

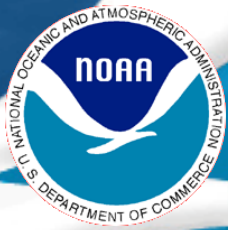


# IOOS Coastal and Ocean Modeling Testbed for Puerto Rico and Virgin Islands:

## Year 3 Progress

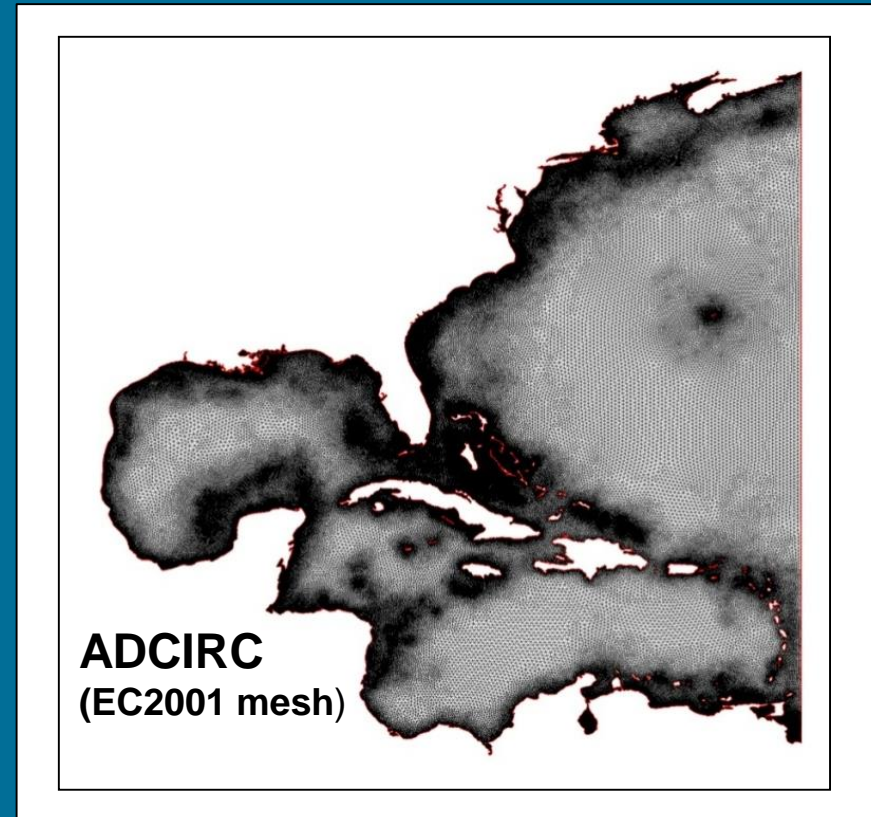
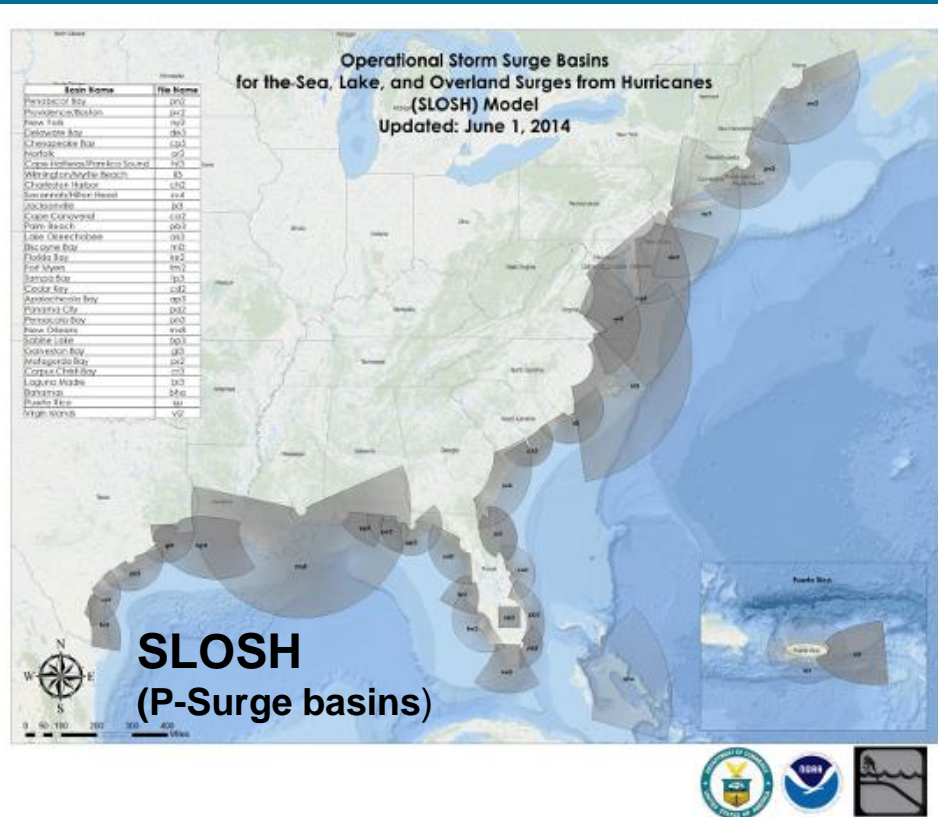
André van der Westhuysen, Brian Mckenna, Kelly Knee, Joannes Westerink,  
Juan Gonzalez, Jane Smith, Jamie Rhome, Cristina Forbes,  
Julio Morell, Aurelio Mercado, Reniel Calzada, Volker Roeber, Dongming Yang,  
Hugh Cobb, Carlos Anselmi, Ernesto Rodriguez (and thanks to Luis Aponte)

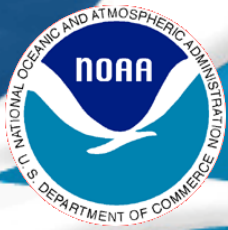




# Background

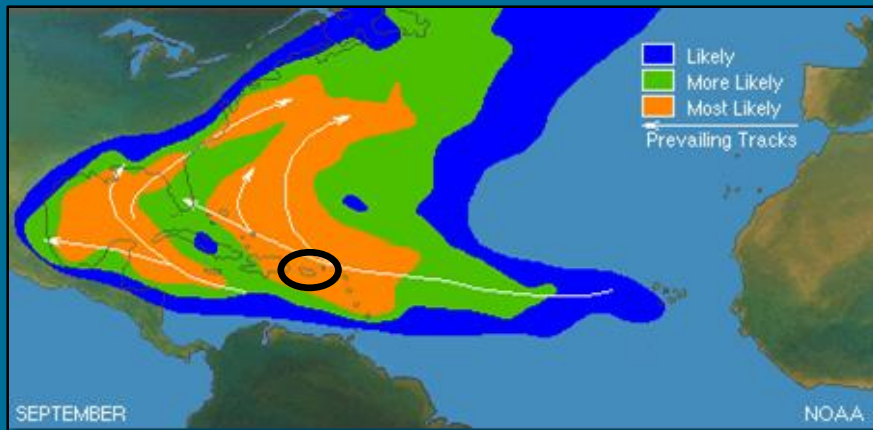
NOAA currently applies both the fast and efficient surge model **SLOSH** (probabilistic guidance) and state-of-the-art **ADCIRC** (deterministic guidance). However, neither of these modeling systems at NOAA has been configured with wave effects or specific focus on island environments.



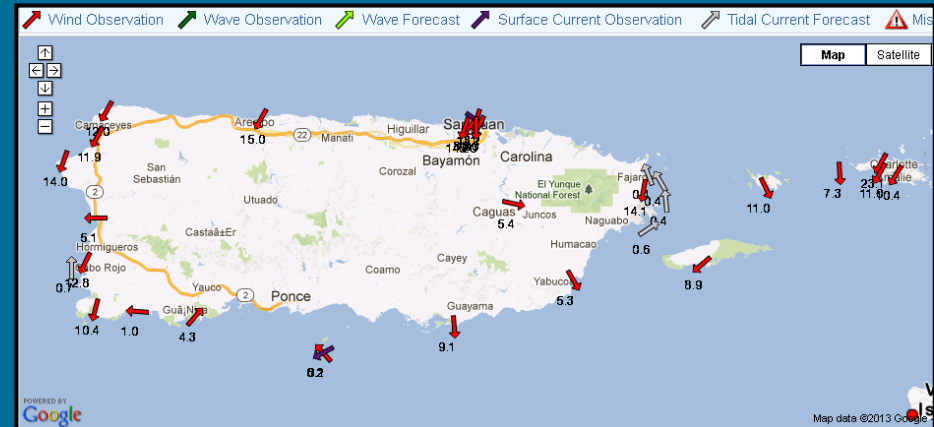


# Objective

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**.



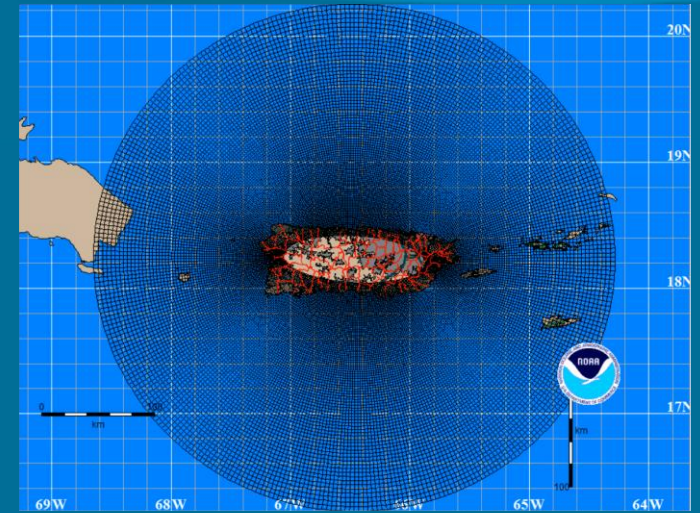
[www.nhc.noaa.gov/climo](http://www.nhc.noaa.gov/climo)



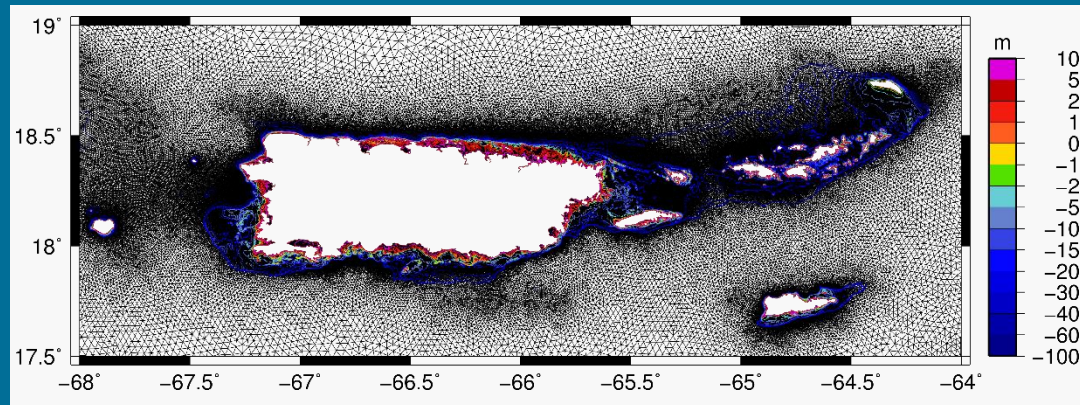
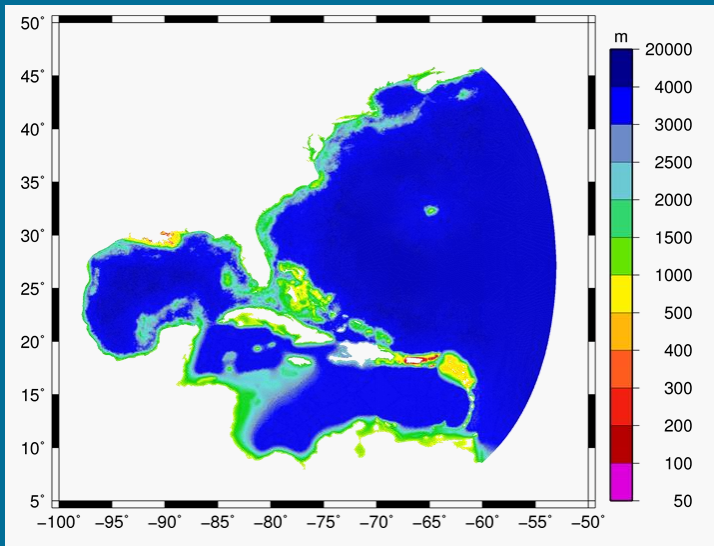
[www.caricoos.org](http://www.caricoos.org)

# Puerto Rico/USVI: Model selection

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



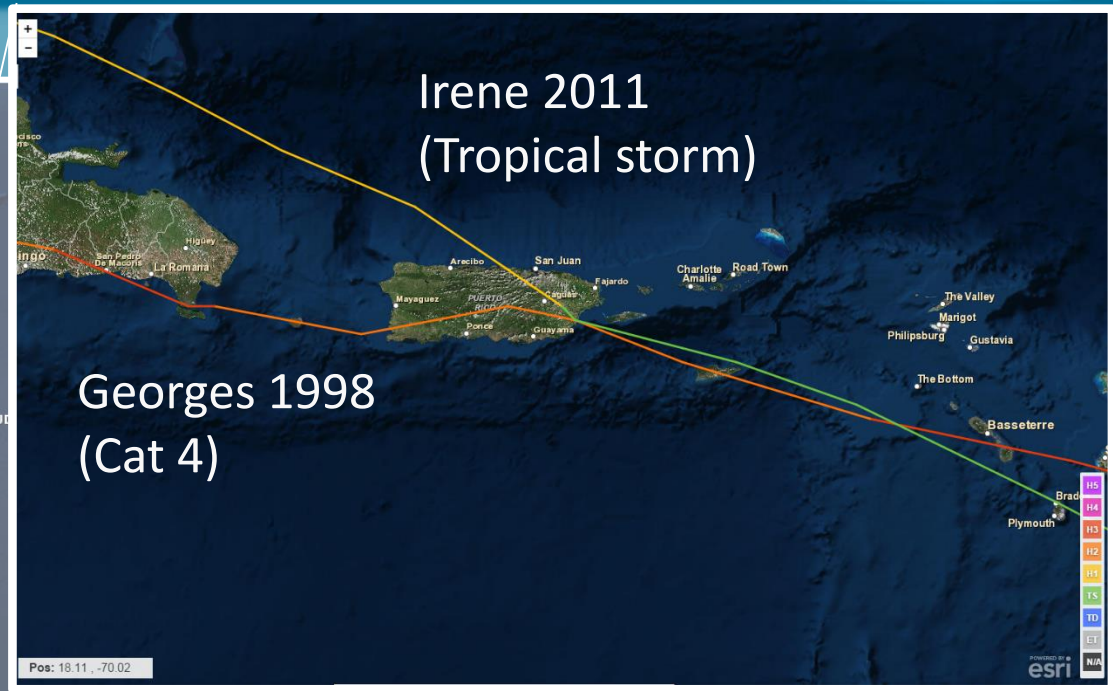
Curvilinear grid (min res: 90 m)



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

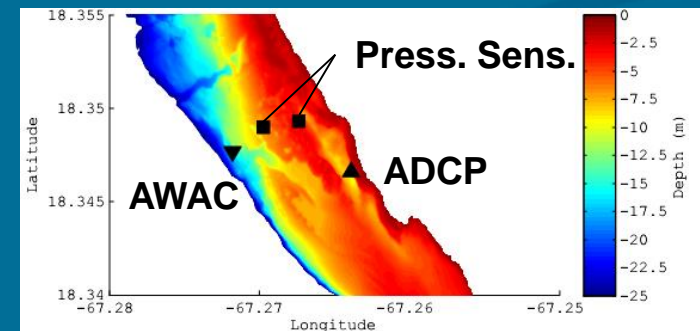
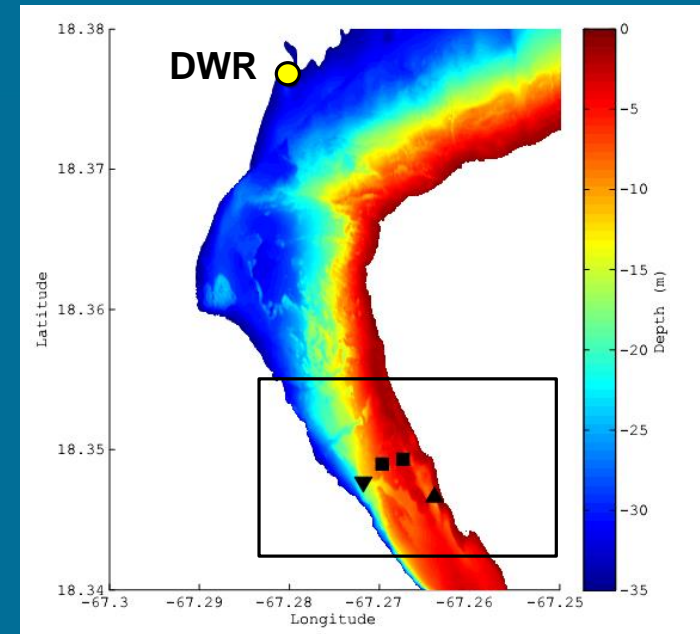
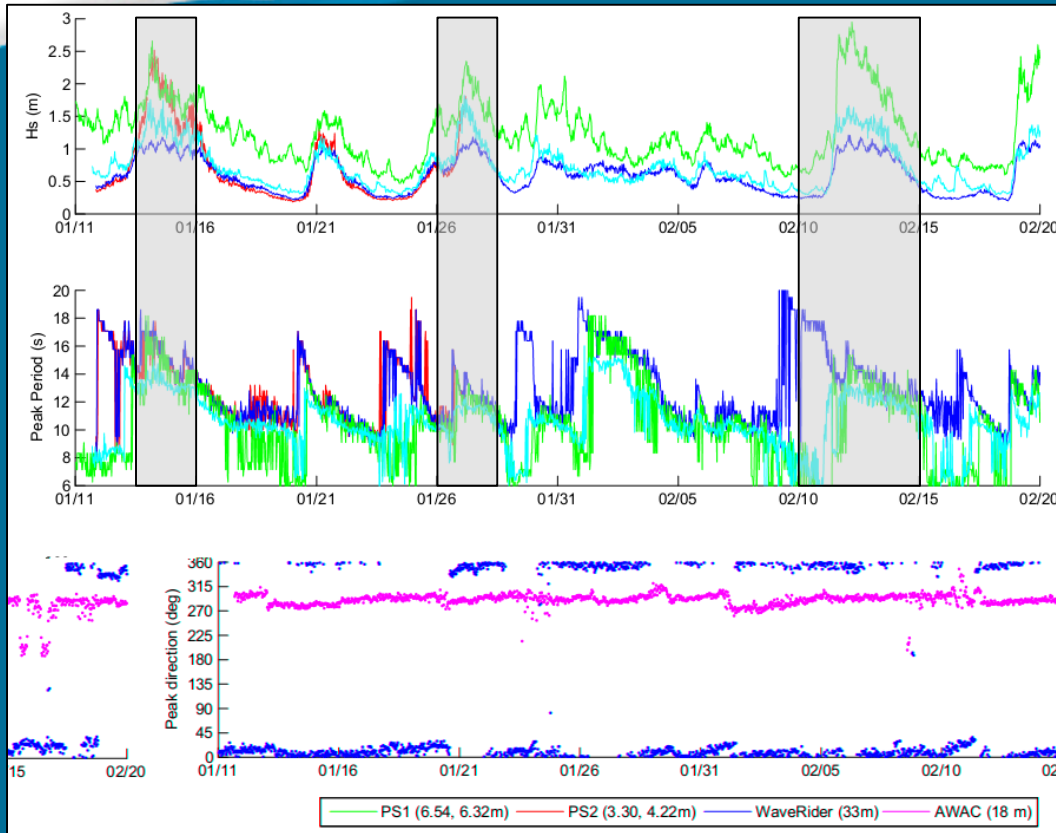


# Regional hindcast cases





# Cross-reef cases (Rincon, PR)



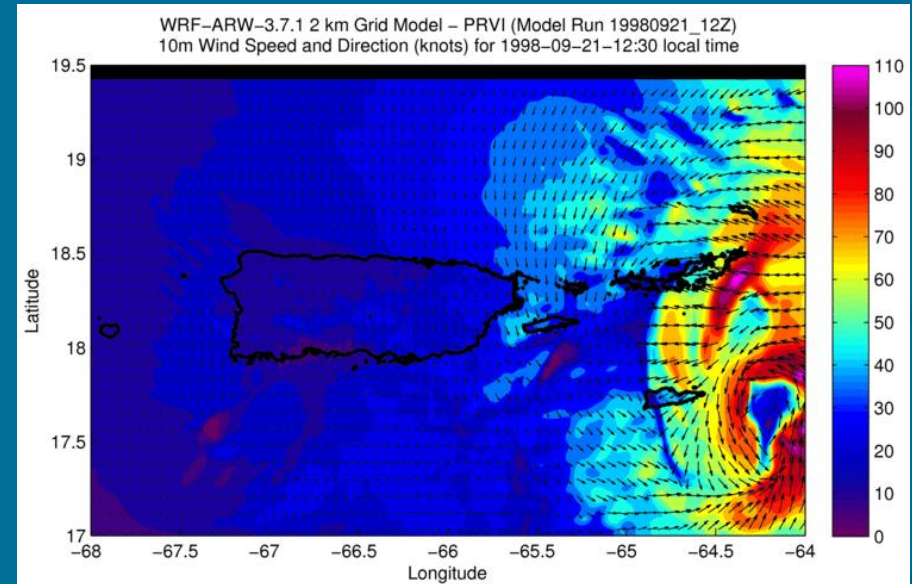
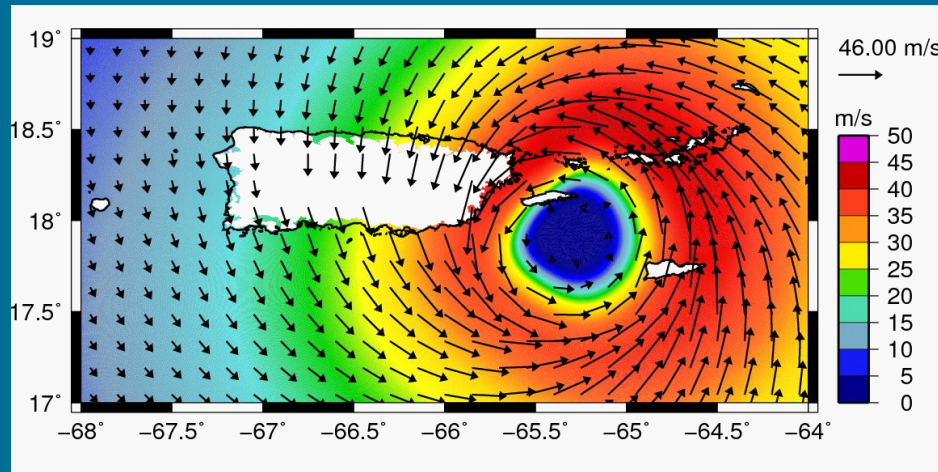
- (1) Datawell Waverider (33 m, 2D wave spectrum)
- (1) Nortek AWAC (18 m, 2D wave spectrum)
- (2) Ocean Sensor Systems Pressure Sensor (6.54 m, 3.33 m)
- (1) Teledyne Sentinel ADCP (10 m channel)





# 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

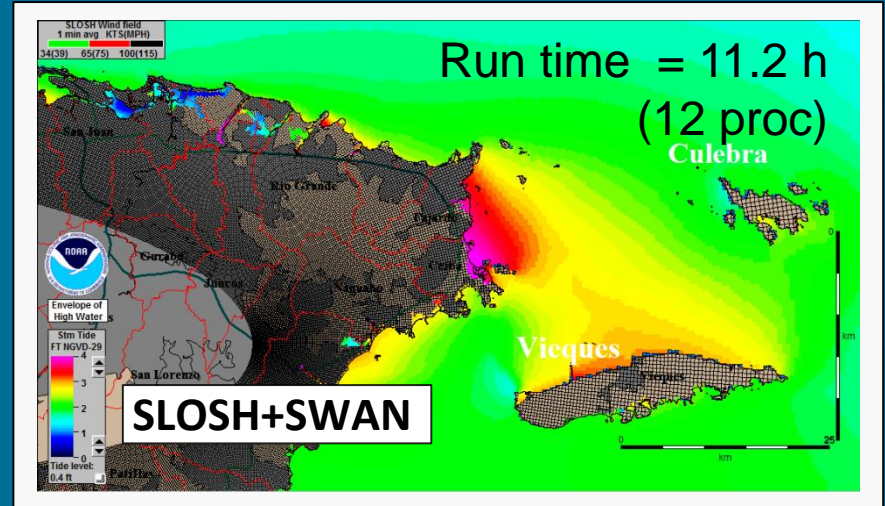
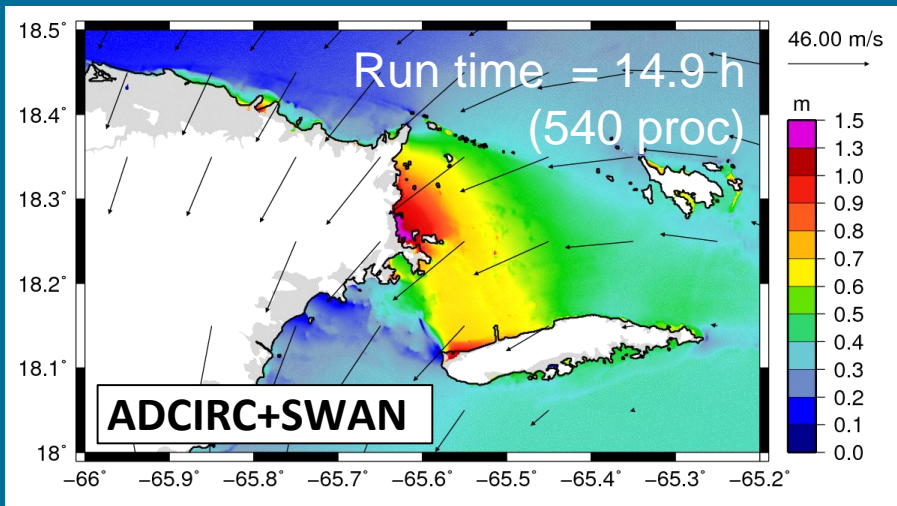
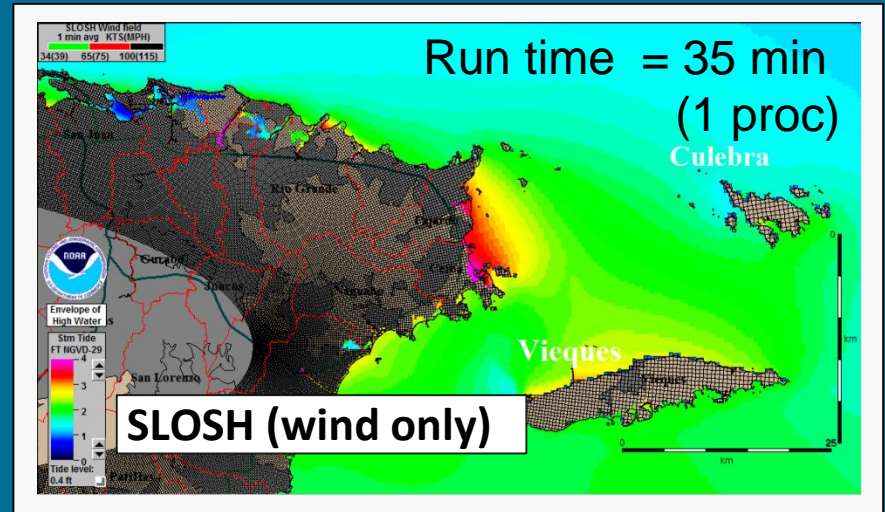
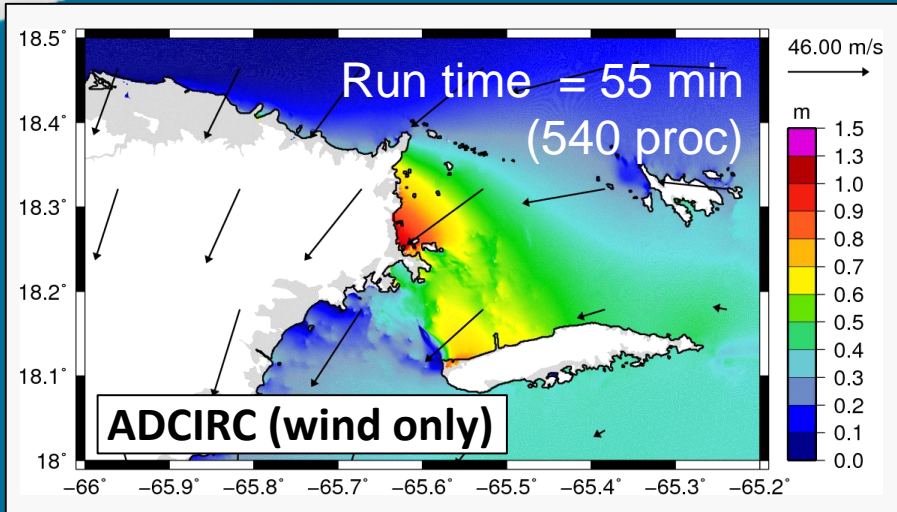


Credit: L. Aponte



# Case 1: ADCIRC vs. SLOSH

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

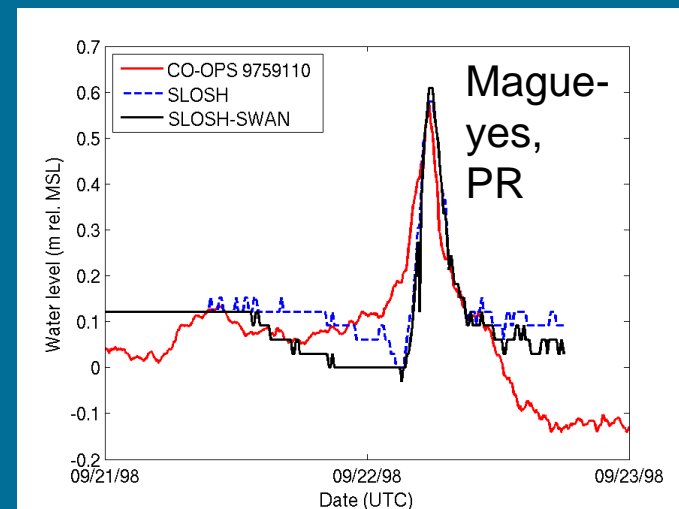
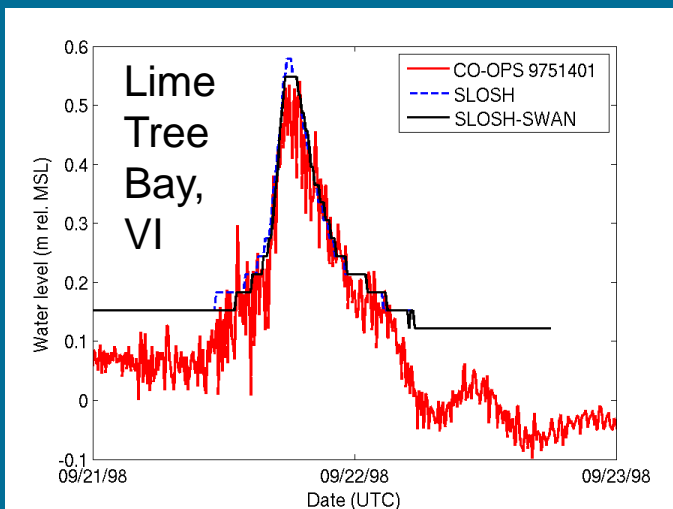
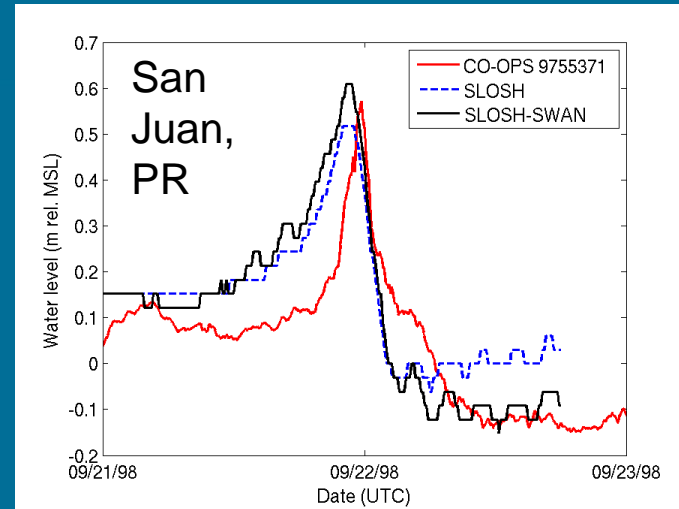
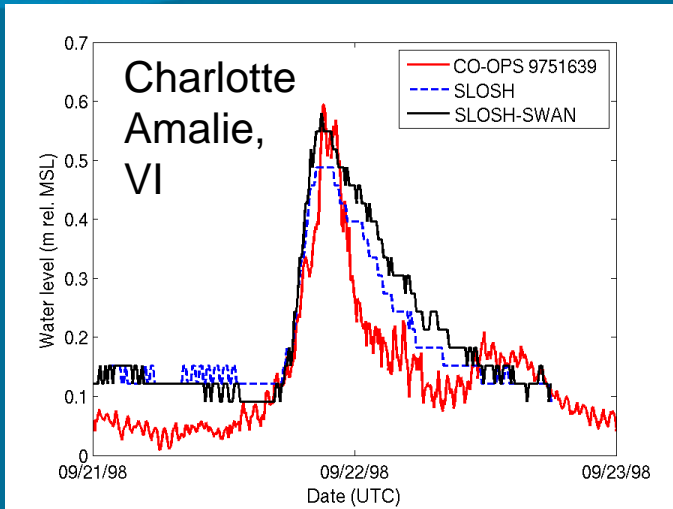






# Case 1: Surge – SLOSH, impact of waves

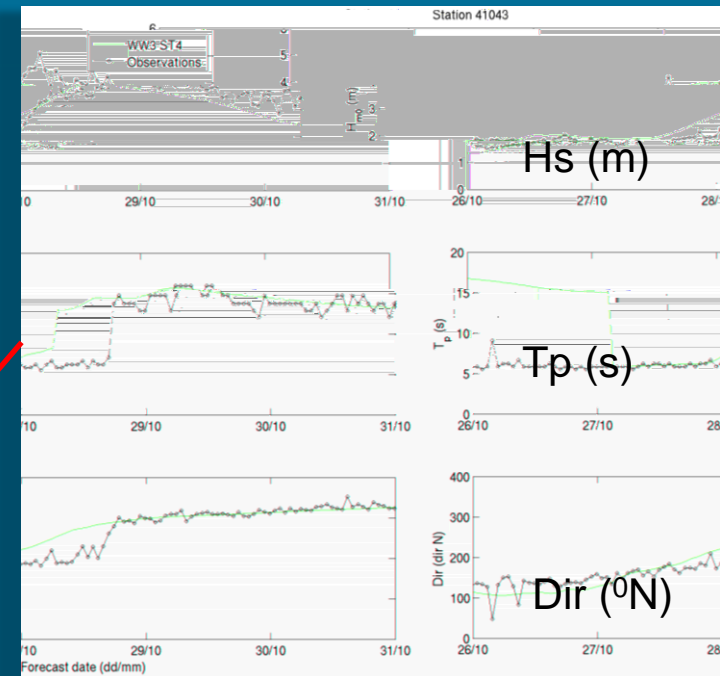
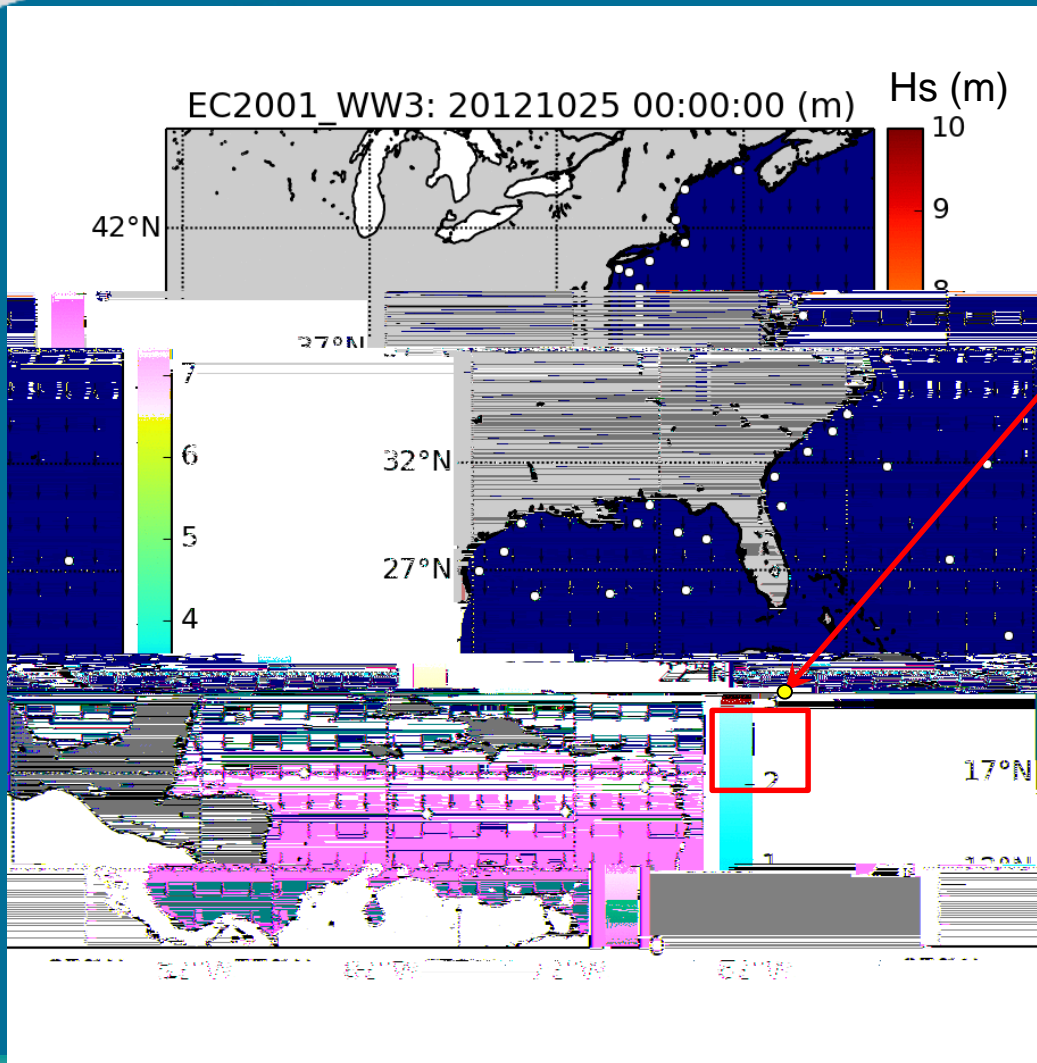
H. George (1998), Asymmetrical vortex model





# Case 3: WW3 Wave field results

## Superstorm Sandy: Waves with CFSR winds



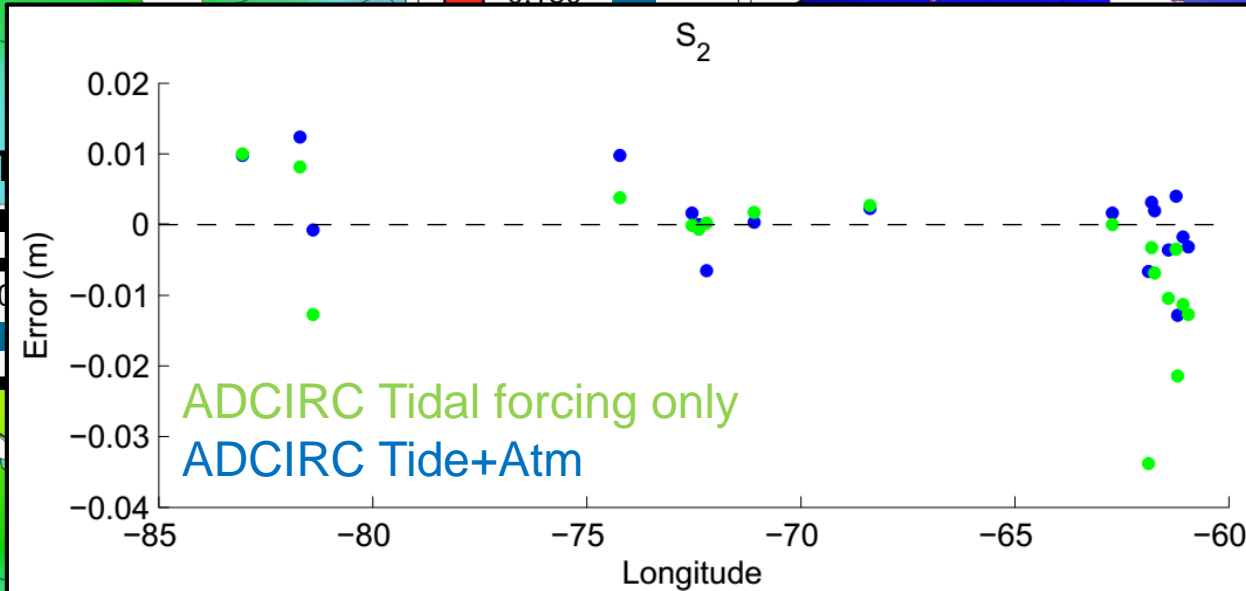
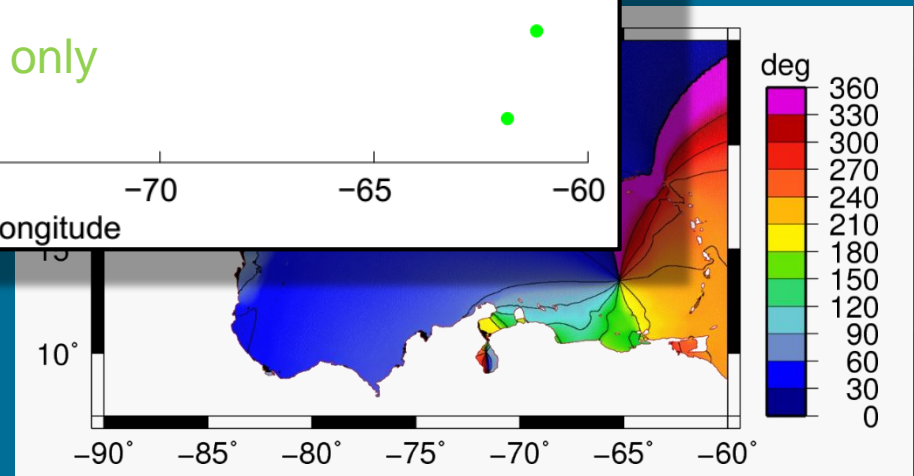
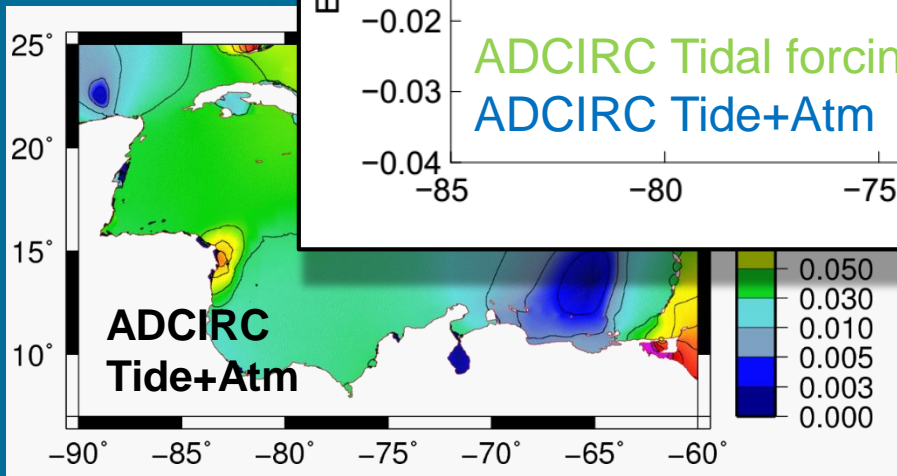
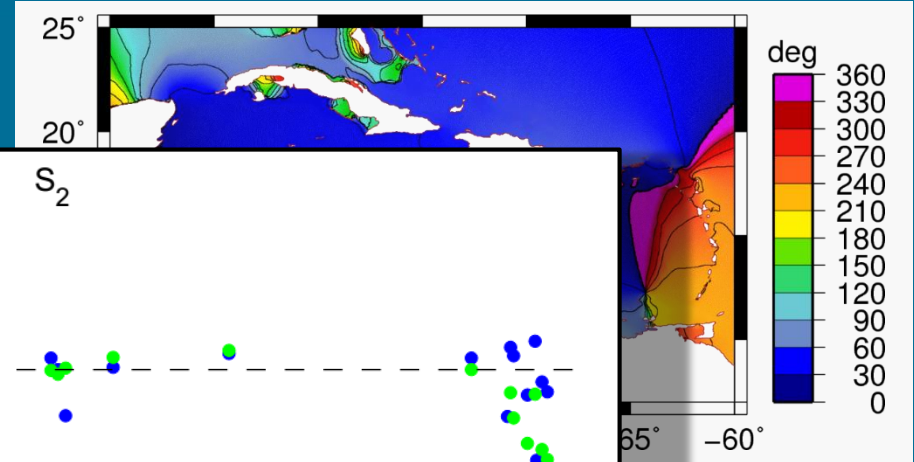
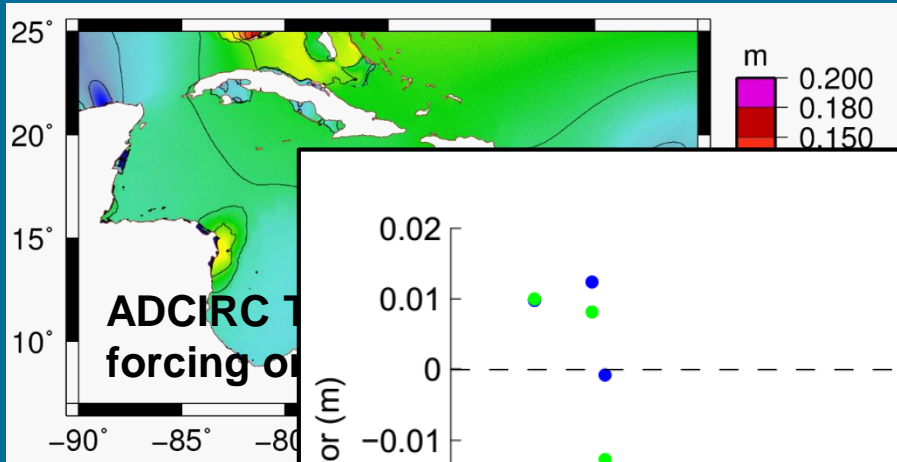


# Sensitivity: Tides & atmospheric effects



## S<sub>2</sub> Constituent (Amplitude)

## S<sub>2</sub> Constituent (Phase)



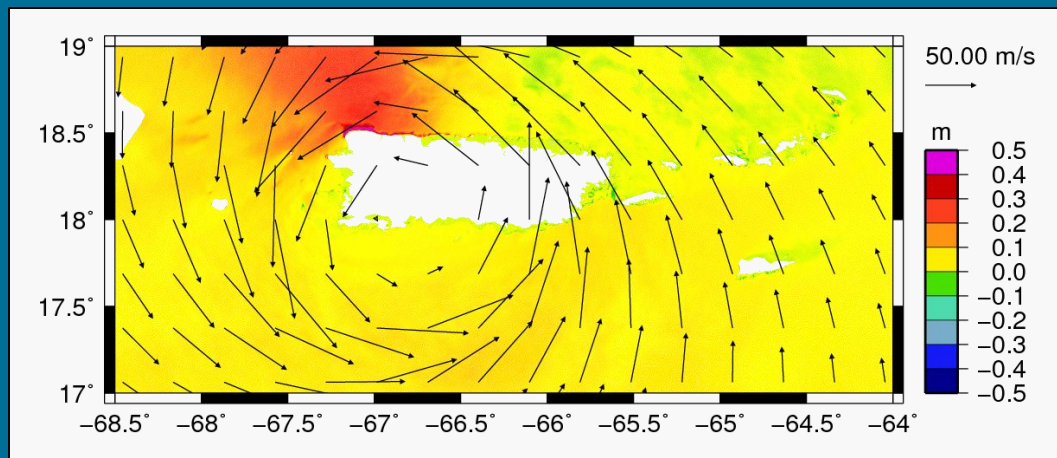
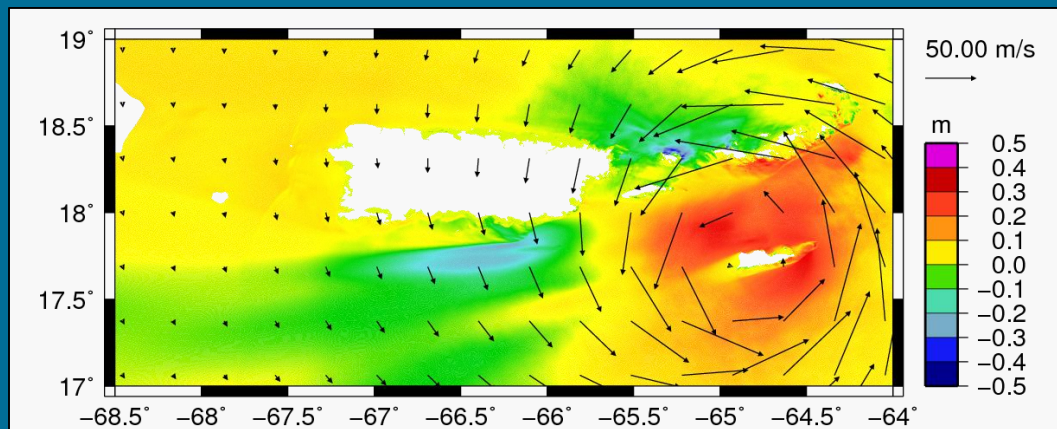


# Sensitivity: Wave model freq. range

## H. Irene: Tropical Storm at landfall



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



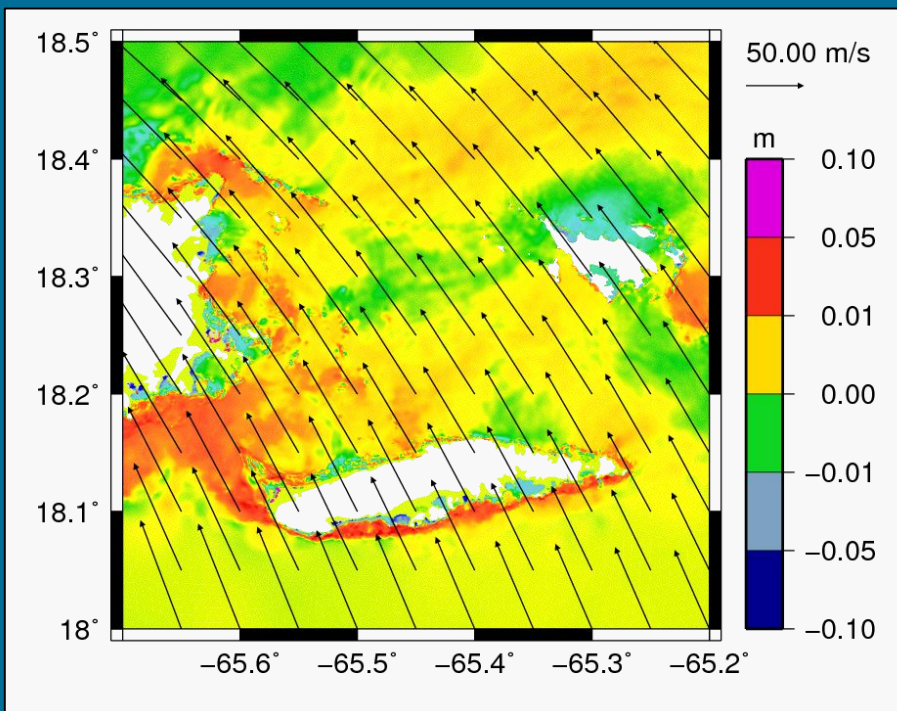
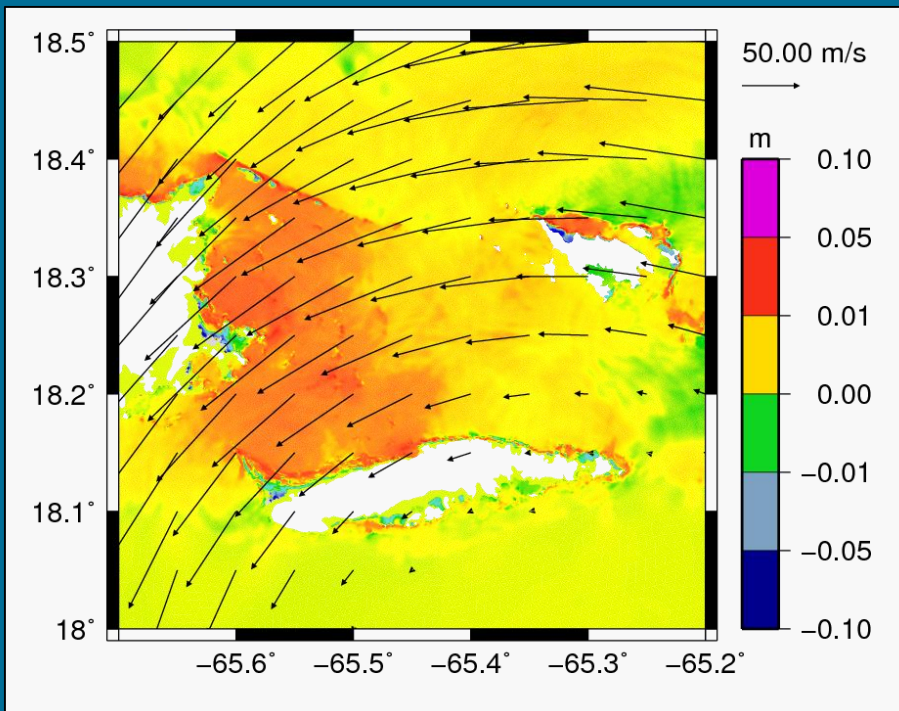


# Sensitivity: Effect of triad interactions

## H. Irene: Tropical Storm at landfall



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



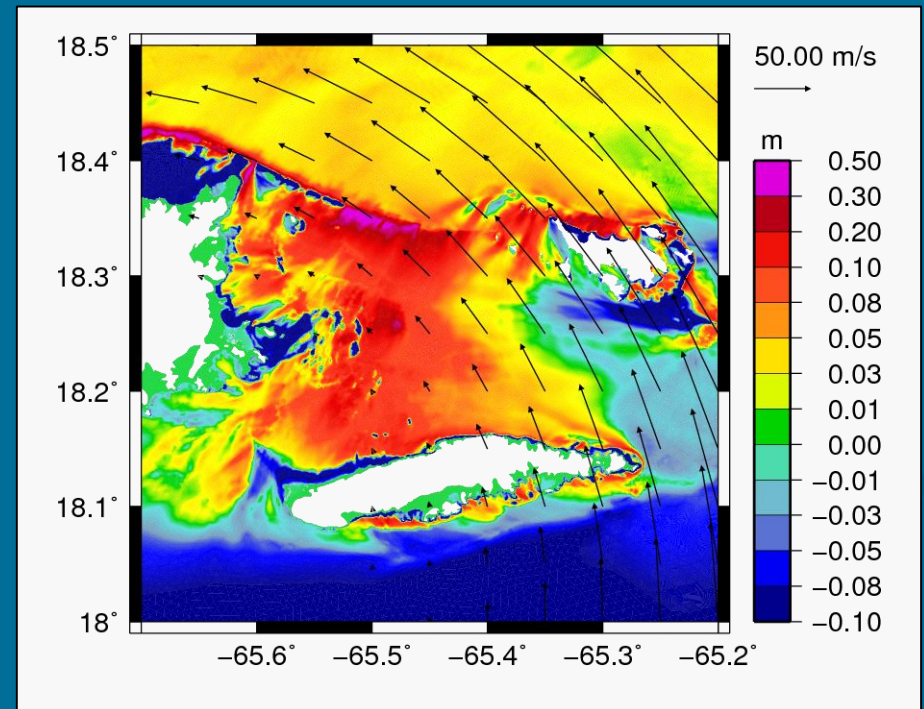
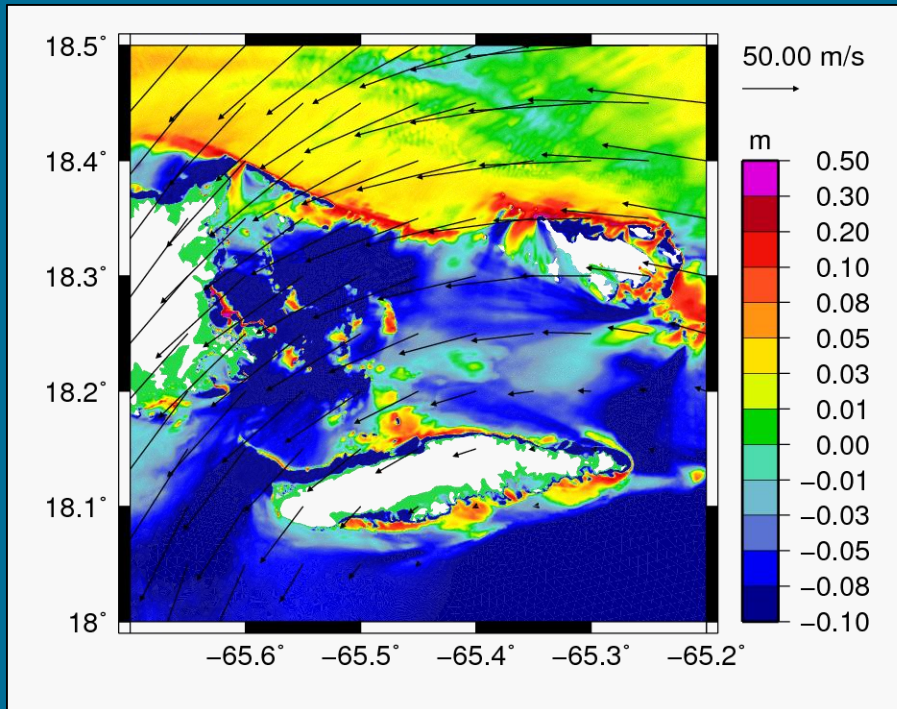
**Difference in surface elevation just around 0.05 m, but effect is clearly driven by reef and shallow features**



# Sensitivity: Effect of triad interactions

## H. Irene: Tropical Storm at landfall

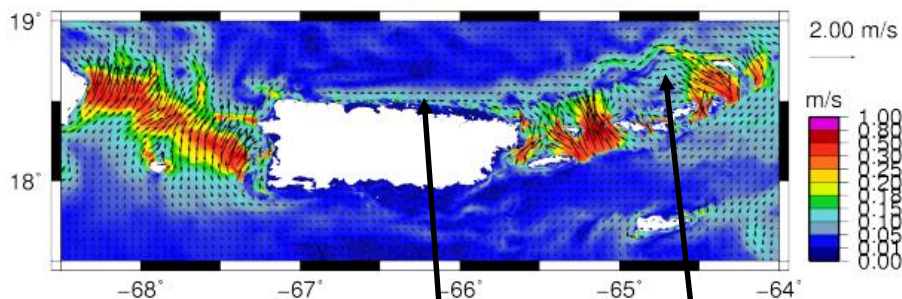
Effect of triads on significant wave height, freq range 0.029-10 Hz



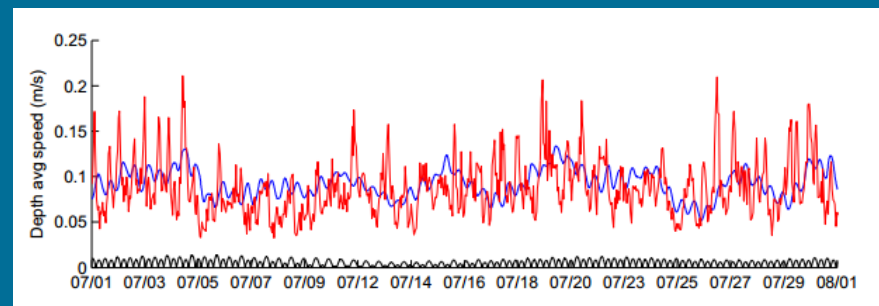
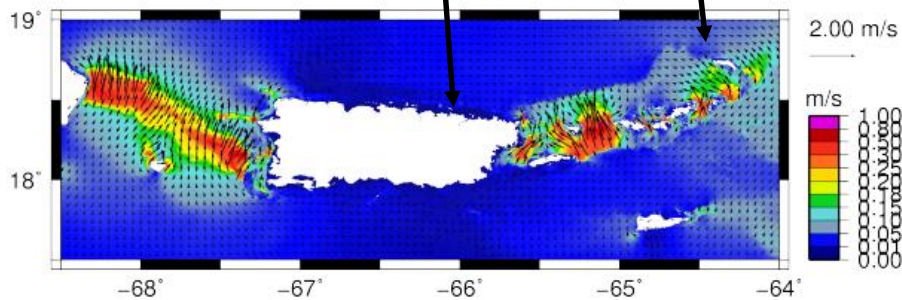
**Very strong signature of reefs, sand banks, underwater features**

# Effect of Atmospheric Forcing on Barotropic Currents

Tidal and Atmospheric Forcing

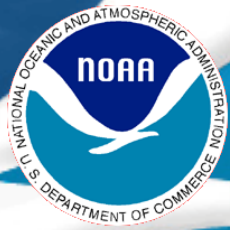


Tidal Forcing Only



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

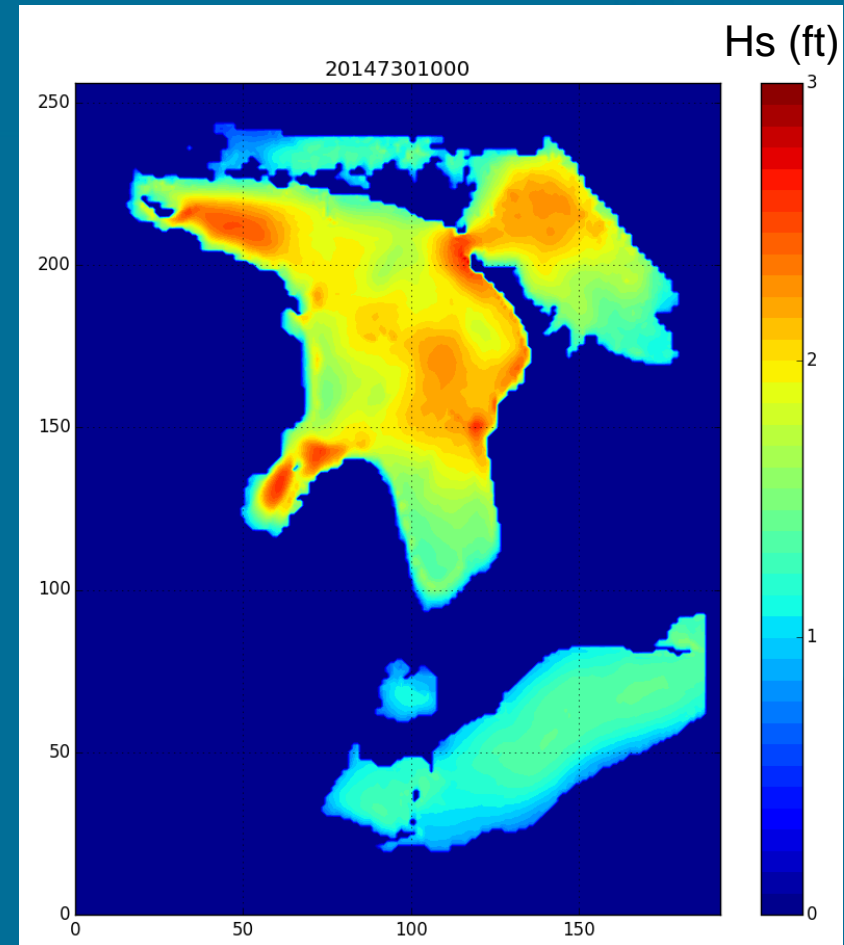
An efficient parametric wave model to couple with SLOSH (within P-Surge)

- Parametric models that reduce full solution space  $N(t,x,y,\sigma,\theta)$ , 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.

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

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

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



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

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

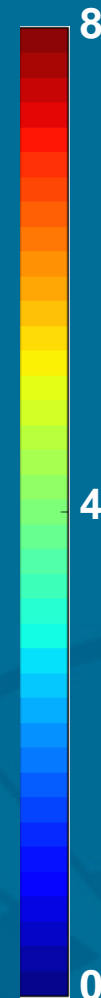
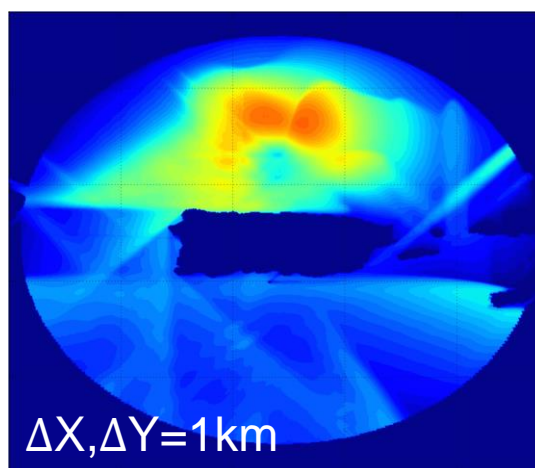
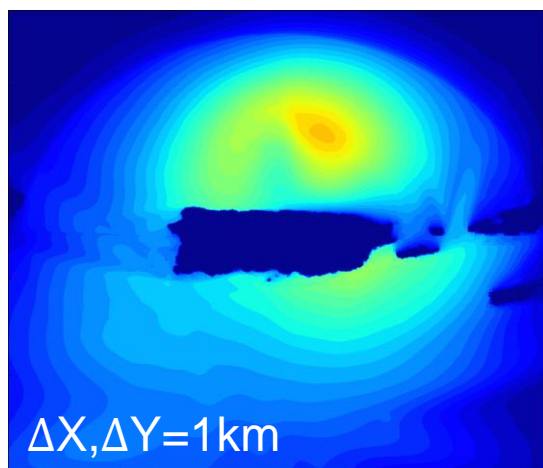
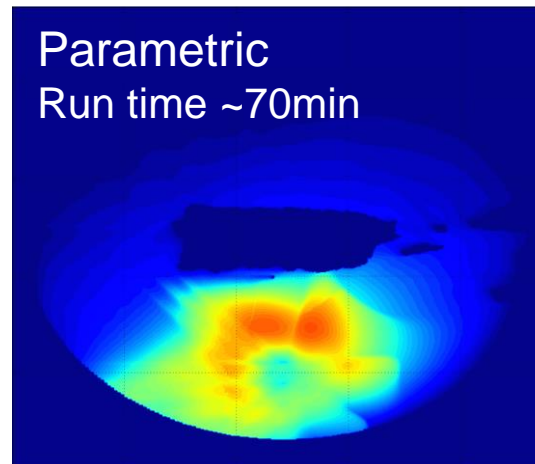
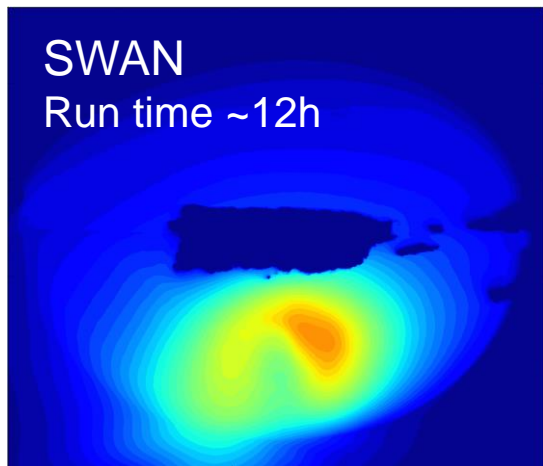




# Parametric wave model results

## Cat 3 Synthetic Storm

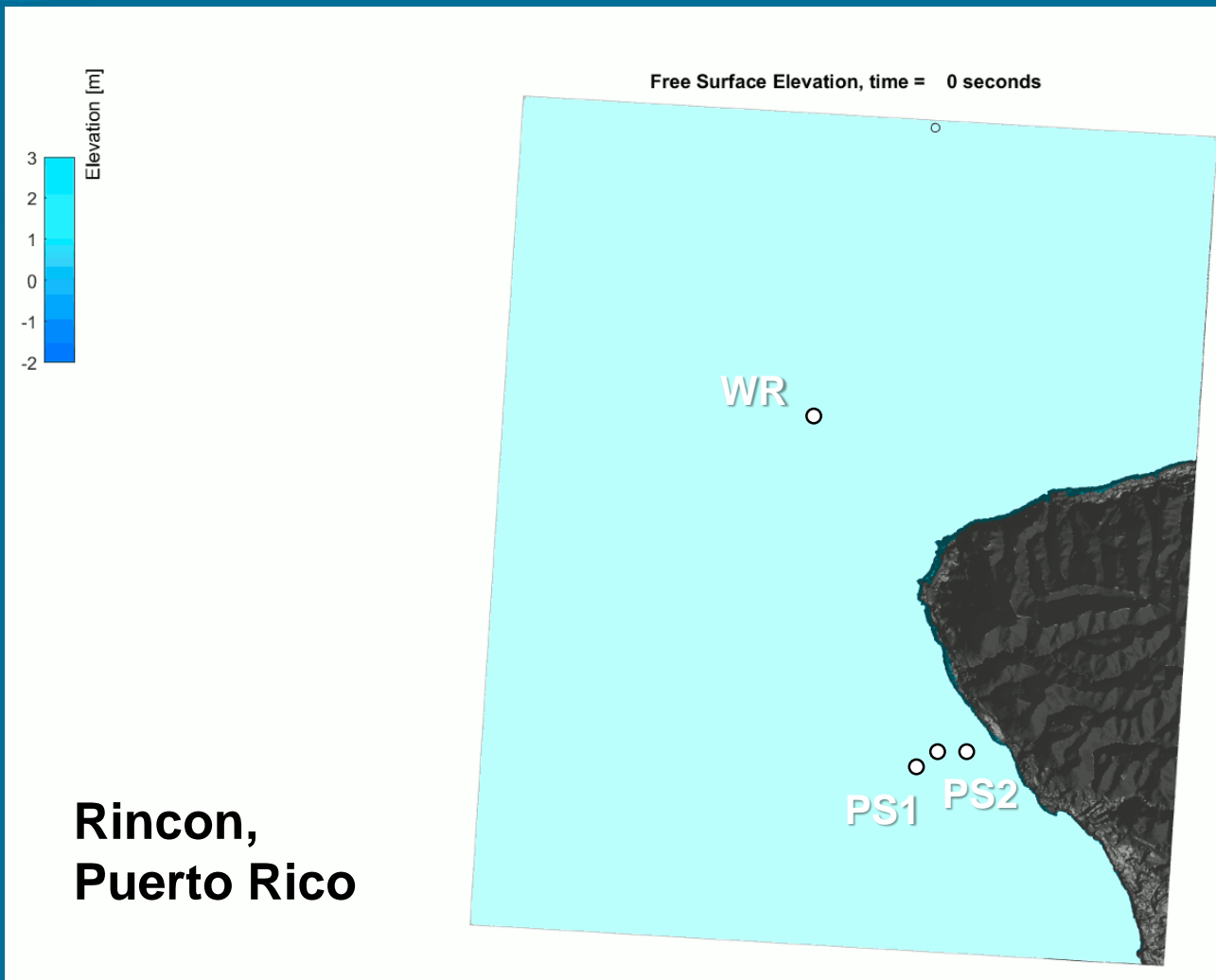
Hs (m)





# BOSZ phase-resolving model

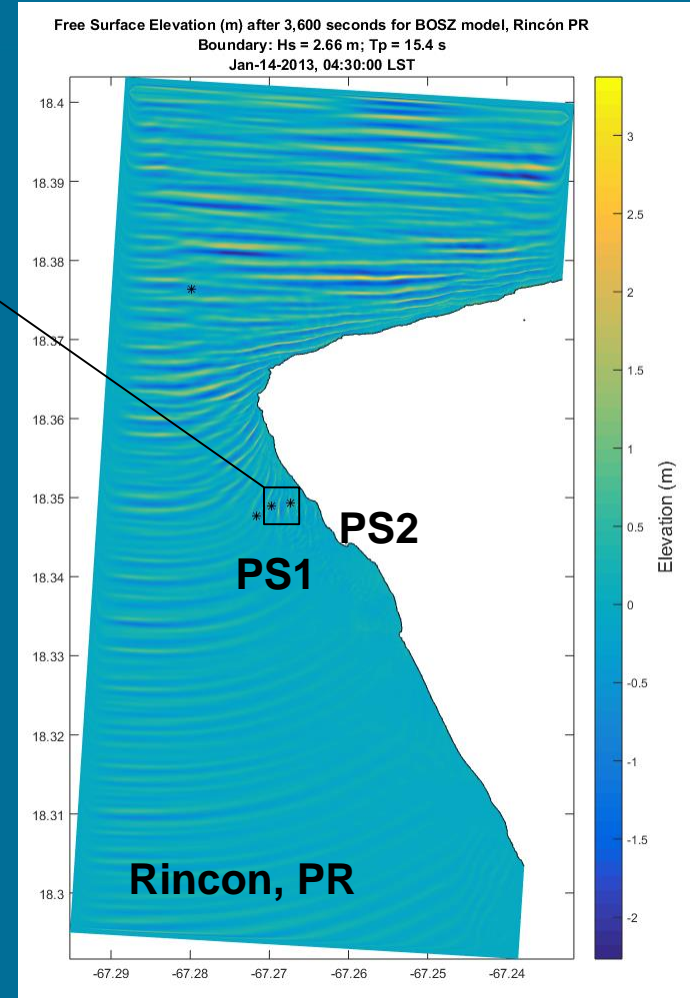
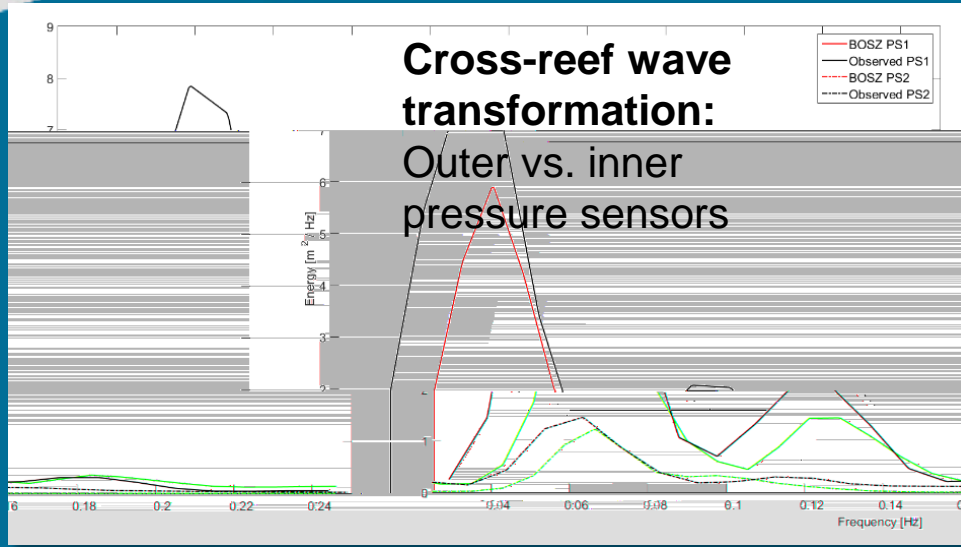
## Swell event, Jan 14, 2013





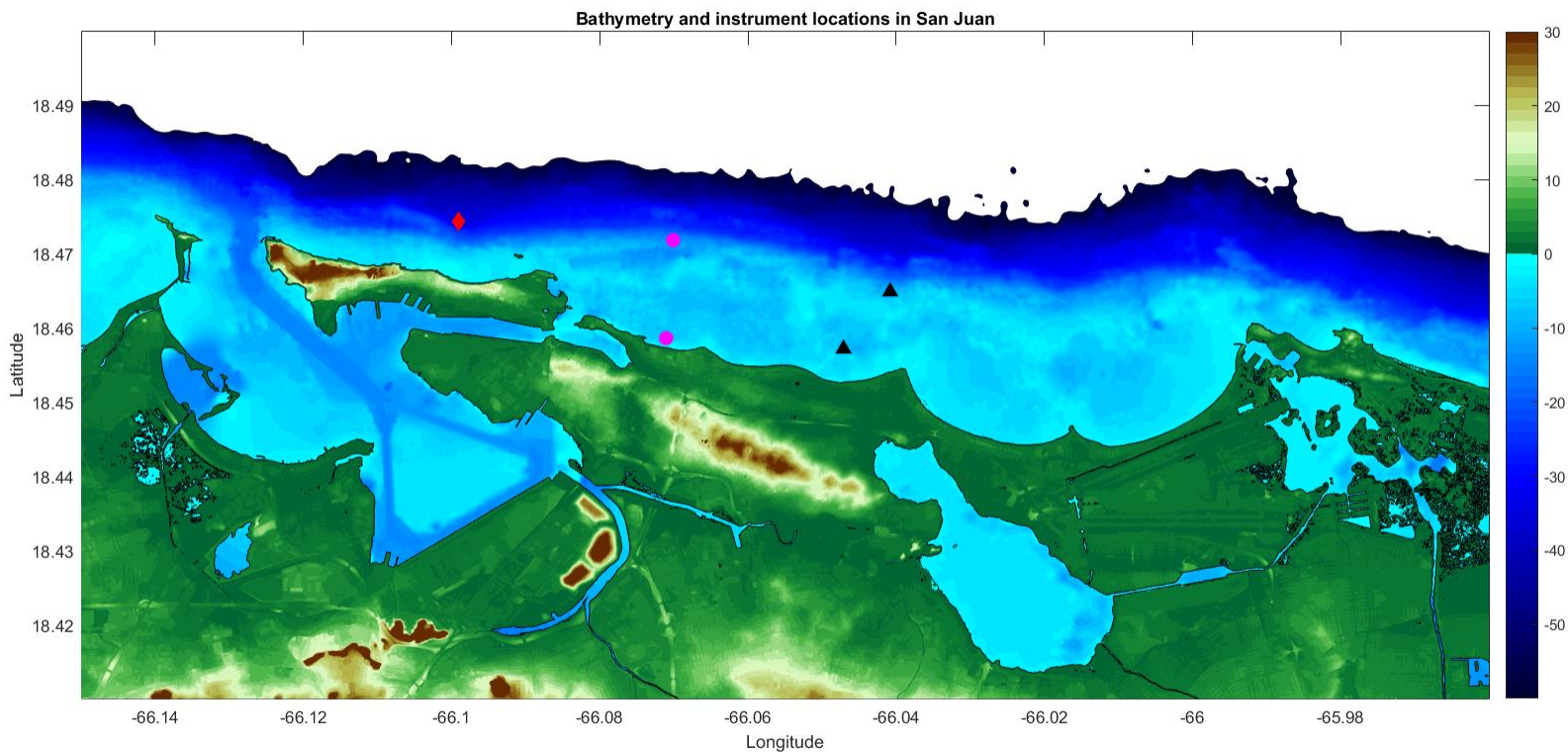
# BOSZ phase-resolving model

## Rincon: Jan 14, 2013, 04:30 LST





# Bathymetry and instrument locations San Juan, PR





# BOSZ phase-resolving model

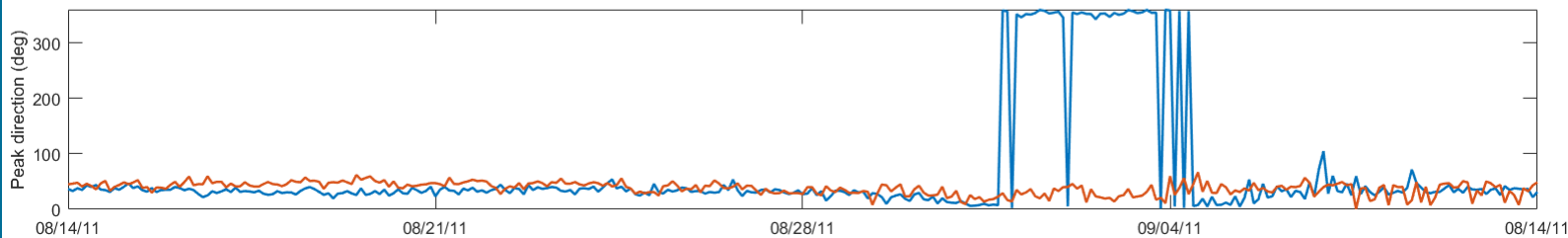
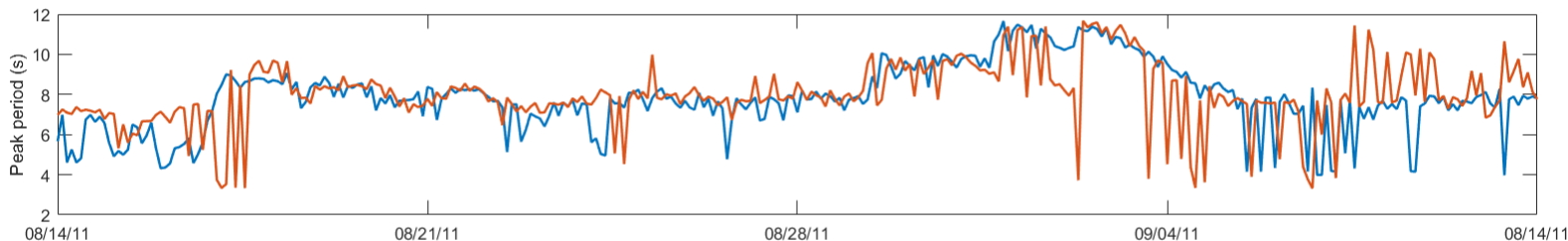
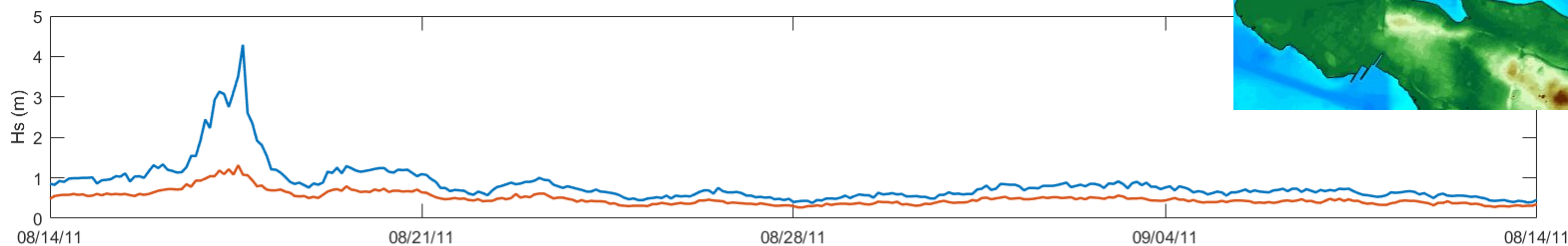
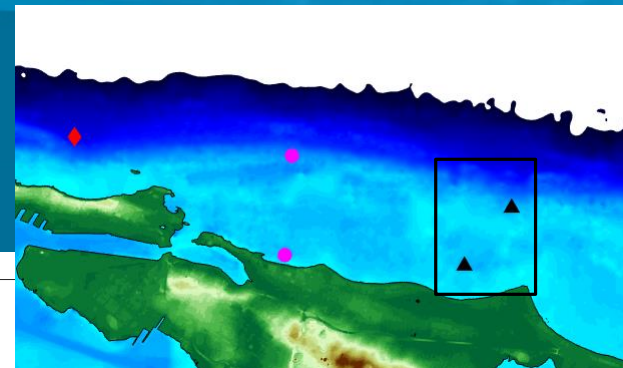
## San Juan: Hurricane Irene, Aug 22, 2011





# BOSZ phase-resolving model

## San Juan: Hurricane Irene



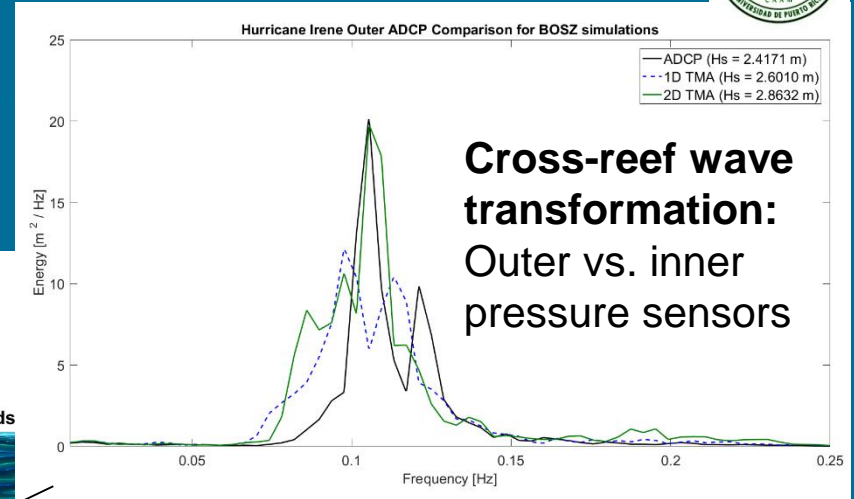
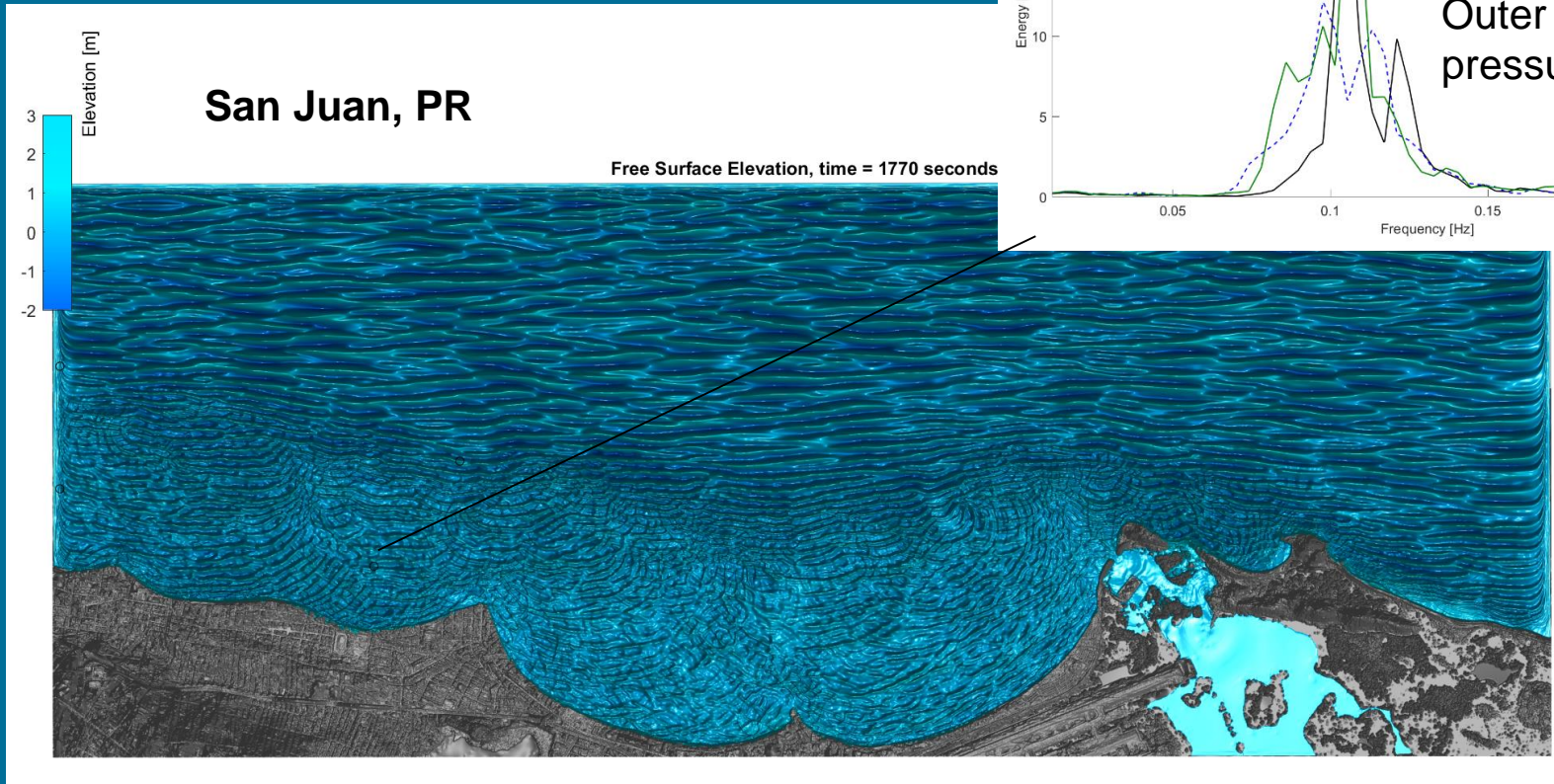
— Outer ADCP — Inner ADCP





# BOSZ phase-resolving model

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





# COMT CyberInfrastructure (CI)

## Presentation/User Interface

### Data Access (eg. OPeNDAP)

OPeNDAP Data

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/Com2/pr\\_mundaton](http://comt.sura.org/thredds/dodsC/Com2/pr_mundaton)

Global Attributes:

- FillValue: -99999.0
- model: ADCIRC
- version: 31.28
- grid\_type: Triangular
- description: PRVI TIDAL

Variables:

- time:** 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

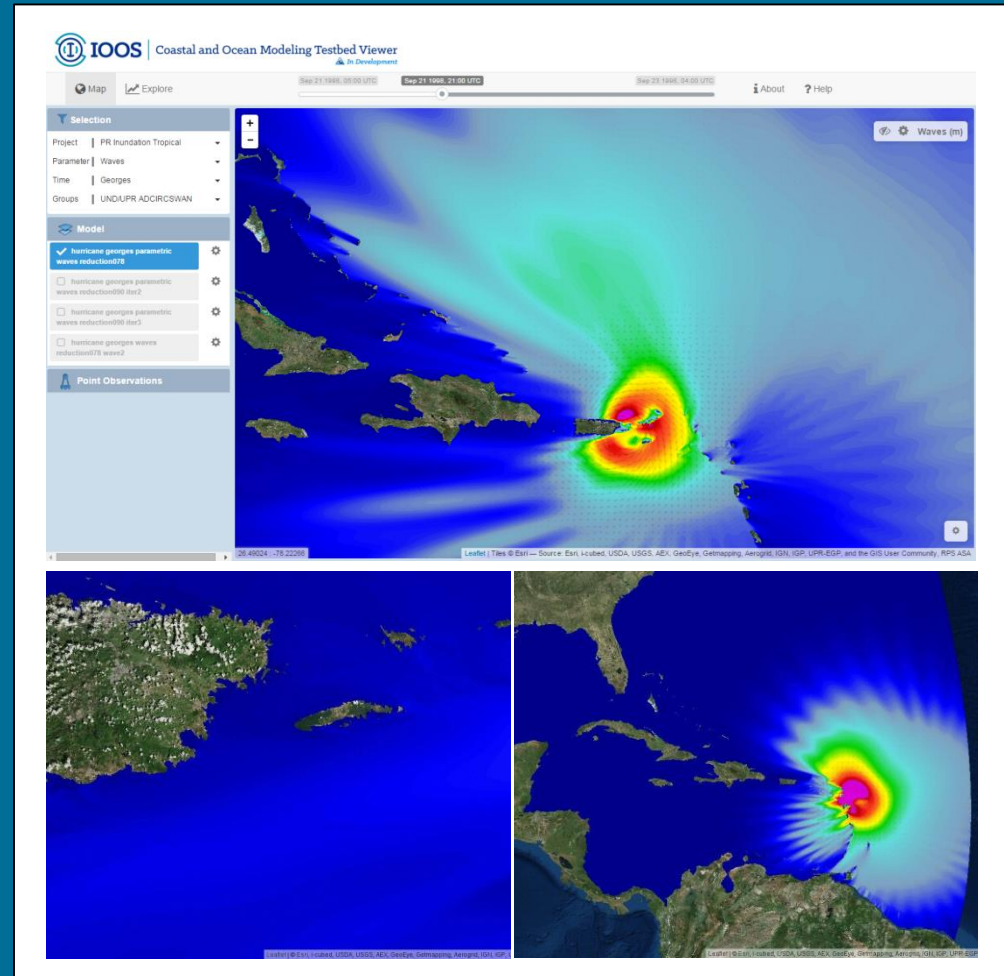
**X:** Array of 64 bit Reals [node = 0.2733257]  
node: [ ]  
long\_name: longitude  
standard\_name: longitude  
units: degrees\_east  
positive: east

**Y:** Array of 64 bit Reals [node = 0.2733257]  
node: [ ]  
long\_name: latitude  
standard\_name: latitude  
units: degrees\_north  
positive: north

**element:** Array of 32 bit Integers [nelt = 0.531]  
nelt: [ ]  
long\_name: element  
of\_role: face\_node\_connectivity  
part\_index: 1  
units: nondimensional

**adcirc\_mesh:** Array of 32 bit Integers [mesh]  
mesh: [ ]  
long\_name: mesh\_topology  
of\_role: mesh\_topology  
topology\_dimension: 2  
node\_coordinates: x y  
face\_node\_connectivity: element

**neta:** 32 bit Integer  
neta = [ ]  
long\_name: total number of elevation spect  
units: nondimensional



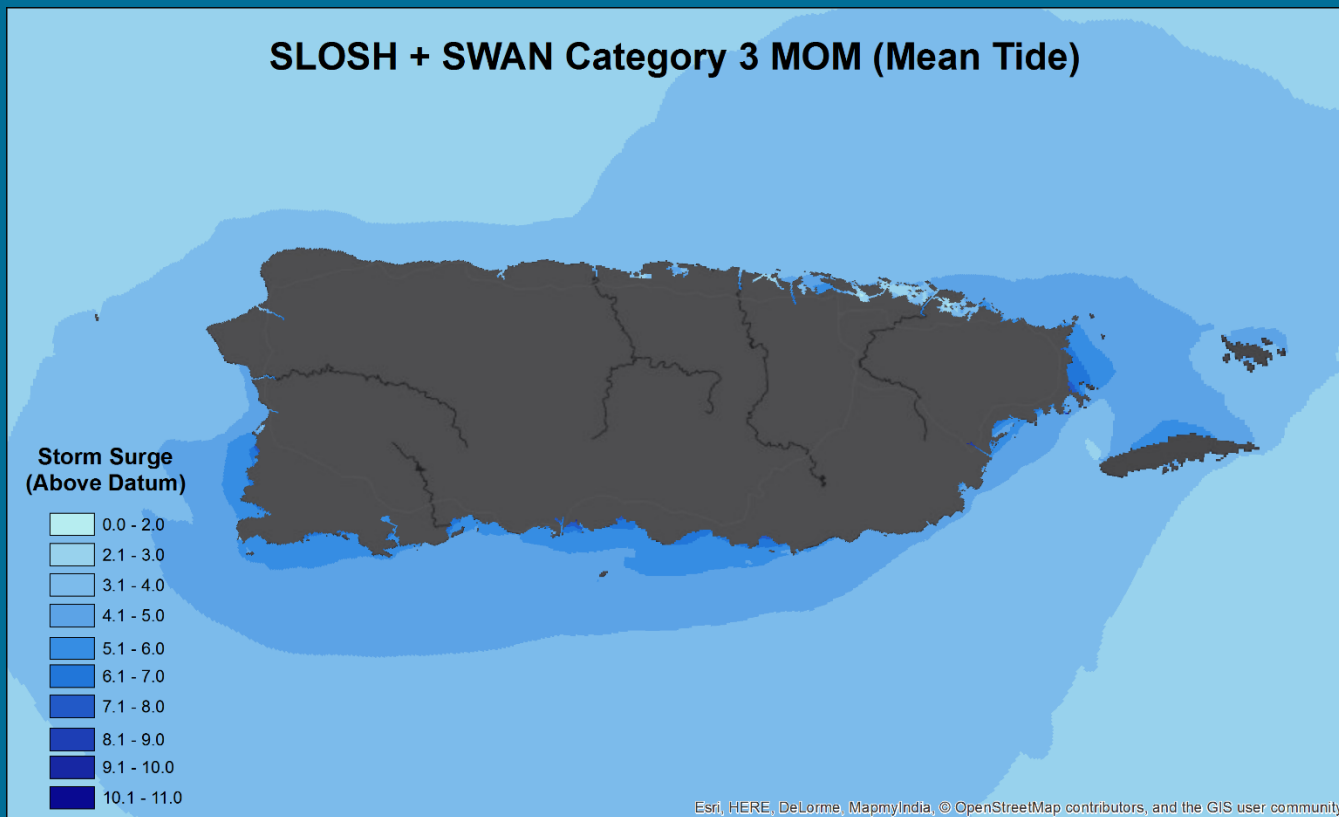




# Transition to Operations

## 1. Storm surge envelopes

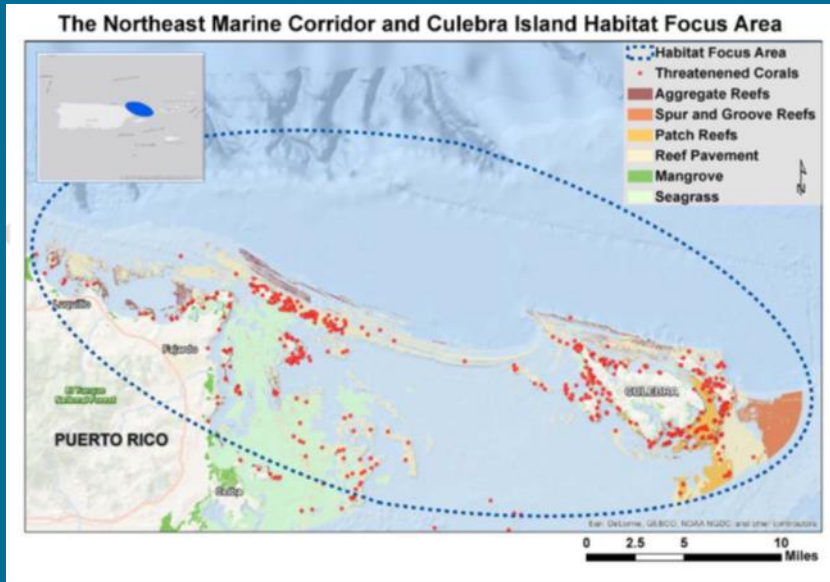
First-ever Maximum of Maximums (MOM) surge hazard database produced for Puerto Rico, using coupled SLOSH+SWAN. To be used for evacuation planning and response.





# 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. R20: 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.

