Review and Update

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

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

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

NATIONAL TSUNAMI HAZARD ASSESSMENT (NTHA) - BACKGROUND

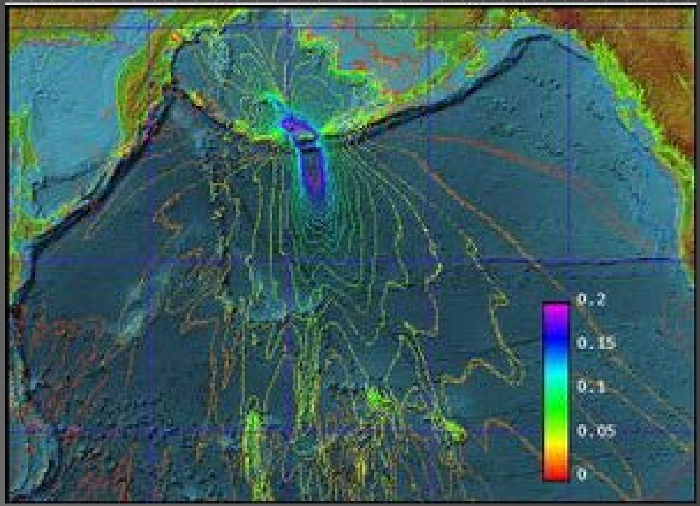
- Tsunami Risk Reduction for the United States: A Framework for Action, 2005, National Science and Technology Council
  - Develop tsunami hazard and risk assessments for all coastal regions of the US states and territories
- NOAA's National Geophysical Data Center (Paula Dunbar, NGDC) and U.S. Geological Survey (Craig Weaver, USGS) collaborated on first NTHA, 2008
- NAS report (2011) recommends development of National Tsunami Risk Assessment
- NTHMP Strategic Plan includes milestone for updating NTHA
- Update of NTHA needed for reevaluation of NTHMP membership and funding priorities

SUPPORT FOR NATIONAL TSUNAMI HAZARD ASSESSMENT (NTHA) UPDATE

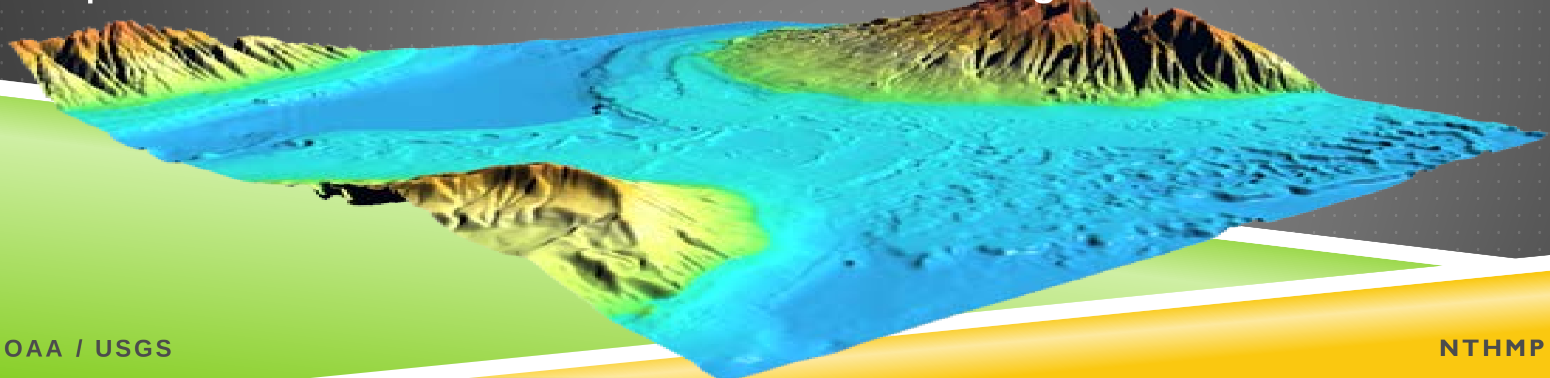
- Major advances in tsunami hazard/ vulnerability/risk assessment information
  - NTHMP held two advanced workshops and two AGU sessions in 2012 and 2013
  - Source characterization improvements
  - New vulnerability assessments
  - New probabilistic assessments and work groups
  - Risk analysis tool development: HAZUS
- Update of NTHA needed for reevaluation of NTHMP membership and funding priorities
- NTHMP requested an update of the NTHA, 2012
  - Brief review of the 2008 assessment and progress to date
  - Good news – Craig Weaver (USGS) has agreed to work on update

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 inundation and propagation simulations for tsunami sources



- Goal of the ***first phase*** of the National Tsunami Hazard Assessment
  - Qualitative assessment of the hazard at the state level
- ***Second phase*** will update the qualitative assessment with new database searches and provide an overview of latest research in each region



NATIONAL TSUNAMI HAZARD ASSESSMENT (NTHA)

- Introduction
- Known Historical Tsunami Record
- USGS Earthquake Hazards
- Gaps in Knowledge of Tsunami Sources
- Next Steps
- Conclusion
- Appendices

UPDATED NTHA

- Generally, the updated document will follow closely the current document with several exceptions:
- The summary of **observed runups** will be updated to the present for all coasts.
- **American Samoa** will be broken into its own geographical area, separated from the Northern Marianas and Guam. In several places in the text, the need for expanded paleotsunami studies will be emphasized.
- Recent work by the USGS on **tsunami sources** in both the **Gulf of Mexico** and the **Atlantic** will be heavily summarized and referenced. Essentially these studies confirm both the current assessments of these coasts and the need, particularly along the Atlantic, for paleotsunami studies.

UPDATED NTHA - CONTD

- The recently completed **Canadian tsunami hazard assessment** will be discussed with the view of a more or less seamless transition across the various US-Canadian boundaries (e.g., Washington-BC, Alaska-BC, etc.)
- A discussion of needed additional work will include some discussion of the **need to verify scenarios**, such as that recently completed in Alaska that predicts strong effects in California.
- The USGS expects to provide **updated seismic hazard maps** for the document, although there remain some hitches in working out the timing of the maps which are currently in review.
- **Scientific controversies**, such as the number of tsunamis in Cascadia, will be noted in the further work section.
- Appendix – **Community Vulnerability** (Nate Wood)

EXAMINE THE HISTORICAL TSUNAMI RECORD

- Count tsunami events affecting each state
  - Bin tsunami events based maximum measured runup
    - 0.01 m ≤ runup ≤ 0.5 m
    - 0.5 m < runup ≤ 1.0 m
    - 1.0 m < runup ≤ 3.0 m, and
    - 3.0 m < runup
- Tsunami event could be counted in several states (e.g. 1952, 1960, 1964)
- Provide dates of first tsunami observation and first tide gauge installation
- 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
  - Count tsunami events binned by local vs distant source

TSUNAMIS AFFECTING U.S. SINCE 2006

- U.S. East Coast: Meteotsunamis in 2008 and 2013 - not included
- Caribbean: 2010 Haiti small tsunamis observed on tide gauges PR, VI
- Pacific: 24 events – 22 earthquakes, 2 eruptions (Alaska, N Mariana Is)
  - Teletsunamis:: 2007 Kuril Islands, Solomon Is, Peru; 2009 Indonesia, Kamchatka, Tonga, New Zealand, Vanuatu, Samoa; 2010 Chile, Japan; 2011 Japan, Alaska, Kermadec Is; 2012 Philippines, Canada, Guatemala; 2013 Solomon Is
  - Local Tsunamis: Alaska (2007, 2011, 2013), N Mariana Is (2010)
  - 1,001runups: 379 tide gauge, 496 field survey, 93 eyewitness, 33 DART
- Pacific: 2009 Samoa, 2010 Chile, 2011 Tohoku Japan, 2012 Haida Gwaii, Canada
  - >3 m runups: American Samoa (2009 Samoa), Hawaii (2011 Tohoku Japan)
  - 1.01-3 m runups: Pismo Beach, CA (2010 Chile); AK, OR, CA, N. Mariana Is (2011 Tohoku)
  - 0.51-1m runups: HI, AK (2010 Chile); American Samoa, Washington (2011 Tohoku); HI (2012 Haida Gwaii Canada)
  - **2009 Samoa: 34 deaths, $125 million damage in American Samoa**
  - **2011 Tohoku: 1 death, $55 million in CA, $31 million HI**

RESULTS – TSUNAMI EVENT RUNUPS BY STATE & REGION

- State tsunami events range from **none** in PA, DE, VA, NC, GA, AL, MS, and LA to **132** in Hawaii
- State tsunami events include both **local sources** of all types as well as runups resulting from a **distant source**
- Tsunami events:
  - **8% are in the Atlantic Basin**
  - **92% are in the Pacific**
- **Meteotsunamis** will be added

Location (year of first confirmed report and tide gauge installation)	Total Events	Un-deter-mined	0.01 to 0.5	0.51 to 1.0	1.01 to 3.0	> 3.0	Total runups	Reported Deaths	$Million damage reported
Maine (1929, 1847)	1	1					3		
New Hampshire (1929, 1926)	1	1					1		
Massachusetts (1929, 1847)	1	1					2		
Rhode Island (1929, 1844)	2	1	1				3		
Connecticut (1964, 1932)	1	1					1		
New York (1895, 1844)	2	1	1				7		
New Jersey (1918, 1844)	6	3	2	1			8		
Pennsylvania (, 1981)									
Delaware (, 1896)									
Maryland (1929, 1844)	1		1				1		
Virginia (, 1844)									
North Carolina (, 1882)									
South Carolina (1886, 1850)	2	1	1				2		
Georgia (, 1851)									
Florida (1886, 1898)	4	3	1				5		
Atlantic Coast Totals	**21**	**13**	**7**	**1**	**0**	**0**	**33**	**0**	**$0**
Florida (, 1847)									
Alabama (, 1966)									
Mississippi (, 1978)									
Louisiana (, 1932)									
Texas (1918, 1908)	1	1					1		
Gulf Coast Totals	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**$0**
Puerto Rico (1867, 1954)	10	2	3	2	1	2	36	140	$62
Virgin Islands (1690, 1975)	9	2	3	1	1	2	22	24	
PR & VI Totals	**19**	**4**	**6**	**3**	**2**	**4**	**58**	**164**	**$62**
Washington (1891, 1855)	28	2	20	2	3	1	98	1	$8
Oregon (1854, 1853)	29		23	1	3	2	98	5	$6
California (1812, 1853)	87	5	60	8	10	4	615	19	$215
West Coast Totals	**144**	**7**	**103**	**11**	**16**	**7**	**811**	**25**	**$229**
Guam (1849, 1948)	16	3	10		2	1	25	1	
Northern Mariana (1990, 1978)	11	1	9		1		12		
Western Pacific Is. Totals	**27**	**4**	**19**	**0**	**3**	**1**	**37**	**1**	
American Samoa (1837, 1948)	**67**	**10**	**48**	**5**	**3**	**1**	**294**	**34**	**$138**
Alaska (1737, 1872) Totals	**97**	**7**	**63**	**5**	**6**	**16**	**459**	**222**	**$767**
Hawaii (1812, 1872) Totals	**132**	**2**	**95**	**5**	**11**	**19**	**1989**	**293**	**$610**
AMERICAN Totals	**508**	**48**	**341**	**30**	**41**	**48**	**3682**	**739**	**$1,806**

Table 2-1. Tsunami events, total number of runups, deaths, and dollar damage by State and region from the NOAA/NGDC tsunami database. Dollars adjusted for inflation to $2013. Data are through 31 January 2014. Changes since 2006 are indicated in red.

RESULTS – TSUNAMI EVENT LOCAL / DISTANT RUNUPS BY STATE AND REGION

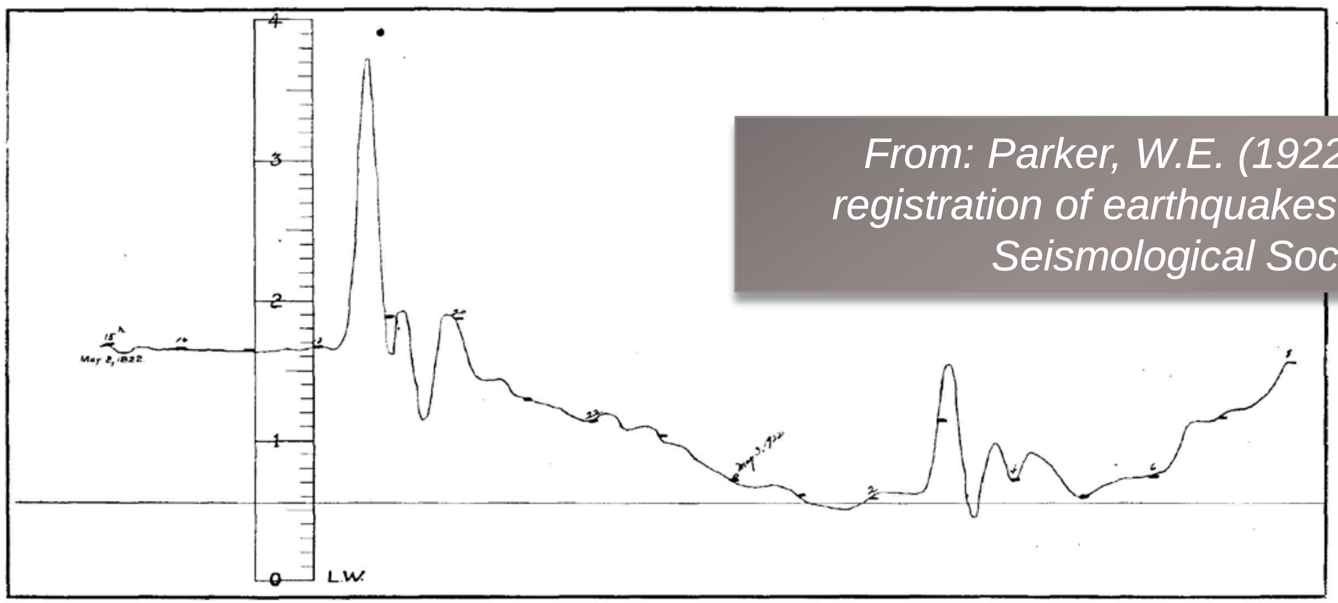
- HI & U.S. west coast States
  - **Distant sources** caused most deaths, $damage
- AK, Caribbean, & Pacific Is
  - **Local sources** caused all deaths, $damage
- All deaths resulted from runups **>3 m**
  - except one in CA (2011)

Table 2-2. Tsunami events, total number of measured runups, deaths, and $damage from local vs distant sources, by State and region from the NOAA/NGDC tsunami database. Dollars adjusted for inflation to $2013. Data are through 31 January 2014. Changes since 2006 are indicated in **red.**

	Local	Distant	Local	Distant	Local	Distant	Local	Distant	Local	Distant	Local	Distant
	0.01 to 0.5 m		0.51 to 1.0 m		1.01 to 3.0		>3.0 m		Deaths*		$M Damage	
Rhode Island	1											
New York	1											
New Jersey		2		1								
Maryland		1										
South Carolina		1										
Florida		1										
Atlantic Coast Totals	**2**	**5**		**1**								
Puerto Rico	1	2	2		1		2		140		$62	
Virgin Islands	1	2	1		1		2		24			
PR & VI Totals	**2**	**4**	**3**		**2**		**4**		**164**		**$62**	
Washington		20		2	2	1		1	1			$8
Oregon	1	22		1		3	1	1		5		$6
California	5	55	3	5	2	8	3	1	2	17		$215
West Coast Totals	**6**	**97**	**3**	**8**	**4**	**12**	**4**	**3**	**3**	**22**		**$228**
Guam		10			2		1		1			
N. Mariana	2	7				1						
W. Pacific Is. Totals	**2**	**17**			**2**	**1**	**1**		**1**			
American Samoa	**8**	**40**		**5**	**1**	**2**	**1**		**34**		**$138**	
Alaska Totals	**20**	**43**	**4**	**1**	**1**	**5**	**15**	**1**	**222**		**$767**	
Hawaii Totals	**2**	**93**		**5**	**2**	**9**	**4**	**15**	**49**	**244**	**$6**	**$604**
AMERICAN Totals	**42**	**299**	**10**	**20**	**12**	**29**	**29**	**19**	**473**	**266**	**$911**	**$832**

UNUSUAL TIDAL REGISTRATION

- May 2, 1922 – unusual curve found on Galveston, TX tide gauge
- "These unusual waves are not of the nature caused by the tides or by meteorological conditions, but undoubtedly are of seismic origin."
- "It may be stated that it is now the practice of the Coast and Geodetic Survey to **examine the tide rolls whenever the seismograms indicate submarine earthquakes in the general region, and also to investigate the seismograms when tidal phenomena are unusual**."



Tidal Registration, Galveston, Texas, May 2–3, 1922

From: Parker, W.E. (1922) Unusual tidal registration of earthquakes. Bulletin of the Seismological Society of America

NINETEENTH CENTURY TIDE DATA

- Memory of most pre-1900 tide records has largely disappeared from the modern scientific literature…
- The only exceptions to this neglect are short segments of marigrams which have been used to reconstruct past tsunamis (e.g. ***Lander, et al., 1993, Tsunamis affecting the west coast of the United States, 1806–1992***, NGDC)
- Lander, et al., examined marigrams for all tsunami publications

  U.S. Tsunamis 1690-1988, Tsunamis Affecting Alaska 1737-1996; Caribbean Tsunamis 1498-1998, Tsunamis of the Eastern U.S. 1668-1992

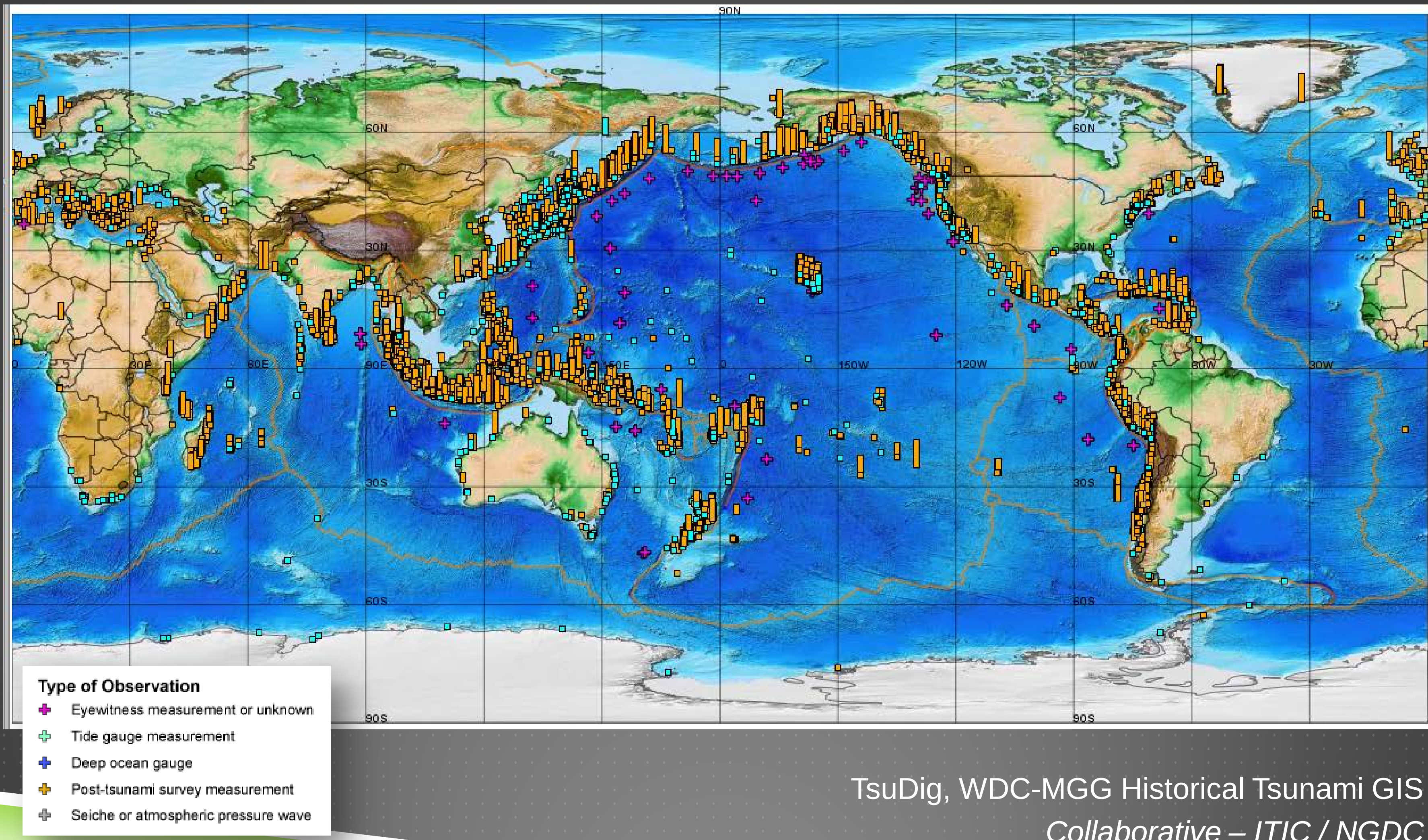
US West Coast and Hawaii

Location	Start Date	Currently Digitized Hourly
San Francisco, CA	1853	1853-pr (present)
San Diego, CA	1853	1906-pr
Astoria, OR	1853	1925-pr
Port Townsend, WA	1855	1966, 1972-pr
Seattle, WA	1891	1899-pr
Kodiak, AK	1880	1975-pr
Honolulu, HI	1877	1877-82, 1905-pr

US East Coast

Location	Start Date	Hourly Data Available
Eastport, ME	1860	1930-pr
Portland, ME	1852	1912-pr
Boston, MA	1847	1921-pr
Newport, RI	1844	1930-pr
Willets Point, NY	1885	1957-2000
New York, NY	1844	1920-pr
Sandy Hook, NJ	1844	1910-pr
Baltimore, MD	1845	1902-pr
Annapolis, MD	1844	1928-pr
Washington, DC	1852	1931-pr
Old Point Comfort, VA	1844	1927-pr
Wilmington, NC	1882	1930-pr
Charleston, SC	1850	1921-pr
Fort Pulaski, GA	1851	1935-pr
Key West, FL	1847	1913-pr

From: Talke and Jay (2013) Nineteenth Century North American and Pacific Tidal Data: Lost or Just Forgotten?

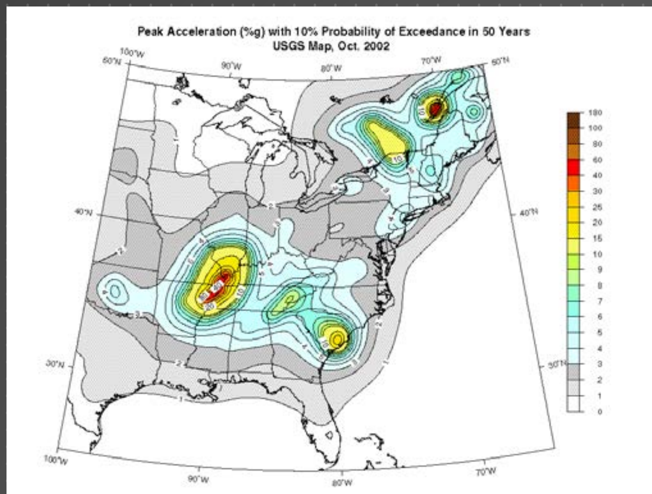


TsuDig, WDC-MGG Historical Tsunami GIS

Collaborative – ITIC / NGDC

USGS EARTHQUAKE HAZARDS ASSESSMENT

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



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	

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

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

LATEST RESEARCH

- ten Brink, U., Chaytor, Geist, Brothers, Andrews (in press) Tsunami hazard assessment for the U.S. Atlantic margin: Progress Procedures, and Processes
  - "Tsunamis along the U.S. Atlantic margin are rare events, because potential earthquake-generated tsunamis are located in areas of slow tectonic activity, and because landslide-generated tsunamis are probably triggered by infrequent earthquakes along the margin."
- Goldfinger, Nelson, Morey, et al. (2012) Turbidite event history—Methods and implications for Holocene paleoseismicity of the Cascadia subduction zone: *USGS Professional Paper 1661–F*
  - "The sequence of 41 events defines an average recurrence period for the southern Cascadia margin of ~240 years during the past 10 k.y."
- Leonard, L.J., G.C. Rogers, and S. Mazzotti (2012). A Preliminary Tsunami Hazard Assessment of the Canadian Coastline. Geological Survey of Canada, Open File 7201
- Frankel (2011) Summary of Nov 2010 Meeting to Evaluate Turbidite Data for Constraining the Recurrence Parameters of Great Cascadia Earthquakes for the Update of National Seismic Hazard Maps, USGS OF 2011–1310
  - **"Participants were comfortable with the 500-600 yr average recurrence time for long ruptures of the entire CSZ accomplished either by M9 or serial M8 earthquakes."**

LATEST RESEARCH - CONTD

- Shennan, Bruhn, Plafker (2009) Multi-segment earthquakes and tsunami potential of the Aleutian megathrust, *Quaternary Science Reviews*, v. 28
- Priest, Goldfinger, Wang, Witter, Zhang, Baptista (2009) Confidence limits for tsunami-inundation limits in northern Oregon inferred from a 10,000-year history of great earthquakes at the Cascadia subduction zone, *Natural Hazards*
- Burak, Eble, Titov, Bernard (2010) Tsunami Hazard Assessment Special Series: Vol. 2 Distant tsunami threats to the ports of Los Angeles and Long Beach, California
- Thio, Somerville, Polet (2010) Probabilistic tsunami hazard in California, Pacific Earthquake Engineering Research Center Report 2010/108
- Rabinovich, Thomson, Titov, Stephenson, Rogers (2008) Locally Generated Tsunamis Recorded on the Coast of British Columbia. *Atmosphere-Ocean*, v. 46
  - "Contrary to accepted understanding, our findings demonstrate that local earthquakes with magnitudes far below the generally accepted threshold level of 7.0 are capable of generating significant tsunamis."

QUALITATIVE
NATIONAL TSUNAMI HAZARD ASSESSMENT

Table A. Qualitative tsunami hazard assessment based on NGDC and USGS databases.

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	24
Alaska	Very high	Very high	High	222
Hawaii	Very high	Very high	High	326
U.S. Pacific island territories	Moderate	High	High	1

2008

Suggested 2014

Region	***Hazard based on runups***	***Hazard based on frequency***	***Hazard based on local earthquakes***	***Hazard based on distant 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		164
U.S. west coast	High	High	High		25*
Alaska	Very high	Very high	Very High		222
Hawaii	Very high	Very high	Moderate		293
American Samoa	High	High	High		34
U.S. Western Pacific Island territories	Moderate	High	High		1

COMMUNITY VULNERABILITY

- Population vulnerability to future tsunamis is a function of three components -
  - ***Population exposure*** is related to hazard proximity and the physical characteristics of the tsunami (e.g., arrival times, spatial extent).
  - ***Sensitivity*** refers to differential degrees of potential harm among at-risk populations, based on the internal characteristics of an individual, group, or socioeconomic system
  - ***Adaptive capacity*** describes possible adjustments and responses of a system to reduce a population's exposure or sensitivity.

Estimates of population exposure to tsunami-hazard zones in various States

	California	Hawaii	Oregon	Washington
Report publication date	Wood et al., 2012	Wood et al., 2007	Wood, 2007	Wood and Soulard, 2008
Date of population/economic data	2010, 2011	2000, 2006	2000, 2006	2000, 2006
Geographic extent	Open-ocean coast and San Francisco Bay	Entire coastline	Entire coastline	Olympic Peninsula counties (4)
Tsunami-hazard zone	Maximum based on multiple scenarios	Maximum based on multiple scenarios	Cascadia subduction zone	Cascadia subduction zone
Number of residents in hazard zone	267,347	80,443	22,201	42,972
Number of employees in zone	168,565	67,113	14,857	24,934
Number of public venues in zone	1,152	603	231	252
Number of dependent-care facilities in hazard zone	1,388	313	43	121
Average estimated daily visitors to coastal State and/or National Parks	166,322	n/a[1]	53,714	17,029
Average estimated daily visitors to city or county beaches	384,801	n/a[1]	n/a[1]	n/a[1]

[1]Data unavailable at the time of analysis

QUESTIONS?