Further Development and Testing of M_L - M_C as a Depth Discriminant at Local Distances

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1. Abstract

Seismic source discrimination at local distances (< 200 km) is becoming increasingly important within the nuclear monitoring community. A study conducted by Koper et al. (2016) found that the difference between local magnitude (M_L) and coda/duration magnitude (M_C) could distinguish between mining-induced seismicity and natural seismicity in Utah. They found that the shallower mining-induced earthquakes (depths < 2–3 km) had more negative M_L-M_C values than the generally deeper (> 5 km) tectonic events. Similar results showing that M_L-M_C decreases as source depth approaches the surface have recently been found in Yellowstone, Oklahoma, and Italy. Here we investigate how well direct measurements of peak amplitude (A) and duration (τ) made at individual stations can be used as proxies for the network averaged M_L–M_C values. In particular, we investigate how $\log_{10}(A/\tau)$ varies as a function of distance, how quickly the variance decreases as more stations are averaged together, and whether individual station corrections are warranted. We also examine how changes to the procedures used to measure A and τ affect the performance of $\log_{10}(A/\tau)$ as a depth discriminant. We aim to replicate and explain our M_L-M_C observations using a three-dimensional, fourth-order, finite-difference code (SW4) to synthesize high-frequency waveforms in realistic Earth models that contain topographic and volumetric scattering. The ultimate goal of this study is to introduce a new depth discriminant to nuclear monitoring practices that can be applied to all networks and help differentiate mid- and lower- crustal earthquakes from potential explosions.

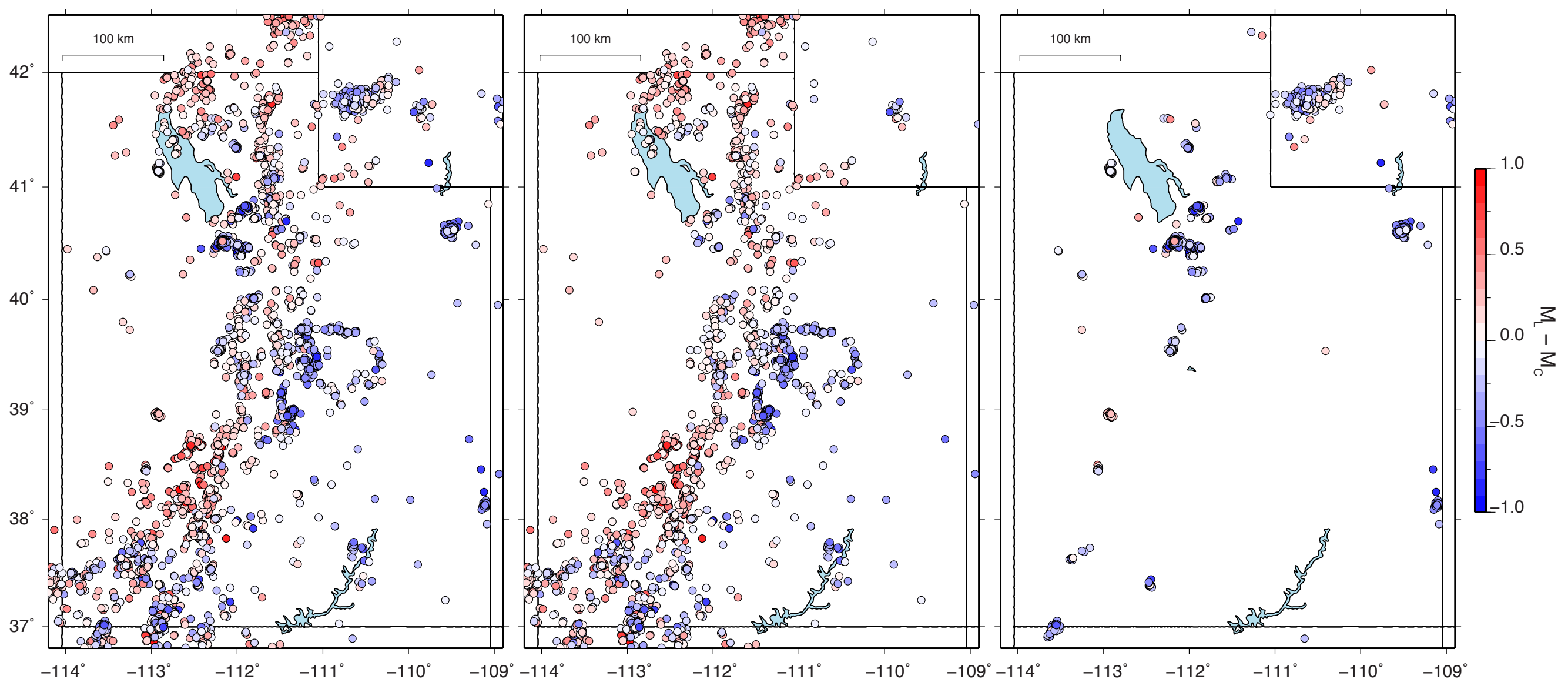


Figure 1: M_L-M_C for seismic events in the Utah region from October 2012 through June 2017. The catalogs are (Left) Earthquakes and blasts, (Middle) earthquakes, and (Right) blasts

2. Magnitudes Review

Quarry Blast
Depth: -2 km
M_L-M_C = -0.81

Calculating Local Magnitude: $M_L = \log A - \log A_0 + S_i$

A = The maximum amplitude (in mm) on a Wood-Anderson seismogram
A_0 = Empirical distance correction
S_i = Empirical station/instrument correction

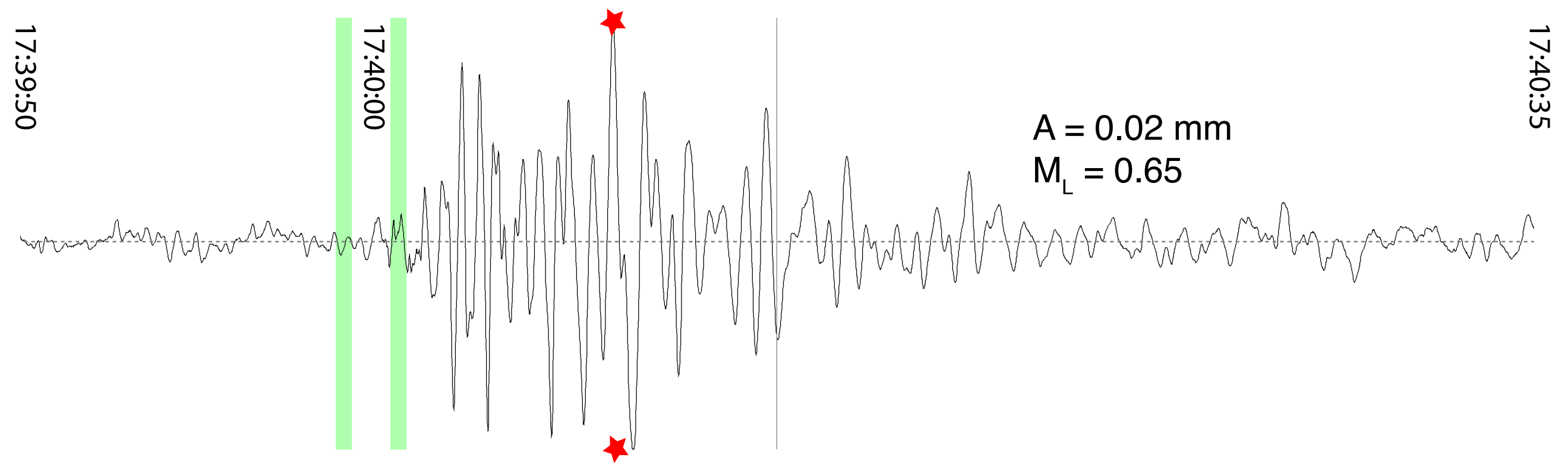


Figure 2: A synthetic Wood-Anderson seismogram for one horizontal component of station JLU. The maximum amplitude is determined by measuring the maximum peak-to-peak amplitude and dividing by 2.

Calculating Coda Magnitude: $M_C = -2.25 + 2.32\log\tau + 0.0023$

τ = The signal duration from the P-wave onset to a threshold ground velocity as measured on a vertical component, short-period seismogram

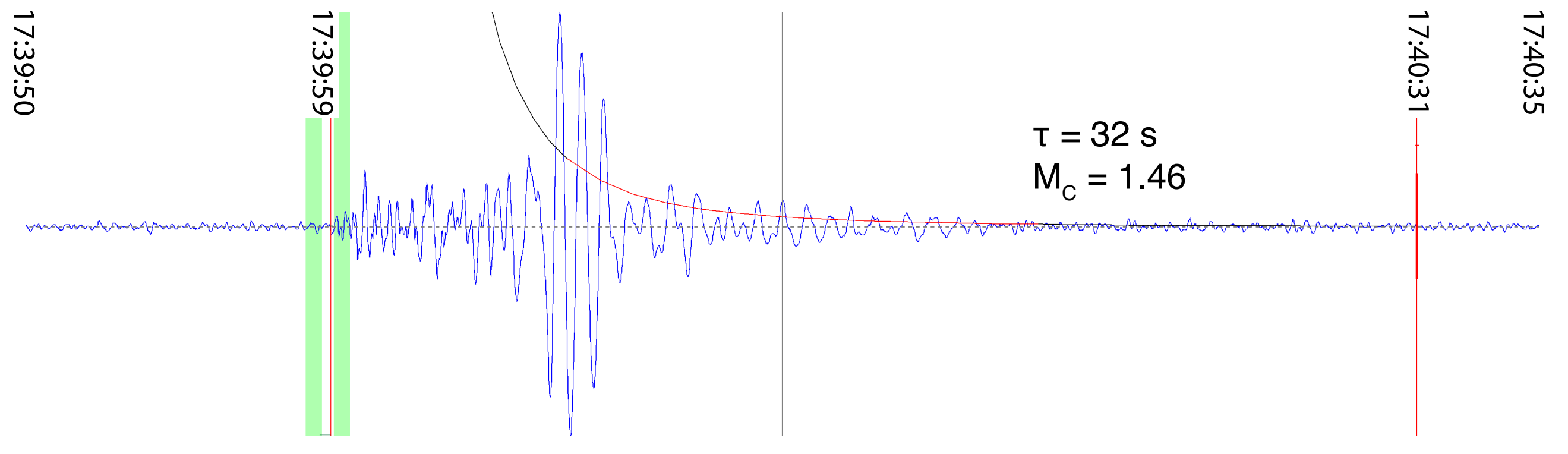
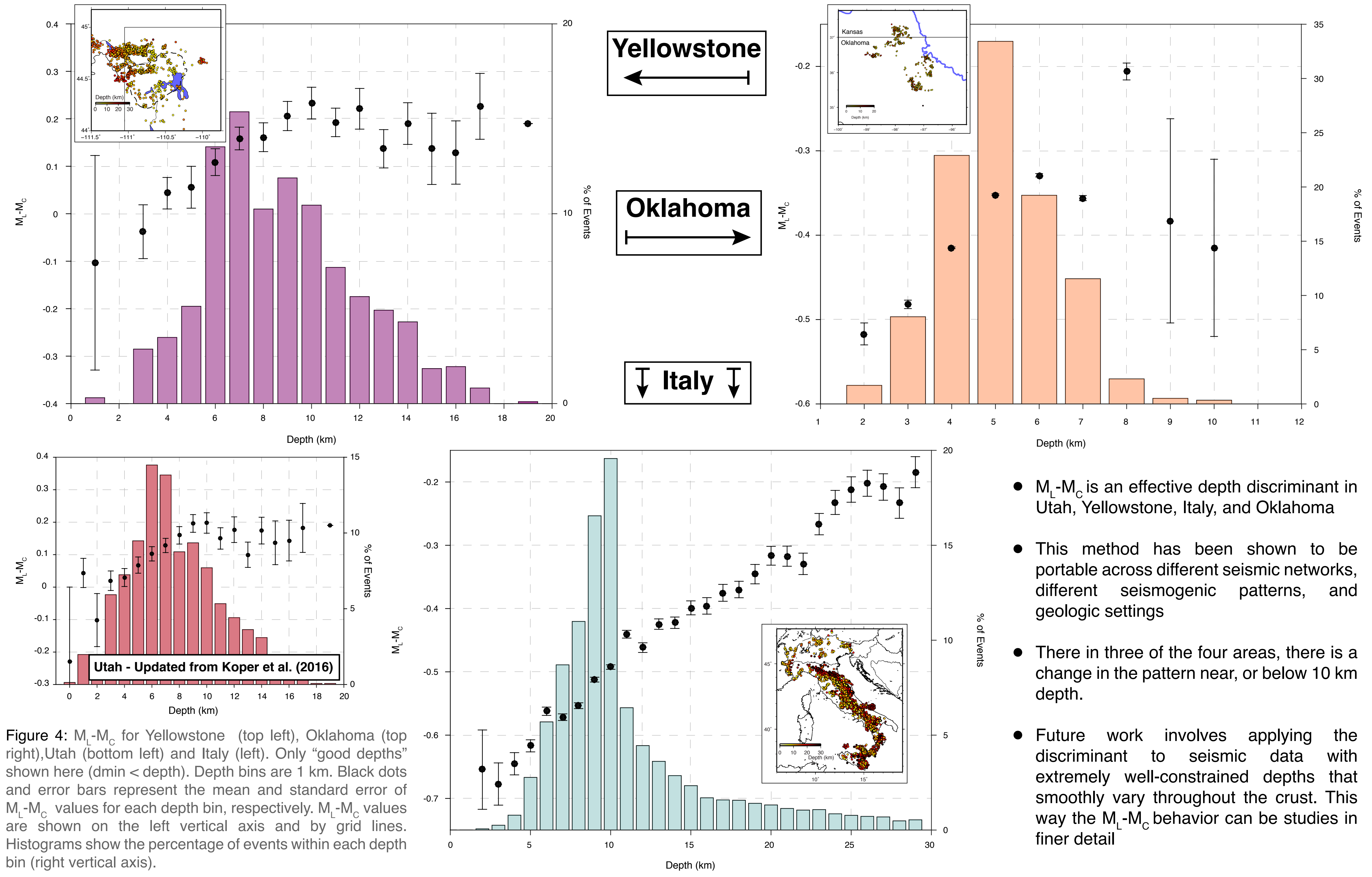


Figure 3: The vertical component of station RCJ filtered from 1-4 Hz for ease of viewing. The duration is determined by fitting the exponential decay of the highest-amplitude portion of the coda to the noise.

3. Portability



- M_L-M_C is an effective depth discriminant in Utah, Yellowstone, Italy, and Oklahoma
- This method has been shown to be portable across different seismic networks, different seismogenic patterns, and geologic settings
- There in three of the four areas, there is a change in the pattern near, or below 10 km depth.
- Future work involves applying the discriminant to seismic data with extremely well-constrained depths that smoothly vary throughout the crust. This way the M_L-M_C behavior can be studies in finer detail

Figure 4: M_L-M_C for Yellowstone (top left), Oklahoma (top right),Utah (bottom left) and Italy (left). Only "good depths" shown here (dmin < depth). Depth bins are 1 km. Black dots and error bars represent the mean and standard error of M_L-M_C values for each depth bin, respectively. M_L-M_C values are shown on the left vertical axis and by grid lines. Histograms show the percentage of events within each depth bin (right vertical axis).

4. Amplitude and Duration Measurements

Amplitude - M_L

- Automatic amplitude measurements closely follow manually-picked amplitude measurements
- A signal-to-noise ratio of 2 is necessary for well-constrained measurements

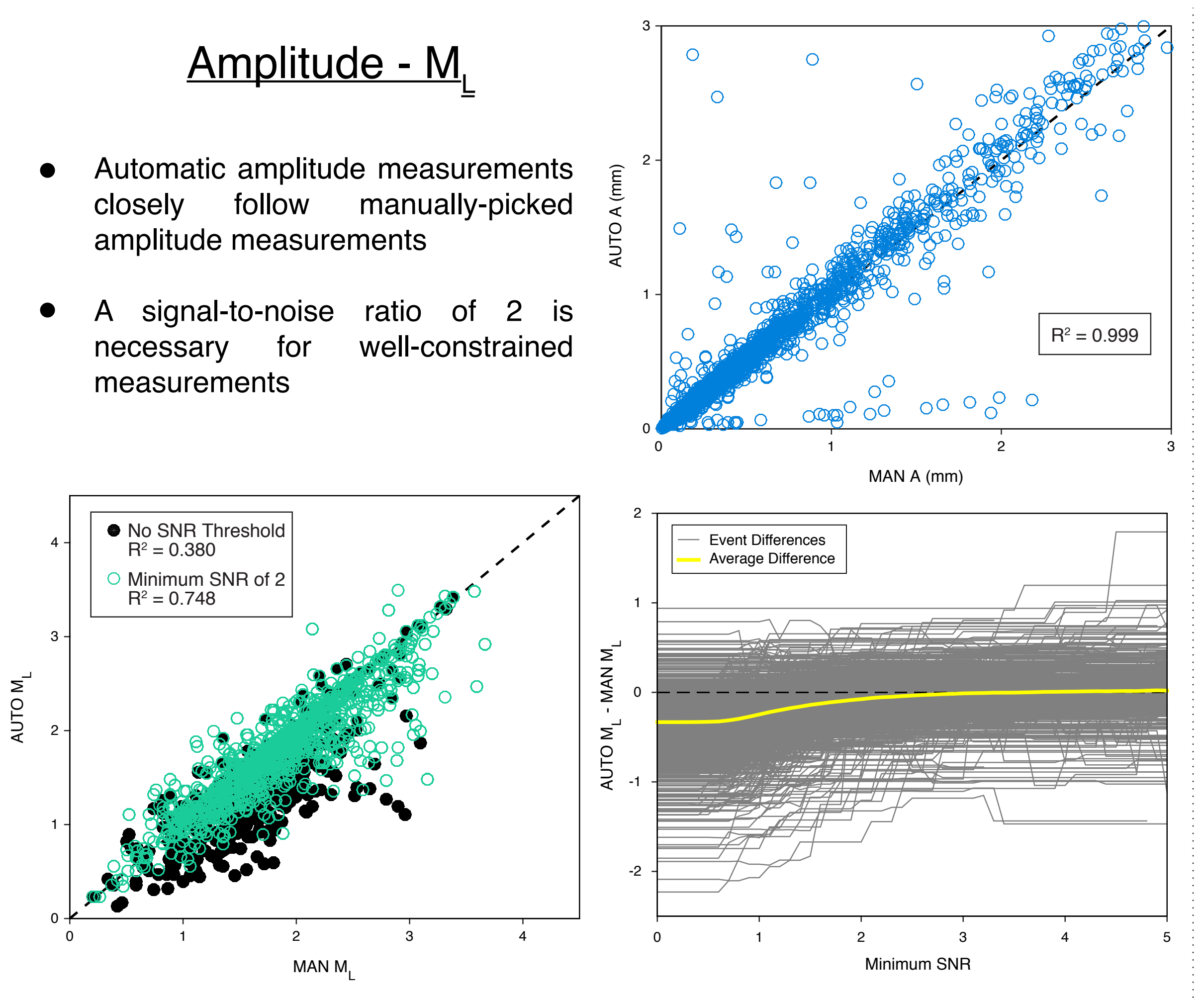


Figure 5: (Top Right) Comparison of automatic (AUTO) and manual (MAN) amplitude measurements (Lower Right) The difference in AUTO vs MAN M_L calculations as a function of SNR (Lower Left) A comparison of AUTO and MAN M_L calculations using a SNR threshold taken from the top right.

Duration - M_C

- Automatic duration measurements follow the same pattern as the manual measurements, but need improvement
- A correlation coefficient of 0.5 is sufficient for agreement between the measurements

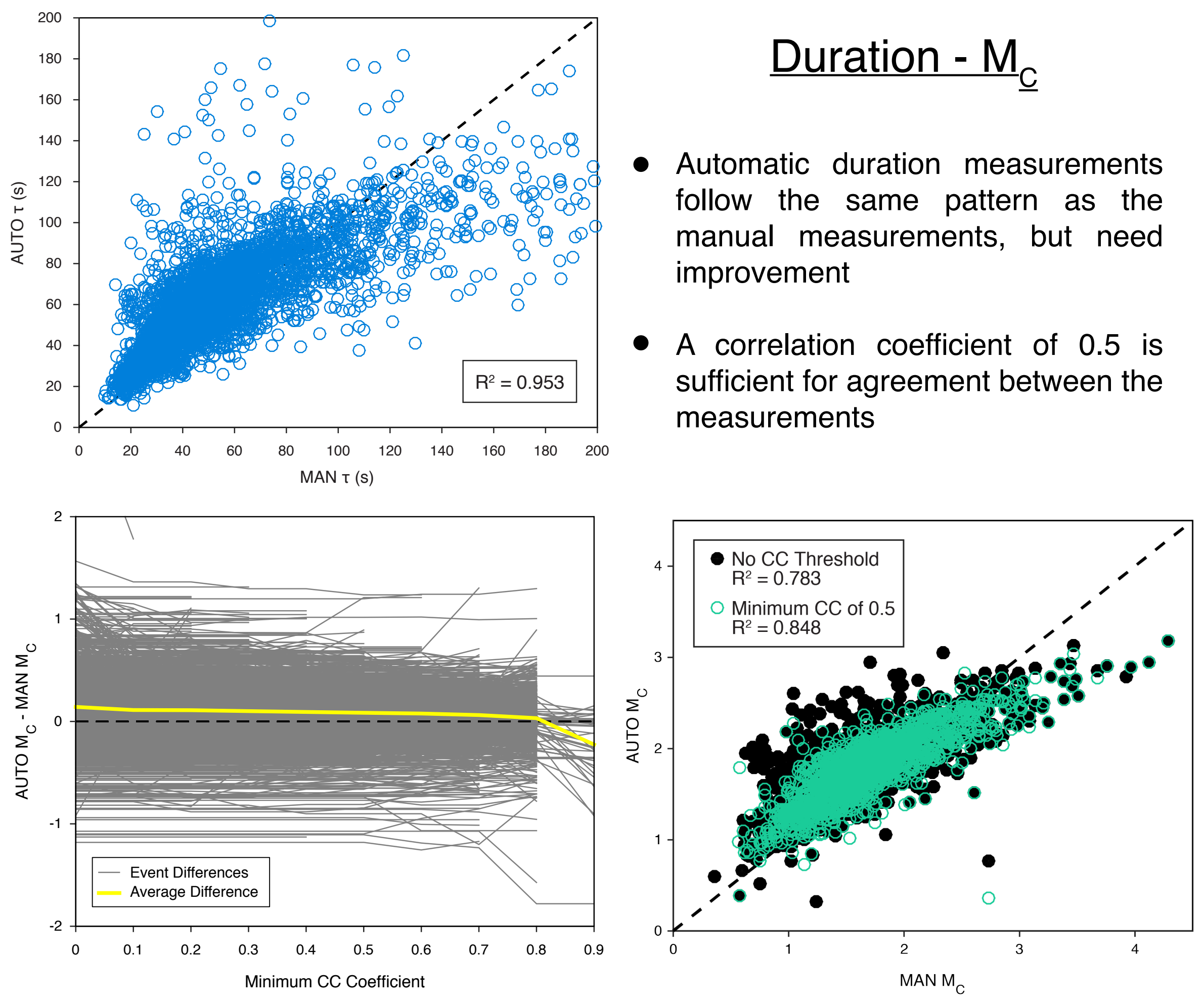


Figure 6: (Top Left) Comparison of automatic (AUTO) and manual (MAN) duration measurements (Lower Left) The difference in AUTO vs MAN M_C calculations as a function of CC (Lower Right) A comparison of AUTO and MAN M_C calculations using a CC threshold taken from the bottom left.

5. Simulations

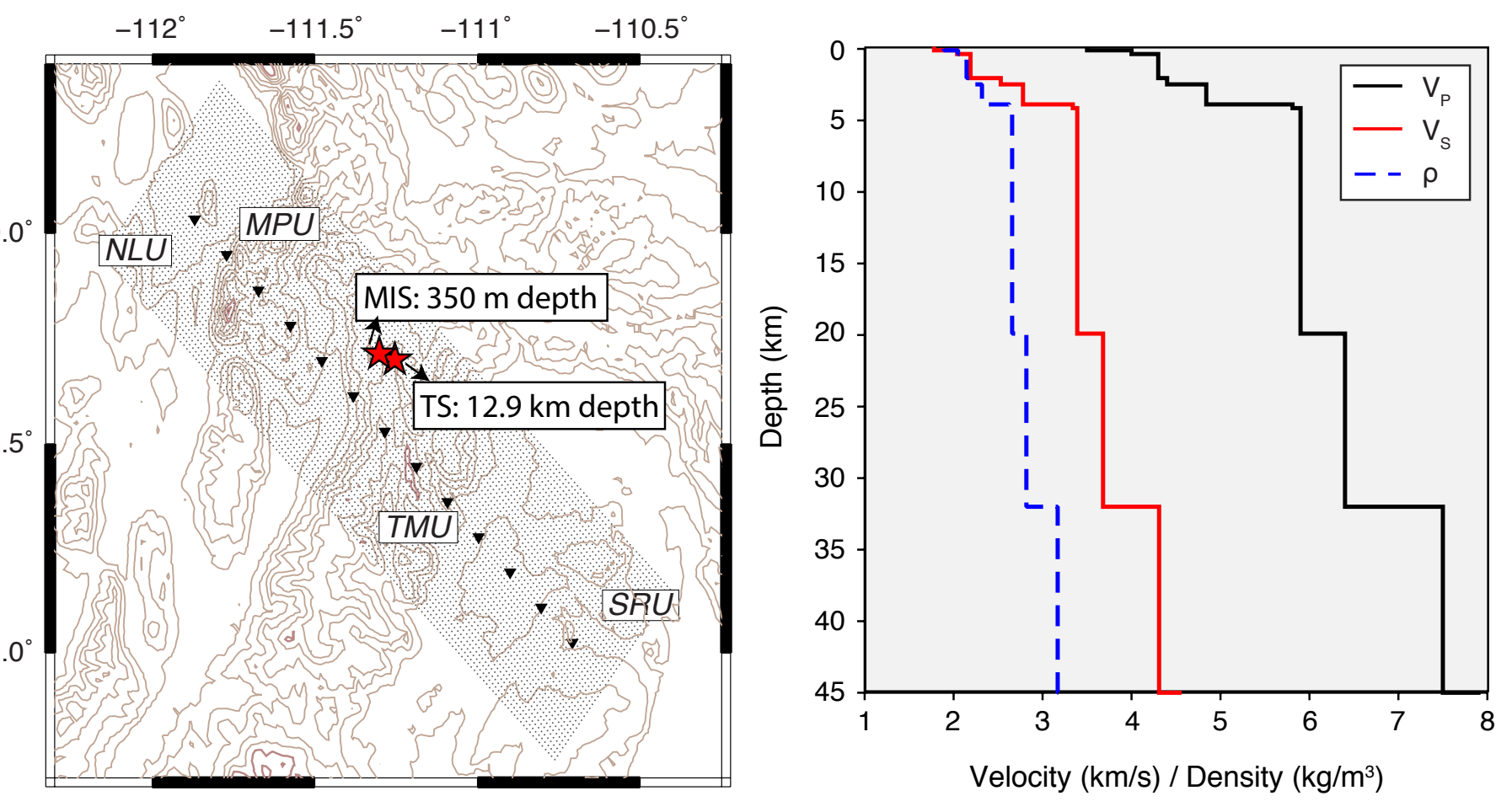


Figure 7: The model space (Top left) Map view of simulation and associated parameters. MIS: Mining-induced seismicity; TS: Tectonic (natural) seismicity (Top Right) 1-D seismic velocity and density model used in simulation

SW4

UofU CHPC
240 cores ~ 10 hr/EQ

- TS has longer duration.
- Likely need heterogeneity for MIS to have larger duration than TS

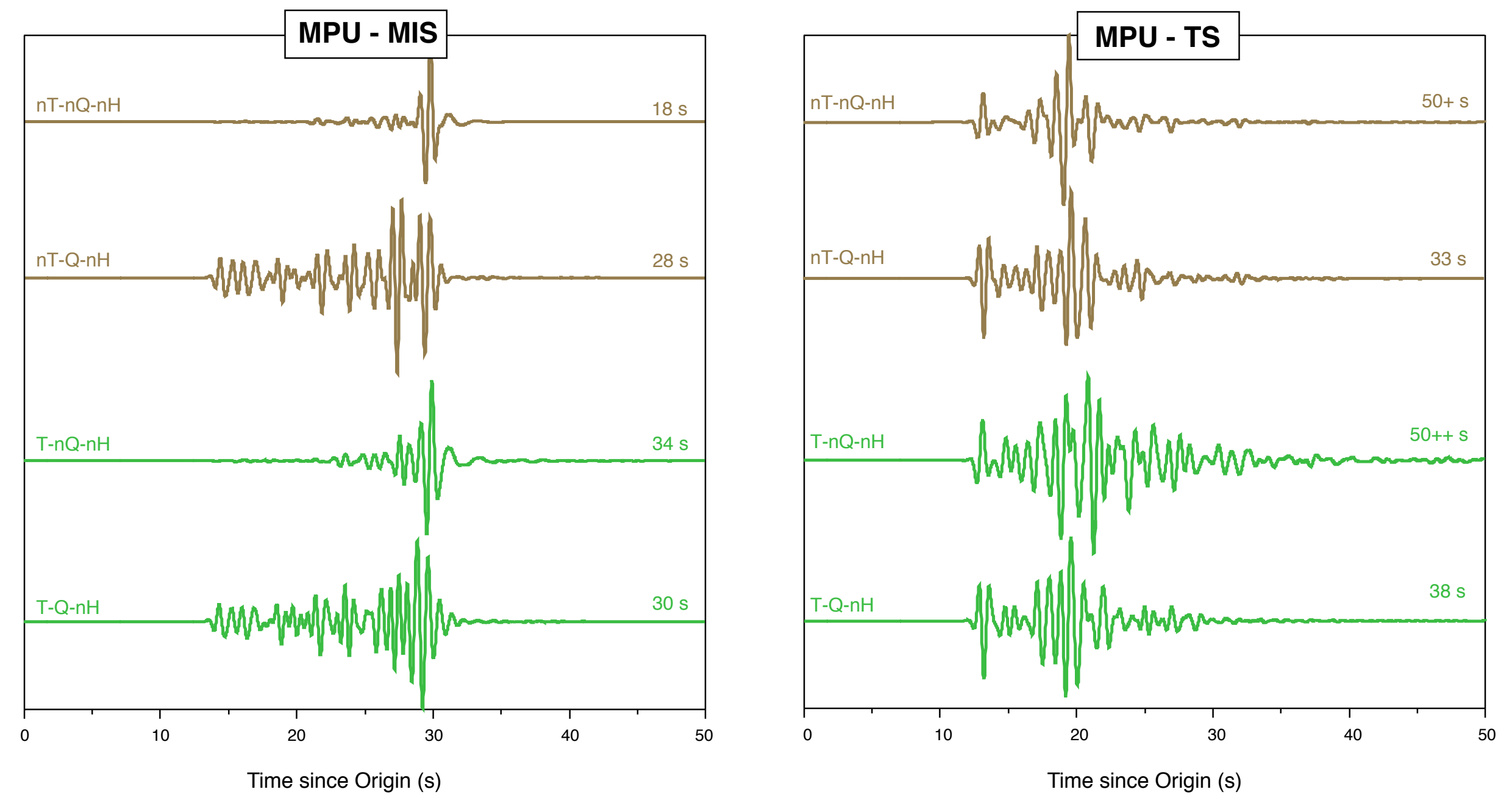


Figure 8: (Left) MIS simulation as recorde on station MPU with various parameters T, Q, H = toppography, attenuation, heterogeneities, respectively. An "n" in front signifies that that property does not exist in the simulation (e.g. nT = no topography). (Right) TS simulations as rercorded on MPU with various parameters.

6. Explosion Catalog Refinement

- Over 500 blasts have been re-analyzed for better-constrained magnitudes. This catalog includes all of southern Utah and parts ofthe north.
- The refinement of the explosion catalog will be completed soon and an updated M_L-M_C relationship will be calculated.

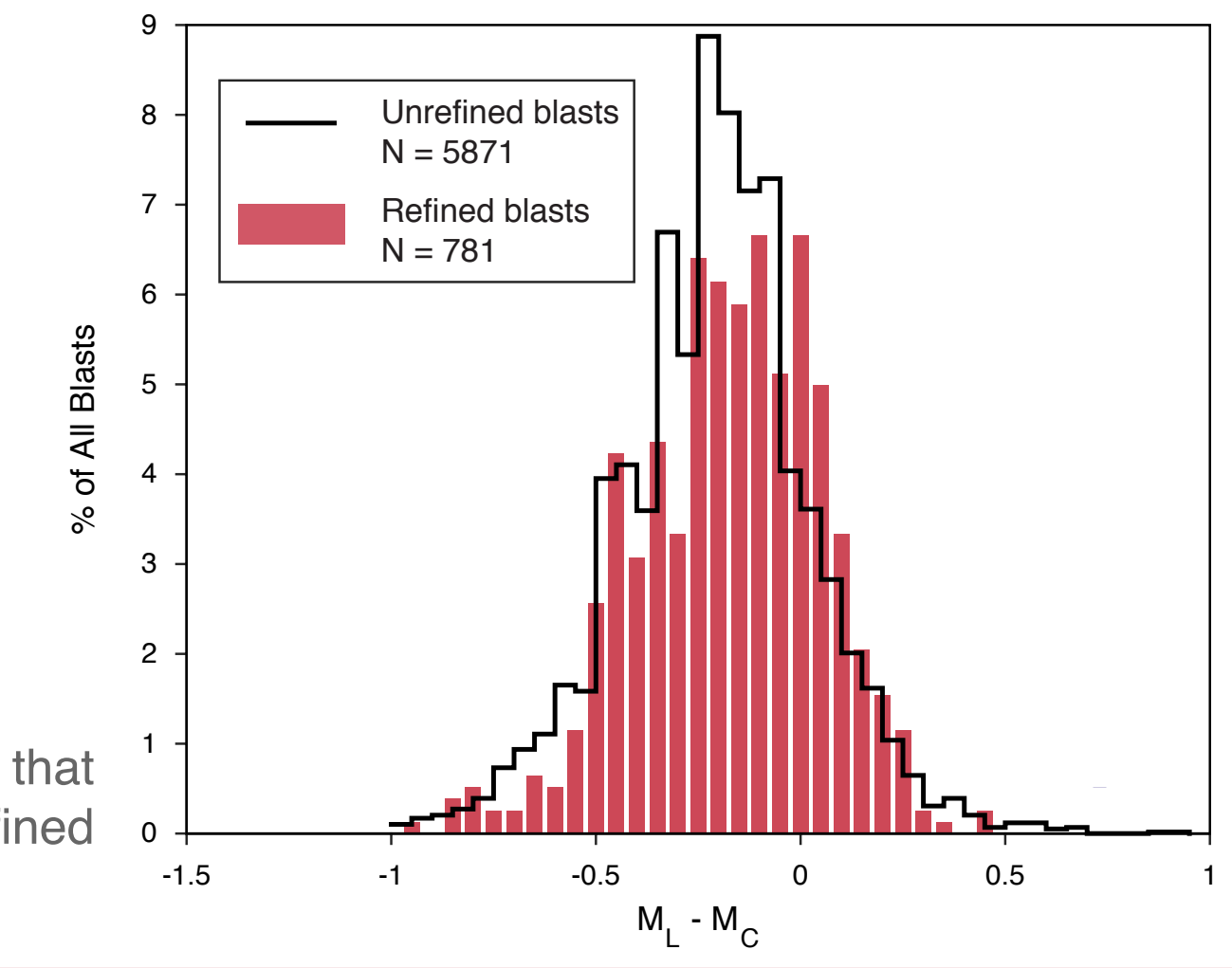


Figure 9: Explosions and quarry blasts in the Utah catalog that have (red bars) and don't have (black stair outline) refined locations and/or magnitudes.

7. Summary

* ***The M_L-M_C depth discriminant is portable***

*Automatic amplitude and duration measurements correlate with manually determined measurements

* Velocity heterogeneities are likely the cause of longer duration for shallow events

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