Emissivities and Back-scattering coefficients of Random Lossy Dielectric Rough Surfaces at Microwave Frequencies Based on 3-Dimensional Numerical Simulations

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Abstract - We present recent results for full three-dimensional simulations of numerical solutions of Maxwell equations for random rough surfaces. Emissivities and back-scattering coefficients are calculated for soil surfaces and ocean surfaces at microwave frequencies. This is unlike analytical methods or empirical models that different roughness parameters are used for different microwave frequencies and for active and passive remote sensing. With recent advances in computational electromagnetics and available computer resources, we calculate 3-dimensional Maxwell equation solutions with 2-D rough surface for practical remote sensing applications. Highlights of our numerical approach are: (i) The sparse-matrix canonical grid method (SMCG) and the physics-based two-grid method (PBTG) are used. (ii) Algorithm has been implemented for parallel computing. Dense discretization of the surfaces is used because of high permittivity and energy conservation check is verified. We present results for soil surfaces in L- and C-bands, and for ocean surfaces at 19 GHz.

INTRODUCTION

Radar backscattering response of soil and ocean surfaces can be used to retrieve the surface roughness parameters [1-3]. To analyze the wave scattering from surfaces with random roughness analytically, the approximate solutions of small perturbation method (SPM) and Kirchoff approximation were usually used. However, these methods have restricted domain of validity.

With the advent of modern computer and the development of fast computational methods, numerical methods have been used to simulate the emissivities and back-scattering coefficients of dielectric media with rough interfaces. In this paper, We present recent results for full three-dimensional simulations of numerical solutions of Maxwell equations for random rough surfaces. Emissivities and back-scattering coefficients are calculated for soil surfaces and ocean surfaces at microwave frequencies. The advantages of numerical simulations are: (i) Unlike analytical methods, which have approximations, the simulations are based on numerical solutions of Maxwell equation. (ii) The same physical roughness parameters can be used for various microwave frequencies. (iii) The same physical roughness parameters and numerical method can be used for both active and passive microwave remote sensing. This is unlike analytical methods or empirical models that different roughness parameters are used for different microwave frequencies and for active and passive remote sensing. Most of the results presented in literature are for 2-dimensional Maxwell equations with 1-dimensional surfaces. With recent advances in computational electromagnetics and available computer resources, we calculate 3-dimensional Maxwell equation solutions with 2-D rough surface for practical remote sensing applications. Highlights of our numerical approach are: (i) The sparse-matrix canonical grid method (SMCG) and the physics-based two-grid method (PBTG) are used. (ii) Algorithm has been implemented for parallel computing. We use a Beowulf cluster that consists of 32 processors connected by 100 Base TX Ethernet switch. The workloads of computing the sparse-matrix-vector multiplication corresponding to the near interactions and the fast Fourier transform (FFT) operations corresponding to the far interactions in MOM can be easily distributed among all the processors. (iii) Dense discretization of the surfaces is used because of high permittivity and energy conservation check is verified. We present results for soil surfaces in L- and C-bands, and for ocean surfaces at 19 GHz.

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NUMERICAL RESULTS OF BACKSCATTERING COEFFICIENTS AND COMPARISONS WITH THE EXPERIMENTAL MEASUREMENTS OF SOIL SURFACES

We compare the backscattering coefficients of natural soil surfaces between the experimental and calculated from the IEM model with the proposed spectra. The experimental data are taken from Oh et al [4]. The reasons we choose these data are (i) they cover a wide range of surface roughness from smooth to very rough, (ii) the rms heights and correlation lengths of each field are given, (iii) the measurements are made for both dry and wet soil, and (iv) the measurements are performed at three frequency bands of L, C, and X and the incidence angles of 10 to 70 degrees. In addition, there are several papers that use this data set to develop the empirical formulas for the backscattering response of the soil surfaces [4, 5] The fixed surface roughness parameters and spectra are used for all the three frequency bands. The relative permittivities of soil surfaces at the different fields and frequencies can be found in [4].

The comparisons of the backscattering coefficients and emissivities for hh polarization between the experimental measurements and numerical simulations are given in Table 1 for various incident angles at C band. The results are from soil surface 1 with wet soil moisture. The rms height and the correlation length of the surface are 0.4 cm and 8.4 cm, respectively. The spectrum used in the simulations is the exponential spectrum. The relative soil permittivity of C band is 15.23+i2.1. It can be seen that they are in reasonable agreements with experimental data for all incident angles. The good match between the simulations and measurements is reached at this frequency.

NUMERICAL RESULTS OF EMISSIVITIES AND BRIGHTNESS TEMPERATURES FOR OCEAN SURFACES

In this part, we give some numerical results for ocean surfaces. To demonstrate the significance of performing dense sampling of random rough surfaces, we give an investigation on 2-D scattering ocean problem. In Table II, the ocean rough surface is generated using 240 points/wavelength. Numerical simulations of scattering and emission are performed for one realization on the same profile from 10 to 80 points per wavelength in the sparse grid. k_L=100rads/m, and k_U =4000rads/m. It is shown that results converge and accuracy requirement is satisfied with 40 points per wavelength discretization for TE polarization, while 80 points per wavelength are required for TM polarization.

Some results for 3-D ocean scattering are given in Table III, which show that more points per wavelength may be needed to obtain accurate results, based on the requirement of the energy conservation check within a relative error of 0.001 and brightness temperature error less than $0.3K$.

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Table I. Comparisons of numerical results of backscattering coefficients with the experimental measurements of soil surfaces, and numerical results of emissivities.

Incident angle θ (degree)	Back-scattering (dB)		Back-scattering difference (dB) Expr - expo	Exponential		Emission of flat surface
	experimental	exponential		Emission	Energy con. check	
10	-2.374	-4.85	2.5	0.71975	1.022	0.6429
20	-9.223	-12.8	3.5	0.6838	1.011	0.62701
30	-15.000	-16.58	1.58	0.63328	1.0036	0.59788
40	-17.987	-18.7	0.71	0.57046	1.0024	0.55369
50	-20.783	-19.1	-1.68	0.4952	1.0116	0.49191
60	-24.094	-23.9	-0.19	0.40335	1.035	0.40934
70	-28.36	-26.5	-1.85	0.40354	1.15	0.30230

Table II. Emissivity with various sampling density, for 2-D ocean scattering problem, k_L =100rads/m, and k_U =4000rads/m.

No. of points/λ	Polar.	Emissivity	Energy cons.	Emissivity of flat surfaces	$T_B(K)$	ΔT_B(rough-flat surface)
10	TE	0.30400	1.0189	0.28728	86.03	4.73
40	TE	0.29710	1.00050	0.28728	84.08	2.78
60	TE	0.29695	1.00016	0.28728	84.04	2.74
80	TE	0.29686	0.999968	0.28728	84.01	2.71
10	TM	0.56097	0.99511	0.55927	158.75	0.48
40	TM	0.56894	1.00155	0.55927	161.01	2.74
60	TM	0.56849	1.00121	0.55927	160.88	2.61
80	TM	0.56823	1.00096	0.55927	160.81	2.54

Table III. Emissivity and brightness temperature with various values of k_U , for 3-D ocean scattering problem. k_L =100rads/m.

Polar.	k_U (rads/m)	emission	Energy cons.	Emission of flat surface	T_B(K)	ΔT_B(rough-flat surface)
TE	400	0.30667	0.99763	0.28728	86.79	5.49
TE	1000	0.31120	0.99813	0.28728	88.07	6.77
TE	4000	0.31230	0.99887	0.28728	88.38	7.08
TM	400	0.54289	0.99997	0.55927	153.64	-4.63
TM	1000	0.54469	1.0025	0.55927	154.15	-4.12
TM	4000	0.54303	1.00078	0.55927	153.67	-4.60