California Integrated Seismic Network (CISN) Local Magnitude Determination in California and Vicinity

By

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Electronic supplement versions of the appendices and programs for calculating new SNCL dMLs and ML is at URL: www.ncedc.org/ftp/outgoing/CISN_ML.

Abstract

Determining local magnitude (M_L) in a manner that is uniform and internally consistent for earthquakes throughout California and vicinity is an important component of the California Integrated Seismic Network (CISN). We present a new local magnitude attenuation function and corresponding station adjustments that are valid throughout California. The new attenuation function is an analytic function of the radial hypocentral distance between 1 and 500 km. Associated station adjustments are also available for 1185 horizontal seismometer and accelerometer channels from five seismic networks operating in California. The new attenuation function and adjustments provide several advantages to CISN: They allow a more robust M_L computation; the M_Ls are more consistent between northern and southern California than they have been in the past; and because adjustments are now available for more SNCLs, M_Ls can be computed for small earthquakes in more locations than was previously possible. In addition to describing our method for calibrating the new CISN M_L, we also present a tool for adding adjustments for new or upgraded stations.

Introduction

Since Richter (1935) and Gutenberg and Richter (1942) developed the local or Richter magnitude (M_L) scale for earthquakes in Southern California using records from Wood-Anderson (WA) seismographs, M_L has been used to describe earthquake sizes in the catalogs of both Northern and Southern California. To maintain historical consistency, it is important to continue to report local magnitude. Different amplitude decay functions ($-\log A_0$) have, however, been used for some time in each region (Uhrhammer et al., 1996, Kanamori et al., 1999). With each change in instrumentation and each addition of a station, careful calibration procedures were necessary to ensure catalog continuity. Now, many digital broadband stations and strong motion stations have been added to the networks in both Northern and Southern California, but have not yet been calibrated. The institutions charged with monitoring earthquakes in the State of California, the Seismological Laboratories of the University of California Berkeley (UCB), the California Institute of Technology (Caltech), and the United States Geological Survey offices in Menlo Park and Pasadena (USGS-MP and USGS-P), have joined capabilities as the California Integrated Seismic Network (CISN) to provide earthquake information to various agencies and institutions, and to the public. The need to include the new stations in M_L determination and the desire to unify magnitude reporting led to this project to define a $-\log A_0$ function that is valid throughout the entire state, and to determine associated channel adjustments for horizontal channels from both broadband and strong motion sensors.

In our analysis to provide an historically consistent, state-wide method for determining the local magnitude of earthquakes, we opted not to use absolute magnitudes for the calibration. An absolute calibration would require the arbitrary selection of one site as the "origin". Instead, we chose a differential approach in which the differences in "local magnitudes" for a suite of earthquakes for each possible pair of channels (excluding channels oriented the same direction at a station) were inverted in two steps. First, a new state-wide $-\log A_0$ function was determined. For this inversion $-\log A_0(100\ \text{km})$ was constrained to be 3.0, to match Richter's (1935) original definition. In addition, the sum of $dM_L(\text{SNCL})$ for a set of stations that have been operating for most of the catalog interval was constrained to match their historical sum. In the second step, channel adjustments were calculated for all horizontal components, both those of broadband seismometers and of accelerometers.

Candidate Earthquakes

A list of candidate earthquakes was developed from the ANSS on-line earthquake catalog (http://www.ncedc.org/anss/catalog-search.html) for 2000 through 2006. This catalog provides a composite list that includes both Northern and Southern California events. To achieve a relatively uniform coverage of event-station pairs, California and the neighboring regions were divided into grid squares of 50 km by 50 km (Figure 1). From each square, two events were selected, if possible: the largest event with $M_L \geq 3$ in the interval 2000-2006, and the largest earthquake with $M_L \geq 3$ from the year 2006. The requirement that the candidate events have $M_L \geq 3$ ensured that each event has a good signal to noise ratio at many stations. The events from

2006 were added to provide data from recently installed stations and from the Transportable Array stations of the USArray (http://www.usarray.org/), a component of the Earthscope project (http://www.earthscope.org/) funded by the National Science Foundation. If the largest earthquake in any grid square took place in 2006, then the second largest event from 2000 – 2006 from that grid square was added to the set. This procedure netted 253 candidate earthquakes (Appendix A, Figure 1).

Candidate Horizontal Channels (SNCLs)

In 2006, five networks operated broadband and strong motion seismic stations in California that contributed to real-time earthquake monitoring:

- The Anza network operated by the University of California San Diego (abbreviation ANZA, network code AZ).
- The Berkeley Digital Seismic Network operated by UCB (BDSN, BK).
- The Southern California Seismic Network operated by Caltech and the USGS-P (SCSN, CI).
- The Northern California Seismic Network operated by the USGS-MP (NCSN, NC).
- The Transportable Array operated by the USArray component of Earthscope (USArray, TA).

From these networks, a list of 1230 candidate broadband and strong motion horizontal channels (each designated by its station-network-channel-location code or SNCL) was compiled (Figure 1, Appendix B). All channels are recorded digitally with high resolution (24-bit integer) at sampling rates of 20 to 100 samples per second. Data from the SNCLs were acquired as described in the Data Sources section.

Candidate Waveforms

We compiled a list of candidate waveforms by reviewing the following criteria each combination of candidate earthquake and candidate SNCL.

- Is the distance from the hypocenter to station ≤ 700 km?
- Is the theoretical maximum trace amplitude for the event on a WA seismograph ≥ 0.03 mm.

These criteria were chosen to select for good signal to noise ratio. Approximately 100,000 waveforms met all criteria and were extracted for this study. The time window for the data extracted from the archives for each waveform started 30 seconds prior to the theoretical P-wave onset and ended 60 s after a 2 km/s wave would have arrived at the station.

Data Processing

Prior to decommissioning the last WA seismographs with photographic recording in the BK network of northern California in early 1993, we demonstrated that equivalent, synthetic WA seismograms could be generated accurately from digitally recorded broadband or strong motion waveforms via convolution (Uhrhammer and Collins, 1990; Uhrhammer et al., 1996). The empirically determined WA transfer function is equivalent to an inertial pendulum with a free period of 0.8 seconds, a damping coefficient of 0.7 critical and a static magnification of 2080. It is important to note that the value for the WA static magnification is 2080 and not 2800 as originally reported by Anderson and Wood (1925) and commonly used since that time. While this difference is unimportant when using amplitudes measured from the original WA sensors, it is crucial when producing synthetic WA seismograms. If the correct magnification value is not used, M_L estimates will be biased low by 0.129 M_L. The error apparently occurred because Anderson and Wood (1925) incorrectly assumed that the taut-wire suspension used in the WA sensor did not deflect from a straight line. The deflection is actually sufficient to increase the polar moment of inertia and lower the static magnification by approximately 30 percent (Uhrhammer and Collins, 1990). Theoretically, the synthetic WA seismic records have approximately 80 dB greater dynamic range than can be measured on a photographic WA seismogram. In practice, however, the difference is closer to 44 dB. The seismic background noise limits resolution at low signal amplitudes and the linearity of the sensors limits it at high amplitudes.

For an important reason, we produced our own set of WA amplitudes, starting with the raw data, rather than using WA amplitudes extracted from the Northern and Southern California event catalogs for the selected events and SNCLs. For several years, the WA amplitudes have been calculated using different algorithms in each part of the state (Uhrhammer et al 1996, Kanamori et al 1999). For the analysis to be valid, it required that the WA amplitudes be determined in a uniform way, producing a consistent set for comparison.

For our analysis, each time series was preprocessed in the time domain before being converted to a synthetic WA seismogram in the frequency domain. The mean was removed from each record, and it was windowed to minimize contamination of the data by spurious amplitudes. The preprocessed waveforms for each earthquake were (1) converted to the frequency domain using a FFT, (2) filtered using a 0.5–10 Hz, 6-pole Butterworth band-pass filter; (3) transformed into a synthesized WA seismogram by deconvolution of the instrument response and the convolution with the empirical WA transfer function (Uhrhammer et al, 1996); (4) transformed into the time domain; and (5) automatically scanned to pick the maximum trace amplitude, A. All the WA maximum amplitudes, A, were indexed by SNCL and event, and stored in a file for further processing. The band-pass filter was applied to reduce contamination of the waveforms by microseisms or surface waves at low frequencies, and by noise spikes at high frequencies. Figure 2 shows an example of the waveform processing for a local event riding on the surface waves of the M_w 8.8, 27 February 2010, Maule earthquake in Chile. The waveform for this M_L 2.7 local earthquake which occurred 66 km north of the recording station ORV is nearly invisible in the original record, but has a good signal to noise ratio after the waveform processing. It is our experience that the frequencies associated with the maximum trace amplitudes recorded by standard WA torsion seismographs predominantly occur in the 2–4 Hz frequency band and rarely at frequencies either below 1 Hz or above 6 Hz.

Data from the amplitude file was again winnowed using period and amplitude criteria that depended on whether the data came from a broadband sensor or from an accelerometer. The period selection criteria effectively rejected data contaminated by low frequency waves or glitches. The amplitude criteria ensured that the WA maximum trace amplitudes were unlikely to be due to noise and also that the sensor was responding linearly to the ground motions (i.e., the feedback electronics was not saturated or clipped). For the broadband sensors A was required to be in the range 0.3 mm to 650 mm; for accelerometers the range was 3 mm to 12000 mm. The maximum WA trace amplitudes that met these selection criteria were used in the subsequent analysis.

Initial Analysis: The differential dataset and -logA_0(r)

The differential dataset inverted is not formed directly from differences of the maximum WA trace amplitudes, A, but by differences of M_L determined from A. To do this, we fundamentally followed the procedures for determining M_L originally defined by Richter (1935), with one change. To determine the attenuation function, Richter relied on the determination of the epicentral distance from the earthquake to the station, and assumed the event's hypocentral depth to be 15 km, a more or less reasonable average value for Southern California. This biased magnitudes measured at short hypocentral distances, where M_L is overestimated. For the formulation of the CISN attenuation function, we adopted the use of hypocentral distance (r) rather than epicentral distance to facilitate the accurate determination of M_L at close distances.

Local magnitude for a given channel is thus defined as:

$$M_L = \log(A) - \log A_0(r) + dM_L \quad (1)$$

where A is the maximum WA trace amplitude, measured in mm, r is the hypocentral distance in km, and dM_L is the station or SNCL adjustment. Given the hypocentral distance for each earthquake-SNCL pair, we calculated the M_L corresponding to the WA maximum trace amplitude, A, using the analytical attenuation function derived from Richter's (1935) attenuation function (Kanamori et al., 1993):

$$-\log A_0(r) = 1.11 * \log(r) + 0.00189 * r + 0.591 \qquad (2)$$

Then, for each earthquake *i*, we determined the differences between the M_L estimates for all SNCLs, *j*, *k*, (j≠k) that recorded that earthquake:

$$\Delta M_{L i,jk} = M_{L i,j} – M_{L i,k}, \qquad (3)$$

The result was a differential dataset with approximately 11.6 million observations for all earthquakes and SNCLs. This differential M_L data set was used in the inversions. The primary advantages of using a differential data set are that the "true" M_L of the earthquakes need not be known, and that all observed differential M_L's contribute to the solution.

Subsequently, we performed a number of inversions using a constrained least-squares method to solve simultaneously for various discrete and analytical forms of perturbations to the analytical attenuation function (equation 2), and for corresponding SNCL dM_Ls. Only one constraint was supplied for the attenuation function in all inversions. We required that $-\log A_0(r=100km) = 3.0$ to conform to Richter's (1935) original concept that a M_L 3 earthquake will have a maximum WA trace amplitude of 1 mm at a distance of 100 km. Various constraints for the station adjustments were tested, generally using combinations of selected BK and CI network stations for which historical dM_Ls existed. Both regional (Northern and Southern California) and global (statewide) perturbations to the attenuation function were determined along with the corresponding SNCL M_L adjustments.

After numerous inversions it was found that the simplest attenuation perturbation function form that fit the observed data statewide, in a constrained least-squares sense, was a linear combination of the initial analytic function (Equation 2) and a sixth order Chebyshev polynomial (Figure 3). The form for the new $-\log A_0(r)$ function is:

$$-\log A_0(r) = 1.11\log(r) + 0.00189r + 0.591 + TP(n)T(n,z) \qquad (4)$$

Where n is summed from 1 to 6. The TP(n) coefficients are:

TP(1) = +0.056,

TP(2) = -0.031,

TP(3) = -0.053,

TP(4) = -0.080,

TP(5) = -0.028,

TP(6) = +0.015,

And z is the scale transformation of r:

$$z(r) = 1.11366 * \log(r) – 2.00574 \qquad (5)$$

that transforms ($8 \le r \le 500$) to ($-1 \le z \le +1$) and T(n,z) is the Chebyshev polynomial:

$$T(n,z) = \cos(n*\mathrm{acos}(z)). \qquad (6)$$

This form of $-\log A_0(r)$ was found to provide a robust fit to the decay of earthquake amplitude as a function of hypocentral distance between 8 km and 500 km (Figure 3). In this case, robustly means that the good fit was relatively independent of the constraints on dM_L and that this $–\log A_o(r)$ formulation ultimately resulted in a fifty percent variance reduction. At hypocentral distances greater than 500 km, there were only few differential amplitude values. This is mainly due to the fact that only few of the events included in the analysis had magnitudes greater than 5 and, thus, measurable amplitudes at great distances. Thus, we capped the definition of $-\log A_0(r)$ at 500 km. Likewise, for hypocentral distance less than 8 km there were only a few differential amplitude values. For hypocentral distances shorter than 8 km, the average slope of $-\log A_0(r)$ between 8 km and 60 km was linearly extrapolated to 0.1 km. The resulting $-\log A_0(r)$ at distances less than 8 km is lower than either Richter's (1935) or Kanamori's (1999) $-\log A_0(r)$ and it produces consistent M_L estimates with smaller variances at short hypocentral distances. Thus both broadband and strong motion estimates of M_L at short distances will be more reliable and also that M_L can be reliably calculated for smaller earthquakes recorded at short distances.

The FORTRAN function given in Appendix C implements the above algorithm, and has been adopted for the CISN $-\log A_0(r)$ attenuation function.

Subsequent Analysis: Station (component) adjustments or dM_L

After adopting the CISN $-\log A_0(r)$, we focused on determining the set of channel adjustments most consistent with past practices in Northern and Southern California. The dM_L (SNCL) were determined using a linear least-squares fit. We discussed and tested a large suite of constraints before settling on one. We agreed that the sum of dM_L(SNCL) for a set of stations that have been operating for most of the catalog interval (60+ years) should be constrained to match their historical sum. For

Southern California 9 SNCLs were chosen that had been operating WA instruments and are now equipped with broadband seismometers (PAS.CI.HHE, PAS.CI.HHN, BAR.CI.HHN, MWC.CI.HHE, MWC.CI.HHN, PLM.CI.HHE, PLM,CI.HHN, RVR.CI.HHE and RVR.CI.HHN). Northern California only had 3 WA stations that now host broadband seismometers, with 6 SNCLs (BKS.BK.HHE, BKS.BK.HHN, BRK.BK.HHE, BRK.BK.HHN, MHC.BK.HHE and MHC.BK.HHN). MIN.BK, which housed WA and broadband seismometers, was closed prior to 2000. To maintain equal weighting for Northern and Southern California, the sum for the BK SNCLs was multiplied by 1.5. The final constraint equation was:

$$
\begin{aligned}
-0.943 = {} & dM_L(\text{PAS.CI.HHE}) + dM_L(\text{PAS.CI.HHN}) + dM_L(\text{BAR.CI.HHN}) + \\
& dM_L(\text{MWC.CI.HHE}) + dM_L(\text{MWC.CI.HHN}) + dM_L(\text{PLM.CI.HHE}) + \\
& dM_L(\text{PLM.CI.HHN}) + dM_L(\text{RVR.CI.HHE}) + dM_L(\text{RVR.CI.HHN}) + \\
& 1.5 *((dM_L(\text{BKS.BK.HHE}) + dM_L(\text{BKS.BK.HHN}) + \\
& dM_L(\text{BRK.BK.HHE}) + dM_L(\text{BRK.BK.HHN}) + dM_L(\text{MHC.BK.HHE}) + \\
& dM_L(\text{MHC.BK.HHN})).
\end{aligned}
$$

Figure 1 shows and Appendix B lists the stations for which dM_L(SNCL) were adopted in the CISN. At each site, the dM_L for a given orientation (i.e. N or E) is valid for all components with that orientation. For example, the same dM_L value applies for adjusting WA amplitudes measured on the East components of the broadband seismometer and of the accelerometer at BKS.BK. In a second round of calculations, dM_Ls were determined for sites that had only accelerometers. The currently valid dM_Ls are available in the online material.

New SNCL calibration

When a new broadband/strong motion station is installed in California, the new SNCL dM_L adjustments can be determined once a sufficient number of local/regional earthquakes that meet the amplitude selection criteria have been recorded and WA amplitudes collected. To obtain robust dM_L estimates, we recommend using at least 30 observations per SNCL and also that the dM_L and its uncertainty be calculated using median statistics of the differential M_L residuals. Thus, once sufficient data are available from a new SNCL, its dM_L adjustment can be determined using the observed differences between the new SNCL dM_L estimates and the M_L estimates from stations with known dM_L. We provide a subroutine and instructions for this procedure in the online material.

CISN M_L and dM_L Validation

We performed several validation exercises for CISN M_L, three of which are shown and discussed here (Figure 4). We did not compare M_Ls from the catalogs for the events used here with CISN M_Ls determined from the WA amplitudes used in this study. There were two main reasons for this. First, the sets of stations used for the catalog M_Ls was almost certain to be different than the sets we used. Second, the method for calculating the WA amplitudes differed, at least for Southern California (Kanamori et al, 1999). We consider it important that the WA amplitudes used for these M_L comparisons be calculated in the same way. Thus, the network M_Ls shown in Figure 4 were calculated using WA amplitudes determined in this study.

The first pair of comparisons allows the evaluation of how "old" M_Ls, for Northern and Southern California respectively, compare with the "new" values (Figure 4a,b). To allow the comparison, "old" network M_L values were determined for events with data from Northern California (BK, NC, some TA) stations. They are calculated from the WA amplitudes used in this study, using the former Berkeley $-\log A_0(r)$ and dM_L (Uhrhammer et al., 1996). The same was done for events with data from Southern California (CI, AZ, some TA stations), but the former Caltech $-\log A_0(r)$ and dM_L (Kanamori et al, 1999) were used. Then, the "old" M_L values were regressed against the network CISN M_L values derived from the same WA amplitudes using the CISN $-\log A_0(r)$ and dM_L (Figure 4a,b). The network M_L is always taken to be the median value, and the uncertainties are proportional to the inverse of the number of SNCLs contributing to the M_L value. Since the different types of M_L have similar uncertainties, the best-fit line is determined using a bi-linear regression, which minimizes the inverse-variance weighted, normal distances from each datum to the least-squares fit line. For both the Northern and Southern California comparisons (Figure 4a,b), the slopes and intercepts of the best-fit lines are one and zero, respectively, to within the uncertainties. This indicates that given a consistently determined set of WA amplitudes, magnitudes determined in Northern and Southern California using CISN M_L are consistent, overall, with the local magnitudes determined in the past.

A second important goal toward which the CISN networks are striving is that

Northern California can reliably locate and determine magnitudes for big Southern California events and vice versa. Figure 4c shows a set of events for which WA amplitudes exist for both Northern and Southern California stations, and M_L values for each event have been determined using either only Northern or Southern California SNCLs. As before, the uncertainties are proportional to the inverse of the number of SNCLs contributing to the magnitude. As there are usually more Southern California SNCLs contributing to a magnitude, the uncertainty on the Southern California M_L is generally smaller than on the Northern California M_L. Although the scatter is larger for this set of magnitudes, overall, the slope of a bi-linear-fit line and its intercept are again one and zero, respectively. This indicates that Northern California magnitude estimates for Southern California events match, on average, and vice versa. These two validation exercises show that the goal of unifying local magnitude reporting for Northern and Southern California has been satisfied.

Discussion

For historical consistency, it is important to continue to report local magnitude, as that is our connection with old catalogs. We have shown that unbiased and internally consistent local magnitudes can be determined for earthquakes occurring throughout California and vicinity.

The CISN magnitude strategy is to provide a uniform and robust methodology for determining the local magnitude of earthquakes that occur throughout California. The determination of local magnitude continues to fill an important role for two primary reasons; 1) it provides for continuity in determination of the size of earthquakes in historical seismicity catalogs that are used for determining the rate of seismicity and the earthquake hazard; and 2) it provides a uniform and internally consistent measure of earthquake size over a broad range of ground motions.

M_L for historical earthquakes can be recalculated using the new algorithm, as far back in time as a sufficient number of digital broadband stations existed. The broadband seismometers, some of which have operated since 1986, provide a large amount of waveform data from which to compute synthetic Wood-Anderson amplitudes, and perform the CISN calibration procedure. This effort will provide improved continuity with the older data and prevent an unnecessary discontinuity in the earthquake catalogs. Other magnitudes used such as duration magnitude M_d may then be recalibrated to match the revised M_Ls.

The CISN -logA_0(r) and corresponding SNCL adjustments, dM_L, determined in this study result in more robust estimates of M_L with less scatter. The variance of the M_L estimates is reduced by approximately a factor of two and the corresponding uncertainty in the M_L estimates is reduced from ±0.19 to ±0.14 when using the CISN methodology compared to the original methodologies employed separately by Northern and Southern California. The uncertainty in the CISN ML estimates is limited by the innate uncertainty in ML when amplitude variations caused by source radiation pattern and lateral crustal structure are not taken into account. In addition, M_L estimates at short distances (<20 km) using the CISN -logA_0(r) are much more robust owing to: 1) the incorporation of hypocenter distance (r) in place of epicenter distance (Δ), and; 2) the large amount of short hypocenter distance data available for determining the $-\log A_0(r)$. Also, there are no significant differences between M_L determined by Northern and Southern California earthquake data subsets. Thus previously noted differences between magnitudes computed in northern and southern California, for the same earthquakes, have been largely removed.

Magnitudes of very small earthquakes (<1.5) are substantially smaller with the CISN method than previous estimations, due to the revised attenuation function for very close distances, and also due to the high-pass filter used, which excludes much of the energy from microseisms and teleseisms from the amplitude computation. These improvements, along with the ability of the data processing software "Jiggle" (URL: pasadena.wr.usgs.gov/jiggle/) to interactively select seismogram segments for amplitude computation, allows M_L to be estimated for much smaller earthquakes than was previously possible in areas where the networks are dense. In practice, the lower bound for robust M_L estimation is limited by the hypocental distances to the proximal stations and by the size of the SNCL dMLs and it is unlikely to be much below +1.0, say.

For consistency with Richter's original methodology and simplicity in the calculations, scatter in M_L due to radiation pattern was not included in this analysis. Inclusion of the radiation pattern when determining M_L in Northern California indicates that there is a slight difference in attenuation and/or SNCL dM_L adjustments between paths that are parallel to and perpendicular to the crustal structure in Northern California.

The most robust estimates of dM_L(SNCL) are obtained using either mean statistics with outliers removed when large numbers of observations are available or median statistics when the data set is small (less than 30 observations) since it is insensitive to outliers.

The improved M_L calibration using the CISN $-\log_o(r)$ and dM_L results has produced a corresponding improvement in M_L determinations throughout the State. In Southern California, where M_L is attempted for all events, approximately 90 percent of the locatable events now have a M_L. For the remaining Southern California events, the data fail the acceptance criteria. In Northern California, M_L has in the past only been applied to events with $M_d > 3$, mainly due to the sparse network of broadband stations. Now, with many more "M_L qualified" stations available because of the calibration, the threshold for M_L has decreased. In the near future, we will review whether we may calculate M_L for small events, too.

Other networks in the western US will benefit from this study if they used the same methodology and cross-calibrate with CISN to produce a uniform and internally consistent estimation of local magnitude across the entire region. A significant question is whether or not the CISN attenuation function is applicable throughout the western US. We suspect that the CISN attenuation function will be applicable in Oregon,and Washington (Qamar et al., 2003)_and off Canada's west coast (Ristau et al., 2003) and possibly in the basin and range province in Nevada (Savage and Anderson, 1995). However, Uhrhammer et al., 1996 found that Berkeley M_L estimates of earthquakes occurring in the basin and range province were small by ~0.4 M_L when compared to the University of Nevada, Reno (UNR) determined M_L and that not all of the difference could be explained solely by differences in the attenuation model.

Data Sources

The events analyzed in this study were selected from the ANSS Composite Catalog (URL: www.ncedc.org/cnss).

BK, NC and northern California TA network waveforms were requested as SEED data volumes (URL: www.iris.edu/manuals/SEEDManual_V2.4.pdf) from the Northern California Earthquake Data Center (NCEDC; URL: www.ncedc.org) which is located at the Berkeley Seismological Laboratory (URL: www.seismo.berkeley.edu) at the University of California, Berkeley. The data were requested via NetDC (URL: www.iris.edu/manuals.netdc). Miniseed and response data were extracted via rdseed (URL: www.iris.edu/manuals/rdseed.htm). The NetDC requests returned about 50,000 waveforms.

AZ, CI and southern California TA network waveforms were requested in miniseed format from the Southern California Earthquake Data Center (SCEDC; URL: www.data.scec.org) that is located at the Southern California Earthquake Center (SCEC; URL: www.scec.org) at the University of Southern California. The data were requested via STP (URL: www.data.scec.org/STP/STP_Manual_v1.01.pdf). The corresponding response information was extracted via rdseed from dataless SEED volumes downloaded from SCEC. The STP requests also returned about 50,000 waveforms.

The TA network waveforms used in this study were all recorded locally at either the NCEDC or the SCEDC. The TA data are also available from their primary archive located at the Incorporated Research Institutions for Seismology (IRIS; URL: www.iris.edu).

Some plots were made using the Generic Mapping Tools version 4.2.0 (URL: www.soest/hawaii.edu/gmt ; Wessel and Smith, 2007).

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Figure Captions

Figure 1. This map shows the study area including candidate earthquakes (small gray circles), candidate stations with both broadband and strong motion sensors (large black circles) and the 50 km x 50 km grid (dotted lines) used for selecting the earthquakes. Stations with only strong motion sensors are not shown on the map for clarity, but their adjustments are given in the Appendix B. The colors of the vertical (N component) and horizontal (E component) lenses superimposed on the station symbols give the magnitude of the CISN SNCL adjustment (dM_L) as shown on the color scale. The magnitude of the CISN dM_L correlates with the competence of the soil/rock on which the station is sited. Hard rock sites have large positive dM_L values and very soft soil sites have large negative dM_L values. Stations in the region of the LA Basin are shown in the insert at a larger scale.

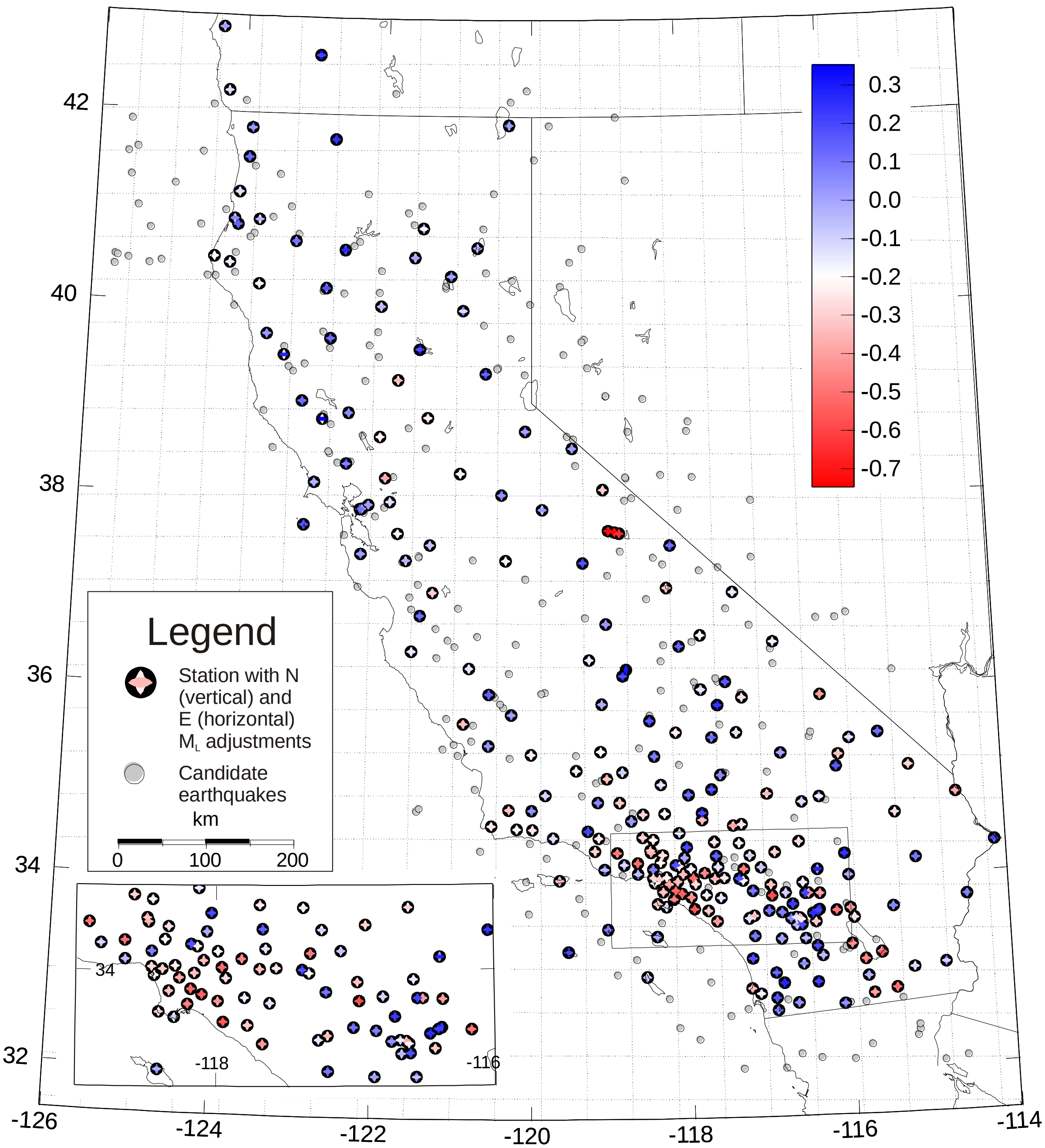
Figure 2. Example of waveform processing showing (a) the “raw” ORV.BK.HHE broadband data, (b) the corresponding synthesized Wood-Anderson (WA) data, and (c) the synthesized WA record band-pass filtered with a 0.2-10 Hz, 6-pole Butterworth filter, to remove microseismic background and long-period surface wave signal contamination. The local event is a M_L 2.7 earthquake located 66 km North of ORV riding on the wavefield of the M_w 8.8, 27 February 2010 Maule earthquake in Chile.

Figure 3. Comparison of $-\log A_o(r)$ attenuation functions. The CISN function was developed during this project; the other two have been used in Southern California

(Caltech; CI), and Northern California (Berkeley; UCB), respectively. All three attenuation functions are constrained so that $-\log A_o(100km) == 3$. The CISN attenuation function is only valid to 500 km and at distances shorter than 8 km the function is an extrapolation of the average slope between 8 km and 60 km (see Appendix C).

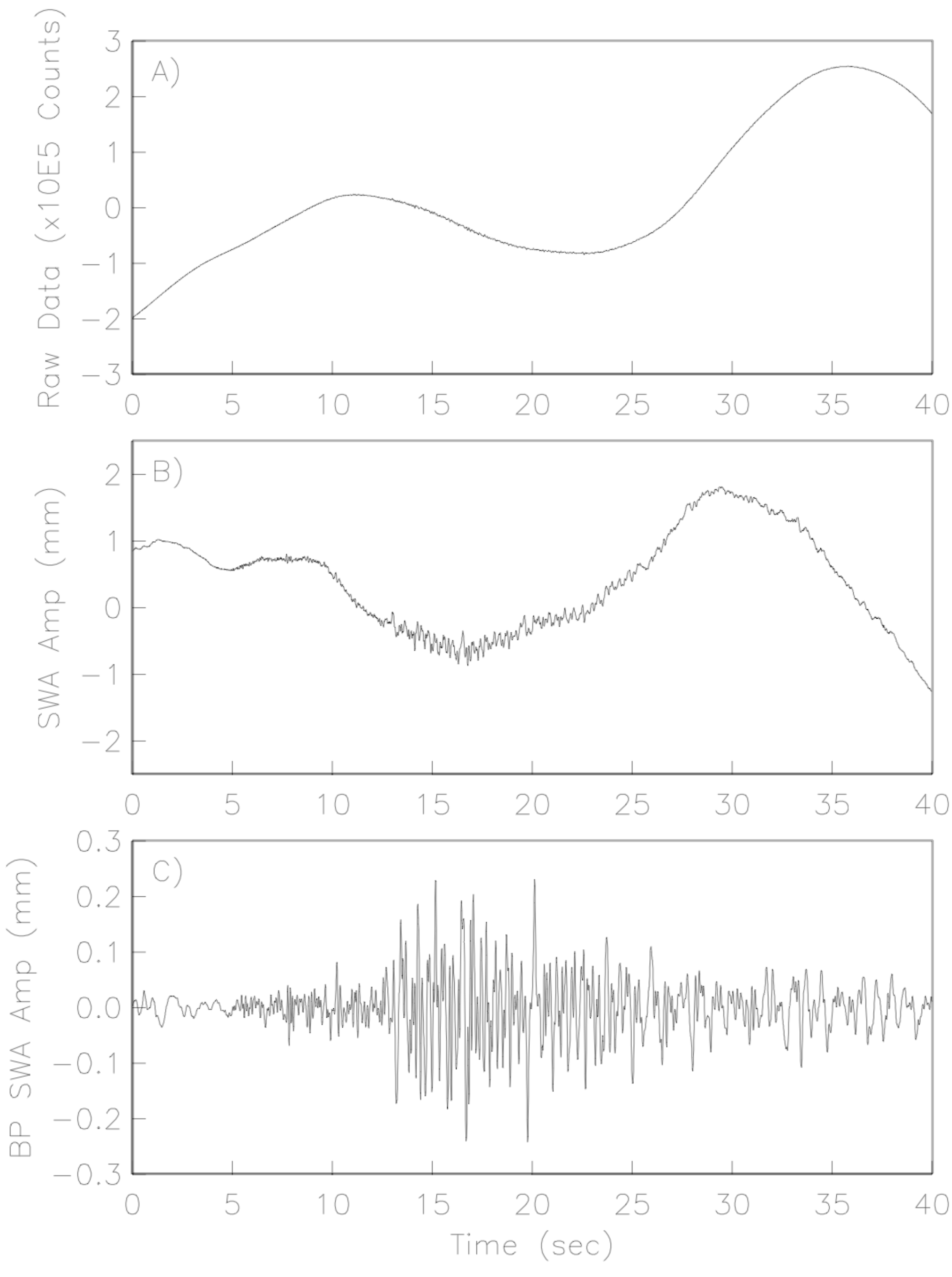
Figure 4. Validation of CISN M_L. (a) Comparison of M_L determined for Northern California events using CISN M_L (horizontal axis) and UCB M_L (vertical axis). (b) Comparison of M_L determined for Southern California events using CISN M_L (horizontal axis) and CI M_L (vertical axis). (c) Comparison of CISN M_L for events determined using amplitude data from Northern California (horizontal axis) and from Southern California (vertical axis) SNCLs. Data are shown for 96 selected earthquakes that occurred between 2000 and 2006. The linear regression was determined using a bi-linear L1 norm and the standard error is 0.159. Thus there are no significant differences between M_Ls of earthquakes determined using NC and SC SNCL subsets and the CISN $-\log A_o(r)$ and corresponding CISN dM_L determined in this study.

Figure 1.



42
40
38
36
34
32
-126
-124
-122
-120
-118
-116
-114
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
Legend
Station with N (vertical) and E (horizontal) M_L adjustments
Candidate earthquakes
km
0
100
200
34
-118
-116

Figure 2.



A)
Raw Data (x10E5 Counts)
3
2
1
0
−1
−2
−3
0
5
10
15
20
25
30
35
40
B)
SWA Amp (mm)
2
1
0
−1
−2
0
5
10
15
20
25
30
35
40
C)
BP SWA Amp (mm)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0
5
10
15
20
25
30
35
40
Time (sec)

Figure 3.

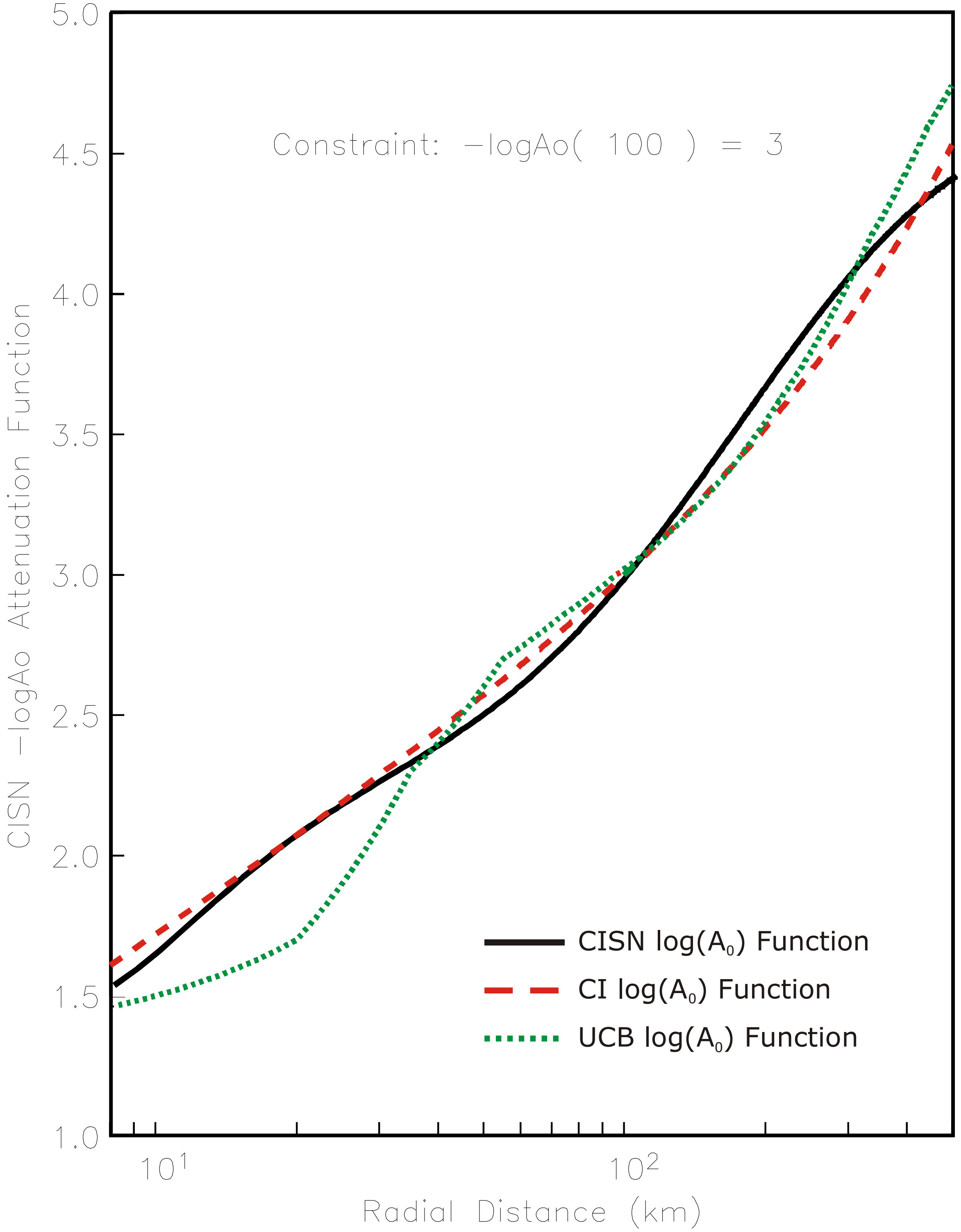
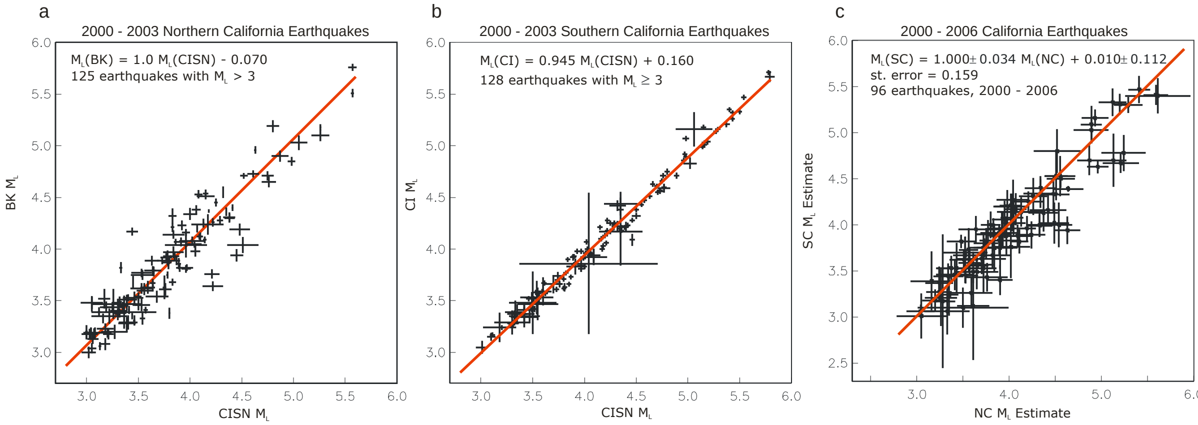

Constraint: −logAo(100) = 3
CISN −logAo Attenuation Function
Radial Distance (km)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
10^1
10^2
CISN log(A0) Function
CI log(A0) Function
UCB log(A0) Function

Figure 4.


a
2000 - 2003 Northern California Earthquakes
M_L(BK) = 1.0 M_L(CISN) - 0.070
125 earthquakes with M_L > 3
BK M_L
CISN M_L
b
2000 - 2003 Southern California Earthquakes
M_L(CI) = 0.945 M_L(CISN) + 0.160
128 earthquakes with M_L ≥ 3
CI M_L
CISN M_L
c
2000 - 2006 California Earthquakes
M_L(SC) = 1.000± 0.034 M_L(NC) + 0.010± 0.112
st. error = 0.159
96 earthquakes, 2000 - 2006
SC M_L Estimate
NC M_L Estimate

.

Appendix A. Candidate Events. The first column is the 50 km by 50 km grid square where the event is located. The events are extracted from the ANSS composite catalog. See Table SA in the electronic supplement.

055	2003/06/11	21:13:05	32.0767	-114.6255	6.00	3.50	ML	CI
056	2001/12/08	23:36:10	32.0380	-114.9060	10.00	5.80	Mw	NEI
056	2006/05/24	04:20:26	32.3067	-115.2278	6.00	5.37	Mw	CI
057	2002/12/10	21:04:00	32.2317	-115.7982	6.99	4.84	ML	CI
058	2005/12/30	12:17:10	32.1105	-116.4253	9.11	3.78	ML	CI
058	2006/02/15	22:56:42	32.0867	-116.0138	6.00	3.01	ML	CI
059	2000/05/03	14:54:06	32.0140	-116.8640	6.00	3.09	ML	CI
059	2006/08/20	20:44:23	32.1558	-116.6690	6.00	3.09	ML	CI
060	2003/06/26	06:20:01	32.0157	-117.3840	6.00	4.06	ML	CI
061	2004/06/15	22:28:48	32.3287	-117.9175	10.00	4.98	Mw	CI
078	2000/08/08	03:18:09	32.4480	-113.4740	5.00	3.50	ML	NEI
081	2002/12/12	21:03:43	32.3672	-115.2018	7.02	4.21	ML	CI
081	2006/05/24	04:25:14	32.4180	-115.2000	6.00	3.90	Mc	ECX
082	2000/04/09	10:48:09	32.7040	-115.3930	10.00	4.28	ML	CI
082	2006/06/02	00:56:15	32.6762	-115.8550	6.00	3.79	ML	CI
083	2006/11/03	15:56:43	32.6760	-116.0482	13.67	4.37	ML	CI
083	2006/11/03	15:56:43	32.6760	-116.0482	13.67	4.37	ML	CI
084	2005/04/12	11:06:46	32.7248	-116.8212	10.00	3.94	ML	CI
085	2005/05/29	18:30:45	32.5688	-117.5293	6.00	3.82	ML	CI
085	2006/05/09	00:13:36	32.6380	-117.3158	14.28	3.56	ML	CI
086	2005/10/16	21:11:35	32.4545	-118.1633	10.00	4.87	ML	CI
087	2001/08/16	18:04:33	32.7595	-118.2882	6.94	4.36	ML	CI
107	2005/09/02	01:27:19	33.1598	-115.6370	9.76	5.11	Mw	CI
108	2002/09/21	21:26:16	33.2248	-116.1128	14.57	4.31	ML	CI
108	2006/06/30	00:28:06	33.2407	-116.0360	3.58	4.29	ML	CI
109	2002/03/30	13:50:51	33.1947	-116.7280	9.35	3.84	ML	CI
111	2001/09/20	23:43:23	32.9255	-117.7703	7.00	3.17	ML	CI
112	2006/12/18	11:01:46	33.1723	-118.6853	0.00	3.18	ML	CI
113	2003/04/25	22:00:28	33.0153	-118.9277	6.00	3.33	ML	CI
132	2001/11/13	20:43:14	33.3172	-115.7002	5.50	4.11	ML	CI
133	2002/01/02	12:11:28	33.3793	-116.4345	12.58	4.21	ML	CI
133	2006/10/09	20:26:50	33.2610	-116.0723	8.54	3.92	ML	CI
134	2005/06/12	15:41:46	33.5288	-116.5727	14.19	5.20	Mw	CI
135	2005/12/04	17:47:44	33.6108	-117.2715	13.83	3.34	ML	CI
136	2003/03/24	17:34:53	33.2695	-117.8950	10.00	3.14	ML	CI
137	2004/04/20	12:41:26	33.5558	-118.3682	15.49	3.15	ML	CI
138	2003/01/01	00:51:44	33.3668	-119.1312	7.01	3.49	ML	CI
139	2002/03/16	21:33:23	33.6660	-119.3300	7.00	4.60	ML	CI
140	2005/04/21	06:36:19	33.6570	-120.0333	6.00	3.95	ML	CI
158	2005/01/12	08:10:46	33.9527	-116.3953	7.59	4.26	ML	CI
158	2006/12/24	03:43:38	33.7077	-116.0497	13.19	4.02	ML	CI
159	2005/06/16	20:53:26	34.0580	-117.0113	11.61	4.90	Mw	CI
159	2006/06/08	22:45:54	33.9197	-116.7937	18.71	3.84	ML	CI
160	2005/01/06	14:35:27	34.1250	-117.4387	4.15	4.42	ML	CI
160	2006/07/10	02:54:43	33.8560	-117.1122	11.53	3.81	ML	CI
161	2002/09/03	07:08:51	33.9173	-117.7758	12.92	4.75	ML	CI
162	2001/09/09	23:59:18	34.0590	-118.3885	7.90	4.24	ML	CI
163	2004/07/06	16:05:44	34.0608	-118.8527	13.50	3.40	ML	CI
164	2006/03/14	01:41:46	33.8173	-119.4010	6.00	3.18	ML	CI
165	2001/10/09	15:30:54	33.9963	-120.0695	7.00	3.25	ML	CI
183	2003/03/11	19:28:17	34.3592	-116.1332	3.89	4.64	ML	CI
184	2001/02/10	21:05:05	34.2895	-116.9458	9.12	5.13	ML	CI
185	2001/05/14	17:13:30	34.2262	-117.4397	8.73	3.84	ML	CI
185	2006/11/04	19:43:44	34.2058	-117.5762	4.92	3.51	ML	CI
186	2004/08/30	20:51:36	34.4238	-117.6820	7.27	3.18	ML	CI
187	2001/01/14	02:26:14	34.2840	-118.4040	8.80	4.26	ML	CI
188	2000/10/12	16:51:19	34.5598	-118.9022	25.73	3.86	ML	CI
188	2006/02/24	19:58:32	34.4207	-119.0603	14.89	3.10	ML	CI
189	2004/07/24	12:55:19	34.3805	-119.4360	3.61	4.27	ML	CI
189	2006/02/05	15:43:33	34.2407	-119.8103	7.89	3.22	ML	CI
190	2004/05/09	08:57:17	34.3947	-120.0223	4.42	4.40	ML	CI

191	2000/07/13	15:37:11	34.3120	-120.6490	6.00	3.19	ML	CI
208	2002/10/29	14:16:54	34.8027	-116.2665	4.60	4.77	ML	CI
209	2003/07/15	06:15:50	34.6217	-116.6672	7.64	4.15	ML	CI
212	2001/04/19	09:02:40	34.7093	-118.7153	14.03	3.24	ML	CI
213	2005/04/16	19:18:13	35.0272	-119.1783	10.29	5.15	ML	CI
214	2003/02/19	17:10:24	34.8928	-119.3617	11.93	3.38	ML	CI
216	2000/03/12	06:59:35	34.9607	-120.7257	2.46	3.78	Md	NC
217	2000/02/03	04:32:45	34.7240	-121.4670	6.00	3.60	ML	PAS
217	2006/12/26	21:53:34	34.7532	-121.4338	25.45	3.02	Md	NC
228	2003/08/10	00:33:23	35.0660	-113.3700	5.00	3.00	ML	NEI
233	2000/10/22	14:54:25	35.4722	-116.4463	6.00	3.45	ML	CI
234	2005/02/08	17:35:32	35.1152	-116.9975	4.33	3.03	ML	CI
235	2001/02/24	06:09:59	35.1120	-117.5250	3.63	3.80	ML	CI
235	2006/03/03	13:44:05	35.1213	-117.5563	2.10	3.69	ML	CI
236	2003/05/23	18:35:41	35.2083	-118.1172	5.05	3.04	ML	CI
237	2004/09/29	22:54:54	35.3898	-118.6235	3.55	5.03	Mw	CI
238	2004/02/17	07:16:03	35.0553	-119.1075	14.34	3.40	ML	CI
239	2004/07/15	01:43:22	35.3148	-119.4325	1.09	3.50	ML	CI
240	2004/01/09	07:34:50	35.2872	-120.2808	5.60	3.01	ML	CI
241	2005/06/27	00:30:28	35.4283	-121.0003	5.96	3.71	ML	NC
241	2006/01/04	23:56:59	35.3137	-120.9455	4.06	3.13	ML	NC
241	2006/08/26	08:45:39	35.4655	-120.7752	3.66	3.09	ML	NC
242	2003/12/31	05:13:16	35.3780	-121.1410	5.00	3.70	ML	NEI
258	2006/07/19	13:23:19	35.5195	-116.4257	6.00	3.38	ML	CI
259	2004/08/31	00:09:13	35.5995	-117.0350	5.60	3.17	ML	CI
260	2002/09/28	10:34:47	35.9462	-117.3035	3.72	4.13	ML	CI
260	2006/03/29	01:36:23	35.6218	-117.5875	8.77	4.00	ML	CI
261	2001/05/17	21:53:45	35.7990	-118.0437	8.74	4.25	ML	CI
262	2001/08/04	19:05:55	35.7305	-118.4823	4.92	3.16	ML	CI
265	2004/09/28	17:15:24	35.8182	-120.3660	8.58	5.96	Mw	NC
265	2006/10/31	20:26:06	35.8555	-120.4073	9.31	3.63	ML	NC
266	2005/05/16	07:24:37	35.9288	-120.4770	10.07	4.69	ML	NC
266	2006/11/28	04:06:40	35.6318	-120.7543	6.87	4.10	ML	NC
267	2003/12/22	19:15:56	35.7002	-121.0973	8.05	6.50	Mw	NC
281	2001/02/04	03:29:02	36.1426	-115.3455	0.00	3.53	ML	NN
284	2002/02/25	19:48:36	36.2478	-116.8797	9.25	3.42	ML	NN
285	2000/02/28	23:08:42	36.0720	-117.6010	0.16	4.21	ML	CI
285	2006/06/03	20:09:08	36.1053	-117.6235	2.07	3.00	ML	CI
286	2001/07/17	12:07:26	36.0163	-117.8743	2.97	5.17	Mw	CI
286	2006/07/12	22:20:50	36.0710	-117.9022	4.45	3.93	ML	CI
287	2001/04/14	14:51:22	35.9893	-118.3312	5.60	3.77	ML	CI
287	2006/12/31	00:50:51	36.2970	-118.3280	1.21	3.21	ML	CI
289	2005/12/31	21:31:28	35.9750	-119.8295	25.44	3.92	ML	NC
289	2006/04/02	08:16:56	35.9627	-119.8753	22.02	3.08	ML	NC
290	2006/12/16	06:14:05	36.1738	-120.2937	9.91	4.23	ML	NC
291	2004/09/29	17:10:04	35.9537	-120.5022	11.37	5.00	Mw	NC
292	2005/07/04	07:11:28	36.3360	-121.2340	5.16	5.69	Md	NC
307	2000/03/13	14:11:32	36.7619	-115.9109	4.85	3.09	ML	NN
308	2002/06/14	12:40:44	36.7163	-116.3013	11.73	4.36	ML	NN
308	2006/04/17	20:14:51	36.7140	-116.0550	5.60	3.30	ML	REN
309	2006/11/30	20:12:57	36.4020	-116.9080	12.80	3.20	ML	REN
310	2003/03/21	18:46:34	36.6581	-117.1742	9.06	3.44	ML	NN
310	2006/12/16	04:18:23	36.8360	-117.4730	5.48	3.09	ML	CI
311	2001/01/04	12:23:31	36.4940	-117.9220	5.72	3.40	ML	CI
312	2003/08/19	22:02:08	36.4652	-118.2908	9.47	3.65	ML	CI
313	2005/05/29	03:51:35	36.7572	-119.3048	0.28	3.20	Md	NC
315	2005/06/04	05:11:43	36.4810	-120.2045	4.90	4.31	Md	NC
316	2003/04/21	15:46:45	36.5622	-120.7085	13.34	3.51	ML	NC
316	2006/09/15	17:04:44	36.4535	-121.0033	8.45	3.09	ML	NC
317	2001/12/28	21:14:01	36.6402	-121.2510	6.86	4.67	ML	NC
317	2006/04/01	12:25:59	36.5195	-121.0935	1.88	4.34	ML	NC
318	2005/03/01	02:35:42	36.8400	-121.5720	6.84	3.02	Md	NC
335	2006/08/21	00:09:13	37.2692	-117.5582	0.58	3.21	Md	NC
336	2001/08/02	16:21:18	37.2410	-117.8075	9.01	4.32	ML	NN
337	2001/01/18	15:12:47	36.9503	-118.5030	7.10	3.83	ML	CI
338	2001/04/14	03:34:24	37.2015	-119.0085	13.98	3.15	Md	NC

339	2002/09/22	15:08:32	36.9170	-119.8580	3.38	4.90	Md	NC
340	2002/06/17	15:15:50	37.1638	-120.0832	5.35	4.24	Md	NC
341	2002/06/13	11:41:24	36.8557	-120.9602	4.94	3.60	Md	NC
342	2006/06/15	12:24:51	37.1015	-121.4920	3.27	4.67	ML	NC
343	2002/05/14	05:00:29	36.9668	-121.5983	6.94	4.94	ML	NC
344	2004/11/01	22:02:33	37.0692	-122.2792	9.10	3.57	ML	NC
360	2000/10/14	04:53:29	37.3714	-117.1197	8.03	4.22	ML	NN
361	2006/12/19	15:21:42	37.4957	-118.1878	5.88	3.70	Mw	NC
362	2002/07/15	20:18:17	37.3843	-118.4063	13.17	4.07	ML	NC
362	2006/09/07	01:38:59	37.3118	-118.2832	8.13	3.63	ML	NC
363	2006/11/26	22:11:48	37.4537	-118.8403	8.57	4.27	ML	NC
366	2004/11/24	04:43:19	37.3620	-120.7732	0.02	3.96	Md	NC
367	2005/02/05	18:43:30	37.4003	-121.4833	8.10	4.42	ML	NC
367	2006/01/25	15:29:57	37.3865	-121.4847	6.10	3.74	ML	NC
368	2001/02/25	23:18:22	37.3325	-121.6992	7.60	4.44	ML	NC
369	2002/12/24	08:22:30	37.6072	-122.4750	8.97	3.60	Mw	NC
385	2002/12/14	13:07:09	37.9656	-117.1052	10.68	3.60	ML	NN
386	2003/04/03	15:31:51	37.8804	-118.0709	5.98	3.06	ML	NN
387	2004/09/18	23:02:17	38.0095	-118.6785	5.49	5.55	Mw	NC
388	2006/02/16	17:47:59	37.9848	-118.7735	10.43	4.25	ML	NC
393	2005/06/20	18:14:57	37.9028	-121.9508	0.63	5.24	Md	NC
393	2006/03/21	21:41:42	37.8093	-122.0710	12.94	3.70	Mw	NC
394	2003/09/05	01:39:53	37.8432	-122.2225	11.14	4.13	ML	NC
394	2006/12/23	06:49:57	37.8577	-122.2452	9.35	3.71	ML	NC
411	2003/11/15	20:11:59	38.2217	-117.8730	8.75	4.47	ML	NN
412	2001/02/17	22:54:19	38.2500	-118.2900	12.36	4.06	ML	NN
412	2006/05/07	13:59:42	38.2180	-118.7500	13.60	3.60	ML	REN
413	2006/05/05	06:36:19	38.2280	-118.7570	14.00	4.30	ML	REN
414	2003/06/23	12:19:26	38.6317	-119.4452	6.45	3.33	ML	NN
414	2006/02/25	12:15:50	38.3542	-119.4202	3.94	3.07	Md	NC
417	2003/10/03	16:32:42	38.5282	-121.4123	112.69	3.53	Md	NC
418	2002/05/08	14:59:36	38.2238	-121.8375	17.67	3.68	ML	NC
419	2000/09/03	08:36:30	38.3788	-122.4133	9.87	5.17	ML	NC
419	2006/08/03	03:08:12	38.3635	-122.5887	8.86	4.40	Mw	NC
420	2003/05/25	07:09:33	38.4582	-122.6990	4.88	4.32	ML	NC
420	2006/05/28	01:07:25	38.4795	-122.7120	6.03	3.05	Md	NC
421	2006/07/06	20:43:24	38.5043	-123.4590	0.02	3.68	ML	NC
436	2001/05/06	00:38:53	38.7060	-117.9346	12.22	3.37	ML	NN
436	2006/09/24	12:42:52	38.8040	-117.9110	11.00	3.30	ML	REN
437	2002/12/15	02:30:20	39.0466	-118.5086	10.33	3.89	ML	NN
437	2006/03/11	15:29:59	38.7080	-118.7180	14.70	3.30	ML	REN
438	2005/11/29	04:45:41	39.0790	-119.0110	6.10	3.60	ML	REN
438	2006/04/05	12:03:16	39.0820	-119.0060	4.90	3.40	ML	REN
439	2000/09/26	07:20:28	38.6588	-119.5307	9.30	4.72	ML	NN
443	2002/07/18	15:03:54	38.7378	-121.6473	20.97	3.26	Md	NC
444	2000/06/24	11:04:17	38.7650	-122.6925	3.91	3.42	ML	NC
444	2006/11/29	03:20:22	38.6545	-122.2613	0.07	3.23	ML	NC
445	2006/10/20	17:00:08	38.8667	-122.7873	3.46	4.50	Mw	NC
446	2005/02/04	23:27:40	38.8892	-123.5978	0.02	3.14	ML	NC
463	2003/04/05	14:18:26	39.3763	-119.2506	12.37	3.67	ML	NN
464	2003/05/04	12:07:10	39.5160	-119.5688	7.50	3.39	ML	NN
465	2005/06/26	18:45:57	39.3050	-120.0928	0.09	4.80	Mw	NC
466	2000/12/02	15:34:15	39.3787	-120.4507	14.28	4.91	ML	NN
466	2006/05/29	10:38:43	39.3660	-120.4650	9.60	3.80	ML	REN
468	2004/08/03	18:46:44	39.4792	-122.0673	23.01	3.27	Md	NC
469	2003/07/28	19:10:58	39.2250	-122.2405	14.01	3.18	ML	NC
470	2000/05/17	22:32:07	39.3912	-123.0655	8.09	4.15	ML	NC
470	2006/09/26	20:56:13	39.3120	-123.2185	12.48	3.80	Mw	NC
471	2006/11/09	08:38:13	39.3587	-123.2823	4.88	4.00	Mw	NC
488	2000/11/25	17:38:20	39.6757	-119.2930	8.92	3.39	ML	NN
489	2005/03/04	05:33:45	39.6500	-119.3240	12.20	3.00	ML	REN
490	2000/03/10	23:56:56	39.6821	-120.2843	10.32	3.04	ML	NN
491	2001/08/10	20:19:26	39.8233	-120.6459	17.82	5.31	ML	NN
493	2003/03/29	00:40:33	39.7390	-122.0807	19.06	3.48	ML	NC
494	2004/03/21	20:41:35	39.5983	-122.1950	95.81	4.11	Md	NC
495	2001/02/02	23:03:11	39.7302	-122.8290	7.39	3.96	ML	NC

495	2006/05/02	11:04:20	39.5615	-122.7342	0.02	3.14	Md	NC
496	2006/04/07	10:04:28	39.5647	-123.3500	9.99	3.50	ML	NC
497	2002/11/24	22:46:56	39.9737	-124.0520	4.06	3.45	Md	NC
514	2000/07/05	12:26:31	40.2289	-119.6130	4.54	3.89	ML	NN
515	2000/12/18	18:41:05	40.2922	-120.2721	12.91	3.38	ML	NN
515	2006/02/22	05:37:45	40.0422	-120.0187	0.02	3.06	Md	NC
516	2004/04/19	06:20:14	40.3700	-120.6250	7.00	3.70	Mw	NC
517	2005/11/29	14:29:32	40.2075	-121.1697	1.07	3.33	Md	NC
517	2006/02/24	23:54:47	40.2297	-121.1673	0.02	3.17	ML	NC
518	2000/07/30	09:16:37	40.3785	-122.0507	19.88	3.58	ML	NC
518	2006/11/17	13:33:36	40.1513	-122.0715	28.40	3.50	Md	NC
519	2004/04/26	16:38:56	40.1348	-122.5567	20.69	3.25	Md	NC
520	2005/07/28	01:28:24	40.1545	-122.8415	43.72	3.46	Md	NC
521	2004/02/03	16:04:11	40.1913	-123.7332	22.44	3.01	ML	NC
522	2004/08/01	15:43:32	40.3205	-124.0593	32.31	3.75	Md	NC
522	2006/10/19	15:20:05	40.2795	-124.3247	16.70	3.65	Md	NC
523	2006/07/19	11:41:43	40.2807	-124.4335	20.69	5.00	Mw	NC
524	2000/03/16	15:19:56	40.3887	-125.2383	5.54	4.81	Md	NC
524	2006/12/17	15:13:39	40.4203	-125.0737	0.31	4.30	Mw	NC
525	2005/05/22	10:35:24	40.3600	-125.7120	5.10	3.60	Mc	NC
525	2006/06/10	03:18:37	40.4327	-125.5288	5.15	3.23	Md	NC
538	2003/10/01	08:33:43	40.6251	-119.3157	11.64	3.32	ML	NN
539	2000/11/19	12:54:50	40.4822	-119.4855	12.92	4.40	ML	NN
541	2002/03/02	07:19:04	40.8280	-120.6630	4.20	3.30	ML	NC
543	2001/11/07	19:39:01	40.8652	-121.6127	15.02	3.28	ML	NC
544	2003/06/23	13:34:16	40.6345	-122.4347	23.48	3.38	Md	NC
544	2006/11/02	20:59:06	40.6795	-122.3578	22.15	3.00	Md	NC
545	2005/04/06	08:10:03	40.7438	-123.1973	31.11	3.14	Md	NC
546	2004/12/05	01:48:04	40.7392	-123.8145	29.32	4.30	Mw	NC
547	2004/12/12	09:13:33	40.6965	-123.8675	28.49	4.46	Mw	NC
547	2006/11/01	08:27:28	40.5288	-124.0605	19.24	3.34	ML	NC
548	2002/06/17	16:55:07	40.8088	-124.5538	21.19	5.09	ML	NC
549	2001/01/13	13:08:42	40.7557	-125.2450	2.62	5.19	ML	NC
550	2000/01/16	01:51:32	40.4630	-125.7080	2.50	4.30	Mw	NC
550	2006/06/25	17:21:20	40.4510	-125.6780	5.00	3.30	Mc	NC
562	2003/02/14	23:48:22	41.3358	-118.7086	0.00	3.37	ML	NN
566	2003/06/27	00:26:12	41.1980	-120.5230	17.10	3.30	ML	NC
567	2005/11/13	14:53:51	41.0628	-121.5077	8.56	3.48	ML	NC
568	2000/12/20	23:39:14	40.9885	-121.6935	18.44	4.62	ML	NC
569	2005/11/29	06:12:00	41.1773	-122.2560	10.77	3.08	ML	NC
571	2005/10/20	16:26:50	41.0273	-123.3127	36.14	3.57	ML	NC
571	2006/04/13	17:40:49	40.9130	-123.5602	22.27	3.24	ML	NC
572	2001/10/22	08:23:52	40.9712	-124.2157	19.30	3.54	ML	NC
573	2001/10/20	22:05:51	41.2332	-124.9347	2.54	3.16	Md	NC
574	2003/08/15	09:22:14	40.9850	-125.4300	8.60	5.30	Mw	NC
575	2004/02/20	08:38:07	41.3020	-125.5500	2.50	3.60	ML	NC
590	2002/07/20	15:09:13	41.5530	-119.9690	0.00	3.00	ML	REN
596	2000/11/29	18:57:17	41.3623	-123.4810	36.45	3.01	Md	NC
597	2004/01/17	03:00:15	41.4382	-123.8335	30.13	3.26	Md	NC
598	2004/03/21	20:09:02	41.5733	-124.5657	6.20	3.31	Md	NC
599	2006/06/04	05:39:21	41.5960	-125.4800	2.60	3.70	Mb	NC
600	2004/10/12	00:53:53	41.5450	-125.6050	10.00	4.60	Mb	NEI
613	2006/04/12	10:55:22	41.9940	-118.8350	0.00	3.00	ML	REN
614	2000/11/26	01:09:37	41.9073	-119.7597	23.26	3.08	Md	NC
615	2004/06/30	12:21:45	42.1540	-120.2940	5.00	4.70	Mw	NEI
618	2002/05/15	17:54:48	42.2313	-121.9012	8.11	4.30	Mc	UW
622	2005/07/04	09:21:47	42.1190	-123.9960	5.00	3.00	ML	NEI
623	2002/02/03	06:46:14	42.0688	-124.4453	30.43	3.04	Md	NC
625	2002/06/01	00:15:59	41.8840	-125.5810	2.50	4.20	ML	NC
640	2005/06/11	11:16:10	42.2730	-120.0690	5.00	3.60	Mw	NEI

Appendix B. CISN dM_L Adjustments.

Initial set of 666 CISN dM_L adjustments determined using the 2000-2006 data set analyzed in this study. The table entries are (SNCL, dM_L, standard error) triplets with four triplets per row. See Table SB in the electronic supplement.

ADO.CI.N	-0.347	0.016	ADO.CI.E	-0.393	0.016	AGA.CI.N	0.259	0.019	AGA.CI.E	0.204	0.018
AGO.CI.N	-0.079	0.015	AGO.CI.E	-0.097	0.016	ALP.CI.N	-0.178	0.016	ALP.CI.E	-0.192	0.016
ARC.BK.N	-0.084	0.063	ARC.BK.E	0.048	0.079	ARV.CI.N	-0.141	0.018	ARV.CI.E	-0.090	0.018
BAK.CI.N	-0.221	0.016	BAK.CI.E	-0.221	0.016	BAR.CI.N	0.039	0.018	BAR.CI.E	0.032	0.018
BBR.CI.N	-0.269	0.016	BBR.CI.E	-0.306	0.016	BBS.CI.N	-0.312	0.017	BBS.CI.E	-0.333	0.016
BC3.CI.N	0.030	0.020	BC3.CI.E	0.061	0.021	BCC.CI.N	-0.135	0.017	BCC.CI.E	-0.151	0.018
BDM.BK.N	-0.124	0.021	BDM.BK.E	-0.130	0.021	BEL.CI.N	0.017	0.018	BEL.CI.E	-0.029	0.018
BFS.CI.N	0.169	0.017	BFS.CI.E	0.138	0.016	BKR.CI.N	-0.298	0.027	BKR.CI.E	-0.342	0.026
BKS.BK.N	-0.004	0.013	BKS.BK.E	0.004	0.013	BLA.CI.N	0.004	0.017	BLA.CI.E	0.269	0.017
BLY.CI.N	0.063	0.031	BLY.CI.E	0.070	0.032	BOR.CI.N	0.194	0.018	BOR.CI.E	0.182	0.018
BRE.CI.N	-0.401	0.016	BRE.CI.E	-0.443	0.016	BRIB.BK.N	-0.009	0.023	BRIB.BK.E	0.012	0.023
BRK.BK.N	0.137	0.025	BRK.BK.E	0.102	0.025	BTC.CI.N	-0.146	0.019	BTC.CI.E	-0.120	0.019
BTP.CI.N	-0.281	0.016	BTP.CI.E	-0.297	0.016	BZN.AZ.N	-0.079	0.017	BZN.AZ.E	-0.046	0.017
CAC.CI.N	-0.175	0.017	CAC.CI.E	-0.227	0.016	CADB.NC.N	-0.060	0.025	CADB.NC.E	-0.096	0.023
CAG.NC.N	-0.251	0.020	CAG.NC.E	-0.209	0.020	CAL.NC.N	0.017	0.023	CAL.NC.E	0.029	0.023
CAP.CI.N	0.116	0.017	CAP.CI.E	0.090	0.017	CBC.CI.N	-0.305	0.016	CBC.CI.E	-0.289	0.016
CBP.NC.N	-0.229	0.019	CBP.NC.E	-0.286	0.020	CBR.NC.N	-0.395	0.021	CBR.NC.E	-0.386	0.021
CCC.CI.N	-0.221	0.016	CCC.CI.E	-0.146	0.017	CCO.NC.N	-0.269	0.020	CCO.NC.E	-0.312	0.020
CDOB.NC.N	-0.428	0.019	CDOB.NC.E	-0.474	0.019	CFS.CI.N	-0.339	0.018	CFS.CI.E	-0.342	0.019
CGO.CI.N	-0.178	0.018	CGO.CI.E	-0.192	0.018	CHF.CI.N	0.211	0.016	CHF.CI.E	0.186	0.016
CHN.CI.N	-0.320	0.015	CHN.CI.E	-0.348	0.015	CHR.NC.N	-0.104	0.022	CHR.NC.E	-0.154	0.021
CIA.CI.N	0.035	0.017	CIA.CI.E	-0.023	0.016	CLC.CI.N	0.287	0.017	CLC.CI.E	0.231	0.017
CLCB.NC.N	-0.488	0.022	CLCB.NC.E	-0.502	0.022	CLT.CI.N	-0.498	0.016	CLT.CI.E	-0.489	0.015
CMB.BK.N	0.066	0.019	CMB.BK.E	0.033	0.020	CMOB.NC.N	-0.178	0.033	CMOB.NC.E	-0.297	0.031
CPI.NC.N	-0.376	0.019	CPI.NC.E	-0.433	0.020	CPM.NC.N	-0.058	0.027	CPM.NC.E	-0.013	0.026
CPP.CI.N	-0.438	0.020	CPP.CI.E	-0.465	0.019	CRH.NC.N	-0.400	0.021	CRH.NC.E	-0.391	0.022
CRN.CI.N	-0.111	0.015	CRN.CI.E	-0.073	0.016	CRP.CI.N	-0.212	0.019	CRP.CI.E	-0.237	0.019
CRPB.NC.N	-0.009	0.021	CRPB.NC.E	-0.090	0.020	CRY.AZ.N	0.100	0.016	CRY.AZ.E	0.034	0.016
CSL.NC.N	-0.425	0.020	CSL.NC.E	-0.370	0.020	CTA.NC.N	-0.313	0.019	CTA.NC.E	-0.347	0.020
CTC.CI.N	-0.357	0.017	CTC.CI.E	-0.408	0.017	CVS.BK.N	0.152	0.022	CVS.BK.E	0.066	0.022
CWC.CI.N	0.158	0.020	CWC.CI.E	0.133	0.020	CYB.NC.N	-0.344	0.022	CYB.NC.E	-0.289	0.023
DAN.CI.N	-0.241	0.017	DAN.CI.E	-0.288	0.017	DEC.CI.N	-0.284	0.015	DEC.CI.E	-0.268	0.016
DEV.CI.N	-0.165	0.016	DEV.CI.E	-0.163	0.016	DGR.CI.N	0.126	0.016	DGR.CI.E	0.100	0.016
DJJ.CI.N	0.073	0.015	DJJ.CI.E	0.077	0.016	DLA.CI.N	-0.537	0.016	DLA.CI.E	-0.544	0.016
DNR.CI.N	-0.352	0.018	DNR.CI.E	-0.393	0.018	DPP.CI.N	0.184	0.020	DPP.CI.E	0.123	0.018
DRC.CI.N	-0.369	0.028	DRC.CI.E	-0.420	0.027	DRE.CI.N	-0.500	0.018	DRE.CI.E	-0.512	0.018
DSC.CI.N	0.181	0.019	DSC.CI.E	0.156	0.019	DVT.CI.N	0.095	0.020	DVT.CI.E	0.029	0.019
EDW.CI.N	0.224	0.019	EDW.CI.E	0.159	0.019	EDW2.CI.N	0.160	0.018	EDW2.CI.E	0.109	0.018
ELFS.BK.N	-0.083	0.037	ELFS.BK.E	-0.017	0.041	EML.CI.N	0.268	0.019	EML.CI.E	0.268	0.018
ERR.CI.N	-0.469	0.018	ERR.CI.E	-0.463	0.017	FARB.BK.N	0.172	0.023	FARB.BK.E	0.162	0.025
FIG.CI.N	0.082	0.018	FIG.CI.E	0.030	0.017	FMP.CI.N	-0.163	0.016	FMP.CI.E	-0.113	0.016
FON.CI.N	-0.120	0.016	FON.CI.E	-0.142	0.015	FPC.CI.N	0.025	0.038	FPC.CI.E	0.055	0.037
FRD.AZ.N	0.205	0.018	FRD.AZ.E	0.178	0.017	FUL.CI.N	-0.385	0.016	FUL.CI.E	-0.433	0.017
FUR.CI.N	-0.130	0.016	FUR.CI.E	-0.174	0.016	GASB.BK.N	0.161	0.057	GASB.BK.E	0.111	0.048
GDXB.NC.N	0.407	0.041	GDXB.NC.E	0.343	0.040	GLA.CI.N	0.057	0.019	GLA.CI.E	-0.106	0.018
GOR.CI.N	0.190	0.017	GOR.CI.E	0.175	0.016	GRA.CI.N	-0.137	0.017	GRA.CI.E	-0.157	0.018
GSA.CI.N	-0.227	0.016	GSA.CI.E	-0.246	0.016	GSC.CI.N	0.037	0.016	GSC.CI.E	-0.003	0.016
HAST.BK.N	-0.155	0.029	HAST.BK.E	-0.154	0.029	HATC.BK.N	-0.042	0.046	HATC.BK.E	-0.194	0.034
HEC.CI.N	-0.013	0.017	HEC.CI.E	-0.172	0.016	HELL.BK.N	0.032	.029	HELL.BK.E	0.020	0.024
HLL.CI.N	-0.223	0.016	HLL.CI.E	-0.209	0.015	HLN.CI.N	-0.108	0.017	HLN.CI.E	-0.151	0.016
HOPS.BK.N	0.128	0.025	HOPS.BK.E	0.113	0.026	HUMO.BK.N	0.311	0.050	HUMO.BK.E	0.205	0.052
IRM.CI.N	0.106	0.020	IRM.CI.E	0.093	0.019	ISA.CI.N	0.217	0.017	ISA.CI.E	0.163	0.017
JBG.NC.N	-0.476	0.019	JBG.NC.E	-0.594	0.020	JBMB.NC.N	-0.042	0.020	JBMB.NC.E	-0.011	0.021
JBN.NC.N	0.151	0.023	JBN.NC.E	0.026	0.023	JBR.NC.N	-0.411	0.020	JBR.NC.E	-0.374	0.020
JCC.BK.N	0.142	0.040	JCC.BK.E	0.128	0.039	JCH.NC.N	-0.142	0.019	JCH.NC.E	-0.140	0.020
JCS.CI.N	-0.035	0.017	JCS.CI.E	0.044	0.017	JECB.NC.N	-0.196	0.020	JECB.NC.E	-0.251	0.019
JGR.NC.N	-0.025	0.021	JGR.NC.E	-0.064	0.023	JHU.NC.N	-0.415	0.020	JHU.NC.E	-0.451	0.019
JJO.NC.N	-0.241	0.019	JJO.NC.E	-0.211	0.019	JLAB.NC.N	-0.196	0.021	JLAB.NC.E	-0.217	0.019
JMGB.NC.N	-0.037	0.020	JMGB.NC.E	-0.061	0.020	JPC.NC.N	-0.536	0.018	JPC.NC.E	-0.523	0.020
JPSB.NC.N	-0.434	0.021	JPSB.NC.E	-0.410	0.021	JRC.CI.N	-0.082	0.022	JRC.CI.E	-0.129	0.022
JRC2.CI.N	-0.093	0.018	JRC2.CI.E	-0.153	0.018	JRSC.BK.N	0.057	0.025	JRSC.BK.E	0.006	0.023
JSA.NC.N	-0.247	0.019	JSA.NC.E	-0.268	0.019	JSB.NC.N	-0.076	0.023	JSB.NC.E	-0.068	0.021
JSF.NC.N	-0.175	0.053	JSF.NC.E	-0.098	0.038	JSFB.NC.N	-0.254	0.019	JSFB.NC.E	-0.295	0.020
JSGB.NC.N	-0.248	0.018	JSGB.NC.E	-0.202	0.021	JSP.NC.N	-0.178	0.020	JSP.NC.E	-0.109	0.022
JUM.NC.N	-0.356	0.022	JUM.NC.E	-0.334	0.023	JVA.CI.N	-0.207	0.016	JVA.CI.E	-0.298	0.016
KBO.NC.N	-0.113	0.049	KBO.NC.E	-0.136	0.054	KCC.BK.N	0.203	0.022	KCC.BK.E	0.171	0.022

KCPB.NC.N	0.036	0.034	KCPB.NC.E	0.017	0.035	KCT.NC.N	-0.218	0.046	KCT.NC.E	-0.212	0.046
KEB.NC.N	-0.056	0.054	KEB.NC.E	-0.003	0.052	KHBB.NC.N	0.048	0.031	KHBB.NC.E	0.099	0.033
KHMB.NC.N	-0.134	0.040	KHMB.NC.E	-0.043	0.039	KML.CI.N	0.196	0.020	KML.CI.E	0.083	0.019
KMPB.NC.N	-0.171	0.044	KMPB.NC.E	-0.161	0.048	KMR.NC.N	-0.144	0.044	KMR.NC.E	-0.190	0.043
KNW.AZ.N	0.203	0.016	KNW.AZ.E	0.222	0.017	KRMB.NC.N	0.145	0.052	KRMB.NC.E	0.120	0.052
KRP.NC.N	-0.130	0.039	KRP.NC.E	-0.132	0.044	KSXB.NC.N	0.106	0.043	KSXB.NC.E	0.009	0.047
LAF.CI.N	-0.343	0.017	LAF.CI.E	-0.337	0.017	LBW1.CI.N	-0.496	0.018	LBW1.CI.E	-0.532	0.017
LCG.CI.N	-0.281	0.016	LCG.CI.E	-0.317	0.016	LCP.CI.N	-0.339	0.016	LCP.CI.E	-0.336	0.016
LDF.CI.N	-0.345	0.017	LDF.CI.E	-0.288	0.016	LDH.NC.N	-0.057	0.034	LDH.NC.E	-0.010	0.033
LDR.CI.N	-0.091	0.016	LDR.CI.E	-0.145	0.017	LEV.CI.N	-0.110	0.018	LEV.CI.E	-0.105	0.017
LFP.CI.N	-0.388	0.015	LFP.CI.E	-0.320	0.015	LGB.CI.N	-0.318	0.015	LGB.CI.E	-0.342	0.016
LGU.CI.N	0.059	0.016	LGU.CI.E	-0.056	0.016	LJR.CI.N	-0.299	0.016	LJR.CI.E	-0.326	0.016
LKL.CI.N	-0.368	0.019	LKL.CI.E	-0.344	0.018	LLS.CI.N	-0.574	0.016	LLS.CI.E	-0.558	0.017
LMR2.CI.N	0.221	0.021	LMR2.CI.E	0.165	0.020	LRL.CI.N	0.044	0.016	LRL.CI.E	0.125	0.016
LTP.CI.N	-0.535	0.016	LTP.CI.E	-0.532	0.016	LUG.CI.N	-0.203	0.016	LUG.CI.E	-0.164	0.016
LVA2.AZ.N	0.045	0.016	LVA2.AZ.E	-0.070	0.016	MAG.CI.N	0.074	0.018	MAG.CI.E	0.099	0.021
MCB.NC.N	-0.694	0.021	MCB.NC.E	-0.745	0.021	MCCM.BK.N	-0.005	0.034	MCCM.BK.E	-0.037	0.035
MCT.CI.N	0.272	0.019	MCT.CI.E	0.234	0.017	MGE.CI.N	-0.416	0.016	MGE.CI.E	-0.409	0.016
MHC.BK.N	-0.097	0.020	MHC.BK.E	-0.038	0.020	MIK.CI.N	-0.901	0.015	MIK.CI.E	-0.950	0.016
MIS.CI.N	0.676	0.021	MIS.CI.E	0.731	0.022	MLAC.CI.N	-0.644	0.019	MLAC.CI.E	-0.657	0.019
MLS.CI.N	-0.112	0.017	MLS.CI.E	-0.250	0.015	MMLB.NC.N	-0.699	0.020	MMLB.NC.E	-0.733	0.020
MNRC.BK.N	0.039	0.023	MNRC.BK.E	0.048	0.024	MOD.BK.N	-0.003	0.036	MOD.BK.E	0.007	0.038
MONP.AZ.N	0.262	0.018	MONP.AZ.E	0.208	0.017	MOP.CI.N	-0.458	0.015	MOP.CI.E	-0.503	0.015
MPI.CI.N	0.084	0.017	MPI.CI.E	0.050	0.018	MPM.CI.N	0.181	0.017	MPM.CI.E	0.153	0.017
MPP.CI.N	-0.086	0.017	MPP.CI.E	-0.112	0.017	MSJ.CI.N	-0.571	0.016	MSJ.CI.E	-0.588	0.016
MTP.CI.N	0.139	0.020	MTP.CI.E	0.106	0.019	MUR.CI.N	-0.280	0.021	MUR.CI.E	-0.347	0.023
MWC.CI.N	-0.013	0.015	MWC.CI.E	-0.015	0.016	NAPC.NC.N	-0.223	0.020	NAPC.NC.E	-0.235	0.020
NBO.NC.N	-0.185	0.022	NBO.NC.E	-0.179	0.020	NBRB.NC.N	-0.200	0.020	NBRB.NC.E	-0.154	0.022
NBS.CI.N	-0.073	0.018	NBS.CI.E	-0.132	0.019	NEA.NC.N	0.126	0.030	NEA.NC.E	0.066	0.024
NEE.CI.N	-0.404	0.018	NEE.CI.E	-0.381	0.019	NEH.NC.N	-0.164	0.028	NEH.NC.E	-0.216	0.030
NFV.NC.N	0.061	0.025	NFV.NC.E	-0.038	0.027	NGVB.NC.N	0.225	0.023	NGVB.NC.E	0.077	0.022
NHF.NC.N	0.017	0.025	NHF.NC.E	-0.130	0.024	NHM.NC.N	-0.342	0.022	NHM.NC.E	-0.449	0.023
NHS.NC.N	-0.342	0.022	NHS.NC.E	-0.090	0.041	NHV.NC.N	0.081	0.022	NHV.NC.E	0.126	0.024
NJQ.CI.N	-0.231	0.016	NJQ.CI.E	-0.230	0.016	NLH.NC.N	-0.143	0.022	NLH.NC.E	-0.197	0.020
NMH.NC.N	-0.049	0.023	NMH.NC.E	0.000	0.024	NMI.NC.N	-0.190	0.019	NMI.NC.E	-0.273	0.020
NOLB.NC.N	-0.463	0.019	NOLB.NC.E	-0.469	0.018	NOT.CI.N	-0.485	0.015	NOT.CI.E	-0.485	0.016
NPRB.NC.N	0.125	0.027	NPRB.NC.E	0.130	0.024	NSM.NC.N	-0.552	0.021	NSM.NC.E	-0.486	0.020
NSP.NC.N	-0.149	0.021	NSP.NC.E	-0.147	0.022	NSS.CI.N	-0.162	0.032	NSS.CI.E	-0.191	0.024
NSS2.CI.N	-0.153	0.019	NSS2.CI.E	-0.264	0.018	NTAB.NC.N	0.073	0.022	NTAB.NC.E	0.120	0.024
NTAC.NC.N	0.086	0.036	NTAC.NC.E	0.015	0.039	NTO.NC.N	-0.216	0.021	NTO.NC.E	-0.322	0.021
NTR.NC.N	0.096	0.033	NTR.NC.E	0.110	0.032	NTYB.NC.N	-0.193	0.019	NTYB.NC.E	-0.163	0.020
O02C.TA.N	0.082	0.067	O02C.TA.E	0.169	0.053	O03C.TA.N	-0.096	0.029	O03C.TA.E	-0.049	0.029
O04C.TA.N	0.078	0.033	O04C.TA.E	-0.012	0.032	O05C.TA.N	0.074	0.032	O05C.TA.E	-0.122	0.026
OGC.CI.N	-0.240	0.016	OGC.CI.E	-0.289	0.016	OLI.CI.N	-0.288	0.016	OLI.CI.E	-0.276	0.016
OLP.CI.N	0.029	0.019	OLP.CI.E	0.096	0.019	ORV.BK.N	0.289	0.024	ORV.BK.E	0.180	0.025
OSI.CI.N	-0.009	0.016	OSI.CI.E	0.018	0.016	P01C.TA.N	0.381	0.067	P01C.TA.E	0.270	0.064
P05C.TA.N	0.198	0.040	P05C.TA.E	0.132	0.029	PACP.BK.N	-0.324	0.022	PACP.BK.E	-0.306	0.022
PAGB.NC.N	0.058	0.023	PAGB.NC.E	0.001	0.022	PAS.CI.N	0.195	0.017	PAS.CI.E	0.171	0.017
PDE.CI.N	-0.351	0.015	PDE.CI.E	-0.290	0.015	PDM.CI.N	0.139	0.021	PDM.CI.E	0.195	0.021
PDR.CI.N	-0.201	0.018	PDR.CI.E	-0.226	0.017	PDU.CI.N	-0.155	0.016	PDU.CI.E	-0.142	0.016
PER.CI.N	0.141	0.018	PER.CI.E	0.091	0.018	PFO.AZ.N	0.260	0.017	PFO.AZ.E	0.251	0.018
PHL.CI.N	0.021	0.019	PHL.CI.E	0.028	0.019	PHOB.NC.N	-0.139	0.021	PHOB.NC.E	-0.219	0.023
PKD.BK.N	0.135	0.019	PKD.BK.E	0.141	0.019	PLC.CI.N	-0.406	0.018	PLC.CI.E	-0.406	0.018
PLM.CI.N	-0.031	0.016	PLM.CI.E	0.001	0.016	PLS.CI.N	-0.183	0.016	PLS.CI.E	-0.145	0.016
PMD.CI.N	0.237	0.023	PMD.CI.E	-0.145	0.016	PMPB.NC.N	-0.167	0.022	PMPB.NC.E	-0.146	0.021
POTR.BK.N	-0.342	0.025	POTR.BK.E	-0.397	0.026	PSD.CI.N	0.224	0.023	PSD.CI.E	0.203	0.023
Q03C.TA.N	-0.252	0.027	Q03C.TA.E	-0.224	0.026	Q04C.TA.N	-0.270	0.028	Q04C.TA.E	-0.228	0.029
QUG.CI.N	-0.153	0.017	QUG.CI.E	-0.135	0.017	R04C.TA.N	-0.206	0.023	R04C.TA.E	-0.184	0.024
R05C.TA.N	0.077	0.038	R05C.TA.E	-0.007	0.032	R06C.TA.N	0.018	0.041	R06C.TA.E	0.000	0.035
R07C.TA.N	-0.290	0.035	R07C.TA.E	-0.319	0.036	RAMR.BK.N	-0.351	0.021	RAMR.BK.E	-0.337	0.021
RCT.CI.N	-0.161	0.018	RCT.CI.E	-0.160	0.018	RDM.AZ.N	0.094	0.016	RDM.AZ.E	0.074	0.016
RFSB.BK.N	-0.177	0.021	RFSB.BK.E	0.085	0.070	RIN.CI.N	-0.407	0.017	RIN.CI.E	-0.358	0.019
RINB.CI.N	-0.455	0.019	RINB.CI.E	-0.390	0.019	RIO.CI.N	-0.185	0.016	RIO.CI.E	-0.199	0.016
RPV.CI.N	-0.222	0.016	RPV.CI.E	-0.324	0.016	RRX.CI.N	-0.270	0.016	RRX.CI.E	-0.345	0.016
RSB.CI.N	-0.127	0.016	RSB.CI.E	-0.181	0.017	RSS.CI.N	-0.174	0.016	RSS.CI.E	-0.206	0.016
RUS.CI.N	-0.354	0.016	RUS.CI.E	-0.349	0.016	RVR.CI.N	0.233	0.016	RVR.CI.E	0.168	0.016
RXH.CI.N	-0.129	0.025	RXH.CI.E	-0.106	0.025	S04C.TA.N	-0.071	0.028	S04C.TA.E	-0.081	0.031
S05C.TA.N	-0.209	0.023	S05C.TA.E	-0.179	0.024	S06C.TA.N	-0.092	0.029	S06C.TA.E	0.013	0.028
S08C.TA.N	0.167	0.052	S08C.TA.E	0.115	0.046	SAL.CI.N	-0.484	0.017	SAL.CI.E	-0.437	0.017
SAN.CI.N	-0.355	0.017	SAN.CI.E	-0.339	0.016	SAO.BK.N	0.170	0.021	SAO.BK.E	0.104	0.021
SBB2.CI.N	0.272	0.020	SBB2.CI.E	0.186	0.022	SBC.CI.N	-0.123	0.016	SBC.CI.E	-0.130	0.017
SBI.CI.N	0.099	0.018	SBI.CI.E	0.079	0.019	SBPX.CI.N	-0.177	0.016	SBPX.CI.E	-0.103	0.016
SCCB.BK.N	-0.283	0.022	SCCB.BK.E	-0.265	0.022	SCI.CI.N	-0.059	0.026	SCI.CI.E	-0.020	0.024
SCI2.CI.N	-0.160	0.019	SCI2.CI.E	-0.067	0.018	SCZ.CI.N	-0.237	0.032	SCZ.CI.E	-0.186	0.030
SCZ2.CI.N	-0.330	0.021	SCZ2.CI.E	-0.344	0.017	SDD.CI.N	-0.394	0.017	SDD.CI.E	-0.428	0.017

SDG.CI.N	-0.119	0.020	SDG.CI.E	-0.188	0.020	SDP.CI.N	-0.240	0.017	SDP.CI.E	-0.254	0.017
SDR.CI.N	0.169	0.020	SDR.CI.E	0.169	0.020	SES.CI.N	-0.187	0.016	SES.CI.E	-0.252	0.016
SHO.CI.N	-0.417	0.016	SHO.CI.E	-0.412	0.016	SIO.CI.N	-0.458	0.017	SIO.CI.E	-0.406	0.017
SLA.CI.N	-0.172	0.016	SLA.CI.E	-0.269	0.016	SLR.CI.N	-0.114	0.017	SLR.CI.E	-0.104	0.017
SMM.CI.N	-0.225	0.016	SMM.CI.E	-0.239	0.017	SMS.CI.N	-0.283	0.016	SMS.CI.E	-0.283	0.016
SMV.CI.N	-0.358	0.016	SMV.CI.E	-0.347	0.016	SNCC.CI.N	0.231	0.019	SNCC.CI.E	0.189	0.019
SND.AZ.N	-0.145	0.016	SND.AZ.E	-0.221	0.016	SOL.AZ.N	-0.397	0.020	SOL.AZ.E	-0.331	0.019
SOT.CI.N	-0.282	0.028	SOT.CI.E	-0.217	0.029	SPF.CI.N	-0.027	0.016	SPF.CI.E	-0.062	0.016
SPG.CI.N	0.252	0.019	SPG.CI.E	0.185	0.019	SPG2.CI.N	0.299	0.038	SPG2.CI.E	0.185	0.019
SRN.CI.N	-0.151	0.016	SRN.CI.E	-0.174	0.016	SSW.CI.N	-0.601	0.025	SSW.CI.E	-0.554	0.024
STC.CI.N	-0.282	0.015	STC.CI.E	-0.301	0.015	STG.CI.N	-0.345	0.018	STG.CI.E	-0.316	0.017
STS.CI.N	-0.512	0.016	STS.CI.E	-0.470	0.016	SUTB.BK.N	-0.243	0.030	SUTB.BK.E	-0.352	0.035
SVD.CI.N	-0.102	0.016	SVD.CI.E	-0.076	0.016	SWS.CI.N	-0.018	0.018	SWS.CI.E	-0.039	0.018
SYP.CI.N	-0.231	0.016	SYP.CI.E	-0.265	0.016	TA2.CI.N	-0.312	0.015	TA2.CI.E	-0.236	0.015
TEH.CI.N	0.097	0.016	TEH.CI.E	0.076	0.017	TFT.CI.N	-0.234	0.017	TFT.CI.E	-0.244	0.018
THX.CI.N	-0.537	0.017	THX.CI.E	-0.495	0.017	TIN.CI.N	-0.327	0.019	TIN.CI.E	-0.300	0.019
TOV.CI.N	-0.050	0.016	TOV.CI.E	-0.122	0.016	TRO.AZ.N	-0.298	0.019	TRO.AZ.E	-0.321	0.019
TUQ.CI.N	-0.045	0.018	TUQ.CI.E	-0.142	0.018	USC.CI.N	-0.256	0.016	USC.CI.E	-0.229	0.016
VCS.CI.N	-0.092	0.015	VCS.CI.E	-0.173	0.016	VES.CI.N	-0.029	0.017	VES.CI.E	-0.027	0.017
VTV.CI.N	-0.215	0.017	VTV.CI.E	-0.252	0.016	WBS.CI.N	-0.250	0.016	WBS.CI.E	-0.231	0.016
WDC.BK.N	0.199	0.030	WDC.BK.E	0.260	0.030	WENL.BK.N	-0.177	0.019	WENL.BK.E	-0.186	0.019
WER.CI.N	-0.370	0.022	WER.CI.E	-0.329	0.023	WES.CI.N	-0.448	0.018	WES.CI.E	-0.407	0.018
WGR.CI.N	0.153	0.016	WGR.CI.E	0.204	0.016	WLT.CI.N	-0.517	0.016	WLT.CI.E	-0.521	0.015
WMC.AZ.N	-0.098	0.016	WMC.AZ.E	-0.164	0.016	WSS.CI.N	-0.520	0.017	WSS.CI.E	-0.512	0.016
WTT.CI.N	-0.429	0.016	WTT.CI.E	-0.381	0.016	YAQ.AZ.N	-0.007	0.018	YAQ.AZ.E	-0.058	0.018
YBH.BK.N	0.243	0.050	YBH.BK.E	0.243	.046						

Appendix C. CISN $-\log A_0(r)$ FORTRAN Function. See also SP1 in the electronic supplement.

```
      real*8 function CISN_mlAo( rdist )
c
c ...... calculate CISN -logAo ML attenuation function
c
      implicit none
      integer*4 j
      real*8 rdist, TP(6), mlogAo, T, z, x, CISN_mlAo, b, logAo
c
      TP( 1 ) = +0.056d0
      TP( 2 ) = -0.031d0
      TP( 3 ) = -0.053d0
      TP( 4 ) = -0.080d0
      TP( 5 ) = -0.028d0
      TP( 6 ) = +0.015d0
c
      if( rdist .le. 0.1d0 ) then
c
c ...... invalid for rdist less that 0.1 km
c       return with -9.d0
c
        mlogAo = -9.d0
c
      elseif( rdist .le. 8.d0 ) then
c
c ...... linear extrapolation of average slope between 8 km and 60 km
c
        b = ( 2.6182d0-1.5429d0)/(dlog10(60.d0)-dlog10(8.d0))
        mlogAo = 1.5429d0 + b * ( dlog10( rdist ) - dlog10( 8.d0 ) )
c
      elseif( rdist .le. 500.d0 ) then
c
c ...... Chebychev polynomial expansion
c
        x = z( rdist )
        mlogAo = logAo( rdist ) + 0.0054d0
        do j = 1 , 6
          mlogAo = mlogAo + TP( j ) * T( j , x )
        end do
c
      else
c
c ...... invalid for rdist greater than 500 km
c       return with -9.d0
c
        mlogAo = -9.d0
c
      endif
c
      CISN_mlAo = mlogAo
c
      return
      end
```

```
      real*8 function T( n , x )
c
c ...... Chebyshev Polynomial
c
      implicit none
      integer*4 n
      real*8 T, x, theta
c
      theta = dacos( x )
      T = dcos( dble( n ) * theta )
c
      return
      end

      real*8 function z( r )
c
c ...... translate scale from r to z
c
      integer*4 ncall
      real*8 r, r0, r1, z0, z1, a , b, l_r0, l_r1
c
      data ncall /0/
      data r0,r1 /8.d0,500.d0/
      data z0,z1 /-1.d0,+1.d0/
c
      if( ncall .eq. 0 ) then
        l_r0 = dlog10( r0 )
        l_r1 = dlog10( r1 )
        b = ( z1 - z0 ) / ( l_r1 - l_r0 )
        a = z0 - b * l_r0
        ncall = 1
      endif
c
      z = a + b * dlog10( r )
c
      return
      end

      real*8 function logAo( rdist )
c
c ...... -logAo attenuation function
c
      implicit none
      real*8 rdist, logAo
c
      logAo = 1.11d0 * dlog10( rdist ) +
     1    0.00189d0 * rdist + 0.591d0
c
      return
      end
```

California Integrated Seismic Network (CISN) Local Magnitude Determination in California and Vicinity

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By

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Electronic supplement versions of the appendices and programs for calculating new SNCL dMLs and ML is at URL: www.ncedc.org/ftp/outgoing/CISN_ML.

Abstract

Determining local magnitude (M_L) in a manner that is uniform and internally consistent ~~manner~~ for earthquakes ~~that occur in~~throughout California and vicinity is an important~~one~~ component of the California Integrated Seismic Network (CISN). We ~~developed~~ present a new local magnitude attenuation function and corresponding station adjustments that are valid throughout California. The new attenuation function is an analytic function of the radial hypocentral distance between 1 and 500 km. ~~, and corresponding s~~Associated station adjustments are also available for 1185 horizontal seismometer and accelerometer channels ~~(described by Station-Network-Channel-Location, or SNCL, codes)~~ from five seismic networks ~~that are currently~~ operating in California. -The new attenuation function and adjustments provide several advantages to CISN: They allow ~~computation o~~a more robust ~~fof more robust~~ M_L' computations~~;~~, the M_Ls ~~which~~ are more consistent between northern and southern California than they have been in the past;~~,~~ and because adjustments are now available for more SNCLs, M_Ls can be computed for

smaller earthquakes in more locations than was than were previously amenable to M_L computation possible. In addition to describing our method for calibrating the new CISN M_L, we also present a tool for adding adjustments for new or upgraded stations.

Introduction

Since Richter (1935) and Gutenberg and Richter (1942) developed the local or Richter magnitude (M_L) scale for earthquakes in Southern California using records from Wood-Anderson (WA) seismographs, M_L has been used to describe earthquake sizes in the catalogs of both Northern ~~(BK network)~~ and Southern California ~~(CI network)~~. To maintain historical consistency, it is important to continue to report local magnitude. Different amplitude decay functions (-logA_0) have, however, ~~long~~ been used for some time in each region (Uhrhammer et al., 1996, Kanamori et al., 1999). With each change in instrumentation and each addition of a station, careful calibration procedures were necessary to ensure catalog continuity. ~~In the past decade~~Now, many digital broadband stations and strong motion stations have been added to the networks in both Northern and Southern California, but have not yet been calibrated. ~~During the same interval, t~~The institutions charged with monitoring earthquakes in the State of California,~~,~~ the Seismological Laboratories of the University of California Berkeley (UCB), ~~and~~ the California Institute of Technology (Caltech), and the United States Geological Survey offices in Menlo Park and Pasadena (USGS-MP and USGS-P), have ~~have~~ joined capabilities as the California Integrated Seismic Network (CISN) to provide earthquake information to various agencies and institutions, and to the public. The need to include the new stations in M_L determination and the desire to unify magnitude reporting ~~throughout the state~~ led to this project to define a ~~new~~ -logA_0 function that is valid throughout the entire state, and to determine associated channel adjustments for horizontal channels from both broadband and strong motion sensors.

~~Our goal i~~In our~~the~~ analysis~~ was~~ to provide an historically consistent, state-wide method for determining the local magnitude of earthquakes, we opted ~~that occur in or near California that are consistent with historical values and which are applicable throughout the state. A ~~not to ~~calibration ~~use~~ing~~ absolute magnitudes for the calibration. ~~was not advisable, as it~~An absolute calibration would require the~~an~~ arbitrary selection of one site as the "origin". ~~Thus~~Instead, we chose a differential approach in which the differences in “local magnitudes” for a suite of earthquakes for each possible pair of channels (excluding channels oriented the same direction at a station) were inverted in two steps.~~ The dataset for the inversion consisted of "Wood-Anderson amplitudes" measured from events distributed more or less evenly in California and in neighboring regions. Rather than inverting these amplitudes directly, they were converted to "local magnitudes", and the differences in these local magnitudes for each possible pair of channels were inverted. The inversion took place in two steps.~~ First, a new state-wide $-\log A_0$ function wa~~wa~~s determined. For this inversion $-\log A_0$(100 km) was constrained to be 3.0, to match Richter’s (1935) original definition. In addition, the sum of dM_L(SNCL) for a set of stations that have been operating for most of the catalog interval was constrained to match their historical sum. In the second step, channel adjustments we~~we~~re calculated for ~~each~~ all horizontal components, both those of ~~the ~~broadband seismometers and of accelerometers. ~~Each component is identified by its SNCL (Station-Network-Channel-Location) Code. For the inversion $-\log A_0$(100 km) was constrained to be~~

3.0, to match the original definition by Richter (1935). In addition, the sum of dM_L(SNCL) for a set of stations that have been operating for most of the catalog interval was constrained to match their historical sum, 6 SNCLs from Northern and 9 SNCLs from Southern California:

$$-0.943 = dM_L(PAS.E) + dM_L(PAS.N) + dM_L(BAR.N) + dM_L(MWC.E) + dM_L(MWC.N) + dM_L(PLM.E) + dM_L(PLM.N) + dM_L(RVR.E) + dM_L(RVR.N) + 1.5\,(dM_L(BKS.E) + dM_L(BKS.N) + dM_L(BRK.E) + dM_L(BRK.N) + dM_L(MHC.E) + dM_L(MHC.N))$$

Candidate Earthquakes

A list of candidate earthquakes was developed from the ANSS on-line earthquake catalog (http://www.ncedc.org/anss/catalog-search.html) for 2000 through 2006. This catalog provides a composite list that which includesing both Northern and Southern California events. To achieve a relatively uniform coverage of event-station pairs, California and the neighboring regions were divided into grid squares of 50 km by 50 km (see Figure 12). From each square, two events were selected, if possible: the largest event with $M_L \geq 3$ in the interval 2000-2006, and the largest earthquake with $M_L \geq 3$ from the year 2006. The requirement that the candidate events have $M_L \geq 3$ ensured that each event has a good signal to noise ratio at many stations. The events from 2006 were added to provide more data from recently installed stations and from the Transportable Array stations of the USArray (http://www.usarray.org/), a component of the Earthscope project (http://www.earthscope.org/) funded by the National Science Foundation. If the largest earthquake in any grid square took place in 2006, then the second largest event from 2000 – 2006 ~~that occurred in the~~from that grid square was ~~also~~ added to the set. This procedure netted 253 candidate earthquakes (Appendix A, Figure 1~~2~~).

Candidate Horizontal Channels (SNCLs)

In 2006, five networks operated broadband and strong motion seismic stations in California that contributed to real-time earthquake monitoring:

- The Anza network operated by the University of California San Diego (abbreviation ANZA, network code AZ).
- The Berkeley Digital Seismic Network operated by UCB (BDSN, BK).
- The Southern California Seismic Network operated by Caltech and the USGS-P (SCSN, CI).
- The Northern California Seismic Network operated by the USGS-MP (NCSN, NC).
- The Transportable Array operated by the USArray component of Earthscope (USArray, TA).

From these networks, a list of 1230 candidate broadband and strong motion horizontal channels (each designated by ~~their~~ its station-network-channel-location code or SNCL~~s~~) was compiled (Figure 1~~2~~, ~~and~~ Appendix B). All ~~these~~ channels are recorded digitally with high resolution (24-bit integer) at sampling rates of 20 to 100 samples per second~~) with high resolution (24-bit integer)~~. ~~, and their d~~Data ~~are available and~~from the SNCLs were acquired as described in the Data Sources section below.

Candidate Waveforms

We compiled a list of candidate waveforms by reviewing the following criteria each combination ofGiven the candidate earthquakes and candidate SNCL.s, a list of candidate waveforms was compiled, which met the following selection criteria:

- Is the distance from the hHypocenter to station distance ≤ 700 km?.
- Is the tTheoretical maximum trace amplitude for the event on a Wood-AndersonWA seismograph maximum trace amplitude ≥ 0.03 mm.

These criteria were chosen to select for good signal to noise ratio. Approximately 100,000 waveforms met all criteria and were extracted for this study. The time window for the data extracted from the archives for associated with each waveform startedwas from 30 seconds prior to the theoretical P-wave onset and ended to 60 sthe time after for a 2 km/sec wave wouldto have arrived at the station + 60 seconds. Approximately 100,000 waveforms were extracted for this study.

Data Processing

Prior to decommissioning the last ~~BK network~~ WA ~~instruments~~ seismographs with photographic recording in the BK network of northern California in early 1993, we demonstrated that equivalent, synthetic ~~Wood-Anderson~~WA ~~record~~seismograms ~~(WAS)~~ could be ~~accurately be~~ generated accurately from ~~the~~ digitally recorded broadband or strong motion waveforms via convolution ~~with an empirically determined WA transfer function~~ (Uhrhammer and Collins, 1990; Uhrhammer et al., 1996). The empirically determined WA transfer function is equivalent to an inertial pendulum with a free period of 0.8 seconds, a damping coefficient of 0.7 critical and a static magnification of 2080. It is important to note that the value for the WA static magnification is 2080 and not 2800 as originally reported by Anderson and Wood (1925) and commonly used since that time. While this difference is unimportant when using amplitudes measured from the original WA sensors, it is crucial when producing synthetic WA seismograms. If the correct magnification value is not used, M_L estimates will be biased low by 0.129 M_L. The error apparently occurred because Anderson and Wood (1925) incorrectly assumed that the taut-wire suspension used in the WA sensor did not deflect from a straight line. The deflection is actually sufficient to increase the polar moment of inertia and lower the static magnification by approximately 30 percent (Uhrhammer and Collins, 1990). Theoretically, the synthetic WA seismic record~~amplitude~~s have approximately ~~an~~ 80 dB greater dynamic range than ~~the range of amplitudes that~~ can be measured on a photographic W~~ood-Anderson~~A seismogram. In practice, however, the difference is closer to 44 dB. ~~owing to the limitations of t~~The seismic background noise limits resolution at low signal amplitudes ~~on the low end~~ and the linearity of the sensors limits it at~~on the~~ high ~~end~~amplitudes. ~~The transfer function is equivalent to an inertial pendulum with a free period of 0.8 seconds, a damping coefficient of 0.7 critical and a static magnification of 2080. It is important to note that the value for the WA static magnification is 2080 and not 2800 as originally reported by Anderson and Wood (1925) and commonly used since that time. While this difference is unimportant when using amplitudes measured from the original WA sensors, it is crucial when generating synthetic Wood-Anderson seismograms (WAS). If the correct magnification value is not used, M_L estimates will be biased low by 0.129 M_L. The error apparently occurred because Anderson and Wood incorrectly assumed that the taut-wire suspension used in the WA sensor did not deflect from a straight line. The deflection is actually sufficient to increase the polar moment of inertia and lower the static magnification by approximately 30 percent (Uhrhammer and Collins, 1990).~~

For an important reason, we produced our own set of WA amplitudes, starting with the raw data, rather than using WA amplitudes extracted from the Northern and Southern California event catalogs for the selected events and SNCLs. For several years, the WA amplitudes have been calculated using different algorithms in each part of the state (Uhrhammer et al 1996, Kanamori et al 1999). For the analysis to be valid, it required that the WA amplitudes be determined in a uniform way, producing a consistent set for comparison.

For our analysis, each time series was preprocessed in the time domain before being converted to a synthetic WA seismogram in the frequency domain. The mean was removed from each record, and it was ~~response, by removing its mean and~~ windowed~~ing~~ to minimize contamination of the data by spurious amplitudes. The preprocessed waveforms for each earthquake were (1) converted to the frequency domain using a FFT, (2) filtered using a 0.5–10 Hz, 6-pole Butterworth band-pass filter; (3~~2~~) transformed into a synthesized WA seismogram by deconvolution of the instrument response and the convolution with the empirical WA transfer function~~S~~ (Uhrhammer et al, 1996); (4) transformed into the time domain; and (5~~3~~) automatically scanned to pick the maximum trace amplitude, ~~(~~A~~)~~. All the WA maximum amplitudes, A, were indexed by SNCL and event, and stored in a file for further processing. —The b~~B~~and-pass filter was applied to~~ing~~ reduce~~moved~~ contamination of the waveforms by microseisms or surface waves at low frequencies, and by noise spikes at high frequencies. Figure 2 shows an example of the waveform processing for a local event riding on the surface waves of the M_w 8.8, 27 February 2010, Maule earthquake in Chile. The waveform for this M_L 2.7 local earthquake which occurred 66 km north of the recording station ORV is nearly invisible in the original record, but has a good signal to noise ratio after the waveform processing. It is our experience that the frequencies associated with the maximum trace amplitudes recorded by~~on~~ standard ~~Wood-Anderson~~WA torsion seismograph~~am~~s predominantly occur in the 2–4 Hz frequency band and rarely at frequencies either below 1 Hz or above 6 Hz.

Data from the amplitude file~~s~~ was~~ere~~ again winnowed ~~subjected to~~using ~~separate~~

period and amplitude criteria that depended on whether the data came from a ~~for the~~ broadband sensor~~s~~ or~~and~~ f~~o~~rom a~~ the~~n accelerometer~~ strong motion sensors~~. The period selection criteria effectively rejected data contaminated by low frequency waves or glitches. The amplitude criteria ensured that the WA~~S~~ maximum trace amplitudes were unlikely to be due to noise and ~~, but~~ also that the sensor was responding linearly to the ground motions (i.e., the feedback electronics~~ SNCL~~ was not ~~probably not~~ saturated or clipped)~~clipped~~. For the broadband sensors ~~the WAS amplitude~~A was required to be in the range 0.3 mm to 650 mm;~~, and~~ for ~~strong motion sensors~~accelerometers the range~~it~~ was 3 mm to 12000 mm. The maximum WA~~S~~ trace amplitudes that met these selection criteria were used in the subsequent analysis.

Initial Analysis: The differential dataset and -logA_0(r)

The differential dataset inverted is not formed directly from differences of the maximum WA trace amplitudes, A, but by differences of M_L determined from A. To do this, we f~~F~~undamentally~~, we~~ followed the procedures for determining M_L originally defined by Richter (1935), with one change. To determine the attenuation function, ~~as the basis for determining the new attenuation function and corresponding station adjustments.~~ Richter~~'s~~ ~~original M_L scale~~ relied on the determination of the epicentral distance from the earthquake to the station, and~~, and the measurement of the maximum WA trace amplitude. Richter~~ assumed the event's~~'~~ hypocentral depth~~s~~ to be 15 km, a more or less reasonable average value for Southern California~~, when determining the attenuation function~~. This ~~subsequently~~ biased magnitudes measured at short hypocentral distances, where ~~the~~ M_L is overestimated. For the formulation of the CISN attenuation function, we adopted the use of hypocentral distance (r) rather than epicentral distance to facilitate the accurate determination of M_L at close distances.

Local magnitude for a given channel is thus defined as:

$$M_L = \log(A) - \log A_0(r) + dM_L \qquad (1)$$

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where ~~-~~A is the maximum WA trace amplitude, measured in mm, r is the hypocentral distance in km, and dM_L is the station or SNCL adjustment. Given the hypocentral distance for each earthquake-SNCL pair, we calculated the M_L corresponding to the WA~~S~~ maximum trace amplitude, A, using the analytical attenuation function derived from Richter's (1935) attenuation function (Kanamori et al., 1993):

$$-\log A_0(r) = 1.11 * \log(r) + 0.00189 * r + 0.591 \qquad (2)$$

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Then, for each earthquake *i*, w~~W~~e ~~then~~ determined the differences between ~~all~~ the ~~different~~ M_L estimates for all SNCLs, ~~(~~*j*, *k*,~~)~~ (j≠k) that recorded that earthquake~~for a given earthquake, *i*~~:

$$\Delta M_{L i,jk} = M_{L i,j} - M_{L i,k}, \qquad (3)$$

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The result was a differential dataset with approximately 11.6 million observations for all earthquakes and SNCLs. This differential M_L data set was used in the ~~subsequent~~ inversions. The primary advantages of using a differential data set are that the "true" M_L of the earthquakes need not be known, and that all observed differential M_L's contribute to the solution.

Subsequently, we performed a number of inversions using a constrained least-squares method to solve simultaneously for various discrete and analytical forms of perturbations to the analytical attenuation function (equation 2), and for corresponding SNCL dM_Ls. Only one constraint was supplied for the attenuation function in all inversions. We required that $-\log A_0(r=100km) = 3.0$ to conform to Richter's (1935) original concept that a M_L 3 earthquake will have a maximum WA trace amplitude of 1 mm at a distance of 100 km. Various ~~different~~ constraints for the station adjustments were testedried, generally using combinations of selected BK and CI network stations for which historical dM_Ls existed. Both regional (Northern and Southern California) and global (statewide) perturbations to the attenuation function were determined along with the corresponding SNCL M_L adjustments.

After numerous inversions it was found that the simplest attenuation perturbation function form that fit the observed data statewide, in a constrained least-squares sense, was a linear combination of the initial analytic function (Equation 2) and a sixth order Chebyshev polynomial (Figure 3). The form for the new $-\log A_0(r)$ function is:

$$-\log A_0(r) = 1.11\log(r) + 0.00189r + 0.591 + TP(n)T(n,z) \qquad (4)$$

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Where n is summed from 1 to 6. The TP(n) coefficients are:

TP(1) = +0.056,

TP(2) = -0.031,

TP(3) = -0.053,

TP(4) = -0.080,

TP(5) = -0.028,

TP(6) = +0.015,

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And z is the scale transformation of r:

z(r) = 1.113609525 * log(r) – 2.00574 0.041593

(5)

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that transforms (8≤r≤500) to (-1≤z≤+1) and T(n,z) is the Chebyshev polynomial:

$$T(n,z) = \cos(n*\text{acos}(z)). \qquad (6)$$

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This form of $-\log A_0(r)$ was found to provide a robust fit to the decay of earthquake amplitude as a function of hypocentral distance between 810 km and 500 km (Figure 3). In this case, robustly means that the good fit was relatively independent of the constraints on dM_L -and that this $-\log A_0(r)$ formulation ultimately resulted in a fifty percent variance reduction. At hypocentral distances greater than 500 km, there were only few differential amplitude values. This is mainly due to the fact that only few of the events included in the analysis had magnitudes greater than 5 and, thus, measurable amplitudes at great distances. Thus, we capped the definition of $-\log A_0(r)$ at 500 km. Likewise, for hypocentral distance less than 8 km there were only a few differential amplitude values. For hypocentral distances shorter than 8~~10~~ km, the average slope of $-\log A_0(r)$ between 8 km and 60 km was linearly extrapolated to 0.1 km. The resulting $-\log A_0(r)$ at distances less than 8 km is lower than either Richter's (1935) or Kanamori's (1999) $-\log A_0(r)$ and it produces consistent M_L estimates with smaller variances at short hypocentral distances. Thus both broadband and strong motion estimates of M_L at short distances will be more reliable and also that M_L can be reliably calculated for smaller earthquakes recorded at short distances.

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The FORTRAN function given in Appendix C implements the above algorithm, and has been adopted for the ~~statewide~~ CISN $-\log A_0(r)$ attenuation function.

Subsequent Analysis: Station (component) adjustments or dM_L

After adopting the ~~new statewide~~ CISN $-\log A_0(r)$, we focused on determining the set of channel adjustments most consistent with past practices in Northern and Southern California. The dM_L (SNCL) were determined using a linear least-squares fit. We discussed and tested a large suite of constraints before settling on one. We agreed that the sum of dM_L(SNCL) for a set of stations that have been operating for most of the catalog interval (60+ years) should be constrained to match their historical sum. For Southern California 9 SNCLs were chosen that had been operating WA instruments and are now equipped with broadband seismometers (PAS.CI.HHE, PAS.CI.HHN, BAR.CI.HHN, MWC.CI.HHE, MWC.CI.HHN, PLM.CI.HHE, PLM,CI.HHN, RVR.CI.HHE and RVR.CI.HHN). Northern California only had 3 WA stations that now host broadband seismometers, with 6 SNCLs (BKS.BK.HHE, BKS.BK.HHN, BRK.BK.HHE, BRK.BK.HHN, MHC.BK.HHE and MHC.BK.HHN). ~~(~~MIN.BK, which housed WA and broadband seismometers, was closed prior to 2000.~~), and 6 SNCLs (BKS.BK.HHE, BKS.BK.HHN, BRK.BK.HHE, BRK.BK.HHN, MHC.BK.HHE and MHC.BK.HHN).~~ To maintain equal weighting for Northern and Southern California, the sum for the BK SNCLs was multiplied by 1.5. The final constraint equation was:

$$
\begin{aligned}
-0.943 = {} & dM_L(PAS.CI.HHE) + dM_L(PAS.CI.HHN) + dM_L(BAR.CI.HHN) + \\
& dM_L(MWC.CI.HHE) + dM_L(MWC.CI.HHN) + dM_L(PLM.CI.HHE) + \\
& dM_L(PLM.CI.HHN) + dM_L(RVR.CI.HHE) + dM_L(RVR.CI.HHN) + \\
& 1.5 *((dM_L(BKS.BK.HHE) + dM_L(BKS.BK.HHN) + \\
& dM_L(BRK.BK.HHE) + dM_L(BRK.BK.HHN) + dM_L(MHC.BK.HHE) + \\
& dM_L(MHC.BK.HHN)).
\end{aligned}
$$

~~The map in~~ Figure 1~~2~~ shows and Appendix B lists the stations for which dM_L(SNCL) were adopted in the CISN. At each site, the dM_L for a given orientation (i.e. N or E) is valid for all components with that orientation. For example, the same dM_L value applies for adjusting WA amplitudes measured on the East components of the broadband seismometer and of the accelerometer at BKS.BK. In a second round of calculations, dM_Ls were determined for sites that had only accelerometers. The currently valid dM_Ls are available in the online material.

New SNCL calibration

When a new broadband/strong motion station is installed in California, the new SNCL dM_L adjustments can be determined once a sufficient number of local/regional earthquakes thatwhich meet the amplitude selection criteria have been recorded and WA amplitudes collected. To obtain robust dM_L estimates, we recommend using at least 30 observations per SNCL and also that the dM_L and its uncertainty be calculated using median statistics of the differential M_L residuals. Thus, once sufficient data are available from a new SNCL, its dM_L adjustment can be determined using the observed differences between the new SNCL dM_L estimates and the corresponding M_L estimates from stations with known dM_L. We provide a subroutine and instructions for this procedure in the online material.

CISN M_L and dM_L Validation

We performed several validation exercises for CISN M_L, three of which are shown and discussed here (Figure 4). We did not compare M_Ls from the catalogs for the events used here with CISN M_Ls determined from the WA amplitudes used in this study. There were two main reasons for this. First, the sets of stations used for the catalog M_Ls was almost certain to be different than the sets we used. Second, the method for calculating the WA amplitudes differed, at least for Southern California (Kanamori et al, 1999). We consider it important that the WA amplitudes used for these M_L comparisons be calculated in the same way. Thus, the network M_Ls shown in Figure 4 were calculated using WA amplitudes determined in this study.

The first pair~~set~~ of comparisons allows ~~was~~ the~~done to~~ ~~determine~~ evaluation of how "old" M_Ls, for Northern and Southern California respectively, compare~~d~~ with the "new" values (Figure 4a,b). To allow the comparison, ~~Since both types of M_L have similar uncertainties, the best-fit line is determined using a bi-linear regression, which minimizes inverse-variance weighted normal distances from each datum to the least-squares fit line. The "network M_L" is the median value, and the uncertainties are proportional to the inverse of the number of SNCLs contributing to the M_L value.~~ "old" network M_L ~~Amplitudes~~ values were determined for~~for~~ events with data from ~~Southern~~ Northern California (BK, NC, some TA) stations. They are ~~(Caltech stations) were~~ calculated~~converted~~ from the WA amplitudes used in this study, ~~to M_L~~ using~~,~~ the former ~~Caltech~~ Berkeley -logA_0(r) and dM_L (Uhrhammer et al., 1996)~~(Kanamori et al, 1999) was used to determine the "old" values for the network M_L~~. The same was done ~~Likewise, amplitudes~~ for events with data from ~~Northern~~ Southern California (CI, AZ, some TA stations)~~(Berkeley stations)~~, but ~~were converted to M_L using~~ the former Caltech~~Berkeley~~ -logA_0(r) and dM_L (Kanamori et al, 1999) ~~(Uhrhammer et al., 1996)~~ we~~w~~re~~as~~ used ~~to determine the "old" values for the network M_L~~. Then~~In both cases~~, the "old" M_L ~~ML~~ values we~~we~~re regressed against the network ~~corresponding~~ CISN M_L ~~ML~~ values derived from the same WA amplitudes using the CISN $-\log A_0(r)$ and dM_L~~.~~ (Figure 4a,b). The network M_L is always taken to be the median value, and the uncertainties are proportional to the inverse of the number of SNCLs contributing to the M_L value. Since the different types of M_L have similar uncertainties, the best-fit line is determined using a bi-linear regression, which minimizes the inverse-variance weighted, normal distances from each datum to the least-squares fit line. For both ~~these examples~~the Northern and Southern California comparisons (Figure 4a,b), the slopes and intercepts of the best-fit lines are one and zero, respectively, to within the uncertainties. This indicates that given a consistently determined set of WA amplitudes, magnitudes determined in Northern and Southern California using CISN M_L ~~will be~~are consistent, overall, with the local magnitudes determined in the past.

A second important goal toward which the CISN networks are striving ~~for~~ is that Northern California can reliably locate and determine magnitudes for big Southern California events and vice versa. Figure 4c shows a set of events for which WA amplitudes exist for both Northern and Southern California stations, and M_L values for each event have been determined using either only Northern or Southern California SNCLs. As before, t~~T~~he uncertainties are ~~again~~ proportional to the inverse of the number of ~~stations~~ SNCLs contributing to the magnitude. ~~In this case, they are not the same for the NC and SC MLs, as there are~~ As there are u~~u~~sually more Southern California ~~stations~~ SNCLs contributing to ~~the~~ a magnitude, the uncertainty on the Southern California M_L is generally smaller than on the Northern California M_L~~s~~. Although the scatter is larger for this set of magnitudes, overall, the slope of a bi-linear-fit line and its intercept are again one and zero, respectively. This indicates that Northern California magnitude estimates for Southern California events match, on average, and vice versa. These two validation exercises show that the goal of unifying local magnitude reporting for Northern and Southern California has beenis satisfied.

Discussion

For historical consistency, it is important to continue to report local magnitude, as that is our connection with old catalogs. –We have shown that unbiased and internally consistent measurement of local magnitudes can be determined for earthquakes occurring throughout California and vicinity.

The CISN magnitude strategy is to provide a uniform and robust methodology for determining the local magnitude of earthquakes that occur throughout California. The determination of local magnitude continues to fill an important role for two primary reasons; 1) it provides for continuity in determination of the size of earthquakes in historical seismicity catalogs that are used for determining the rate of seismicity and the earthquake hazard; and 2) it provides a uniform and internally consistent measure of earthquake size over a broad range of ground motions.

M_L for historical earthquakes can be recalculated using the new algorithm, as far back in time as a sufficient number of digital broadband stations existed. The broadband seismometers, some of which have operated since 1986, provide a large amount of waveform data from which to compute synthetic Wood-Anderson amplitudes, and perform the CISN calibration procedure. This effort will provide improved continuity with the older data and prevent an unnecessary discontinuity in the earthquake catalogs. Other magnitudes used such as duration magnitude M_d may then be recalibrated to match the revised M_Ls.

The CISN -logA_0(r) and corresponding SNCL adjustments, dM_L-, determined in this study result in more robust estimates of M_L with less scatter*****. The variance ofvariance of the M_L estimates is reduced by by approximately a factor of two and the corresponding uncertainty in the M_L estimates is reduced from ±0.19 to ±0.14 when using the CISN methodology compared to the original methodologies employed separately by Northern and Southern California. The uncertainty in the CISN ML estimates is limited by the innate uncertainty in ML when amplitude variations caused by source radiation pattern and lateral crustal structure are not taken into account. In addition, M_L estimates at short distances (<20 km) using the CISN -logA_0(r) are much more robust owing to: 1) the incorporation of hypocenter distance (r) in place of epicenter distance (Δ), and; 2) the large amount of short hypocenter distance data available for determining the -logA_0(r). Also, there are no significant differences between M_L determined by Northern and Southern California earthquake data subsets. Thus previously noted differences between magnitudes computed in northern and southern California, for the same earthquakes, have been largely removed.

Magnitudes of very small earthquakes (<1.5) are substantially smaller with the CISN method than previous estimations, due to the revised attenuation function for very close distances, and also due to the high-pass filter used, which excludes much of the energy from microseisms and teleseisms from the amplitude computation. These improvements, along with the ability of the data processing software “Jiggle” (URL: pasadena.wr.usgs.gov/jiggle/) to interactively select seismogram segments for amplitude computation, allows M_L to be estimated for much smaller earthquakes than was previously possible~~,~~ in ~~dense areas of~~ areas where the networks are dense~~, that was previously possible~~. In practice, the lower bound for robust M_L estimation is limited by the hypocental distances to the proximal stations and by the size of the SNCL dMLs and it is unlikely to be much below +1.0, say.

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For consistency with Richter’s original methodology and simplicity in the calculations, scatter in M_L due to radiation pattern was not included in this analysis. Inclusion of the radiation pattern when determining M_L in Northern California indicates that there is a slight difference in attenuation and/or SNCL dM_L adjustments between paths that are parallel to and perpendicular to the crustal structure in Northern California.

The most robust estimates of dM_L(SNCL) are obtained using either mean statistics with outliers removed when large numbers of observations are available or median statistics when the data set is small (less than 30 observations~~, say~~) since it is insensitive to outliers.

The improved M_L calibration using the CISN -log$_0$(r) and dM_L results has produced a corresponding improvement in M_L determinations throughout the State. In Southern California, where M_L is attempted for all events, approximately 90 percent of the locatable events now have a M_L. For the remaining Southern California events, the data fail the acceptance criteria. In Northern California, M_L has in the past only been applied to events with M_d > 3, mainly due to the sparse network of broadband stations. Now, with many more "M_L qualified" stations available because of the calibration, the threshold for M_L has decreased. In the near future, we will review whether we may calculate M_L for small events, too.

~~The improved M_L calibration using the CISN -logA_0(r) and dM_L results in approximately 90 percent of the locatable events having a M_L and the data for the remaining events fail the acceptance criteria.~~

Other networks in the western US will benefit from this study if they used the same methodology and cross-calibrate with CISN to produce a uniform and internally consistent estimation of local magnitude across the entire region. A significant question is whether or not the CISN attenuation function is applicable throughout the western US. We suspect that the CISN attenuation function will be applicable in Oregon, ~~and~~and ~~-~~Washington (Qamar et al., 2003) and off Canada's west coast (Ristau et al., 2003) and possibly~~but not~~ in the basin and range province in Nevada (Savage and Anderson, 1995). However, Uhrhammer et al., 1996 found that Berkeley M_L estimates of earthquakes occurring in the basin and range province were small by ~0.4 M_L when compared to the University of Nevada, Reno (UNR)

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determined M_L and that not all of the difference could be explained solely by differences in the attenuation model.

Data Sources

The events analyzed in this study were selected from the ANSS Composite Catalog (URL: www.ncedc.org/cnss).

BK, NC and northern California TA network waveforms were requested as SEED data volumes (URL: www.iris.edu/manuals/SEEDManual_V2.4.pdf ~~www.iris.edu/manuals/SEEDManual_V2.4.pdf~~) from the Northern California Earthquake Data Center (NCEDC; URL: www.ncedc.org ~~http://www.ncedc.org~~) which is located at the Berkeley Seismological Laboratory (URL: www.seismo.berkeley.edu ~~http://seismo.berkeley.edu~~) at the University of California, Berkeley. The data were requested via NetDC (URL: www.iris.edu/manuals.netdc ~~http://www.iris.edu/manuals/netdc~~). Miniseed and response data were extracted via rdseed (URL: www.iris.edu/manuals/rdseed.htm ~~http://www.iris.edu/manuals/rdseed.htm~~). The NetDC requests returned about 50,000 waveforms.

AZ, CI and southern California TA network waveforms were requested in miniseed format from the Southern California Earthquake Data Center (SCEDC; URL: www.data.scec.org~~http://www.data.scec.org~~) that~~which~~ is located at the Southern California Earthquake Center (SCEC; URL: www.scec.org~~http://www.scec.org~~) at the

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University of Southern California. The data were requested via STP (URL: www.data.scec.org/STP/STP_Manual_v1.01.pdf) http://data.scec.org/STP/STP_Manual_v1.01.pdf). The corresponding response information was extracted via rdseed from dataless SEED volumes downloaded from SCEC. The STP requests also returned about 50,000 waveforms.

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The TA network waveforms used in this study were all recorded locally at either the NCEDC or the SCEDC. The TA data are also available from their primary archive located at the Incorporated Research Institutions for Seismology (IRIS; URL: www.iris.edu) http://www.iris.edu).

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Some plots were made using the Generic Mapping Tools version 4.2.0 (URL: www.soest/hawaii.edu/gmt ; Wessel and Smith, 2007) http://www.soest.hawaii.edu/gmt ; Wessel and Smith, 2007).

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Acknowledgements

We acknowledge the support of this study by the California Integrated Seismic Network (CISN) (URL: www.cisn.org http://www.cisn.org), the US Geological Survey (USGS) (URL: www.usgs.govhttp://www.usgs.gov) and the California Office of Emergency Services Management Agency (CalEMAA OES) (URL: www.calema.ca.gov http://www.calemaoes.ca.gov).

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Figure Captions

Figure 1. This map shows the study area including candidate earthquakes (small gray circles), candidate stations with both broadband and strong motion sensors (large black circles) and the 50 km x 50 km grid (dotted lines) used for selecting the earthquakes. Stations with only strong motion sensors are not shown on the map for clarity, but their adjustments are given in the Appendix B. The colors of the vertical (N component) and horizontal (E component) lenses superimposed on the station symbols give the magnitude of the CISN SNCL adjustment (dM_L) as shown on the color scale. The magnitude of the CISN dM_L correlates with the competence of the soil/rock on which the station is sited. Hard rock sites have large positive dM_L values and very soft soil sites have large negative dM_L values. Stations in the region of the LA Basin are shown in the insert at a larger scale.

Figure 21. Example of waveform processing showing (a) the "raw" ORV.BK.HHE broadband data (a), (b) the corresponding synthesized Wood-Anderson ("SSWA)" data (b), and (c) the synthesized WA record band-pass filtered with a 0.2-10 Hz, 6-pole Butterworth band-pass filtered SWA data (c) (, to remove microseismic background and long-period surface wave signal contamination. The local event is a M_L 2.7 earthquake located 66 km North of ORV riding on the wavefield of the M_w 8.8, 27 February 2010.058 Mw 8.8 Maule Chile earthquake in Chile.

~~Figure 2. Small dots are locations of earthquakes and large dots are locations of stations used in this study. The colored crosses embedded in the large dots give the~~

magnitude of the CISN SNCL adjustment (dM_L) (see inset scale) with the vertical bar representing the NS component dM_L and the horizontal bar representing the EW component dM_L. The magnitude of the CISN dM_L correlates with the competence of the soil/rock on which the station is sited with the large positive dM_L corresponding to hard rock sites and the large negative dM_L corresponding to very soft soil sites.

Figure 3. Comparison of $-\log A_o(r)$ attenuation functions. the The CISN function was developed during this project; the other two have been used in, Caltech (Ssouthern California (Caltech; CI), and NBerkeley (northern California (Berkeley; UCB), respectively M_L $-\log A_o(r)$ attenuation functions. All three attenuation functions are constrained so that $-\log A_o(100km) == 3$. The CISN attenuation function is only valid to 500 km and at distances shorter than 8 km the function is an extrapolation of the average slope between 8 km and 60 km (see Appendix C).

Figure 4. Validation of CISN M_L. (a) Comparison of M_L determined for Northern California events using CISN M_L (horizontal axis) and UCB M_L (vertical axis). (b) Comparison of M_L determined for Southern California events using CISN M_L (horizontal axis) and CI M_L (vertical axis). (c) Comparison of CISN M_L for events determined using amplitude data from Northern California (horizontal axis) and from Southern California (vertical axis) SNCLs.

Shown are dData are shown for 96 selected earthquakes that occurred between 2000 and 2006. The linear regression $M_L(SC) = (1.000 \pm 0.034) M_L(NC) + (0.010 \pm 0.112)$ wasas determined using a bi-linear L1 norm and the standard error is

0.159. Thus there are no significant differences between M_Ls of earthquakes determined using NC and SC SNCL subsets and the CISN -logA_o(r) and corresponding CISN dM_L determined in this study.

Figure 1.

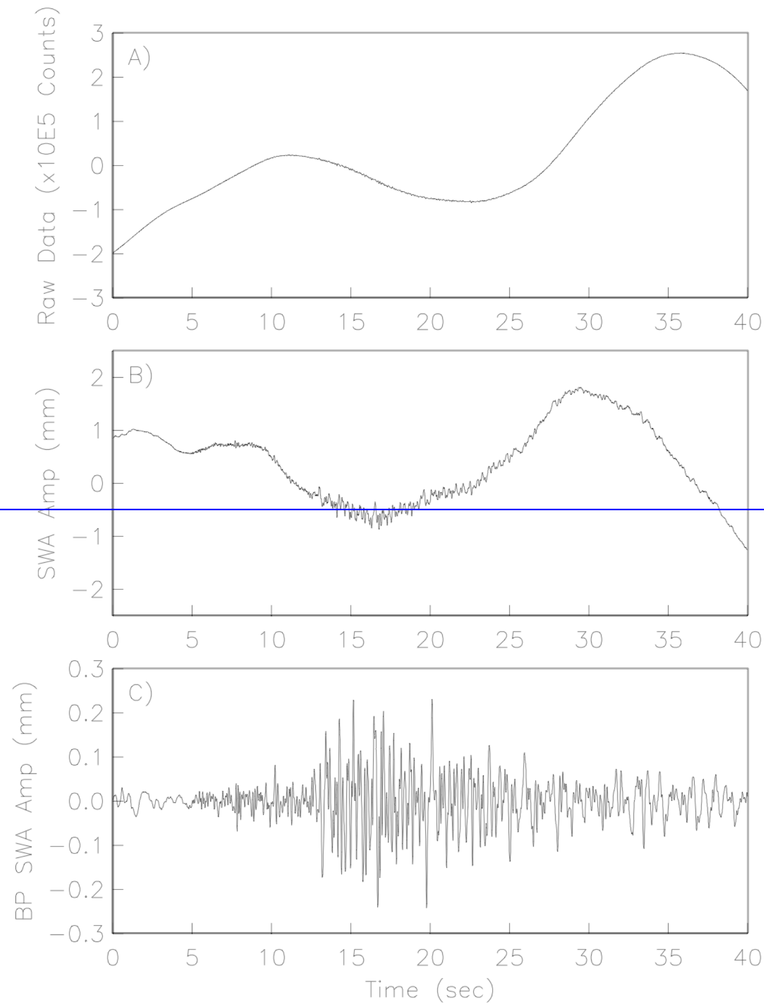
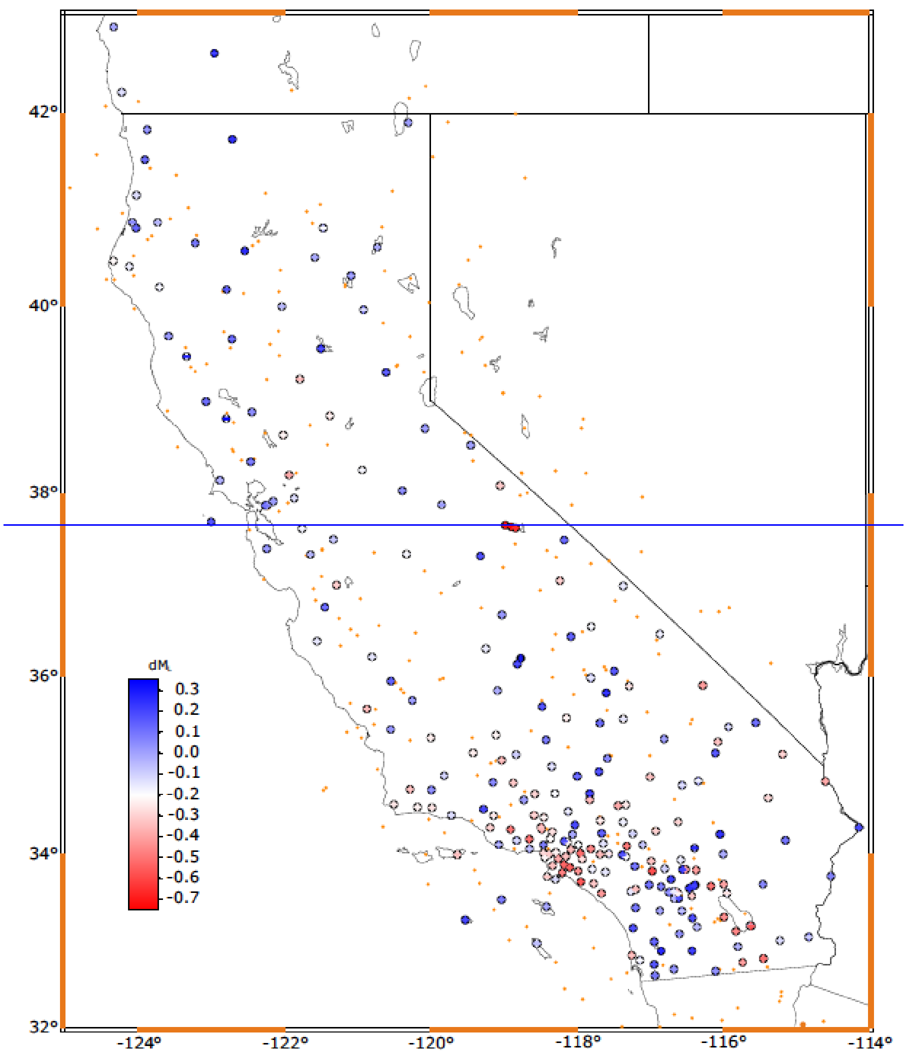


Figure 12.


42°
40°
38°
36°
34°
32°
-124°
-122°
-120°
-118°
-116°
-114°
dM
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7

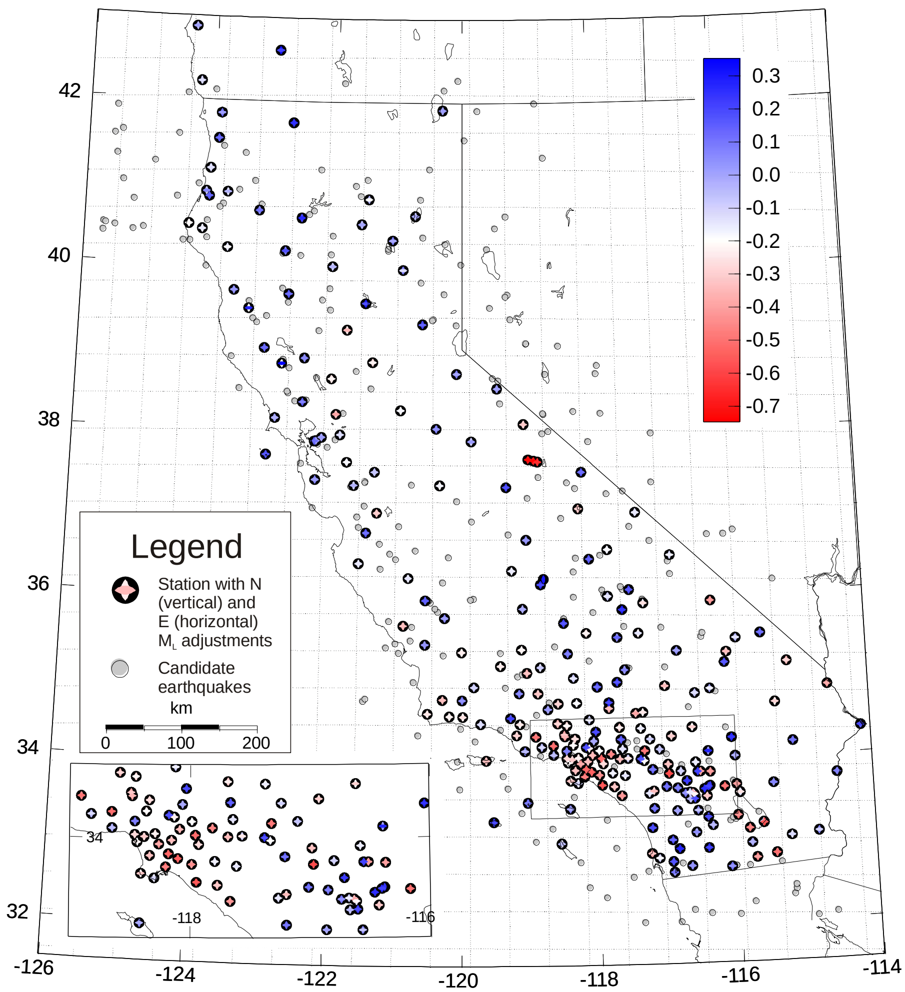

Legend
Station with N (vertical) and E (horizontal) M_L adjustments
Candidate earthquakes
km
0
100
200
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
42
40
38
36
34
32
-126
-124
-122
-120
-118
-116
-114
34
-118
-116

Figure 2.

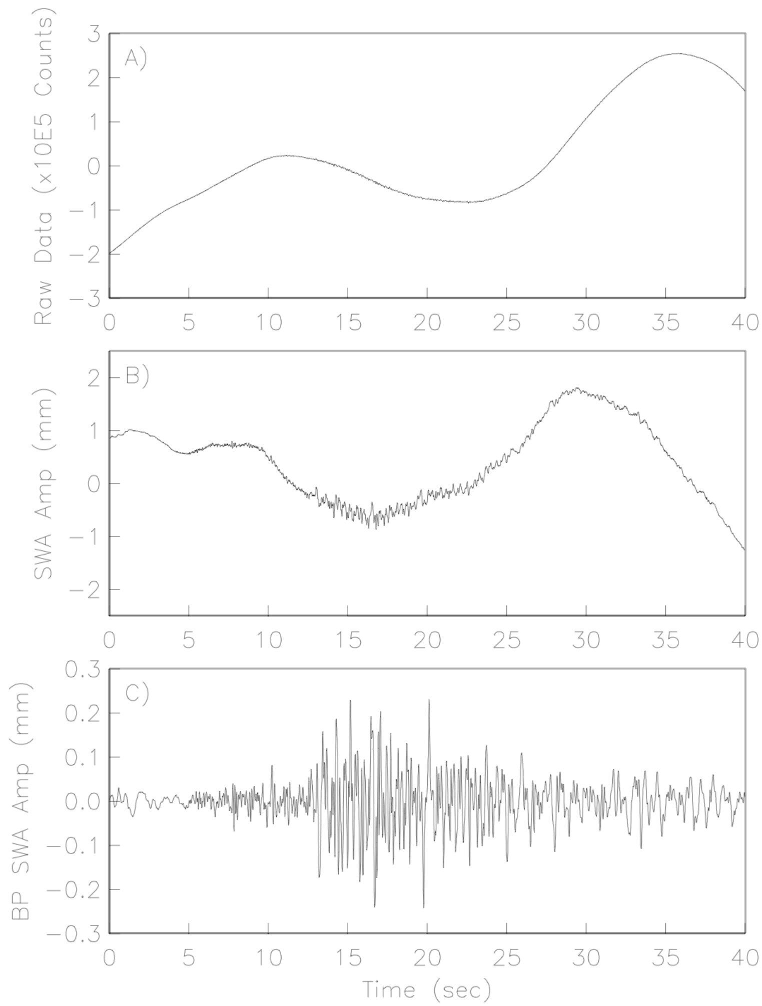
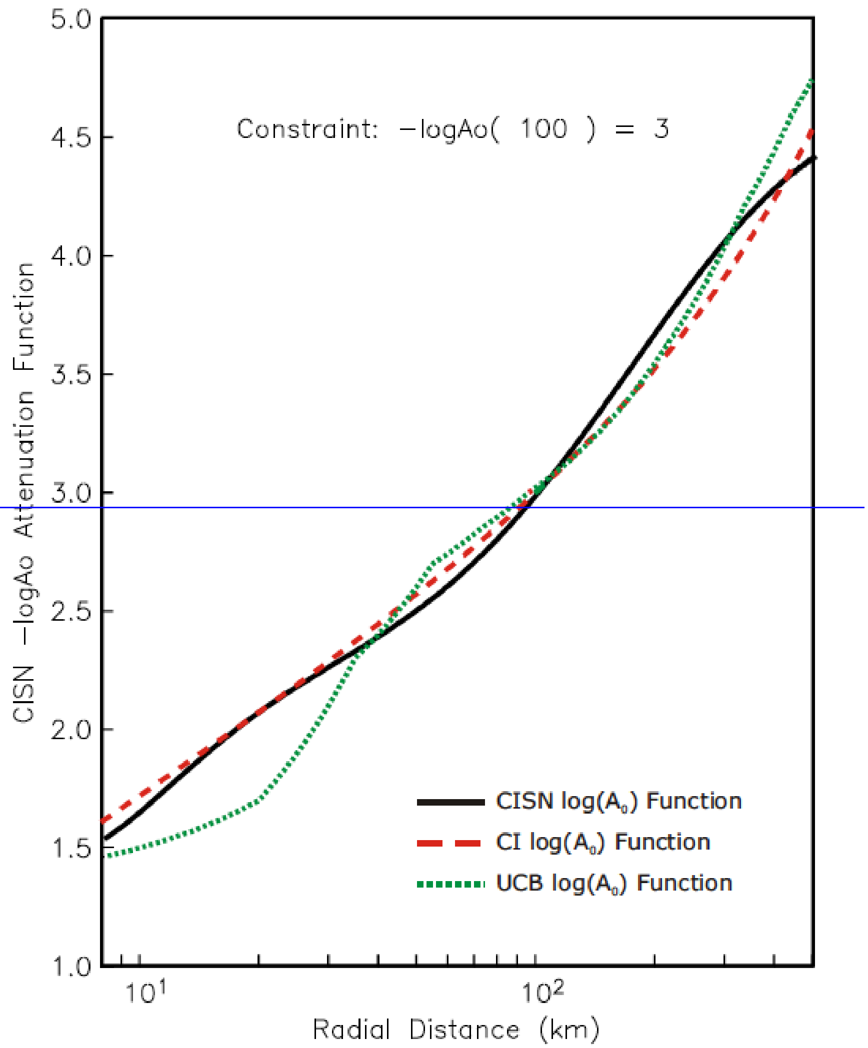

A)
Raw Data (x10E5 Counts)
3
2
1
0
−1
−2
−3
0 5 10 15 20 25 30 35 40
B)
SWA Amp (mm)
2
1
0
−1
−2
0 5 10 15 20 25 30 35 40
C)
BP SWA Amp (mm)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
0 5 10 15 20 25 30 35 40
Time (sec)

Figure 3.


5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
CISN −logAo Attenuation Function
Constraint: −logAo(100) = 3
CISN log(A0) Function
CI log(A0) Function
UCB log(A0) Function
10¹
10²
Radial Distance (km)

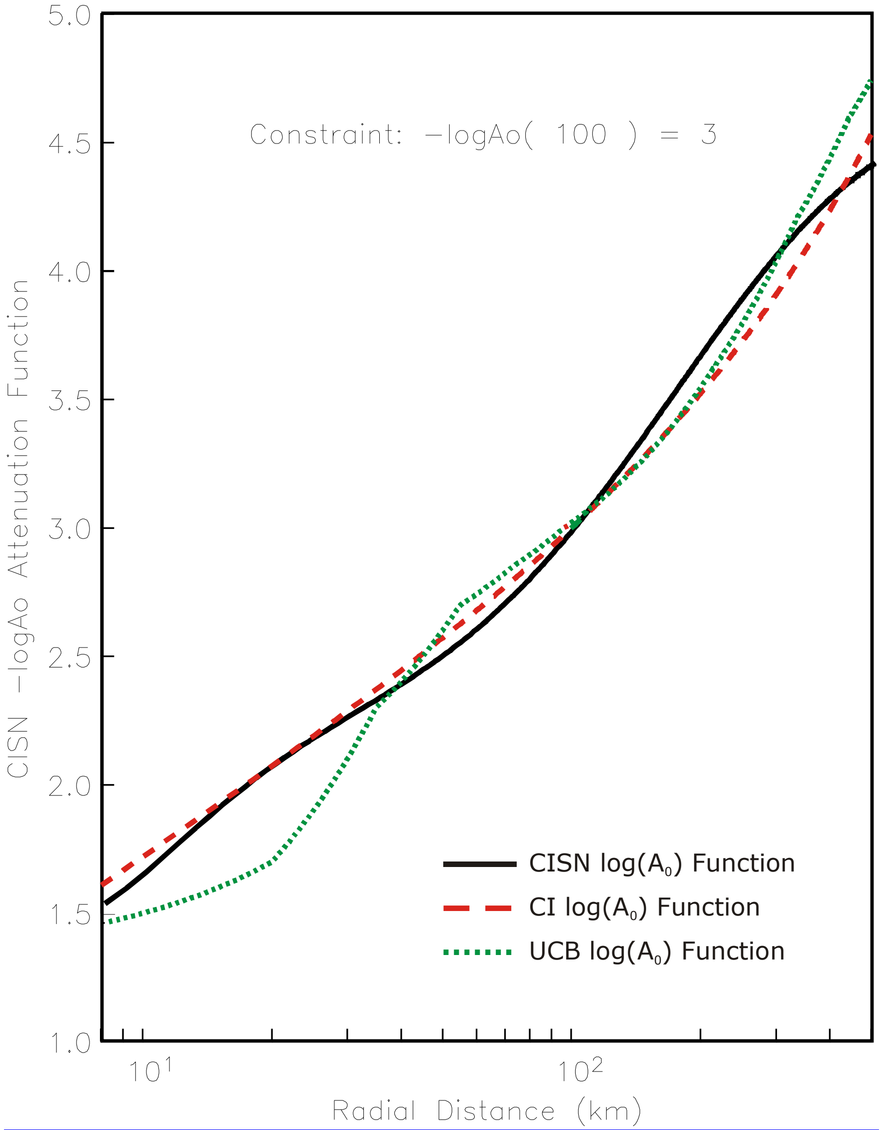
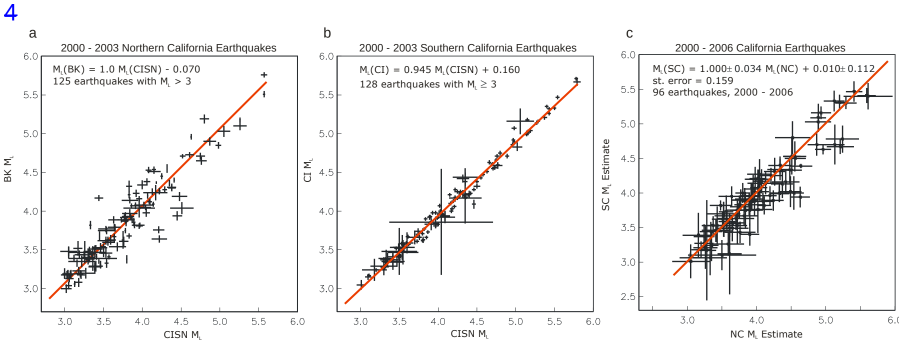
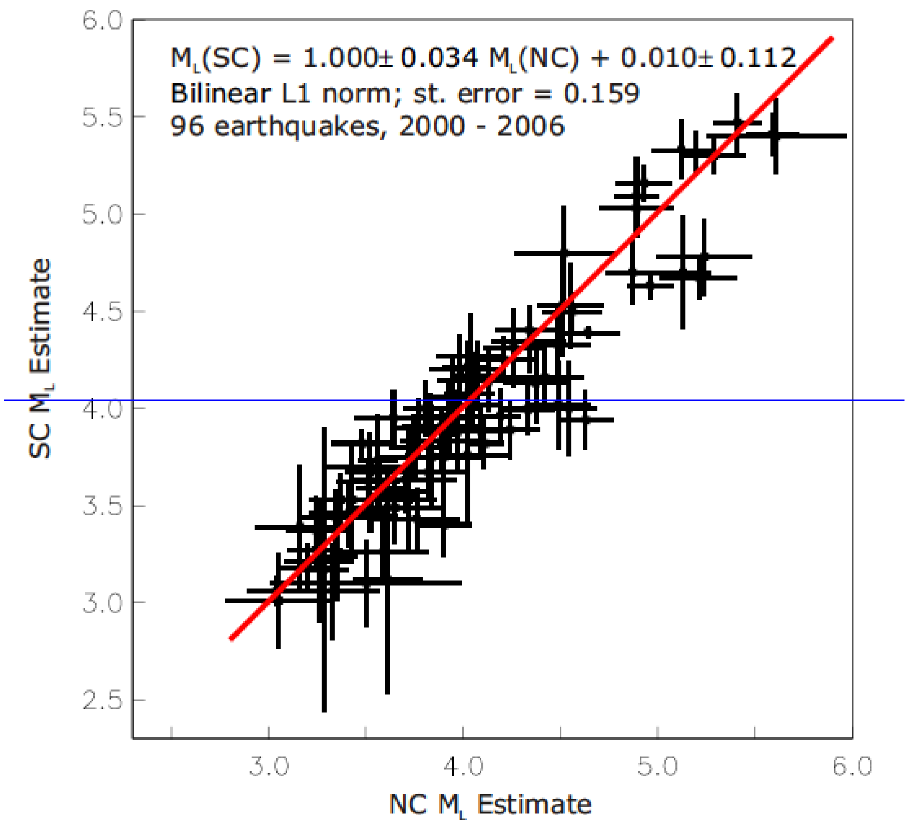

5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
CISN −logAo Attenuation Function
Constraint: −logAo(100) = 3
CISN log(A0) Function
CI log(A0) Function
UCB log(A0) Function
10¹
10²
Radial Distance (km)

Figure 4.
4


a
2000 - 2003 Northern California Earthquakes
M_L(BK) = 1.0 M_L(CISN) - 0.070
125 earthquakes with M_L > 3
BK M_L
CISN M_L
b
2000 - 2003 Southern California Earthquakes
M_L(CI) = 0.945 M_L(CISN) + 0.160
128 earthquakes with M_L ≥ 3
CI M_L
CISN M_L
c
2000 - 2006 California Earthquakes
M_L(SC) = 1.000± 0.034 M_L(NC) + 0.010± 0.112
st. error = 0.159
96 earthquakes, 2000 - 2006
SC M_L Estimate
NC M_L Estimate

.



$M_L(SC) = 1.000 \pm 0.034\ M_L(NC) + 0.010 \pm 0.112$
Bilinear L1 norm; st. error = 0.159
96 earthquakes, 2000 - 2006
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
SC M_L Estimate
3.0
4.0
5.0
6.0
NC M_L Estimate

Appendix A. Candidate Events. The first column is the 50 km by 50 km grid square where the event is located. The events are extracted from the ANSS composite catalog. See Table SA in the electronic supplement.

055	2003/06/11	21:13:05	32.0767	-114.6255	6.00	3.50	ML	CI
056	2001/12/08	23:36:10	32.0380	-114.9060	10.00	5.80	Mw	NEI
056	2006/05/24	04:20:26	32.3067	-115.2278	6.00	5.37	Mw	CI
057	2002/12/10	21:04:00	32.2317	-115.7982	6.99	4.84	ML	CI
058	2005/12/30	12:17:10	32.1105	-116.4253	9.11	3.78	ML	CI
058	2006/02/15	22:56:42	32.0867	-116.0138	6.00	3.01	ML	CI
059	2000/05/03	14:54:06	32.0140	-116.8640	6.00	3.09	ML	CI
059	2006/08/20	20:44:23	32.1558	-116.6690	6.00	3.09	ML	CI
060	2003/06/26	06:20:01	32.0157	-117.3840	6.00	4.06	ML	CI
061	2004/06/15	22:28:48	32.3287	-117.9175	10.00	4.98	Mw	CI
078	2000/08/08	03:18:09	32.4480	-113.4740	5.00	3.50	ML	NEI
081	2002/12/12	21:03:43	32.3672	-115.2018	7.02	4.21	ML	CI
081	2006/05/24	04:25:14	32.4180	-115.2000	6.00	3.90	Mc	ECX
082	2000/04/09	10:48:09	32.7040	-115.3930	10.00	4.28	ML	CI
082	2006/06/02	00:56:15	32.6762	-115.8550	6.00	3.79	ML	CI
083	2006/11/03	15:56:43	32.6760	-116.0482	13.67	4.37	ML	CI
083	2006/11/03	15:56:43	32.6760	-116.0482	13.67	4.37	ML	CI
084	2005/04/12	11:06:46	32.7248	-116.8212	10.00	3.94	ML	CI
085	2005/05/29	18:30:45	32.5688	-117.5293	6.00	3.82	ML	CI
085	2006/05/09	00:13:36	32.6380	-117.3158	14.28	3.56	ML	CI
086	2005/10/16	21:11:35	32.4545	-118.1633	10.00	4.87	ML	CI
087	2001/08/16	18:04:33	32.7595	-118.2882	6.94	4.36	ML	CI
107	2005/09/02	01:27:19	33.1598	-115.6370	9.76	5.11	Mw	CI
108	2002/09/21	21:26:16	33.2248	-116.1128	14.57	4.31	ML	CI
108	2006/06/30	00:28:06	33.2407	-116.0360	3.58	4.29	ML	CI
109	2002/03/30	13:50:51	33.1947	-116.7280	9.35	3.84	ML	CI
111	2001/09/20	23:43:23	32.9255	-117.7703	7.00	3.17	ML	CI
112	2006/12/18	11:01:46	33.1723	-118.6853	0.00	3.18	ML	CI
113	2003/04/25	22:00:28	33.0153	-118.9277	6.00	3.33	ML	CI
132	2001/11/13	20:43:14	33.3172	-115.7002	5.50	4.11	ML	CI
133	2002/01/02	12:11:28	33.3793	-116.4345	12.58	4.21	ML	CI
133	2006/10/09	20:26:50	33.2610	-116.0723	8.54	3.92	ML	CI
134	2005/06/12	15:41:46	33.5288	-116.5727	14.19	5.20	Mw	CI
135	2005/12/04	17:47:44	33.6108	-117.2715	13.83	3.34	ML	CI
136	2003/03/24	17:34:53	33.2695	-117.8950	10.00	3.14	ML	CI
137	2004/04/20	12:41:26	33.5558	-118.3682	15.49	3.15	ML	CI
138	2003/01/01	00:51:44	33.3668	-119.1312	7.01	3.49	ML	CI
139	2002/03/16	21:33:23	33.6660	-119.3300	7.00	4.60	ML	CI
140	2005/04/21	06:36:19	33.6570	-120.0333	6.00	3.95	ML	CI
158	2005/01/12	08:10:46	33.9527	-116.3953	7.59	4.26	ML	CI
158	2006/12/24	03:43:38	33.7077	-116.0497	13.19	4.02	ML	CI
159	2005/06/16	20:53:26	34.0580	-117.0113	11.61	4.90	Mw	CI
159	2006/06/08	22:45:54	33.9197	-116.7937	18.71	3.84	ML	CI
160	2005/01/06	14:35:27	34.1250	-117.4387	4.15	4.42	ML	CI
160	2006/07/10	02:54:43	33.8560	-117.1122	11.53	3.81	ML	CI
161	2002/09/03	07:08:51	33.9173	-117.7758	12.92	4.75	ML	CI
162	2001/09/09	23:59:18	34.0590	-118.3885	7.90	4.24	ML	CI
163	2004/07/06	16:05:44	34.0608	-118.8527	13.50	3.40	ML	CI
164	2006/03/14	01:41:46	33.8173	-119.4010	6.00	3.18	ML	CI
165	2001/10/09	15:30:54	33.9963	-120.0695	7.00	3.25	ML	CI
183	2003/03/11	19:28:17	34.3592	-116.1332	3.89	4.64	ML	CI
184	2001/02/10	21:05:05	34.2895	-116.9458	9.12	5.13	ML	CI
185	2001/05/14	17:13:30	34.2262	-117.4397	8.73	3.84	ML	CI
185	2006/11/04	19:43:44	34.2058	-117.5762	4.92	3.51	ML	CI
186	2004/08/30	20:51:36	34.4238	-117.6820	7.27	3.18	ML	CI
187	2001/01/14	02:26:14	34.2840	-118.4040	8.80	4.26	ML	CI
188	2000/10/12	16:51:19	34.5598	-118.9022	25.73	3.86	ML	CI
188	2006/02/24	19:58:32	34.4207	-119.0603	14.89	3.10	ML	CI
189	2004/07/24	12:55:19	34.3805	-119.4360	3.61	4.27	ML	CI
189	2006/02/05	15:43:33	34.2407	-119.8103	7.89	3.22	ML	CI
190	2004/05/09	08:57:17	34.3947	-120.0223	4.42	4.40	ML	CI

191	2000/07/13	15:37:11	34.3120	-120.6490	6.00	3.19	ML	CI
208	2002/10/29	14:16:54	34.8027	-116.2665	4.60	4.77	ML	CI
209	2003/07/15	06:15:50	34.6217	-116.6672	7.64	4.15	ML	CI
212	2001/04/19	09:02:40	34.7093	-118.7153	14.03	3.24	ML	CI
213	2005/04/16	19:18:13	35.0272	-119.1783	10.29	5.15	ML	CI
214	2003/02/19	17:10:24	34.8928	-119.3617	11.93	3.38	ML	CI
216	2000/03/12	06:59:35	34.9607	-120.7257	2.46	3.78	Md	NC
217	2000/02/03	04:32:45	34.7240	-121.4670	6.00	3.60	ML	PAS
217	2006/12/26	21:53:34	34.7532	-121.4338	25.45	3.02	Md	NC
228	2003/08/10	00:33:23	35.0660	-113.3700	5.00	3.00	ML	NEI
233	2000/10/22	14:54:25	35.4722	-116.4463	6.00	3.45	ML	CI
234	2005/02/08	17:35:32	35.1152	-116.9975	4.33	3.03	ML	CI
235	2001/02/24	06:09:59	35.1120	-117.5250	3.63	3.80	ML	CI
235	2006/03/03	13:44:05	35.1213	-117.5563	2.10	3.69	ML	CI
236	2003/05/23	18:35:41	35.2083	-118.1172	5.05	3.04	ML	CI
237	2004/09/29	22:54:54	35.3898	-118.6235	3.55	5.03	Mw	CI
238	2004/02/17	07:16:03	35.0553	-119.1075	14.34	3.40	ML	CI
239	2004/07/15	01:43:22	35.3148	-119.4325	1.09	3.50	ML	CI
240	2004/01/09	07:34:50	35.2872	-120.2808	5.60	3.01	ML	CI
241	2005/06/27	00:30:28	35.4283	-121.0003	5.96	3.71	ML	NC
241	2006/01/04	23:56:59	35.3137	-120.9455	4.06	3.13	ML	NC
241	2006/08/26	08:45:39	35.4655	-120.7752	3.66	3.09	ML	NC
242	2003/12/31	05:13:16	35.3780	-121.1410	5.00	3.70	ML	NEI
258	2006/07/19	13:23:19	35.5195	-116.4257	6.00	3.38	ML	CI
259	2004/08/31	00:09:13	35.5995	-117.0350	5.60	3.17	ML	CI
260	2002/09/28	10:34:47	35.9462	-117.3035	3.72	4.13	ML	CI
260	2006/03/29	01:36:23	35.6218	-117.5875	8.77	4.00	ML	CI
261	2001/05/17	21:53:45	35.7990	-118.0437	8.74	4.25	ML	CI
262	2001/08/04	19:05:55	35.7305	-118.4823	4.92	3.16	ML	CI
265	2004/09/28	17:15:24	35.8182	-120.3660	8.58	5.96	Mw	NC
265	2006/10/31	20:26:06	35.8555	-120.4073	9.31	3.63	ML	NC
266	2005/05/16	07:24:37	35.9288	-120.4770	10.07	4.69	ML	NC
266	2006/11/28	04:06:40	35.6318	-120.7543	6.87	4.10	ML	NC
267	2003/12/22	19:15:56	35.7002	-121.0973	8.05	6.50	Mw	NC
281	2001/02/04	03:29:02	36.1426	-115.3455	0.00	3.53	ML	NN
284	2002/02/25	19:48:36	36.2478	-116.8797	9.25	3.42	ML	NN
285	2000/02/28	23:08:42	36.0720	-117.6010	0.16	4.21	ML	CI
285	2006/06/03	20:09:08	36.1053	-117.6235	2.07	3.00	ML	CI
286	2001/07/17	12:07:26	36.0163	-117.8743	2.97	5.17	Mw	CI
286	2006/07/12	22:20:50	36.0710	-117.9022	4.45	3.93	ML	CI
287	2001/04/14	14:51:22	35.9893	-118.3312	5.60	3.77	ML	CI
287	2006/12/31	00:50:51	36.2970	-118.3280	1.21	3.21	ML	CI
289	2005/12/31	21:31:28	35.9750	-119.8295	25.44	3.92	ML	NC
289	2006/04/02	08:16:56	35.9627	-119.8753	22.02	3.08	ML	NC
290	2006/12/16	06:14:05	36.1738	-120.2937	9.91	4.23	ML	NC
291	2004/09/29	17:10:04	35.9537	-120.5022	11.37	5.00	Mw	NC
292	2005/07/04	07:11:28	36.3360	-121.2340	5.16	5.69	Md	NC
307	2000/03/13	14:11:32	36.7619	-115.9109	4.85	3.09	ML	NN
308	2002/06/14	12:40:44	36.7163	-116.3013	11.73	4.36	ML	NN
308	2006/04/17	20:14:51	36.7140	-116.0550	5.60	3.30	ML	REN
309	2006/11/30	20:12:57	36.4020	-116.9080	12.80	3.20	ML	REN
310	2003/03/21	18:46:34	36.6581	-117.1742	9.06	3.44	ML	NN
310	2006/12/16	04:18:23	36.8360	-117.4730	5.48	3.09	ML	CI
311	2001/01/04	12:23:31	36.4940	-117.9220	5.72	3.40	ML	CI
312	2003/08/19	22:02:08	36.4652	-118.2908	9.47	3.65	ML	CI
313	2005/05/29	03:51:35	36.7572	-119.3048	0.28	3.20	Md	NC
315	2005/06/04	05:11:43	36.4810	-120.2045	4.90	4.31	Md	NC
316	2003/04/21	15:46:45	36.5622	-120.7085	13.34	3.51	ML	NC
316	2006/09/15	17:04:44	36.4535	-121.0033	8.45	3.09	ML	NC
317	2001/12/28	21:14:01	36.6402	-121.2510	6.86	4.67	ML	NC
317	2006/04/01	12:25:59	36.5195	-121.0935	1.88	4.34	ML	NC
318	2005/03/01	02:35:42	36.8400	-121.5720	6.84	3.02	Md	NC
335	2006/08/21	00:09:13	37.2692	-117.5582	0.58	3.21	Md	NC
336	2001/08/02	16:21:18	37.2410	-117.8075	9.01	4.32	ML	NN
337	2001/01/18	15:12:47	36.9503	-118.5030	7.10	3.83	ML	CI
338	2001/04/14	03:34:24	37.2015	-119.0085	13.98	3.15	Md	NC

339	2002/09/22	15:08:32	36.9170	-119.8580	3.38	4.90	Md	NC
340	2002/06/17	15:15:50	37.1638	-120.0832	5.35	4.24	Md	NC
341	2002/06/13	11:41:24	36.8557	-120.9602	4.94	3.60	Md	NC
342	2006/06/15	12:24:51	37.1015	-121.4920	3.27	4.67	ML	NC
343	2002/05/14	05:00:29	36.9668	-121.5983	6.94	4.94	ML	NC
344	2004/11/01	22:02:33	37.0692	-122.2792	9.10	3.57	ML	NC
360	2000/10/14	04:53:29	37.3714	-117.1197	8.03	4.22	ML	NN
361	2006/12/19	15:21:42	37.4957	-118.1878	5.88	3.70	Mw	NC
362	2002/07/15	20:18:17	37.3843	-118.4063	13.17	4.07	ML	NC
362	2006/09/07	01:38:59	37.3118	-118.2832	8.13	3.63	ML	NC
363	2006/11/26	22:11:48	37.4537	-118.8403	8.57	4.27	ML	NC
366	2004/11/24	04:43:19	37.3620	-120.7732	0.02	3.96	Md	NC
367	2005/02/05	18:43:30	37.4003	-121.4833	8.10	4.42	ML	NC
367	2006/01/25	15:29:57	37.3865	-121.4847	6.10	3.74	ML	NC
368	2001/02/25	23:18:22	37.3325	-121.6992	7.60	4.44	ML	NC
369	2002/12/24	08:22:30	37.6072	-122.4750	8.97	3.60	Mw	NC
385	2002/12/14	13:07:09	37.9656	-117.1052	10.68	3.60	ML	NN
386	2003/04/03	15:31:51	37.8804	-118.0709	5.98	3.06	ML	NN
387	2004/09/18	23:02:17	38.0095	-118.6785	5.49	5.55	Mw	NC
388	2006/02/16	17:47:59	37.9848	-118.7735	10.43	4.25	ML	NC
393	2005/06/20	18:14:57	37.9028	-121.9508	0.63	5.24	Md	NC
393	2006/03/21	21:41:42	37.8093	-122.0710	12.94	3.70	Mw	NC
394	2003/09/05	01:39:53	37.8432	-122.2225	11.14	4.13	ML	NC
394	2006/12/23	06:49:57	37.8577	-122.2452	9.35	3.71	ML	NC
411	2003/11/15	20:11:59	38.2217	-117.8730	8.75	4.47	ML	NN
412	2001/02/17	22:54:19	38.2500	-118.2900	12.36	4.06	ML	NN
412	2006/05/07	13:59:42	38.2180	-118.7500	13.60	3.60	ML	REN
413	2006/05/05	06:36:19	38.2280	-118.7570	14.00	4.30	ML	REN
414	2003/06/23	12:19:26	38.6317	-119.4452	6.45	3.33	ML	NN
414	2006/02/25	12:15:50	38.3542	-119.4202	3.94	3.07	Md	NC
417	2003/10/03	16:32:42	38.5282	-121.4123	112.69	3.53	Md	NC
418	2002/05/08	14:59:36	38.2238	-121.8375	17.67	3.68	ML	NC
419	2000/09/03	08:36:30	38.3788	-122.4133	9.87	5.17	ML	NC
419	2006/08/03	03:08:12	38.3635	-122.5887	8.86	4.40	Mw	NC
420	2003/05/25	07:09:33	38.4582	-122.6990	4.88	4.32	ML	NC
420	2006/05/28	01:07:25	38.4795	-122.7120	6.03	3.05	Md	NC
421	2006/07/06	20:43:24	38.5043	-123.4590	0.02	3.68	ML	NC
436	2001/05/06	00:38:53	38.7060	-117.9346	12.22	3.37	ML	NN
436	2006/09/24	12:42:52	38.8040	-117.9110	11.00	3.30	ML	REN
437	2002/12/15	02:30:20	39.0466	-118.5086	10.33	3.89	ML	NN
437	2006/03/11	15:29:59	38.7080	-118.7180	14.70	3.30	ML	REN
438	2005/11/29	04:45:41	39.0790	-119.0110	6.10	3.60	ML	REN
438	2006/04/05	12:03:16	39.0820	-119.0060	4.90	3.40	ML	REN
439	2000/09/26	07:20:28	38.6588	-119.5307	9.30	4.72	ML	NN
443	2002/07/18	15:03:54	38.7378	-121.6473	20.97	3.26	Md	NC
444	2000/06/24	11:04:17	38.7650	-122.6925	3.91	3.42	ML	NC
444	2006/11/29	03:20:22	38.6545	-122.2613	0.07	3.23	ML	NC
445	2006/10/20	17:00:08	38.8667	-122.7873	3.46	4.50	Mw	NC
446	2005/02/04	23:27:40	38.8892	-123.5978	0.02	3.14	ML	NC
463	2003/04/05	14:18:26	39.3763	-119.2506	12.37	3.67	ML	NN
464	2003/05/04	12:07:10	39.5160	-119.5688	7.50	3.39	ML	NN
465	2005/06/26	18:45:57	39.3050	-120.0928	0.09	4.80	Mw	NC
466	2000/12/02	15:34:15	39.3787	-120.4507	14.28	4.91	ML	NN
466	2006/05/29	10:38:43	39.3660	-120.4650	9.60	3.80	ML	REN
468	2004/08/03	18:46:44	39.4792	-122.0673	23.01	3.27	Md	NC
469	2003/07/28	19:10:58	39.2250	-122.2405	14.01	3.18	ML	NC
470	2000/05/17	22:32:07	39.3912	-123.0655	8.09	4.15	ML	NC
470	2006/09/26	20:56:13	39.3120	-123.2185	12.48	3.80	Mw	NC
471	2006/11/09	08:38:13	39.3587	-123.2823	4.88	4.00	Mw	NC
488	2000/11/25	17:38:20	39.6757	-119.2930	8.92	3.39	ML	NN
489	2005/03/04	05:33:45	39.6500	-119.3240	12.20	3.00	ML	REN
490	2000/03/10	23:56:56	39.6821	-120.2843	10.32	3.04	ML	NN
491	2001/08/10	20:19:26	39.8233	-120.6459	17.82	5.31	ML	NN
493	2003/03/29	00:40:33	39.7390	-122.0807	19.06	3.48	ML	NC
494	2004/03/21	20:41:35	39.5983	-122.1950	95.81	4.11	Md	NC
495	2001/02/02	23:03:11	39.7302	-122.8290	7.39	3.96	ML	NC

495	2006/05/02	11:04:20	39.5615	-122.7342	0.02	3.14	Md	NC
496	2006/04/07	10:04:28	39.5647	-123.3500	9.99	3.50	ML	NC
497	2002/11/24	22:46:56	39.9737	-124.0520	4.06	3.45	Md	NC
514	2000/07/05	12:26:31	40.2289	-119.6130	4.54	3.89	ML	NN
515	2000/12/18	18:41:05	40.2922	-120.2721	12.91	3.38	ML	NN
515	2006/02/22	05:37:45	40.0422	-120.0187	0.02	3.06	Md	NC
516	2004/04/19	06:20:14	40.3700	-120.6250	7.00	3.70	Mw	NC
517	2005/11/29	14:29:32	40.2075	-121.1697	1.07	3.33	Md	NC
517	2006/02/24	23:54:47	40.2297	-121.1673	0.02	3.17	ML	NC
518	2000/07/30	09:16:37	40.3785	-122.0507	19.88	3.58	ML	NC
518	2006/11/17	13:33:36	40.1513	-122.0715	28.40	3.50	Md	NC
519	2004/04/26	16:38:56	40.1348	-122.5567	20.69	3.25	Md	NC
520	2005/07/28	01:28:24	40.1545	-122.8415	43.72	3.46	Md	NC
521	2004/02/03	16:04:11	40.1913	-123.7332	22.44	3.01	ML	NC
522	2004/08/01	15:43:32	40.3205	-124.0593	32.31	3.75	Md	NC
522	2006/10/19	15:20:05	40.2795	-124.3247	16.70	3.65	Md	NC
523	2006/07/19	11:41:43	40.2807	-124.4335	20.69	5.00	Mw	NC
524	2000/03/16	15:19:56	40.3887	-125.2383	5.54	4.81	Md	NC
524	2006/12/17	15:13:39	40.4203	-125.0737	0.31	4.30	Mw	NC
525	2005/05/22	10:35:24	40.3600	-125.7120	5.10	3.60	Mc	NC
525	2006/06/10	03:18:37	40.4327	-125.5288	5.15	3.23	Md	NC
538	2003/10/01	08:33:43	40.6251	-119.3157	11.64	3.32	ML	NN
539	2000/11/19	12:54:50	40.4822	-119.4855	12.92	4.40	ML	NN
541	2002/03/02	07:19:04	40.8280	-120.6630	4.20	3.30	ML	NC
543	2001/11/07	19:39:01	40.8652	-121.6127	15.02	3.28	ML	NC
544	2003/06/23	13:34:16	40.6345	-122.4347	23.48	3.38	Md	NC
544	2006/11/02	20:59:06	40.6795	-122.3578	22.15	3.00	Md	NC
545	2005/04/06	08:10:03	40.7438	-123.1973	31.11	3.14	Md	NC
546	2004/12/05	01:48:04	40.7392	-123.8145	29.32	4.30	Mw	NC
547	2004/12/12	09:13:33	40.6965	-123.8675	28.49	4.46	Mw	NC
547	2006/11/01	08:27:28	40.5288	-124.0605	19.24	3.34	ML	NC
548	2002/06/17	16:55:07	40.8088	-124.5538	21.19	5.09	ML	NC
549	2001/01/13	13:08:42	40.7557	-125.2450	2.62	5.19	ML	NC
550	2000/01/16	01:51:32	40.4630	-125.7080	2.50	4.30	Mw	NC
550	2006/06/25	17:21:20	40.4510	-125.6780	5.00	3.30	Mc	NC
562	2003/02/14	23:48:22	41.3358	-118.7086	0.00	3.37	ML	NN
566	2003/06/27	00:26:12	41.1980	-120.5230	17.10	3.30	ML	NC
567	2005/11/13	14:53:51	41.0628	-121.5077	8.56	3.48	ML	NC
568	2000/12/20	23:39:14	40.9885	-121.6935	18.44	4.62	ML	NC
569	2005/11/29	06:12:00	41.1773	-122.2560	10.77	3.08	ML	NC
571	2005/10/20	16:26:50	41.0273	-123.3127	36.14	3.57	ML	NC
571	2006/04/13	17:40:49	40.9130	-123.5602	22.27	3.24	ML	NC
572	2001/10/22	08:23:52	40.9712	-124.2157	19.30	3.54	ML	NC
573	2001/10/20	22:05:51	41.2332	-124.9347	2.54	3.16	Md	NC
574	2003/08/15	09:22:14	40.9850	-125.4300	8.60	5.30	Mw	NC
575	2004/02/20	08:38:07	41.3020	-125.5500	2.50	3.60	ML	NC
590	2002/07/20	15:09:13	41.5530	-119.9690	0.00	3.00	ML	REN
596	2000/11/29	18:57:17	41.3623	-123.4810	36.45	3.01	Md	NC
597	2004/01/17	03:00:15	41.4382	-123.8335	30.13	3.26	Md	NC
598	2004/03/21	20:09:02	41.5733	-124.5657	6.20	3.31	Md	NC
599	2006/06/04	05:39:21	41.5960	-125.4800	2.60	3.70	Mb	NC
600	2004/10/12	00:53:53	41.5450	-125.6050	10.00	4.60	Mb	NEI
613	2006/04/12	10:55:22	41.9940	-118.8350	0.00	3.00	ML	REN
614	2000/11/26	01:09:37	41.9073	-119.7597	23.26	3.08	Md	NC
615	2004/06/30	12:21:45	42.1540	-120.2940	5.00	4.70	Mw	NEI
618	2002/05/15	17:54:48	42.2313	-121.9012	8.11	4.30	Mc	UW
622	2005/07/04	09:21:47	42.1190	-123.9960	5.00	3.00	ML	NEI
623	2002/02/03	06:46:14	42.0688	-124.4453	30.43	3.04	Md	NC
625	2002/06/01	00:15:59	41.8840	-125.5810	2.50	4.20	ML	NC
640	2005/06/11	11:16:10	42.2730	-120.0690	5.00	3.60	Mw	NEI

Appendix B. CISN dM_L Adjustments.

Initial set of 666 CISN dM_L adjustments determined using the 2000-2006 data set analyzed in this study. The table entries are (SNCL, dM_L, standard error) triplets with four triplets per row. See Table SB in the electronic supplement.

ADO.CI.N	-0.347	0.016	ADO.CI.E	-0.393	0.016	AGA.CI.N	0.259	0.019	AGA.CI.E	0.204	0.018
AGO.CI.N	-0.079	0.015	AGO.CI.E	-0.097	0.016	ALP.CI.N	-0.178	0.016	ALP.CI.E	-0.192	0.016
ARC.BK.N	-0.084	0.063	ARC.BK.E	0.048	0.079	ARV.CI.N	-0.141	0.018	ARV.CI.E	-0.090	0.018
BAK.CI.N	-0.221	0.016	BAK.CI.E	-0.221	0.016	BAR.CI.N	0.039	0.018	BAR.CI.E	0.032	0.018
BBR.CI.N	-0.269	0.016	BBR.CI.E	-0.306	0.016	BBS.CI.N	-0.312	0.017	BBS.CI.E	-0.333	0.016
BC3.CI.N	0.030	0.020	BC3.CI.E	0.061	0.021	BCC.CI.N	-0.135	0.017	BCC.CI.E	-0.151	0.018
BDM.BK.N	-0.124	0.021	BDM.BK.E	-0.130	0.021	BEL.CI.N	0.017	0.018	BEL.CI.E	-0.029	0.018
BFS.CI.N	0.169	0.017	BFS.CI.E	0.138	0.016	BKR.CI.N	-0.298	0.027	BKR.CI.E	-0.342	0.026
BKS.BK.N	-0.004	0.013	BKS.BK.E	0.004	0.013	BLA.CI.N	0.004	0.017	BLA.CI.E	0.269	0.017
BLY.CI.N	0.063	0.031	BLY.CI.E	0.070	0.032	BOR.CI.N	0.194	0.018	BOR.CI.E	0.182	0.018
BRE.CI.N	-0.401	0.016	BRE.CI.E	-0.443	0.016	BRIB.BK.N	-0.009	0.023	BRIB.BK.E	0.012	0.023
BRK.BK.N	0.137	0.025	BRK.BK.E	0.102	0.025	BTC.CI.N	-0.146	0.019	BTC.CI.E	-0.120	0.019
BTP.CI.N	-0.281	0.016	BTP.CI.E	-0.297	0.016	BZN.AZ.N	-0.079	0.017	BZN.AZ.E	-0.046	0.017
CAC.CI.N	-0.175	0.017	CAC.CI.E	-0.227	0.016	CADB.NC.N	-0.060	0.025	CADB.NC.E	-0.096	0.023
CAG.NC.N	-0.251	0.020	CAG.NC.E	-0.209	0.020	CAL.NC.N	0.017	0.023	CAL.NC.E	0.029	0.023
CAP.CI.N	0.116	0.017	CAP.CI.E	0.090	0.017	CBC.CI.N	-0.305	0.016	CBC.CI.E	-0.289	0.016
CBP.NC.N	-0.229	0.019	CBP.NC.E	-0.286	0.020	CBR.NC.N	-0.395	0.021	CBR.NC.E	-0.386	0.021
CCC.CI.N	-0.221	0.016	CCC.CI.E	-0.146	0.017	CCO.NC.N	-0.269	0.020	CCO.NC.E	-0.312	0.020
CDOB.NC.N	-0.428	0.019	CDOB.NC.E	-0.474	0.019	CFS.CI.N	-0.339	0.018	CFS.CI.E	-0.342	0.019
CGO.CI.N	-0.178	0.018	CGO.CI.E	-0.192	0.018	CHF.CI.N	0.211	0.016	CHF.CI.E	0.186	0.016
CHN.CI.N	-0.320	0.015	CHN.CI.E	-0.348	0.015	CHR.NC.N	-0.104	0.022	CHR.NC.E	-0.154	0.021
CIA.CI.N	0.035	0.017	CIA.CI.E	-0.023	0.016	CLC.CI.N	0.287	0.017	CLC.CI.E	0.231	0.017
CLCB.NC.N	-0.488	0.022	CLCB.NC.E	-0.502	0.022	CLT.CI.N	-0.498	0.016	CLT.CI.E	-0.489	0.015
CMB.BK.N	0.066	0.019	CMB.BK.E	0.033	0.020	CMOB.NC.N	-0.178	0.033	CMOB.NC.E	-0.297	0.031
CPI.NC.N	-0.376	0.019	CPI.NC.E	-0.433	0.020	CPM.NC.N	-0.058	0.027	CPM.NC.E	-0.013	0.026
CPP.CI.N	-0.438	0.020	CPP.CI.E	-0.465	0.019	CRH.NC.N	-0.400	0.021	CRH.NC.E	-0.391	0.022
CRN.CI.N	-0.111	0.015	CRN.CI.E	-0.073	0.016	CRP.CI.N	-0.212	0.019	CRP.CI.E	-0.237	0.019
CRPB.NC.N	-0.009	0.021	CRPB.NC.E	-0.090	0.020	CRY.AZ.N	0.100	0.016	CRY.AZ.E	0.034	0.016
CSL.NC.N	-0.425	0.020	CSL.NC.E	-0.370	0.020	CTA.NC.N	-0.313	0.019	CTA.NC.E	-0.347	0.020
CTC.CI.N	-0.357	0.017	CTC.CI.E	-0.408	0.017	CVS.BK.N	0.152	0.022	CVS.BK.E	0.066	0.022
CWC.CI.N	0.158	0.020	CWC.CI.E	0.133	0.020	CYB.NC.N	-0.344	0.022	CYB.NC.E	-0.289	0.023
DAN.CI.N	-0.241	0.017	DAN.CI.E	-0.288	0.017	DEC.CI.N	-0.284	0.015	DEC.CI.E	-0.268	0.016
DEV.CI.N	-0.165	0.016	DEV.CI.E	-0.163	0.016	DGR.CI.N	0.126	0.016	DGR.CI.E	0.100	0.016
DJJ.CI.N	0.073	0.015	DJJ.CI.E	0.077	0.016	DLA.CI.N	-0.537	0.016	DLA.CI.E	-0.544	0.016
DNR.CI.N	-0.352	0.018	DNR.CI.E	-0.393	0.018	DPP.CI.N	0.184	0.020	DPP.CI.E	0.123	0.018
DRC.CI.N	-0.369	0.028	DRC.CI.E	-0.420	0.027	DRE.CI.N	-0.500	0.018	DRE.CI.E	-0.512	0.018
DSC.CI.N	0.181	0.019	DSC.CI.E	0.156	0.019	DVT.CI.N	0.095	0.020	DVT.CI.E	0.029	0.019
EDW.CI.N	0.224	0.019	EDW.CI.E	0.159	0.019	EDW2.CI.N	0.160	0.018	EDW2.CI.E	0.109	0.018
ELFS.BK.N	-0.083	0.037	ELFS.BK.E	-0.017	0.041	EML.CI.N	0.268	0.019	EML.CI.E	0.268	0.018
ERR.CI.N	-0.469	0.018	ERR.CI.E	-0.463	0.017	FARB.BK.N	0.172	0.023	FARB.BK.E	0.162	0.025
FIG.CI.N	0.082	0.018	FIG.CI.E	0.030	0.017	FMP.CI.N	-0.163	0.016	FMP.CI.E	-0.113	0.016
FON.CI.N	-0.120	0.016	FON.CI.E	-0.142	0.015	FPC.CI.N	0.025	0.038	FPC.CI.E	0.055	0.037
FRD.AZ.N	0.205	0.018	FRD.AZ.E	0.178	0.017	FUL.CI.N	-0.385	0.016	FUL.CI.E	-0.433	0.017
FUR.CI.N	-0.130	0.016	FUR.CI.E	-0.174	0.016	GASB.BK.N	0.161	0.057	GASB.BK.E	0.111	0.048
GDXB.NC.N	0.407	0.041	GDXB.NC.E	0.343	0.040	GLA.CI.N	0.057	0.019	GLA.CI.E	-0.106	0.018
GOR.CI.N	0.190	0.017	GOR.CI.E	0.175	0.016	GRA.CI.N	-0.137	0.017	GRA.CI.E	-0.157	0.018
GSA.CI.N	-0.227	0.016	GSA.CI.E	-0.246	0.016	GSC.CI.N	0.037	0.016	GSC.CI.E	-0.003	0.016
HAST.BK.N	-0.155	0.029	HAST.BK.E	-0.154	0.029	HATC.BK.N	-0.042	0.046	HATC.BK.E	-0.194	0.034
HEC.CI.N	-0.013	0.017	HEC.CI.E	-0.172	0.016	HELL.BK.N	0.032	.029	HELL.BK.E	0.020	0.024
HLL.CI.N	-0.223	0.016	HLL.CI.E	-0.209	0.015	HLN.CI.N	-0.108	0.017	HLN.CI.E	-0.151	0.016
HOPS.BK.N	0.128	0.025	HOPS.BK.E	0.113	0.026	HUMO.BK.N	0.311	0.050	HUMO.BK.E	0.205	0.052
IRM.CI.N	0.106	0.020	IRM.CI.E	0.093	0.019	ISA.CI.N	0.217	0.017	ISA.CI.E	0.163	0.017
JBG.NC.N	-0.476	0.019	JBG.NC.E	-0.594	0.020	JBMB.NC.N	-0.042	0.020	JBMB.NC.E	-0.011	0.021
JBN.NC.N	0.151	0.023	JBN.NC.E	0.026	0.023	JBR.NC.N	-0.411	0.020	JBR.NC.E	-0.374	0.020
JCC.BK.N	0.142	0.040	JCC.BK.E	0.128	0.039	JCH.NC.N	-0.142	0.019	JCH.NC.E	-0.140	0.020
JCS.CI.N	-0.035	0.017	JCS.CI.E	0.044	0.017	JECB.NC.N	-0.196	0.020	JECB.NC.E	-0.251	0.019
JGR.NC.N	-0.025	0.021	JGR.NC.E	-0.064	0.023	JHU.NC.N	-0.415	0.020	JHU.NC.E	-0.451	0.019
JJO.NC.N	-0.241	0.019	JJO.NC.E	-0.211	0.019	JLAB.NC.N	-0.196	0.021	JLAB.NC.E	-0.217	0.019
JMGB.NC.N	-0.037	0.020	JMGB.NC.E	-0.061	0.020	JPC.NC.N	-0.536	0.018	JPC.NC.E	-0.523	0.020
JPSB.NC.N	-0.434	0.021	JPSB.NC.E	-0.410	0.021	JRC.CI.N	-0.082	0.022	JRC.CI.E	-0.129	0.022
JRC2.CI.N	-0.093	0.018	JRC2.CI.E	-0.153	0.018	JRSC.BK.N	0.057	0.025	JRSC.BK.E	0.006	0.023
JSA.NC.N	-0.247	0.019	JSA.NC.E	-0.268	0.019	JSB.NC.N	-0.076	0.023	JSB.NC.E	-0.068	0.021
JSF.NC.N	-0.175	0.053	JSF.NC.E	-0.098	0.038	JSFB.NC.N	-0.254	0.019	JSFB.NC.E	-0.295	0.020
JSGB.NC.N	-0.248	0.018	JSGB.NC.E	-0.202	0.021	JSP.NC.N	-0.178	0.020	JSP.NC.E	-0.109	0.022
JUM.NC.N	-0.356	0.022	JUM.NC.E	-0.334	0.023	JVA.CI.N	-0.207	0.016	JVA.CI.E	-0.298	0.016
KBO.NC.N	-0.113	0.049	KBO.NC.E	-0.136	0.054	KCC.BK.N	0.203	0.022	KCC.BK.E	0.171	0.022

KCPB.NC.N	0.036	0.034	KCPB.NC.E	0.017	0.035	KCT.NC.N	-0.218	0.046	KCT.NC.E	-0.212	0.046
KEB.NC.N	-0.056	0.054	KEB.NC.E	-0.003	0.052	KHBB.NC.N	0.048	0.031	KHBB.NC.E	0.099	0.033
KHMB.NC.N	-0.134	0.040	KHMB.NC.E	-0.043	0.039	KML.CI.N	0.196	0.020	KML.CI.E	0.083	0.019
KMPB.NC.N	-0.171	0.044	KMPB.NC.E	-0.161	0.048	KMR.NC.N	-0.144	0.044	KMR.NC.E	-0.190	0.043
KNW.AZ.N	0.203	0.016	KNW.AZ.E	0.222	0.017	KRMB.NC.N	0.145	0.052	KRMB.NC.E	0.120	0.052
KRP.NC.N	-0.130	0.039	KRP.NC.E	-0.132	0.044	KSXB.NC.N	0.106	0.043	KSXB.NC.E	0.009	0.047
LAF.CI.N	-0.343	0.017	LAF.CI.E	-0.337	0.017	LBW1.CI.N	-0.496	0.018	LBW1.CI.E	-0.532	0.017
LCG.CI.N	-0.281	0.016	LCG.CI.E	-0.317	0.016	LCP.CI.N	-0.339	0.016	LCP.CI.E	-0.336	0.016
LDF.CI.N	-0.345	0.017	LDF.CI.E	-0.288	0.016	LDH.NC.N	-0.057	0.034	LDH.NC.E	-0.010	0.033
LDR.CI.N	-0.091	0.016	LDR.CI.E	-0.145	0.017	LEV.CI.N	-0.110	0.018	LEV.CI.E	-0.105	0.017
LFP.CI.N	-0.388	0.015	LFP.CI.E	-0.320	0.015	LGB.CI.N	-0.318	0.015	LGB.CI.E	-0.342	0.016
LGU.CI.N	0.059	0.016	LGU.CI.E	-0.056	0.016	LJR.CI.N	-0.299	0.016	LJR.CI.E	-0.326	0.016
LKL.CI.N	-0.368	0.019	LKL.CI.E	-0.344	0.018	LLS.CI.N	-0.574	0.016	LLS.CI.E	-0.558	0.017
LMR2.CI.N	0.221	0.021	LMR2.CI.E	0.165	0.020	LRL.CI.N	0.044	0.016	LRL.CI.E	0.125	0.016
LTP.CI.N	-0.535	0.016	LTP.CI.E	-0.532	0.016	LUG.CI.N	-0.203	0.016	LUG.CI.E	-0.164	0.016
LVA2.AZ.N	0.045	0.016	LVA2.AZ.E	-0.070	0.016	MAG.CI.N	0.074	0.018	MAG.CI.E	0.099	0.021
MCB.NC.N	-0.694	0.021	MCB.NC.E	-0.745	0.021	MCCM.BK.N	-0.005	0.034	MCCM.BK.E	-0.037	0.035
MCT.CI.N	0.272	0.019	MCT.CI.E	0.234	0.017	MGE.CI.N	-0.416	0.016	MGE.CI.E	-0.409	0.016
MHC.BK.N	-0.097	0.020	MHC.BK.E	-0.038	0.020	MIK.CI.N	-0.901	0.015	MIK.CI.E	-0.950	0.016
MIS.CI.N	0.676	0.021	MIS.CI.E	0.731	0.022	MLAC.CI.N	-0.644	0.019	MLAC.CI.E	-0.657	0.019
MLS.CI.N	-0.112	0.017	MLS.CI.E	-0.250	0.015	MMLB.NC.N	-0.699	0.020	MMLB.NC.E	-0.733	0.020
MNRC.BK.N	0.039	0.023	MNRC.BK.E	0.048	0.024	MOD.BK.N	-0.003	0.036	MOD.BK.E	0.007	0.038
MONP.AZ.N	0.262	0.018	MONP.AZ.E	0.208	0.017	MOP.CI.N	-0.458	0.015	MOP.CI.E	-0.503	0.015
MPI.CI.N	0.084	0.017	MPI.CI.E	0.050	0.018	MPM.CI.N	0.181	0.017	MPM.CI.E	0.153	0.017
MPP.CI.N	-0.086	0.017	MPP.CI.E	-0.112	0.017	MSJ.CI.N	-0.571	0.016	MSJ.CI.E	-0.588	0.016
MTP.CI.N	0.139	0.020	MTP.CI.E	0.106	0.019	MUR.CI.N	-0.280	0.021	MUR.CI.E	-0.347	0.023
MWC.CI.N	-0.013	0.015	MWC.CI.E	-0.015	0.016	NAPC.NC.N	-0.223	0.020	NAPC.NC.E	-0.235	0.020
NBO.NC.N	-0.185	0.022	NBO.NC.E	-0.179	0.020	NBRB.NC.N	-0.200	0.020	NBRB.NC.E	-0.154	0.022
NBS.CI.N	-0.073	0.018	NBS.CI.E	-0.132	0.019	NEA.NC.N	0.126	0.030	NEA.NC.E	0.066	0.024
NEE.CI.N	-0.404	0.018	NEE.CI.E	-0.381	0.019	NEH.NC.N	-0.164	0.028	NEH.NC.E	-0.216	0.030
NFV.NC.N	0.061	0.025	NFV.NC.E	-0.038	0.027	NGVB.NC.N	0.225	0.023	NGVB.NC.E	0.077	0.022
NHF.NC.N	0.017	0.025	NHF.NC.E	-0.130	0.024	NHM.NC.N	-0.342	0.022	NHM.NC.E	-0.449	0.023
NHS.NC.N	-0.342	0.022	NHS.NC.E	-0.090	0.041	NHV.NC.N	0.081	0.022	NHV.NC.E	0.126	0.024
NJQ.CI.N	-0.231	0.016	NJQ.CI.E	-0.230	0.016	NLH.NC.N	-0.143	0.022	NLH.NC.E	-0.197	0.020
NMH.NC.N	-0.049	0.023	NMH.NC.E	0.000	0.024	NMI.NC.N	-0.190	0.019	NMI.NC.E	-0.273	0.020
NOLB.NC.N	-0.463	0.019	NOLB.NC.E	-0.469	0.018	NOT.CI.N	-0.485	0.015	NOT.CI.E	-0.485	0.016
NPRB.NC.N	0.125	0.027	NPRB.NC.E	0.130	0.024	NSM.NC.N	-0.552	0.021	NSM.NC.E	-0.486	0.020
NSP.NC.N	-0.149	0.021	NSP.NC.E	-0.147	0.022	NSS.CI.N	-0.162	0.032	NSS.CI.E	-0.191	0.024
NSS2.CI.N	-0.153	0.019	NSS2.CI.E	-0.264	0.018	NTAB.NC.N	0.073	0.022	NTAB.NC.E	0.120	0.024
NTAC.NC.N	0.086	0.036	NTAC.NC.E	0.015	0.039	NTO.NC.N	-0.216	0.021	NTO.NC.E	-0.322	0.021
NTR.NC.N	0.096	0.033	NTR.NC.E	0.110	0.032	NTYB.NC.N	-0.193	0.019	NTYB.NC.E	-0.163	0.020
O02C.TA.N	0.082	0.067	O02C.TA.E	0.169	0.053	O03C.TA.N	-0.096	0.029	O03C.TA.E	-0.049	0.029
O04C.TA.N	0.078	0.033	O04C.TA.E	-0.012	0.032	O05C.TA.N	0.074	0.032	O05C.TA.E	-0.122	0.026
OGC.CI.N	-0.240	0.016	OGC.CI.E	-0.289	0.016	OLI.CI.N	-0.288	0.016	OLI.CI.E	-0.276	0.016
OLP.CI.N	0.029	0.019	OLP.CI.E	0.096	0.019	ORV.BK.N	0.289	0.024	ORV.BK.E	0.180	0.025
OSI.CI.N	-0.009	0.016	OSI.CI.E	0.018	0.016	P01C.TA.N	0.381	0.067	P01C.TA.E	0.270	0.064
P05C.TA.N	0.198	0.040	P05C.TA.E	0.132	0.029	PACP.BK.N	-0.324	0.022	PACP.BK.E	-0.306	0.022
PAGB.NC.N	0.058	0.023	PAGB.NC.E	0.001	0.022	PAS.CI.N	0.195	0.017	PAS.CI.E	0.171	0.017
PDE.CI.N	-0.351	0.015	PDE.CI.E	-0.290	0.015	PDM.CI.N	0.139	0.021	PDM.CI.E	0.195	0.021
PDR.CI.N	-0.201	0.018	PDR.CI.E	-0.226	0.017	PDU.CI.N	-0.155	0.016	PDU.CI.E	-0.142	0.016
PER.CI.N	0.141	0.018	PER.CI.E	0.091	0.018	PFO.AZ.N	0.260	0.017	PFO.AZ.E	0.251	0.018
PHL.CI.N	0.021	0.019	PHL.CI.E	0.028	0.019	PHOB.NC.N	-0.139	0.021	PHOB.NC.E	-0.219	0.023
PKD.BK.N	0.135	0.019	PKD.BK.E	0.141	0.019	PLC.CI.N	-0.406	0.018	PLC.CI.E	-0.406	0.018
PLM.CI.N	-0.031	0.016	PLM.CI.E	0.001	0.016	PLS.CI.N	-0.183	0.016	PLS.CI.E	-0.145	0.016
PMD.CI.N	0.237	0.023	PMD.CI.E	-0.145	0.016	PMPB.NC.N	-0.167	0.022	PMPB.NC.E	-0.146	0.021
POTR.BK.N	-0.342	0.025	POTR.BK.E	-0.397	0.026	PSD.CI.N	0.224	0.023	PSD.CI.E	0.203	0.023
Q03C.TA.N	-0.252	0.027	Q03C.TA.E	-0.224	0.026	Q04C.TA.N	-0.270	0.028	Q04C.TA.E	-0.228	0.029
QUG.CI.N	-0.153	0.017	QUG.CI.E	-0.135	0.017	R04C.TA.N	-0.206	0.023	R04C.TA.E	-0.184	0.024
R05C.TA.N	0.077	0.038	R05C.TA.E	-0.007	0.032	R06C.TA.N	0.018	0.041	R06C.TA.E	0.000	0.035
R07C.TA.N	-0.290	0.035	R07C.TA.E	-0.319	0.036	RAMR.BK.N	-0.351	0.021	RAMR.BK.E	-0.337	0.021
RCT.CI.N	-0.161	0.018	RCT.CI.E	-0.160	0.018	RDM.AZ.N	0.094	0.016	RDM.AZ.E	0.074	0.016
RFSB.BK.N	-0.177	0.021	RFSB.BK.E	0.085	0.070	RIN.CI.N	-0.407	0.017	RIN.CI.E	-0.358	0.019
RINB.CI.N	-0.455	0.019	RINB.CI.E	-0.390	0.019	RIO.CI.N	-0.185	0.016	RIO.CI.E	-0.199	0.016
RPV.CI.N	-0.222	0.016	RPV.CI.E	-0.324	0.016	RRX.CI.N	-0.270	0.016	RRX.CI.E	-0.345	0.016
RSB.CI.N	-0.127	0.016	RSB.CI.E	-0.181	0.017	RSS.CI.N	-0.174	0.016	RSS.CI.E	-0.206	0.016
RUS.CI.N	-0.354	0.016	RUS.CI.E	-0.349	0.016	RVR.CI.N	0.233	0.016	RVR.CI.E	0.168	0.016
RXH.CI.N	-0.129	0.025	RXH.CI.E	-0.106	0.025	S04C.TA.N	-0.071	0.028	S04C.TA.E	-0.081	0.031
S05C.TA.N	-0.209	0.023	S05C.TA.E	-0.179	0.024	S06C.TA.N	-0.092	0.029	S06C.TA.E	0.013	0.028
S08C.TA.N	0.167	0.052	S08C.TA.E	0.115	0.046	SAL.CI.N	-0.484	0.017	SAL.CI.E	-0.437	0.017
SAN.CI.N	-0.355	0.017	SAN.CI.E	-0.339	0.016	SAO.BK.N	0.170	0.021	SAO.BK.E	0.104	0.021
SBB2.CI.N	0.272	0.020	SBB2.CI.E	0.186	0.022	SBC.CI.N	-0.123	0.016	SBC.CI.E	-0.130	0.017
SBI.CI.N	0.099	0.018	SBI.CI.E	0.079	0.019	SBPX.CI.N	-0.177	0.016	SBPX.CI.E	-0.103	0.016
SCCB.BK.N	-0.283	0.022	SCCB.BK.E	-0.265	0.022	SCI.CI.N	-0.059	0.026	SCI.CI.E	-0.020	0.024
SCI2.CI.N	-0.160	0.019	SCI2.CI.E	-0.067	0.018	SCZ.CI.N	-0.237	0.032	SCZ.CI.E	-0.186	0.030
SCZ2.CI.N	-0.330	0.021	SCZ2.CI.E	-0.344	0.017	SDD.CI.N	-0.394	0.017	SDD.CI.E	-0.428	0.017

SDG.CI.N	-0.119	0.020	SDG.CI.E	-0.188	0.020	SDP.CI.N	-0.240	0.017	SDP.CI.E	-0.254	0.017
SDR.CI.N	0.169	0.020	SDR.CI.E	0.169	0.020	SES.CI.N	-0.187	0.016	SES.CI.E	-0.252	0.016
SHO.CI.N	-0.417	0.016	SHO.CI.E	-0.412	0.016	SIO.CI.N	-0.458	0.017	SIO.CI.E	-0.406	0.017
SLA.CI.N	-0.172	0.016	SLA.CI.E	-0.269	0.016	SLR.CI.N	-0.114	0.017	SLR.CI.E	-0.104	0.017
SMM.CI.N	-0.225	0.016	SMM.CI.E	-0.239	0.017	SMS.CI.N	-0.283	0.016	SMS.CI.E	-0.283	0.016
SMV.CI.N	-0.358	0.016	SMV.CI.E	-0.347	0.016	SNCC.CI.N	0.231	0.019	SNCC.CI.E	0.189	0.019
SND.AZ.N	-0.145	0.016	SND.AZ.E	-0.221	0.016	SOL.AZ.N	-0.397	0.020	SOL.AZ.E	-0.331	0.019
SOT.CI.N	-0.282	0.028	SOT.CI.E	-0.217	0.029	SPF.CI.N	-0.027	0.016	SPF.CI.E	-0.062	0.016
SPG.CI.N	0.252	0.019	SPG.CI.E	0.185	0.019	SPG2.CI.N	0.299	0.038	SPG2.CI.E	0.185	0.019
SRN.CI.N	-0.151	0.016	SRN.CI.E	-0.174	0.016	SSW.CI.N	-0.601	0.025	SSW.CI.E	-0.554	0.024
STC.CI.N	-0.282	0.015	STC.CI.E	-0.301	0.015	STG.CI.N	-0.345	0.018	STG.CI.E	-0.316	0.017
STS.CI.N	-0.512	0.016	STS.CI.E	-0.470	0.016	SUTB.BK.N	-0.243	0.030	SUTB.BK.E	-0.352	0.035
SVD.CI.N	-0.102	0.016	SVD.CI.E	-0.076	0.016	SWS.CI.N	-0.018	0.018	SWS.CI.E	-0.039	0.018
SYP.CI.N	-0.231	0.016	SYP.CI.E	-0.265	0.016	TA2.CI.N	-0.312	0.015	TA2.CI.E	-0.236	0.015
TEH.CI.N	0.097	0.016	TEH.CI.E	0.076	0.017	TFT.CI.N	-0.234	0.017	TFT.CI.E	-0.244	0.018
THX.CI.N	-0.537	0.017	THX.CI.E	-0.495	0.017	TIN.CI.N	-0.327	0.019	TIN.CI.E	-0.300	0.019
TOV.CI.N	-0.050	0.016	TOV.CI.E	-0.122	0.016	TRO.AZ.N	-0.298	0.019	TRO.AZ.E	-0.321	0.019
TUQ.CI.N	-0.045	0.018	TUQ.CI.E	-0.142	0.018	USC.CI.N	-0.256	0.016	USC.CI.E	-0.229	0.016
VCS.CI.N	-0.092	0.015	VCS.CI.E	-0.173	0.016	VES.CI.N	-0.029	0.017	VES.CI.E	-0.027	0.017
VTV.CI.N	-0.215	0.017	VTV.CI.E	-0.252	0.016	WBS.CI.N	-0.250	0.016	WBS.CI.E	-0.231	0.016
WDC.BK.N	0.199	0.030	WDC.BK.E	0.260	0.030	WENL.BK.N	-0.177	0.019	WENL.BK.E	-0.186	0.019
WER.CI.N	-0.370	0.022	WER.CI.E	-0.329	0.023	WES.CI.N	-0.448	0.018	WES.CI.E	-0.407	0.018
WGR.CI.N	0.153	0.016	WGR.CI.E	0.204	0.016	WLT.CI.N	-0.517	0.016	WLT.CI.E	-0.521	0.015
WMC.AZ.N	-0.098	0.016	WMC.AZ.E	-0.164	0.016	WSS.CI.N	-0.520	0.017	WSS.CI.E	-0.512	0.016
WTT.CI.N	-0.429	0.016	WTT.CI.E	-0.381	0.016	YAQ.AZ.N	-0.007	0.018	YAQ.AZ.E	-0.058	0.018
YBH.BK.N	0.243	0.050	YBH.BK.E	0.243	.046						

Appendix C. CISN -logA_0(r) FORTRAN Function. See also SP1 in the electronic supplement.

```
      real*8 function CISN_mlAo( rdist )
c
c ...... calculate CISN -logAo ML attenuation function
c
      implicit none
      integer*4 j
      real*8 rdist, TP(6), mlogAo, T, z, x, CISN_mlAo, b, logAo
c
      TP( 1 ) = +0.056d0
      TP( 2 ) = -0.031d0
      TP( 3 ) = -0.053d0
      TP( 4 ) = -0.080d0
      TP( 5 ) = -0.028d0
      TP( 6 ) = +0.015d0
c
      if( rdist .le. 0.1d0 ) then
c
c ...... invalid for rdist less that 0.1 km
c        return with -9.d0
c
        mlogAo = -9.d0
c
      elseif( rdist .le. 8.d0 ) then
c
c ...... linear extrapolation of average slope between 8 km and 60 km
c
        b = ( 2.6182d0-1.5429d0)/(dlog10(60.d0)-dlog10(8.d0))
        mlogAo = 1.5429d0 + b * ( dlog10( rdist ) - dlog10( 8.d0 ) )
c
      elseif( rdist .le. 500.d0 ) then
c
c ...... Chebychev polynomial expansion
c
        x = z( rdist )
        mlogAo = logAo( rdist ) + 0.0054d0
        do j = 1 , 6
          mlogAo = mlogAo + TP( j ) * T( j , x )
        end do
c
      else
c
c ...... invalid for rdist greater than 500 km
c        return with -9.d0
c
        mlogAo = -9.d0
c
      endif
c
      CISN_mlAo = mlogAo
c
      return
      end
```

```
      real*8 function T( n , x )
c
c ...... Chebyshev Polynomial
c
      implicit none
      integer*4 n
      real*8 T, x, theta
c
      theta = dacos( x )
      T = dcos( dble( n ) * theta )
c
      return
      end

      real*8 function z( r )
c
c ...... translate scale from r to z
c
      integer*4 ncall
      real*8 r, r0, r1, z0, z1, a , b, l_r0, l_r1
c
      data ncall /0/
      data r0,r1 /8.d0,500.d0/
      data z0,z1 /-1.d0,+1.d0/
c
      if( ncall .eq. 0 ) then
        l_r0 = dlog10( r0 )
        l_r1 = dlog10( r1 )
        b = ( z1 - z0 ) / ( l_r1 - l_r0 )
        a = z0 - b * l_r0
        ncall = 1
      endif
c
      z = a + b * dlog10( r )
c
      return
      end

      real*8 function logAo( rdist )
c
c ...... -logAo attenuation function
c
      implicit none
      real*8 rdist, logAo

c
      logAo = 1.11d0 * dlog10( rdist ) +
     1   0.00189d0 * rdist + 0.591d0
c
      return
      end
```

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October 12, 2010

Re: BSSA-D-10-00106

Dear Cezar,

The reviewer's comments were most helpful in improving the manuscript and we have incorporated their suggestions into the attached revision.

Thank you.

Sincerely,

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