ELECTROMAGNETIC WAVE SCATTERING FROM OCEAN SURFACE AT LOW GRAZING ANGLES

Naheed SAJJAD, Ali KHENCHAF and Arnaud COATANHAY

ENSIETA/E^{3}I^2-Laboratory,
2 rue Francois Verny, 29806 Brest Cedex 09,France
Email:$\{naheed.sajjad, ali.khenchaf, arnaud.coatanhay\}$@ensieta.fr

ABSTRACT

Bragg scattering is widely recognized as the dominant mechanism at moderate incident angles, by which the ocean surface backscatters microwave radiation. In this paper we have shown that the validity domain of the Bragg/composite surface theory can be extended to low grazing angles by taking into account the contribution of second order scattering effects into the first order at small scale. An improved two scale model (TSM) has been investigated at low grazing angles for (radar frequencies) L-, C- and Ku-band with wind speeds of 7m/s and 15m/s. It is observed that for higher wind speeds the intensity of σ_{HH} increases up to 8 dB. In backscattering configuration predictions of the model are compared with the experimental data at Ku-band. Comparison shows good agreement at higher wind speeds. Finally, we use the improved TSM to predict the sea scattering in bistatic configuration and compare the results with classical TSM.

Index Terms**—** low grazing angles, sea surface scattering, two scale model, horizontal polaization

1. INTRODUCTION

Scattering from sea surface at low grazing angle (LGA) has attracted much attention due to practical importance in the areas of the low-attitude/long-range radar surveillance, target tracking, communication, and navigation systems operating at low grazing conditions above the ocean surface. Historically normalized radar cross section of vertical polarization σ_{VV} has been known to be rather well explained by Bragg scattering augmented by a composite, or two-scale, sea surface over the range of incidence angles from approximately $20°$ to $60°$ and probably at even higher incidence angles, into the so called LGA regime [1, 2]. σ_{HH} on the other hand, has been, and continuous to be, more mysterious. It has appeared to be fairly well predicted by Bragg/composite surface scattering from $20°$ to $45°$ incidence but at larger incident angles this intensity is considerably stronger than that expected from theoretical computation. Many non-Bragg scattering mechanisms attributable to wave breaking have been suggested to explain the strong radar returns. The Doppler property of horizontal polarization (HH) return is also found to be very different from the VV return [3, 4] . However there are other mechanisms e.g., fading [5] and higher order scattering etc. that are responsible for strong backscatter intensity. In this paper we have shown that TSM predictions for HH can be improved by taking into account the contribution of second order scattering effects into the first order at small scale. An improved TSM [7] is investigated at incident angles from $60°$ to $85°$. The simulations has been done for L-, C- and Ku-band with wind speeds of 7m/s and 15m/s. The performance of this model has been assessed by comparing the numerical results with experimental data [5] in backscattering configuration at Ku-band.

In the following section we briefly review the development of improved TSM. In the third section we cite a short description of the elfouhaily model for the sea roughness spectrum used in our simulations. The simulation section begins by the model comparisons with experimental measurements in backscattering configuration. Finally, we present the numerical simulations of the ocean surface for bistatic configuration and compare the predictions by improved TSM with classical TSM.

2. SCATTERING MODEL

In this section, we take a small review of improved TSM used in our study. Geometrical configuration adopted to resolve the wave-scattering problem from the sea surface is given in figure1.

The classical two-scale model introduced by Fuks [8] and Fung et al. [9] in backscattering configuration and extended by Khenchaf et al. [11, 10] in bistatic configurations approximate the sea surface as a two-scale surface with small-scale ripples or capillary waves riding on the top of large-scale surfaces or gravity waves. The key idea of this method is to take advantages of the classic approaches, small-perturbation model of first order (SPM1) and Kirchhoff approximation (KA) to enlarge the application domain [11]. The scattering coefficients are estimated in two steps: Firstly, the classical

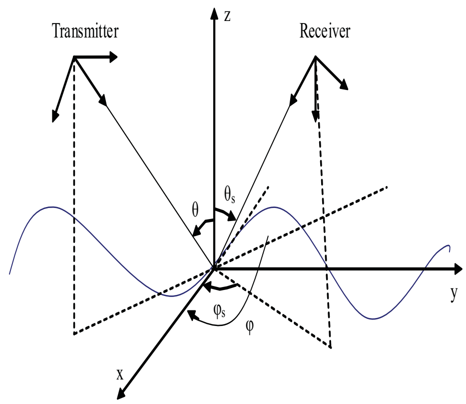


Fig. 1. Geometrical representation of bistatic configuration

TSM uses SPM1 on small scale waves and then secondly the determination of the diffuse component in the global reference by a tilting process.

For SPM calculations we consider a three dimensional problem and use the formulation given by Tsang [13] . The extended boundary condition method, which relates the surface tangential fields to the incident fields, is used to solve the surface field parameters to second order for small rms height. For complete second order scattering contribution one must calculate third order field $E_s^{(3)}$, but for three dimensional problem it is complicated. Moreover, for horizontal polarzation $\sigma^{(13)}$ is small compared with $\sigma^{(22)}$ and $\sigma^{(22)}$ is sufficient for SPM2 [6]. Then, in the first part of classical TSM we add the second order scattering effects given by SPM2 in SPM1 and get the improved version of TSM [7].

3. SEA SPECTRUM

A typical mathematical representation of gravity and capillary waves is the sea surface spectrum. We utilize the results of Elfouhaily et al. [12] in our model. This spectrum takes into account several physical parameters like wind speed, wind direction and wind friction velocity etc. and its analytic expression is available for all the wave number bands. Moreover, this spectrum takes in account the fetch influence on the wave behavior so that not only fully developed seas but also younger seas can be taken in to account.

The basic approach is to factor the spectrum into two parts, a part dependent only on wave number and the other part dependent also on direction along with wave number behqving i.e.,

$$W(K,\phi) = W(K)\, f(K,\phi) \tag{1}$$

where

$$W(K) = (B_L + B_H)/K^3 \tag{2}$$

and

$$f(K,\phi) = \left[1 + \Delta(K)\cos(2\phi)\right]/2\pi \tag{3}$$

In (1), $W(K)$ denotes the non-directional spectrum (isotropic part) modulated by the $f(K,\phi)$ spreading function. In (2), B_L and B_H are the respective contributions from low (gravity waves) and high (capillary waves) wavenumbers. ϕ is the azimuthal angle measured with respect to the mean wind direction. $\Delta(K)$ is recognized as the coefficient of the second harmonic when truncating the Fourier series expansion of $f(K,\phi)$.

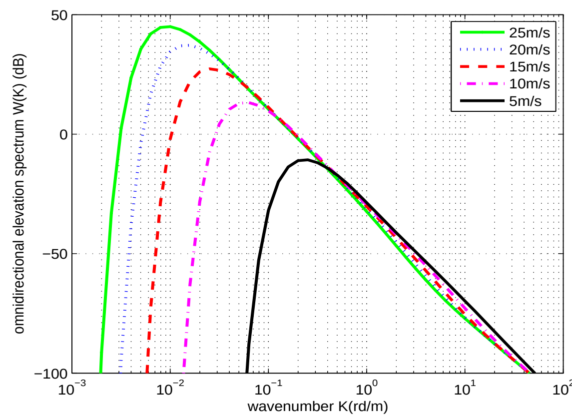


Fig. 2. Elfouhaily sea surface Omnidirectional spectrum with different windspeeds

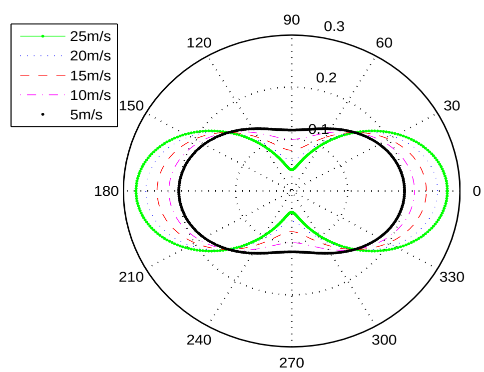


Fig. 3. Elfouhaily sea surface Angular function with different windspeeds

Figures 2 and 3 respectively show the fully developed isotropic Elfouhaily spectrum and the unified spreading function behavior for different wind speeds.

4. NUMERICAL RESULTS

Before simulating scattering coefficients in bistatic configuration, we compare our results with experimental data at Ku-band. As we stated that σ_{VV} is well explained by composite TSM so we present the simulation results by improved TSM for σ_{HH} only. The first part of this section deals with backscattering configuration. The bistatic case is represented at the end of this section.

Backscattering configuration: This configuration is omnipresent in the literature, it is simple to implement since the emitter is behaving as a receiver at the same time. It is used in many applications as classic radars, SAR images and GBR...

To fulfil the backscattering configuration conditions, incident angles in emission and reception must be identical and the corresponding azimuth difference equal to π

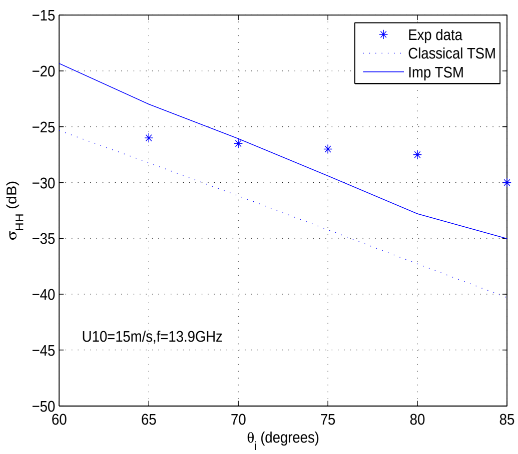


Fig. 4. Backscattering coefficients:Comparison of Improved TSM with experimental data [5], and classic TSM for HH polarization. F=13.9 GHz, wind speed=15m/s (at 10m).

The first simulation (figure 4), deals with the incidence angle effect on the scattering coefficients. The electromagnetic frequency is fixed to 13.9 GHz (Ku-band), the wind speed to 15 m/s then to 7 m/s (figure 5) at a 10 meters altitude above the sea surface. The dielectric constant is given by the Debye equation [14] and the emitter is supposed to be in the upwind direction. We observe that greater accuracy is achieved for higher wind speed (i.e., when U10=15 m/s) and the results are in good agreement with measurements. For lower wind speed (U10=7m/s) there is no significant difference between the results of classical TSM and improved TSM and both modeles underestimate σ_{HH} on the LGA domain. The same type of results are obtained for C-band (f= 4.45 GHz) and L-band (f=1.5 GHz) (figure 6).

Bistatic configuration: Now lets move on to bistatic scattering. The incident angle in the emission is fixed $80°$ while

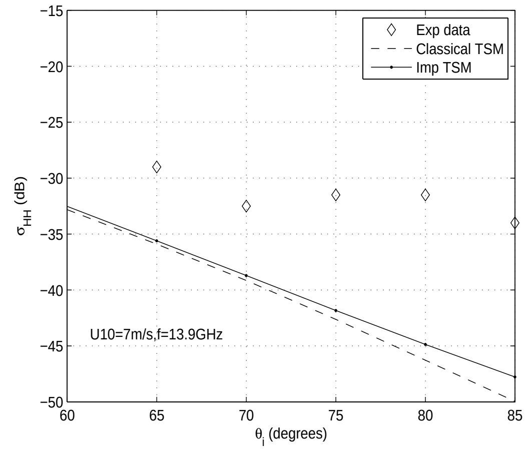
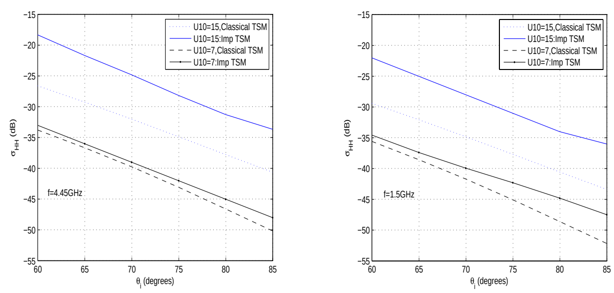


Fig. 5. Backscattering coefficients:Comparison of Improved TSM with experimental data [5], and classic TSM for HH polarization. F=13.9 GHz, wind speed=7m/s (at 10m).



(a)F=5.3 Ghz(C-band) (b)F=1.5 GHz (L-band)

Fig. 6. Backscattering coefficients:Comparison of Improved TSM classic TSM for HH polarization.

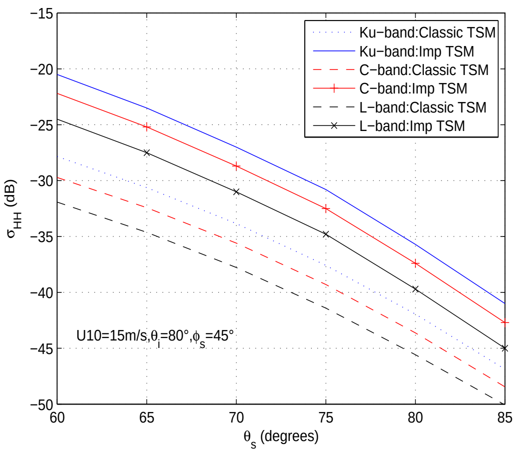
the received one varies from $60°$ to $85°$ for wind speed equal to 15 m/s. Received azimuth is set to $45°$. Figure 7 presents a comparison between improved TSM and classical TSM in a bistatic configuration described above.

Results show that the the addition of second order scattering theory increases the RCS intensity of up to 7dB in the choosen configuration.

5. CONCLUSION

An improved TSM has been investigated at low grazing angles. For HH polarization an improvement upto 8dB is found for relatively higher wind speeds. The validity is examined through comparison with the published experimental data in monostatic configuration at Ku-band. Hence under certain

Fig. 7. Bistatic scattering coefficients: Comparison between Improved TSM and Classic TSM. wind speed=15m/s(at 10m), $\theta_i = 80°$, $\varphi_i = 0°$, $\varphi_s = 45°$.



conditions the proposed model can be used for NRCS predictions at LGA's.

6. REFERENCES

[1] Bass, F. Fuks, I. Kalmykov, A. Ostrovsky, I. Rosenberg, A."Very high frequency radiowave scattering by a disturbed sea surface Part II: Scattering from an actual sea surface", IEEE Trans. Antenna and Propagation, AP-16(5), 560-568,1968.

[2] Wright, J.W., "A new model for sea clutter", IEEE Trans. Ant. Prop., vol. 16, issue 2, pp. 217-223, 1968.

[3] Pidgeon, V. W., "Doppler dependence of radar sea return," J. Geophys. Res., vol. 73, pp. 1333-1341, 1968.

[4] Keller, W., W. Plant, and G. Valenzuela, "Observations of breaking ocean waves with coherent microwave radar," in Wave dynamics and radio probing of the sea surface, ed. O. M. Phillips and K. Hasselmann, Plenum, New York, pp. 295-293,1986.

[5] W. J. Plant, "Microwave sea return at moderate to high incidence angles," Waves in Random Media, vol. 13, no. 3, pp. 339-354, Oct. 2003.

[6] E. I. Thorsos and D. R. Jackson, "The validity of the perturbation approximation for rough surface scattering using a Gaussian roughness spectrum," J. Acoust. SOC. Amer., vol. 86, pp. 261-277, 1989.

[7] N. Sajjad, A. Khenchaf, A. Coatanhay and A. Awada, "An improved two scale model for the ocean surface bistatic scattering, IGARSS, Boston, USA, 6-11 july, 2008.

[8] F. Bass and I. Fuks, Wave Scattering from Statistically Rough Surfaces, Pergamon, Oxford (1979).

[9] A. K. Fung, Z. Li, and K. S. Chen, "Backscattering from a randomly rough dielectric surface," IEEE Trans. Geosci. Rem. Sens. 30, 356–369, 1992.

[10] A. Khenchaf, "Bistatic scattering and depolarization by randomly rough surface: application to the natural rough surface in X-band," Waves Random Media 11, 61–87 (2001).

[11] A. Khenchaf and O. Airiau, "Bistatic radarmoving returns fromsea surface," IEICE Trans. Elect. E83, 1827–1835 (2000).

[12] T. Elfouhaily, B. Charpon, K. Katsaros: "A unified directional spectrum for long and short wind-driven waves", JGR, 102, 15781-15796, 1997

[13] L. Tsang and J.A. Kong, Scattering of Electromagnetic Waves, Vol. 3: Advanced Topics, Wiley Interscience, 2001

[14] P. Debye. Polar molecules. Chemical cathalog compabny, New York, 1929.