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 asteroids, submarine landslides, volcanic processes
    - **Probabilistic THA** – difficult to interpret since not based on one event
Local, Regional, and National PTHAs

- **Probabilistic Analysis of Strong Ground Motion and Tsunami Hazards in Southeast Asia**, 2007, H.K. Thio, P. Somerville, G. Ichonise
- **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
- **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

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<th>Segment Name</th>
<th>Maximum Magnitude</th>
<th>Dip</th>
<th>Maximum Seismogenic Depth</th>
<th>Number p.a. ≥ Mw7.0</th>
<th>Slip-rate (mm/yr)</th>
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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
Pre-computed tsunami propagation scenarios for 182 “Unit sources”
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.

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