IOOS Coastal and Ocean Modeling Testbed for Puerto Rico and Virgin Islands:

Year 3 Progress

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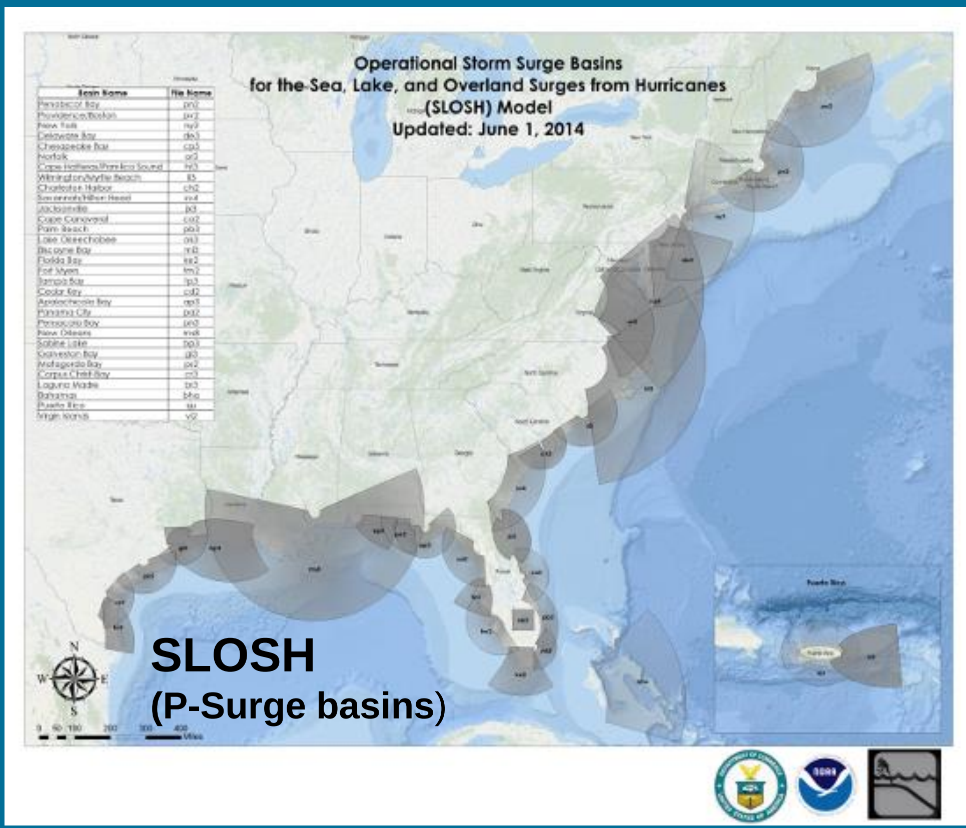
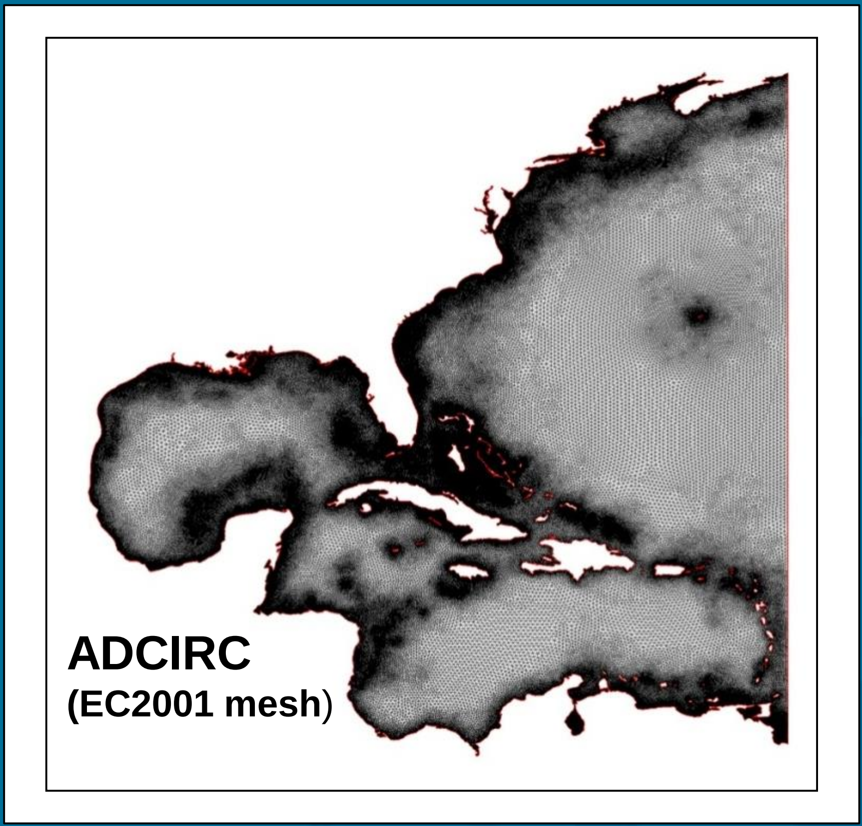
Background

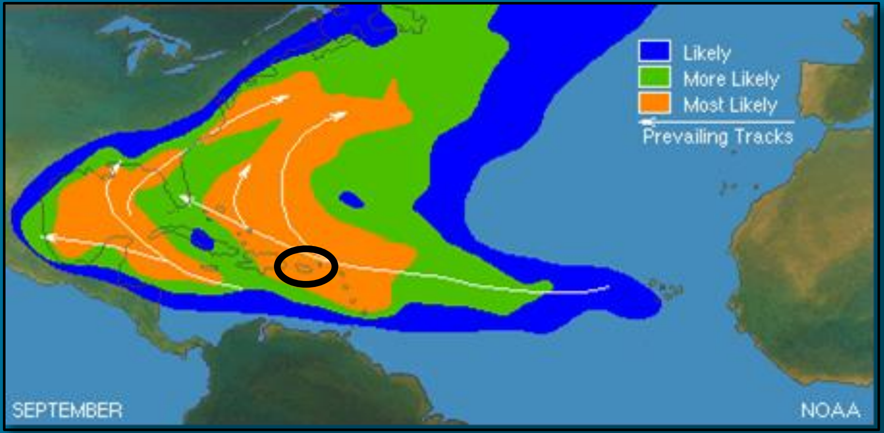
NOAA currently applies both the fast and efficient surge model **SLOSH** (probabilistic guidance) and state-of-the-art **ADCIRC** (deterministic guidance). However, neither of these modeling systems at NOAA has been configured with wave effects or specific focus on island environments.



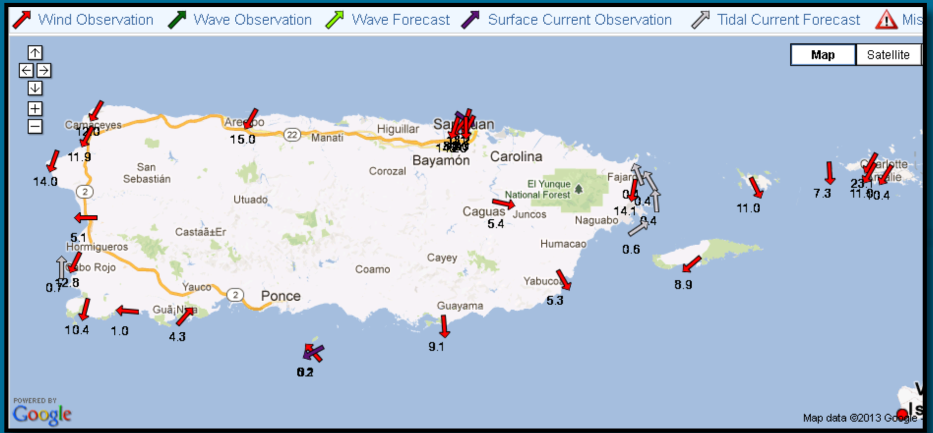


Objective

To extend the present **operational surge forecasting** capability from mild-sloped coastal areas such as the US East and Gulf of Mexico coasts to **steep-sloped areas** such as Caribbean and Pacific islands, and study the **contribution of waves**. Identify models or techniques to transition to NOAA's **National Hurricane Center** and **local WFOs**.



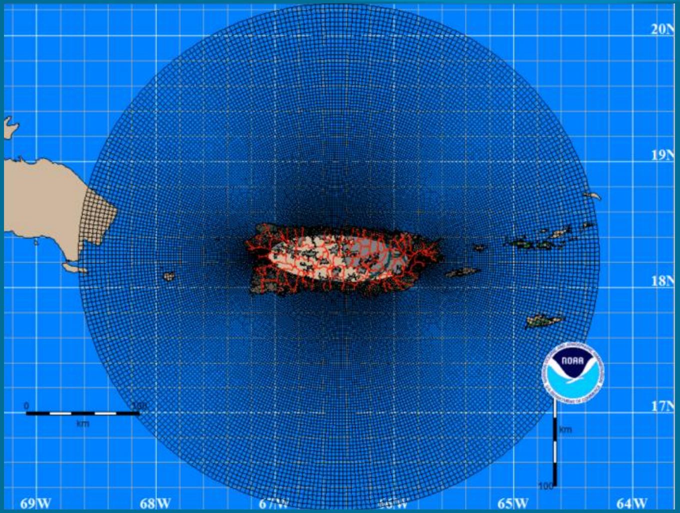
www.nhc.noaa.gov/climo



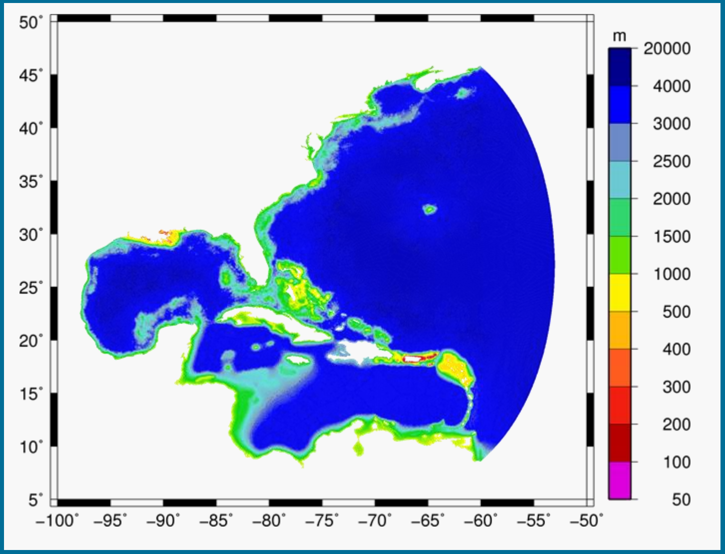
www.caricoos.org

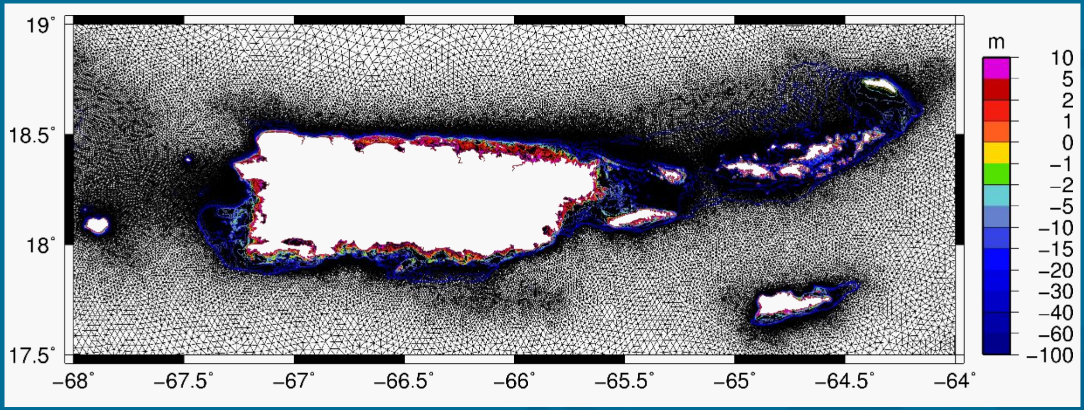
Puerto Rico/USVI: Model selection

- **UND:** ADCIRC+SWAN
- **NCEP/USACE:** ADCIRC+WW3
- **NHC:** SLOSH+SWAN
- **UPR:** BOSZ/FUNWAVE/XBeach



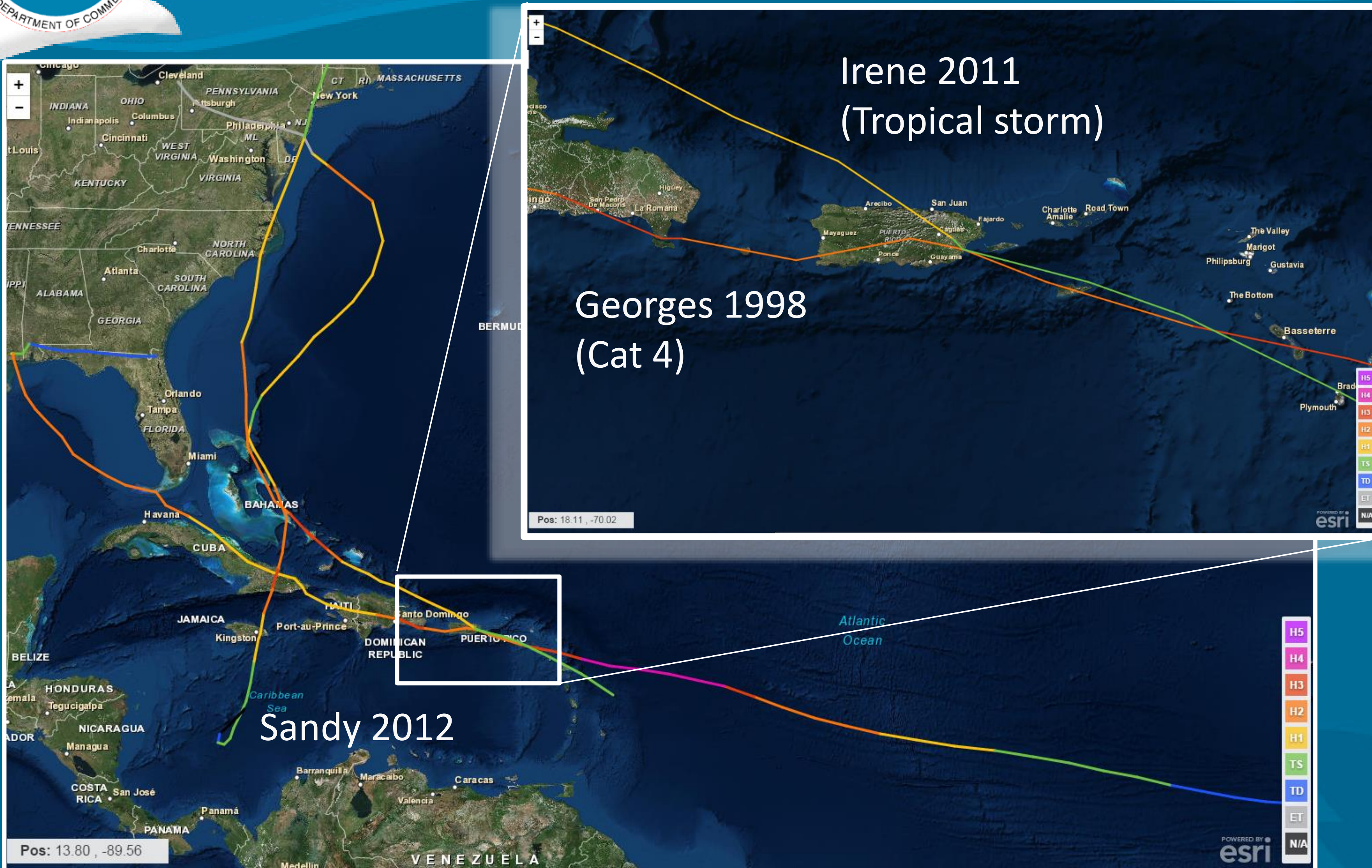
Curvilinear grid (min res: 90 m)



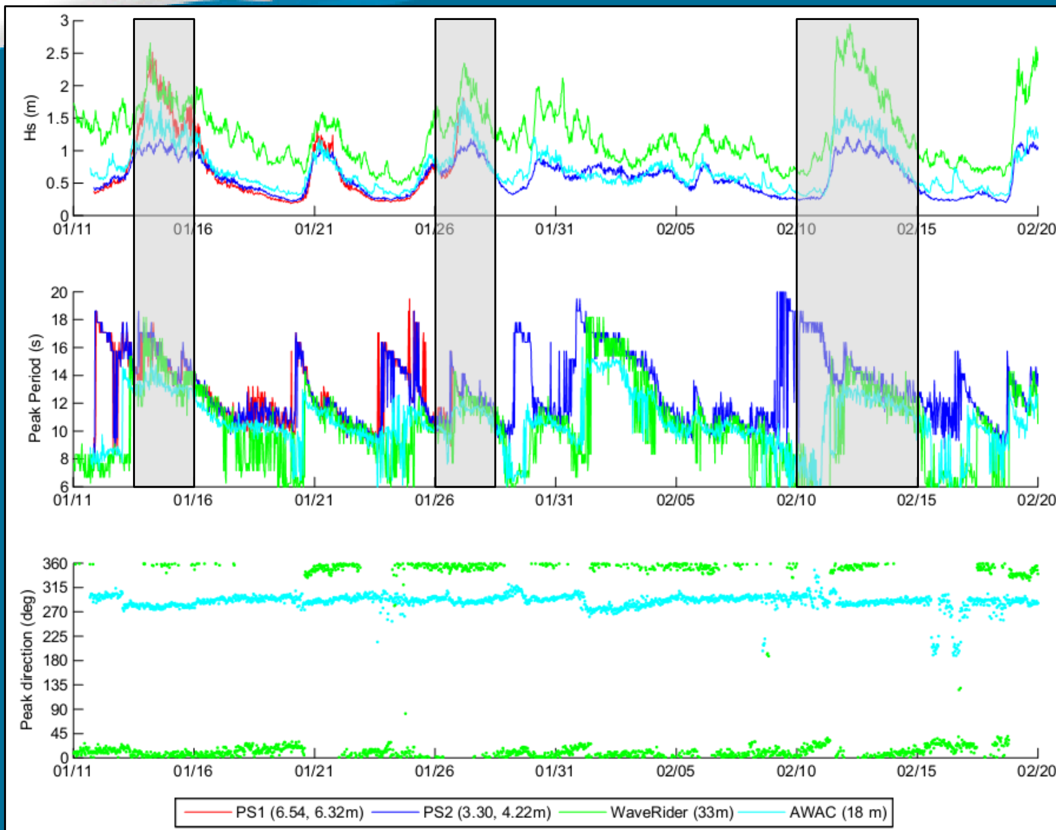


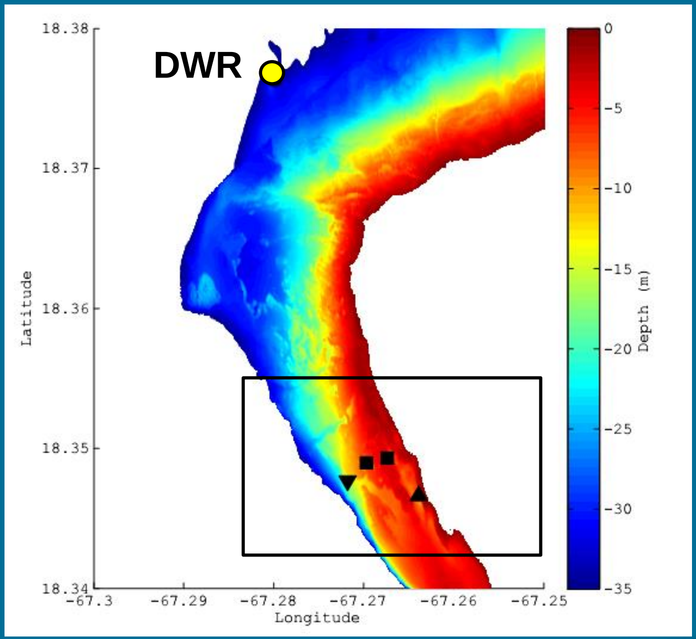
Unstructured, 2,733,258 nodes (min res: 50 m)

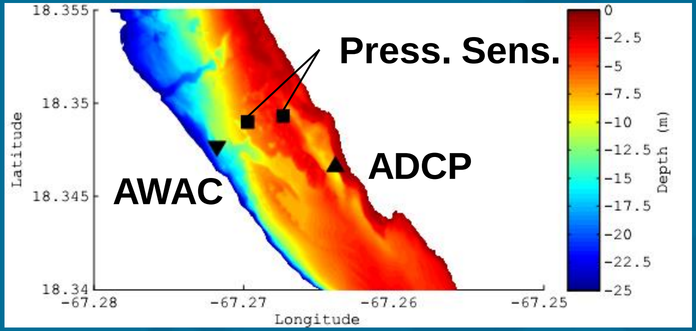
Regional hindcast cases



Cross-reef cases (Rincon, PR)



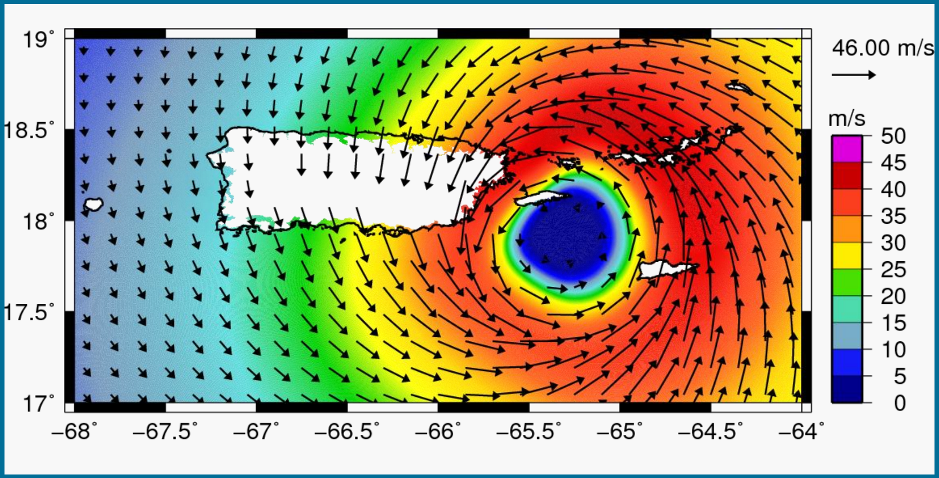


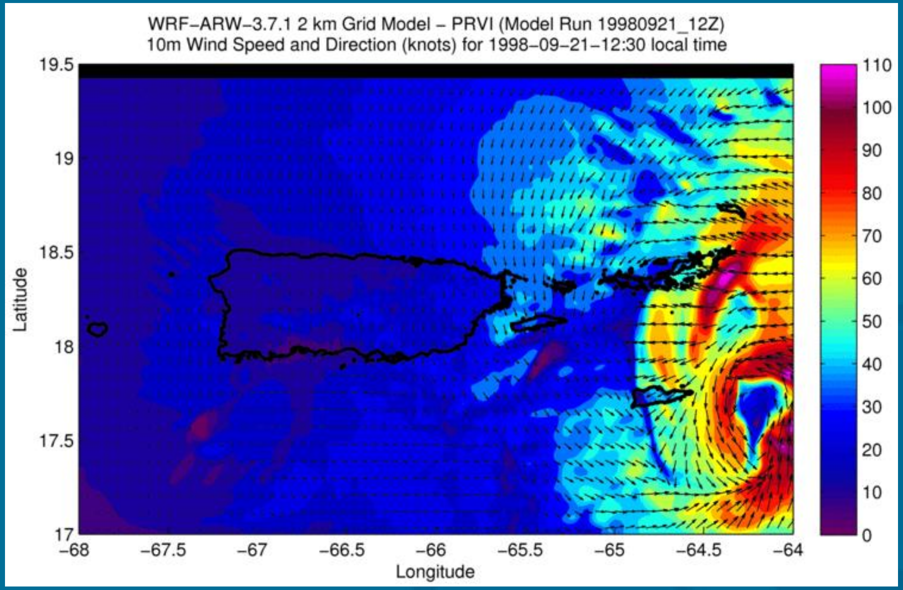


(1) Datawell Waverider (33 m, 2D wave spectrum)
(1) Nortek AWAC (18 m, 2D wave spectrum)
(2) Ocean Sensor Systems Pressure Sensor (6.54 m, 3.33 m)
(1) Teledyne Sentinel ADCP (10 m channel)

Input/Validation Data Collection

- **Atmospheric input** – Parametric vortex models, CFSR, WRF model simulations
- **Bathymetry** - 1/3-1 arc-sec NOAA Tsunami Inundation DEMs, NOAA benthic map classifications
- **Observations** - CO-OPS tidal data, NDBC buoys, CariCOOS stations (>2011), WeatherFlow winds

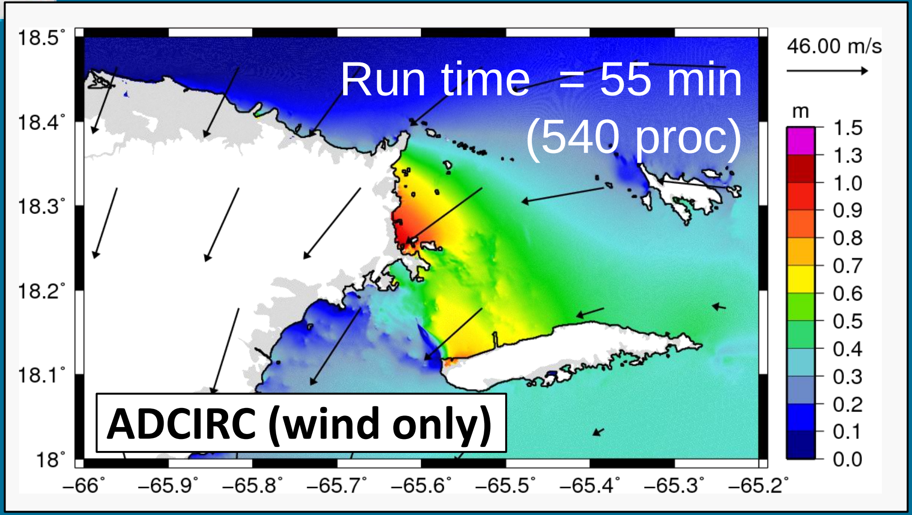


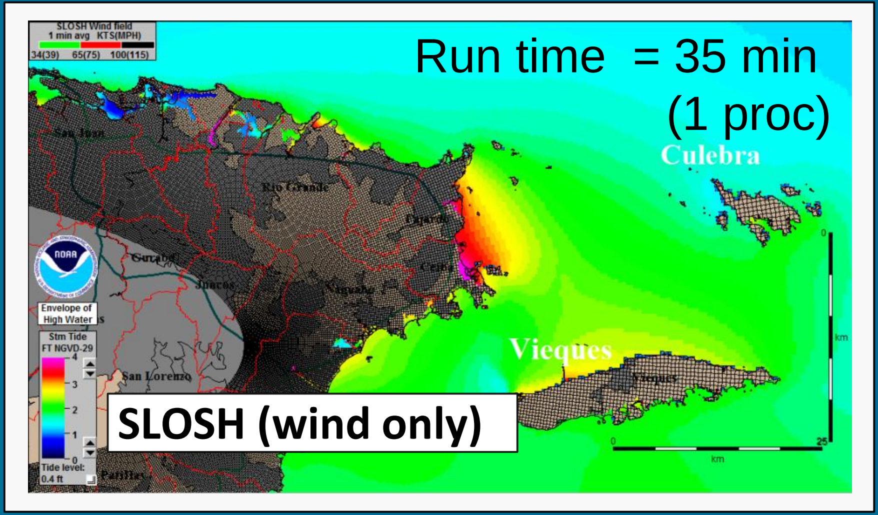


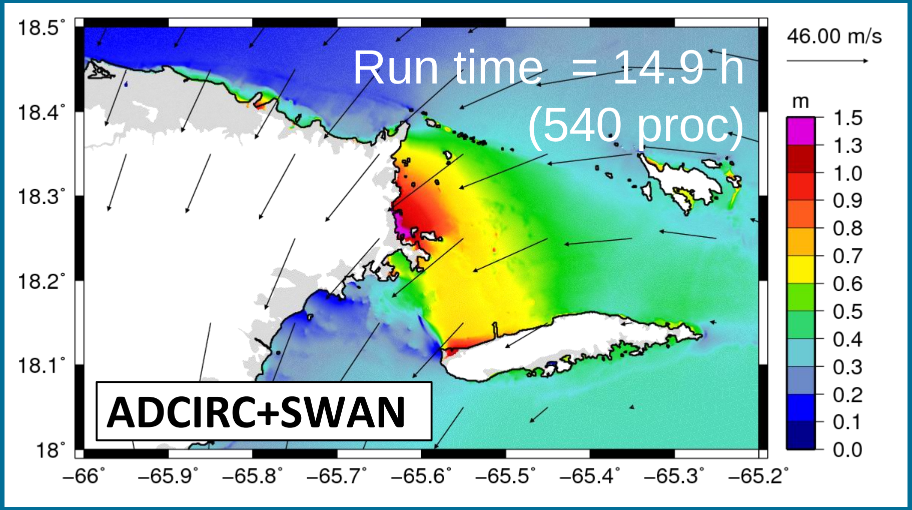
Credit: L. Aponte

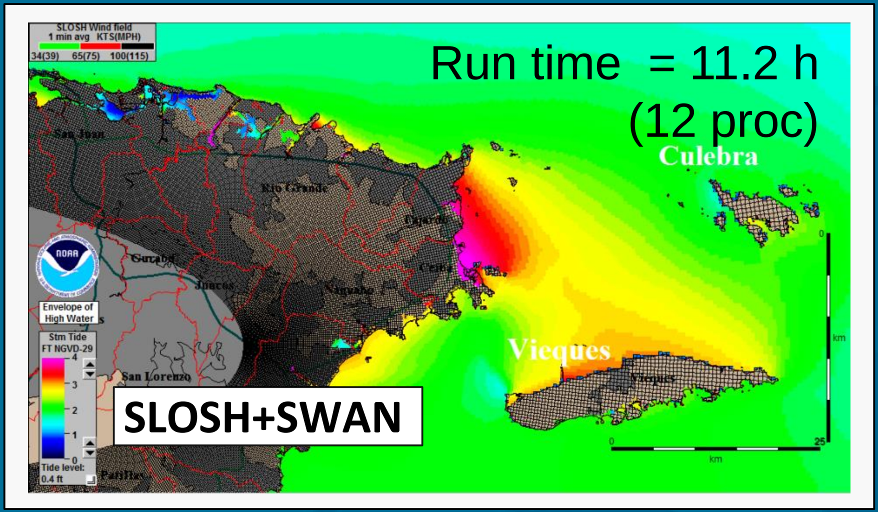
Case 1: ADCIRC vs. SLOSH

H. George (1998), Cat 4 – Asymmetrical vortex model



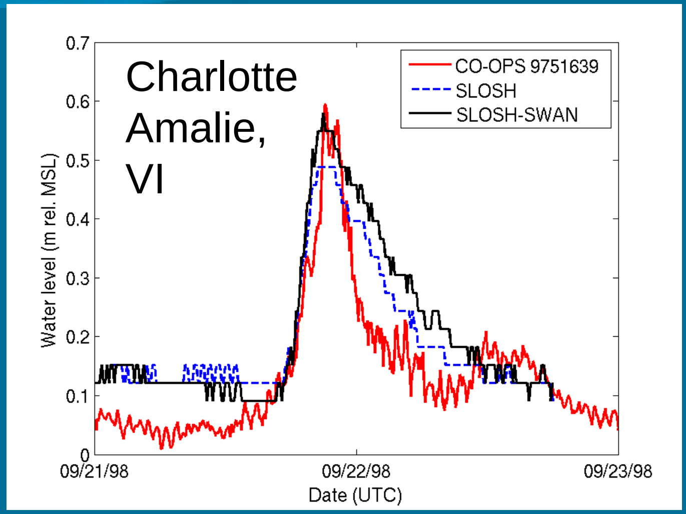


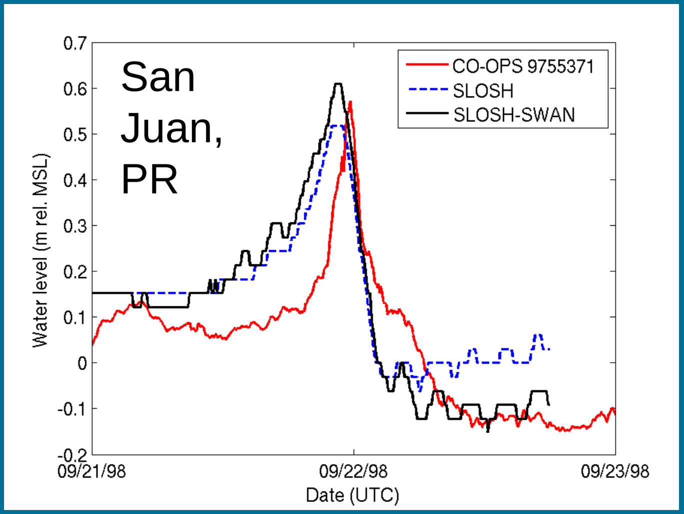


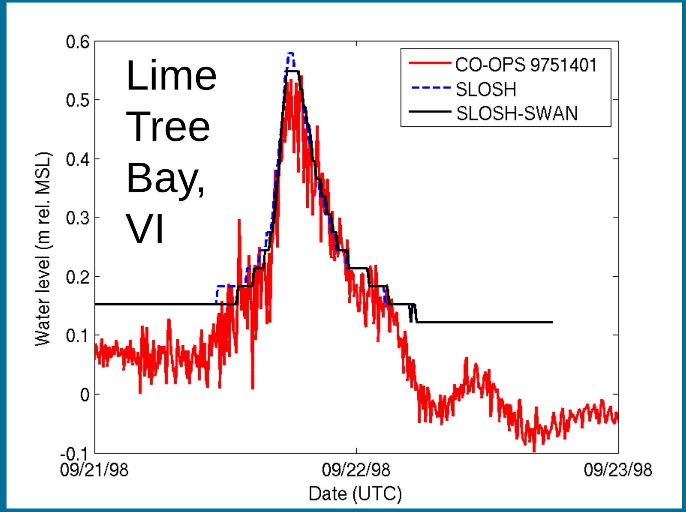


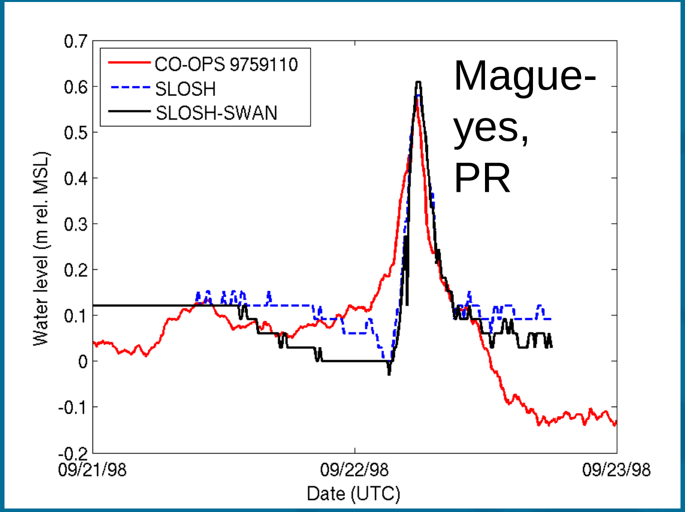
Case 1: Surge – SLOSH, impact of waves

H. George (1998), Asymmetrical vortex model



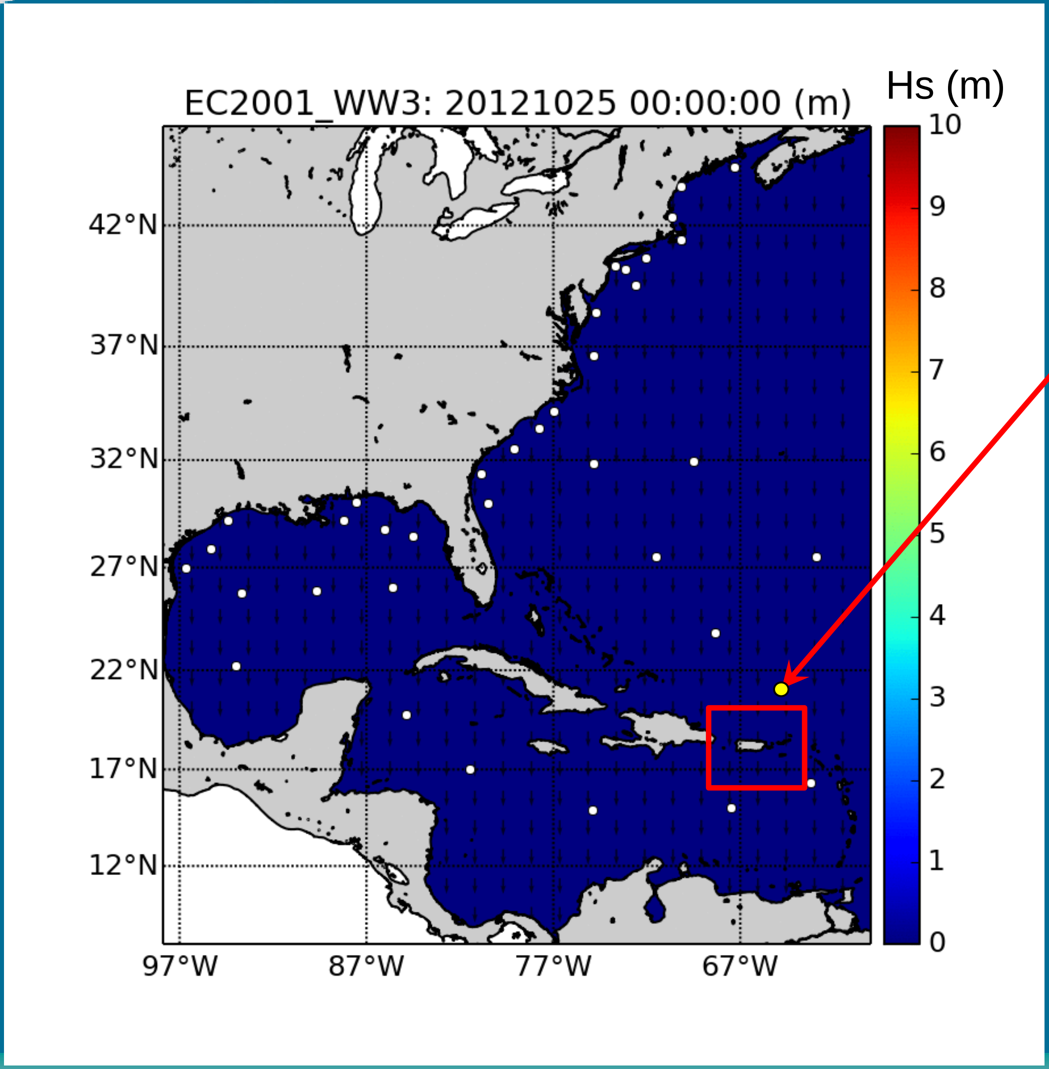


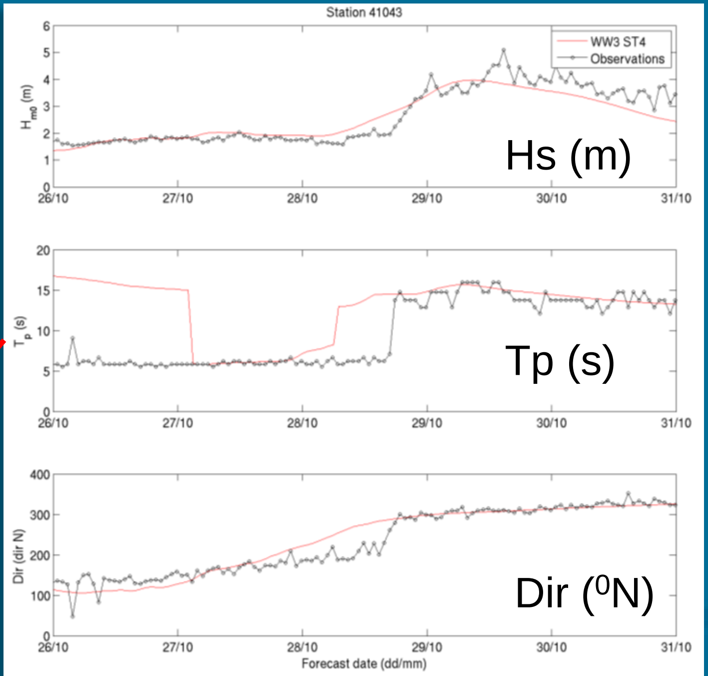




Case 3: WW3 Wave field results

Superstorm Sandy: Waves with CFSR winds





Sensitivity: Tides & atmospheric effects

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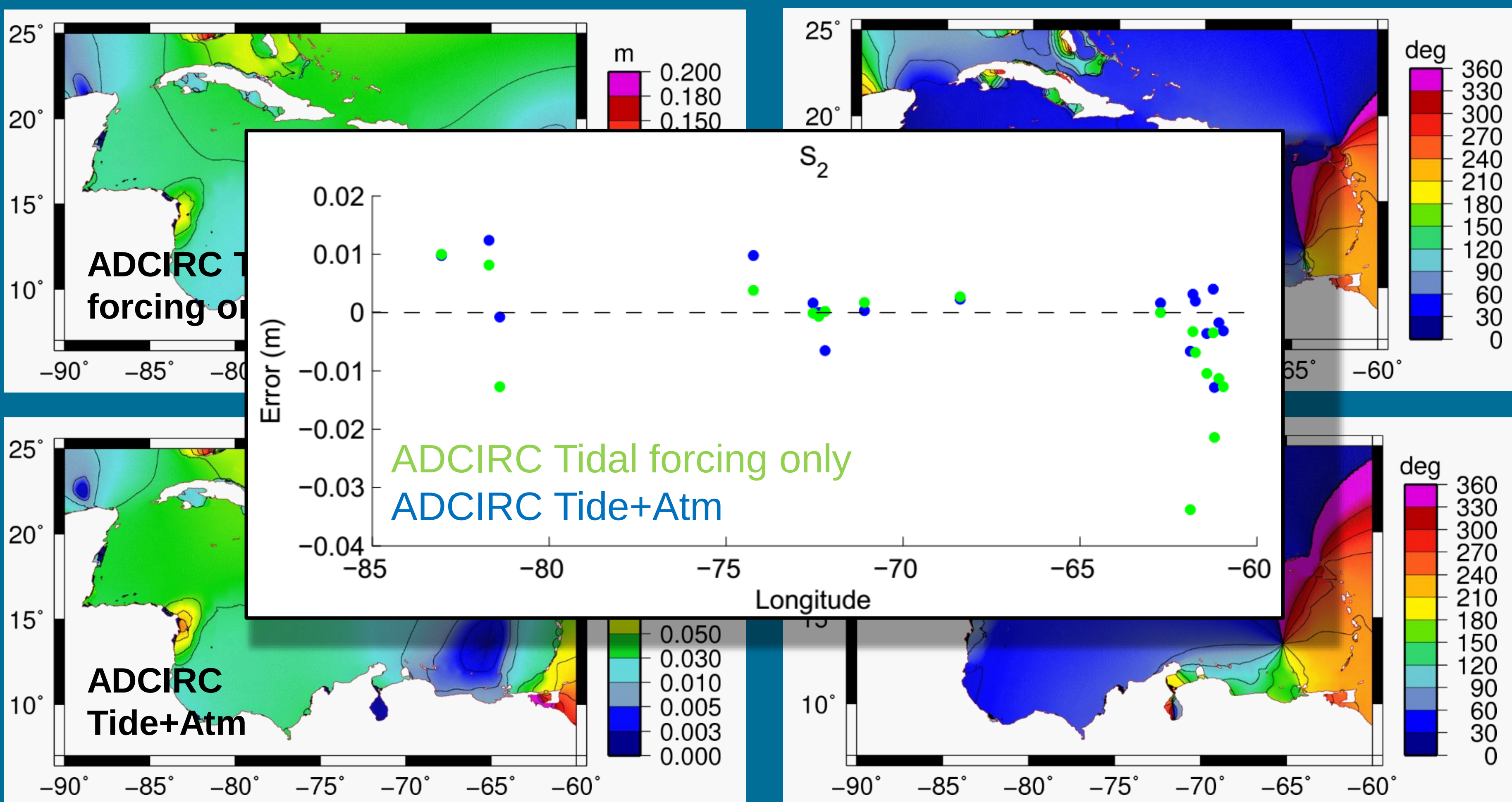
S_2 Constituent (Amplitude)

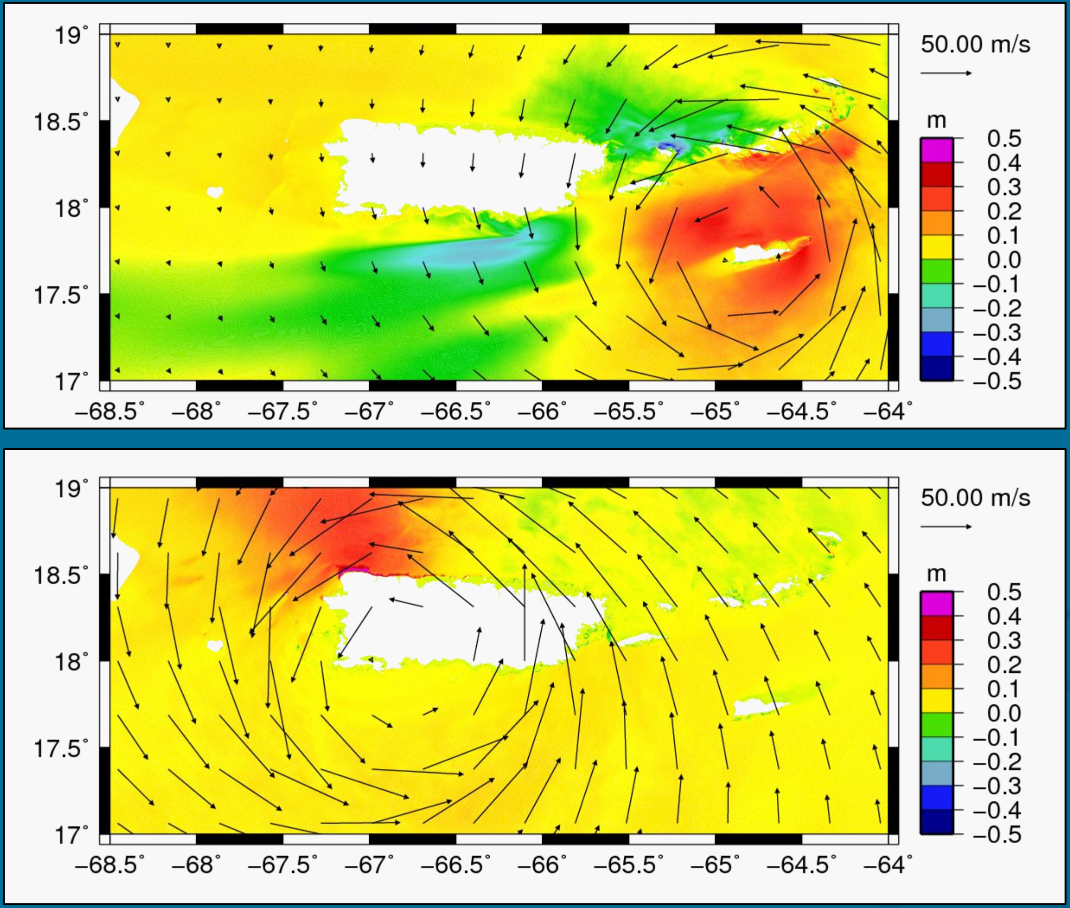
S_2 Constituent (Phase)



Sensitivity: Wave model freq. range

H. Irene: Tropical Storm at landfall

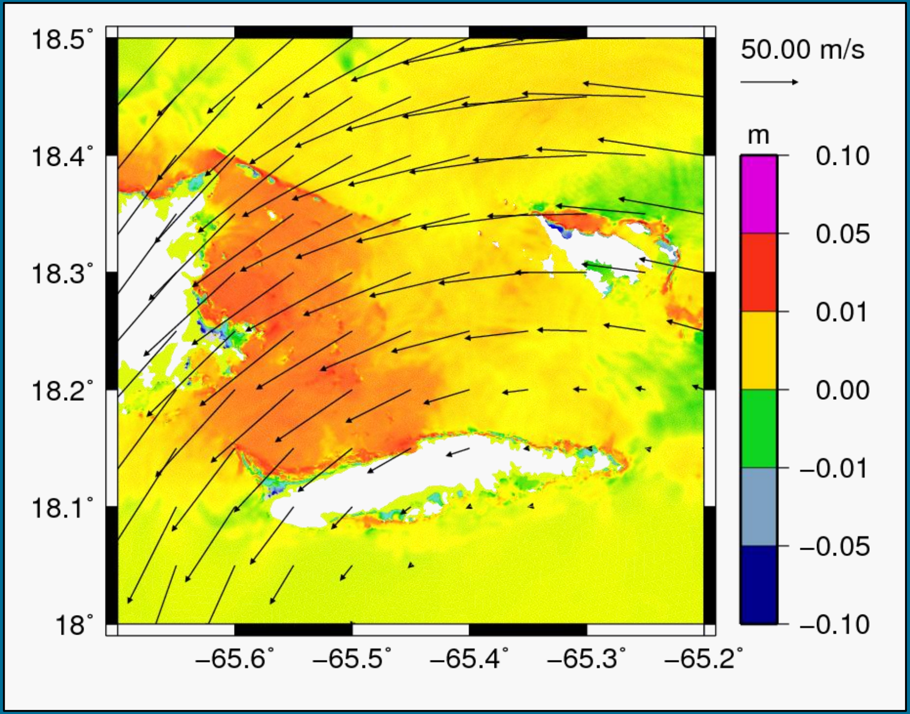
Significant wave height difference between freq range 0.029-10 Hz and 0.05-1 Hz

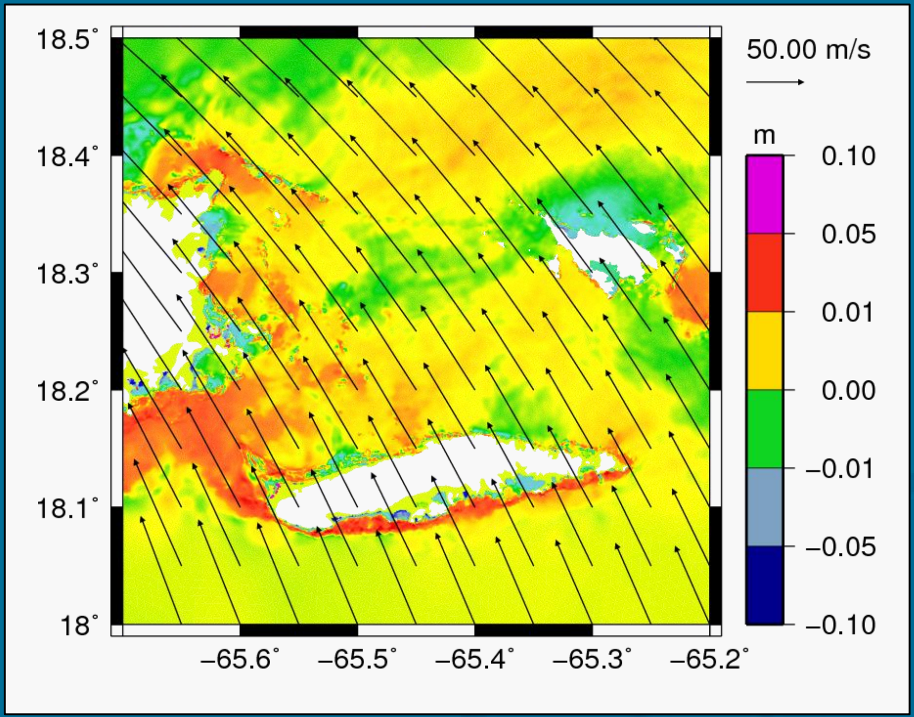


Sensitivity: Effect of triad interactions

H. Irene: Tropical Storm at landfall

Effect of triads on surface elevation, freq range 0.029-10 Hz





Difference in surface elevation just around 0.05 m, but effect is clearly driven by reef and shallow features

Sensitivity: Effect of triad interactions

H. Irene: Tropical Storm at landfall

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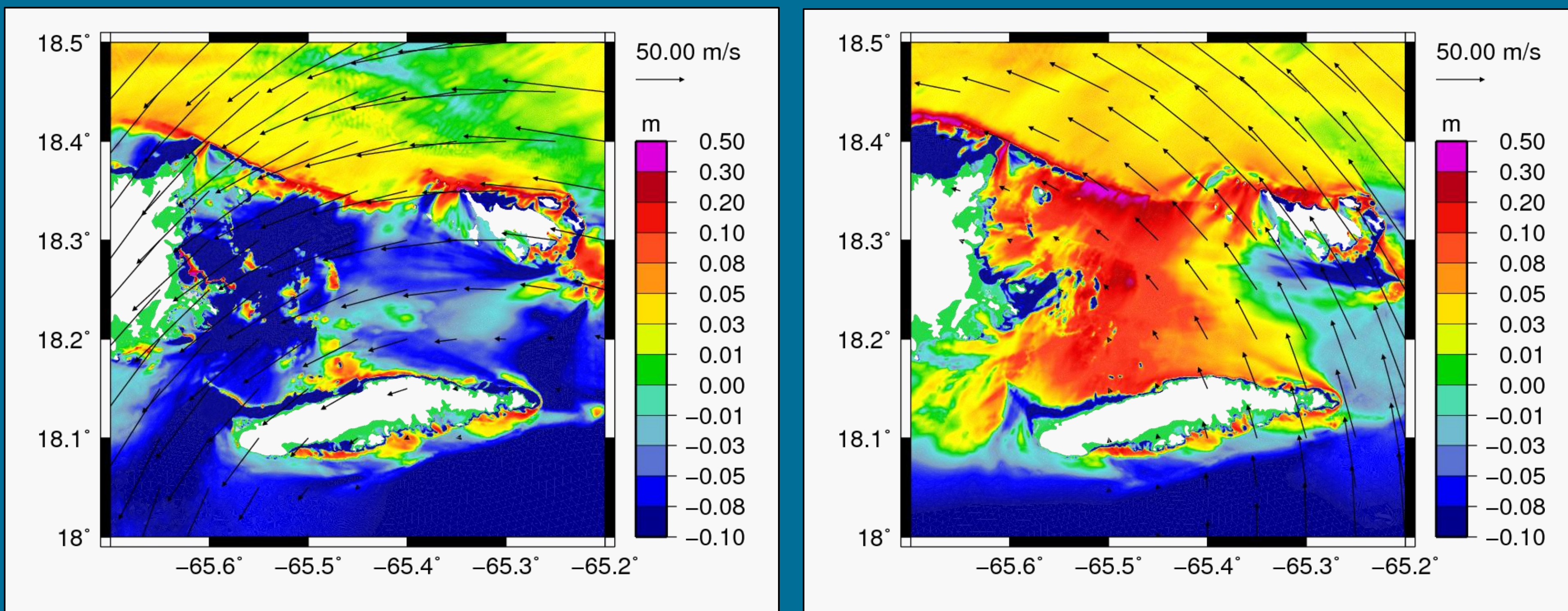
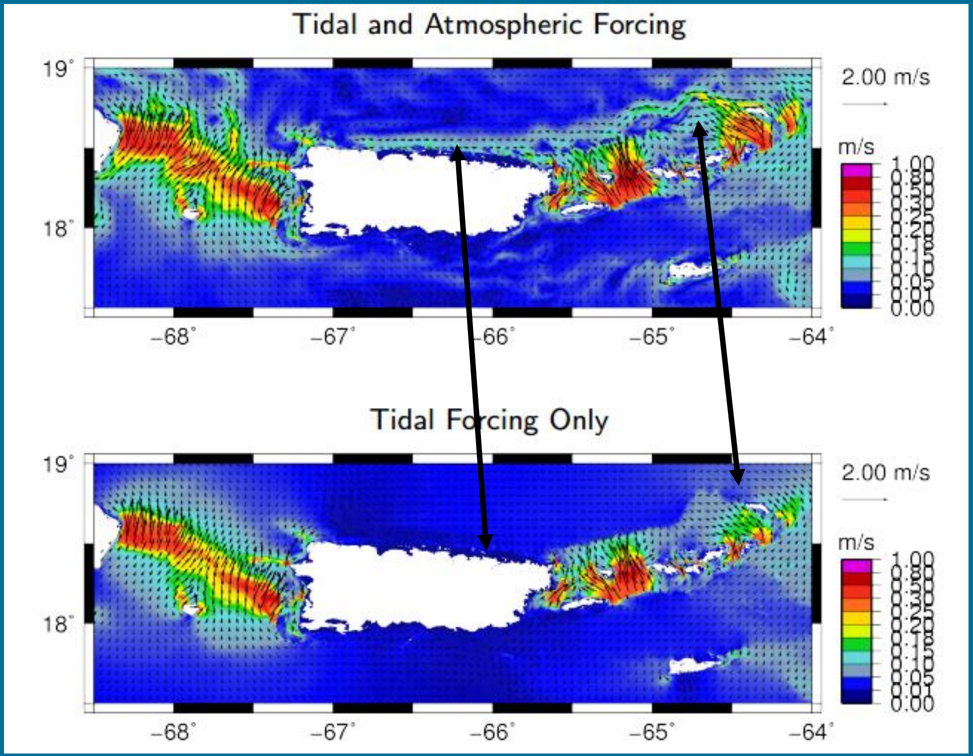
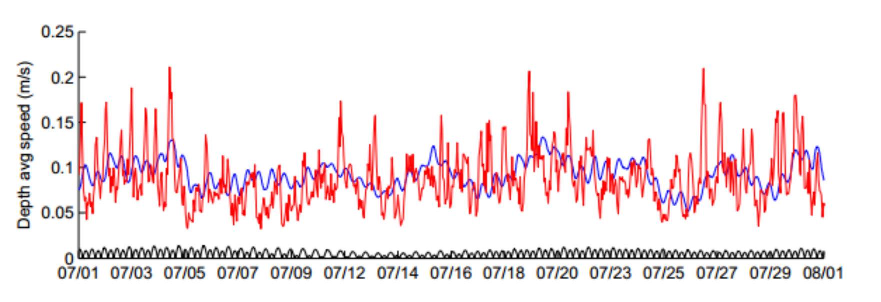
Effect of triads on significant wave height, freq range 0.029-10 Hz



Very strong signature of reefs, sand banks, underwater features

Effect of Atmospheric Forcing on Barotropic Currents





Red:Observed, Blue:ADCIRC Tide+Atm, Black: ADCIRC Tide

- Atmospheric forcing is a necessary condition for generation of East-West currents
  - Horizontal tidal gradient is not sufficient to generate observed currents

Parametric wave model

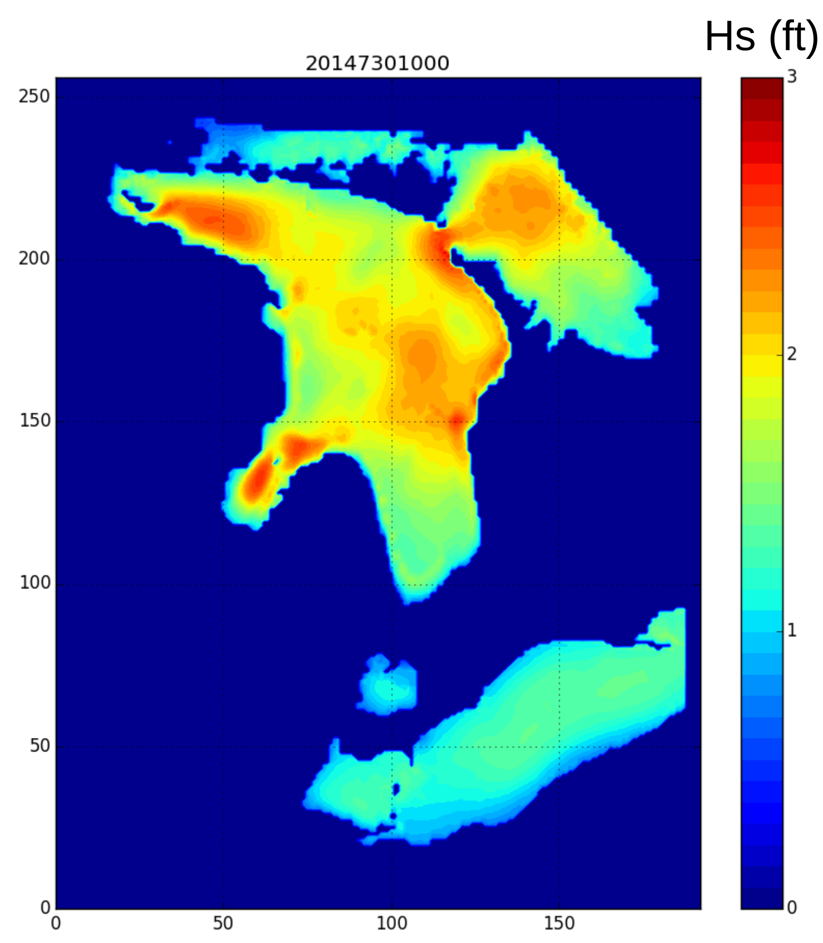
An efficient parametric wave model to couple with SLOSH (within P-Surge)

- Parametric models that reduce full solution space N(t,x,y,σ,θ), to e.g. M(t,x,y) (Schwab et al. 1984).
- Simplified physics, but significantly cheaper than SWAN or WW3
- More suitable to couple with SLOSH than SWAN.

$$\frac{\partial \vec{M}}{\partial t} + \vec{v} \cdot \nabla_{x,y} \vec{M} = \vec{\tau}_w$$

$$\vec{\tau}_w = 0.028 \rho_a D_f \left| \vec{U} - 0.83 C_p \right| \left(\vec{U} - 0.83 C_p \right)$$

$$\sigma^2 = 6.23 \times 10^{-6} \left(\frac{f_p U}{g} \right)^{-10/3} \frac{U^4}{g^2}$$



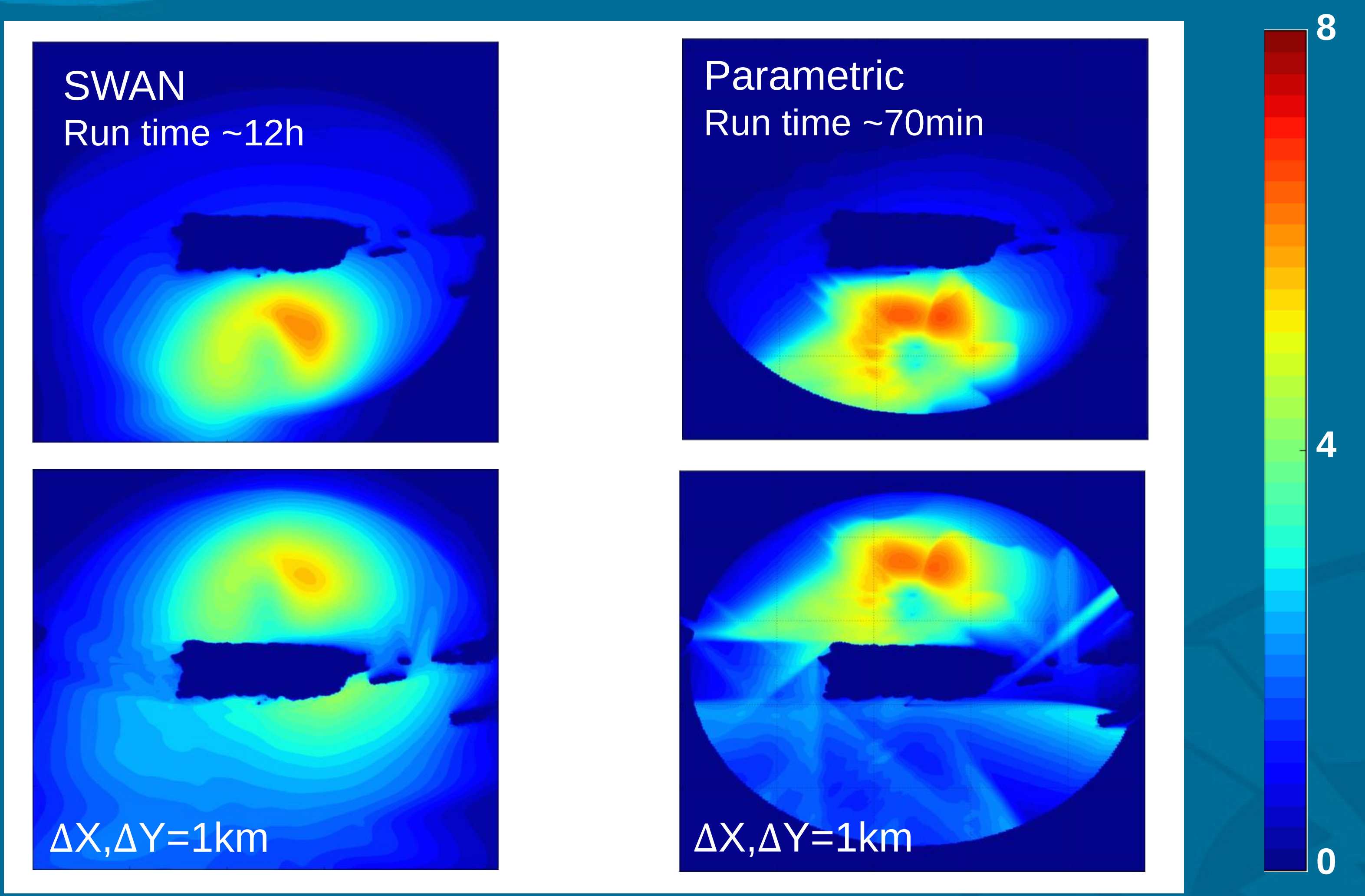
Res: X=193; Y=257. dx=dy=2.5km.

Run time = 84 s (vs. SWAN: 120 min)

Schwab, D.J., J.R. Bennett, P.C. Liu and M.A. Donelan, 1984. Application of a simple numerical wave prediction model to Lake Erie. J. Geophys. Res., 89(C3), 3586-3592.

Parametric wave model results

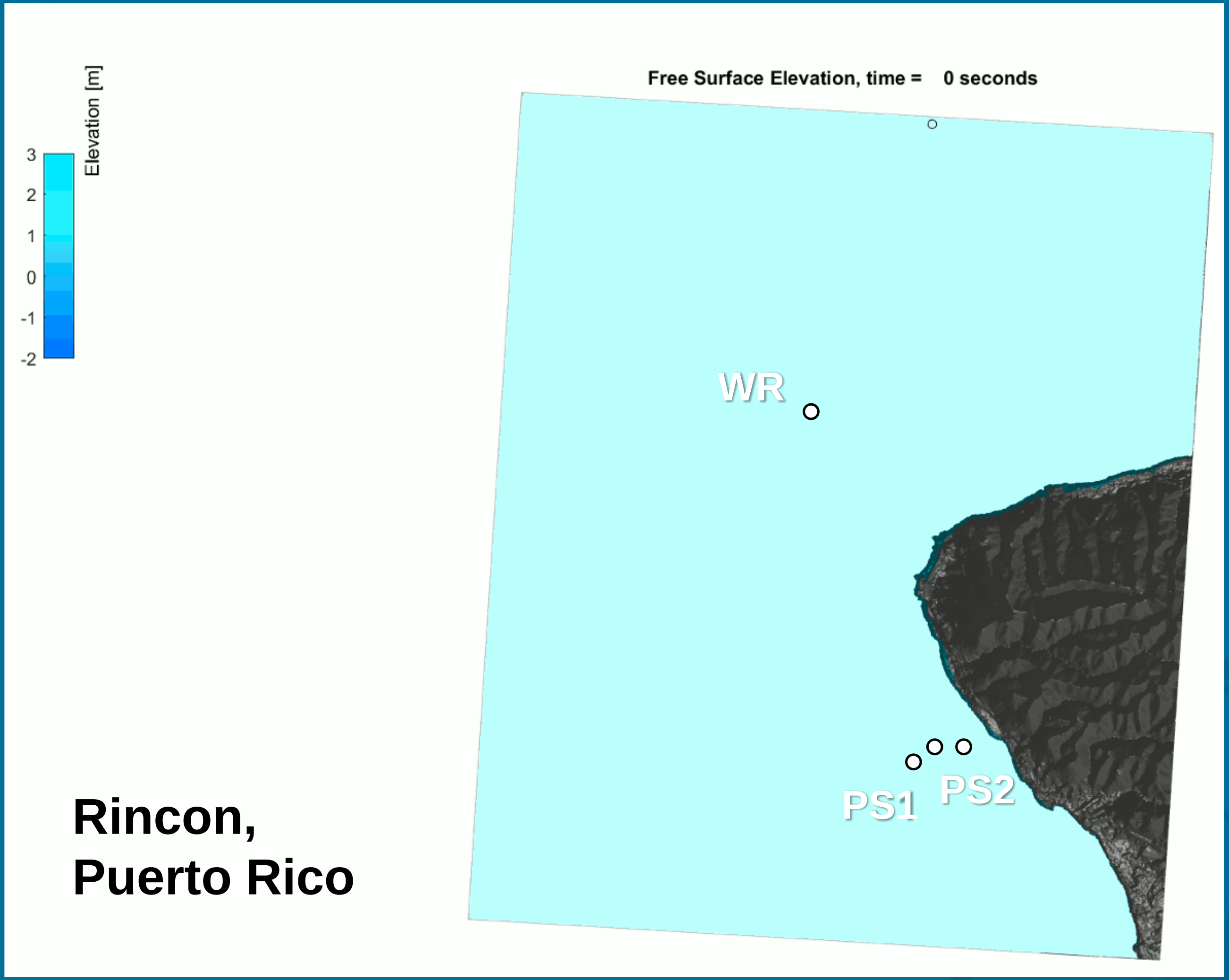
Cat 3 Synthetic Storm



Schwab, D.J., J.R. Bennett, P.C. Liu and M.A. Donelan, 1984. Application of a simple numerical wave prediction model to Lake Erie. J. Geophys. Res., 89(C3), 3586-3592.

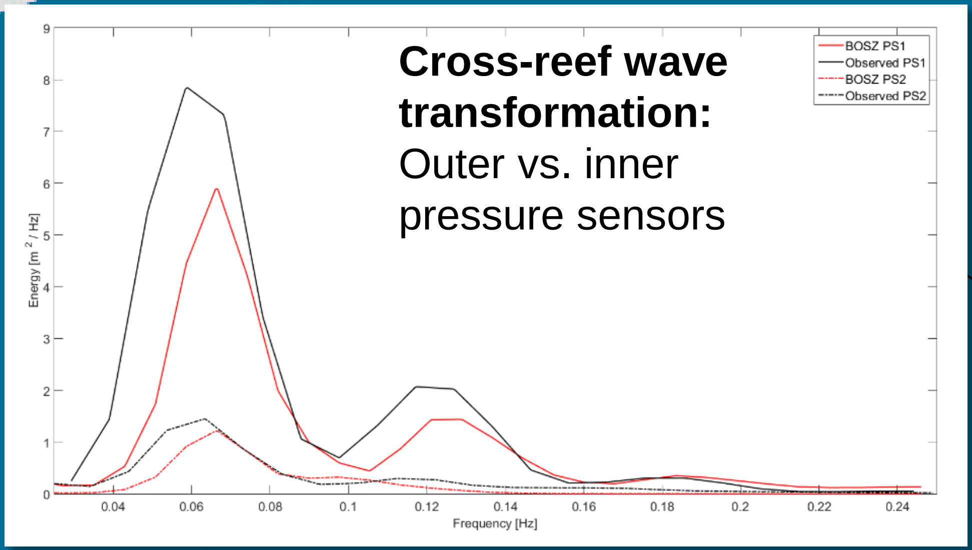
BOSZ phase-resolving model

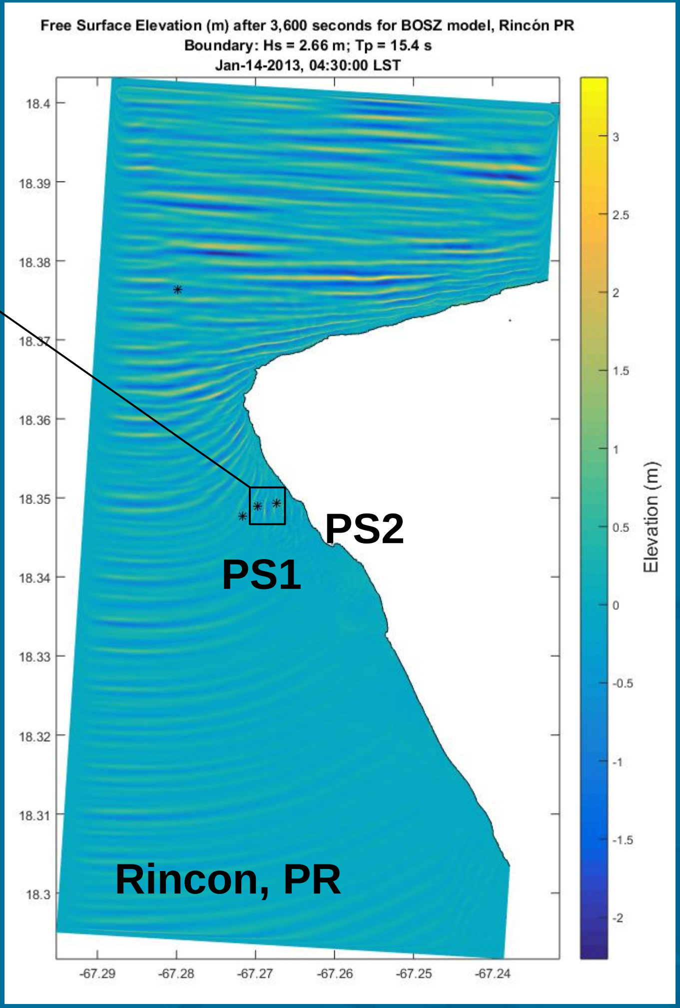
Swell event, Jan 14, 2013



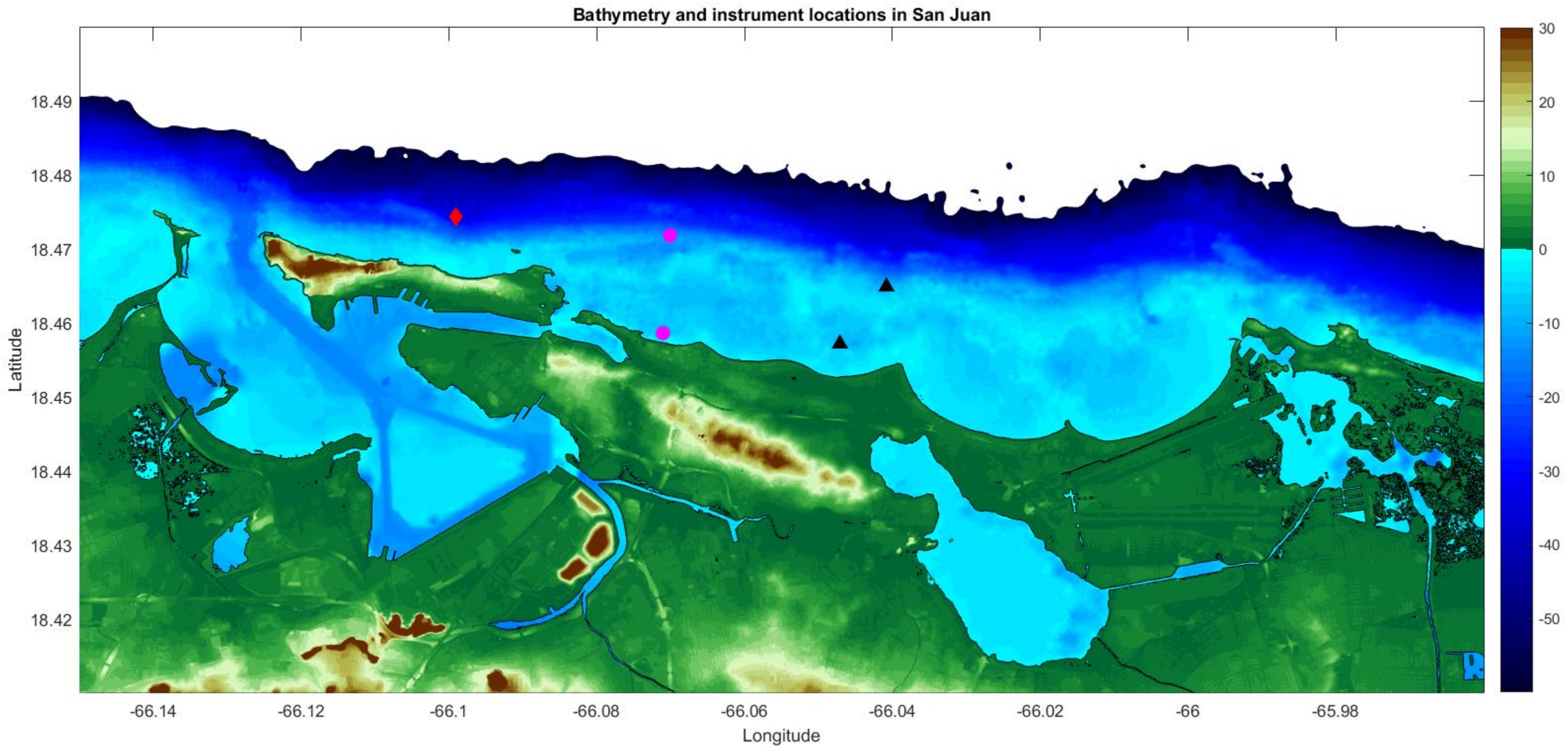
BOSZ phase-resolving model

Rincon: Jan 14, 2013, 04:30 LST



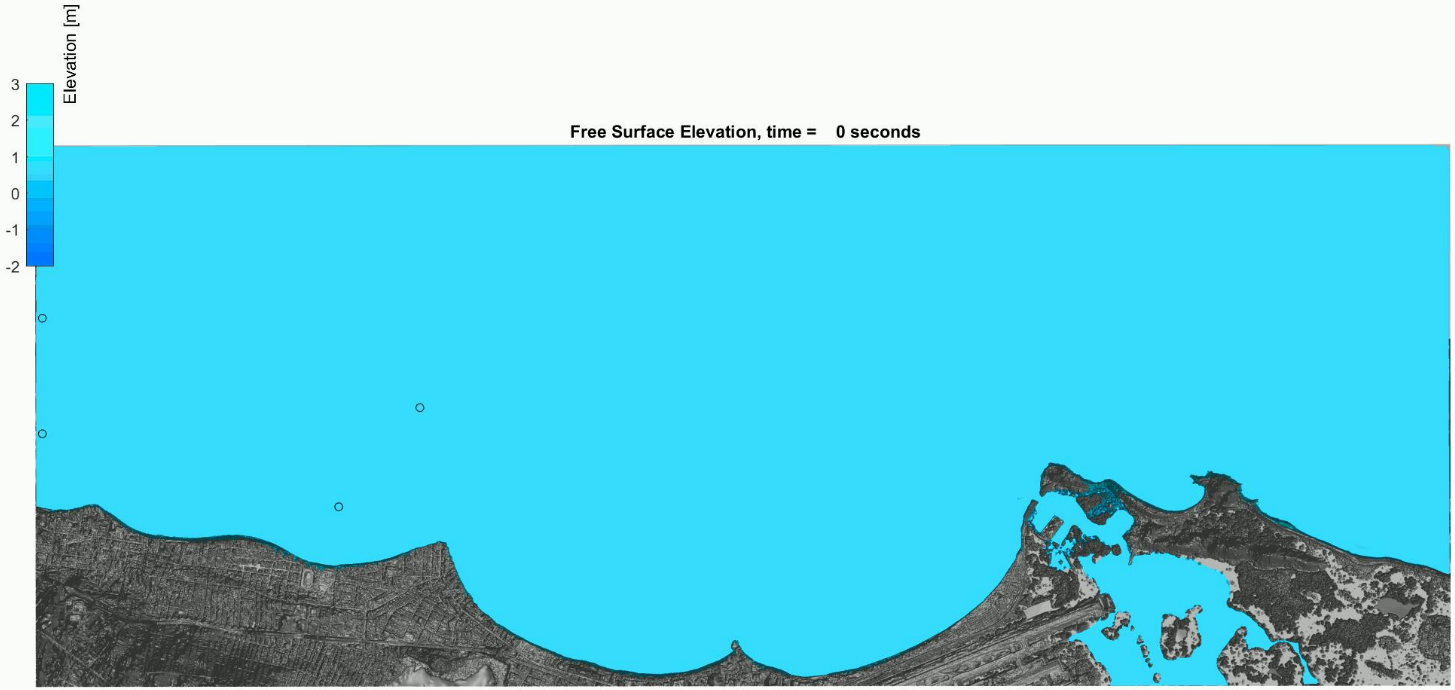


Bathymetry and instrument locations
San Juan, PR



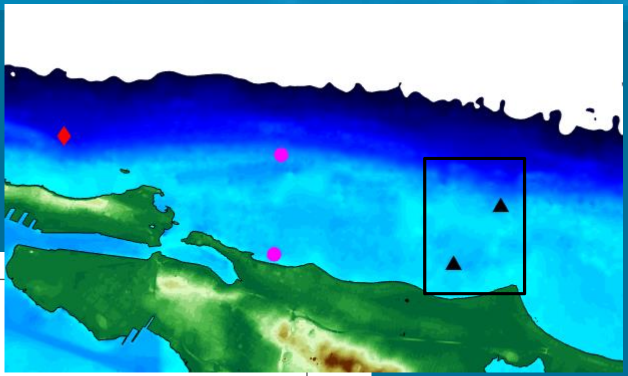
BOSZ phase-resolving model

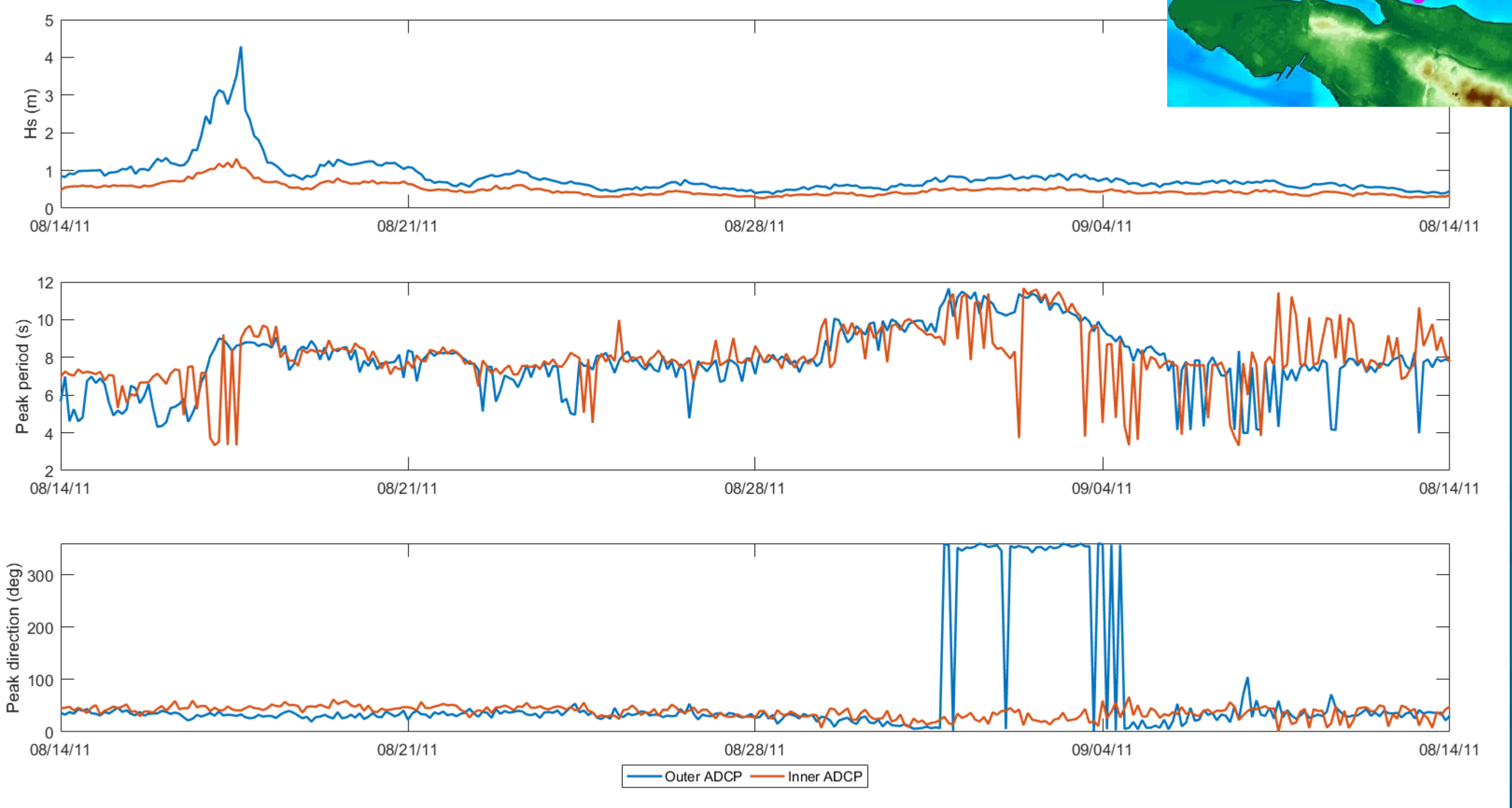
San Juan: Hurricane Irene, Aug 22, 2011



BOSZ phase-resolving model

San Juan: Hurricane Irene

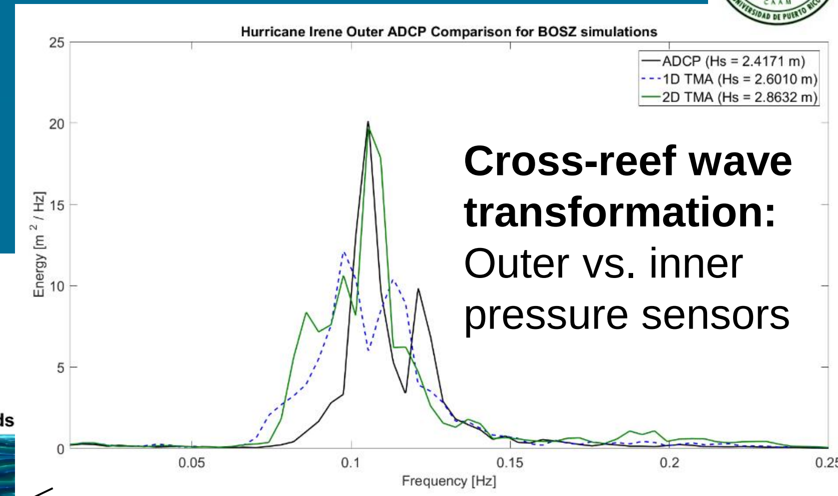


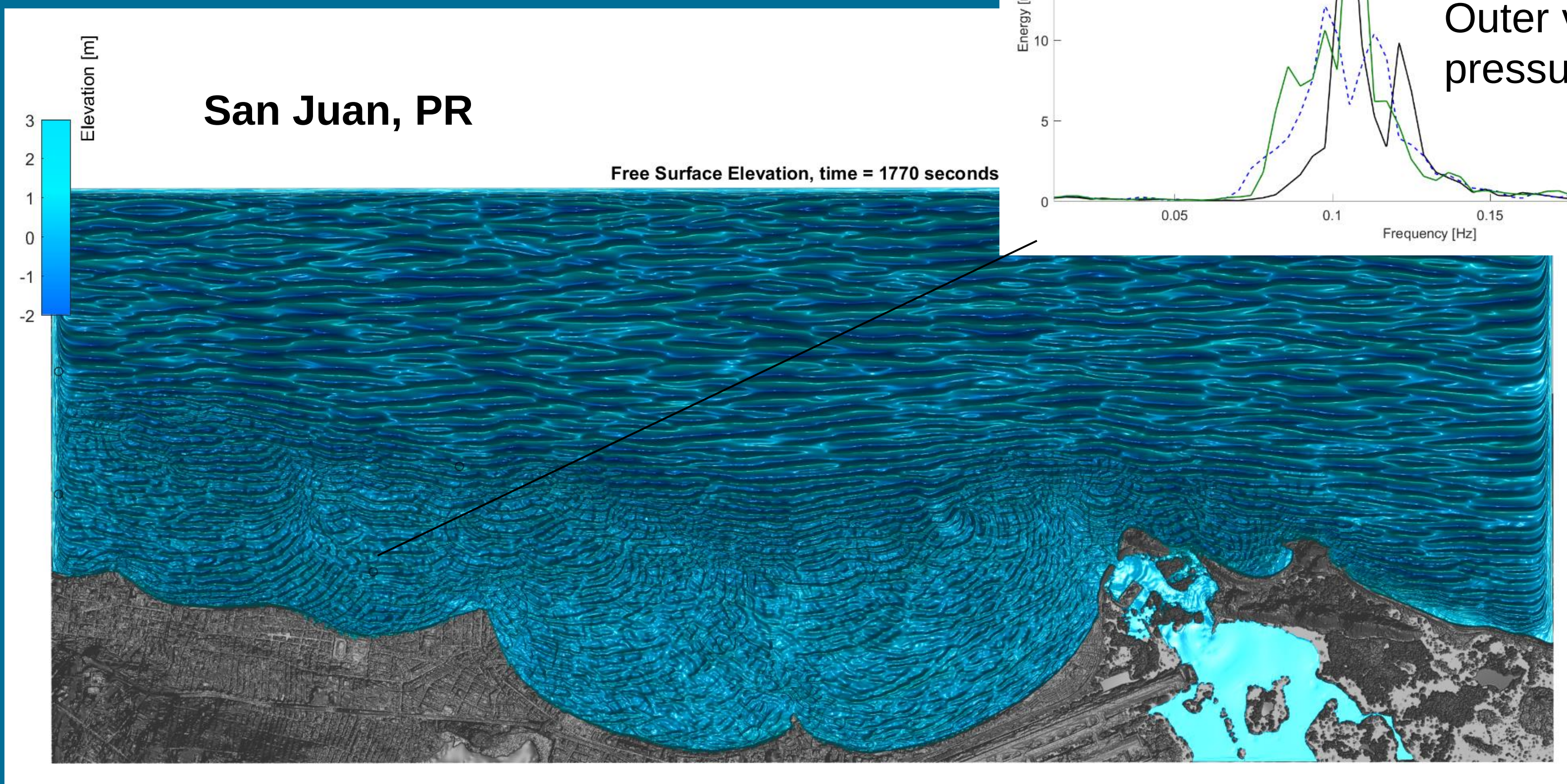


BOSZ phase-resolving model

San Juan: H. Irene, Aug 22, 2011 03:00 LST

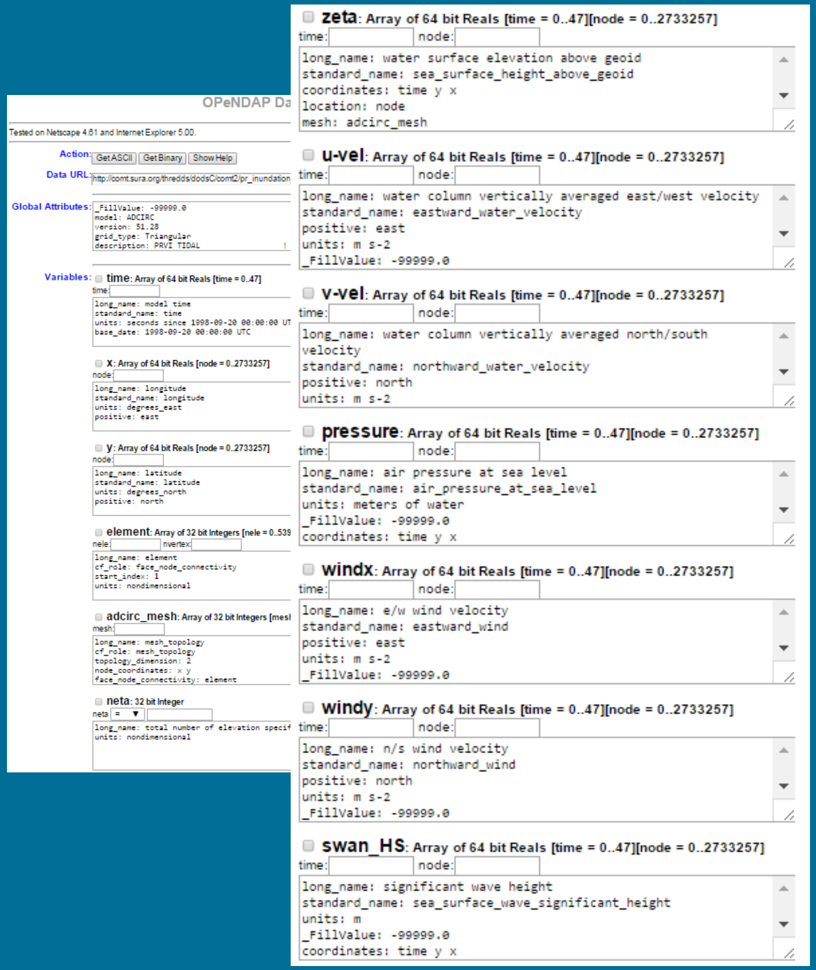
Cross-reef wave transformation:
Outer vs. inner pressure sensors





COMT CyberInfrastructure (CI)

Data Access (eg. OPeNDAP)


OPeNDAP Da

Tested on Netscape 4.61 and Internet Explorer 5.00.

Action: Get ASCII | Get Binary | Show Help

Data URL: http://comt.sura.org/thredds/dodsC/comt2/pr_inundation

Global Attributes:
```
_FillValue: -99999.0
model: ADCIRC
version: 51.28
grid_type: Triangular
description: PRVI TIDAL
```

Variables:

time: Array of 64 bit Reals [time = 0..47]
```
long_name: model time
standard_name: time
units: seconds since 1998-09-20 00:00:00 UT
base_date: 1998-09-20 00:00:00 UTC
```

x: Array of 64 bit Reals [node = 0..2733257]
```
long_name: longitude
standard_name: longitude
units: degrees_east
positive: east
```

y: Array of 64 bit Reals [node = 0..2733257]
```
long_name: latitude
standard_name: latitude
units: degrees_north
positive: north
```

element: Array of 32 bit Integers [nele = 0..539
```
long_name: element
cf_role: face_node_connectivity
start_index: 1
units: nondimensional
```

adcirc_mesh: Array of 32 bit Integers [mesh
```
long_name: mesh_topology
cf_role: mesh_topology
topology_dimension: 2
node_coordinates: x y
face_node_connectivity: element
```

neta: 32 bit Integer
```
long_name: total number of elevation specif
units: nondimensional
```

zeta: Array of 64 bit Reals [time = 0..47][node = 0..2733257]
time: node:
```
long_name: water surface elevation above geoid
standard_name: sea_surface_height_above_geoid
coordinates: time y x
location: node
mesh: adcirc_mesh
```

u-vel: Array of 64 bit Reals [time = 0..47][node = 0..2733257]
time: node:
```
long_name: water column vertically averaged east/west velocity
standard_name: eastward_water_velocity
positive: east
units: m s-2
_FillValue: -99999.0
```

v-vel: Array of 64 bit Reals [time = 0..47][node = 0..2733257]
time: node:
```
long_name: water column vertically averaged north/south velocity
standard_name: northward_water_velocity
positive: north
units: m s-2
```

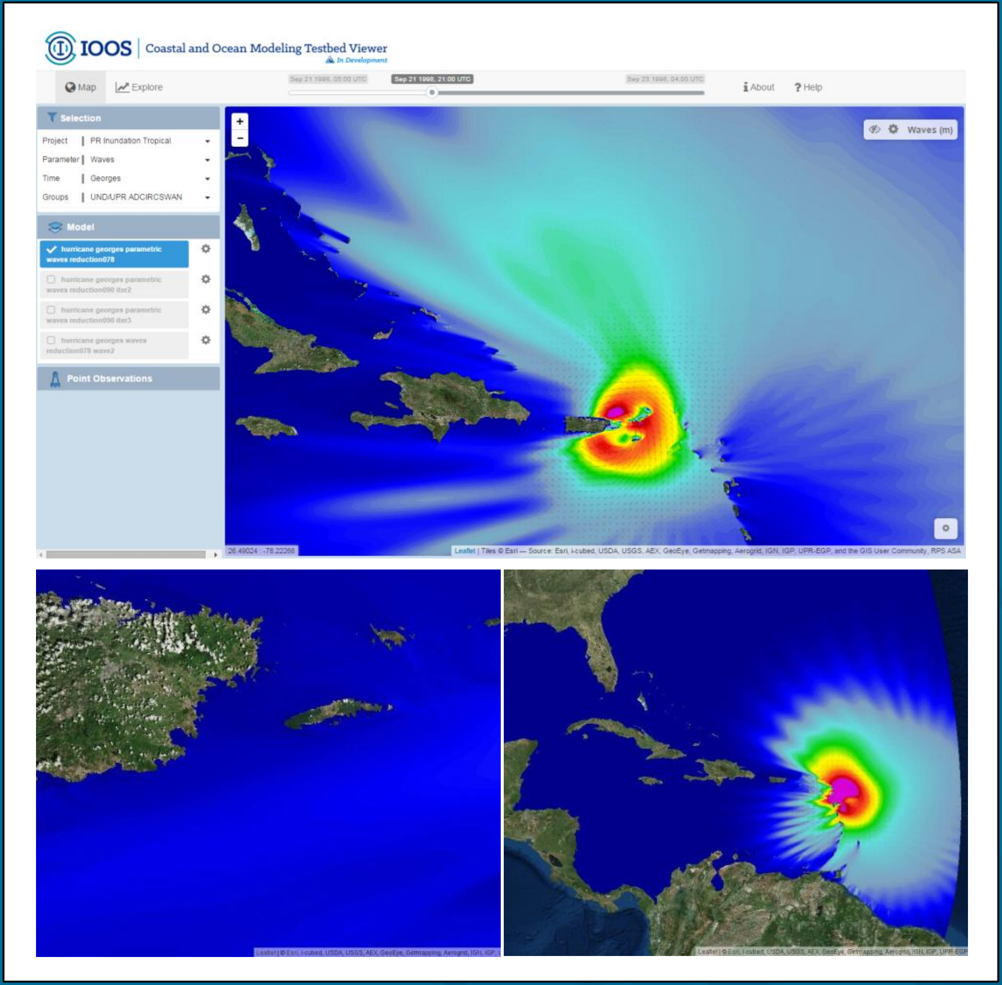
pressure: Array of 64 bit Reals [time = 0..47][node = 0..2733257]
time: node:
```
long_name: air pressure at sea level
standard_name: air_pressure_at_sea_level
units: meters of water
_FillValue: -99999.0
coordinates: time y x
```

windx: Array of 64 bit Reals [time = 0..47][node = 0..2733257]
time: node:
```
long_name: e/w wind velocity
standard_name: eastward_wind
positive: east
units: m s-2
_FillValue: -99999.0
```

windy: Array of 64 bit Reals [time = 0..47][node = 0..2733257]
time: node:
```
long_name: n/s wind velocity
standard_name: northward_wind
positive: north
units: m s-2
_FillValue: -99999.0
```

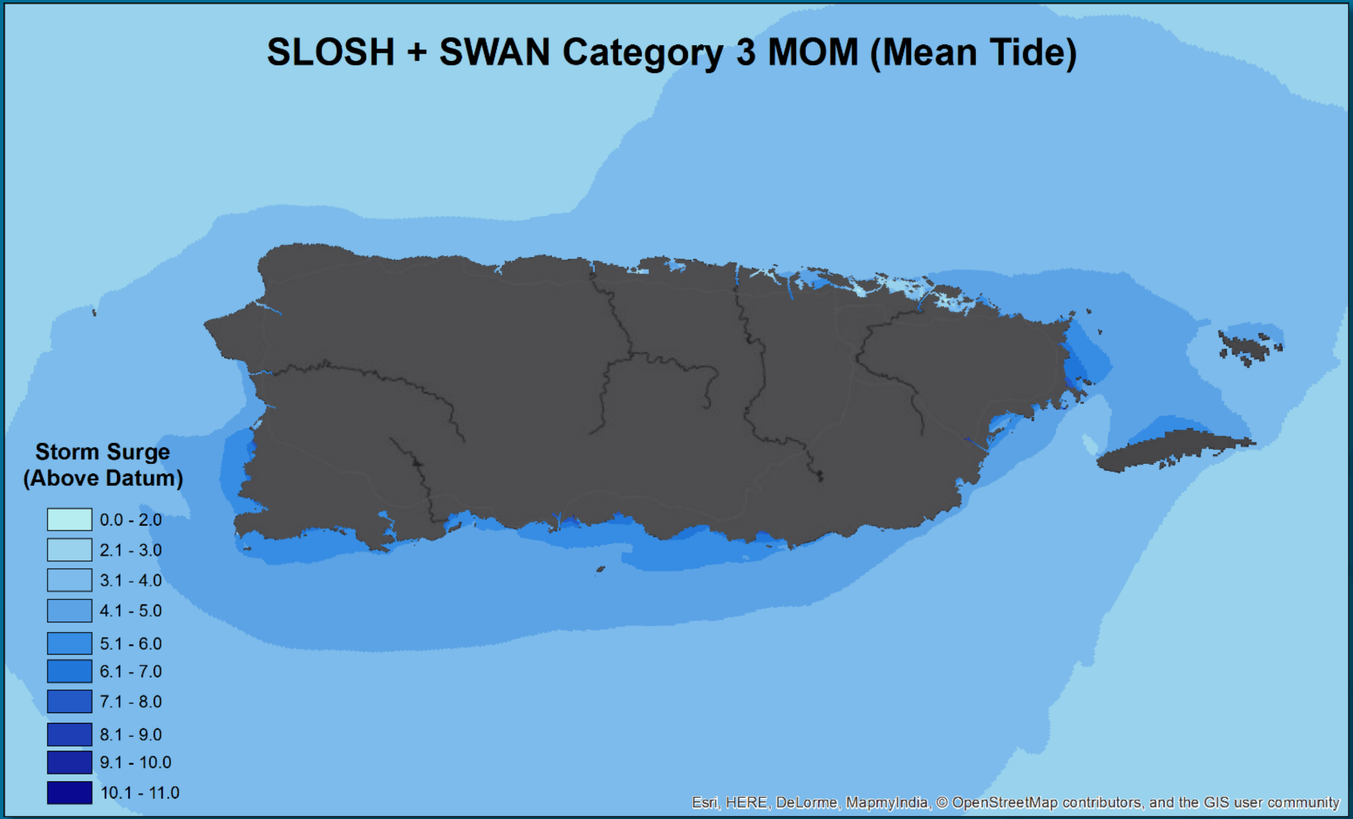
swan_HS: Array of 64 bit Reals [time = 0..47][node = 0..2733257]
time: node:
```
long_name: significant wave height
standard_name: sea_surface_wave_significant_height
units: m
_FillValue: -99999.0
coordinates: time y x
```

Presentation/User Interface

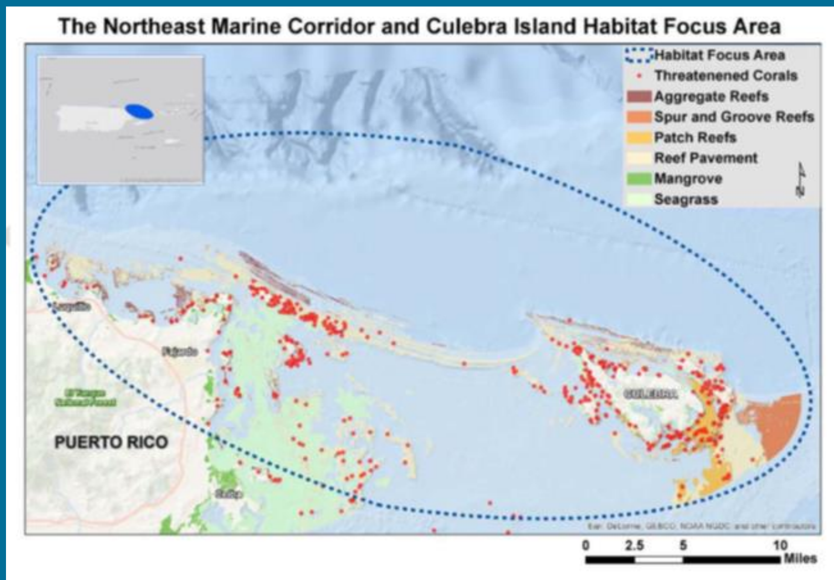


Transition to Operations
1. Storm surge envelopes

First-ever Maximum of Maximums (MOM) surge hazard database produced for Puerto Rico, using coupled SLOSH+SWAN. To be used for evacuation planning and response.



Transition to Field Operations
2. NOAA's Habitat Focus Area in the Caribbean



Puerto Rico's Northeast Marine Corridor and Culebra Island were chosen as the Caribbean region's Habitat Focus Area (HFA) in 2014.

The Northeast Marine Corridor and Culebra Island HFA encompass a wide array of ecosystems in a relatively small geographic area. Therefore, this would be of great help to understand what could be the future scenario.

Changes in the marine wave field and energy transformation affected by the reef natural barriers modify the subsequent coastal flooding.

The main goal of this group is to identify the potential storm surge impacts with different benthic characteristics.

Conclusions

1. Island environments such as Puerto Rico have highly-detailed coastline features, best resolved with unstructured meshes.

2. Including wave effects has a clear impact on total surge levels, but magnitude is location-dependent.

3. The 3rd-gen wave model is a computationally-expensive component of the forecast system. For real-time operational application more efficient parameterized methods are being pursued.

4. The CI model repository and web-based map view enables rapid exploration and comparison of model output from large scale to local.

5. R2O: First-ever Maximum of Maximums (MOM) surge hazard database produced for Puerto Rico, using coupled SLOSH+SWAN. To be used for evacuation planning and response. Application to NOAA's Habitat Focus Area in the Caribbean.