

Hawaii Historical Tsunami Effects

AGU Ocean Sciences Meeting 2014, Session 086 Tsunami Research: Recent Advances in Instrumentation and Modeling

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 Geophysical Data Center (NGDC) 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 NGDC/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 subductions zones ringing the Pacific. Therefore, Hawaii has a long history of damaging tsunamis (Fig. 1).

TSUNAMIS AFFECTING HAWAII

Examination of the NGDC/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 came on 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 150 tsunamis (132 confirmed and 27 unconfirmed) have been observed in Hawaii, resulting in over **2000 runup observations** (Fig. 2).

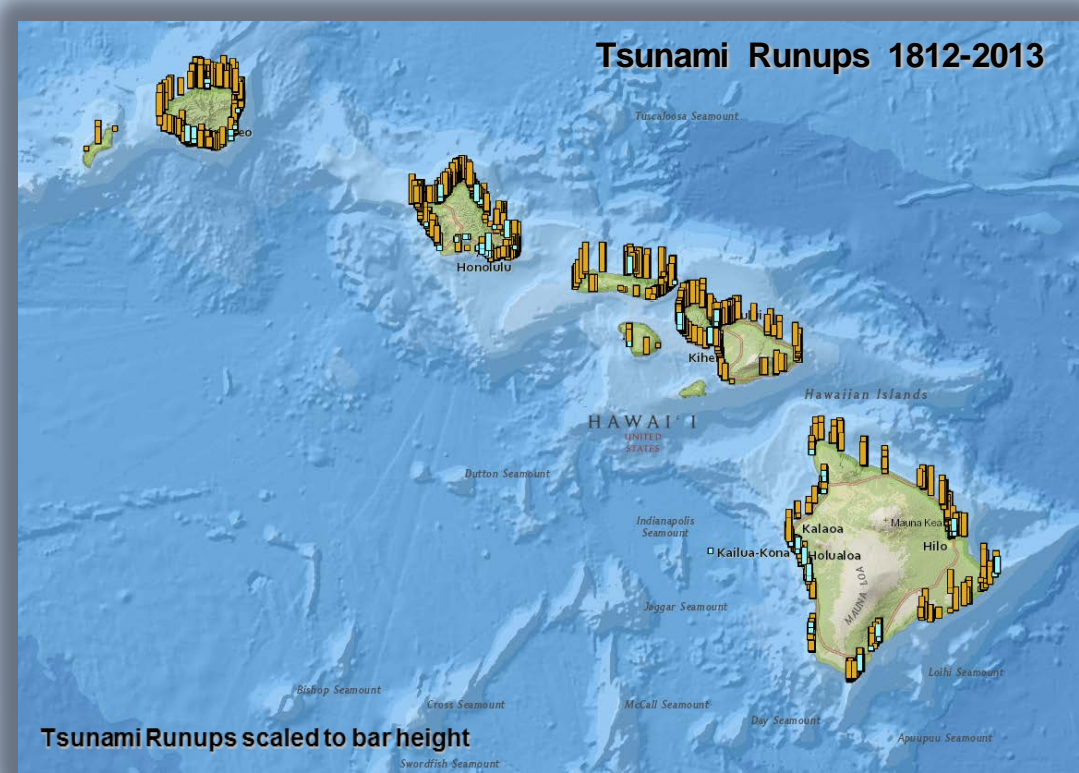


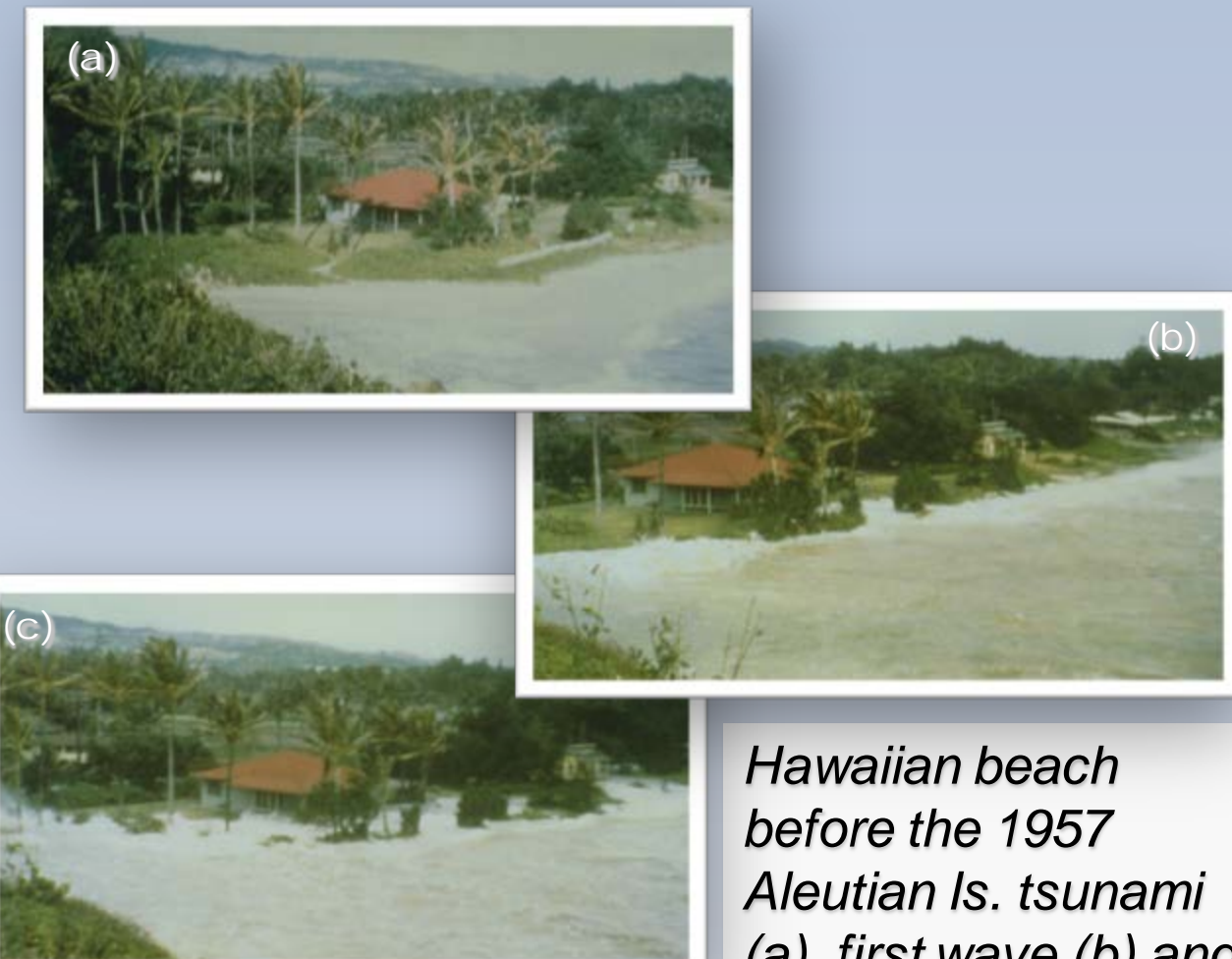
Figure 2. Plot of tsunami runups (locations where tsunami waves were observed by eyewitnesses, field reconnaissance surveys, tide gauges, or deep ocean sensors) from 1812 to 2013. (<http://maps.ngdc.noaa.gov/viewers/hazards/>)

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 Hawaii ¹ (1812 to 2013) | | |
|--|------------|---|
| Volcanic Eruption | Earthquake | Source Region |
| 18% | 16% | West Coast of South America |
| | 13% | Kamchatka and Kuril Islands |
| | 12% | West Coast of North and Central America |
| | 12% | Alaska (including Aleutian Islands) |
| | 12% | New Zealand, S. Pacific Islands |
| | 8.3% | New Caledonia, Papua New Guinea, Solomon Islands, Vanuatu |
| < 1% | 8.3% | Japan |
| | 2% | Philippines |
| | 2% | Indonesia (Pacific Ocean) |
| < 1% | 92% | Total Pacific Ocean (Remote) |
| < 1% | 6% | Hawaii |
| | < 1% | Total Indian Ocean (E. Indonesia) |

¹ Confirmed (event validity >3) tsunamis.



Hawaiian beach before the 1957 Aleutian Is. tsunami (a), first wave (b) and engulfed (c). 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.

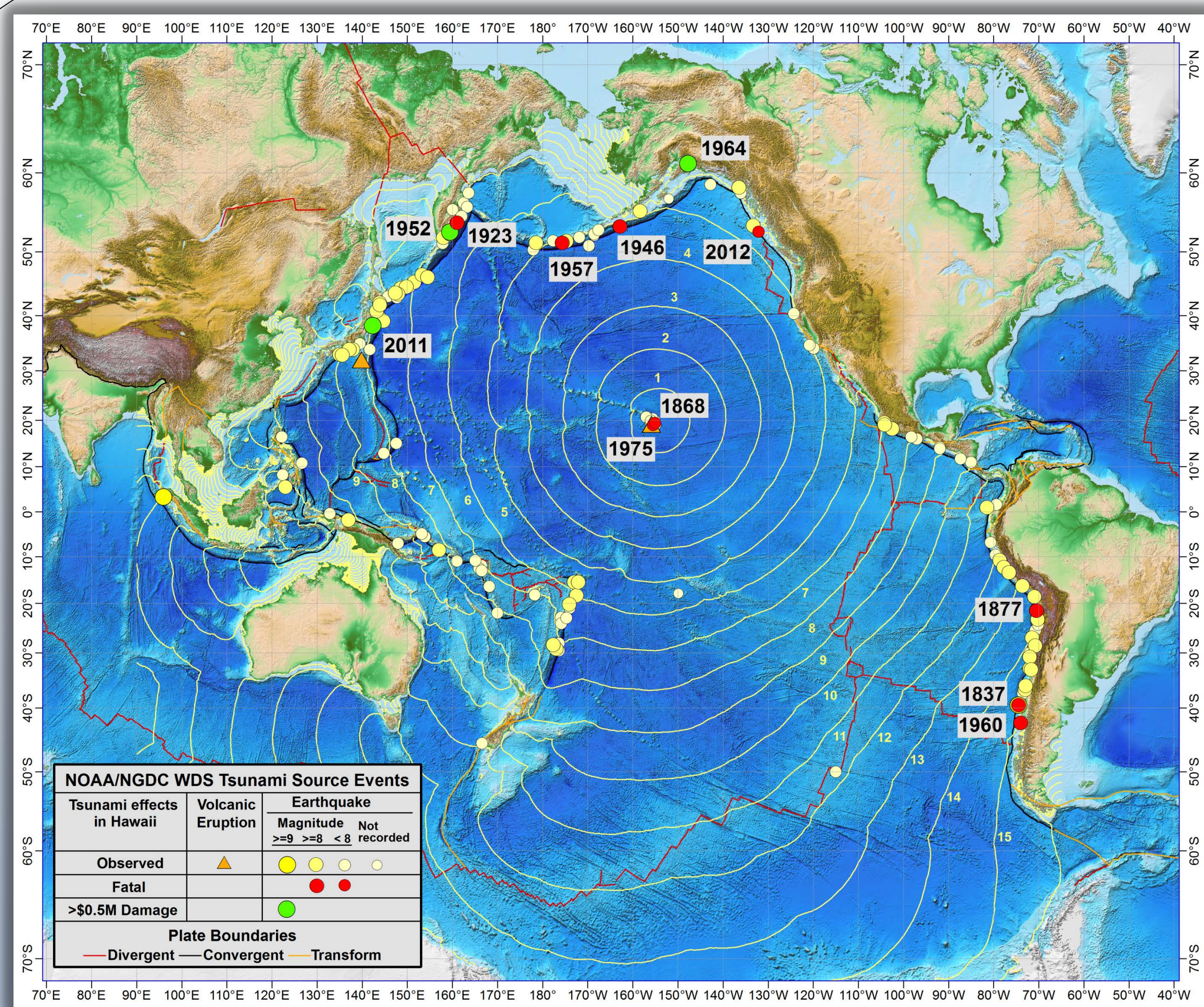


Figure 1. Plot of tsunami sources observed in Hawaii from 1812 to 2013. The map also displays estimated pre-computed tsunami travel times from Hilo, Hawaii to locations around the Pacific Basin. Travel times (in hours) were calculated with TTT Software (P. Wessel, Geoware) using bathymetry derived from 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 | TTT ² (Hrs) | Runup ³ Height (m) at Location of Effects | Damage \$million ⁴ 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 | \$20.43 | 1 | 1 killed at Hilo. (Additional deaths in Russia) |
| 1946 | Unimak Is, AK | 8.6 | 4 to 5 | 2 to 16 | \$310.70 | 159 | 122 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 | \$8.79 | 0 | Damage on Hawaii, Kauai, Maui, and Oahu. (Deaths in Russia) |
| 1957 | Andreanof Is, AK | 8.6 | 4 to 5 | 2 to 16 | \$41.45 | 2 | 2 indirect fatalities from airplane crash near Oahu. |
| 1960 | Central Chile | 9.5 | 14.8 | 10.7 | \$190.85 | 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 | \$6.50 | 2 | 2 killed at Halape. |
| 2011 | Tohoku, Japan | 9.0 | 7 to 8 | 2 to 5 | \$31.82 | 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 NGDC).

² Tsunami Travel Times (TTT) are observed times taken from the NGDC 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 2013 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**.

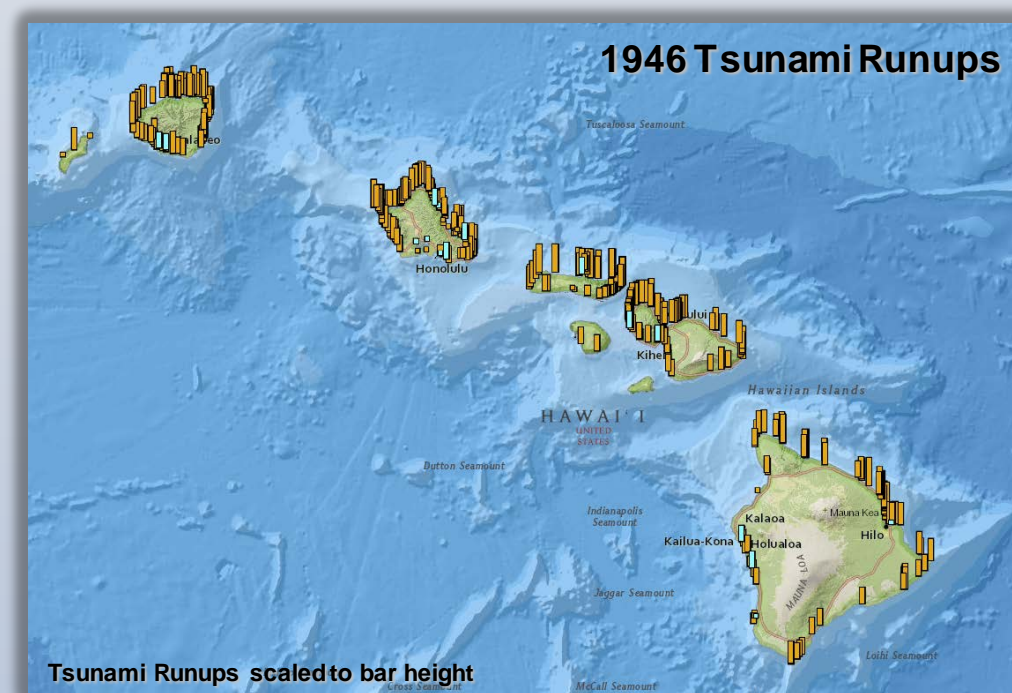
Table 3. Tsunami events affecting Hawaii by maximum runup height per event¹ (1812 to 2013)

| Local | Distant | Local | Distant | Local | Distant | Local | Distant | Local | Distant | Local | Distant | Local | Distant |
|--------------|---------------|---------------|---------------|--------|---------|------------|---------|-------|---------|-------|---------|-------|---------|
| Undetermined | 0.01 to 0.3 m | 0.31 to 1.0 m | 1.01 to 3.0 m | >3.0 m | Deaths | \$M Damage | | | | | | | |
| 1 | 1 | 2 | 79 | 19 | 2 | 9 | 4 | 15 | 49 | 245 | \$6 | \$604 | |

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

POST TSUNAMI FIELD SURVEYS

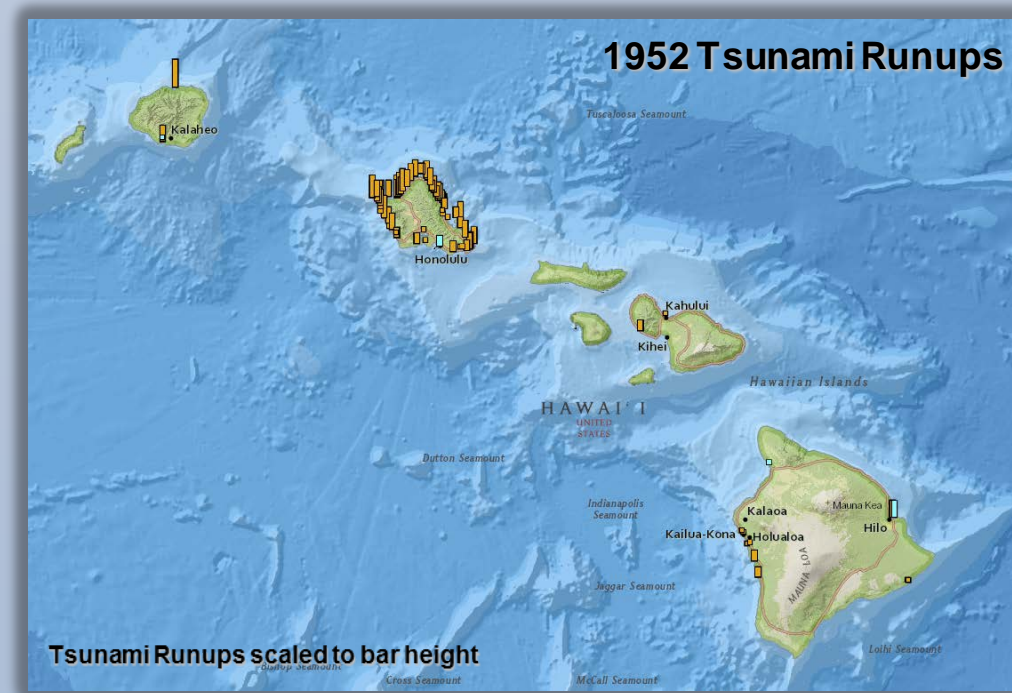
The tsunami hazard in the islands of Hawaii is not uniform. For example, the extensive reefs in Kaneohe Bay on Oahu help to reduce tsunami impact by reflecting or dissipating the waves. The shape and submarine morphology of Hilo's bayfront amplifies the incoming waves creating larger heights and stronger inland surges. The plots below show the distribution of tsunamis on the islands of 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 the Hawaiian Islands. **159 people were killed**. Maximum wave heights were 17 m, 10 m, 11 m, and 14 m on Hawaii, Maui, Oahu, and Kauai respectively.

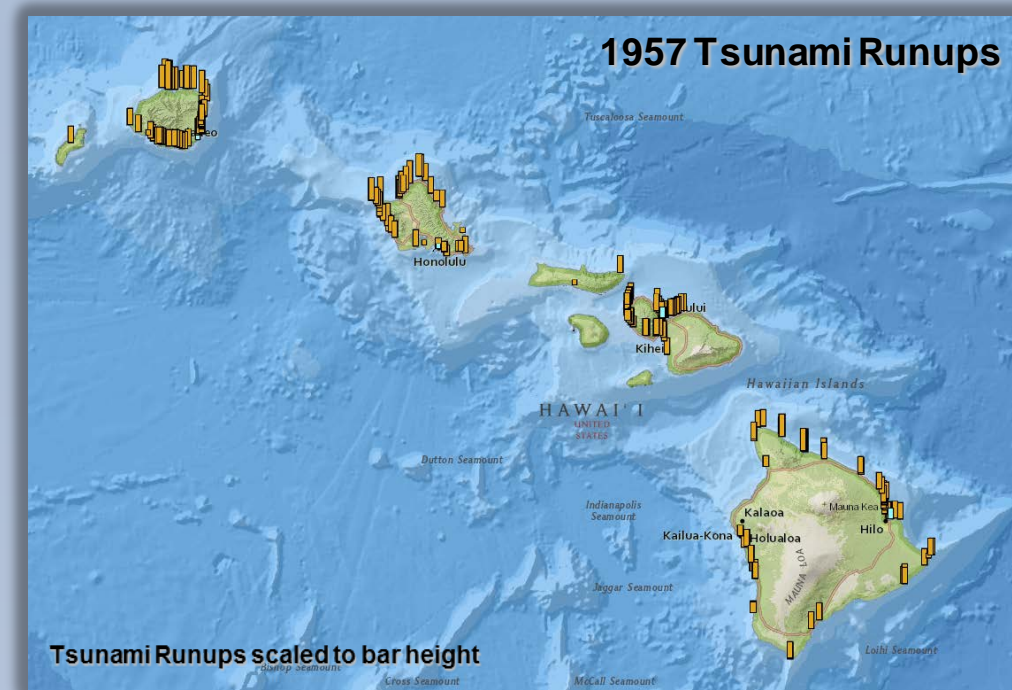
Tsunami damage to Hilo pier (1946). Image credit: Univ of Calif. Berkeley



1952 KAMCHATKA, RUSSIA

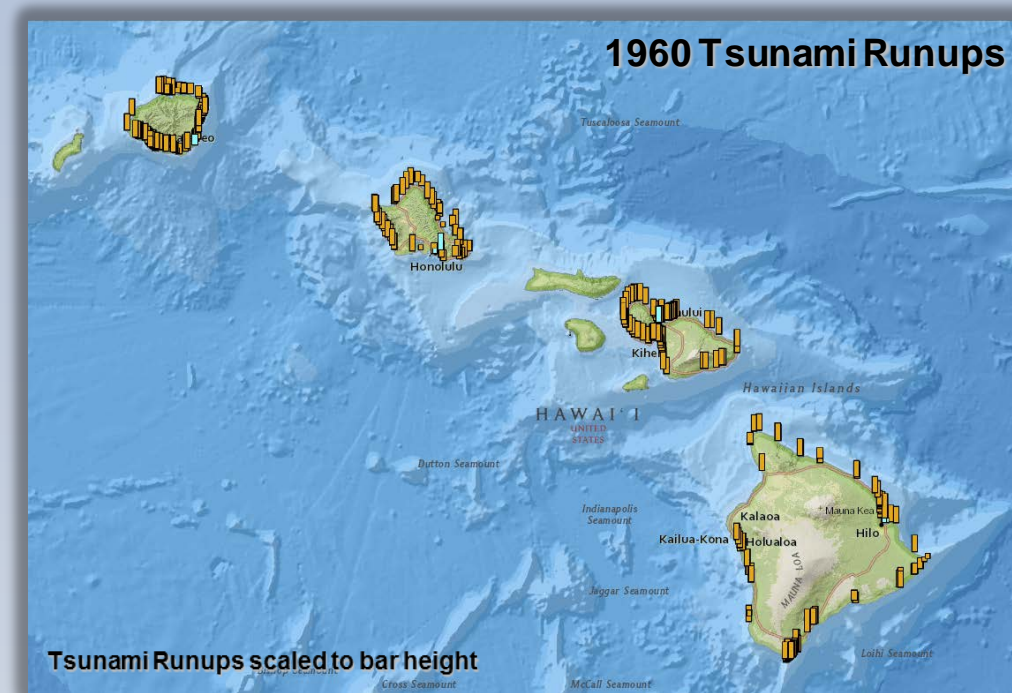
There were no deaths in Hawaii, but the waves caused houses to collide, beached boats, destroyed piers, scoured beaches, and moved road pavement. Maximum wave heights were 4 m, 1 m, 9 m, and 3 m on Hawaii, Maui, Oahu, and Kauai respectively.

Aerial view of wave striking Hawaiian beach (1952). Image credit: G Curtis



1957 ANDREANOF ISLANDS, ALASKA

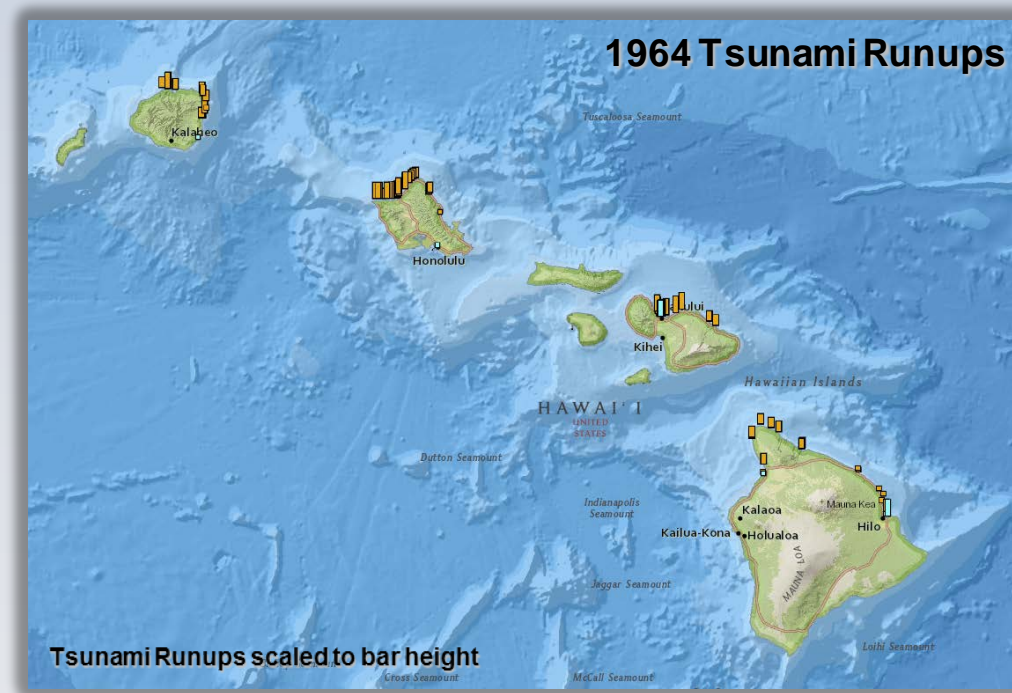
The tsunami knocked out bridges and flooded highways. Maximum wave heights were 10 m, 5 m, 9 m, 16 m on Hawaii, Maui, Oahu, and Kauai respectively.



1960 CENTRAL CHILE

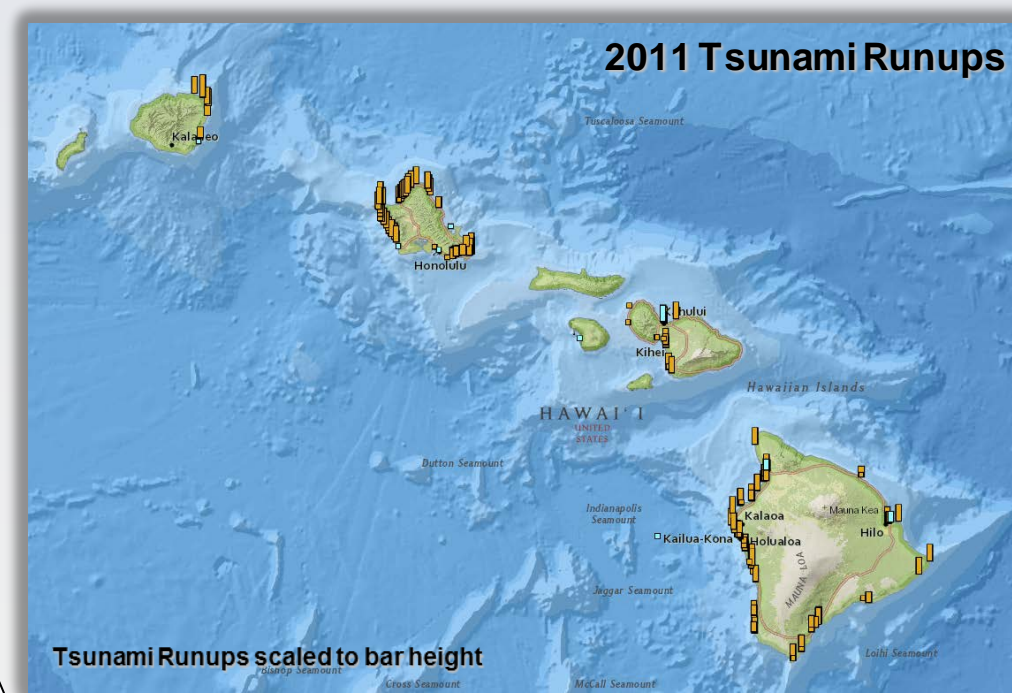
The wave action along Hawaiian shores was quiet, except in Hilo Bay where the third wave was converted into a bore that flooded inland. Nearly 240 hectares inland of Hilo harbor were inundated; **the 61 deaths** and the majority of the damage occurred in this area. Maximum wave heights were 11 m, 5 m,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

Tsunami damage in Hilo (1960). Image credit: U.S. Navy



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