Impact of Changes in Morphology on Extent and Duration of Inundation during Tropical Cyclones

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Award Number: N0001414WX20608

LONG-TERM GOALS

The long term goal is to accurately predict the onset, peak and duration of inundation in coastal regions that are vulnerable to tropical and extratropical storm systems.

OBJECTIVES

In 2014, a Naval Research Laboratory (NRL) Rapid Transition Project (RTP) “Coastal Surge and Inundation Prediction System” was completed and transitioned to the Naval Oceanographic Office (NAVOCEANO) for operational use. The model predicts the peak and onset of inundation well within the requirements set forth by the US Navy. However, the predicted duration of inundation, a quantity that is necessary for mustering humanitarian assistance and disaster response teams, is severely underestimated. The objective of this research is to assess the importance of morphological changes that occur during an extreme event such as hurricanes to the duration of inundation in coastal regions.

APPROACH

The FLOW and WAVE components of the Delft3D modeling suite are used to predict the water levels, currents and wave heights due to high winds. We will use the three-way coupled system that includes the morphological component of Delft3D (MOR) in addition to the coupled FLOW and WAVE components to determine whether:

1. Changes in morphology due to tropical storms cause significant changes in surge and inundation.
2. Inclusion of morphology in the modeling system improve predictions of waves and currents.
Observations of water levels and significant wave height during Hurricane Ike will be compared to simulation results of the Delft3D FLOW-WAVE-MOR model. To address Task 1, a systematic comparison of model performance with and without coupled morphologic change were conducted using the best available wind field, bathymetry and topography. Sediment data was acquired through USGS databases and bathymetric data was obtained from the NOAA Tsunami Inundation Project. To address Task 2, we will determine the fidelity of the model to predict morphologic change during extreme storms by comparing the predictions to field data.

**WORK COMPLETED**

We have successfully run coupled Delft3D FLOW-WAVE-MOR simulations at Galveston Bay during Hurricane Ike to assess the effects of morphological changes on inundation predictions. We also tested several bottom roughness schemes in both the WAVE and FLOW modules to determine the effect on the morphologic predictions. We applied two different bottom friction schemes in the Delft3D WAVE model and compared the predicted significant wave height to observations. Additionally, we varied the Manning’s $n$ value in the Delft3D FLOW module and compared the resulting morphologic change.

**RESULTS**

To determine the effect of morphologic change on inundation predictions for Hurricane Ike, we ran two simulations: one including (Basem) and one excluding (Base) the effects of morphologic change. In the Basem simulation, default morphology parameters were applied and the initial sediment thickness was set at 15 m. A varying bottom roughness, determined as function of water depth for areas below mean sea level and from the USGS Land Use database for areas above mean sea level was used in the Delft3D FLOW model. The default bottom friction scheme (Madsen) was used in the Delft3D FLOW model. Figure 1(a) is a plot of the cumulative sediment erosion (red) and deposition (blue) predicted by the Basem simulation throughout the entire domain after the storm. Figure 1(b) is a zoomed in area of Figure 1(a) of the barrier island that observed to be breached during the storm. With the current morphological parameters, the simulation does not predict a breach in the barrier island after the storm.

![Figure 1](image_url)

*Figure 1: Erosion (red) and deposition (blue) of the (a) entire Galveston Bay domain and (b) zoomed in region of the northeast portion of the domain where the barrier island should have breached during the storm. The gray lines indicate the pre-storm zero contour and the black lines indicate the post-storm zero contour.*

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The differences between the predicted water levels in the two simulations (Base and Basem) are negligible (Figure 2). The water levels predicted in the Base simulation (red line) and the Basem simulation (blue line) did not vary significantly at any of the observation points. However, the model predictions in both simulations agree very well with the observations. We attribute the improvement in predictions from previous studies to the usage of higher resolution grids and more accurate initial bathymetry. Figure (3) shows the locations of all the observation points compared in Figure (2). Additional simulations were investigated to determine if a larger morphologic change would have more of an effect on the predicted water levels, but still only observed small differences.

**Figure 2:** Predicted water levels in the Base simulation with no morphology (red line) and the simulation including morphologic change (blue line) compared to observations collected by the USGS and NDBC.

To examine the predictions further, we ran three Hurricane Ike simulations with different wave bottom friction schemes to determine the effect of bottom friction on the water level, significant wave height, and morphologic change predictions. The Base simulation uses the default Madsen et al., bottom friction scheme. Two additional simulations applied the JONSWAP scheme with coefficients of 0.019 and 0.038. We found that the specification of the WAVE bottom friction scheme significantly affects
the wave height and bottom orbital velocity predictions, but not the water level or morphologic change predictions. Varying the bottom friction scheme in the WAVE model caused up to a 0.7 m/s difference in the bottom orbital velocities (Figure 4) and up to a 2 m difference in significant wave height (Figure 5) specifically in shallow water where bottom friction is important. The JONSWAP bottom friction scheme produced significant wave heights that agree better with the observations than the default Madsen scheme. There was negligible difference in the predicted water levels and erosion/deposition of sediment with the varying WAVE bottom friction scheme.

![Figure 3](image)

**Figure 3: Locations of observation points. Stations beginning with “SSS” were collected from USGS instruments deployed before the storm. Stations beginning with “8” are NDBC buoys.**

Lastly, we compared the morphologic change with varying bottom friction routines in the FLOW module. The Manning’s bottom roughness method was used with two different coefficients of $n$. The galvbay007 applied a coefficient of 0.02 and the galvbay008 simulation applied a coefficient of 0.03. Figure 6 are contour plots of the erosion (red) and deposition (blue) predicted by both simulations. There is an O(1 m) difference in the erosion between the two simulations. The barrier island is breached in both simulations, but is eroded about 3 m more in the simulation with the smaller Manning’s $n$ (galvbay007). To further illustrate the difference in the morphology predictions from varying bottom friction, Figure 7 shows contour plots of the land inundated (a) pre-storm and predicted post-storm with a Manning’s $n$ of (b) 0.02 and (c) 0.03. Much more land is eroded and inundated with the smaller friction value.

We can make the following conclusions regarding our completed work thus far:

- Accurate initial bathymetry is essential for correct prediction of surge and inundation.
- Higher-resolution grids are necessary for surge and inundation predictions.
- The morphology predictions are highly sensitive to the bottom roughness in the Delft3D-FLOW module. Care must be taken to select realistic and appropriate values.
- Water level and morphology predictions are not sensitive to the bottom friction in the Delft3D WAVE module.

- Significant wave heights and bottom orbital velocities can vary $O(1 \text{ m})$ and $(0.5 \text{ m/s})$, respectively with varying Delft3D WAVE bottom friction routines.

Ongoing work includes comparing the results of the morphologic change results to LIDAR surveys of topography to assess the fidelity of the model to correctly simulation morphologic changes. We will also compare wave and currents predicted by the coupled WAVE-FLOW-MOR modeling system to measured data and continue the sensitivity analysis on model inputs, as well as physical inputs such as rainfall and river flow.

*Figure 4: Predicted bottom orbital velocities during Hurricane Ike using the default Madsen (blue line) and JONSWAP with coefficient 0.019 (yellow line) and 0.038 (red line) bottom friction schemes.*
Figure 5: Predicted significant wave height near Galveston during Hurricane Ike using the default Madsen (blue line) and JONSWAP with coefficient 0.019 (yellow line) and 0.038 (red line) bottom friction schemes plotted with the observed wave height recorded by NDBC buoys (black dots).

Figure 6: Erosion (red) and deposition (blue) of the breached barrier island for the simulation with the (a) less bottom roughness \(n=0.02\) and (b) more bottom roughness \(n=0.03\). The gray lines indicate the pre-storm zero contour and the black lines indicate the post-storm zero contour.
Figure 7: Contour plots of the land inundated (a) pre-storm and (b) post-storm for a Manning’s n of 0.02 and (c) post-storm for a Manning’s n of 0.03.

IMPACT/APPLICATIONS

This work indicates that the coupled Delft3D WAVE-FLOW-MOR modeling system has the potential to predict the morphologic change caused by extreme events, which can greatly impact Navy operations and humanitarian efforts in hurricane response.

RELATED PROJECTS