An Enhanced Earthquake Catalog for the 2020 Monte Cristo Range Sequence Derived from Machine Learning Processing of a Dense Aftershock Deployment

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1. Introduction

High resolution, near-source data can provide crucial information about earthquake processes, including enhanced detection of small earthquakes and improved source characterization due to minimal path attenuation. Conventional seismic networks with broadband seismometers excel at capturing a wide magnitude range of events though often lack the station coverage and density to effectively record near-source seismicity. Thus, temporary nodal deployments are increasingly used to supplement permanent networks during aftershock sequences and periods of heightened seismicity. One such deployment (termed the LASSO) captured three months of aftershock activity following the 2020 M_w 6.5 Monte Cristo Range Earthquake (MCRE) Sequence in Nevada. From this previously untapped data, we present a machine learning-augmented near-source catalog. This unique catalog improves constraints on the source characteristics of a highly active aftershock sequence while laying the foundation for future analyses of near-source waveforms and event spectra.

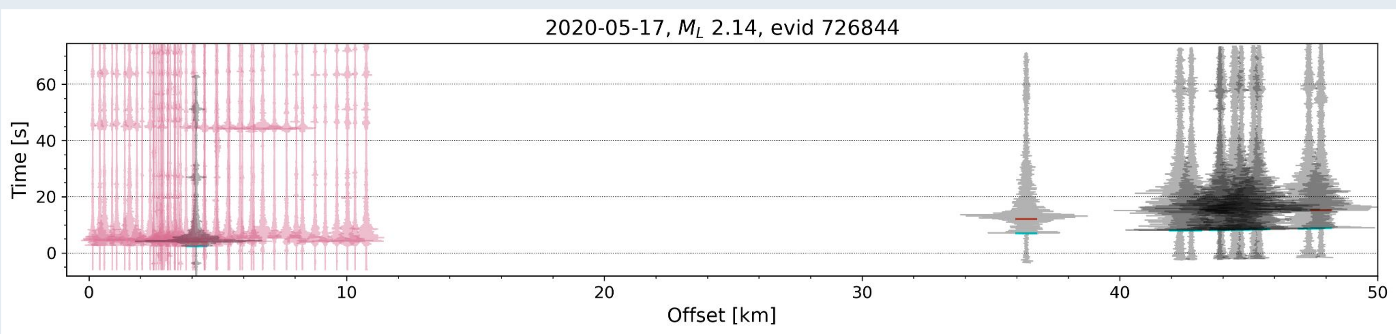

Figure 1: Waveform data from an early MCRE aftershock. NSL (Nevada Seismological Laboratory) broadband waveforms are shown in grey; waveforms from the nodal deployment (LASSO) are shown in pink. Analyst-picked arrivals are marked in blue and red for P and S waves respectively. Observe the scale of additional near-source coverage provided by the LASSO, with even smaller, undocumented events becoming visible.

2. Natural Laboratory

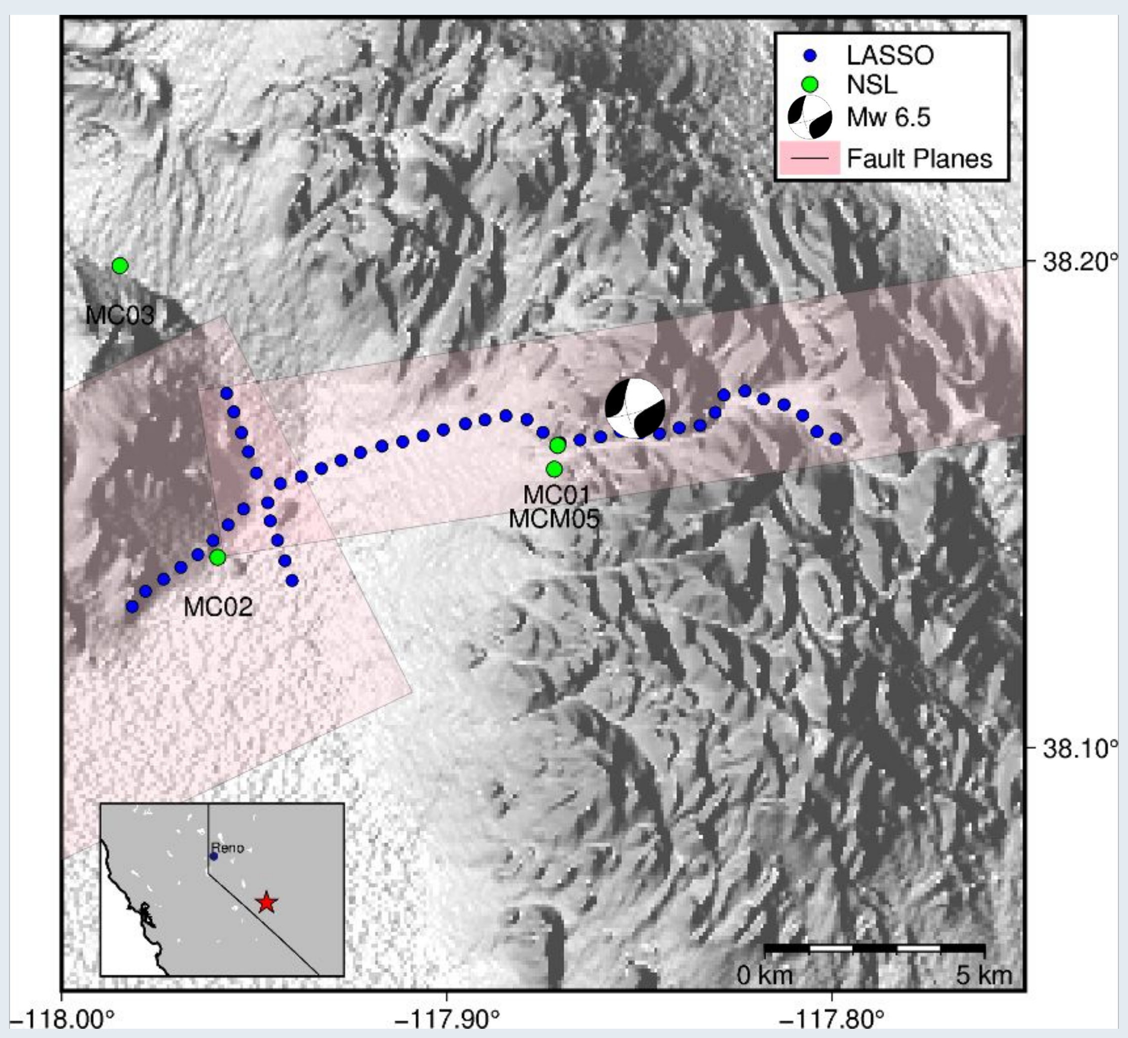

Figure 2: The geometry of the near-source deployment (blue) with nearby broadband seismometers (green), proposed fault plane from *Li et al. 2021* (pink), and moment tensor released by the NSL. Larger geographic location of study area is shown in bottom left inset, with the MCRE marked in red.

The MCRE occured on May 5, 2020, at 11:03 UTC (4:03 a.m. local time) in an area of the Central Walker Lane known as the Mina Deflection. The Nevada Seismological Laboratory (NSL) deployed eight, 3-component seismic stations and The Nevada National Security Site (NNSS) deployed 48 3-component nodal geophones, termed LASSO (Large Array for Seismic Sensing and Observations) to capture aftershock activity.

3. Building the Catalog

- Seisbench, an open source machine learning (ML) infrastructure for seismology, was used to implement picking and associating tools
- Due to spatiotemporal density, presumable small magnitude of newly identified events, and complexity of workflow, we must balance maximizing the number of new events with mitigating uncertainty and bias.
- On the order of 250,000 new events
- Distinguishing between workflow artifacts and genuine features of seismicity may be challenging

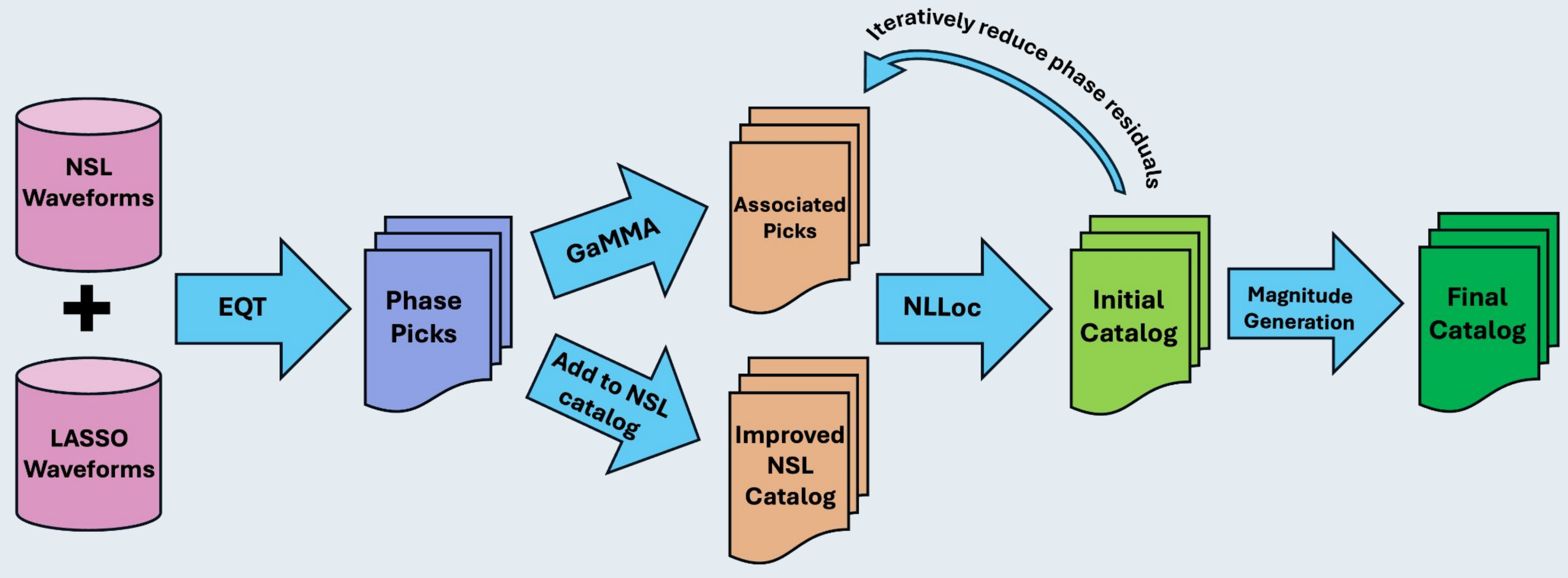

Figure 3: Our workflow: An ML phase picker, EQTransformer, is run on waveform data collected by broadband NSL stations and LASSO. These picks are either associated to new events or to the existing NSL catalog with GaMMA. All events are iteratively located with NonLinLoc (NLLoc) to reduce station pick time residuals. Finally, local magnitudes are estimated.

4. Quality Control

Detection and Picking

- Create large window overlap
- Account for window edge effects
- Impose higher detection/phase thresholds

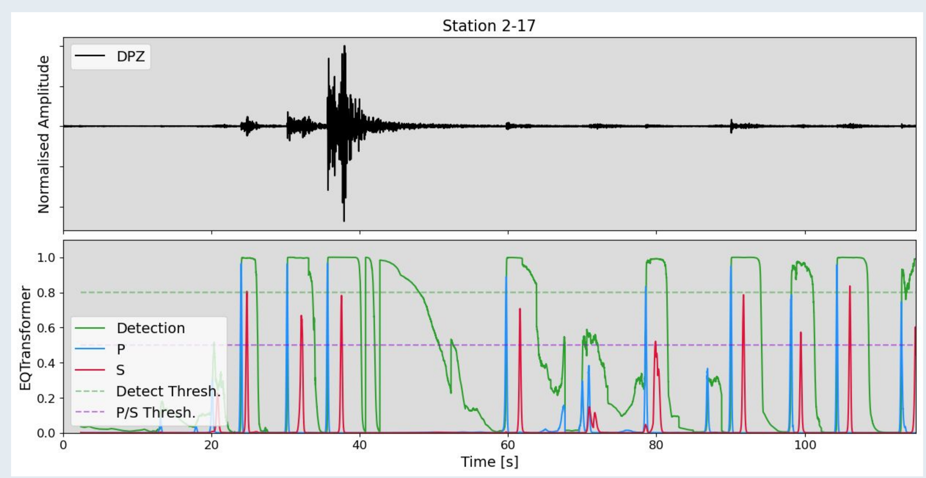

Figure 4: Top: raw 60-second waveform. Bottom: Event and phase scores corresponding to the waveform. Thresholds marked with dotted horizontal lines.

Association

- Require minimum number of picks
- Impose spatial coverage criteria

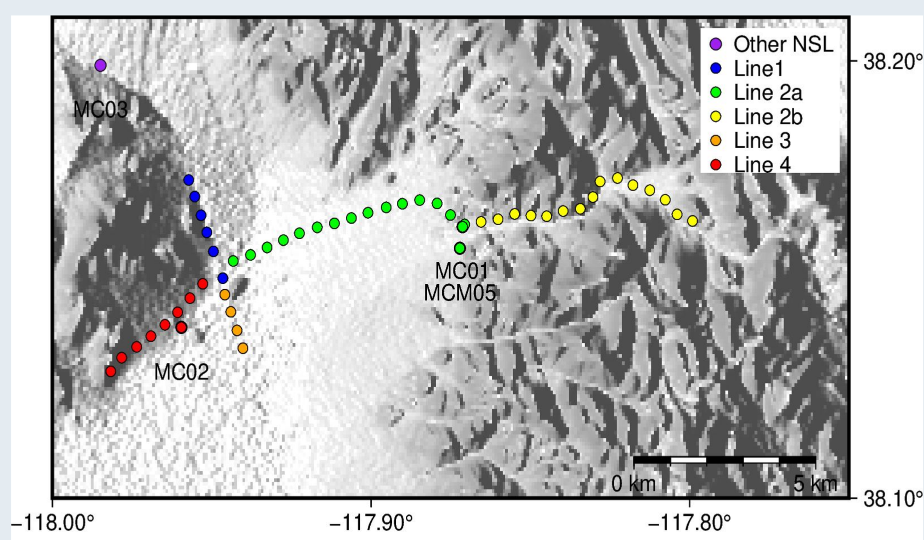

Figure 5: Array is divided into strands to enforce adequate N-S and E-W event coverage.

Locating

- Iteratively locate events while minimizing station phase arrival residuals
- Apply station correction term to stations with systematic biases

5. Attaching Magnitudes

- Local magnitudes estimated for each event in initial catalog via a workflow analogous to the process currently followed by NSL analysts
- Calculated waveform amplitudes are validated with known NSL events' station magnitudes (Figure 7).
- The local magnitude relation used was proposed for the state of Nevada by *Trugman 2023*

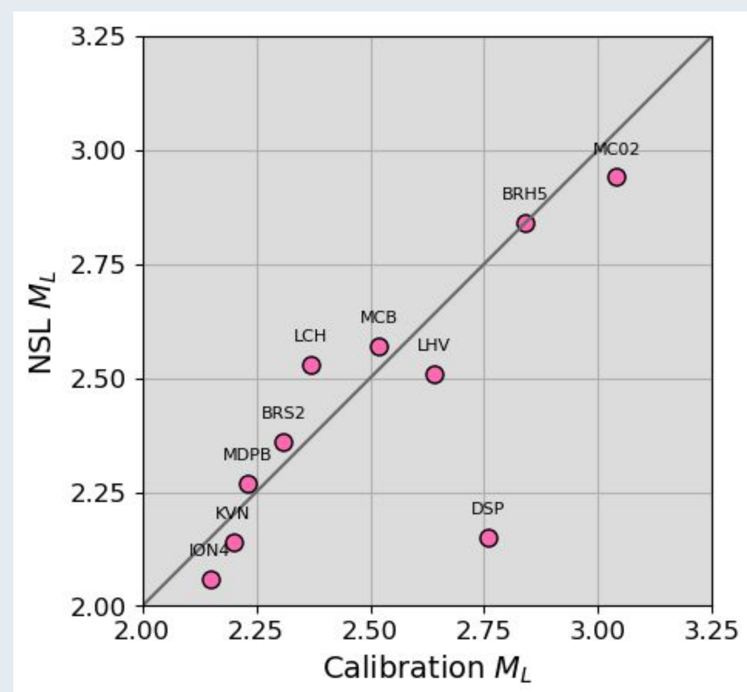

Figure 6: (Left) Peak-to-peak amplitude workflow is validated against existing NSL events, showing good agreement between stations.

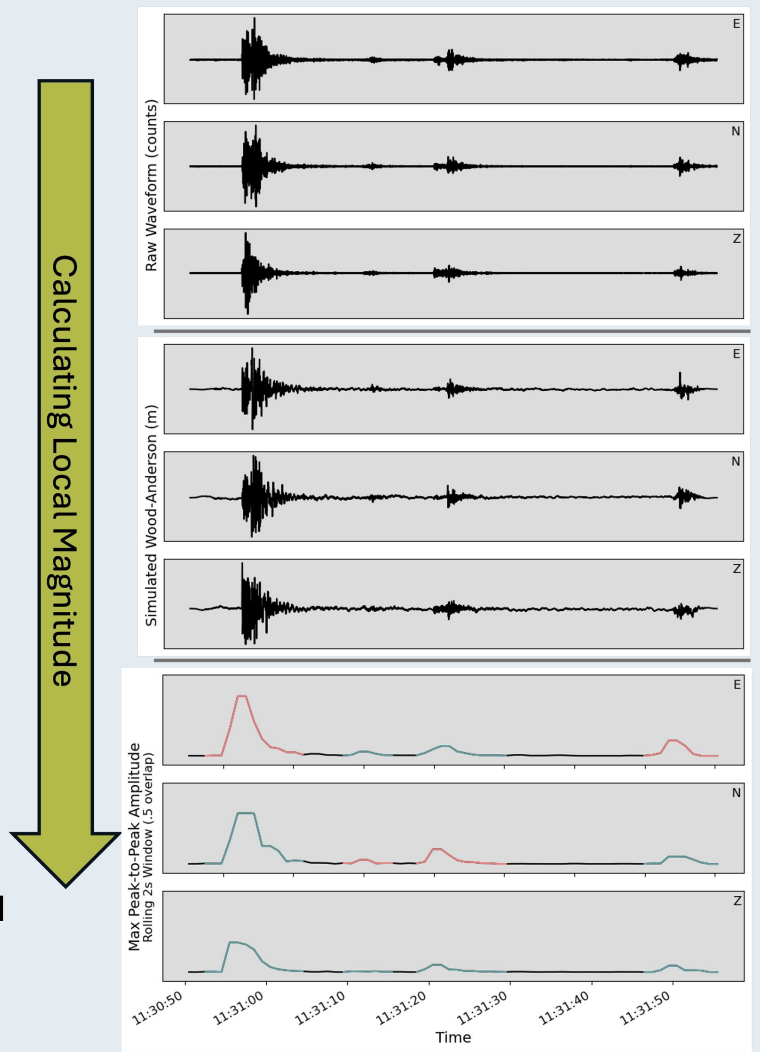

Figure 7: (Above) Top to bottom: Response corrections are applied to raw waveforms. Corrected waveforms are transformed to Wood-Anderson equivalent displacements. Maximum peak-to-peak amplitudes are measured around the known P and S-wave arrival, the largest of which is used to generate a local station magnitude.

6. Future Work

- Identify origins of N-S "streaking"
- Calculate magnitudes for all events when locations have been satisfactorily resolved
- Characterize spatiotemporal evolution of aftershock sequence
- Explore source properties as depth and magnitude vary

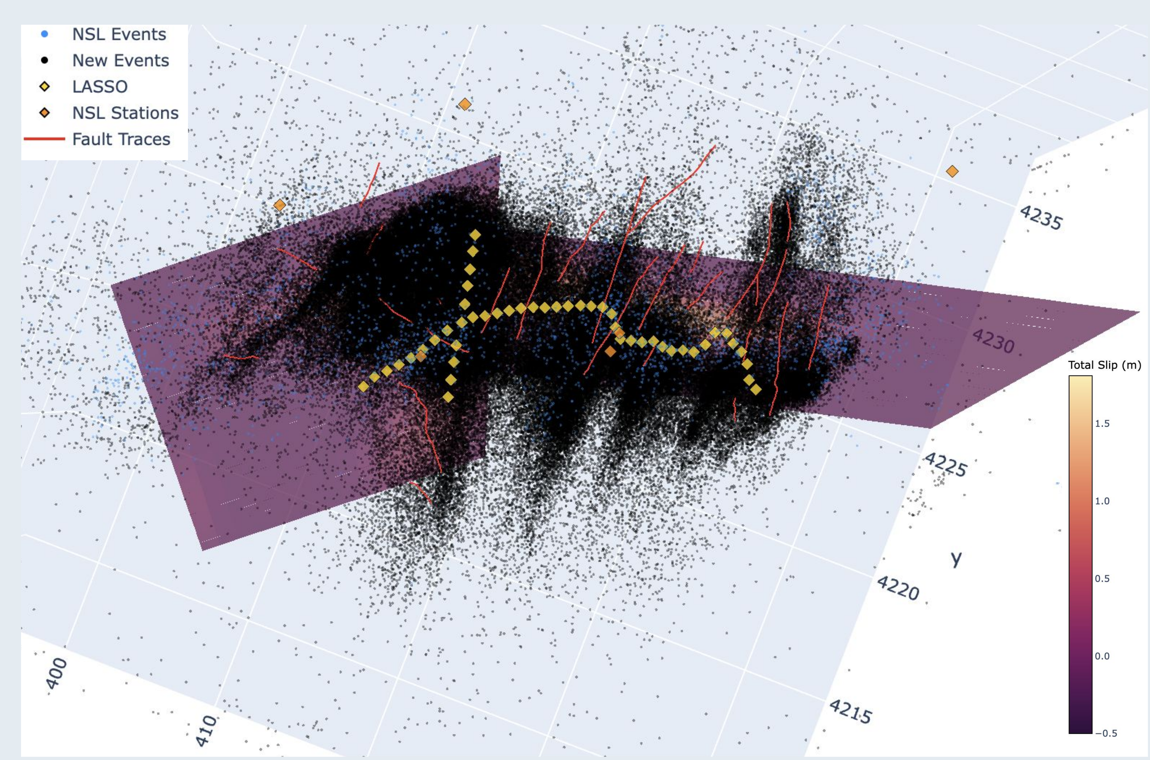

Figure 8: 3D view of locations on proposed slip plane from *Li et al. 2021* and fault traces from *Kariche 2022*

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