Modeling System for Applications to Very-Low Probability Events and Flood Response

Ty Wamsley, PhD

Chief, Flood and Storm Risk Reduction Division

U.S. Army Engineer Coastal and Hydraulics Laboratory

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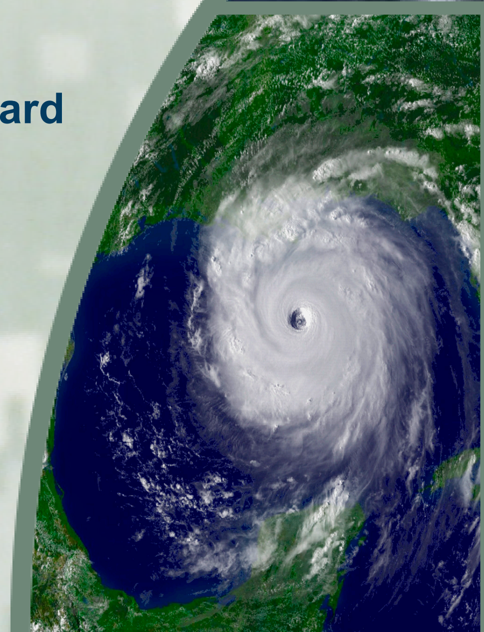

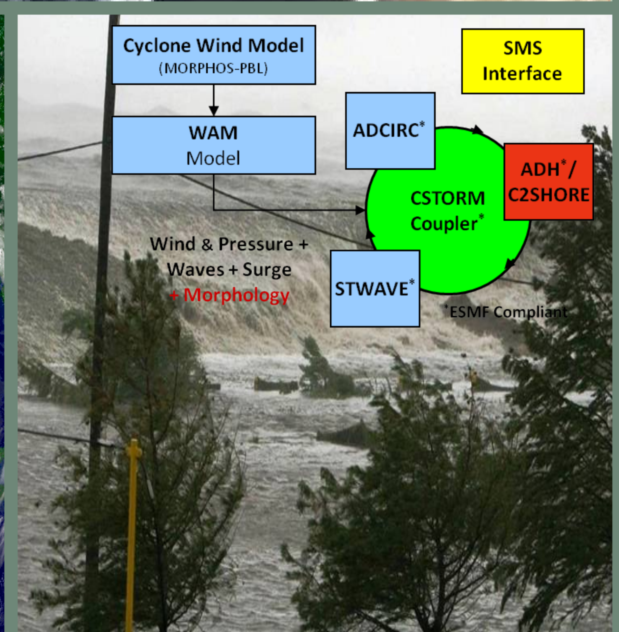

Workshop on Probabilistic Flood Hazard Assessment

Panel 7: Extreme Storm Surge for Coastal Areas

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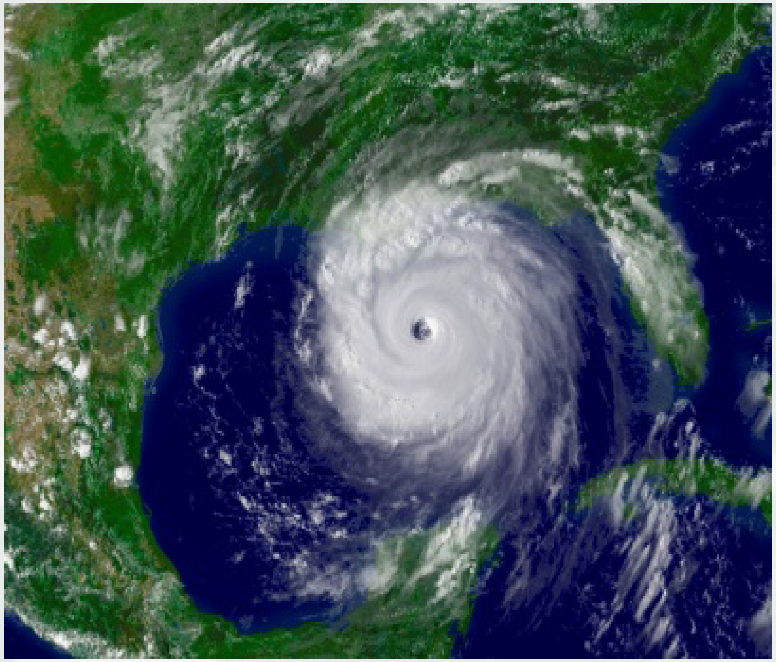
Storm Surge

- Function of
  - Storm Characteristics (e.g. central pressure, size, forward speed, angle of storm heading, Holland B parameter, rainfall)
  - Tides and river flows at time the storm approaches the coast
  - Shelf and coastal landscape over which the storm surge propagates.

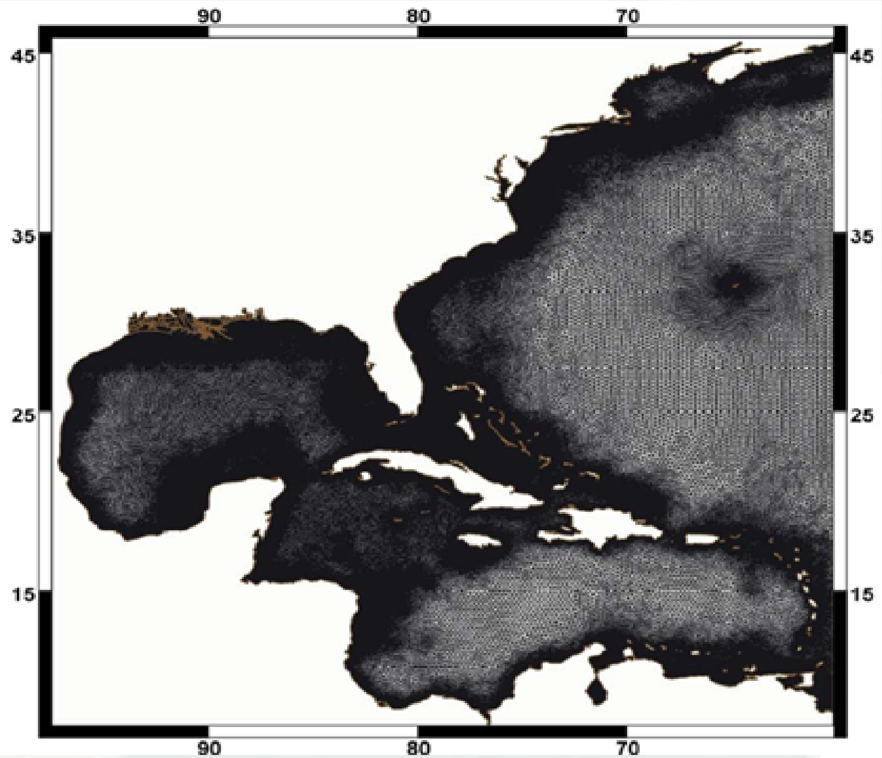


Simulation Requirements*

- Basin to shelf to floodplain domains to simplify boundary conditions and capture shelf waves
- Sufficient resolution of the physical system (topography/bathymetry and land cover)
- Consideration of all terms contributing to the surge:
  - Coupled multi-process system including winds, wind waves, tides, rivers, rainfall-runoff
- Validated with historical data in the area of interest

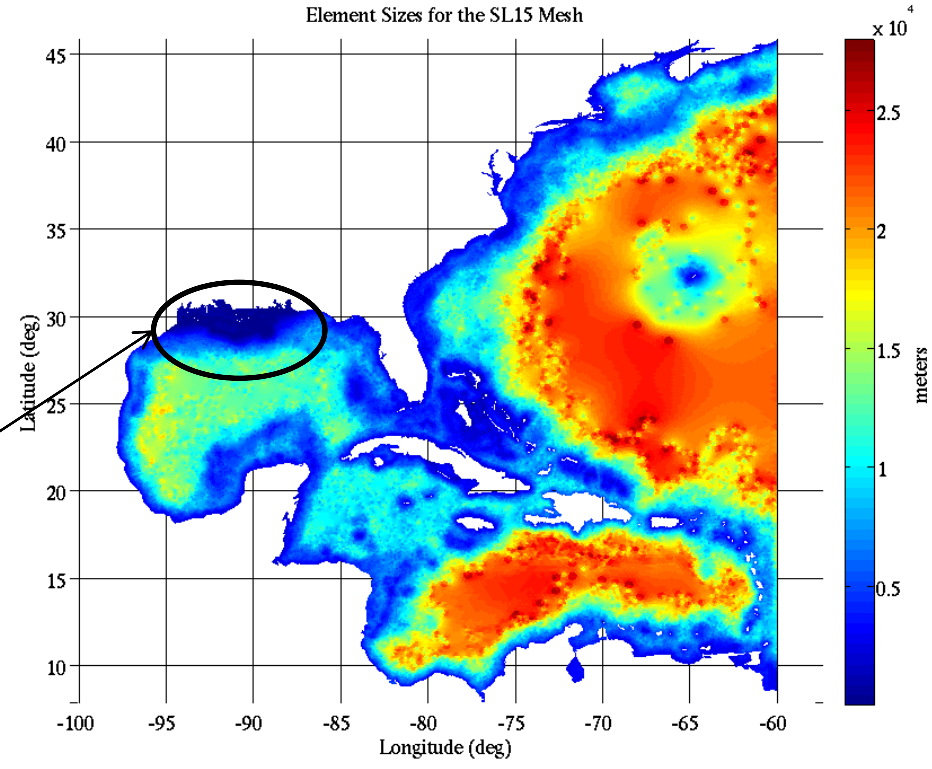
*Needed for objective estimates of flood magnitude and to properly reflect flood duration

Physical System



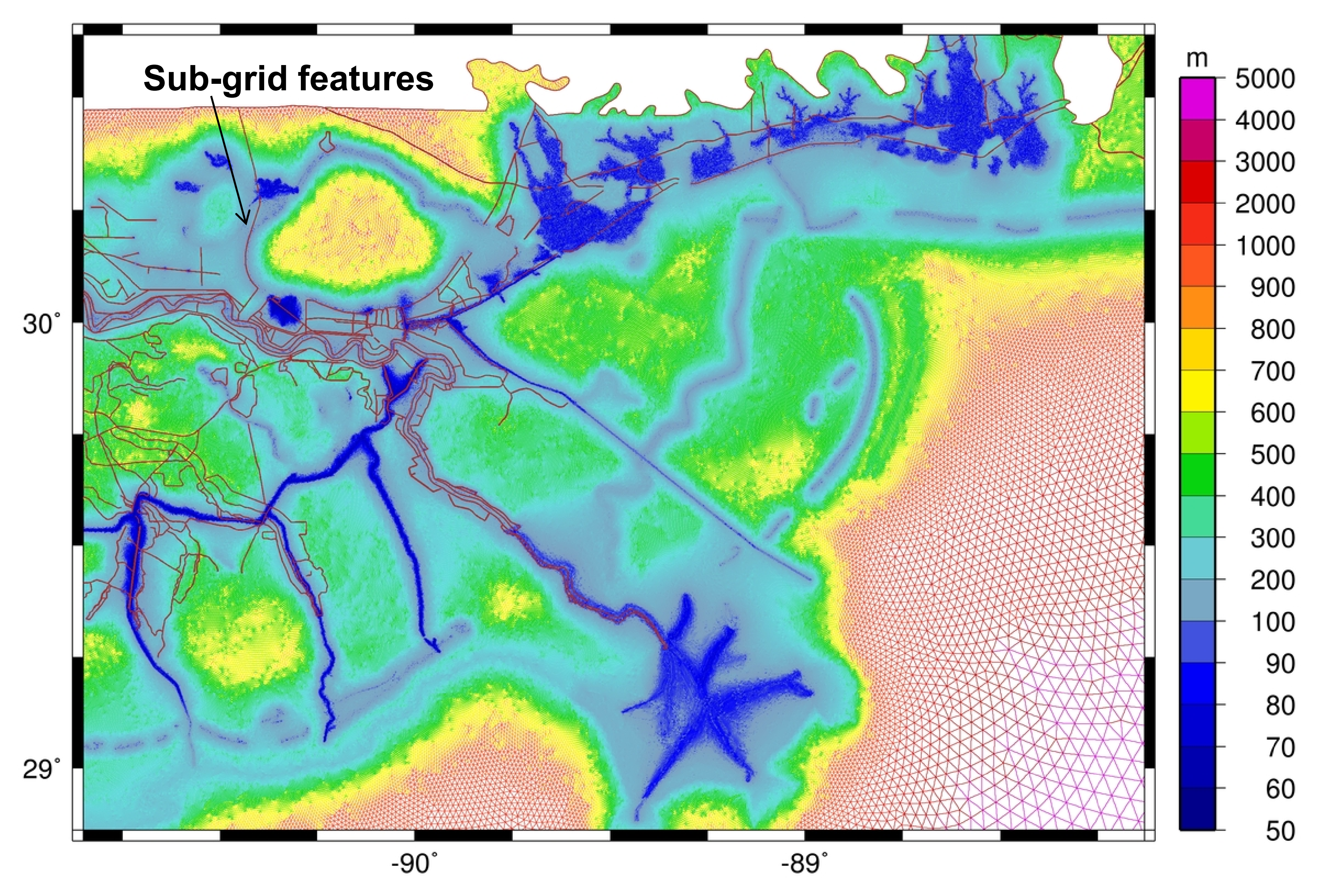
- **Appropriate definition of physical system while maintaining reasonable computational efficiency is facilitated through the application of unstructured surge meshes.**

Mesh resolution From 28 km down to 23 m



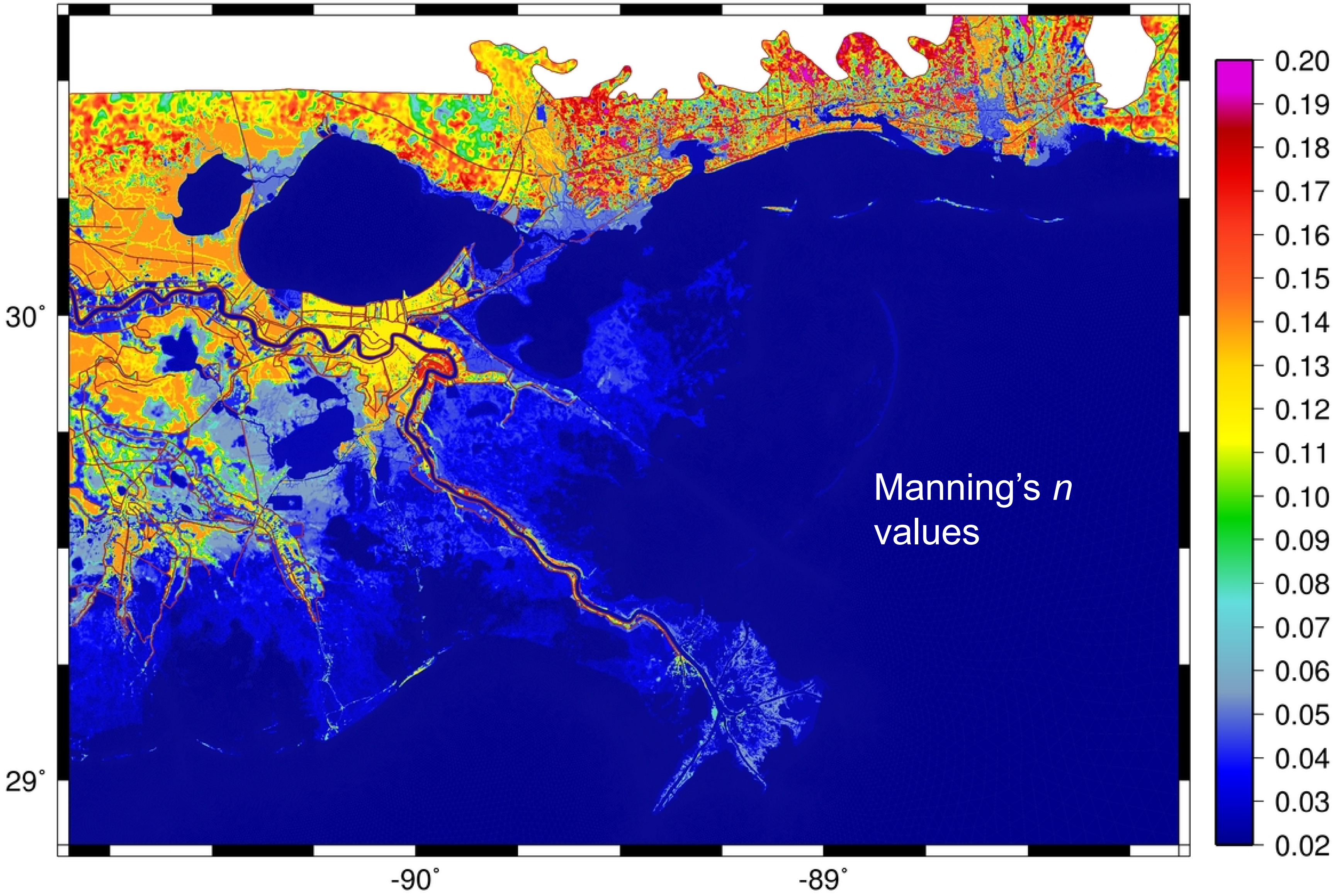
Approximately 98% of all elements are in the study area.

Resolution



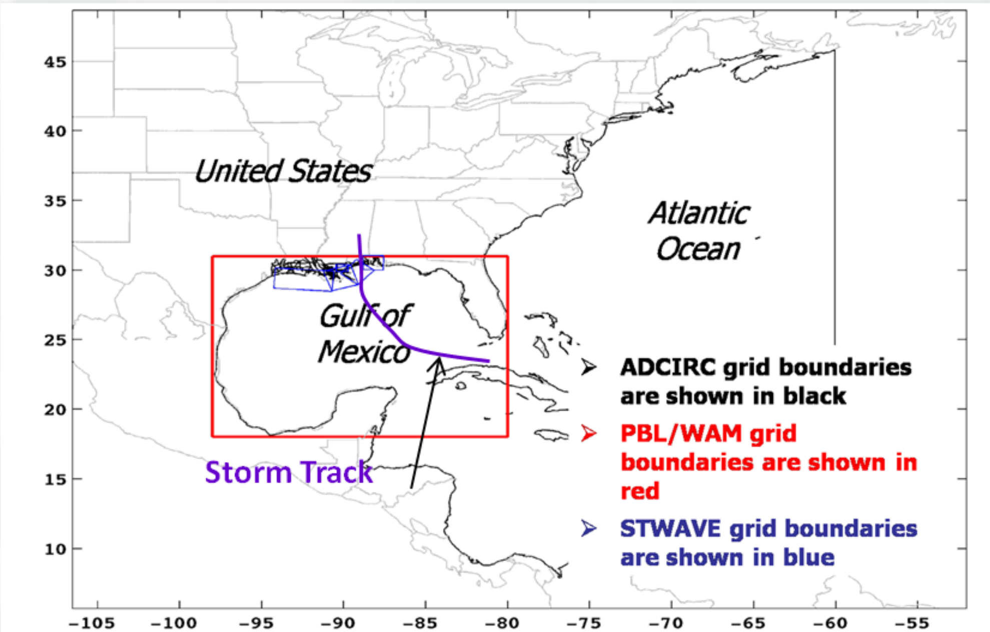
Sub-grid features
30˚
29˚
-90˚
-89˚
m
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50

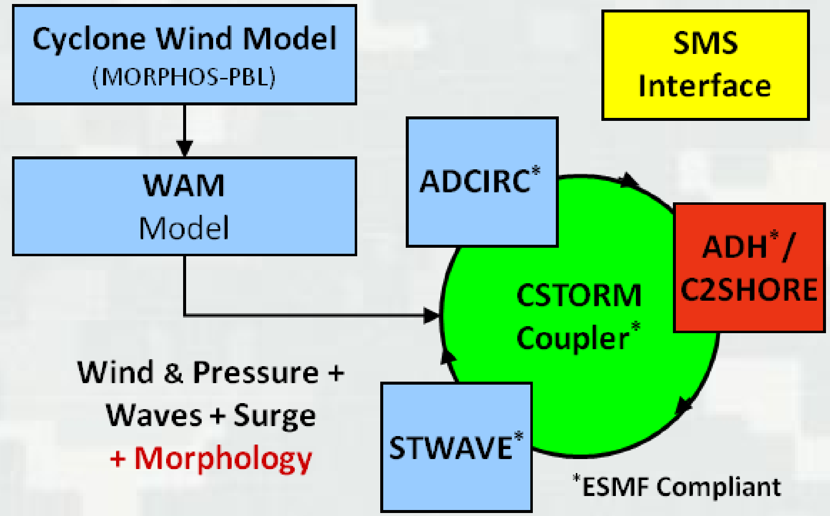
Parameterization of Land Cover



Coastal Storm-Modeling System (CSTORM)

Application of multi-scale, highly skilled numerical models in a tightly integrated modular modeling system with user friendly interfaces



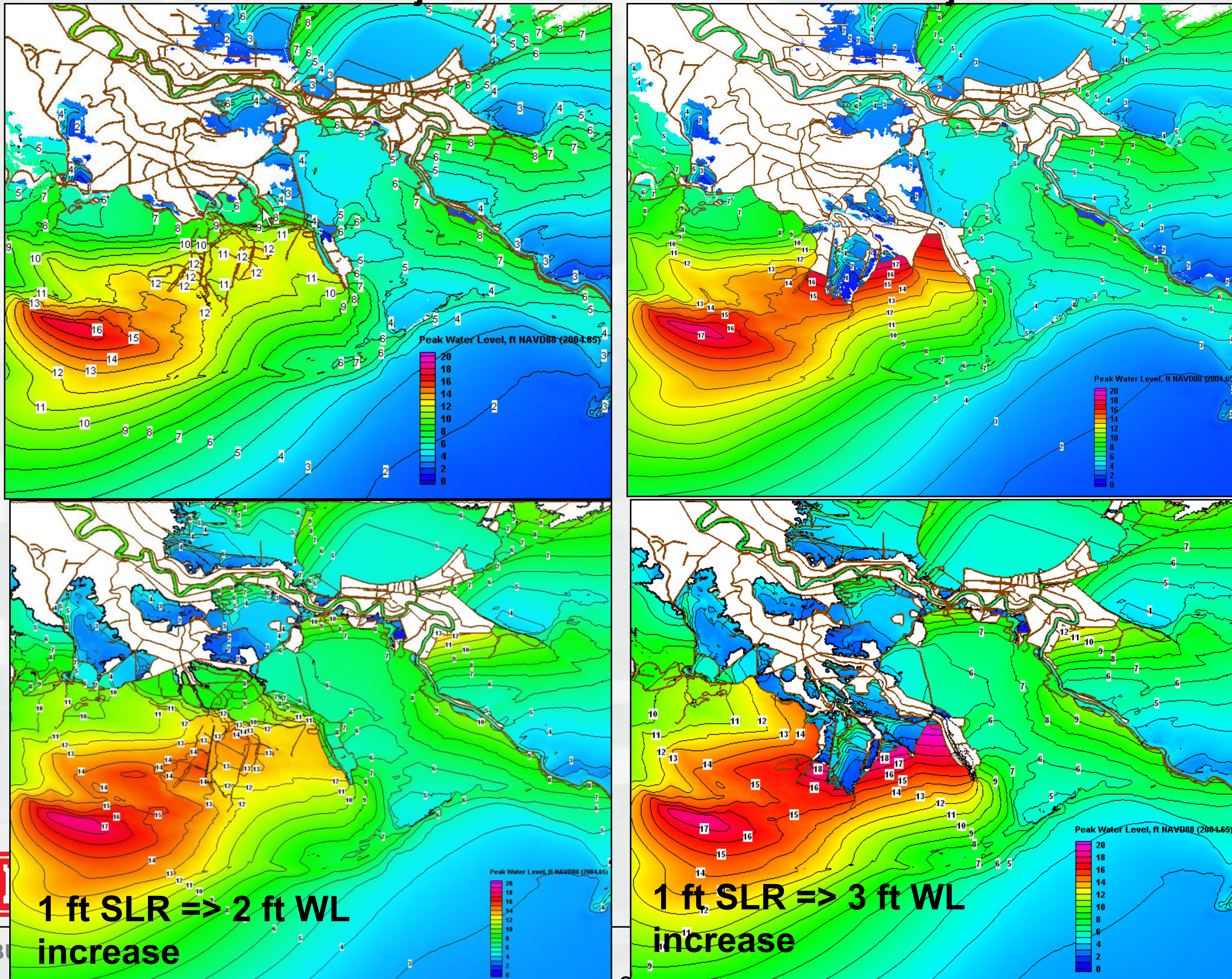


Sample CSTORM-MS Workflow

The **CSTORM-MS** was “born” during IPET and provides for a robust, standardized approach to characterizing storm hazards.

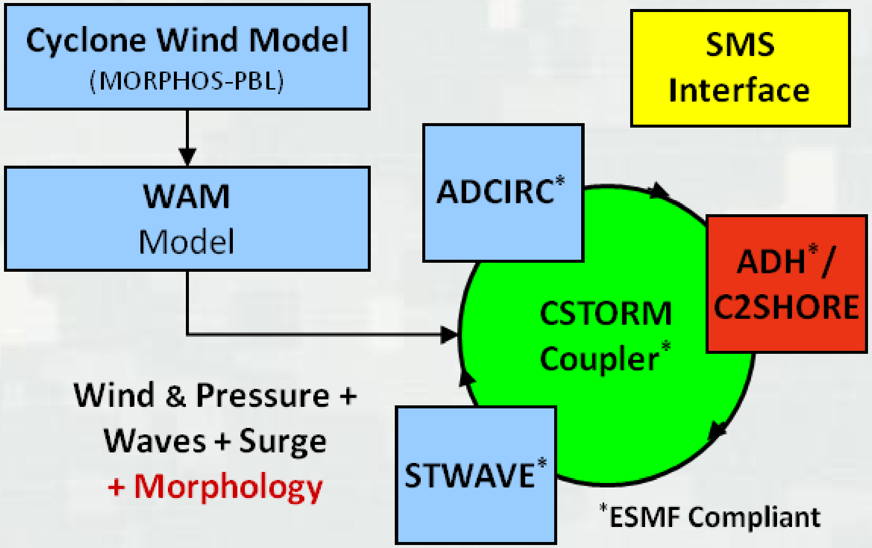
Without Project | **With Project**

Existing Water Level



Sea Level Rise 0.35 m

The Earth System Modeling Framework



ESMF

Code is organized into three distinct phases: initialization, run, and finalization.

- ESMF are open source tools with multi-agency buy in.
- Having models ESMF compliant makes them readily available to be linked with each other and with other agencies' ESMF compliant models.
- This leads to expanded collaborations and community development.

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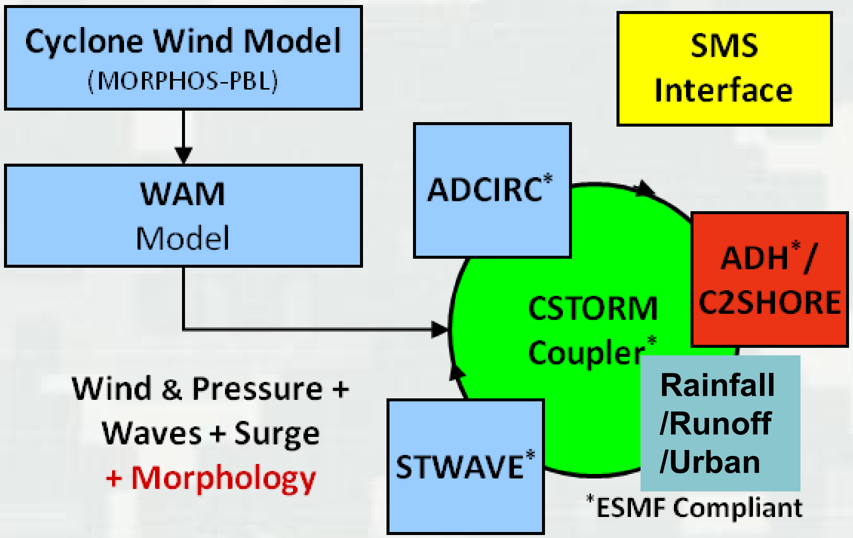
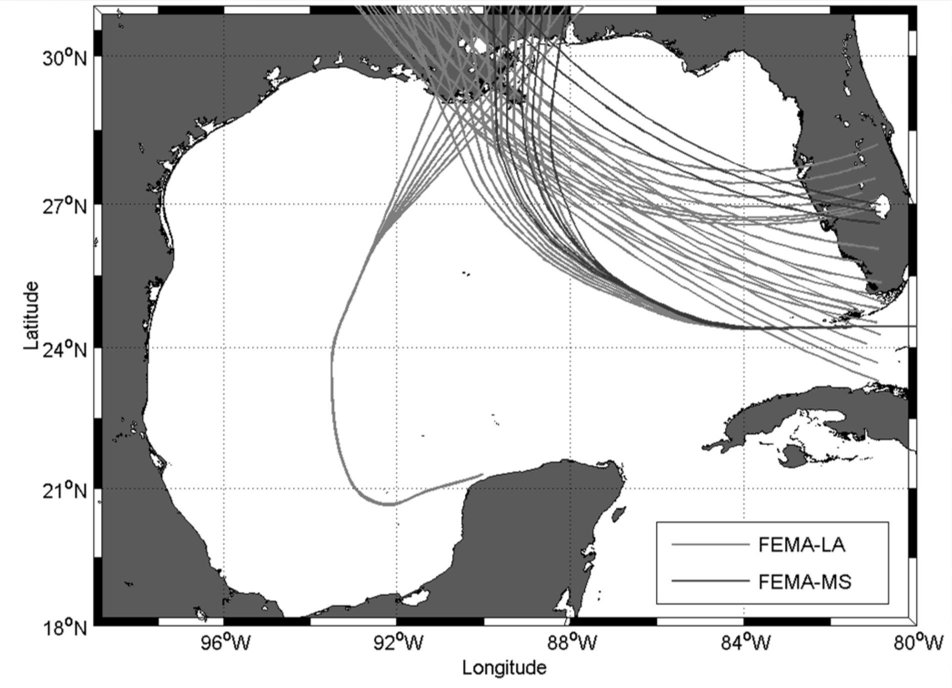
Advantages of Framework

- Reduced required human operator time by 75%, cut required computer simulation time by 50%. (Ex: Coastal Louisiana Storm with half-plane waves: Old System – 3 days, New System – 4 hrs)
- Allows for models to be at appropriate resolution and on appropriate domains for the process being modeled.
- Models can be improved (by the development community) and easily pulled back into the framework.
- New models can be implemented allowing for multiple model options.
- Easily expandable to include rainfall/runoff/urban flooding models (e.g. GSSHA)



Synthetic Storms

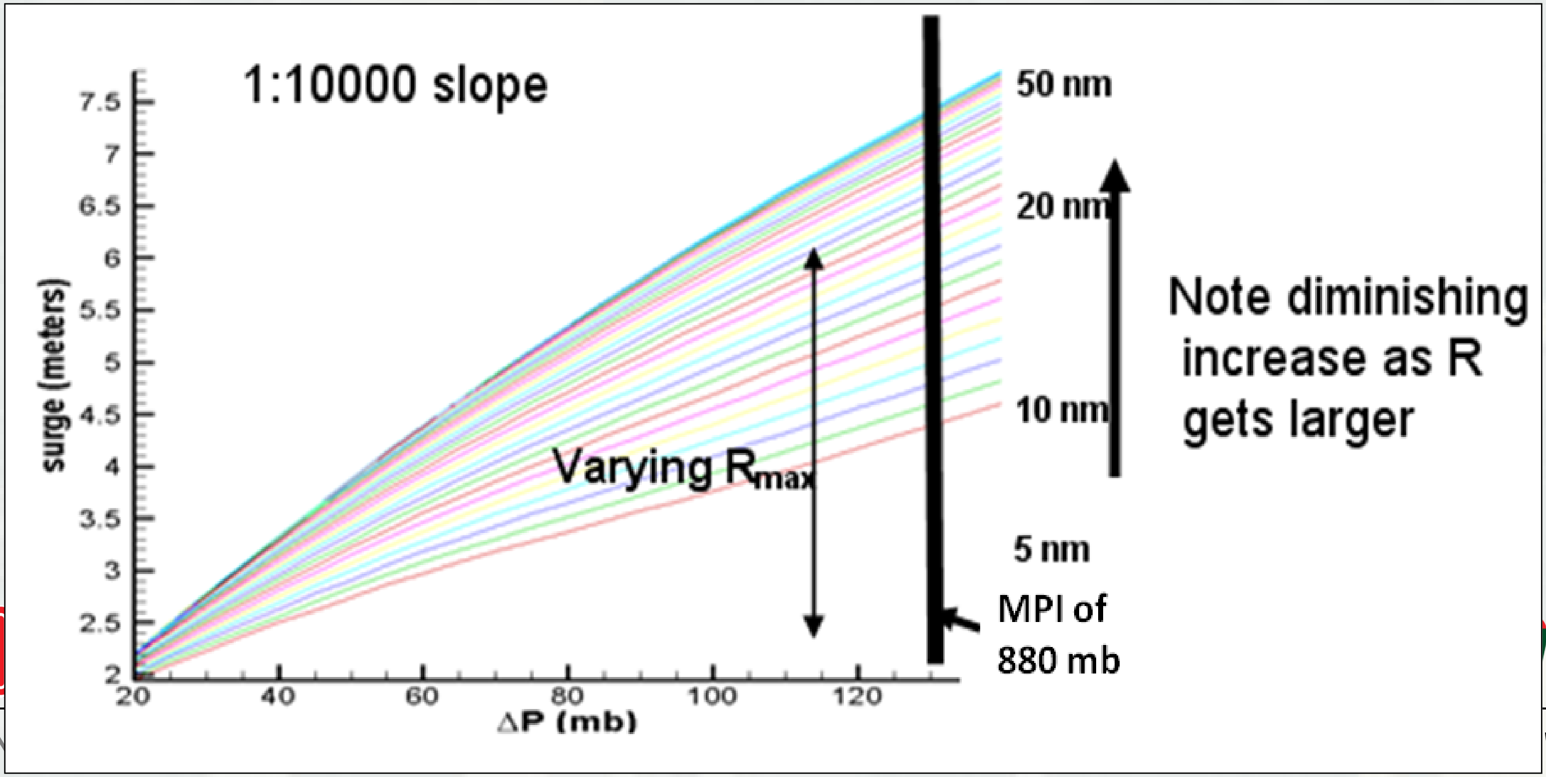
- **Joint Probability Method with Optimal Sampling (JPM-OS).**
  - Paucity of storm data necessitates using numerical simulations of synthetic storms and joint probability methods to estimate the expected probability density functions and cumulative density functions
  - Optimal sampling minimizes the number of required storm simulations by limiting the parameter space based on known physical constraints and improved interpolations.
  - For very low probability storms, we look for asymptotic upper limits of parameters affecting storm surge



Hurricane Parameters with Asymptotic Limits

$$\eta_{max} = \Phi_1(\Delta p)\Phi_2(R_{max})\Phi_3(x - x_0)\Phi_4(v_f)\Phi_5(\theta_f)$$

Storm Size (Φ_2): As noted by Irish and Resio (2010), when the storm size becomes as large as the region of primary surge generation, additional increases in storm size do not produce substantial increases in storm surge.



Hurricane Parameters with Asymptotic Limits

$$\eta_{max} = \Phi_1(\Delta p)\Phi_2(R_{max})\Phi_3(x - x_0)\Phi_4(v_f)\Phi_5(\theta_f)$$

Landfall Location (Φ_3): Maximum surge occurs near the location where the maximum winds come ashore with surge levels

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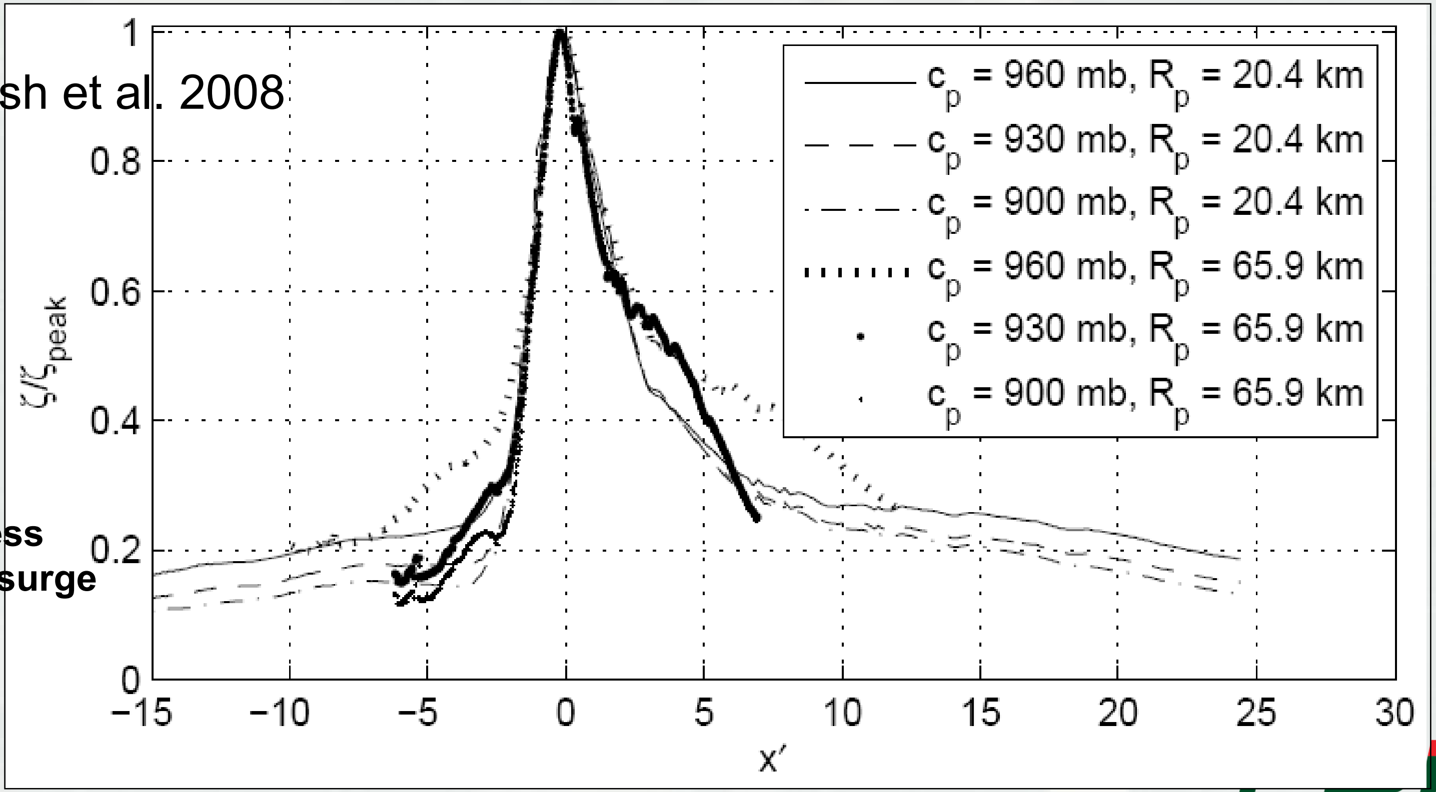
From Irish et al. 2008



dimensionless alongshore surge

deviation between a site and the landfall location divided by the radius to maximum winds

Hurricane Parameters with Asymptotic Limits

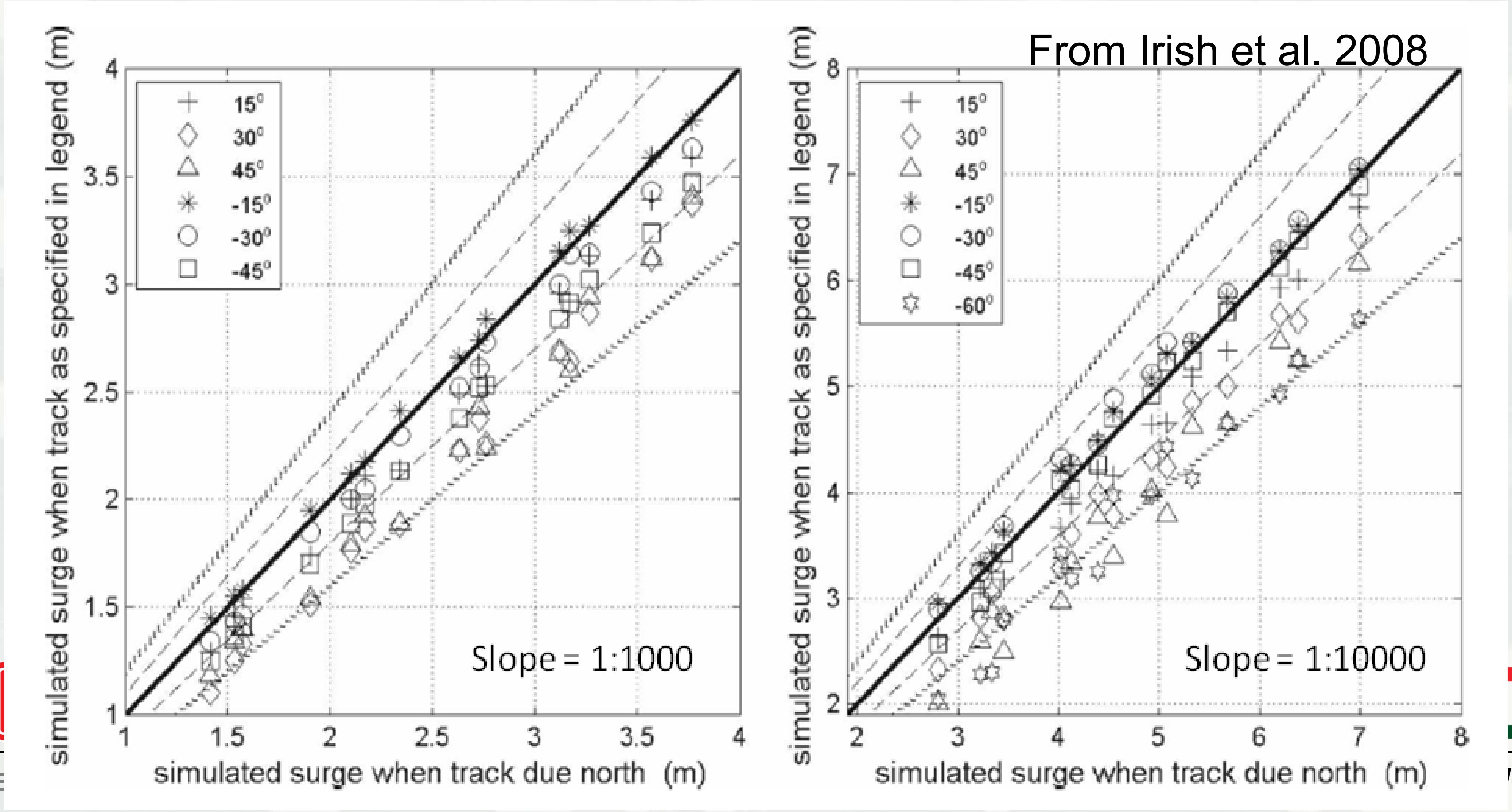
$$\eta_{max} = \Phi_1(\Delta p)\Phi_2(R_{max})\Phi_3(x - x_0)\Phi_4(v_f)\Phi_5(\theta_f)$$

Forward Speed (Φ_4): Two physical mechanisms which tend to have opposite effects on surge levels. On one hand, as the storm speeds up, wind speeds inside a hurricane increase due to the contribution of these background winds. On the other hand, as the storm speeds up the time winds blow over the surge generation area is decreased. As might be expected in such a situation, the result of combining these two effects is that the surges typically increase to a maximum value at some intermediate forward speed and decrease monotonically to either side of this maximum value.

Hurricane Parameters with Asymptotic Limits

$$\eta_{max} = \Phi_1(\Delta p)\Phi_2(R_{max})\Phi_3(x - x_0)\Phi_4(v_f)\Phi_5(\theta_f)$$

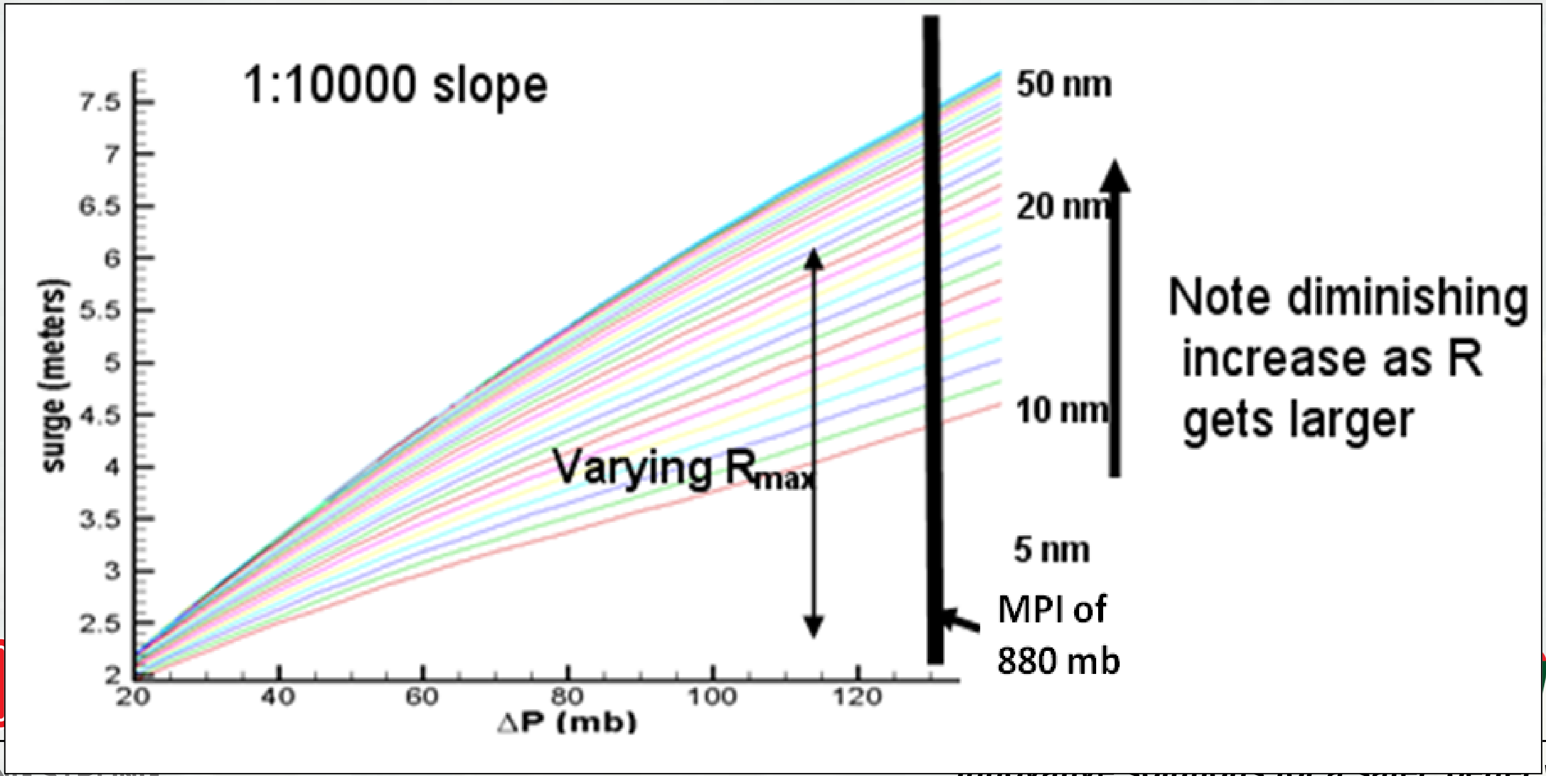
Angle of Approach (Φ_5): Changes in track angle increase peak surge by no more than 10% with respect to a shore normal approach.



Very Low Probability Events

$$\eta_{max} = \Phi_1(\Delta p)\Phi_2(R_{max})\Phi_3(x - x_0)\Phi_4(v_f)\Phi_5(\theta_f)$$

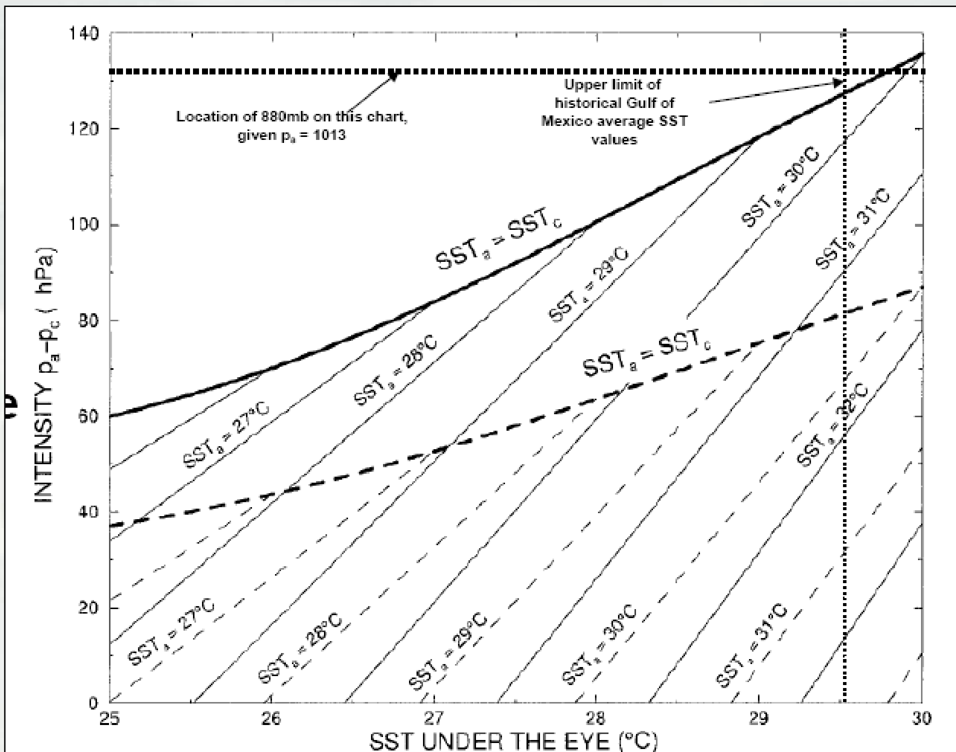
Pressure Differential (Φ_1): Does not appear to have a clear upper limit.



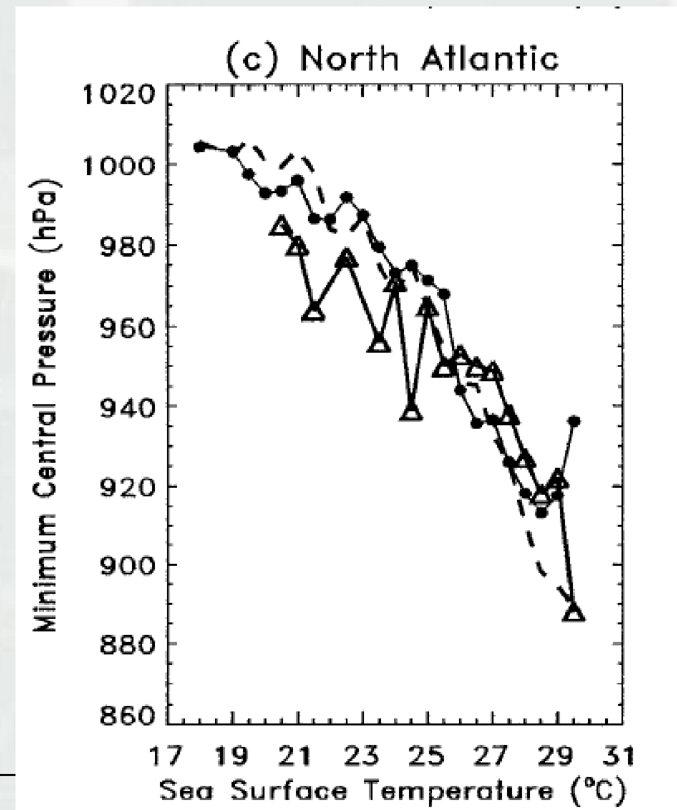
Very Low Probability Events

$$\eta_{max} = \Phi_1(\Delta p)\Phi_2(R_{max})\Phi_3(x - x_0)\Phi_4(v_f)\Phi_5(\theta_f)$$

MPI Concept: The lowest North Atlantic Values appear to support a value around 880 mb as the lowest central pressure for the range of water temperatures in the Gulf of Mexico



Schade 2000



Tonkin et al. 2000

Very Low Probability Events

$$\eta_{max} = \Phi_1(\Delta p)\Phi_2(R_{max})\Phi_3(x - x_0)\Phi_4(v_f)\Phi_5(\theta_f)$$

Pressure Differential (Φ_1): Another factor suggesting a natural limit is that wind speed profile data recently collected in real hurricanes (e.g. Powell *et al.* 2003, and Powell 2006) indicate that wind drag coefficients are not constant but rather increase until wind speeds of approximately 30-40 m/sec are reached and then the drag coefficient is reduced for increasing wind speeds above this range of values. Capping or reducing the wind drag coefficient results in a nonlinear surge response to further increase in pressure differential.

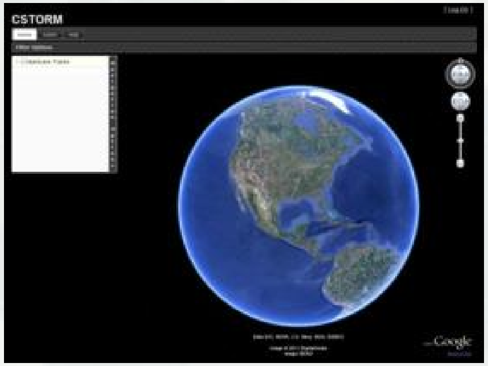
Schade 2000

Tonkin et al. 2000

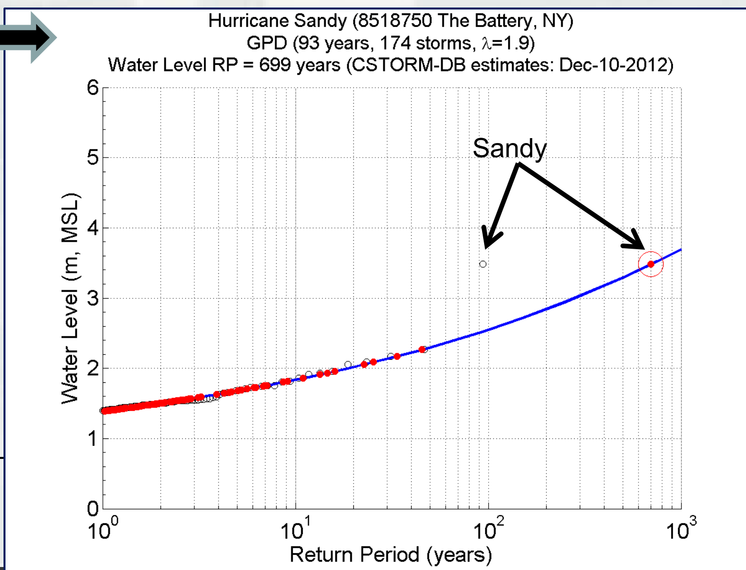
Synopsis of Simulation Approach for Very Low Probability Storms

- Use near MPI values for central pressure and large R_{max} values (e.g. 880 and 870 mb and 30,45 nm, respectively for the Gulf of Mexico)
- Set track to correspond to expected position of maximum surge
- Allow speed and track angle vary consistent with expected large intense storms
- Use state of the art modeling system with good resolution and physics to simulate the storm set including inland propagation of surge

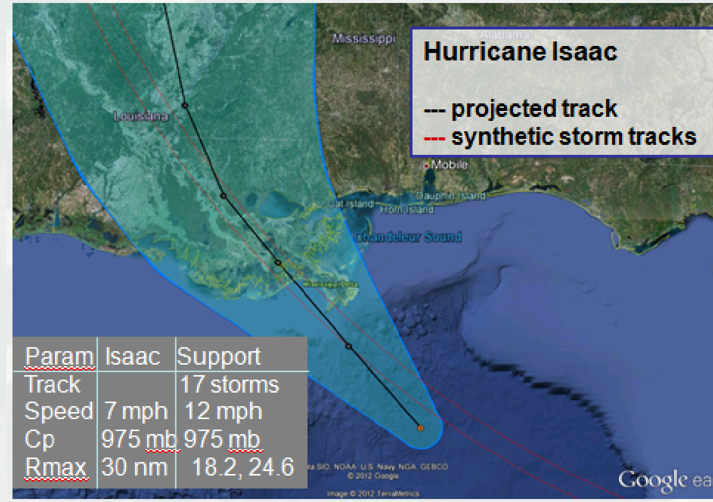
CSTORM-DB



System: Archive, database and Google Map based web application
Authoritative measurements
Authoritative high-fidelity model results
Query/sort capability
Plotting
StormSim: Extremal statistical analysis



Surge Forecasting Capability



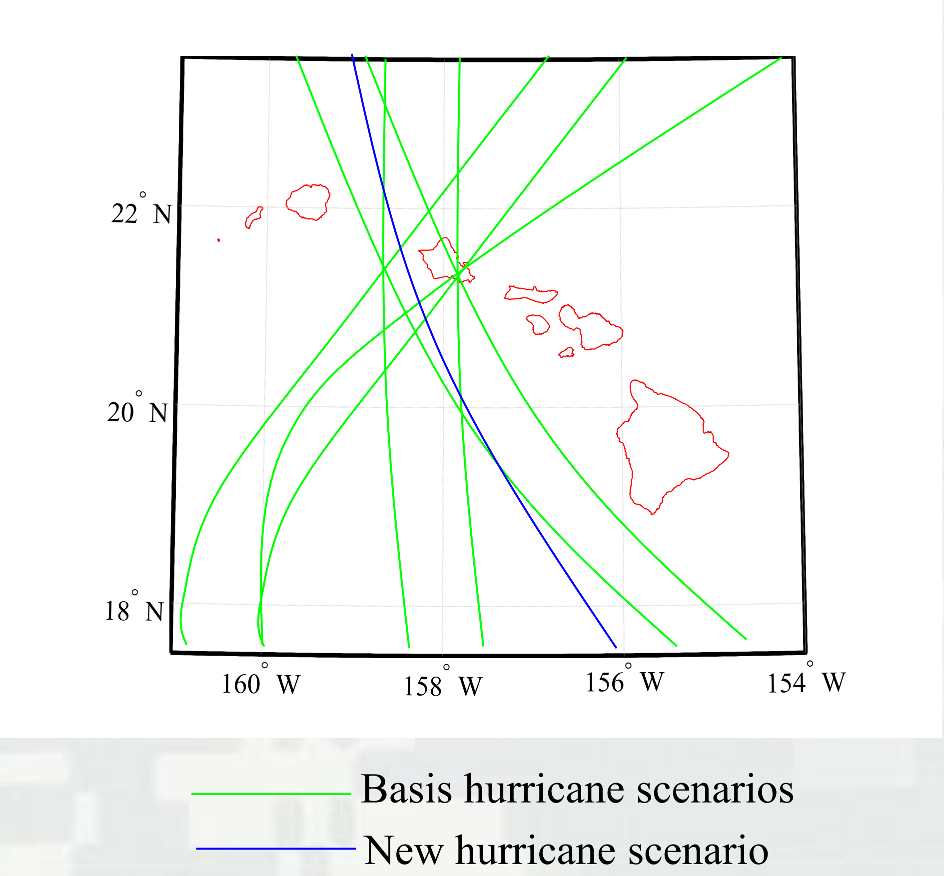
Maximum WL (NAVD88) Hurricane Isaac:

Measured	**~14 ft**
CSTORM-DB	**13 ft**
LSU - Coastal Emergency Risk Assessment	**13ft**
NHC-NOAA	**7 ft**

Expedient Hurricane Inundation

- **CSTORM-DB stores** a large suite of **basis hurricane scenarios** that cover statistical range of events
  - Tracks and landfall locations
  - Hurricane characteristics (min central pressure, forward speed, radius of max winds, etc.)
  - Regional high-fidelity wave and surge response (e.g. CSTORM-MS)

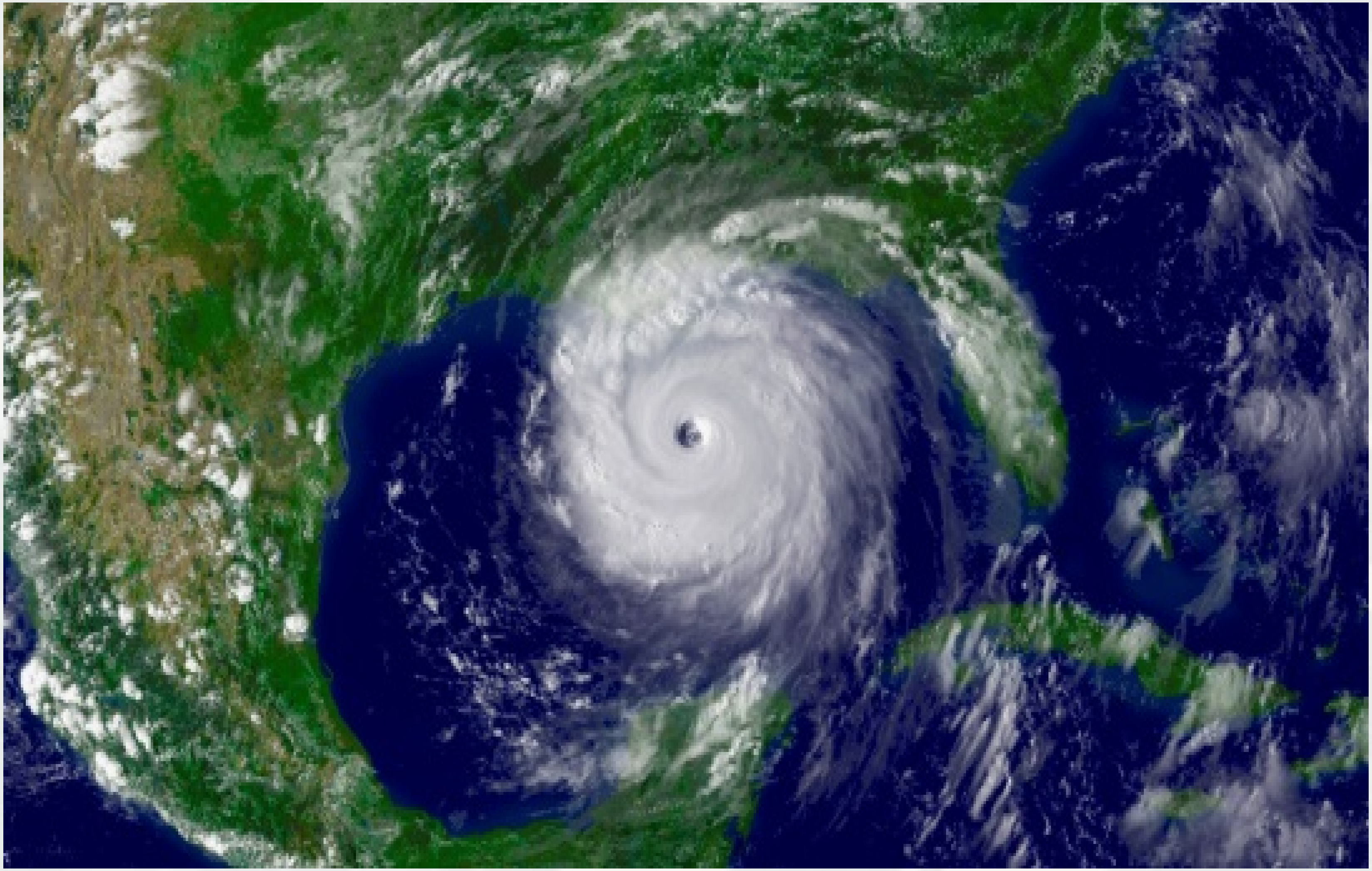
- Use basis scenarios as support for surrogate model **to rapidly and accurately predict inundation** for any **new** hurricane scenario
  - **Radial basis function weighted least squares moving average**



Tool to facilitate flood fighting to mitigate hazard

StormSim

- Formalized and Generalized Coastal Storm Statistics Tools for PFHA
  - **JPM-OS**: Joint Probability Method-Optimal Sampling for Tropical Storms
  - **StormSim-ES**: Traditional parametric marginal and joint probability method
  - **Empirical Simulation Technique (EST)**: Nonparametric bootstrap with re-sampling techniques
  - **Wave/water level Empirical Lifecycle Simulation (WELS)**: Empirical joint probability to generate continuous long-term time series of any number of storm parameters



Questions?

Parameterization of Frictional Resistance

- Wind Reduction
  - Winds in ADCIRC and STWAVE are reduced to account for higher surface roughness through a directional land masking procedure

Roughness length scales

$$f_r = \left(\frac{z_{0_{marine}}}{z_{0_{land}}} \right)^{0.0706}$$

Varies w/land cover and quantified by FEMA-HAZUS study (NLCD)

$$z_{0_{marine}} = \frac{\alpha_c C_d W_{10}^2}{g}$$

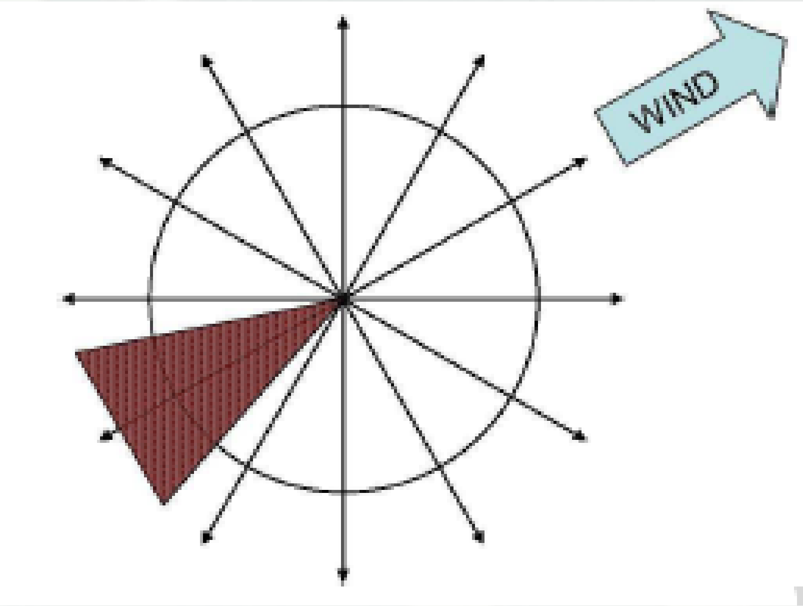
α_c=0.18 (Charnock parameter)

As inundation takes place, roughness is reduced

$$z_0' = z_{0land} - \frac{d}{30} \quad \text{for} \quad z_0' \geq z_{0_{marine}}$$

Parameterization of Frictional Resistance

- Wind Reduction
  - Winds in ADCIRC and STWAVE are reduced to account for higher surface roughness through a directional land masking procedure



$$w_i = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{d_i^2}{2\sigma^2}}$$

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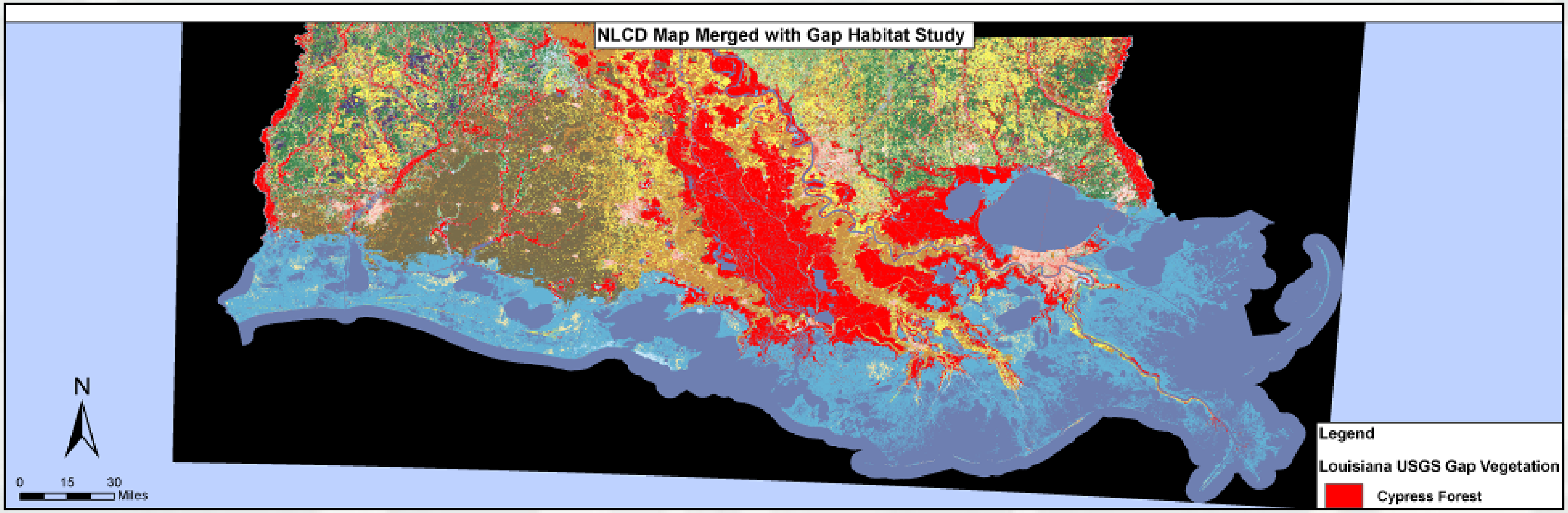
Parameterizations of Frictional Resistance

- Wind Reduction
  - A canopy is applied to areas classified as NLCD/GAP forest precluding momentum transfer from the wind fields to the water column



ADCIRC

Natural feature impacts on surge:

- Depth (surge gradient is inversely proportional to depth)
- Wind
- Bottom Friction (through Manning formulation) slows surge propagation
  - Momentum equations use standard quadratic parameterization for bottom stress and applies the following bottom friction coefficient:

$$C_f = g\frac{n^2}{d^{1/3}}$$

Evolution of the Modeling System

- **New Workflow / Coupler:** Reduced required human operator time by 75%, cut required computer simulation time by 50%. (Ex: Coastal Louisiana Storm with half-plane waves: Old System – 3 days, New System – 4 hrs)
- **Improved Coupling**: STWAVE gets feedback response.
- **Upgraded Full-Plane STWAVE**: Computations parallel in space (reduced STWAVE full-plane simulation times by 97%).
- **New and/or Improved GUIs** for Coupler, PBL, WAM, STWAVE. Models can be set up on PCs and executed either on a PC or an HPC.
- **Morphology Evolution** has been developed and is being tested.