Use of Relationships between Moment Magnitude and Water Level Measurement Station Amplitudes by the Tsunami Warning System to Forecast Tsunamis in the Far Field

by

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ABSTRACT

The United States Tsunami Warning System uses the surface wave magnitude as its criteria for issuing either a Tsunami Information Bulletin or a Regional Warning/Watch immediately following the occurrance of potentially tsunamigenic earthquakes in the Pacific. Recent developments in seismometry and the characterization of earthquake size by the relatively rapid determination of seismic moment has led the System to consider adopting the moment magnitude, derived from the seismic moment, as the criteria for message issuance in the next few years. Moment magnitude is now used by the System to assist in making decisions about continuance or cancellation of warnings. This is possible because statistically significant relationships have been derived between tsunami source area and impact area pairings, which is in essance a quantification of tsunami history. Using Hawaii as an example, it would take an earthquake with at least a moment magnitude of 8.4 in the Alaska-Aleutian area to generate a tsunami in Hilo that would begin to be considered destructive. Thus, one would certainly lean toward canceling a warning for an earthquake with a moment magnitude around 8.0.

KEY WORDS: surface wave magnitude; moment magnitue; tsunami warning; tsunami amplitude; destructive tsunami

1. INTRODUCTION

Since the establishment of the Tsunami Warning System in the United States the Warning Centers traditionally have not included estimates of the severity of the expected tsunami in warnings they issue. This is primarily due to the fact that tsunamis, which are destructive in the far field, result from earthquakes with surface wave magnitudes that are near, or above, the saturation level for this type of magnitude determination. The Tsunami Warning System bases its initial warning message on the location and surface wave magnitude of the potentially tsunamigenic earthquake without reference to any water level measurements in the near field. This is done in order to disseminate the warning as rapidly as possible following the earthquake's origin time.

Recent advances in the ability to estimate quickly the moment magnitude, Mw, of potentially tsunamigenic earthquakes and the determination of better relationships between Mw and tsunami amplitudes recorded on water level measuring instruments has led to the possibility of including a qualification of the potential far field tsunami in the initial warnings issued. This paper shall describe the advances that have made far field tsunami severity estimation a possibility.

2. MAGNITUDE ESTIMATION

The threshold used by United States Tsunami Warning Centers for the issuance of far field tsunami warnings is a surface wave magnitude of 7.5. For warnings within their areas of regional responsibility the Centers use lower magnitude thresholds: 6.8 for the Hawaii region and 7.0 for Alaska, Washinton, Oregon, California, and the Canadian Province of British Columbia. . It is assumed that other regional tsunami warning systems use similar lower thresholds since a lower magnitude earthquake may generate a locally destructive tsunami that can be barely noticed in the far field. The type of magnitude determined for the regional potentially tsunamigenic earthquake may or may not be the

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traditional Ms. Nevertheless whatever type of magnitude is used, it is usually related to the Ms by typically considering only a small portion of the spectrum of energy radiating from the earthquake rupture. This is due largely to the prevalent use of seismometers that respond to a relatively narrow frequency band of the radiated seismic energy

Over the last couple of decades or so a new class of seismometers have begun to supplant the narrow band instruments. These seismometers not only have a more uniform response to a much broader band of the seismic energy, but they also are able to accomodate a much larger range of earthquake size than was possible with the earlier instruments. The cost and ease of installation of this new class of seismometers is becoming comparable to the traditional narrow band instruments, thus it can be assumed that in time they will probably become instrument of choice for seismic studies and applications such as the Tsunami Warning System.

As the number of broadband, high dynamic range seismometers increase around the globe, and the means to communicate with them cheaply and reliably in near real time becomes a reality, it becomes possible to determine moment magnitudes in a time frame that allows the Warning Centers to apply these determinations to the forecasting of tsunami amplitudes,as well as their arrival times, which has been possible for some time.

The Pacific Tsunami Warning System is now routinely using TREMORS to process seismic data from the broadband station KIP. TREMORS is an automatic system, developed by the French Laboratorie d'Geophysique in French Polynesia, that provides a rough estimate of an earthquake's location and a determination of the earthquake's seismic moment from a single stations's data following an algorithm developed by Okal and Talandier (1987). The system outputs its determinations, based on very long periond waves, at approximately twelve minutes and fifty minutes after detection. Of course, several minutes may pass before a detection occurs at KIP from a distance source. The possibility of sending the data to the Warning Centers from other TREMORS equipped stations automatically when it becomes available is under consideration.

The Alaska Center makes use of its long period and broad band data to calculate automatically seismic moments based on the body waves recorded at several of its staions. This method of seismic moment determination is based on the work of Tsuboi, et al. (1995). The Center uses the body waves because of the necessity to make very rapid determinations of the seismic moment in the regional environment

3. RELATIONSHIPS BETWEEN MOMENT MAGNITUDE AND WATER LEVEL GAUGE AMPLITUDE

In order to relate the size of great earthquakes of the last century to modern day moment magnitude, Katsuyuki Abe (1979) developed relationships between the tsunami amplitudes recorded on representative water level guages and more modern great earthquakes whose seismic moments could be determined independently. In order to derive statistically significant coefficients, Abe devided his limited data set into three source areas: the northwest Pacific subduction zones including those off the Kamchatka peninsula, the Kuril Islands, and the Pacific shores of northeastern Japan, the Alaska-Aleutian subduction zone, and the Peru-Chile subduction zone of South America. He also identified five "receiver " areas: Japan, Alaska, California, Honolulu, and Hilo Hawaii. Suffient differences exist between the responses of the Honolulu and Hilo to common tsunamis to merit the distinction. In his study the independent variable was the earthquake magnitude, termed Mt, which was equivalent to Mw except that it was derived from tsunami amplitudes recored on water level gauges.

This paper examines the inverse of this relationship and considers the independent variable to be the tsunami amplitude. A base of sixty-five tsunamigenic earthquakes was used to determine values for variables a and b in the relationship:

$$\log H = -a + bM$$

where H is the tsunami amplitude in meters and M is the moment magnitude. The results of this study are given in Table 1 together with measures of the error of a and statistical parameters bearing on the significance of the relationship. Most of the source-receiver combinations could also be grouped into three sets with similar values for a and b. Reasons for this grouping are not readily apparent.

4. "DESTRUCTIVE" TSUNAMI CRITERIA

The initial issuance of tsunami warnings is based solely on earthquake magnitude without giving consideration to water level gauge measurements. Criteria for canceling a warning, however, can take into account the tsunami amplitude that can be expected based on data presented in Table 1. If some lower limit can be set to define the tsunami amplitude separating "destructive" tsunamis from those doing no significant harm, then a minimum moment magnitude of concern can also be identified.

As an example, for Hawaii a minimum tsunami amplitude of seventy-five centimeters is used to distinguish destructive from non-destructive tsunamis. In this case the mean moment magnitude and worst case moment magnitude can be determined and used as part of the information considered to decide whether to cancel a tsunami warning, continue the warning in borderline cases where additional data is desires before cancellation, or to upgrade the limited warning to include the entire Pacific because the tsunami is expected to be destructive to some degree throughout the Pacific. Table 2 summarizes this example.

5. CONCLUSIONS

Statistically significant relationships can be made between moment magnitude and tsunami gauge amplitude. In order to accomplish this it is necessary to consider the data in terms of source receiver pairs. These relationships can, in turn, be used to provide assistance in making the decision whether or not to cancel a warning before a region would need to initiate a costly evacuation that may not be necessary. This process of establishing relationships between tsunami source areas and impact areas is in essence a quantification of the historical tsunami information known about the area.

6. REFERENCES

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Table 1: Parameters and statistics for logH = -a + b*M

Data Set	n	Grp	a	Std. est. err.of a	b	corr. coef.	T	p
NWHO	10	A	7.677	0.135	0.822	0.875	5.124	9.030E-4
NWHI	8	B	10.153	0.239	1.169	0.847	3.899	7.991E-3
NWCA	7	B	9.317	0.107	1.013	0.940	6.188	1.607E-3
NWAK	7	A	7.263	0.110	0.804	0.930	5.657	2.399E-3
AKHO	6		5.092	0.194	0.513	0.818	2.840	4.687E-2
AKHI	7	A	7.580	0.223	0.862	0.915	5.069	3.871E-3
AKCA	3	A	7.887	0.134	0.832	0.959	3.378	1.832E-1
AKJA	4		3.772	0.220	0.389	0.641	1.180	3.594E-1
SAHO	8	C	6.302	0.172	0.655	0.880	4.548	3.900E-3
SAHI	7	B	8.745	0.206	1,044	0.933	5.798	2.151E-3
SACA	5	C	6.148	0.075	0.641	0.977	7.868	4.278E-3
SAJA	4		8.198	0.158	0.898	0.963	5.602	3.687E-2
SAAK	3	C	6.331	0.130	0.679	0.965	3.724	1.670E-1
GRPA	27		7.254	0.255	0.791	0.817	7.076	<1.00E-6
GRPB	22		10.148	0.383	1.164	0.764	5.301	3.445E-5
GRPC	16		6.341	0.154	0.655	0.922	8.892	<1.00E-6

Table 2: Mean and worst case Mw for 75cm. tsunami amplitude

NWHO	NWHI	AKHO	AKHI	SAHO	SAHI
9.2 9.0	8.6 8.4	9.7 9.3	8.6 8.4	9.4 9.2	8.3 8.1