Modeling Hazards from Seismic and SMF Sources

Jim Kirby
Center for Applied Coastal Research
Department of Civil and Environmental Engineering
University of Delaware

PREDICT Workshop
Victoria BC

March 24, 2014

Outline

- Discussion of models employed
  - Jim Kirby, Fengyan Shi, Joe Geiman (UD), Ganfeng Ma (ODU), Jeff Harris, Stephan Grilli (URI), Dmitry Nicolsky (UA)
- Review NTHMP East Coast USA Effort
  - Jim Kirby, Fengyan Shi, Babak Tehranirad, Saeideh Banihashemi (UD), Stephan Grilli, Annette Grilli, Jeff Harris, Chris Baxter, Tayebah Tajalli Bakhsh, Chris O'Reilly (URI), Stephan Abadie (UB), Jara Schnyder (UM)
- SMF's as (potentially important) parts of large tsunami events.
  - Stephan Grilli, Jeff Harris (URI), David Tappin (BGS), Robert Geller (UT), Tim Masterlark (SDSM), Jim Kirby, Fengyan Shi (UD), Gangfeng Ma (ODU)

Seismic tsunami generation, propagation and inundation

- Generation phase for seismic cases: either
  - FEM of ground deformation in 3-D (Masterlark, Grilli)
  - Dynamic water surface displacement using NHWAVE

  …or
  - Static surface displacement using Okada sources

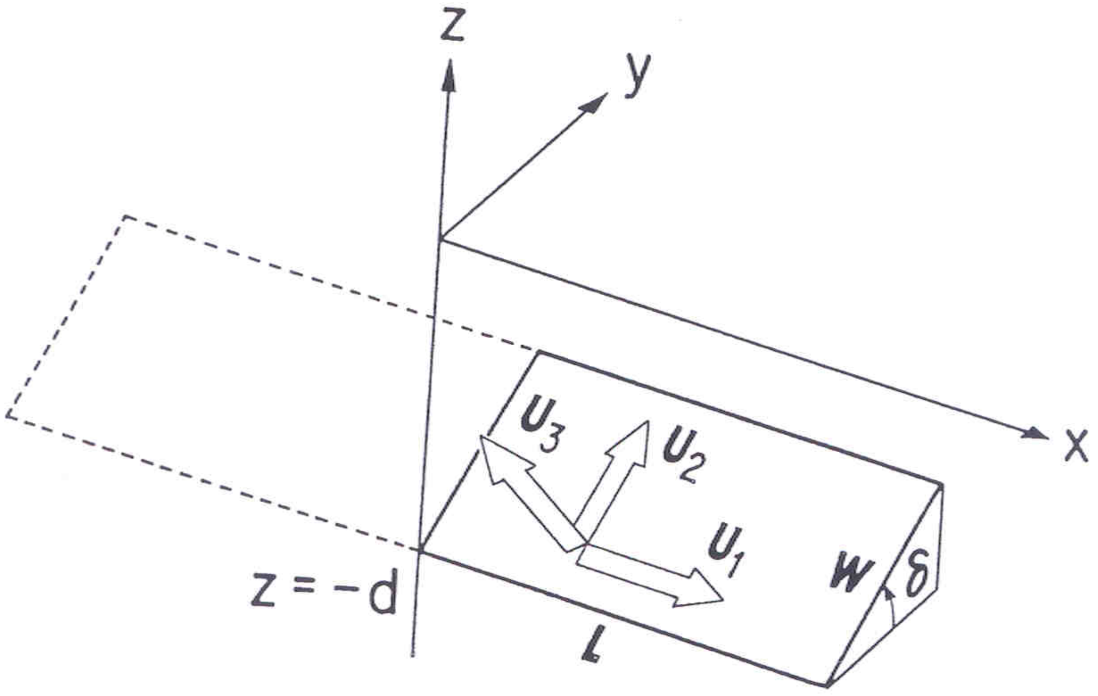
- Propagation phase:
  - FUNWAVE in spherical coordinate version. Boussinesq model for weakly nonlinear, weakly dispersive waves

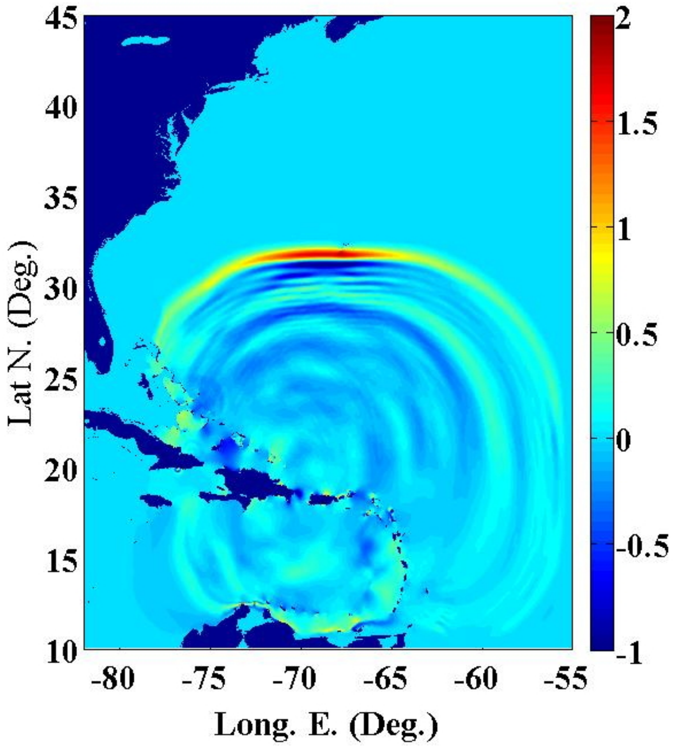
- Inundation phase:
  - FUNWAVE in Cartesian coordinate version. Boussinesq again.

(1) Continuous source subdivided into a set of “Okada” sources, each representing a finite slip in an elastic half space.

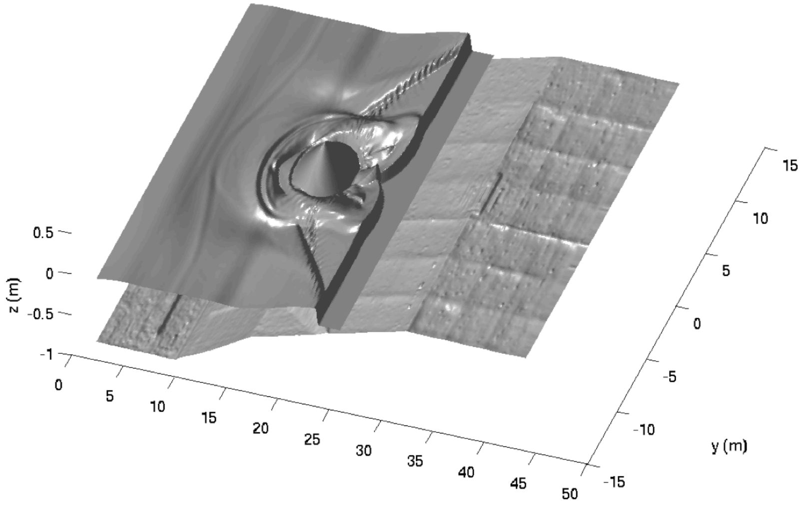
Predicted displacement at earth-water interface transferred instantaneously to a static deformation of the water surface

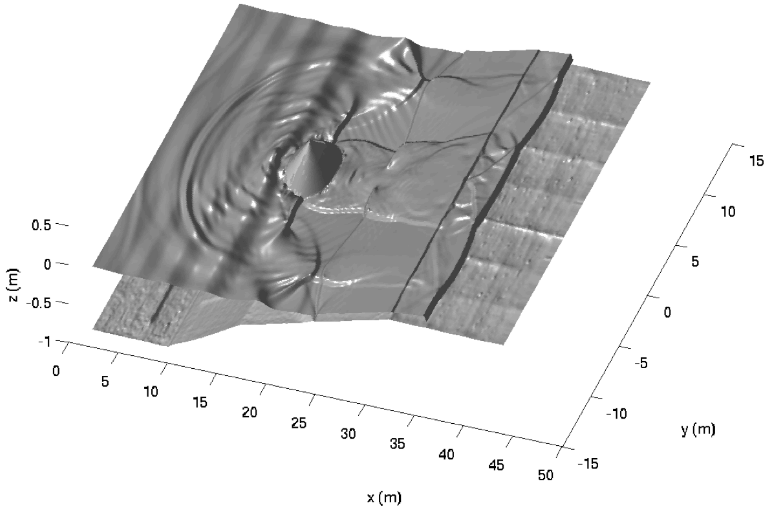
- U_1: Strike-slip
- U_2: Dip-slip
- U_3: Tensile dislocation
- δ: dip angle





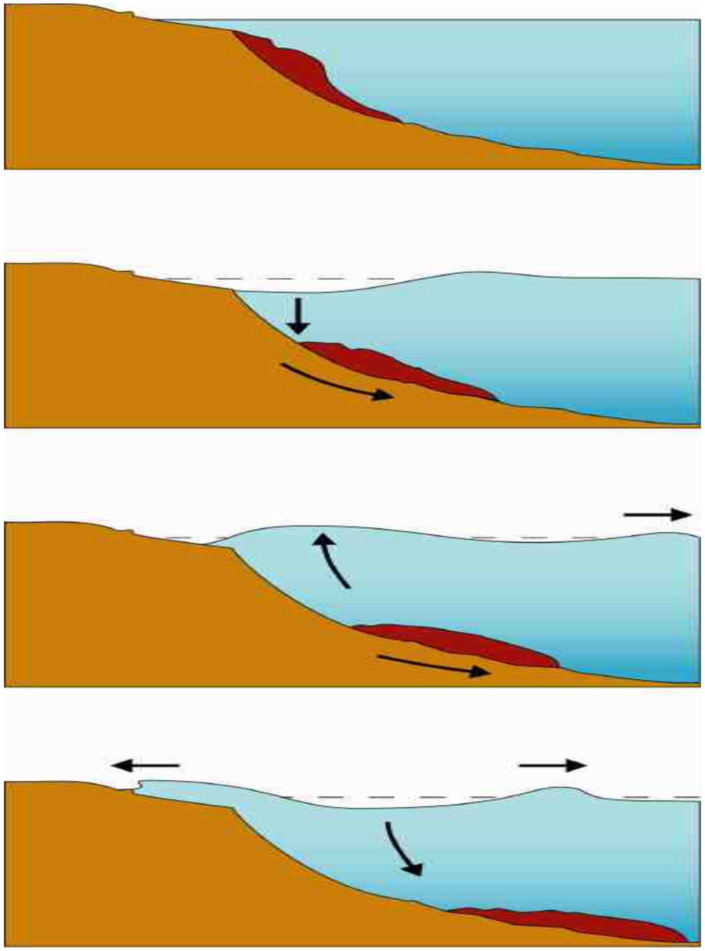
Puerto Rico trench event: propagation phase





Solitary wave overtopping an island located at a shelf break (data from Lynett)

Submarine Mass Failure



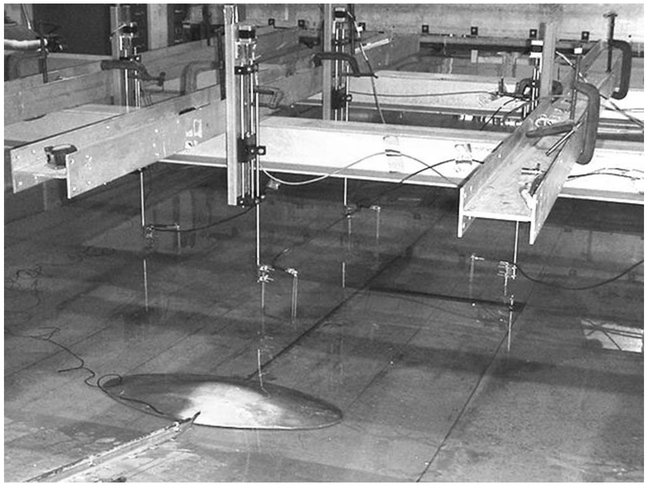
Watts and Borrero, 2001

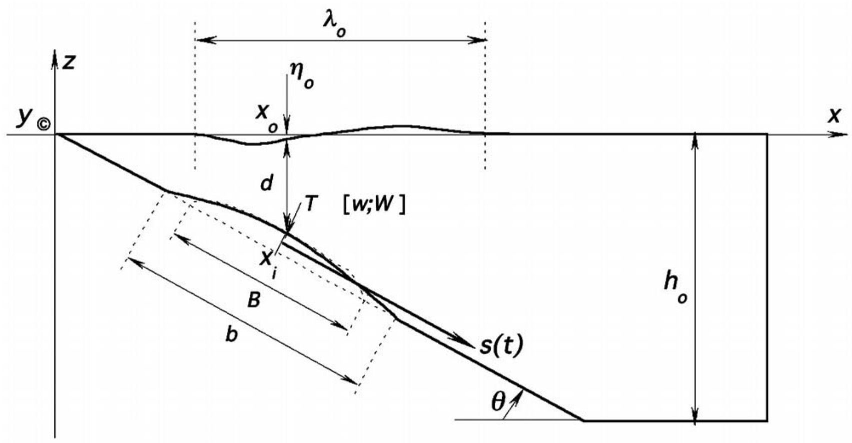
Modeling methodology: SMF

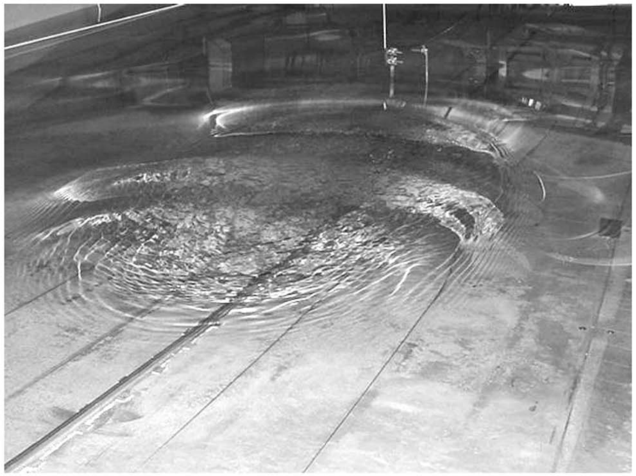
- Here, time-dependent kinematics of bottom motion used directly in 3-D hydrodynamic model NHWAVE

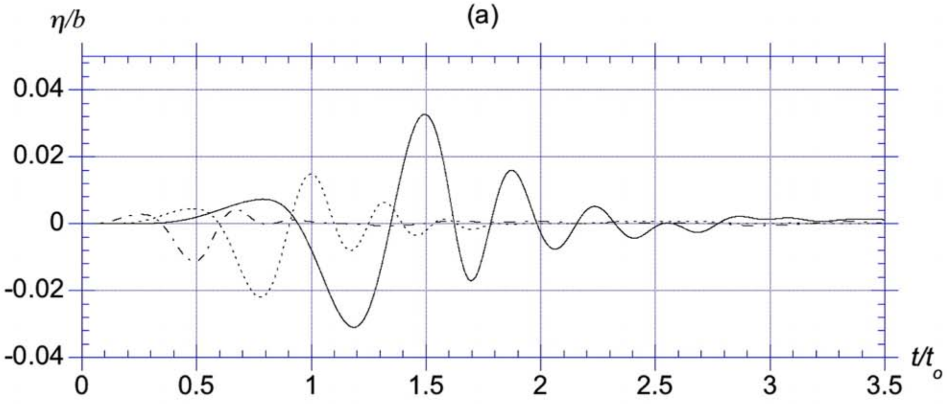
1. Model solves 3-D Euler equations in surface and terrain following σ coordinates.
2. Model parallelized, uses public domain package HYPRE to solve pressure Poisson equation.
3. Bottom may be specified as a time-dependent function.

Example: Solid slide of Enet and Grilli (2007)



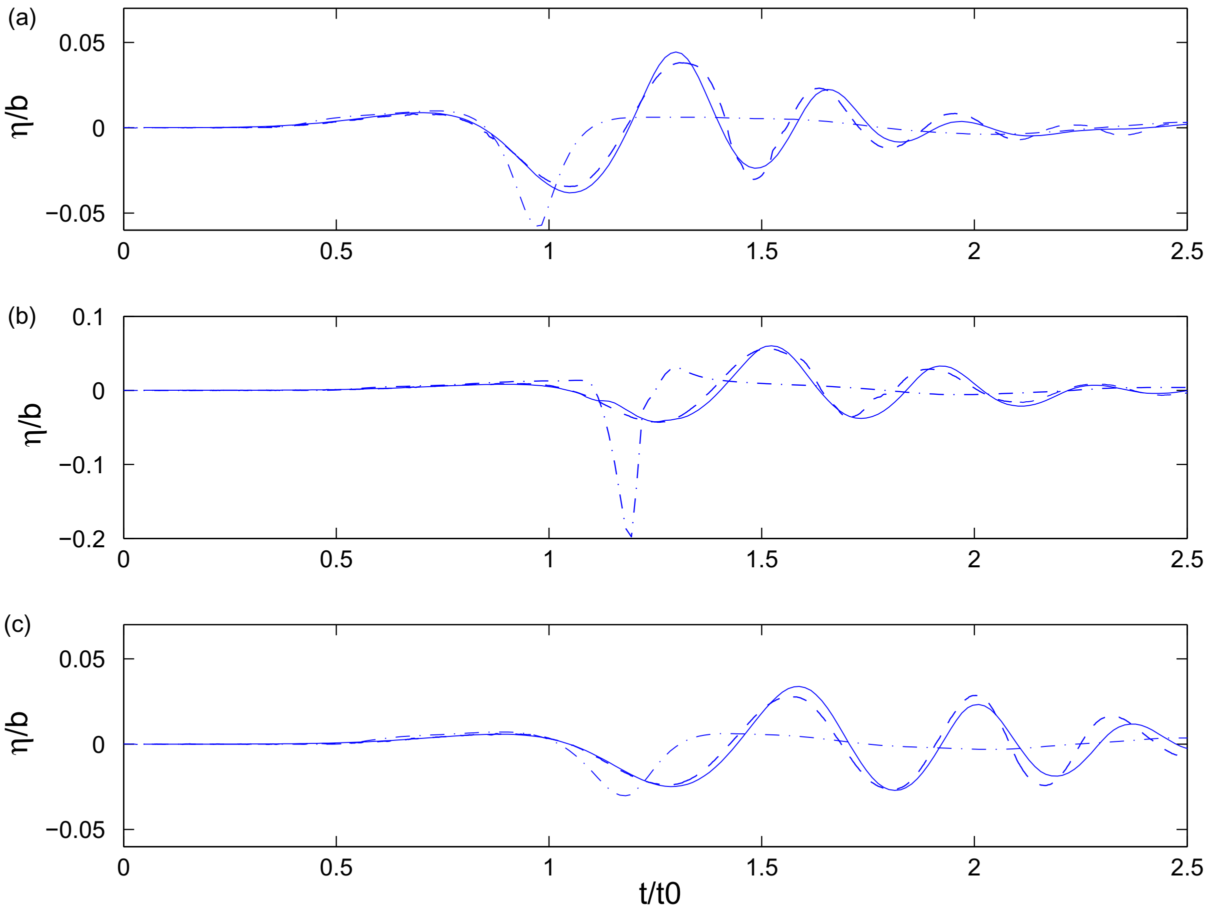




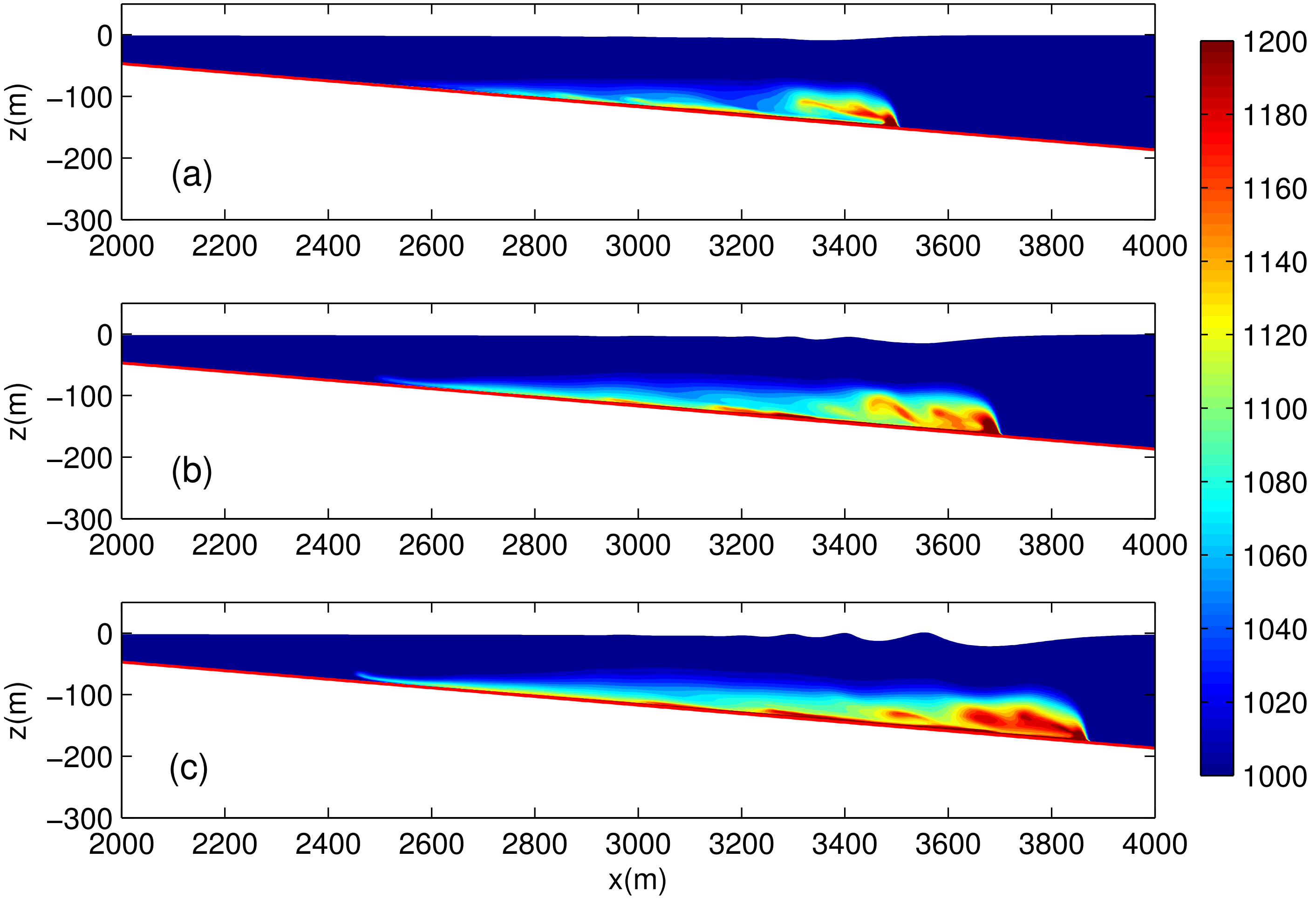


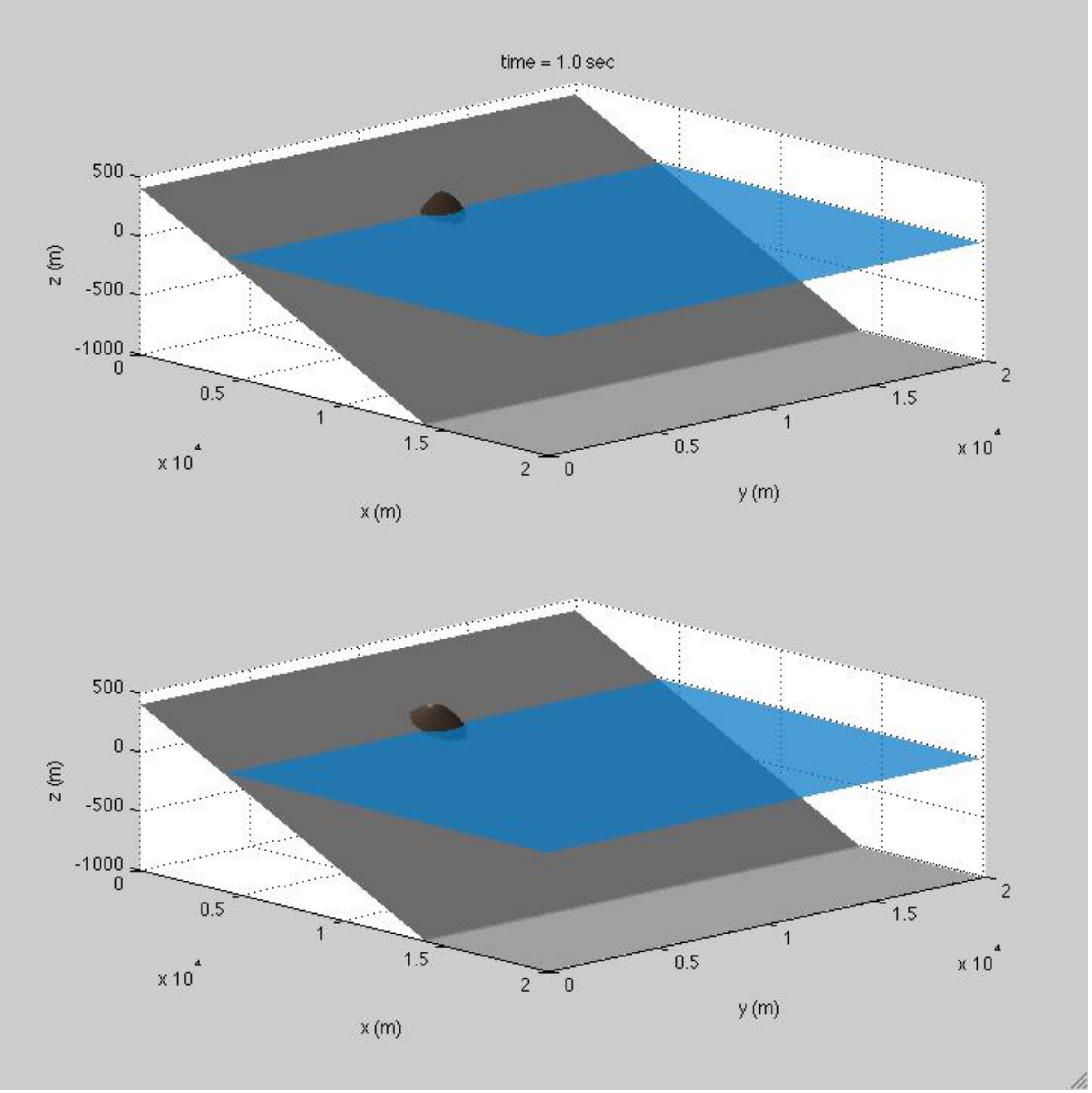
Enet & Grilli: Model – data comparison.

Solid: observed, dash: fully-dispersive, dash-dot: nondispersive



Future: representation of deformable slides with various rheologies (Ma et al, forecoming)





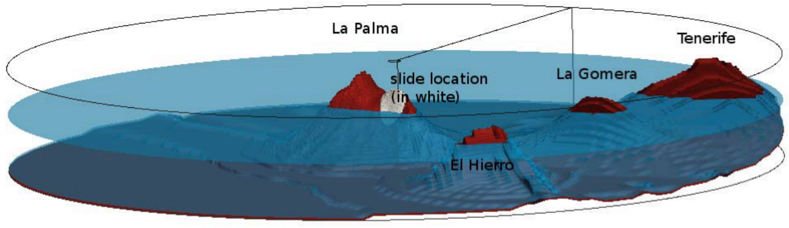
Viscous fluid slide
(Nicolsky)

Solid slide

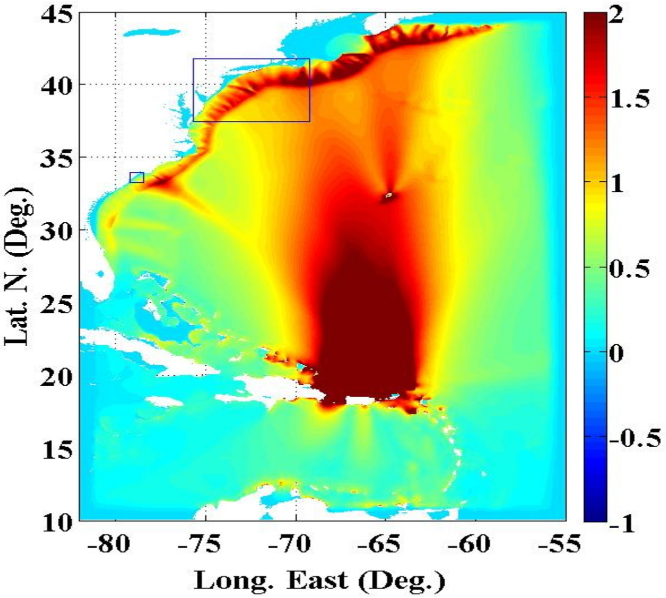
Outline

- Discussion of models employed
- Review NTHMP East Coast USA Effort
- SMF's as (potentially important) parts of large tsunami events.

Sources for East Coast modeling documented in technical reports available at http://chinacat.coastal.udel.edu/nthmp.html

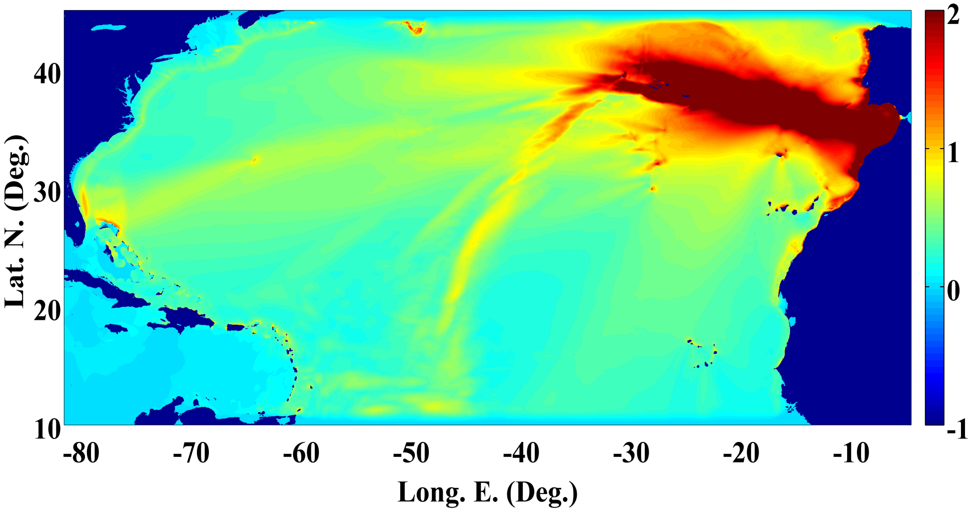


Cumbre Vieja

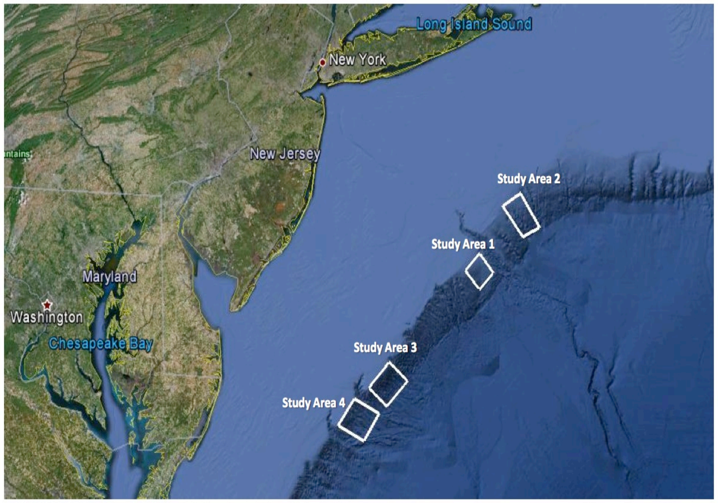


Puerto Rico

Azores



SMF sources



Florida Straits SMF of Grand Bahama Bank carbonate platform

Jara S. D. Schnyder[1]
Gregor P. Eberli[1]
J.T. Kirby[2]
F. Shi[2]
B. Tehranirad[2]
T. Mulder[3]
E. Ducassou[3]

1) Center for Carbonate Research, Miami
2) University of Delaware, Newark
3) Université Bordeaux I, Talence Cedex

NH41A-1689

potential for
tsunami generation by submarine slope failures
along the western Great Bahama Bank

jschnyder@rsmas.miami.edu

slope failures

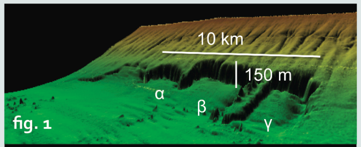


fig. 1

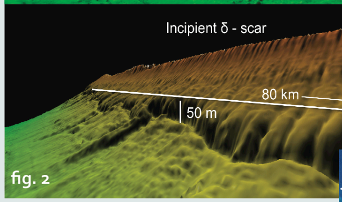


fig. 2

The western slope of Great Bahama Bank shows **slope failures** at various scales (fig. 1). Three landslides were identified; i.e. alpha-, beta-, and gamma-landslide.

In addition, creeping and **incipient slump scars** indicate slope instabilities that will lead to large-scale failures in the near future (fig. 2).

Bathymetry and hydroacoustic data was used to identify the volume and nature of past large mass movements within this area and the mass transport complexes (MTC) in the basin (fig. 3).

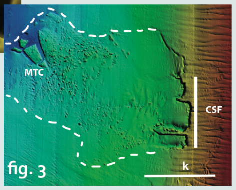


fig. 3

failure scenarios

Three possible failure scenarios were designed based on estimated volume and nature of the failure mechanisms (tab. 1).

Single Slope Failure (SSF)
An isolated collapse of the beta-failure mass is simulated (fig. 1).

Combined Slope Failure (CSF)
The failure of alpha-, beta-, and gamma-mass simultaneously is simulated and approximated as single landslide mass (fig. 2).

Potential Major Slope Failure (pMSF)
The failure of an over 80 km long scar is simulated (fig. 3).

tab. 1

Parameters	Landslide Names				Failure Scenarios		
	α	β	γ	δ	SSF	CSF	pMSF
Thickness [m]	150	150	150	50 (visible)	150	150	150
Length [km]	1.4	3.2	3.0	2	3.2	3.8	2
Width [km]	2.2	3.7	1.6	80	3.7	10	80
Water depth [m]	600	500	570	300	500	550	300
Slope angle [degree]	2.9	3.2	3.3	3	3.2	3.2	3

numerical domain

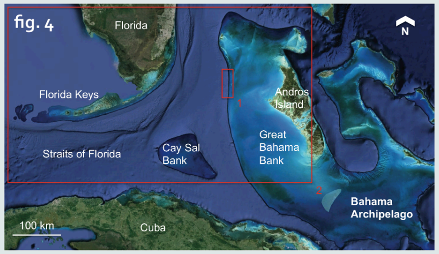


fig. 4

Two bathymetric grids were used for the simulations (fig. 4).
(1) is a 30 x 30 m grid based on multibeam data acquired during CARAMBAR cruise (Mulder et al. 2012). The grid was used for landslide and tsunami initiation.
(2) is the general bathymetric chart of the oceans, GEBCO-grid, in a 700 x 700 m resolution and was used for the propagation simulations.

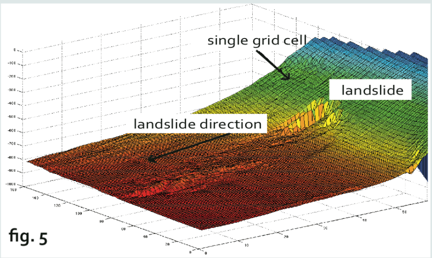


fig. 5

The 30 x 30 m resolution bathymetric grid was converted into UTM and re-gridded in MATLAB (fig. 5).

tsunami wave propagation

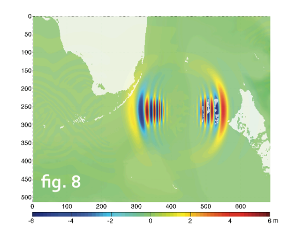


fig. 8

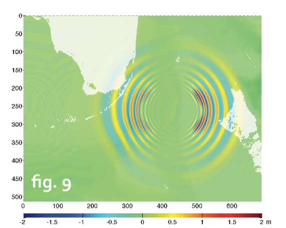


fig. 9

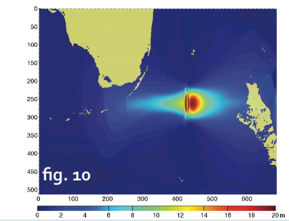


fig. 10

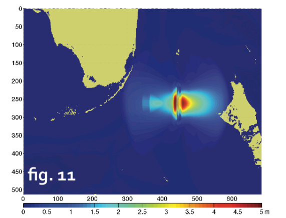


fig. 11

Sea surface elevation for 15 min propagation time of CSF scenario for 240 s landslide duration (fig. 8) and 10 min propagation time of pMSF scenario for 240 s landslide duration (fig. 9).

Maximum wave elevation computed with FUNWAVE-TVD in Cartesian grid for the pMSF source with 50 ms^{-1} terminal landslide velocity and 120 s outrun time (fig. 10) and with 100 ms^{-1} terminal landslide velocity and 240 s outrun time (fig. 11).

All simulations ending in a considerable wave impact on the coastline show arrival times of less than 20 min between landslide initiation and wave impact. For bigger waves, the propagation velocity is larger.

tsunami wave initiation

fig. 6

landslide duration

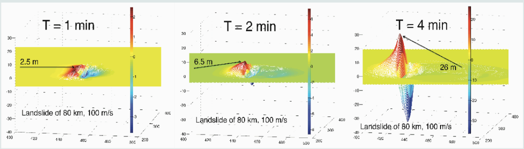
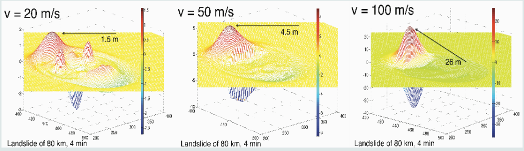


fig. 7

terminal velocity



For the simulations we chose landslide durations of 1, 2, 3, and 4 minutes. Terminal velocities of 20, 50 and 100 ms^{-1} were used. Landslide outrun direction was assumed to be westwards.

numerical models

The tsunami wave generated by a landslide was modeled using the non-hydrostatic wave model NHWAVE (Ma et al., 2012). The model was developed for submarine landslide induced tsunami wave simulation and simulates fully dispersive surface wave processes.

The resulting wave from these first simulations, then was reinterpolated as input into the fully nonlinear and dispersive Boussinesq model FUNWAVE-TVD to simulate the wave propagation and estimate an impact with the coastline (Shi et al., 2012).

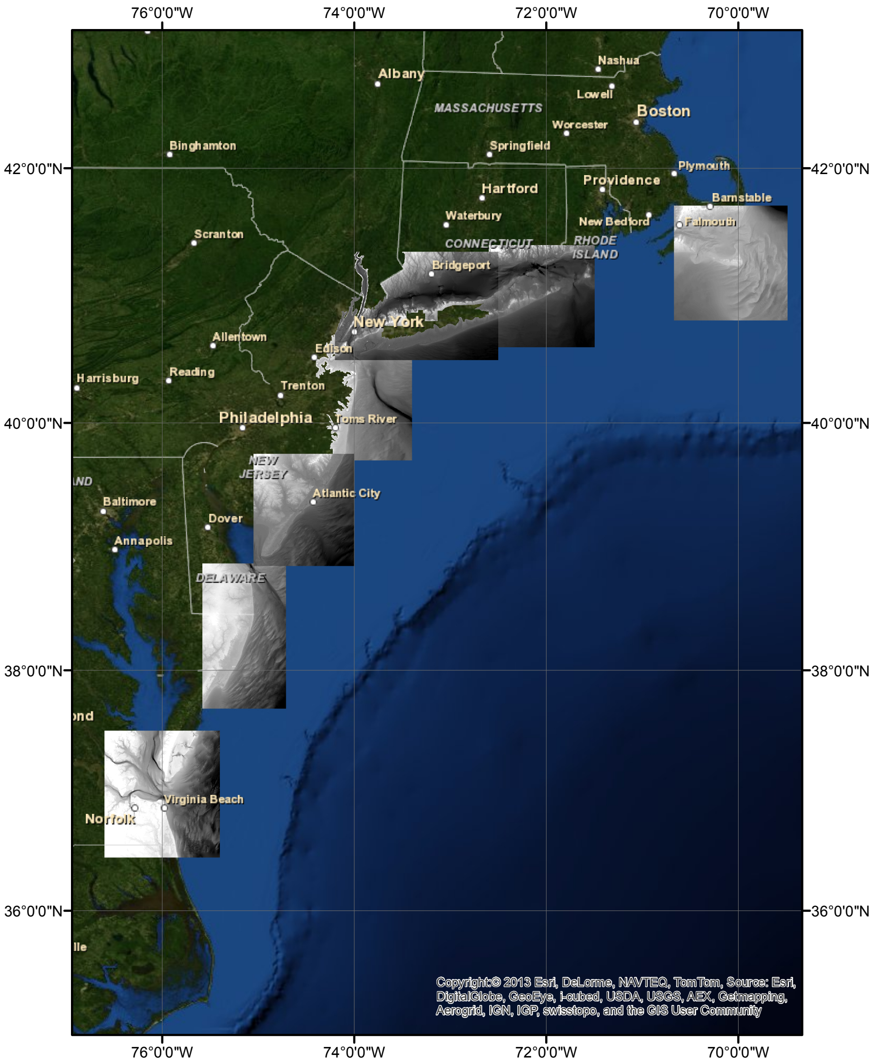
conclusions

Our simulations show that the submarine landslides along Western Great Bahama Bank have the potential to create hazardous tsunami waves.
First order predictions show local wave crests can build up to 26 m height for a worst-case scenario and result in a 6 m run-up on the coastline.
The shallow waves dissipate quickly during propagation through the ocean. More conservative estimates result in 5 m crest height and 1 m run-up.
However, the fast moving run-up can create dangerous currents in surf zone, inlets, and river entrances.
The governing factor for a disastrous event is the terminal velocity of the landslide and the duration of the slide event (fig. 6&7).
An over 80 km extending incipient scar indicates a large-scale failure in the near future.
These are low probability but high impact events.

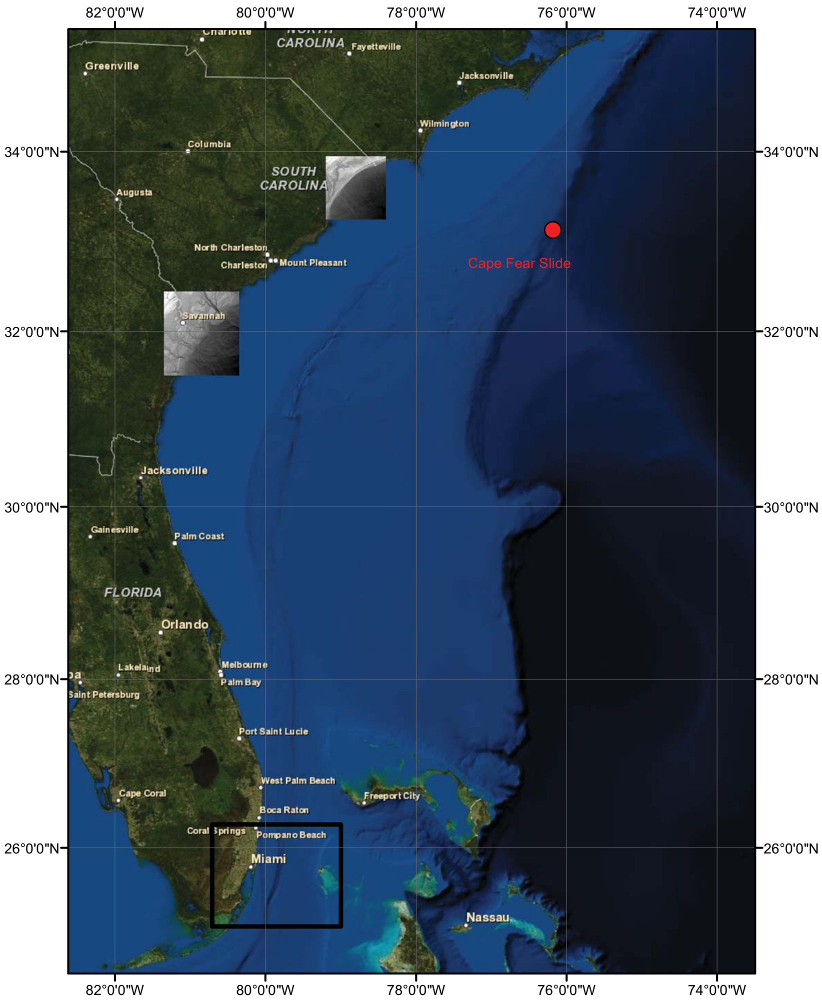
references

Ma, Gangfeng, Fengyan Shi, and James T. Kirby. "Shock-capturing non-hydrostatic model for fully dispersive surface wave processes." Ocean Modelling 43 (2012): 22-35.
Mulder, T., E. Ducassou, G. P. Eberli, V. Hanquiez, E. Gonthier, P. Kindler, M. Principaud et al. "New insights into the morphology and sedimentary processes along the western slope of Great Bahama Bank." Geology 40, no. 7 (2012): 603-606.
Shi, Fengyan, James T. Kirby, Jeffrey C. Harris, Joseph D. Geiman, and Stephan T. Grilli. "A high-order adaptive time-stepping TVD solver for Boussinesq modeling of breaking waves and coastal inundation." Ocean Modelling 43 (2012): 36-51.

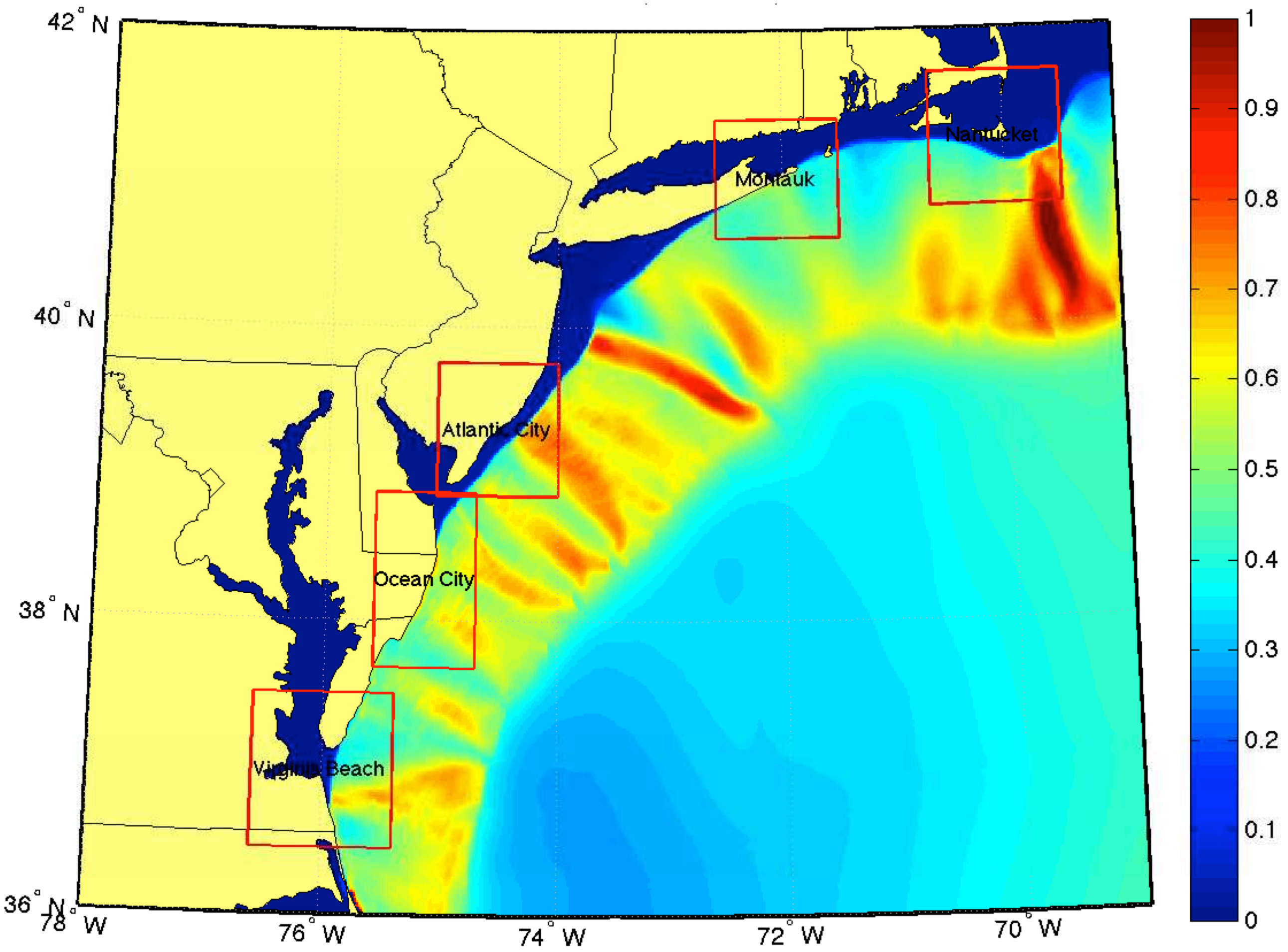
FY10-12 and FY 13 DEM coverage



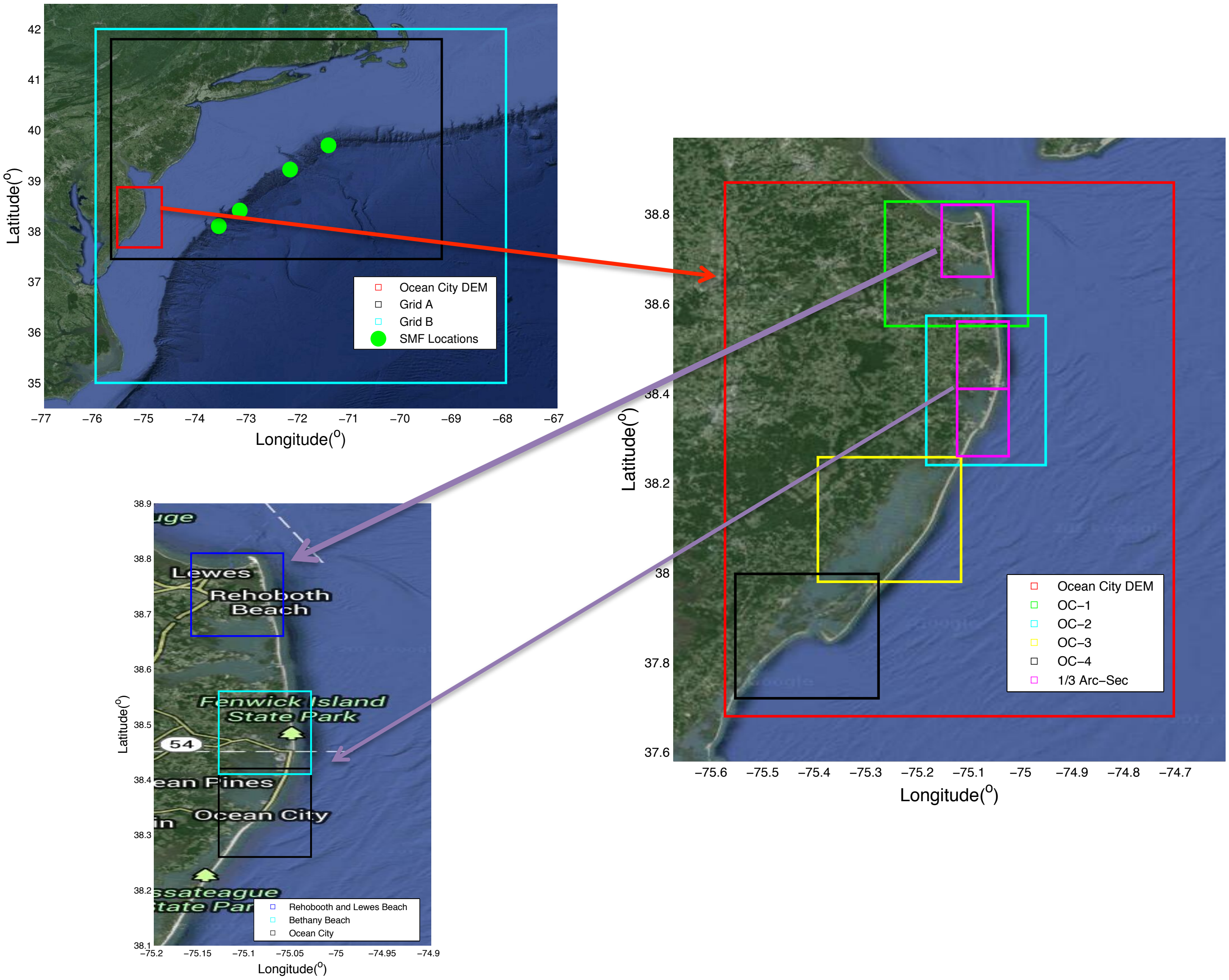
Copyright:© 2013 Esri, DeLorme, NAVTEQ, TomTom, Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



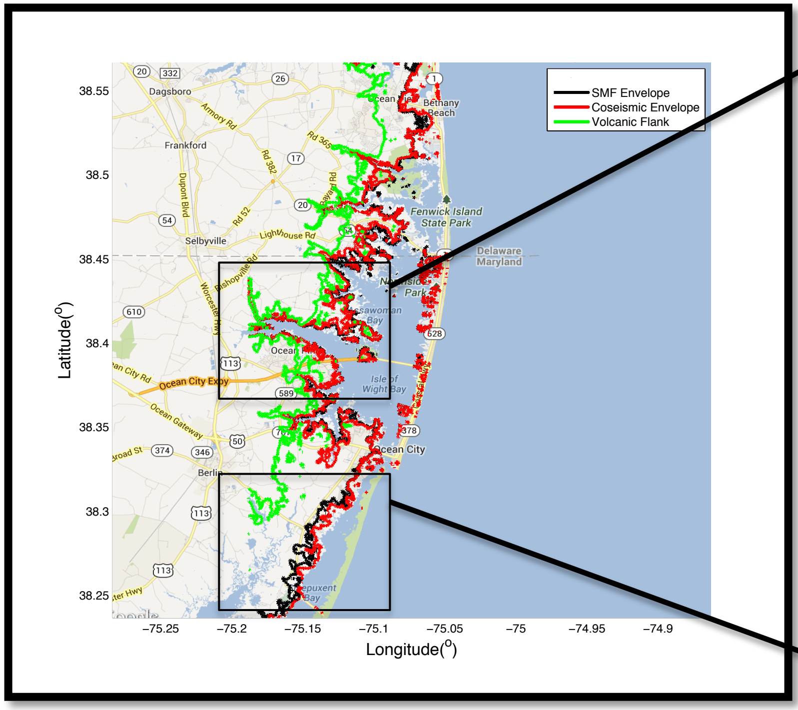
Strong bathymetric control of wave height distribution by outer shelf edge geometry and shelf depth variations

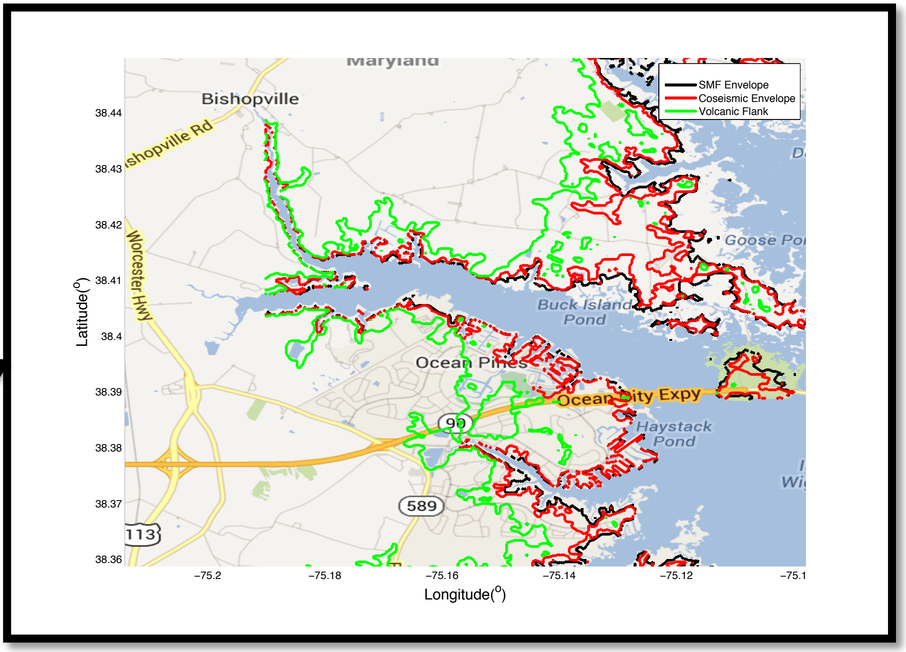


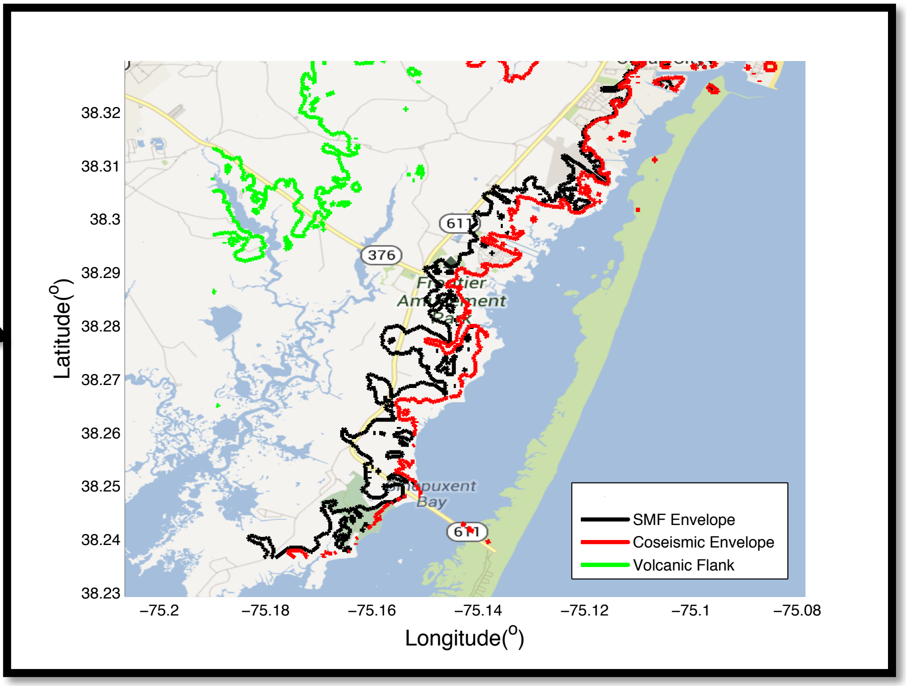
Grid nesting from ocean to DEM and DEM to local 1 arc second



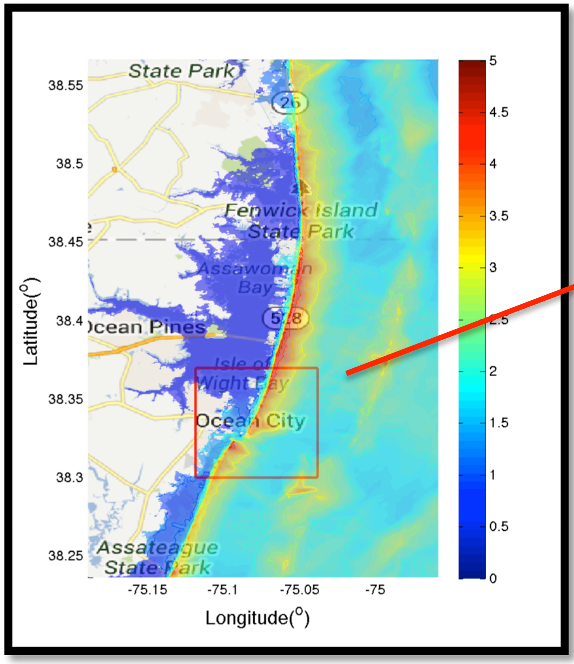
Inundation Lines

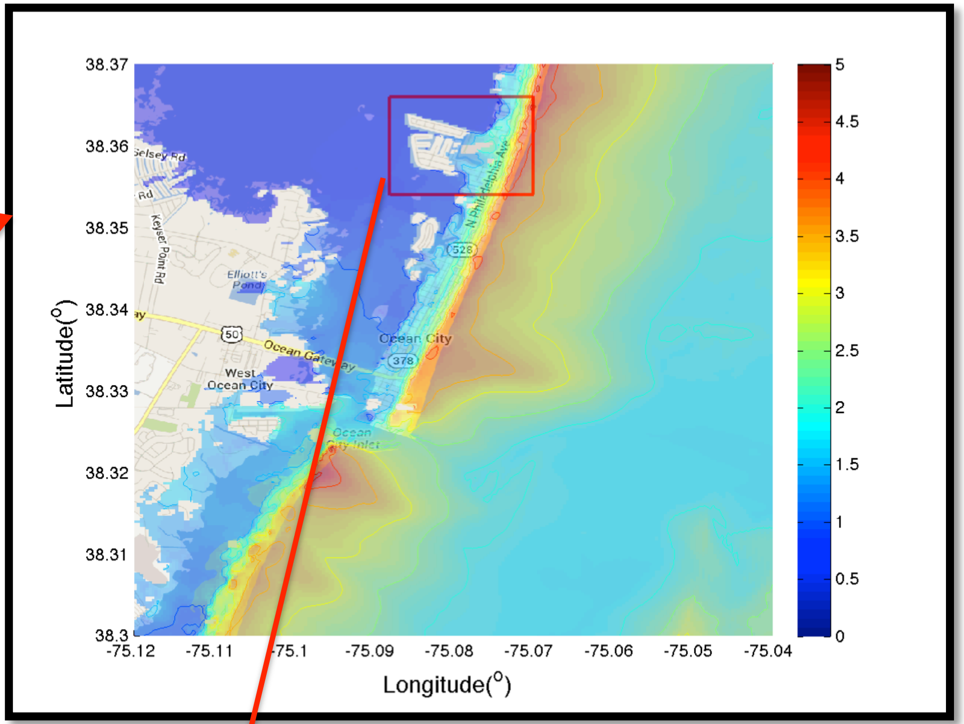




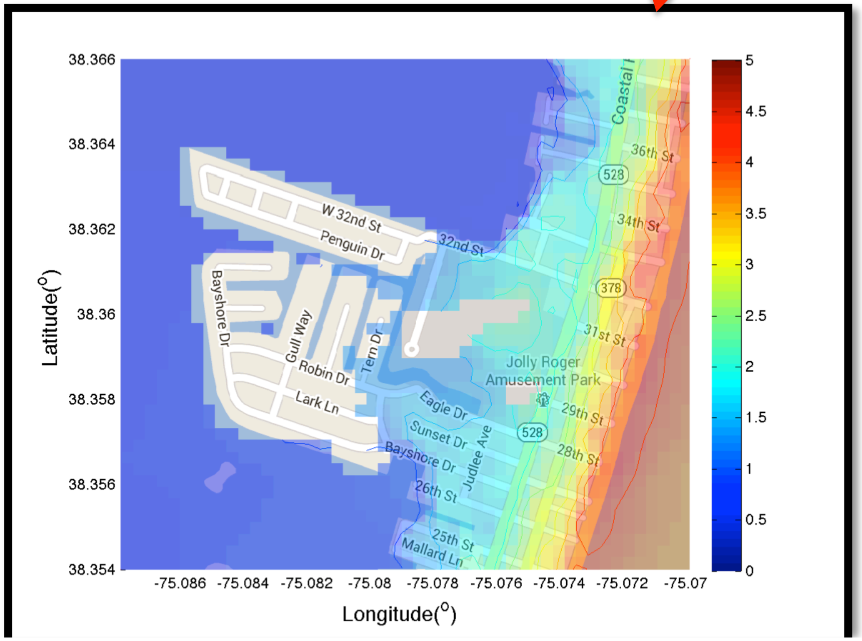


Lines shown here for individual event categories: CVV, coseismic and east coast SMF

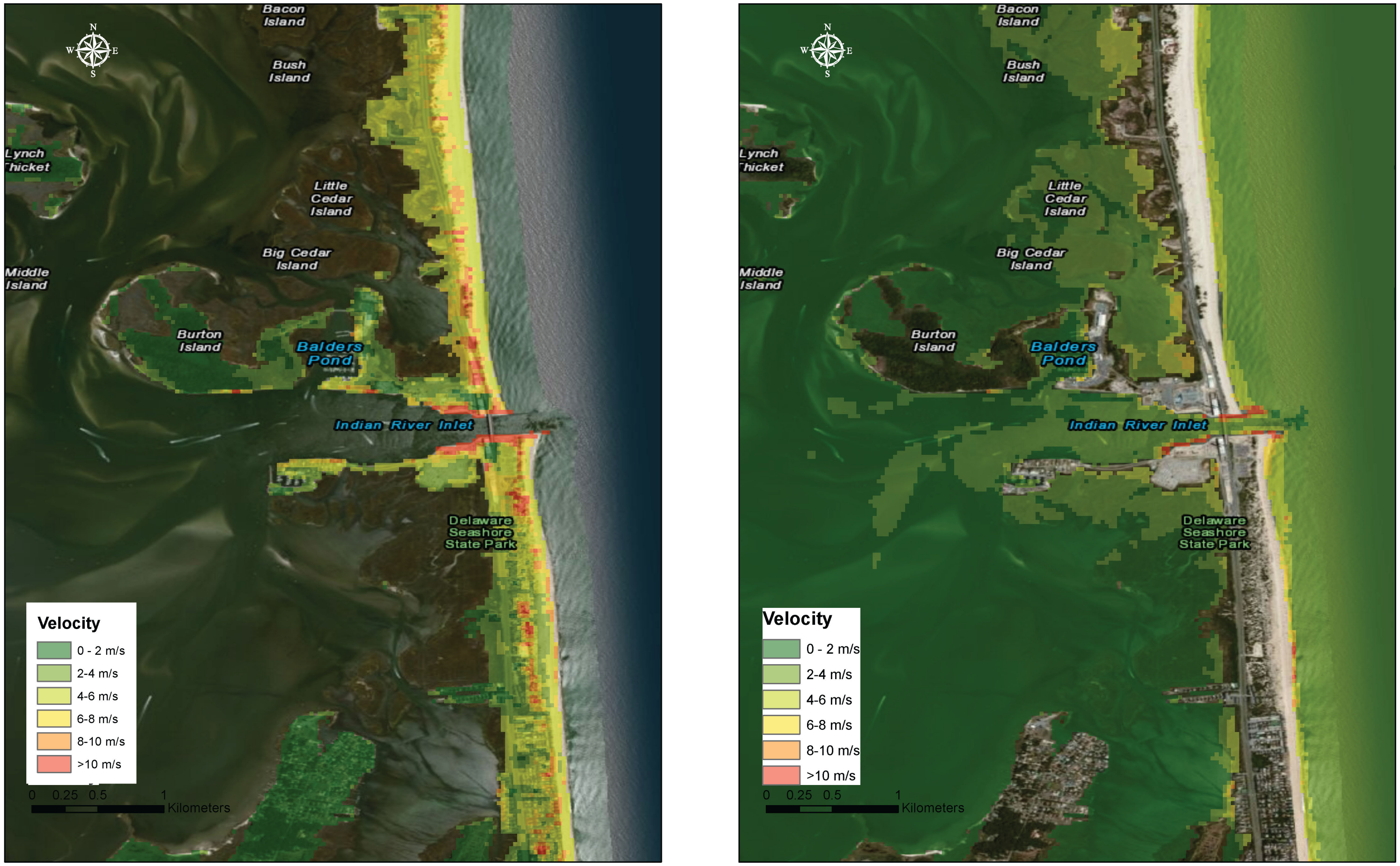




Inundation depths



Maximum occurring velocities



(a)

“Dry” areas

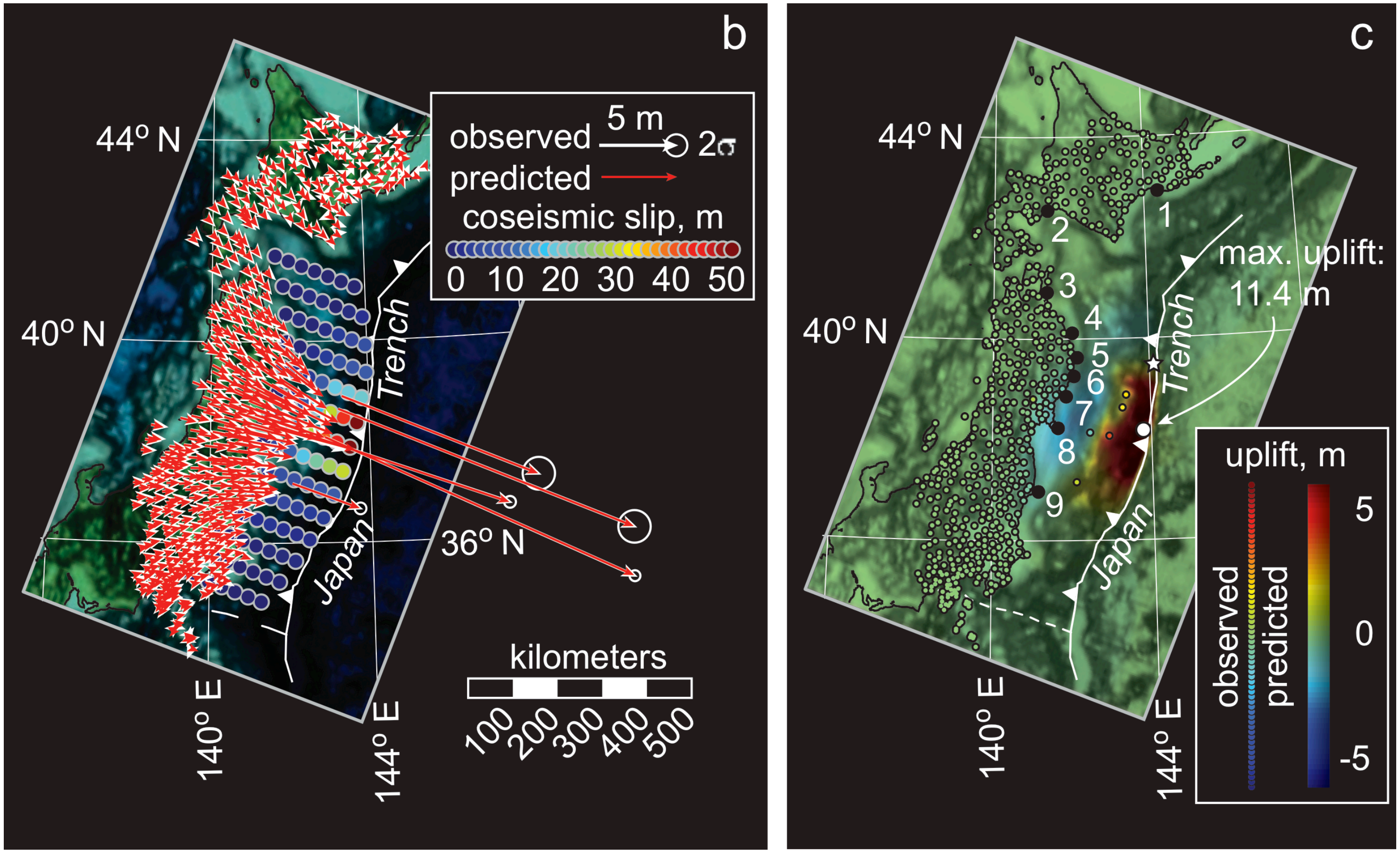
(b)

“Wet” areas

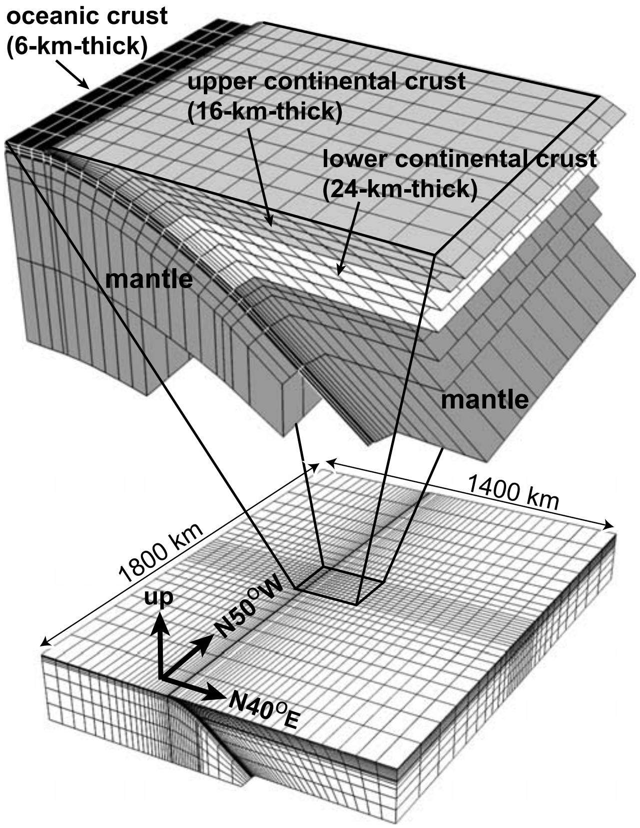
Outline

- Discussion of models employed
- Review NTHMP East Coast USA Effort
- SMF’s as (potentially important) parts of large tsunami events.

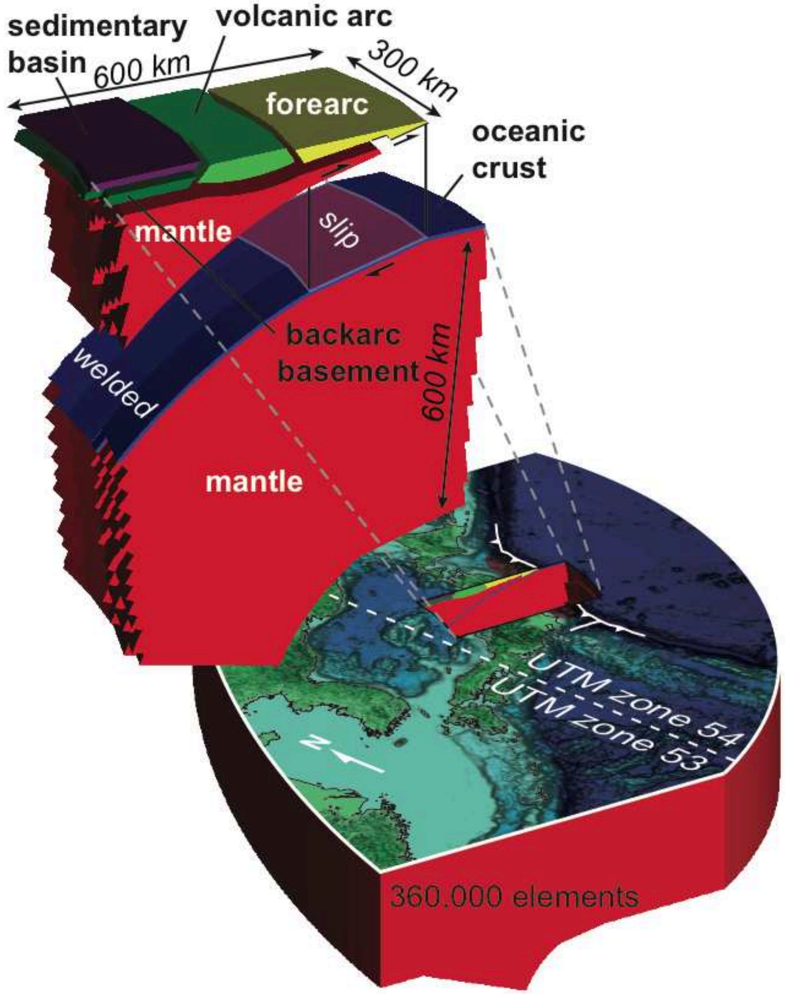
Tohoku (2011) event: Coseismic slip and deformation. a) slip and horizontal deformation. b) Vertical deformation.



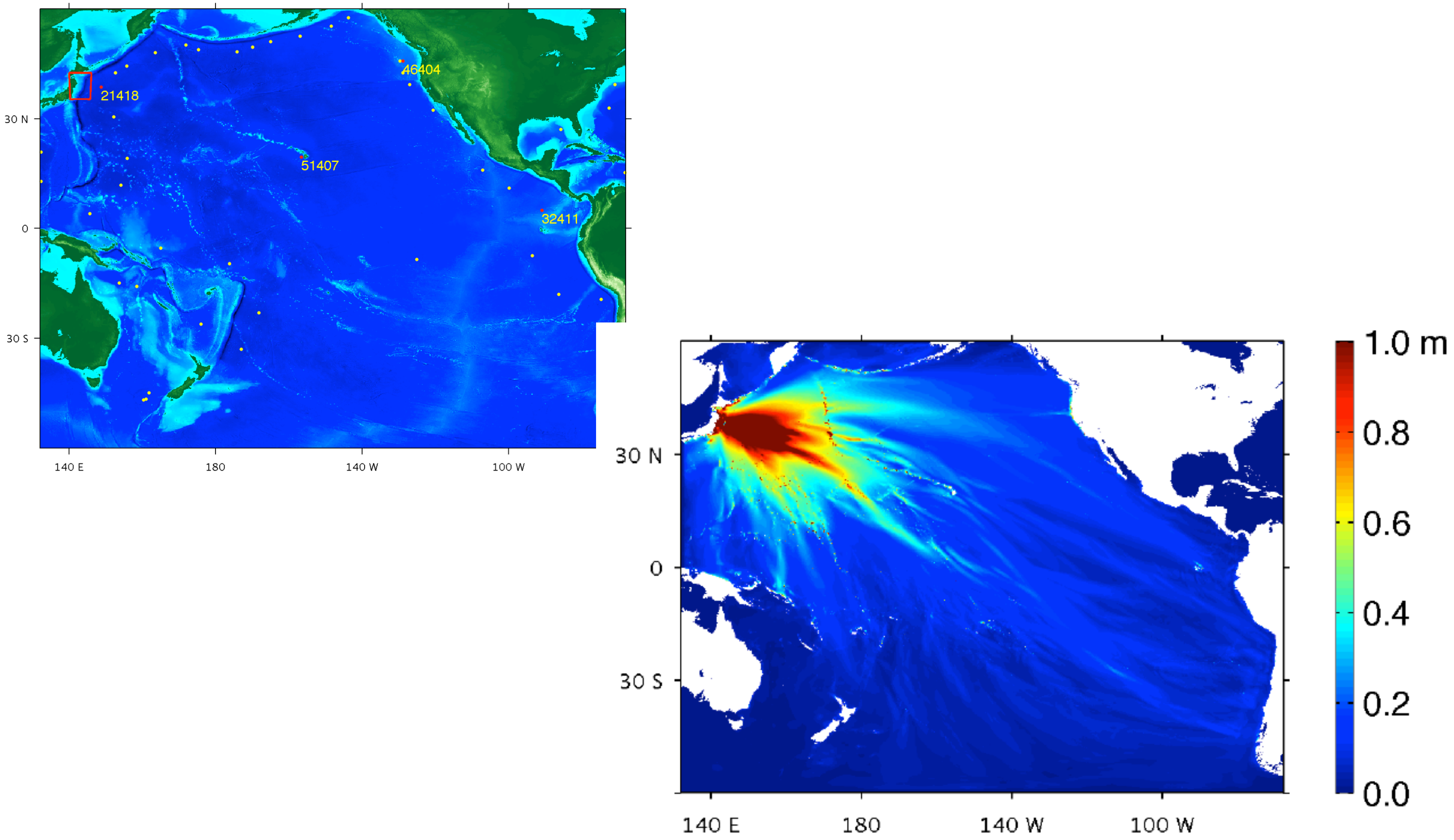
Finite Element model of deforming forearc, oceanic crust and mantle, accounting for variations in material properties (Masterlark, JGR 2003). Source based on seismic and GPS data inversion.



FEM model configuration (Masterlark, JGR 2003)



Example: Maximum far field wave heights for Tohoku event



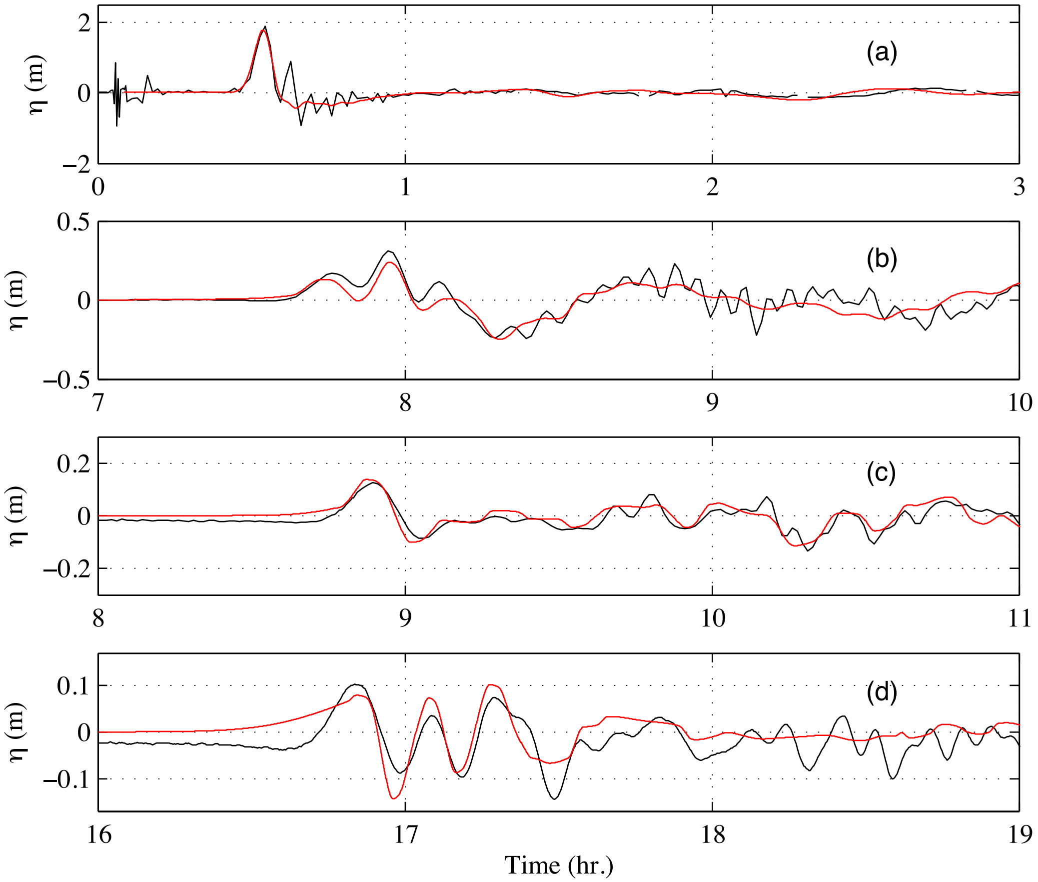
Farfield results (Kirby et al, 2013). Observed (black), modeled (red)

DART 21418 (Japan)

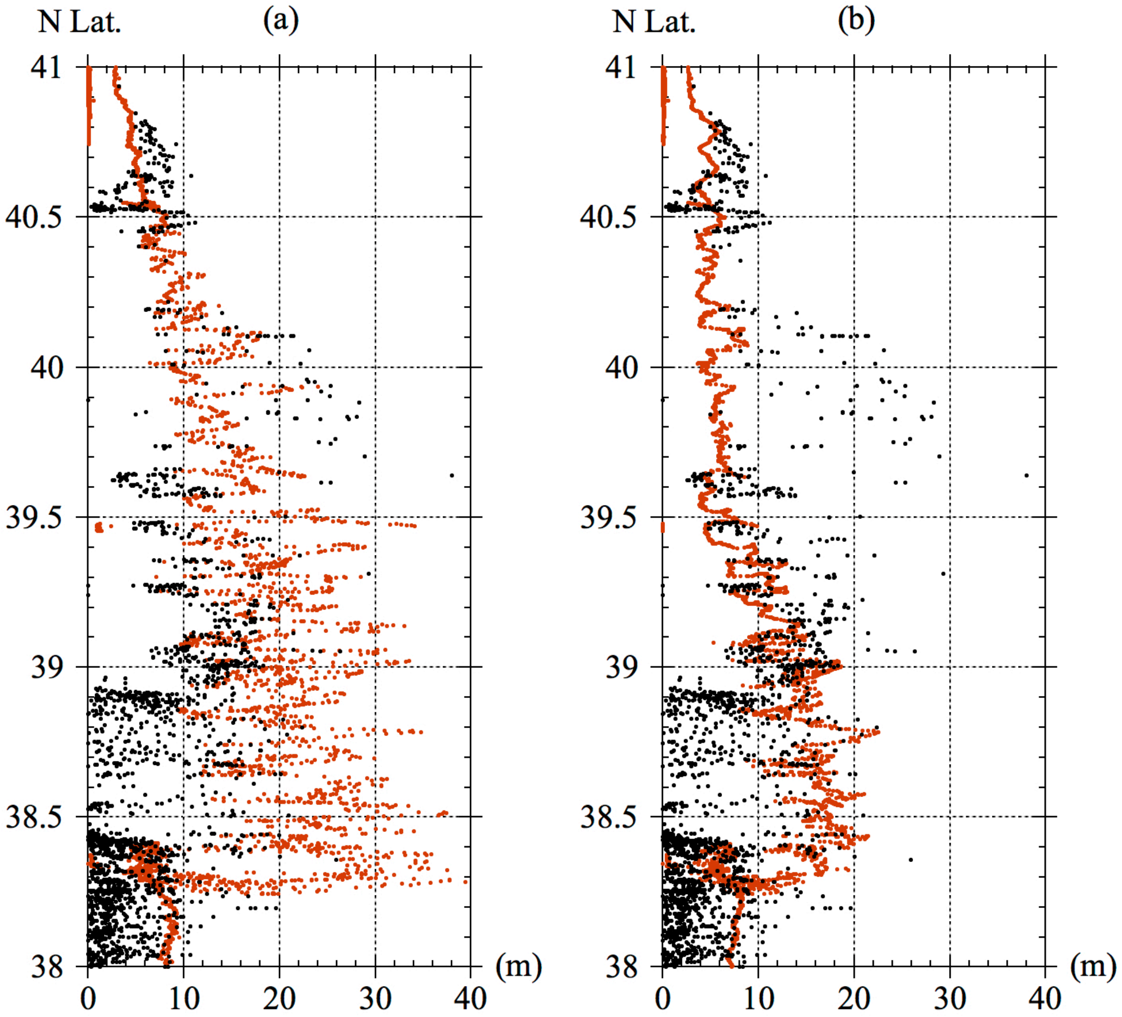
DART 51407 (Hawaii)

DART 46404 (Oregon)

DART 32411 (Panama)



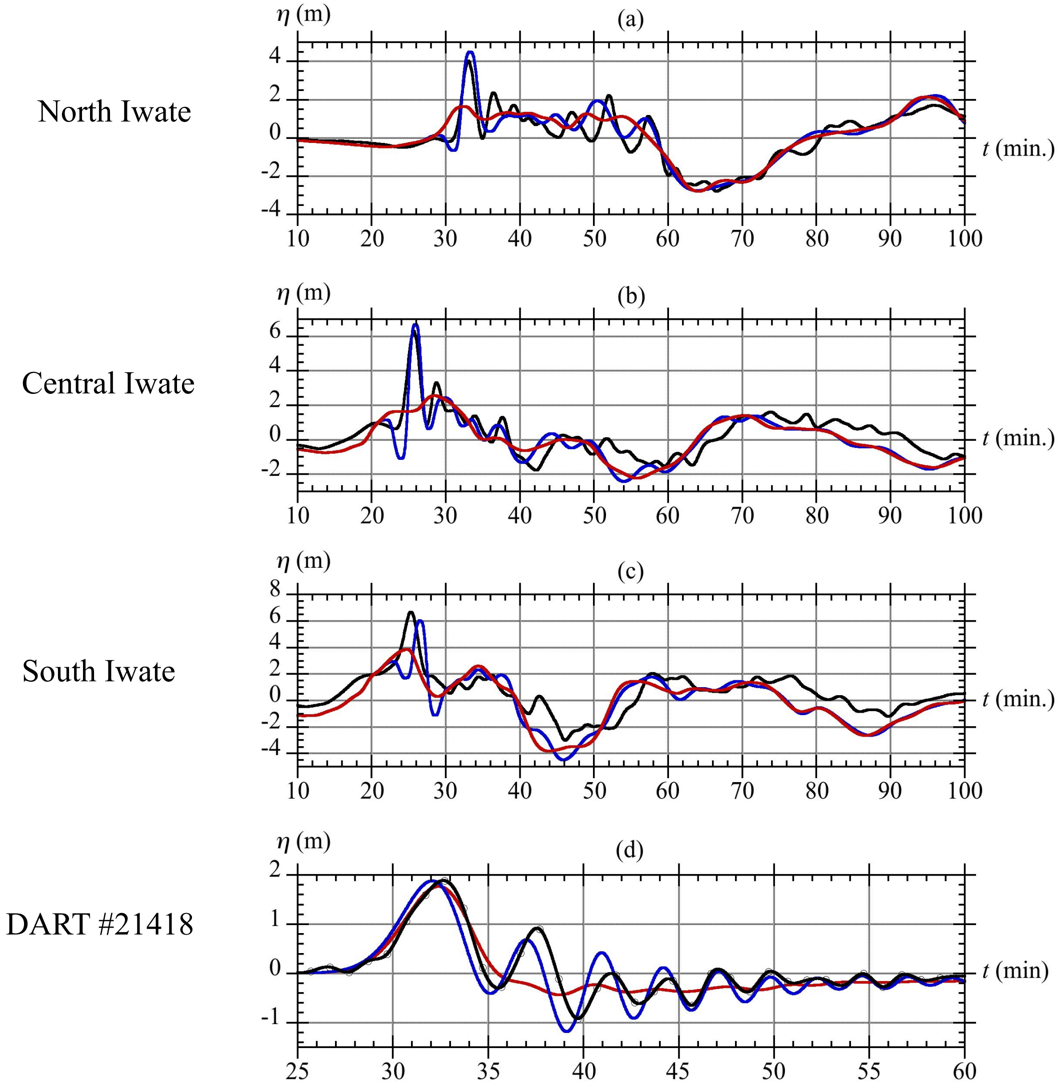
Model (red) vs. measured (black) inundation: Sanriku coast

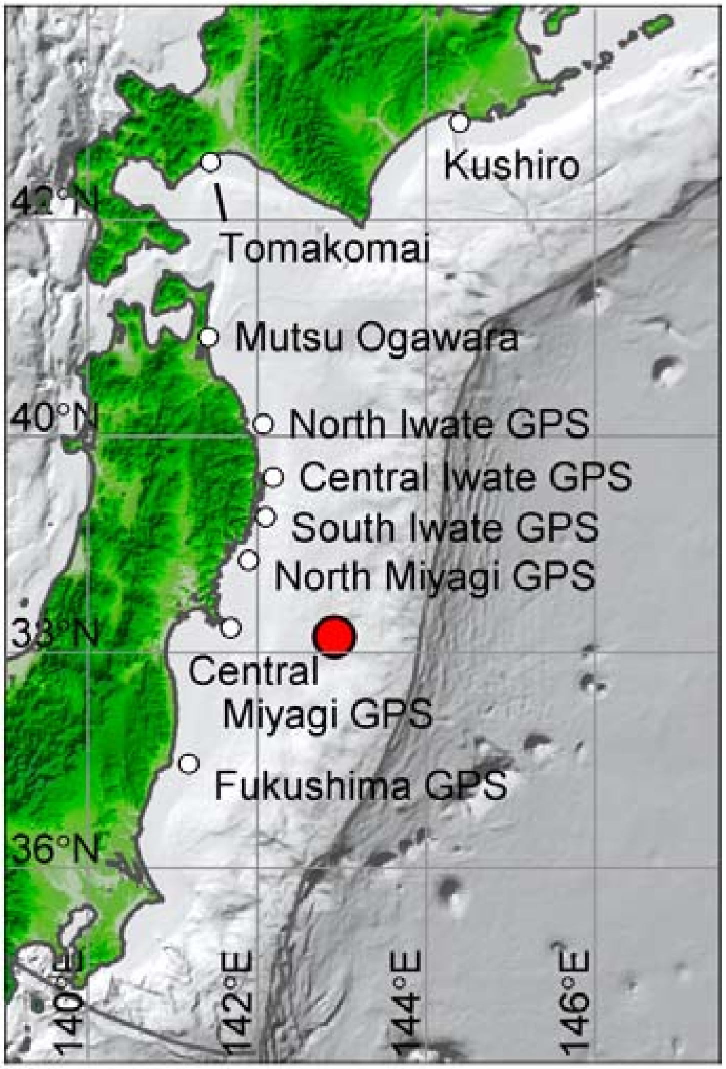


a) UCSB source

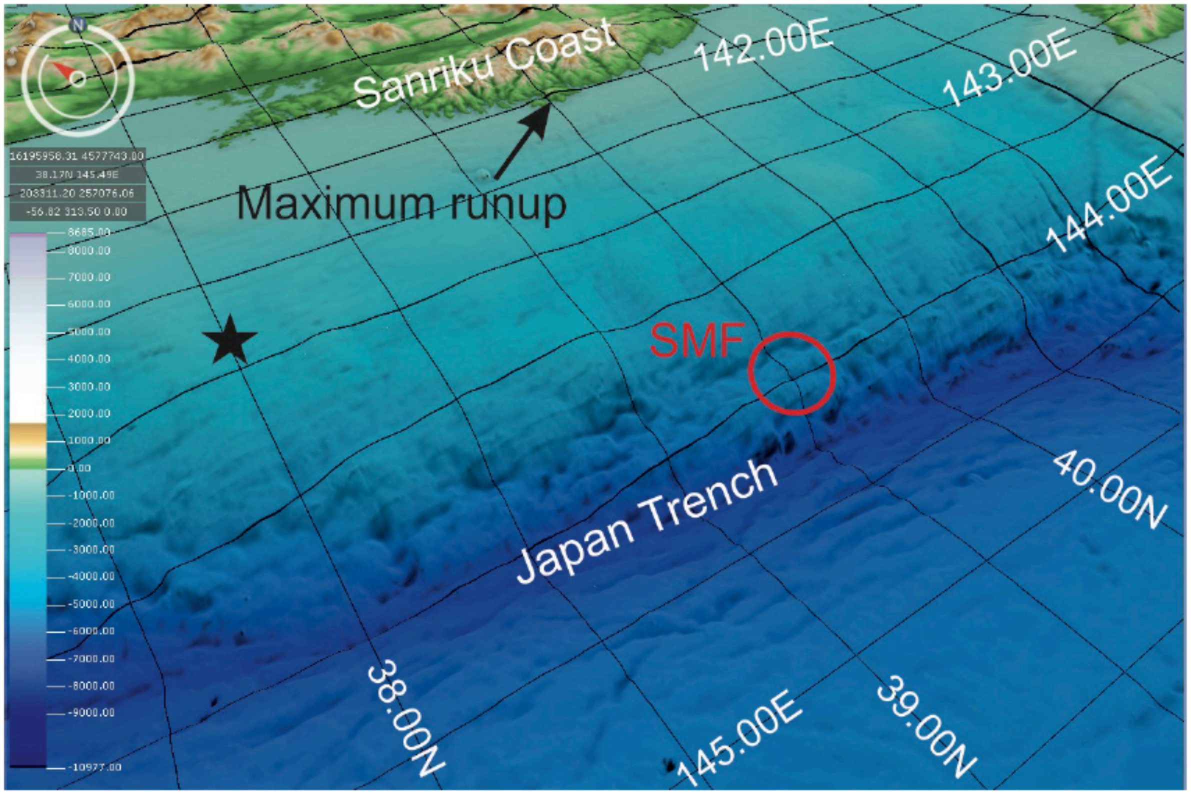
b) UA source

Response at GPS and DART buoys: black (measured), red (UA - seismic + GPS), blue (UA + slump)



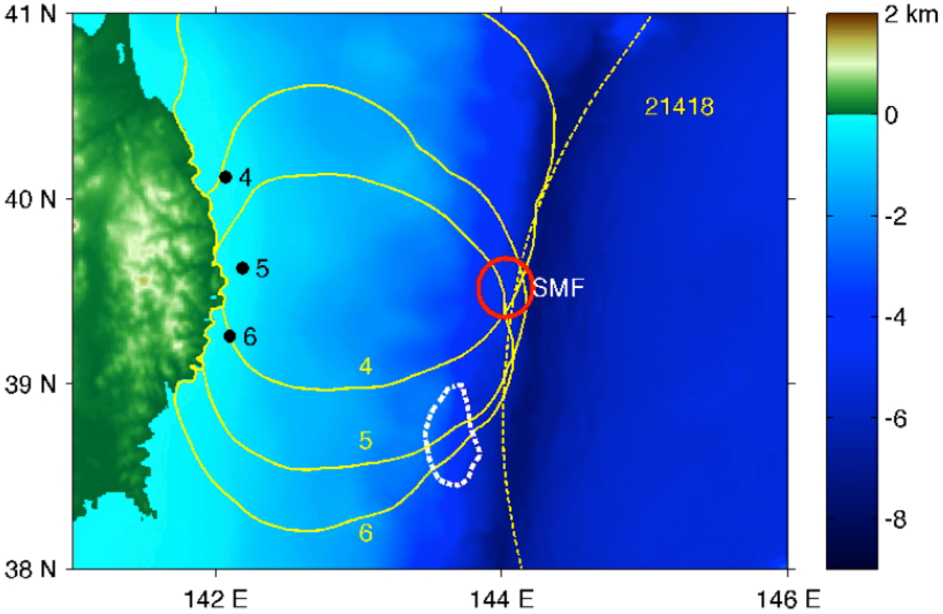


A plausibly more complete answer?

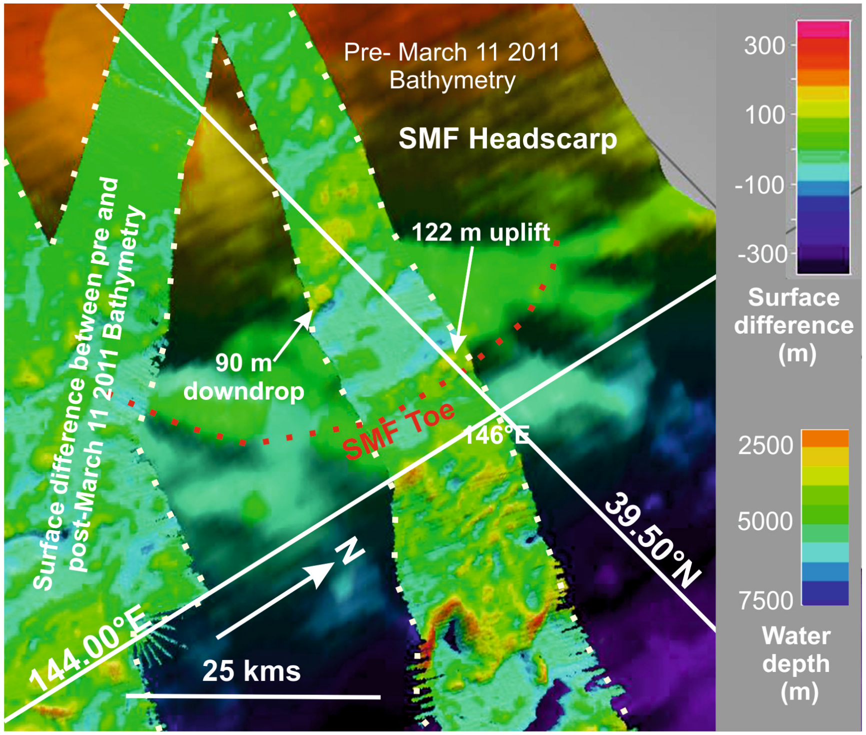


Bathymetry along trench boundary suggests history of mass-wasting events. Several prior events have been attributed to possible landslides. (Sanriku 1896; Kanamori and Kikuchi, 1993)

Constraining the SMF location based on travel time analysis



Survey evidence for significant vertical displacement in source region



a) Inundation and b) runup along Japanese coast. Measured (black), UA (red), UA+slump (blue)