U.S. States and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves

Update

In Final review

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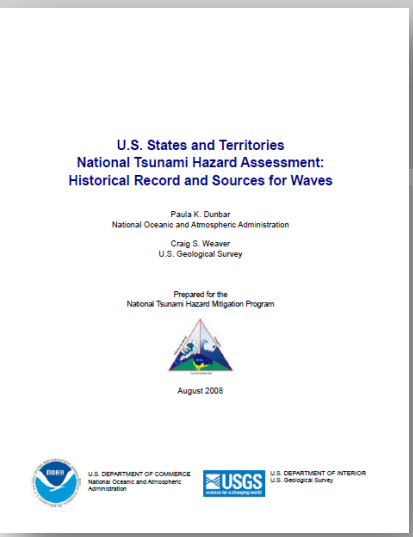
NTHMP July 14, 2015

Background


U.S. States and Territories
National Tsunami Hazard Assessment:
Historical Record and Sources for Waves

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Prepared for the
National Tsunami Hazard Mitigation Program

August 2008

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

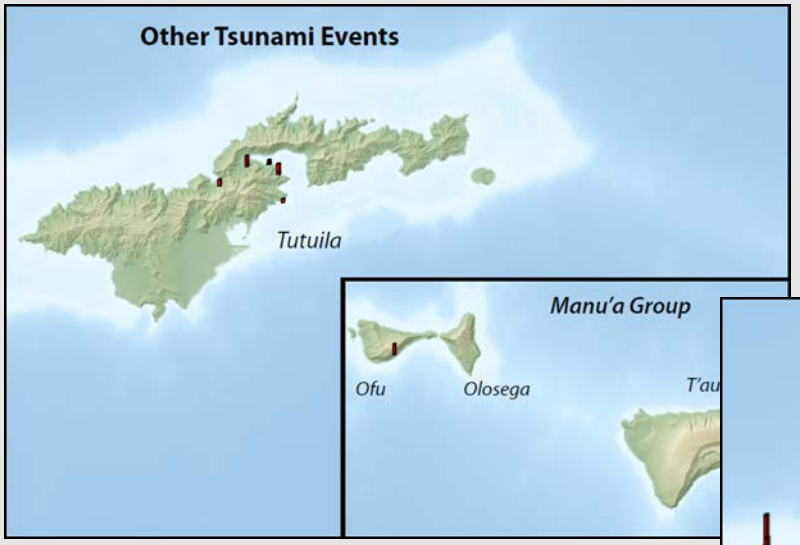
U.S. DEPARTMENT OF INTERIOR
U.S. Geological Survey

- The U.S. National Tsunami Hazard Mitigation Program (NTHMP) requested 1st Assessment
  - NTHMP: federal, state, territorial agencies
  - Natl Science & Technology Council released report ***Tsunami Risk Reduction for the United States***, 2005
    - Develop tsunami hazard and risk assessments for all coastal regions of the U.S. States and Territories
- NOAA's National Centers for Environmental Information (NCEI), *formerly National Geophysical Data Center (NGDC)*
  - Catalogs information on global historical tsunamis
- U.S. Geological Survey (USGS)
  - Conducts research on earthquake hazards facing the U.S.
- NCEI & USGS conducted the 1st U.S. Tsunami Hazard Assessment, published 2008

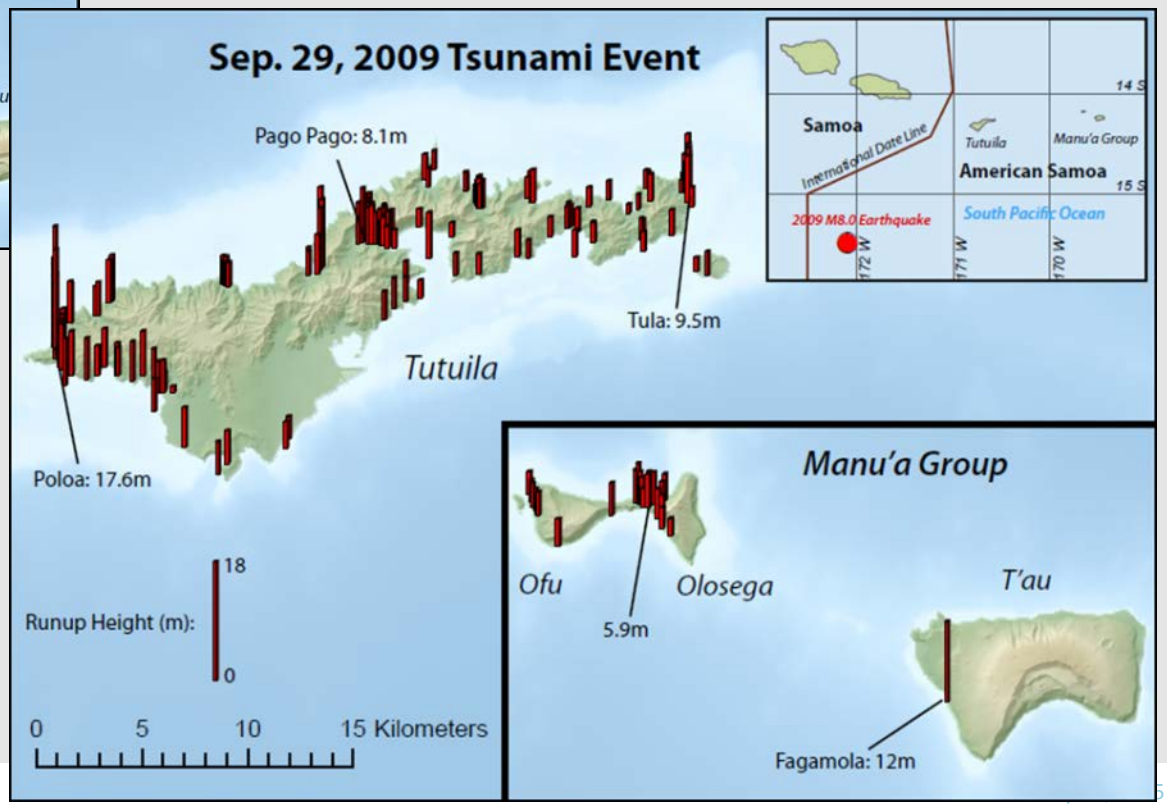
Since the 1st Assessment

- Significant events
  - 2009 Samoa, Mw 8.0
    - American Samoa: 3-18m runups, 39 Deaths, $126 million
  - 2010 Maule, Chile Mw 8.8
    - California: 1m runups & strong currents, $3 million
  - 2011 Great East Japan, Mw 9.0
    - Hawaii: 3-5m runups, $31 million
    - California: 1-2.5m runups & strong currents, 1 Death, $50 million
- New research results
- National Academies Assessment of Tsunami Program, 2011
  - Periodic assessment of the sources of tsunamis that threaten the U.S.
- NTHMP requested an Update

American Samoa



- 59 events observed in AS < 2009
  - 56 tide gauge (Pago Pago):
    - **majority < 0.3m**
  - 9 eyewitness: < 3.0 m



- Sept 29, 2009
  - Tide gauge 2.7 m
  - 218 field survey points
    - **>3m – 169**
    - **>10m - 10**

Tsunami Hazard Assessment

- Probabilistic tsunami hazard analysis
  - Historical and Prehistorical (paleo) tsunami data
  - Quantitative probabilistic models of local and far-field tsunami sources (earthquake, landslide, volcano)
  - High-resolution DEMs (topography, bathymetry, tidal information)
  - Numerous propagation and inundation simulations for tsunami sources
- Goal of the ***First Assessment***
  - Qualitative assessment of the hazard at the state level
- Goal of the ***Second Assessment***
  - Update the qualitative assessment with new database searches, provide an overview of latest research, evaluate hazard levels

NOAA/NCEI Historical Tsunami Database

- Tsunami Sources and Runups
  - Source event (date, location, cause, magnitude, maximum wave height)
  - Runup locations where tsunami waves were observed (tide gauge, field survey, eyewitness - water heights, arrival times)
  - Damage, deaths, injuries from the source and the tsunami
- Tsunami source events affecting the U.S. and runups were reviewed for accuracy
  - Check original sources, crosscheck with earthquake, volcano, hurricane catalogs
- Events were selected for further examination
  - Validity 3 or 4
  - Not meteorologically caused – not enough data to include
  - Runup not flagged as doubtful
  - Waves reported on inland waters were not counted
  - All dates were included - 1690 Virgin Islands earliest report

Examine the Historical Tsunami Record

- Count tsunami events affecting each state
  - Bin tsunami events based maximum measured runup
    - Undetermined
    - 0.01 m ≤ runup ≤ 0.3 m
    - 0.3 m < runup ≤ 1.0 m ⟵ ***Advisory - U.S. Tsunami Warning Centers***
    - 1.0 m < runup ≤ 3.0 m ⟵ ***Warning - U.S. Tsunami Warning Centers***
    - 3.0 m < runup
- Tsunami event could be counted in several states
  - 1952, 1960, 1964, etc.
- Although not a vulnerability or risk assessment
  - Examine the severity of tsunamis by counting total number of deaths and dollar damage due to tsunamis in each state

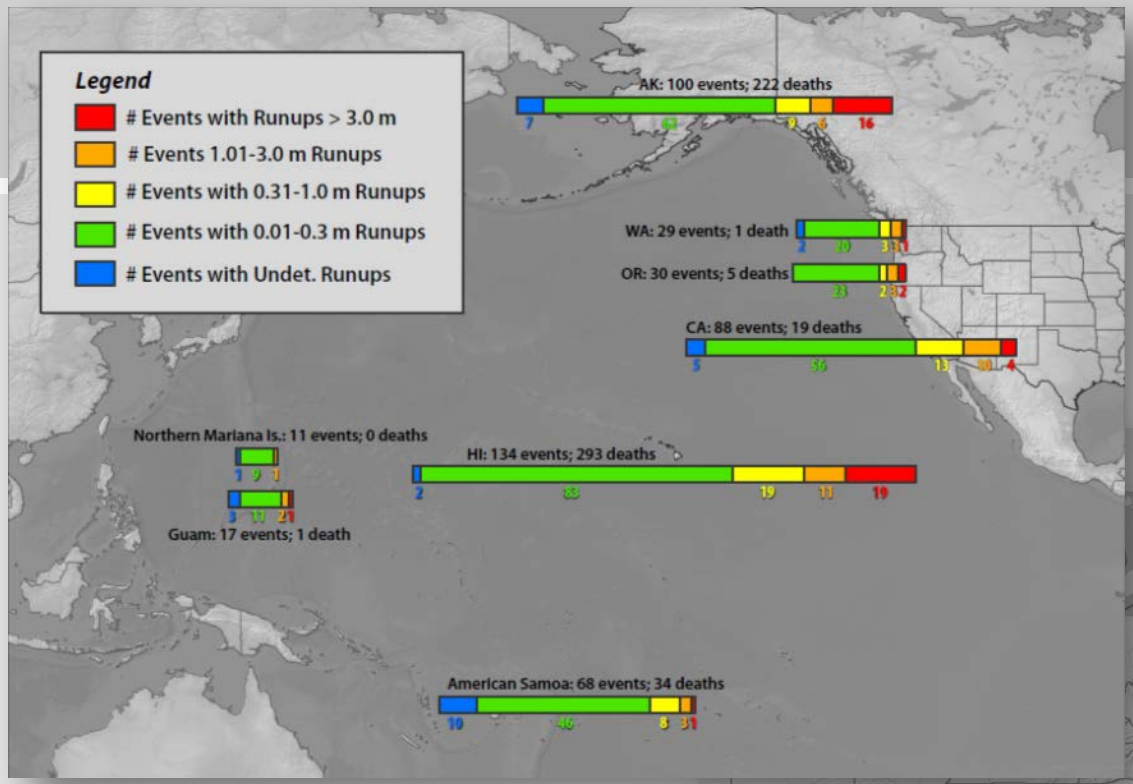
Tsunami Events

- State tsunami events range from **none** in PA, DE, VA, NC, GA, AL, MS, and LA to **134** in Hawaii
- Change from 1st: Pacific Island Territories grouping

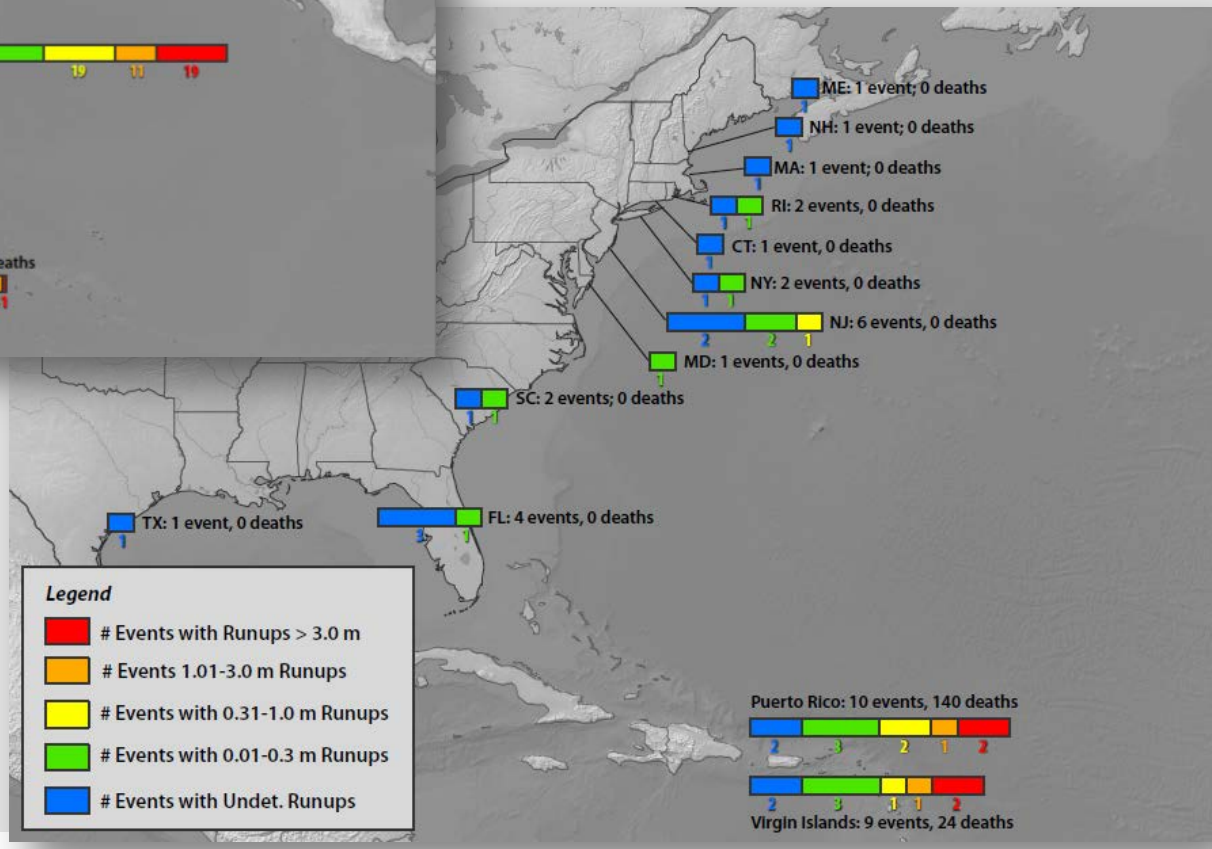
Location (year of tide gauge installation, first confirmed report)	Total Events	Undeter-mined	0.01 to 0.3	0.31 to 1.0	1.01 to 3.0	> 3.0	Total runups	Reported Deaths	$Million damage reported
Maine (1847, 1929)	1	1					3		
New Hampshire (1926, 1929)	1	1					1		
Massachusetts (1847, 1929)	1	1					2		
Rhode Island (1844, 1929)	2	1	1				3		
Connecticut (1932, 1964)	1	1					1		
New York (1844, 1895)	2	1	1				7		
New Jersey (1844, 1918)	6	3	2	1			8		
Pennsylvania (1922 , _)									
Delaware (1896 , _)									
Maryland (1844, 1929)	1		1				1		
Virginia (1844 , _)									
North Carolina (1882, _)									
South Carolina (1850, 1886)	2	1	1				2		
Georgia (1851, _)									
Florida (1855, 1886)	4	3	1				5		
Atlantic Coast Totals	**21**	**13**	**7**	**1**	**0**	**0**	**33**	**0**	**$0**
Florida (1858, _)									
Alabama (1846, _)									
Mississippi (1848, _)									
Louisiana (1932, _)									
Texas (1852, 1918)	1	1					1		
Gulf Coast Totals	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**$0**
Puerto Rico (1954, 1867)	10	2	3	2	1	2	36	140	$4
Virgin Islands (1975, 1690)	9	2	3	1	1	2	23	24	
PR & VI Totals	**19**	**4**	**6**	**3**	**2**	**4**	**59**	**164**	**$4**
Washington (1855, 1891)	29	2	20	3	3	1	100	1	$1
Oregon (1853, 1854)	30		23	2	3	2	106	5	$1
California (1853, 1812)	88	5	56	13	10	4	641	19	$80
West Coast Totals	**147**	**7**	**99**	**18**	**16**	**7**	**847**	**25**	**$82**
Guam (1948, 1849)	17	3	11		2	1	26	1	
Northern Mariana (1978, 1990)	11	1	9		1		12		
Guam & N. Mariana Is. Totals	**28**	**4**	**20**	**0**	**3**	**1**	**38**	**1**	
American Samoa (1922, 1837)	**68**	**10**	**46**	**8**	**3**	**1**	**293**	**34**	**$126**
Alaska Arctic Coast (1993, _) Totals	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**$0**
Alaska (1872, 1737) Totals	**100**	**7**	**62**	**9**	**6**	**16**	**492**	**222**	**$110**
Hawaii (1872, 1812) Totals	**134**	**2**	**83**	**19**	**11**	**19**	**2002**	**293**	**$90**
AMERICAN Totals	**518**	**48**	**323**	**58**	**41**	**48**	**3765**	**739***	**$412**

**includes 5 indirect deaths: Hawaii in 1957 (2) and 2012 (1); California 1960 (1) and 1964 (1)*

Tsunami Events



10% - Atlantic Basin
90% - Pacific Basin



U.S. experience with tsunamis is greatest in the Pacific Basin

Difference 1st and 2nd Tsunami Counts

Regional Totals	Total tsunami events	Total runups for all events	Deaths	$Million Damage Reported
Atlantic Coast	0	0	0	$0
Gulf Coast	0	0	0	$0
PR and VI	3	11	-8	$0
West coast	34	297	1	$60
Guam & N. Mariana Is	12	14	0	$0
American Samoa	12	233	34	$126
Alaska	19	140	0	-$12
Hawaii	20	410	-33	$31

Frequency of Runup Heights

- Tsunami Events Per Year
  - **Very Low**: Zero events
  - **Low**: all events >0.0 and no events with runups >1.0m
  - **Moderate**: >0.01 for runups **>1.0m** and no runups >3.0m
  - **High**: ≥0.01 for runups **>3.0m**
    ~ >3m once every 100 years
  - **Very High**: ≥0.02 for runups **>3.0m**
    ~ >3m at least once every 50 years

Location (year of tide gauge installation, first confirmed report)	Total Events	Time Interval (Years)	Total Events per Year	Total Events >1.0m	Events with >1.0m per year	Total Events >3.0m	Events with >3.0m per year	Tsunami Hazard
Maine (1847, 1929)	1	167	0.01	0	0.00	0	0.00	Low
New Hampshire (1926, 1929)	1	88	0.01	0	0.00	0	0.00	Low
Massachusetts (1847, 1929)	1	167	0.01	0	0.00	0	0.00	Low
Rhode Island (1844, 1929)	2	85	0.02	0	0.00	0	0.00	Low
Connecticut (1932, 1964)	1	82	0.01	0	0.00	0	0.00	Low
New York (1844, 1895)	2	170	0.01	0	0.00	0	0.00	Low
New Jersey (1844, 1918)	6	170	0.04	0	0.00	0	0.00	Low
Pennsylvania (1922 , _)	0	92	0.00	0	0.00	0	0.00	Very Low
Delaware (1896 , _)	0	118	0.00	0	0.00	0	0.00	Very Low
Maryland (1844, 1929)	1	170	0.01	0	0.00	0	0.00	Low
Virginia (1844 , _)	0	170	0.00	0	0.00	0	0.00	Very Low
North Carolina (1882, _)	0	132	0.00	0	0.00	0	0.00	Very Low
South Carolina (1850, 1886)	2	164	0.01	0	0.00	0	0.00	Low
Georgia (1851, _)	0	163	0.00	0	0.00	0	0.00	Very Low
Florida, Atl Coast (1855, 1886)	4	159	0.03	0	0.00	0	0.00	Low
Florida, Gulf Coast (1858, _)	0	156	0.00	0	0.00	0	0.00	Very Low
Alabama (1846, _)	0	168	0.00	0	0.00	0	0.00	Very Low
Mississippi (1848, _)	0	166	0.00	0	0.00	0	0.00	Very Low
Louisiana (1932, _)	0	82	0.00	0	0.00	0	0.00	Very Low
Texas (1852, 1918)	1	162	0.01	0	0.00	0	0.00	Very Low
Puerto Rico (1954, 1867)	10	147	0.07	3	0.02	2	0.01	High
Virgin Islands (1975, 1690)	9	324	0.03	3	0.01	2	0.01	High
Washington (1855, 1891)	29	159	0.18	4	0.03	1	0.01	High
Oregon (1853, 1854)	30	161	0.19	5	0.03	2	0.01	High
California (1853, 1812)	88	202	0.44	14	0.07	4	0.02	Very High
Guam (1948, 1849)	17	165	0.10	3	0.02	1	0.01	High
N. Mariana Is (1978, 1990)	11	36	0.31	1	0.03	0	0.00	Moderate
Alaska Arctic Coast (1993, _)	0	21	0.00	0	0.00	0	0.00	Very Low
American Samoa (1922, 1837)	68	177	0.38	4	0.02	1	0.01	High
Alaska (1872, 1737)	100	277	0.36	22	0.08	16	0.06	Very High
Hawaii (1872, 1812)	134	202	0.66	30	0.15	19	0.09	Very High

Qualitative Tsunami Hazard Assessment based on NCEI Databases

Region	*Hazard based on runups*	*Hazard based on frequency*	*Number of reported deaths*
U.S. Atlantic coast	Very low to low	Very low	None
U.S. Gulf coast	Very low	Very low	None
Puerto Rico and the Virgin Islands	High	High	164
U.S. west coast	High	High	25*
U.S. Pacific island territories	Moderate	High	1
Alaska	Very high	Very high	222
Hawaii	Very high	Very high	293

*Does not include any deaths caused by the 1700 Cascadia tsunami on the U.S. west coast

1st Assessment

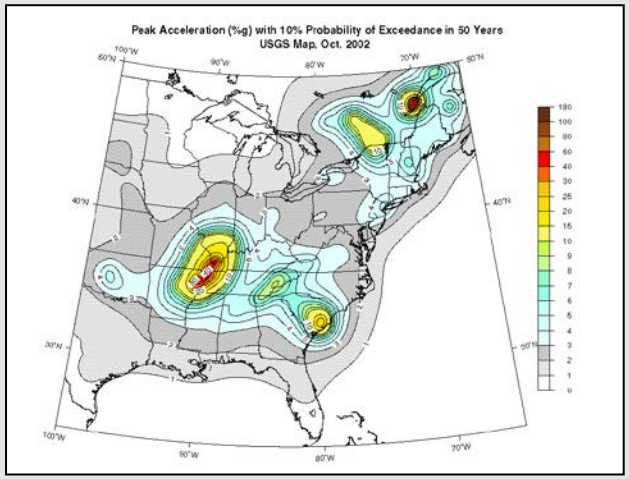
2nd Assessment

Region	*Hazard based on frequency and height of runups*	*Number of reported deaths*
U.S. Atlantic coast	Very low to low	None
U.S. Gulf coast	Very low	None
Puerto Rico and the Virgin Islands	High	164
U.S. west coast	High to Very high	25*
American Samoa	High	34
Guam and N. Mariana Islands	Moderate to High	1
Alaska	Very high	222
Hawaii	Very high	293

*Does not include any deaths caused by the 1700 Cascadia tsunami on the U.S. west coast

USGS National Seismic Hazard Maps (NSHM)

Earthquake databases can be used to extend the historical tsunami record backward in time.



Subduction zones

State/Territory	Non-subduction earthquake with mag > 6.5 in 500 years within 50 km of coast	Subduction zone event with mag >msubduct in 500 years within 150 km of coast	Maximum magnitude observed or estimated for nearshore or offshore	Comment
Puerto Rico and the Virgin Islands, msubduct = 7.5				
Puerto Rico	100%	~100%	7.5	1918 Mona Passage, severe tsunami**
Virgin Islands	100%	~100%	7.5	1867 Virgin Islands, severe tsunami
Pacific Coast--Cascadia, msubduct = 8.1				
Washington	30% to 90%	~100%	9+	1700 Cascadia, severe tsunami
Oregon	10% to 100%	~100%	9+	1700 Cascadia, severe tsunami
California	100%	~100%	9+	1700 Cascadia, severe tsunami
Pacific Coast--Alaska, msubduct = 7.5				
Alaska	100%*	~100%	9.2	1964 Alaska, severe tsunami
Western Pacific, msubduct = 7.8				
Guam	N/A	~100%	7.8	1993 Guam, non-destructive tsunami
Northern Mariana	N/A	~100%	7.8	1993 Guam, non-destructive tsunami
American Samoa	N/A	~100%	8.5	1917 Northern Tonga trench, moderate tsunami

Alaska calculation for mag>6.5 includes subduction interface events
*Events as large as magnitude ~8 are estimated in the Puerto Rico trench

Non-Subduction zones

State/Territory	Earthquake with Mag > 6.5 in 500 years within 50 km of coast	Earthquake with Mag > 6.5 in 5000 years within 50 km of coast	Historical maximum magnitude observed nearshore or offshore	Comment
U.S. Atlantic Coast				
Maine	<3%	<30%	<6	
New Hampshire	<3%	<30%	<6	
Massachusetts	<3%	<25%	<6	
Rhode Island	<2%	<15%	<6	
Connecticut	<2%	<30%	<6	
New York	<4%	<30%	<6	
New Jersey	<4%	<30%	<6	
Pennsylvania	<3%	<15%	<6	
Delaware	<3%	<15%	<6	
Maryland	<2%	<15%	<6	
Virginia	<1%	<4%	<6	
North Carolina	<1 to 5%	<5%	<6	
South Carolina	<35%	100%	7.3	1886 Charleston, non-destructive tsunami
Georgia	<1%	<10%	<6	
Florida	<1%	<3%	<6	
U.S. Gulf Coast				
Florida	<1%	<3%	<6	
Alabama	<1%	<4%	<6	
Mississippi	<1%	<5%	<6	
Louisiana	<1%	<5%	<6	
Texas	<1%	<4%	<6	

Hawaii, Southern California, and Arctic Coast of Alaska

State/area	Mag > 6.5 in 500 years within 50 km of coast	Mag > 7.5 in 500 years within 50 km of coast s	Maximum magnitude observed or estimated for nearshore or offshore	Comment
Hawaii and Southern California				
Hawaii	~100%	~100%	7.9	1868 Ka'u district, severe tsunami
Southern California	~100%	~100%	7.1	1927 Lompoc, moderate tsunami
Arctic Coast—Alaska				
Alaska	<1%	N/A	<6	Arctic coast rated no tsunami risk by Alaska

Qualitative Tsunami Hazard Assessment based on USGS NSHM databases

No change in tsunamigenic earthquakes in NSHM since 1st assessment

Region	*Probability that an earthquake generates a local tsunami in 500 years by seafloor displacement*
U.S. Atlantic coast	Very low to low
U.S. Gulf coast	Very low
Puerto Rico and the Virgin Islands	High
U.S. west coast	High
Guam and N. Mariana Islands	High
American Samoa	High
Alaska	High
Hawaii	High

Qualitative Tsunami Hazard Assessment for the U.S. States and Territories

Region	*Hazard based on Historical Record*
U.S. Atlantic coast	Very low to low
U.S. Gulf coast	Very low
Puerto Rico and the Virgin Islands	High
U.S. west coast	High to Very high
Guam and N. Mariana Islands	Moderate to High
American Samoa	High
Alaska	Very high
Hawaii	Very high

NCEI + USGS databases

Region	*Hazard based on Historical Record and Earthquake Probabilities*
U.S. Atlantic coast	Very low to low
U.S. Gulf coast	Very low
Puerto Rico and the Virgin Islands	High
U.S. west coast	High to Very high
Guam and N. Mariana Islands	High
American Samoa	High
Alaska	High to Very high
Hawaii	High to Very high

Region	*Hazard based on Earthquake Probabilities*
U.S. Atlantic coast	Very low to low
U.S. Gulf coast	Very low
Puerto Rico and the Virgin Islands	High
U.S. west coast	High
Guam and N. Mariana Islands	High
American Samoa	High
Alaska	High
Hawaii	High

Research – Atlantic coast

- Ten Brink et al. (2014) reviewed the research on tsunamis sources in the Atlantic Basin
  - "**Landslide tsunamis** likely constitute the biggest tsunami hazard to the coast"
  - Both deterministic and probabilistic methods tsunami hazard assessments have been developed - but their **implementation requires better data than currently is available**
- Ten Brink et al. (2009) reviewed the research on tsunami sources along the Gulf Coast
  - "Likelihood of a major tsunami was **very small**"
  - The source for potential Gulf Coast tsunamis is underwater landslides, but the current record suggests that the large landslides were probably active prior to **7000 years ago**

USGS National Seismic Hazard Maps

- Southern portion of the Cascadia subduction zone has a more frequent repeat of large magnitude earthquakes
  - Evidence - **turbidite flows** recorded off the Pacific NW coast
  - USGS Workshop for the 2014 National Seismic Hazard Maps
    - **full weight be given to the larger partial ruptures of southern Cascadia** in hazard calculations
    - Scientific consensus: average recurrence time for full-rupture Cascadia events is well-constrained at between **500 to 550 years** and ***this rate continues to support our current assessment of high***
  - Periodically re-examine this assessment as the turbidite studies and efforts to correlate these findings with onshore evidence are published

Research – Atlantic & Pacific

- Canadian National Tsunami Hazard Assessment (Leonard, et al., 2012)
  - Two maps identify cumulative probabilities of exceedance (in 50 years) of potentially damaging runup (1.5 m and 3 m) on the Pacific and Atlantic coasts from multiple tsunami sources
  - Binned into four groups: <2%, 2-10%, 10-40%, 40-70%
    - Very Low, Low, Moderate, High to Very High
  - Region next to U.S. northwest coast are in the 10-40% bin
    - Correspond to U.S assessment of High
  - Region next to U.S. northeast coast are in the 2-10% bin
    - Correspond to U.S. assessment of Low

Qualitative Tsunami Hazard Assesment

Region	Hazard based on runups	Hazard based on frequency	Hazard based on local earthquakes	Number of reported deaths
U.S. Atlantic coast	Very low to low	Very low	Very low to low	None
U.S. Gulf coast	Very low	Very low	Very low	None
Puerto Rico and the Virgin Islands	High	High	High	172
U.S. west coast	High	High	High	25
Alaska	Very high	Very high	High	222
Hawaii	Very High	Very high	High	326
U.S. Pacific Isand territories	Moderate	High	High	1

2008

2015

Region	Hazard based on Historical Record and Earthquake Probabilities	Number of reported deaths
U.S. Atlantic coast	Very low to low	None
U.S. Gulf coast	Very low	None
Puerto Rico and the Virgin Islands	High	164
U.S. west coast	High to Very high	25*
Guam and N. Mariana Islands	High	1
American Samoa	High	34
Alaska	High to Very high	222
Hawaii	High to Very high	293

*Does not include any deaths caused by the 1700 Cascadia tsunami on the U.S. west coast

Conclusion and Discussion

- No change in the assessment except American Samoa, Guam, N. Mariana Islands, and U.S. West Coast
- 2010 Chile and 2011 Japan tsunamis confirmed levels in 1st assessment
- Document Reviewed by: C. Rabenold (NOAA), M. Eble (NOAA), T. Brocher (USGS), R. Witter (USGS)
- Final manuscript preparation in progress
- Re-evaluate in the future based on research results
  - Cascadia recurrence intervals
  - East coast landslide assessment
  - Document should continue to be a qualitative tsunami hazard assessment
  - Specific areas - Probabilistic tsunami hazard assessments
    - Vulnerability, Risk, Evacuation maps

Pu'umaile, Keaukaha area, Hiilo, Hawaii. 1946 April 1, Mw 8.6, Aleutian Islands, Alaska earthquake and tsunami. (Credit: Pacific Tsunami Museum)

Thank you

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