Water Level and Storm Surge Modeling in Puerto Rico and U.S. Virgin Islands

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Model Overview

- Modeling of water levels, currents, storm surge and hurricane waves was done using the Advanced Circulation (ADCIRC) finite element model and ADCIRC+SWAN (coupled with SWAN wave model).

- ADCIRC solves the two-dimensional, depth integrated fully nonlinear shallow water equations.

- The use of an unstructured mesh gives the advantage of solving for various physical and time scales on a single mesh:
  - Basin scale (100’s of km) to coastal and nearshore scales (100’s to 10’s of m).
  - Time scales of days to minutes.

- Domain scale atmospheric forcing provided by global NCEP CFSv2 and CFSR reanalysis atmospheric pressure and wind fields.

- For hurricane simulations atmospheric forcing provided by asymmetric Holland parametric wind model:
  - Dependent on cyclone track, central pressure, radius of maximum winds (per cyclone quadrant), B-parameter.

- Open ocean boundary conditions: tidal constituent amplitudes and phases obtained from the OSU TPXO8 tidal inversion model.
• Unstructured mesh has 2,733,258 nodes and 5,392,748 elements
• Spatial resolution ranges from 15 km to 50 m at selected areas
  • Computational timestep of 1 second
• Over Puerto Rico and Virgin Islands spatial resolution of at least 100 m along all coastlines
• Over Lesser Antilles spatial resolution averages 500 m to capture passages that control Atlantic-Caribbean tidal flow exchange
Manning’s n Coefficient Mapped from Global and Local Reef/Mangrove Coverage Maps
Validation of ADCIRC, Non-Hurricane (Baseline)
Effect of tide-atmosphere coupling on observed daily water levels

Magueyes Island

Red: Observed, Blue: ADCIRC Tide+Atmosphere, Black: ADCIRC Tide Only
ADCIRC Water Level Validation, 2012

The diagram shows the Root Mean Square Error (RMSE) over time, with two lines representing different datasets. The x-axis represents the months from January (J) to November (N), and the y-axis represents the RMSE in meters. The graph indicates fluctuations in RMSE throughout the year, with peaks and troughs corresponding to different months.
This means that depths, extent of shelves, coastal geometry and forcing mechanisms are very well represented by ADCIRC
ADCIRC Generation of Seiching, High-Frequency Oscillations

San Juan
Mean Sea Level during January-December 2012 at NOAA Water Level Stations Locations

• Mean computed over the entire January-December 2012 water level records
• Observed mean sea levels vary from location to location
  • Greatest error occurred at Yabucoa Harbor, which also has the largest observed mean sea level
• Bathymetry files documentation indicate a general constant conversion factor between MHW and MSL
  • This was determined taking into consideration only San Juan and Magueyes Island
3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Puerto Rico DEMs were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Mean Low Water (MLW), Mean Sea Level (MSL), and North American Vertical Datum of 1988 (NAVD88). All datasets were transformed to MHW, to provide the worst-case scenario for inundation modeling, by averaging tidal values measured at the NOAA tidal stations at San Juan (#9755371) and Maguays Island (#9759110).

1) Bathymetric data

The NOS hydrographic soundings, and SHOALS and NOS LiDAR surveys were transformed from MLW and MLLW to MHW, using FME software, by adding constant offsets of -0.270 and -0.300 m, respectively (Table 10). The USGS multibeam sonar DEMs and multibeam swath sonar data are referenced to MSL and were shifted by adding a constant offset of -0.132 m.
Effect of Tide-Atmospheric Coupling on Depth-Averaged Currents
Effect of Tide-Atmospheric Coupling on Depth-Averaged Currents

San Juan

- Depth avg speed (m/s)
- Direction (deg)

Black: ADCIRC with tidal forcing only, Blue: ADCIRC with tidal and atmospheric forcing, Red: Observed
Hurricane Modeling
Significant Wave Height

Water Levels

Currents along the reef line: Extremely hazardous, effect on reef structure? Recovery time of barrier? Enhanced sediment transport?

San Juan During Hurricane Georges (1998)
Parametric winds generate a second peak due to parametric formulation requiring speed at cyclone center to be 0 and high dependency on radius of maximum winds. Also lack of dynamic effect from topography, i.e., wind field is not distorted by topography.

CFSR provides excellent winds and atmospheric pressure before and after Hurricane Georges, parametric wind provides very good approximation to peak winds and pressure during Hurricane Georges.
ADCIRC+SWAN and NOAA NOS observed and predicted harmonic (tide forcing only) water surface elevations relative to mean sea level.
Comparison of CFSv2 (Global Reanalysis) and Parametric Wind Forcing, H. Irene (2011)
Localized Effects of Surge and Waves During Hurricane Georges (Surface Elevation/Surge)

Fajardo-Culebra reef chain and shelf edge acts as a physical barrier which obstructs surge caused by barometric pressure and winds.
Effect of reef chain and shelf edge is even more dramatic over the significant wave heights generated along the radius of maximum winds.
Localized Effects of Surge and Waves During Hurricane Georges (Surface Elevation/Surge)

- Reef chain
- Large sand bank
Localized Effects of Surge and Waves During Hurricane Georges (Surface Elevation/Surge)

Area where ADCIRC+SWAN+GSSHA coupling has been done (Dr. Silva and Felix Santiago)
Effect of reefs, shallow banks, and shelf break on non-linear wave field transformation and dissipation
Effect of reefs, shallow banks, and shelf break on non-linear wave field transformation and dissipation

- Figures show difference of significant wave height when allowing and not allowing non-linear wave interactions
- Greatest differences mimic reef, shallow banks, and shelf break areas
- This is an indication that these features are responsible for generating the non-linear interactions and thus wave field transformation and dissipation

After shelf/reef line
main non-linear effect is wave breaking in excess of 0.5 m over >10 km distance

At shelf/reef line main non-linear effect is enhanced wave shoaling with wave height > 0.4 m than when neglecting non-linearities
Spectral wave energy transfer due to CEN reefs, shallow banks, and shelf break

Non-linear interactions due to CEN bottom features cause wave energy to move from >12 s waves to <5 s waves. This has direct effects on the amount of wave energy that affects the coast (coastal protection), bottom wave velocities, sediment transport.
Latest Developments
Figure A1. ADCIRC+SWAN A) storm surge due to wind and wave setup and B) significant wave heights at Arecibo during Hurricane Georges (1998). Vectors represent the wind forcing. The square bounds the Rio Grande de Arecibo river mouth area where the failing bridge was located.

- Individual/combined flood, velocities
- Riverine vs ocean current/wave forces on bridge
Upgrading and Refining of PRVI Unstructured Mesh (Dr. Norberto Nadal, USACE)

Funding: ERDC-UPRM Education and Research Program

Using latest USACE JALBTCX 1 meter spatial resolution DEM
USGS High Resolution Orthoimagery for Puerto Rico Island (1 foot resolution)
Focus on depths <15 m, reefs, sand banks, channels
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