Revising Moment-Magnitude Based Earthquake Catalogs for use in Generating the National Seismic Hazard Maps

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Investigations Undertaken

The purpose of this research work is to directly determine seismic moment magnitudes (M_W) for earthquakes in the seismicity catalogs used to generate the National Seismic Hazard Maps. In particular, instrumentally recorded events in the period period 1963 (the advent of the World-Wide Seismic Network) to the present are being analyzed. Several tasks are being pursued for this purpose.

First, seismic moments previously determined in source studies throughout the literature and from current seismic catalogs such as the Harvard CMT solutions are being compiled. Besides being directly incorporated into the revised national earthquake catalogs, these moments are also being used to calibrate the moment determination method(s) used to analyze other events; in other words they are to be master events for moment determination. These earthquakes are shown in Figure 1. For events with multiple moment estimates, i.e. separate reporting values, the final moment magnitude value will be the average of the reported values.

Although the seismicity catalogs used to generate the current hazard maps only extend to 1995, we are also analyzing more recent events in order to augment the master event population in regions with relatively little seismicity. In the past few years, several moderate-sized earthquakes which were well recorded by present modern digital networks have occurred in the central and eastern United States. These events, on which conventional long-period source studies have been

conducted, provide excellent master events for calibrating the short-period moment measurement methods. These earthquake moments can also be directly incorporated into the hazard seismicity catalogs as they are updated to later years.

Secondly, we have investigated several methods to calculate moment for the remainder of the earthquake catalog populations. As these catalogs contain fairly small events, down to M=3 and M=4 for the EUS and WUS catalogs respectively, the methods examined all make use of short-period measurements which are less constrained by signal to noise level considerations than are conventional long-period waveform or spectra analysis. In particular we have examined methods involving time-domain measurements of coda amplitudes; these require no additional waveform processing, thereby enabling fast straightforward measurements directly from short-period analog records which are difficult at best to digitize.

Coda measurements have the advantage, implied by scattering theory, that they provide a more stable and averaged measure of the earthquake source spectrum compared to methods involving specific short-period phases such as Pn and Lg. These two phases can have strongly variable propagation effects with Lg in particular known to be susceptible to blockage in the crustal waveguide. P_n is also strongly dependent on the azimuthal radiation pattern, thereby requiring numerous observations at a range of azimuths to obtain stable magnitude measurements. Further, these two short period phases do not necessarily well characterize the long-period spectrum of earthquakes; there is considerable scatter in plots of M_W vs. $m_b(P_n)$ and $m_b(Lg)$.

The coda measurement methods we have examined also have the advantage of being quite simple and straight forward to obtain and are easily applied to analog data. One problem with regional WWSSN short-period records is that the primary phases are often clipped for even moderate-sized earthquakes while coda amplitudes are still measurable.

To produce accurate moment estimates from these coda measurements it is necessary to develop path corrections. These corrections are being determined for individual stations to specific regions using, as much as possible, modern digital data from master events for which moments are already available. As the current digital stations are often at the site of or near the location of older analog WWSSN stations, the station-region path corrections developed from the recent digital data can also be directly applied to the older analog stations.

Results

Seismic moments were compiled from various sources — published studies and the Harvard CMT (Dziewonksi *et al.*, 1981) and Berkeley Regional-Moment-Tensor (Pasaynos *et al., 1996)* catalogs — for 88 and 26 earthquakes for the WUS and EUS catalogs respectively. These moments, for the earthquakes shown in Figure 1, are plotted vs. the current catalog moments in Figure 2. There is considerable scatter in these relationships, particularly at smaller magnitudes, suggesting that the M_W values in the present catalog for mapping seismic hazards, which are based on short-period magnitude measurements, do not accurately reflect seismic moment. For events with several moment estimates from other studies, the M_W values are very consistent, with standard deviations being less than 0.15 for all but 1 event, suggesting that they are consistent and reliable M_W values.

Two time-domain moment estimate measures of the coda amplitude were examined. The more promising method, of Biswas and Aki (1994), was found to provide stable measures of coda amplitude which correlate well with seismic moment. The formula used, derived from theirs, which was based on empirical analysis of Alaskan earthquakes, is:

$$log_{10}(M_0)=log_{10}(A) + 3.85 \times log_{10}(t) + 18.301, \; 100 < t < 1000$$

where M_0 is in dyne-cm, and A is the amplitude, in centimeters, measured from a world-wide short-period (WWSP) instrument at time t after origin time. The measurement window is anywhere within the coda wavetrain as delineated by T1 and T2 in Figure 3. Measurements are taken at any point which reflects the general $1/t$ character of the coda envelope curve, rather than at spikes reflecting a specific late arriving phase. For the most stable and accurate measures, it is best to take the envelope of the wavetrain and then smooth over a 2 to 5 second window before measuring the amplitude. This latter processing, of course, can only be applied to the digital data. Direct comparisons of measurements of envelope values to picks from the unprocessed waveform still need to be made in order to validate the method for analog records.

The coefficient of the $log_{10}(t)$ term, 3.85, was obtained empirically for Alaskan earthquakes. In calibrating other regions using the master events, it was found that this value varied from 4.05 in the western United States to 3.5 in the eastern United States. These variations, due to the differences in tectonic regime, are expected since the more stable eastern craton, with a more homogeneous crust, should have lower scattering and attenuation levels than the tectonically active WUS. Events in the EUS crossing the Appalachian Mountains show an additional static offset of 0.5-0.75 units relative to other paths in the same region, suggesting that this mountain range is causing some level of blockage of the coda wavetrain.

For events with multiple observations it was found that the standard deviations for the coda Mw measurements are quite small, on the order of 0.05 to 0.15 magnitude units. Thus this method provides very consistent measures of M_W. Further, these coda M_W values scale very well with the long-period M_W values of the master events as is evidenced in Figure 4, which plots M_W(coda) vs. M_W determined from long-period data. This method shows considerable promise for determining seismic moment.

Non-technical Summary

The current earthquake catalogs used to generate the National Seismic Hazard Maps rely on moment magnitudes based on conversions of other magnitude scales which do not necessarily well characterize the long-period earthquake source spectrum. The purpose of this work is to revise these moment-magnitudes (M_W) for the period 1963 to 1995 by directly measuring seismic moment. This is being done by compiling existing moment values from various long-period source studies and by measuring M_W from the short-period coda of seismic wavetrains.

Reports Published

None at this time.

Data availability

A catalog of the revised seismic moments, taken from published sources and catalogs, as decribed above, is available at the ftp site: ftp.urscorp.com; (name="ftp"; password=your e-mail address). The file is: Pasadena/usgs.mw_catalog. Contact person: Bradley Woods, ph: 626-791-7973; e-mail: bradley_woods@urscorp.com. This catalog will be updated as more revised earthquake moment magtnitudes are determined.

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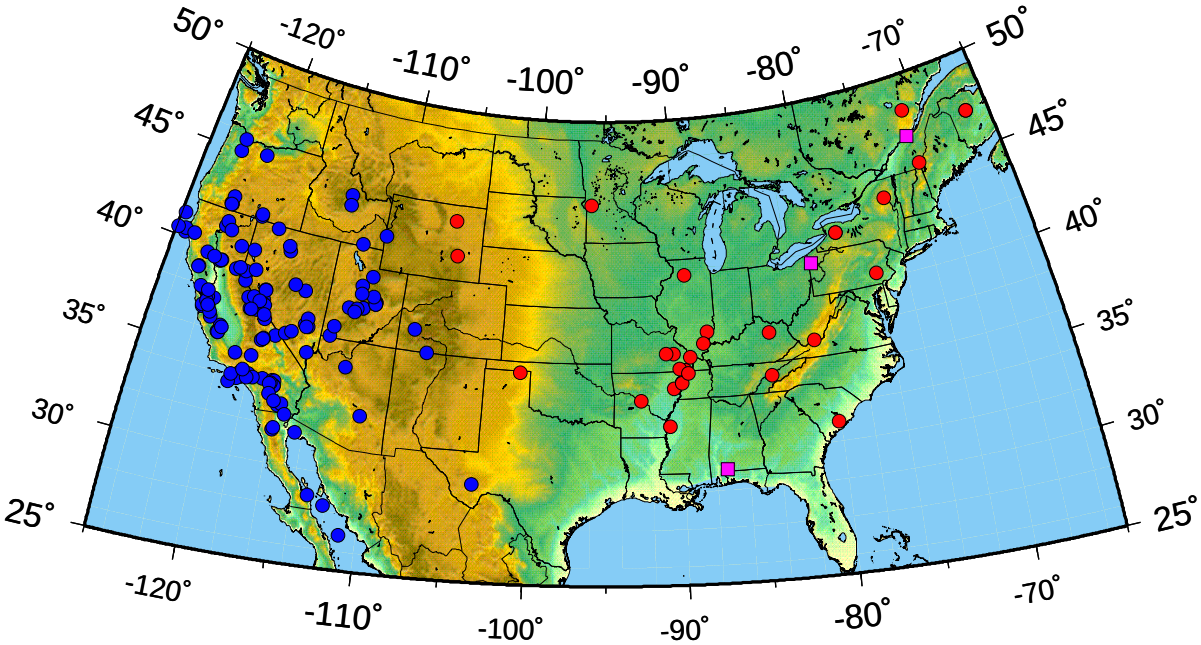


Figure 1. Map of the continental United States with earthquakes from the moment magnitude catalog (blue circles indicate WUS catalog events, red circles EUS catalog events) for which seismic moment has been directly measured. Pink squares are large post-1995 events used for path calibration.

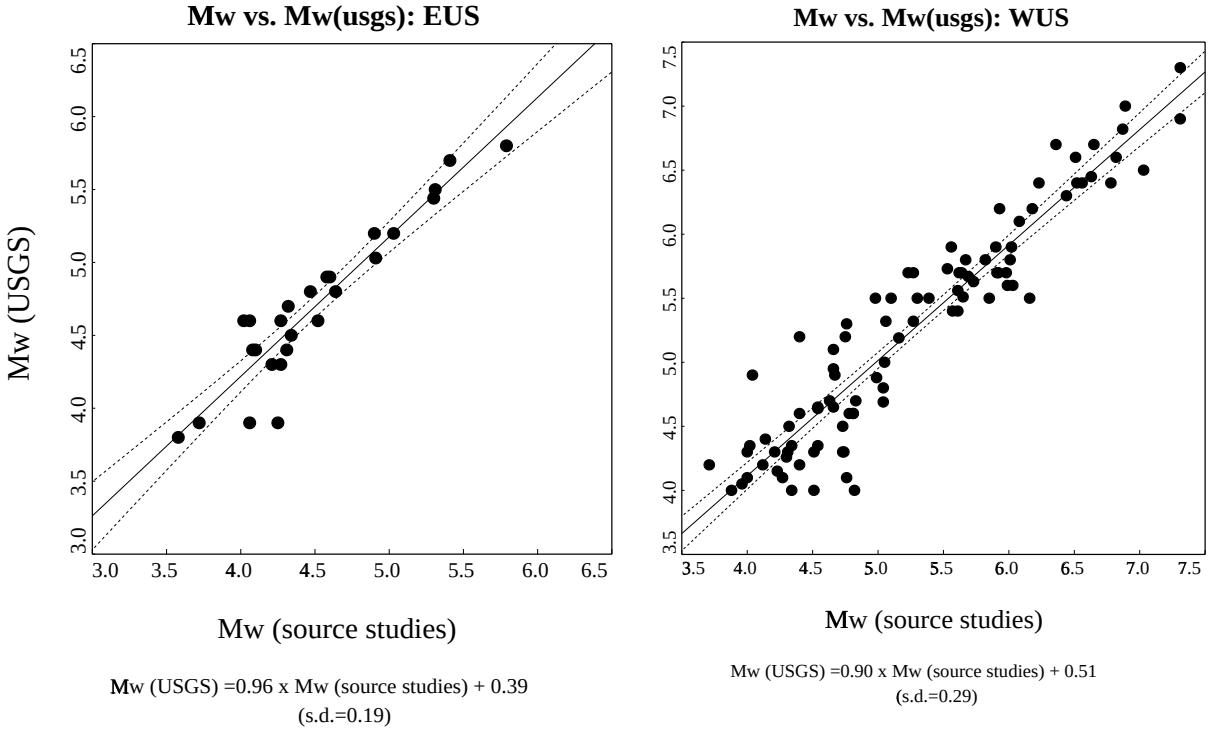


Figure 2. Linear regressions of current seismic-hazard-mapping catalog M_W vs. M_W compiled from various published source studies and catalogs (left: EUS catalog, right: WUS catalog).

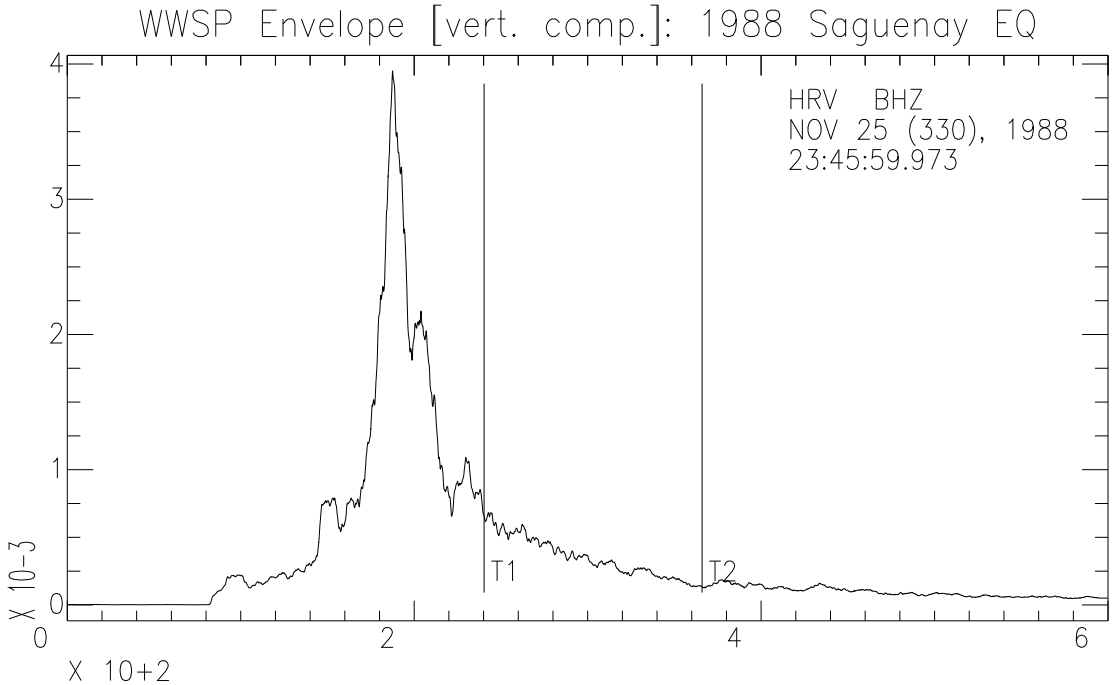
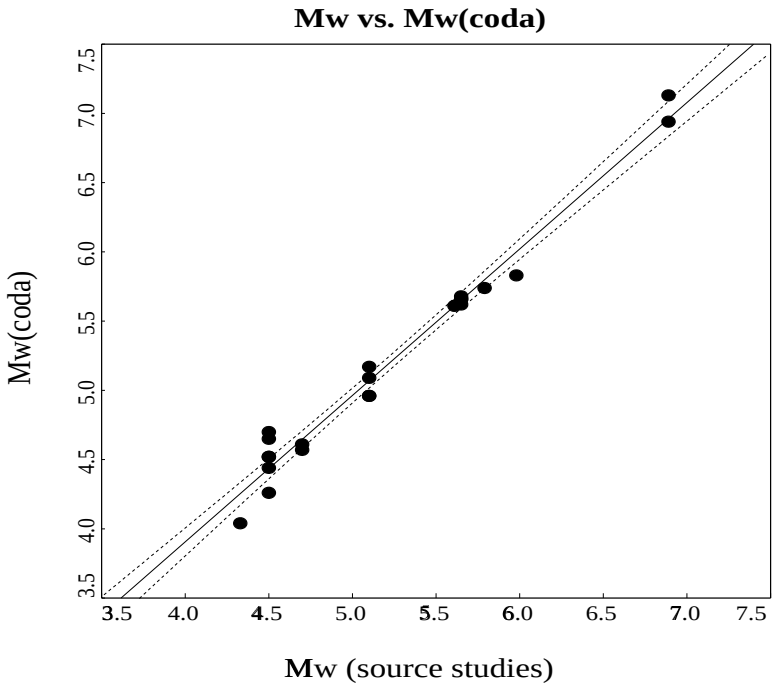


Figure 3. Example of an enveloped short-period record used to measure coda amplitude. The time window used is delineated by time marks T1 and T2.



Mw(coda) =1.06 x Mw (source studies) -0.32
(s.d.=0.12)

Figure 4. Linear regression M_W(coda) vs. M_W for a selection master events, that is earthquakes with independent moment determination.