OCEAN WAVE FIELD MEASUREMENTS USING COHERENT AND NONCOHERENT RADARS AT LOW GRAZING ANGLES

David Lyzenga and Okey Nwogu
University of Michigan

Dennis Trizna
Imaging Science Research

Ocean wave measurements have been made using marine radars for more than 20 years [1], but technological developments and new naval requirements have led to a resurgence of interest in these measurements [2]-[4]. A recent theoretical study [5] has compared the retrieval of ocean wave profiles from conventional (noncoherent) marine navigational radars, Doppler radars, and interferometric systems. In this paper we present results from two at-sea experiments conducted as part of a Multidisciplinary University Research Initiative (MURI) project at the University of Michigan. These results were obtained using digitally recorded data from a conventional marine radar, and from a commercial radar that was modified to provide Doppler information using a coherent-on-receive mode. In addition, we present result from a fully coherent radar system [4] operated at the Field Research Facility (FRF) in Duck, NC. The Doppler data was processed using a new methodology for estimating wave fields from radial velocity measurements [6]. The shipboard radar data is compared with concurrent buoy measurements, and the data collected at Duck, NC is compared with pressure sensor array measurements made at the FRF.

The first field experiment was conducted in the Gulf of Alaska in April 2006, and utilized the FURUNO X-band radar installed on the R/V Thompson. The output video signal was recorded digitally along with the radar heading and bearing pulses using an ISR A/D board, and a rough calibration was applied by recording the backscattered signals from floating corner reflectors. The radar cross section is assumed to be related to the local grazing angle θ using a scaled Bragg scattering model, *i.e.* $\sigma^o(\theta) \approx f_o \sin^4\theta$ where the scale factor f_o is determined from the average observed NRCS at near range, and the local grazing angle is related to the surface elevation η and the radial component of the surface slope η_r by the equation $\sin\theta \approx \eta_r + (z_o - \eta)/r$ where r is the range distance and z_o is the antenna height. These equations were used to calculate the surface elevation as a function of the range r and azimuthal angle ϕ, and the resulting surface elevation maps were Fourier transformed in polar spatial coordinates and in time to produce estimates of the three-dimensional spectrum $S(k, \phi, \omega)$. For the purpose of comparisons with buoy measurements, this spectrum was integrated over k and ϕ to produce estimates of the frequency spectrum and the mean wave propagation direction at each frequency. Comparisons of the radar and buoy spectra for one case are shown in Figure 1.

The second field experiment was conducted off the coast of Northern California in August 2008, and utilized a SITEX^{TM} radar that was modified by ISR to operate in a coherent-on-receive mode in order to provide estimates of the radial velocity using a pulse-pair processing method. To convert the radial velocities directly into surface elevation estimates, we must first perform a Fourier decomposition of the radial velocities in order to separate the contributions from each wave component. The Fourier transform is computed in polar spatial coordinates and this transform is divided by the wave frequency to obtain the three-dimensional Fourier transform of the surface elevation. For comparison with buoy measurements, the resulting 3-D spectrum is again integrated over wavenumbers to obtain the frequency spectrum. Comparisons of the radar and buoy spectra for one of the data sets from the 2008 experiment are shown in Figure 2.

We conclude that wave spectra can be estimated from both noncoherent and coherent radar data, but it is not yet clear which method produces more robust results. There is ample evidence that the modulation transfer function (MTF) that has traditionally been used to relate backscatter variations to surface slopes or elevations is environmentally dependent, and this has been used as an argument in favor of Doppler measurements. Our processing of noncoherent data does not use an MTF, and it is possible that this approach can produce reliable results under a range of environmental conditions, but the range of conditions under which it has been applied so far is not wide enough to validate this conclusion. Doppler data tends to be somewhat noisier, but is more straightforwardly related to the surface elevation (at least for linear waves). The new method described in [6] does not require a Fourier transform as the first step and can be used in cases where surface wave nonlinearities are important. Since Doppler radars can be used to produce estimates of the radar cross section as well as the radial velocity, it is conceivable that the optimum method of processing would utilize both for the purposes of wave field estimation.

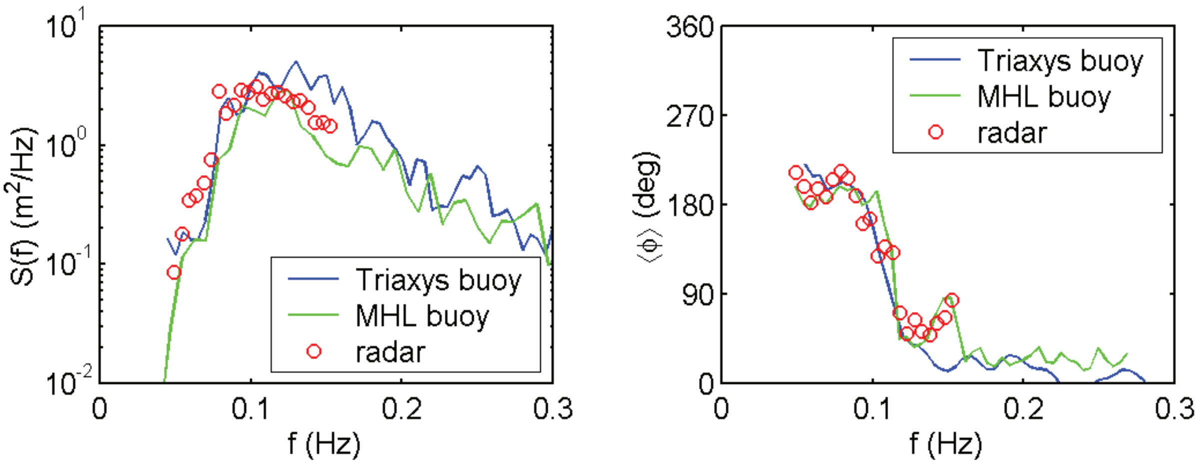

Figure 1. Comparison of noncoherent radar and buoy spectra for 5 April 2006 data set. (Note that ϕ indicates direction waves are coming from, not propagating toward.)

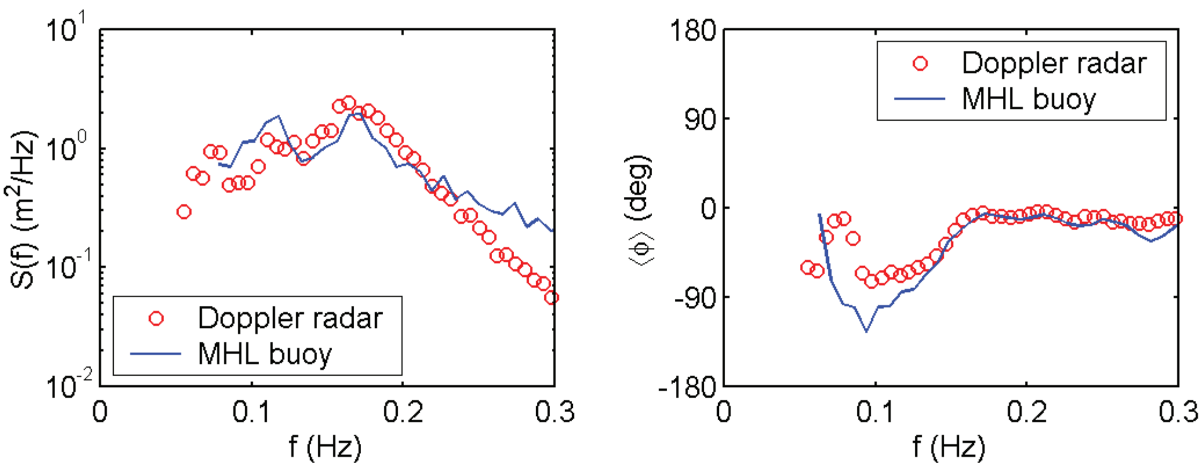

Figure 2. Comparison of Doppler radar and buoy spectra for 13 August 2008 data set. (Same sign convention for wave propagation direction as in Figure 1.)

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