# Bracing For Future Impacts
## The Possible Extreme Scenario of Tropical Cyclones

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ICCE - Session 11A: Coastal Hazards and Risk – Extreme Events

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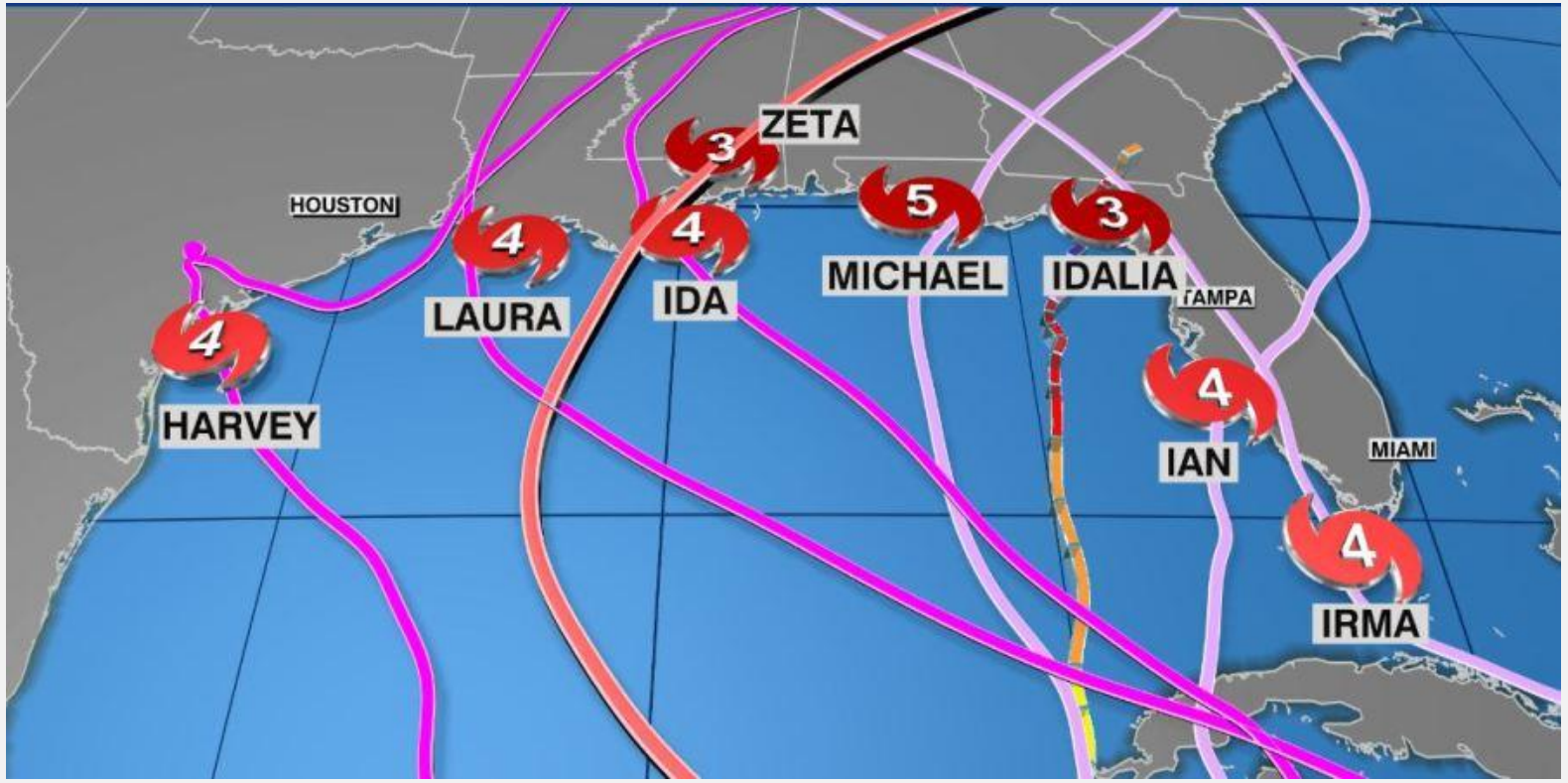
NC STATE UNIVERSITY

ESTCP

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

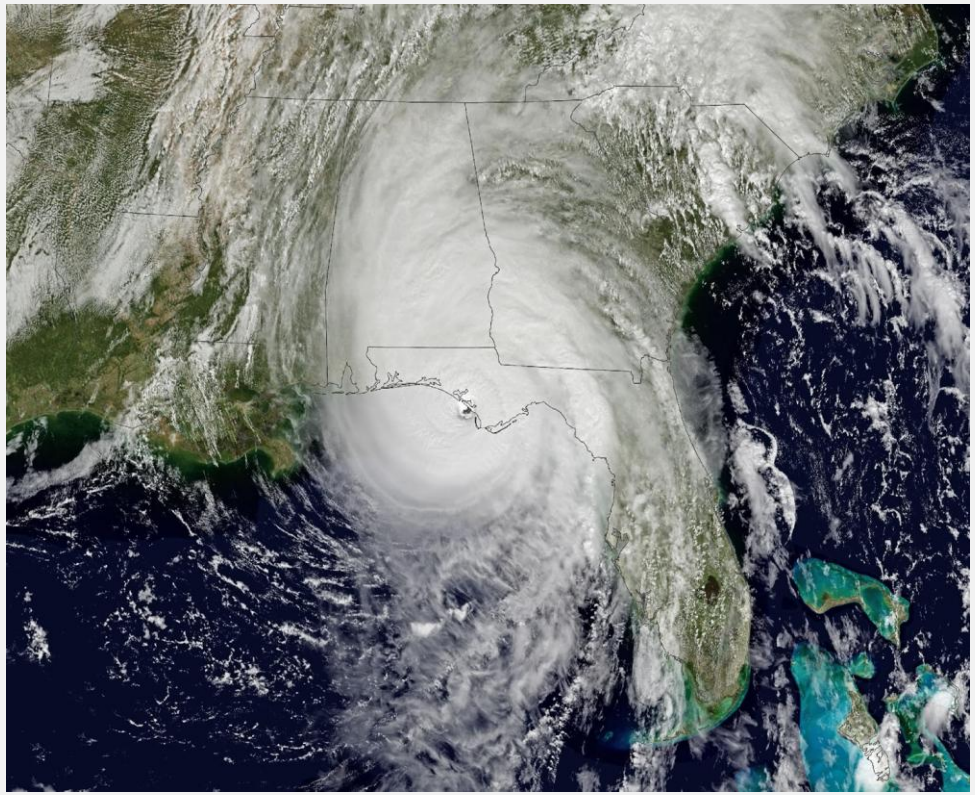
- Military Installations
- Dams
- Hospitals

## 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.

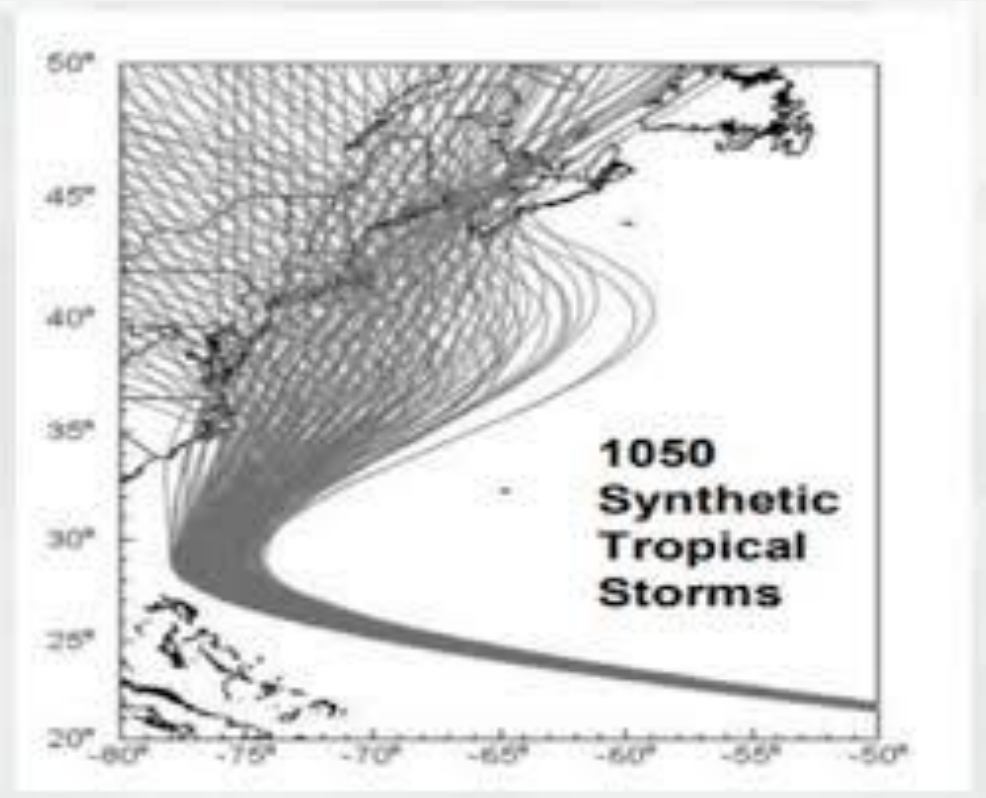


Hurricane Michael (2018) at landfall near Mexico Beach, Florida

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

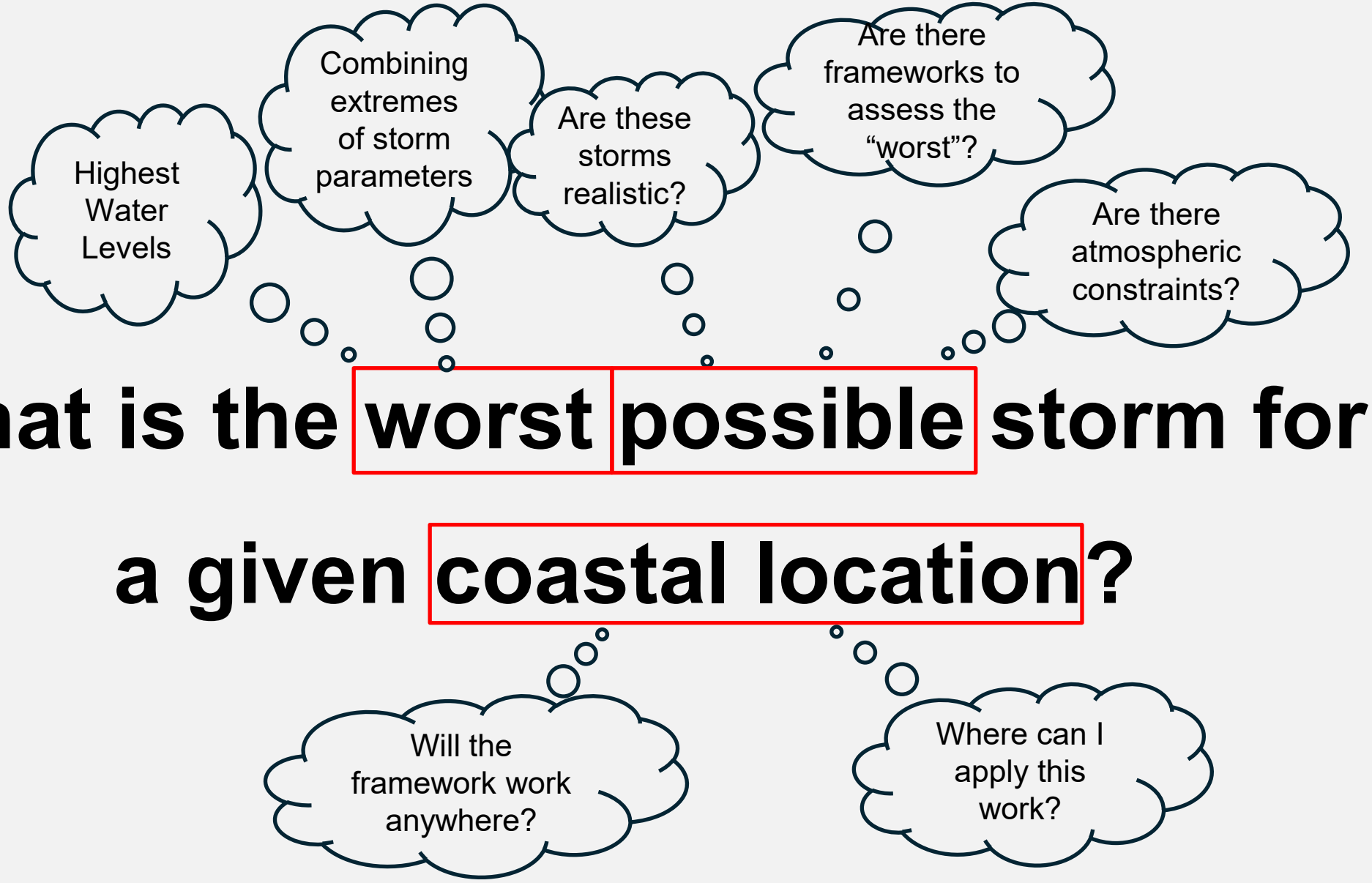
# Extreme Storm Tide Studies

- 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

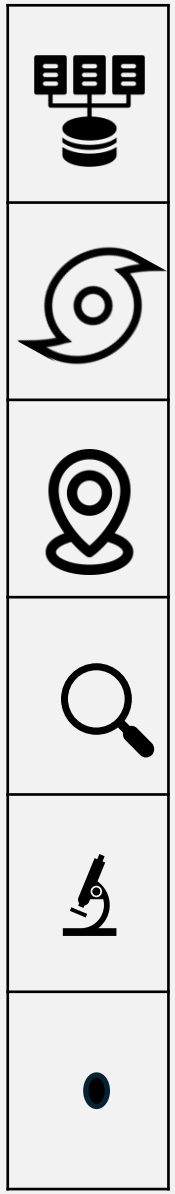
# Research Question

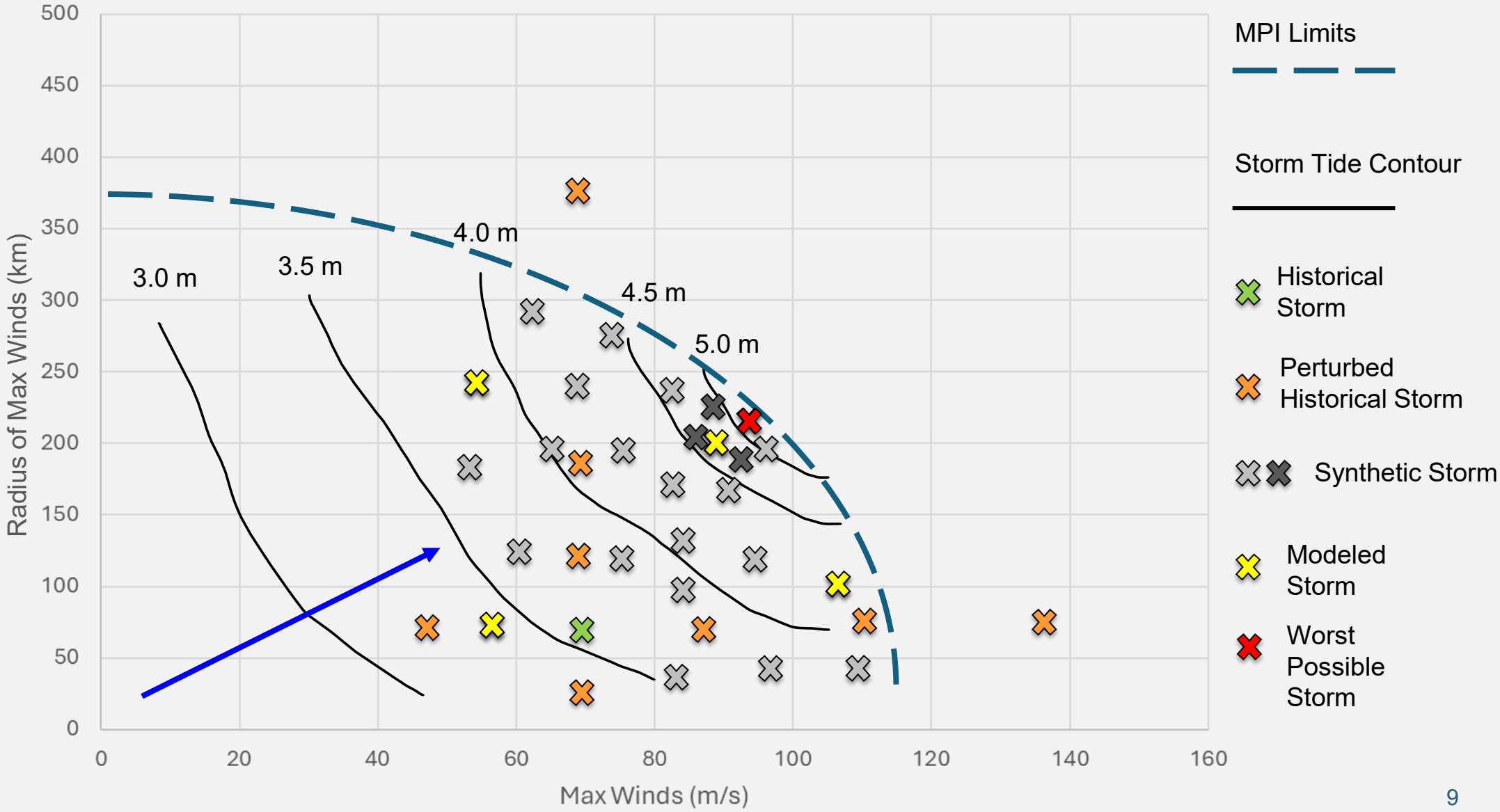


# The Integrated Framework

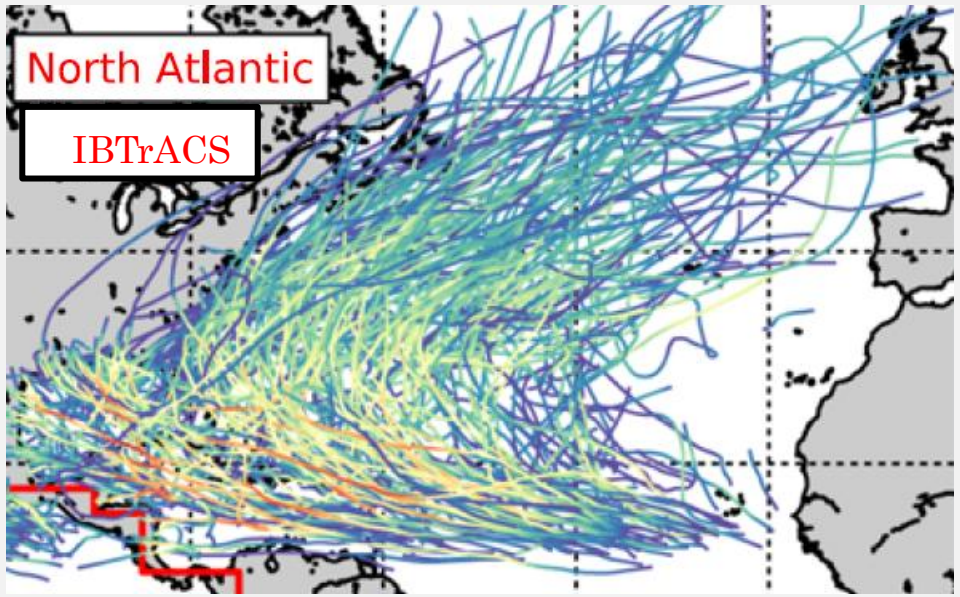
1. Historical Data Acquisition
2. Synthetic Storm Generation
3. Site Specific Filter
4. Dissimilarity Based Modeling
5. Iterative Parameter Refinement
6. The “Worst-Possible” Storm

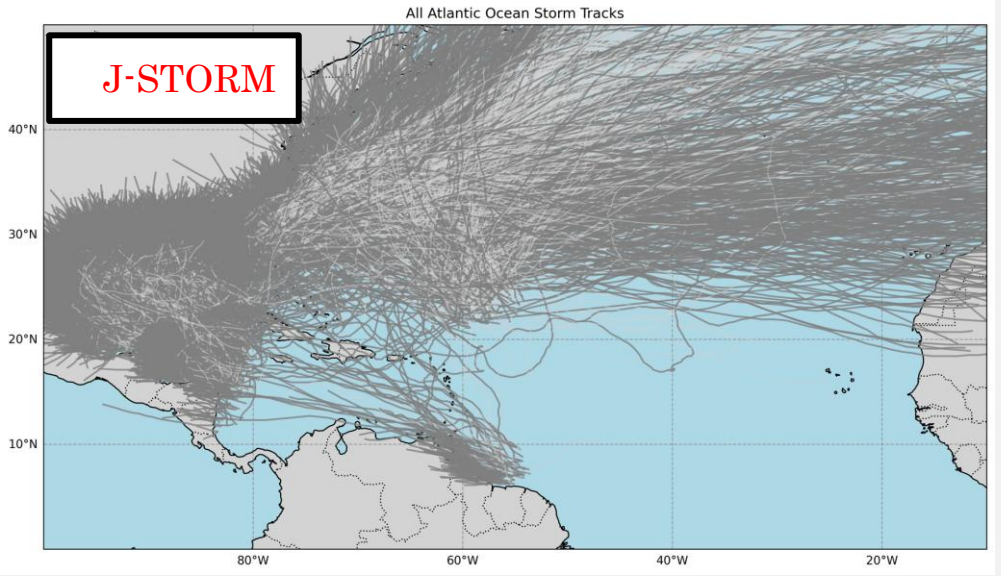
# Here's the concept of the framework...





# 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*

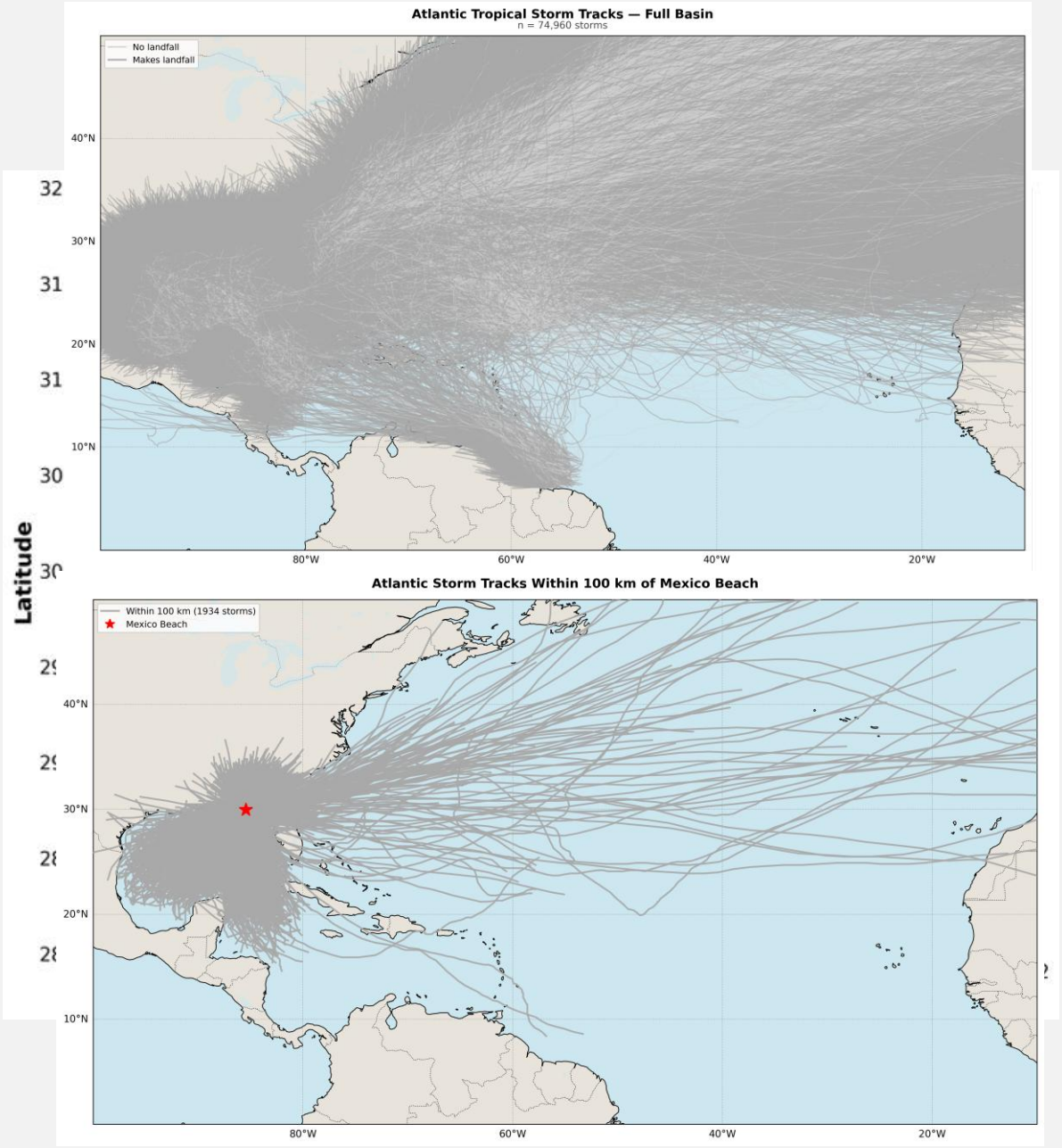
1 – Bloemendaal et al. (2020)

# 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

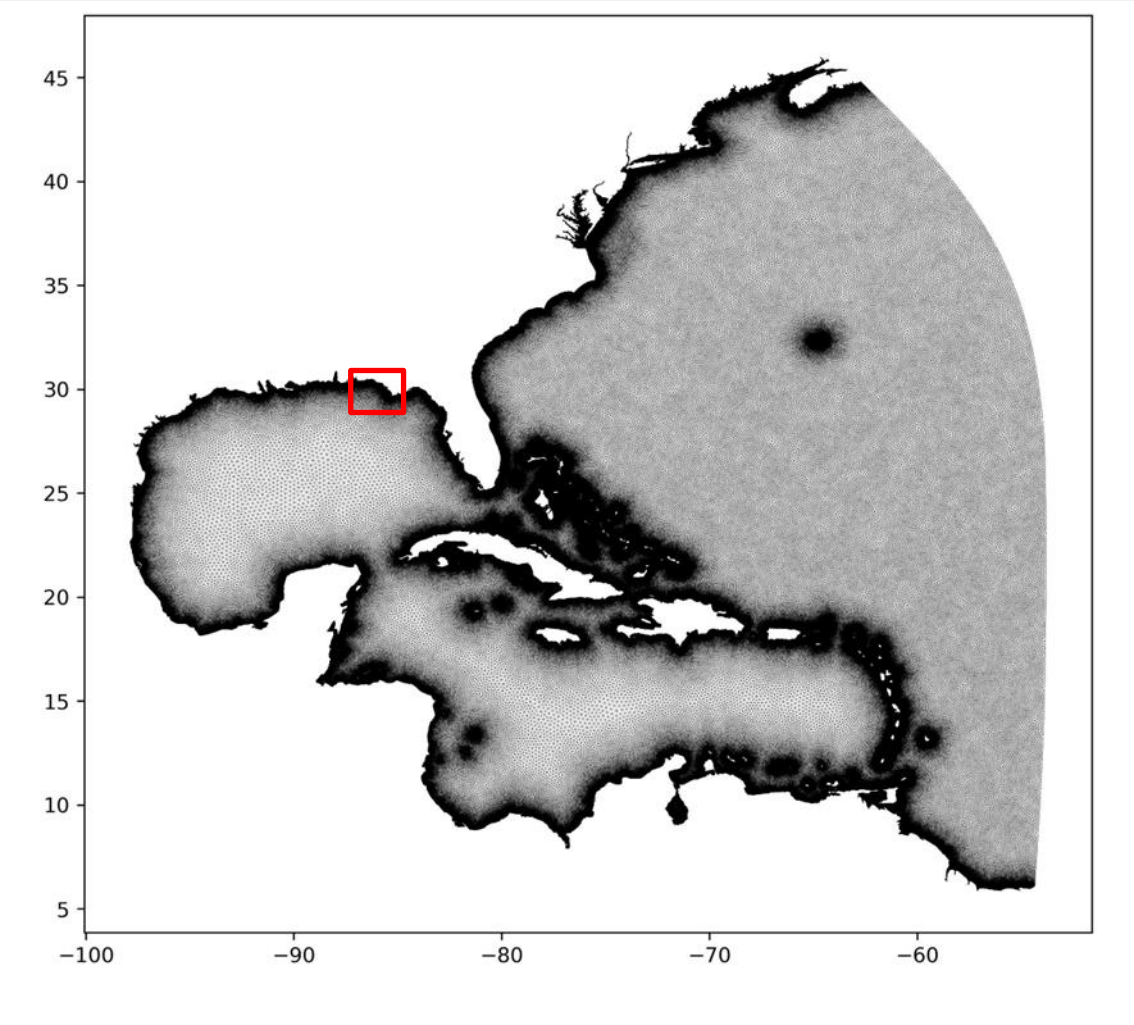



- Site Area: Mexico Beach
- Filter storms by:
  - Max Sustained winds (>29m/s)
  - Min Storm Lifetime (>24 hours)
  - Within Study Area (<100km)
- Reduced set from ~75k to 896 storms

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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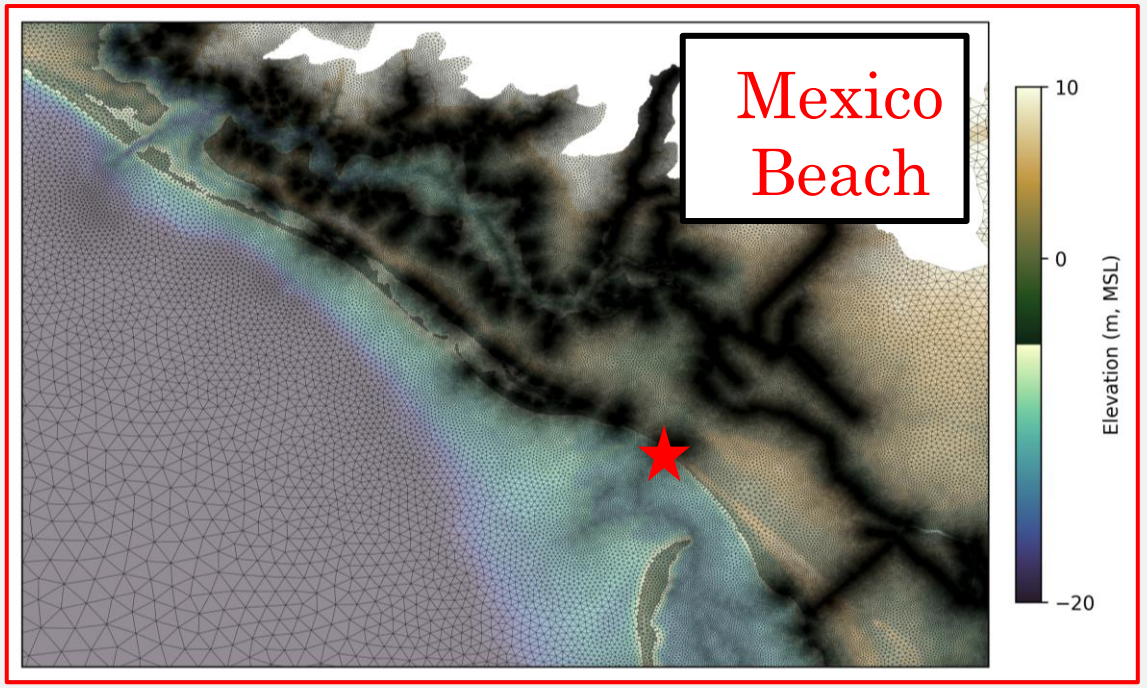
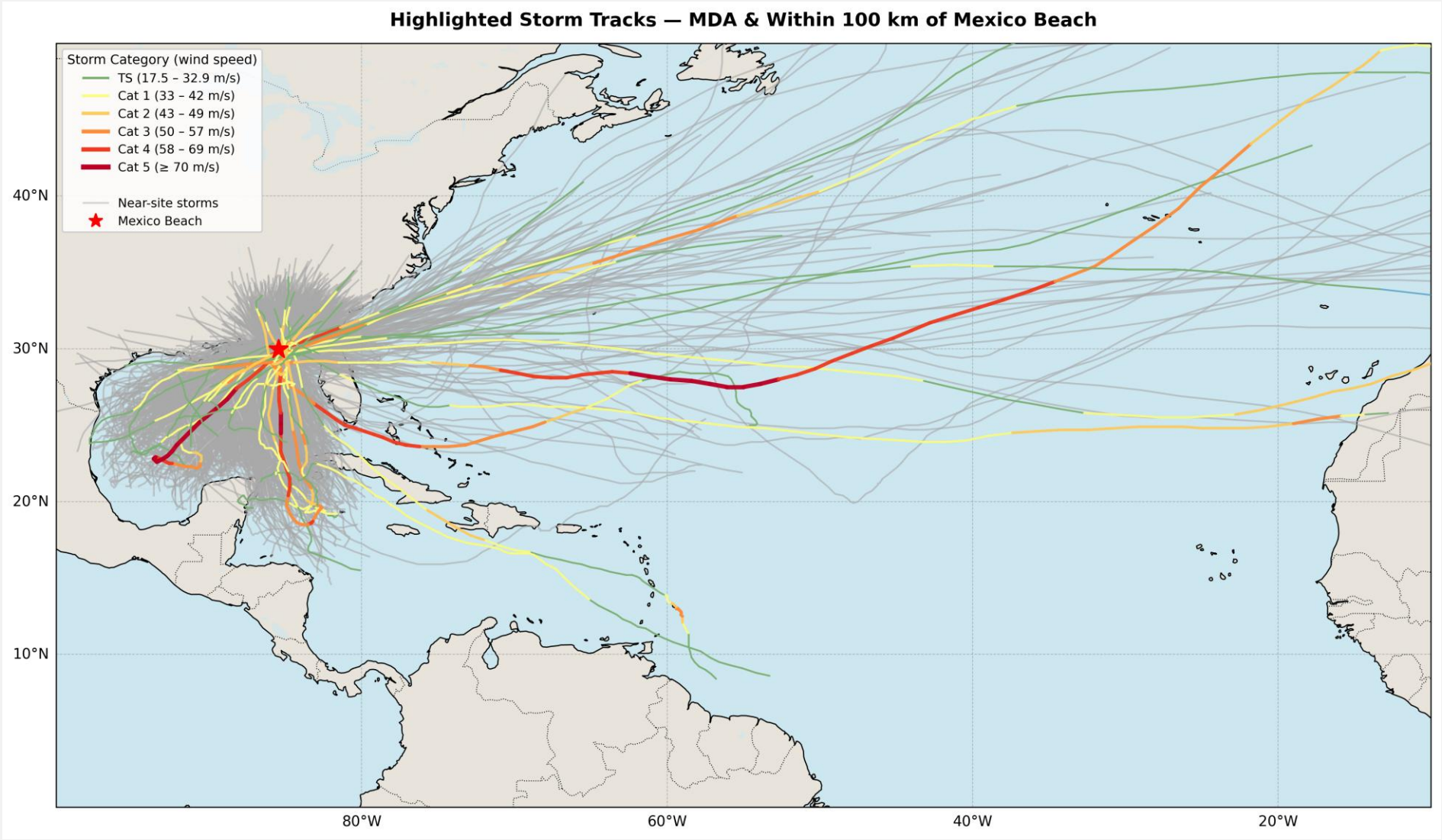




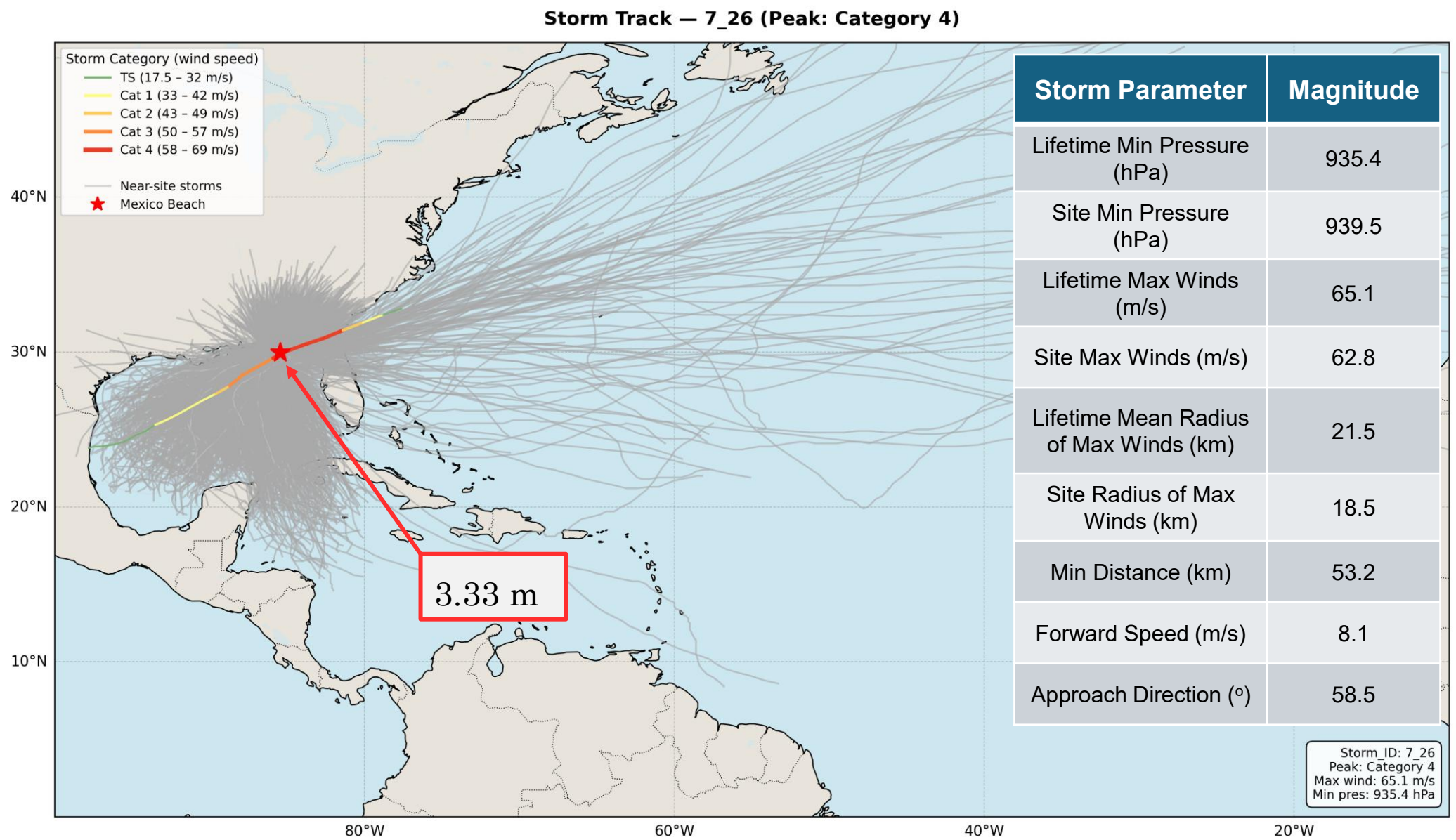
14

# 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 |

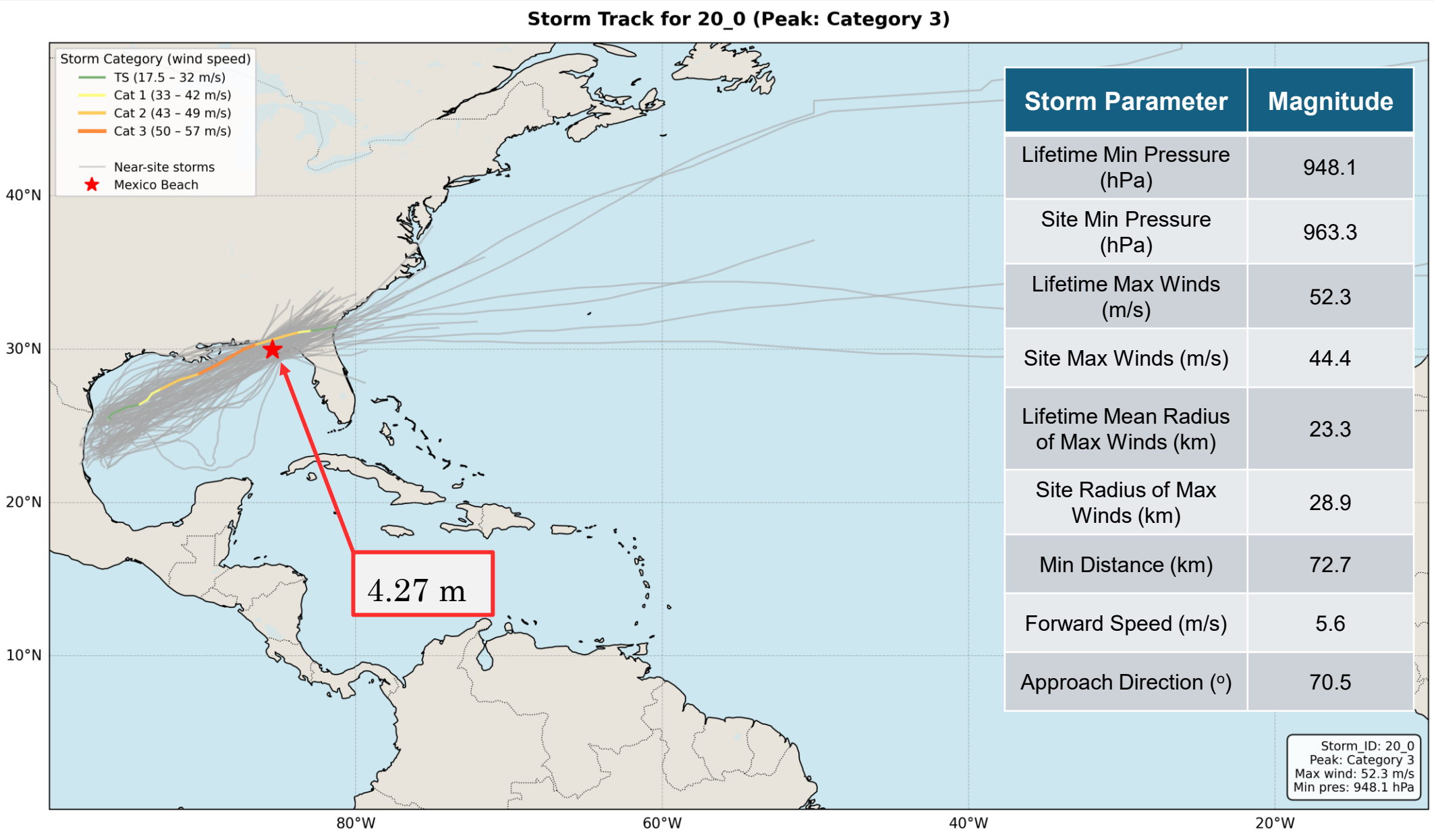
# Iterative Parameter Refinement

- 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 |
| … | … | … | … | … | … | … | … | … | … | … |

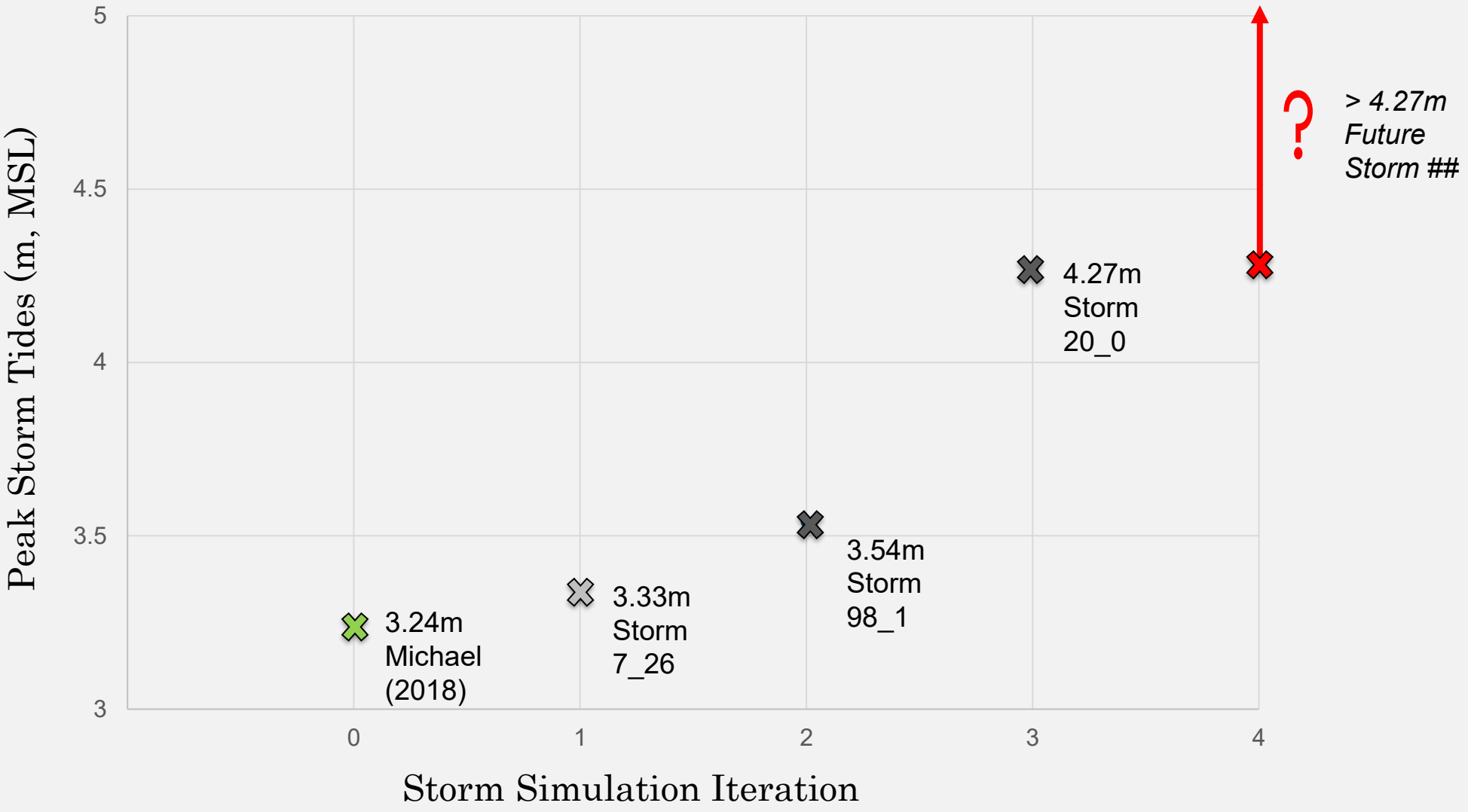
- Storm Generation → Site Filtering → Dissimilarity Based Modeling
- Repeated until increase in storm tides < 5 cm.

# 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 |

# 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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