ABSTRACT
Statistical properties of rough surfaces can be affected by the spatial resolution of the radar sensor. This study aims to understand effects of the spatial resolution on the statistical description of surface roughness and on the surface scattering characteristics of radar signal. A new expression for the surface autocovariance function is proposed to characterize surface scattering. Simulation results of high resolution radar backscattering indicate that traditional computation of the surface backscattering coefficient based on the autocovariance function of infinite surface leads to an underestimation of the backscattering signature of high resolution radar.

1. INTRODUCTION
Several studies have reported the dependence of surface scattering responses on the spatial resolution of the imaging radar sensor [1-3]. Since these studies have been conducted under fixed dielectric conditions, the effect of the spatial resolution on the roughness statistics probably cause the variation of backscattering response. Particularly, in the microwave surface scattering problem, the actual or realistic expression of roughness autocovariance function has been an important issue.

The objectives of this study include understanding the effects of the spatial resolution of the radar sensor on statistical descriptions of surface roughness and on the surface backscattering characteristics particularly for the high resolution polarimetric radar systems. A new expression for roughness autocovariance function of the truncated surface is proposed in order to characterize surface scattering.

2. ROUGHNESS PARAMETERS FOR TRUNCATED SURFACE
The statistical properties of soil surface are described by the height probability distribution and the surface autocorrelation properties. The height probability distribution function of random rough surfaces is usually assumed as zero mean Gaussian characterized by its rms heights, \( \sigma \). On the other hand, the spatial correlation property within the surface can be described by the surface autocovariance, \( R(l) \). For a large resolution cell, the target surface can be considered infinite, and the autocovariance is written as

\[
R(l) = \langle z(x)z(x+l) \rangle - \langle z(x) \rangle, \tag{1}
\]

where \( z(x) \) is the height profile.

For a high spatial resolution, however, roughness statistics for the finite interval corresponding to the size of ground range resolution cell become essential to realistic description of high resolution radar backscatter. In this case, the autocovariance function of truncated surface, \( \rho(l) \), can be expressed by [4,5]

\[
\rho(l) = \left\{ \frac{1-|l|}{L_0} \right\} \left( R(l) - \text{var}(z) \right), \tag{2}
\]

where \( \text{var}(z) = \langle (\mu - z)^2 \rangle \) is the variance of the sample means. The the autocovariance of truncated surface is defined in a constant range \( L_0 \) through the triangular function, \( (1-|l|)/L_0 \).

In order to illustrate the roughness statistics of truncated surface for a high resolution radar system, Fig. 1. Surface profiles generated for both a Gaussian and an exponential correlation function.
ideal one-dimensional rough surfaces having Gaussian and exponential autocovariance were generated numerically with rms height of 0.4 cm and correlation length of 6 cm as shown in Fig. 1. The profile length sets to be 60 m which is equal to thousand times longer than the correlation length so that it can be considered as an infinite surface.

Fig. 1. Averaged autocorrelation function of simulated (a) Gaussian surface and (b) exponential surface for three different segments length.

Fig. 2 shows autocorrelation function of generated Gaussian and exponential surface for 10 m, 2 m, 80 cm long segments. The shape of autocorrelation function changes according to the size of the segment length. Fig. 3 shows autocorrelation functions of truncated surface calculated from the equations presented in this study. They well fit into the autocorrelation of numerical surface and describe changes in the shape of the observed autocorrelation.

3. BACKSCATTERING SIMULATION

In order to study the effect of the spatial resolution on back scattering signatures, the autocovariance of truncated surface are applied to the surface scattering model based on IEM [6]. The $pp$ polarized backscattering coefficient of the IEM is given as

$$
\sigma_{pp}^0 = \frac{k^2}{4\pi} \exp\left[-2(kh\cos\theta)^2\right] \sum_{n=1}^{\infty} \frac{H_n^2}{n!} \frac{S_n^{(\alpha)}(-2k\sin\theta)}{n!} (3)
$$

where $k$ is the radar wave number, $\theta$ is the incidence angle, and $T_{pp}^n$ is a function determined by Fresnel reflection coefficient given in [6]. Here, $h$ is the rms height of truncated surface and $S_n^{(\alpha)}(K)$ is Fourier transform of the $n$th power of the autocovariance function of truncated surface.

Fig. 4 shows the dependence of VV-polarized backscattering coefficients on the resolution cell sizes for the generated Gaussian surface. The simulation is performed at X-band (10 GHz), C-band (4.8 GHz), and L-band (1.2 GHz) frequencies over the angular range from 15° to 75°. Here, the spatial resolution $\delta$ indicates the slant range resolution. At high frequency bands, the backscattering coefficient increases as an increase of the resolution. At lower incidence angle, however, the backscattering coefficient remains insensitive to the resolution due to large ground resolution. As a decrease of radar frequency, e.g., L-band, the angular response becomes insensitive to the spatial resolution.

On the other hand, angular backscattering responses of the exponential surface are less affected by the spatial resolution even for the high radar frequency as shown in Fig. 5. As for high resolution radar, the backscattering responses based on the Gaussian autocovariance function become similar to those based on the exponential autocovariance function.
4. CONCLUSIONS

In this study, an appropriate description of the effect of spatial resolution on statistical characteristics of rough surface was presented by introducing the autocovariance function 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. However, further studies on the two dimensional spatial variability of local Fresnel coefficients are necessary to fully resolve high resolution forward and inverse scattering of rough surface.

5. REFERENCES


Fig. 4. Effect of the spatial resolution on the angular response of $\sigma_{VV}^0$ for Gaussian surfaces at (a) X-band (10 GHz), (b) C-band (4.8 GHz), and (c) L-band (1.2 GHz).

Fig. 5. Effect of the spatial resolution on the angular response of $\sigma_{VV}^0$ for exponential surfaces at (a) X-band (10 GHz), (b) C-band (4.8 GHz), and (c) L-band (1.2 GHz).