Bistatic Radar Scattering from the Ocean Surface: Assessment of Validity of the Kirchhoff-Geometric Optics Approach Using the Small Slope Approximation

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Because of its simplicity, the Kirchhoff approximation taken in geometric optics limit (KA-GO) is a widely used approach in the modeling of the forward bistatic radar scattering from the rough ocean surface. It estimates the Kirchhoff diffraction integral by the stationary phase method applied to the smoothed, or low-pass filtered rough surface. For the forward quasi-specular geometry scattering from small-scale surface roughness is considered negligible. The normalized bistatic radar cross section (NBRCS) in the KA-GO can be expressed through the probability density function of surface slopes. Frequently, this function can be characterized by the mean square slope of the low-pass filtered rough surface. At this point, an empirical cutoff spectral wavenumber is introduced in the model. This method produces satisfactory results for linearly co-polarized and circular cross-polarized radio waves, and generates discrepancies for the circular co-polarized radio waves. A more accurate method, the small slope approximation of the first order (SSA1), can be applied to assess the validity of the KA-GO approximation.

We performed calculations of the L-band cross-polarized NBRCS in the forward direction for incidence angles from 0 to 90°, and for several wind speeds using the SSA1. The empirical Elfouhaily et al. ocean surface spectrum was employed here. It was modified by truncating its high-wavenumber tail at a variable cutoff number, k_*. The purpose of this truncation was to obtain values of k_* above which the NBRCS stops changing. Our calculations confirmed that the NBRCS calculated using the SSA1 is not sensitive to short surface waves which correspond to wavenumbers higher than some k_*, the value of which depends on the required accuracy of the calculated NBRCS and the angle of incidence. It is confirmed that the obtained k_* is quite close to $k_1 = 2\pi \cos\theta_{inc} /3\lambda$, the empirical value used in bistatic scattering models based on the KA-GO. A very good agreement between the NBRCS calculated using this approximation and the SSA1 can be achieved for a significant range of incidence angles by slightly modifying the numerical coefficient in k_1. At the same time, the NBRCS values calculated using these two methods start to diverge from each other at larger incidence angles due to an inability of the geometric optics approximation to account for diffraction effects emerging at larger angles. Of course, the practical significance of the difference between the NBRCS obtained with these methods depends on the required accuracy of the modeled quantities.