STORM SURGE PREDICTIONS AT HYPERLOCAL SITES

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ADCIRC USERS GROUP MEETING 2024

NC STATE UNIVERSITY

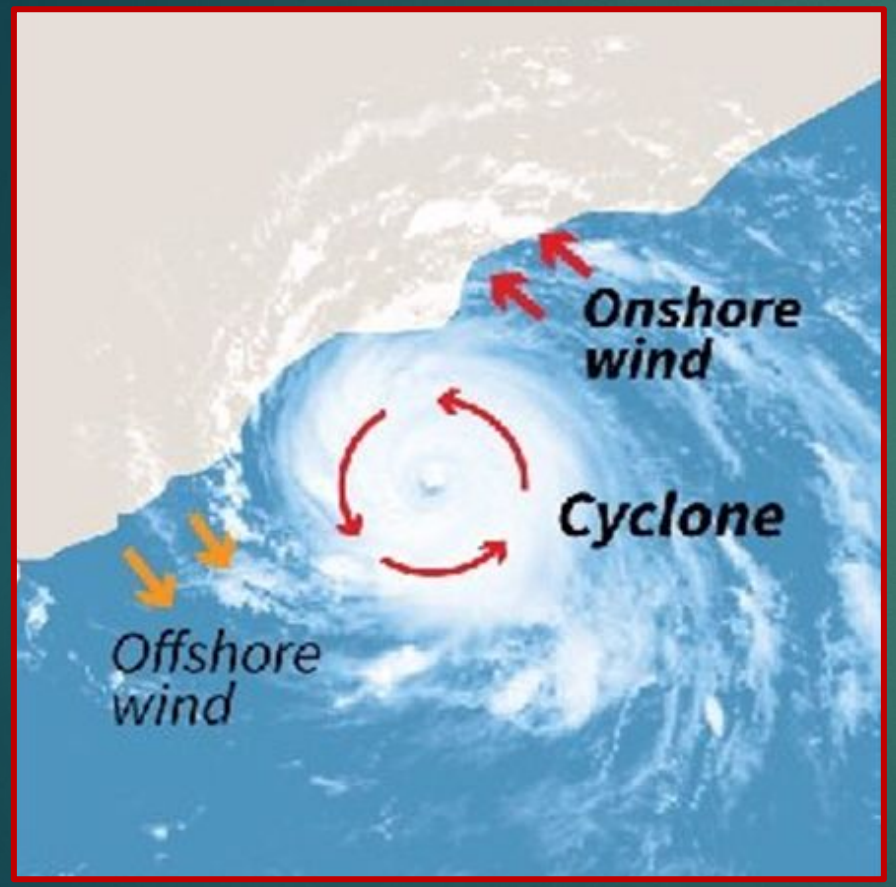
SOUTHEAST Climate Adaptation Science Center

ESTCP

Today's Goals

- Motivation
  - Uncertainties of Storm Surge Sensitivity
  - Sensitivity at Hyperlocal Sites
  - Application of ADCIRC to Hyperlocal Sites
- Research Questions & Objectives
  - DEMs, Mesh Development & Storm Simulations
- Results
  - Storm Uncertainties at a hyperlocal site
  - The 'Worst-Case' Scenario
- Main Conclusions

High Winds Cause Storm Surge!!



Storm Surge from hurricane wind fields[1]

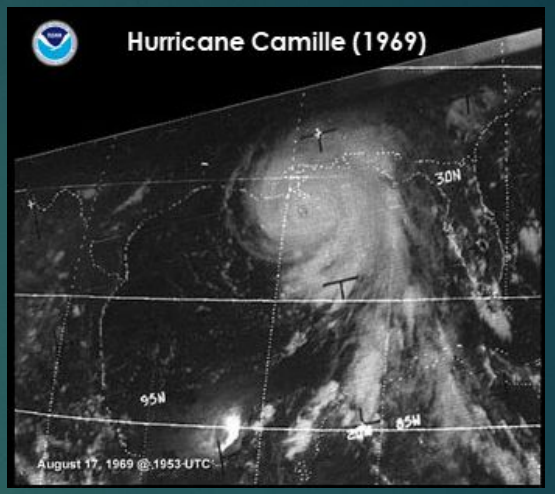
- Hurricane winds push sea water towards the coast
- Basic Storm Parameters[2]:
  - Diameter (km) : 300 - 1000
  - Eye(km): 30 - 80
  - Rotational Velocity(m/s): 30-70
  - Linear Velocity(m/s): 2 -10
  - Duration (days): 1-20

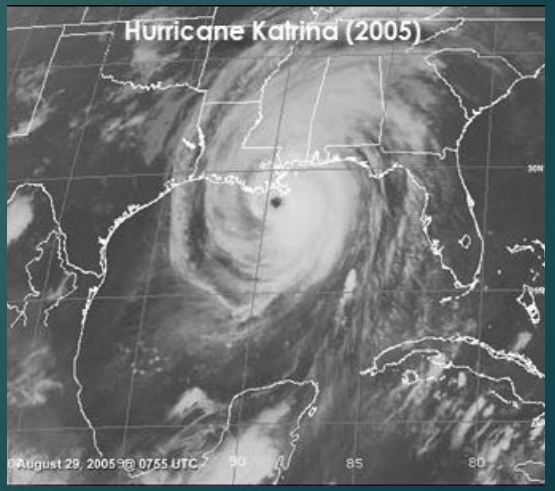
Uncertainties in storm surge sensitivity

1 – NOAA, Met Office (2016)
2 – Perez – Peraza et.al. (2008)

A Storm Sensitivity Study

- The Influence of Storm Size on Hurricane Surge
  - Irish et. al (2008)
  - Compares Hurricanes Katrina (Cat 3), Betsy (Cat 3) & Camile (Cat 5).
  - Katrina had more surge than Camile, which was more intense but smaller.
  - Betsy has the 3rd largest surge of historical record at the time.
  - Examines multiple storm parameters collectively.
  - Focuses on the Mississippi River Delta.



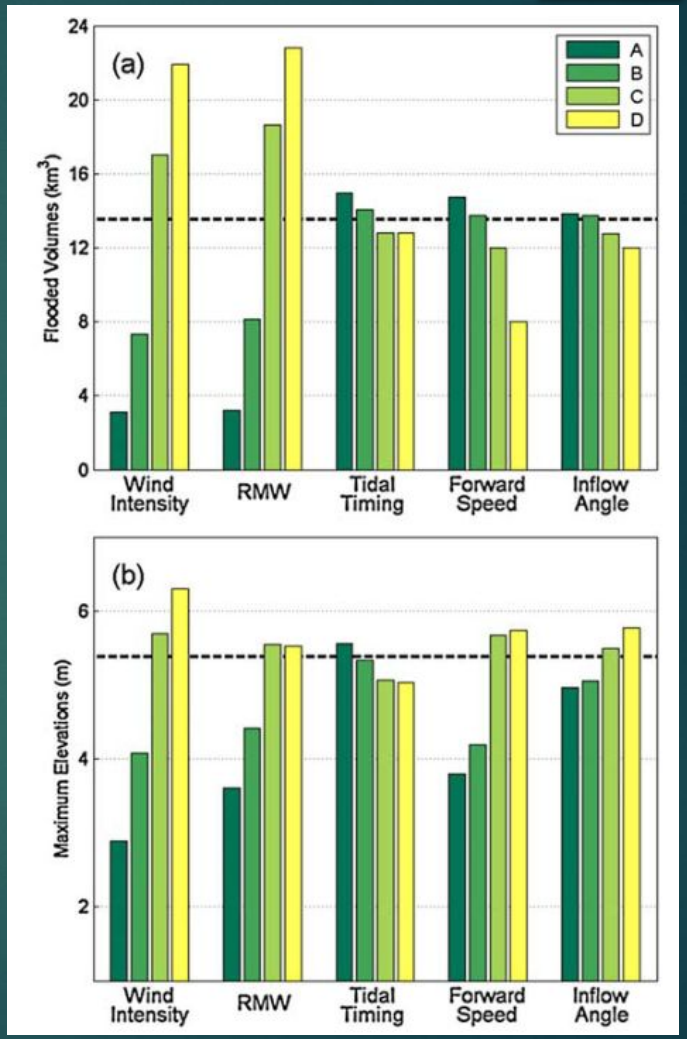


Aerial Images of Hurricanes Camille and Katrina[1]

1 – National Weather Service

Another Storm Sensitivity Study

- On the importance of the forward speed of hurricanes in storm surge forecasting: A numerical study
  - Rego & Li (2009)
  - Increasing forward speed decreases flooded volumes while increasing peaks by 40%.
  - Examines multiple storm parameters collectively.
  - Focuses on the Louisiana- Texas Shelf.
  - Not an ADCIRC study.



Total Flooded Volumes and Max Surge Heights[1]

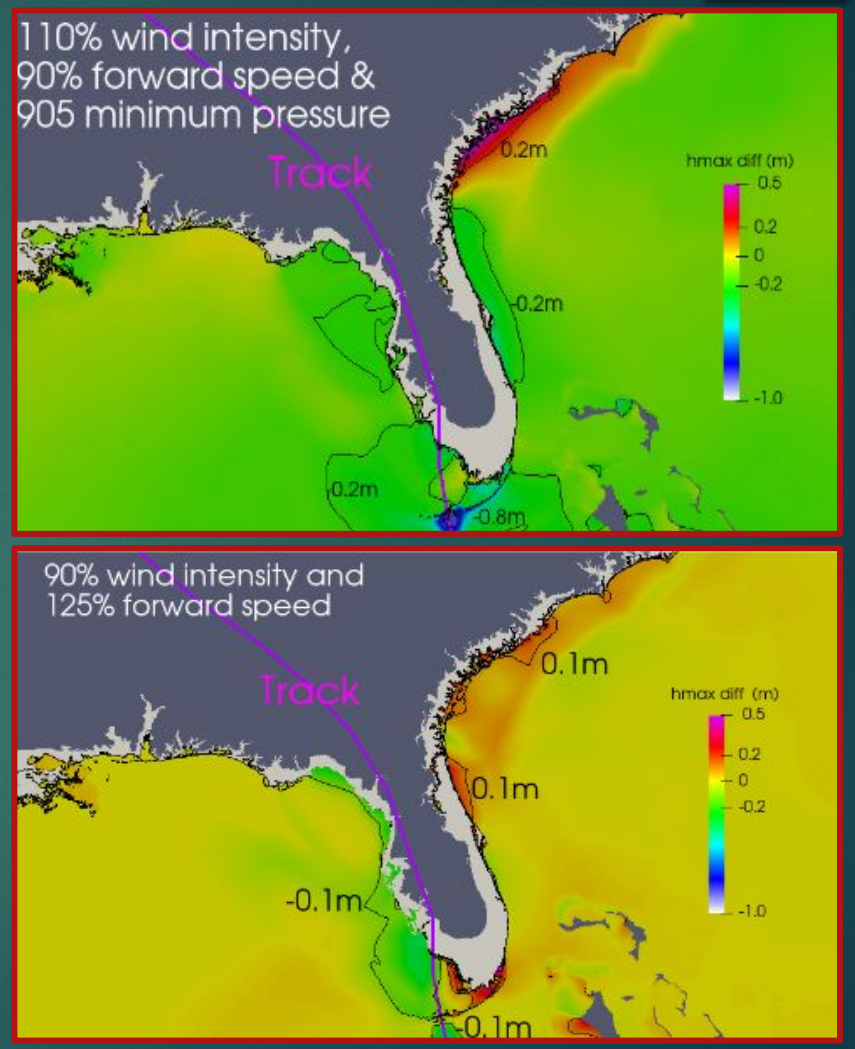
1 –Rego & Li (2009)

More Storm Sensitivity Studies

- Understanding the Effects of Wind Intensity, Forward Speed, Pressure and Track on Generation and Propagation of Hurricane Irma
  - Musinguzi et. al (2021)
  - Examines multiple storm parameters collectively.
  - Focuses on the east and west coasts of Florida as well as the Georgia- Carolinas coastline.

A)

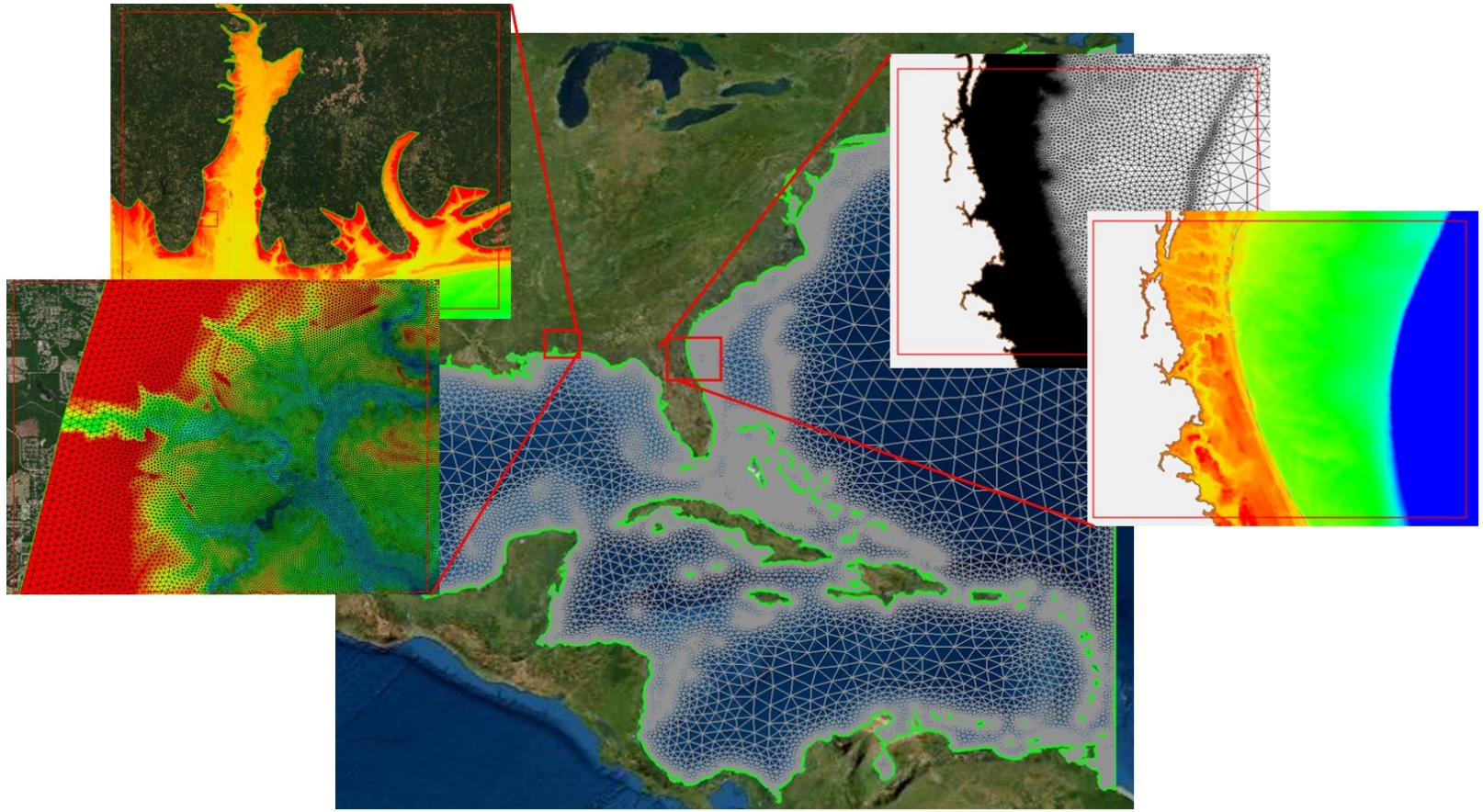
B)



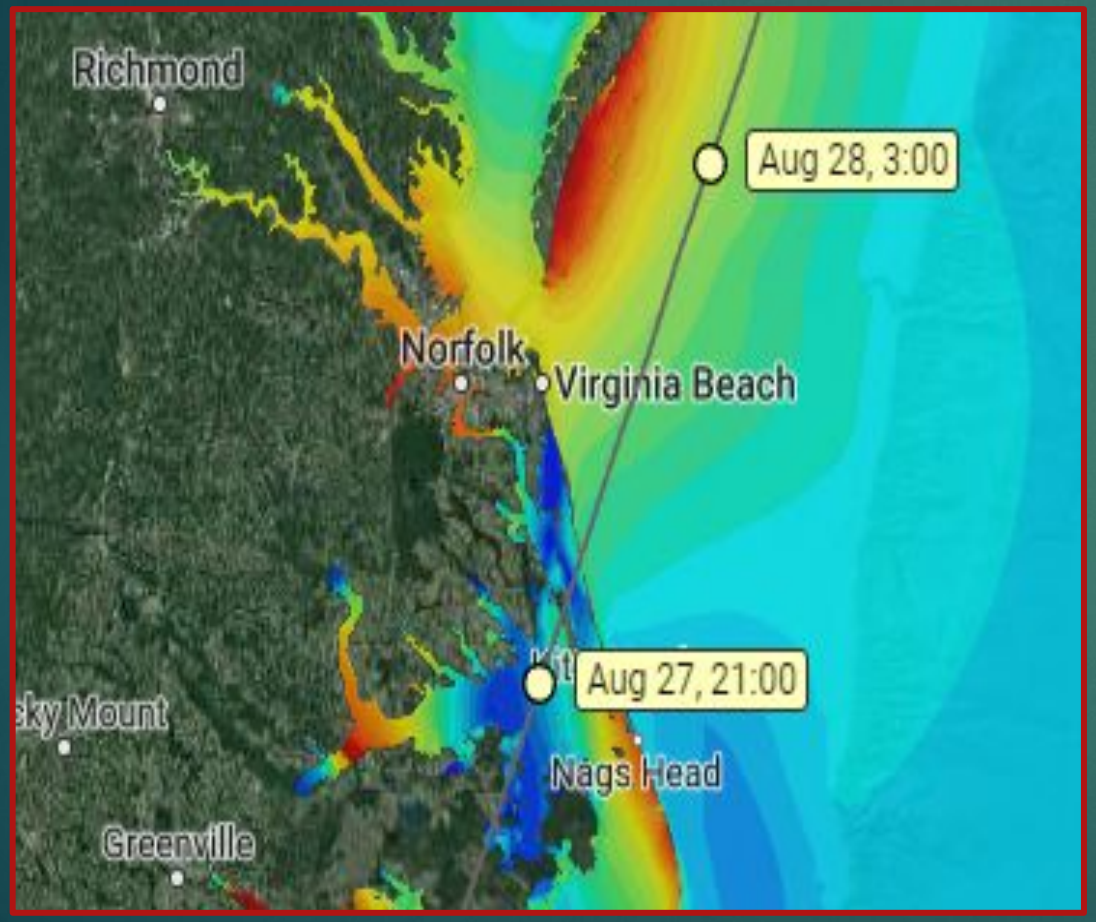
Variations of Max Water elevations from different cases[1]

1 – Musinguzi et.al (2021)

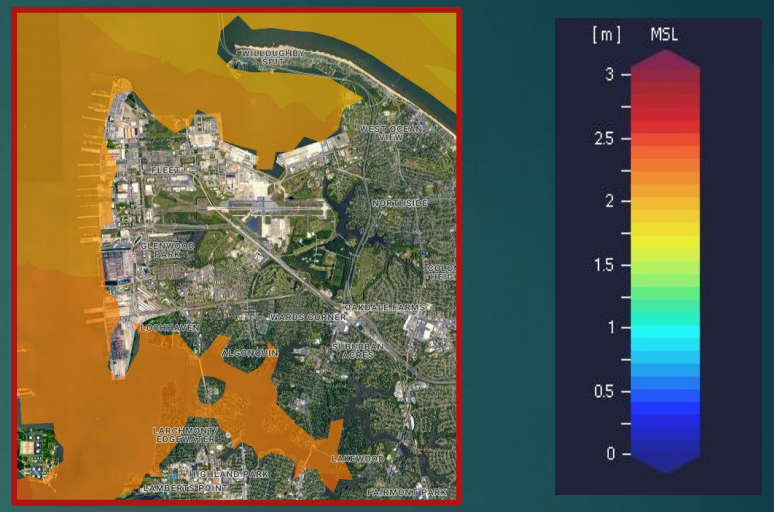
Storm Surge Predictions over Large Scales



What does this look like at hyperlocal sites?



Storm Track for Hurricane Irene (2011) from CERA



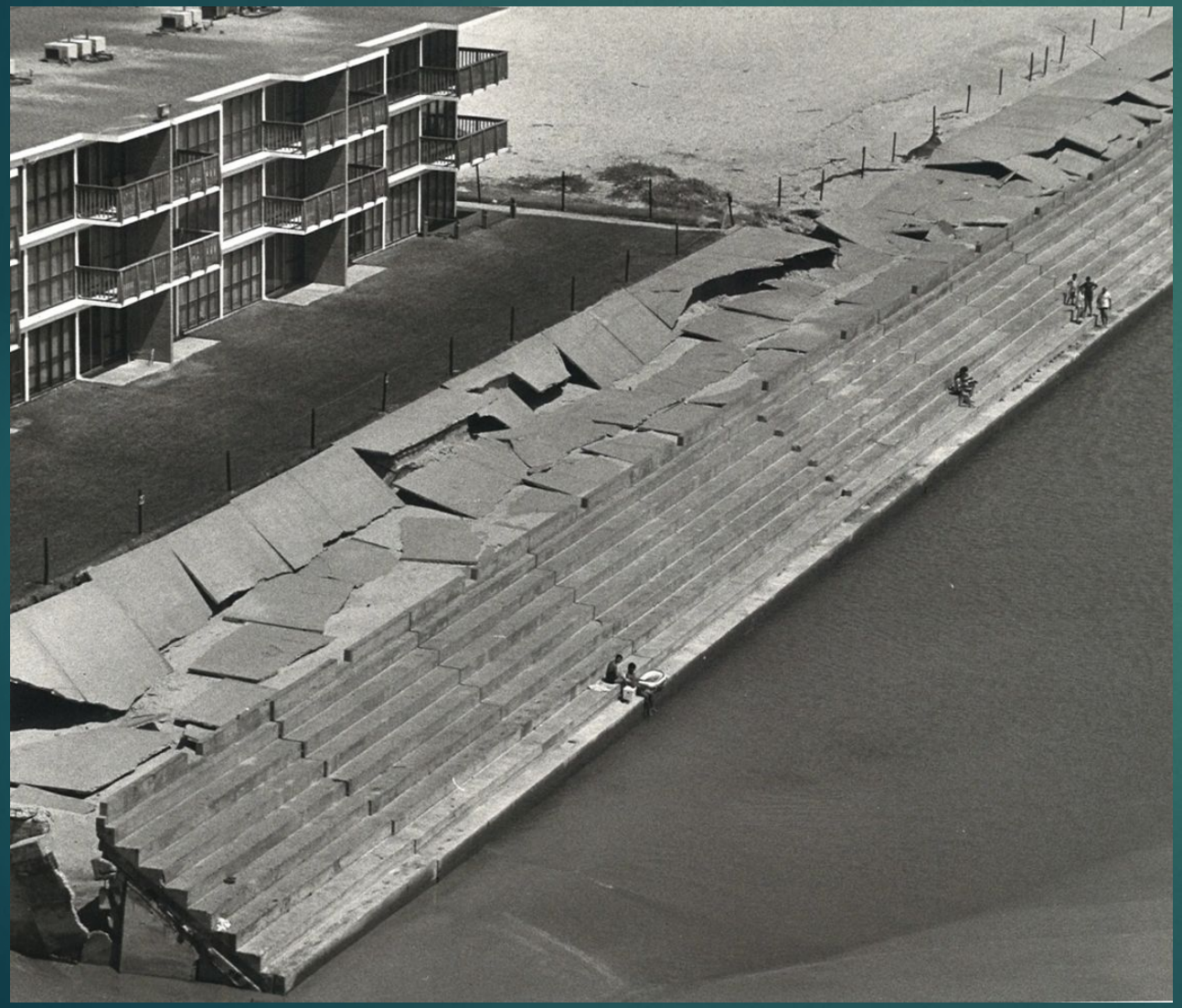
Modeled Water Levels in Norfolk

Local Community in Norfolk

What is a hyperlocal site?

- Critical Infrastructure
- Protective Structures
- Single Building or Home

Storm Surge has been affecting hyperlocal sites!

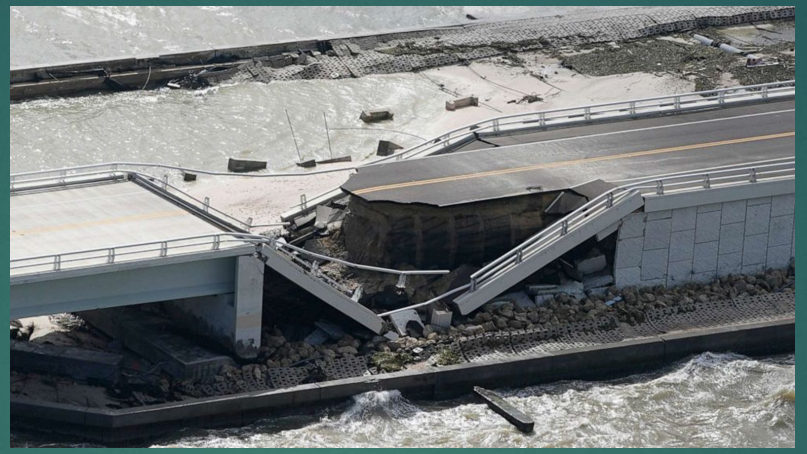


- Padre Island Seawall
- Hurricane Allen (1980)[1]
  - Longest Category 5 at that time
  - Highest Winds: 190 mph
  - Lowest Pressure: 899 mbar
  - $1.57B in damages
    - Mostly due to flooding
  - +200 deaths

1 – Corpus Christi Caller Times (2020)

Many are affected from the impacts to these hyperlocal sites!

Hurricane Ian damaged nearly every structure on Sanibel[1]



Sections of the Sanibel Island Causeway cutting off access to the island[2]

Residents of Sanibel evacuating by boat after Hurricane Ian[3]

- 1 of 2 bridges to the mainland Florida.
- At least 3 sections of causeway over washed or broken.
- Half-mile road leading to causeway was impassible.

- Home to 6,500 people
- Residents of 200 remained[4]
- Coast Guard Rescued those trapped.
- 12 deaths + 2 Severely Injured[4]

1 – Getty Images (2022)
2 – NBC News (2022)
3 – New York Times (2022)
4 – National Public Radio (2022)

Many are affected from the impacts to these hyperlocal sites!

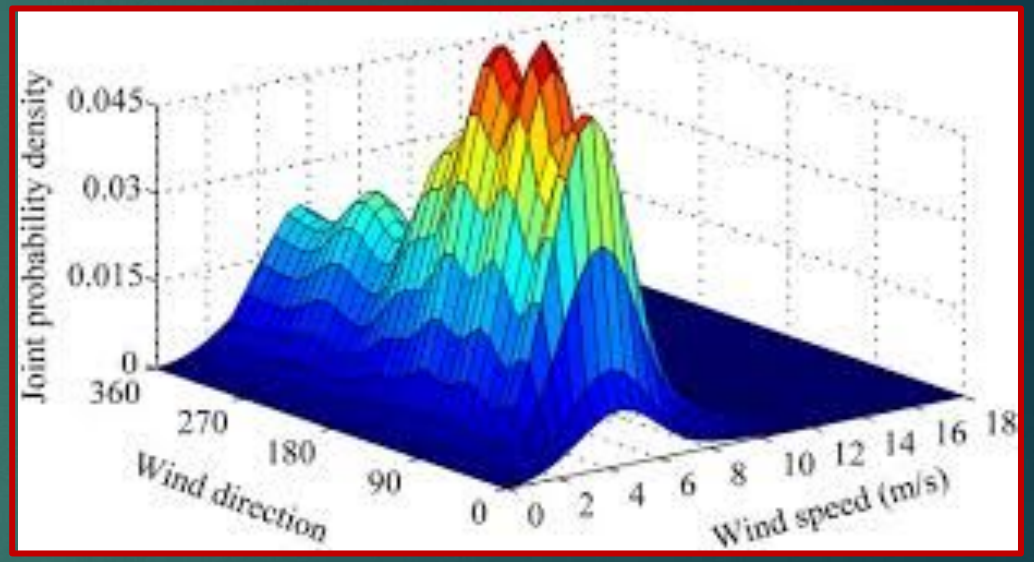
Partially Submerged hospital in New Orleans after Hurricane Katrina in 2005[1]

Flooding seen at the Tampa General Hospital from Tropical Storm Eta[2]

1 – SCI AM (2022)
2 – Perez – Peraza et.al. (2008)

Storm Surge Study at Hyperlocal Sites

- Framework for Probabilistic Storm Surge Hazard Assessment for United States Nuclear Power Plants
  - Bensi & Kanney (2015)
  - Is site specific.
  - Uses 50-to-500-year return periods.
  - Compares 2 methods for probabilistic risk assessment
    - Empirical Simulation Technique (EST)
    - Joint Probability Method (JPM)

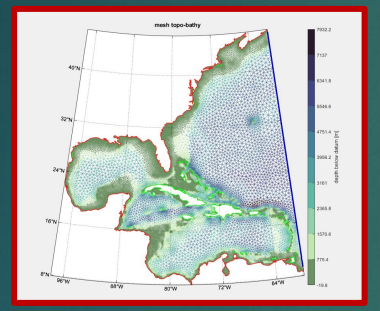


Examples of application of the Joint Probability Method[1]

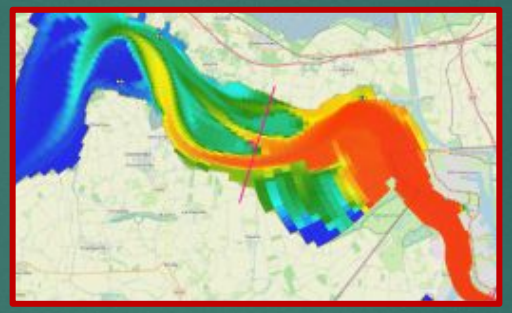
1 – Musinguzi et.al (2021)

This is bigger than us!!

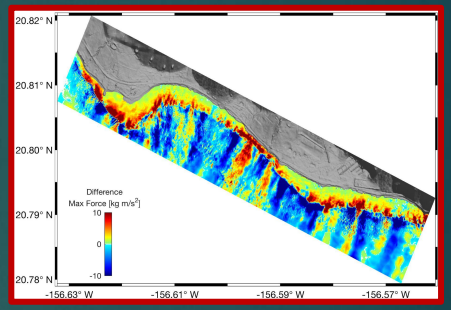
- "Comparative Assessment Of Total Water Levels For Coastal Military Facility Readiness And Resilience Using Numerical Models"



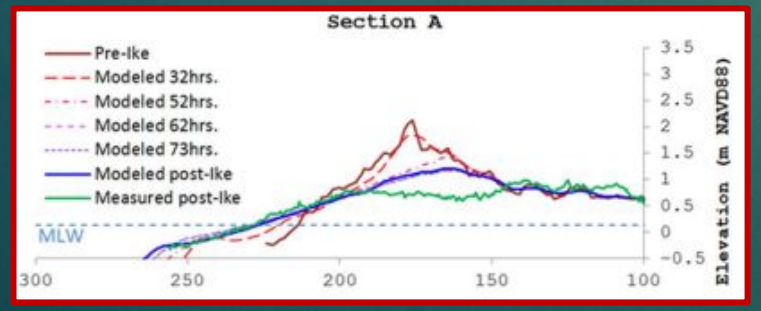
ADCIRC



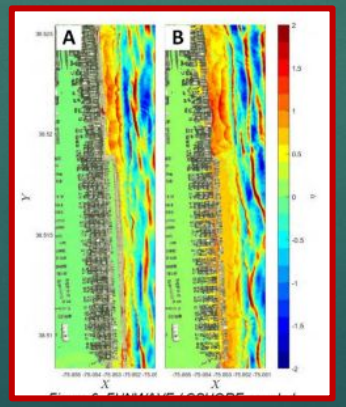
Delft3D



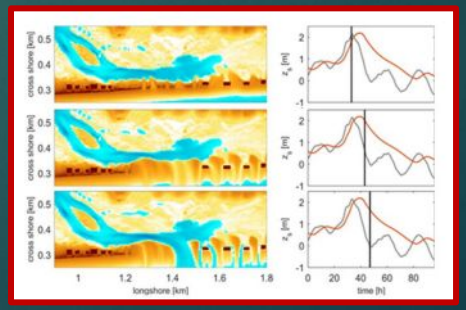
NearCOM



CSHORE



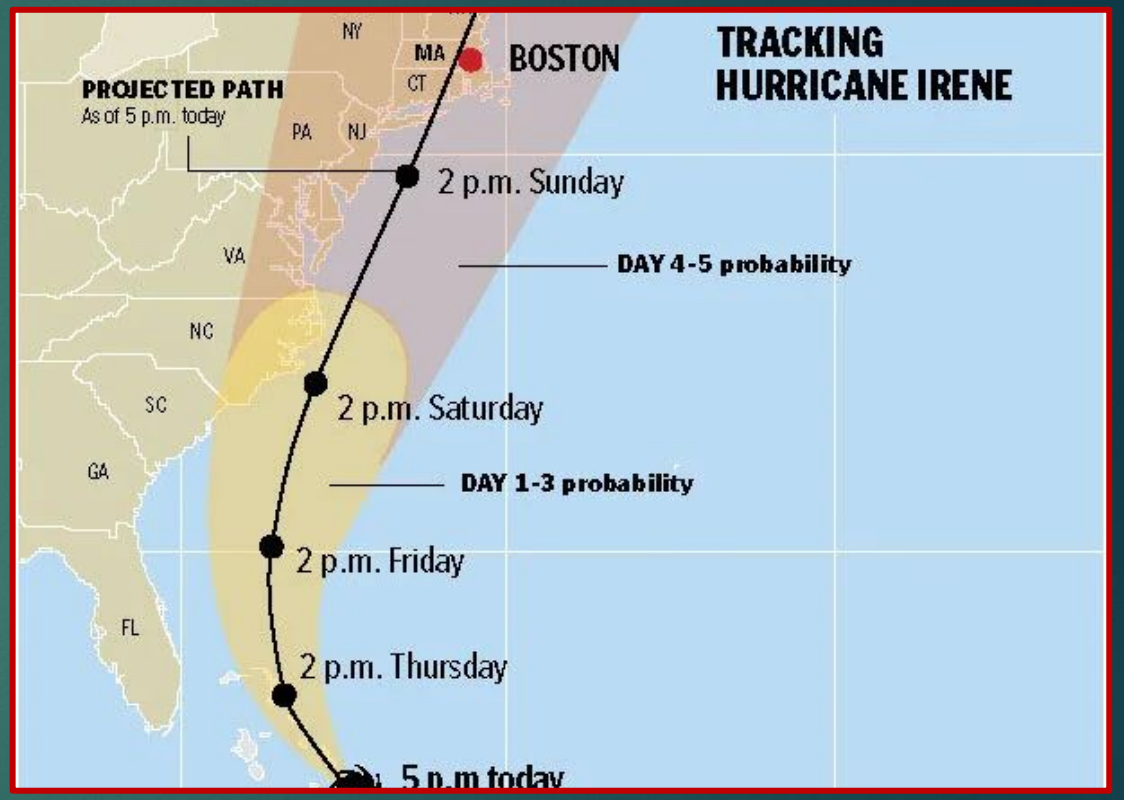
FUNWAVE



X-Beach

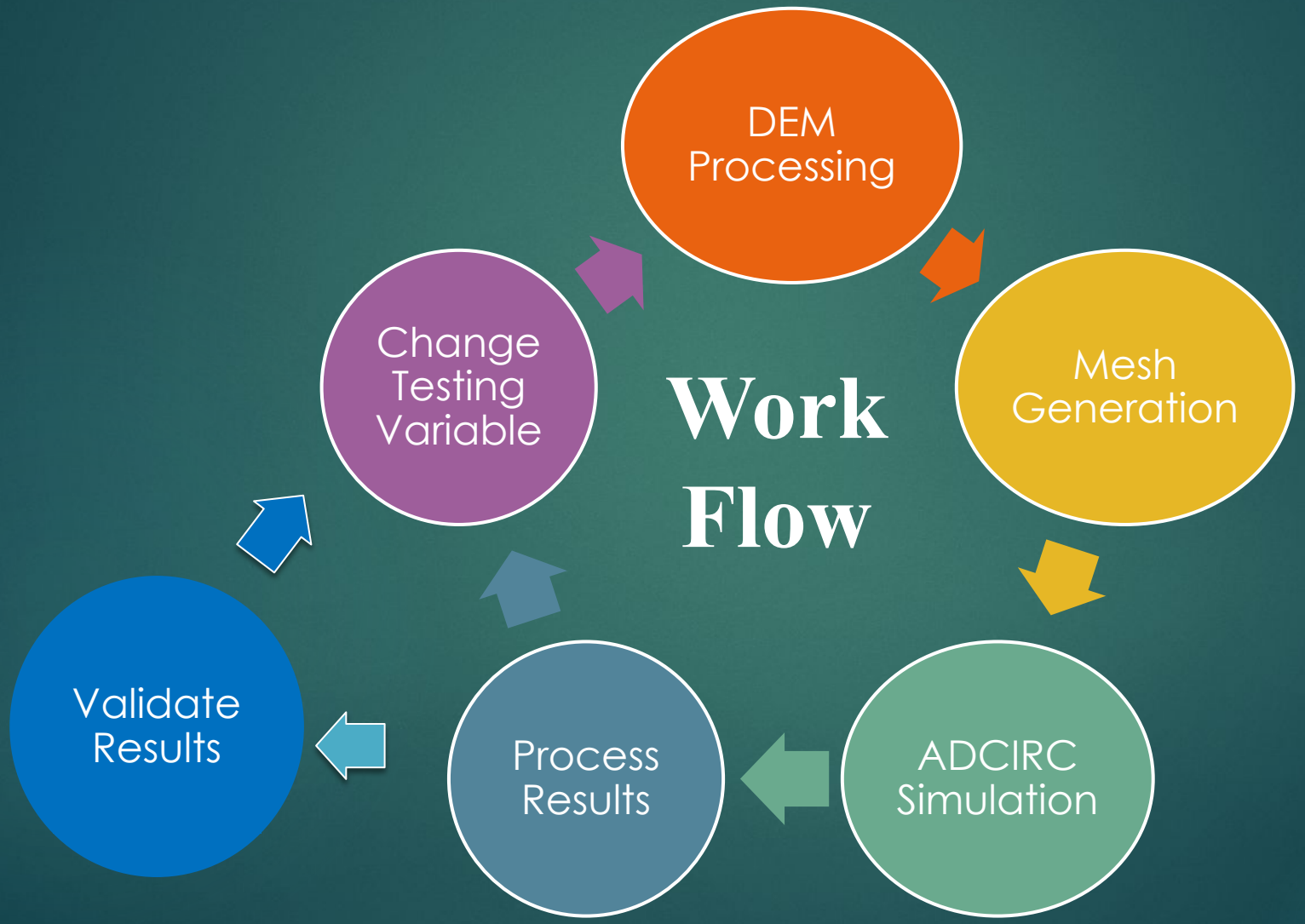
Research Questions

- How do uncertainties in tropical cyclones influence the extent and magnitude of storm surge at a hyperlocal site?
- How much greater is the storm surge impacts when determining the “worst-case” scenario for a hyperlocal site?

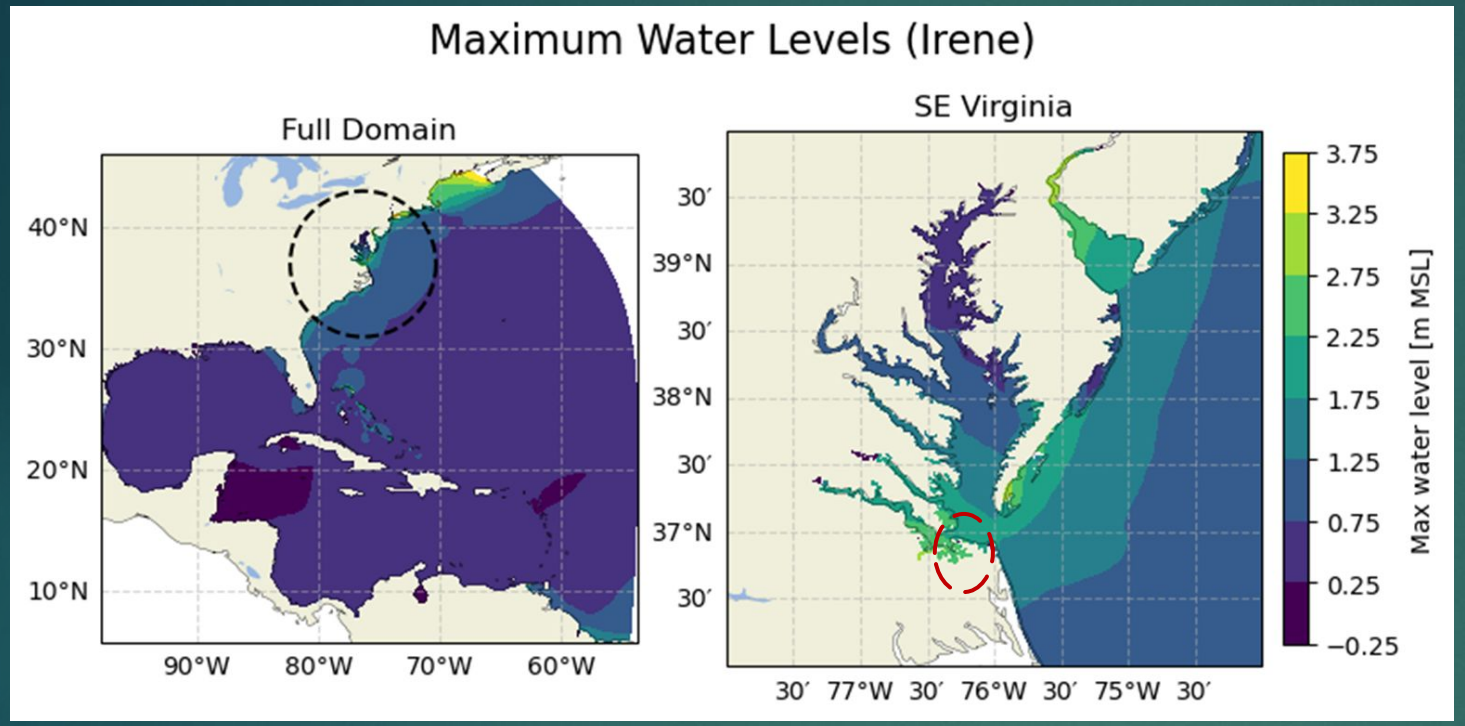


The impact of storm surge varies as the storm changes before it makes landfall.

Research Objectives



Naval Station Norfolk

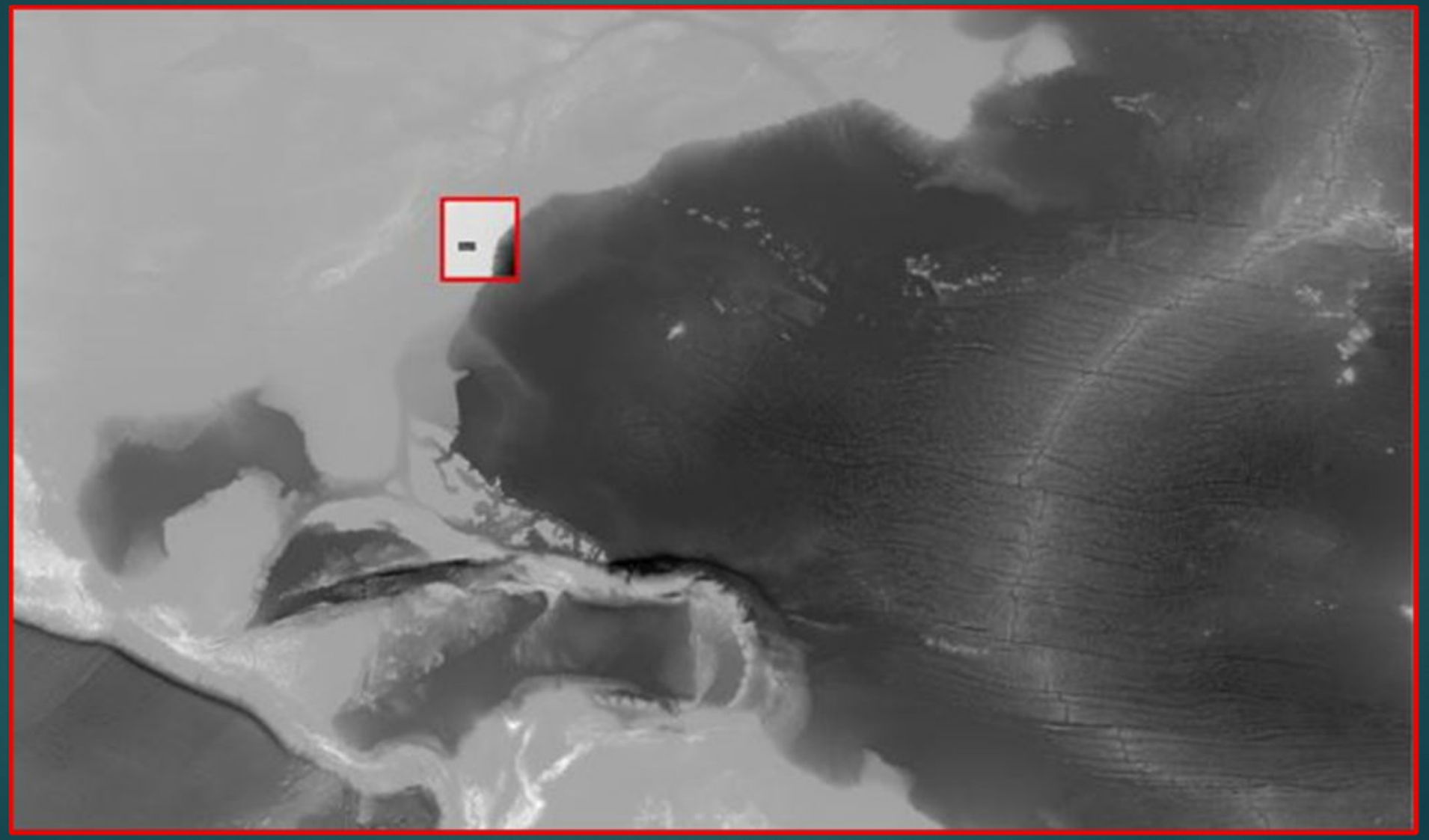


Location Map Using Kalpana Results from Hurricane Irene

Naval Station Norfolk

https://github.com/ccht-ncsu/Kalpana

3 DEMs at Different Resolutions



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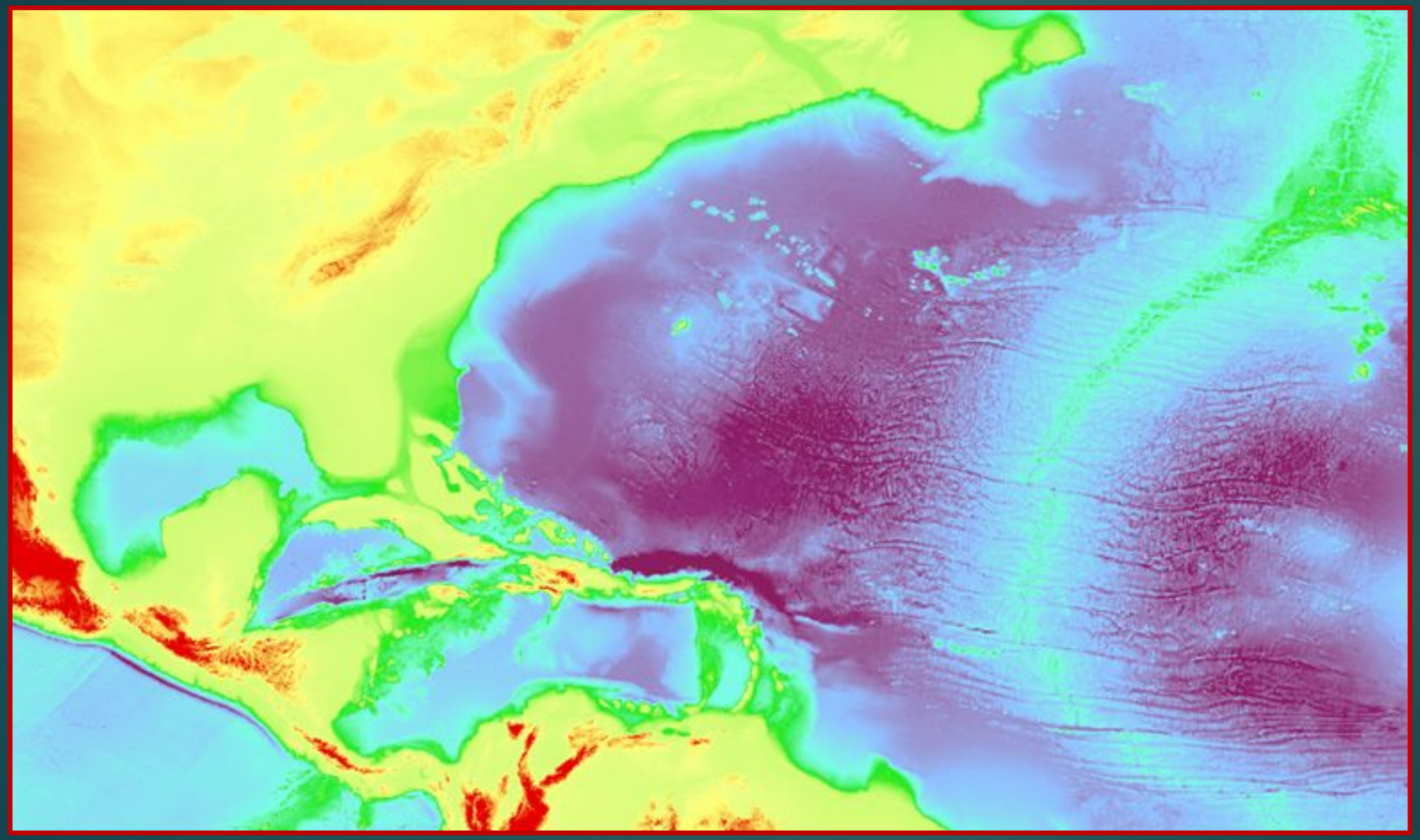
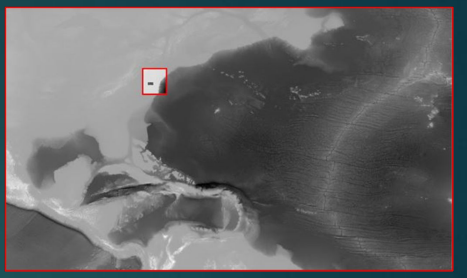
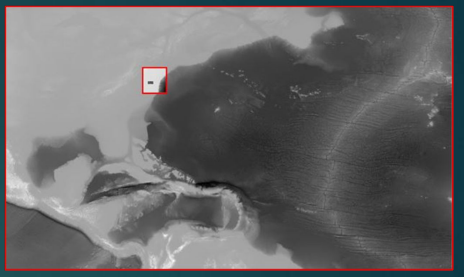
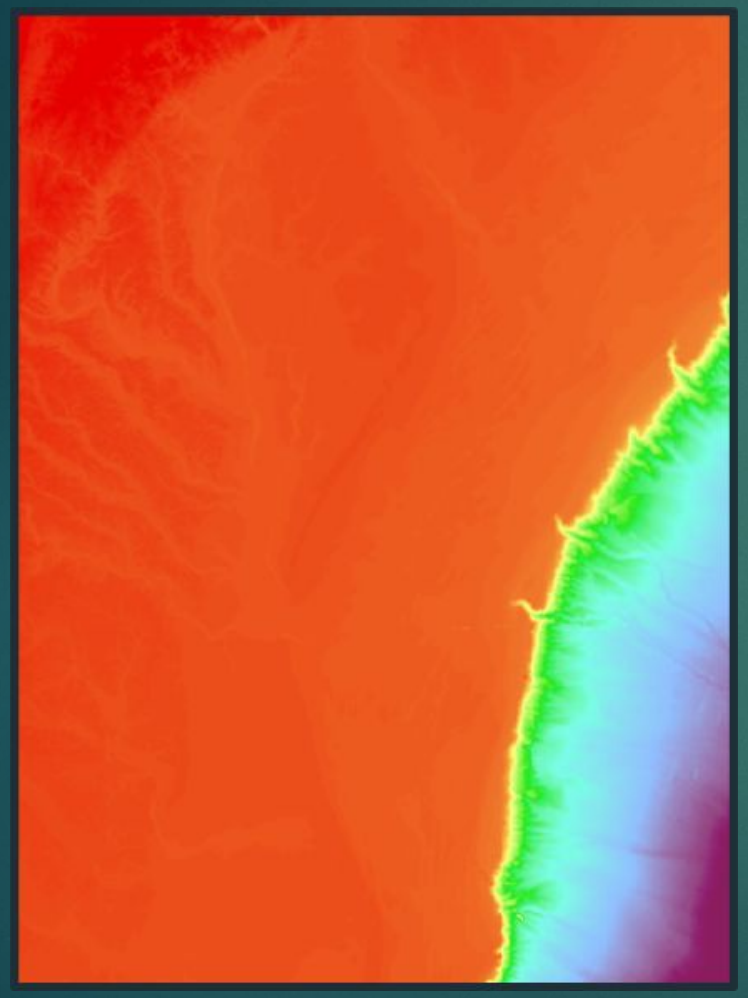




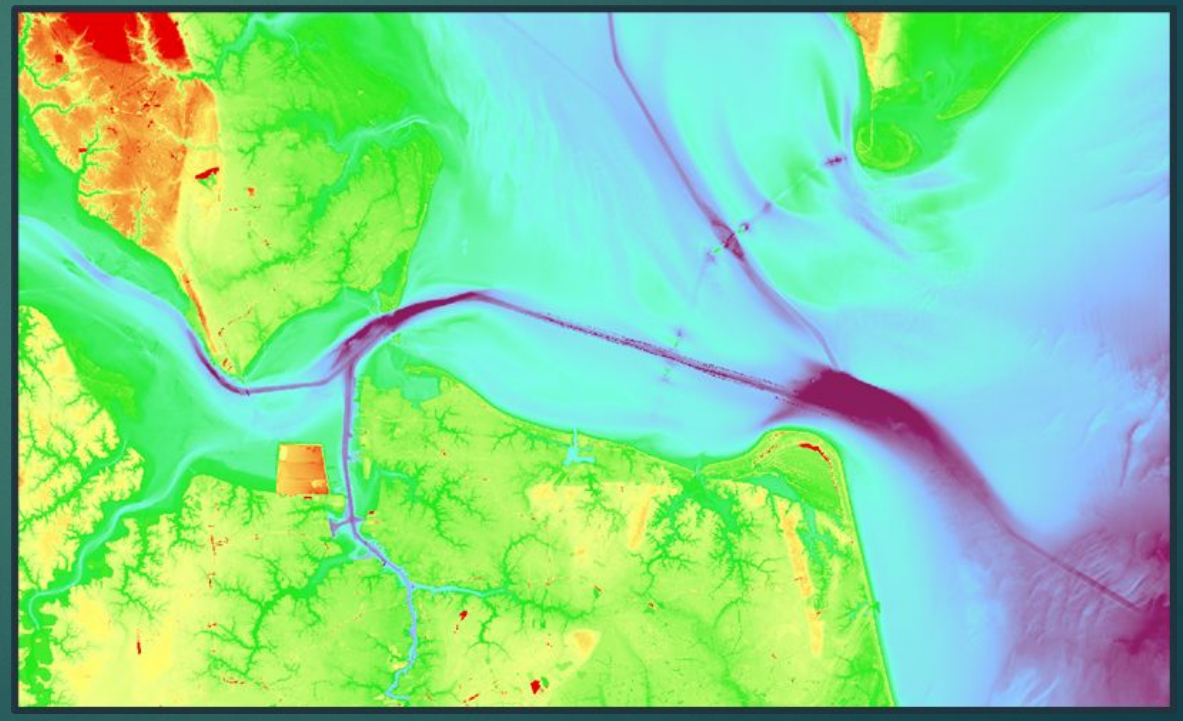
500m - 2018 Shuttle Radar Topography Mission (SRTM)

3 DEMs at Different Resolutions



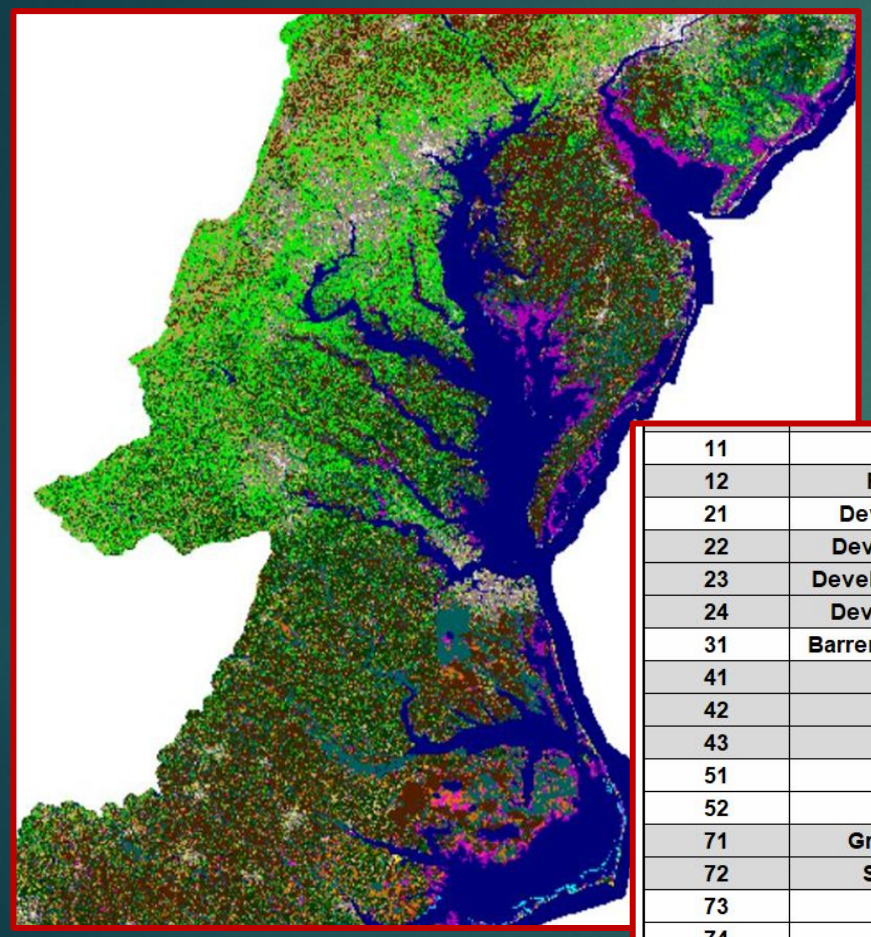


30m - Nested 2014 CUDEM



10m - Nested 2014 CUDEM

Mesh Development – Land Use and Land Cover



The 2016 Coastal Change Analysis Program (CCAP)

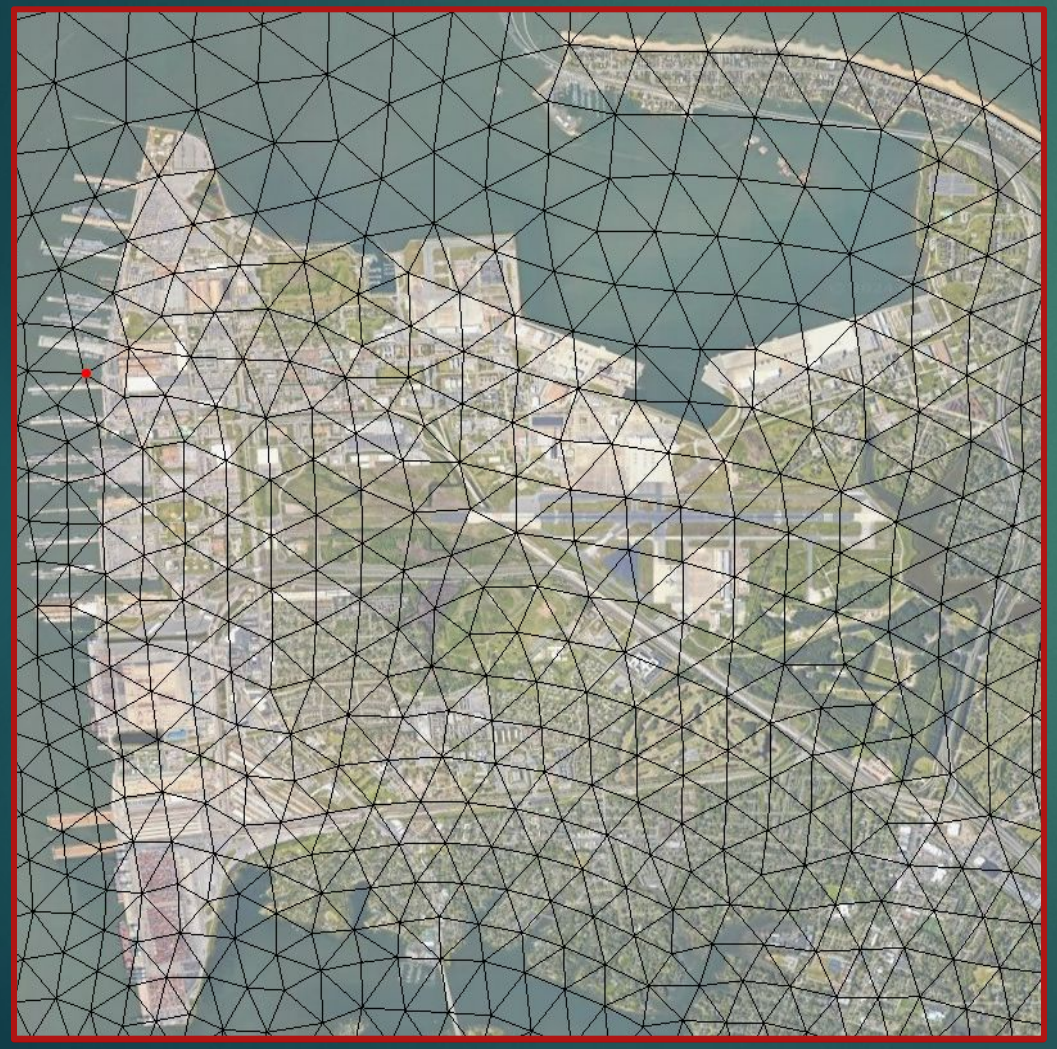
11	Open Water	0.025 - 0.05
12	Perennial Ice/Snow	N/A
21	Developed, Open Space	0.03 - 0.05
22	Developed, Low Intensity	0.06 - 0.12
23	Developed, Medium Intensity	0.08 - 0.16
24	Developed, High Intensity	0.12 - 0.20
31	Barren Land (Rock/Sand/Clay)	0.023 - 0.030
41	Deciduous Forest	0.10 - 0.20
42	Evergreen Forest	0.08 - 0.16
43	Mixed Forest	0.08 - 0.20
51	Dwarf Scrub*	0.025 - 0.05
52	Shrub/Scrub	0.07 - 0.16
71	Grassland/Herbaceous	0.025 - 0.05
72	Sedge/Herbaceous*	0.025 - 0.05
73	Lichens*	N/A
74	Moss*	N/A
81	Pasture/Hay	0.025 - 0.05
82	Cultivated Crops	0.020 - 0.05
90	Woody Wetlands	0.045 - 0.15
95	Emergent Herbaceous Wetlands	0.05 - 0.085

- Covers Mid-Atlantic Region
- Coordinate Ranges
- Min. resolution at 30m
- Use for Wind Reduction Factors and Canopy Coefficient
- Includes 24 classifications [1]

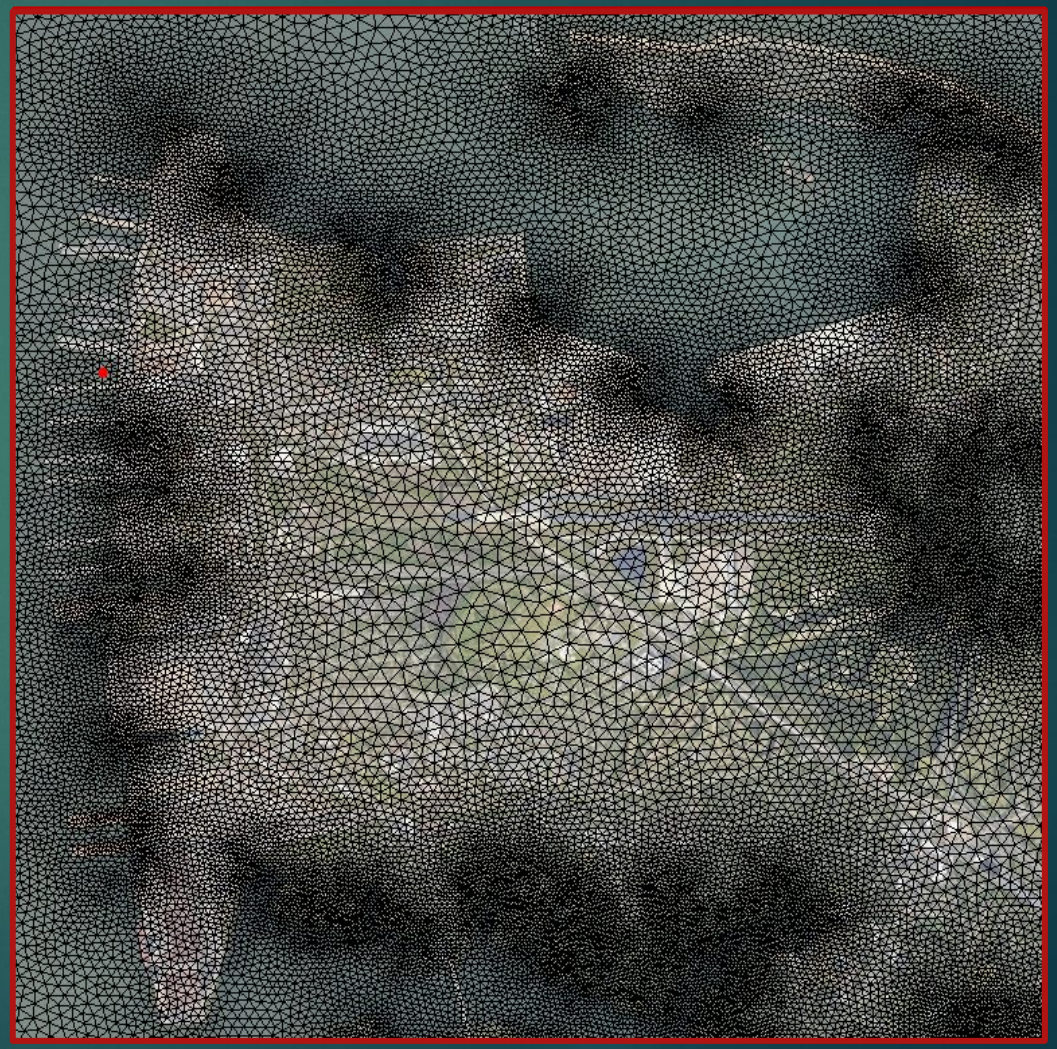
1 – US Army Corps of Engineers (2021)

Less Elements & More Hyperlocal

HSOFS Mesh (3.6 Million Elements)



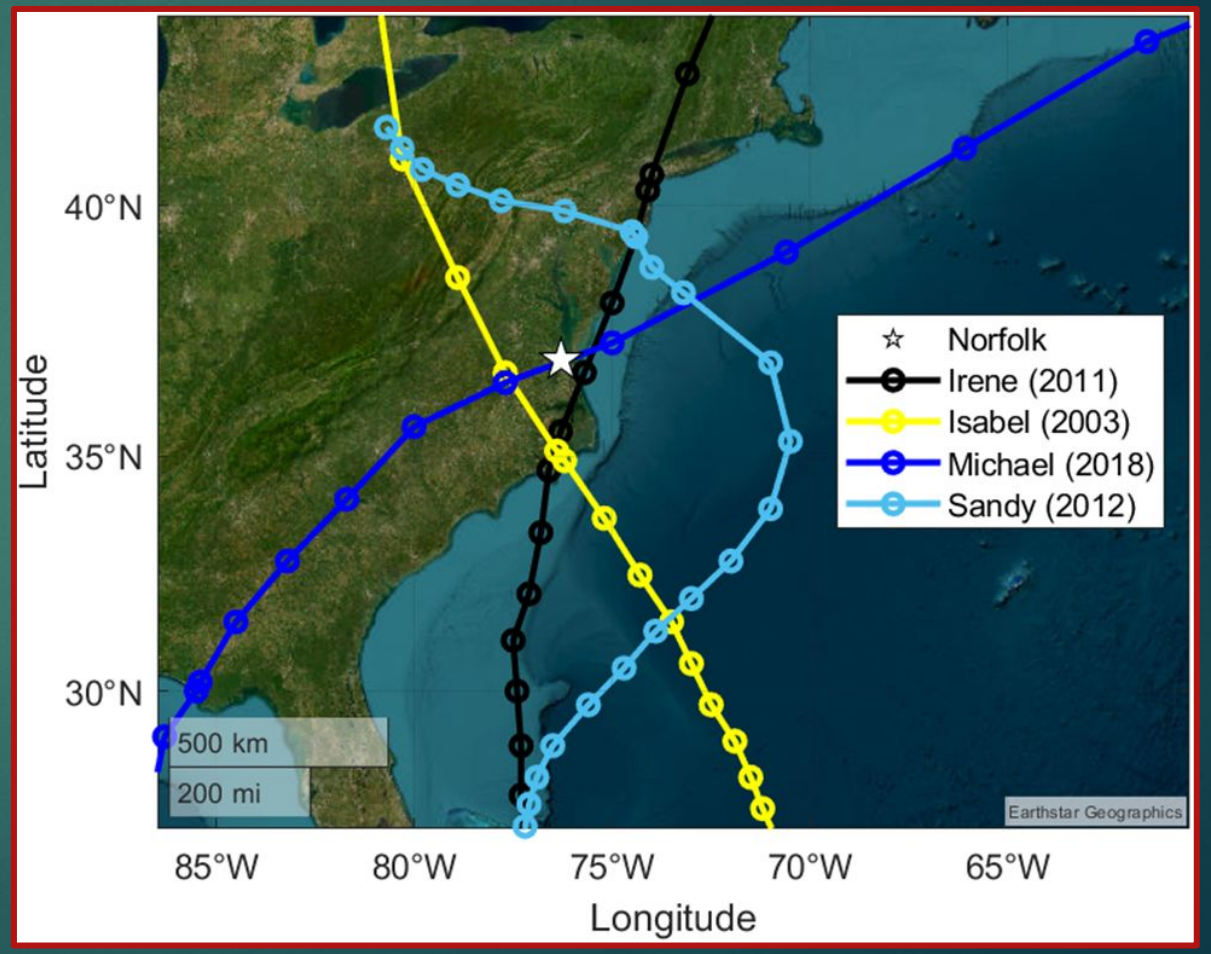
NSNv4 (2.5 Million Elements)



Simulations With ADCIRC+SWAN

- GAHM Wind Model
  - NWS = 20
  - NHC Best Track
- 4 Base Storms Simulated
  - Sea Level Rise[1]
  - Storm Track Deviations[2]
  - Central Pressure Drop[3]
  - Central Wind Speeds[4,5]
  - Radius of Max Winds[6]

Storm Track for simulated storms from National Hurricane Center



1 – Sweet et al (2022)
2 – Salehi (2018)
3 – Mousavi et al (2011)
4 – Camelo et al (2020)
5 – Emanuel (1987)
6 – Xu & Huang (2014)

Storm Simulation Build-Up

Irene (2011)
Isabel (2003)
Sandy (2012)
Micahel (2018)

Irene (2011)	Base
	Central Pressure Drop
	Storm Track (West Shift)
	Storm Track (East Shift)
	Central Wind Speeds
	Radius Max Winds

Base	-
Central Pressure Drop	1.12
	1.24
	1.36
Storm Track (West Shift)	-100 km
	-178 km
	-255 km
Storm Track (East Shift)	100 km
	178 km
	255 km
Central Wind Speeds	0.925
	1.075
	1.225
Radius Max Winds	0.9
	1.1
	1.25

Irene (2011) - Central Pressure Drops

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
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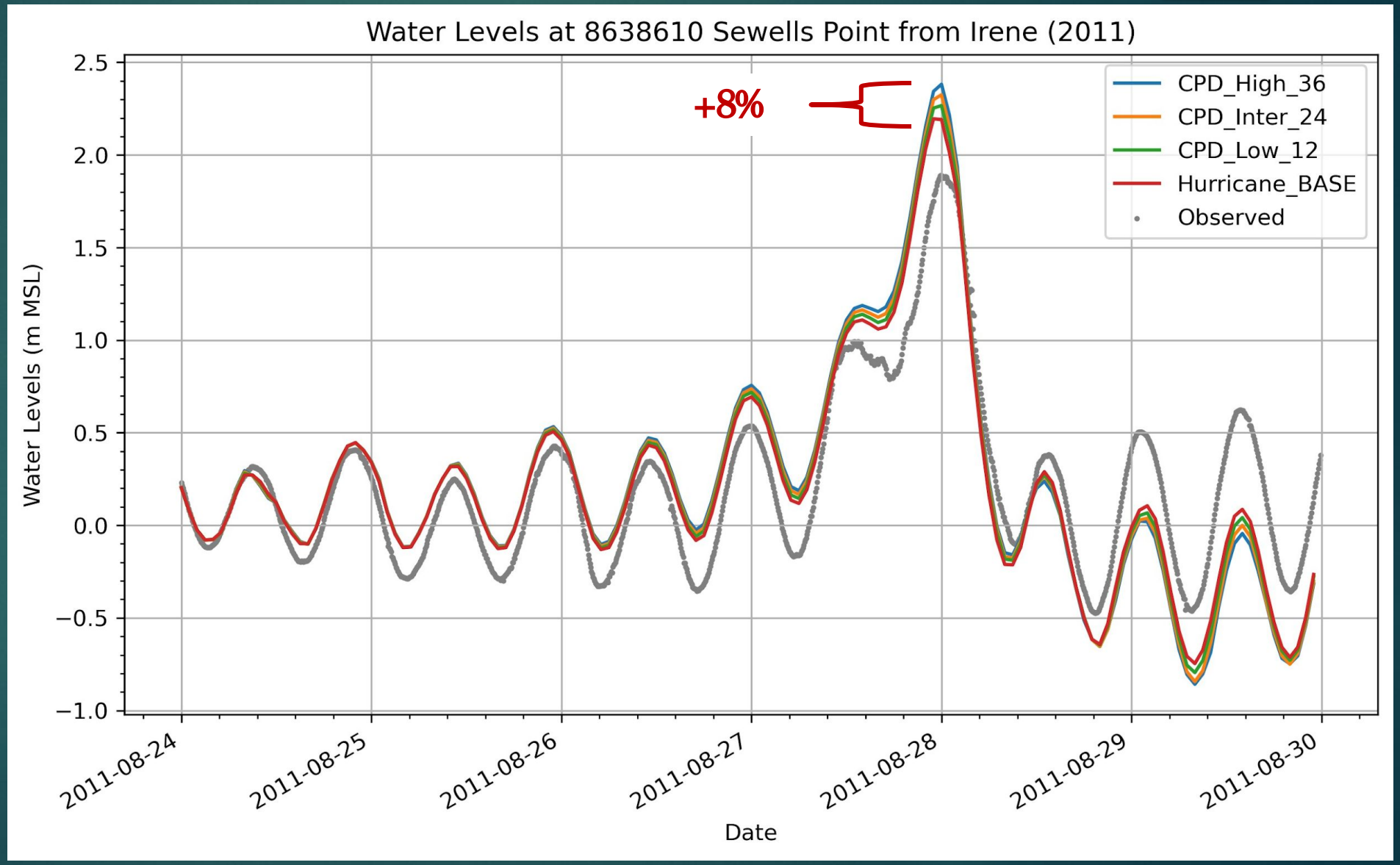

Irene (2011) - Central Pressure Drops

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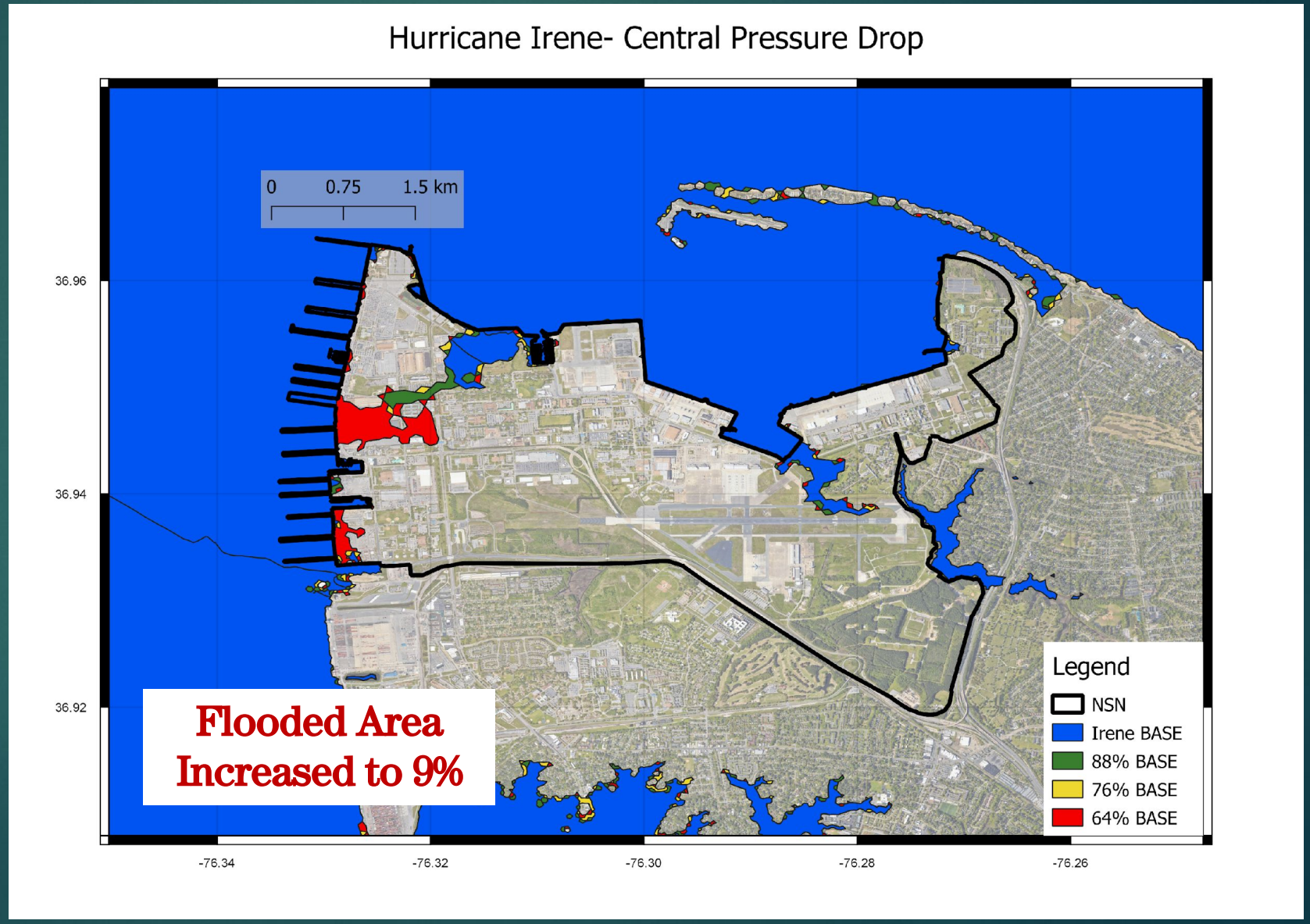

Irene (2011) – Storm Track Deviations

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
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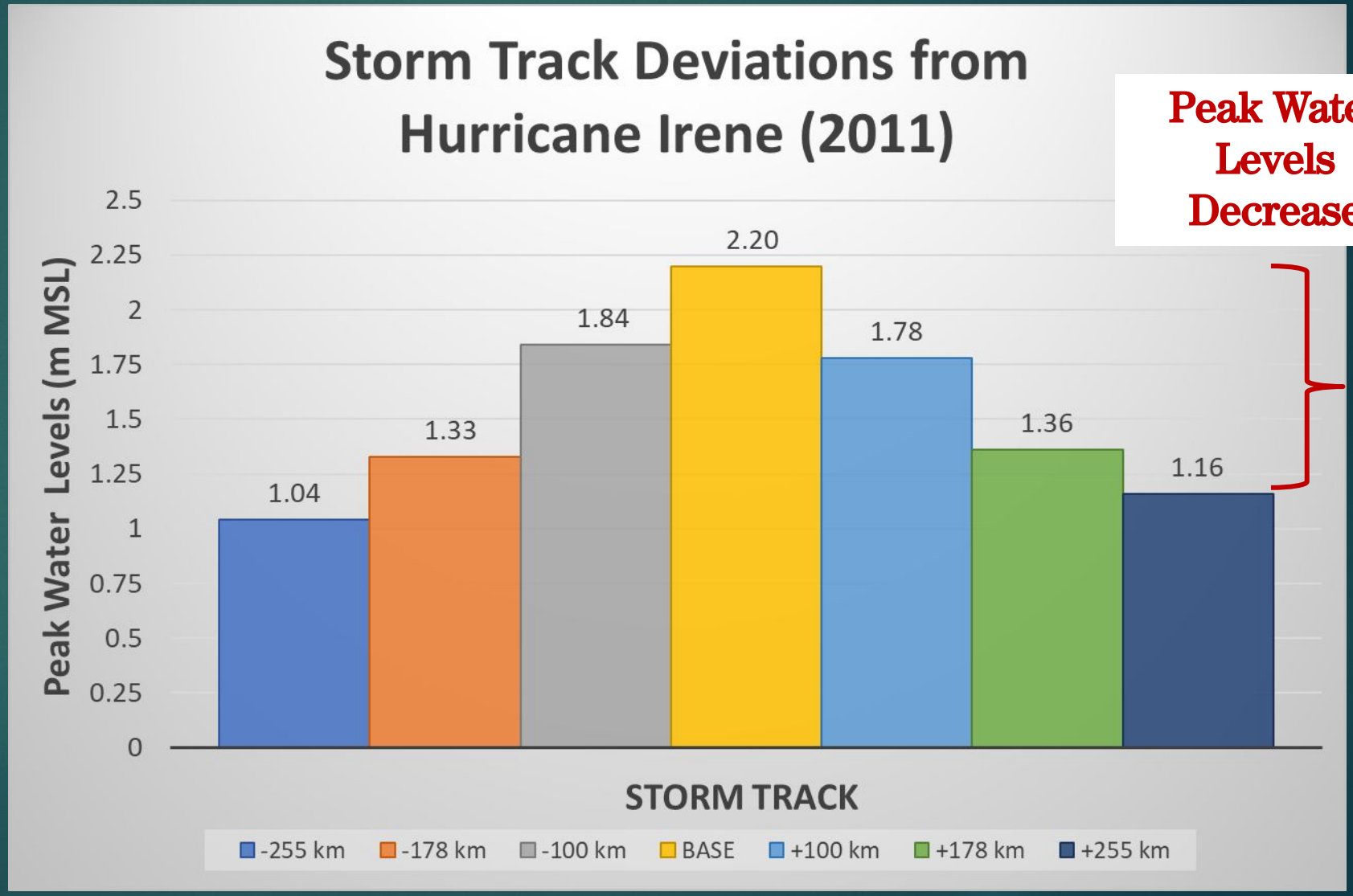

Irene (2011) – West Storm Tracks

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
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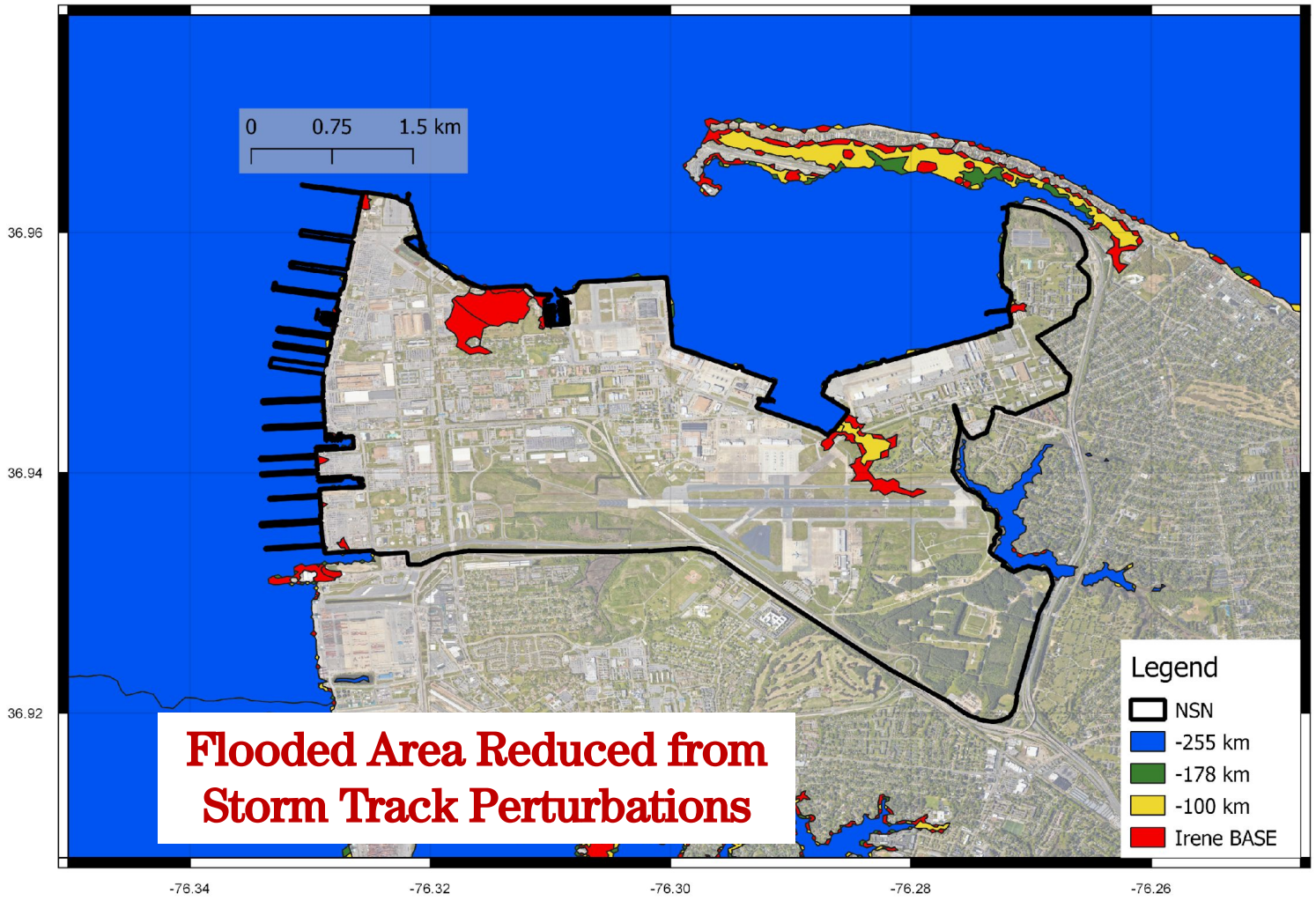

Irene (2011) – East Storm Tracks

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
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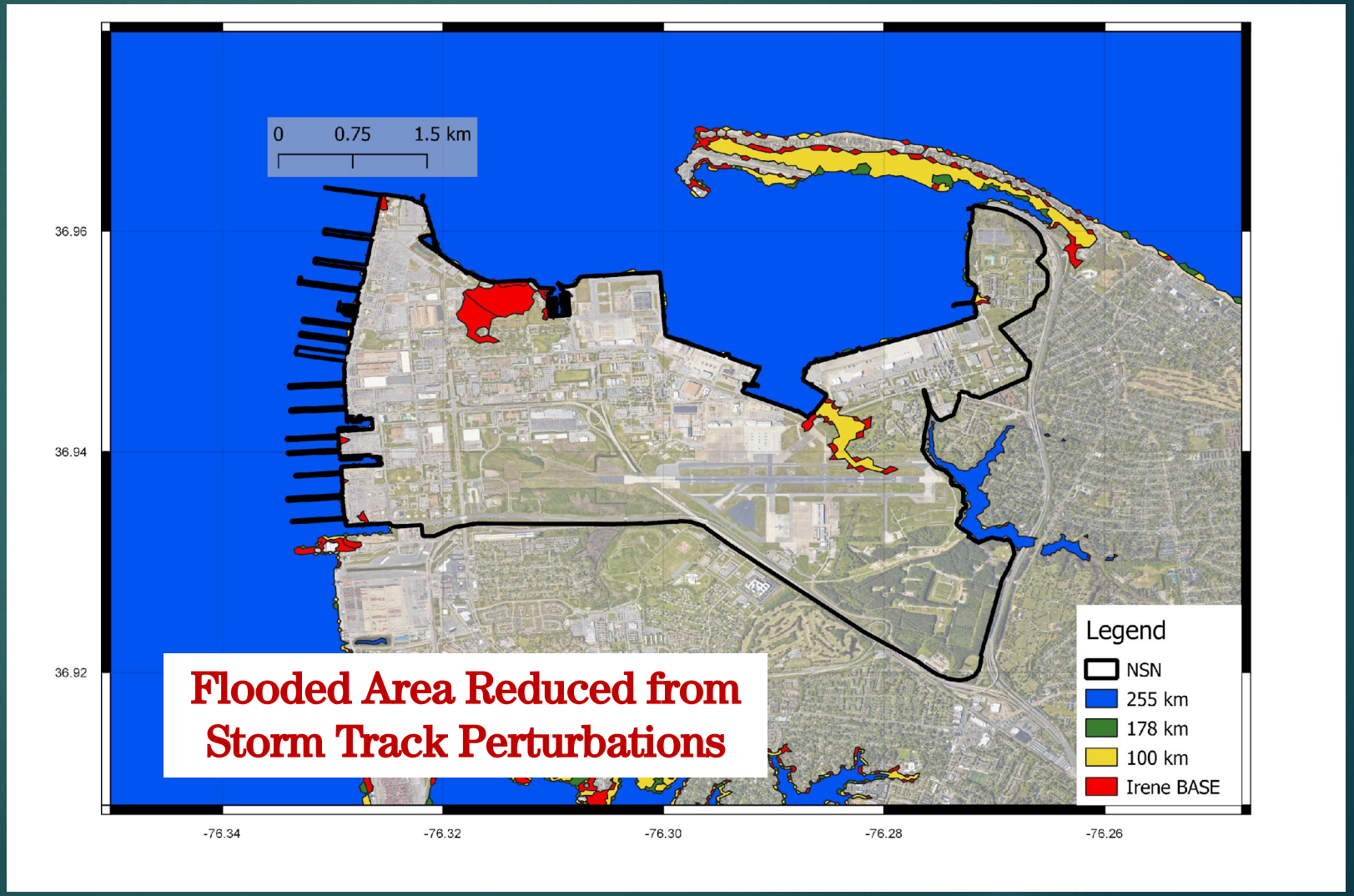

Irene (2011) - Central Wind Speeds

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	Radius Max Winds	0.9
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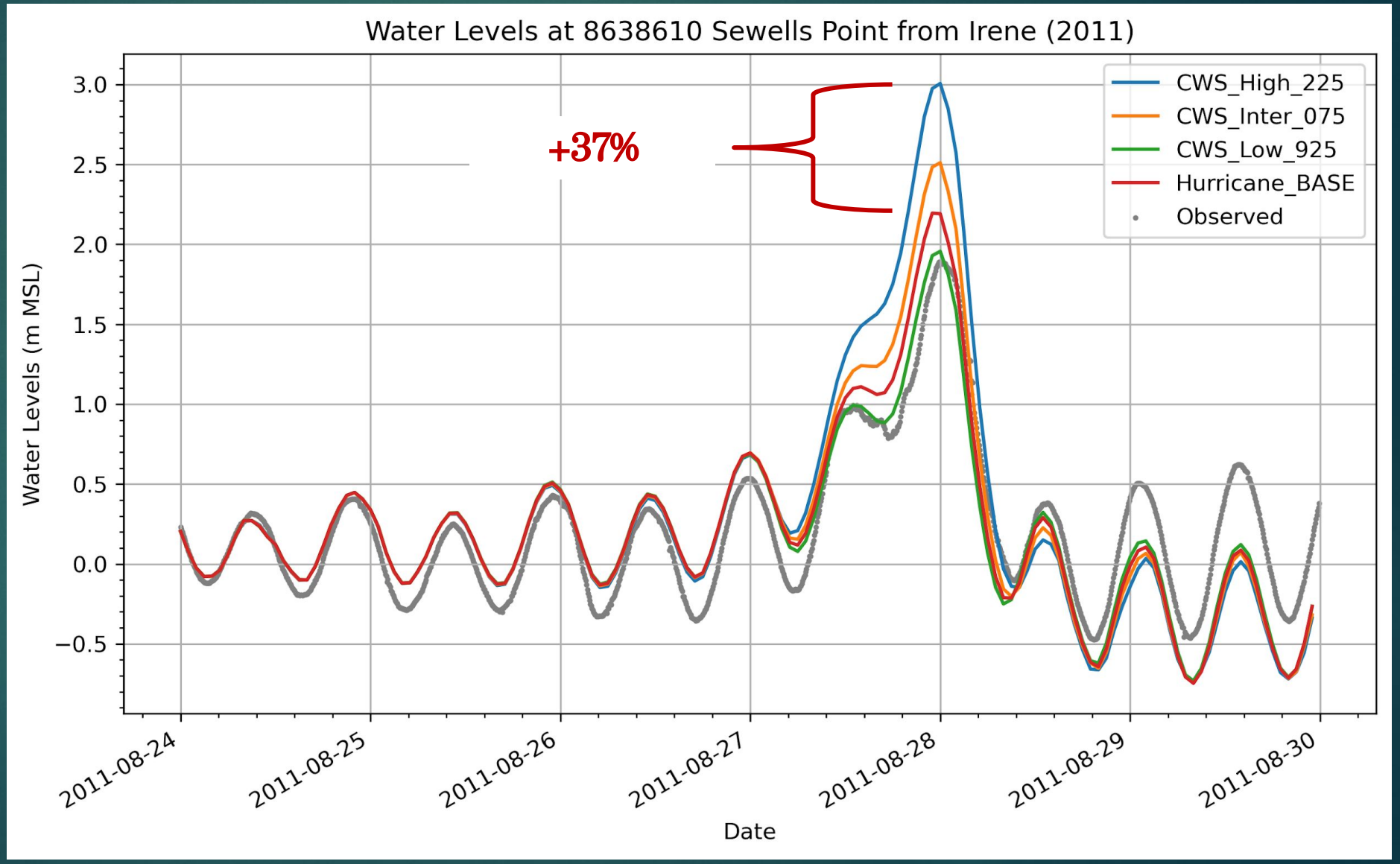

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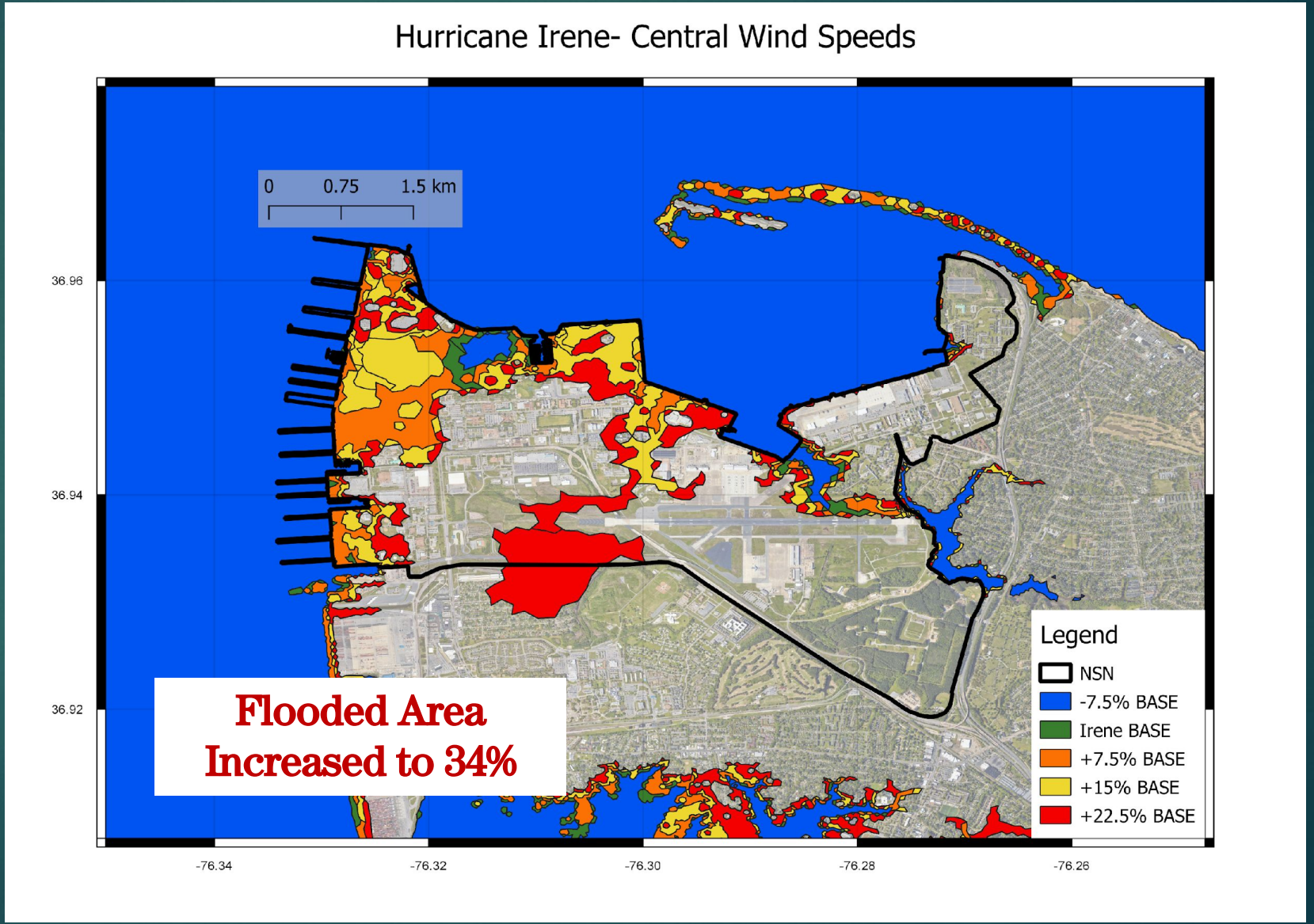
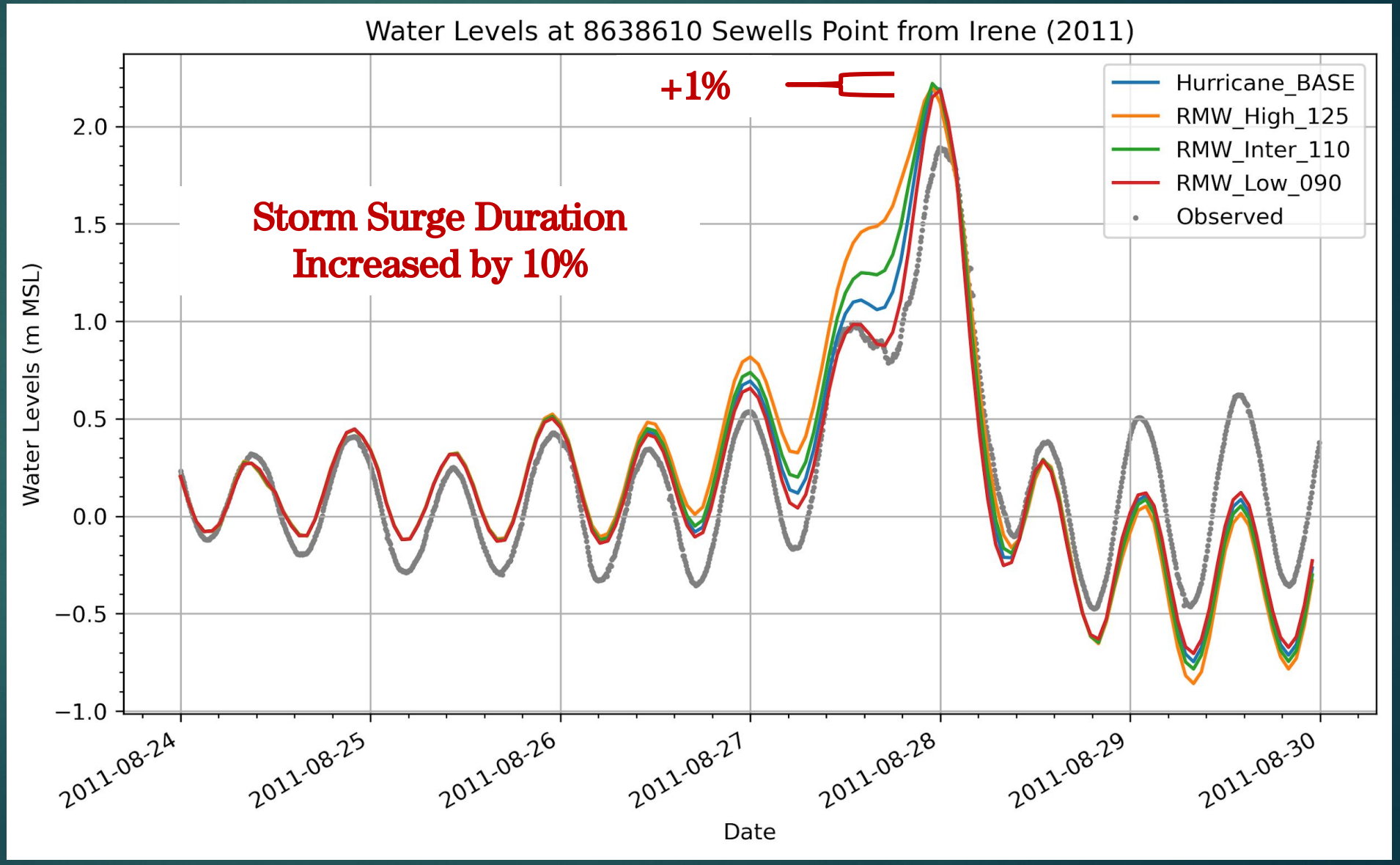
		1.1
		1.25



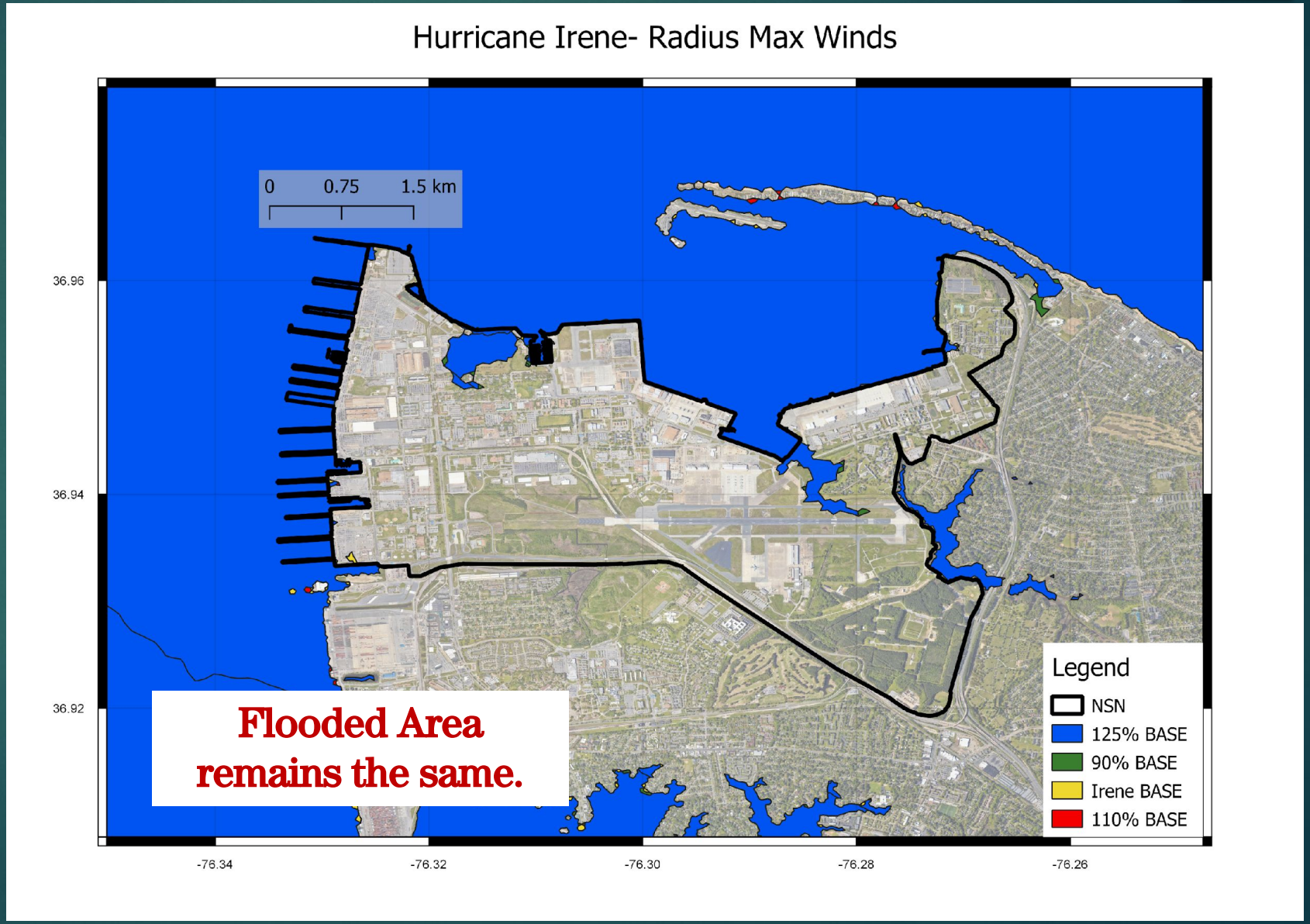
Irene (2011) – Radius of Max Winds

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
	Storm Track (East Shift)	100 km
		178 km
		255 km
	Central Wind Speeds	0.925
		1.075
		1.225
	Radius Max Winds	0.9
		1.1
		1.25



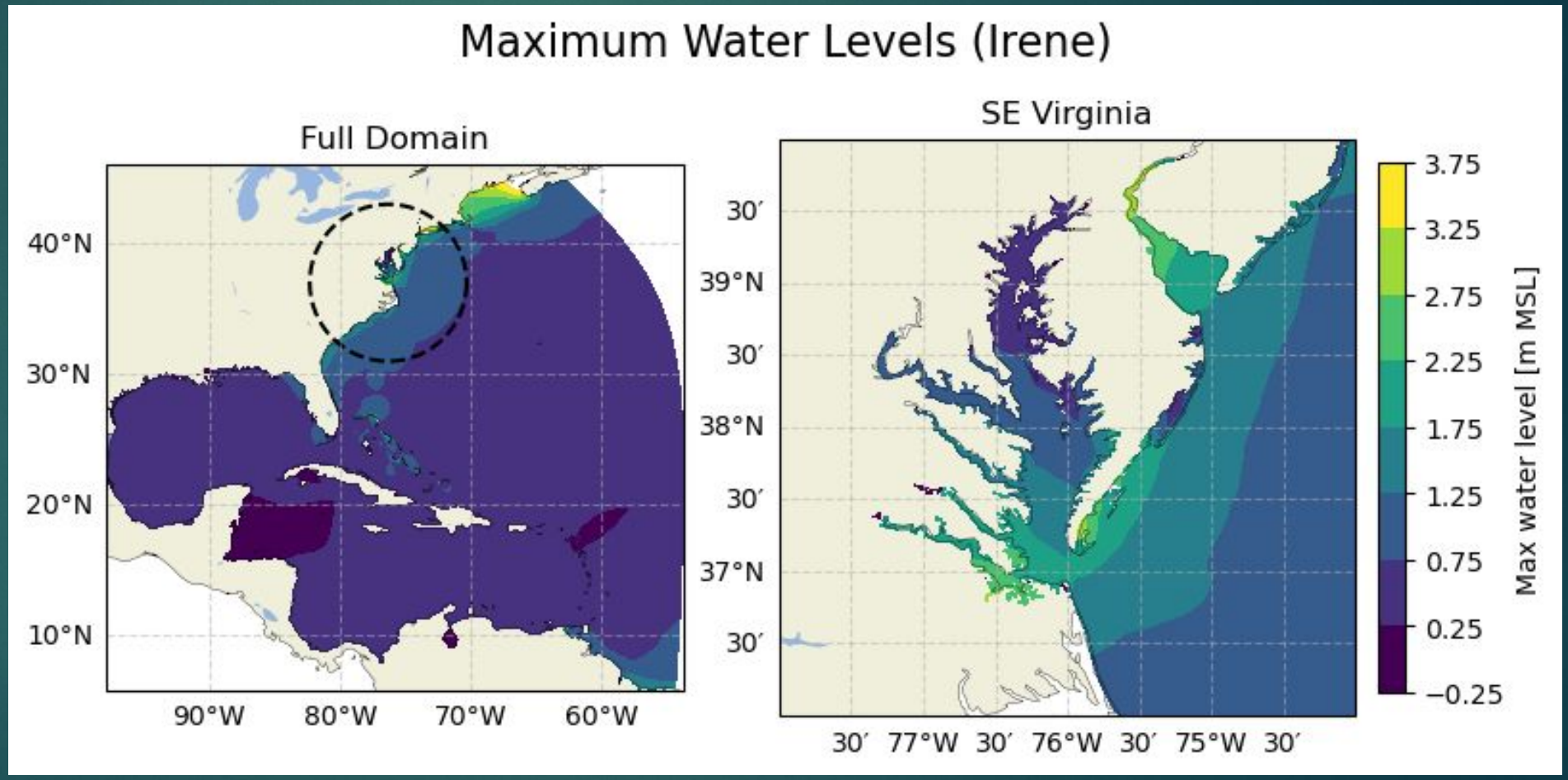
Irene (2011) – Radius of Max Winds

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
	Storm Track (East Shift)	100 km
		178 km
		255 km
	Central Wind Speeds	0.925
		1.075
		1.225
	Radius Max Winds	0.9
		1.1
		1.25



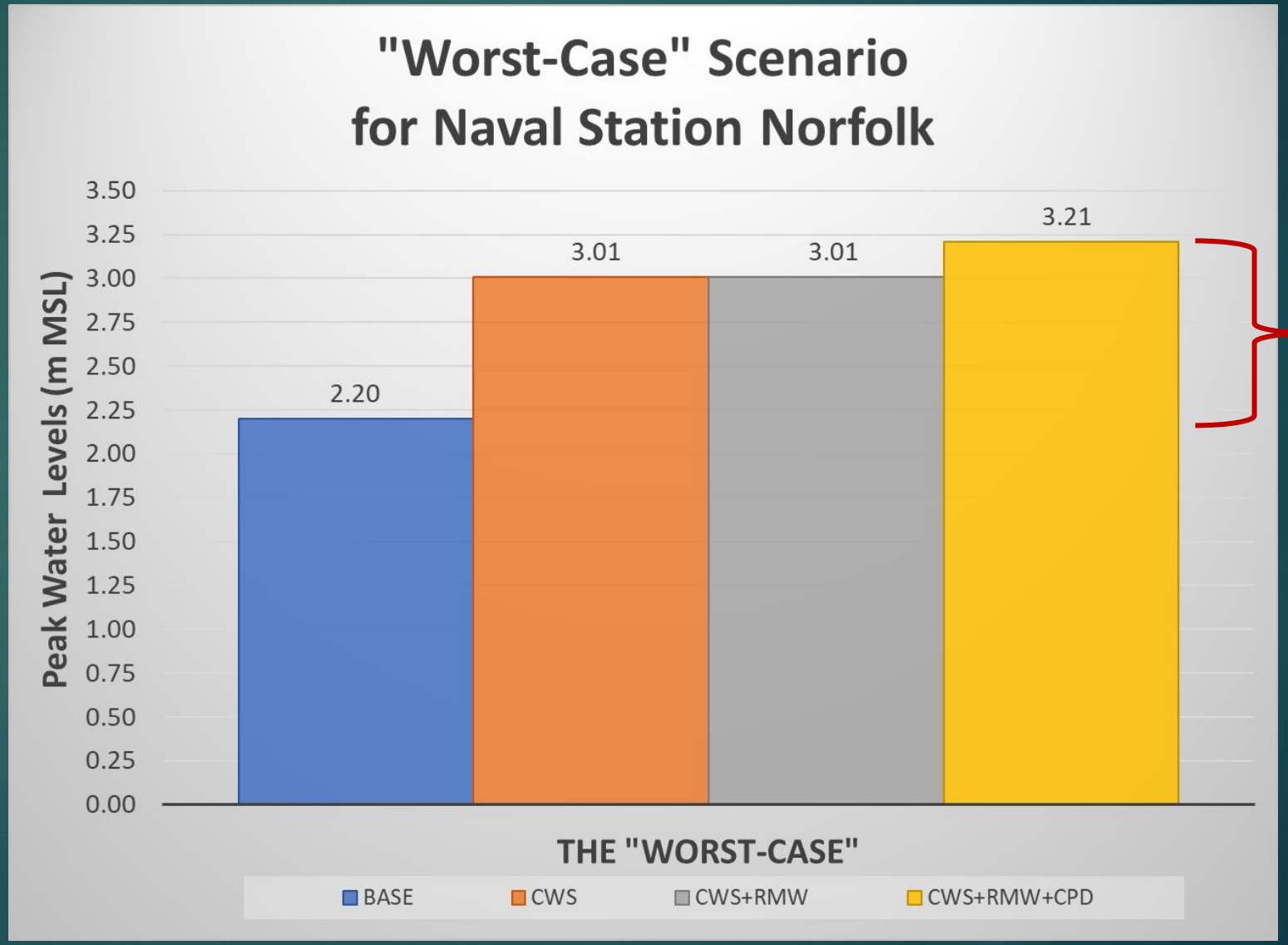
The "Worst-Case" Scenario

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
	Storm Track (East Shift)	100 km
		178 km
		255 km
	Central Wind Speeds	0.925
		1.075
		1.225
	Radius Max Winds	0.9
		1.1
		1.25



"Worst-Case" Scenario: Peak Levels?

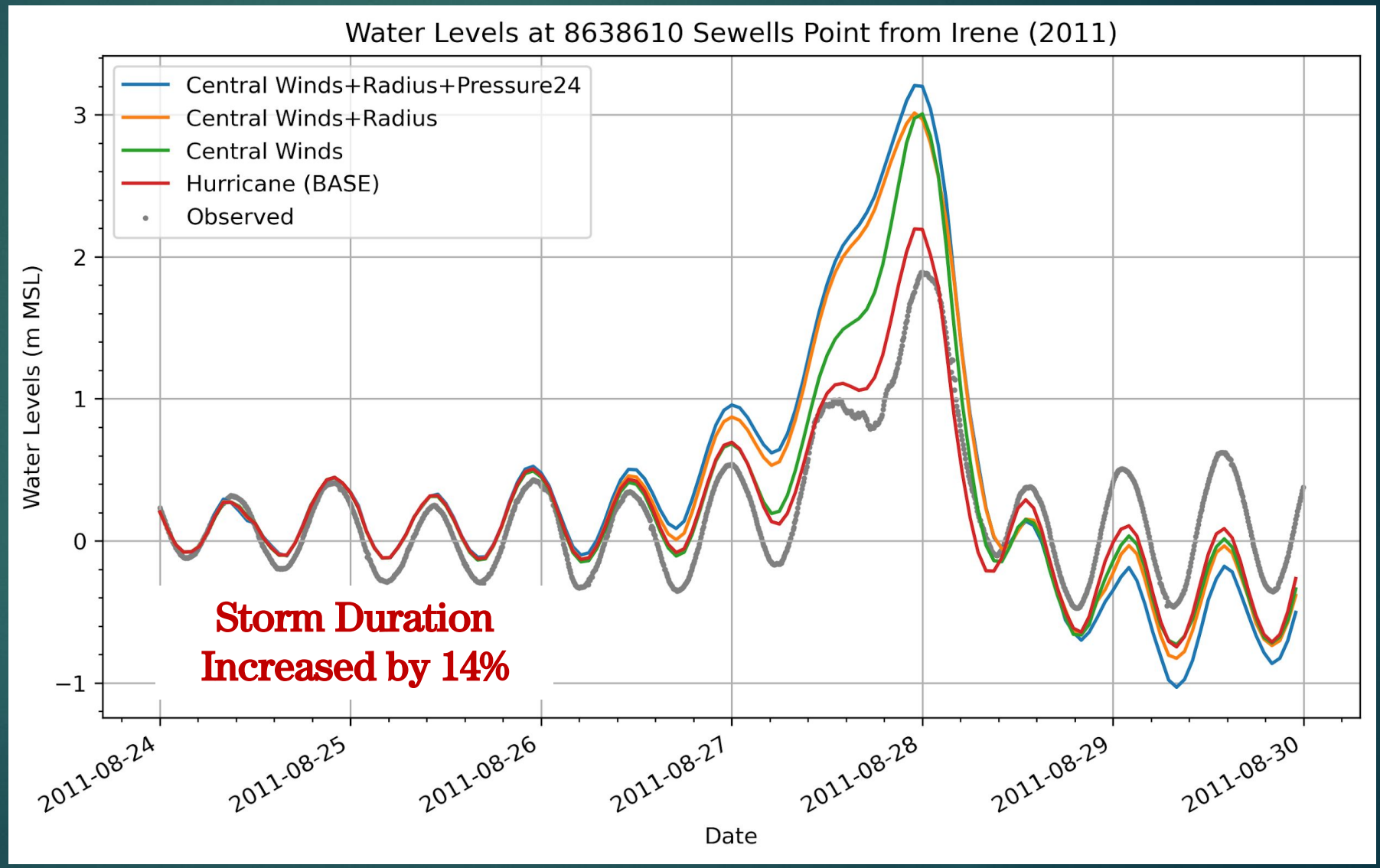
Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
	Storm Track (East Shift)	100 km
		178 km
		255 km
	Central Wind Speeds	0.925
		1.075
		1.225
	Radius Max Winds	0.9
		1.1
		1.25



+46%

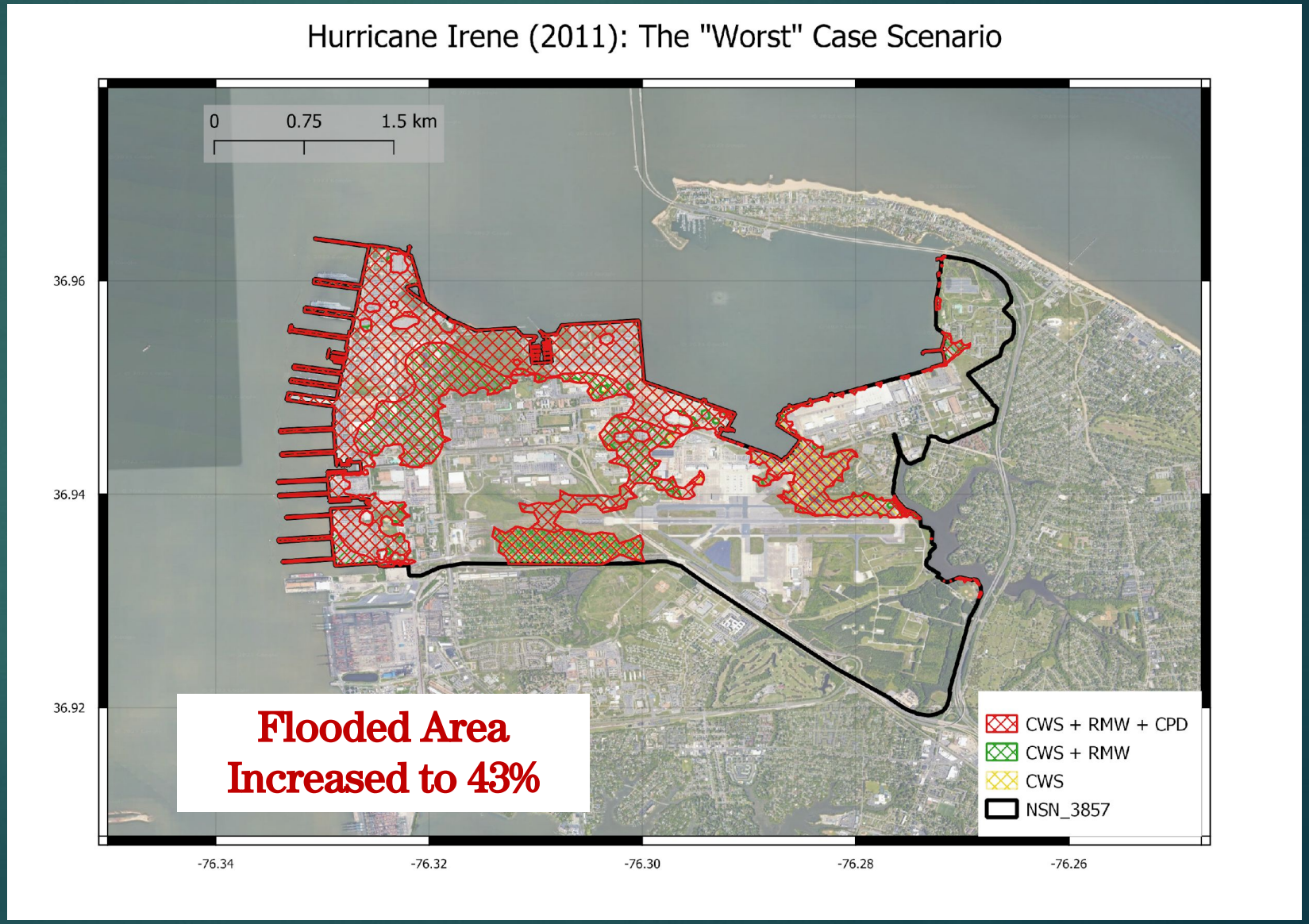
Worst Case Scenario: Surge Duration?

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
	Storm Track (East Shift)	100 km
		178 km
		255 km
	Central Wind Speeds	0.925
		1.075
		1.225
	Radius Max Winds	0.9
		1.1
		1.25

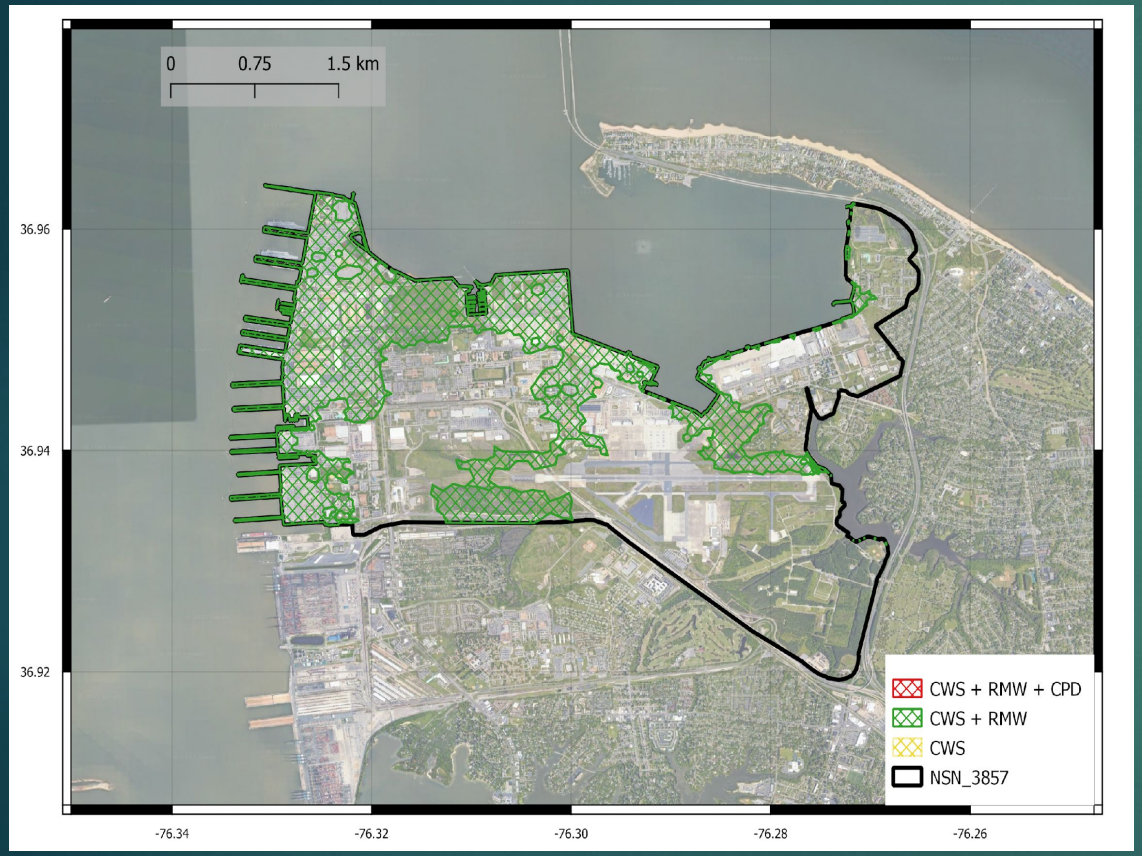


Worst Case Scenario: Inundated Area?

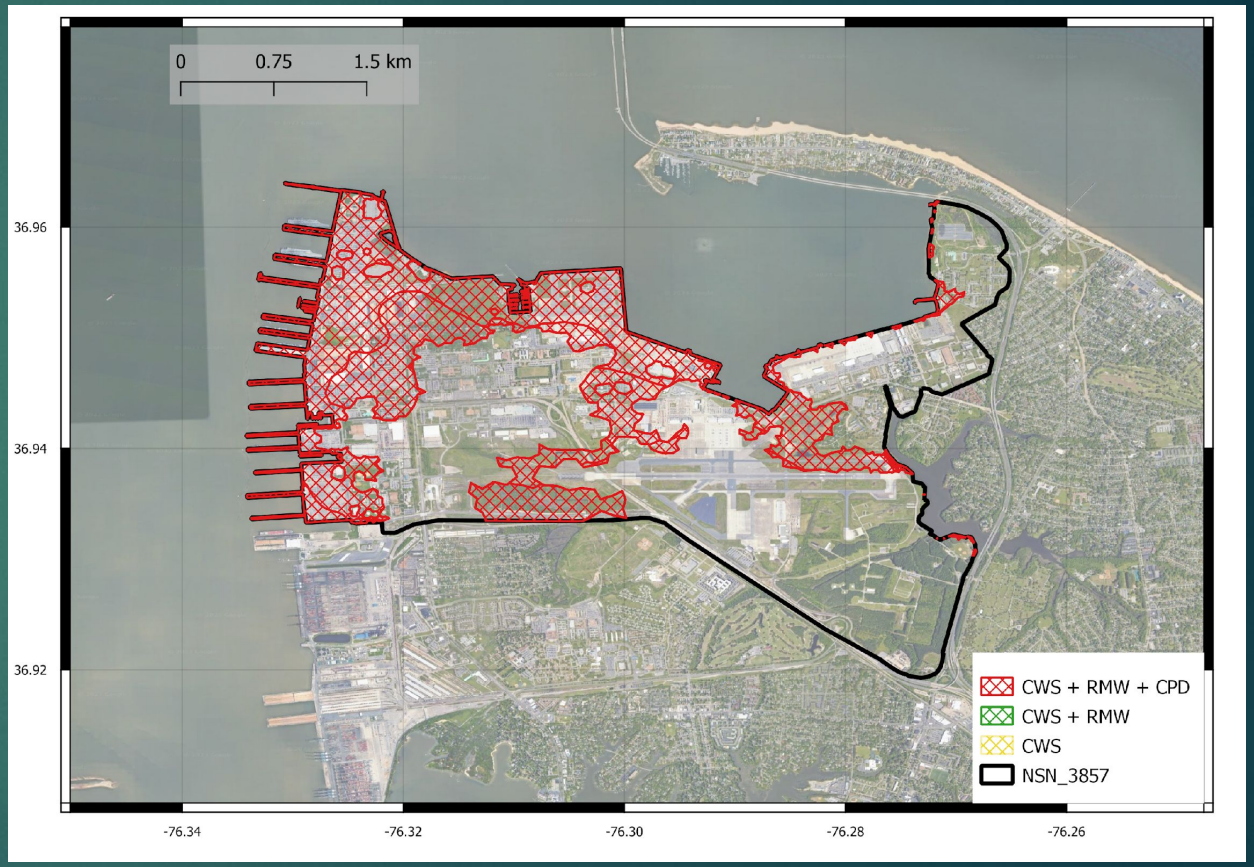
Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
	Storm Track (East Shift)	100 km
		178 km
		255 km
	Central Wind Speeds	0.925
		1.075
		1.225
	Radius Max Winds	0.9
		1.1
		1.25



Contour Lines Show Elevation Changes



Winds Speed + Radius of Winds



Winds Speed + Radius of Winds + Central Pressure

Conclusions

- Storm Parameters influence the Peak Water Levels (PWL), Flooded Areas and Storm Durations for storm surge.
  - -36% CPD has an **+8%** PWL and **+9%** Flooded Area.
  - +22.5% CWS has an **+37%** PWL and **+34%** Flooded Area.
  - +25% RMW has an +**10%** Storm Surge Duration.
  - The position of the storm has a significant impact to storm surge.
- Magnitude of storm surge depends on the coupling effects of different storm parameters.
- Linear coupling of storm parameters may not be realistic (Low probability).

Thank You

Storm Simulation Build-Up

Hurricane	Max Category	Max Wind Speed (m/s)	Min. Pressure (mb)	Storm Size (km)[1]
Isabel (2003)	5	75	915	83
Irene (2011)	3	54	942	820
Sandy (2012)	3	51	940	1450
Michael (2018)	5	72	919	90

Base	-
Central Pressure Drop	1.12
	1.24
	1.36
Storm Track (West Shift)	-100 km
	-178 km
	-255 km
Storm Track (East Shift)	100 km
	178 km
	255 km
Central Wind Speeds	0.925
	1.075
	1.225
Radius Max Winds	0.9
	1.1
	1.25