Seismic coda-derived source properties of small earthquakes near Rock Valley, Nevada

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Background

The Rock Valley Direct Comparison experiment aims to understand the seismic differences between earthquakes and chemical explosions for applications in nuclear monitoring. To analyze these differences, the seismic context of the study area must be well understood. To that end, we studied the nature of earthquake source properties of historic events near the Nevada National Security Site to better constrain the magnitudes of the 1993 Rock Valley earthquake sequence, which contains the target event for the RV/DC experiment.

Data

Waveform data was provided by LLNL, which processes the data collected at NNSS. Waveforms from 20 stations concentrated near Rock Valley were analyzed (Figure 3). Pre-processing of the waveforms consisted of removing the instrument response and configuring the SAC header of each waveform to allow the files to be fed into CCT.

Methodology – Coda Calibration Tool

We used the Coda Calibration Tool (CCT) to produce moment-rate spectra for our dataset. CCT generates the S-wave coda envelopes in frequency bands specified by the user, then automatically determines the peak of the envelope using the S-pick time as a reference. The envelope is fit using parameters controlling the slope, peak, and curvature of the envelope. Since the seismic coda averages the heterogeneity of the sampled crust, CCT corrects for distance by minimizing the scatter between stations.

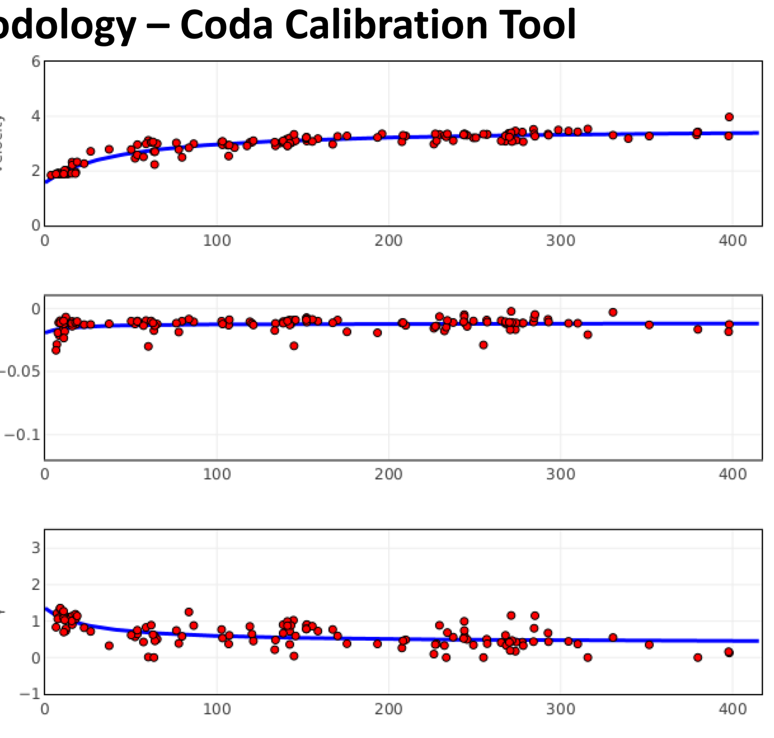


Figure 1 (left). Calibration shape parameters fitting (from top to bottom) the amplitude, distance dependence, and early decay of the envelope.

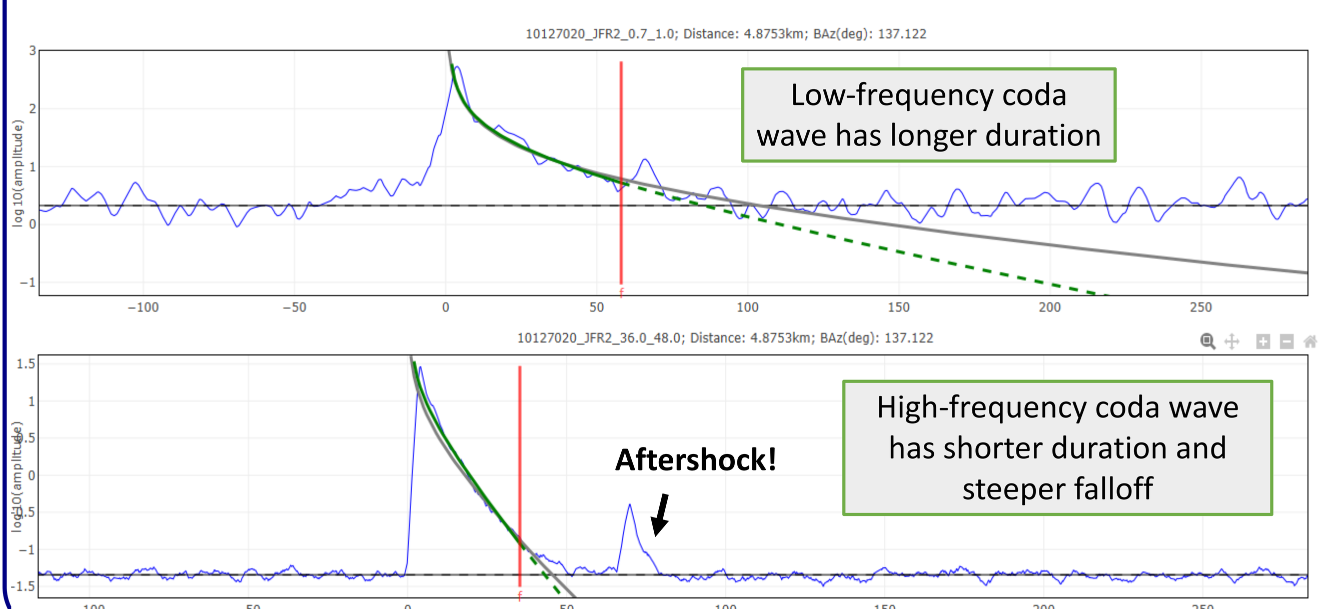


Figure 2 (left). Examples of coda envelopes for different frequency bands (top: 0.7-1.0 Hz; bottom: 36-48 Hz). The blue line indicates the spectral amplitude of the waveform, and the green line shows the fit. The red vertical line indicates the user-defined end of the fitted coda envelope.

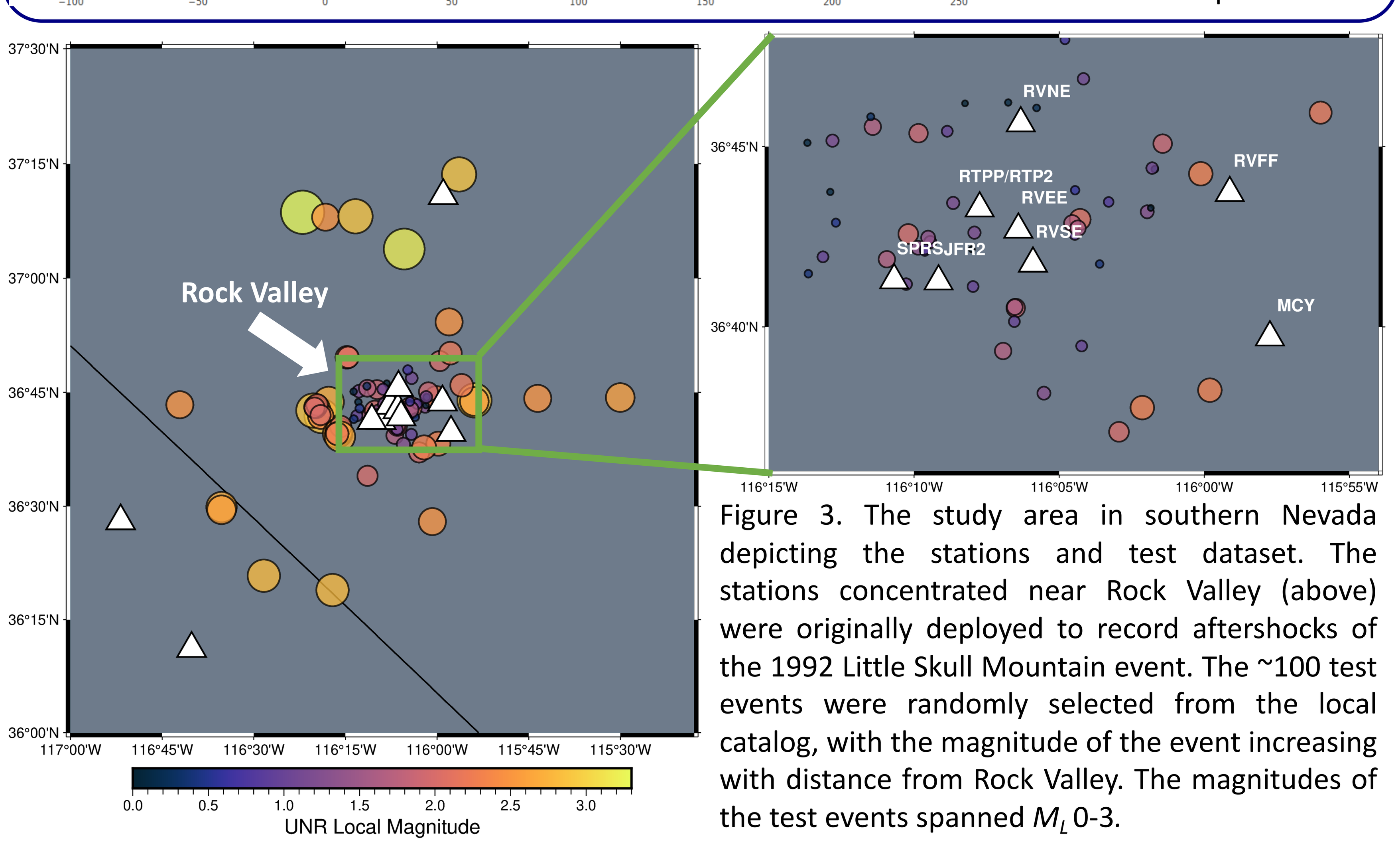


Figure 3. The study area in southern Nevada depicting the stations and test dataset. The stations concentrated near Rock Valley (above) were originally deployed to record aftershocks of the 1992 Little Skull Mountain event. The ~100 test events were randomly selected from the local catalog, with the magnitude of the event increasing with distance from Rock Valley. The magnitudes of the test events spanned M_L 0-3.

Results

CCT successfully calculated moment-rate spectra for many events $M_L < 3$. To best constrain these results, envelope bands up to 48 Hz were used (with 50 Hz being the Nyquist frequency of many stations). For stations sampling at 200 Hz, frequency bands of up to 80 Hz were tested, but produced results no better than those using 48 Hz. Prior to this project, CCT had not been used to calculate spectra on a scale this small since it is difficult to find a study site with dense and permanent station coverage. Having a station within ~10 km of the source is incredibly important for using high-frequency envelopes since high frequency energy is attenuated quickly.

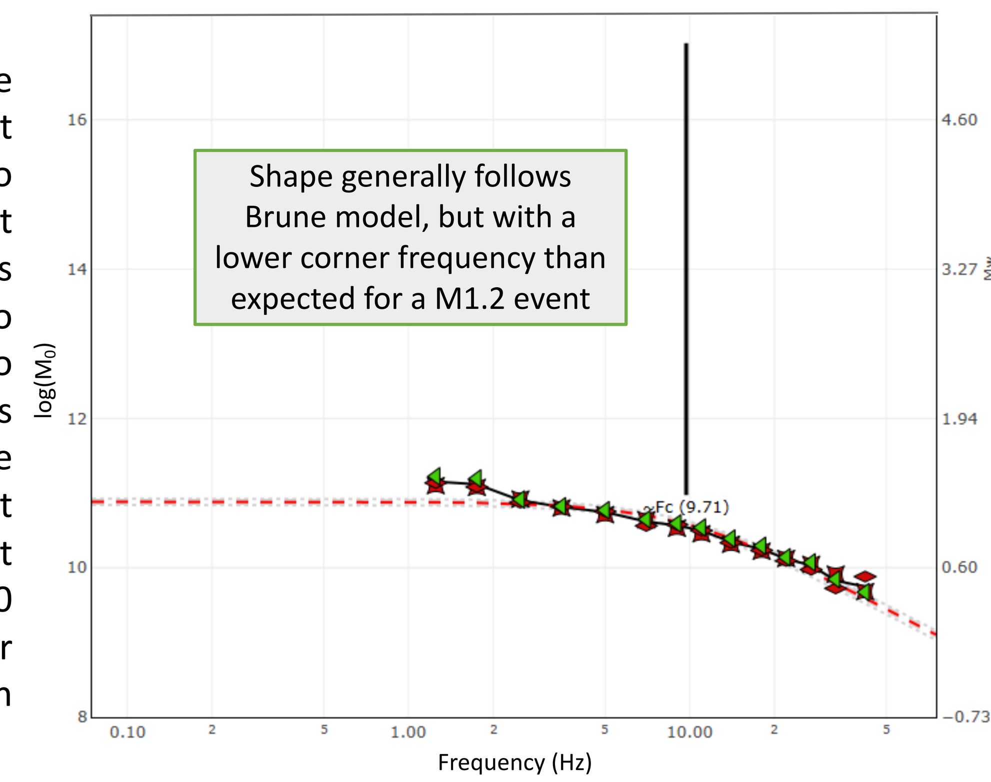


Figure 4 (left). Example of moment-rate spectrum produced by CCT, with $M_W = 1.19$, and a corner frequency of 9.7Hz.

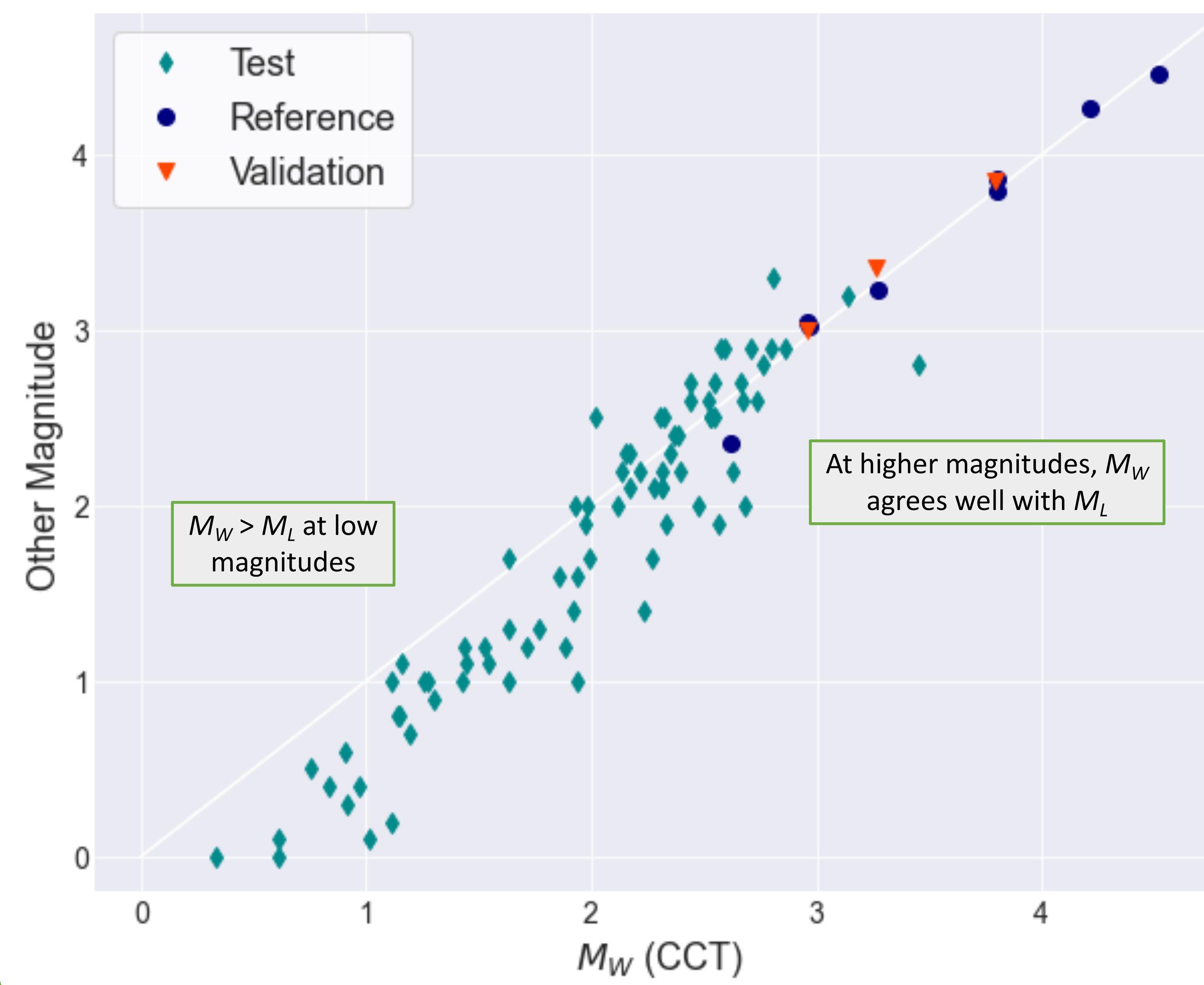


Figure 6 (left). Comparison of CCT-calculated M_W with independent M_W estimates (in the case of the reference and validation events) or local magnitude estimates (for the test dataset). Green diamonds represent test events, while blue circles and red triangles represent reference and validation events, respectively.

Comparing to the Local Catalog

Below M_L ~2.3, CCT calculated M_W to be systematically higher than the existing M_L catalog. Around M_L ~2.3, the scatter in M_W estimates decreased significantly, corresponding to the magnitude of the smallest reference event. Good agreement existed between $M_{W,CCT}$ and $M_{W,ind.}$ for all but the smallest reference event (Figure 6). A linear fit at small ($M < 2.5$) magnitudes shows a slightly decreasing difference between M_W and M_L as the event size increases (Figure 6).

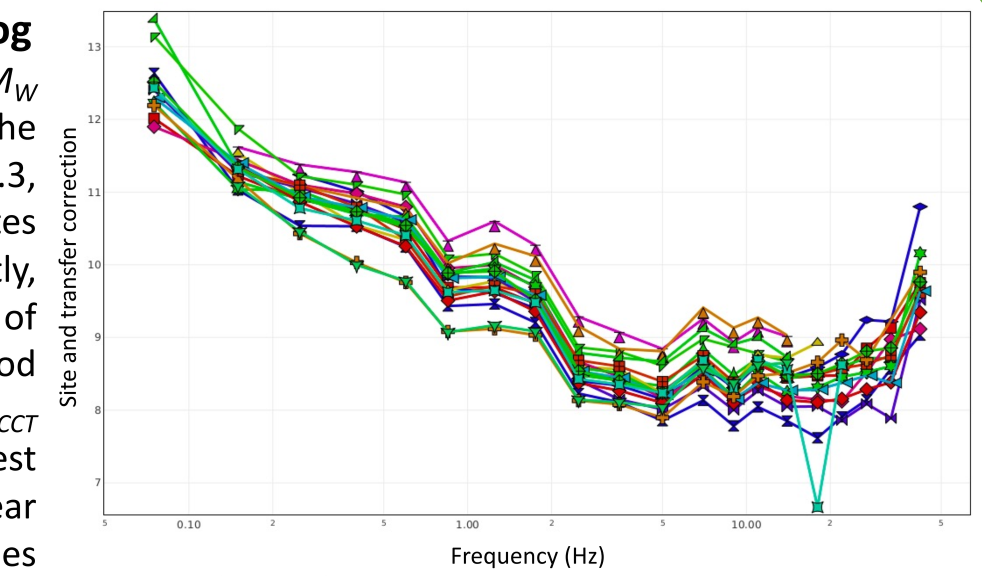


Figure 5 (above). Site and transfer corrections for the calibration dataset in different frequency bands from 0-48Hz. Each symbol represents a station.

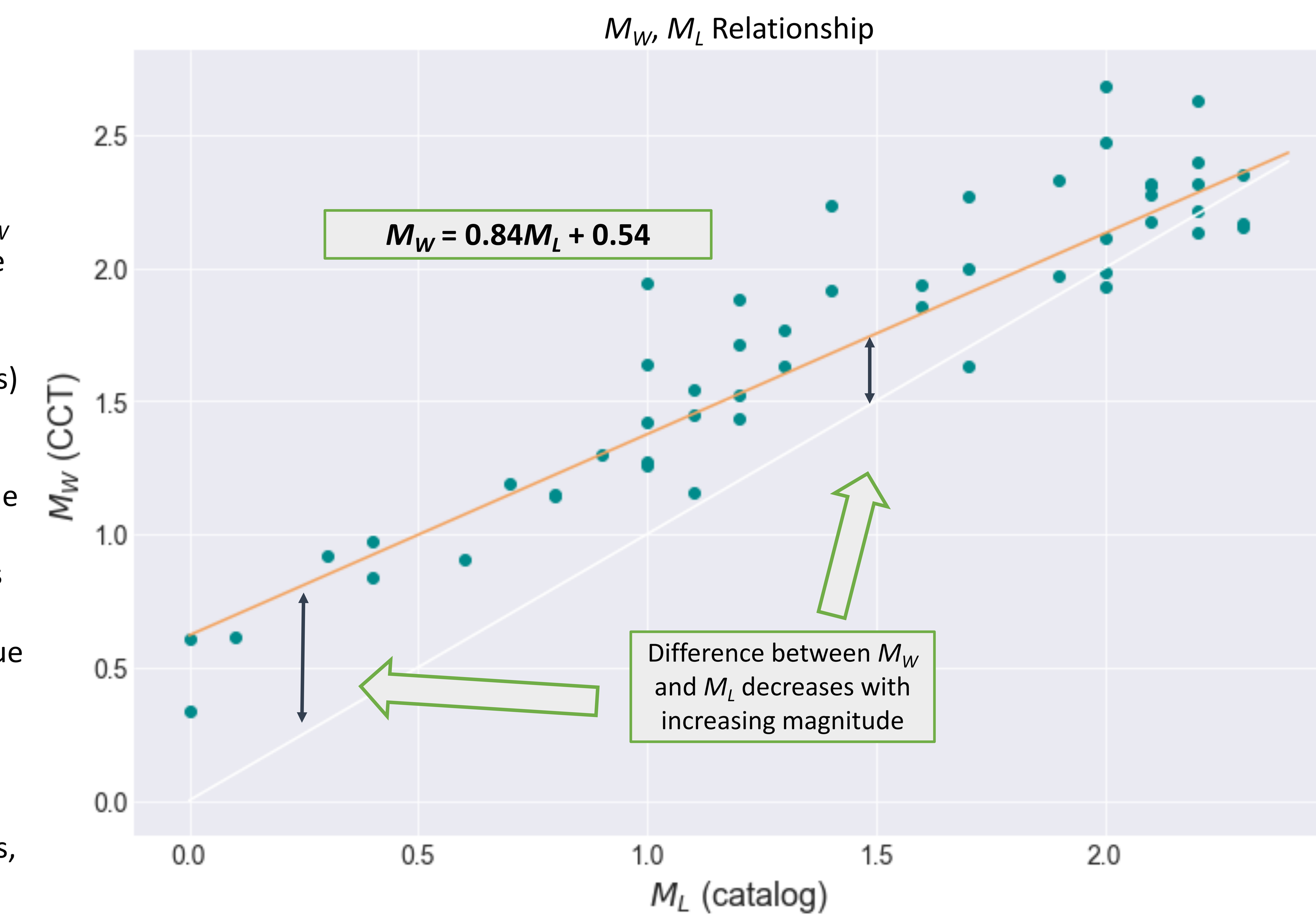
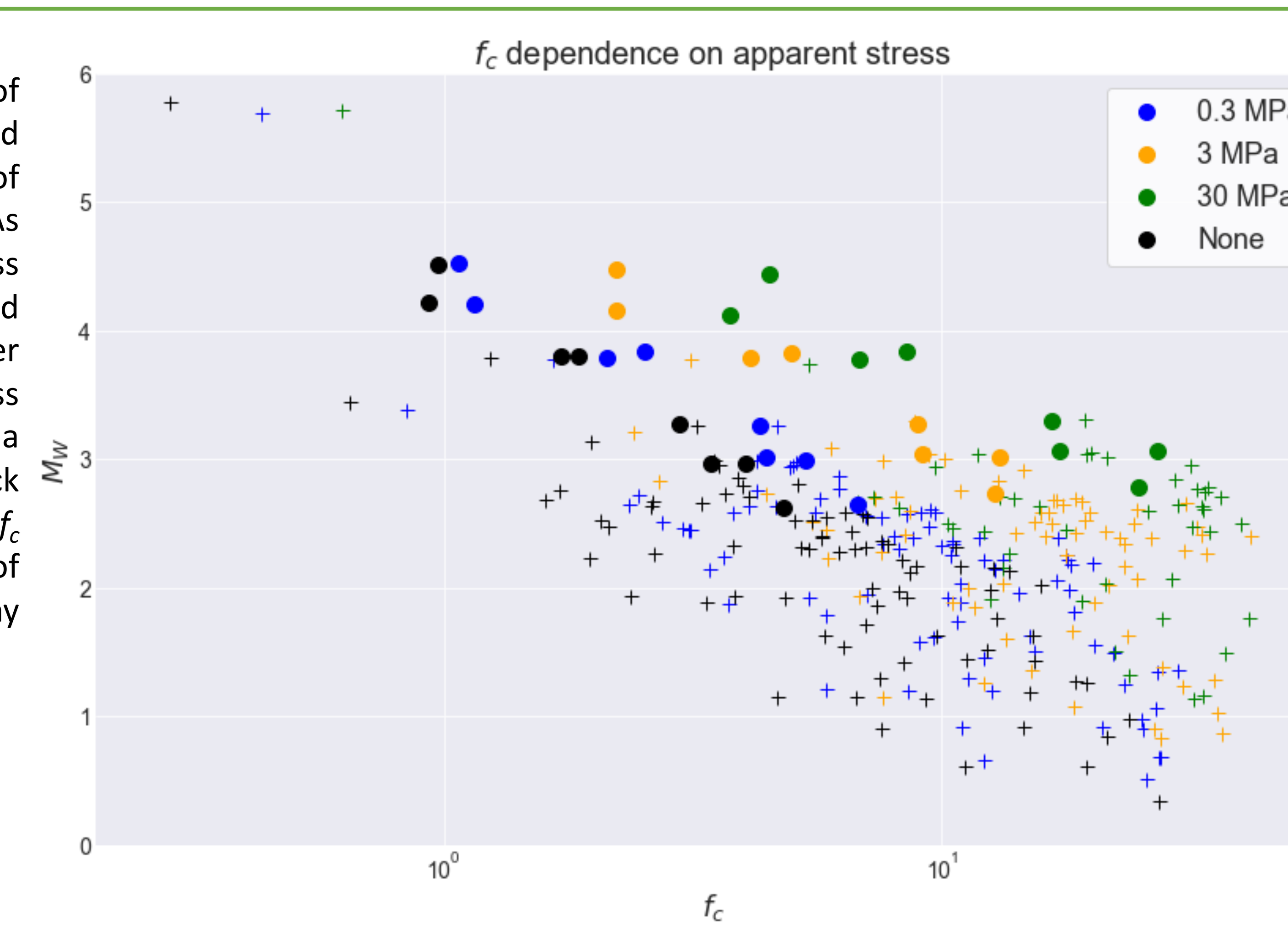


Figure 7 (left). Linear fit (orange line) of M_W as a function of M_L. For small events, M_W is higher than M_L by about half of a magnitude unit, whereas at events above M_L~2.3, the scatter in measurements decreases and M_W and M_L generally agree well.

Introducing Reference Apparent Stress

M_W was recalculated with different values of apparent stress assigned to the reference and validation events to determine the effect of apparent stress on source parameters. As expected, increasing the reference stress increased the estimated corner frequency, and slightly increased M_W for small events. For larger events ($M_W > 3.5$), increasing the apparent stress resulted in slightly lower M_W estimates. Without a reference, the estimated corner frequency (black symbols in Figure 8) was below the f_c corresponding to the smallest reference value of 0.3MPa. This result suggests that CCT may underestimate the true apparent stress.

Figure 8 (right). The dependence of M_W and f_c on reference apparent stress for both the reference (circles) and test (crosses) datasets. Blue, yellow, and green points indicate different levels of reference stress. Gray points are the events without reference stress.



Conclusions & Future Directions

We conclude that **(1) CCT produces reasonable M_W estimates for very small earthquakes**, and **(2) a linear relationship exists between CCT's M_W and the Nevada Seismological Laboratory's M_L for $M < 2.5$**. Additionally, introducing reference apparent stress values controlled the estimated corner frequency, but had little impact on M_W estimates. Future study will aim to:

- Better constrain event depth to increase understanding of spectral shape of shallow events
- Analyze the uncertainty in M_W estimates
- Obtain independent estimates of apparent stress

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