

**ATMOSPHERIC, VOLUME AND SURFACE  
SCATTERING AND PROPAGATION**



**Single and Multiple Scatter from Random Rough Surfaces**

**Full Wave Solutions**

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**Abstract**

The full wave solution is used to predict the observed enhanced backscatter from rough surfaces. Single and multiple scatter are accounted for in the analysis.

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## Summary

A full wave approach was used to compute the like- and the cross-polarized bistatic scattering cross sections for finitely conducting two-dimensional random rough surfaces (Bahar and Fitzwater 1987, 1989). These computations for plane waves at oblique incidence, which were performed before the experimental data were provided to the authors, are in good agreement with the results of recent experiments conducted by Mendez and O'Donnell (1987a, 1987b) and reported by Flood (1987). However in these full wave solutions, the field impressed upon the rough surface is assumed to be the incident and specularly reflected plane waves. Thus, only single scattered fields were considered in the earlier work (Bahar and Fitzwater 1987, 1989). These single scatter results were not sufficient to predict and interpret the experimental results for normal incidence, and the authors noted that "the experimental results of Mendez and O'Donnell stimulate the identification and development of reliable scattering theories that are valid over a broad range of rough surface characteristics. These theories should take into account both single and multiple scattered fields in a tractable manner." In this paper, we report the progress made in extending the full wave solution such that both single and multiple scattered fields are accounted for in the analysis. These new results for normal incidence show that the enhanced backscatter is due to multiple scatter if the mean square slope is  $\sigma_s^2 \gtrsim 1$  and the surface material is highly reflective (Bahar and El-Shenawee 1991). However, the observed peak in the scattered intensity around the backscatter direction is primarily due to single scatter. In a fixed plane normal to the mean surface, these peaks of the scattered fields show up as double humps about the backscatter direction. In three dimensions, these scattered fields for normal incidence exhibit a four-fold polarimetric symmetry (Mendez and O'Donnell 1987b, Bahar and Fitzwater 1987).

As the mean square slope decreases well below unity, the multiply scattered fields are shown to be significantly smaller than the single scattered fields; and in these cases, the very sharp peak in the backscatter direction is not predicted on the basis of the full wave analysis (in agreement with experiments, Mendez, et al., 1991). However, the peak in the scattered intensity around the backscatter direction persists unless the mean square slope is very small. Thus for intermediate values of mean square slopes, the field scattered in the backward direction is actually smaller than the field scattered around the backscatter direction. As the mean square slope becomes smaller, the scattered field becomes quasi specular. When the radii of curvature (related to correlation



length) becomes sufficiently large, these results are in agreement with the physical optics (specular point) theory of Beckmann and Spizzichino (1963). These computer predictions are also useful in interpreting the experimental results reported by Mendez et al. (1991).

To obtain the single and multiple scatter full wave results, the impressed field on the surface is assumed to be the sum of the incident and specularly reflected wave as well as the diffusely scattered field that impringes upon the rough surfaces before it is rescattered to the observation point at a large distance from the surface. Thus, the spectral form (rather than spherical wave form) of the full wave analysis is used in this phase of the analysis. Random distributions of realistic models of rough surface scatters (with different mean square height, slope, width and mean depth) are assumed in this work. It is shown that as the incident angle increases, the contributions to the observed backscatter enhancement due to multiple reflection decreases more rapidly than the contributions due to the single scatter.

In their earlier work (Bahar and Fitzwater 1989), it was also suggested that, "the statistical assumptions made in order to facilitate the numerical evaluation of the scattering cross section need to be re-examined." In his recent work Bahar (1991) has shown that when all the correlations between the surface heights and slopes at two points on the surface are accounted for the same full wave expression for the scattering cross sections reduce in the low frequency limit to Rice's (1951) small perturbation solution (if the mean square slope is also small) and to the high frequency physical optics results (Beckmann and Spizzichino 1963) when the major contribution to the scattered fields come from the neighborhood of the specular points. The computer implementation of this phase of the full wave analysis for one-dimensionally rough surfaces (which involved three-dimensional integrals) is currently in progress. All the unified full wave computer codes contain only "ground truth" input data. Thus, artificial effective media parameters or scaling and normalization parameters are not introduced to obtain best "curve fits" with computed or experimental data.

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