# Modelization of microwave doppler spectrum from nonlinear ocean profiles at grazing angles

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The ocean surface being time-evolving, the radar return experiences a Doppler effect. Most salient characteristics of the so-called Doppler spectrum can be analytically depicted by the first- and second-order perturbative solutions of the hydrodynamical and radiowave scattering equations, an approach which was pionnered by Crombie in 1955 and completed by Weber and Barrick in the 70's. Following these approaches, the mean frequency shift is essentially given by the Bragg theory, with almost no dependency on wind speed nor polarization. Experimental measurements in the HF and VHF domain confirm this analytical approach.

However, Bragg's theory is no longer valid in the microwave domain. Experimental measurements with shipborne or coastal coherent microwave radars have reported repeatedly the occurence of "fast scatterers", that is Doppler components well beyond the Bragg frequency shift. This phenomenon, observed dominantly at grazing angles, is particularly pronounced in horizontal polarization.

In the last decade a certain number of numerical simulations have been performed in the literature to model the microwave Doppler shift and the fast scatterers. This has been done mainly for one-dimensional surfaces by coupling rigorous numerical models for radiowave scattering from rough surfaces and nonlinear numerical hydrodynamical models for ocean surface. However, the employed technique (based on tapered incident beam) does not allow to consider the case of extreme grazing angles. Furthermore, these purely numerical approaches are not adapted to the prediction and interpretation of fast scatterers in terms of geophysical parameters.

We show that in the framework of a recent analytical weakly nonlinear model, namely the Choppy Wave Model, a simple relationship can be estabished between the mean Doppler shift and the wind speed in the limit of grazing angles. This result is validated through one-dimensional ocean surface Doppler spectrum simulations using a rigorous dedicated electromagnetic approach. Comparisons are given with the classical Creamer model.