Concepts for an efficient SAR ocean simulator

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ABSTRACT

Three essential demands claimed in the literature are here considered for describing the interaction mechanism between SAR and ocean surface. They can briefly synthetized as: extended stochastic time-variant scene model, applicability of the two-scale approximation, and inclusion of nonlinear hydrodynamic interactions. In the following the nonlinear interactions between the small and large scale structure is in particular taken into account. It is also shown how to include the proposed model in an efficient simulation tool.

INTRODUCTION

Synthetic Aperture Radar (SAR) is a coherent microwave system to generate high resolution images: by means of different and efficient processors of raw data.

SAR simulators may be helpful for a full understanding of such images. Henceforth, design of an efficient SAR simulator of extended scene is a demanding approach.

From a general viewpoint, simulation must rely on a model, which by definition is not the real world. Two points of view must undergo the project: on one side a simple and efficient model is highly appreciable for implementation purposes; from the other the model must to be not too far apart from the real world. It is clear that such needs are competitive and a reasonable compromise must be reached. In particular, the ocean is a very interesting and intriguing case study.

Several ocean models have been presented in the literature [1-6]. A definite word has not yet been stated about the qualitative and quantitative influence on the SAR image of the sea surface. The models are based on very different basic and fundamental assumptions. Moreover, feature extraction, based on SAR ocean imagery, is generally quite a hard task due to the fact we are in presence of a rather cumbersome scenario.

Aim of this paper is to design an efficient simulator of the ocean SAR raw signal: for the ocean surface modelling three points needs to be specified: its movement, its geometrical description and the electromagnetic behaviour.

First of all we consider the ocean profile as composed by two-scale structure: the large scale is simply a sinusoidal profile, while the small scale has a continous spectrum. We use the phase velocity model [1,2,7], therefore considering a progressive wave exhibiting a normalized phase velocity [8]:

$$\mathbf{u} = u_r \hat{r} + u_x \hat{x} \,, \tag{1}$$

$\hat{r}$ and $\hat{x}$ being unit vectors along range and azimuth directions, respectively (see fig.1)

The second point is the one we want to stress in this paper. A swell can possibly be modelled as a sinusoidal long wave with superimposed a continous spectrum of capillary waves. Recent theories have shown that the physical model to be adopted for oceanographic purposes must include the nonlinear hydrodinamic interaction between long and short waves: amplitude and phase of the capillary waves are nonlinearly related to their position on the long wave. A simplified expression for this interaction has been included in a SAR image oriented theory [2]. The way to include this effect in the model is necessarily related to the adopted backscattering function and in particular to the influence of the capillary waves amplitude on the reflectivity function.

The third point of the procedure is the scattering model which allows evaluation of the reflectivity function $\gamma(\cdot)$. A piecewise planar approximation of the ocean profile is applied , then backscattering from coherent areas must be evaluated. Backscattering from each facet of the sea surface is computed by considering, among other contributions, that relative to the resonant wave only (Bragg scattering). Bragg scattering mechanism seems to be appropriate [9,10] under some sea and surveying conditions: this is the main backscattering mechanism involved in our simulation tool [8]. We note that the modular nature of the simulation code turns out to be interesting for future developments.

In particular, it must be noted that, although marginal in this discussion, an important feature to be addressed and taken properly into account is the stochastic nature of the scene. Henceforth, space-time statistics must be included: space statistics affect spatial phase of the short waves, hence determinining the coherence regions; time statistics reduce SAR ability to coherently integrate different echo returns.

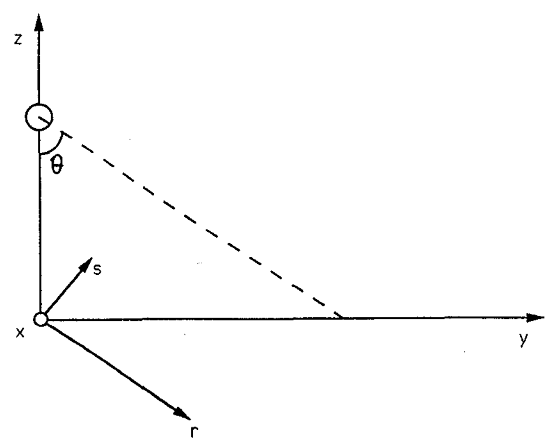


fig.1:*Relevant to the adopted and fixed reference systems: Oxyz and Oxrs*

SUGGESTED PROCEDURE

The SAR raw signal $s(\cdot)$ can be written [8] as:

$$s(x',r') = \int\int dxdr\, \gamma(x-u_x x', r-u_r x')\, g(x-x', r-r'; x, r)\,, \quad (2)$$

wherein $g(\cdot)$ is the unit response function of the system. A two-dimensional approach is desirable and applicable when eq.(2) is Fourier transformed (FT), inasmuch FT analytical evaluation of the unit response is avalaible [8].

It has been shown in Ref.[8] how to efficiently implement eq.(2) by an appropriate transformation and sampling techniques. Accordingly, time requirements are not dramatically increased [8].

The geometrical description of the ocean is addressed by modelling its surface by means of planar cells so that its profile is described in a fixed reference system by:

$$z = z_a + z_b\,, \quad (3)$$

wherein z_a is the mean plane equation:

$$z_a = z_0 + (x - x_0)a_x + (y - y_0)a_y\,, \quad (4)$$

and z_b is the capillary wave modification to the mean profile:

$$z_b = \frac{1}{4\pi^2}\int\int dk_x dk_y exp[i(k_x x + k_y y)]B(k_x, k_y). \quad (5)$$

In eq.(4) a_x and a_y describe the slope of the facet, and are depending on its position on the long wave, as well as its amplitude and wavelength. In eq.(5) $\mathbf{k} = k_x\hat{x} + k_y\hat{y}$ is the capillary wave spectral wavenumber and $B(k_x, k_y)$ the corresponding amplitude which can be assumed accordingly to avalaible literature [11]. We note that the amplitude spectrum is the Fourier Transform of an element of the stochastic process ensemble which describes the altitude profile [12].

The nonlinear hydrodynamic interaction implies a continous variation of amplitude and phase of the short gravity wave along the long wave; i.e. the short waves spectrum is no more long-wave position invariant. For a given long wave,

$$h(x,y) = A\,cos(K_x x + K_y y)\,, \quad (6)$$

the ripple spectral amplitude $B(k_x, k_y)$ is modified according to [2]:

$$B(k_x, k_y; x, y) = B_o\left[1 + A\sqrt{{K_x}^2 + {K_y}^2}cos(K_x x + K_y y)\right]\,, \quad (7)$$

wherein we emphasize the new dependence on x, y, i.e., on the position of the wavelet with respect to the monochromatic long wave. Henceforth, the nonlinear hydrodynamic modulation affects (nonlinearly) the amplitude of the short resonant wave in accordance with the long wave amplitude, wavelength and ripple position.
As shown in [8], evaluation of $\gamma(\cdot)$ is finally obtained as:

$$\underline{\gamma} = g\,\underline{\underline{S}}\,D\,, \quad (8)$$

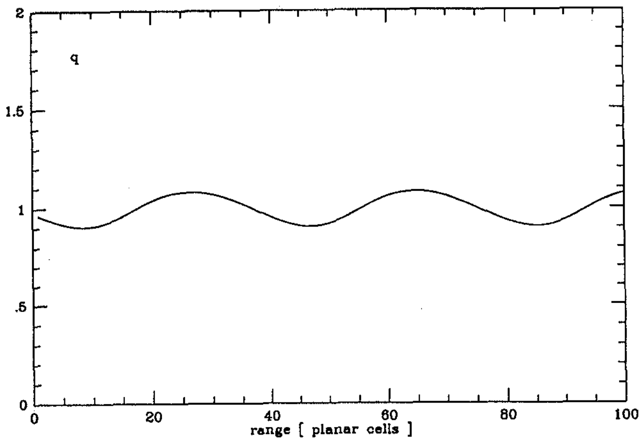
wherein $\underline{\underline{S}}$ is the backscattering matrix including the polarimetric behaviour of the surface, and D is the reirradiation diagram of the facet accounting for the resonant Bragg model. In particular [8], the reirradiation diagram is governed by Bragg resonance and is given by:

$$D(\cdot) = \sum_s J_s\left[\frac{4\pi}{\lambda}B(\cdot)cos\theta\right]N_x N_y\,, \quad (9)$$

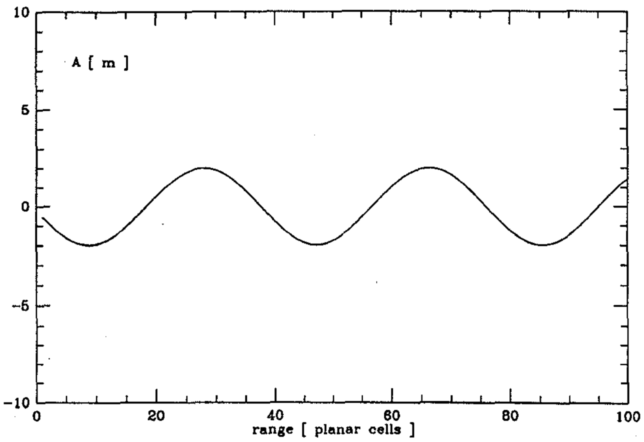
wherein $J_s(\cdot)$ are the first kind Bessel functions of s order, N_x, N_y the crests numbers along the corresponding axes, and finally $B(\cdot)$ is given by eq.(7).

We note that the tilting effect [4], i.e., the variation of the local incidence angle with respect to the facet normal, modifying the radar echo return by changing the Bragg resonant line spectrum and its backscattering amplitude, is included in $\underline{S}$ and $D(\cdot)$.

The above discussion highlights the nonlinear relevance of the ripple amplitude on the reflectivity coefficient. In order to show the influence of the nonlinear hydrodynamic modulation, it is convenient to depict the backscattering modification due to such phenomenon. Hence, the ratio q between the backcscattering coefficients evaluated with the inclusion of nonlinear hydrodynamic modulation and without it, is depicted in fig.2a. The long wave profile is also presented (see fig.2b), with $\mathbf{K} = K\hat{\mathbf{r}}$ and $KA = 1/8$.



(a)



(b)

fig.2: *(a) Graph relevant to the modulus of the backscattering coefficient including the nonlinear hydrodynamic interaction normalized to the corresponding one neglecting such dependence. (b) Long wave height profile.*

We observe that such nonlinear hydrodinamic modulation corresponds to a backscattering enhancement at the crests and a proportional decrease at the troughs of the long wave. Such result is in accordance with Ref.[2].

CONCLUSIONS

A SAR ocean raw signal simulator has been outlined. It relies on the phase velocity model and Bragg theory. In this paper it has been shown how to implement a model which also takes into account the nonlinear interaction between a long and short waves. The suggested procedure exhibits a non linear depence of the backscattering coefficient upon the small scale structure of the ocean. Corresponding results are in agreement with the literature. For a better understanding of the nonlinear hydrodynamic interaction, the quantitave analysis has been performed skipping out the space-time statistics.

A realistic ocean model requires introduction of appropriate space-time statistics. This problem is under study.

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