Influence of the sea surface on electromagnetic propagation in a sea transport context

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As for radar surveillance of the sea traffic or telecommunication with ships during bad weather condition (Search And Rescue), electromagnetic wave propagation in the maritime environment requires more and more realistic models. A major aspect to model the propagation in the maritime environment is the electromagnetic scattering by the sea surface. Indeed, to estimate the interaction between an electromagnetic wave and natural environment, several approaches have been developed. We can mainly cite Kirchhoff Approximation (KA), Small-Perturbation Model (SPM), Phase Perturbation Technique (PPT), Integral Equation Model (IEM) and Small Slope Approximation (SSA). Each one of these models is either limited in its application domain or need a time consuming processing. In reasonable way, ocean surface roughness can be split into two scales: a large and small one related to the incident electromagnetic wave. Two-scale Model (TSM) [2][3] covers a wide domain from small to large scale of roughness and it is commonly used in the recent literature.

In this paper the Elfouhaily sea spectrum is presented. Next a special focus on the Two-scale model principles will be given. The simulation section will began by the model validation with experimental measurements in backscattering configuration. Next a forward scattering configuration and finally a general bistatic configuration will be described and analysed.

1. SEA SPECTRUM

One of the most reliable sea models is the Elfouhaily spectrum [6]. Its omnidirectional analytic expression is available for all the wave number bands. It is a sum of two components capillary and gravity, each of them is dominant when situated in its band.

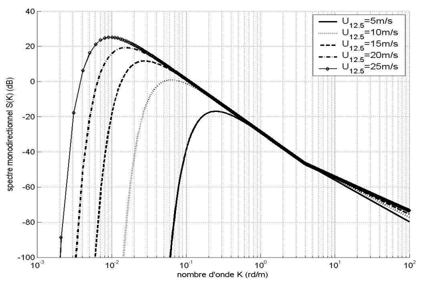
$$S(K) = \left(S_c(K) + S_g(K)\right) S_{com}(K) \tag{1}$$

c and *g* correspond to the capillarity and gravity waves.

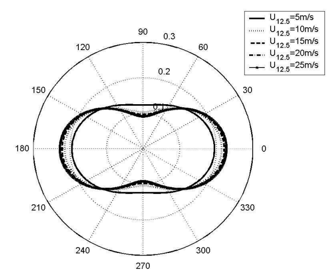
To cover the bidimentional domain, the Unified spreading function was defined as follows:

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

This function is centrosymmetric as required by Guissard work (see figure-1). *Δ(K)* is recognized as the coefficient of the second harmonic when truncating the Fourier series expansion of *f*(*K*, ϕ).



(a) omnidirectional spectrum



(b) spreading function

Fig- 1: describe wind velocity effect on both the omnidirectional and the spreading function of Elfouhaily model.

This Elfouhaily surface definition will be used when estimating the electromagnetic matrix coefficients.

2. TWO-SCALE MODEL

In reasonable way, ocean surfaces roughness can be split into two scales: a large and small with the incident electromagnetic wavelength (see figure-2).

The key idea of this method is to take advantages of the classic approaches (Small perturbation and Kirchhoff models) and enlarge the application domain [1-5]. Then scattering coefficients are estimated in two steps. We first focus on small scale waves using the small perturbation model and then by a tilting process we may easily determine the diffuse component in the global reference. The specular component is evaluated using the Kirchhoff approximation.

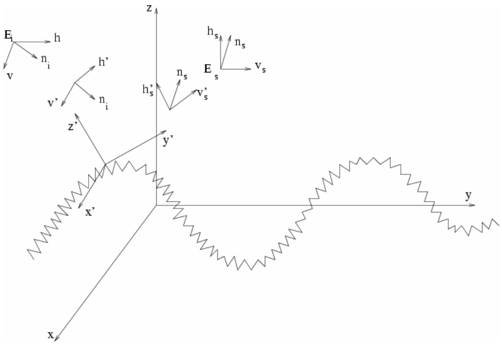


Fig- 2: Geometry of a surface bistatic scattering in the two-scale model

Two-scale model has a larger domain then the Kirchhoff and the small perturbations approaches. It covers small and large waves so it is the well adapted to estimate the specular electromagnetic fields as well as the diffuse one especially for the grazing angles.

3. NUMERICAL RESULTS

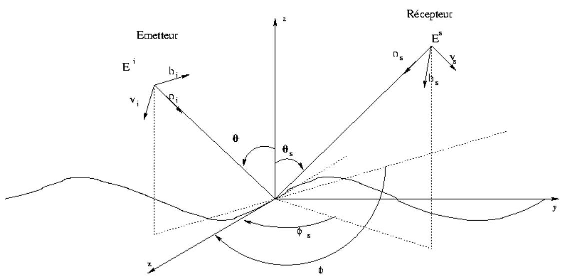


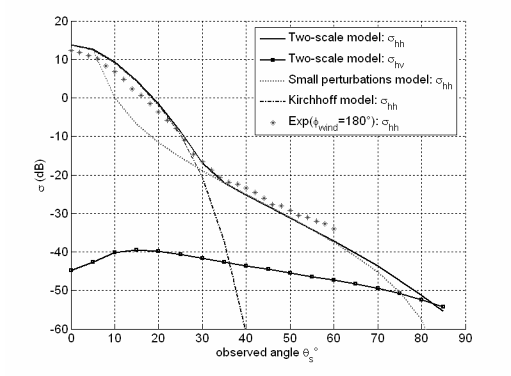
Fig-3 Geometrical representation of bistatic configuration

Before simulating scattering coefficients in bistatic configuration, a comparison with literature is necessary to validate our model. The first part of this section deals with backscattering configuration. The bistatic case is represented at the end of this section.

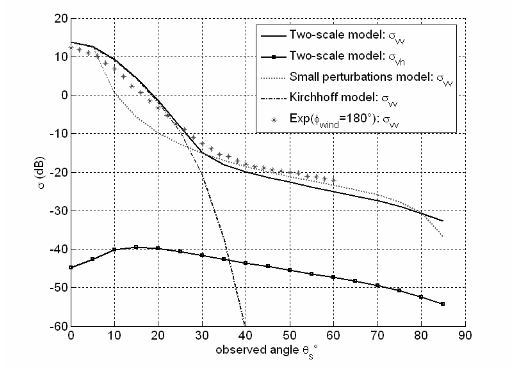
3.1. Backscattering configuration

This configuration is omnipresent in the literature, it is simple to implement since the emitter is in the same time the receiver. 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.



a



b

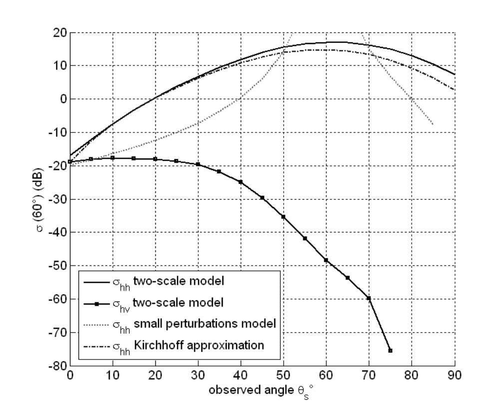
Fig-4: Backscattering coefficients

F=14 GHz, T=20°C, S=35ppt, wind speed=5 m/s (at 10 m) (Two-scale model, Small perturbations model, Kirchhoff model are compared with Voronovitch experimental data [7])

Numerical simulations of scattering coefficients in backscattering configuration underline the two-scale model validity in specular and diffuse domain. Indeed the results are in good agreement with measurements (see Figure-4).

3.2. Forward-backward scattering configuration

Most of the bistatic simulations illustrated in the literature treat forward scattering. In this case emitter and receiver are in the same plane, separated by the surface incident field impact. We represent this configuration for two incident angles (60° and 80°) while the observed one θ_s varies from 0° to 90°. Received azimuth φ_s is set to 0°.



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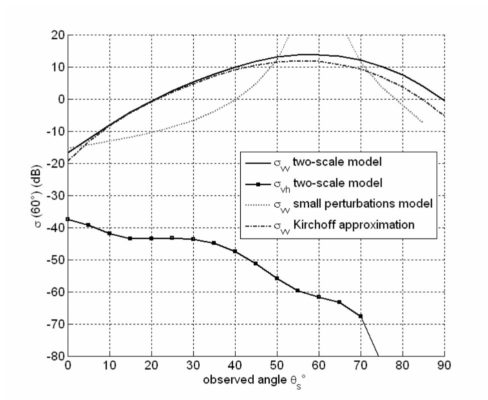


b

Fig-5 :Scattering coefficients **(bistatic configuration)** F=14 GHz, T=20°C, S=35ppt, wind speed=5 m/s (at 10 m) φ_s=180°, θ=60°) (Two-scale model (σ_{hh}, σ_{hv} (a), σ_{vv}, σ_{vh} (b)), Small perturbations model (σ_{hh} (a,c), σ_{vv} (b,d)), Kirchhoff model (σ_{hh} (a,c), σ_{vv} (b,d))

Figure-5 confirms the limits of the two classical approaches and the supremacy of the two-scale model. This later cover specular, intermediate and the grazing regions

3.3 Bistatic configuration

In this section, to provide a global view of the sea surface electromagnetic scattering, we set the emitter angles to θ=60° and φ=0° and we vary the receiver position, where $\theta_s \in$ [0°, 90°] and $\varphi_s \in$ [0°, 360°].

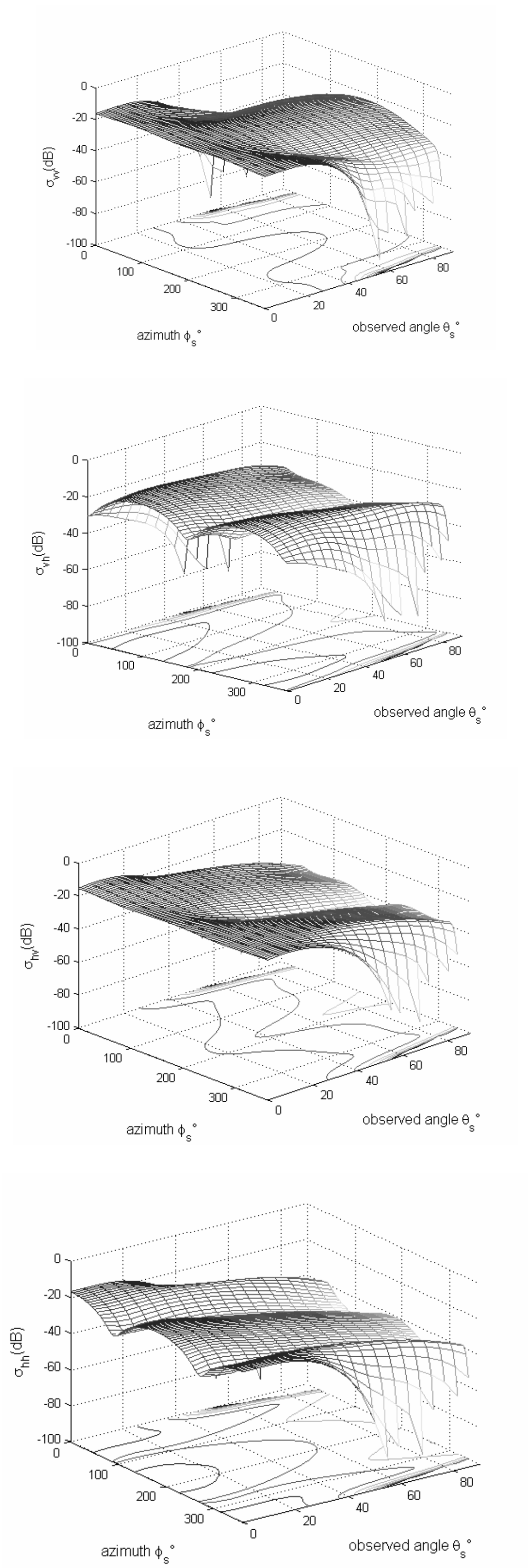
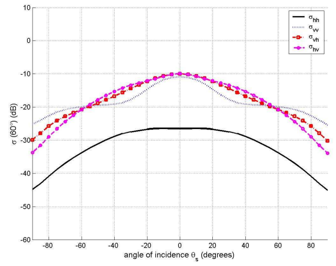


Fig-6: Scattering coefficients (bistatic configuration) F=14 GHz, T=20C, S=35ppt, wind speed=15 m/s (at 10 m φ=0° and θ=60°)

From (figure-6) one note that in vv and hh polarizations, the scattered signal major energy is located in the specular region. The case is different for the cross polarized coefficients.

In the last simulation figure-7, all the previous conditions are unchanged except the receiver azimuth φ_s that is set to 90° Focus will be on the two-scale approach.



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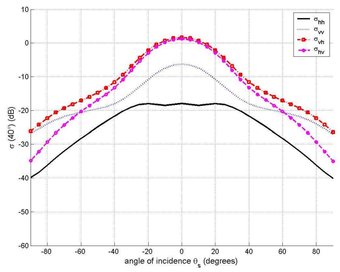

b

Fig-7 : Scattering coefficients (bistatic configuration)
F=14 GHz, T=20°C, S=35ppt, wind speed=15 m/s (at 10 m)
φ_s=90°, θ=40° (a) and θ=60° (b)

4. CONCLUSION

In the present paper, a bistatic two scale approach of electromagnetic scattering by the sea surface is described and applied to a realistic sea wave model: Elfouhaily unified spectrum.

More, for grazing angle or non standard bistatic configurations, various computation simulations are shown for each vertical and horizontal polarization (four coefficients of the bistatic scattering matrix). As far as we are aware, these simulations, based on the Elfouhaily sea model, constitute original numerical results.

Finally, our approach is proved to be very consistent with previously obtained computation results or data, and is confirmed to be a very promising method to study any bistatic configurations.

As possible perspectives, our approach can be used to unravel the sea surface scattering problem and enable the best use of the navigation equipments such as GPS, radars and radio communication facilities.

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