Wind farm impacts on HF radar current and wave measurements in Liverpool Bay

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***Abstract*- HF radar systems are increasingly used as components of coastal monitoring systems but the accuracy of the measurements can be compromised if there are other significant non-wave targets (e.g. ships or wind turbines) in the field of view. Liverpool Bay, on the North West coast of England and Wales, is an area of significant wind farm development and is also the site of an HF radar deployed as part of the Liverpool Bay coastal observatory. In this paper the HF radar current and wave measurements are compared with co-located in situ measurement devices and with data at the Rhyl-Flats wind farm for three month periods in 2009 and 2010 to demonstrate the impact of the wind farm installation on radar performance.**

I. INTRODUCTION

The National Oceanographic Centre (NOC), previously the Proudman Oceanographic Laboratory, operates a Coastal Observatory in Liverpool Bay on the North West coast of England and Wales [1]. Liverpool Bay experiences large tidal ranges, up to 10m, strong M_2 currents up to $1ms^{-1}$, fresh water inputs, and frequent shipping activity. Numerous oceanographic parameters are measured using a wide variety of instrumentation, including a WaveNet Waverider buoy, ADCPs, a 13MHz HF WavE RAdar (WERA radar) [2], X-band radar, tide gauges, satellites and pressure sensors.

HF Radar is an established tool for measuring ocean currents and waves by interpretation of backscatter from the ocean surface [3]. Backscatter from objects, moving or stationary, introduces noise by returning unwanted signals. Stationary returns, such as those from land, produce zero Doppler shifts in the backscatter signal and fall outside the region for current and wave measurement therefore not degrading the quality. Objects in motion on the ocean surface, for example ships and wind turbines, produce unwanted backscatter in the Doppler spectra if moving at similar speeds to those of currents and waves. This can then cause disagreement with current measurements from acoustic Doppler current profilers (ADCPs) and wave measurements made with buoys to a greater extent than would be expected due to their differing measurement techniques.

Liverpool Bay is attractive to wind farm development due to its shallow waters and high wind speeds. During the last 10 years there has been extensive development with three wind farms now fully operational each with 20-25 wind turbines. This investigation compares HF radar current and wave measurements with those of fixed moorings at radar measurement cells co-located with the wind farms and in particular for the most recent development, Rhyl Flats, using periods of data before and after wind turbine construction. The oldest wind farm, North Hoyle, is on the edge of the radar footprint i.e. at the limit of the region where current and wave measurements should normally be obtained with reasonable accuracy. The Burbo Bank wind farm falls outside this region. Neither of these would therefore provide convincing data to assess the impact of wind farms on metocean data accuracy. Rhyl Flats is in a better location for this study.

II. THE IMPACT OF RHYL FLATS WIND FARM

Rhyl Flats wind farm is in a prominent position directly in front of one of the HF radar's transmit and receive antennas. Current and wave measurements at this location have previously been good with significant wave height (H_s) correlations of 0.6 with nearby buoy data and excellent agreement for H_s over 1m [4]. The three month period of February to April 2009 is defined as "before" the RFWF installation. At this time the wind farm towers were in place but introduce only a large stationary return in the backscatter power spectrum (referred to as the Doppler Spectrum) which should not affect current and wave measurements. Turbine blade attachment, the rotation of which is thought to be the significant contribution to characteristics of the radar return, began at the end of April 2009 and first power was exported in July 2009. The same three month period in 2010 is defined as "after" the installation and at this point RFWF is fully operational.

The impact of the wind farm is seen clearly in the measurements of noise in the radar signal as shown in Fig. 1 which also shows the location of the radars and measurements cells, the wind farms and various measurement devices used for the evaluation of the radar data. The turbine signals do not just raise the noise floor but also change the nature of the Doppler spectrum by introducing additional peaks at many discrete frequencies across its bandwidth as can be seen in Fig. 2. The central peak in this figure is the Doppler return from a stationary target, the two peaks surrounding this are the returns from the Bragg waves propagating towards and away from the radar and these are clearly seen in both before and

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after cases. These are the returns that are used for surface currents measurement and this study has confirmed that the wind farms have little impact on the accuracy of this measurement.

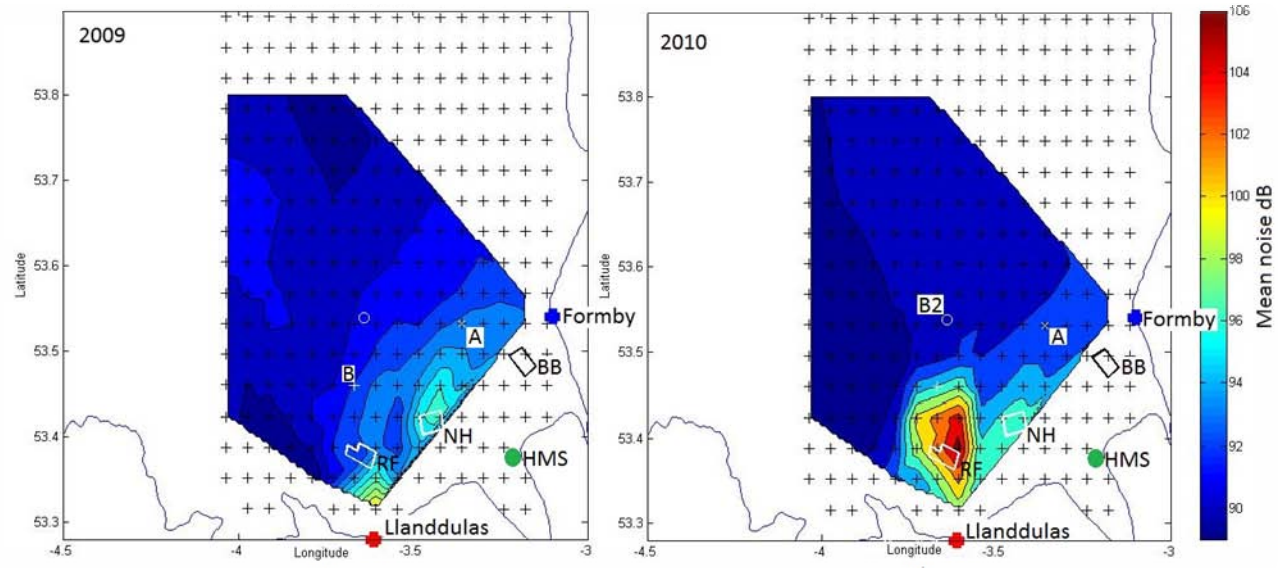

Figure 1. Liverpool Bay. Two radar sites at Formby and Llandulas and measurement cell centers indicated by a black '+'. The mean noise in dB from the Llanddulas HF WERA radar for the months of February, March, and April in (left) 2009 and (right) 2010. North Hoyle (NH), Burbo Bank (BB), and Rhyl-Flats (RF) wind farms, and Hilbre Island Meteorological Station (HMS). Location A, indicated with a white 'x' is the location of nearest radar measurement cell, the wave buoy, and the Acoustic Doppler Current Profiler (ADCP) A. Location B, indicated by a white '+', is the nearest radar measurement cell and ADCP B in 2009. Location B2, indicated by a white 'o', is the ADCP B in 2010.

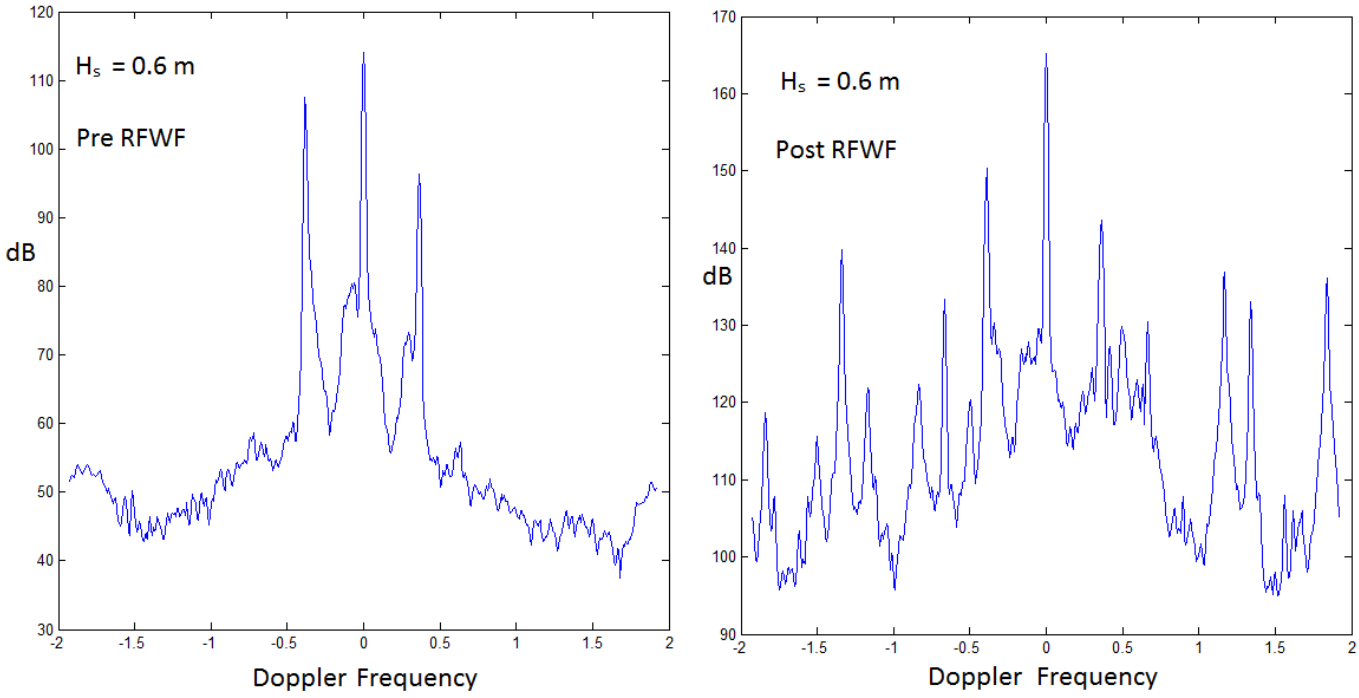

Figure 2. Doppler spectra for pre and post operation of Rhyl Flats wind farm (RFWF).

Significant wave heights were similar during February - April in 2009 and 2010 and were generally low. For this radar installation wave measurements are less accurate, and often not available for waveheights less than 1m [5] and there were few events with higher waveheights during the selected periods. Nonetheless the preliminary results indicate that the correlation between buoy and radar significant waveheight is reduced from 0.6 to 0.2 and the rms difference increased from 0.6 to 1.5 at one radar cell within the wind farm.

III. Discussion

With the introduction of the Rhyl Flats wind farm the difference between buoy and radar H_s is increased and the correlation is decreased. Current measurement agreement with the ADCP is still relatively good with correlations of around 0.9, typical for Liverpool Bay [6].

Wind farms in Liverpool Bay have so far been relatively small and effects limited to only a few radar measurement cells but this will not always be the case. Construction is planned to commence on a fourth wind farm in late 2011 which will be of one of the largest offshore wind farms in the world covering an area of up to 79km^2 and having up to 250 wind turbines. The impact of this development on the HF radar measurements will be significant unless current efforts to remove the turbine signal from the radar data before making the metocean measurements are successful.

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