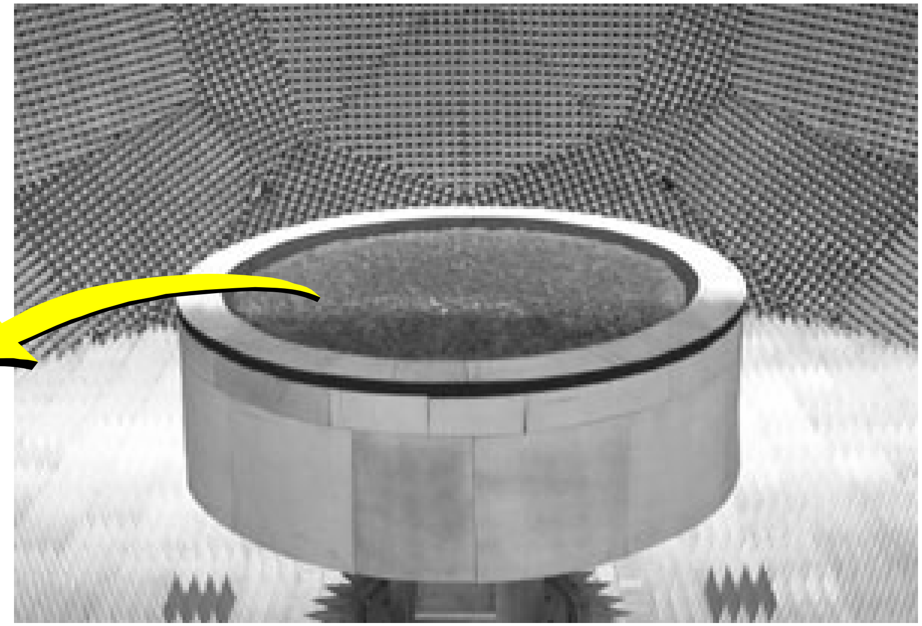
JRC EUROPEAN MICROWAVE SIGNATURE LABORATORY
EUROPEAN COMMISSION

Gaussian isotropic surfaces

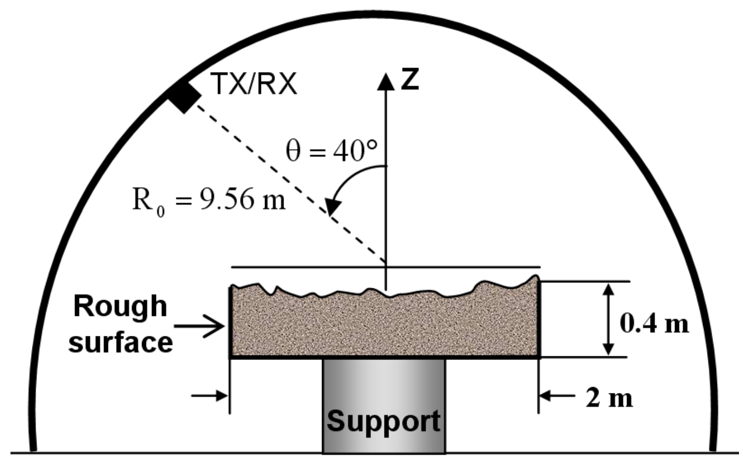
$\sigma = 0.4cm$

$l = 6cm$

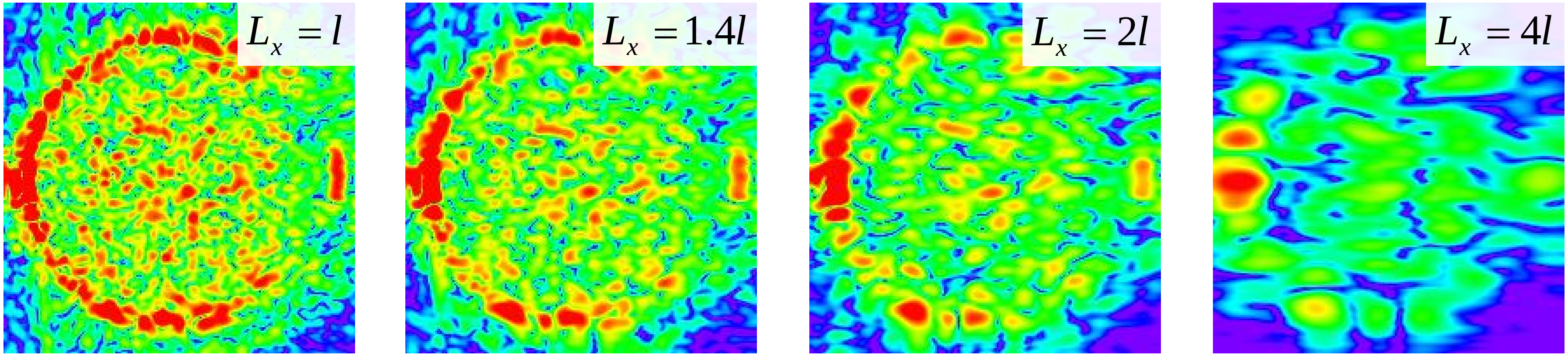


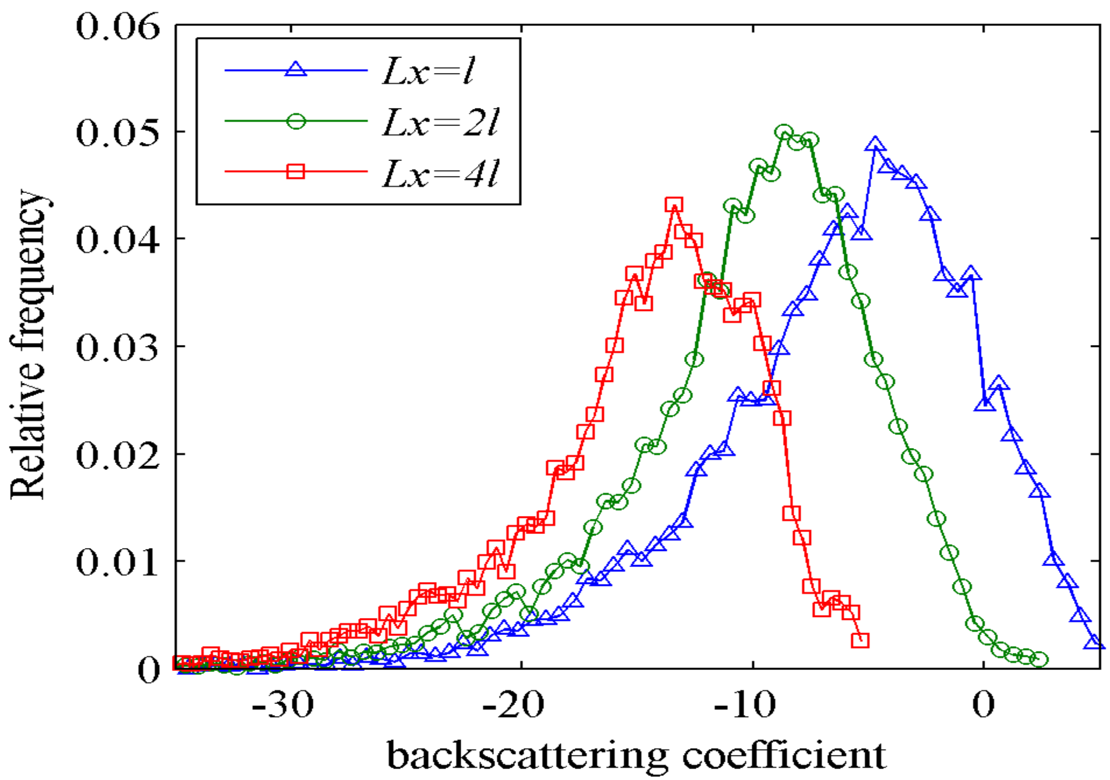


- Incidence angle = 40°
- Frequency = 14 GHz
- Resolution = 4.2 cm - 24 cm

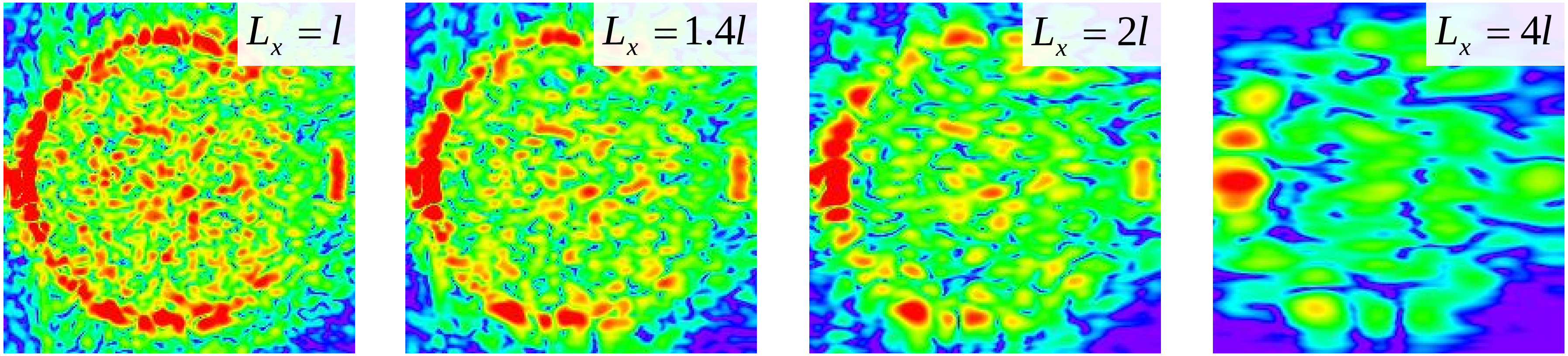


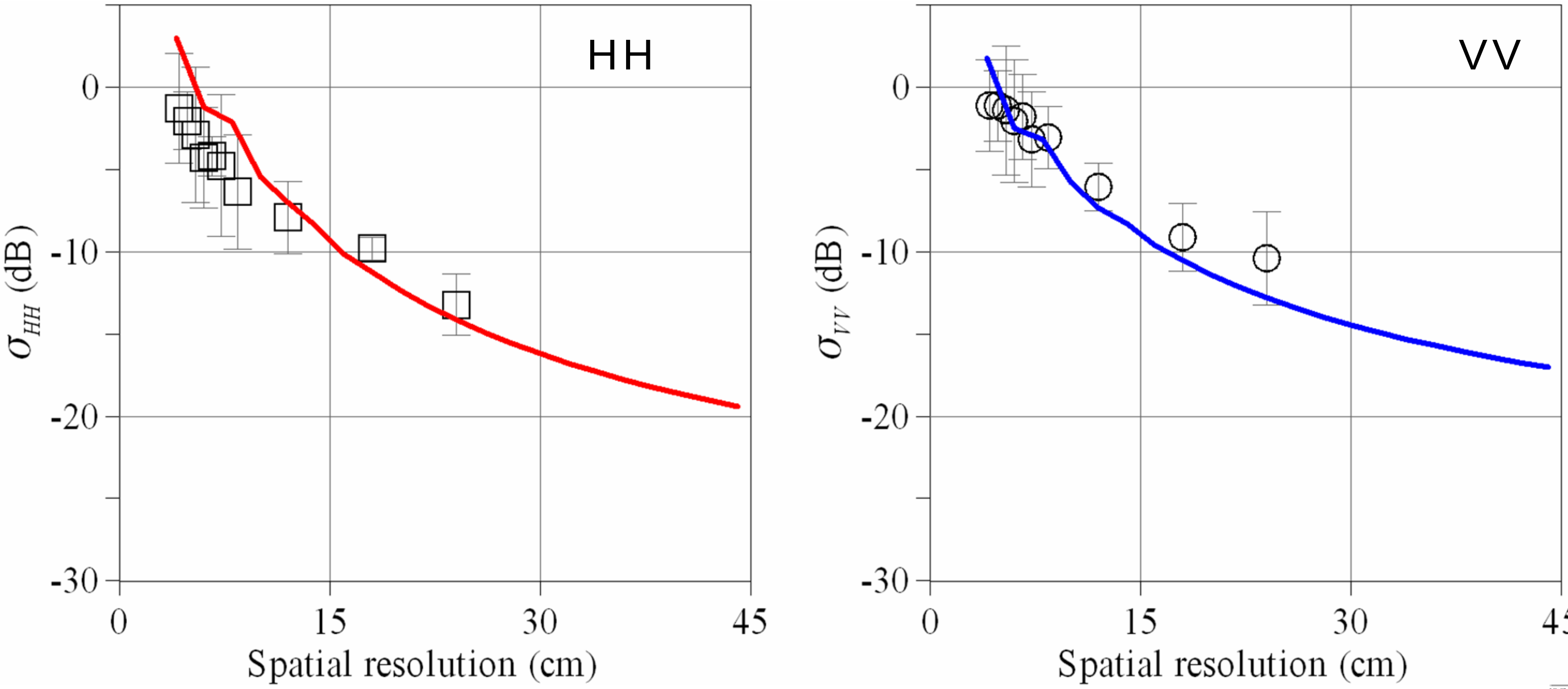
Experimental Measurements





Experimental Measurements





CONCLUSIONS

- An appropriate description of the effect of spatial resolution on statistical characteristics of rough surface has been presented by introducing the ACVF of truncated surface.

- Traditional computation of the surface backscattering based on the autocovariance function of infinite surface leads to an underestimation of the backscattering signature of high resolution radar.

- Forward and Inverse modeling of backscattering response based on the sample roughness statistics has not been completely resolved yet particularly due to the spatial variability of local Fresnel coefficients in high resolution radar.