CRITICAL EVALUATIONS FOR THE STATE OF HAWAII SUBSEQUENT TO THE 26 DECEMBER 2004 ASIAN TSUNAMI

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SUMMARY

A reexamination of historic data for Pacific-wide tsunamis suggests the need for modeling the effects of potential "100-year 9.0 magnitude earthquakes" from the Western and Southwestern Pacific, and possibly from Japan. Such modeling would either confirm the reliability of existing evacuation maps for the Hawaiian Islands or indicate necessary modifications. Long term observations of human responses to tsunamis in Hawaii, and more recently in Asia, suggest that tsunami education should be required in public and private schools. Destructive local tsunamis generated by small, unfelt earthquakes have struck, and will strike, portions of the Big Island without warning unless detectors similar to those protecting the Kona Coast are installed. Government and business leaders need to continually be reminded of the destructive potential of tsunamis, as well as the limitations and requirements of the warning system. Finally, critical infrastructure should be hardened to prevent damage from salt water flooding so as to facilitate a more rapid recovery from inevitable future tsunamis.

INTRODUCTION

Several key elements are now generally recognized as contributing factors in the tragedies of the Asian tsunami. Among these are the absence of a warning system for the Indian Ocean, failure to accurately assess the risks associated with tsunamis in the Indian Ocean, the absence of a general understanding of the characteristics and destructive potential of tsunamis, little or no timely intergovernmental communications, no existing evacuation plans, and possibly little or no zoning or engineering requirements to protect structures and critical lifeline facilities. Steps are now being taken by Asian countries and the international community to address some, if not all, of these issues. Perhaps the single greatest lesson to be learned from this tragedy is, once again, the failure of scientists and government agencies to analyze situations critically and objectively so as to eliminate any biases favoring desirable conclusions. As an example, thinking prior to 26 December 2004 might have been that recorded history provided no evidence of an ocean-wide tsunami in the Indian Ocean, so such a phenomenon seemed unlikely to happen. Furthermore, even if such an event were to occur, it would more than likely be a small tsunami. Therefore, concerning the local population and visitors with such an unreasonable possibility would be unnecessary and unwise. Thus, one would arrive at an acceptable, desirable, but horribly wrong conclusion. In an effort to avoid somewhat similar mistakes, the assessments that follow are offered as critical and objective evaluations of the current status of Hawaii's tsunami preparedness.

EVALUATIONS

An Asian Type Tsunami in Hawaii

In the 20th century, the Hawaiian Islands have been struck by several large Pacific-wide tsunamis. Moment magnitudes (Mw) and runups for these events are given in Walker (2000). The largest magnitudes are 9.6 (Chile '60), 9.2 (Alaska '64), 9.0 (Kamchatka '52), 8.7 (Aleutians '65), and 8.6 (Aleutians '57). [The Mw of the Indonesian earthquake west of Sumatra that produced the Asian tsunami is reported to be 9.0. Hereafter, all magnitudes cited in this report, unless otherwise indicated, will be moment magnitudes.] With some of the largest earthquakes in recorded history among those above, along with other destructive tsunamis including the powerful and anomalous 1946 event (Mw = 8.0), "worst case" scenarios may have already been experienced in the Hawaiian Islands. Also, with an existing warning system in the Pacific, it would seem improbable that Hawaii could be "surprised" by a tsunami from a 9.0 earthquake. However, a more careful examination of the data reveals that Hawaii's experience with large ocean-wide tsunamis is limited to source areas from the circum-Pacific arc extending from Japan through Alaska and from the west coast of South America. Since other portions of the circum-Pacific arc have not generated significant tsunamis in Hawaii (i.e., greater than or equal to 1 meter), does that mean that none will be generated? Isn't this the same type of "logic" that contributed to the Asian tragedy? Perhaps. It may be reasonable to dismiss large portions of the circum-Pacific arc because of the nature of faulting (e.g., the prevalent horizontal strike-slip motions along the west coast of North

America) or the orientation of subduction zones relative to Hawaii (e.g., Central America and margins of the Pacific plate extending south of Tonga). Remaining portions of the circum-Pacific arc extend south from Japan to New Guinea and continue eastward to Tonga and Samoa (Figure 1). These predominately vertical subducting margins have many segments oriented towards Hawaii. Although large locally destructive tsunamis frequently occur in some of these regions, there is no record of significant Pacific-wide propagation for the regions shown other than for Japan. In view of the Asian tragedies, a more careful analysis of these seemingly benign portions of the Pacific may be appropriate.

The question to be asked is whether these regions have been benign in terms of significant Pacific-wide tsunamis because of a deficiency of large earthquakes or because of attenuation by the large number of extensive island groups (e.g., the Caroline, Marshall, Gilbert, Ellis, and Phoenix groups) to the east and north of some of these regions. In this investigation the magnitudes of large earthquakes are examined for differing regions of subducting margins to the west and southwest of Hawaii - generally extending from south of Japan to New Guinea and eastward through to Tonga and Samoa. To find the origin times of these earthquakes, searches were made of U. S. Geological Survey on-line data bases. Only earthquakes with either body wave, surface wave, or moment magnitudes of 7.0 or greater and focal depths of less than 100 km were used. Also, foreshocks and aftershocks were excluded. With the "Significant Worldwide Earthquakes (2150 B.C - 1994 A.D.)" data base, the only earthquakes found for the regions of interest occurred in the 20th century with most of the magnitudes being based only on surface waves from a variety of different sources. Substantially more magnitudes based on seismic moments were found in the "USGS/NEIC (PDE) 1973 - Present" data base. However, to give meaning to this study, uniformly computed moment magnitudes are needed for as much of the time period as possible. To achieve this requirement, comprehensive reevaluations of seismic moments for historic earthquakes provided in the 1900 though 1989 catalog of Pacheco and Sykes (1992) were used. A formulation given in Hanks and Kanamori (1979) was then applied to convert seismic moments to moment magnitudes. For moment magnitudes subsequent to 1989, Harvard values, if available, were used (25 earthquakes). The remaining 6 values of the 113 shown in Table 1 are USGS moment magnitudes. [Regarding the moment magnitudes already cited in this report, the Indonesian value was from Harvard and all others were from Pacheco and Sykes (1992).]

It is well known that earthquake magnitude is merely an indicator of tsunamigenic potential rather than an essential determinant of a tsunami's destructive power. Critical factors are the displacement of the ocean floor and the transmission efficiency to potential runup sites. All of the five earthquakes along the margins of the Pacific with magnitudes of 8.6 or greater in the 20th century generated significant tsunamis in Hawaii (Fig 2; Walker, 2000). However, for magnitudes of 8.0 to 8.5, only 6 of 31 earthquakes generated significant tsunamis in Hawaii. Thus, the data in Table 1 indicates a substantial deficiency of large earthquakes capable of generating significant Pacific-wide tsunamis. The question remains as to whether attenuation by islands would block the transmission of an Asian-type 9.0 Mw tsunami from these regions into other areas of the Pacific. The low magnitudes of Table 1 might suggest that such large events are unlikely and an investigation of the extent of "9.0 Mw tsunami attenuation" is unwarranted.

However, such a position is no longer tenable after 26 December 2004. Region B in Table 1, described as "West of New Guinea", is indeed far to the west of New Guinea. In fact, this region encompasses the subducting margins under, and adjacent to, Sumatra (the search grid used was 15 N to 15 S and 90 E to 105 E). The only magnitude excluded from Table 1 for this region is the 9.0 of 26 December 2004. The fact that for a span of more than 100 years the next largest magnitudes were only two 7.9's is disturbing, to say the least!

In terms of tsunamigenic potential as evidenced only by earthquake magnitudes, Table 1 indicates the western and southwestern margins of the Pacific Ocean may be as dangerous as the eastern margin of the Indian Ocean. Thus the question of "island attenuation" transforms from a questionable academic exercise to a critical and urgently needed inquiry. Modeling of a "100 year tsunami" (i.e., one generated by a 9.0 earthquake) for differing regions of the Western and Southwestern Pacific will be needed to determine whether island chain attenuation would be substantial or whether a significant Pacific-wide tsunami would, in fact, be generated. If attenuation is not substantial, inundations in some areas, especially along the southern and western shores of Hawaii, could exceed historical values from tsunamis in the North Pacific and South America. It should be noted that there are no island chains between Hawaii and the subducting margins south of Japan to Guam. Also, the largest magnitude for tsunamis recorded in Hawaii from Japan is only an 8.4 (in 1933) suggesting that the effects on Hawaii of a tsunami generated by a 9.0 earthquake in Japan should also be modeled.

Education

In addition to avoiding biases favoring acceptable, desirable, but potentially horribly wrong conclusions, an essential component of any successful warning system is education. As has occurred with teachers and students at Laupahoehoe in 1946, residents of Hilo in 1960, and hundreds of surfers on Oahu's north shore in 1994, curiosity, short-term memories, and a failure to understand the nature and destructive power of tsunamis can undermine the effectiveness of any warning system. To best overcome the realities of human nature, tsunami education should be institutionalized in public and private schools to ensure that children know the characteristics and destructive power of tsunamis, and to ensure that they and their teachers know what to do regardless of whether they are at school or elsewhere. A small amount of time dedicated to this topic on siren test days could be an effective method for achieving this objective.

Communications

Most aspects of communications are continually tested and upgraded by State and County Civil Defense agencies, as well as the Pacific Tsunami Warning Center. However, one perceived glaring deficiency in communications is likely unless corrective actions are taken. Because of an absence of instrumentation along parts of the Puna and Kona coastline from Punaluu to Kapoho, a small unfelt earthquake could generate a highly localized but destructive tsunami along shorelines popular with residents and tourists (i.e., Punaluu, Pohoiki, and Ahalanui), and in coastal campground areas of the

Hawaii Volcanoes National Park. No warnings would be possible in those areas for such a tsunami although some other shorelines at risk on the Big Island are instrumented with devices (i.e., along the Kona Coast from Honokohau to Milolii) that would detect such tsunamis and provide Civil Defense personnel with an opportunity to sound warning sirens. History confirms that such a tsunami will occur (Walker and Cessaro, 2002). Instruments will have to be installed sooner or later. Will this be done before or after such a tsunami? If "after", the public will ask why a technologically possible warning was not given to them - thus a major communications and credibility problem for State and County leaders, Civil Defense agencies, and the Pacific Tsunami Warning Center.

Warnings

Potential problems with warnings are related to instrumentation, education, and communication issues. Until data from the National Oceanic and Atmospheric Administration's tsunami buoys, or from some other as yet undiscovered methodology, has a substantial history of success, warnings perceived as "false" by the public are always a possibility. People of Hawaii need to understand the limitations of our warning system. They need to know that once the reliability of data used in the warning system is established, false warnings will be reduced or eliminated. Also, for some warnings only limited evacuations may be required (Walker, 2004) resulting in a substantial reduction in business losses to our economy. Not only does Hawaii have a warning system for Pacific-wide tsunamis but, as has already been mentioned, a warning system for locally generated tsunamis for part of the Big Island. This system also provides an early warning for the rest of the State should a large tsunami occur on the Kona Coast. Historical data and the successful operation of the tsunami sensors on the Kona Coast suggest that local warning criteria should be reviewed to eliminate overcautious, and obviously false, local warnings. Also, some criteria might be eliminated so that warnings can be called more quickly. Necessary upgrades and expansions of the local warning system should be made. The people of Hawaii need to understand the differences and characteristics of both Pacific-wide and local warnings.

Infrastructure

There may be no justification for the destruction of critical facilities by salt water flooding. In some areas most of the potential flooding damage will be the result of a gradual increase in water level rather than powerful horizontal surges. Earthen berms, sandbags, or waterproof doors could prevent much of this damage. In other areas more drastic protection may be required. Government agencies should be sure that such critical lifelines (i.e., electrical, water, sewage, fuel, communications, fire, police, and transportation) are "hardened" not only for tsunamis but also for hurricanes. These suggestions have previously been made for Hawaii, and generally ignored, in a U. S. Army Corps of Engineers Report (1999).

CONCLUSIONS

The following recommendations should be urgently adopted as "action items" with strategies and timelines. (1) Proactive government agencies should implement modeling to determine the effect on Hawaii of a "100-year 9.0 magnitude earthquake" from regions in the Western and Southwestern Pacific, including Japan. (2) The local warning system should be expanded and upgraded. (3) The State Department of Education and other educational institutions should be encouraged to implement standardized tsunami education in their schools. (4) Warning criteria for local earthquakes should be reviewed. (5) If necessary, critical facilities managers should be made aware of tsunami hazards and be required to harden their facilities against salt water flooding. (6) Finally, our government leaders need to understand the potential impact of tsunamis on our people and economy so as to minimize losses and speed recovery in the next large tsunami. Anything less than these actions and we will have learned little from the tragedies of 26 December 2004.

ACKNOWLEDGMENTS

I thank my colleagues at Civil Defense, the Pacific Tsunami Warning Center, the International Tsunami Information Center, the University of Hawaii, the Pacific Tsunami Museum, and other tsunami researchers, past and present, for their dedication to the improvement of tsunami warnings in Hawaii.

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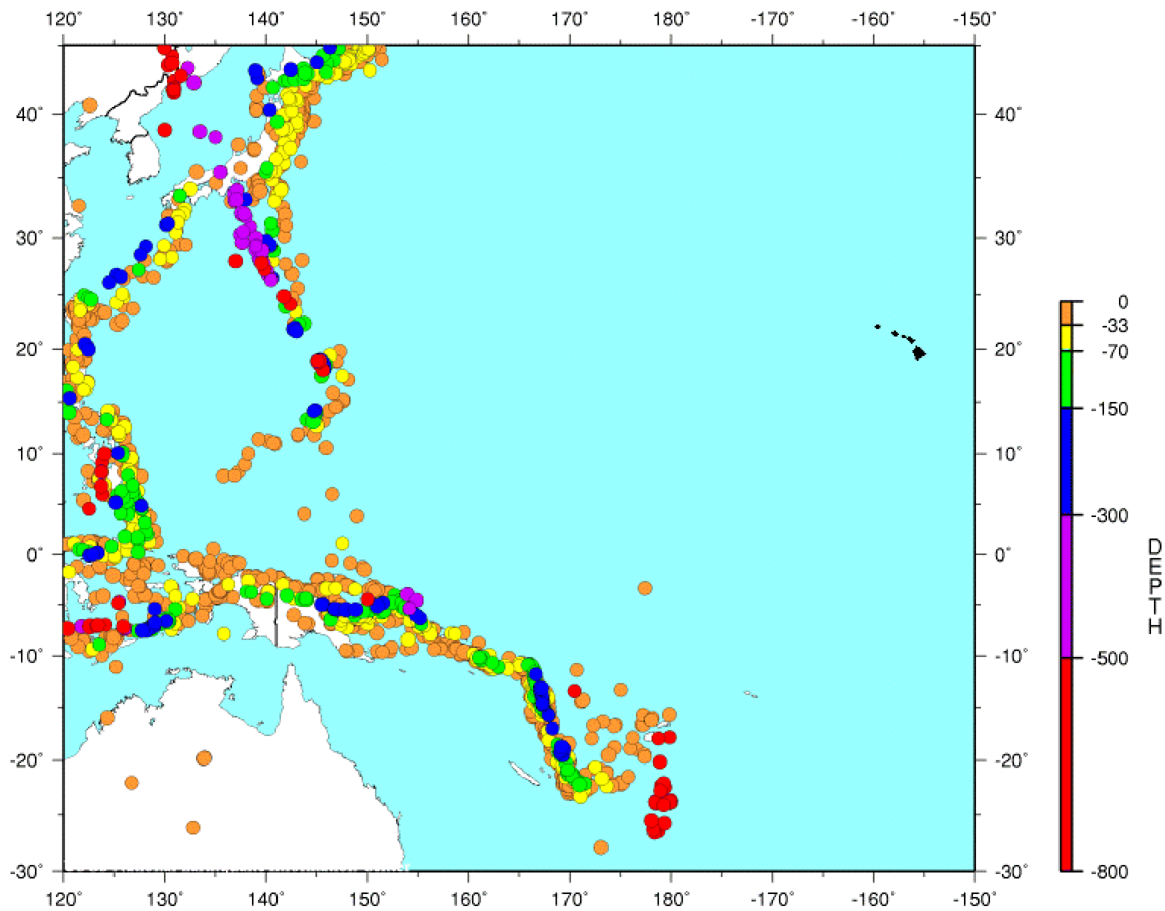

Figure 1. Subducting margins of the Western and Southwestern Pacific. Plot taken from the "USGS/NEIC (PDE) 1973 - Present" on-line data base for all magnitudes greater than or equal to 6.0.

TABLE 1

Moment Magnitudes for Subducting Margins to the West and Southwest of Hawaii (1900 - 2004) for Earthquakes with Focal Depths of Less than 100 Kilometers*

Moment Magnitude	**Region**							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
7.0	x	x	x	xxx	xxxx		xxx	x
7.1	x	x	x	xx	xx	xxx	xxx	
7.2				x	xxx	x	xxxx	x
7.3		xx	xx	xxx	x	x	xx	x
7.4	xxxx	xxx	x		x	xx		xx
7.5	xx	xx	x	x	xxxx	xxx	xx	x
7.6	x			x	xxx	xx		x
7.7		x	x		xx		xx	x
7.8	x	x				xxx	xx	
7.9	x	xx	x					
8.0			x	x	x			
8.1	xx				x			
8.2			x					
8.3								x
8.4								
8.5								x
8.6								
8.7								
8.8								
8.9								
9.0								

* Regions investigated are: (A) - Western Pacific; (B) - West of New Guinea; (C) - Western New Guinea; (D) - Eastern New Guinea; (E) - Western Solomons; (F) - Eastern Solomons; (G) - Santa Cruz; and (H) - Tonga/Samoa. Grids used to search the on-line U.S. Geological Survey/National Earthquake Information Center data bases will be provided upon request.