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Bistatic Scattering of GPS Signals from Sea Surfaces

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Abstract-the Global Positioning System (GPS) was first conceived and built for the purpose of navigation. Recently, the possibility to utilize the GPS signal scattered off the ocean as a means of doing altimetry and scatterometry has generated considerable interest. Specifically, a GPS receiver and transmitter pair would form a bistatic radar geometry when the receiver is equipped with a properly oriented antenna designed to collect the GPS signal traveling in the specular direction after having scattered off the ocean surface. When considering the constellation of GPS transmitters and receiver a multistatic system is obtained, capable of intercepting scattered signals from several areas of the ocean simultaneously. By measuring the delay between the time of signal transmission and that of reception after undergoing scattering, the path traveled by the signal can be recovered from which certain characteristics of the ocean surface around the reflection point. Basically, the received power can be represented by an appropriate form of the radar equation containing the bistatic scattering coefficient at L-band. Hence, any attempt to recover sea state parameters rests with the ability to understand the scattering processes for general sea state conditions and direction of incidence. In fact, the choice of the pointing direction of the receiving antenna and its gain are affected by the scattered signal level and sensitivity to sea state parameters. This work was motivated by such needs.

I. INTRODUCTION

A bistatic electromagnetic wave scattering model for the sea surface is developed to examine its wind dependence property over a wide range of incident angles along the specular direction. This is done by combining an existing scattering model with a sea spectrum recently reported in the literature. In general, electromagnetic wave scattering from a rough surface is dependent on the Fourier transform of the nth power of its height correlation function which can be computed numerically from the surface spectrum. This transform relation indicates that scattering is sensitive not only to the surface spectrum but also to its convoluted properties. Generally, surface scattering is sensitive only to a portion of the surface correlation measured from the origin. The size of this portion is a function of three variables, the incident angle, the surface height standard deviation and the exploring wavelength. When this portion includes the entire correlation function, surface scattering is dependent mainly on the transform of the correlation known as the surface height spectrum. As this portion narrows, scattering begins to depend also on the transform of higher powers of the correlation. These transforms represent the slope effects of the low wavenumber components of the surface.

Under a special geometric condition (such as backscattering at large angles of incidence, scattering along the specular direction etc.) one can always introduce effective surface parameters and obtain the same results for scattering coefficients as those obtained starting with the true ones. To demonstrate this point we shall use the Kirchhoff surface scattering model first. For theoretical models with limited range of applicability the selection of a certain portion of the sea spectrum responsible for scattering becomes necessary to reconcile predictions with experimental data. On the other hand, if a scattering model is applicable to the entire surface spectrum, such a selection is not needed, because the selection will be carried out by the scattering model automatically. Secondly we illustrate the wind dependence of the sea surface correlation function based on an existing sea spectrum. Finally we illustrate and discuss the wind dependence of radar scattering along the specular direction using the given sea spectrum.

II. MODEL DEVELOPMENT

The particular portion of the correlation sensed is determined by the exploring wave length, the incident angle and the state of the sea. To understand this dependence consider the bistatic incoherent scattering coefficient for like polarization under the Kirchhoff approximation [7]

$$\sigma^0{}_{pp} = \frac{k^2\left|f_{pp}\right|^2}{4\pi} \int_{-\infty}^{\infty} e^{-\sigma^2(k_{sz}+k_z)^2} \int_{-\infty}^{\infty} [e^{-\sigma^2(k_{sz}+k_z)^2\rho(\xi,\eta)} - 1]$$

$$\exp[j(k_{sx}-k_x)\xi + j(k_{sy}-k_y)\eta]d\xi d\eta \tag{1}$$

where σ is the standard deviation of surface heights, ρ is the normalized surface correlation function. For an isotropically rough surface (1) can be simplified and let $\kappa = \sigma^2(k_{sz}+k_z)^2$, the scattering coefficient becomes

$$\sigma^0{}_{pp} = \frac{k^2\left|f_{pp}\right|^2}{2} \int_0^{\infty} \left\{e^{-\kappa[1-\rho(r)]} - e^{-\kappa}\right\} J_0[kr]rdr$$

or

$$\sigma^0{}_{pp} = \frac{(kL)^2\left|f_{pp}\right|^2}{2} \int_0^{\infty} \left\{e^{-\kappa[1-\rho(r)]} - e^{-\kappa}\right\} J_0[kL\gamma]\gamma d\gamma \tag{2}$$

We normalized the integration variable of the second scattering coefficient in (2) by the correlation length to make it dimensionless. A clearer view of the dependence of the scattering coefficient on the surface correlation properties can be seen by rewriting (2) as

$$\sigma^0{}_{pp} = \frac{k^2\left|f_{pp}\right|^2}{2} e^{-\kappa} \sum_{n=1}^{\infty} \frac{\kappa^n}{n!} \int_0^{\infty} \rho(r)^n J_0[kr]rdr \tag{3}$$

From (3) the scattering coefficient is dependent on the Bessel transform of all powers of the correlation function. Only one of the terms (n=1) corresponds to the surface spectrum. The n>1 terms correspond to the convolution of the surface spectrum. Thus, in surface scattering it is the powers of the surface correlation or the convolutions of the sea spectrum that are important for scattering calculations. The wavenumber in the surface spectrum or its convolutions selected by the scattering model as the one responsible for scattering is given by the argument of the Bessel function, , which depends on both the electromagnetic wavelength and the incident angle. The combination of this selection and the impact of κ in the integration support the use of effective surface parameters in explaining scattering when limited knowledge of surface spectrum is available. On the other hand, when the surface spectrum is known, the scattering model will carry out this selection automatically and hence real surface parameters can be used in scattering models without modification.

the sea surface has a correlation function quite different from a Gaussian or an exponential and that it has a very strong wind dependence. To illustrate these points we use a recent sea spectral model represented as

$$S(K,\phi) = S(K)A(\phi) \tag{4}$$

reported by Elfouhaily et al [1997]. We calculate the wind dependence of the scattering coefficient along the specular direction at 1.48 GHz from the sea surface as a function of wind velocity and incident angle. This is done by using the correlation function of the previous section in the bistatic surface scattering model available from Chapter 5 of Fung [1994]. It has the form,

$$\sigma^0{}_{pp} = \frac{k^2}{2} e^{-\sigma^2 (k_{sz}+k_z)^2} \sum \left| I''{}_{pp} \right|^2 \frac{W''(k_{sx}-k_x, k_{sy}-k_y)}{n!} \tag{5}$$

where $k_z = k\cos\theta$, $k_{sz} = k\cos\theta_s$, the polarIzatIon state Is *pp* =*vv* or *hh,*

$$I''{}_{pp} = [\sigma(k_{sz}+k_z)]'' f_{pp} \exp(-k_{sz}k_z\sigma^2) + \frac{k''_{sz} F_{pp(-k,-k)} + k''_z F_{pp}(k_{sx}, k_{sy})}{2} \tag{6}$$

and $W^{(n)}(k_{sx}-k_x, k_{sy}-k_y)$ Is the Fourier transform of the nth power of the surface correlation coefficient. The field coefficients f_{pp} and F_{pp} are available from Appendix 4B of Fung[1994].

The shadowing function for bistatic scattering used is the one defined by Sancer [1967]

$$R_1(\theta,\sigma_s) = [1 - \frac{1}{2} erfc(\frac{\cot\theta}{\sigma_s\sqrt{2}})][1 + f(\theta,\sigma_s)]^{-1} \tag{7}$$

where

$$f(\theta,\sigma_s) = \frac{1}{2}\{\sqrt{\frac{2}{\pi}} \frac{\sigma_s}{\cot\theta} \exp(-\frac{\cot\theta^2}{2\sigma_s^2}) - erfc(\frac{\cot\theta}{\sigma_s\sqrt{2}})\} \tag{8}$$

and σ_s is the rms slope of the surface; θ is the incident angle and *erfc* is the error-function complement related to the error function *erf* by

$$erfc(z) = 1 - erf(z) = 1 - \sqrt{\frac{2}{\pi}} \int_o^z \exp(-t^2)dt \tag{9}$$

The computed result for along the specular direction is of major interest to bistatic sensing of the scattered signal from the global positioning system. At a wind speed of 4 m/s the horizontally polarized coefficient is seen to rise with the incident angle until about 70 degrees. Beyond 70 degrees the scattering coefficient turns back down [Figure 4]. This down turn is due to integration into the negative correlation region. rise with the incident angle until about 70 degrees. Beyond 70 degrees the scattering coefficient turns back down [Figure 4]. This down turn is due to integration into the negative correlation region. Beyond 70 degrees the scattering coefficient turns back down [Figure 4]. This down turn is due to integration into the negative correlation region. When we increase the wind speed to 6 m/s, the surface rms height increases. This yields a larger κ which restricts the range of integration to a smaller value than at 4 m/s and causes a decrease in the value of the scattering coefficient. Physically, this decrease is due to an increase in the mean square slope associated with a higher wind speed [Figure 2]. This narrowing of the range of integration also avoided the negative correlation region and hence the horizontally polarized scattering coefficient continues to rise with the incident angle up to 80 degrees.

III. CONCLUSION

Scattering at L-band is controlled by the surface correlation function instead of simply the surface slope distribution. When determining surface parameters through data fitting we generally obtain effective surface parameters rather than the real parameters. These effective parameters relate to the surface components responsible for scattering but may not agree with those of the real surface especially when the surface has a full spectrum of components. On the other hand, when the surface spectrum or its correlation function is known, it is possible to predict the radar scattering using the real surface parameters. An additional finding is that in specular scattering wind dependence is stronger at larger angles of incidence for incident angles between 0 and 70 degrees over the wind speed range, 4 m/s to 20 m/s.

REFERENCE

J.L. Garrison, A. Komjathy, V.U. Zavorotny and S.J. Katzberg, "Wind speed Measurement from bistatically scattered GPS signals," submitted for publication in IEEE TGARS, 1999.

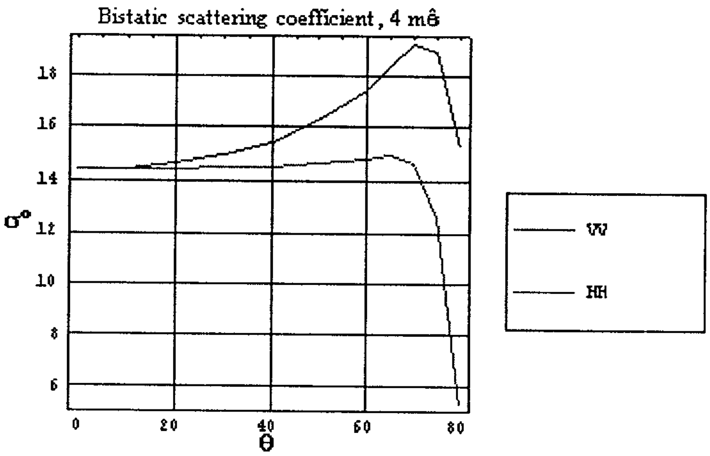

Figure 1. Incoherent scattering along the specular direction for vertical and horizontal polarization at a wind speed of 4 m/s and Ω=0.83. The relative dielectric constant of water is taken to be 73-j57.

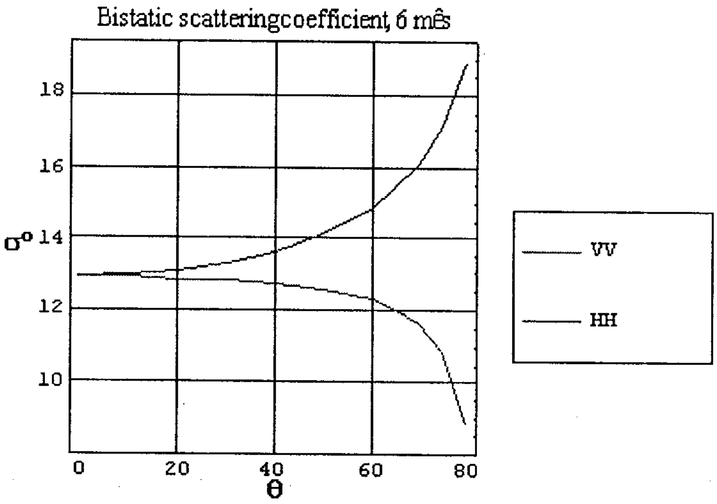

Figure 2. Incoherent scattering along the specular direction for vertical and horizontal polarization at a wind speed of 6 m/s and Ω=0.83. The relative dielectric constant of water is taken to be 73-j57.