Numerical Studies of Rough Surface Scattering Models

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LONG-TERM GOALS

To develop a practical set of rough surface scattering strength equations for use in real-world Navy applications.

OBJECTIVES

To examine and develop theoretical surface scattering models that accurately predict acoustic wave scattering at the air-sea interface and at the ocean-bottom interface in shallow water.

APPROACH

A practical rough surface scattering model based on the non-local small slope approximation (NLSSA) [1],[2] is being developed and examined for pressure-release surfaces and fluid-fluid interfaces.

To be practical, a rough surface scattering model must be easy to implement and easily incorporated into existing propagation models. At the same time, it must be accurate enough to give useful results. For purposes of this research, "practical" means that a rough surface scattering model must satisfy the following requirements:

1. No more than N-D integration away from low grazing angles, where N represents the dimension of the surface

2. No more than 2N-D integration at low grazing angles

3. Accuracy to within a few dB

The lowest-order small slope approximation (SSA) satisfies all three criteria away from grazing angles, but does not satisfy the third criterion for large-scale roughness at low grazing angles. The NLSSA is accurate at low grazing angles, but in its original form, 1-D surfaces require 5-D integration and, thus, the NLSSA does not meet the second criterion. Earlier, we introduced an approximation that reduces the integration by two dimensions while retaining the accuracy at low grazing angles [3]. However, the second criterion was still not satisfied.

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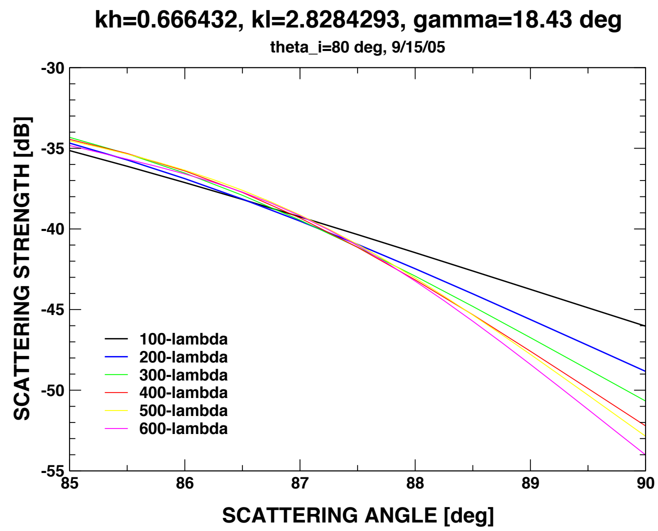

Figure 1: Bistatic scattering strength results as a function of scattering angle for the Monte Carlo integral equation for kh = 0.67, kl = 2.83, and an incident angle of 80° for a Gaussian roughness spectrum.

In past work for pressure-release surfaces, we showed that the NLSSA cross section can be written as the sum of the lowest-order SSA and an additional term, the latter of which can be considered a correction term for the lowest-order SSA [4]. The approximation mentioned earlier is made only to this correction term, and the approximate NLSSA can still be written as the sum of two terms, the lowest-order SSA and a correction term. In our scheme, the SSA term is used away from low grazing angles where it is accurate and where the correction term makes no contribution. The correction term is added only at low grazing angles where it makes a contribution. Through numerical studies we learned that we could make a linear approximation to part of the innermost integrands which allowed us to reduce the order of integration and, thus, satisfy the criteria for a practical cross section. We adopted the name SSA+ for the final form of the cross section terms:

$$\sigma_{SSA+} = \sigma_{SSA} + \sigma_c$$

where the first term is the lowest-order SSA cross section, and the second term includes three approximations to the original integrals of the NLSSA.

WORK COMPLETED

This year we continued our development and numerical studies of the SSA+, especially for larger angles of incidence (low grazing angles), for pressure-release surfaces. As part of this work, we examined Monte Carlo integral equation (MCIE) results because the length of the surfaces used increases in importance as the grazing angles decrease. We studied surface lengths starting from $L = 100\lambda$, where λ is the incident wavelength, and continuing to $L = 600\lambda$. Figure 1 shows an example for an incident angle of 80° and scattering angles between 85° and 90° for a Gaussian roughness spectrum. Assuming the results have converged when scattering strengths are within 1 dB, we see that even with $L = 600\lambda$, convergence has occurred only to about 88.5°.

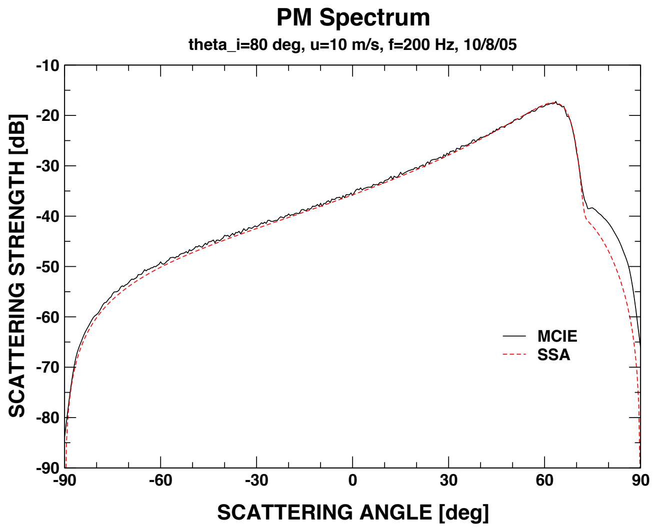

Figure 2: Bistatic scattering strengths as a function of scattering angle for the lowest-order SSA and the Monte Carlo integral equation for a Pierson-Moskowitz roughness spectrum with u = 10 m/s, f = 200 Hz, and an incident angle of 80°.

We compared the SSA+ results with the MCIE results and learned that the lowest-order SSA is accurate at least to a scattering angle of 88.5° for the examples we studied. At low grazing angles in the backward direction, the lowest-order SSA is inaccurate, and the SSA+ is not expected to correct this inaccuracy.

We also performed surface-length studies for the MCIE for a Pierson-Moskowitz roughness spectrum, and the results were similar to those for a Gaussian spectrum. Our work with the SSA+ indicates that the SSA is actually quite accurate for wind speeds of 10 and 20 m/s for scattering angles less than about 70°. However, at 80° the SSA results are low as shown, for example, in Fig. 2. Although not visible in this figure, the SSA scattering strength is low in both the forward and back directions at low grazing angles.

Work on this project was performed by the PI and Yanqiu Wang, a PhD graduate student.

RESULTS

The past year's research has led to some interesting results that contradict what we thought to be true earlier. We discovered that the lowest-order SSA is accurate at lower grazing angles than we had previously believed to be the case for a Gaussian roughness spectrum. We also found that the SSA is accurate for the more realistic Pierson-Moskowitz spectrum for scattering angles larger than 20° grazing.

IMPACT/APPLICATIONS

The development of approximate models that accurately predict wave scattering from rough surfaces is important in a number of Navy applications. For example, rough surface scattering models are needed in the simulations used by torpedo guidance and control personnel to test torpedoes. Another application for which rough surface scattering is critical is the detection of underwater mines, especially those buried in soft sediments. Other applications include ship wake detection, communications, and anti-submarine warfare. Of particular importance is that the models be as simple as possible while retaining the physical information necessary for the application.

Much of the knowledge we have gained has been disseminated via publications and conference presentations. A search of the Science Citation Index online shows that previous ONR-sponsored work on rough surface scattering has been cited 177 times, and it is believed that the SSA+ has the potential to be of practical use to the Navy.

RELATED PROJECTS

This work is related to research in shallow water acoustics, high-frequency acoustics, and long-range propagation. The SSA+ is of particular interest when forward scatter is important since it includes nonlocal interactions. Additionally, this work is related to that of several other ONR-sponsored researchers including Eric Thorsos and John Schneider [`http://www.eecs.wsu.edu/~schneidj/`].

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2. Broschat, S.L., and E.I. Thorsos, "A preliminary numerical study of the non-local small slope approximation," *J. Acoust. Soc. Am.*, vol. 100, p. 2702, 1996.

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PUBLICATIONS

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2. Broschat, S.L., "The SSA+ for scattering at low grazing angles," to be submitted to the *IEEE Trans. Geosci. Rem. Sens.*, 2005.

HONORS/AWARDS/PRIZES

Elected Fellow of the Institute of Physics