Modeling of backscattering of radar signals from sea surface at Ku- and C bands

Alexander G. Voronovich, V.U. Zavorotny

NOAA Environmental Technology Laboratory, Boulder CO, USA – alexander.voronovich@noaa.gov, valery.zavorotny@noaa.gov

Monitoring of the wind field over vast ocean areas using active means is usually accomplished by measuring backscattering radar cross-section (RCS) of the radar signals from different directions. Those values are then related to the wind-vector through appropriate empirical relations. The empirical approach would be quite sufficient if sea-surface roughness that eventually determines RCS was determined entirely by wind. However, there are many other parameters except for a wind, which are also affecting surface roughness. Those are fetch, atmospheric stability, presence of swell, sea waves coming from neighboring regions, etc. Effective solution of the problem that involves many parameters can not rely on purely empirical approach, and an ability to calculate RCS theoretically is important.

Theoretical calculations of RCS for a given spectrum of roughness are usually based on a two-scale model. However, two-scale model suffers from at least two inherent drawbacks. The first is introduction of a scale-dividing parameter separating large- and small-scale roughness, which could be arbitrarily chosen within wide limits. Different prescriptions could be invoked to fix the value of this parameter, however those prescriptions are also arbitrary. The RCS calculated by two-scale model would depend on the choice of this parameter, and this adds up to the uncertainty of the results of comparison of theoretical calculations and experimental data. The second drawback of the two-scale model is its inability to control accuracy of the results since corrections to the two-scale model are not available. For these reasons discrepancy between the theoretical calculations and experimental data could be equally attributed either to inaccuracy of scattering calculations or to an inadequate model of surface roughness used.

To avoid this uncertainty we employed in our study Small-Slope Approximation (SSA) that is free from both of mentioned above drawbacks. It does not require introduction of scale-dividing parameter and it allows calculation of the corrections to the basic approximation of the theory. SSA provides explicit expressions for the RSC in terms of statistical characteristics of roughness. We assumed Gaussian statistics of roughness when all statistical characteristics can be expressed in terms of roughness spectrum. Thus, our theoretical model didn't have any adjustment parameters. Theoretical calculations according to SSA were performed for both Ku- and C-bands for Elfouhaily *et al* spectrum of sea-surface roughness. The results of computer calculations were compared against experimental data represented by empirical models CMOD2-I3 (for C band) and SASS-II for (for Ku-band).

The dependencies of RCS on incidence angle for along- and cross-wind directions were calculated for wind speeds equal to 5, 10, and 15 m/s (there is no difference between up- and downwind directions in theoretical calculations in this case). The results appeared to be in an overall good agreement with experimental data with discrepancies in most cases not exceeding 2-3 dB. The only exception was the case of HH-polarization in the upwind direction when the difference reached 5.7 dB. This difference significantly exceeded accuracy of our calculations that was controlled by simultaneous calculations of both the first and the second order of the SSA. Thus, it has to result from inadequate surface roughness model.

We attributed the mismatch between theory and experiment to the contribution from steep waves. Based on this hypothesis we were able to evaluate theoretically the probability density of slopes of steep breaking waves. Simple empirical relation for probability density function (PDF) of steep slopes (exceeding 0.8) was derived which indicates exponential dependence of the PDF on both slope and wind speed. Note that such slopes are beyond validity limits of the Cox-Munk slope distribution. The numerical values of the PDF for steep waves seem to be reasonable and it could be smoothly extrapolated to the Cox-Munk distribution.

Then we recalculated our results with account for contribution from steep waves. Now underestimation of HH-polarization was fixed without deteriorating good correspondence obtained previously in all other cases. The reason is that in contrast to the HH-case scattering from background spectrum for VV-polarization is strong enough and contribution from steep waves does not change it much. On the other case, for HH-polarization this contribution is of the same order of magnitude as a background clutter.

Thus, correspondence between theoretical calculations and experimental data appeared to be within 2 dB (in a few exceptions within 3 dB) accuracy for all incidence angle, winds and polarizations considered.

Another finding of this research is a conclusion the Elfouhaily *et al* spectrum seems to overestimate by 2-4 dB probability density of short, centimeter waves in the cross-wind direction.

REFERENCES

[1] A.G. Voronovich and V.U. Zavorotny, "Theoretical model for scattering of radar signals in Ku- and C-bands from a rough sea surface with breaking waves", Waves in Random Media, v. 11, pp. 247-269, 2001.