Environmental Influences on Nearshore X-Band Navigational Radar Images

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***Abstract*—Shore based X-band navigational radars are becoming operational instruments for spatial and temporal mappings of surface waves and coastal currents. The quality of retrieved data, however, remains to be examined. In a campaign to refine retrieval algorithms for wave and current data with navigational radar, we have reviewed images acquired from our shore-based radar system located near a tidal inlet with complex bathymetry. Both wind and waves are measured from a nearby data buoy; water level is also monitored from a tide station. Radar echo intensities in the grids along the straight line extending from the offshore to inlet are further analyzed; linear wind and wave dependences of normalized sea echo intensities are most effective at the grids away from the inlet; tidal influence of sea echo is most significant at grid located in the inlet.**

Keywords- radar sea echo; wind; wave; water level; X-band navigational radar; tidal inlet

I. INTRODUCTION

Land-based X-band navigational radars are becoming operational instruments for spatial and temporal mappings of various oceanic parameters, such as waves and currents [1, 2]. More recently, various algorithms to retrieve bathymetry [3, 4] and surface wind field [5] are also proposed.

As an operational instrument, proper interpretations of radar images with ambient environmental conditions are needed to provide adequate retrievals of these oceanic parameters. In an effort in refining available algorithms in wave and current mappings with navigational radar, we have conducted intensive observation of radar backscattering of shore-based X-band navigational radar. The radar sea echoes of the four grids along the straight line from offshore to tidal inlet are further investigated in details together with ground truth data, such as wind, wave and sea levels; the relevant findings are presented herewith.

II. EXPERIMENTAL SITE AND DATA FORMAT

To monitor coastal waters, the Coastal Ocean Monitoring Center (COMC) at the National Cheng Kung University has deployed a shore-based X-band navigational radar system at Beiti which is at the west coast of Taiwan (23° 6.7900’ N, 120° 3.1378’ E), as shown in Figure 1. The radar antenna is about 20 m above the mean water level; it has the frame rate of 0.66 Hz and the range of 4.5 km (Figure 2). Either hourly or bi-hourly radar measurements have been conducted during January 1 to January 8 of 2012. The COMC’s radar system was designed mainly for operational measurements of coastal waves; the image matrix consisting of 256 × 256 pixels and 128 frames is used to derive wave parameters. With nearby ground-truth measurements of wind, waves, currents, sea levels, air- and water- temperatures from a data buoy and nearby tide station, we have examined all radar images against these surface truth data.

In this sea area, the sea states are dominated by different monsoon systems. During the winter, the strong northeasterly wind has speeds as high as 19 m/s, which can introduce wave heights of more than 3 m. Compared to the winter monsoon, the summer monsoon is much weaker and blows from the southwest. Additionally, the Taiwan Strait is located between the tropics and the subtropics and is sometimes influenced by typhoons.

Figure 2 shows the bathymetry of the water being investigated; the radar range is marked by a dashed circle. The radar data will be compared with the data from the in-situ moored buoy measurements in a later section. Although the distance between the locations of the in-situ moored buoy and the radar monitoring area is approximately several kilometers, the wave data from the data buoy is used in this study assuming a homogeneous sea state. The data buoy is located at the water depth of 17 m.

Figure 1. Experimental site.

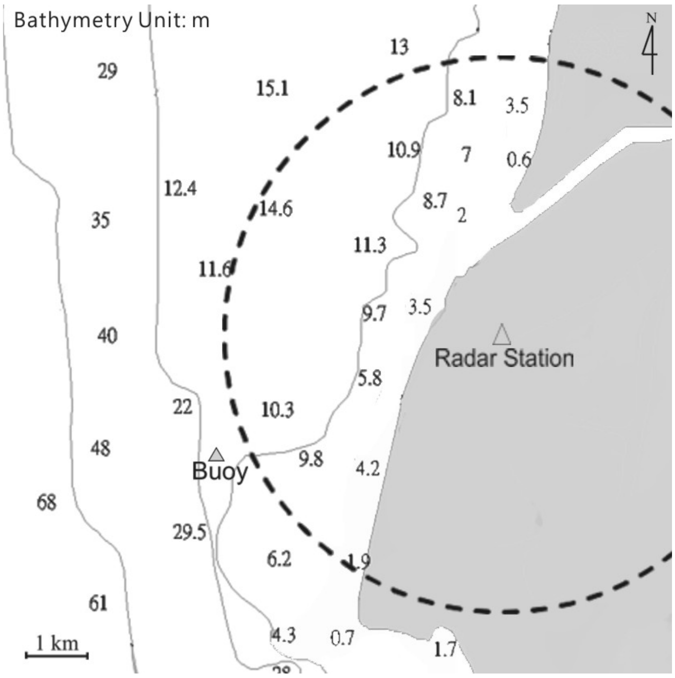

Figure 2. Bathymetry (in meters) near radar's coverage (dashed circle).

The probability density functions of the wave height and period observed from the moored buoy are shown in Figure 3. The results show that most wave heights less than 2.5 m, and 3~5 sec wave periods are common in this area. Under these wave period conditions, some parts of waves detected at the location of the moored buoy belong to deep waves. However, the water depths from most of the radar monitoring areas are less than 12 m, which means that the influence of sea bottom friction within the radar monitoring areas is unavoidable for most of our wave data.

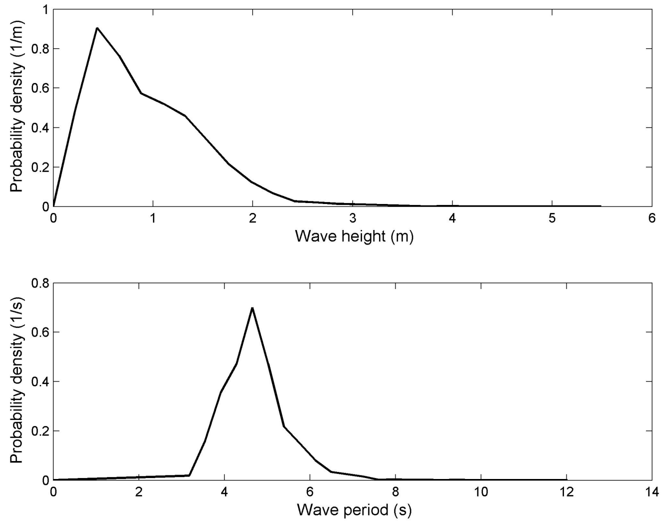

Figure 3. Probability density functions (solid lines) of (a) wave height and (b) wave period derived from bin distribution s (vertical bar).

Radar backscatter is presented as a gray value. Although the backscatter energy from radar images is not indicative of the elevation of sea surface level, it has been, until now, the most popular way to obtain near-wave field information both in temporal and spatial domains from field measurement. A typical radar image is shown in Figure 4; within the range of radar, the cyclic variations of echo intensities in temporal domain are most obvious near the tidal inlet near the mid-section of Figure 4. In order to investigate in details of the variations, we select 4 sub-grids along a line extended from the tidal inlet; each grid has 10 × 10 pixels. Results of the detailed analysis together with ground-truth data are given in the following paragraphs.

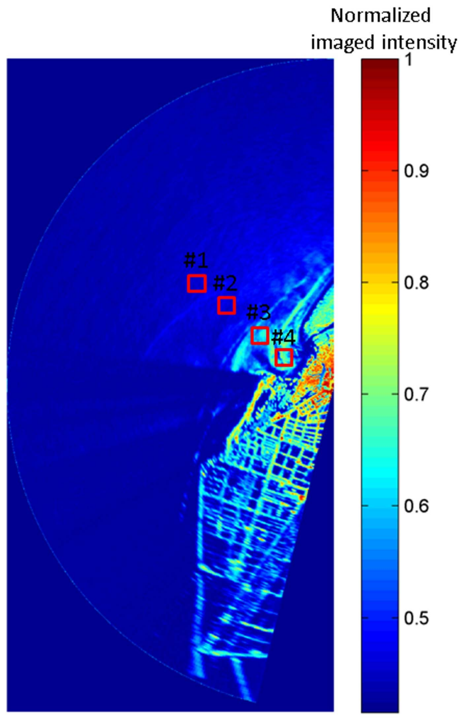

Figure 4. Locations of 4 radar sub-images for present analysis.

III. Data Analysis and Discussion

For a uniformed comparison, the radar sea echo is normalized with the maximum echo intensity in the radar image frame. The variations of normalized radar echo intensities with winds are given in Figure 5. The linear variation is clearly shown at the grid which is the farthest from the shore with correlation coefficient (marked as CC in the Figure 5) of 0.6; the correlation coefficients are decreasing as the grids are closing to the shore; the wind dependence is quite scatter for grid #4 which is located inside the inlet. This indicates the radar echo-wind dependence as suggested by Wright [6] is valid at the outer grids #1and 2; the complexity of the sea environments at the inlet further smear out the linear wind dependence of sea echo.

The dependence of sea echo on wave height is shown in Figure 6. This trend is similar to the variation of normalized sea echo with wind, i.e. the correlation coefficients are decreasing as grids are closing to shore.

It is noted that the linear wind dependence is further justified if the echo intensities are bin-averaged within the accuracies of ground-truth measurements. To investigate the tidal influences the normalized sea echo, the normalized radar sea echo and water level are presented in Figure 7.

The tidal influences on the normalized radar sea echoes are most obvious for the grid most close to shore. These findings trigger further research on tidal level retrieval algorithms using shore based X-band radar. The tidal influences are further demonstrated from the spectra of these four grids, as shown in Figure 8. The peak at diurnal period is clearly shown, with maximum spectral peak at the grid #4 which is within the tidal inlet.

Finally, the cross correlation function between normalized radar sea echo at the grid #4 and sea surface elevation reveals periodical variations (Figure 9).

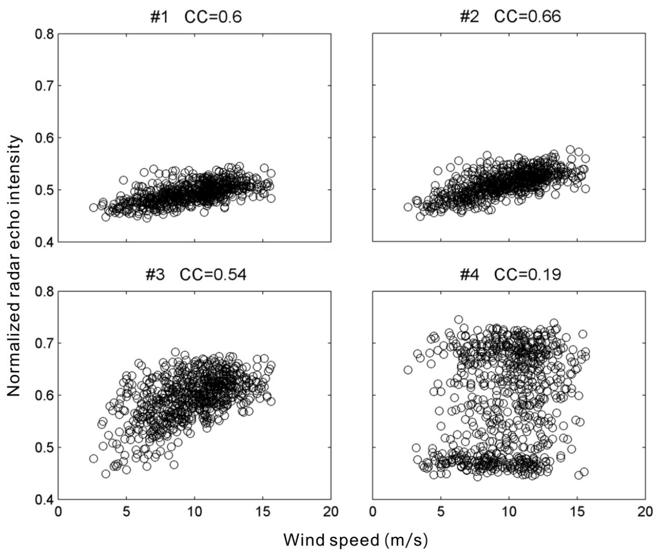

Figure 5. Variations of normalized radar backscatter with winds.

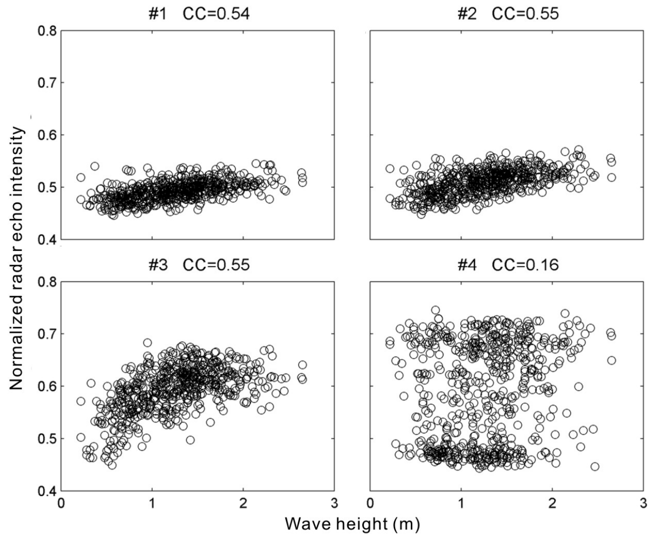

Figure 6. Variations of normalized radar backscatter with wave heights.

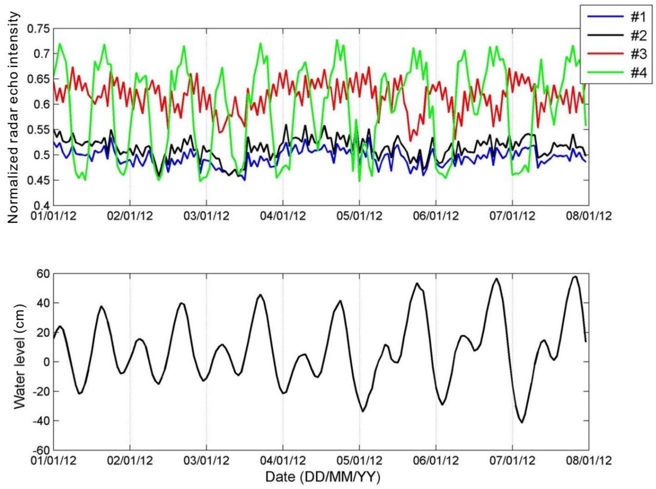

Figure 7. The relationship between radar backscatter and sea elevation.

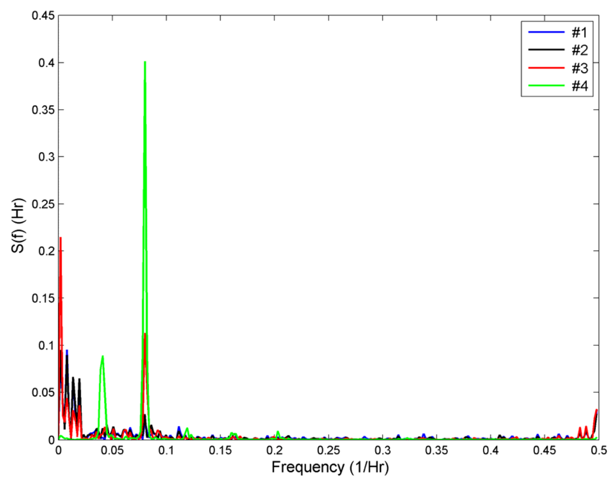

Figure 8. Spectra of normalized radar backscatter.

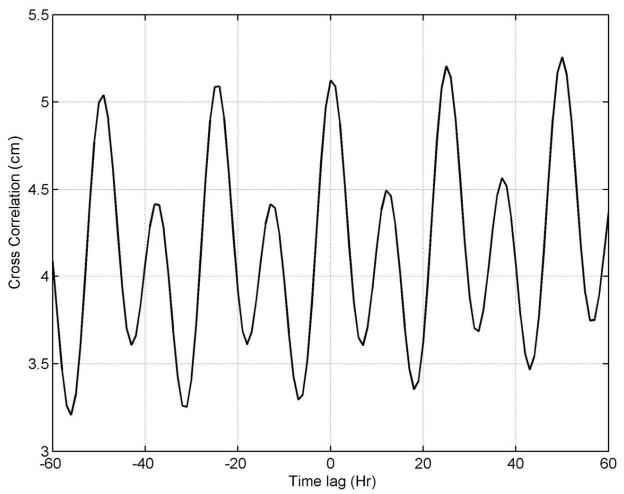

Figure 9. Cross correlation between radar backscatter and sea elevation.

IV. SUMMARY

The images of an X-band navigational radar system at tidal inlet have been examined together with ground truth measurements of winds, waves and sea levels. The detail analysis indicates the validity of the wind and wave dependencies of radar sea echo at coastal areas with less complexity. At the vicinity of tidal inlet, the wind and wave retrieval from radar sea echoes needs to be further refined. The high correlation between the radar sea echoes at grid #4, which is located in the tidal inlet, triggers an opportunities for water level retrieval.

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