SHIP BASED OBSERVATIONS OF OCEAN WAVES USING MULTIPLE X-BAND RADARS

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1. INTRODUCTION

Retrieving the height and velocity of sea waves has been of increasing interest in the recent years [1]-[7] due to many potential applications. In addition to obtaining instantaneous sea surface conditions, height and velocity information can be used for short term sea wave forecasting by combining radar measurements with methods for predicting sea surface evolution in time. Among many remote sensing options, microwave radar measurements from ship- or ground-based platforms have the capability of measuring waves to at least a few kilometers while providing the added benefit of operating under a wide range of weather conditions both day and night. A wide array of X-band radar systems are already utilized for marine navigation, hence the addition of a wave height measurement option to a standard X-band marine radar is highly desirable to manage costs and simplify the system development process.

Several challenges remain with achieving robust wave measurements. In particular, the "low grazing angle" geometry of ship- or ground-based radar measurements at long ranges complicates the physics of the surface scattering process [5] and makes inversion of radar measurements into sea wave information difficult. However, previous studies and experiments have shown the capability of retrieving wind fields using X-band marine radar systems [8]. Due to close coupling between local wind fields and small-scale roughness of the sea surface, similar approaches can be taken to obtain sea wave information. To date, two primary options for performing the inversion have received the most emphasis: those based on the use of radar backscattered power measurements and those based on measurements of velocity. The latter require the use of a coherent radar system, which can be achieved either through use of a truly coherent radar or through use of an incoherent radar with the addition of either traditional "coherent-on-receive" methods [9] or a "mean phase removal" method.

2. SYSTEM DESCRIPTION

To address these challenges, a team from the University of Michigan and The Ohio State University has developed an X-band marine radar system for wave height and velocity measurements. The original system is a KODEN MDS-63R marine radar, which is modified using low cost commercial off the shelf (COTS) components to enable wave field measurements. The system development uses the COTS 25 kW magnetron-based transmitter augmented with a stable local oscillator in the receiver and a “mean phase removal” algorithm. In traditional coherent-on-receive methods, the randomized phase of the high power radio frequency (RF) signal generated by the magnetron is measured and fed into the receiver processing chain to restore coherence, which enables Doppler processing. The “mean phase removal” method in contrast does not determine the transmitter phase by observing the transmitted signal, but rather removes any average phase versus range encountered in each radial measurement. The “mean phase removal” method is based on the assumption that ocean-wave induced modulations should have zero mean when averaged over range, so that any average observed is due to the random phase variations of the transmitter as well as any mean velocity of the entire scene with respect to the radar. The final approach is highly cost effective compared to a high power coherent radar system since a COTS incoherent system is utilized. In addition, the horizontally polarized antenna of the original radar is replaced with a vertically polarized antenna due to the increased sea backscatter returns expected in “VV” as opposed to “HH” polarization.

The radar scans the sea surface at 24 revolutions per minute. It is currently configured to provide sea surface backscattered power for ranges between 0.1 and 5 km. Doppler velocity measurements are obtained for ranges between 0.1 and 1 km. An on board data acquisition computer extracts power and Doppler information, which get forwarded to a subsequent Wave Field Processor for surface wave height reconstruction. Wave height and Doppler information are then used for short term sea wave estimation and forecasting. The current system is capable of real-time data acquisition and processing with ship motion corrections.

3. MARINE SURVEILLANCE TESTING

To test and verify the design concept, two such radar systems were deployed aboard the research vessel RV Melville, which is owned and operated by Scripps Institution of Oceanography in San Diego, California. The tests were conducted between September 6th and 17th, 2013 off the coast of California. The primary radar, which was mounted on top of the crow’s nest approximately 31 m above sea surface, was used for sea surface forecasting. The secondary radar was mounted on top of the pilot house. Radars were operational the majority of the time, which enabled the collection of data under a wide range of environmental conditions and ship headings relative to the dominant wave direction.

A small boat with a high cross section radar reflector was used as an additional test of radar performance. The known position and velocity of the boat offer the ability to verify radar measurements of target velocity as well as the associated range resolution and other radar parameters. A variety of wind conditions ranging from less than 1 m/s to greater than 15 m/s were observed during the experiment. The low backscattered power levels under low wind conditions (<~5 m/s) can represent a performance challenge for radar wave measurements; detailed examinations of radar performance in low wind conditions are therefore of interest. Additionally, in-situ wave measurements taken from buoys are used to verify the accuracy of the wave field estimation process.

4. PRELIMINARY RESULTS

Early results show successful measurement of modulations in both backscattered power and velocity associated with waves. Wave information is present to several hundred meters even in the lowest wind conditions, but further data analysis is needed to determine the maximum range for which useful data can be obtained as a function of wind speed. Data from the small boat deployment were used successfully determine azimuth and range offsets at long- and short-ranges. In addition, the small boat radial velocity was calculated using its recorded velocity and position, along with the host ship velocity. A very close agreement was observed between known truth relative radial velocity and the small boat velocity observed by the radar, as shown in Figure 1.

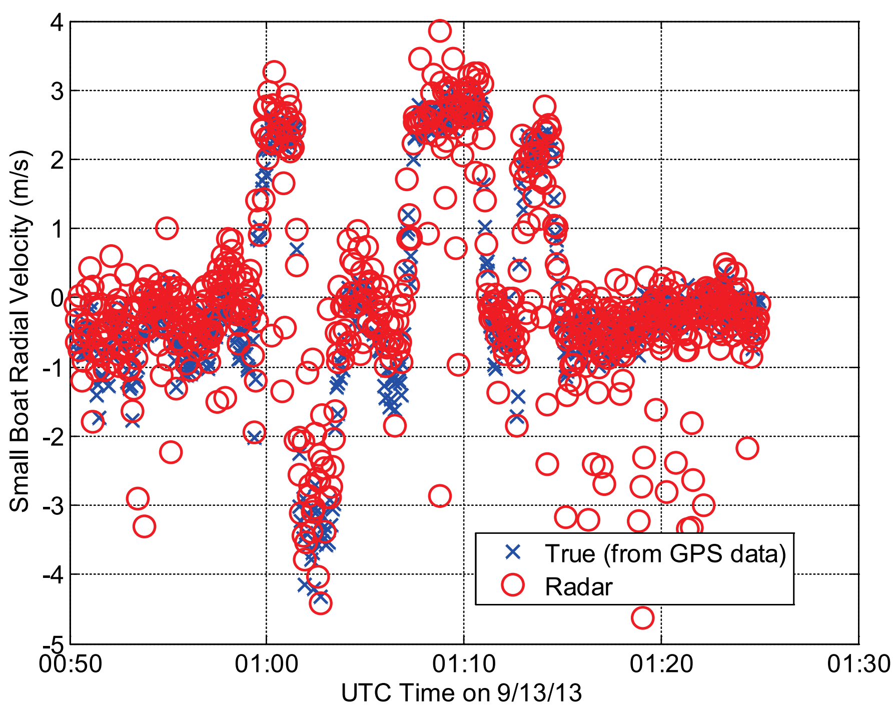

Fig 1. True small boat radial velocity vs. velocity extracted from radar imagery

5. DESCRIPTION OF PRESENTATION

The presentation will provide additional information on the campaign, radar systems utilized, conditions encountered, and updated results. Results from further studies on the signal-to-noise (SNR) as a function of wind speed will also be presented. The overall implications of the campaign with regard to improvements in radar systems for deterministic wave height and velocity measurements will also be presented.

5. RERERENCES

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