GZA

WATERFRONT/COASTAL ENGINEERING AND DESIGN

GZA Metocean Data Analysis and Numerical Model Simulations – Nantucket, MA

June 26, 2019

Daniel Stapleton, PE

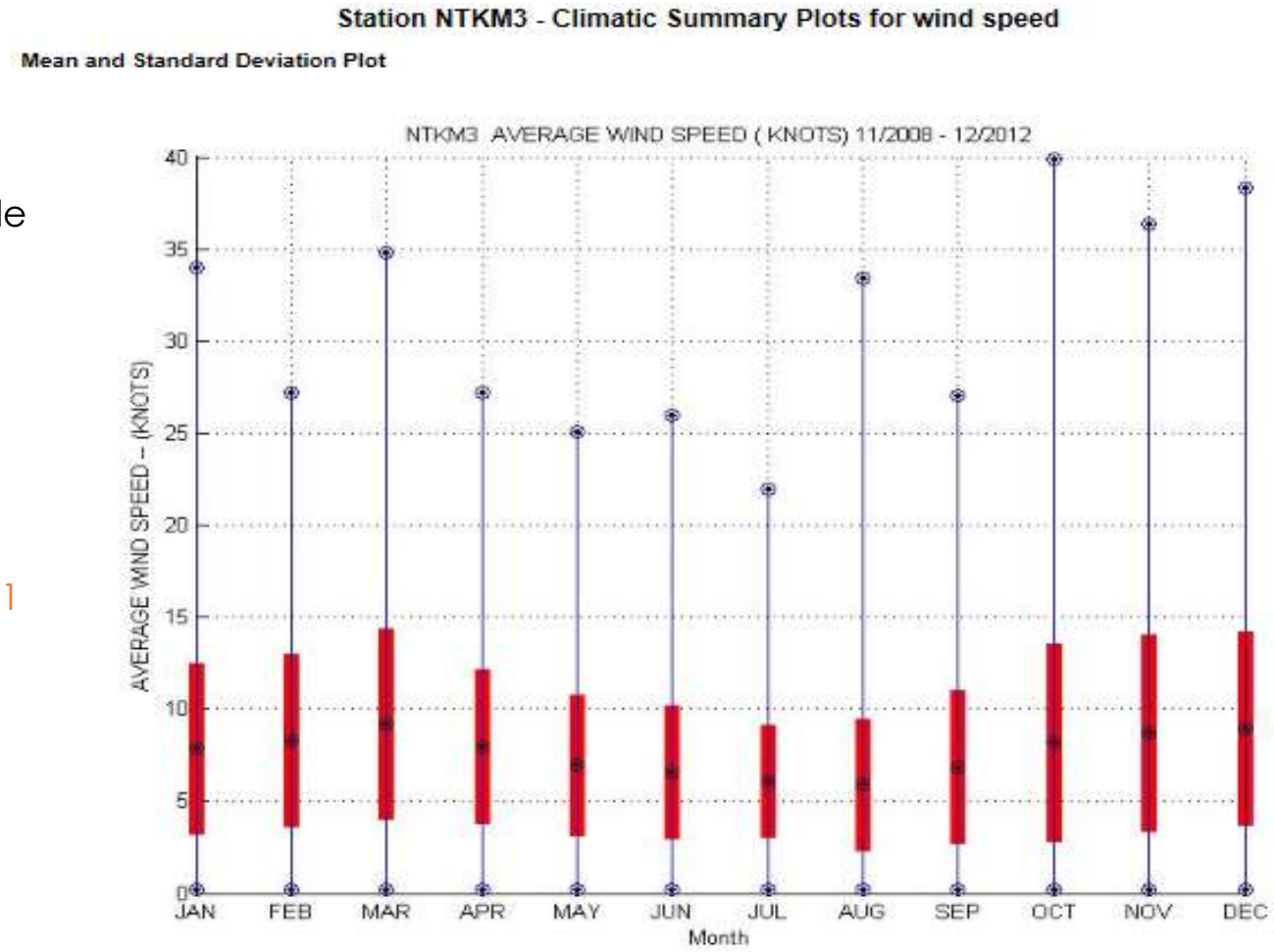
GZA Coastal Engineering Study

Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Wind Intensity and Direction

Prevailing Winds:

- NOAA National Data Buoy Center Station NTKM3 - 8449130 - Nantucket Island, MA (a land station), available for the period of November 2008 through December 2012. The data includes: a) 2-minute average wind speed by month; b) 5-second gust speed by month; c) peak gust speed; and d) 2-minute average wind speed by direction.
- Mean monthly wind speed: between 5 and 10 knots (+/- 6 to 12 mph)
- One standard deviation: upper bound 8 to 15 knots (+/- 1 to 17 mph)



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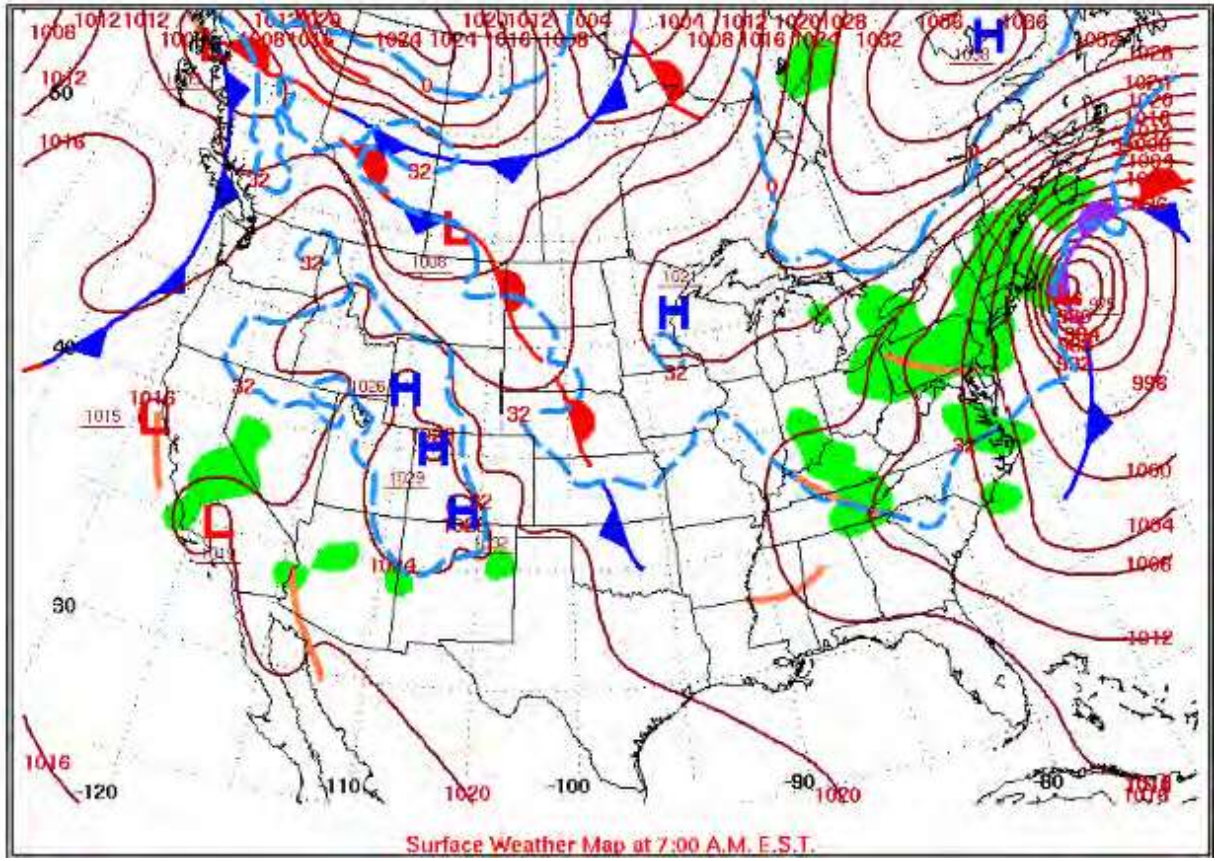
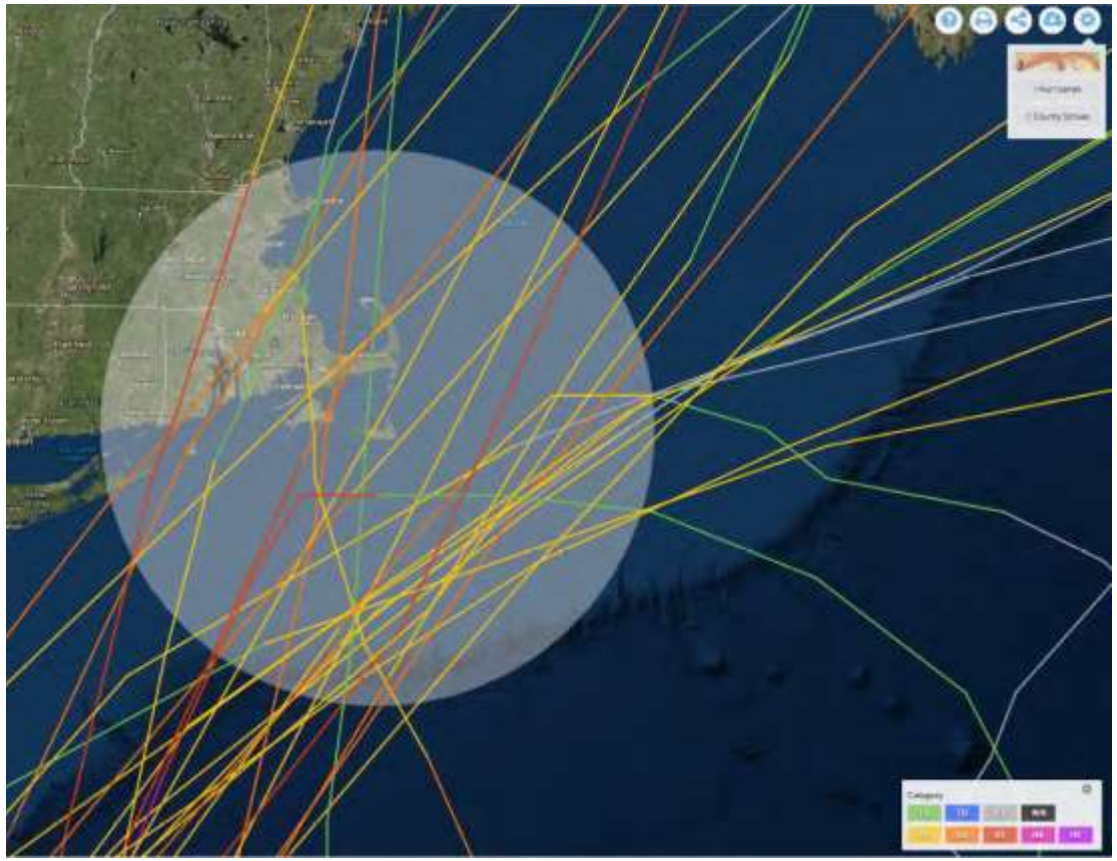
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Extreme waves, wind, water levels - two characteristic coastal storm types

Extratropical Nor'easters



Tropical Cyclones (Hurricanes)



GZA Coastal Engineering Study

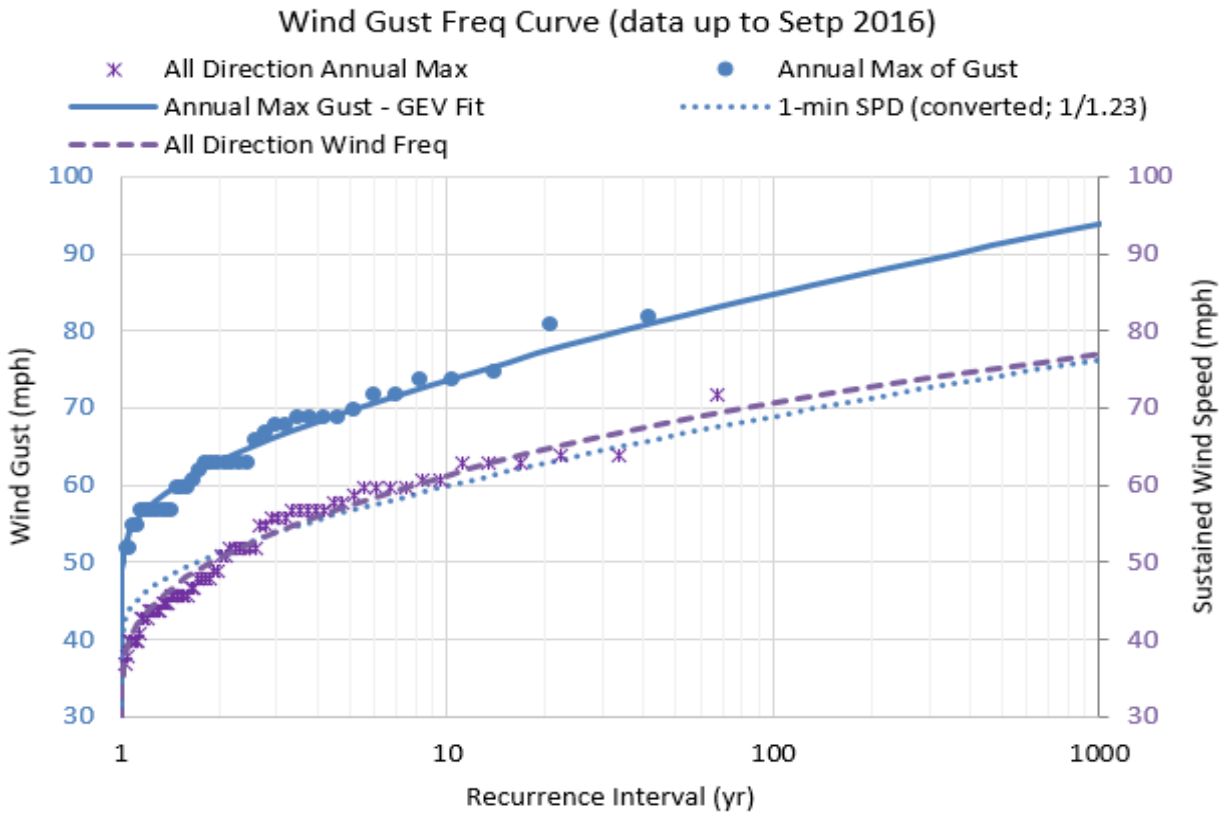
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Wind Intensity and Direction

Extreme Winds:

- Nantucket Airport - Nantucket Island, MA (a land station), available for the 71 year record. The data includes: a)1/2-minute average wind speed by month; b) 3-second gust speed by month; c) peak gust speed; and d) ½ -minute average wind speed by direction.
- Directional Wind speeds:

Direction	Maximum Wind Speed (mph)[1]	Occurrence Date
North Wind (315° to 45°)	64	11/13/2014
East Wind (45° - 135°)	60	6/20/1974
South Wind Freq (135° - 225°)	72	9/2/1984
West Wind Freq (225° - 315°)	61	2/17/1982
All Direction Wind	72	9/2/1984



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Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Wind Intensity and Direction

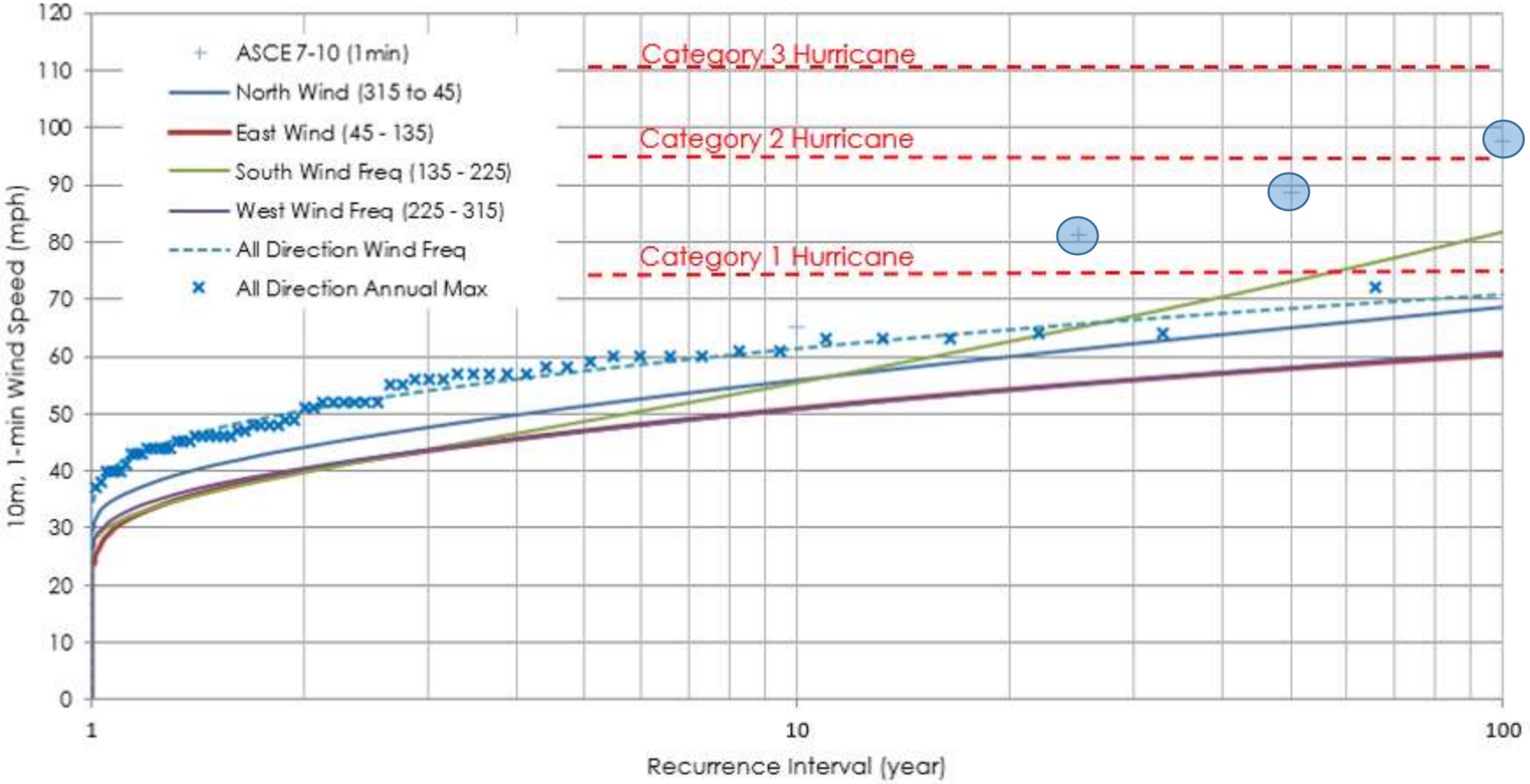

Figure 3 – GZA GEV analysis of Nantucket Airport Wind Speeds (1-minute, 10-meter); ASCE/SEI 7-10 converted wind speeds shown for comparison

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Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Tidal Datums

	ft-MLLW	ft-NAVD88
MHHW	3.57	1.53
MHW	3.23	1.19
NAVD88	2.04	0
MSL	1.77	-0.27
MTL	1.72	-0.32
MLW	0.2	-1.84
MLLW	0	-2.04

Prevailing Water Levels:

- NOAA Nantucket Tide Station 8449130

Station Info ▾ Tides/Water Levels ▾ Meteorological Obs Phys. Oceanography

Nantucket Island, MA - Station ID: 8449130

Station Info Today's Tides Photos Sensor Information Observations Directions and Map Available Products

Established:	Oct 04, 1963
Time Meridian:	0° E
Present Installation:	Sep 18, 1990
Date Removed:	N/A
Water Level Max (ref MHHW):	4.30 ft. Oct 30, 1991
Water Level Min (ref MLLW):	-2.14 ft. Feb 12, 1981
Mean Range:	3.04 ft.
Diurnal Range:	3.57 ft.
Latitude:	41° 17.1' N
Longitude:	70° 5.8' W
NOAA Chart#:	13241
Met Site Elevation:	7.1 ft. above MSL

Today's Tides (LST)

next tide at 2:00 PM high

2:11 AM	high	2.7 ft.
7:27 AM	low	0.6 ft.
2:00 PM	**high**	**3.5 ft.**
8:16 PM	low	0.0 ft.

Nantucket Island, MA

7 more station photos available, click to view

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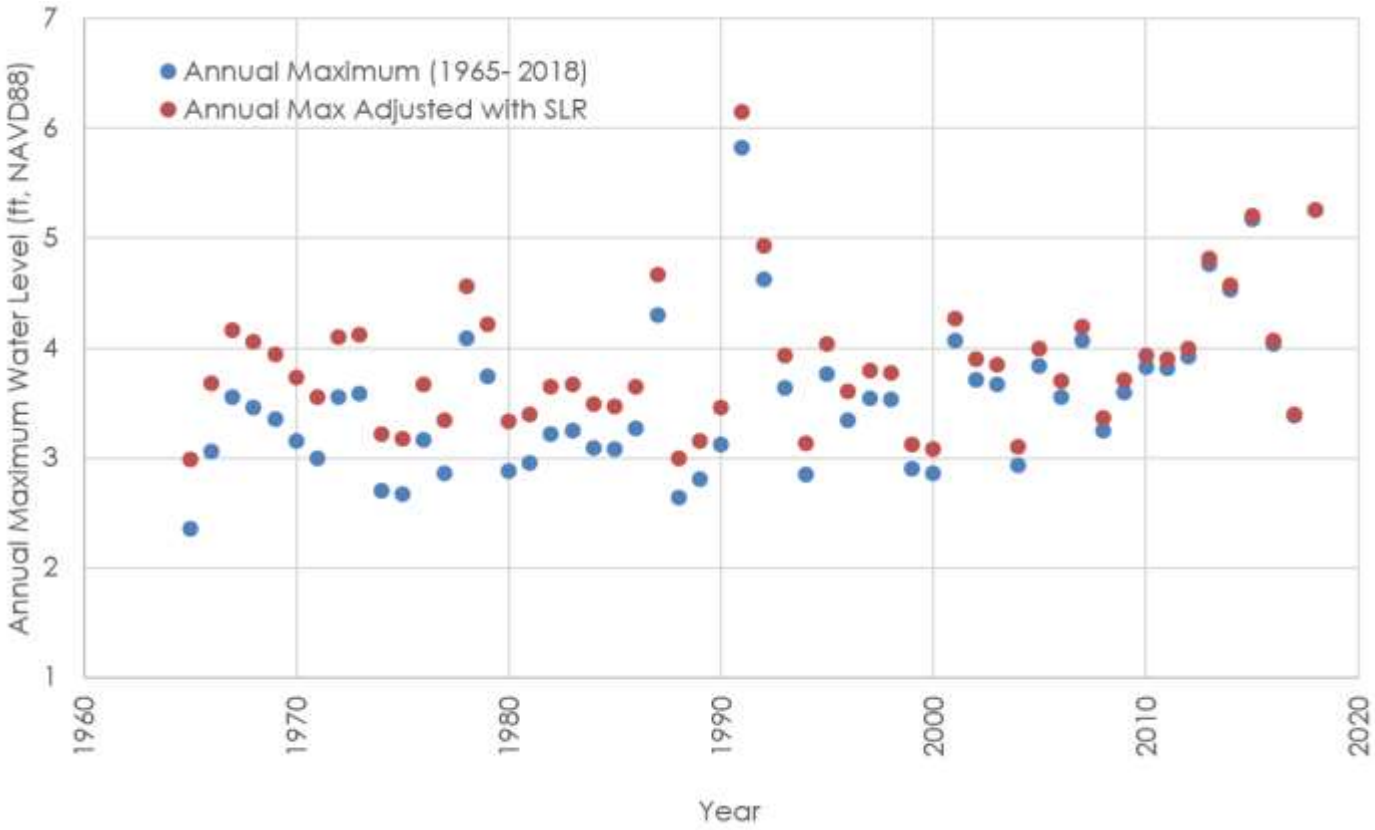
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Extreme Water Levels

Extreme Water Levels:

- Data Sources:
  - NOAA Nantucket Tide Station
  - FEMA FIS and FIRMs
  - USACE North Atlantic Coast Comprehensive Study (NACCS)
- Coastal Flooding Components:
  - Stillwater elevations
  - Wind-generated waves
  - Wave set-up
  - Wave crest elevation
  - Wave condition (breaking or non-breaking)



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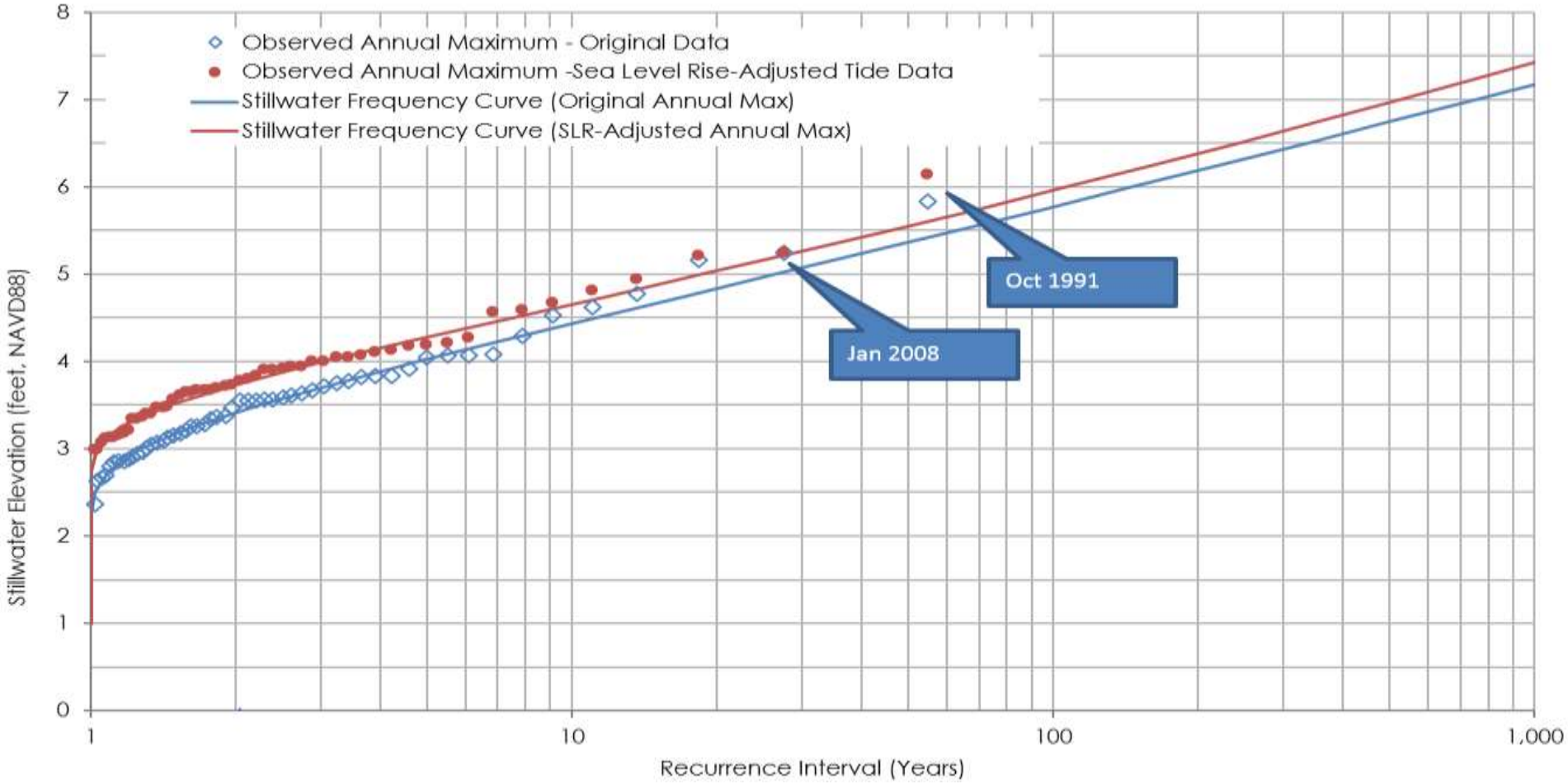
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Extreme Water Levels



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Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Extreme Water Levels

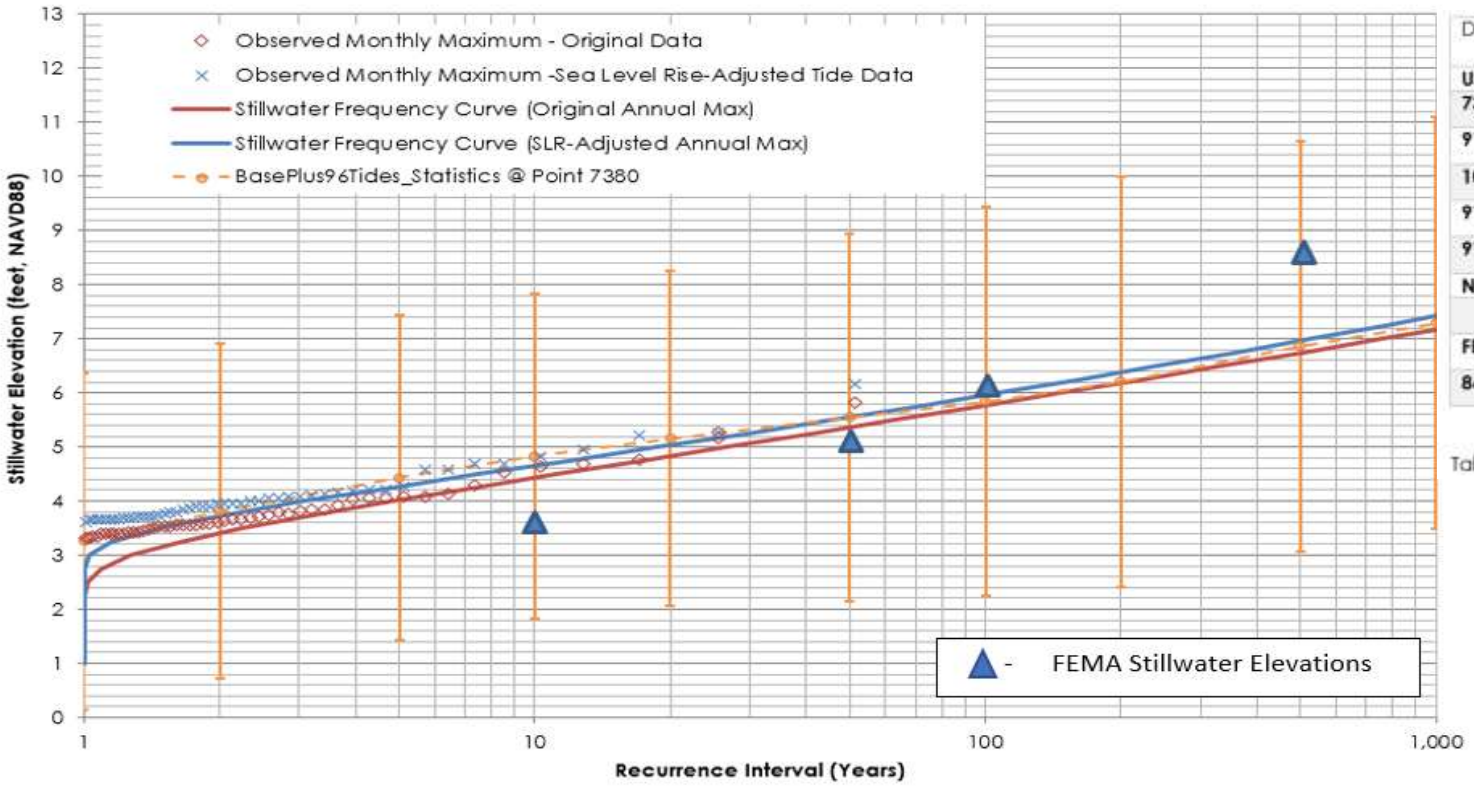

Figure 11: Combined Stillwater Flood-Frequency Data from Multiple Data Sources

Data Source	Mean Stillwater Elevation (SWEL)					
	1 yr	10 yr	20 yr	50 yr	100 yr	500 yr
USACE NACCS						
7380	3.3	4.8	5.2	5.6	5.8	6.9
9187	3.3	4.8	5.2	5.5	5.8	6.9
10082	3.3	4.8	5.1	5.5	5.8	7.1
9186	3.3	4.8	5.1	5.8	6.5	8.1
9185	3.3	4.9	5.4	6.3	7.1	8.9
NOAA Tide Station						
	3.6	4.6	5.0	5.6	6.0	7.0
FEMA Transect 25						
8683	-	3.6	-	5.1	6.1	8.6

Table 2: Combined Stillwater Flood-Frequency Data from Multiple Data Sources

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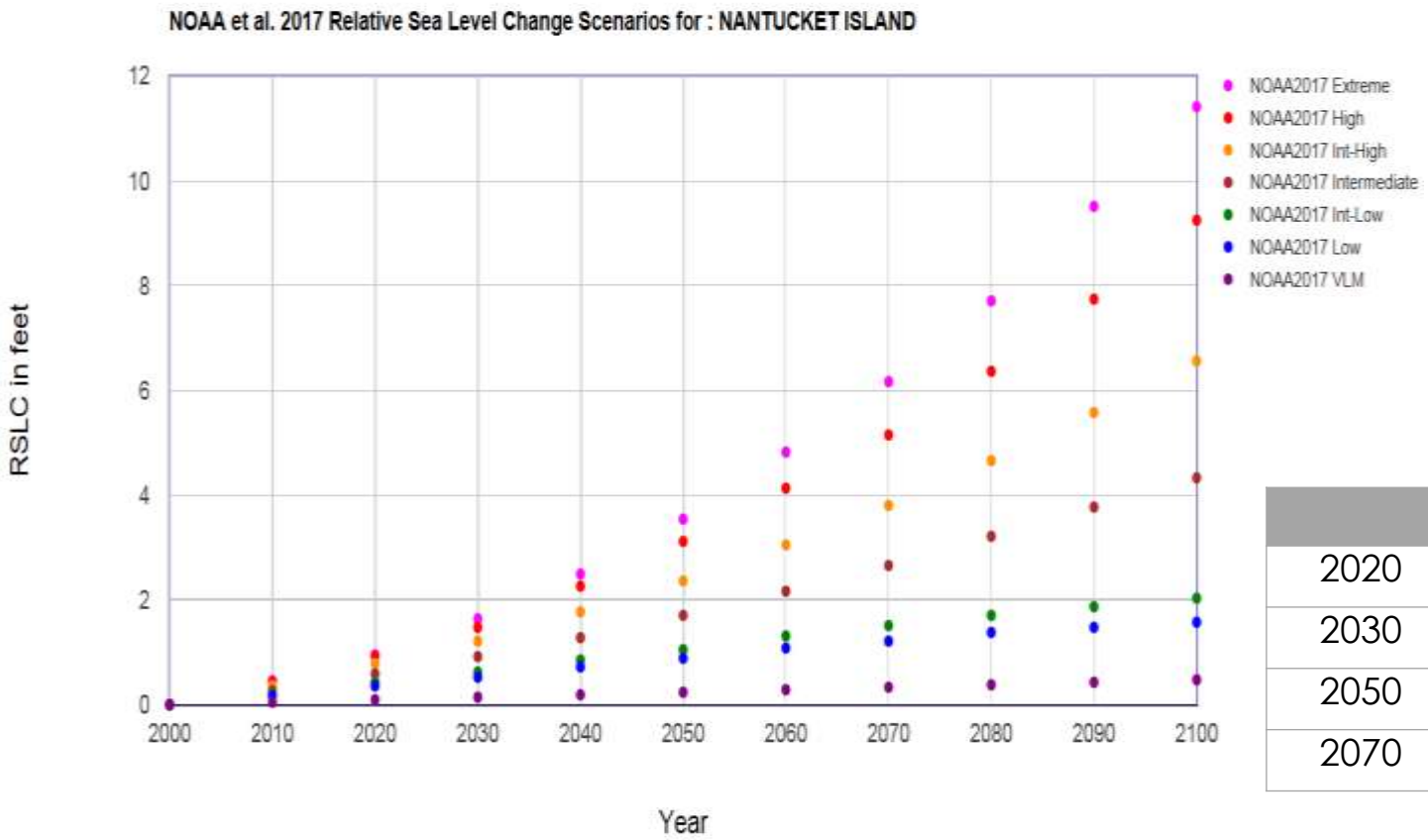
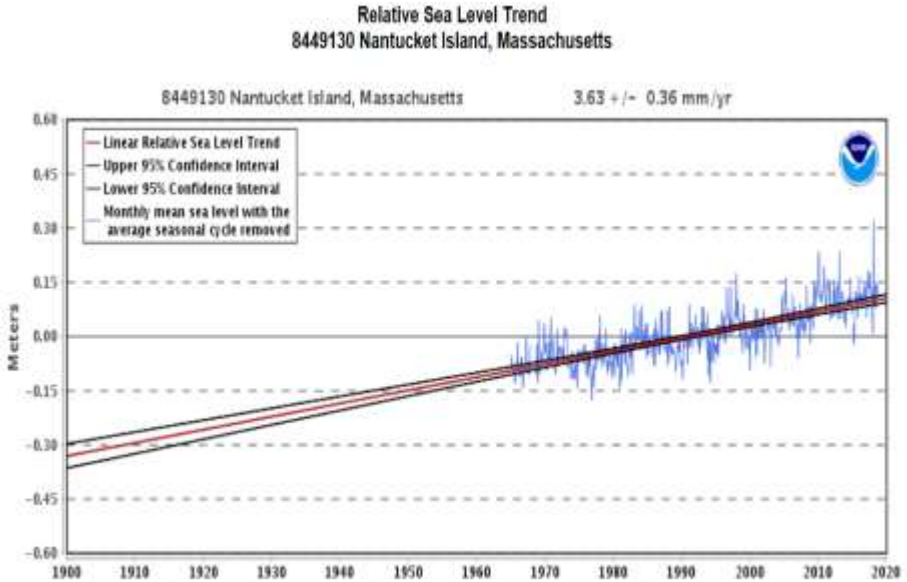
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Sea Level Rise



Predicted Sea Level Rise (NOAA 2017)



Observed Sea Level Rise (avg. 0.14 in/yr; 0.12 ft/10 years; 1.2 feet/100-years)

	Low	Int-Low	Int	Int-High	High	Extreme
2020	-	-	-	-	-	-
2030	0.16	0.26	0.56	0.85	1.12	1.28
2050	0.53	0.69	1.35	2.0	2.76	3.18
2070	0.85	1.15	2.30	3.45	4.79	5.81

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Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Effect of Sea Level Rise on Extreme Water Levels

Data Source	Mean Stillwater Elevation (SWEL)					
	1 yr	**10 yr**	**20 yr**	**50 yr**	**100 yr**	**500 yr**
USACE NACCS 7380						
Year 2020	3.3	4.8	5.2	5.6	5.8	6.9
Year 2030	3.9	5.4	5.8	6.2	6.4	7.5
Year 2050	4.7	6.2	6.6	7.0	7.2	8.3
Year 2070	5.6	7.1	7.5	7.9	8.1	9.2

Table 6: Predicted Water Levels for different Recurrence Intervals at Nantucket assuming NOAA 2017 Intermediate SLR Projection

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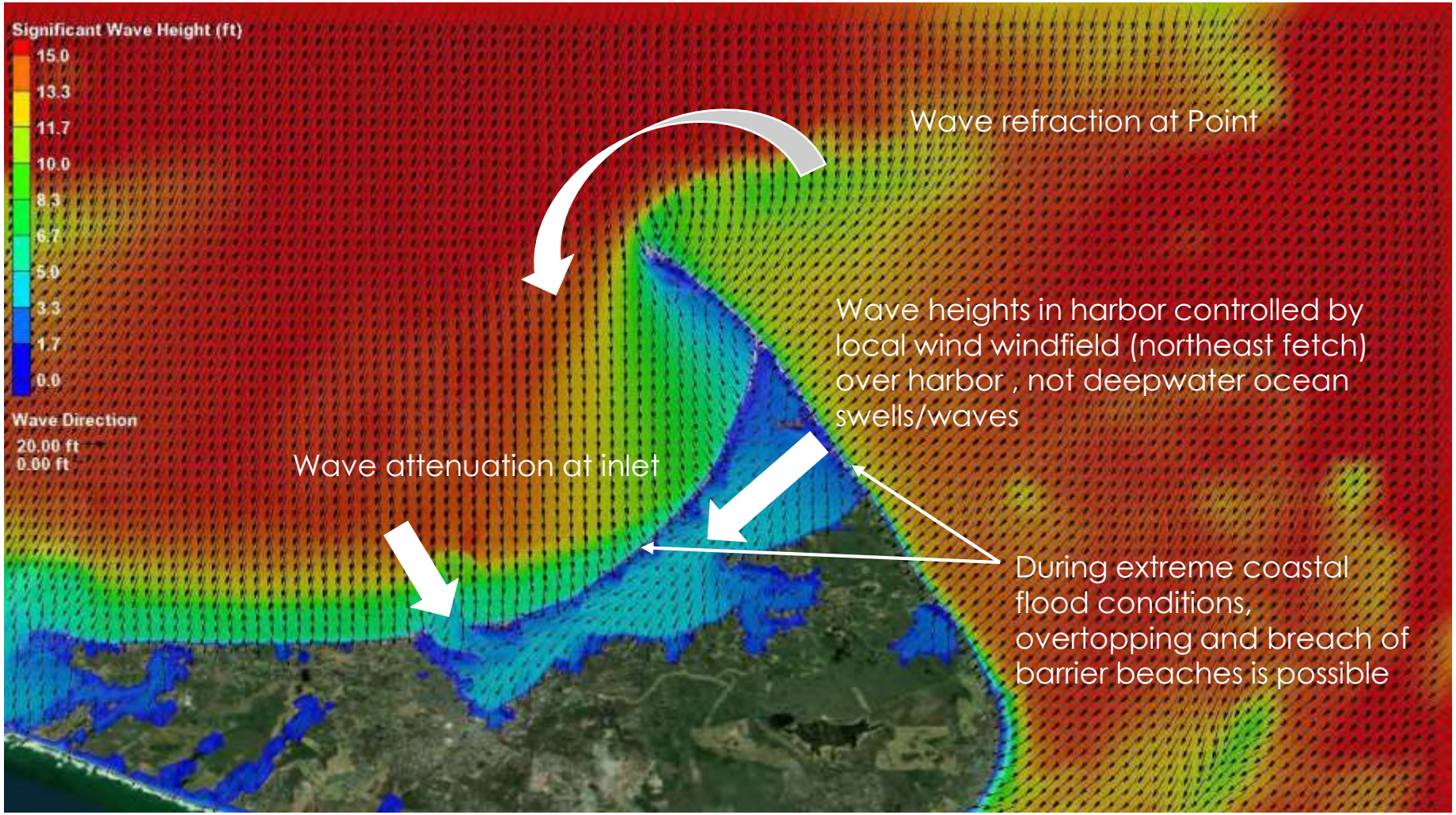
Metocean Data Analysis and Numerical Wave Modeling

Study Results (Metocean Data Analysis): Wave Simulation Nantucket Harbor



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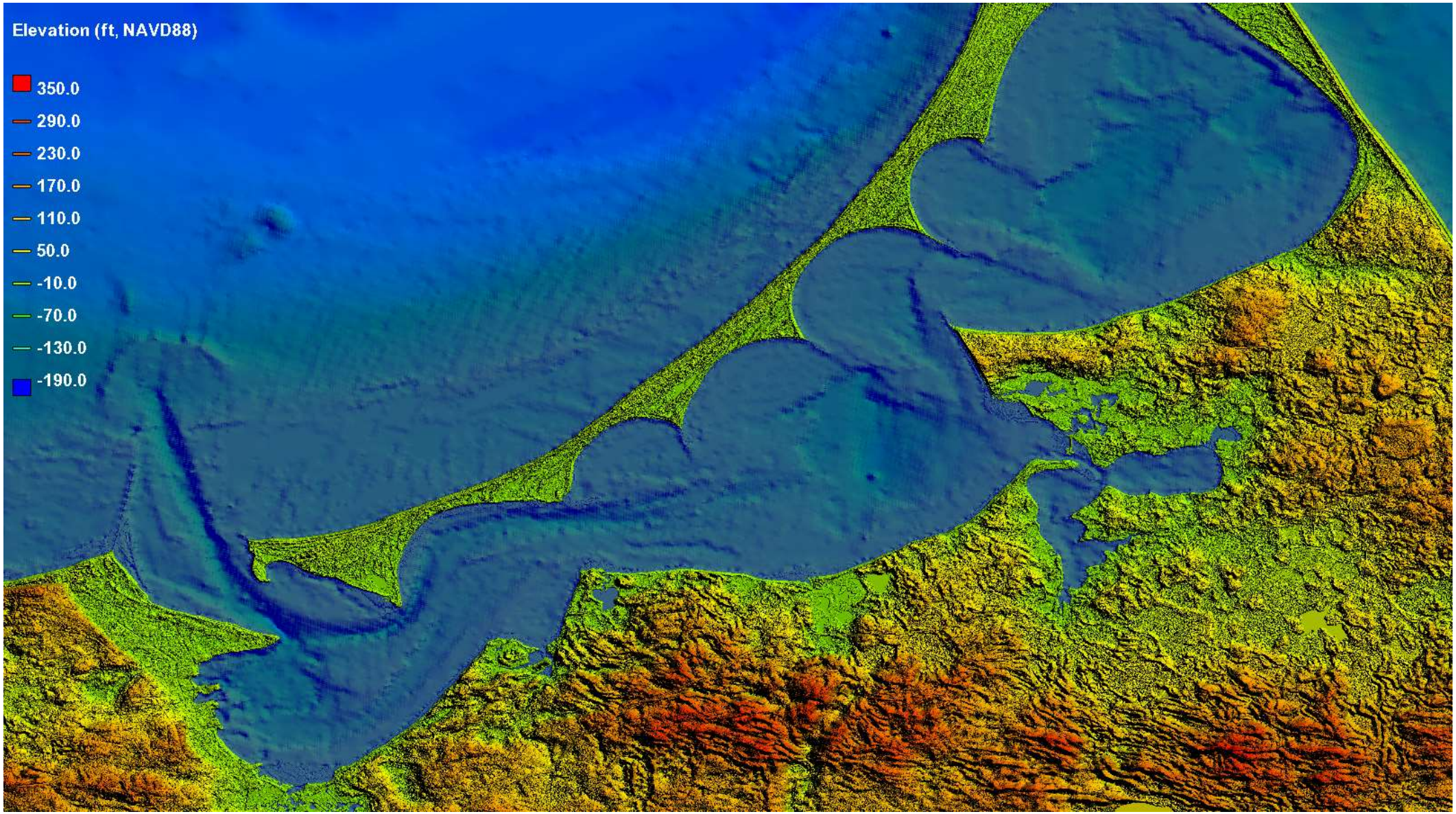
Metocean Data Analysis and Numerical Wave Modeling

(Bathytopo Data)



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Metocean Data Analysis and Numerical Wave Modeling

(Bathytopo Data)

GZA Coastal Engineering Study

Metocean Data Analysis and Numerical Wave Modeling

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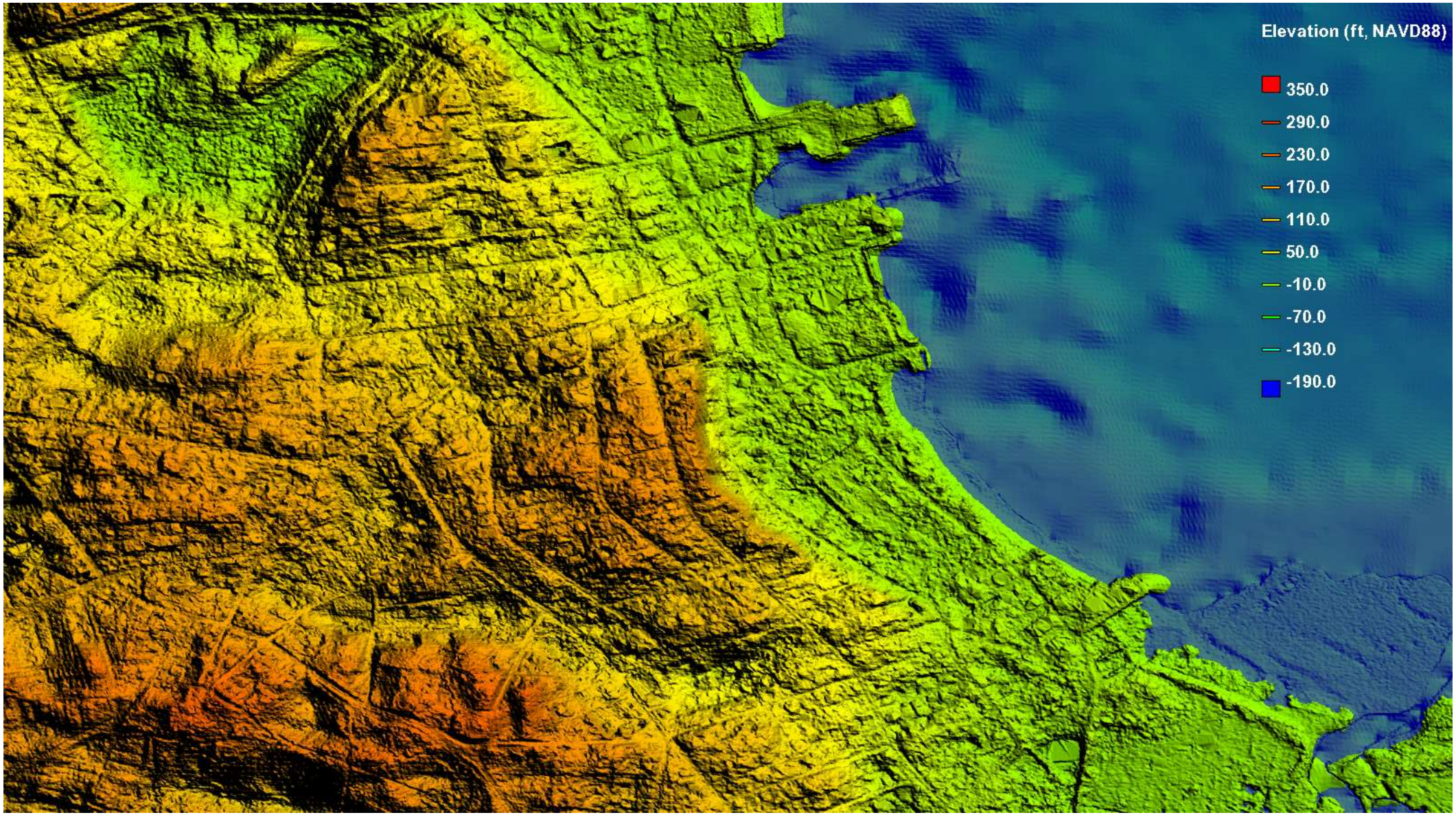

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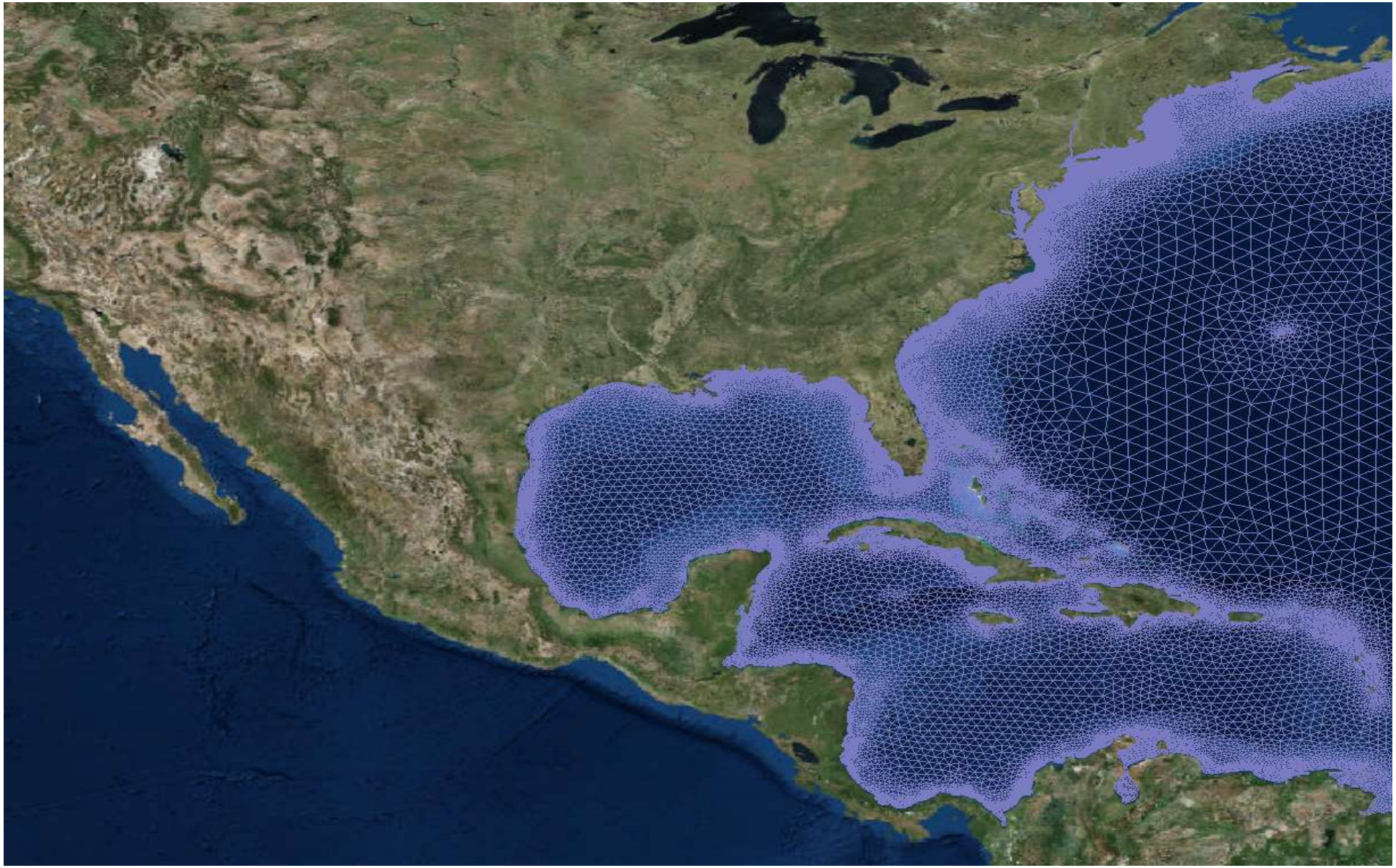
Metocean Data Analysis and Numerical Wave Modeling

(Modeling Mesh)



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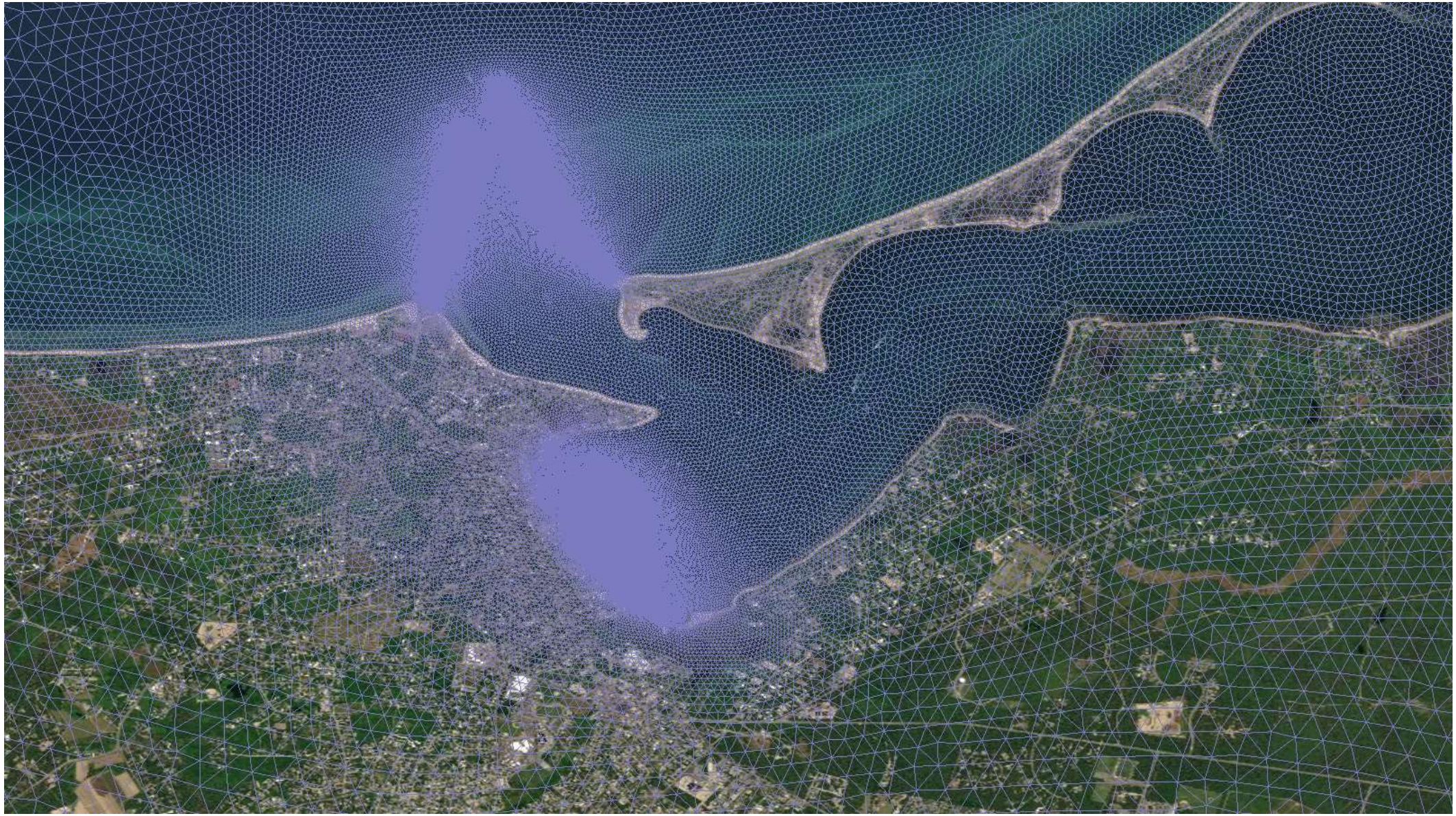
Metocean Data Analysis and Numerical Wave Modeling

(Modeling Mesh)

GZA Coastal Engineering Study

Metocean Data Analysis and Numerical Wave Modeling

(Modeling Mesh)



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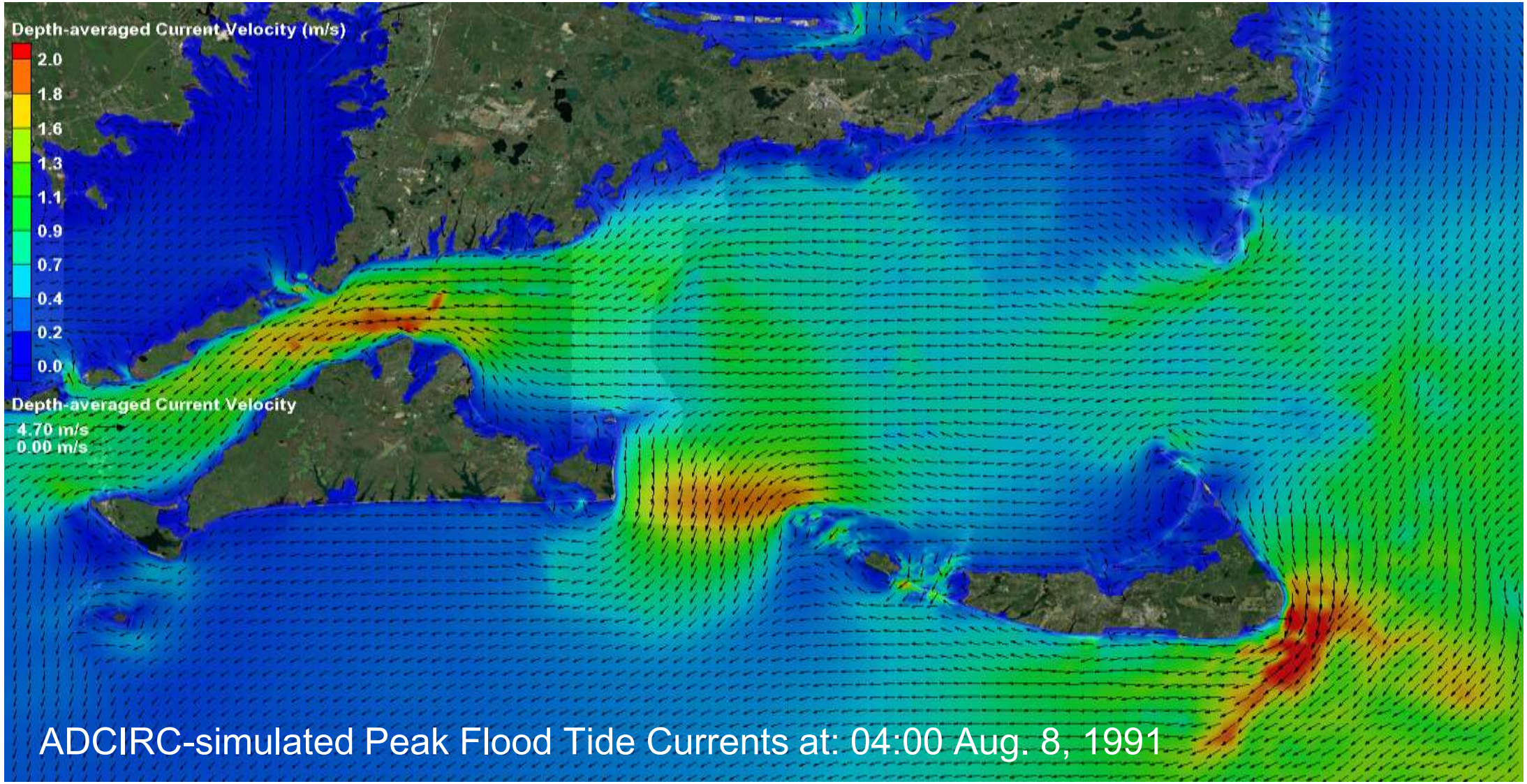
Metocean Data Analysis and Numerical Wave Modeling

(Tidal Circulation Model: ADCIRC)



ADCIRC-simulated Peak Flood Tide Currents at: 04:00 Aug. 8, 1991

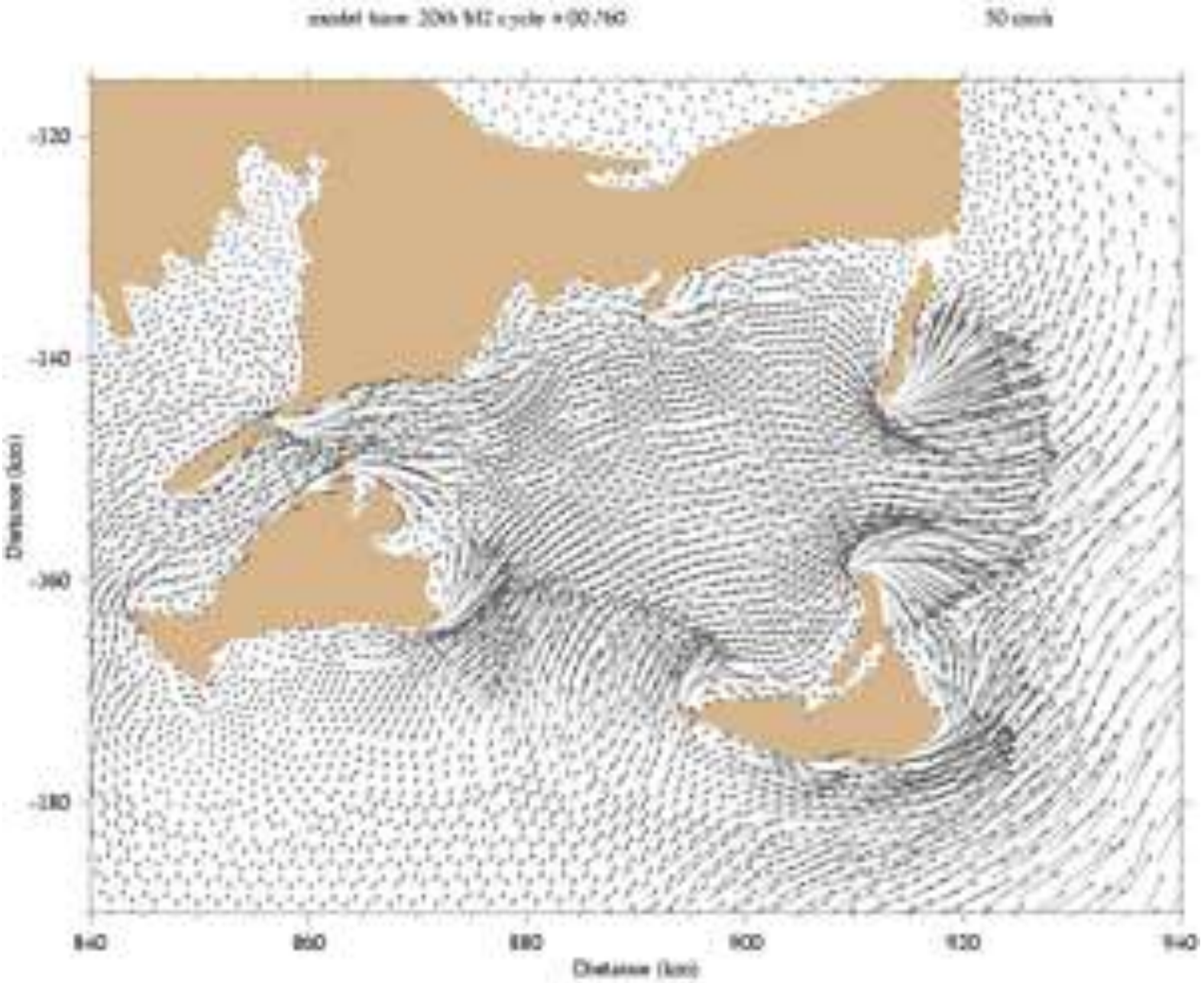
UMASS Dartmouth

FVCOM Tidal Simulation

Finite -Volume Coastal Ocean Model (FVCOM) developed by Chen et al. (2006a-b)

University of Massachusetts, Dartmouth, MA

[Reference: http://fvcom.smast.umassd.edu/research_projects/Nsound/](http://fvcom.smast.umassd.edu/research_projects/Nsound/)



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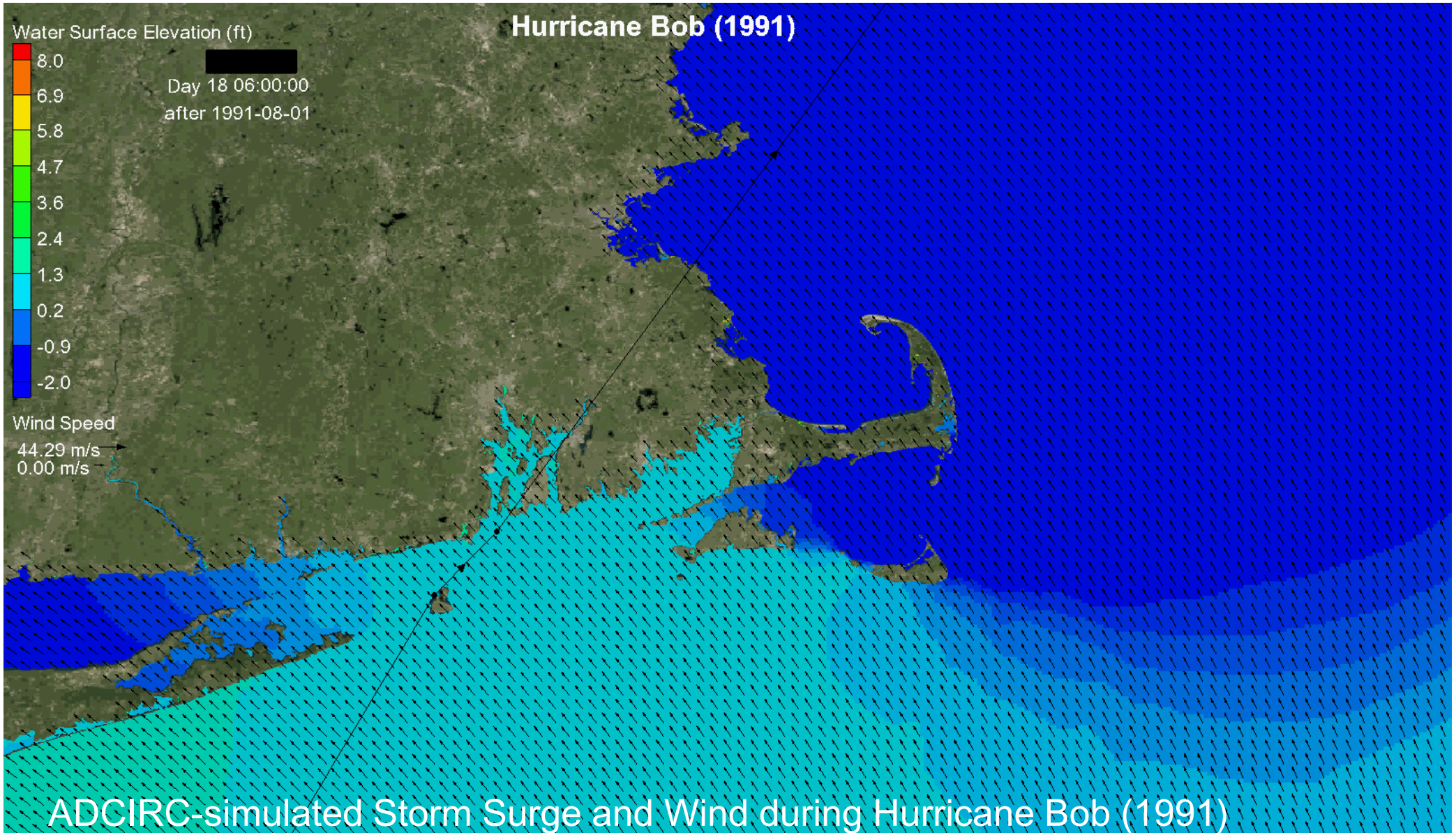
Metocean Data Analysis and Numerical Wave Modeling

(Scenario Simulation Circulation Model: ADCIRC)



ADCIRC-simulated Storm Surge and Wind during Hurricane Bob (1991)

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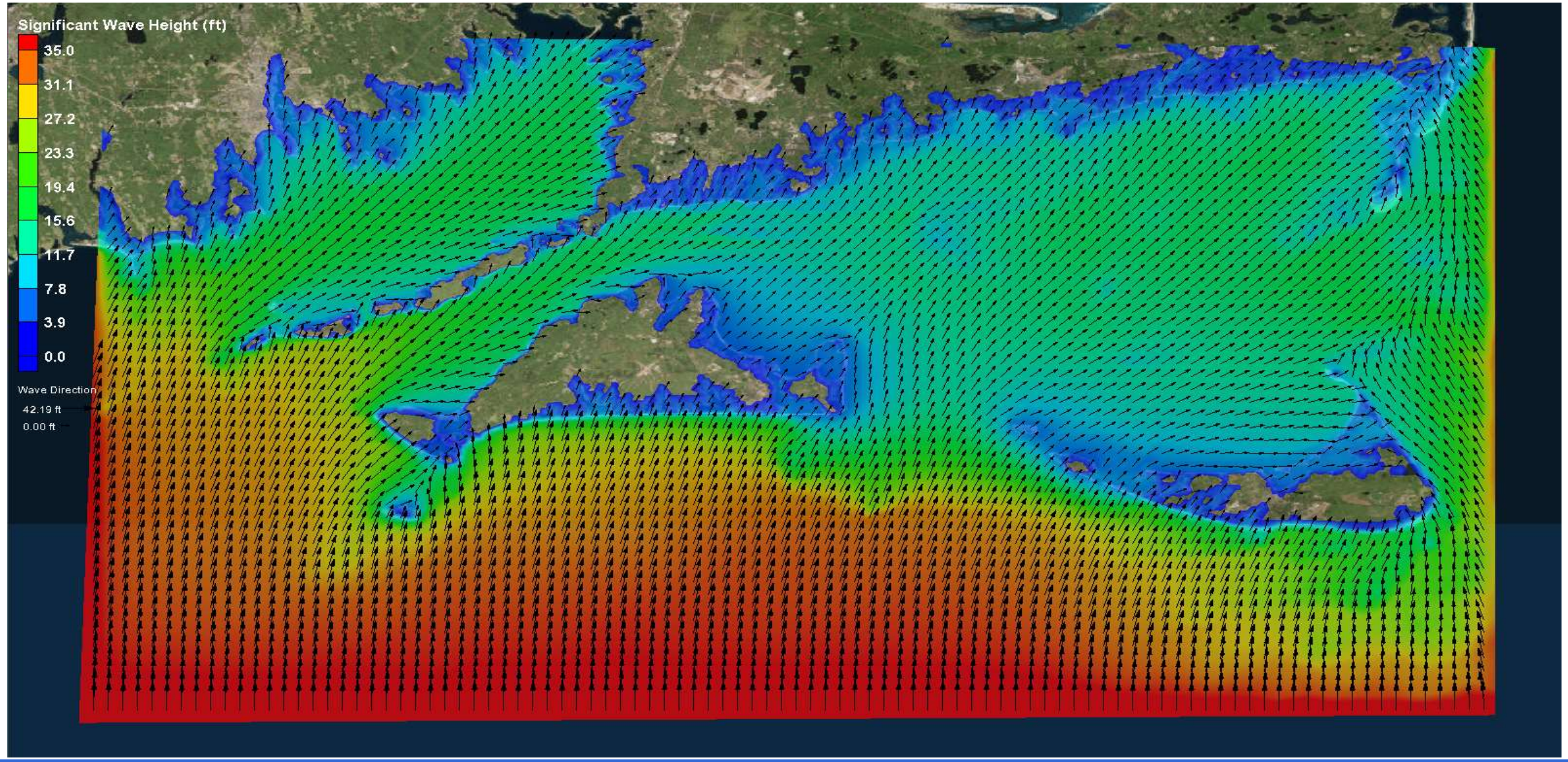
Metocean Data Analysis and Numerical Wave Modeling

(Wave Model: SWAN)



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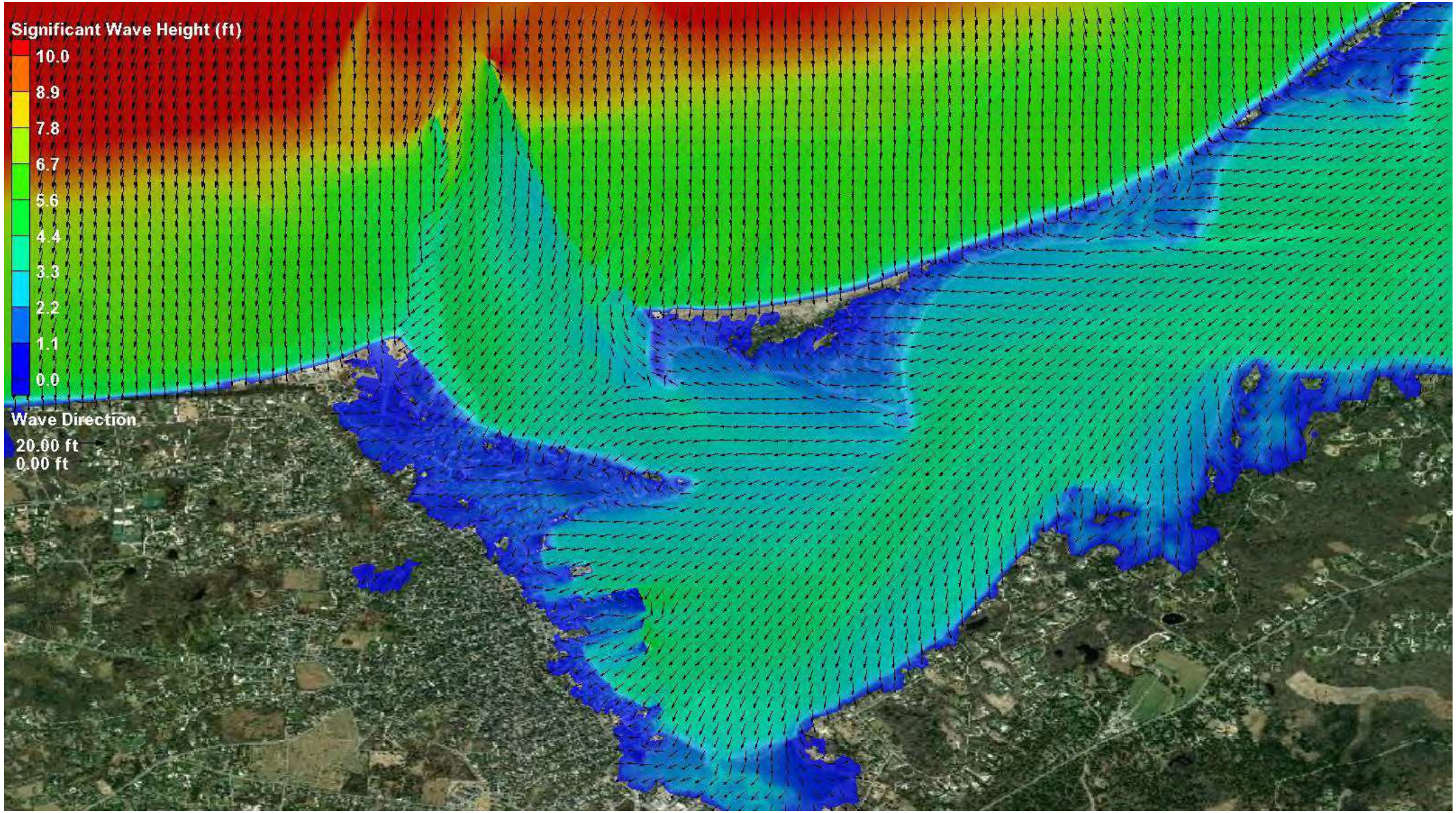
Metocean Data Analysis and Numerical Wave Modeling

Study Results (+/- 50 to 100-year; 70 mph 1-minute, 10-meter wind)



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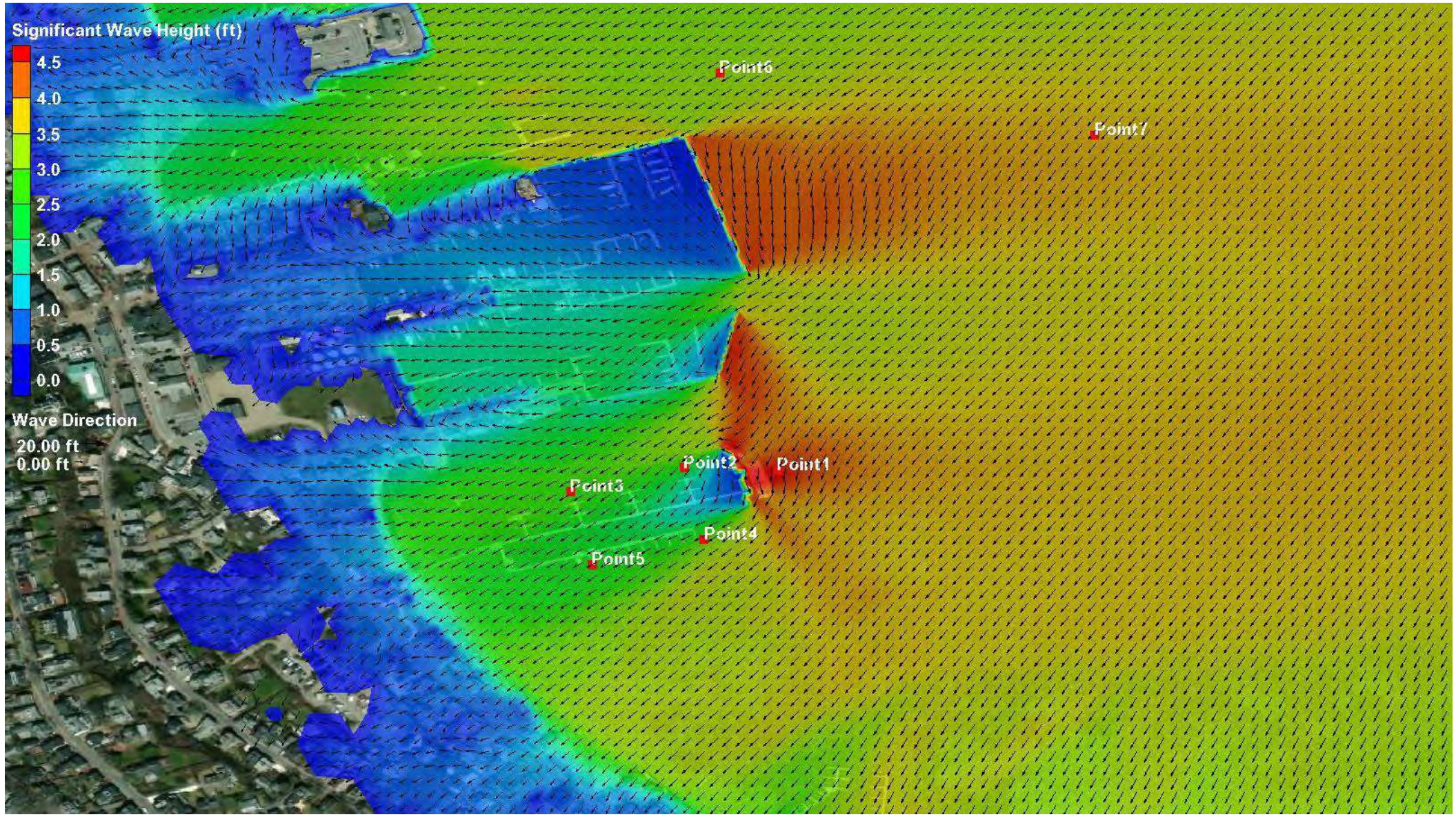

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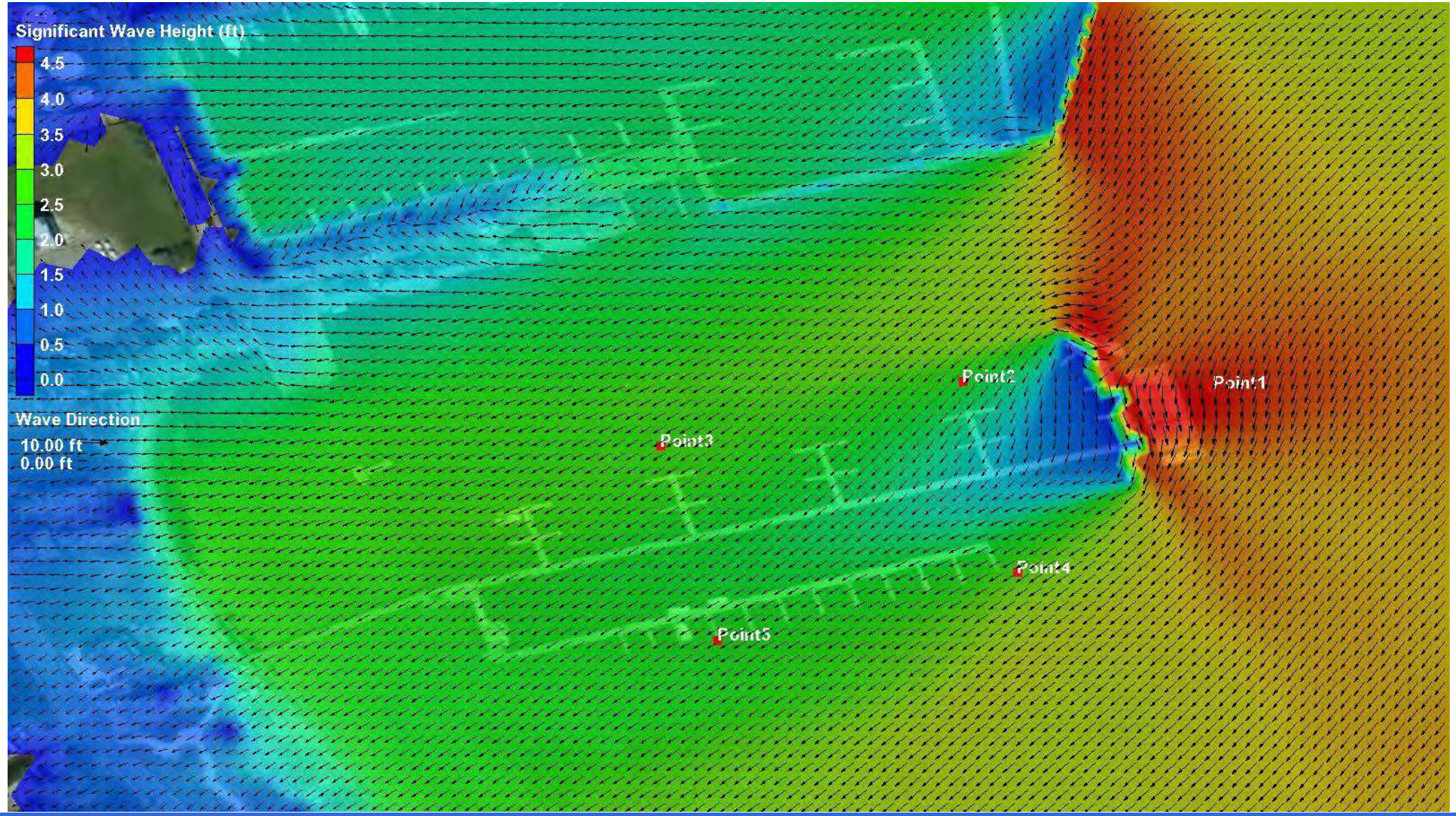

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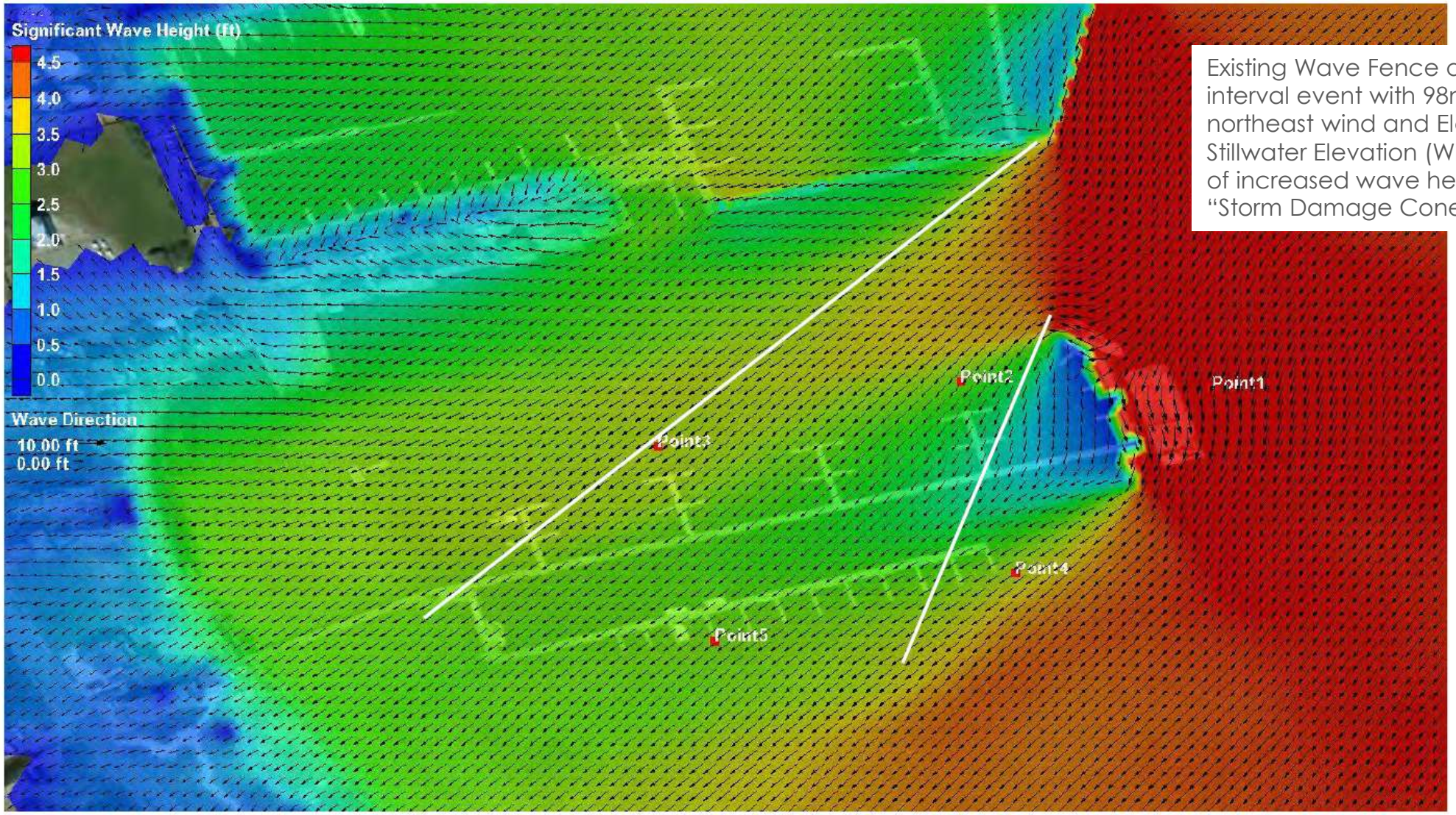
Metocean Data Analysis and Numerical Wave Modeling

Study Results: wave modeling consistent with observed effects of wave fences on wave transformation at Town Pier



Existing Wave Fence during 100-year recurrence interval event with 98mph 1-minute sustained northeast wind and Elevation 6 feet NAVD88 Stillwater Elevation (White lines indicate the zone of increased wave height due to structure effects "Storm Damage Cone" observed by Town)

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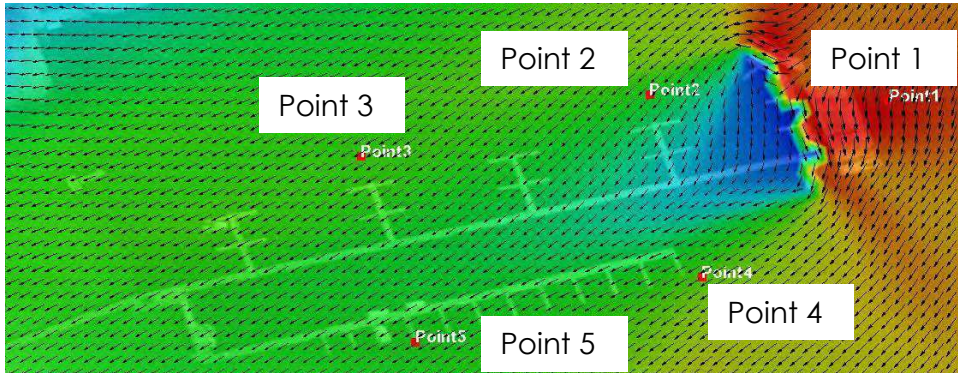
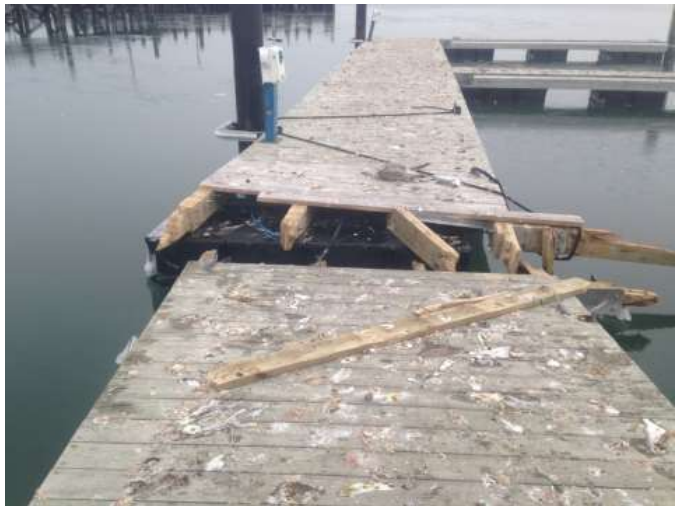
Metocean Data Analysis and Numerical Wave Modeling

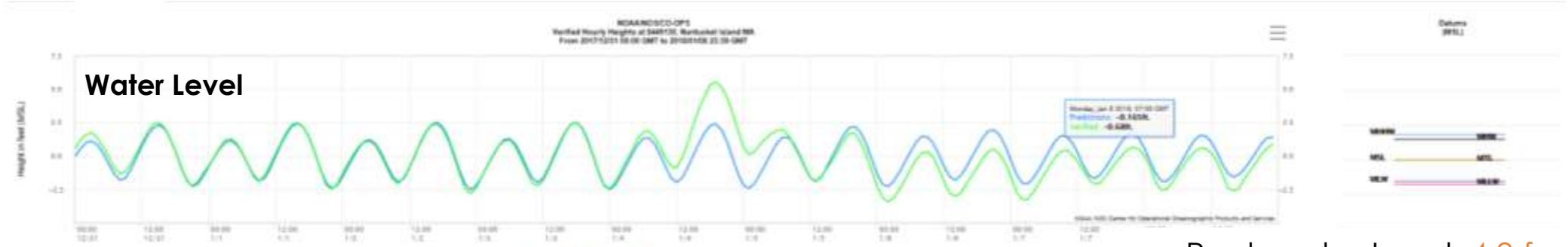


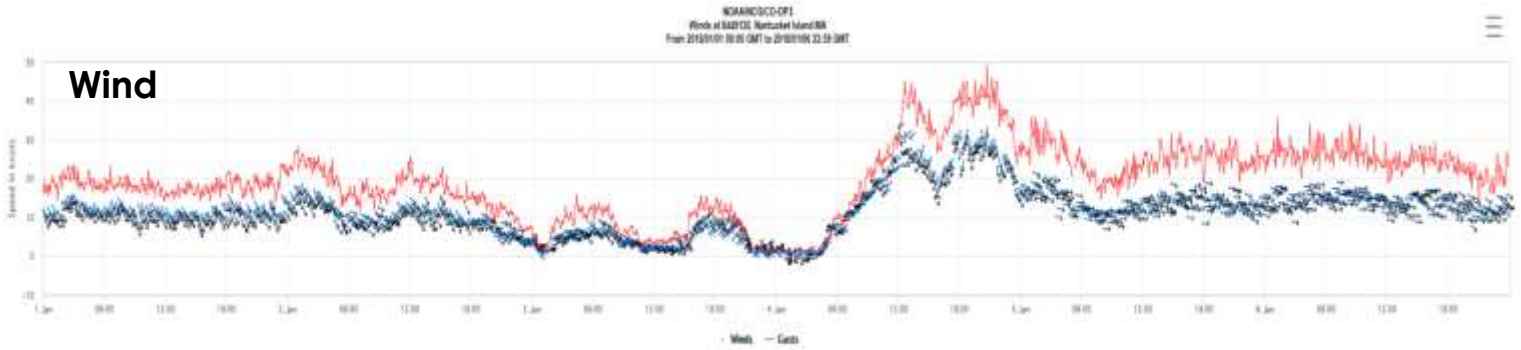
Recurrence Interval (years)	Significant Wave Heights (Hs) at SWAN Model Output Save Points at Town Pier (in feet)			
	2	3	4	5
Prevailing Monthly Wind Speed	0.7	0.7	0.8	0.7
1	1.1	1.2	1.3	1.1
2	1.6	1.8	1.9	1.6
5	1.8	2.0	2.2	1.8
10	1.9 to 2.0	2.2 to 2.3	2.3 to 2.4	2.0 to 2.1
25	2.1 to 2.4	2.3 to 2.8	2.4 to 2.8	2.1 to 2.5
50	2.2 to 2.6	2.4 to 3.0	2.5 to 3.0	2.2 to 2.7
100	2.2 to 2.7	2.5 to 3.2	2.7 to 3.2	2.3 to 2.8

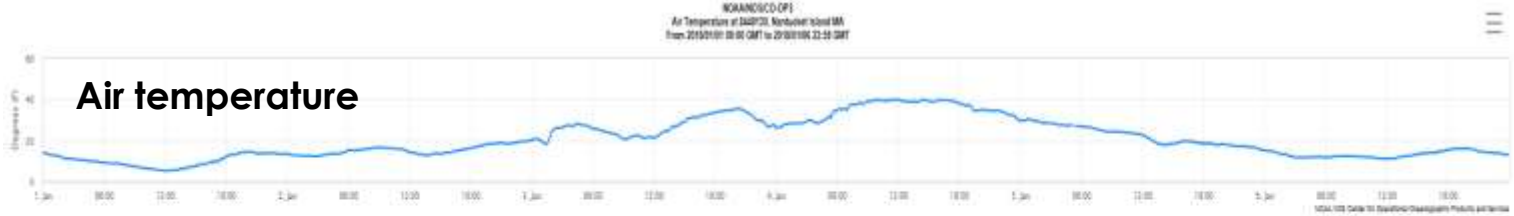
Perspective based on observed conditions: January 27, 2015 Nor'easter Town Pier Damage

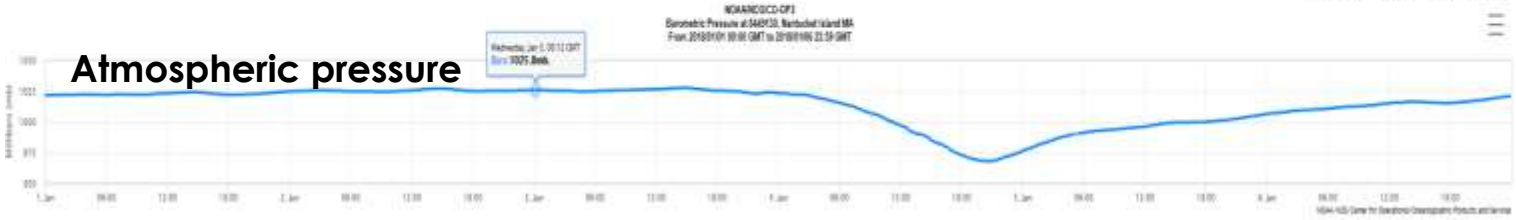


January 27, 2015 Nor'easter Water Level, Wind and Wave Conditions









- Peak water Level: 4.9 feet NAVD88
- Maximum Sustained 1-minute 10 meter Wind: +/- 35 to 40 mph
- Wind Direction: North to Northeast
- Predicted Peak H_s Wave Heights @ Pier: 2 to 2.5 feet
- Predicted Peak H_{max}: 4 to 5 feet
- Predicted peak wave crest elevation (H_s): 7 feet NAVD88
- Predicted peak wave crest elevation (H_{max}): 8 to 9 feet NAVD88
- Annual Exceedance Probability: +/- 10-year recurrence interval
- 2030 Annual Exceedance Probability: +/- 1 to 5-year recurrence interval
- 2050 Annual Exceedance Probability: +/- <1-year recurrence interval

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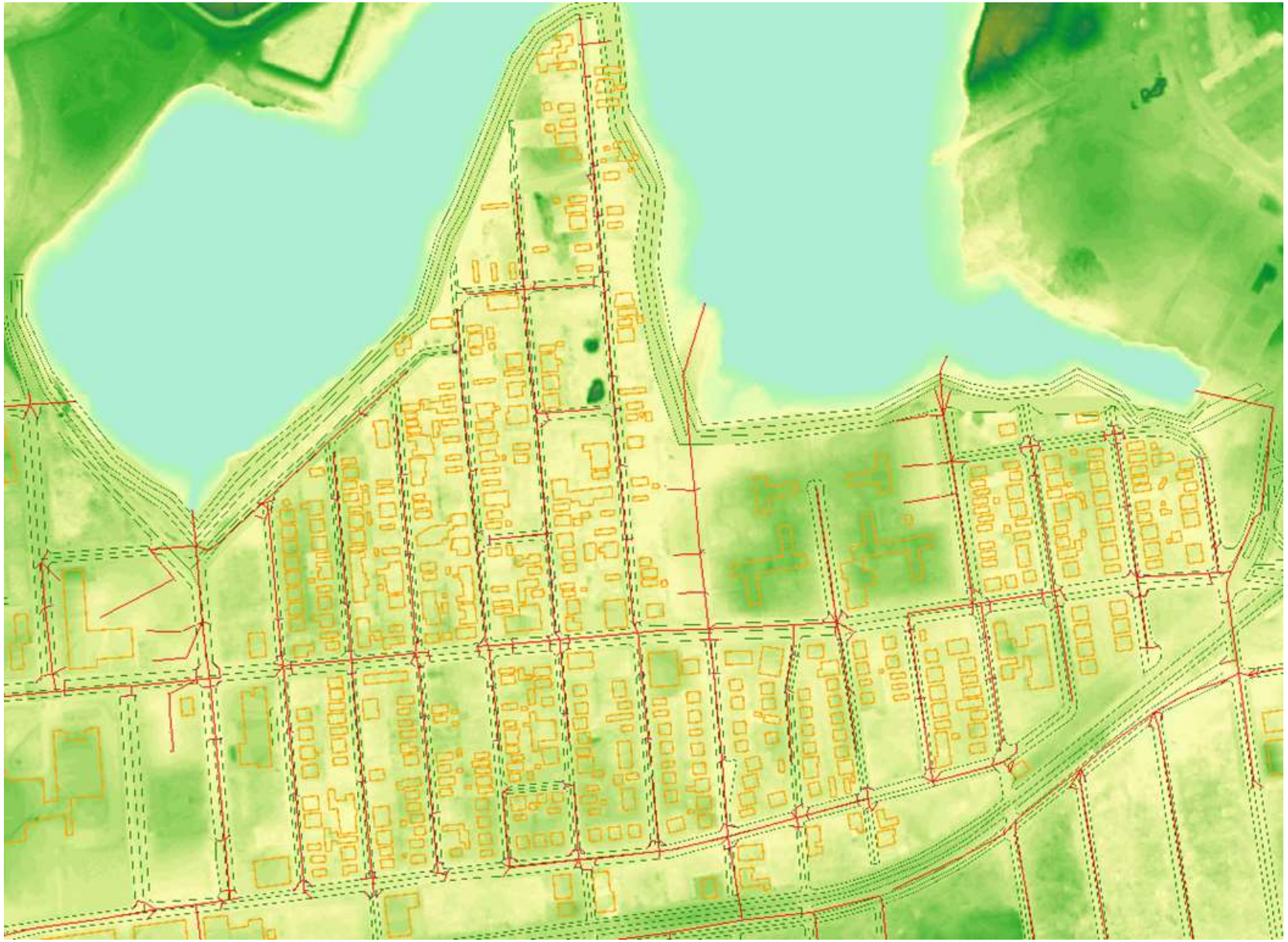
Metocean Data Analysis and Numerical Wave Modeling



Street Scale – GZA Coupled Coastal, Surface Flow, Stormwater Infrastructure, Groundwater Model

Interconnected Channel and Pond Routing Model v4.0 (ICPR4)

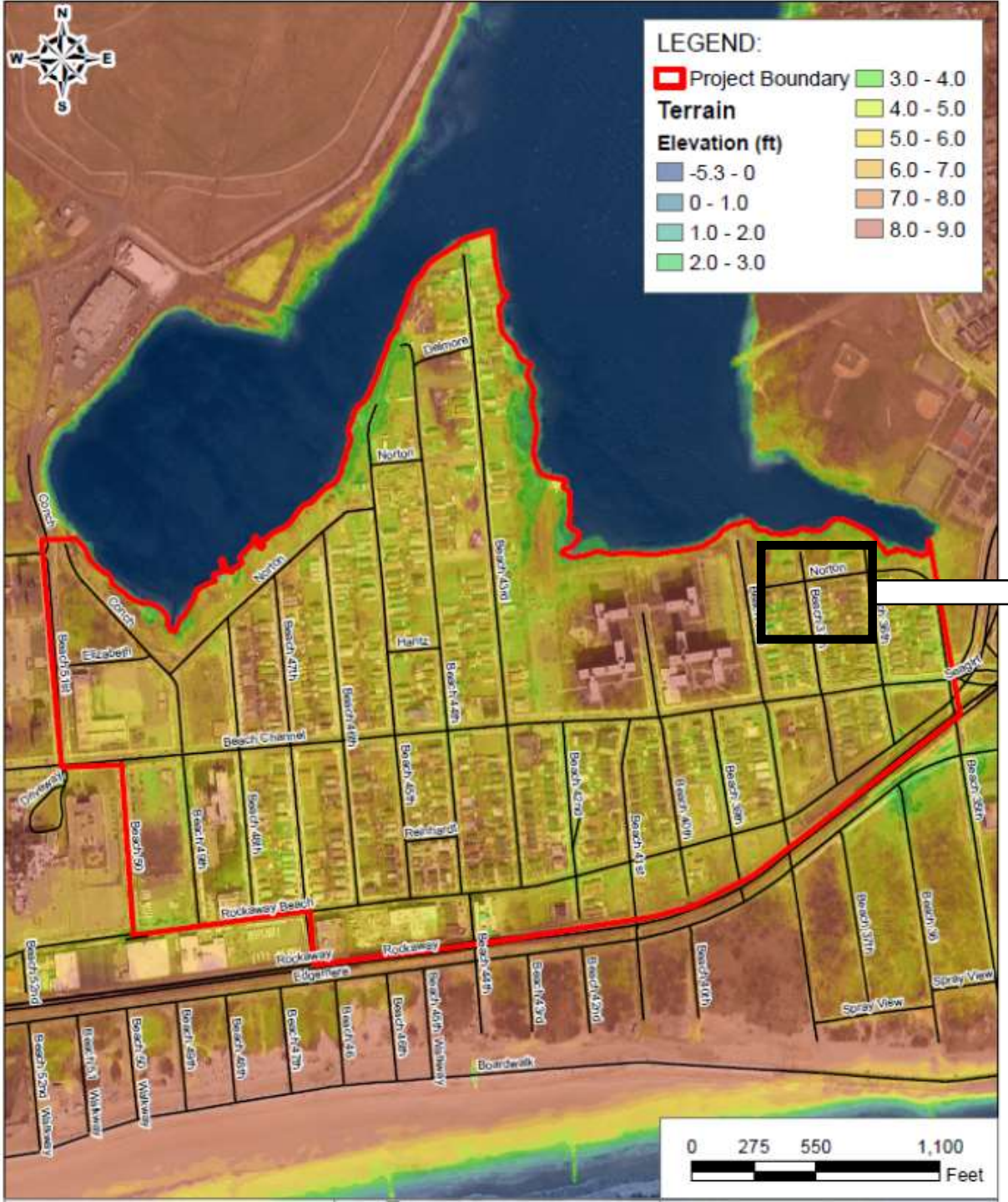
GZA Project Example: Queens, New York City

Model terrain (green) with building extrusions (orange) and stormwater network (red).

GZA Engineering Study

Metocean Data Analysis and Numerical Wave Modeling

Project Example: Queens, New York City
Interconnected Channel and Pond Routing Model v4.0 (ICPR4)



Model terrain (left) with building extrusions, topographic breaklines, and stormwater catch basin locations (right)

GZA Engineering Study

Metocean Data Analysis and Numerical Wave Modeling

Project Example: Queens, New York City

Intersection:	Max Ponding Depth:	Ponding Duration:
A	0.9 ft	2.0 hr
B	1.4 ft	2.9 hr
C	1.2 ft	2.9 hr
D	1.4 ft	4.7 hr

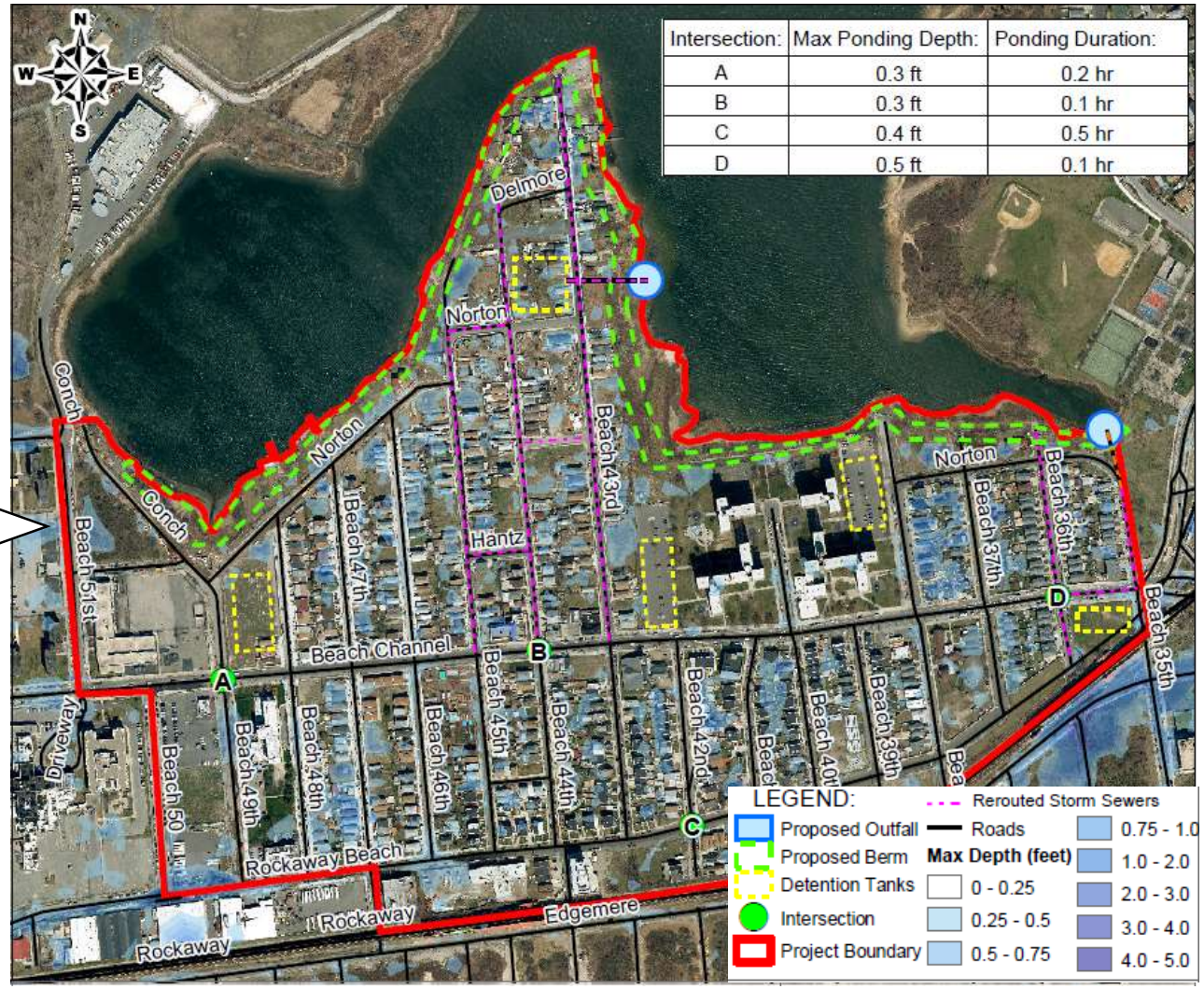
SUMMARY OF ANALYSIS:

Expected 2050 flood inundation at peak high tide with 32" SLR and a 2050 5-yr, 24-hr rain event. No mitigation measure implemented.

LEGEND:

- Intersection
- Project Boundary
- Roads

Max Depth (feet): 0 - 0.25; 0.25 - 0.5; 0.5 - 0.75; 0.75 - 1.0; 1.0 - 2.0; 2.0 - 3.0; 3.0 - 4.0; 4.0 - 5.0

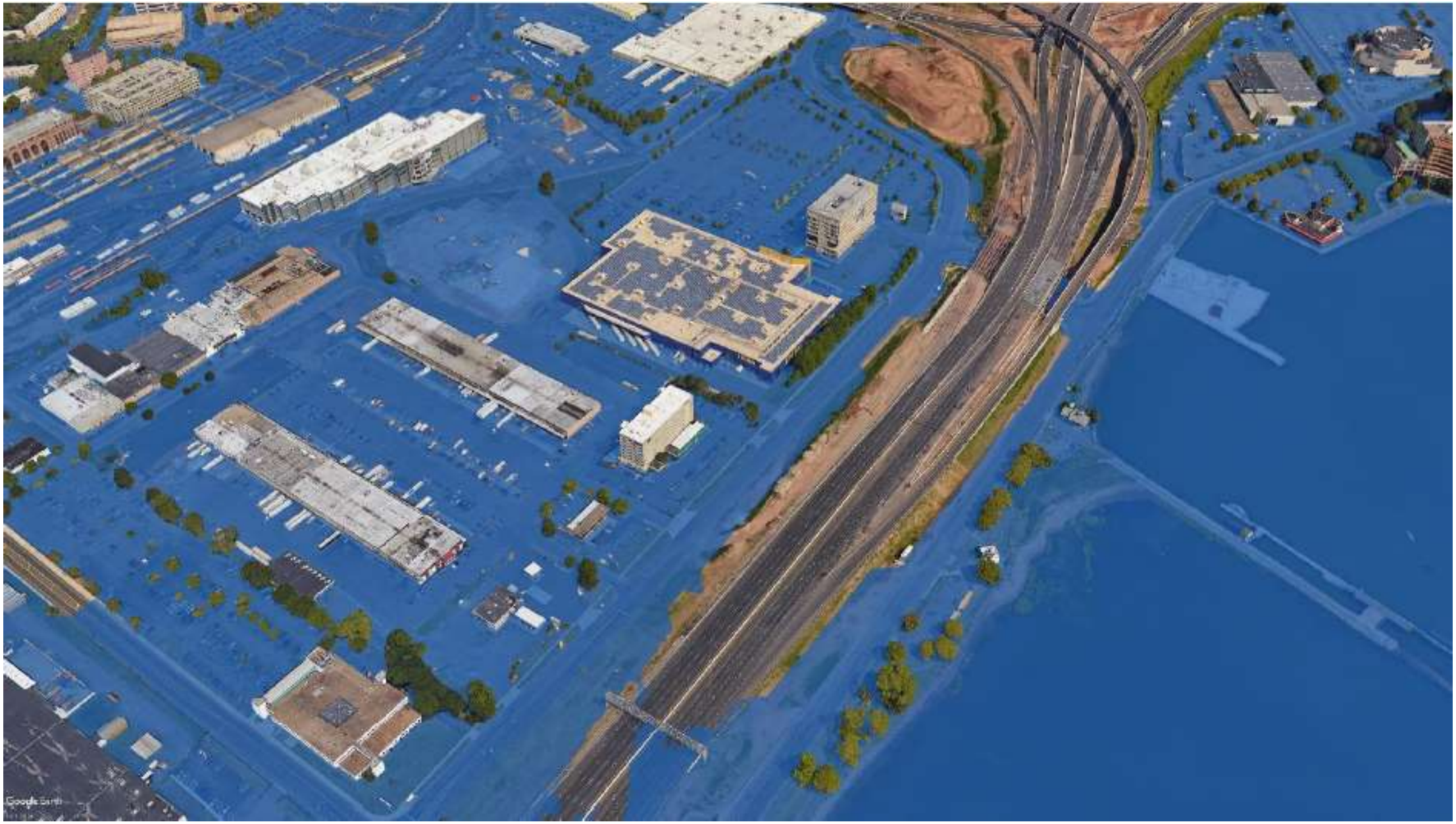


Intersection:	Max Ponding Depth:	Ponding Duration:
A	0.3 ft	0.2 hr
B	0.3 ft	0.1 hr
C	0.4 ft	0.5 hr
D	0.5 ft	0.1 hr

Model results show reduced ponding through implementing flood mitigation measures (shoreline berms, tide gates, additional stormwater infrastructure)

GZA Data Visualization: Coastal Flood Simulation, Long Wharf, New Haven, Ct

GZA Data Visualization: Coastal Flood Simulation, Long Wharf, New Haven, Ct



University of Florida: Data Visualization – Envision Nantucket

Envision Nantucket is a collaboration between the University of Florida Preservation Institute Nantucket, Nantucket Preservation Trust, and the Town of Nantucket.

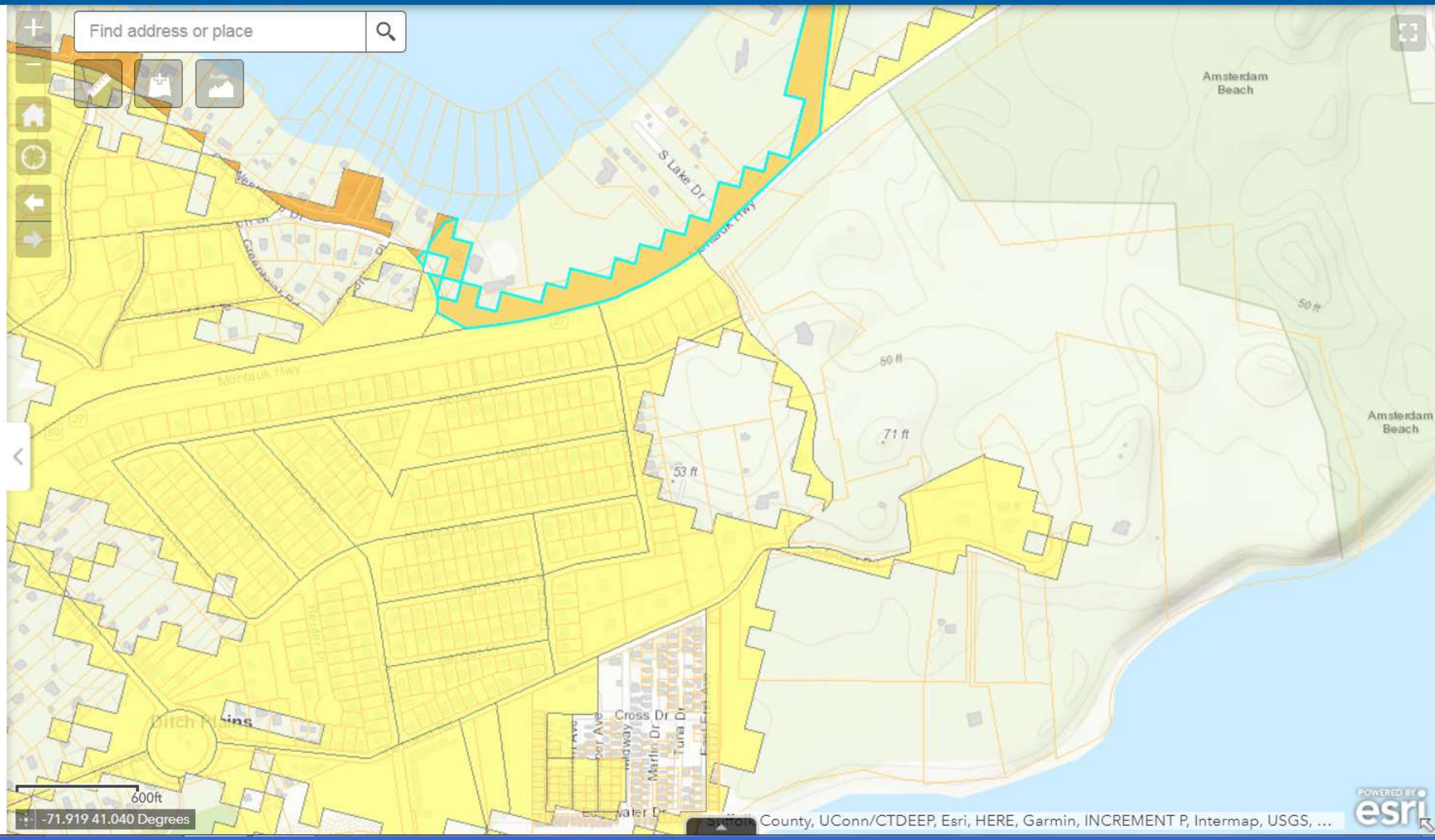
GZA Data Visualization: Coastal Flood Losses, East Hampton, New York

Natural Hazards Risk Management NOAA nowCOAST USGS CMGP USACE FIMPRS East Hampton Google Earth Web FEMA FIS/FIRM NY GIS Gateway

(1 of 1) Clear

Zoom to •••

Annual GBS Economic Loss Full Replacement - Total: 361032010041054

Census Block: 361032010041054
Census Tract: 36103201004
Return Period: Annual
Building Scheme: NY1
Block Type: C
Block Area: 0.20 Sq.Mi.
Percent with Basement: 58%
Percent 1-Story Residential: 25%
Percent 2-Story Residential: 68%
Percent 3-Story Residential: 5 %
Percent Split Level: 2%
Percent 1-2 Story: 44%
Percent 3-4 Story: 30%
Percent 5+ Story: 26%
Percent Low-Rise: 97%
Percent Mid-Rise: 2%
Percent High-Rise: 1%
Percent 1-car Garage: 29%
Percent 2-car Garage: 31%
Percent 3-car Garage: 5%
Percent Carport: 2%
Percent No Garage: 33%
Income Ratio: 1.32

Losses ($1,000's)
Total Losses: $66
Building: $10
Contents: $17
Inventory: $0
Relocation Costs: $2
Income: $13
Rental Income: $7
Wages: $17
Direct Output: $44
Employment: 0