Florida Public Flood Loss Model
V1.0

Model Overview

- The FPFLM (flood loss model) project for personal and commercial residential properties was funded by the Florida Office of Insurance Regulation.
- We are currently funded to develop, operate, and maintain the model at Florida International University.
- Model was developed by a team of experts in meteorology, coastal surge, wave, hydrology, engineering, computer science, actuarial science, finance, and statistics at multiple institutions.
- Our major client is the FL-OIR.
- Model development was not influenced by either Florida-OIR or the insurance industry.

General Comments

- The model is transparent in the sense that we make available technical reports, flowcharts etc. on the assumptions, methods, theories, component designs, and tests.
- Technical documents are available at the project website: www.cis.fiu.edu/hurricaneloss/
- The source code, however, is not open.

Participating Institutions

- Florida International University/ IHRC (lead institution)
- Florida State University
- University of Florida
- Florida Institute of Technology
- University of Missouri Kansas City
- Hurricane Research Division, NOAA
- University of Miami
- Notre Dame University
- Rutgers University
- AMI Risk Consultants

Meteorology Team

- Dr. Steven Cocke — Dept of Meteorology, Florida State University
- Dr Dong-Wook Shin — Dept of Meteorology, Florida State University
- Dr. Bachir Annane — University of Miami – CIMAS

Engineering Team

- Dr. Jean Paul Pinelli — Dept of Civil Engineering, Florida Institute of Technology
- Dr. Kurtis Gurley — Dept of Civil Engineering, University of Florida
- Dr. Andres Paleo–Torres — Dept of Civil Engineering, University of Florida
- Dr. Mohammad Shoraka — Dept of Civil Engineering, Florida Institute of Technology
- Christian Badwell — Dept of Civil Engineering, University of Florida

Coastal Surge and Wave Flood Team

• Dr. Yuepeng Li	Extreme Event Institute at Florida International University
• Dr. Keqi Zhang (deceased)	Dept Earth & Environment and EEI, FIU
• Dr. Qiang Chen	Extreme Event Institute at FIU
• Peng Hou	Extreme Event Institute at FIU
• Dr. Andrew Kennedy	Notre Dame University

Inland Flood Team

• Dr. Steven Cocke	Dept of Meteorology, FSU (pluvial flood)
• Dr Dong-Wook Shin	Dept of Meteorology, FSU (pluvial flood)
• Dr Efthymios Nilolopoulos	Dept of Civil Engr, Rutgers Univ, Hydrologist (fluvial flood) (previously at Florida Institute of Technology)
• Zimeena Rasheed	Dept of Civil Engr, Rutgers Univ (fluvial flood)
• Dr. Humberto Vergara	Dept Civil & Environ Engineering, Univ of Iowa (fluvial flood)
• Dr. Marika Koukoula	University of Lausanne (fluvial flood)

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Computer Science Team

- Dr. Shu-Ching Chen School of Computer Science, FIU until June 2022
  University of Missouri KC since July 2022
- Dr. Mei-Ling Shyu Dept. of Electrical and Computer Engineering,
  Previously Univ of Miami. Currently UMKC
- Dr. Tianyi Wang EEI, Florida International University
- Numuun Lkhagvadorj Dept of Computer Science, UMKC
- Ayushman Das Dept of Computer Science, UMKC
- Odai Athamneh Dept of Computer Science, UMKC
- Other graduate and undergraduate students at UMKC and FIU

Actuarial/Finance Team

- Dr. Shahid Hamid — Dept of Finance and IHRC/EEI, FIU, PI and Project Director
- Gail Flannery — Actuary, FCAS, AMI Risk Consultant
- Bob Ingco — Actuary, FCAS, AMI Risk Consultant
- Joeffery Somera — Actuary, ACAS, AMI Risk Consultant

Statistics Team

- Dr. Sneh Gulati — Dept. of Statistics, FIU
- Dr. G. Kibria — Dept. of Statistics, FIU
- Dr. Wensong Wu — Dept. of Statistics, FIU

Technical Editor

- Dr. Steven Cocke — Dept of Meteorology, Florida State University

Model Design

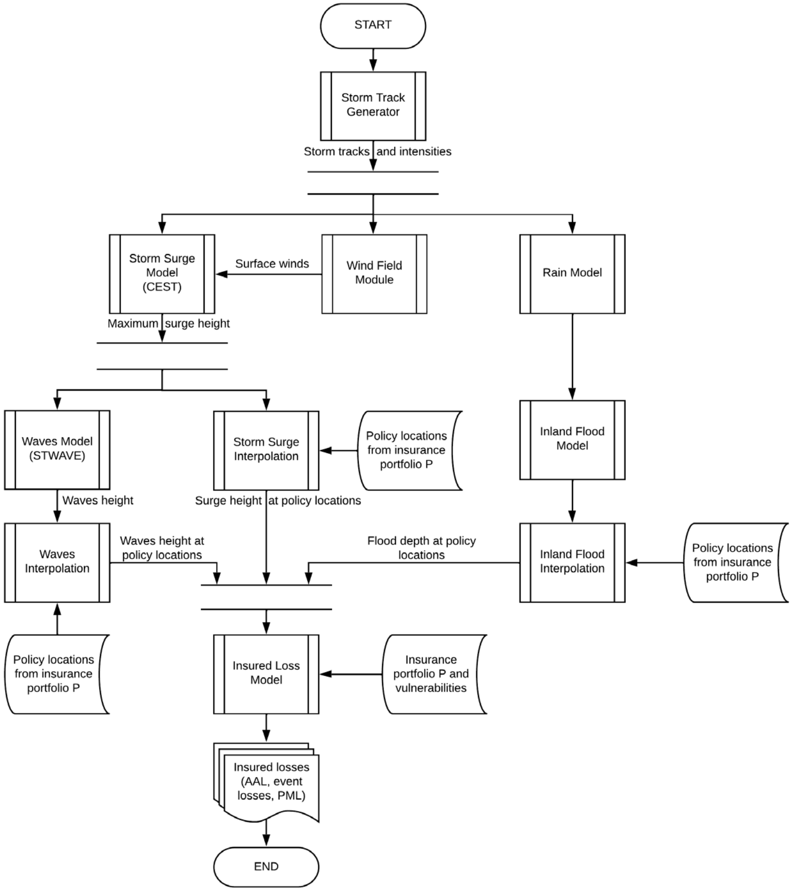
- The model consists of the following components: meteorology, coastal flood hazard (CEST), wave, inland flood hazard (pluvial and fluvial), vulnerability (engineering), and insured loss cost (actuarial).
- The major components were developed independently before being integrated.
- The computer platform is designed to accommodate future hookups of additional sub-components or enhancements.

- Overview of the meteorology, coastal flood (CEST), wave, inland flood, and vulnerability components will be provided by the respective teams in their presentations.

Computer System Architecture

- The FPFLM is a large-scale system designed to store, retrieve, and process large amounts of historical and simulated storm/rainfall data. In addition, intensive computation is supported for flood damage assessment and insured loss projection
- A three-tier architecture is adopted and deployed in our system
  - User interface layer
  - Application logic layer
  - Database layer

FPFLM Computer Model Flow Diagram



Hardware and Software Structure

- The FPFLM is designed and operates on a computing cluster of 60 servers interconnected by network routers
  - 2,412 total CPU cores
  - 509TB storage
- Regular backups of the server are performed
  - Physically and electronically
  - Backups are performed daily

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Hardware and Software Structure Cont.

- The user-facing part of the system consists of a collection of scripts written in Bash and Python
- Backend probabilistic calculations are coded in C++ and Python
- The system uses a PostgreSQL database that runs on a Linux server
- Minimal end-user workstation requirements
  - Any current version of Internet Explorer, Firefox, Chrome, or Safari running on a currently supported version of Windows, Mac or Linux should deliver optimal user experience

FPFLM Actuarial component

- The actuarial component consists of a set of algorithms.
- The process involves a series of steps: rigorous check of the input data; selection and use of the relevant output produced by the coastal surge and inland flood hazard components; selection and use of the appropriate coastal and inland flood vulnerability functions for building structure, contents, and additional living expenses; running the actuarial algorithm to produce expected losses; aggregating the losses in a variety of manners to produce a set of expected annual flood losses; and produce probable maximum losses for various return periods.
- The expected losses can be reported by construction type (e.g., masonry, frame, manufactured homes), by geographic zone, county or ZIP Code, by rating territory, and combinations thereof.

- To estimate annual loss costs and probable maximum loss levels, losses are estimated for individual policies in the portfolio for each event in a stochastic set of storms. Losses are estimated separately for structure, contents, and time element coverage.

- For each event the hydrological state and inundation depth is determined for coastal and/or inland flooding.

- A vulnerability matrix is assigned to the exposure based on the characteristics of the exposure. The matrix specifies the percent damage for a given hydrological state and inundation depth. If both coastal and inland flooding applies to the exposure for a given event, the matrix is read twice, and the larger damage ratio is selected.

- The estimated damages are reduced by applicable deductibles, increased to allow for the impact of demand surge on claim costs and subjected to policy limits.

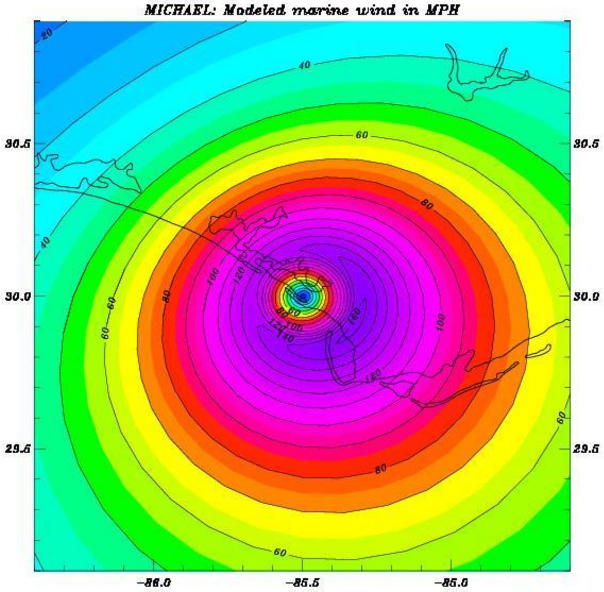
- The demand surge factors are estimated by a separate model and applied appropriately to each storm in the stochastic set.
- The modeled insured losses can then be summed across all properties in a ZIP Code or across all ZIP Codes in a county to obtain expected aggregate loss. The losses can also be aggregated by policy form, construction type, rating territories, etc.
- Finally, modeled insured losses are divided by the number of years in the simulation and by the total amount of insurance to estimate annual loss costs.
- To estimate Probable maximum loss on an “annual aggregate” basis modeled losses for storms occurring in the same year of the simulation are summed to produce annual storm losses.
- Probable maximum loss levels are calculated non parametrically from the ordered set of annual losses.
- To estimate Probable maximum loss on an “annual occurrence” basis the ordered set consists of the largest loss in each year of the simulation.

Meteorological Model Overview

Florida Public Flood Loss Model v1.0

Meteorology

Steve Cocke, Florida State University
DW Shin, Florida State University
Bachir Annane, University of Miami



Met Components

- Storm Track Generator
  generates tracks which have position, intensity and storm parameters (e.g., Rmax, B) for duration of storm

- Wind Model
  generates surface wind field for each storm

- Rain Model
  generates rainfall for stochastic events

Storm Track Generator

- Storm seeds based on historical storms that entered a threat area surrounding Florida and neighboring states
  - Initial seed position started at the historical position of the storm 36 hours prior to entering threat area, plus uniform random perturbations
  - Initial speed and intensity based on historical data plus random perturbations

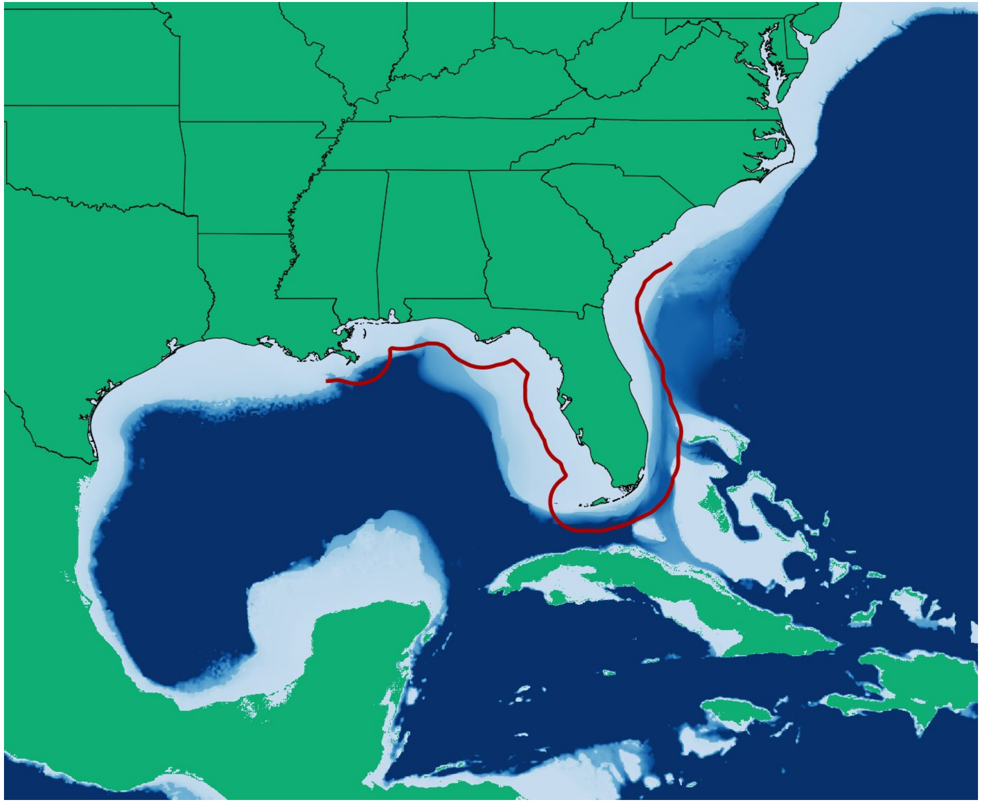
- Changes in speed, direction and relative intensity are sampled from empirical PDFs derived from HURDAT2 data, with random perturbations added. PDFs depend on location and current motion or intensity

- Storm parameters (Rmax and Holland B) are sampled from distributions derived from historical data

Storm Track Generator

- When storm is over land, a pressure filling model is used (exponential decay of central pressure deficit in time). If storms re-enters water, intensity changes are again resampled from the PDFs derived from HURDAT2.
- Storms seeds are recycled, but with new random perturbations, to generate more than 50,000 years of storms
- Storm tracks are in 1 hr increments, and includes position, intensity (pressure), date and storm parameters (Rmax, B)
- Storm terminates when it exits domain or central pressure exceeds 1011 mb

Model Domain



Sample Stochastic Tracks

Wind Model

- Numerical solution of a "slab" model of the hurricane boundary layer, 450 m deep over ocean, 1 km deep over land (see Powell et al., 2005)
- Includes surface friction, with different drag coefficient over land vs water.
- Initialized by a vortex in gradient balance with pressure field described by a Holland B pressure profile.
- Mean wind of the slab is converted to a surface wind based on GPS sonde research

Rain Model

- Generates rainfall using historical or stochastic track information.
- Rate rates are determined using the NOAA HRD R-CLIPER algorithm.
- R-CLIPER was originally based on rain gauge data, but has been recalibrated using TRMM rain rates.
- R-CLIPER operationally used by NHC.

TRMM Rain Rates

- Satellite-derived estimates using a microwave imager (TMI)
- Instantaneous TMI rain rates based on an algorithm in Kummerow et al. (1996)
- TMI swath data was collocated to tropical cyclone positions globally
- Data coverage was from 1 Jan 1998 to 31 Dec 2000. There were 2121 observations for 260 cyclones.
- Rain rates averaged azimuthally to analyze radial dependence of rainfall within a cyclone

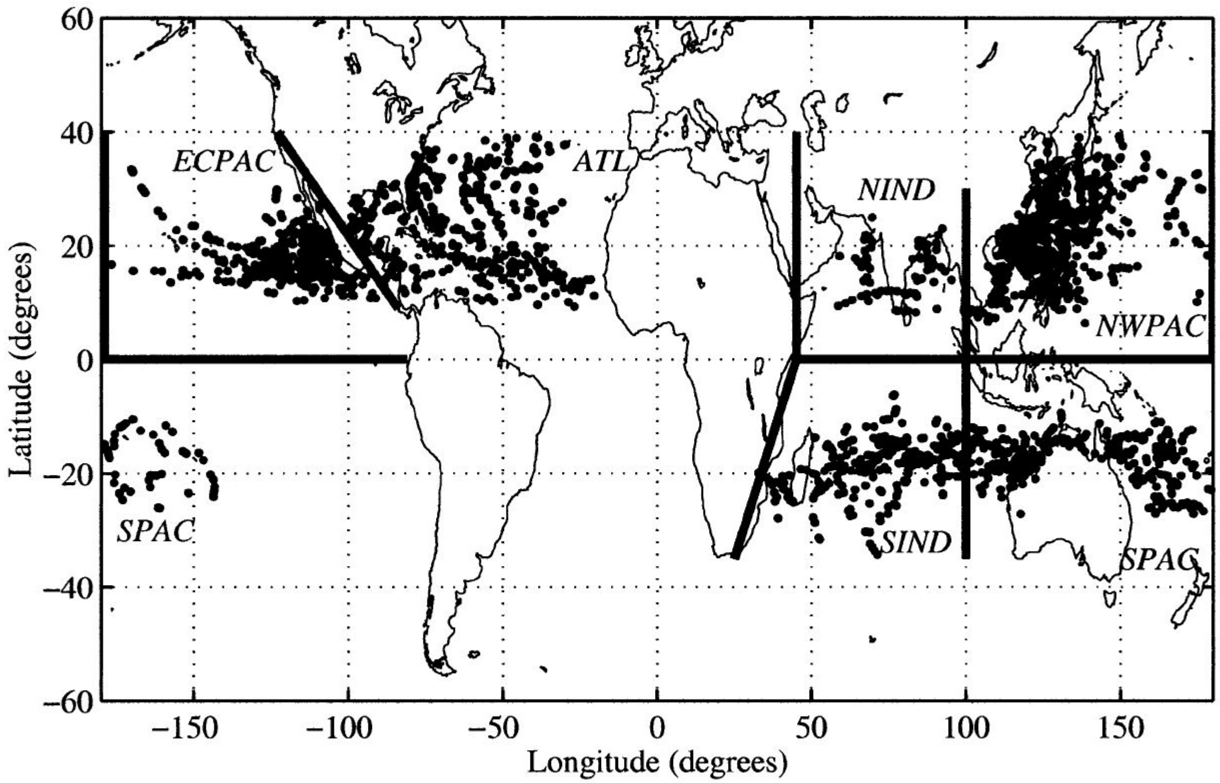


FIG. 1. Tropical cyclones observed by TMI during the period from 1 Jan 1998 to 31 Dec 2000. Each dot represents one TRMM observation. The solid lines indicate the boundaries of the six active oceanic basins.

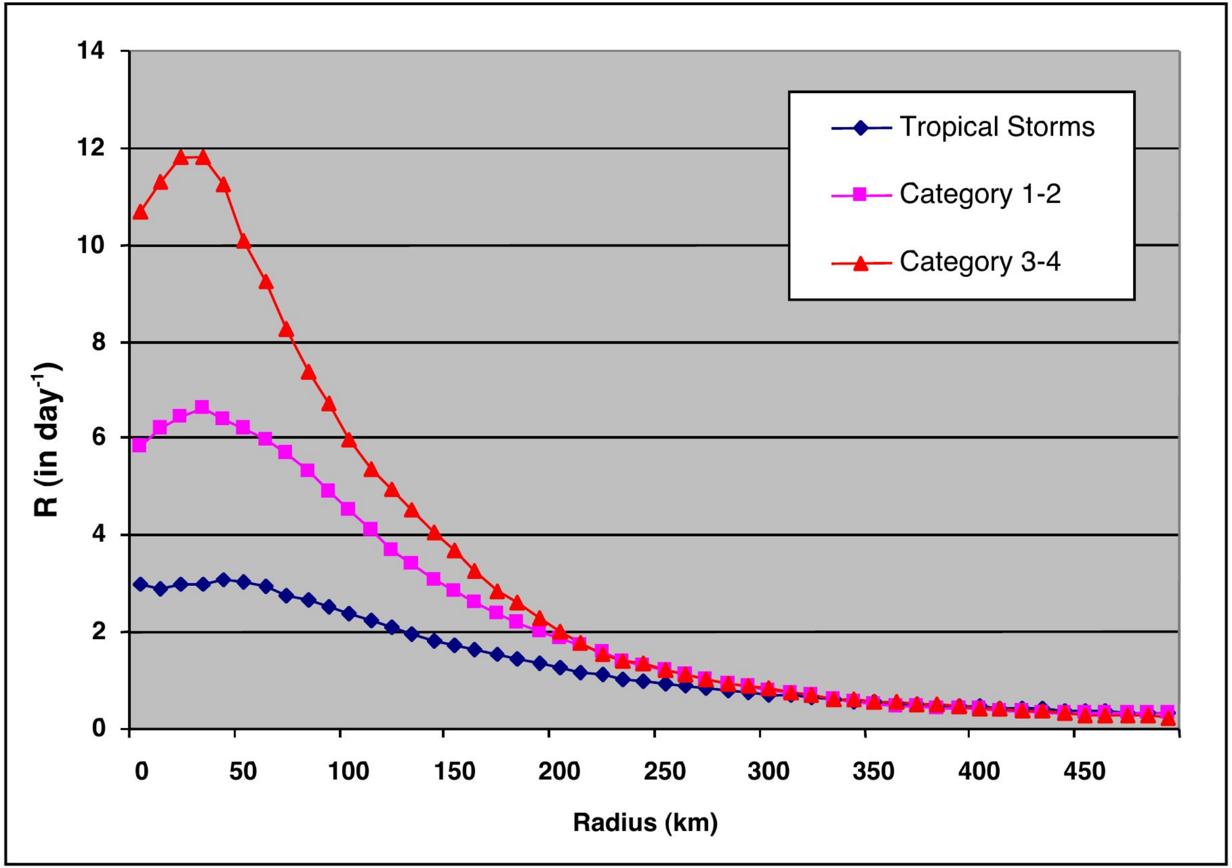


Fig. 4. TMI-based rainfall climatology (in day^{-1}) for tropical storms, Category 1-2, and Category 3-5 hurricanes.

R-CLIPER Algorithm

- Assumes a simple profile of the azimuthally averaged rain rate
- Parameters include *radius*, *maximum storm intensity*, r*adius of maximum rain*, *rain extent*, *center* and *maximum rain rate*. The latter four are a function of maximum intensity.
- Regression performed to estimate rain rate from the above parameters
- Description and coefficients can be found in Tuleya et al. (2007)

$$\mathrm{TRR}(r, V) = T_0 + (T_m - T_0)(r/r_m) \quad r < r_m$$

$$\mathrm{TRR}(r, V) = T_m \exp[-(r - r_m)/r_e] \quad r \geq r_m,$$

Non-tropical Rainfall Events

- In Florida, heavy non-tropical rainfall events occur often, but are typically localized and produces flood losses that are a small fraction of the losses due to storm surge (based on analysis of NFIP claims data).
- In a prior study of COOP station data, we found that non-tropical heavy rain events are relatively frequent and well distributed over Florida.
- Modeling non-tropical events is challenging since there are a number of unique and diverse meteorological conditions that lead to the events.
- In another prior internal study we analyzed the causes of loss using unredacted NFIP claims data and found that the top 5 or 6 non-tropical losses were due to different meteorological conditions, some of which have only occurred once.

Approach to Estimating Losses due to Non-tropical Events

- Since non-tropical events are relatively frequent over the entire Florida region, we decided to use the historical record for simulating flood with the inland models to estimate loss costs.
- We chose the NOAA CPC Unified Gauge-Based Analysis of Daily Precipitation over CONUS, that is based on historical station gauge data from 1948 to 2023 (Xie et al, 2007; Chen et al, 2008).
- The CPC data is a gridded product of daily rainfall data with a 0.25 degree resolution (~25 km or 15.5 mi).
- We identified 399 heavy rainfall events (at least one daily precipitation amount > 4 in) that were not influenced by tropical cyclones by comparing the location and date of the rainfall event with the HURDAT2 database.

Approach (cont'd)

- The flood depths from the 399 events were processed by the ILM to get the AAL for each policy and coverage type.
- These AAL amounts are added to the tropical AAL on the policy level.
- To account for extreme events that have not historically occurred, and in order to estimate the PML of the combined tropical and non-tropical losses, the non-tropical event losses were fitted to a probability distribution function (PDF). Another PDF takes into account the number of events in a given year.
- These PDFs are sampled for each year in the stochastic set (73200 years).
- The results are combined with the tropical PML results as appropriate (aggregate or annual occurrence).

PML Estimation

- Only total event losses in excess of $3,000 are considered for the PML fitting. This leaves 252 events to be fitted.
- The losses are transformed in a manner similar to a *power transformation*: $y = x^{(1/n)}$
- The exponent n is chosen such that the loss distribution mean is in close approximation (<1%) of the observed (simulated historical events mean).
- The transformed variable is fitted to a *normal distribution*.
- The annual occurrence of the number of events is modeled by a *Poisson distribution*.
- For each year of the stochastic set, the number of events for that year is sampled from the Poisson distribution.
- The transformed loss is sampled from the normal distribution for each event, and then transformed back to a dollar loss: $x = y^n$

Florida Public Flood Loss Model

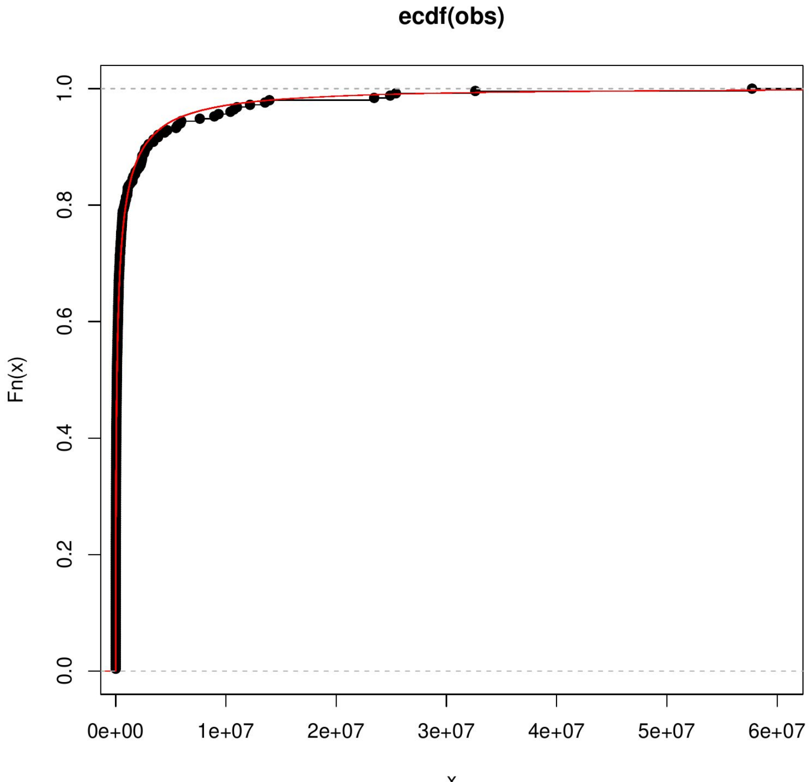
Loss Estimation	Event Mean	Annual Frequency
Historical runs (N=252), 76 yrs	$1,520,409	3.316
Modeled PML (N=1m)	$1,509,182	
Modeled PML (N=241365), 73200 yrs	$1,488,204	3.297

PML Estimation

Top: fitting of the mean loss of the events

Right: fitting of the cumulative distribution of the event losses

x is loss, in dollars



Florida Public Flood Loss Model

Return period losses (aggregate) for *non-tropical rainfall events only* based on sampling for each year of stochastic set

Note that these numbers are *not* directly used in the combined PML. For the combined PML, the sampled loss events are *aggregated* or *maxed* with the tropical events and then the PML is then calculated using the order statistics

These values are for diagnostic info only

Return Period	Return Loss
Top Event	$790,989,858.23
10000	$415,928,257.15
5000	$366,974,511.03
2000	$249,755,824.11
1000	$190,451,411.10
500	$140,787,546.22
250	$95,707,631.18
100	$58,905,908.85
50	$38,778,638.23
20	$20,093,976.93
10	$11,083,892.96
5	$5,328,770.79

STORM SURGE MODEL
COASTAL AND ESTUARINE STORM TIDE (CEST)

Yuepeng Li, Qiang Chen, Keqi Zhang

Extreme Events Institute
International Hurricane Research Center
Florida International University

MERITS OF THE CEST MODEL

Stability

- This refers to the mathematical property that the numerical solution to the governing equations remains bounded and behaves in a physically meaningful way as the simulation progresses.
- CEST has been tested with various time step sizes, spatial resolutions, and other parameters, as well as various historical hurricane events, to ensure that the model behaves stably for a range of conditions.

Accuracy

- This refers to the degree to which the result of numerical simulation aligns with the physical observations.
- CEST was used to simulate all the historical hurricanes affecting Florida, and results show acceptable accuracy compared to the observed data.

Efficiency

- This refers to the capability of the model to produce accurate and reliable results within an acceptable time frame.
- For each of the four CEST basins covering Florida, FPFLM requires CEST to complete more than 50,000 stochastic storms for the loss cost estimation. CEST can simulate all 200,000 stochastic storms in 2 weeks.
- CEST has a parallel version (through the OpenMPI approach) that is well-suited for storm surge forecasting.

CEST IS APPROVED BY NOAA

- In 2019, the former director of the National Hurricane Center, Dr. Kenneth Graham, stated, “This (Transition of the Coastal and Estuarine Storm Tide Model CEST to an Operational Model for Forecasting Storm Surge) is a unique and very important example of R2O.”.

- In 2020, CEST was approved for transition into National Hurricane Center operation through the Joint Hurricane Testbed (JHT) project.

Project Title: Transition of the Coastal and Estuarine Storm Tide Model (CEST) to an Operational Model for Forecasting Storm Surges

Funded Project Period: FY15-17 (NCE FY18)
Principal Investigators: Keqi Zhang (FIU)
NHC Points of Contact: Mike Brennan, Robbie Berg, Jamie Rhome, Arthur Taylor (MDL), Chris Landsea
JHT Staff: Mark DeMaria, Chris Landsea, Brian Zachry, Jason Sippel, Alan Brammer
Final Report Provided: May 29, 2019

Assessments:
1. **Forecast or Analysis Benefit:** Favorable
2. **Efficiency:** Neutral to Favorable
3. **Compatibility:** Favorable
4. **Sustainability:** Favorable

JHT Staff Recommendation:
__X__ Accept ___ Defer ___ Decline ___ N/A

Notes: Although the project goals were adjusted during the course of the JHT, the final project outcomes are extremely useful for the SSU and informing SLOSH of the appropriate slip coefficient to be used for each SLOSH basin that is developed. Additional coordination is needed between SSU and Zhang (FIU) to make the process more efficient in the future. This is not a real-time product, but the project resulted in a method to improve an operational model used by NHC.

NHC Director Decision for Operational Implementation:
X Accept ___ Defer ___ Decline ___ N/A

NHC Director Notes: This is a unique and very important example of R2O.

X

Kenneth E. Graham
National Hurricane Center Director

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Hurricane Center
11691 Southwest 17th Street
Miami, Florida 33165

March 9, 2020

Yuepeng Li, Ph.D.
Research Scientist
International Hurricane Research Center
Department Earth and Environment
Florida International University
11200 SW 8th Street
Miami, FL 33199

Dear Yuepeng:

I am very pleased to inform you that the National Hurricane Center (NHC) has approved your Joint Hurricane Testbed (JHT) project titled “**Transition of the Coastal and Estuarine Storm Tide Model to an Operational Model for Forecasting Storm Surges**” for transition into NHC operations.

The mission of the NHC is “to save lives, mitigate property loss, and improve economic efficiency by issuing the best watches, warnings, and forecasts and improve economic efficiency […]” (Hurricanes.gov). The mission of the JHT is “to transfer more rapidly and smoothly new technology, research results, and observational advances of the United States Weather Research Program (USWRP), its sponsoring agencies, the academic community and other groups into improved tropical cyclone analysis and prediction at operational centers.” Your project and its outcomes support these extremely important missions.

Thank you for your valuable contribution to the National Hurricane Center supported through the Joint Hurricane Testbed.

Sincerely,

Brian Zachry, Ph.D.
Science and Operations Officer
Director, Joint Hurricane Testbed
National Hurricane Center

Florida Office of Insurance Regulation | FIU | UF | Florida Tech | Florida State University 1851 | Miami | NOAA | University of Notre Dame | Rutgers | UMKC | AMI Risk Consultants, Inc.

GOVERNING EQUATIONS

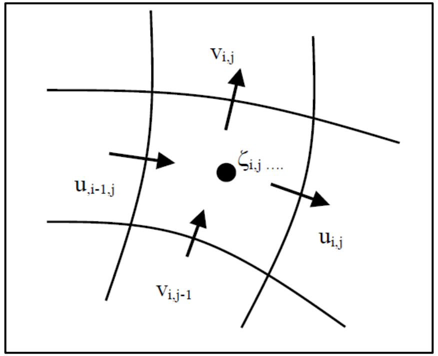
Continuity equation

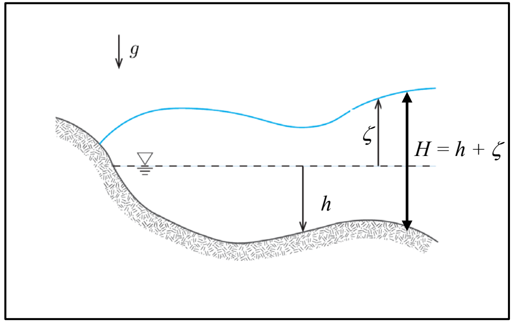
$$\frac{\partial \zeta}{\partial t} + \frac{\partial HU}{\partial x} + \frac{\partial HV}{\partial y} = 0$$

Momentum equations

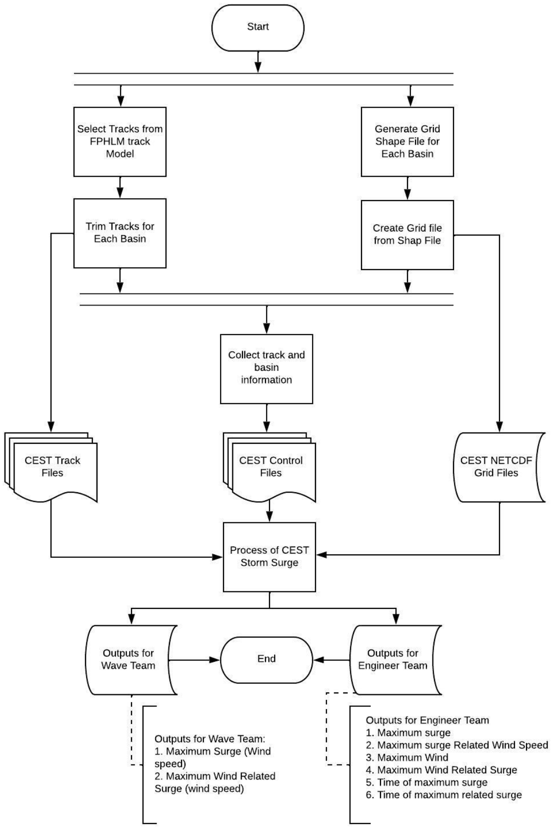
$$\frac{\partial HU}{\partial t} + \frac{\partial HU^2}{\partial x} + \frac{\partial HUV}{\partial y} = fHV - gH\frac{\partial}{\partial x}\left(\zeta + \frac{\Delta P_a}{\rho g}\right) - \frac{\tau_b^x}{\rho} + \frac{\tau_s^x}{\rho} + A_h\frac{\partial^2 HU}{\partial x^2} + A_h\frac{\partial^2 HU}{\partial y^2}$$

$$\frac{\partial HV}{\partial t} + \frac{\partial HUV}{\partial x} + \frac{\partial HV^2}{\partial y} = -fHU - gH\frac{\partial}{\partial y}\left(\zeta + \frac{\Delta P_a}{\rho g}\right) - \frac{\tau_b^y}{\rho} + \frac{\tau_s^y}{\rho} + A_h\frac{\partial^2 HV}{\partial x^2} + A_h\frac{\partial^2 HV}{\partial y^2}$$

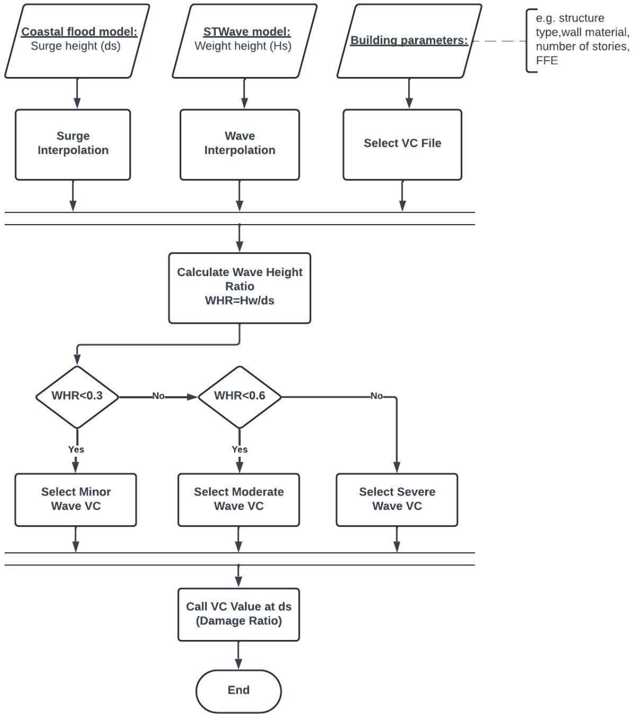




Execution flow of CEST storm surge model in FPFLM

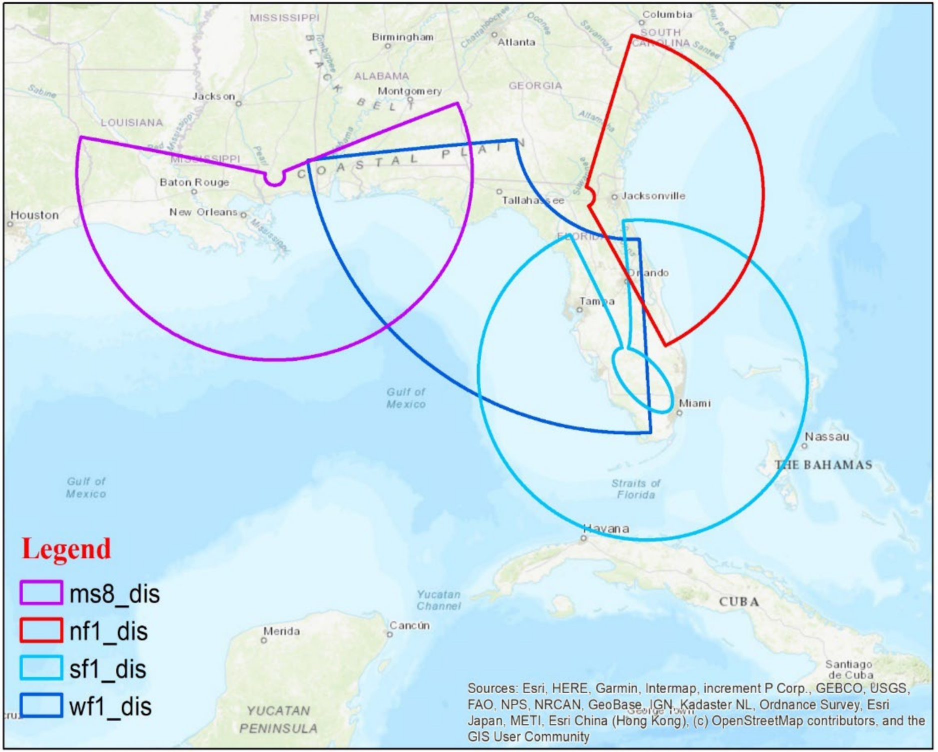


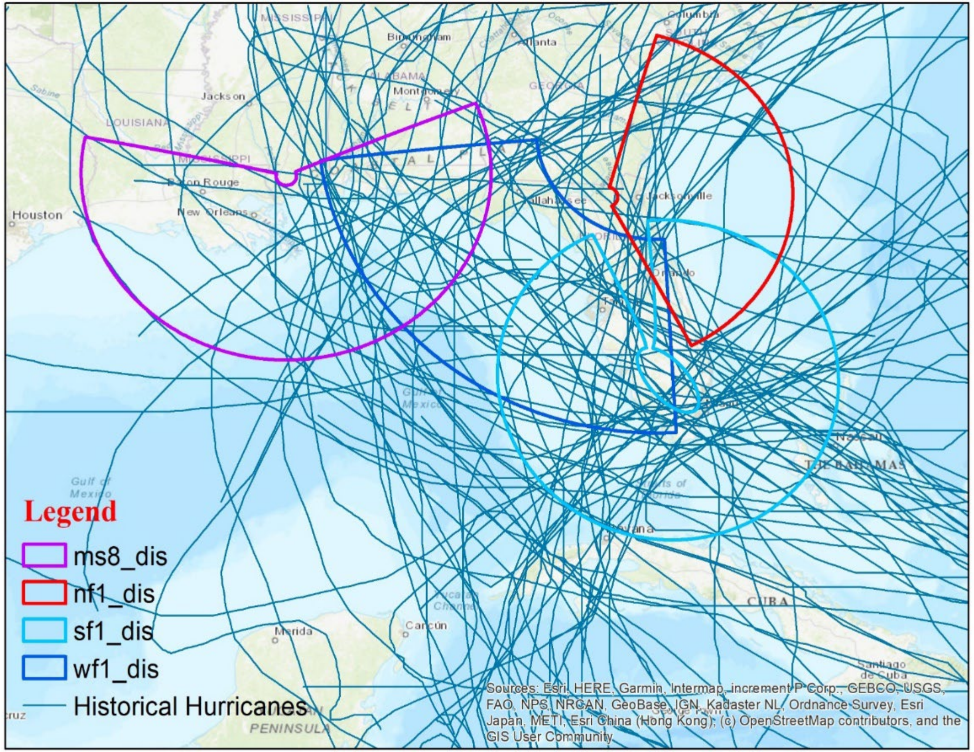
(a) The CEST storm surge model



(b) The Damage Ratio model

Four CEST Model basins with historical hurricanes





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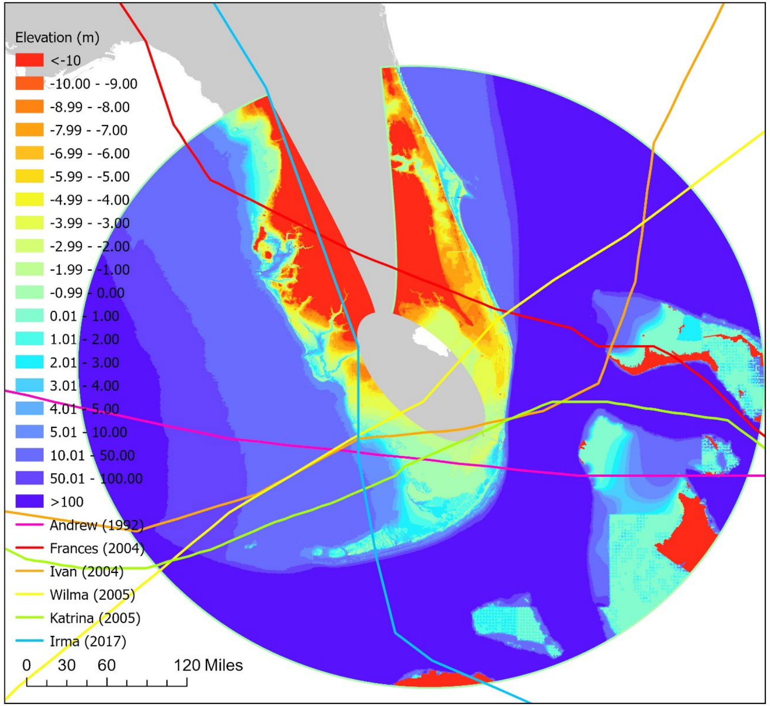
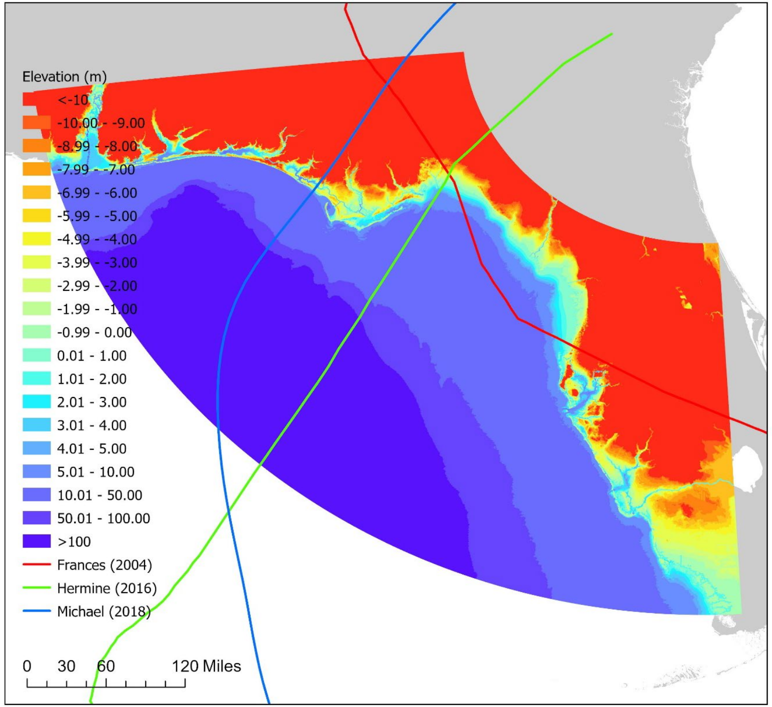
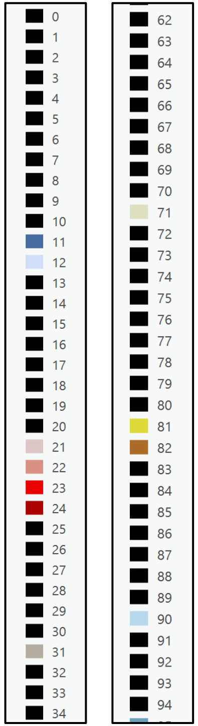
SF1 AND WF1 BASINS FOR FLORIDA

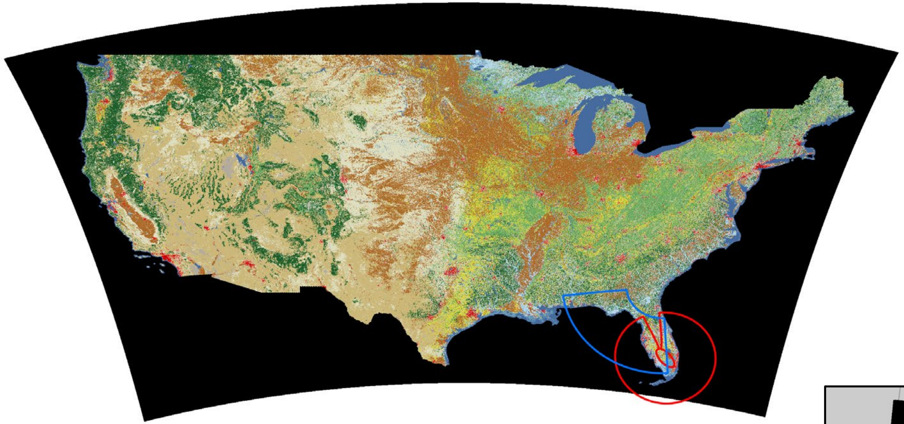




The NLCD2016 downloaded from USGS



Landcover Class Number



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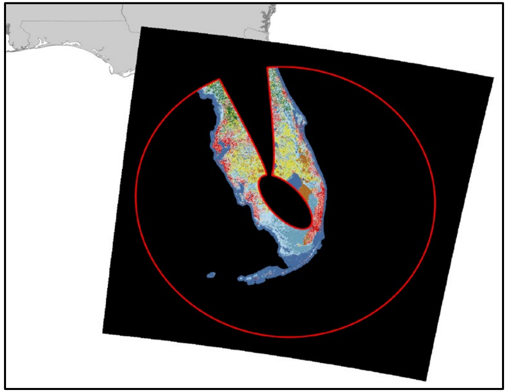

CEST SF1 Basin

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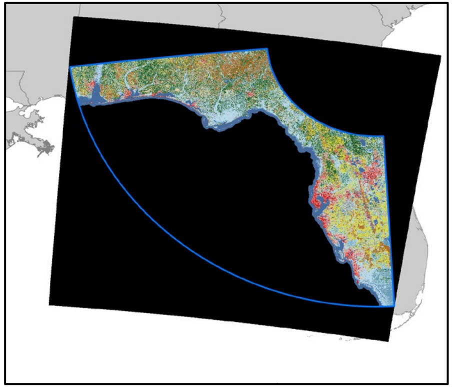

CEST WF1 Basin

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Convert NLCD2016 to Manning coefficient map

$$n_a = \frac{\sum_{i=1}^{N}(n_i\alpha) + n_w\beta}{N\alpha + \beta} \qquad \text{(HAZ-20)}$$

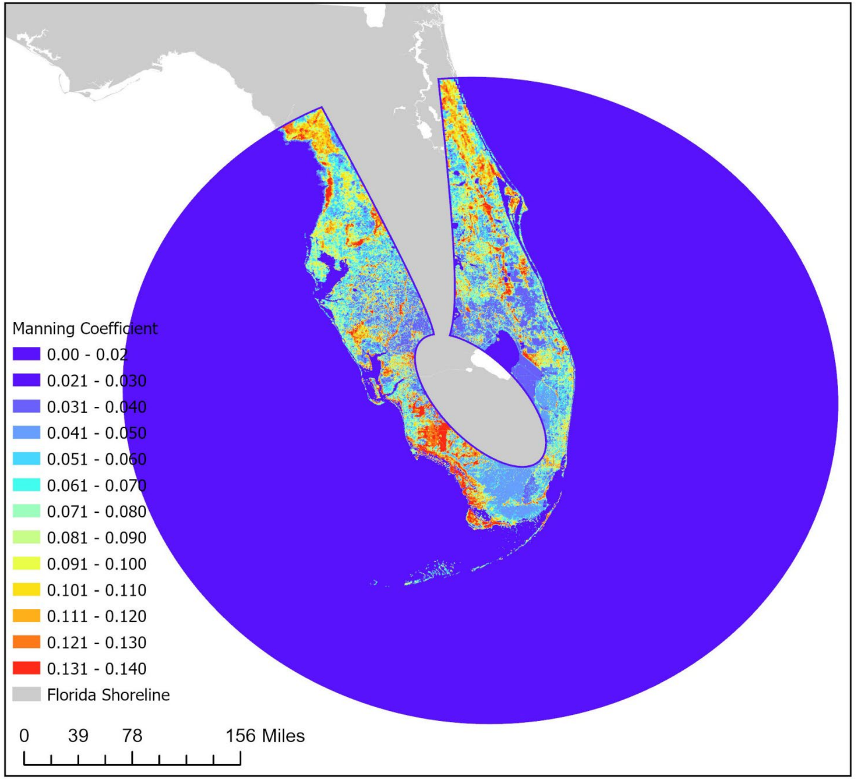
where n_i is the Manning's coefficient value of a NLCD pixel within a model grid cell, α is the area of a NLCD pixel, N is the total number of NLCD pixels within a model cell, n_w is the Manning's coefficient for the oceanic area β that are not covered by NLCD pixels.

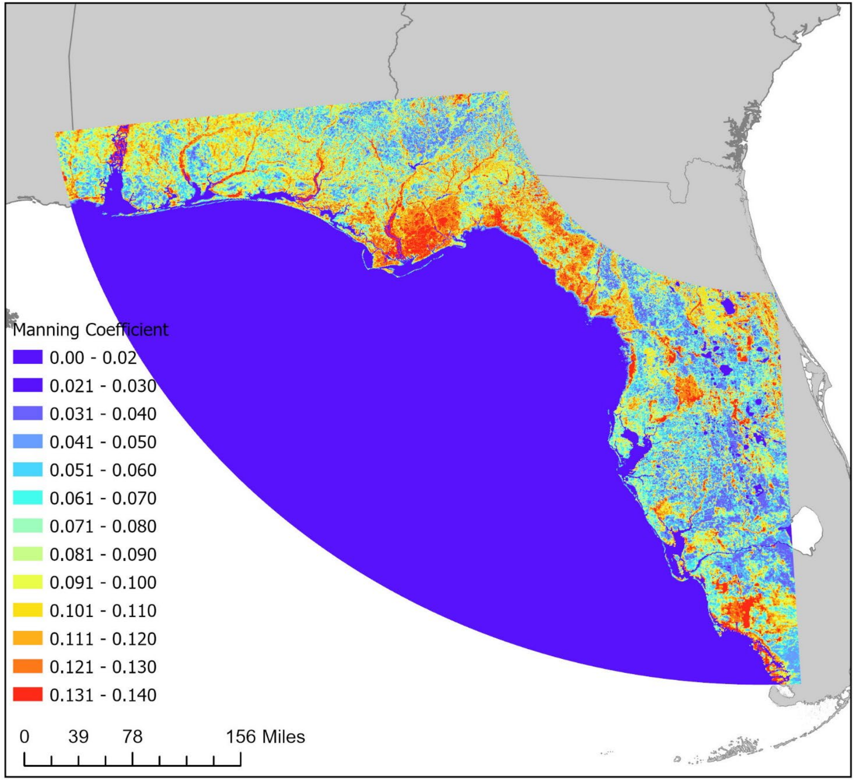
Table 1. Manning's coefficients for various categories of land cover.

NLCD Class Number	NLCD Class Name	Manning Coefficient
11	Open Water	0.020
12	Perennial Ice/Snow	0.010
21	Developed Open Space	0.020
22	Developed Low Intensity	0.050
23	Developed Medium Intensity	0.100
24	Developed High Intensity	0.130
31	Barren Land (Rock/Sand/Clay)	0.090
32	Unconsolidated Shore	0.040
41	Deciduous Forest	0.100
42	Evergreen Forest	0.110
43	Mixed Forest	0.100
51	Dwarf Scrub	0.040
52	Shrub/Scrub	0.050
71	Grassland/Herbaceous	0.034
72	Sedge/Herbaceous	0.030
73	Lichens	0.027
74	Moss	0.025

NLCD Class Number	NLCD Class Name	Manning Coefficient
81	Pasture/Hay	0.033
82	Cultivated Crops	0.037
90	Woody Wetlands	0.140
91	Palustrine Forested Wetland	0.100
92	Palustrine Scrub/Shrub Wetland	0.048
93	Estuarine Forested Wetland	0.100
94	Estuarine Scrub/Shrub Wetland	0.048
95	Emergent Herbaceous Wetlands	0.045
96	Palustrine Emergent Wetland (Persistent)	0.045
97	Estuarine Emergent Wetland	0.045
98	Palustrine Aquatic Bed	0.015
99	Estuarine Aquatic Bed	0.015

The Manning coefficient map for the CEST SF1 and WF1 basins.



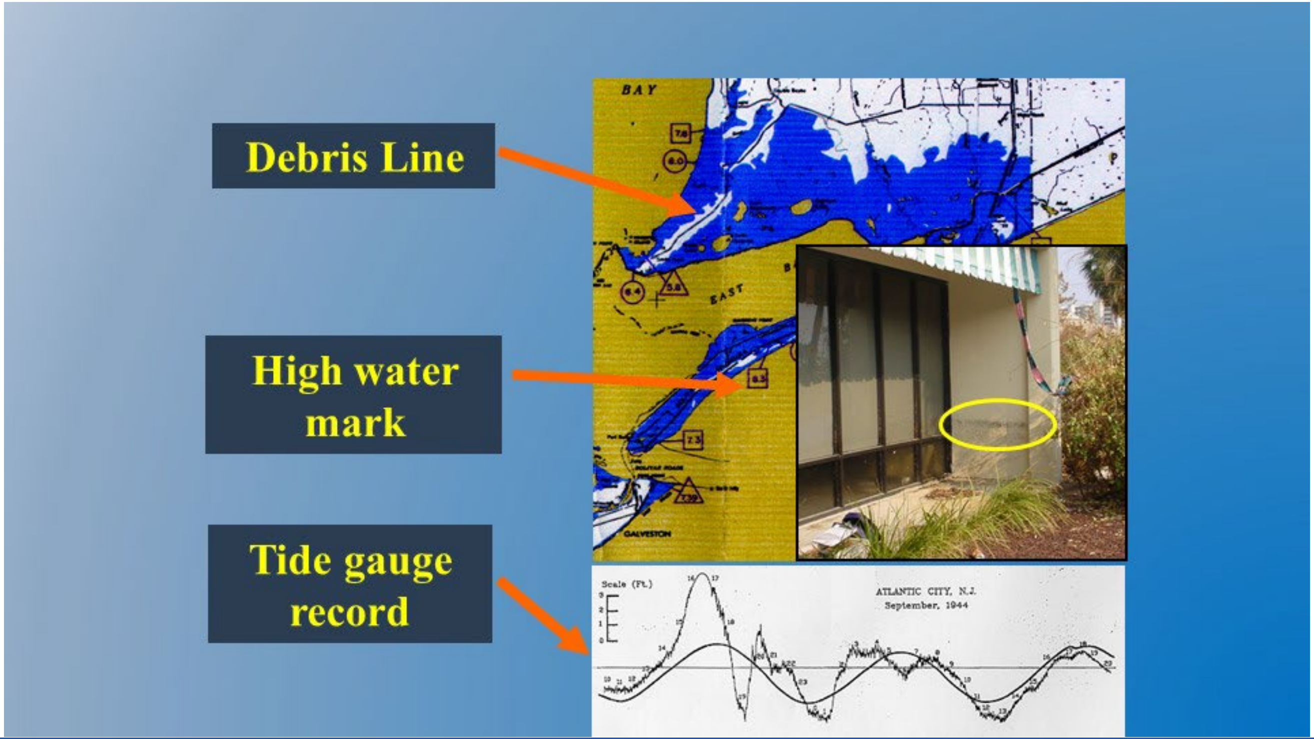


THE TIDE BOUNDARY CONDITION

Dirichlet-type (clamped) condition, with 7 constituents (M2, S2, N2, K1, O1, K2, and Q1)

Symbol	Species	Period (hour)	Speed (degree/hour)
M2	Principal lunar semidiurnal	12.42	28.98
S2	Principal solar semidiurnal	12.00	30.00
N2	Larger lunar elliptic semidiurnal	12.66	28.44
K2	Lunisolar semidiurnal	11.97	30.08
K1	Lunar diurnal	23.93	15.04
O1	Lunar diurnal	25.81	13.94
Q1	Larger lunar elliptic diurnal	26.87	13.40

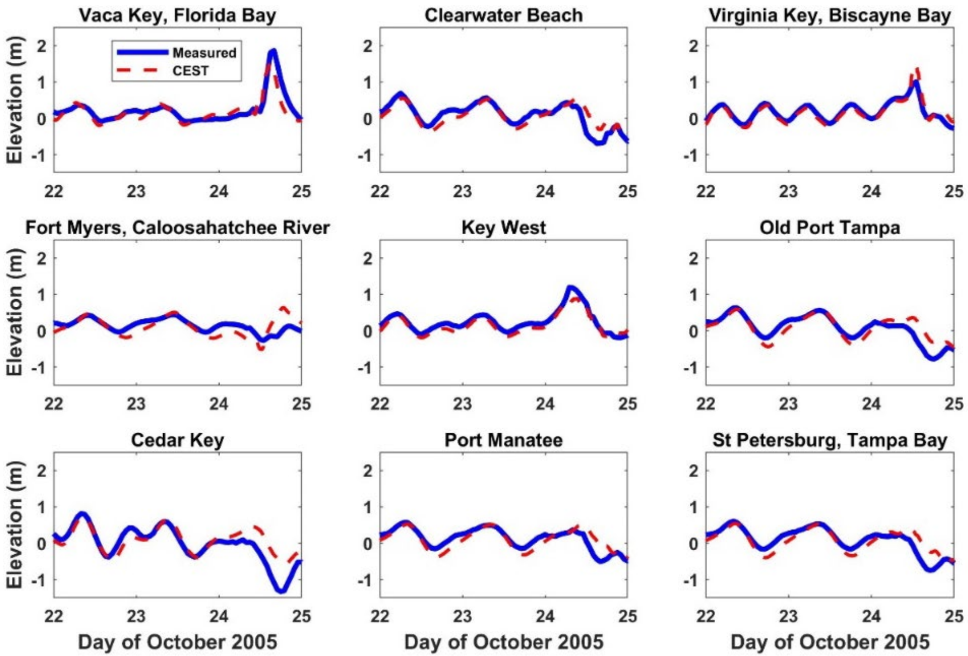
CEST Validation



High Water Mark of Ian 2022

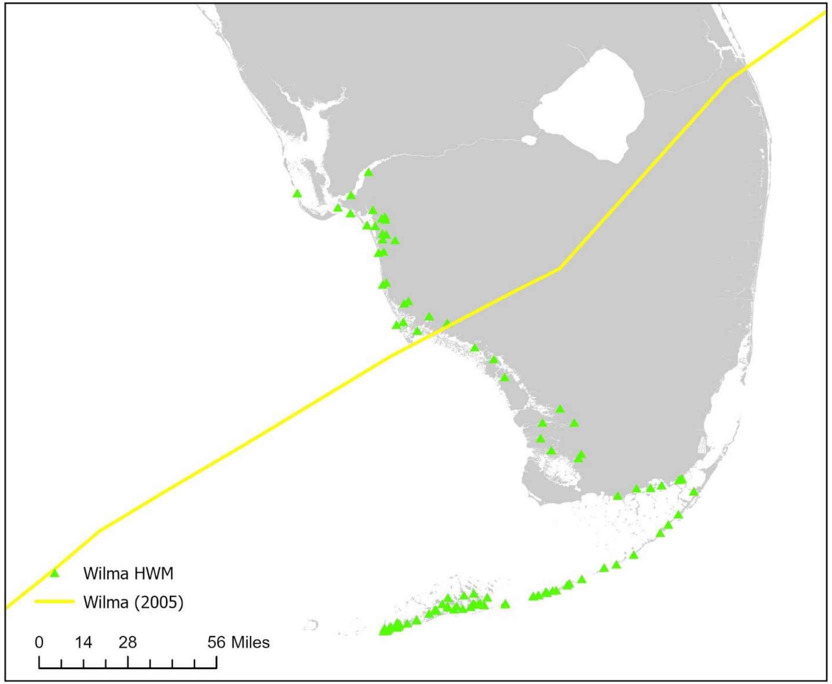
Florida Office of Insurance Regulation | FIU | UF | Florida Tech | Florida State University 1851 | Miami | NOAA | University of Notre Dame | Rutgers | UMKC | AMI Risk Consultants, Inc.

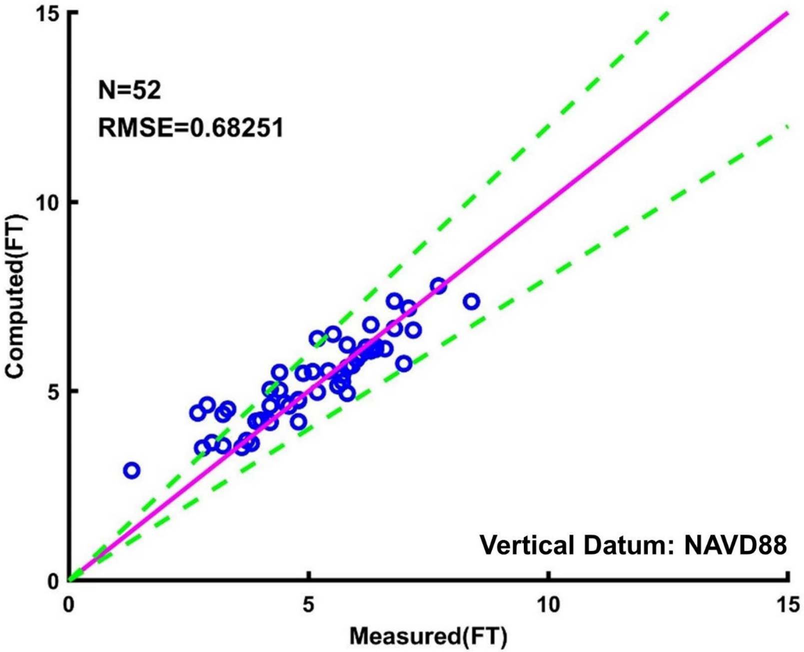
Historical Hurricanes Calibration – Wilma 2005
Comparison of water level at NOAA stations



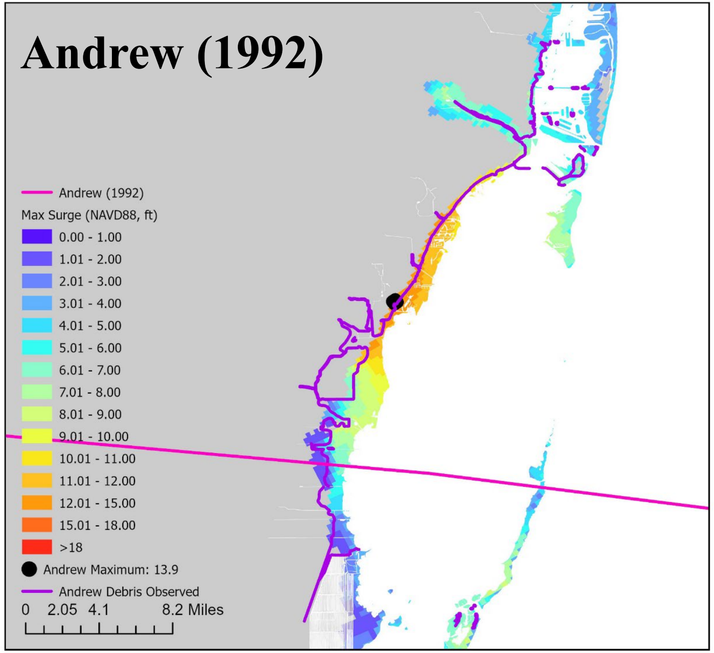
Florida Office of Insurance Regulation | FIU | UF | FLORIDA TECH | MIAMI | NOAA | UMKC | AMI Risk Consultants, Inc.

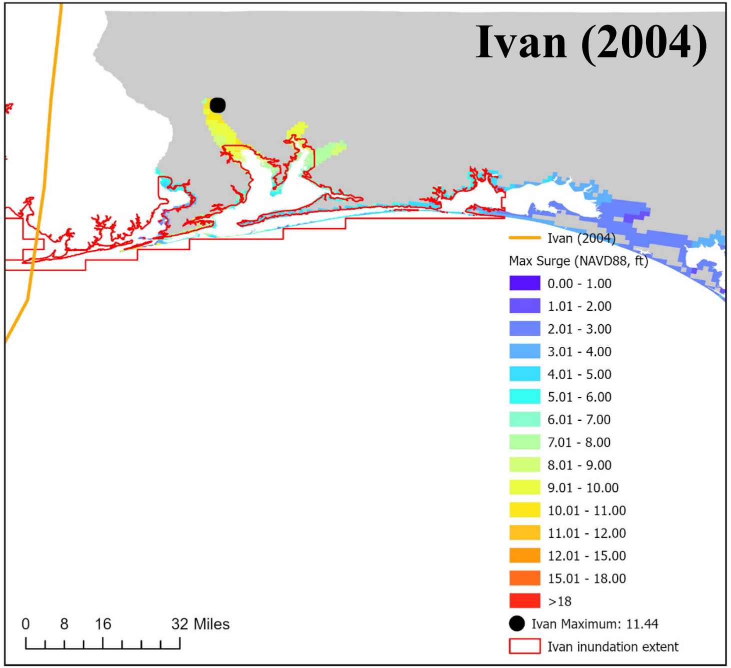
Historical Hurricanes Calibration – Wilma 2005
Computed vs. Observed High Water Mark





Historical Hurricanes Calibration
Computed surge extent vs. Observed debris line





Florida Office of Insurance Regulation | FIU | UF | Florida Tech | Florida State University | Miami | NOAA | University of Notre Dame | Rutgers | UMKC | AMI Risk Consultants, Inc.

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Wave Modeling for Florida Public Flood Model V1.0

Andrew Kennedy, Julia Simon, Scott Hampton

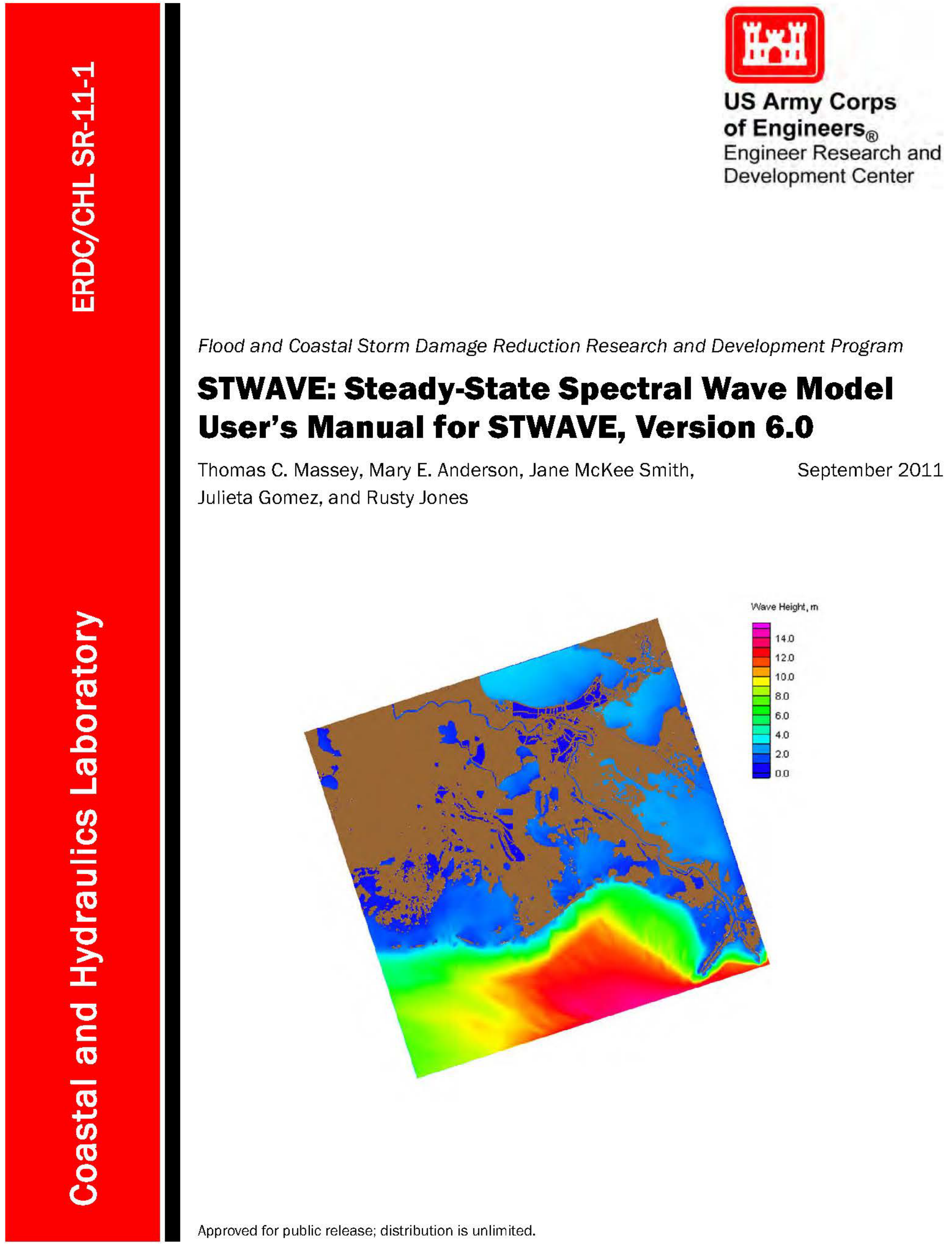
University of Notre Dame

Considerations for Wave Modeling

- Engineering team needs significant wave heights as input for damage models
  - Only wave heights that matter are in developed areas with insured structures
  - Nothing other than significant wave height is required
- Need to be able to run wave model for tens of thousands of storms generated stochastically for entire Florida Peninsula, plus a small number of additional historical storms
  - Far more than typical FEMA or other studies and over a larger area
- Wave model uses outputs from other models
  - Surge, Wind models run before and provide inputs for specific storms

STWAVE Model

- Developed by US Army Corps of Engineers
- Steady-State Model (no time variation)
- Frequency and directional spreading
  - Half-plane (180 degrees) version used here
- Rectangular grids only
- Includes wave generation, dissipation, refraction, breaking
- Orders of magnitude faster than time-varying models (SWAN, WAVEWATCH III, etc.)



ERDC/CHL SR-11-1

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Flood and Coastal Storm Damage Reduction Research and Development Program

STWAVE: Steady-State Spectral Wave Model User's Manual for STWAVE, Version 6.0

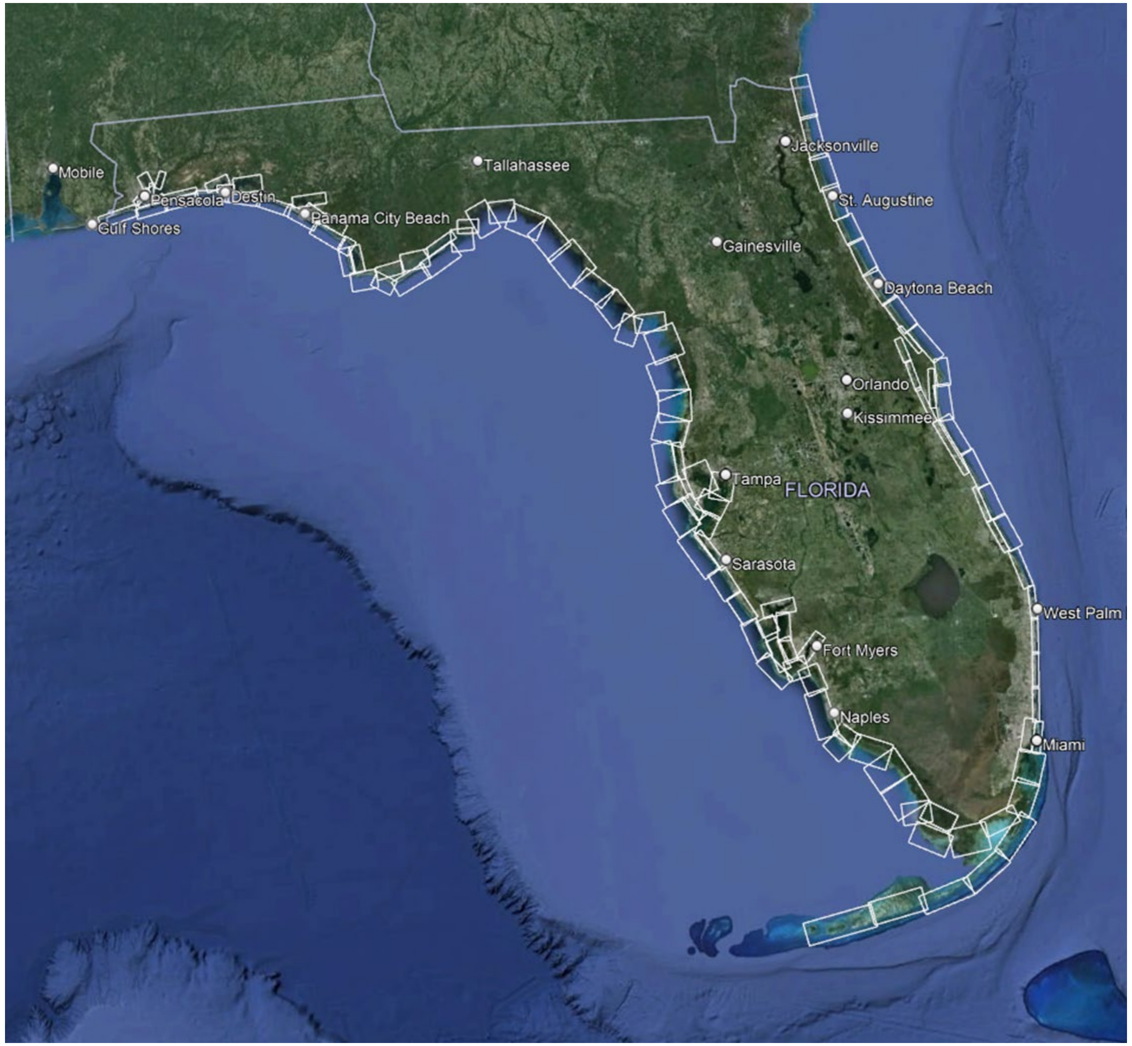
Thomas C. Massey, Mary E. Anderson, Jane McKee Smith, Julieta Gomez, and Rusty Jones

September 2011

Approved for public release; distribution is unlimited.

Considerations for Implementation of STWAVE

- Florida is much too big to be covered by one rectangular grid
- Offshore wave conditions are not used by the damage models
- Wave dissipation overland is the dominant process
- Process must be automated for tens of thousands of storms, order 1 million separate runs
- Damage models use heights at peak surge, and at peak wind



The 116 subgrids used by STWAVE

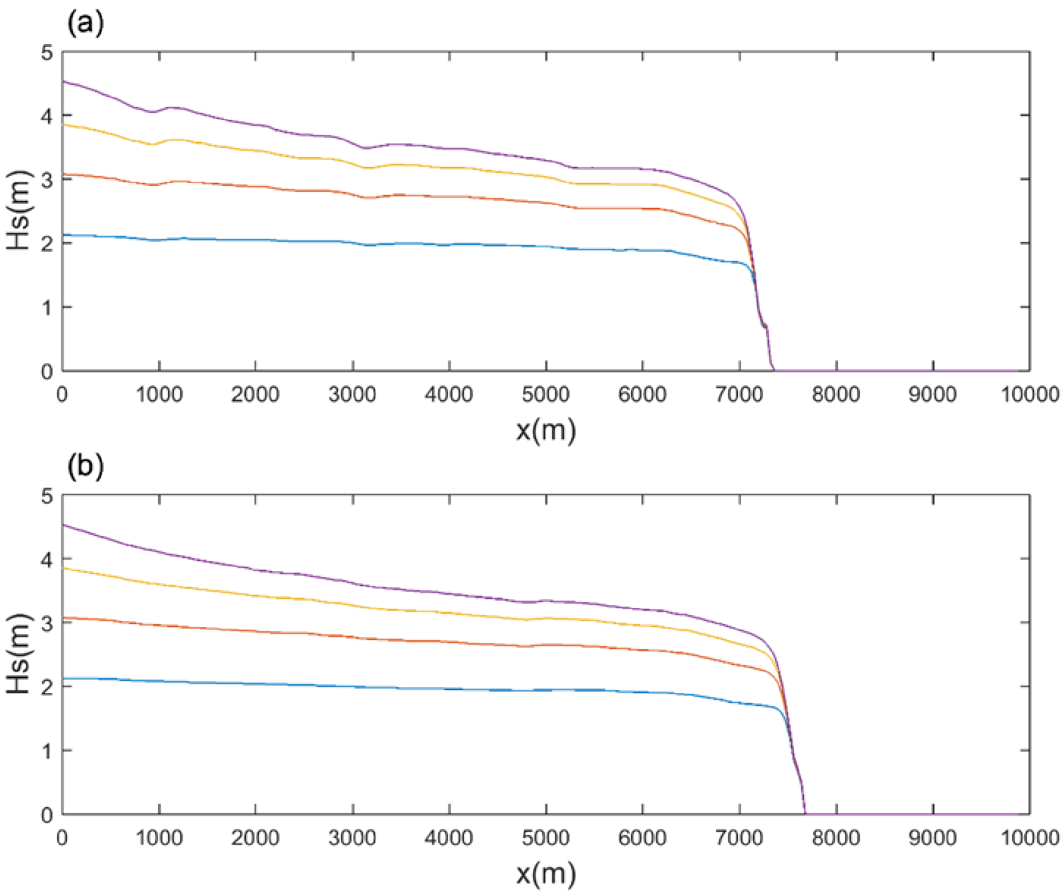
Implementation Strategy

- Divide Florida into 116 overlapping 40m grids, run separately
  - Small distances offshore only
- Many wave directions, peak wave frequency only
  - Order of magnitude faster
- Boundary wave heights, periods from surge, wind models, designated fetch lengths, parametric relations
- Thornton and Guza stochastic breaking, Mendez and Losada vegetation dissipation
- Land use/Land cover provide dissipation coefficients

Description	ID	Manning's n	CdbvN (m^{-1})	Vegetation Height (m)
Open Water	11	0.025	0	0
Developed Open Space	20	0.035	0.02	1
Developed Low Intensity	22	0.120	0.075	10
Developed Medium Intensity	23	0.120	0.1	10
Developed High Intensity	24	0.120	0.15	10
Barren Land	31	0.030	0.01	0.05
Deciduous Forest	41	0.160	0.05	15
Evergreen Forest	42	0.180	0.05	15
Mixed Forest	43	0.170	0.05	15
Shrub/Scrub	52	0.080	0.1	2
Grassland/Herbaceous	71	0.035	0.03	0.1
Pasture/Hay	81	0.050	0.3	0.5
Cultivated Crops	82	0.100	0.3	0.4
Woody Wetlands	90	0.150	0.3	3
Emergent Herbaceous Wetlands	91	0.055	0.1	0.4

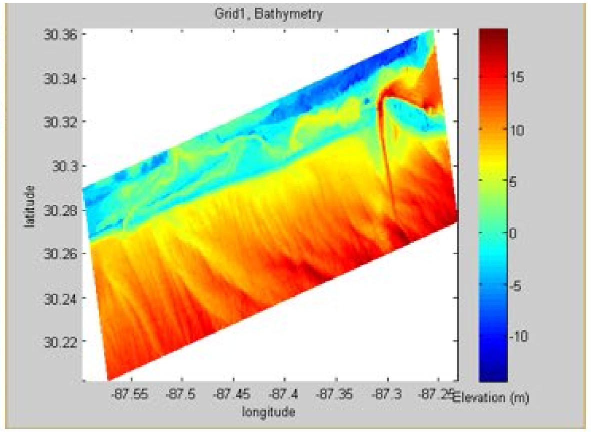
Synthetic Test of Wave Heights Overland

- Test effects of initial wave heights on overland waves
  - Wave heights from wind speeds
  - Same surge levels
- Wave heights offshore vary with boundary conditions
- Wave heights converge to same values in shallow water
  - Boundary wave heights here have little influence on overland wave heights

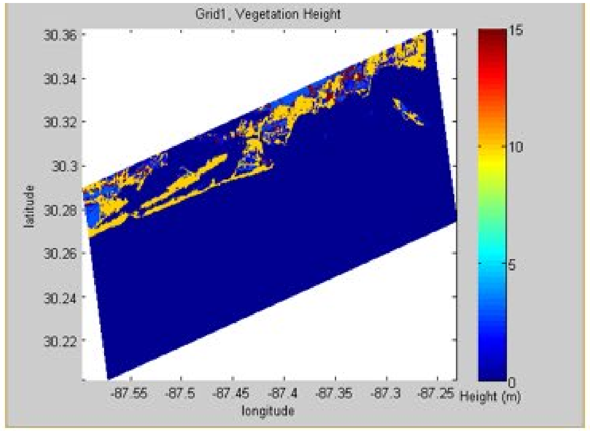


Example Run, Wave Grid 1

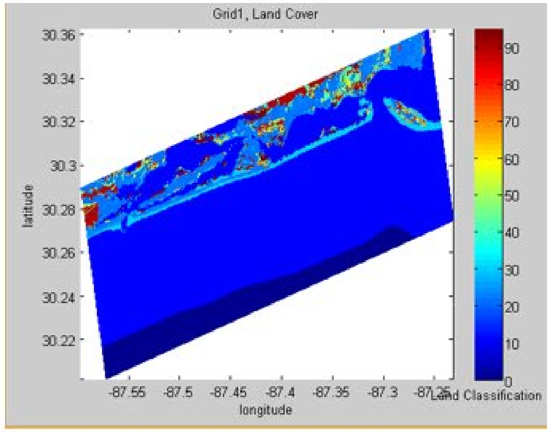
Satellite Image



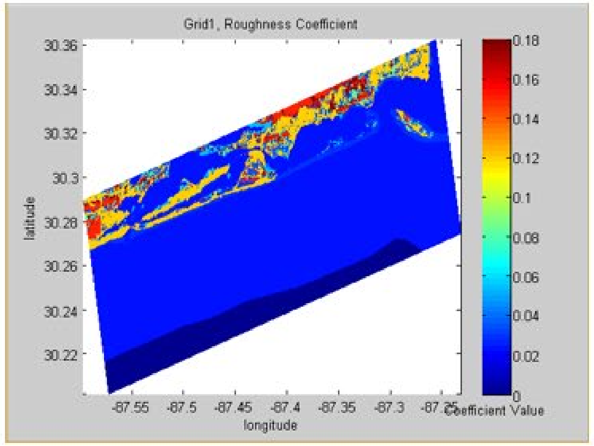
Bathymetry



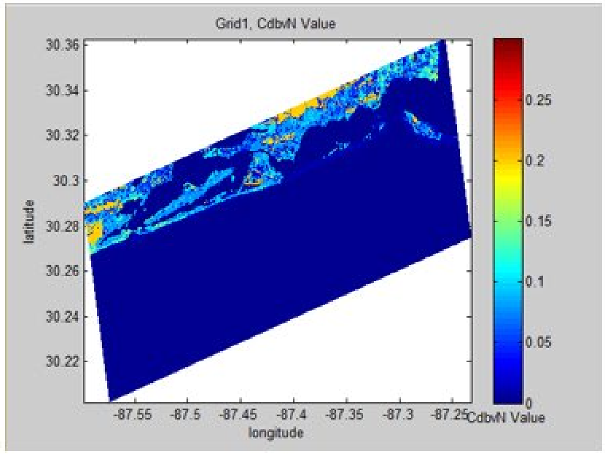
Vegetation Height



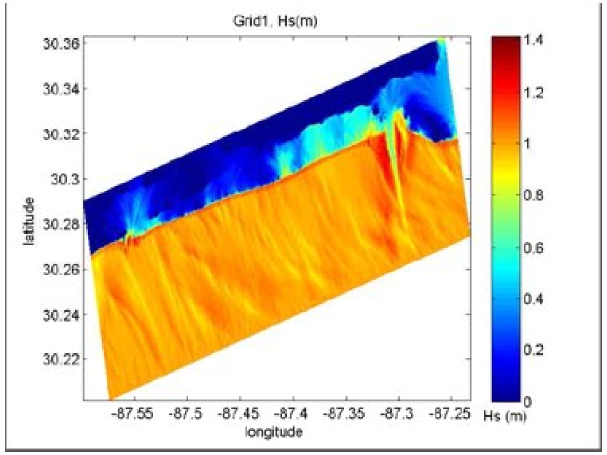
Land Cover



Roughness Coefficient



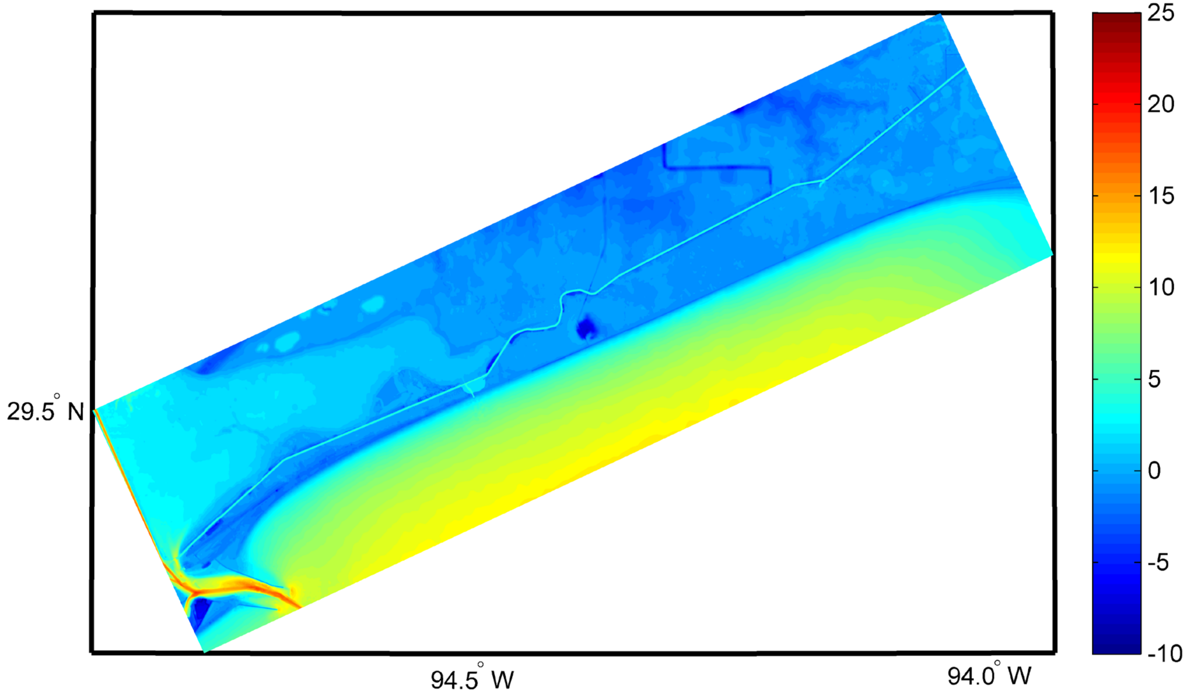
CdbvN Value



Wave Height

Overland Wave Heights During Hurricane Ike

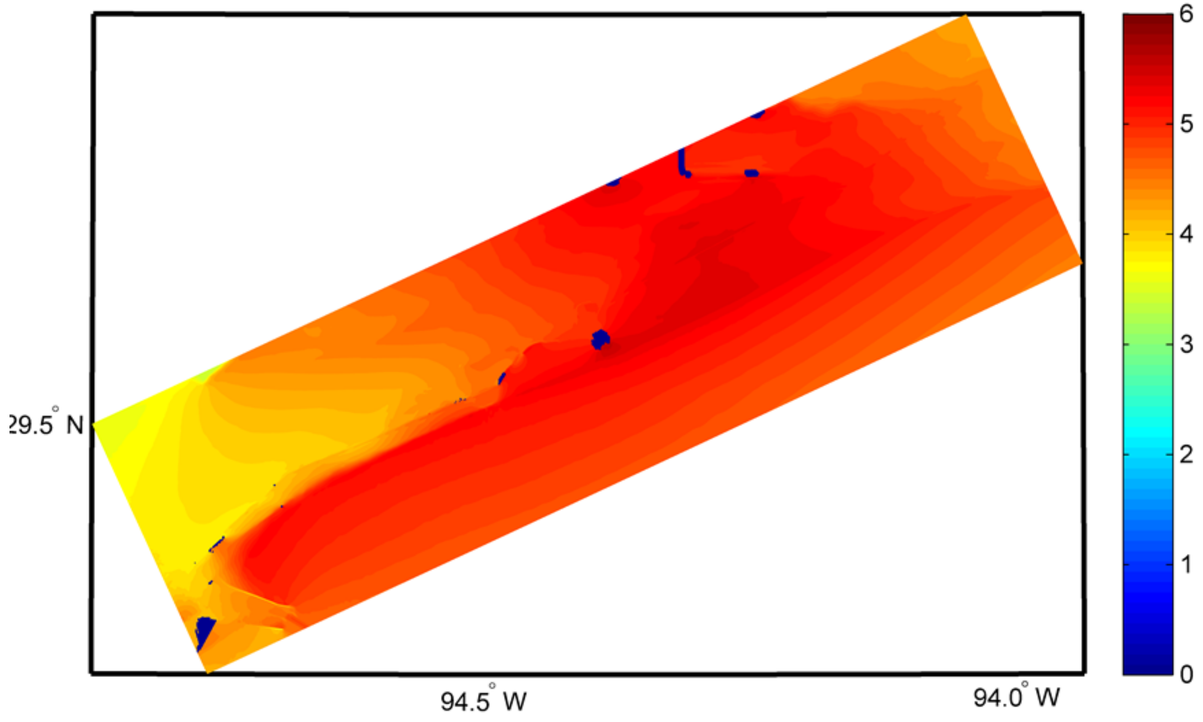
- Largehurricane that completely inundated Bolivar Peninsula, Texas
  - Wave heights measured near Gulf of Mexico and near Gulf Intracoastal Waterway at several locations
- Compare present wave breaking-dissipation with default values
  - Use hindcast surge over peninsula to get water levels
- Present dissipation provides much better results



STWAVE no-surge water depths

Overland Wave Heights During Hurricane Ike

- Large hurricane that completely inundated Bolivar Peninsula, Texas
  - Wave heights measured near Gulf of Mexico and near Gulf Intracoastal Waterway at several locations
- Compare present wave breaking-dissipation with default values
  - Use hindcast surge over peninsula to get water levels
- Present dissipation provides much better results



Surge elevations used in this test

Overland Wave Heights During Hurricane Ike

- Largehurricane that completely inundated Bolivar Peninsula, Texas
  - Wave heights measured near Gulf of Mexico and near Gulf Intracoastal Waterway at several locations
- Compare present wave breaking-dissipation with default values
  - Use hindcast surge over peninsula to get water levels
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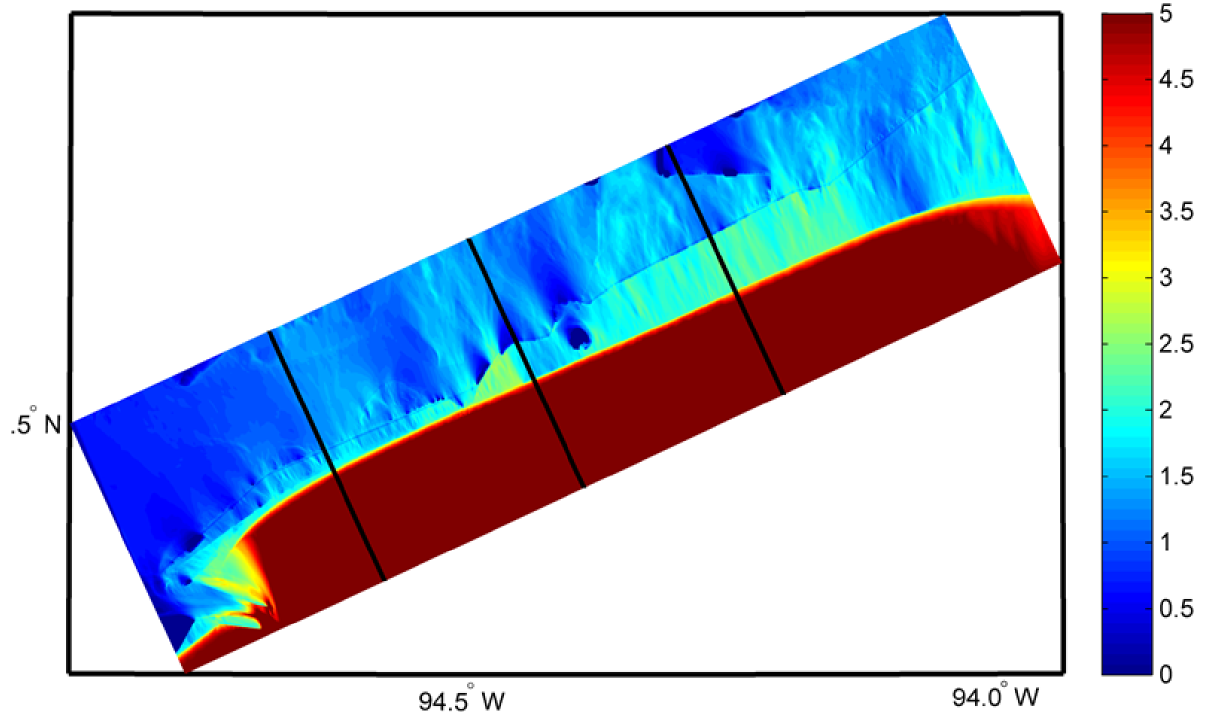
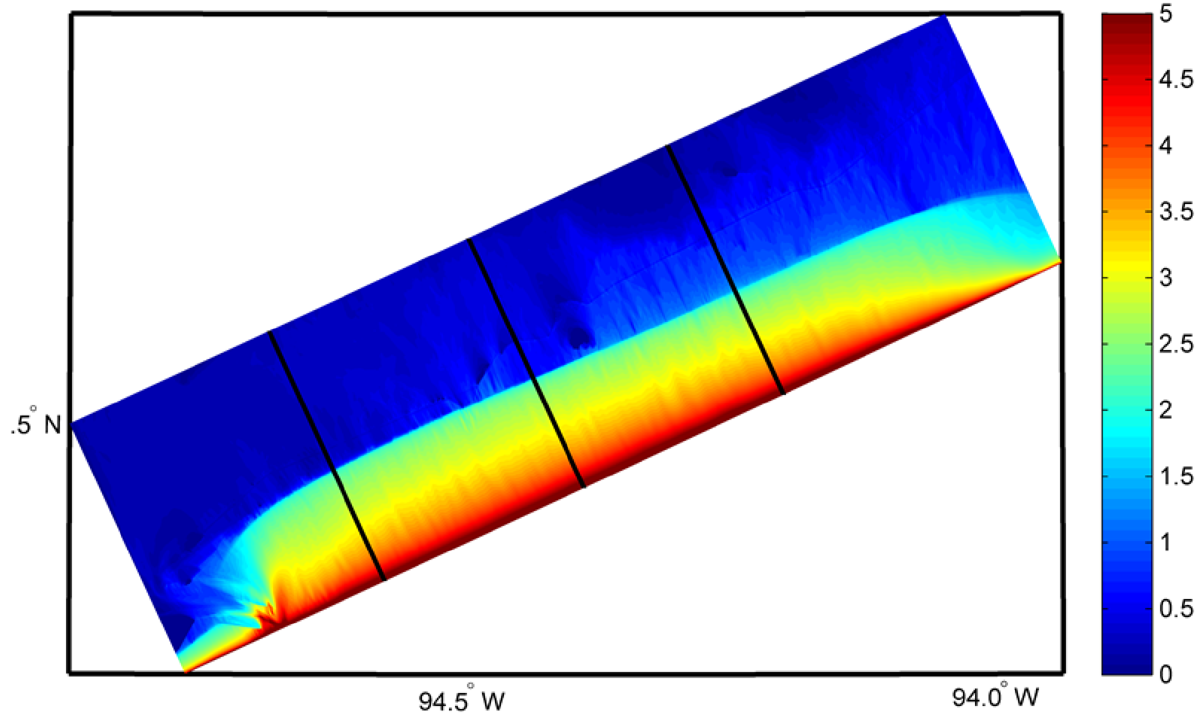


Wave heights from default dissipation

Overland Wave Heights During Hurricane Ike

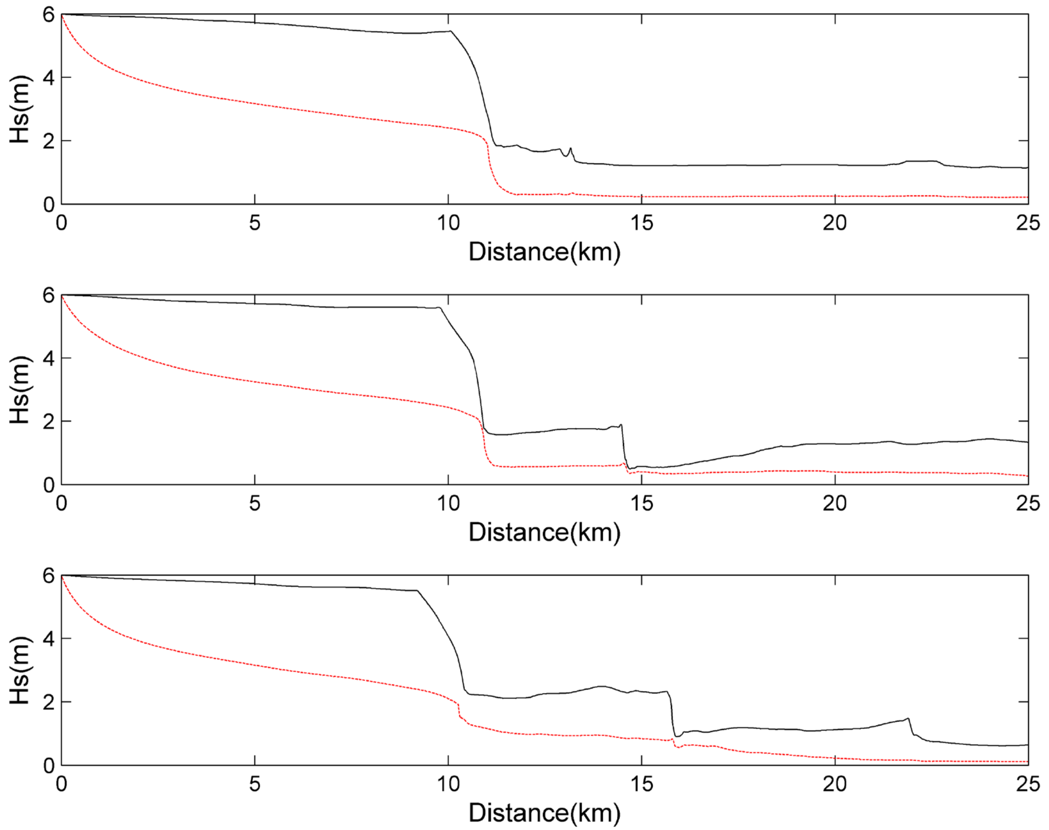
- Largehurricane that completely inundated Bolivar Peninsula, Texas
  - Wave heights measured near Gulf of Mexico and near Gulf Intracoastal Waterway at several locations
- Compare present wave breaking-dissipation with default values
  - Use hindcast surge over peninsula to get water levels
- Present dissipation provides much better results



Wave heights using present dissipation

Overland Wave Heights During Hurricane Ike

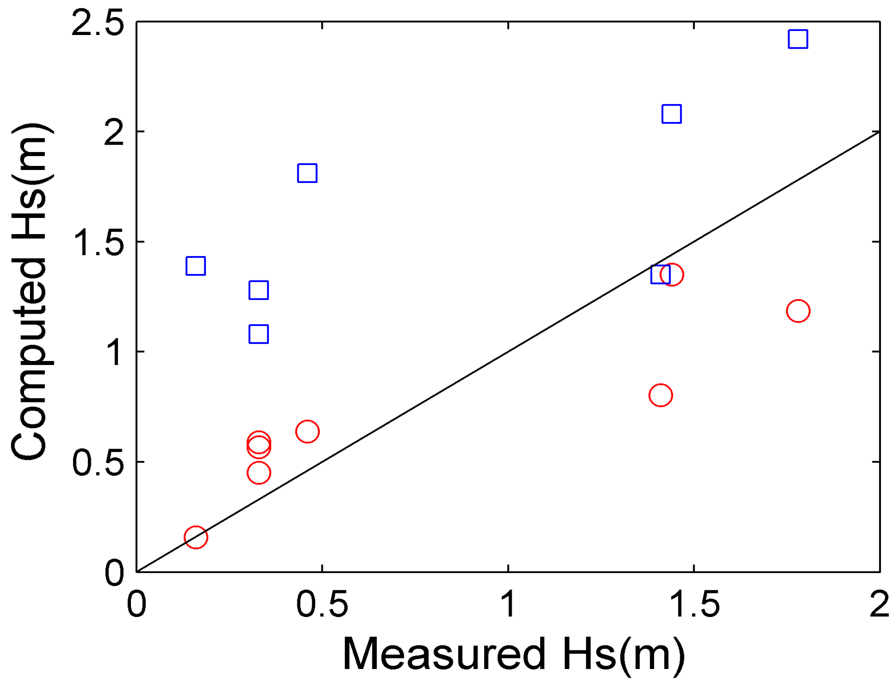
- Largehurricane that completely inundated Bolivar Peninsula, Texas
  - Wave heights measured near Gulf of Mexico and near Gulf Intracoastal Waterway at several locations
- Compare present wave breaking-dissipation with default values
  - Use hindcast surge over peninsula to get water levels
- Present dissipation provides much better results



Wave heights for default (black) and present dissipation (red) along three transects

Overland Wave Heights During Hurricane Ike

- Large hurricane that completely inundated Bolivar Peninsula, Texas
  - Wave heights measured by USGS at several locations near Gulf of Mexico and near Gulf Intracoastal Waterway
- Compare present wave breaking-dissipation with default values
  - Use hindcast surge over peninsula to get water levels
- Present dissipation provides much better results



Wave height comparison with measured USGS values. (□) default; (○) present setup.

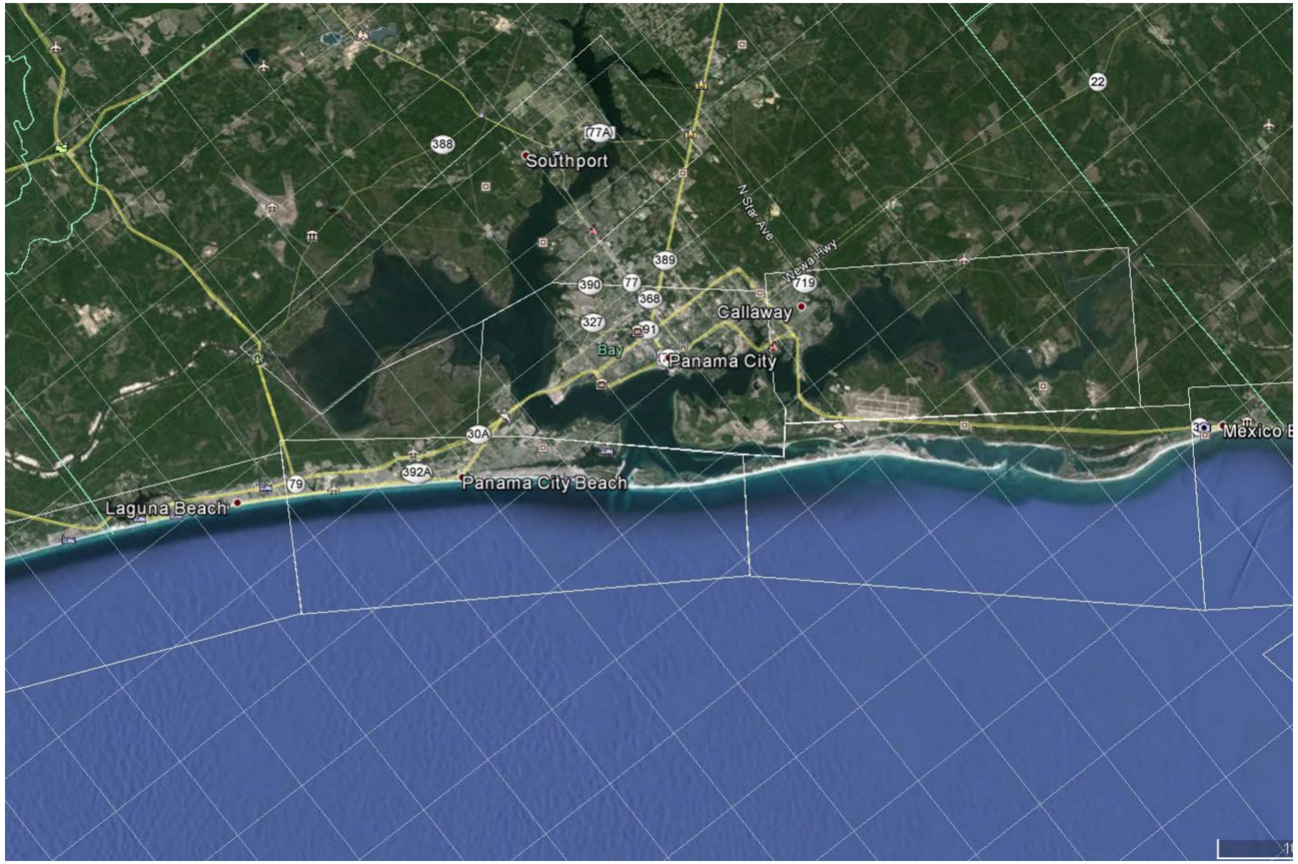
Computational Implementation

- All runs are trivially task-parallel
  - Run different storms on different cores/machines
  - Present implementation runs on HTCondor – uses scavenged cycles from mostly idle systems
- MATLAB scripts set up and distribute runs, organize output (e.g. rewrite text outputs to netcdf)
- Set up results for use by engineering team to assess damage

- Grid inputs from topobathy, land use/land cover – do not change
- Storm-specific water levels, winds from Surge Team
- Run wave model for all subgrids/surge grids where max surge exceeds 0.25m on subgrid
  - Max surge, Surge at max windspeed
- Consolidate results for interpolation to individual properties

Clipped Polygons Each Correspond to a Subgrid

- STWAVE rectangular subgrids overlap to some degree
- Polygons defined where locations within that polygon correspond to a single subgrid
- Lookup tables created for property to grid location to make wave height lookup straightforward



Clipped Polygons Each Correspond to a Subgrid

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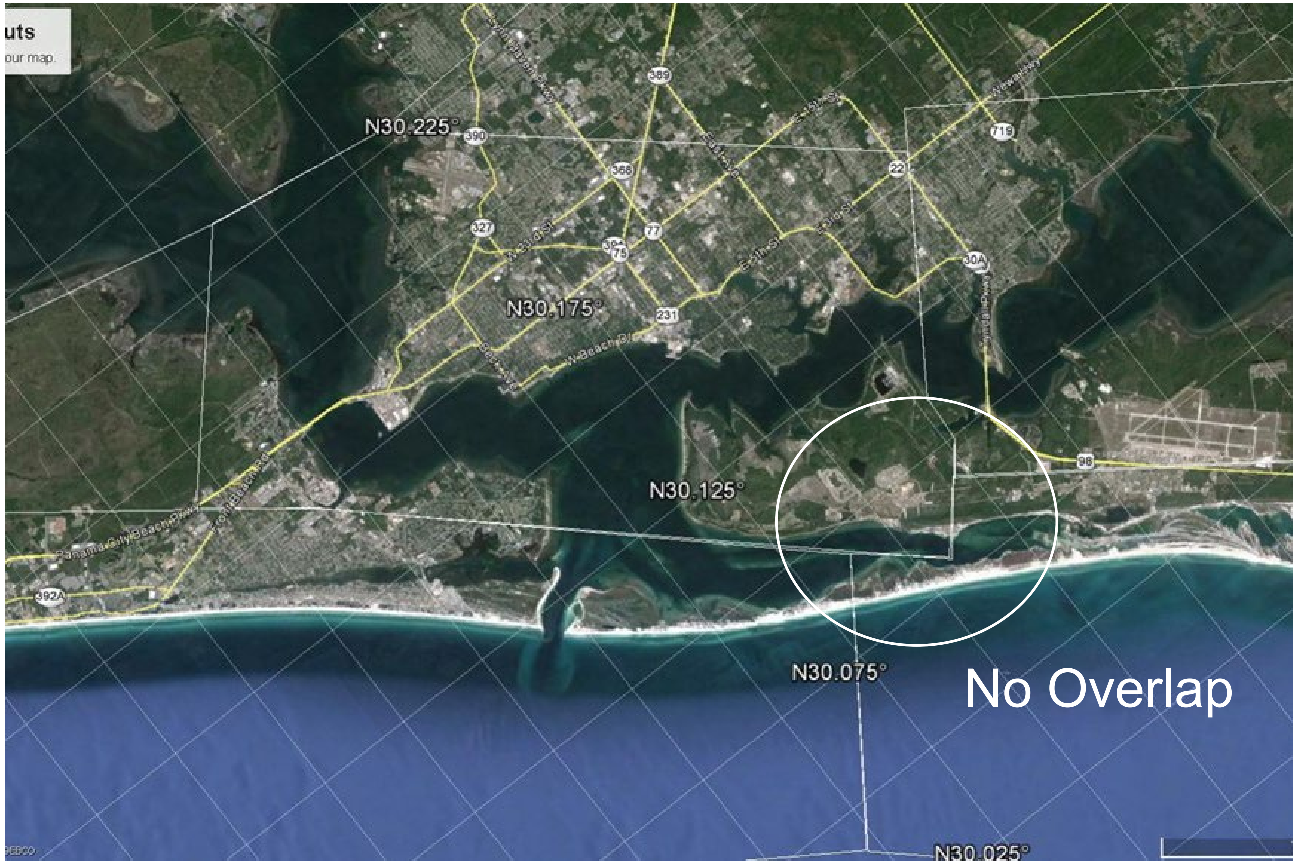
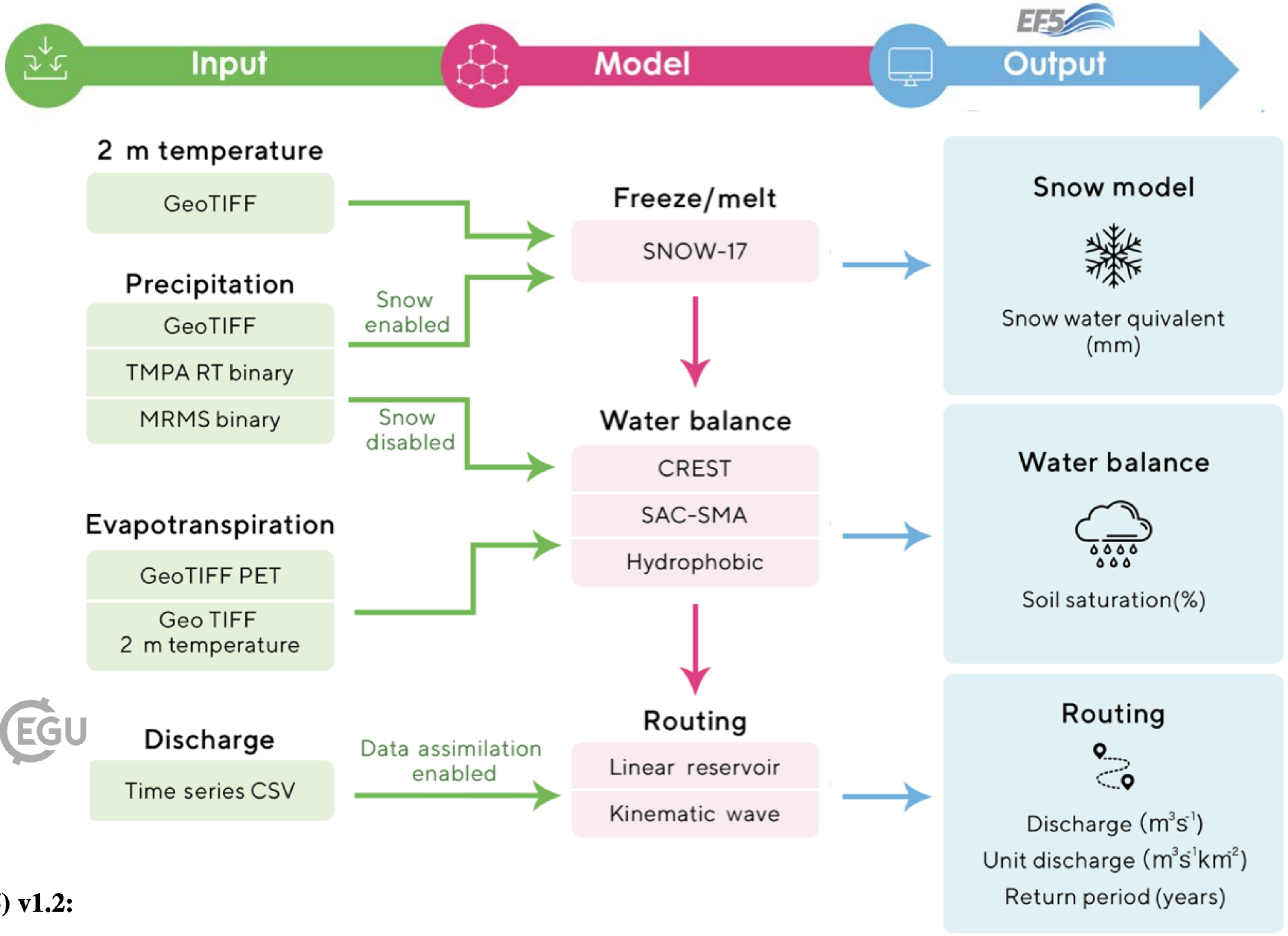


Inland Model Overview

Riverine Flood Model

BACKGROUND

The **Ensemble Framework For Flash Flood Forecasting** (EF5) is a distributed hydrologic modeling system that features multiple water balance models and two routing schemes. EF5 is used to simulate hydrologic variables such as streamflow and soil saturation.



Geosci. Model Dev., 13, 4943–4958, 2020
https://doi.org/10.5194/gmd-13-4943-2020

Geoscientific Model Development
Open Access
EGU

The Ensemble Framework For Flash Flood Forecasting (EF5) v1.2: description and case study

Zachary L. Flamig[1,2,3], Humberto Vergara[1,2], and Jonathan J. Gourley[2,3]

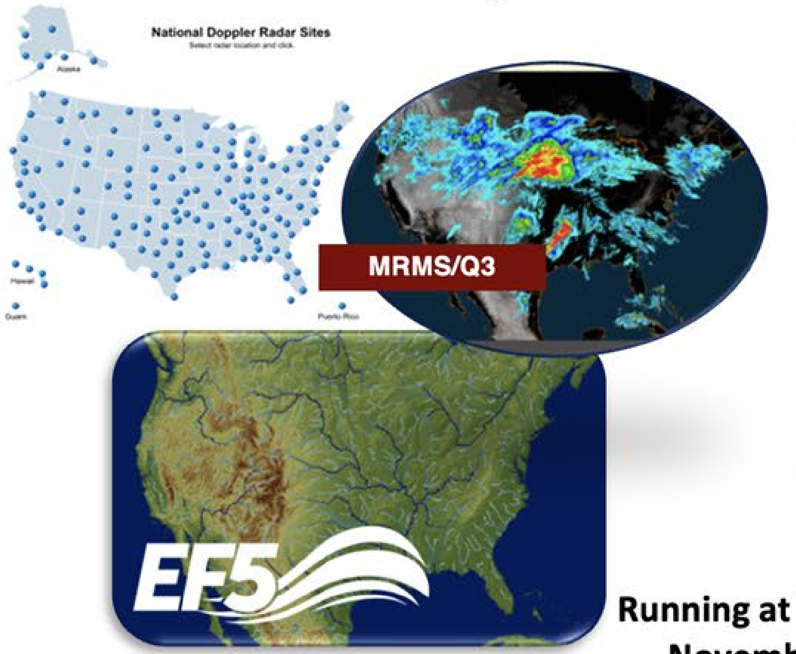
EF5 is the hydrologic modeling core of the Multi-Radar Multi-Sensor (MRMS) - Flooded Locations And Simulated Hydrographs (FLASH) system

MRMS – FLASH System

FLASH

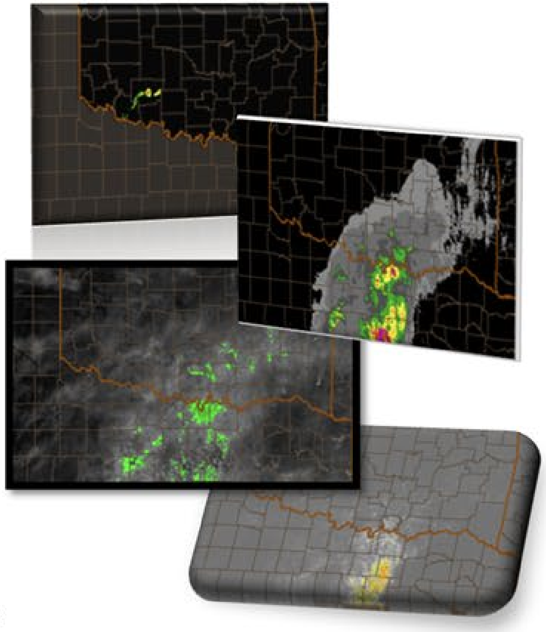
An NWS CONUS-wide flash-flood forecasting system

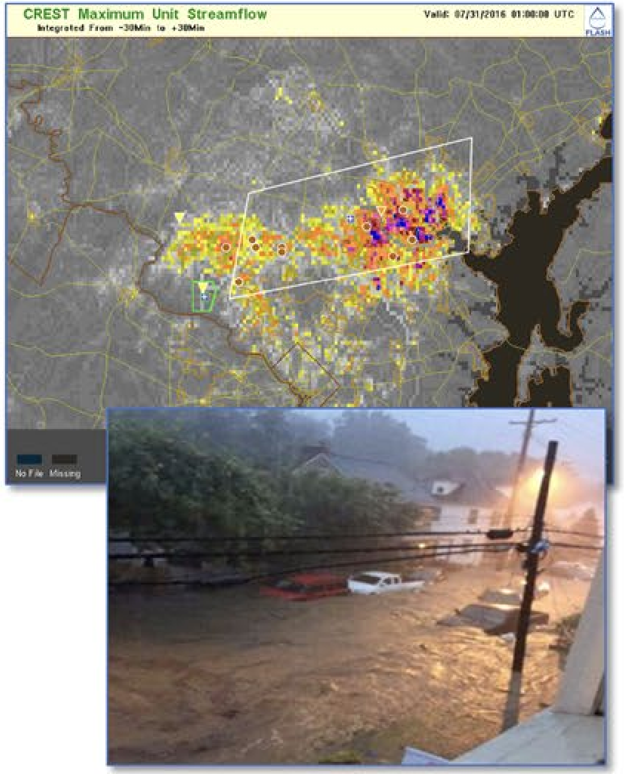
Mosaic of reflectivity from NEXRAD and Environment Canada radars. **Running at NCEP since 2014**



Running at NCEP since November 2016

A Suite of Products





Ellicott City, MD, *July 30, 2016*

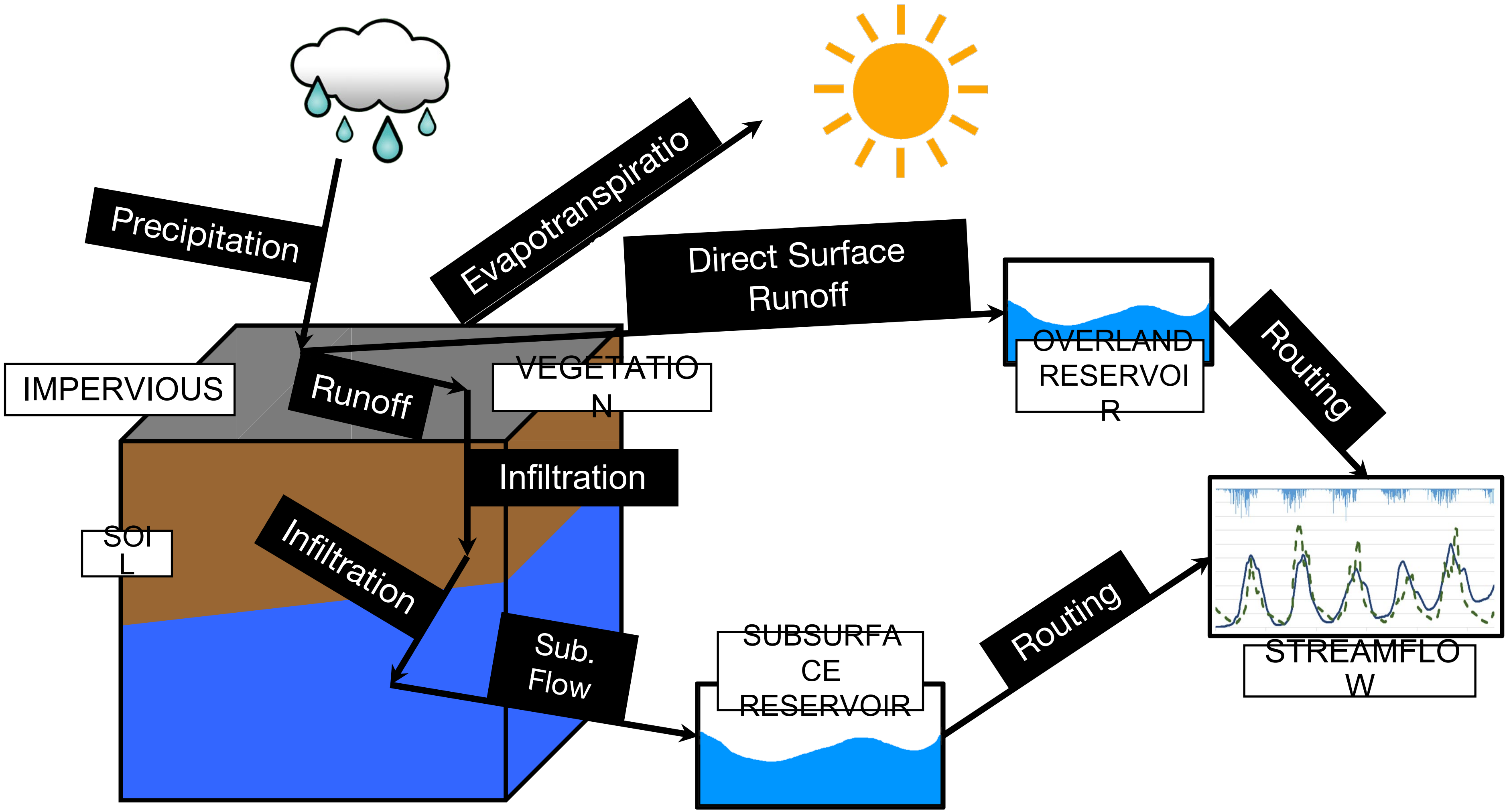
The EF5 implementation for FPFLM :

- Uses CREST (Coupled Routing and Excess Storage) model for the water balance component.
- Kinematic wave for overland and channel routing.
- Linear reservoirs scheme for subsurface routing.

Soil moisture and surface/subsurface runoff are simulated at ~90m spatial and 1h temporal resolution at **~1.3 million grid points**

EF5 WITHIN FPFLM

Schematic of processes resolved at each grid point



Infiltration is modeled using the VIC (Variable Infiltration Capacity) model (Flamig et al. 2020)

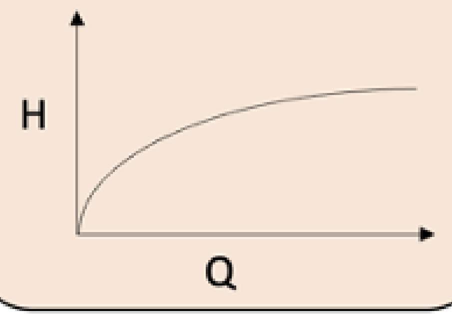
FROM STREAMFLOW TO WATER STAGE

Rainfall and potential evapotranspiration

Water Balance

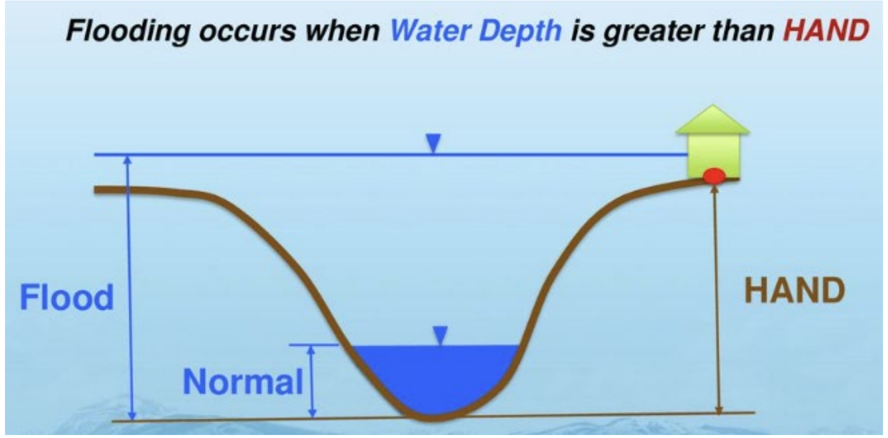
Routing

Streamflow (Q)



Gridded output of water stage in rivers

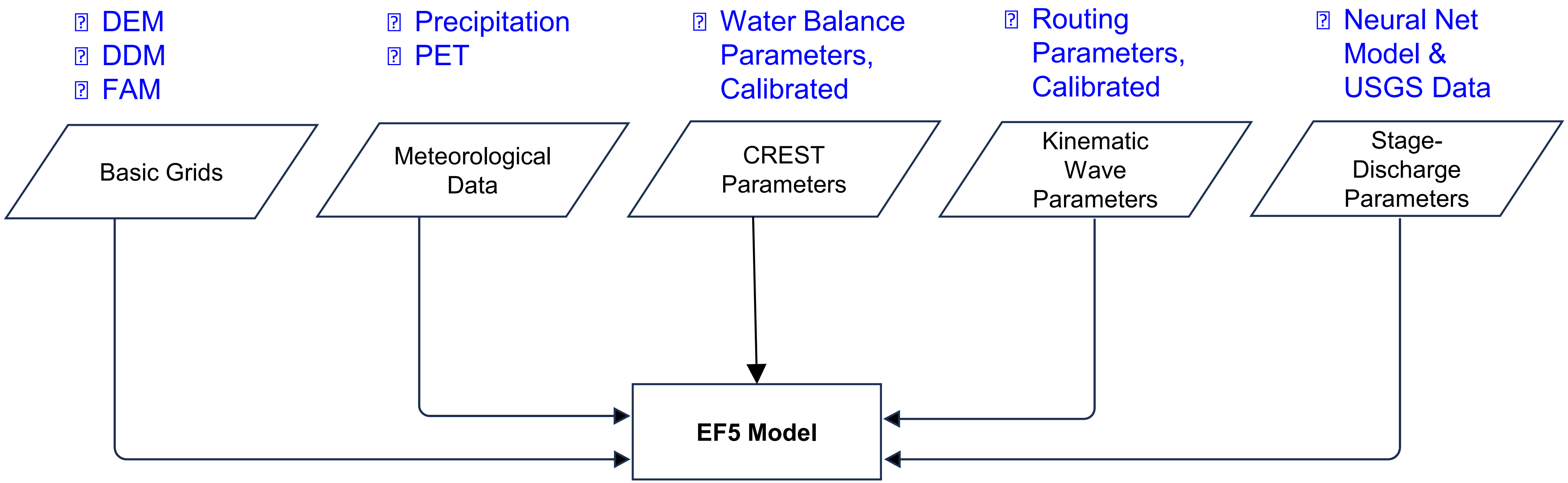
To flood depth using HAND*
(Height Above Nearest Drainage)



Source: https://slideplayer.com/slide/17404686/

***HAND method for inundation mapping is currently used in National Water Model of NOAA (Aristizabal et al 2023)**

INPUT DATA & PARAMETERS REQUIRED

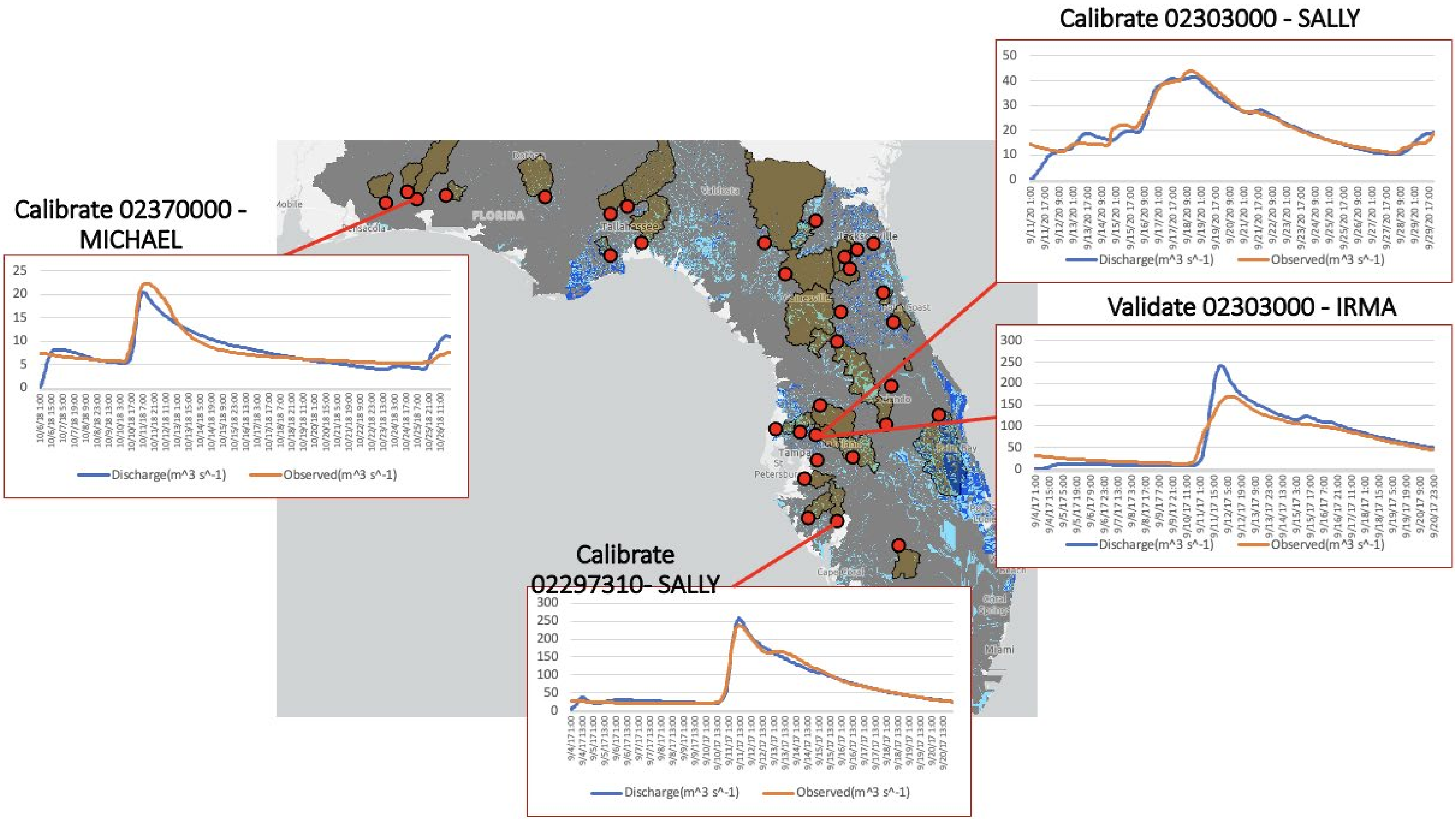


- DEM,DDM,FAM are derived from National Elevation Dataset using ArcGIS Spatial Analyst Toolbox
- Precipitation from multiple sources (MRMS, PRISM, Rain Model)
- PET from monthly climatology
- Water balance and routing parameters are calibrated using DREAMS algorithm
- Rating curve parameters are estimated using NN model trained with USGS data

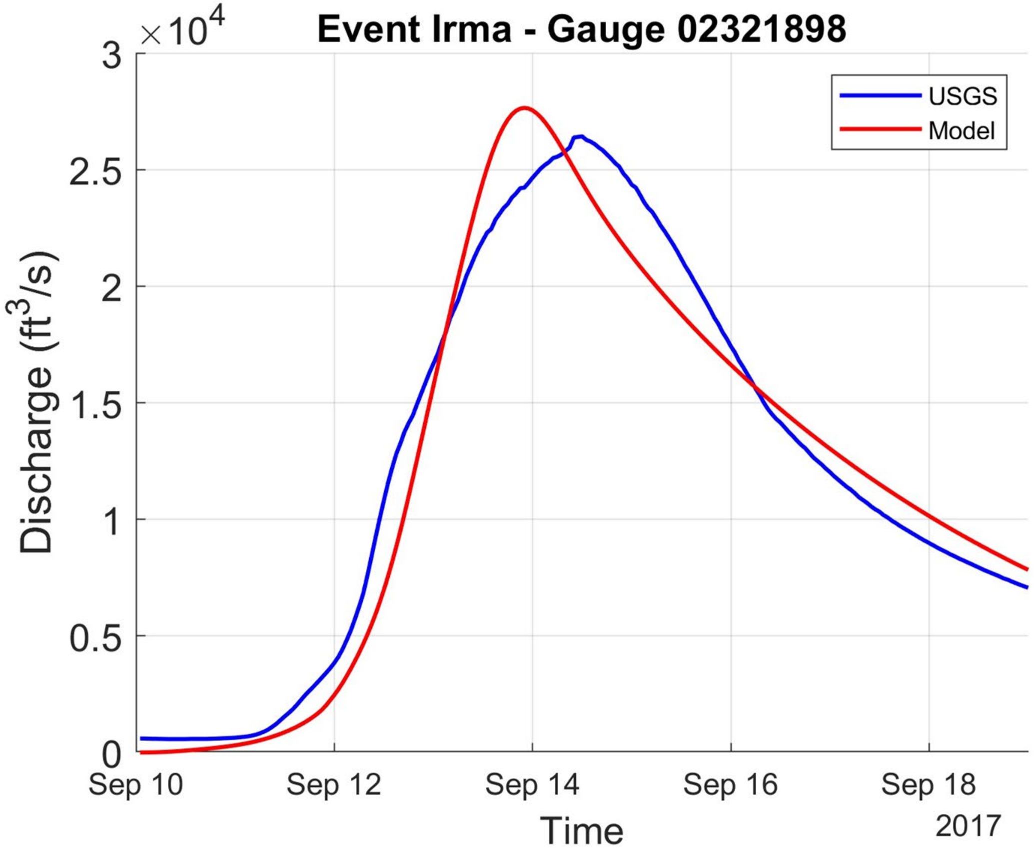
MODEL DOMAIN

Figure on the left shows the spatial extent of riverine model domain (shaded area) that covers drainage basins that extent the state boundaries such as the Apalachicola basin shown in the USGS HUC06 map on the right.

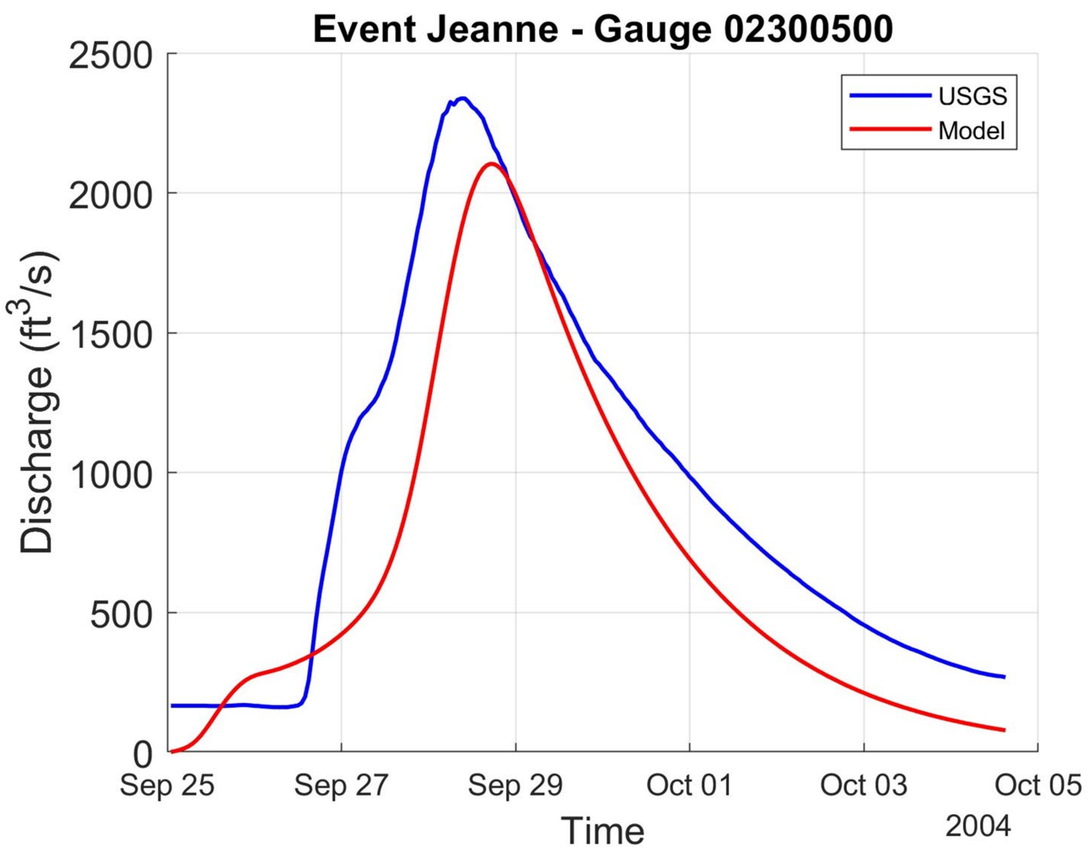
CALIBRATION & VALIDATION



VALIDATION

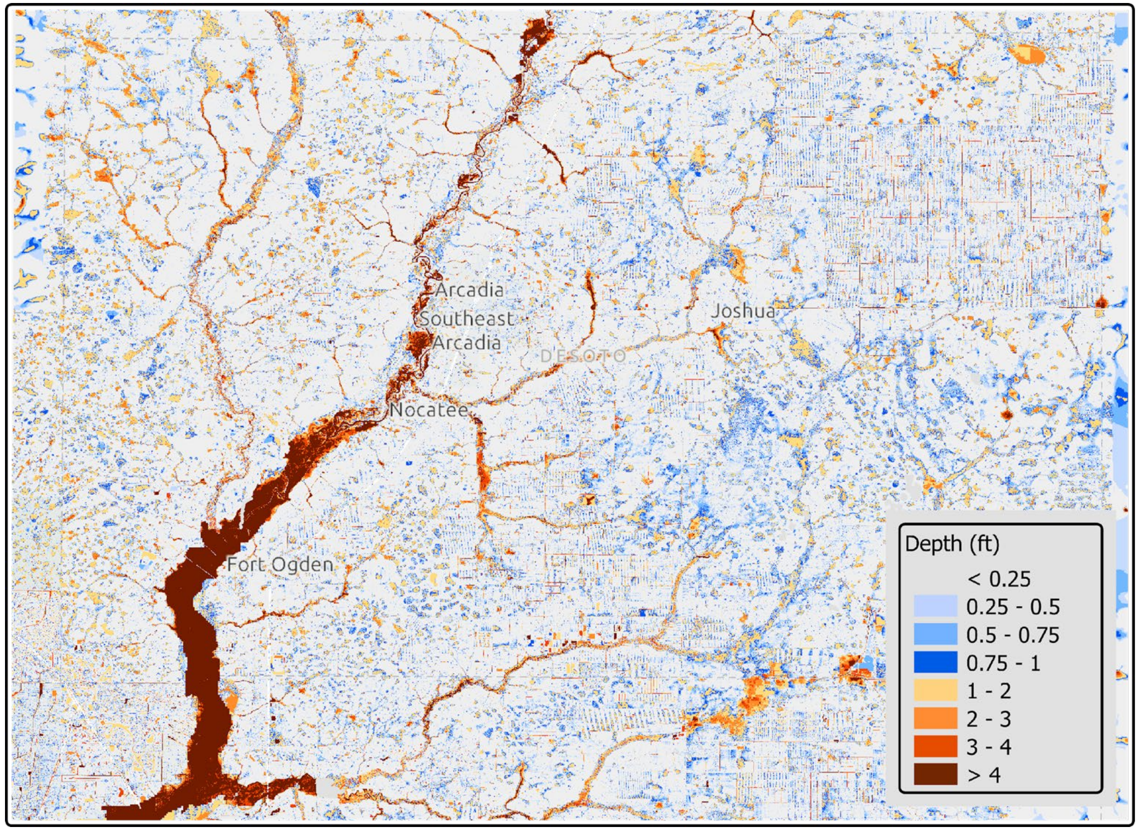


Comparison of the modeled riverine flood flow to recorded flow data for Hurricane Irma (2017) from selected USGS gauging station 02321898 located at Santa FE River at O'leno State Park.

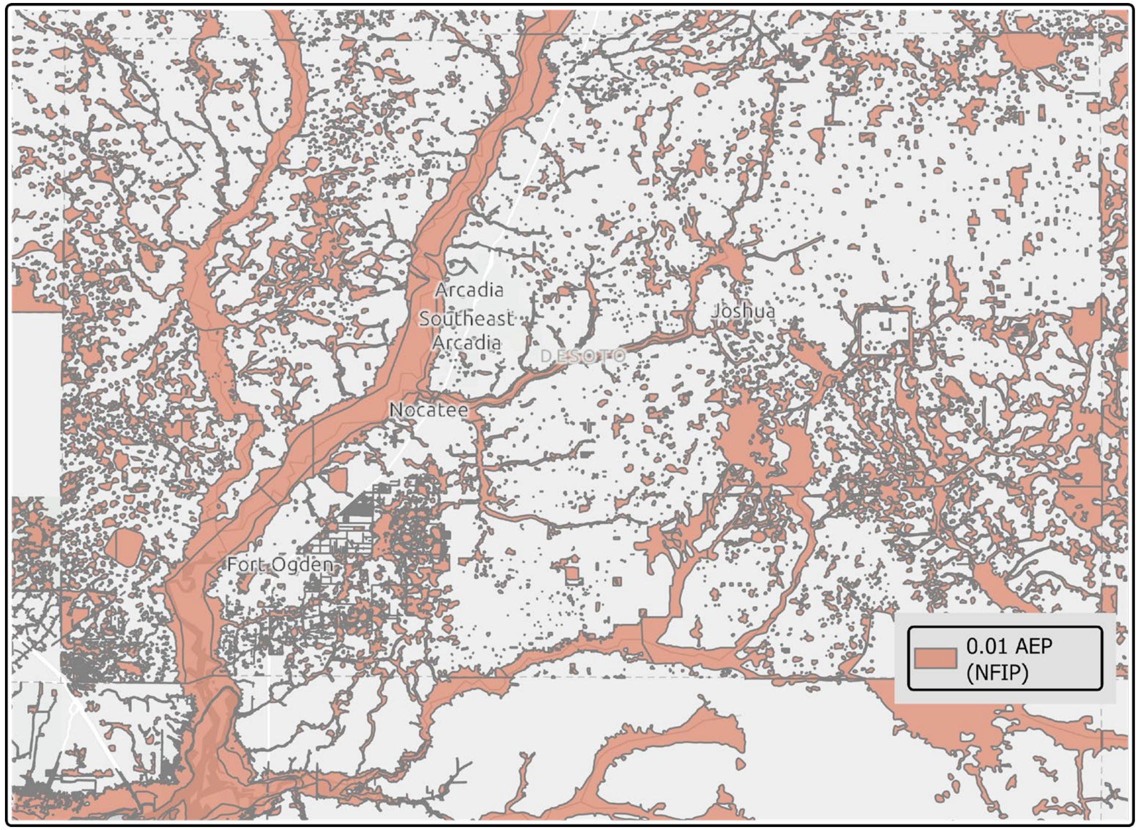


Comparison of the modeled riverine flood flow to recorded flow data for Hurricane Jeanne (2004) from selected USGS gauging station 02300500 located at Little Manatee River at US 301 Near Wimauma

VALIDATION



(a)



(b)

Modeled flood extent and depth (a) and NFIP flood extents (b) corresponding to 0.01 annual exceedance probability (AEP) for region selected in Southwest Florida (Desoto). Figure 179 in submission document

CONCLUDING REMARKS

- EF5 is a robust hydrologic modeling system that is being used operationally by National Weather Service and has been used in several research publications.
- CREST is used for water balance components and kinematic wave method for overland/channel routing.
- EF5 implementation for FPFLM includes a configuration that models hydrologic variables at ~90m resolution for about 1.3 million grid points.
- The model domain covers all basins draining in the state of Florida.
- Model parameters have been calibrated and validated against USGS streamflow observations for historic hurricane events.
- Flood depth is estimated using HAND methodology, an approach currently used in the National Water Model of NOAA.
- Comparison of 100yr flood extent with FEMA maps exhibits a good agreement.

REFERENCES

Aristizabal, F., Salas, F., Petrochenkov, G., Grout, T., Avant, B., Bates, B., Spies, R., Chadwick, N., Wills, Z. and Judge, J., 2023. Extending height above nearest drainage to model multiple fluvial sources in flood inundation mapping applications for the US National Water Model. *Water Resources Research*, *59*(5), p.e2022WR032039.

Flamig, Z.L., Vergara, H. and Gourley, J.J., 2020. The ensemble framework for flash flood forecasting (EF5) v1. 2: Description and case study. *Geoscientific model development*, *13*(10), pp.4943-4958.

List of examples of peer reviewed research publications involving application of EF5 modeling system:

Gourley, J.J., Flamig, Z.L., Vergara, H., Kirstetter, P.E., Clark, R.A., Argyle, E., Arthur, A., Martinaitis, S., Terti, G., Erlingis, J.M. and Hong, Y., 2017. The Flooded Locations And Simulated Hydrographs (FLASH) project: improving the tools for flash flood monitoring and prediction across the United States.

Lengfeld, K., Kirstetter, P.E., Fowler, H.J., Yu, J., Becker, A., Flamig, Z. and Gourley, J., 2020. Use of radar data for characterizing extreme precipitation at fine scales and short durations. *Environmental Research Letters*, *15*(8), p.085003.

Chen, M., Nabih, S., Brauer, N.S., Gao, S., Gourley, J.J., Hong, Z., Kolar, R.L. and Hong, Y., 2020. Can remote sensing technologies capture the extreme precipitation event and its cascading hydrological response? A case study of Hurricane Harvey using EF5 modeling framework. *Remote Sensing*, *12*(3), p.445.

Pluvial Flood Model

Overview of PLUV2D

- Two-dimensional surface flow model developed by Dr. S. Cocke
- Computationally fast - similar to cellular automata (CA) models and simple finite volume (FV) models
- Typically 10 m (33 ft) to 30 m (98 ft) 2D resolution with grid cells defined by the input DEM data
- Flow between cells governed by Manning's equation or optionally the inertial shallow water equation
- Modified Horton method for soil infiltration, varying according to soil type
- Accounts for antecedent soil moisture conditions (e.g., dry, wet, saturated)
- Accounts for surface roughness and impervious cover based on land use/land cover data
- Variety of spatially and temporally varying rain input – e.g., NOAA Atlas 14 return period rain, historical gridded rainfall data, rain generated by stochastic rain model

Manning’s Equation for flow velocity:

$$v_{ij} = (1/C)\, d^{2/3} \left((w_i - w_j) / \Delta s_{ij} \right)^{1/2}$$

where *i,j* are source, destination cells, *C* is Manning’s coefficient, *d* is channel depth, Δs_{ij} is the cell spacing, *w* is water level of corresponding center and neighbor cells.

Velocity increases with energy gradient (channel slope) and channel depth, but decreases with increasing surface roughness (higher Manning coefficient).

PLUV2D also has the option for using the inertial shallow water equation (Bates et al., 2010).

PLUV2D now incorporates a 1D routing method for flow that is not adequately represented by the DEM (e.g. sewers, culverts).

PLUV2D – Soil Infiltration

- Uses modified Horton method for soil infiltration.
- Infiltration parameters based on published literature and depend on soil type and vegetation cover.
- Soil type based on well-known Global Hydrological Soil Group 1566 from ONRL (250 m resolution globally).
- Vegetation cover is an input option that ranges from bare soil to dense cover. For Florida, we assume moderate coverage in residential exposure areas.
- Modified to include antecedent soil moisture conditions, ranging from “bone dry” to saturated, or anything in between.
- Impervious cover based on MRLC 2016 Impervious Cover data set.

PLUV2D – Precipitation Input

- Model can use virtually any gridded precipitation product, or manually specified rain amount.
- ***Validation***: PRISM, MRMS data sets.
- ***Return period flood maps***: the NOAA Atlas 14 Intensity-Duration Maps.
- ***Stochastic tropical cyclone simulations***: the R-CLIPER-based tropical cyclone rainfall algorithm.
- ***Non-tropical rainfall loss estimation***: the CPC CONUS gridded precipitation data set.

PLUV2D - Roughness

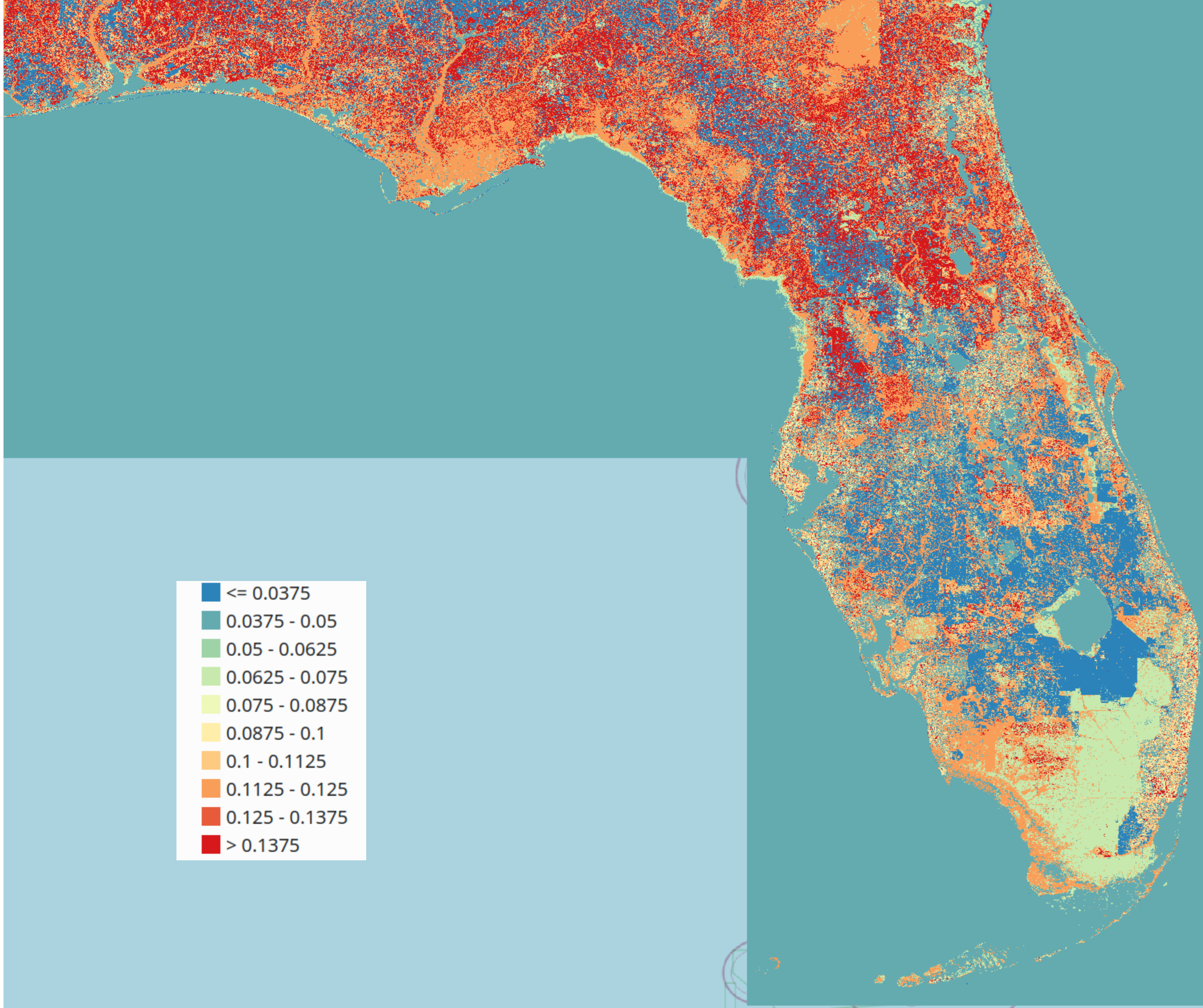
- Terrain roughness impacts the rate of flow via the Manning Coefficient. Higher roughness impedes the flow of surface water, and can enhance the local accumulation of surface water, at least temporarily.
- Roughness is currently based on *MRLC 2016 NLCD Land Use Land Cover*. The Manning coefficient is assigned based on a HEC-RAS 2D table that assigns a value based on NLCD classification. Values are from published literature.

Manning Coefficient

Table 2-11: Land Use/Manning's N-Value Matrix Used in HEC-RAS 2D Model

NLCD Value[1]	Normal Manning's n Value	Allowable Range of n Values	Land Cover Definition	Reference
11	**0.040**	0.025–0.05	Open Water. All areas of open water, generally with less than 25% cover or vegetation or soil.	Table 5-6 D-1.a.3[2]
21	**0.040**	0.03–0.05	Developed, Open Space. Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of the total cover. These areas most commonly include large-lot, single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	Figure 3-19[3]
22	**0.100**	0.08–0.12	Developed, Low Intensity. Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20–49% of the total cover. These areas most commonly include single-family housing units.	Figure 3-19[3]
23	**0.080**	0.06–0.14	Developed, Medium Intensity. Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50–79% of the total cover. These areas most commonly include single-family housing units.	Figure 3-19[3]
24	**0.150**	0.12–0.20	Developed, High Intensity. Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80–100% of the total cover.	Figure 3-19[3]
31	**0.025**	0.023–0.030	Barren Land (Rock/Sand/Clay). Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of the total cover.	Table 5-6 C.b.1[2]
41	**0.160**	0.10–0.16	Deciduous Forest. Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	Table 5-6 D-2.d.5 Max. Debris[2]
42	**0.160**	0.10–0.16	Evergreen Forest. Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.	Table 5-6 D-2.d.5 Max. Debris[2]
43	**0.160**	0.10–0.16	Mixed Forest. Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.	Table 5-6 D-2.d.5 Max. Debris[2]
52	**0.100**	0.07-–0.16	Shrub/Scrub. Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.	Table 5-6 D-2.c.5[2]
71	**0.035**	0.025–0.050	Grassland/Herbaceous. Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.	Table 5-6 D-2.a.2[2]
81	**0.030**	0.025–0.050	Pasture/Hay. Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.	Table 5-6 D-2.a.1[2]
82	**0.035**	0.025–0.050	Cultivated Crops. Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.	Table 5-6 D-2.b.2[2]
90	**0.120**	0.045–0.15	Woody Wetlands. Areas where forest or shrub land vegetation accounts for greater than 20% of substrate or substrate is periodically saturated with or covered with water.	Table 5-6 D-1.a.8[2]
95	**0.070**	0.05–0.085	Emergent Herbaceous Wetlands. Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.	Table 5-6 D-1.a.7[2]

(1) National Land Cover Database (USGS, 2011)
(2) *Open-Channel Hydraulics* (Chow, 1959)
(3) *HEC-RAS River Analysis System: 2D Modeling User's Manual* (USACE, 2016)



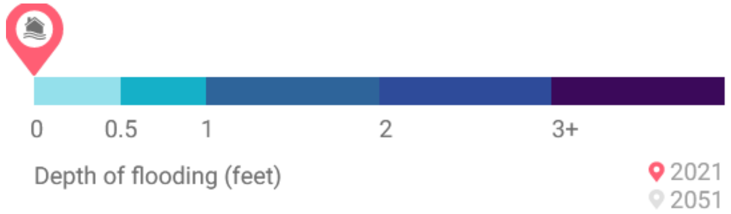
Validation of PLUV2D Maps

- Return period flood maps for the entire state of Florida created for the 1, 2, 5, 10, 25, 50, 100, 200, 500 and 1000 year return periods at 30 m (98 ft) resolution based on NOAA 14 Atlas Data
- Simulations performed for most major recent historical flood events in Florida using observed rainfall data
- Compared return period maps with the FSF LISFLOOD model (FloodFactor.com)
- Compared 100 year return period map with the FEMA flood zones
- Compared simulated flood depths using historical rain data as well as return period maps with NFIP claims data, NOAA reports

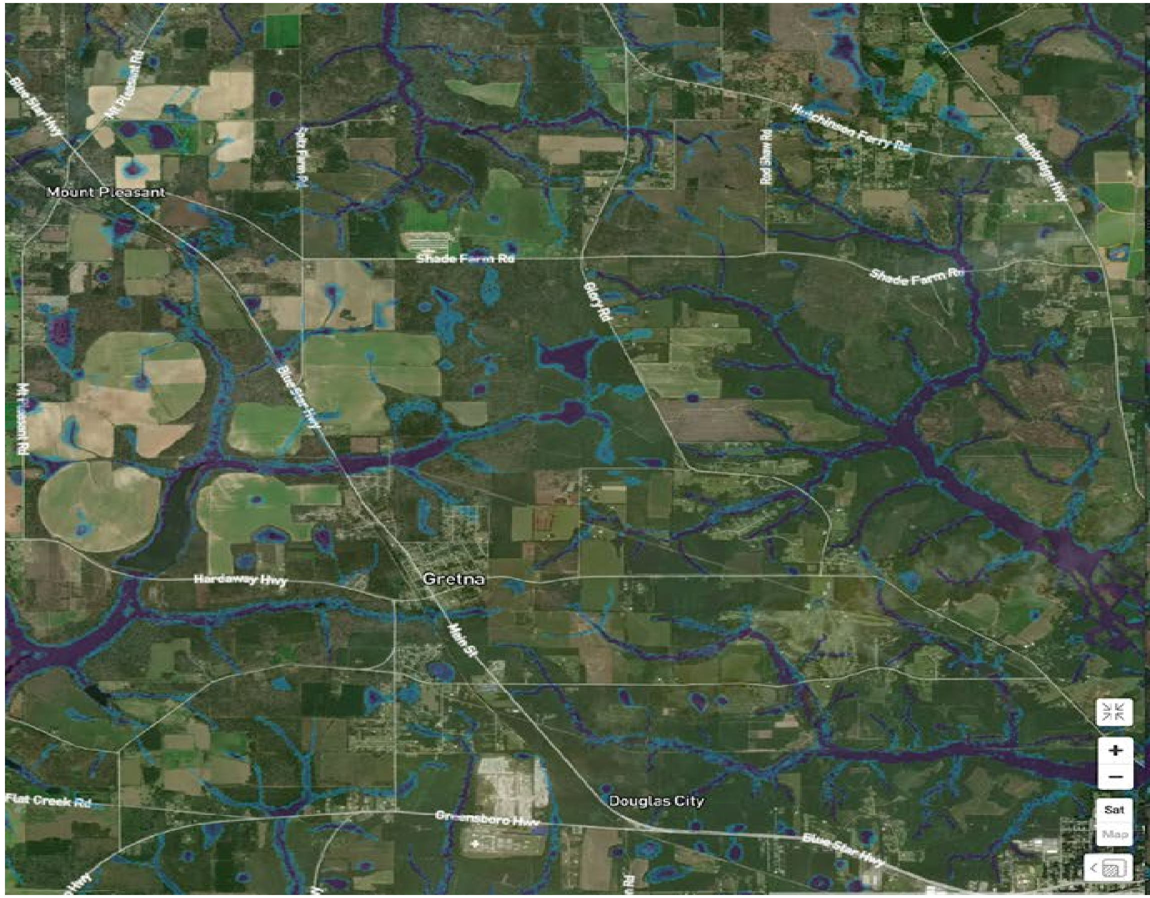
Validation against Other Models

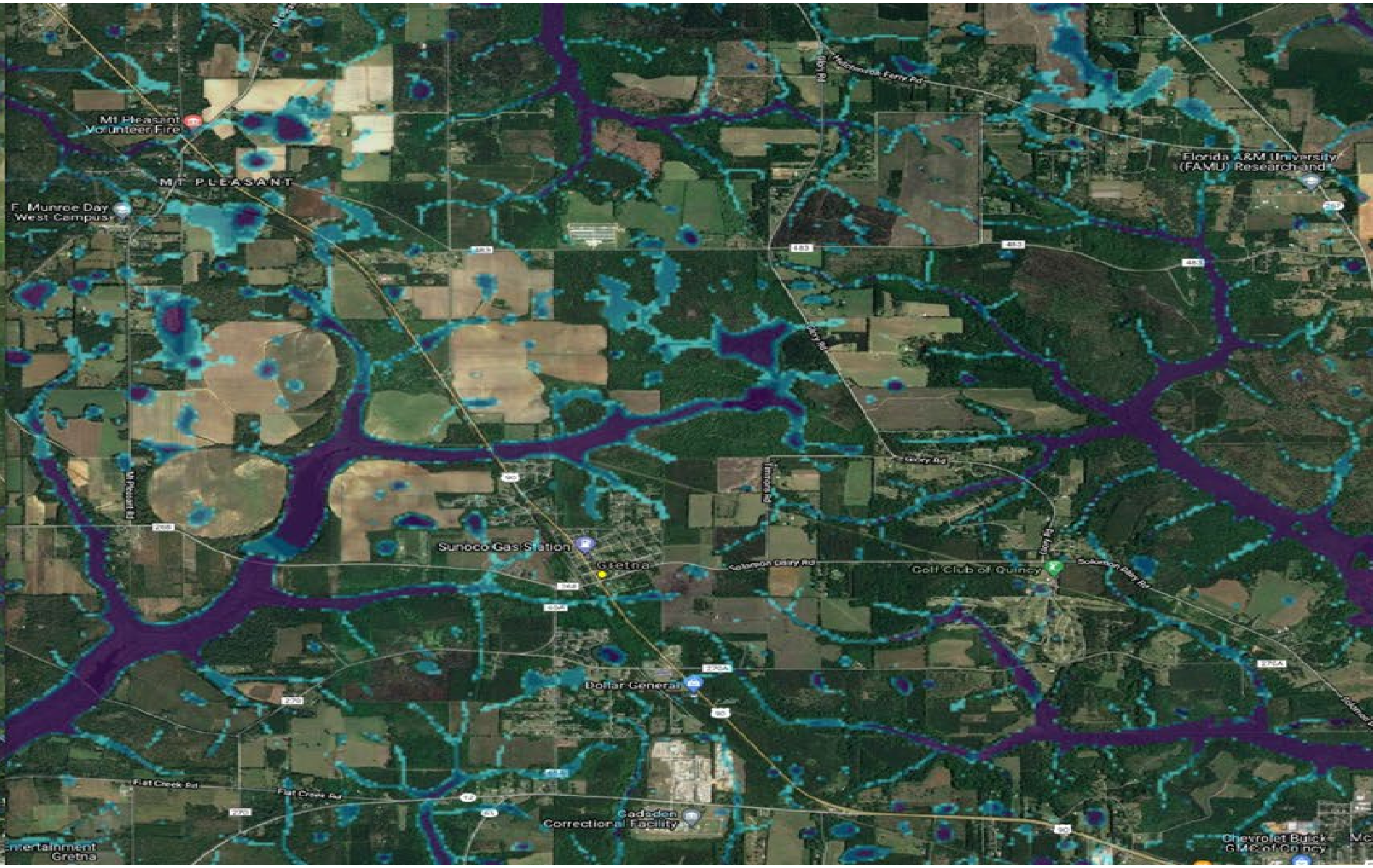
- We compared the return period flood depths with those published by *FloodFactor.com*, which were produced by First Street Foundation (FSF) using the LISFLOOD model.
- The LISFLOOD model was run at 30 m (98 ft) resolution, but downscaled to higher resolution.
- The LISFLOOD model used NOAA Intensity and Duration data, as we have as well, and used the Horton method for infiltration, as we do, but with a small modification.
- The PLUV2D results compare very well with the LISFLOOD results in flood depth and extent.
- Unfortunately, it appears that *FloodFactor* no longer makes their data publicly available.

Comparison of 100 year flood depth with FSF LISFLOOD for Gretna, Florida



Note: image sizes are different, and there are differences in color rendering.

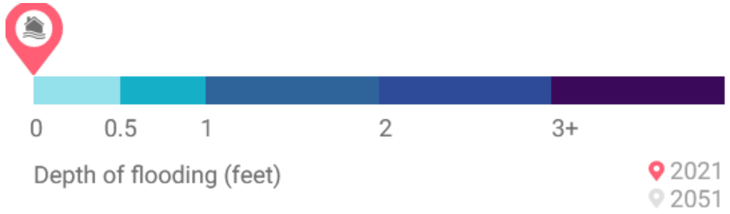




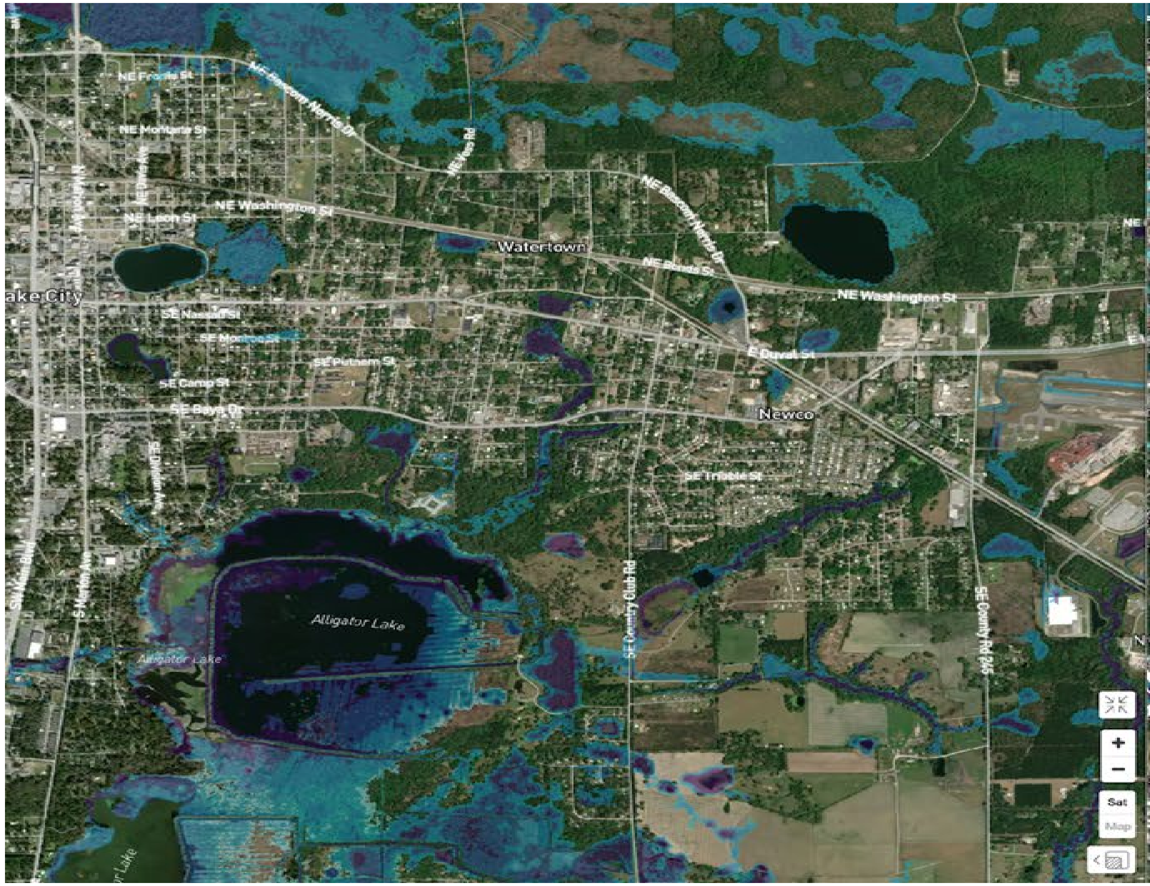
LISFLOOD (30 m, downscaled)

PLUV2D (30 m, no downscaling)

Comparison of 100 yr flood depth with FSF LISFLOOD and FEMA for Lake City, Fl



White contours are FEMA 100 yr flood zones



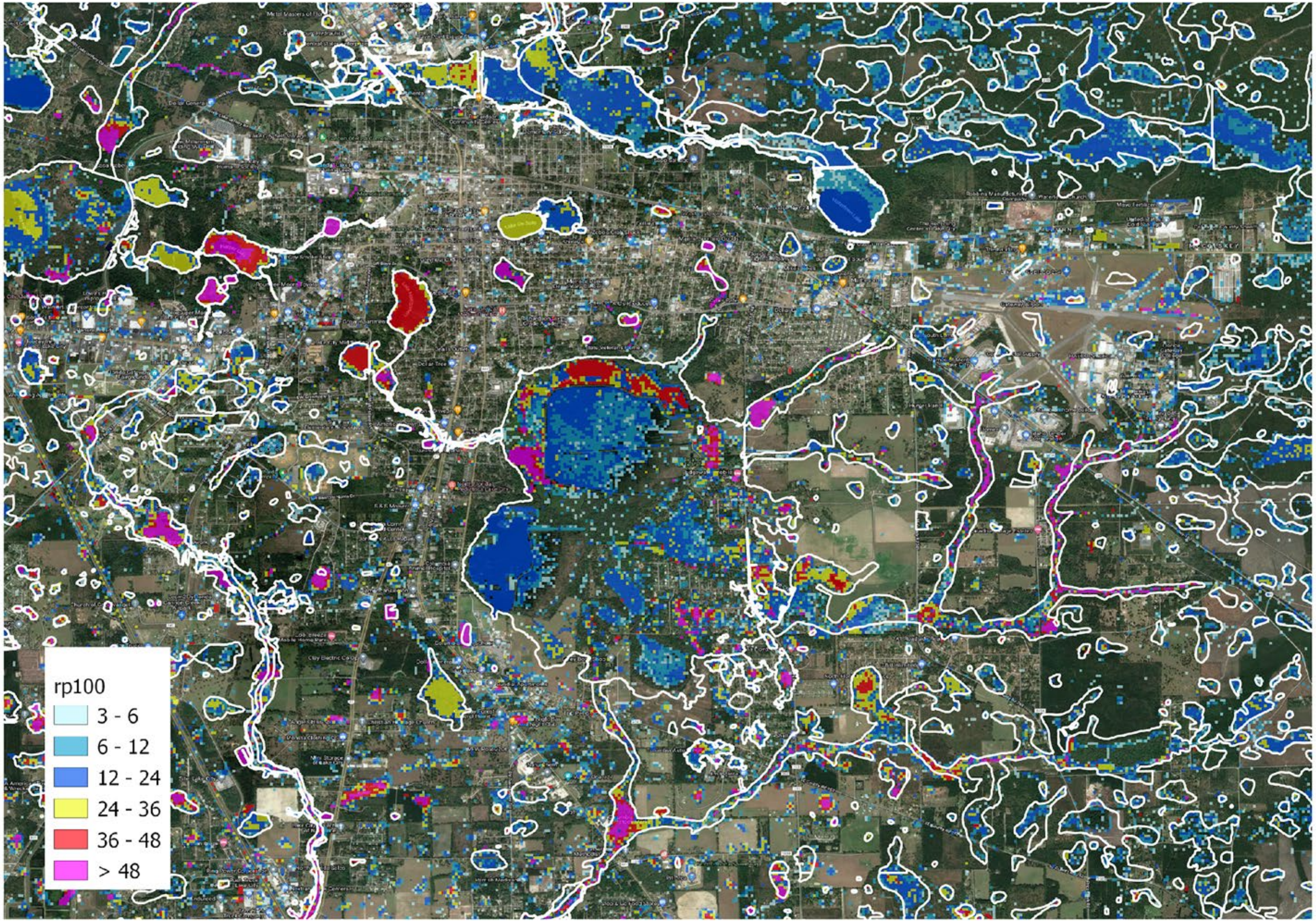
FSF LISFLOOD

PLUV2D

Validation with FEMA Flood Zones

- We have compared the 100 year flood maps produced by PLUV2D with FEMA flood zones for a number of counties in Florida.
- Overall there is very good agreement in flood extent. PLUV2D sometimes shows flooding in locations that are not in FEMA zones, but most of these cases are where there are *holding ponds* or *natural depressions* and *channels* where water accumulation is expected to occur. PLUV2D produces flood in all FEMA flood zones that we have investigated so far.

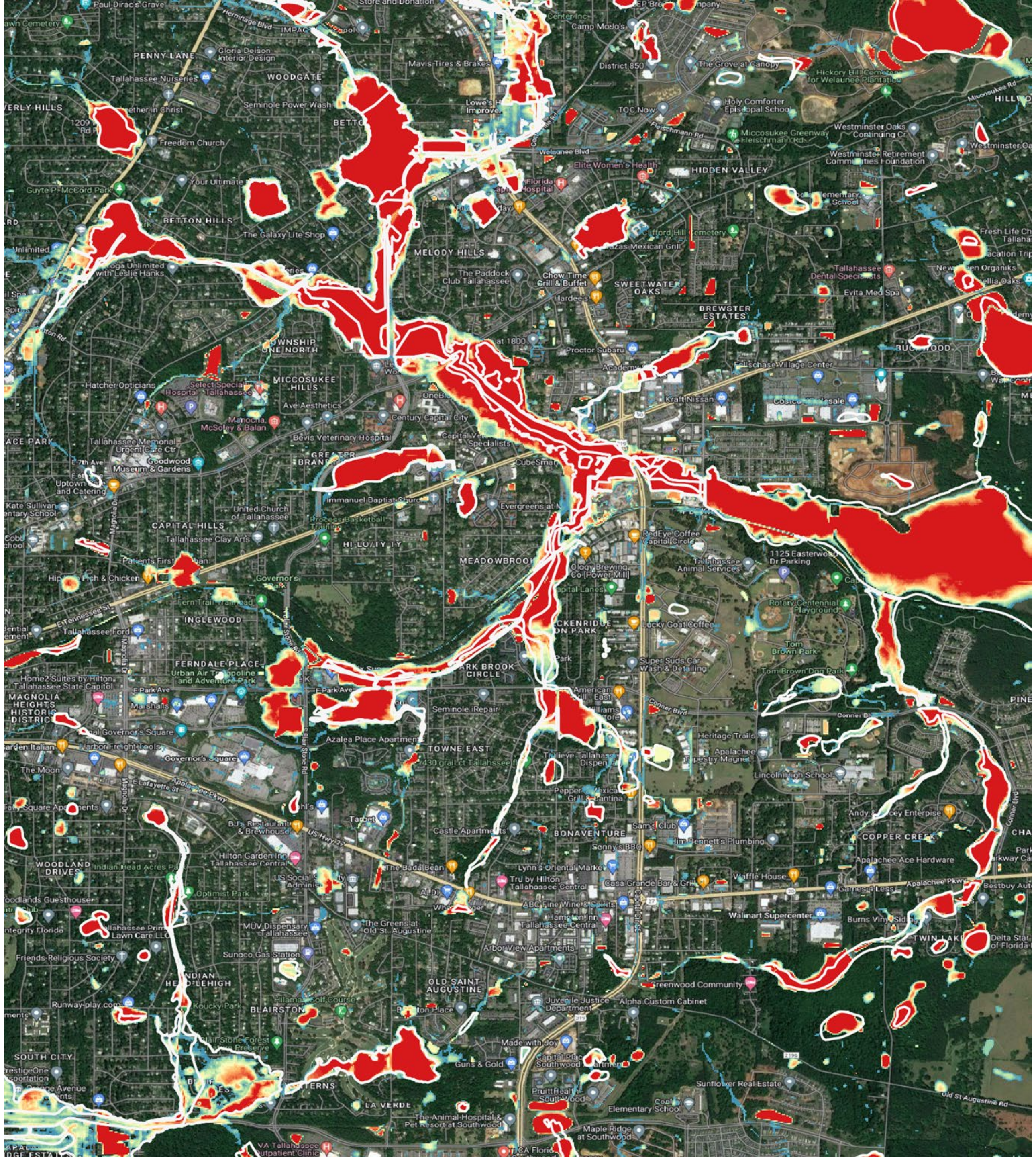
Comparison of PLUV2D 100yr flood depths (in inches) and FEMA flood zones for Lake City, Florida



100 yr flood depth for an area in Tallahassee, FL
White contours are FEMA flood zones.

Flood depth in inches
1 inch = 2.54 cm

<= 3
3 - 6
6 - 9
9 - 12
12 - 15
15 - 18
18 - 21
21 - 24
24 - 27
27 - 30
30 - 33
33 - 36
36 - 39
39 - 42
42 - 45
45 - 48
48 - 51
51 - 54
54 - 57
> 57



Validation with FEMA Claims data

- We have compared the PLUV2D flood depths with locations of FEMA claims.
- The FPFLM project was given special permission to use unredacted FEMA claims data, which provides precise location of the flooded properties.
- There is high correlation with claims locations and locations where PLUV2D indicates flooding could occur.
- For inland-only flood events (**Fay 2008**, **Allison 2001**, **May 2009 storm**, and **July 2013 storms**): more than 95% had at least 1 inch flooding, and more than 86% had at least 6 inches of flooding.

PLUV2D historical case preliminary results (2/2)

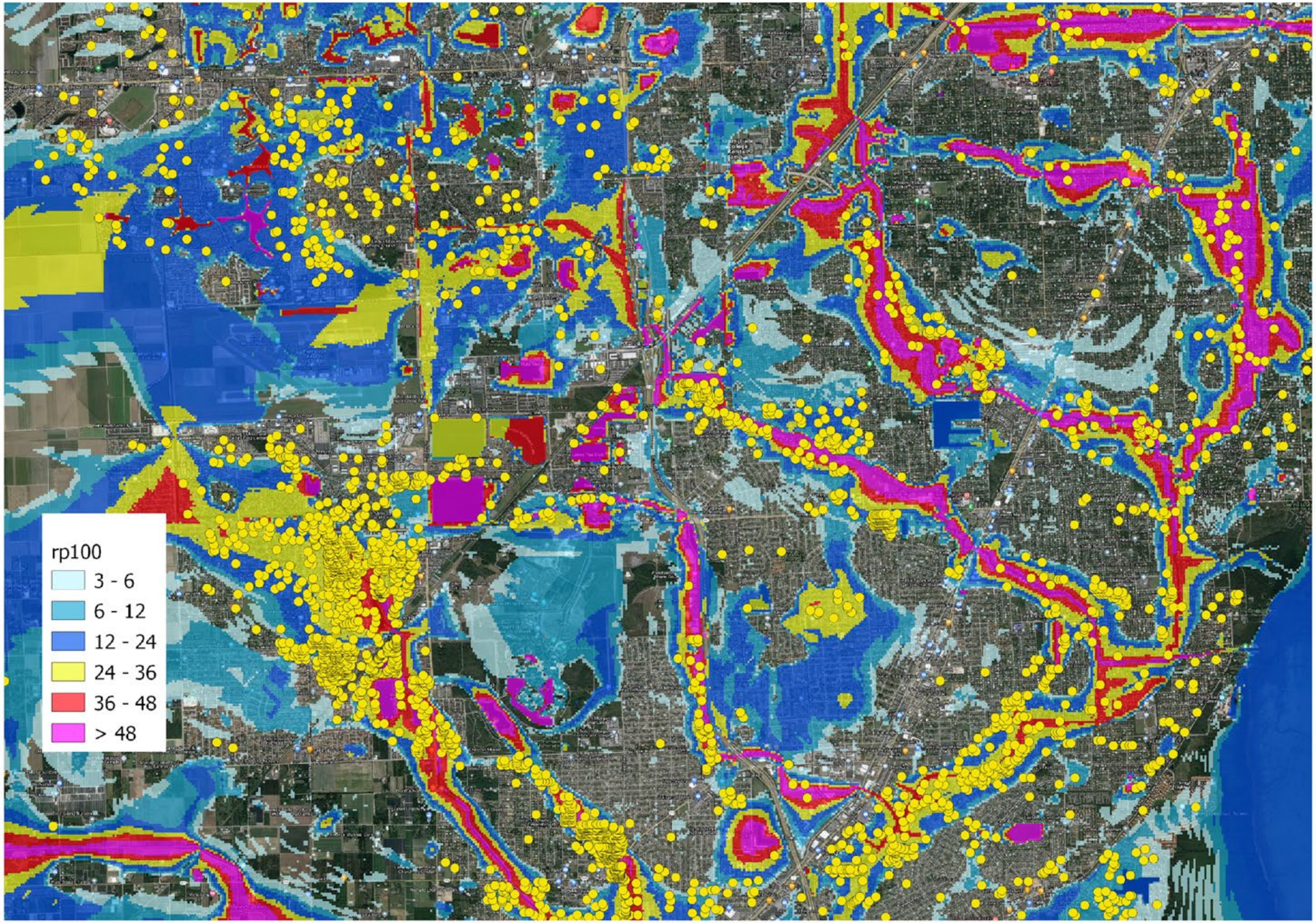
For **inland** claims only (Here **inland** means greater than 1 km or 0.62 mi from coast)

events	HURDAT	total/all	match1	%	match6	%
andrew92	AL041992	**264**/2604	**249**	**94.3**	**57**	**21.6**
ivan04	AL092004	**111**/8534	**79**	**71.2**	**66**	**59.5**
jeanne04	AL112004	**835**/2977	**628**	**75.2**	**320**	**38.3**
wilma05	AL252005	**1036**/7953	**622**	**60.0**	**196**	**18.9**
fay08	AL062008	**1935**/1978	**1868**	**96.5**	**1564**	**80.8**
allison01	AL012001	**92**/93	**90**	**97.8**	**82**	**89.1**
frances04	AL062004	**1268**/3952	**1143**	**90.1**	**750**	**59.1**
katrina05	AL122005	**4222**/5027	**3180**	**75.3**	**591**	**14.0**
may09		**478**/479	**464**	**97.1**	**428**	**89.5**
july13		**345**/349	**336**	**97.4**	**298**	**86.4**

where match1: > 0 inch (dmax from PLUV2D)
match6: >=6 inch (dmax from PLUV2D)
numbers are nfip claim counts

*The match uses maximum of dmax surrounding ±1 PLUV2D model grids (total 9 grids)

Comparison with PLUV2D
100 yr flood depths and NFIP claims data for Miami, FL area



Summary

- Return period flood maps for pluvial flooding appear very reasonable and are consistent with FSF LISFLOOD results. The 100 year flood maps are also very consistent with FEMA flood zone maps.
- Simulation of historical rain events and return period rain show flood depths consistent with NFIP claims data as well as NOAA reports (not shown here, but in the submission document).

Vulnerability Overview

JOURNAL PUBLICATIONS

- Paleo-Torres, A., Zhao, M., Gurley, K., Pinelli, J.P., and Baradaranshoraka, M., (2021). “Modeling the influence of flood mitigation measures on the vulnerability of coastal residential construction”, Natural Hazards Review, 22 (4). 10.1061/(ASCE)NH.1527-6996.0000507.
- Paleo-Torres, A., Gurley, K., Pinelli, J.P., Baradaranshoraka, M, Zhao, M., Suppasri, A., Peng, X. (2020) “Vulnerability of Florida residential structures to hurricane induced coastal flood”, Engineering Structures, https://doi.org/10.1016/j.engstruct.2020.111004
- Pinelli, J.P., Da Cruz, J., Gurley, K., Paleo-Torres, A., Baradaranshoraka, M., Cocke, S., Shin, D.W. (2020) “Uncertainty reduction through data management in the development, validation, calibration, and operation of a hurricane vulnerability model,” International Journal of Disaster Risk Science, 11(6). https://doi.org/10.1007/s13753-020-00316-4
- Baradaranshoraka, M., Pinelli, J.P., Gurley, K., Zhao, M., Peng, X. (2019). "Characterization of Coastal Flood Damage States for Residential Buildings," ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, 5(1): 04019001, DOI: 10.1061/AJRUA6.0001006
- Baradaranshoraka, M., Pinelli, J.P., Gurley, K., Peng, X., Zhao, M. (2017) “Hurricane wind versus storm surge damage in the context of a risk prediction model,” ASCE Journal of Structural Engineering,143 (7). DOI: 10.1061/(ASCE)ST.1943-541X.0001824

Florida Office of Insurance Regulation | FIU | UF | Florida Tech | Florida State University 1851 | Miami | NOAA | University of Notre Dame | Rutgers | UMKC | AMI Risk Consulta

OBJECTIVES

- Develop a robust and flexible vulnerability model that considers different building characteristics for residential and manufactured homes
- Model the influence of flood mitigation measures on vulnerability
- Use National Flood Insurance Program (NFIP) claims to validate the vulnerability models

VULNERABILITY OF UNMITIGATED RESIDENTIAL CONSTRUCTION

BACKGROUND

- In general, fragility and vulnerability functions are either:
  - Empirical models derived from post-disaster damage assessments and/or insurance claims data
  - Engineering-based models derived from structural behavior principles
  - Models based on expert opinion
  - Some combination of the three
- Peng (2015) established a basis to translate tsunami fragility functions into coastal flood fragility functions using a force equivalency.

TSUNAMI AND COASTAL FLOOD DAMAGE

- Basis: Adapt a large body of tsunami building fragility functions (physical damage) to coastal surge vulnerability functions (damage ratio)

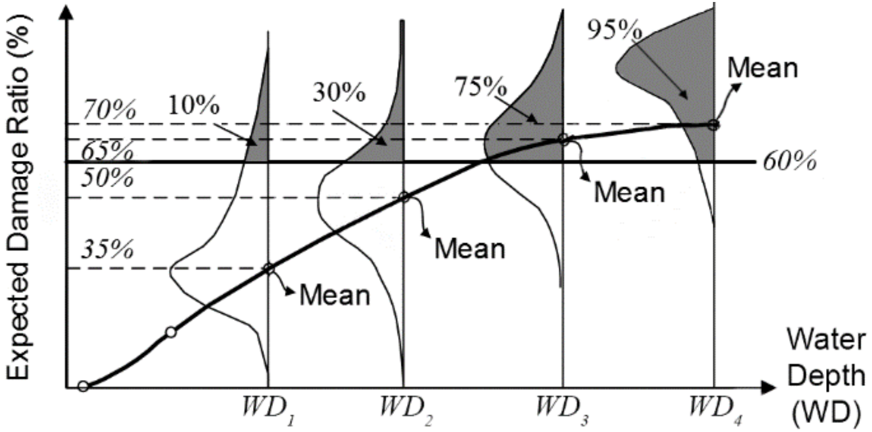
Example of residential damage after the 2011 Great East Japan tsunami

Example of residential damage after hurricane Michael, 2018

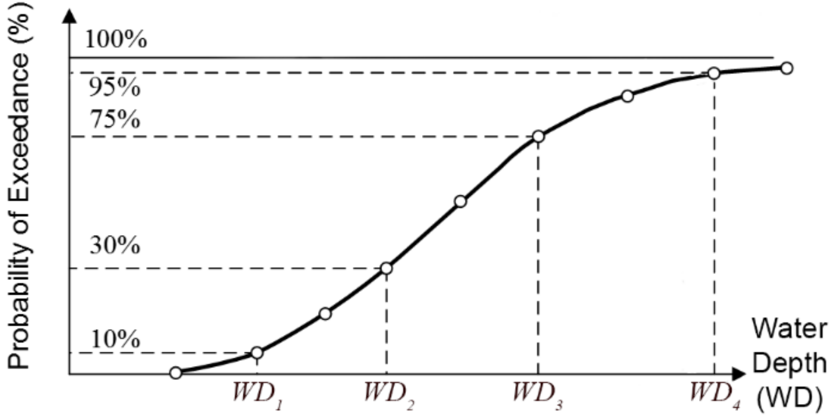
TSUNAMI DATASET

- Suppasri, A., Mas, E., Charvet, I., Gunasekera, R., Imai, K., Fukutani, Y., Abe, Y., and Imamura, F. (2013). "Building damage characteristics based on surveyed data and fragility curves of the 2011 Great East Japan tsunami." Natural Hazards, 66(2), 319-341
- Dataset of 250,000+ damaged buildings
- Structures were stratified by their structural material and number of stories
- Tsunami fragility curves classified according to six quantitative damage states

VULNERABILITY VS FRAGILITY

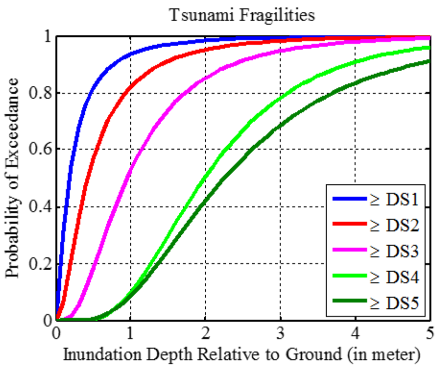


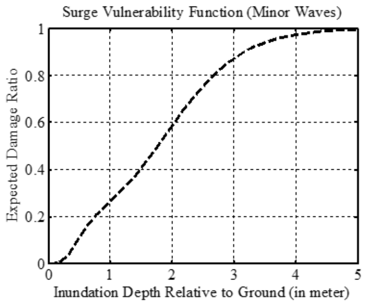
Example of vulnerability function



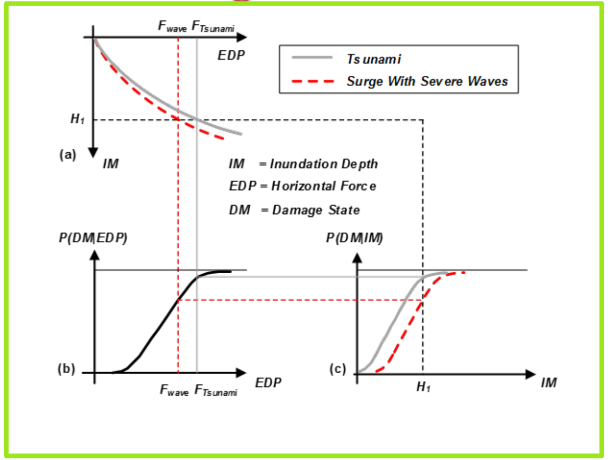
Example of fragility function

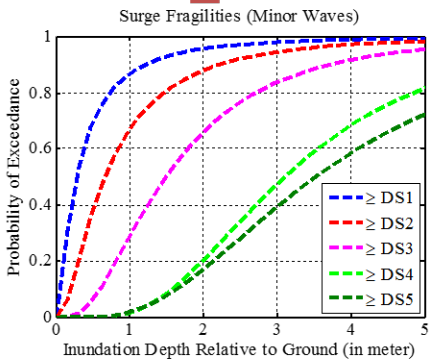
BUILDING DAMAGE COMPONENT





CONVERT FRAGILITY CURVES INTO VULNERABILITY CURVE



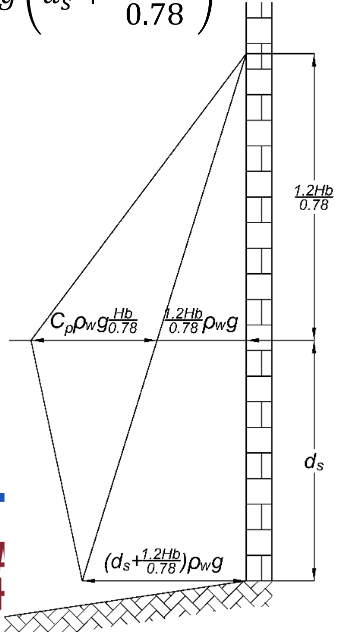


WATER FORCES: FORCE EQUIVALENCY CALCULATIONS

- CF derived from ASCE, FEMA:

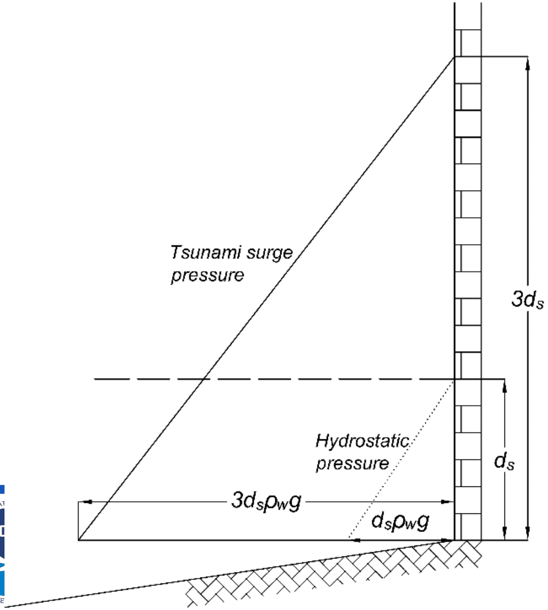
$$F_{wave}/l = \frac{1}{2} C_p \rho_w g \frac{H_w}{0.78}\left(d_s + \frac{1.2H_w}{0.78}\right) + \frac{1}{2}\rho_w g \left(d_s + \frac{1.2H_w}{0.78}\right)^2$$

Coastal Flood Conditions		Wave Height Range
CF1	Minor Waves	$0 < H_w/d_s \leq 0.3$
CF2	Moderate Waves	$0.3 < H_w/d_s \leq 0.6$
CF3	Severe Waves	$0.6 < H_w/d_s \leq 0.78$



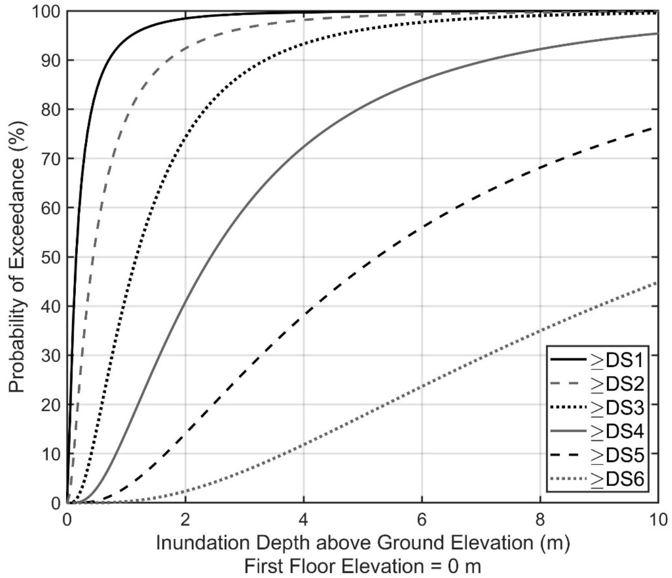
- Tsunami from CCH:

$$F_{ts}/l = 4.5\rho_w g {d_s}^2$$

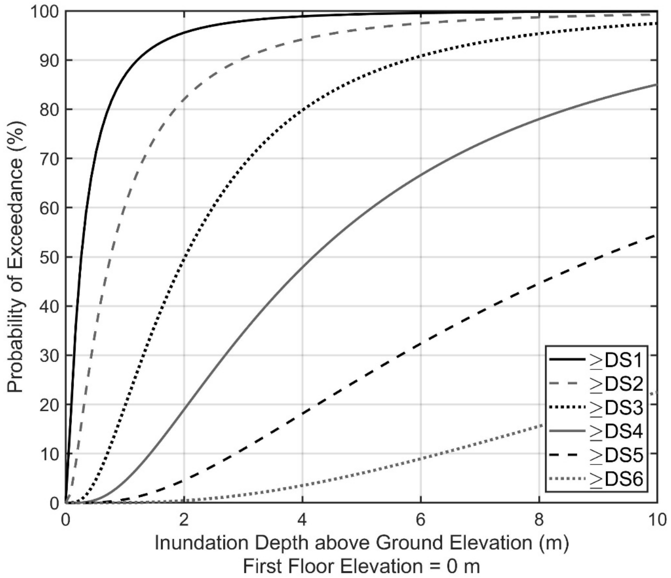


COASTAL FLOOD FRAGILITY

- Example for a 1-story on-grade masonry structure

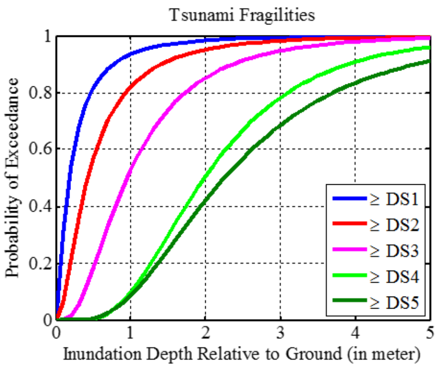


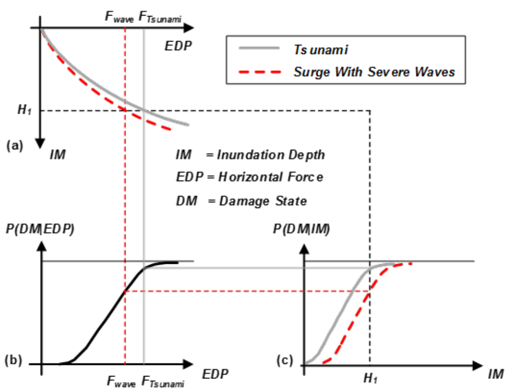
a) Tsunami fragility

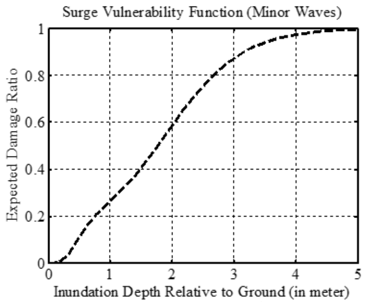


b) CF minor waves fragility

BUILDING DAMAGE COMPONENT

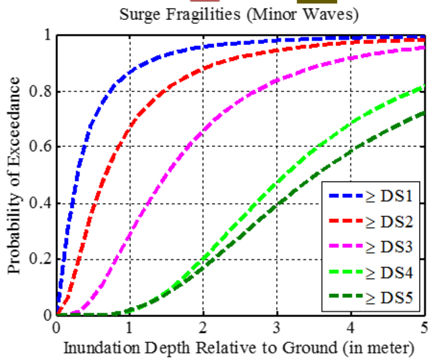






Damage Ratio
Repair $/value

CONVERT FRAGILITY CURVES I O VULNERABILITY CURVE



Physical
Damage

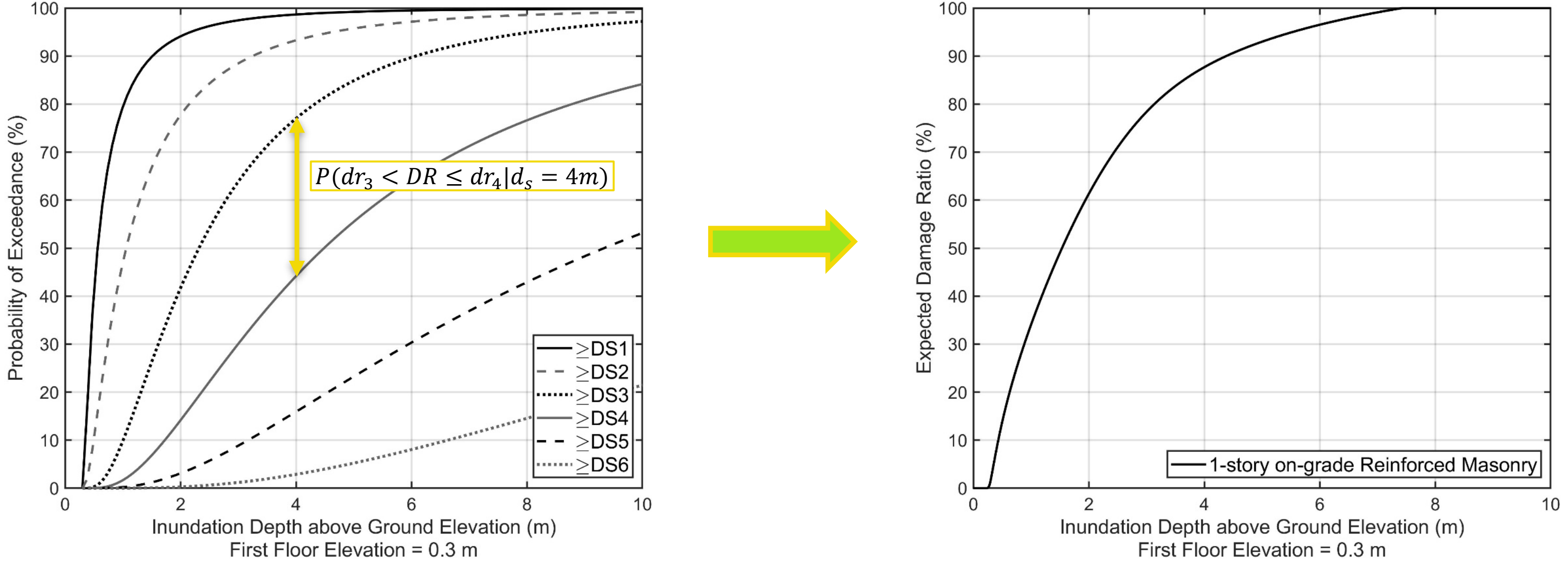
Component	Surge Damage States					
	DS 1	DS 2	DS 3	DS 4	DS 5	DS 6
Roof	No visible damage	Few roof covering missing or damaged (<15% of roof area) Roof covering damage only	Significant amount of roof covering missing (15-50%) Few roof sheathing damage (<15%)	The majority of roof covering missing Many roof sheathing damage (15-40%) Few roof trusses damage (<15%)	Extensive roof trusses damaged Severe damage to interior content due to water intrusion	Entire roof missing
Exterior Walls	No visible damage	Minor wall siding removal (<10% of 1 wall) Small scratches Cracks in breakaway wall	Wall siding has been removed from >10% of 1 wall or from multiple walls Few wall sheathing damage (<10%) Cracks in many walls Breakaways walls damaged or removed	Extensive damage to wall siding (50% of walls) Partial loss of wall sheathing caused by water or debris Large and extensive cracks in most wall Few wall frame damage	Large holes due to floodborne debris Extensive loss of wall sheathing Reparable wall frame damage	Overall wall system has collapsed
Interiors	No visible damage	Infiltration damage to floor covering & items below the first floor Light damage to plumbing, mechanical and electric systems Minor water damage to utility and cabinets	Water marks 0 to 2 ft above the first floor Significant interior damage, including plumbing and electrical systems Dampness on >20% of dry wall (Mold)	Water marks 2 to 4 ft above the first floor Water damage to interiors at high level Interior stairway damaged or removed Dampness on >50% of dry wall (Mold)	Water marks 4 to 6 ft above the first floor Interior damage >60%	Interior damage > 80%
Foundation	No visible damage	Slightly scour Evidence of weathering on piles	Slab and piles experience extensive scour without apparent building damage	Slab and piles sustain significant scour with repairable structural damage Moderate slab crack	Structure shifted off the foundation or overturning foundation Piles: racking Slab: undermining leads to significant deformation	Buildings collapse
Openings	No visible damage	One window or door is broken (glass only) Screens may be damaged or missing	>1 window and ≤ the larger of 20% and 3 Damage to frames of doors and windows	> the larger of 20% & 3 and ≤ 50%	> 50%	Damage >80%

QUANTIFICATION OF DAMAGE STATES

- Damage ratios per Damage State are quantified
- Cost analyses performed for different structures per assembly
- Probability of damage assigned to each component
- Assemblies taken into account:
  - Foundation
  - Walls
  - Interiors
  - Openings
  - Roof

COASTAL FLOOD VULNERABILITY

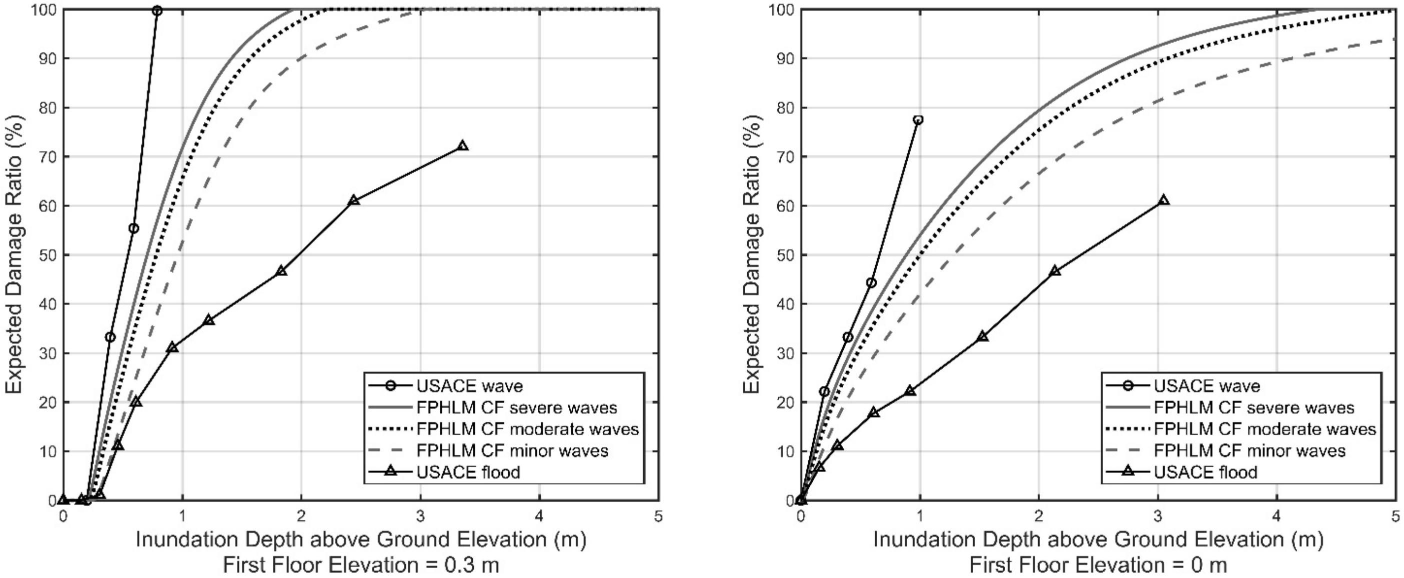
- Fragility to vulnerability example (SFG 1-st reinforced masonry structure):



$$E[DR|d_s, CF, BC] = \sum_{i=0}^{6} \{[dr_i + (dr_{i+1} - dr_i) \times f(d_s|BC)] \times [P(DR \geq dr_i|D_s, CF, BC) - P(DR \geq dr_{i+1}|D_s, CF, BC)]\}$$

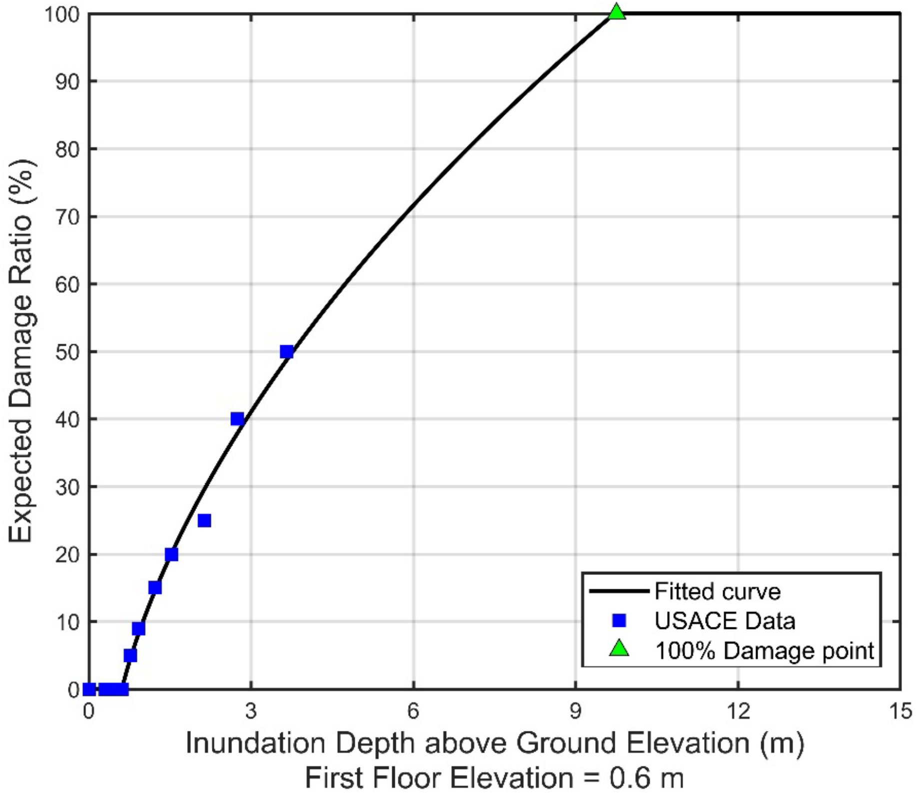
COMPARISON WITH USACE (2015)

- Results for a) 1-story slab on-grade weak timber, 0.3 m FFE; and b) 1-story slab on-grade strong masonry, 0 m FFE



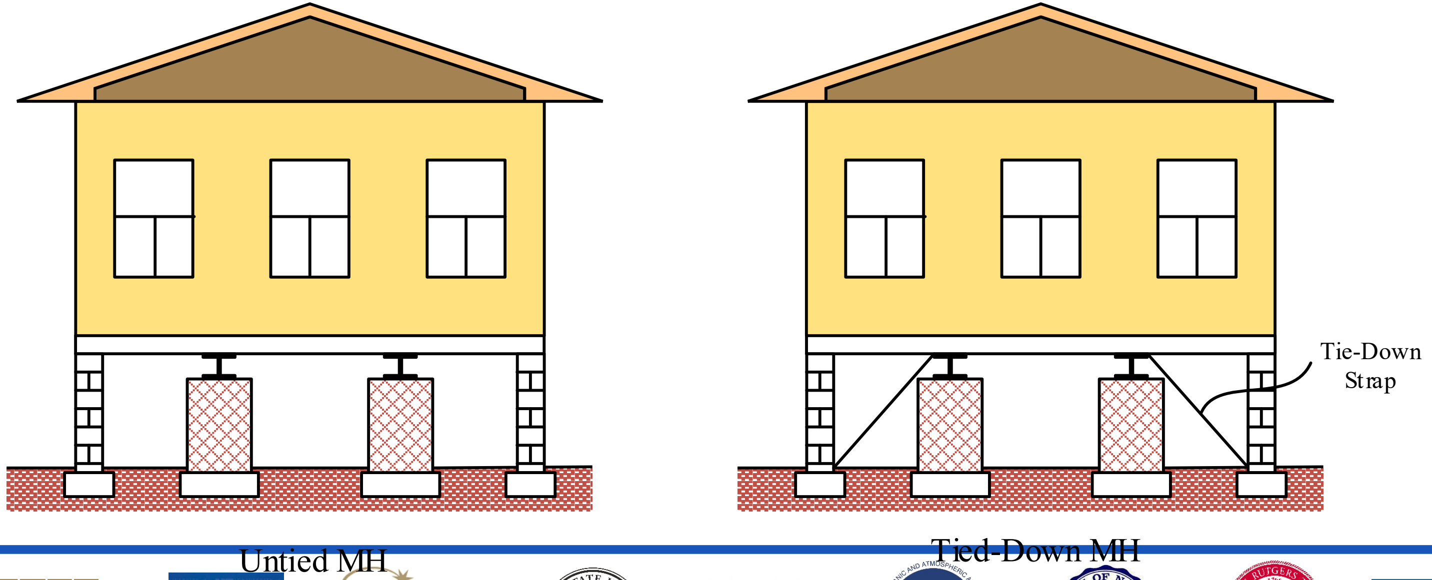
INLAND FLOOD BUILDING VULNERABILITY

- Inland Flood vulnerability functions based on USACE (2015)
- Example: 2-story masonry house (2-ft FFE)

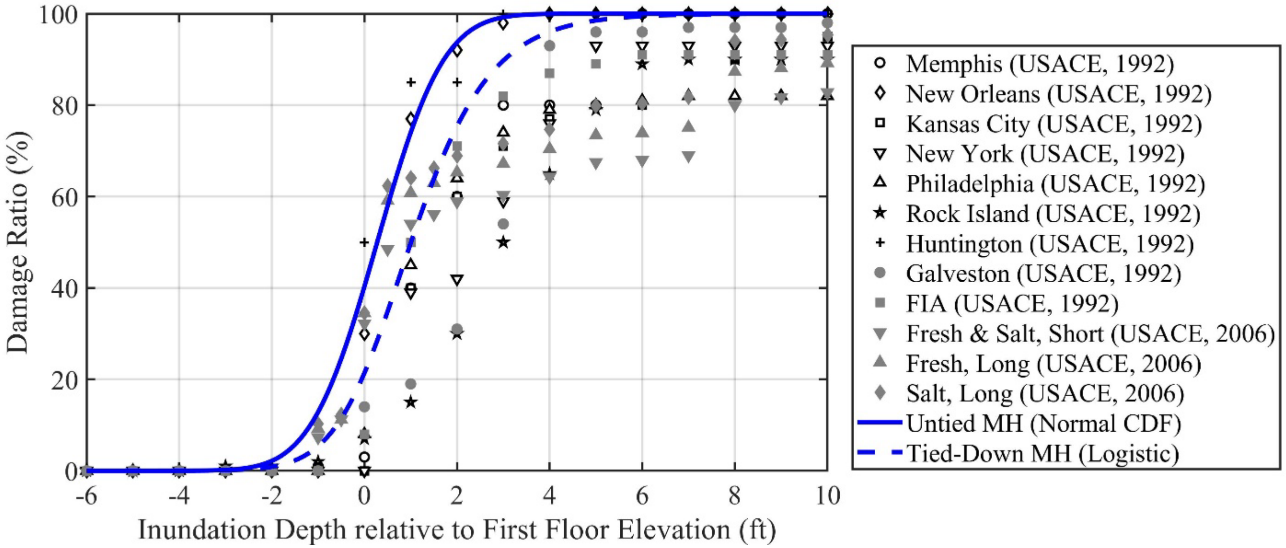


VULNERABILITY OF MANUFACTURED HOUSES

TYPES OF MANUFACTURED HOUSES



INLAND FLOOD VULNERABILITY



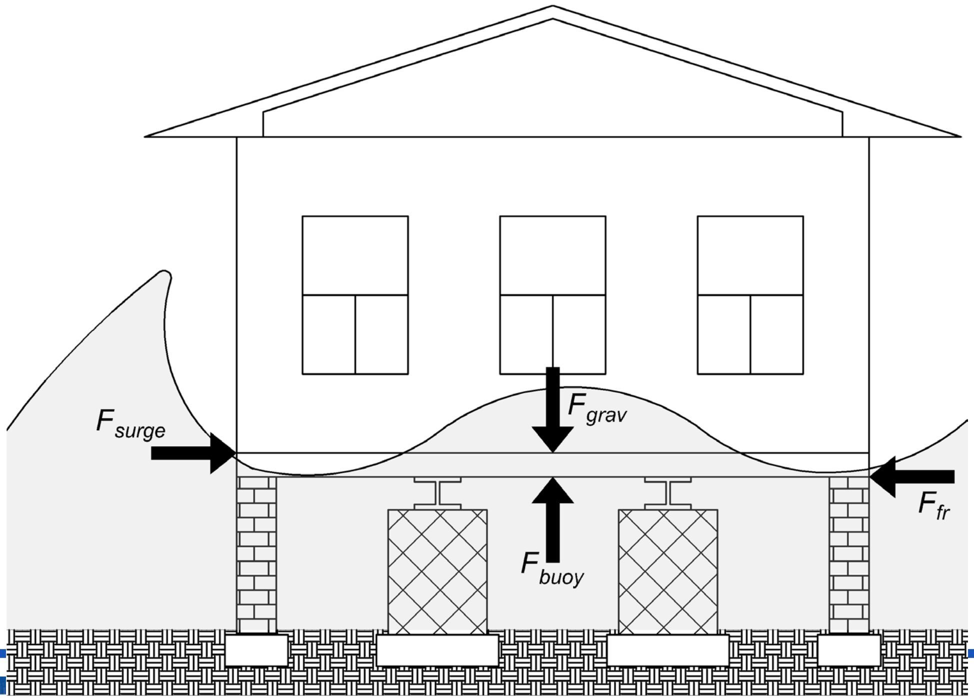
Untied: Normal CDF

$$f(d_{sFFE}) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\left(\frac{d_{sFFE}-\mu}{\sigma}\right)} e^{-\frac{v^2}{2}} dv$$

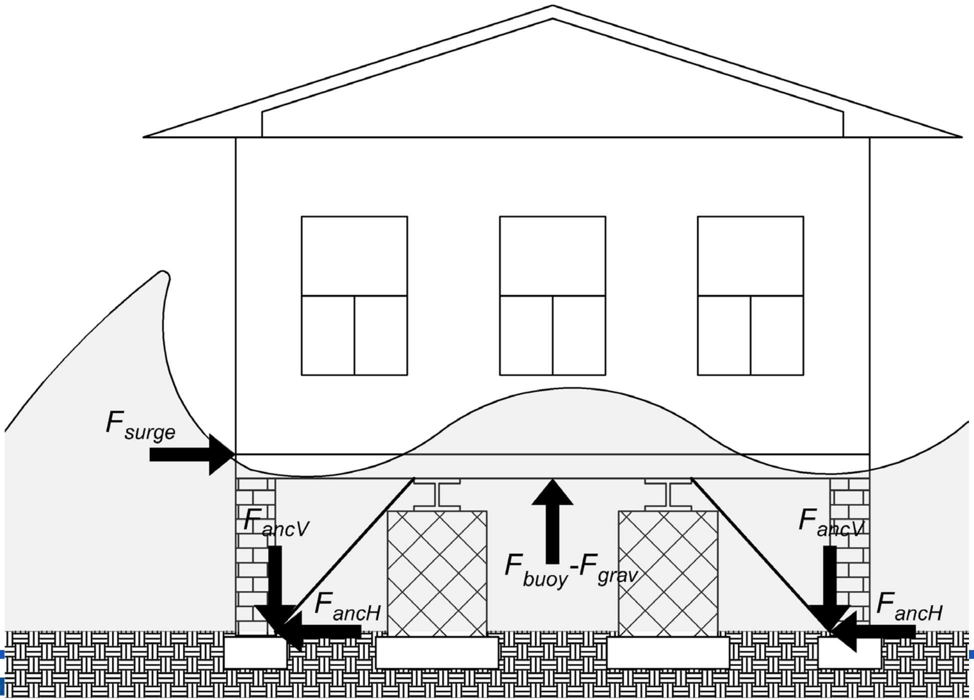
Tied-down: Generalized Logistic

$$f(d_{sFFE}) = \left(1 + e^{-d_{sFFE}}\right)^{-\alpha}$$

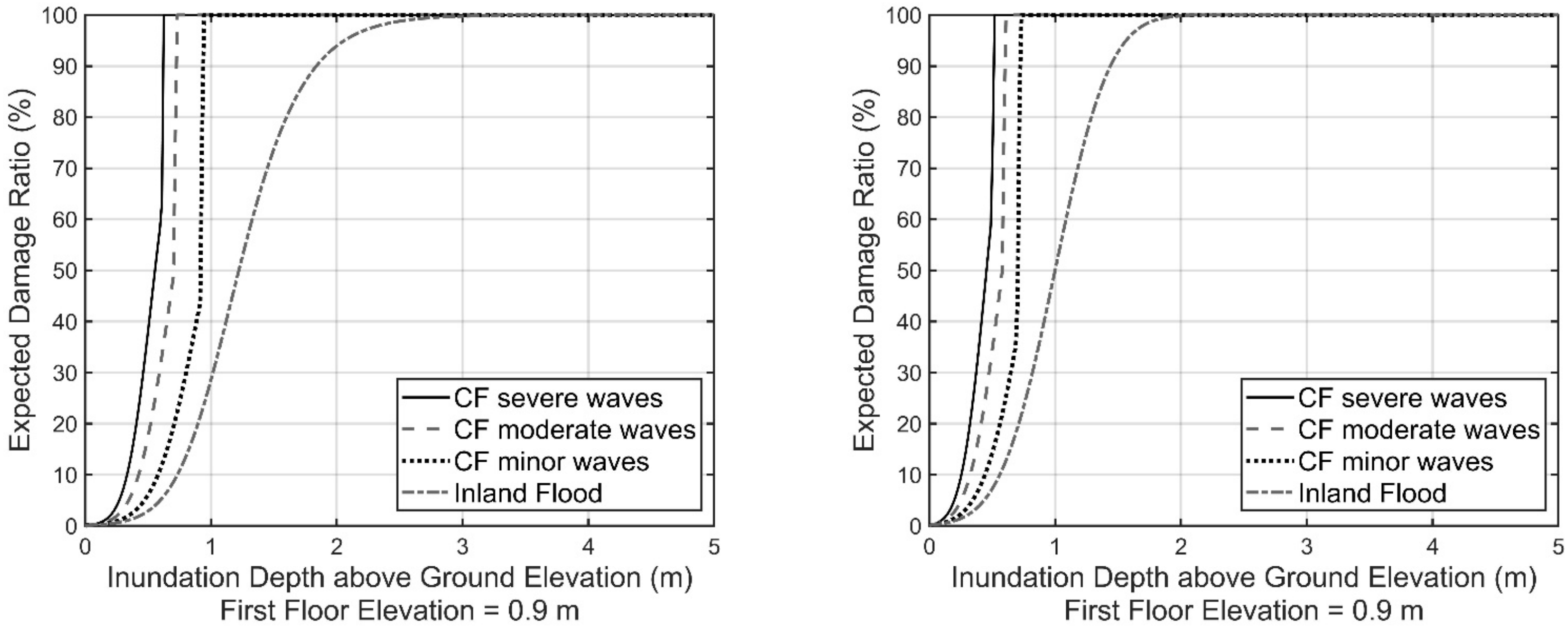
FORCES ON AN UNTIED MH



FORCES ON A TIED-DOWN MH



RESULTING VULNERABILITY FUNCTIONS



a) tied-down

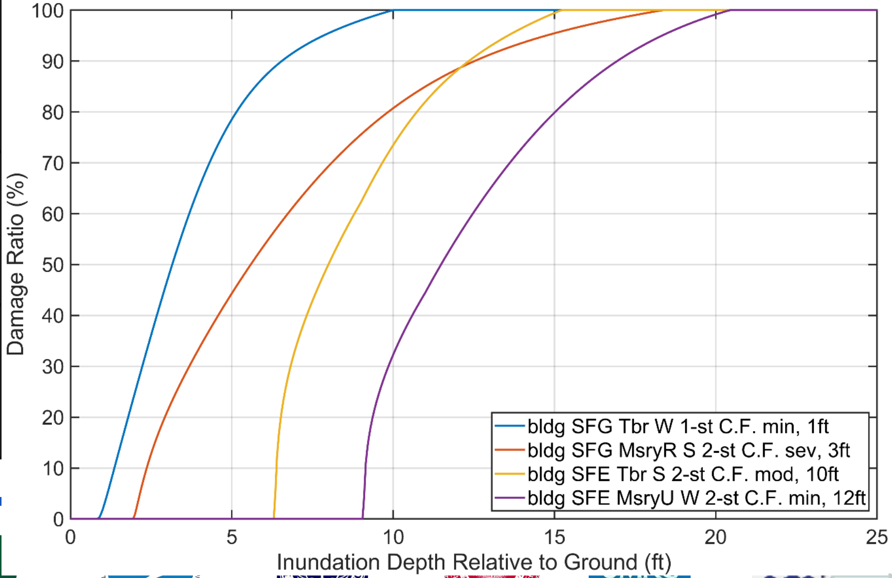
b) untied

INVENTORY OF FLOOD VULNERABILITY MODELS

- Vulnerability functions derived:

Residential on-grade	2 Models: Timber Masonry	2 Strengths: Weak Strong	3 Stories: 1 to 3-story	4 FFE: 0 ft to 3 ft	4 Flood conditions: I.F. and 3 C.F.	192
Residential elevated	2 Models: Timber Masonry	2 Strengths: Weak Strong	2 Stories: 1 to 2-story	9 FFE: 4 ft to 12 ft	4 Flood conditions: I.F. and 3 C.F.	288
Manufactured housing		2 Strengths: No Tied down Tied down		8 FFE: 1 ft to 8 ft	4 Flood conditions: I.F. and 3 C.F.	64
					Total	544

- Examples of Vulnerability functions:

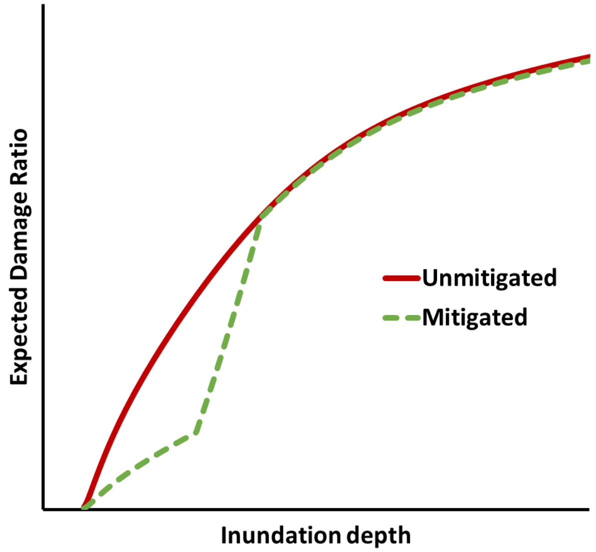


INFLUENCE OF FLOOD MITIGATION MEASURES

MITIGATION MODELS

Paleo-Torres, A., Zhao, M., Gurley, K., Pinelli, J.P., and Baradaranshoraka, M., (2021). "Modeling the influence of flood mitigation measures on the vulnerability of coastal residential construction", Natural Hazards Review, 22 (4). 10.1061/(ASCE)NH.1527-6996.0000507.

- General behavior of mitigated vulnerability functions:

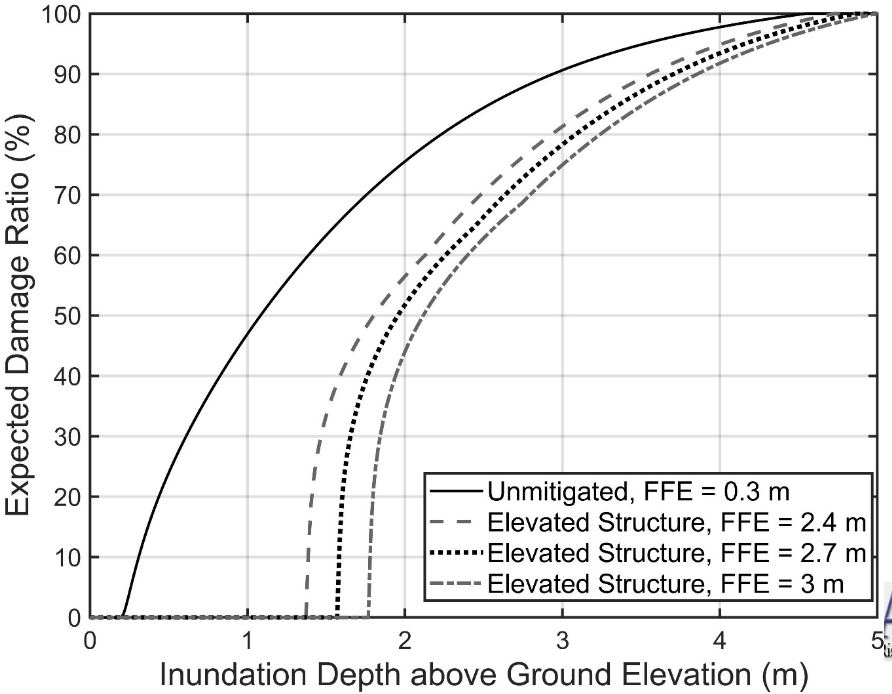


- Elevated structure
- Elevating utilities
- Wet floodproofing
- Dry floodproofing
- Combined mitigation

ELEVATION OF THE STRUCTURE

- Example of vulnerability functions for elevated structures:

Unmitigated (FFE = 0.3 m) vulnerability function vs vulnerability with FFE = 2.4, 2.7 and 3 m, for a reinforced masonry one-story single-family home subject to coastal flood with severe waves

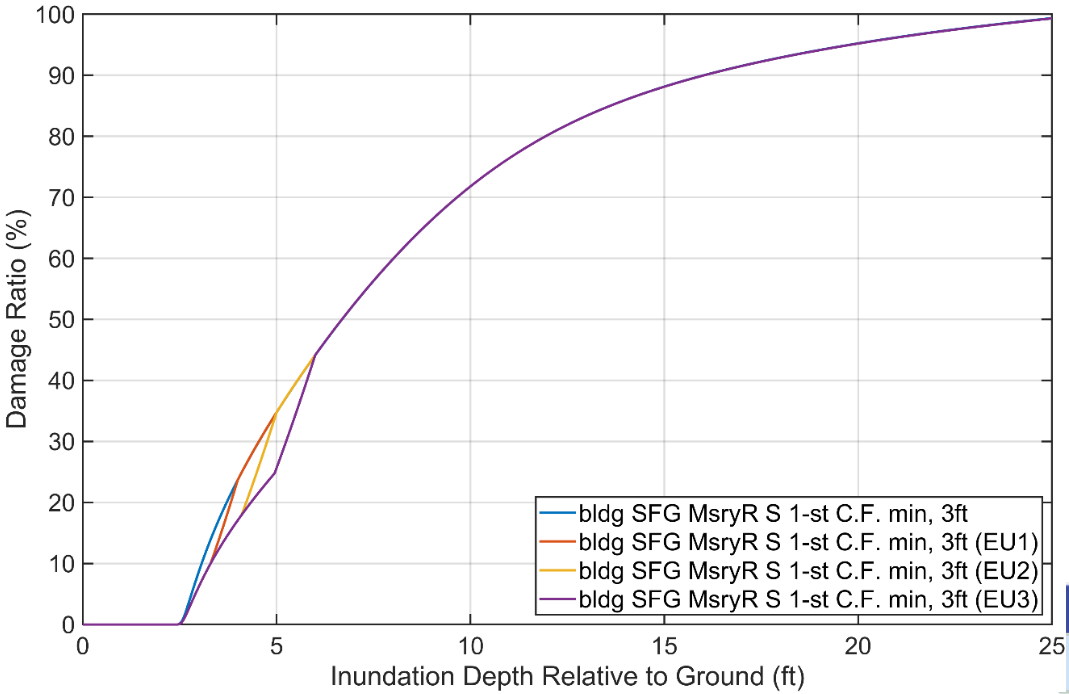


ELEVATING UTILITIES

- Example of vulnerability curve elevating utilities up to 1, 2 and 3 ft:

Unmitigated vulnerability function vs mitigated vulnerability functions with utilities elevated 0.3, 0.6 and 0.9 m., for a reinforced masonry one-story single family on-grade home subject to coastal flood with severe waves

Cost of repairing utility components removed until water reaches them



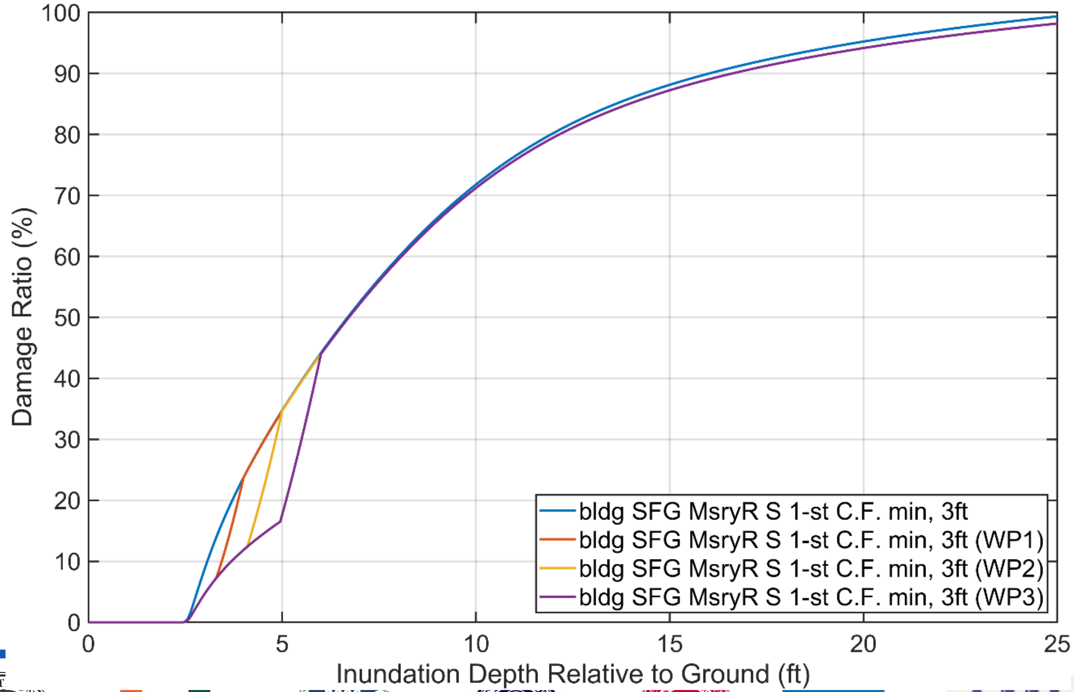
FLORIDA OFFICE OF INSURANCE REGULATION

FIU UF FLORIDA TECH

WET FLOODPROOFING

- Common practice for wet floodproofing primarily consists of:
  - Waterproofing interior with paint
  - Use of non-wood furring strip boards and plastic base boards
  - Tile or terrazzo flooring
  - PVC or composite frames for the openings

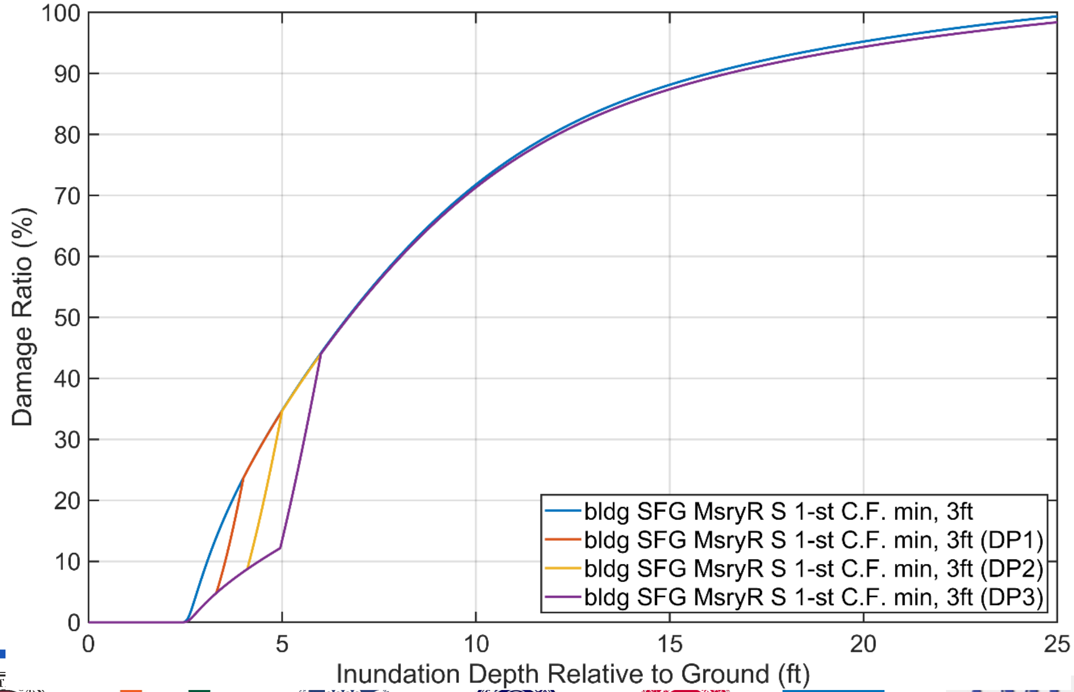
Unmitigated vulnerability function vs vulnerability functions with wet flood proofing up to 0.3, 0.6 and 0.9 m., for a reinforced masonry one-story single family on-grade home subject to coastal flood with severe waves



DRY FLOODPROOFING

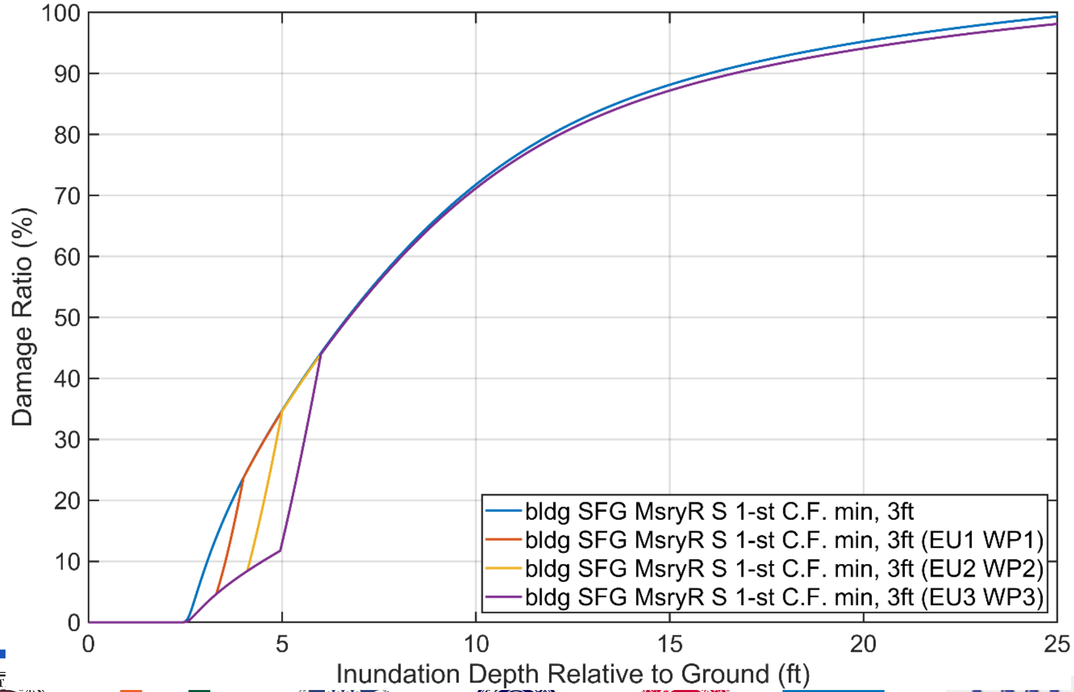
- Common practice for dry floodproofing primarily consists of:
  - Waterproofing with impervious materials
  - Acrylic latex wall coating
  - High performance sealant in openings

Unmitigated vulnerability function vs vulnerability functions with dry flood proofing up to 0.3, 0.6 and 0.9 m., for a reinforced masonry one-story single family on-grade home subject to coastal flood with severe waves



COMBINED MITIGATION

- Combinations of elevating utilities and wet floodproofing up to 1, 2 and 3 ft.



VALIDATION FROM CLAIMS DATA

Andres Paleo-Torres, Kurt Gurley, Jean-Paul Pinelli, Mohammad Baradaranshoraka, Mingwei Zhao, Anawat Suppasri and Xinlai Peng, “Vulnerability of Florida residential structures to hurricane induced coastal flood”, Engineering Structures 2020.
https://doi.org/10.1016/j.engstruct.2020.111004

VALIDATION NFIP DATASETS

- NFIP claim dataset is a robust source of validation, containing 150,000+ claims between 1975 and 2014 for 126 events
- Contains information such as the date of loss, year of construction, physical address, cause of damage, total property value, building and content coverages and financial damage to building and contents.
- NFIP does not include important information such as water height at time of event, property's structural material, # stories, FFE, total value of contents.

VALIDATION ENHANCING THE NFIP DATASETS

- Create a hybrid dataset that includes NFIP fields plus hazard information (surge height, wave height), plus information about the structure (material, # of stories).
- Tax Appraisals (TA) provide valuable information about properties
- Using information from Hurricane Ivan (2004), a "complete" set was created for some of those claims
- Hazard information comes from field observations from FEMA

BUILDING VALIDATION – NFIP

- Results for a) 1-story slab on-grade weak timber, 0.3 m FFE; and b) 1-story slab on-grade strong masonry, 0 m FFE