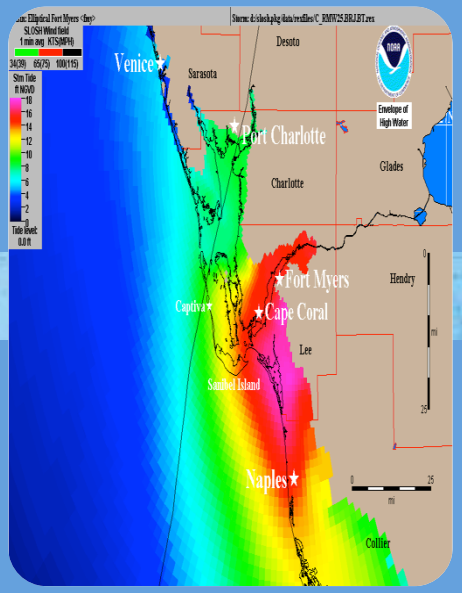
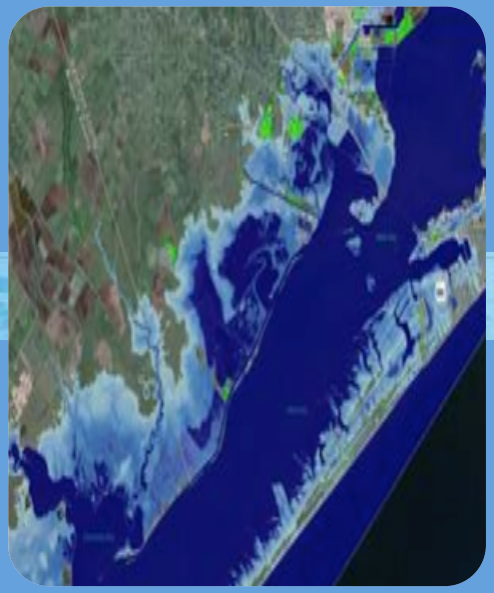
1-23-2015

The Storm Surge Hazard

Jeff Orrock
National Weather Service

THE STORM SURGE HAZARD

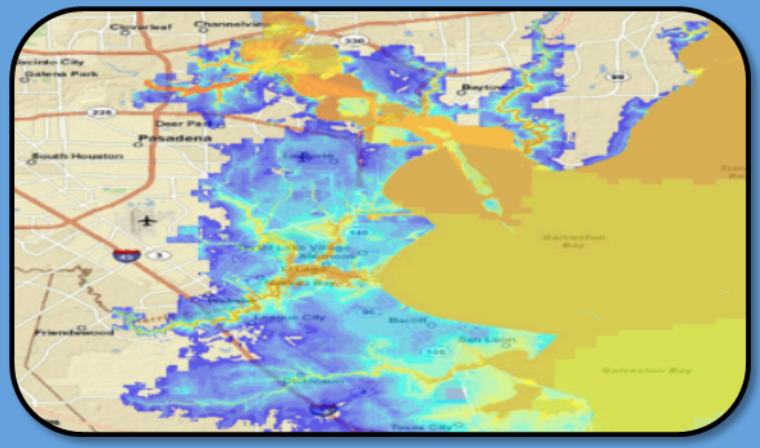





Storm Surge Roadmap: Overview

Jesse C. Feyen, Jamie Rhome

The Vision



Highly accurate, relevant, and timely information

CLEARLY COMMUNICATED

which results in reductions in loss of life and ensures communities are resilient

Jesse C. Feyen, Jamie Rhome

The Bottom Line for NOAA

Customers Ask:

- Who will get flooded? How much?
- When will it arrive and leave?
- What will the impacts be?
- How often will it occur?
- How should I act?

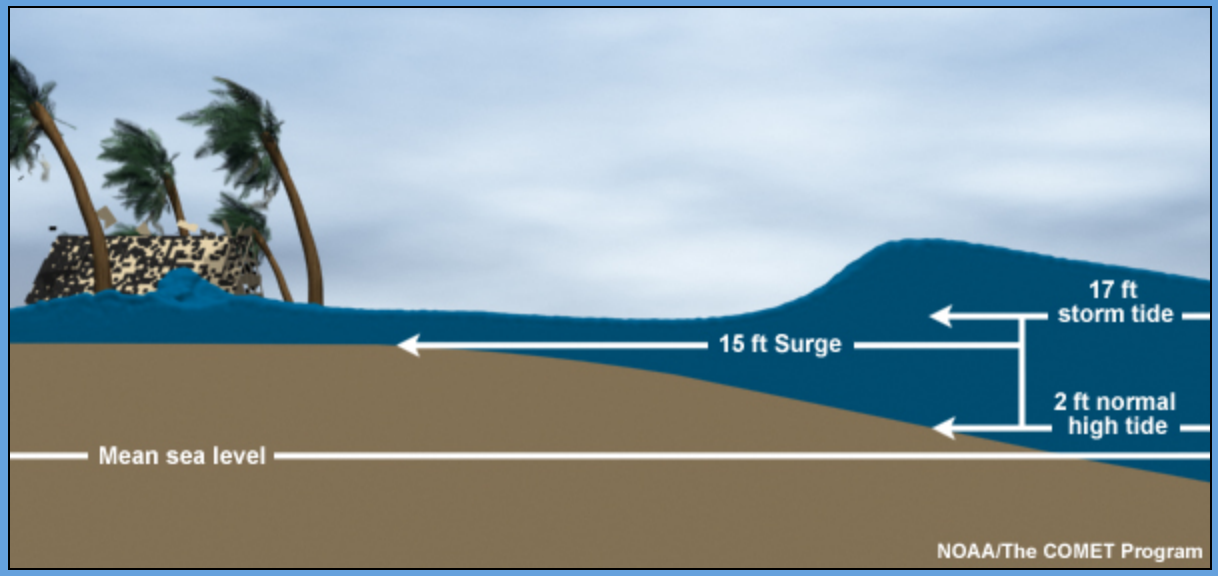
Roadmap Goals:

1. Accurately predict and assess storm water levels
   - Total Water Level (TWL) models with surge + tides + waves + rivers
   - Account for uncertainty (ensembles, probabilities)
2. Intuitively describe inundation as flooding above ground level
   - In statements and maps
3. Communicate actionable information
   - Based on social science

What is Storm Surge?

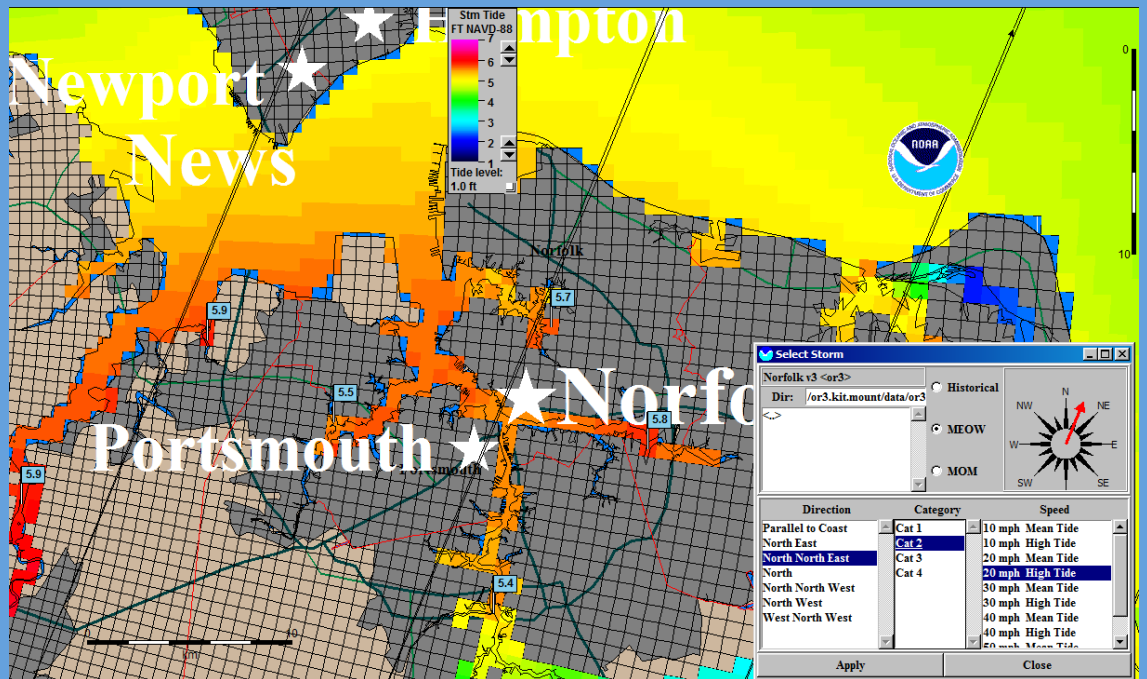
STORM SURGE is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

STORM TIDE is the water level rise during a storm due to the combination of storm surge and the astronomical tide



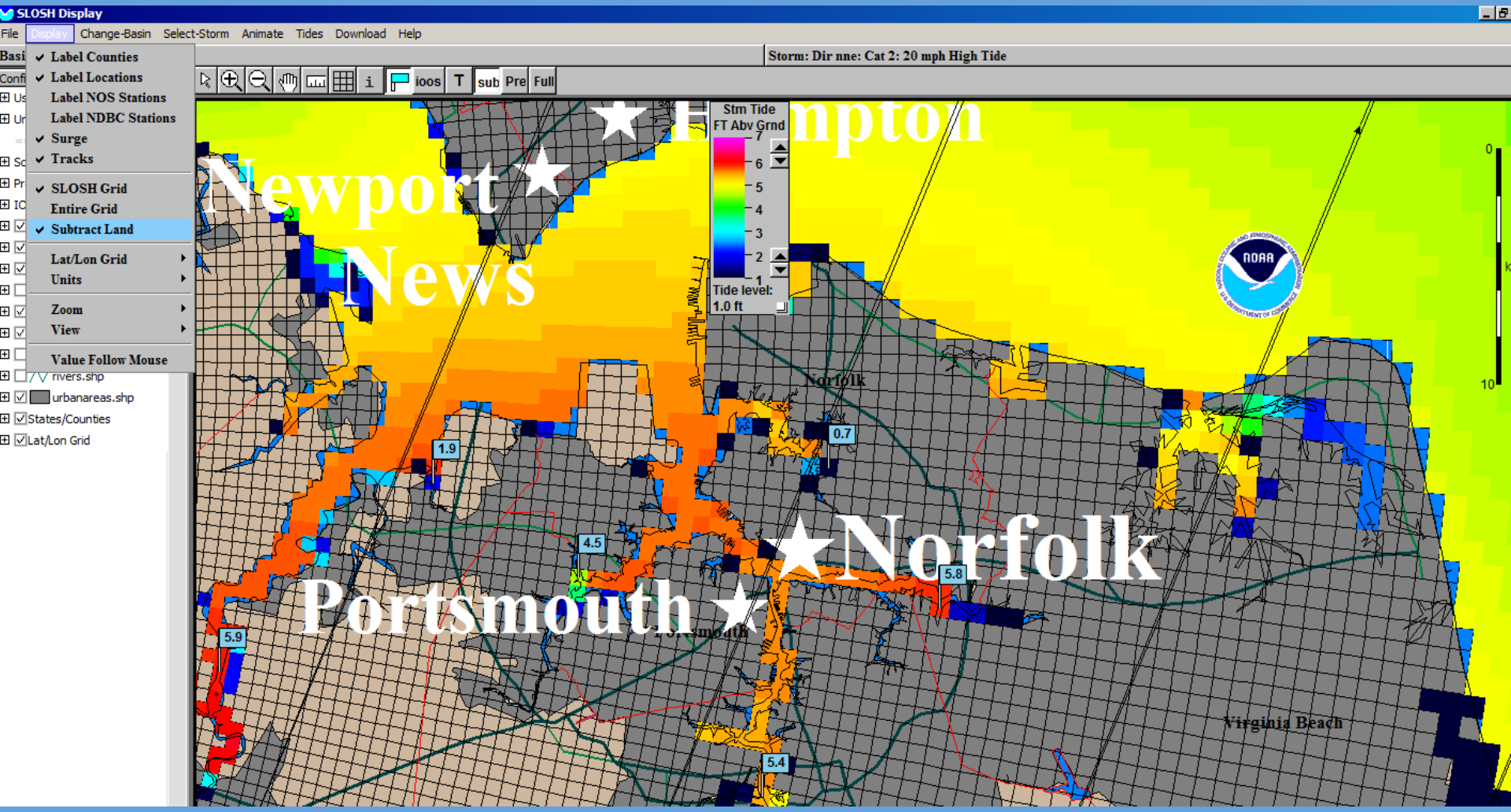
Sea, Lake & Overland Surges from Hurricanes (SLOSH)

- SLOSH is a numerical model developed by the NWS to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes taking into account atmospheric pressure, size, forward speed, and track data.
- SLOSH model physics are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, levees and other physical features.



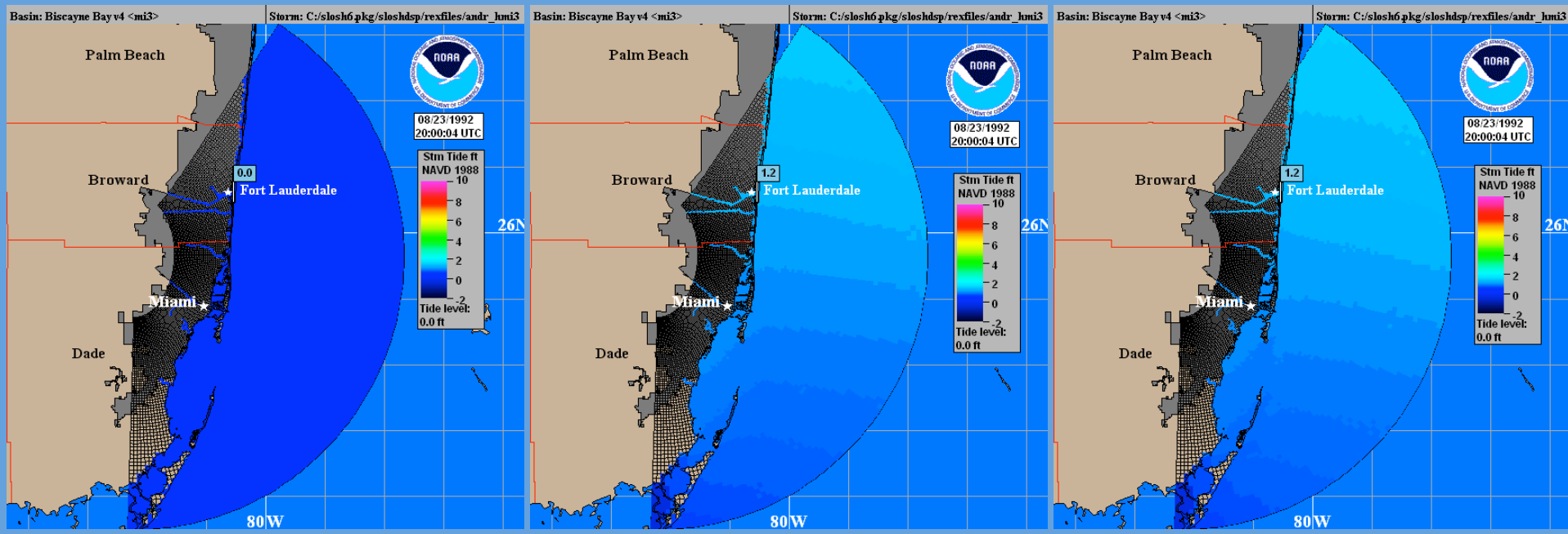
SLOSH Inundation

- Subtract Land (per grid cell)



Total Water Level: Adding Tides to SLOSH

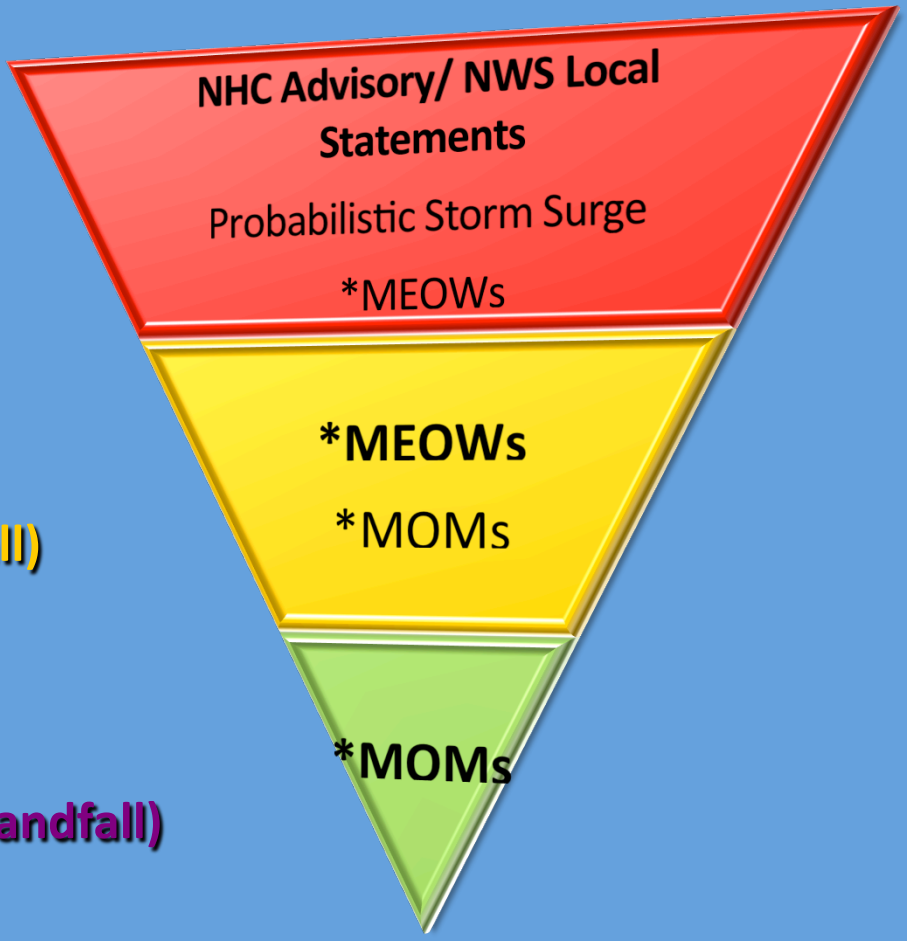
- NOS' model tide predictions coupled to NWS' surge model
- ***Operational requirement for probabilistic P-Surge predictions for Potential Storm Surge Flooding map***



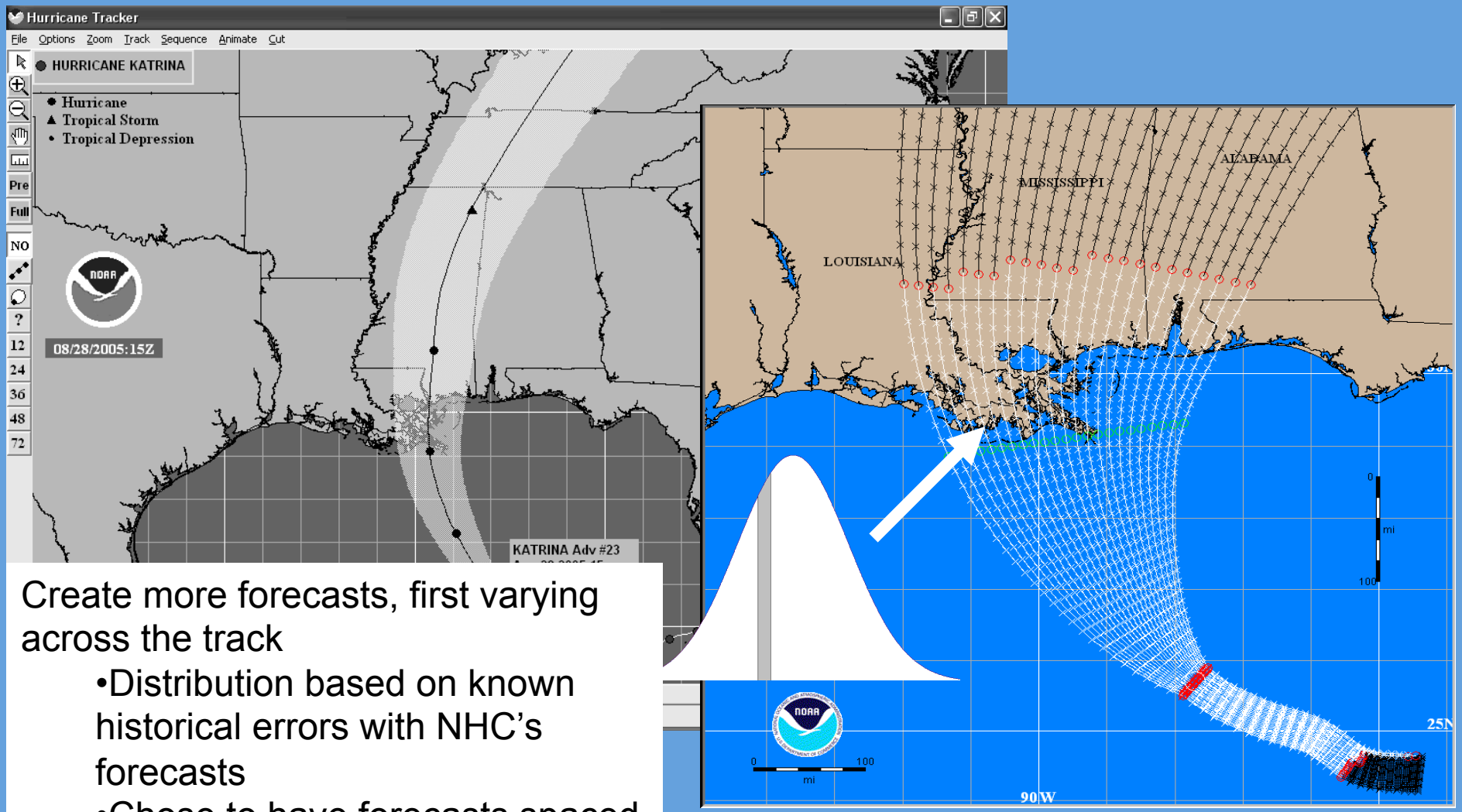
NWS Surge + NOS Tides = SLOSH+Tides

SLOSH Approach

- P-Surge
  - Probabilistic Storm Surge
  - **Response (<48 hr of landfall)**
- MEOW
  - Maximum Envelope Of Water
  - **Readiness (48hr – 120 hr of landfall)**
- MOM
  - Maximum Of the MEOWs
  - **Planning / Mitigation (>120 hr of landfall)**



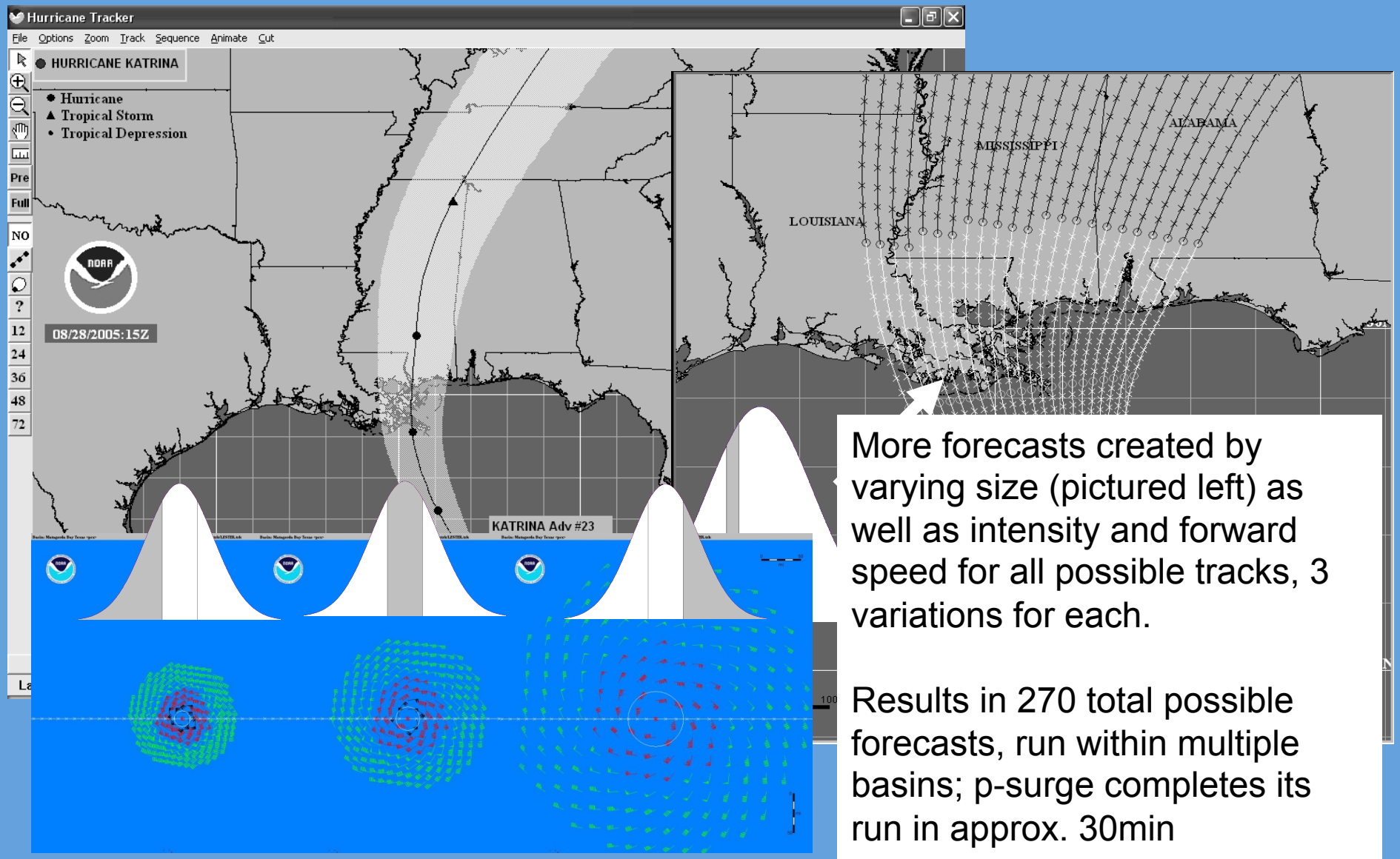
P - Surge



Create more forecasts, first varying across the track

- Distribution based on known historical errors with NHC's forecasts
- Chose to have forecasts spaced Rmax apart at the 48hr forecast point

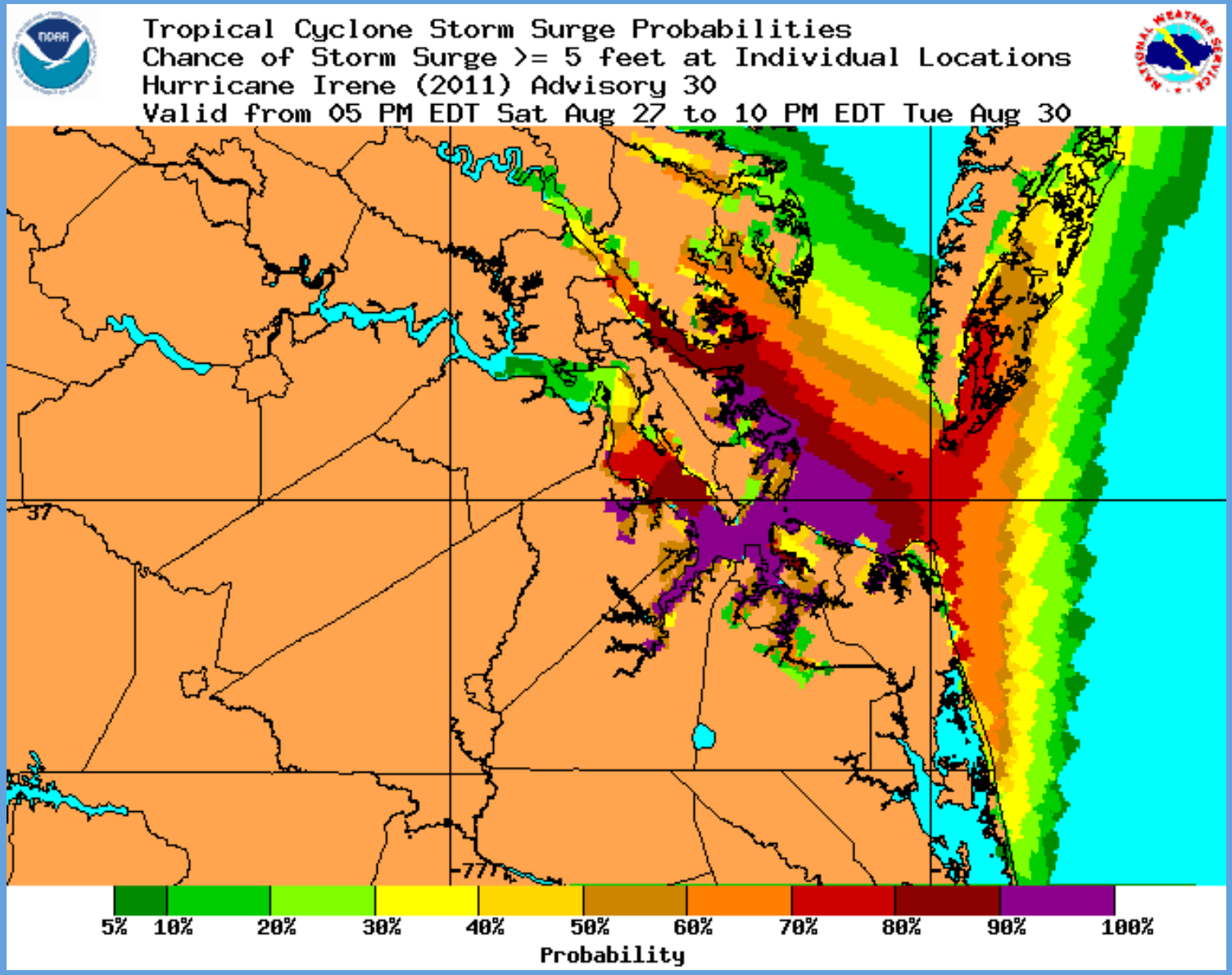
P - Surge



More forecasts created by varying size (pictured left) as well as intensity and forward speed for all possible tracks, 3 variations for each.

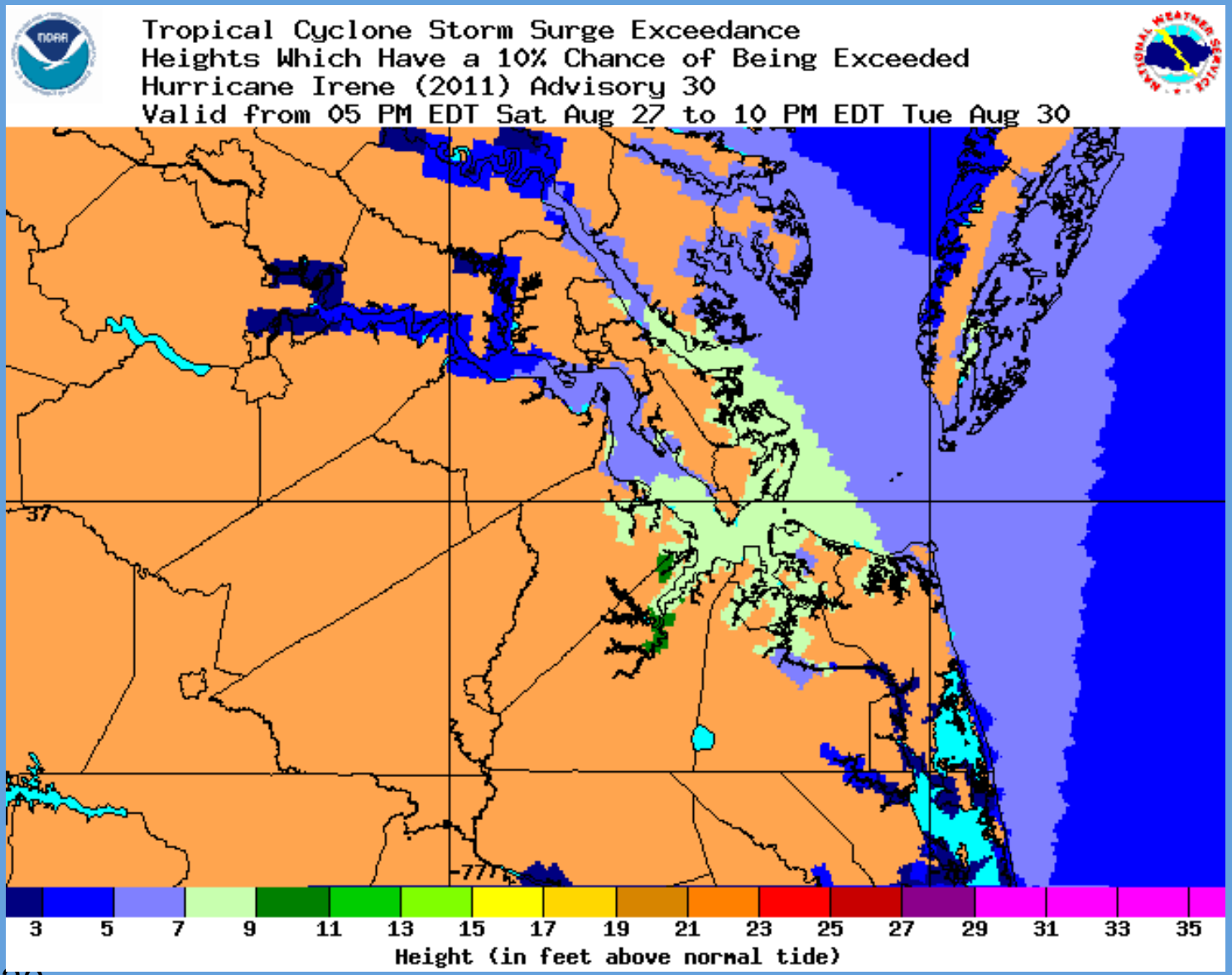
Results in 270 total possible forecasts, run within multiple basins; p-surge completes its run in approx. 30min

Probability of Surge >= 5 feet



Irene adv 30

Surge Height Exceeded by 10% of Ensemble Members



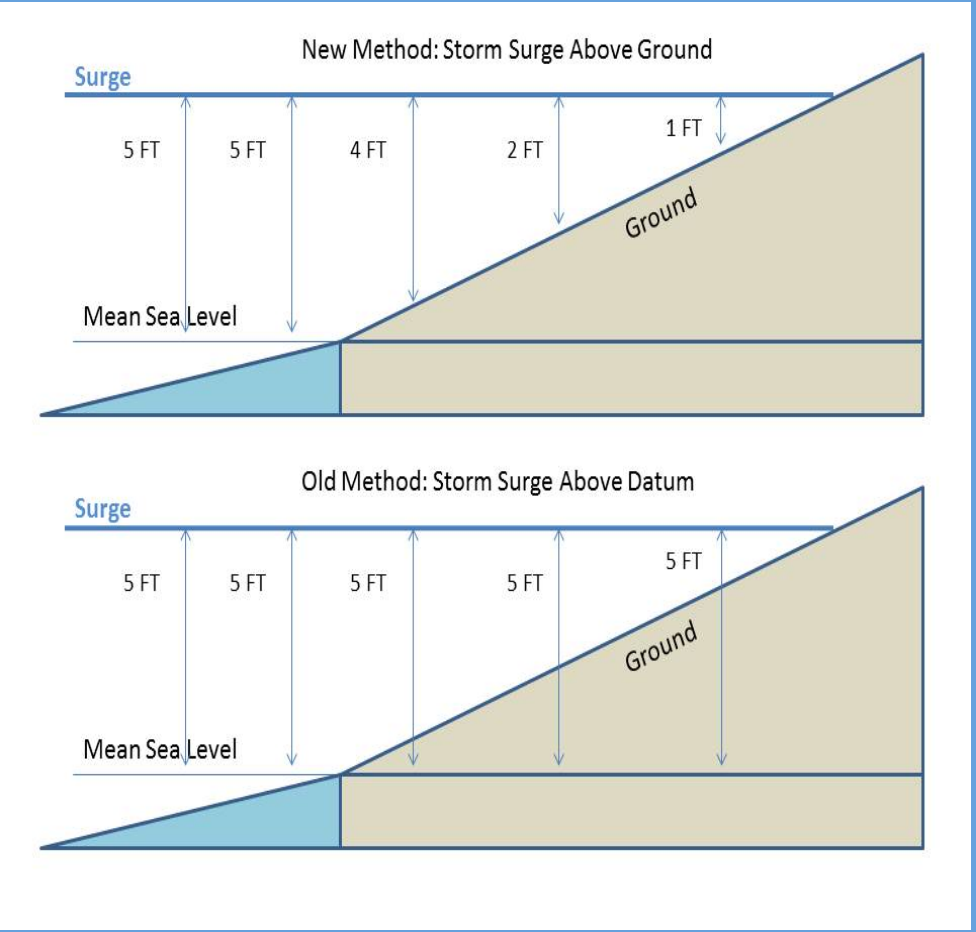
Irene adv 30

Rationale for PHISH

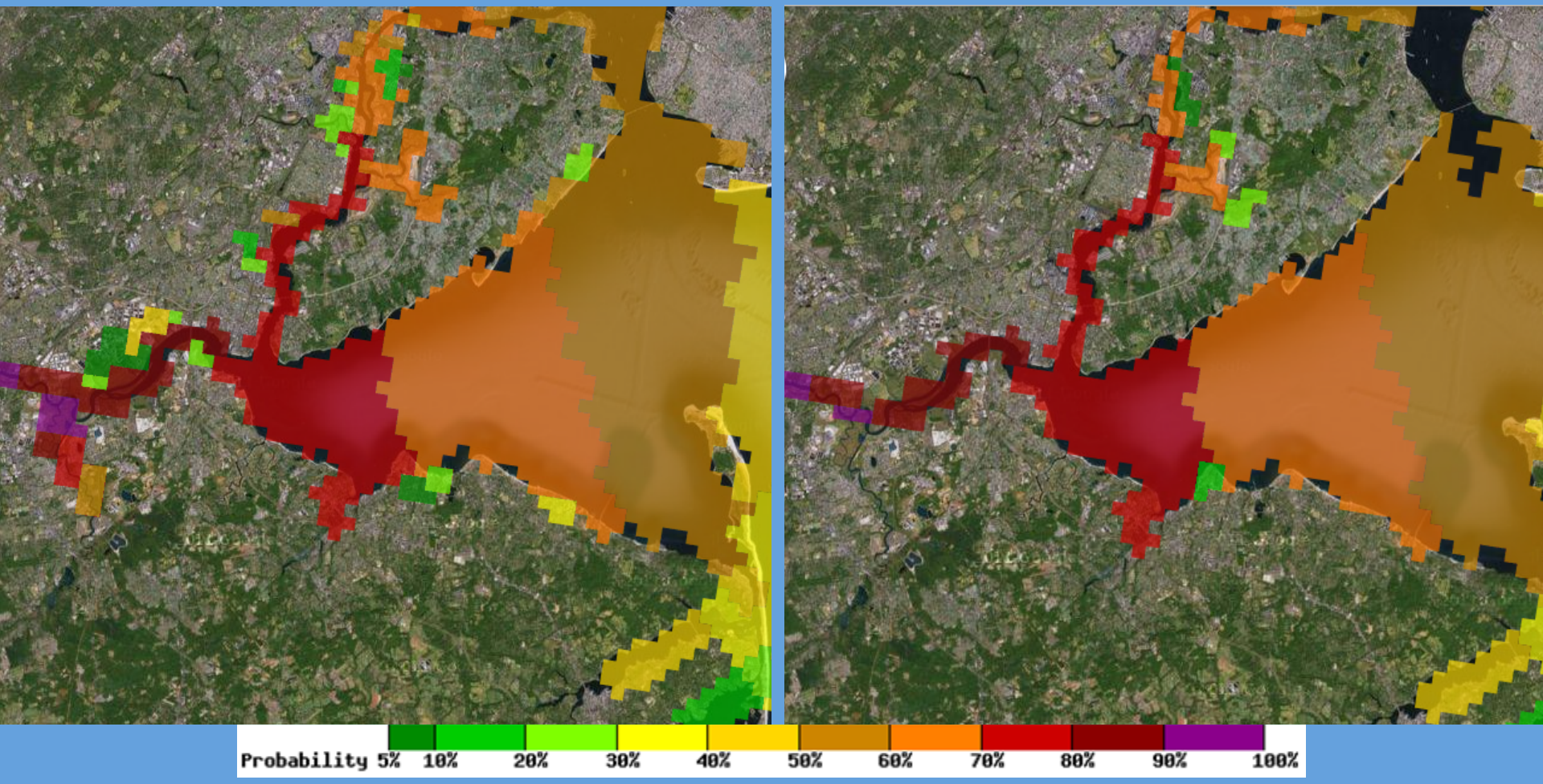
P-surge gives results above datum, which can be confusing for some users.

How to move p-surge to above ground level?

- Subtract land from p-surge products
  - Could work for exceedance product
  - Unable to subtract land from a probability
- Subtract land before combing into probabilities
  - Expert users may still need above datum product, so cannot replace p-surge
- Create a new product (PHISH)



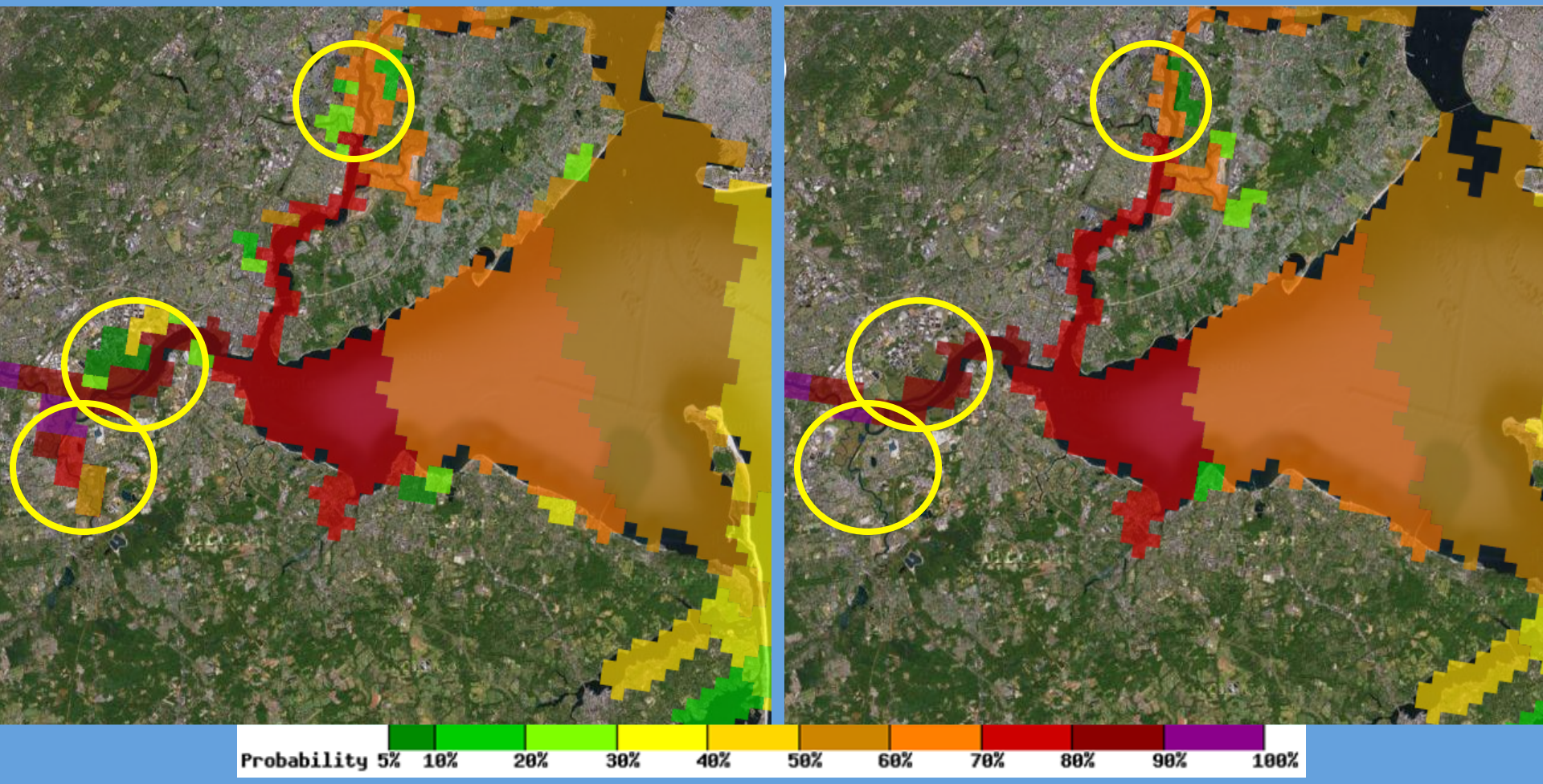
PHISH Example (Probability)



P-surge (above datum)
Probabilistic product

PHISH (above ground level)
Probabilistic product

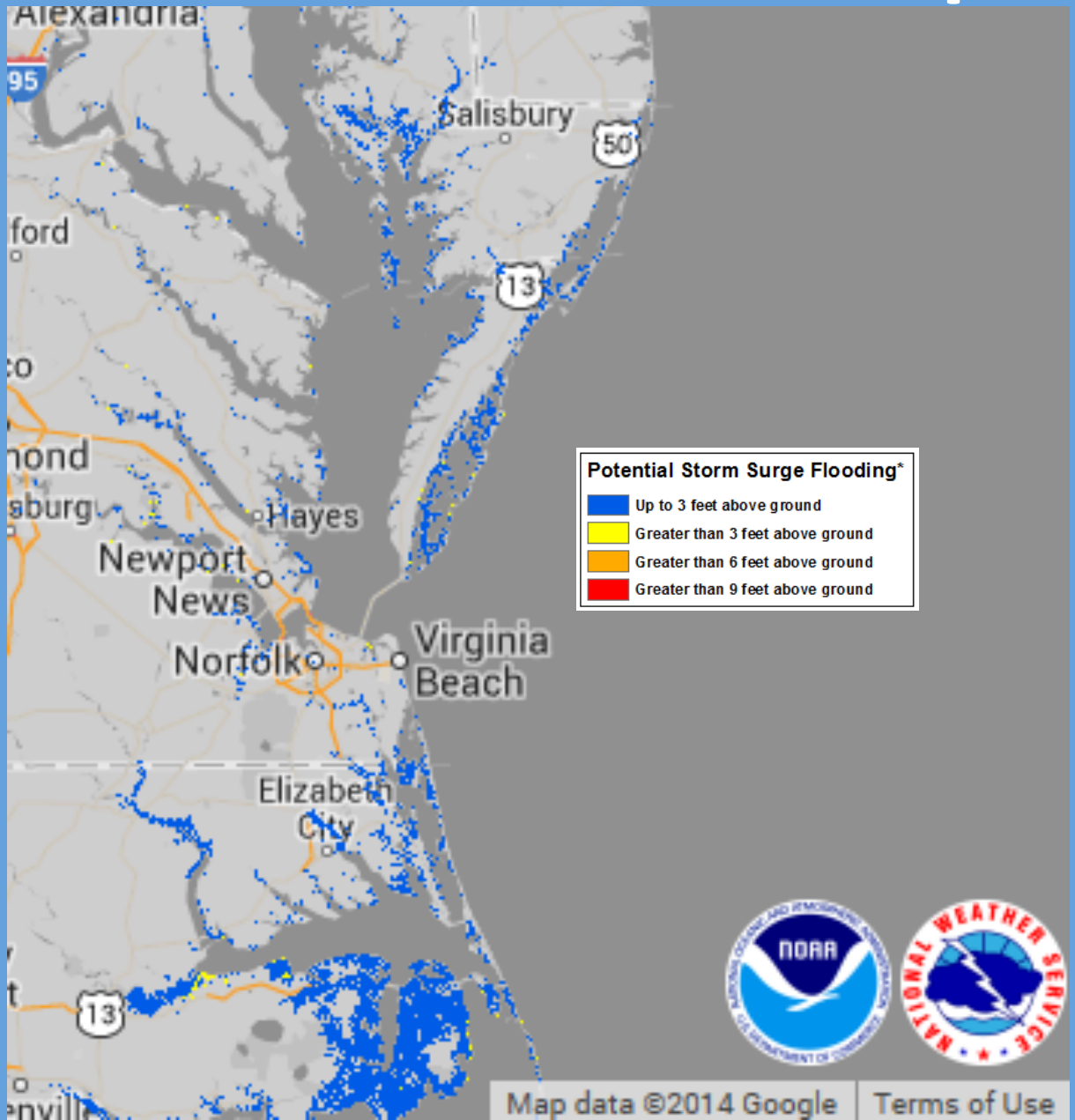
PHISH Example (Probability)



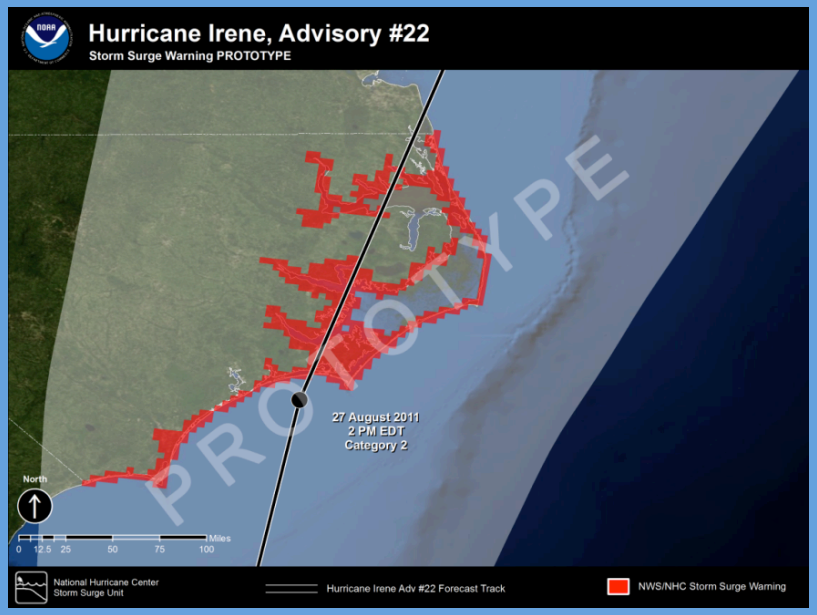
P-surge (above datum)
Probabilistic product

PHISH (above ground level)
Probabilistic product

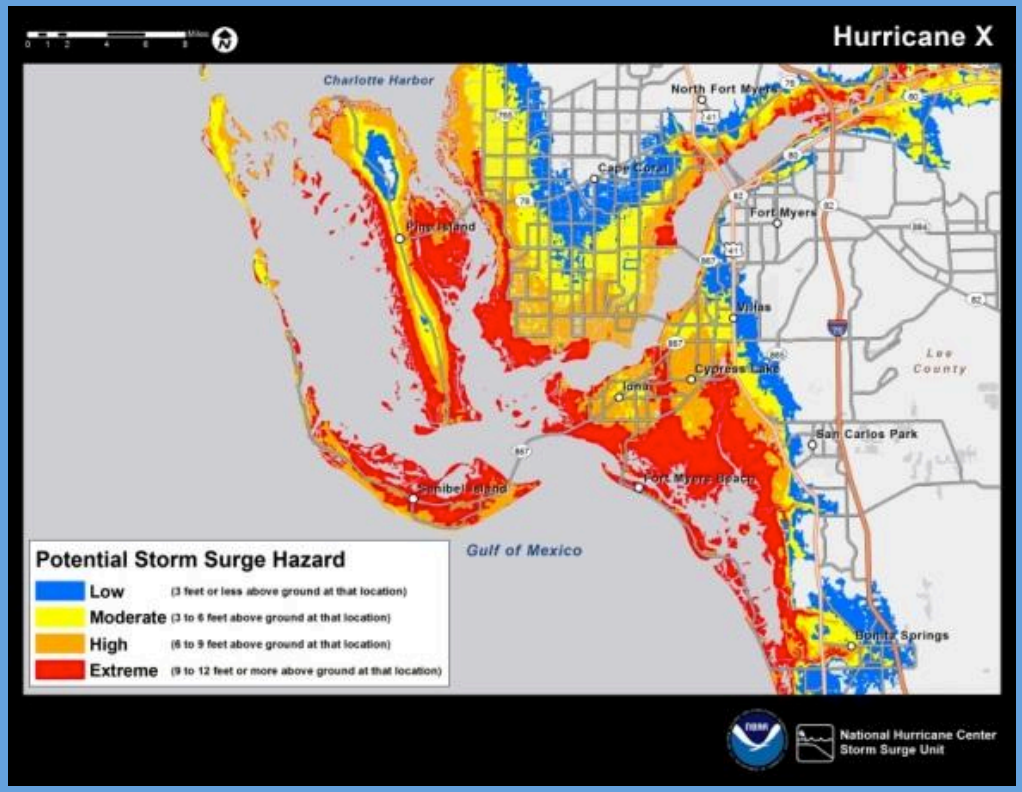
Hurricane Arthur Example



Communicating Actionable Information



TC storm surge warning - experimental in 2015



Potential Storm Surge Flood Map

Updated SLOSH Basins (OR3 vs. CP5)

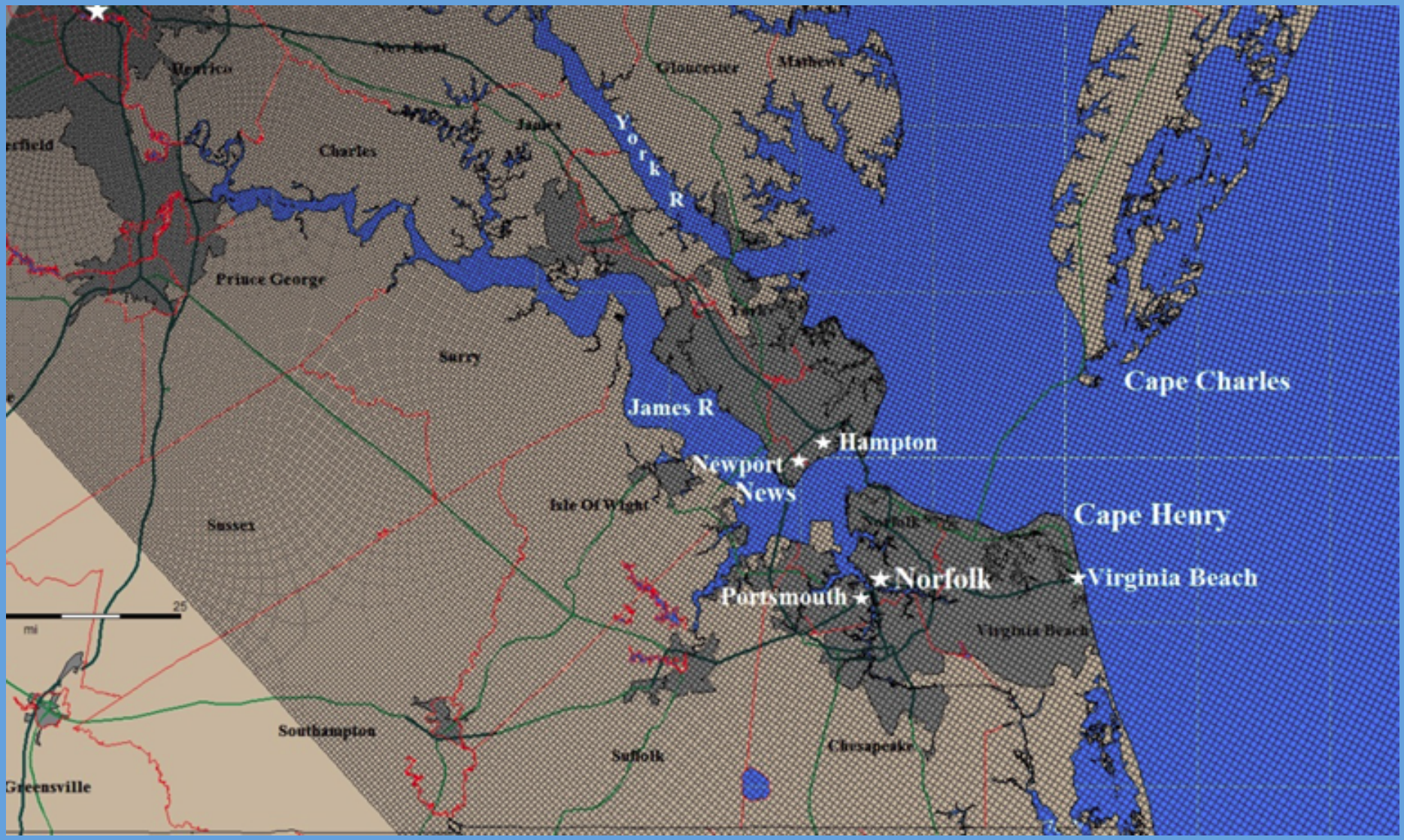
The new Norfolk basin (OR3), completed 2012

The new Chesapeake Bay basin (CP5), completed 2014

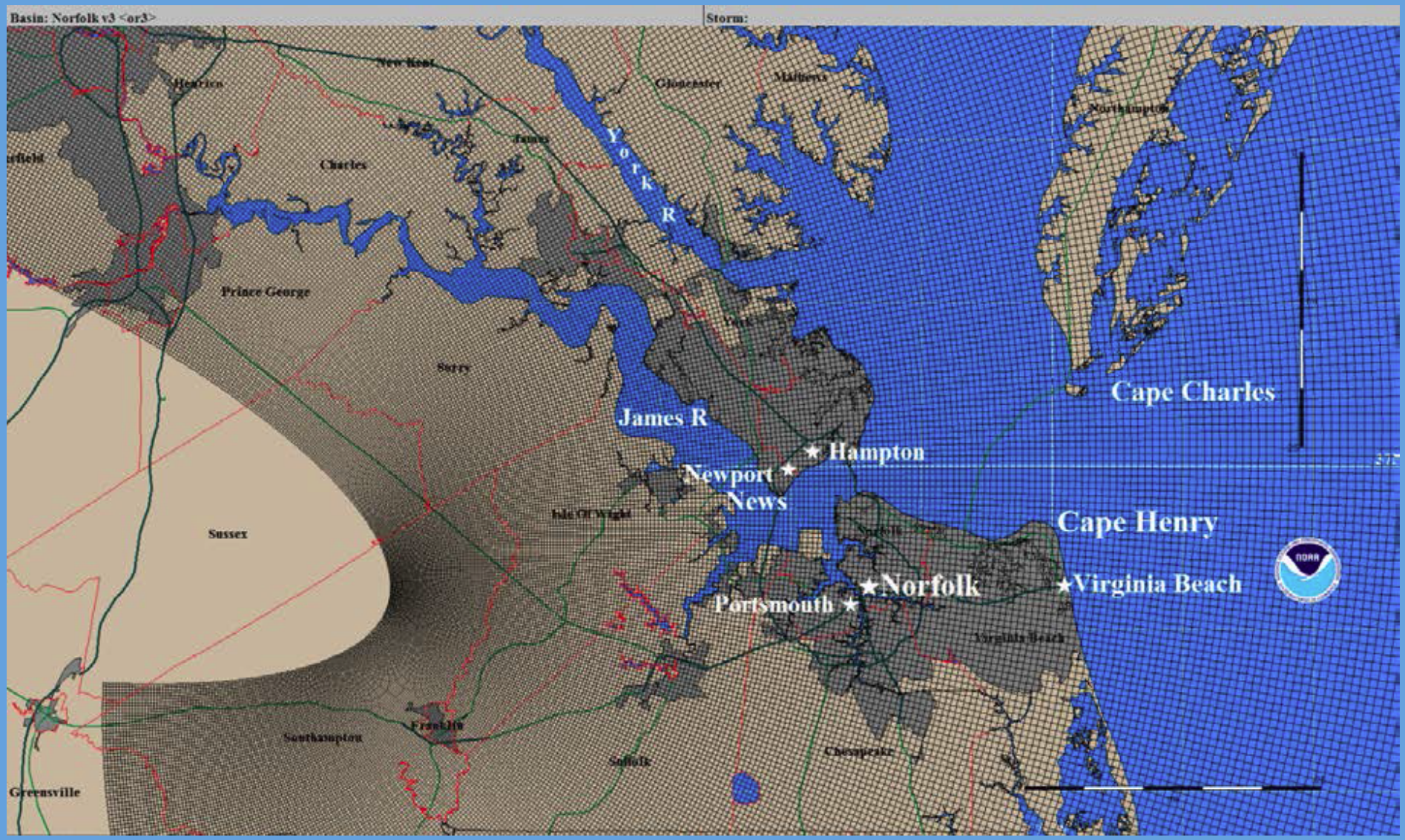
CP5 represents the first large SLOSH basin transitioned to the NOAA supercomputer.

The increased computing allowed for the inclusion of more storm tracks and scenarios, over double that included in the previous grid. For example, slower storm motions were included within the Chesapeake Bay area. Additionally, CP5 has much higher resolution, includes tighter track spacing, larger radius of maximum wind storms, and the overall grid is larger than previous grid.

CP5

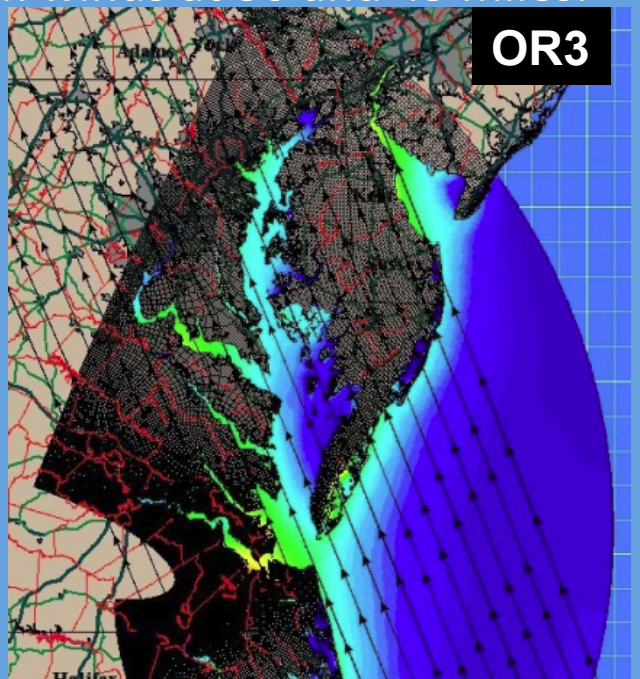

Henrico
Charles
Prince George
Surry
Sussex
James R
York R
Gloucester
Mathews
Cape Charles
Hampton
Newport News
Isle Of Wight
Cape Henry
Norfolk
Virginia Beach
Portsmouth
Southampton
Suffolk
Chesapeake
Greensville
25
mi

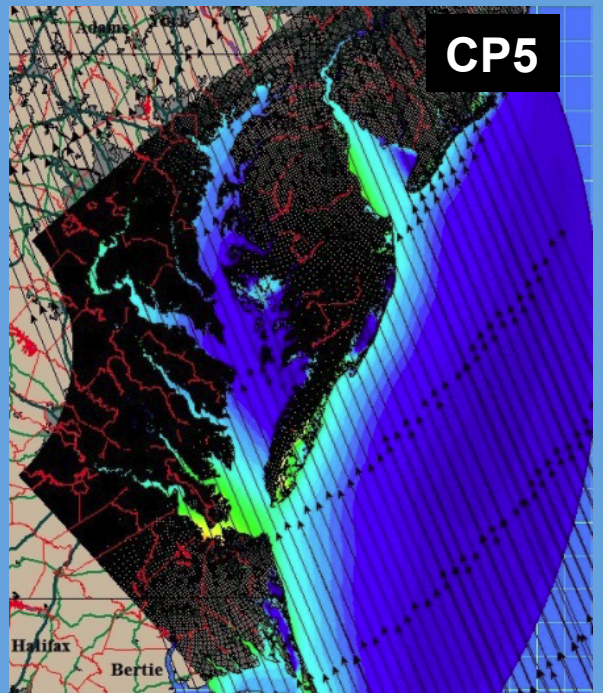
OR3


Basin: Norfolk v3 <or3>
Storm:
Henrico
New Kent
Gloucester
Mathews
Northampton
Charles
James
York R
Prince George
Surry
James R
Hampton
Newport News
Cape Charles
Cape Henry
Isle Of Wight
Sussex
Norfolk
Portsmouth
Virginia Beach
Southampton
Franklin
Suffolk
Chesapeake
Greensville

Hypothetical Storms Modeled

- NHC is now simulating hypothetical hurricanes with a larger radius of maximum winds to reflect observations from past storm events, such as Hurricanes Isabel, Isaac, Irene, Ike, and Katrina. In general, bigger storms produce more storm surge, so more flooding is likely.
- **OR3 modeled 4,920 hypothetical storms** during a high tide, which included evaluating a radius of maximum winds at 30 and 45 miles. **CP5 modeled 16,320 hypothetical storms** during a high tide, which also included evaluating a radius of maximum winds at 30 and 45 miles.



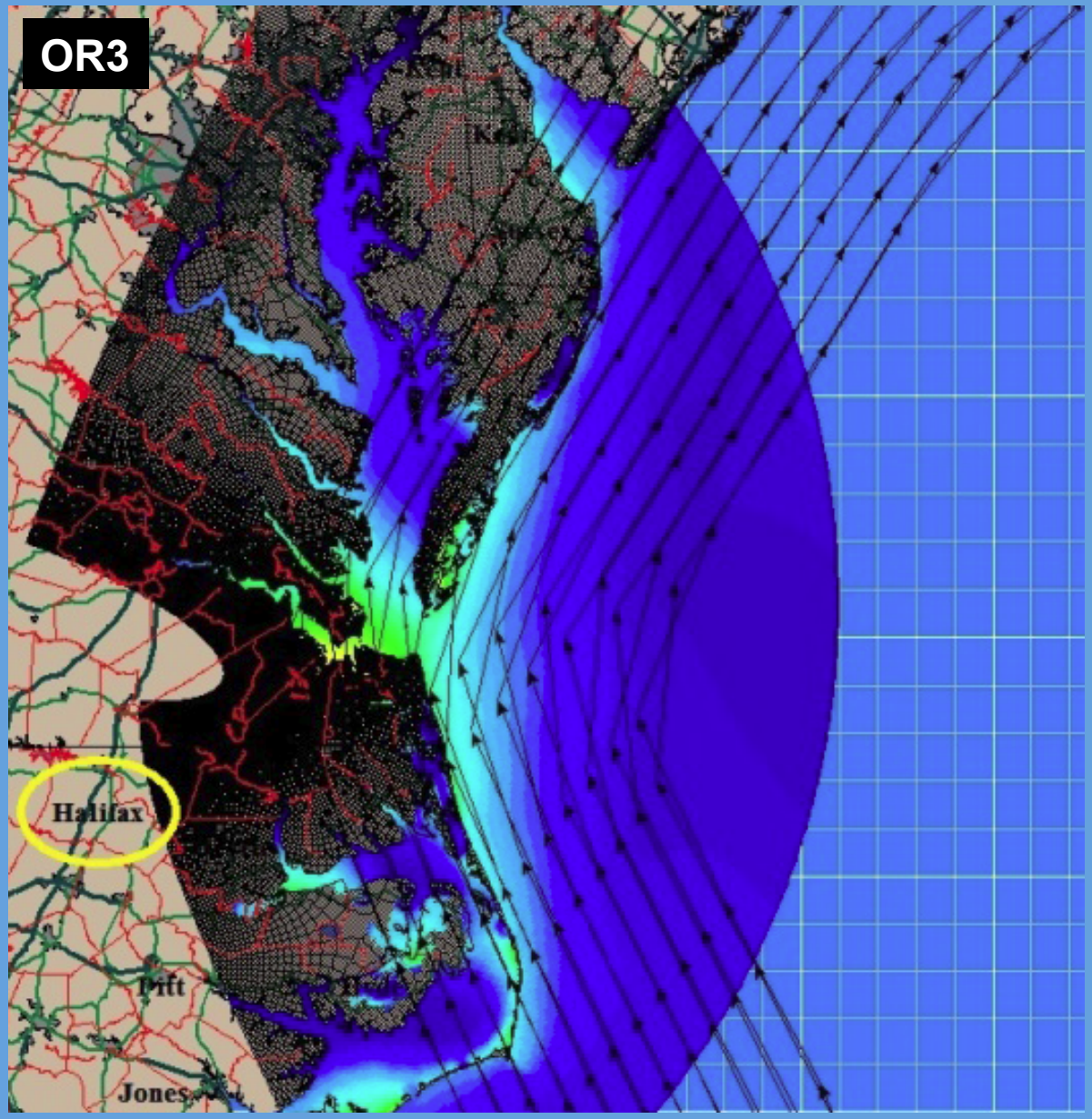


Direction	Speed (mph)	Intensities	Tracks
WNW	10, 20, 30, 40, 50	1 through 4	27
NW	10, 20, 30, 40, 50	1 through 4	23
NNW	10, 20, 30, 40, 50	1 through 4	17
N	10, 20, 30, 40, 50	1 through 4	11
NNE	10, 20, 30, 40, 50	1 through 4	17
NE	10, 20, 30, 40, 50	1 through 4	17
Parallel to Coast	10, 20, 30, 40, 50	1 through 4	11

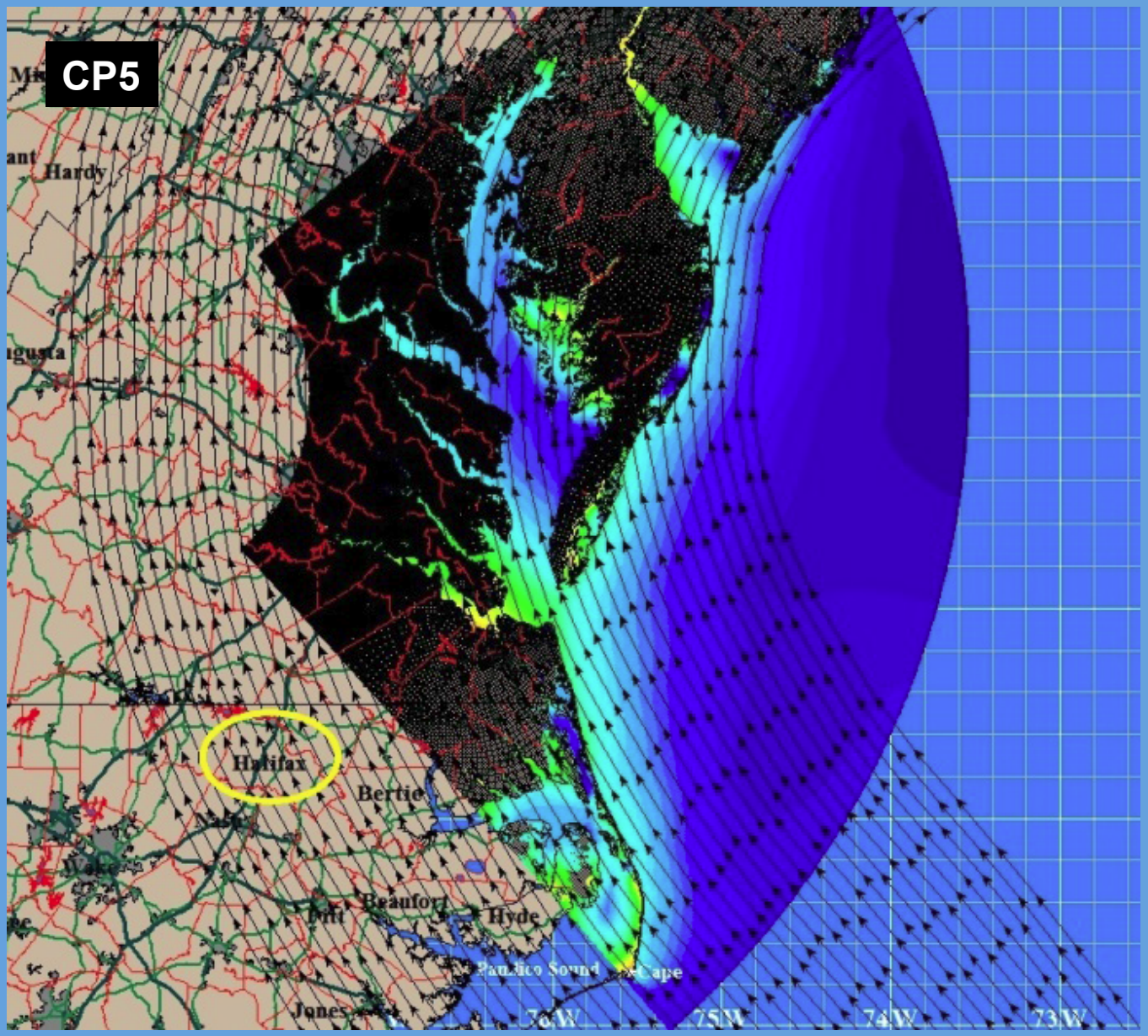
Table 2 - New Chesapeake Bay Basin (CP5) - Hypothetical Storms Modeled – (16,320 runs)

Direction	Speed (mph)	Intensities	Tracks
WNW	5, 10, 20, 30, 40, 50	1 through 4	55
NW	5, 10, 20, 30, 40, 50	1 through 4	47
NNW	5, 10, 20, 30, 40, 50	1 through 4	43
N	5, 10, 20, 30, 40, 50	1 through 4	40
NNE	5, 10, 20, 30, 40, 50	1 through 4	54
NE	5, 10, 20, 30, 40, 50	1 through 4	56
Parallel to Coast	5, 10, 20, 30, 40, 50	1 through 4	45

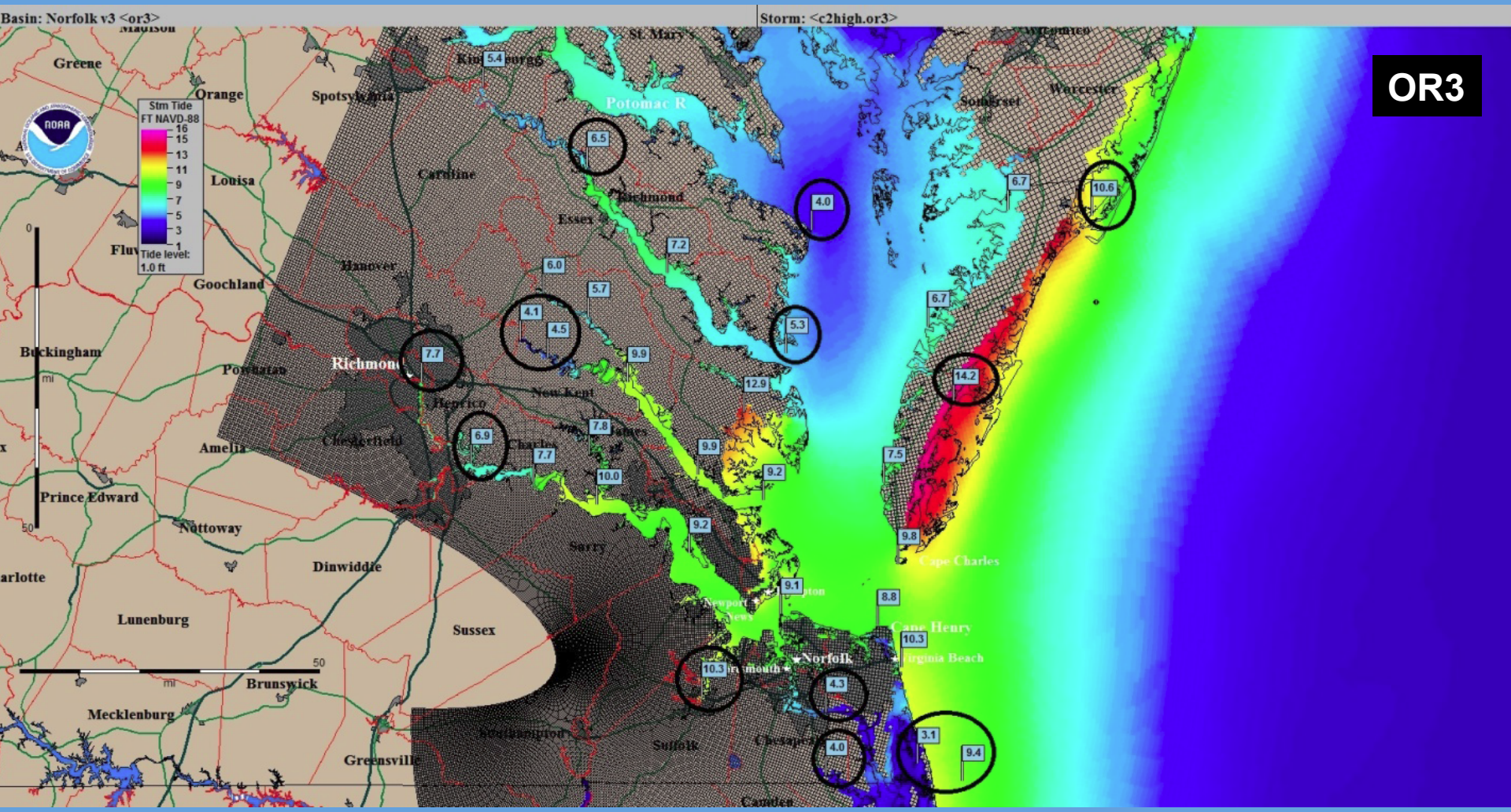
CP5 Runs Beyond Domain



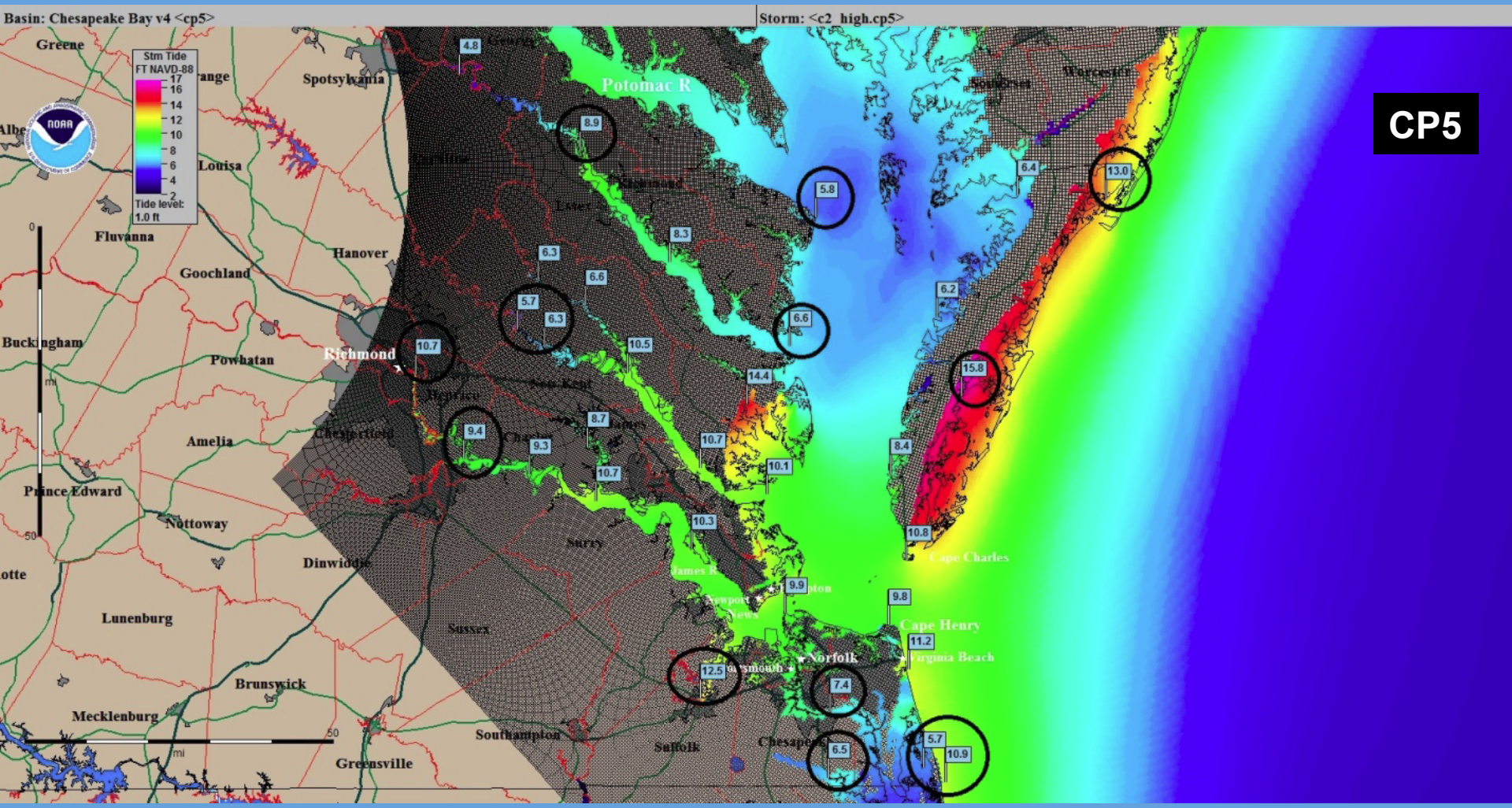
CP5 Runs Beyond Domain



Basin Differences (Cat 2 Example)



Basin Differences (Cat 2 Example)



Results show CP5 storm tide elevations tend to be higher, except for the Chesapeake Bay side of the middle and upper Eastern Shore for a Category 4

ET Modeling Strategy

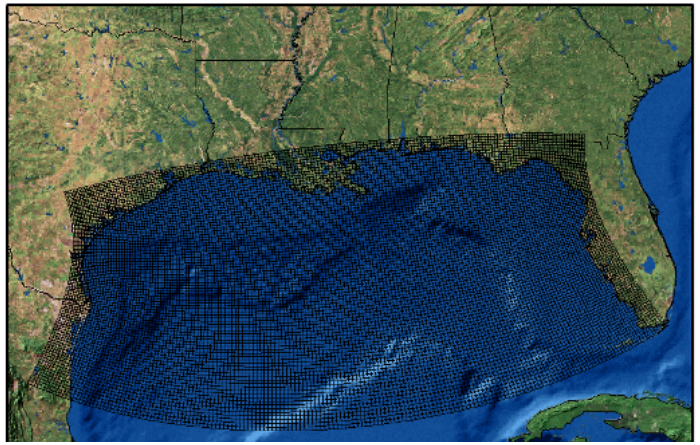
- Storm Surge Roadmap is coordinating development of multi-model ensembles of total water level guidance, leveraging extensive federal investments
  - SLOSH (ETSS)
    - Uses simplified physics and efficient numerical scheme to run extremely quickly, enabling a large number of ensemble runs
    - Operational for TC and ET across US coasts
    - Developing tide and wave coupling, nesting
  - ADCIRC (ESTOFS)
    - Uses advanced physics and a complex numerical scheme to provide high fidelity predictions but are costly to compute, minimizing ensemble members
    - Extensive set of grids developed for federal projects
    - Operational for ET Atlantic
    - Couples to tide, wave, and hydraulic models

ETSS background

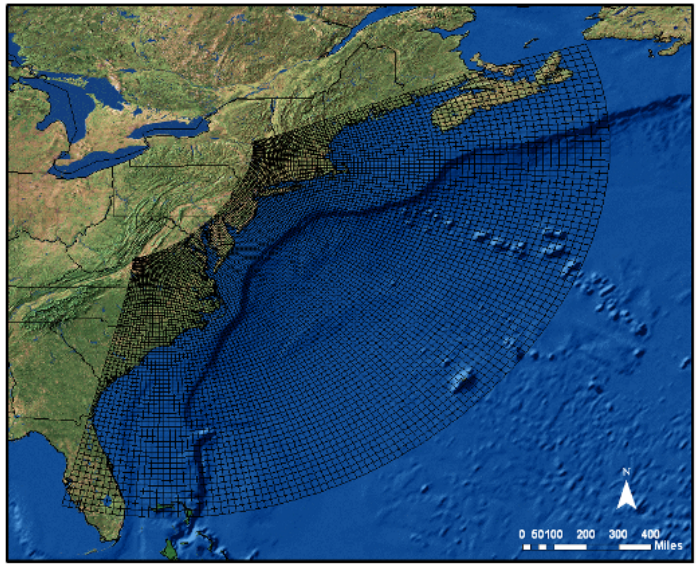
- **Resolution varies**
  - **Gulf of Mexico ~ 4km**
  - **East Coast ~ 9.4km**
  - **Alaska ~ 6.7km**
  - **West Coast ~ 6.5km**

- **Results posted to the web**
  - **http://www.nws.noaa.gov/mdl/etsurge/ (text & hydrographs)**
  - **http://weather.noaa.gov/pub/SL.us008001/ST.expr/DF.gr2/DC.ndgd/GT.slosh/ (gridded data)**
  - **http://www.opc.ncep.noaa.gov/Loops/SURGE_GOM_EAST/SURGE_GOM_EAST_96_HR.shtml (gridded)**

MDL's Gulf Coast Extratropical Storm Surge Grid



MDL's East Coast Extratropical Storm Surge Grid



Overhauling ETSS Guidance

- Finer resolution wind forcing
- Output to 2.5 km NDFD (vs 5 km)
- Better data dissemination (SHEF encoding for AHPS, enhanced website)

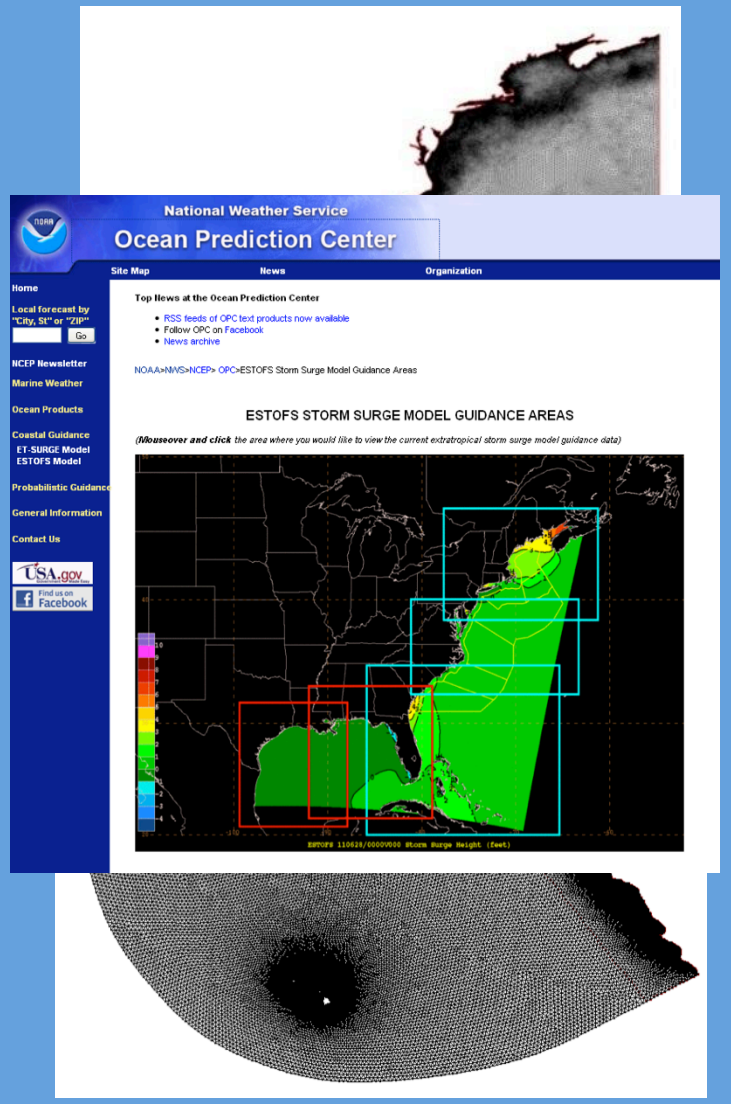
Extra Tropical Storm Surge Model Development

- **Extra Tropical Storm Surge (ETSS) model with overland and tide capabilities**
  - **Introduce tide versions of SLOSH**
  - **Nest with SLOSH's finer (< 500 m) overland tropical grids**

- **Probabilistic Extra-Tropical Storm Surge (PETSS)**
  - **Forcing via the 21 GFS ensemble members (scalable to include other ensemble model's members)**

Improving Extratropical Surge Prediction

- Extratropical Surge + Tide Operational Forecast System (ESTOFS) for Atlantic and Pacific
- Uses ADCIRC to model surge and tide with coastal resolution of 1 to 3 km
- 180 hour forecast produced 4 times per day on WCOSS operational high performance computer

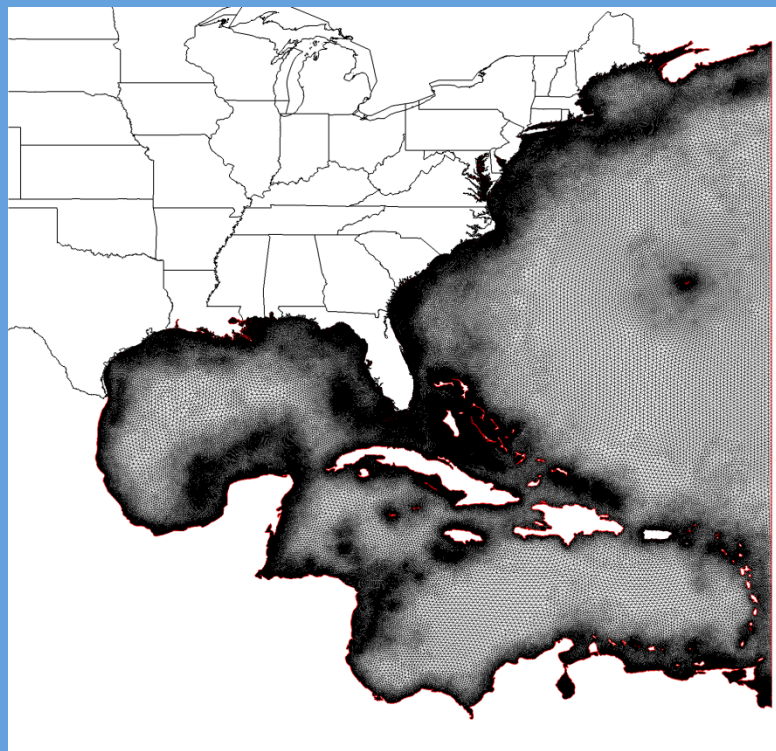


ESTOFS Overview

- Purpose
  - Provide an operational set of forecast guidance for extratropical storm surge that includes tides
  - Supports coupling to wave models
    - Provide surge+tide boundary conditions for NWS's Nearshore Wave Prediction System (NWPS)
    - Mimics WAVEWATCHIII® (WW3) set-up for future coupling
  - Leverages community-based model ADCIRC

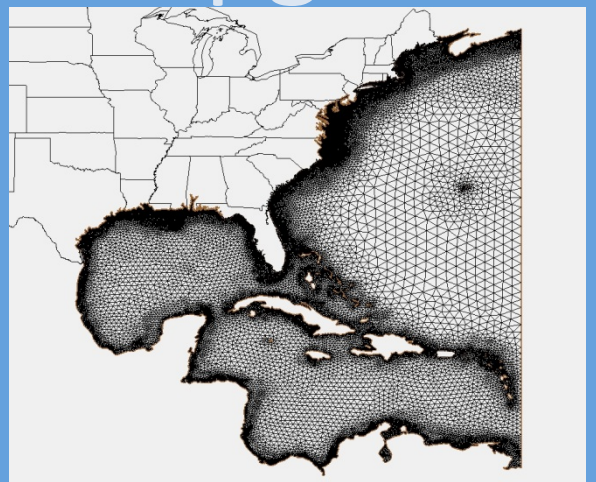
ESTOFS Output

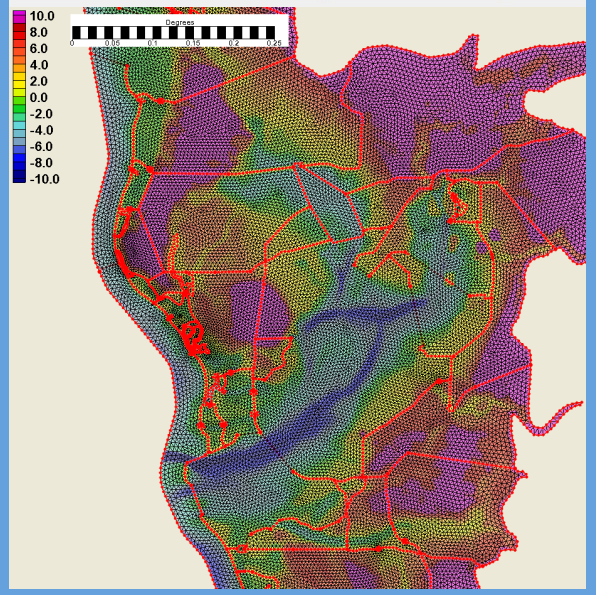
- Delivers three types of water level
  - Combined Water Level (CWL): Surge + tides
  - Harmonic Tidal Prediction (HTP): Astronomical tides
  - Subtidal Water Level (SWL): SWL = CWL – HTP = "surge"
- Generates output on ADCIRC unstructured grid



Sandy Supplemental ESTOFS Upgrade

- Funding to develop ADCIRC TC ensemble implementation
- Extend ESTOFS Atlantic overland and add ensemble members
  - An ensemble of 5 to 10 members will predict overland flooding along East and Gulf coasts at 200-500 m resolution
  - Potential ensemble members: GFS, GEFS, NAM, NDFD, ECMWF
  - Operational in FY16



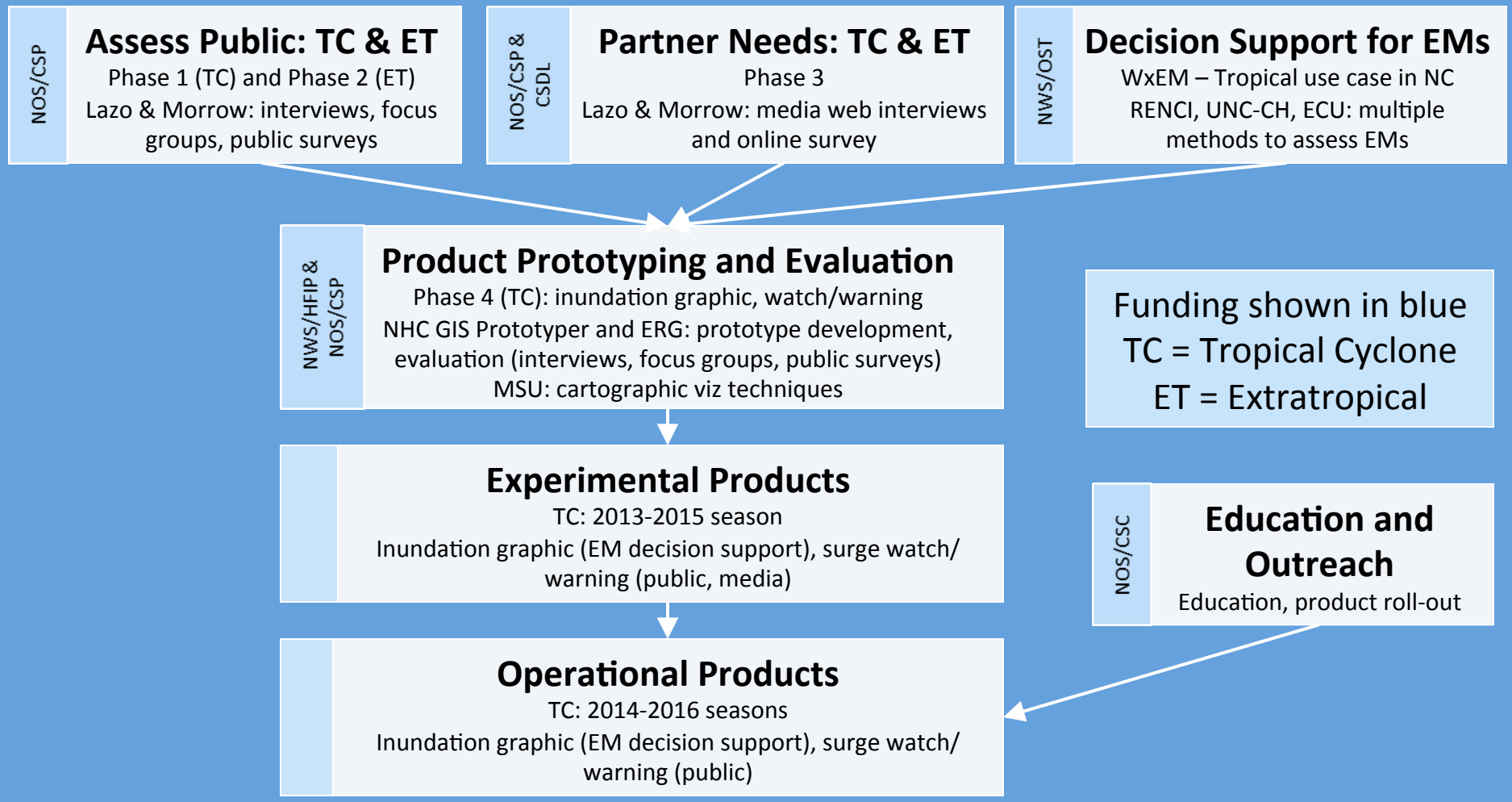


Coastal & Ocean Modeling Testbed

- Provides NOAA with shared, systematic methodology for evaluating benefits of research models for transition to operations
- Coastal inundation subgroup
  - Round 1 evaluated 4 models for tropical (Ike, Rita) and extratropical (Scituate, MA) surge+wave prediction
  - Delivered SLOSH coupled to SWAN wave model, ADCIRC surge guidance system for experimental use
  - Round 2 in Puerto Rico to evaluate wave-dominated inundation; includes SLOSH, ADCIRC, SWAN, and WAVEWATCH III

testbed.sura.org

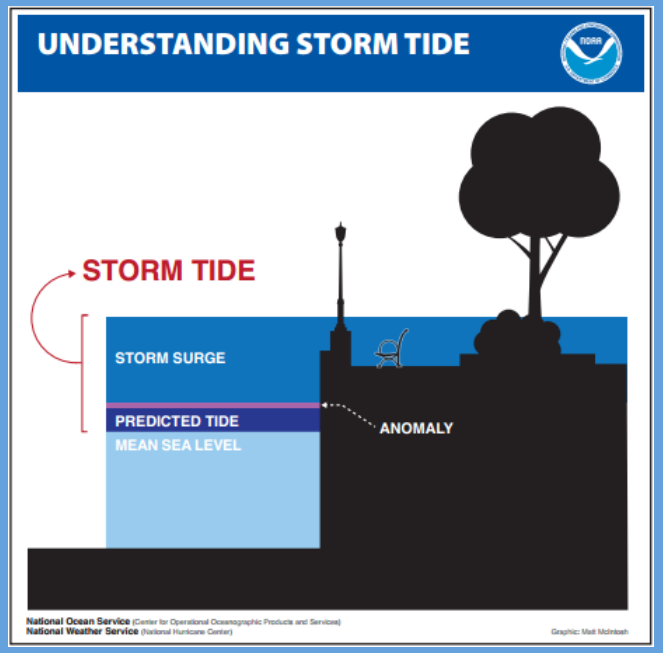
Storm Surge Social Science Strategy



Clarifying Water Levels and Datums

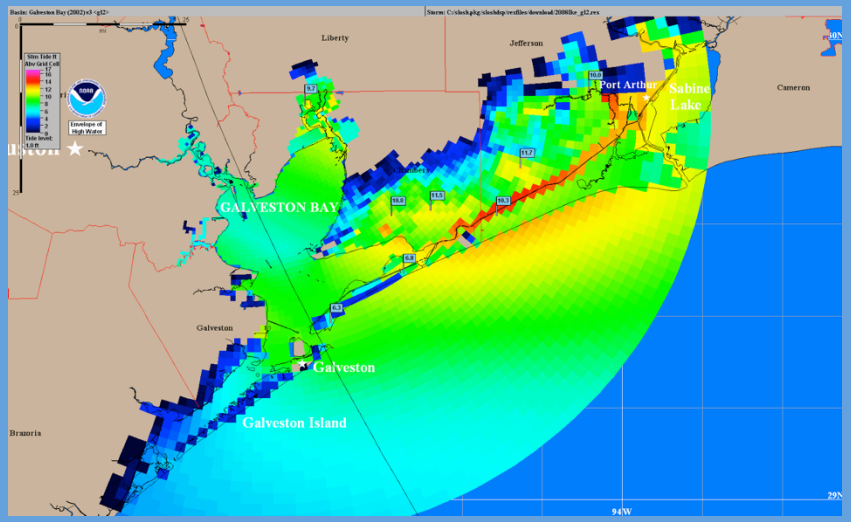
National Ocean Service worked with the National Hurricane Center (NHC) to alleviate confusion regarding tidal datums

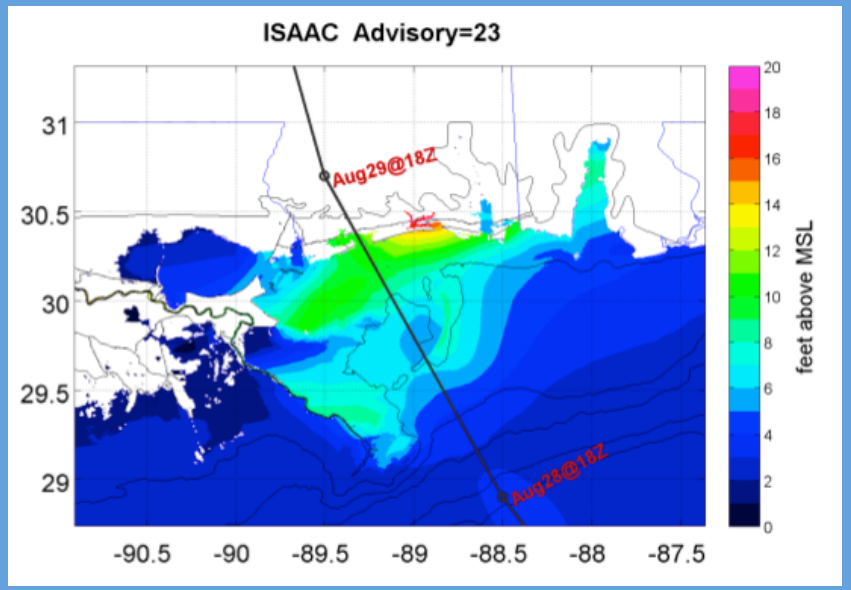
- NWS forecasts describe height of water above ground
- Mean Higher High Water (MHHW) is being used to approximate where inundation could begin
- *Storm Quicklook* and NOS web services include water level data relative to MHHW



Combining different models into an ensemble

- SLOSH (Sea, Lakes, and Overland Surge from Hurricanes) model
  - Uses simplified physics and an efficient scheme to run extremely quickly
- ADCIRC (ADvanced CIRCulation) model
  - Uses advanced physics and a complex high resolution scheme but more costly





Advancement of Ensemble TC Guidance

- Improving utility and accuracy of P-Surge forecast guidance
  - 2015: Efficiency, increase lead time, include trop storms, upgrade tide accuracy
  - 2016: Nesting, simultaneous storms
  - Hawaii operational implementation
- Enhance ensembling capability
  - 2015: experimental ADCIRC tropical ensemble
  - HWRF coupling, evaluation of StormSurge Viz

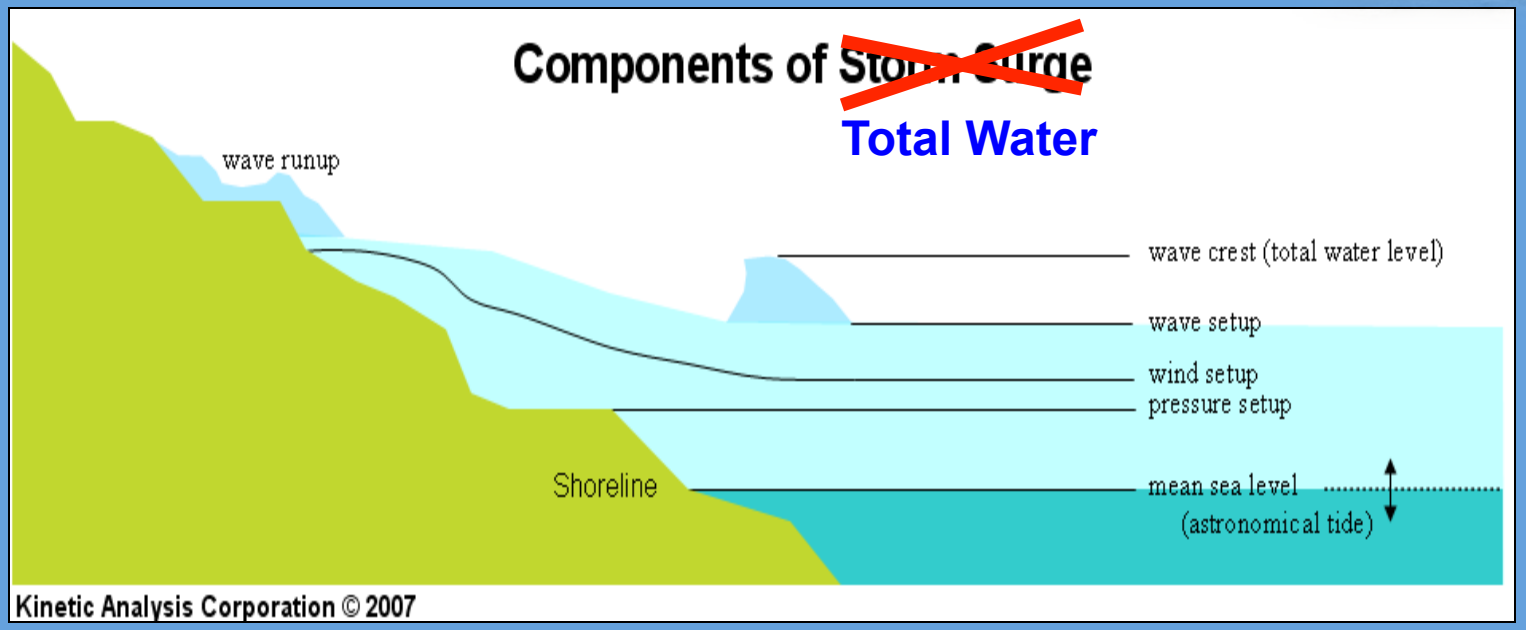
National Tidal Datum Epoch (NTDE)

A common time period to which tidal datums are referenced

- **A specific 19 year period that includes the longest periodic tidal variations caused by the astronomic tide-producing forces.**
- **Averages out long term seasonal meteorological, hydrologic, and oceanographic fluctuations.**
- **Provides a nationally consistent tidal datum network (bench marks) by accounting for seasonal and apparent environmental trends in sea level that affects the accuracy of tidal datums.**

NWS Wakefield Total Water Level Pilot

Total Water



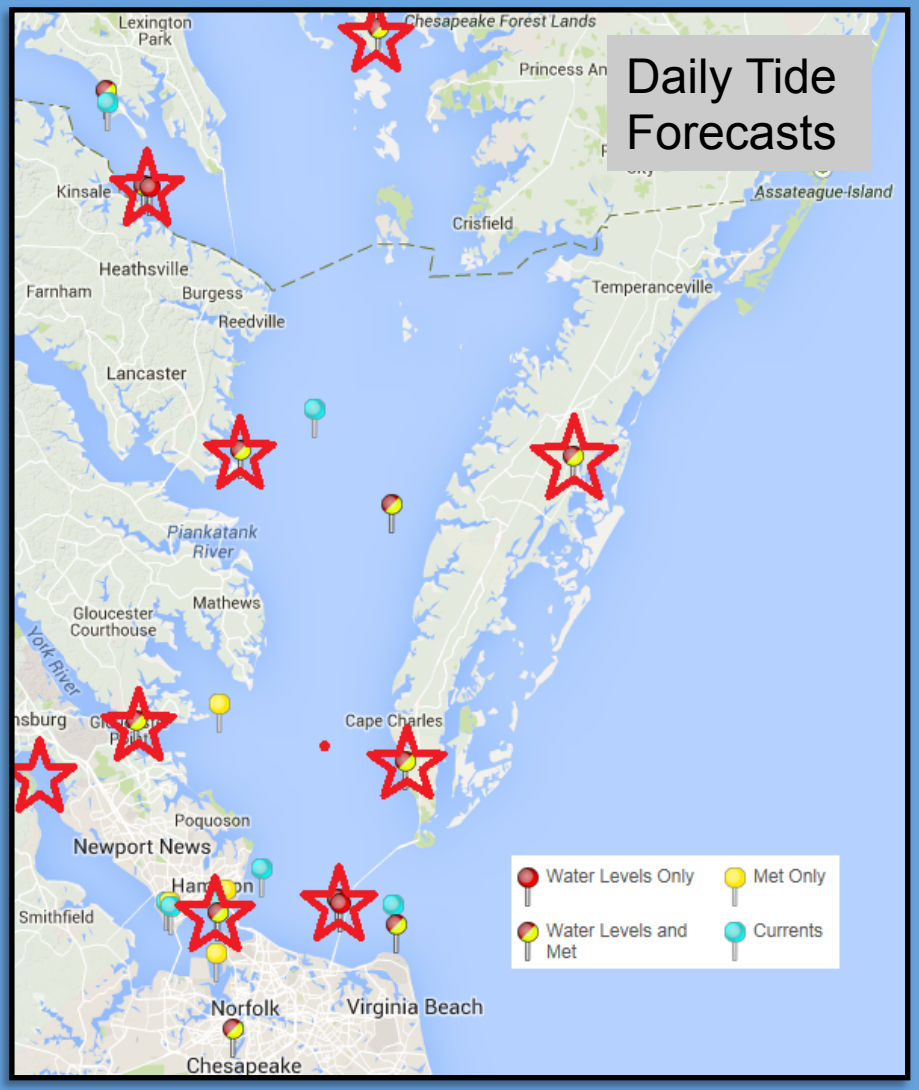
Total water level =

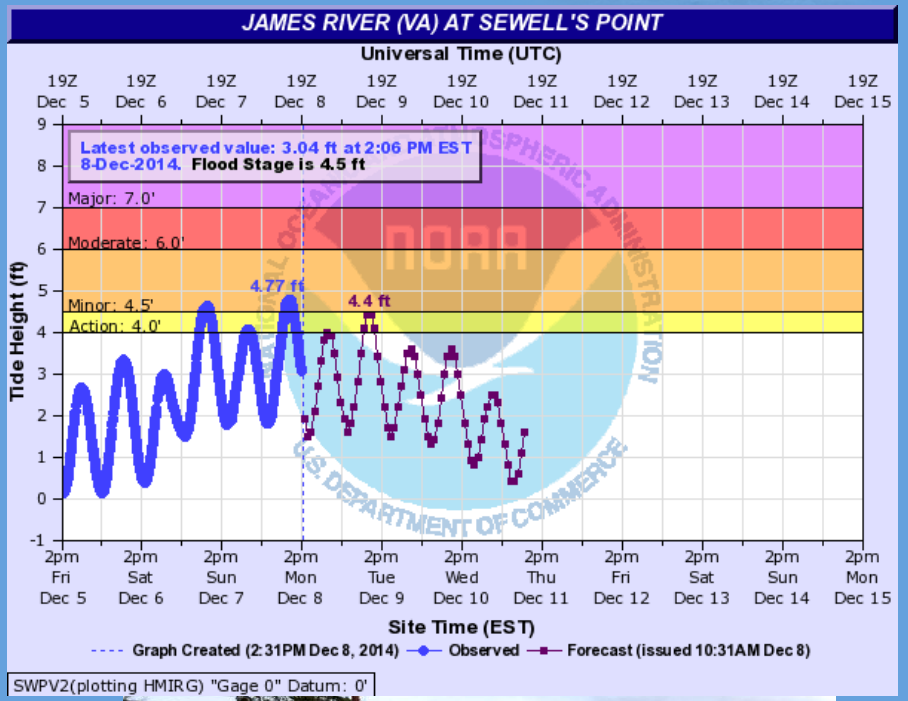
Storm surge +

Tides +

Freshwater

NWS Total Water Predictions





http://www.erh.noaa.gov/akq/brief/tides.php

Total Water Predictions

- Provides hydrographs and enhanced warnings
- Integrated into AHPS with all river flood data
- Coordinating with NOS on a one stop shop interface.

VAZ095>098-100-020200-
/O.EXT.KAKQ.CF.Y.0033.141101T1900Z-141102T1300Z/
NORFOLK/PORTSMOUTH-SUFFOLK-CHESAPEAKE-VIRGINIA BEACH-
NORTHAMPTON VA-
154 PM EDT SAT NOV 1 2014

...COASTAL FLOOD ADVISORY NOW IN EFFECT UNTIL 8 AM EST SUNDAY...

* LOCATION...NORTHAMPTON COUNTY AT KIPTOPEKE BEACH.

* TIMING/IMPACTS...MINOR FLOODING POSSIBLE WITHIN 2 TO 3 HOURS ON EITHER SIDE OF HIGH TIDE LATE TONIGHT.

* TIDES...TIDAL DEPARTURES WILL AVERAGE 1.5 TO 2.0 FT ABOVE NORMAL DURING HIGH TIDE LATE THIS AFTERNOON AND EARLY SUNDAY MORNING.

AT KIPTOPEKE...HIGH TIDE OCCURS AT 421 PM EDT THIS AFTERNOON...AND 405 AM EST SUNDAY MORNING. A PEAK WATER LEVEL OF AROUND 4.9 FEET MLLW IS EXPECTED EARLY SUNDAY MORNING. MINOR FLOODING BEGINS AT 4.5 FEET MLLW.

AT SEWELLS POINT...HIGH TIDE OCCURS AT 459 PM EDT THIS AFTERNOON...AND 431 AM EST SUNDAY MORNING. A PEAK WATER LEVEL OF AROUND 5.1 FEET MLLW IS EXPECTED EARLY SUNDAY MORNING. MINOR FLOODING BEGINS AT 4.5 FEET MLLW.

ALL TIDE HEIGHTS ARE RELATIVE TO MEAN LOWER LOW WATER.
TIME OF HIGH TOTAL TIDES ARE APPROXIMATE TO THE NEAREST HOUR.
FLOOD CATEGORY BASED ON TOTAL TIDE.

SEWELLS POINT VA
MINOR 4.5 FT, MODERATE 6.0 FT, SEVERE 7.0 FT

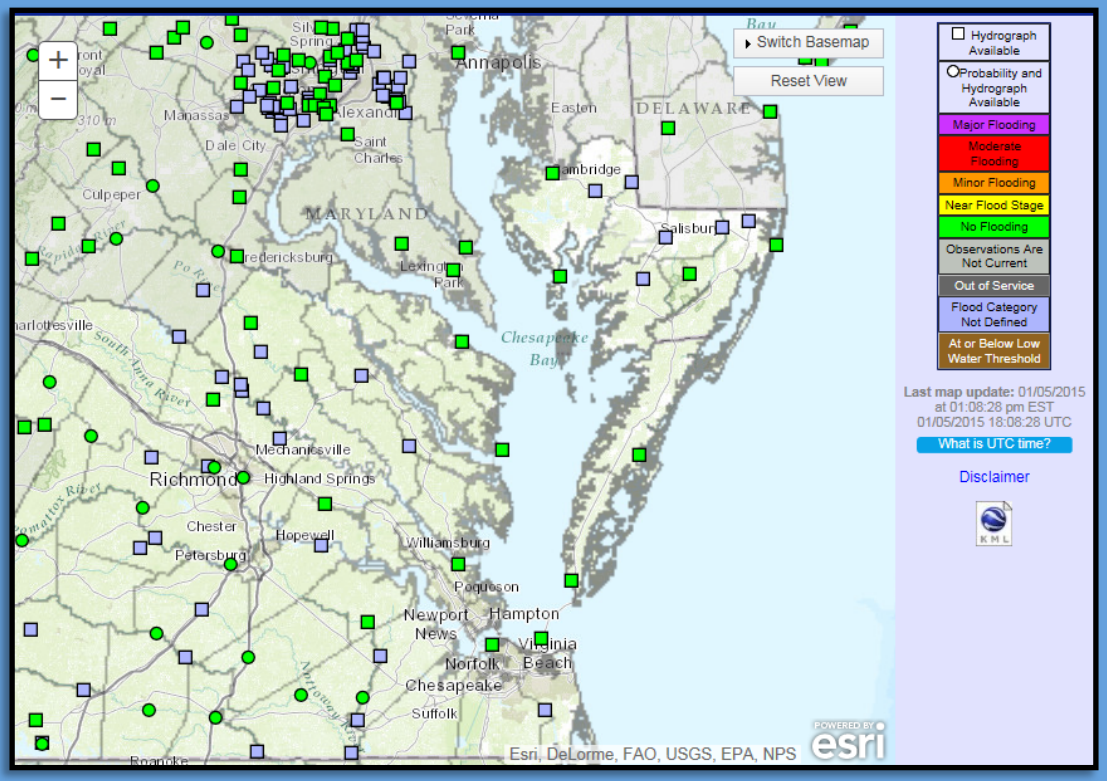
DAY/TIME	TOTAL TIDE /FT/	ASTRO TIDE /FT/	SURGE /FT/	WAVES /FT/	FLOOD CATEGORY
01/04 PM	4.8	2.7	2.1	4-5	MINOR
02/05 AM	5.1	2.8	2.3	5-6	MINOR
02/06 PM	3.8	2.8	1.0	3-4	NONE
03/06 AM	3.4	3.0	0.4	2-3	NONE
03/07 PM	2.6	2.8	-0.2	1	NONE
04/07 AM	2.8	3.2	-0.4	1	NONE

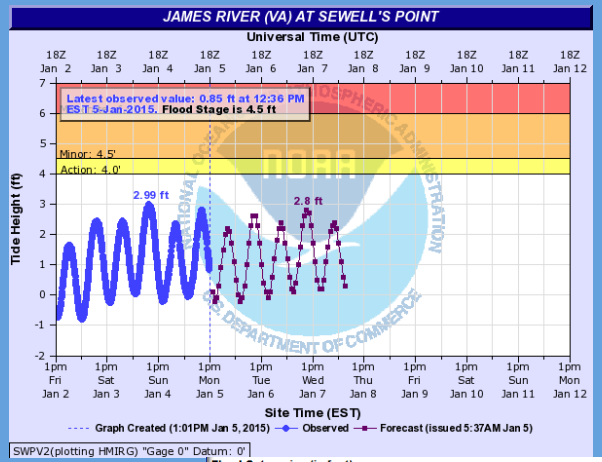
CHESAPEAKE BAY BRIDGE TUNNEL VA
MINOR 5.0 FT, MODERATE 5.5 FT, SEVERE 6.0 FT

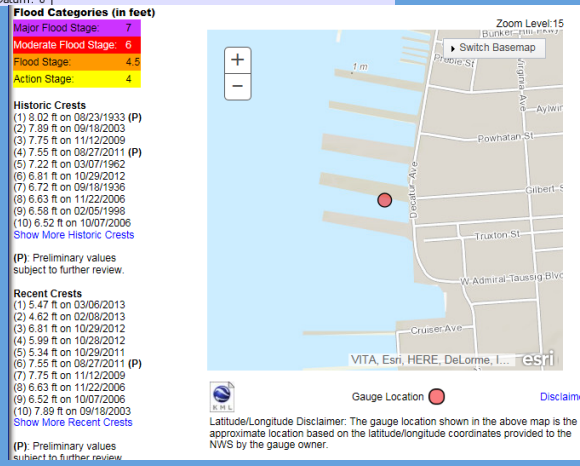
DAY/TIME	TOTAL TIDE /FT/	ASTRO TIDE /FT/	SURGE /FT/	WAVES /FT/	FLOOD CATEGORY
01/04 PM	5.1	2.9	2.2	4-5	MINOR
02/05 AM	5.4	2.9	2.5	6	MINOR

http://www.erh.noaa.gov/akq/brief/tides.php

AHPS Interface







Plan to add the following as they come online in cooperation with the USGS and NOS;
Colonial Beach (Dahlgren)
Suffolk (tide guidance could be problematic)
James R and Weyanoke Point (HECRAS model in development)

Working with NOS to develop a prototype interface focused on Norfolk expanding beyond AHPS expanding impact statements and visualizations.

Digital Coast SLR Viewer (ESRI Story Maps)

Sea Level Rise | Confidence | Marsh | Vulnerability | Flood Frequency

Sea Level Rise

5 ft SLR

Legend

Water Depth
Low-lying Areas
Area Not Mapped
Visualization Location

View Levees

Overview

Use the slider bar above to see how various levels of sea level rise will impact this area.

Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth).

Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Understanding The Map

Additional Information

Imagery | Streets | Share Map

Zoom to: State or Territory

Huntersville

The Hague

Norfolk

Navy Medical Center Portsmouth

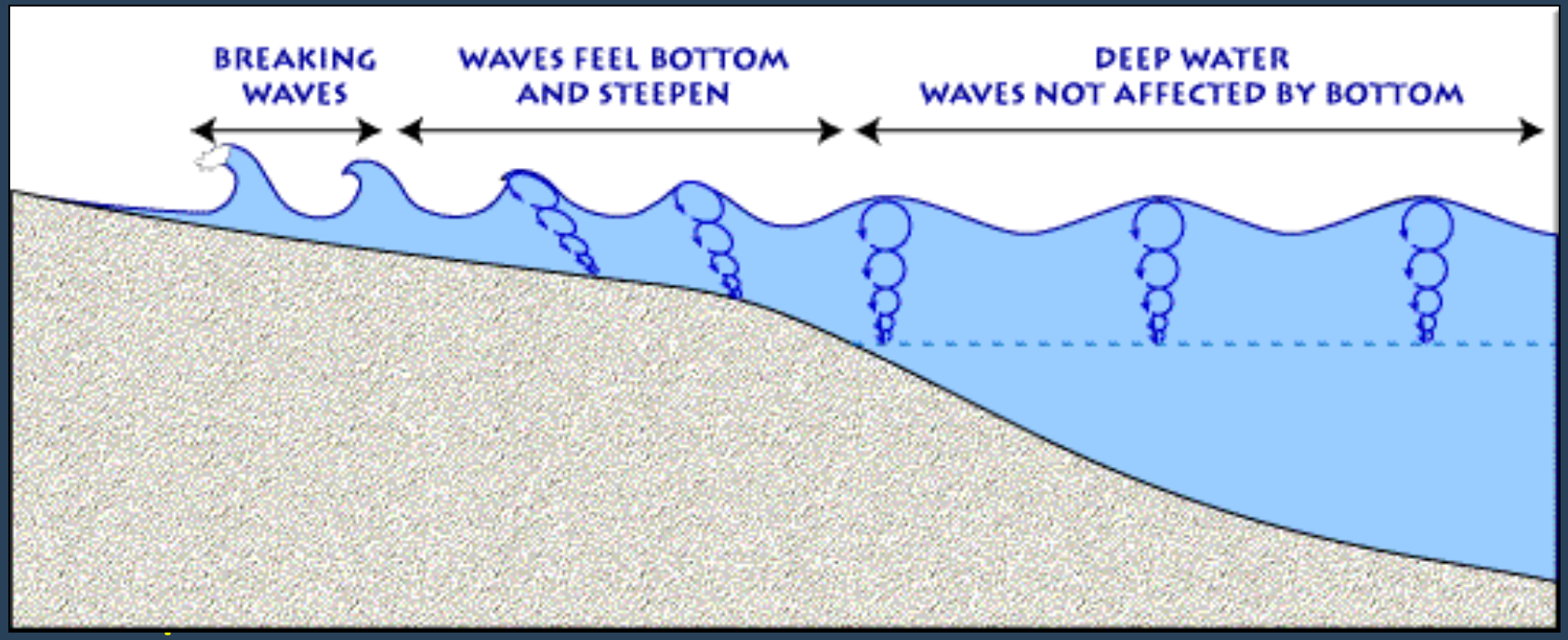
Wisconsin Square

Use the slider to view a simulation

Comparable to a forecast of 7.5 ft MLLW – Major Flooding (Hurricane Irene)

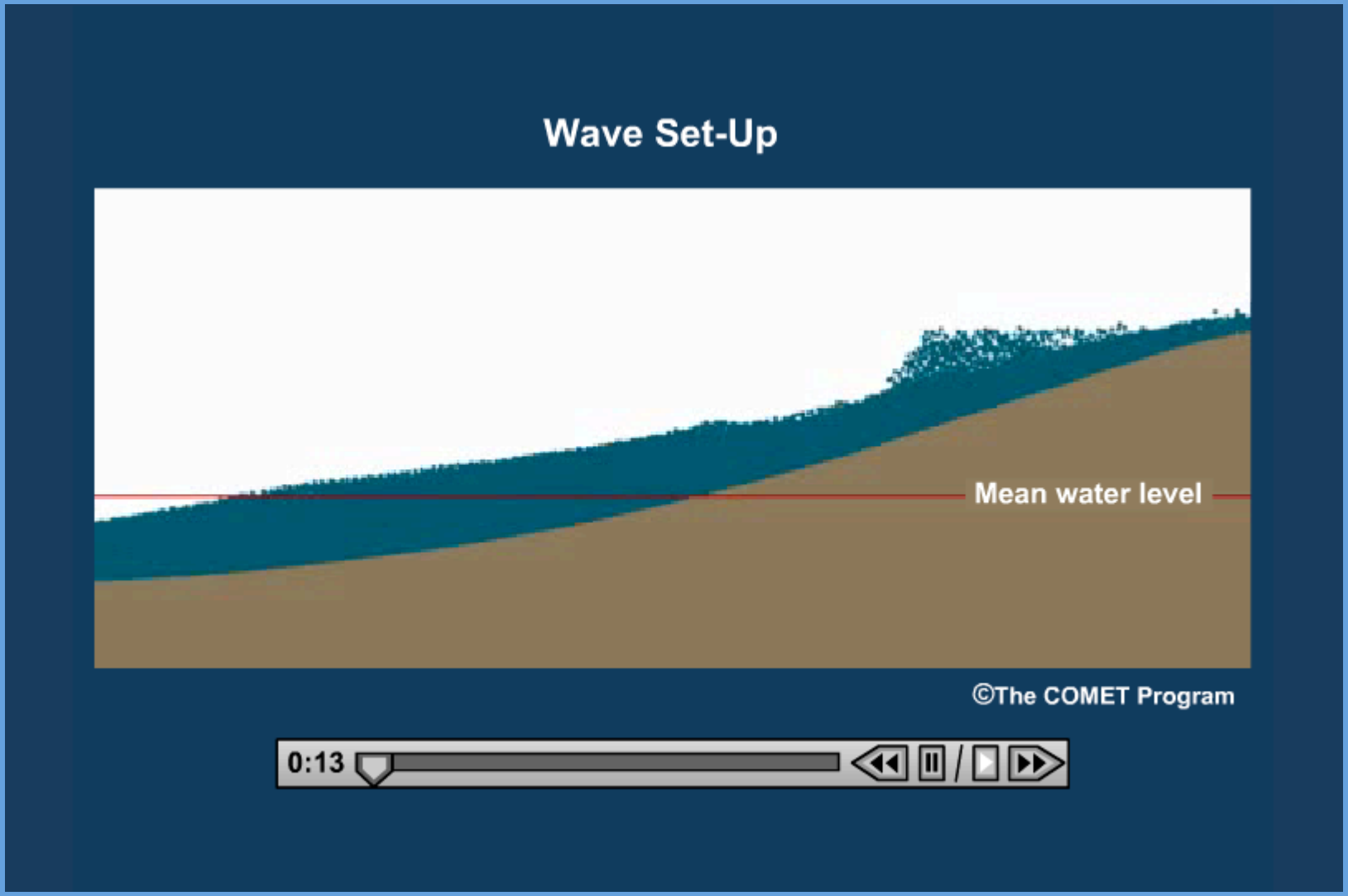
What about Waves?

- Breaking waves also contribute to the total water level through wave runup/setup



Wave Setup


SOUTHERNMOST
POINT
CONTINENTAL
U.S.A.

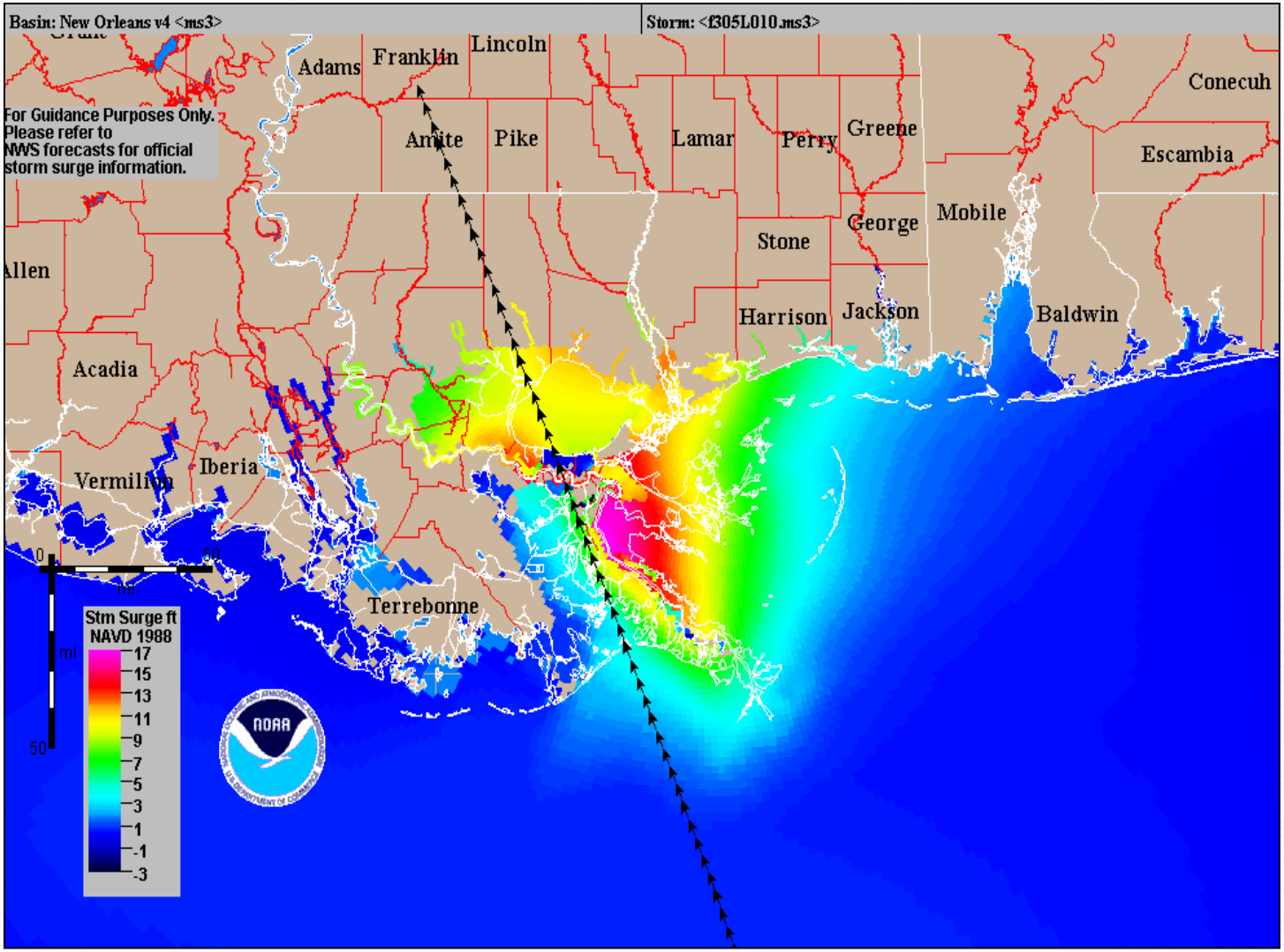

Wave Set-Up
Mean water level
©The COMET Program
0:13

The Dangers of Using Single Track Deterministic Guidance

- Users will go "weather shopping" with other model guidance. Users need to be aware of what they're looking at.
- Can be visually appealing, while suggesting a degree of accuracy and precision that cannot be justified.
- Most storm surge models perform quite well and comparable *only if* meteorological conditions are perfectly correct.
- Deterministic/Single Track runs are subject to a host of potential errors, including…
  - Direction – where/angle storm will approach coast
  - Forward speed – when storm will approach coast
  - Intensity and size of wind field

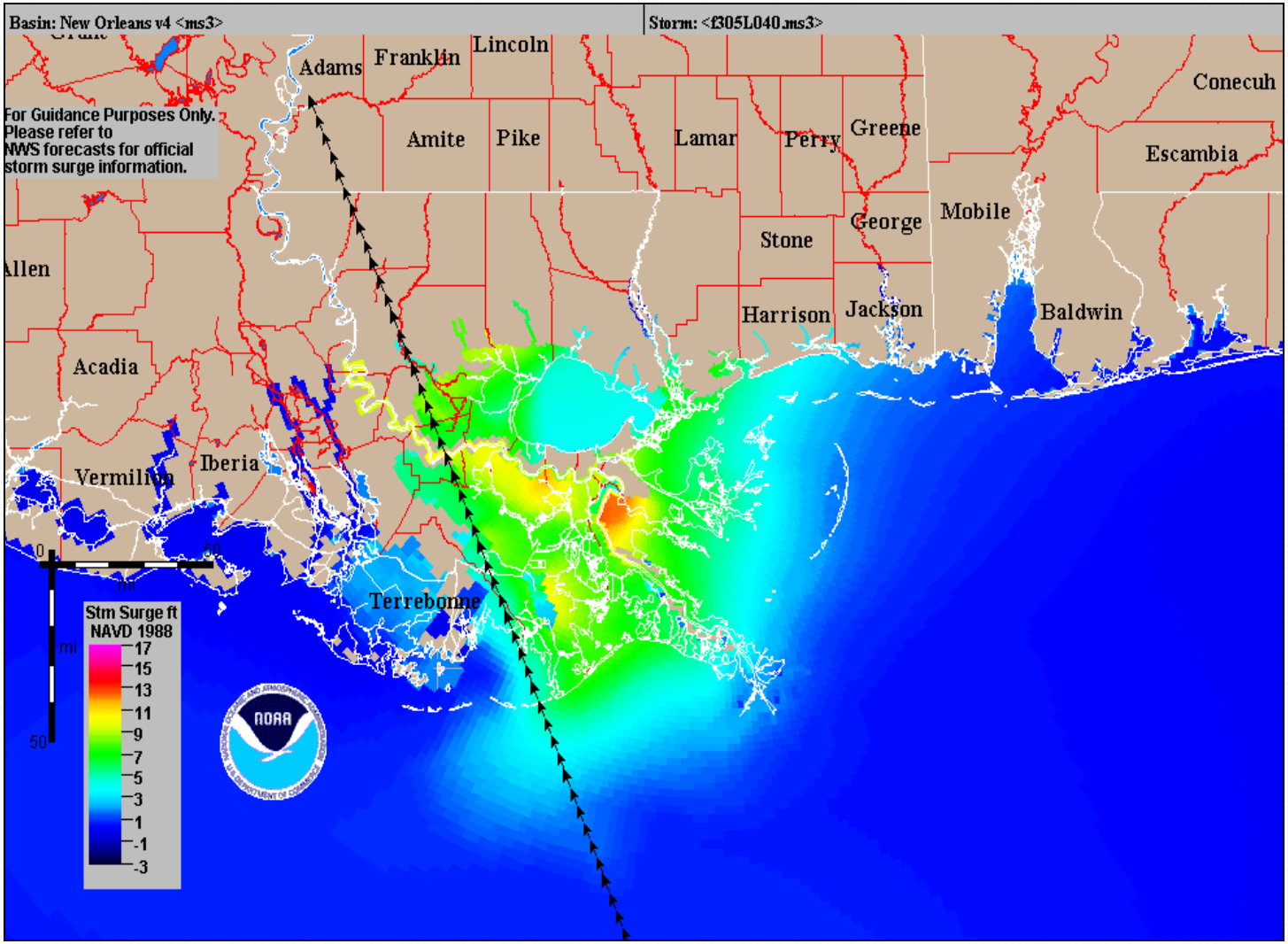
Deterministic Surge Forecast

Original Forecast Track



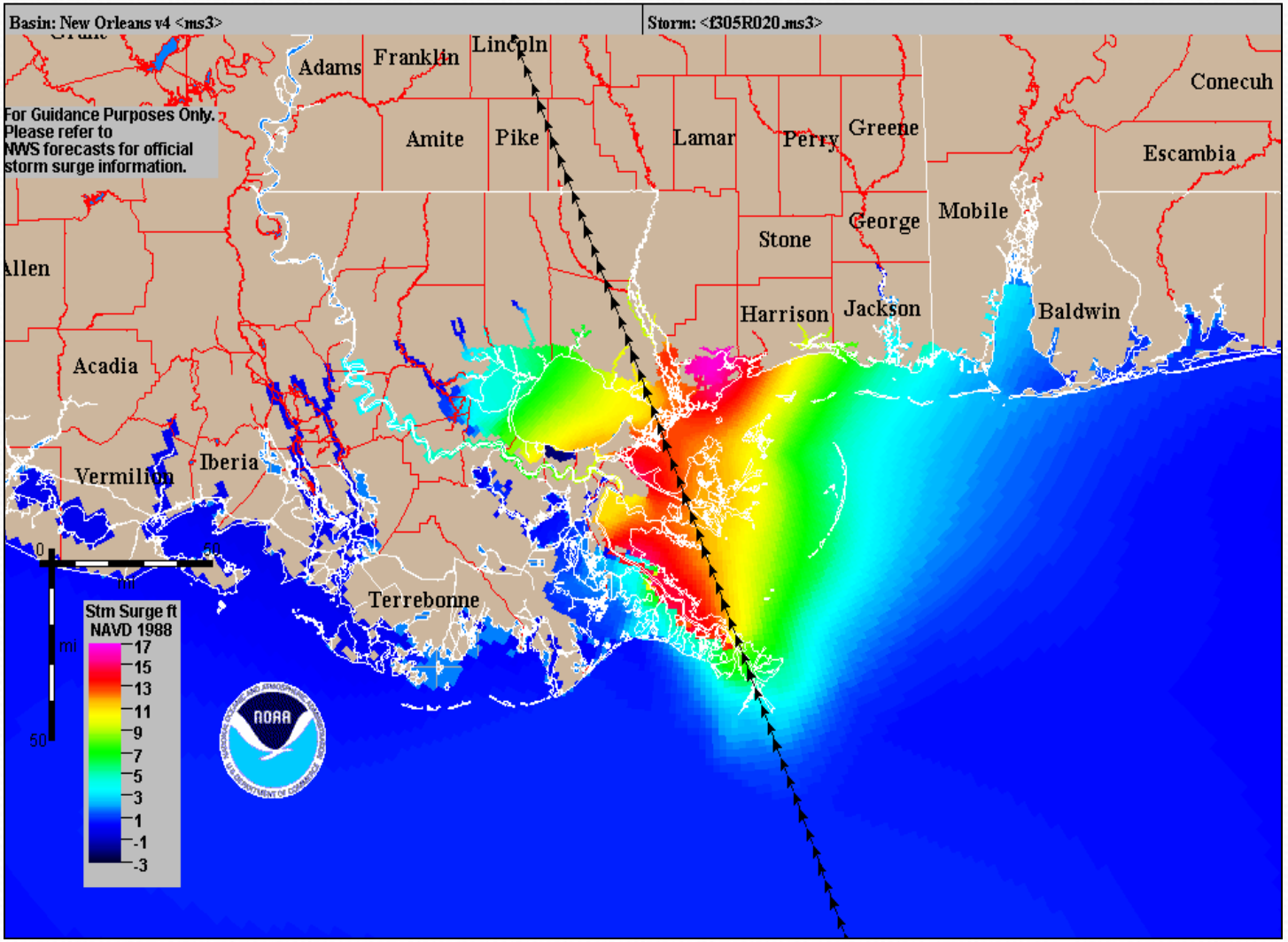
Deterministic Surge Forecast

Track Shifted Slightly West



Deterministic Surge Forecast

Track Shifted Slightly East



QUESTIONS/ COMMENTS?