Morphological Evolution Near an Inlet

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LONG-TERM GOALS

The long-term objective is to develop field-verified models for the wave fields, circulation patterns, and morphological evolution near inlets.

OBJECTIVES

The primary objective of our recent work is to develop, test, and improve models for nearshore processes near and within inlet channels.

APPROACH

Our approach is to collect field observations to test existing hypotheses, to discover new phenomena, to provide ground truth for remote sensing studies, to initialize and test data assimilative models that invert for bathymetry, and to calibrate, evaluate, and improve models for inlet hydrodynamics and morphological evolution.

WORK COMPLETED

i) New River Inlet
Waves and current sensors were deployed at 32 locations near New River Inlet from April 27 through June 1, 2012 (Fig. 1). The data have undergone extensive quality control and are available on the WWW. The effects of waves on the along-channel momentum balance have been evaluated (Wargula et al. 2014). The data also are being used in collaboration with other ONR team members and colleagues to evaluate numerical model simulations (Chen et al. 2014), propagation of sea level fluctuations (MacMahan et al. 2014), dye dispersion and transport (Feddersen et al. 2013), drifter trajectories (Spydell et al. 2014), and remotely sensed observations (Jessup et al. 2012).
(ii) Katama Inlet

A numerical model for the water levels and flows in a two-inlet system was developed (Orescanin et al. 2014) based on the momentum and continuity equations. Predictions of the currents observed in Katama Inlet are more accurate when wave forcing is included than when waves are ignored. During Hurricanes Irene and Sandy, when incident (12-m water depth) significant wave heights were greater than 5 m, breaking-wave cross-shore (along-inlet-channel) radiation stress gradients enhanced flows from the ocean into the bay during flood tides, and reduced (almost to zero during Irene) flows out of the bay during ebb tides.

In August 2014 current meters and pressure gages were deployed in Vineyard Sound, Katama Bay, Katama Inlet, and the ebb shoal and inner shelf offshore of Katama Inlet (Fig. 2). These data are being used by PhD students Mara Orescanin and Julia Hopkins to investigate the effects of tides, waves, and bathymetry on circulation in and near Katama Bay and Inlet. In particular, Mara is using an ADCIRC model to investigate the effects of the changing inlet configuration on the circulation in the inlet and bay. In addition, several bathymetric surveys of the rapid morphological evolution of the shoreline near the inlet mouth are being used by Julia Hopkins to investigate nearshore morphological change near the inlet mouth. Julia has a SWAN-Delft3D-Flow model running for this area (Fig. 3).
Figure 2. Array of wave and current sensors (diamonds are pressure gages, solid circles and black-white circles are current profilers and pressure gages, and hexagons are single-point current meters and pressure gages) deployed near Katama Inlet in August 2014. The color contours are water depth (red is shallow (1 m depth), blue is deep (10 m depth), the entire bay was surveyed, data are being processed). Instruments are located from Vineyard Sound in the north, along Edgartown Channel, within Katama Bay and Katama Inlet, and in the surf zone, ebb shoal, and inner shelf (offshore of the ebb shoal) in the Atlantic Ocean.
Figure 3. Nested inner shelf and surfzone grids that include 1000- (full box), 200- (middle box), and 40-m (inner box) resolutions spanning the inner continental shelf and Katama Bay. 20- and 10-m resolution grids inside the inner box (not shown) are required to resolve the complex bathymetry near the inlet mouth and shoreline. Color contours are elevation (red is land and blue is 60 m water depth, scale on the right).

(v) Other Investigations
A new method was developed to obtain temporally dense maps of bathymetry by updating a spatially dense initial survey with the bathymetric change (e.g., erosion and accretion) estimated from a spatially sparse array of continuously measuring altimeters (Moulton et al. 2014a). Maps produced by this update method are more accurate than maps obtained by spatially interpolating the sparse altimeter measurements at any given time. The resulting high temporal resolution bathymetric estimates suggest the observed alongshore movement of a rip current may have been caused by migration of the channel (Moulton et al. 2014b), and that there may be tidal fluctuations in the cross-shore location of a sandbar.

The propagation of tides from the ocean into Elkhorn Slough to a reflecting area at the shallow head of the slough and back out to the ocean was investigated with observations, models, and data analysis. Unlike many estuaries where the tide dissipates, and thus reflection can be neglected, in this estuary reflection is an important process, leading to asymmetrical shapes of the tidal wave (Thornton et al., 2014).

The alongshore surfzone momentum balances onshore of irregular bathymetric features was investigated using observations and simulations with numerical models (Hansen et al., 2014a, 2014b). Simulations with Delft3D accurately reproduced the dominant alongshore momentum balance estimated from observations collected about 1 km north of and onshore of a deep submarine canyon near La Jolla, CA (Hansen et al., 2014b). The model results suggest that friction coefficients estimated from the alongshore momentum balance are sensitive to neglecting advective accelerations. Alongshore pressure gradients were shown to be important to the alongshore momentum balance even in regions with gradual alongshore gradients in the wave forcing (Hansen et al., 2014a).
RESULTS

The hydrodynamics and morphodynamics of tidal inlets have been studied for many years. However, most studies have neglected the effects of waves. Numerical model simulations incorporating surface gravity waves indicate that wave forcing may play a significant role in inlet circulation. Model results suggest cross-shore radiation stress gradients owing to dissipation as waves propagate across the ebb shoal can drive fluxes into an inlet (Bertin et al. 2009). Alongshore inhomogeneous forcing is predicted to arise from refraction owing to the inlet jet and the alongshore-inhomogeneous bathymetry. In addition, models suggest that tidal prism and bay water levels may be increased as a result of wave forcing (Malhadas et al. 2009). This increase in bay water levels can result in enhanced ebb flows from the bay (Olabarrieta et al. 2011). However, there are few observational studies to verify these predictions.

PhD student Anna Wargula has shown that wave forcing during moderate storms resulted in increased subtidal flows into New River Inlet. During storms the radiation-stress gradient term became larger than the pressure gradient term, enhancing subtidal flows into the inlet, and was needed to balance the bottom stress (Wargula et al., 2014). The tidally averaged discharge measured by a boat-mounted current profiler across the inlet width supports the result that wave forcing enhances flood flows.

Observations of water levels, winds, waves, and currents in Katama Bay, Edgartown Channel, and Katama Inlet on Martha's Vineyard, Massachusetts were used by PhD student Mara Orescanin to examine the effects of wave forcing on circulation in inlet channels of two-inlet systems and to water levels in the bay between the inlets. Katama Bay is connected to the Atlantic Ocean via Katama Inlet and to Vineyard Sound via Edgartown Channel (Fig. 2). A numerical model based on the momentum and continuity equations that uses measured bathymetry and is driven with observed water levels in the ocean and sound, ocean waves, and local winds predicts the currents observed in Katama Inlet more accurately when wave forcing is included than when waves are ignored. During Hurricanes Irene (Fig. 4A) and Sandy (Fig. 4B), when incident (12-m water depth) significant wave heights were greater than 5 m, breaking-wave cross-shore (along-inlet-channel) radiation stress gradients enhanced flows from the ocean into the bay during flood tides, and reduced (almost to zero during Irene) flows out of the bay during ebb tides (arrow, Fig. 4A).
Without considering the effects of waves during a one-month period that included Hurricane Irene and a small nor'easter storm, model errors (relative to observations) increased as wave energy increased. In contrast, by including the effects of waves, model errors were approximately constant, and smaller than the errors when neglecting wave effects (Fig. 5).

Figure 4. Observed (black dots) and modeled [with (red curve) and without (blue curve) wave forcing] along-channel currents in Katama Inlet before, during, and after Hurricanes (A) Irene (arrow on 28 Aug 2011) and (B) Sandy (arrow on 29 Oct 2012). [The model without waves does not predict the flow into the inlet during hurricanes, but the model that includes wave forcing does predict the observed flows.]
Model simulations without the effects of waves predict net discharge from the sound to the ocean both during Hurricane Irene and over a 1-month period with a range of conditions. In contrast, simulations that include wave forcing predict net discharge from the ocean to the sound, consistent with the observations (not shown).

**IMPACT/APPLICATIONS**

Results from New River and Katama Inlets suggest that offshore waves can have a strong influence on currents and circulation near and within the inlet channel.

Field observations in a range of nearshore environments have been used to test and improve model predictions for waves, circulation, and morphological change, as well as to provide ground truth for remote sensing of littoral areas and to initialize and test models that invert for the underlying bathymetry.

**RELATED PROJECTS**

The observations of waves and currents near New River Inlet are being used as ground truth for remote sensing studies (MURI colleagues), and the observations from New River and Katama Inlets are being used to test and improve models for wave propagation, circulation, and morphological evolution, and to initialize and test models that invert for the underlying bathymetry.

Many investigators are using our observational databases to test components of models (eg, the NOPP nearshore community model, DELFT3D, ADCIRC, COAWST, nonlinear wave propagation schemes) for nearshore waves, currents, and bathymetry, and as ground truth for remote sensing studies. More
than 100 scientists, engineers, postdoctoral researchers, and students, have accessed our data
distribution WWW site [http://science.whoi.edu/users/elgar/main.html] since 2006 to download time
series and processed data products for their studies. In FY14 several journal papers used data we
gathered in Duck, NC in 1994 (!), and more than 20 people (including investigators from U.S. and
international universities, government and DoD laboratories, and private companies) downloaded data
from the Duck94, SandyDuck, NCEX, SWASHX, WORMSEX, STIFEX, and RIVET1 projects.

Some of the work discussed here was in collaboration with Dr. Elgar's NSSEFF project to study
morphological evolution in littoral areas.

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**PUBLICATIONS**


**HONORS/AWARDS/PRIZES**

Britt Raubenheimer, Woods Hole Oceanographic Institution, Doherty Education Chair, Woods Hole Oceanographic Institution.

Steve Elgar, Woods Hole Oceanographic Institution, appointed to Outer Continental Shelf Science Committee, Bureau of Ocean Energy Management, Deptartment of Interior (officer, parliamentarian).
Britt Raubenheimer, Woods Hole Oceanographic Institution, Arons Award, Woods Hole Oceanographic Institution.