MODELING OF MICROWAVE BACKSCATTERING FROM A ROUGH SEA SURFACE WITH STEEP WAVES

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1. INTRODUCTION

Traditionally, K_u- and C-band radars are used in ocean scatterometry to retrieve an ocean wind vector. Examples are QuikSCAT and ASCAT satellites. Recently, attempts have been made to use X-band SAR aboard the German TerraSAR-X satellite for the same purpose [1]. Usually, wind retrieval is performed using empirical Geophysical Model Functions (GMF). In the past, a set of GMFs have been designed based on data sets obtained in calibration missions with K_u- and C-band radars. In the paper [1] the development of a GMF for X-band has been reported, which was utilized to retrieve ocean surface wind speeds from TerraSAR-X. In order to better design the GMFs, use of physical models for radar ocean scattering can be helpful. Previously, such a model was successfully developed for K_u- and C-band. The mismatch between the model predictions and GMFs was of the order of 1-2 dB [2]. Here, we present results produced by this model for normalized radar cross section (NRCS) from ocean surface at X-band and provide comparisons with cross sections at K_u- and C-bands.

2. OCEAN SURFACE ROUGHNESS MODEL

The ocean surface model used here is adopted from [2] which is a combination of two types of roughness related to (1) linear small-slope waves of an arbitrary horizontal scale, and (2) non-linear steep-slope, small-scale waves at a pre-breaking or breaking stage of evolution. Roughness of type 1 is described by Gaussian statistics for both elevation and slopes, and PDF of slopes is limited by slopes not exceeding 0.3. This type of roughness was described by the Elfohaily et al. spectrum [3]. Larger slopes that belong to roughness of type 2 are described by the PDF having a non-Gaussian tail. The wind–dependent analytical expression for it was obtained in [2] by fitting the NRCSs obtained from the physical model to corresponding GMFs (CMOD2-I3 and SASS-II) for both K_u- and C-bands.

3. ELECTROMAGNETIC SCATTERING MODEL

For calculation of NRCS from the surface described by the above model we used electromagnetic scattering model [2] which is based on two different approaches. One, the small-slope approximation of the 2nd order (SSA-2) [3, 4] is applied to the type 1 roughness, and reduces to a closed analytical expression containing multiple integrations. In essence, it is equivalent to the well-known two-scale model but does not require an artificially introduced scale-dividing parameter. It is appropriate for calculations of scattering from both large- (the Kirchhoff regime) and small-scale (the Bragg regime) roughness. However, it cannot properly account for steep waves, of type 2, with slopes > 0.6—0.7. To overcome this deficiency of the SSA-2, we calculate backscattering from such steep waves using geometric optics limit of the Kirchhoff approximation [2]. The expression for this part of the NRCS is proportional to the PDF of slopes > 0.6—0.7, the Fresnel reflection coefficient at normal incidence, which depends on the dielectric constant of the sea water, and inversely proportional to the forth power of the cosine of the incidence angle [2].

4. RESULTS

Since the parameters of the slope PDF for type 2 roughness should not depend on the frequency of the incident wave (see [2] for details) the same model can be used for calculations of the NRCS at X-band located between the K_u- and C-bands. Here we present results of computations for NRCS at two polarizations for various winds and various radar frequencies (see Figures 1-3). In [1] it was suggested that an empirical X-band GMF can be obtained by the interpolation of the K_u- and C-band GMFs. Our calculations support this suggestion. In Figure 4 a comparison is shown between the NRCS at X-band directly calculated using the above model and the NRCS obtained by interpolating NRCSs at the K_u- and C-bands also obtained from this physical model. The presented plots are obtained for the upwind direction and for fully-developed seas. This result means that for wind retrieval purposes the corresponding X-band GMF can be obtained by interpolating K_u- and C-band GMFs.

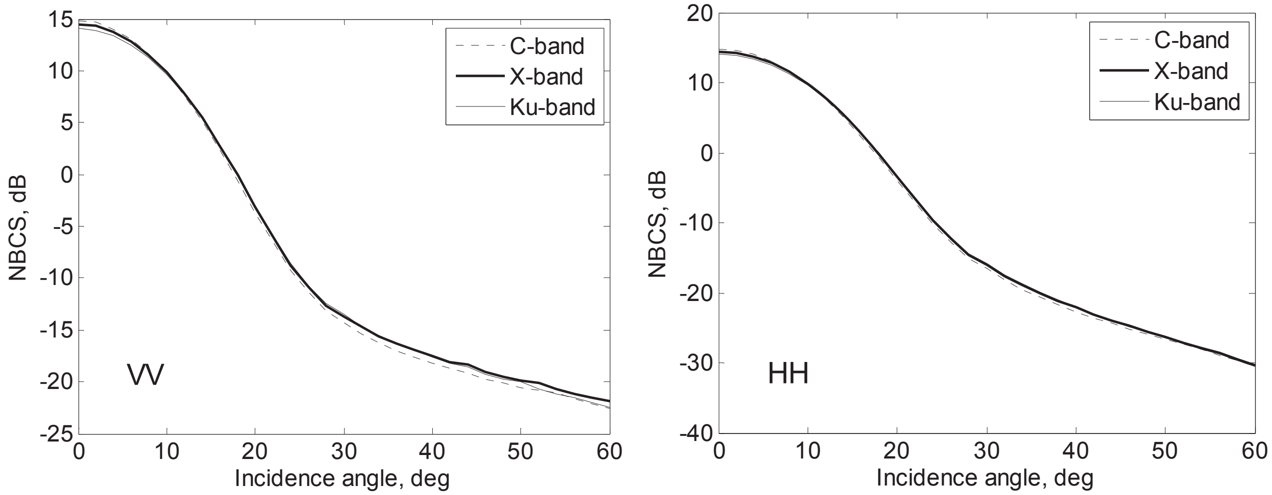

Figure 1. NRCS for VV and HH polarizations at three frequencies for 5 m/s wind speed at 10-m height.

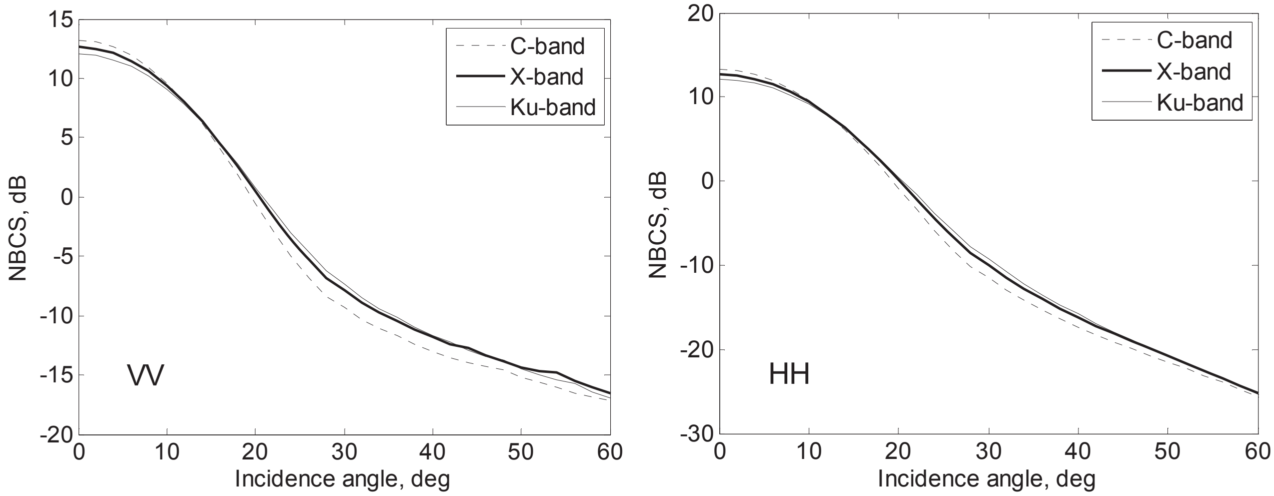

Figure 2. NRCS for VV and HH polarizations at three frequencies for 10 m/s wind speed at 10-m height.

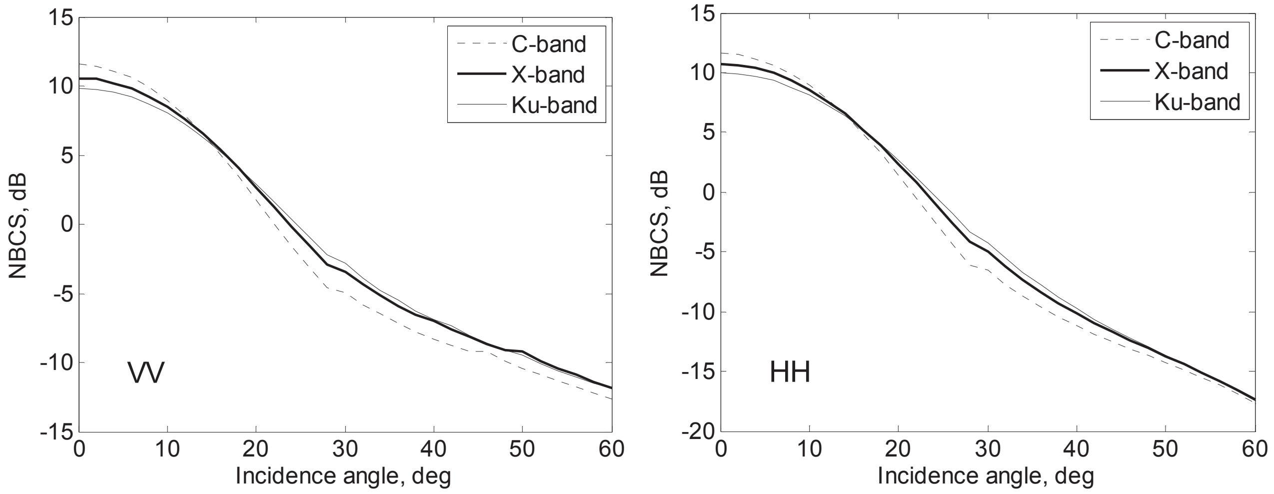

Figure 3. NRCS for VV and HH polarizations at three frequencies for 20 m/s wind speed at 10-m height.

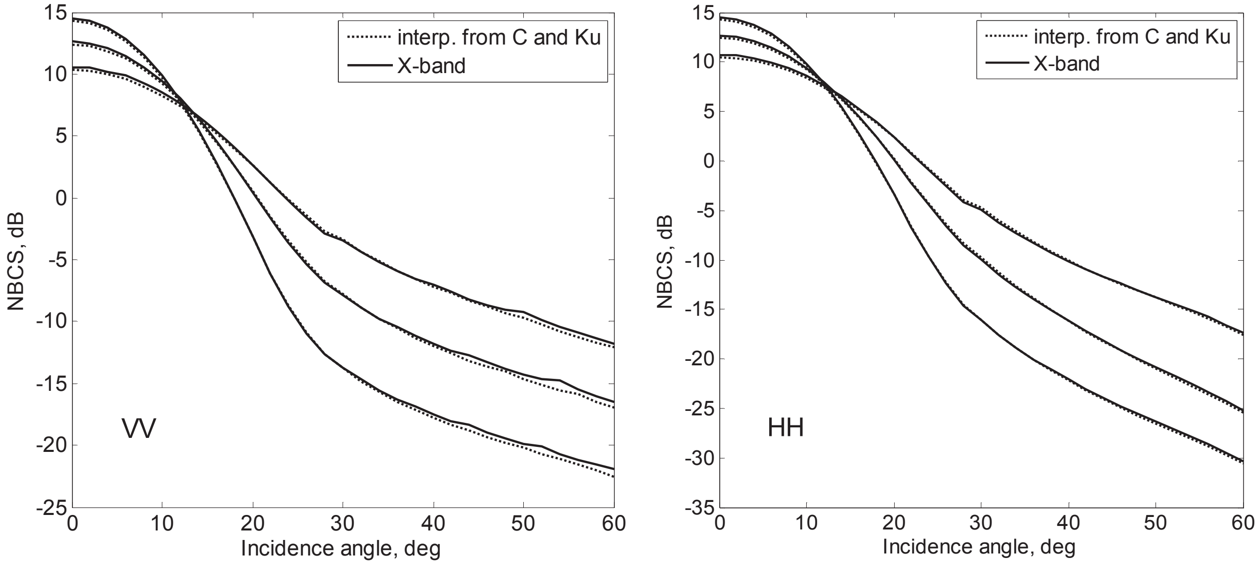

Figure 4. X-band NRCS for VV and HH polarizations at wind speeds 20, 10, and 5 m/s (from top to bottom). Solid curves are NRCS obtained directly from the physical model, and dashed curves are X-band NRCS obtained by interpolating between K_u- and C-band NRCSs.

5. DISCUSSION

The fact that the X-band NRCS can be obtained by the interpolation of the K_u- and C-band NRCSs can be qualitatively explained as follows. In the interval of incidence angles between 30 and 60 degrees typically employed in the scatterometric wind retrievals the major scattering mechanism is Bragg resonant scattering on gravity-capillary waves. The expression for the NRCS written in the limit of small perturbation method contains a frequency dependence in the form of k^4 times the elevation spectrum taken at the Bragg resonant wavenumber. Since sea surface spectra behave as k^{-4} over the wide interval of the wavenumbers these two frequency dependences cancel each other, and the NRCS becomes frequency independent if to disregard a weak frequency dependence of polarization coefficients. More importantly, for the sea surface spectrum "k^{-4}" power law holds only for k < 100 rad/m, whereas for larger wavenumbers, according to [3], it exhibits a wind-dependent "bump." This feature causes the spectrum to depart from the "k^{-4}" power law in the range of wavenumbers which overlaps with K_u-, X- and C-bands. Because of this, the NRCS dependences over an incidence angle at these three frequencies demonstrate a small but noticeable divergence from each other seen in Figures 1-3. For discussed bands, which occupy a small portion of the "bump," the frequency dependence of NRCS is close to linear, especially if to use a double-logarithmic scale. That is why the linear interpolation is successful here. However, the linear interpolation might not work for a larger span of wavenumbers that exceeds the width of the spectral "bump."

6. CONCLUSION

In general, if for a certain frequency range and an interval of angles the Bragg resonant wavenumber falls into an interval of a roughness spectrum with a power-law dependence on wavenumber, the frequency (or wavelength) dependence of the NRCS will also be of a power-law type. For this reason, one may expect that the linear interpolation of the NRCS in a double-logarithmic scale will provide a reasonably good approximation assuming that the frequency dependence of the polarization factor and the modulation effect of tilting by large-scale waves are relatively weak.

7. REFERENCES

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