Bracing For Future Impacts
The Possible Extreme Scenario of Tropical Cyclones

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ADCIRC Users Meetings
Tuesday, June 23rd, 2026

NC STATE UNIVERSITY

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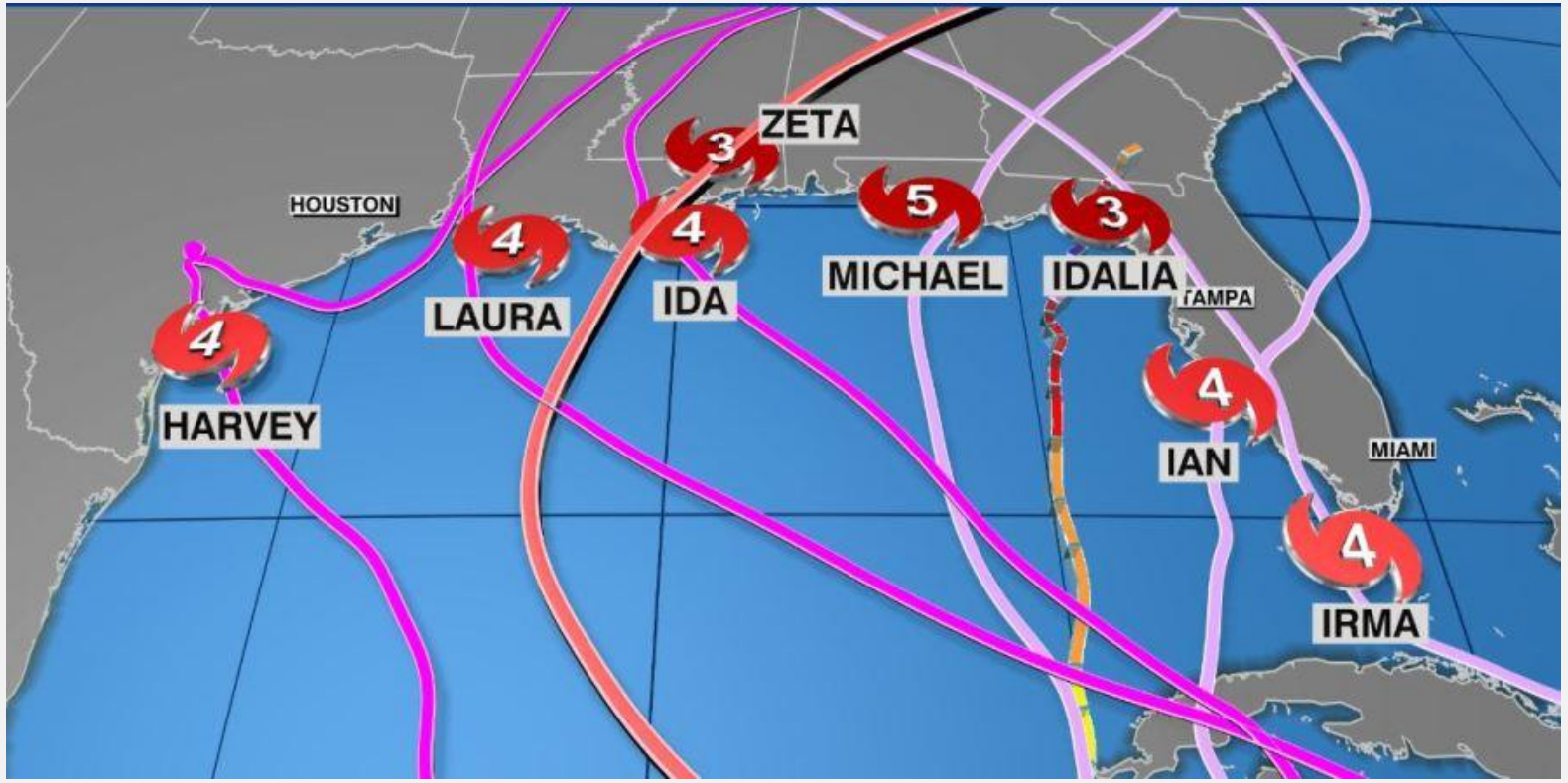
SOUTHEAST Climate Adaptation Science Center

Major Hurricanes Cause Extreme Storm Tides



8 Major Hurricanes in the Gulf of Mexico Between 2017 and 2023 (WFAL, 2023)

Hurricane (Year)	Peak Water Levels (m)
Harvey (2017)	3.81
Laura (2020)	5.24
Ida (2021)	4.27
Zeta (2020)	3.05
Michael (2018)	6.28
Idalia (2023)	3.66
Ian (2022)	4.57
Irma (2017)	3.05

Latest Category 5 Hurricane At Landfall

Extreme Storm Tides Bring Severe Impacts

Transportation Blockage

- Collapsed/ Damaged Bridges
- Flooded Roads
- Flooded Rail

Structural Failure

- Homes
- Hospitals
- Levees
- Lift Stations

Critical Infrastructure

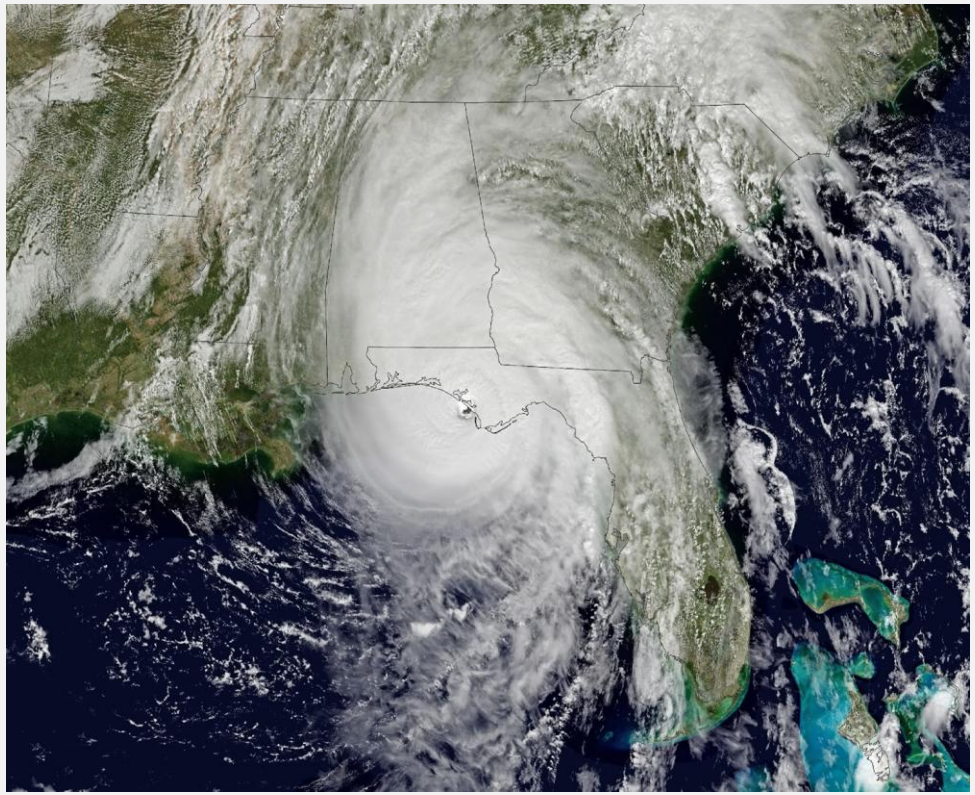
- Military Installations
- Dams
- Hospitals

Critical Utility Failure

- Downed Electricity
- Water/Wastewater Plants

Current Extreme Storm Tide Research

- Studies usually isolate one storm variable.
  - Intensity (Wind Speed & Central Pressure)[1]
  - Size (Radius of Maximum Winds)[2]
  - Forward Speed[3]
  - Angle of Approach[4]
- Research Gaps:
  - Underestimates “worst-case’ storm without multi-variable analysis.
  - Do not consider the Maximum Potential Intensity (MPI) with perturbations.

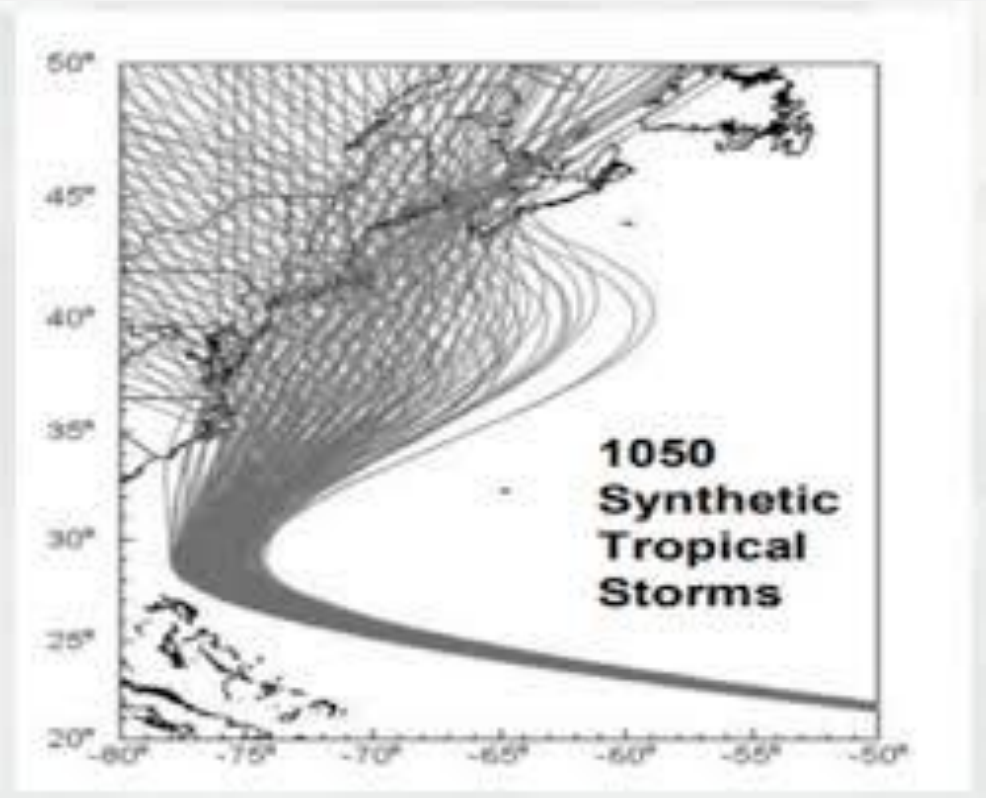


Hurricane Michael (2018) at landfall near Mexico Beach, Florida

1 – Shashank et al. (2021)
2 – Irish et al. (2008)
3 – Park & Young (2021)
4 – Pandey & Rao (2019)

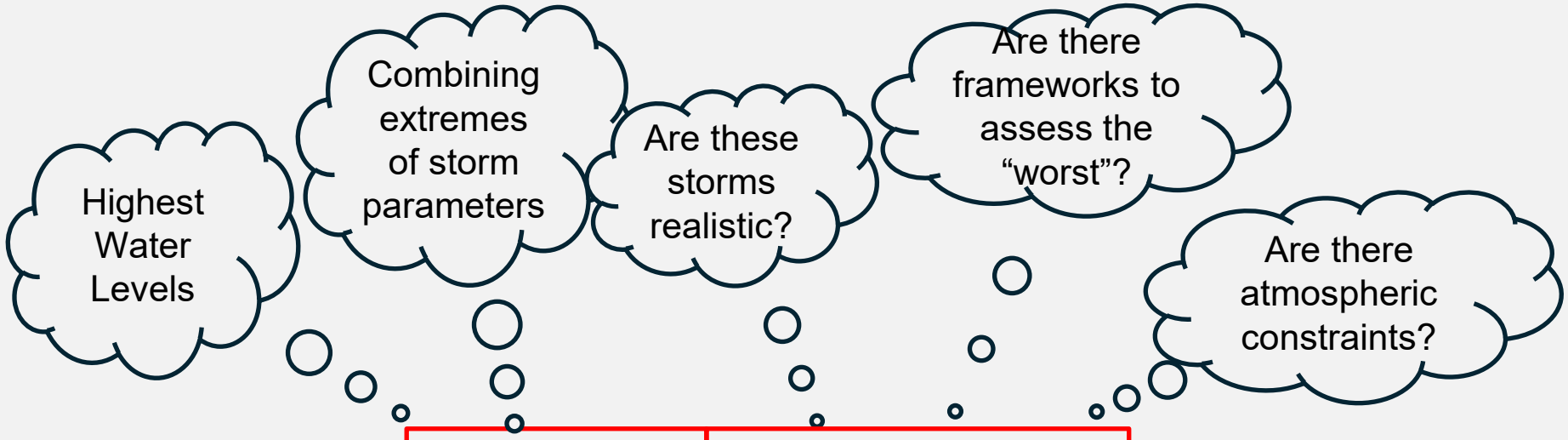
Extreme Storm Tide Studies

- North Atlantic Coast Comprehensive Study (NACCS – 2015)
- South Atlantic Coastal Study (SACS - 2021)
- Both use over 1000 storm simulations
  - 1050 synthetic and 100 historical
- Research Gaps:
  - Synthetic Storms not based on possibilities but deviations
  - Computationally Expensive (+100 Million CPU-hours)
  - Absolute Extreme Storm Tides are estimated for large regions



Synthetic Storms from NACCS used to assess risk in the North Atlantic Basin

Research Question

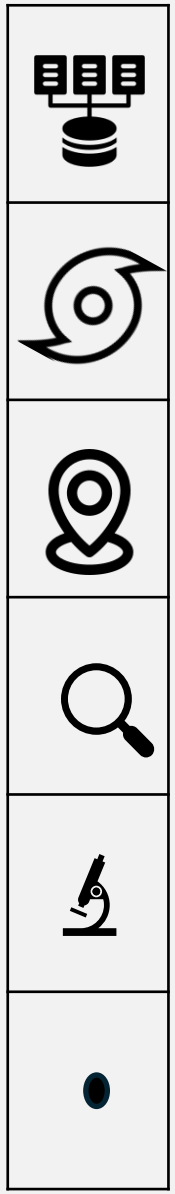


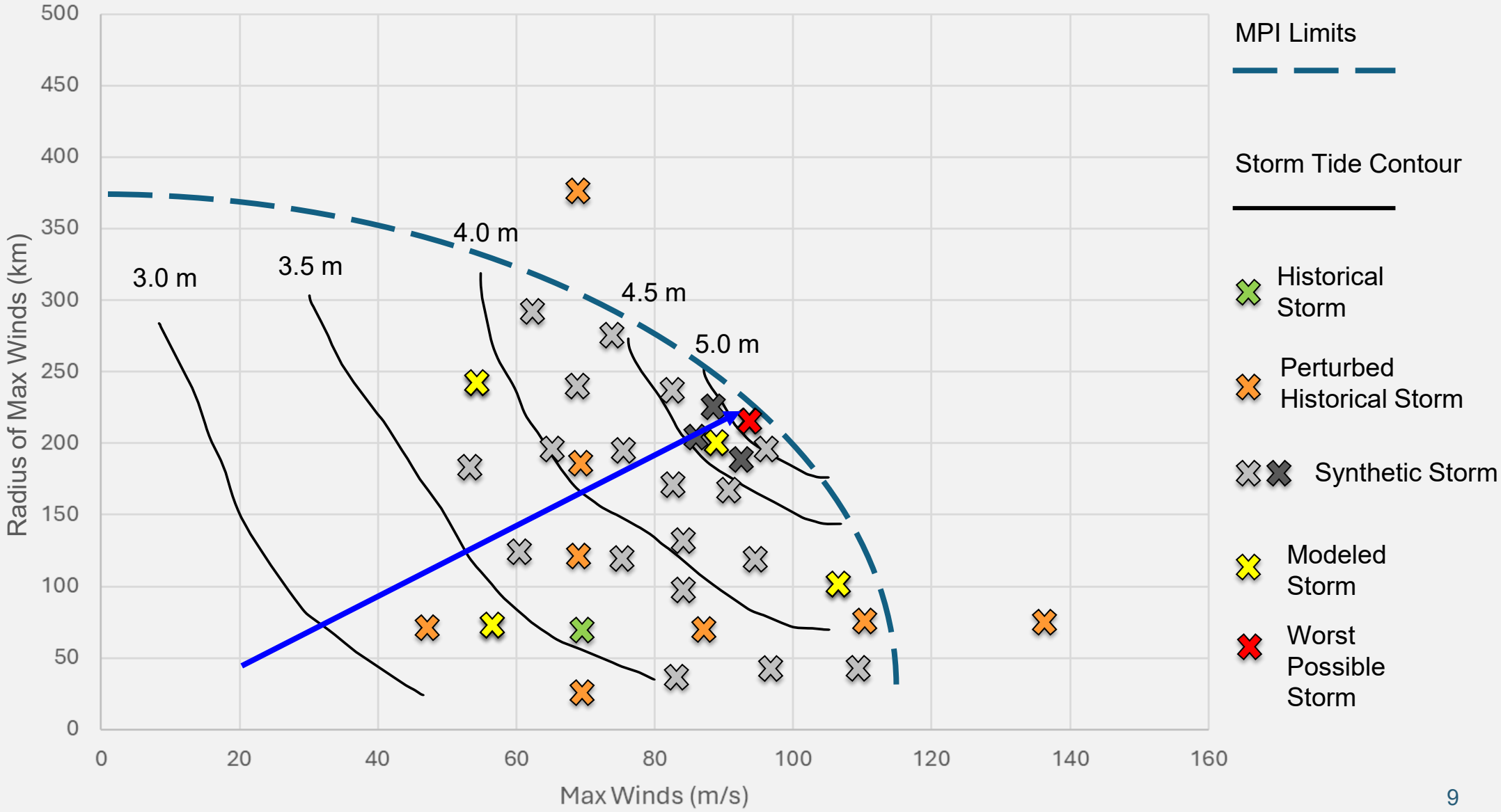
What is the worst possible storm for a given coastal location?

The Integrated Framework

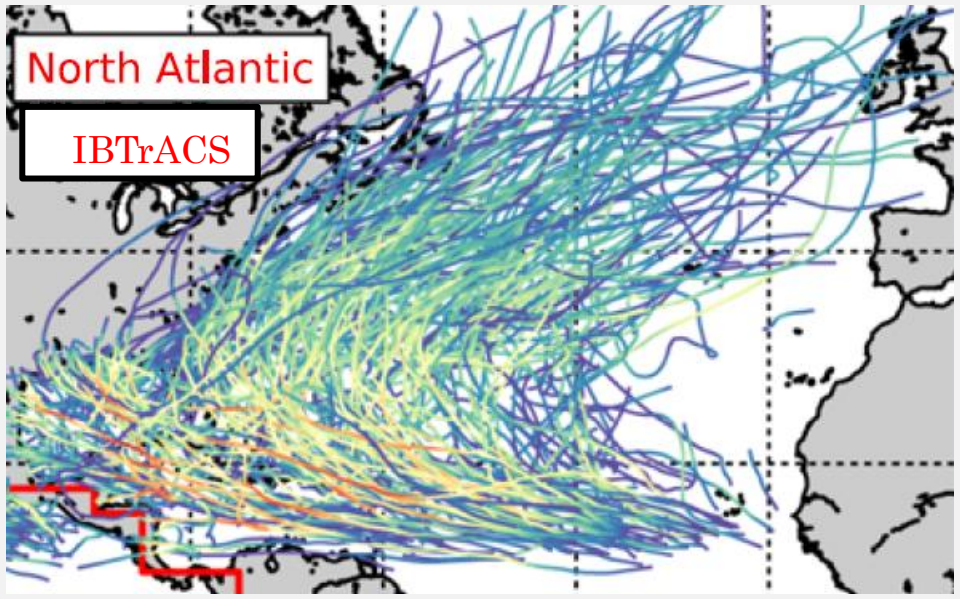
1. Historical Data Acquisition
2. Synthetic Storm Generation
3. Site Specific Filter
4. Dissimilarity Based Modeling
5. Iterative Parameter Refinement
6. The “Worst-Possible” Storm

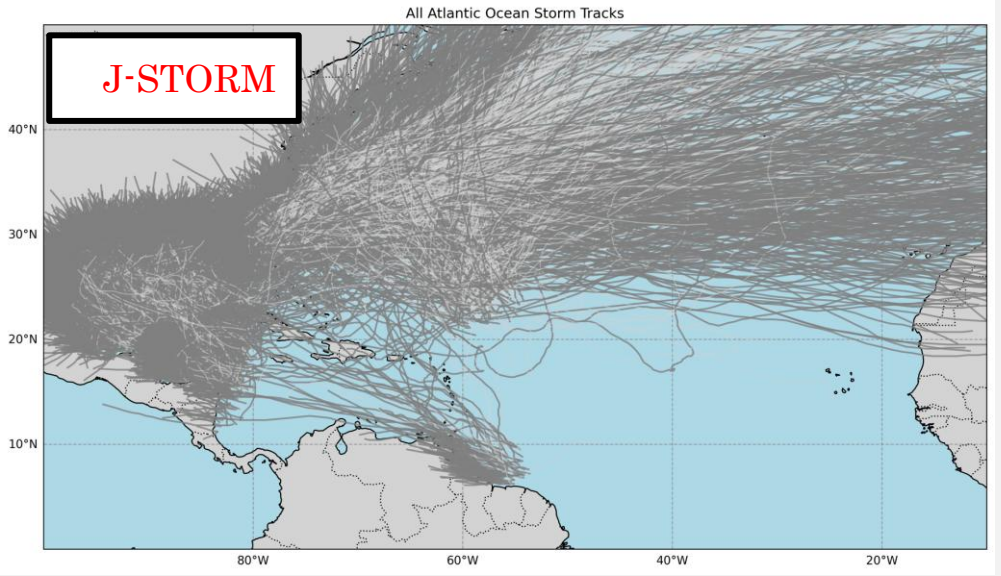
Here's the concept of the framework...





Using STORM to create synthetic storms[1]





- Uses statistical properties of historical storms from 1980 – 2025.
- 74,960 synthetic storms generated.
- Caveats:
  - *Assumes static atmospheric conditions.*
  - *Extrapolation is needed for extreme storms events*

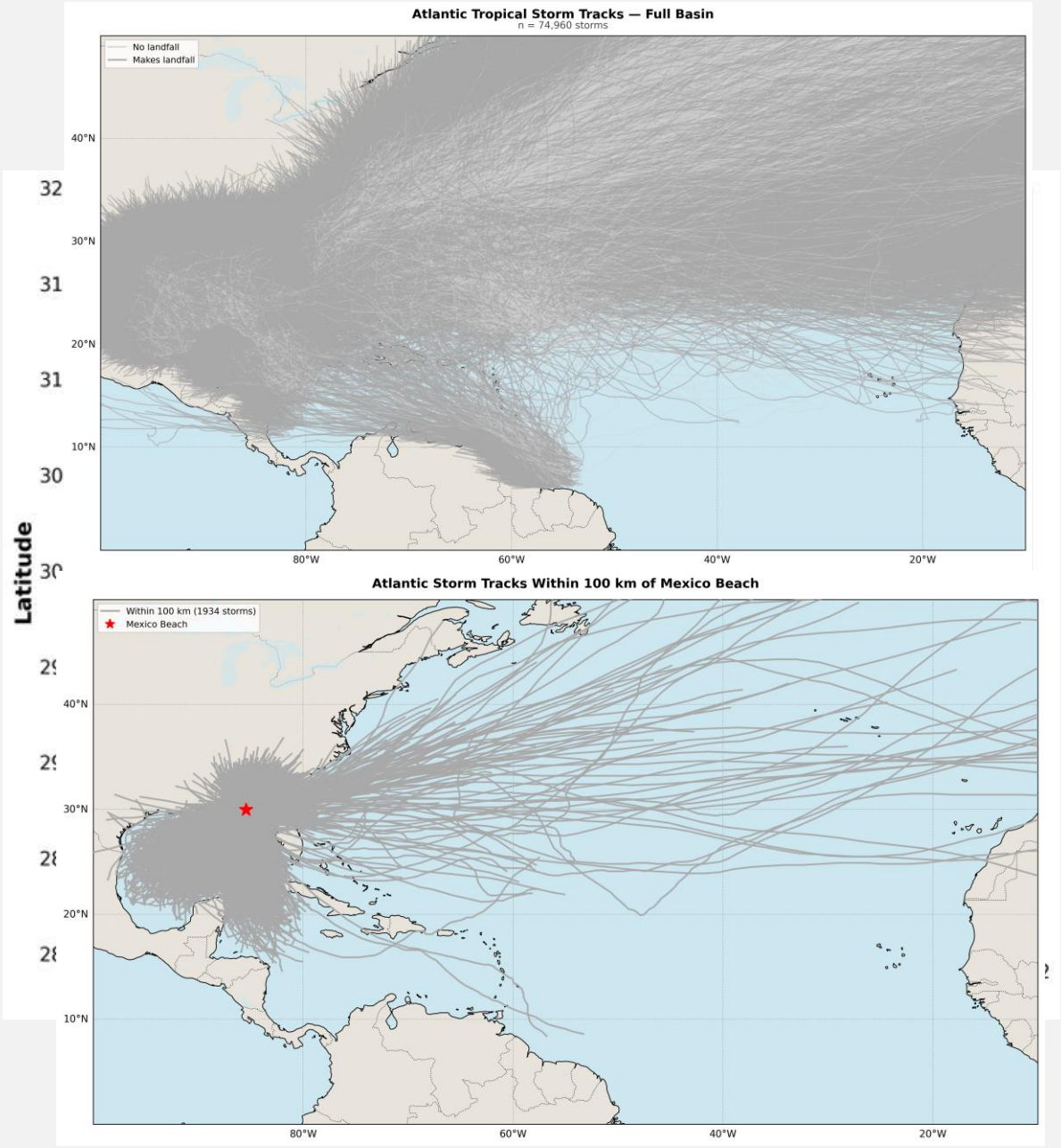
1 – Bloemendaal et al. (2020)

Generation of Synthetic Storms

Storm Statistics	IBTrACS	STORM	J-STORMs
Total Events	38	38,000	74,960
Total landfall counts (Avg/yr)	8.2	6.0	8.5
Genesis Pressure (hPa)	1003.0	997.0	1003.2
Average pressure along track (hPa)	991.5	985.6	996.1
Minimum pressure along track (hPa)	977.0	972.7	988.1
Landfall pressure (hPa)	984.0	978.1	995.0
Maximum wind speed along track (m/s)	34.8	34.7	28.69
Radius to maximum winds (km)	69.7	50.3	51.36

Storms from J-STORMs are both **REAL and POSSIBLE** storms!

Site Specific Filtering

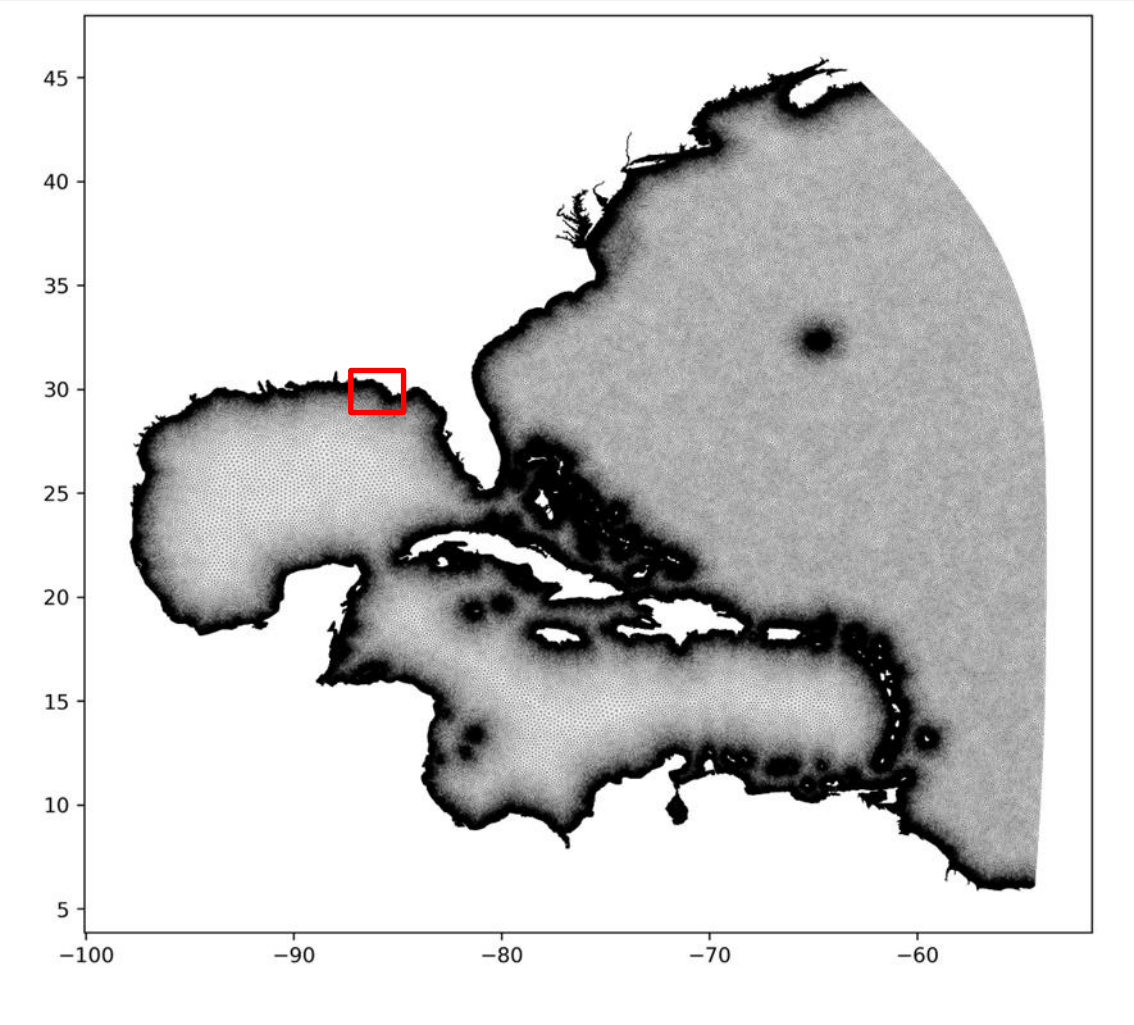


- Site Area: Mexico Beach
- Filter storms by:
  - Max Sustained winds (>29m/s)
  - Min Storm Lifetime (>24 hours)
  - Within Study Area (<100km)
- Reduced set from ~75k to 896 storms

Storm Tides are predicted at **hyperlocal sites**!!

Dissimilarity Based Modeling

- High Resolution (10m) in ADCIRC
  - NWS = 8 (Symmetric Winds)
- 6 Key Storm Parameters:
  - Max Winds, Min Pressure, Radius of Max Winds, Min Distance, Heading, Direction, & Forward Speed
- Goal: Modeling Efficiency



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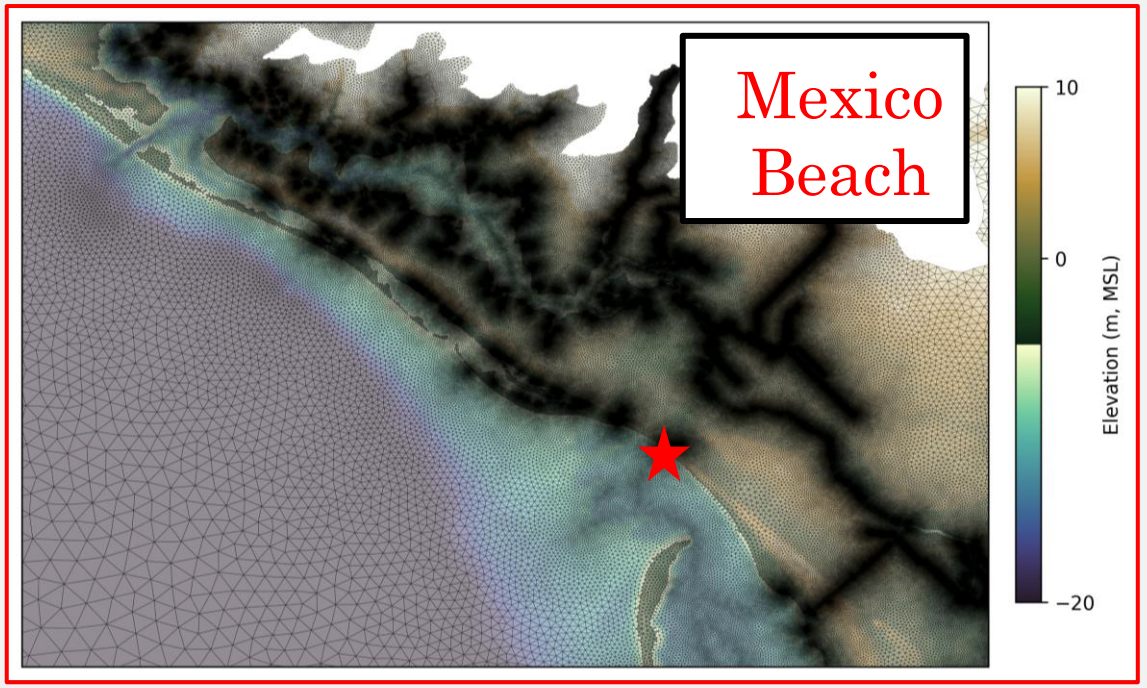
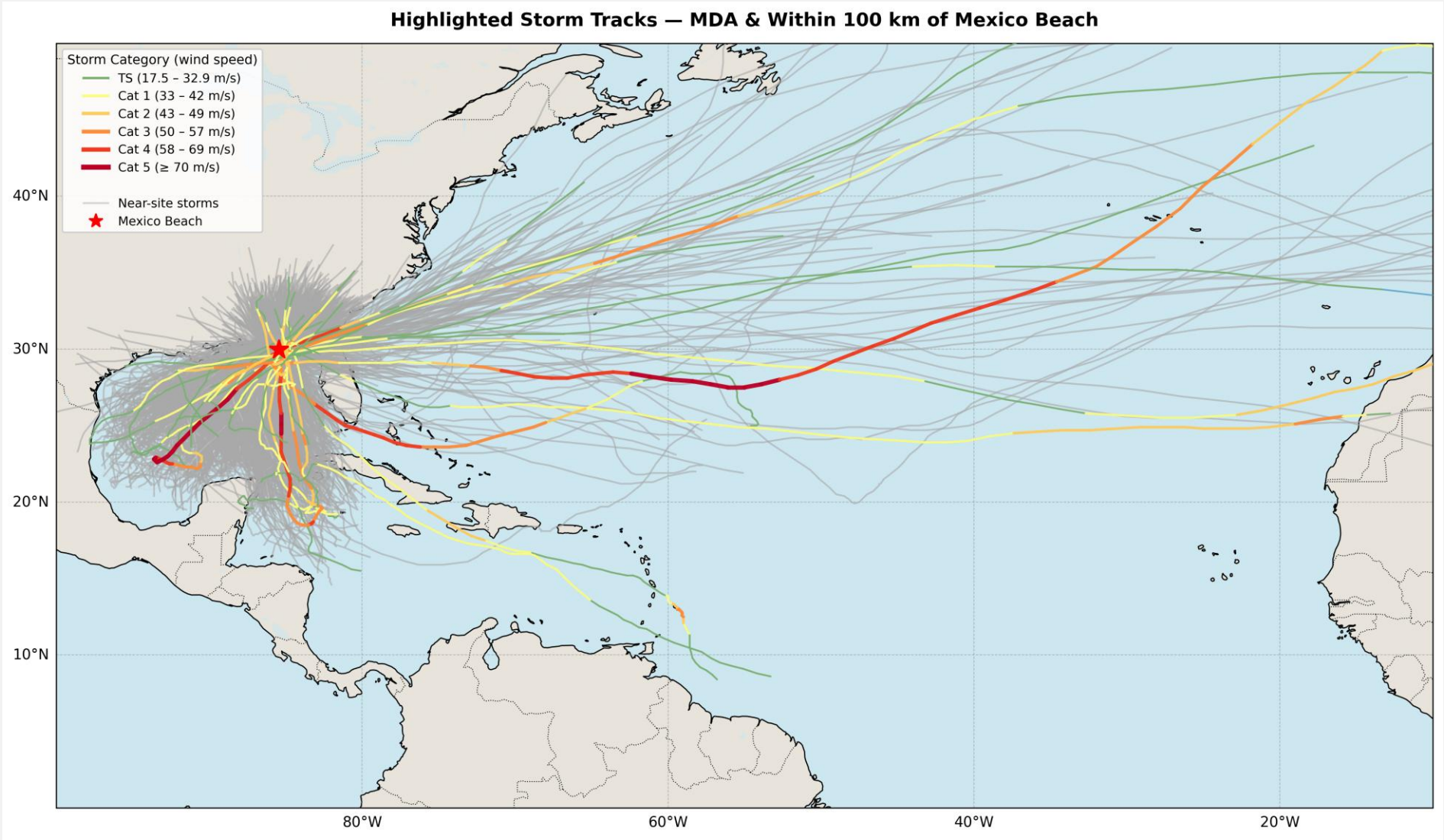


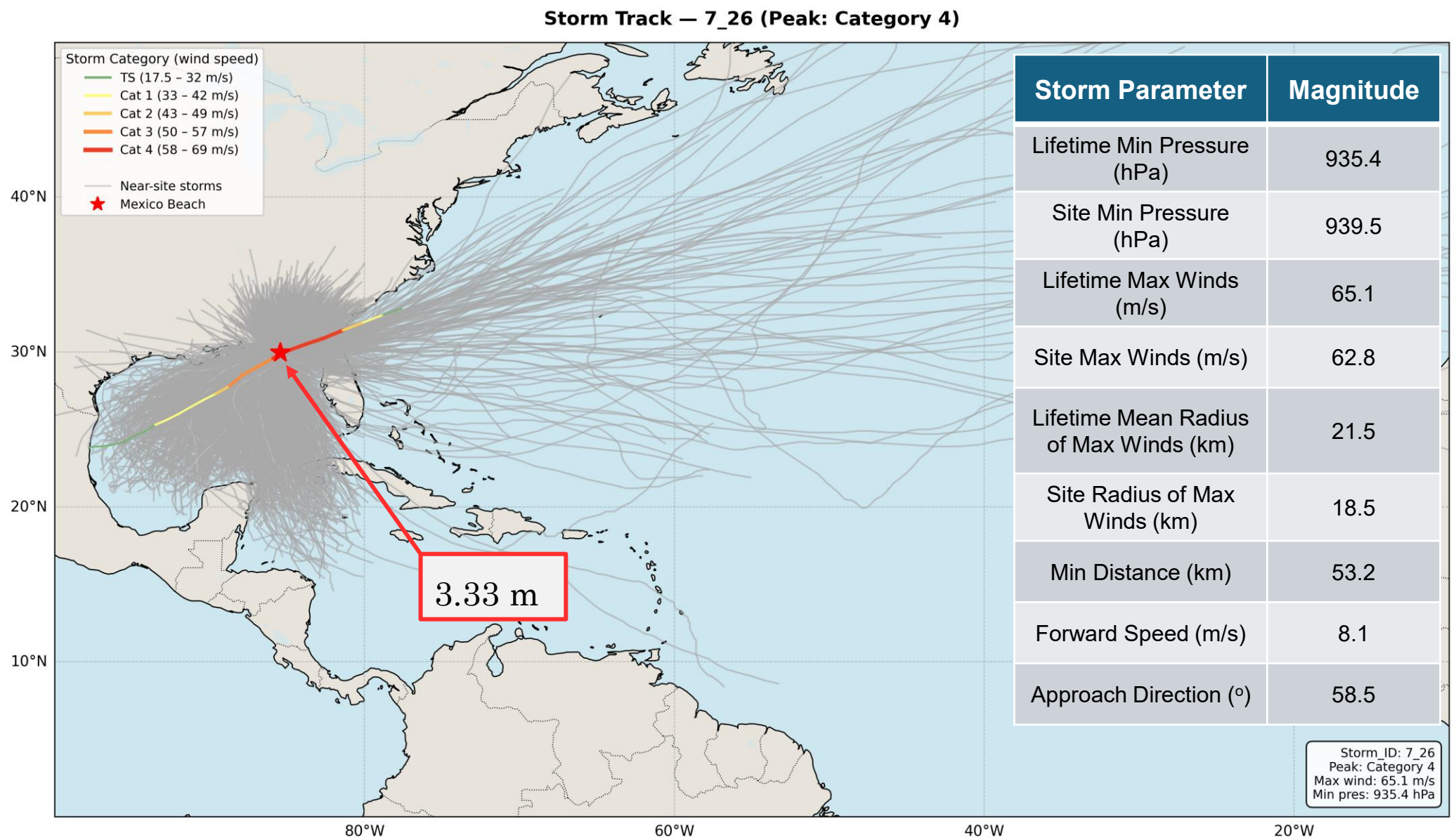
14

Spatial Smart Sampling



MDA includes **6 storm parameters**, both near site and in the storm's lifetime!

Storms Modeled for Mexico Beach



Storm Parameter	Magnitude
Lifetime Min Pressure (hPa)	935.4
Site Min Pressure (hPa)	939.5
Lifetime Max Winds (m/s)	65.1
Site Max Winds (m/s)	62.8
Lifetime Mean Radius of Max Winds (km)	21.5
Site Radius of Max Winds (km)	18.5
Min Distance (km)	53.2
Forward Speed (m/s)	8.1
Approach Direction (°)	58.5

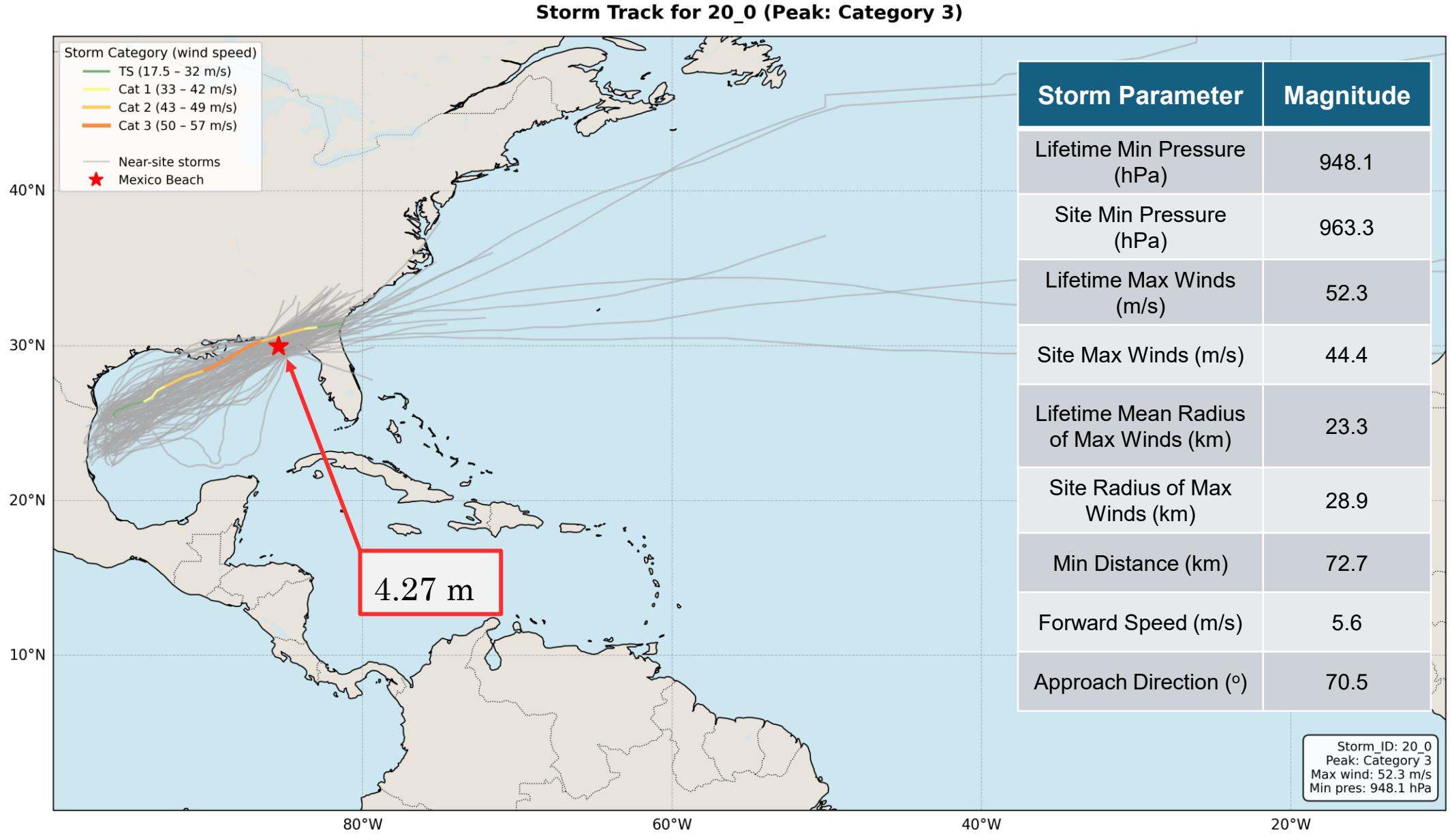
Iterative Parameter Refinement

- Steps 2-4 are repeated with similar storms as an input into J-STORM.

Rank	Storm ID	Lifetime Min Pressure (hPa)	Site Min Pressure (hPa)	Lifetime Max Winds (m/s)	Site Max Winds (m/s)	Lifetime Mean Radius of Max Winds (km)	Site Mean Radius of Max Winds (km)	Min Distance (km)	Forward Speed (m/s)	Approach Direction (°)
0	*7_26*	*935.4*	*939.5*	*65.1*	*62.8*	*21.5*	*18.5*	*53.2*	*8.1*	*58.5*
1	745_5	938.5	938.5	58.8	58.8	28.9	28.4	41.3	5.6	21.8
2	4407_6	946.5	948.5	54.4	53.3	26.9	21.2	50.0	6.7	64.6
3	2488_5	922.0	938.2	66.9	59.0	19.7	18.5	71.1	4.7	69.3
…	…	…	…	…	…	…	…	…	…	…

- Storm Generation → Site Filtering → Dissimilarity Based Modeling
- Repeated until increase in storm tides < 5 cm.

The “Worst-Possible” Storm…so far…



Storm Parameter	Magnitude
Lifetime Min Pressure (hPa)	948.1
Site Min Pressure (hPa)	963.3
Lifetime Max Winds (m/s)	52.3
Site Max Winds (m/s)	44.4
Lifetime Mean Radius of Max Winds (km)	23.3
Site Radius of Max Winds (km)	28.9
Min Distance (km)	72.7
Forward Speed (m/s)	5.6
Approach Direction (°)	70.5

*The “Worst-Possible” Storm...so far...

Rank	Storm ID	Lifetime Min Pressure (hPa)	Site Min Pressure (hPa)	Lifetime Max Winds (m/s)	Site Max Winds (m/s)	Lifetime Mean Radius of Max Winds (km)	Site Mean Radius of Max Winds (km)	Min Distance (km)	Forward Speed (m/s)	Approach Direction (°)	Peak Storm Tides (m)
*1**	*20_0*	948.1	963.3	52.3	44.4	23.3	28.9	72.7	5.6	70.5	4.27
2	*98_1*	936.9	936.9	55.5	55.5	57.6	46.3	17.8	4.3	64.3	3.54
3	*7_26*	935.4	939.5	65.1	62.8	21.5	18.5	53.2	8.1	58.5	3.33
4	*Michael*	920.0	920.0	69.5	69.5	123.1	27.8	28.0	4.6	31.7	3.24
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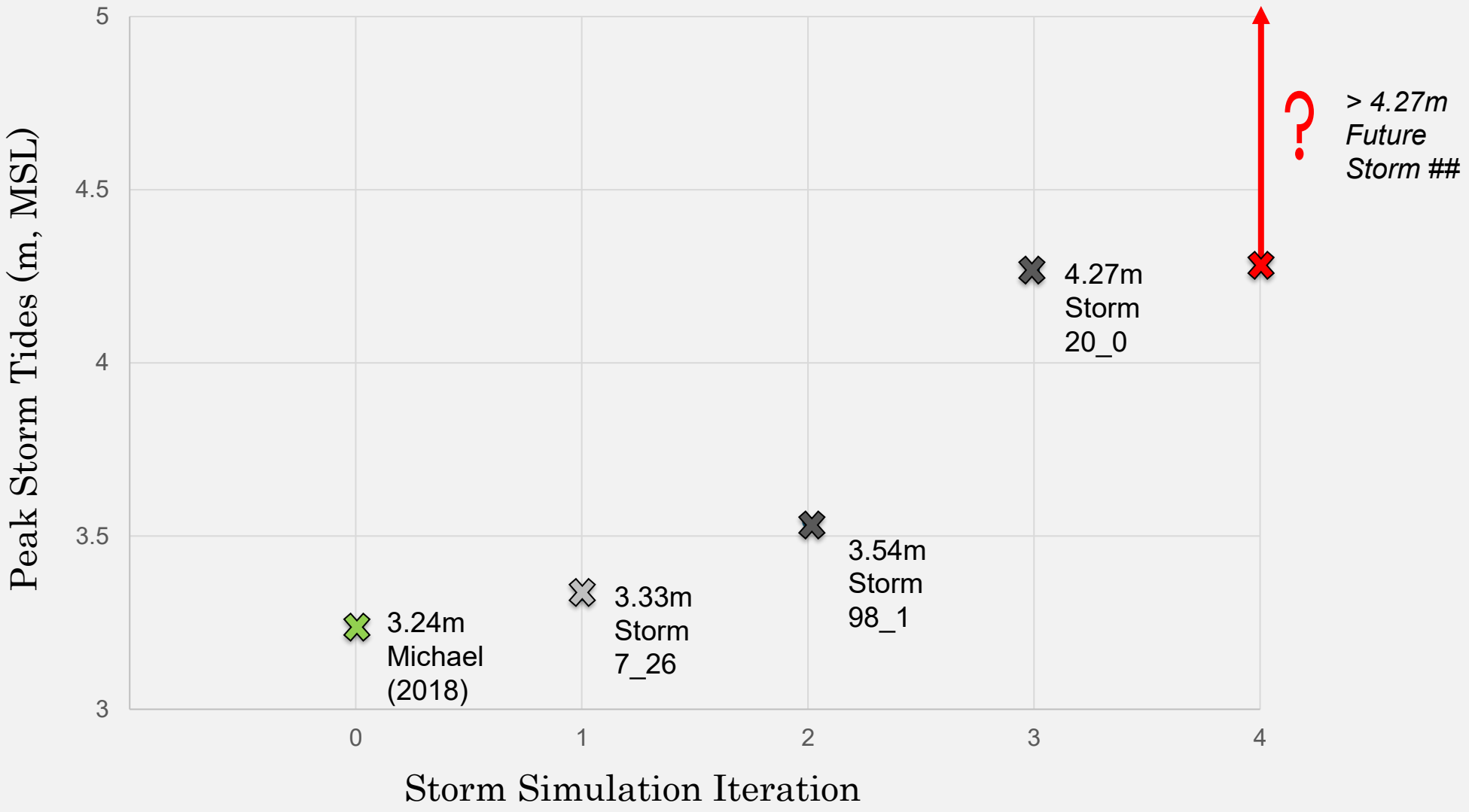
- Full MDA uses:
  - 6 parameters near site
  - 3 lifetime parameters

What will more similar storms look like?



Study uses **less than 50k CPU-Hours** from 3 iterations!!

Main Findings

1) Using datasets for synthetic storms allows them to be **real and possible** storms.

2) Extreme storm tides from the ‘worst-possible’ are **localized predictions**.

3) This framework looks at **6 storm parameters,** over their lifetime and near the site of interest for a multivariable analysis.

4) Using 3 iterations of the framework uses less than **50k CPU Hours**!

Thank You

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