Radar Remote Sensing of Waves and Episodic Flow Events

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LONG-TERM GOALS

The inner shelf is an important region of the ocean for naval operations in the littoral zone; yet, the physical oceanography of the inner shelf is poorly understood. Our goals are to contribute to an overall effort (the Inner Shelf—Directed Research Initiative) to accelerate understanding and discovery of the complex processes of the inner shelf in order to improve predictability. We plan to collect marine radar observations of wave and current events during the field experiment of the Inner Shelf DRI. Analysis of the data will focus on quantifying the importance of wave forcing in the dynamical balances between the surf zone and the outer shelf, as well as identifying specific, episodic flow events such as rip currents, upwelling/downwelling fronts, and internal waves and quantifying their frequency of occurrence and their relationship to the in-situ ocean properties.

OBJECTIVES

1. Collect marine radar observations during the Inner Shelf field experiment(s). Extract wave properties in the shoaling zone, such as wave directional distributions and the frequency and location of wave breaking over scales of several kilometers. Quantify the importance of wave forcing in the dynamical balances of the inner shelf.

2. Analyze the remote sensing data to identify specific episodic flow events, such as rip currents and internal waves. Quantify their frequency of occurrence and their relationship to the in-situ ocean properties.

3. In support of the field effort, continue our development of methodologies and analysis of data acquired under the DARLA (ONR-MURI) project as well as recent acoustic work performed at the Mouth of the Columbia River (Ben Reeder, Rocky Geyer, et al.). Improve our understanding of remote sensing signals and their relationship to hydrodynamics. Identify and assess dependencies of underwater acoustic signal propagation on fronts observable via the marine radar.

APPROACH

Our project started in January of the present year and during this pre-experiment period we are continuing to develop our methodologies and our comparisons of remote sensing data to in situ. One of
our main approaches to analyzing current-related phenomena is through the use of “wave-averaged” marine radar image time series. The wave-averaging process is essentially a pixel-by-pixel lowpass filter in time, which removes the wave signal and brings out signals at longer time scales. In addition, our approach has been to actively collaborate with those collecting in situ measurements. Specifically, we have been working considerably with Rocky Geyer (WHOI) in developing an understanding of multiple hydraulic jump features at the MCR.

Other aspects of our approach include: real-time radar observing at the MCR in support of the acoustic work done this September by Ben Reeder et al.. Also, we developing methodologies to extend the “cBathy” algorithm of Holman et al. to environments where both wave and currents are important. Finally, a recent Masters-level graduate student (Rebecca Kloster) has adapted models for radar scattering from internal waves to the study of radar backscatter from rip currents. This work is being tested against our rip current observations via marine radar from Duck, NC.

During the Inner Shelf field experiments, our approach will be to collect synoptic, marine radar observations of waves and episodic currents at the field site chosen for the Inner Shelf DRI. Most of our previous observations have always been from low (10-15 m above sea level) shore-based towers. Even with such low grazing angles we often have maximum ranges of several kilometers, we believe if there is a headland available that our ranges will extend even further to as far as 5-10 km from the radar.

Our system consists of commercial, X-band imaging radar coupled with a customized data acquisition system. The system is wholly contained within a mobile trailer with an attached tower that is extendable to 30 ft. The trailer is equipped with a propane generator, a rack of lead cell batteries, and solar panels on the roof. The mobile system is deployable to any remote site with all-terrain vehicle access. Within the trailer there is a workspace for managing the data acquisition system and a separate ventilated compartment that houses the power generator and electric components.

**WORK COMPLETED AND RESULTS**

We have extended analyses of an oblique, internal hydraulic jump at the MCR to a second jump located adjacent to Jetty A, and to data collected during low river discharge conditions in September, 2013. The positions of these two jumps were also tracked via an automated image processing algorithm that utilizes the Radon transform. The jump near Jetty A (corroborated by in situ data of Rocky Geyer, Figure 1) appears as ebb approaches maximum flow, 1.5 hours before the onset of the North Jetty jump, and it occurs with more regularity during strong tidal forcing. The angles of the oblique jumps can vary up to 40 degrees during a single ebb, resulting in excursions of more than 1 km along the shipping channel. Despite this intra-tidal variability, the trend follows expected dynamics: obliquity increases with increasing ebb flow and associated decreasing stratification; obliquity then decreases with decreasing ebb flow. The jumps were observed to persist during low freshwater discharge, although less often than in the spring. We attribute this to the lower levels of stratification typically present at the MCR during low discharge. Motivated by a recent study that stressed the importance of pycnocline thickness on internal bore characteristics (White and Helfrich, 2014), we also confirmed that the two discrete layer model remains sufficient for classification of the internal jumps. These analyses have been implemented in revisions of Honegger et al., 2014, will be presented at the CERF 2015 meeting in Portland, OR, and an abstract has been submitted to the AGU 2016 Ocean Sciences meeting in New Orleans, LA.
Figure 1: Data collected 11-12 June, 2013. (a) lowpass filtered marine radar image (13:14 UTC) and instrumented vessel transect (cyan), (b) density anomaly contours, (c) along-channel velocity (positive eastward), (d) cross-channel velocity contours (positive northward). The two-layer interface isopycnal, 1012 kg m\(^{-3}\), is a dashed red line.

Enhanced marine radar sampling of the MCR from Cape Disappointment, WA was performed in support of ONR-funded acoustic work and in-situ observations during 09-11 September, 2015. Using knowledge gained from prior observations, we directed ship-board in-situ transects of (a) the oblique, internal jump near Jetty A, (b) periodic convergent-divergent instabilities near the North Jetty, and (c) the convergent, surface front of the salt wedge during flood. Preliminary results from this experiment suggest that such fronts significantly affect underwater acoustic propagation (data of Ben Reeder).
Figure 2 shows a pair of lowpass filtered marine radar images separated by 11 min, and the acoustic signal-to-noise (SNR) observed between two vessels during that time period. When the frontal feature (imaged as enhanced backscatter intensity) separates the two vessels, the SNR is very low (Figure 2a); the SNR rises as the vessel with receivers deployed moves past the frontal feature (Figure 2b).

Figure 2: Lowpass filtered marine radar images of the Columbia River Mouth and acoustic SNR (insets) between a transmitting vessel (colored circle) and a receiving vessel (colored diamond). Color of the vessels and the current time (vertical line, inset) denote poor (red) and improved (green) SNR.
Finally, we have spent a limited amount of time quantifying the relationship between radar images of rip currents and the underlying flow field gradients. Utilizing data collected early-on in the DARLA project (Haller et al., JWPCOE, 2014) we have begun to analyze the radar imaging mechanisms for currents and associated surf zone eddies. The radar imaging analysis utilizes the wave-action balance equation in order to quantify changes in the mean squared slope of the surface wind-generated waves due to the underlying surf zone flow fields. Both the rip current and the surf zone eddy are modeled using pre-existing analytic solutions for the mean flow. Results show that radar imaging of rip currents is dependent on two components of the deformation tensor: the surface current divergence and the surface strain in the wind direction. The level of dependency on these two components varies between the rip current and surf zone eddy. This work will be presented at the Ocean Sciences Meeting in the Spring.

**Figure 3:** (left) Cartoon of a rip/feeder current system, (center) rip current imaged in X-band marine radar, and (right) mean squared slope anomaly induced by rip current with surf zone eddy.

**IMPACT/APPLICATIONS**

Marine radar data collected at the MCR in 2013 effectively demonstrated the complexity of stratified flow in the dynamic region, and has become an important tool for the interpretation and characterization of both surface and subsurface processes. Features identified in the marine radar data are associated with strong flow gradients, which can significantly affect underwater navigation, as well as strong stratification, which may affect underwater acoustic propagation. We anticipate that the density fronts and internal waves that occur on the inner shelf will be visible in the marine radar data, and will hold relevance to underwater navigation and acoustic propagation.

**RELATED PROJECTS**

*ONR-MURI DARLA*: Assimilation of remote sensing data into numerical models for estimating currents and depth. We collected marine radar data and developed methodologies during field experiments under this ONR-MURI that we will build upon for this Inner Shelf DRI.
Rocky Geyer (WHOI): Comparison of marine radar data to in-situ measurements in the water column, and collaborative hydraulic characterization of density fronts and internal hydraulic jumps at the MCR.

Gordon Farquharson (APL-UW): We collaborate on microwave remote sensing of the MCR, and compare results to more effectively characterize backscatter signals.

Rob Holman/Coastal Imaging Lab (Coastal Geosciences funding): We are active collaborators in remote sensing data analysis and interpretation, especially where we have co-located data.

Ben Reeder (NPS): Underwater acoustic signal propagation. Preliminary results (Figure 2) suggest that fronts visible in our marine radar imagery significantly affect the near-field propagation of underwater acoustic waves. We plan to collaborate further to characterize and assess the underlying mechanisms.

REFERENCES

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PUBLICATIONS