SCIENCE BEHIND TSUNAMIS: MODELING AND MAP PRODUCTION

Tsunami Roadshow
April 10th-13th, 2018

Daniel Eungard, LG
Washington Geological Survey
Looking past. Looking forward.

Using our knowledge of past events captured in the geologic record how can we predict what might happen next?

- Recurrence interval and extent of paleo-tsunami deposits
- Plate convergence rates, accumulating strain
- Earthquake and tsunami observations from other subduction zones
Common terms/definitions

• Inundation extent– farthest extent of tsunami wave on land
• Inundation depth– maximum height of water above ground surface
• Current velocity– Speed of water flowing from tsunami (static tide)
• Arrival time– Time since earthquake; arrival of the first wave (typically the time the inundation starts rather than reaches it’s peak)
Modern geodetic uplift

Example: Tohoku cumulative GPS displacement

Cruikshank, K. and Peterson, C. (2017) Late Stage Interseismic Strain Interval, Cascadia Subduction Zone Margin, USA and Canada. Open Journal of Earthquake Research, 6, 1-34
Recent events at other subduction zones

- 2004 Sumatra, Mw 9.1, 225,000 fatalities
- 2010 Chile, Mw 8.8, 525 fatalities
- 2011 Tohoku, Mw 9.0, 15,890 fatalities

*All images from NOAA-PMEL*
Cascadia earthquake scenarios

Table 3. Cascadia earthquake source parameters used to define 15 rupture scenarios. Logic tree branch weights shown in parentheses. Total scenario weight listed in right column.

<table>
<thead>
<tr>
<th>Earthquake Size</th>
<th>Interevent Time (yrs)</th>
<th>Fault Geometry</th>
<th>Slip Range (m)</th>
<th>Scenario Name</th>
<th>Total Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra Extra Large (0.025)</td>
<td>1,200</td>
<td>Splay fault (0.8)</td>
<td>Maximum: 36–44, Average: 18–22</td>
<td>Mw: ~9.1</td>
<td>XXL 1: 0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shallow buried rupture (0.1)</td>
<td>Maximum: 36–44, Average: 18–22</td>
<td>Mw: ~9.2</td>
<td>XXL 2: 0.0025</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deep buried rupture (0.1)</td>
<td>Maximum: 36–44, Average: 18–22</td>
<td>Mw: ~9.1</td>
<td>XXL 3: 0.0025</td>
</tr>
<tr>
<td>Extra Large (0.025)</td>
<td>1,050–1,200</td>
<td>Splay fault (0.8)</td>
<td>Maximum: 35–44, Average: 17–22</td>
<td>Mw: ~9.1</td>
<td>XL 1: 0.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shallow buried rupture (0.1)</td>
<td>Maximum: 35–44, Average: 17–22</td>
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<td>Maximum: 35–44, Average: 17–22</td>
<td>Mw: ~9.1</td>
<td>XL 3: 0.0025</td>
</tr>
<tr>
<td>Large (0.16)</td>
<td>650–800</td>
<td>Splay fault (0.8)</td>
<td>Maximum: 22–30, Average: 11–15</td>
<td>Mw: ~9.0</td>
<td>L 1: 0.128</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shallow buried rupture (0.1)</td>
<td>Maximum: 22–30, Average: 11–15</td>
<td>Mw: ~9.1</td>
<td>L 2: 0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deep buried rupture (0.1)</td>
<td>Maximum: 22–30, Average: 11–15</td>
<td>Mw: ~9.0</td>
<td>L 3: 0.016</td>
</tr>
<tr>
<td>Medium (0.53)</td>
<td>425–525</td>
<td>Splay fault (0.6)</td>
<td>Maximum: 14–19, Average: 7–9</td>
<td>Mw: ~8.9</td>
<td>M 1: 0.318*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shallow buried rupture (0.2)</td>
<td>Maximum: 14–19, Average: 7–9</td>
<td>Mw: ~9.0</td>
<td>M 2: 0.106</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deep buried rupture (0.2)</td>
<td>Maximum: 14–19, Average: 7–9</td>
<td>Mw: ~8.9</td>
<td>M 3: 0.106</td>
</tr>
<tr>
<td>Small (0.26)</td>
<td>275–300</td>
<td>Splay fault (0.4)</td>
<td>Maximum: 9–11, Average: 4–5</td>
<td>Mw: ~8.7</td>
<td>SM 1: 0.104</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shallow buried rupture (0.3)</td>
<td>Maximum: 9–11, Average: 4–5</td>
<td>Mw: ~8.8</td>
<td>SM 2: 0.078</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deep buried rupture (0.3)</td>
<td>Maximum: 9–11, Average: 4–5</td>
<td>Mw: ~8.7</td>
<td>SM 3: 0.078</td>
</tr>
</tbody>
</table>

*Scenario M1 carries the highest weight and represents the “most likely” event in our analysis.

Modeling the next Cascadia

• Modeling programs predict wave behavior based on earthquake source and local topography

• Creates estimates of inundation extent, depth, timing, and current velocities
Slides 8-14: L1 scenario animations of wave arrival for all of Washington, Pacific County, Grays Harbor County, Hoh Reservation, La Push, Port Angeles, and Port Townsend

Removed as animations are not publicly available at this time.
Raymond/South Bend area specifics
Ilwaco area specifics
Westport/Grayland area specifics
Westport/Grayland area specifics
Ocean Shores area specifics

**MAP SYMBOLS**

- Modeled inundation depth (feet):
  - >6
  - 2.5-6
  - 0-2.5

- Shoreline where inundation is inferred but not quantified

- US or state highway
- Road
- Non-motorized route
- Lidar extent
- Study area boundary

- Pre-earthquake open water

Arrow indicates actual tsunami inundation may extend farther than modeled inundation outside of high-resolution lidar coverage or study extent.

**MAP SYMBOLS**

- Modeled maximum current speed (knots):
  - >9
  - 6-9
  - 3-6
  - 0-3

- US or state highway
- Road
- Non-motorized route
- Pre-earthquake water boundary
- Lidar extent
- Study area boundary

Arrow indicates actual tsunami inundation may extend farther than modeled inundation outside of high-resolution lidar coverage or study extent.
Ocean Shores area specifics

MAP SYMBOLS

- **Point elevation**
- **Shoreline where inundation is inferred but not quantified**
- **US or state highway**
- **Road**
- **Non-motorized route**
- **Lidar extent**
- **Study area boundary**

Modeled inundation depth (feet)

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>Dark purple</td>
</tr>
<tr>
<td>50</td>
<td>Purple</td>
</tr>
<tr>
<td>40</td>
<td>Blue</td>
</tr>
<tr>
<td>30</td>
<td>Green</td>
</tr>
<tr>
<td>20</td>
<td>Yellow</td>
</tr>
<tr>
<td>10</td>
<td>Orange</td>
</tr>
<tr>
<td>0</td>
<td>Red</td>
</tr>
</tbody>
</table>

Pre-earthquake open water

Arrow indicates actual tsunami inundation may extend farther than modeled inundation outside of high-resolution lidar coverage or study extent.

WAVE ARRIVAL ~15 minutes

Point Brown

Spinnaker Park ~283 feet

Ocean Shores ~213 feet

Elks Lodge ~67 feet

Point Brown Ave at E Chance A La Mer NE ~37.2 feet

Damon Point ~61 feet

Armstrong Bay

Damon Point

Oyshut

North Bay

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES

dnr.wa.gov
Hoh Reservation area specifics
Hoh Reservation area specifics
La Push area specifics
La Push area specifics
Port Angeles area specifics
Port Angeles area specifics

Sources: Esri, HERE, Garmin, Intermap, Increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong)
Port Townsend area specifics
Port Townsend area specifics
Port Townsend walk map
WGS Information

Google: Washington Geology Portal
https://geologyportal.dnr.wa.gov/

Google: Washington Tsunami
https://www.dnr.wa.gov/programs-and-services/geology/geologic-hazards/tsunamis

Google: Washington Geology Mobile
https://www.dnr.wa.gov/mobilegeology
Tsunami Map Layers: Why can't I view the Tsunami Evacuation and Tsunami Inundation layers at the same time?

The tsunami evacuation maps and brochures were created for specific regions that do not include surrounding areas found in the tsunami inundation map layer. Therefore, we do not wish to imply that any inundation-prone area that does not appear in the evacuation map layer is safe—a misconception that may occur if these layers are viewed together. Instead, we allow the user to toggle between the tsunami evacuation and tsunami inundation layers.

During a tsunami evacuation situation, occupants of any threatened low-lying coastal areas should immediately move to higher ground.

I Agree
What is new (or coming soon)

2018–

Inundation maps and evacuation maps for Southwest Washington (Long Beach and Ocean Shores)

• Pedestrian walk map for Aberdeen/Hoquiam
• Inundation and pedestrian walk map for Anacortes-Bellingham vicinity
• Inundation and pedestrian walk map for Port Angeles and Port Townsend
• Hiring a new tsunami modeler!!!

2019–

• Inundation modeling for remaining outer coast
• Create new and improved animations posted on our website
What is coming soon in tsunami science

• High resolution 3D models (site specific)
• State maritime guidance
• Sediment transport and debris tracking models (maritime focused)
“Civilization exists by geological consent, subject to change without notice.”

— Will Durant