STORM SURGE PREDICTIONS AT HYPERLOCAL SITES

The "Worst-Case" Scenario for Naval Station Norfolk

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Young Coastal Scientists and Engineers – Americas 2024

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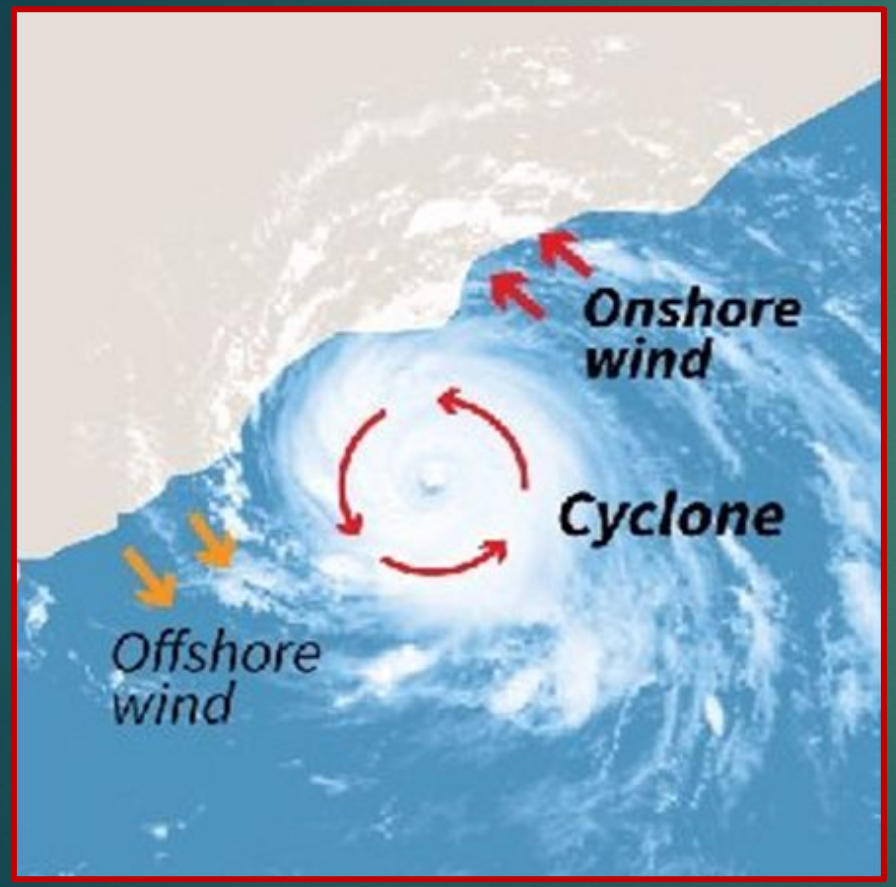
NC STATE UNIVERSITY

SOUTHEAST Climate Adaptation Science Center

ESTCP

High Winds Cause Storm Surge!!



Storm Surge from hurricane wind fields[1]

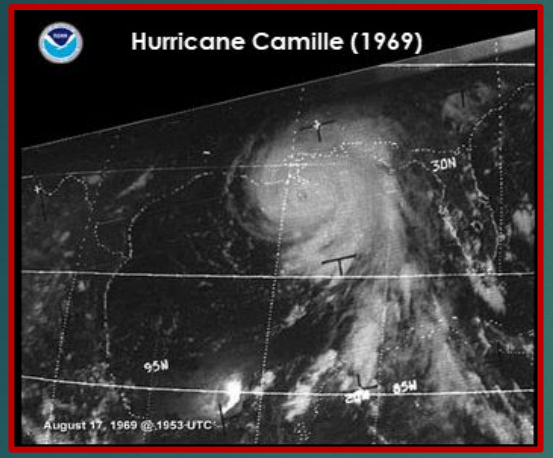
- Hurricane winds push sea water towards the coast
- Basic Storm Parameters[2]:
  - Diameter (km) : 300 - 1000
  - Eye(km): 30 - 80
  - Rotational Velocity(m/s): 30-70
  - Linear Velocity(m/s): 2 -10
  - Duration (days): 1-20

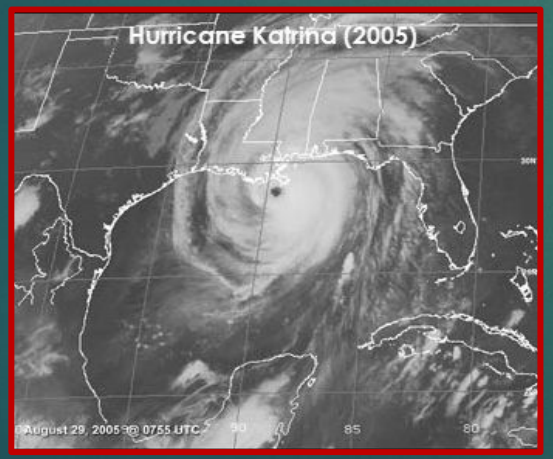
Uncertainties in storm surge sensitivity

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

Storm Sensitivity Studies

Influence of Storm Size

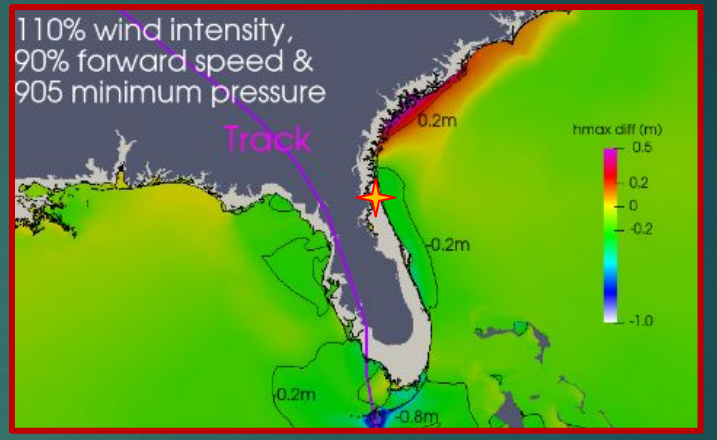




Aerial Images of Hurricanes Camille and Katrina[1,2]

Effects of Wind Intensity, Forward Speed, & Pressure

A)



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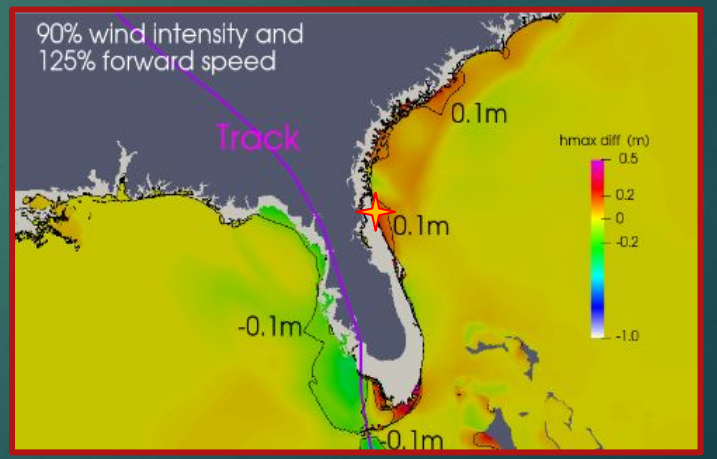
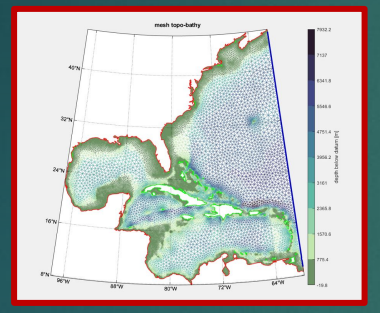


Variations of Max Water elevations from different cases[3]

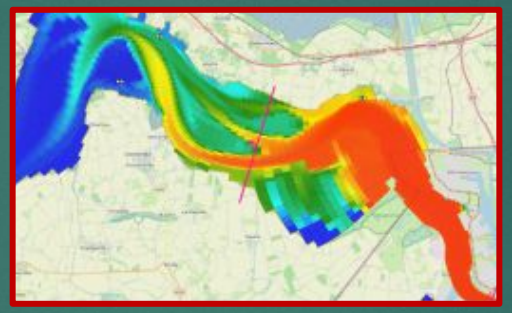
1 – National Weather Service
2 – Irish et. al (2008)
3 – Musinguzi et.al (2021

On-Going Study!!

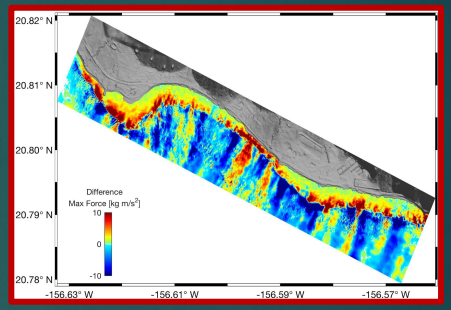
- "Comparative Assessment Of Total Water Levels For Coastal Military Facility Readiness And Resilience Using Numerical Models"



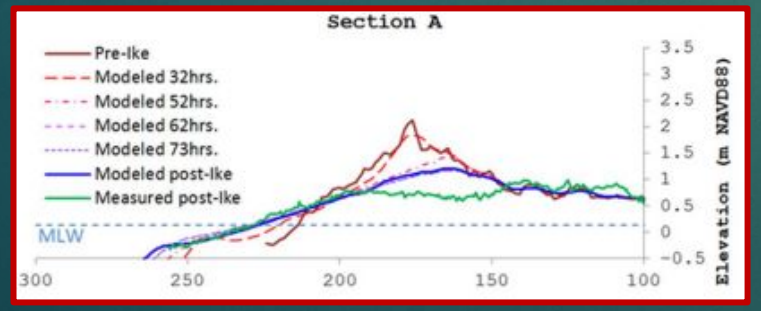
ADCIRC



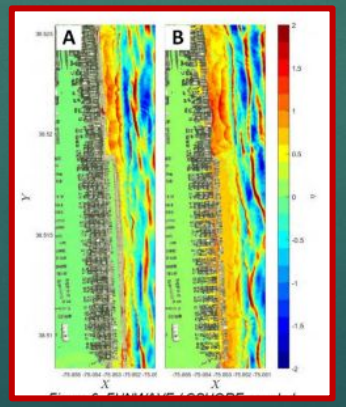
Delft3D



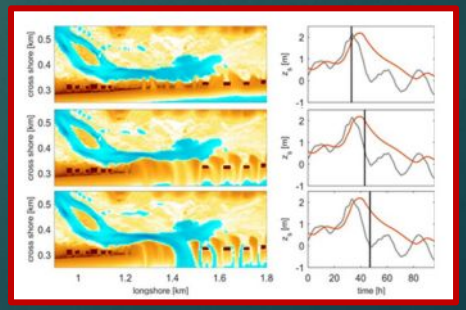
NearCOM



CSHORE

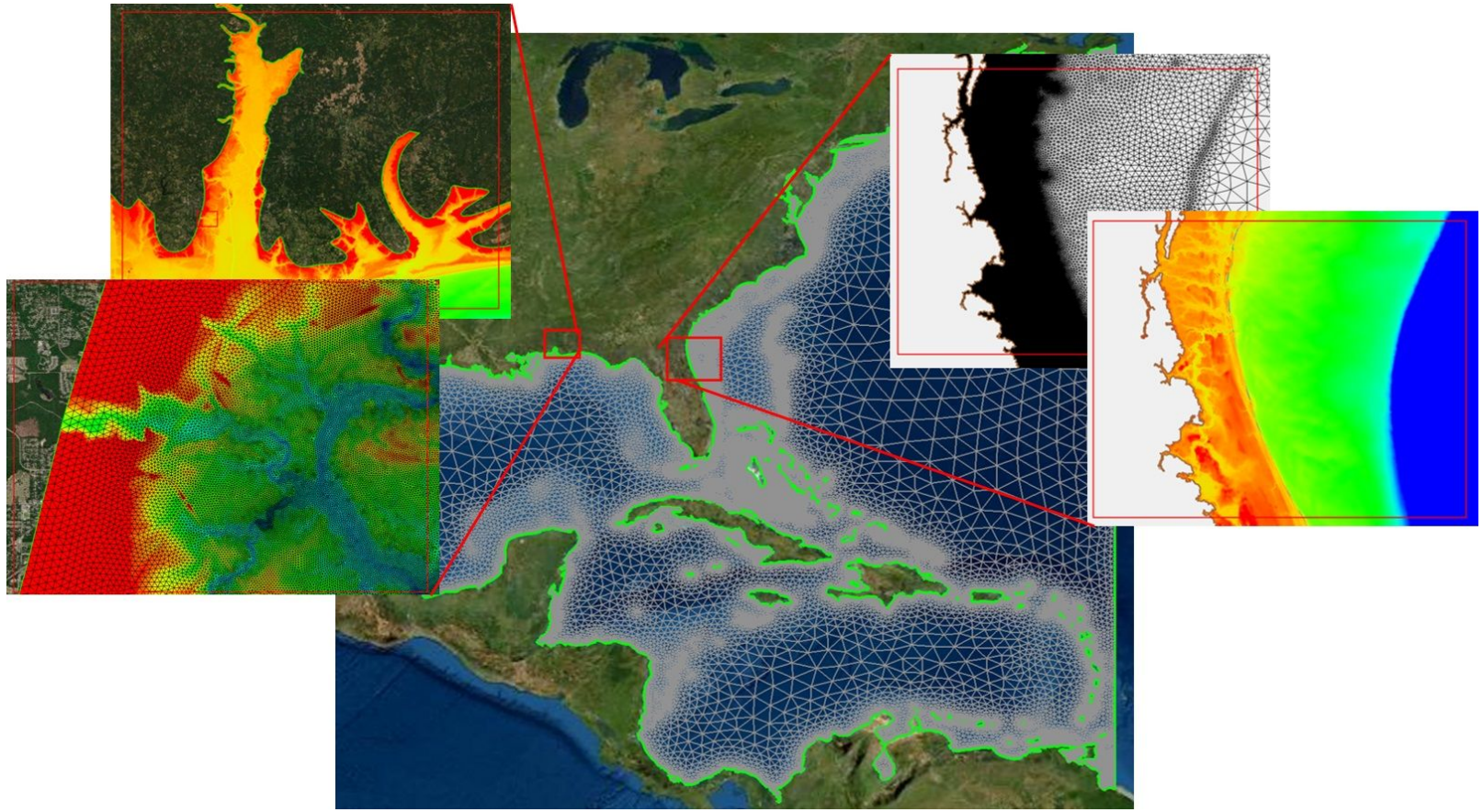


FUNWAVE

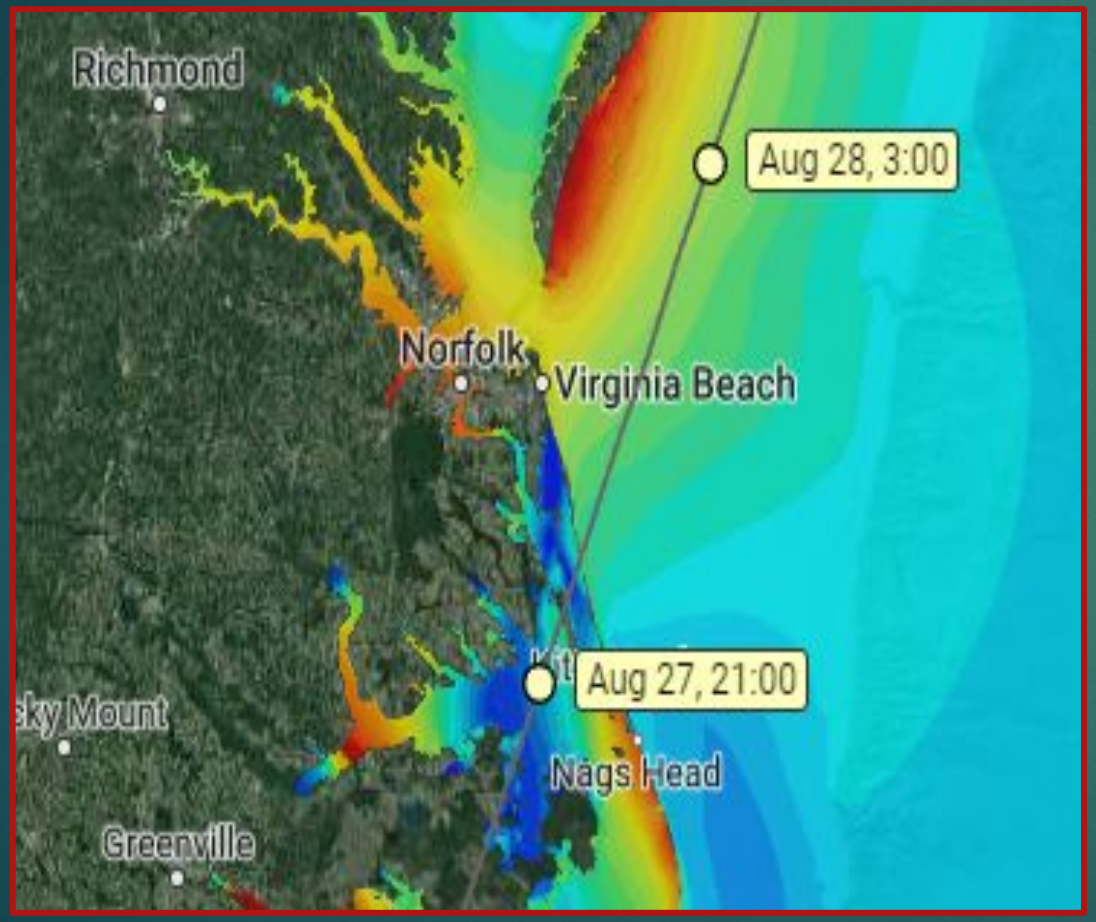


X-Beach

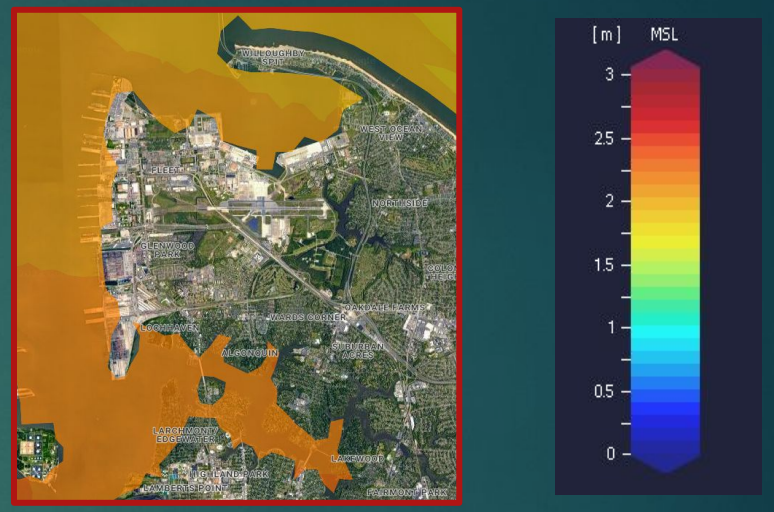
Storm Surge Predictions over Large Scales



What does this look like at hyperlocal sites?



Storm Track for Hurricane Irene (2011) from CERA



Modeled Water Levels in Norfolk

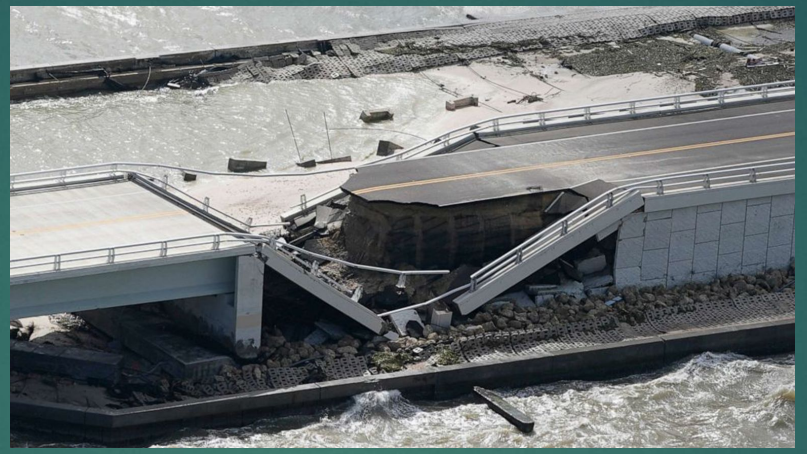
Local Community in Norfolk

What is a hyperlocal site?

- Critical Infrastructure
- Protective Structures
- Single Building or Home

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]

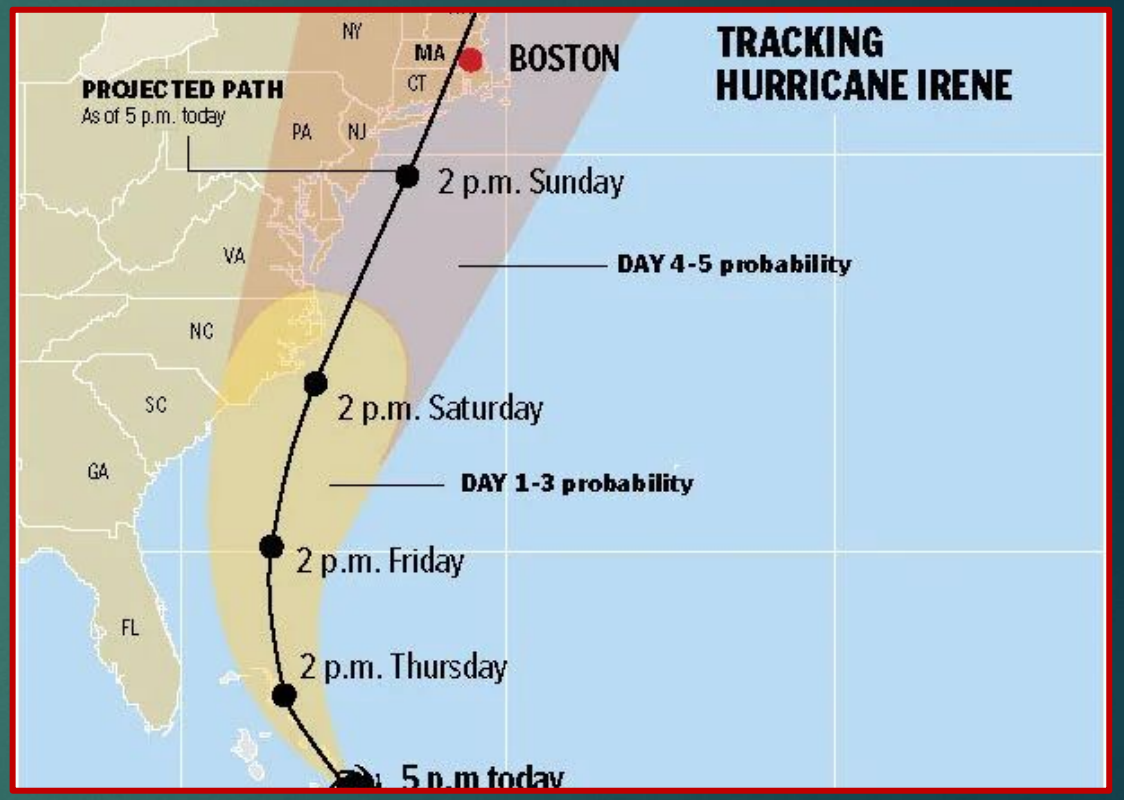
- 1 of 2 bridges to the mainland Florida.
- At least 3 sections of causeway over washed or broken.
- Half-mile road leading to causeway was impassible.

- 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)

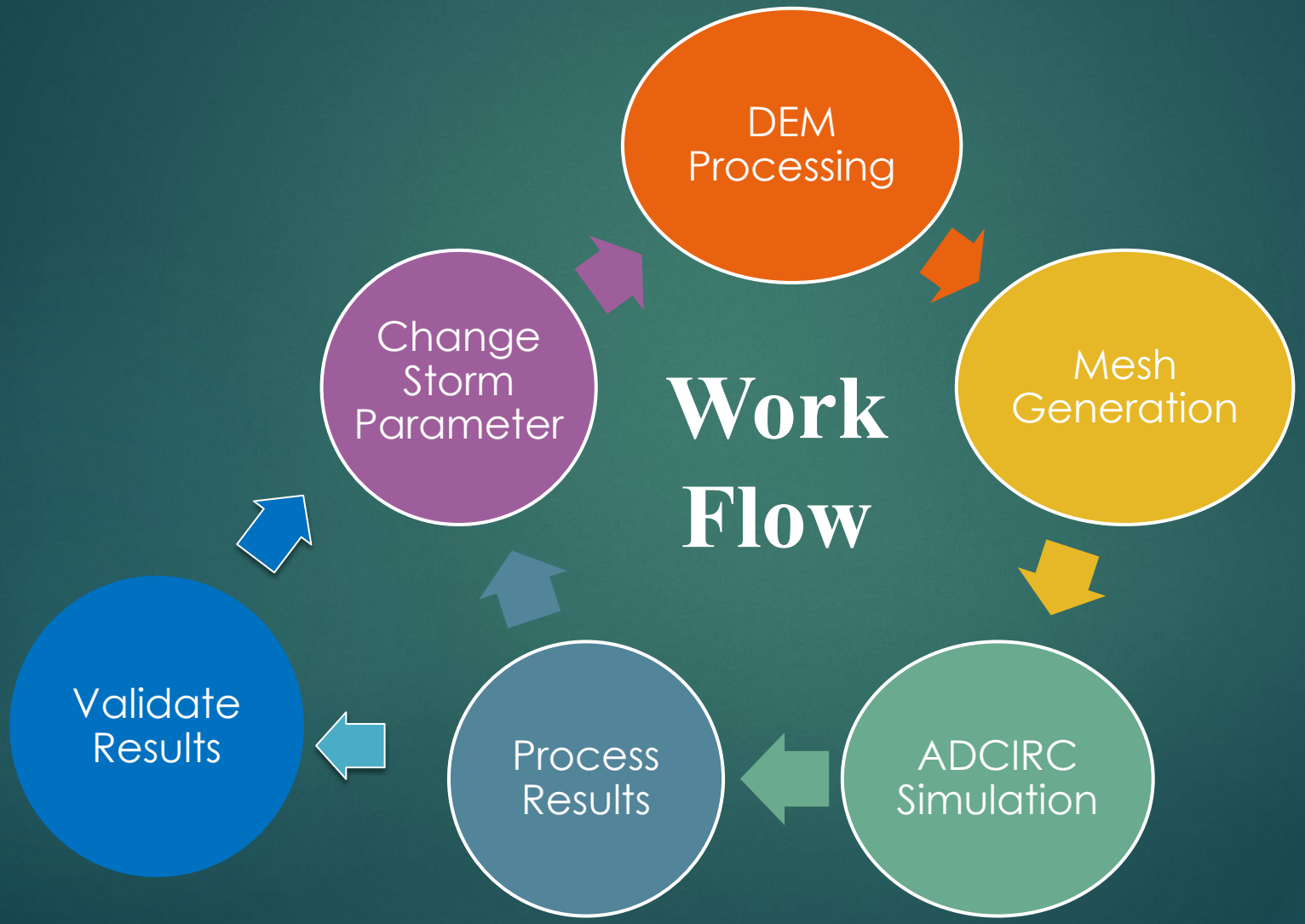
Research Questions

- 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?

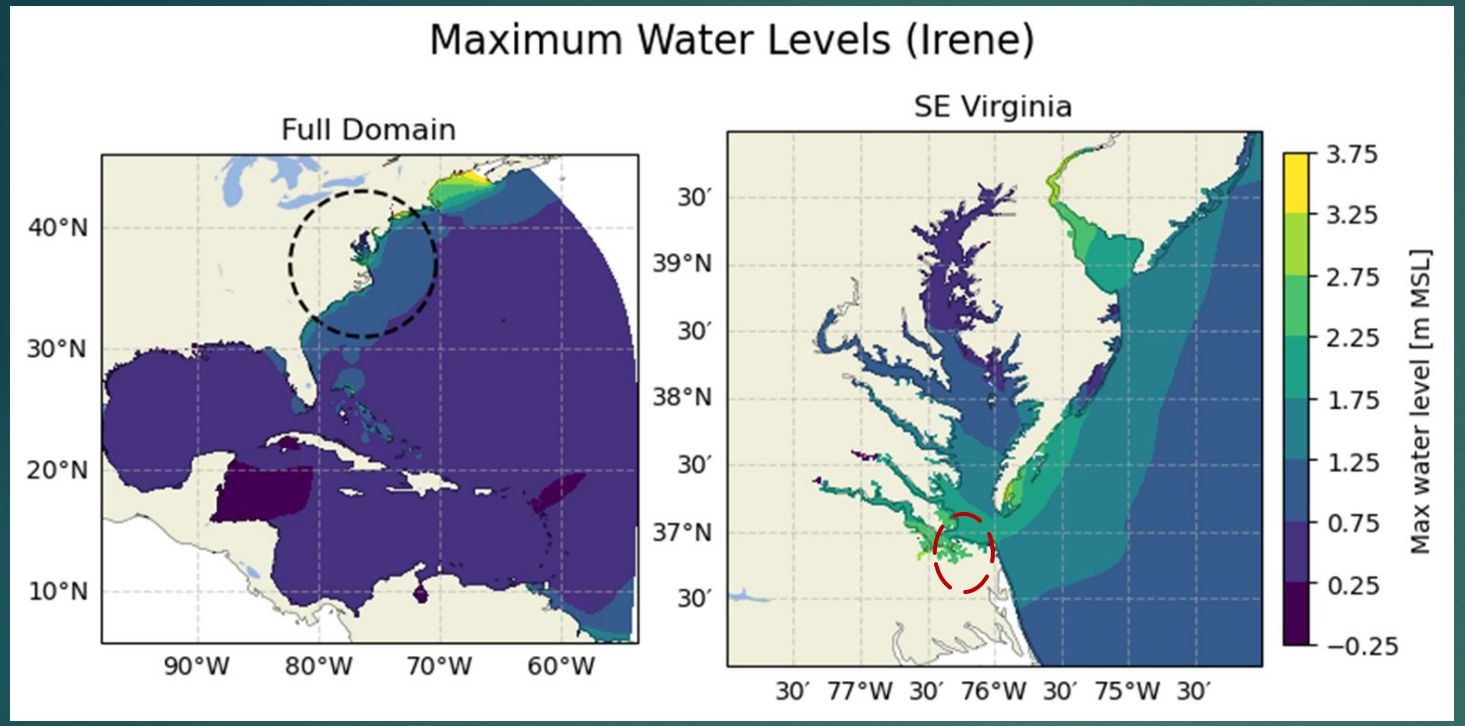


The impact of storm surge varies as the storm changes before it makes landfall.

Research Objectives



Naval Station Norfolk

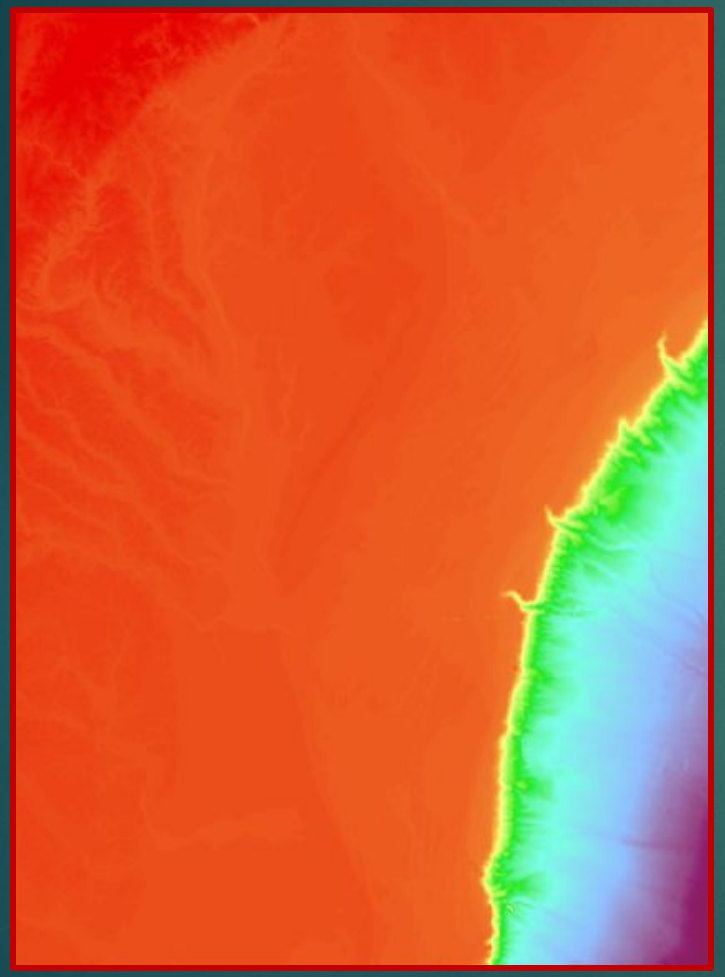


Location Map Using Kalpana Results from Hurricane Irene

Naval Station Norfolk

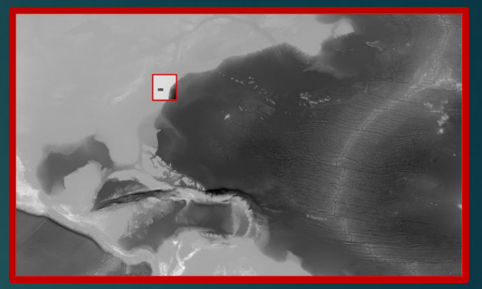
https://github.com/ccht-ncsu/Kalpana

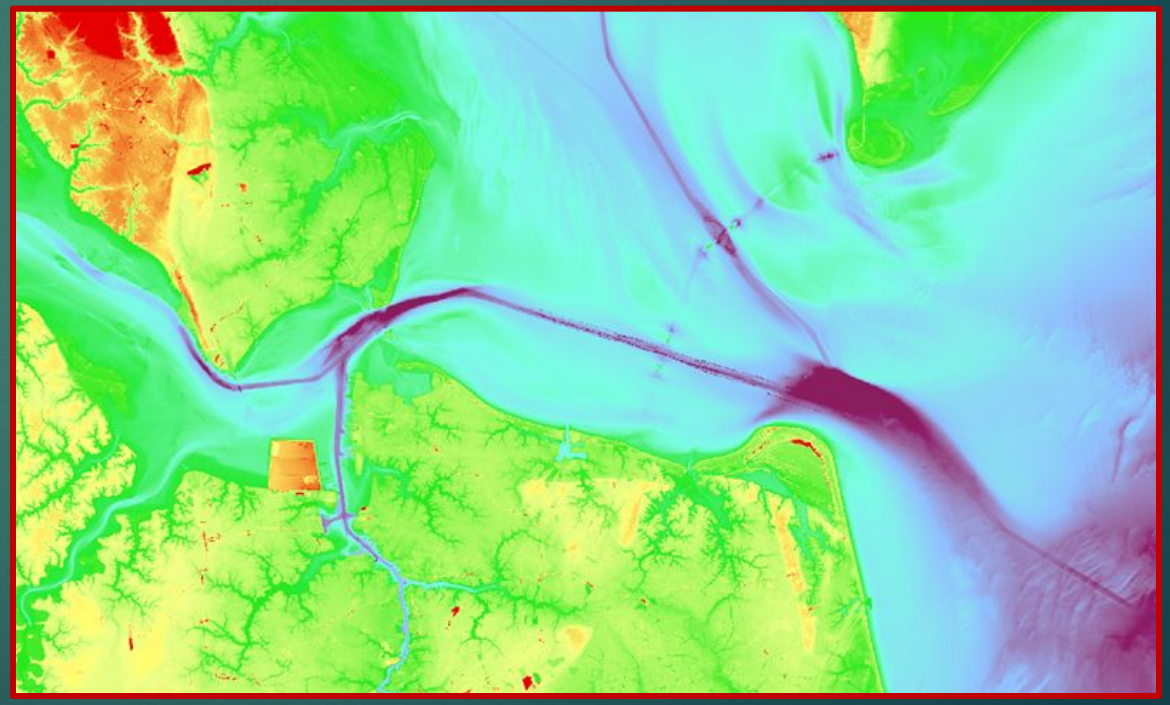
2 DEMs at 3 Different Resolutions



30m - Nested 2014 CUDEM

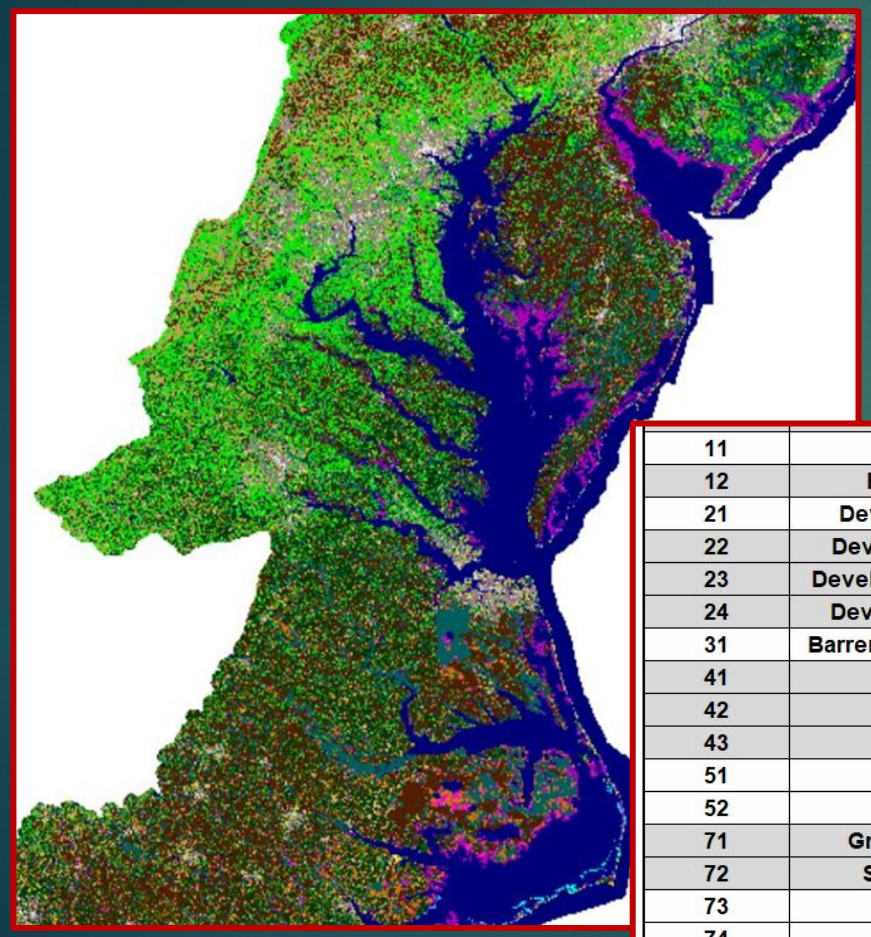
500m - 2018 Shuttle Radar Topography Mission (SRTM)





10m - Nested 2014 CUDEM

Land Use & Land Cover for Nodal Attributes in Mesh



The 2016 Coastal Change Analysis Program (CCAP)

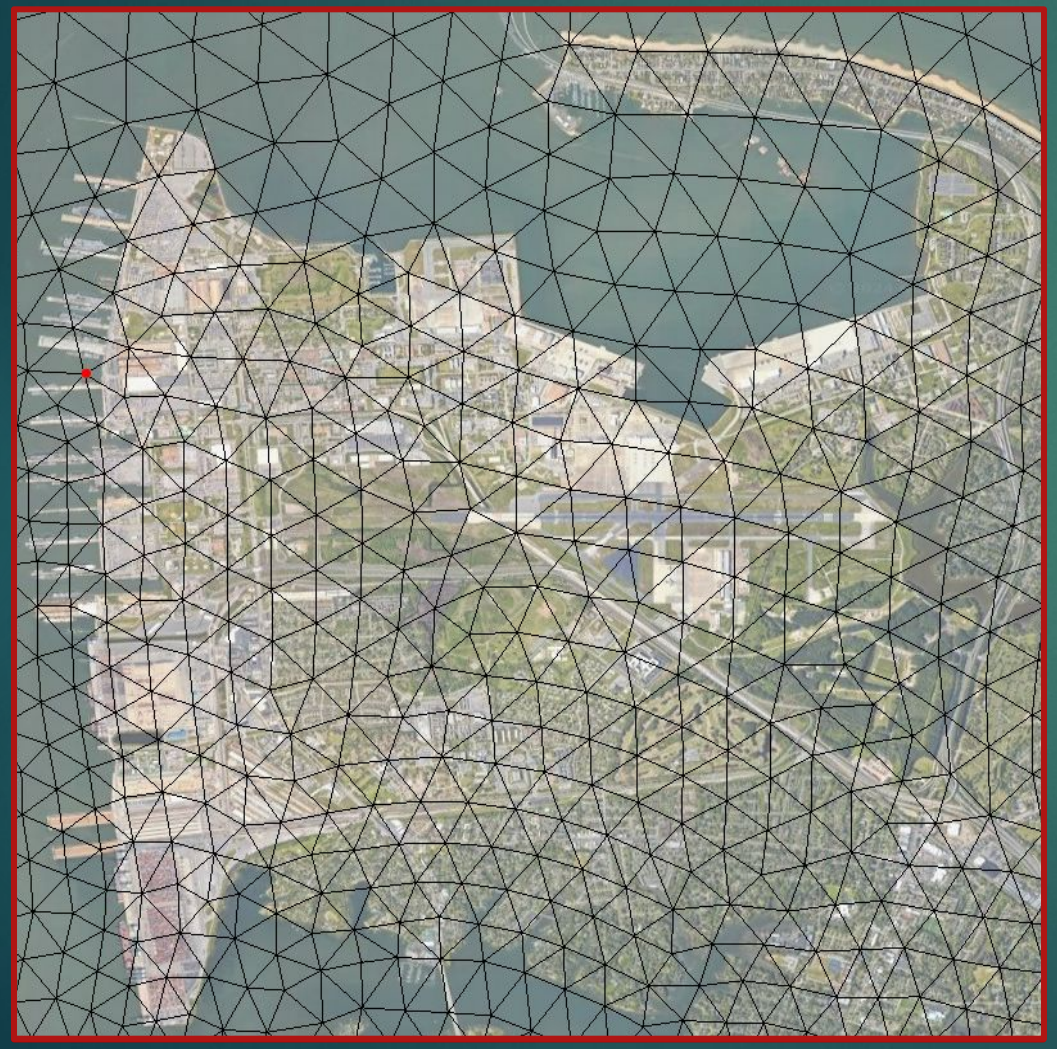
11	Open Water	0.025 - 0.05
12	Perennial Ice/Snow	N/A
21	Developed, Open Space	0.03 - 0.05
22	Developed, Low Intensity	0.06 - 0.12
23	Developed, Medium Intensity	0.08 - 0.16
24	Developed, High Intensity	0.12 - 0.20
31	Barren Land (Rock/Sand/Clay)	0.023 - 0.030
41	Deciduous Forest	0.10 - 0.20
42	Evergreen 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
- Includes 24 classifications [1]
- Used for:
  - Wind Reduction Factors
  - Bottom Friction
  - Canopy Coefficient

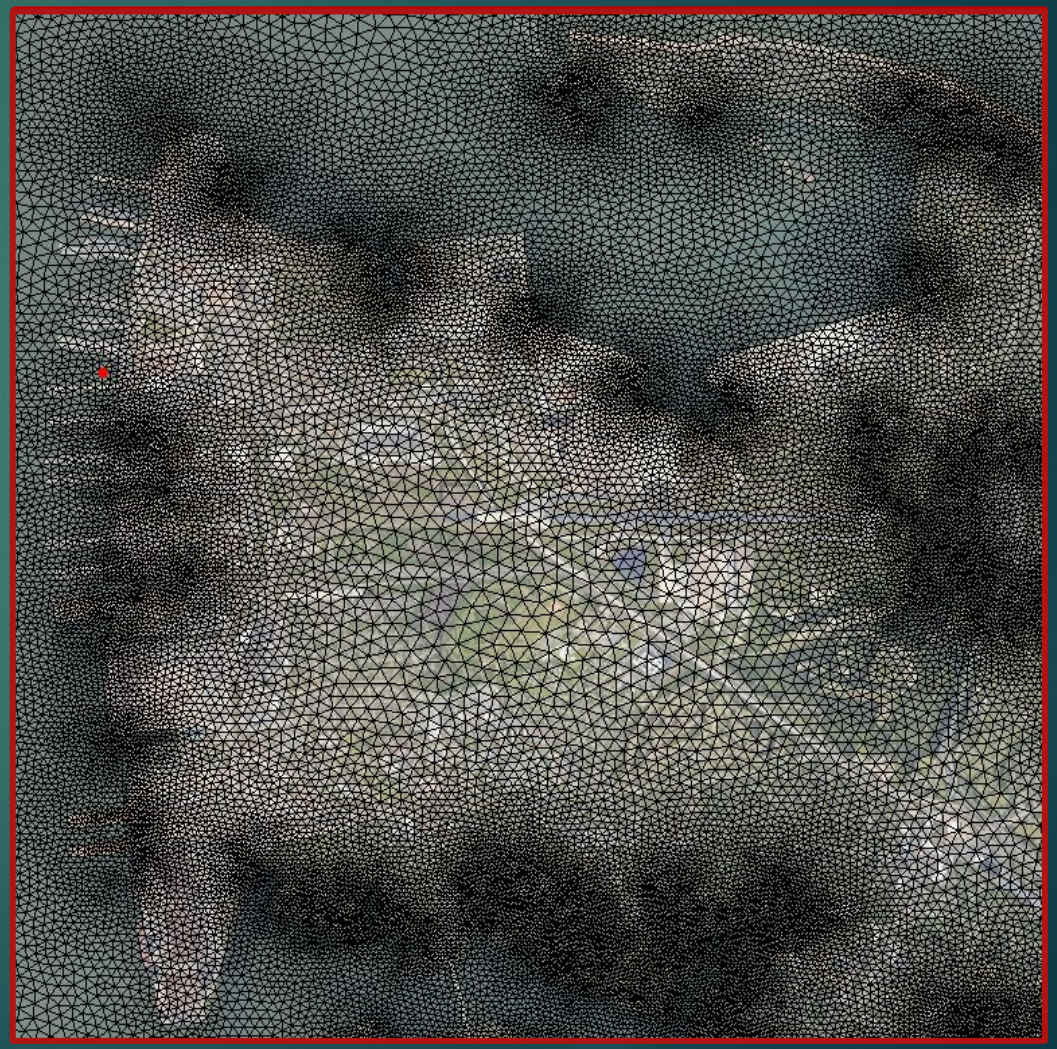
1 – US Army Corps of Engineers (2021)

Less Elements & More Hyperlocal

HSOFS Mesh (3.6 Million Elements)



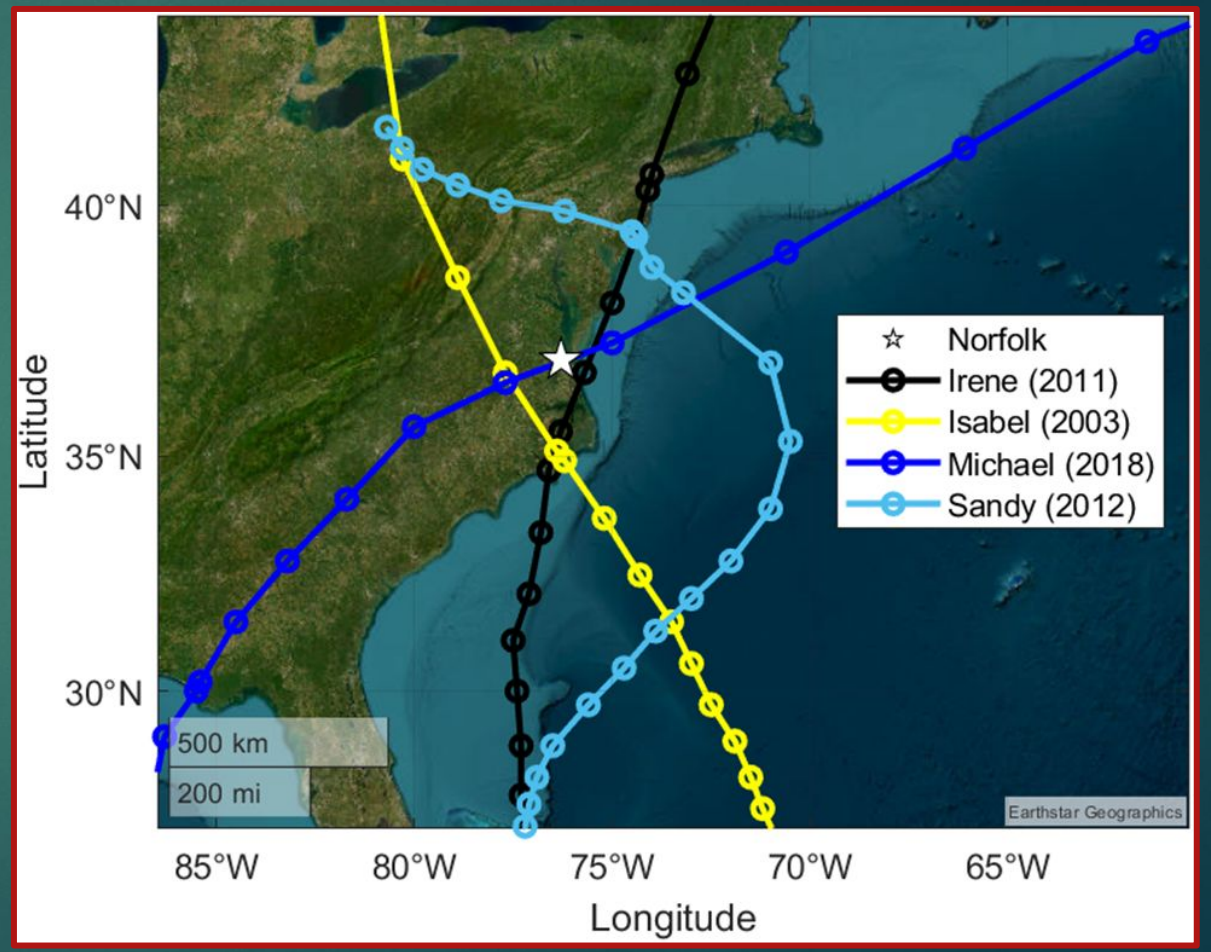
NSNv4 (2.5 Million Elements)



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)

Previous Studies

Storm Name

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

Perturbation Group

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

Perturbation

Perturbation Group	Perturbation
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
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		-178 km
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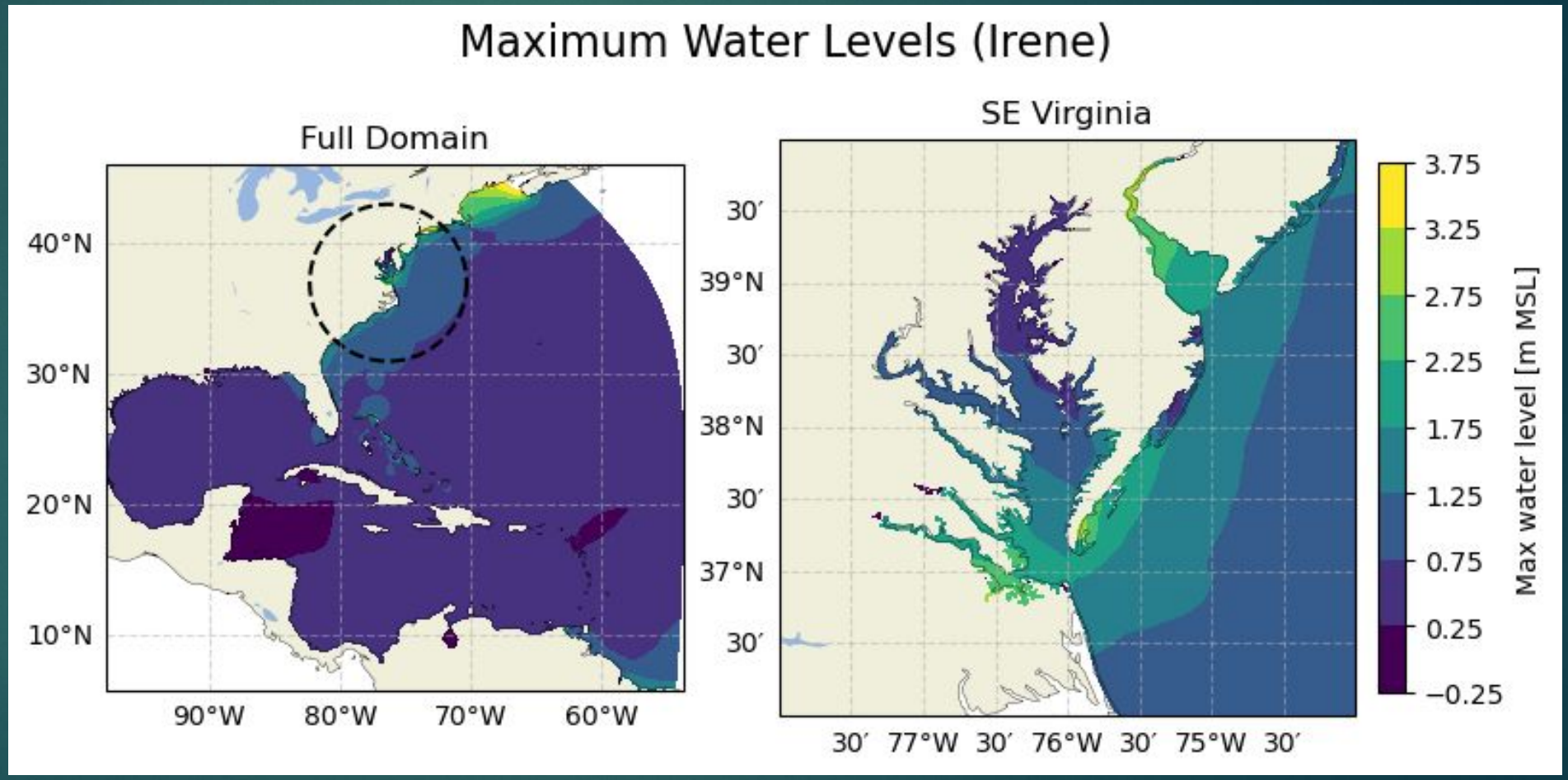

"Worst-Case" Scenario: Peak Levels?

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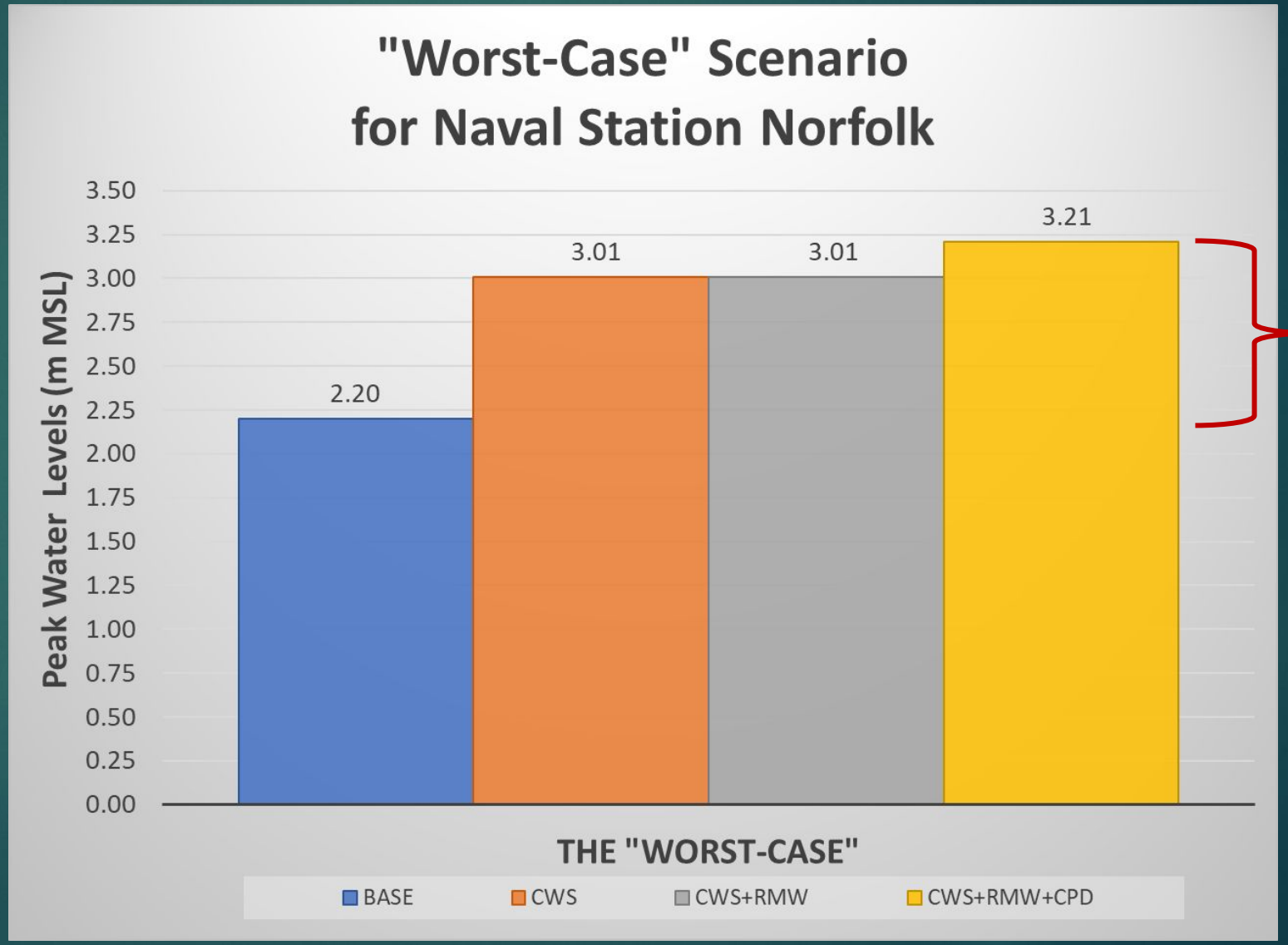

Worst Case Scenario: Surge Duration?

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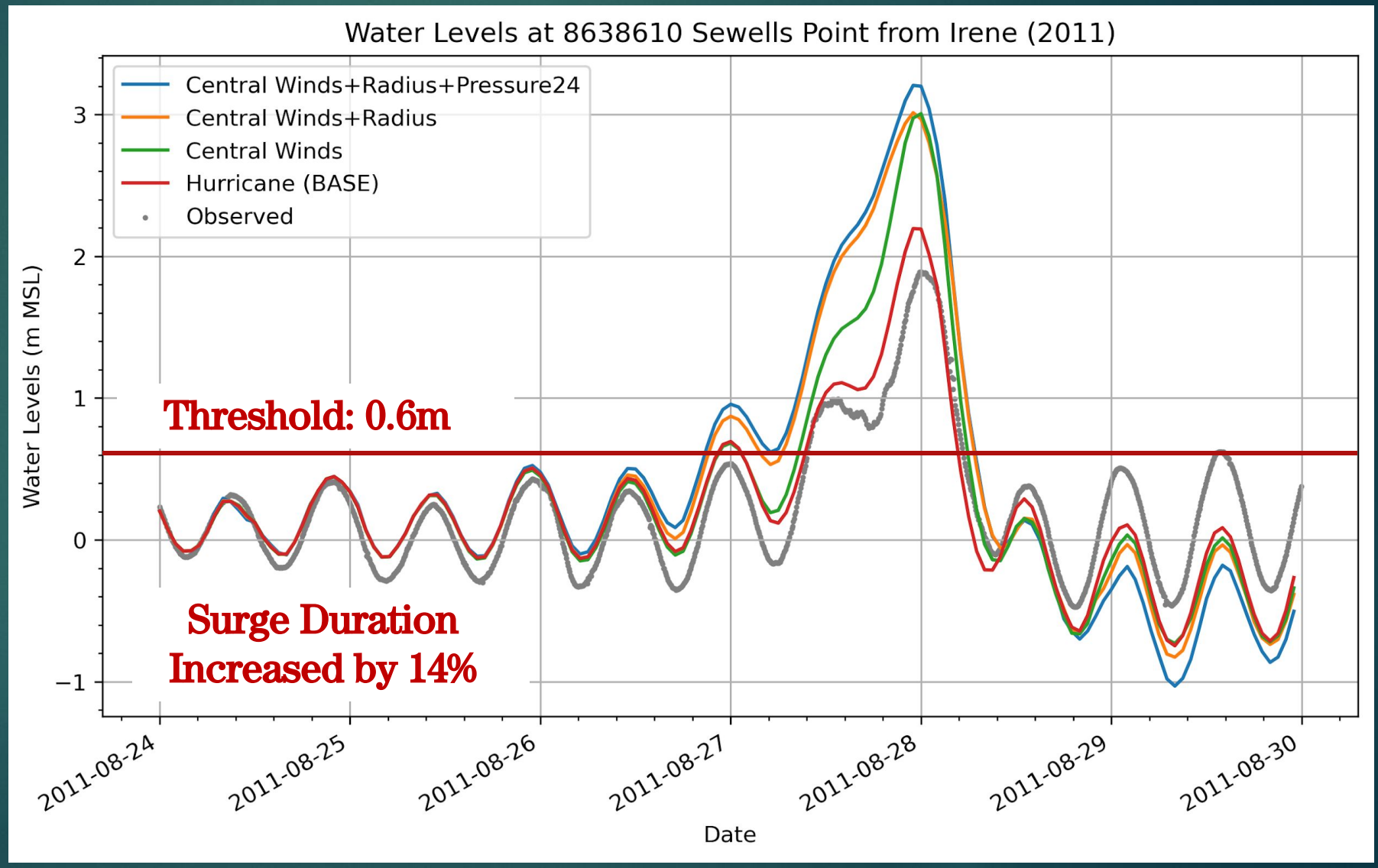

Worst Case Scenario: Flood Depth?

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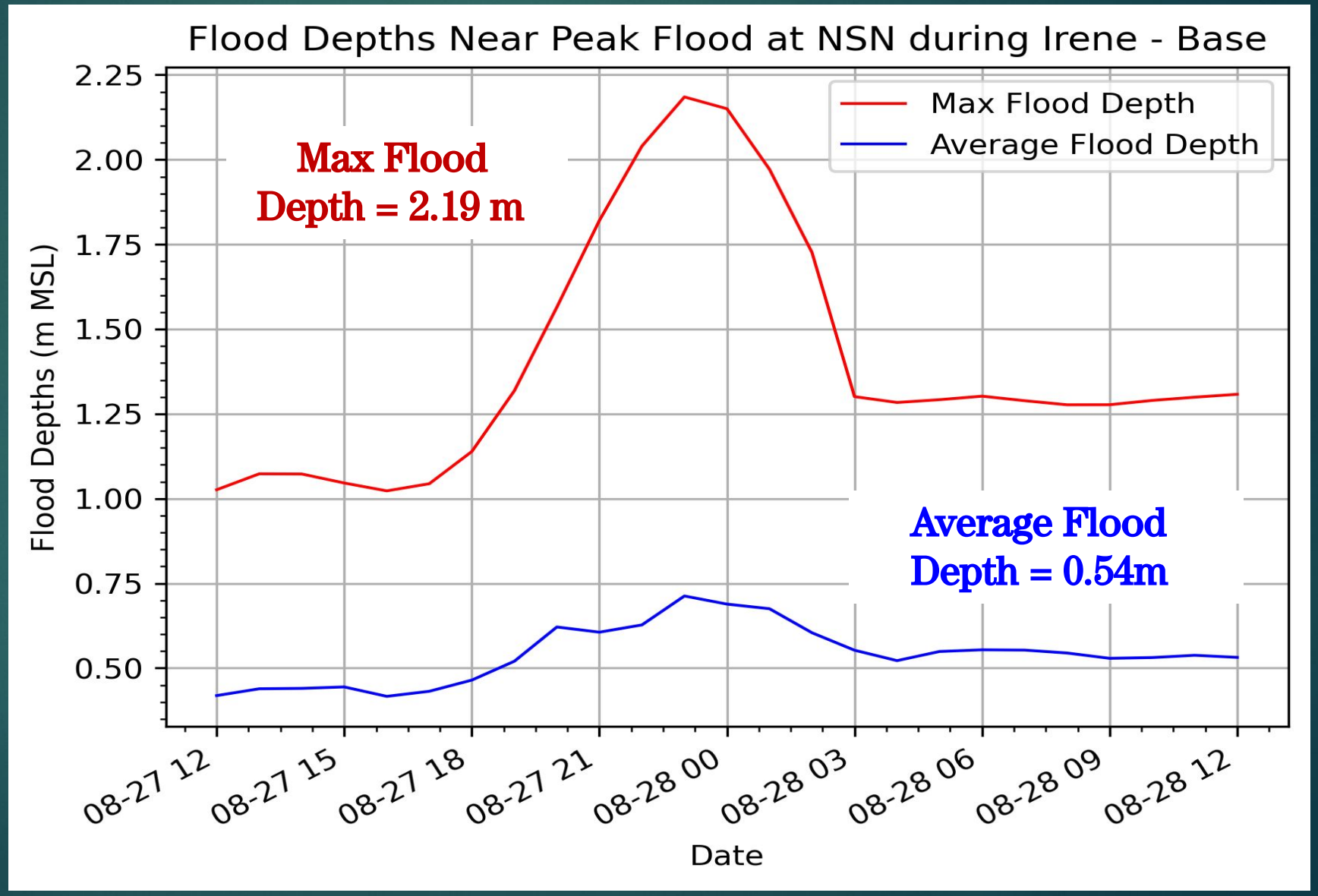

Worst Case Scenario: Flood Depth?

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
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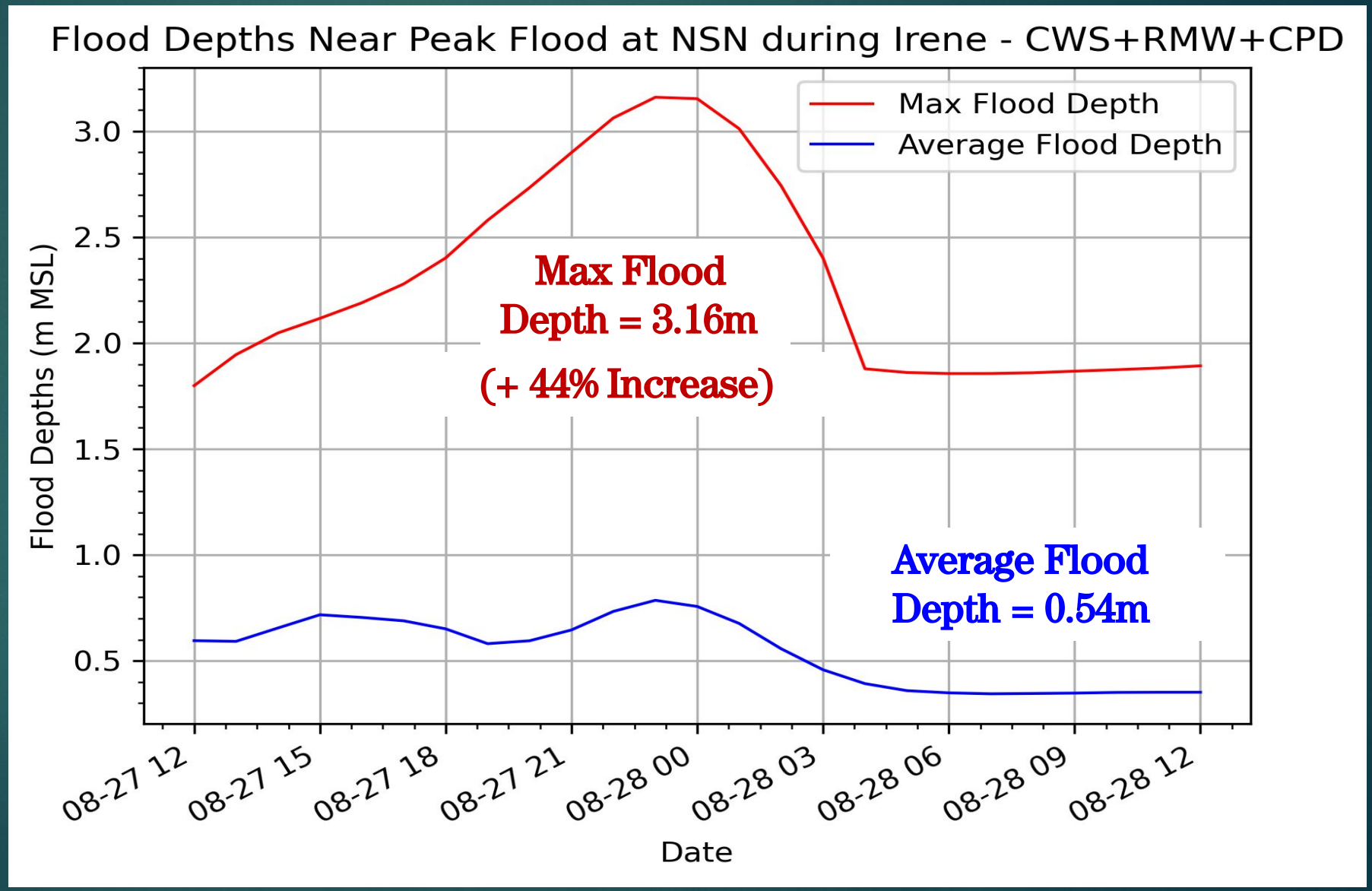

Worst Case Scenario: Flooded Area?

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
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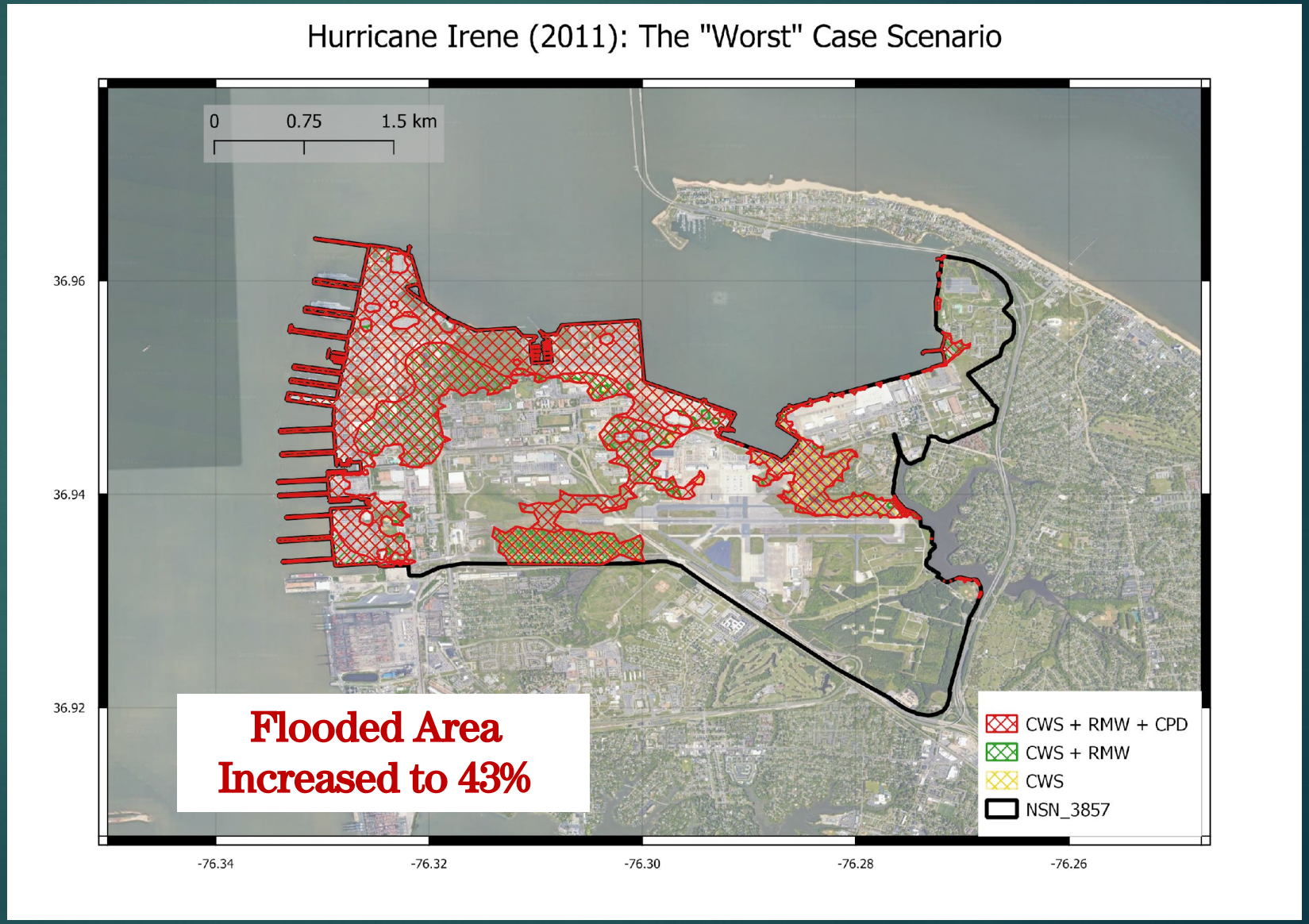

Conclusions

- Magnitude of storm surge depends on the coupling effects of different storm parameters.
- Linear coupling of storm parameters may not be realistic (Low probability).
- Storm Parameters influence different measures of the “worst-case”.
  - **+46%** increase in Peak Water Level.
  - **+14%** increase in Storm Surge Duration.
  - **+44%** increase in Max Flood Depth.
  - Average Flood Depth remains the same.
  - **+43%** increase in Flooded Area.
  - The position of the storm has a significant impact to storm surge.

Thank You

Deltares

NOAA

USGS

ESTCP

UD

A&M

USA
UNIVERSITY OF SOUTH ALABAMA

Irene (2011) - Central Pressure Drops

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
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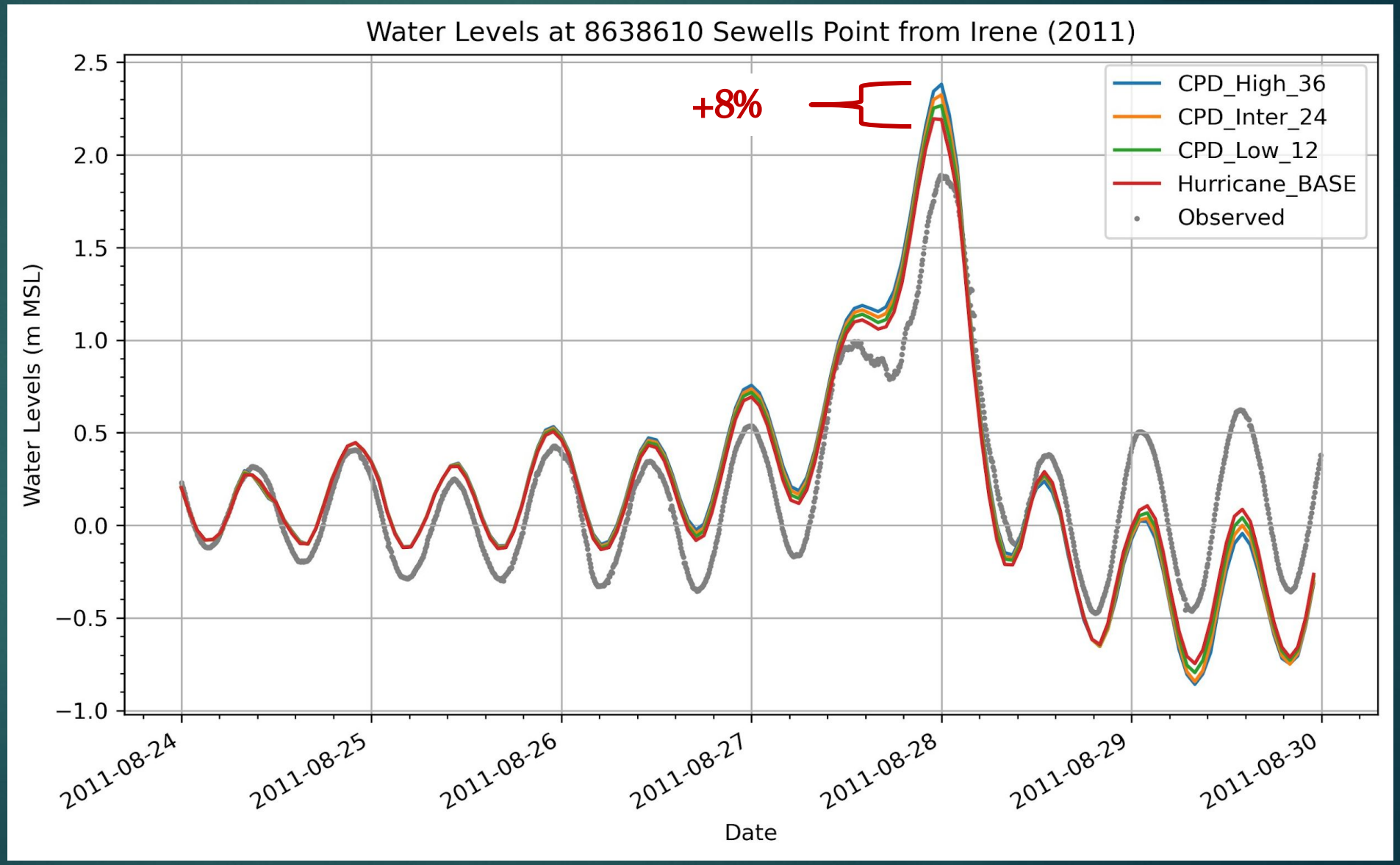

Irene (2011) - Central Pressure Drops

Irene (2011)	Base	-
	Central Pressure Drop	1.12
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		-178 km
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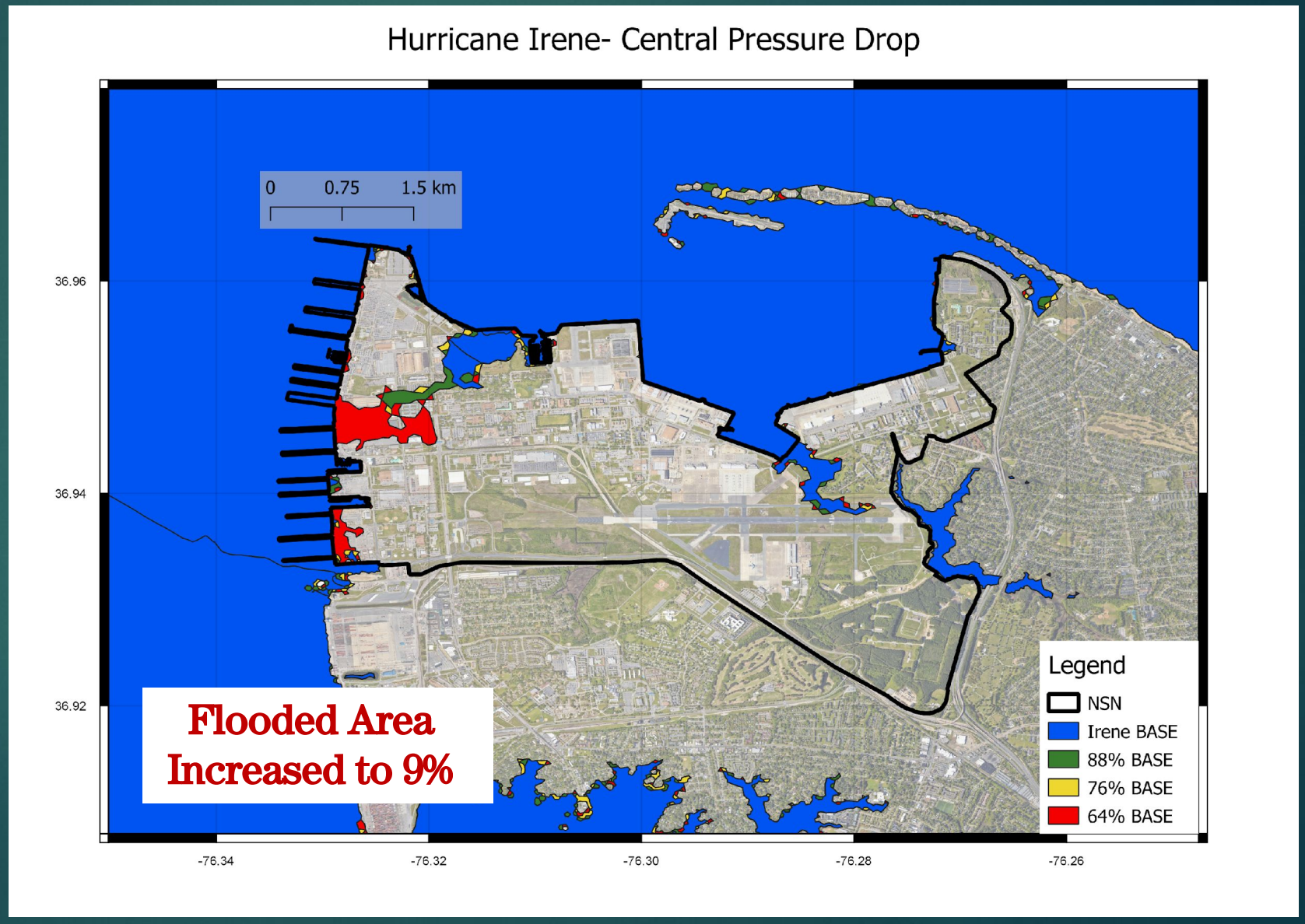

Irene (2011) – Storm Track Deviations

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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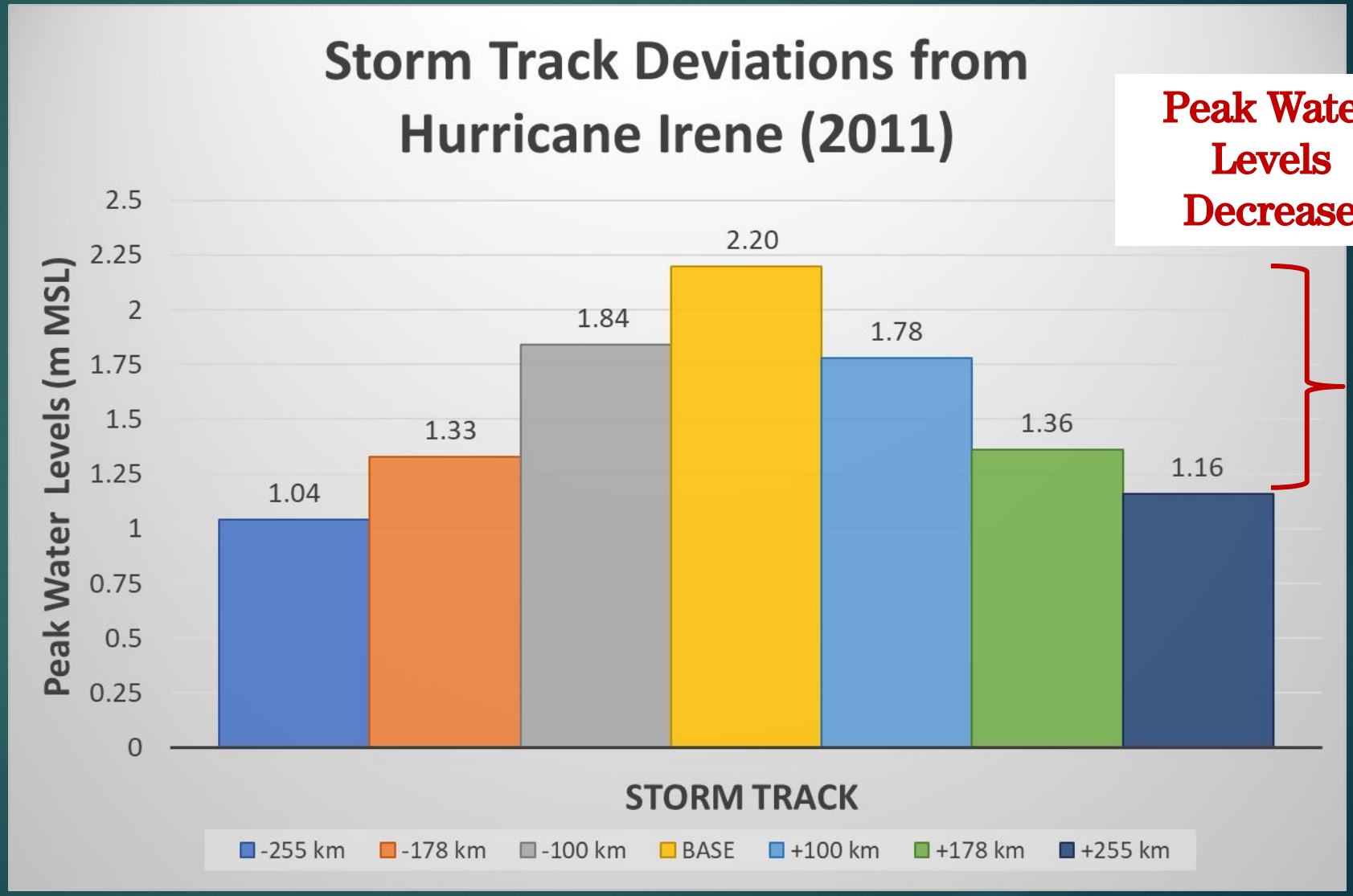

Irene (2011) – West Storm Tracks

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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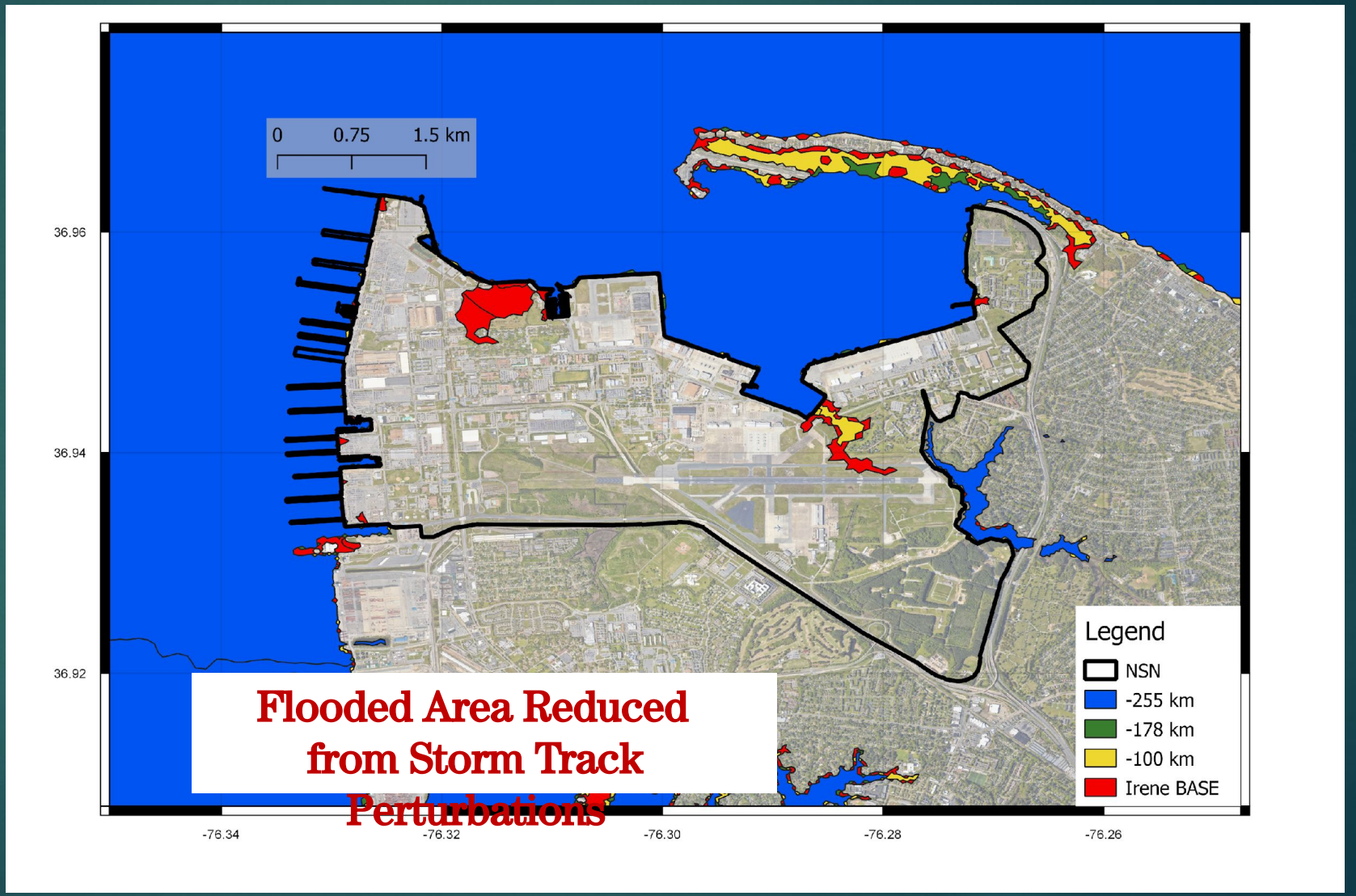

Irene (2011) – East Storm Tracks

Irene (2011)	Base	-
	Central Pressure Drop	1.12
		1.24
		1.36
	Storm Track (West Shift)	-100 km
		-178 km
		-255 km
	Storm Track (East Shift)	100 km
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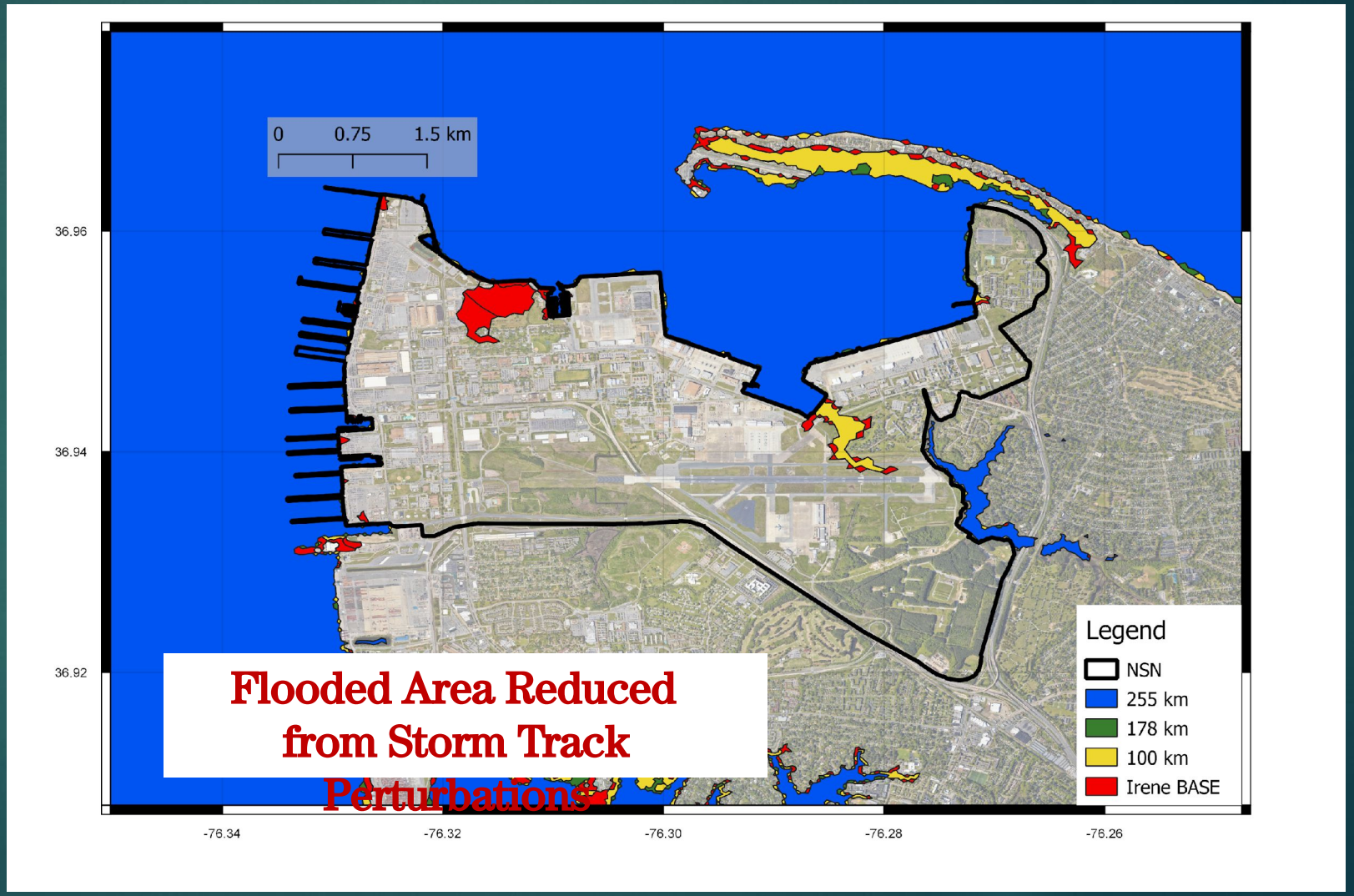
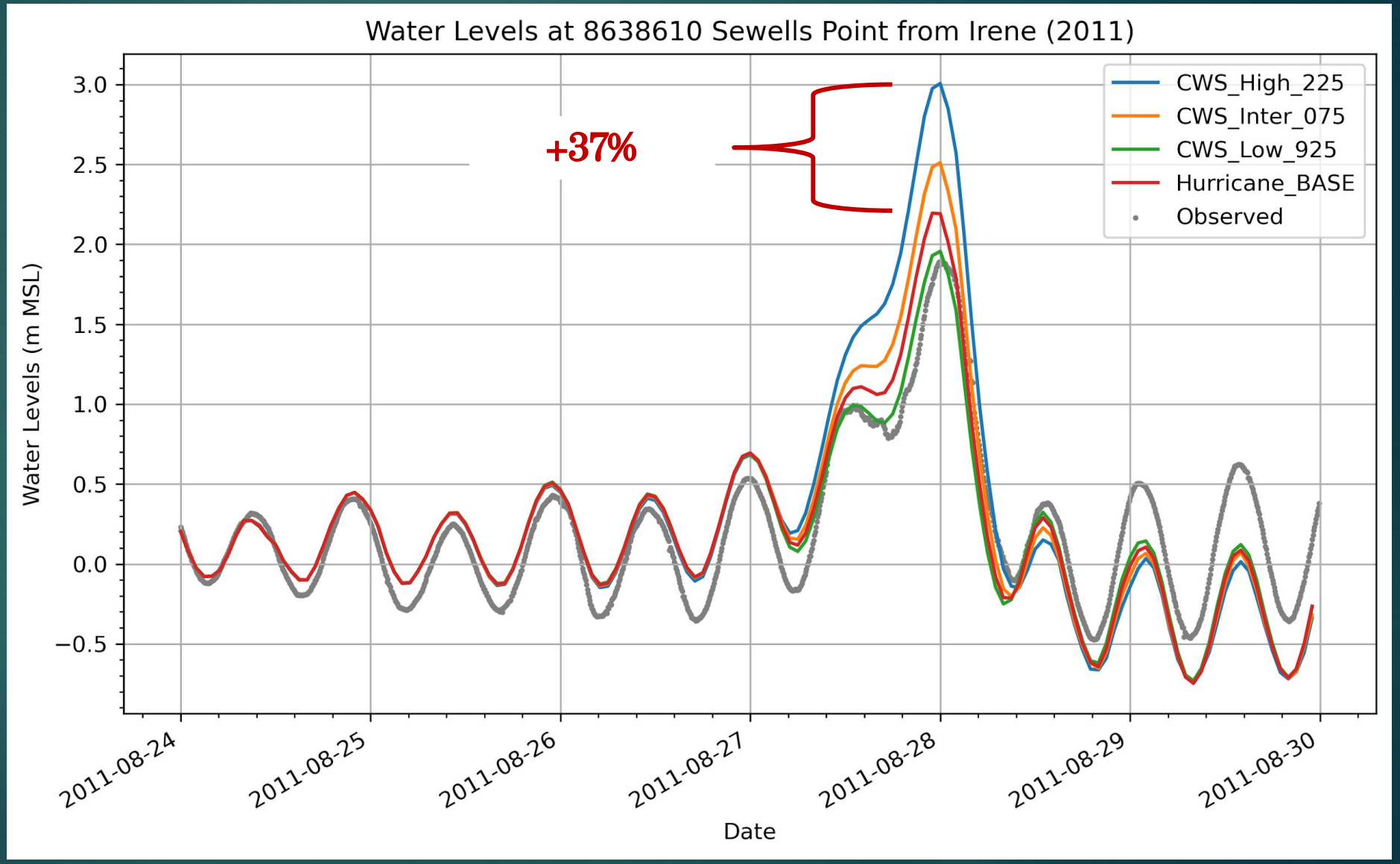
		1.1
		1.25



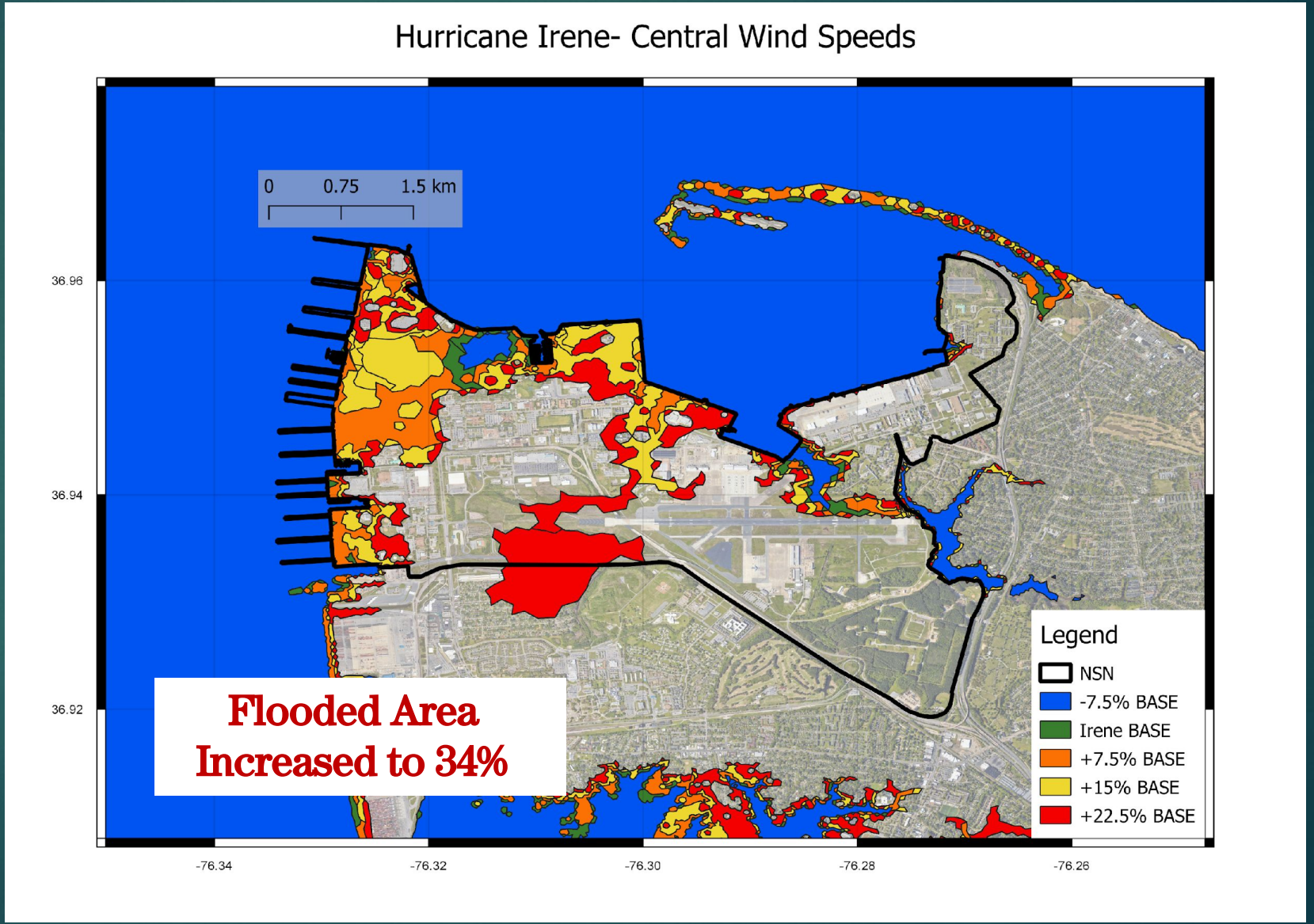
Irene (2011) - Central Wind Speeds

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



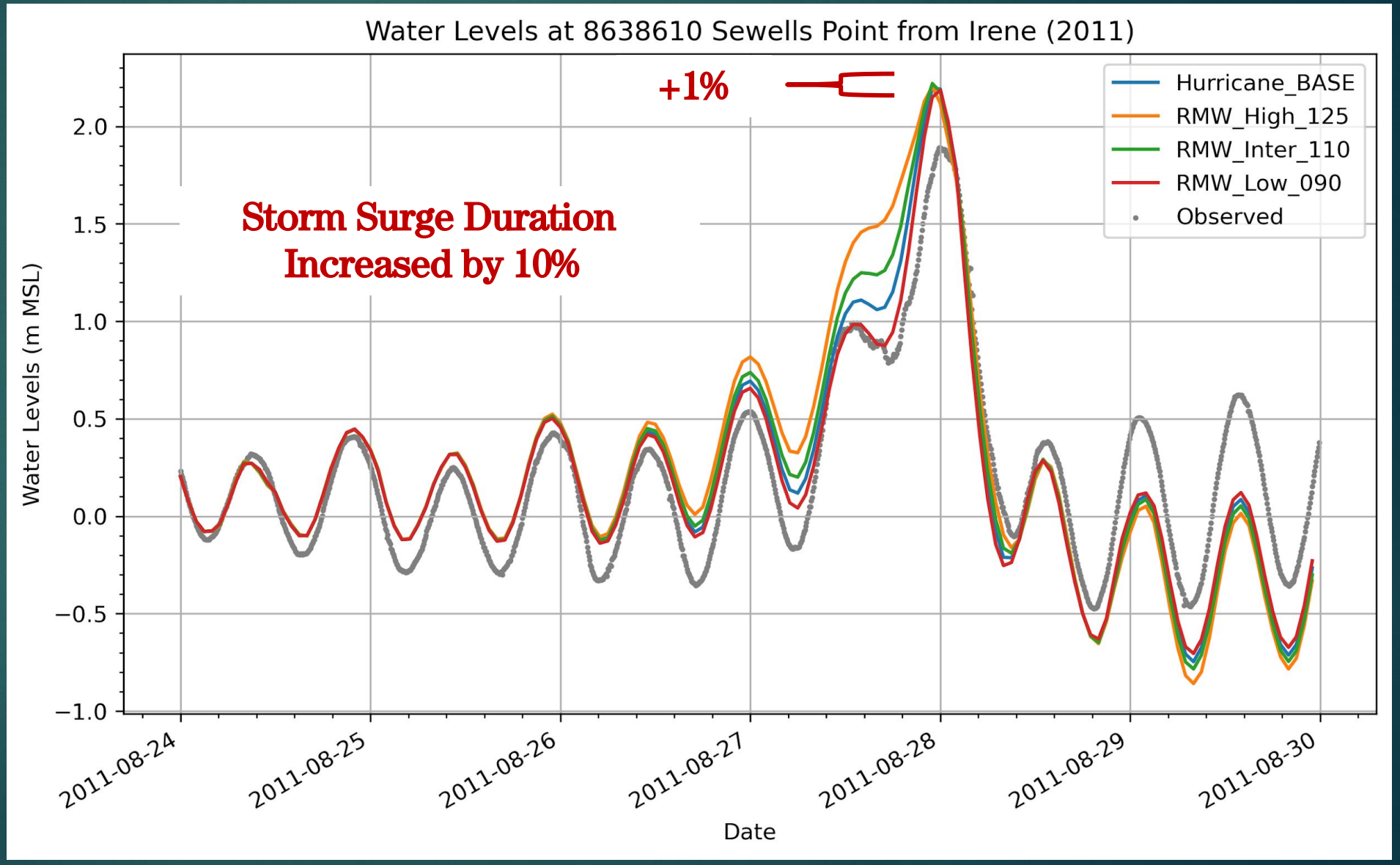
Irene (2011) - Central Wind Speeds

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



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
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		1.075
		1.225
	Radius Max Winds	0.9
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		1.25