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SAND2019-4393C

Microseismicity Associated With the DAG-2 Chemical Explosion

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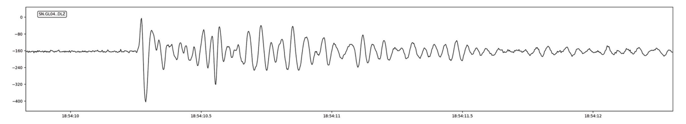
Abstract

The Dry Alluvium Geology (DAG) 2 chemical explosion conducted at the Nevada National Security Site (NNSS) in December, 2018, initiated a robust sequence of microseismic events immediately following the explosion. DAG-2 is a 50,000 kg TNT-equivalent charge of nitromethane detonated at 300 meters below ground surface in the alluvium of Yucca Flat, Nevada, on the NNSS. Within seconds of the detonation, a microseismic swarm, detectible on a seismic array to over 1500 m distance from ground zero, was initiated. At its peak, the swarm comprised over 100 events per minute. A high rate of seismicity (> 30 events per hour) continued for over 24 hours. We present data and analysis of this swarm in terms of event decay rate, moment release, and hypocenter distribution. Events were picked via template matching on a 500-channel array of surface geophones and accelerometers and two downhole fiber optic distributed acoustic sensing (DAS) cables deployed 80 m from ground zero. We also explore time-reversal location methods with imaging conditions adapted to microseismicity to determine hypocenter locations for comparison purposes. Early indications are that these events are associated with collapse of the stemming material above the detonation into the post-explosion cavity.

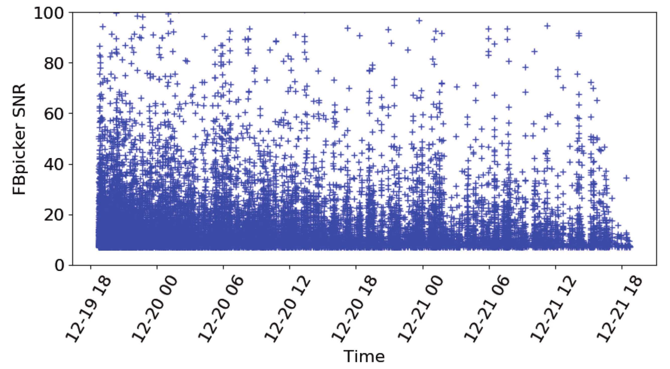
Cross-Correlation Templates

For this initial analysis, we limited our efforts to examine surface instruments that were within a 2 km distance from the DAG-2 chemical explosion. We also limited the amount of time processed to the first 48 hours following the DAG-2 chemical explosion.
Event templates were identified and P-wave arrivals were picked by an analyst for an event on the vertical component at recording sites with sufficient signal-to-noise ratio.



Example vertical-component seismogram for an event that occurred about 10 minutes after DAG-2.

Template event phase arrivals were partly chosen by arrivals identified using the frequency band FBpicker (Figure 2) from PhasePApy (Chen and Holland, 2016) as well as through visual inspection of waveforms. All template P-phases were picked by an analyst.



Time evolution of phase picks using FBpicker vs. phase signal-to-noise ratio.

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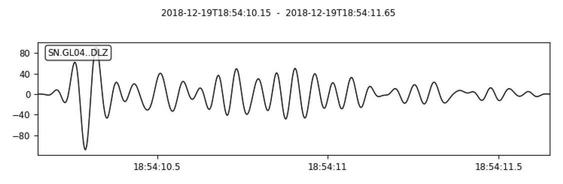
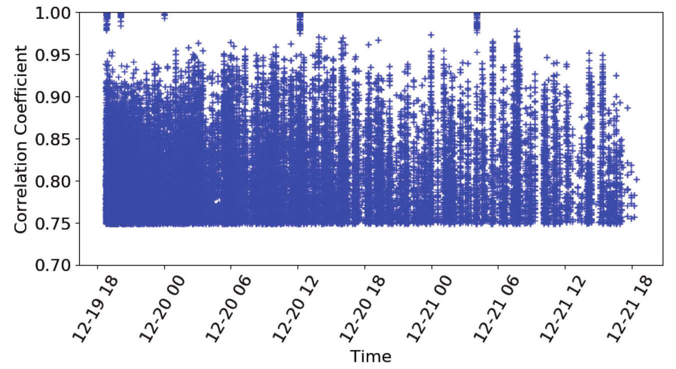
Template Matching

Each template event was then cross-correlated with the first 48 hours of waveform data following the DAG-2 chemical explosion, similar to the method of Holland (2013). The waveform data was decimated and then band-pass filtered (5 to 20 Hz) in order to reduce the number of unique templates. This filter increased the number of cross-correlation detections by more than an order of magnitude and requires fewer unique templates to identify events in the sequence. Obspy (Beyreuther et al., 2010) was used to aid in the data processing.



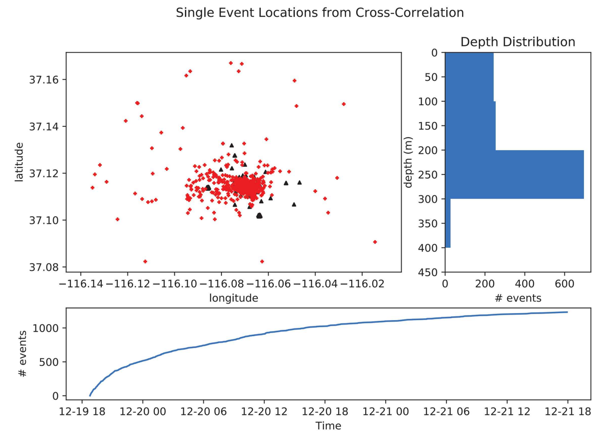
Example of a filtered template with a pass-band of 5 to 20 Hz



Cross-correlation phase detections. A phase detection was required to have a correlation coefficient of 0.749 or greater.

Cross-correlation P-phase detections were associated to events by comparing lag-times for each template event to the cross-correlation detections. Lag times were required to be some origin-time difference plus a maximum of 0.2 seconds from the template phase to detection lag-time with a minimum of four phase arrivals.

Cross-correlation phases and identified events were then used to calculate single-event locations using Hypoinverse2000 (Klein, 2002). These events and their spatial and temporal extent push the limits of resolution for this method. They did, however, provide a sanity check for template events and their associated identified events. Single event location algorithms with greater accuracy will be used in further processing (see Future Work).

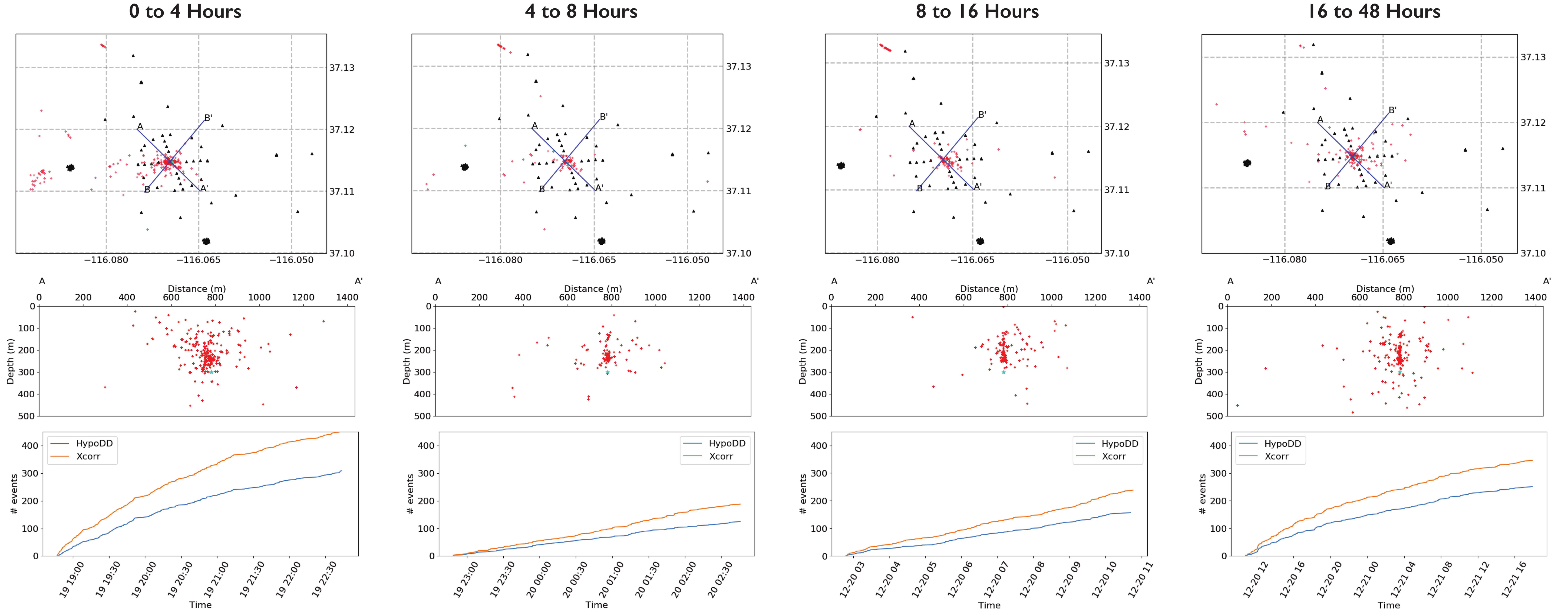


Hypoinverse locations and time evolution of 1,233 unique events identified from cross-correlation detection of phases. Most events were located at depths above the depth of DAG-2.

Time Evolution of Microseismicity Following DAG-2

Earthquake locations are shown as red crosses, stations as black triangles, and the location of DAG-2 as a cyan star. Cross-section locations are identified as blue lines.

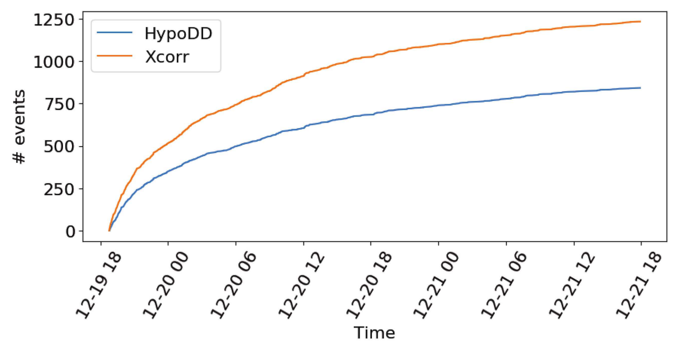
From the cross-sections it is possible to see a concentration of seismicity directly above the DAG-2 explosion indicating collapse of the stemming material.

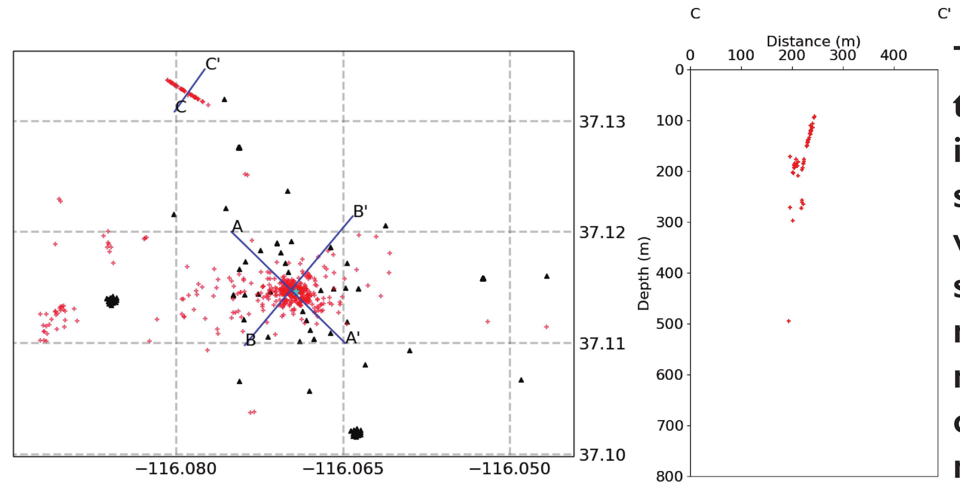


Double Difference Relocations using HypoDD

Cross-correlated events were relocated using hypoDD (Waldhauser and Ellsworth, 2000; Waldhauser, 2001). Of the 1,233 unique events only 758 were relocated by HypoDD. Most events that were not relocated were identified as air-quakes and removed.

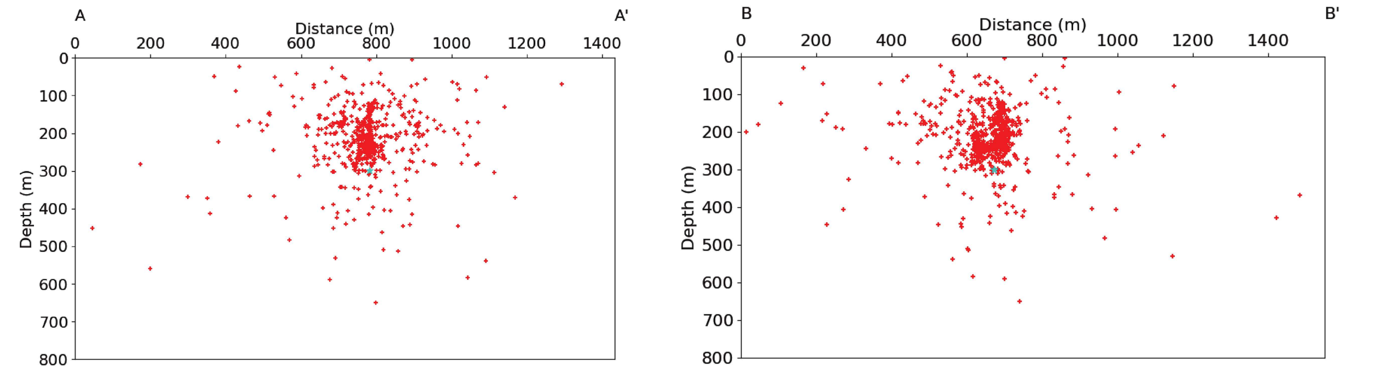
Due to the similarity of seismicity-rate curves for both methods, it is reasonable to use this set of events to examine the temporal evolution of the sequence.





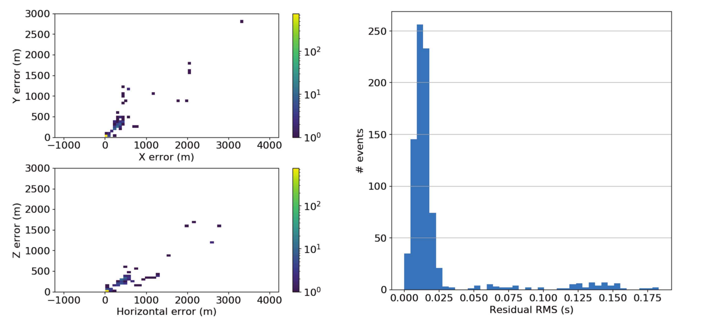
Earthquake locations are shown as red crosses, stations as black triangles, and the location of DAG-2 as a cyan star. Cross-section locations are identified as blue lines.

The only apparent structure to the seismicity seen in these plots is the linear seismicity in the Northwest of the study area and shown in C-C'. This seismicity is parallel to faults mapped in the area, but does not correspond to a mapped fault. Although HypoDD uncertainties for this cluster are on average 300 m.

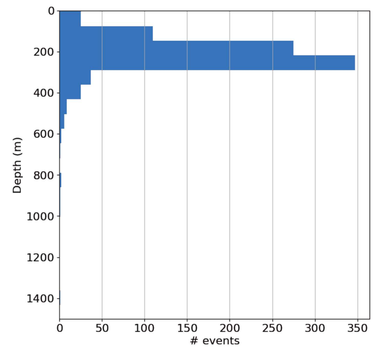


Location Quality Measures

Absolute uncertainties and locations reported by HypoDD are not necessarily accurate, but the distribution of those measures can be informative.



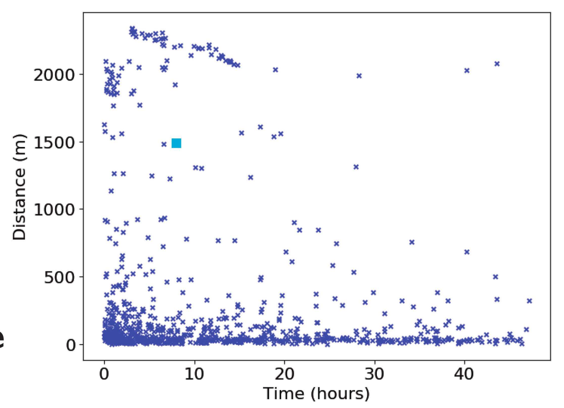
The average uncertainty in locations is reported at about 10 m. The RMS arrival residual distribution indicates that most locations provide a very good fit to the cross-correlation phase detections.



The depth distribution shows that more earthquakes are being located below the depth of DAG-2, the majority remain above the explosion.

Diffusion Analysis

Events are plotted as radial distance and relative time from DAG-2. If diffusion was helping drive seismicity at greater distances a general increase in distance with increasing time should be apparent.



Conclusions

- It appears that many of these events are associated with collapse of the stemming material above the detonation into the post-explosion cavity.
- Significant microseismicity activity appears to be occurring at distances too great to be attributed to collapse of stemming material. Based on the comparison of time and distance of microseismicity in relation to the DAG-2 chemical explosion, it does not appear that a diffusion process is helping drive microseismicity at greater distances.
- The linear trend of seismicity northwest of DAG-2 is parallel to nearby mapped structures, but is not spatially associated to any mapped structures. The average uncertainty for these events as reported by HypoDD is about 300 meters. This uncertainty is more than an order of magnitude larger than for events within the cluster of seismicity near DAG-2. Further analysis and location will be necessary to evaluate the validity of this seismicity and it's trend. Additional sensors beyond 2 km will be analyzed.
- Cross-correlation using template events was effective at identifying events and providing quality identifications of the microseismicity and associated phase arrivals at stations.

Future Work

- Add additional templates to capture more of the microseismicity following the DAG-2 chemical explosion.
- Include phase arrival data from cable-cutter shots (with known origin parameters) as calibration and evaluation of relocation methods.
- Determine moment release and magnitude for microseismicity and evaluate the temporal and spatial patterns of moment release.
- Relocate events starting with higher resolution single-event locations and double-difference relocations (Preston et al., 2018).
- Process fiber optic distributed acoustic sensing (DAS) data for microseismicity using the same template events.
- Further evaluation of factors that may be causing microseismicity further away from site of the chemical explosion.

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