Application of an Efficient Second-Generation Wave Model to Coupled Surge Modeling

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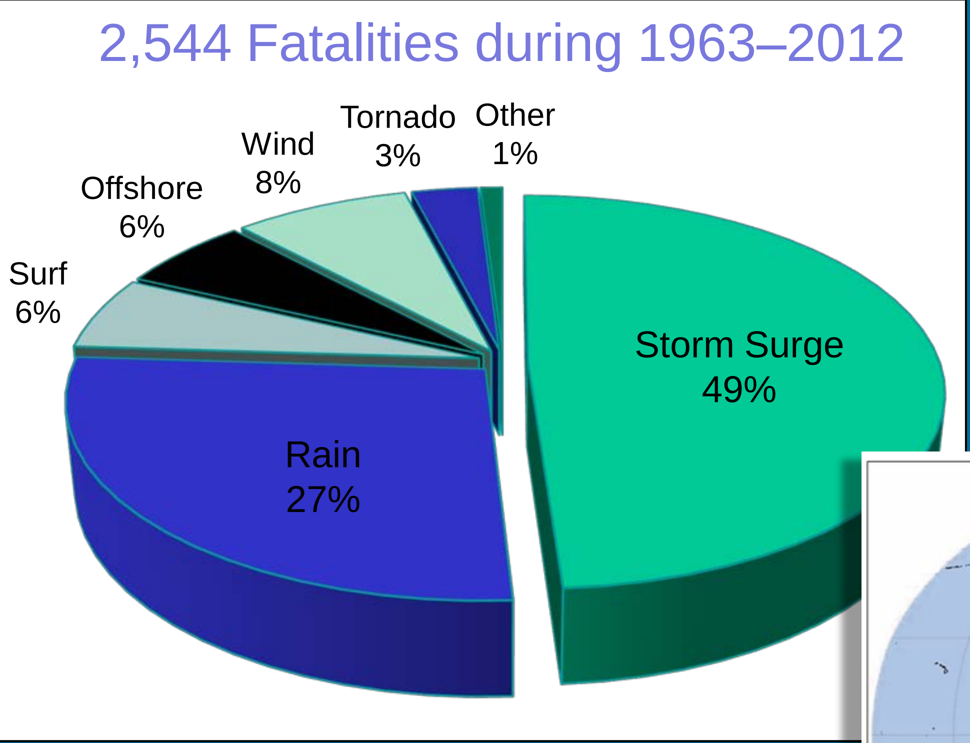
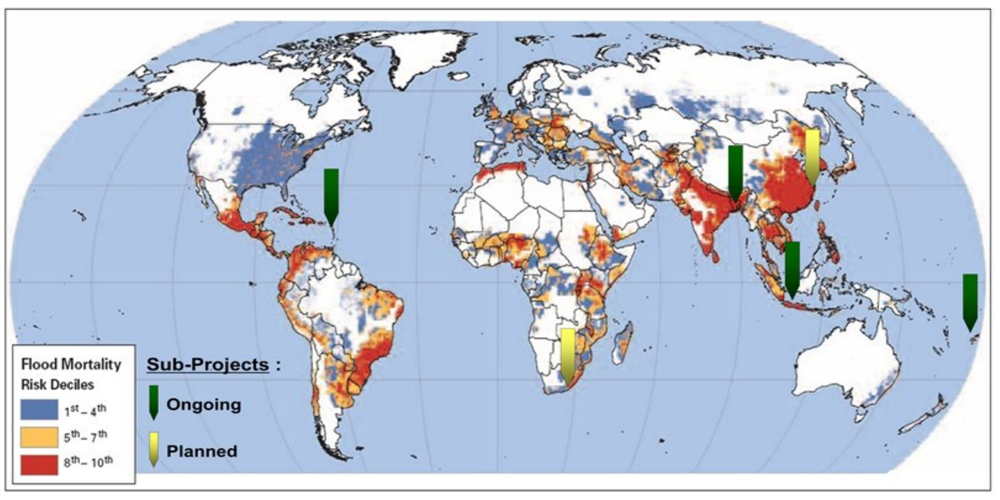
WMO Coastal Inundation & Flooding Demonstration Projects



- ***Almost 50% of hurricane deaths in US are due to storm surge***
- ***Over 80% of deaths are due to water***
- ***Wind causes less than 10% of deaths***

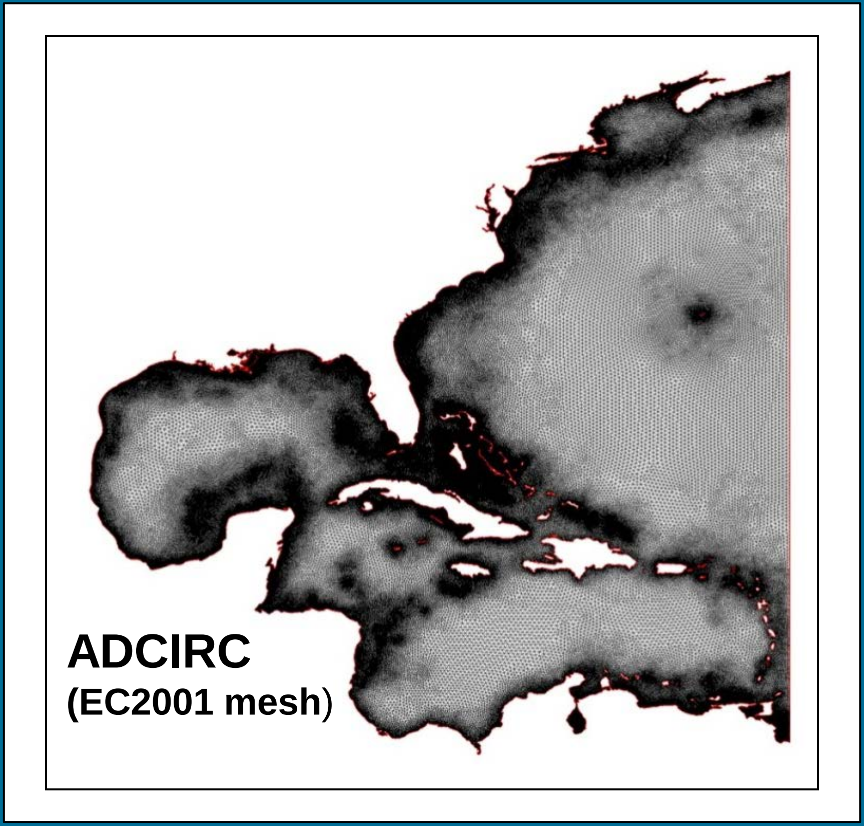
Demonstration project sites

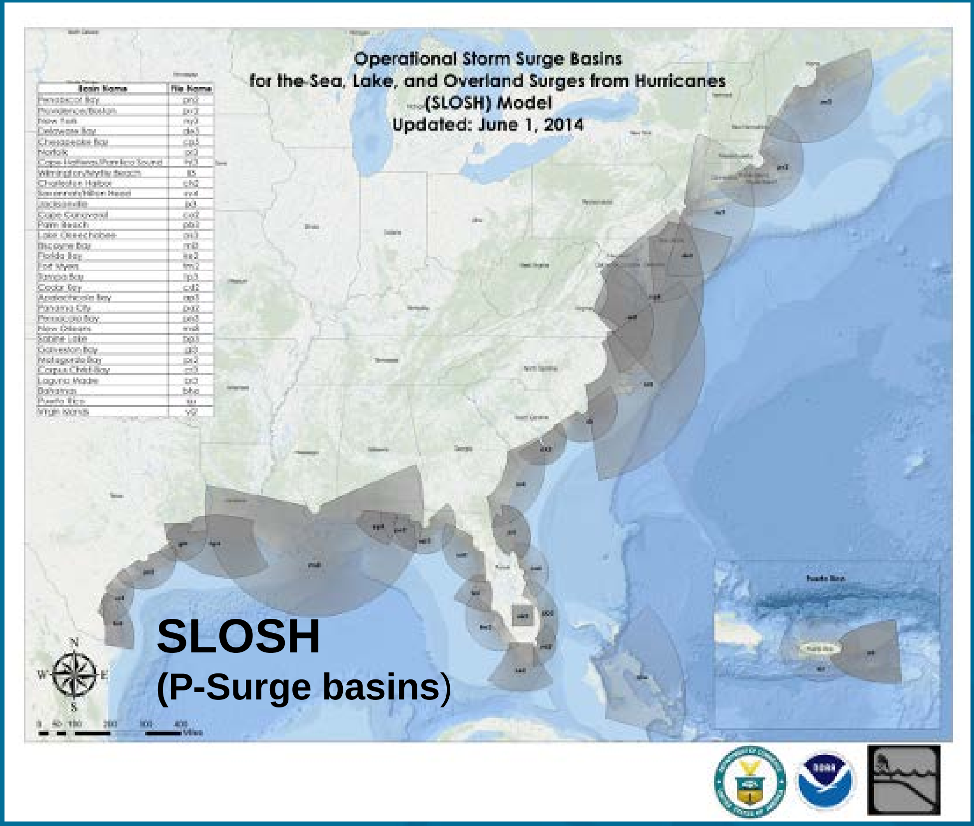


Edward N. Rappaport, 2014: Fatalities in the United States from Atlantic Tropical Cyclones: New Data and Interpretation. Bull. Amer. Meteor. Soc., 95, 341–346.

Storm surge modeling options

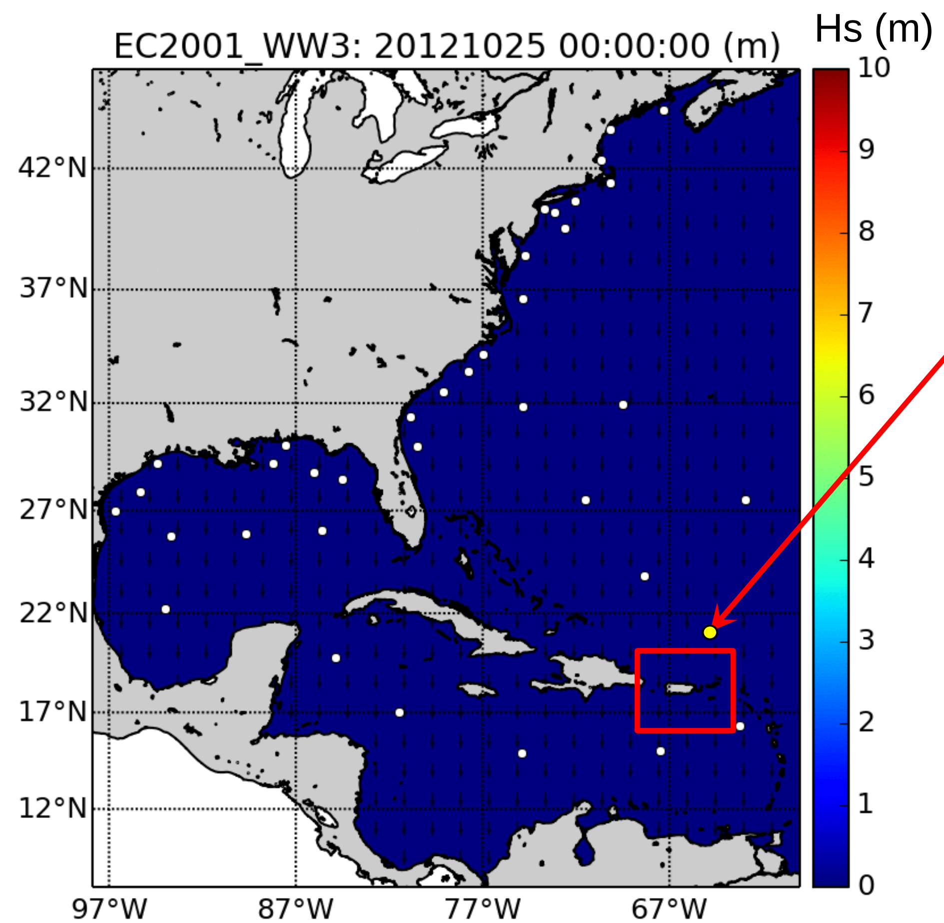
NOAA currently applies both the state-of-the-art **ADCIRC** model (deterministic guidance) and the fast and efficient surge model **SLOSH** (probabilistic guidance). However, neither of these modeling systems at NOAA has been configured with wave effects or specific focus on island environments.

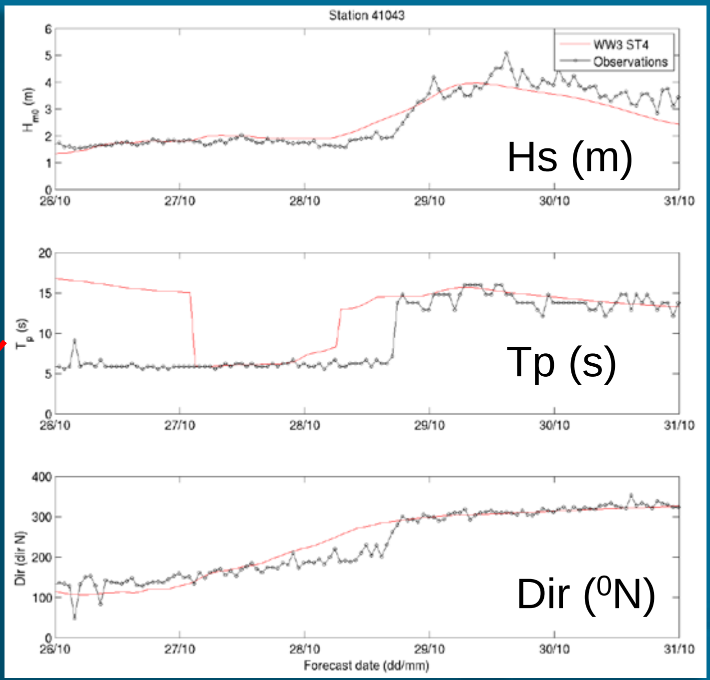




3rd Gen Unstructured WW3

Superstorm Sandy: Waves with CFSR winds





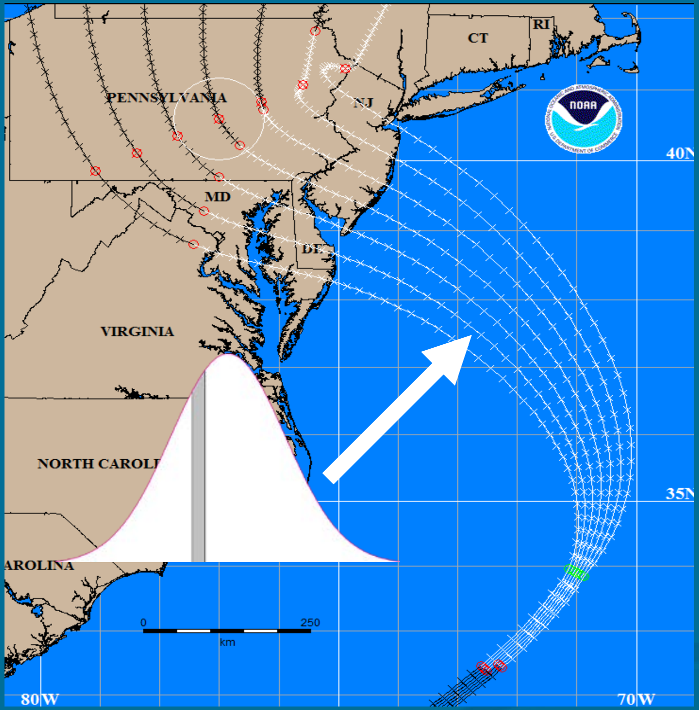
Tropical operations: TCM and P-Surge

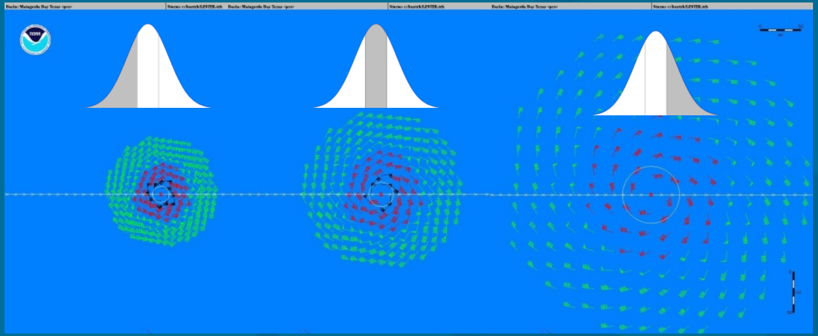
Derive probabilistic guidance from an ensemble of SLOSH model runs

- Ensemble centered on NHC's official advisory
- Error spaces (except size) are based on normal distribution with 5-y MAE = 0.7979 sigma

Hurricane forecast error spaces considered

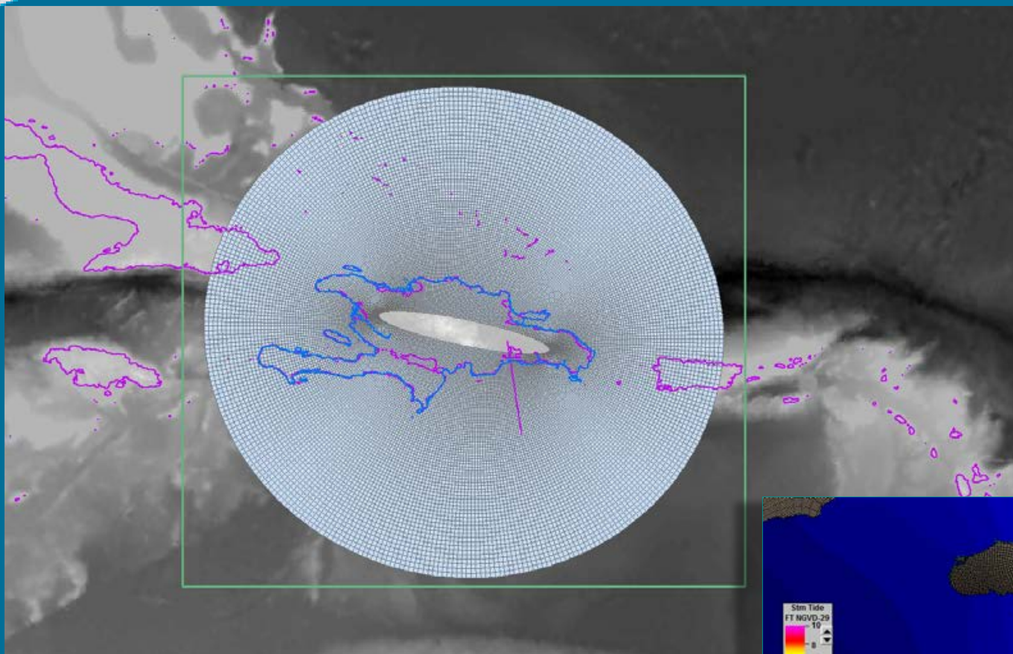
- Cross track
- Along track (or Forward Speed)
- Intensity
- Size of the storm



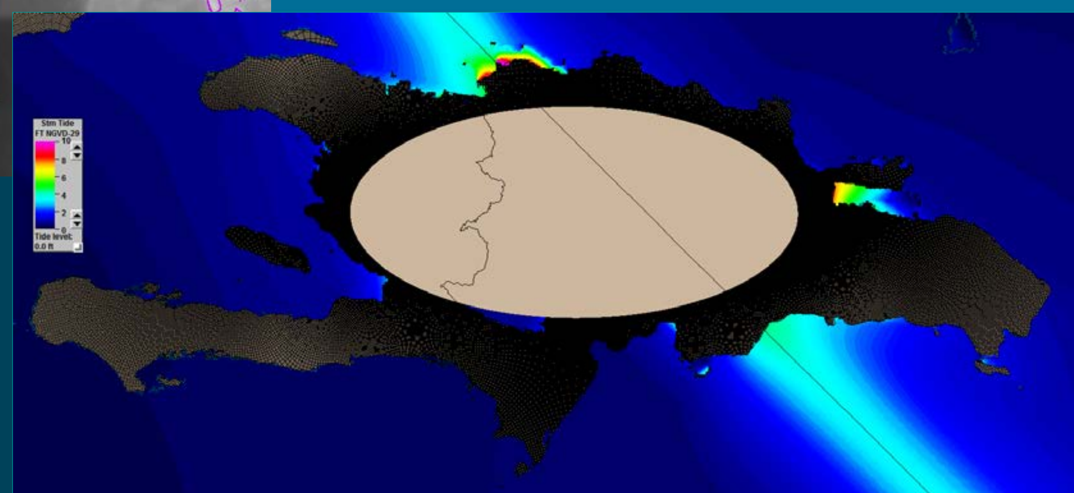


SLOSH mesh for Hispaniola

Preliminary mesh: 1,653,750 nodes
Avg. coastal res.: 250-500 m



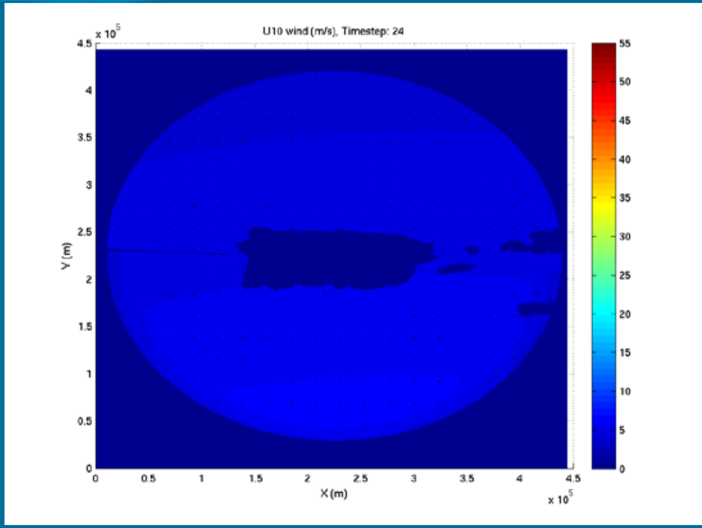
Category 5 Hurricane
Moving NW at 20 mph



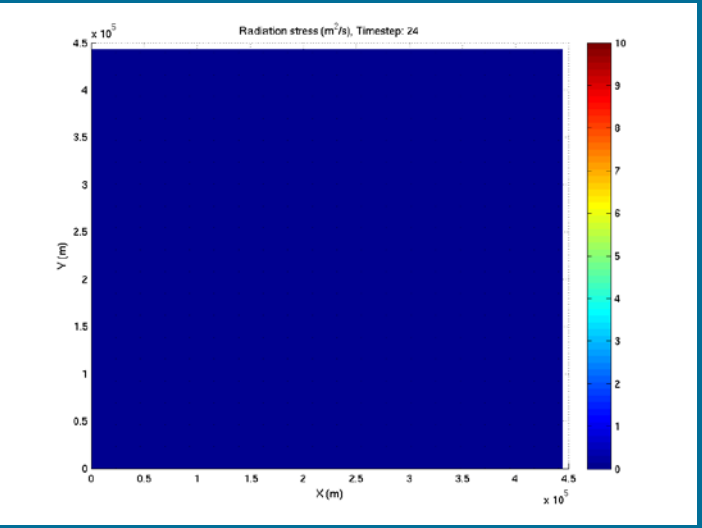
Wave coupling: SLOSH-SWAN (D. Slinn)

Cat 5 storm synthetic storm (MEOW element)

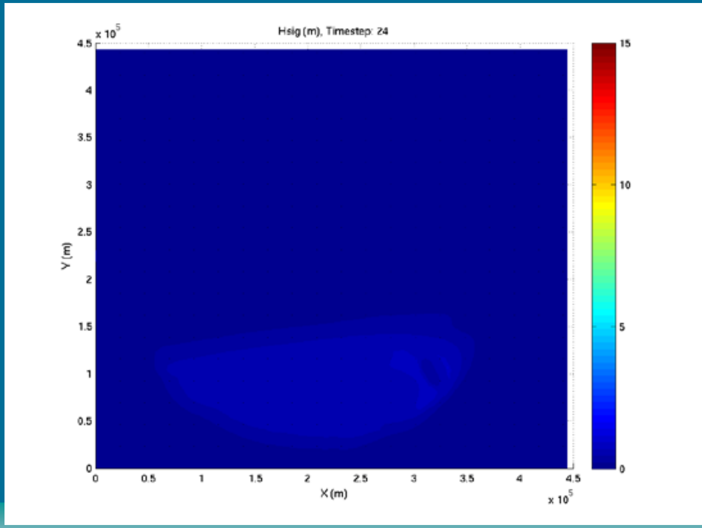
U10 wind



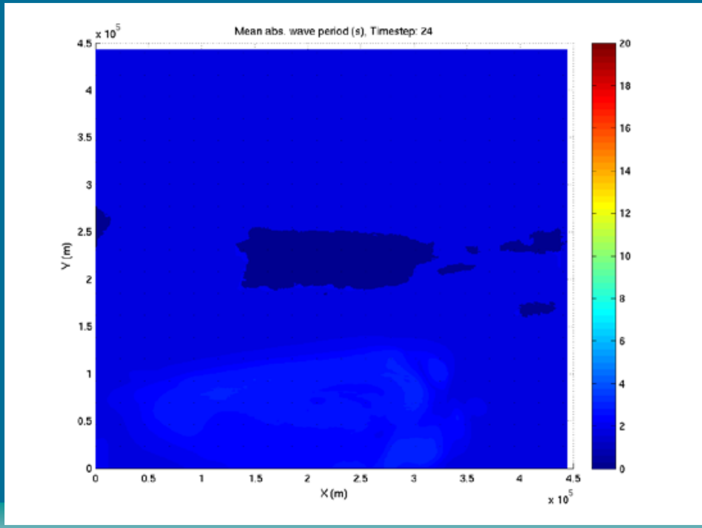
Radia-tion stress



Sign. Wave height

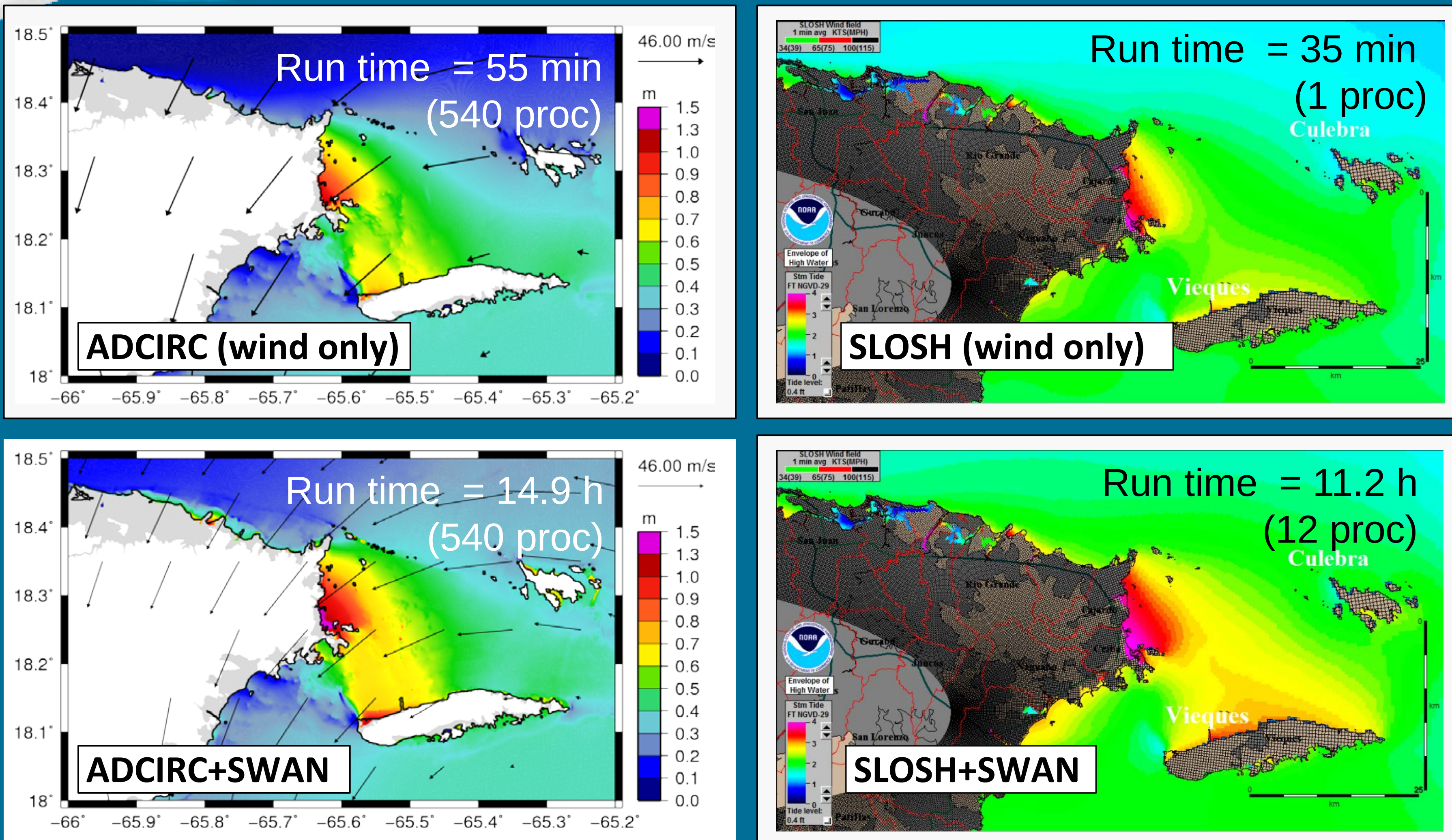


Mean Period



IOOS COMT testbed: ADCIRC vs. SLOSH

H. George (1998), Cat 4, landfall NE Puerto Rico (48 h sim)



Second-generation wave model

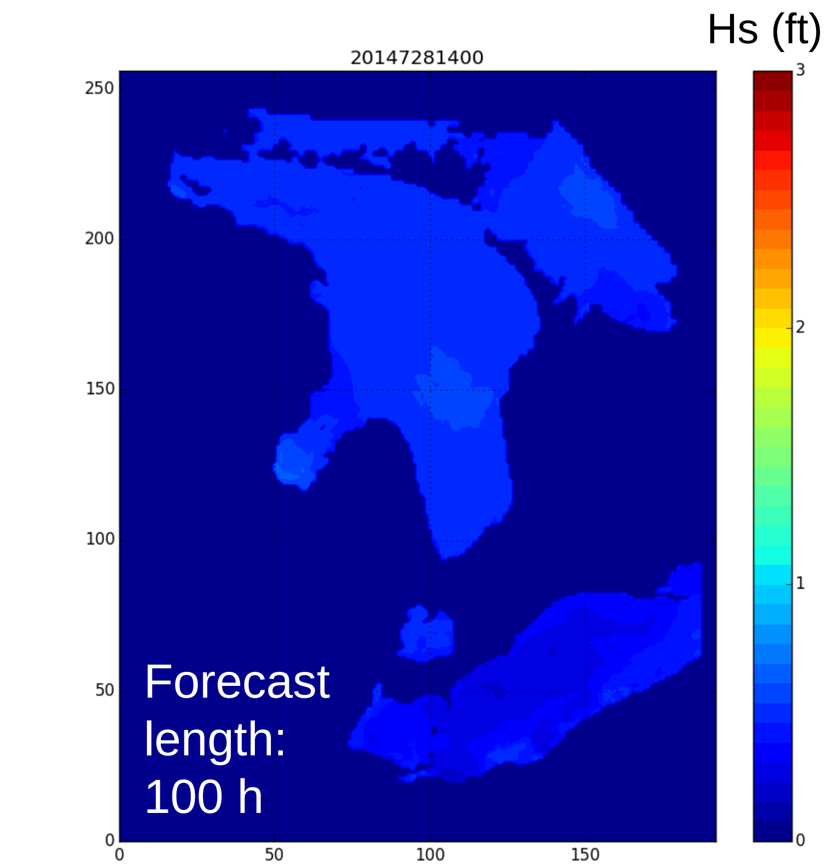
An efficient parametric wave model to couple with SLOSH (within P-Surge)

- 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.
- Separate propagation and wave growth steps
- More suitable for *real-time* application with SLOSH

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

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

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



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.

Reformulation in terms of energy balance

Energy balance
(in x,y components):

$$\frac{\partial E_x}{\partial t} + \frac{\partial C_{g,x} \cdot E_x}{\partial x} + \frac{\partial C_{g,y} \cdot E_x}{\partial y} = S_{wind,x}$$

$$\frac{\partial E_y}{\partial t} + \frac{\partial C_{g,x} \cdot E_y}{\partial x} + \frac{\partial C_{g,y} \cdot E_y}{\partial y} = S_{wind,y}$$

Source term
(based on
Snyder et al. 1981):

$$S_{wind}(\theta, \sigma) = \alpha(\theta, \sigma) + \beta(\theta, \sigma) \cdot E$$

$$\alpha(\theta, \sigma) = \frac{1.5 \times 10^3}{g^2 \cdot 2\pi} [u_* \cdot \cos(\theta - \theta_{wind})]^4 \cdot G$$

$$G(\sigma) = \exp\left[-\left(\frac{\sigma}{\sigma_{PM}^*}\right)^{-4}\right], \qquad \sigma_{PM}^* = 2\pi \cdot \frac{0.13 \cdot g}{28 \cdot u_*}$$

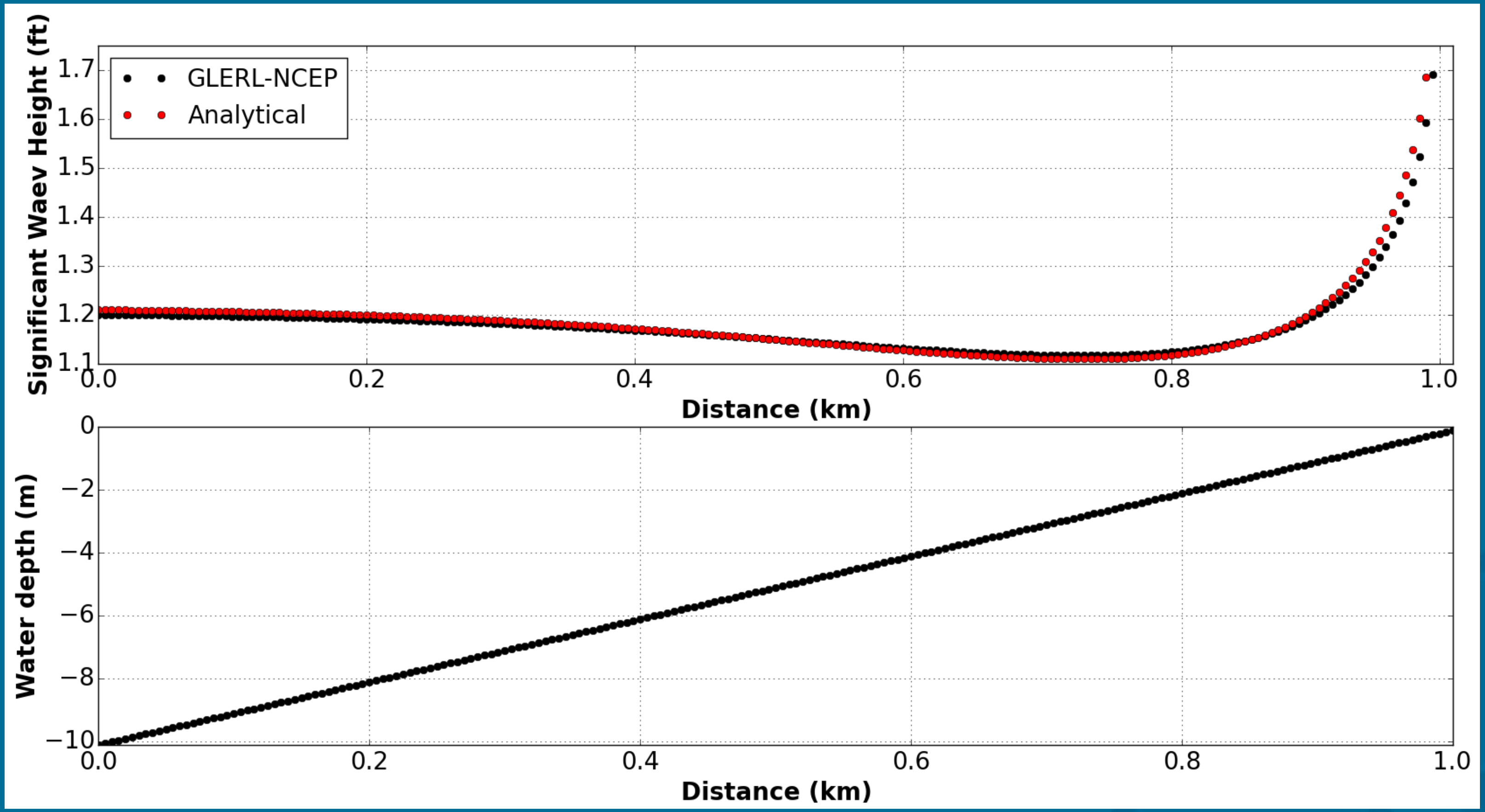
$$\beta(\theta, \sigma) = \boxed{0.18} \cdot \frac{\rho_{air}}{\rho_{water}} \cdot [28 \cdot \frac{u_*}{C_p} \cdot \cos(\theta - \theta_{wind}) - 1] \cdot \sigma$$

Shape relation
(based on Kahma &
Calkoen 1994):

$$f = 3.08 \cdot (\frac{(6.5 \times 10^{-4})^3 \cdot g^4 \cdot {u_*}^2}{E^3})^{0.1}$$

$$\sigma = 2\pi \cdot f$$

Wave kinematics: Shoaling



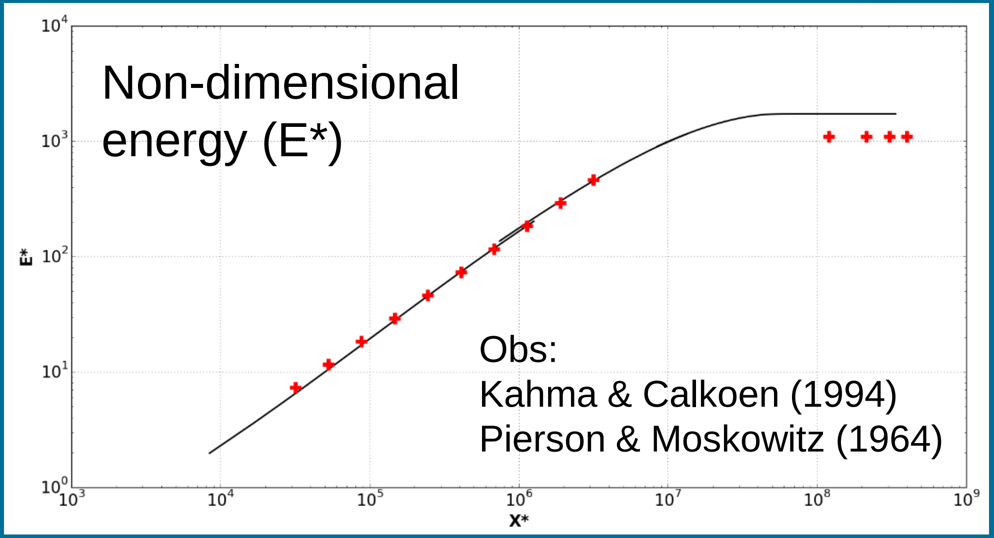
Wave dynamics: Deep-water growth

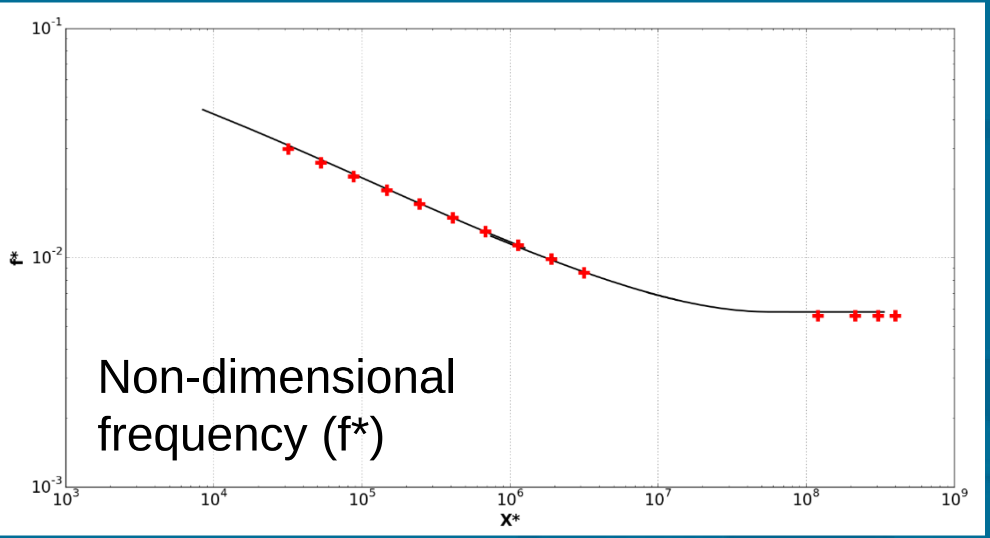
Wind Forcing:
- Spatial Uniform
- Temporal Constant
- U_{10} = 30 m/s

$$X^* = \frac{g \cdot X}{U_*^{\,2}}$$

$$E^* = \frac{g^2 \cdot E}{U_*^{\,4}}$$

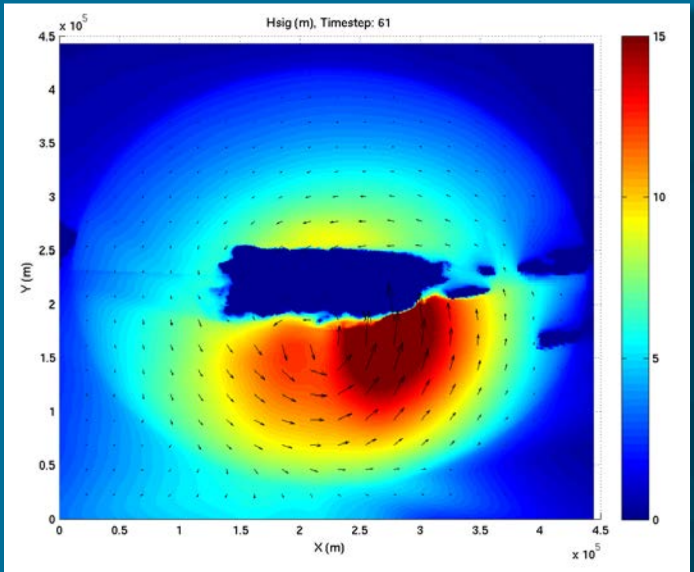
$$f_p^* = \frac{f_p \cdot U_*}{g}$$





Next steps

- Validate newly-formulated 2nd gen wave model for realistic hurricane field cases.
- Implement shallow water physics (refraction, depth-induced breaking).
- Couple 2nd gen code to SLOSH as an imbedded subroutine.
- Conduct validation of coupled model using cases from the IOOS COMT Puerto Rico testbed and Hispaniola.
- Produce MEOWs and MOMs with the efficient coupled model



Conclusions

- Probabilistic storm surge prediction (100s of model runs) requires optimizing the numerical efficiency and parameterization of model physics.
- GLERL model (Schwab et al. 1984) recast in terms of energy balance, to better reproduce shallow water behavior. Growth terms redefined to Snyder et al. (1981) and calibrated.
- Coupled SLOSH-GLERL model projected to be significantly cheaper than SLOSH-SWAN (order 100 times), enabling large real-time ensembles.
- To continue with field validation and coupling of reformulated 2nd gen GLERL-NCEP model.