# Earthquake Magnitudes in California

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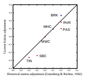
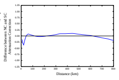
## Standardizing ML in California

As part of the CISN effort to develop a statewide earthquake monitoring system, a working group has been examining the different methods used to compute ML in northern and southern California. For the last several years, southern Califonia has used a recursive filter developed by Kanamori et al (1999) to compute synthetic Wood Anderson amplitudes in the time domain, with filter parameters tuned to provide an effective gain of 2800, using horizontal and vertical components. Northern Califonia has used a frequency-domain computation that removes the full instrument response and applies a Wood Anderson gain of 2080, as determined by Uhrhammer and Collins (1990), to the horizontal components. Both northern and southern California have computed station adjustments separately and use different attenuation relationships.



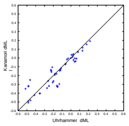

Comparison of current magnitude adjustments for Berkeley (blue) and Caltech (red) with the values reported by Gutenberg and Richter in 1942.

Difference between the ML attenuation functions in use in northern and southern California, as a function of distance. The differences are most pronounced at distances less than 50 and greater than 600 km.




In the fall of 2002, the magnitude working group recommended that the CISN standardize on the use of 2080 as the Wood Anderson gain and the use of horizontal components. These changes were made in southern California in the summer of 2003. In parallel, efforts were initiated to determine a statewide set of magnitude adjustments and single attenuation correction.

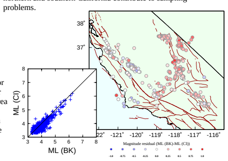
Two different approaches have been applied to determine statewide station adjustments. One approach applies the method of Kanamori et al (1993) to invert amplitude data for station adjustments and attenuation function simultaneously. Application of this approach to a dataset of northern California earthquakes yields station adjusments that are in good agreement with those determined independently by the method of Uhrhammer et al (1996).



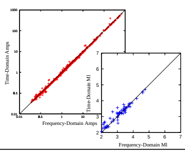

However, inversion of a combined northern and southern California dataset has been problematic. First, the canonical northern and southern California datasets have very few earthquakes in common, which makes it difficult to constrain the relative station adjustments between northern and southern California. Furthermore, most of the common events are in southern California, rather than geographically distributed. Second, disparities in the distribution of stations between northern and southern California contribute to sampling problems.

In the effort to determine a unified set of station adjustments statewide, an additional complication is an apparent discrepancy between the Berkeley (BK) and Caltech (CI) estimates of ML For example, inverting the BK and CI datasets separately with the same technique reveals a 0.2 magnitude difference for common events, with the BK values yielding larger magnitudes.

This result is confirmed by a simple comparison of the estimates of ML reported by Caltech and Berkeley for 480 earthquakes of M3.5 and higher from 1981-2003. Focusing on an area that spans the formal boundary between the networks, we observe a systematic bias (~0.14) between the estimates, with a strong apparent geographic signal.




As part of the effort to establish a statewide system, northern California has implemented the southern California time-domain magnitude estimation software on a test platform. The system has been running for several months. In general, amplitudes computed by the time-domain approach agree very well with the frequency-domain amplitudes. However, the frequency domain amplitudes are consistently larger than the time domain amplitudes. This slight difference (the mean amplitude ratio is 1.05 from 781 amplitudes) may be due to differences in using the full versus simplified instrument response.




Magnitudes from the time domain approach agree well wiht the frequency domain method, although there is some scatter at lower magnitudes. This is due to differences in the two algorithms in terms of windowing, use of signal to noise ratios for selecting stations, and differences in attenuation relations.

In southern California, the density of broadband stations permits the computation of Ml for every earthquake. In northern California, the more sparse station distribution imposes limits. In thecurrent northern California system, local magnitude is computed if Md or duration magnitude is greater than 3.

## Abstract

**The California Integrated Seismic Network (CISN) is working toward the goal of establishing a statewide earthquake monitoring system. This effort involves the testing and calibration of software and the development of common standards for earthquake processing between northern and southern California. As part of this effort, a CISN working group has been addressing issues related to local magnitude (ML) and moment magnitude (Mw).**

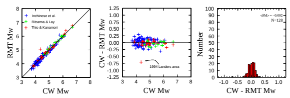
**In order to standardize the estimation of ML, the working group has addressed issues such as differences in the assumed gain of Wood Anderson torsion seismometer, methodologies for the computation of synthetic amplitudes, attenuation corrections, and station adjustments. Efforts to determine a consistent set of statewide station adjustments and attenuation curve revealed a systematic difference between magnitudes estimated at UC Berkeley and Caltech, with Berkeley estimates generally being larger than Caltech's estimates. Several factors appear to contribute to this discrepancy including differences in the attenuation corrections, significant path dependencies, and drift from historical station adjustments.**

**Comparisons of Mw and ML in northern California have shown good correlation between the magnitudes, but indicate a systematic geographic signal. For example, events in the Cape Mendocino and Geysers area show Mw larger than ML; while events in the eastern Sierra and western Nevada show ML larger than Mw. This geographic signal appears to be a combination of source and path effects.**

## Mw

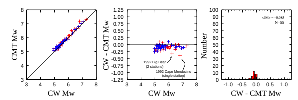
In nothern California, modules to estimate the moment tensor and moment magnitude have been integrated in to the automatic processing system for over eight years (Pasaynos et al., 1996). Two methods have been routinely employed - the complete waveform modeling technique (CW) of Dreger and Romanowicz (1994) and the surface wave inversion method (SW) of Romanowicz et al. (1993). In southern California, effort is underway to implement the CW methodology.

As part of the CISN investigation of magnitude reporting hierarchies, we have explored comparisons between the northern California estimates of moment and moment magnitude with other regional methodologies as well as with solutions from the Harvard Centroid Moment Tensor Project (CMT).The figures below illustrate the comparisons between the CW inversion and other regional moment tensor solutions and between the CW and the Harvard Centroid Moment Tensor solution, based on the BSL moment tensor catalog (1989-2003).




Comparison of estimates of Mw between the CW method at the BSL and the regional moment tensor (RMT) methods employed by Ritsema & Lay (1995), Thio & Kanamori (1995), and Inchinose et al.(2003) shows very good agreement in the estimates of Mw.

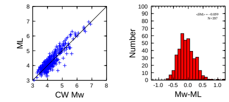
Comparison of estimates of Mw between the CW method and results from the Centroid Moment Tensor project (Dziewonski & Woodhouse, 1981) shows excellent agreement between the CW and CMT estimates of Mw, but with an apparent bias: the CMT estimates of Mw are on average ~0.09 higher than the CW estimates. There is a slight suggestion that the residual is increasing at the lower end of the magnitude range. Note that the depths of the CMT solutions are generally fixed at 15 km depth for these shallow events. The two events with the largest residuals occurred in 1992 and the CW solutions were computed with a limited number of stations.




Comparison of the CW estimates of Mw with other regional methods and the CMT solutions indicate the robustness of the procedures and the continuity between the regional and global estimates. The difference between the CW and the CMT estimates of Mw shows more scatter in the results for events in the early 1990s (red crosses - events in 1990-1993), reflecting the limited number of the regional broadband stations at that time. However a slight bias is consistent over time. We do not observe a correlation with this difference and the difference in depths, and are currently investigating the influence of the different velocity models.

## Comparison of ML & Mw

One issue facing the CISN is the question of magnitude reporting hierarchies. When should Mw be preferred to ML? The automatic estimation of Mw appears to be robust for events of M4.5 and higher and for all events with a variance reduction of 40%. In the plots below, we select events in located within the northern California catalog to compare the reviewed determination of ML and Mw from the perspective of reporting magnitude in real time.

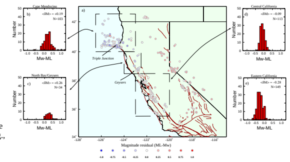



Comparison of Mw and ML for 397 events in the northern California catalog (1990-2004), using the CW determination of Mw. Left: ML plotted against Mw. Right: histogram of the magnitude residuals. These plots show good correlation between Mw and ML, but a mean difference of -.06 and significant scatter.

Although the average Mw-ML residual is quite small (-0.06) over northern California, the distributions in figure above mask the strong geographic signal in the data. Below, earthquakes with ML > Mw are drawn in red; events with Mw > ML are drawn in blue. In general, ML is consistently larger than Mw, with the exception of two regions - the North Bay/Geysers area and the Cape Mendocino/Gorda plate region. In the North Bay/Geysers area, the mean difference between Mw and ML is 0.26; in the Cape Mendocino area, it is 0.19 (although there are 9 events with differences greater than 0.5). Events in central California appear to be more more evenly distributed (with ML ~ Mw), while events in eastern California/western Nevada show a distinct bias with ML > Mw.

In Cape Mendocino region, new studies (Wurman et al, 2003) have shown that events along the Mendocino transform exhibit anomalously low apparent stress drops associated with abnormal moment-rate spectra. The spectra associated with these events show a characteristic enrichment in low frequency (< 1 Hz) content and a regression of the Brune corner frequency. These spectral characteristics have been associated with slow earthquakes, particularly on oceanic transform faults.

In the North Bay, the magnitude discrepancy may be related to strong attenuation of high frequencies (e.g., Antolik,1996) or to source processes in the Geysers geothermal region (Mayeda, 2004).




## Reporting magnitude in real time

While the CISN is finalizing the implementation of statewide estimation of multiple magnitudes (Md, ML, Me, and Mw), it is necessary to adopt a magnitude hierarchy for reporting earthquake information. At the low end of the magnitude scale, the limited distribution of broadband stations in northern California necessitates continued reporting of Md at the present time, with ML reported for events of Md 3 and higher. In southern California, ML is reported for all events.

Me is used in southern California to provide a rapid and robust estimate of event size when ML is likely to have saturated (M6.5 and higher), and will soon be implemented in northern California at the same level. Yet to be finalized is the threshold for reporting Mw in real time. Estimates of Mw are generally available within 6-7 minutes after an event in northern California. Details are still being worked out for the common reporting structure.

## Ongoing Work

Current efforts in the CISN are directed in several areas.
1) Continued efforts to establish a consistent statewide attenuation relationship and ML adjustments, using different parameterizations and inversion schemes.
2) Implementation of the time-domain estimation procedures in northern California and the complete waveform moment tensor software in southern California. This step will move the CISN beyond calibration of algorithms into sharing software resources and collaborative development.
3) Implementation of software allowing northern and southern California to share waveform data as well as amplitude timeseries for statewide magnitude computation.
4) Exploration of the apparent ML discrepancy between Berkeley and Caltech.
5) Exploration of the ML-Mw differences, particularly in eastern California where they apparently correlate with the largest differences between the Berkeley and Caltech estimates of ML.
6) Establishment of statewide magnitude reporting procedures.