RECONSTRUCTION OF SAR WAVE IMAGE EFFECTS THROUGH PSEUDO RANDOM SIMULATION

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ABSTRACT

The limited wavelength and the rapidly changing conditions due to short fetches and complex coastal shapes in enclosed seas pose a big challenge to the applications of satellite SAR data. In order improve the understanding of some aspects of image formation in such conditions, the authors are pursuing a long term work mainly based on numerical implementation of satellite SAR two-wavelength models of the sea surface. Numerical sea surface instantaneous height and velocity realizations are produced from given spectral shapes and the images are synthesized by taking into account the local surface tilt and orbital velocity. Different hypotheses are tested for the local scattering function, such Valenzuela's -like shapes.
The work presented here is aimed in particular at clarifying the treatment of Doppler-induced effects such as velocity bunching; its role in identifying spectral characteristics is shown by making use of simple monochromatic wave fields and by taking into account the influence of resolution on the image formation.
An example is also given of image spectral analysis in the vicinity of a wave measuring buoy in the Mediterranean.

1 INTRODUCTION

Pseudo Random “Montecarlo” simulation of sea surface is a useful technique to reconstruct the response of active remote sensing sensor (mostly SAR and altimeter). Pioneering work by Lyzenga [1] and Alpers [2] was not developed because at the same time direct methods to extract wave spectra information from the SAR image were made available (see for instance [3] and [4]). The increased performances of present day computers, as well as the interest in non spectral information on the wave and winds (Schulz-Stellenflethet et al. in [5] and Yi-Yu Kuoet et al. in [6]) may lead to a revival of such techniques. In the last few years a number of experiments with this approach have been carried out by the several authors as in [7], [8] and [9]. The approach seems offers a number of advantages, such as the ease through which non-linear and non-spectral effects can be introduced for the so called hydrodynamic modulation and the possibility of taking into account sharp wind changes as can be specially expected in enclosed seas expected, as well as the possibility of testing extreme wave and wave group shapes. The capability of present computers allows an unprecedented level of detail in this kind of simulation, but all the aspects of the image formation have to be carefully tested and evaluated before reliable results are produced.

2 TITL AND DOPPLER SHIFT EFFECTS

Results referring to full spectral simulation have already been carried out and published in [9], [10] and [11]; in order to highlight the effect of Doppler shifting, it is useful to consider the effect of the wavelength on the image formation; numerical experiments have therefore been carried out for very simple sea states, i.e. for monochromatic wave fields of various direction and period.
The following pictures show the (local) backscattering coefficient σ_l result for both Azimuth and Range travelling waves computing by taking into account the tilt effect; here “local” refers to the spatial resolution of the simulation (1m). A Valenzuela-style backscattering function as proposed in [12] is assumed (see Eqs. 1 and 2):

$$\sigma_l = \cos^4 \vartheta \;\; \text{HH polarization} \tag{1}$$

$$\sigma_l = \cos^4 \vartheta \cdot \left(\frac{\varepsilon^2 \cdot \left(1+\sin^2 \vartheta\right)}{\left(\varepsilon \cdot \cos\vartheta + \sqrt{\varepsilon}\right)^2} \right)^2 \;\; \text{VV polarization} \tag{2}$$

Geometrical parameters – here and in the following – are those relevant to both ENVISAT and ERS SAR. Two different cases for wavelength L and wave height H are considered; i.e. L = 120 m, H= 4 m and L = 25 m, H= 0,9 respectively.
Doppler shift is simulated by shifting the σ_l thus computed in the azimuth direction by an amount $(V/R)u_r$, V and R being the satellite velocity and range distance respectively and u_r the particle orbital velocity component in the radial direction. The method is very much in the same way as in [1] or in [2], with the difference that the computational step in our case is much smaller (1 m) than the image resolution. No separate treatment is therefore required for azimuthal smearing.
As it was to be expected, the tilting effect is much smaller for azimuth travelling compared to range

travelling waves, so that the wavelength for the former case is practically unidentifiable. This is clearly shown in Fig. 1.

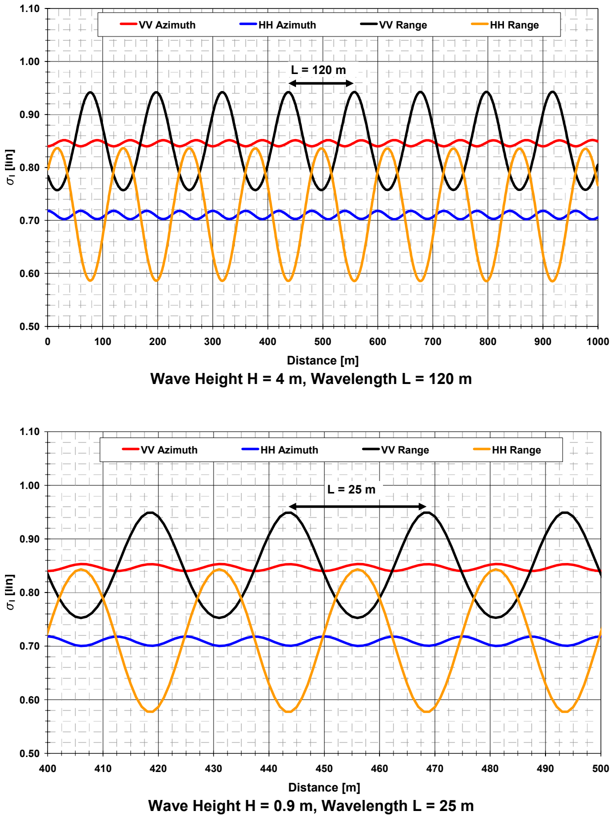

Figure 1. Tilt modulation mechanism for Azimuth and Range travelling waves and for VV and HH polarization

It is well known indeed that in SAR images the azimuth direction wave component can only be identified thanks to the Doppler shift; Fig. 2 seems to confirm this result, by showing that the image contrast due to the Doppler induced superposition of scattering facets (velocity bunching) for azimuth travelling waves is strongly increased while it is virtually unaffected for range travelling waves. The presence of peaks is well known theoretically as shown in [13] and [14]. Of course a SAR image of a wave field does not show such a marked peakedness, since its resolution (25 odd meters for ERS or ENVISAT) will smooth it away. In order to reproduce it, a moving average is carried out and shown on the curves in the Fig. 3 and Fig. 4.

If Doppler effect were not accounted for, all information would be lost for azimuth travelling waves, while range travelling waves would still be recognizable for L = 120m. Needless to say, for L = 25m no feature can be extracted in either direction.

Due to velocity bunching, both azimuth and range wave components are visible, and the order of magnitude of the crest to trough contrast is not too different, as long as long wave components are considered.

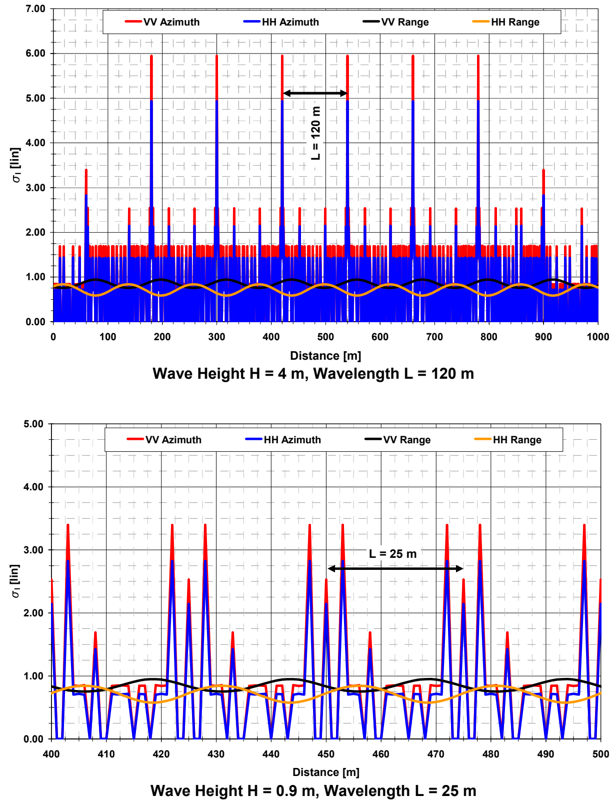

Figure 2. Doppler shift mechanism for Azimuth and Range travelling waves and for VV and HH polarization

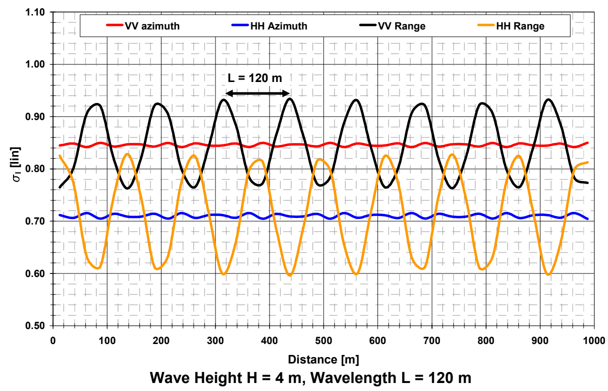

Figure 3. Tilt modulation mechanism at SAR resolution

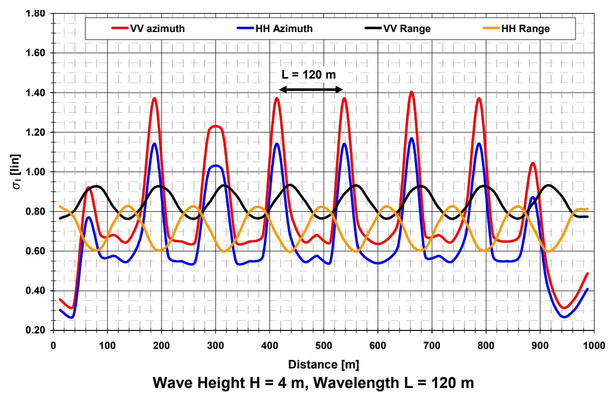

Figure 4. Doppler shift at SAR resolution

This latter consideration explains why there is a reasonable correspondence between the spectrum reflectance and the actual wave spectrum.
A good example is reported in Fig. 5 and in [11] which refers to ERS-2 orbit 24482 on December 26th 1999 at 09:54 on the Tyrrhenian sea; wave parameters measured at 09:00 by the Italian National Wavemeter Network buoy near Ponza. (about 1 km south of the islands) are: H_s = 1.70 m, T_m = 5.3 s, T_p = 6.7 s, propagating towards 246°.

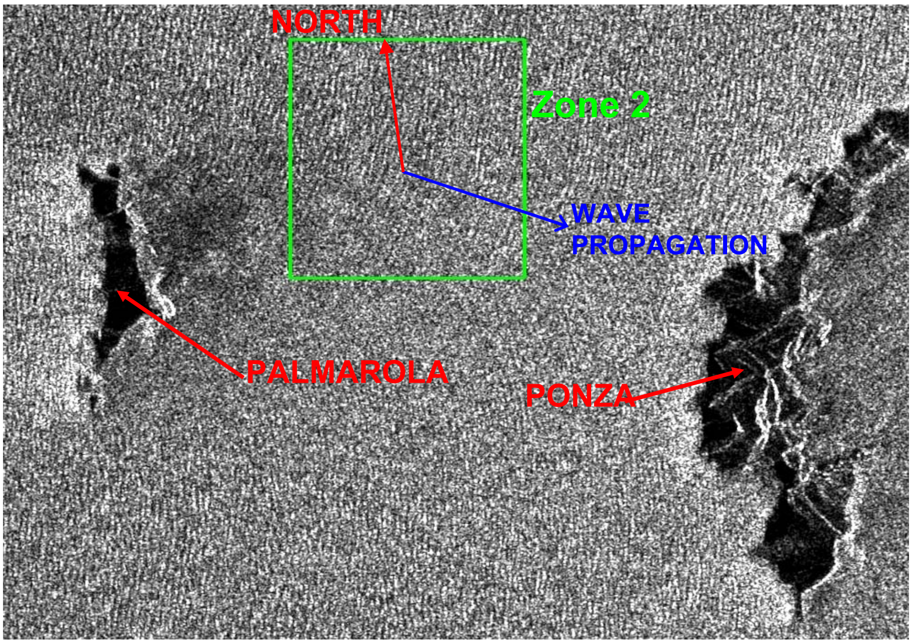

Figure 5. SAR image of ERS-2 satellite: 26 December 1999

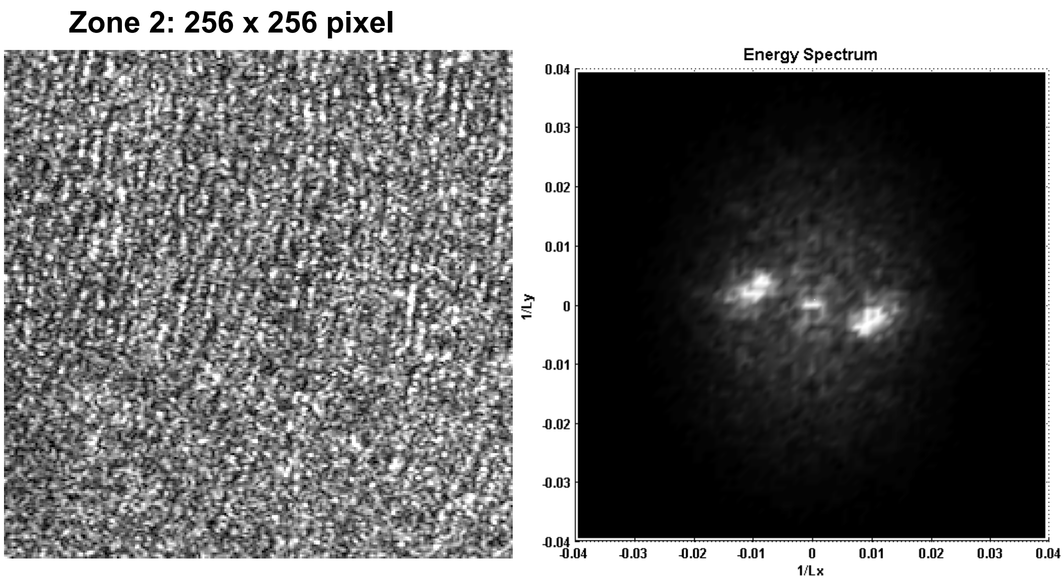

Figure 6. Power spectrum

Power spectra of the pixel intensity in the square window were calculated and the results are shown in Fig. 6.

All the information that can be gathered form such an elaboration concerns spectral components with a wave length greater than about 60 meters average direction as obtained from the spectrum roughly coincides with the

direction estimated from the image, i.e toward 280°; the difference between the buoy value can be partly explained by the fact that shorter wavelengths are not present in the image and in the computed spectrum, while they do contribute to the mean spectral directional as computed by the buoy system. The spectrum centre is located at about 1/L = 0,010(1/m) which yields an average wavelength of 100 meters and there are no visible components beyond 1/L = 0,015(1/m) i.e. L = 65m, as it was to be expected also from the previous discussion.
Results seem to suggest that in similar circumstances – very much like in [15] there seems to be no substantial advantage in making use of a more complex spectrum inversion method.

3 CONCLUSIONS

Computations carried out on monochromatic waves highlight the effects of Doppler shift effect in improving SAR visibility of sea waves and confirm the reliability of numerical simulation of the wave field as a tool to reconstruct sea wave SAR images. Also the effects of image resolution is shown and a real life example in Mediterranean conditions is discussed.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

1. Lyzenga, D.R. (1986). Numerical Simulation of Synthetic Aperture Radar Image Spectra for Ocean Waves. *IEEE Transactions on Geoscience and Remote Sensing*,**Vol. GE – 24 NO. 6**, 863 – 872.

2. Brüning, C., Alpers, W. & Hasselmann, K. (1990). Monte – Carlo simulation studies of the nonlinear imaging of a two dimensional surface wave field by a synthetic aperture radar. International Journal of Remote Sensing. Vol. 11, NO. 10, 1695 – 1727.

3. Kudryavtsev, V., Hauser, D., Caudal, C. & Chapron, B. (2003). A semiempirical model of the normalized radar cross-section of the sea surface 1. Background model. Journal of Geophysical Research. Vol. 108 NO. C3,8054, doi:10.1029/2001JC001003.

4. Schulz-Stellenfleth, J., Lehner, S. & Hoja, D. (2005). A parametric scheme for the retrieval of two-dimensional ocean wave spectra from synthetic aperture radar look cross spectra. Journal of Geophysical Research. Vol 110, C05004, doi:10.1029/2004JC002822.

5. Schulz-Stellenfleth, J., König, T. & Lehner, S. (2007). An empirical approach for the retrieval of integral ocean wave parameters from synthetic aperture radar data. Journal of Geophysical Research. VOL. 112, C03019, doi:10.1029/2006JC003970.

6. Yi-Yu Kuo, Li-Guang Leu & I Lang Kao. (1999). Directional spectrum analysis and statistics obtained from ERS-1 SAR wave images. Ocean Engineering. Vol. 26, 1125–1144.

7. Della Rocca M.R. & Pugliese Carratelli, E. (2000). A model for Wind Speed and Wave Height Retrival from Radar Altimeter Measurements. ERS_ENVISAT Symposium. Gothenburg – Sweden.

8. Giarrusso C., Pugliese Carratelli, E. & Spulsi, G. (2004). Satellite SAR Sea and Wind Response over Shallow Seas. XII Convención Científica de Ingeniería y Arquitectura (CCIA 2004). La Habana, Cuba.

9. Pugliese Carratelli, E., Dentale, F. & Reale, F. (2006). Numerical Pseudo-Random Simulation of SAR Sea and Wind Response. In Proc. of SEASAR 2006 'Advances in SAR Oceanography from Envisat and ERS Mission' (Eds. H. Lacoste & H. Xerxes), ESA SP-613 (CD-ROM), ESA Publications Division, European Space Agency, Noordwijk, The Netherlands.

10. Pugliese Carratelli, E., Dentale, F., Giarrusso, C.C., Reale, F., & Spulsi, G. (2005). Application of Satellite SAR Images to Sea and Wind Monitoring in Coastal Seas. Arabian Coast 2005 - Coastal Zone Management And Engineering. Dubai, United Arab Emirates.

11. Pugliese Carratelli, E., Dentale, F., Rakha, K. & Reale, F. (2007). Wave Field Analysis From SAR Images of Enclosed Seas. Accepted for presentation 32nd IAHR Congress. Venice, Italy, July 1st -6th 2007.

12. Romeiser, R., Schimdt, A. & Alpers, W. (1994). A three – scale composite surface model for the ocean wave – radar modulation transfer function. Journal of Geophysical Research. Vol. 99, NO. C5, pages 9785 – 9801.

13. Wakasugi, K., Naru-Fumi, K. & Masaru M. (1986). A Three–Dimensional Formulation for Synthetic Aperture Radar Images of Ocean Waves in Orbital motions. IEEE Transactions on Geoscience and Remote Sensing. Vol GE – 24, NO. 5, 732 – 737.

14. Vachon, P. W., Monaldo, F. M., Holt B. & Lehner S. (2005). Synthetic Aperture Radar Marine User's Manual, Chapter 5, pp 139-169. Online at http://www.sarusersmanual.com.

15. De Carolis G., Parmiggiani F. & Arabini E. (2004). Observations of wind and ocean wave fields using ERS Synthetic Aperture Radar imagery. International Journal of Remote Sensing. Vol. 25, NO.7-8, pp. 1283 – 1290.