Study Of Electromagnetic Scattering From Sea Surface Contaminated by Oil Using The Forward-Backward Method

Helmi GHANMI [1], Ali Khenchaf [2], Fabrice Comblet [3]
ENSTA Bretagne
[1,2,3] Lab-STICC UMR CNRS 6285
Brest, France
{Helmi.Ghanmi, Ali.Khenchaf, Fabrice.Comblet}@ensta-bretagne.fr

Abstract— **In this paper, by using the numerical Forward-Backward Method (FBM), a spatial focus is given to the influence of the oil spills on the electromagnetic scattering by a sea surface observed in bistatic configuration (Forward propagation). Therefore, we represent the influence of the pollutants (oil spills) on the physical and geometrical properties of sea surface using a damping model. Indeed, we will start the numerical analysis of the bistatic scattering coefficients of a clean sea surface. Then we represent the numerical simulation of bistatic scattering coefficients of clean and contaminated sea surface as a function of various parameters (frequency, incident angle, sea state, type of pollutant…). The numerical simulation results are compared with those given by the asymptotic methods for clean sea surface.**

Key words: Sea surface, Oil Spills, Forward-Backward Method, asymptotic method, Electromagnetic Scattering Coefficients

I. INTRODUCTION

In recent years, many systems have been developed such as SAR (Synthetic Aperture Radar) to detect the presence of the oil spill on the sea surface. To improve the performance of existing systems, it is necessary to analyze in greater detail the information contained in the electromagnetic field scattered by the sea surface [1]. In this context, modeling the interaction of electromagnetic waves with polluted seas or not takes all its importance. In particular, the estimation of the electromagnetic scattering based on geometric properties (roughness) and physical (dielectric properties of sea water with or without pollutant) of the ocean surface is an essential tool in the design of detection systems, in particular for pollutant. In recent literature, the study of the electromagnetic scattering from ocean surface covered by oil spills was performed in monostatic case by using the numerical method of moment and Monte-Carlo simulation [2]. In this paper we study and present this effect in bistatic configuration, which is interested in presence of pollution in sea surface. Indeed, we start the numerical simulations of the effect of the oil spills on the sea surface height spectrum. Then, we represent our numerical results of the bistatic scattering coefficients from a clean and contaminated ocean surface by using the numerical Forward-Backward method [3] [4] [5] [6].

II. FORMULATIONS

Fig.1 shows the geometric of one dimensional rough sea surface (1D) contaminated by oil spills. Region 0, 1 and 2 represent respectively the air, the oil slick film and the sea water. The parameters ε_0, ε_1 and ε_2 denotes respectively the relative permittivity in air, in the oil layer and in the sea water.

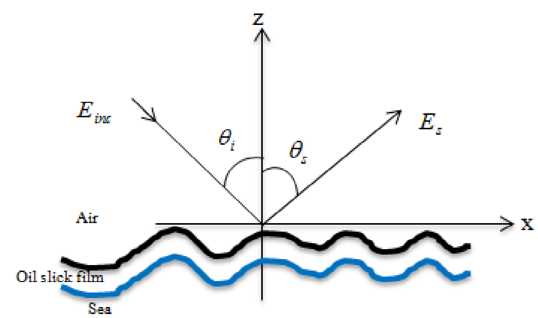

Fig. 1. Geometric of sea surface contaminated by oil film

In this section, we study the effect of the oil spills on the geometrical properties of the sea surface (ocean spectrum). Indeed, we will focus on the oil from a layer up the sea surface (contaminated sea surface). Then we present its influence on the ocean spectrum using a damping model [7], and we compared the obtained results with the representation of clean sea surface spectrum.

According to Lombardini et al, the influence of the pollution is introduced in the form of an attenuation coefficient $y(f, E_0, \omega_D)$ applied to the sea spectrum without polluting:

$$S_{po} = \frac{S_{cl}}{y(f, E_0, \omega_D)} \tag{1}$$

This damping effect is expressed by the attenuation coefficient explicitly given by the following equation

$$y(f, E_0, \omega_D) = \frac{1 \pm 2\tau + 2\tau^2 - X + Y(X + \tau)}{1 \pm 2\tau + 2\tau^2 - 2X + 2X^2} \tag{2}$$

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Where

$$X = \frac{E_0\, K^2}{\rho(2\upsilon\omega^3)^{1/2}} \quad Y = \frac{E_0\, K}{4\rho\upsilon\omega} \quad \tau = \left(\frac{\omega_D}{2\omega}\right)^{1/2} \tag{3}$$

A dimensional quantities and

$$f = \frac{\omega}{2\pi} = \frac{(\sigma\, K^3/\rho \ + gK)^{1/2}}{2\pi} \tag{4}$$

The dispersion law, ρ is the sea water density, υ is the kinematic viscosity, σ is the surface tension, g acceleration of gravity, E_0 is the elasticity modulus and ω_D is a characteristic pulsation which for soluble film depends upon the diffusional relaxation, and for insoluble films, depends upon structural relaxation between intermolecular forces. In equation (2) a plus sign indicate soluble films, while a minus sign refers to insoluble films. In this paper we will focus 1 D rough sea surface contaminated by insoluble films.

Fig.2 shows the comparison between the height spectrum of clean sea surface and the contaminated sea surface. The normalized height spectrum of contaminated sea surface is plotted for different parameters of oil film.

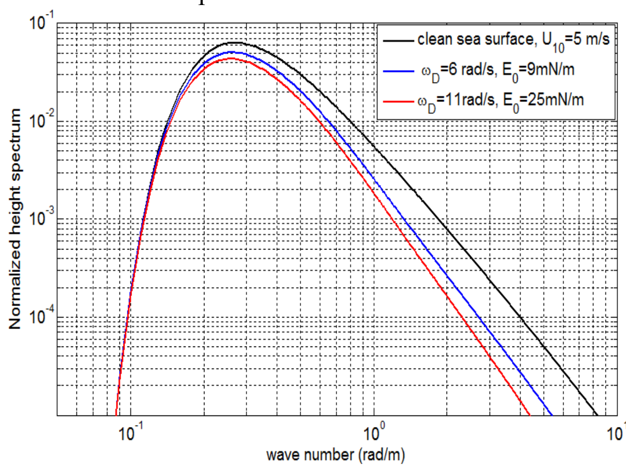

Fig. 2. Comparaison between a clean and oil spilled sea surface

The parameters for the oil film are $\{E_0\ = 25\ \mathrm{mN/m},\ \omega_D =\ 11\ \mathrm{rad/s}\}$ and $\{E_0\ = 9\ \mathrm{mN/m}, \omega_D\ = 6\ \mathrm{rad/s}\}$.
The attenuation due to pollutant film is essentially located at the high frequencies, which corresponds to the capillary waves.

III. Bistatic Scattering from Rough Sea Surface by Using the Forward-Backward Method

In the second part of this work, we will focus on electromagnetic scattering from ocean surface covered by oil spills. First, we study the case of one-dimensional rough sea surface (clean sea surface without pollutants). We realize the numerical simulation of the bistatic scattering coefficients (in forward propagation configuration) from clean rough sea surface by using the Forward-Backward method (FBM), and we compare the numerical results with those obtained by using the asymptotic methods such as small perturbation method (SPM) [8,9]. This step will allow to validate the results obtained by the developed model, and to have a reference on an ocean surface without oil slicks. It should be noted that the chosen method (FBM) in this paper has already been applied, in particular to calculate the electromagnetic signature of a breaking wave, and the results obtained in this context were compared with measurements made in the anechoic chamber with profiles of breaking waves in aluminum [10] [11].

In the work presented in this paper, the numerical FBM is used to calculate the scattering coefficients from one-dimensional rough sea surface (clean and polluted surface).

A. Comparison with asymptotic methods

In this part, we will show the simulation of the bistatic scattering coefficients (in forward propagation configuration) from clean rough sea surface by using the Forward-Backward method (FBM), and we compare the numerical results with those obtained by using the asymptotic methods, especially with those given by the small perturbation method (SPM) . In this simulation, we will consider the ocean surface as a dielectric surface.

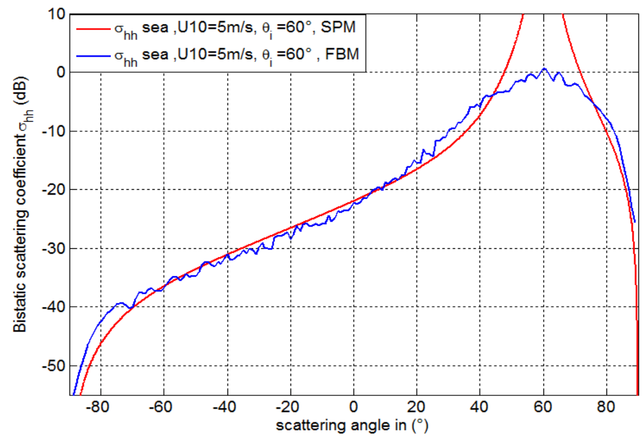

Fig. 3. Comparison between the numerical method (FBM) and the asymptotic method (SPM)

Fig.2 shows that the results obtained by using the numerical method FBM are in good agreements with those given by the asymptotic method SPM.

B. Bistatic scattering coefficients from contaminated sea surface

To analyze the influence of the oil pollutants on the electromagnetic signature from sea surface, we represented the variation of the bistatic scattering coefficients (in forward propagation configuration). Fig.4 gives the bistatic scattering coefficients for both clean and polluted surface by using the Forward-Backward method (FBM). The sea surface is presented by Elfouhaily spectrum [12], the wind speed U_{10} = 5m/s, the sea temperature and salinity to respectively T=20°C and S=35 ppt the frequency f =3GHz, the incident angle is fixed to θ_i =0°, HH polarizations, and the scattering angle in vary from -90° to 90°. The pollutant is considered insoluble film and its relative dielectric constant is (2.25 + i0.01) [13], and the relative dielectric constant of the sea water is equal to (70.5+i40) [14].

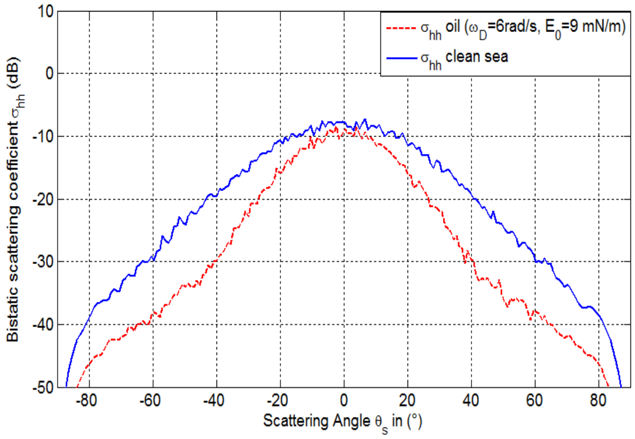

Fig. 4. Scattering coefficients in forward propagation configuration from clean and contaminated sea surface.

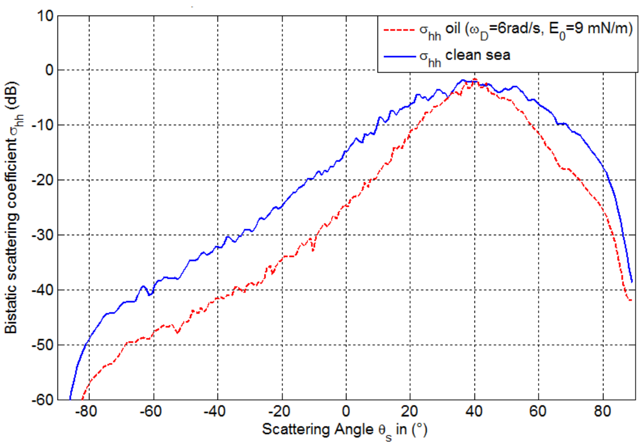

Fig. 5. Scattering coefficients in forward propagation configuration from clean and contaminated sea surface.

Fig.5 give the scattering coefficient of the clean and the contaminated rough sea surface, for HH polarizations. the incident angle is fixed to θ_i =40° and the other parameters are the same as those given in the Fig.4.

We compared the scattering coefficients of the celan and contaminated rough sea surface with various incidence angles. Fig.4 and Fig.5 schows the differences between the scattering coeffcients of the clean and the oil spilled sea surface. The difference is essentially due to the influence of the pollutant in surface height spectrum and the relative dielectric constant of the pollutant.

IV. CONCLUSION

In this paper, we introduced the numerical simulation of electromagnetic signature of clean and polluted rough sea surface in forward propagation configuration by using the numerical Forward-Backward method (FBM). The numerical results (FBM) were compared with those given by using the asymptotic methods small perturbation method (SPM) for clean sea surface. The electromagnetic scattering simulation showed the influence of the pollution on the electromagnetic signature of the sea surface. This work is being developed by considering other geometric configurations of observation and other types of surfaces (including 2D dielectric surface). Further comparisons are also made, especially with the results obtained by considering other asymptotic methods (TSM, SSA, ...).

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