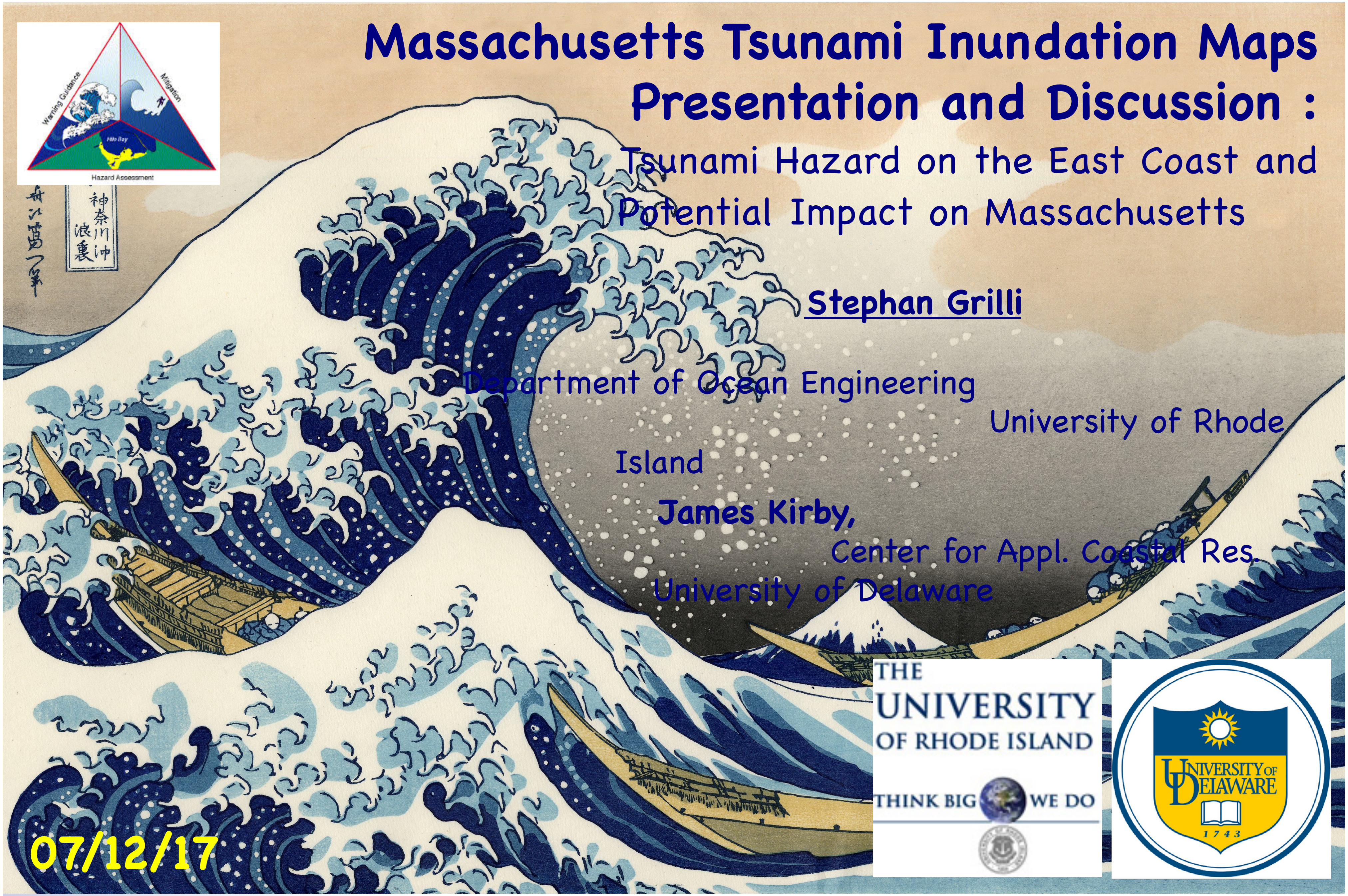

Massachusetts Tsunami Inundation Maps Presentation and Discussion :

Tsunami Hazard on the East Coast and Potential Impact on Massachusetts

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University of Rhode Island

James Kirby,
Center for Appl. Coastal Res.
University of Delaware

07/12/17

NTHMP East Coast Mapped areas FY10-16

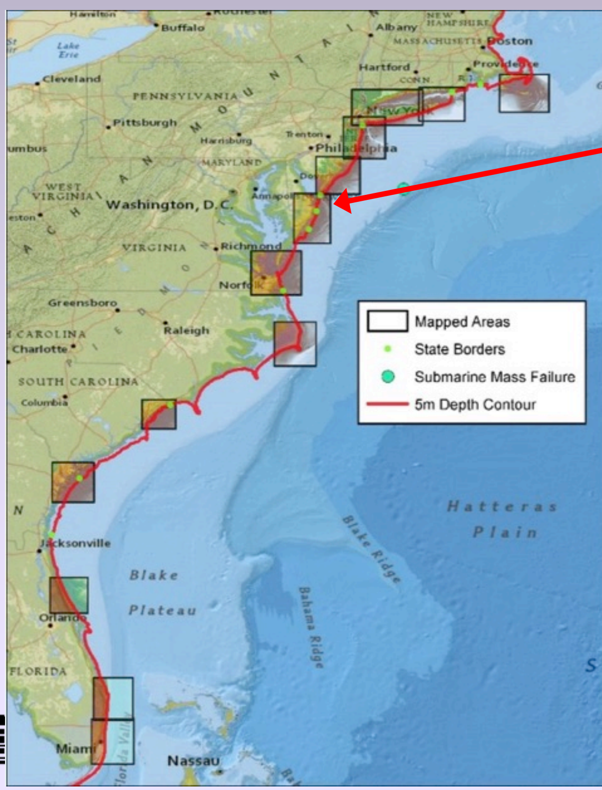
-> First generation maps based on Probable Maximum Tsunami (PMT) sources in the Atlantic Ocean Basin

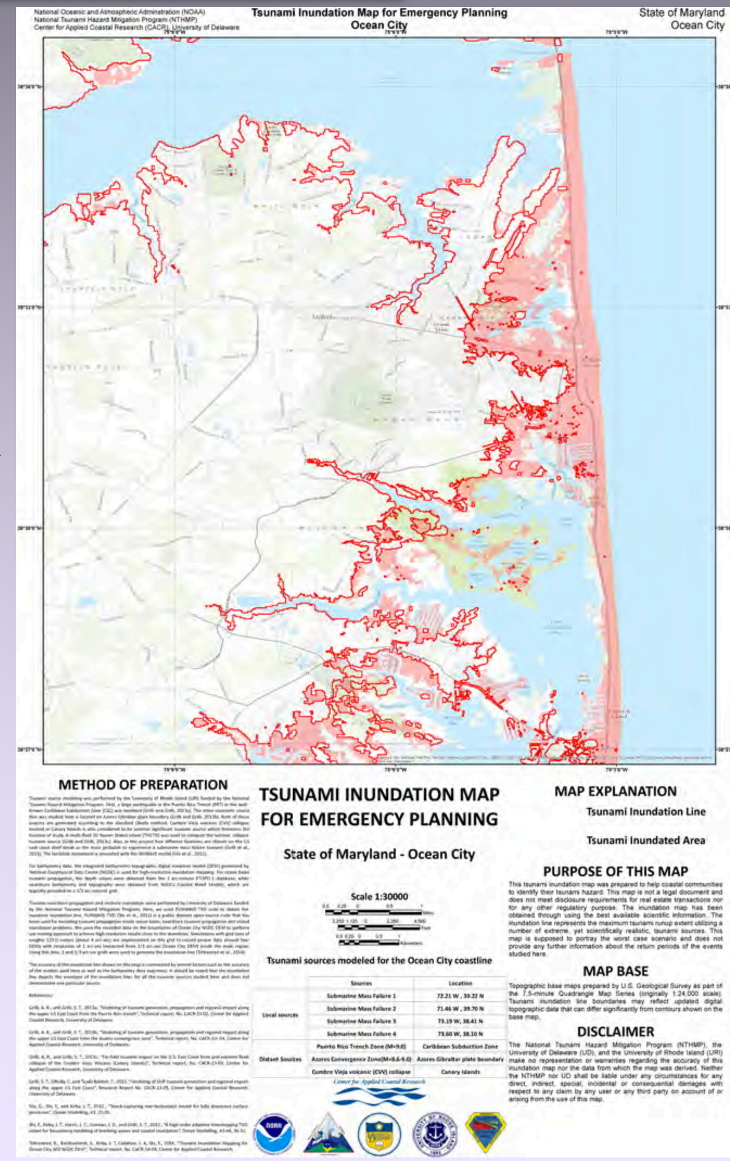
=> not a probabilistic study; envelope maps

=> variety of models (not discussed here)

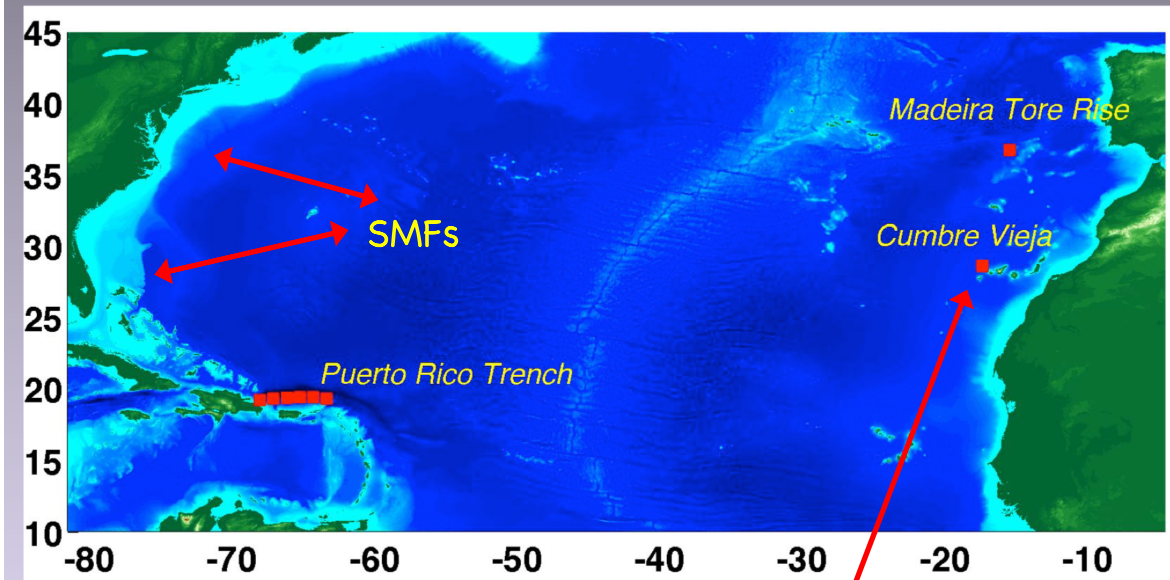
-> Locations of Maps, East Coast (2010-2015) :

www.udel.edu/kirby/nthmp_protect.html





Tsunami sources: SMFs, seismic, volcano collapse



-> EC: Little paleo-tsunami deposits/records evidence:

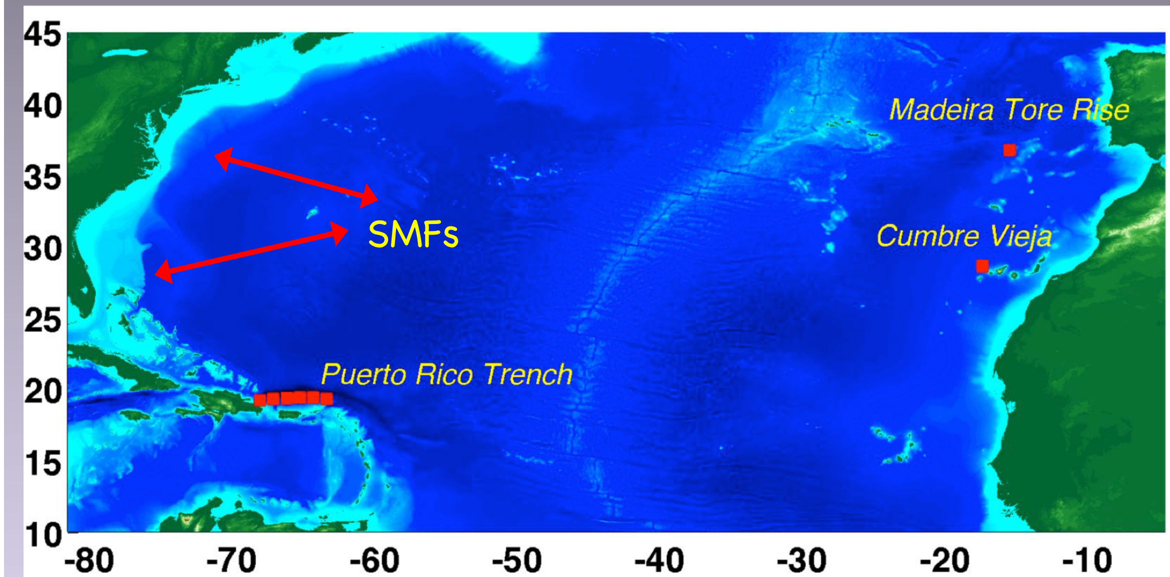
=> PMT approach

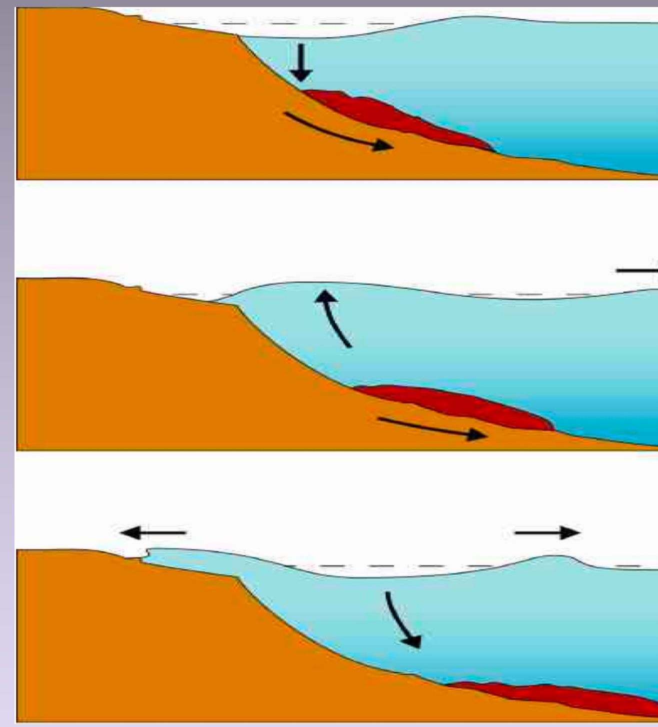
-> M9 historical far-field seismic source in MTR: repeat of Lisbon 1755 (multiple sources, various strike angl.)

-> M9 hypothetical far-field seismic source in PRT: designed as extreme event, (600 yrs of full convergence)

-> Hypothetical Far-field flank collapse of CVV with 80 or 450 m^3 volume (extreme and most extreme events), with return period (?) perhaps 1,000-100,000 yrs.

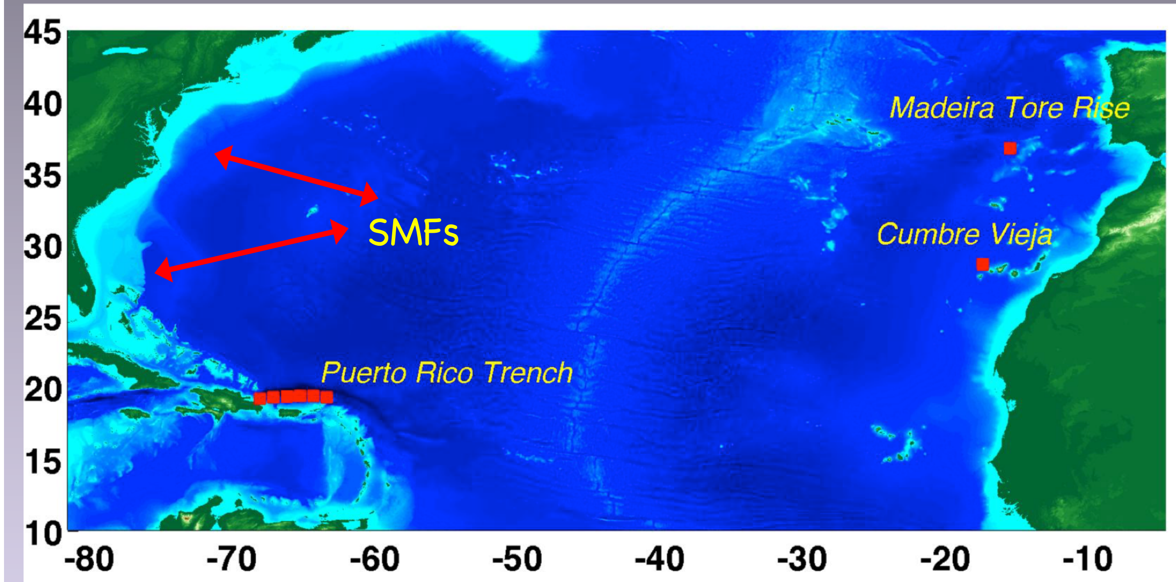
Tsunami sources: SMFs, seismic, volcano collapse

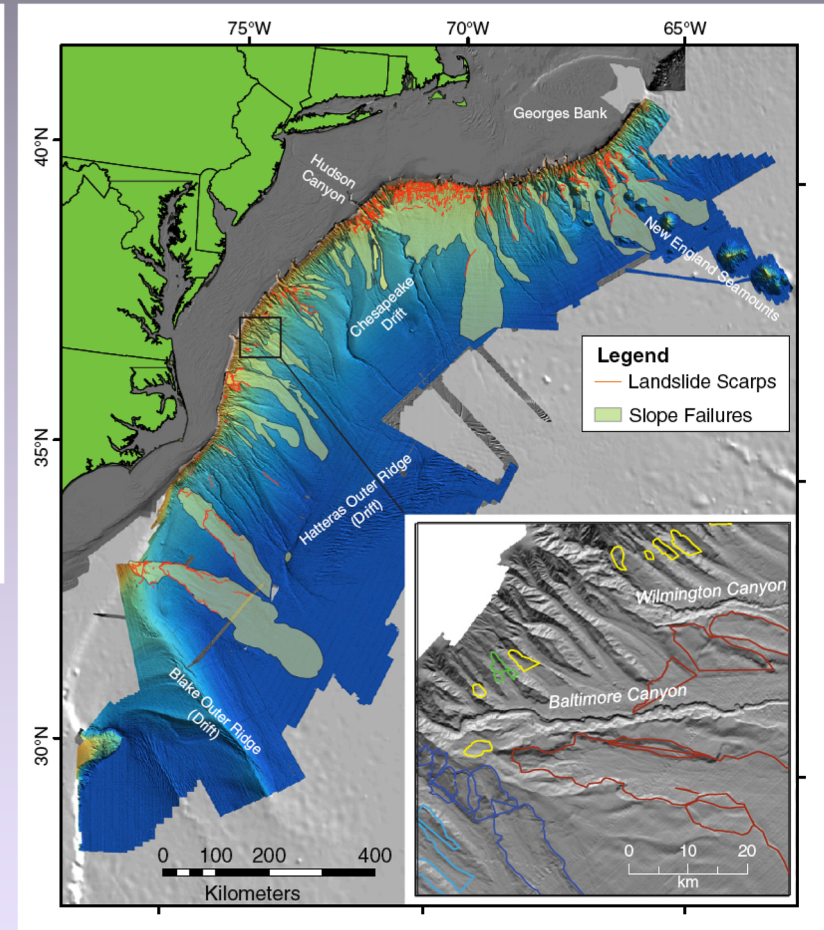




-> SMF triggered by earthquakes or not can generate large damaging tsunamis

Tsunami sources: SMFs, seismic, volcano collapse



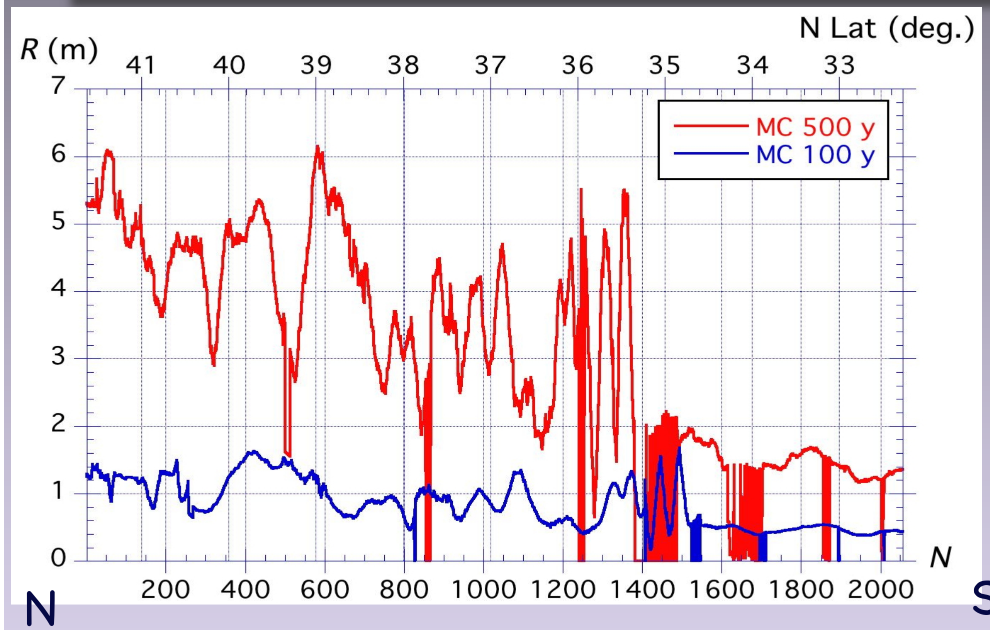


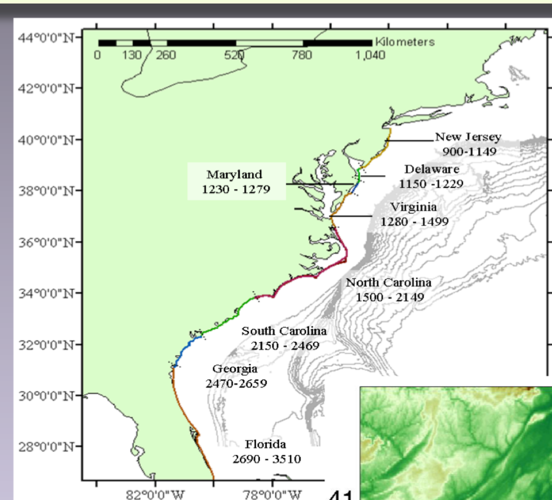
-> SMF triggered by earthquakes or not can generate large damaging tsunamis

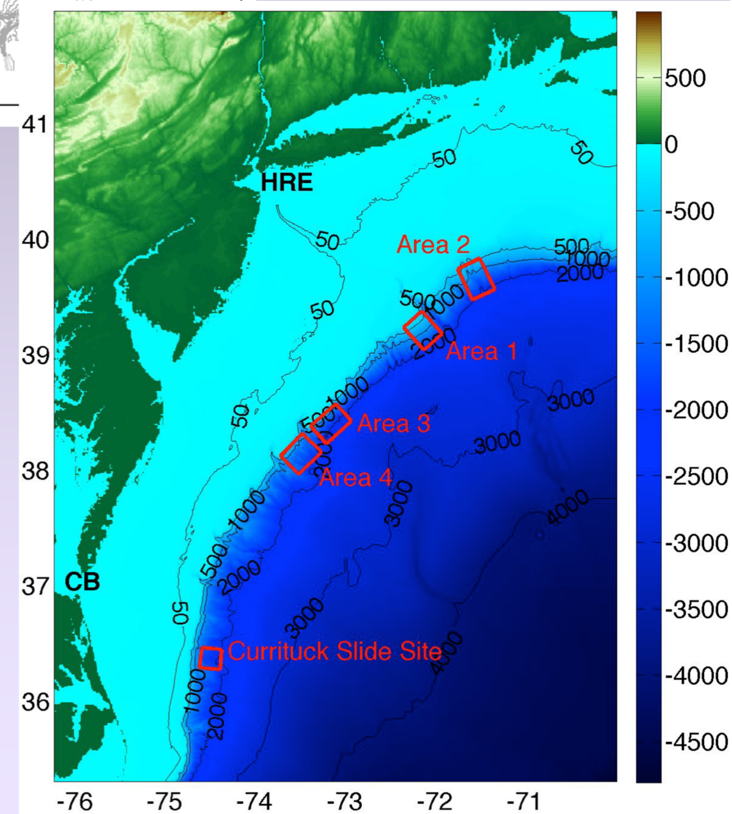
-> SMF scars are widespread on US Atlantic margin, but mostly old 1,000s of yrs. But see 1929 Grand Bank SMF tsunamis

[Ten Brink et al (2014)]

Near-field SMF sources: Monte Carlo + proxies



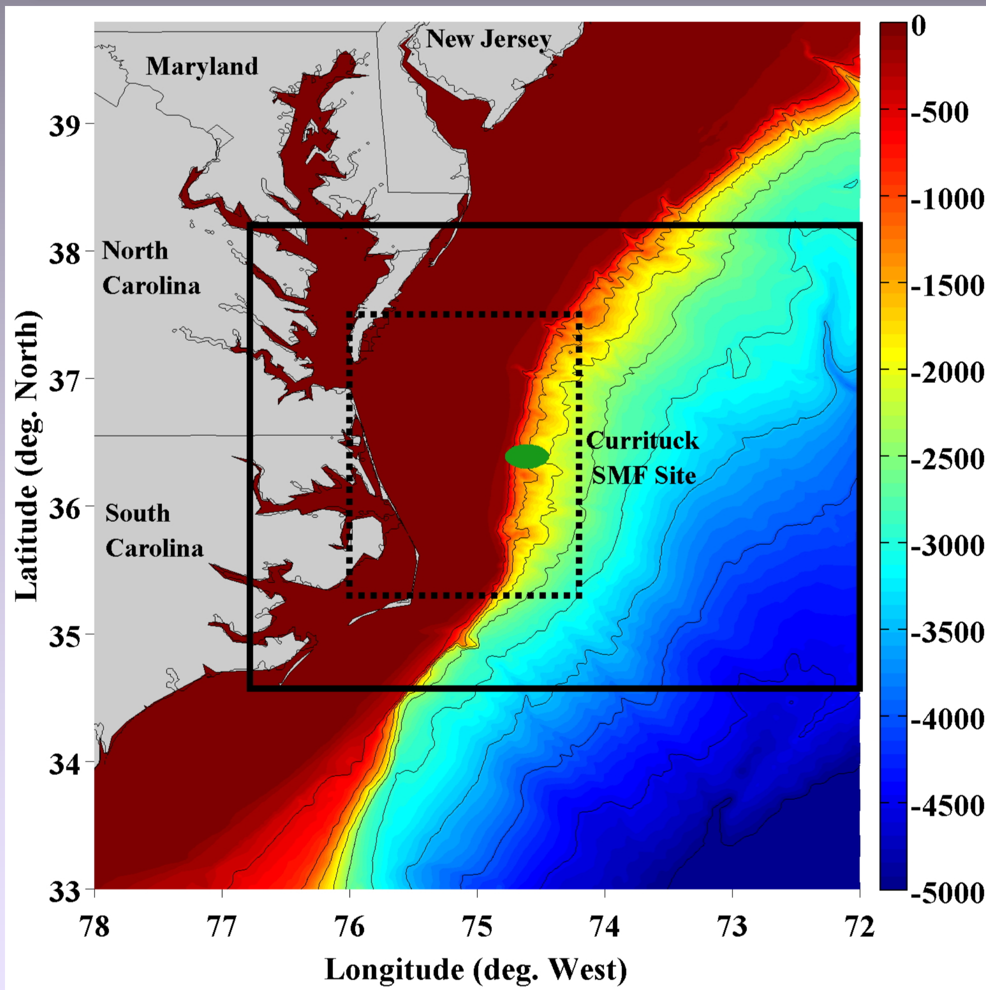


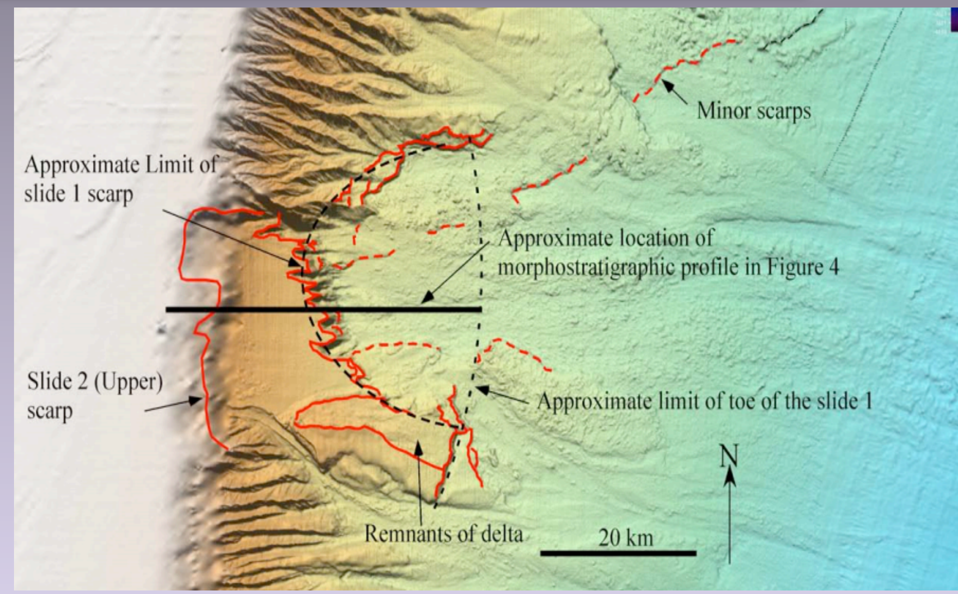


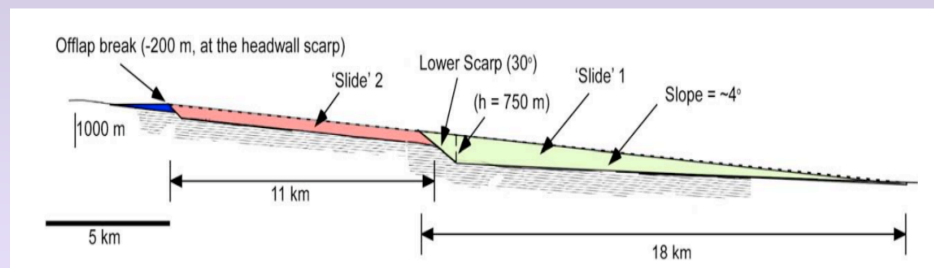
-> Grilli et al's (2009, MG) Simple Monte Carlo slope stability analyses along transects:
=> areas of estimated (100-500 year) runup

-> Sediment availability/geology, :
=> Areas 1 to 4: Currituck SMF proxies, with 165 km^3, 14,000 y old (Grilli et al., 2015; NH)

Case study of US East Coast SMF: Currituck

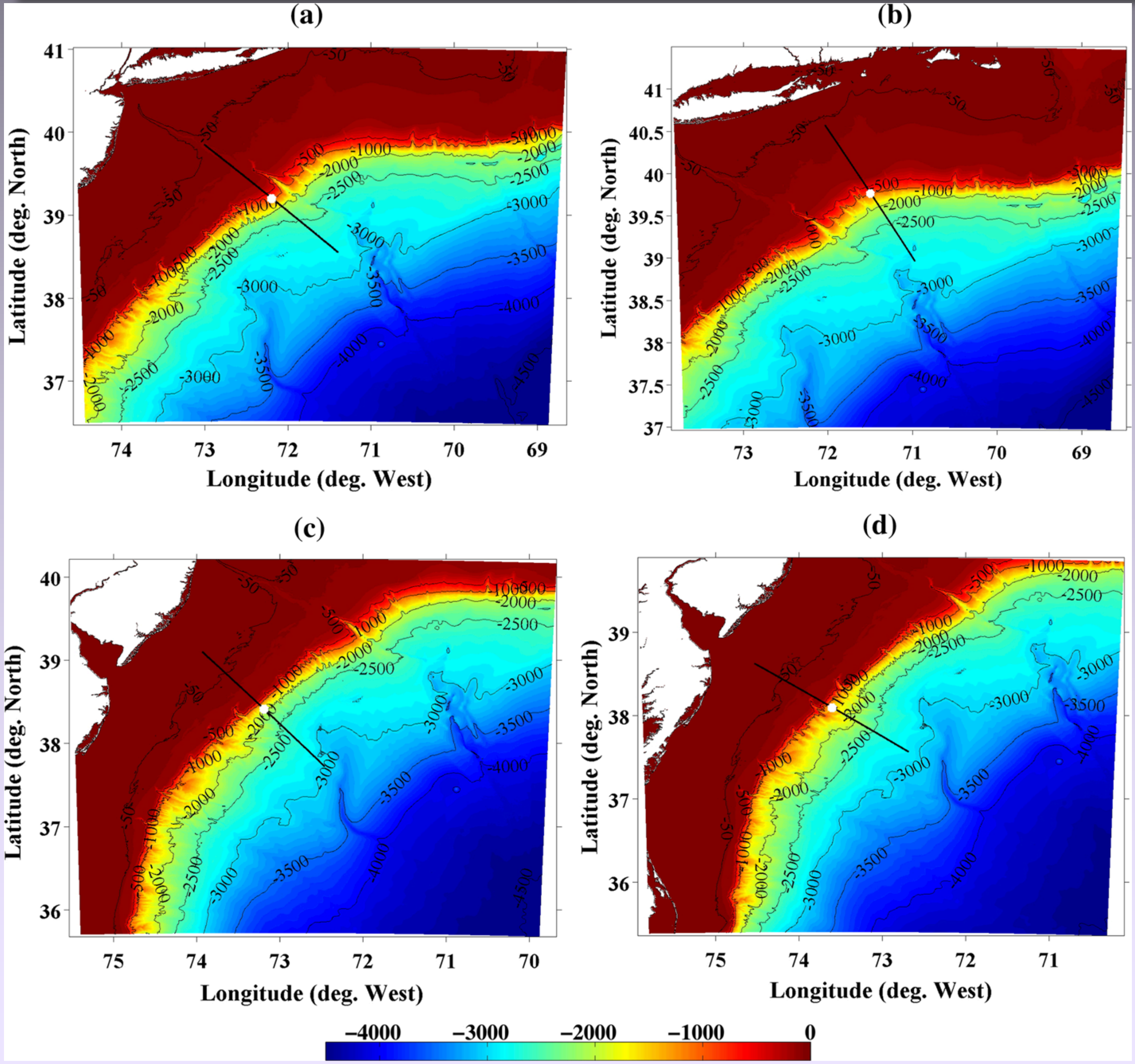




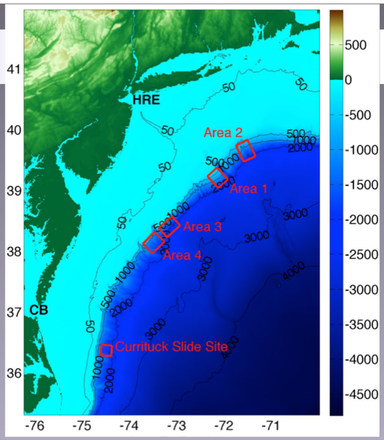


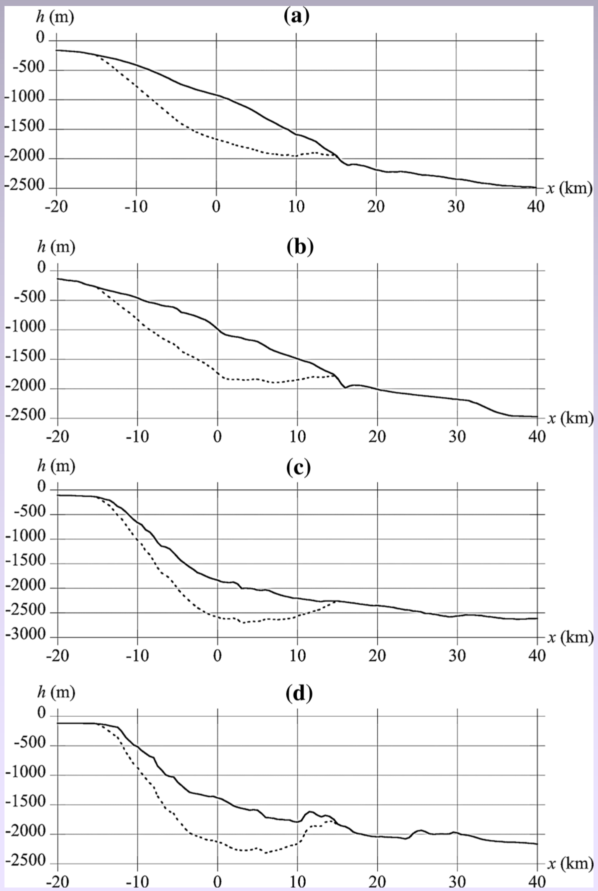
[Grilli et al., 2015 (Nat. Haz.)]

Curritück SMF proxies in areas 1 to 4

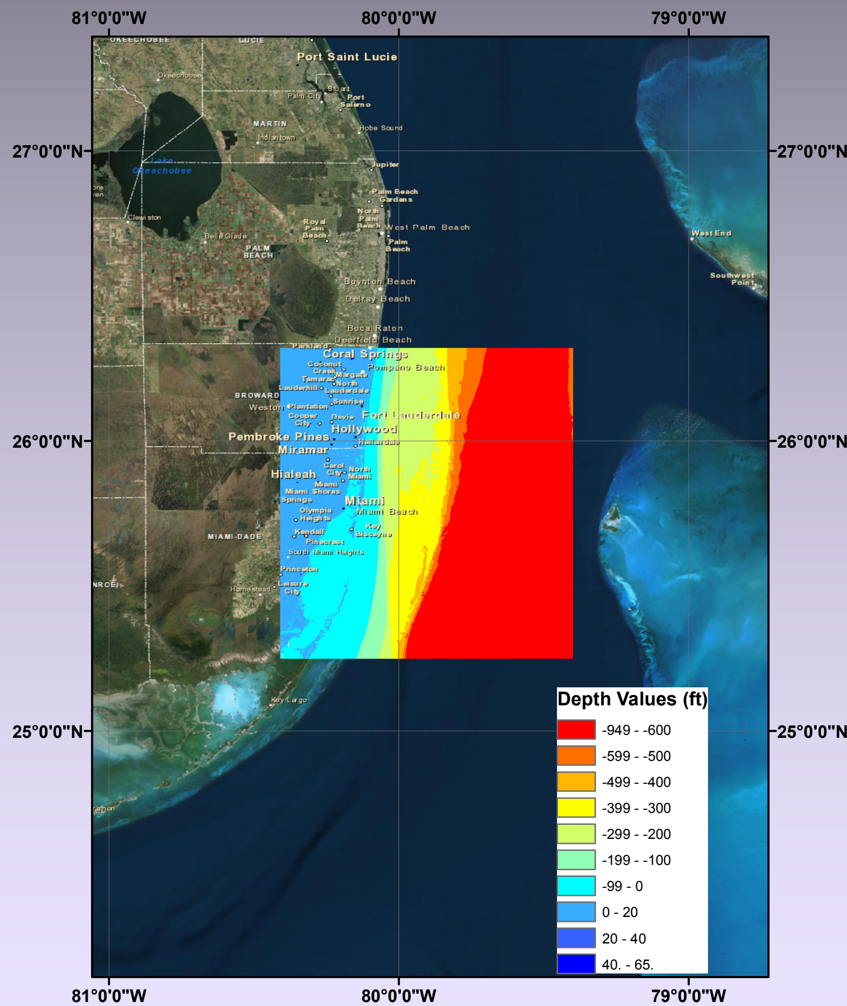


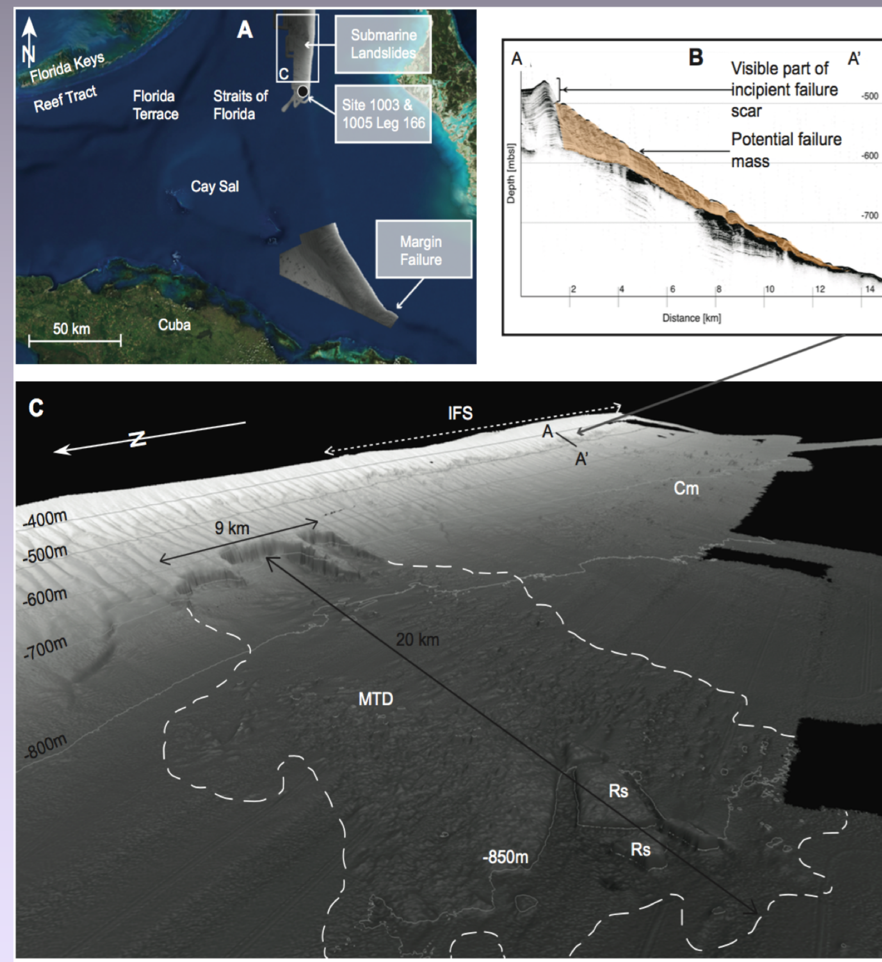
SMFs: 165 km³ rigid slumps





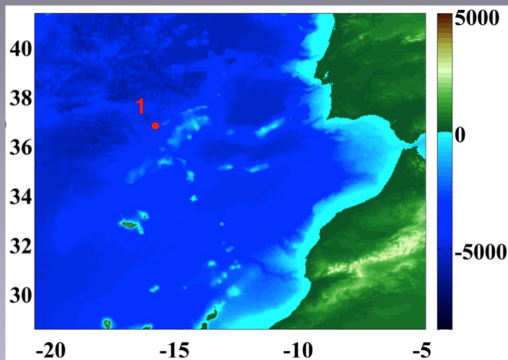
Near-field SMF sources: West Bahamas Banks

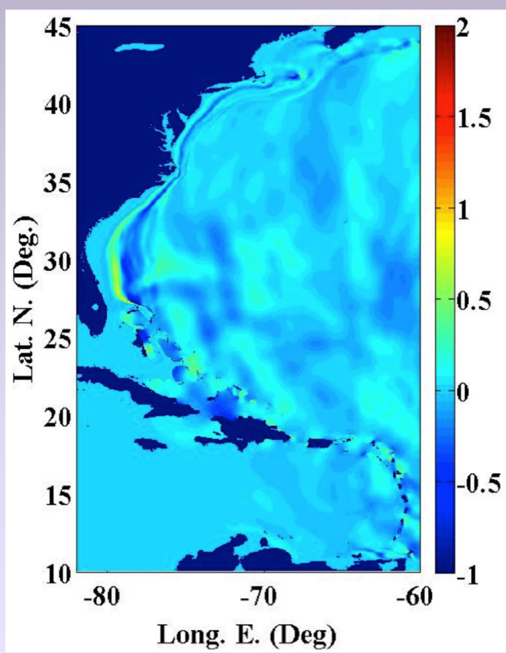


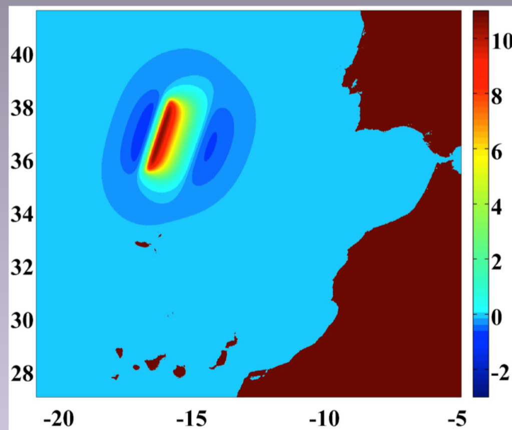


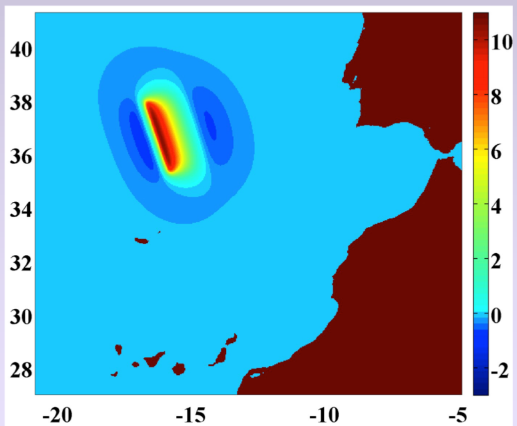
(Schnyder et al., 2013)

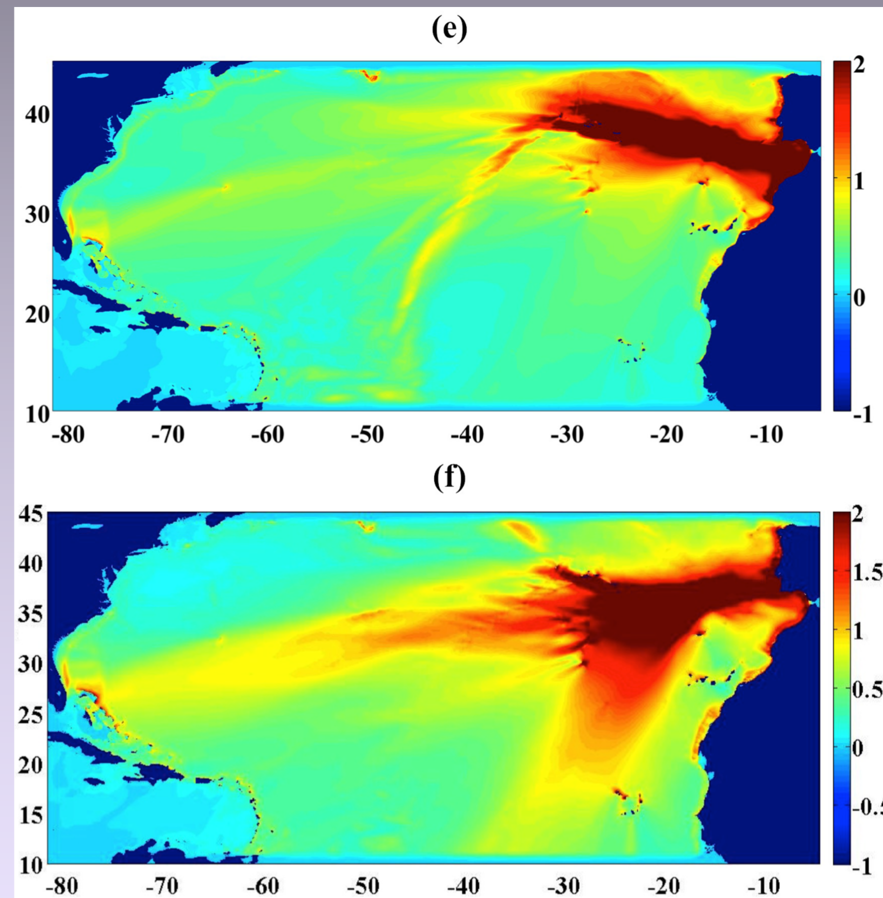
Far-field source modeling : M9 MTR





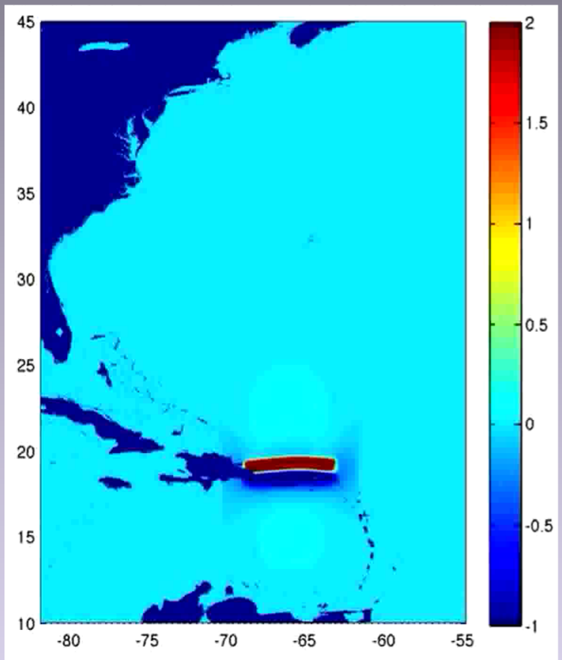


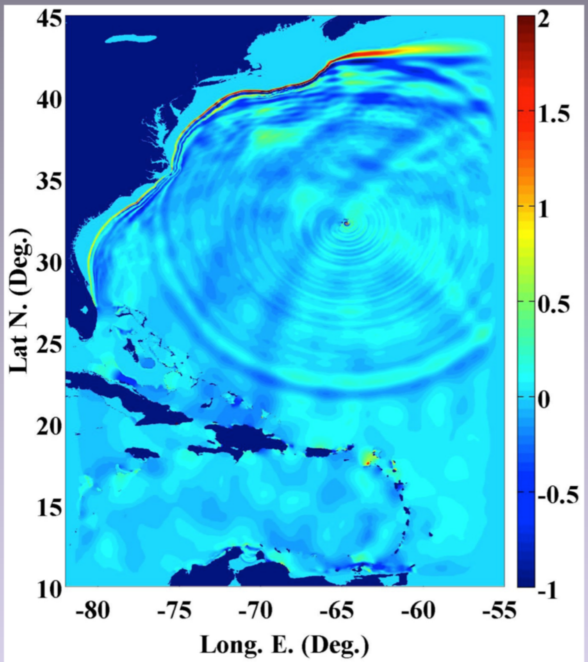


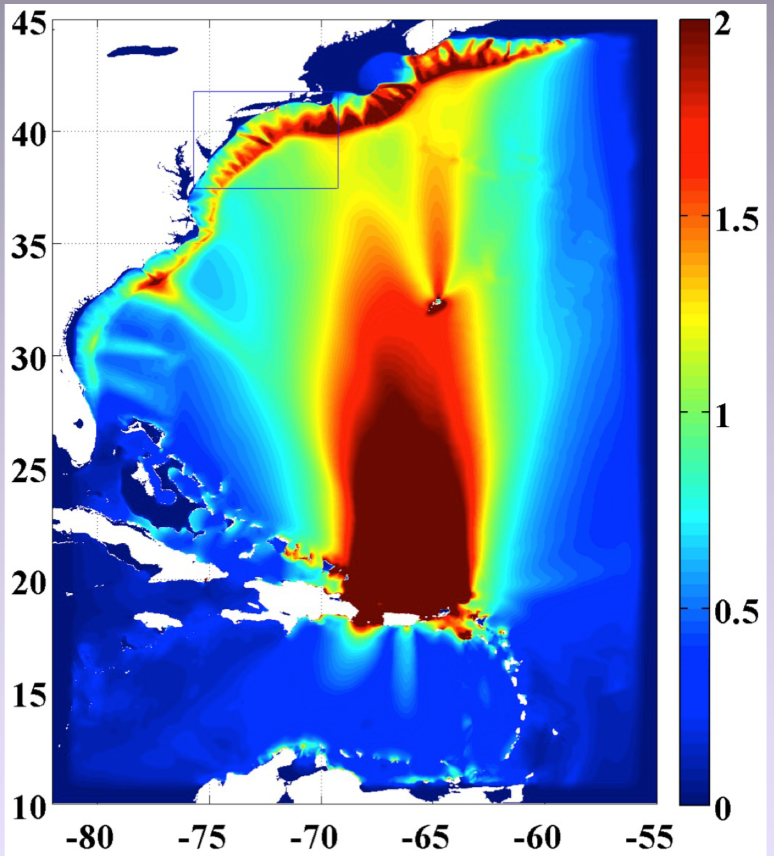


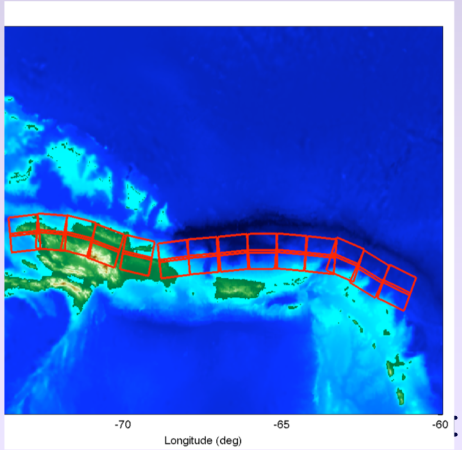
-> Order 1 m max runup/inundation, not dominant

Far-field source modeling : M9 PRT







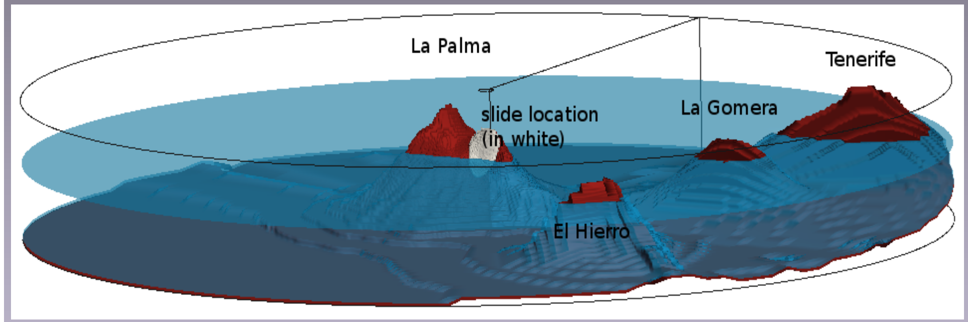


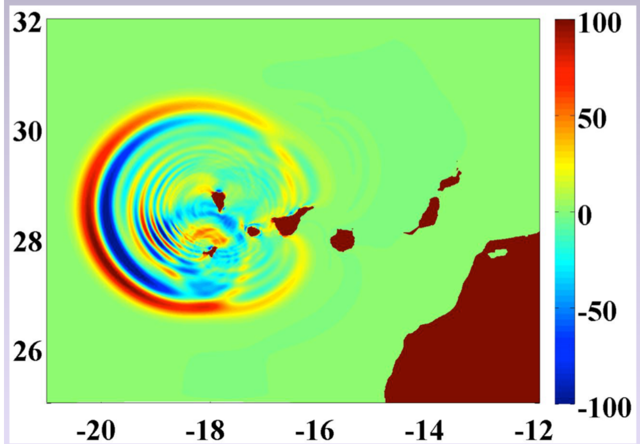
"SIFT" sources

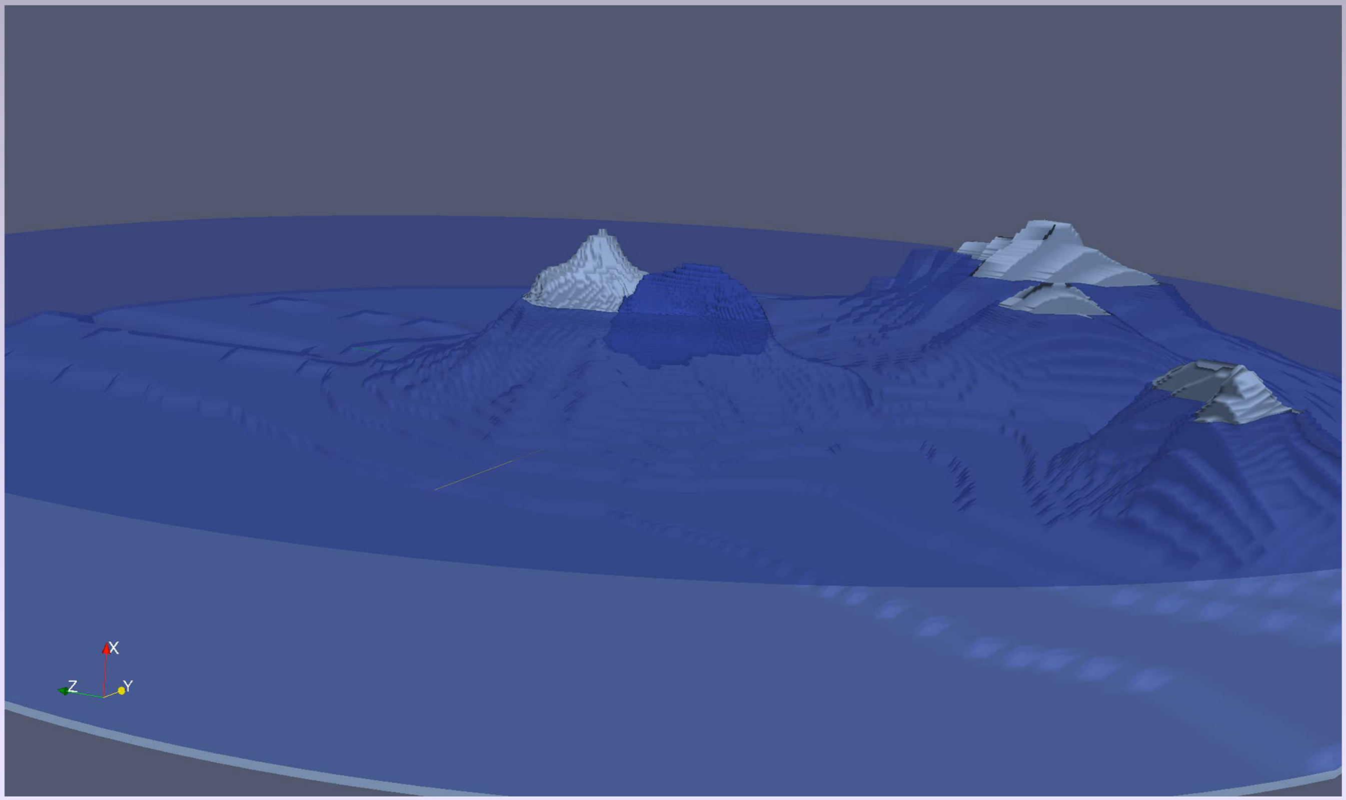
Fault planes, in the area

-> Order 2 m runup/inundation

CVV Flank Collapse source (450 km^3)



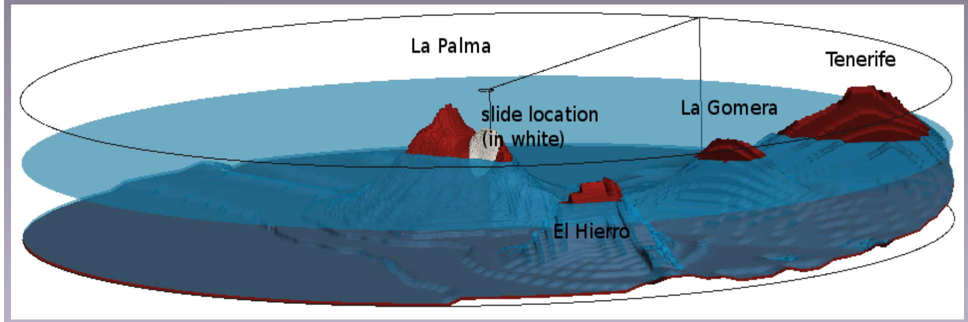




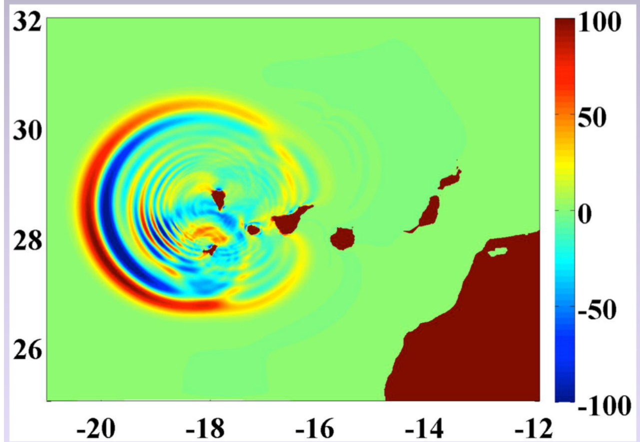
-> Surface elevation (meter) after 20 min

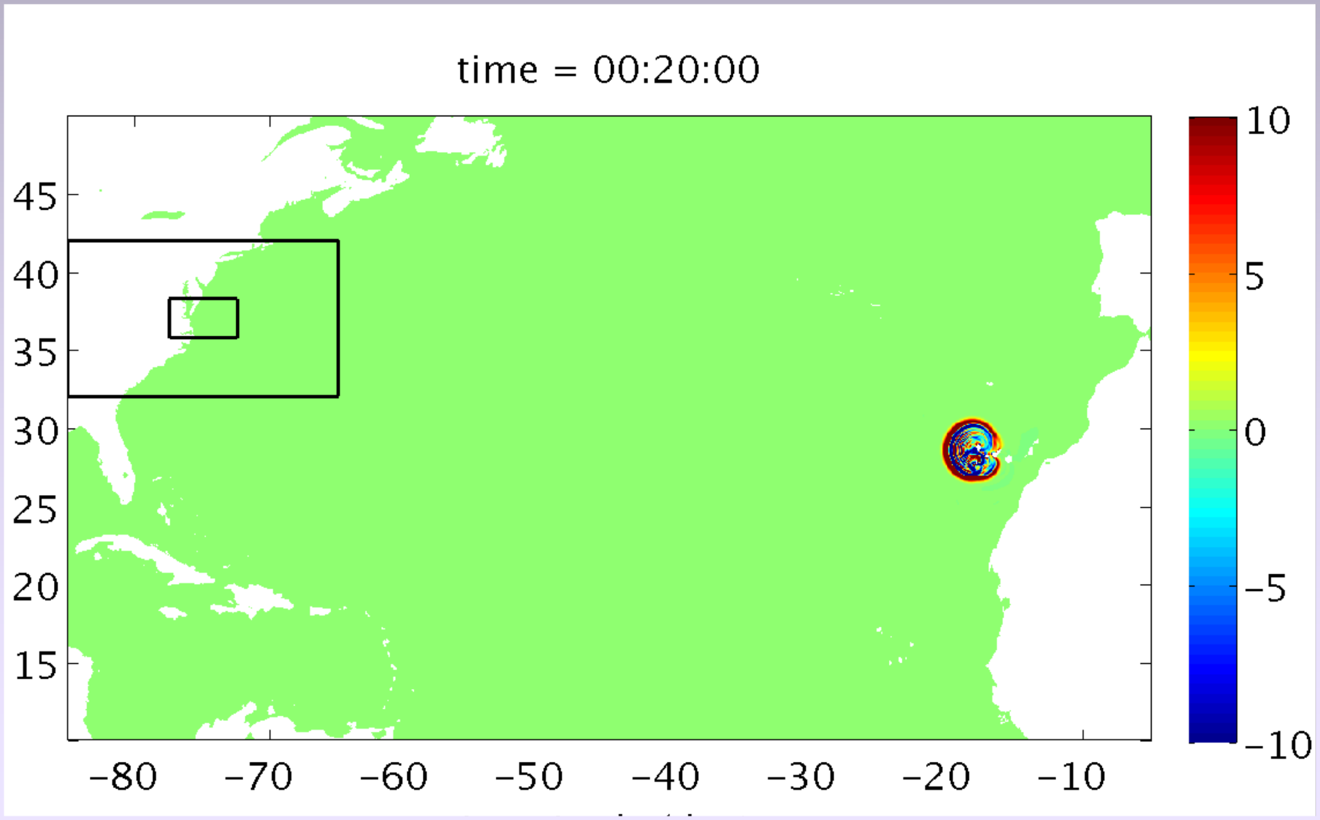
Dept. of Ocean Engineering, URI

CVV Flank Collapse source (450 km³)



-> Surface elevation as a function of time (meter)

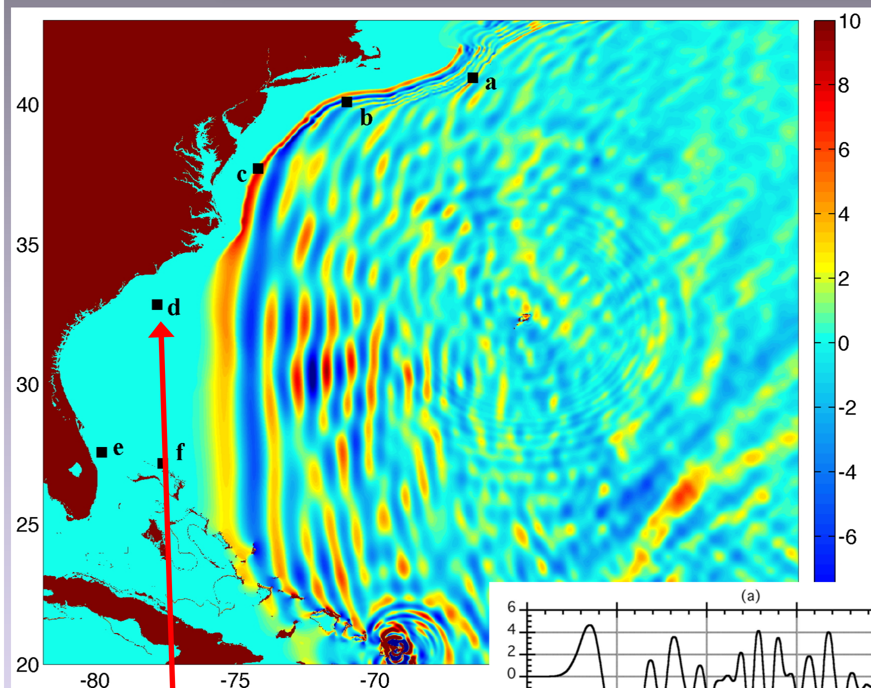


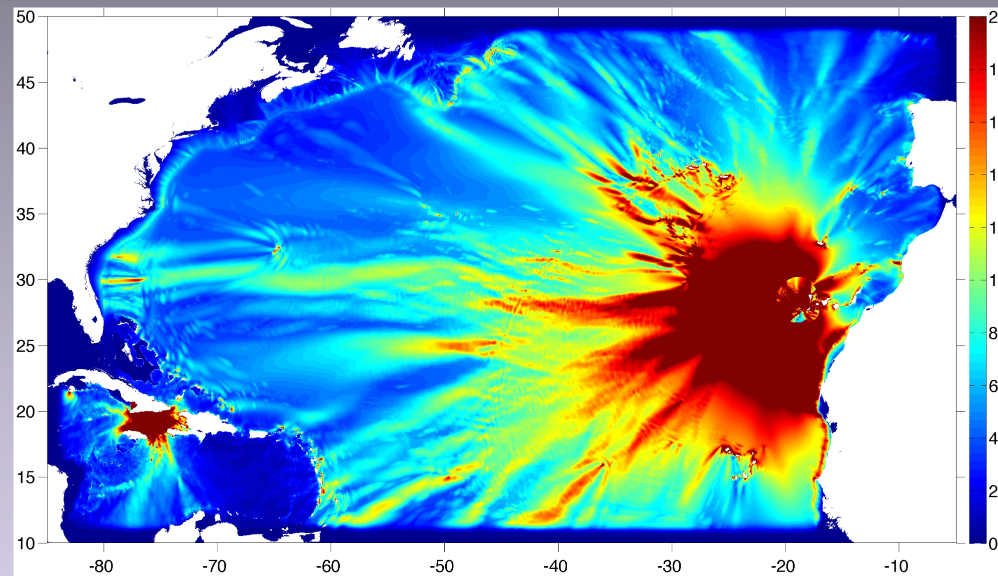


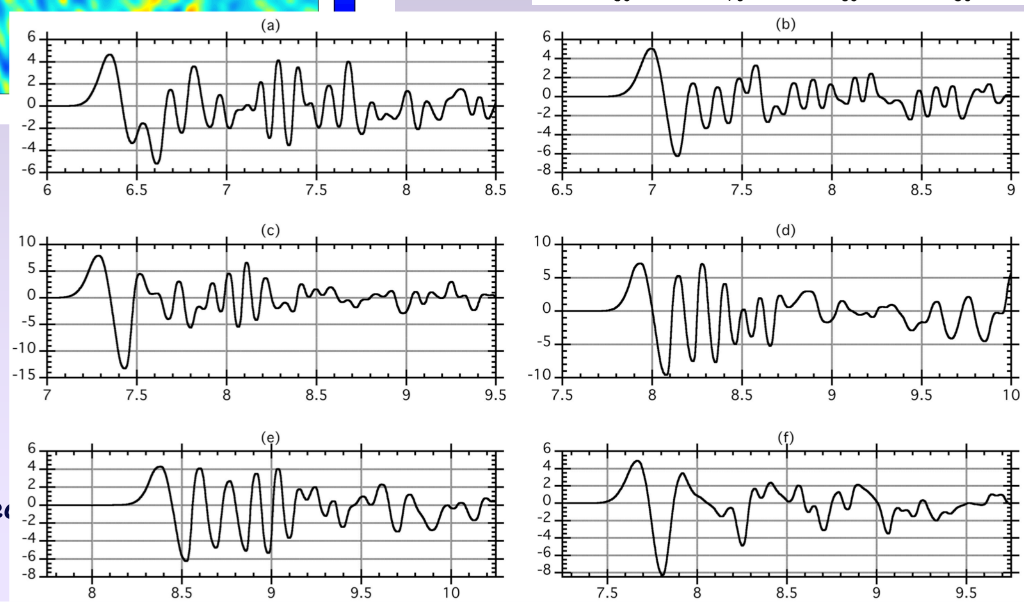
-> Surface elevation (meter) after 20 min

Dept. of Ocean Engineering, URI

CVV Flank Collapse source (450 km^3)







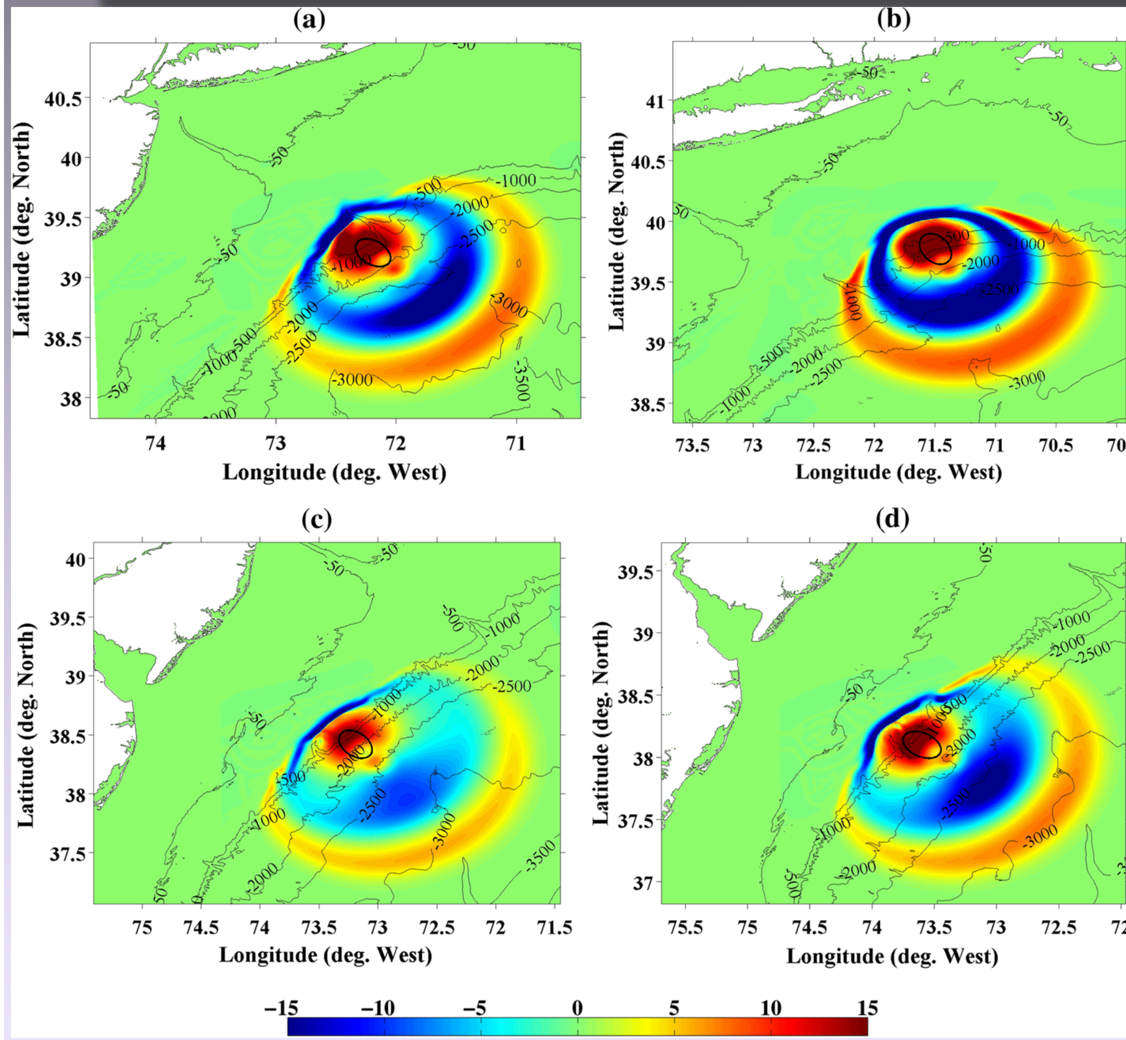
-> Dispersive trains of large waves, 9-12 min period

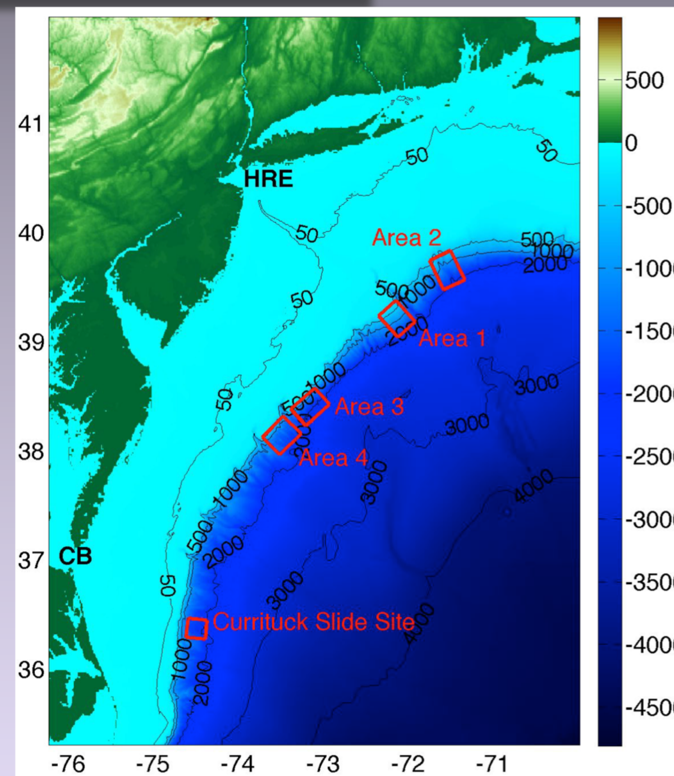
-> 450 km^3:
Up to 5-6 m runup/inundation

-> 80 km^3:
Up to 2-2.5 m runup/inundation

Dept. of Ocea
Engineering,

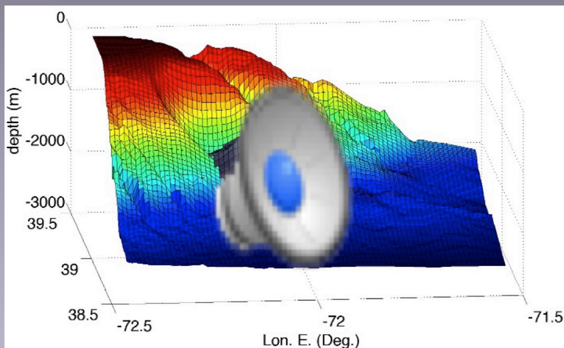
Currituck SMF proxies in areas 1 to 4



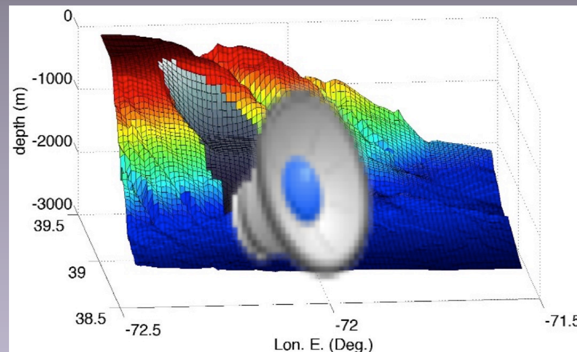


- Modeled as rigid slumps (surface elevations after 13.3 min)
  [Details in Grilli et al. (2015) NH]
- Deformation is being studied

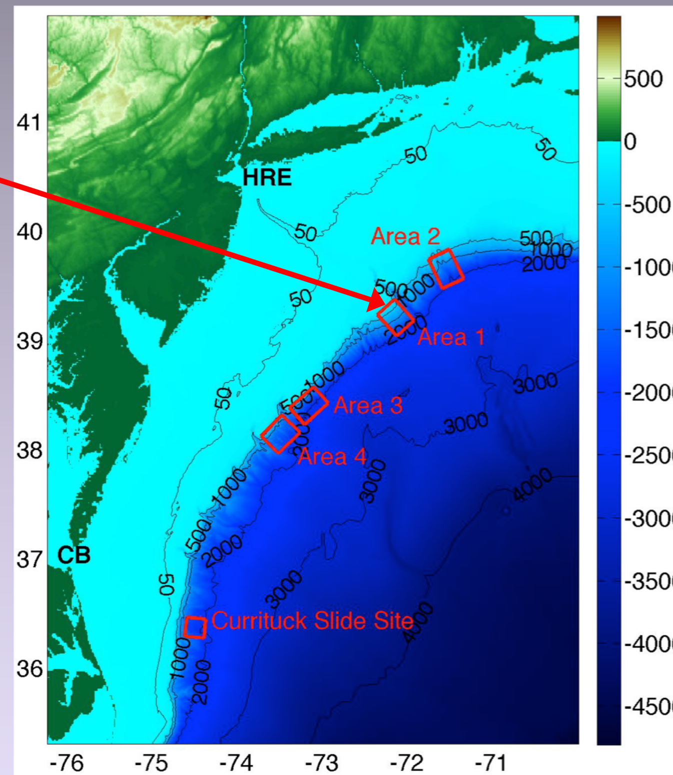
Currituck SMF proxies 1: rheology effect

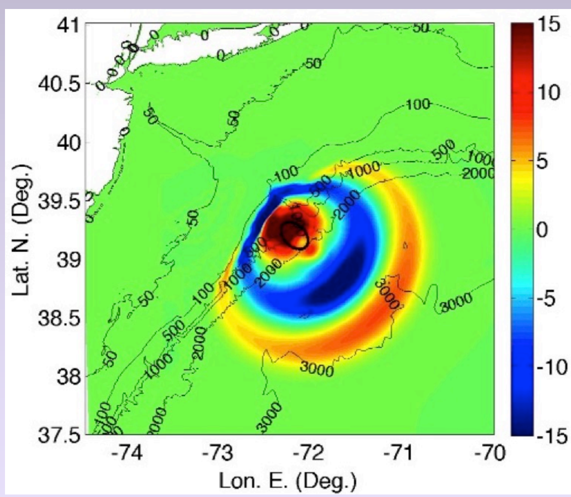


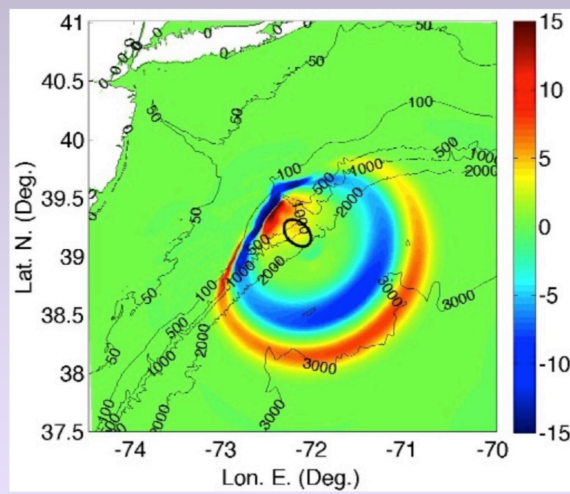
Rigid slump



Deforming slide



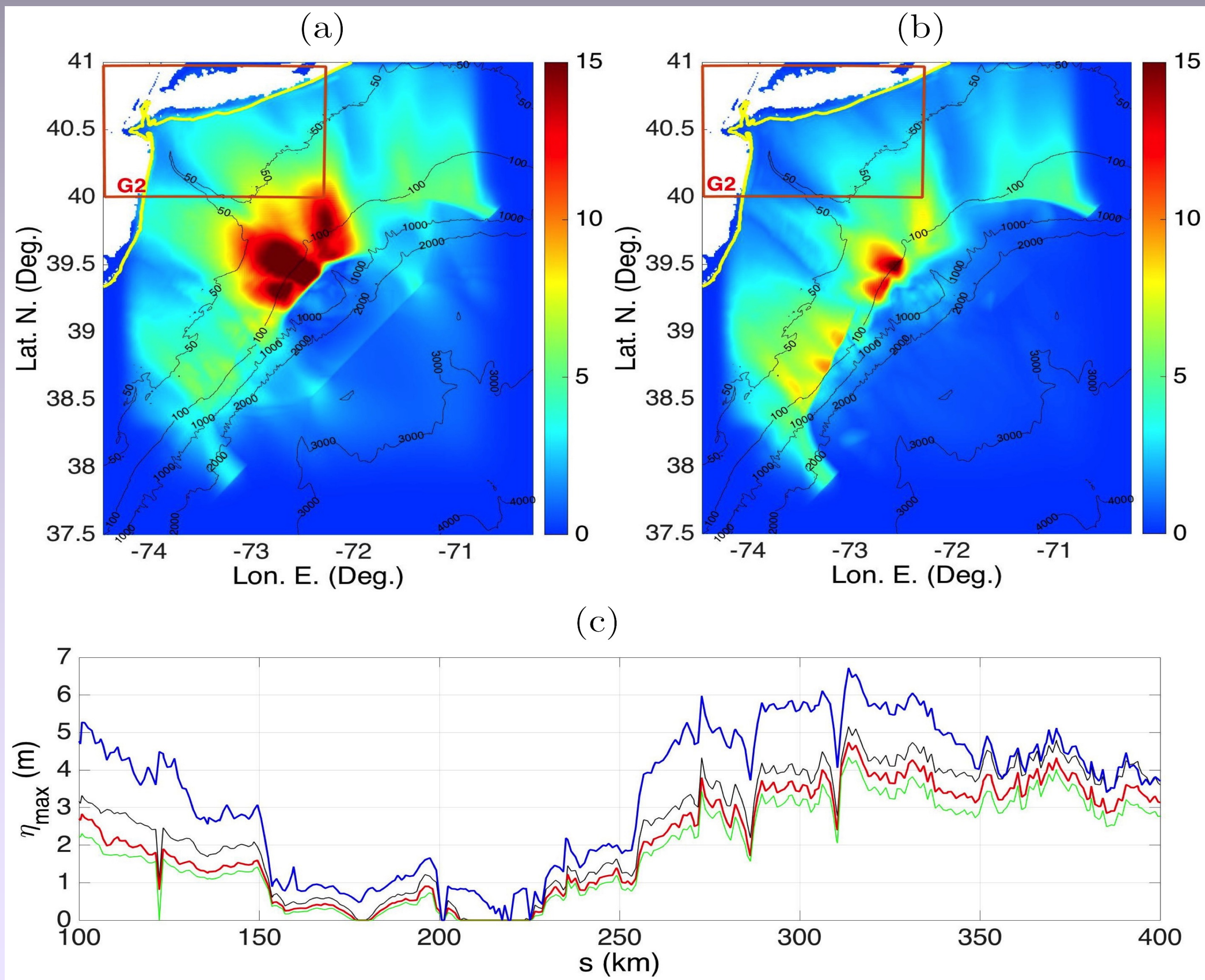




Surface elevation after 13.3 min (slump stops at 12 min; same runout)

Currituck SMF proxies 1: rheology effect

Rigid slump   Deforming slide

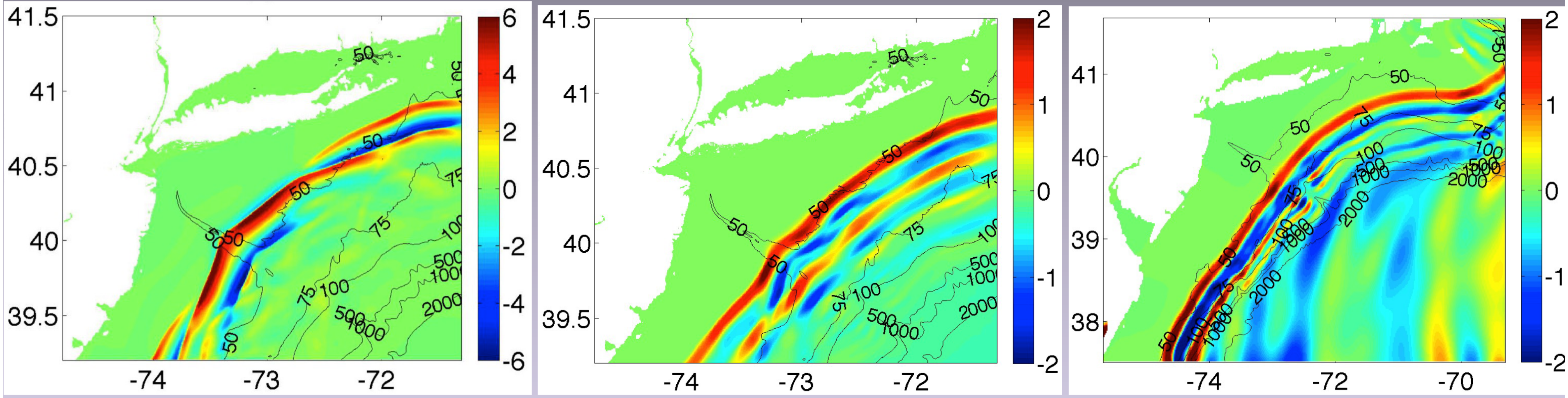


-> Hudson River CRT proxy elevation at 5 m isobath

-> Comparing rigid slump (blue) to 3 deforming slides with varying rheology (Grilli et al., 2017)

-> Rheology effects are not included in 1st generation maps

Comparing coastal impact CVV/SMF/PRT



SMF-1 (rigid slump) 1h18' PRT (4h) CVV (80 km^3) (8h)

-> Similar patterns of nearshore waves are observed for all sources

-> Coastal wave height distribution suggest tsunami coastal hazard is controlled by nearshore bathymetry, particularly that of a wide shelf.

Comparing coastal impact CVV/SMF/PRT

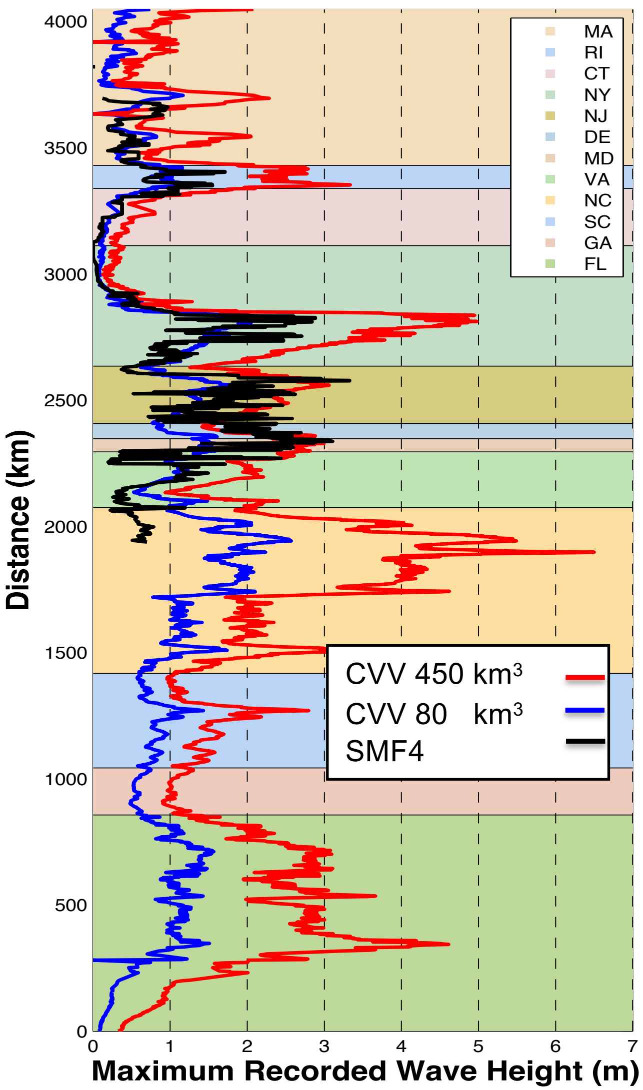
-> CRT coastal impact in Hudson River estuary, including dynamic tidal effects

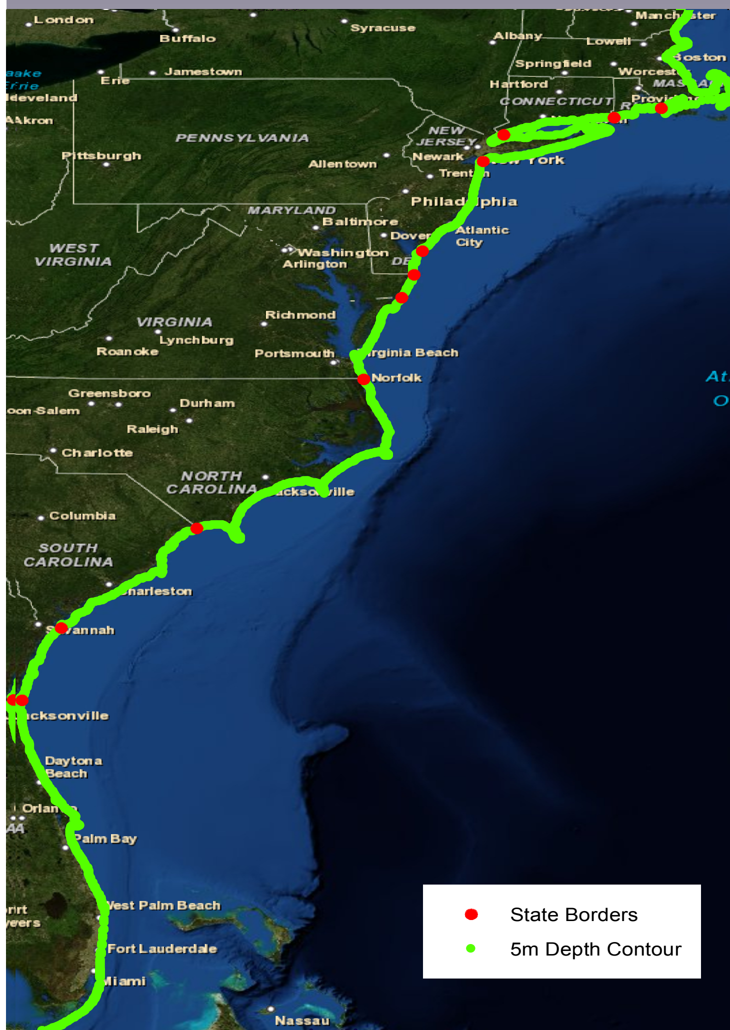
-> Tide may enhance tsunami impact

(Shelby et al., 2016)

-> Tide effects are not included in 1st generation maps

Comparing coastal impact CVV/SMF1-4/PRT





MEMA 07/12/2017

- -> A similar wave height distribution pattern is observed for all of the sources simulated in this study.
- -> Wave height distribution and tsunami propagation control by nearshore bathymetry,

Discussion – East Coast Risk

1) First generation maps are based on extreme sources/PMTs, with no consideration for return periods of LSB, PRT, CVV, SMFs.

=> Return periods are needed to assess risk => future work on PTHA ?

=> Realistic SMF rheology needs to be considered => ongoing work

=> Last major PRT earthquake was in 1787 (M8.1); is a 200-300 year return period possible for a 600 year M9-PRT event ?

Discussion during USGS workshop (Boulder 2016)

- No EC SMF has been found that is more recent than 10,000 years (but 1929)
- Main SMF trigger is seismicity => slope stability analysis with peak horizontal earthquake acceleration (Approach in Grilli et al.'s, 2009 MC work)
- Maximum PRT event is linked to whether plates are coupled or uncoupled
  => No apparent consensus at USGS on this (100s to 1,000s of years) and need for more paleo-tsunami work in the PRT area to help decide.

Discussion – East Coast Risk

2) Size and likelihood of CVV failure (e.g., 80, 450 km^3; single/multiple)

=> might dominate east coast hazard for most extreme case, or not ?

(see Cape Verde mega-tsunami 73ka ago, 200+ m runup; Ramalho et al., 2015)

Discussion during USGS workshop

- No guidance from USGS as they are not funded to study these volcano failures

3) SMF siting and rheological properties have major influence on coastal hazard

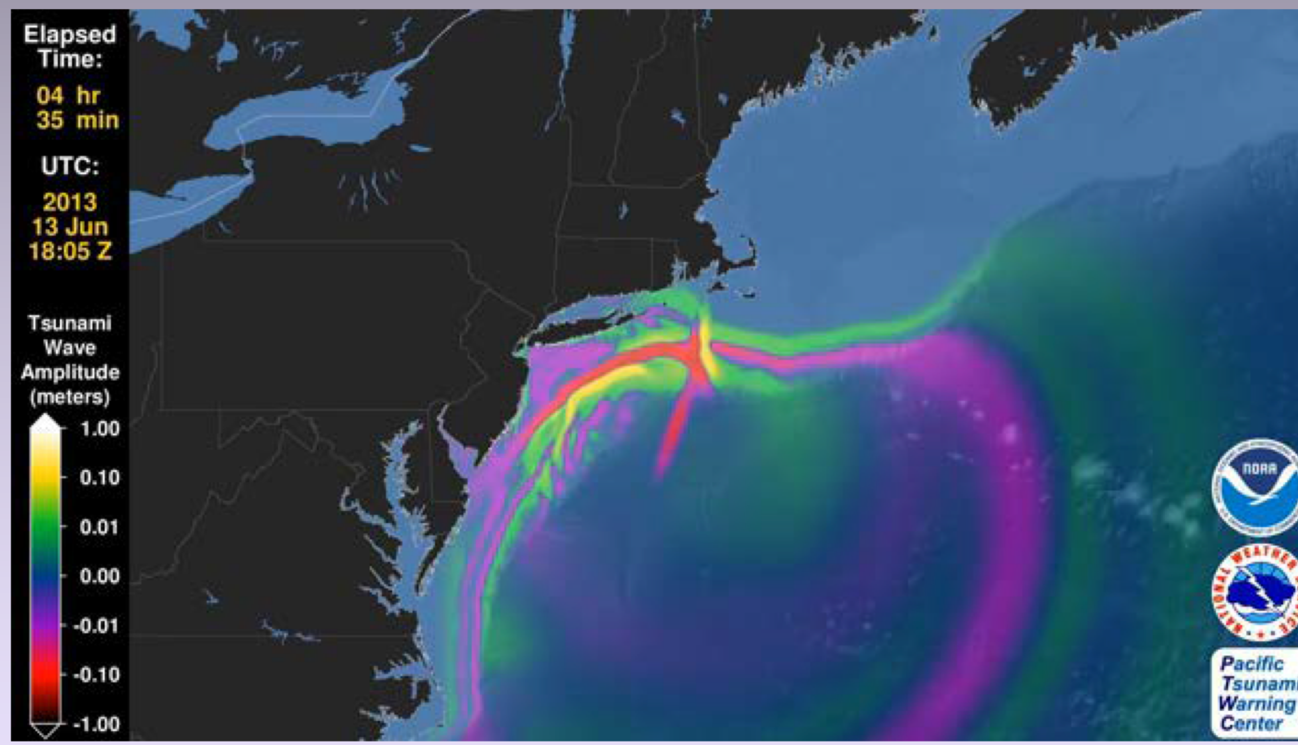
=> Need for geological/geotechnical data, siting, … for east coast SMFs

Discussion during USGS workshop (Boulder 2016)

- USGS (Chaytor's group) will provide data based on recent field survey
- This can be fed into more accurate MC studies of east coast landside tsunamis

4) Geist et al. (2014,2015) study of 2013 EC meteotsunami => 1-2 m runup can be expected on a 100-200 y time scale -> similar risk => ongoing work

Meteo-tsuamis hazard (ongoing)



-> June 13, 2013 EC meteotsunami -> 2 m waves off of New Jersey

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Thank you

UNIVERSITY of DELAWARE

NTHMP Inundation Mapping for Massachusetts

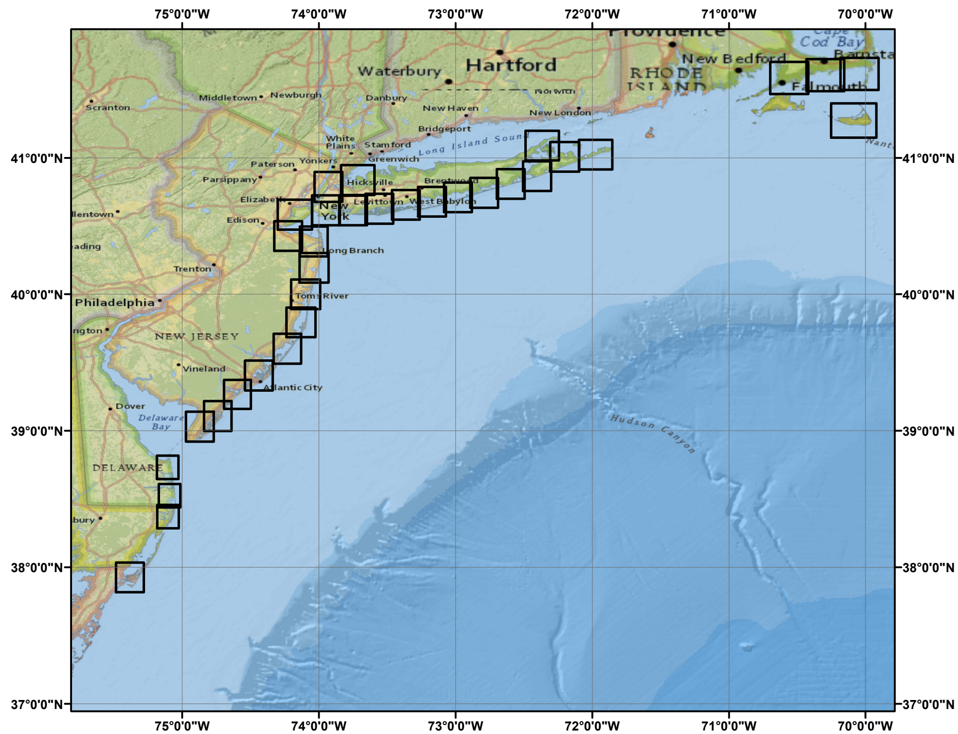
Massachusetts Emergency Management Agency
400 Worcester Road
Framingham, MA

July 12, 2017

Center for Applied Coastal Research

THE UNIVERSITY OF RHODE ISLAND

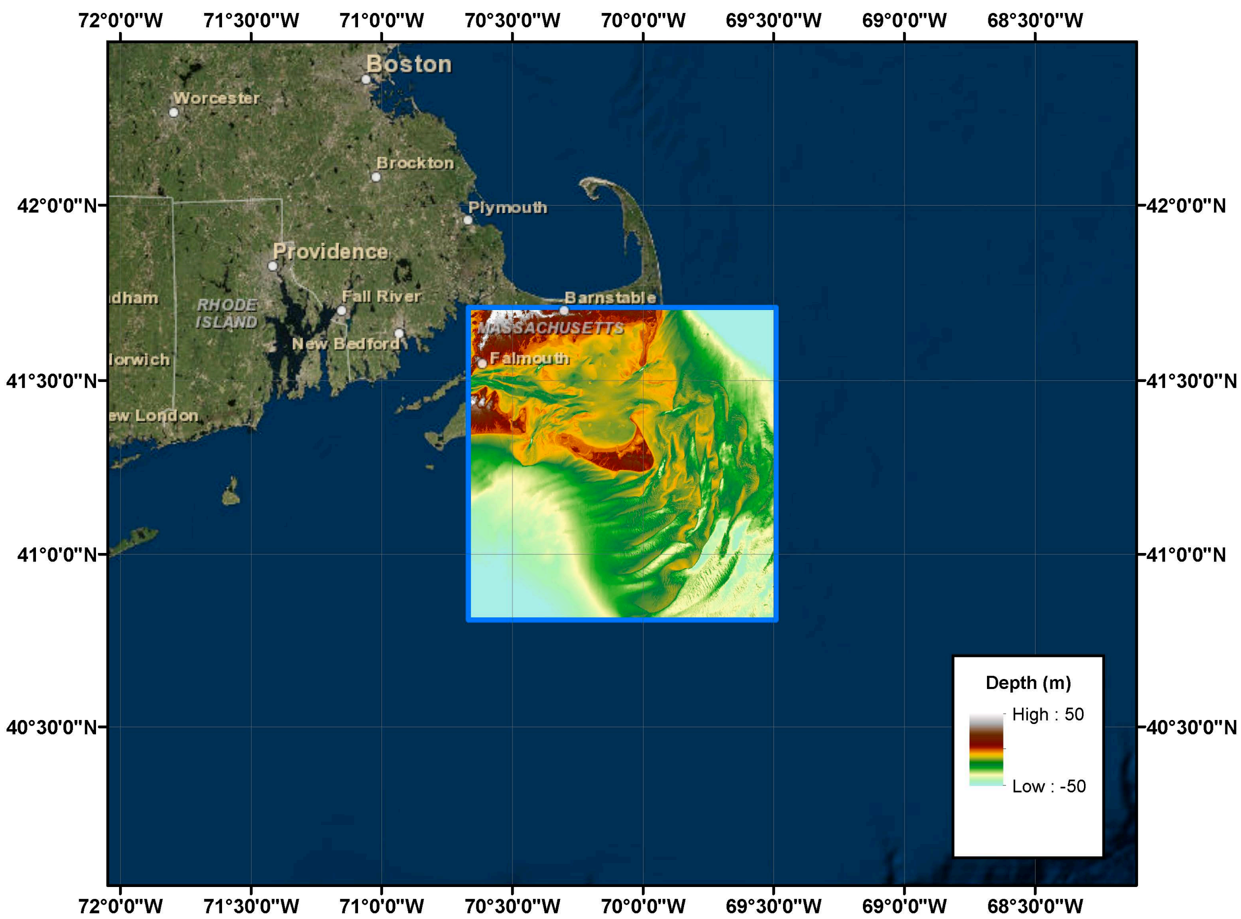
Location of Maps Generated for the Upper East Coast (FY10-12)



Reporting:

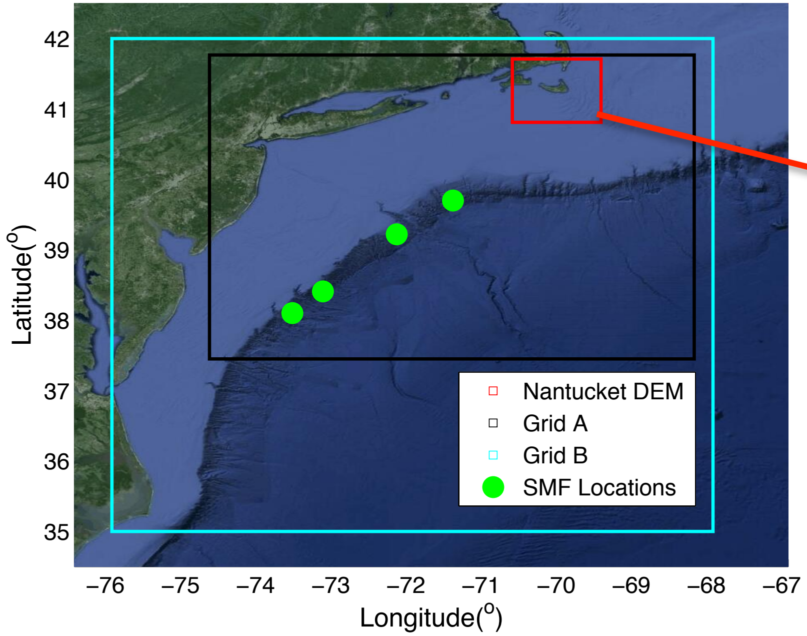
1. Source reports
   - Organized by event or class of event.
2. Inundation reports
   - Organized by DEM
   - Provide:
     - Information on sources for each region
     - Arrival time information
     - Description of maps
     - Description of additional products (mainly maritime, momentum flux estimates on land)
     - ArcGIS information.
3. Maps!

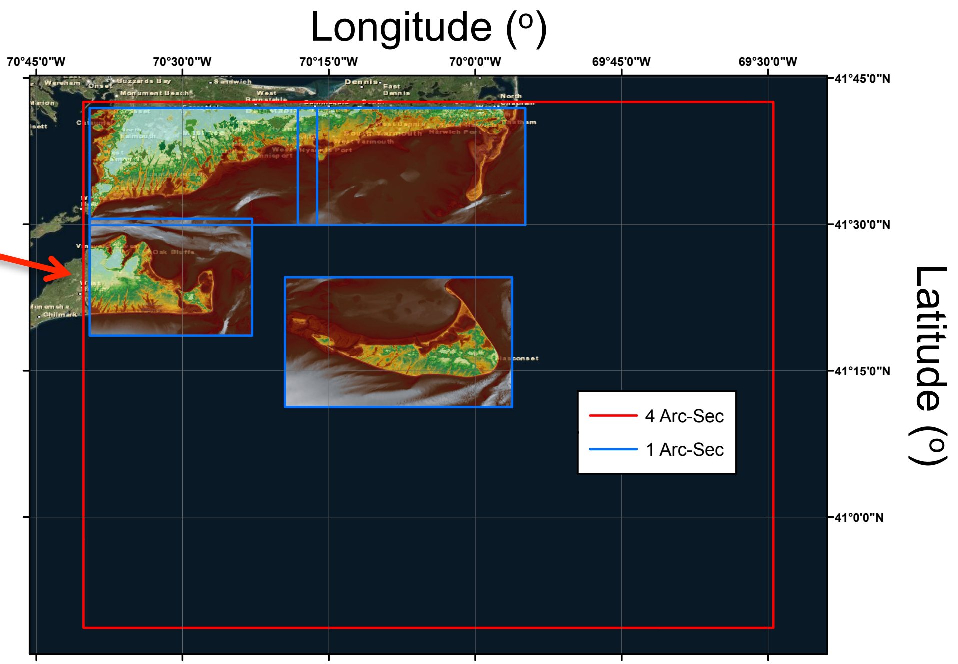
Basis for local mapping: NGDC Nantucket DEM



(Eakins et al, 2009)

Nesting of computations from large to small scale



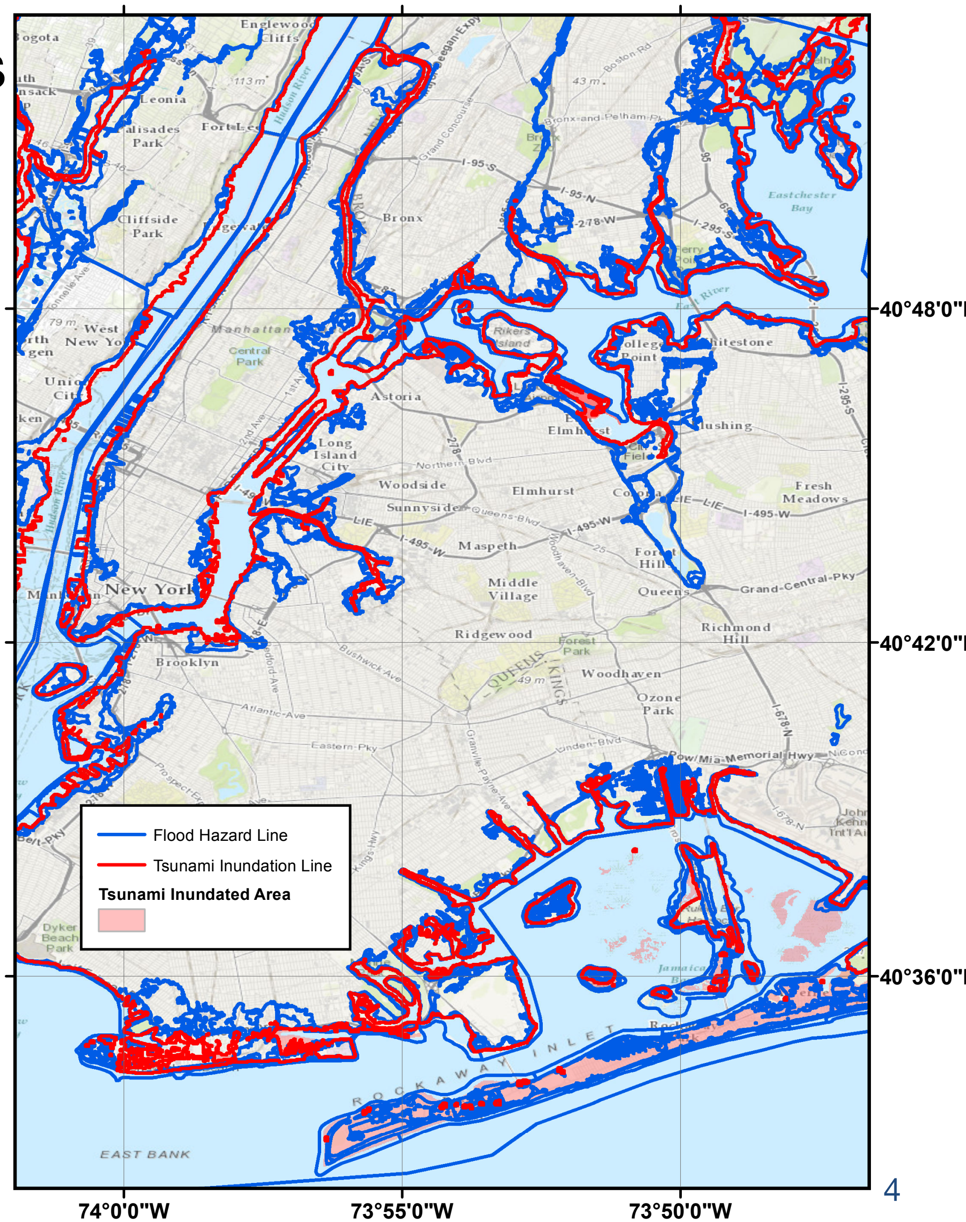


- The sequence of grid nesting. The left depicts Grid A and B and the location of the Nantucket DEM. The right frame shows the 1 arc-second grids.

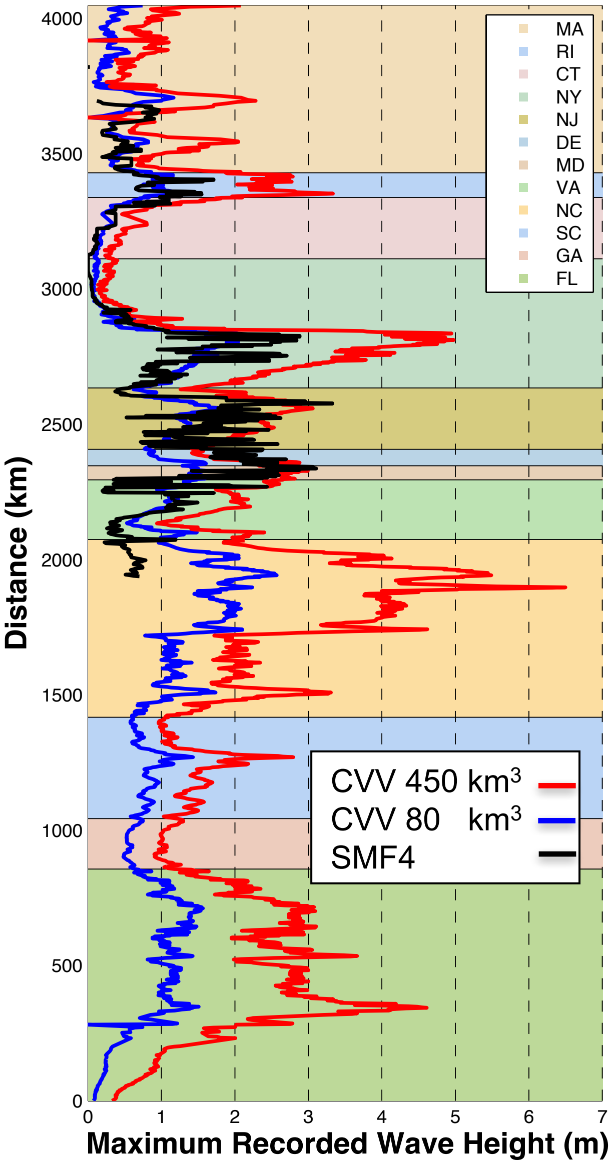
Guidance for unmodeled areas

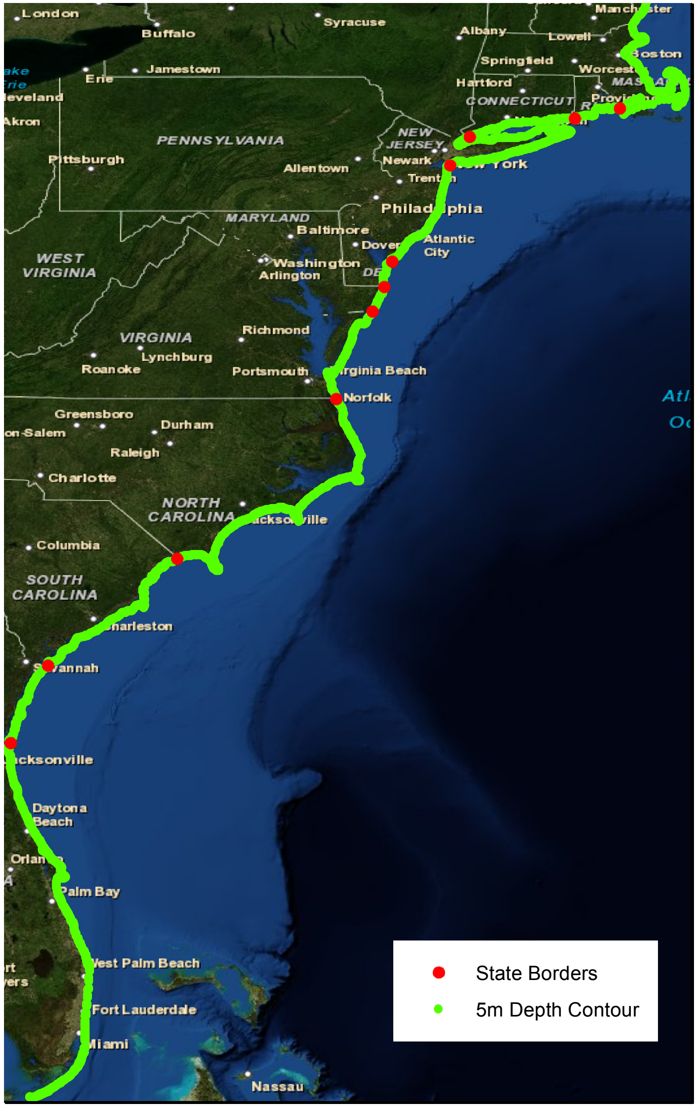
Comparison of tsunami inundation line and Storm Surge hazard maps

- Tsunami inundation is dominant in areas directly facing open water.
- In the areas behind barrier islands or other protected areas, storm surge effects are dominant.



UNIVERSITY of DELAWARE



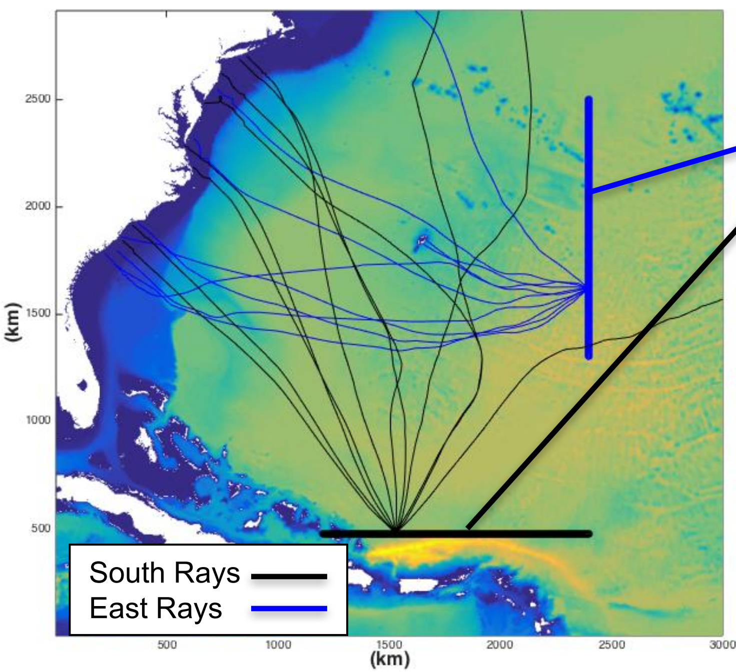


- A similar wave height distribution pattern was observed for all of the sources simulated in this study.
- Tsunami wave height distributions along the east coast suggest that the tsunami propagation is determined by the bathymetry due to the existence of a wide shelf.

Wave Ray Analysis

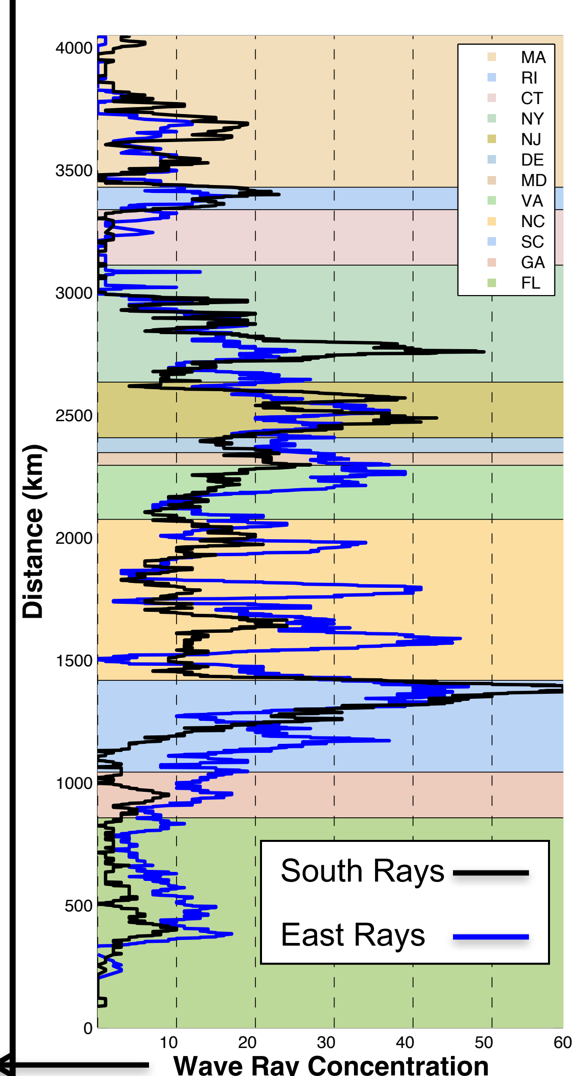
- To investigate the hypothesis of the bathymetric features determining the propagation pattern of tsunamis, a wave ray analysis over the shelf is being performed.

- We traced more than 3000 rays with various angles in the north direction originating from the south to replicate the PR source. Also, we performed the same analysis for waves propagating toward the west to replicate the CVV source conditions.

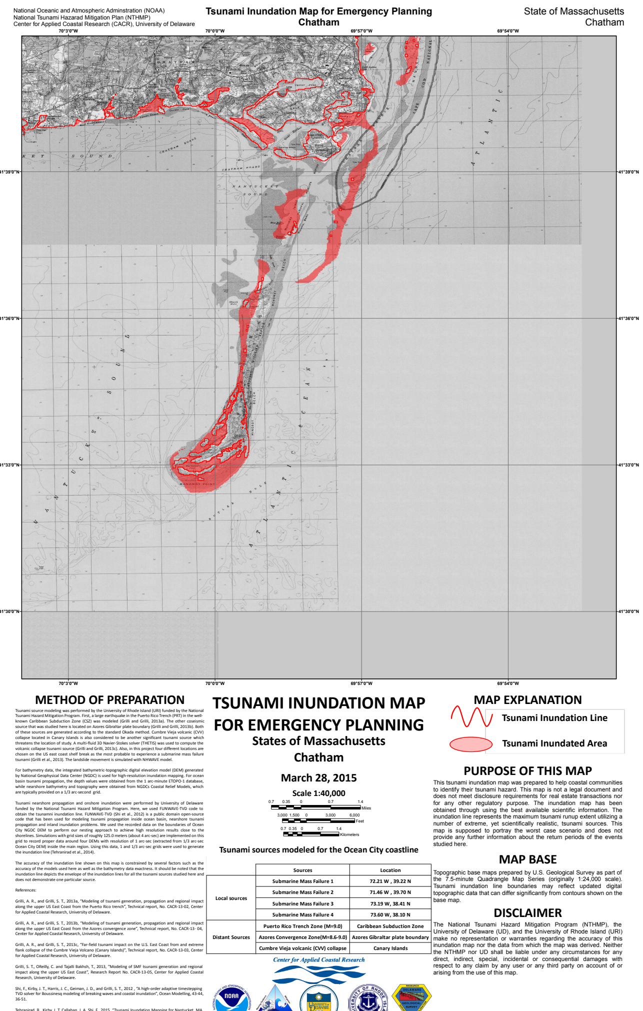


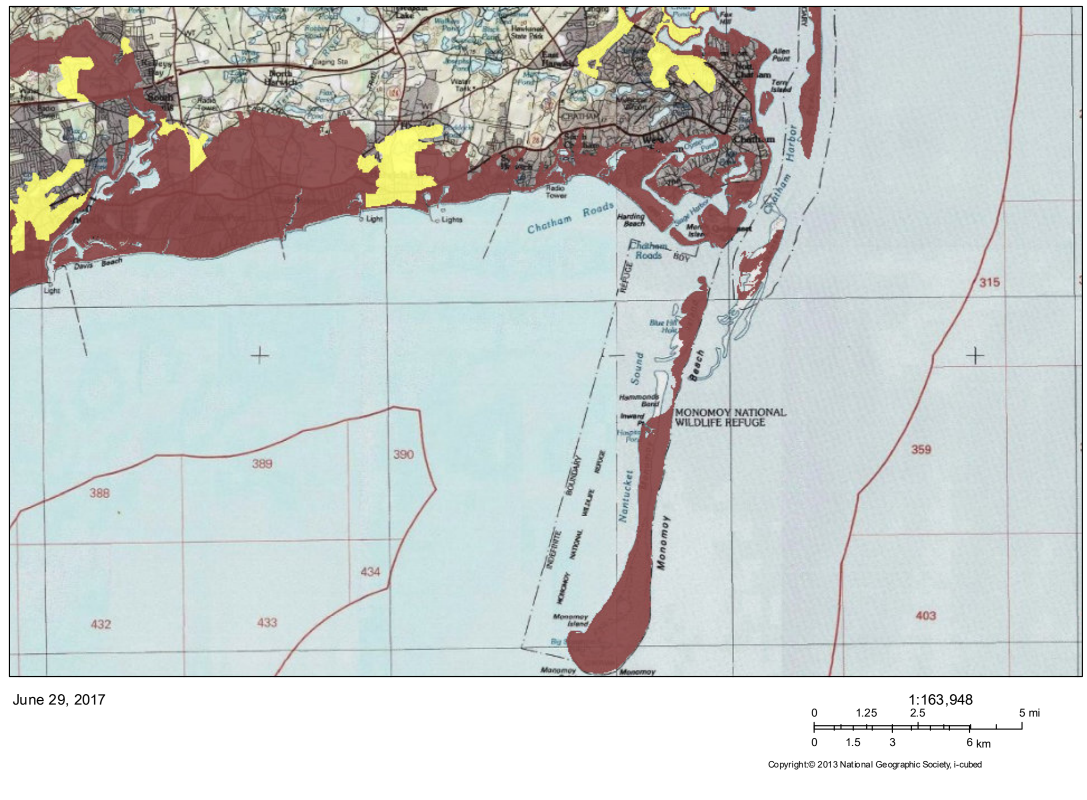
Starting Locations of Wave Rays

Wave Ray Concentration is the number of rays that end up in a circle with 0.1° radius at a certain location on the shoreline



Inundation maps vs. storm surge maps for MA

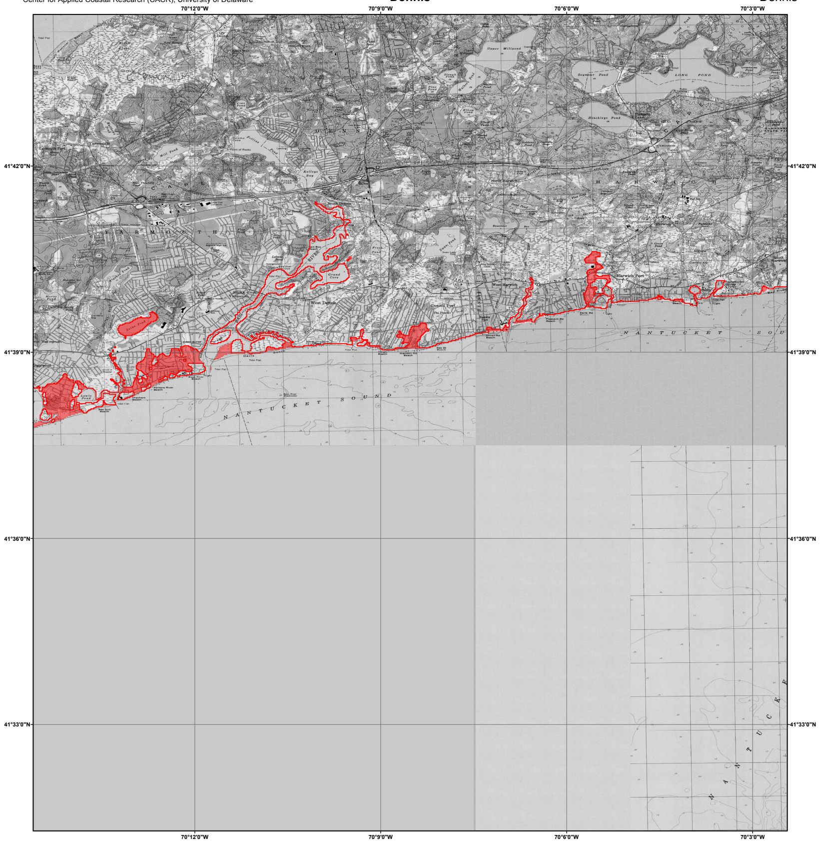




National Oceanic and Atmospheric Adminstration (NOAA)
National Tsunami Hazard Mitigation Plan (NTHMP)
Center for Applied Coastal Research (CACR), University of Delaware

Tsunami Inundation Map for Emergency Planning
Dennis

State of Massachusetts
Dennis



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TSUNAMI INUNDATION MAP FOR EMERGENCY PLANNING

States of Massachusetts

Dennis

March 28, 2015

Scale 1:40,000

0.7 0.35 0 0.7 1.4 Miles
3,000 1,500 0 3,000 6,000 Feet
0.7 0.35 0 0.7 1.4 Kilometers

Tsunami sources modeled for the Ocean City coastline

	Sources	Location
Local sources	Submarine Mass Failure 1	72.21 W , 39.22 N
	Submarine Mass Failure 2	71.46 W , 39.70 N
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Center for Applied Coastal Research

MAP EXPLANATION

Tsunami Inundation Line

Tsunami Inundated Area

PURPOSE OF THIS MAP

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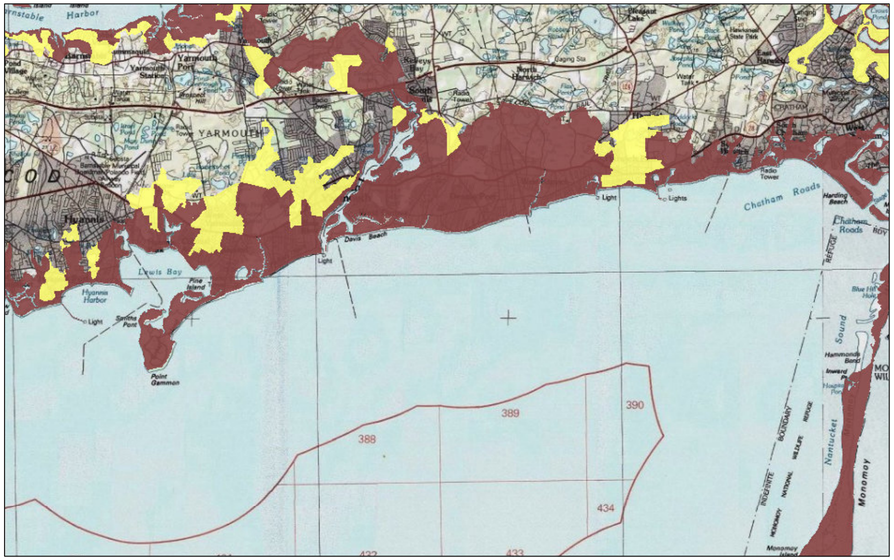
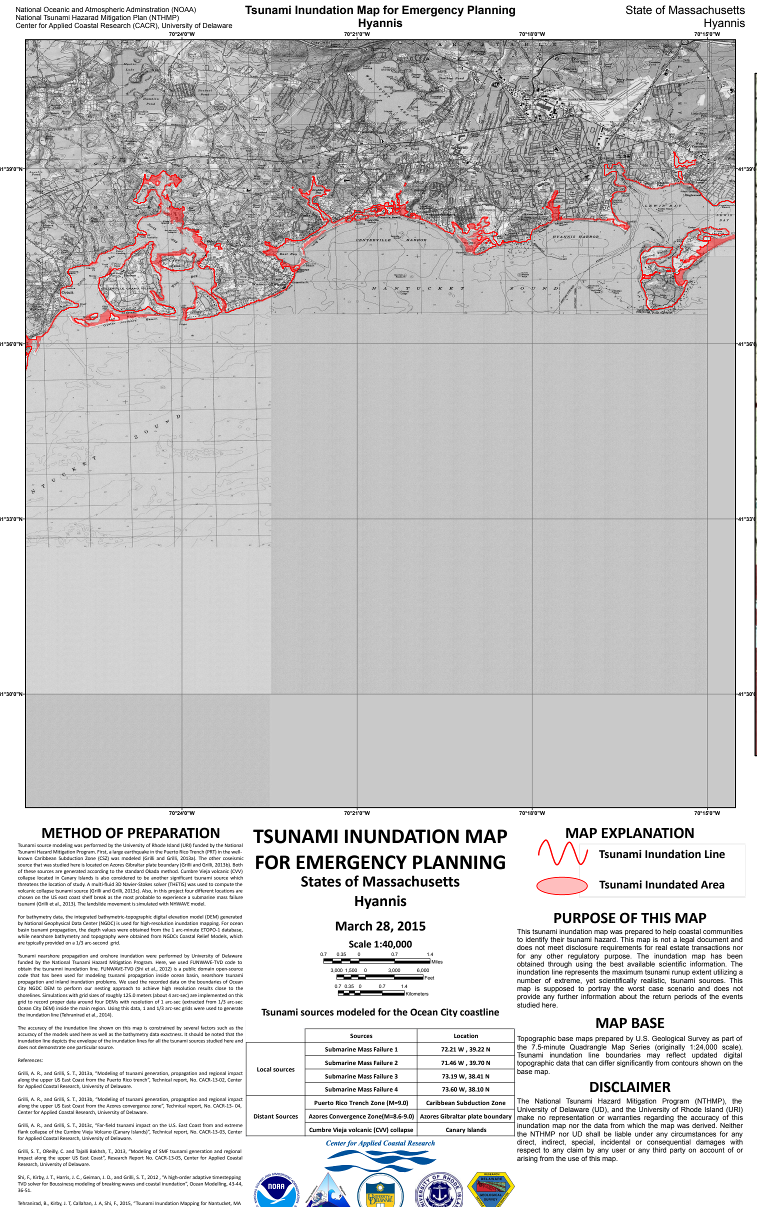


June 29, 2017

1:153,355
0 1.25 2.5 5 mi
0 1.5 3 6 km

dlkocis



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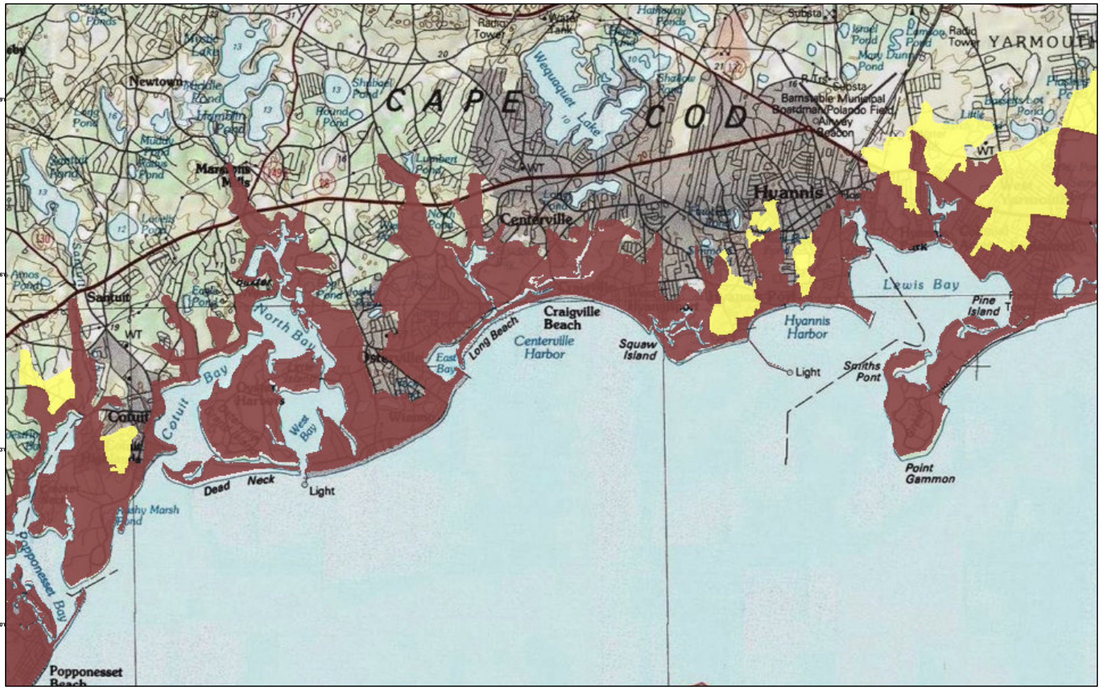


June 29, 2017

1:108,035

0 0.75 1.5 3 mi

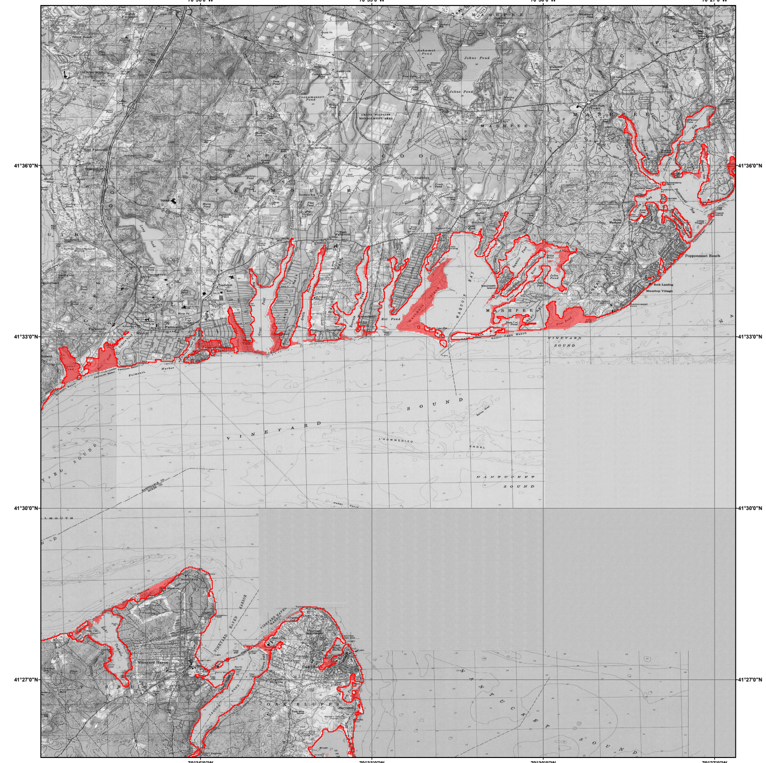
0 1 2 4 km

dlkocis

National Oceanic and Atmospheric Administration (NOAA)
National Tsunami Hazard Mitigation Plan (NTHMP)
Center for Applied Coastal Research (CACR), University of Delaware

Tsunami Inundation Map for Emergency Planning
Falmouth

State of Massachusetts
Falmouth



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States of Massachusetts
Falmouth

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Center for Applied Coastal Research

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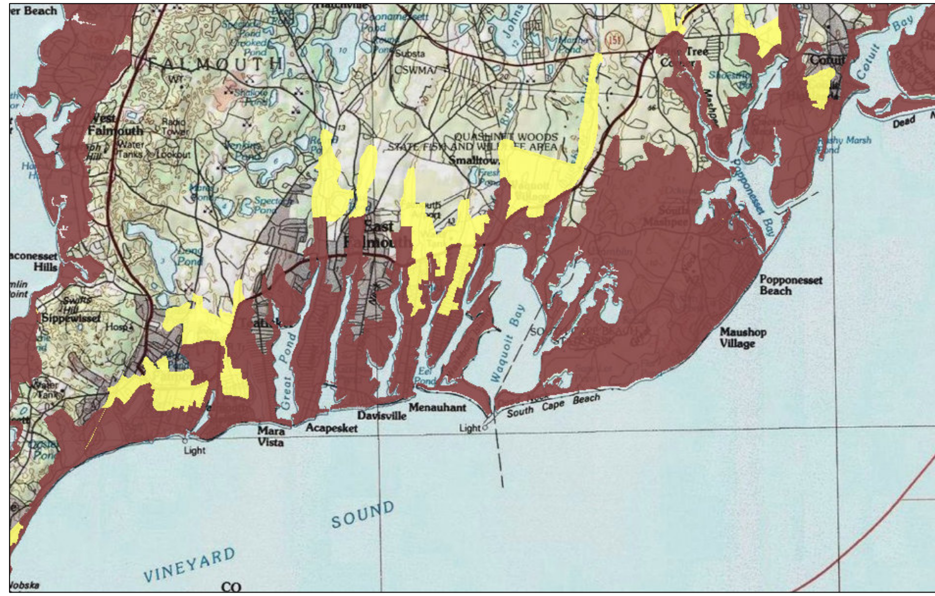
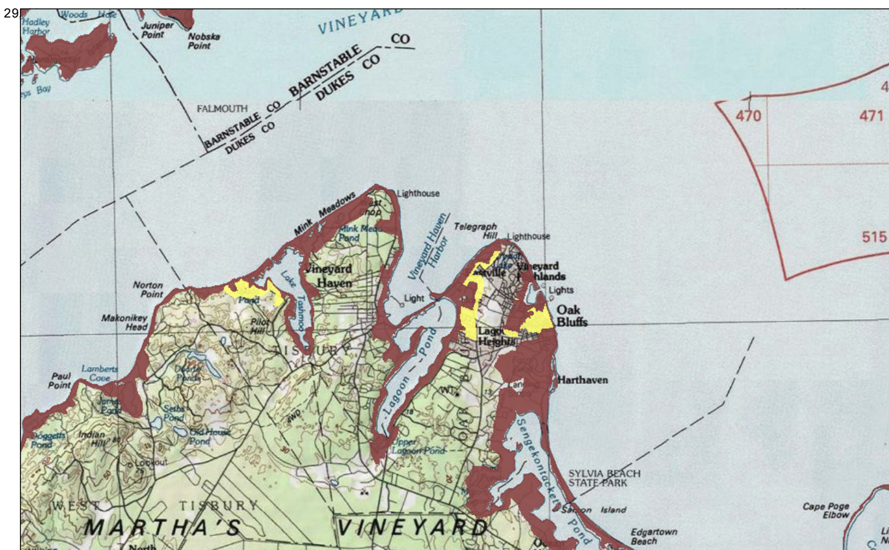


June 29



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1:108,035
0 0.75 1.5 3 mi
0 1 2 4 km

dkocis

National Oceanic and Atmospheric Adminstration (NOAA)
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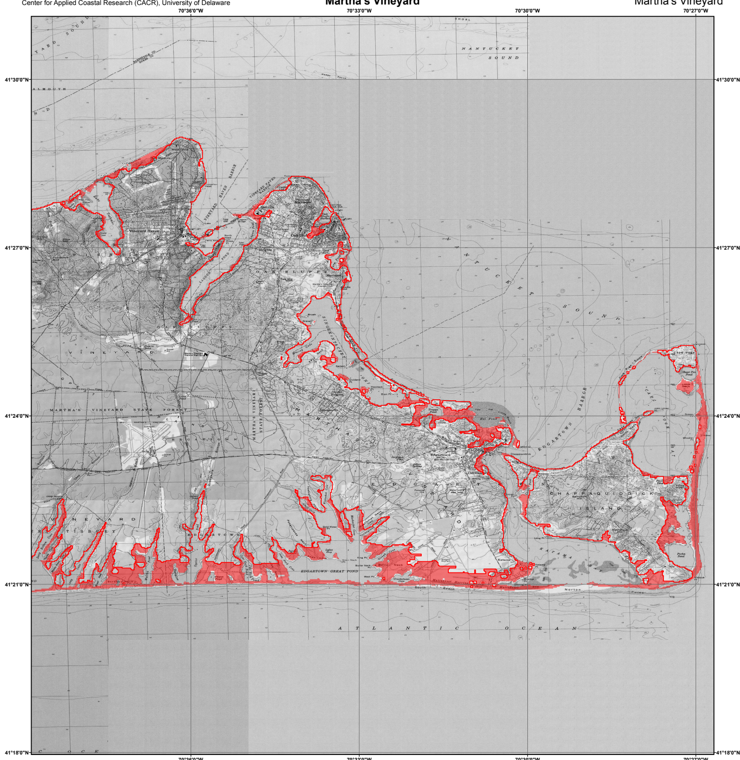
Tsunami Inundation Map for Emergency Planning
Martha's Vineyard

State of Massachusetts
Martha's Vineyard



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TSUNAMI INUNDATION MAP FOR EMERGENCY PLANNING

States of Massachusetts
Martha's Vineyard

March 28, 2015

Scale 1:40,000

0.7 0.35 0 0.7 1.4 Miles
3,000 1,500 0 3,000 6,000 Feet
0.7 0.35 0 0.7 1.4 Kilometers

Tsunami sources modeled for the Ocean City coastline

	Sources	Location
Local sources	Submarine Mass Failure 1	72.21 W , 39.22 N
	Submarine Mass Failure 2	71.46 W , 39.70 N
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Distant Sources	Puerto Rico Trench Zone (M=9.0)	Caribbean Subduction Zone
	Azores Convergence Zone(M=8.6-9.0)	Azores Gibraltar plate boundary
	Cumbre Vieja volcanic (CVV) collapse	Canary Islands

Center for Applied Coastal Research

MAP EXPLANATION

Tsunami Inundation Line
Tsunami Inundated Area

PURPOSE OF THIS MAP

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MAP BASE

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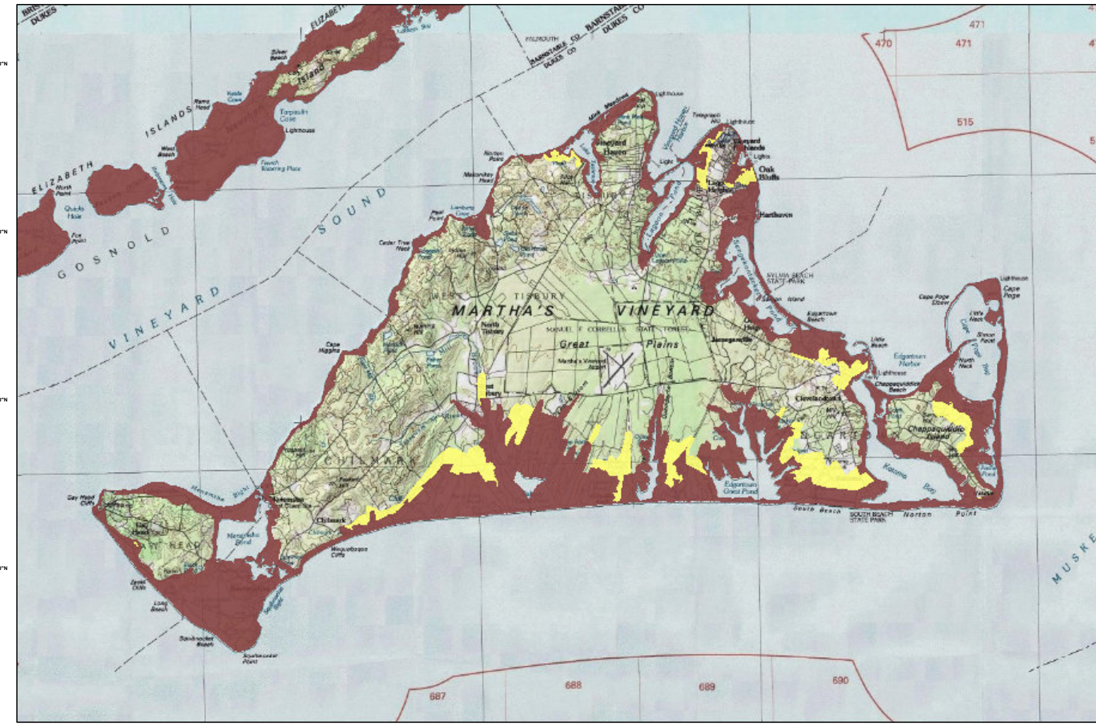


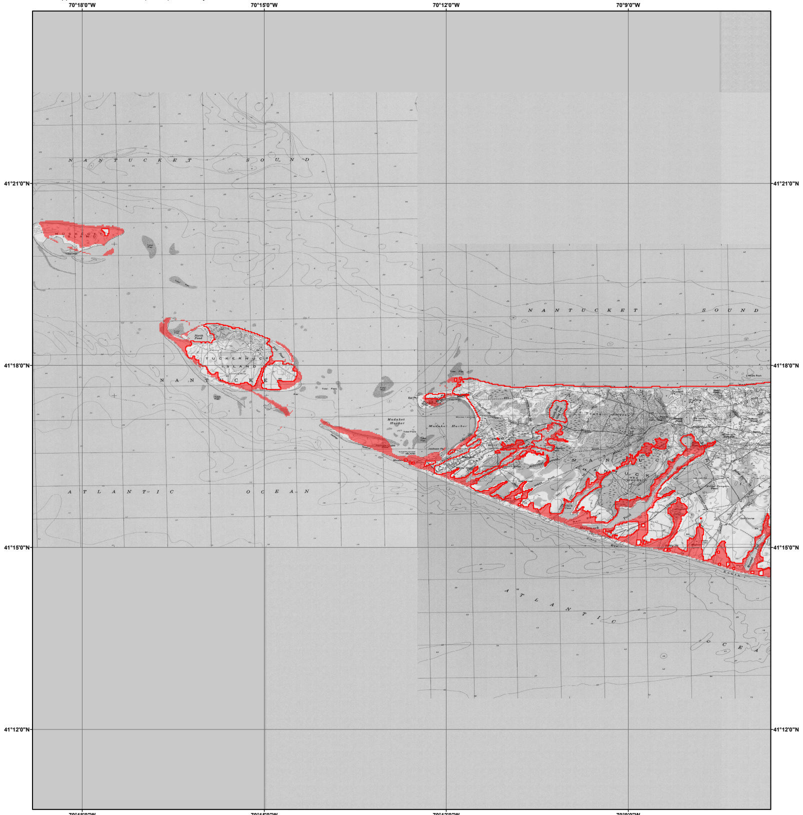
June 29, 2017

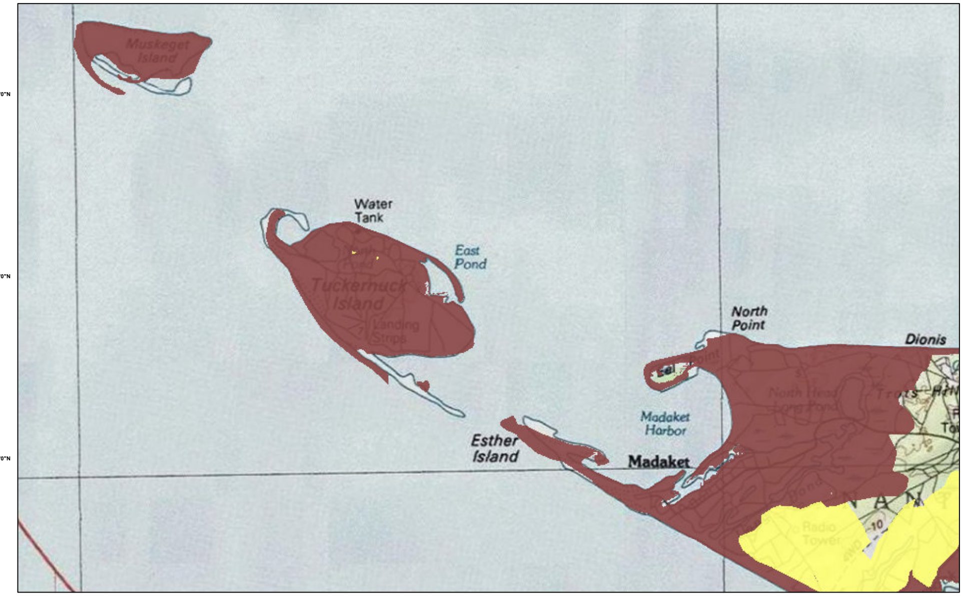
1:216,070
0 1.75 3.5
0 2 4 8 km

National Oceanic and Atmospheric Adminstration (NOAA)
National Tsunami Hazarad Mitigation Plan (NTHMP)
Center for Applied Coastal Research (CACR), University of Delaware

Tsunami Inundation Map for Emergency Planning
West Nantucket

State of Massachusetts
West Nantucket





June 29, 2017

1:76,678
0 0.5 1 2 mi
0 0.75 1.5 3 km

dlkocis

METHOD OF PREPARATION

Tsunami source modeling was performed by the University of Rhode Island (URI) funded by the National Tsunami Hazard Mitigation Program. First, a large earthquake in the Puerto Rico Trench (PRT) in the well-known Caribbean Subduction Zone (CSZ) was modeled (Grilli and Grilli, 2013a). The other coseismic source that was studied here is located on Azores Gibraltar plate boundary (Grilli and Grilli, 2013b). Both of these sources are generated according to the standard Okada method. Cumbre Vieja volcanic (CVV) collapse located in Canary Islands is also considered to be another significant tsunami source which threatens the location of study. A multi-fluid 3D Navier-Stokes solver (THETIS) was used to compute the volcanic collapse tsunami source (Grilli and Grilli, 2013c). Also, in this project four different locations are chosen on the US east coast shelf break as the most probable to experience a submarine mass failure tsunami (Grilli et al., 2013). The landslide movement is simulated with NHWAVE model.

For bathymetry data, the integrated bathymetric-topographic digital elevation model (DEM) generated by National Geophysical Data Center (NGDC) is used for high-resolution inundation mapping. For ocean basin tsunami propagation, the depth values were obtained from the 1 arc-minute ETOPO-1 database, while nearshore bathymetry and topography were obtained from NGDCs Coastal Relief Models, which are typically provided on a 1/3 arc-second grid.

Tsunami nearshore propagation and onshore inundation were performed by University of Delaware funded by the National Tsunami Hazard Mitigation Program. Here, we used FUNWAVE-TVD code to obtain the tsunamni inundation line. FUNWAVE-TVD (Shi et al., 2012) is a public domain open-source code that has been used for modeling tsunami propagation inside ocean basin, nearshore tsunami propagation and inland inundation problems. We used the recorded data on the boundaries of Ocean City NGDC DEM to perform our nesting approach to achieve high resolution results close to the shorelines. Simulations with grid sizes of roughly 125.0 meters (about 4 arc-sec) are implemented on this grid to record proper data around four DEMs with resolution of 1 arc-sec (extracted from 1/3 arc-sec Ocean City DEM) inside the main region. Using this data, 1 and 1/3 arc-sec grids were used to generate the inundation line (Tehranirad et al., 2014).

The accuracy of the inundation line shown on this map is constrained by several factors such as the accuracy of the models used here as well as the bathymetry data exactness. It should be noted that the inundation line depicts the envelope of the inundation lines for all the tsunami sources studied here and does not demonstrate one particular source.

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TSUNAMI INUNDATION MAP FOR EMERGENCY PLANNING

States of Massachusetts
West Nantucket

March 28, 2015

Scale 1:40,000

0.7 0.35 0 0.7 1.4 Miles
3,000 1,500 0 3,000 6,000 Feet
0.7 0.35 0 0.7 1.4 Kilometers

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Center for Applied Coastal Research

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Tsunami Inundated Area

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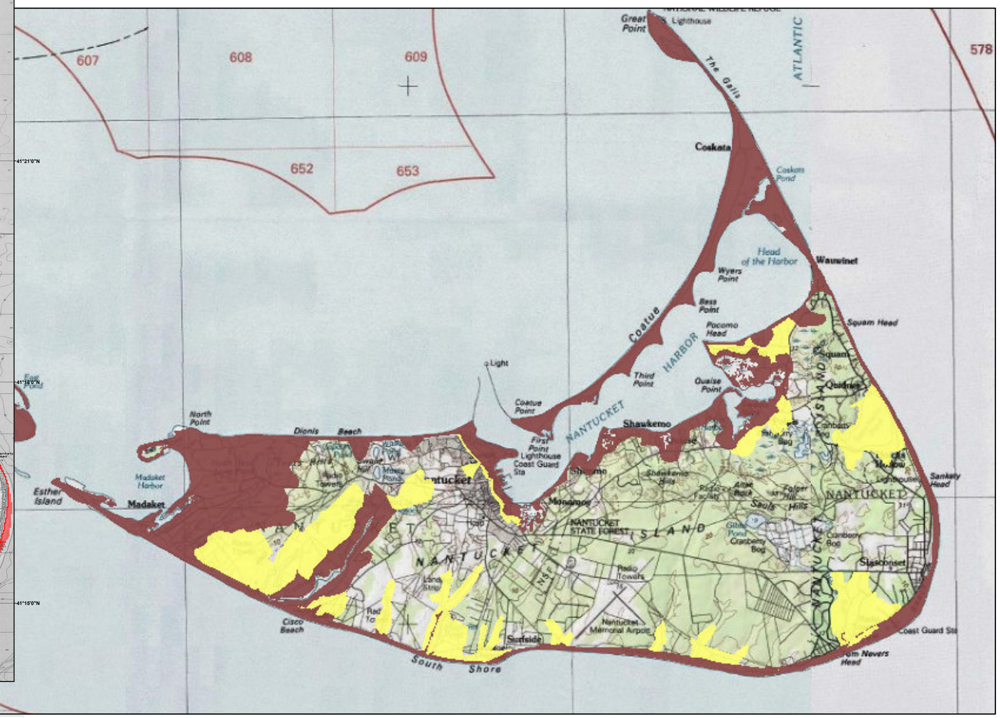
National Tsunami Hazard Mitigation Plan (NTHMP)
Center for Applied Coastal Research (CACR), University of Delaware

Tsunami Inundation Map for Emergency Planning
East Nantucket

State of Massachusetts
East Nantucket



1:153,355
0 1.25 2.5 5 mi
0 1.5 3 6 km

dlkocis

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TSUNAMI INUNDATION MAP FOR EMERGENCY PLANNING

States of Massachusetts
East Nantucket

March 28, 2015

Scale 1:30,000

0.5 0.25 0 0.5 1 Miles
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0.5 0.25 0 0.5 1 Kilometers

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