MODELING TSUNAMI INUNDATION AND ASSESSING TSUNAMI HAZARDS FOR THE U.S. EAST COAST (NTHMP)

NOAA NTHMP Workshop
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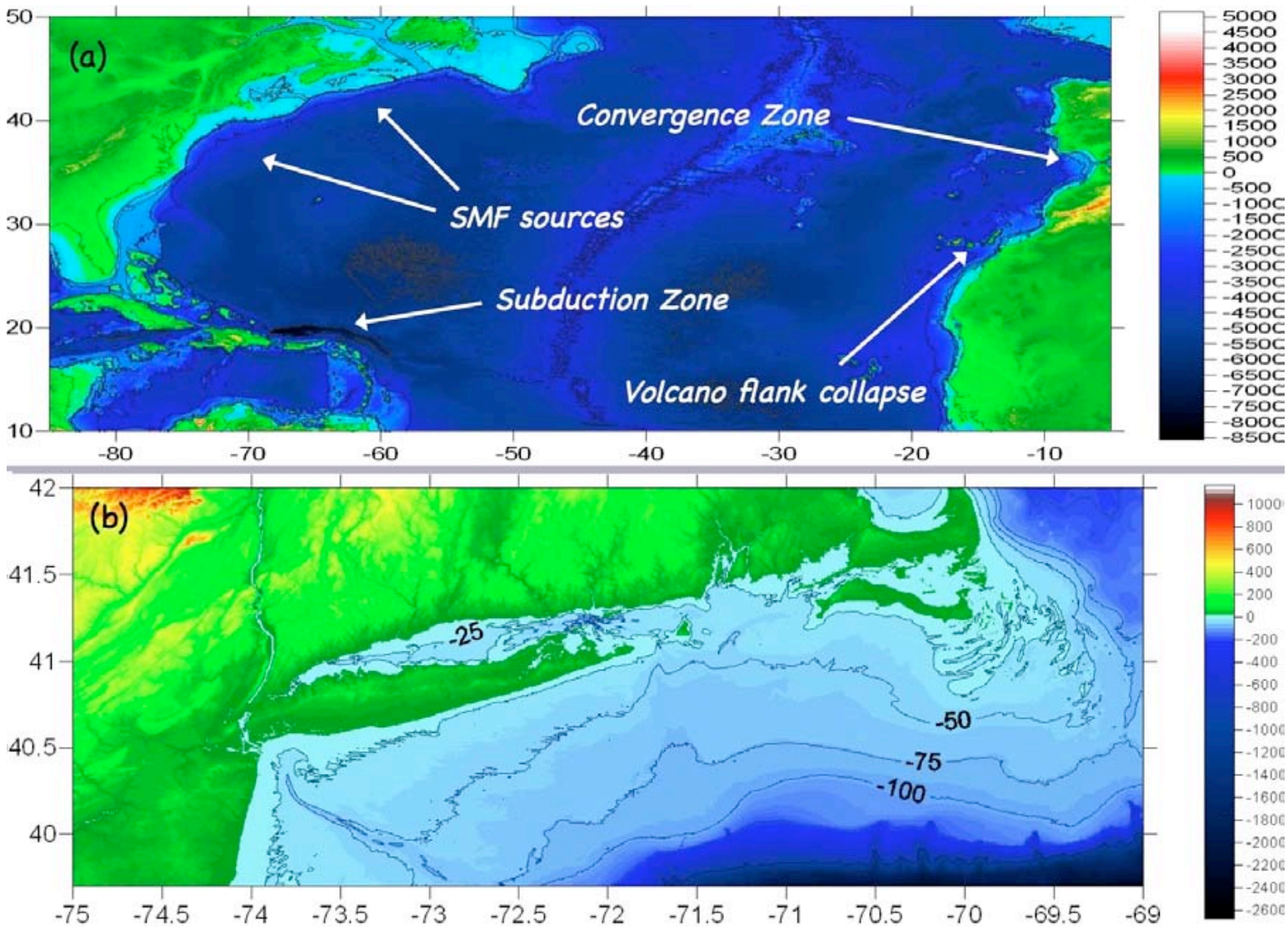
Tamara Eggeling (Graduate Research Asssistant (IEP funded); SMF stability analyses),

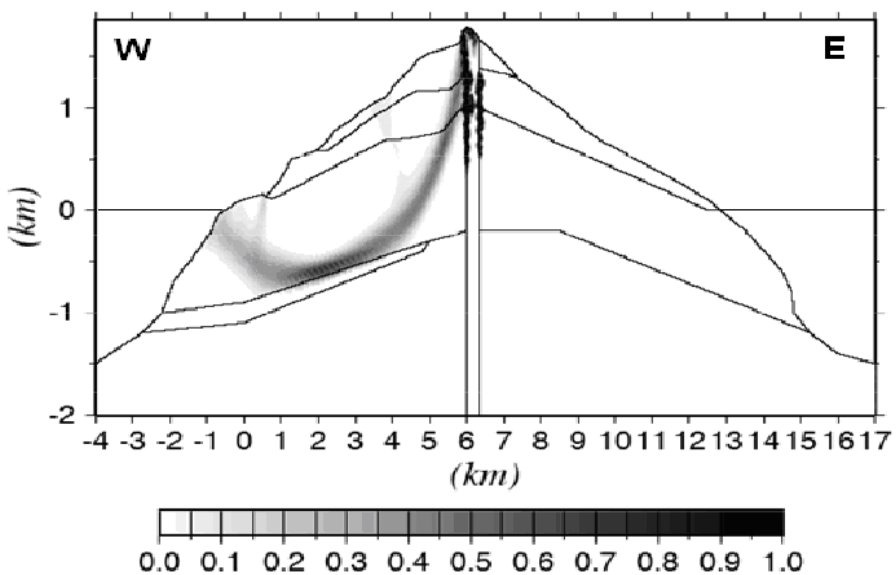
Literature review established broad selection of potential sources for US East Coast



An Overview of Distant Sources I: Flank collapse of Cumbre Vieja Volcano using 3D multi-fluid VOF model

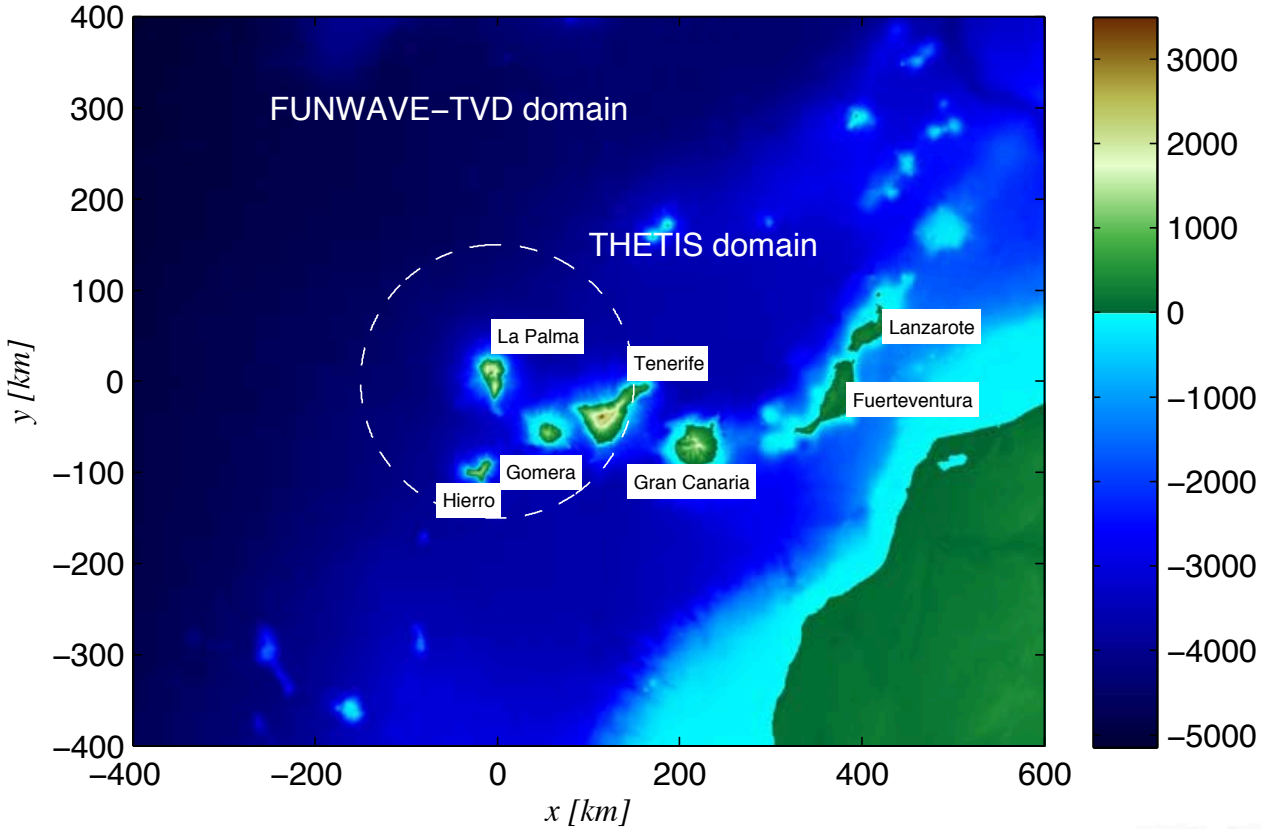
- 2D slope stability computations (with 2 different models) on various cross sections. Geotechnical parameters are progressively reduced (mimicking hydrothermal alteration) until unstable state.
- 3D slide volumes are inferred using a 3D ellipsoid shape, based on the 2D failure contours and geological considerations for lateral extent.

  => Slide volumes range from 20 to 80 km^3, depending on the scenario, with an additional extreme 450 km^3 scenario. (similar to Ward and Day, 2000)



[Vizualisation of the quasi elliptic failure contour (Drucker-Prager failure criterion) calculated with the finite element code ADELI]

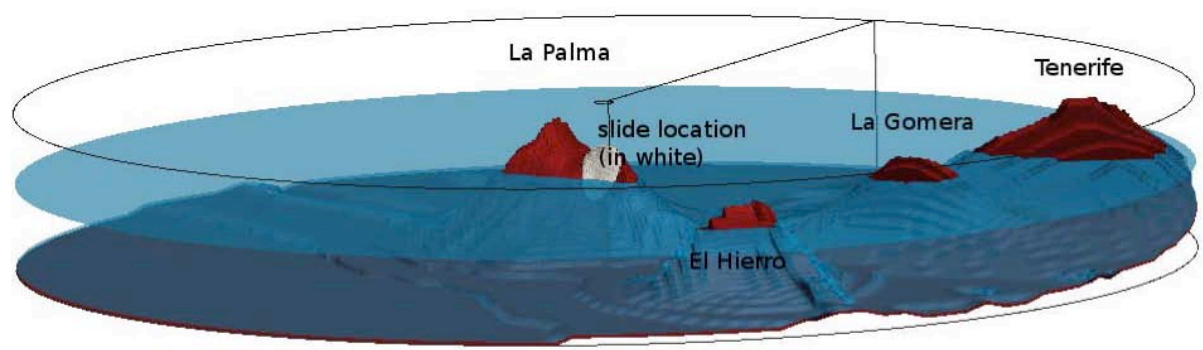
Set-up of 3D tsunami generation model (THETIS)



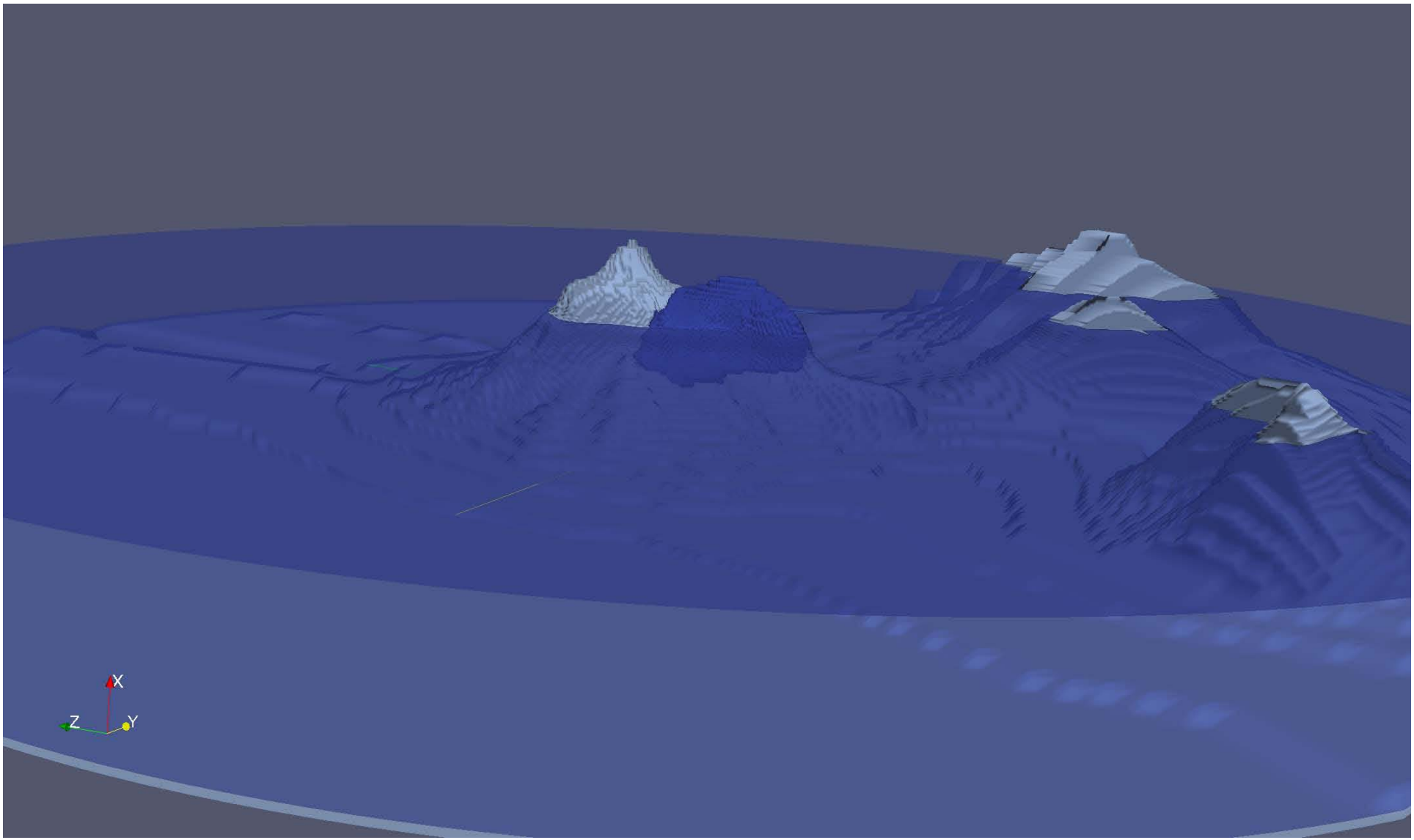
Geometry of 3D THETIS domain Nested within larger scale domain for propagation model

(Abadie et al., JGR, 2012)

3-D view of THETIS domain

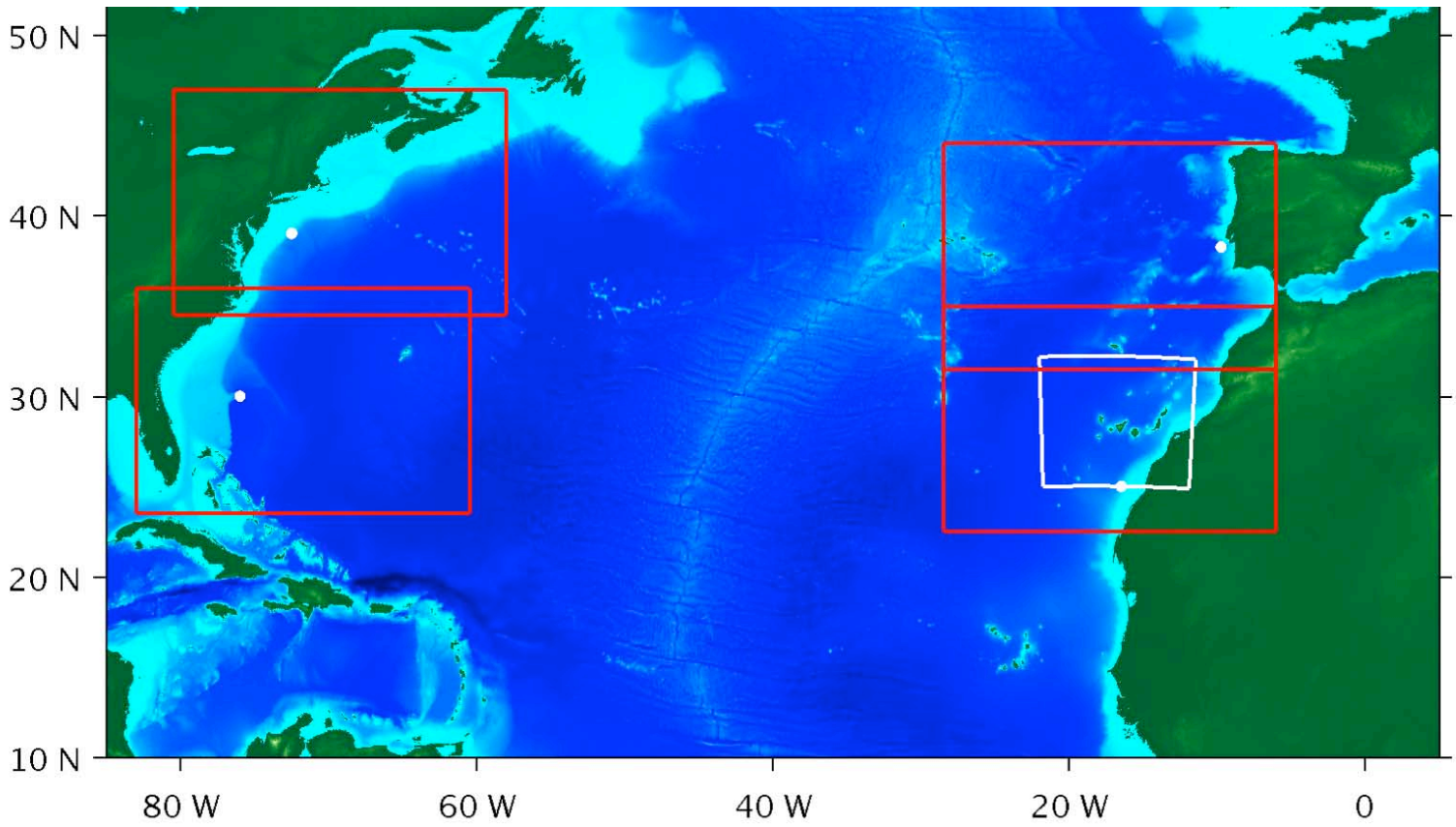


CVV 450 km^3 3D tsunami generation (THETIS)

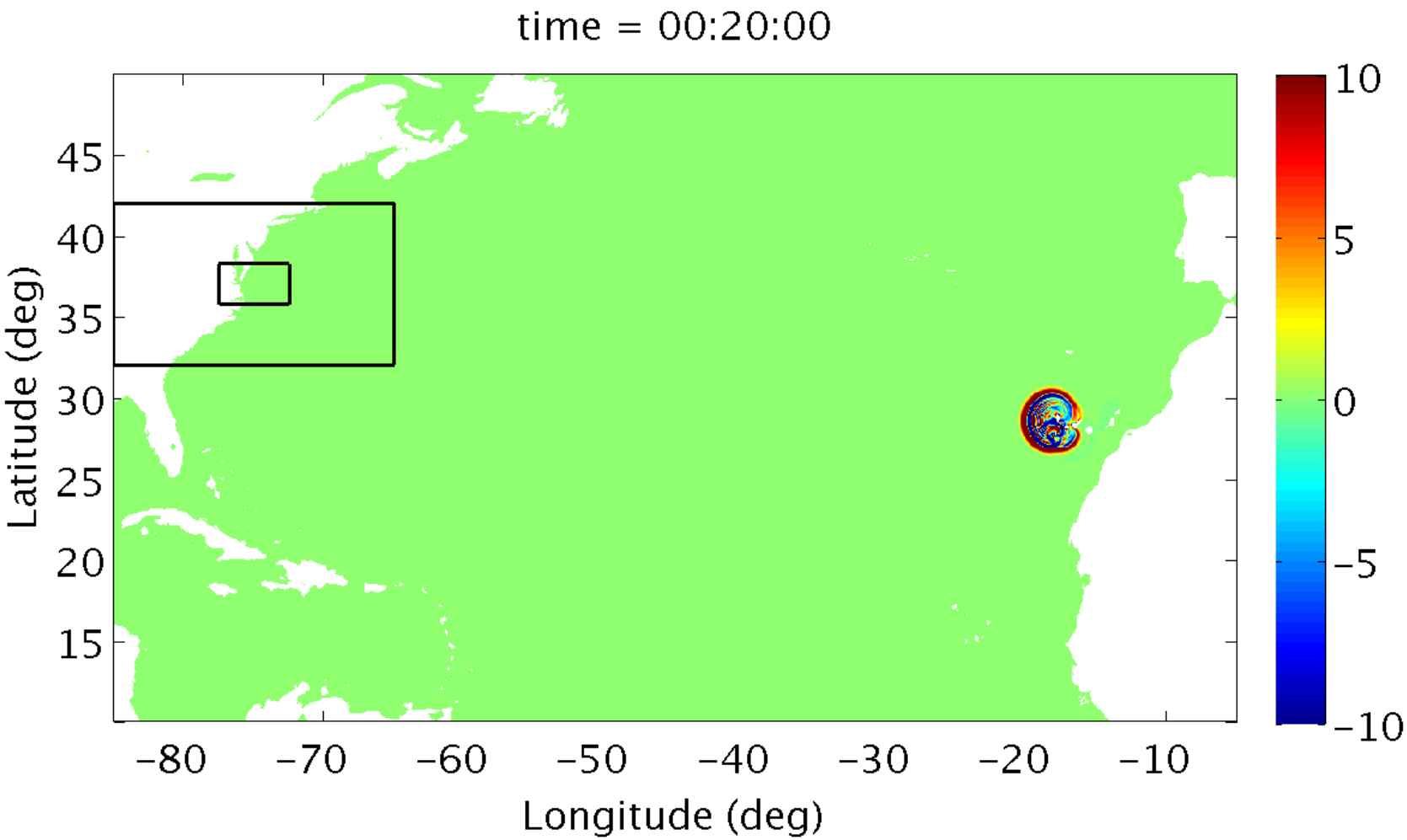


Computational domains for FUNWAVE propagation modeling

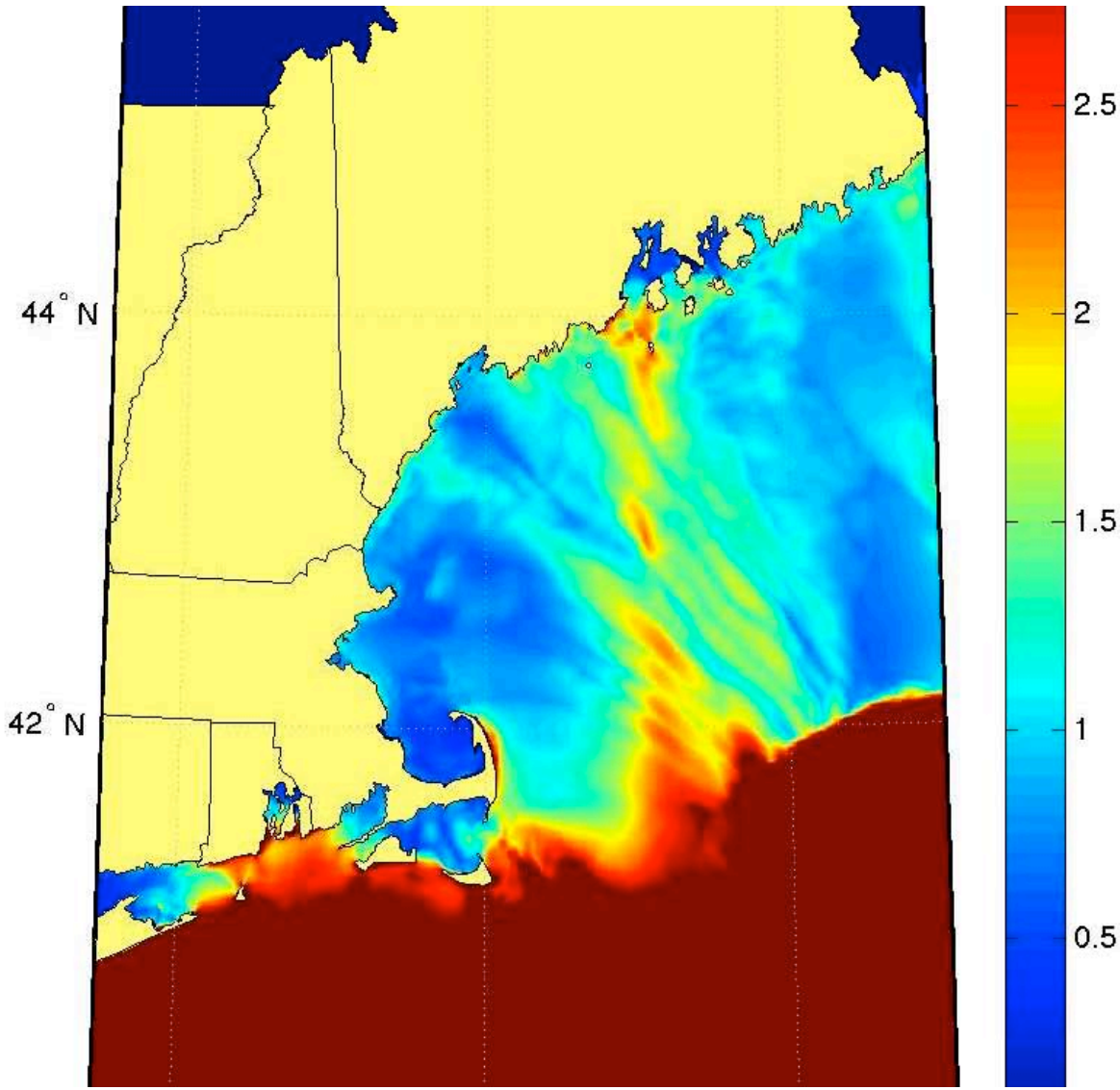
Multi-model, nested grid simulations => Thetis (3D) 500 m grid, to FUNWAVE (Cart. 2D) 1000 m grid, to FUNWAVE 2', 30" (Spherical 2D), 7.5" and 30 m (Cart. 2D) grids.



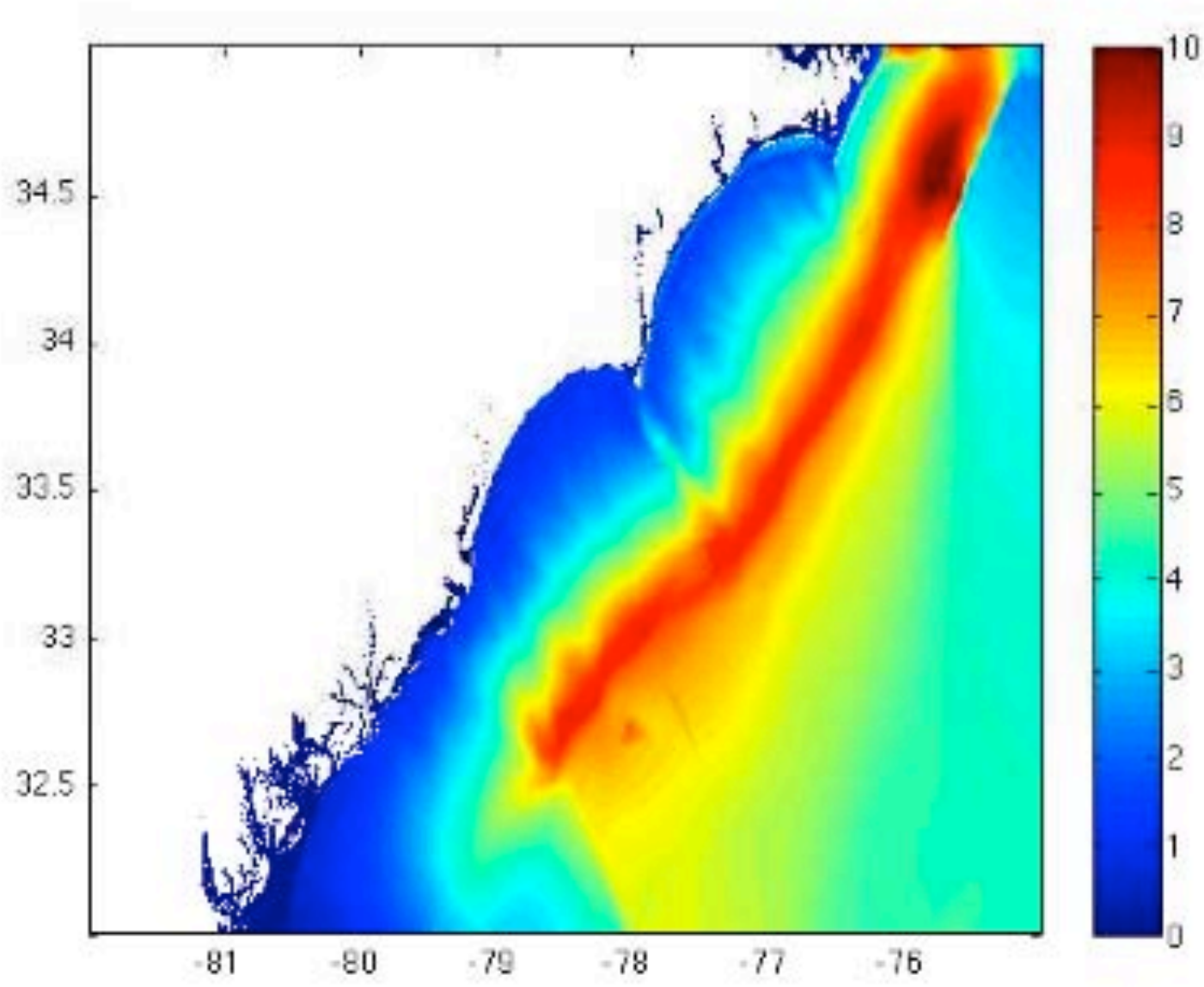
CVV FUNWAVE-TVD propagation modeling (spherical to Cartesian inundation grids)



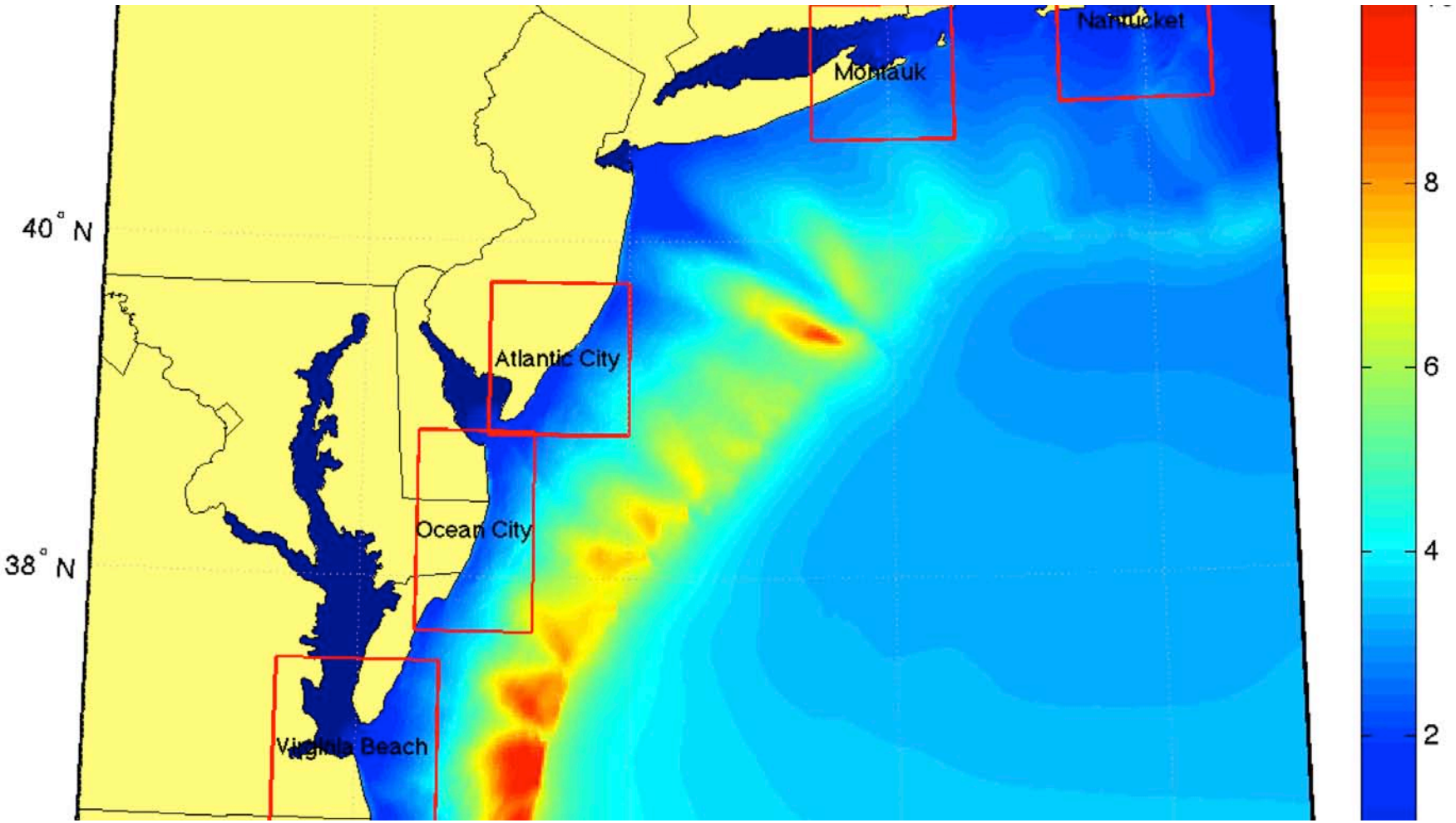
CVV impact on East Coast: New England (30” grid)



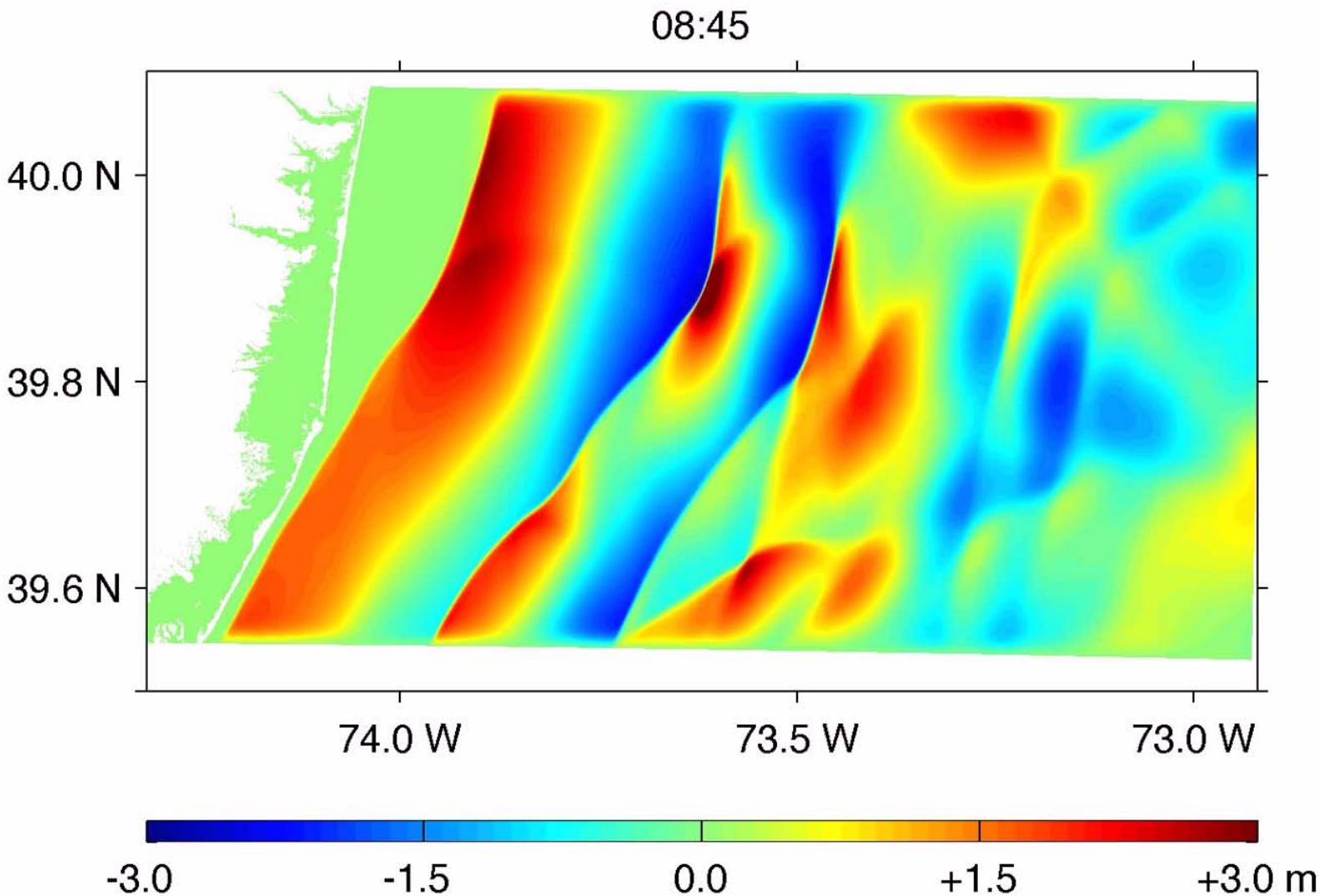
CVV impact on East Coast: South-East (30” grid)



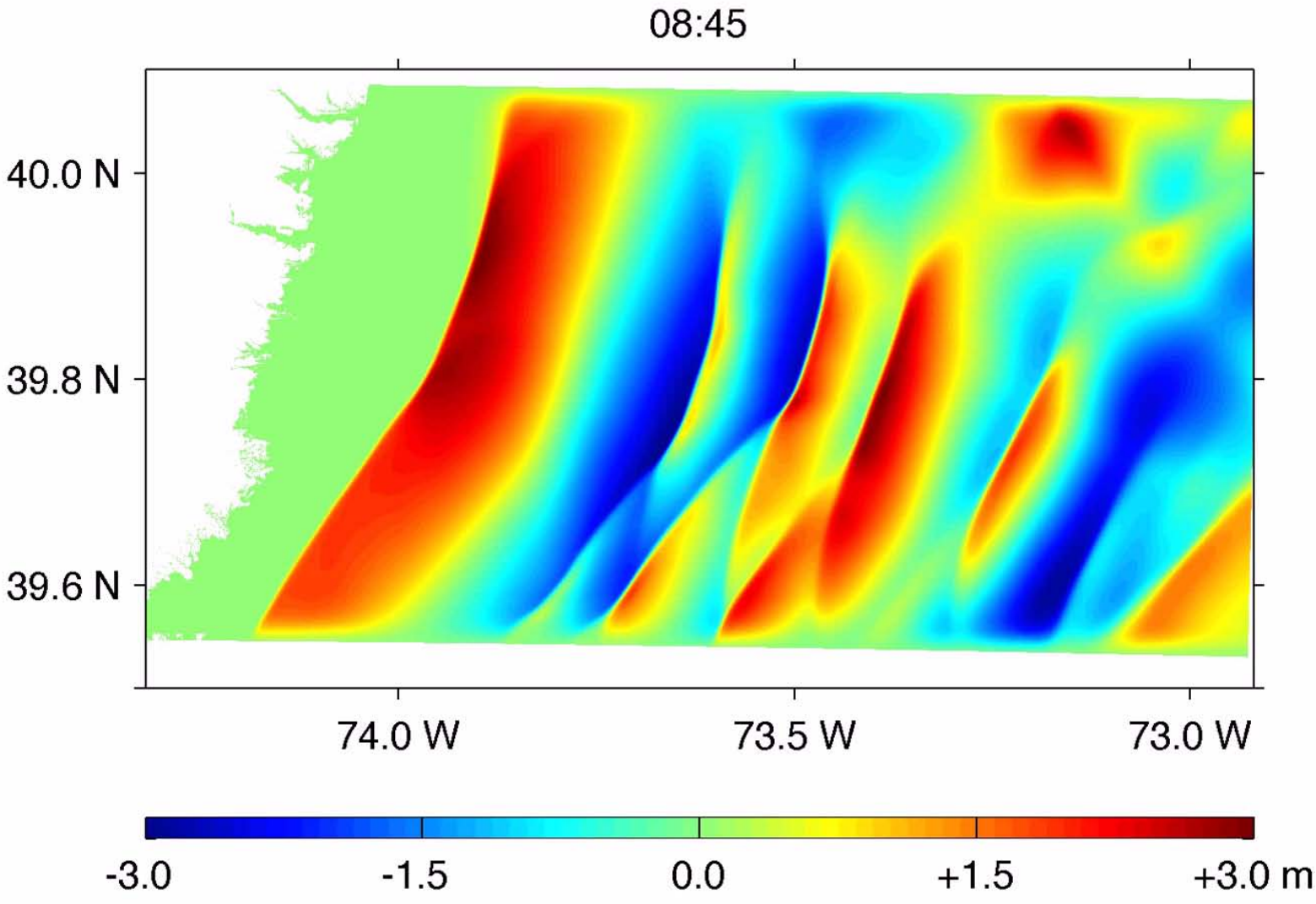
CVV impact on East Coast: Mid-Atlantic (30” grid)



CVV impact off of NJ: <u>with barrier</u> (30 m grid)



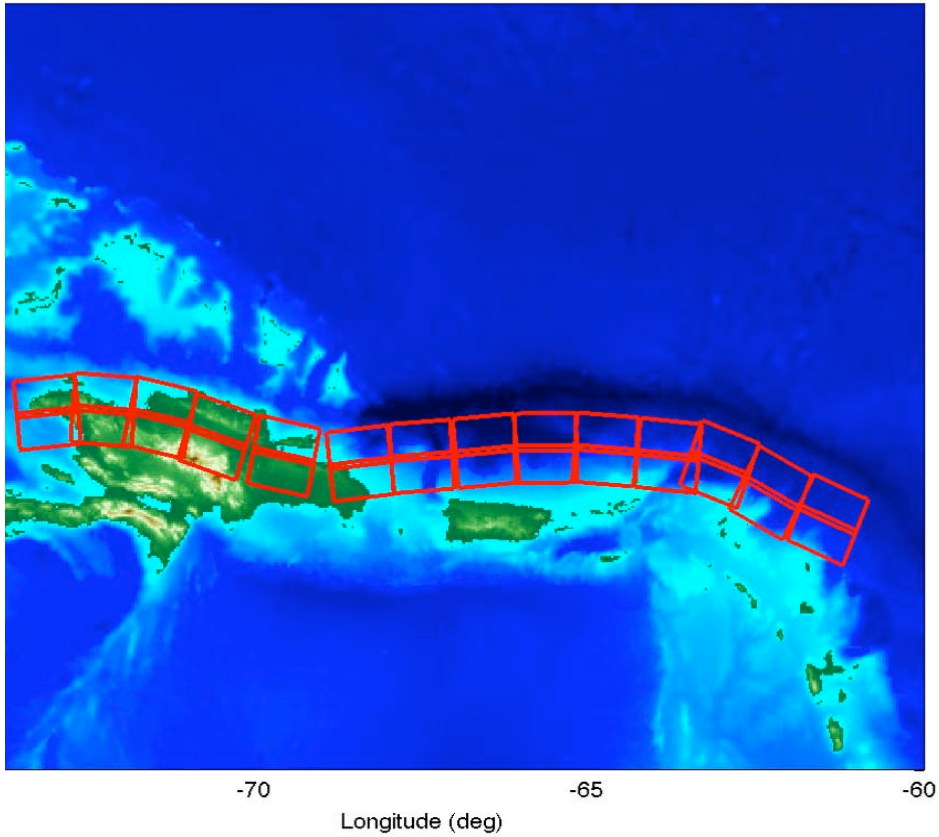
CVV impact off of NJ: <u>no barrier</u> (30 m grid)



Overview of Distant Sources II: PRT/Caribbean subduction zone tsunamigenic earthquakes

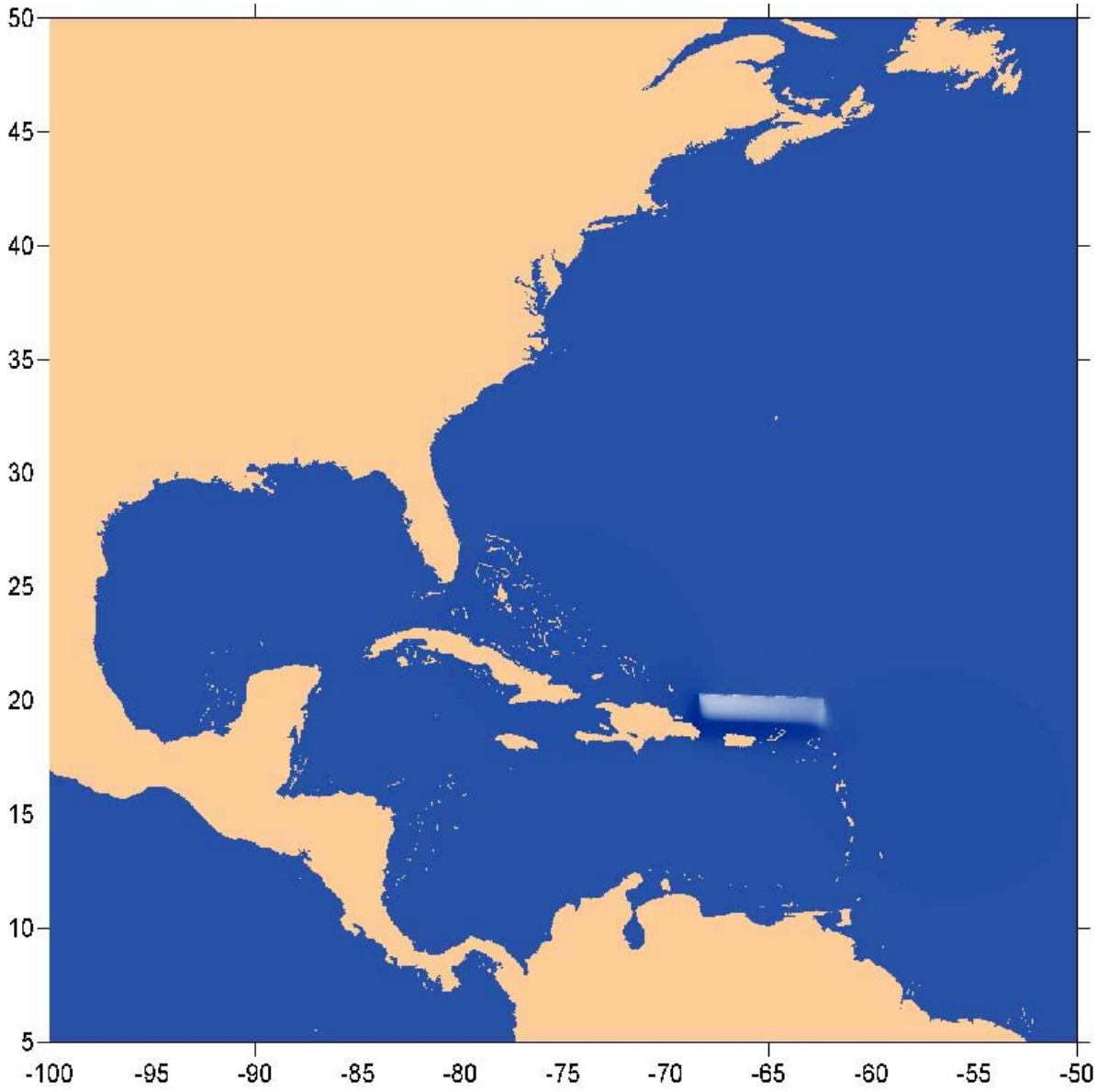
Summary

- Historical examples include 1867 (7.7 near US Virgin Islands); 1918 (7.3 from PR); 2010 (7.0 from PR)
- Tsunami risk studied by many (e.g., Zahibo and Pelinovsky 2001)
- NOAA Forecast Source Database (Gica et al. 2008) modeled series of potential sources (SIFT)
- Potential high risk to particular communities (e.g., S. Carolina)
- Use Okada (1985) to initialize FUNWAVE (spherical) on the free surface as a hot start

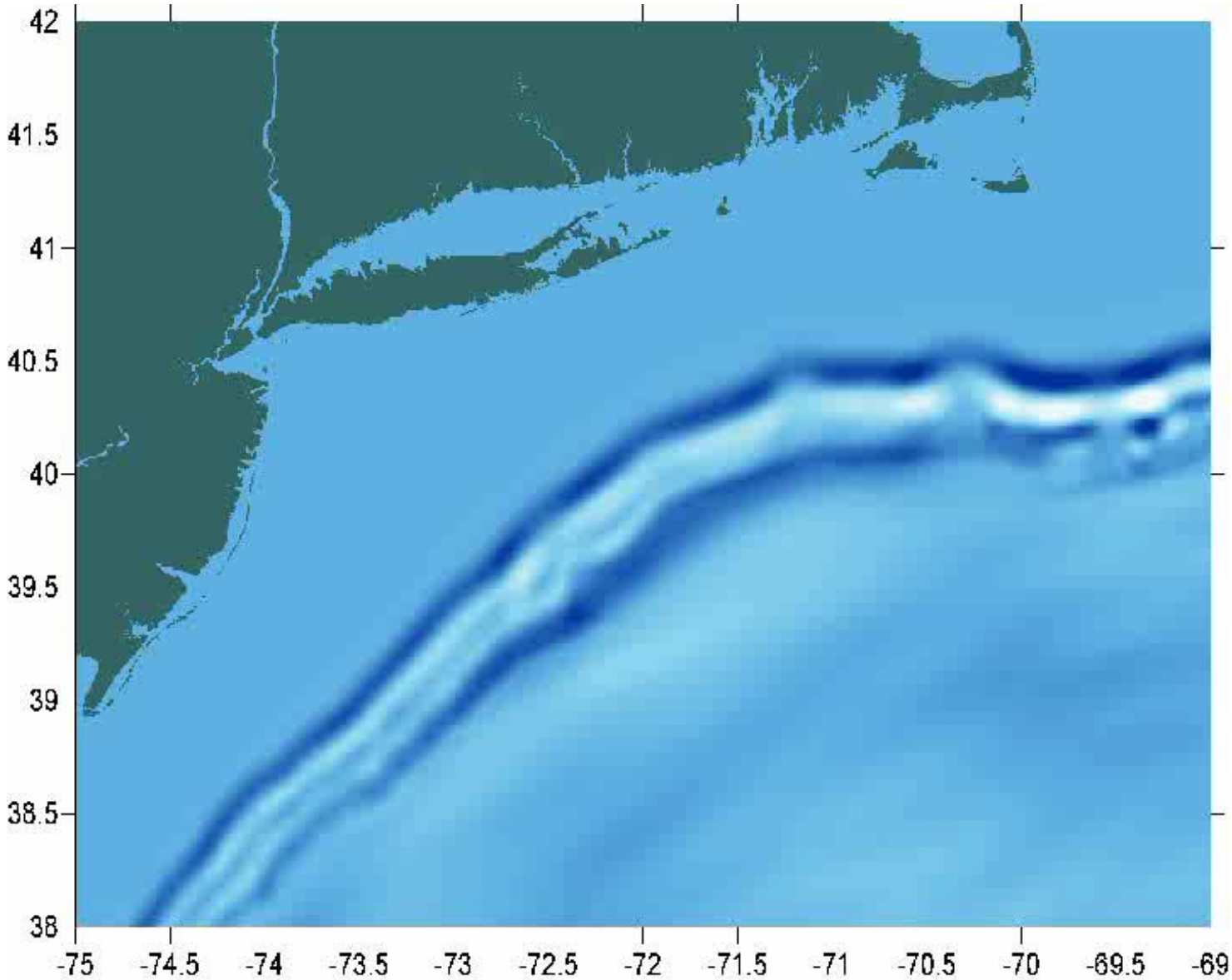


NOAA Forecast Source Database Example (at49b)

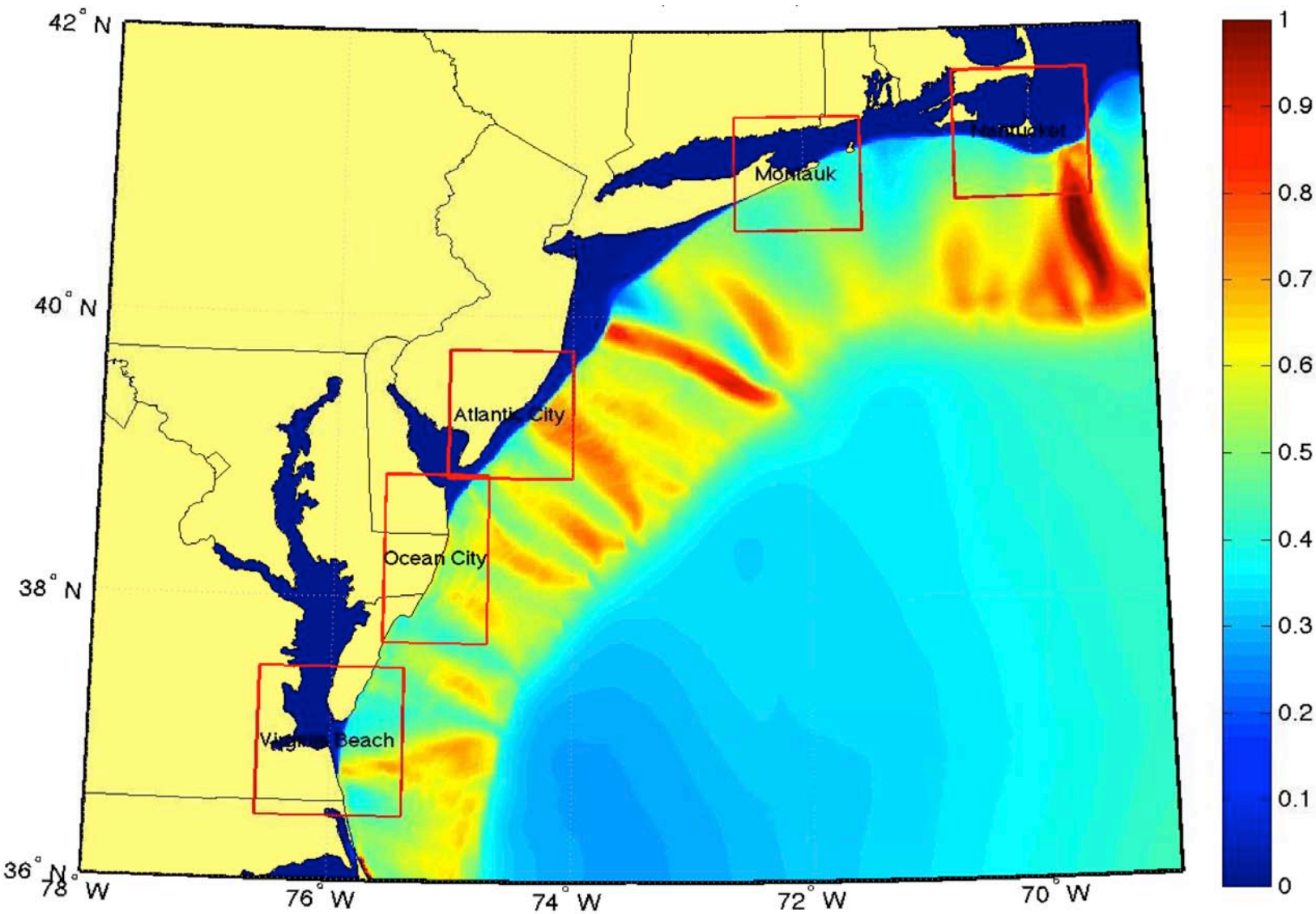
Overview of Distant Sources II: PRT/Caribbean subduction zone tsunamigenic earthquakes



Overview of Distant Sources II: PRT/Caribbean subduction zone tsunamigenic earthquakes



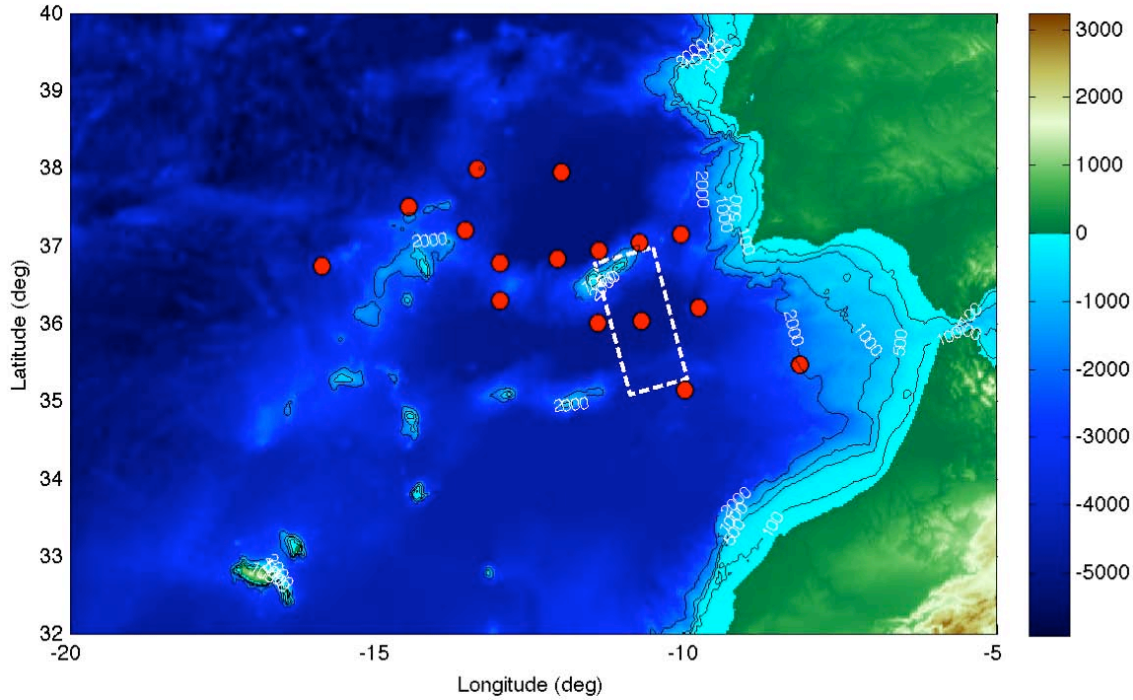
Max. Elevation for a PRT M9 source (30” grid)



Overview of distant sources III: Azores-Gibraltar convergence zone

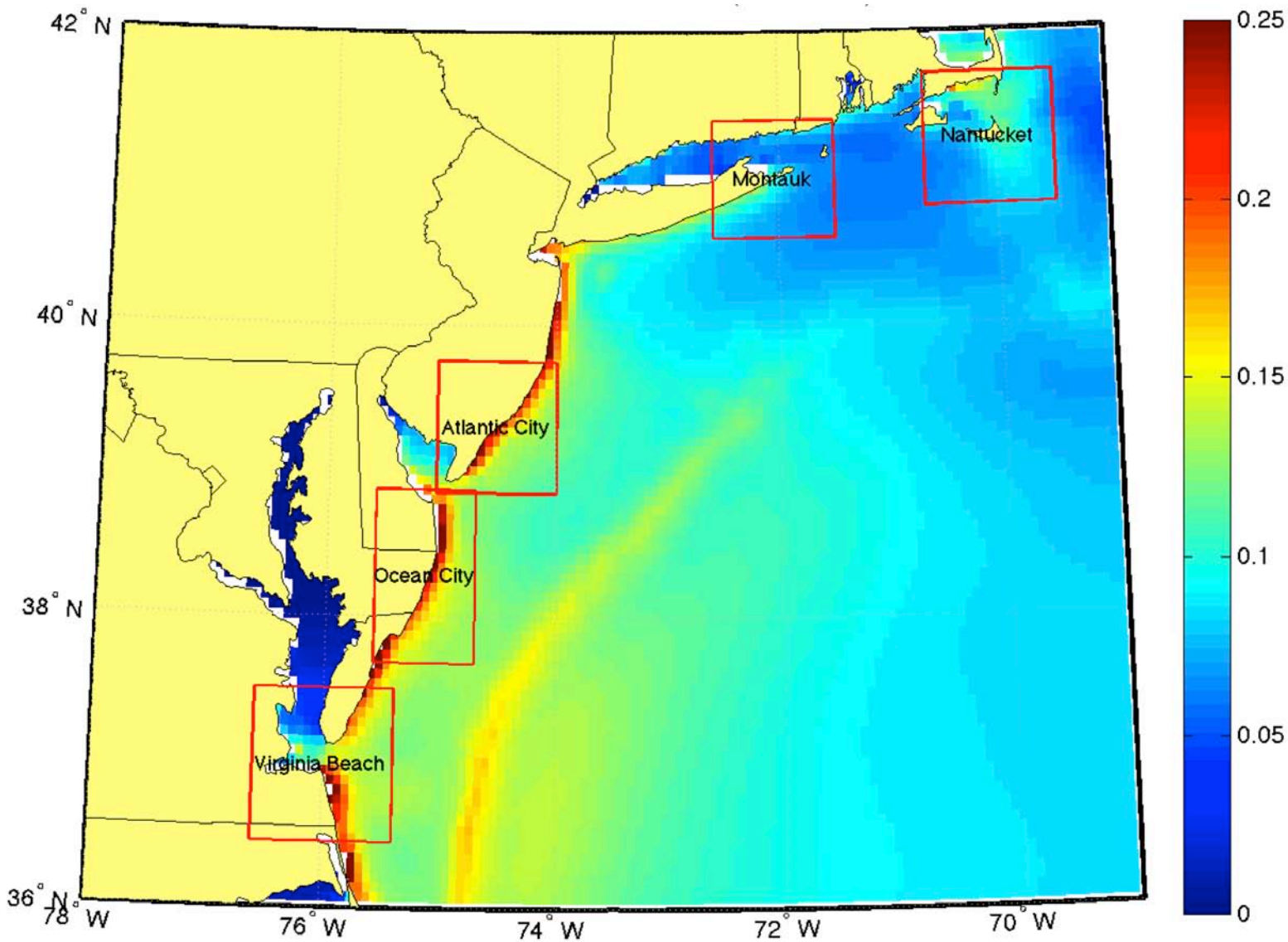
Summary

- Region best known for 1755 Lisbon earthquake (8.5-9.0 magnitude; 100,000 deaths)
- Earthquake extensively studied (e.g., Johston 1996; Baptista et al. 1998; Gutscher et al. 2006; Grandin et al. 2007)
- Source of 1755 quake not known; Barkan et al. 2009 simulated possibilities based on far-field effect
- Not included in NOAA Forecast Source Database



16 sources considered for East Coast Inundation Studies

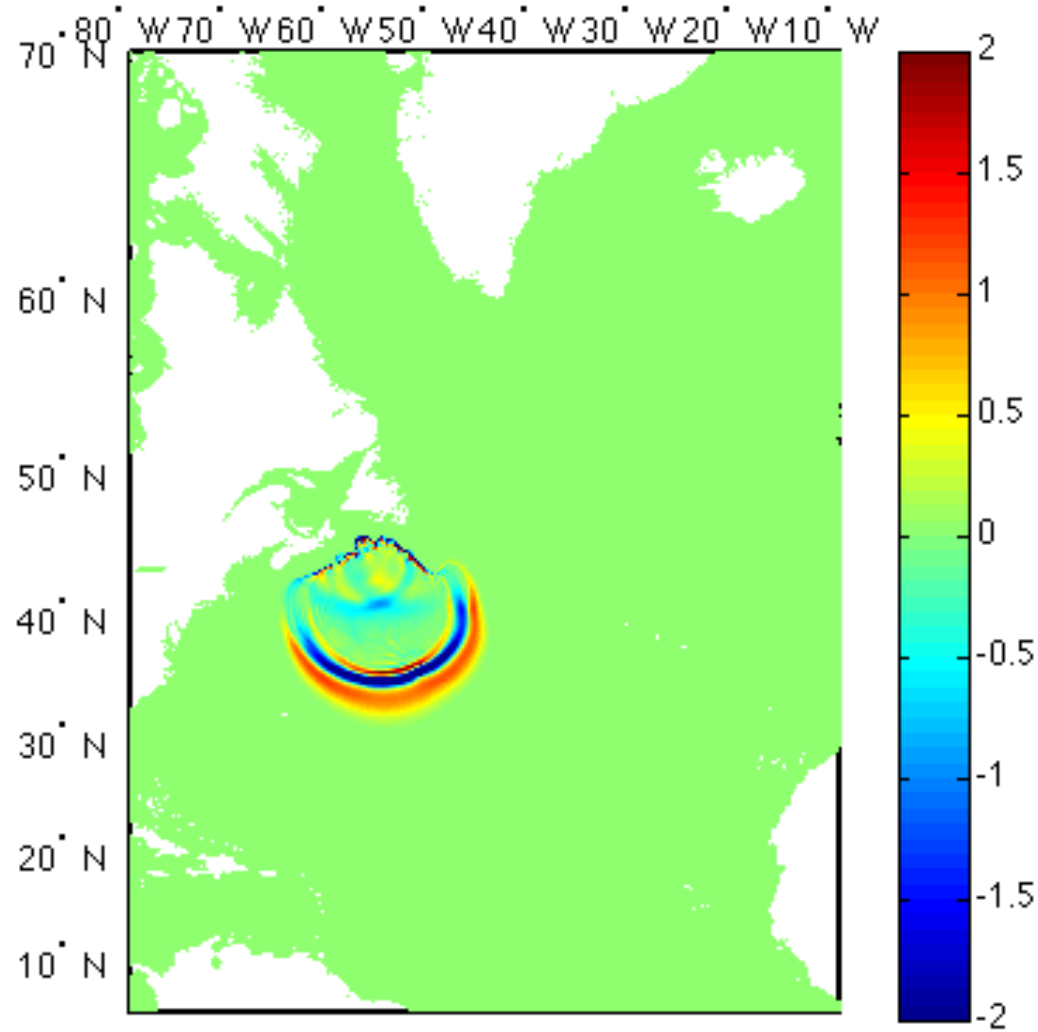
Max. Elevation for M9 Lisbon 1755 sources (1' grid)



SMF source selection: Probabilistic analysis of coastal hazards associated with submarine mass failures

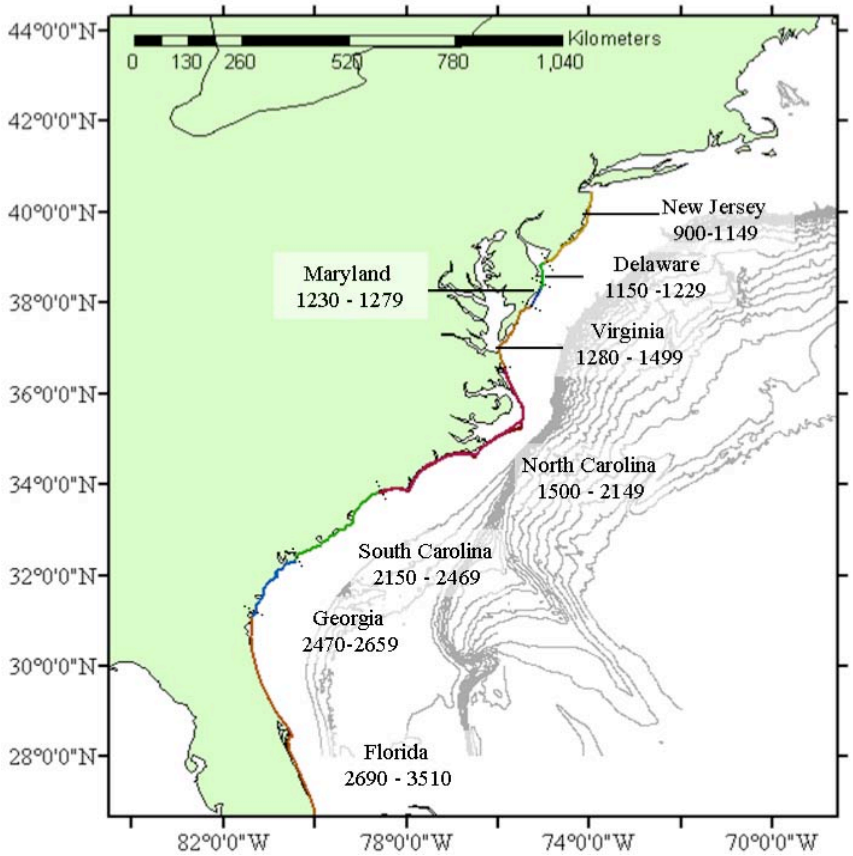
Summary

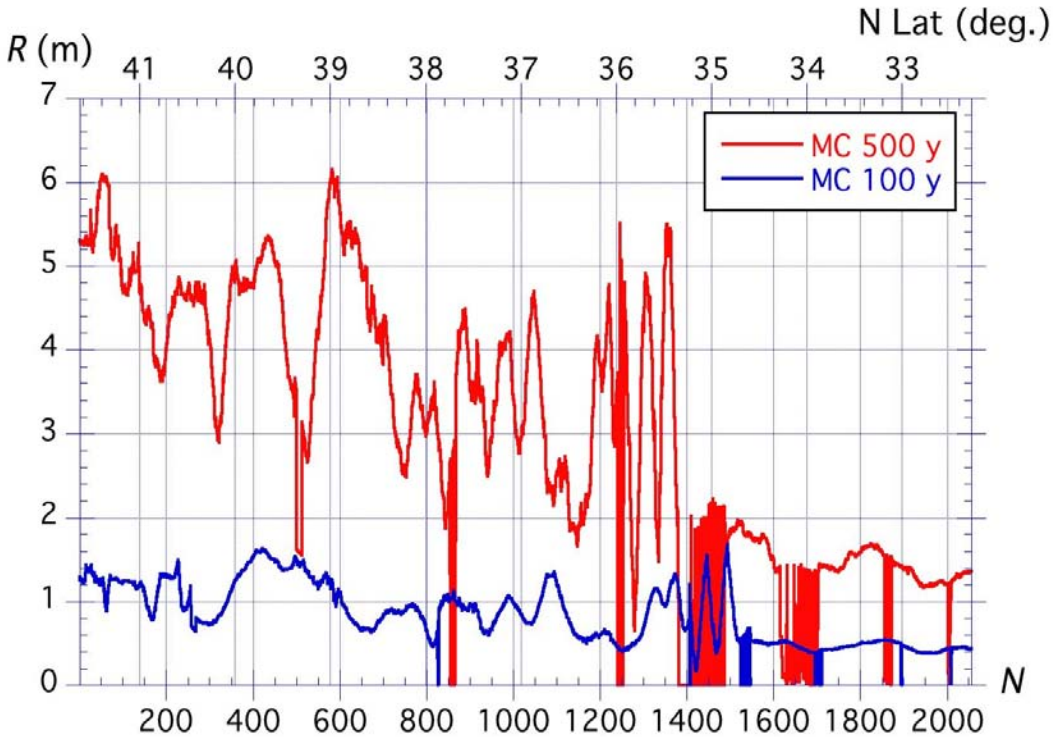
- *Two major historical SMF tsunamis* caused by Grand Banks (1929) and Currituck (24-50,000 years ago)
- 33% of US East Coast *continental slope covered by landslide scars* and deposits (Twichell et al. 2009)
- Large number of SMFs were analyzed using *Monte Carlo analysis (MCS)* in addition to historical cases



1929 Grand Banks source

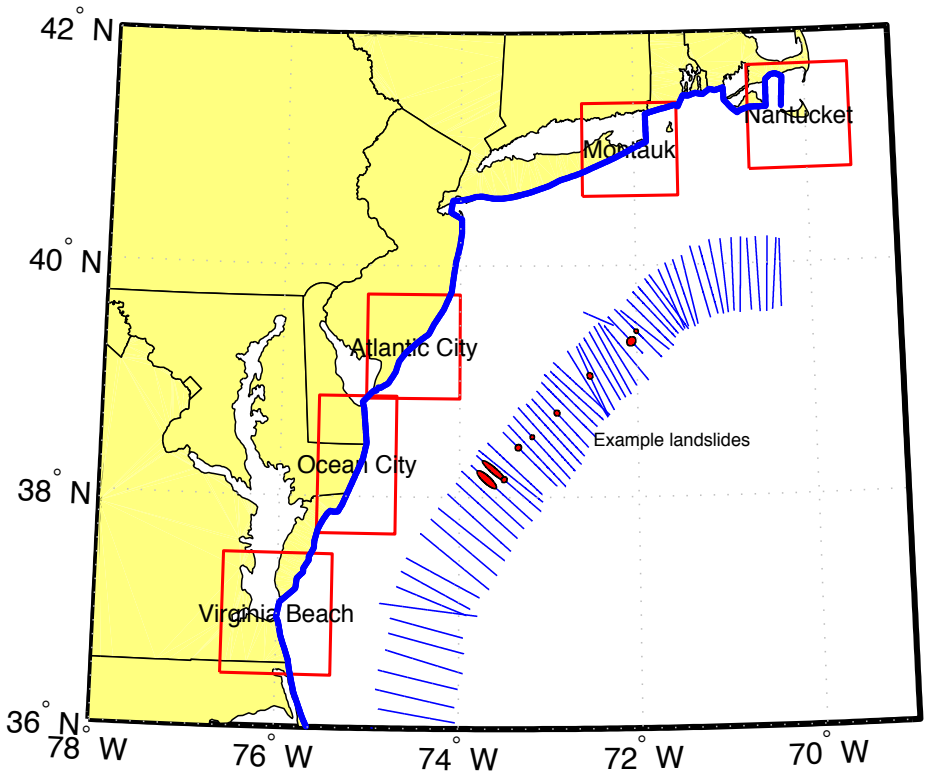
Results of MCS analysis of SMF tsunami hazard

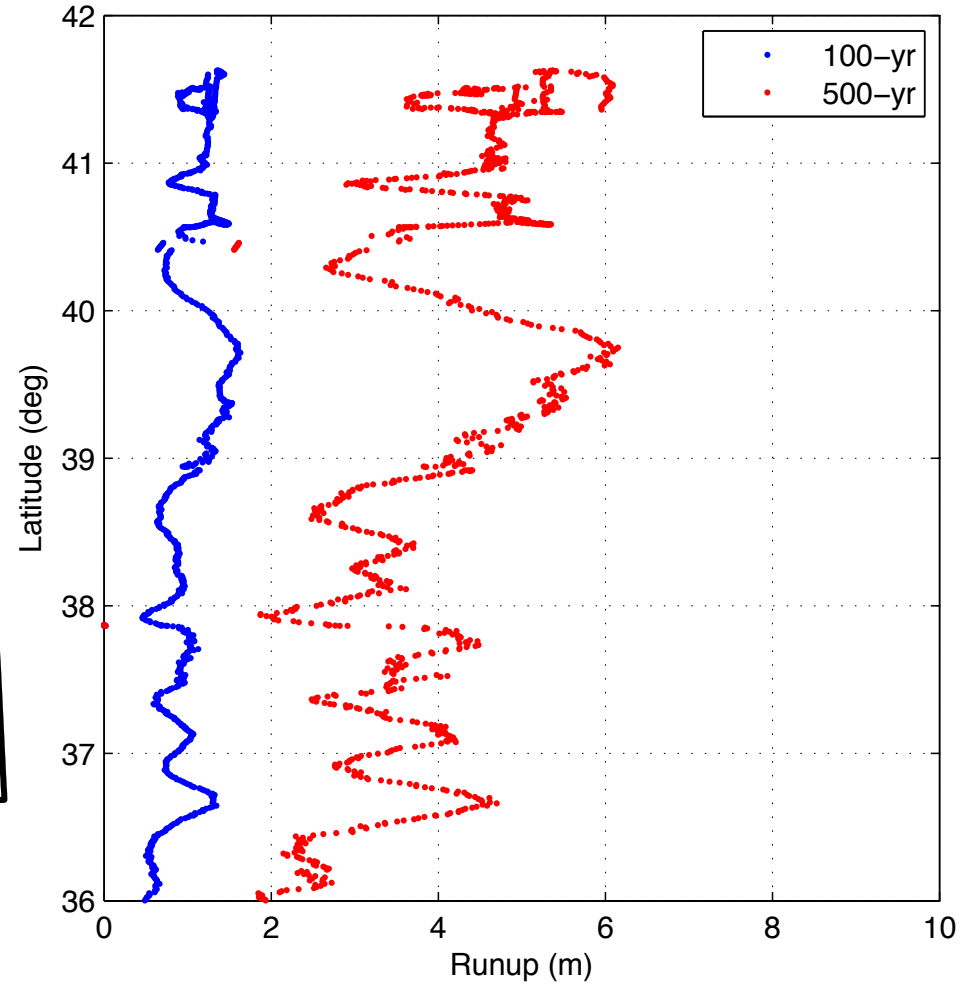




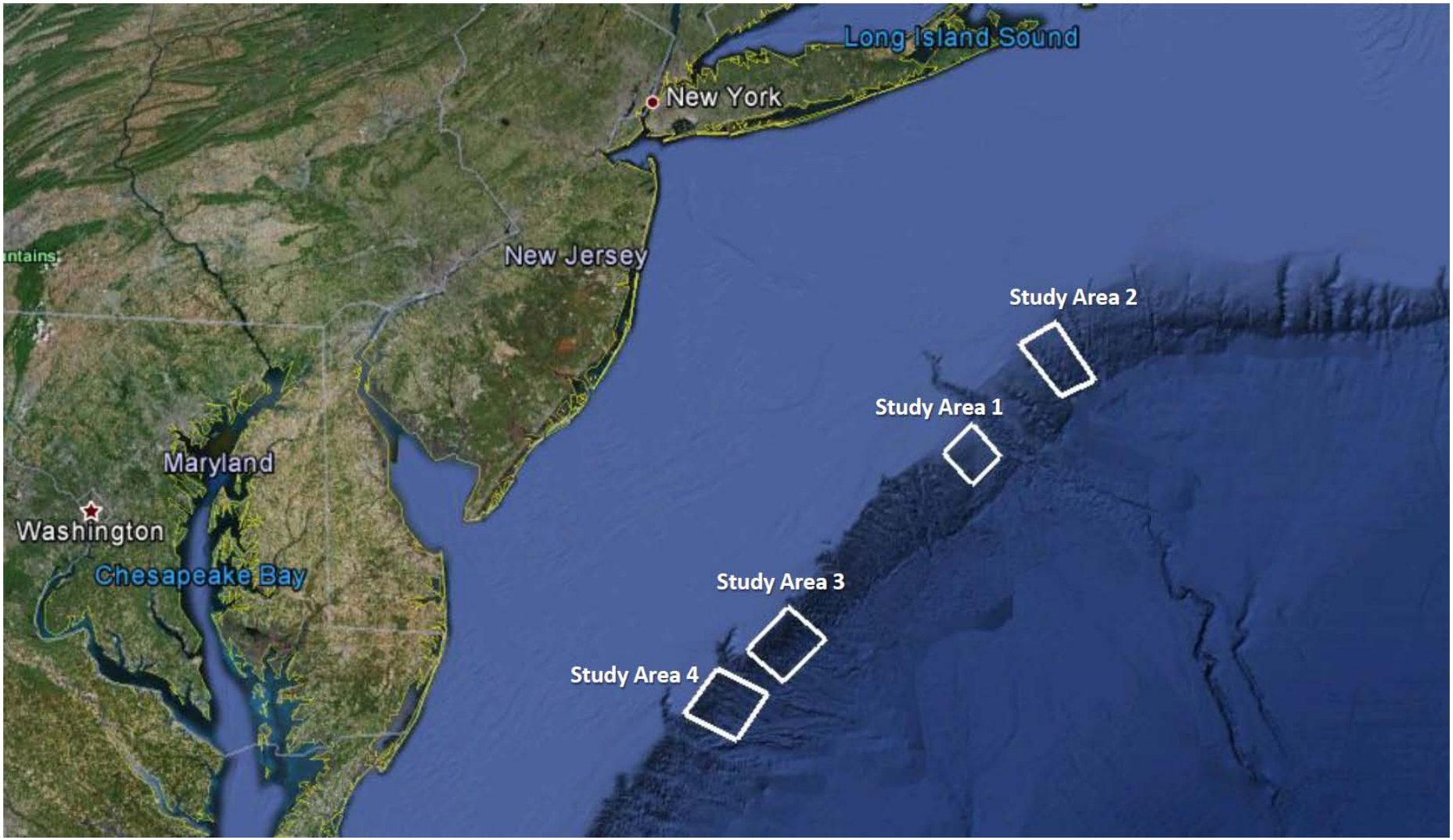
- Simplified coastline with names of corresponding coastal states, ranges of indices of studied coastal points, numbered N-S (

[Baxter et al., 2011; Krauss, 2011; Grilli et al. 2009.]

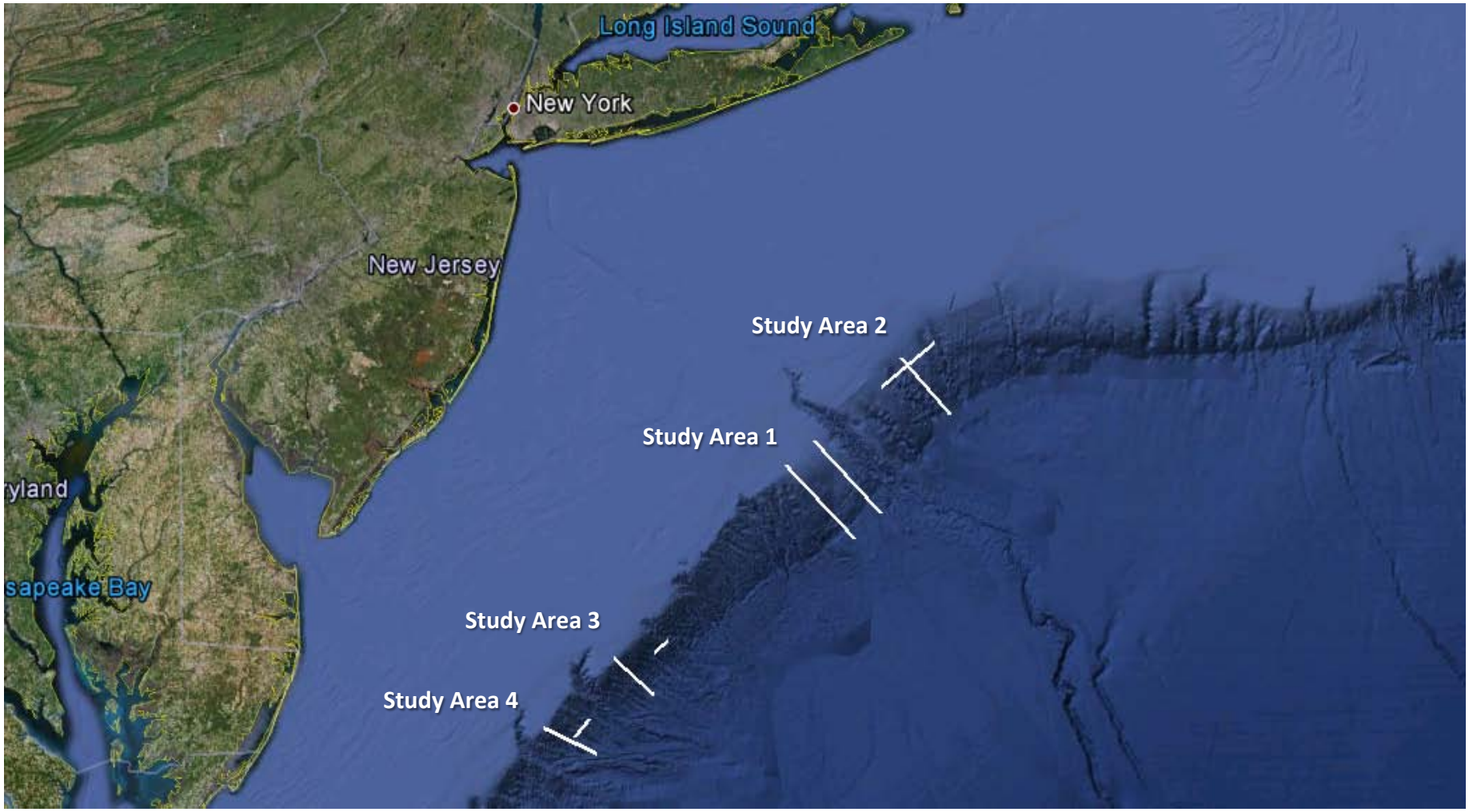

42° N
40° N
38° N
36° N
78° W
76° W
74° W
72° W
70° W
Nantucket
Montauk
Atlantic City
Ocean City
Virginia Beach
Example landslides


100−yr
500−yr
Latitude (deg)
Runup (m)
42
41
40
39
38
37
36
0
2
4
6
8
10

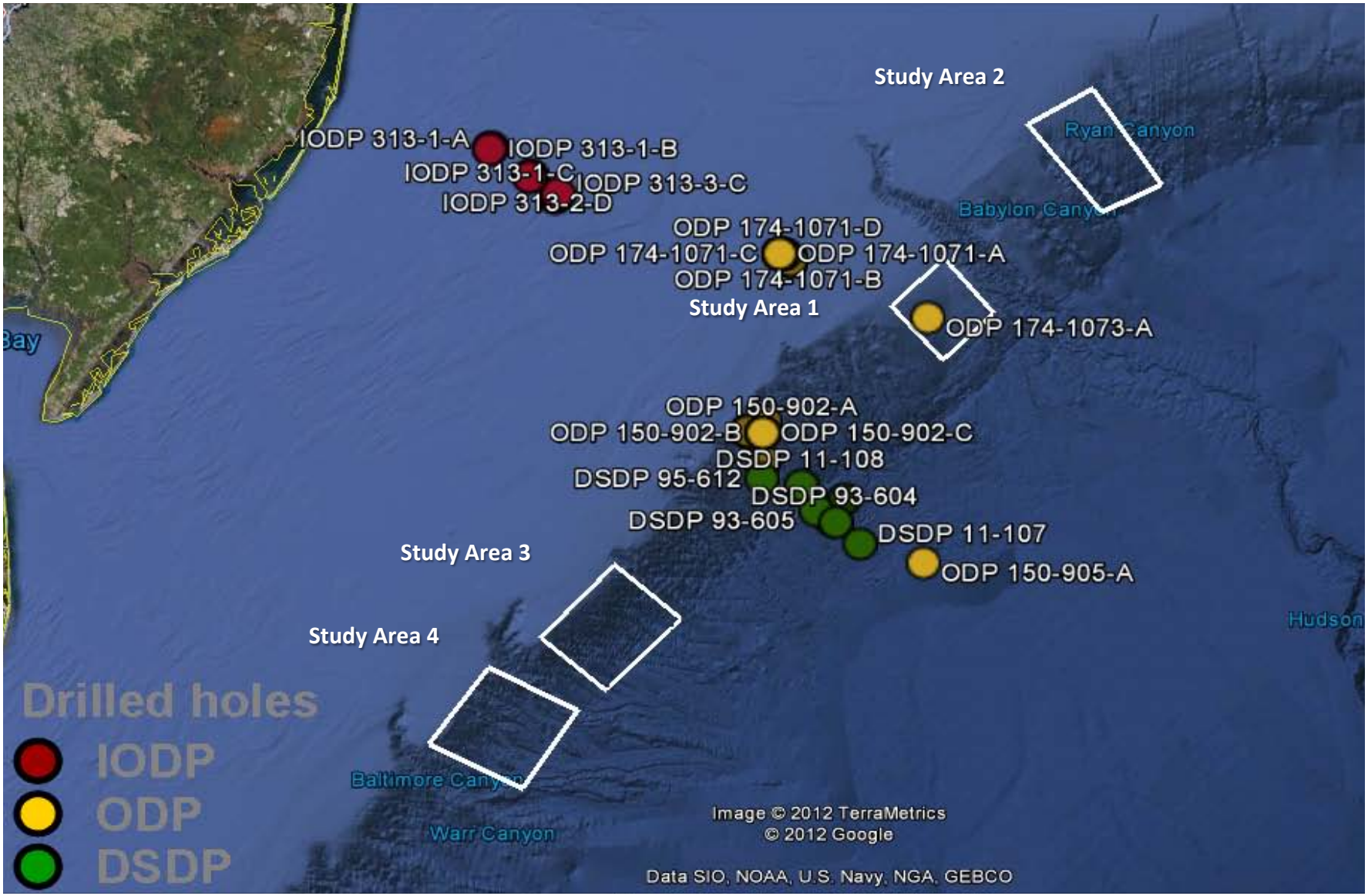
Collaborative work with USGS (J. Chaytor, U. Ten Brink) for site specific validation of MCS



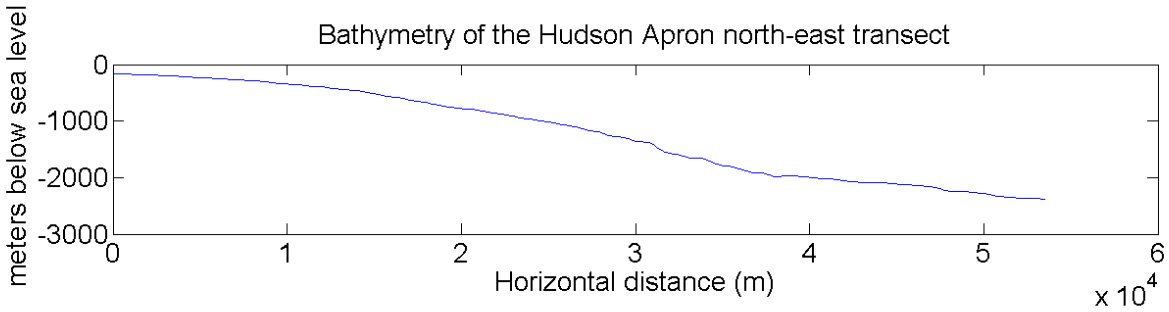
Locations of the transects for site specific analysis of seismically triggered SMFs

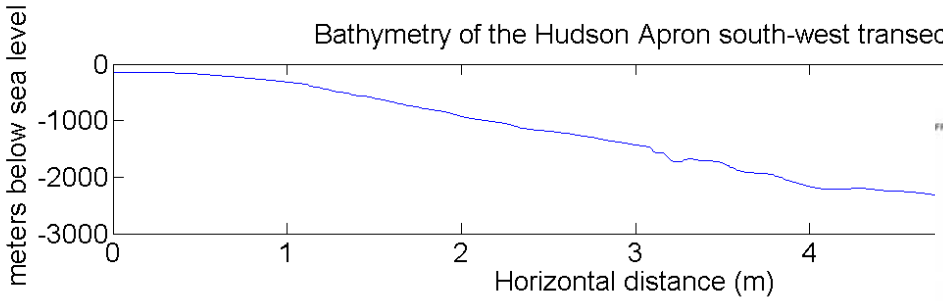


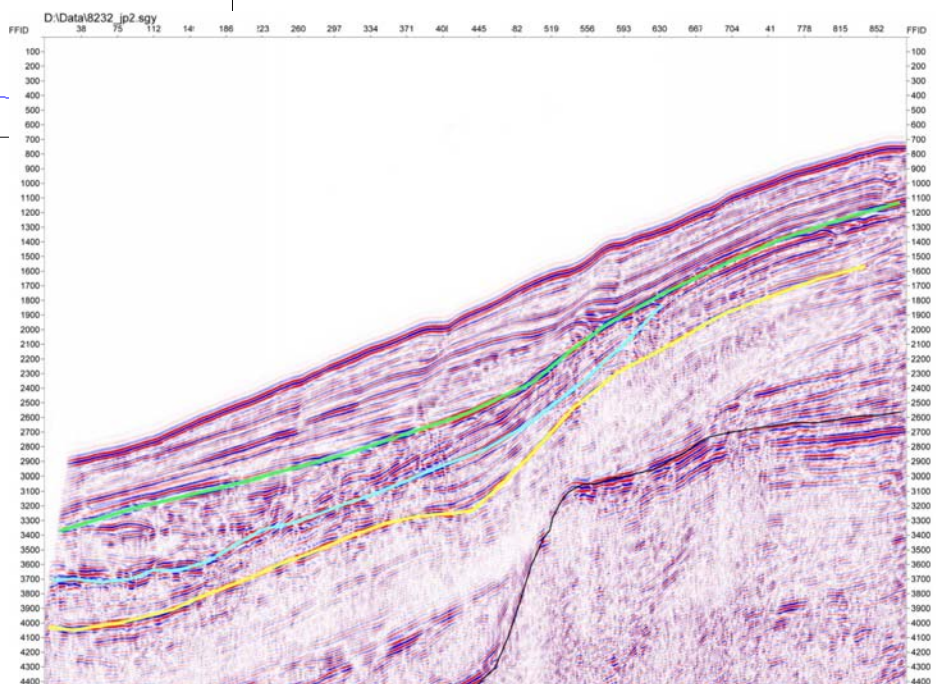
Locations of boreholes and available data



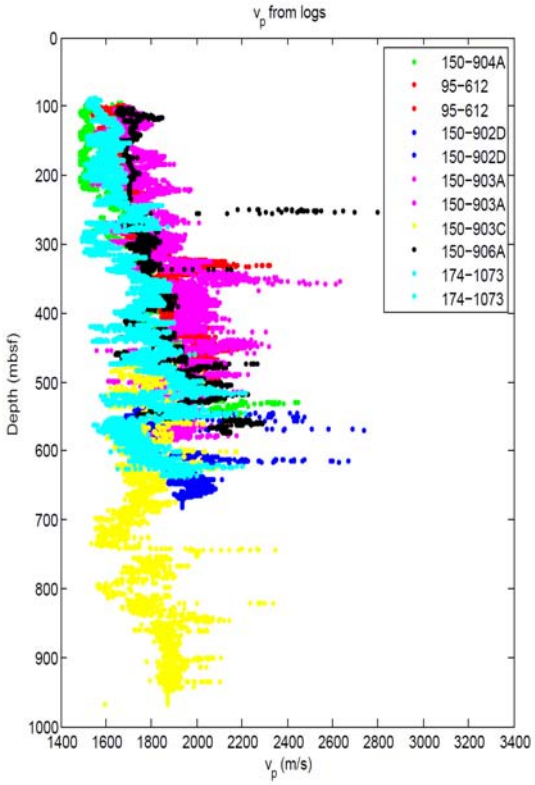
Bathymetry/seismic lines along transects

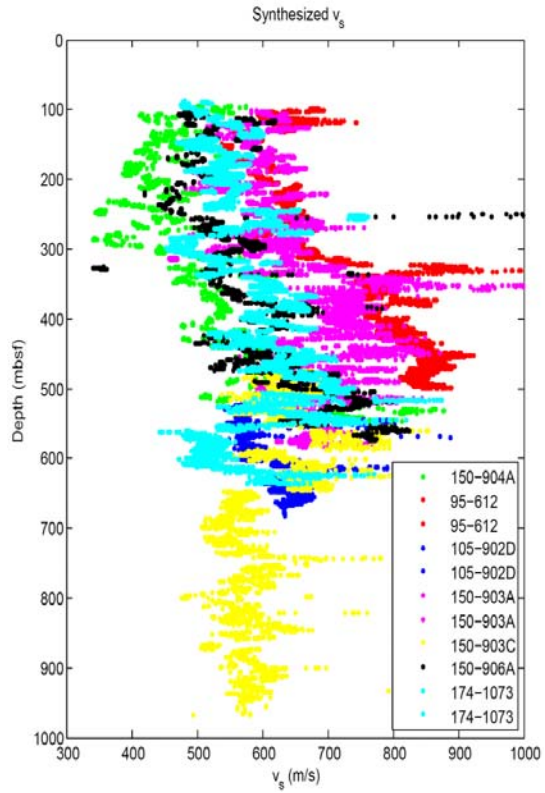


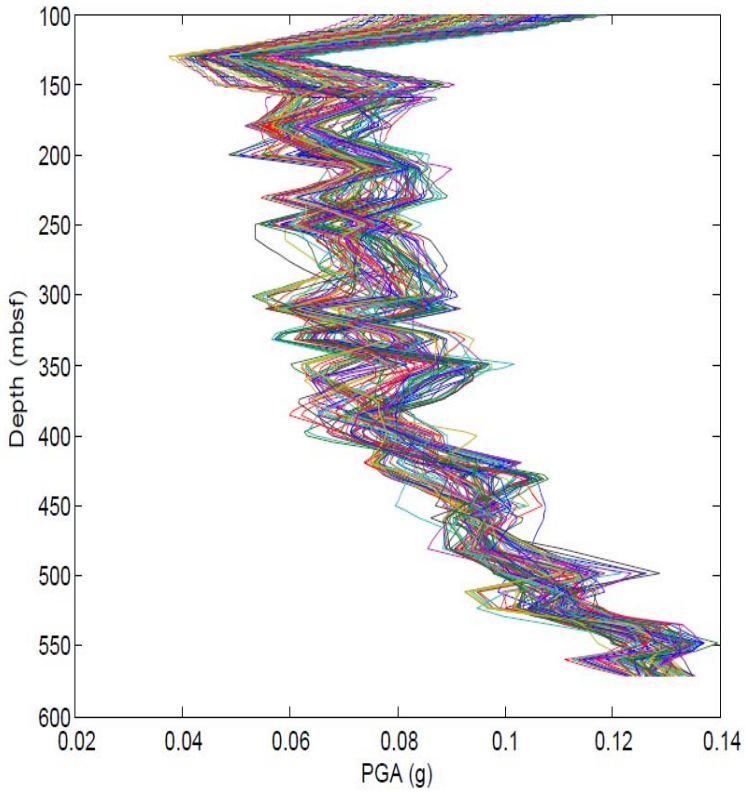




Site response analysis along transects (P-, S-wave, PGA analyses from log/core data)
=> Stability analysis/tsunami genesis to follow







Modeling of SMF Tsunami generation and propagation (NHWAVE-FUNWAVE.TVD)

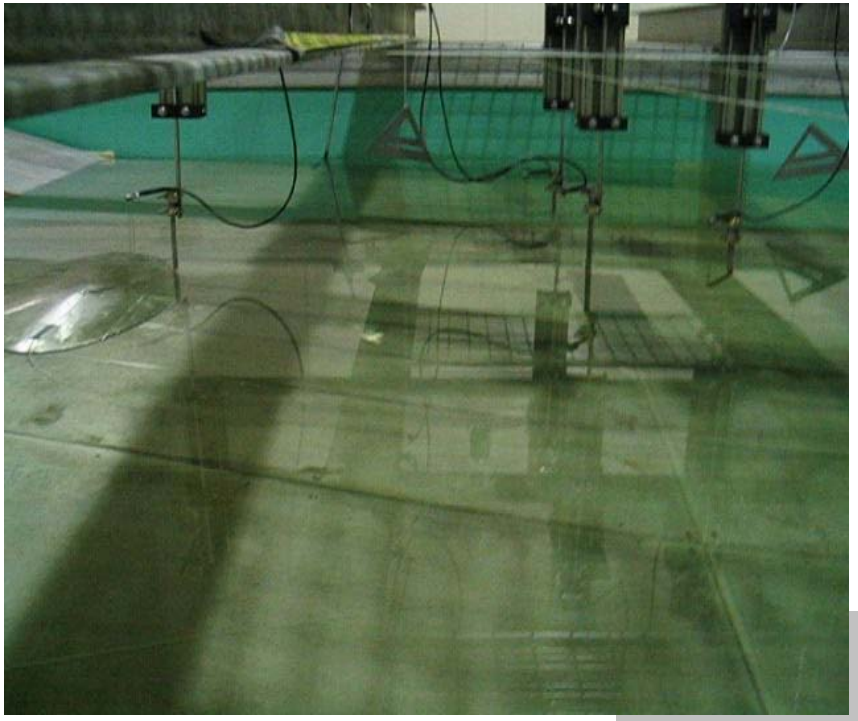
Old approach for SMF tsunamis

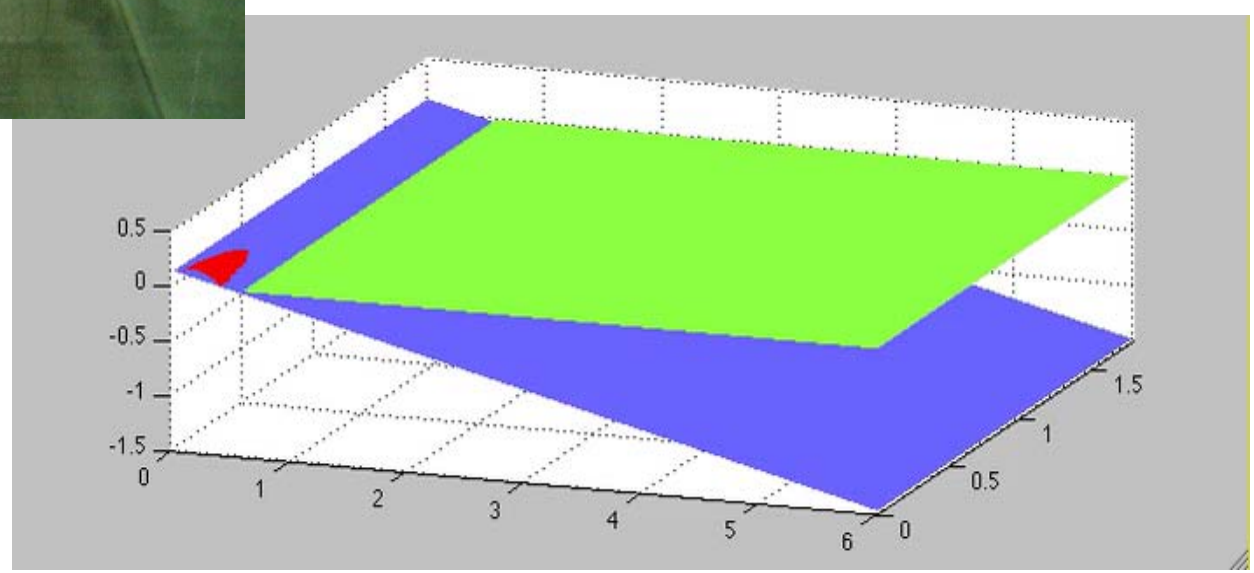
- Generated by TOPICS (see e.g., Watts et al., 2003)
- Propagation as a restart of FUNWAVE (2D)
- Successfully used previously for submarine landslides (e.g., Watts et al., 2003) and co-seismic sources (e.g., Grilli et al., 2005-2010)

New approach for SMF tsunamis

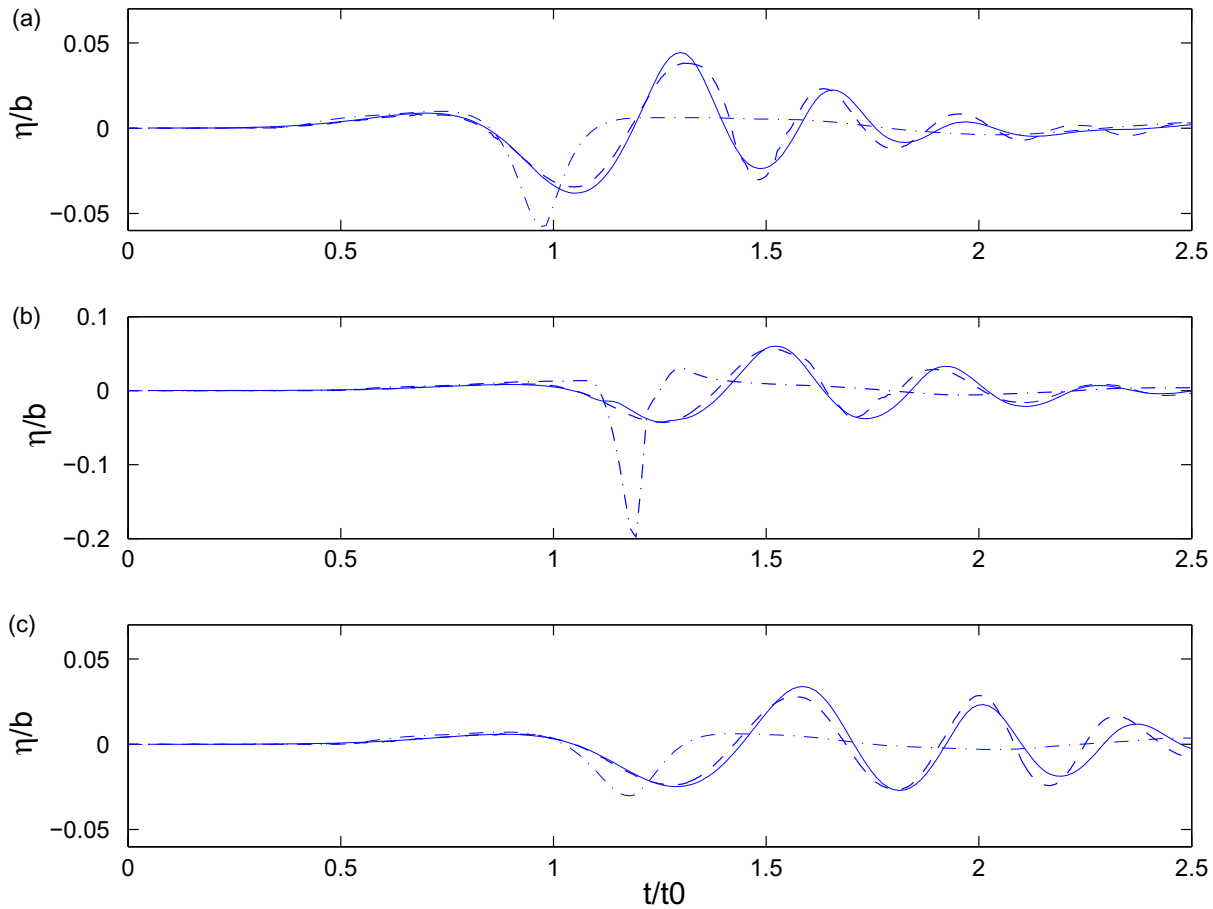
- Generation by NHWAVE (Ma et al., 2012) => 3D sigma-level non-hydrostatic model
- Propagation by FUNWAVE-TVD : (Shi et al., 2012) => 2D Boussinesq model
- Successfully used to simulate laboratory experiments and a few case studies

NHWAVE simulation of Enet and Grilli's (2007) slide





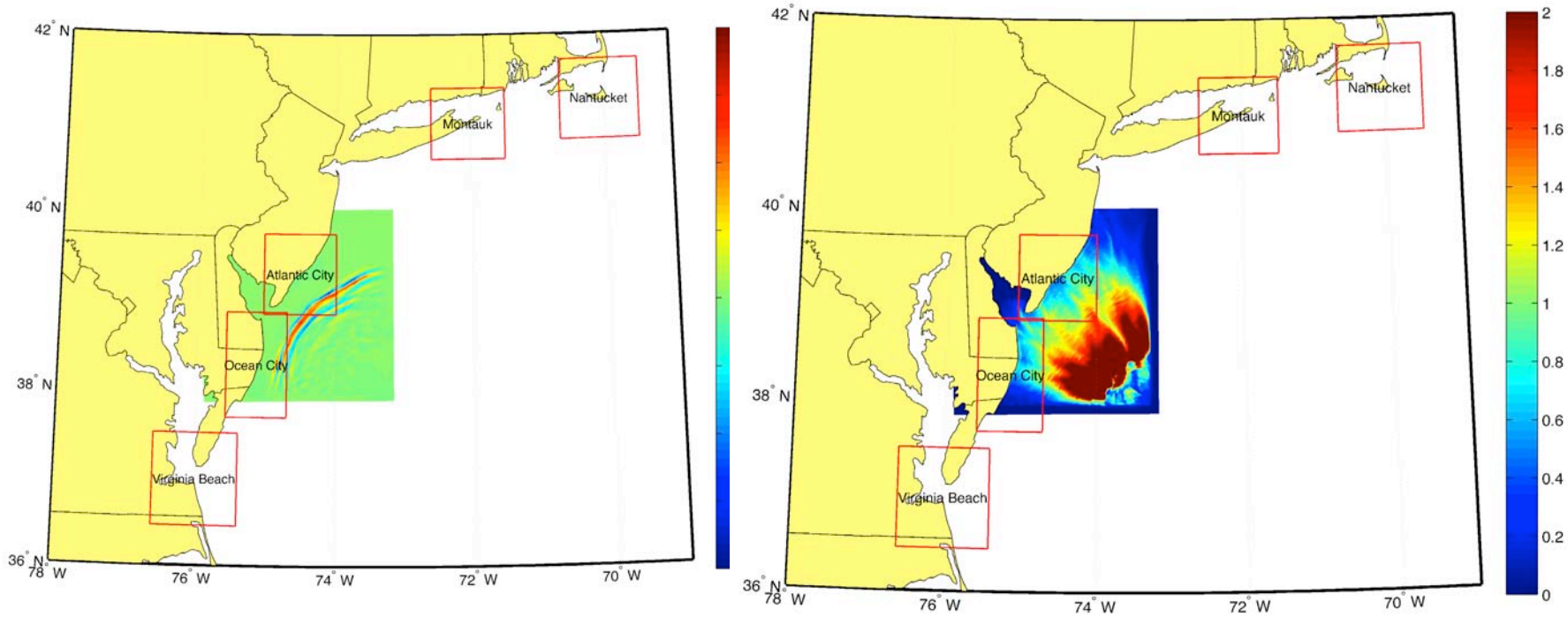
Enet and Grilli: Model – data comparison



Solid: observed; dash: fully-dispersive; dash-dot: non-dispersive

Simulations of SMF tsunami generation, propagation and coastal impact

Tsunami elevation computed with NHWAVE (up to 15 mins.) and FUNWAVE-TVD, in a 500 m regional grid, for the first SMF source. (a) instantaneous elevation after 75 mins of propagation; (b) maximum envelope of elevation



SMF/landslide issues

1. Appropriateness of SMF-MCS *events from a geological standpoint*:
   - MCS estimated sources are being validated by USGS working with the UD/URI team (completion by end of August 2012)

2. Appropriateness of using SMF-MCS *probabilistic results,* or should *worst-case historical scenarios* form the basis of NTHMP mapping, or both ?.
   - UD/URI have sought input from the NTHMP program on this question.
   - Guidance on this question could be gained from this workshop.

3. Tsunami wave trains generated by *SMF events* show *large (perhaps excessive) dissipation over wide continental shelves*:
   - Coastal tsunami hazard depends on wave shoaling/dissipation balance

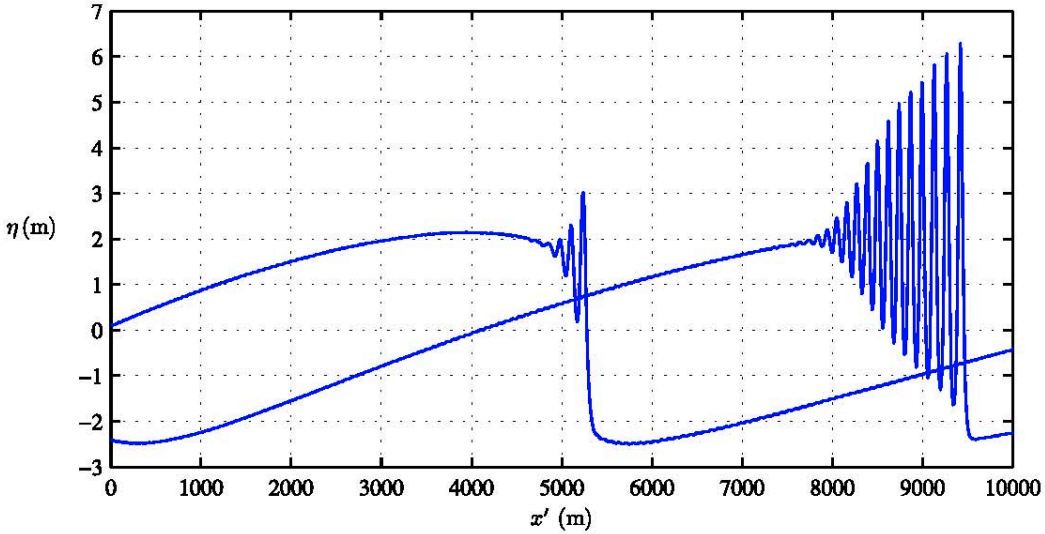
4. Effects of *extensive barrier islands/beaches* on arriving tsunamis*:*
   - Should barriers be removed to simulate worst breaching/erosion ?

5. One should be actively looking for *paleotsunami evidence* on the East Coast (return periods, size….)

Issue: Large dissipation of (SMF) tsunami wave trains over wide shelves

- Tsunamis often arrive onshore as much more complex wavetrains than had been typically assumed (e.g., long solitary or N-waves)

  => *Long waves with superimposed undular bores* made of shorter and steeper waves (intense breaking of those in shallow water)

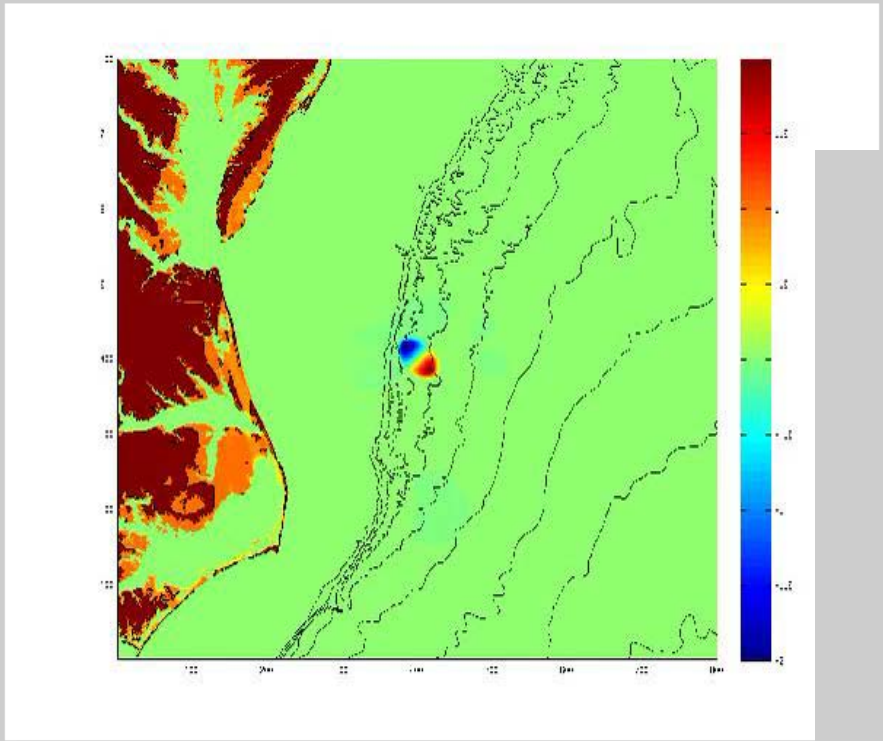
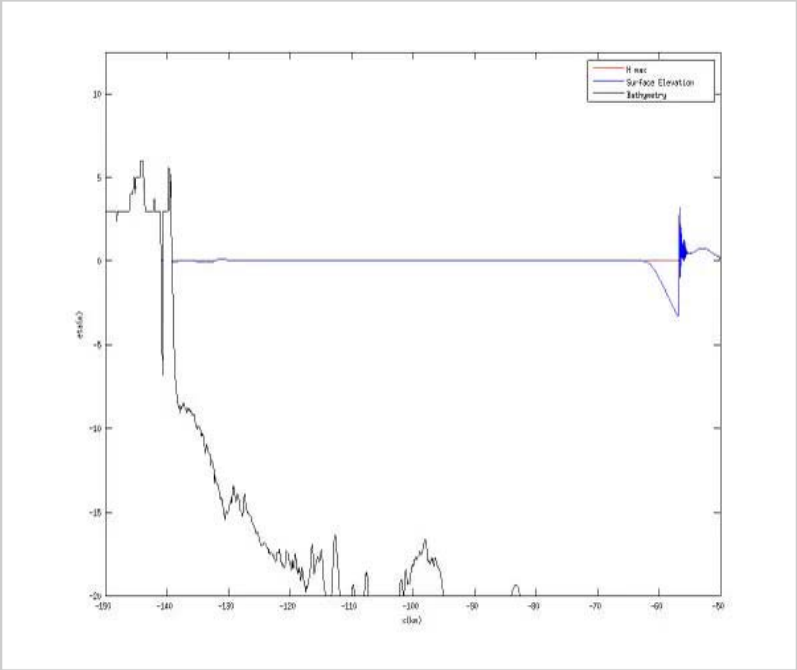


[From Madsen et al. (2008) : 12/26/04 observations and 1D BM modeling]

Large dissipation of SMF tsunami wave trains over wide shelves (rationale)

- Modeling coastal tsunami hazard => shoaling and breaking of such wave trains over complex bathymetry/topography, including *interplay* and effects on runup and inundation of *nonlinear, dispersive, and breaking dissipation processes*. [Even more so for SMF tsunamis]
- Fully nonlinear/dispersive BM models feature this kind of physics => FUNWAVE-TVD (Shi et al., 2012) switches from BM to NSW at breaking, controlled by breaking criterion (H < 0.8 times local depth).

Modeling approach affects SMF tsunami hazard

- NTHMP coastal tsunami hazard assessment => Intense dissipation of incoming tsunami wave trains, particularly for SMF tsunamis (e.g., *Currituck source*: 3D-NHWAVE -> FUNWAVE

-> Must be further studied/ elucidated !!