Comparison between Small Slope Approximation and Two Scale Model in bistatic configuration

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Abstract—The Small Slope Approximation (SSA) and Two Scale Model (TSM) are applied to the prediction of microwave sea scattering in bistatic configuration. The calculations were made by assuming the surface-height spectrum of Elfouhaily 

et al for fully developed seas. Both the co- and cross-polarization cross section are calculated in several bistatic configuration. The simulations showed good agreement between SSA and TSM for Ku- and C-bands. For the HH polarization, a significant difference between results obtained with two models is remarked specially near the grazing angles and for large wind speed. Numerical results are obtained as a function of wind speed, incident/scattering angles and polarization states.

I. INTRODUCTION

Wave scattering by rough sea surface is an important issue in several remote sensing applications. In more recently, bistatic and multistatic radar systems operating from air-borne platforms received a renewed interest for its advantages in remote sensing of ocean surfaces. These applications require developing accurate models to predict radar bistatic scattering from such surfaces. Approximate models are still a necessity due to the insurmountable numerical complexity of realistic scattering problem. The two basic methods were used before in scattering problem: the Kirchhoff Approximation (KA), which is valid for small values of the ratio of wavelength to curvature radius of the surface and the Small Perturbation Method (SPM) which is valid for small values of the Rayleigh parameter, the ratio of roughness height to the incident wavelength. These two methods are only applicable to surfaces with only one scale of roughness, but natural surfaces in particular the sea ones are characterized by several degrees of roughness, a model which treats at least two scales of roughness was necessary. Several models were proposed to solve this problem. In this study, we focus on two models: the Small Slope Approximation (SSA) [1] and Two Scale Model (TSM) (composite-surface) [3]. The last one is a combination of two basic methods KA an SPM. In this theory, a large-scale surface is defined on which the KA is assumed to hold, and a small-scale surface defined on which the SPM is applicable. Therefore, this model introduces a scale-dividing parameter $k_d$ separating small- and large-scale components of the roughness which can be arbitrarily chosen within wide limits what grants a disadvantage to this model in particular when treating the inverse problem. The second theory SSA, have not the above mentioned partition requirement, was proposed by Voronovich as a unifying theory that could reconcile SPM an KA. So SSA is appropriate for scattering from both large- and small-scale roughness within a single theoretical scheme. The objective of this study is to examine the bistatic scattering of electromagnetic waves from anisotropic ocean surface using SSA and TSM, who represent two different types: one is a unifying and the other is a composite theory, for numerical computations then a comparison between their results. In section II, theoretical principles of SSA and TSM are briefly reviewed. In section III, we cite a short description of the Elfouhaily model for the sea roughness spectrum used in our simulations. Finally, we present numerical comparison in several configurations, between scattering cross section of these two models in both co- and cross-polarization.

II. SCATTERING MODEL

Many approches were developed to evaluate the electromagnetic sea surface scattering, each is available in certain hypothesis and conditions. Elfouhaily et al [4] published the latest critical and up-to-date survey of the analytical approximate. In this paper, we focus on two models: SSA and TSM.

The geometry of the surface scattering is shown in figure 1.

![Fig. 1. Geometry for scattering from sea surface](image)

A. Small Slope Approximation

The small-slope approximation is appropriate for scattering from large-(Kirchhoff regime), intermediate- and small-scale (the Bragg regime) roughness within a single theoretical scheme. The SSA can be applied for an arbitrary wavelength, provided the tangent of grazing angles of incident/scattered radiation sufficiently exceeds the rms (root mean square) slopes of roughness. It is noteworthy that slopes of sea-surface
roughness are generally small except for steep breaking waves [2]. Another advantage of the SSA is that it represents regular expansion with respect to powers of slopes. In the first order of the SSA, used in our numerical computations, the expression for the normalized bistatic cross-section (NBCS) is as follows:

\[
\sigma_{\alpha\alpha_0}(k, k_0) = \frac{1}{2} \left| \frac{2q_k q_0 B_{\alpha\alpha_0}(k, k_0)}{q_k + q_0} \right|^2 \\
\times \exp\left[-(q_k + q_0)^2 W(0) \right] \\
\times \int \{ \exp\left[\{(q_k + q_0)^2 W(r) - 1\} \exp\left[-i(k - k_0)r\right]\right]dr \quad (1)
\]

where \(k_0, q_0\) are horizontal and vertical projections of the wave vector of an incident wave, and \(k, q\) are appropriate components of the wave vector of scattered wave. \(B_{\alpha\alpha_0}(k, k_0)\) is a non-singular dimensionless function depending on polarization. Explicit expressions for it can be found in [1]. \(\alpha, \alpha_0\) correspond to the polarization of scattered and incident plane wave respectively. The evaluation of the correlation function \(W(r)\) throughout the area of integration in (1) increases the computing time especially for large incidence angles.

B. Two Scale Model

The most widely used method for relating microwave scattering to surface roughness is composite-roughness theory (TSM) [3]. The main idea of this method is to take advantages of the KA and SPM and enlarge the application domain. In this case, the surface spectra of large-scale waves and small-scale waves, denoted by \(S_l\) and \(S_s\) respectively, are related to the sea surface spectrum \(S\) by:

\[
S_l(K, \psi) = \begin{cases} 
S(K, \psi) & \text{if } K < k_d \\
0 & \text{otherwise}
\end{cases} \quad (2)
\]

\[
S_s(K, \psi) = \begin{cases} 
0 & \text{if } K > k_d \\
S(K, \psi) & \text{otherwise}
\end{cases} \quad (3)
\]

where \(k_d\) is the two scale cutoff, it is often estimated to \(k/3\) [6] where \(k = 2\pi/\lambda\) is the electromagnetic wavenumber. There are therefore two treatments. The first one corresponds to the Kirchhoff solution for the large-scale component (specular reflections), and the second one corresponds to the Bragg scattering solution for the small-scale component modulated by tilts of large-scale waves. TSM has a larger domain than KA and SPM. It covers the small and the large waves. The existence of the scale-dividing parameter allot a disadvantage to TSM especially when we attempt to solve the inverse problem. The advantage of this method is that it is easily applied.

III. SEA SPECTRUM MODEL

To calculate statistical characteristics of scattering using the SSA and TSM one must know the characteristic functions of the random field of elevations. These characteristic functions for sea-surface roughness are unknown. However, for Gaussian statistics they can be expressed through a correlation function of roughness. In our simulations we used the Elfouhaily et al [5] model for the sea roughness spectrum, which was recently developed solely from in situ or tank measurements, along with physical arguments. It is noteworthy that this model was developed without any relation to remote-sensing data. Elfouhaily et al assume a directional spectrum \(S(K, \psi)\) defined in polar coordinates as

\[
S(K, \psi) = M(K)G(K, \psi)
\]

where

\[
M(K) = (B_L + B_H)/K^3
\]

and

\[
G(K, \psi) = [1 + \Delta(K)\cos(2\psi)]/2\pi
\]

In (4), \(M(K)\) denotes the non-directional spectrum (isotropic part) modulated by the \(G(K, \psi)\) spreading function. In (5), \(B_L\) and \(B_H\) are the respective contributions from low (gravity waves) and high (capillary waves) wavenumbers. \(\psi\) is the azimuthal angle measured with respect to the mean wind direction. The factor \(\cos(2\psi)\) (6) is responsible to return the spectrum symmetric compared to the wind direction axis, so it is not capable to differentiate upwind (\(\psi = 0^\circ\)) to downwind (\(\psi = 180^\circ\)) case. Some proposal could be introduced to improve the performances of this spectrum in [7][8]. We will take in consideration these ameliorations in our futur work. This spectrum will be used in the next section when we evaluate bistatic sea scattering cross section.

IV. NUMERICAL RESULTS AND DISCUSSION

A. Forward scattering

Before presenting the comparison between SSA and TSM in bistatic configuration, we present a simulation in forward scattering which is a particular case of bistatic configuration. To fulfil the forward scattering configuration conditions, incident azimuths in emission and reception must be equal. When examining simulations in figure 2, several items of importance may be deduced. First, the maximum of energy is received around the specular direction 60° which is a logic statement. The level of this maximum decreases when the wind speed increases from 5m/s case (a) to 15 m/s case (b). SSA and TSM results appear to be in good agreement, with an average absolute difference within 1-2 dB for small scattering angles. However, there is a significant difference of the order of 3-4 dB of the forward scattering cross section for large scattering angles for HH polarization. The last observation becomes more important when wind speed increases.

B. Bistatic scattering

It is well recognized that bistatic systems offer certain advantages of spatial diversity and some level of covertness not offered by monostatic systems. So in this part, we present numerical simulations using SSA and TSM of scattering cross section in several bistatic configurations as a function of wind speed, incident/scattering angles and polarization states for Ku-band.
In this paper, the normalized radar cross section is calculated from SSA and TSM by considering Gaussian statics of the sea surface. One can see that there is a good agreement between these two models in bistatic configuration both in co- and cross-polarization within an average absolute difference within 1-2 dB. In HH polarization a significant difference is observed near the grazing angles and for large wind speed. The ultimate test for the above results in bistatic case could be provided by experimental measurements. Finally, after agreement and satisfactory results obtained with SSA and TSM in bistatic case, this comparison can be useful to choose one of these methods in bistatic practical applications in our future work.

V. CONCLUSION
Fig. 4. Bistatic scattering cross section with SSA and TSM (F = 13.9GHz, \( \theta = 40^\circ \), \( \phi = 0^\circ \), \( \phi_s = 135^\circ \), wind speed=5m/s : (a) co-polarization, (b) cross-polarization)

Fig. 5. Bistatic scattering cross section with SSA and TSM (F = 13.9GHz, \( \theta = 40^\circ \), \( \phi = 0^\circ \), \( \phi_s = 135^\circ \), wind speed=15m/s : (a) co-polarization, (b) cross-polarization)

REFERENCES


