Probabilistic Tsunami Hazard Analysis

Eric L. Geist
Pacific Coastal & Marine Science Center
US Geological Survey
Menlo Park, CA
https://www.usgs.gov/staff-profiles/eric-geist

Panel 2 – Cascading Hazards: Earthquake and Tsunami Impacts
What is the Chance of a Tsunami?

- **Necessary Ingredients**
  - Statement of the Problem
    - What Size?
    - Where?
    - Exposure Time?
    - Starting What Year?
  - Runup Probability
  - Tsunami Hazard Curve

[Map of Cascadia with Puget Sound and Seaside, OR marked]
Who Uses PTHA Results?

- Flood Insurance Agencies
  - FEMA
  - Reinsurance

- Structural Engineers
  - ASCE Design Standards
  - Risk Analysis

- Nuclear Engineers
  - NRC
  - IAEA

- Global Risk Analysis
  - UNISDR
Probabilistic Tsunami Hazard Analysis (PTHA)

- Developed mainly from Probabilistic Seismic Hazard Analysis (PSHA: Cornell, 1968)
- Main differences with respect to PSHA
  - Inclusion of far-field sources
  - Numerical modeling of propagation, runup, & inundation

Identification of Significant Sources of Uncertainty

- Source Parameters: Specifies geometric parameters and long-term rates of occurrence.
- Temporal Models: Gives the probability that each source will occur in a specified time span.
- Generation & Propagation Models: Calculates the tsunami wave height at the site for each source.
- Aggregation: Determines the hazard curve for each branch of the logic tree.

Development and Calculation of all Logic Tree Branches
Regional PTHA (Caribbean)
Site-Specific PTHA: Seaside, OR

González et al. (2009)
PTHA: Recent Advances

- Stochastic slip distributions
  (LeVeque\textsuperscript{1} et al., 2016; Melgar\textsuperscript{2} et al., 2016)

- Bayesian methods
  (Grezio\textsuperscript{3} et al., 2010; Parsons\textsuperscript{4} & Geist, 2009)

- Probabilistic flow velocities, momentum flux
  (Park & Cox\textsuperscript{5}, 2016)

- ASCE design standards
  (Chock\textsuperscript{6}, 2015)

- Tsunami risk
  (Løvholt\textsuperscript{7} et al., 2014; Wiebe & Cox\textsuperscript{5}, 2014)

- Global Tsunami Model (probabilistic)
  (INGV, Norwegian Geotechnical Institute, Geoscience Australia, AECOM, GNS Science, etc.)

\textsuperscript{1}U Washington  \textsuperscript{2}UC Berkeley  \textsuperscript{3}INGV  \textsuperscript{4}USGS  \textsuperscript{5}OSU  \textsuperscript{6}Martin&Chock  \textsuperscript{7}NGI
PTHA: Challenges

- Computational load (Behrens\textsuperscript{1} & Dias\textsuperscript{2}, 2015)
- Accurate & high resolution DEMs (NOAA)
- Trapped waves -> San Francisco etc.
- Intra-plate earthquakes and landslide sources (occurrence rates)
- Reducing epistemic uncertainty (dynamic rupture models)
- Time-dependent models
- Testing PTHA (Geist & Parsons, 2016)

\textsuperscript{1}U. Hamburg  \textsuperscript{2}Univ. College Dublin
Forthcoming Publications

- Pure & Applied Geophysics Special Issue: Global Tsunami Science Past and Future (12/16)
- A global probabilistic tsunami hazard assessment from earthquake sources (Davies et al., in press, Geol. Soc. London Spec. Paper) Predecessor paper to GTM
- Review paper on PTHA (Grezio et al.) (early 2017)
Time-Independent PTHA

- Inter-Event Distribution: Poisson Process

\[
P_{\text{pois}}(R > R_0) = 1 - \exp(-lT)
\]

\[
P_{\text{pois}} \rightarrow l, \text{ for } lT \ll 1
\]

- Runup Threshold
- Rate/Intensity Parameter
- Exposure Time
Aggregate Probabilities

- **General PTHA Framework** (Geist et al., 2008):

\[
(R > R_0) = \sum_{i,j} P(R > R_0 | i,j) f(Y_{i,j}) d_y \text{zone} = j \sum_{type = i}
\]

- \((R > R_0)\): Mean rate that runup will exceed \(R_0\) at a particular coastal location

- \(P(R > R_0 | i,j)\): Mean rate for source type \(i\) in zone \(j\)

- \(f(Y_{i,j})\): Probability density for source parameters

- \(P(R > R_0 | i,j)\): Probability that runup will exceed \(R_0\) for a given set of source parameters
Disaggregation of Seaside PTHA Results

1% annual probability

0.2% annual probability

González et al. (2009)
Empirical PTHA

- Work in Progress: Empirical and Reconstructed Tsunami Hazard Curve for Hilo, Hawai’i

  “10-year” tsunami: 0.6 m
  “100-year” tsunami: 3.0 m
  “1,000-year” tsunami: 7.6 m

- Future 5-year Science Goals
  - Global Tsunami Model (probabilistic)
  - Non-linear aspects: Edge waves (Cascadia tsunami probability at San Francisco)
  - Short-term probabilistic forecasting (days-years)
  - Incorporation of landslide sources (most difficult!)
PTHA Testing (Crescent City)

- Results compared to tide-gage amplitude distributions
- Numerical models of tsunami separately verified & validated (Synolakis et al., 2008)

Study #1

Blue: Empirical (tide gage)
Green: PTHA
Red: PTHA w/ tidal & slip uncertainty

Study #2

Blue: Empirical (tide gage)
Red: PTHA w/ tidal uncertainty
Uncertainty in Cascadia Earthquake Recurrence