Bathymetry Estimation using Satellite-Based SAR observations

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LONG-TERM GOALS

Our long term goal is to gain a quantitative understanding of the environmental conditions at complex coastal sites (e.g. tidal inlets), including information about bathymetry, wave field and circulation, using a combination of numerical models and satellite-based Synthetic Aperture Radar (SAR) observations.

OBJECTIVES

Over the next biennium, our objectives involve applying previously developed methodologies for the prediction of the state of the ocean near inlets using 3D circulation models and satellite-based remote sensing observations. The primary objectives are:

1. Use of the combination of numerical models and satellite-based SAR observations via data assimilation methods in order to obtain an estimate of the underlying bathymetry and the associated ocean state (including wave and circulation predictions). This objective is aided by the next two objectives.

2. Utilize numerical modeling results to aid in the removal of wave effects for the retrieval of surface currents from SAR observations.

3. Aid in the interpretation of SAR images through comparison of coupled 3D wave-circulation model results with SAR imagery, especially images indicating the existence of fronts.

APPROACH

In the recent past, we have made much progress in predicting ocean conditions at complicated sites (e.g. beaches, rivers, navigational inlets) using a combination of numerical models and observations via data assimilation methods. Our methodology has involved an ensemble-based approach and the use of data of multiple physical phenomena. For example, Wilson et al. (2014, JGR) found that bathymetry estimates for an open coastal beach using information about both wave height and longshore currents were superior to those using only one or the other observation. Specifically, using only wave information placed a sand bar too far onshore, whereas using current information placed the bar too far offshore. Using both observation types allowed for the best estimate of the bar location. In a follow-on
study by Kurapov and Özkan-Haller (2013, JGR) used an adjoint data assimilation procedure within a one-way coupled wave-circulation model for an open beach setting and found that alongshore variability in the bar is more readily captured using a circulation model whereas the location of the bar is determined by the wave component. In both studies, the availability of observations of different physical phenomena was found to be a strength.

In a more complex setting, the use of both tidal circulation and wavelength information (derived from two separate remote sensors) was beneficial in estimating bathymetry in a tidal inlet setting (Moghimi et al, 2015a, JTECH). The observations that Moghimi et al. (2015b, JGR) used were derived either from an airborne SAR or a long-dwell tower-based x-band radar system, hence the derived wave and current observations were of very high resolution. Yet, bathymetry estimation carried out in a riverine setting using data denial experiments (involving utilization of increasingly sparse data sets to arrive at an understanding of the minimum required data) showed that high-quality bathymetry estimates could be obtained using a very small number of drifters (Landon et al., 2014, JTECH). Hence, it is worth exploring if observations at lower resolution or short-dwell compared to those obtained from tower-based or airborne observations (though potentially still involving data pertaining to multiple physical processes such as waves and currents) can aid in the estimation of bathymetry in complex settings. Hence, we ask:

*Can bathymetry estimation be accomplished using remote sensing observations that are short-dwell (e.g. a snapshot) and obtained using non-local platforms, such as satellites?*

Satellite-based observations are of high enough spatial resolution to clearly indicate incoming waves and can, therefore, be used to obtain information about dominant wavelength as a function of position with methods similar to Splinter and Holman (2009, TGARS), albeit at a significantly lower resolution compared to long-dwell observations (Plant et al., 2008, TGARS). Further SAR-based observations of surface currents (from any platform) suffer from the biases induced by the motion of surface gravity waves that are miss-represented by the extraction algorithm. This results in a spatially-variable bias that is difficult to correct. Methods for the removal of this bias often use simplified specification of the waves, assuming, for instance, that the wave effect is spatially uniform (e.g. Romeiser et al., 2005, TGARS). In settings where the wave field is highly spatially variable, this can be problematic, leading to the question:

*Can results from a coupled wave-circulation model be used to derive better algorithms for the removal of the wave bias from SAR-derived circulation estimates?*

Finally, recent SAR observations (as well as tower-based radar observations) indicate the presence of bright or dark streaks that may be manifestations of fronts or surface convergence/divergences (resulting in bright/dark streaks) and be indicative of the position or extent of a tidal plume. If so, these observations could provide data on yet another physical phenomenon and aid in the bathymetry estimation process. Hence, we ask:

*How can the bright or dark streaks in SAR observations be interpreted? Can they aid in bathymetry estimation? Can they be assimilated to improve predictions of vertical extent of the plume?*
WORK COMPLETED

We have begun the work just recently (August 2015). As a first step we are carrying out model runs for the periods of time for which SAR imagery is available at two sites, namely the New River Inlet, NC (NRI) and the Mouth of the Columbia River, OR/WA (MCR). Model runs for both sites are carried out with a 3D coupled wave-circulation model system (SWAN+ROMS via COAWST) and involve consideration of scalar transport of temperature and salinity. The next step will be to mine the SAR observations for useful quantitative information as described below.

RESULTS

SAR observations can be used to obtain estimates of the dominant wavelength using spatial 2D FFT methods (e.g. Splinter and Holman, 2009, TGARS). These wavelength estimates will be at lower resolution than those obtained from methods that take advantage of long-dwell observations (e.g. Plant et al., 2008, TGARS) and will also be associated with higher errors for broad-banded or multi-modal seas. Yet, the obtained wavelength estimates will be strongly linked to bathymetry. Further, SAR observations can be used to deduce ocean surface circulation information (e.g. Romeiser et al, 2005, TGARS), they can potentially also be used to obtain information about depth-limited wave breaking (see bright patches on shoals to the north and south of the navigational channels in Figure 2). Finally, SAR images appear to provide information about surface convergences and divergences of the circulation in the form of bright and dark streaks (see Figure 1 for examples from New River Inlet, NRI, and the Mouth of the Columbia River, MCR). These appear to be related to the manifestation of a river plume primarily set apart from the surrounding ocean water by a temperature difference (see model results in Figure 1). The presence or position of these features can potentially also be leveraged. The resulting data set would consist of observations of multiple phenomena that are all individually (and uniquely) related to the bathymetry, namely dominant wavelength as a function of position, surface currents, wave breaking, convergence/divergence features.

Data-model comparisons for NRI and MCR (shown in Figure 1) are so far encouraging. In particular, there is strong indication that surface flow convergences seen in the model results correspond to the frontal patterns seen in the SAR images. For example, convergences associated with the temperature plume front at NRI appear to form multiple expanding fronts as the ebb current oscillates. At the MCR, intersecting features are observed during flood conditions, and these are reproduced in the model results.
Figure 1: (top left panel) TerraSAR-X image of NRI obtained on 12 May 2012 @ 18:58 EDT (top left) and of MCR on June 2 14:39 UTC (bottom left) along with corresponding surface velocity divergence from coupled wave-circulation model results for NRI (top right) and MCR (bottom right). Blue areas indicate surface velocity convergence, red areas indicate divergence. SAR images courtesy of H. Graber and R. Romeiser (U. Miami).

**IMPACT/APPLICATIONS**

As part of this study we are developing methods to estimate the depth in complex nearshore settings given information from only SAR observations. The potential application of this work is primarily related to problems involving navigation in denied areas.

**RELATED PROJECTS**

The work described herein relies heavily on methods developed during the ONR-MURI DARLA that was focused on developing bathymetry estimation methods using remote sensing observations.