# Coastal Storm Vulnerability
# Grindle Point and The Narrrows


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RANSOM
Consulting
Engineers
and Scientists

Maine Coastal Program

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

# Outline

- Coastal Flood Hazard Analysis Overview
- What is the NACCS
    - Limited direct use
- Penobscot Bay Model
    - Validation
- Probalistic Sea Level Rise
- Current Coastal Storm Hazard
- Future Hazard
- Risk Analysis

# Coastal Flood Hazards

- Tides, Storm Surge, Waves
  - Extra-tropical events (e.g. Northeaster, Southwester)
  - Tropical events (e.g. Hurricanes)
- Analyze Historic Records (models where there are no gauges)
- Joint Probability Analysis (Possible events, simulate synthetic storms)
- Combined approach

- Sea Level Rise
  - Scenario Based Approach
  - Probalistic Approach

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# What is the Hazard?

Rising water at a range of time scales

Hours **Storm Surge:**
A increase sea level, above the normal tide, caused by wind stress and changes in barometric pressure during a storm event. AKA “Wind Setup”.

Seconds **Storm Waves:**
Highly energetic fluctuations in the water surface caused by local winds (seas) and/or generated from distant winds (swell).

Decades **Relative Sea Level Rise:**
Gradual increase in the mean water level due to increased volume of ocean water, subsidence, changing large scale ocean currents.

# Storm Surge

14 MAINE COASTAL STORM AND FLOOD OF FEBRUARY 2, 1976

FIGURE 8.—Floodwaters at highest point, Kenduskeag Plaza, Bangor, Maine. This photograph (Bangor Daily News, 1976) shows the depth and area of the downtown flood. The normal channel of the Kenduskeag is between the two light posts on the left, and footbridge guardrails are shown inundated near the center of the photograph. The normal flow is from right to left. Photograph courtesy of Bangor Daily News.

"The flood in Bangor was due to a combination of strong, prolonged, south-southeasterly winds and high astronomical tides. Storm rainfall, ice jams, and streamflow were not major factors causing the flood."

" Water surface elevation in downtown Bangor reached 17.46 feet (5.32 m) (NGVD), approximately 10.5 feet (3.2 m) above predicted astronomical tide."

Morrill et al. 1979. *Maine Coastal Storm and Flood on February 2, 1976*, Geological Survey Professional Paper 1087, Joint report by the U.S. Geological Survey and the National Oceanic and Atmospheric Administration.

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# Storm Waves

"Waves caused by high winds can be more of a factor in flooding and damage than the combination of surge and tide. Flooding from wave action can take many forms.  The storm surge may not reach the height of a seawall, but waves may overtop it.  Water passing over (overwash) a barrier can damage structures behind it."

- Gadoury, R.A. 1979.  *Coastal Flood of February 7, 1978 in Maine Massachusetts, and New Hampsihre.*  Water-Resources Investigations Report 79-61, U.S. Geological Survey.

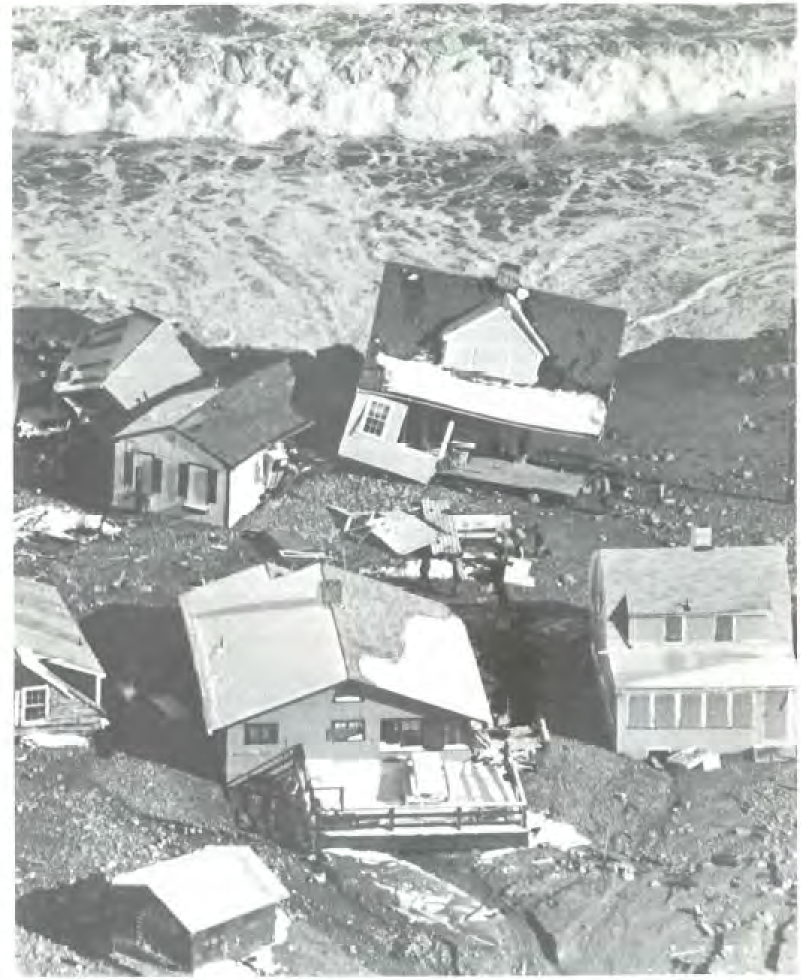

Figure 1.--Waves reduced these houses along the Scituate-Marshfield, Mass., shoreline to tangled wreckage (photograph by Kevin Cole, Boston Herald American)

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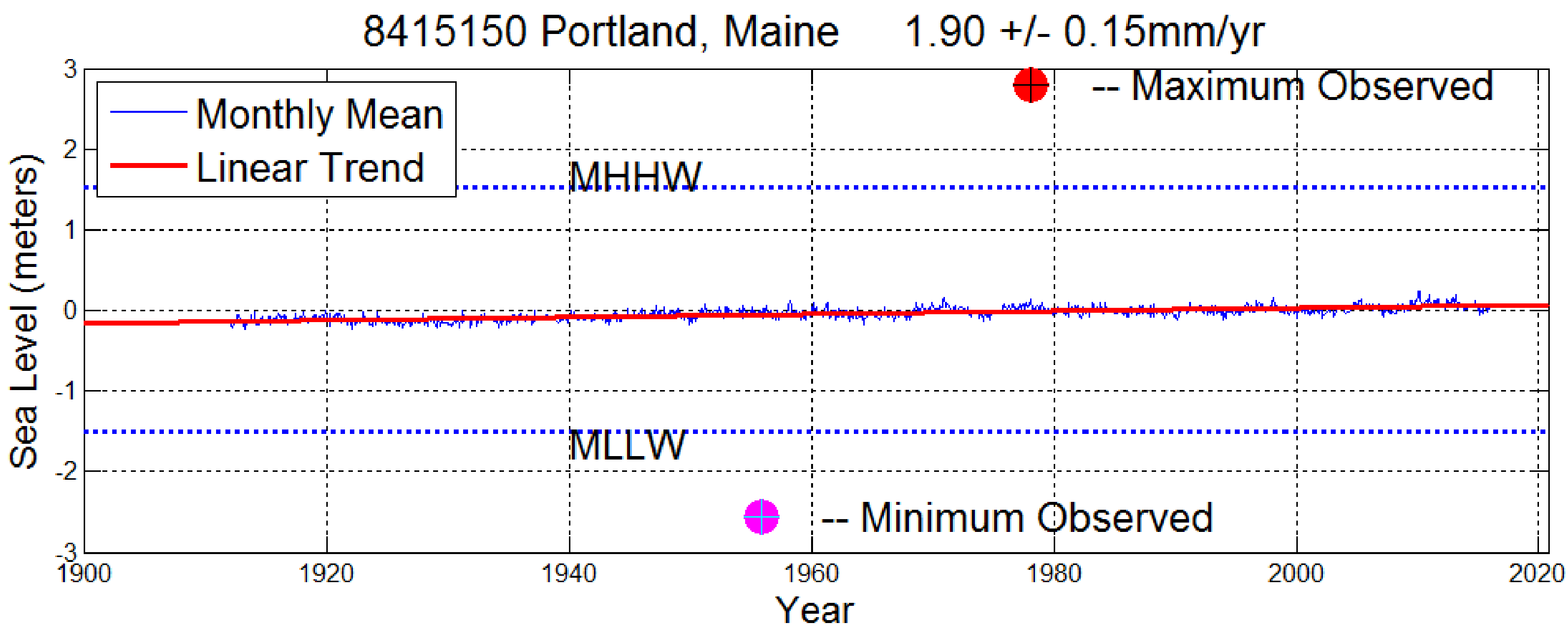
# Sea Level Rise

A gradual increase in the mean water level due to increased volume of ocean water, subsidence, changing large scale ocean currents, etc.




The magnitude of sea level change over the past century has been very small compared to sea level change experienced on a twice daily basis in Maine.

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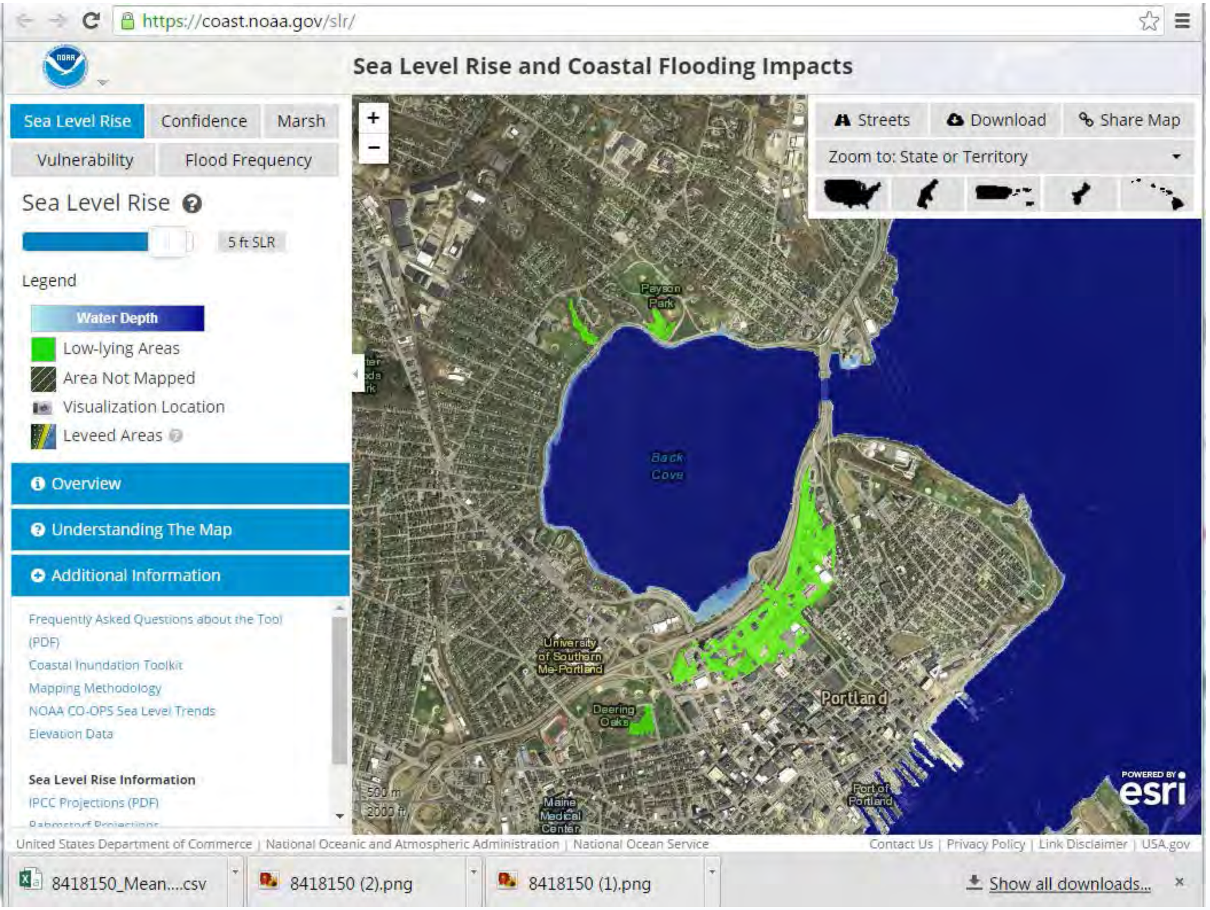
# Sea Level Rise

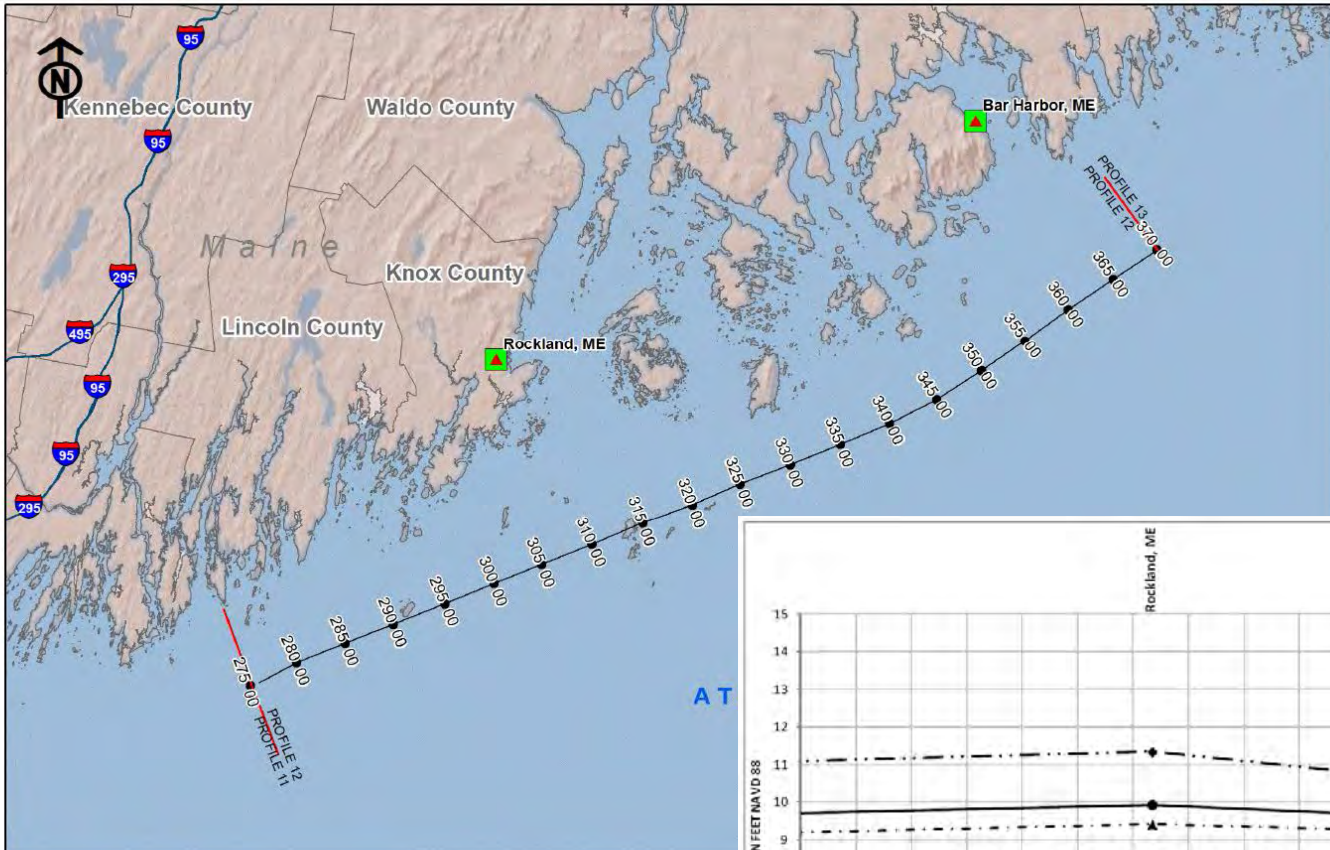



Sea Level rise impacts will almost certainly manifest through discrete extreme events, rather than a gradual “flat” increase in the mean high water.

Although interesting, tools such as this have limited utility since they cannot take into account the highly dynamic nature of actual coastal flooding.

The flooding they portrait is an unlikely future reality.

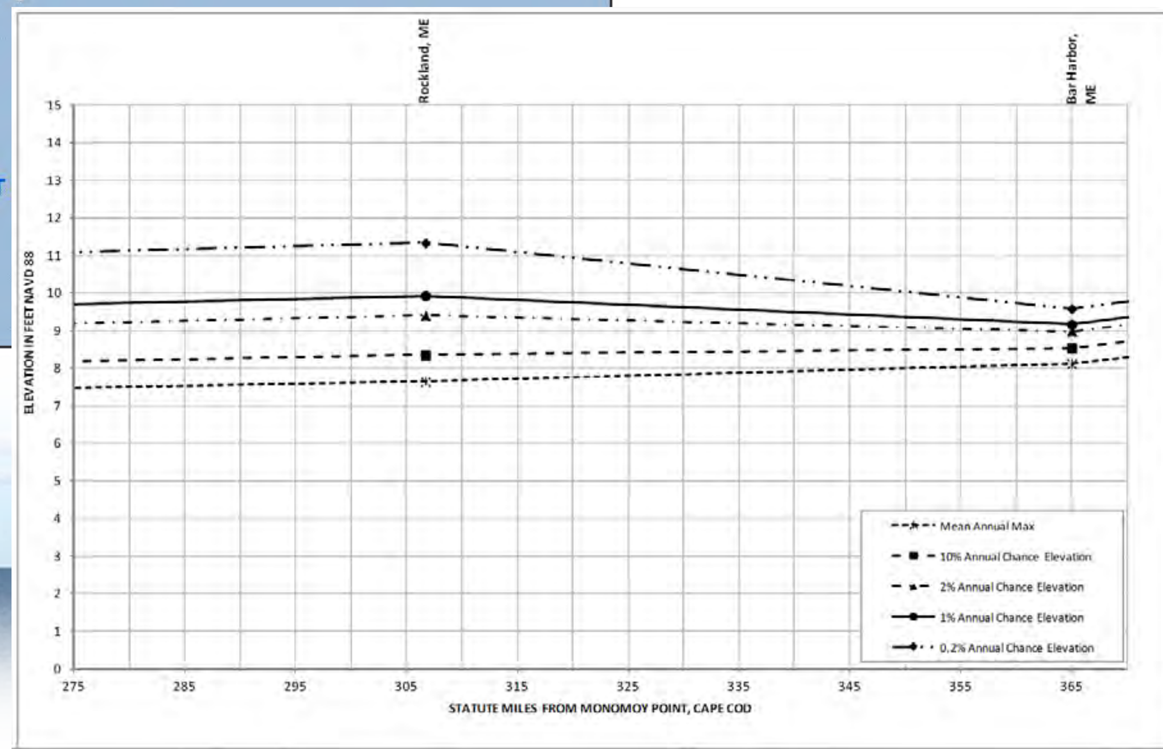
# Storm Surge – Gauge Data Analysis




L-Moment Analysis

Annual Maximum Series

Wakeby Distribution




Strategic Alliance for Risk Reduction. (2012). *Updated Tidal Profiles for the New England Coastline*

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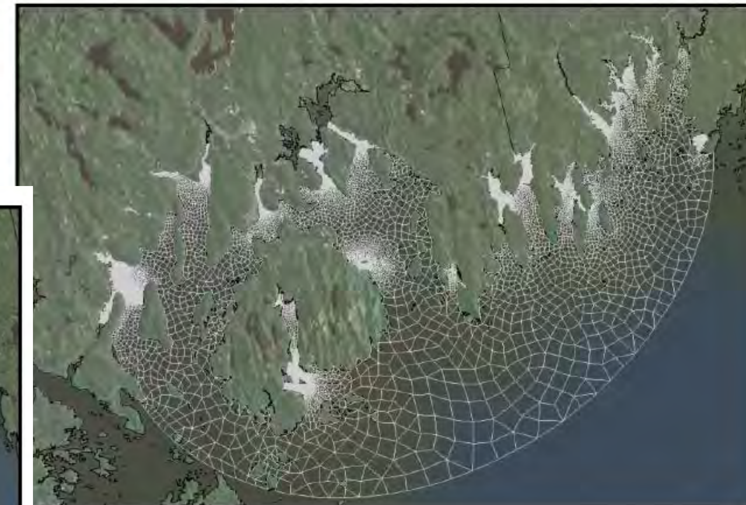
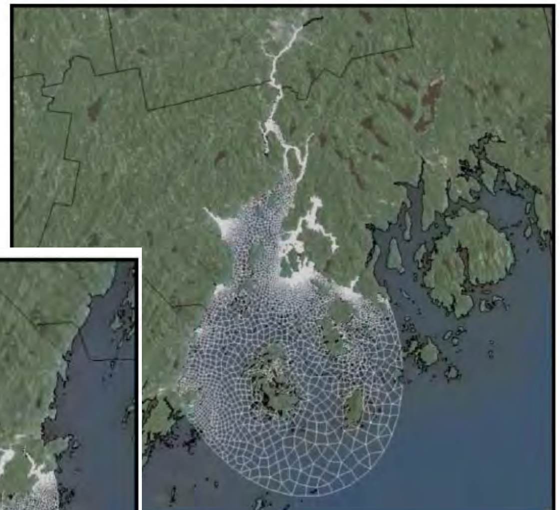
# Storm Surge – Single Event Numerical Modeling

FEMA used the RMA2 model to simulate a single "100-year" storm, recognizing that the gage analysis

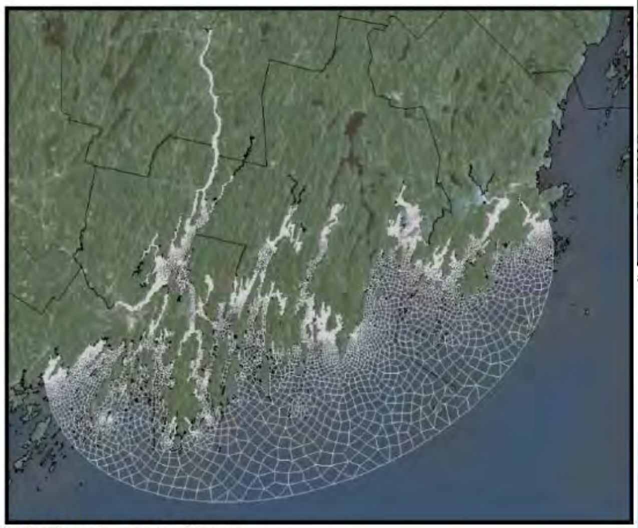
Does not necessarily give accurate results complex Maine coastline



re 3-4 : RMA2 Eastern Model Domain



ay Model Domain



igure 3-2 : RMA2 Western Model Domain

Strategic Alliance for Risk Reduction. (undated). Coastal Hydraulics and Hydrology.

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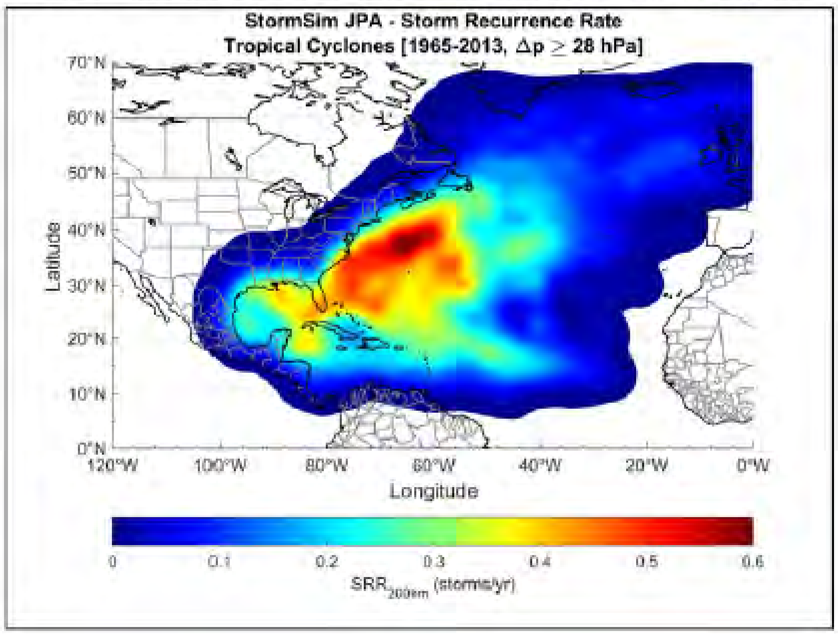
# Storm Surge – Probabilistic Modeling
# Joint Probability Methods (JPM)

- Simulate hundreds to thousands of storms that **could** occur as well as many that have.
- Based on Joint probability of storm size, intensity, speed, approach angle, landfall location.

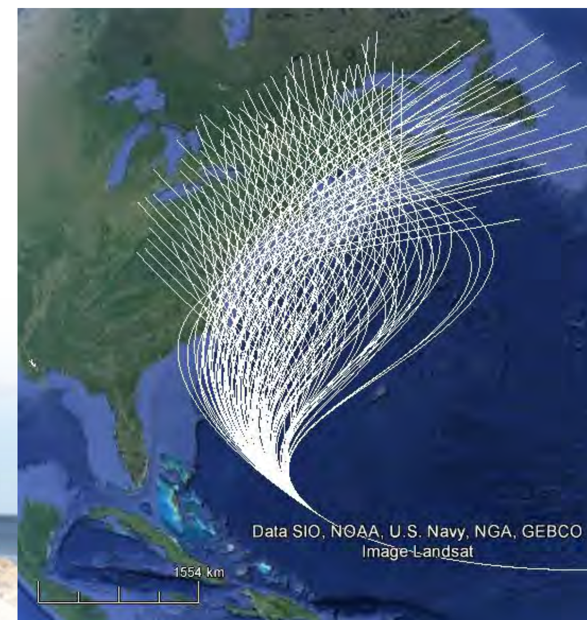
Figure 3-7. $SRR_{200km}$ of TCs in the North Atlantic basin for the 1965–2013 period.




Nadal-Caraballo et al. 2015. *Coastal Storm Hazards from Virginia to Maine*, ERDC/CHL TR-15-5

e.g. North Atlantic Coast Comprehensive Study (NACCS).

Simulate Sea Level Rise cases to assess one aspect of climate change

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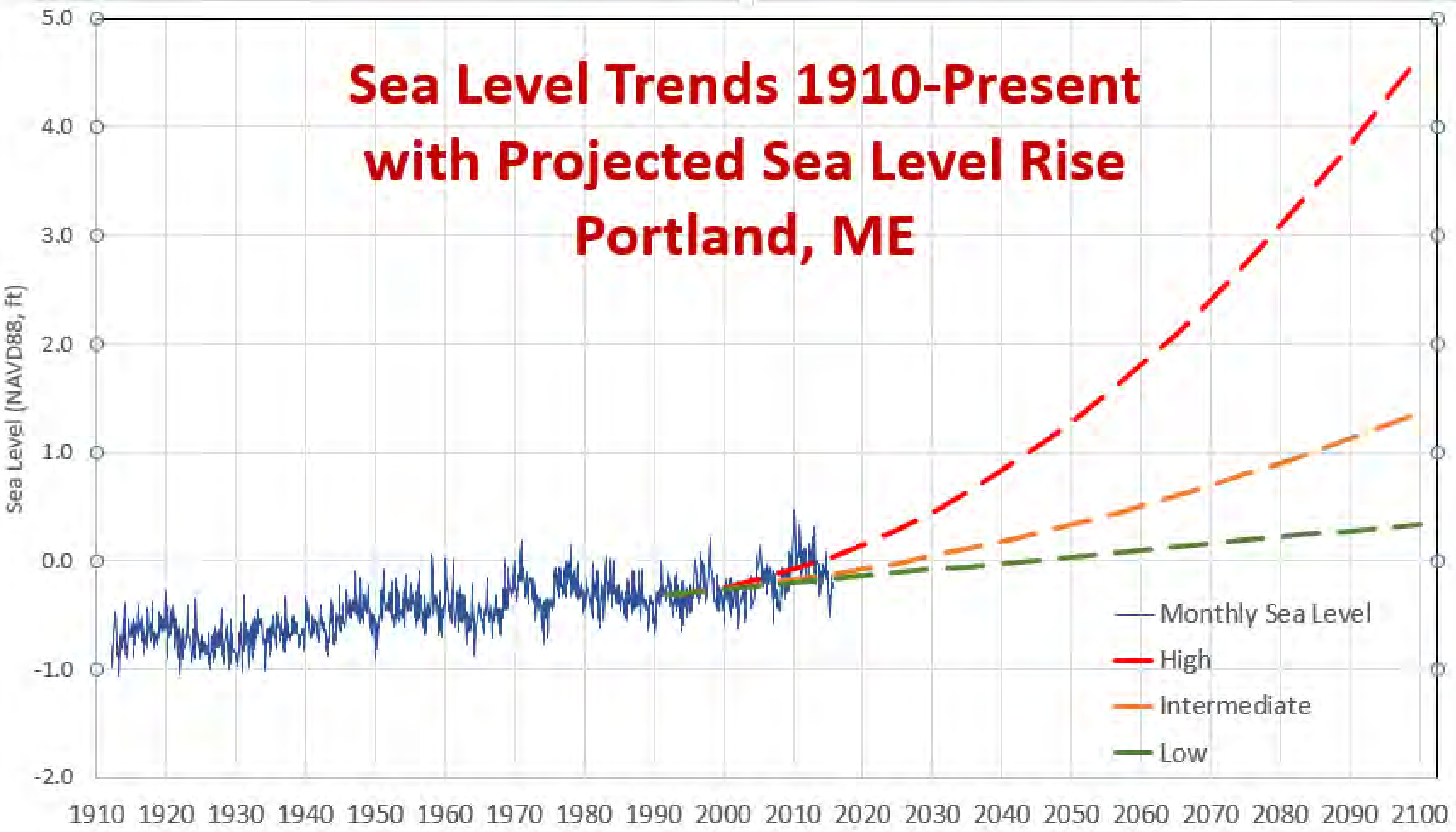
# Processes – Sea Level Rise

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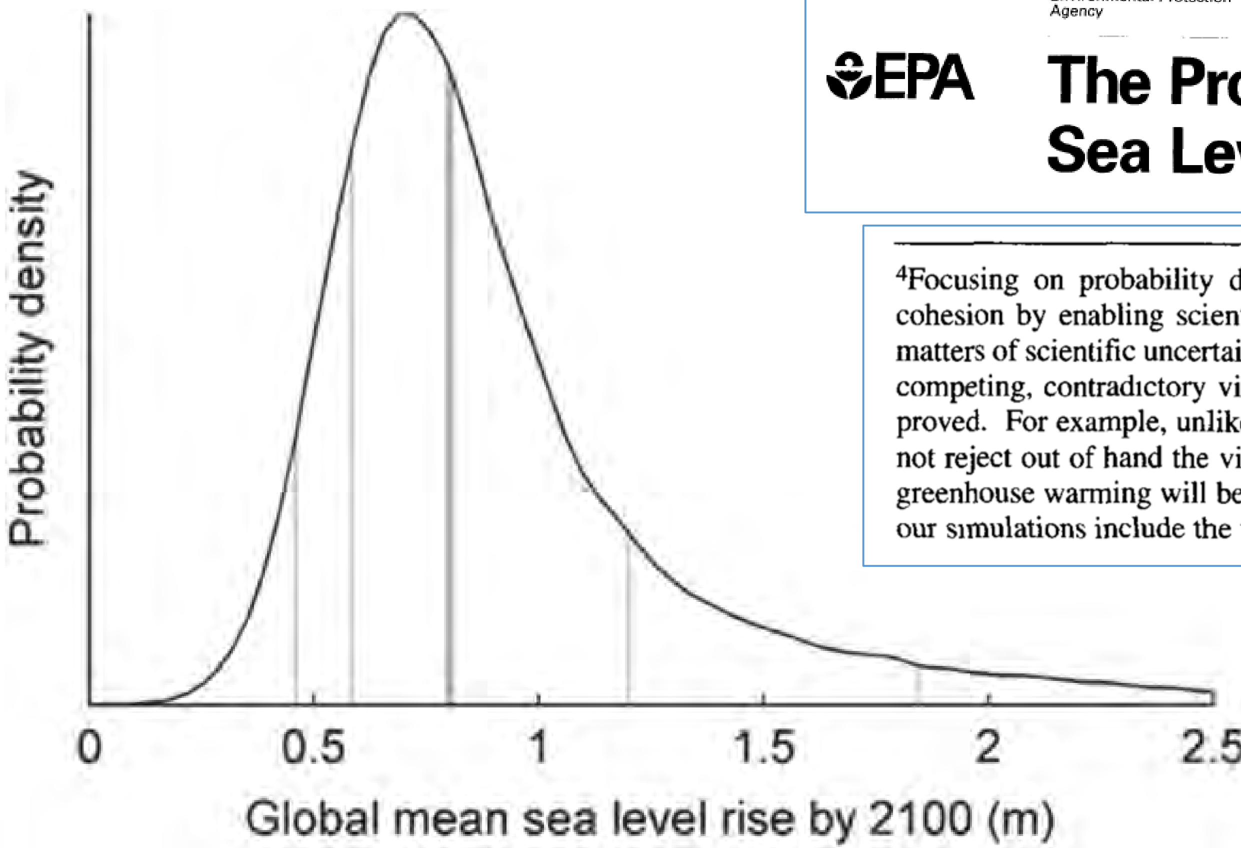
# Processes – Sea Level Rise Probabilistic Guidance: e.g.




United States Environmental Protection Agency

Office of Policy, Planning, and Evaluation (2122)

EPA 230-R-95-008
October 1995

EPA

**The Probability of Sea Level Rise**

[4]Focusing on probability distributions may also foster scientific cohesion by enabling scientific panels to avoid choosing sides in matters of scientific uncertainty, and instead lend partial credence to competing, contradictory viewpoints, until one or the other is disproved. For example, unlike previous EPA reports, this study does not reject out of hand the view of some "greenhouse skeptics" that greenhouse warming will be negligible. As discussed in Chapter 3, our simulations include the views of a representative skeptic.

Figure from Grinsted, Aslak, S. Jevrejeva, R. E. M. Riva, and D. Dahl Jensen. *Sea level rise projections for northern Europe under RCP8.5*. Climate Research. Vol 64: 15-23. June 17, 2015.

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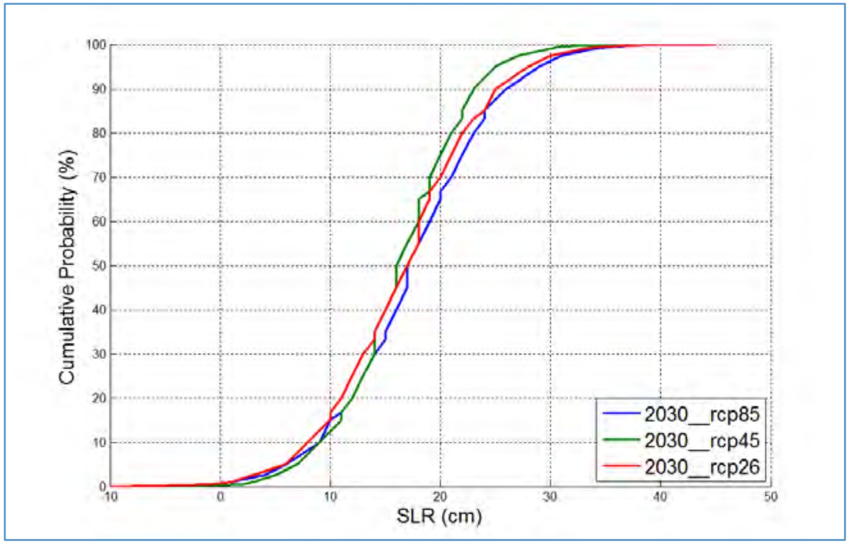
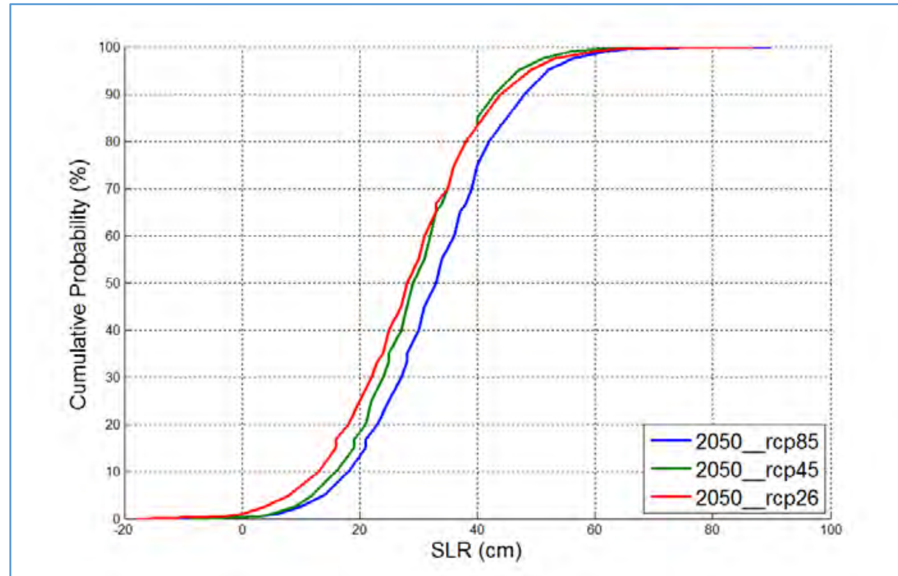
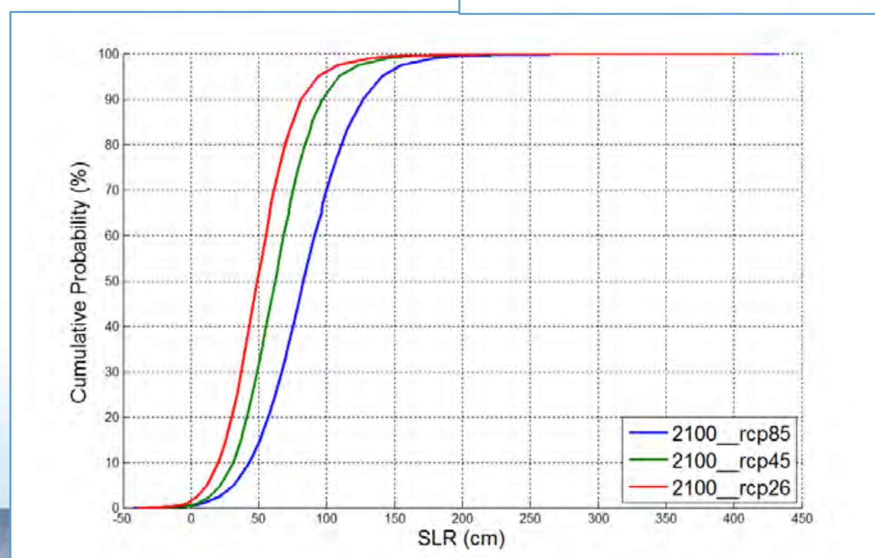
# Localized, State-of-the-Science, Probabilistic Guidance:




Data From:

Kopp, R. E., R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, and C. Tebaldi (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites, *Earth's Future*, *2*, 383–406, doi:10.1002/2014EF000239.

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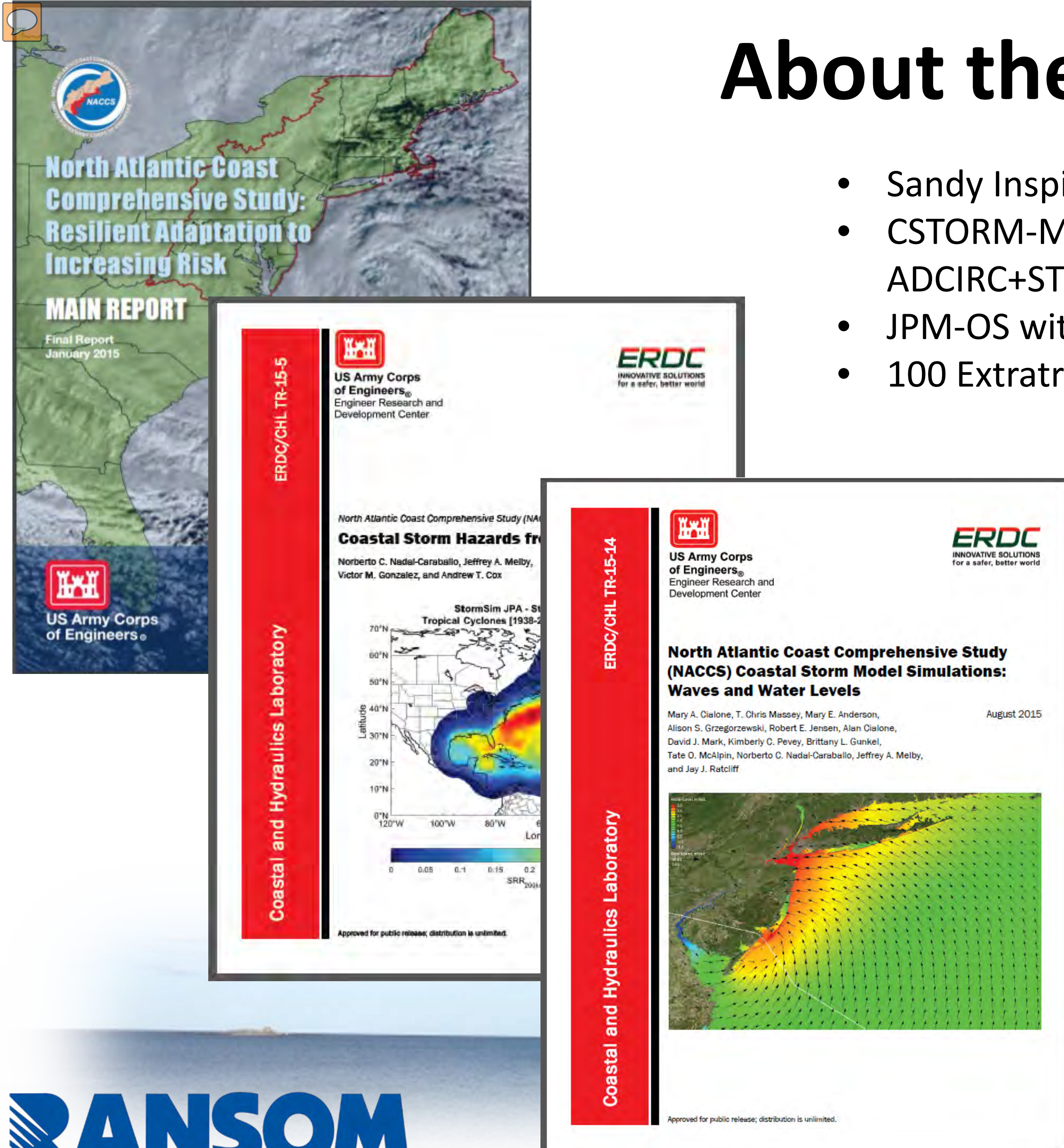
# About the NACCS

- Sandy Inspired
- CSTORM-MS (PBL - WAM - ADCIRC+STWAVE)
- JPM-OS with 1050 Tropical Cyclones
- 100 Extratropical Cyclones




"This study did not include engineering calculations, such as wave runup, nearshore morphology change, sediment transport, probabilistic analysis of riverine stage, or overland flooding." -TR15-14

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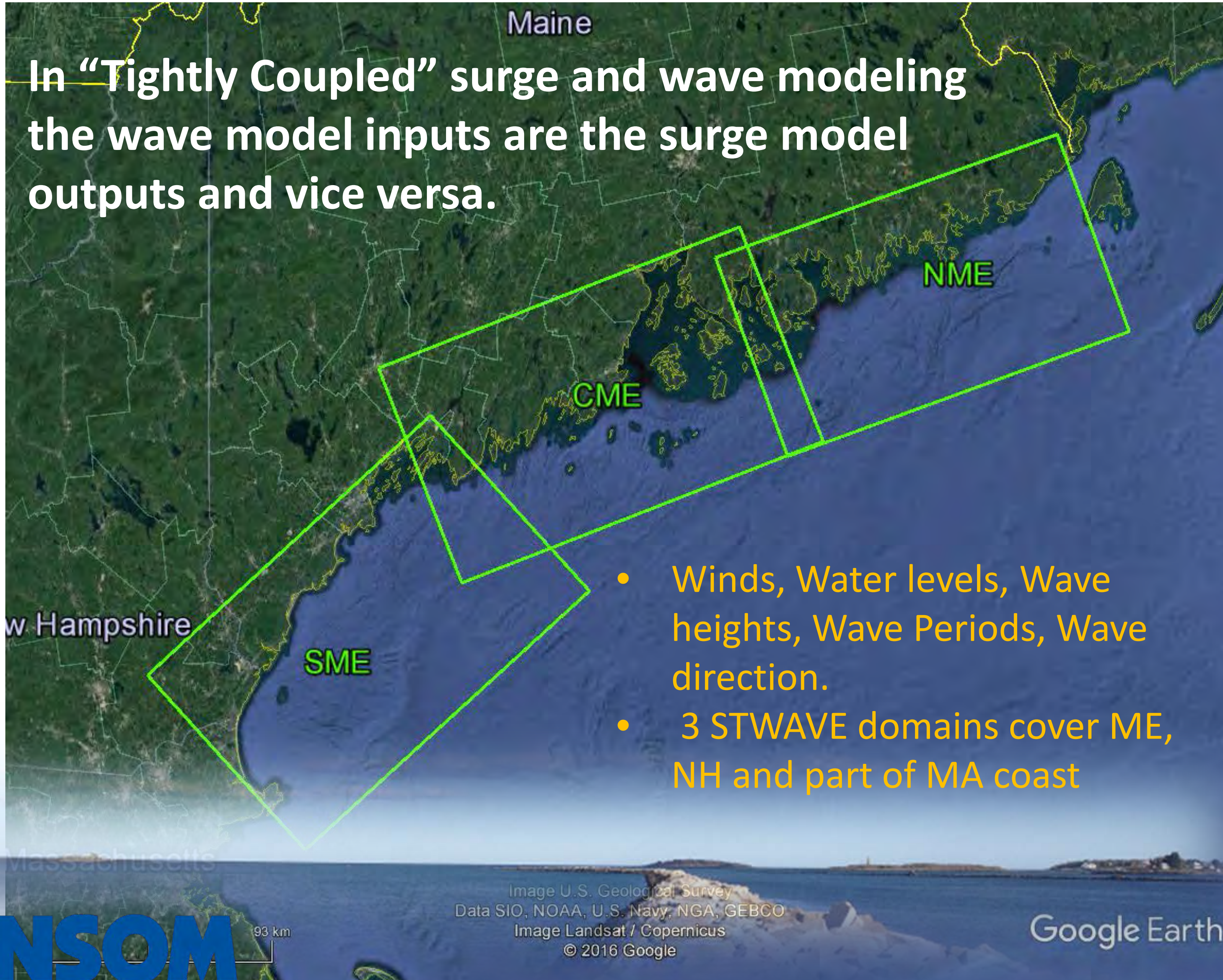
# NACCS – STWAVE Files

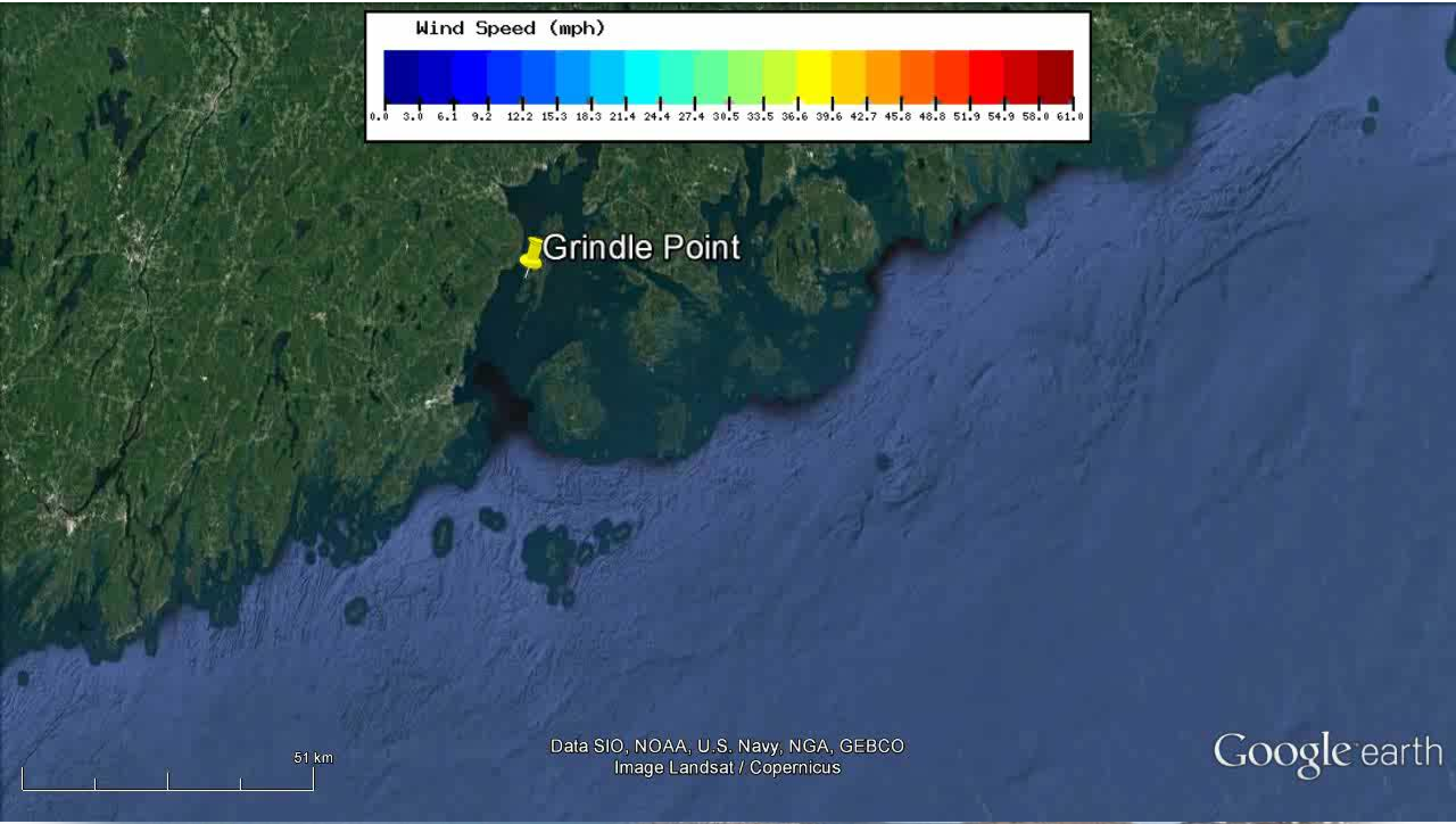
In “Tightly Coupled” surge and wave modeling the wave model inputs are the surge model outputs and vice versa.




- Winds, Water levels, Wave heights, Wave Periods, Wave direction.
- 3 STWAVE domains cover ME, NH and part of MA coast

# NACCS Central Maine – Wind

## 1976 Groundhog day storm

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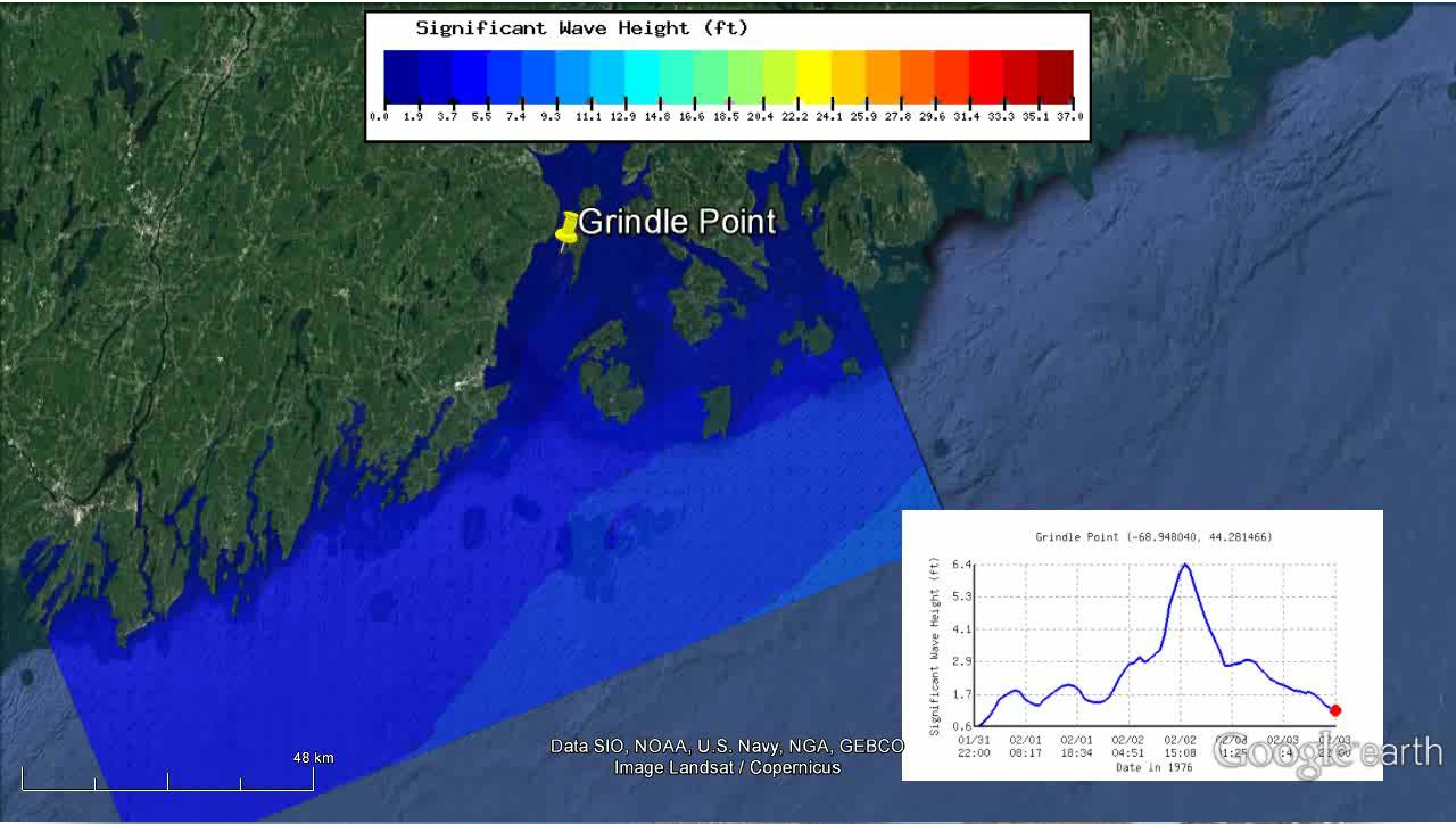
# NACCS Central Maine - Waves

## 1976 Groundhog day storm

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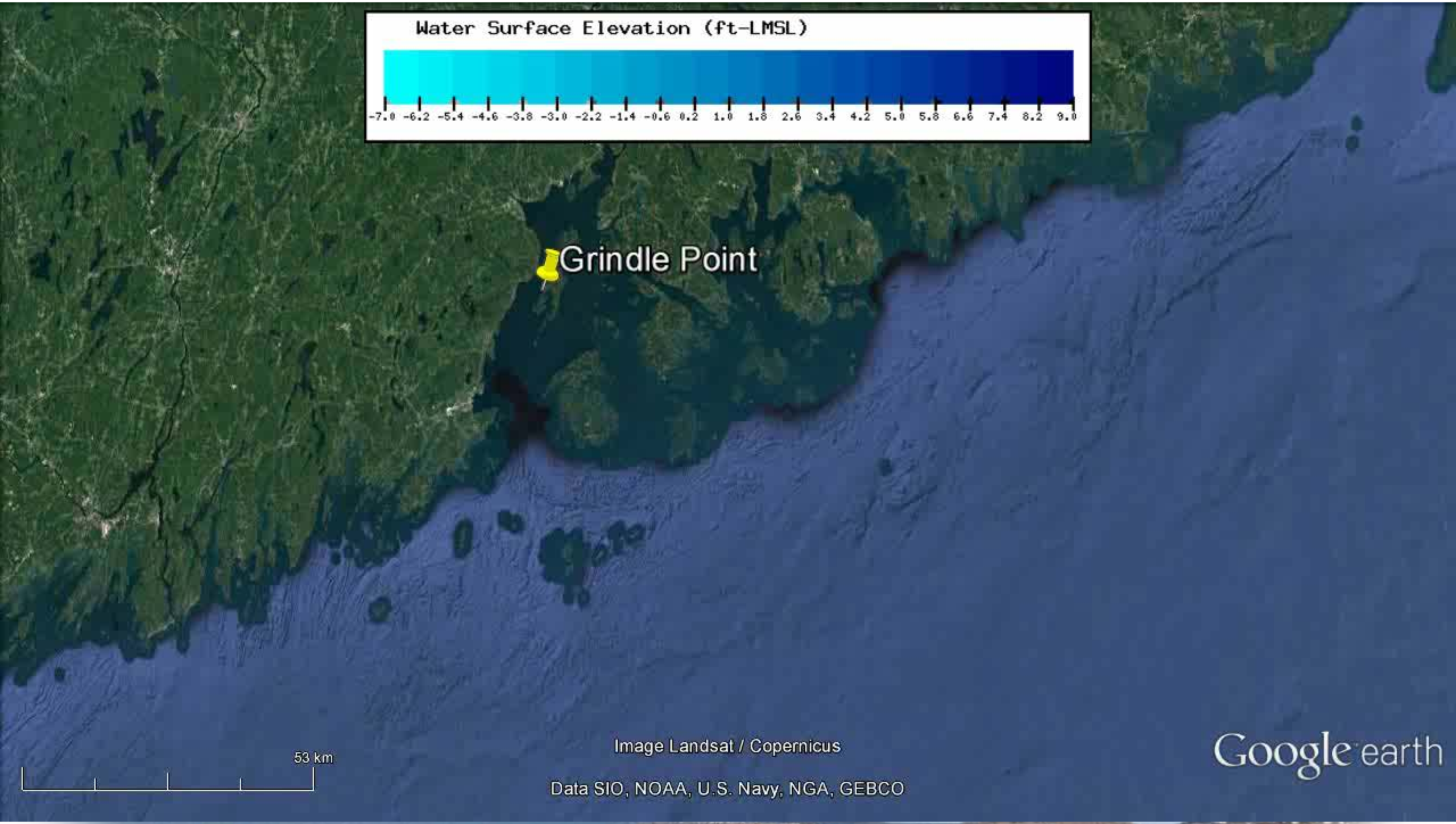
# NACCS Central Maine – Water Level

## 1976 Groundhog day storm

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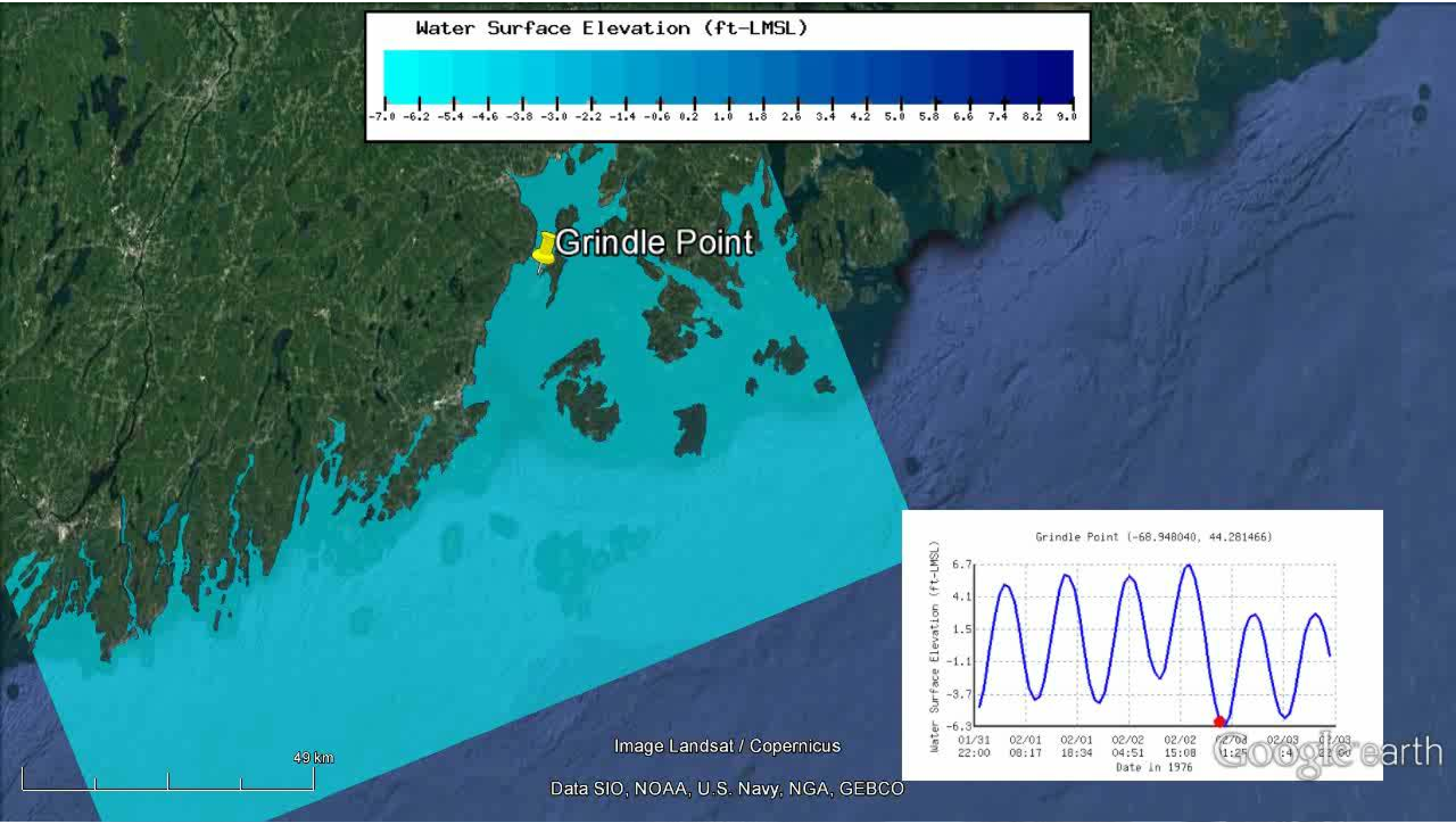
# NACCS Central Maine – Water Level close-up

## 1976 Groundhog day storm

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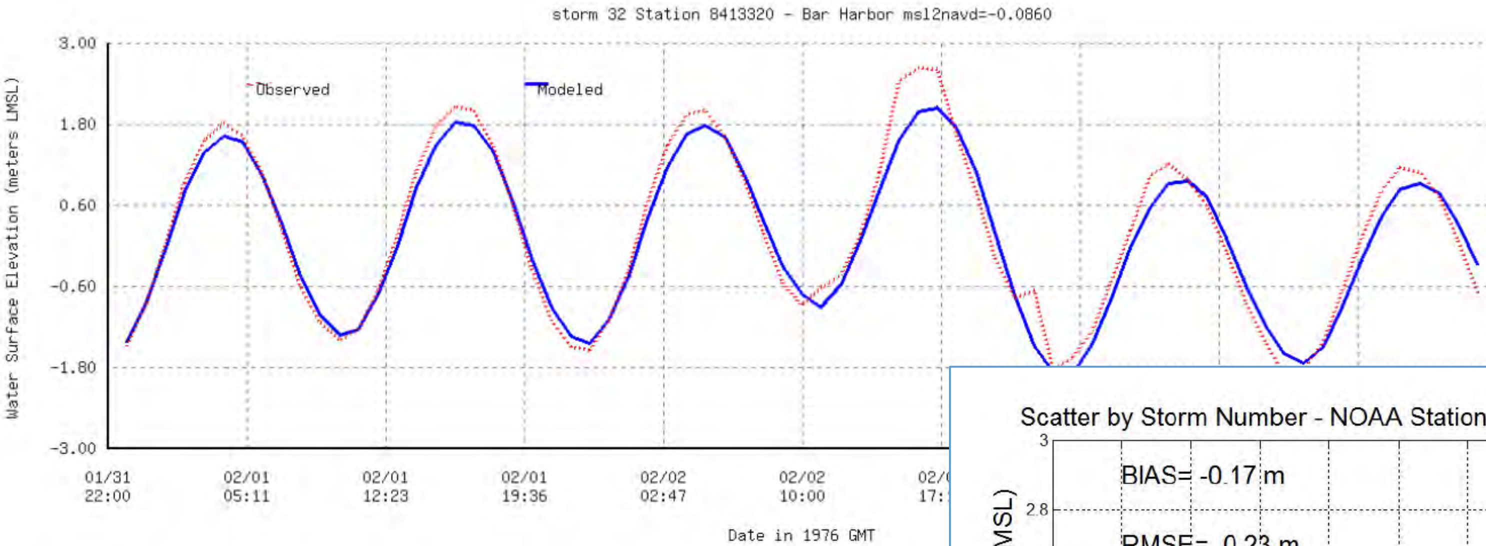
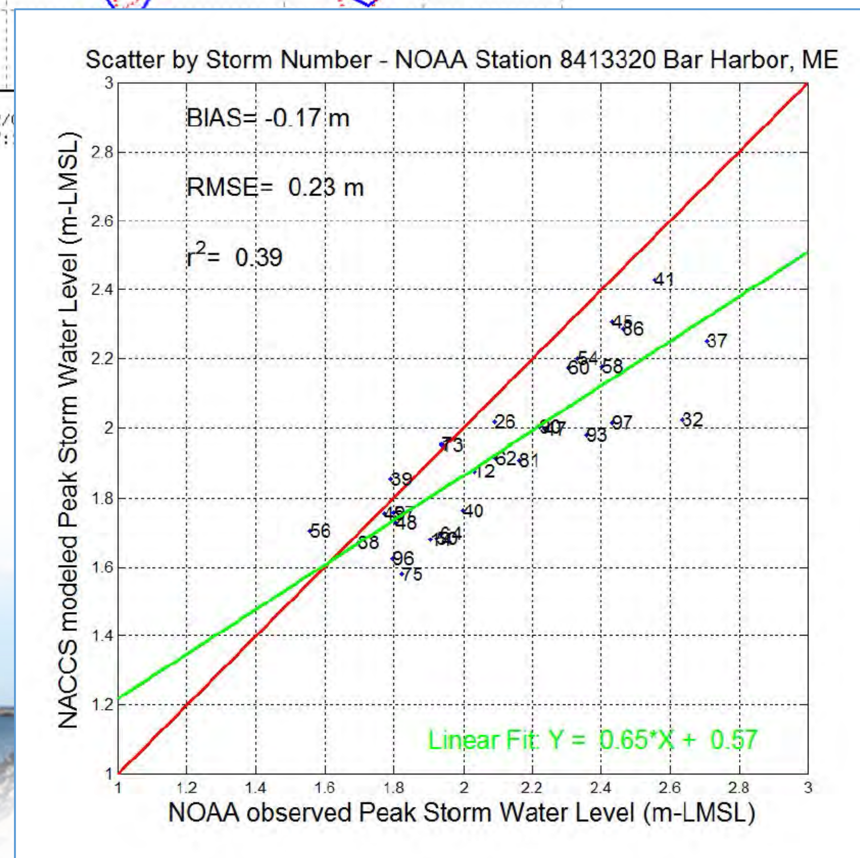
# NACCS Model – Local Validation

## Historic Extra-tropical storms at Bar Harbor

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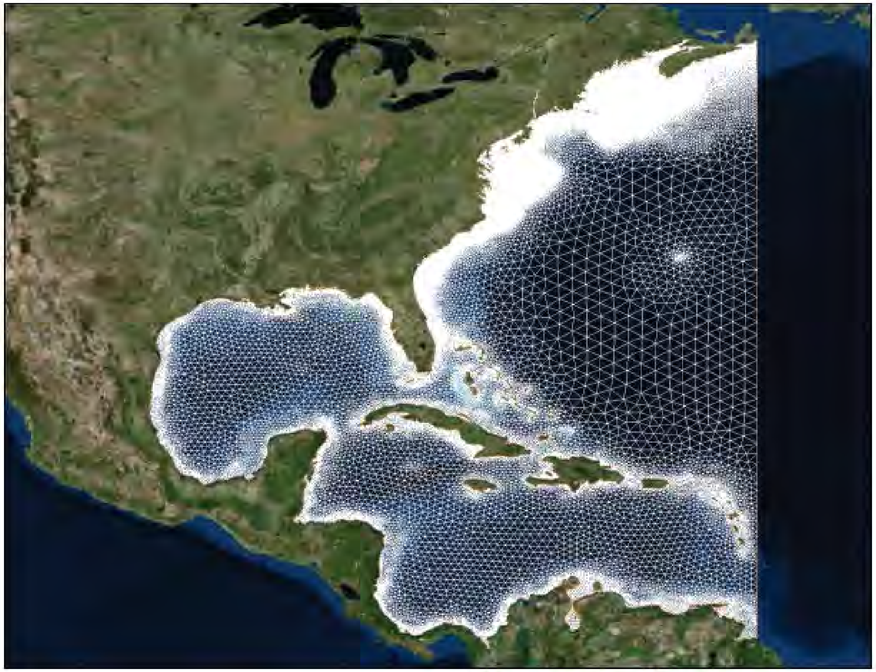
# NACCS Model Grid

Figure 6-2. ADCIRC mesh for NACCS.



FEMA Region 2
FEMA Region 3
NOAA New England
Vdatum + overland areas
to ~ Cape Ann

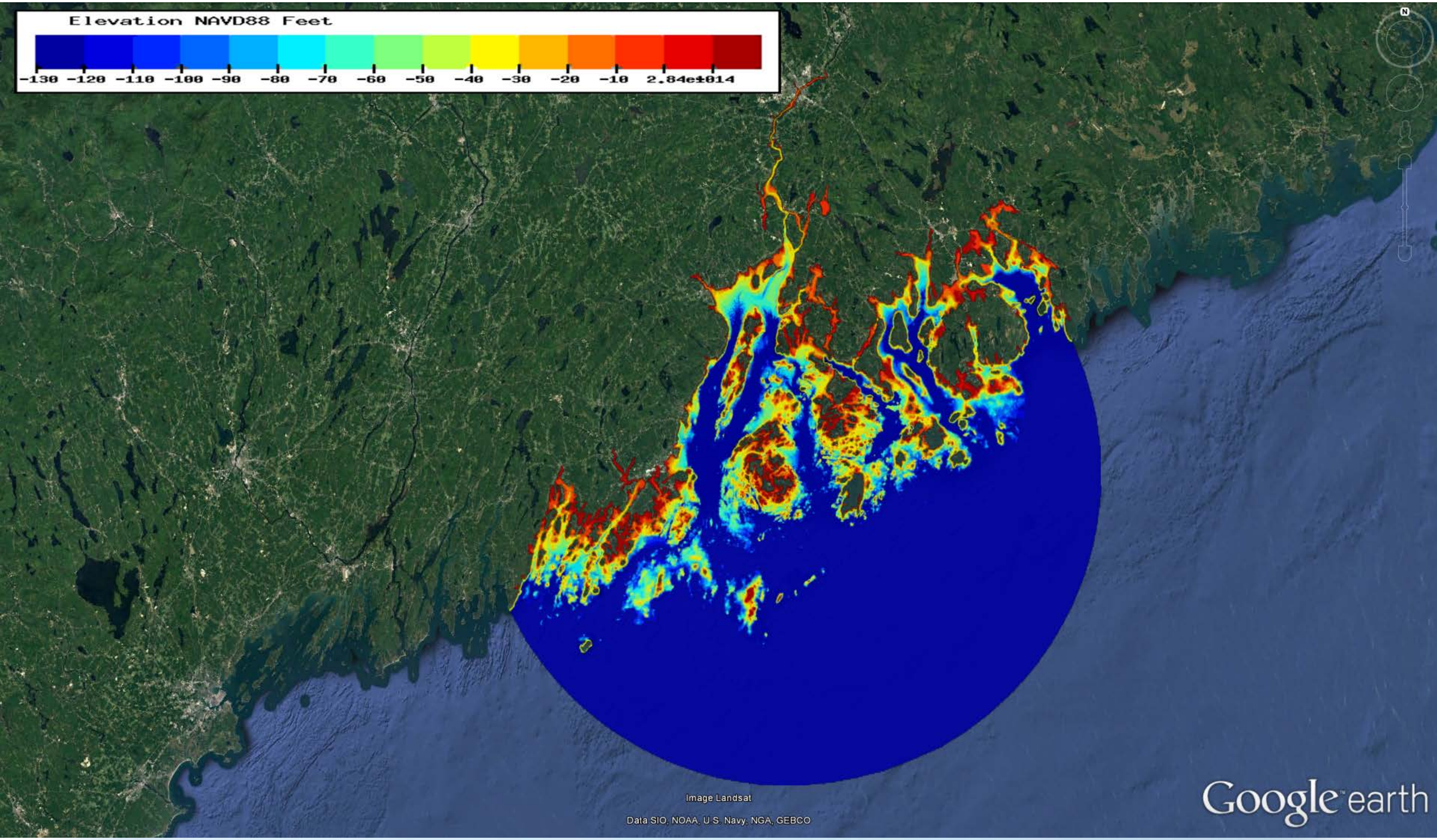
# NACCS Grid


Bangor
Skowhegan
Waterville
Belfast
Augusta
Rockland
Brunswick
Columbia Ledge
37 km
Image Landsat
© 2016 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth

# NACCS Grid


Belfast
Castine
Belmont
Northport
Islesboro
Lincolnville
Hope
7.59 km
© 2016 Google
Google earth

# Penobscot Bay ADCIRC Model

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Refined model, driven by results from NACCS model will be used to develop spatially refined estimates of the extreme storm surge and wave conditions for the critical locations. Results will also be used to evaluate Nonlinear residuals due to tide and sea level change.


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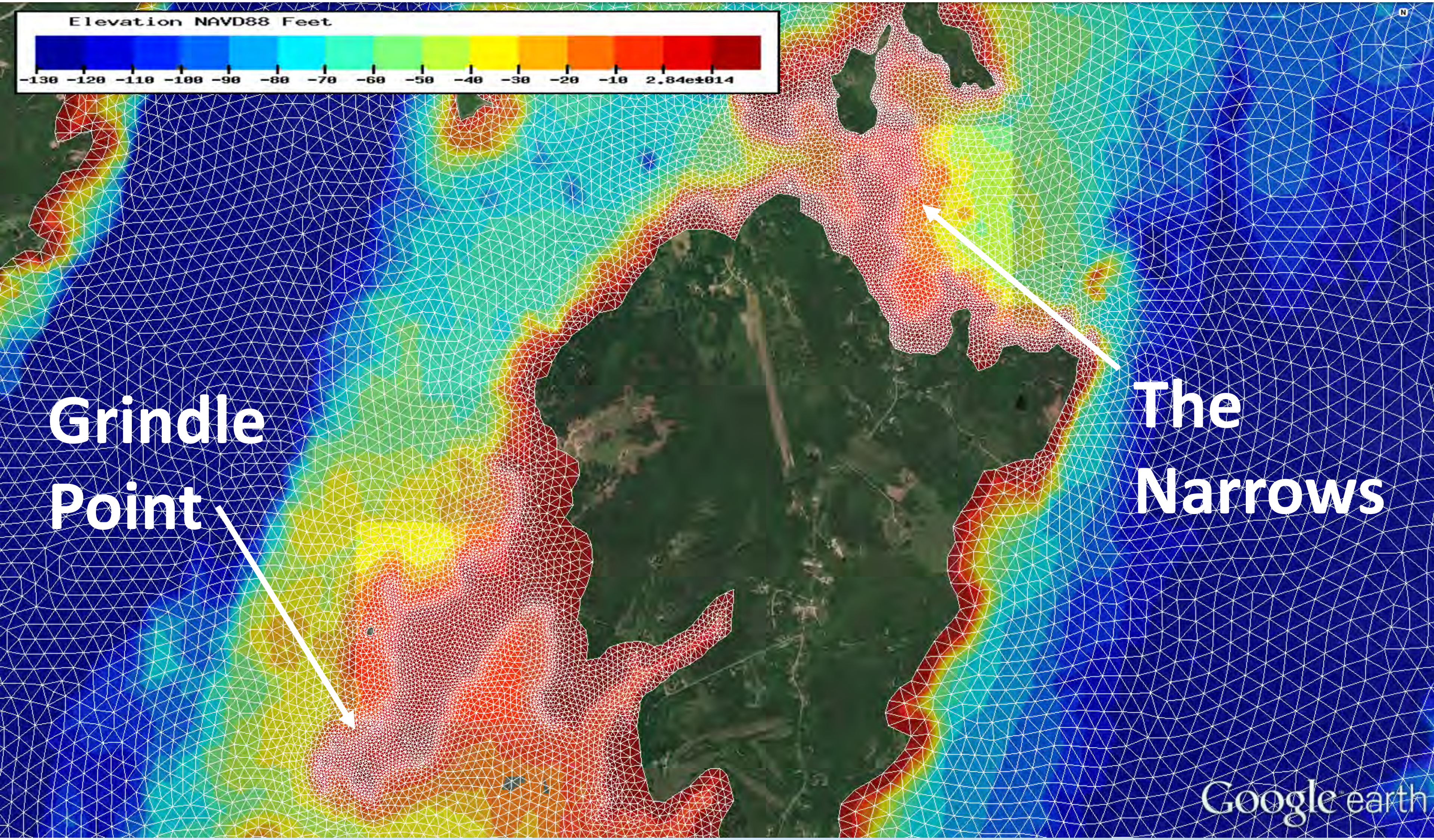
# ADCIRC Grid and Bottom Elevation

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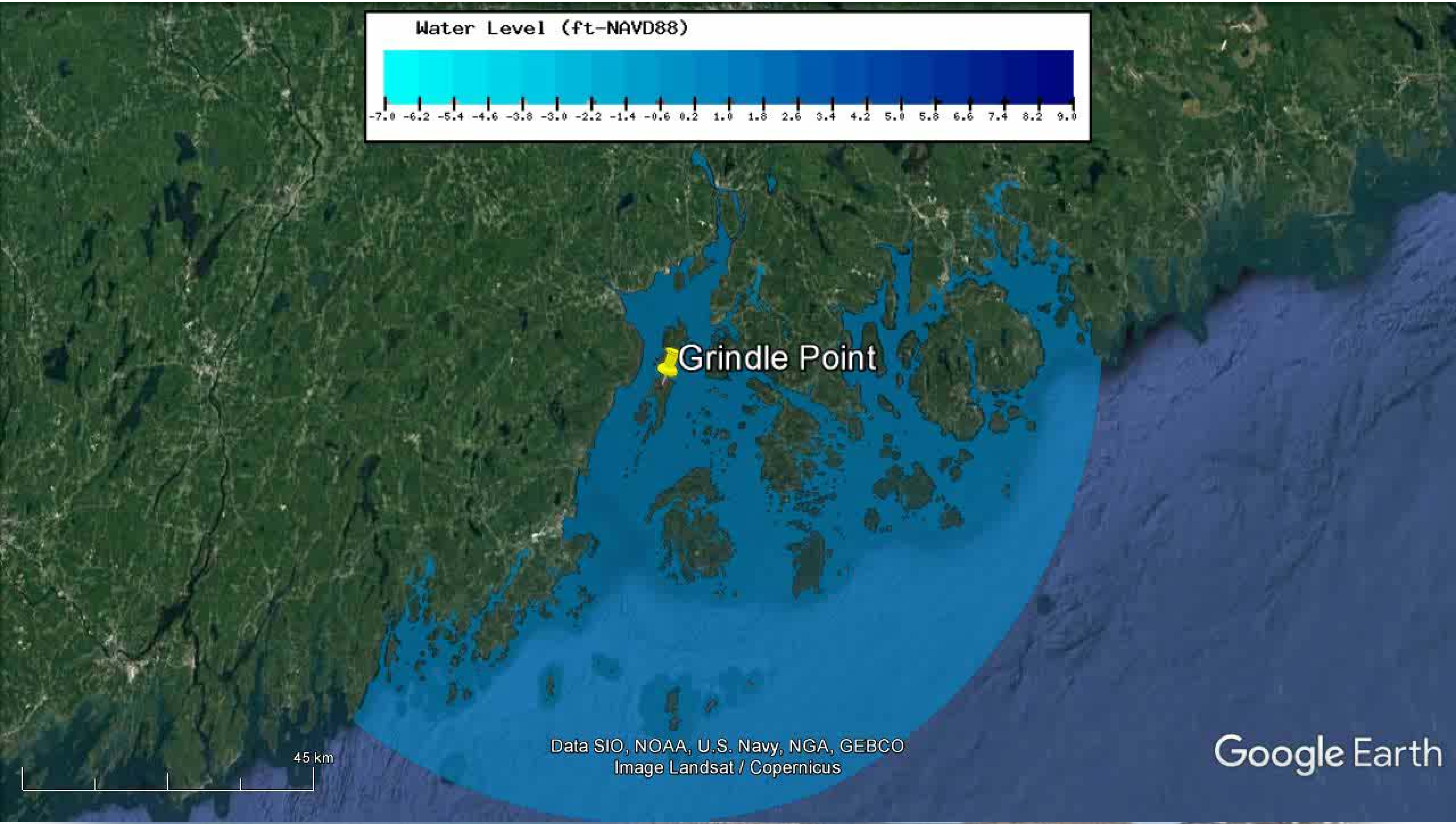
# Penobscot Bay ADCIRC+SWAN model – Water Level

## 1976 Groundhog day storm

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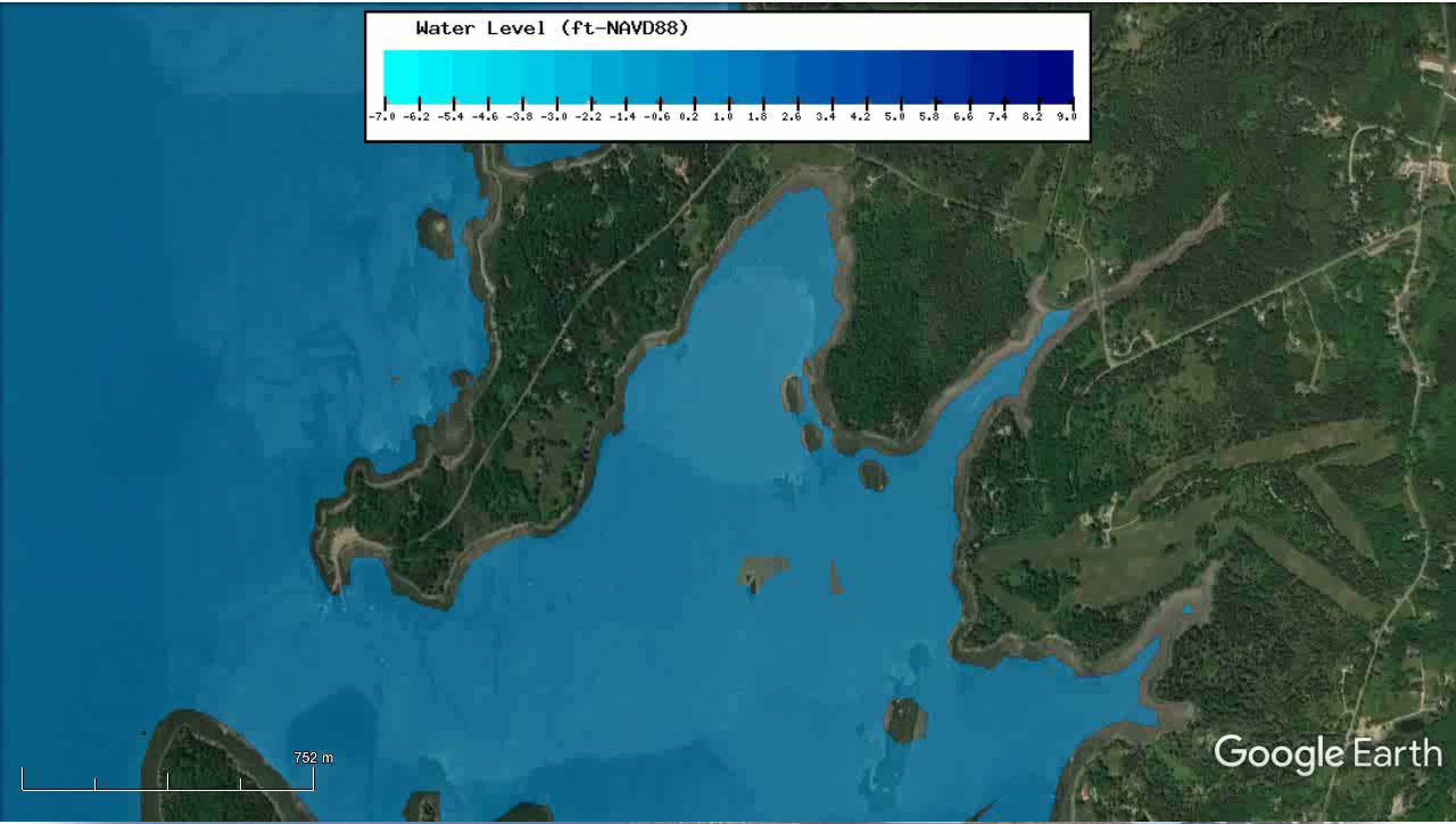
# Penobscot Bay ADCIRC+SWAN model – Water Level

## 1976 Groundhog day storm

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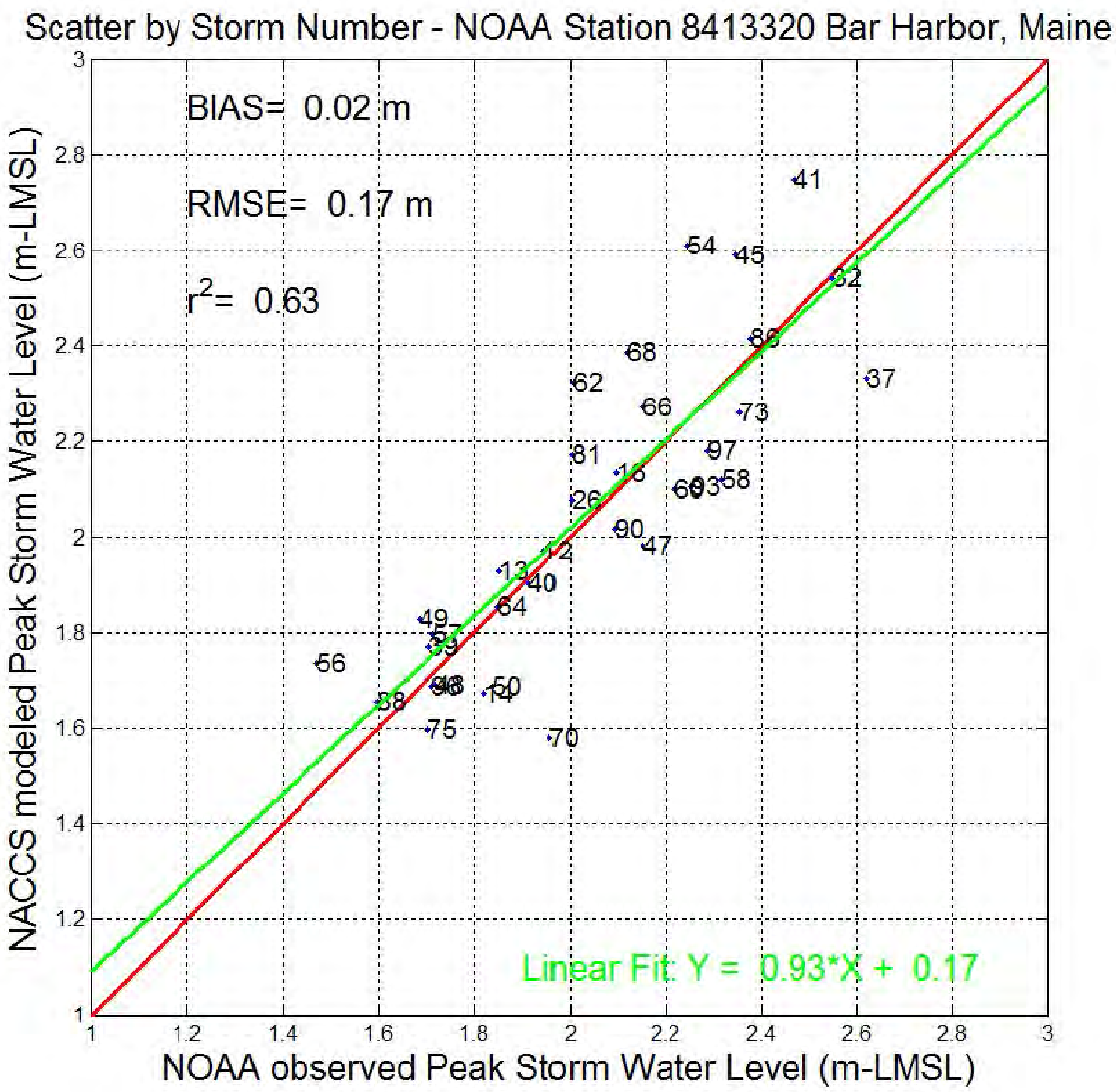
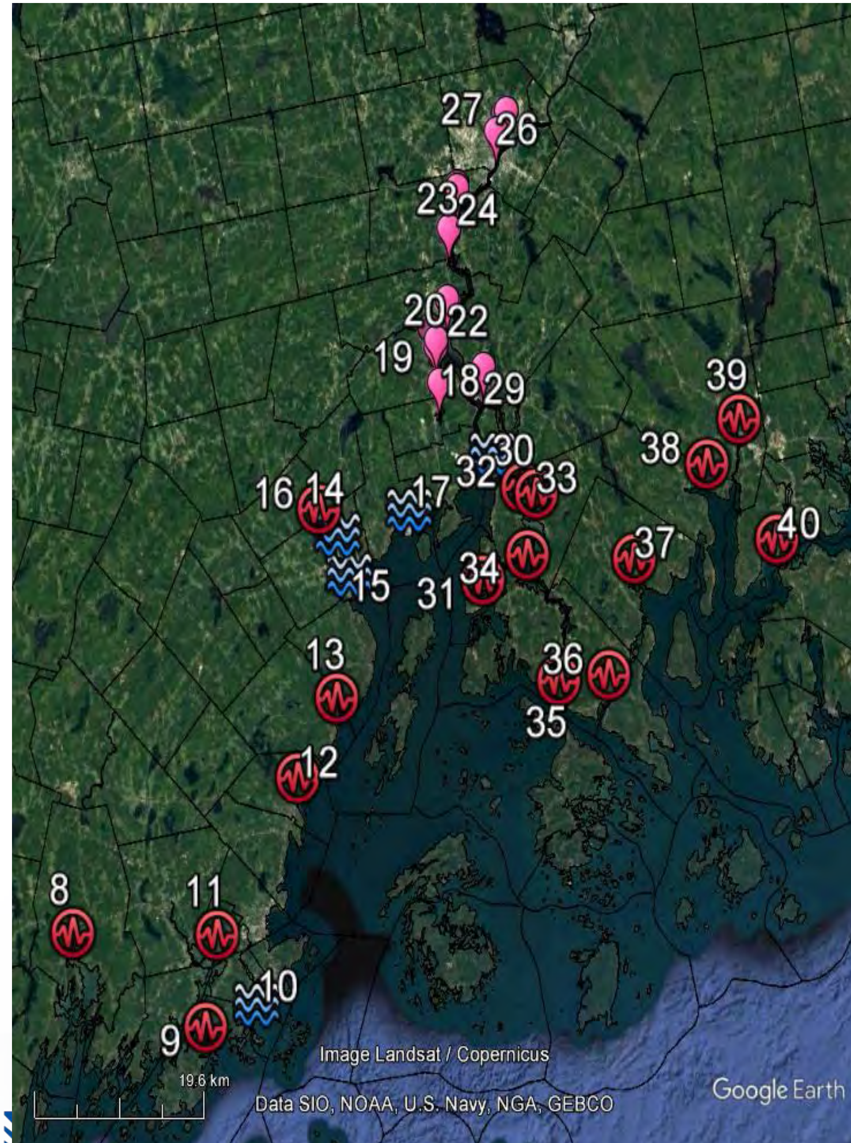
# PenBay Model – Validation

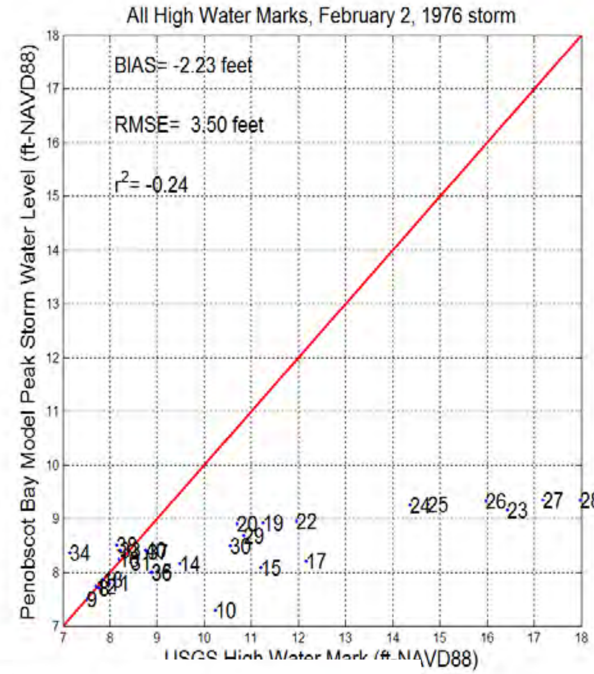
## Historic Extra-tropical storms at Bar Harbor

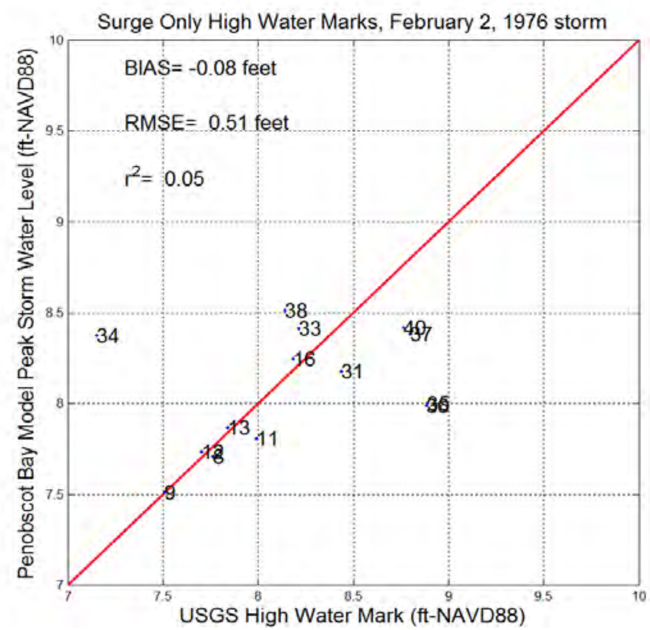


# PenBay Model – Validation

## 1976 Groundhog day Storm HWMs

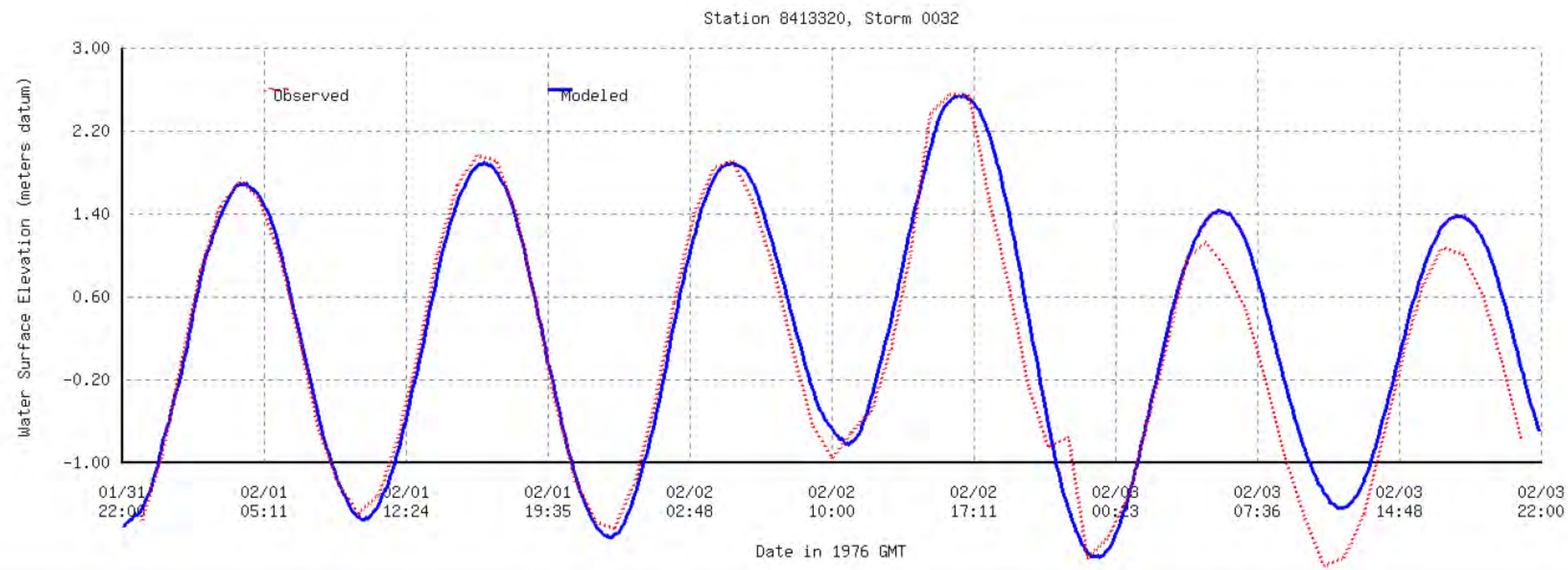


# PenBay Model – Validation

## 1976 Groundhog day time series at Bar Harbor

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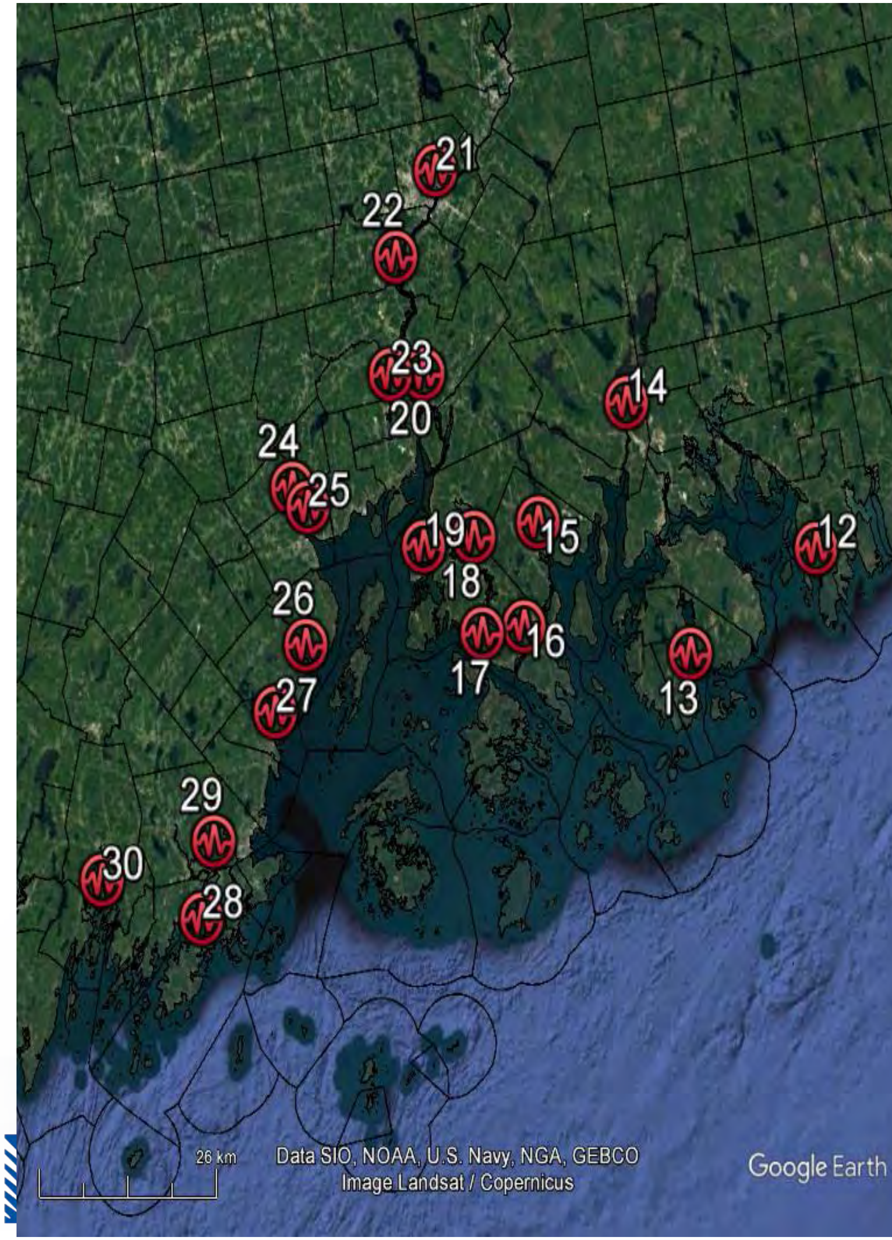
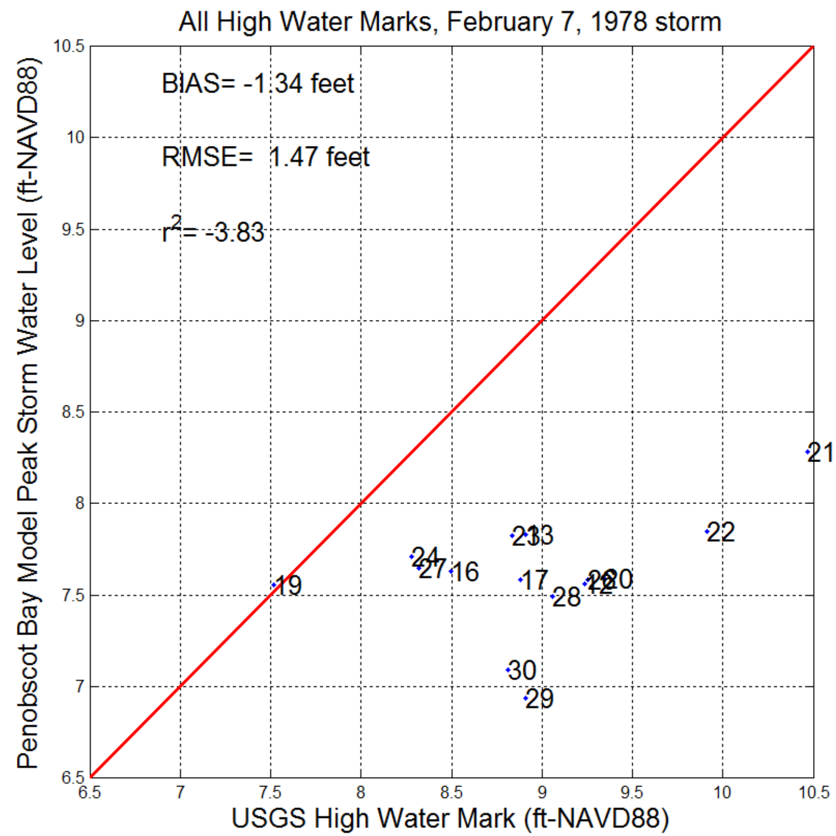
# PenBay Model – Validation

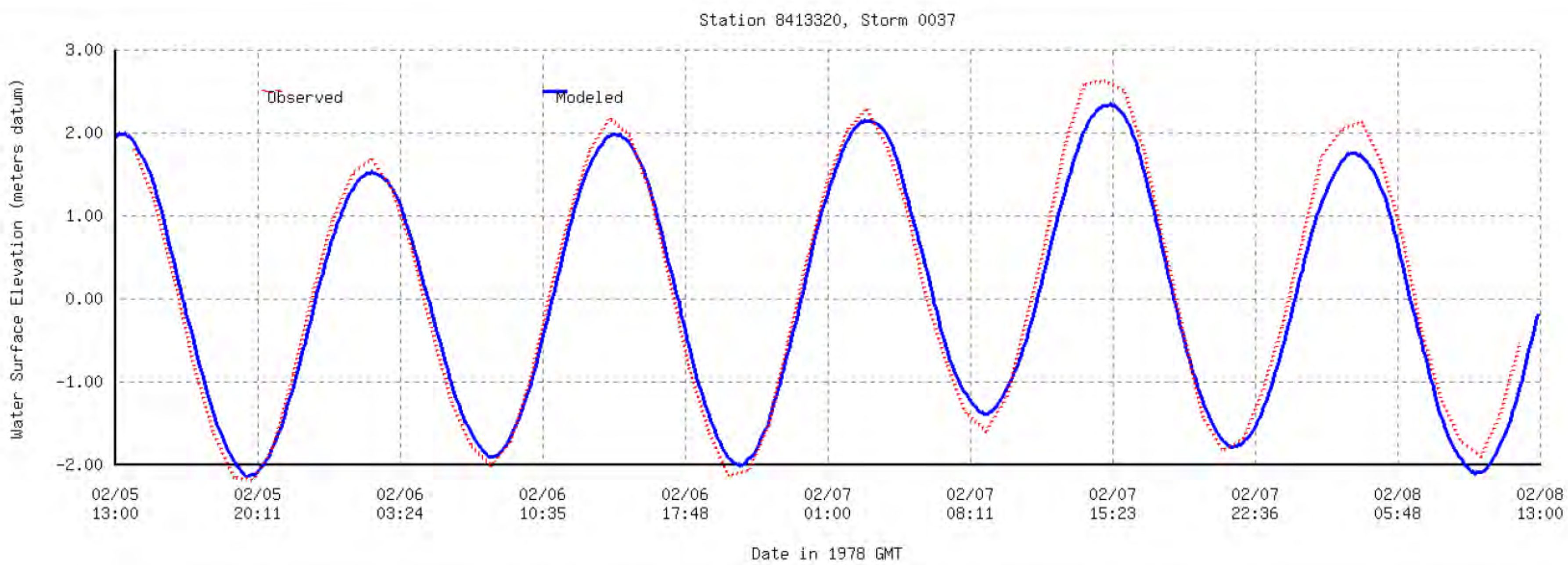
## 1978 February 7 Blizzard HWMs




# PenBay Model – Validation

## Feb 7, 1978 Blizzard
## at Bar Harbor

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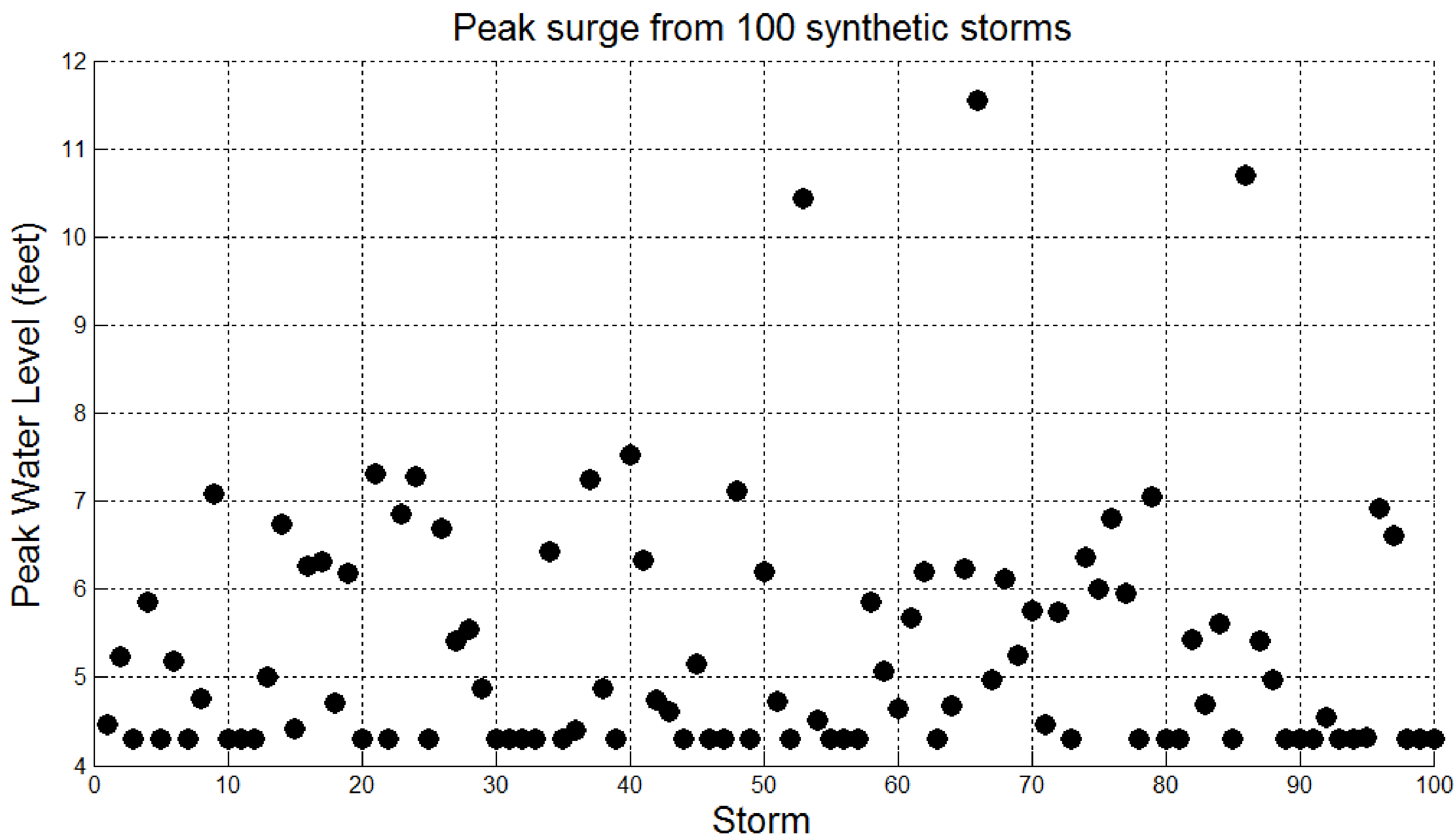
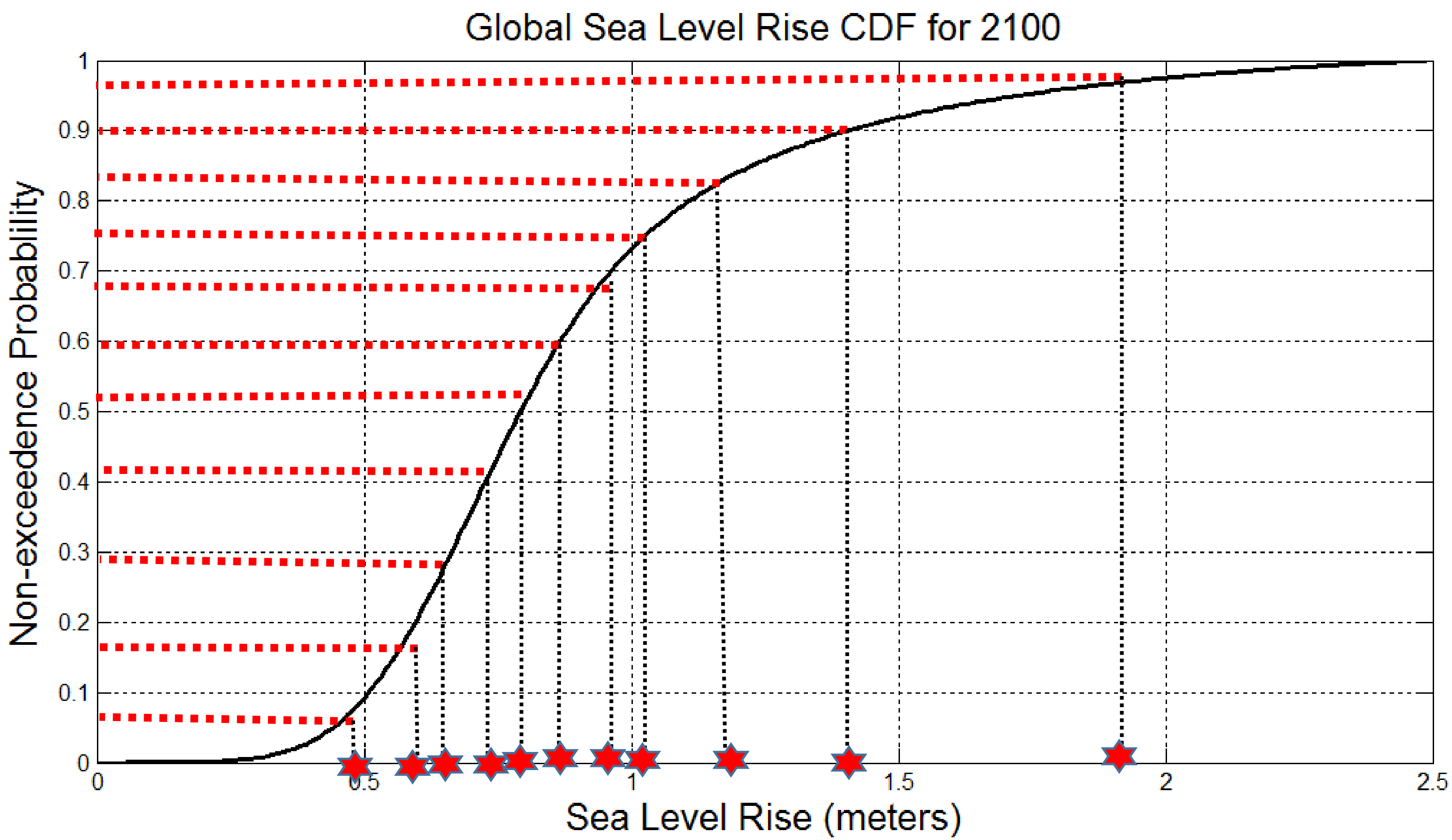
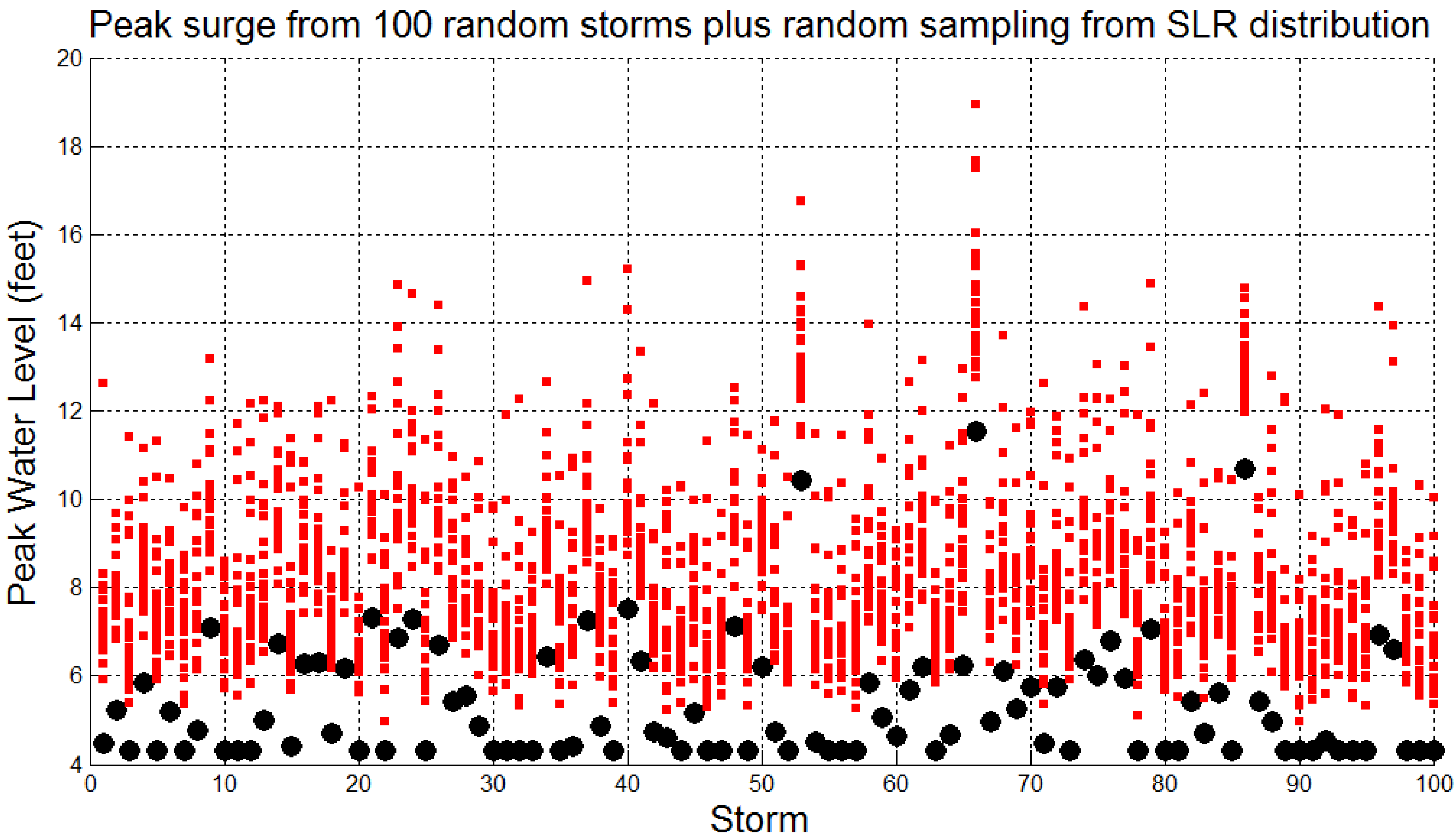

Peak surge from 100 synthetic storms
Peak Water Level (feet)
Storm
12
11
10
9
8
7
6
5
4
0
10
20
30
40
50
60
70
80
90
100



Global Sea Level Rise CDF for 2100
Non-exceedence Probability
Sea Level Rise (meters)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.5
1
1.5
2
2.5


RANSOM




Note: here we may also incorporate distributions for other types of uncertainty (aleatory uncertainty in surge predictions, error estimates for non-linear residuals, etc.)

Additional re-sampling is done for a series of years with non-stationary probability distributions for SLR.

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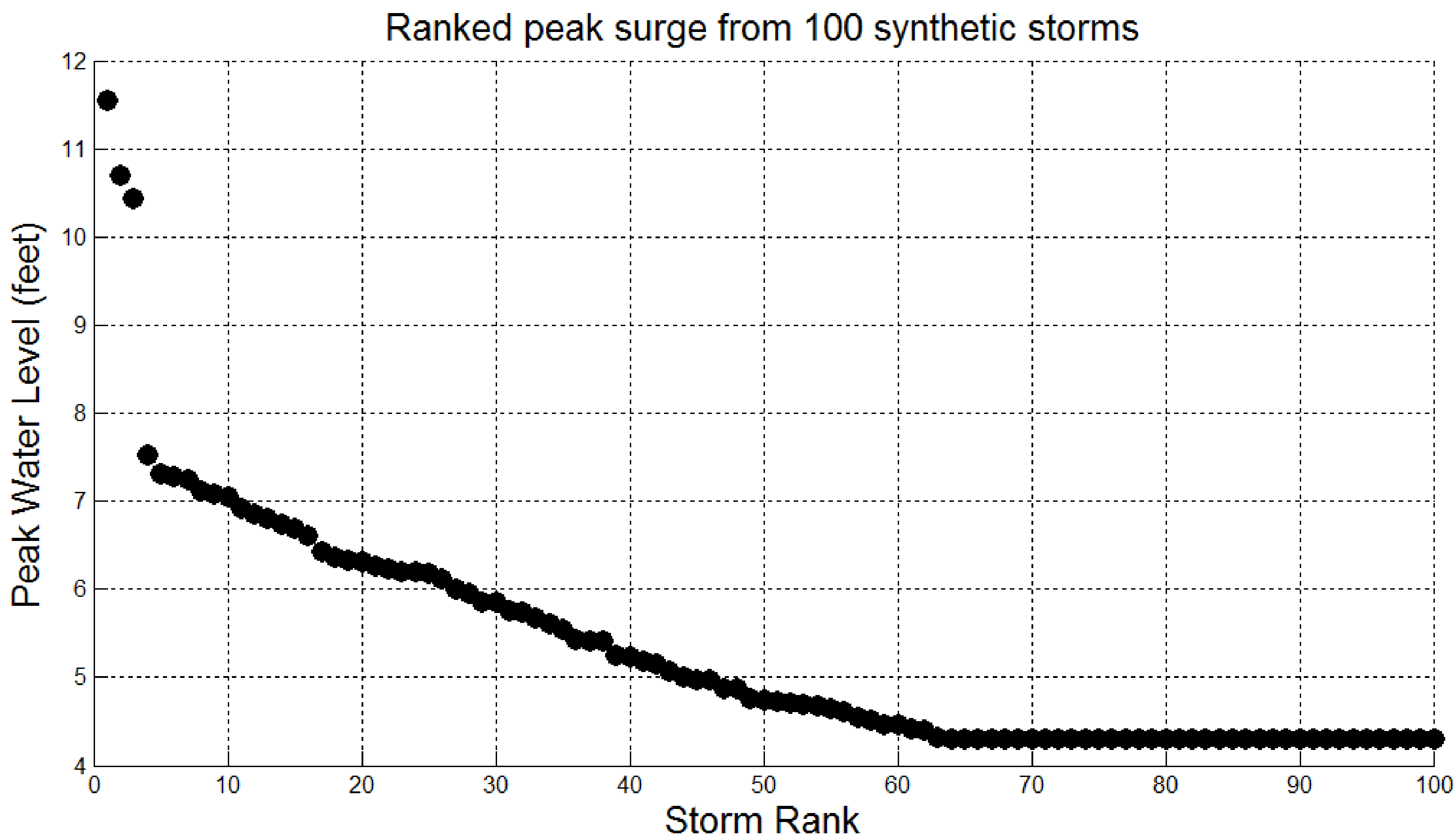
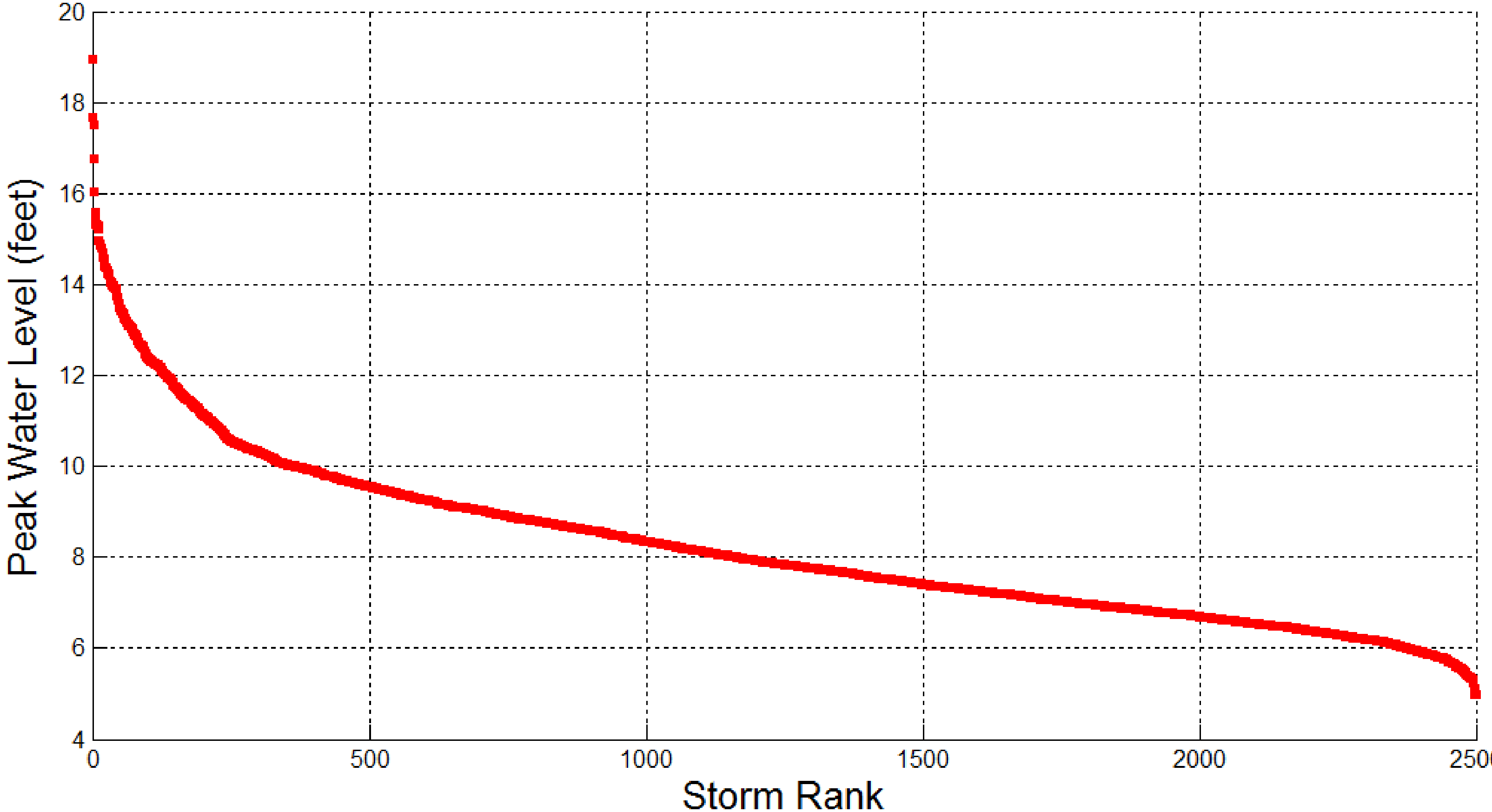
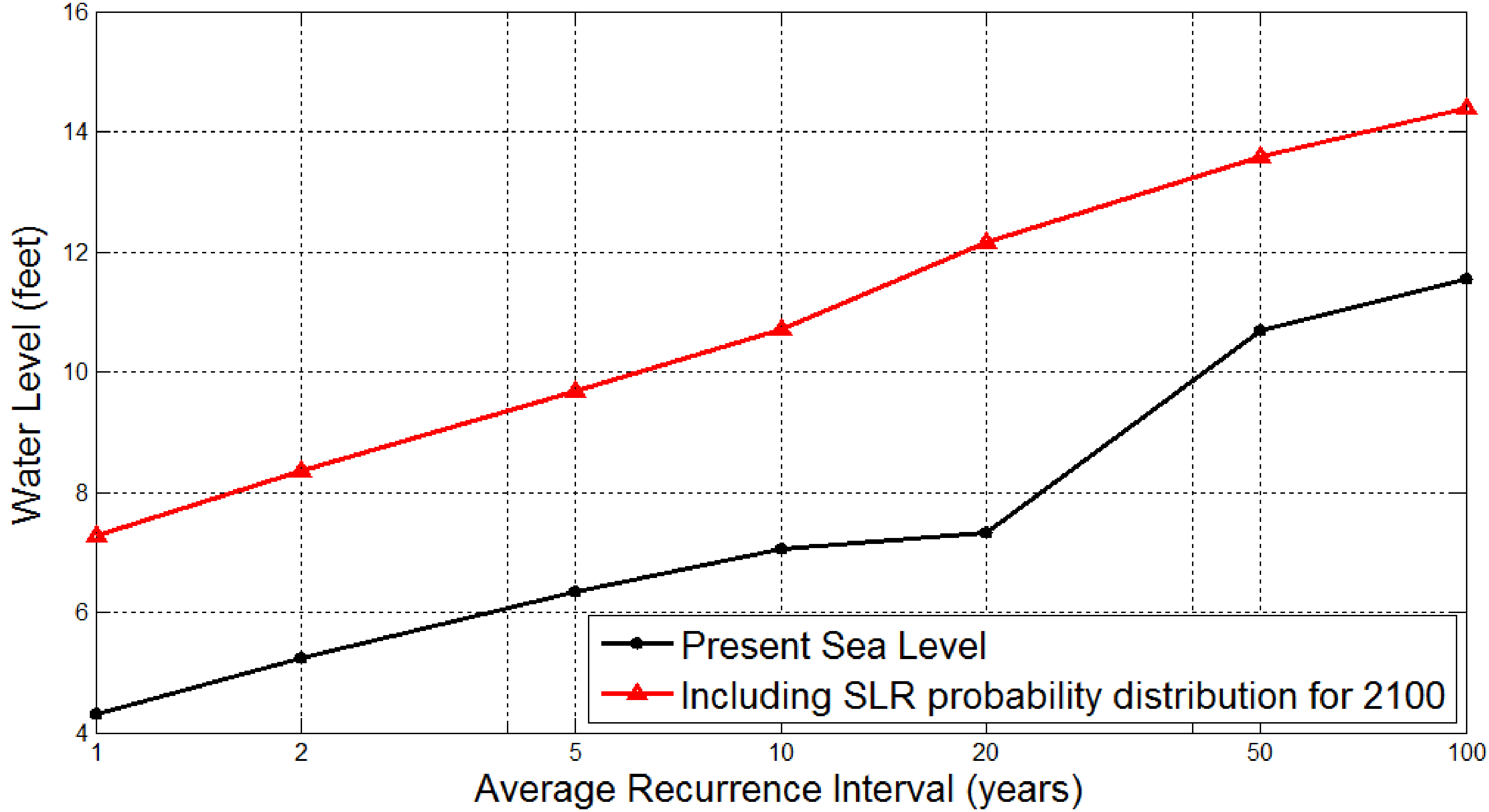

Ranked peak surge from 100 synthetic storms
Peak Water Level (feet)
Storm Rank
12
11
10
9
8
7
6
5
4
0
10
20
30
40
50
60
70
80
90
100

RANSOM

Ranked peak surge from 100 random storms plus random sampling from SLR distribution




# Example Empirical Storm Surge CDFs

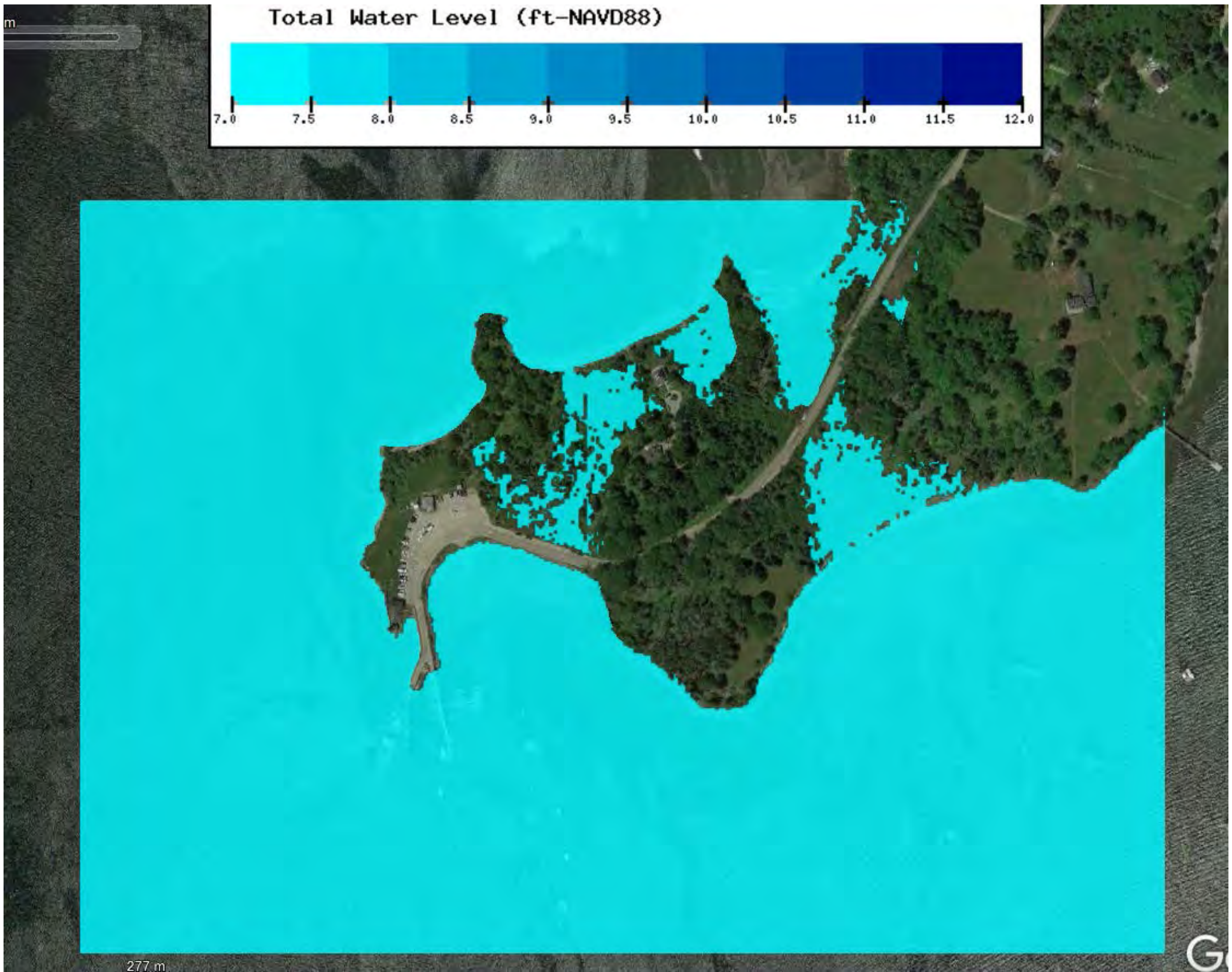



# Grindle Point Results

FEMA flood zone VE16-VE15

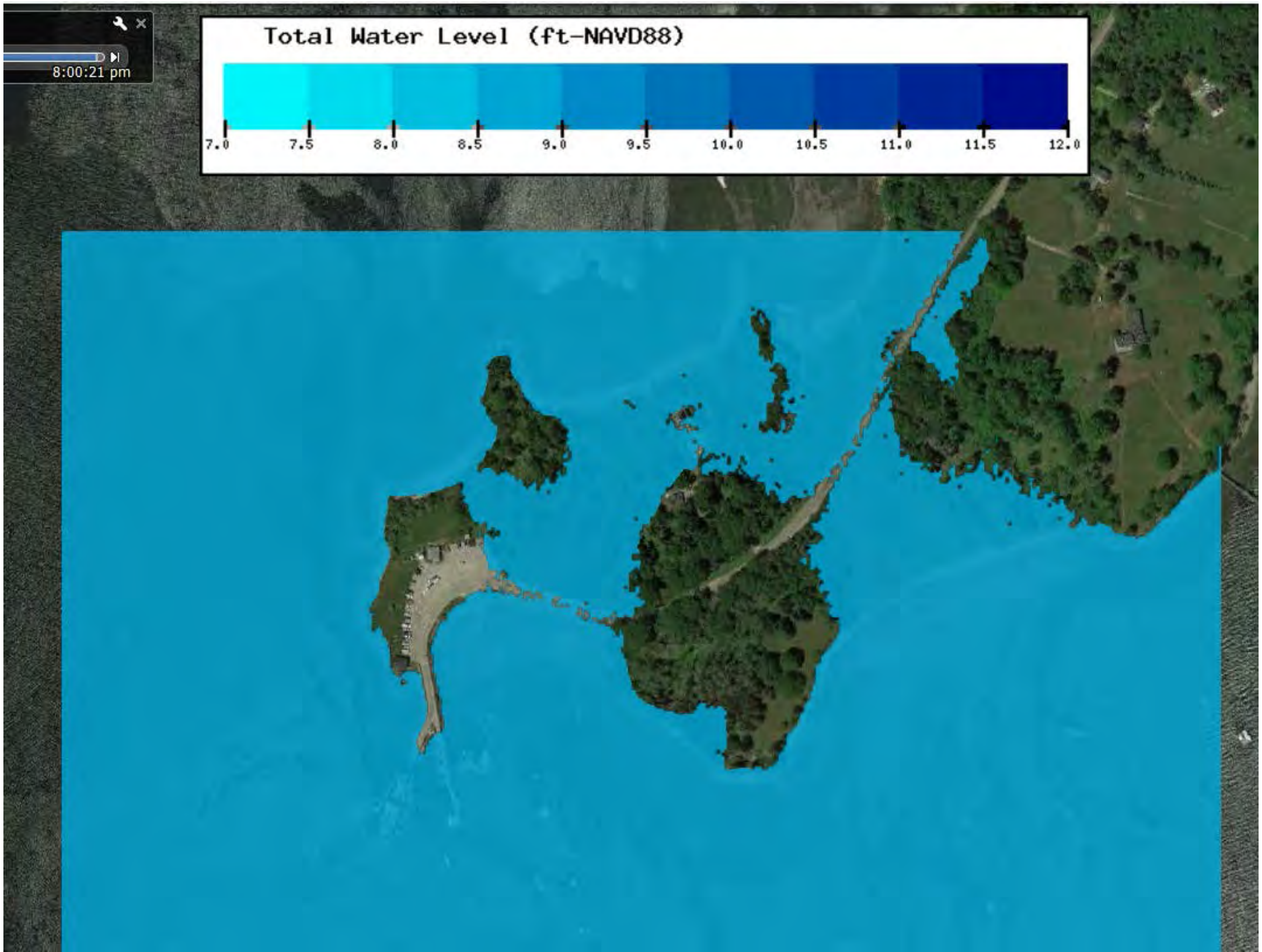
# Grindle Point Results

## PenBay Model – 2017 sea level – 5-yr (20% water level)



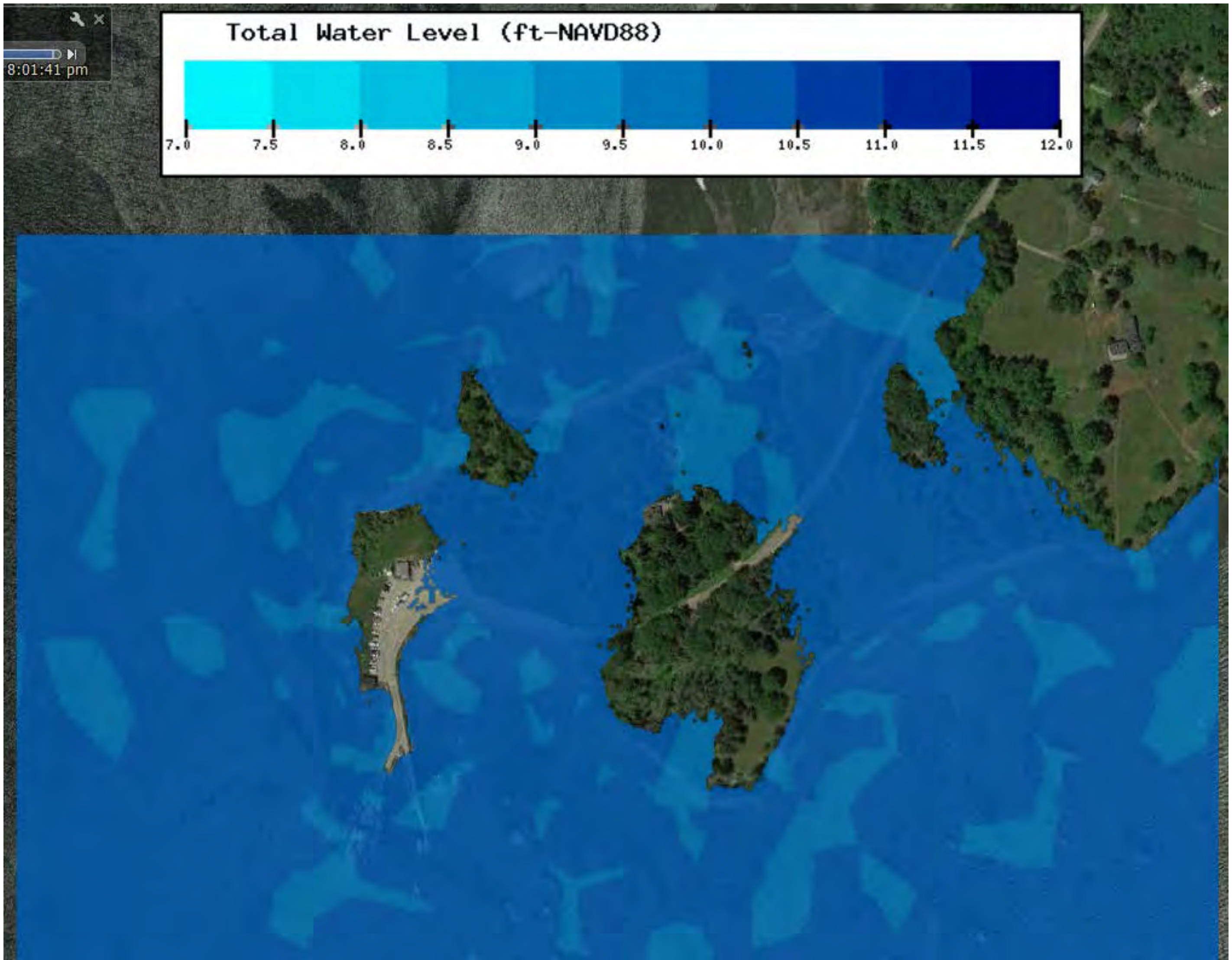
# Grindle Point Results

PenBay Model – 2017 sea level – 20-yr (5% water level)



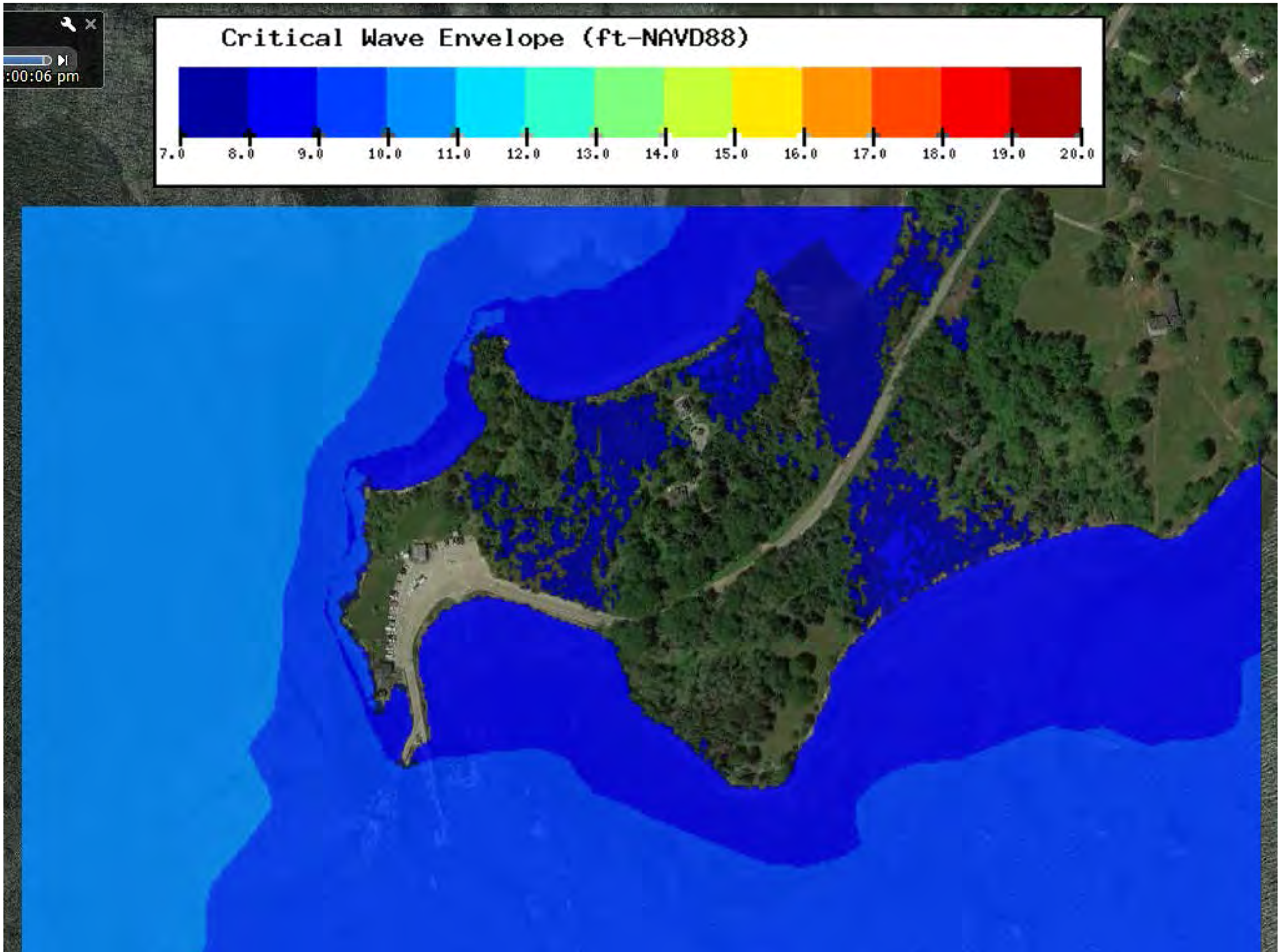
# Grindle Point Results

## PenBay Model – 2017 sea level – 100-yr (1% water level)



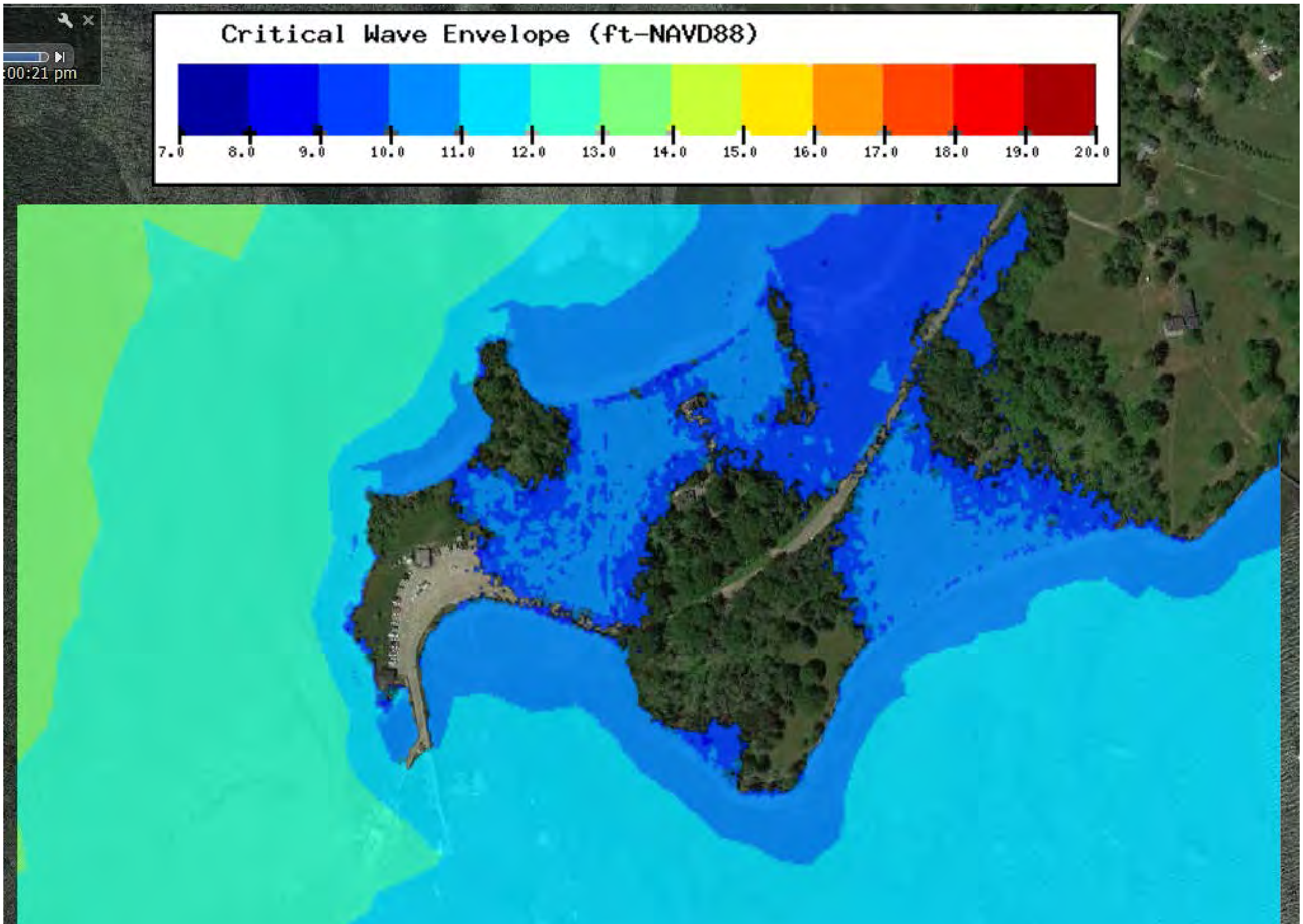
# Grindle Point Results

PenBay Model – 2017 sea level – 5-yr (20%) Wave Envelope



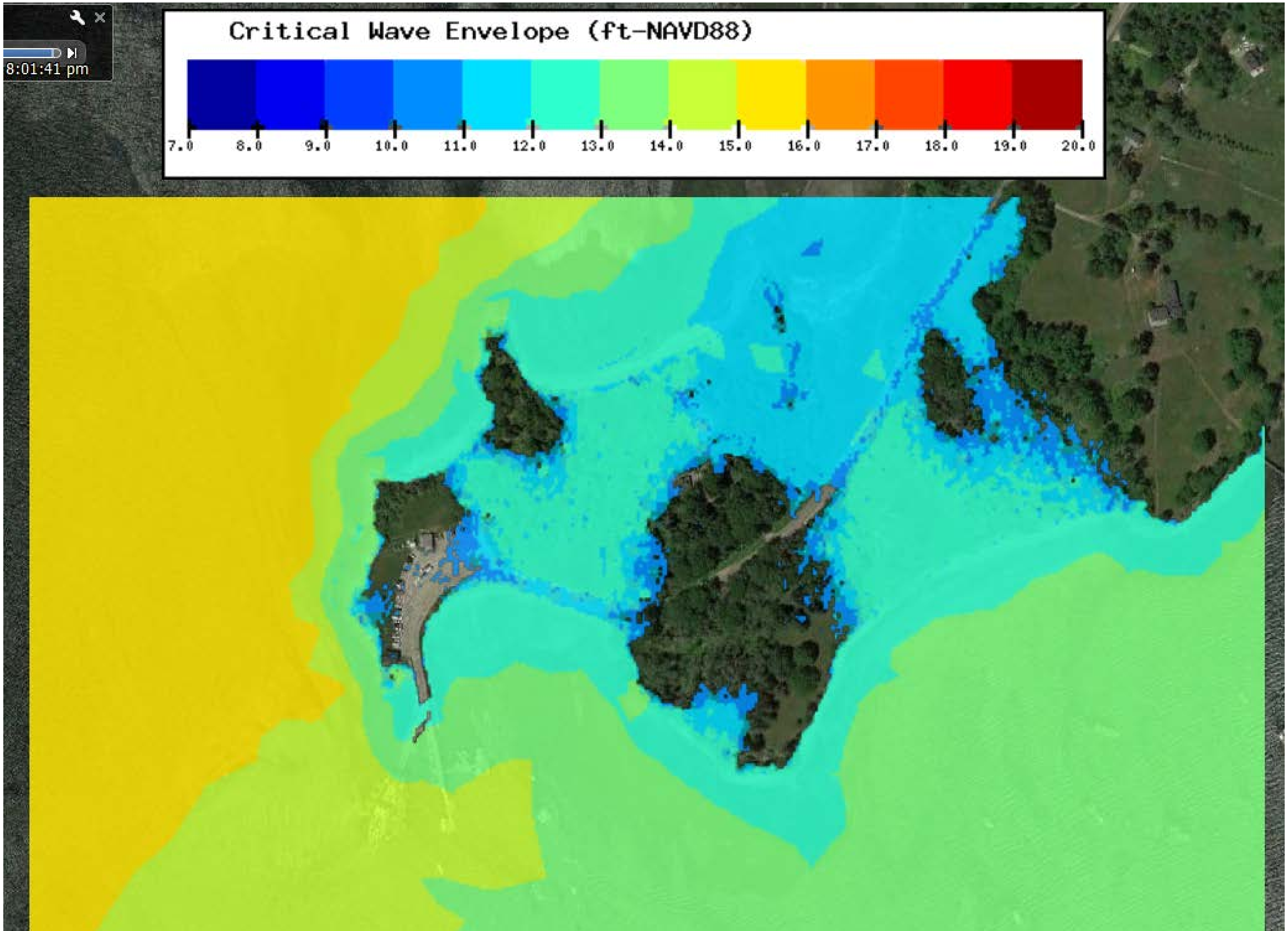
# Grindle Point Results

PenBay Model – 2017 sea level – 20-yr (5%) Wave Envelope



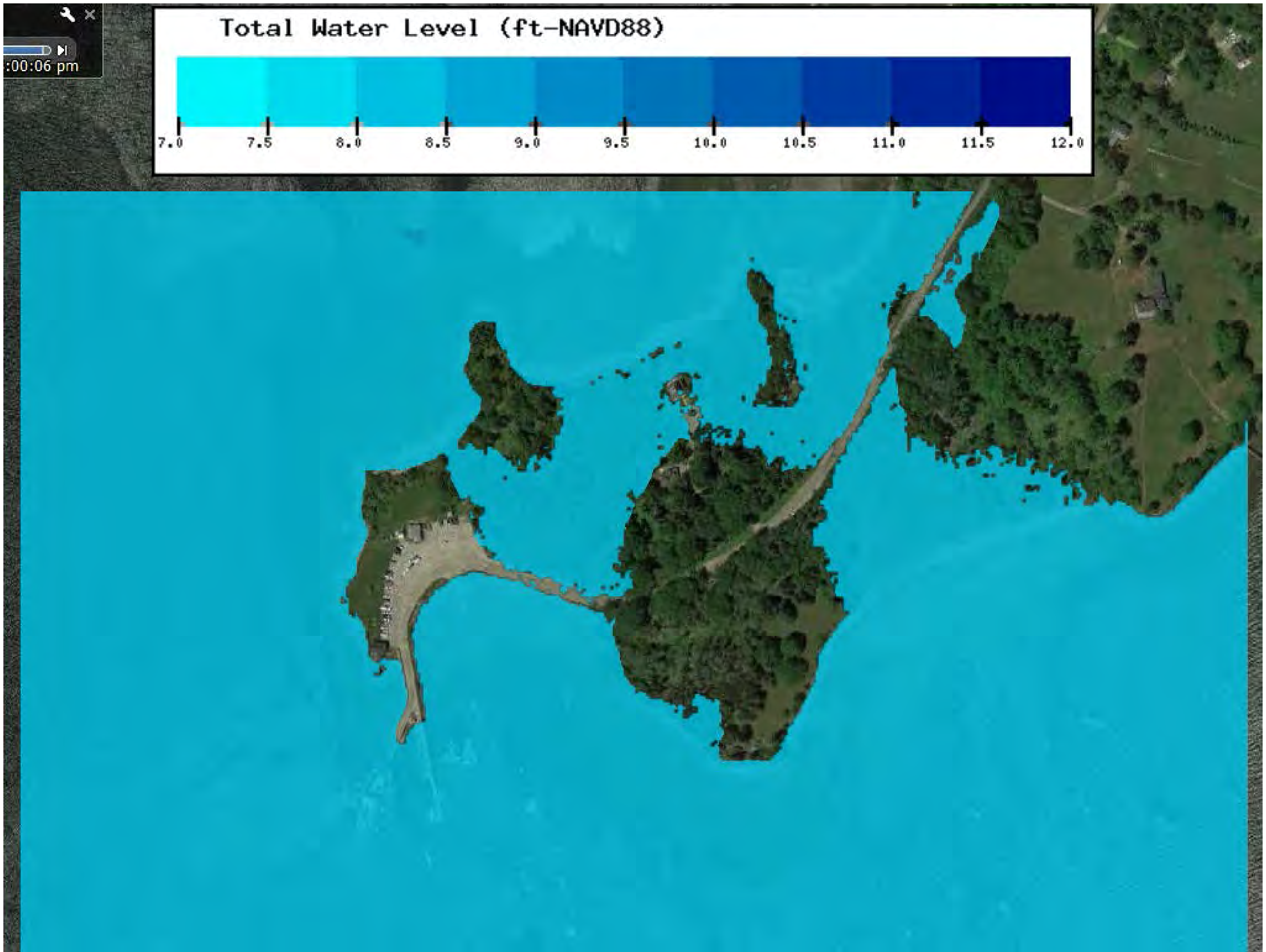
# Grindle Point Results

PenBay Model – 2017 sea level – 100-yr (1%) Wave Envelope



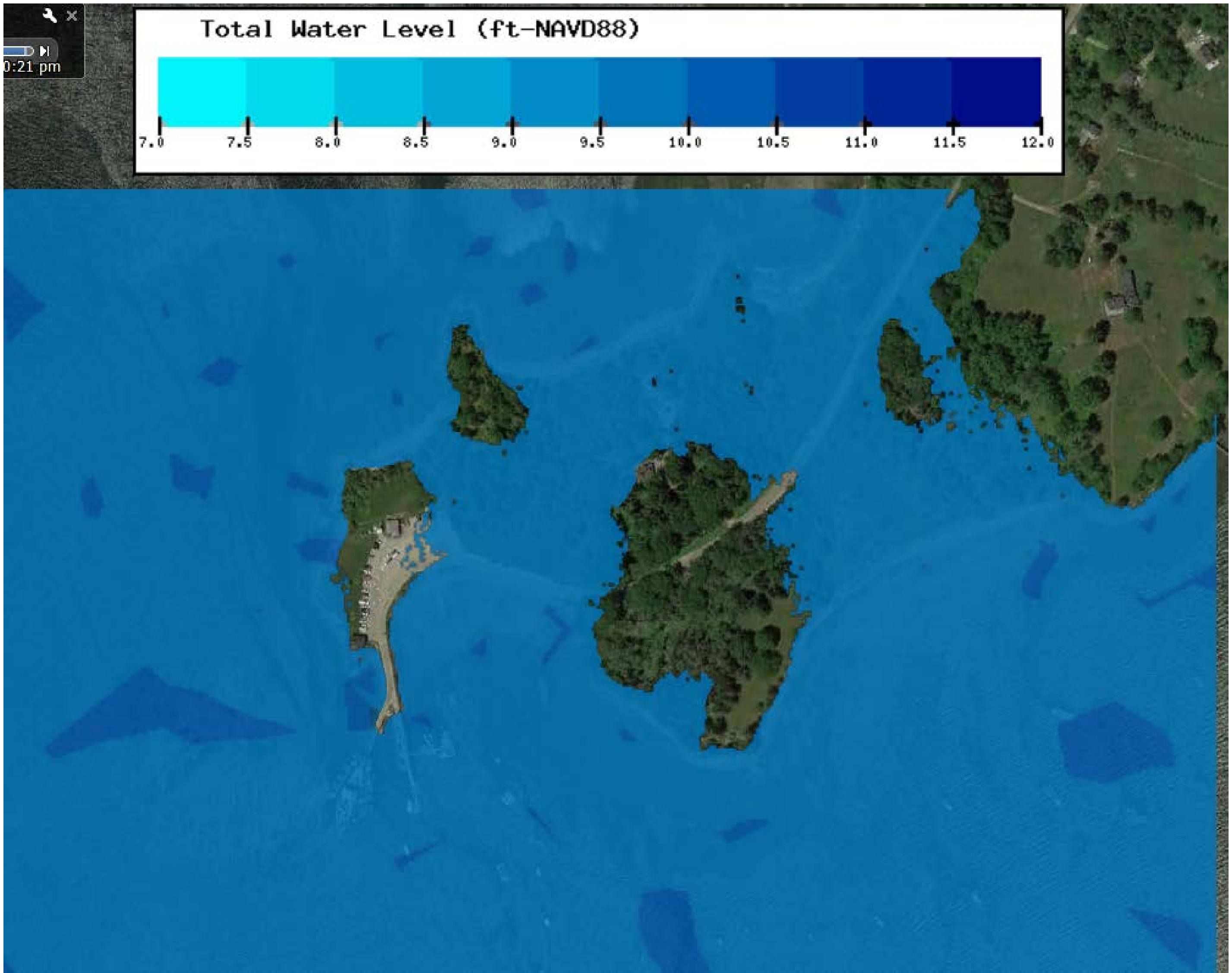
# Grindle Point Results

PenBay Model – 2037 sea level – 5-yr (20% water level)



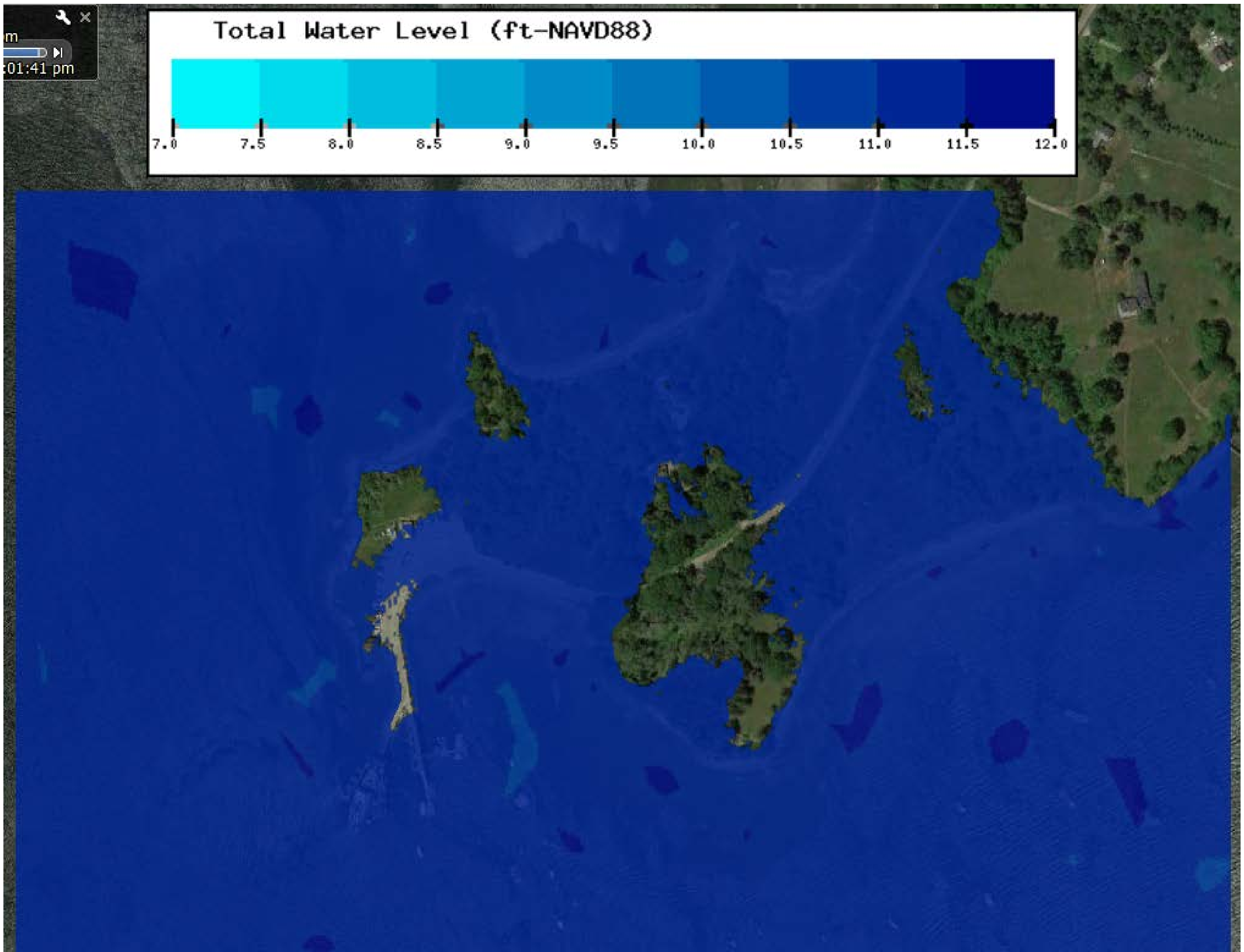
# Grindle Point Results

PenBay Model – 2037 sea level – 20-yr (5% water level)



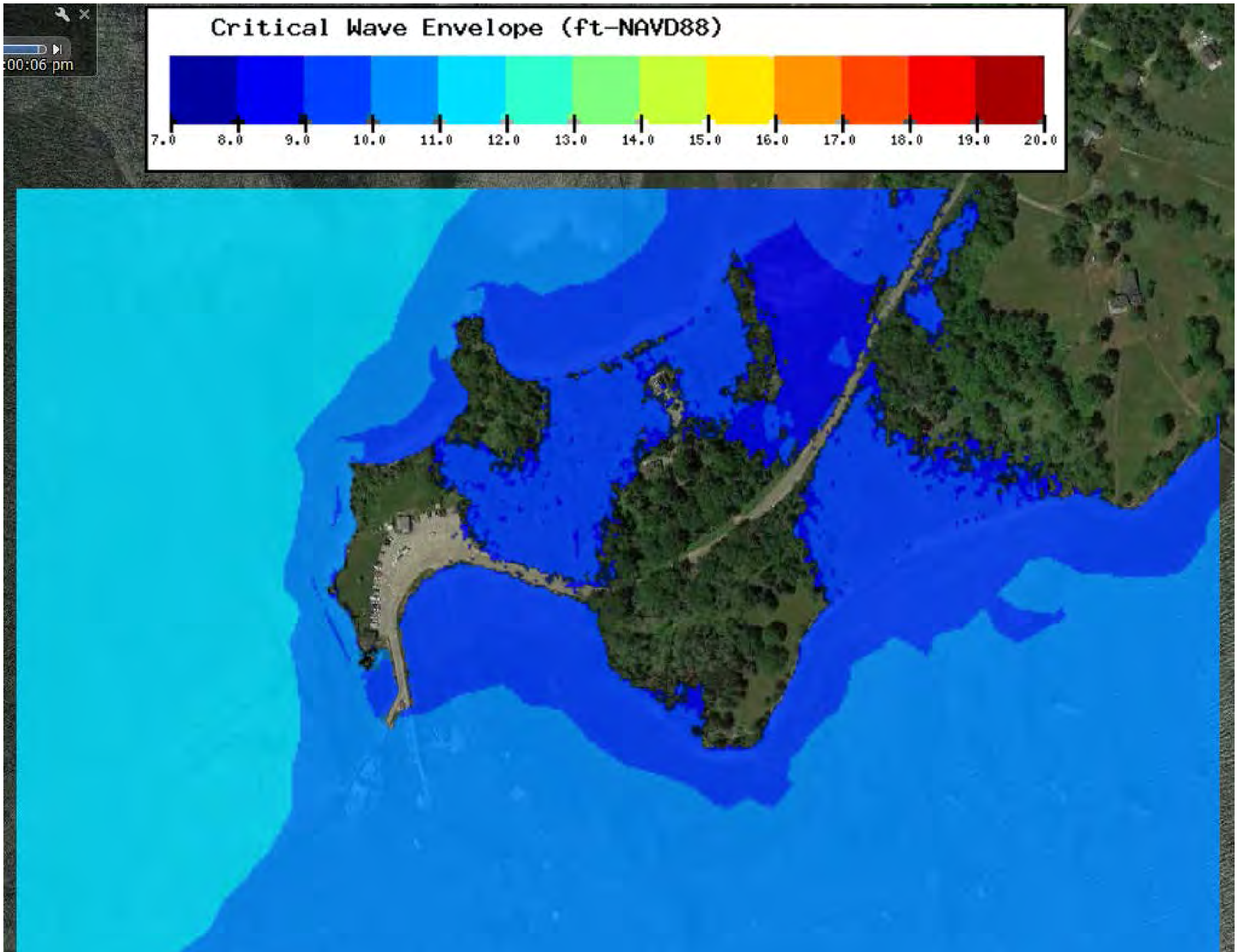
# Grindle Point Results

PenBay Model – 2037 sea level – 100-yr (1% water level)



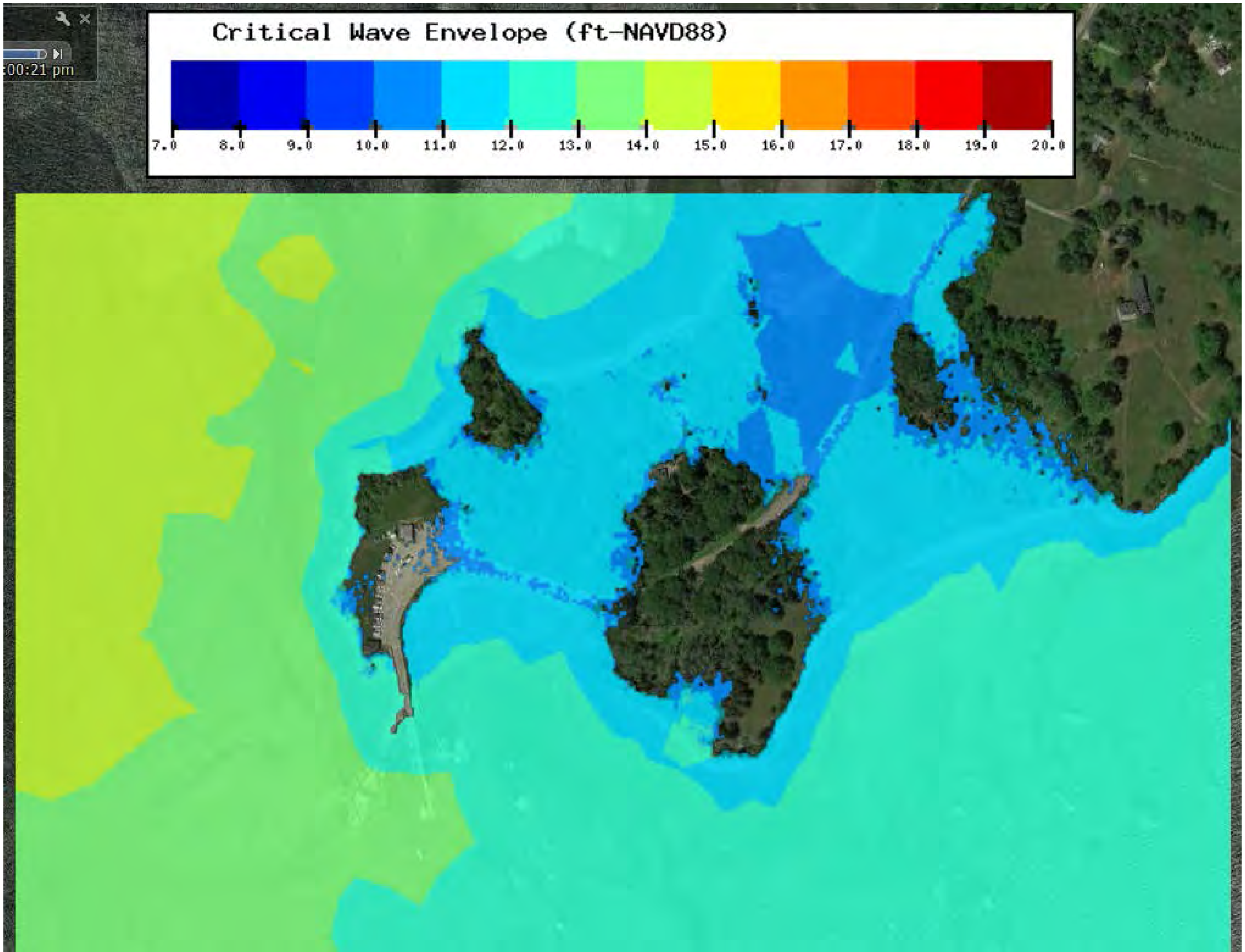
# Grindle Point Results

PenBay Model – 2037 sea level – 5-yr (20%) Wave Envelope



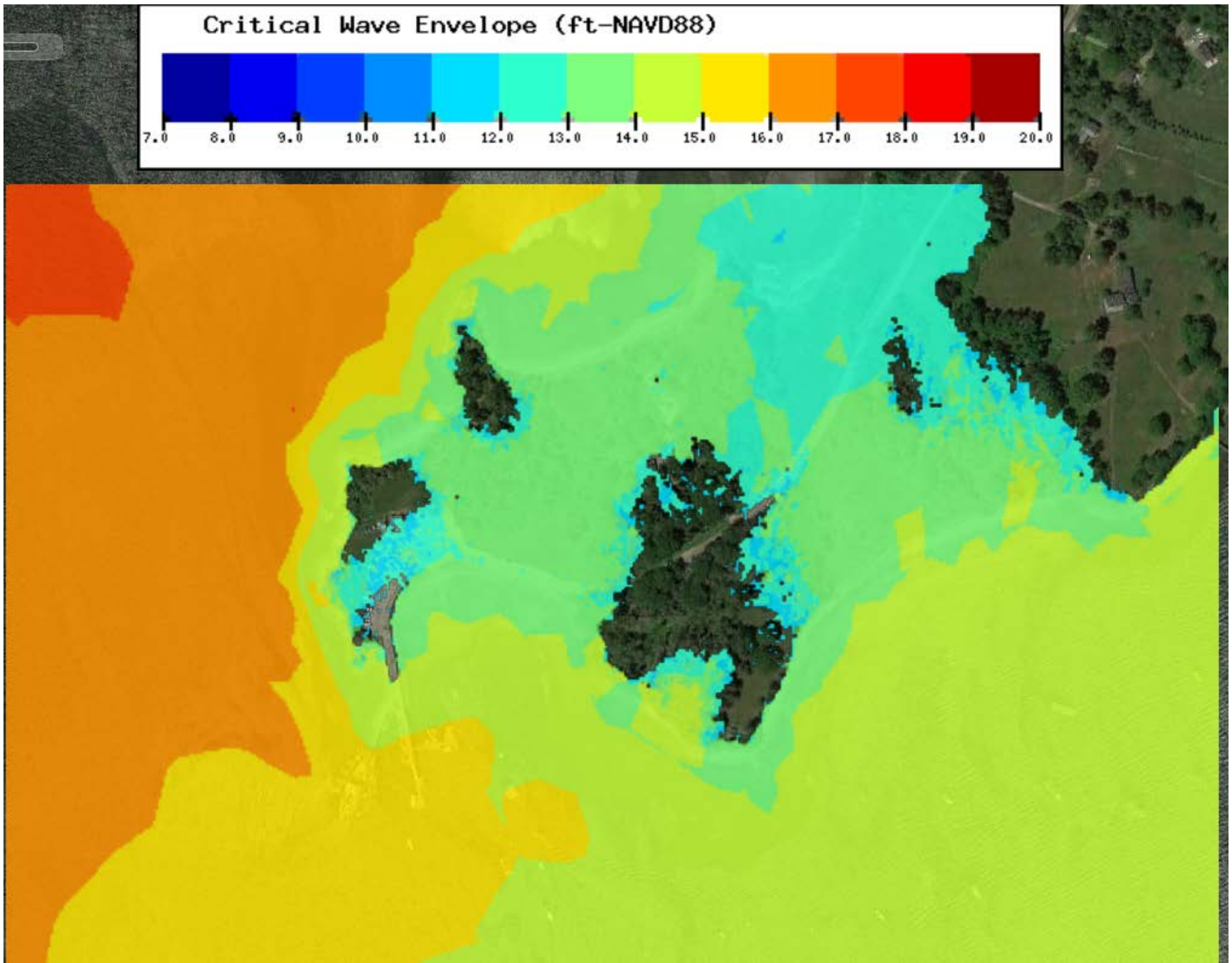
# Grindle Point Results

## PenBay Model – 2037 sea level – 20-yr (5%) Wave Envelope



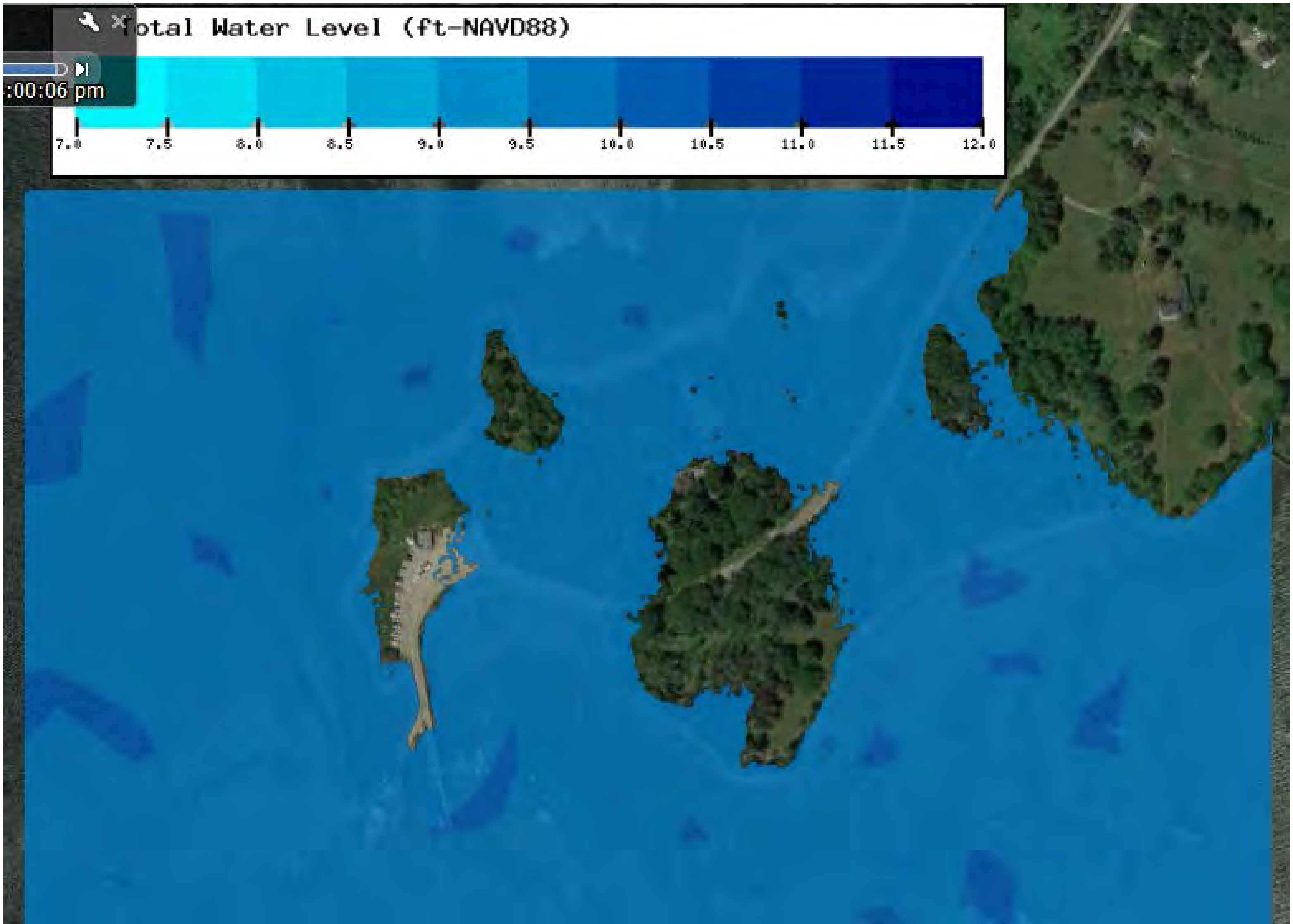
# Grindle Point Results

PenBay Model – 2037 sea level – 100-yr (1%) Wave Envelope



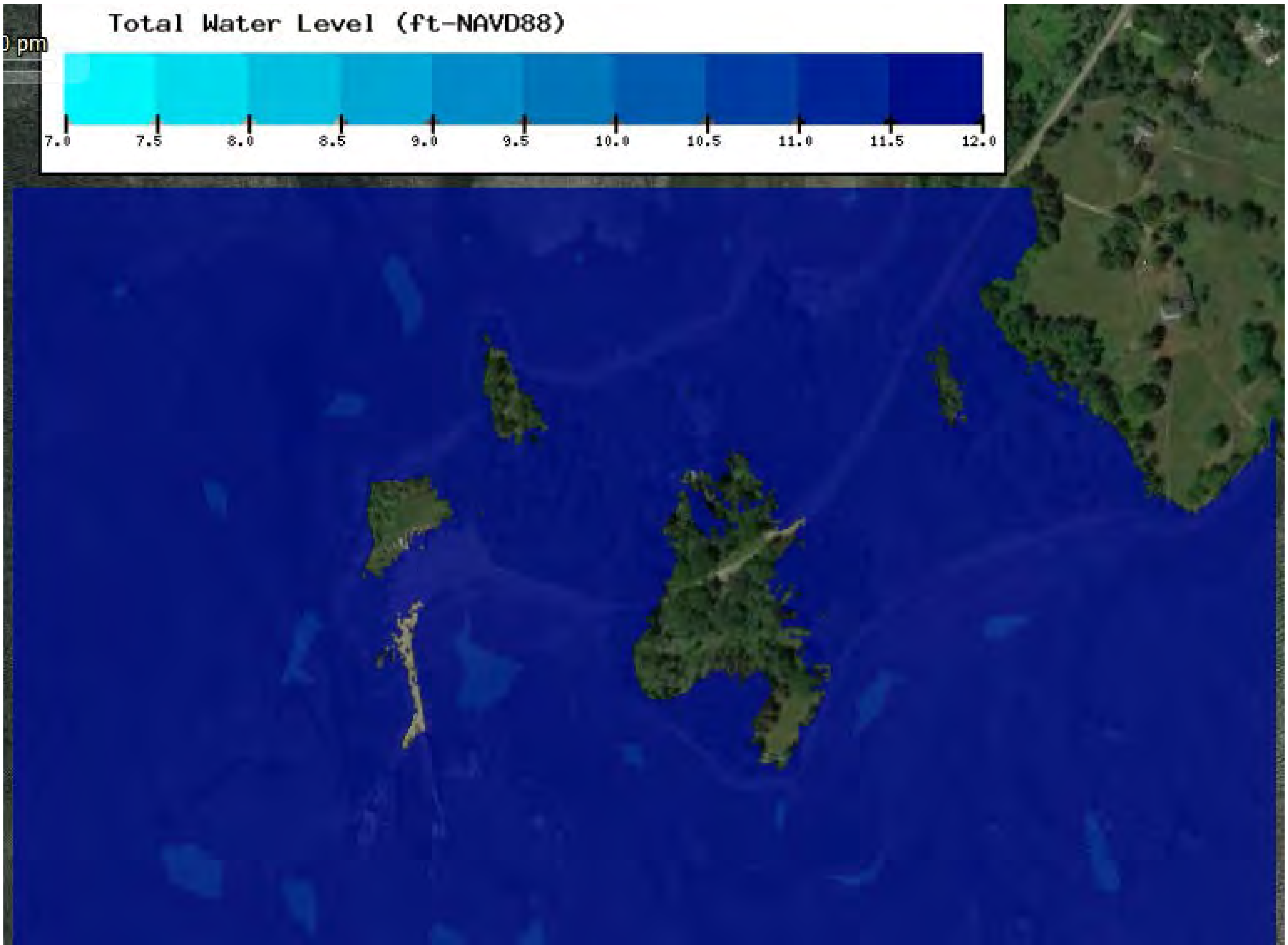
# Grindle Point Results

PenBay Model – 2067 sea level – 5-yr (20% water level)



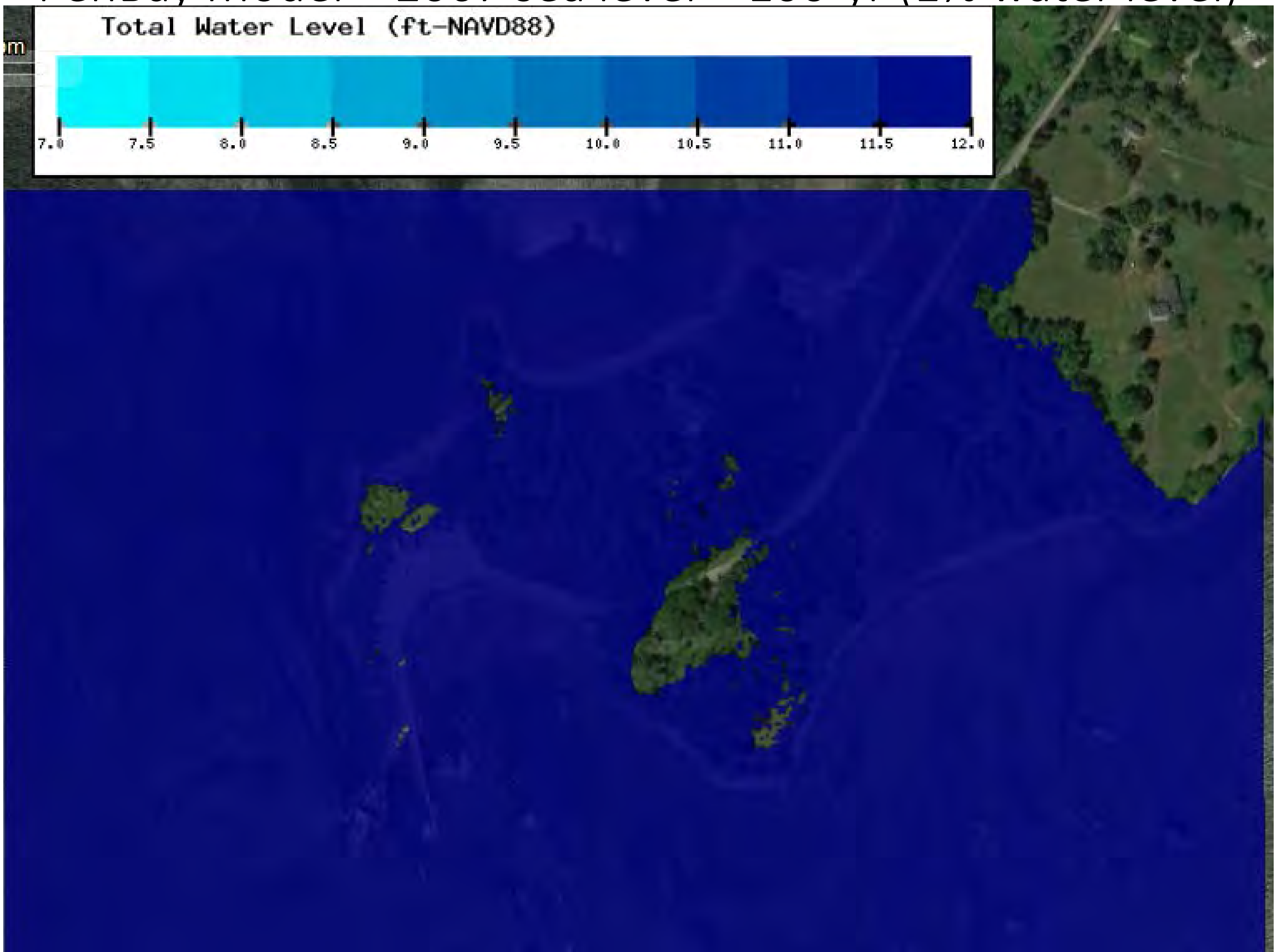
# Grindle Point Results

PenBay Model – 2067 sea level – 20-yr (5% water level)



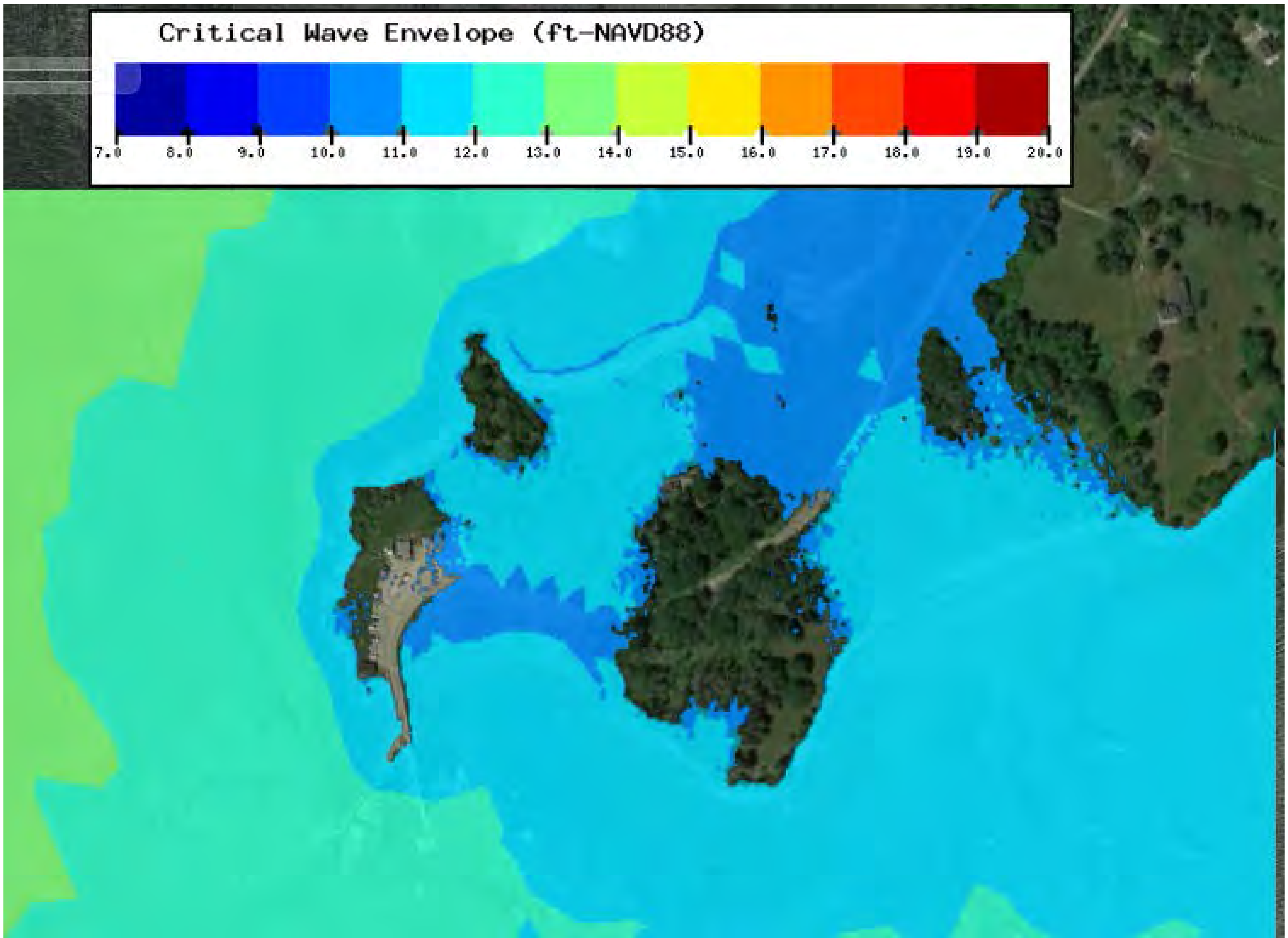
# Grindle Point Results

PenBay Model – 2067 sea level – 100-yr (1% water level)



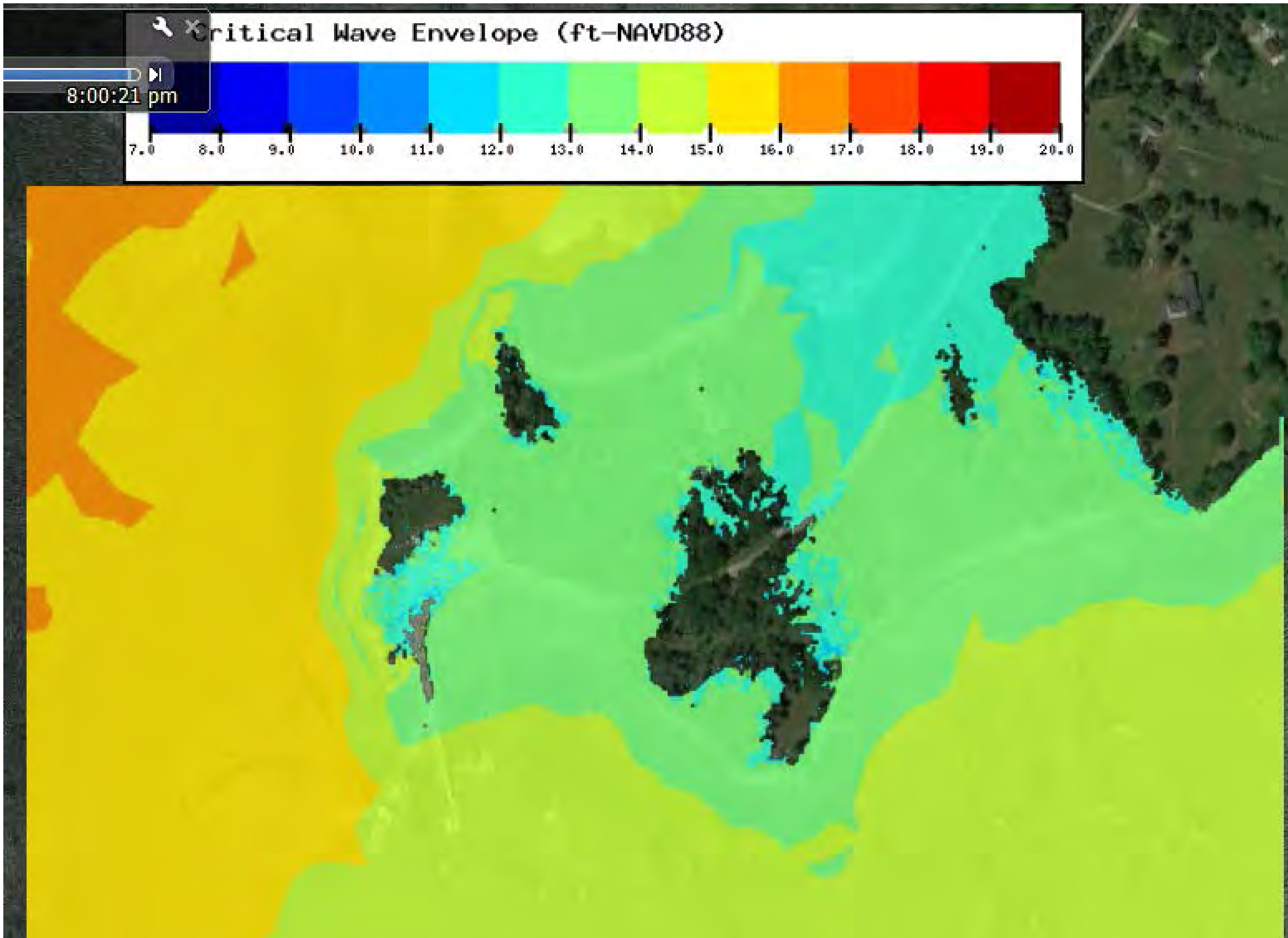
# Grindle Point Results

PenBay Model – 2067 sea level – 5-yr (20%) Wave Envelope



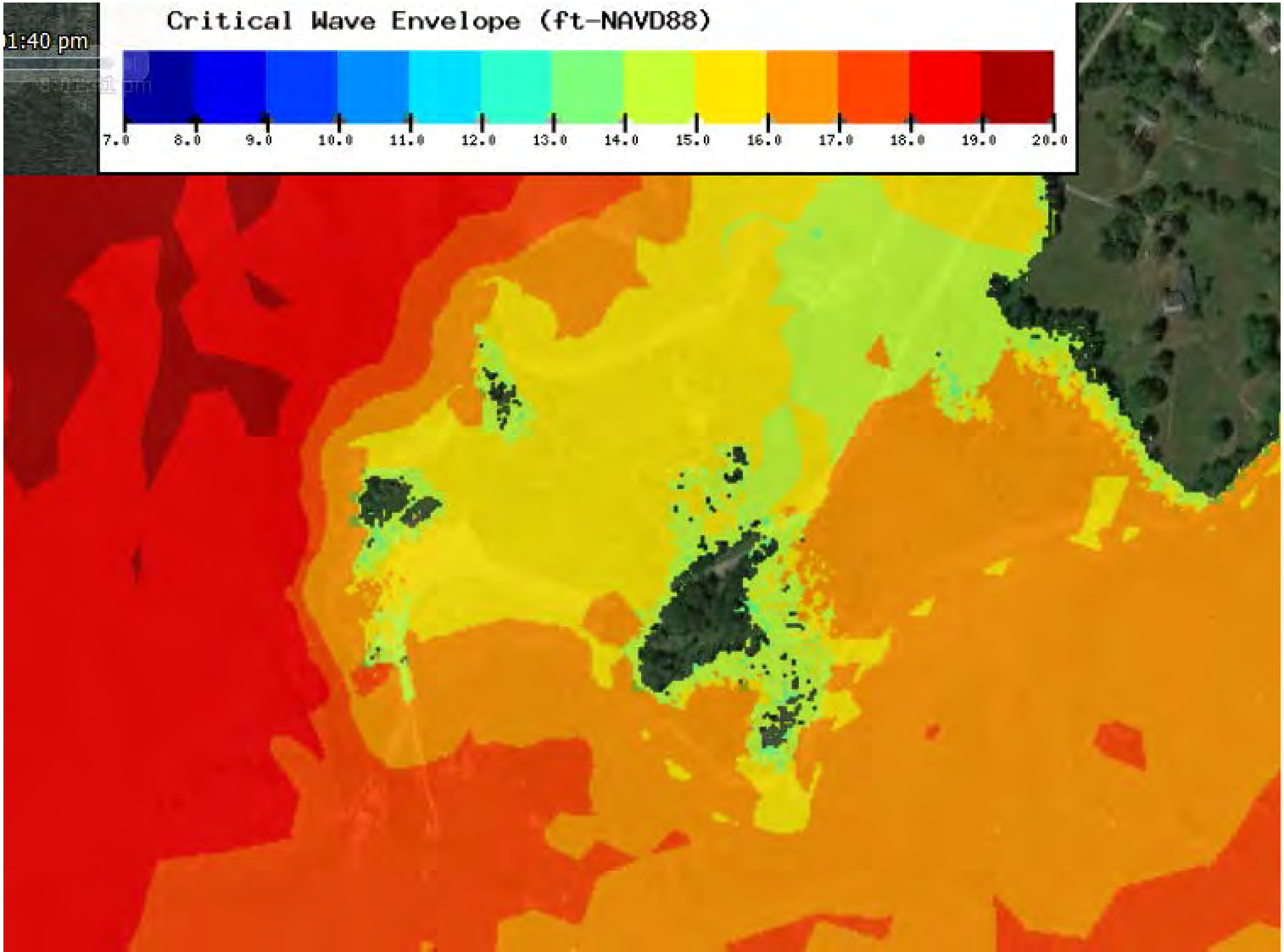
# Grindle Point Results

PenBay Model – 2067 sea level – 20-yr (5%) Wave Envelope



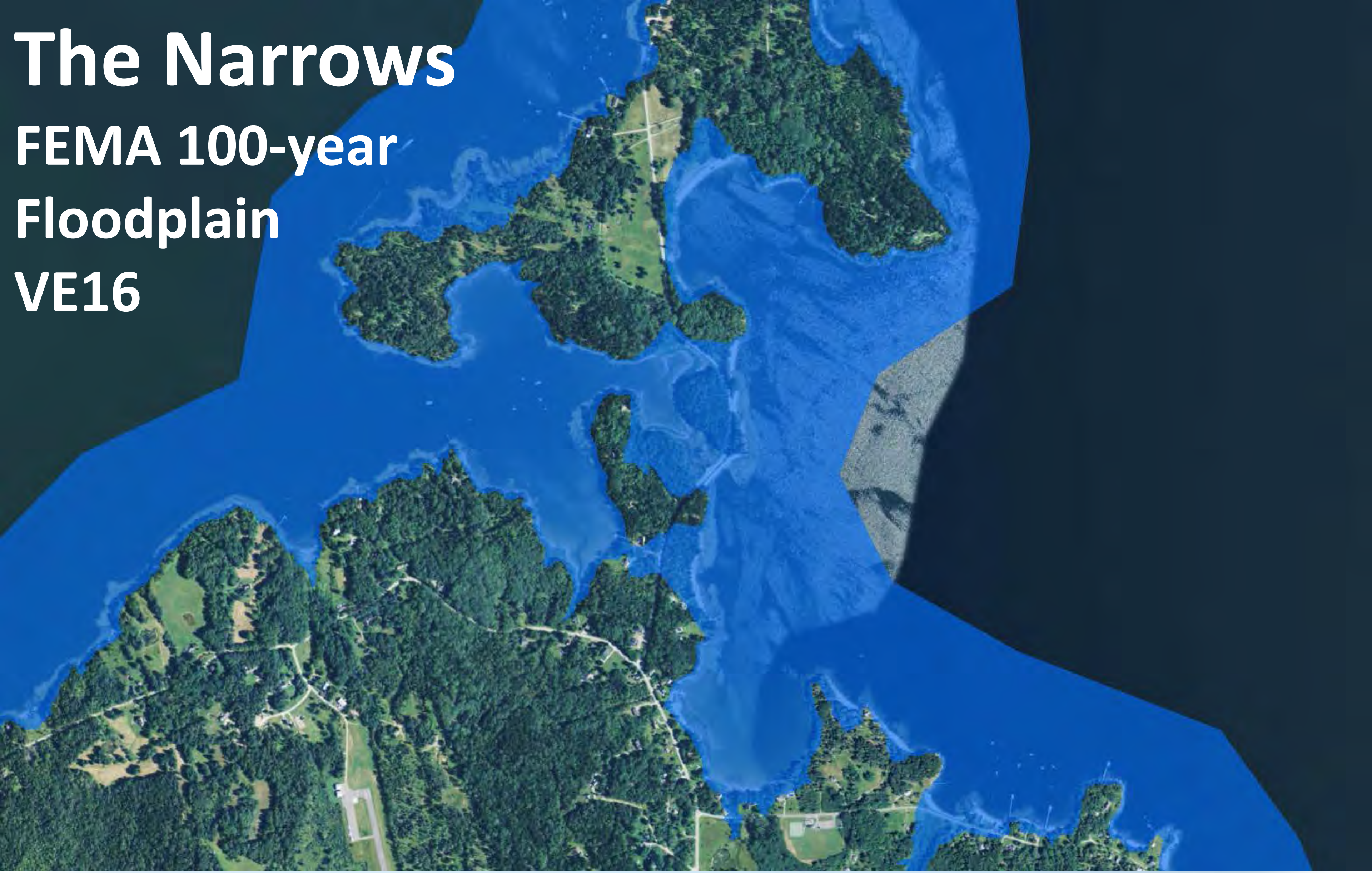
# Grindle Point Results

## PenBay Model – 2067 sea level – 100-yr (1%) Wave Envelope



# The Narrows

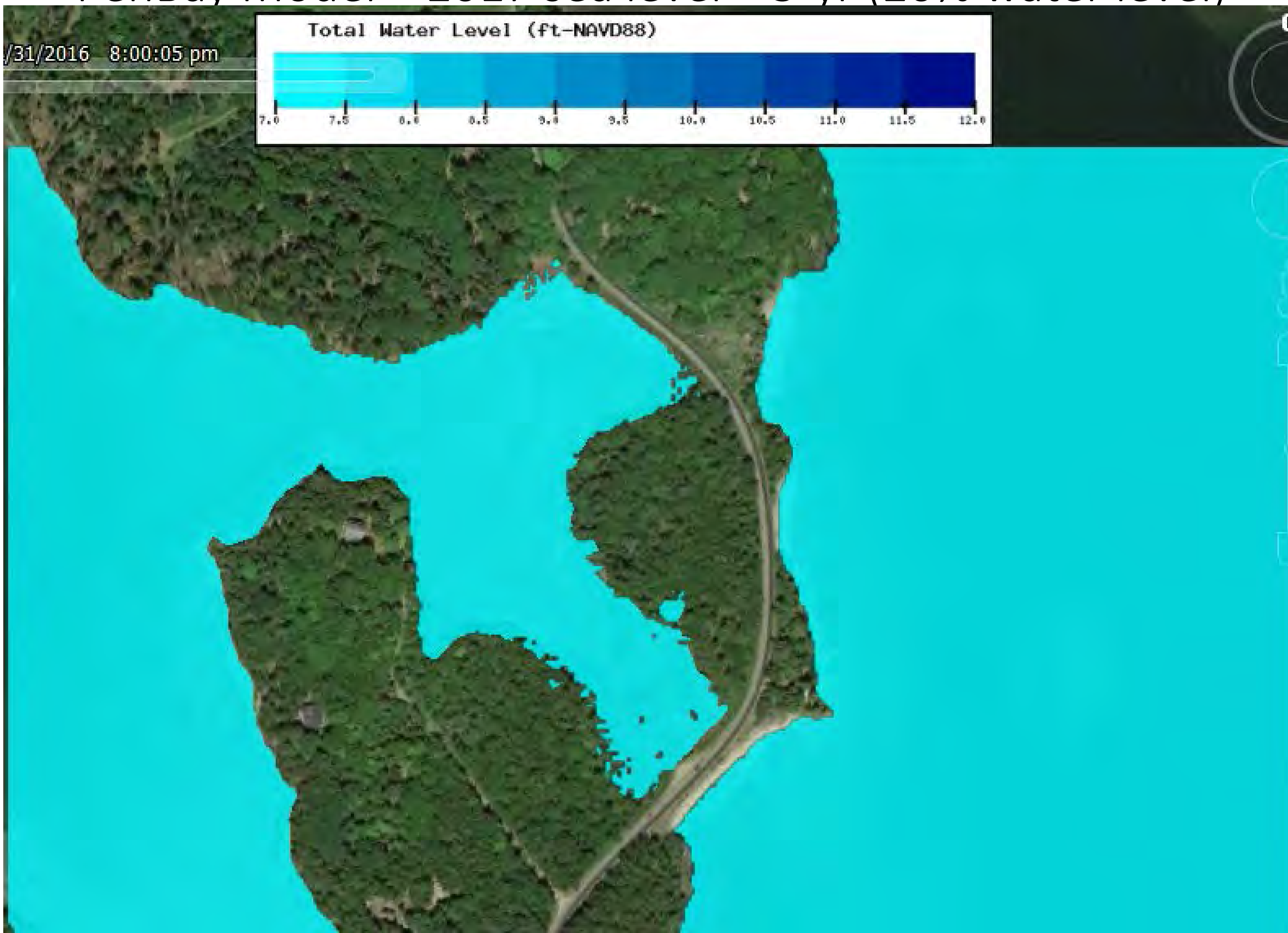
## FEMA 100-year Floodplain VE16



RANSOM

# The Narrows Results

## PenBay Model – 2017 sea level – 5-yr (20% water level)

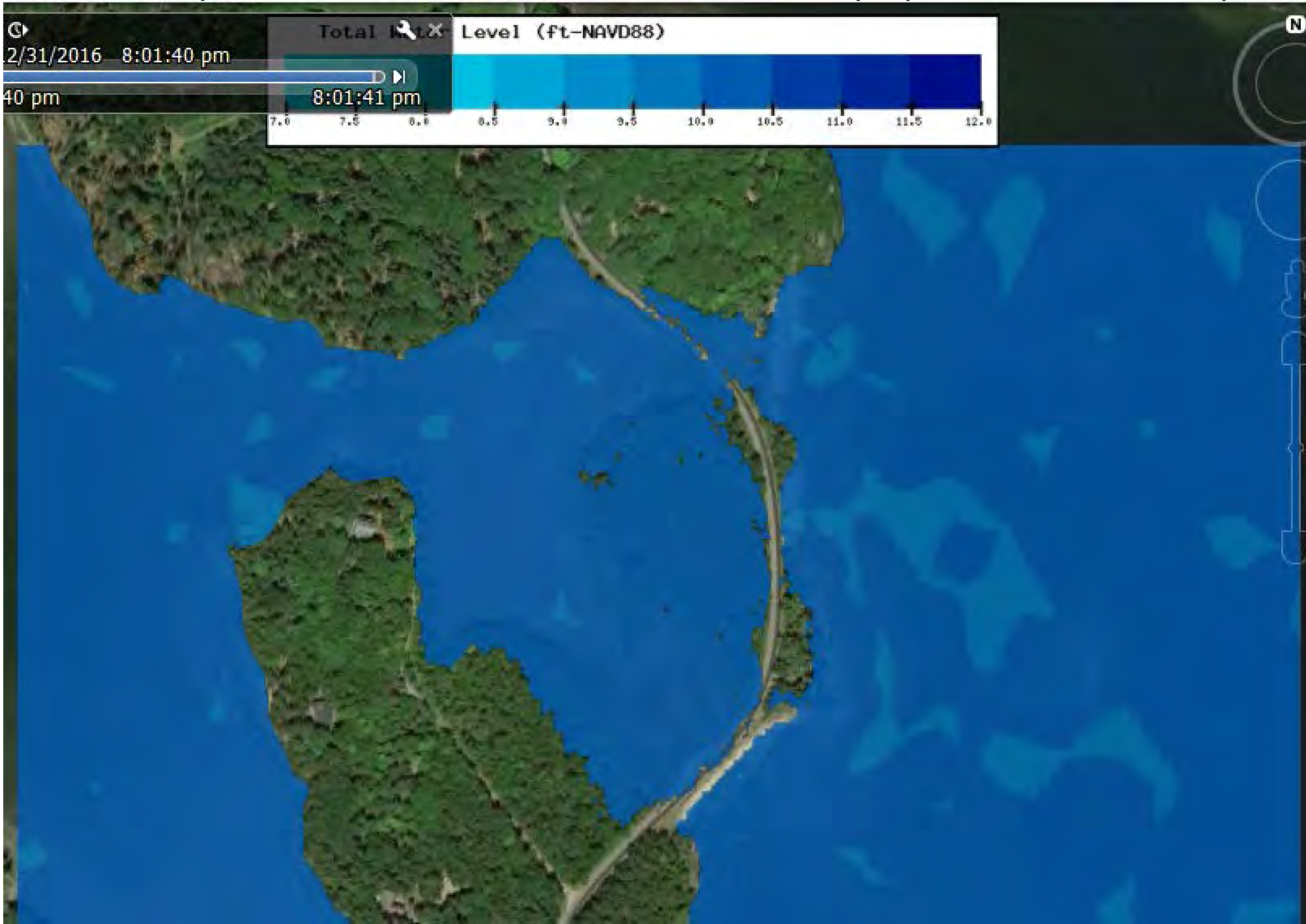


# The Narrows Results

PenBay Model – 2017 sea level – 20-yr (5% water level)

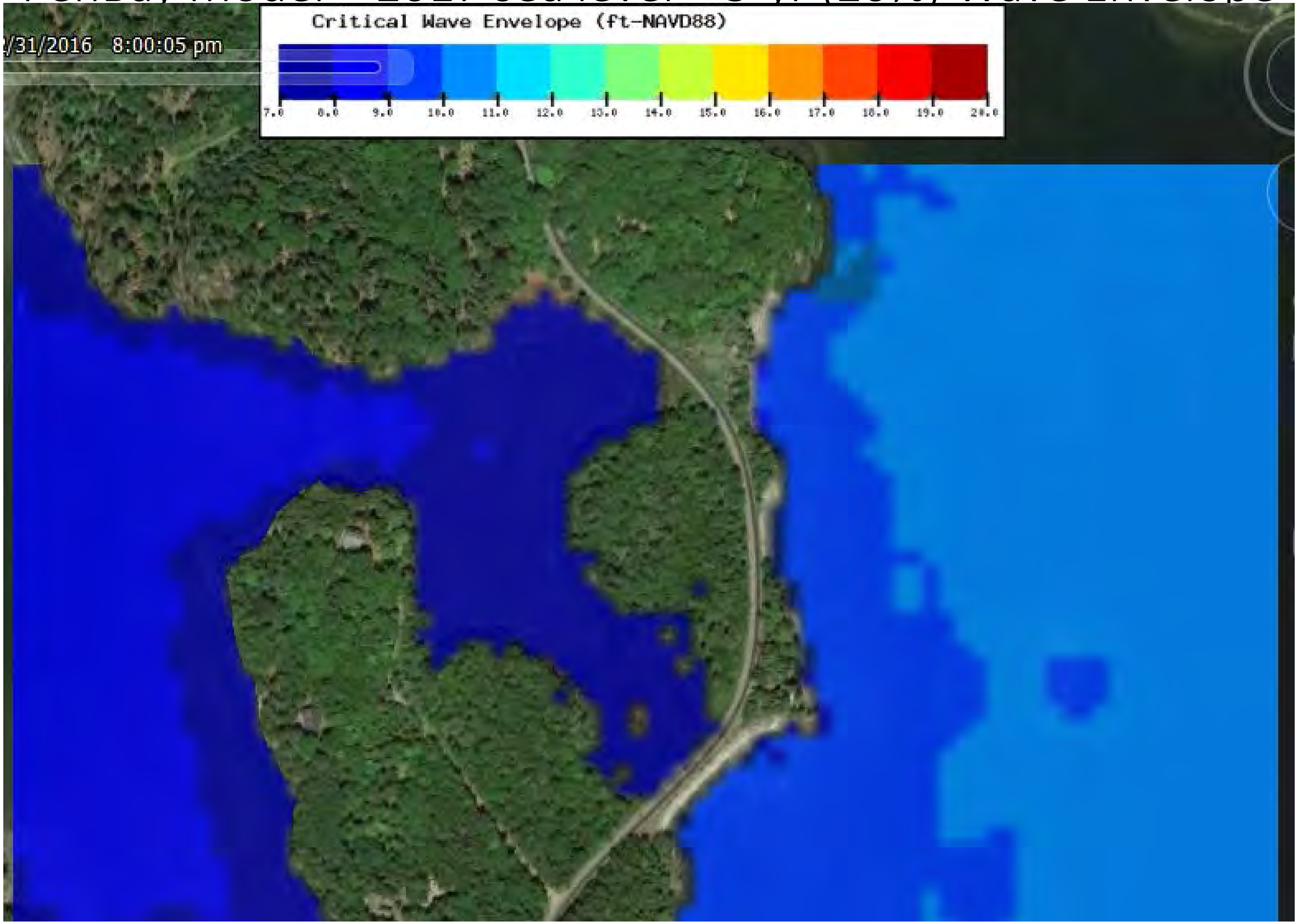
# The Narrows Results

PenBay Model – 2017 sea level – 100-yr (1% water level)



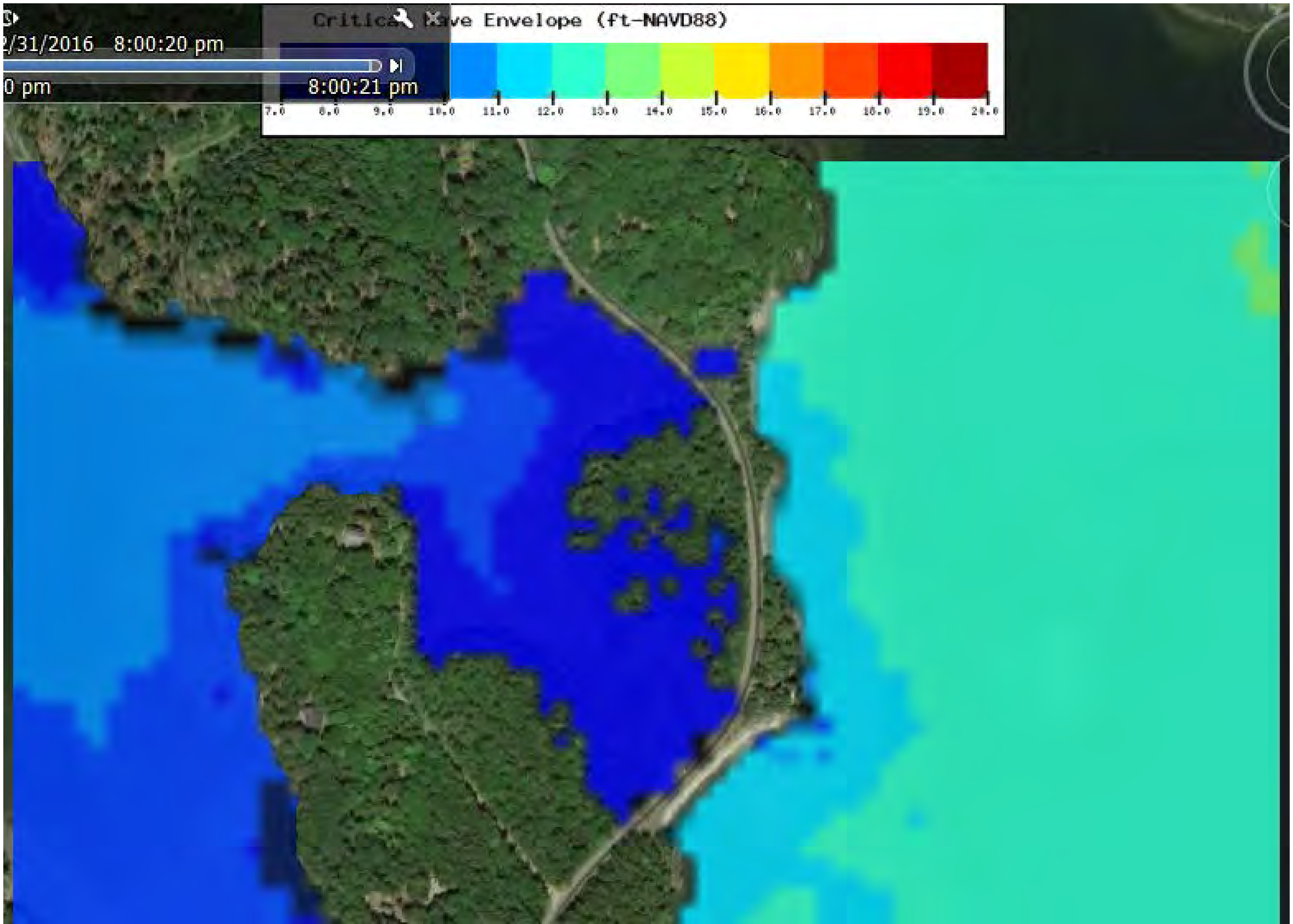
# The Narrows Results

## PenBay Model – 2017 sea level – 5-yr (20%) Wave Envelope

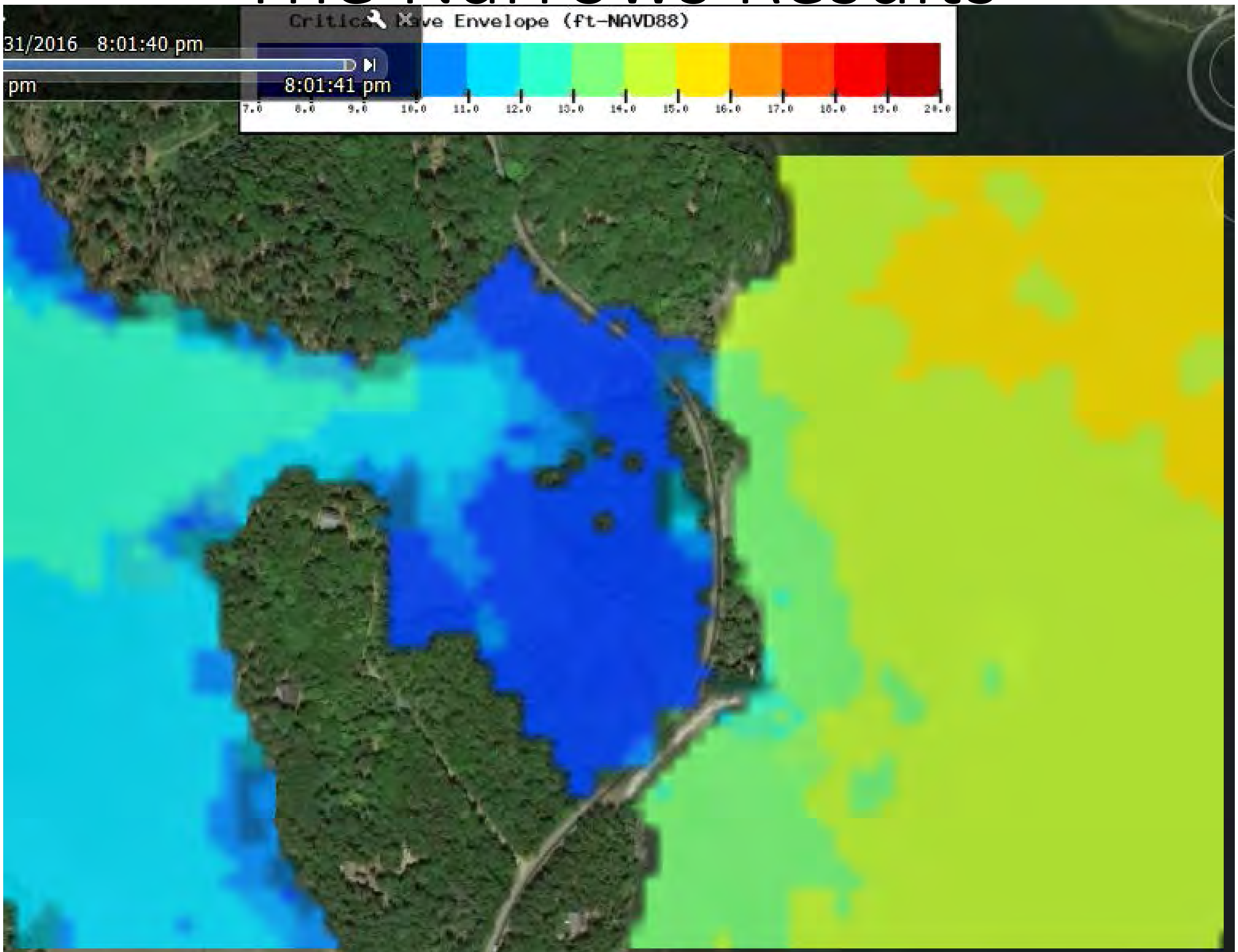


# The Narrows Results

## PenBay Model – 2017 sea level – 20-yr (5%) Wave Envelope

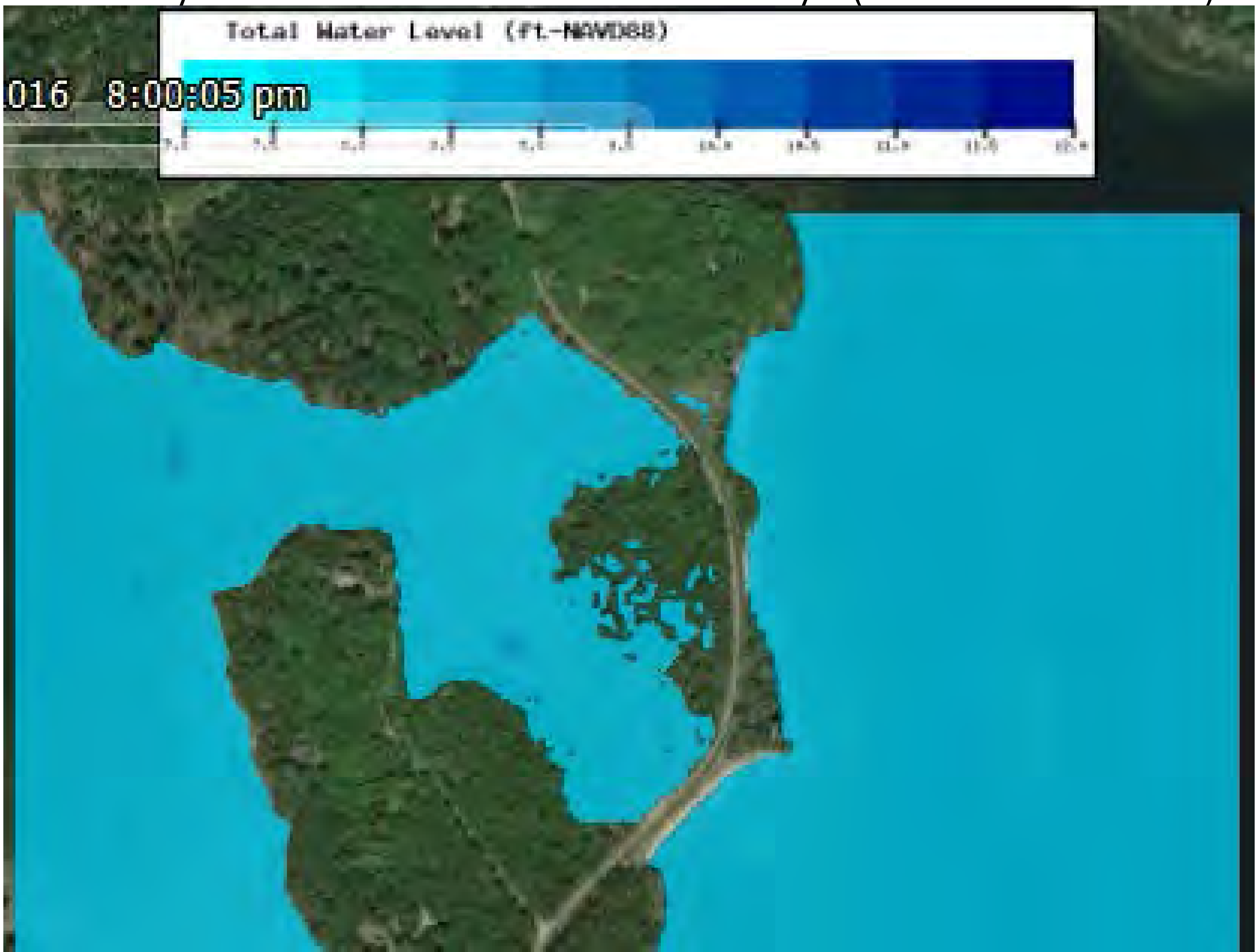


# The Narrows Results



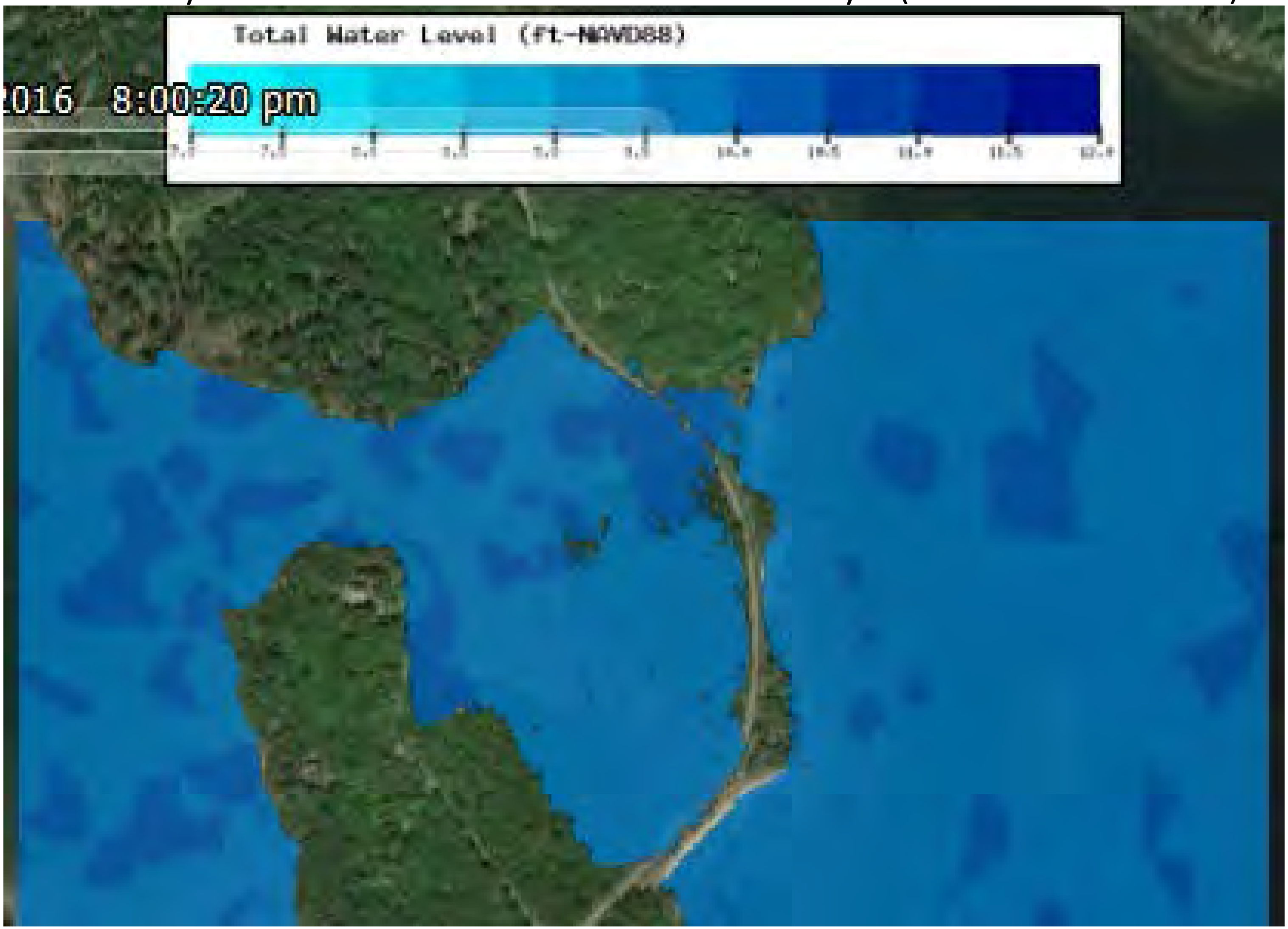
# The Narrows Results

## PenBay Model – 2037 sea level – 5-yr (20% water level)



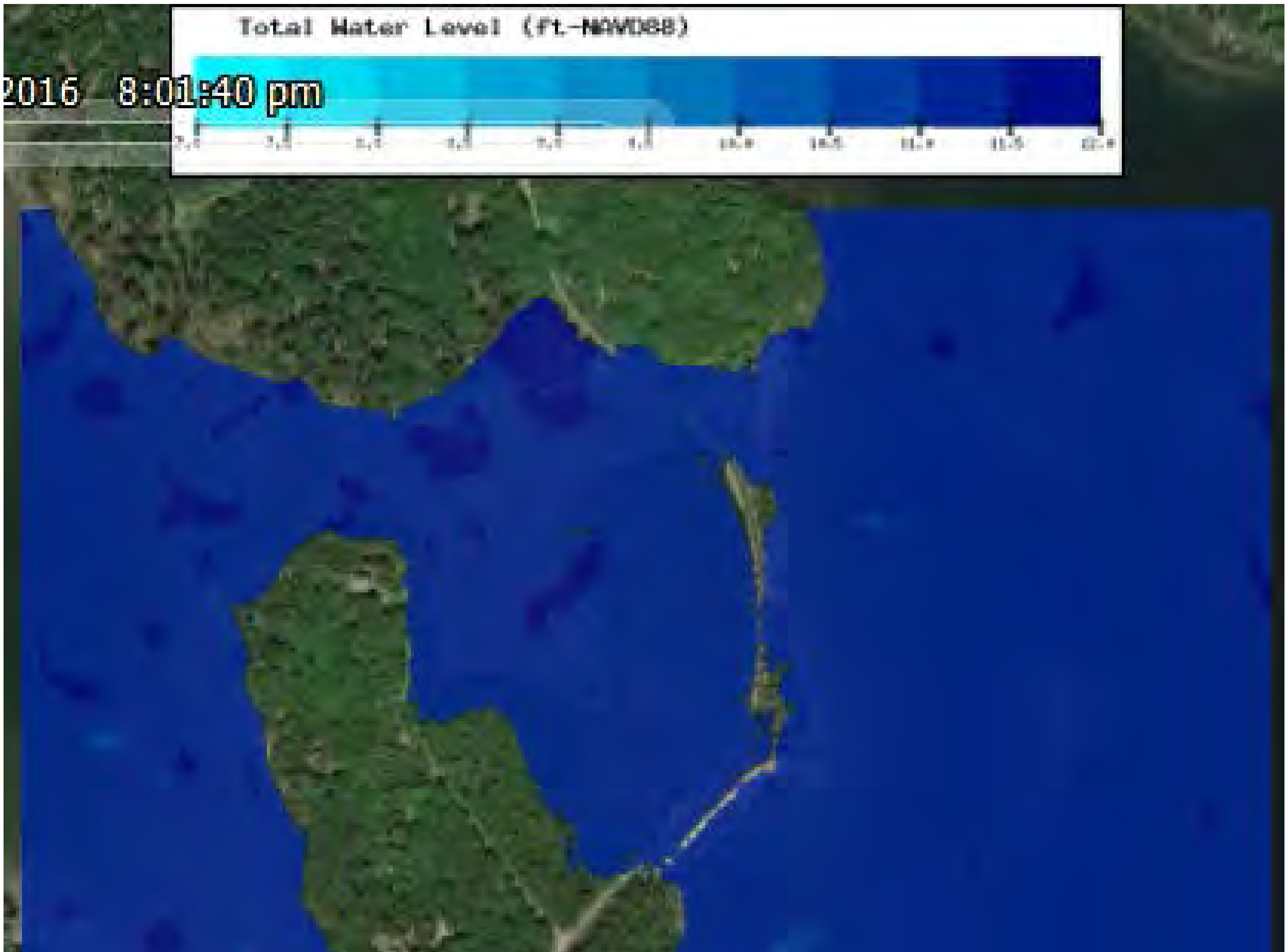
# The Narrows Results

## PenBay Model – 2037 sea level – 20-yr (5% water level)



# The Narrows Results

PenBay Model – 2037 sea level – 100-yr (1% water level)



# Acknowledgements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