# Sea Surface Simulation for SAR Remote Sensing Based on the Fractal Model

Ding Guo, Xingfa Gu, Tao Yu, Xiaoyin Li, Jingjun Zheng, Hui Xu

**Abstract**— Based on the fractal ocean surface model, electromagnetic scattering model under Kirchhoff Approximation and the raw signal simulation procedure of dynamic scene based on time domain, the sea surface of the SAR remote sensing has been simulated. The images of the wave and complex fractal sea surface are in accordance with the hydrodynamic modulation, the tilt modulation and the velocity bunching modulation. The simulation has been developed in the Matlab programming language.

**Index Terms**— sea fractal surface, multi-polarization, scattering matrix, synthetic aperture radar, electromagnetic wave.

## 1. Introduction

THE concept "fractal" is popularly was used in the world after the book "The fractal geometry nature" published in 1982. The fractal geometry is a simple tool of describing complicate world and mechanism and then many researchers paid attention to it.

Numerical simulation sea SAR surface is one of the foci of research now. Signification of applying "fractal" to the researching field lying to:

1. Researches such as multiple scattering and sea clutter et al., are in favor of improving performance of the radar system and communication.
2. It can not only promote the development of characteristics of sea surface, the application of SAR measurement of environment but also convenient for the management of navigation et al.
3. It can be used to explain physical phenomenon of sea surface, for example, the hydrodynamic evolvement of ocean wave, the air-sea power exchanging and the analyzing the ocean current of sea et al,.

### Theoretical facts

Recently, F.Berizzi et al. presented sea fractal surface models, the 1-D and 2-D sea fractal model. We find: whether one dimensional or two dimensional sea Fractal surface model, the surface becomes rough when one of b and S increases while another of them is invariable. So both b and S are effect on the roughness of the sea fractal surface.

$$\rho(\xi) = \frac{1-b^{2(s-2)}}{1-b^{2(s-2)N_f}} \sum_{n=0}^{N_f-1} b^{2(s-2)n} \cos\left[\frac{2\pi}{\Lambda_0} b^n \xi\right] \quad (1)$$

In order to study the polarization effects on scattering coefficient and Radar Cross Section, exploiting Huygen's principle, Kirchhoff approximation and the model of sea fractal surface presented by F.Berizzi et al .,we derived the scattering fields, scattering coefficient, RCS and Poynting vector of 2-D sea fractal surface with finite conductivity illuminated by arbitrary polarization wave under the condition that the shadowing effect and multiple scattering are neglected. Our results coincide with those of other literatures. Meanwhile, receiving signals in different position are simulated. The result shows that depolarization effects in any position can be neglected though we derived out the expression of depolarization, while the cross polarization can't neglected.

Exploiting the scattering matrix which is worked out and calculated full polarimetric radar cross section (RCS) in the third part. The numerical results show: Normal backscattering RCS of sea fractal surface is degraded in exponential form with

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increasing of incident angles in HH polarization and VV polarization. When θ3 is a certain invariable value, the maximum RCS appears at θ2=θ1and RCS decreases when │θ2-θ1│increases. We also find that values of the radar cross section calculated according to the formula which is presented by F.Berizzi et al. are greater than those of our results because it is assumed that the conductivity of the sea is infinite and then there is no loss when wave is reflected on the sea surface. In fact, however, the conductivity of sea surface is finite. Comparing theoretic result with numerical result, one can find that whether the relation between σhh and σvv or the relation between σhv and σvh is decided by the relative position between receiving antenna and transmit antenna. Critical angles(θc1 and θc2) are derived in theory.

In the last part, numerically simulating the co-polarization signature with different sea fractal surface parameters in the experiments, we conclude: Sea fractal surface roughness has no effect on polarized parameters. The fundamental spatial wavelengths of the ocean wave have no effect on orient angle shift but have effect on ellipticity while other sea fractal Surface parameters are invariable. The radar incident angle only effects on the orient angle shift. The orient angle shift becomes zero when the radar incident angle is larger than a certain value. We find that the effects of sea fractal parameters on the ellipse parameters are virtually caused by mean slope of the sea surface.

## I. Simulation and results

In this section, the 2-D ocean surface has been simulated according to (R. Garello et al.1993, Berizzi et al. 2002, Nunziata, F. et al.2008). It is shown in figure.

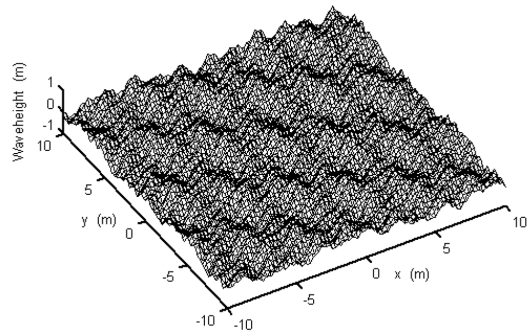


Fig 1 Simulated ocean suface

The RCS of the ocean surface is $\sigma_{qj} = 4\pi r^2 \left|S_{qj}\right|^2$, $q=h_s,v_s$, $j=h_i,v_i$ (Ruck G T et al. 1970), $\sigma_{k_s h_i}$ and $\sigma_{k_s v_i}$ are the depolarization parameters, where the radar wavelength is $\lambda = 0.23m$, $\varepsilon_r = 72.1 + 60.979i$.

The normalized RCS of the 2-D ocean surface when $\theta_1 = 10^\circ$, $\theta_3 = 0^\circ$ is shown in figure 3. We can find that the maximum RCS at $\theta_2 = \theta_1$ and RCS increases with $\theta_2$ varies from $-90^\circ$ to $90^\circ$, $\theta_2 = \theta_1$ while decrease with the increasing of $\theta_2$ after the peak value. It is agreed with literatures( Jakov V. et al. 1998, Ericl.Thorsos,1990). Rcs0 is the RCS when the electrical conductivity of ocean water is infinite.

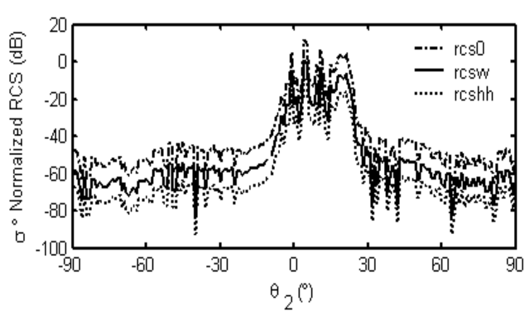


Fig 2 Normalized RCS with VV and HH polarization when $\theta_1 = 10^\circ$, $\theta_3 = 0^\circ$, $\theta_2$ varies from $-90^\circ$ to $90^\circ$.

When the $\theta_1 = 30^\circ, \theta_2 = 30^\circ$, $\theta_3$ varies from

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$0^\circ$ to $180^\circ$.Figure shows the normalized radar cross section for HH and VV polarization. And the normalized radar cross section for HV and VH polarization.

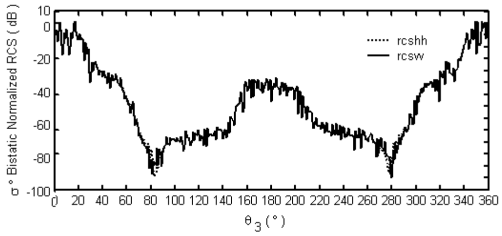



Fig 3 Normalized RCS with VV and HH polarization when $\theta_1 = 30^\circ$, $\theta_2 = 30^\circ$, $\theta_3$ varies from $0^\circ$ to $360^\circ$.

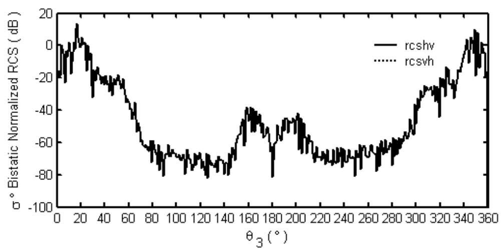
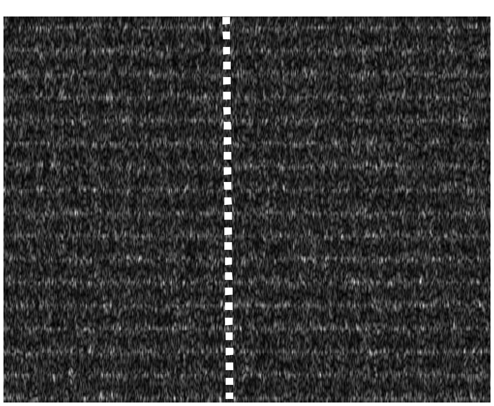



Fig 4 Normalized RCS with HV and VH polarization when $\theta_1 = 30^\circ$, $\theta_2 = 30^\circ$, $\theta_3$ varies from $0^\circ$ to $360^\circ$.

In the first sea surface simulation case a single 60 m wavelength azimuth travelling long wave is simulated and the noisy SAR intensity image is shown in Fig. 5(a). To appreciate the results an azimuth transect (see white dotted line in Fig. 5(a)) is made in the noise-free SAR image and referred to the corresponding long wave, see Fig. 5(b), where are plotted the first 200 pixels. Since an azimuth travelling wave has been simulated, it can be experienced that the SAR imaging process is strongly non-linear in this case as clearly shown in Fig. 5(b). In fact analyzing the plots of Fig. 5(b) it is possible to recognize the non-linear effect of VB. It can be also evaluated the C parameter (section II) which, in this case, is equal to 1 witnessing a strongly non-linear imaging process. It can also be experienced that in this case Rt(·) is equal to zero.



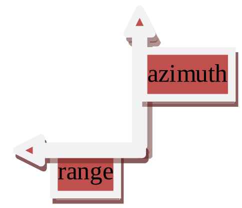



Fig 5(a)

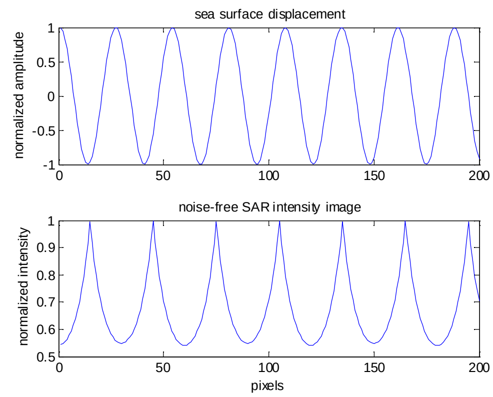



Fig 5(b)

As final cases, a broader spreading function is considered, described by 30 components. In particular the noisy SAR intensity images shown in Figs. 8 and 9 are relevant to a 100 m sea peak wavelength, range travelling, and azimuth travelling. The SAR images clearly show that a broaden spreading function has been employed. Once again it can be evaluated the C parameter, making reference to the peak wavelength and direction, recognizing that VB is a linear process in the first case and highly non-linear in the second one. And it can also be appreciated that the degree of non-linearity of the SAR imaging process decreases increasing the wind speed, as expected for fully-developed wind-seas.

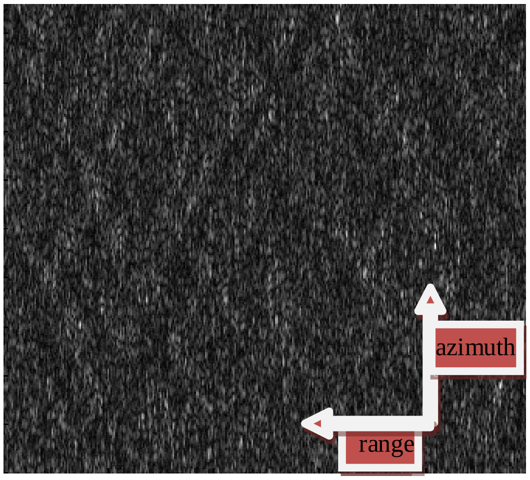



Fig 6

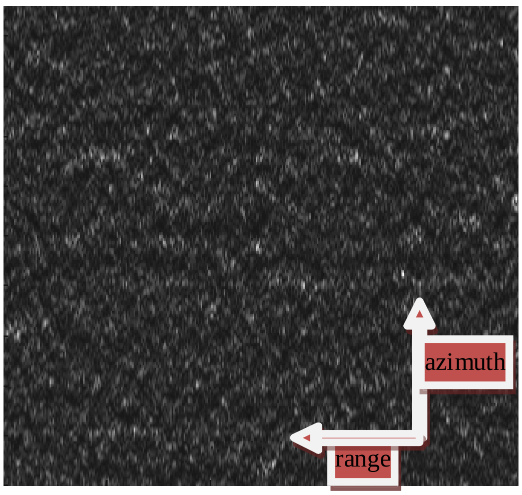



Fig 7

## II. Conclusion facts

Using the 2-D ocean surface model, Huygen's principle, Kirchhoff approximation and the neglected multiple scattering, we simulated the full polarization RCS of the ocean surface scattering fields.

The numerical results show that the full polarization scattering model coincides with other literatures. And the other conclusions as bellow:

1) The normalized radar cross section of cross polarization with significant information can't be neglected.
2) When $\theta_1$ , $\theta_2$ are determined and $\theta_3$ varies from $0^\circ$ to $360^\circ$ ,the relationship among $\theta_1$ , $\theta_2$ and $\theta_3$ has been known. It can be used to predict the critical angle $\theta_3$.
3) It's obviously that the effects of depolarization can be neglected.

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