INFLUENCE OF WETLAND DEGRADATION ON SURGE

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INTRODUCTION

Topography, landscape features, and vegetation have the potential to reduce storm surge elevations. Land elevations greater than the storm surge elevation act as a physical barrier and create bathymetric resistance for the surge. Landscape features such as wetlands also have the potential to create frictional resistance and affect storm surge even when below the surge elevation. The purpose of this study is to apply numerical models to assess the influence of wetlands on hurricane storm surge. Limitations on how coastal landscape features are represented in the ADCIRC (Luettich et al. 1992, Westerink et al. 1994, Luettich and Westerink 2004) model will be discussed and areas for further development identified. The analysis provides valuable information on trends and relative performance but should not be taken as an absolute quantitative assessment of surge and wave reduction. The analysis does not consider the changes to the landscape that occur during a storms passage, where vegetation cover can be stripped away and land masses eroded. It should also be noted that the analysis does not consider changes in the structure of the hurricane itself due to the landfall infilling phenomenon that may be influenced by landscape features.

An integrated modeling system was applied to perform a sensitivity analysis to assess the impact of wetland degradation on hurricane surge. Storms were defined by a track and time-varying wind field parameters. The TC96 PBL model (Thompson and Cardone, 1996) is applied to construct snapshots of wind and atmospheric pressure fields every 15 minutes for driving surge and wave models. ADCIRC is then run to compute the pressure- and wind-driven surge component. In parallel with the initial ADCIRC runs, the large-domain, discrete, time-dependent spectral wave model WAM (Komen et al, 1994) is run to calculate directional wave spectra that serve as boundary conditions for the local-domain, near-coast wave model STWAVE (Smith, Sherlock, and Resio 2001, Smith and Sherlock 2007). Using

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computed surge levels from ADCIRC, winds that include the effects of sheltering due to land boundaries and reduction due to land roughness, and spectral boundary conditions from the large-domain wave model, STWAVE is run to produce wave fields and estimated radiation stress fields. The radiation stress fields are added to the estimated wind stresses, and the ADCIRC model is run again for the time period during which the radiation stresses potentially make a significant contribution to the water levels.

REPRESENTATION OF WETLANDS

Wetlands are represented in the numerical models by bathymetric and frictional resistance changes. Wetlands can reduce surge potential when land elevations greater than the storm surge elevation act as a physical barrier and create bathymetric resistance for the surge and waves. They may also reduce surge potential by reducing surface winds due to higher sub-aerial surface roughness and by slowing surge propagation due to bottom friction in shallow flow at the inundation front.

The winds input to the ADCIRC and STWAVE models are reduced to account for the higher surface roughness through a directional land masking procedure. In addition to reducing wind speeds, forested wetlands can also inhibit wind from penetrating through the tree canopy and shelter the water surface from wind stress. Features such as heavily forested canopies allow little momentum transfer from wind fields to the water column (Reid and Whitaker 1976) and thus the model does not apply a wind stress in wetlands or other areas classified as forest. The speed at which a storm surge propagates is affected by wetlands through bottom friction and form drag. Bottom friction is generated by fluid shear stresses at the water bottom and flow-drag resistance is generated by fluid stresses on objects extending through the water column. Bottom friction occurs in relatively shallow areas and bottom friction and flow-drag resistance can occur in vegetated areas. Atkinson et al. (2007) provide a complete discussion of the frictional formulations and parameterizations applied to represent the effect of vegetation on the wind boundary layer and bottom friction.

The ADCIRC and STWAVE models presently employ a Manning's *n*-type frictional formulation which is a limitation as this approach may not be the most appropriate means to account for energy and momentum losses due to vegetated features. The actual resistance to flow is not only through bottom friction, but also from the form drag of plant stems, branches, etc, particularly before the vegetation is completely submerged. The effect of form drag can only be approximated by increasing the bottom friction coefficient. The surface roughness for the base condition was developed as discussed by Atkinson et al. (2007) based on land cover type taken from the United States Geological Survey (USGS) National Land Cover Dataset (NLCD) classification raster map based upon Landsat imagery and the USGS Landsat Data Gap study. Each NLCD/Gap classification has an associated land roughness length and Manning *n* value.

To evaluate future conditions, modifications to the grid and surface roughness were made based on future landscape predictions from the Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) model. The CLEAR model is a coastal forecast system that includes estimates of land building and loss due to various physical processes. The future condition projection used for this analysis estimates the southern Louisiana coastal landscape in 50 years if no additional restoration activities are undertaken. Figure 1 shows the bathymetric changes made to the model. The land roughness length and Manning *n* values were also updated based on changes to land cover type (for example, brackish marsh to open water). Wamsley et al. (in preparation) provide details on how the grids are updated to represent landscape changes.

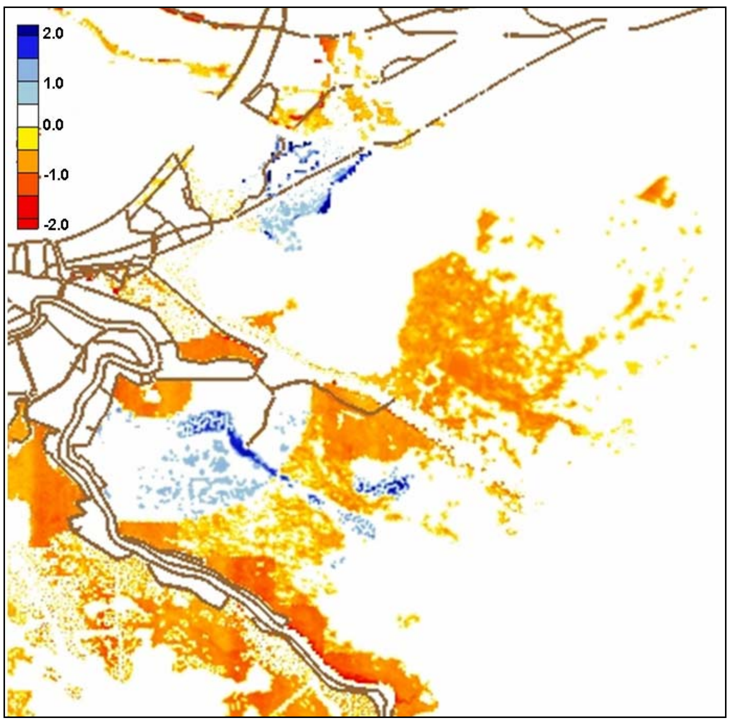

FIGURE 1 – BASE CONDTION BATHYMETRY MINUS FUTURE CONDITION (WARM COLORS INDICATE WETLAND DEGRADATION)

SAMPLE RESULTS

The impact of wetland degradation on local surge conditions was examined by comparing peak water level maps for each of the projected future condition to the base condition for two storms of varying intensity. Results east of the Mississippi river for two storms simulated for the base and degraded conditions will be presented. The first storm (HUR1), is a large hurricane of moderate intensity with a central pressure of approximately 960 mb, a radius to maximum winds of 39 km, and a forward speed of 20 km/hr. HUR1 parameters are similar to Hurricane Hilda, which struck south central Louisiana in 1964. The second storm (HUR2) is a large hurricane of severe intensity with a central pressure of approximately 900 mb, a radius to maximum winds of 39 km, and a forward speed of 20 km/hr, these parameters are similar to Hurricane Katrina. Both storms followed a track oriented primarily south to north through the Biloxi marsh. The track path is plotted in Figures 2 and 3 with the base condition peak water level results for storms HUR1 and HUR2, respectively. HUR1 produces maximum surges of approximately 2.5 m in the funnel area between East Orleans and the north St. Bernard levees. Maximum surges for HUR1 in the pocket between the south St. Bernard and Plaquemines levees (Caernarvon pocket) are 2 to 2.5 m. Surges increase for HUR2 with peak water levels of 4 to 4.5 m in the funnel. In the Caernarvon pocket, peak water levels for HUR2 are 2.5 to 5 m.

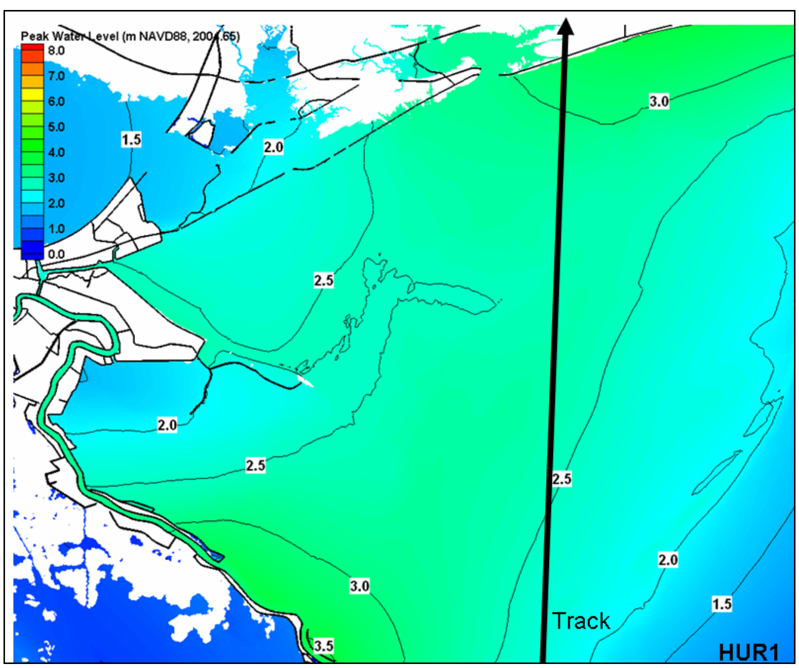

FIGURE 2 – PEAK SURGE LEVEL FOR HUR1, BASE CONDITION

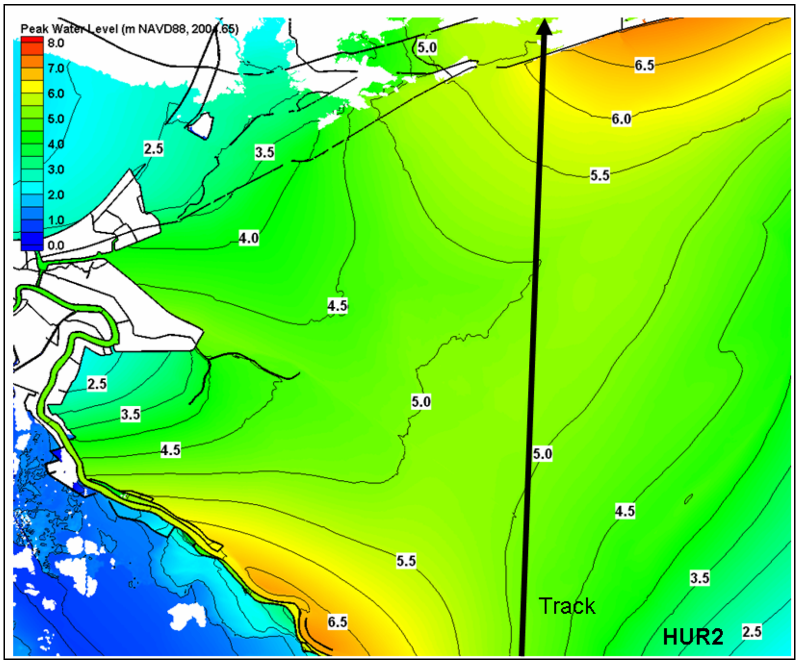

FIGURE 3 – PEAK SURGE LEVEL FOR HUR2, BASE CONDITION

Figure 4 plots the difference between the degraded and base condition peak water levels for both HUR1 and HUR2. The marsh degradation allows surge to propagate more rapidly, resulting in a rise in peak water level relative to the base condition for both storms. The model predicts a 10 to 15 % increase in surge relative to the base condition for both storms.

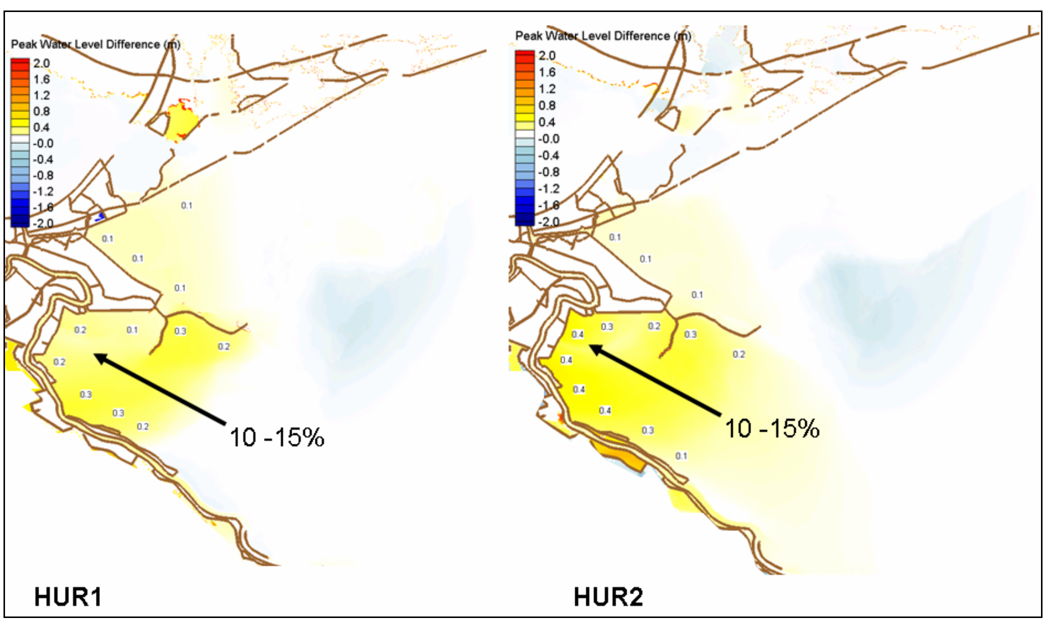

FIGURE 4 – DIFFERENCE IN PEAK SURGE LEVEL BETWEEN FUTURE AND BASE CONDITIONS

A stochastic analysis based on simulation results from a suite of 152 storms is also being conducted to evaluate the impact of wetland degradation on water levels along the hurricane protection system at the South Shore of Lake Pontchartrain, East Orleans, St. Bernard, Plaquemines, and at the West Bank. Wamsley et al. (in preparation) provides a complete discussion of this analysis, but preliminary results indicate that the 100-year water levels are increased by less than 5% at the South Shore, East Orleans, north St. Bernard, and Plaquemines. The 100-yr water levels are increased in the Caernarvon pocket similar to the results above (approximately 10%). The greatest change in the 100-year water level is predicted at the West Bank with increases of approximately 20 to 25%.

DISCUSSION

The impact of landscape features on surge propagation is a relatively new application for surge models and research is required. The current method for characterizing the friction influence of vegetated landscapes (the Manning's *n* treatment of bottom friction) is limited and values were derived for steady flow conditions, not the unsteady flow situations that characterize hurricane storm surge/wave conditions. Our understanding of frictional resistance by vegetation in unsteady flow regimes (for example, relative importance of wave-induced and ambient current velocities, dependence of frictional resistance on different wave frequencies and energy levels, different inundation depths, or different types and densities of vegetation) is poor. Data is required to document surge and wave attenuation by wetlands, to calibrate and verify models, and to develop improved algorithms for quantifying frictional influence. Of particular interest is the inclusion of form drag formulations for larger vegetation and vegetation that is not submerged.

A limited field data collection program has been initiated in southern Louisiana to measure water level and wave attenuation across a wetland between Lake Borgne and the Mississippi River Gulf Outlet channel. The program consists of four non-directional water level/ wave gauges, and anemometer, and a periodic characterization of the wetland, including elevation, plant type, plant density, and plant height. The data collected will be analyzed to determine the surge and wave attenuation based on the vegetation type, density, and height. However, to obtain comprehensive measurements for algorithm development, collaboration with other field and laboratory measurement programs is required.

CONCLUSION

The purpose of this analysis was to apply numerical models to assess the impact of wetland degradation on hurricane surge. The analysis provides valuable information on relative performance but should not be taken as a definitive quantitative assessment of surge and wave reduction. Results indicate that coastal wetland degradation does result in increased surge, consistent with general observations and anecdotal evidence. The magnitude of change was generally greatest for the more intense storm and the relative change for both storms was an increase of 10 to 15% in the area impacted. Limitations on how coastal wetlands are modeled have been identified and requirements for further development discussed.

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