Numerical Modeling of the Impact of Wetlands on Hurricane Storm Surge in Coastal Bays

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CSDMS 2011 Annual Meeting
Impact of Time and Process Scales

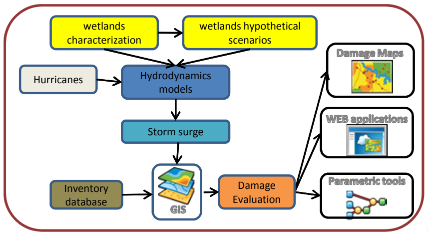
INTRODUCTION

Hurricanes pose one of the largest natural threats to communities along the Texas coast.

Research Question:
Can Wetlands Help Reduce Coastal Disasters Damage in Corpus Christi, TX?

Figure 1: Damages caused by storm surges from Hurricanes are one of the most costly disasters along the Texas coast.

METHODOLOGY



- *Our goal is to gain an improved understanding of the benefits of dunes and wetlands for hurricane surge mitigation along the Texas Coast.*
- *These benefits will be quantified using physics-based numerical models and geospatial damage analyses.*
- *Expected results will include parametric models relating spatial inundation and property damages for the city of Corpus Christi to dune and wetlands configuration.*

Figure 2: Overall research methodology

IMPACT OF TIME: Effects of Climate Change and Sea Level Rise

Effects of Climate Change incorporating scenarios based on IPCC projections for selected emissions (A1F1, B1, A1B) for 2030 and 2080

Hurricane intensification based on Central Pressure increase with SST.

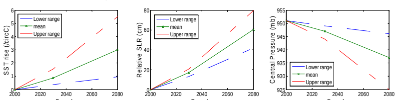


Figure3: Projected Sea Surface Temperature, Sea Level Rise and Hurricane Central Pre.

Simulated Wetland losses due to SLR

Figure 4: Inundated wetlands based on A1F1 2080 Scenario

Impacts of Eustatic Sea Level Rise + Land Subsidence on Wetlands and coastal and estuarine land cover simulated using a modified SLAMM methodology

TERRESTRIAL COMPONENT

How to represent wetlands in the numerical model?

1. Changes in bathymetry
2. Frictional resistance
   - Bottom stress
     - •Non-linear bottom drag coefficient is a function of the Manning's n
   - Wind stress
     - •Surface canopy coefficient
     - •Surface directional effective roughness length

Available Databases

C-CAP (1996, 2001, 2006)	NLCD (1992, 2001)	NWI (1993)	GAP

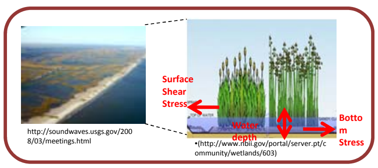


Figure 5: a) coastal wetlands in the Gulf of Mexico; and b) Schematics of wetlands parameterization on numerical modeling.

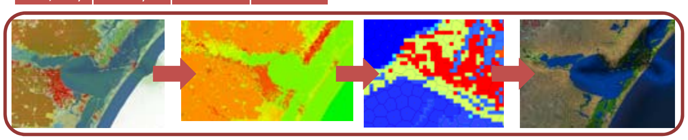


Figure 6: Bottom Friction and Surface Canopy parameters extracted from Wetlands databases and hypothetically generated in GIS. Spatially weighted formulation to calculate finite element node parameter. a) Database; b) Bottom Friction; c)Thiessen Polygon spatial averaging; d)Updated FE nodes

Hypothetical wetlands restoration projects to evaluate cost benefit of surge reduction x cost of implementation x potential damage reduction

Figure 7: Illustration of wetlands restoration project on the Texas coast. Hypothetical restoration scenarios 1 and 2

ATMOSPHERIC COMPONENT

Planetary Boundary Layer Model (PBL)

- Historical Storms parameters from NOAA Hurdat
- Developed by Ocean Weather Inc.
- Conceptual model by Thompson and Cardone (1996)
- Velocities computed from pressure drop

Input:

- Hurricane Track
- Central Pressure (Cp)
- Radius of storm (Rp)
- Forward Speed (Vf)
- Approach Angle (Θ)
- Sea Level Rise (SLR

Output: Wind and Pressure, every 15mins

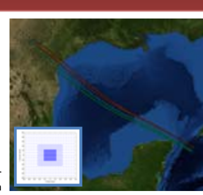


Figure 8: Plotting of synthetic hurricanes storm tracks along the Gulf of Mexico. Detail: grid for wind and pressure field generation

POPULATION/INFRASTRUCTURE COMPONENT

Geospatial analysis

- Calculate spatial water depth using GIS and DEM vs. Surge water levels .Inventory databases from HAZUS MH, city parcels and Reference USA.
- Damage assessment using a comprehensive set of damage functions.
- Uncertainty analysis from damage functions and randomness in inventory.

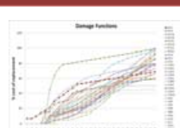


Figure 9: Damage functions with respect to water depth and building type.

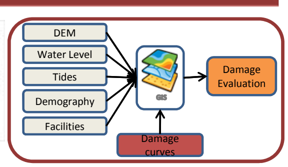


Figure 10: Damage assessment framework.

NUMERICAL MODELING

LINUX Clusters Supercomputing

- Eos at Texas A&M University
- Lonestar at University of Texas at Austin
- Next step: Beach at CSDMS

- Parallel MPI
- FORTRAN Source Code
- Simulation time: 6 to 10 days

Average wall clock in hours

GRID (million nodes)	ADCIRC	ADCIRC+SWAN
1.3	< 1000	Up to 3.000
3.3	~ 3.000	Up to 15.000

COASTAL AND MARINE COMPONENT

ADCIRC Advanced Circulation Model

- Storm surge calculated using hurricane wind and pressure forcing.
- Barotropic Two Dimension Depth Integrated (2DDI).
- Finite element in space.
- Parallel and unstructured version.

Continuity Eq.

$$\frac{\partial h}{\partial t}+\nabla_h(\vec{U}h)=0$$

Momentum Eq.

$$\frac{\partial \vec{U}}{\partial t}+(U\cdot\nabla_h)\vec{U}=-g\nabla_h\left(\zeta+\frac{p(x,y)}{g\rho}\right)+\hat{f}\,k\times\vec{U}+\frac{\vec{\tau}_s}{h\rho}-\frac{\vec{\tau}_b}{h\rho}+\frac{\vec{\tau}_w}{h\rho}$$

SWAN Simulating Waves Near Shore

- Parallel and unstructured version.
- Calculation of wave radiation stress.

Wave density spectrum

$$\frac{\partial N}{\partial t}+\nabla_{\vec{x}}\cdot\left[(\vec{c}_g+\vec{U})N\right]+\frac{\partial c_\theta N}{\partial \theta}+\frac{\partial c_\sigma N}{\partial \sigma}=\frac{S_{tot}}{\sigma}$$

Figure 11: Numerical unstructured GRID with 3.3

MODEL COUPLING

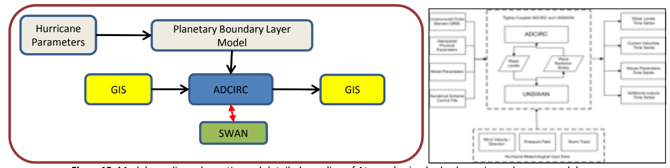


Figure12: Model coupling schematics and detailed coupling of Atmospherics, hydrodynamics and waves models.

GIS COMPONENT: ArcStormSurge

An unified repository data model for hurricane storm surge and to pre and post-process data ADCIRC and SWAN modeling

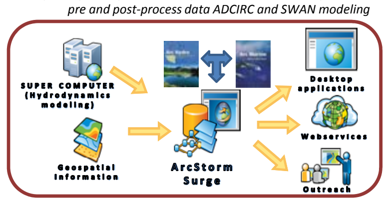


Figure 13: ArcStormSurge Framework.

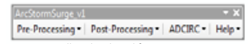


Figure 14: Toolbar developed for ArcGIS10 using PYTHON and ArcObjects.

Figure 15: GIS web viewer using the ESRI Flex API Template.

PRELIMINARY RESULTS

◦ Wetlands Databases

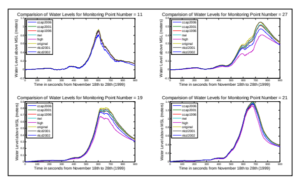
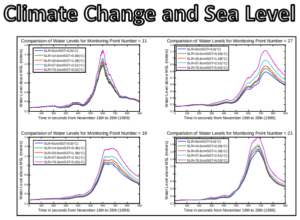


Figure 16: a) Water levels for selected stations using different wetlands databases (Left)

Figure 17: Monitoring Stations in the Finite element GRID (Above)

◦ Climate Change and Sea Level



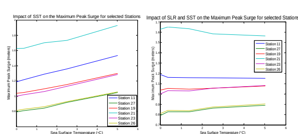
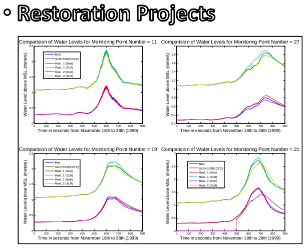


Figure 18: a) Maximum peak surge at selected stations for SST on the left and SLR on the right

Figure19: a) Water levels for selected stations considering SLR + SST rise

◦ Restoration Projects



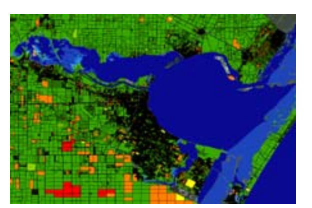


Figure 20: Inventory for estimating potential damage from Hurricane Bret with Restoration project 1 implemented (Above)

Figure 21: Maximum peak surge at selected stations for Restoration projects (left)

CONCLUSIONS

- Wetlands databases can produce different peak surges for selected locations, with very similar water levels in others. More work is needed to quantify and spatially analyze its implications.
- Seal level rise alterations to wetlands (as modeled) did not cause an increase in peak surge without considering hurricane intensification.
- Wetlands restoration projects have the potential to reduce surge, but in some places it can also increase it. More work is needed to correctly quantify its benefits.

FUTURE WORK

- Compile and run ADCIRC coupled with SWAN (ADCIRC+SWAN) on BEACH/CSDMS.
- Statistical analyses of peak surge variations for all scenarios
- Perform the proposed damage assessment analyses for all scenarios
- Perform cost/damage comparison for restoration projects
- Implement LINUX/GRASS GIS Component
- Learn how to implement CSDMS model coupling to my model components

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