massDOT
Massachusetts Department of Transportation

U.S. Department of Transportation
Federal Highway Administration

2014 NHEC

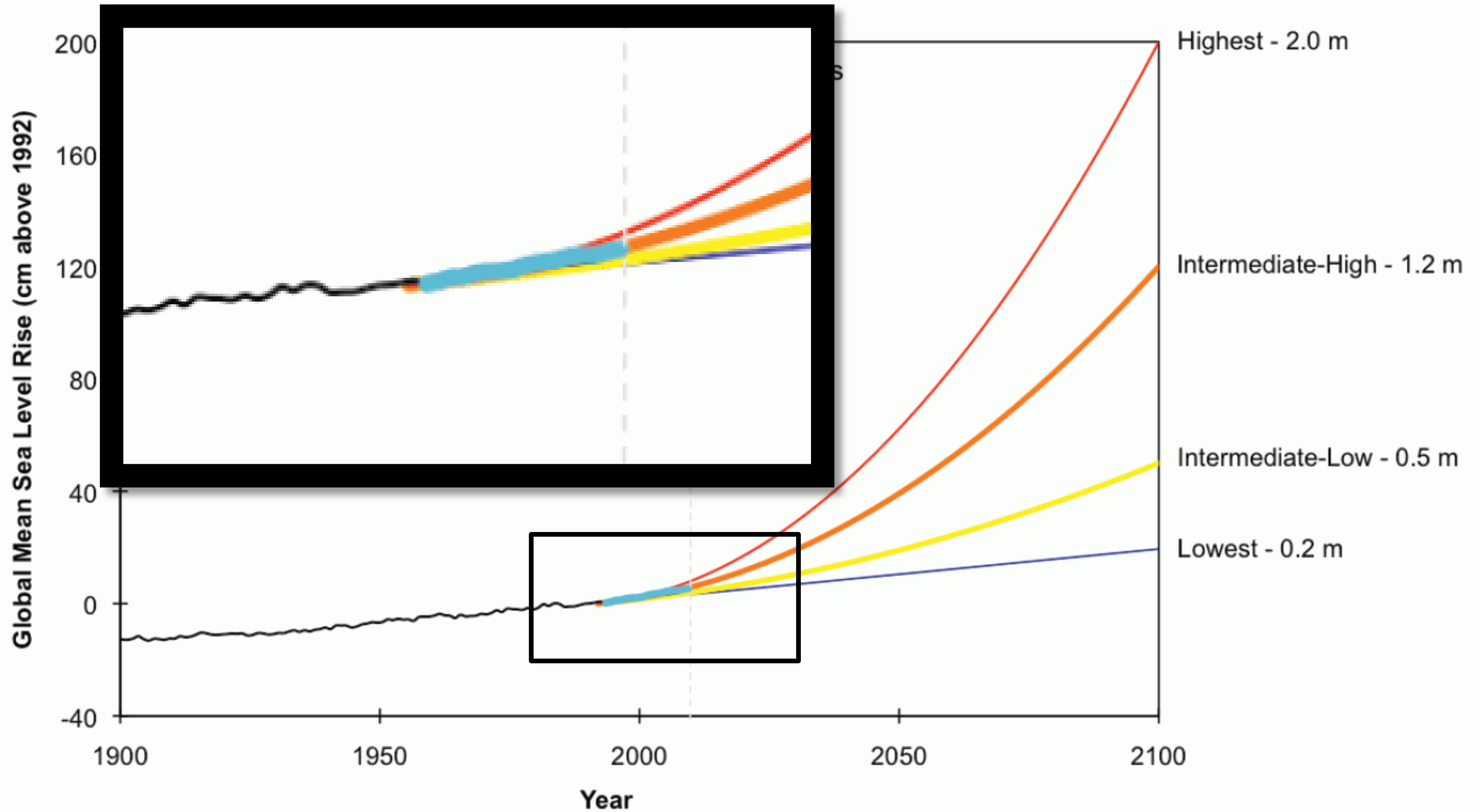
Sea Level Rise and Storm Surge Modeling

MassDOT-FHWA Pilot Project: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options of the Central Artery

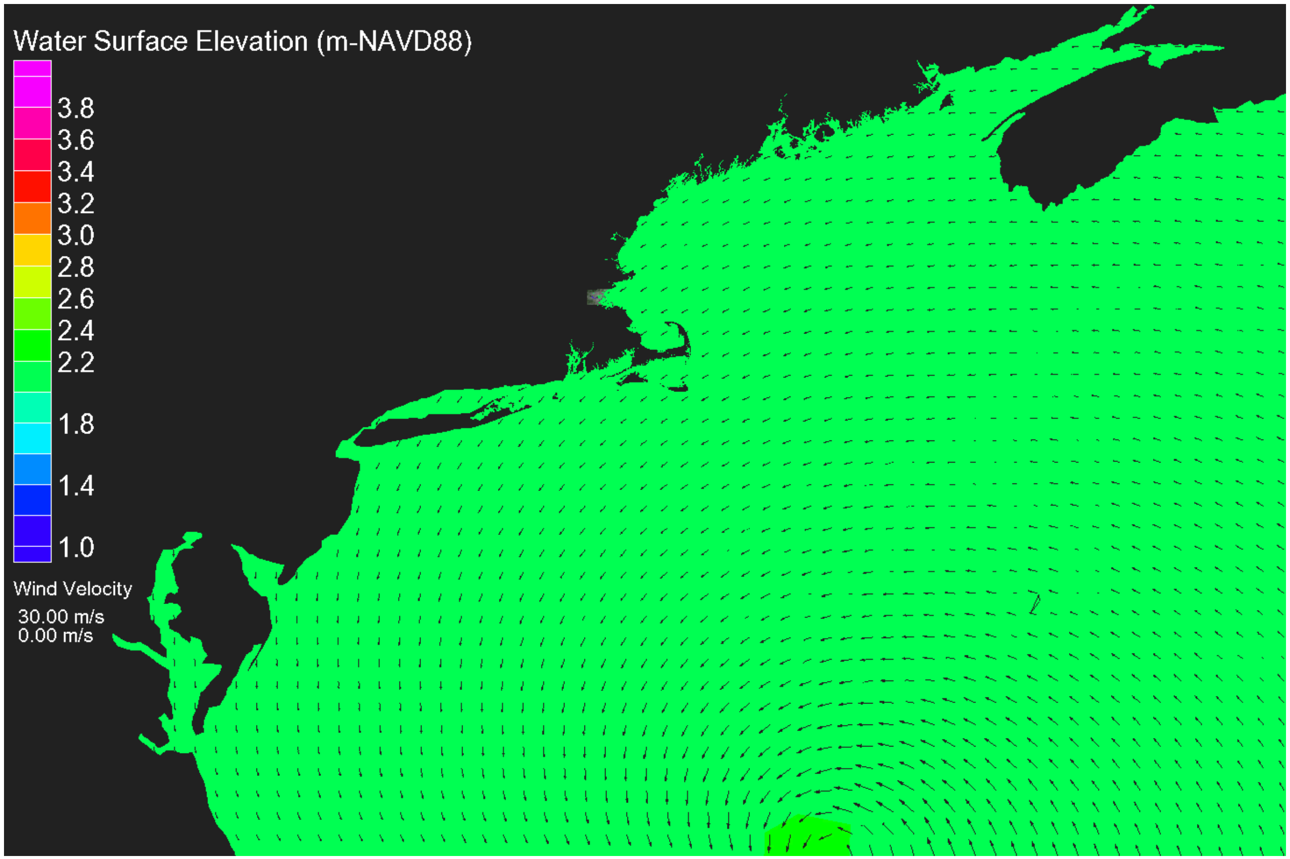
- Sea Level Rise (SLR)
  - Thermal expansion of ocean water
  - Increased input of water from land-based sources
- Northeast and Mid-Atlantic SLR is higher than global average
  - 1.75 mm/yr (Maine) to 6.05 mm/yr (Virginia)
  - Changes in ocean circulation (Yin et al., 2009, 2010)
- People live on the coast
  - 80% within 60 miles
  - ¾ of the cities

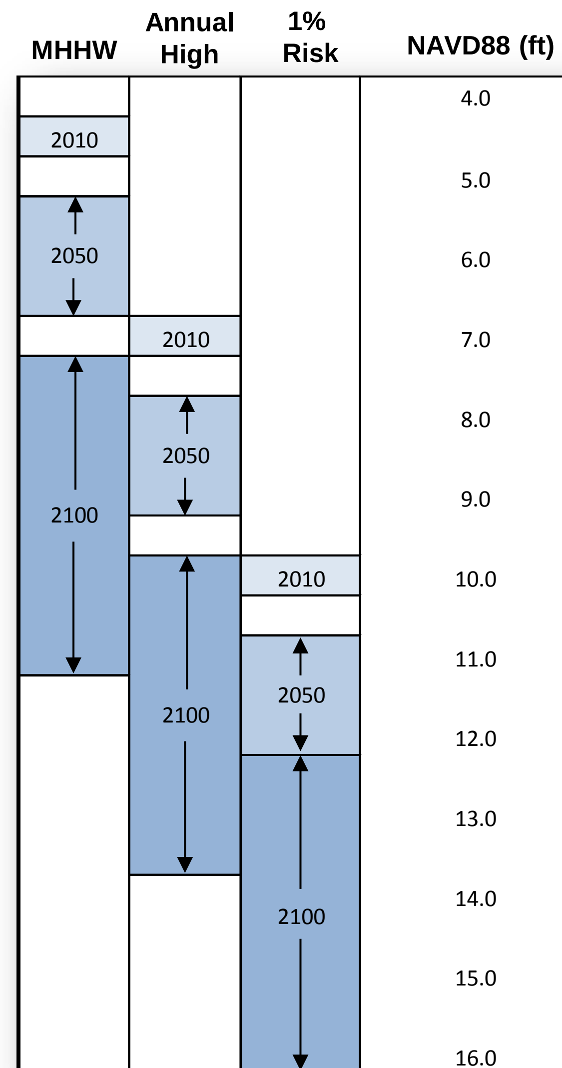
Photo by Andrew Burton, Getty Images

Photo by John Minchilo, AP

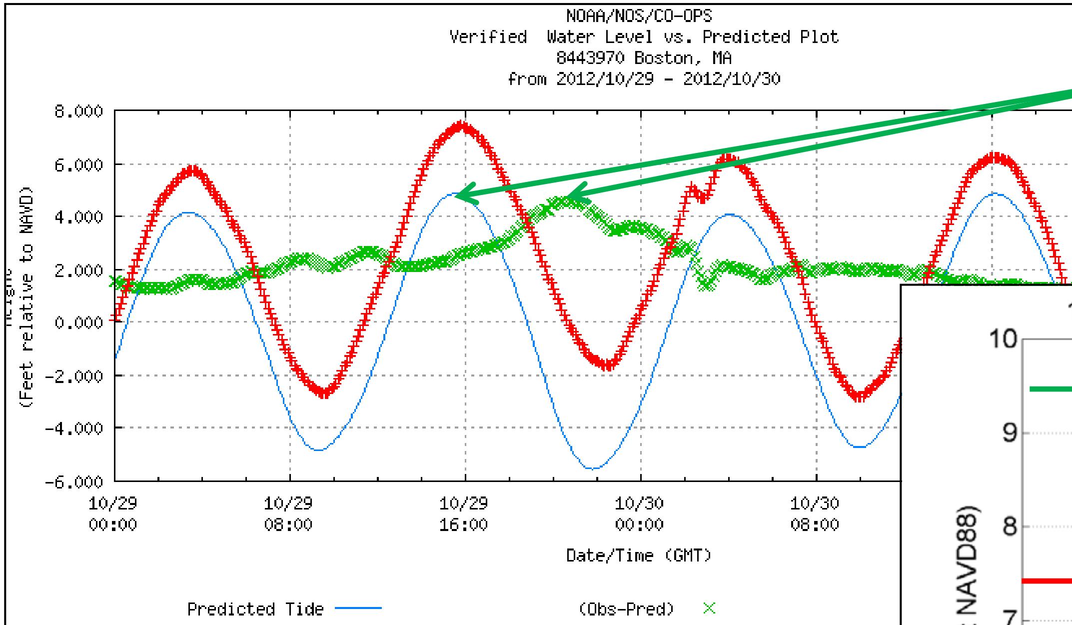

Highest - 2.0 m
Intermediate-High - 1.2 m
Intermediate-Low - 0.5 m
Lowest - 0.2 m
Global Mean Sea Level Rise (cm above 1992)
200
160
120
80
40
0
-40
1900
1950
2000
2050
2100
Year

Importance of Storms

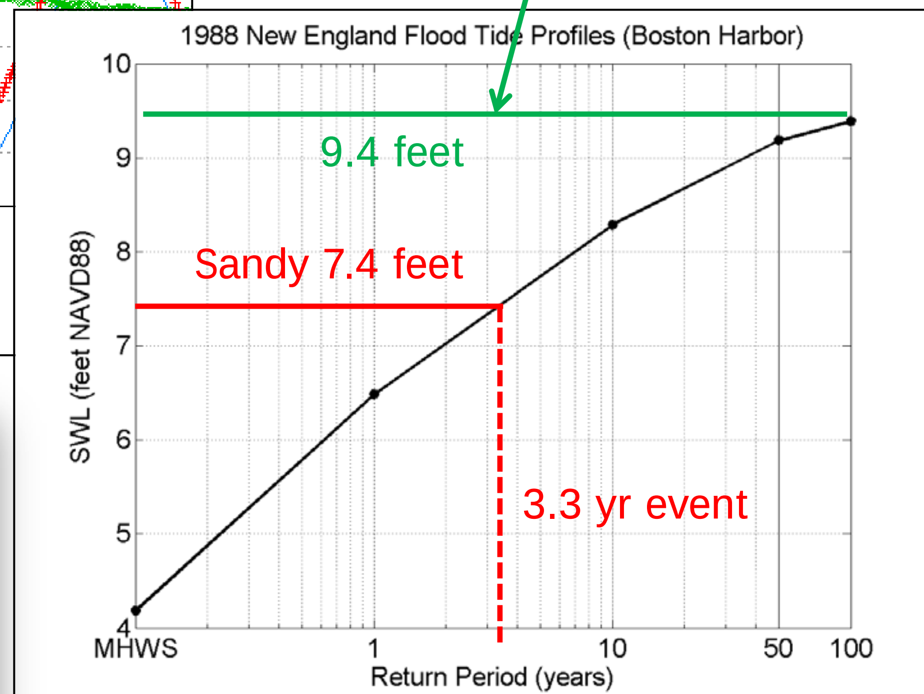




Hurricane Sandy in Boston



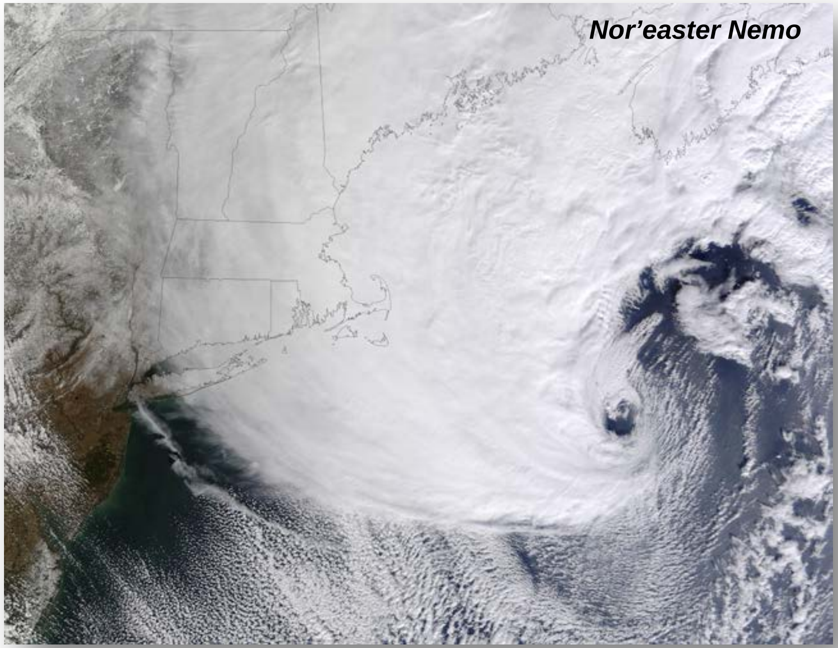
If peaks were simultaneous...



$50 billion damages in NYC

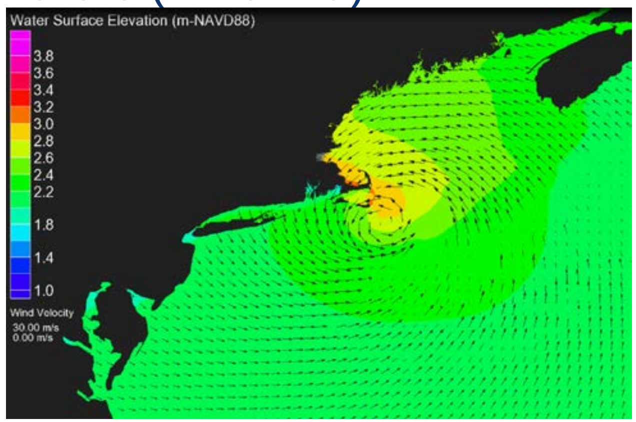
Hydrodynamic Modeling

- Includes relevant physical processes (tides, storm surge, wind, waves, wave setup, river discharge, sea level rise, future climate scenarios)
- Covers a larger physical area to correctly represent the storm dynamics



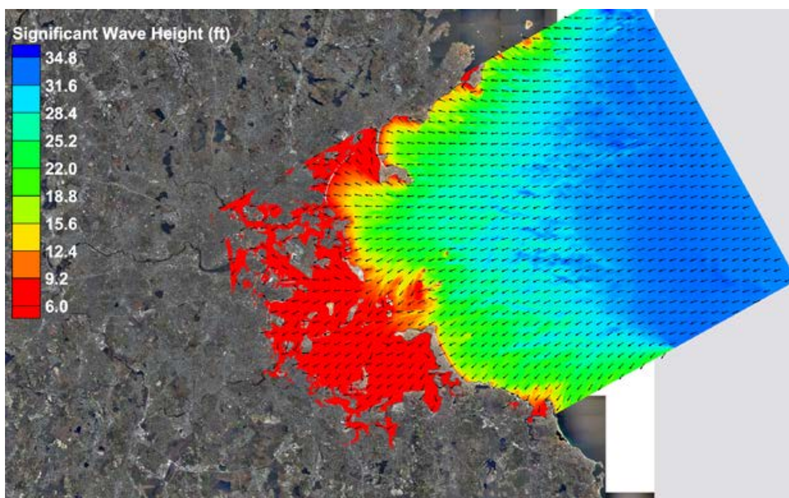
Hydrodynamic Modules

- Advanced Circulation Model for Oceanic, Coastal, and Estuarine Waters (ADCIRC)



- Currents
- Storm Surge
- Tides
- Water Levels
- Winds
- SLR
- Discharge

- Simulating WAves Nearshore (SWAN)



- Waves
- Wave Setup

Tightly Coupled

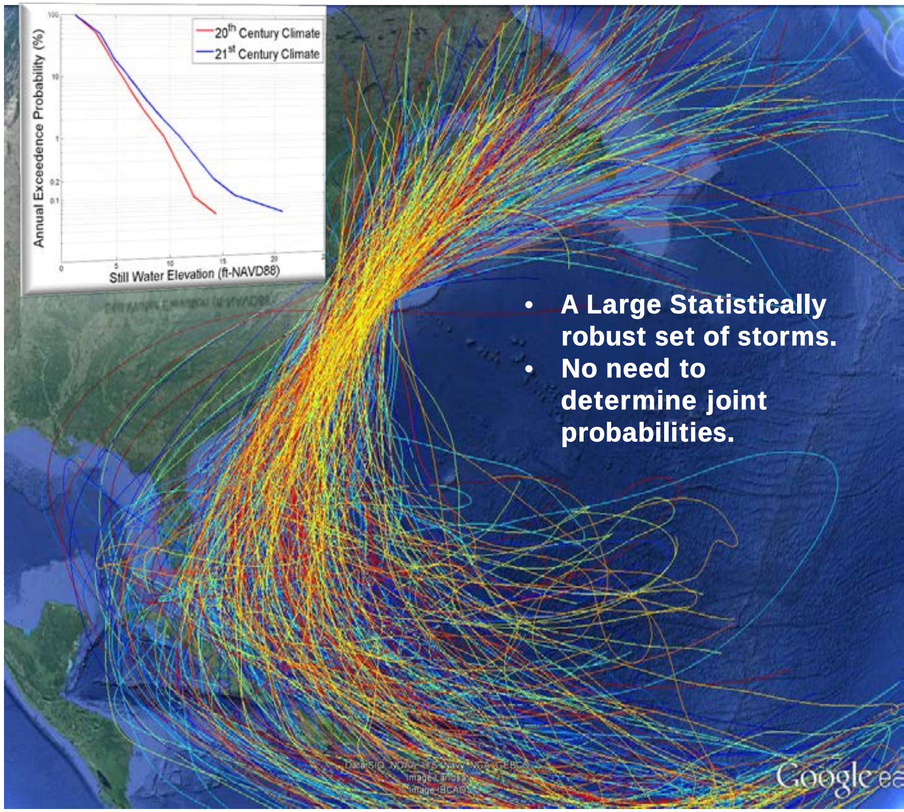
Why do we need a sophisticated approach?

- The risk is high
- There are a lot of factors that are important
  - Bathymetric effects
  - Storm types and parameters
  - Coastline geometry
  - Infrastructure
  - Frictional effects
  - Coastal processes (waves, tides, etc.)
- Flooding pathways can be significantly influenced by dynamic processes
- Achieve more detailed results to answer what is causing the flooding (e.g., increased river discharge, wave overtopping, storm surge, etc.)
- Test performance of engineering adaptations

Data Need	Source
LiDAR and topography	MassGIS, MassDOT, USGS, NOAA CSC, Site-specific surveys
Bathymetry	NOAA/NGDC, USGS, Site-specific surveys
Land cover	MassGIS, USGS
River flow and stage	BWSC, USGS, City of Cambridge
Historical high water marks	USGS, Gadoury (1979), NOAA Tides and Currents
Sea level rise scenarios	US National Climate Assessment (2012) Vermeer and Rahsmstorf (2009)
Flow control structure info.	Massachusetts DCR, USACE, MCZM
Storm climatology	Emanuel et al. (2006), Cheung et al. (2007), Vickery et al. (2007)

Model Validation

- Inundation maps based on standard “bathtub” model do not reflect dynamic nature of coastal flooding (e.g., bathymetry, coastal geometry, infrastructure, frictional effects, and processes)
- FEMA is only backward looking
- Simulation Scenarios
  - Combined Surge and Sea Level Rise
  - Present and future climate change scenarios
    - Simulate flooding associated with projections for 2030, 2070, 2100
  - Robust tropical and extra-tropical storm sets
  - Monte Carlo simulations, using a large statistically robust set of storms (Emanuel, et al., 2006)

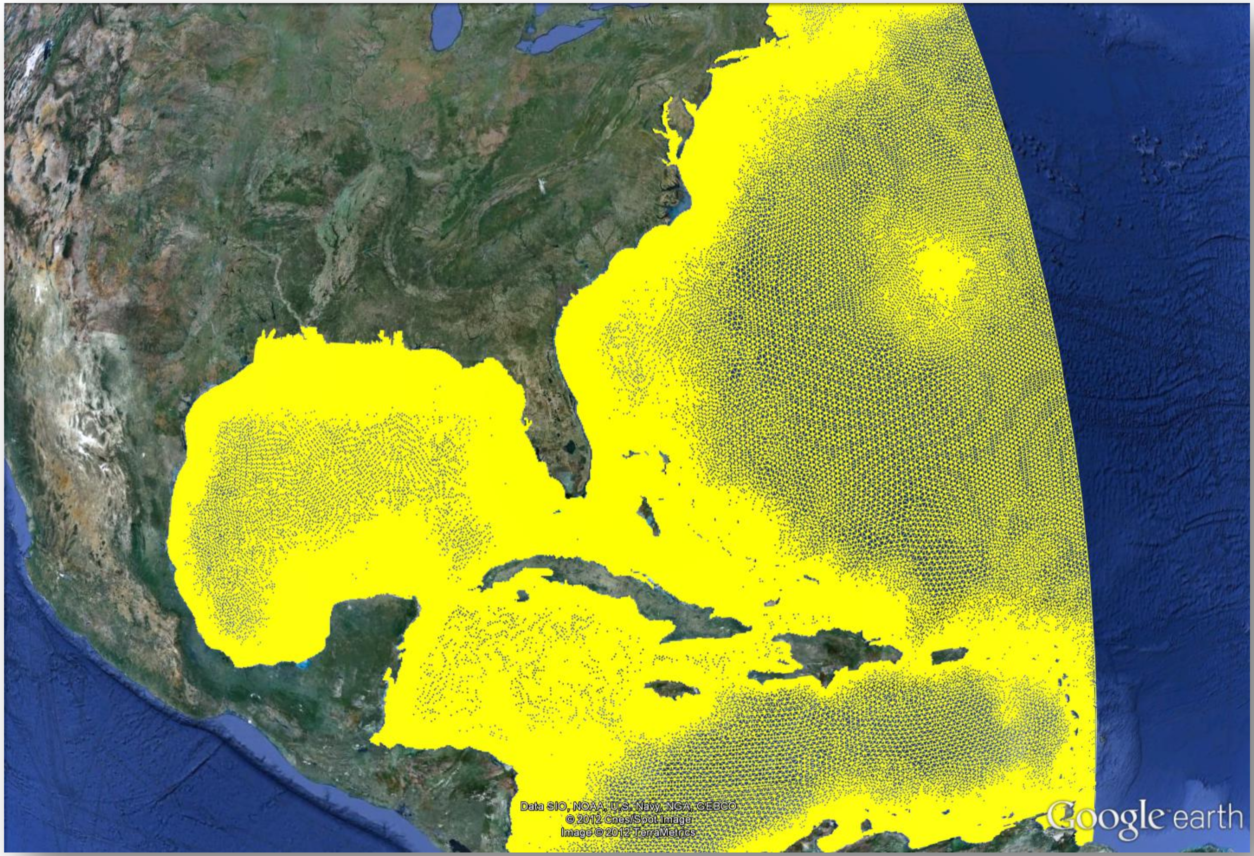


Storm Climatology Technical Memorandum

WOODS HOLE GROUP
UNIVERSITY of NEW HAMPSHIRE
UMASS BOSTON

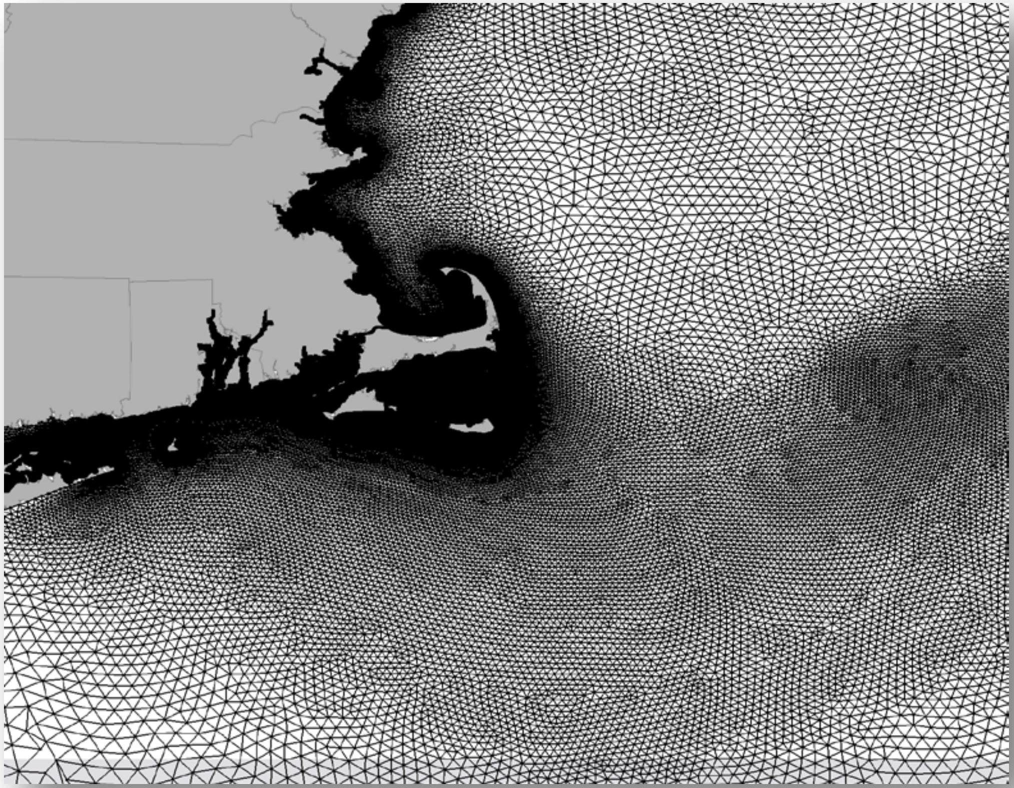
Grid Development

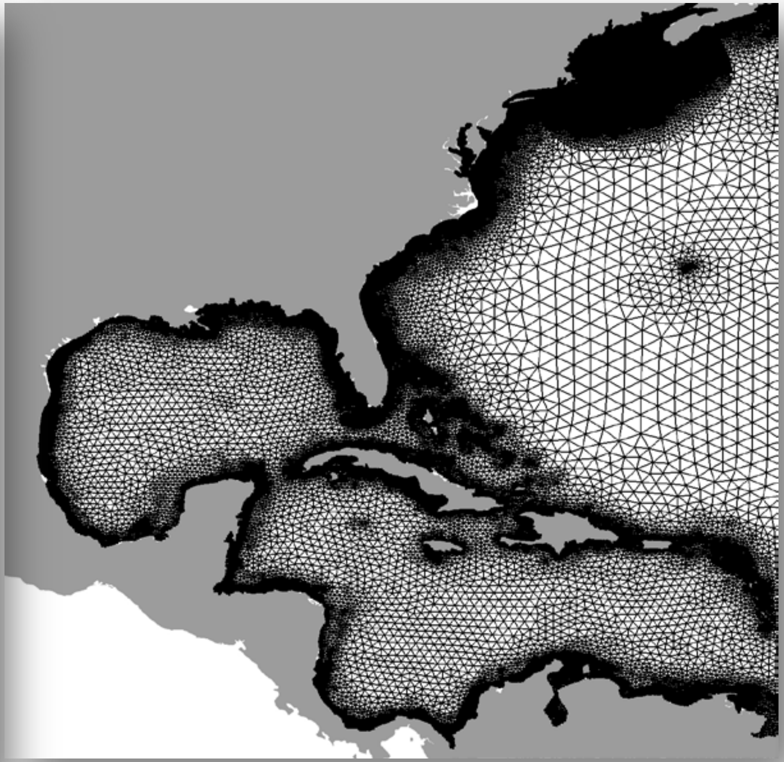
- Grid covers a large regional area (North Atlantic) to capture large-scale storm (hurricane, nor'easter) dynamics.

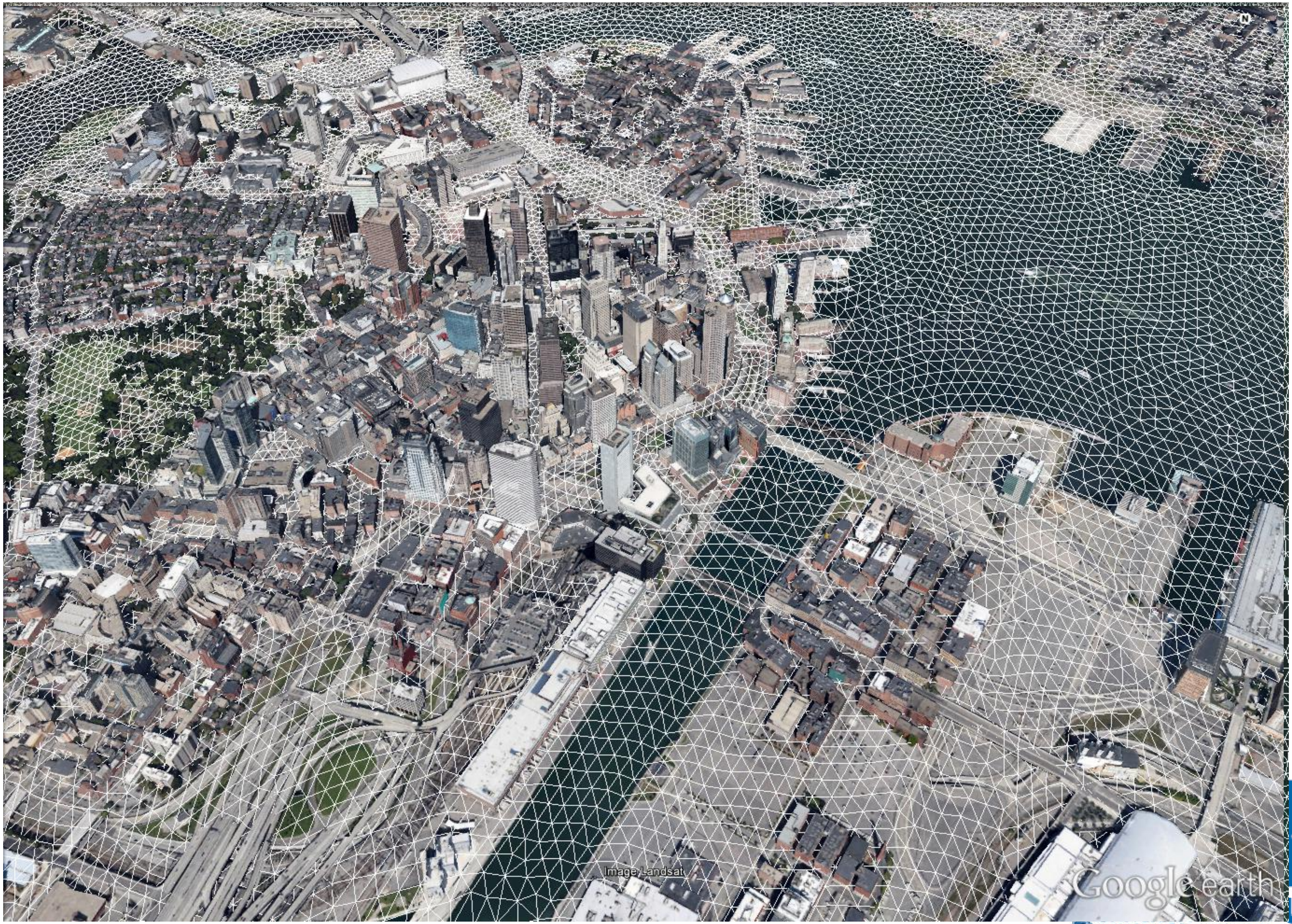


Grid Development

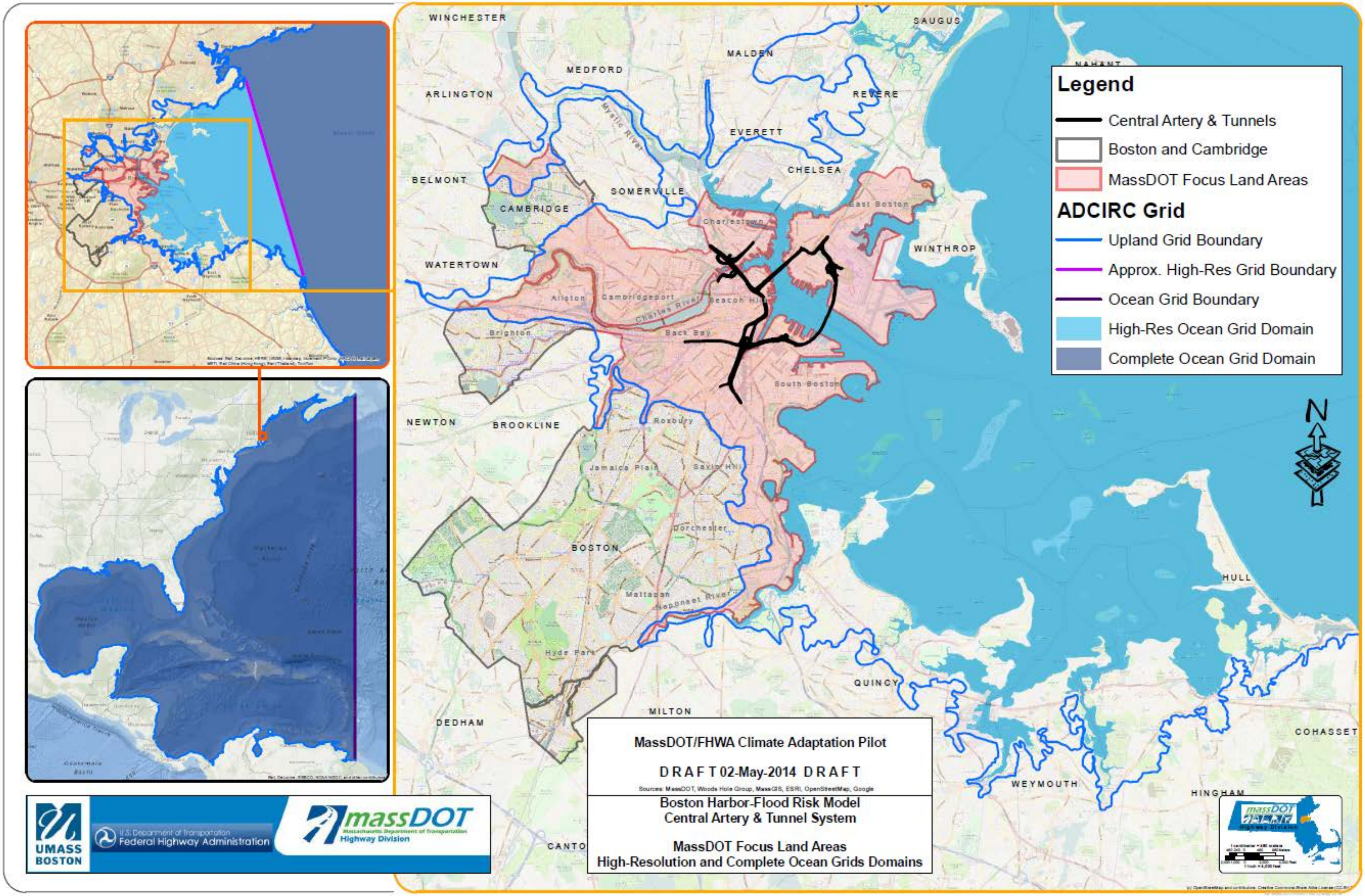
- Unstructured grid = varying resolution with high resolution in areas of interest (Central Artery)







of New Hampshire


Legend
Central Artery & Tunnels
Boston and Cambridge
MassDOT Focus Land Areas
ADCIRC Grid
Upland Grid Boundary
Approx. High-Res Grid Boundary
Ocean Grid Boundary
High-Res Ocean Grid Domain
Complete Ocean Grid Domain
WINCHESTER
SAUGUS
MALDEN
MEDFORD
NAHANT
ARLINGTON
REVERE
Mystic River
EVERETT
CHELSEA
BELMONT
SOMERVILLE
CAMBRIDGE
East Boston
Charlestown
WINTHROP
WATERTOWN
Allston
Cambridgeport
Charles River
Beacon Hill
Brighton
Back Bay
South Boston
NEWTON
BROOKLINE
Roxbury
Jamaica Plain
Savin Hill
Dorchester
BOSTON
HULL
Mattapan
Neponset River
Hyde Park
QUINCY
MILTON
DEDHAM
COHASSET
WEYMOUTH
HINGHAM
CANTON
N
MassDOT/FHWA Climate Adaptation Pilot
DRAFT 02-May-2014 DRAFT
Sources: MassDOT, Woods Hole Group, MassGIS, ESRI, OpenStreetMap, Google
Boston Harbor-Flood Risk Model
Central Artery & Tunnel System
MassDOT Focus Land Areas
High-Resolution and Complete Ocean Grids Domains
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- Challenges
  - Urban model grid development
  - Extra-tropical (Nor'easters) and tropical (hurricanes) storms
  - Nor'easters have not been modeled in this manner previously
  - Tidal influence
  - Temporal alignment of peak discharge and peak storm surge
  - Simulation time for Monte Carlo approach
  - Tremendous stakeholder interest – required FAQ sheet generation

Multivariate Probability

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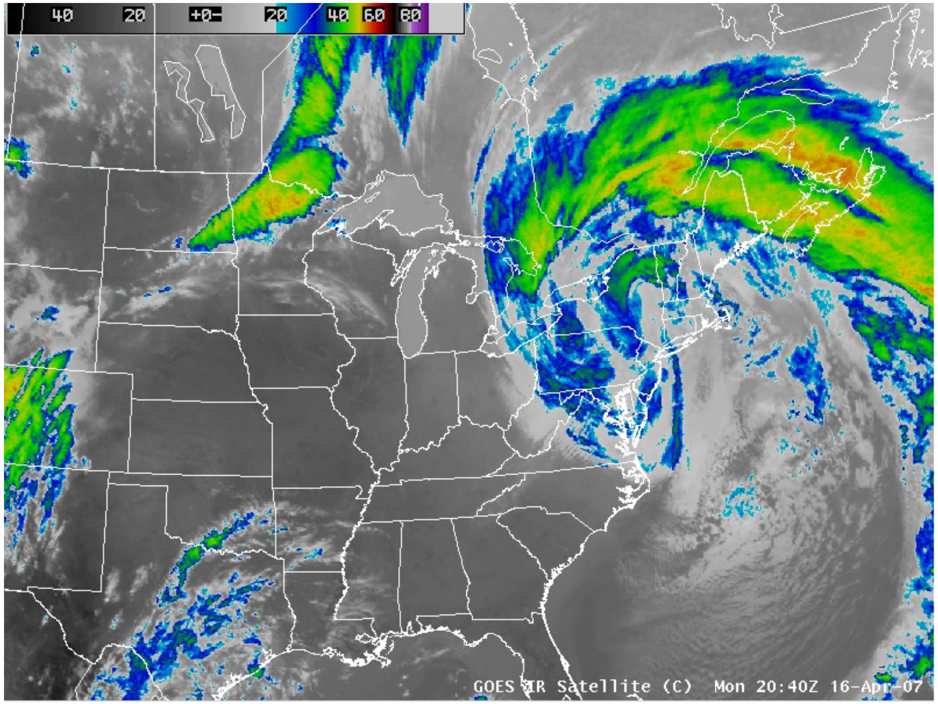
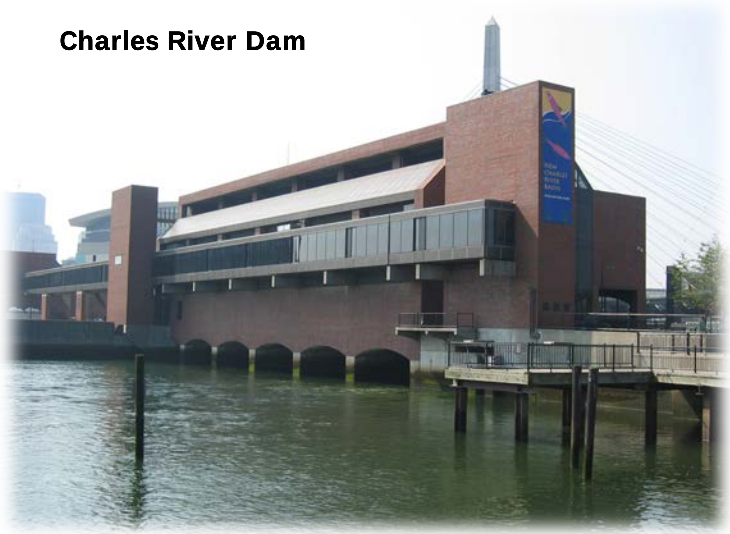
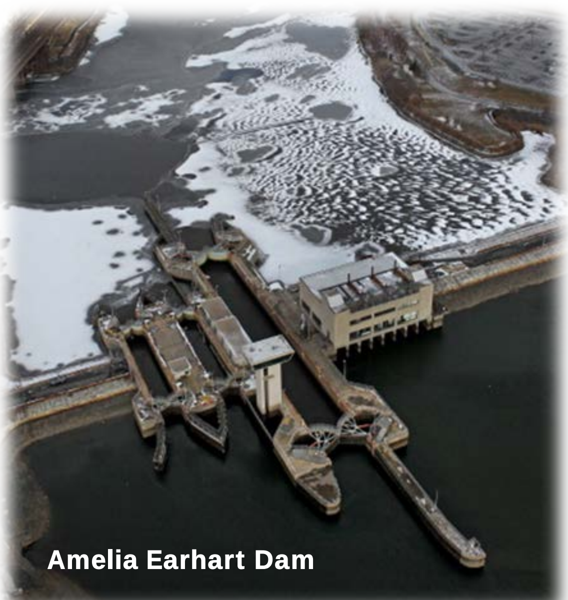
- Storm Climatology
  - Includes both tropical and extra-tropical storm sets
- Tropical Storms
  - Data set provided by WindRiskTech (Emanuel, et al., 2006)
  - Optimized selection by integrated kinetic energy approach
  - Select storms used to develop a surface response function
  - Increased storm intensities for 21st century based on climate models
- Extra-Tropical Storms
  - Data set developed by examining Boston tidal residual water levels
  - Re-analysis data used to feed a balanced wind model
  - Probability determined based on Rudeva (2008)



Charles River Dam





Amelia Earhart Dam

- Integration of Urban Dams
  - Charles River Dam (Charles River)
  - Amelia Earhart Dam (Mystic River)
- Implementation of new boundary condition in the ADCIRC model
  - Includes pumping systems to maintain specific range of water levels in upstream basins
- Allows evaluation of combined processes
  - Discharge, SLR, and Storm Surge
  - Assess infrastructure adequacy under the combined influence under climate change conditions
  - Pumps can handleprojected freshwater discharge, but combined discharge and overtopping needs to be considered

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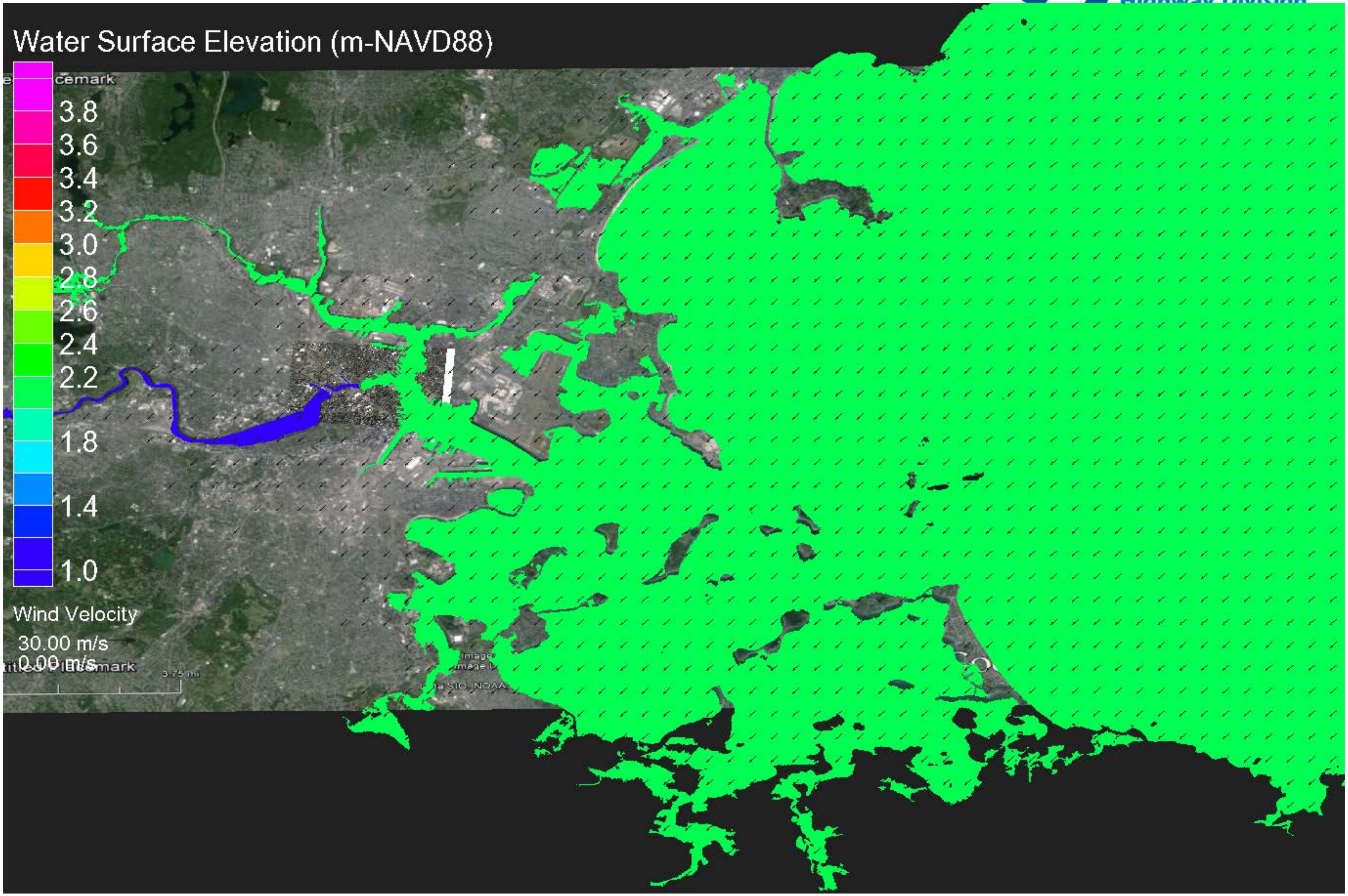

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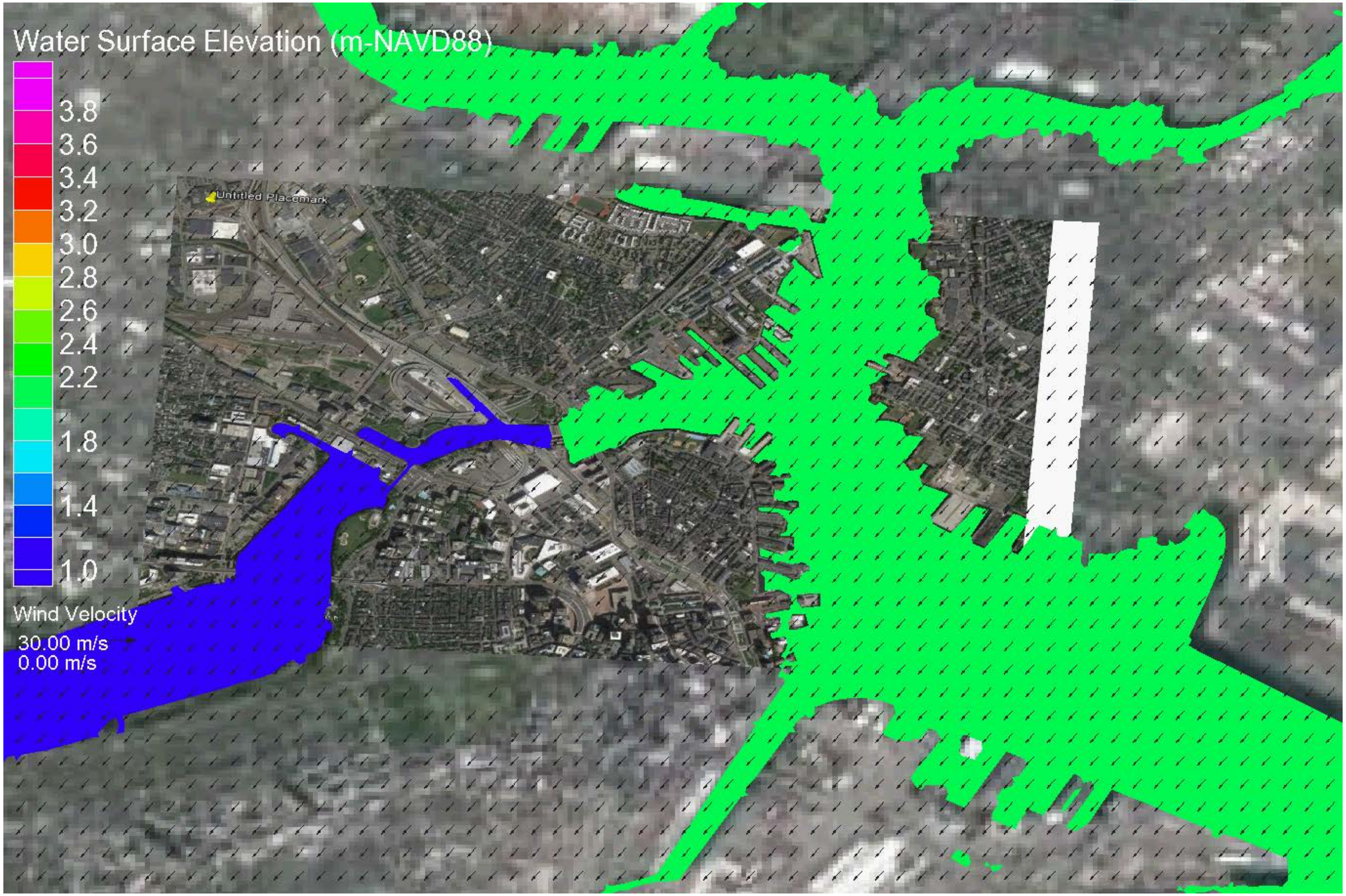
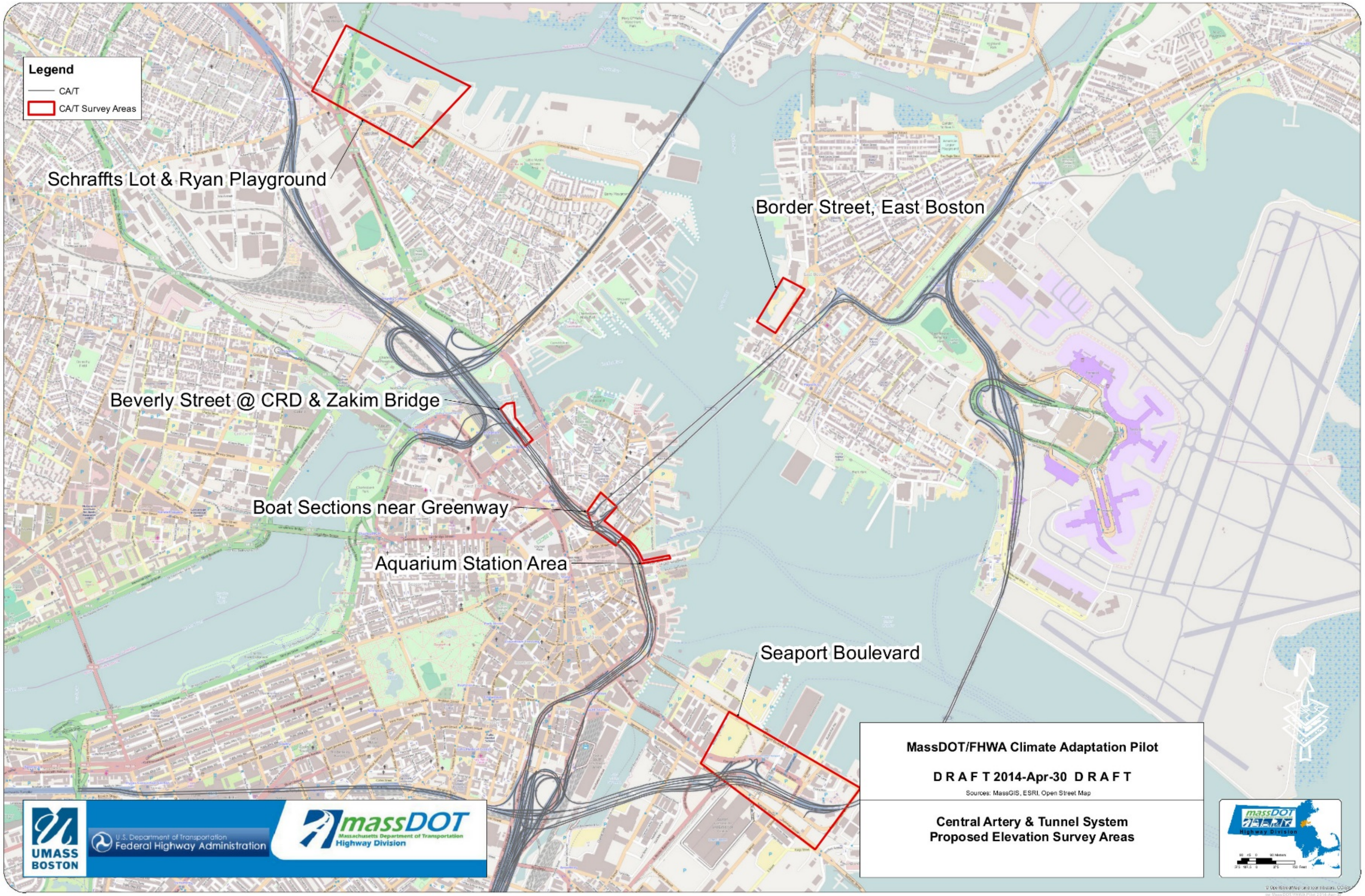

Water Surface Elevation (m-NAVD88)
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
1.8
1.4
1.0
Wind Velocity
30.00 m/s
0.00 m/s
Untitled Placemark

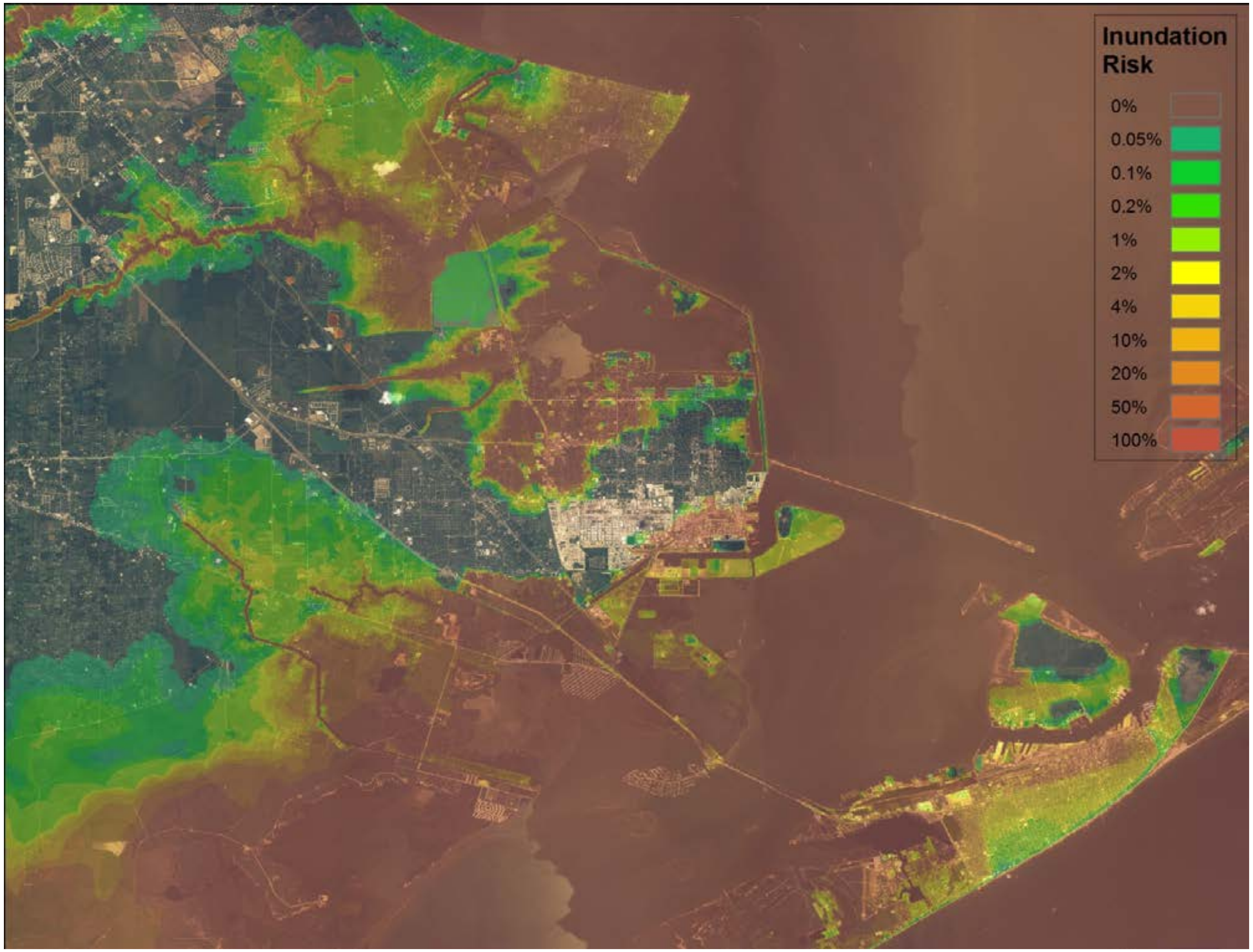


Legend
CA/T
CA/T Survey Areas
Schraffts Lot & Ryan Playground
Border Street, East Boston
Beverly Street @ CRD & Zakim Bridge
Boat Sections near Greenway
Aquarium Station Area
Seaport Boulevard
MassDOT/FHWA Climate Adaptation Pilot
D R A F T 2014-Apr-30 D R A F T
Sources: MassGIS, ESRI, Open Street Map
Central Artery & Tunnel System
Proposed Elevation Survey Areas

Hydrodynamic Model Results

- Detailed inundation maps
  - Risk Contours
  - Percent occurrence depth contours
  - Flooding pathways and sources
  - Specific storm events
- Cumulative distribution functions of water level (at 10s of thousands of locations)
- Visualizations of flooding
- Current and future vulnerabilities
- Input to develop preparedness plans over time and scale
- Ability to test potential performance of engineering adaptations and economic impacts

Hydrodynamic Model Results



Hydrodynamic Model Results