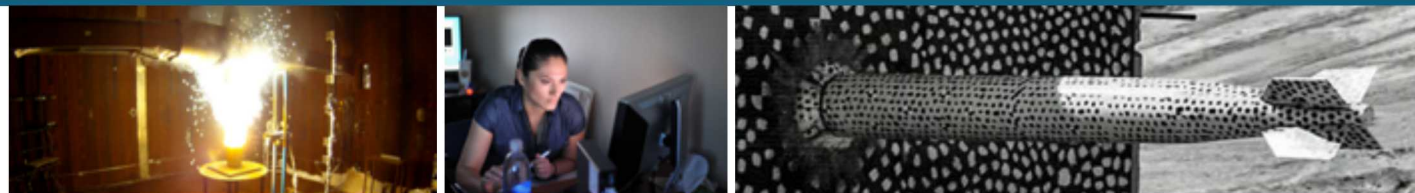




Tracking Scattered Signals in the Acoustic Coda Using Independent Component Analysis in a Topographically Complex Setting



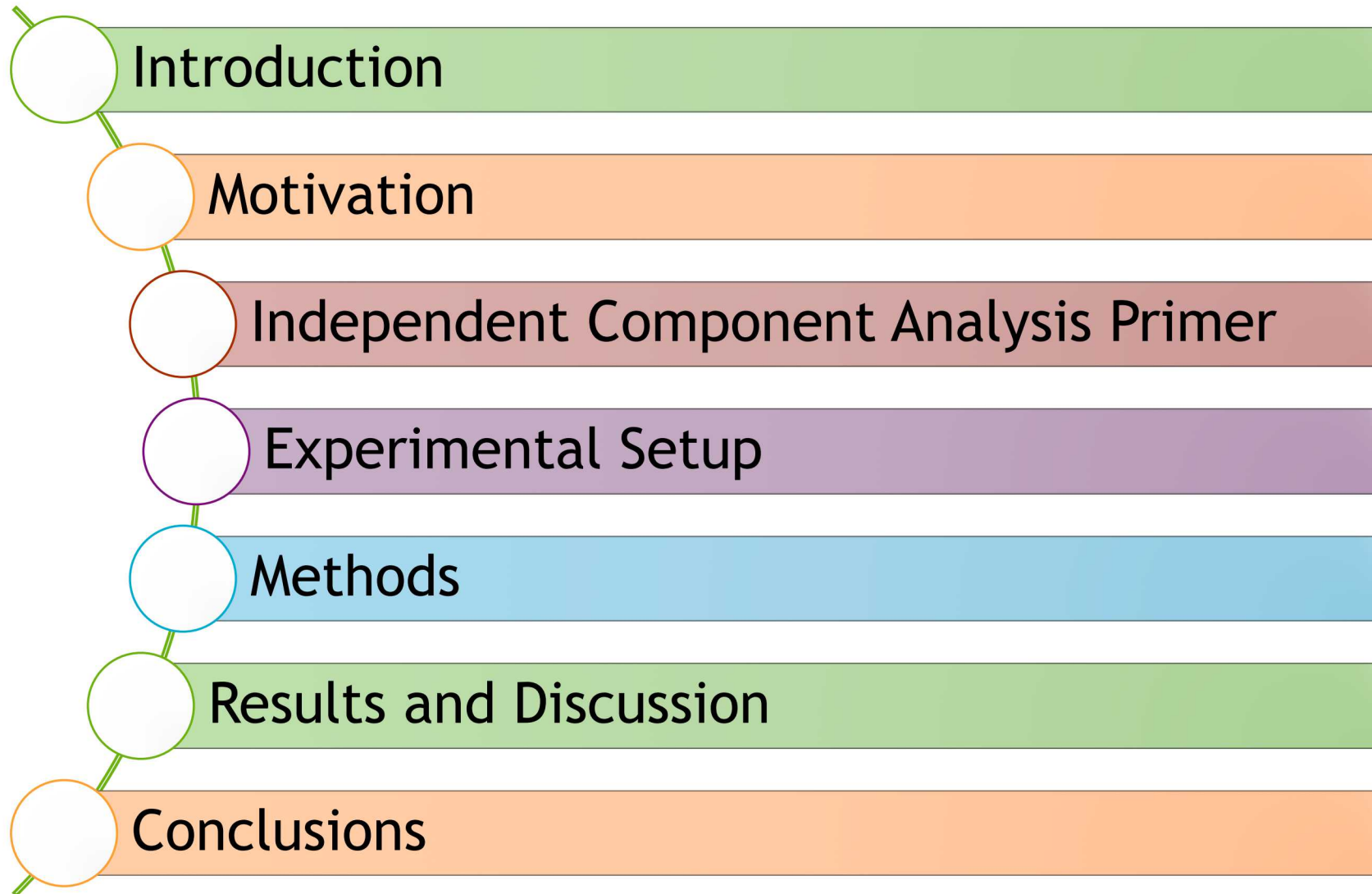
PRESENTED BY

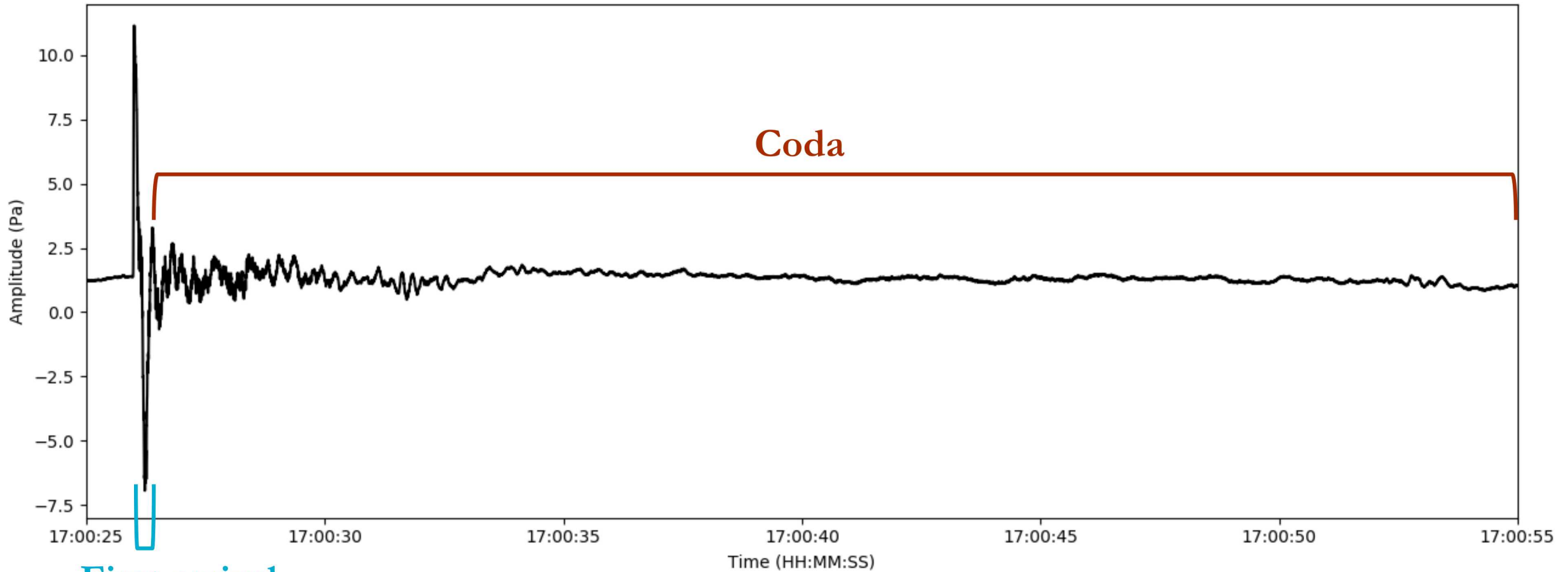
Sarah Albert and Daniel Bowman



Sandia National Laboratories is a multission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND 2018-XXXX





First arrival

Acoustic waves travel various paths from source to sensor

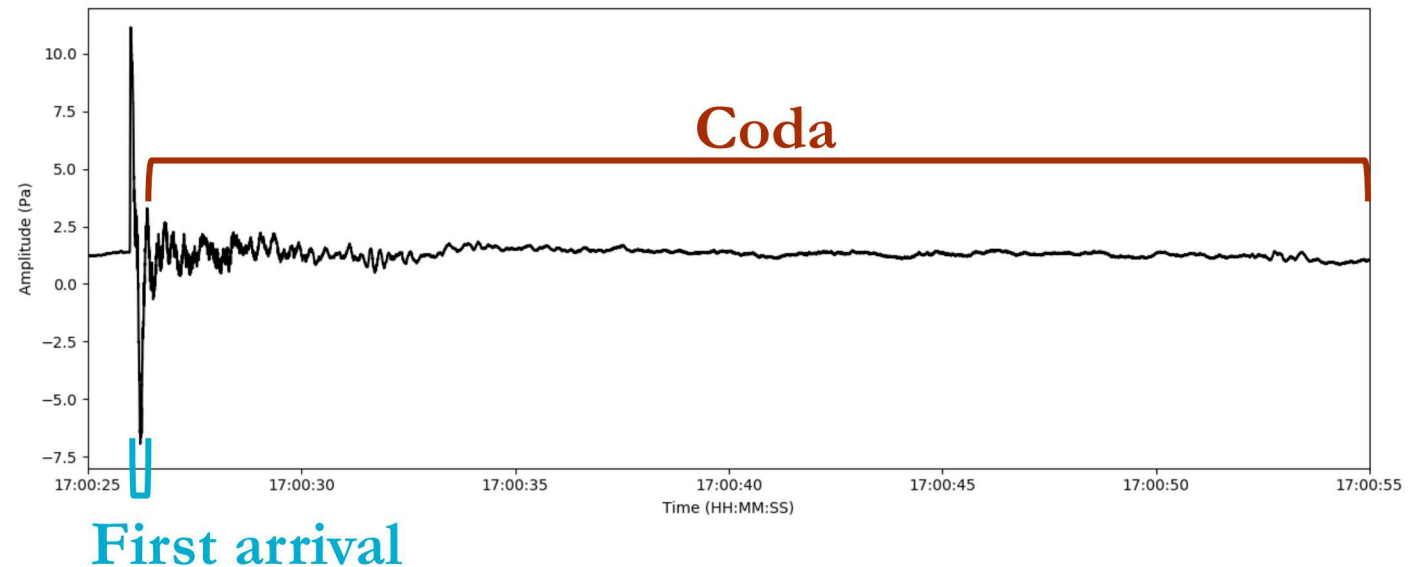
- Direct arrival
- Arrivals from reflections off scatterers

Each interaction with a scatterer alters the shape of the acoustic coda

- Consider each interaction statistically independent
- Can use Independent Component Analysis (ICA) to separate signals

Implications for a variety of studies

- Volcano infrasound
- Waveform inversion
- Yield estimation



Motivation



- Important impacts on **long duration infrasound signals**
- Studies in areas with **complex topography** (i.e. volcanoes)
- Topographical effects often ignored or given cursory treatment
- This study offers a solution to determining (or ruling out) topographical effects in an area with complex topography



www.photovolcanica.com



www.wikipedia.org

Solution – Independent Component Analysis

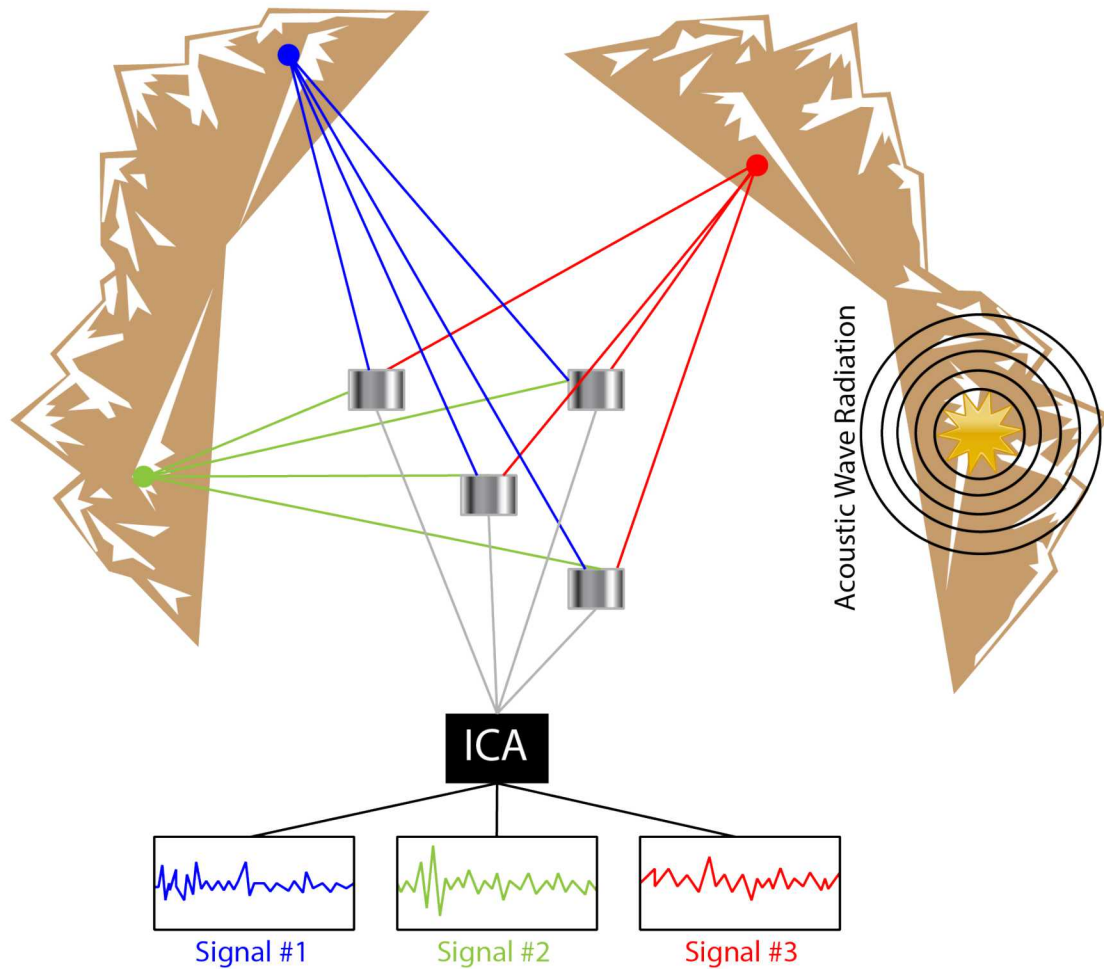


Image not to scale.

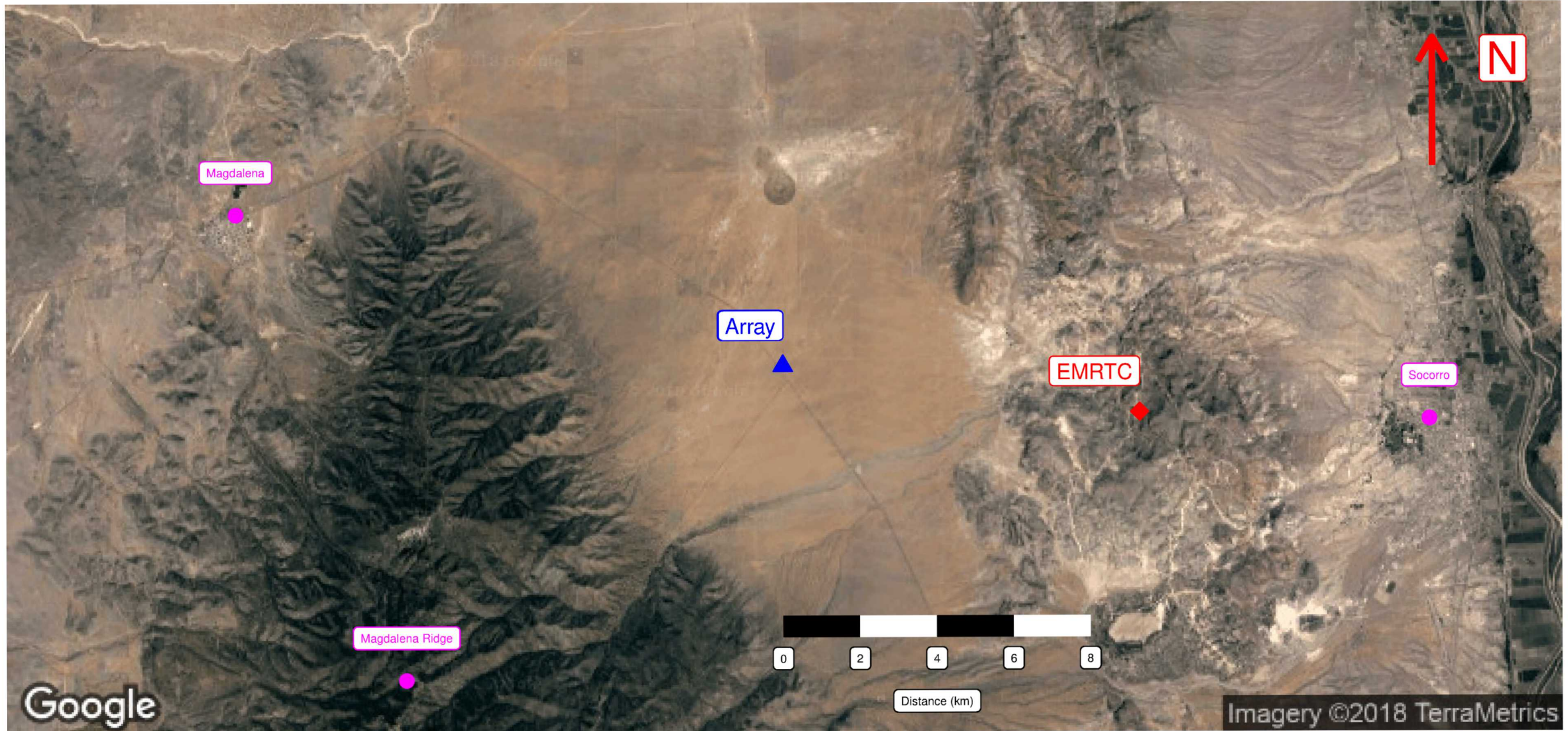
Mixed signal vector

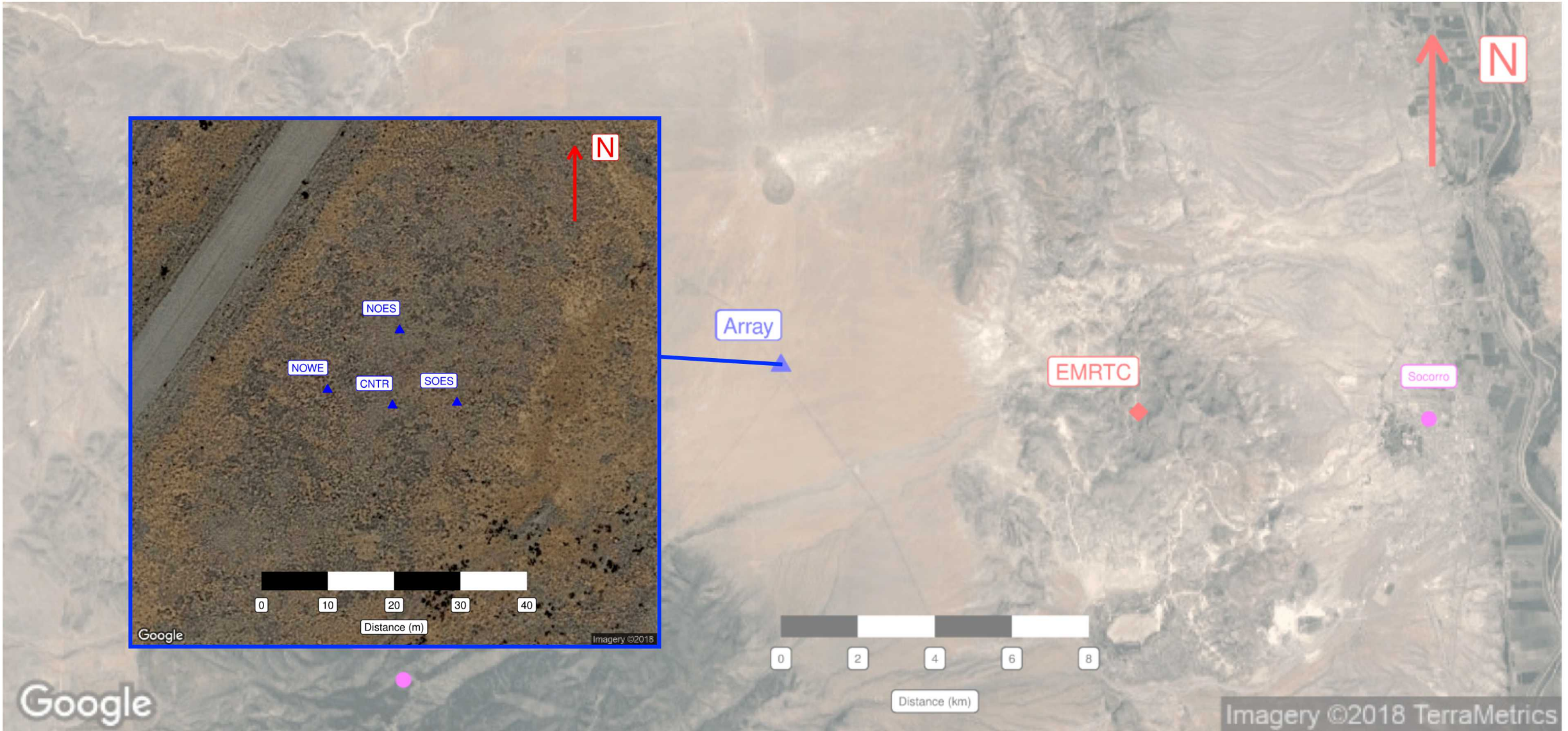
Vector of source signals

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} A_{11} & \cdots & A_{14} \\ \vdots & \ddots & \vdots \\ A_{41} & \cdots & A_{44} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix}$$

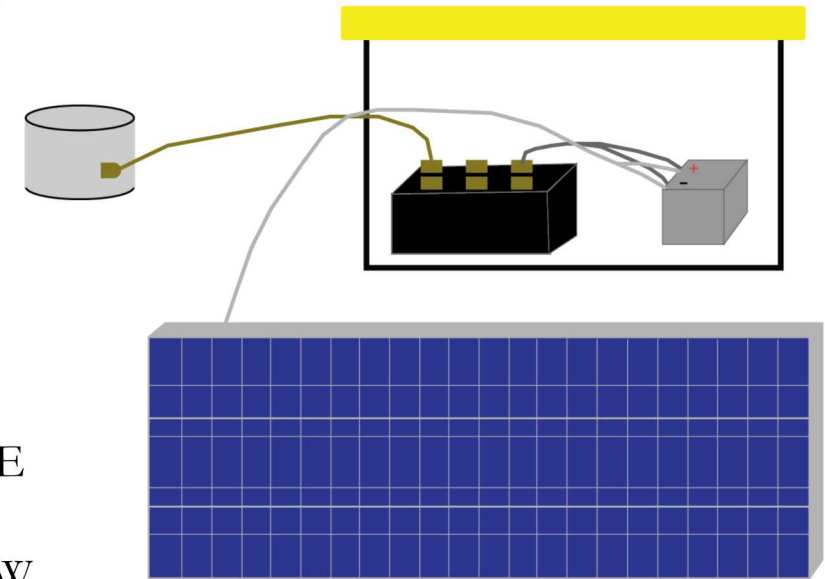
Weight vectors describing how signals are mixed (a.k.a “mixing” matrix)

7 Experimental Setup



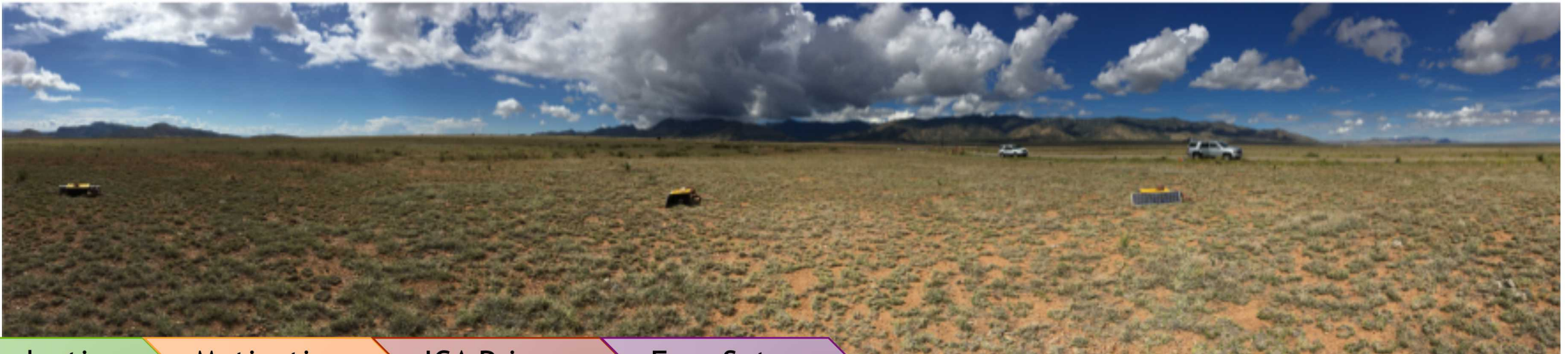


Station Configuration and Topography

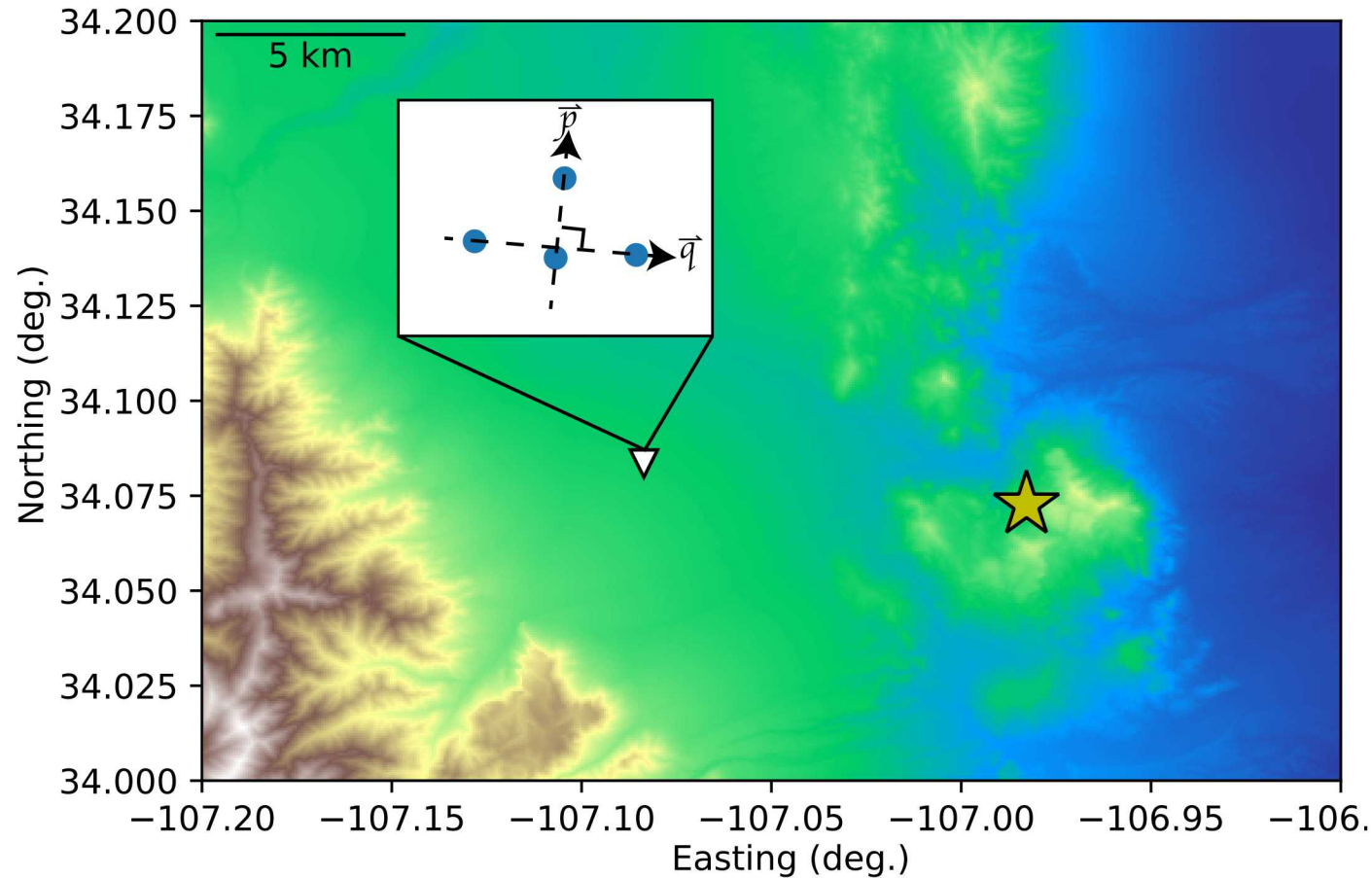


Topography to the E-NE

Topography to the W-SW

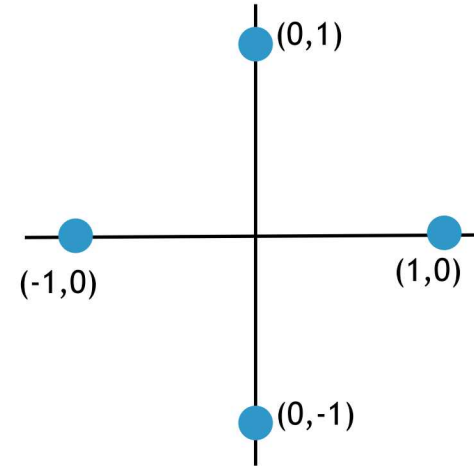
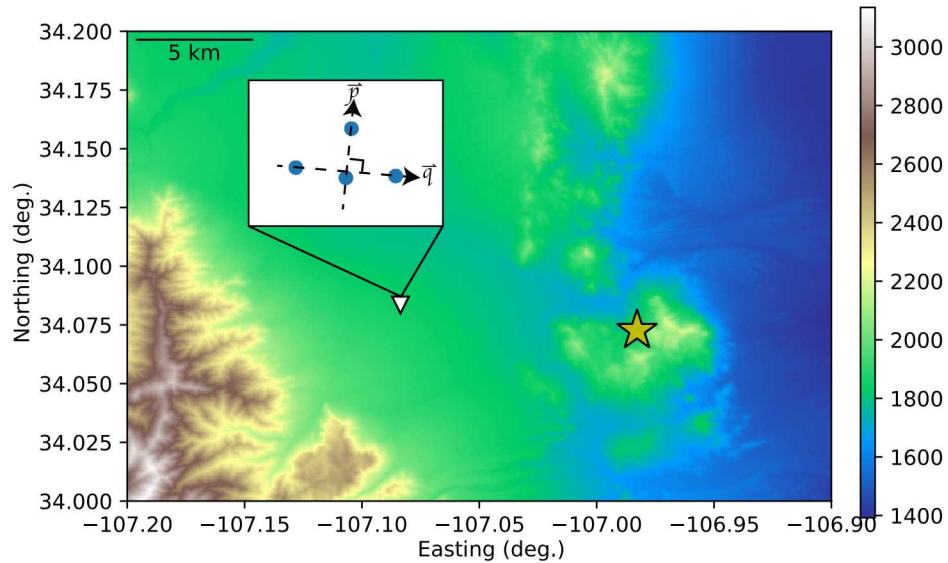


Methods – Gradient Flow Independent Component Analysis



- Closely-spaced array (10 m separation)
- Take spatial time derivatives of signal mixtures along position coordinates
 - Used to determine backazimuths
- Overcomplete ICA bases – use symmetric quasi-decorrelation

Methods - Signal Backazimuth Calculation



- Spatial derivatives:

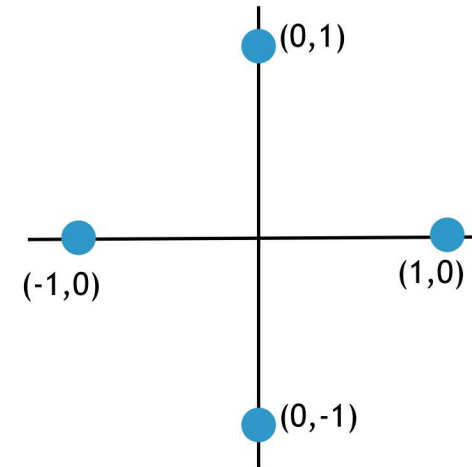
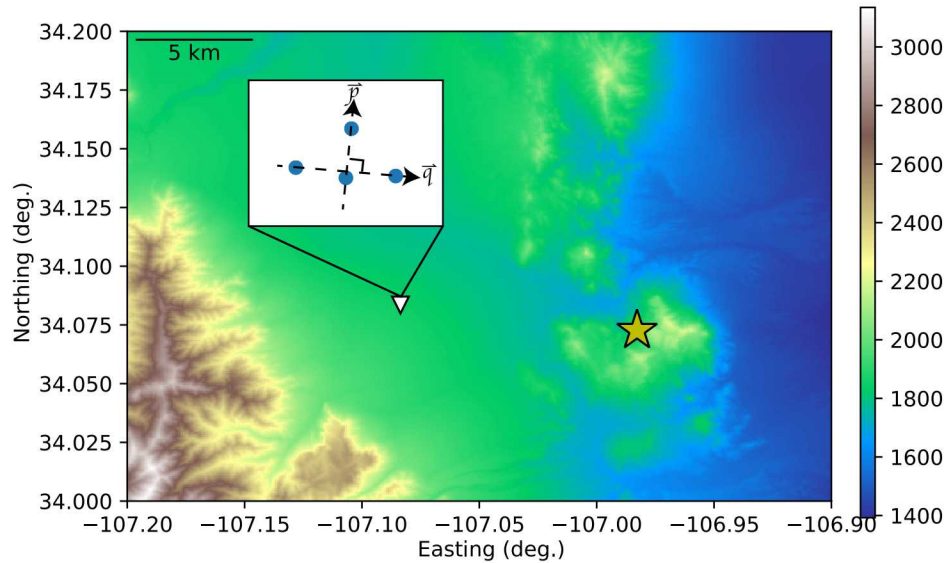
$$\xi_{00} \approx \frac{1}{4} (x_{-1,0} + x_{0,-1} + x_{0,1})$$

$$\xi_{10} \approx \frac{1}{2} (x_{1,0} - x_{-1,0})$$

$$\xi_{01} \approx \frac{1}{2} (x_{0,1} - x_{0,-1})$$

- Forms \vec{x} in the equation, $\vec{x} = A\vec{s}$

Methods - Signal Backazimuth Calculation



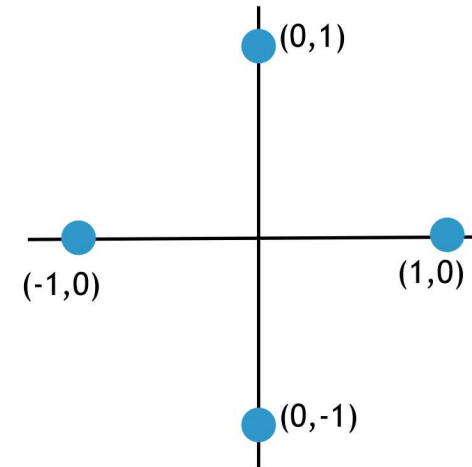
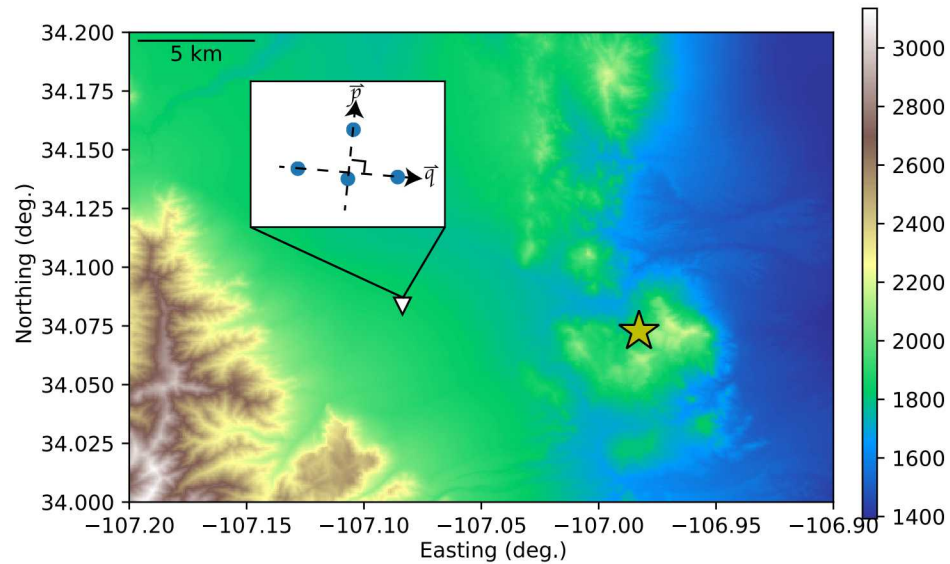
- Use inter-station time differences between sensors:

$$\tau_1^l = \frac{1}{c} \vec{q} \cdot \vec{u}_x^l$$

$$\tau_2^l = \frac{1}{c} \vec{p} \cdot \vec{u}_y^l$$

$$\tan^{-1} \frac{\vec{u}_x^l}{\vec{u}_y^l} = \theta$$

Methods - Signal Backazimuth Calculation



- Use inter-station time differences between sensors:

$$\tau_1^\ell = \frac{1}{c} \vec{q} \cdot \vec{u}_x^\ell$$

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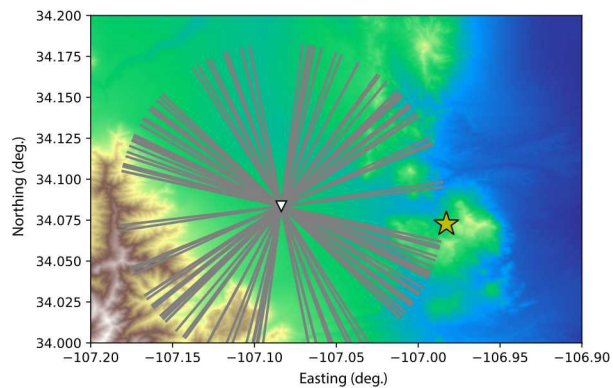
$$\tan^{-1} \frac{\vec{u}_x^\ell}{\vec{u}_y^\ell} = \theta$$

Direction vectors
for source ℓ

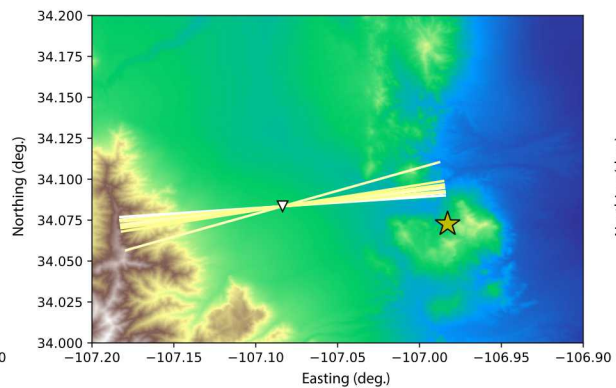
Signal backazimuth



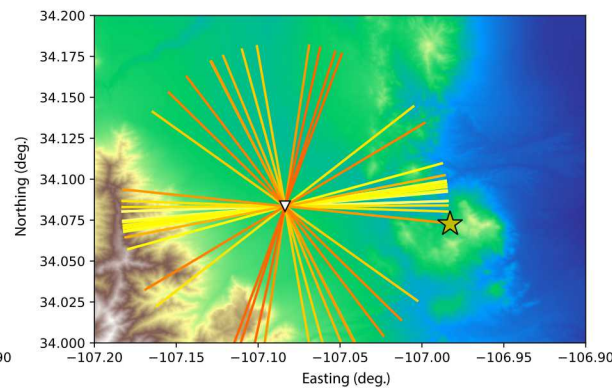
Explosion 1



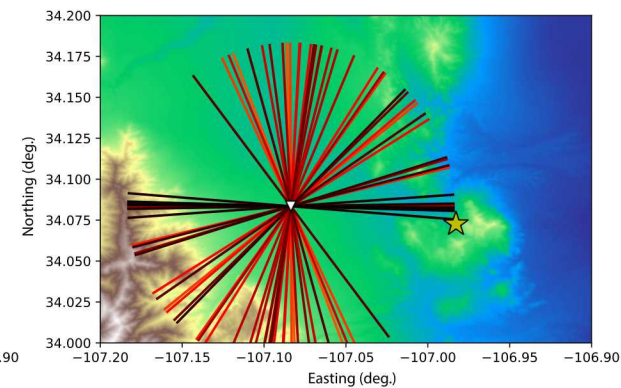
30 s prior to explosion



0 - 4 s

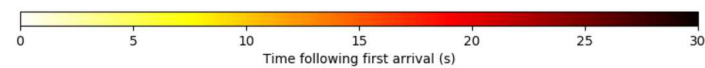
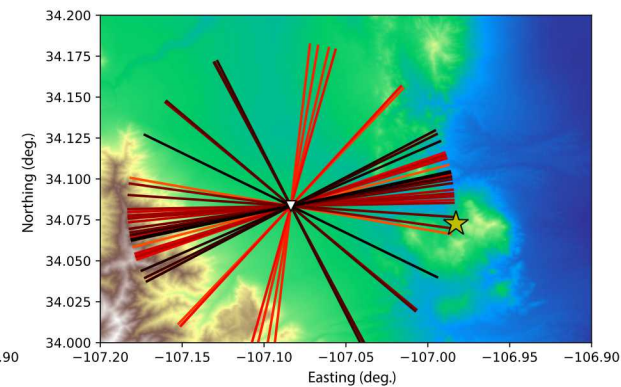
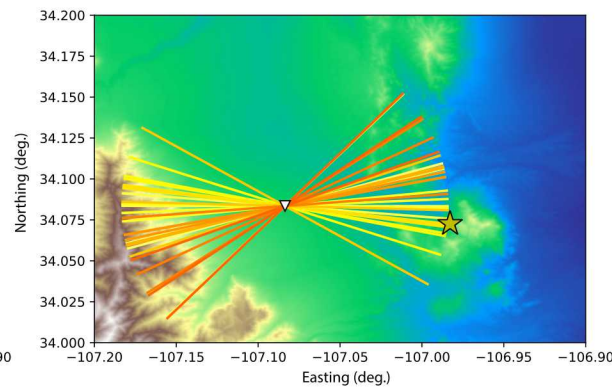
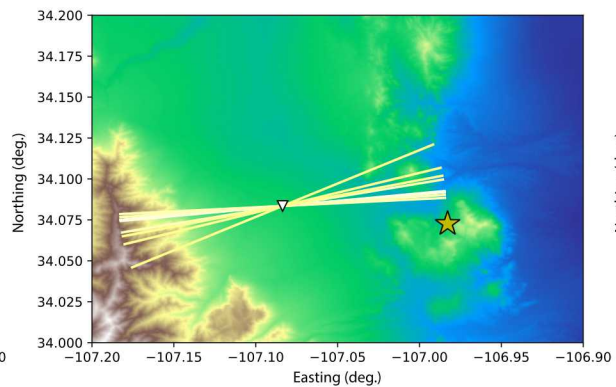
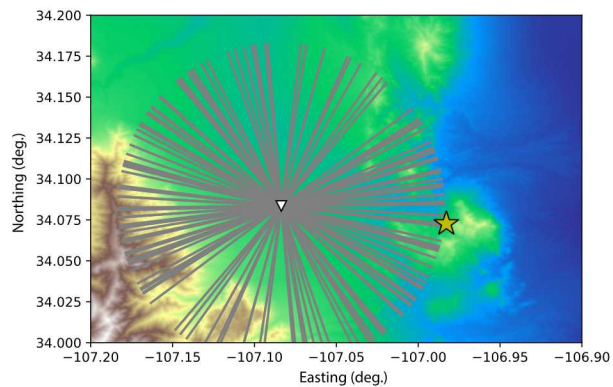


4 - 14 s



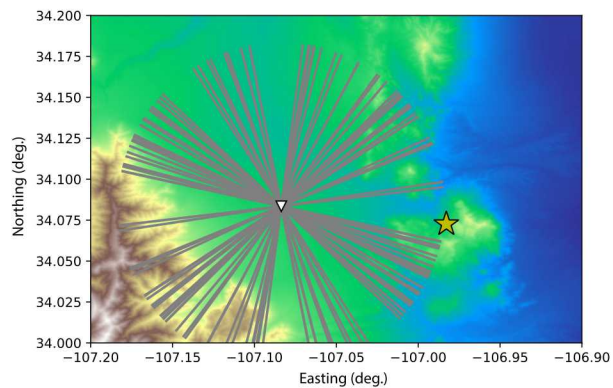
14 - 30 s

Explosion 2

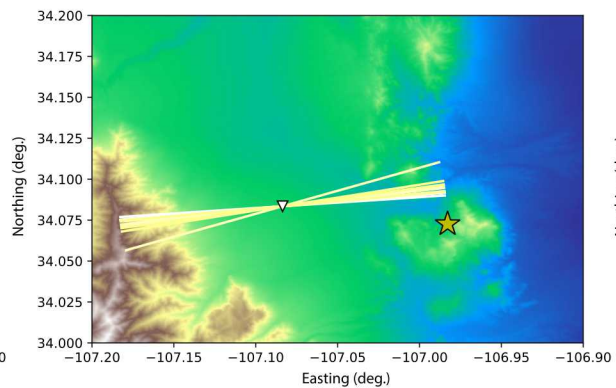




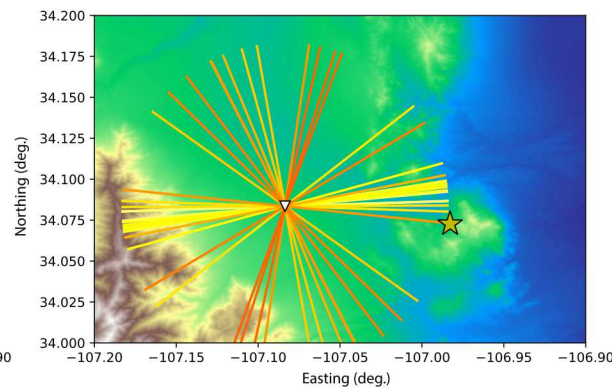
Explosion 1



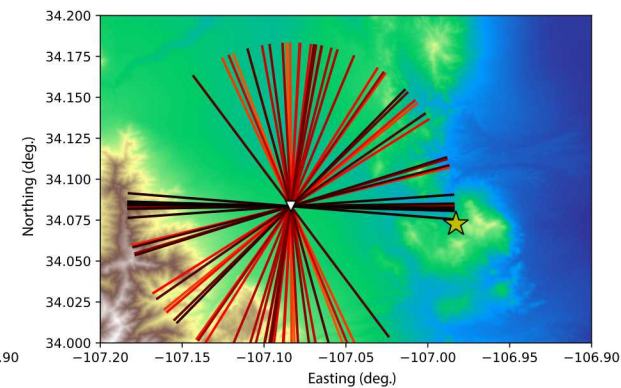
30 s prior to explosion



0 - 4 s

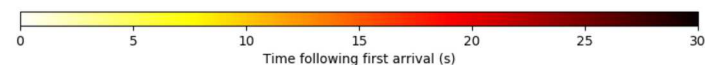
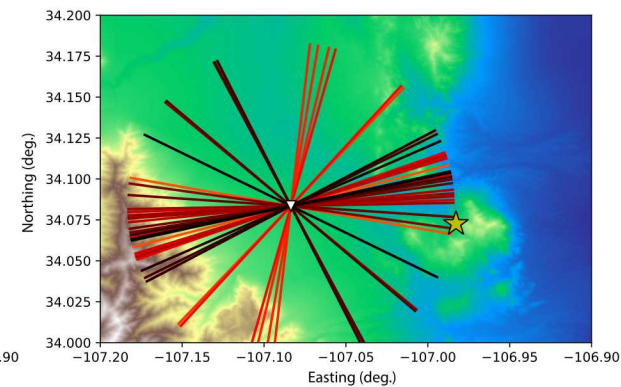
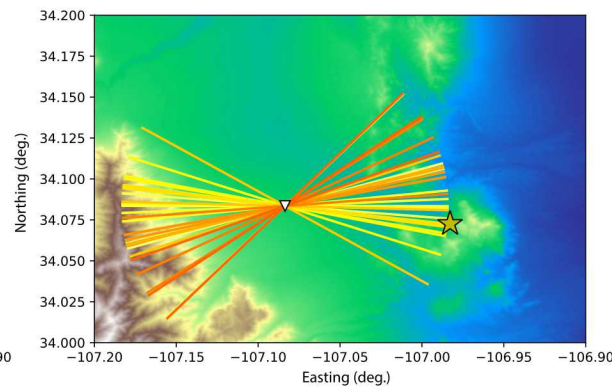
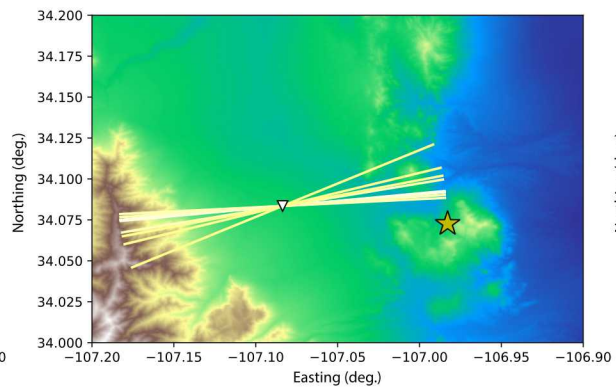
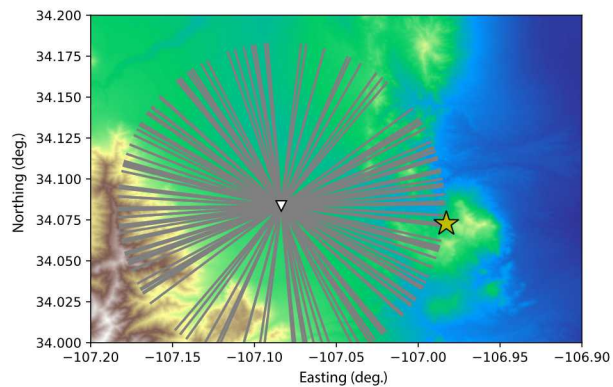


4 - 14 s



14 - 30 s

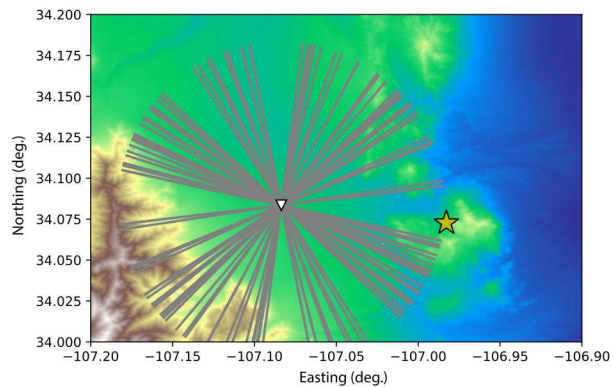
Explosion 2



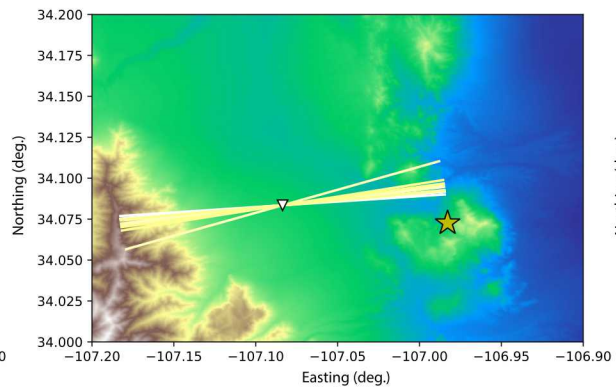
No signals expected



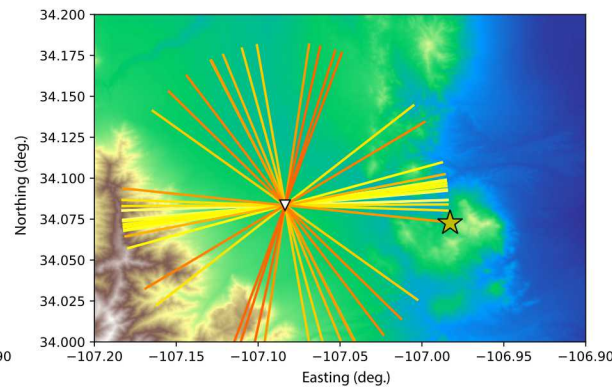
Explosion 1



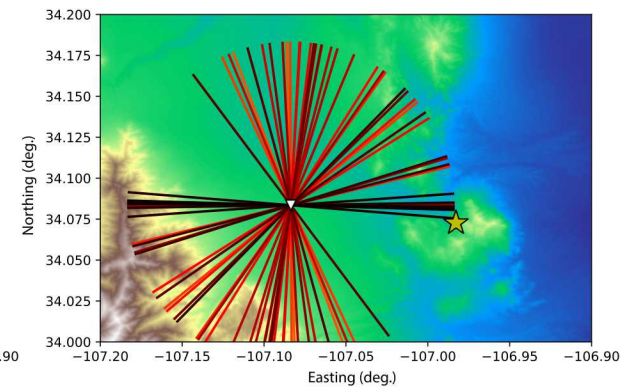
30 s prior to explosion



0 - 4 s

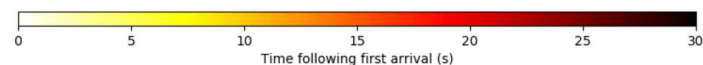
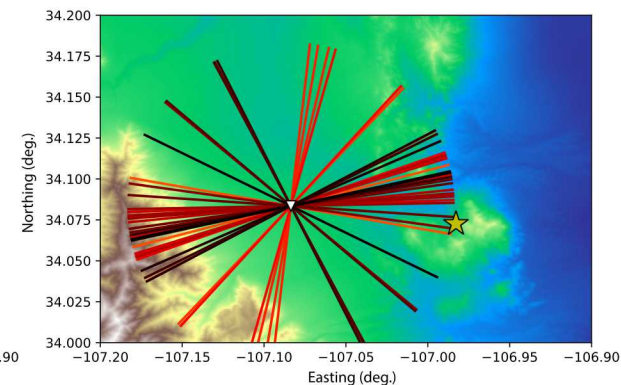
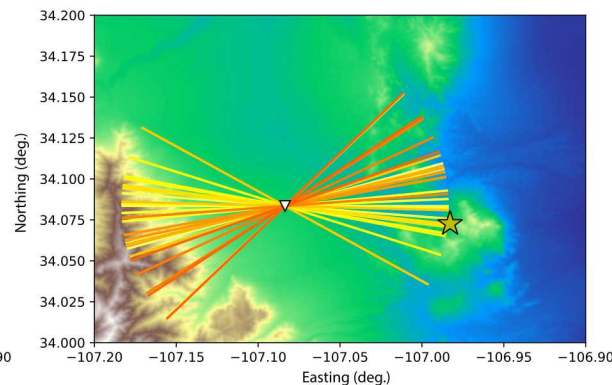
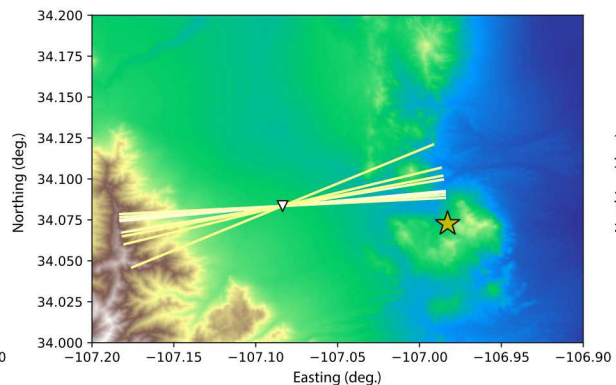
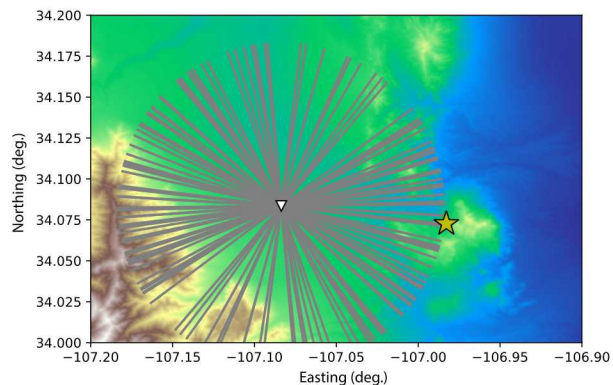


4 - 14 s



14 - 30 s

Explosion 2

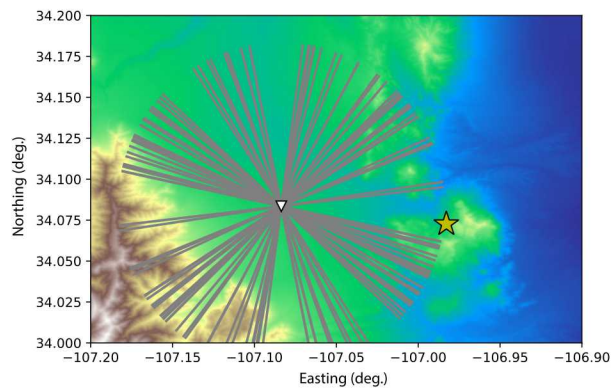


No signals expected

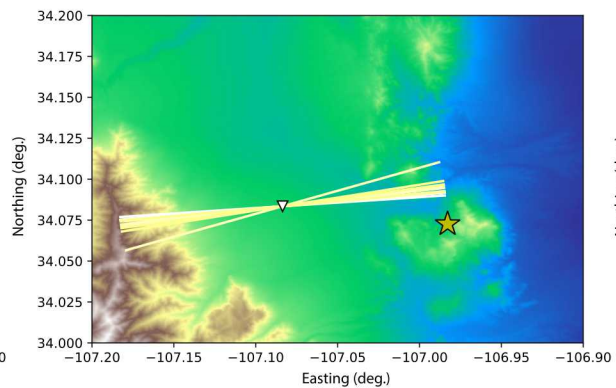
First arrivals



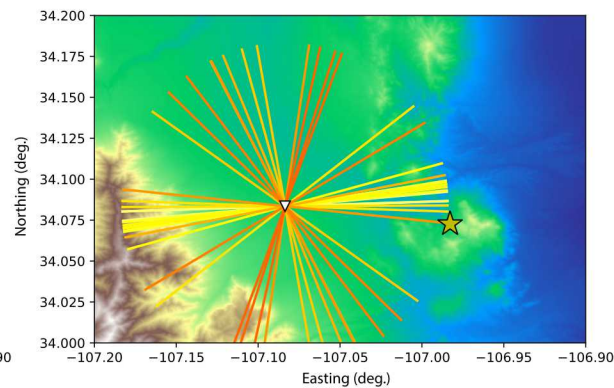
Explosion 1



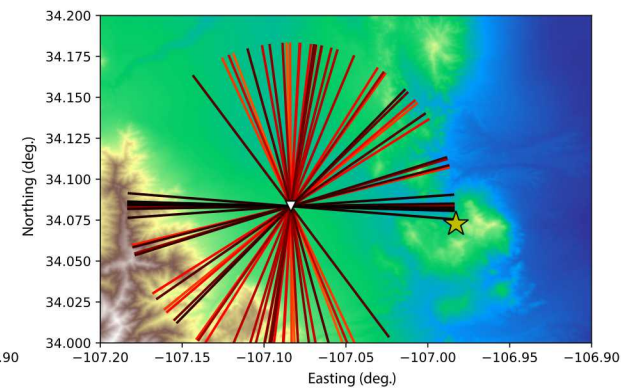
30 s prior to explosion



0 - 4 s

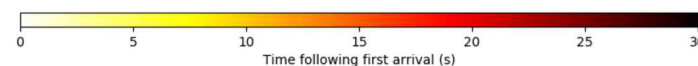
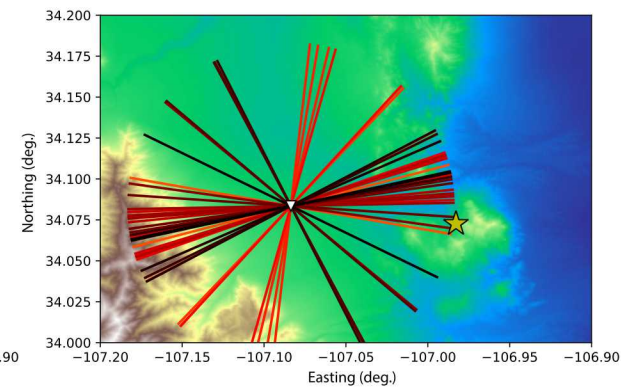
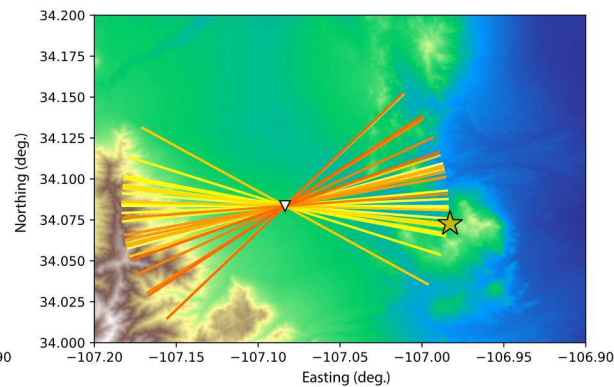
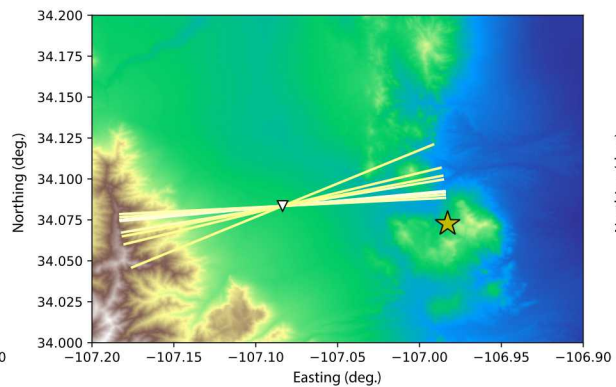
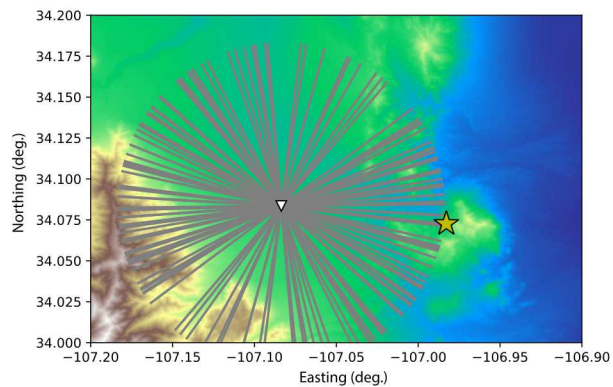


4 - 14 s



14 - 30 s

Explosion 2



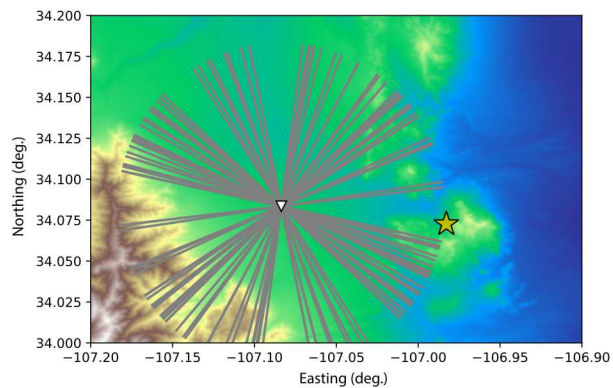
No signals expected

First arrivals

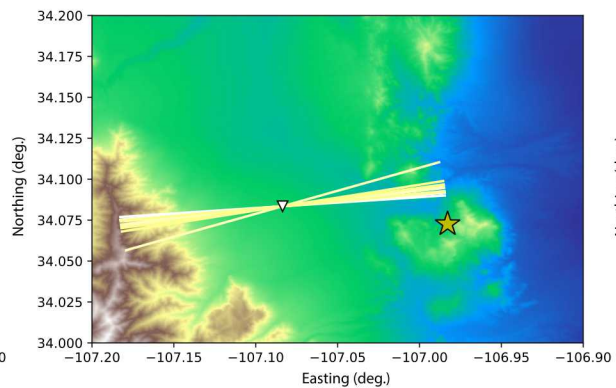
Signals from E-NE



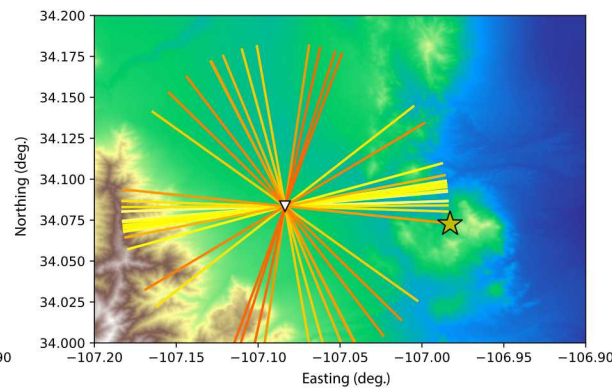
Explosion 1



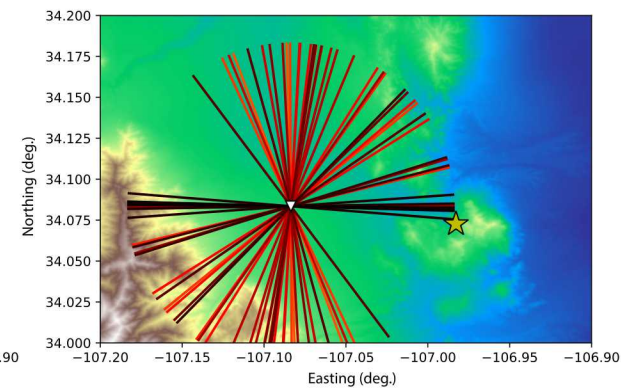
30 s prior to explosion



0 - 4 s

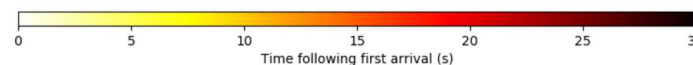
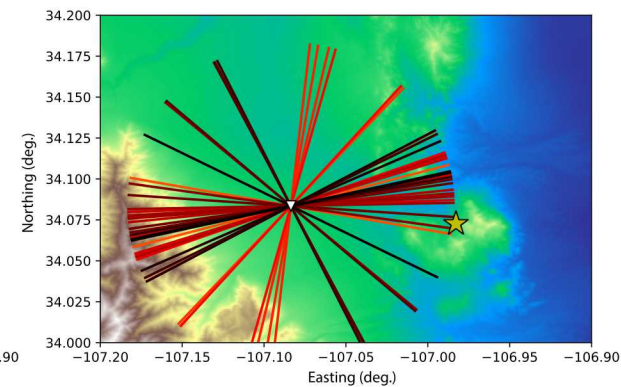
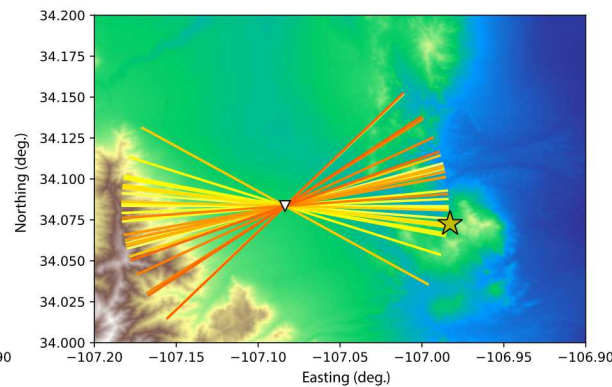
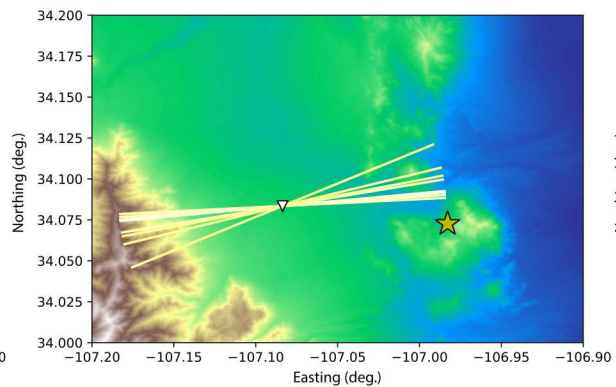
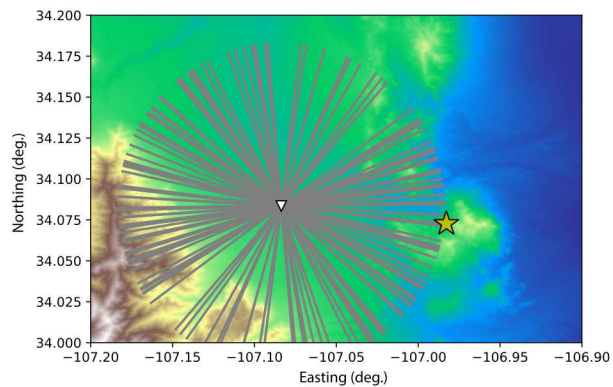


4 - 14 s



14 - 30 s

Explosion 2



No signals expected

First arrivals

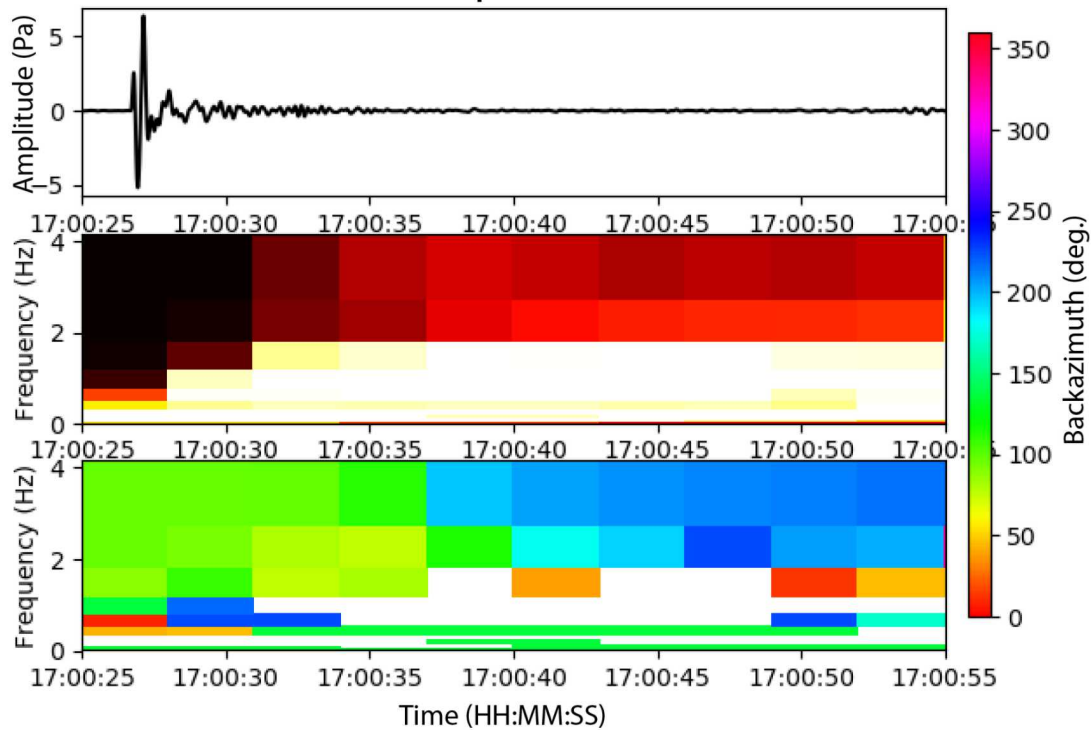
Signals from E-NE

Signals from W-SW
(and others?)

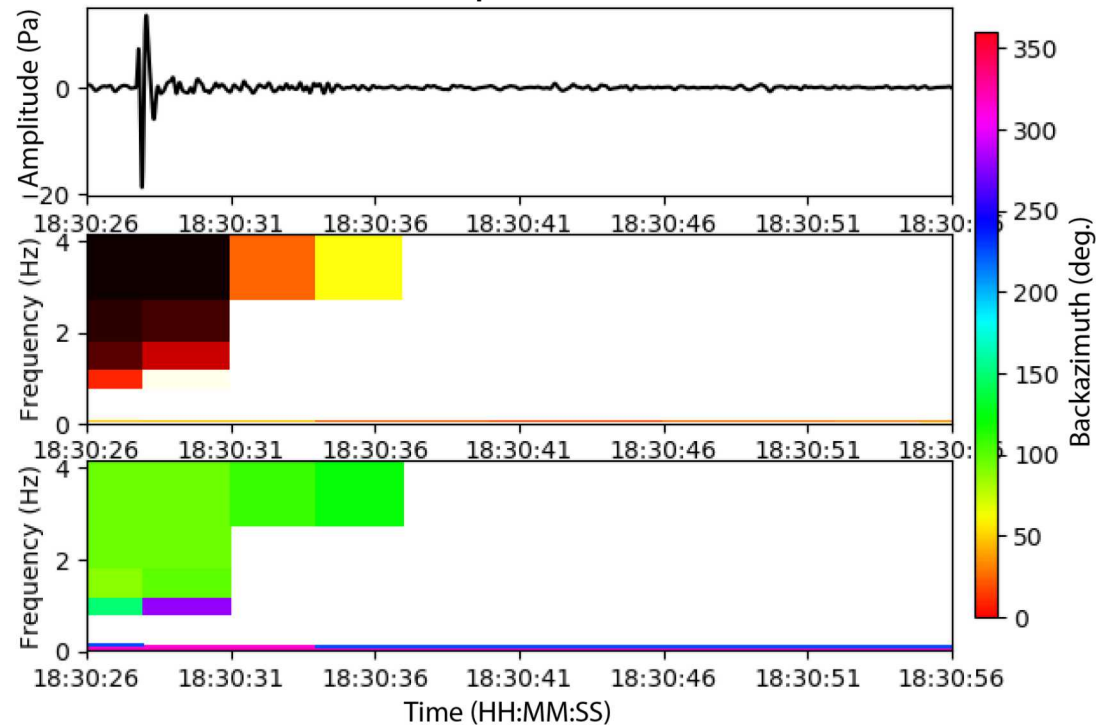
Progressive Multi-Channel Cross Correlation



Explosion 1



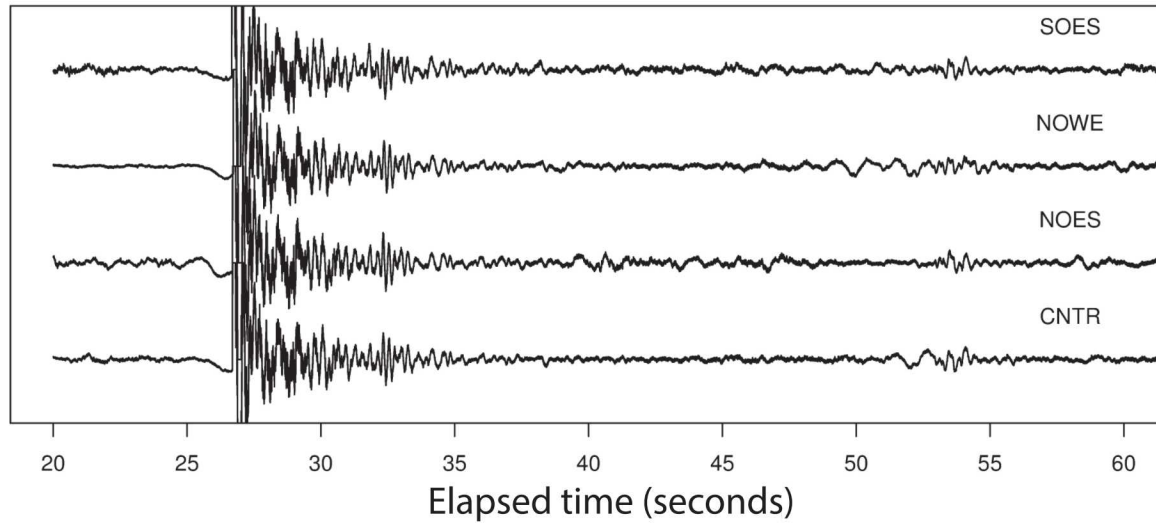
Explosion 2



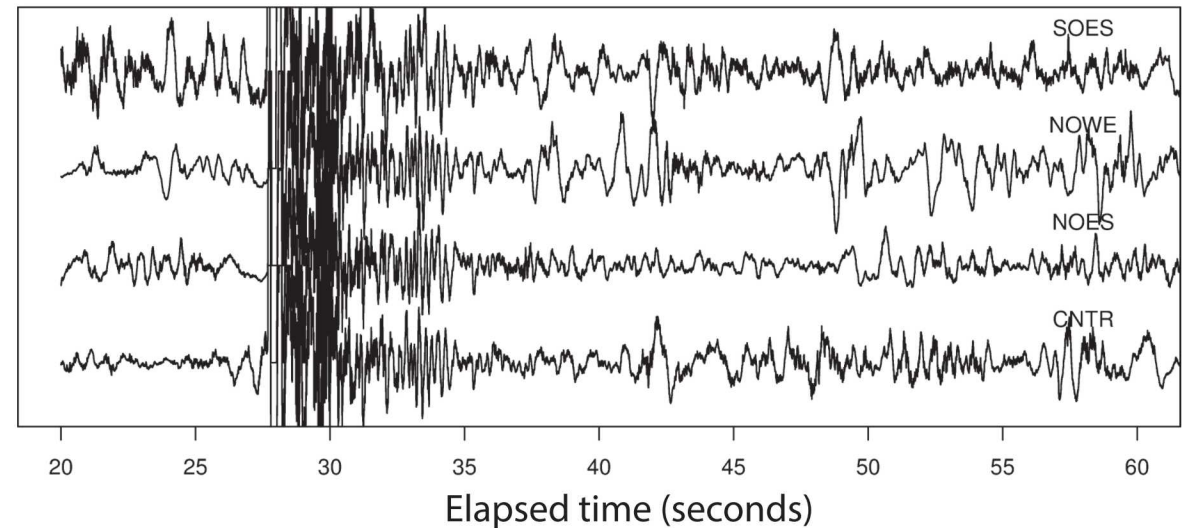
Amplitude Difference Between Explosions



Explosion 1: 1700 UTC



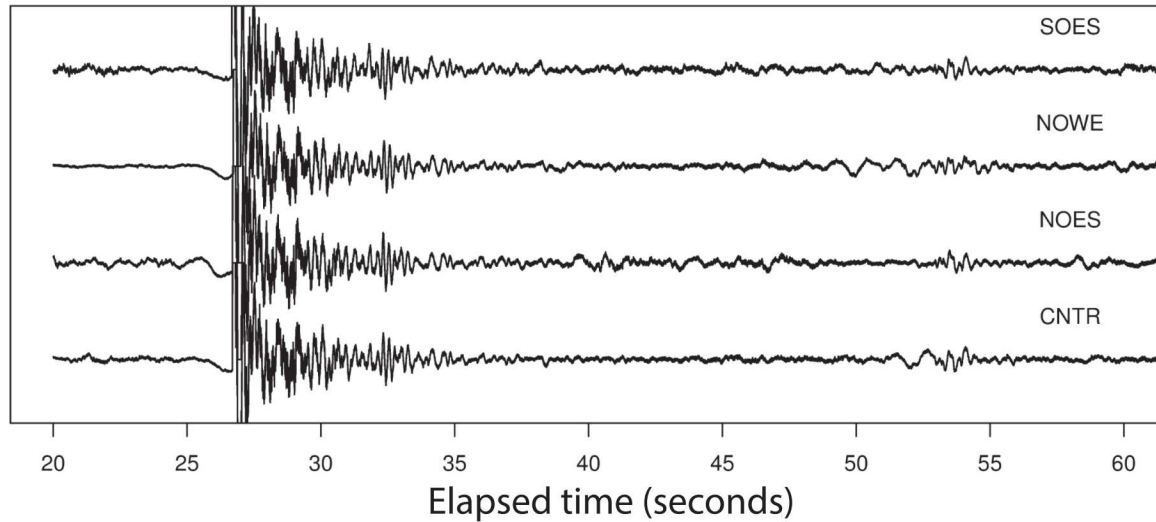
Explosion 2: 1830 UTC



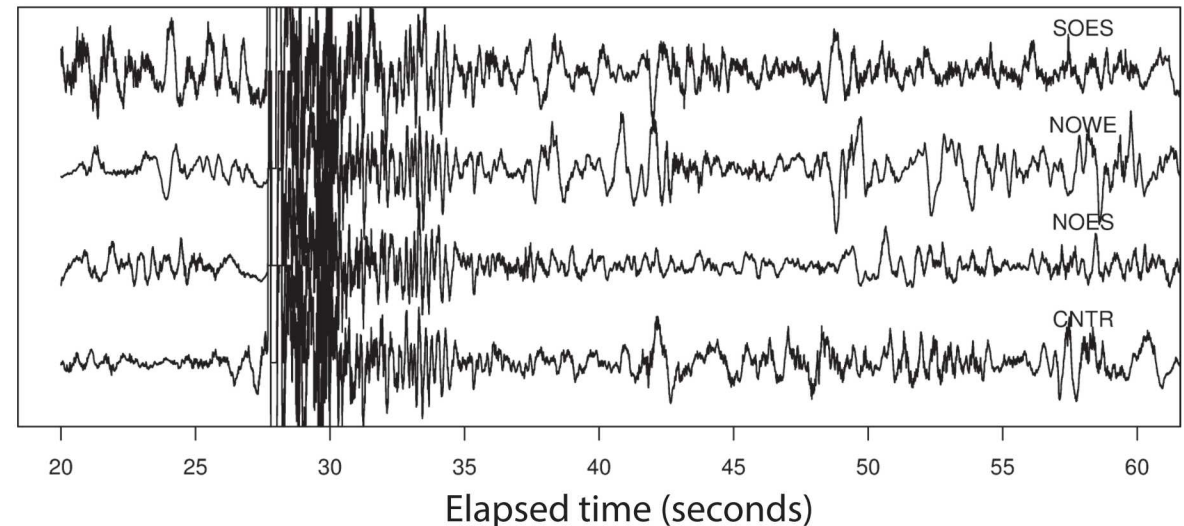
Amplitude Difference Between Explosions



Explosion 1: 1700 UTC



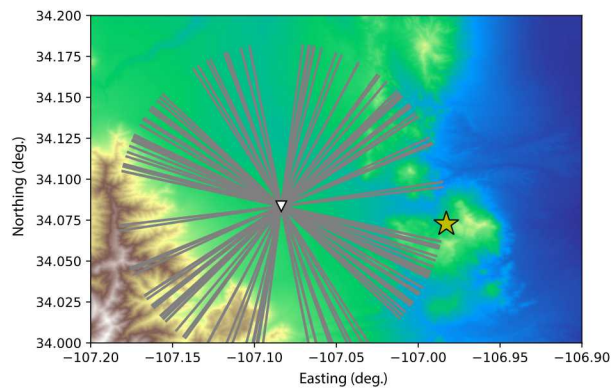
Explosion 2: 1830 UTC



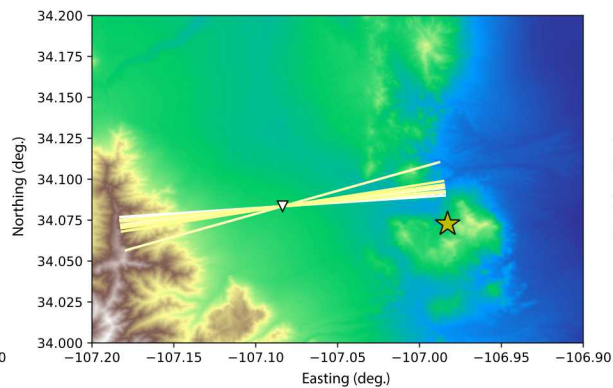
- Amplitudes 3.5 times greater for 2nd explosion
- Atmospheric or topographical ducting
- New atmospheric structure provides more accurate estimates < 25 seconds after first arrival



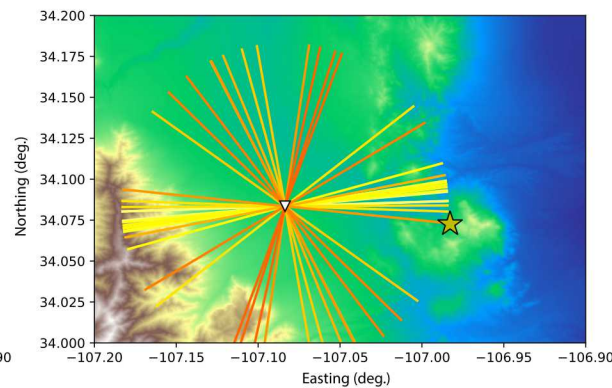
Explosion 1



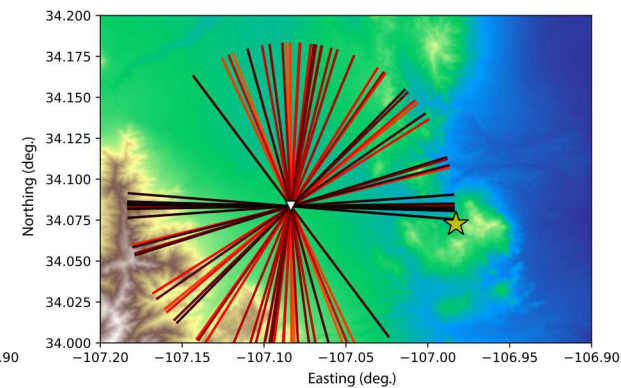
30 s prior to explosion



0 - 4 s

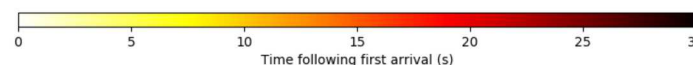
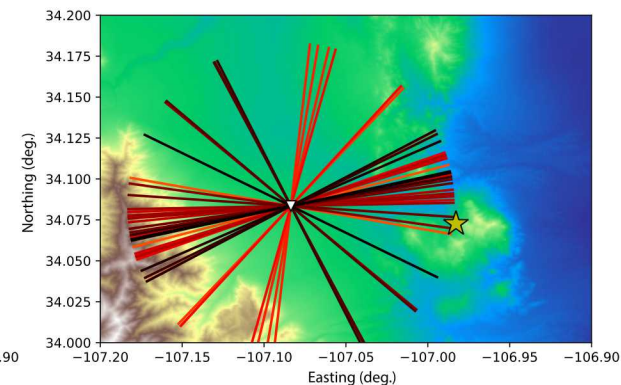
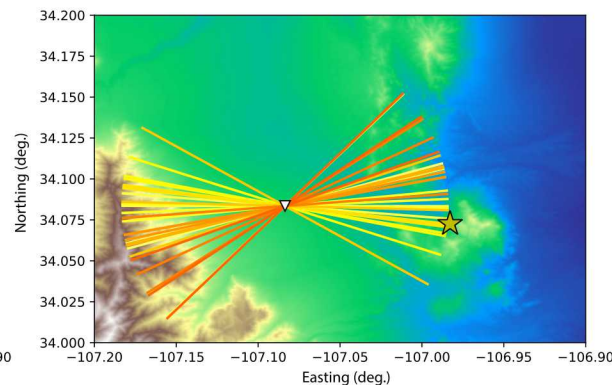
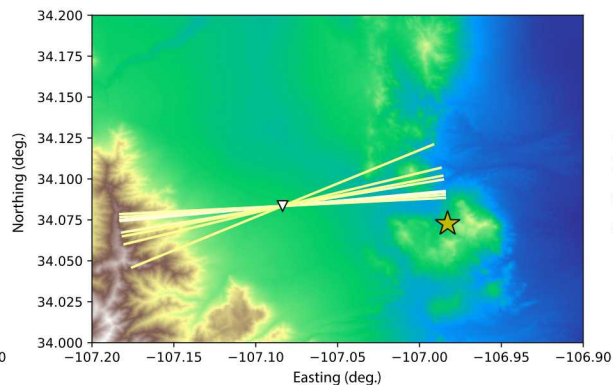
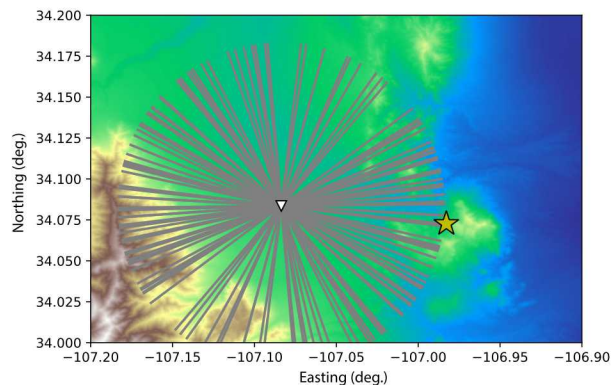


4 - 14 s



14 - 30 s

Explosion 2



No signals expected

First arrivals

Signals from E-NE

Signals from W-SW
(and others?)

Conclusions

- Separated scattered signals in the acoustic coda using Gradient Flow ICA
- Identified the backazimuth of first arrival and subsequent scattered signals
- “Unknown” sources also identified
- Difference in amplitudes suggests change in atmospheric structure

Future Work

- Invert for the wind vector field
- Complete a similar study with large-N array

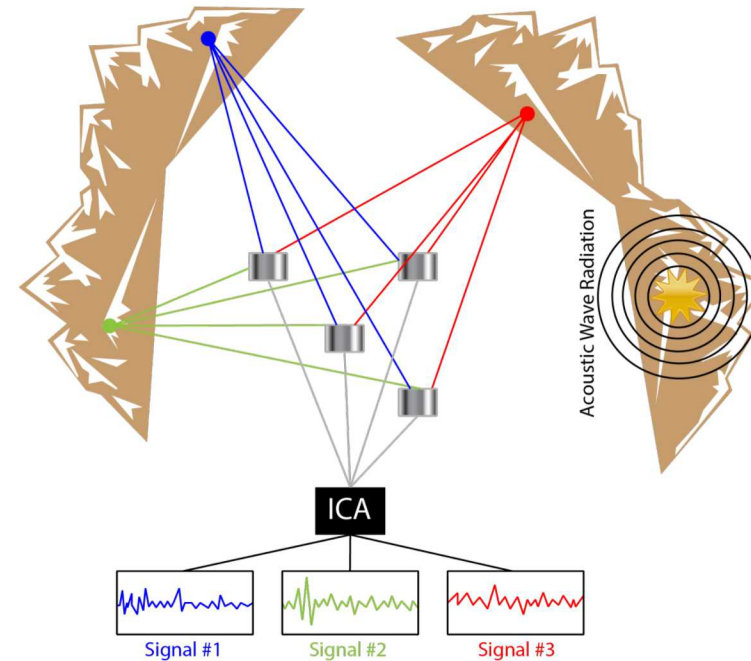


Image not to scale.