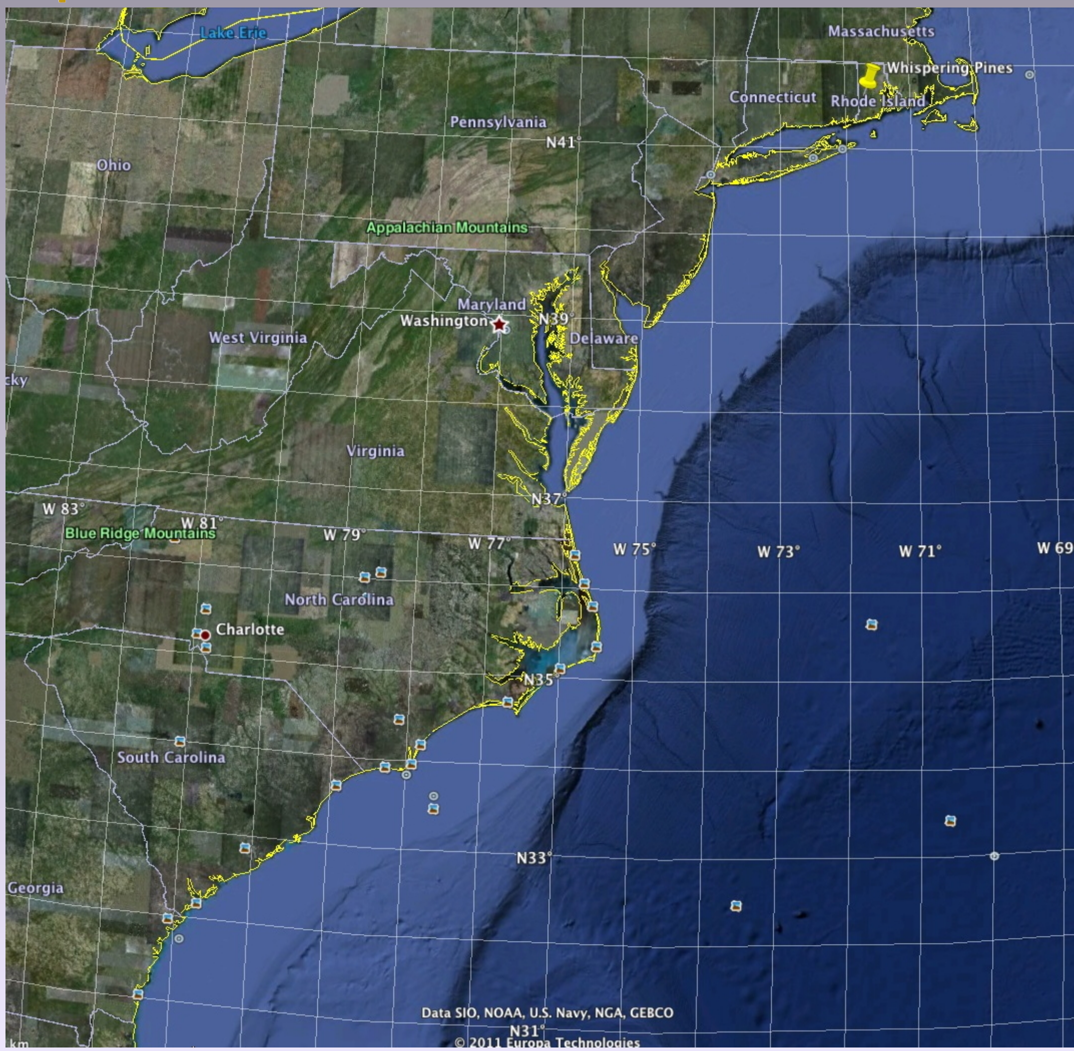
A Monte Carlo Approach for Estimating Tsunami Hazard From Submarine Mass Failures Along the US East Coast



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Outline

- Objectives of Work
- Description of Monte Carlo (MC) Model (Grilli et al., 2009; MG special issue)
- Validation of MC simulations
- Statistical Analysis of Runups
- MC Model and Direct Tsunami Simulations Results
- Limitations and Ways Forward

Objectives

- Broadly assess landslide tsunami hazard for the U.S. East Coast as part of developing inundation maps for NTHMP, including Submarine Mass Failures (SMFs) :

  -> Apply and validate a first-order probabilistic model based on Monte Carlo Simulations of slope stability (Grilli et al., 2009)

  -> Use this model as a screening tool to identify areas at risk to be selected for more detailed analyses

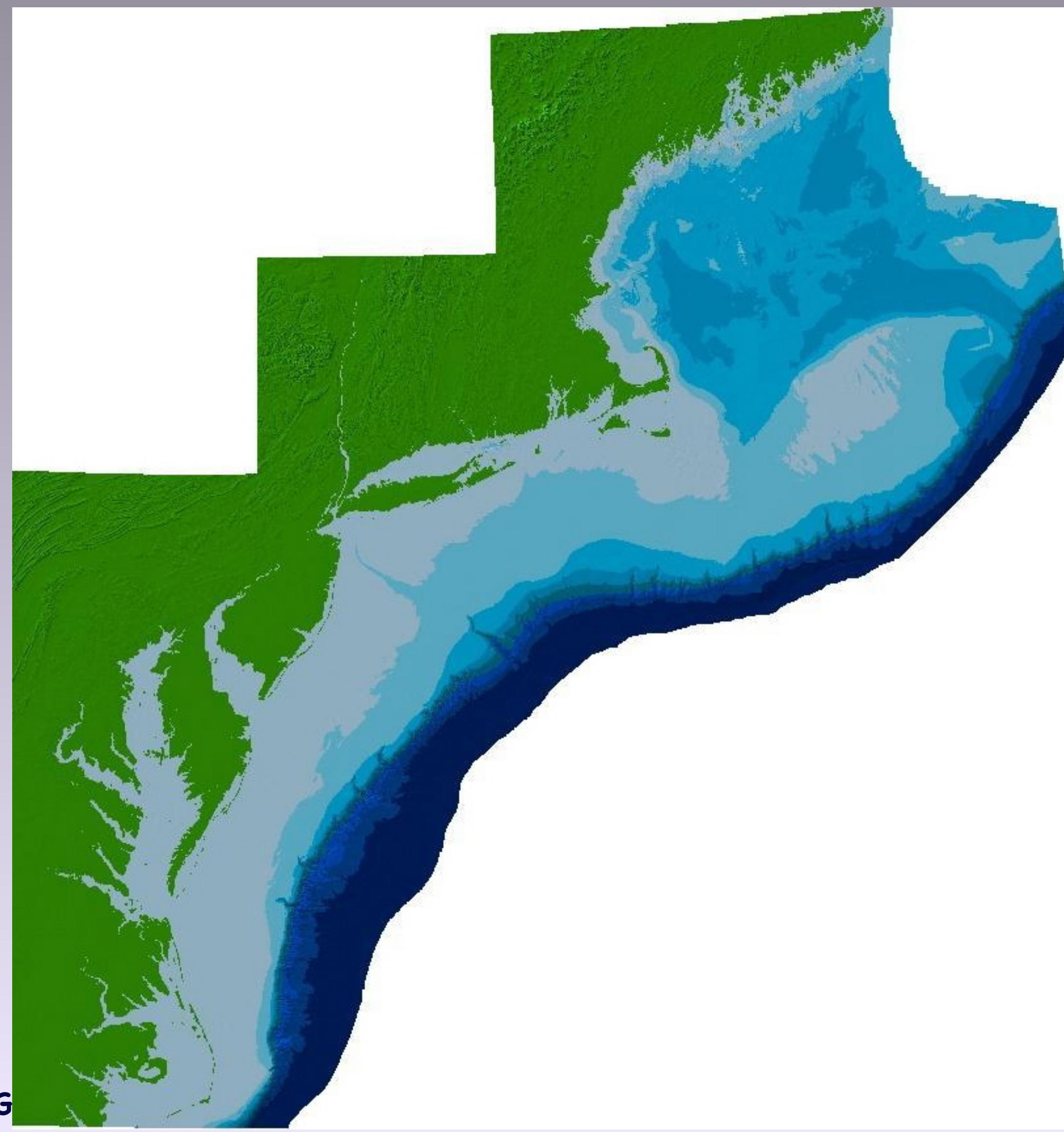
  -> Select parameters of potential SMF source (volumes, length/width, and locations) and perform deterministic analyses of tsunami coastal impact (ongoing task)

Methodology of Monte Carlo Simulations

- Probabilistic computation of slope stability:
  - -> Selection of coastal transects and slope geometry
  - -> Quantify seismicity (PHA) and overpressures as SMF triggering mechanisms
  - -> Quantify sediment properties (type, density,...)
- Prediction of initial tsunami amplitude and coastal runup for each SMF, at a series of (3500+) Coastal Points
- Statistical analysis of predicted MCS runups to estimate 100-year and 500-year runup for each Coastal Point

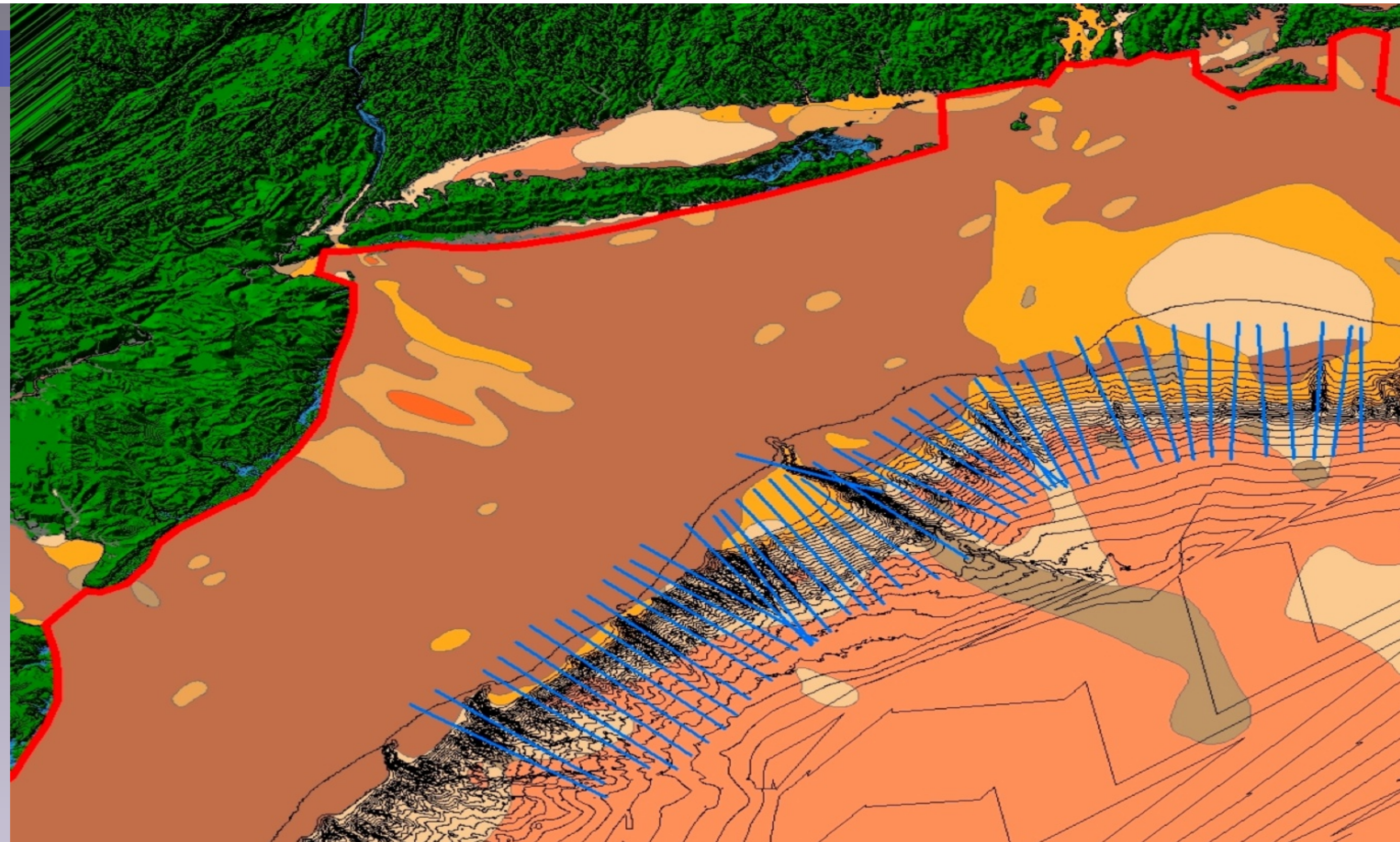
Bathymetry/Topography Data

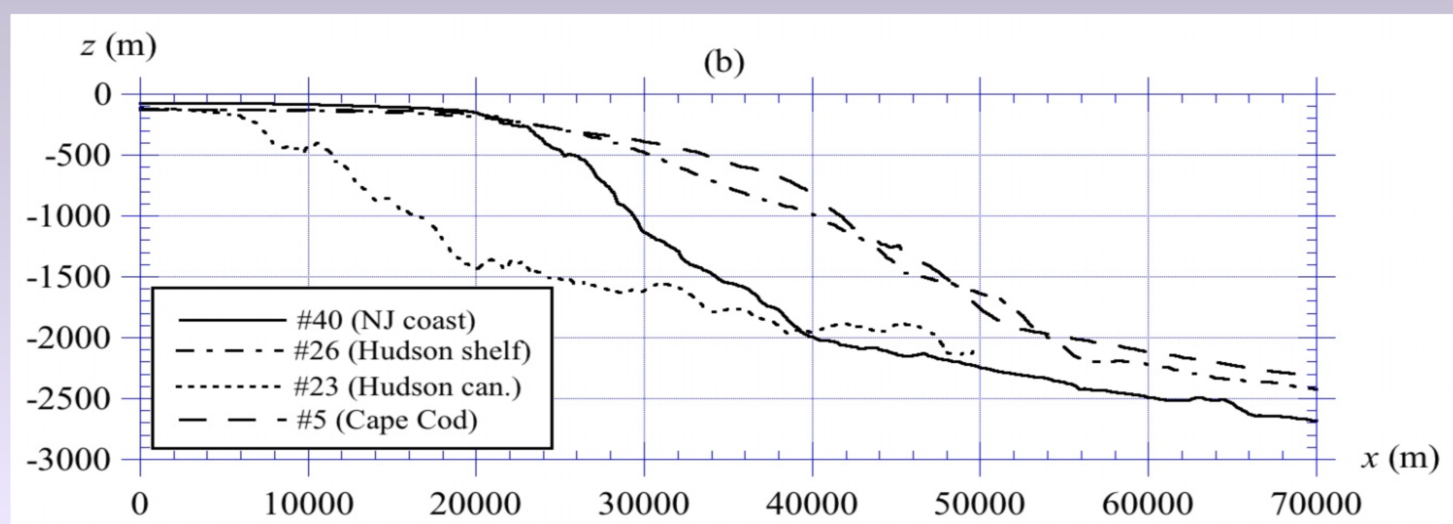
- ArcGIS 9 : Triangulated Irregular Network (TIN) surface
- Elevation data on a 15" grid :
  - 240 data points per degree Lat/Long
  - Elevations to the nearest 0.1 meter
- Data Source : US Coastal Relief Model
  - NOAA NGDC
  - Bathymetry sources:
    - NOS Hydrographic Database
    - USGS
    - MBARI
    - USACE LIDAR (SHOALS)
  - Topography data:
    - USGS Digital Elevation Models (DEMs)
    - Shuttle Radar Topography data (SRTM)



Northern Transects

[as in Grilli et al. (2009), MG special issue for detail]





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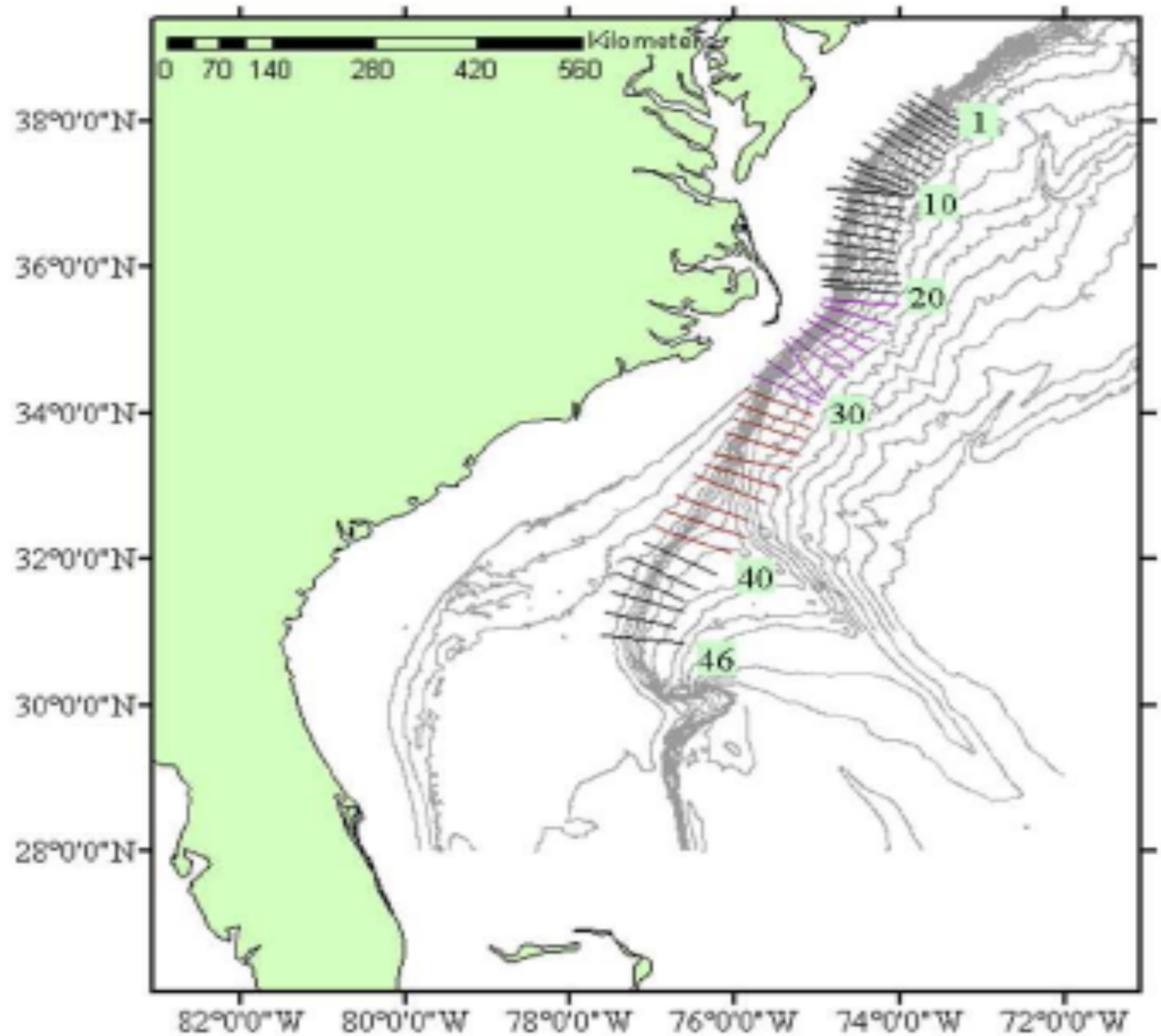
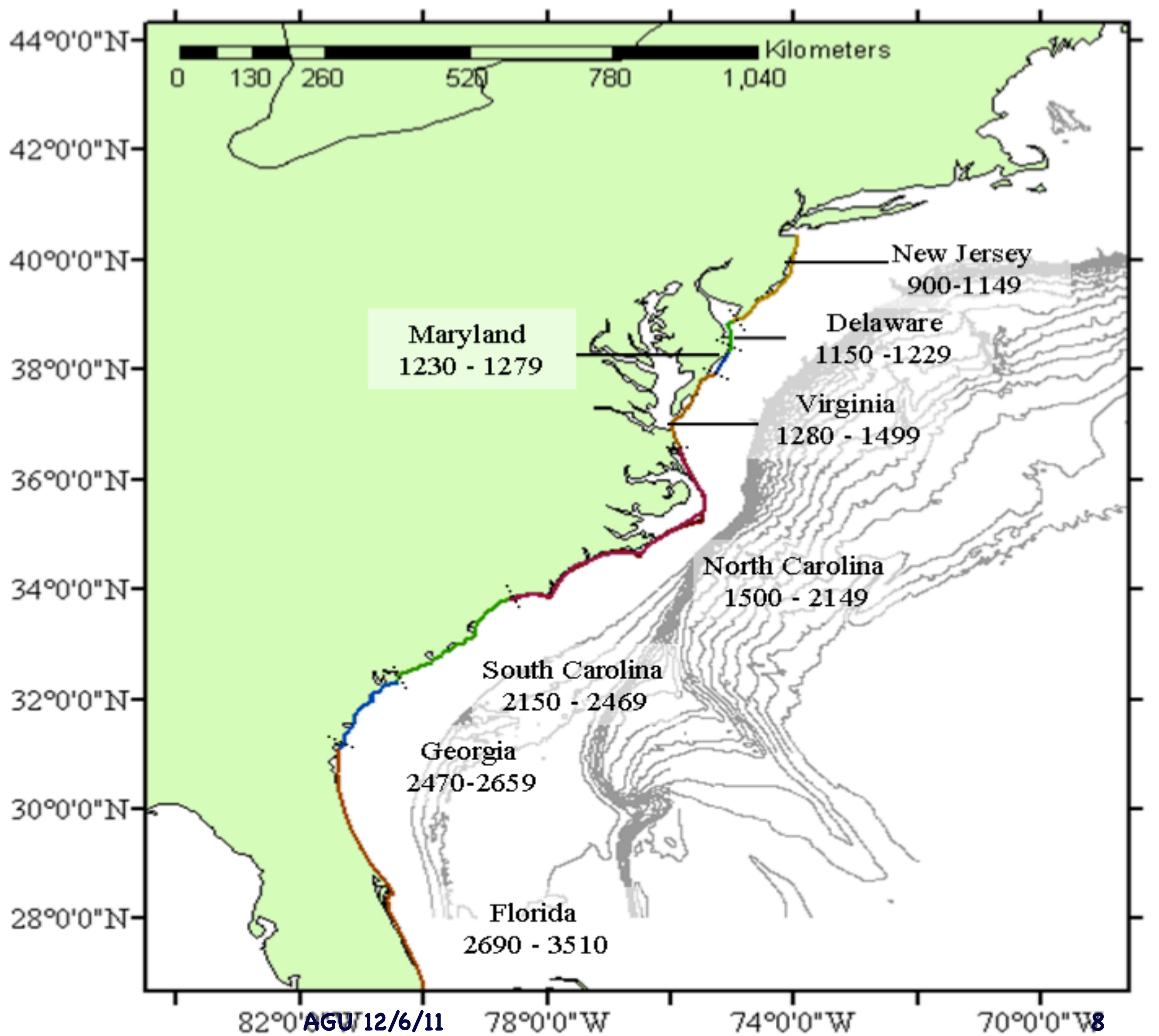
Southern Transects

[New area of study for NTHMP to add to Northern transects]

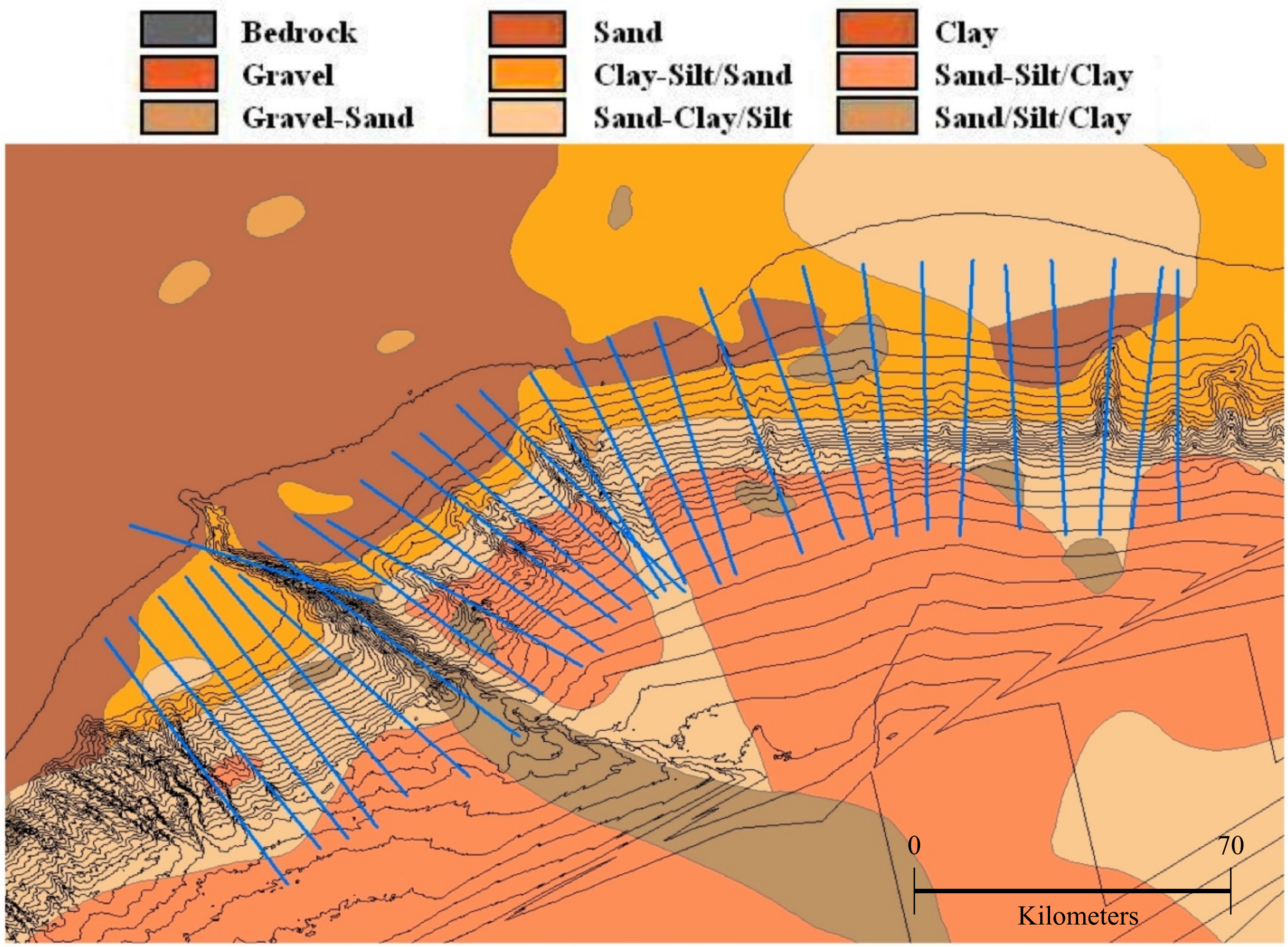


Coastline simplified by *N* = 1 - 3510 coastal points

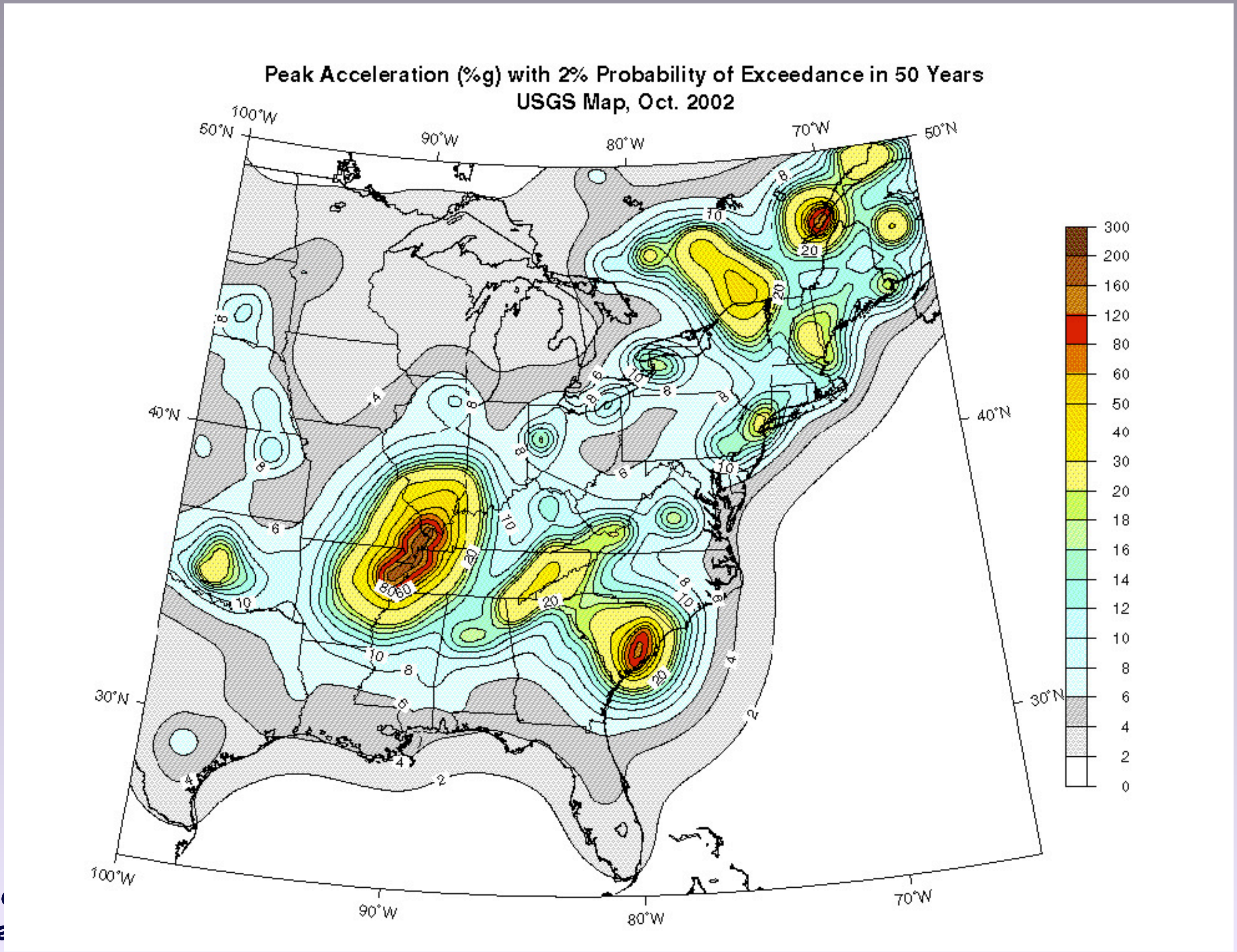
[New NTHMP area of study; 3510 Coastal points]



Surficial sediment properties on transects (Shephard)

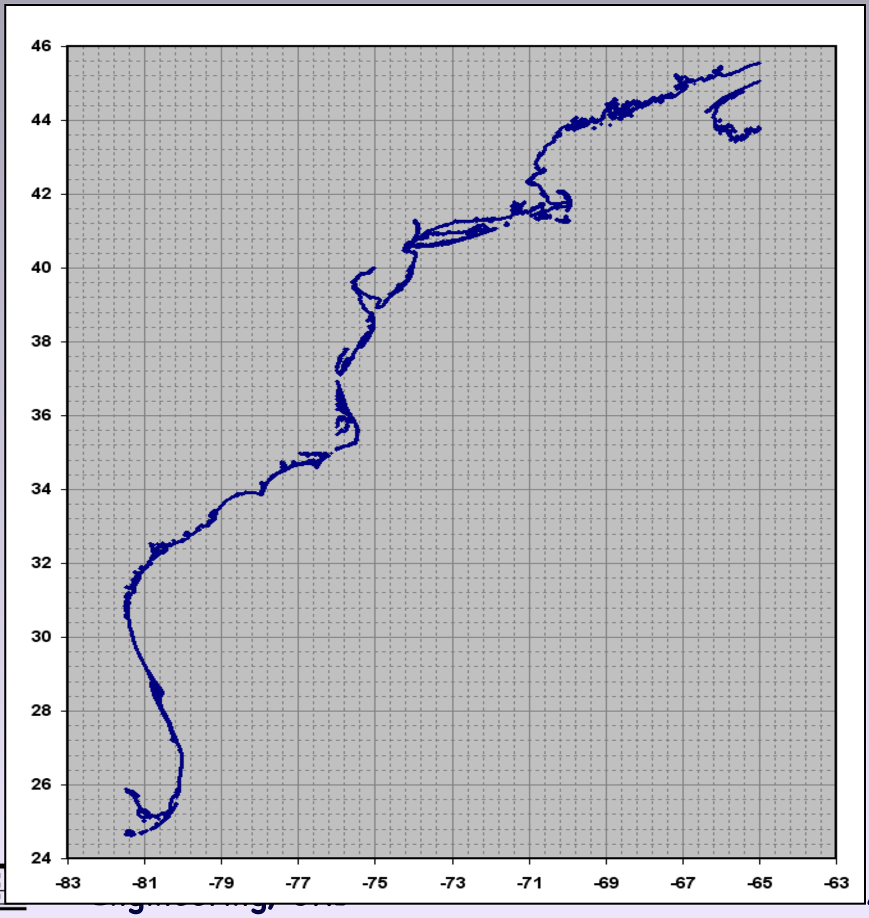


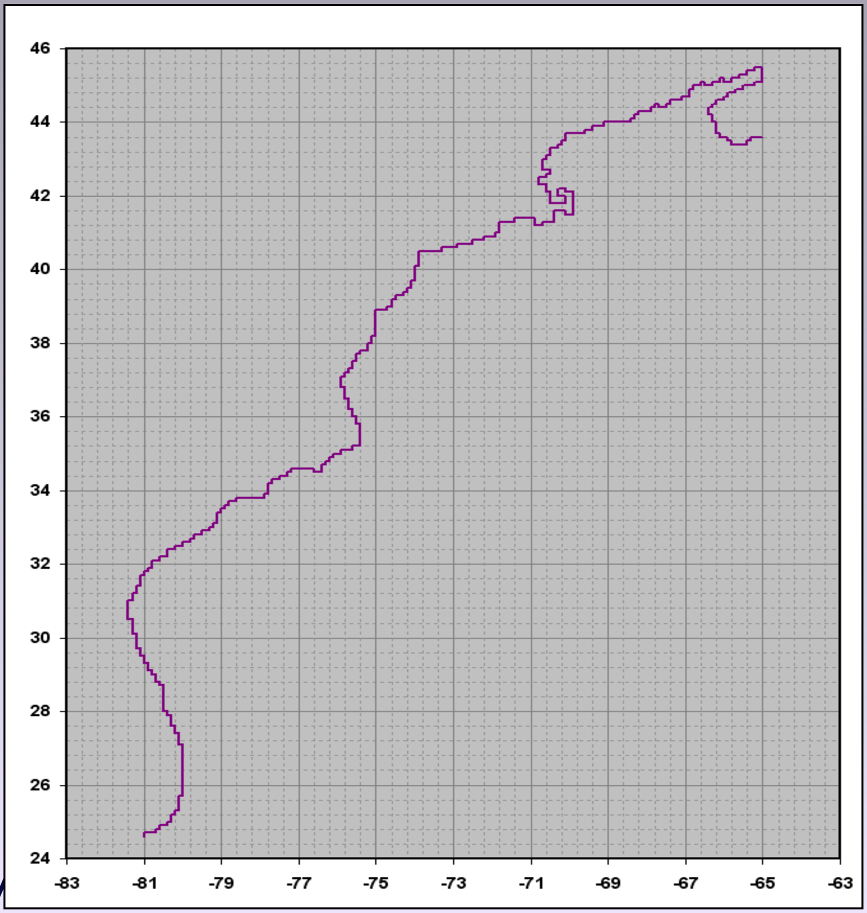
Seismicity near US East Coast (PHA)



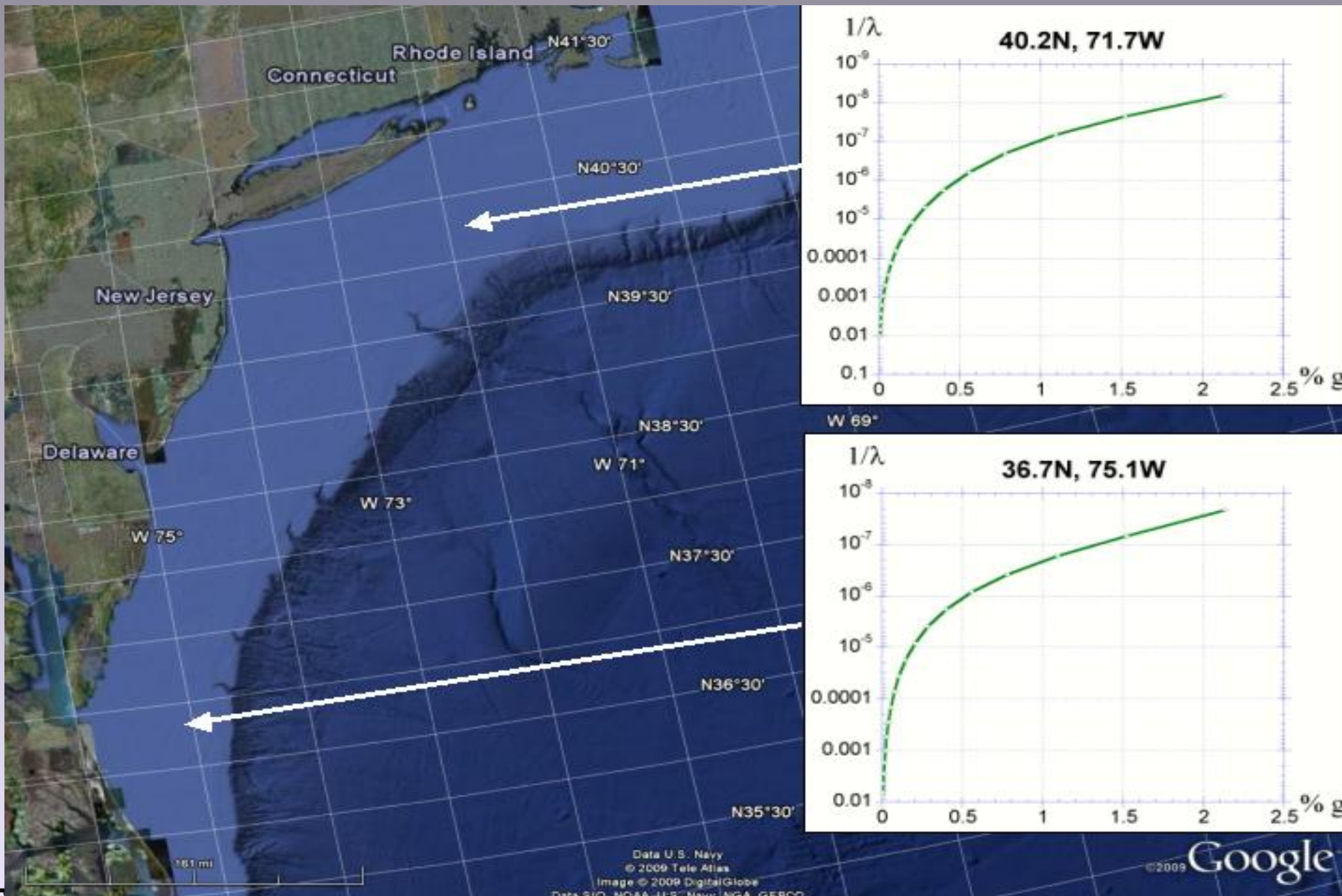
Seismicity Grid, simplified coastline, coastal points

- Coastline Data from NOAA-NGDC (LHS), and approximated Coastline in a 6' seismicity data grid (RHS)





Seismicity Data from USGS Hazard Maps

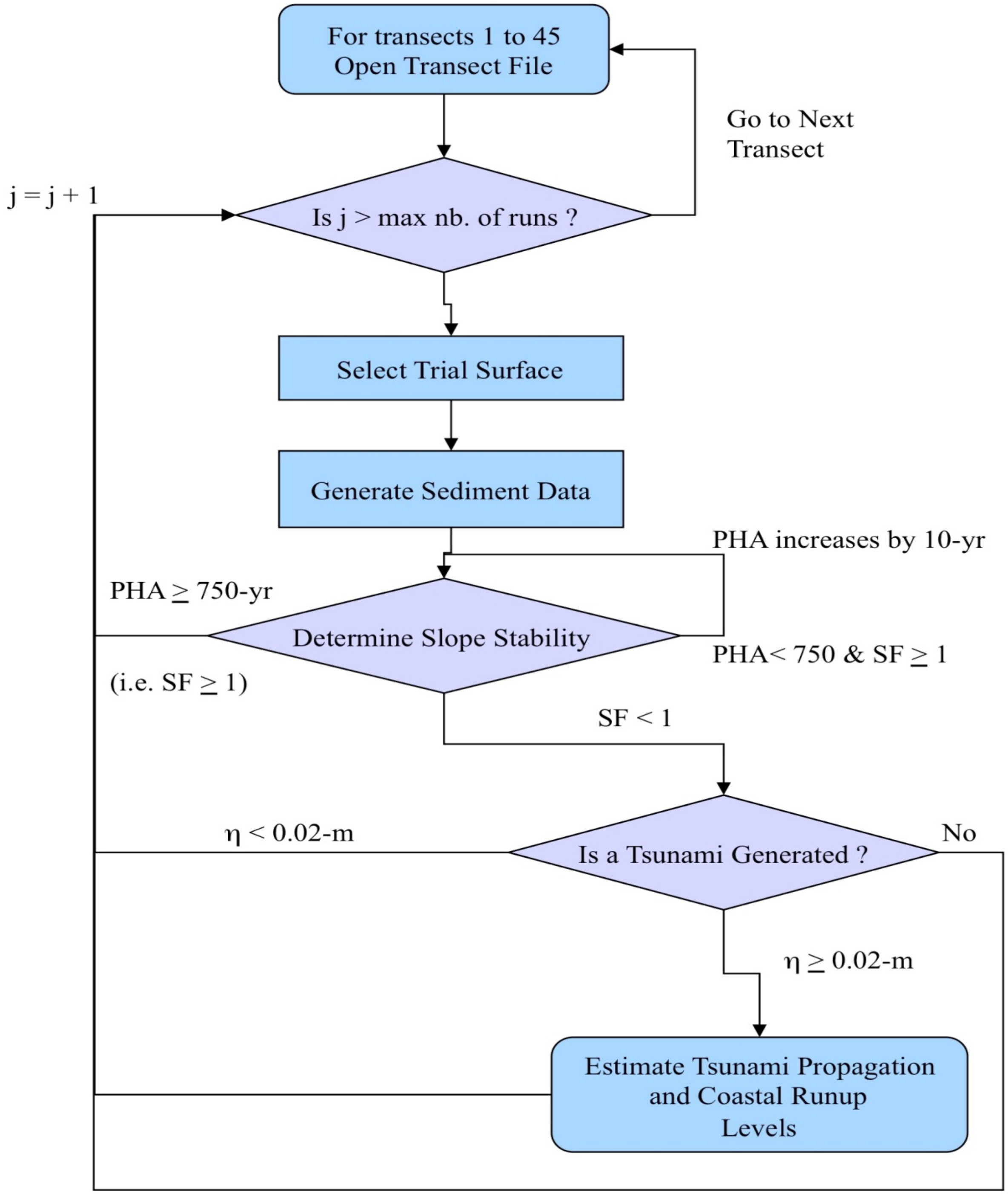


Principles of Monte Carlo simulations of SMF tsunami runup

- Monte Carlo simulations (MCS): stochastic simulations of SMF tsunami runup => parameters described by *random variables* χ_i , for $i = 1,\ldots N$
- Parameterization of χ_i distributions for :
  - earthquake excitation (magnitude, distance, acceler.) from location,
  - sediment properties (density, nature, cohesion,…), from location
  - slope geometry (angle, depth, length, width,…), from transect data
  - failure and type (landslide/slump) from slope stability analyses,
  - tsunami generation/runup (empirical, based on numerical modeling)
- Computation of tsunami hazard (coastal runup) at coastal points in terms of probability of occurrence.

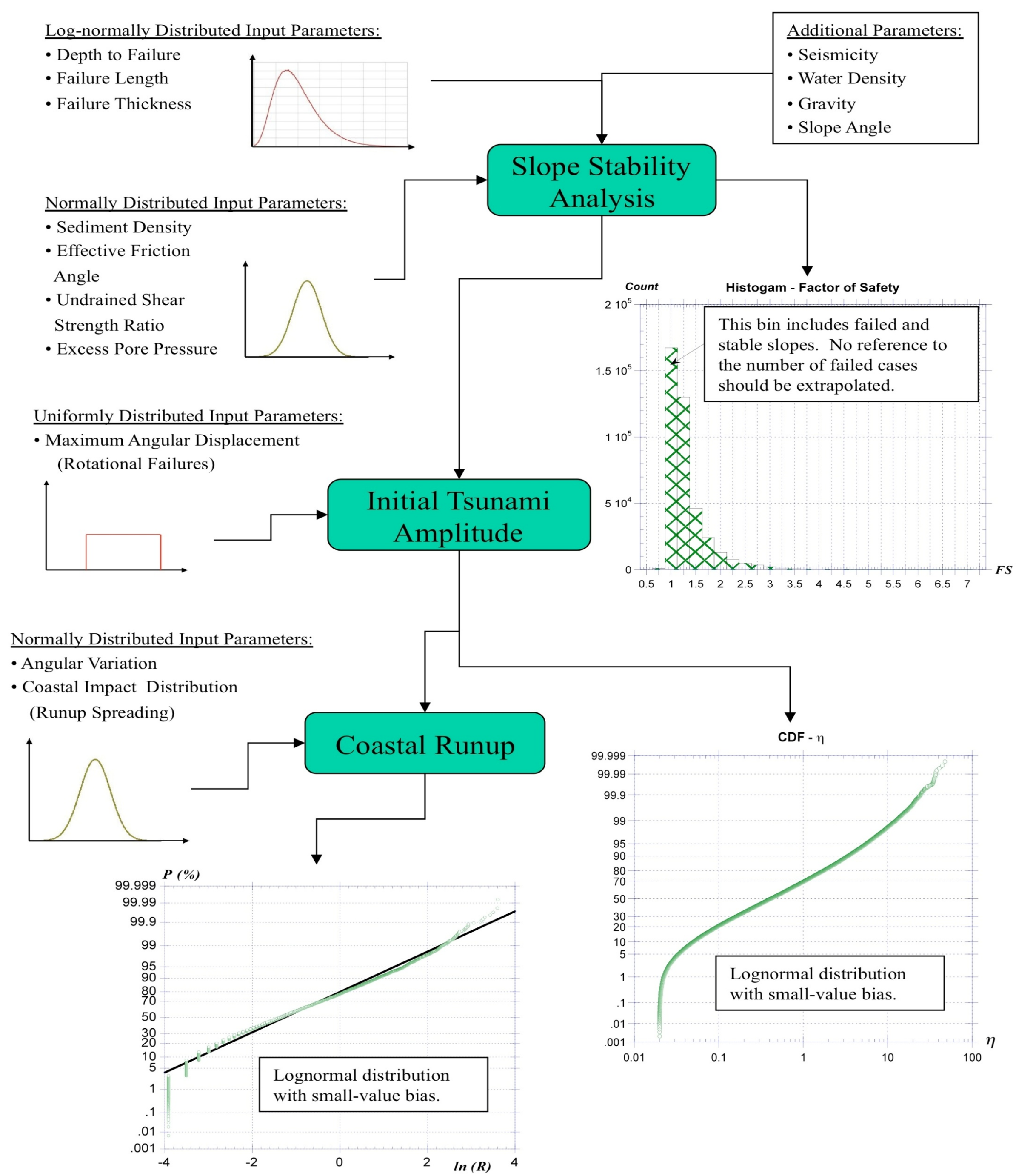
MCS Flowchart

[See, Grilli et al., MG special issue for detail]



Probability Distributions of Input Data and Predicted Runup

[See, Grilli et al., MG special issue for detail]



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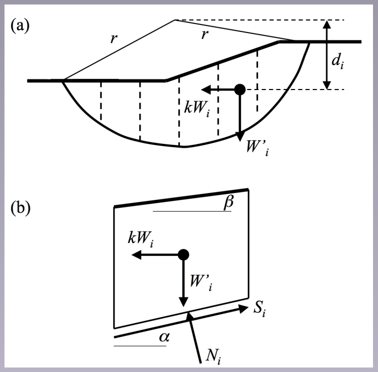
Slope Stability by Limit Equilibrium

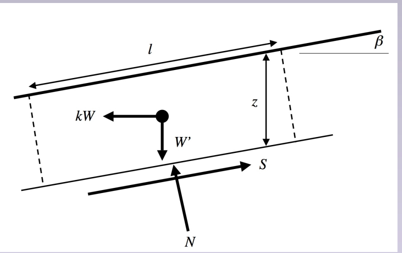
- Slumps/Rotational SMFs are modeled using Modified Bishop's Method :

$$FS = \frac{\sum_{i=1}^{I} S_{ui}\Delta l_i}{\sum_{i=1}^{I}\left(W'_i \sin\alpha_i + kW_i\left(\cos\alpha_i - \frac{\bar{h}_i}{2r}\right)\right)}$$



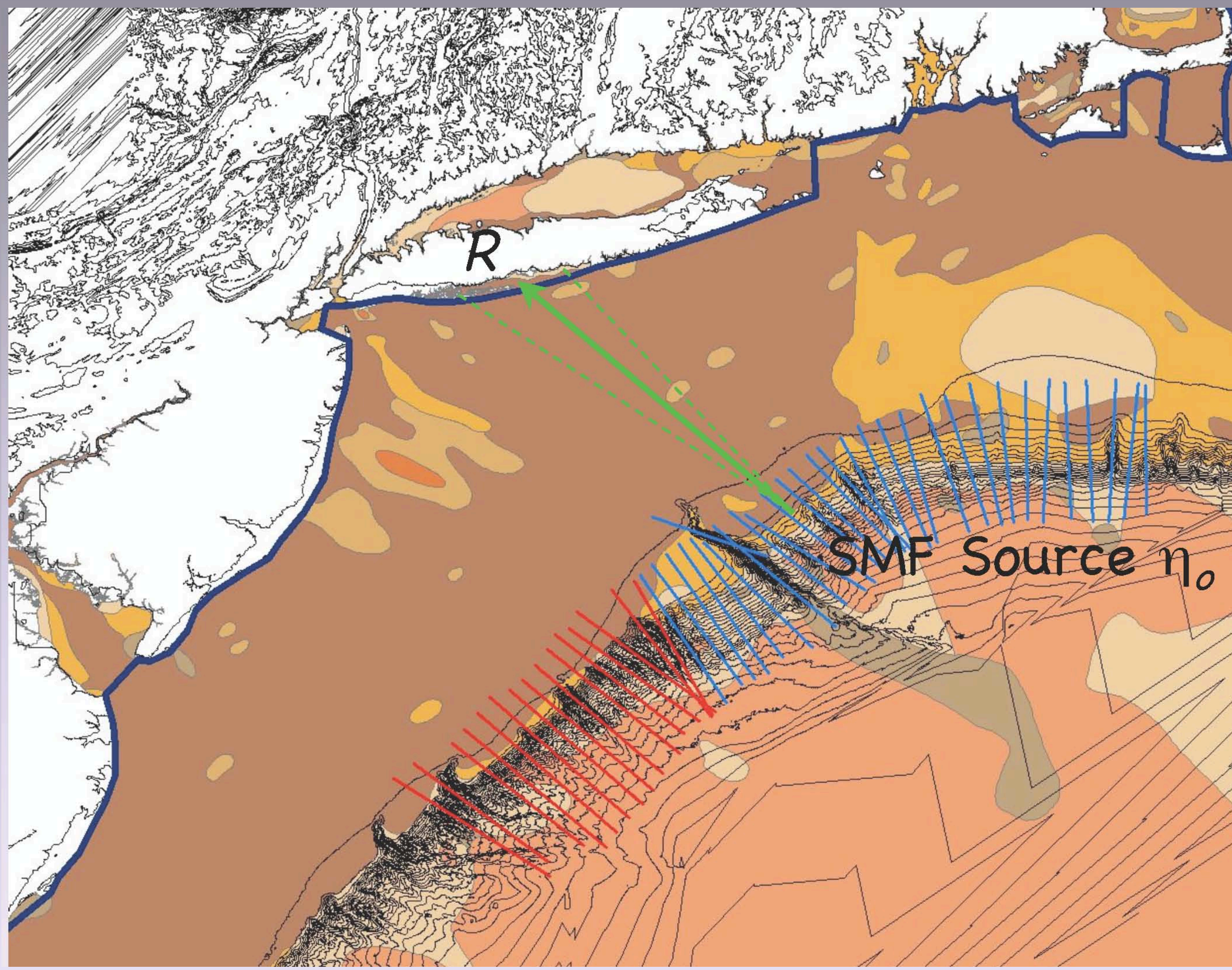
- Slides/translational SMFs were modeled using Infinite Slope Method :

$$FS = \frac{(\gamma - 1)(1 - R_u) - k\,\gamma \tan\beta}{(\gamma - 1)\tan\beta + k\,\gamma}\tan\phi'$$

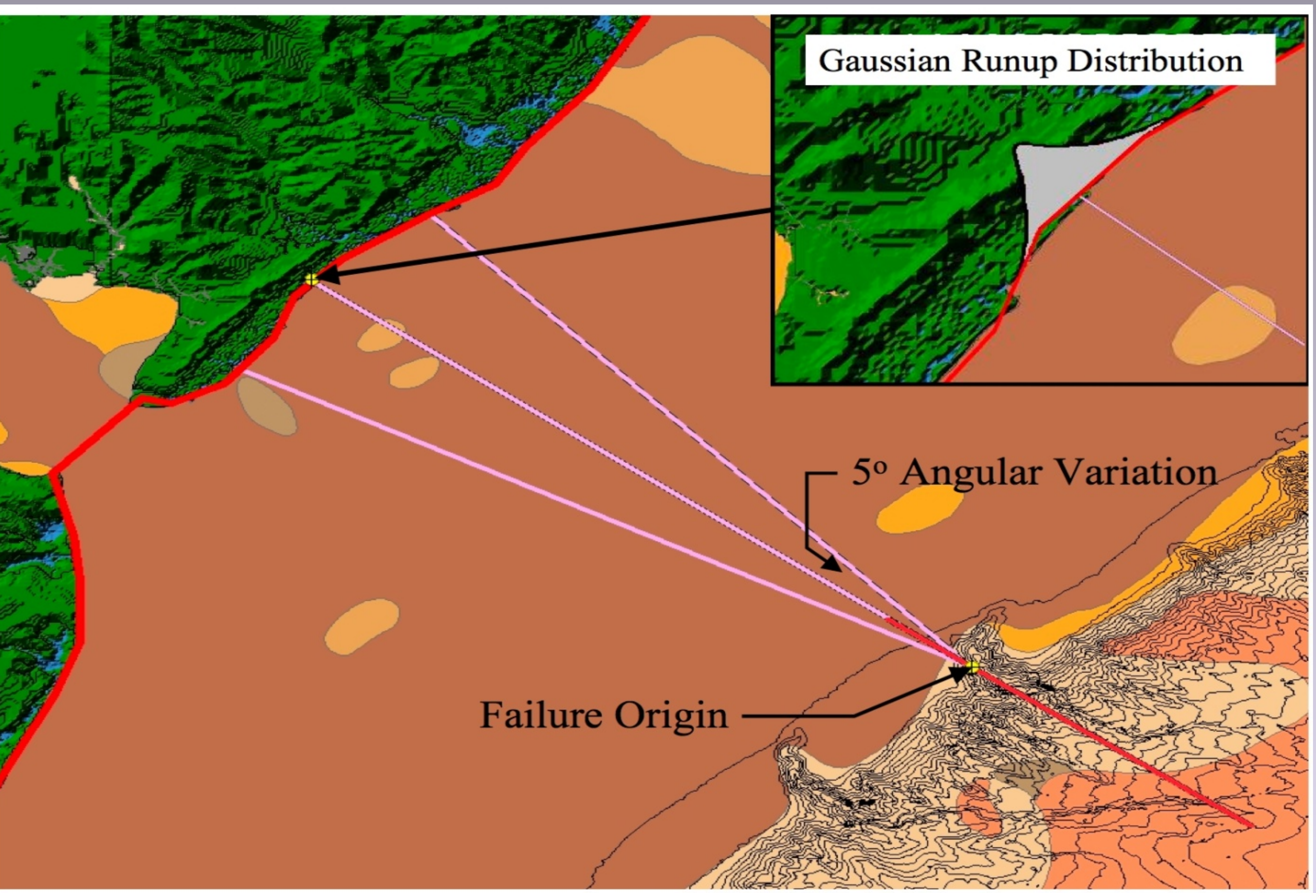


- Pseudostatic coefficient *k* is assumed to be equal to peak horizontal acceleration (PHA)
- Pore pressure ratio (*Ru*) based loosely on ODP 174 field data

MC Runup: Simplified coastline and coastal points



MC Runup: Simplified coastline and coastal points



- Generation
  - -> Empirical Eqs. for slides (trans)/slumps (rot) from SMF model simulations (Grilli and Watts, 2005 and others)
- Inundation
  - -> Correspondence Principle
  - -> Gaussian Distribution
- Shoreline simplified and defined by 3500+ coastal points

Statistical Analysis of Runup

- *SMF Tsunami Return Periods* :
  - Based on FEMA Guidelines for Coastal Flooding Analyses :

  => A *Y* year return period event (or recurrence interval) is equaled or exceeded once on average every *Y* years.

  => The reciprocal of the return period is the probability that the event is equaled or exceeded in any given year.

  - Not all earthquakes cause SMFs and not all SMFs cause tsunamis (i.e., are tsunamigenic) !

Statistical Analysis of Runup

- *Probability* of tsunamigenic slope failure (i.e., SMF) :

$$P_f = \frac{n}{N}$$

  - n : total number of tsunamigenic slope failures
  - N : total number of MC simulations

- *Annual probability* of tsunamigenic slope failure :

$$P_{SMF} = P_{PHA} \cdot P_f$$

  - P_{PHA} : earthquake annual probability

Statistical Analysis of Runup

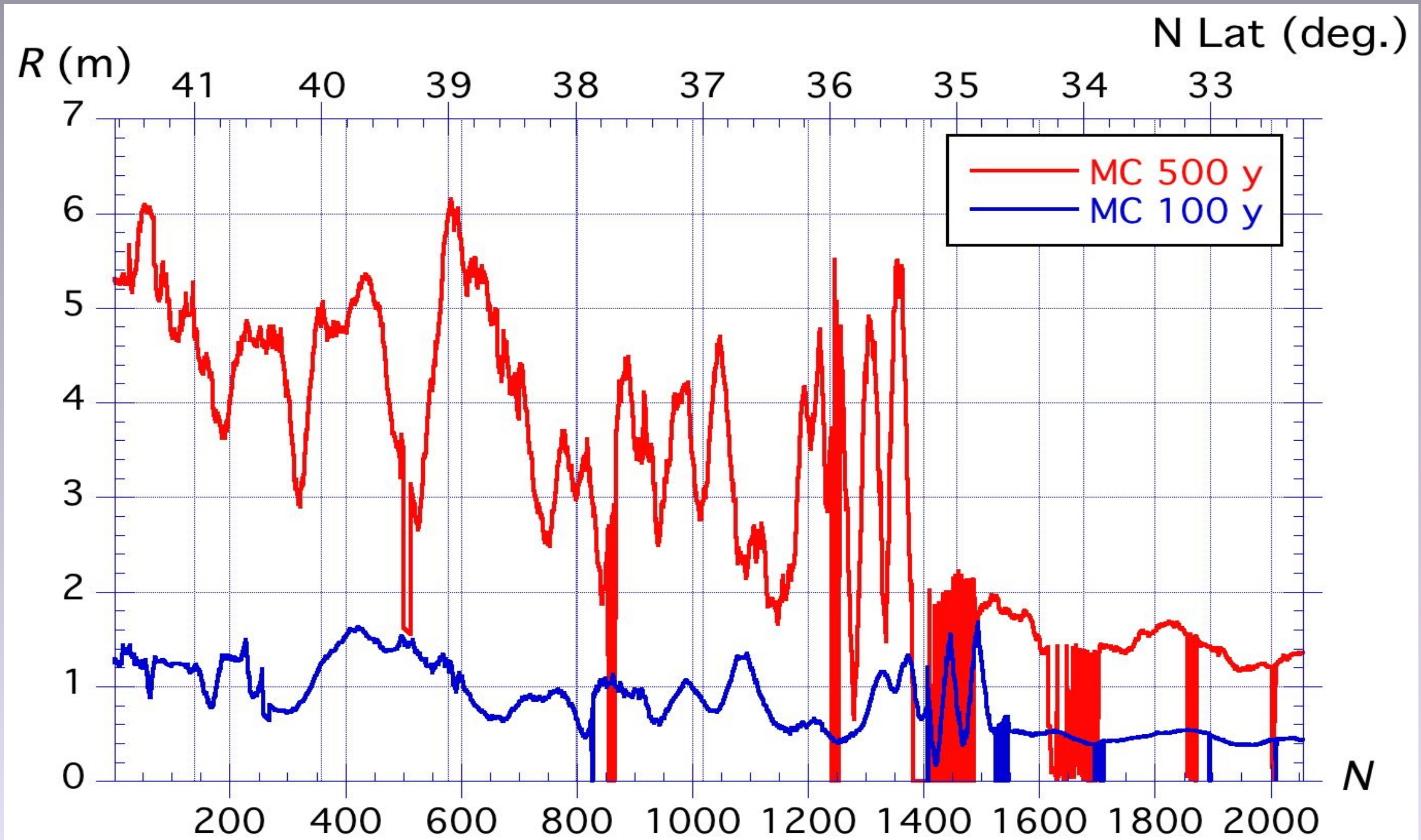
- *Design runup* : 1% of descending runup values starting with the highest possible return period in the study area (as in FEMA).
- *Design runup magnitude* :
  - Runups generated from tsunamigenic SMFs in MCS at each coastal point, are sorted in descending order from 1 to *m*-th.
  - The value of runup for a given probability of exceedance (P_z) corresponds to the z^{th} data point:

$$z = \frac{P_Z}{(P_{SMF})100} \cdot m$$

=> we computed and plotted 100 and 500 year runups

Results of runup statistical analysis

- *Runup:*



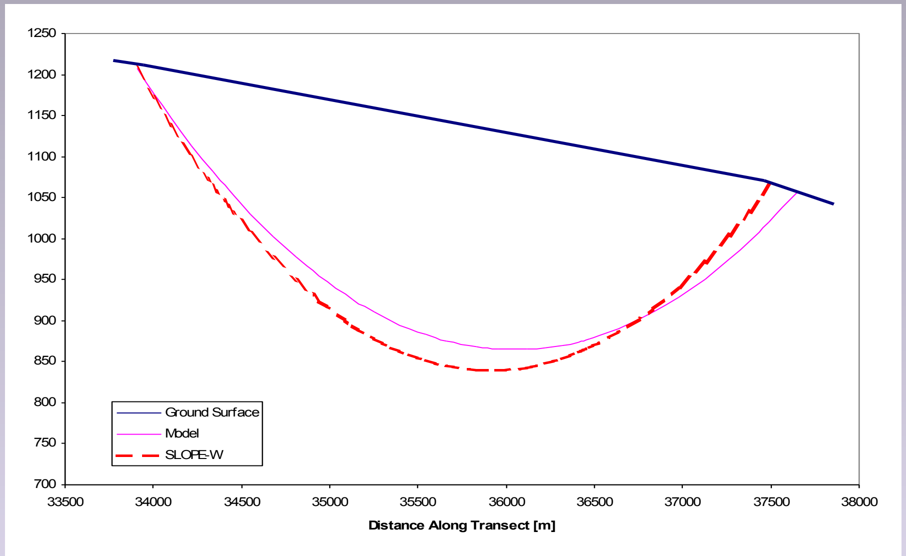
Slope Stability Result Validation

- Input Parameters:

  -> Distributions (normal, log normal) of randomly selected MC parameters were compared to known distributions (Density, Depth, Length, etc.)

- Slope Stability:

  -> MC results were compared with SLOPE-W TM results =>



- Published Sediment Properties:

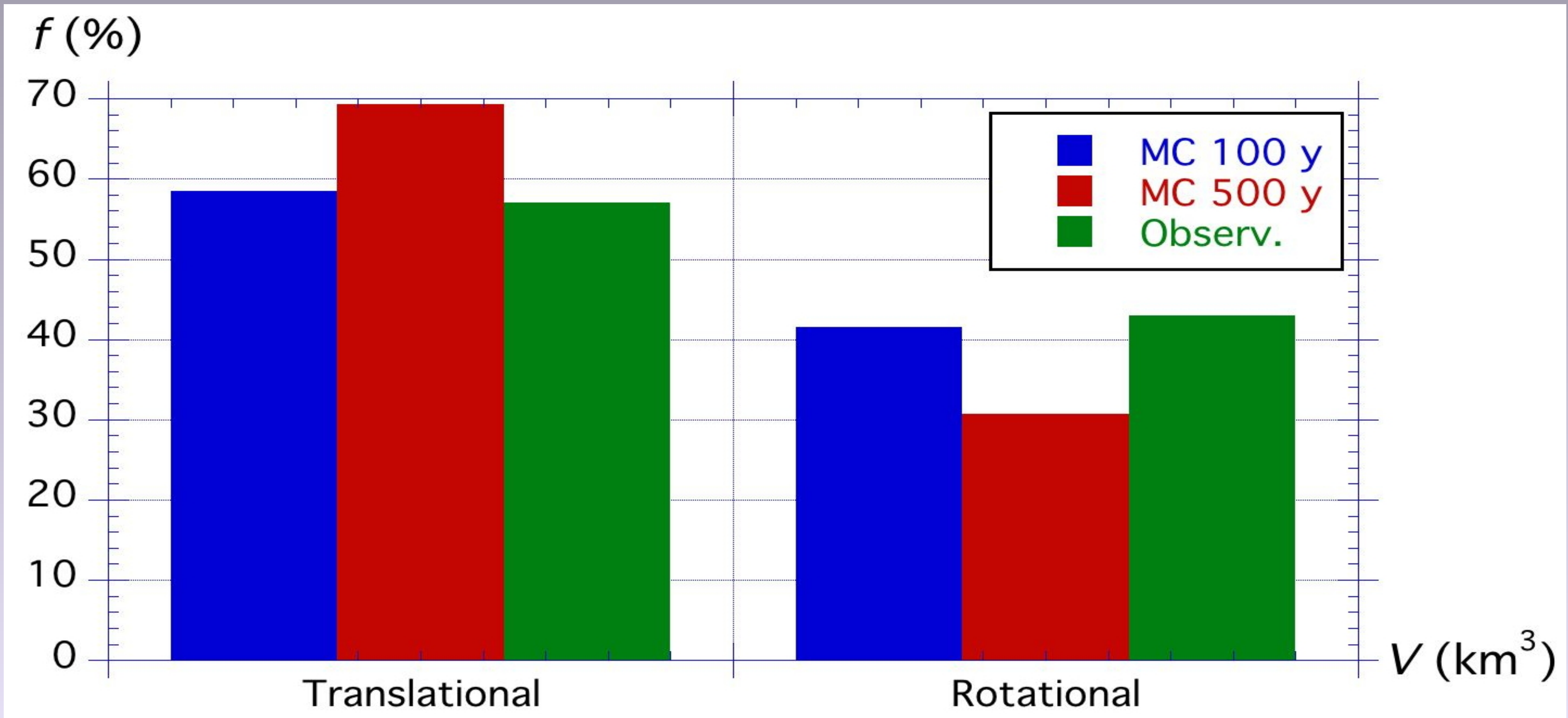
  -> Coefficient of variation

- Geological Observations:

  -> MC predictions for freq. of Slump/Slide, SMF area and volume were compared to observations of Booth et al. (1993) and Chaytor et al. (2009)

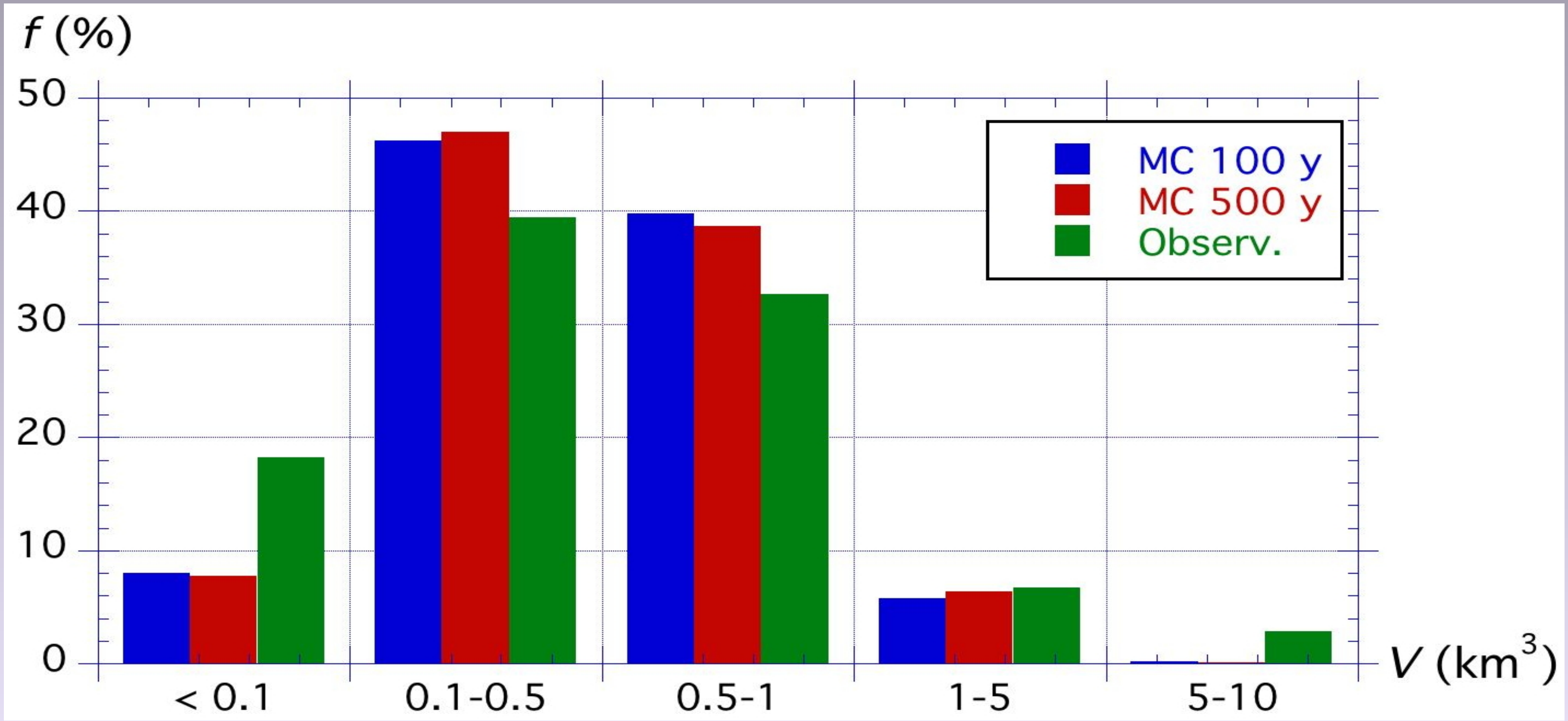
Validation with observations (Chaytor et al., 2009)

- SMF *Types:*



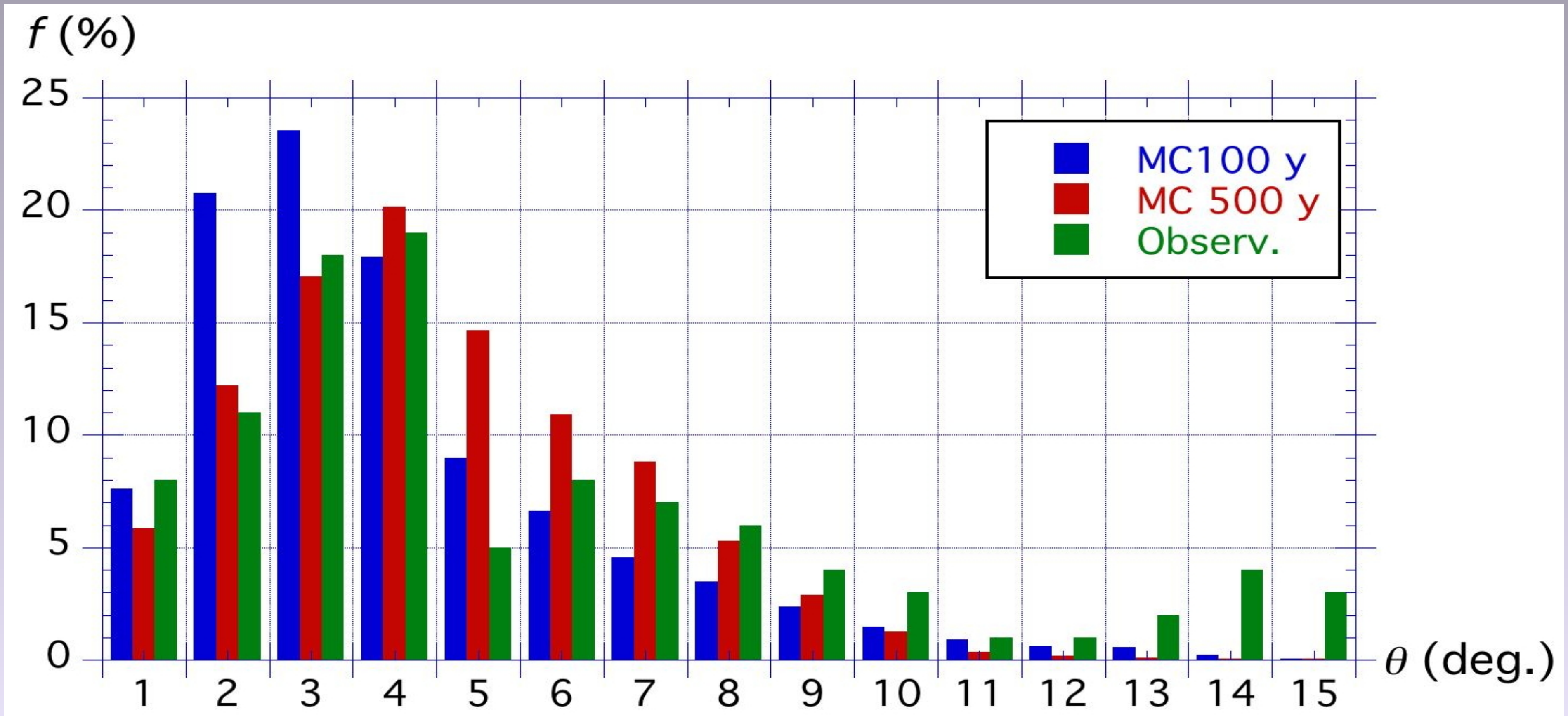
Validation with observations (Chaytor et al., 2009)

- SMF *Volume:*



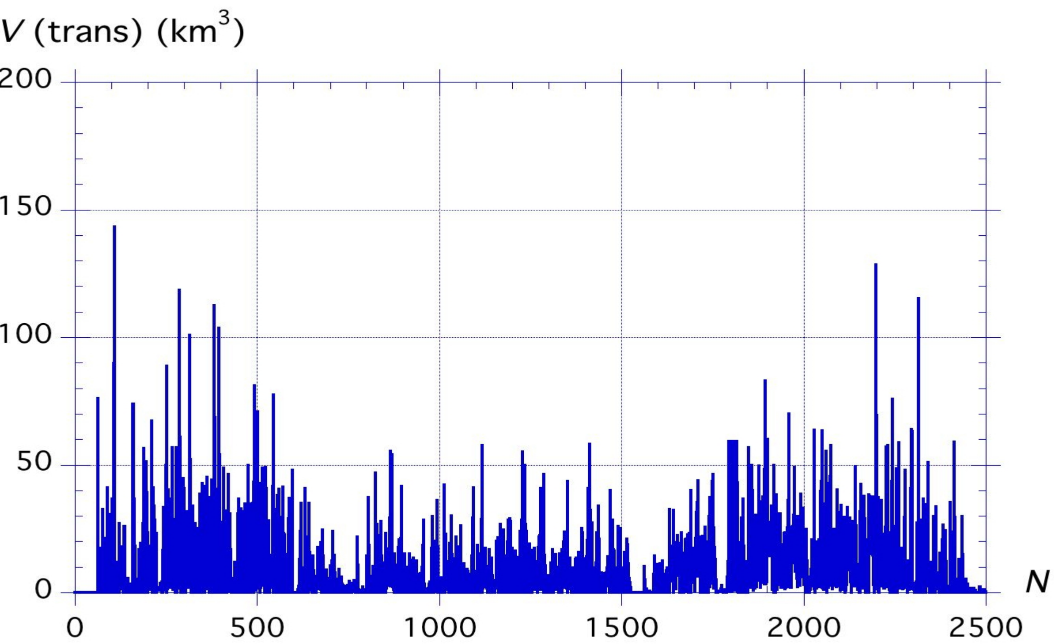
Validation with observations (Chaytor et al., 2009)

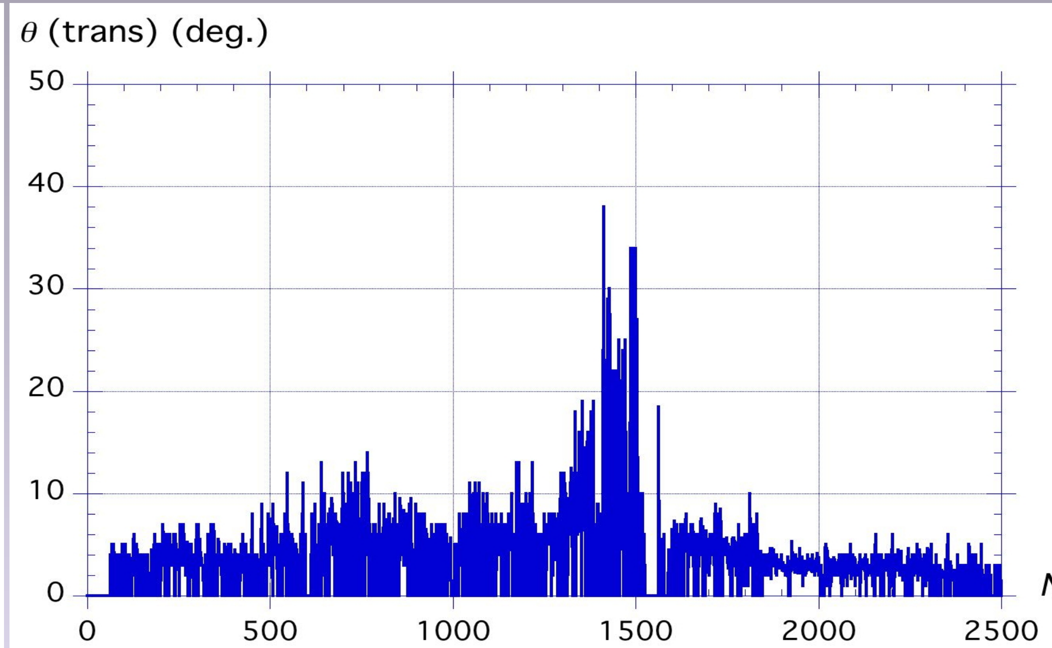
- SMF *Slope* angle:



Characterization of failures causing 500 y runup

- *Translational:*





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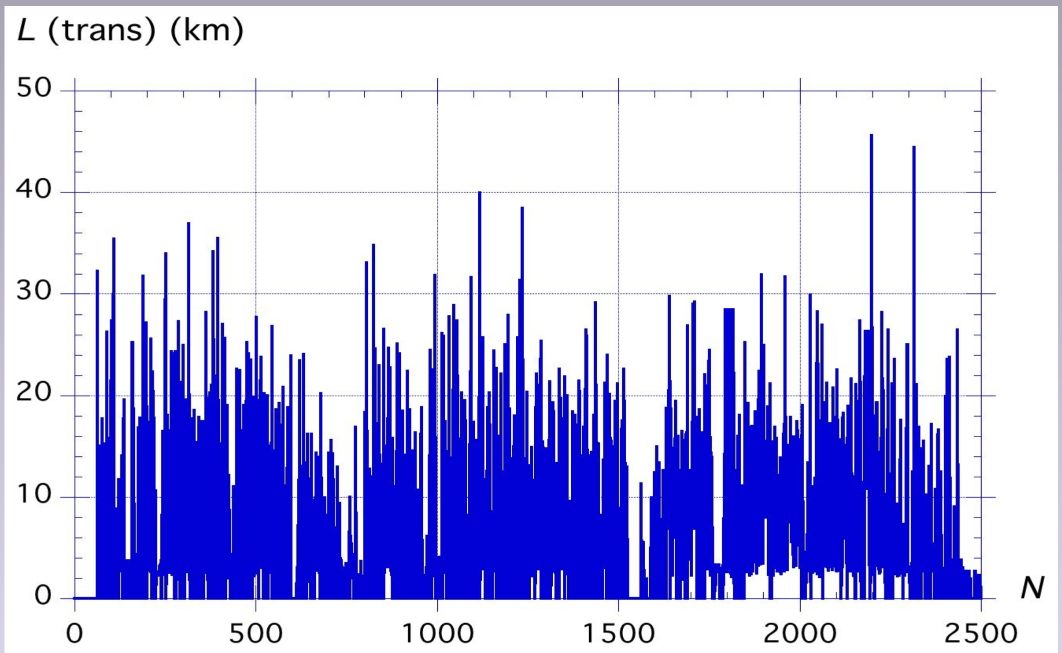

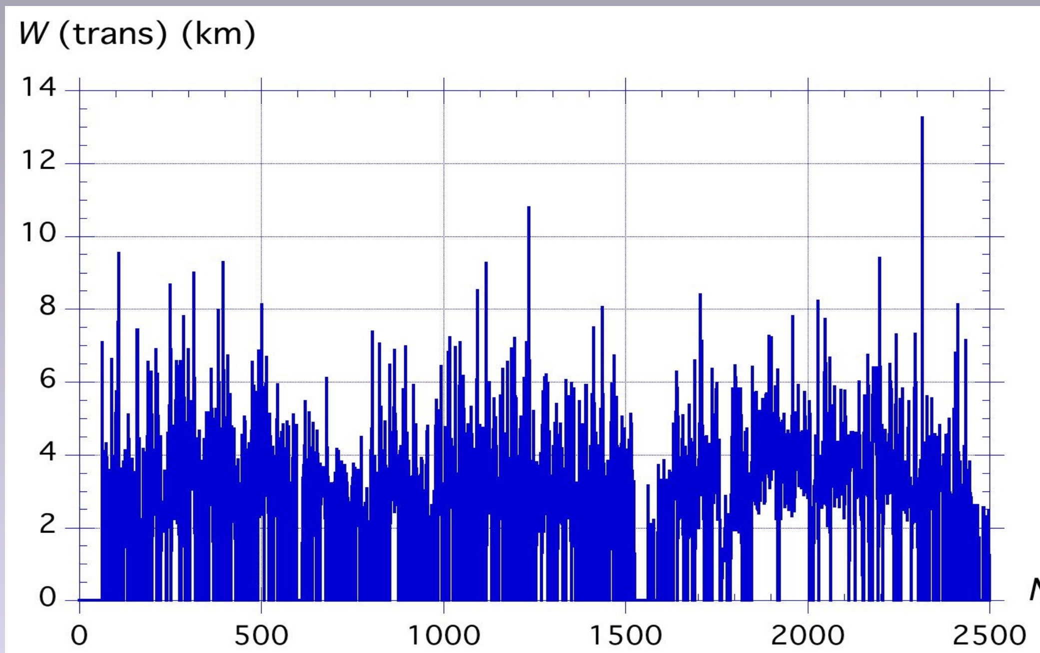

=> and similarly for rotational failures…

Characterization of failures causing 500 y runup

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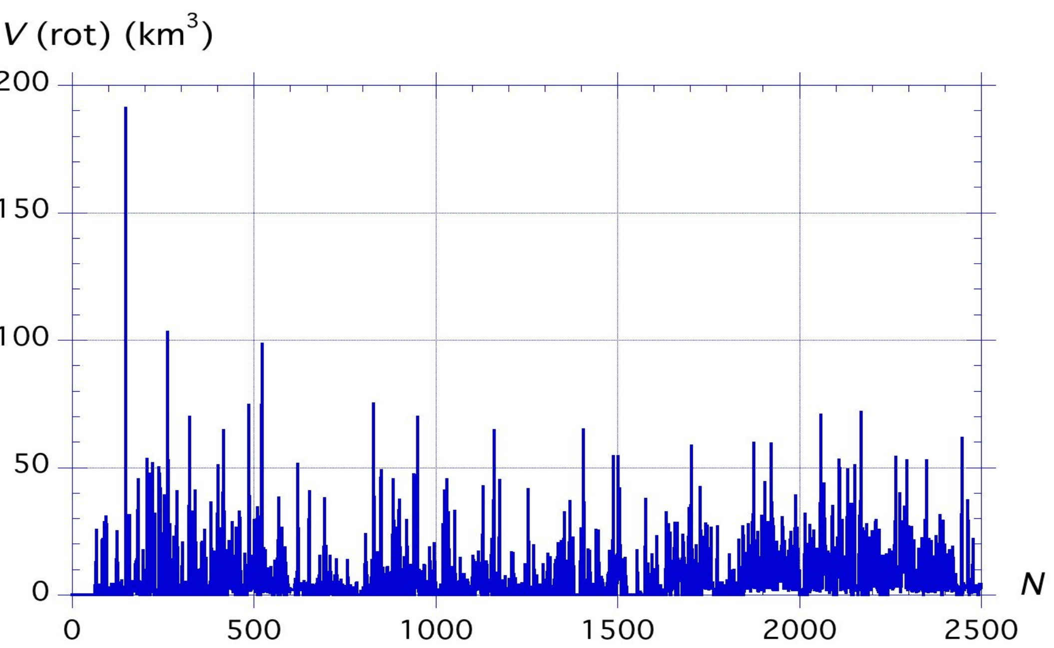

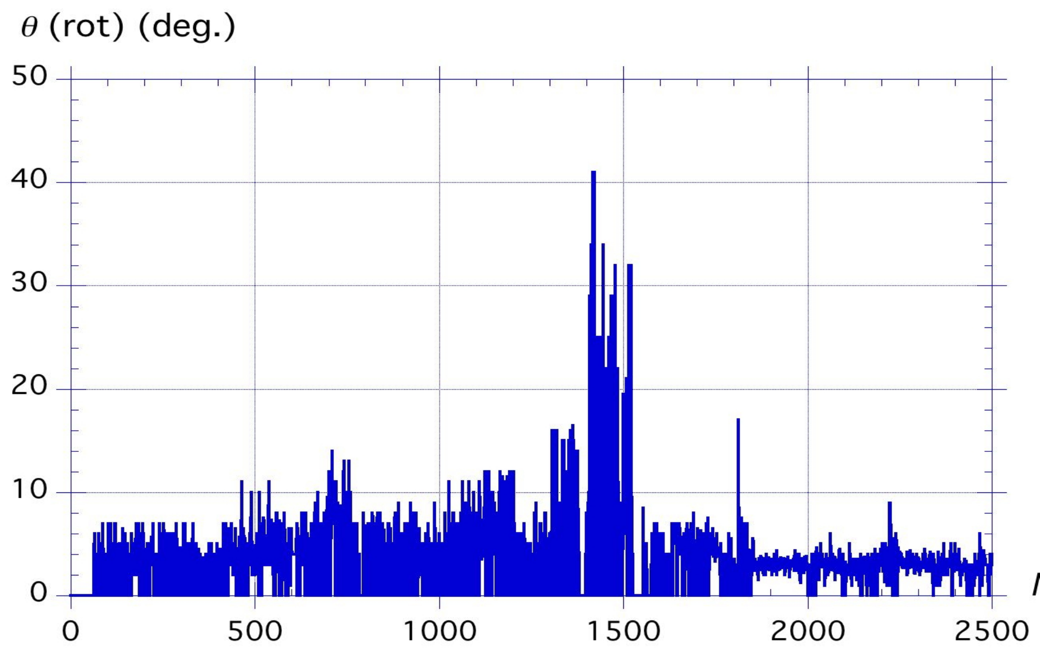

Characterization of failures causing 500 y runup

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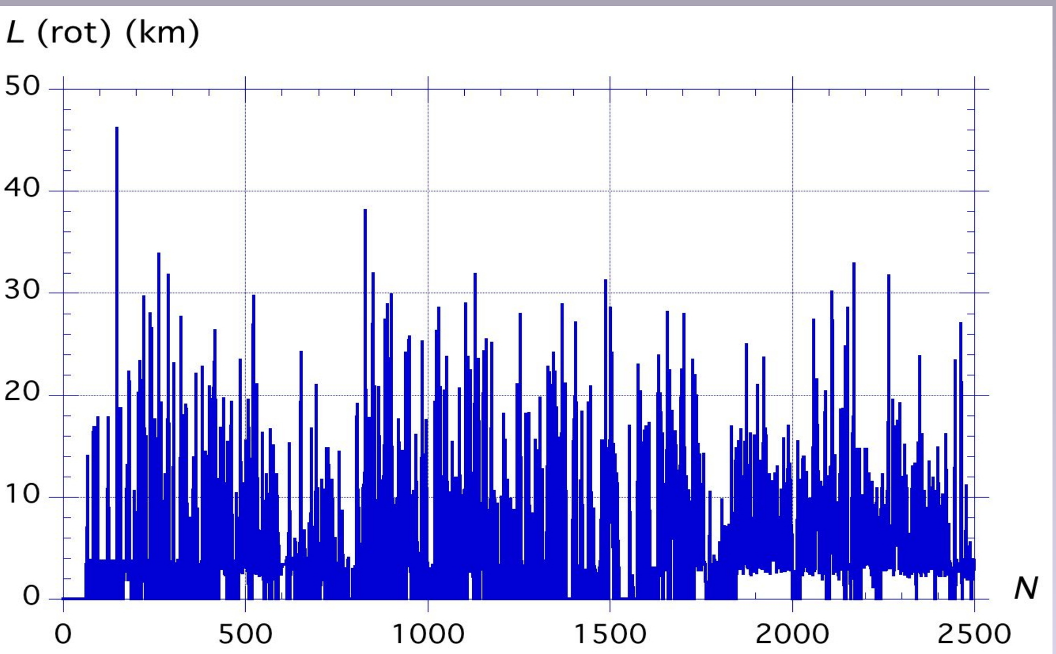
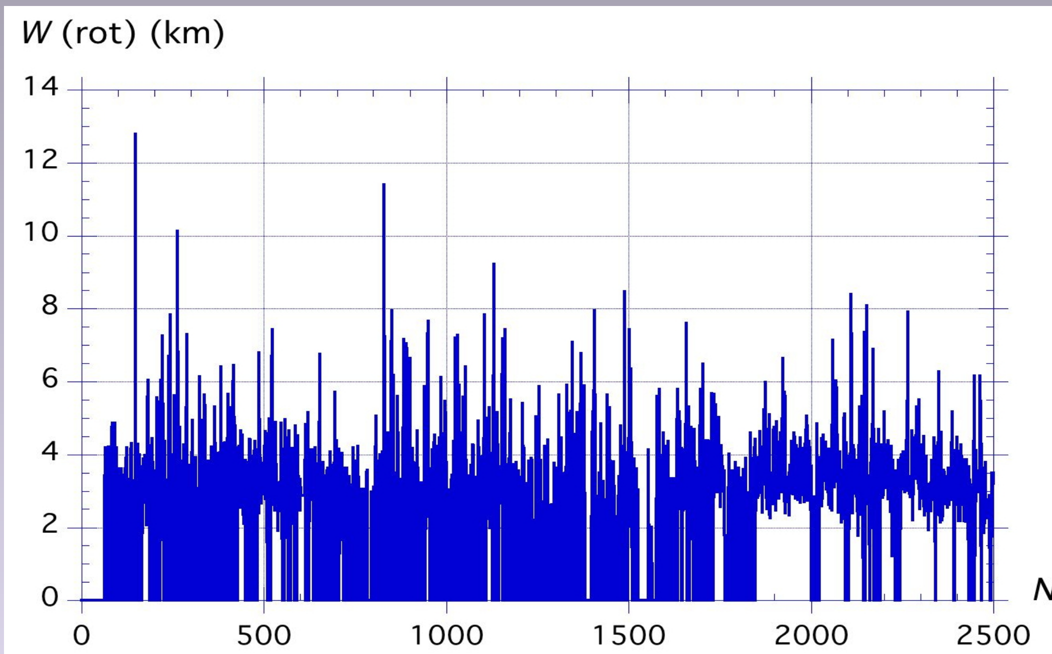
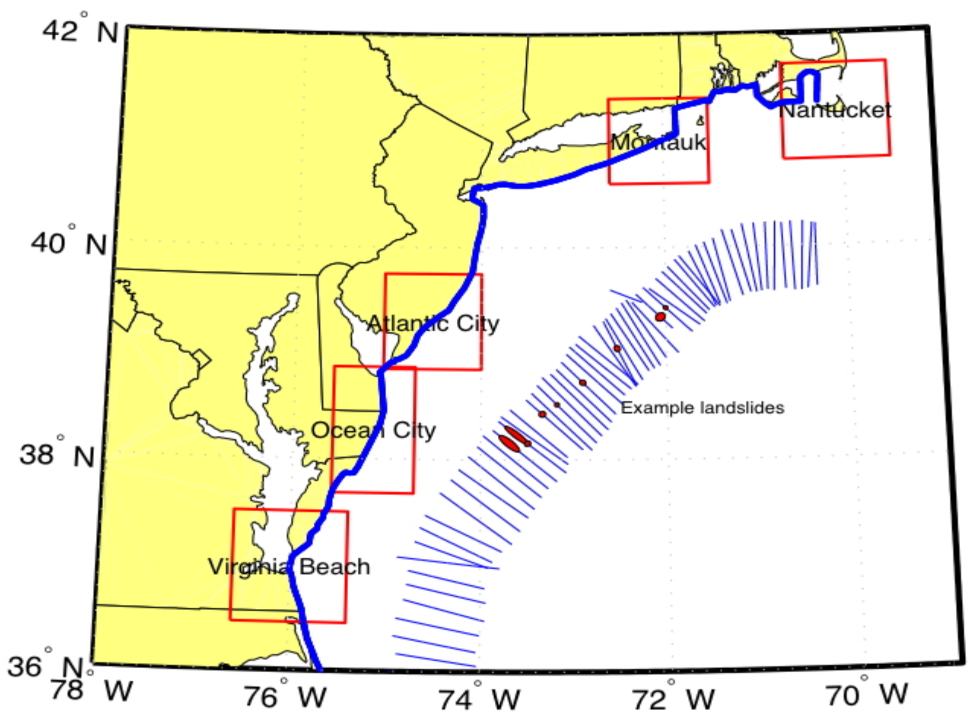
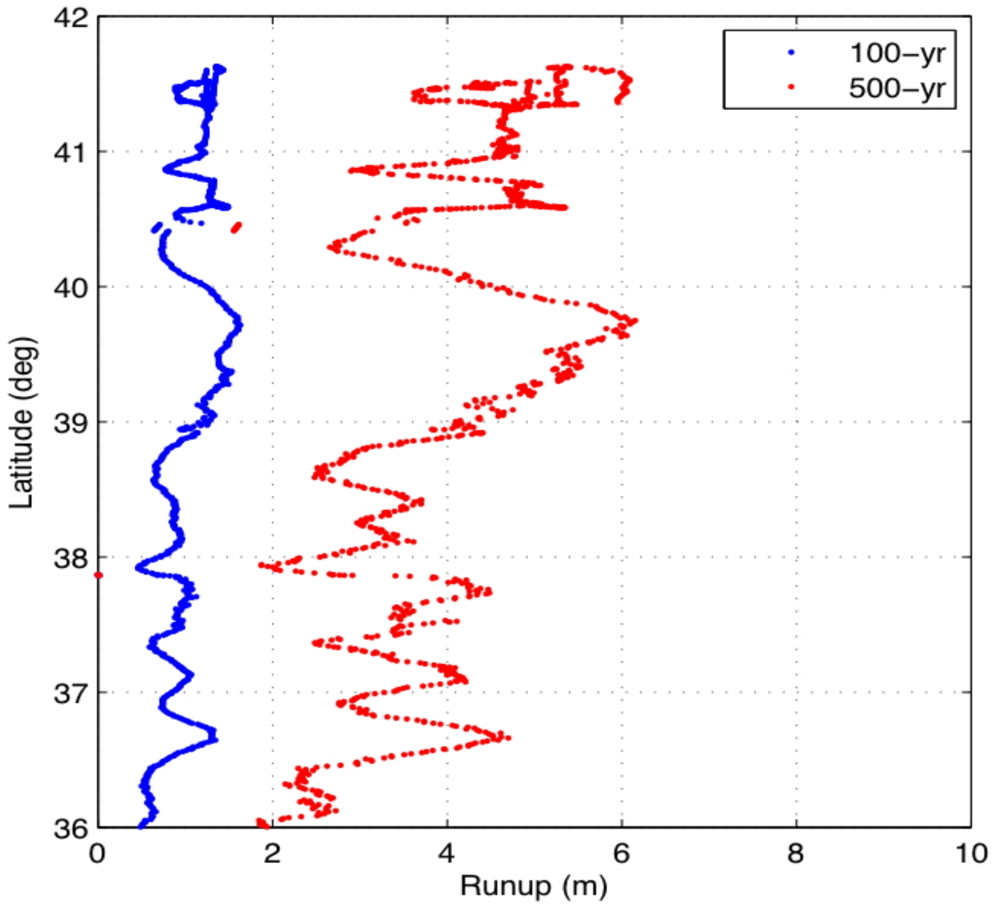




Full modeling of "500 y runup" tsunami impact

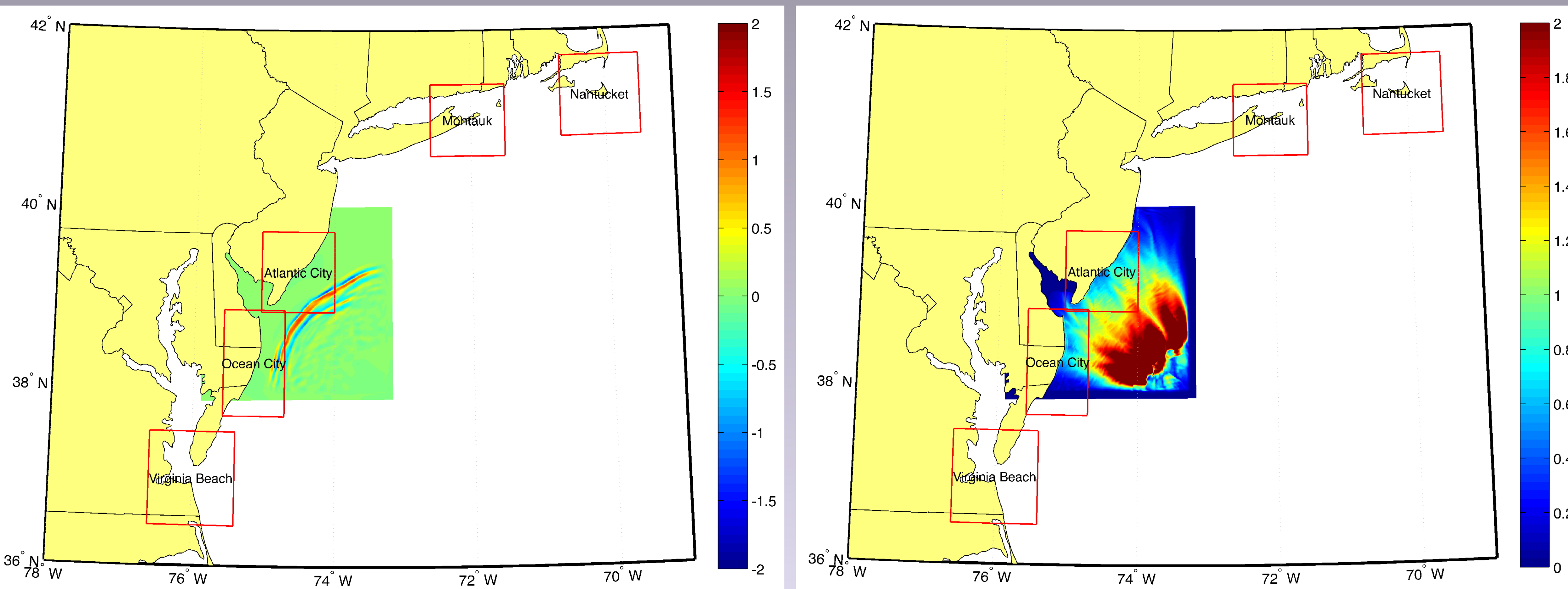
- Selection of *500 y SMFs* off of *high risk areas* :





Full modeling of "500 y runup" tsunami impact

- Modeling of *500 y SMFs* off of Atlantic City:

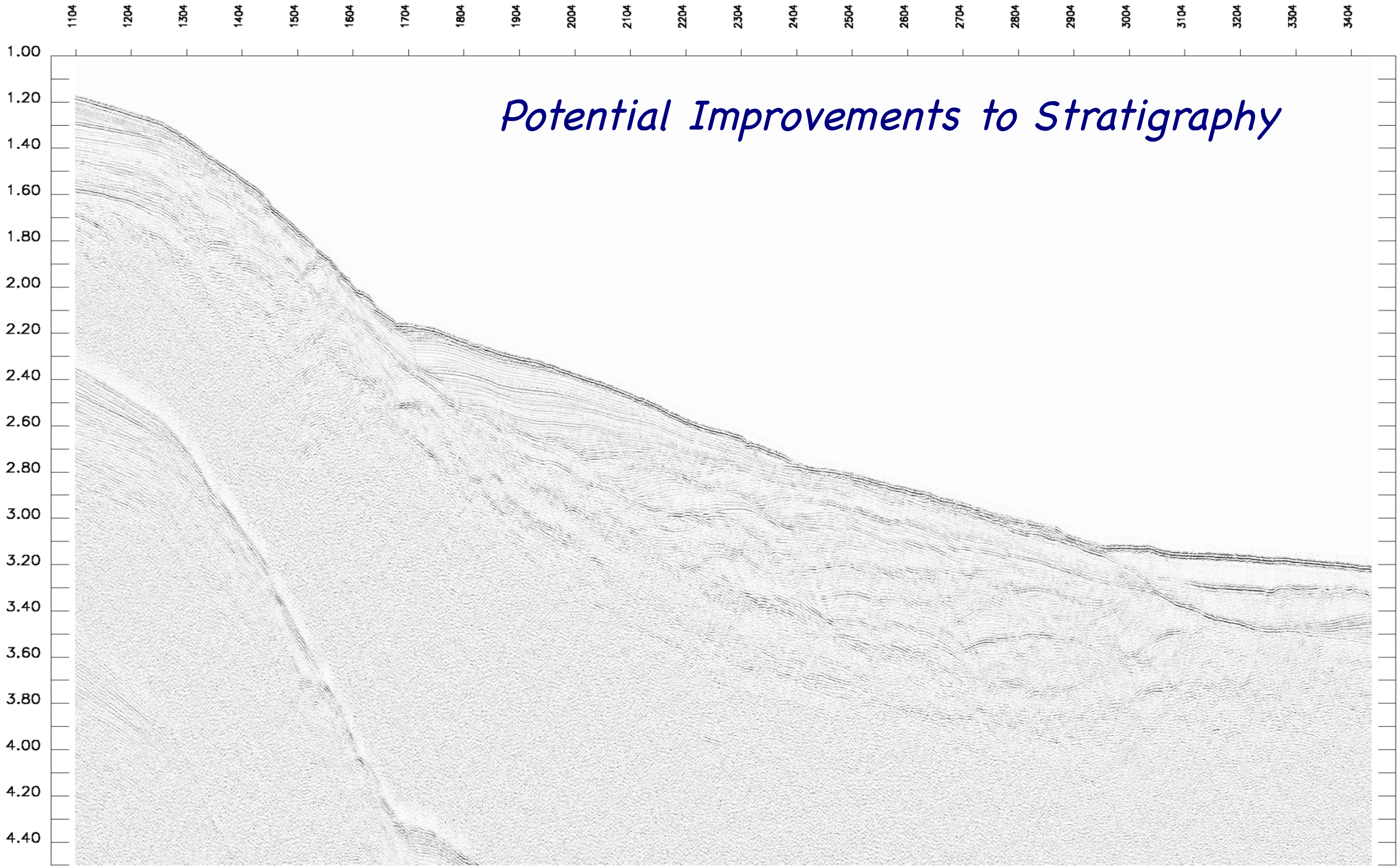


[Boxes denote available DEMS at 1/3"]

Limitations and Future Improvements

- Field validation of selected SMFs (USGS/URI) (1st presentation)
- Applicability/accuracy of USGS PHA offshore
- Use of surficial sediment data and large uncertainties in stratigraphy for geotechnical properties -> need for more site specific data and coring (more USGS cruises this summer)
- Limitations of limit equilibrium methods to model progressive failure or multiple failure scenarios
- Simplified estimates of runup (correspondence principle, no breaking waves)

Potential Improvements to Stratigraphy



USGS, 2010

Potential Improvements to Sediment Properties