THE WATER INSTITUTE

COMPOUND FLOOD TRANSITION ZONE PILOT STUDY FOR THE AMITE RIVER BASIN

TIFF BROWN BAG SEMINAR SERIES

FEBRUARY 28, 2024

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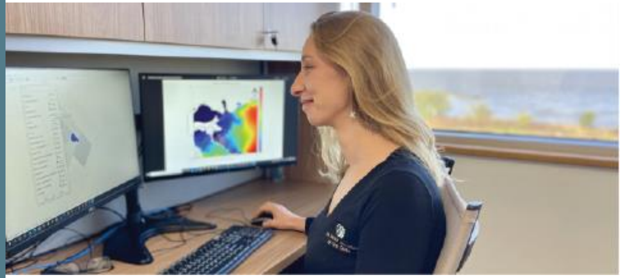
ABOUT THE WATER INSTITUTE

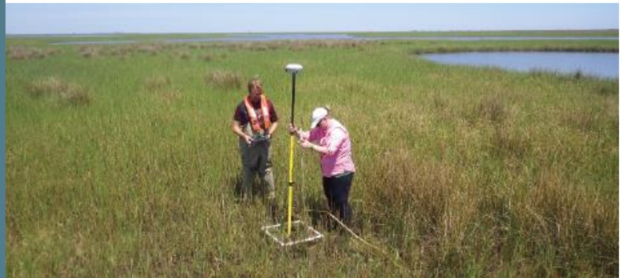
VISION

Resilient and equitable communities
Sustainable environments
Thriving economies

MISSION

Advancing science and developing integrated methods to solve complex environmental and societal challenges





MULTI-DISCIPLINARY RESEARCH

Coastal and Compound Flood Risk

Planning and Policy

Deltaic Systems

Applied Geosciences

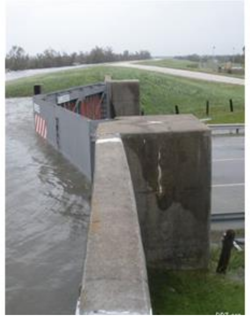
Coastal Ecology

Products Strategy

Data Science & Engineering

COMPOUND FLOODING – TX AND LA

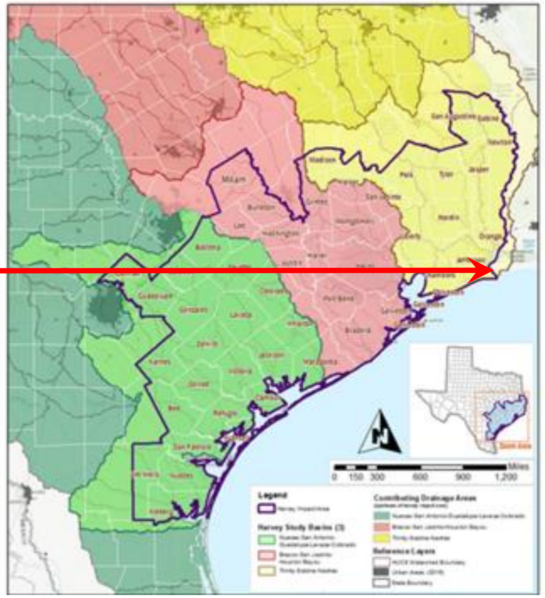

6

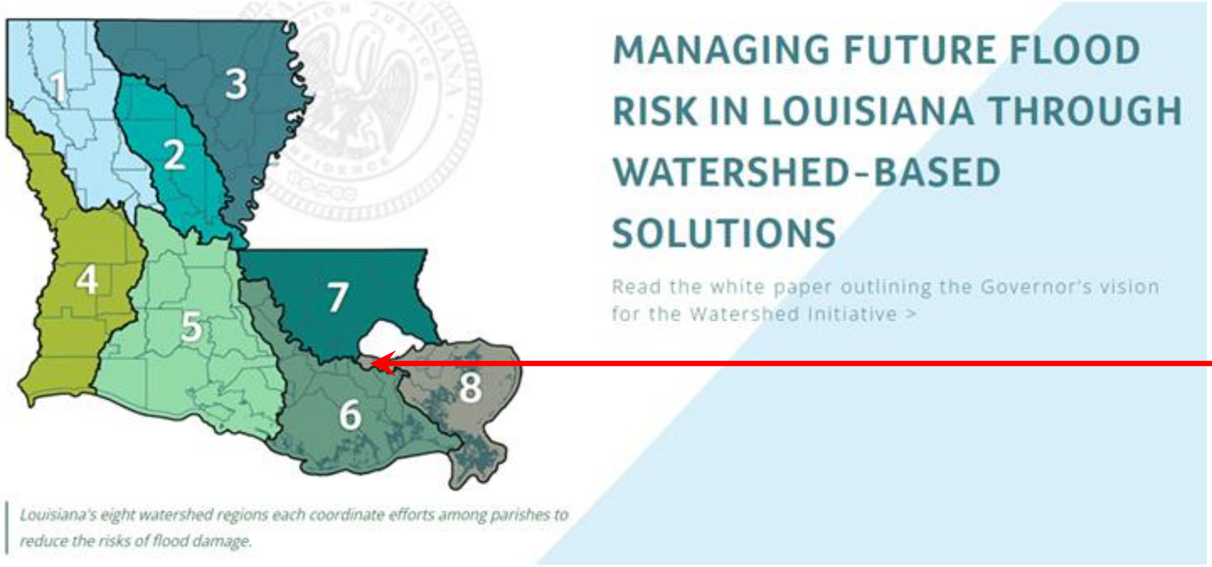


Texas GLO $100MM+ Flood Study

$ 1.2B Louisiana Watershed Initiative

TWI Pilot





TWI Pilot

The Water Institute is collaborating with federal, state, and industry partners to advance compound flooding research including extending JPM-OS.

ACKNOWLEDGEMENTS

Thankful for support from USACE Galveston and New Orleans Districts, USACE-ERDC, FEMA, Technical Design and Quality Committee (TDQ), Thomas Wahl (UNF), Gabrielle Villarini (Princeton) and several other supporters of this effort and other initiatives nationally.

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- Robert Winders (USACE Vicksburg)

STUDY TEAM AND REPORT

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- Hanbeen Kim
- Brendan Yuill
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DOWNLOAD REPORT

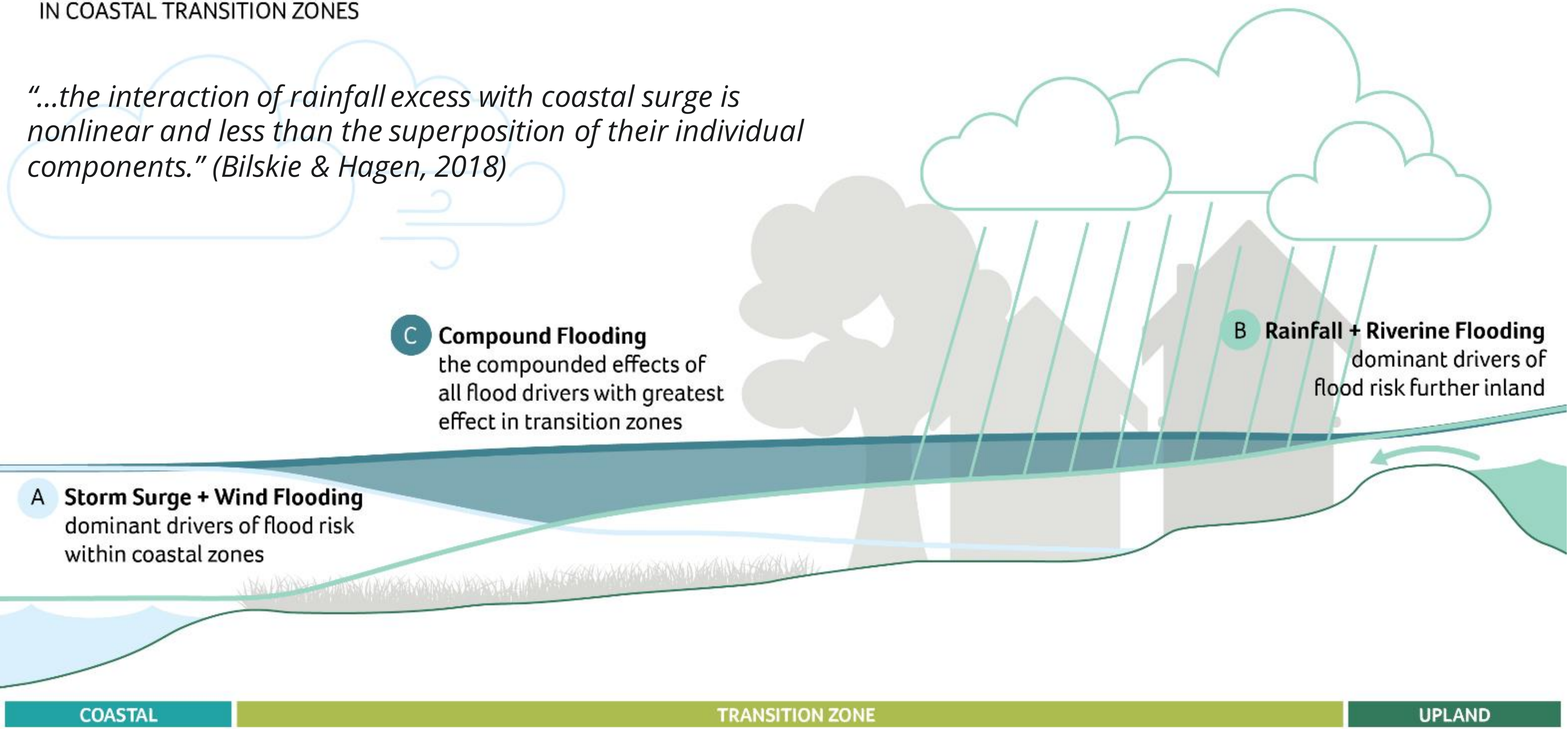
KEY TAKEAWAYS

- An efficient probabilistic and modeling framework has been developed to quantify flood risk due to compounding impacts of surge and precipitation.
- Applicable in regions exposed to flood hazards driven by TCs and non-TCs such as the Gulf of Mexico.
- Joint Probability Method, developed by USCE-ERDC and FEMA, extended to incorporate precipitation and hydrology. Facilitates efficient quantification of compound flood risk due to TCs.
- HEC-RAS with winds and coupled ADCIRC+SWAN can efficiently simulate compounding flooding.
- Feedback provided by the Technical Advisory Group leveraged to develop the LA coastwide compound flood risk assessment framework that us currently ongoing.
- Enhancements to approach for TCs and non-TCs being implemented in the LA coastwide model.
- Institute leading collaborative efforts to quantify current and future compound flood risk in Jacksonville.

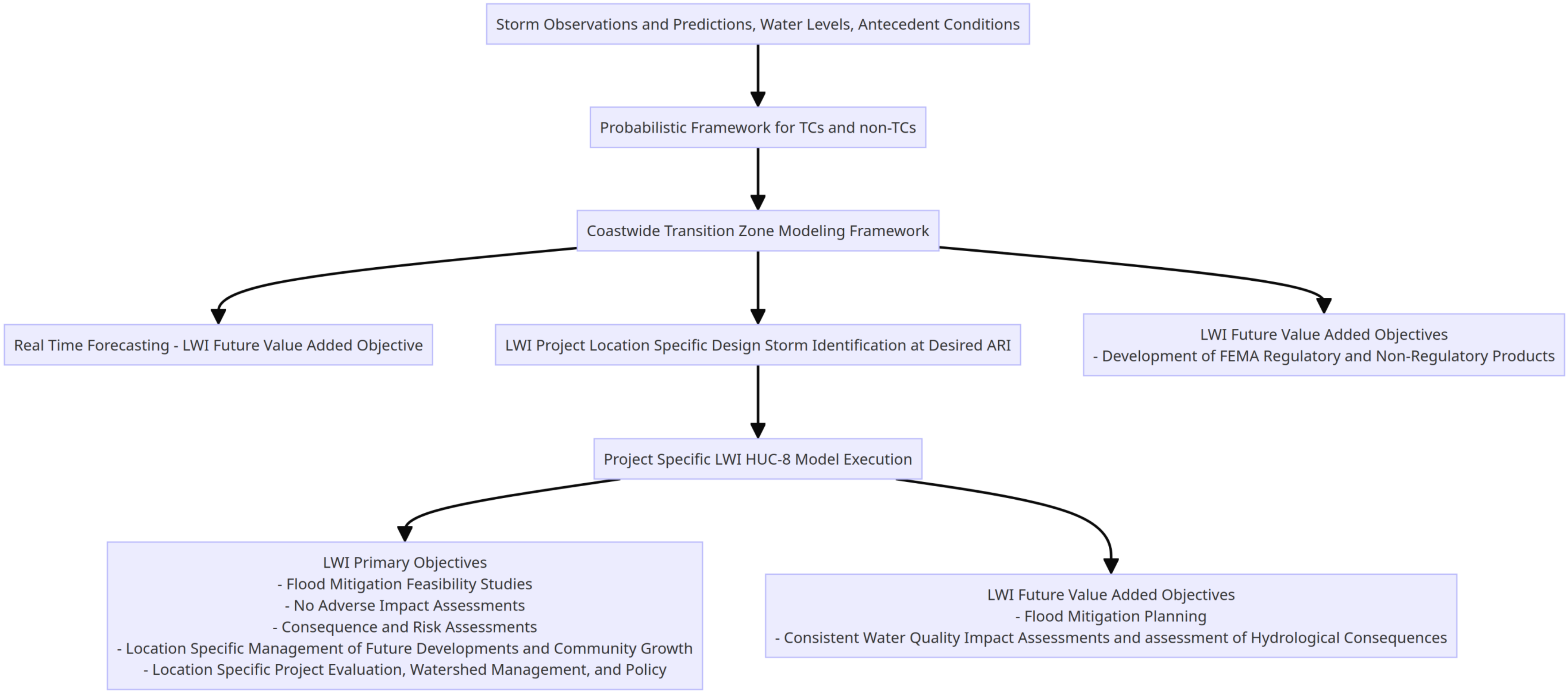
COMPOUND FLOODING

IN COASTAL TRANSITION ZONES

“…the interaction of rainfall excess with coastal surge is nonlinear and less than the superposition of their individual components.” (Bilskie & Hagen, 2018)



WHY A LWI COASTWIDE TZ MODEL?



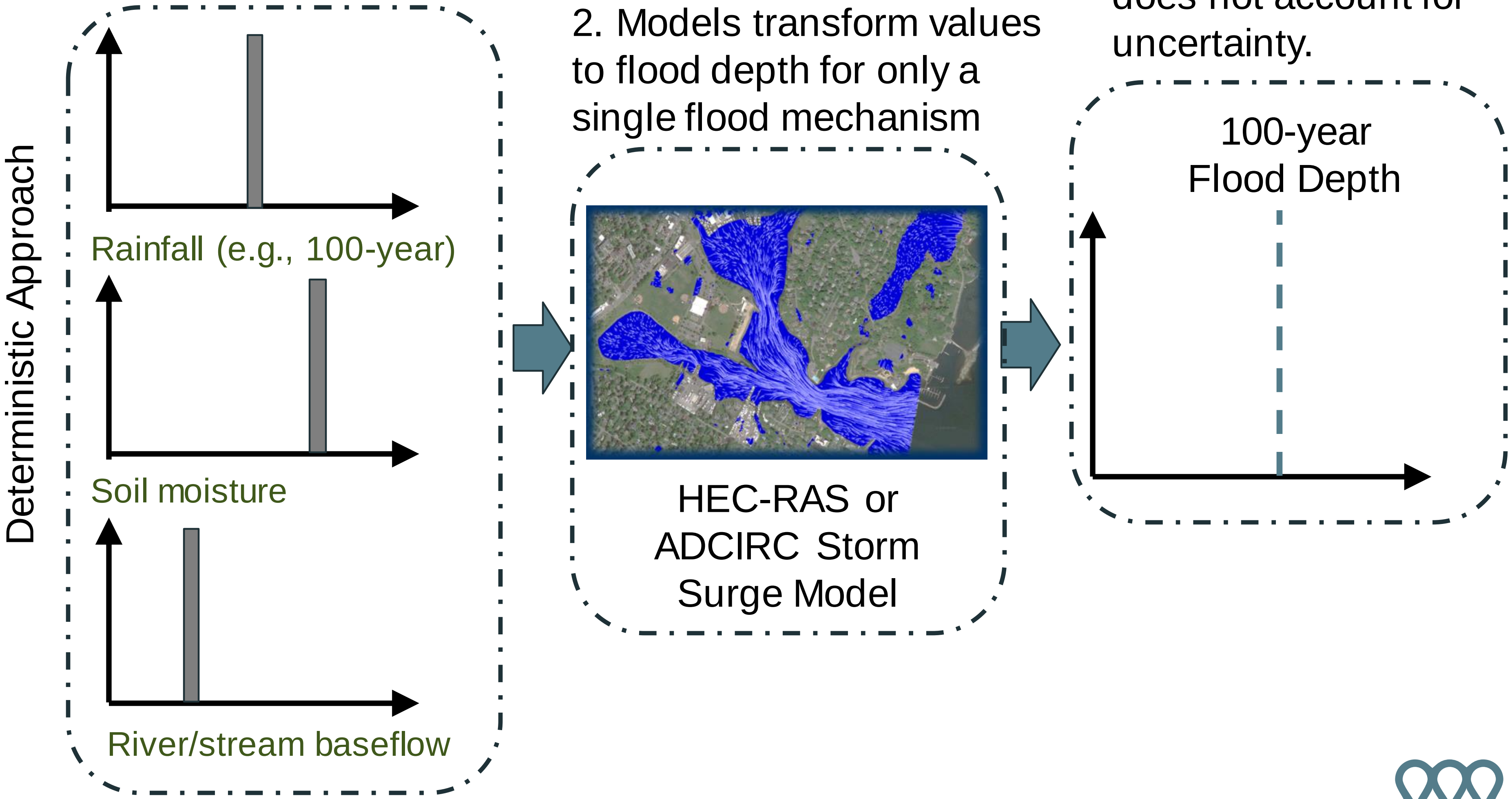
PLUVIAL/FLUIVIAL FLOODING

TRADITIONAL APPROACH

(Select single values for a certain event of interest e.g. 100-year event)

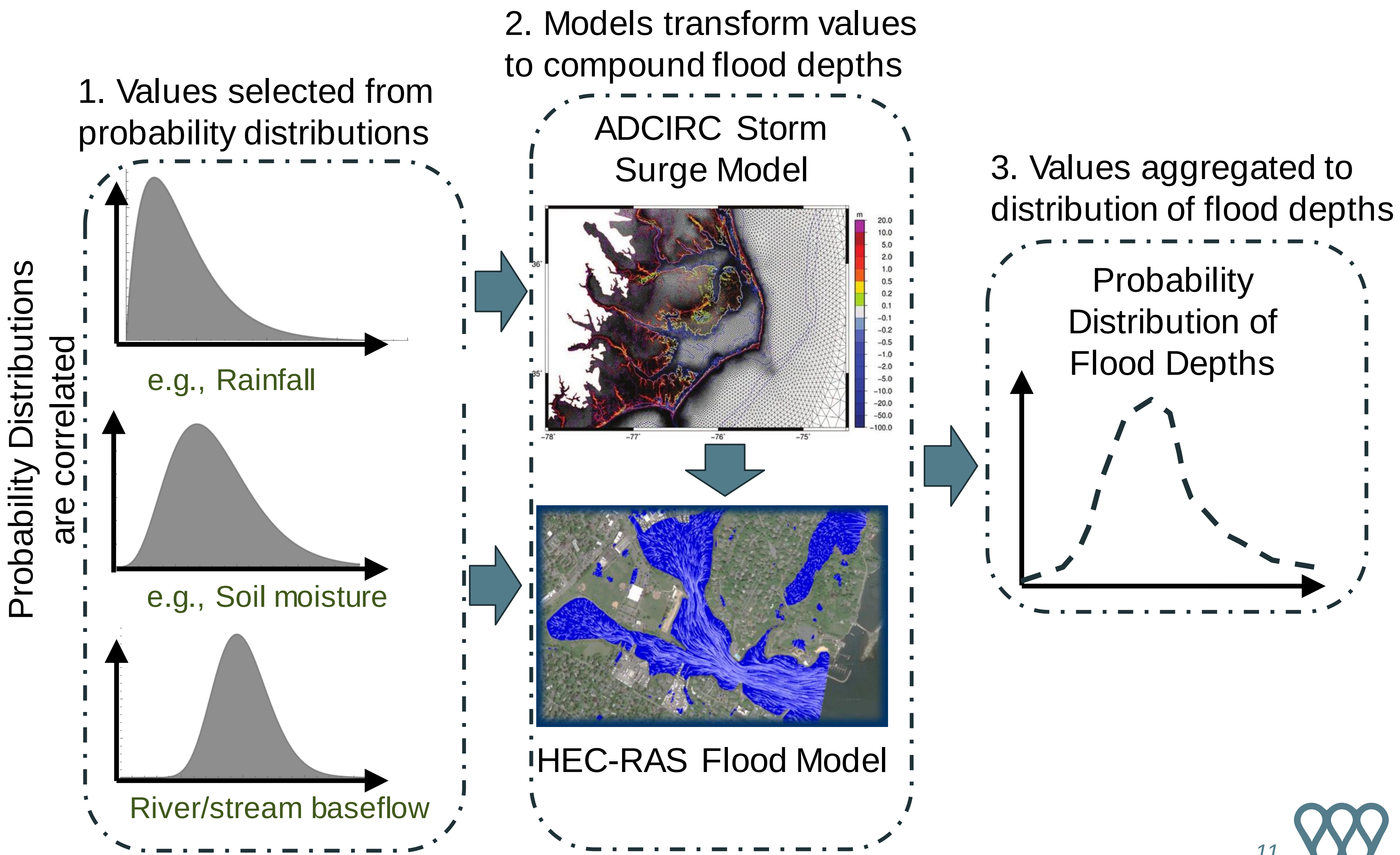
2. Models transform values to flood depth for only a single flood mechanism

3. Single flood depth does not account for uncertainty.



PROBABLISTIC APPROACH

PROBABILISTIC APPROACH



EXTENDING THE JPM METHOD

- *JPM extended to include both tropical and non-tropical storm events.*

$$\underbrace{p(\eta_{\max})}_{\text{Flood depth probability distribution}} = \frac{\lambda_{TC}}{\lambda}\underbrace{p_{TC}(\eta_{\max})}_{\text{Tropical cyclone (TC) flood depth probability distribution}} + \frac{\lambda_{NT}}{\lambda}\underbrace{p_{NT}(\eta_{\max})}_{\text{Non- tropical storm flood depth probability distribution}}$$

$$p_{TC}(\eta;t) = \int \dots \int \underbrace{p_{TC}(\eta|\mathbf{x}_{TC};t)}_{\text{Flood depth response function}}\underbrace{p(\mathbf{x}_{TC};t)}_{\text{Probability distribution of tropical cyclone storm and hydrologic conditions}} d^n\mathbf{x}_{TC}$$

$$p_{NT}(\eta;t) = \int \dots \int \underbrace{p_{NT}(\eta|\mathbf{x}_{NT};t)}_{\text{Flood depth response function}}\underbrace{p(\mathbf{x}_{NT};t)}_{\text{Probability distribution of Non-tropical storm and hydrologic conditions}} d^n\mathbf{x}_{NT}$$

Where:

$\lambda_{TC.}$ Frequency of tropical cyclones

$\lambda_{NT.}$ Frequency of nontropical cyclones

$\lambda_{.} = \lambda_{TC.} + \lambda_{NT.}$ Overall frequency of storms

η_{max} Maximum flood depth

t Time

EXTENDED JPM METHOD

- *JPM extended to capture the compound flood response*

$$p_{TC}(\eta|\mathbf{x}_{TC};t) = \int\int \delta(\eta - \overbrace{f(\mathbf{x}_S, \mathbf{r}, \mathbf{s}, \mathbf{q}; t)}^{\text{HEC-RAS}})\,\delta(\mathbf{q} - \overbrace{f(\mathbf{r}, \mathbf{s}, \mathbf{q}_b; t)}^{HEC-HMS})\,\delta(\mathbf{x}_S - \overbrace{f(\mathbf{x}_{JPM}; t)}^{\text{ADCIRC w/ PBL}})\, d^n\mathbf{x}_S\, d^n\mathbf{q},$$

Tropical cyclone flood depth response function; Compound flood depth; River inflows; Storm surge and winds

$$p_{NT}(\eta|\mathbf{x}_{NT};t) = \int\int \delta(\eta - \overbrace{f(\boldsymbol{\eta}_s, \mathbf{r}, \mathbf{s}, \mathbf{q}; t)}^{\text{HEC-RAS}})\,\delta(\mathbf{q} - \overbrace{f(\mathbf{r}, \mathbf{s}, \mathbf{q}_b; t)}^{\text{HEC-HMS}})\,\delta(\boldsymbol{\eta}_s - \overbrace{f(\tau_l, \kappa; t)}^{\text{General Stage Hydrograph}})\, d^n\boldsymbol{\eta}_s\, d^n\mathbf{q},$$

Non-tropical storm flood depth response function; Compound flood depth; River inflows; Non-tide residual

Where:

η_s	Storm surge depth
$\boldsymbol{r}$	Rainfall values (all points in the study)
$\boldsymbol{s}$	Soil moisture (all points in the watershed)
$\boldsymbol{q}$	River/stream inflows
$\boldsymbol{q}_b$	Baseflow
t	Time

EXTENDED JPM METHOD

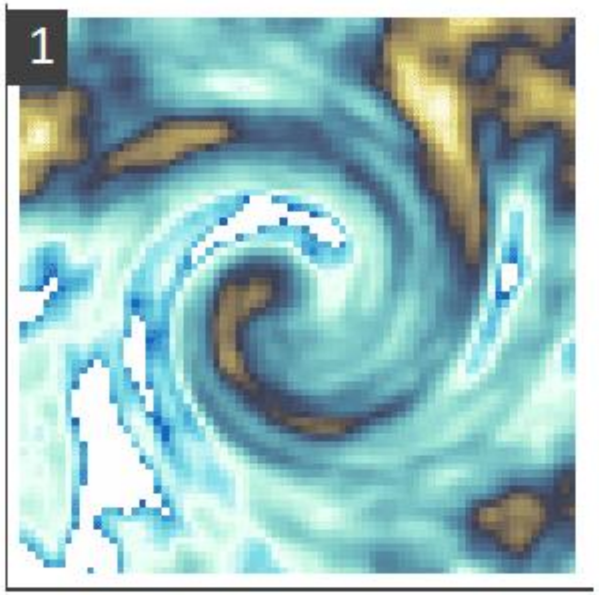
- *JPM extended to include the probability of rainfall and hydrology*

$$p_{(\cdot)}(\mathbf{x}_{(\cdot)};t) = \overbrace{p(\mathbf{x}_{Storm})}^{\text{Storm Parameters}}\ \overbrace{p(\bar{\mathbf{r}}|\mathbf{x}_{Storm};t)\,p(\mathbf{r}|\bar{\mathbf{r}};t)}^{\text{Rainfall Random Field}}\ \overbrace{p(\mathbf{s},\mathbf{w},\bar{\mathbf{s}},\mathbf{q}_b)}^{\text{Hydrology}},$$

$p_{(\cdot)}(\mathbf{x}_{(\cdot)};t)$: Probability distribution of either tropical cyclone or non-tropical storm and hydrologic conditions

$p(\bar{\mathbf{r}}|\mathbf{x}_{Storm};t)$: Distribution spatial avg. rainfall

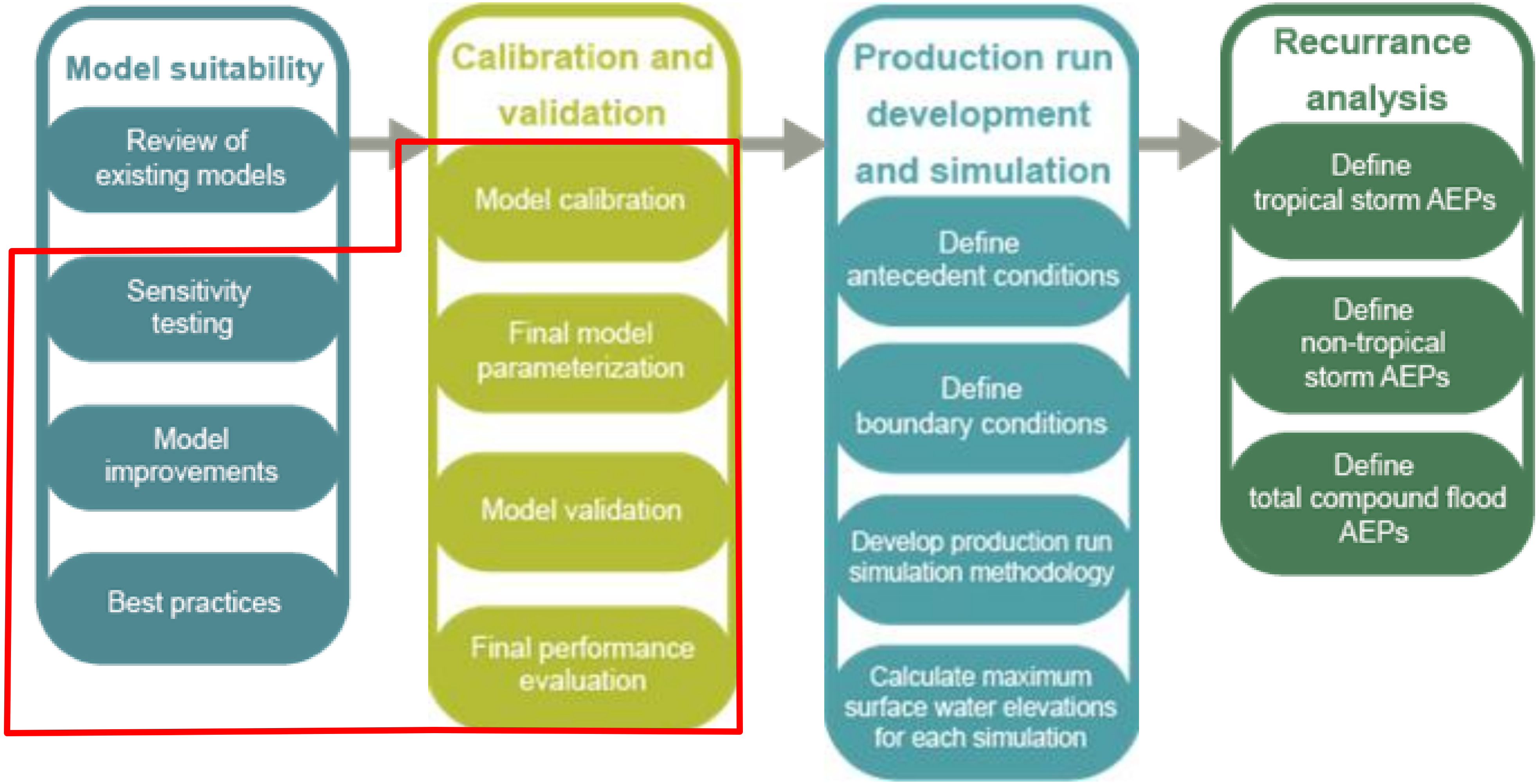
$p(\mathbf{r}|\bar{\mathbf{r}};t)$: Distribution spatial rainfall

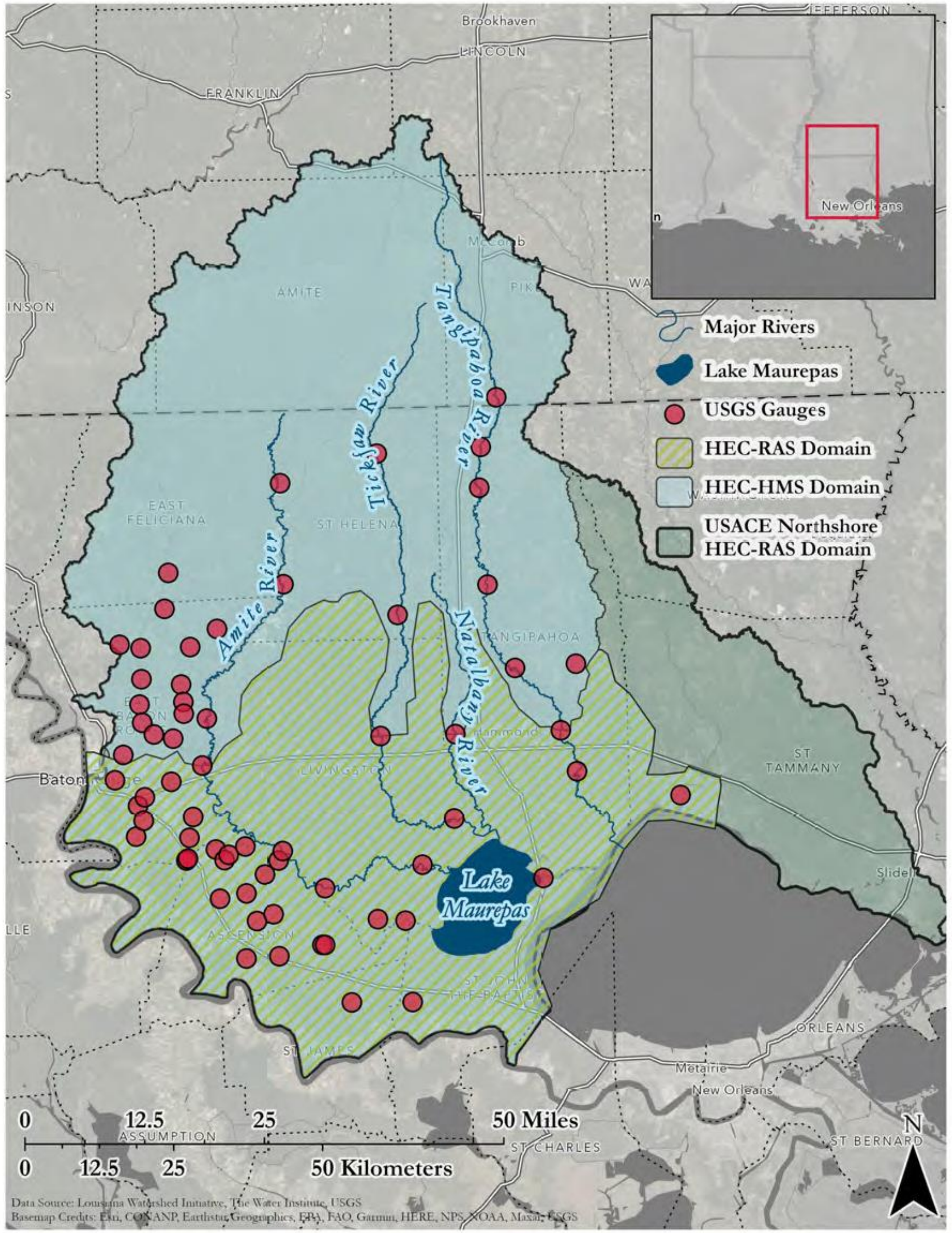


Where:

$\boldsymbol{x}_{Storm}$	Storm parameters, e.g., the typical JPM parameters
$\bar{\boldsymbol{r}}$	Spatial average rainfall
$\boldsymbol{r}$	Rainfall values (all points in the study)
$\bar{\boldsymbol{s}}$	Watershed average soil moisture
$\boldsymbol{s}$	Soil moisture (all points in the watershed)
$\bar{\boldsymbol{w}}$	Watershed average storage depth
$\boldsymbol{w}$	Storage depths (all points in the watershed)
$\boldsymbol{q}_b$	Baseflow

LOUISIANA WATERSHED INITIATIVE – AMITE PILOT STUDY FRAMEWORK





- ✓ USACE MVN provided the original model
- ✓ Full 2D model
- ✓ Average cell spacing = 1000x1000ft
  - ✓ Refined spacing as low as 100x100ft
- ✓ Once it was determined 300,000 + runs were required, we knew that Optimization was needed

PRODUCTION RUNS

Study captured uncertainty and flooding from:
1) tropical storms, 2) non-tropical storms 3) tidal flooding

Number of synthetic tropical cyclones:

5 Soil moisture conditions
1 Baseflow river/stream conditions
645 Combinations of storm attributes (track, velocity, etc.)
100 Rainfall patterns per storm

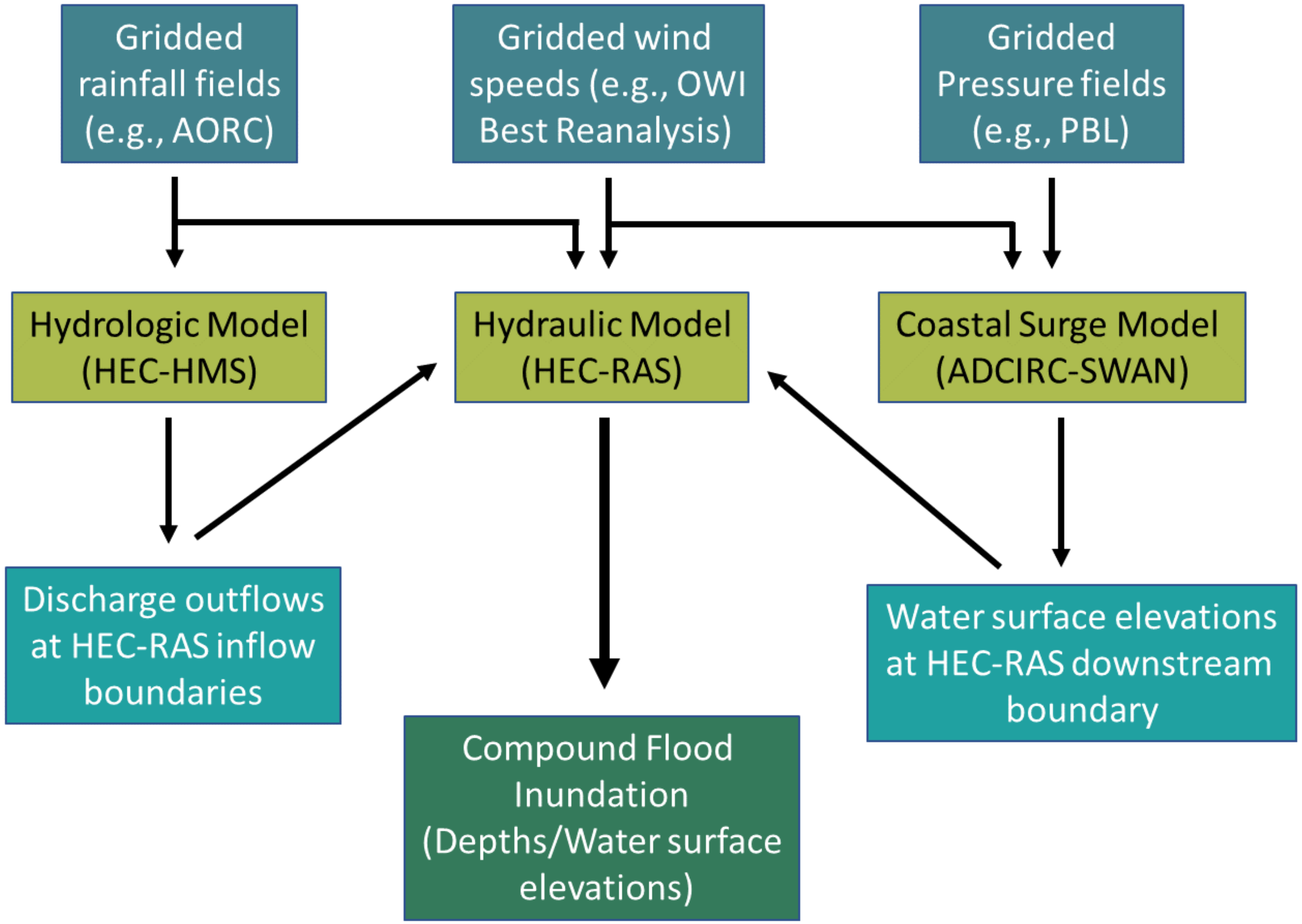
322,500 Simulations in total for tropical cyclones

Number of synthetic non-tropical cyclones :

5 Lags b/t peak streamflow and non-tide residual
1 Baseflow river/stream conditions
5 Storm (ocean) stage hydrographs
x 44 Rainfall patterns per storm

1,100 Simulations in total for non-tropical cyclones

MODEL EXECUTION WORKFLOW

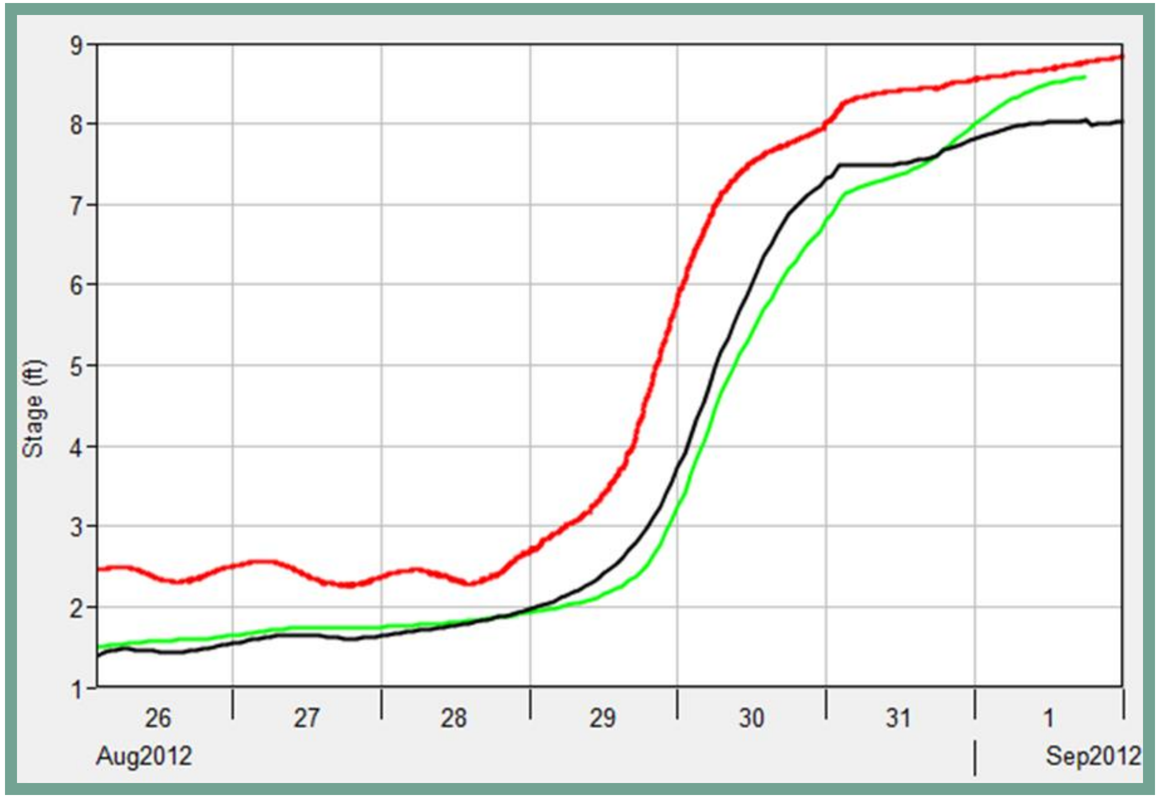


RAS2D OPTIMIZATION

- ✓ There is 1 known USGS gage in the Amite watershed

ISAAC

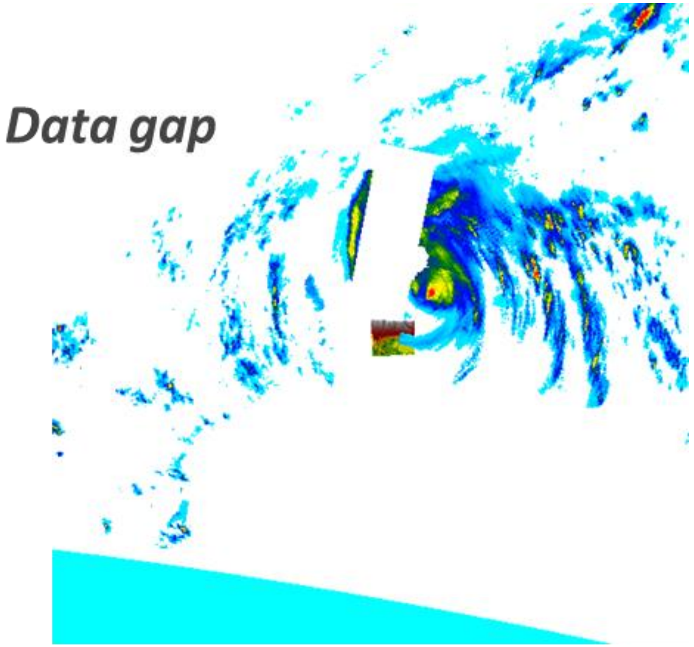
Original Run Time = 4 hours 15 minutes and 13 seconds
% Error = 0.1%
Optimized Run Time (SWE) = 20 minute and 40 seconds
% Error = 0.4%
% Increase in Efficiency =1,134%



RED = USGS gage
GREEN = Optimized (SWE)
BLACK = Original Model (SWE)

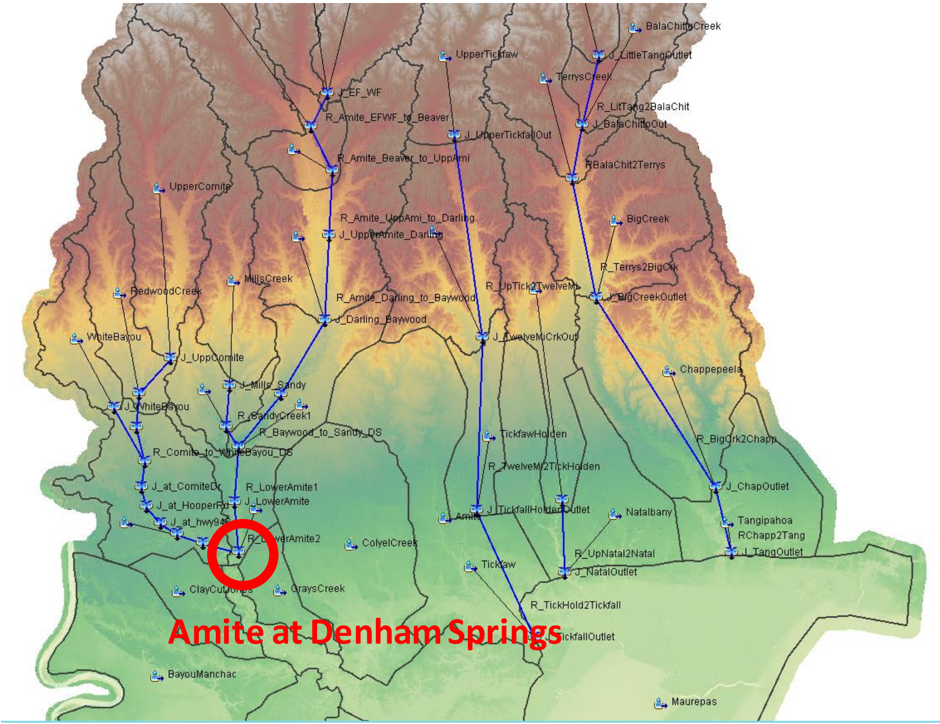
STAGE IV DATA GAPS - AMITE

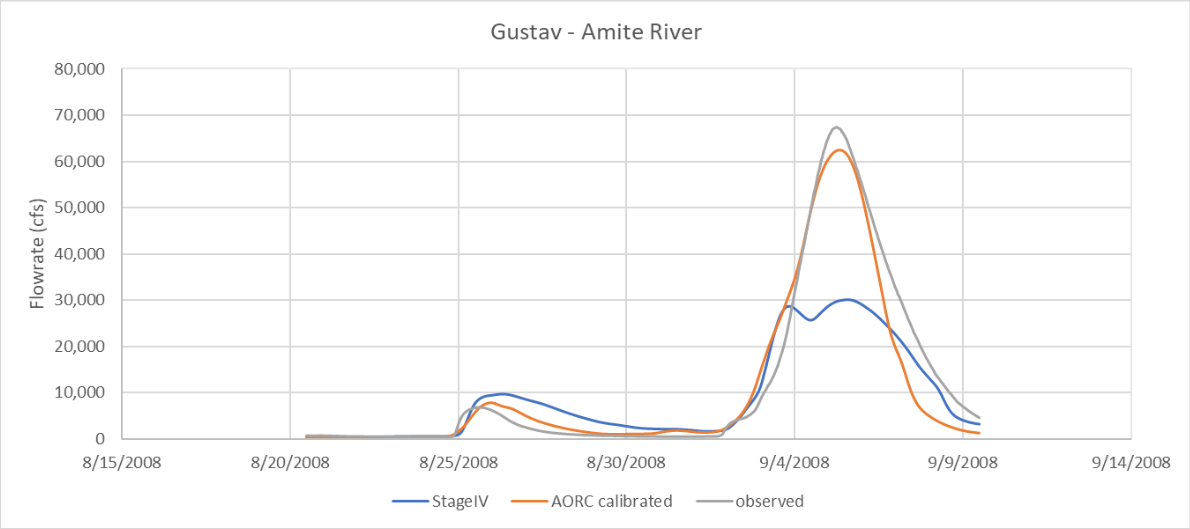
Event	Total Duration (hr)	Hours With Missing Data	% of Duration With Missing Data
Hurricane Katrina 2005	553	192	35
NTS Feb2004	673	105	16
NTS May 2004	745	40	5
Hurricane Ivan 2004	721	25	3
NTS Oct2002	553	14	3
Hurricane Gustav and Ike (8_25-9_15_2008)	793	8	1
NTS Apr2002	721	8	1
TS Bill 2003	521	4	1

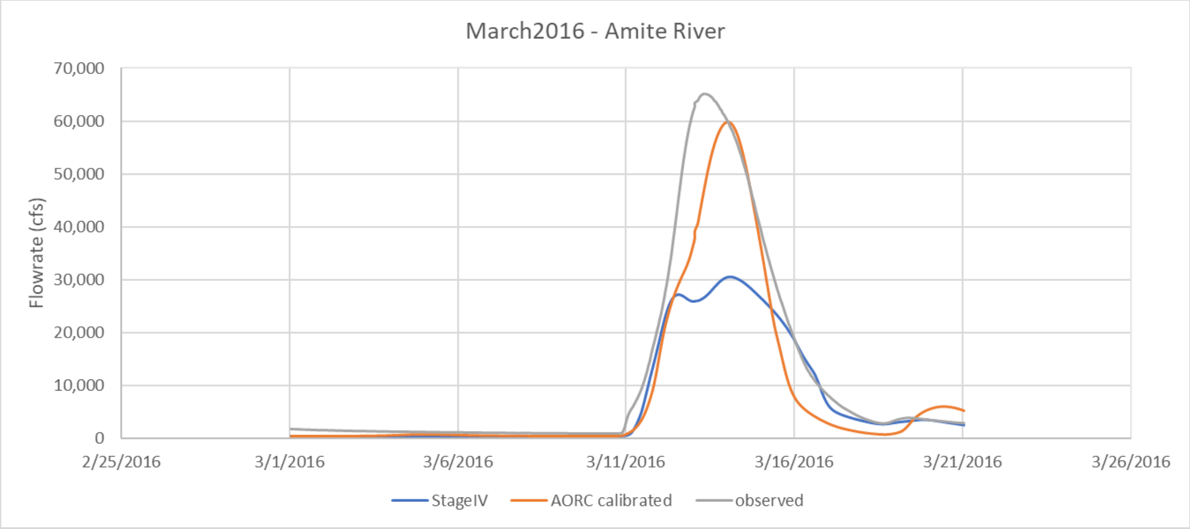


Stage IV (5 km res)

HMS COMPARISONS – AORC AND STAGE IV



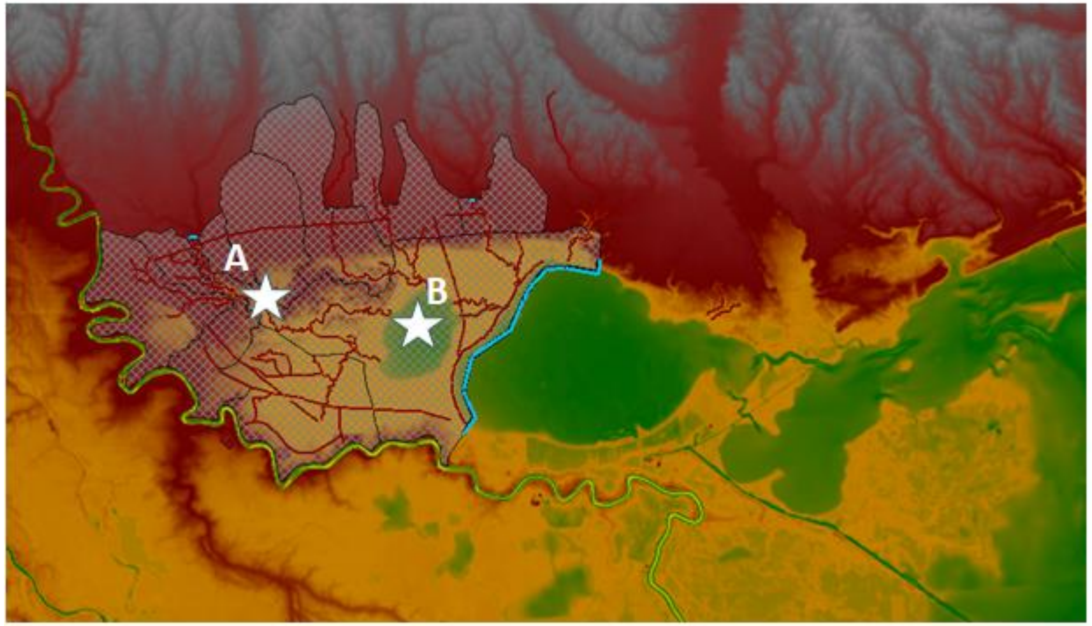




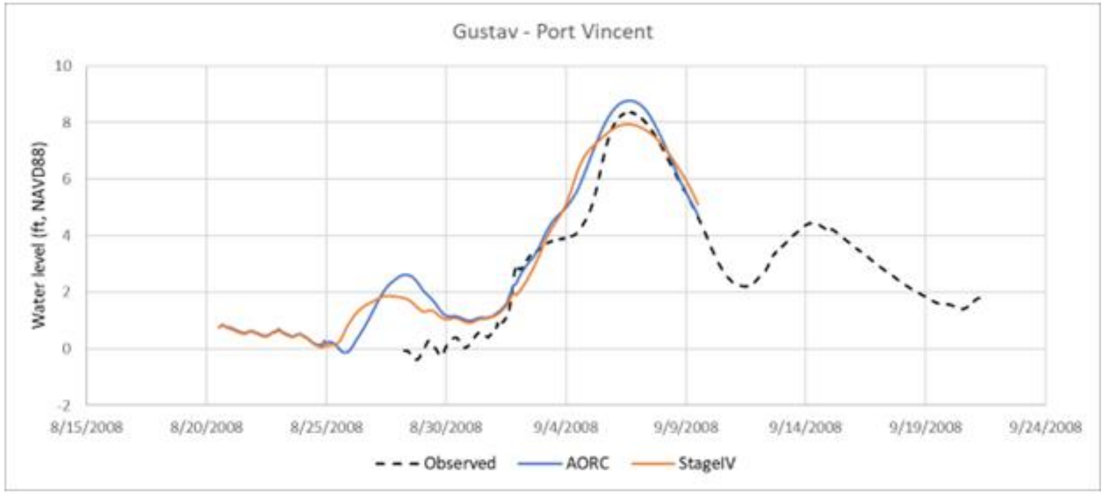
- Overall improvement with AORC compared to Stage IV

RAS COMPARISONS – AORC AND STAGE IV

Hurricane Gustav at (A) Port Vincent



Test properties	
Downstream BC	New ADCIRC simulated
Wind	New ADCIRC/OWI best reanalysis
Inflows	HMS with St4/AORC
Rain on mesh	Gridded St4/AORC



- Marginal improvement with AORC compared to Stage IV, with similar bias.

RAS6.1 DOWNSTREAM BOUNDARY SEGMENTATION

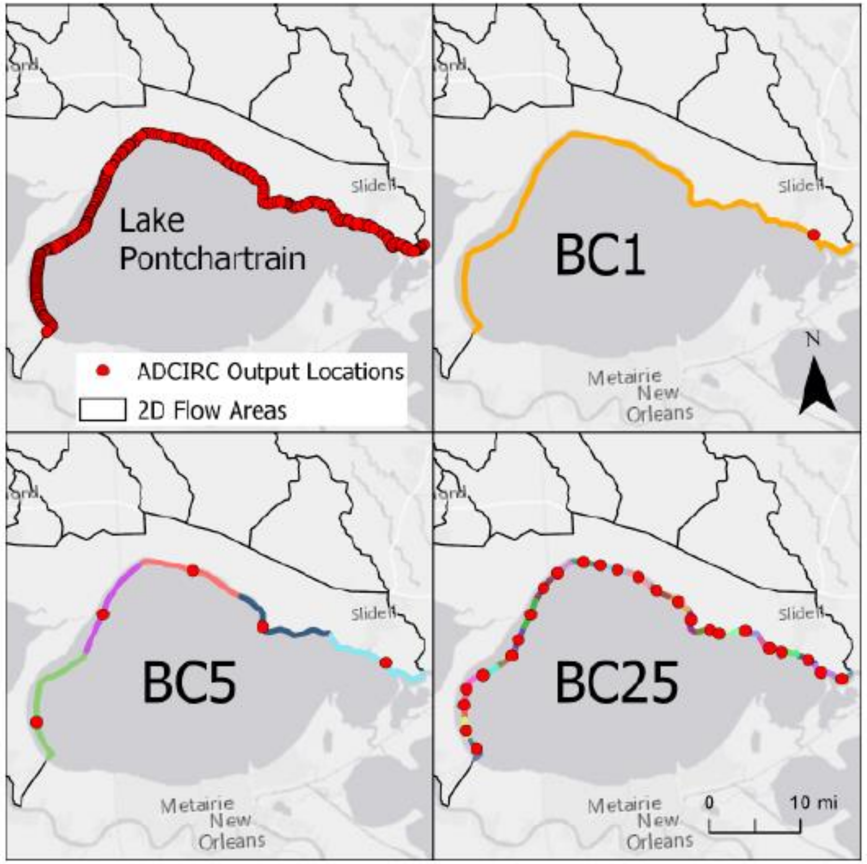
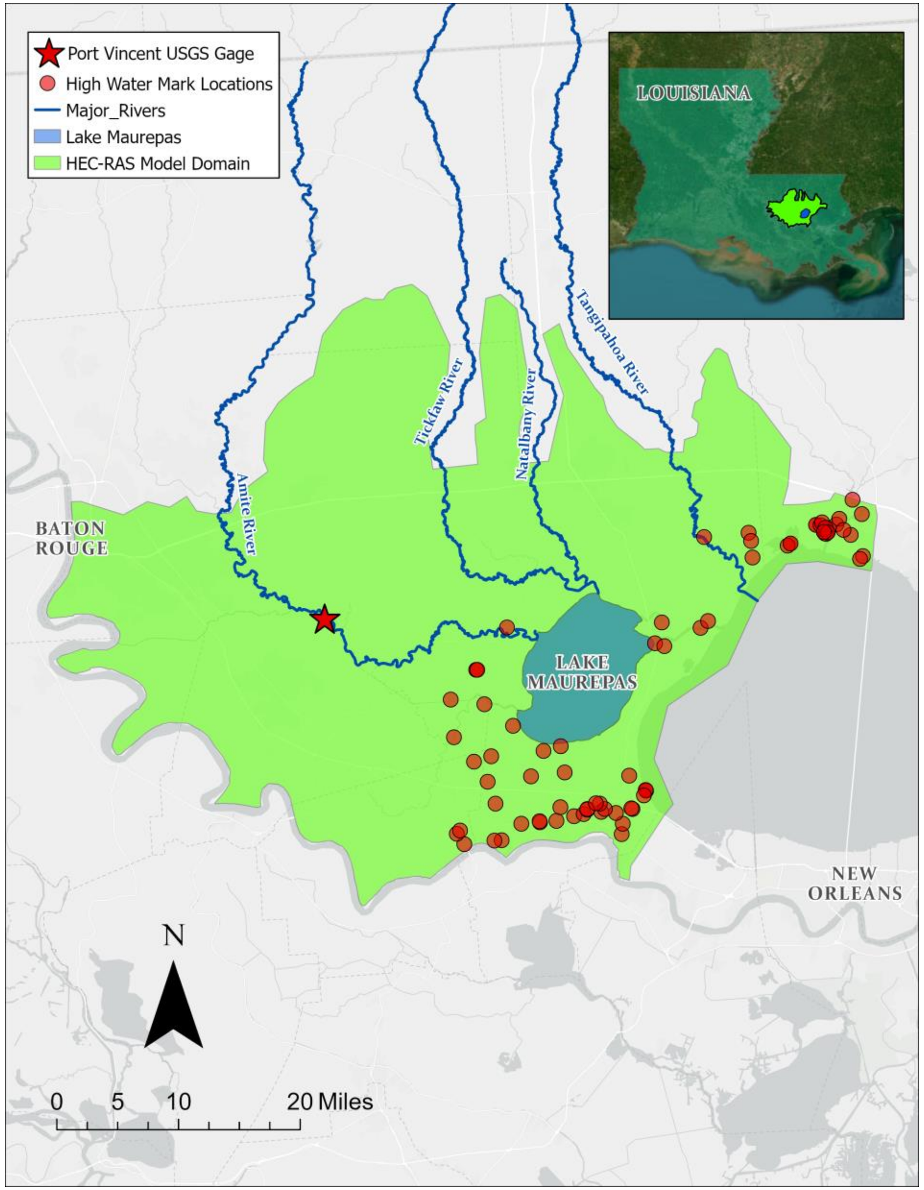


Figure 1. Coastal boundary connection between ADCIRC and the pilot study RAS 2D model domain. ADCIRC water levels are extracted along the boundary at nearly 800 locations (top left). The pilot study RAS 2D model boundary condition layouts and ADCIRC outputs (red dots) for each BC line (multi-colored lines) are shown for BC1 (top right), BC5 (bottom left), and BC25 (bottom right) (LWI, 2020).

Table 1. Average line length (in 1000 ft) for each boundary condition layout (BC1, BC5, BC25) and the peak water surface elevation (WSE) difference in NAVD88 ft.

Boundary Condition Layout	BC1	BC5	BC25
Number of Line Segments	1	5	25
Length of Line (1000 ft)	312	62.4	12.5
Peak WSE Difference in ADICRC output along the Line (ft)	3.9	0.1	<0.01

EPISTEMIC (MODEL) UNCERTAINTY



- Best record of the historical meteorology.
- Model is run with this best record.
- Model depths are compared against observed depths to calculate the model bias and standard deviation (i.e., uncertainty).

EPISTEMIC (MODEL) UNCERTAINTY

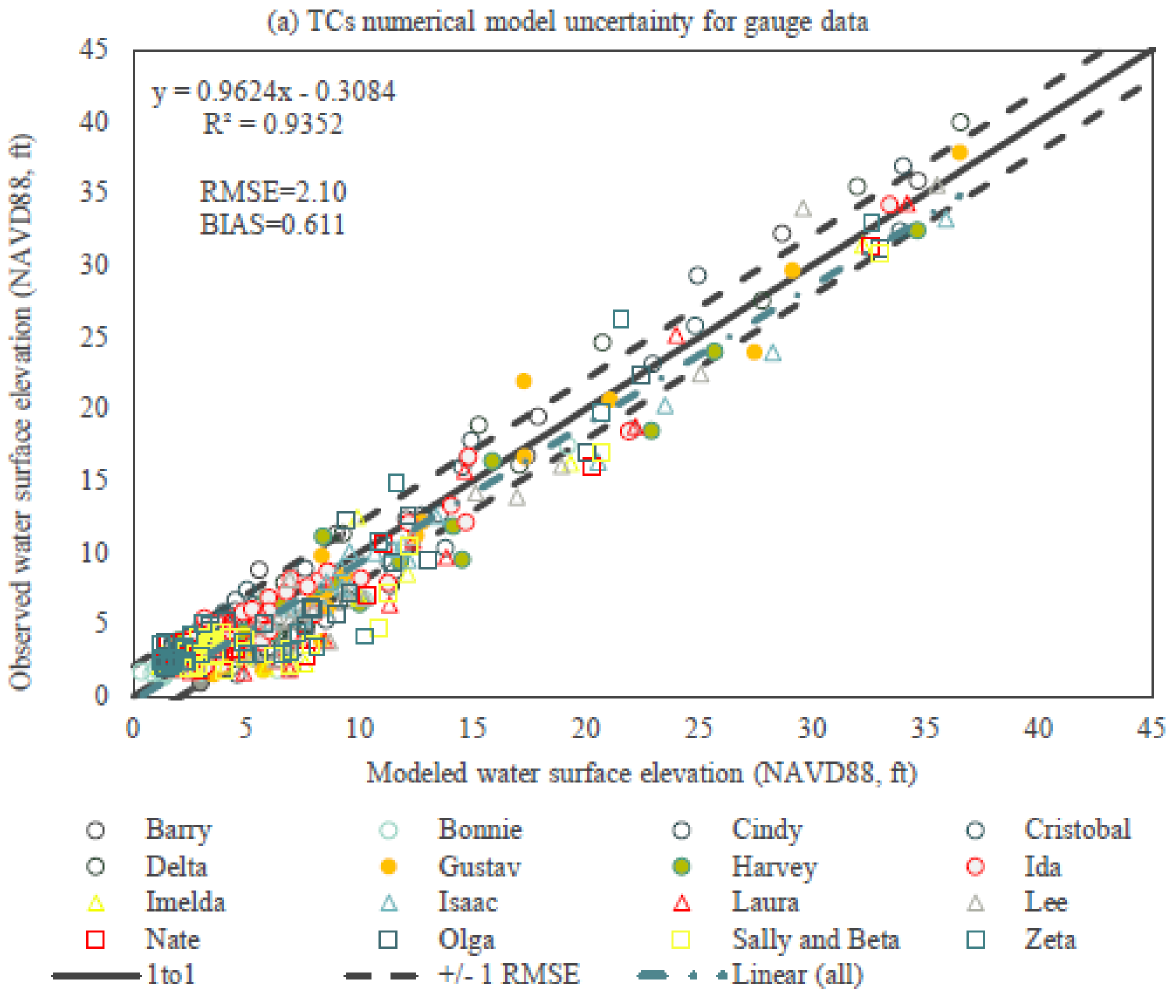


Figure 38. Comparison of modeled peak WSE with (a) USGS gauge data WSE peaks, and (b) HWMs within the HEC-RAS domain for TCs.

SOIL MOISTURE, RUNOFF, AND RIVER/STREAM FLOWS

$$p_{(\cdot)}(\mathbf{x}_{(\cdot)};t) = \overbrace{p(\mathbf{x}_{Storm})}^{\substack{\text{Storm}\\\text{Parameters}}}\overbrace{p(\bar{\mathbf{r}}|\mathbf{x}_{Storm};t)p(\mathbf{r}|\bar{\mathbf{r}};t)}^{\substack{\text{Rainfall}\\\text{Random Field}}}\overbrace{p(\mathbf{s},\mathbf{w},\bar{\mathbf{s}},\mathbf{q}_b)}^{\text{Hydrology}}$$

where $_{(\cdot)}$ is a placeholder for TC and NT for respective tropical cyclone and non-tropical descriptions.

THE JPM METHOD HYDROLOGY ENHANCEMENTS

- *JPM extended to include hydrology*

Dist. Watershed baseflow

Dist. Storage Depths

$$p(\mathbf{s}, \mathbf{w}, \bar{\mathbf{s}}, \mathbf{q}_b) = \underbrace{p(\mathbf{s}|\bar{\mathbf{s}})}_{\text{Dist. soil moisture}} \overbrace{p(\mathbf{q}_b|\bar{\mathbf{s}})}^{\text{Dist. Watershed baseflow}} \underbrace{p(\bar{\mathbf{s}})}_{\text{Dist. Watershed avg. soil moisture}} \overbrace{p(\mathbf{w}|\overline{\mathbf{w}})}^{\text{Dist. Storage Depths}}$$

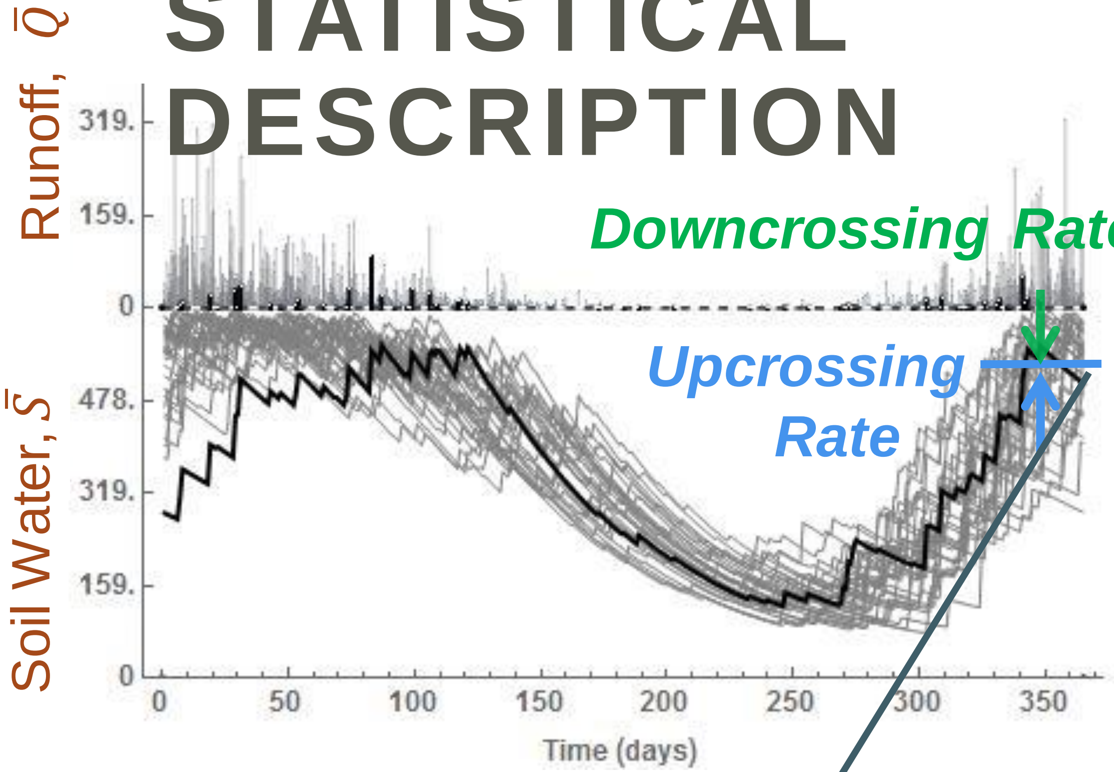
Dist. soil moisture

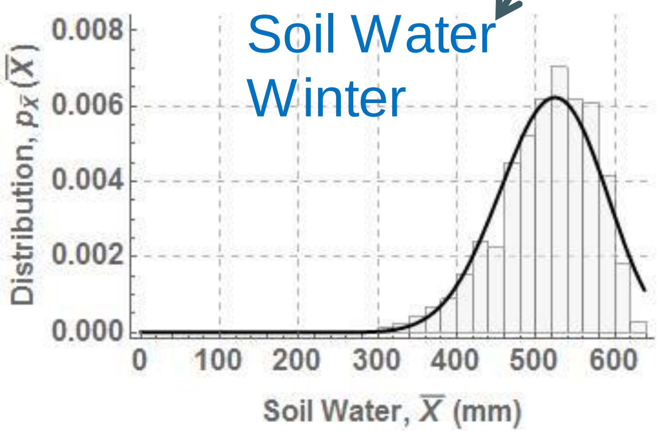
Dist. Watershed avg. soil moisture

<u>Where</u>:

$\bar{s}$	Watershed average soil moisture
s	Soil moisture (all points in the watershed)
$\bar{w}$	Watershed average storage depth
w	Storage depths (all points in the watershed)
q_b	Baseflow

STATISTICAL DESCRIPTION





Soil Water PDF (Distribution)

$$p_{\bar{S}_\cdot}(\bar{S};t) = \frac{C}{\bar{F}_t(\bar{S}_\cdot)} e^{-\frac{1}{\langle \bar{R}_\cdot - \bar{Q}(\bar{R}_\cdot,\bar{S}_\cdot^-)\rangle} + \lambda_\cdot \int \frac{1}{\bar{F}_t(u)} du}$$

Runoff PDF (Distribution)

$$p_{\bar{Q}}(\bar{Q};t) = \int_0^\infty \int_0^w \delta(\bar{Q}(\bar{R}_\cdot,\bar{S}_\cdot^-) - \bar{Q}) p_{\bar{R}}(\bar{R}) p_{\bar{S}_\cdot}(\bar{S}^-;t) d\bar{R} d\bar{S}^-$$

Explicit Dependence on:

Climate

$\lambda_\cdot$ Rainfall frequency

$\bar{R}_\cdot$ Rainfall amount

Vegetation

$\bar{F}_t(\bar{S}_\cdot)$ Evapotranspiration

Runoff description

$\bar{Q}_\cdot(\bar{R}_\cdot,\bar{S}_\cdot^-)$ Runoff curve

Spatial Heterogeneity

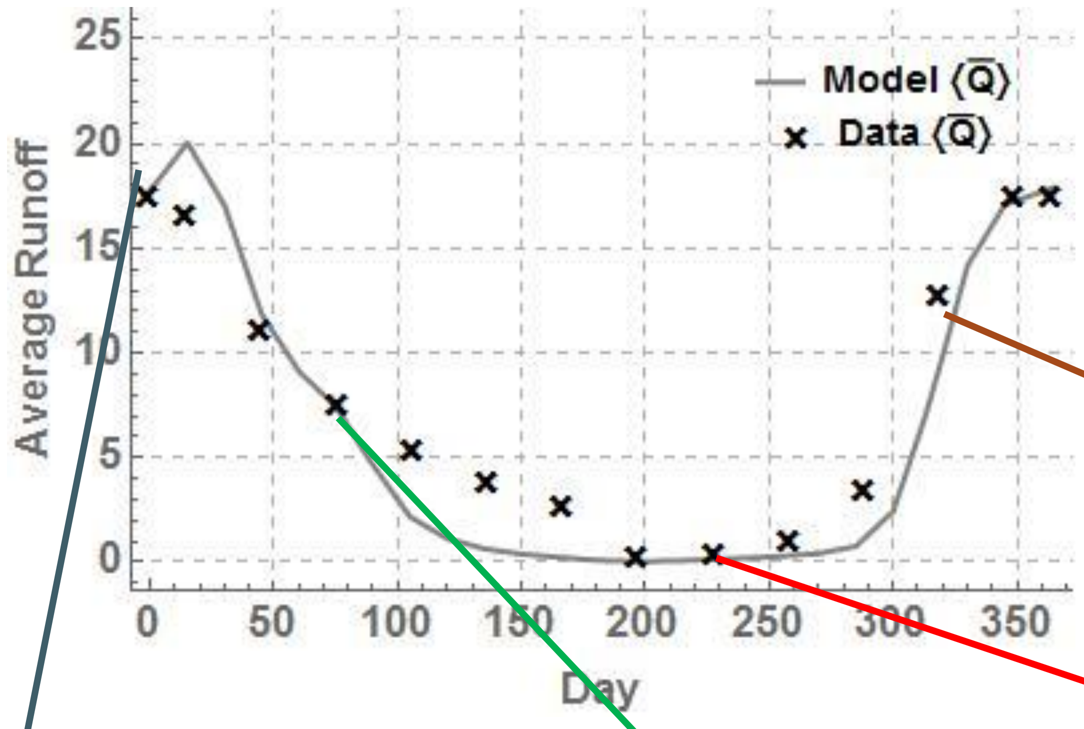
$p_{RSw}(r,X,w;\bar{S})$

Bartlett, M.S., et al. (2015) Proceedings of the Royal Society A; Feng X., et al. (2014) Proceedings of the Royal Society A.
Bartlett, M.S and Porporato (2018) Physical Review E

MODEL DISTRIBUTION AND DATA COMPARISON

Average Runoff for a point in time

$$\left\langle \overline{Q};t \right\rangle = \int_0^\infty \overline{Q}\, p_{\overline{Q}}(\overline{Q};t)\, d\overline{Q}$$

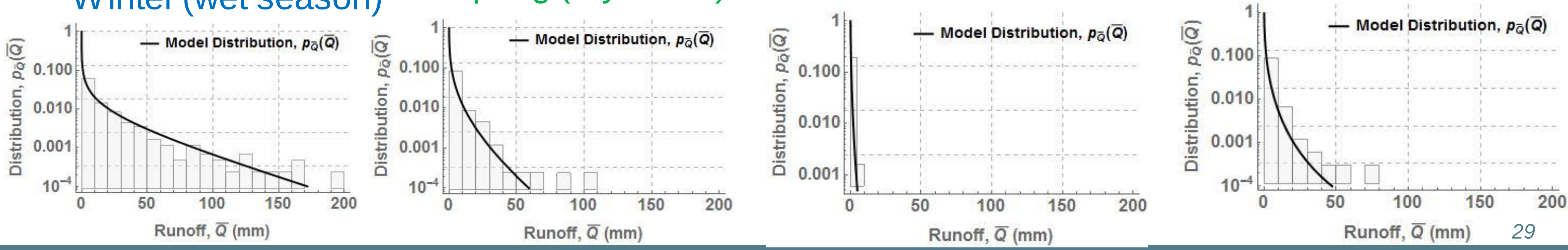


Winter (wet season)

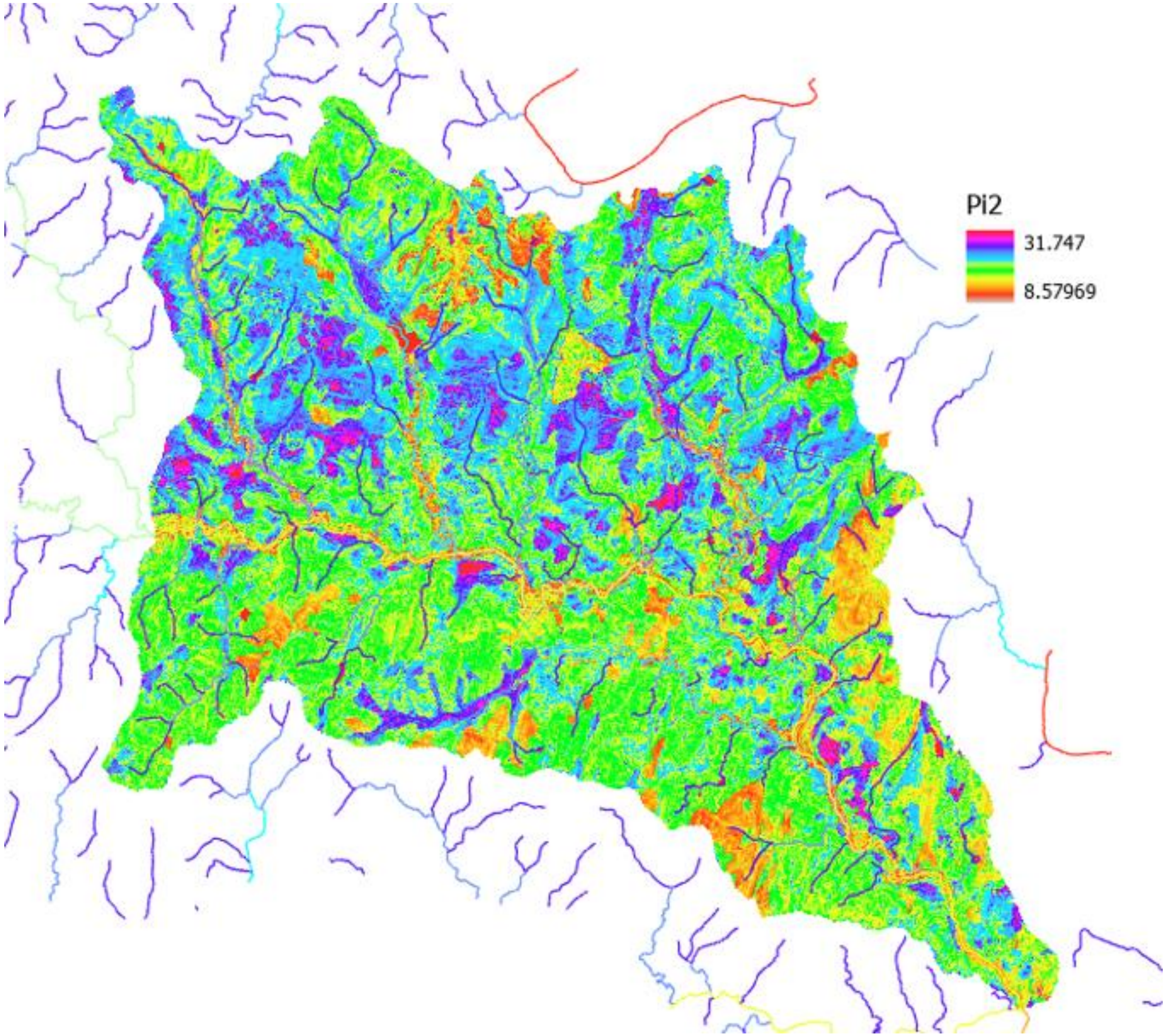
Spring (dry-down)

Summer (dry season)

Fall (wet-up)



LOCAL SOIL MOISTURE VALUES



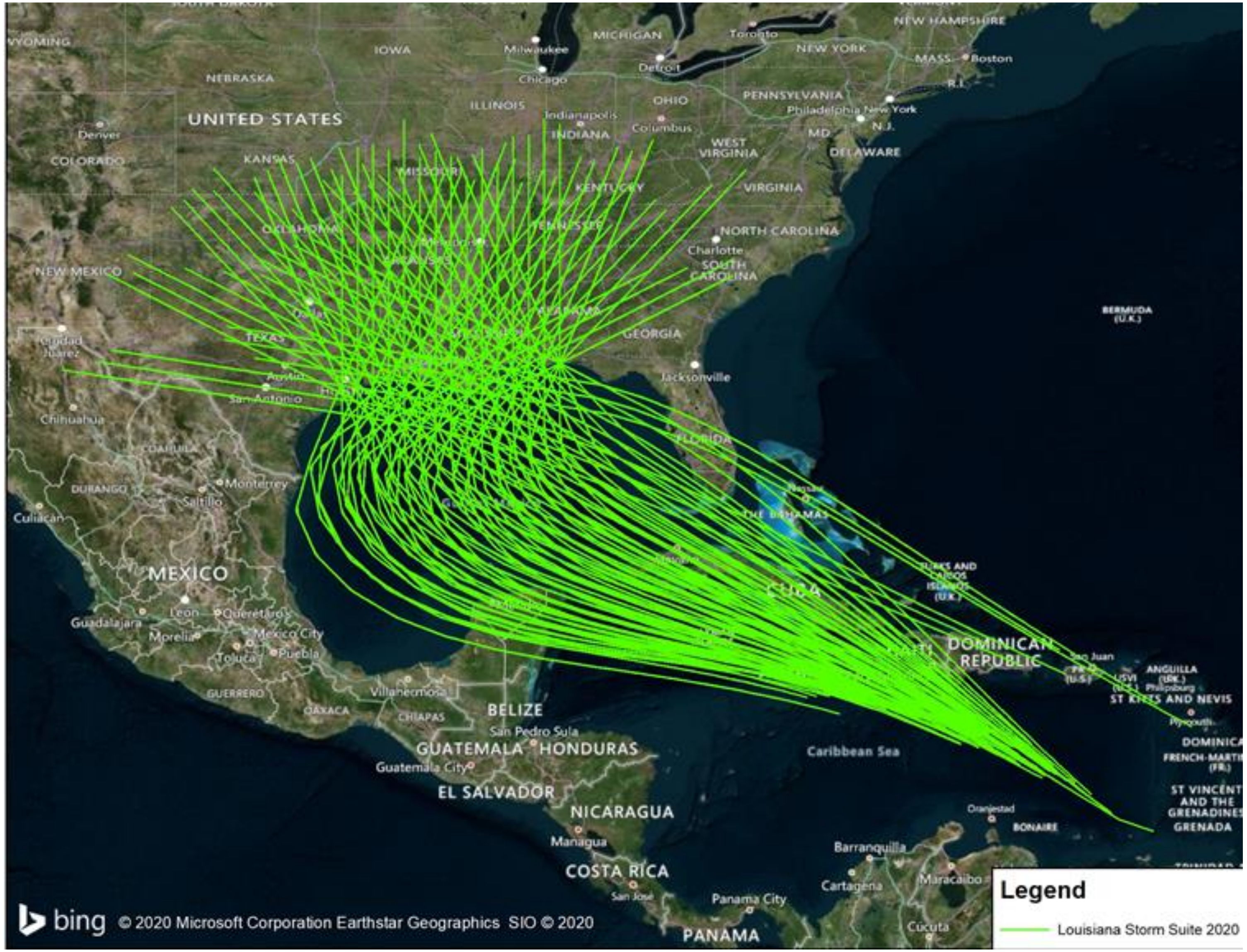
Mapped to cells in HEC-RAS based on a topographic wetness index derived from the DEM

RAINFALL FIELDS

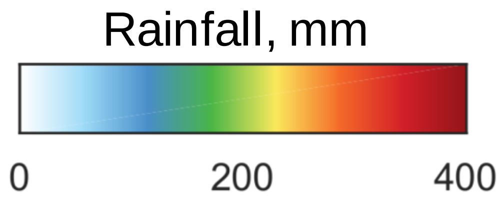
$$p_{(\cdot)}(\mathbf{x}_{(\cdot)};t) = \overbrace{p(\mathbf{x}_{Storm})}^{\text{Storm Parameters}} \overbrace{p(\bar{\mathbf{r}}|\mathbf{x}_{Storm};t)p(\mathbf{r}|\bar{\mathbf{r}};t)}^{\text{Rainfall Random Field}} \overbrace{p(\mathbf{s},\mathbf{w},\bar{\mathbf{s}},\mathbf{q}_b)}^{\text{Hydrology}},$$

where $_{(\cdot)}$ is a placeholder for TC and NT for respective tropical cyclone and non-tropical descriptions.

Given synthetic tropical cyclone (TC) tracks, how can we generate probabilistic rainfall associated with these storms?

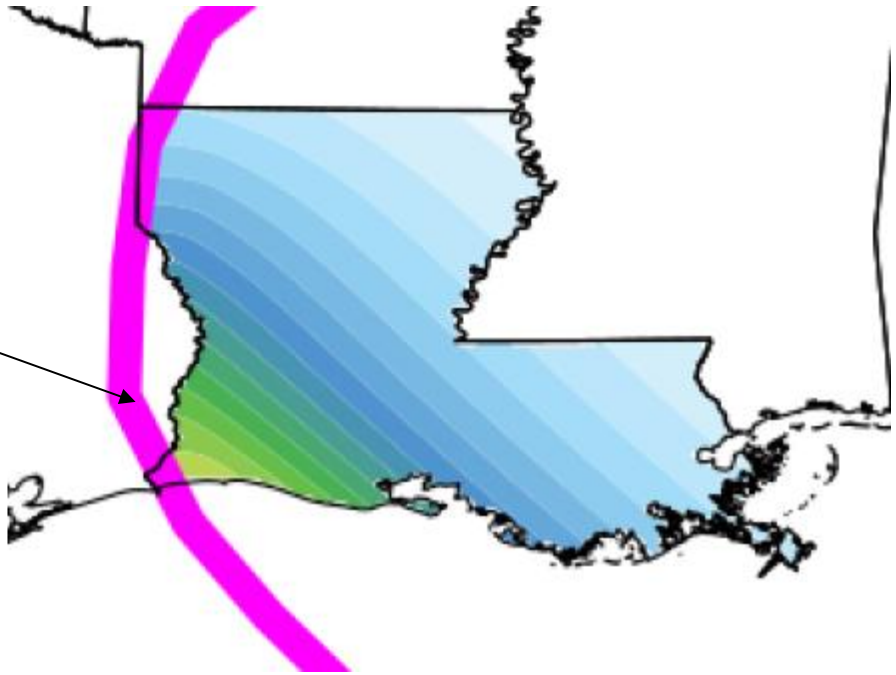


RAINFALL UNCERTAINTY: BIAS CORRECTION

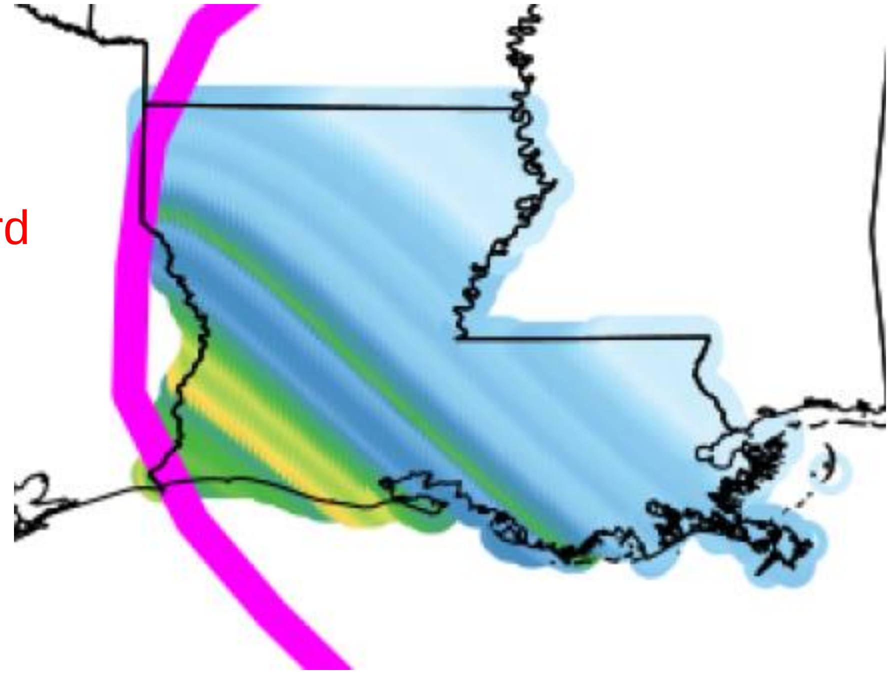


Start with a deterministic model of rainfall (e.g., Interagency Performance Evaluation Task Force Rainfall Analysis (IPET))

Hurricane Rita Track

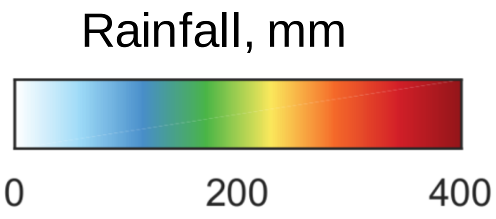


Bias Correct (based on the historical record Stage IV data)

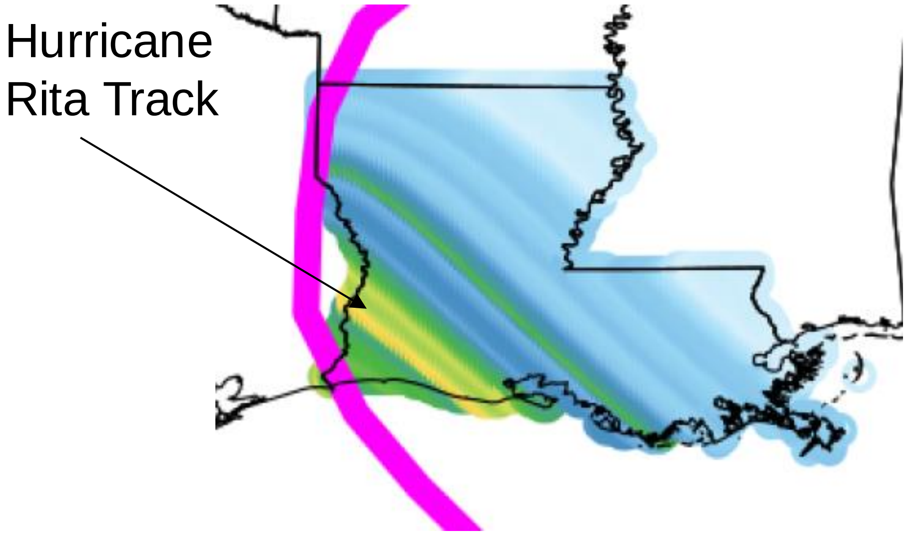


[1] Stage IV Quantitative Precipitation Estimates (QPE) products over the continental United State (CONUS) (http://www.emc.ncep.noaa.gov/mmb/ylin/pcpanl/stage4/) are released by the National Centers for Environmental Prediction (NCEP)

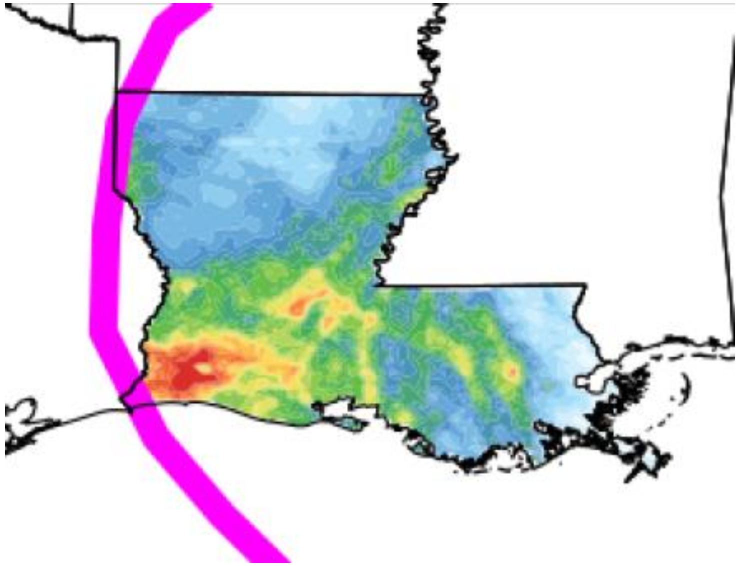
RAINFALL UNCERTAINTY: NOISE CHARACTERIZATION

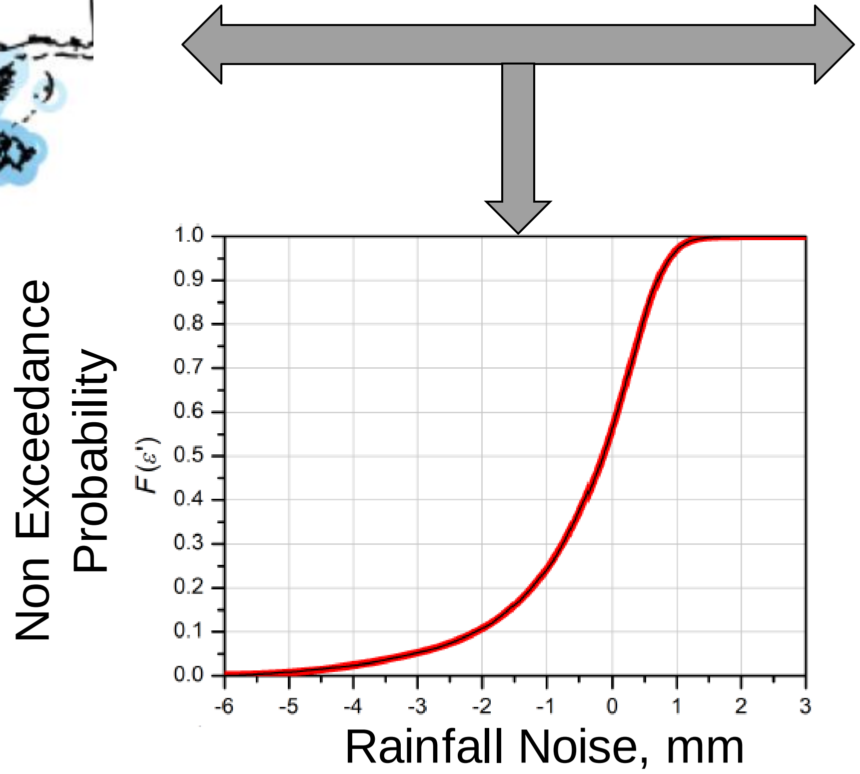


Bias Corrected Rainfall Model

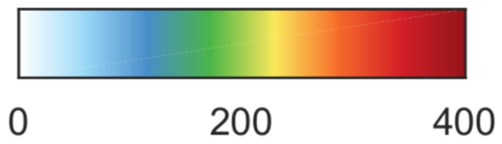


Compare to the historical Record (Stage IV data) to describe the 'Noise'



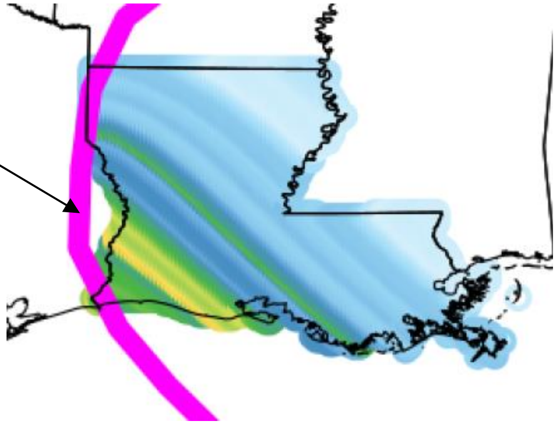


GENERATE NEW (EQUIPROBABLE) ‘REALIZATIONS’ OF RAINFALL

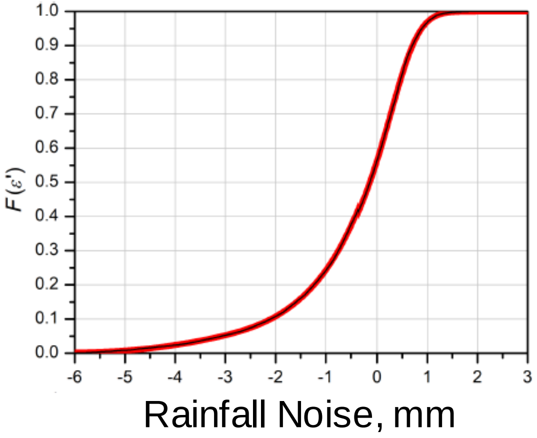


Hurricane Rita Track

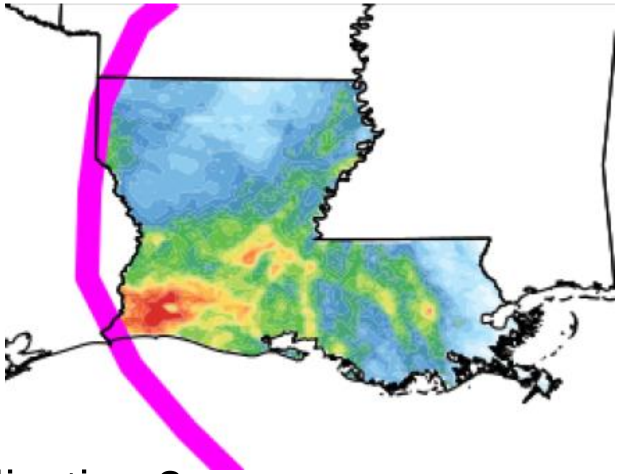
Bias Corrected Rainfall Model



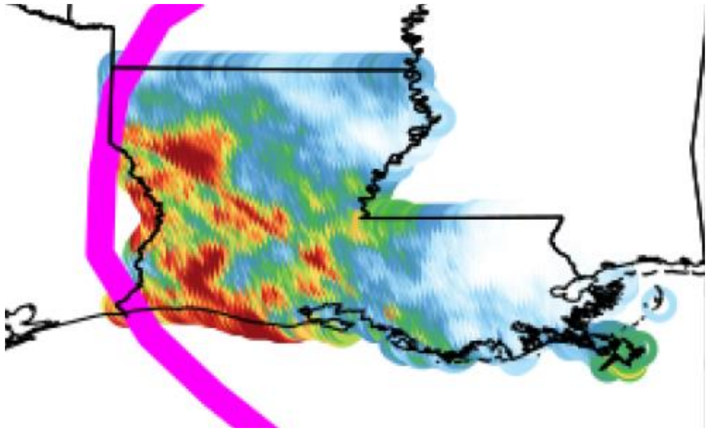
Noise



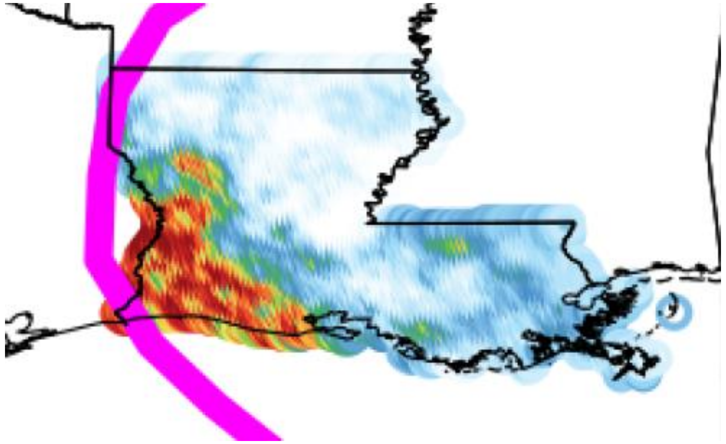
Historical Record



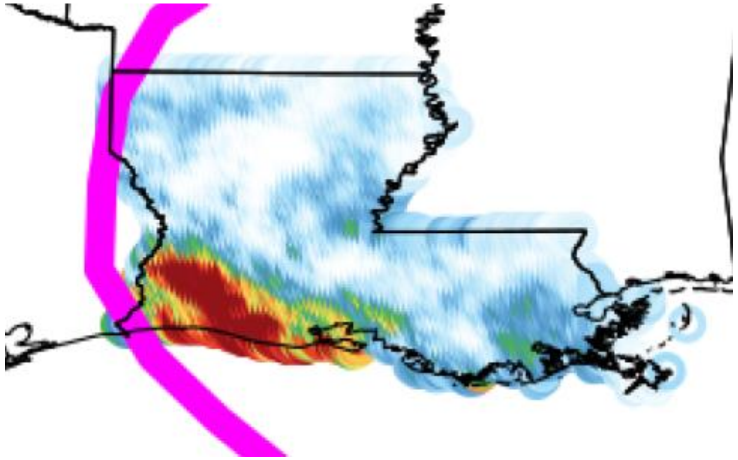
Realization 1



Realization 2

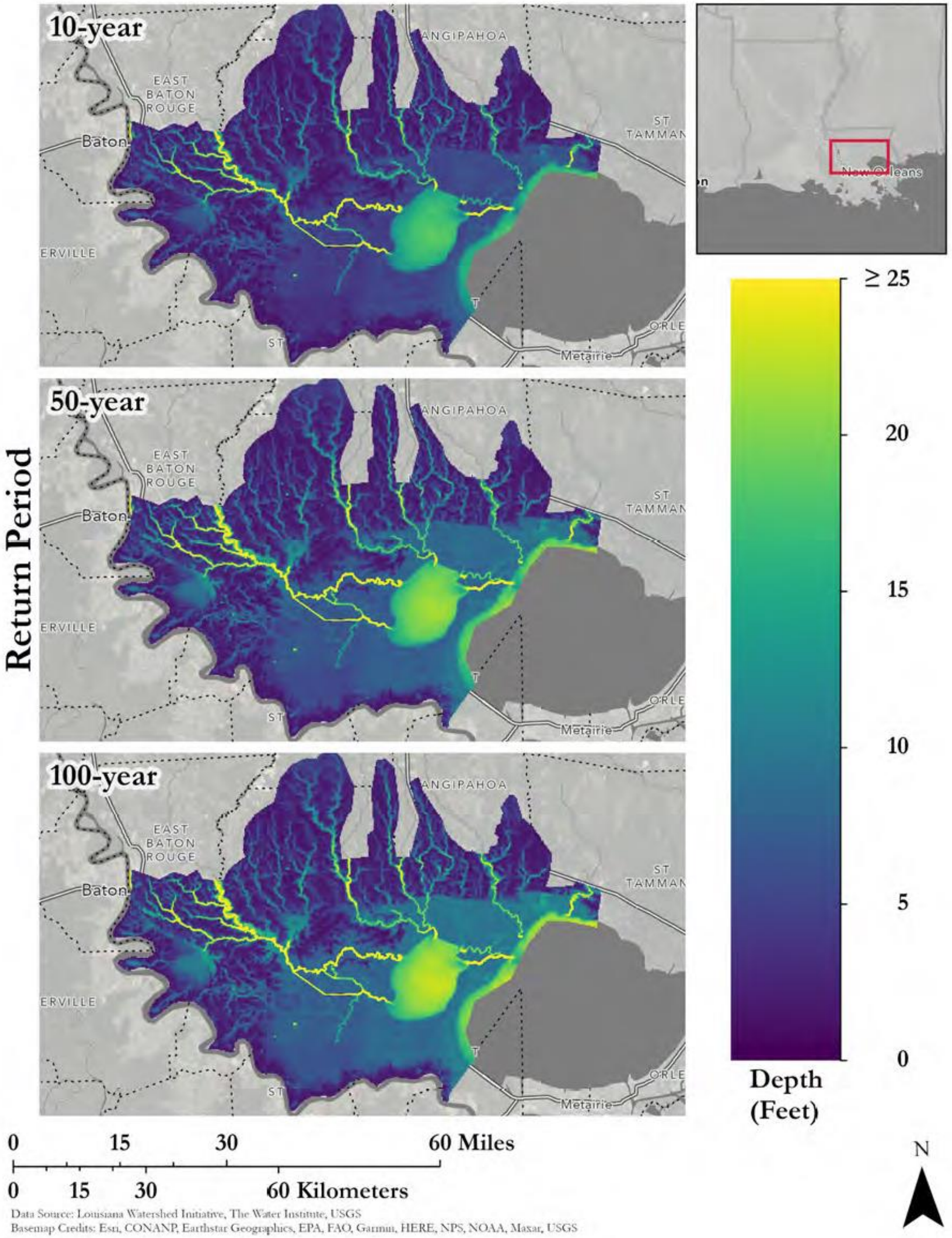


Realization 3

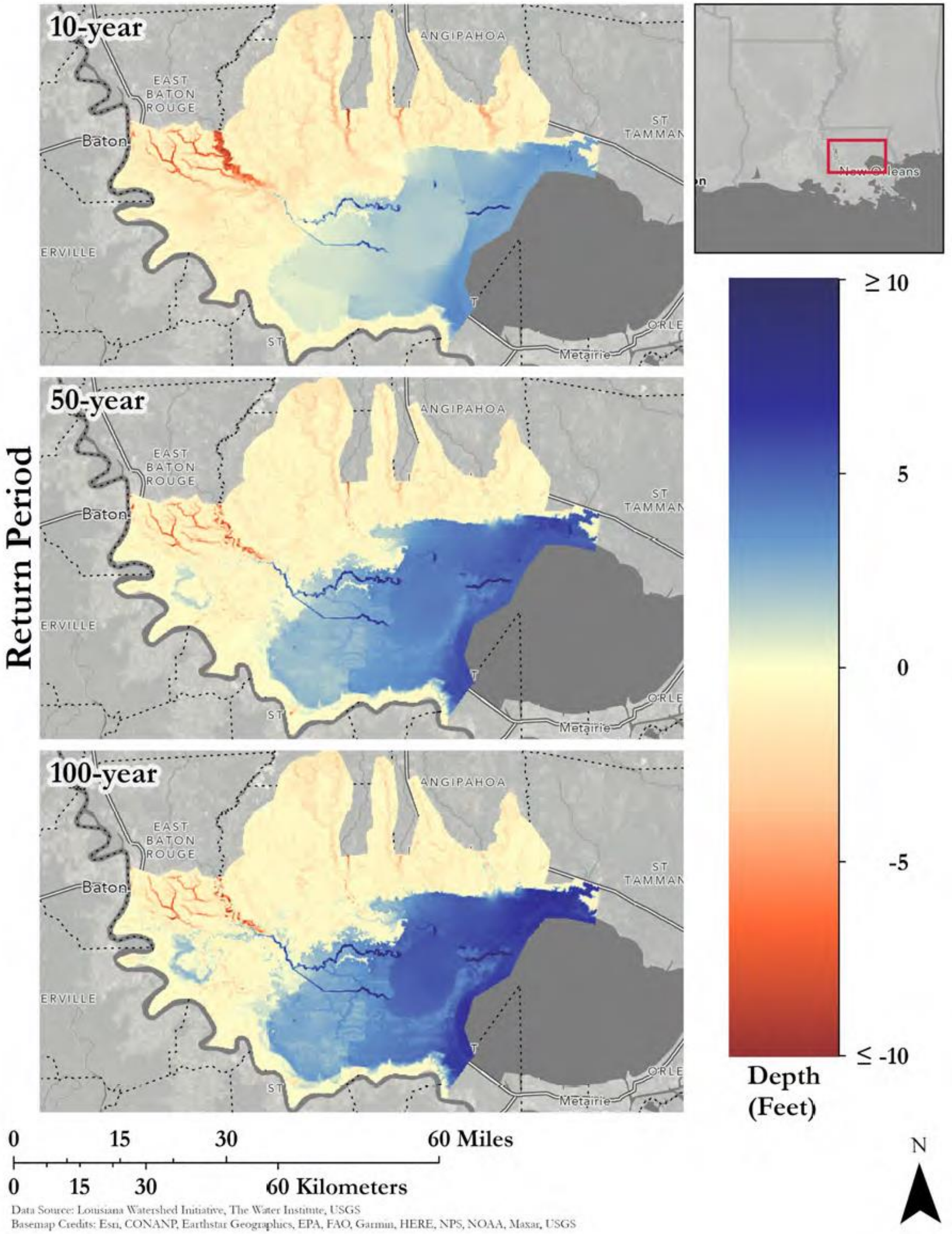


[1] Villarini, G., Zhang, W., Miller, P., Johnson, D. R., Grimley, L. E., & Roberts, H. J. (2022). Probabilistic rainfall generator for tropical cyclones affecting Louisiana. International journal of climatology, 42(3), 1789-1802.

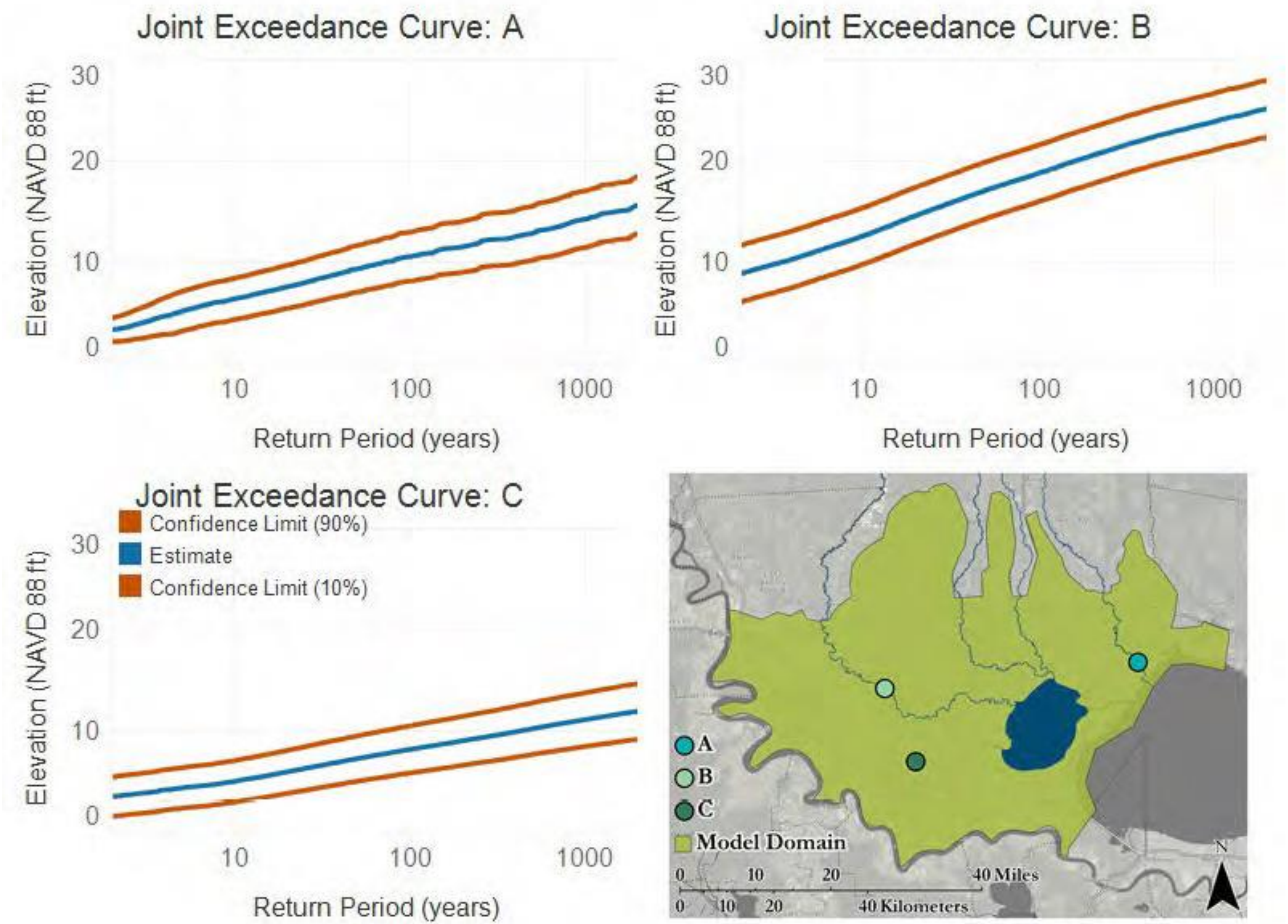
COMPOUND FLOOD DEPTH RASTERS



TROPICAL-NON TROPICAL DEPTHS



JOINT EXCEEDANCE CURVES



FLOODED STRUCTURES ESTIMATES

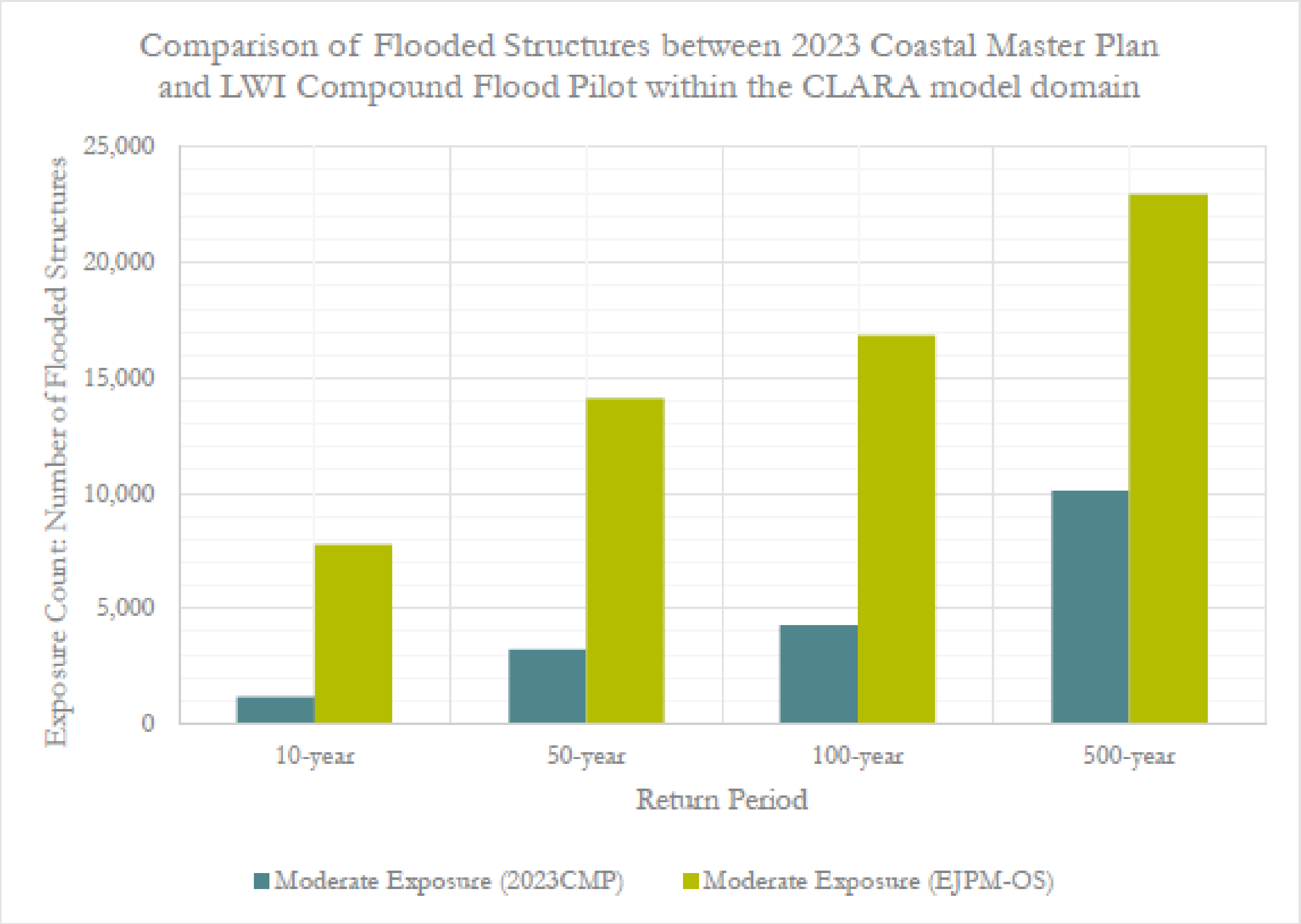
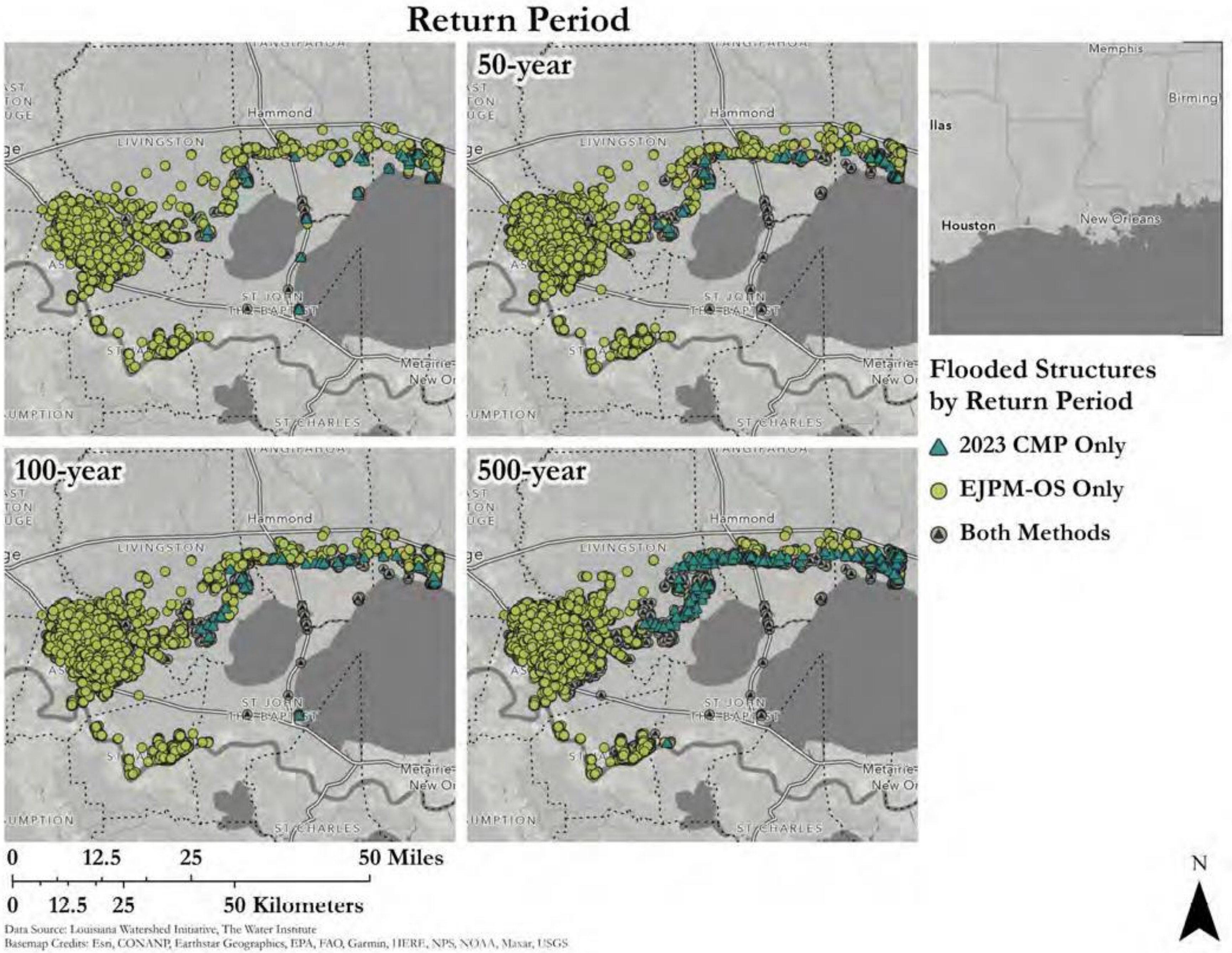


Figure 62. Moderate exposure by return period of number of flooded structures within the CLARA model domain.

FLOODED STRUCTURES ESTIMATES



KEY TAKEAWAYS

- An efficient probabilistic and modeling framework has been developed to quantify flood risk due to compounding impacts of surge and precipitation.
- Applicable in regions exposed to flood hazards driven by TCs and non-TCs such as the Gulf of Mexico.
- Joint Probability Method, developed by USCE-ERDC and FEMA, extended to incorporate precipitation and hydrology. Facilitates efficient quantification of compound flood risk due to TCs.
- HEC-RAS with winds and coupled ADCIRC+SWAN can efficiently simulate compounding flooding.
- Feedback provided by the Technical Advisory Group leveraged to develop the LA coastwide compound flood risk assessment framework that us currently ongoing.
- Enhancements to approach for TCs and non-TCs being implemented in the LA coastwide model.
- Institute leading collaborative efforts to quantify current and future compound flood risk in Jacksonville.

THANK YOU!
QUESTIONS?

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