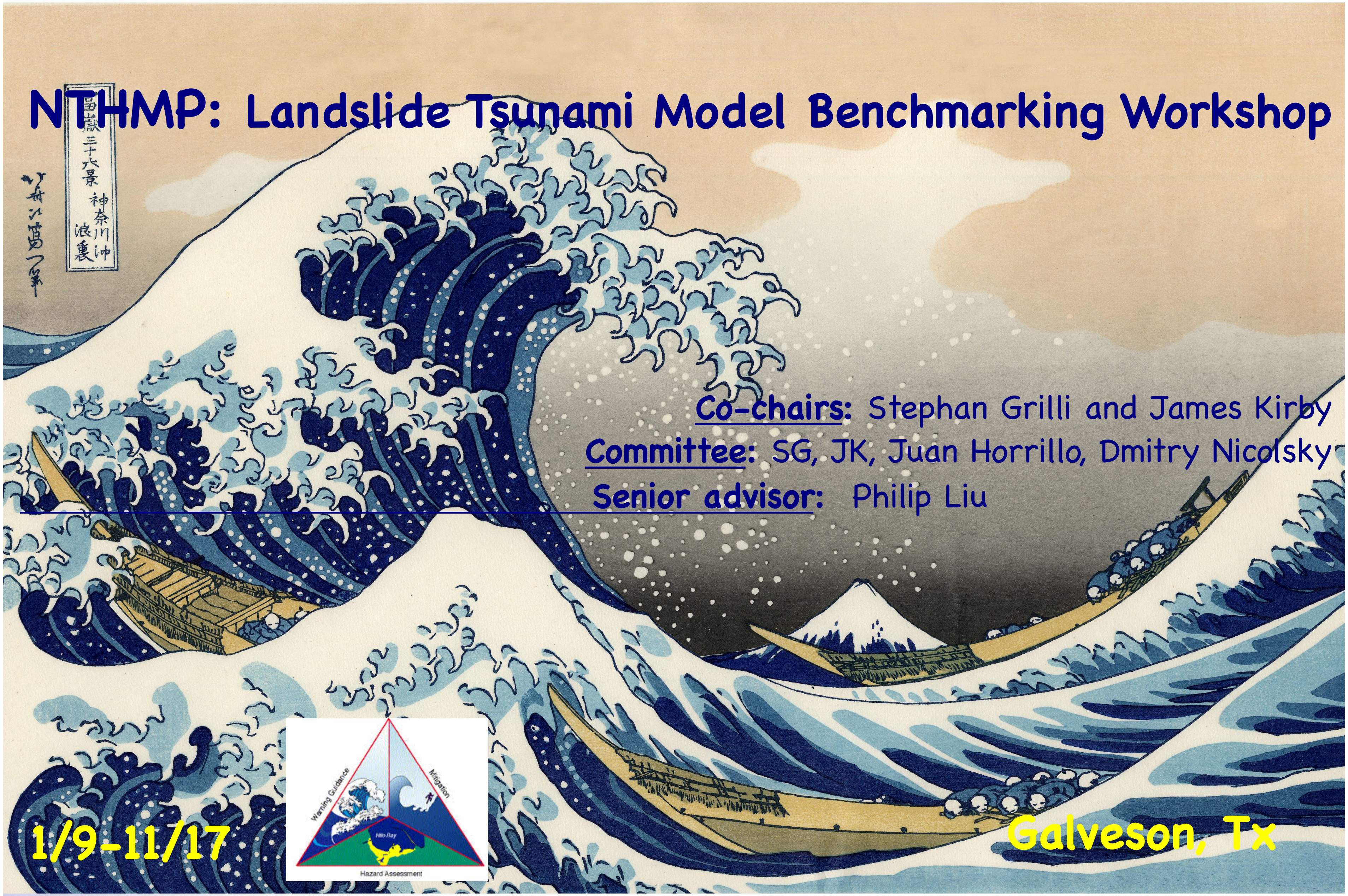
NTHMP: Landslide Tsunami Model Benchmarking Workshop

Co-chairs: Stephan Grilli and James Kirby

Committee: SG, JK, Juan Horrillo, Dmitry Nicolsky

Senior advisor: Philip Liu



1/9-11/17

Galveson, Tx

US Context and Rationale

- National Tsunami Hazard Mitigation Program (NTHMP) :

-> Congress tasked NOAA in 1995 to "form a working group to develop a plan for reducing tsunami risk to U.S. coastal communities".

-> Following the 2004 IO tsunami, congress passed TWEA (Tsunami Warning and Education Act) "to improve tsunami preparedness of at-risk areas in the United States and its territories."

-> Today's NTHMP includes NOAA, FEMA, USGS, and 28 US states/territories

- NTHMP Mapping and Modeling Subcommittee (MMS) :

-> Guidance for producing consistent and accurate *tsunami inundation and evacuation zones*

-> Detailed *tsunami hazard assessments* for all U.S. coastlines and *inundation* maps for evacuation planning for high-risk communities => ***Model Benchmarking Activity***

-> Tsunami hazard guidance/products for maritime, land-use, and recovery planning

- Current EC-NTHMP inundation maps :

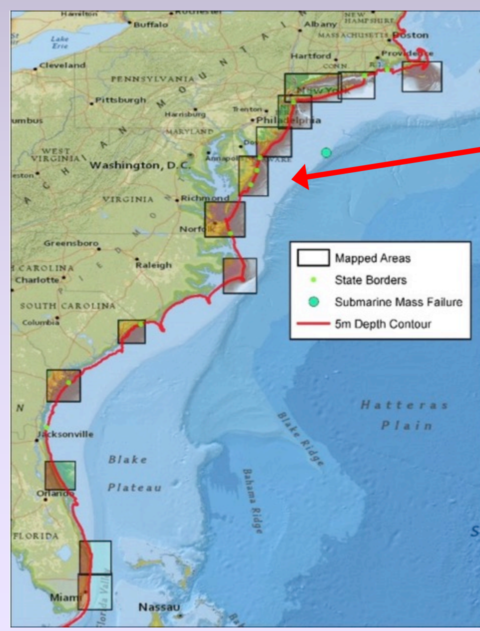
-> Inundation from *Probable Maximum Tsunami* (PMT) sources in Atlantic Ocean:

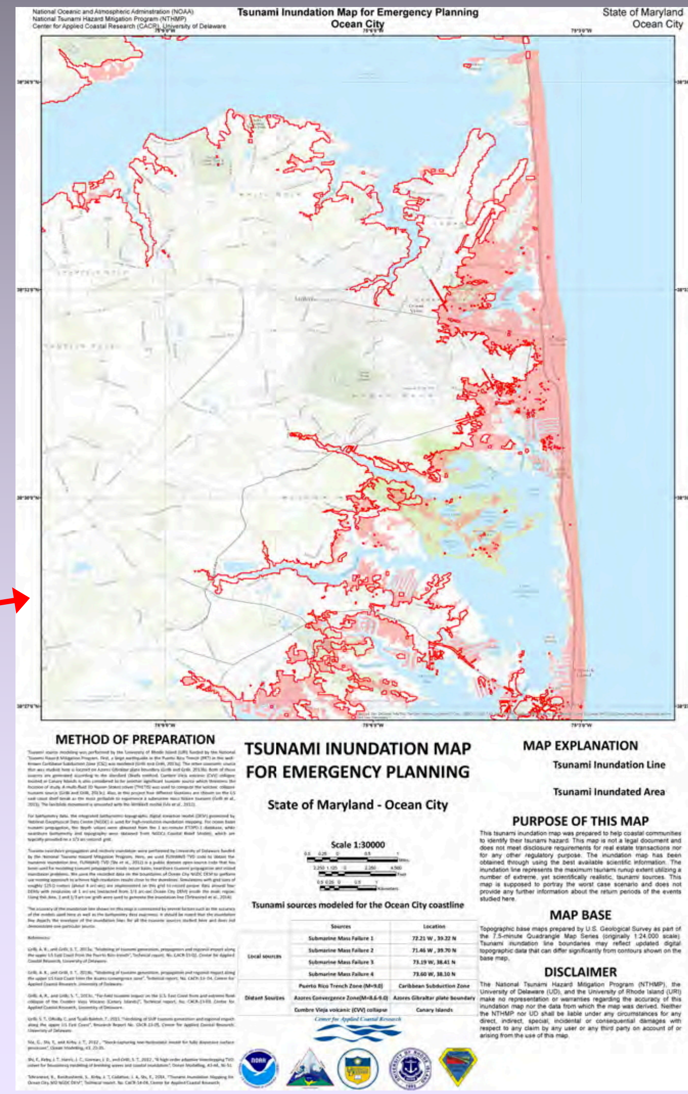
=> ***Volcanic collapse*** (La Palma CVV)

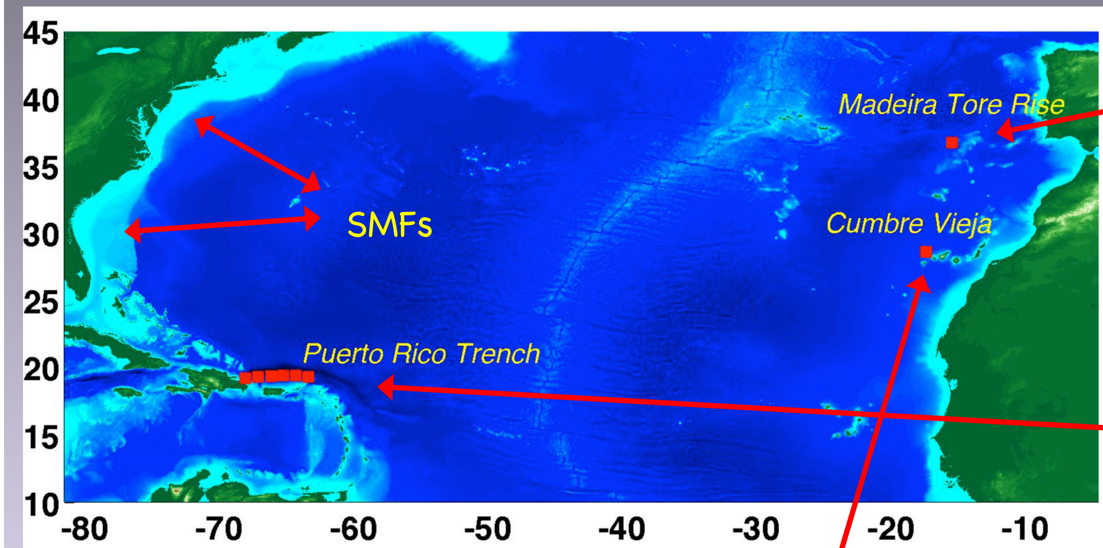
=> ***Submarine Mass Failures*** (SMFs; off the continental shelf)

=> ***Coseismic*** (LSB, PRT)

-> *Bare earth DEM,* no erosion







- Current EC-PMT sources

-> **LSB-M9** far-field *seismic source* : repeat of Lisbon 1755 [Barkan et al., 2008]

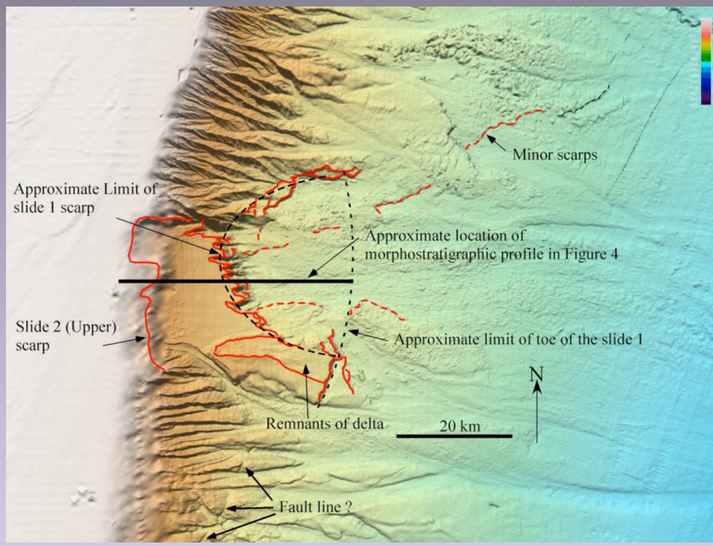
-> **PRT-M9** far-field *seismic source* in PRT: 600 x 150 km (12 SIFT sources; 12 m slip; 600 yr of full convergence)

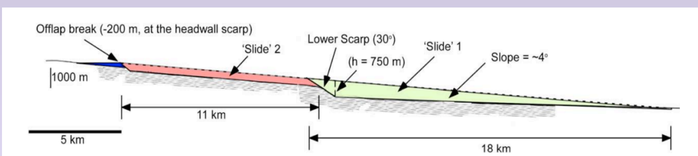
[Knight, 2006; Grilli et al., 2010; NHESS]

-> **CVV** Far-field *flank collapse* of CVV (80 to 450 km^3 volume; return period (?) perhaps 1,000-100,000 yrs.

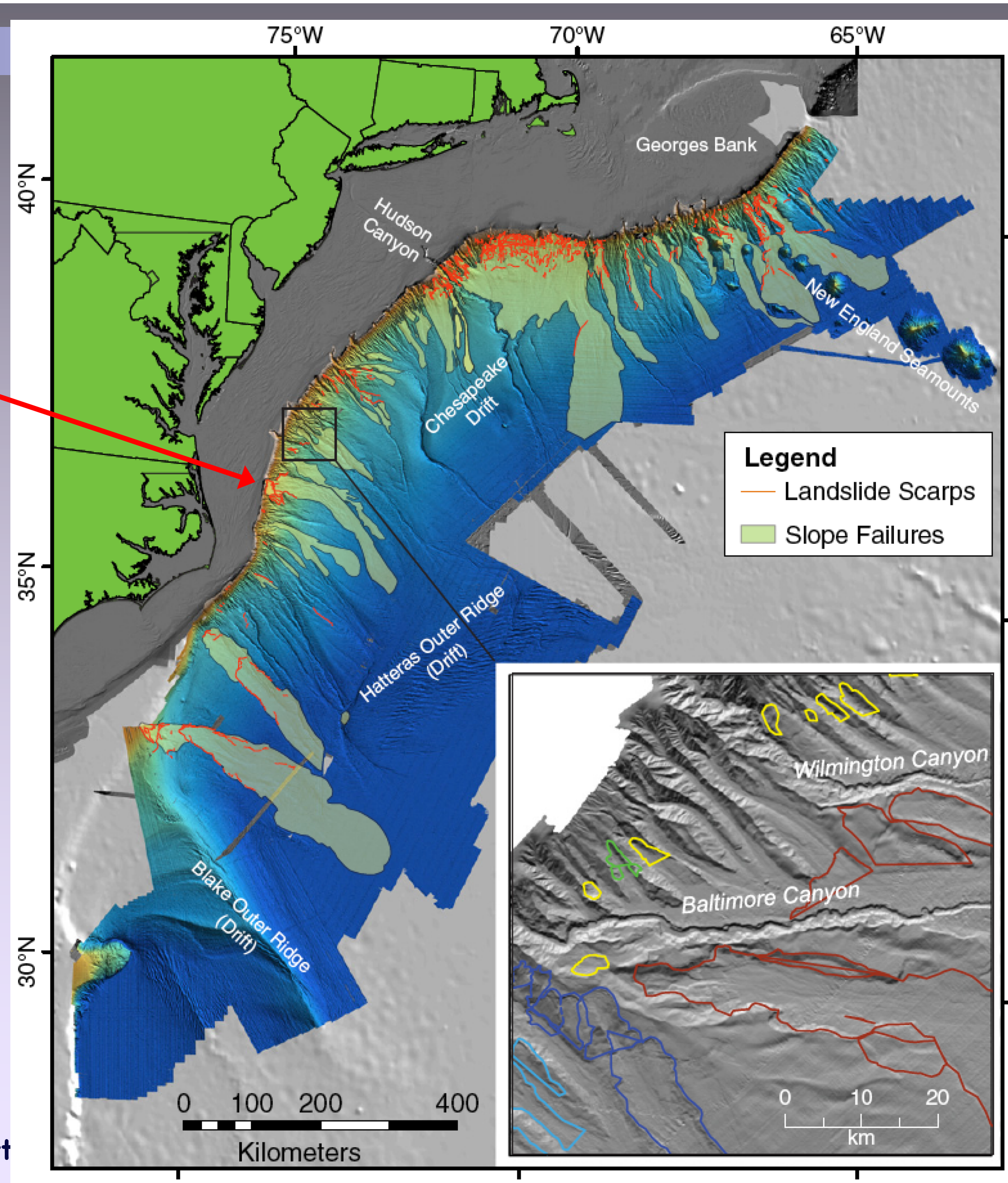
-> near-field **SMFs** on continental slope/margin: assumed to be rigid slumps with Currituck slide characteristics (***proxies***; 135 km^3 volume)

- EC near-field **SMFs**

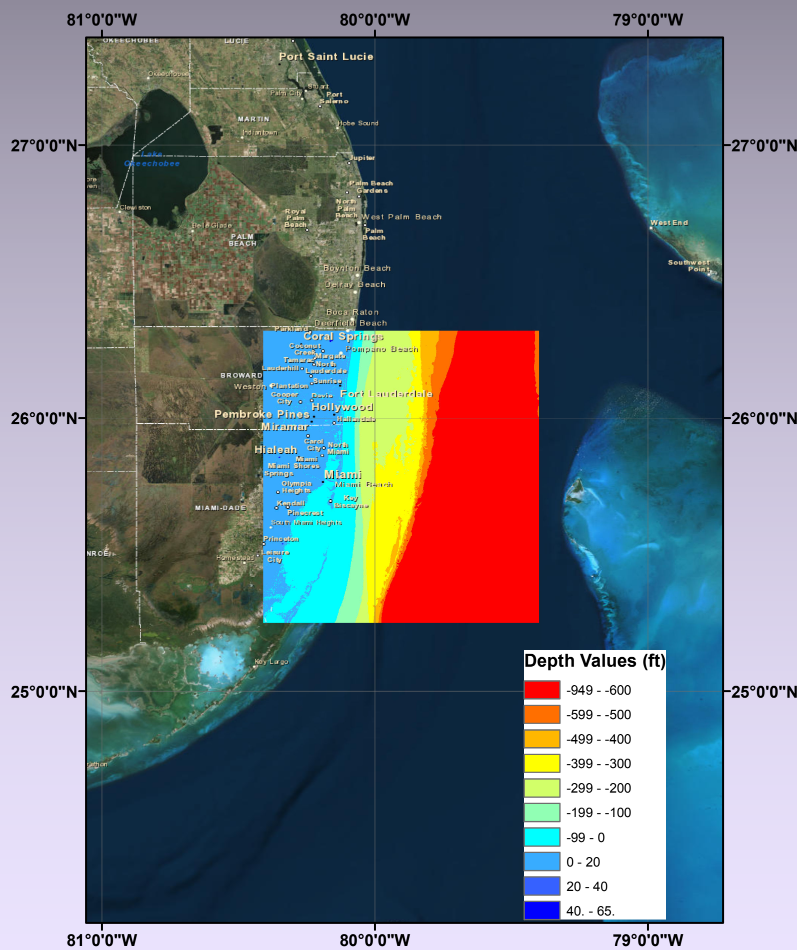


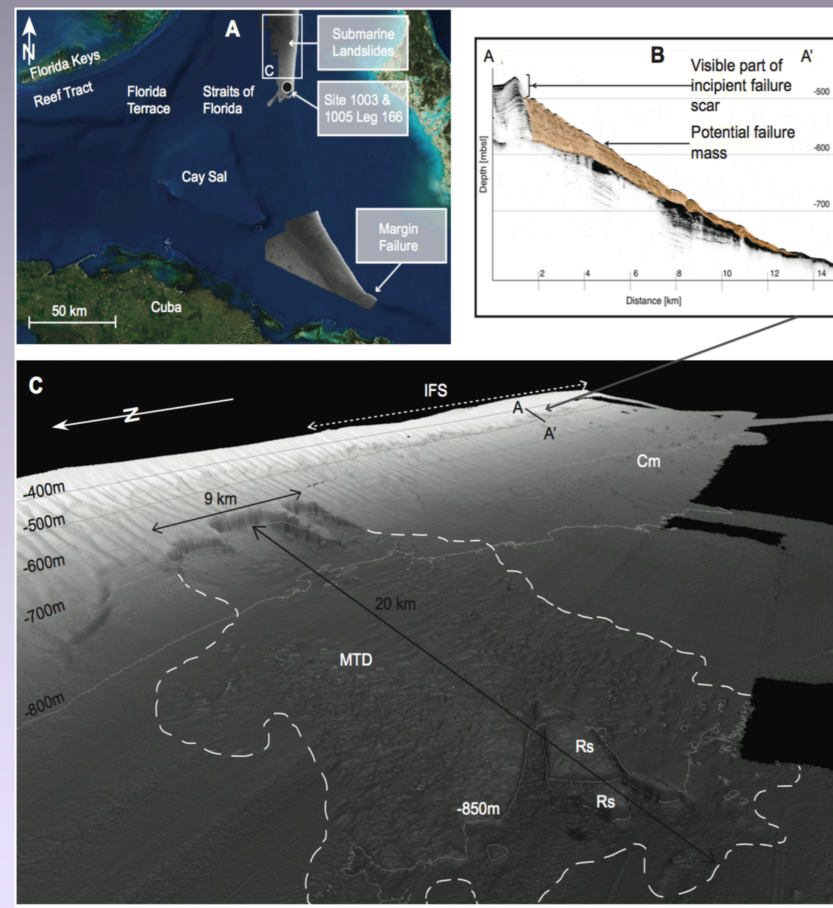


-> *Widespread SMF scarps*
[USGS; tenBrink et al., 2014]
-> *Curritcuk slide complex* (135-165 km^3) [Locat et al., 2009]



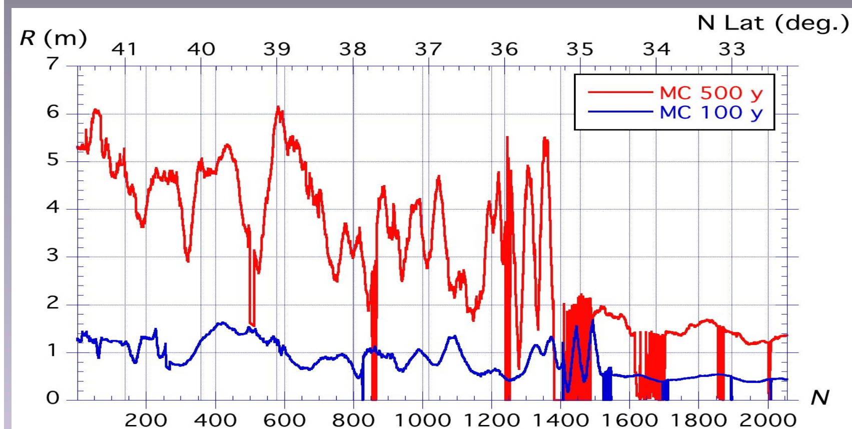
• Florida near-field **SMFs** (West Bahamas Banks)

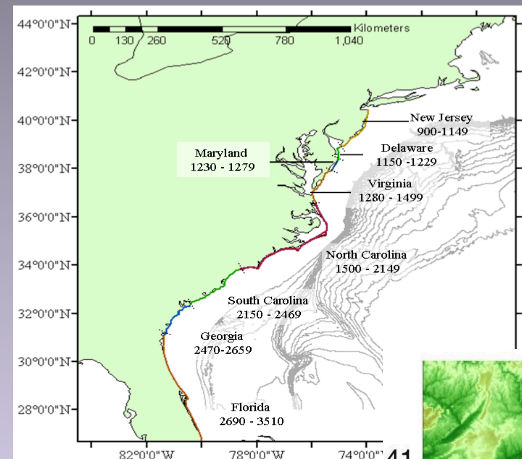


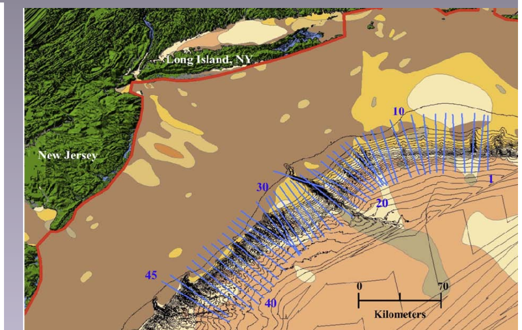


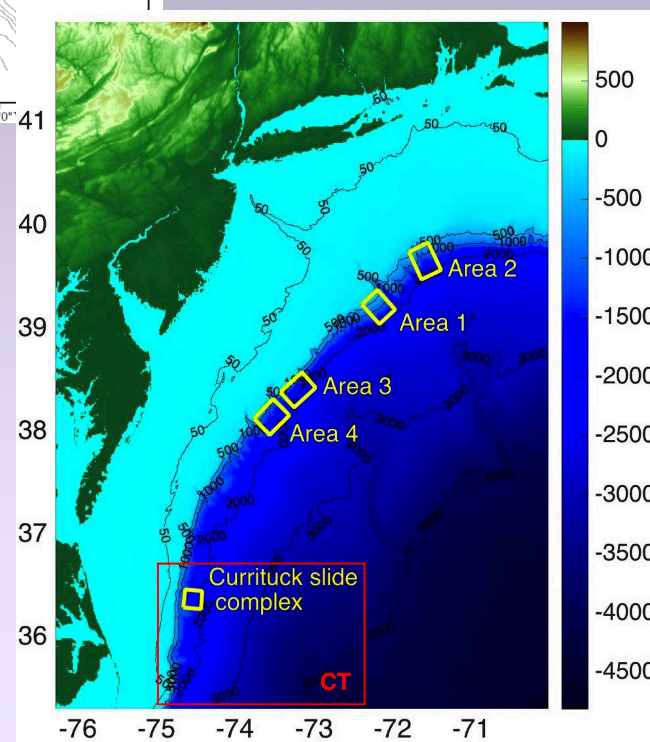
[Schnyder et al., 2016]

• EC SMFs siting and parameterizing









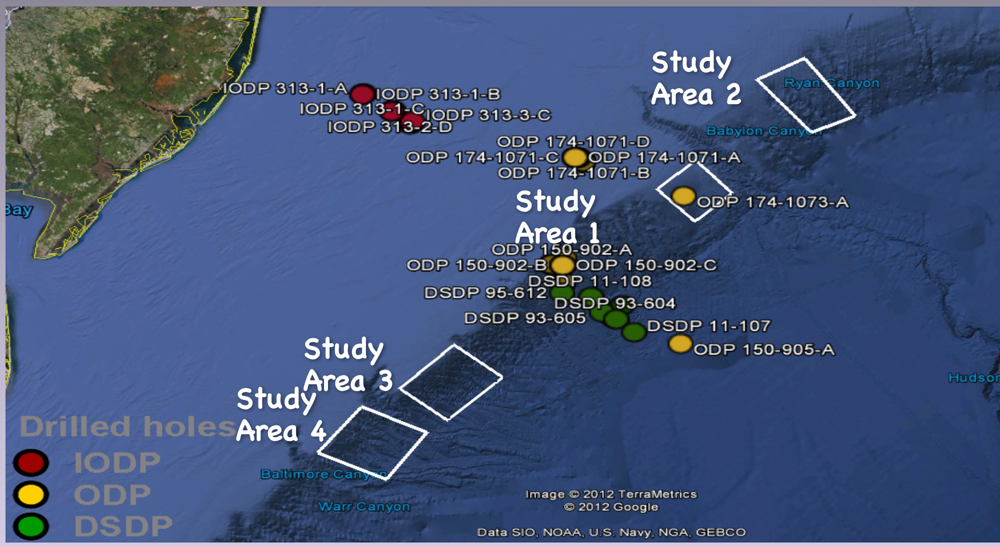
-> Monte Carlo slope stability analyses :
Along shore normal transects, for a simplified coastline (points numbered from N to S)
[Grilli et al., 2009, MG]

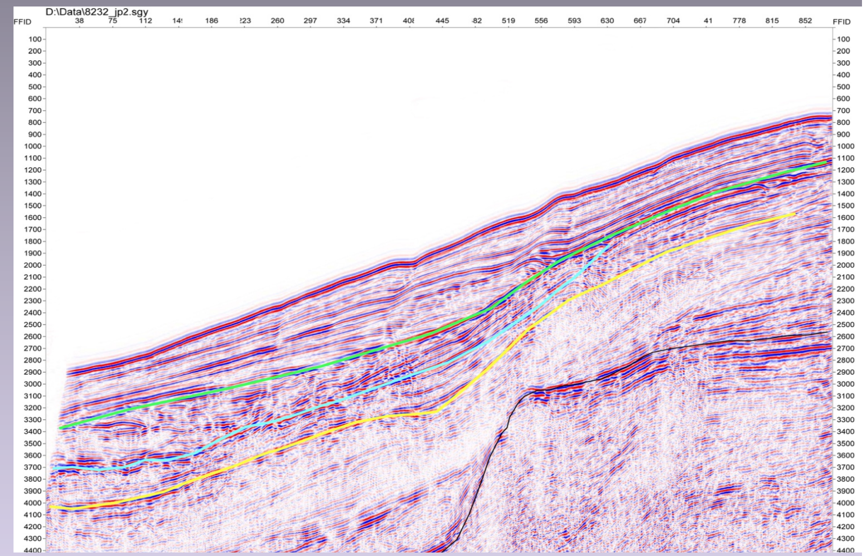
=> areas of large landslide tsunami runup

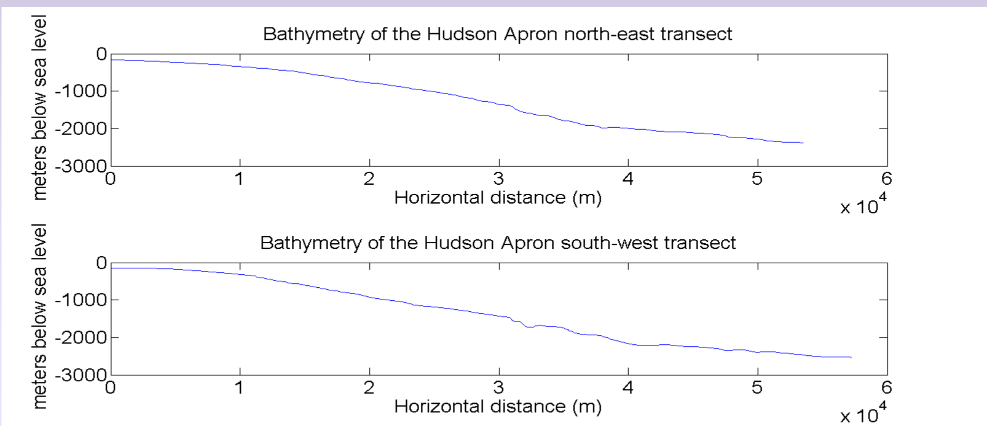
-> Sediment availability/geology :
[Grilli et al. 2015, NH]

=> **Areas 1-4 for** siting Currituck SMF proxies

- Locations of boreholes and some available data for upper EC



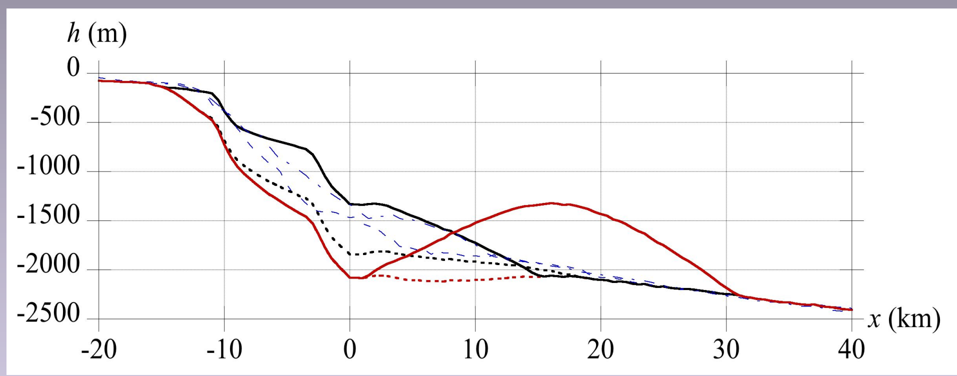




-> SMF siting and parameters :
Must be based on/informed by *bathymetry and sub-bottom data* => need for ***marine geology and geotechnics***

- Currituck SMF proxies :

-> idealized geometry and kinematics for rigid slump modeling



$$\zeta(\xi,\chi) = \frac{T}{1-\varepsilon}\max\left[0,\ \operatorname{sech}(k_b\xi)\operatorname{sech}(k_w\chi)-\varepsilon\right]$$

$$k_b = \frac{2}{b}\operatorname{acosh}\frac{1}{\varepsilon}$$

$$k_w = \frac{2}{w}\operatorname{acosh}\frac{1}{\varepsilon}$$

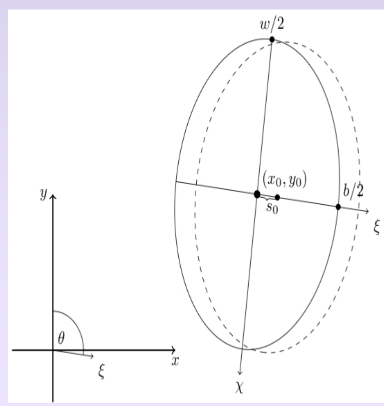
$$s(t) = \begin{cases} 0 & t < t_i \\ s_0\left(1-\cos\left\{\dfrac{t-t_i}{t_0}\right\}\right) & t_i \le t < t_i + \pi t_0 \\ 2s_0 & t_i + \pi t_0 \le t \end{cases}$$

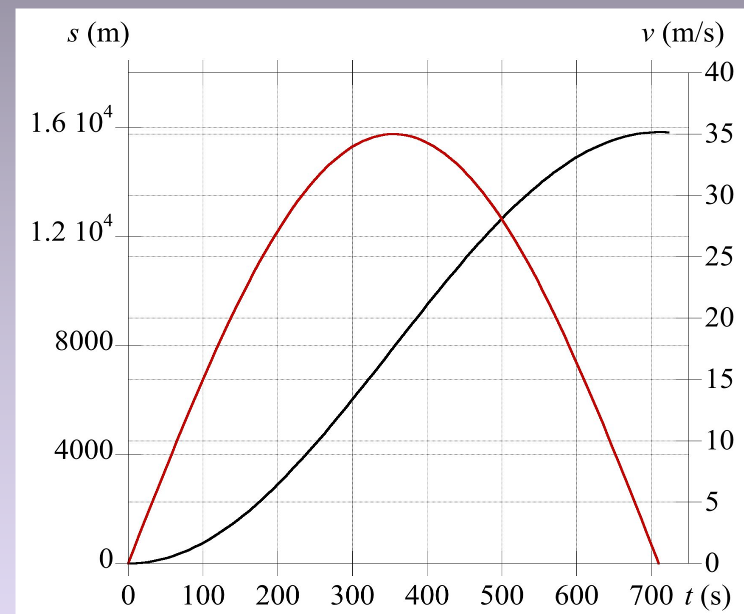
$$\xi = (x-x_0)\cos\theta - (y-y_0)\sin\theta - s(t)$$

$$\chi = (x-x_0)\sin\theta + (y-y_0)\cos\theta$$

$$h(x,y,t) = h_0(x,y) + \zeta\{\xi(x,y),\chi(x,y),t\} - \zeta\{\xi(x,y),\chi(x,y),t_i\}$$

$$\frac{dh}{dt}(x,y,t) = \frac{d}{dt}\{\zeta\{\xi(x,y,s(t)),\chi(x,y)\}\}$$



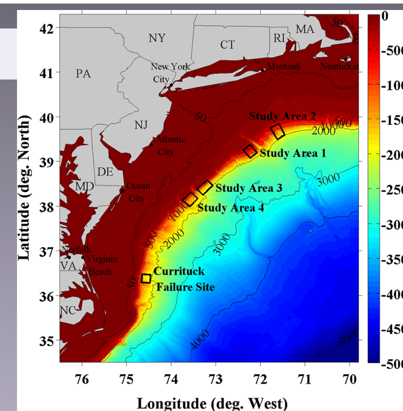


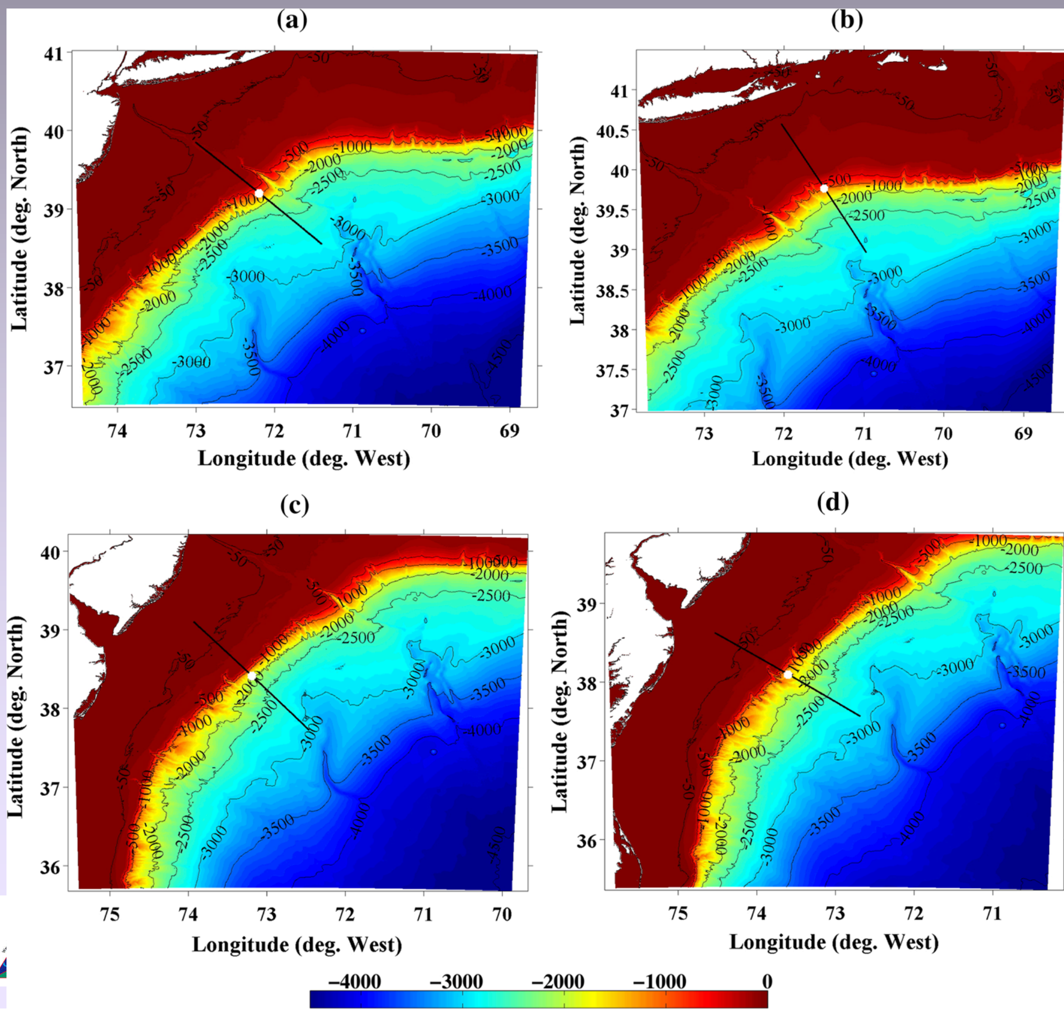
$$s_0 = \frac{R\Delta\phi}{2} \quad \text{and} \quad t_0 = \sqrt{\frac{R}{g}\frac{\gamma + C_m}{\gamma - 1}}$$

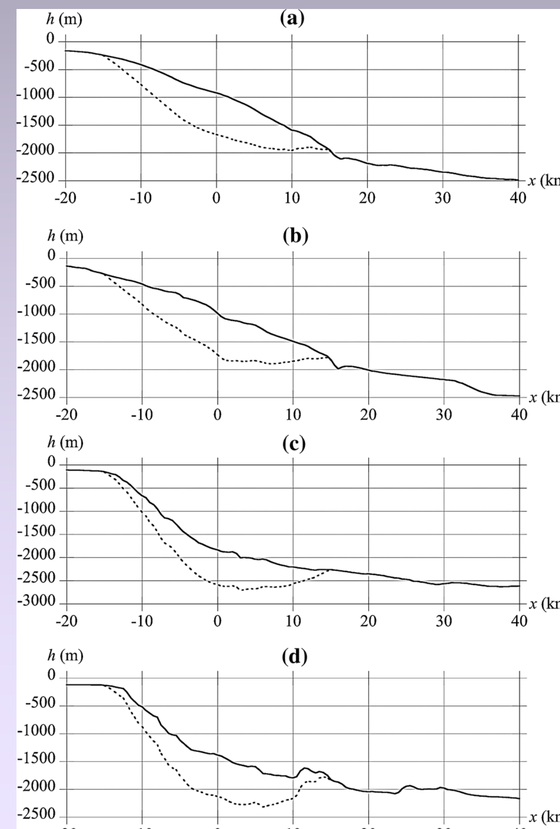
[Grilli et al., 2015, NH]

• Currituck SMF proxies :

-> Siting in Areas 1-4

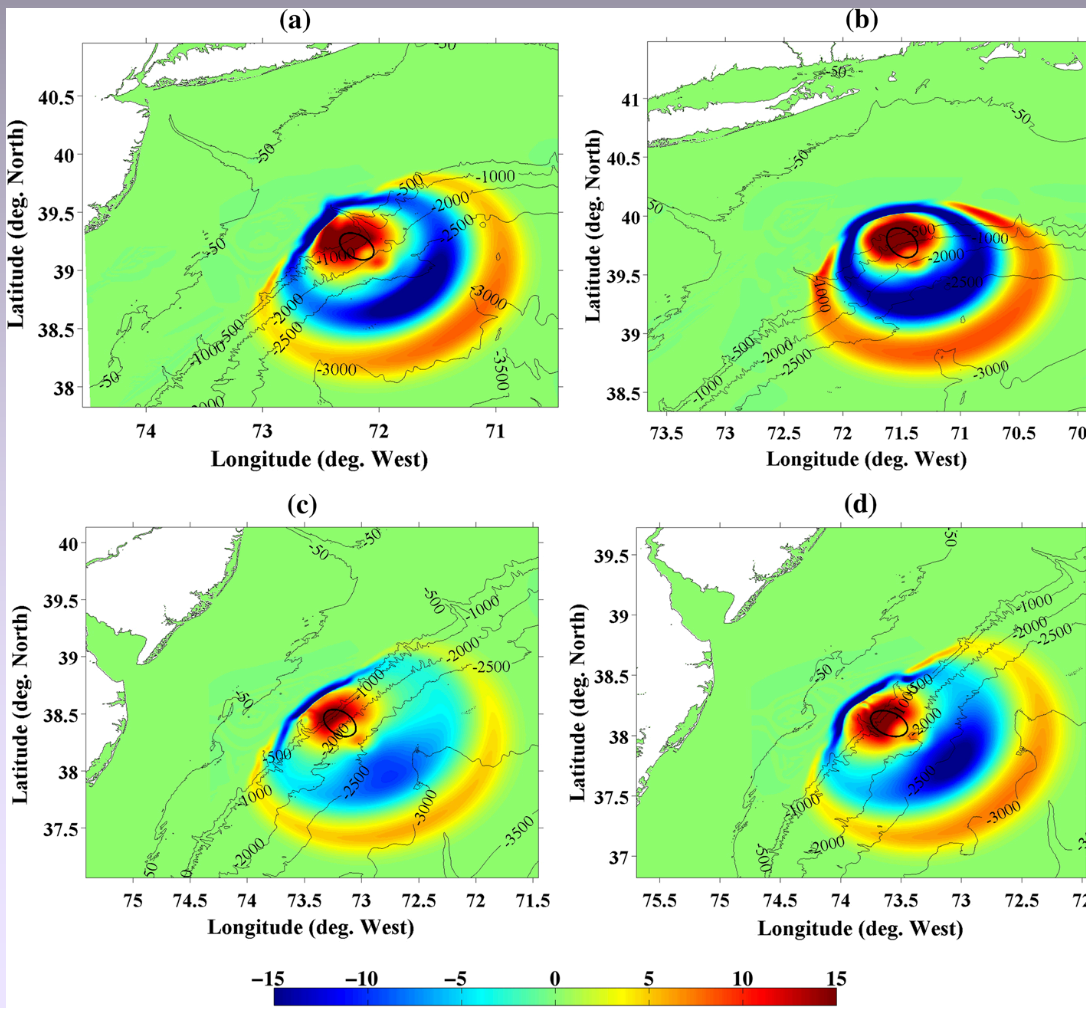


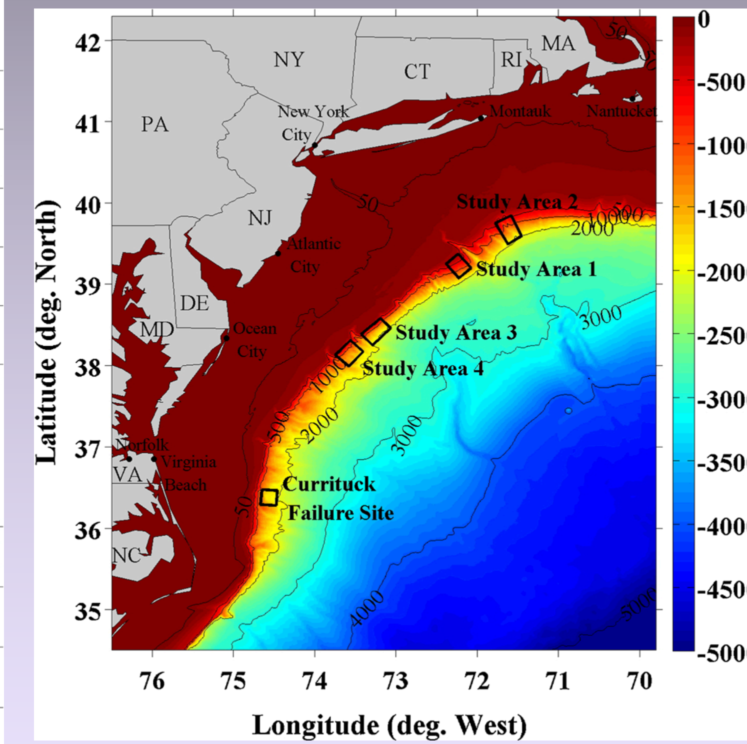




- Curritruck SMF proxies :

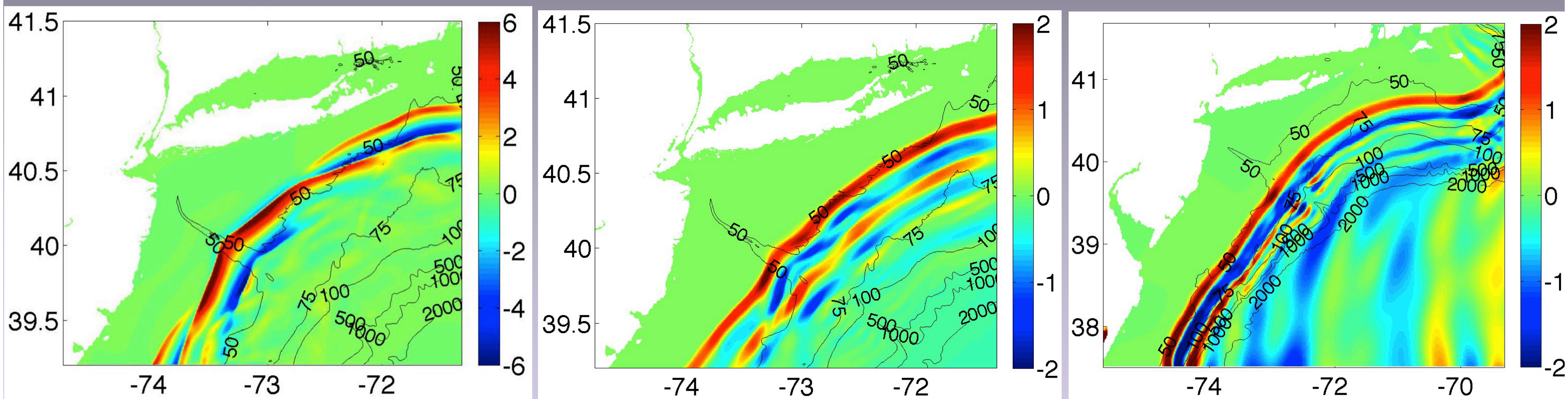
-> Tsunami generation modeling with NHWAVE in Areas 1-4





[Grilli et al., 2015) NH]

• Comparing coastal impact of SMF/PRT/CVV :



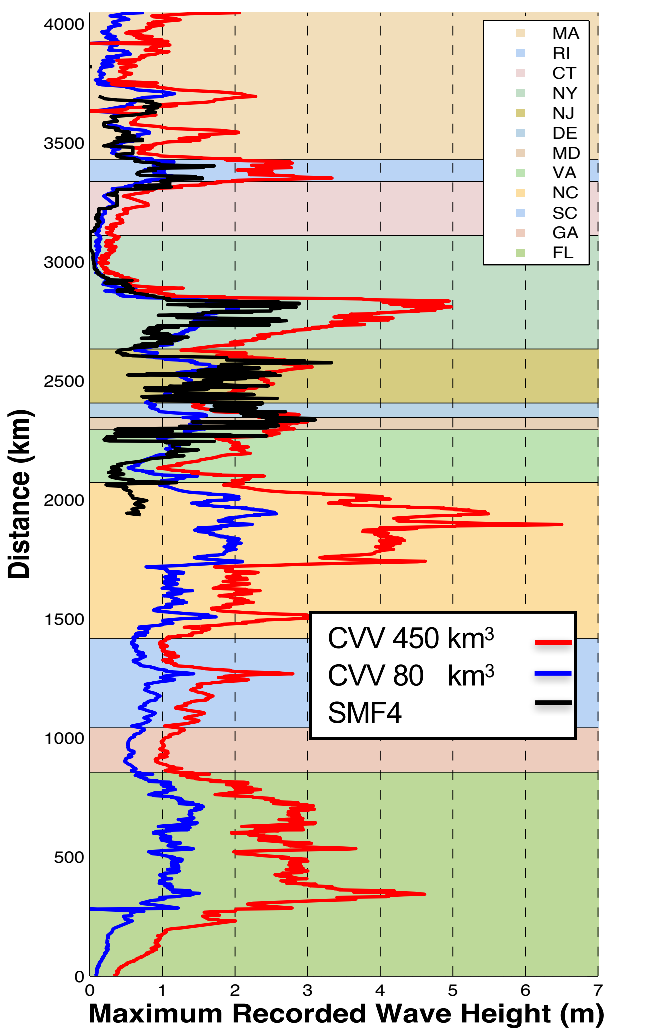
SMF-1 (rigid slump; 1h18') PRT (M9; 4h) CVV (80 km^3; (8h)

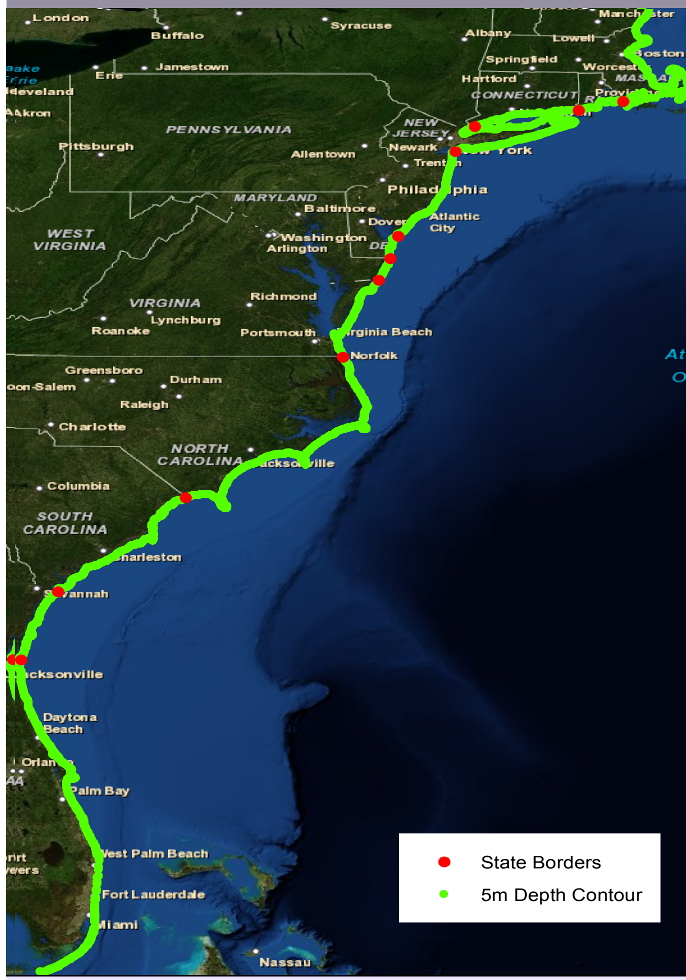
-> SMFs ***dominate Coastal hazard*** (for upper US-EC)

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

-> *Coastal hazard controlled by nearshore bathymetry, particularly for a wide shelf* [Details in Tehranirad et al., 2015, PAGEOH]

• Comparing coastal impact of SMF/PRT/CVV :





-> Similar wave height distribution pattern for all PMTs

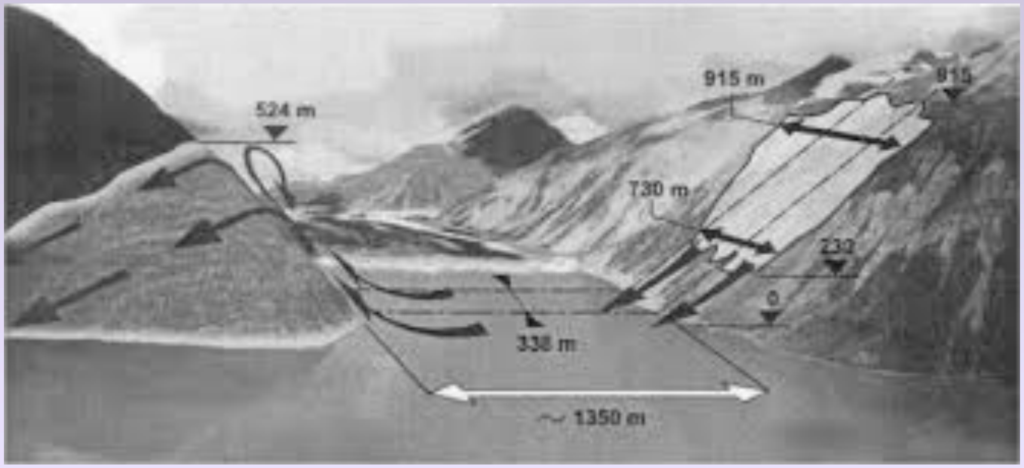
(5 m isobath)

-> SMFs dominate and thus their modeling matters

SMF importance for NTHMP inundation mapping

- Many NTHMP "states" (regions) face significant hazard from potential "landslide tsunamis" (this includes SMFs, subaerial slides, and volcanic collapse/eruption):
  -> Alaska/Aleutian (historical Lituya Bay, Skagway, Kitimat, Unimak, Valdez,...)

Lituya Bay



Skagway

SMF importance for NTHMP inundation mapping

- Many NTHMP "states" (regions) face significant hazard from potential "landslide tsunamis" (this includes SMFs, subaerial slides, and volcanic collapse/eruption):

  -> Oregon/Washington (Cascadia SSZ-induced SMFs)

  -> California (Goleta, Big Sur, Palos Verdes…)

  -> Hawai (Kalapana,…)

  -> Gulf of Mexico (Mississippi Delta,…)

  -> Puerto Rico (Mona Passage,…)

  -> East Coast (Currituck and many others, Grand Bank,…)

- Many mechanisms => Many types of models are required in simulations

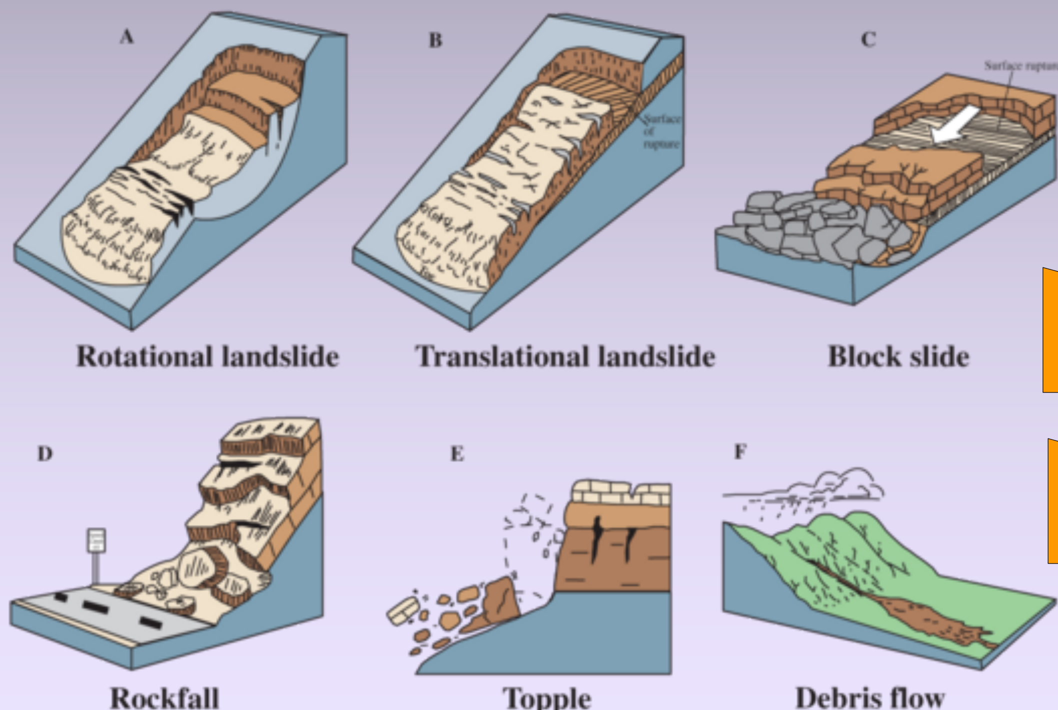
  => Need for model benchmarking

Landslide tsunami generation mechanism

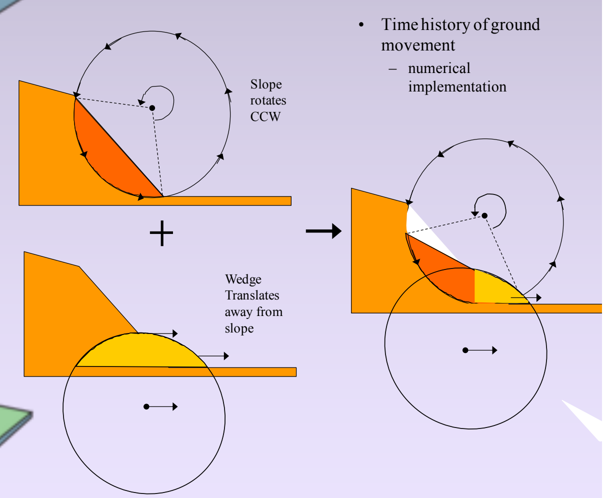
-> Many types of slide failures => various mechanisms of tsunami source

-> Main parameters: volume, initial accel., depth/vertical motion, ***rheology***

-> Worst case: rotational rigid slides (slumps) are the most tsunamigenic



[from USC;
P. Lynett]



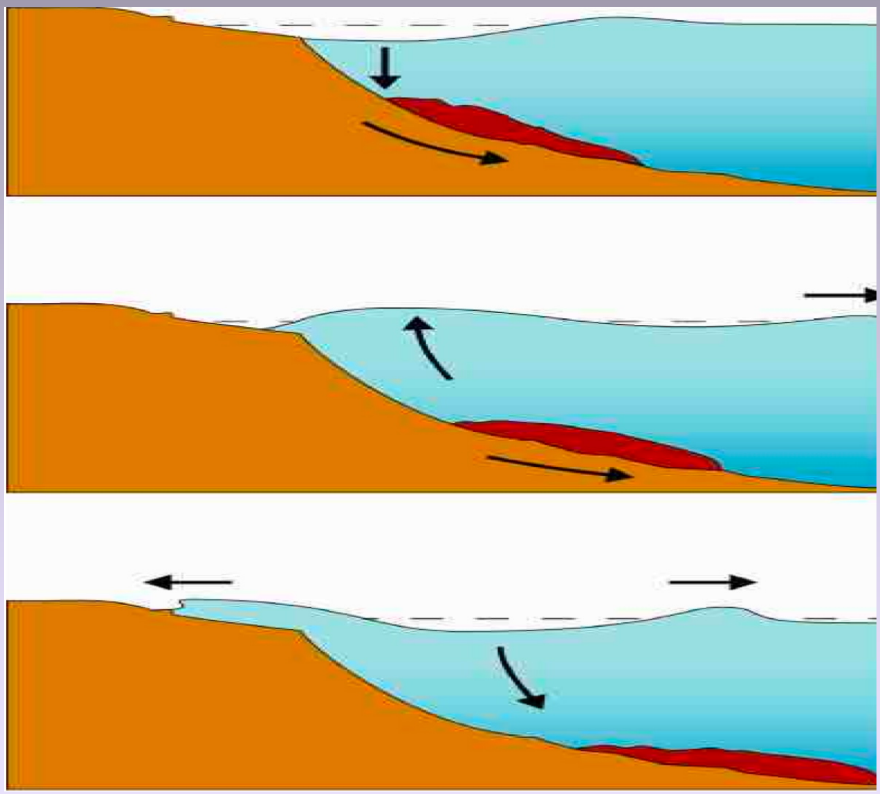
SMF tsunami generation mechanism

- -> Seismic triggering (as low as Mw = 7 ?) => ground acceleration (PHA) triggers landslide motion (Submarine Mass Failure; SMF)

  => tsunami source

- -> SMF parameters and motion => tsunami generation and propagation (on- and off-shore)

- -> Tsunami coastal runup and inundation

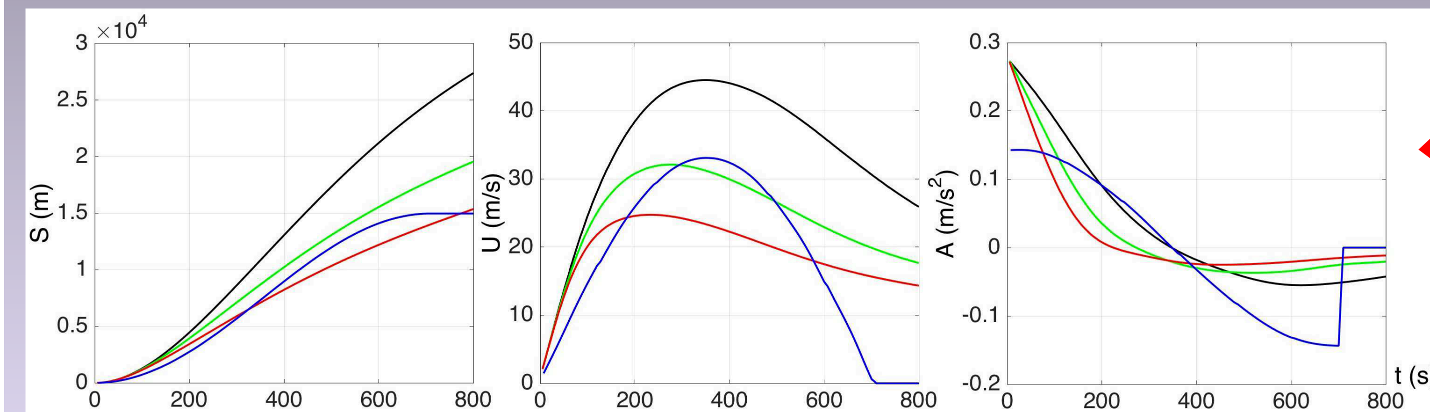


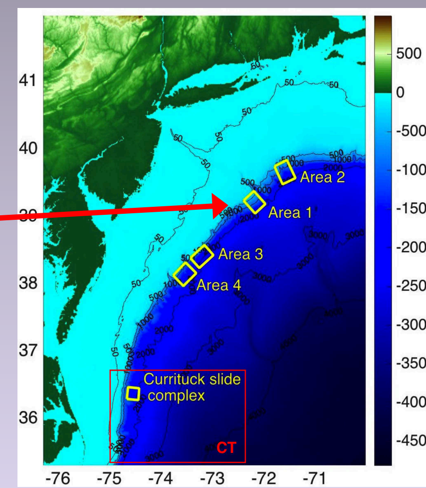
Currituck SMF proxy 1 : rheology effect

-> Compare tsunami generation/coastal hazard for rigid slump vs. deforming slide

-> Use 2-layer model NHWAVE (water) – NSWE (dense fluid) (see Benchmark #4)

-> Center of mass motion, velocity, acceleration :

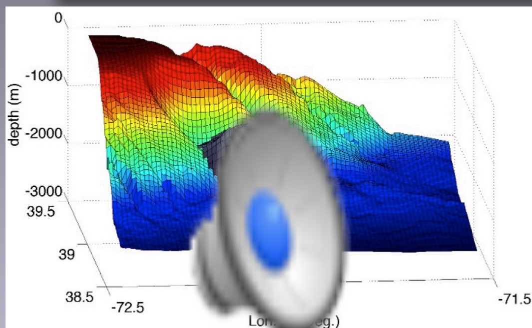


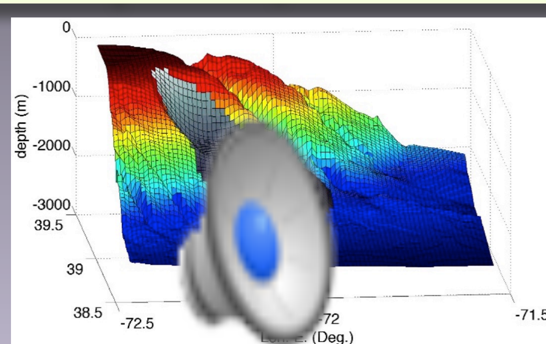


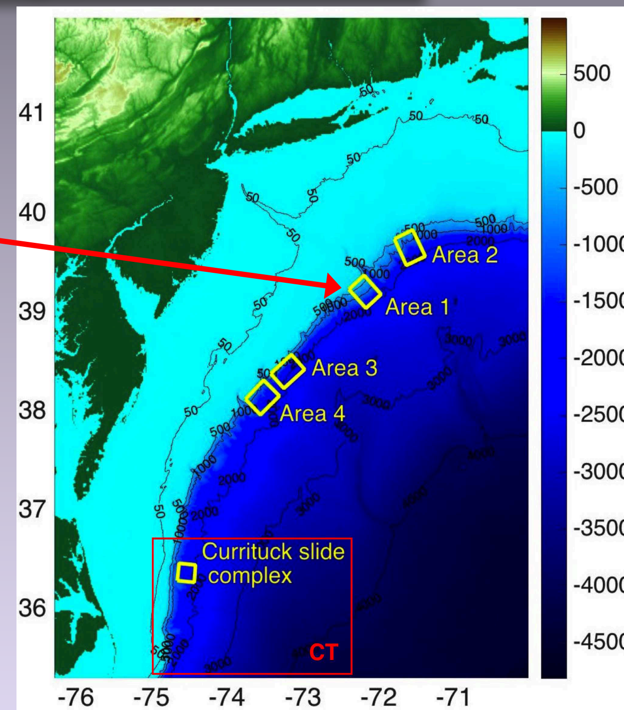
-> Kinematics of fluid-like slide, with *density* ρ_s = 1, 900 kg/m³, *viscosity* μ_s = 500 kg/(m.s) and *Manning coefficient n* = 0.05 (–), 0.10 (–), and 0.15 (–), compared to rigid slump (–)

-> Initial acceleration of deforming slide is larger, but slump has larger one afterwards

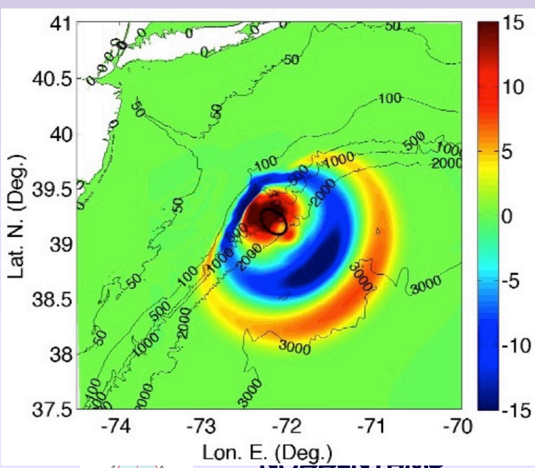
Currituck SMF proxy 1: rheology effect



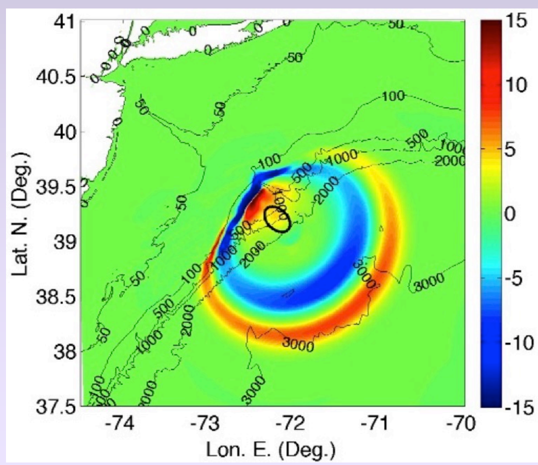




Rigid slump



Deforming slide



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

-> Much larger waves generated by rigid slump (particularly onshore moving)

Currituck SMF proxy 1: rheology effect

-> **Max envelope of surface elevation** for :

(a) *Slump; (b) deforming slide*

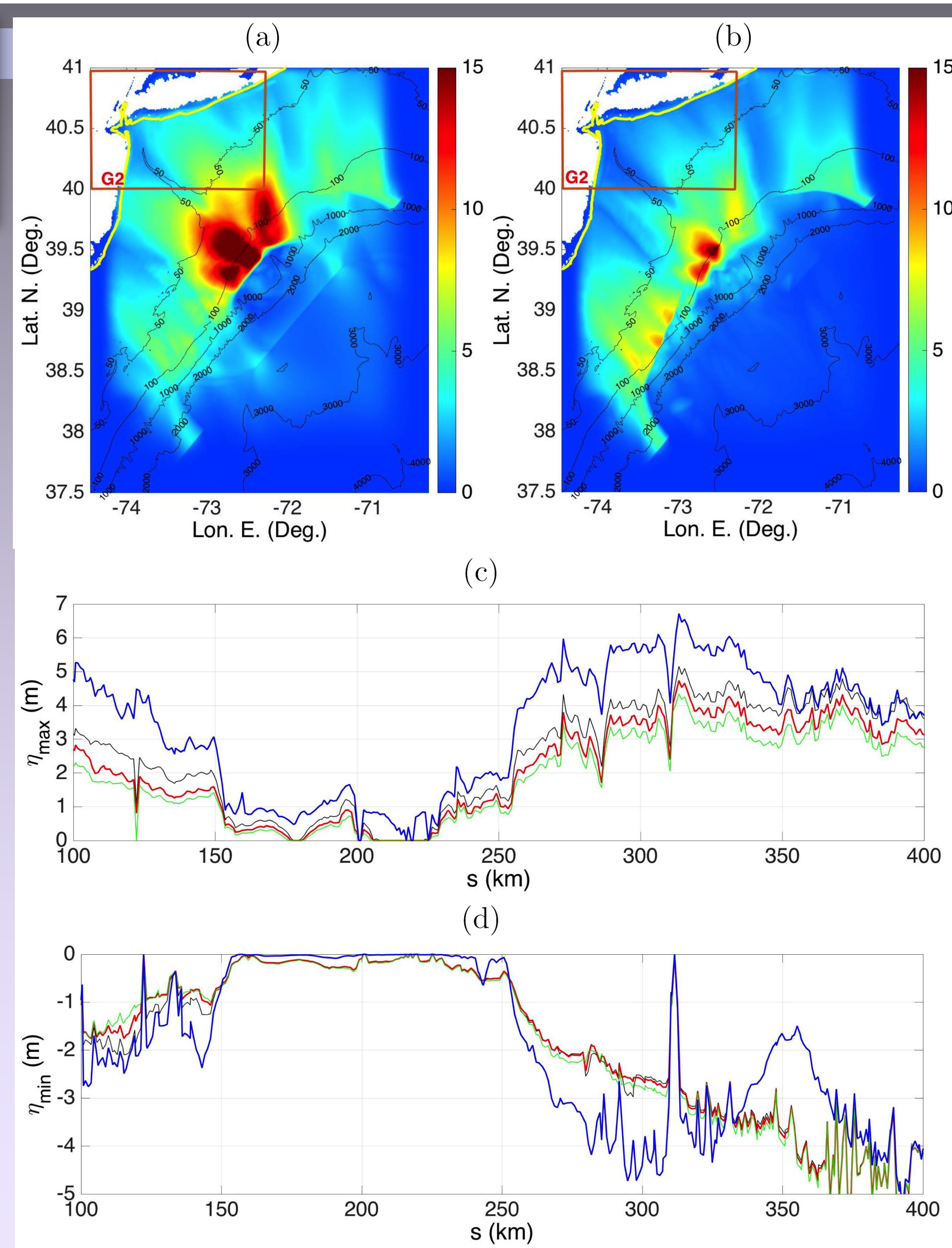
-> (c,d) *max/min surface elevation* fct. of distance s at the 5 m isobath (yellow line)

[Manning coefficient n = 0.05 (–), 0.10 (–), and 0.15 (–), compared to rigid slump (–)]

-> **Coastal hazard from slump** is much higher at most places than for deforming slides

-> **Slide rheology is important** to SMF tsunami coastal hazard

[Grilli et al. 2016, NH]



NOAA-NTHMP
Landslide Workshop

Workshop Rationale

-> A ***variety of models*** have been developed for landslide tsunami generation, propagation and coastal impact

-> The "Tsunami Community" has long ago recognized the ***need for systematic and rigorous benchmarking and validation*** of tsunami models, against analytical, laboratory and field benchmark (see Philip Liu's talk):

- Catalina Island, CA, "Long Wave Runup workshop" (1990) (NSF)
- Friday Harbor, WA," Long Wave Runup workshop" (1995) (NSF)
- Honolulu, HI, "Landslide Tsunami workshop" (2003) (NSF)
- Catalina Island, CA, "Model Benchmarking workshop" (2004) (NTHMP, NSF)
- Galveston, TX, "Model Benchmarking workshop" (runup) and " Landslide Tsunami workshop" (2011) (NTHMP)
- Portland, OR, " Tsunami Model Validation workshop" (velocities) (2015) (NTHMP)

Workshop Rationale

-> Following the earlier NTHMP model benchmarking workshops for *long wave model runup* (Galveston, 2011) and *long wave velocity* (Portland, 2015) => similar approach and goals for this workshop

-> **Expected outcomes:**

1. A set of *community accepted benchmark tests* for validating models for landslide tsunami generation (different classes)
2. A set of *comparison of results of state-of-the-art landslide tsunami generation models* with the set of benchmarks

   => Consensus on acceptable accuracy/error/msifit thresholds
3. Recommendations for *future model/test developments*
4. NTHMP set of *criteria for acceptable landslide tsunami models*

Workshop Agenda

-> A set of ***7 benchmarks*** was developed by the workshop committee to be simulated ahead of time by modelers (see Jim Kirby's talk) :

=> Many *presentations of models and results by modelers* (16 models/variations)

=> *Comparison of model results* for benchmarks 2, 4 and 7

-> Landslides must be understood in their ***geological/geotechnical/field*** context :

=> Three *presentations of those aspects* by : D. Tappin, J. Chaytor and H. Lee

=> *Presentation of a recent slide event* in Alaska and its modeling : P. Lynett

-> ***New laboratory benchmarks*** must be permanently developed and implemented to reflect new knowledge in SMF physics and field issues :

=> Two *presentations of those aspects* : H. Fritz, O. Kimmoun

=> *New experiments on landslide tsunami* on a conical island : Giorgio Bellotti

-> ***Discussion*** of development of a data and modeling web repository

-> ***Discussion*** of workshop results vs. goals (thresholds for model acceptance)

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Workshop Agenda

Day 1: Monday January 9th (morning)

- 9-9:15 Welcoming, logistics - Horrillo, Girimaji
- 9:15-9:45 Overview, Rationale, and Goals for present workshop - Grilli
- 9:45-10:00 Reviewing previous benchmarking workshops - Liu
- 10-10:30 Overview of field work and issues - David Tappin
- 10:30-11:00 Break
- 11-11:45 Description of benchmark problems - Kirby
- 11:45-12:15 "Physical Modeling of Tsunamis generated by 2D and 3D granular Landslides in various Scenarios from Fjords to conical Islands" - Hermann Fritz
- 12:15-1:45 Lunch

Workshop Agenda

Day 1: Monday January 9th (afternoon)

- 1:45-2:15 Model descriptions and results: Landslide-HySEA - Jorge Macias
- 2:15-2:30 Model descriptions and results: Alaska model - Dmitry Nicolsky
- 2:30-2:50 Model descriptions and results: Geo-Claw/D-Claw - David George
- 2:50-3:05 "New experiments on landslide tsunami on a conical island" - Giorgio Bellotti
- 3:05-3:35 Break
- 3:35-3:55 Model descriptions and results: FBSlide - Isaac Fine
- 3:55-4:20 Model descriptions and results: Globouss and BoussClaw - Finn Lovholt
- 4:20-4:45 Model descriptions and results: LS3D and 2LCMFLOW - Behzad Ataie-Ashtiani (Kirby presenting)
- 4:45-5:15 Model descriptions and results: Tsunami3D - Juan Horrillo
- ? Group dinner

Workshop Agenda

Day 2: Tuesday January 10th (morning)

- 9-9:15 Summary of Day 1 - Grilli
- 9:15-9:45 "Characterizing East and Gulf Coast Landslide Sources" - Jason Chaytor
- 9:45-10:25 Model descriptions and results: NHWAVE - Gangfeng Ma, Cheng Zhang, Stephan Grilli, Fengyan Shi
- 10:25-10:45 Presentation on modeling recent slide event in Alaska - Pat Lynett
- 10:45-11:15 Break
- 11:15-11:45 "Small scale experiments of subaerial and submarine landslides" - Olivier Kimmoun
- 11:45-12:15 Model descriptions and results: Coulwave, mild-slope equation, OpenFOAM - Pat Lynett
- 12:15-1:45 Lunch

Workshop Agenda

Day 2: Tuesday January 10th (afternoon)

- 1:45-2:15 Model descriptions and results: THETIS - Stephan Abadie
- 2:25-2:55 "Geotechnical and Geologic Constraints on Tsunamigenic Submarine Landslides" - Homa Lee
- 2:45-3.15 Discussion of development of a data and modeling web repository – Kirby - Grilli
- 3:15-3:45 Break
- 3:45-5:00 Comparison of model results for benchmarks 2, 4 and 7 – Kirby
- ? Group dinner

Workshop Agenda

Day 3: Wednesday January 11th

- 9-9:20 Summary of Day 2
- 9:20-10:45 Discussion: workshop results vs. goals (thresholds for model acceptance)
- 10:45-11:00 Closure

Thank you