SAND2021-12066PE

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Evaluating trends in seismoacoustic event processing using arrivals from repeating explosions

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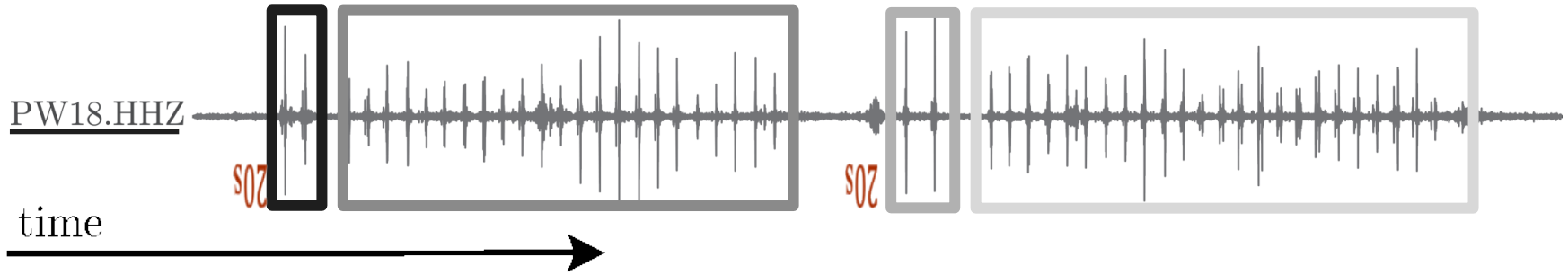
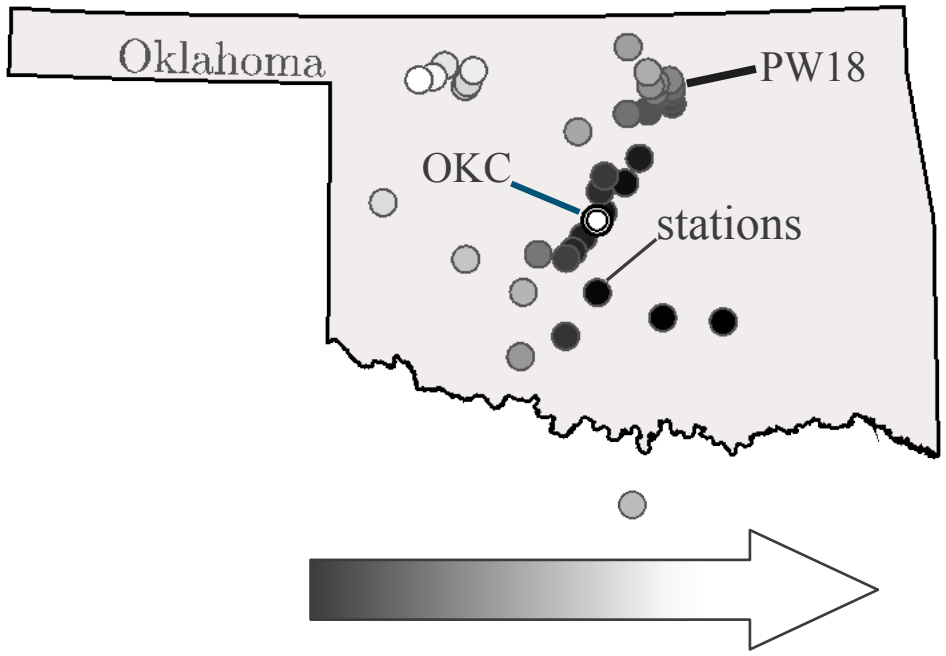
Seismo-Acoustic Networks Deployed within OK State Record and Initially Cannot Identify Repeating Pulses





Background: Over the summer of 2019, Oklahoma seismic networks recorded sequences of ≤ 52 regularly-timed pulses that travelled at acoustic wave speeds. Location of detecting stations, waveform moveout, and signal strength each varied with time. The few available infrasound records showed weak signals

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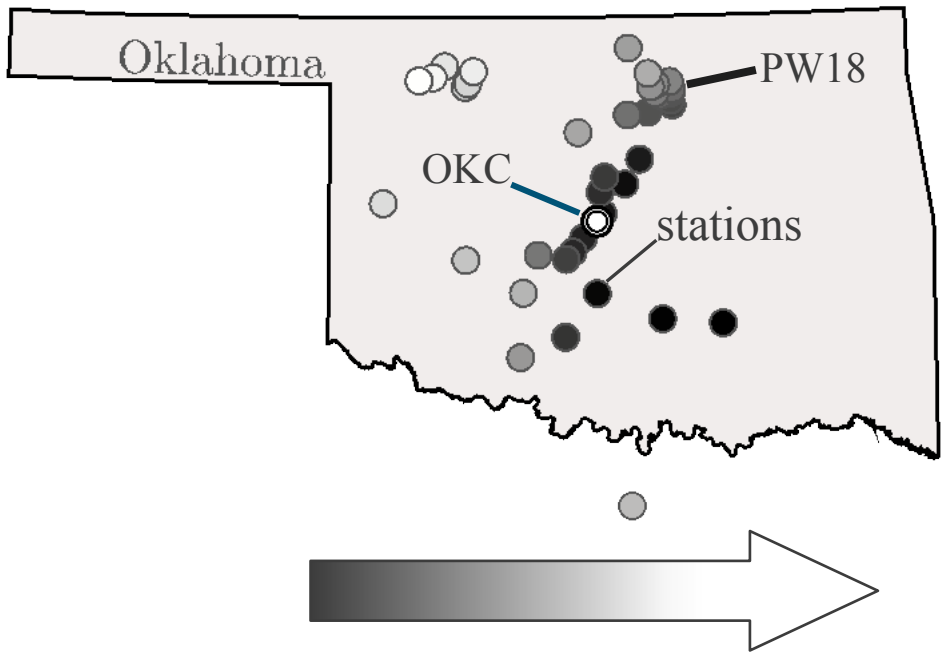
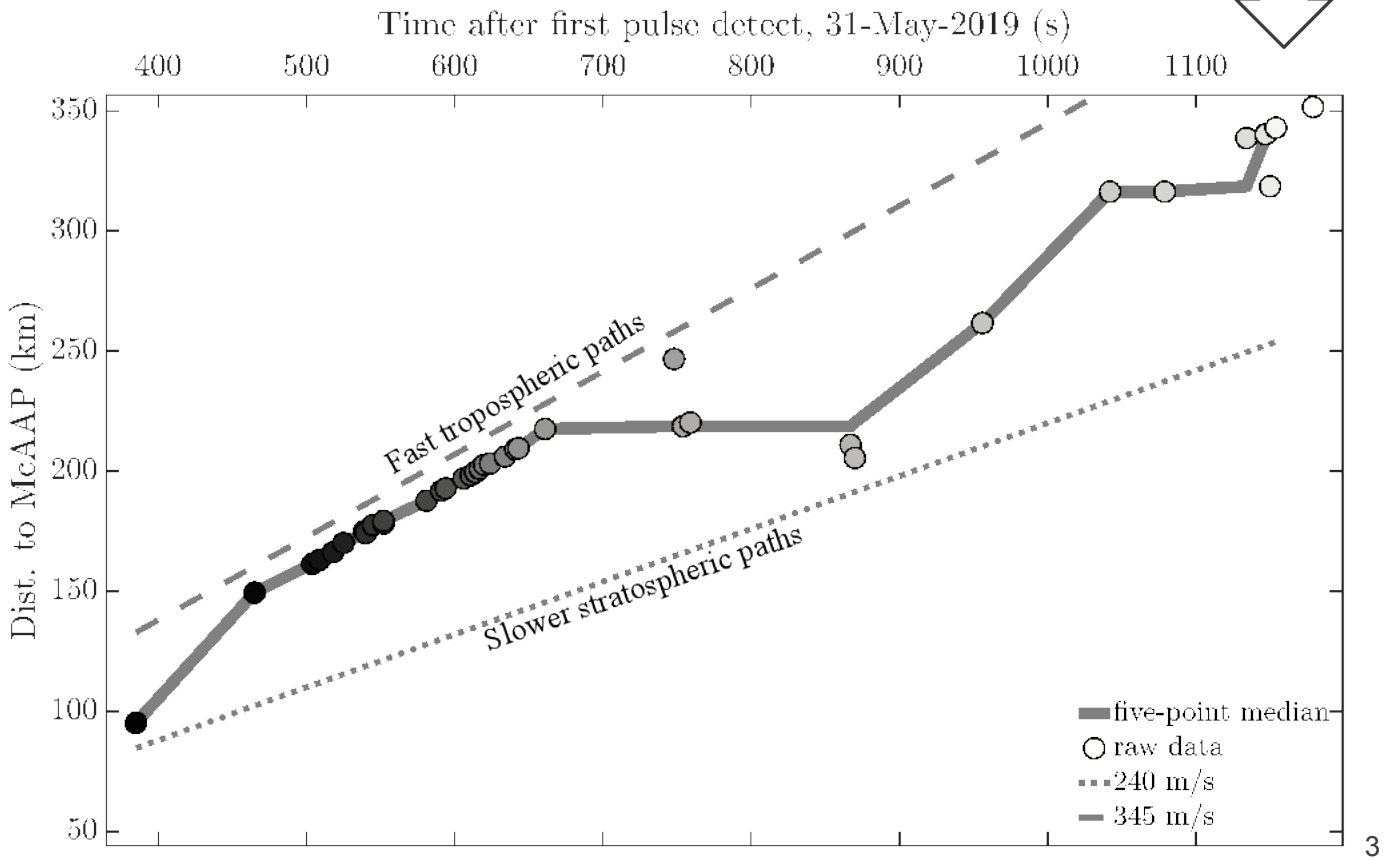
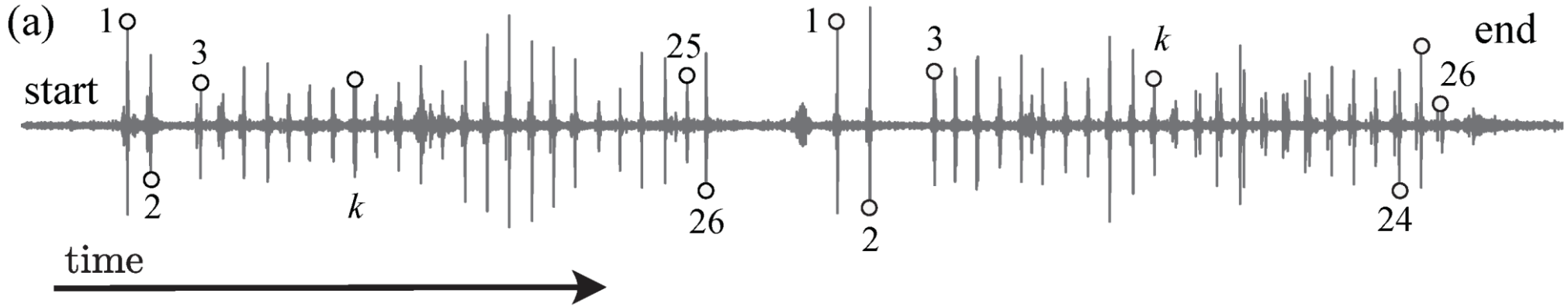
Seismic signals propagate at acoustic, not seismic speeds



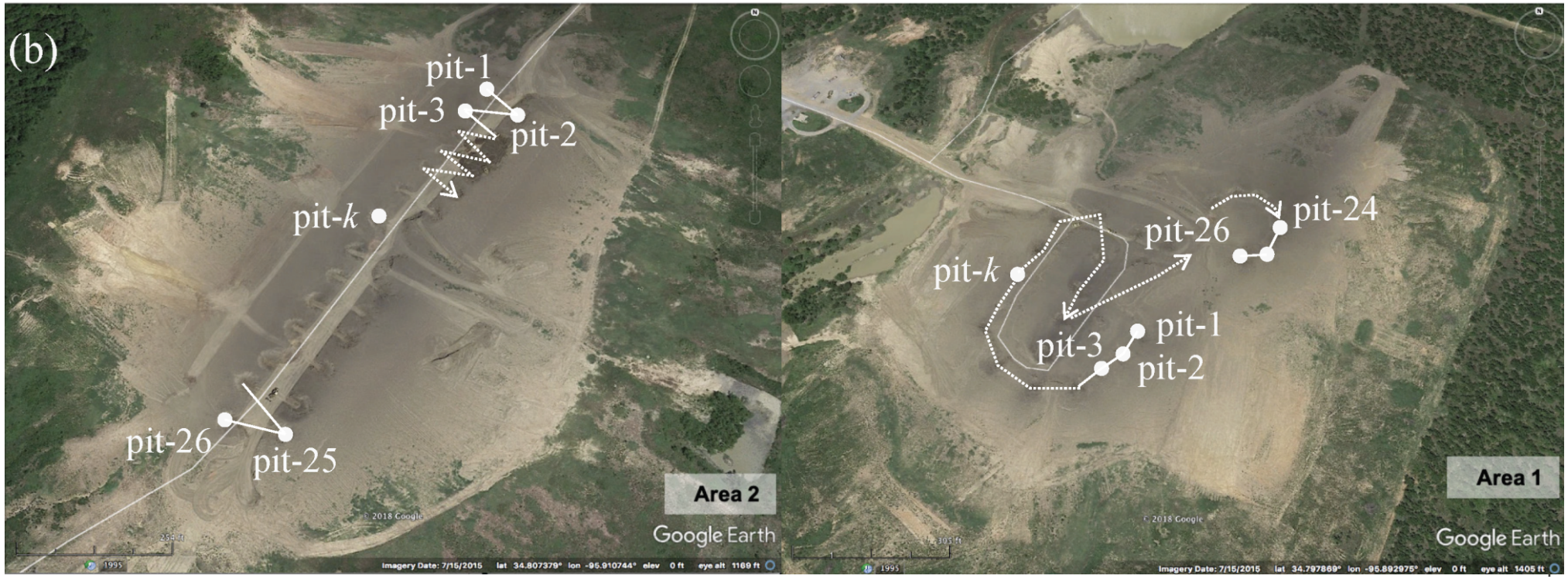


McAlester Army Ammunition Plant Hosts Repetitive, Seismo-Acoustic Sources from Munition Disposal (1/2)

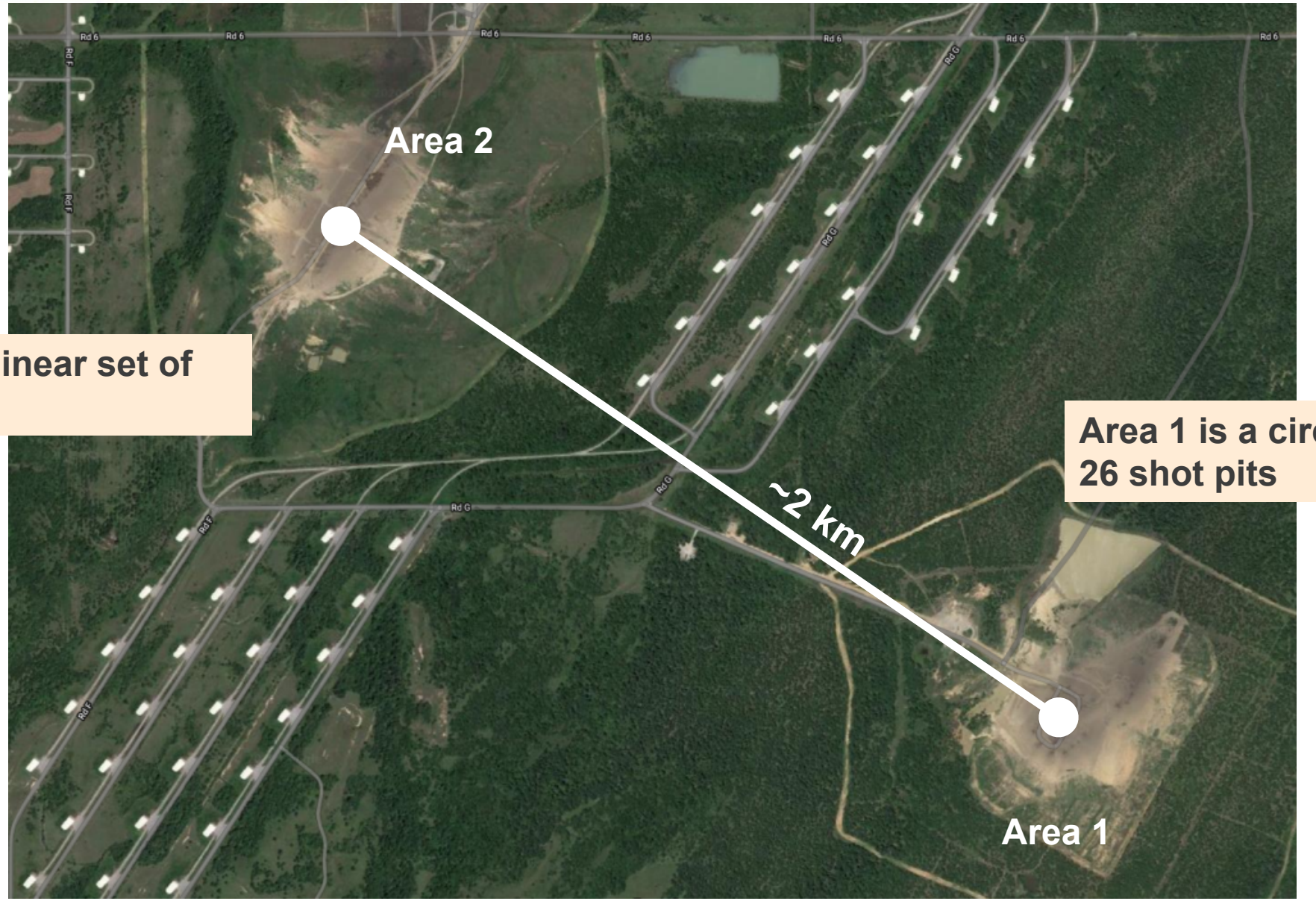
(a) Vertical channel seismic observations



(b) Pulse sequence waveform source locations



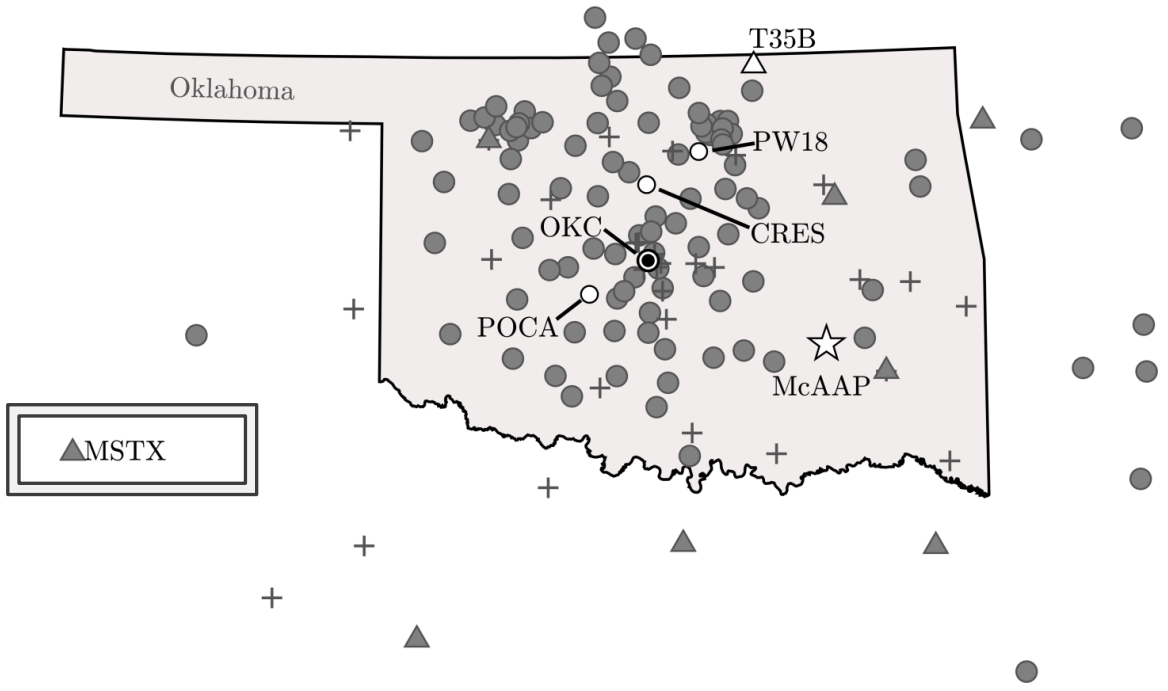
McAlester Army Ammunition Plant Hosts Repetitive, Seismo-Acoustic Sources from Munition Disposal (2/2)



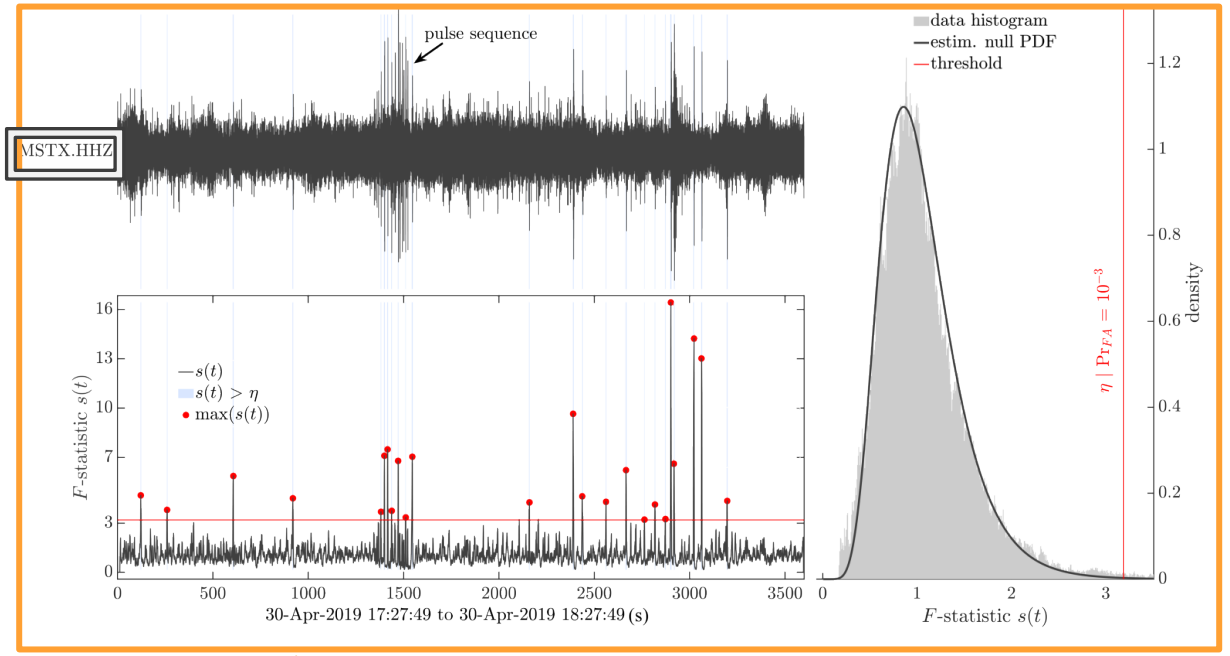
Area 2 is a linear set of 26 shot pits

Area 1 is a circular set of 26 shot pits

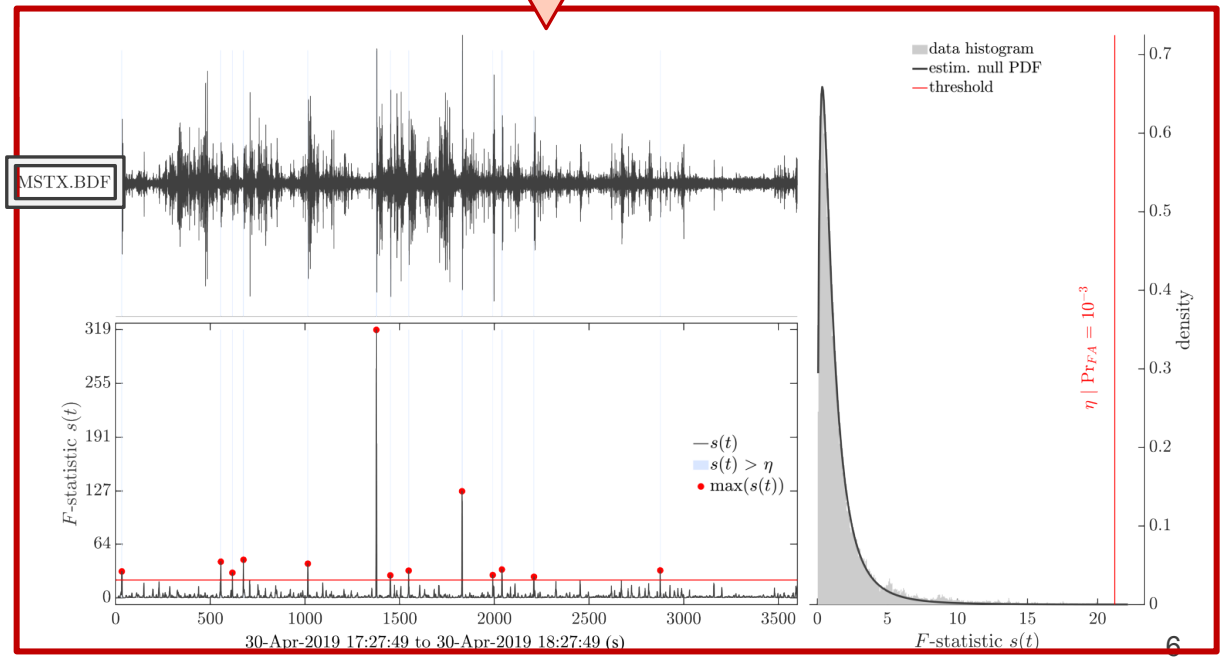
Seismometers Record Pulse Sequences out to 640km



- **U.S. Army provided blast logs as ground truth for ≥ 9 months.** Logs reveal McAAP blasted on **169** of **276** days to destroy **4.3**kT of mass with **7222** shots (**~600** kg/shot)
- Includes **10** infrasound co-deployments, but no arrays
- Vertical channel seismic waveform detections output better pulse identification rate than infrasound

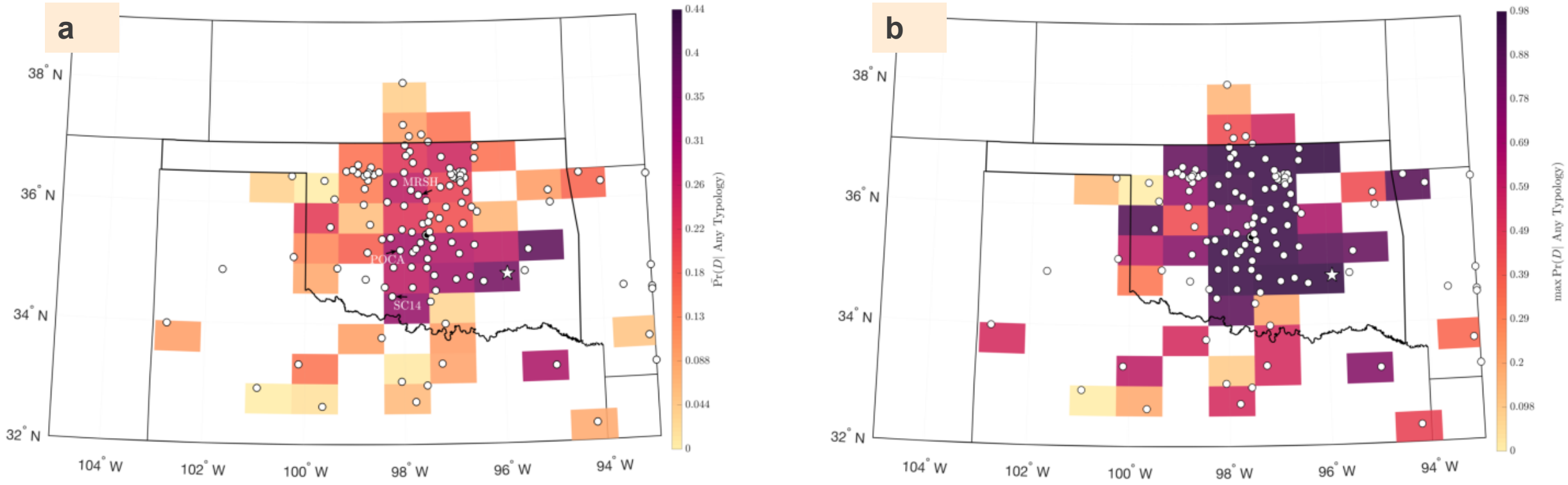


Seismic and Infrasound data, 640 km away



Manual and Digital Pulse Detections Reveal Variable Seismic Detectability Near Dense Populations

- **Result 1:** Social media witnesses correctly identified blasts on days, at times of blasting, when visual review did not.
- **Result 2:** Visual waveform review was more successful than digital pulse detection, on average (**a**)
- **Result 3:** Probability of digitally detecting pulse sequence once per sensor, however, is generally high (**b**)



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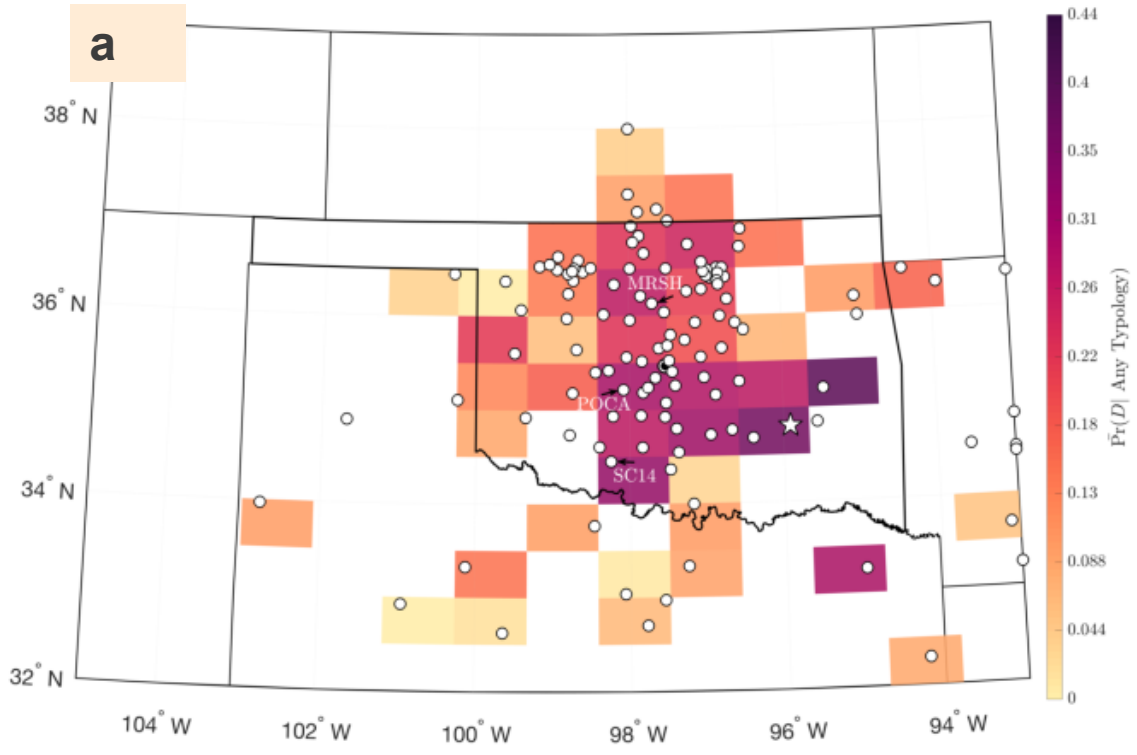
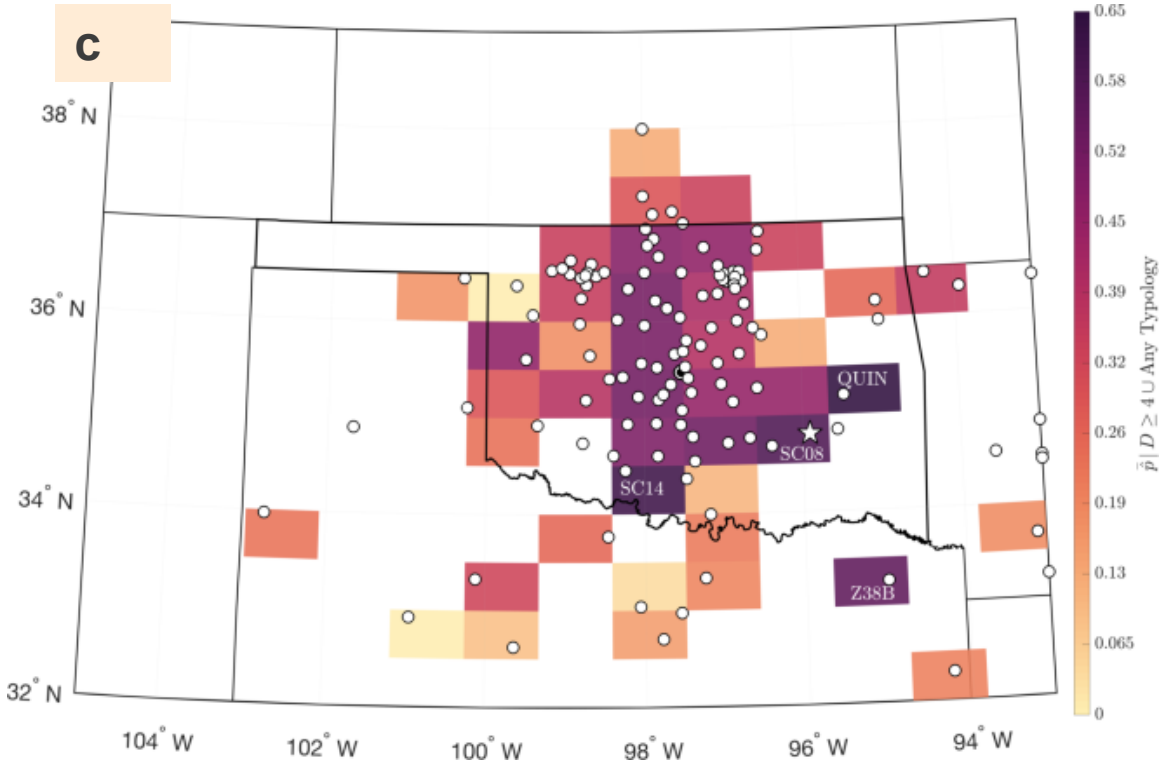
- **Result 4:** Probability of digitally detecting any single pulse *within a* sequence remains moderate over state. Sensors ~200km from McAAP have ≥ 1/2 probability of digitally detecting pulses, on average (**c**)





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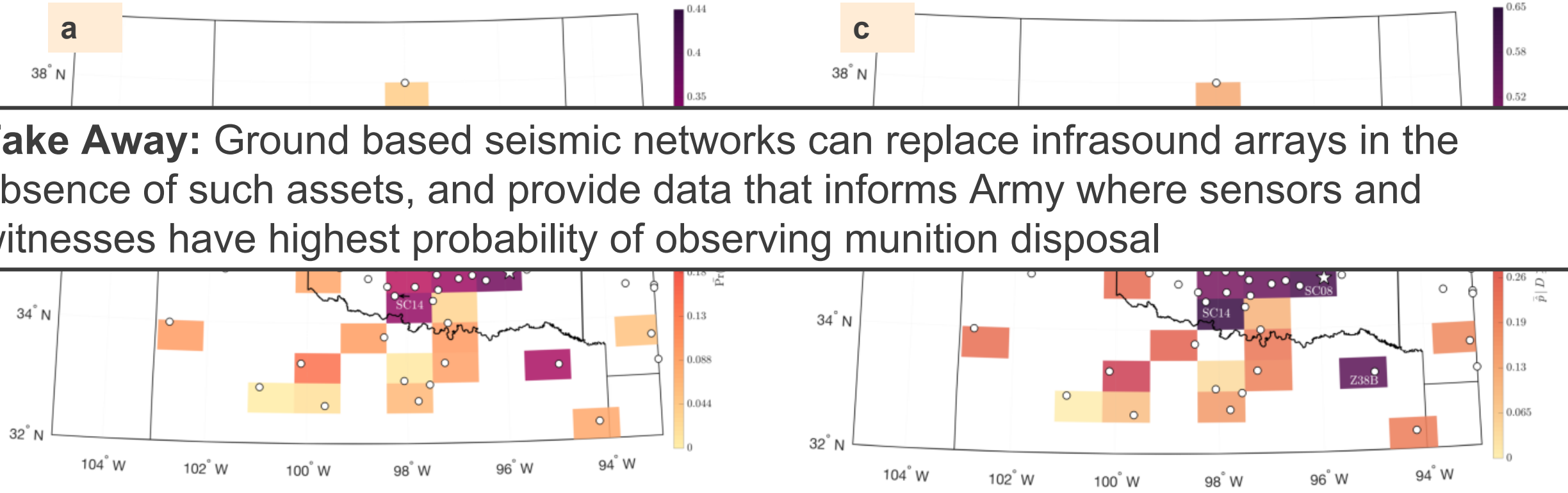
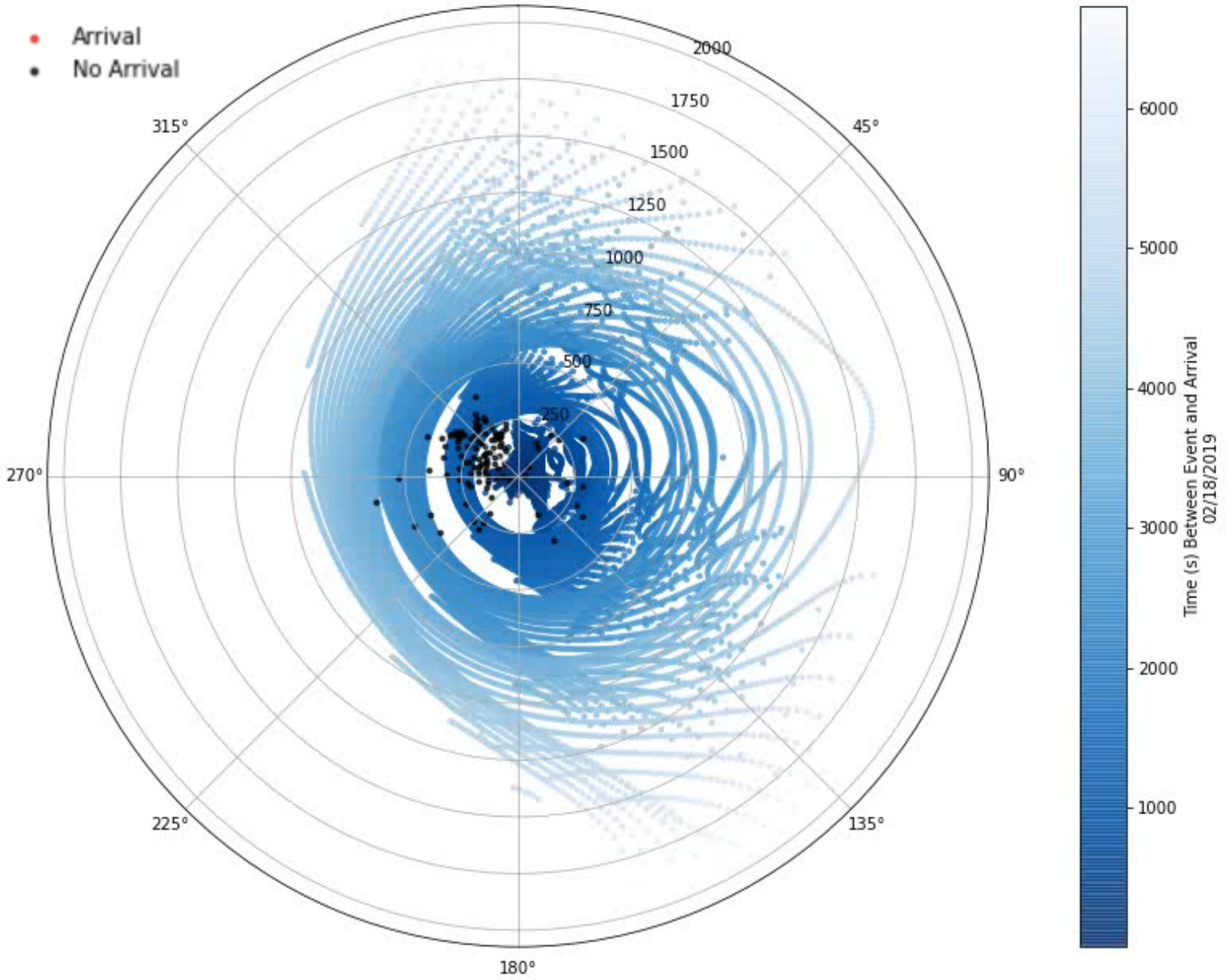


Take Away: Ground based seismic networks can replace infrasound arrays in the absence of such assets, and provide data that informs Army where sensors and witnesses have highest probability of observing munition disposal

Propagation Modeling Results Illustrate Discrepancies Between Observed and Predicted Acoustic Arrivals Across the Seismic Network

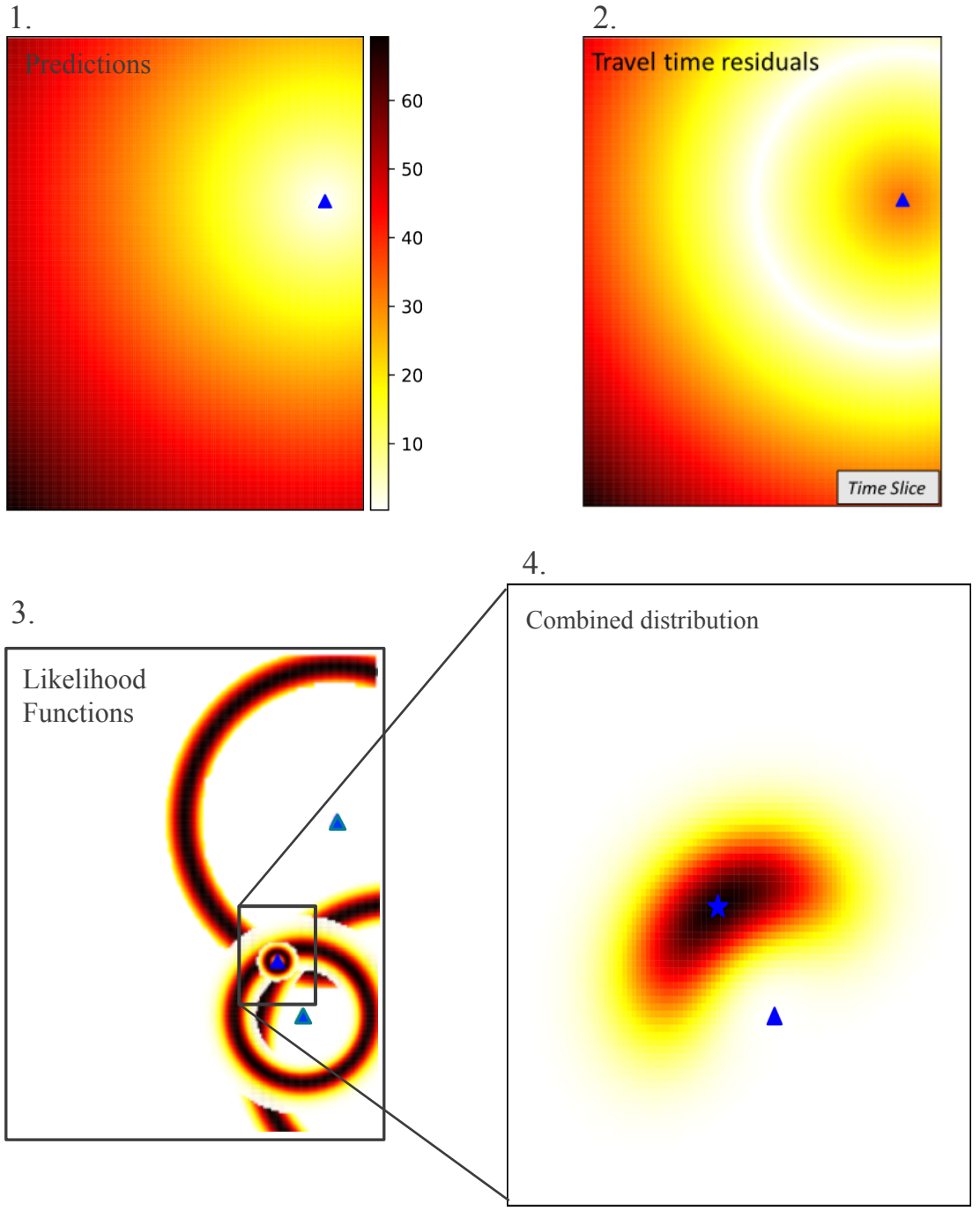


Producing Seismoacoustic Event Location Estimates

Using probabilistic location method from Koch and Arrowsmith (2019)

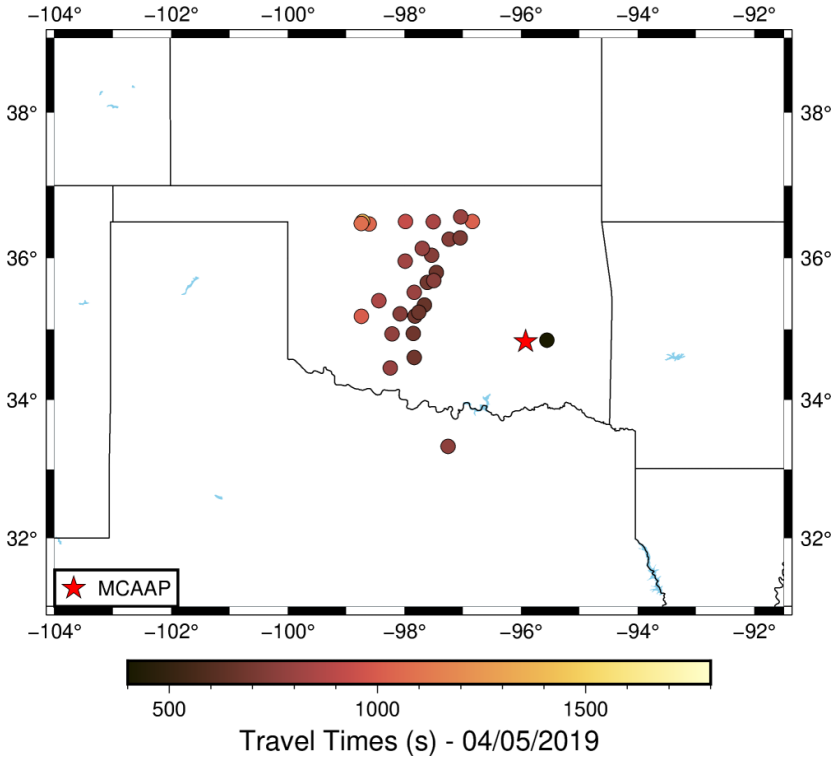
Grid search method

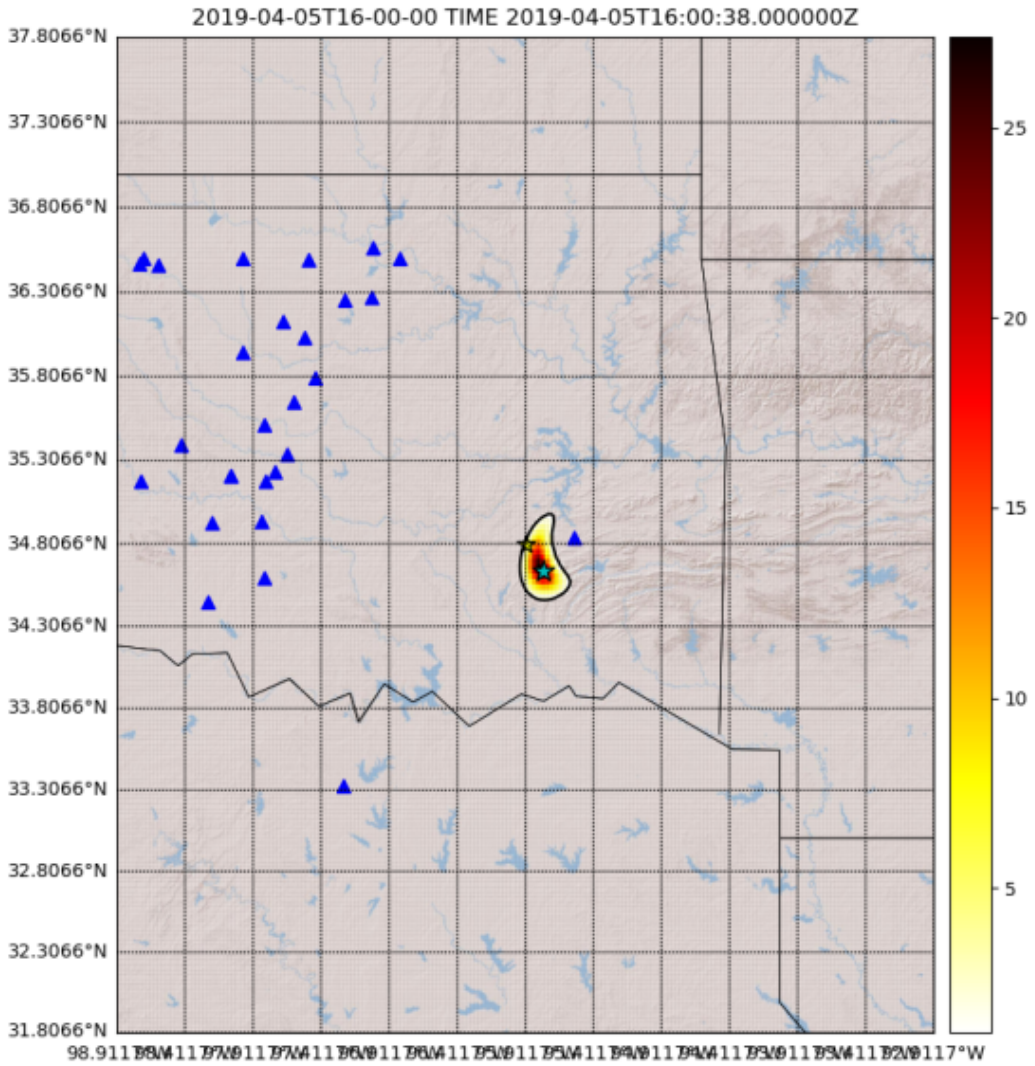
1. Predicts observations
2. Calculates Residuals
3. Calculates individual likelihoods functions
   - Assumes Gaussian Distribution
   - Model and pick uncertainties control the width
4. Combines likelihoods into single distribution
5. Assumes event is at 0 depth



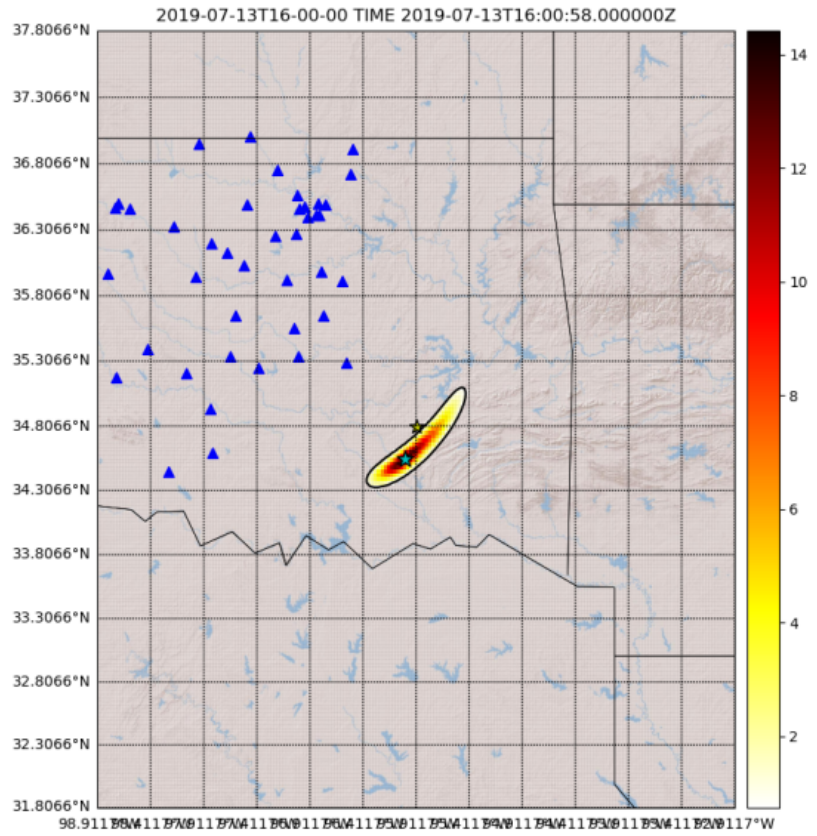
Event Location Estimates Using Analyst-Derived Arrival Times Indicate Spatiotemporal Variability in Arrivals May Bias Location Results

4/5/2019 – Event location estimate is driven by station to the east of MCAAP





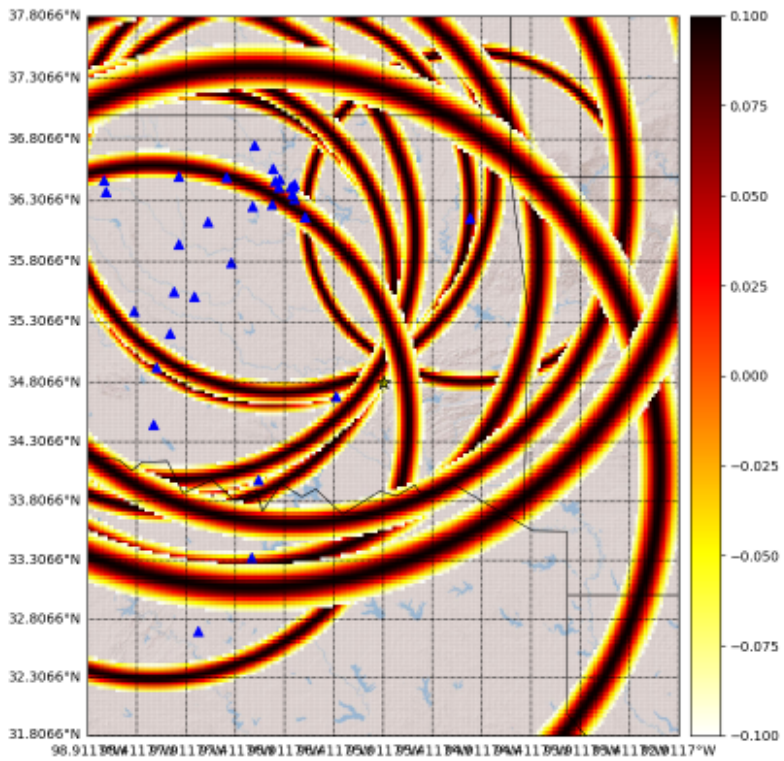
Initial Location Results Suggest that Mis-Associated Arrivals May Contribute to Location Errors



07/13/2019 [left-hand figure]

Fixed time was needed to produce a location

Demonstrates one issue of having all stations in one direction, you g smearing effect of the error.



04/25/2019 [right-hand figure]

Doesn't find a solution

Some arrivals converge pretty well around the center, but some are quite far off – leading to no unique

Conclusions + Future Work Plans

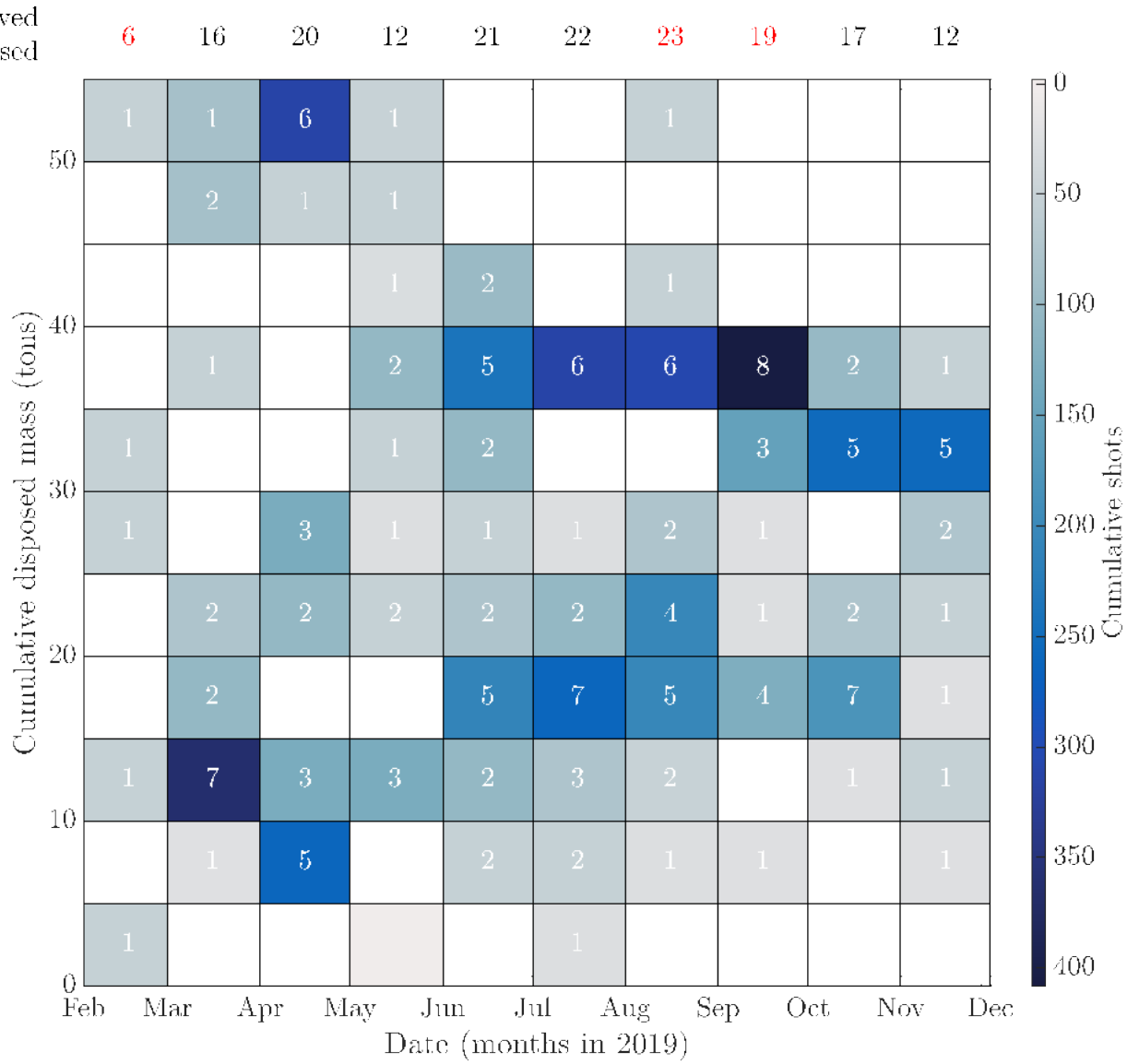
- We have compiled a dataset of both observed and predicted arrivals from McAAP blasts over a period of nine months
- Manual analyst identification demonstrates that stations within a range near 200km from the source more consistently record arrivals. This is consistent with arrivals propagating through a stratospheric duct.
  - Data is currently not consistent enough across the nine month period to complete a full review of celerities and arrival times
- There is significant discrepancy between observed and predicted arrivals, indicating that current propagation modeling efforts do not fully capture atmospheric dynamics in this region
  - Less than 50% consistency between location of actual arrivals and predicted arrivals within a radius of 10 km
- Initial location results indicate that acoustic arrivals recorded on seismic stations can be used to produce event locations following the methodology of Koch and Arrowsmith (2019); location accuracy may be driven by detecting station distribution

Data Products: Available to Geophysical Community

Digitized blast log data provided by Army partners

- McAAP blasted on **169** of **276** days to destroy **4.3**kT of mass with **7222** shots (**~600** kg/shot)
- Only three days lacked any pulse detections for **4033** visual observations at **120** stations
- Linear shot pit Area 2 showed slight preference for blasting (**53%** shots)
- Dependence of observability does not clearly increase with shot size / mass
- Observability of shots has strongest apparent dependence on season

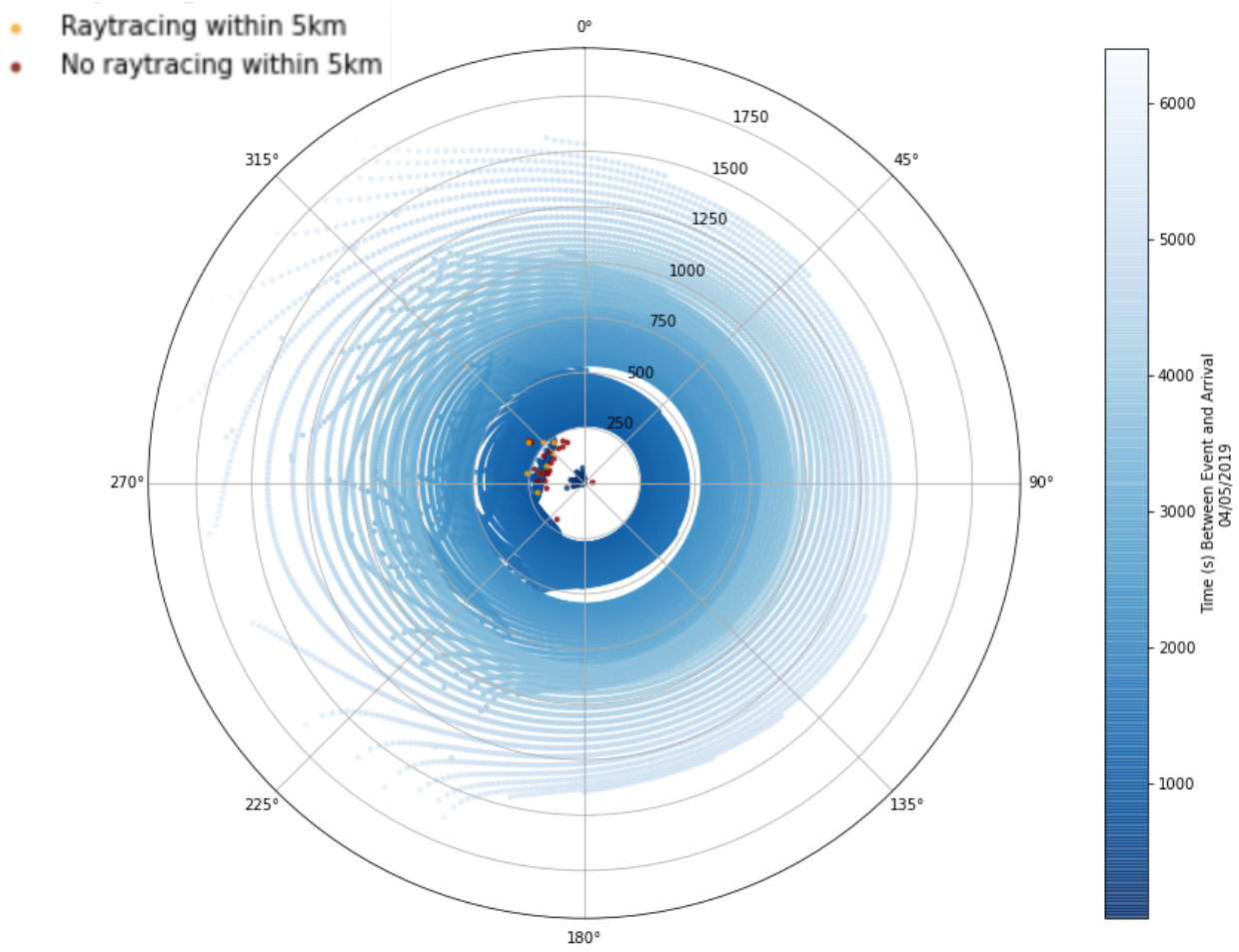
Detection rate = low resolution calendar



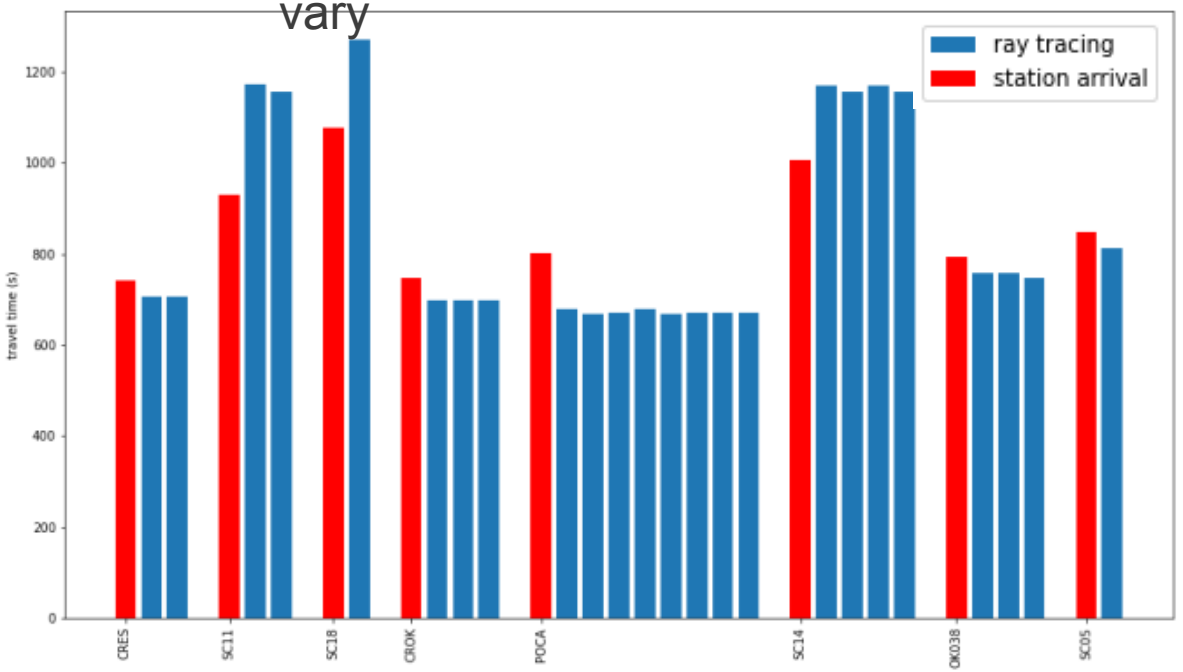
Data product: nine months of digitized blast log data

EXTRA SLIDES FOLLOW HERE

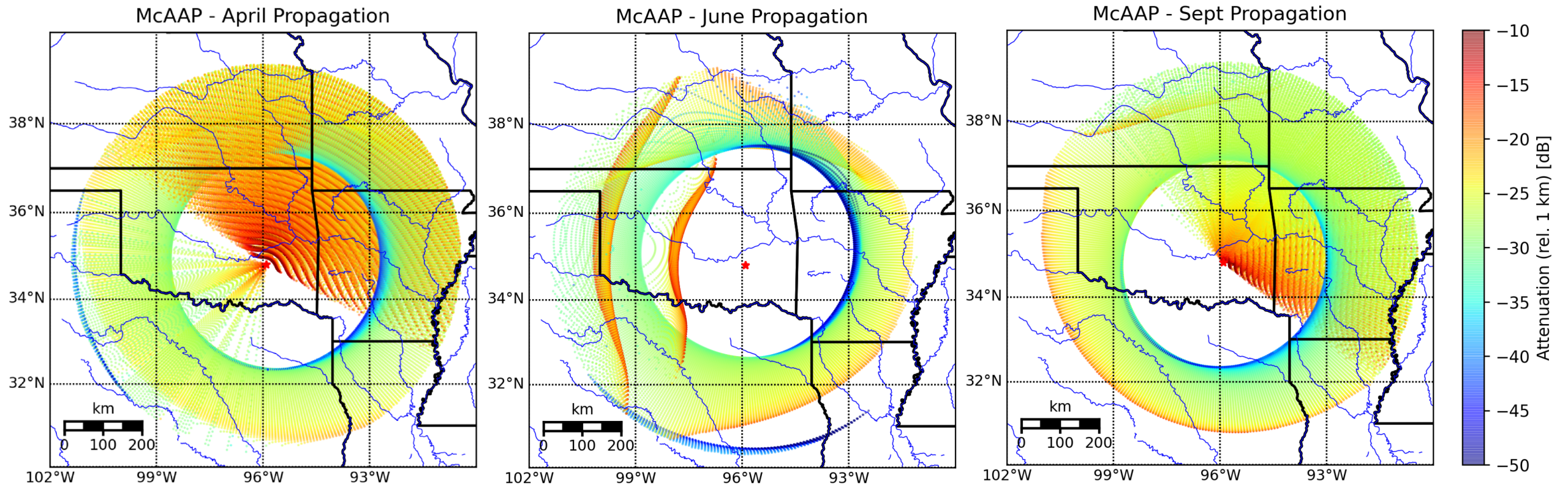
Initial Travel-Time Comparisons Suggest Additional Discrepancies Between Predicted and Observed Signal Travel Times



29% of arrivals have corresponding ray-tracing predicted arrivals; travel time comparisons document that travel times vary



Limited modeling with infraGA explains some spatial patterns in detection, that include multi-pathing and shadow zones



- Movie in BSSA publication shows pulse sequences with mass destroyed every day, from March of 2019, through late November