



# **Chesapeake Bay Inundation Prediction System (CIPS)**

**Tony Siebers**

**Meteorologist in Charge**

**NOAA National Weather Service Forecast Office  
Wakefield VA**

**and**

**Colleagues of the CIPS Team**

**August 18, 2010**



# Outline



- **CIPS Background**
- **CIPS Overall Strategy**
- **Nor'Easter November 2009**
  - *Verification of Inundation*
- **Strengths of CIPS**



# What is CIPS?



- **Demonstration Project to Improve Inundation Forecasts for Tropical Storms and Nor'easters to Meet the Needs of NWS WFOs and Emergency Managers**
- **CIPS funded by the NOAA IOOS office for 3 Years, FY08-FY10**
- **Private Sector, Government, and Universities to Focus on End-to-End Inundation Forecast System for the Chesapeake Bay and Estuaries**



# Chesapeake Inundation Prediction System (CIPS)

## Key Elements and Partners

### Project Management:

- Chesapeake Bay Observing System (CBOS)/Old Dominion University
- Chesapeake Research Consortium

### Atmospheric Modeling and Validation:

- NOAA National Weather Service (NWS) Weather Forecast Offices
  - Wakefield, VA; Sterling, VA; Mt. Holly, NJ
- WeatherFlow, Inc.

### Hydrodynamic and Hydrologic Modeling and Validation:

- Virginia Institute of Marine Science, College of William & Mary
- University of Maryland Center for Environmental Science (UMCES) Horn Point Laboratory
- NOAA NWS Middle Atlantic River Forecast Center

### Overland Inundation Validation:

- USGS Water Science Centers in VA and MD
- USGS Office of Surface Water, Reston, VA

### Visualization and Validation:

- Noblis, Inc.

### Economic Valuation and User Engagement:

- UMCES Chesapeake Bay Laboratory
- CBOS/Old Dominion University

### Data Management and Communications:

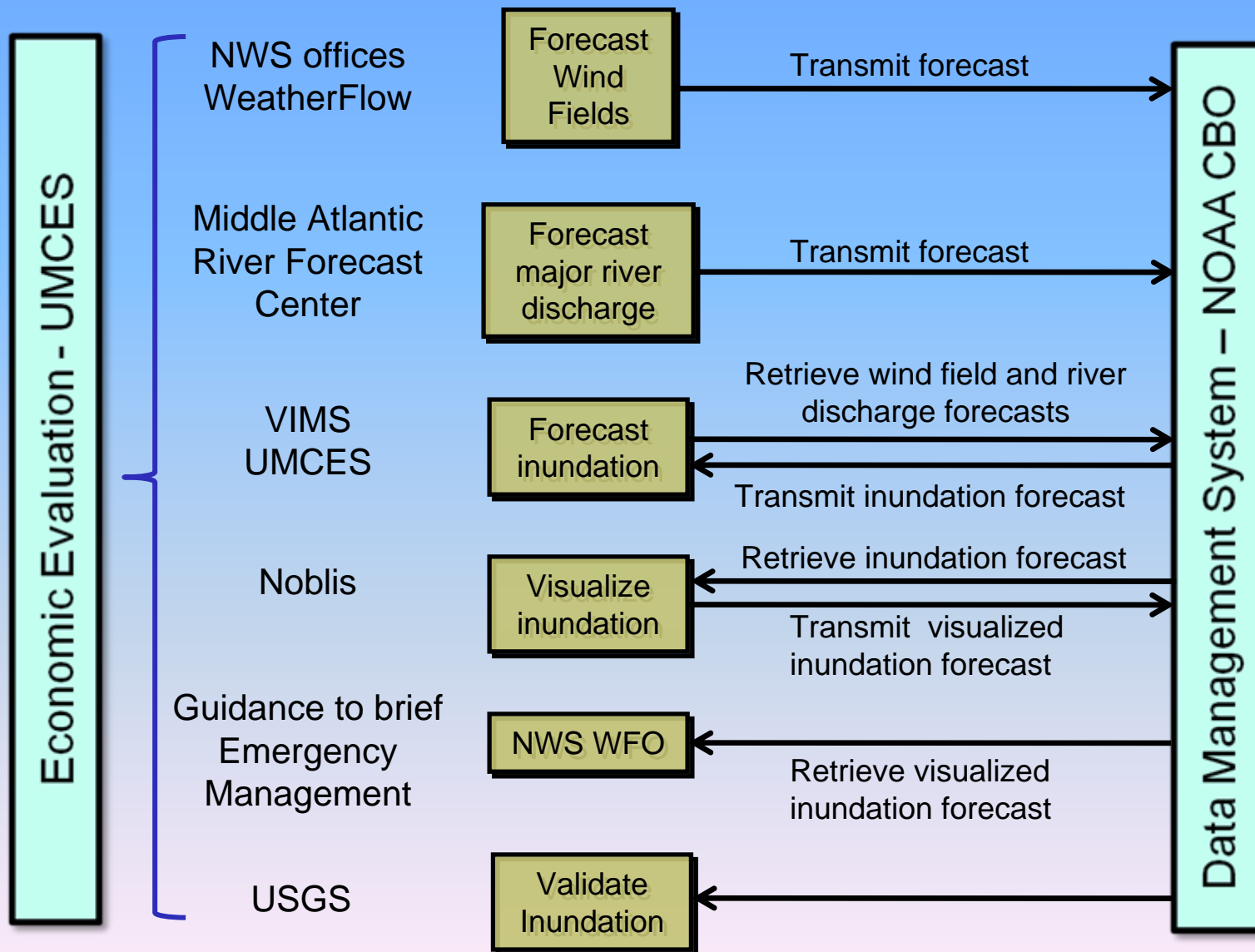
- NOAA Chesapeake Bay Office







# CIPS Elements





# CIPS Genesis - User Needs Assessment



- **NOAA CSC “Storm Surge Tools and Information: A User Needs Assessment”** <http://www.csc.noaa.gov/needsassessments/>
  - *Modeling Improvement*
  - *Decision-Support Tools*
  - *Communication*
  - *Outreach/Training*
- **MACOORA Inundation Workshop for Coastal Zone and Emergency Managers - Nov 2006**
  - *77 attendees representing 9 states*
  - *Purpose: Identify the needs of coastal managers in the Mid-Atlantic*
  - *Need coastal observations, products, and tools*
  - *Need for coastal inundation (EMs), and sea level rise (CZMs)*



# What do Emergency Managers Need for Storm Tide?

- High Resolution Display (down to one city block)
  - *Google Earth type of GIS display*
- Measure of Uncertainty
  - *Use Ensemble Forecasts for winds/water level*

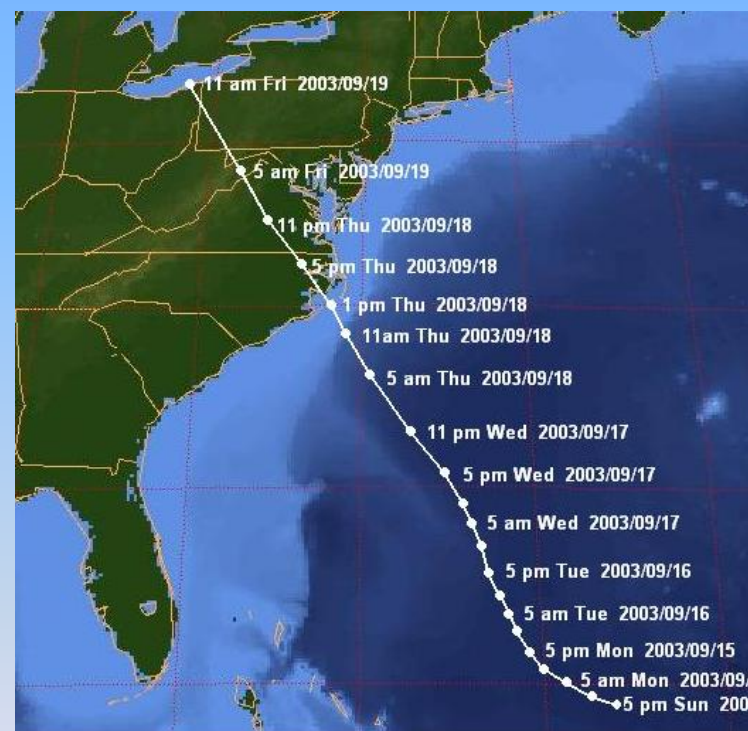


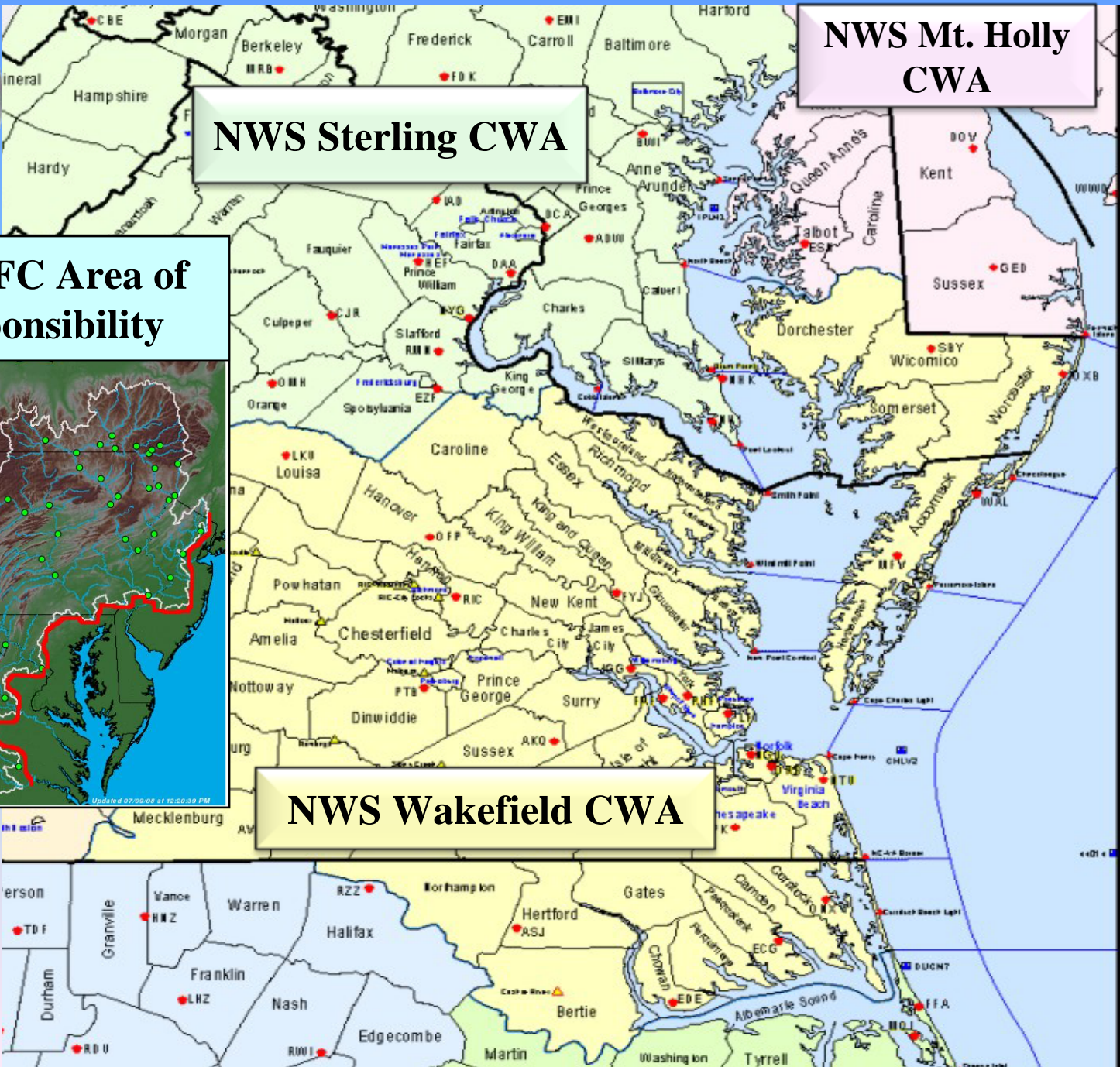




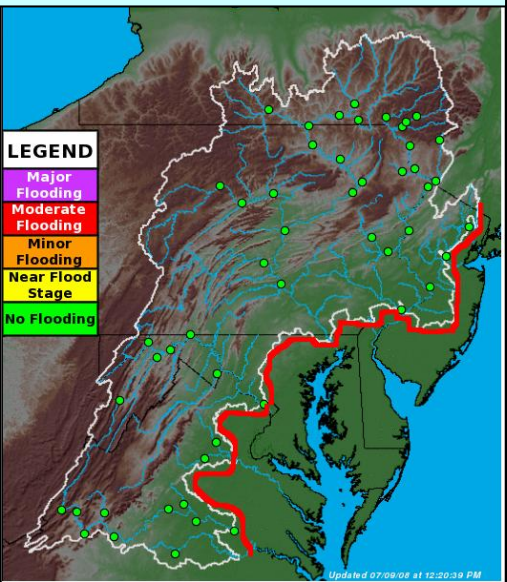
# CIPS Overall Strategy

- **Run 3 historical storms**
  - ***Hurricane Isabel 2003***
  - ***Tropical Storm Ernesto 2006***
  - ***Nor'easter***
    - (dropped due to budget cuts)
- **Capture Real Time Events**
  - ***Nor'easter November 2009***





# MARFC Area of Responsibility



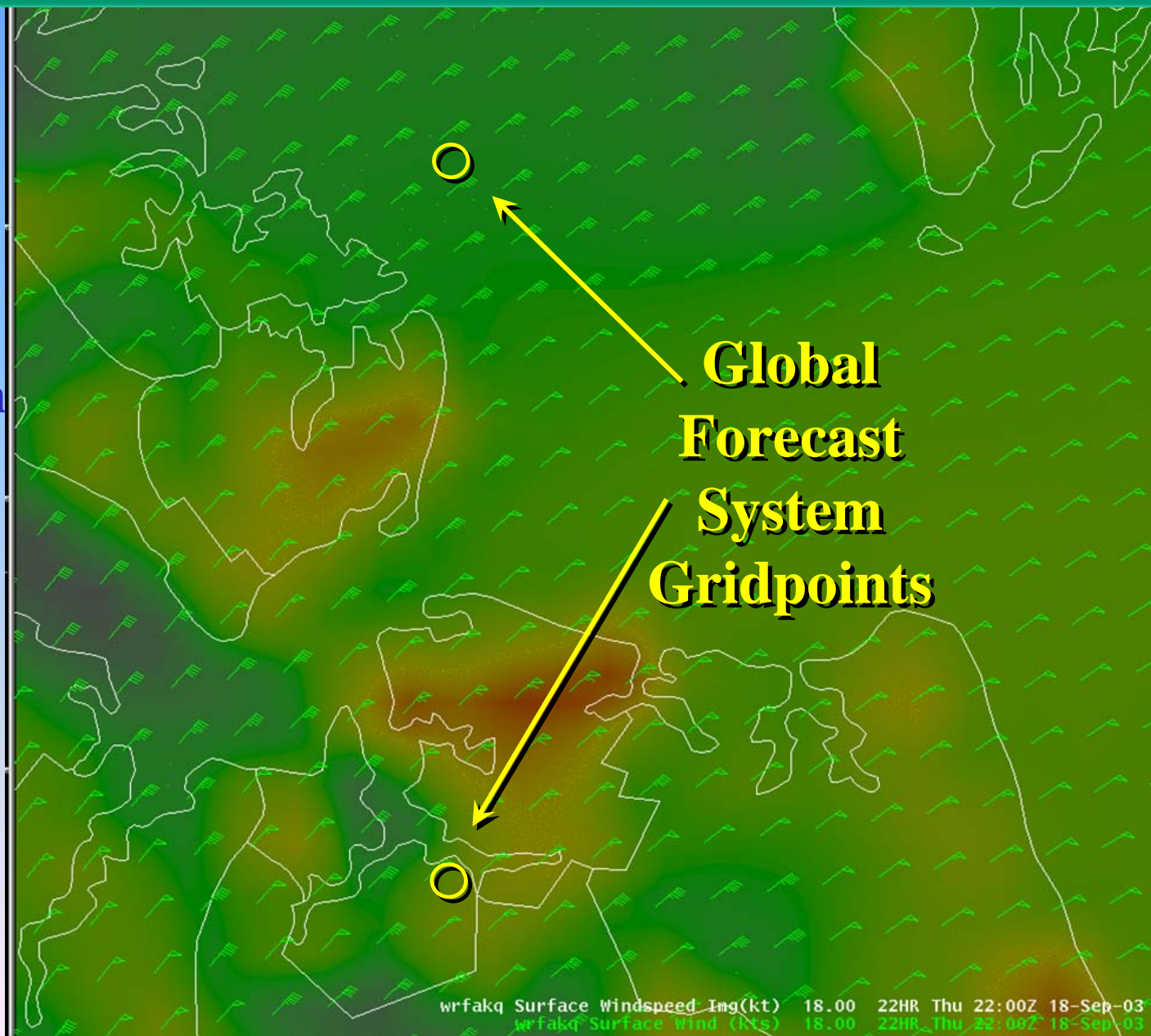
- Major Flooding
- Moderate Flooding
- Minor Flooding
- Near Flood Stage
- No Flooding





# Ensemble of Atmospheric Models

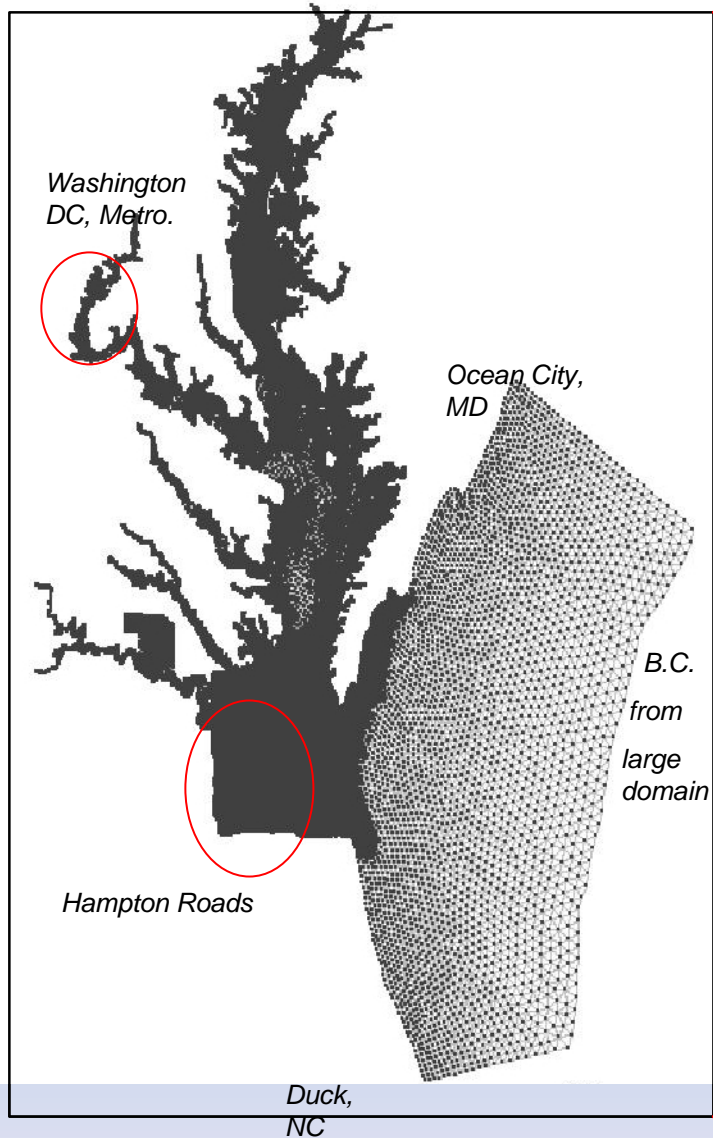
- GFS 32 km
- NAM 12 km
- WRF-GFS 4 km
- WRF-NAM 4 km
- RAMS 2 km (WeatherFlow)



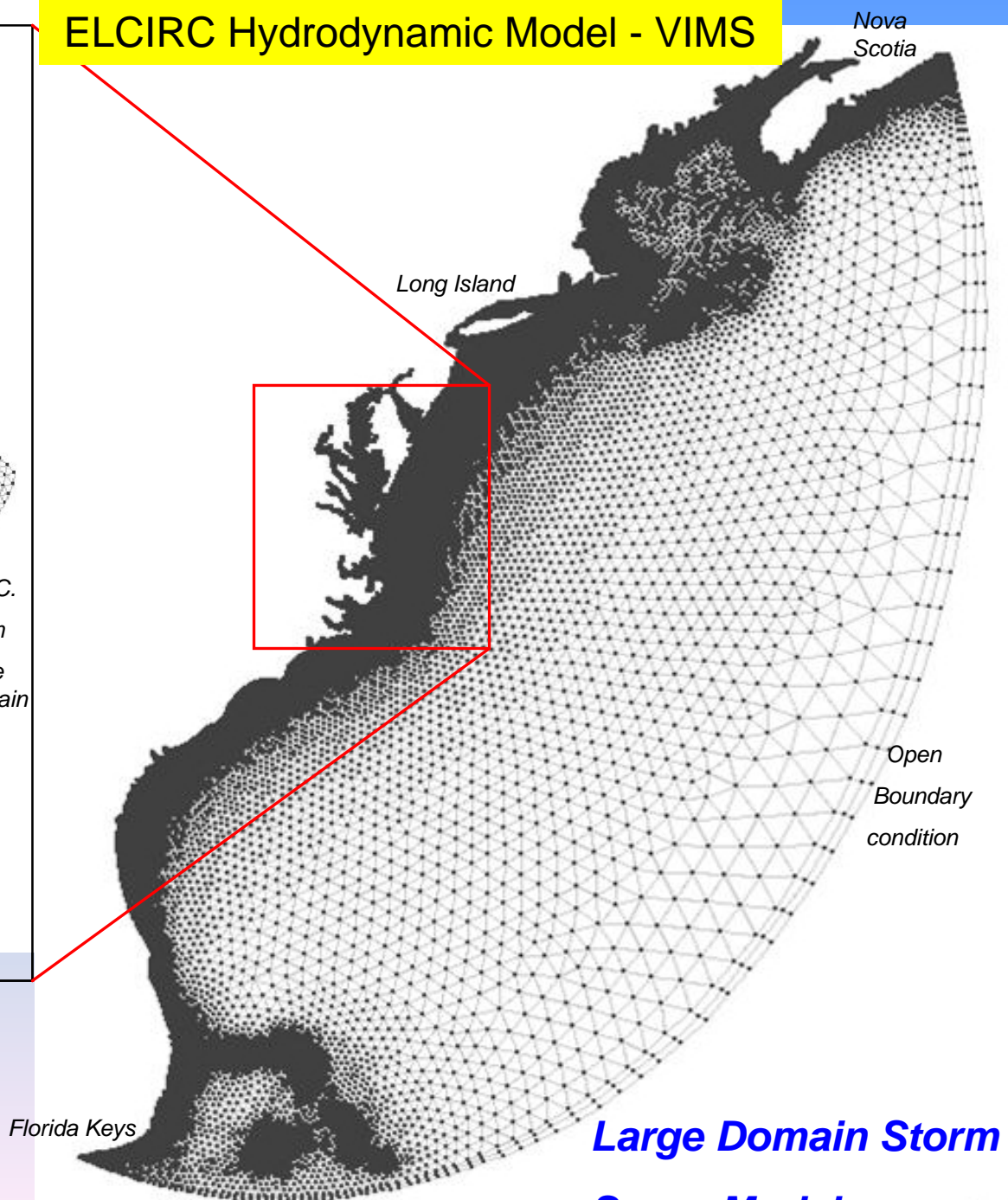


# ELCIRC Hydrodynamic Model - VIMS

Nova  
Scotia



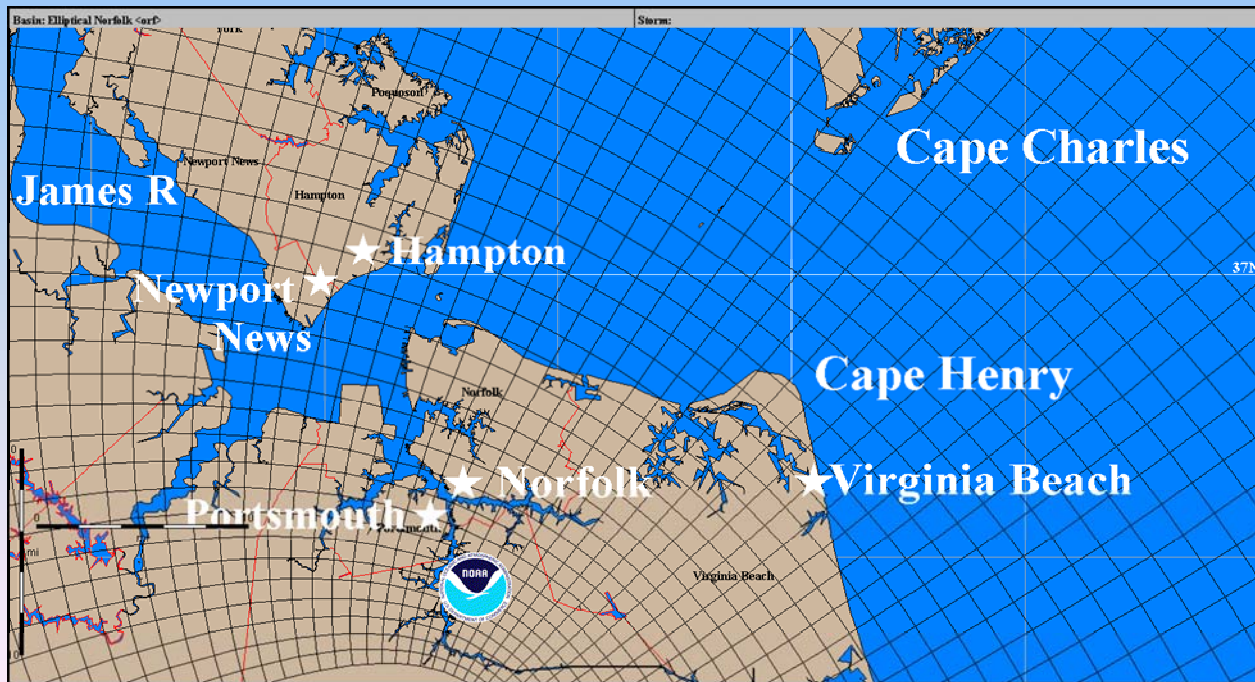
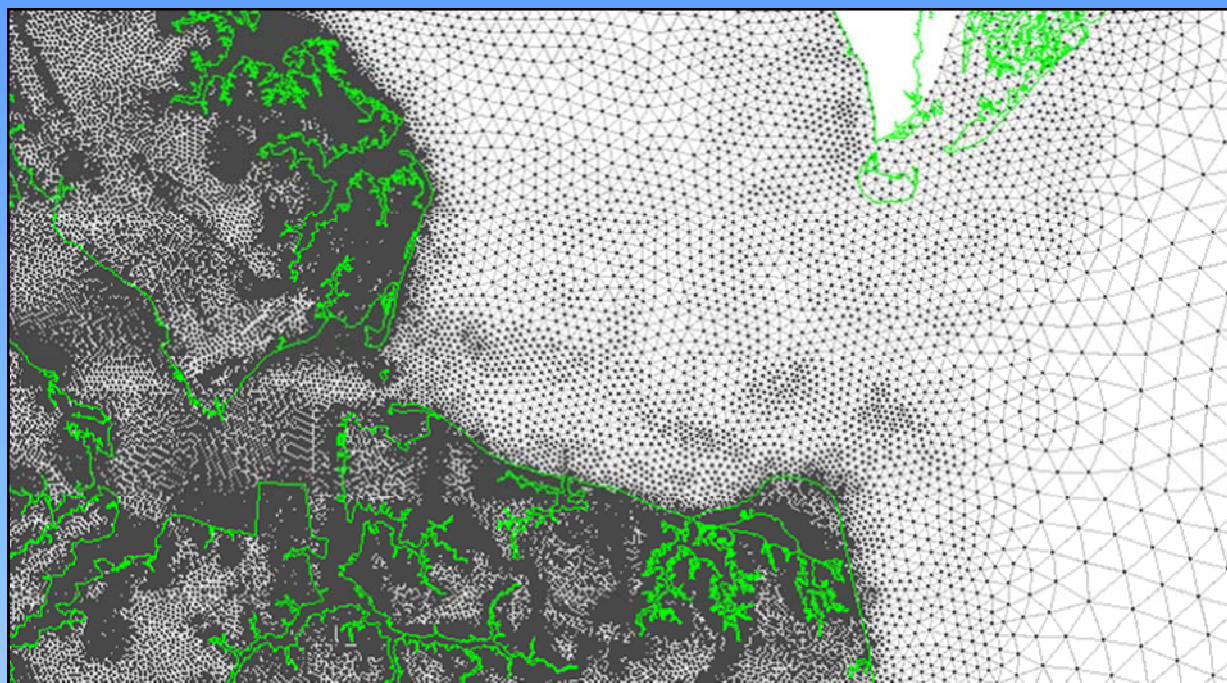
**High resolution nested  
inundation model**



**Large Domain Storm  
Surge Model**



# SLOSH Model Grid



# VIMS Model Grid



# Top High Water Events – Sewells Point

## NOS CO-OPS Data

Date	Storm Type	Above MLLW (1983-2001)	
August 23, 1933	Hurricane (unnamed)	8.02 feet	
September 18, 2003	Hurricane Isabel	7.89 feet	
<b>November 12, 2009</b>	<b>Nor'easter</b>	<b>7.75 feet</b>	3.24" Under All Time Record High Level
March 7, 1962	Ash Wednesday Storm	7.22 feet	
September 18, 1936	Hurricane (unnamed)	6.72 feet	
November 22, 2006	Thanksgiving Nor'easter	6.63 feet	
February 5, 1998	Twin Nor'easter (#2)	6.58 feet	
October 7, 2006	Columbus Day Nor'easter	6.52 feet	
April 27, 1978	Nor'easter	6.41 feet	
April 11, 1956	Nor'easter	6.32 feet	
September 16, 1933	Hurricane (unnamed)	6.12 feet	
January 28, 1998	Twin Nor'easter (#1)	6.04 feet	
September 16, 1999	Hurricane Floyd	5.97 feet	
September 27, 1956	Hurricane Flossy	5.92 feet	
September 12, 1960	Hurricane Donna	5.92 feet	



# 2009 Veteran's Day Nor'easter



**CIPS  
Nor'easter  
Focus Area**

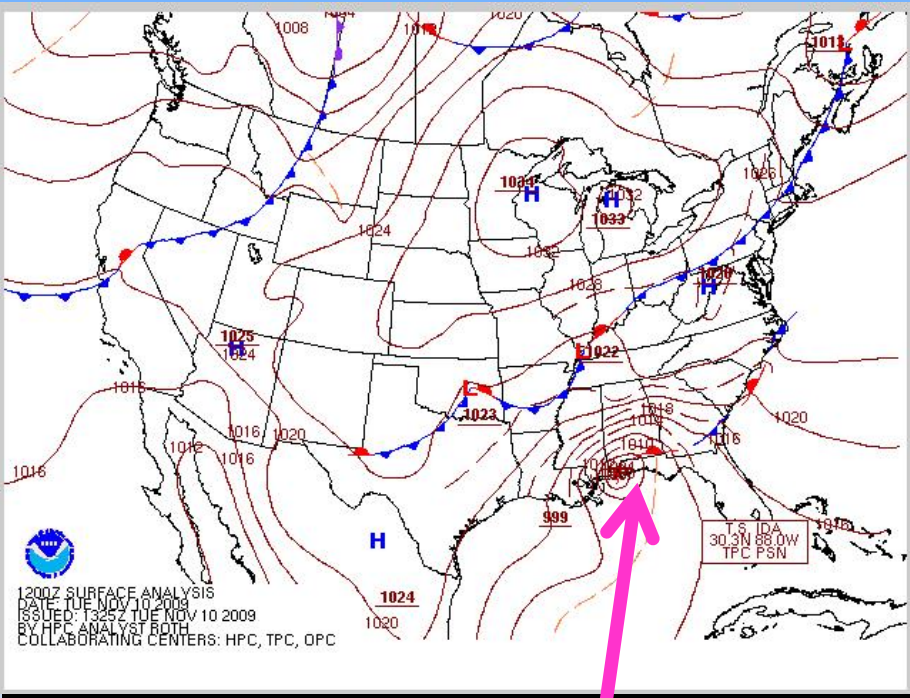




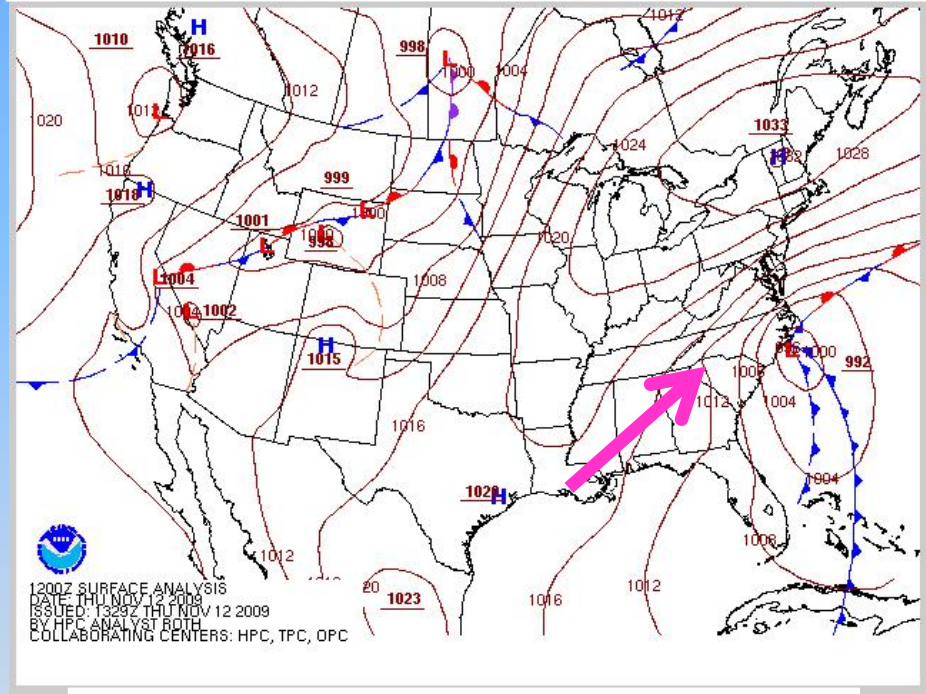
# Nor'easter Synoptic Setup



12Z (7 am EST) Tue Nov 10, 2009



12Z (7 am EST) Thu Nov 12, 2009



Weather across the mid-Atlantic is quiet as Tropical Storm Ida is making landfall along the Gulf coast.

Low pressure redeveloped and intensified off the coastal Carolinas. Note the strong pressure gradient with a high pressure system north of the coastal low.



# Coastal Flood Watch

## Issued 4 AM Tue Nov 10, 2009



408 AM EST TUE NOV 10 2009

...COASTAL FLOOD WATCH IN EFFECT FROM WEDNESDAY AFTERNOON THROUGH THURSDAY MORNING...

THE NATIONAL WEATHER SERVICE IN WAKEFIELD HAS ISSUED A COASTAL FLOOD WATCH...WHICH IS IN EFFECT FROM WEDNESDAY AFTERNOON THROUGH THURSDAY MORNING.

A COMBINATION OF STRONG HIGH PRESSURE BUILDING FROM THE NORTH AND REMNANTS OF IDA OFF THE SOUTHEAST COAST...WILL ALLOW AN EXTENDED PERIOD OF STRONG OFFSHORE FLOW TO DEVELOP ALONG THE COAST OF NORTHEAST NORTH CAROLINA AND SOUTHEAST VIRGINIA.

THE APPROACHING NEW PHASE OF THE MOON...IN TANDEM WITH THE STRONG ONSHORE FLOW...WILL LEAD TO INCREASING TIDAL ANOMALIES OF AROUND 2 TO 3 FT ABOVE NORMAL...BEGINNING WEDNESDAY AFTERNOON AND CONTINUING THROUGH THE SUCCESSIVE HIGH TIDE CYCLES LATE IN THE WEEK.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

A COASTAL FLOOD WATCH MEANS THAT CONDITIONS FAVORABLE FOR FLOODING ARE EXPECTED TO DEVELOP. COASTAL RESIDENTS SHOULD BE ALERT FOR LATER STATEMENTS OR WARNINGS...AND TAKE ACTION TO PROTECT PROPERTY.



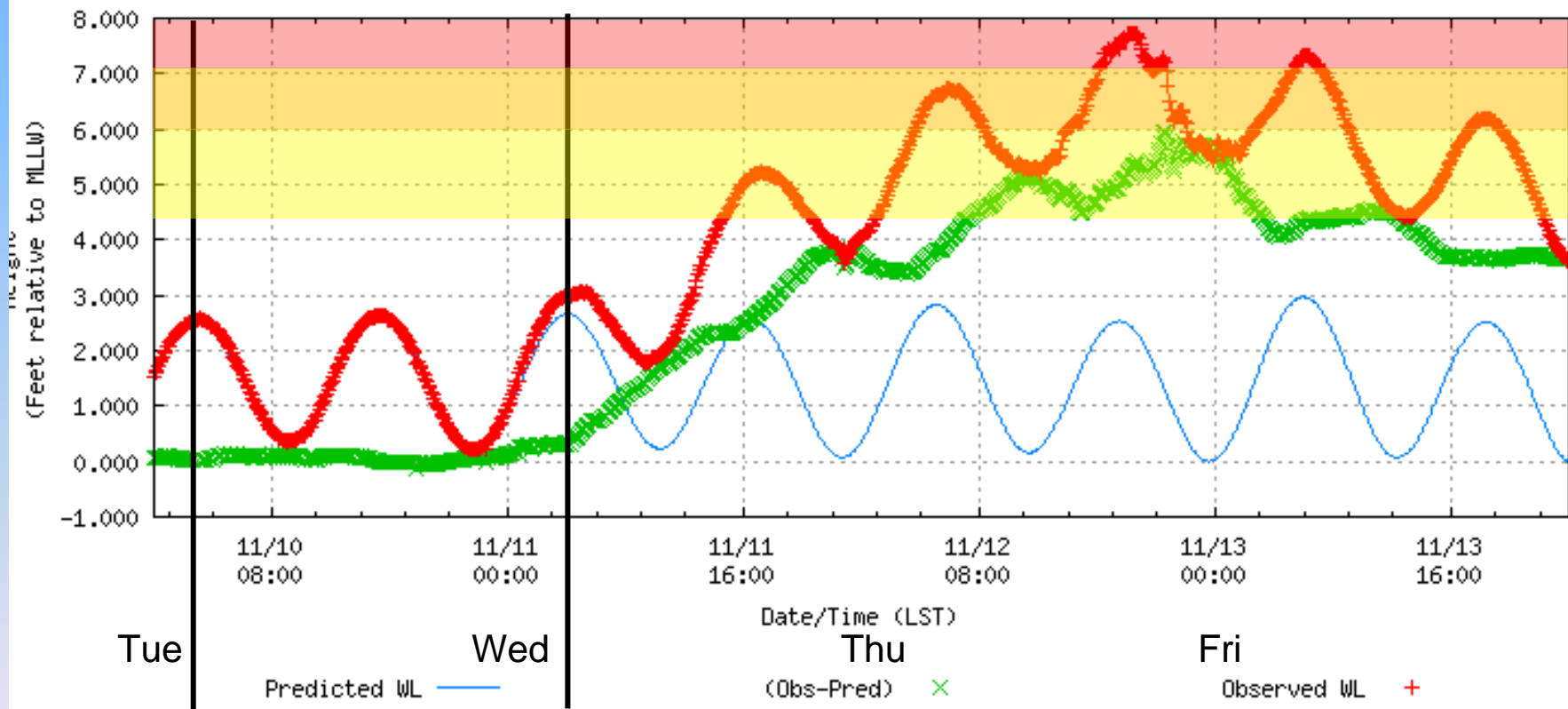


# Norfolk Storm Tide - NOS

## CO-OPS Data Nov 10-13, 2009



NOAA/NOS/CO-OPS  
Verified Water Level vs. Predicted Plot  
8638610 Sewells Point, VA  
from 2009/11/10 - 2009/11/13



**Watch  
Issued**

**Warning  
Issued**

**Major  
Moderate  
Minor**



The Daily Press / Adrin Snider



The Washington Post



AP Steve Helber



The Virginian-Pilot / Hyunsoo Leo Kim





# Nor'easter – Norfolk VA

## Should I Have Moved My Car?



# Nor'easter – Norfolk VA

## Should I Have Moved My Car?





# Nor'easter – Newport News VA FD Evacuates Apartments



VIMS ELCIRC  
RAMS (GFS)  
NAM  
WRF (NAM)







# Nor'easter – Norfolk VA



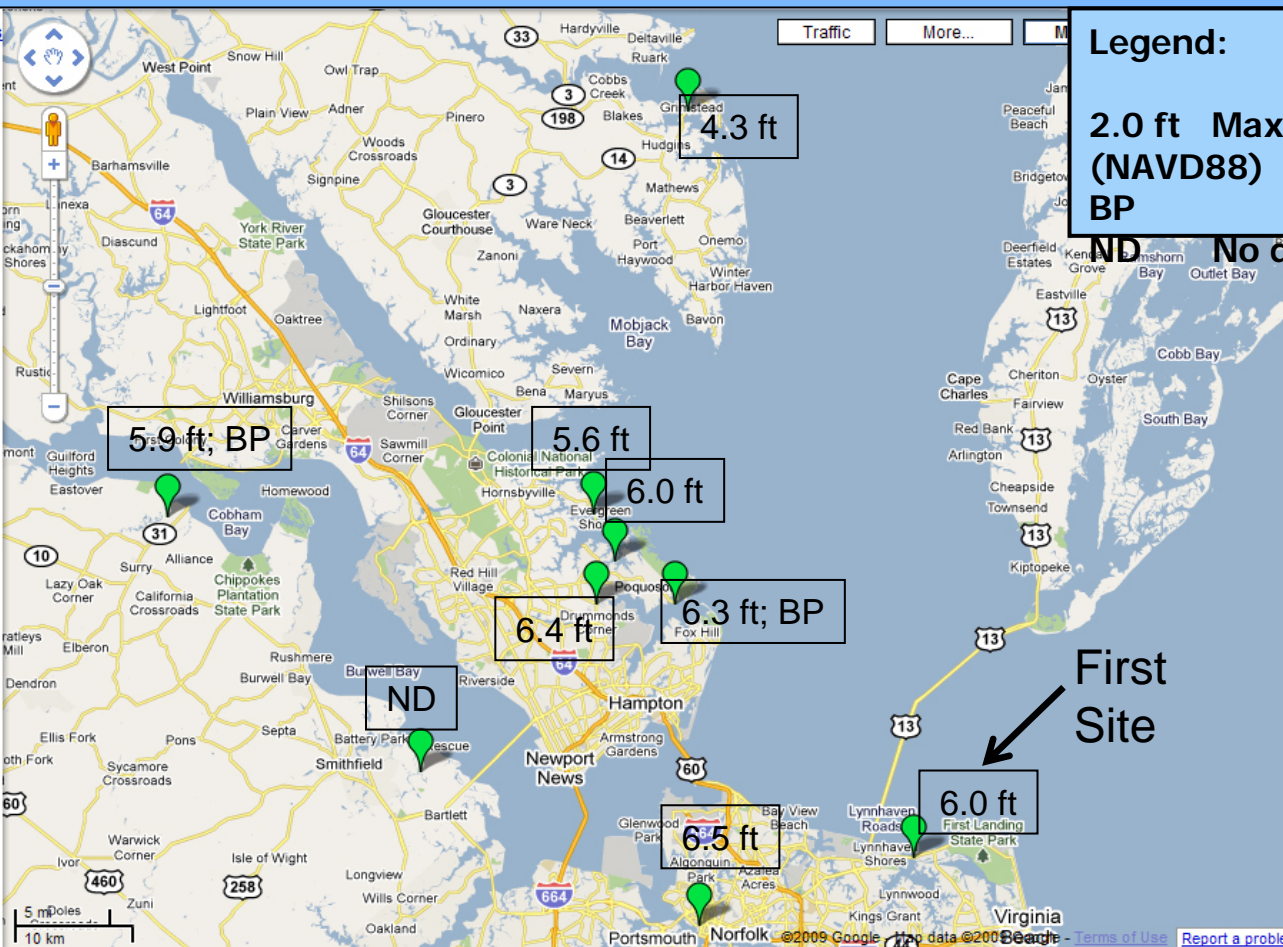




# USGS Flood Sensor Deployments for Nor'easter Nov 11-13, 2009



9 gages installed over land areas to  
measure inundation



**For further information contact**

**In MD-DE-DC area:**

Michael Koterba,  
Hydrologist, U. S. Geological Survey,  
5522 Research Park Drive.  
Baltimore, MD. 21228  
mkoterba@usgs.gov T: (443) 498-5540

**In VA area:**

Shaun Wicklein,  
Supervisory Hydrologist, U. S. Geological  
Survey,  
1730 E. Parham Road,  
Richmond, VA  
smwickle@usgs.gov T: (804) 399-9929



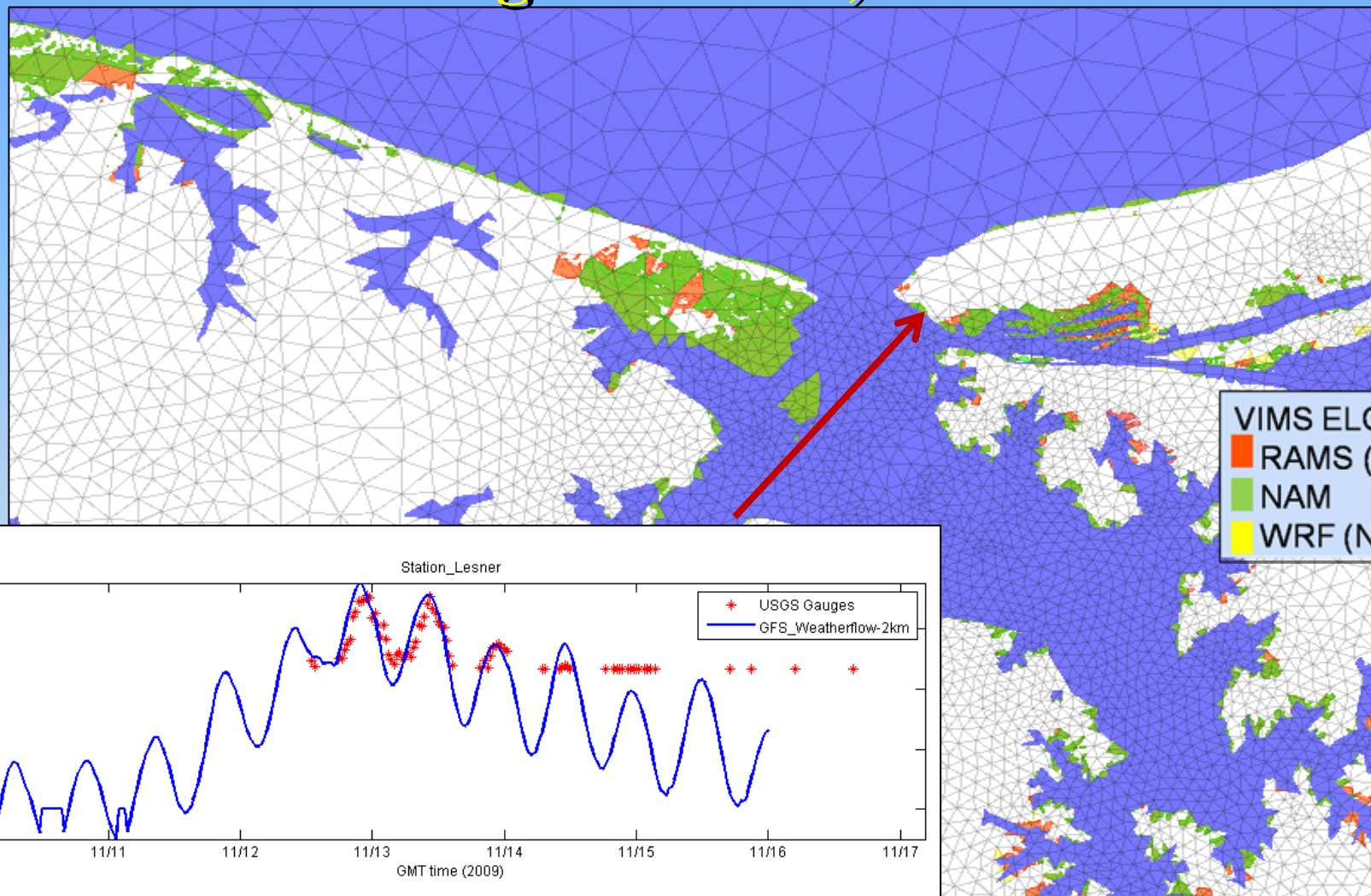
# Lynnhaven Inlet – Virginia Beach, VA



VIMS ELCIRC  
RAMS (GFS)  
NAM  
WRF (NAM)

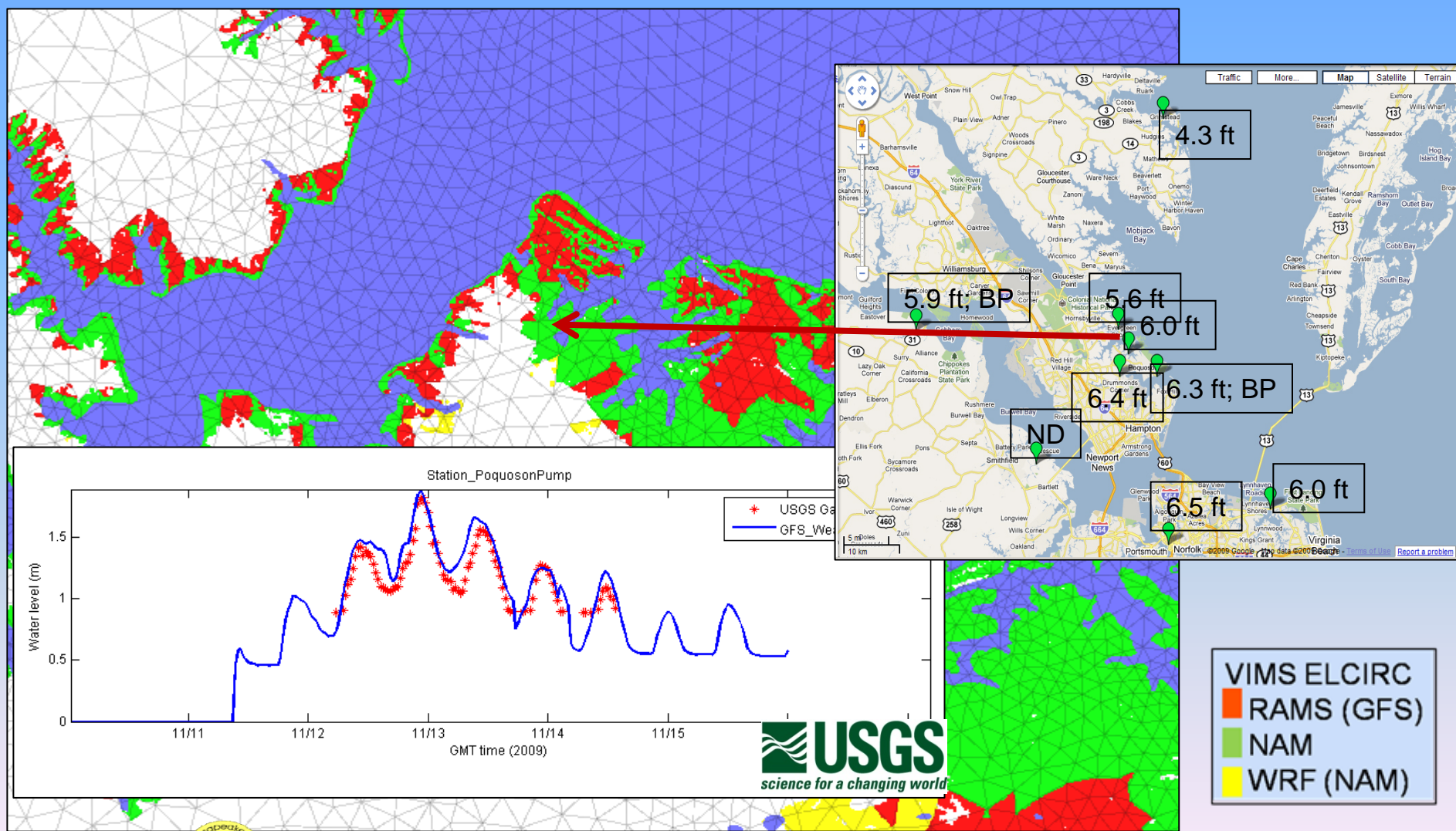


# Inundation Verification Using USGS Deployed Gage at Lynnhaven Inlet, Virginia Beach, VA





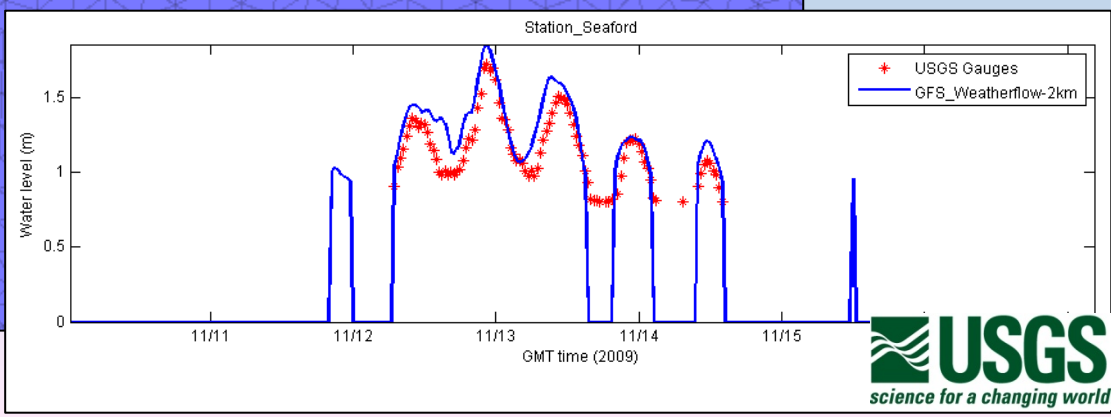
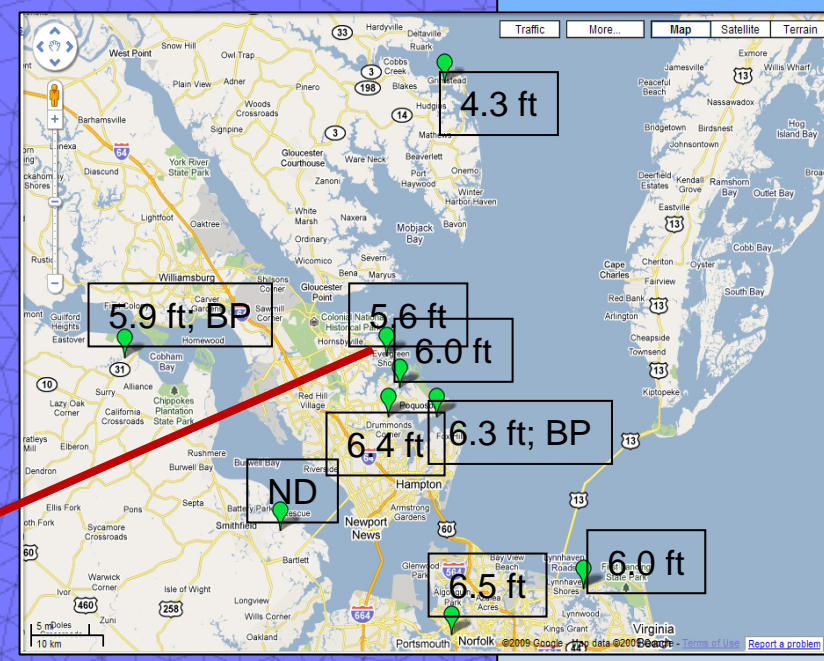
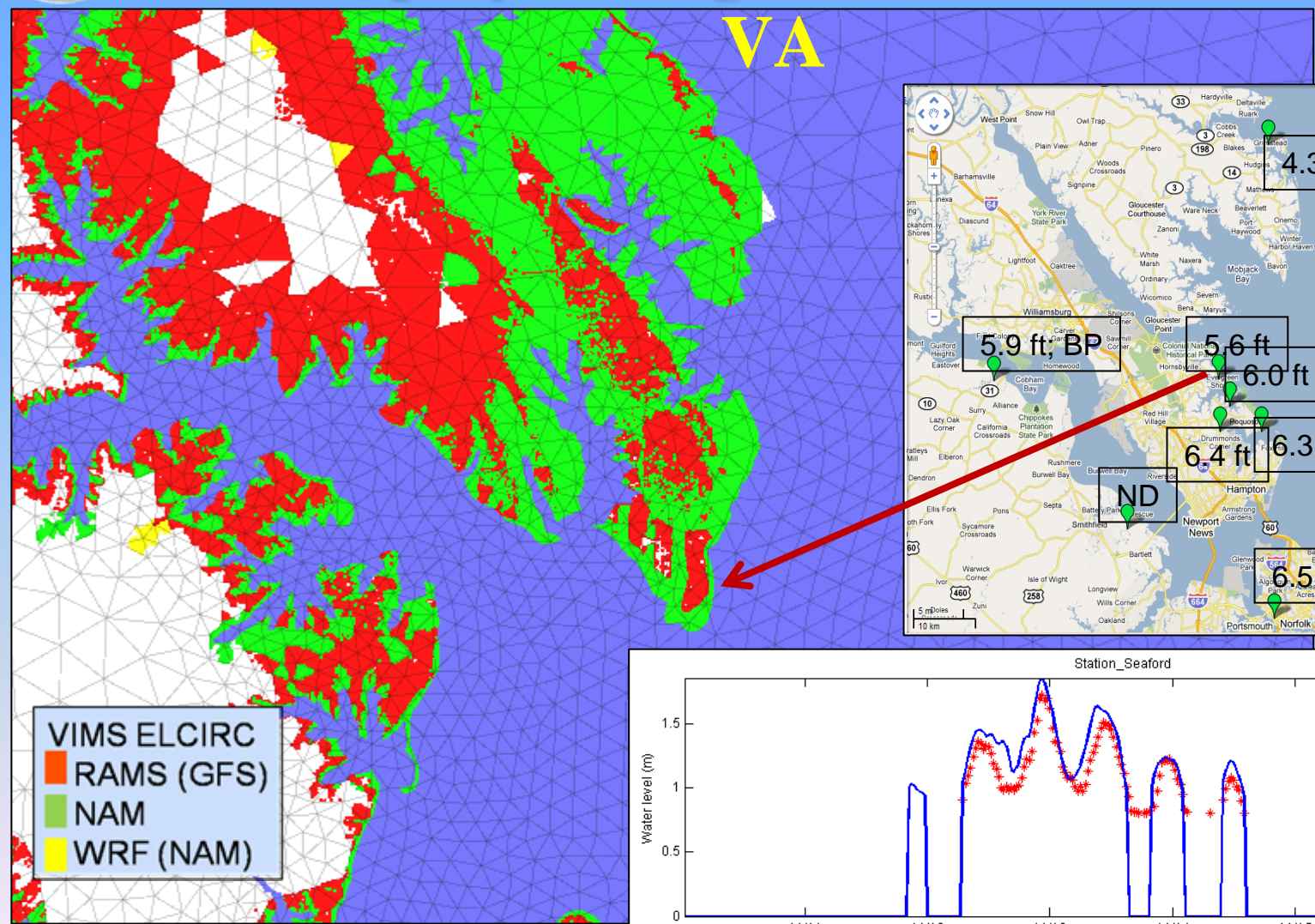
# Inundation Verification Using USGS Deployed Gage at Poquoson Pump, VA





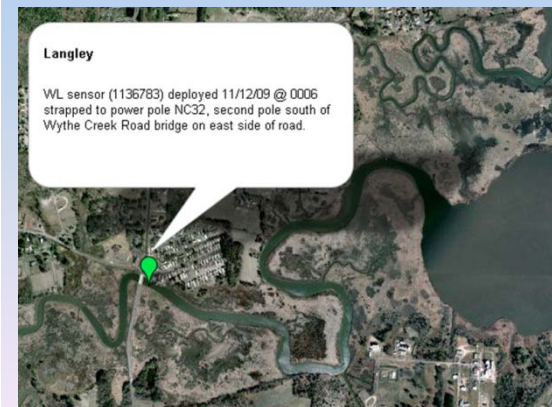
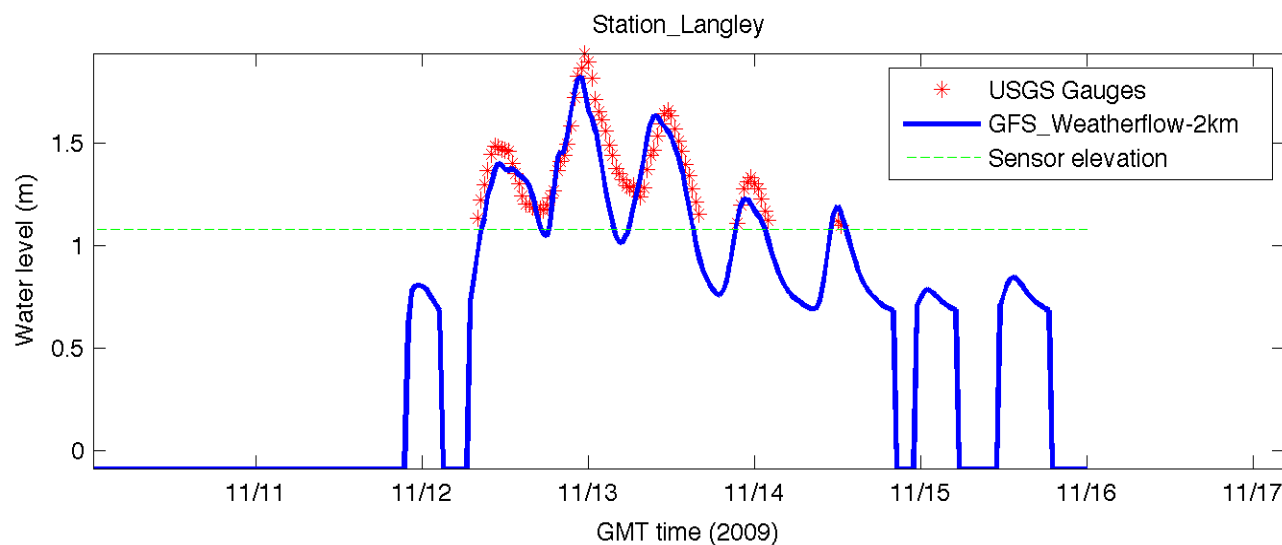
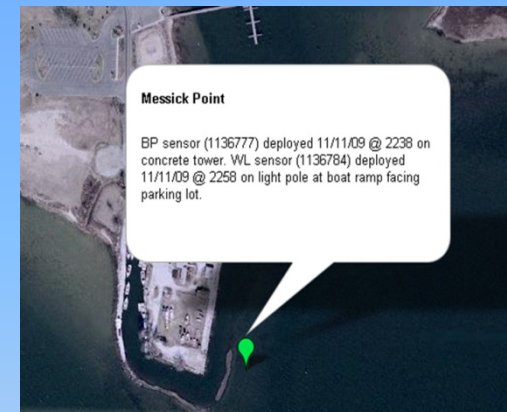
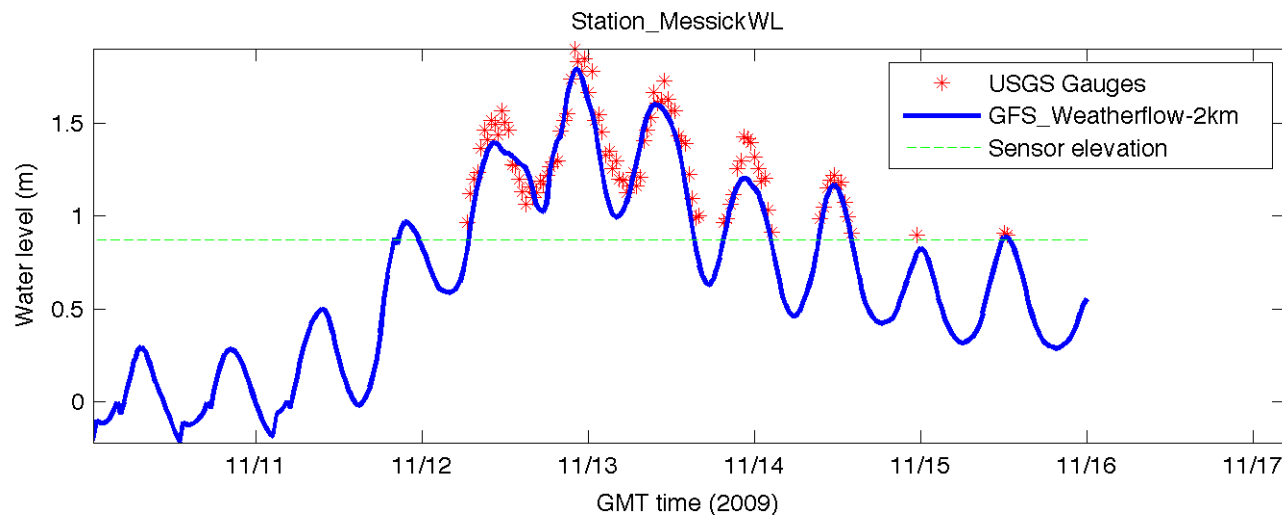


# Inundation Verification Using USGS Deployed Gage at Seaford, VA



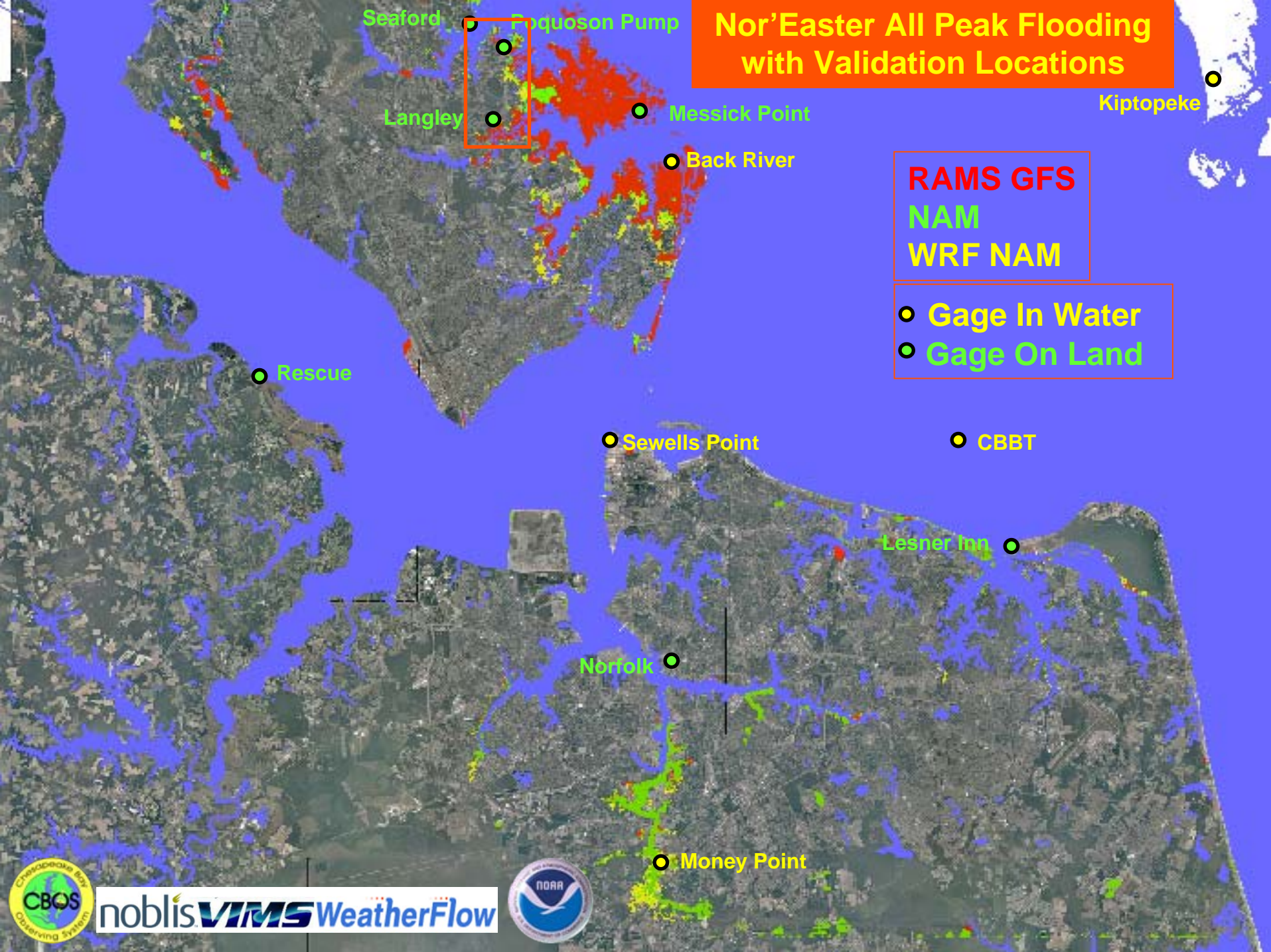


# Inundation Verification Using USGS Deployed Gages





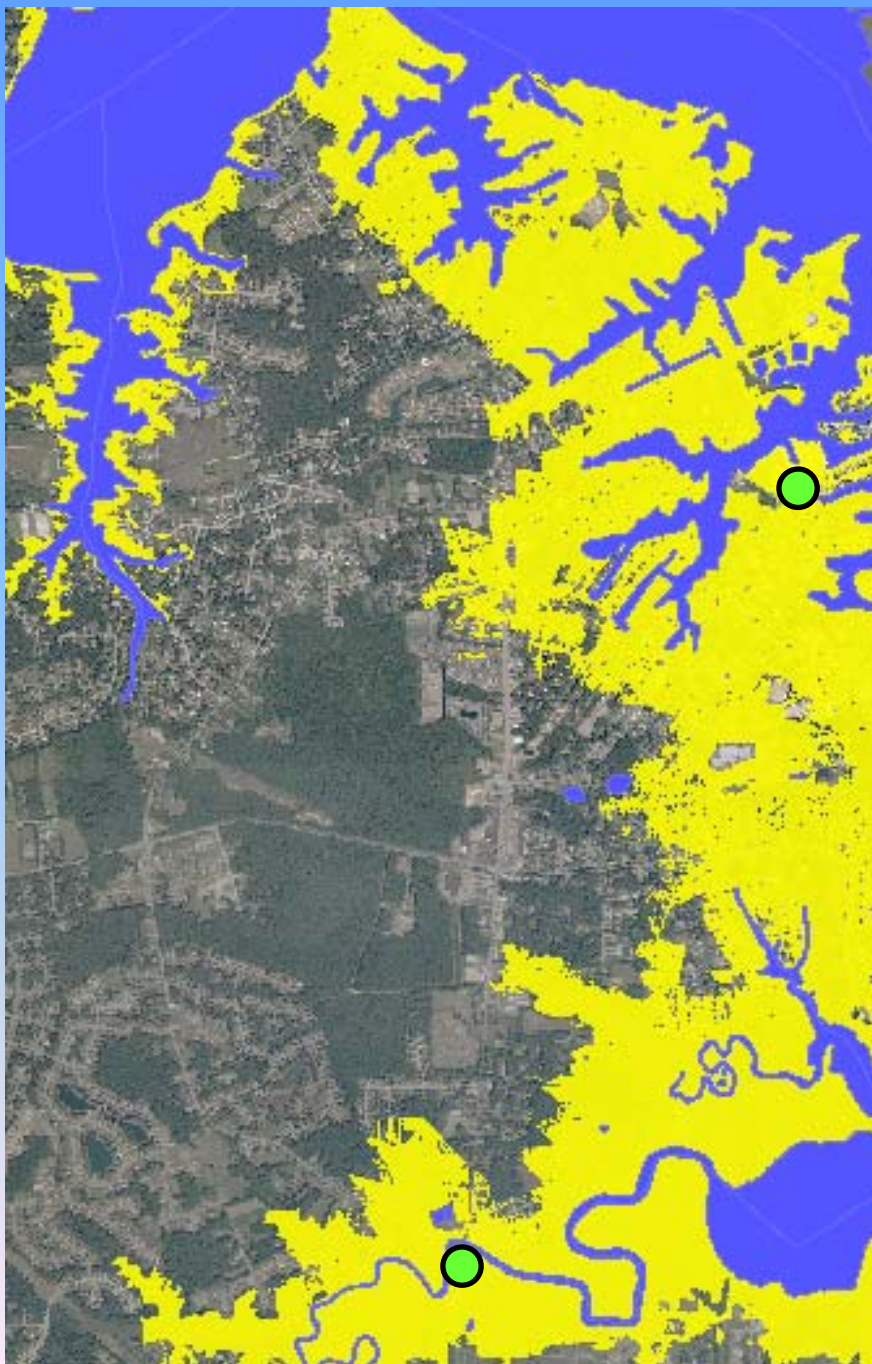
# Nor'Easter All Peak Flooding with Validation Locations







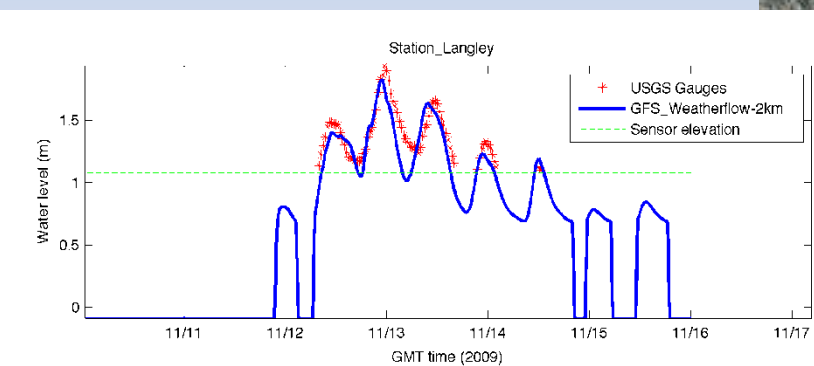
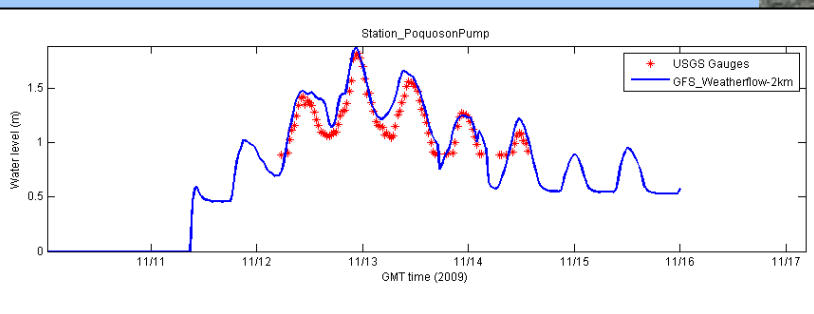
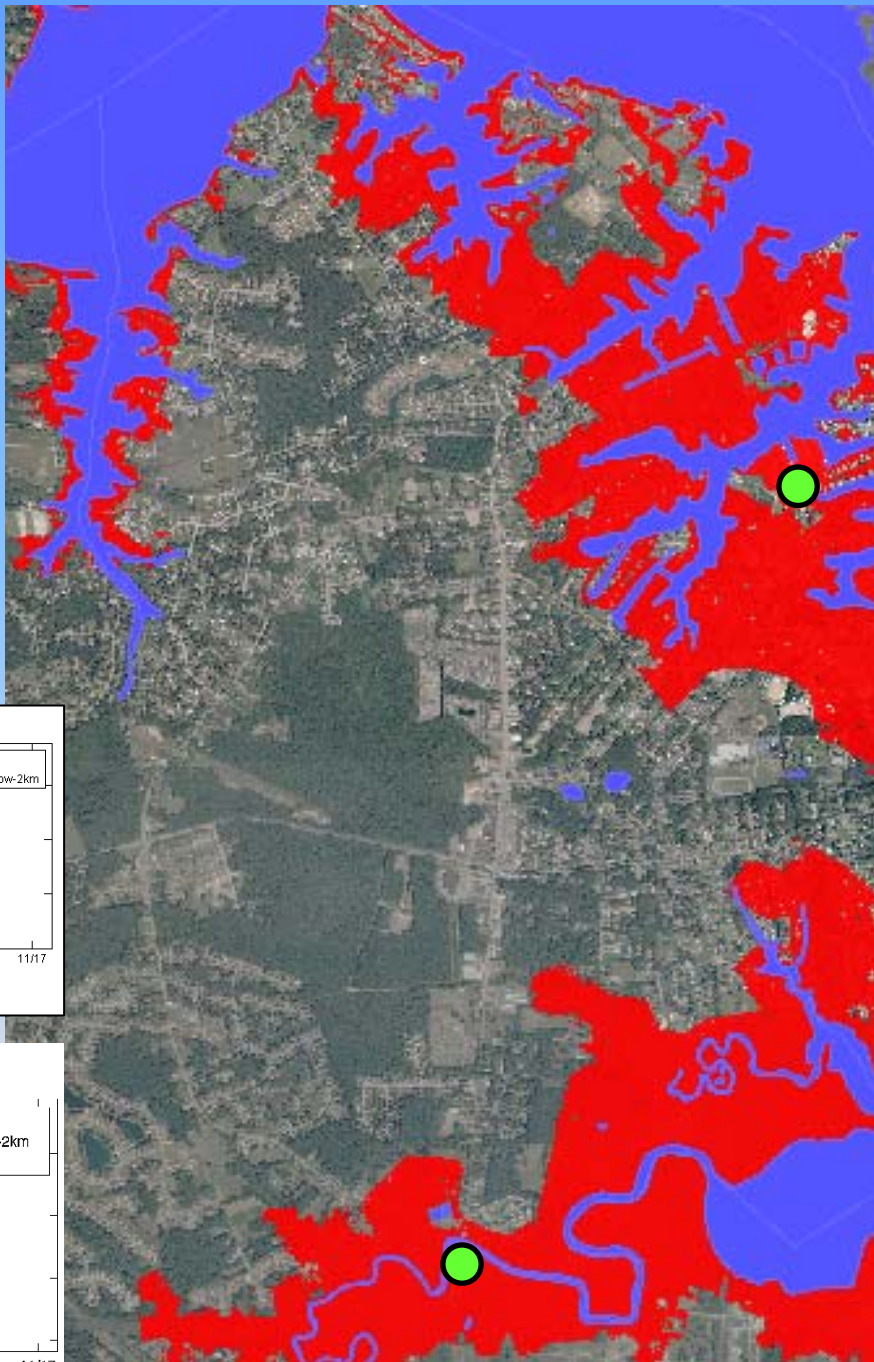
# Inundation Nor'easter WRF NAM





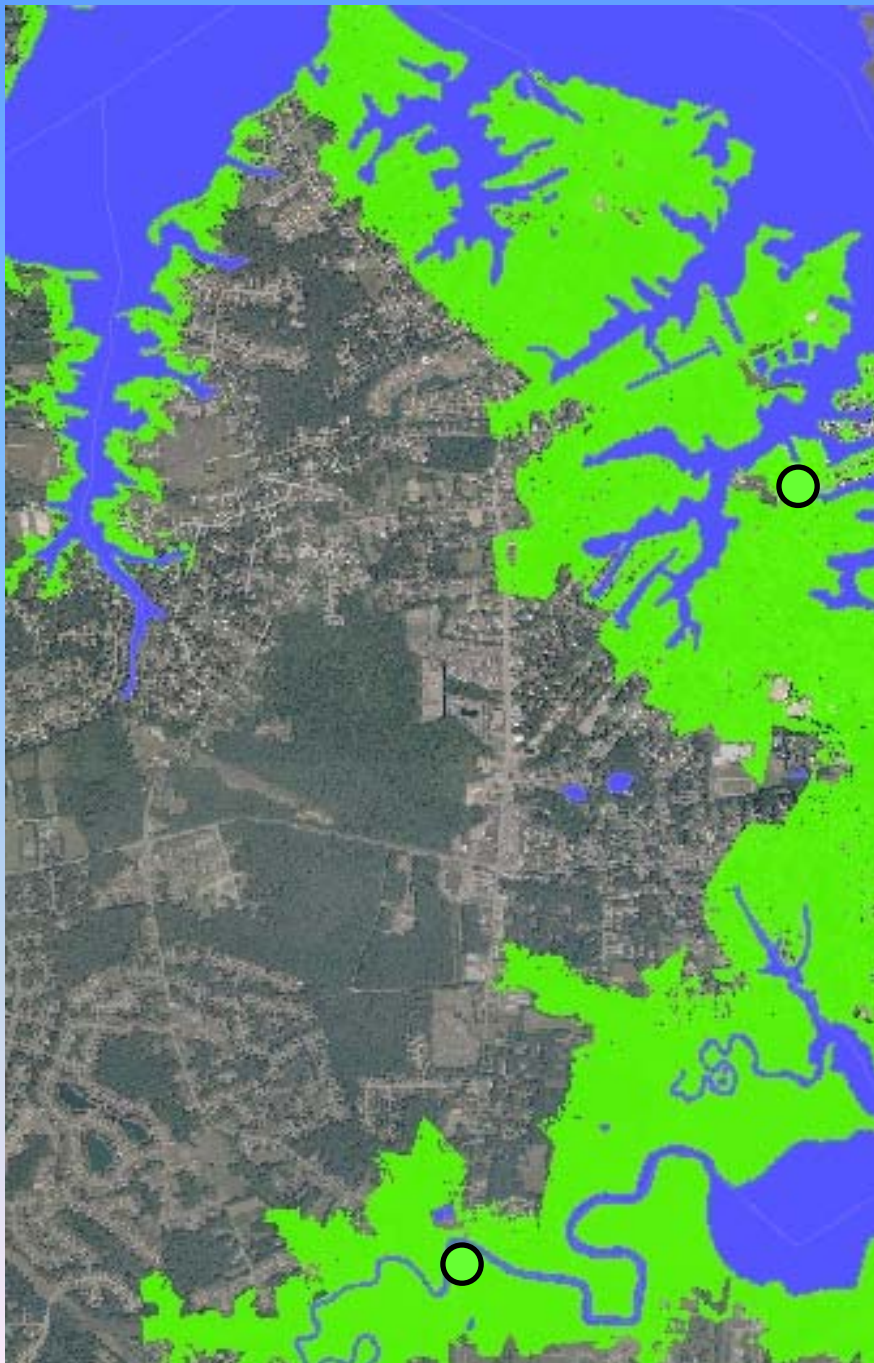


# Inundation Nor'easter RAMS GFS





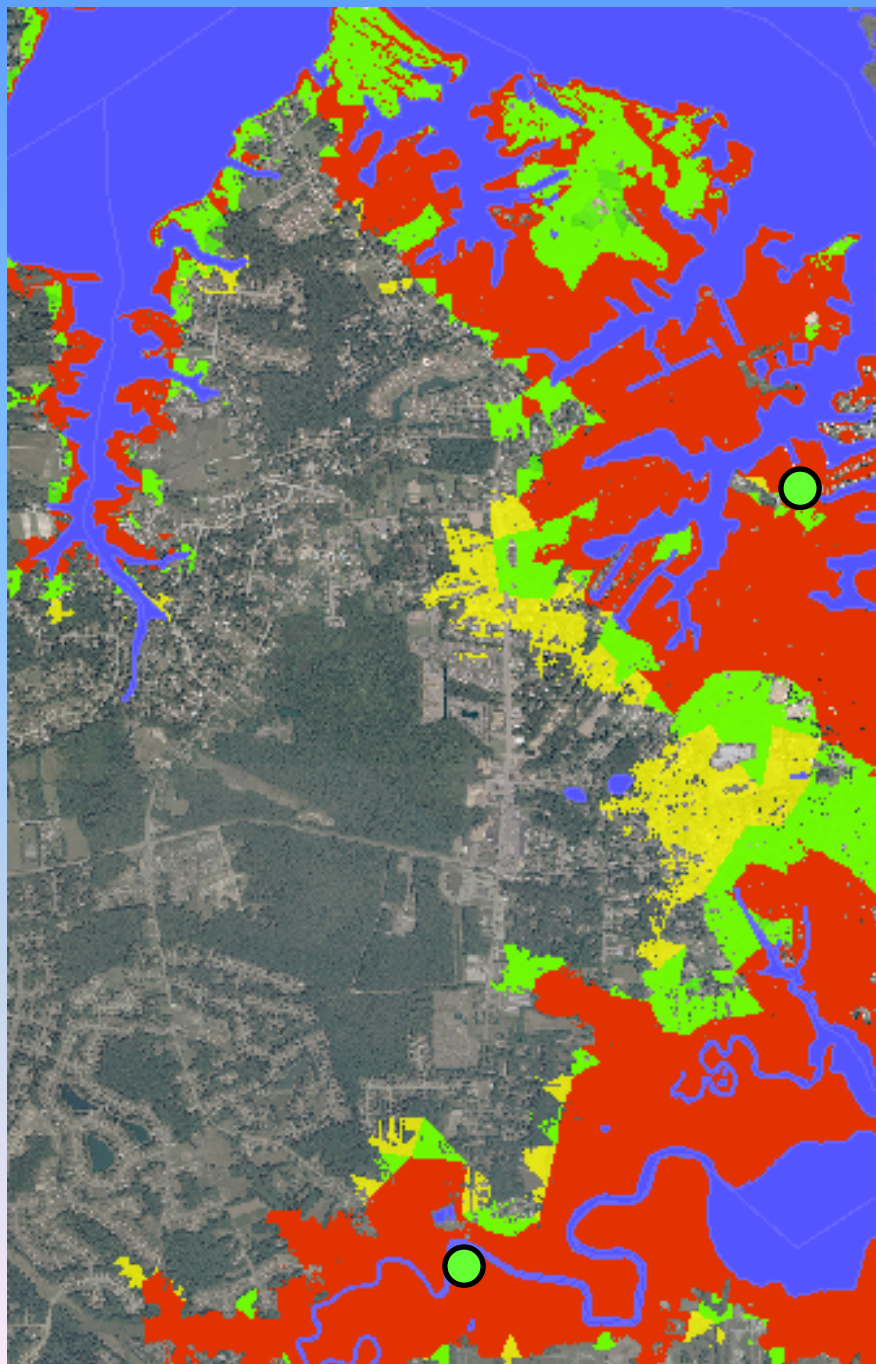
# Inundation Nor'easter NAM







# Inundation Nor'easter ALL





# Norfolk City – Damaged Properties



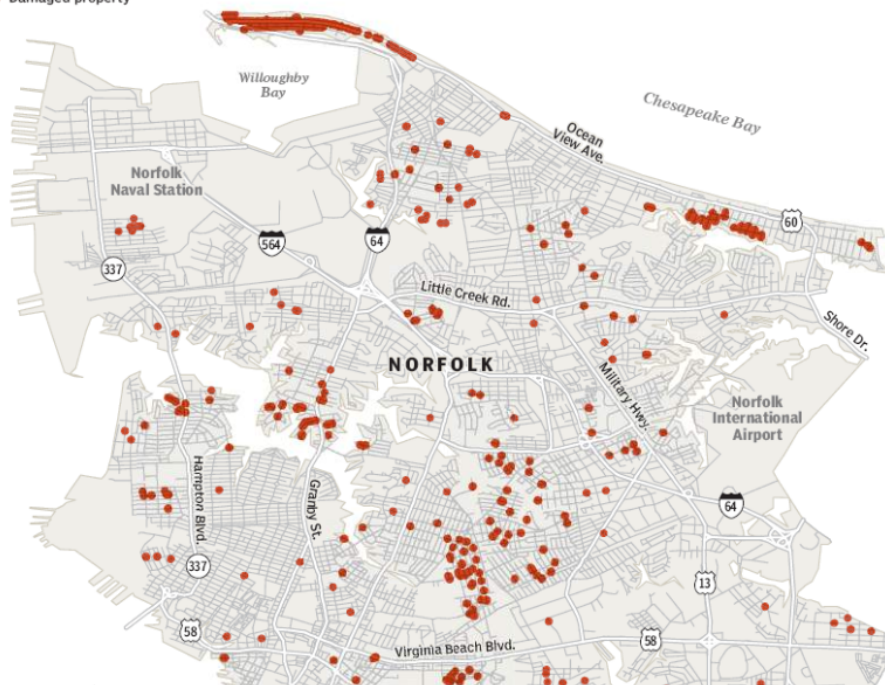
Map Courtesy *Virginian-Pilot*

## WHERE THE NOVEMBER NOR'EASTER'S FURY WAS FELT

Initial assessments by Norfolk city crews show that the recent lumbering nor'easter caused nearly \$26 million in damage to private homes, with an additional \$5 million in losses to public properties.

Each dot on this map represents a damaged property. The most dense concentration is in Willoughby. Among other neighborhoods hit hard: East Ocean View, Riverpoint, East and West Belvedere, Ballentine Place and Middle Towne Arch.

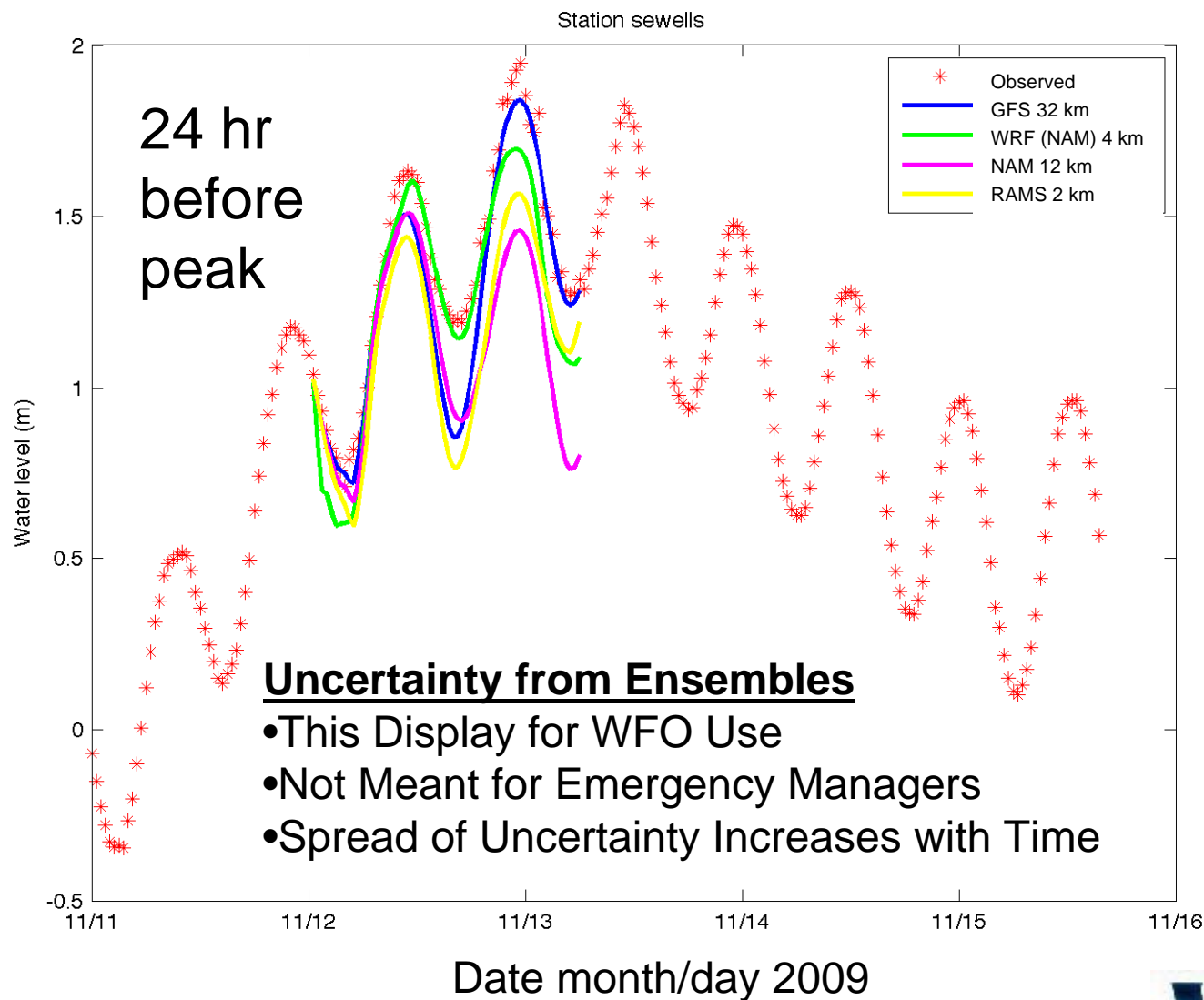
● Damaged property





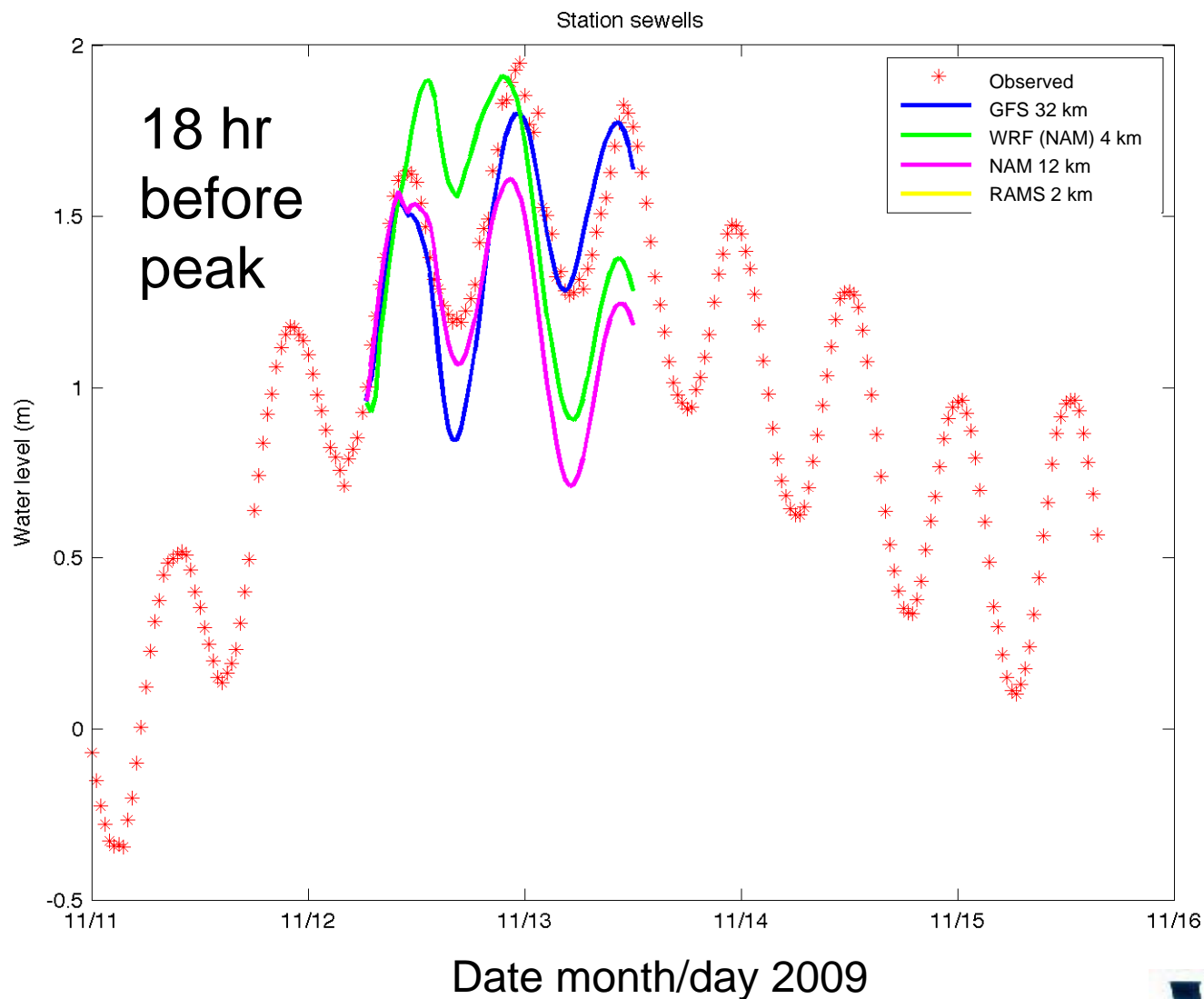


# Sewells Point Atmospheric Model Ensemble 30 Hour Fcst Starting Nov 12 at 0000 UTC





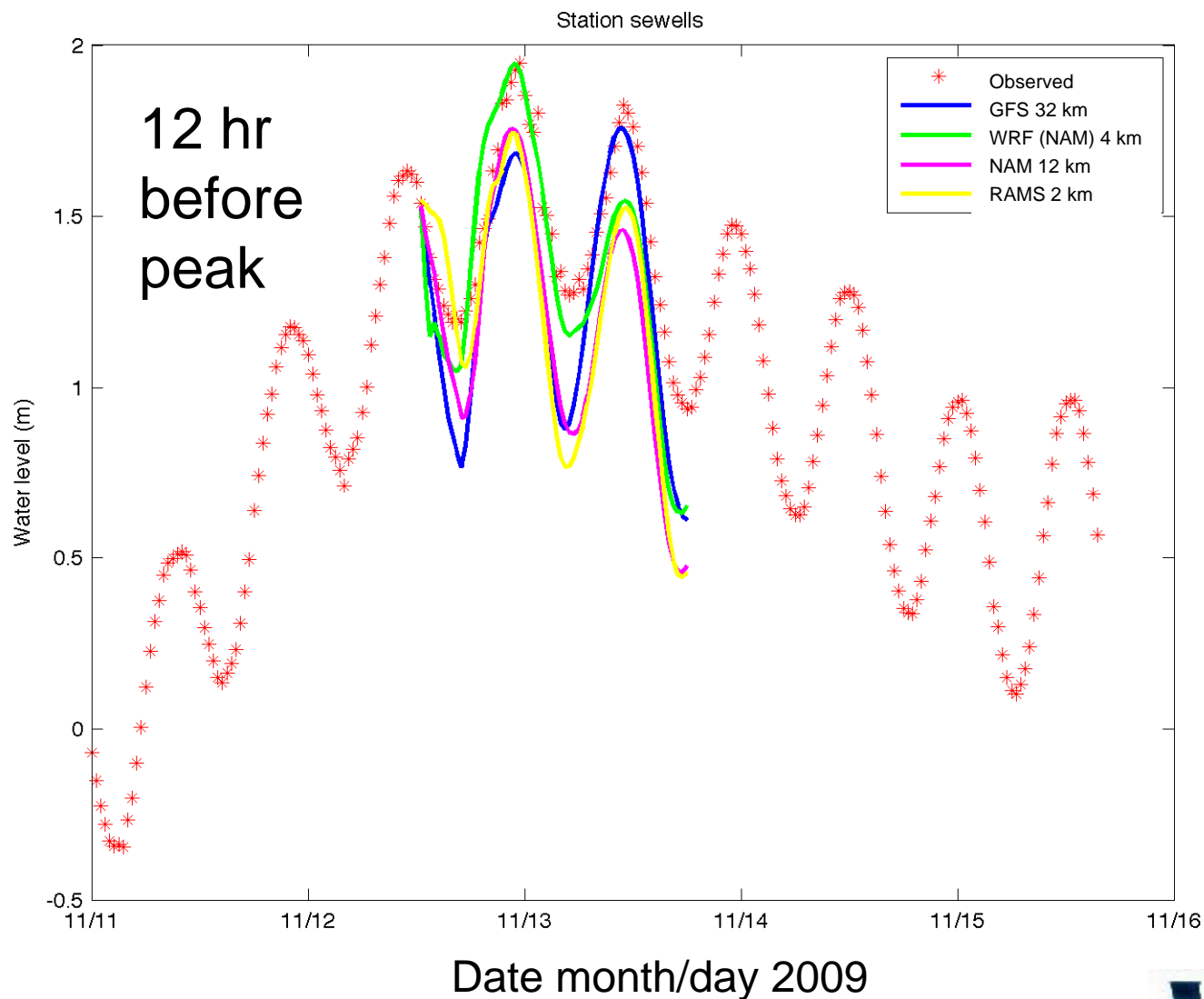
# Sewells Point Atmospheric Model Ensemble 30 Hour Fcst Starting Nov 12 at 0600 UTC





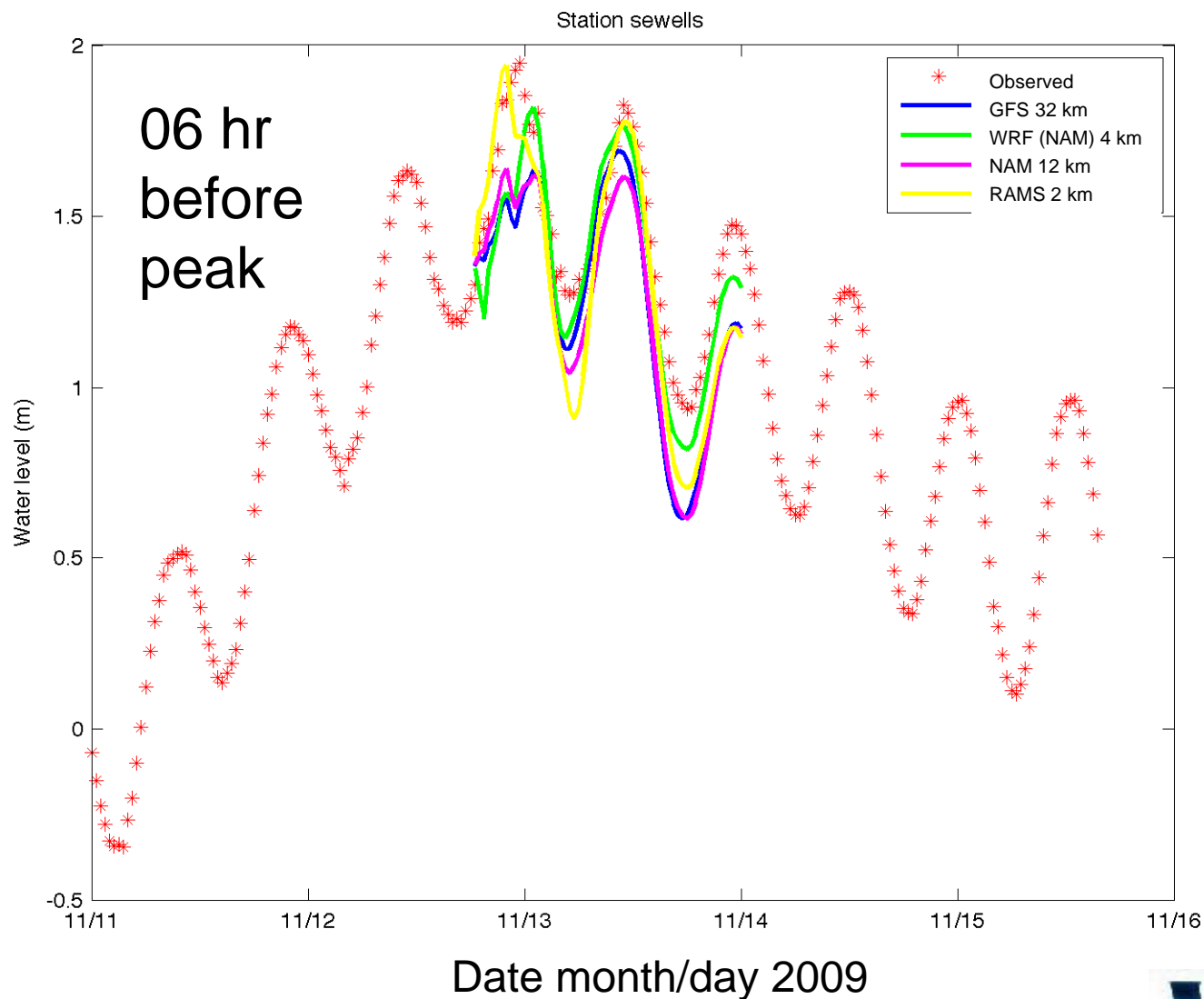


# Sewells Point Atmospheric Model Ensemble 30 Hour Fcst Starting Nov 12 at 1200 UTC





# Sewells Point Atmospheric Model Ensemble 30 Hour Fcst Starting Nov 12 at 1800 UTC















# NOAA Storm Surge: The Bottom-line



## Customers Ask:

- How much water?
- Where will it go? How close to my house?
- When will it arrive, and how fast? When will it recede?
- What is the impact on structures & ecosystem?
- How often will it occur?





# NOAA Storm Surge Goals



- **Total Water Level:** Produce water level analyses, forecasts and observations to support products:
  - *Pre-storm water level conditions, surge, tides, waves, fresh water inflow, speed, impact*
- **Inundation:** Provide information about the water depth over the land (inundation) to street level resolution
  - *include duration of water*
- **Communication of Actionable Information:** Deliver information that people act on
  - *Understandable, consistent information available in multiple formats*
  - *Uncertainty, supports risk assessments, provides impact information, includes scenarios*



# Economic Analysis



- **Interviewed 15 EMs and 17 business owners/managers in one "flood zone"-- lower Old Town Alexandria.**
- **Shared initial CIPS visualizations of Old Town from the CIPS Isabel hindcast**
- **Results indicate that both the precision & visualization of output is highly desired**
- **Suggests that results communicated effectively would improve response**





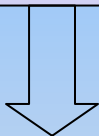


# Economic Benefits

## CAUSE

### *Flood Predictions*

More Effective  
More Accurate  
More Understandable



## EFFECT

### *Emergency Management Decisions*

More Effective  
More Timely  
More Reliable  
More Defensible



## BENEFICIAL RESULTS

### *Expected Reductions in:*

- Lives lost
- Property Damage
- Business Losses
- Household Economic costs
- Health Consequences
- Evacuation Costs
- Indirect Economic Impacts
- Recovery Time/Costs





# Strengths of CIPS



- Forecasts and visualizes land flooding
  - Area flooded at city-block scale
  - Depth at any flooded location
  - USGS gages to validate inundation on land
- Forecasts total water level
  - Surge + tide + ~~rainfall~~ + discharge
  - On land and in water
- Accounts for river discharge
- Ensemble approach to uncertainty
- High resolution for Chesapeake Bay
- Computationally efficient
- Models are robust and stable
- Aligned with NOAA Storm Surge Road Map goals
  - Scalable and relocatable capability system



# **Questions or Comments?**

**[Anthony.Siebers@noaa.gov](mailto:Anthony.Siebers@noaa.gov)**





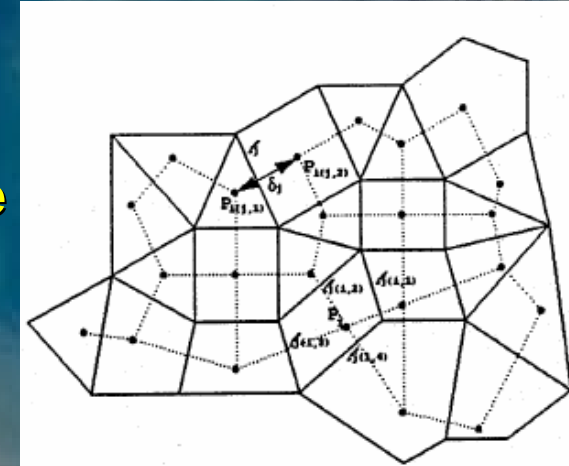
# Extra Information



- **A few additional slides about the hydrodynamic model follow**

# A class of unstructured grid model using semi-implicit, semi-Lagrangian schemes

- ELCIRC (Eulerian Lagrangian Circulation)
- SELFE (Semi-Implicit Eulerian Lagrangian, Finite Element)
- UnTRIM (Unstructured grid, Tidal Residual Intertidal udfat) models



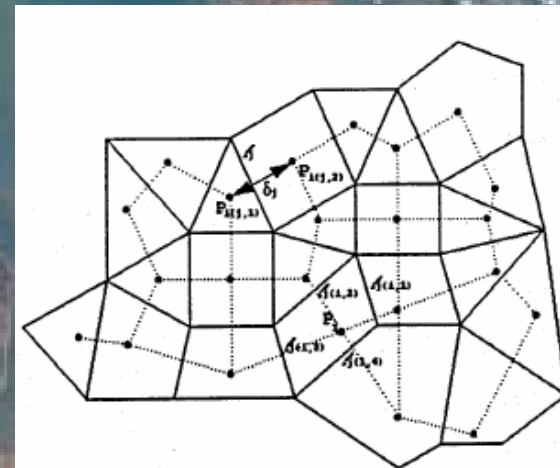
## Unstructured grid model (con't)

- Efficient computational algorithms (semi-Lagrangian advection scheme); time step: 5 minute, used for 30 m resolution grid
- Capable of simulating flooding using semi-implicit wetting-and-drying scheme

- \* Contrast with CFL-bounded scheme; allowing larger time step

**\*Reference:**

1. An advanced piecewise-linear iterative solver recently developed (2008) by Brugnano and Casulli, SIAM, J. Sci. Comp. Vol. 30, No. 1, pp463-472
2. A high-resolution wetting and drying algorithm for free-surface hydrodynamics (2009) by Vincenzo Casulli, *Int. J. Numer. Meth. Fluids* 2009; **60**:391–408





# Model setup

- Hurricane Isabel: 9/17-9/22, 2003 and Veteran day's Northeaster: 11/8/ to 11/16/, 2009 were simulated.
- Time step: 5 minutes
- Number of grid cell: 250,000 (large domain); 370,000 (high resolution domain).
- The model was forced at its open boundary by 7 tidal constituents:  $M_2$ ,  $S_2$ ,  $N_2$ ,  $O_1$ ,  $K_1$ ,  $Q_1$ , and  $K_2$
- Rather than vertical 2D, Quasi-3D barotropic mode with semi-empirical eddy viscosity was used to simulate Ekman transport. Vertical resolution used are: 5 m, 10 m, 20 m, 50 m.. etc in the ocean.
- Benchmark: 5 days simulation in a single Linux processor takes 5 hour CPU