NUMERICAL STUDIES OF GRAZING ANGLE SEA BACKSCATTERING

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LONG-TERM GOAL

The long term goal of this project involves developing improved models for grazing angle sea scattering through the application of efficient numerical methods for electromagnetics and hydrodynamics. These models can then be applied to improve clutter removal for radar systems operating at sea as well as to improve microwave active and passive remote sensing of the ocean surface.

SCIENTIFIC OBJECTIVES

Although validated approximate models exist for microwave scattering from the sea surface at moderate to large grazing angles, no theory has been completely accepted for scattering at low grazing angles. The effects of breaking waves and hydrodynamic modulations have been established but their relative contributions and the physical scattering mechanisms remain a subject of debate given the uncertainty in approximate methods previously applied. This project seeks to apply numerically exact models to avoid the limitations of standard approximate methods so that the influence of different scattering mechanisms can be conclusively established in this angular regime, allowing realistic parametric models for remote sensing retrievals and clutter rejection to be created.

APPROACH

The approach to this project is to apply recently developed numerical models for scattering and hydrodynamic evolution of three dimensional rough sea surfaces. Several efficient models for the computation of scattering from a rough surface have been demonstrated in the literature through one dimensional surface studies, including the canonical grid [1], fast multipole [2], forward-backward [3], and operator expansion [4] methods. However, studies for ocean-like surfaces rough in two directions have been much more limited due to the increased computational complexity involved [4-6]. In addition, the grazing angle regime is very challenging numerically, given the increased contribution of edge effects for finite surface sizes. Inclusion of the effects of finite surface conductivity is also critical, since many proposed scattering mechanisms depend on finite conductivity effects. Accordingly, the project is proceeding in development of three dimensional scattering models for finitely conducting rough surfaces.

A numerical approach to the hydrodynamics problem is being applied as well, following the development of [7]. This model incorporates many non-linear aspects of hydrodynamic evolution, and should therefore help in determining the influence of these effects on grazing angle scattering.

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WORK COMPLETED

Since the project began in June 1997, work has been initiated on both the scattering and hydrodynamic models. Three major areas have been initiated: extending the canonical grid method to apply to this problem, studying other numerical methods to determine their efficiency and applicability, and initial development of the hydrodynamic model.

In the first area, efforts have been made on extending the canonical grid method to apply to grazing angle scattering calculations from three dimensional finitely conducting surfaces. Initial studies for one dimensional surfaces [8] demonstrated that the canonical grid method can yield accurate and efficient calculations down to 1 degree grazing if sufficiently large surface profiles (up to 8,192 wavelengths in the 1-D case) are considered. Earlier studies of the two dimensional case using perfectly conducting surfaces at grazing angles larger than 30 degrees have also shown the canonical grid method to work well for this case. However, problems arise when near grazing angles and finitely conducting surfaces are included for the two dimensional case. The latter issue arises from the fact that a full penetrable surface scattering formulation [5] requires sampling on the scale of the electromagnetic wavelength in the sea water medium, which rapidly becomes intractable. Results from the one dimensional literature, however, illustrate that the impedance boundary condition (IBC) approximation for including the effects of finite surface conductivity should yield very accurate results for ocean surfaces in the microwave frequency range [8]. Use of the IBC avoids the increased sampling requirement, making calculations possible. Problems at near grazing angles are again due to the requirement of large surface sizes to reduce edge effect contributions when the surface is illuminated by a tapered wave type incident field. However, an approach in which a rectangular patch of surface is studied, with the long dimension of the surface along the range direction where extra surface length is needed, has relieved these requirements somewhat so that a 64 by 16 wavelength patch of surface is believed to be sufficient to obtain reasonable scattering results down to 10 degrees grazing. Current efforts are focusing on demonstrating the method's success for this case and on applying the technique to obtain some initial results. A post-doctoral researcher has been primarily assisting with this work.

In the second area, studies of the accuracy and efficiency of various numerical methods for rough surface scattering computations have been performed to assess the differing methods. These studies have been performed primarily using one dimensional surfaces to avoid extreme code development times, but future efforts will extend the most promising methods for a given configuration to the two dimensional case. Methods applied to date include the canonical grid, operator expansion, and fast multipole methods. The relationships found between these methods will be summarized in the results section. In addition, these one dimensional numerical methods are being applied in a numerical study of propagation over the ocean, since a one dimensional model is sufficient for this problem. Results should help clarify the accuracy of the commonly used parabolic wave equation (PWE) method, as an undergraduate student is implementing this approach to the propagation problem for comparison. In addition, some results on the statistics of propagation over the ocean will be pursued, given that these calculations are a relatively straight forward application of the numerical models already developed. Research in this effort is being performed primarily by a graduate student with the undergraduate student providing the PWE model.

Finally, initial work on implementing the numerical hydrodynamic code of [7] has begun. This model is also based on an operator expansion approach to the hydrodynamics problem, and results in a fully three dimensional surface evolution that includes many non-linear effects. The code however is limited to surfaces that do not exceed a specified steepness, and therefore cannot include breaking wave effects. Although this can be a serious limitation in the scattering problem, the model does include many wave modulation effects, so the influence of these effects can at least be determined. Other hydrodynamic models will be considered once this code has been completed and more experience gained in the hydrodynamics area. Research in this effort is being performed primarily by a single graduate student.

RESULTS

Several interesting results have been obtained from earlier work and from the one dimensional studies. Figure one below is a plot from the near grazing angle study of one dimensional surface scattering using the canonical grid method [8]. The plot illustrates normalized backscattered radar cross sections in VV and HH polarizations obtained from a Monte Carlo simulation with a Pierson-Moskowitz ocean surface at 14 GHz and wind speed 3 m/s. The two sets of symbol results correspond a case in which the low frequency part of the spectrum was removed (so that a much less rough surface resulted) and the case in which it was retained. The smooth surface case shows a very good agreement with the small perturbation method (SPM) result, demonstrating that the canonical grid method is providing accurate calculations in this regime. Comparisons of the rougher surface result with various approximate theories, including the composite surface, higher order perturbation, small slope, operator expansion, and curvature corrected SPM theories, showed that none of these theories provided accurate predictions over the entire range of grazing angles. Thus, even for the case in which no hydrodynamic effects are considered, the standard approximate theories are shown to have problems in the near grazing angle range. Other one dimensional studies have helped to illustrate the effects of surface roughness on propagation over the ocean, and these effects are currently being quantified through a Monte Carlo study.

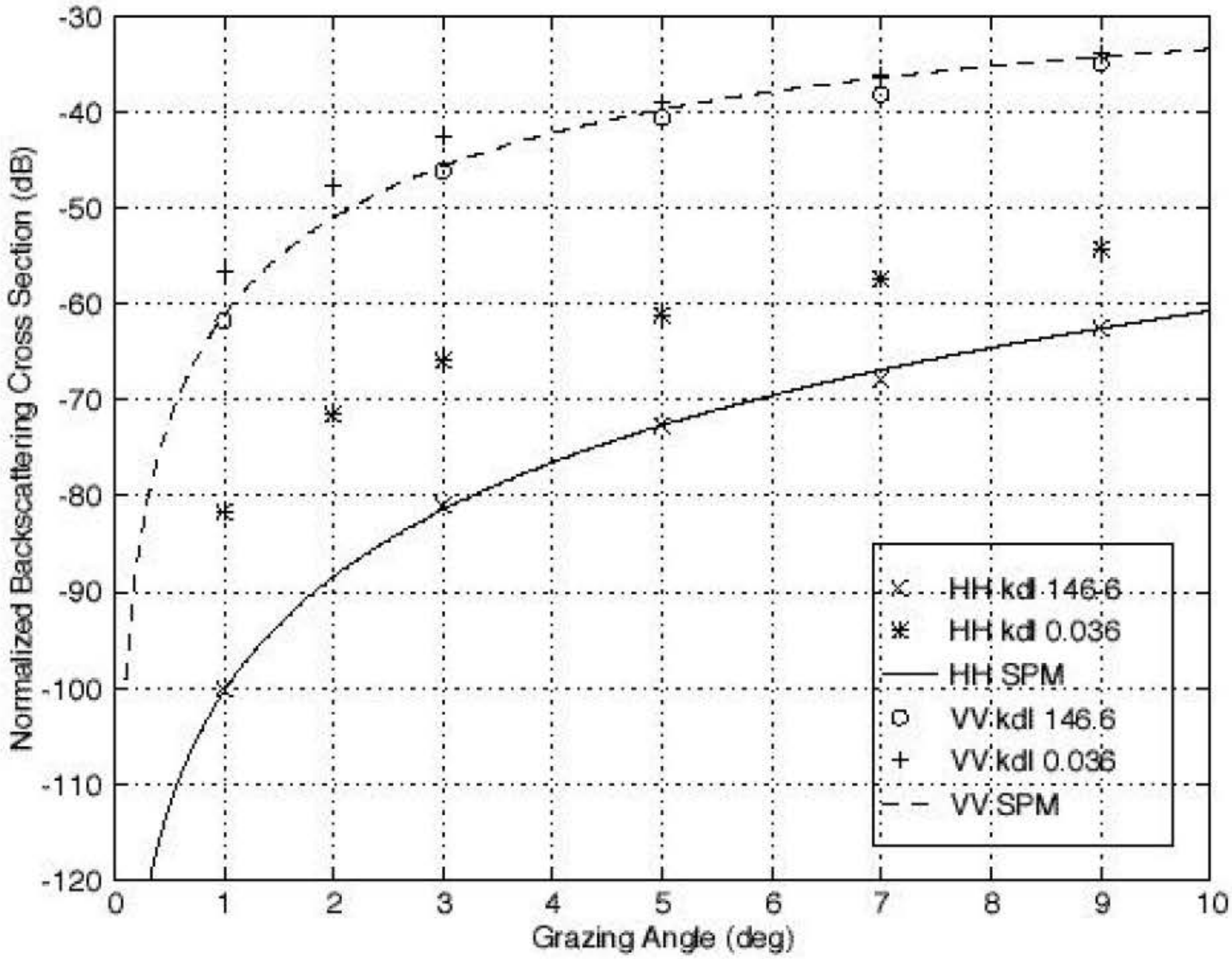

Figure 1. 14 GHz low Grazing Angle Backscattering from a One Dimensional 3m/s Pierson-Moskowitz Ocean Surface. Comparison of Numerical Results in High (kdl=0.036) and Low (kdl=146.6) Surface Height Cases with Small Perturbation Method (SPM) Predictions

Earlier two dimensional studies of scattering from perfectly conducting power law surfaces have demonstrated the accuracy of the composite surface and small slope approximations at larger grazing angles. Figure 2 compares Monte Carlo results with the composite surface approximation for a relatively smooth power law surface, and now includes cross polarized cross sections since a three dimensional scattering problem is being considered.

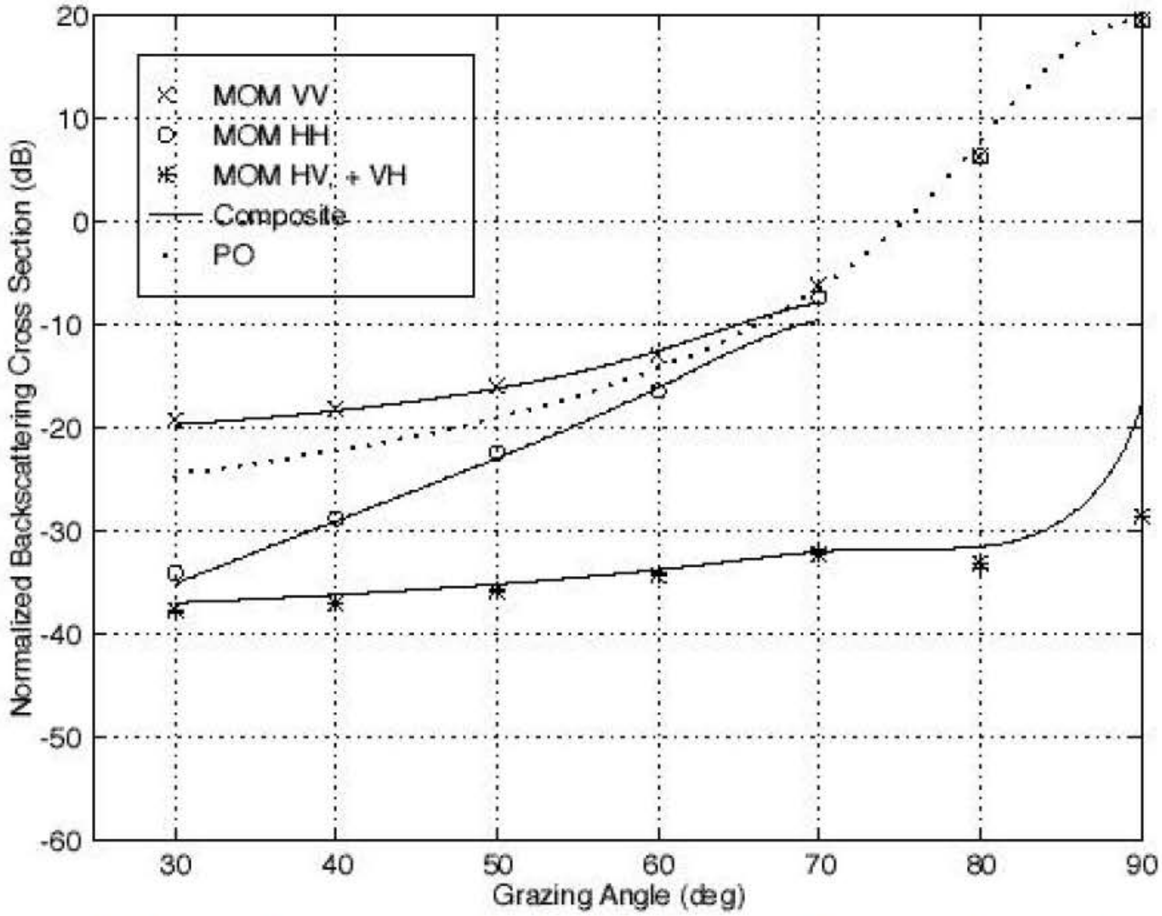

Figure 2. Moderate to large grazing angle 14 GHz backscattering from a two dimensional perfectly conducting power law surface. Comparison of numerical results with composite surface theory.

Analytical and numerical studies of the various rough surface scattering methods have clarified the advantages and disadvantages of the individual approaches. It has been found that the canonical grid (CGM) and operator expansion methods (OEM) are both based on a similar series approximation for the Green's function, which becomes less accurate as surface slopes increase. The OEM however is a quasi-analytical technique in which a perturbation series in surface slope is solved analytically, while the CGM retains a numerical solution of these equations with less approximation. Thus, while both methods become less accurate and less efficient for larger surface heights in terms of a wavelength, the CGM should retain more accuracy than the OEM but require more computation. The fast multipole method (FMM) is based on a different expansion, and should apply regardless of surface heights or slopes. However, the method is relatively inefficient when compared to CGM and OEM for smaller surface heights, but does not lose efficiency as surface heights increase, thereby becoming the most efficient technique tested to date for very rough surfaces. Future efforts will concentrate on investigating other numerical methods, and on extending the most successful to the two dimensional penetrable surface problem.

IMPACT/APPLICATION

The results of this project will have impact in any technology where rough surface scattering has effects. Although the primary application for the project is the use of radar over the ocean surface, the models developed can also be applied to passive remote sensing of the ocean, in particular to the recent area of design of a polarimetric passive remote sensor for ocean winds. Other applicable areas include soil surface scattering effects on ground penetrating radar and soil moisture remote sensing systems, synthetic aperture radar remote sensing of the ocean, and remote sensing of forest and vegetated areas.

TRANSITIONS

Current transitions have been limited given the limited duration of the project to date. It is expected that insights gained from this work will be applied to the design of future experiments and sensors.

RELATED PROJECTS

Current related projects in our research group include numerical and experimental studies of soil surface scattering effects on ground penetrating radar systems, in which many of the models developed in this project will be applied. Other research in the group involves studying techniques for soil modification in ground penetrating radar systems, and also models for 35 GHz radar scene simulation in foliated areas.

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