OCEAN-WIDE TSUNAMIS, MAGNITUDE THRESHOLDS, AND 1946 TYPE EVENTS

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SUMMARY

An analysis of magnitudes and runups in Hawaii for more than 200 tsunamigenic earthquakes along the margins of the Pacific reveals that all of the earthquakes with moment magnitudes of 8.6 or greater produced significant Pacific-wide tsunamis. Such findings can be used as a basis for early warnings of significant ocean-wide tsunamis as a supplement to, or in the absence of, more comprehensive data from other sources. Additional analysis of magnitude and runup data suggests that 1946 type earthquakes and tsunamis may be more common than previously believed.

INTRODUCTION

In the aftermath of 26 December 2004, attention has been focused on strategies for reducing or eliminating those factors that contributed to the Asian tsunami tragedies. In this regard one of the first questions to be asked is whether there exists an earthquake magnitude threshold above which the generation of a significant ocean-wide tsunami becomes a certainty. This question is important because such a threshold might be useful in providing the basis for an early warning of a significant ocean-wide tsunami, perhaps well in advance of comprehensive data from ocean buoys, tide gauges, or other sources.

ANALYSIS

Magnitude Threshold

In an earlier report (Walker, 2000) more than two hundred earthquakes from 1900 through 1999 with epicenters along the margins of the Pacific were analyzed in terms of their surface wave magnitudes, moment magnitudes, and runups in Hawaii. For this report these data have been updated through 2004 (Table 1). Also added is the only known ocean-wide tsunamigenic earthquake in the Pacific prior to 1900 for which a surface wave magnitude (Ms) and moment magnitude (Mw) have been computed (i.e., the 1896 Sanriku earthquake). Data from Table 1 and the earlier report are shown in Figure 1. Smaller runups may actually be estimates from water level recordings. Values through 1999 may be found in Table 1 of Walker (2000).

Earthquakes with Ms/Mw values above the dashed line in Figure 1 appear to have the potential for generating destructive tsunamis in Hawaii. Earthquakes with Ms/Mw values below the line have not generated Pacific-wide tsunamis or have generated only moderate or small Pacific-wide tsunamis. As might be expected, most of the significant tsunamis (i.e., those having runups of 1 meter or more) have large moment magnitudes. All earthquakes with moment magnitudes of 8.6 or greater produced significant ocean-wide tsunamis. However, this does not hold true for two of the five earthquakes with Mw's of 8.5. One occurred in the Kurils with an Ms = 8.1 and runup (A) = 0.4 meters. This earthquake had no obvious characteristics (i.e., location, orientation, depth, or source mechanism) that might explain the absence of a significant ocean-wide tsunami. The other earthquake occurred south of Samoa (Ms = 8.2; A = 0.1 m), close enough to have much of the energy that might have traveled to Hawaii blocked by those islands. Moving further down the Mw scale to 8.4 and 8.3, four of the five earthquakes did not produce significant tsunamis in Hawaii. The orientation of faulting relative to Hawaii could be a factor in explaining the absence of a significant ocean-wide tsunami for the Peru earthquake (Mw = 8.4, Ms = 8.2, A = 0.7 m). No obvious characteristics can explain the absence of significant tsunamis for the other earthquakes (an 8.4 and two 8.3's). Therefore, based on the available limited data, the Mw threshold indicated for the Pacific is 8.6. However, an earthquake in the Central Aleutians with an Ms = 8.2, Mw = 8.7, and A = 1.1 meters is indicative of how close the 8.6 threshold could be to producing "false warnings" (i.e., warnings perceived as false because the maximum runup was less than 1 meter). There are no obvious characteristics that might explain the absence of a larger tsunami for this Central Aleutians event. Aside from values in the source area, the largest runup reported for this earthquake was the 1.1 meters in Hawaii (Iida, Cox, and Pararas-Carayannis; 1967). The central Aleutian earthquake with its 8.7 Mw and relatively small ocean-wide tsunami may be somewhat comparable to the recent 8.7 Mw Sumatra aftershock of 28 March 2005.

Additional 1 April 1946 Type Tsunamis

Other important insights into the relationships (or non-relationships) between tsunamis and earthquake magnitudes may be found in Figure 1. Most disturbing is the fact that of all the significant Pacific-wide tsunamis reported in Hawaii, none had a larger runup (A = 16.4 m), a smaller Ms (7.1), or smaller Mw (8.0). A generally accepted explanation for the size of this tsunami, given its relatively modest magnitudes, has yet to be found. If this earthquake can generate a 16.4 meter runup in Hawaii, would it be possible for earthquakes with Ms and Mw values far less than 7.1 and 8.0, respectively, to produce 1 meter or more runups in Hawaii? Would it be possible for a 1946 type tsunami with Ms and Mw values far greater than 7.1 and 8.0, respectively, to produce runups in Hawaii far greater than 16.4 meters? For years the hope had been that this tsunami was a "one of a kind" anomaly for which an explanation could be found. However, with the publication of an analysis of the 1896 Sanriku earthquake (Tanioka and Satake, 1996), the 1946 event, while still the most prominent, may no longer stand alone. The 1896 earthquake (Figure 1) has the same Mw (8.0) as the 1946 earthquake and a slightly larger Ms (7.2 versus 7.1). The largest reported runup in Hawaii was 5.5 meters at Keauhou on the western coast of the Big Island. This value is larger than the 3.2 meters reported at Keauhou (Lander and Lockridge, 1989) for the much larger (Ms = 8.3, Mw = 8.4) Sanriku earthquake of 1933. The largest runup reported for this larger earthquake was 3.3 meters at Kaalualu on the Big Island (Lander and Lockridge, 1989). An investigation of the differences in the mechanisms of these earthquakes may provide some insights into the unusual strength of the 1946 tsunami.

Another pair of earthquakes similar to, but less spectacular than, the Sanriku earthquakes, occurred in the Kurils in 1963 on the 13th and 20th of October. Both had maximum reported runups of 0.4 meters in Hawaii. However, the 13 October earthquake had an Ms = 8.1 and an Mw = 8.5 while the 20 October earthquake had an Ms = 7.2 and an Mw = 7.8. Like the Sanriku earthquakes, these Kurile events might provide some insights into the unusual strength of the 1946 tsunami. Finally, it should be noted that a small region generating a large number (9) of reported tsunamis in Hawaii is the offshore area of Kamchatka. Many of these earthquakes have nearly identical mechanisms, orientations, depths, and travel paths to Hawaii. For an earthquake with an Ms of only 7.0 and Mw of only 7.0, a runup in Hawaii of 0.3 meters was reported (13 April 1923); yet for an earthquake with an Ms of 8.2 with no available computed Mw, a runup of only 0.2 meters was reported (4 May 1959). The 7.0 / 7.0 / 0.3 m earthquake could also be compared to another Kamchatka earthquake with Ms / Mw / A values of 7.3 / 7.5 / 0.12 m (8 June 1993). Also there are three Kamchatka earthquakes with nearly identical epicenters (i.e., within about 100 km of one another) with values of 8.1 / 8.5 / 6.1 m (3 February 1923), 8.2 / 9.0 / 9.1 m (4 November 1952), and the previously mentioned 8.2 / NA / 0.2 m earthquake. As with the Sanriku and Kurile earthquakes, Kamchatka events could be useful in resolving the enigma of the 1 April 1946 tsunami.

CONCLUSIONS

All shallow earthquakes along margins of the Pacific with moment magnitudes of 8.6 or greater through 2004 produced significant tsunamis in the Hawaiian Islands. This threshold could be used to provide early ocean-wide tsunami warnings as a supplement to, or in the absence of, more comprehensive data from ocean buoys, tide gauges, or other sources. Runup values in Hawaii that are seemingly inconsistent with the magnitudes of the earthquakes that produced those tsunamis are found off Japan, the Kurile Islands, and Kamchatka. These earthquakes suggest that the 1946 tsunami may not be as anomalous as previously believed, possibly providing additional data for resolving the mechanism of the 1946 tsunami. Of the six earthquakes in Figure 1 having the largest reported runups in Hawaii, two (1896 and 1946) have unusually low magnitude values. These findings should serve as a reminder of the potential danger of recurring 1946 type tsunamis.

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Table 1

Additional Pacific-Wide Tsunamis in Hawaii through 2004*

Year	Date	Source Locations	Ms	Mw	A (meters)	Location
1896	06 15	Japan	7.2	8.0	5.5	Keauhou
2001	06 23	Peru	8.2	8.4	0.7	Hilo
2003	09 25	Japan	8.1	8.3	0.4	Kahului
2003	11 17	Aleutians	7.2	7.8	0.7	Kahului

* Data are supplemental to listings in Table 1 of Walker (2000). Magnitudes for the 1896 earthquake are taken from Tanioka and Satake (1996). Other data are from searches of U.S. Geological Survey (USGS), National Geophysical Data Center, or International Tsunami Information Center on-line databases. Surface wave magnitudes (Ms) are USGS values and moment magnitudes (Mw) are those of Harvard.

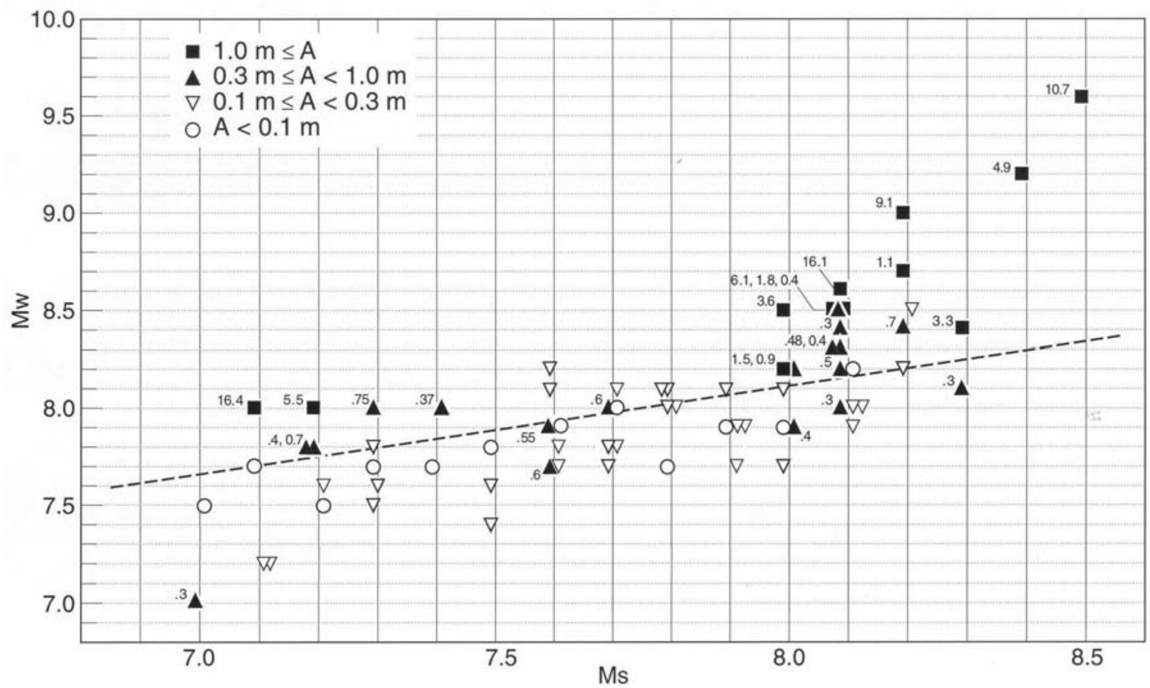

Figure 1. Surface wave magnitudes (Ms), moment magnitudes (Mw), and maximum reported runups or tide gauge readings (A) in Hawaii from Table 1 and Walker (2000). Of the more than 200 earthquakes examined for these regions, most did not generate reported tsunamis in Hawaii or their tsunamis were reported either to be less than 0.1 m or to be "observed". Only the largest of these in terms of Mw for each Ms value are plotted in this figure. The dashed line is an estimated delineation of those earthquakes with (above the line) or without (below the line) the potential for generating significant tsunamis in Hawaii.