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WESTON GEOPHYSICAL

VALIDATION OF SOURCE SCALING USING GROUND MOTIONS
From the 2008 Wells, Nevada Earthquake Sequence

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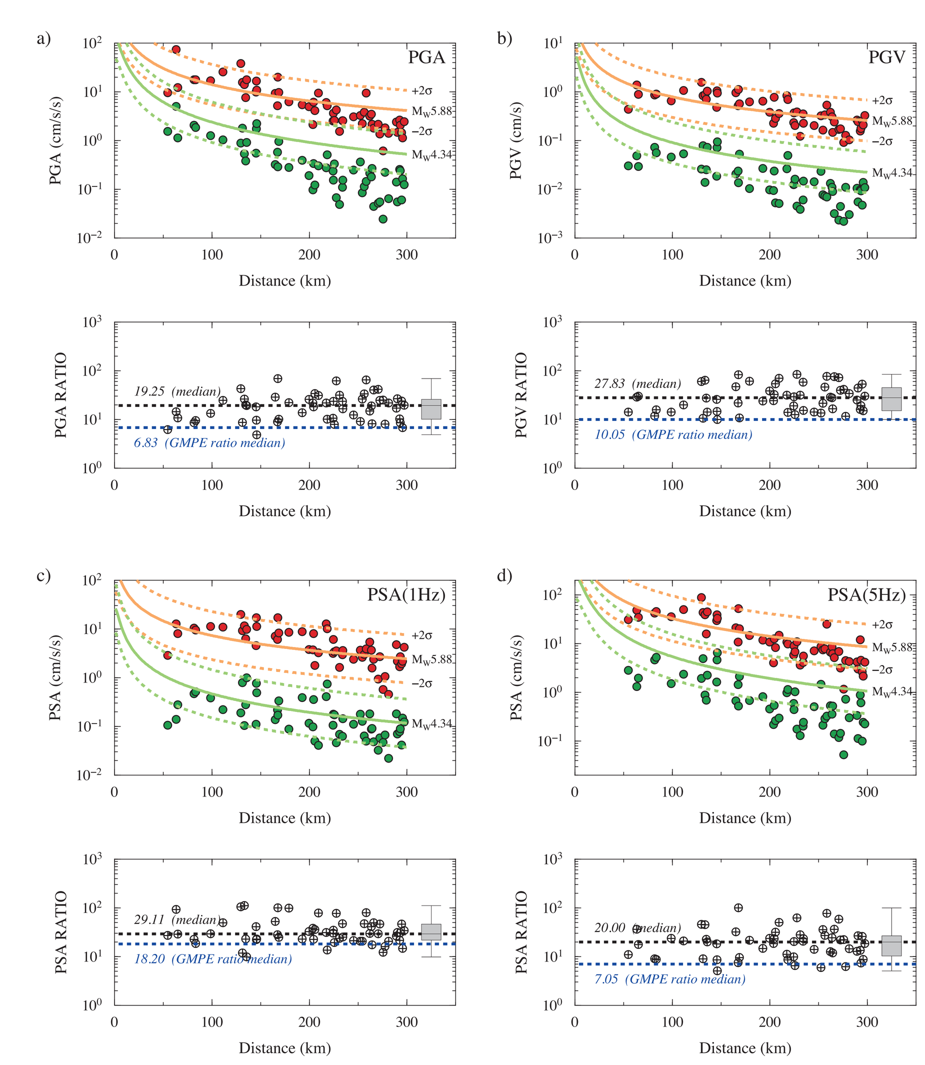
Why is the Wells sequence interesting?

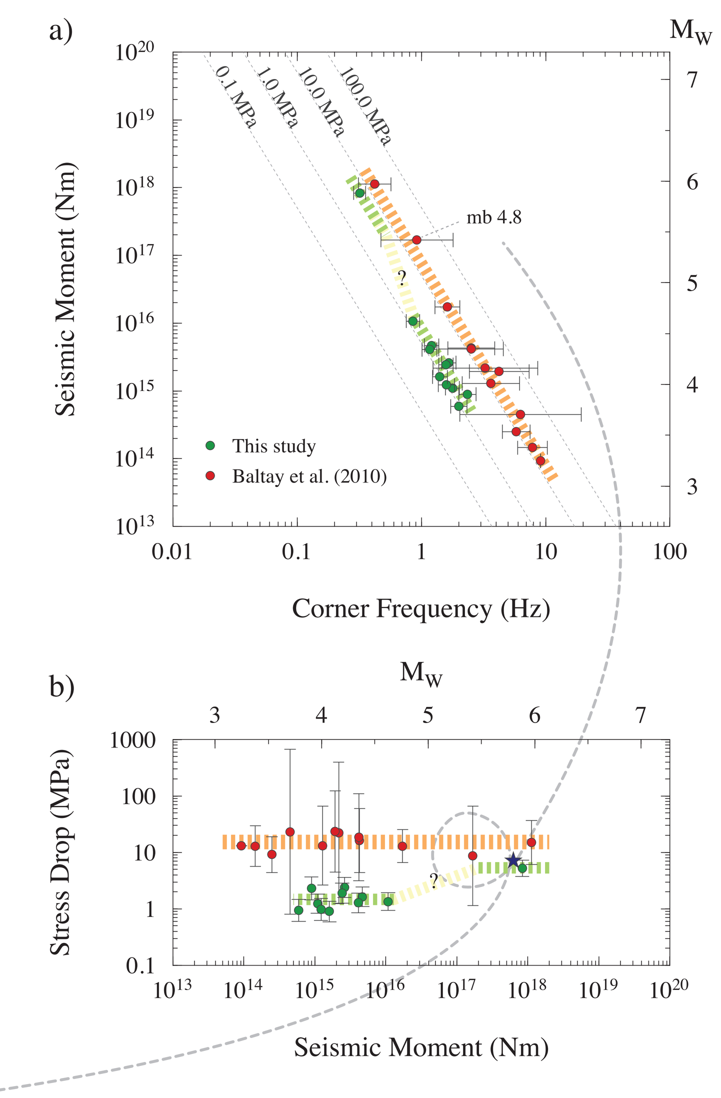
What's wrong with GMPEs?



LEFT: Ground-motions from the mainshock and an Mw 4.3 aftershock that occurred the day after the mainshock were evaluated by Petersen *et al.* (2011) using the ground-motion prediction equation (GMPE) (Campbell and Bozorgnia, 2008). They found that the aftershock's ground-motions were systematically overestimated by the GMPE while the ground-motions from the mainshock agreed relatively well with the predicted values. Observed ratios of ground-motions of the two earthquakes are about 2-to-3 times larger than those predicted from the NGA ground-motion model.

RIGHT: For this earthquake sequence, two different source scaling relations were reported by Mayeda and Malagnini (2010) and Baltay *et al.* (2010) both based on coda envelope measurements, but very different methods. Mayeda and Malagnini (2010) applied a coda spectral ratio method to closely located event pairs and found a non-self-similar scaling (6.5 MPa static stress drop for the mainshock and 2-5 times smaller values for the aftershocks). Baltay *et al.* (2010) applied an empirical Green's function calibration method to obtain coda-derived source spectra (e.g., Mayeda and Walter, 1996; Mayeda *et al.*, 2003) and found about 15 MPa constant static stress drop for the mainshock and its aftershocks (A. Baltay, pers. comm., August, 2011) and concluded that there was no dependence of the source scaling on magnitude (Baltay et al., 2010).

Is source scaling self-similar? Or not?



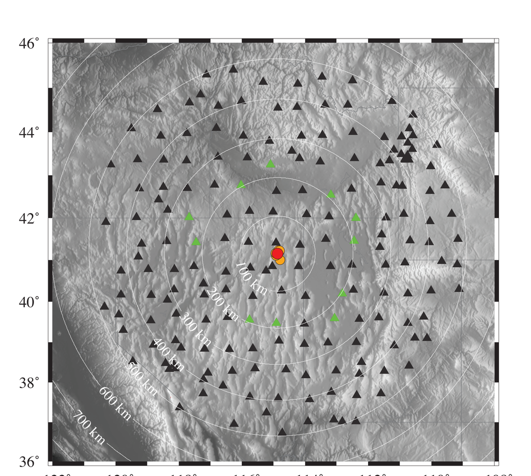
NOTE The first ratio is for an aftershock that occurred within 5 minutes of the mainshock and is severely contaminated for frequencies last than 1-Hz and was therefore not used.

ABSTRACT

The behavior of earthquake source scaling has been the topic of significant debate in the earthquake source community over the past two decades and validating recent results has been difficult. In this study we focus on high quality records from the Mw 5.9 Wells, Nevada earthquake of February 21, 2008, and its aftershocks which provide an unprecedented opportunity to take an in-depth look at the source scaling and ground-motions. For this earthquake sequence, conflicting scaling relations were reported in two previous studies (Mayeda and Malagnini, 2010; Baltay *et al.*, 2010). In addition, recent comparisons of the ground-motion prediction equations (GMPEs) with this data set have shown significant overestimation of ground-motions for the aftershocks, while being in rough agreement with the mainshock ground-motions (Petersen *et al.*, 2011). In order to evaluate the reported scaling relationships and better understand the observed discrepancy in the GMPE's, we chose to revisit the Wells, NV earthquake sequence. We investigate the source parameters of the earthquakes using the *S*-wave and coda spectral ratio methods (Mayeda *et al.*, 2007) and find that the stress drops of the aftershocks are 2-5 times lower than that of the mainshock. We compute pseudo spectral acceleration (PSA) ratios using direct *S*-waves from broadband records and compare with theoretical source ratios assuming the self-similar and non-self-similar source scaling assumptions as well as ratios derived from state-of-the-art GMPE estimates. We find that we can only simultaneously match source ratios between the mainshock and selected aftershocks if we use non-self-similar scaling . Accounting for the significant differences in the stress drop between the small and large earthquakes will help to enhance the prediction capability of ground-motions for this region. By validating the source scaling with PSA ratios, these results can be used as constraints in stress parameterization used in the GMPE's.

Revisiting the Wells, Nevada sequence

More Data

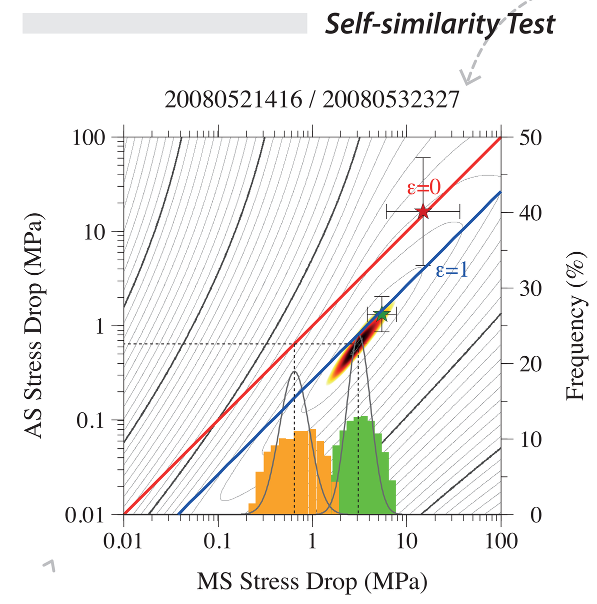


LEFT: Map of stations (triangles) within 500 km of the 2008 Wells, Nevada mainshock (red circle) and those used in the coda ratio measurement (green triangles). The orange circles indicate the 11 aftershocks.

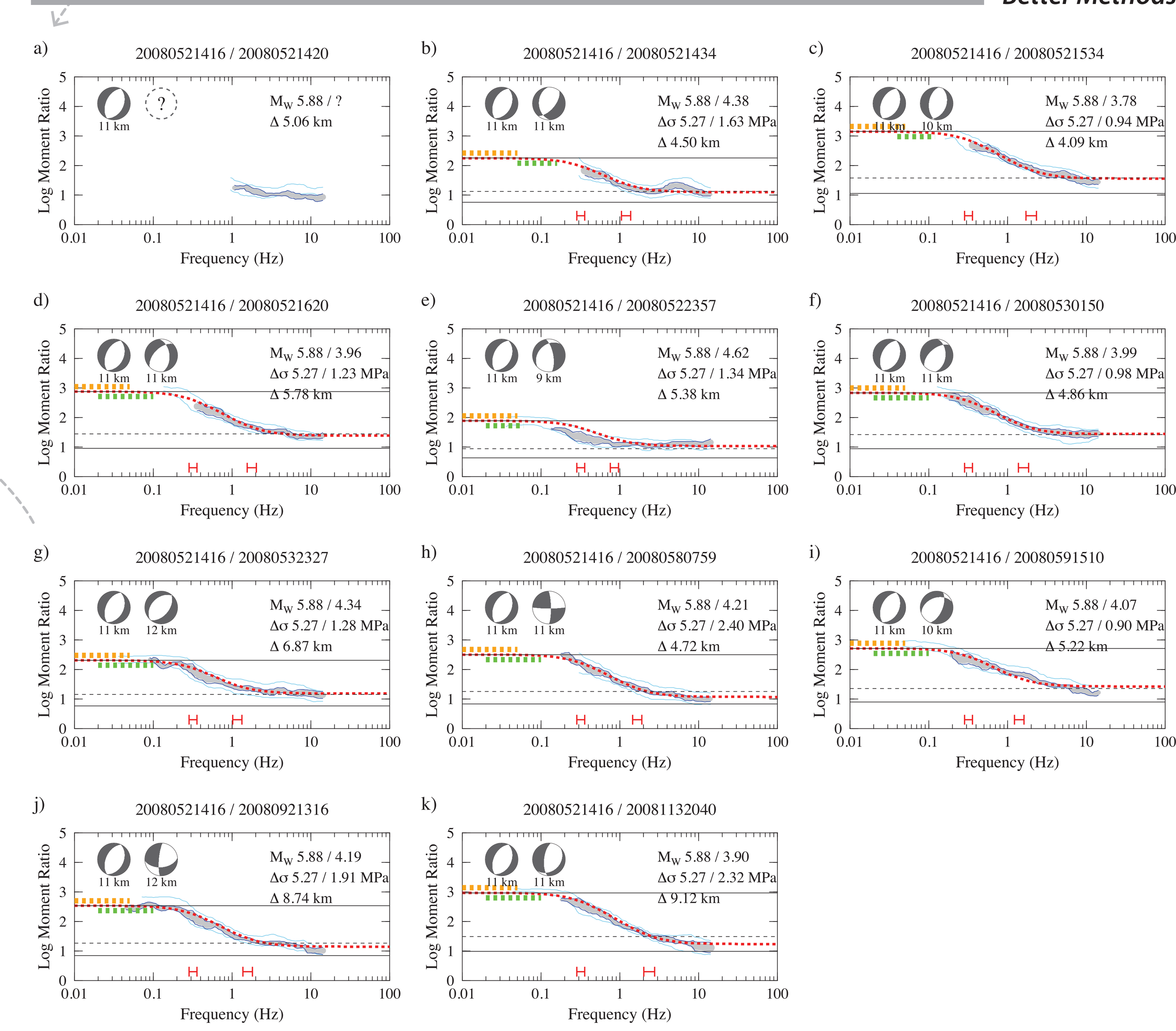
RIGHT: The averaged spectral ratios for the mainshock relative to the aftershocks are shown as light-blue lines from direct S-waves and gray shaded regions from coda-waves (±1 standard deviation). Red dotted curves represent the best fitting spectral ratios and red horizontal error bars indicate corner frequency estimates for both the mainshock and aftershocks. Orange and green dotted lines below 0.1 Hz indicate the frequency bands used in regional moment tensor analysis for the mainshock and aftershocks, respectively (R. Herrmann, pers. comm., 2008). Δ is the epicentral distance of the two events, focal mechanisms and depths are from the SLU moment-tensor catalog.

LEFT: Misfit error surface. We see that the area of the global minimum clearly departs from the diagonal, 1-to-1 line (red diagonal line) and instead is closely located to the non-self-similar asymptote (blue diagonal line).

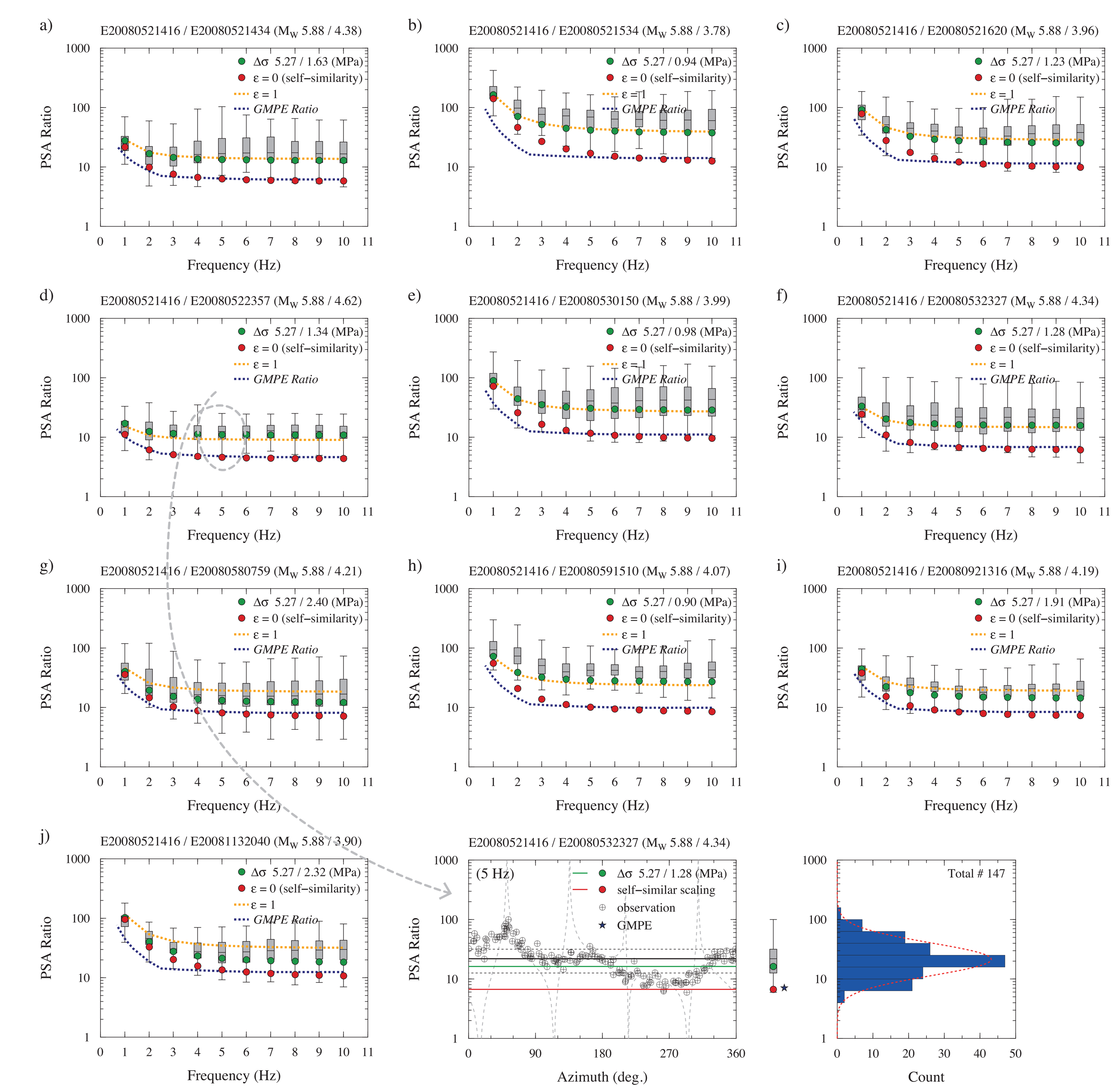
Self-similarity Test



Better Methods



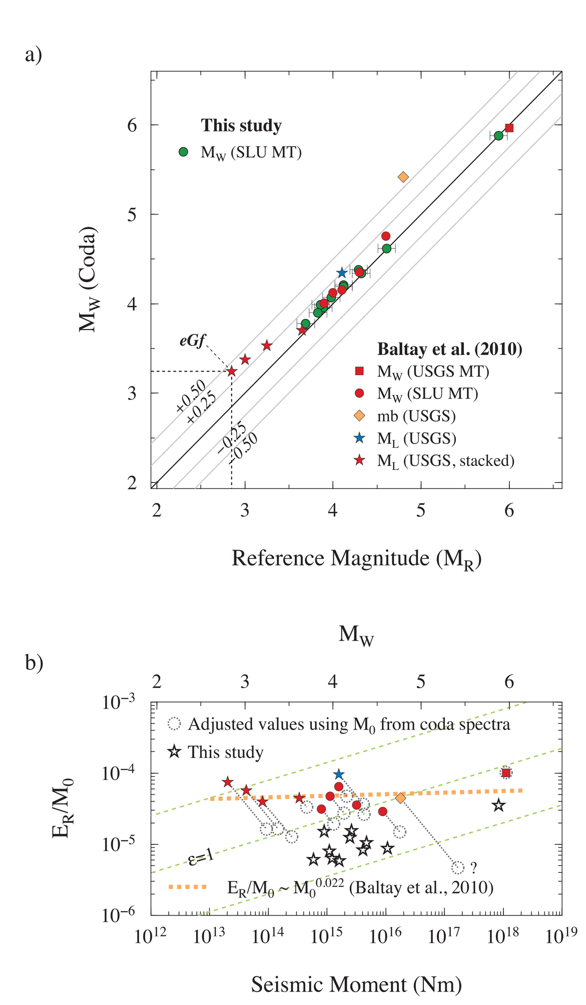
VALIDATION: Scalings & Ground-Motions



ABOVE: PSA ratios between the mainshock and 10 aftershocks from 1 to 10-Hz. Vertical gray boxes indicate median values of the data distribution where 50 % of the observed data is distributed in each gray box. Green circles represent the theoretical predictions from our results. Orange doted lines represent the predictions based upon non-constant scaling (e.g., Mayeda and Walter, 1996) and red circles represent the case of self-similar scaling (e.g., Baltay et al., 2010). It is clear that the predictions from self-similar scaling and GMPEs do not match the observed PSA ratios.

DISCUSSION: What causes the differences in souce scaling?

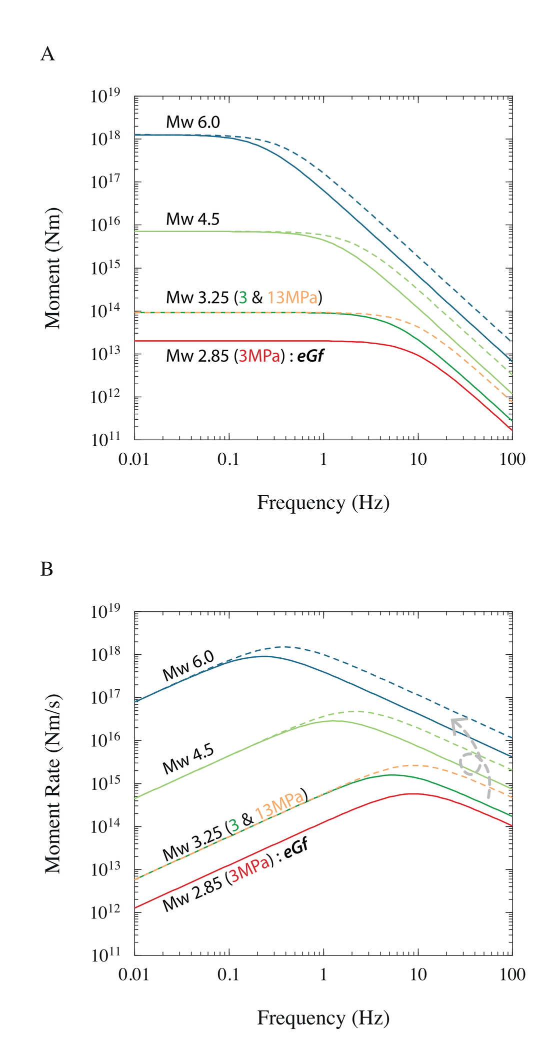
Magnitude and Seismic Moment



(a) Reference magnitude from the SLU moment-tensor (this study) and NEIC (Baltay *et al.*, 2010) catalog versus coda-derived moment magnitude from each study. The mb 4.8 event (yellow diamond) represents a significant outlier and is roughly 10 times larger in seismic moment before and after the Baltay *et al.* (2010) calibration. Smallest red star represents the eGf event that was used to derived spectral shape corrections for the Baltay *et al.* (2010) coda-derived source spectra. We see however, that after calibration, the eGf event shows a factor 5 larger seismic moment.

(b) Scaled energy comparison between original values in Baltay *et al.* (2010) and adjusted values (dotted circles) using seismic moment estimates from their coda-derived source spectra. Green dotted line based upon the Baltay *et al.* (2010) results will not match the adjusted data points. We note that the mb 4.8 event (yellow diamond) should be removed due to severe contamination at long periods (< 1.0-Hz). Lines with appear to fit the data trend, but we believe the absolute levels of Baltay *et al.* (2010) are biased high due mostly to the 13 MPa eGf assumption.

eGf Correction



Because there was a significant amount of corrections applied to their source spectra, (e.g., roughly a factor of 5 in seismic moment), the smallest stacked event, their so-called empirical Green's function event, has a much higher Brune stress drop than the original assumption of 3 MPa, and is actually 13.02 MPa even though its corner frequency is still 9.08-Hz based upon the assumption of 3 MPa stress drop for an M 2.85 event. In simple terms, this is equivalent to assuming a 13.02 MPa stress drop for an Mw 3.25 eGf event. We suspect that this 13.02 MPa stress drop assumption resulted in erroneously high stress drops for all subsequent larger earthquakes during the course of their coda-derived source spectral calibration.

CONCLUSION

1. Previous coda-derived scaling studies have shown a departure from self-similarity which if known a priori, can help in MDAC calibration for seismic discrimination.

2. We revist the Wells, NV sequence using a high resolution coda spectral ratio method and find that corner frequency and stress drop do not follow constant scaling.

3. Furthermore, we validated our results using pseudo spectral acceleration (PSA) ratios using direct S-waves and find that we cannot simulataneously fit both the mainshock and aftershocks using self-similar assumptions, including current GMPEs. This is consistent with recent findings from Atkinson and Boore (2011) who found a systematic bias in GMPEs for small to moderate earthquakes in North America.