BISTATIC SCATTERING, BACKSCATTERING AND EMISSIVITIES OF RANDOMLY ROUGH SOIL SURFACES AT L BAND BASED ON NUMERICAL SOLUTIONS OF MAXWELL EQUATIONS OF 3 DIMENSIONAL SIMULATIONS

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1. ABSTRACT

In this paper, we used NMM3D (Numerical Maxwell Model of 3 Dimensional simulations) to study the full wave 3 dimensional scattering of random soil surfaces. In 3D simulations, the height function z=f(x,y) of the rough surfaces vary in both two horizontal directions. Several hundreds of cases are simulated by varying incident angles, surface roughness and soil permittivities. The incident angles vary from 20^o to 50^o. The coherent/incoherent bistatic coefficients, backscattering coefficients, and emissivities are computed. The results are compared with empirical models and analytical methods. The backscattering coefficients are compared with measurement data and are found to be in good agreement. Based on the several hundreds of computed case, interpolation tables are made for the full range of parameters that can be directly applied to L band active and passive microwave remote sensing of soil moisture, such as the SMAP Mission and the SMOS Mission.

The NASA Soil Moisture Active/Passive (SMAP) Mission [1] and the ESA Soil Moisture and Ocean Salinity (SMOS) Mission [2] at L band will enable the mapping of soil moisture with unprecedented resolution. The SMAP is a combined active and passive sensor at 1.26 GHz and 1.41 GHz respective with 40o incident angle. The SMOS mission, launched in 2009, is passive at 1.4 GHz with multiple incident angles. In this paper, the microwave scattering of soil surfaces are studied in relation to the SMAP mission and the SMOS mission by using Numerical Maxwell Model of 3 Dimentional simulations (NMM3D). In 3 dimensional simulations, the height function z=f(x,y) of the rough surfaces vary in both two horizontal directions. The computation is much more intensive than, 2 dimensional simulations, where height function z=f(x) only varies in one horizontal directions.

The study of 3 dimensional scattering by soil surfaces is an important problem for both bare soil surfaces and vegetated surfaces. The backscattering contributes to the radar return signals and the emissivities are related to the radiometer brightness temperatures. In the past decades, experimental measurements have been conducted [3].

Empirical formulas including Dubois formula [4] and Q-h model, and physical models including Small Perturbation Method (SPM), Kirchhoff Approximation (KA) [5] and Advanced Integral Equation Model (AIEM) [6] have been established. The 3D full wave simulations using numerical solutions of Maxwell equations began in the mid-1990's. The most prevail numerical approach for random rough surfaces are Method of Moment (MoM). In the past decade, fast methods have been developed, including the Sparse Matrix Canonical Grid (SMCG) method [7], the Physical Based Two Grid (PBTG) method, and the multilevel UV method.

In the past, because of the scarcity of computed results, the role of NMM3D was merely to validate analytical models. On the other hand, this paper shows that based on the computed hundreds of cases, interpolation tables are made for the full range of parameters that can be directly applied to L band active and passive microwave remote sensing of soil moisture, such as SMAP mission and SMOS mission. We use NMM3D with SMCG and Rao-Wilton-Glission (RWG) basis functions to analyze the scattering of randomly rough soil surfaces with exponential correlation function. The decomposition of bistatic field into coherent bistatic field and incoherent bistatic field of finite surface size used in NMM3D simulations are performed. The coherent bistatic coefficients and incoherent bistatic coefficients are calculated from the decomposition bistatic field. Several hundred cases are computed for different incident angles from 20o to 50o, with varying rms height, correlation length, and soil permittivities. The energy conservations are checked and are obeyed to within 1%. The results are compared with empirical models and analytical methods. The NMM3D backscattering results are compared with experimental data [3] where measurements of soil roughness and permittivity were made, and are found in good agreement without adjustable parameters. The tabulated NMM3D results of interpolation cover the full range of parameters of interest in the SMAP mission and the SMOS mission. The results are part of the SMAP data cube. A parameter retrieval approach in SMAP uses a pre-computed “data cube” as a look-up method for iterating to a fast real time retrieval solution.

In this paper, NMM3D were used to study the scattering of randomly rough soil surfaces. The bistatic coefficients, the backscattering coefficients and the emissivities for hundreds of cases are computed, and a data table is created. The results are compared with other models and with measurement data. The NMM3D results agree well with experimental data. Results covering the full range of parameters at L band are obtained by interpolation and can be directly applied to the SMAP mission and the SMOS mission.

2. BIBLIOGRAPHY

[1] D. Entekhabi, E. Njoku, P. O’Neill, K. Kellogg, W. Crow, W. Edelstein, J. Entin, S. Goodman, T. Jackson, J. Johnson, J. Kimball, J. Piepmeier, R. Koster, K. McDonald, M. Moghaddam, S. Moran, R. Reichle, J. C. Shi, M. Spencer, S. Thrman, L. Tsang, and J. van Zyl, “The Soil Moisture Active and Passive (SMAP) Mission,” submitted to Proceedings of the IEEE., 2009.

[2] Y. H. Kerr, P. Wigneron, J. -P. Martinuzzi, J. Font and M. Berger, “Soil moisture retrieval from space: the Soil Moisture and Ocean Salinity (SMOS) mission,” IEEE Trans. Geosci. Remote. Sens., vol. 39, no. 8, pp. 1729–1735, Aug., 2001.

[3] Y. Oh, K. Sarabandi, and F. T. Ulaby, “An empirical model and an inversion technique for radar scattering from bare soil surfaces,” IEEE Trans. Geosci. Remote. Sens., vol. 30, no. 2, pp. 370–381, Mar., 1992.

[4] P. C. Dubois, J. van Zyl, and T. Engman, “Measuring soil moisture with imaging radars,” IEEE Trans. Geosci. Remote. Sens., vol. 33, no. 4, pp. 915–926, Nov., 1995. (Corrections)

[5] L. Tsang and J. A. Kong, Scattering of Electromagnetic Waves, Vol. 3: Advanced Topics. New York: Wiley Interscience, 2001.

[6] K. S. Chen, T. D. Wu, L. Tsang, Qin Li, J. C. Shi, and A. K. Fung, “Emission of rough surfaces calculated by the integral equation method with comparison to three-dimensional moment method simulations,” IEEE Trans. Geosci. Remote. Sens., vol. 41, no. 1, pp. 99-101, Jan. 2003.

[7] L. Zhou, L. Tsang, V. Jandhyala, Qin Li, and C. H. Chan, “Emissivity simulations in passive microwave remote sensing with 3-dimensional numerical solutions of Maxwell equations,” IEEE Trans. Geosci. Remote. Sens., vol. 42, no. 8, pp. 1739-1748, Aug., 2004.

[8] L. Tsang, J. A. Kong, and K. H. Ding, Scattering of Electromagnetic Waves, Vol. 1: Theory and Applications. New York: Wiley Interscience, 2000.