

EM Scatter Modeling in Support of Space Sensing

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LONG-TERM GOAL

The primary long-term goal of this research is to provide the Navy with accurate, rapid, and versatile methods to apply to the understanding and subsequent exploitation of electromagnetically derived remote sensing data. Auxiliary goals are to (1) use the methods to develop a fundamental understanding of the interaction between electromagnetic waves and natural rough surfaces, (2) demonstrate how these methods can also be applied to the development of new remote sensing concepts and sensor design, and (3) investigate the applications of these results to U.S. Navy needs.

OBJECTIVES

The scientific objectives of this study are to combine electromagnetic scattering theory, rigorous and rapid new mathematical computation techniques, and basic descriptions of complex and possibly nonlinear natural wave-wave and wind-wave interactions on the ocean surface to determine the scattering characteristics of the ocean surface. In order to be of use in understanding present and potential remote sensors, the characterization must include all potentially “sensible” electromagnetic wave parameters, e.g., amplitude, phase, polarization, frequency, and angles of incidence and scattering.

APPROACH

Our approach comprises the on-going enhancement or reformulation of the Method of Ordered Multiple Interactions (MOMI) coupled with the Fast Multi-pole Method (FMM) and its derivatives to provide the numerical means to robustly model the rough surface scattering process. Of particular importance are (1) developing a Doppler scattering prediction capability without reverting to a true time dependent electromagnetic scattering formalism, (2) extending MOMI or a more computationally efficient derivative of it to the case of 2-D rough ocean-like surfaces, (3) developing a means for exactly accounting for the finite conductivity of the ocean surface in our scattering calculations, and (4) applying our rough surface scattering knowledge to designing new sensing methodologies and enhancement schemes. The approach we use during this study is predicated on the end goal of being able to relate surface features and characteristics to their electromagnetic scattering signatures.

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WORK COMPLETED

During the past year, we have continued our collaboration with Drs. Jakov Toporkov (NRL) and Joel Johnson (Ohio State University) on modeling and understanding the Doppler signature of rough ocean surfaces. Our emphasis here has been on the introduction of a small nonlinearity in the surface roughness generation process. Two nonlinear mathematical wave generation processes have been considered – the Cramer and the Watson-West approaches, and these continue to be studied. These two provide significantly different Doppler signatures from that given by a simple Bragg scattering prediction. In addition, the Doppler spectra for the horizontal-horizontal (HH) and vertical-vertical (VV) transmit and receive polarization states look remarkably like measured spectra! There is some difference between the results provided by the two different wave generation models, but the difference is much less significant than the similarity. It should be noted that neither model produces any significant enhancement of the HH scattering relative to the VV return. This indicates that some additional large-scale (relative to the electromagnetic wavelength) surface structure may be responsible for the measured polarization discrepancy. This latter issue continues to be studied.

An additional effort this past year is an investigation of the widely used impedance boundary condition (IBC) approximation within an ocean scattering context. The IBC approximation was to be investigated through comparison with exact scattering results derived from the coupled integral equations for the surface electromagnetic currents. Scattering from one-dimensional randomly rough ocean surfaces was the emphasis for this undertaking. We quickly found that the direct or indirect solution of these coupled integral equations was not so easy. Consequently, this led us to a reformulation of the dielectric problem into a more physically intuitive form. In order to assess the accuracy of the IBC, a reliable benchmark must be established. However, most “exact” formulations for penetrable surfaces involve the use of the aforementioned coupled integral equations. For the most part, such results have been confined to closed bodies where the number of unknowns is relatively small and this is clearly not the case with the rough surface problem. Contributing to this problem is that the fact that the coupled integral equation approach can become poorly conditioned and even in the case of a flat surface will require matrix inversion.

RESULTS

As a consequence of these problems a new formulation of the integral equations for scattering by penetrable (dielectric) surfaces was investigated. Since the ocean surface is often approximated as perfectly conducting (PEC), the new integral equation formulation was cast as a perturbation to the PEC problem. The thinking was that this approach should guarantee relatively fast convergence of an iterative solution as the actual surface is well approximated as a very good conductor. However, as work progressed, it became obvious that a new formulation for penetrable (dielectric) surfaces was necessary due to a problem attributable to the Brewster angle effect. This reformulation produced an integral equation that is a computationally more efficient and better conditioned than our first attempt based on a perturbation of the PEC integral equation. This work was carried out in conjunction with Dr. Robert Adams (University of Kentucky) who developed the original and modified approaches while at Virginia Tech as a Research Assistant Professor.

Comparison of the approximate IBC with exact results produced by our new approach is underway for one of the two electromagnetic polarizations, HH. This work is based on the PEC perturbation approach integral equation because it is easier to implement than the reformulated approach. The effects of parameters such as dielectric contrast (real and imaginary parts), surface roughness and

incidence angles are all presently under investigation. Simulation of the VV-polarization scattering problem is still in the formulation stage as it requires much greater care to deal with its ill conditioning resulting from the Brewster angle induced effect.

IMPACT/APPLICATIONS

These results provide a new insight into the necessity of accurate hydrodynamic modeling of the ocean surface generation process. While scattering measurements may provide the kind of data that that will aid in resolving this hydrodynamic uncertainty, it cannot solve the entire puzzle. These results clearly illustrate the point that hydrodynamic understanding of small-scale wave-wave and wind wave interactions is essential to fully solving the ocean scattering problem. It is also obvious that the simple addition of first order surface generation nonlinearities will not explain the HH vs. VV cross section reversal near low grazing angle. This appears to be due to an underlying large-scale surface feature.

The development of an alternate penetrable surface formulation and its solution is a major advance because it is considerably simpler than dealing with the coupled equations that are normally used. It further gives us a tool that may be readily used to evaluate the Leontovich Impedance Boundary Condition (IBC) approximation. It is clear that the IBC approximation should not be expected to remain accurate when the scattering mechanism is Bragg resonance; however, its use in this situation is rather common. The results of our computations should provide a more quantitative limit on this approximation.

TRANSITIONS

Contacts and working relationships with NRL continue to be maintained and other connections with user Navy elements are presently being pursued.

RELATED PROJECTS

Some of the work reported herein was accomplished in conjunction with Dr Jakov Toporkov of NRL and Prof. Joel Johnson of the Ohio State University. The specific research encompassed the work on estimating the effects of the Cramer and the Watson-West nonlinear surface generation processes.

PUBLICATIONS

J.V. Toporkov & G.S. Brown, "Numerical Study of the Extended Kirchhoff Approach for Scattering from Ocean-like Surfaces: Doppler Analysis," *IEEE Trans. Antennas & Propagation*, accepted for publication, June 2001.

J.T. Johnson, J.V. Toporkov, & G.S. Brown, "A Numerical Study of Backscattering from Time Evolving Sea Surfaces: Comparisons of Hydrodynamic Models," *IEEE Trans. Geosciences & Remote Sensing*, accepted for publication, July 2001.