Integrating Marine Radar Observations into Nearshore Modeling Systems

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Award Number: N00014-06-1-0317
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LONG-TERM GOALS

The long-range goal of this research is to extend the scientific basis for extracting environmental information regarding the nearshore ocean from remote sensing data. In particular, we seek to quantify how both optical and remote sensors image the breaking of waves in shallow water.

OBJECTIVES

The objectives of this project are as follows:

1. Assemble a marine radar wave observation system suitable for the nearshore ocean. Deploy assembled system at Duck, NC.
2. Collect a long time series (weeks to months) of radar and video data, including both time-exposure and time-series products.
3. Assist/collaborate with the effort to incorporate radar time-exposures from an ongoing collection effort into the Beach Wizard data assimilation program and interpret differences in model outputs arising from the different input data sources.
4. Analyze the differences between the wave breaking signals at wave time scales (i.e. not time exposures) for both optical and microwave wavelengths and relate the different signals to the underlying nearshore wave field.
5. Investigate potential model parameterizations for predicting the coverage of whitewater and foam that will generate clutter at optical wavelengths.

APPROACH

Our approach has been twofold. The first approach has been to continue our analysis of the details of wave breaking as imaged by optical sensors. Specifically, thus far we have concentrated mostly on data we collected in a large-scale laboratory experiment. This approach is new for two reasons, first by using a laboratory facility of this size we are able to control our wave conditions and still operate at large scales; secondly, performing the analysis on a wave-by-wave basis (as opposed to the time exposure approach) is also new. In addition, since the data set includes a number of in-situ wave gage time series that are highly synchronized with the video cameras, we have been able to investigate both the effects of nonlinearity on wave kinematics and the details of the relationship between optical signals and wave conditions in the surf zone.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Integrating Marine Radar Observations into Nearshore Modeling Systems**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oregon State University,220 Owen Hall,Corvallis,OR,97331-2302**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The second aspect of our approach has been to compare collocated marine radar and high-resolution video collected at the USACE Field Research Facility at Duck, NC. The data collected include both mean intensity (i.e. time-exposure) images and synoptic pixel time series (i.e. movies) from both remote sensors. Our analysis of this data has focused on comparing the differences between the two sensors; differences such as how well each sensor can be used to extract wave phase speed and the spatio-temporal differences in the imaging of individual wave breaking events. Phase speeds extracted from the marine radar data have also served as an input to the ONR-funded "Beach Wizard" project. That project has utilized the radar-derived phase speeds from outside the surf zone to complement the dissipation-based optical data in order to estimate bathymetry.

The key individuals in this effort have been the PI along with Patricio Catalan (PhD Candidate, Coastal & Ocean Engineering). We have also worked with the Coastal Imaging Lab in regards to the processing of the optical data. Our primary interactions within the Beach Wizard project have been with the group at WL|Delft Hydraulics (Ap van Dongeren and Anna Cohen).

WORK COMPLETED

- Analysis of nonlinear phase speeds completed, manuscript submitted Aug. 2006 (Catalán, P.A. and M.C. Haller, Remote sensing of breaking wave phase speeds with application to nonlinear depth inversions, submitted *Coastal Engineering*).
- Developed radar image rectification methodology, Sept. 2005 Duck radar image sequences were rectified and full-frame video time series were merged and rectified.
- Radar-derived phase speeds were calculated from the Sept. 2005 data using a CEOF method and passed to WL|Delft group for assimilation into Beach Wizard. (This work was presented by Cohen et al. at *ICCE 2006*, San Diego, CA)
- Radar system design has been improved to provide for improved synchronization between radar and video, nearshore radar system is on order with Imaging Science Research, Inc.

RESULTS

The objectives of the nonlinear phase speed analysis were to investigate wave celerity behavior in the surf zone (as observed by tracking remotely sensed wave crests) and to identify a model that could be used to improve bathymetric estimates through depth inversion. We investigated experimentally whether bathymetric estimates could be improved by incorporating nonlinear effects using local values of the wave amplitude.

A wide range of nonlinear phase speed models were tested and the composite model of Kirby and Dalrymple (1986) was shown to provide the best agreement with remotely measured phase speeds. Using the composite model, depth retrievals in intermediate to shallow water ($0.08<kh<0.81$) were significantly improved with RMS errors for the median profile reduced from 30% to 10%. Thus, inclusion of nonlinearity allowed shallow water estimates to have the same degree of accuracy obtained by previous studies in intermediate water using linear dispersion.

In addition, we asked the question as to whether, given the error bounds for nonlinear depth inversions that we established in the laboratory, bottom features that are typical to field beaches would be detectable by depth inversion algorithms. For example, minimum detectable bar heights as a function of the local unperturbed depth for a range of incident wave conditions were calculated as shown in Figure 1. The gray-shaded region of Figure 1 represents the range of observable sand bar heights and indicates that the minimum height increases with water depth. The white region in the left side of the figure represents surface piercing bars, which were removed from consideration. Using the cross-shore profile model of Hsu et al. (2006), the relationship between expected bar heights, Δh, and local (unperturbed) depth, h, is given by the white line in Figure 1 and is approximately $\Delta h \approx 3.0*h$ based on our calibration for a Duck-like beach.

The figure shows that depth inversions based on the composite model should be capable of identifying typical bathymetric features such as bars and depressions, provided the remote sensing observations are sufficiently accurate and the range of existing wave conditions is sufficiently wide. The results of this analysis also indicate that as wave steepness (*H/T*) increases in relatively shallow water, the sensitivity of the phase speed to bottom perturbations must necessarily decrease.

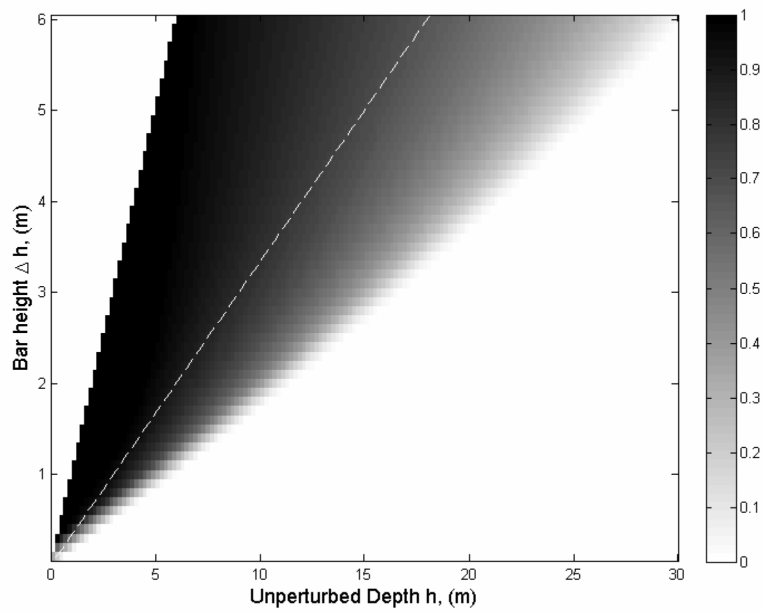

Figure 1. Fraction of wave conditions in the range 3<T<16 sec,0.1<H<3.0 m capable of detecting a sand bar (using nonlinear phase speed depth inversions). Dashed white line indicates typical bar height at each depth.

We are also investigating the details of the optical signal retrieved from individual breaking waves. There are several reasons this is of interest. Such as the fact that high intensity optical signals are the best available "ground truth" we have for investigating the marine radar returns from breaking waves. However, the relationship between high intensity optical signals and the underlying breaking wave characteristics are still poorly understood. It is also noted that surprisingly little published data exists regarding the time and space characteristics of individual wave breaking rollers. Yet, the parameterization of the wave breaking roller is a key component in the modeling of nearshore hydrodynamics. In this regard, Figure 2 demonstrates the types of comparisons we can make with our highly resolved laboratory data with synchronized remote video and in-situ wave gages. The figure demonstrates that the peak of the observed video intensity occurs very near the location of the wave crest. Ongoing analysis of these data includes measurements of the size and spatial evolution of the wave breaking roller through the surf zone of a barred beach. In addition, the observed roller characteristics are being compared to the predictions of existing models.

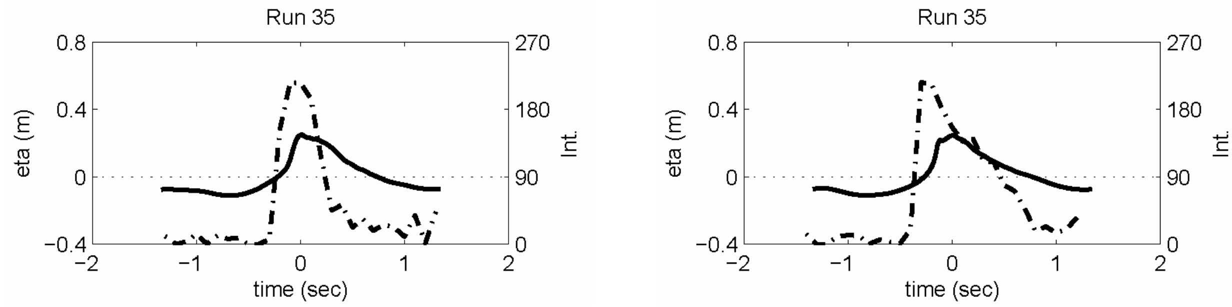

Figure 2. Relationship between the phase-averaged water surface elevation (solid lines) and associated video intensity signals (dashed lines) for breaking waves. Results demonstrate the location of the intensity peak with respect to the wave crest.

Our synoptic combination of both marine radar and video observing systems at the Duck, NC site allows direct comparisons between the two imaging mechanisms and lead to a better understanding of the strengths and weaknesses of both for nearshore research and observational remote sensing. Our approach here, again, is to analyze individual breaking events. Hence, our video collection scheme has been to obtain full-frame video at 2Hz (which is data intensive). At this stage, we have successfully developed a radar image rectification methodology, which was a non-trivial exercise, and all of the Sept. 2005 Duck radar image sequences were rectified and full-frame video time series have been merged and rectified. A comparison of time exposures from the two sensors is shown in the bottom panels of Figure 3. The figure shows that the average intensities (from 15 minute time exposures) from each sensor provide similar information about the underlying morphology. However, this also suggests that radar can be utilized to provide valuable morphologic change data during nighttime periods when the beach profile is active. However, we are more interested in the details of individual events and analysis is continuing along this line.

These data have also been used to calculate phase maps using a Complex Empirical Orthogonal Function technique. These phase maps have been used to calculate maps of wave phase speeds (maps of both types are shown in upper panels of Figure 3), which have then been passed to the Beach Wizard group as data to be assimilated into Delft3D. They have used these data (along with other video estimates of dissipation) to provide bathymetric and hydrodynamic hindcasts for the Sept. 2005 time period. Those results were presented at ICCE 2006 and are not repeated here.

IMPACT/APPLICATIONS

The proposed program directly supports the Navy goal of predicting the 4D nearshore environment for amphibious operations that involve surf zone breaching. We are increasing our fundamental understanding of the remotely observed signals at both optical and microwave wavelengths. This will lead to improved utilization of these data in the numerical simulations of the time and space variability of shallow water breaking and the prediction of surf zone conditions. In addition, the initial results from this project suggest that marine radar is an effective tool for filling in the gaps between very nearshore observing systems (video) and larger scale observing systems (such as HF radar, satellites).

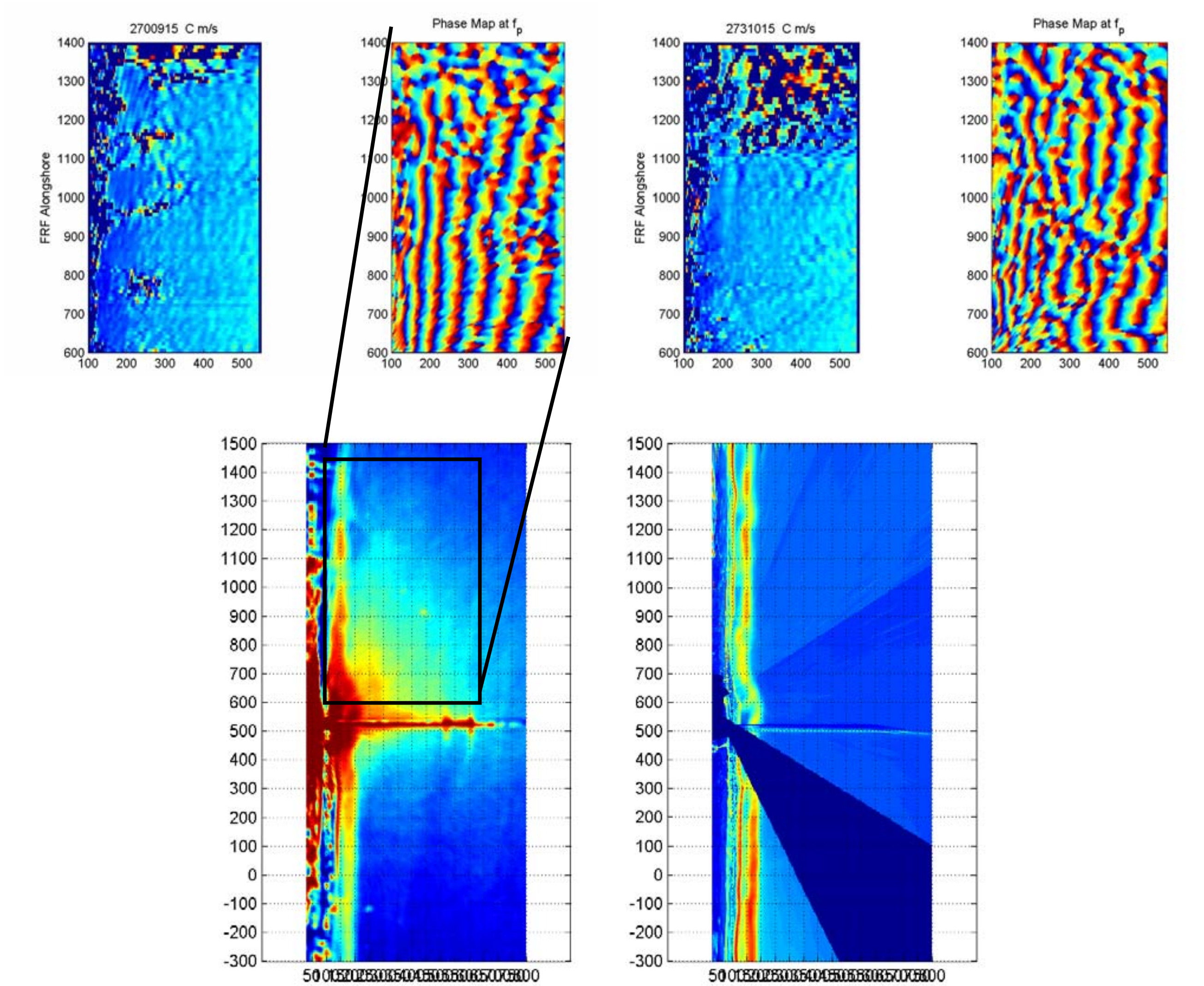

Figure 3. Upper panels are radar-derived phase speeds (C) and phase maps at the peak frequency (fp) from two days at Duck. Lower panels are (left) radar time exposure and right) video time exposure from one day at Duck. Black square on lower left panel indicates the boundaries of the minigrid over which phase maps were calculated.

RELATED PROJECTS

Beach Wizard Project (Roelvink et al.)—we are actively supplying radar data products to this group and collaborating on data interpretation.

R. Holman/Coastal Imaging Lab (Coastal Geosciences funding, SecNav funding)—we are active collaborators in remote sensing data analysis and interpretation.

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