

Hawaii Historical Tsunami Effects (1812-2015)

INTRODUCTION

Hawaii is one of the most unique locations in the world for studying tsunami effects. Not only are there large local tsunami sources, but Hawaii is also in the crosshairs of tsunamis generated around the Pacific from South America to Alaska, Russia, and Japan. The NOAA National Centers for Environmental Information (NCEI, formerly the National Geophysical Data Center) and collocated World Data Service for Geophysics (WDS) provides long-term archive, data management, and access to national and global tsunami data. The Global Historical Tsunami Database includes information on the tsunami source, maximum wave heights, and effects such as deaths and damage. The UNESCO/IOC – NOAA International Tsunami Information Center (ITIC) has worked in collaboration with the NCEI/WDS to collect post-tsunami event information since its inception in 1965. Located in Honolulu, Hawaii, the ITIC is especially active in collecting Hawaii tsunami event data.

HAWAII AND THE PACIFIC BASIN

The Hawaiian Islands are surrounded by the deep waters of the Pacific Basin. Nearly the entire margin of the basin, known as the Pacific Ring of Fire, is seismically active. No large land masses lie between the margin, where the Earth's tectonic plates are subducting, and the islands that form Hawaii. Hence, the islands are vulnerable to tsunamis generated by large earthquakes occurring along the subduction zones ringing the Pacific. Hawaii has a long history of damaging tsunamis (Fig. 1).

TSUNAMIS AFFECTING HAWAII

Examination of the NCEI/WDS Global Historical Tsunami Database reveals that the earliest historical account of a tsunami impacting the U.S. was a 16th century Hawaiian chant describing a huge wave that struck the west coast of Molokai. The earliest confirmed tsunami occurred on Dec. 21, 1812, when a wave generated off the Southern California coast was observed at Hookena on the west coast of Hawaii Island. This was the first recorded event of a remote sourced tsunami, although tsunamis undoubtedly reached the islands prior to this. Since that time, more than 160 tsunamis (135 confirmed and 26 unconfirmed) have been observed in Hawaii, resulting in over 2000 runup observations (Fig. 2).

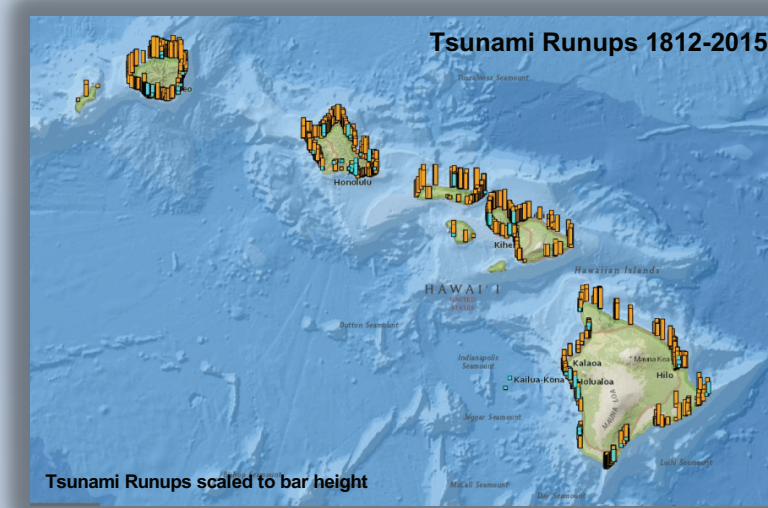


Figure 2. Plot of tsunami runups (locations where tsunami waves were observed by eyewitnesses, field reconnaissance surveys, tide gauges, or deep ocean sensors) from 1812 to 2015. (<http://maps.ngdc.noaa.gov/viewers/hazards/>)

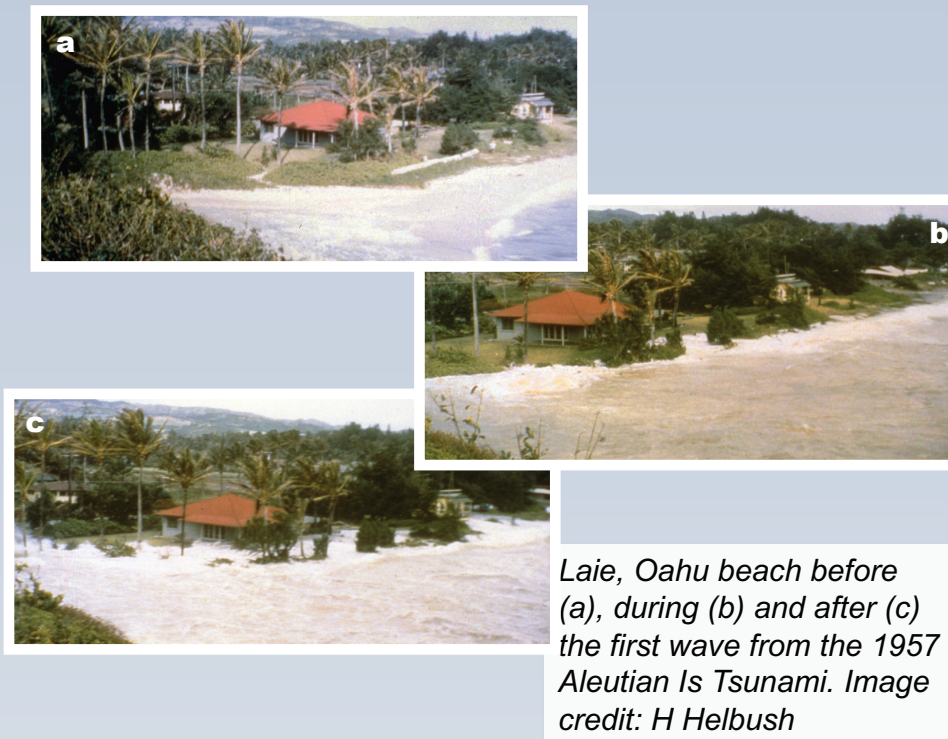
DISTRIBUTION OF TSUNAMI SOURCES

Approximately 43% of the tsunamis observed in Hawaii were from the east coast of the Pacific, including the Aleutian Islands; 49% were from the west coast of the Pacific; 7% were locally generated from Hawaii; and less than 1% were from the Indian Ocean (Table 1). These tsunamis were caused by earthquakes (98%) and volcanic eruptions (2%).

Table 1. Tsunamis Affecting Hawaii¹ (1812 to 2015)

Volcanic Eruption	Earthquake	Source Region
	19%	West Coast of South America
	16%	Kamchatka and Kuril Islands
	13%	West Coast of North and Central America
	13%	Alaska (including Aleutian Islands)
	12%	New Zealand, S. Pacific Islands
	8%	New Caledonia, Papua New Guinea, Solomon Islands, Vanuatu
< 1%	8%	Japan
	2%	Philippines
	1%	Indonesia (Pacific Ocean)
< 1%	92%	Total Pacific Ocean (Remote)
< 1%	6%	Hawaii
	< 1%	Total Indian Ocean (E. Indonesia)

¹ Confirmed (event validity >3) tsunamis.



Laie, Oahu beach before (a), during (b) and after (c) the first wave from the 1957 Aleutian Is Tsunami. Image credit: H Helbush



Images show damage in the Haleiwa Harbor on Oahu from the 2011 Tohoku, Japan tsunami. 2 m runup height. Image credit: Mader Consulting Co.

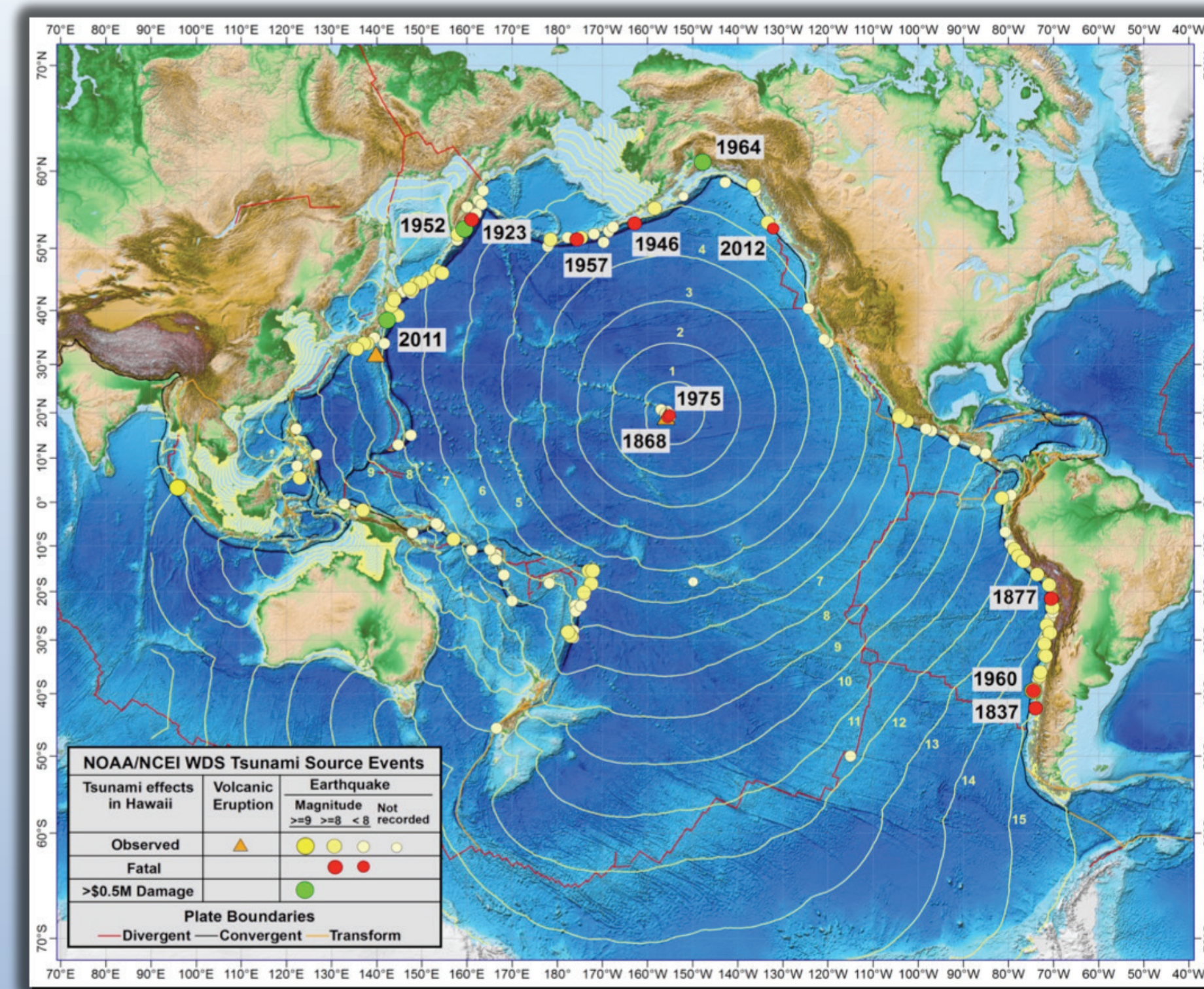


Figure 1. Plot of tsunami sources observed in Hawaii from 1812 to 2015. The map also displays estimated pre-computed tsunami travel times from Hilo, Hawaii to locations around the Pacific Basin. Travel times (in hours) were calculated with TTT Software (P. Wessel, Geoware) using bathymetry derived from the 2 arc-minute ETOPO2 grid.

SOCIO-ECONOMIC IMPACT OF TSUNAMIS

Hawaii has experienced more deaths and damage from tsunamis than any other State in the U.S. Nine tsunamis caused 294 deaths and damage totaling over \$600 million (adjusted for inflation) (Table 2). 88% of all tsunami fatalities in Hawaii have occurred on the Island of Hawaii and Hilo alone accounts for 60% of all the tsunami fatalities in Hawaii. Unlike the other U.S. States, the majority of these effects resulted from distant tsunami sources.

Table 2. Tsunamis Causing Deaths or >\$0.5 Million Damage in Hawaii

Date	Location	EQ Mag ¹	Runup ³ Height (m)	TTT ² (Hrs)	Damage \$million ⁴	Deaths in Hawaii	Deaths in Hawaii	Comments
1837	S. Chile	8.5	16.3	6.0		16	14 killed at Hilo, 2 killed at Kahului.	
1868	Hawaii	7.9	<1	6.1		47	47 killed on Island of Hawaii.	
1877	N. Chile	8.3	14.0	4.8		5	5 killed at Hilo. (Additional deaths in Chile, Fiji, Japan, and Peru)	
1923	Kamchatka	8.3	6.5	6.0	\$20.78	1	1 killed at Hilo. (Additional deaths in Russia)	
1946	Unimak Is, AK	8.6	4 to 5	2 to 16	\$315.90	158	121 killed on Hawaii (96 at Hilo), 17 Kauai, 14 Maui, 6 Oahu. (Additional deaths in Alaska, Calif., Marquesas Is, and Peru)	
1952	Kamchatka	9.0	6 to 7	2 to 10	\$8.94	0	Damage on Hawaii, Kauai, Maui, and Oahu. (Deaths in Russia)	
1957	Andreanof Is, AK	8.6	4 to 5	2 to 16	\$42.15	2	2 indirect fatalities from airplane crash near Oahu.	
1960	Central Chile	9.5	14.8	10.7	\$194.00	61	61 killed at Hilo. (Additional deaths in California, Chile, Japan, and Philippines)	
1964	Prince William Sound, AK	9.2	5.4	3.6	\$0.51	0	Damage on Hawaii and Maui. (Deaths in Alaska, California, and Oregon)	
1975	Hawaii	7.7	<1	7.9	\$6.60	2	2 killed at Halape.	
2011	Tohoku, Japan	9.0	7 to 8	2 to 5	\$32.13	0	Damage on Hawaii, Kauai, Maui and Oahu. (Deaths in California, Indonesia, and Japan)	
2012	Haida Gwaii, Canada	7.7				1	1 indirect fatality from traffic accident in the statewide evacuation on Oahu. No damage.	

¹ Earthquake magnitudes (Ms or Mw) are instrumental (from USGS) or estimated based on intensity before 1900 (from NCEI).
² Tsunami Travel Times (TTT) are observed times taken from the NCEI database.
³ Runup height is the height of the tsunami at the point of maximum inundation above the state of the tide at the time.
⁴ Adjusted for inflation to 2016 dollars.

To further examine the impact of tsunamis in Hawaii, each tsunami was binned by the maximum runup height for each event from either a local or distant source. A tsunami with a runup greater than 3 m, irrespective of source distance, hits Hawaii on average about once every ten years.

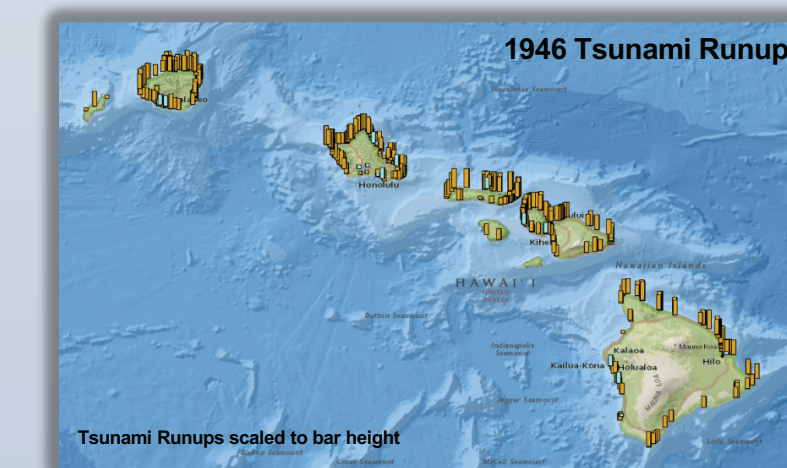
Table 3. Tsunami events affecting Hawaii by maximum runup height per event¹ (1812 to 2015)

Local		Distant		Local		Distant		Local		Distant		Local		Distant		Local		Distant	
Undetermined				0.01 to 0.5 m				0.51 to 1.0 m				1.01 to 3.0 m				>3.0 m			
Deaths		\$M Damage		Deaths		\$M Damage		Deaths		\$M Damage		Deaths		\$M Damage		Deaths		\$M Damage	
1	1	2	94	7	2	9	4	15	49	245	6	604							

¹ Tsunami event validity >=3 or a confirmed tsunami.

POST TSUNAMI FIELD SURVEYS

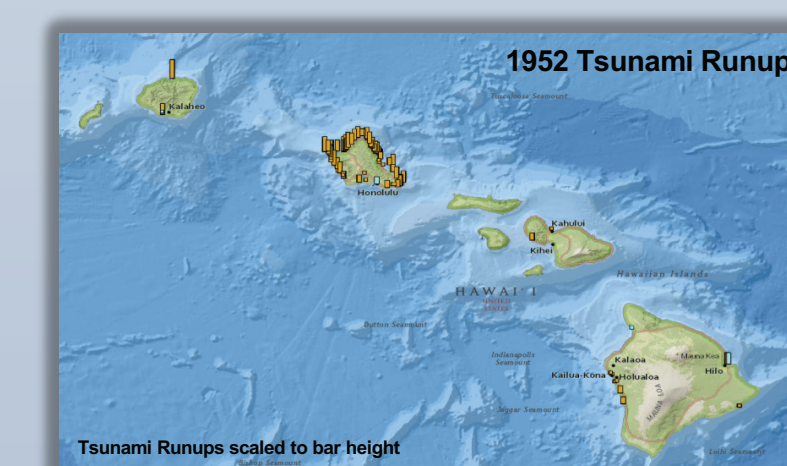
The tsunami hazard in the islands of Hawaii is not uniform. For example, the extensive reefs in Kaneohe Bay on Oahu help to reduce tsunami impact by reflecting or dissipating the waves. The shape and submarine morphology of Hilo's bayfront amplifies the incoming waves resulting in larger heights and stronger inland surges. The plots below show the distribution of tsunamis observed throughout Hawaii following large earthquakes (<http://maps.ngdc.noaa.gov/viewers/hazards/>). Although all types of runups are displayed, the majority are from the pioneering post-tsunami field surveys conducted by D Cox, G Macdonald, and F Shepard starting in 1946, and subsequently by J Eaton, J Mink, and H Loomis. Runup maps for Kauai, Niihau, Oahu, Maui, Molokai, Lanai, and Hawaii islands from the 1946, 1952, 1957, 1960, 1964, and 2011 tsunamis were compiled by D Walker and G Curtis in 2002, and updated to include 2011 by ITIC in 2013.



1946 UNIMAK ISLAND, ALASKA

The tsunami waves were destructive along the shorelines of Hawaii. 158 people were killed. Maximum wave heights were 17 m, 10 m, 11 m, and 14 m on Hawaii, Maui, Oahu, and Kauai, respectively.

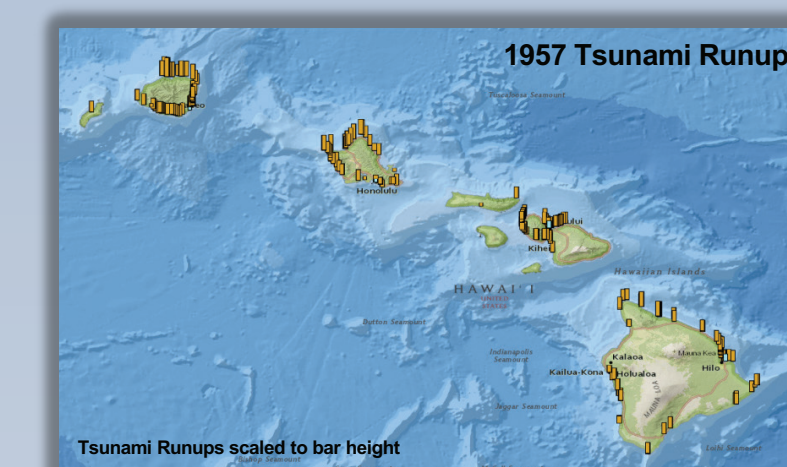
Left: Tsunami damage near Kailihai Bay, Kauai (1946). Image credit: O Magoon



1952 KAMCHATKA, RUSSIA

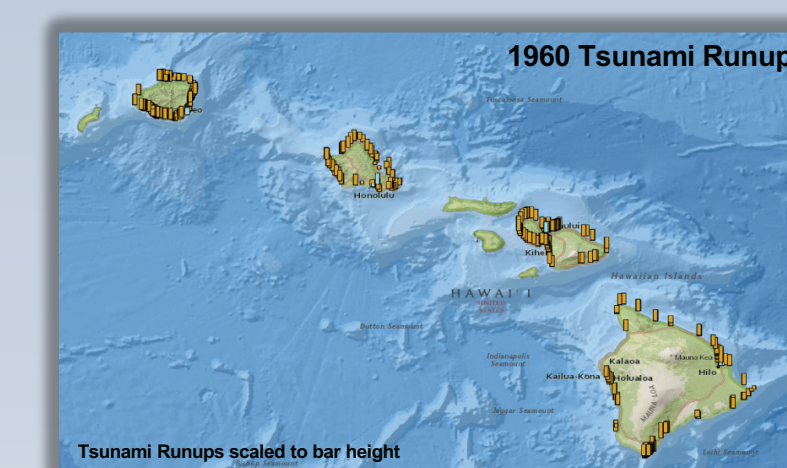
There were no deaths in Hawaii, but the waves caused houses to collide, beached boats, destroyed piers, scoured beaches, and moved road pavement. Maximum wave heights were 4 m, 1 m, 9 m, and 3 m on Hawaii, Maui, Oahu, and Kauai, respectively.

Fourth wave surging inland, Kaiaka Bay, between Waialua and Haleiwa, Oahu (1952). Image credit: R M Towill



1957 ANDREANOF ISLANDS, ALASKA

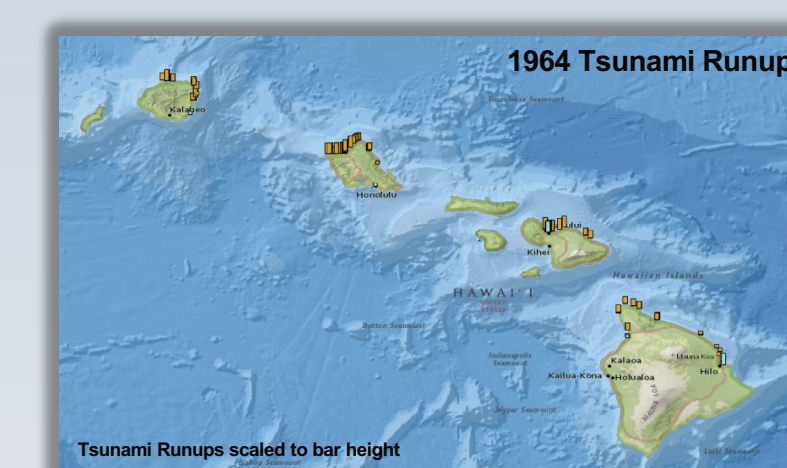
The tsunami knocked out bridges and flooded highways. Maximum wave heights were 10 m, 5 m, 9 m, 16 m on Hawaii, Maui, Oahu, and Kauai, respectively.



1960 SOUTHERN CHILE

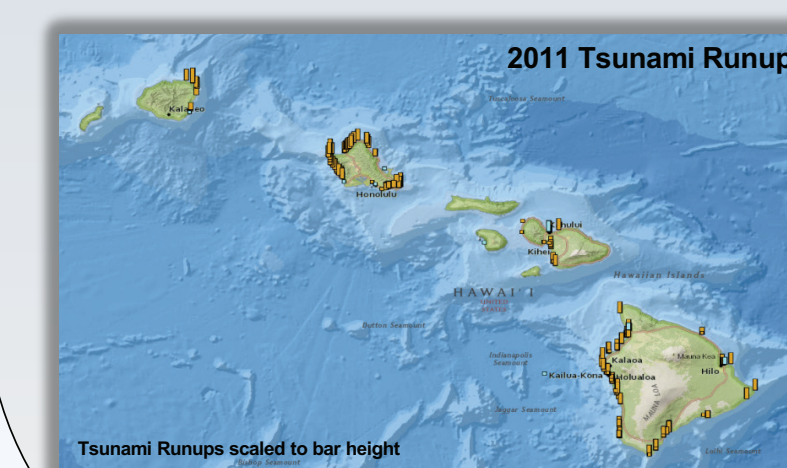
The wave action along Hawaiian shores was quiet, except in Hilo Bay where the third wave was transformed into a bore that rushed inland along the Wailuku River. Nearly 240 hectares inland of Hilo Harbor were inundated; the 61 deaths and the majority of the damage occurred in this area. Maximum wave heights were 11 m, 5 m, 4 m, and 4.5 m on Hawaii, Maui, Oahu, and Kauai, respectively.

Gas station across Moohau Park, Hilo, Hawaii (1960). Image credit: Honolulu Star-Bulletin



1964 PRINCE WILLIAM SOUND, ALASKA

This tsunami caused minor damage in Hawaii. Considerable damage was reported to facilities at Kahului Harbor, Maui. Maximum wave heights were 3 m, 4 m, 5 m and 3 m on Hawaii, Maui, Oahu, and Kauai, respectively.



2011 TOHOKU, JAPAN

Tsunami losses in Hawaii totaled an estimated \$32 million (adjusted for inflation). The Kona Coast suffered the most with damage to restaurants, hotels, homes, and pier facilities. Boat harbors throughout the State, and homes on Maui and Molokai, were damaged. Maximum wave heights were 5 m on Hawaii, Oahu, and Kauai, and 2 m on Maui.