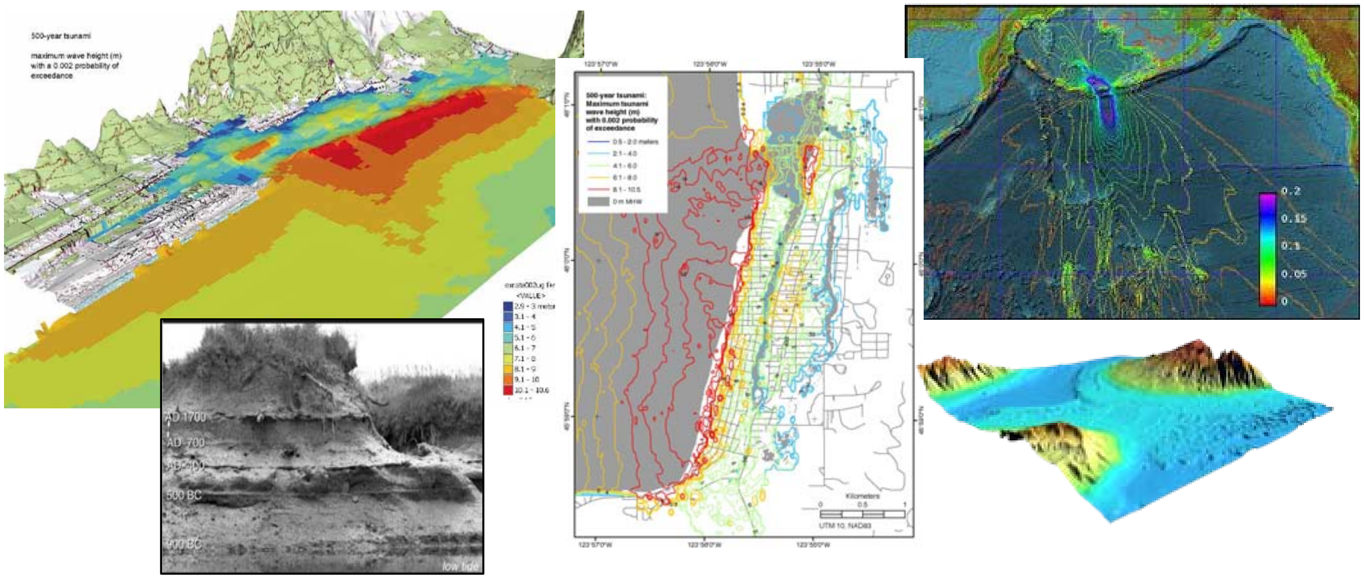
Probabilistic Tsunami Hazard Assessment



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Hazard, Vulnerability, and Risk

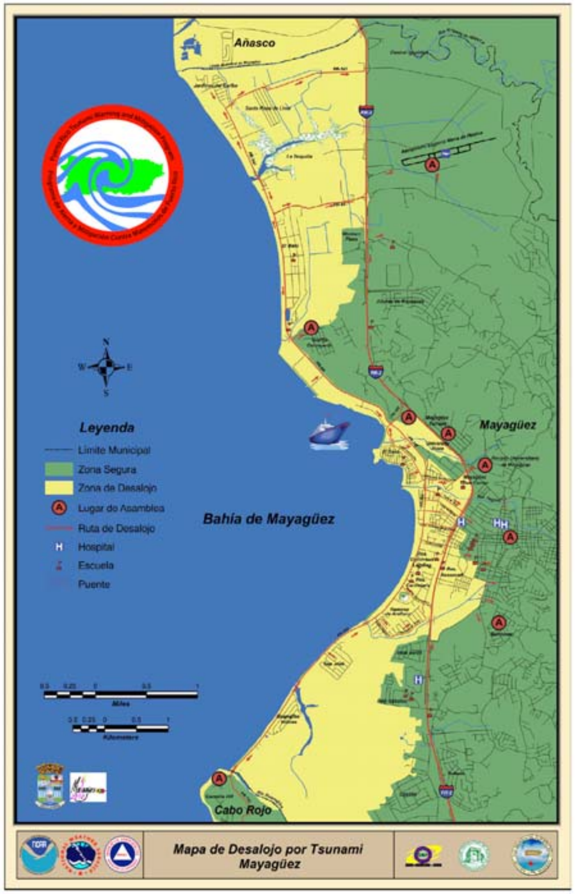
- Hazard Assessment is the first step in determining the actual risk from a hazard
- **Hazard** – the *probability of occurrence* of a potentially damaging phenomenon, e.g. earthquakes, tsunamis
- **Vulnerability** – the *degree of loss* resulting from the occurrence of the phenomenon due to *exposure* and *fragility*
- **Risk** – *hazard and vulnerability are combined* to estimate expected number of casualties, direct economic losses, indirect economic losses due to business interruption

Hazard Assessment

- Identification of sources and calculation of probability of occurrence
  - Historical record of occurrence is analyzed
  - For hazards that occur infrequently, use of geologic data can extend the record significantly
- Hazard assessments for infrequent hazards
  - Deterministic - single-valued events to arrive at a scenario-like description
  - Probabilistic - multi-valued or continuous events and models incorporating the effects and frequencies of all events that could impact a site

Tsunami Hazard Assessment (THA)

- Deterministic vs Probabilistic THA
  - Different analysis for different purposes
    - **Deterministic THA -** Evacuation Maps derived from tsunami inundation maps are based on the maximum credible tsunami
    - **Probabilistic THA –** Insurance applications focus on 1% annual probability of exceedance or the 100-year base flood standard
  - Problems in analysis and interpretation
    - **Deterministic THA –** intuitive measure of probability is used for less common sources such as asteriods, submarine landslides, volcanic processes
    - **Probabilistic THA –** difficult to interpret since not based on one event

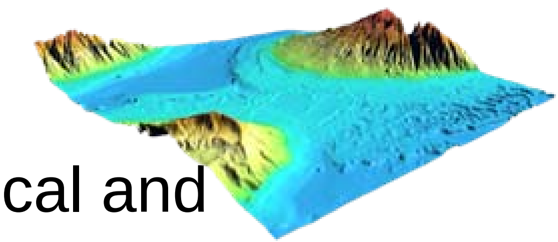


Local, Regional, and National PTHAs

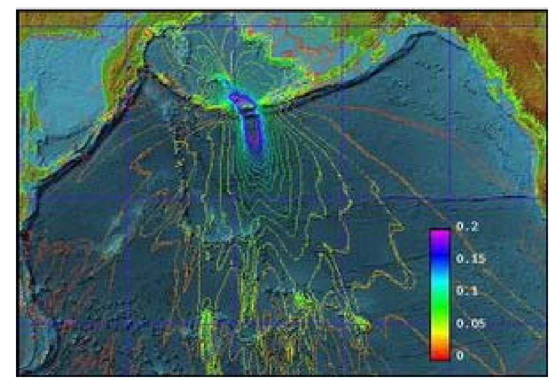
- *Seaside, Oregon Tsunami Pilot Study—Modernization of FEMA Flood Hazard Maps,* 2006, Joint NOAA/USGS/FEMA Special Report
- *Probabilistic Analysis of Strong Ground Motion and Tsunami Hazards in Southeast Asia*, 2007, H.K. Thio, P. Somerville, G. Ichonise
- *Probabilistic SMF [Submarine Mass Failures] Tsunami Hazard Assessment for the Upper East Coast of the United States*, 2007, S. Maretzki, S. Grilli, and C.D.P. Baxter
- *Probabilistic Analysis of Tsunami Hazards* [Acapulco, Mexico and U.S. Pacific Coast], 2006, E. Geist and T. Parsons
- *A Probabilistic Tsunami Hazard Assessment for Western Australia,* 2007, D. Burbidge, P. Cummins, and R. Mieczko
- *Estimation of Tsunami Hazard [probabilistic] in New Zealand due to South American Earthquakes*, 2007, W. Power, G. Downes, and M. Stirling
- *Probabilistic Tsunami Hazard Assessment of El Salvador*, 2005, B. Brizuela

PTHA Data and Modeling Requirements

- Historical and Prehistorical tsunami (deposit) data
- High-resolution DEMs (topography, bathymetry, tidal information)



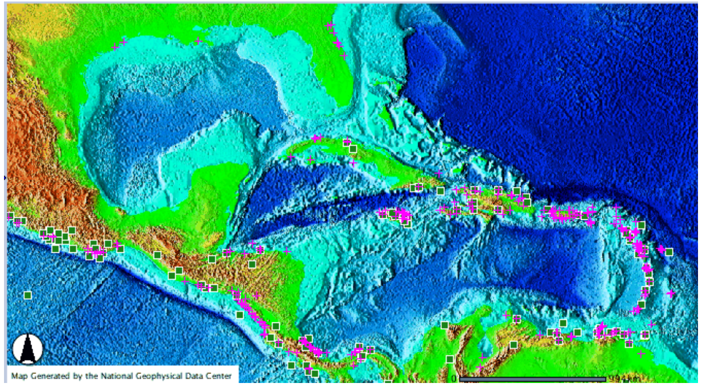
- Quantitative probabilistic models of local and far-field tsunami sources (earthquake, landslide, volcano)
- Numerous inundation and propagation simulations for tsunami sources
- Probabilistic tsunami hazard assessment model



- *Different regions will have varying spatial and temporal data resolutions and data accuracies*

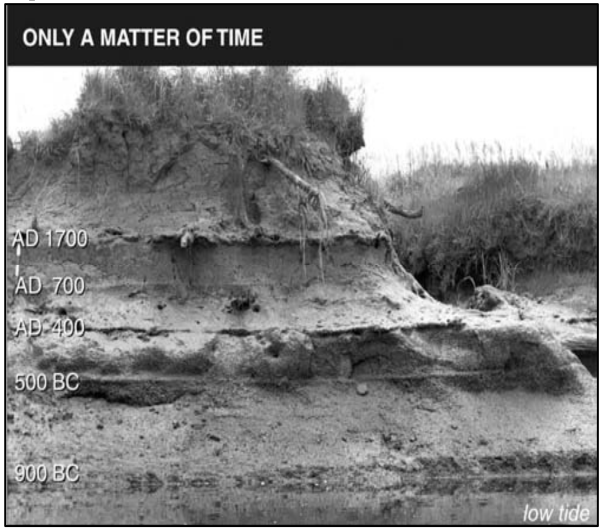
Historical Tsunami Record

- Global Historical Tsunami Data
  - **Source event (time, location, magnitude)**
  - **Run-up locations where tsunami waves were observed (water heights, arrival times, wave periods)**
  - **Damage, deaths, injuries from the source and the tsunami**
- Subset the study area and determine -
  - **Frequency, spatial distribution, characteristics of historical tsunamis in the study area**
  - **Frequency of local, regional and distant tsunamis affecting the study area**
  - **Frequency of tsunami sources (earthquakes, volcanoes, landslides)**
  - **Completeness of the catalog**
  - **Reliability of the tsunami events and runups**



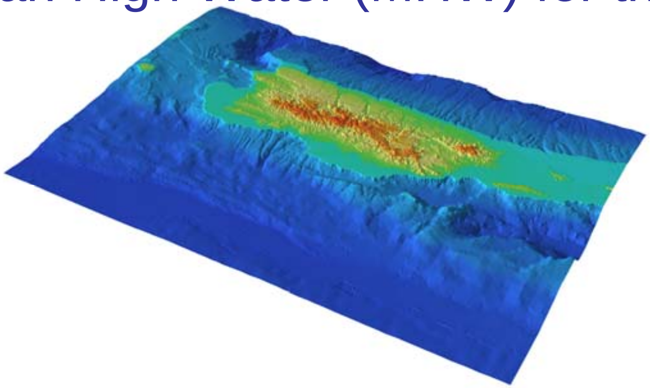
Prehistorical Tsunami (deposit) data

- Evidence of minimum inundation areas
- Spatial distribution and ages used for validation of hydrodynamic modeling
- Changes in topography or bathymetry and shoreline stability need to be accounted for
- Used to develop tsunami recurrence intervals at sites with simple topography and well-preserved tsunami deposits
- Historical and Prehistorical data are used to validate models



Digital Elevation Models

- Determine highest resolution coastal relief data available for the study area, examples:
  - ETOPO2 provides two-minute gridded global relief for both ocean and land areas http://www.ngdc.noaa.gov/mgg/global/global.html
  - International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico http://www.ngdc.noaa.gov/mgg/ibcca/ibcca.html
- Tidal information
  - DEMs should be referenced to Mean High Water (MHW) for the worst-case scenario
- Shoreline changes
  - Can be obtained from historical aerial photography



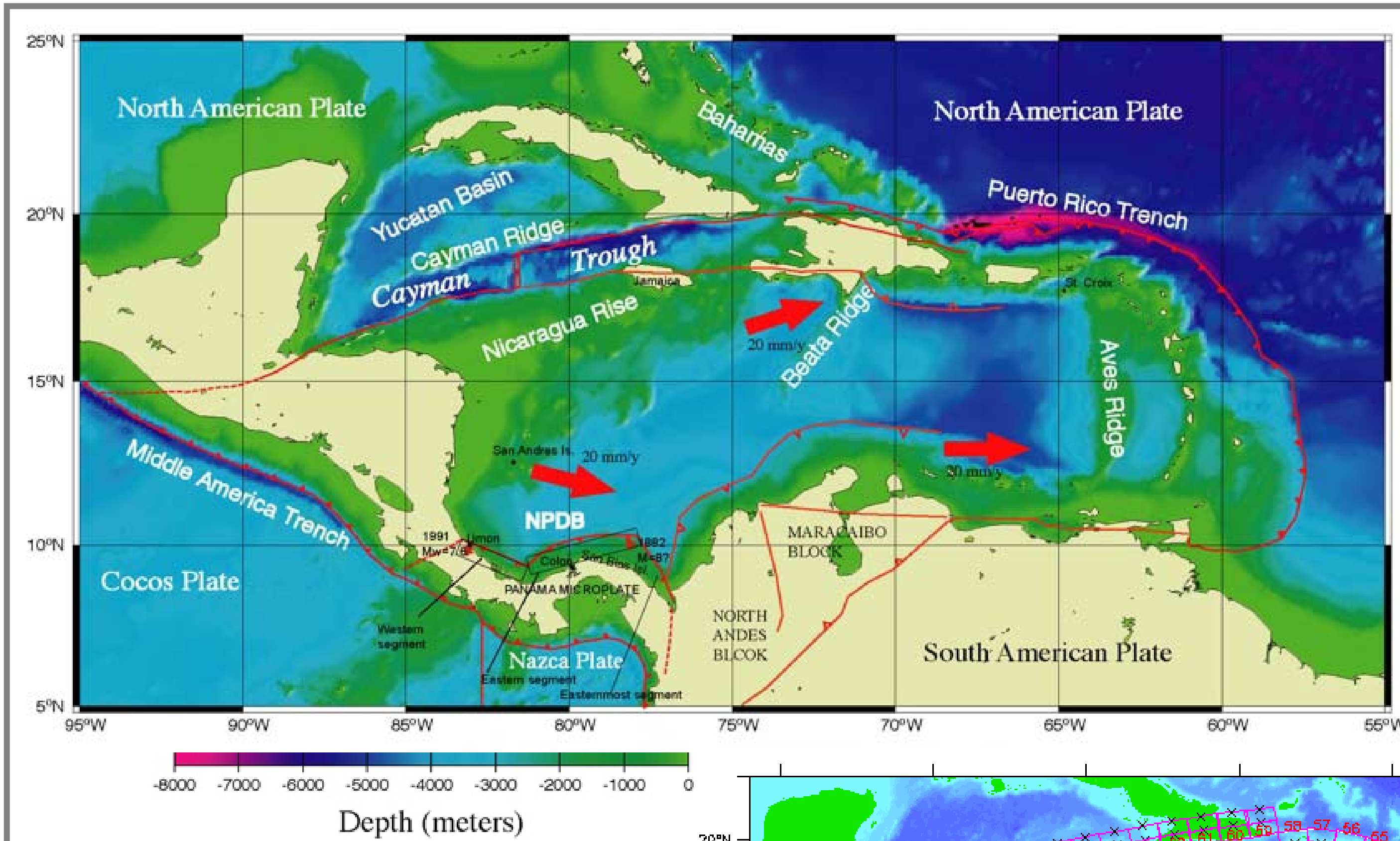
Tsunami Source Specification

- Determine geologic setting of study area
- Determine earthquake source magnitude, geometry and maximum return period for local and distant sources
- NOAA / PMEL Facts database includes pre-calculated time series of tsunami waves from 182 (unit) sources in the Caribbean

Segment Name	Maximum Magnitude (Mw)	Dip (deg)	Maximum Seismogenic Depth (km)	Number p.a. ≥ Mw7.0	Slip-rate (mm/yr)
Andaman Megathrust	9.3/9.5[1]	14	50	0.043	
Sumatra Megathrust	9.3/9.5[1]	15	50	0.075	
Java Megathtust	8.5/9.0/9.3/9.5[2]	16	60	0.093	
Sumba Megathrust[3]	8.5/9.0/9.3/9.5[2]	14	60	0.075	
Sumba Normal[3]	8.5/9.0[1]	55	47	0.075	
West Timor Thrust	7.5/8.0[1]	20	17		23.0
East Timor Strike-Slip	7.5/8.0[1]	73	48		17.3
Tamibar Normal	7.5/8.0[1]	55	41		41.0
Wetar-Flores Thrust	8.0/8.5[1]	20	17		34.5
South Aru Strike-Slip	7.5	73	48		47.8
Aru Normal	7.5	55	41		41.0
South Seram Thrust	7.5	20	17		75.7
Seram Megathrust	8.5/9.1[1]	14	30	0.031	
West Seram Thrust	7.5	20	17		64.9

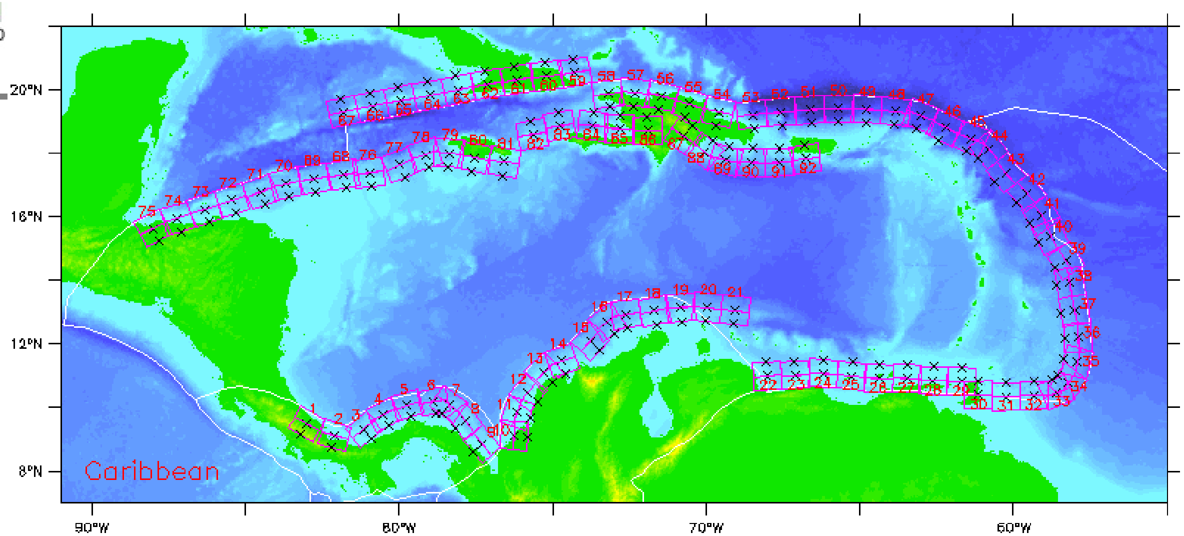
Geometry and physical properties of the fault segments used in the probabilistic tsunami hazard assessment, *A Probabilistic Tsunami Hazard Assessment for Western Australia*, Burbridge, Cummins and Mieczko

Propagation Model Database



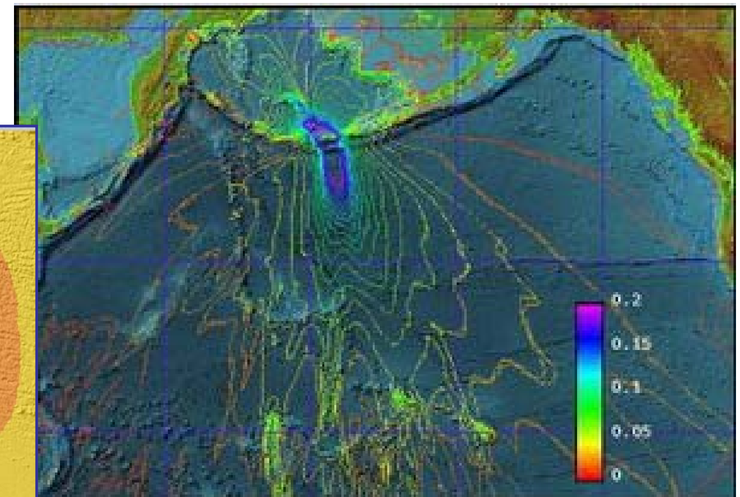
Pre-computed tsunami propagation scenarios for 182 “Unit sources”

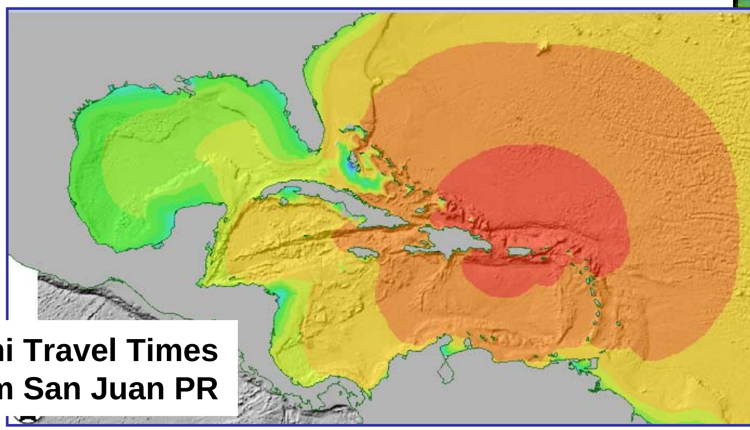
Provided by NOAA/PMEL



Propagation and Inundation Modeling

- Inundation models simulate tsunami evolution from the earthquake generation, transoceanic propagation and inundation of dry land
- Model output is compared with historical data



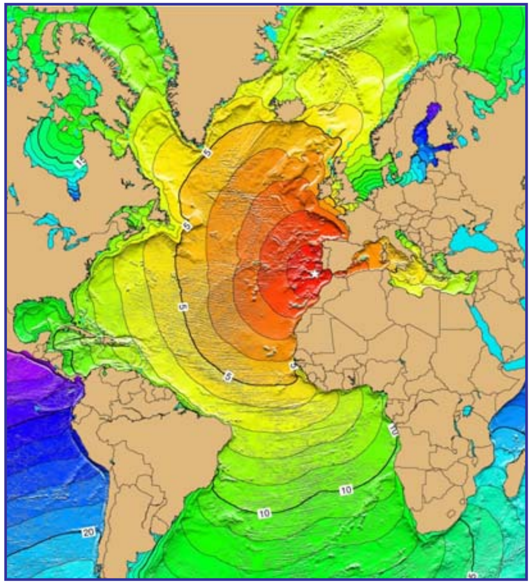


Tsunami Travel Times from San Juan PR

- Examples:
  - **MOST** (Method of Splitting Tsunami) model - developed by Titov of NOAA/PMEL and Synolakis of Univ. of S. California
  - **JRC** – developed by European Commission Joint Research Institute
  - **ANUGA** – developed by Geoscience Australia and Australian Natl Univ
  - **TUNAMI-N2** (Tohoku University's Numerical Analysis Model for Investigation of Near field tsunamis) model, developed by the Disaster Control Research Center of Tohoku University

Probabilistic Method

- Probabilistic Seismic Hazard Assessment (PSHA)
  - Probability that some measure of earthquake ground motion, such as peak ground acceleration, may be exceeded at a location of interest
    1) **Specification of earthquake source parameters and associated uncertainties**
    2) **Specification of the attenuation relationships**
    3) **Probabilistic calculations**
- Probabilistic Tsunami Hazard Assessment (PTHA) developed from PSHA
  - Probability that a tsunami wave height will be exceeded immediately offshore a location of interest
  - PTHA needs to include **far-field** and local sources
  - Most PTHAs only deal with earthquake sources



1755 Liston Portugal Tsunami Travel Time Map (NOAA/NGDC)

PTHA Methods

- Computationally based
  - Relies on knowledge of source parameters, recurrence rates and their uncertainties
  - Useful when few historical records or many possible sources
  - Based on PSHA method
    - **Determine maximum tsunami amplitude at a particular source location**
    - **Propagation – tsunami amplitude is modified by attenuation and shoaling factors**
    - **Calculate the rate of tsunamis per year that exceed a wave height at a coastal location**
    - **Uncertainties**
      - **Epistemic**
      - **Aleatory**

- Empirical analysis of tsunami run-up and amplitude data
  - Based solely on the historical record of tsunamis at a particular location
  - Tsunami amplitudes follow a frequency-size distribution over a long amount of time
  - Catalog completeness is an important factor

Example of a Final Result

500-year tsunami map

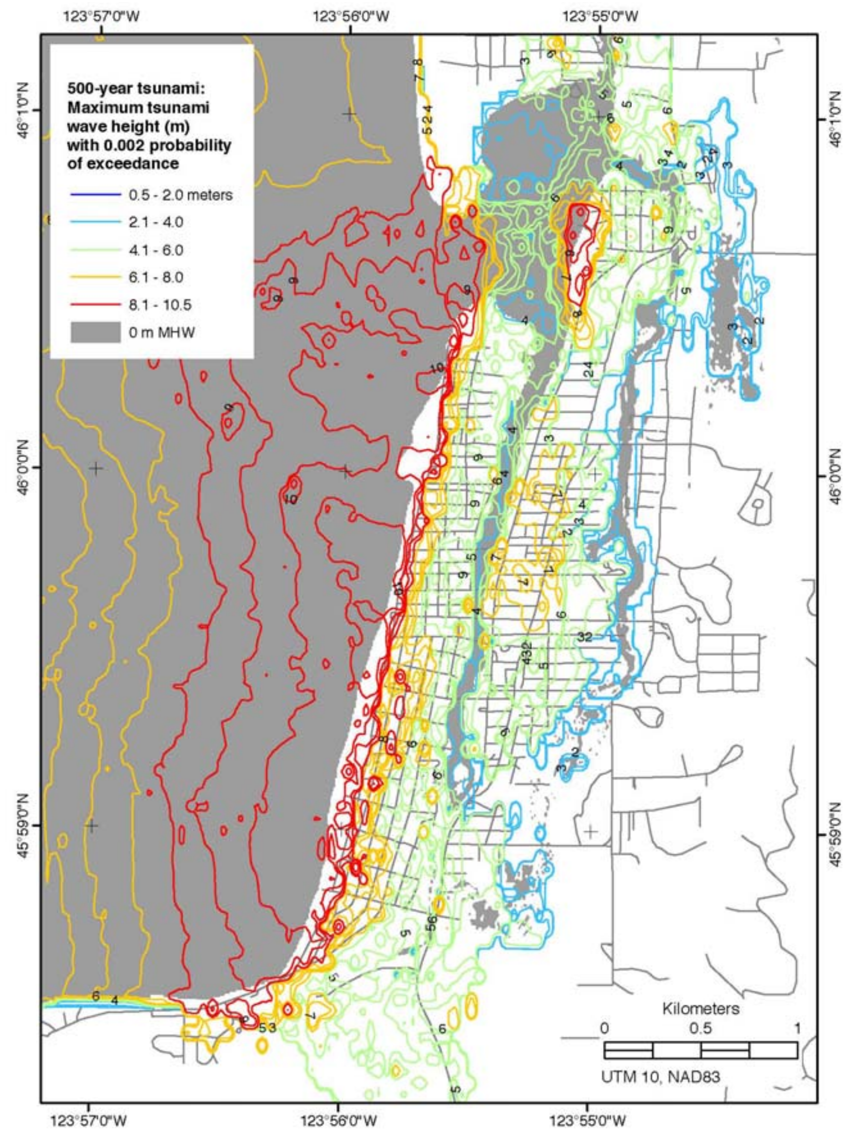
Maximum tsunami wave heights

with 0.2% annual probability of exceedance

Tsunami Pilot Study Working Group

Joint NOAA (PMEL)/USGS/FEMA Special Report, 103 p., 7 appendices

http://pubs.usgs.gov/of/2006/1234



Thank you