BREAKING WAVE MEASUREMENTS WITH SAR DEPOLARIZED RETURNS

Paul A. Hwang[1], *Biao Zhang*[2] *and William Perrie*[2]

[1] Remote Sensing Division, Naval Research Laboratory, Washington DC, USA

[2] Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada

Phillips [1] addresses the radar scattering problem based on the structure of ocean surface waves, which are the roughness elements that scatter the radar waves on the ocean surface. He establishes an analytical framework of the double structure of sea surface scatterers: the wind generates a distribution of small slope waves and sporadic steep breaking events. Applying the results of radar scattering theories [2-4] and his detailed wave dynamic analysis [5], he shows that the wind speed dependence of radar backscatter is expected to be linear in the Bragg contribution and cubic in the breaking contribution. However, based on subsequent comparisons of the theory with several field observations, he concludes that these measurements do not reveal cubic wind speed dependence. The data set [6] he examined in most detail reveals a comprehensive linear dependence on wind speed throughout the whole range of radar frequencies and incidence angles, θ, in the data set (0.428 to 8.91 GHz and 30° to 85°).

Quad-polarization (quad-pol) and dual-polarization (dual-pol) measurements with de-pol radar returns (σ_{0VH}, horizontal transmit vertical receive or vertical transmit horizontal receive) from the ocean surface are now available from many satellites, among them the RADARSAT-2 (R2). Here we present analysis results of quad-pol (414 points) and dual-pol (372 points) backscatter data and collocated wind velocities from ocean buoys maintained by the National Data Buoy Center (NDBC). The co-pol radar returns, σ_{0VV} and σ_{0HH}, as a function of wind speed, U_{10}, are well predicted by the composite Bragg (CB) theory [4] and empirical geophysical model function (GMF) CMOD5. The input surface roughness spectrum for the CB theory is the parameterization function of short scale wave spectra collected from the ocean [7] combined with the directional distribution function described by Plant [8]. The difference between σ_{0VH} and CB theory is somewhat larger especially at both ends of the wind speed range.

When quad-pol and dual-pol σ_{0VH} are plotted together, there is good agreement between the two data sets in high winds. A difference of about 5 to 6 dB in low winds reveals the much larger dual-pol noise floor. The quad-pol product is known to have extremely low noise floor and channel cross-talk corrected. Assuming that the system noise is -30 dB for dual-pol and -36 dB for quad-pol, we average the data with noise subtracted in two θ bins (25±5° and 35±5°) and compare them with the CB theory. The agreement of quad-pol data with CB theory is quite good in mild and moderate winds (U_{10}<~10 m/s). Because R2 measurements include both Bragg and breaking contributions and CB theory only accounts for the former, the difference between R2 data and the CB theory is an estimate of the wave breaking contribution, σ_{0VHb}.

Surface wave breaking is one of the most important sources of turbulence and energy dissipation, ε, in the upper ocean. Theoretical analyses of energy dissipation lead to a cubic wind speed dependence. Fig. 1a compares the energy dissipation estimates from several field experiments discussed in Hwang [9] and breaking contribution of de-pol return, σ_{0VHb}. The cubic wind speed dependence of both ε and σ_{0VHb} is easily detectable (the trend in radar data at low wind speeds is corrupted by the low signal to noise ratio). The energy dissipation per unit area of the ocean surface (in W/m^2) can be approximated by $\varepsilon = 5\times10^{-4}\rho_a U_{10}^3$, where ρ_a is air density (~1.2 kg/m^3). Conceivably, we can measure ocean surface energy dissipation from space using the de-pol radar return, an empirical relationship of $\varepsilon = 1.5\times10^3\sigma_{0VHb}$ is established (Fig. 1b). Quad-pol product with its low noise floor is especially suitable for measuring wave breaking and energy dissipation from space.

References

[1] Phillips, O. M. Radar returns from the sea surface – Bragg scattering and Breaking waves. *J. Phys. Oceanogr.*, **18**, 1065-1074 (1988).

[2] Wright, J. W. Backscattering from capillary waves with application to sea clutter. *Trans. Antennas Propag.,* **14**, 749-754 (1966).

[3] Wright, J. W. A new model for sea clutter. *Trans. Antennas Propag.,* **16**, 217-223 (1968).

[4] Valenzuela, G. R. Theories for the interaction of electromagnetic and oceanic waves – A review. *Bound.-Layer Meteorol.,* **13**, 61-85 (1978).

[5] Phillips, O. M. Spectral and statistical properties of the equilibrium range in wind-generated gravity waves. *J. Fluid Mech.*, **156**, 505-531 (1985).

[6] Guinard, N. W., Ransone, J. T., and Daley, J. C. Variation of the NRCS of the sea with increasing roughness. *J. Geophys. Res.,* **76***,* 1525-1538 (1971).

[7] Hwang, P. A. Observations of swell influence on ocean surface roughness. *J. Geophys. Res.,* **113**, C12024, doi:10.1029/2008JC005075 (2008).

[8] Plant, W. J. A stochastic, multiscale model of microwave backscatter from the ocean. *J. Geophys.*

Res., **107**, C93120, doi:10.1029/2001JC000909 (2002)

[9] Hwang, P. A. Estimating the effective energy transfer velocity at air-sea interface. *J. Geophys. Res.*, **114**, C11011, doi:10.1029/2009JC005497 (2009).

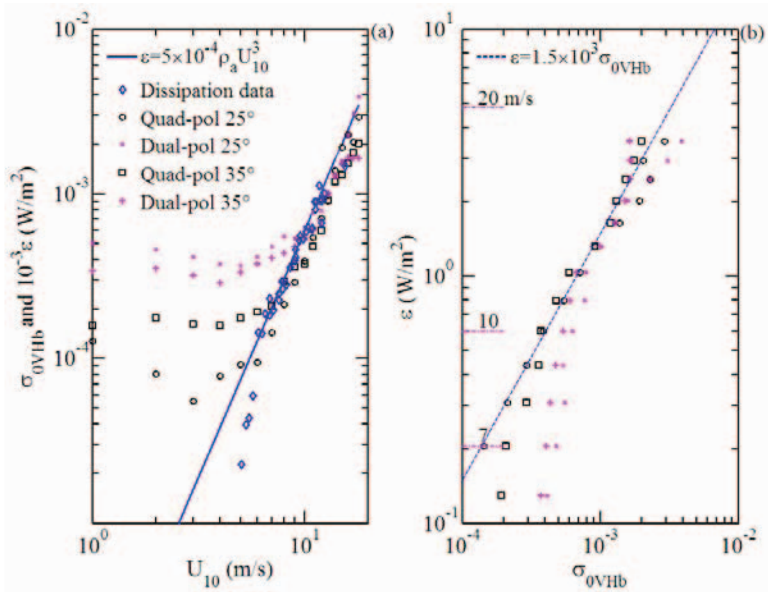

Figure 1. (a) Comparison of energy dissipation and the breaking contribution of de-pol radar return as a function of wind speed. (b) Feasibility of measuring ocean surface energy dissipation from space using de-pol radar returns.