PSEG Early Site Permit – RAI 67 Response
NRC Public Meeting

July 1, 2013

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- Introductions
- Purpose of Meeting
  - Present methodology for performing ESP Flood Re-Analysis
    - RAI 67 Response Approach
    - JPM-OS Methodology
    - ADCIRC Storm Surge Model
  - Facilitate technical discussion with NRC staff
  - Discuss remaining actions for RAI #67 response

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Agenda

- Background
- Discussion of JPM Approach
- Application of JPM at PSEG Site
- Selection of Storm Surge Model
  - FEMA Model Description
  - ADCIRC V&V Steps
  - Comparisons to FEMA Results
  - Refine FEMA ADCIRC Mesh
  - Validate Updated ADCIRC Model

RAI No. 67 Requested:

- …PSEG provide an analysis of the PMH events using a conservative, current practice approach such as those predicted by a two-dimensional storm surge model (e.g., ADCIRC, FVCOM, SLOSH, other) with input from appropriate PMH scenarios and with resolution that captures the nuances of the bathymetry and topography near the project site. Note that, to account for wave-induced water level effects (wave setup), PSEG will likely need to couple a nearshore wave transformation model to a hydrodynamics model.

Background

- Original PSEG ESPA Storm Surge Analysis based on PMH Storm (NWS 23) modeled with Bodine storm surge model, coupled with HEC-RAS and the wind setup model of Kamphuis.
- JLD-ISG-12-06 states Bodine storm surge model recommended in RG 1.59 is not consistent with current state of knowledge.
- JLD-ISG-12-06 also provides the first NRC guidance on probabilistic storm surge analysis and points to NUREG/CR-7134.

JPM Approach and Application to the PSEG Site

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Outline of JPM Development

- Approach to JPM for Tropical and Extratropical storms
  - Definition of Response Surface and storm probabilities
  - River discharge effects on surge probabilities
  - Analysis of the effects of tides on total depth probabilities

- Comparison to and consistency with extrapolated FEMA results

- Incorporation of Epistemic and Aleatory Uncertainties

- Wind field generation
  - Definition and V&V for tropical wind fields
  - Definition of Extratropical storm wind field characteristics and probabilities

- Independent Reviewer Selected (Dr. Jennifer L. Irish – Associate Professor, Virginia Tech)

Definition of Annual Exceedance Probabilities

- For combined Extratropical and Tropical storms, we use the form:

$$P_c(\eta) = 1 - (1 - P_{trop})(1 - P_{extrop})$$

where P denotes an exceedance probability and the subscripts c, $trop$, and $extrop$ refer to combined tropical and extratropical storm set.

Since, by definition $P(\eta) = 1 - F(x)$ where $F(\eta)$ is the cumulative distribution function, this is equal to

$$1 - F_c(\eta) = 1 - F_{trop}(\eta) F_{extrop}(\eta)$$

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- The cumulative distribution is defined via an integral over the storm parameters which influence surge generation (similar to Resio *et al*., 2012 – NUREG/CR-7134):

$$F_c(\eta) = \int \ldots \int p(x_1, \ldots, x_n) H[\eta - \Lambda(x_1, \ldots, x_n) dx_1 \ldots dx_2$$
$$+ \int \ldots \int p(z_1, \ldots, z_m) H[\eta - \Lambda(z_1, \ldots, z_n) dz_1 \ldots dz_2$$

where the first integral represents contributions due to tropical storms and the second integral represents contributions due to extratropical storms, and

$x_1, \ldots, x_n$ are the n parameters influencing tropical surge generation;

$z_1, \ldots, z_m$ are the m parameters influencing extratropical surge generation;

p is the multivariate probability function; and

Λ is the model (system) which links the parameters to surge levels at each point of interest

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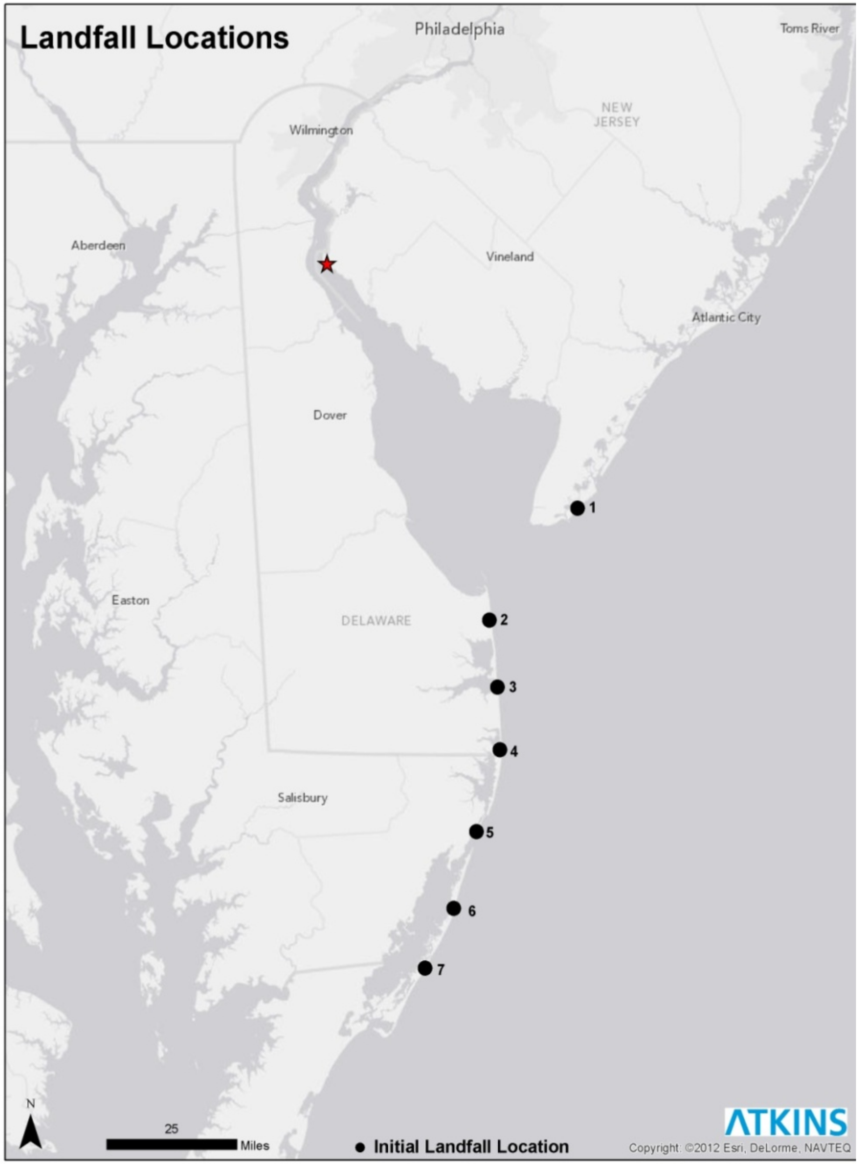
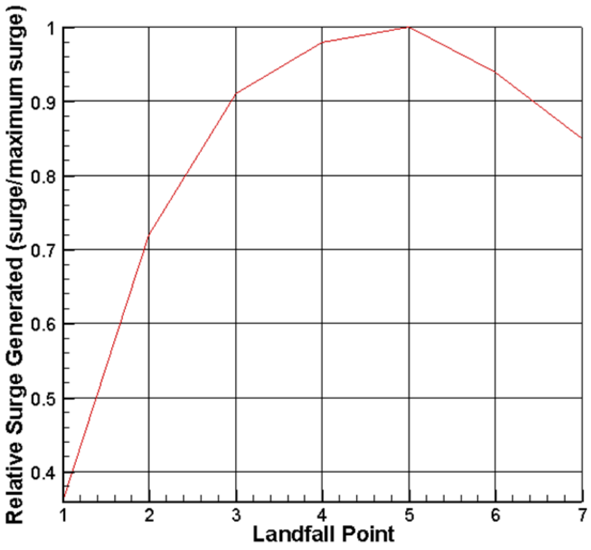
Definition of Parameter Space for Simulations

- Our simulation domain will cover the probability range from 10^{-5} to 10^{-7}
- Similar to earlier efforts, the primary parameters influencing extreme surges at this site include: landfall location, storm intensity and storm size
- The sensitivity to track angle is expected to be much larger than on the open coast
- Forward storm speed does not appear to have a pronounced influence on surge levels at the site

Quantification of the Response Surface



- Relative Surge: Landfall



- Angle restricted to ±22.5 deg
- Size response similar to that of Resio *et al*, 2012.
- Surge increases monotonically with intensity
- Effects of tides and river discharge on water level probabilities are being investigated

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Comparison to FEMA Region 3 Analysis

- FEMA analyses focused on 10 – 500 year range of return periods
- PSEG will focus on much longer return periods
- FEMA could neglect uncertainties in their analyses, given their range of applicability
- PSEG analyses cannot neglect uncertainty
- Modeling tools should be comparable

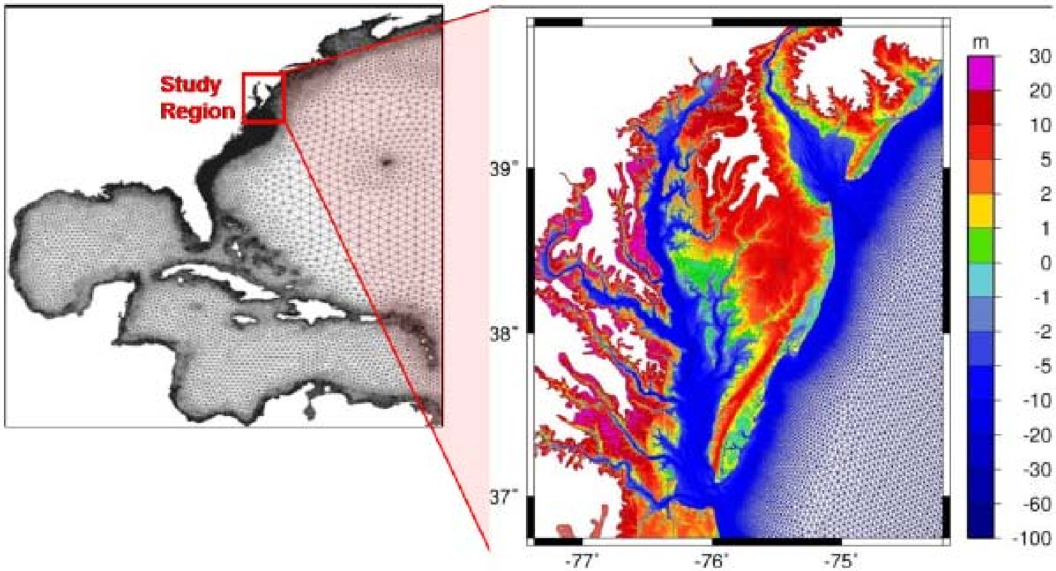

Figure 1.2. FEMA Region III unstructured modeling mesh, showing the overall modeling domain (left), and topographic detail within Region III (right).

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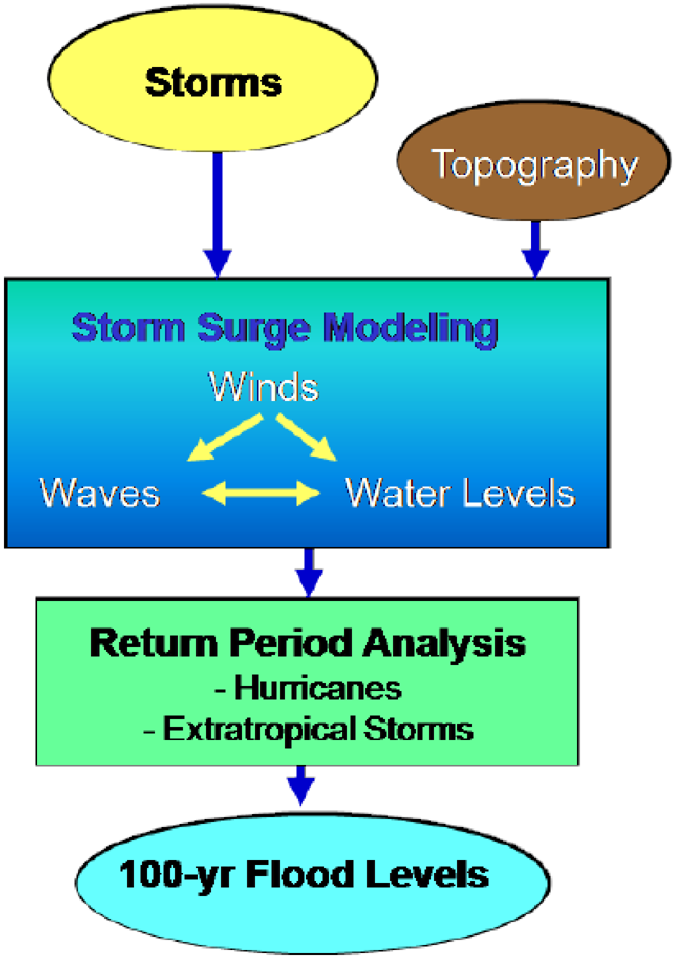
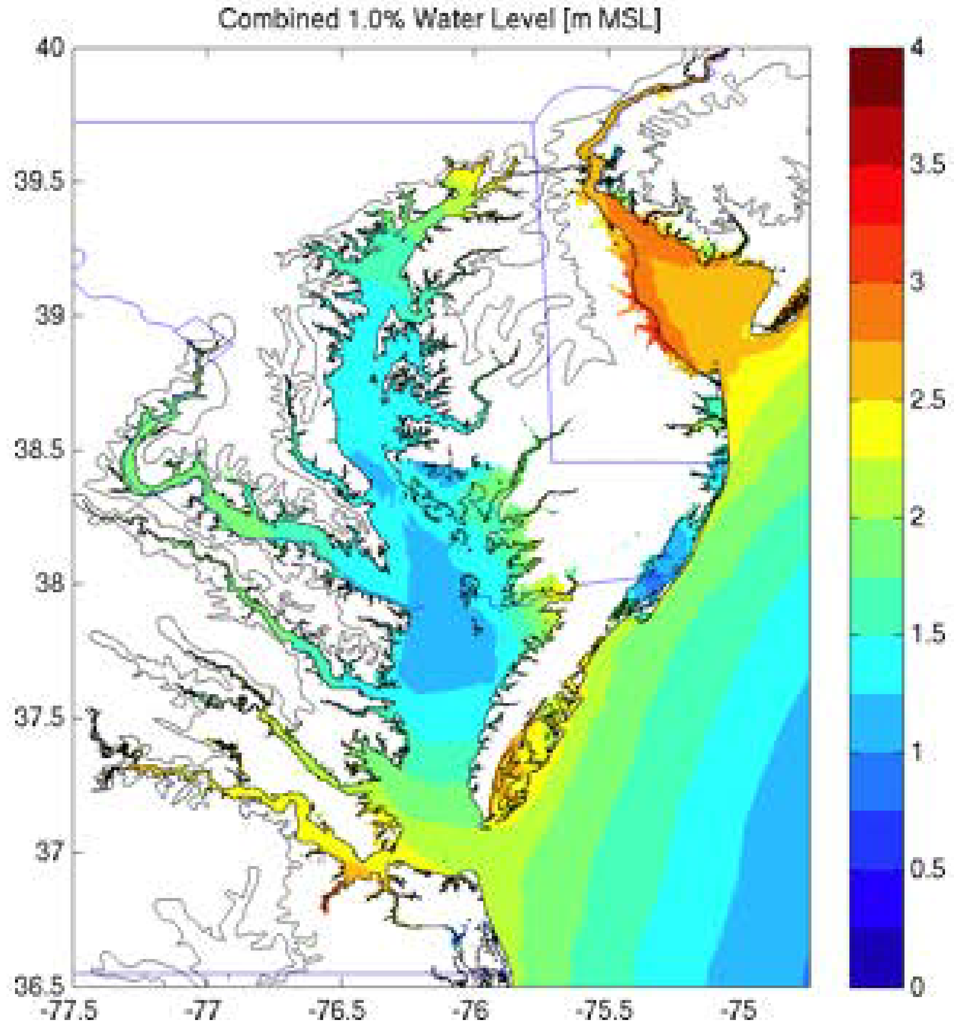
Extratropical Storm Methodology Used Empirical Simulation Technique (EST)

- Period of record covered 1975 – 2009
- Cumulative Distribution Function defined using equivalent to Gumbel plotting position n/(N+1), where n is the rank and N is the total number of years included in the analysis.



100-year combined total water levels

- Combined 100-year water levels are less than 3 m.



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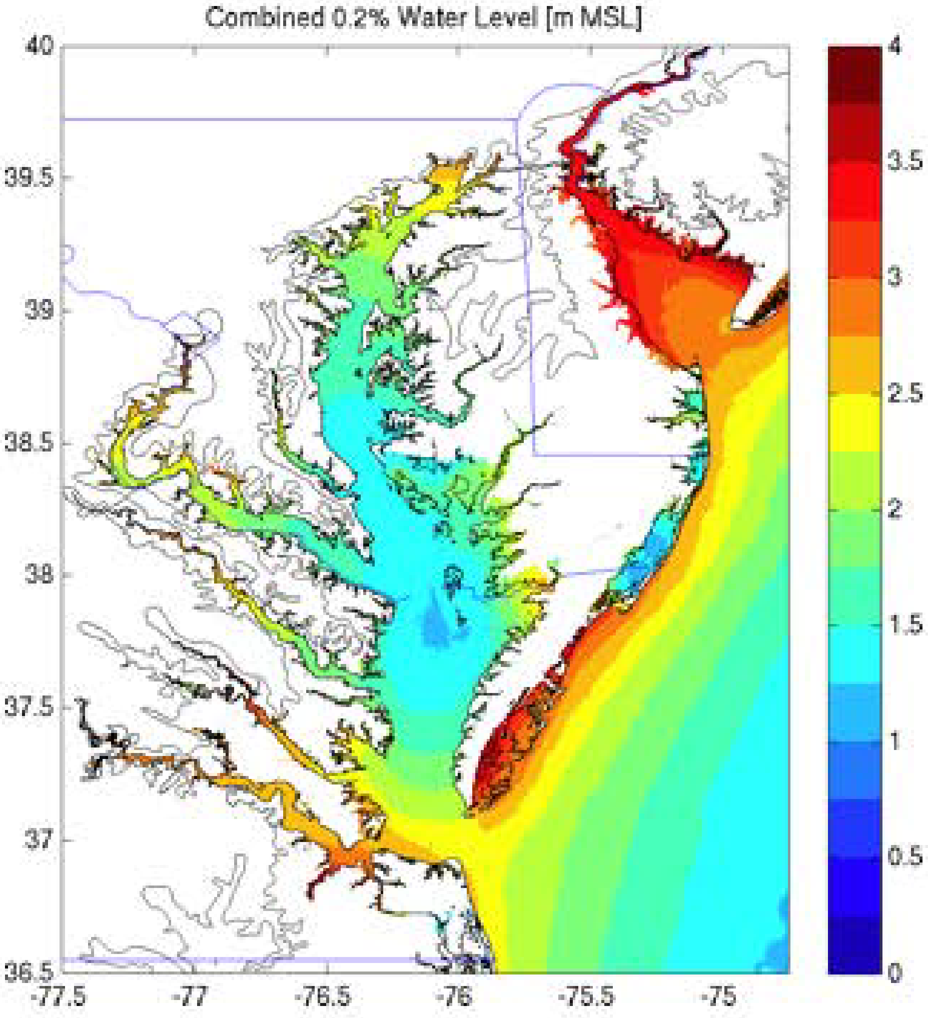
500-year combined total water levels

- Combined 500-year water levels are less than 3.5 m.



The EST method also did not include epistemic or aleatory uncertainty

- This will be included within the JPM analysis conducted for the PSEG Site

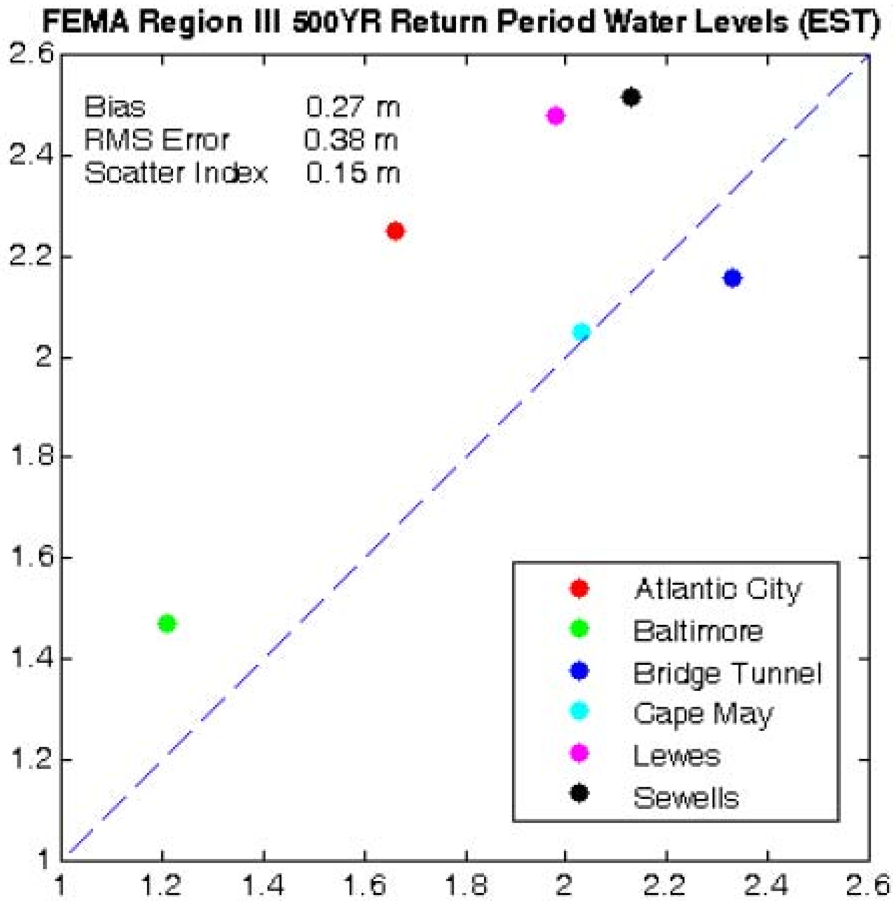


Figure 2.22. 500-year return period scatter plot with error estimates at validation stations.

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Modeling range depends on asymptotic surge response to parameters

Functional dependence of the surge on forcing parameters as they become large-valued.

<u>Becomes Asymptotic</u>

$$\zeta = \left(\frac{\rho_a}{\rho_w}\right)\frac{c_d V^2}{g}\int_0^L \frac{dx}{h(x)} = \left(\frac{\rho_a}{\rho_w}\right)\frac{c_d V^2}{g\langle h\rangle}L \qquad \zeta = \left(\frac{\rho_a}{\rho_w}\right)\frac{c_d}{\langle h\rangle}\frac{\lambda \Delta p}{\rho_a g}L$$

Storm Intensity

NO

$$\zeta = \chi_1 \Delta p \frac{L_*}{h_*\phi_*}\psi_x\left(\frac{R}{L_*}\right) \qquad \psi_x\left(\frac{R}{L_*}\right) = \left(\frac{R}{L_*}\right) \quad when \left(\frac{R}{L_*}\right) \le 1$$

$$= 1 \quad when \left(\frac{R}{L_*}\right) > 1$$

Storm Size

YES

$$\zeta = \chi_1 \Delta p \frac{L_*}{h_*\phi_*}\psi_x\left(\frac{R}{L_*}\right)\psi_t\left(\frac{t_*}{t_\infty}\right) \qquad \psi_t\left(\frac{t_*}{t_\infty}\right) = \left(\frac{t_*}{t_\infty}\right) \quad when \left(\frac{t_*}{t_\infty}\right) \le 1$$

$$= 1 \quad when \left(\frac{t_*}{t_\infty}\right) > 1$$

Storm Forward Speed

YES

If we focus on the "tail" of the distribution, we see that some physical limits appear.

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The inclusion of epistemic and aleatory uncertainty in JPM estimates

- The epistemic uncertatinty is added via:

$$F_c(\eta) = \int \ldots \int p(x_1, \ldots, x_n, \varepsilon) H[\eta - \Lambda(x_1, \ldots, x_n) + \varepsilon] dx_1 \ldots dx_2$$

$$+ \int \ldots \int p(z_1, \ldots, z_m) H[\eta - \Lambda(z_1, \ldots, z_n)] dz_1 \ldots dz_2$$

where

ε is the random uncertainty term, assumed to follow a Normal distribution with a mean of zero and a standard deviation given by the sum of a number of error contributions

$$\sigma^2_{total} = \sigma^2_{tide} + \sigma^2_{\text{model}} + \sigma^2_B + \sigma^2_{waves} + \sigma^2_{winds} + \sigma^2_{residual} \quad +\sigma^2_{\text{sampling}}$$

Epistemic uncertainty

Aleatory uncertainty

Has a different form than epistemic

Aleatory uncertainty becomes very large at large return periods

Uncertainty in an estimate is very difficult to estimate without some assumptions regarding parent distributions and the "effective" number of samples (which depends on the autocorrelation attributes of the phenomenon).

For extremes, the overall characteristics tend to vary as a function of the return period and the number of samples.

$$S_x \sim \phi\left(\frac{T}{\sqrt{N}}\right), \text{ where } S_x \text{ is the rms of the Gaussian uncertainty band}$$

For a Gumbel Distribution, with a distributional rms of S

$$S_x \sim S\sqrt{\frac{1.100y^2 + 1.1396y + 1}{N}}, \text{ for large } T \; y \approx \ln(T) - \frac{T}{2}$$

Unfortunately, this makes the estimation of very-low-probability events very uncertain. For hurricane surges the typical rms value of the uncertainty is in the 10% range for the 100-year return period (assuming a Gumbel Distribution).

For very low frequencies (very large T), the confidence limits become much larger than the predicted surge values.

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Examples of influence of aleatory uncertainty in very low probabilities

Using standard form for CDF and return period, we can develop a continuous estimate for central pressures from Table 7 in the report.

$$a)\ F'(x) = \exp\left\{-\exp\left[-\left(\frac{x-a_0}{a_1}\right)\right]\right\} \qquad x = 1013 - c_p,$$

where

$a_0 = 31.7$ and $a_1 = 12.34$

$F'(x)$ is the best fit to the data not adjusted to an annual basis

and the Poisson-Gumbel Distribution for return period is:

$$b)\ T_r = \frac{1}{\lambda[1-F'(x)]}$$

where

λ is the annual frequency (= 16/280)

[Note: 280 = 70×4 adjusts for size differential in sample] and;

T_r is the return period in years; which yields for the annualized CDF, $F(\eta)$:

$$c)\ F(x) = 1 - \frac{1}{\lambda T_r}.$$

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Equation for aleatory risk from Resio *et al. (2013) Nat. Haz.*

Inclusion of Aleatory risk can be accomplished by incorporating the effect of sampling uncertainty on the input parameters to the JPM.

Examples here are for central pressures.

$$p(x) = \int_{0}^{\infty} \int_{-\infty}^{\infty} p[\hat{x}(T_r) + \varepsilon \mid \hat{x}] p(\hat{x}) p(\varepsilon) \delta(\hat{x} + \varepsilon - x) d\varepsilon d\hat{x}(T_r)$$

where

$\hat{x}(T_r)$ denotes the deterministic estimate of x for a given return period and

ε denotes the deviation from the the deterministic surge estimate.

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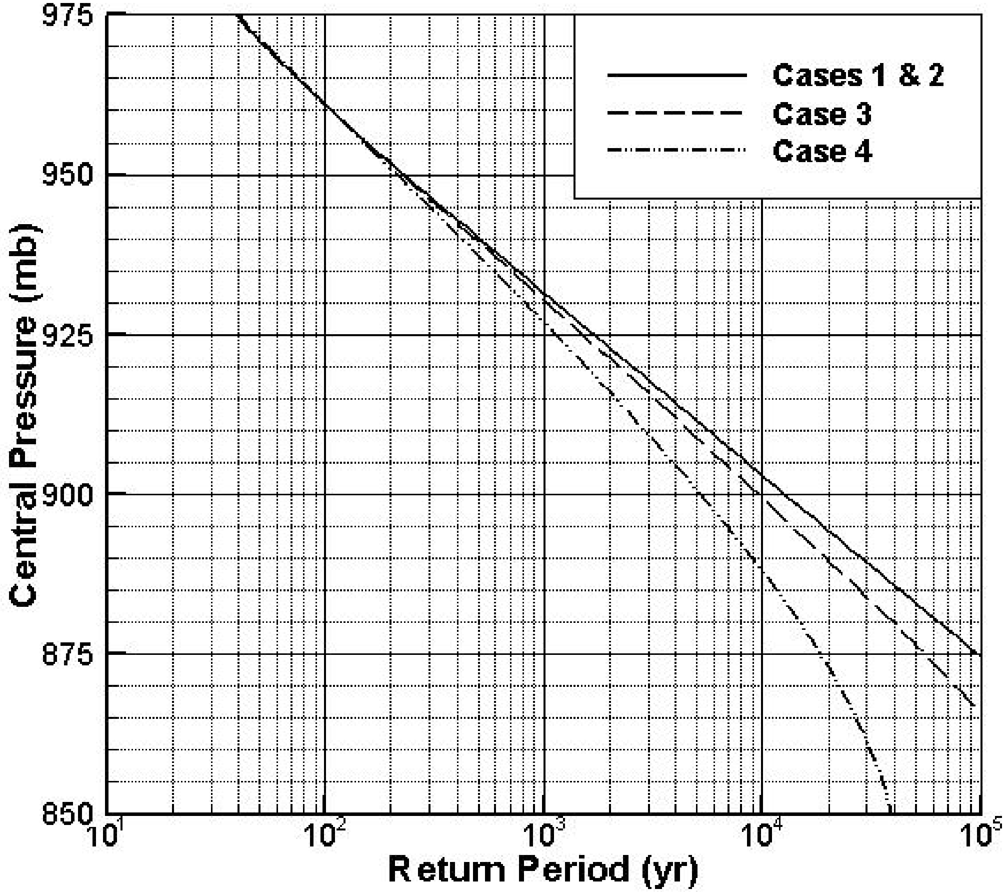
Aleatory Impact on Encounter probabilities of central pressures

Study Area

1



Estimated return periods with and without uncertainty:

Case 1&2: deterministic and delta function approximation

Case 3: estimated standard deviations divided by 2

Case 4: estimated standard deviations

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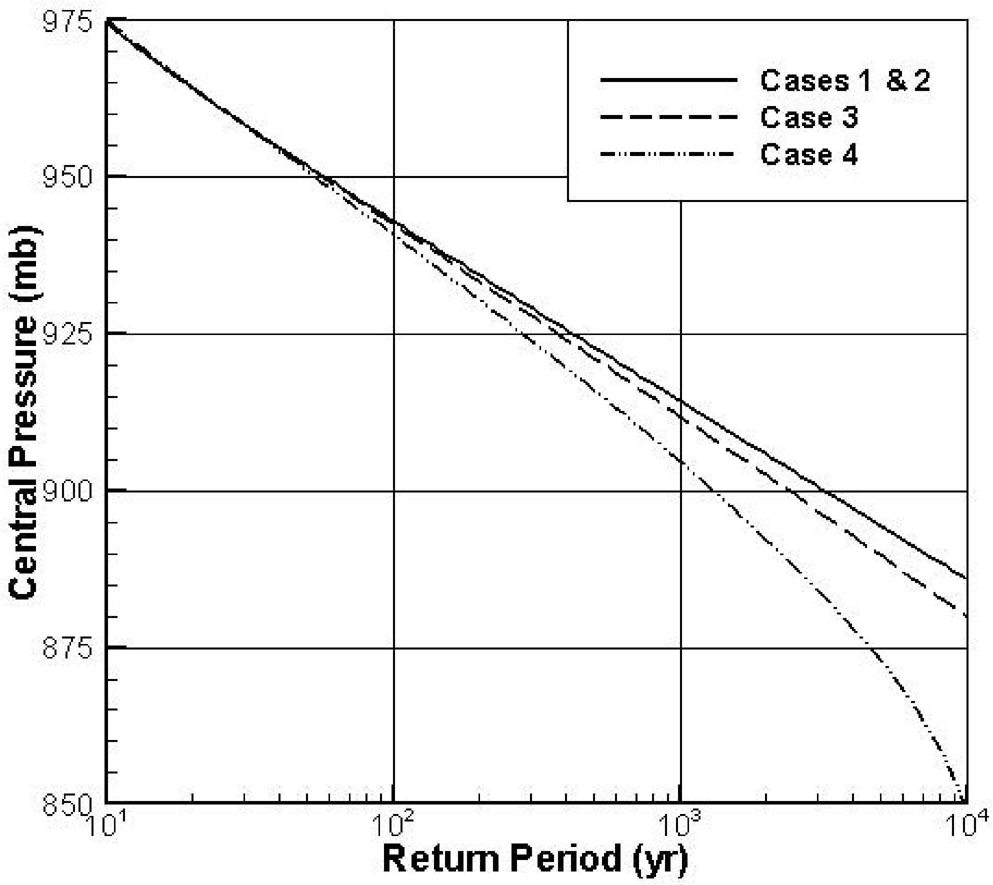
Aleatory Impact on Encounter probabilities of central pressures

Study Area

2



Estimated return periods with and without uncertainty:
Case 1&2: deterministic and delta function approximation
Case 3: estimated standard deviations divided by 2
Case 4: estimated standard deviations

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Wind Field Generation

- Wind fields will be generated using models consistent with recent FEMA and USACE surge studies

- V&V will include comparisons of radial wind profiles, maximum winds, and wind angles within storms

- Extratropical storms will include storms which have transitioned from tropical origins to extratropical form

Summary of JPM approach for PSEG Site

- JPM method used for tropical storms is equivalent to those used in previous USACE, FEMA, and NRC studies
- Very-low probability surges from extratropical storms will likely be dominated by tropical systems that have transitioned to extratropical form and by well-defined storms of extratropical origin
- Definition of combined tropical and extratropical surge probabilities is straightforward
- Wind field methodologies are well-tested
- Incorporation of uncertainty will be performed using previously tested and published methods

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Selection of Storm Surge Model

Storm Surge Model Selection

- JLD-ISG-12-06 describes ADCIRC as a current state of the art storm surge model.

- JLD-ISG-12-06 also describes SWAN (Simulating Waves Nearshore) as a capable model for analyzing wave conditions.

- FEMA Region III Storm Surge Study using ADCIRC w/SWAN

Overview of FEMA Region III Risk Assessment Analysis

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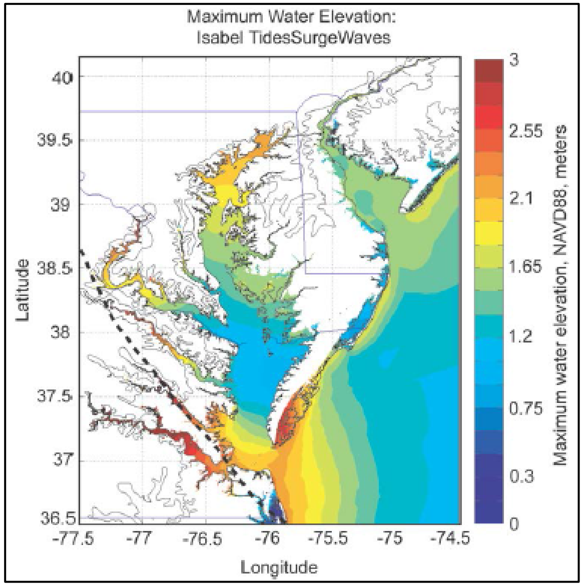
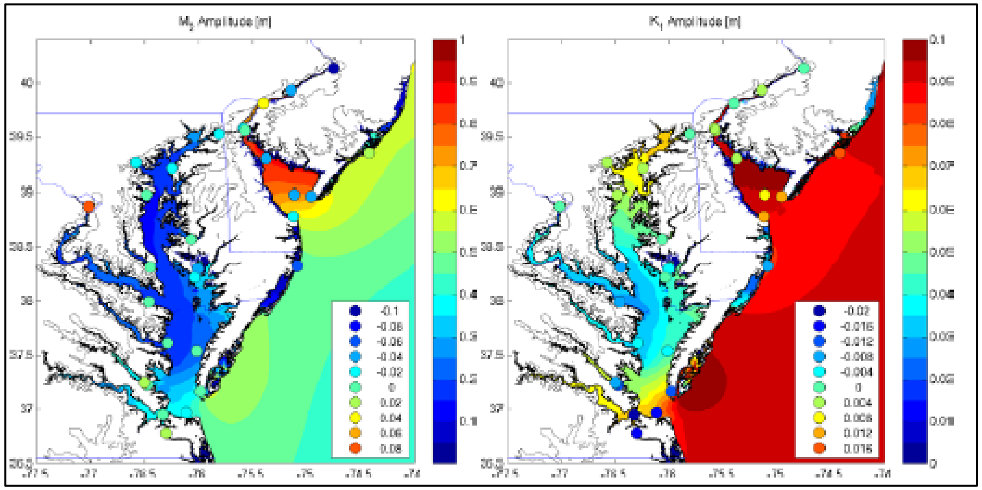
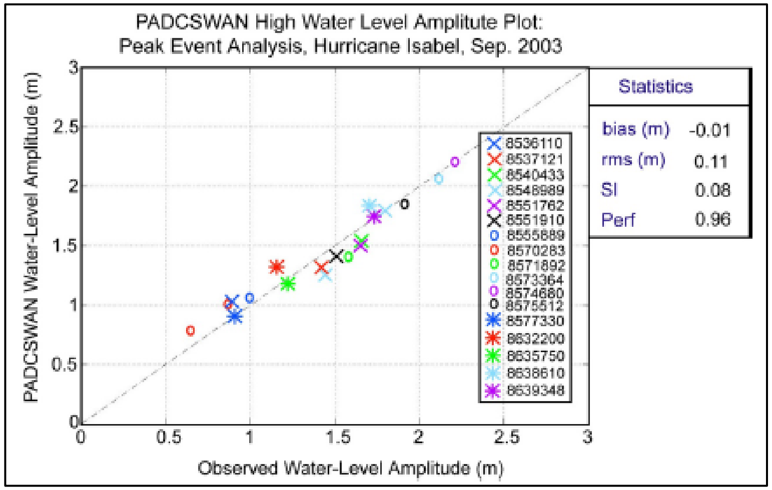
FEMA Study



- Region III (includes Delaware Bay)
- Corps of Engineers were the technical lead
- Model system to assess storm surge risk
- Developed a high resolution ADCIRC mesh
- 10-, 50-, 100- and 500-yr flood levels
- Used the same ADCIRC+SWAN model system that is being applied to the ESP Flood Re-analysis



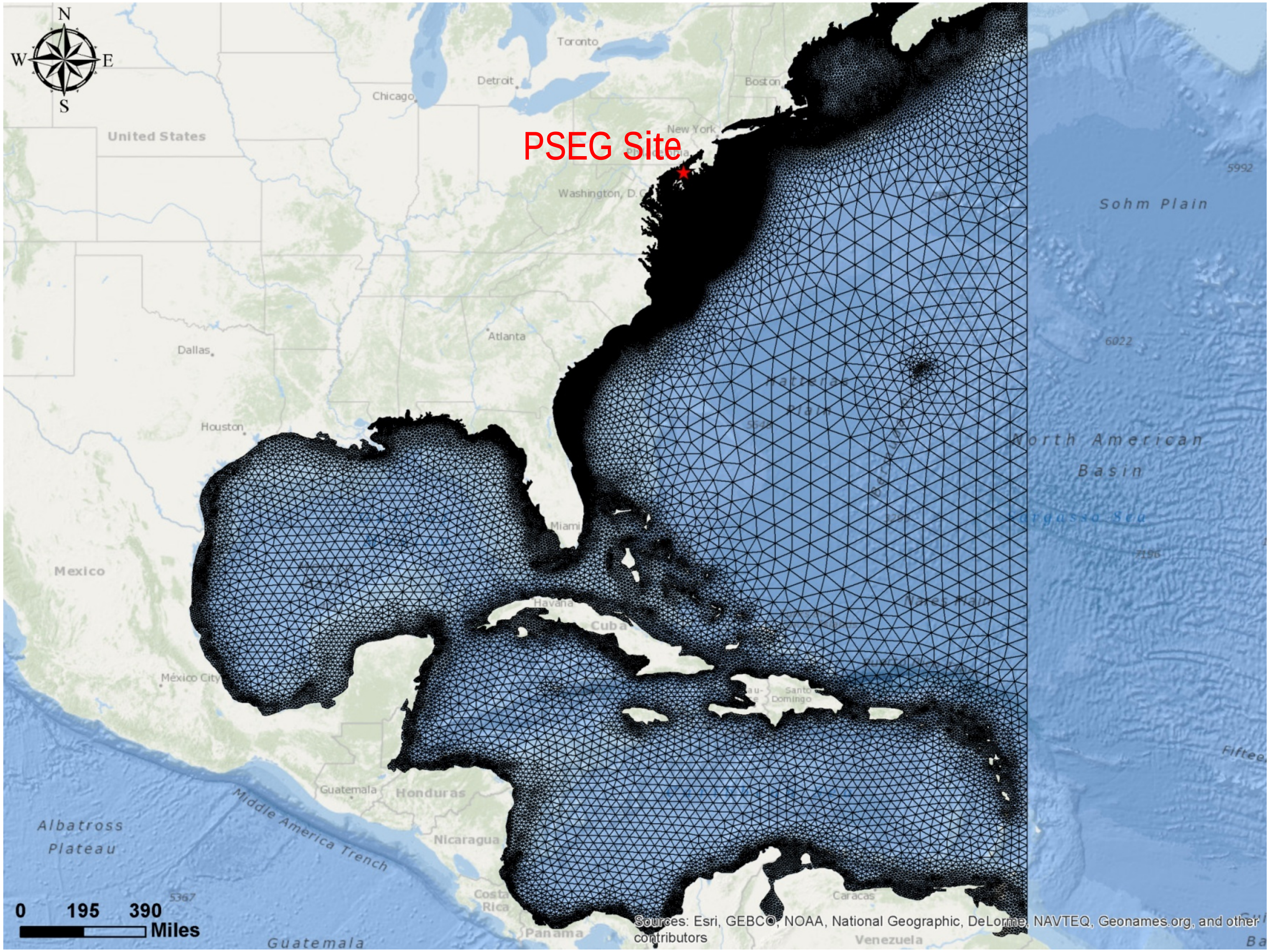


Source: U.S. Army Corps of Engineers, ERDC/CHL TR-13-XX, Submission No. 2

Advanced Circulation, Two-Dimensional Depth-Integrated (ADCIRC-2DDI) model

- Long-wave, coastal and ocean circulation model
- Finite element based
- Simulates astronomic tides and hurricane storm surge
- Can include wave influences through coupling with SWAN
- Both ADCIRC and SWAN are in the current ISG as recommended modeling tools for surge and waves

Western North Atlantic Tidal Model Domain



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Study Region

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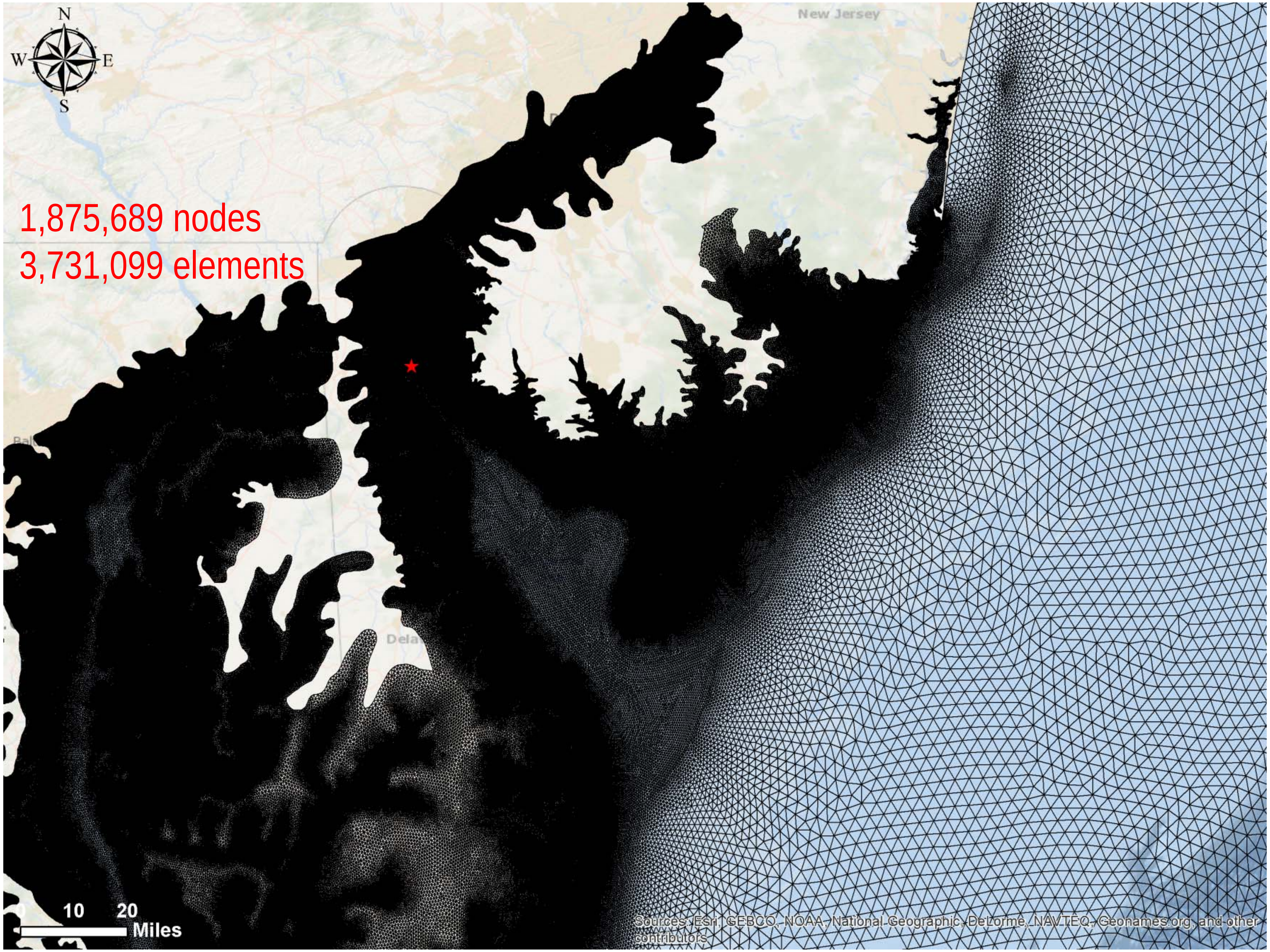
FEMA Region III ADCIRC Mesh



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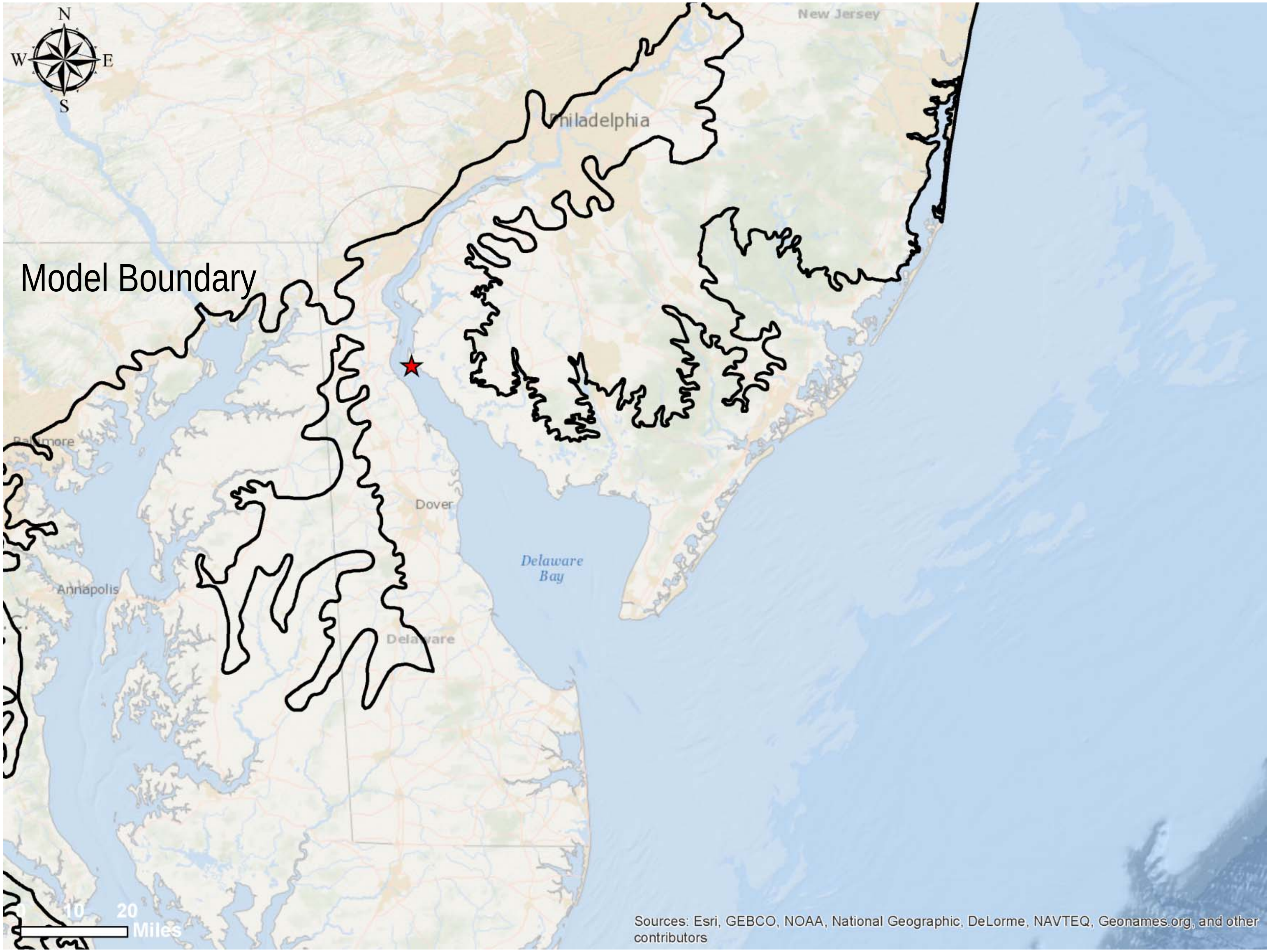
FEMA Region III ADCIRC Mesh



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ADCIRC Verification and Validation for the PSEG ESPA Flood Re-Analysis

ADCIRC V&V Motivation and Purpose

Goal:	To develop and document a state-of-the-art modeling tool that will support JPM-OS work now underway
Purpose A:	Verify that the project computer platform produces the expected results
Purpose B:	Verify that site specific modifications made to the storm surge model produce the expected results

ADCIRC V&V Steps

- Obtain ADCIRC mesh used in recent FEMA study for this region (Purpose A)
- Obtain input/output files from FEMA for a couple storm events to use for verification (Purpose A)
- Recreate FEMA results for the selected events using the project computer platform (Purpose A)
- Adjust ADCIRC mesh to incorporate PSEG site topography (Purpose B)
- Validate new PSEG ADCIRC mesh (Purpose B)

Stokes Advanced Research Computing Center at the University of Central Florida

- http://webstokes.ist.ucf.edu/
- ~16 trillion floating point operations per second
- 3100 total processing cores
- ~6 TB of RAM
- 144+ TB total storage
- RHEL 5.0-5.4 operating system (Linux environment)

Recreate FEMA Results Using the Project Computer Platform

Simulation Process

45-day Tidal Spinup

- Allows enough time for full tidal resonance to be achieved within the domain
- “Hotstart” file is created from this simulation to jump start the ensuing ADCIRC+SWAN simulation

Tides+Surge+Waves

- ADCIRC+SWAN code
- Event specific wind files used

Notes on Results

- Plots compare our results to the previous FEMA results to note any differences
- All results shown were produced using the ADCIRC+SWAN code

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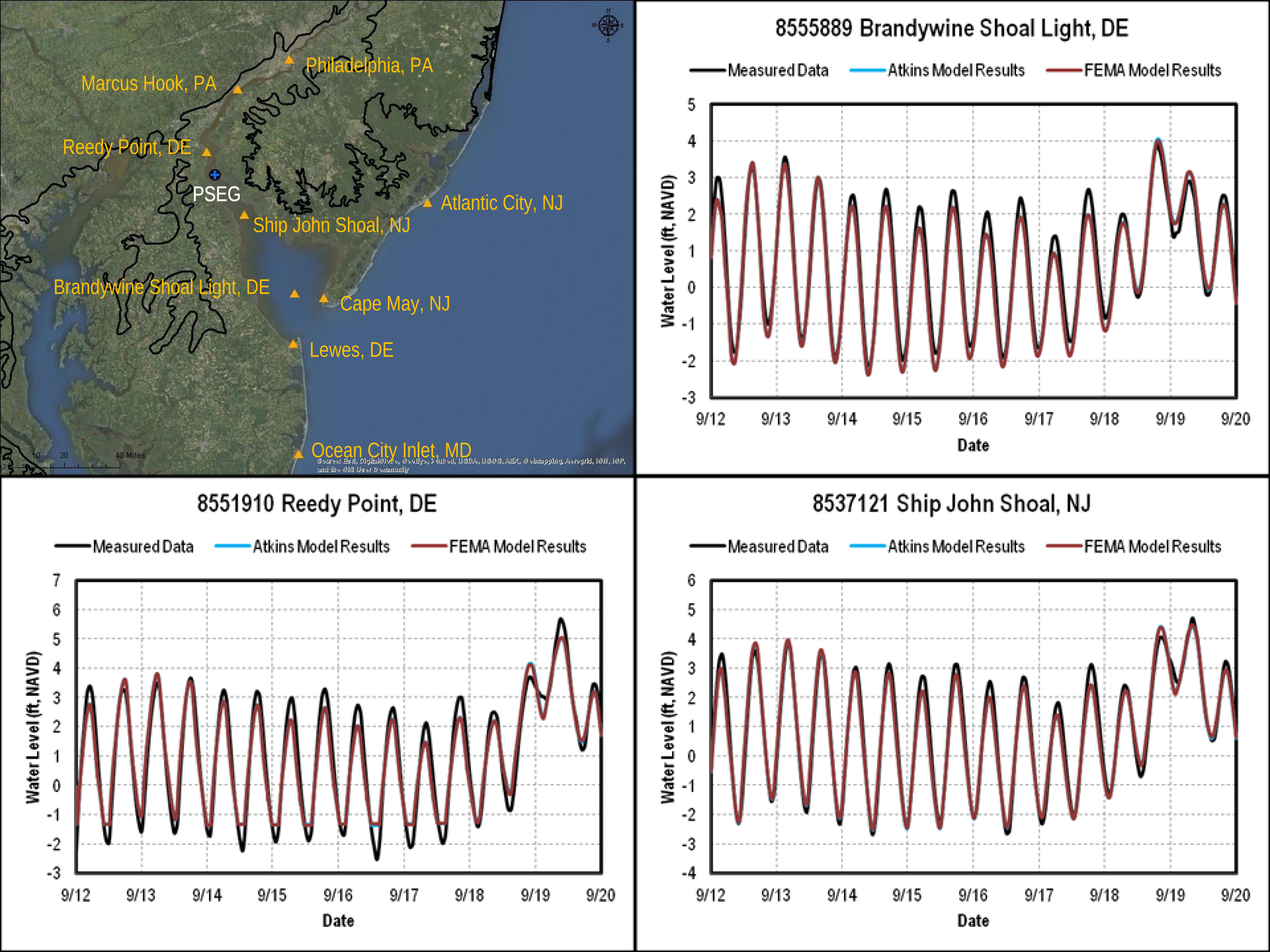
Hurricane Isabel

September 12, 2003 – September 20, 2003



Philadelphia, PA
Marcus Hook, PA
Reedy Point, DE
PSEG
Atlantic City, NJ
Ship John Shoal, NJ
Brandywine Shoal Light, DE
Cape May, NJ
Lewes, DE
Ocean City Inlet, MD
40 Miles
8555889 Brandywine Shoal Light, DE
Measured Data
Atkins Model Results
FEMA Model Results
Water Level (ft, NAVD)
Date
9/12
9/13
9/14
9/15
9/16
9/17
9/18
9/19
9/20
8551910 Reedy Point, DE
Measured Data
Atkins Model Results
FEMA Model Results
Water Level (ft, NAVD)
Date
8537121 Ship John Shoal, NJ
Measured Data
Atkins Model Results
FEMA Model Results
Water Level (ft, NAVD)
Date

Hurricane Isabel Peak Water Level Comparison

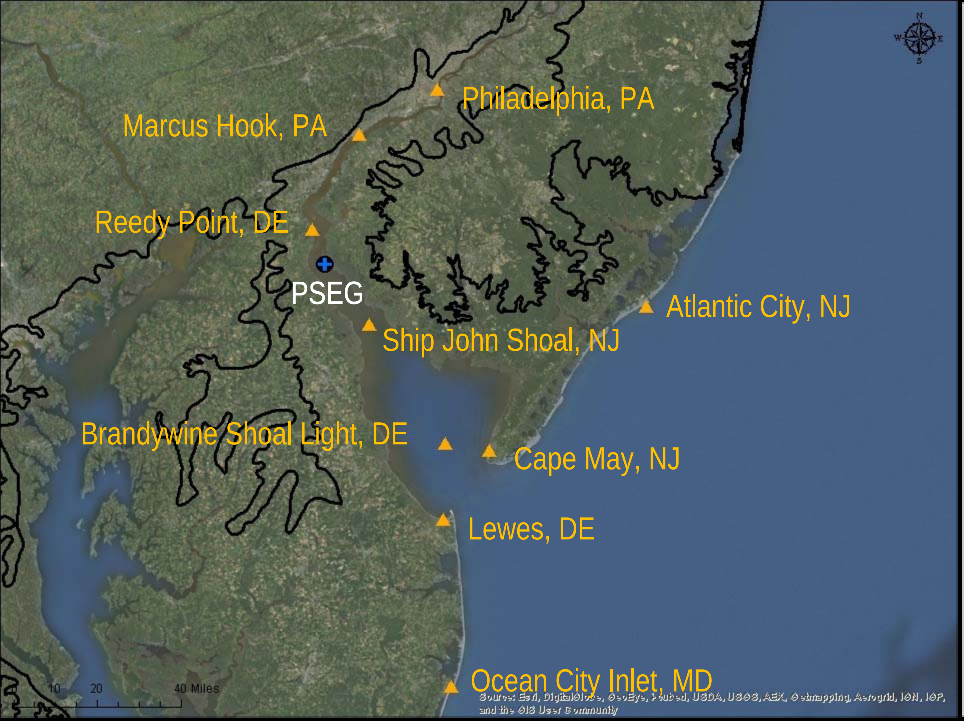
Location	NOAA Gage No.	Atkins Peak (ft)	FEMA Peak (ft)	Difference (%)	Difference (inch)
Ship John Shoal	8537121	4.44	4.48	-0.89%	-0.48
Marcus Hook	8540433	5.65	5.69	-0.70%	-0.48
Philadelphia	8545240	5.18	5.22	-0.77%	-0.48
Reedy Point	8551910	5.04	5.07	-0.59%	-0.36
Brandywine Shoal	8555889	4.05	4.01	0.99%	0.48

Note: Peak water level elevations are referenced to the NAVD88 vertical datum.

Validation Event

Nor'easter Ida

November 10, 2009 – November 16, 2009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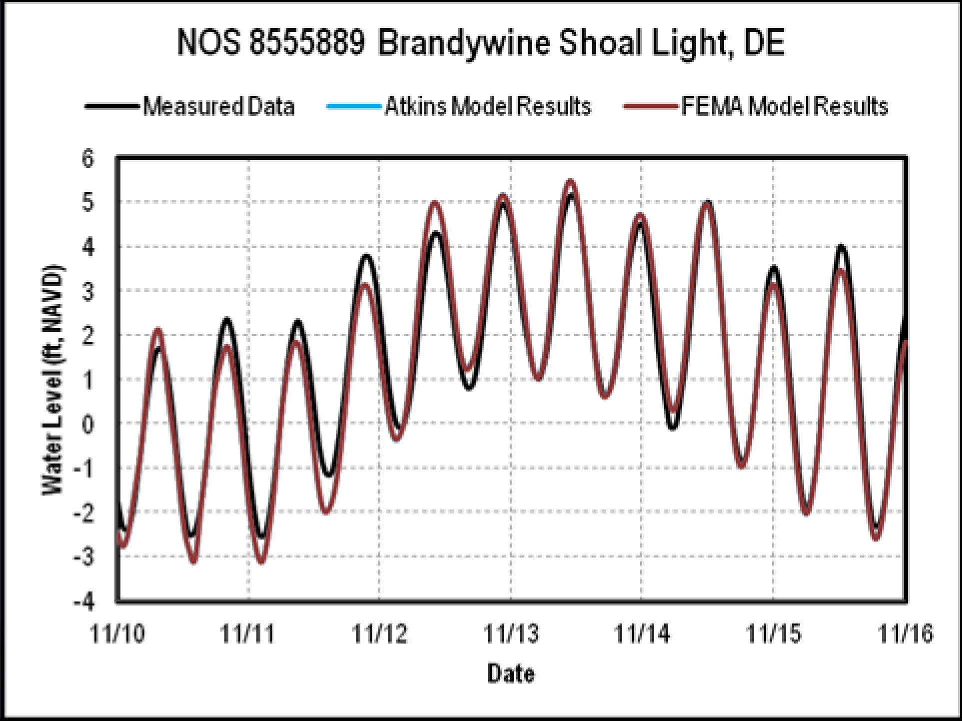
NOS 8555889 Brandywine Shoal Light, DE
Measured Data
Atkins Model Results
FEMA Model Results
Water Level (ft, NAVD)
6
5
4
3
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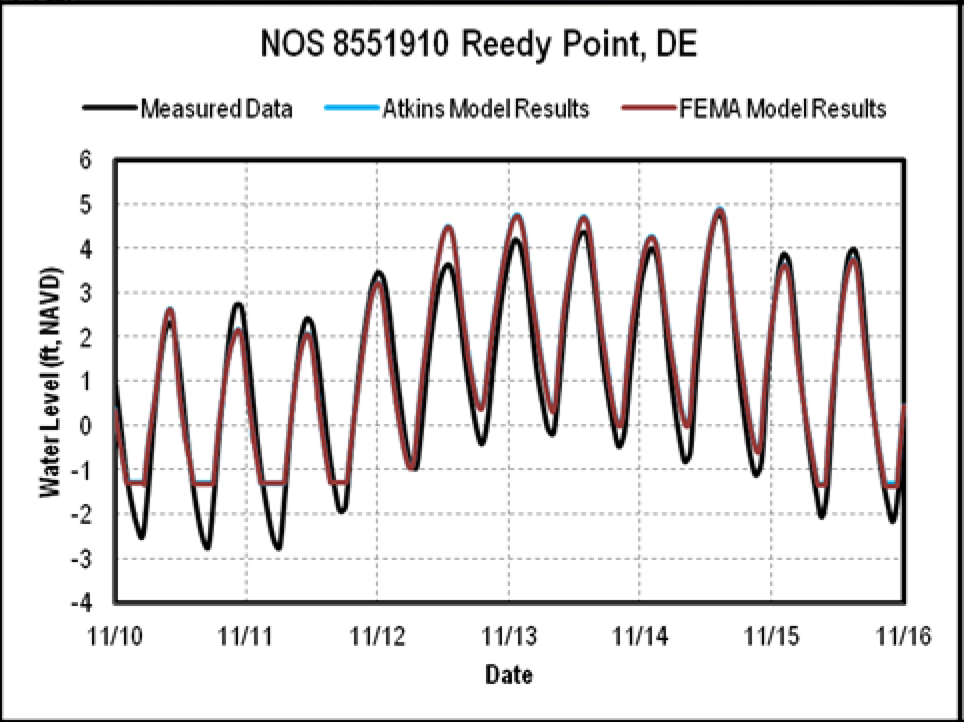
11/15
11/16
Date


NOS 8551910 Reedy Point, DE
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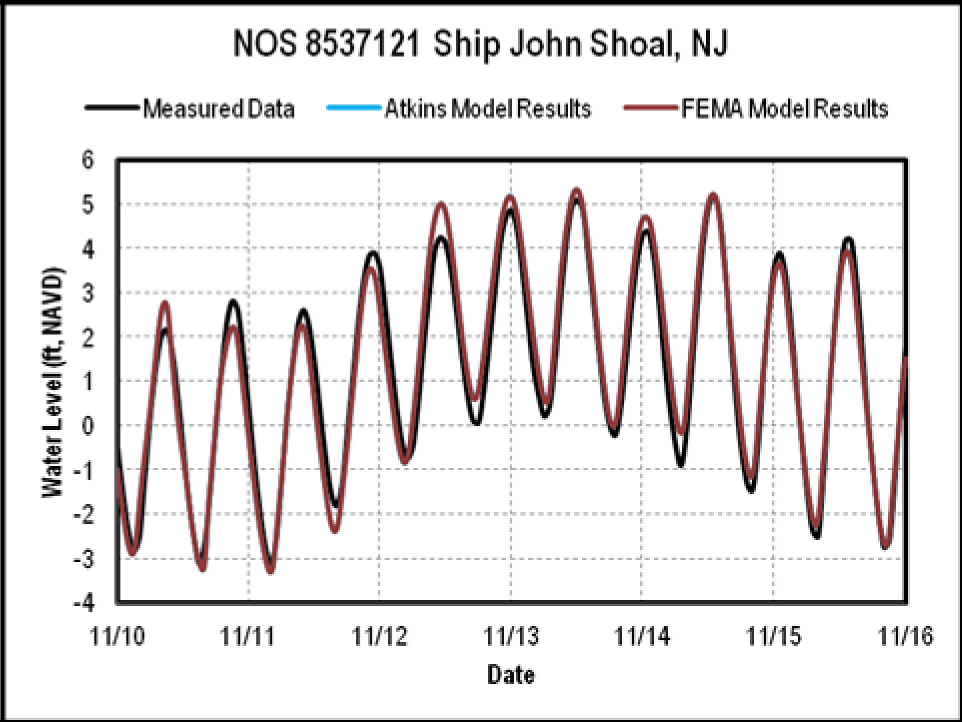
NOS 8537121 Ship John Shoal, NJ
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-2
-3
-4
11/10
11/11
11/12
11/13
11/14
11/15
11/16
Date

Nor'easter Ida Peak Water Level Comparison

Location	NOAA Gage No.	Atkins Peak (ft)	FEMA Peak (ft)	Difference (%)	Difference (inch)
Ship John Shoal	8537121	5.35	5.34	0.19%	0.12
Marcus Hook	8540433	5.12	5.11	0.20%	0.12
Philadelphia	8545240	5.76	5.74	0.35%	0.24
Reedy Point	8551910	4.89	4.88	0.20%	0.12
Brandywine Shoal	8555889	5.50	5.49	0.18%	0.12

Note: Peak water level elevations are referenced to the NAVD88 vertical datum.

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Purpose A Conclusions

- Our modeling platform produces similar results to the FEMA modeling platform

- Slight differences exist due to differences in compilers, changes in the ADCIRC code (they used version 49.60 whereas we are using 50.84), etc.

Refine and Update FEMA ADCIRC Mesh with Site Specific PSEG Topography Data

Desktop Recon

Review PSEG Topo Data

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Site Photos

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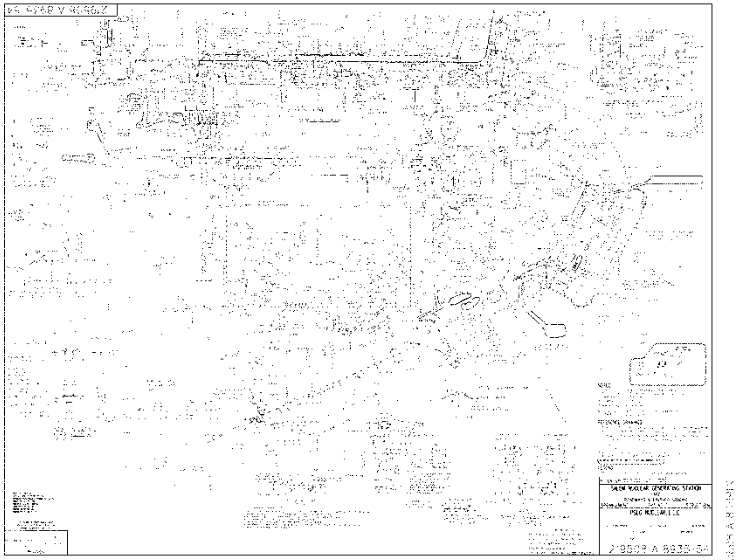
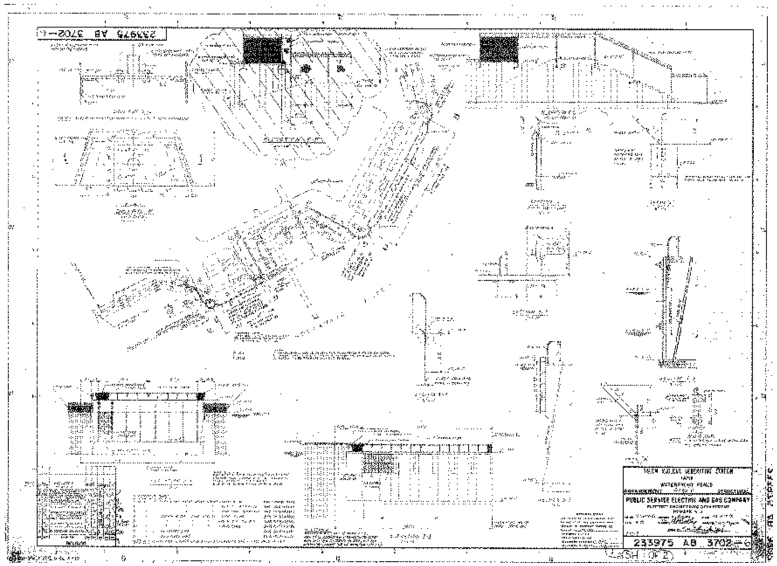
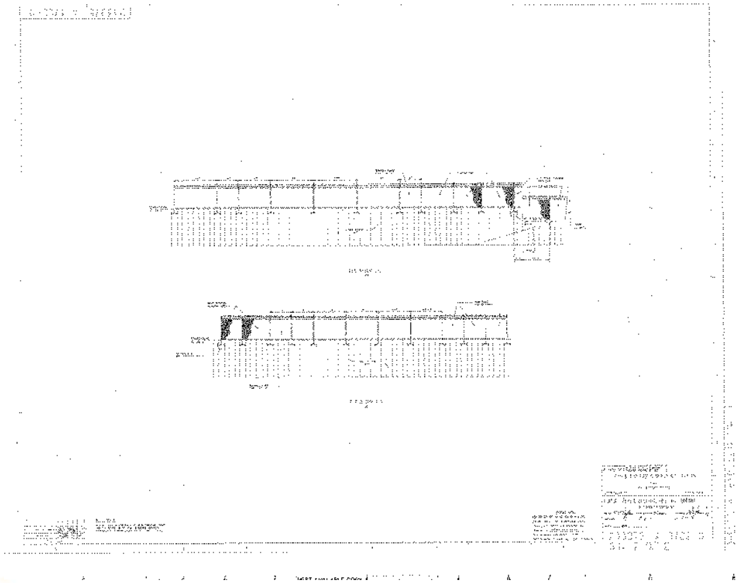
Site Photos

Additional Input







<u>Construction Drawings</u>

-Sea wall crest elevations

-Salem water intake topo

Updated PSEG ADCIRC Mesh

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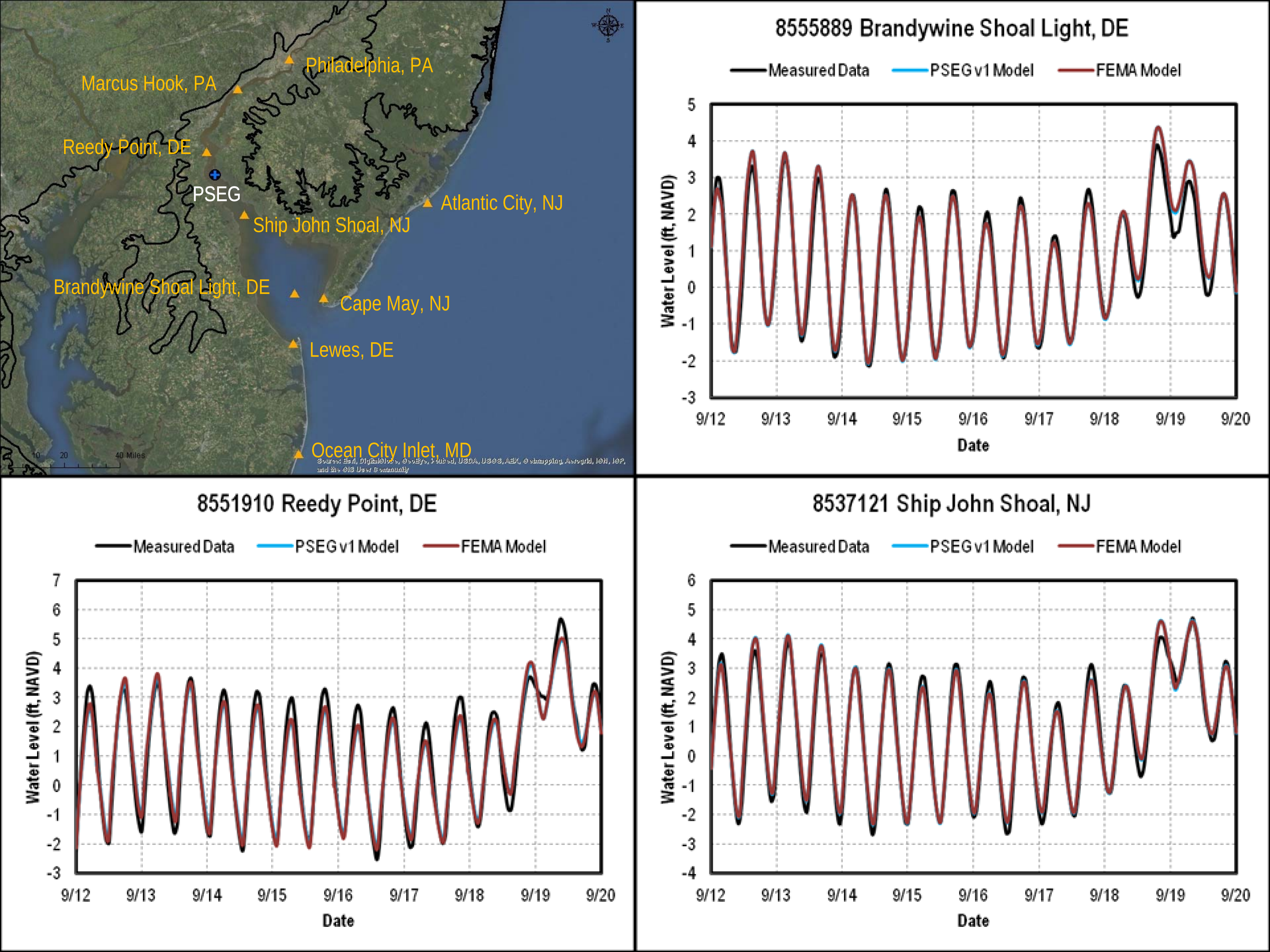
Validate Updated ADCIRC mesh with PSEG Site Specific Topography Included

Validation Event

Hurricane Isabel

September 12, 2003 – September 20, 2003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Water Level (ft, NAVD)
Date
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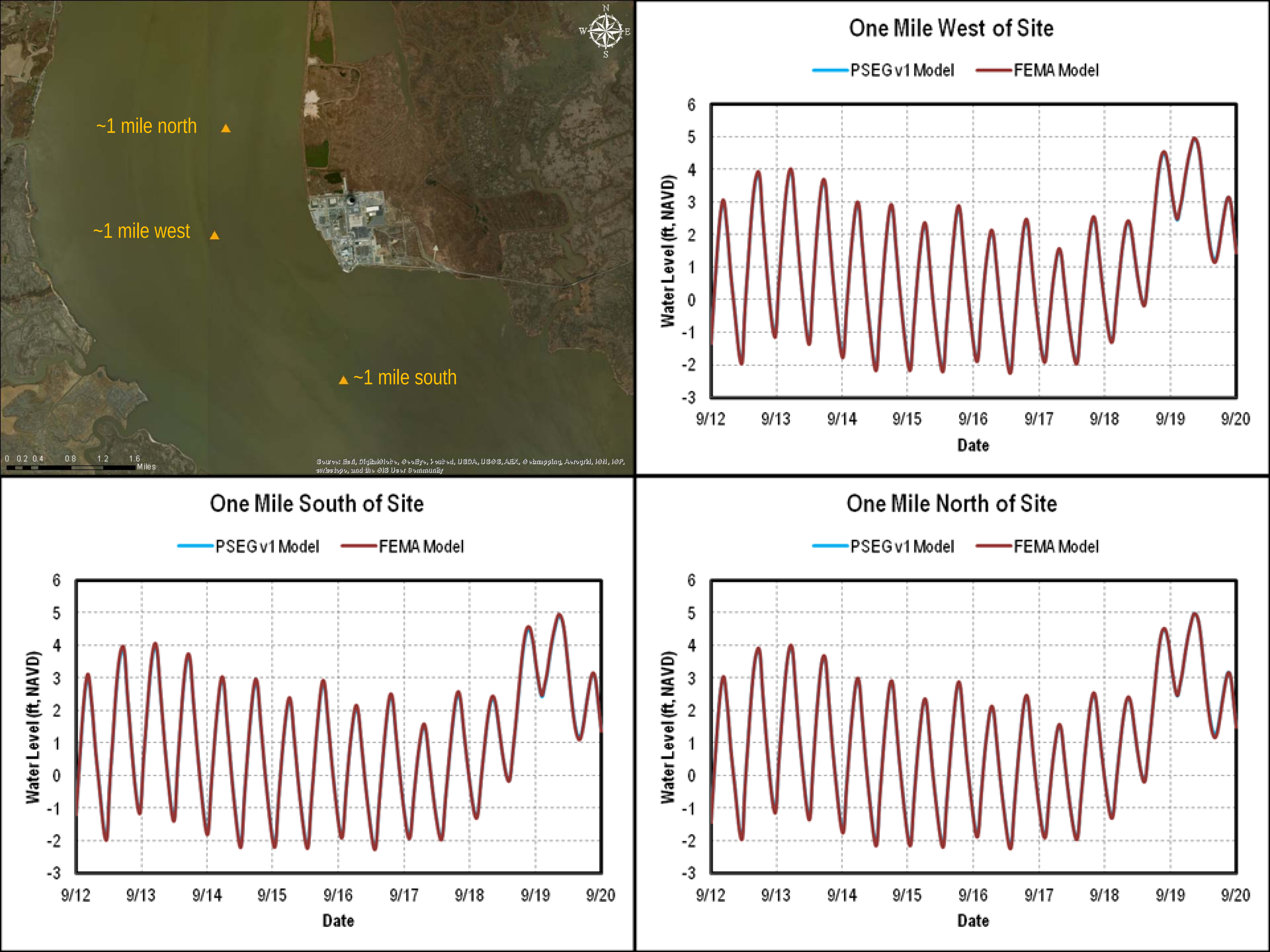
8537121 Ship John Shoal, NJ
Measured Data
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
Date
9/12 9/13 9/14 9/15 9/16 9/17 9/18 9/19 9/20



N
W
E
S
~1 mile north
~1 mile west
~1 mile south
0 0.2 0.4 0.8 1.2 1.6
Miles
One Mile West of Site
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
6
5
4
3
2
1
0
-1
-2
-3
9/12 9/13 9/14 9/15 9/16 9/17 9/18 9/19 9/20
Date
One Mile South of Site
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
6
5
4
3
2
1
0
-1
-2
-3
9/12 9/13 9/14 9/15 9/16 9/17 9/18 9/19 9/20
Date
One Mile North of Site
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
6
5
4
3
2
1
0
-1
-2
-3
9/12 9/13 9/14 9/15 9/16 9/17 9/18 9/19 9/20
Date

Hurricane Isabel Peak Water Level Comparison

Location	Post-Grid Modification Peak (ft)	Pre-Grid Modification Peak (ft)	Difference (%)	Difference (inch)
One Mile West	4.95	4.98	-0.59%	-0.35
One Mile South	4.92	4.96	-0.79%	-0.47
One Mile North	4.97	4.99	-0.46%	-0.28

Note: Peak water level elevations are referenced to the NAVD88 vertical datum.

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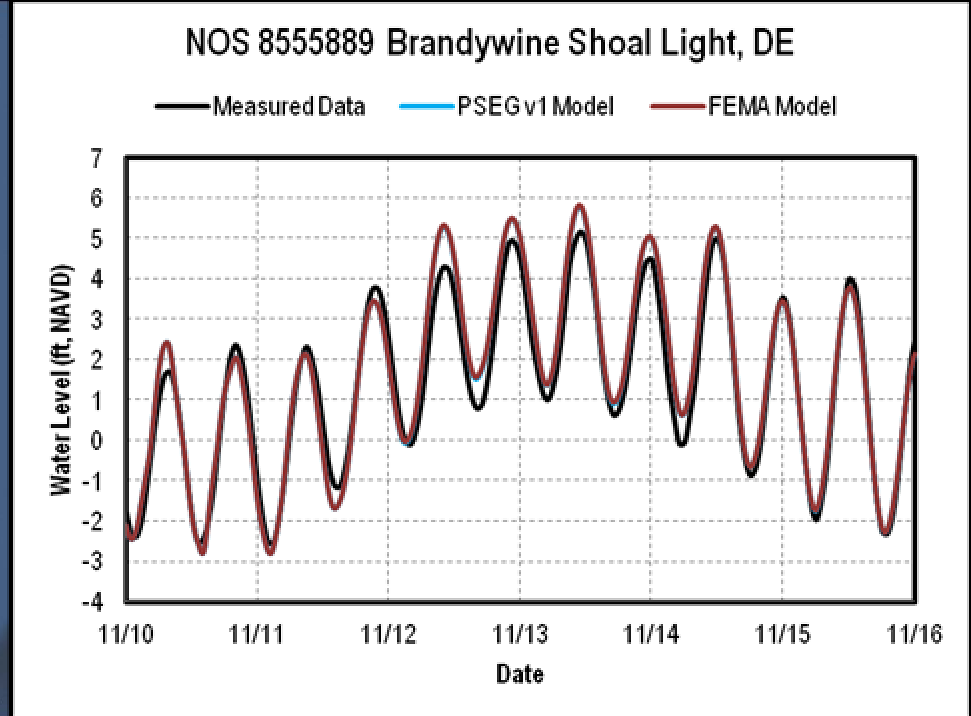
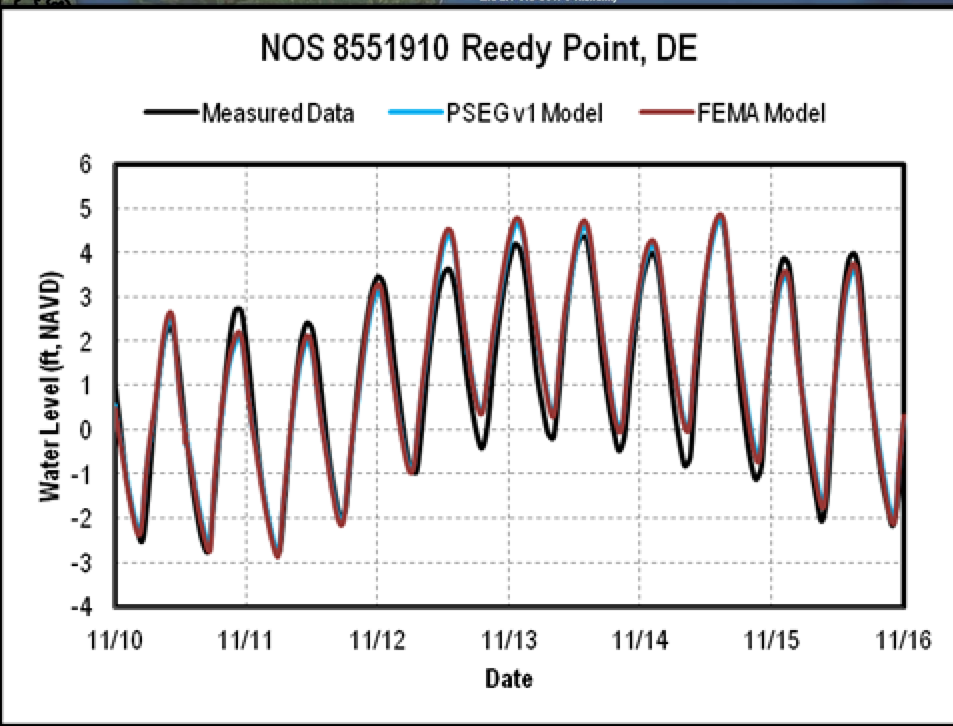
Validation Event

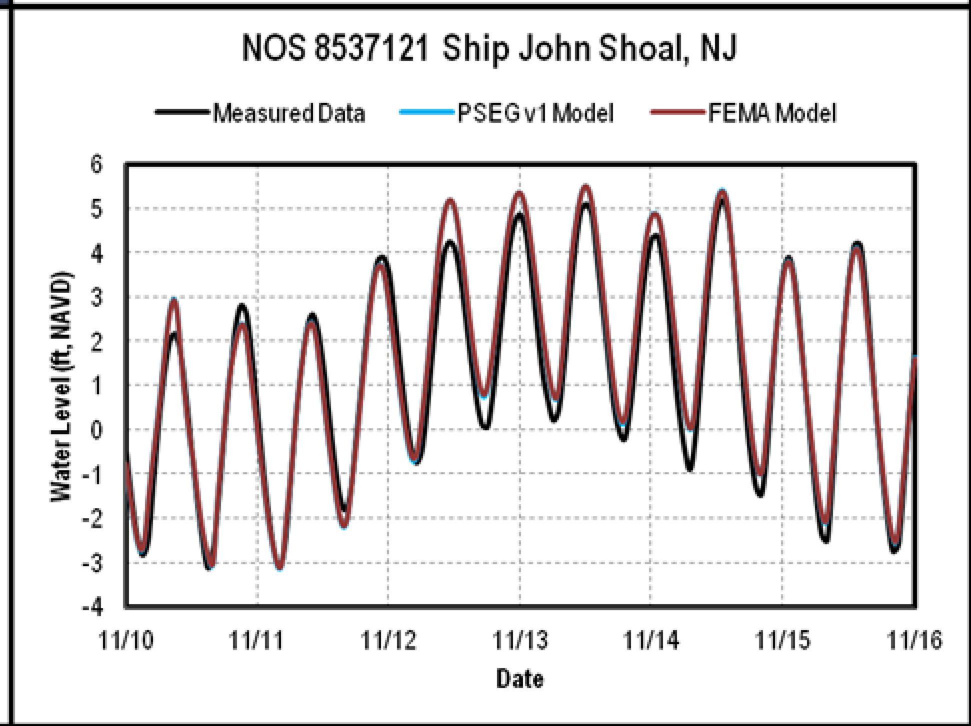
Nor’easter Ida

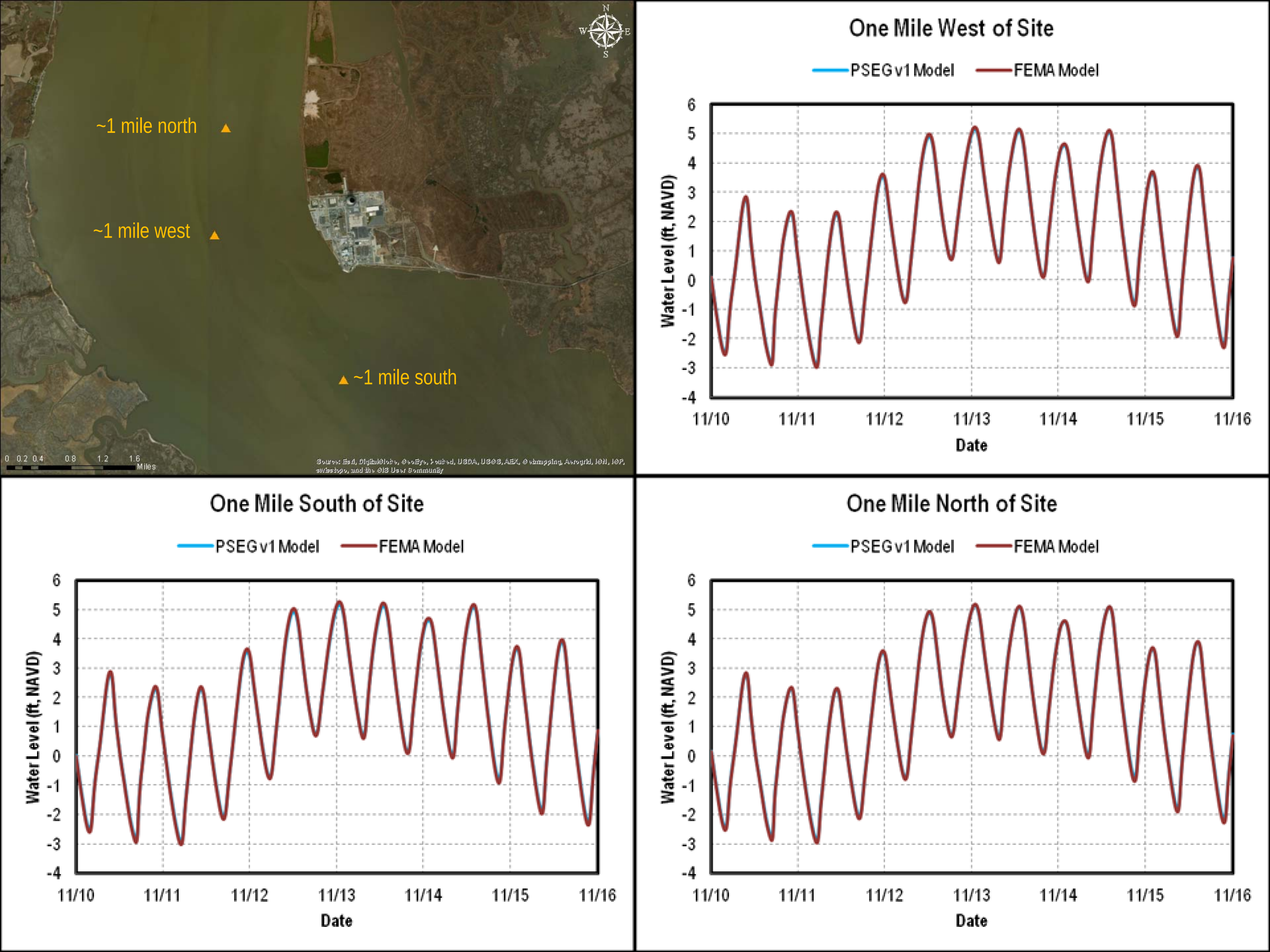
November 10, 2009 – November 16, 2009


Philadelphia, PA
Marcus Hook, PA
Reedy Point, DE
PSEG
Atlantic City, NJ
Ship John Shoal, NJ
Brandywine Shoal Light, DE
Cape May, NJ
Lewes, DE
Ocean City Inlet, MD
10
20
40 Miles


NOS 8555889 Brandywine Shoal Light, DE
Measured Data
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
7
6
5
4
3
2
1
0
-1
-2
-3
-4
11/10
11/11
11/12
11/13
11/14
11/15
11/16
Date


NOS 8551910 Reedy Point, DE
Measured Data
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
6
5
4
3
2
1
0
-1
-2
-3
-4
11/10
11/11
11/12
11/13
11/14
11/15
11/16
Date


NOS 8537121 Ship John Shoal, NJ
Measured Data
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
6
5
4
3
2
1
0
-1
-2
-3
-4
11/10
11/11
11/12
11/13
11/14
11/15
11/16
Date


~1 mile north
~1 mile west
~1 mile south
N
S
W
E
0 0.2 0.4 0.8 1.2 1.6
Miles
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
One Mile West of Site
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
6
5
4
3
2
1
0
-1
-2
-3
-4
11/10
11/11
11/12
11/13
11/14
11/15
11/16
Date
One Mile South of Site
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
Date
One Mile North of Site
PSEG v1 Model
FEMA Model
Water Level (ft, NAVD)
Date

Nor'easter Ida Peak Water Level Comparison

Location	Post-Grid Modification Peak (ft)	Pre-Grid Modification Peak (ft)	Difference (%)	Difference (inch)
One Mile West	5.18	5.25	-1.31%	-0.83
One Mile South	5.20	5.28	-1.49%	-0.95
One Mile North	5.15	5.20	-0.95%	-0.59

Note: Peak water level elevations are referenced to the NAVD88 vertical datum.

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Purpose B Conclusions

- Refined PSEG ADCIRC mesh produces results that are similar to FEMA’s results in Delaware Bay
- Model is ready for the JPM process
  - Currently in progress
  - Preliminary simulations are underway

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Summary of RAI 67 Response Approach

- Use of JPM Approach – presented today
- Develop ADCIRC w/SWAN model that captures the nuances of the bathymetry and topography – presented today
- Refine PMSS parameters and develop synthetic storm set to determine the PMSS water level - Future
- Calculate Wave Run-up for PSEG Site - Future

RAI 67 Response Schedule

NRC Public Meeting	7/1/2013	Today
NRC Public Meeting	9/24/2013	On Schedule
Submit Revised SSAR Subsection 2.4.5	10/31/2013	On Schedule

Discussion and Questions

- Thank You

- Open for discussion and questions

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