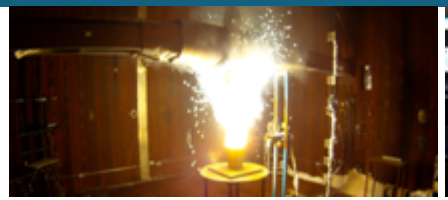
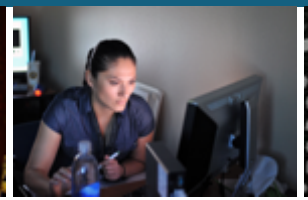
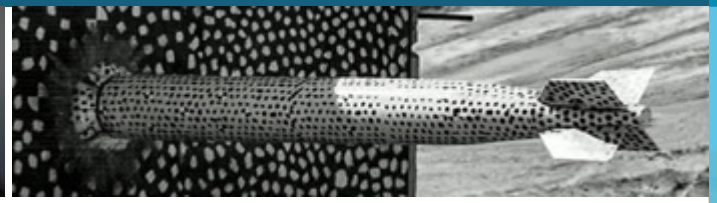
Tracking Scattered Signals in the Acoustic Coda Using Independent Component Analysis in a Topographically Complex Setting







PRESENTED BY

Sarah Albert and Daniel Bowman

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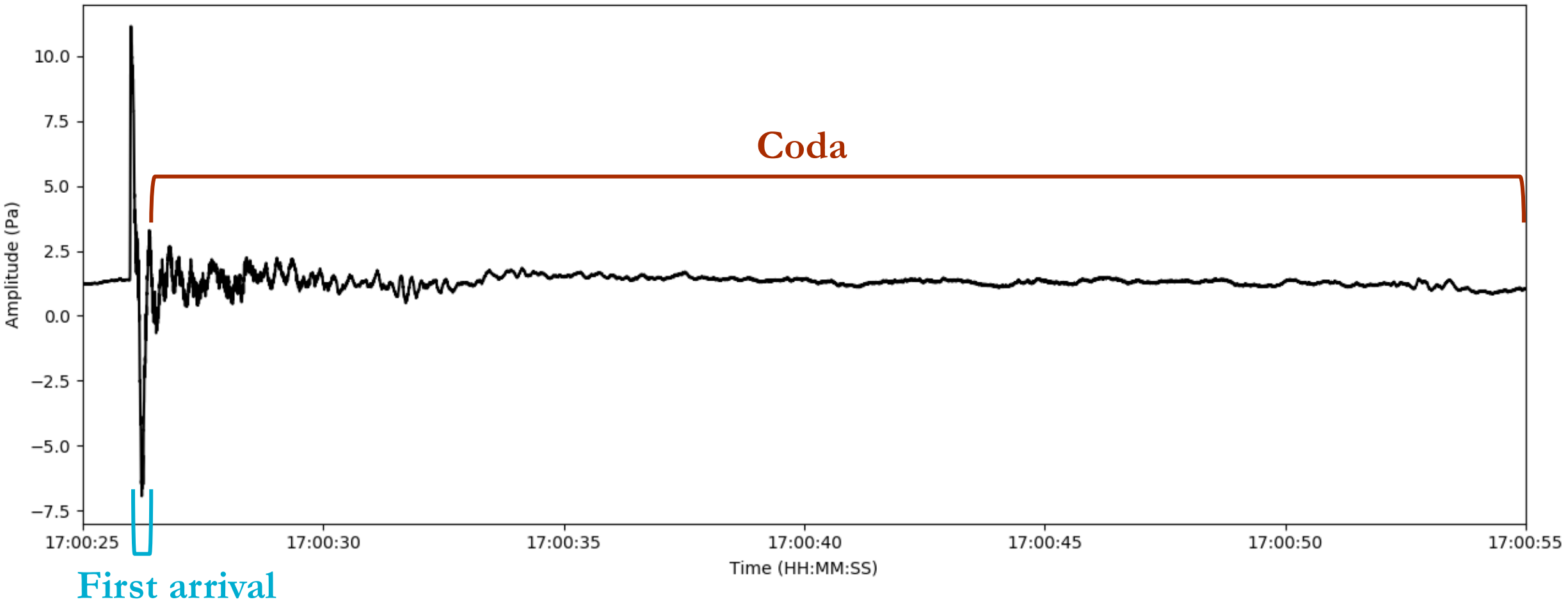
Outline

- Introduction
- Motivation
- Independent Component Analysis Primer
- Experimental Setup
- Methods
- Results and Discussion
- Conclusions

Introduction – The Seismic and Acoustic Coda



Motivation

Acoustic waves travel various paths from source to sensor

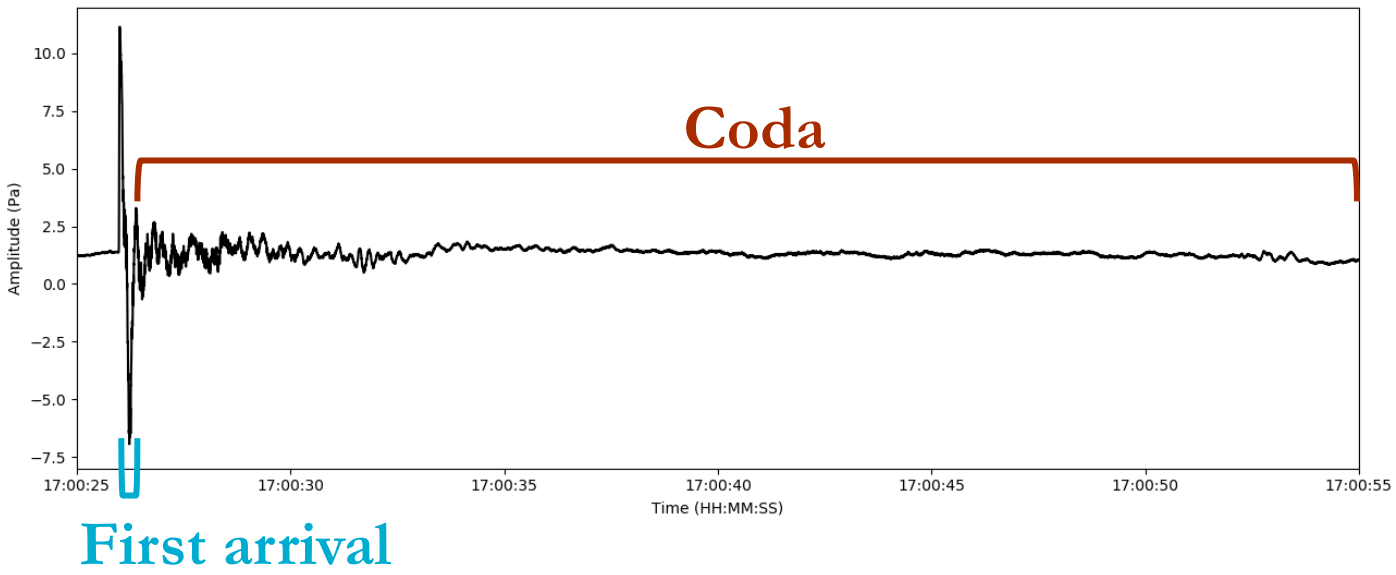
- Direct arrival
- Arrivals from reflections off scatterers

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

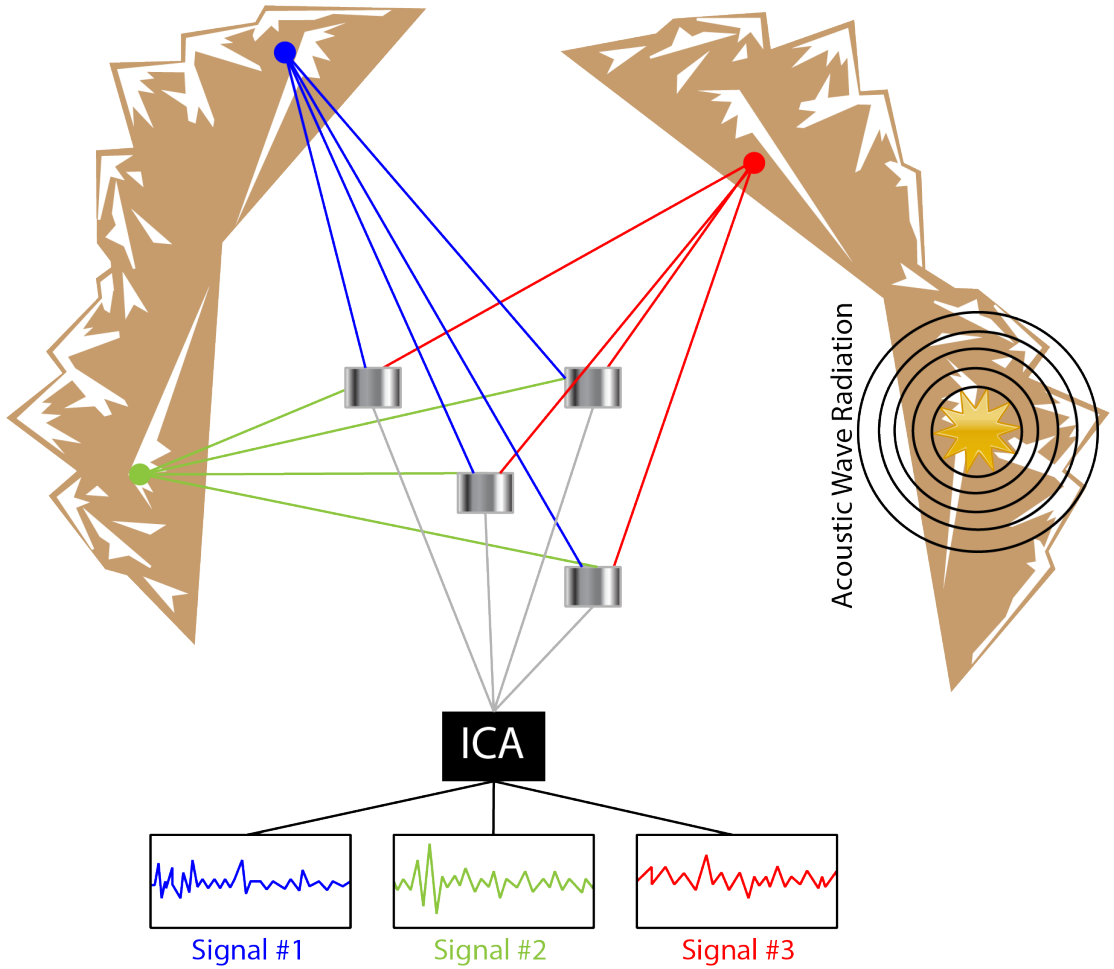


Image not to scale.

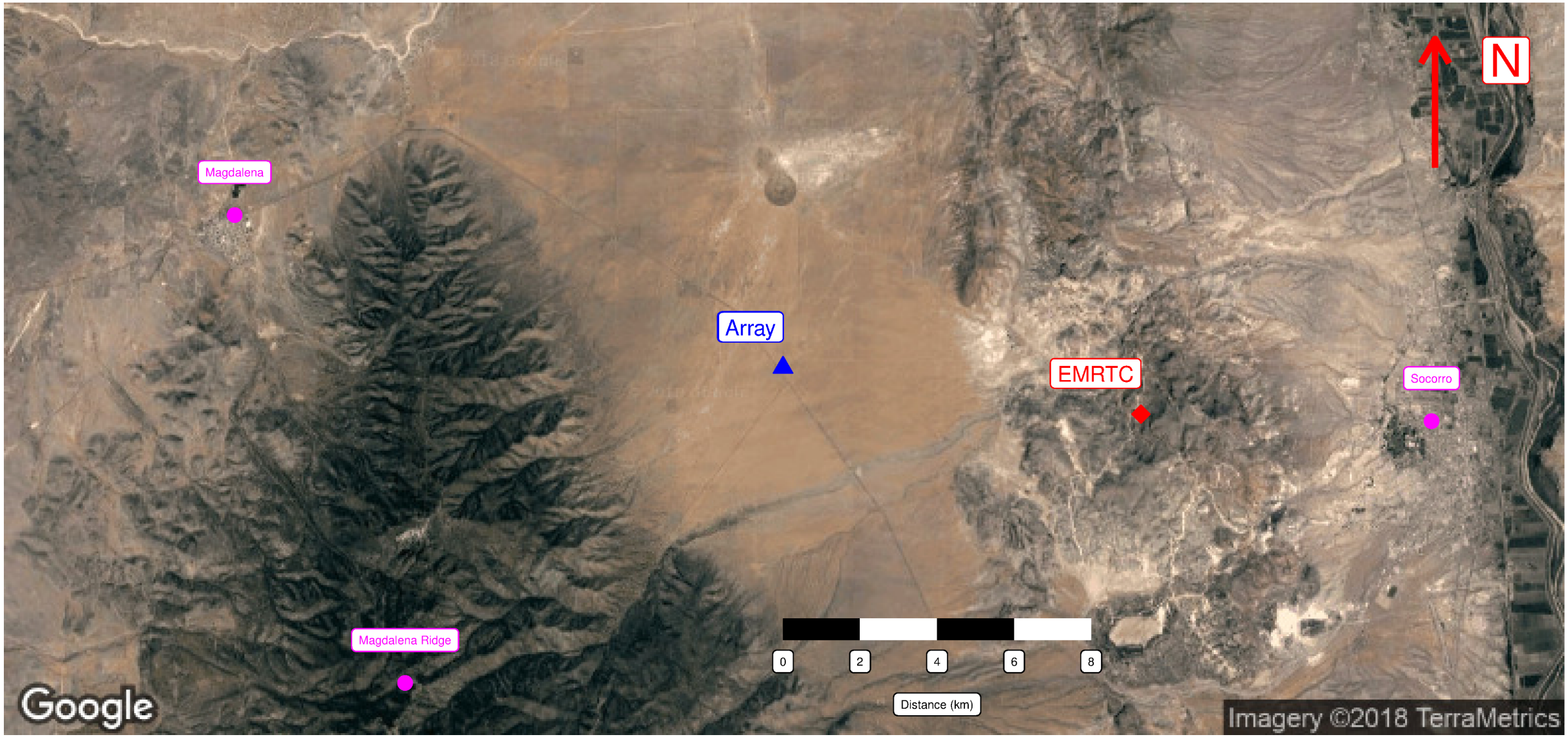
Mixed signal vector

Vector of source signals

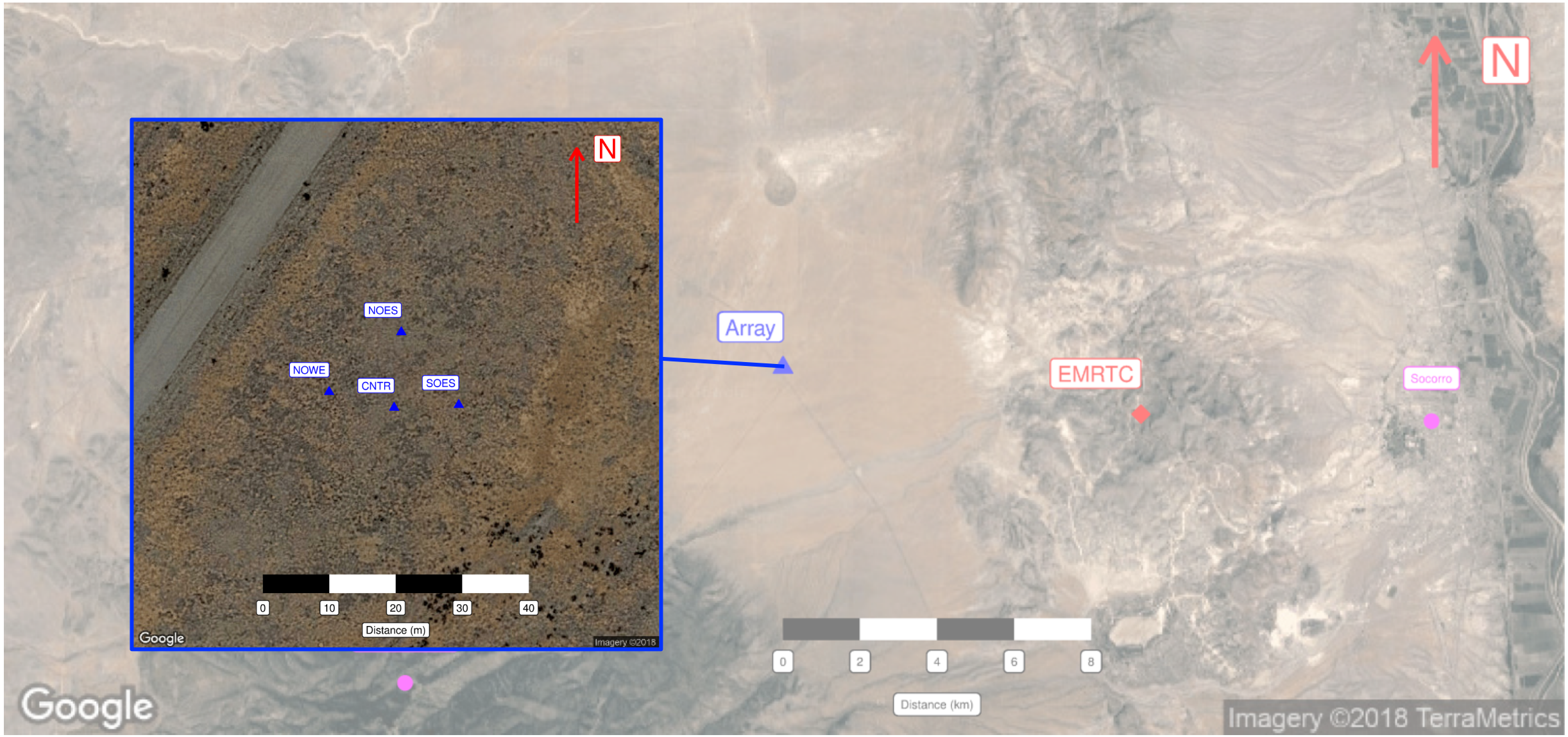
$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} A_{11} & \cdots & A_{14} \\ \vdots & \ddots & \vdots \\ A_{41} & \cdots & A_{44} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix}$$

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

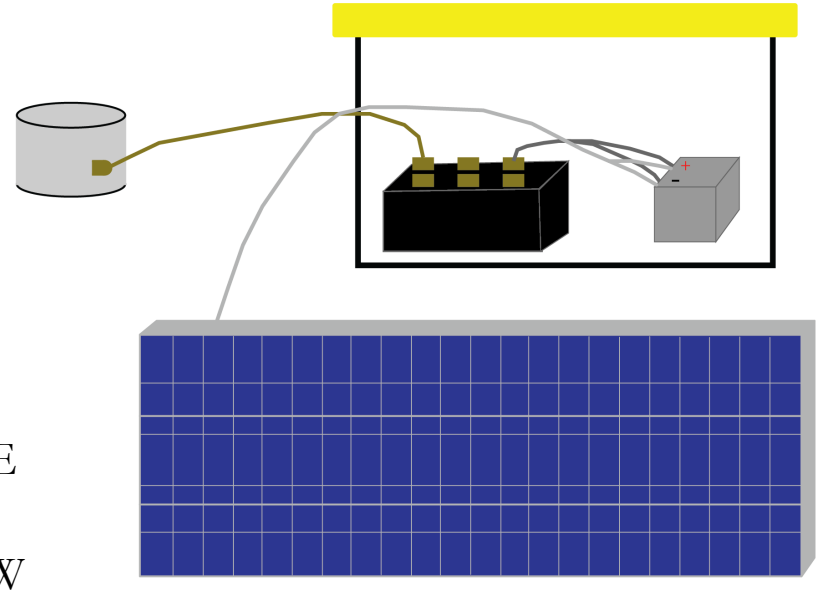
Experimental Setup



Experimental Setup



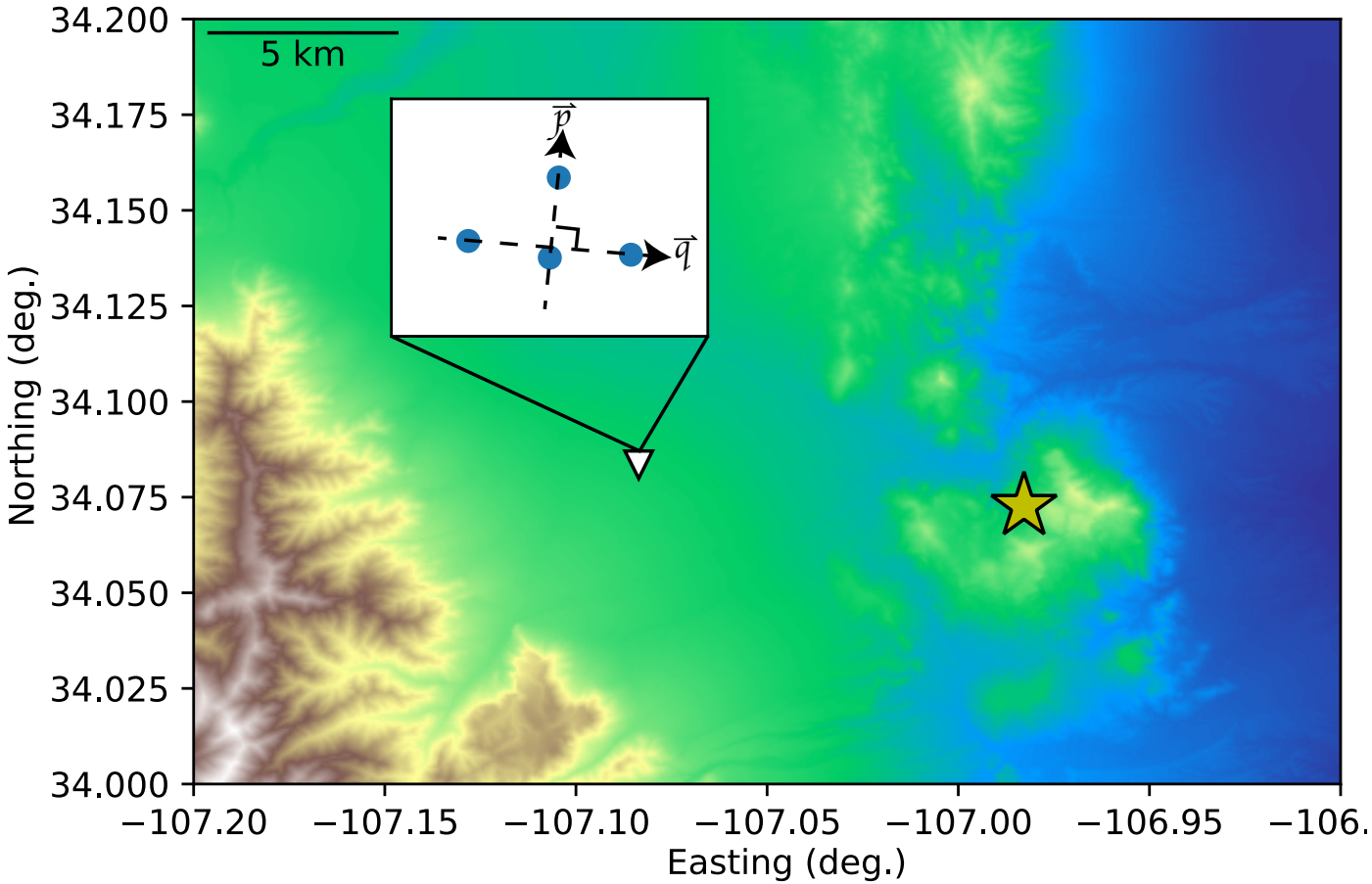
Station Configuration and Topography



Topography to the E–NE

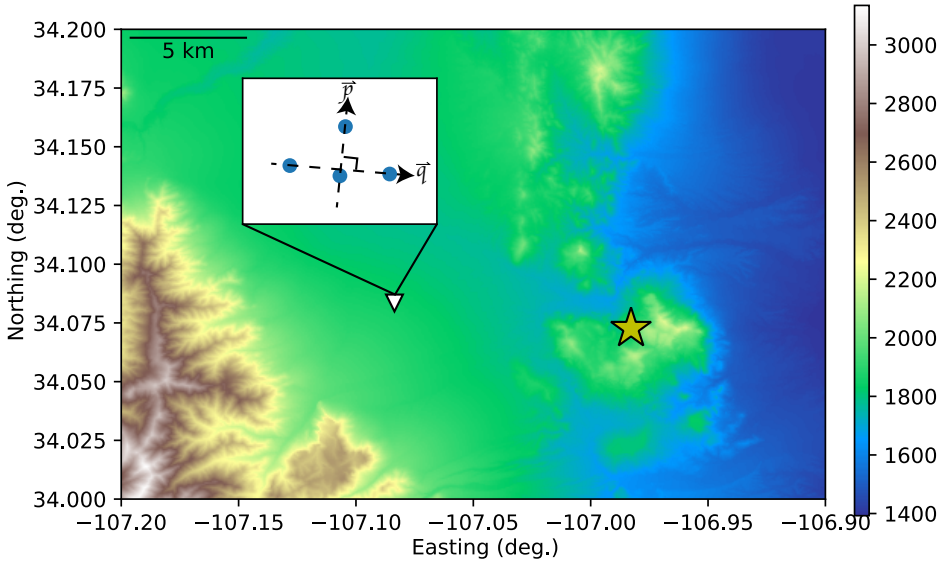
Topography to the W–SW

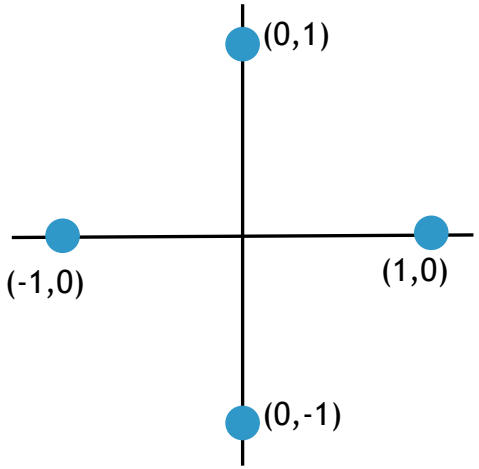
Methods – Gradient Flow Independent Component Analysis



- 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:

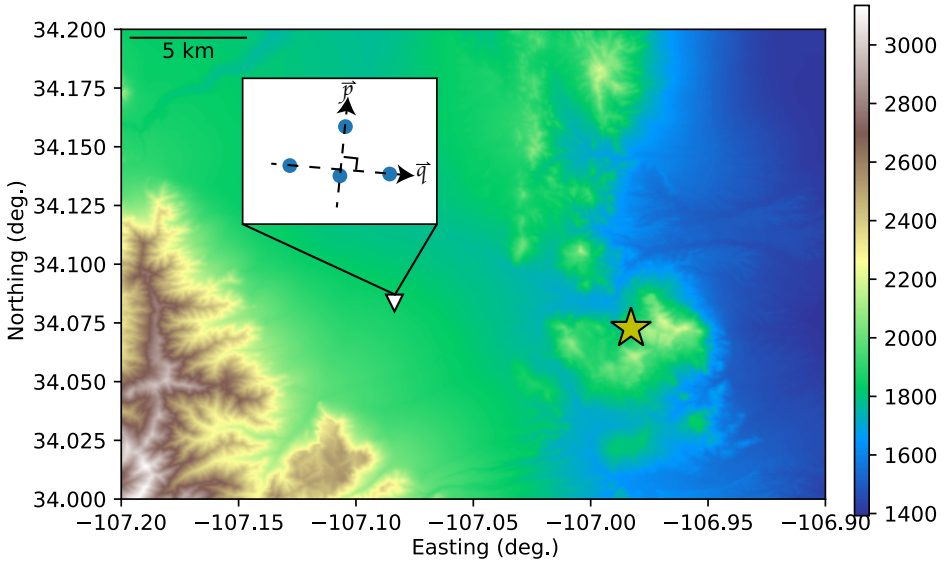
$$\xi_{00} \approx \frac{1}{4}(x_{-1,0} + x_{0,-1} + x_{0,1})$$

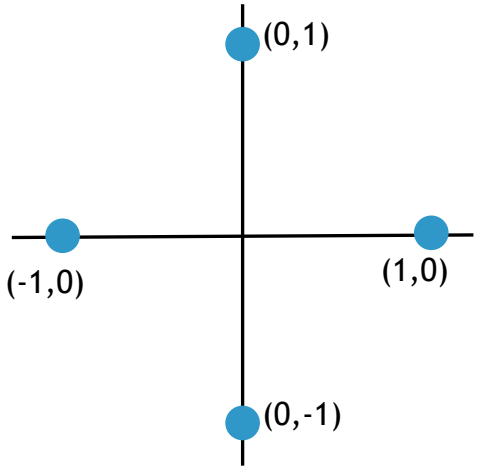
$$\xi_{10} \approx \frac{1}{2}(x_{1,0} - x_{-1,0})$$

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

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

Methods - Signal Backazimuth Calculation





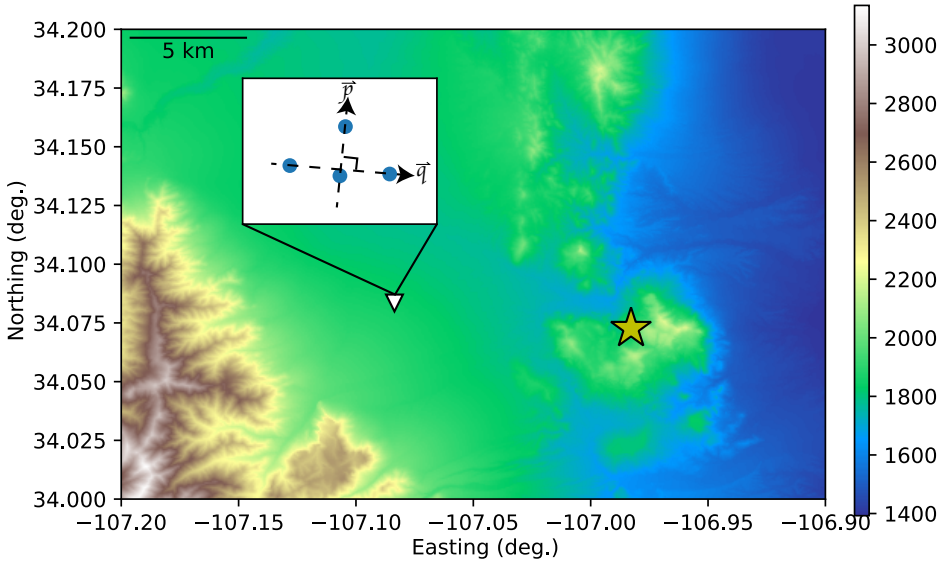
- Use inter-station time differences between sensors:

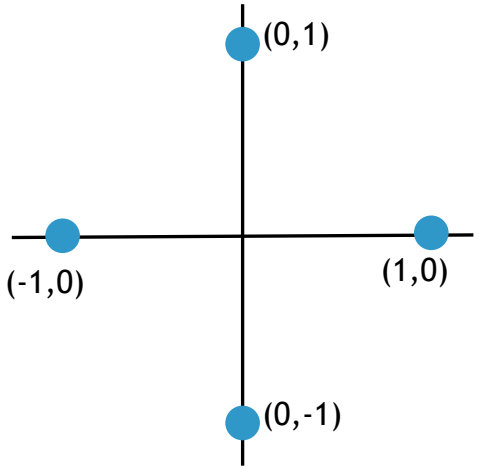
$$\tau_1^\ell = \frac{1}{c}\vec{q} \cdot \vec{u}_x^\ell$$

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

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

Methods - Signal Backazimuth Calculation





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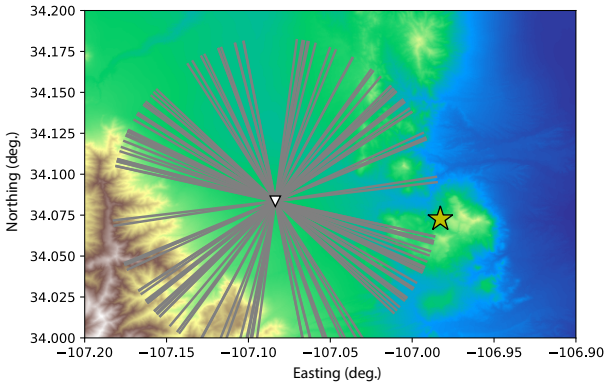
Direction vectors for source ℓ

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

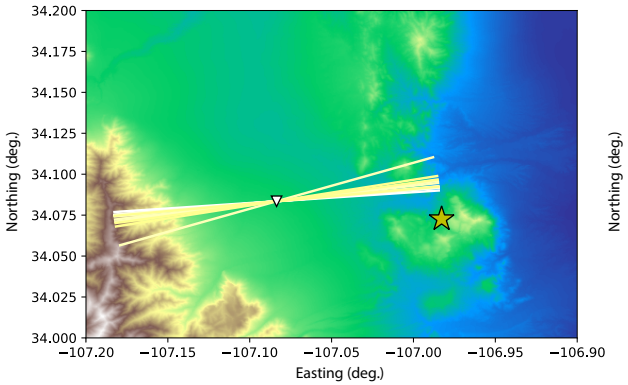
Signal backazimuth

Results

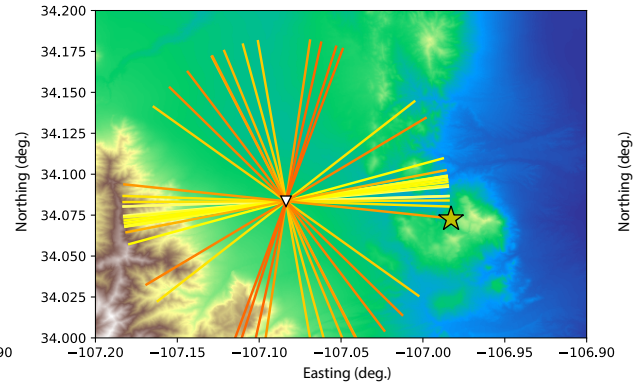
Explosion 1



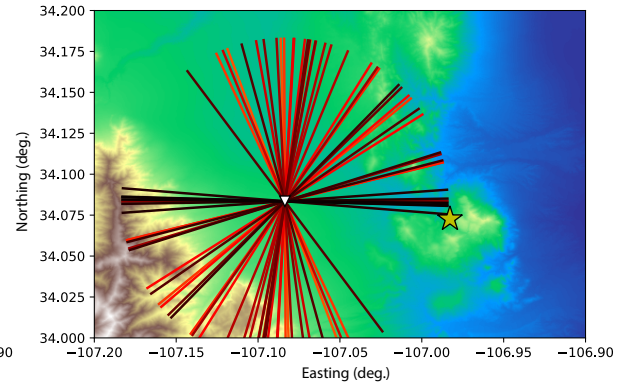
30 s prior to explosion



0 - 4 s

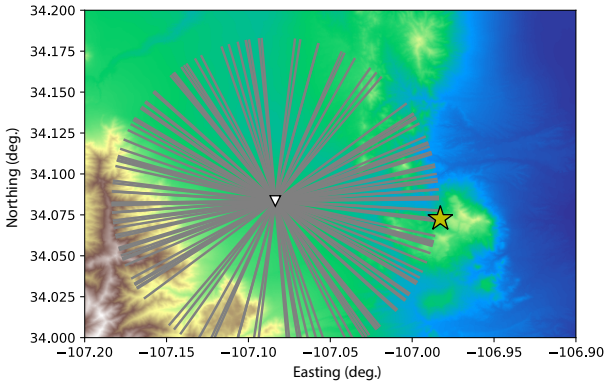


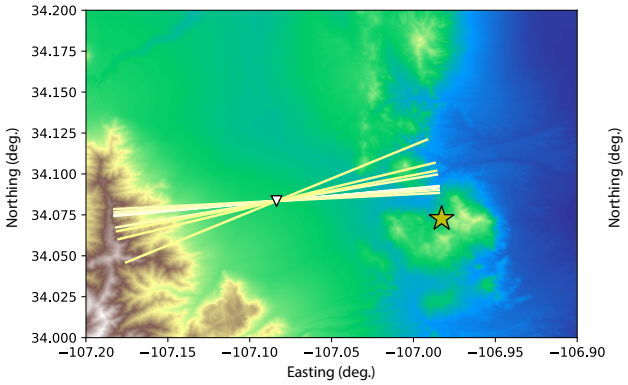
4 - 14 s

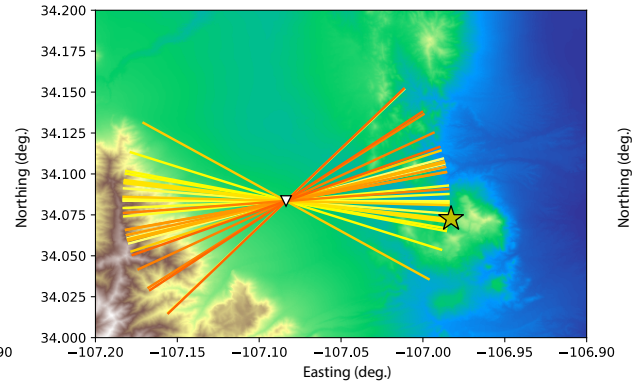


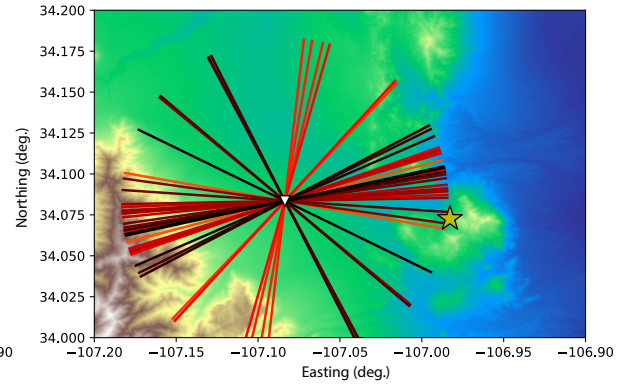
14 - 30 s

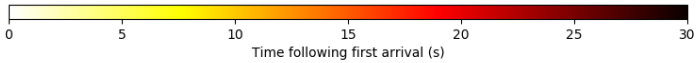
Explosion 2











Results

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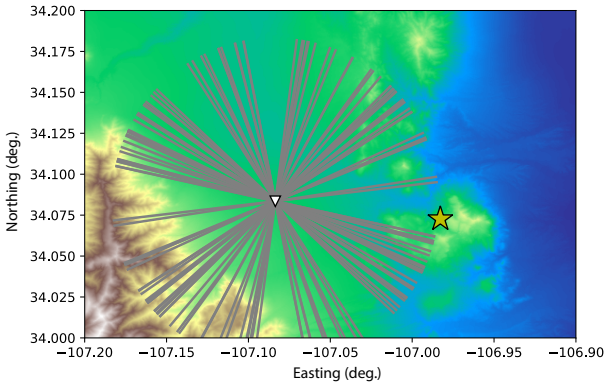

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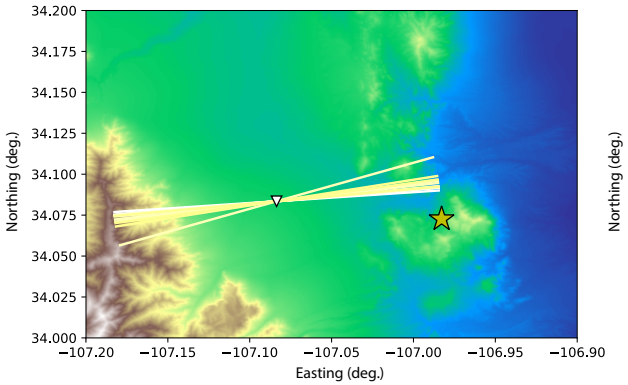

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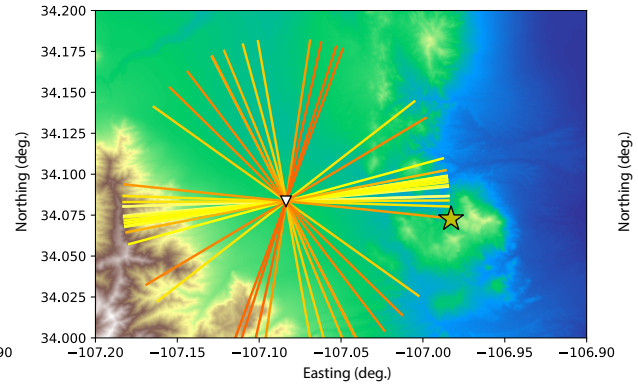

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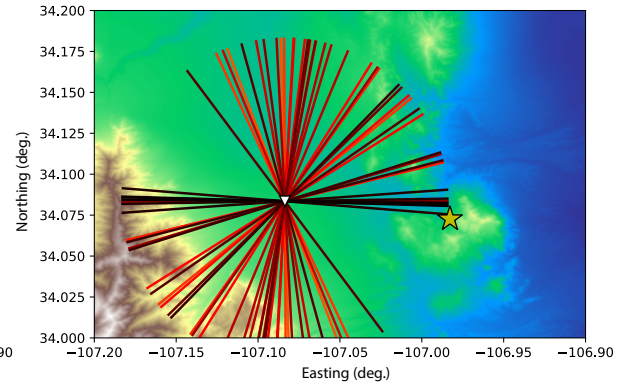
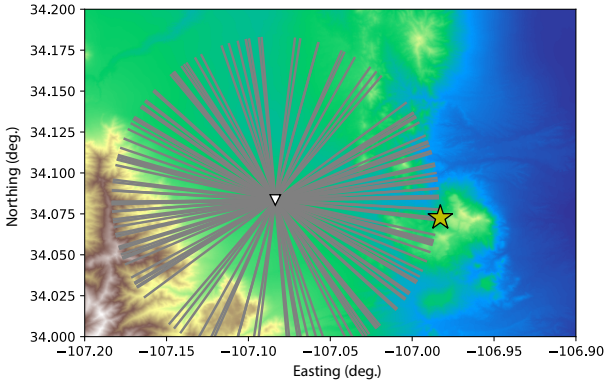
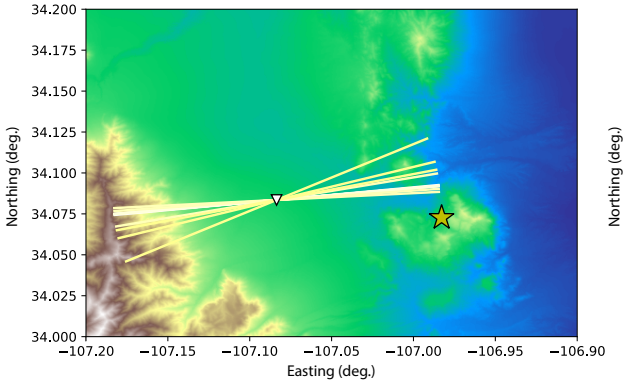
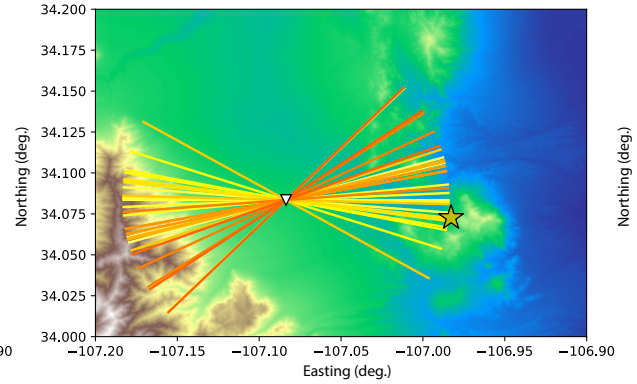


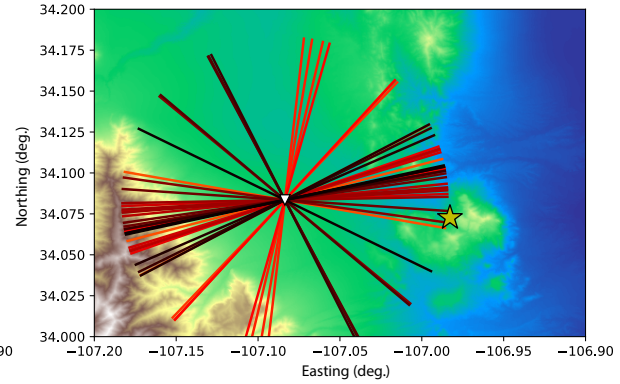
14 - 30 s

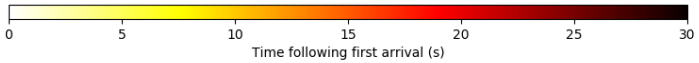
Explosion 2







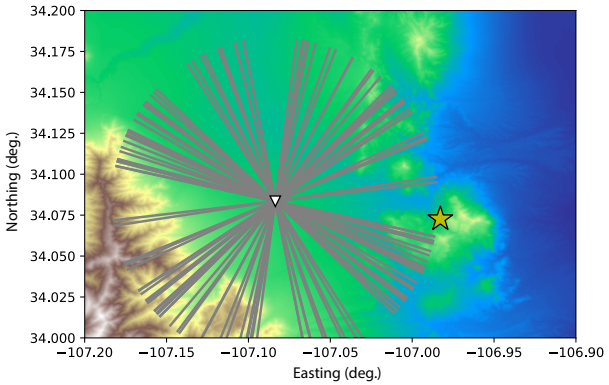




No signals expected

Results

Explosion 1



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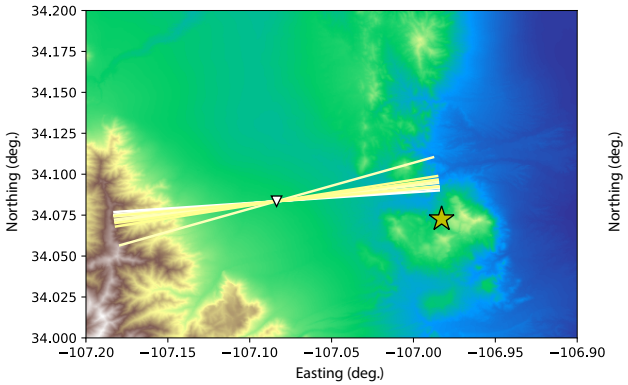
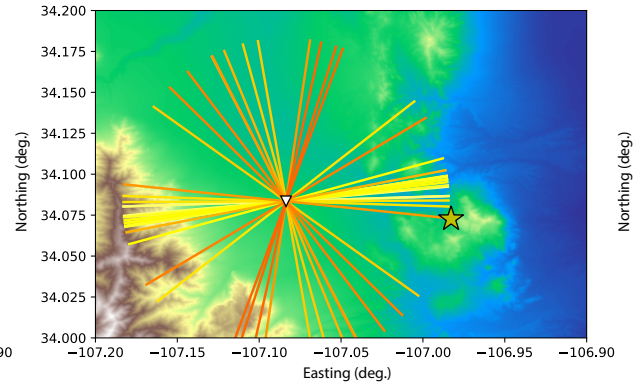
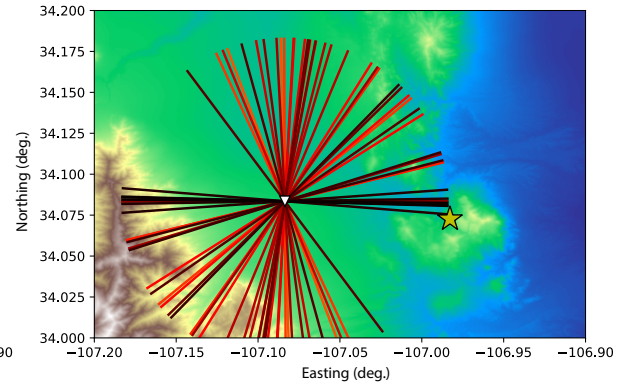


0 - 4 s

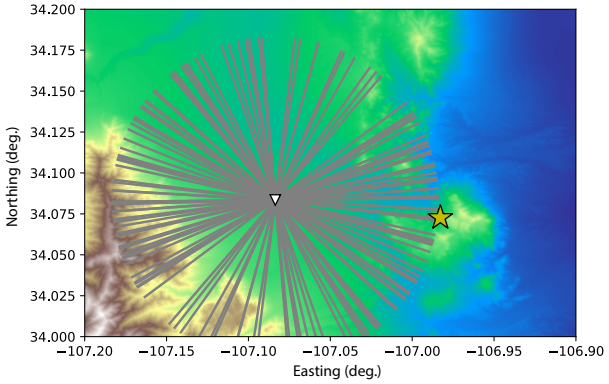


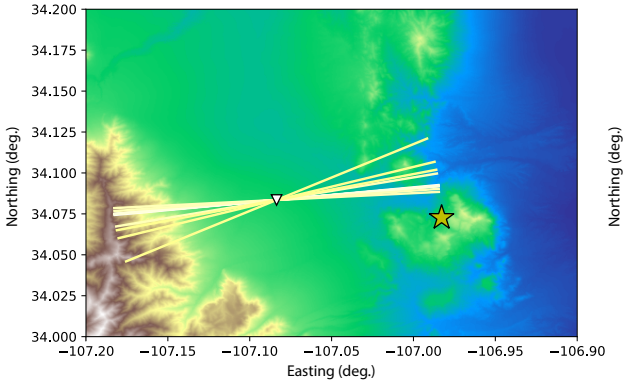
4 - 14 s

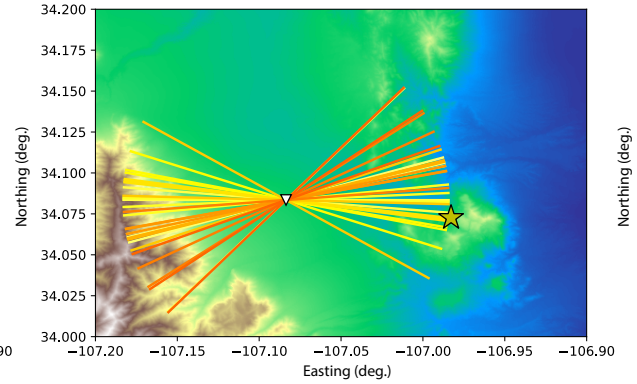


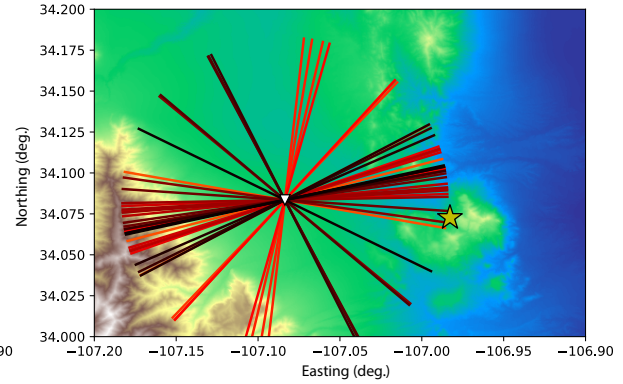
14 - 30 s

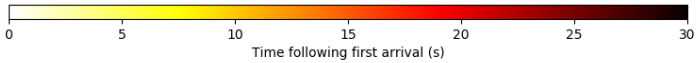
Explosion 2









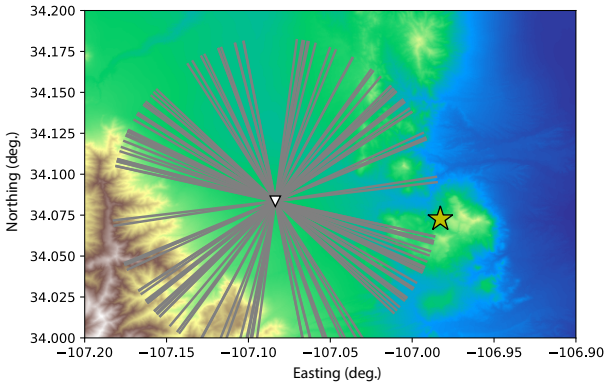


No signals expected

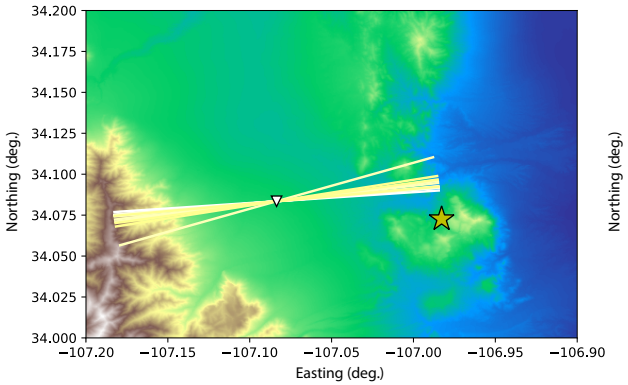
First arrivals

Results

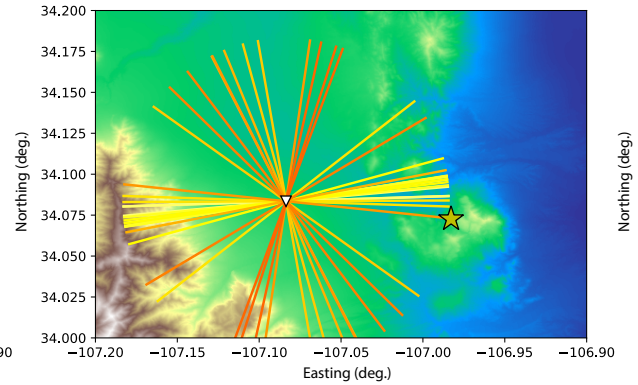
Explosion 1



30 s prior to explosion



0 - 4 s



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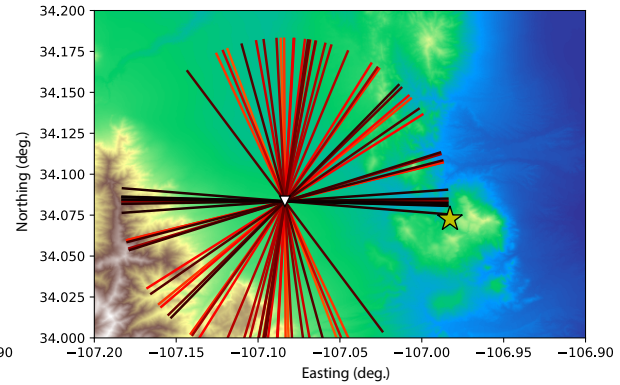
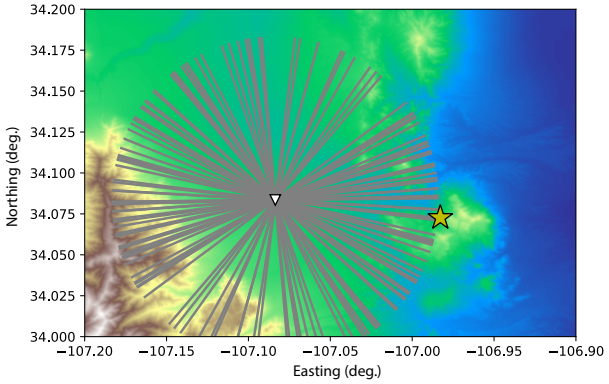
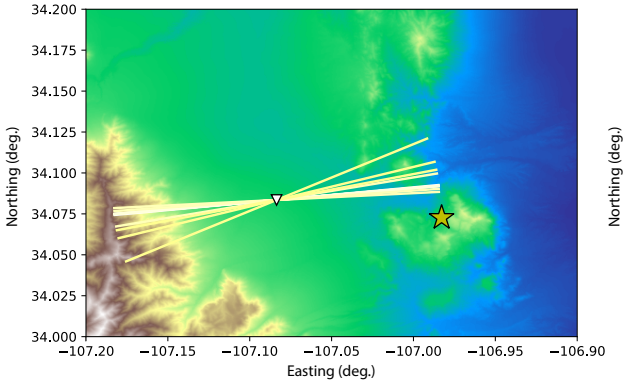
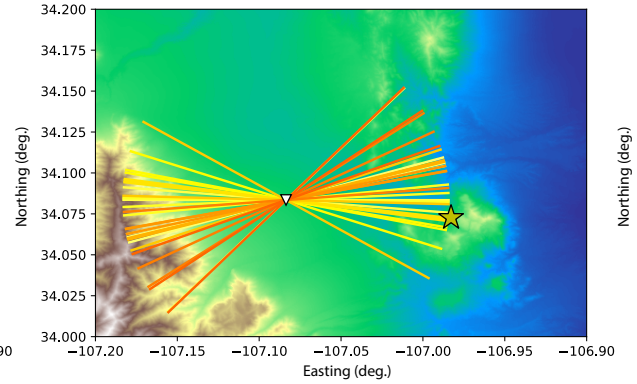


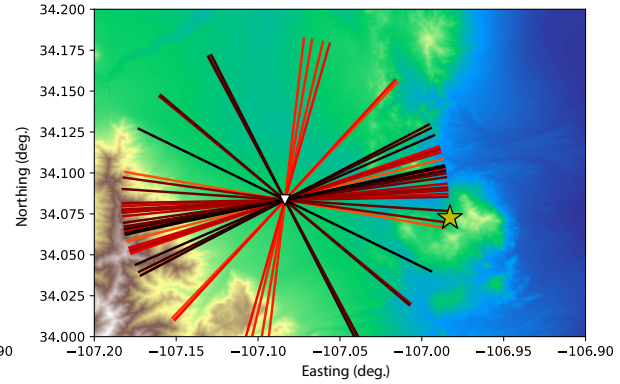
14 - 30 s

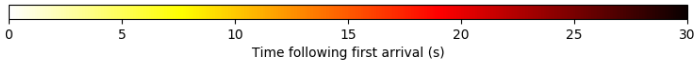
Explosion 2











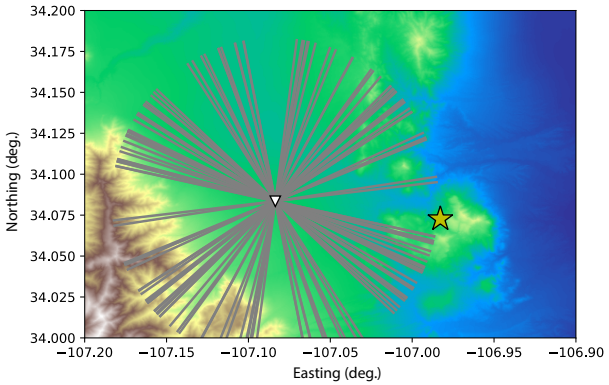
No signals expected

First arrivals

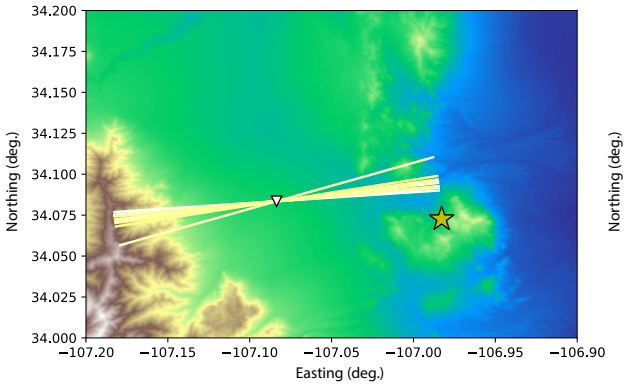
Signals from E-NE

Results

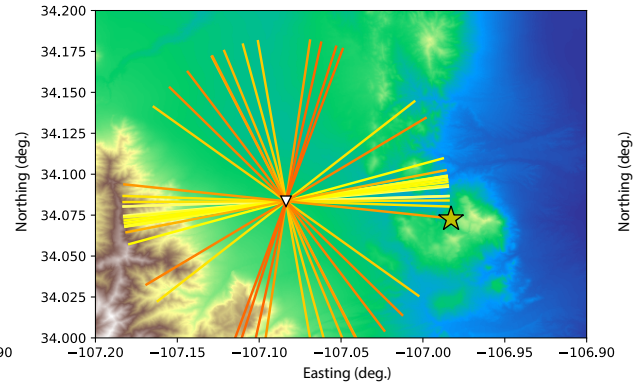
Explosion 1



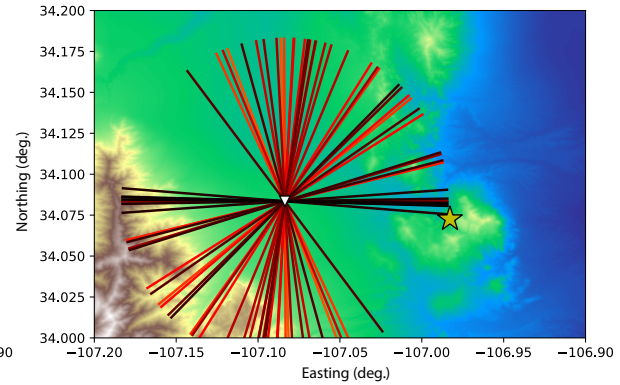
30 s prior to explosion



0 - 4 s

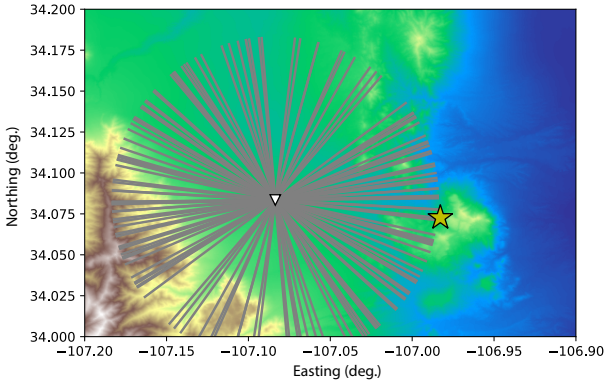


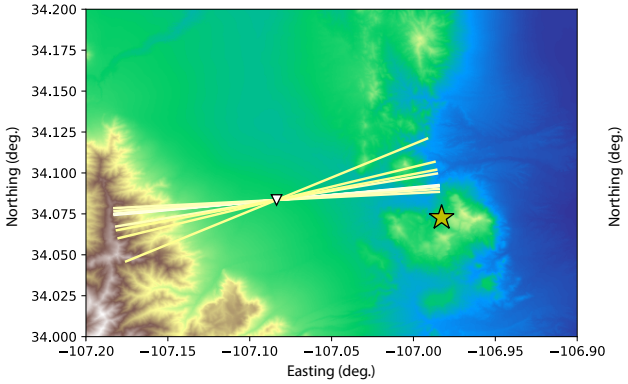
4 - 14 s

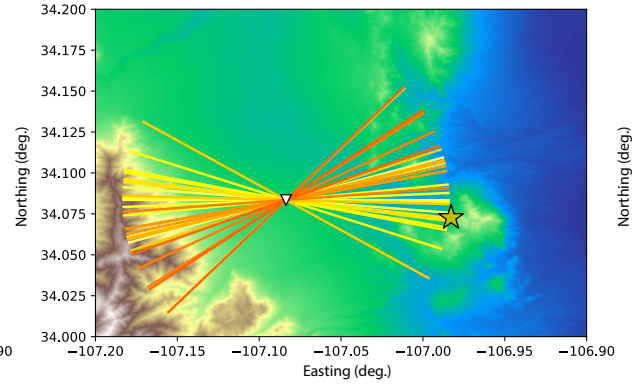


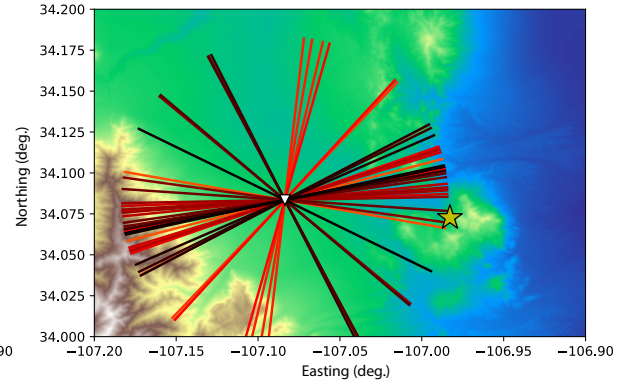
14 - 30 s

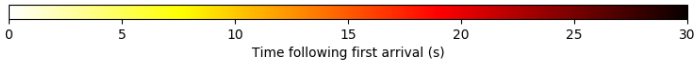
Explosion 2











No signals expected

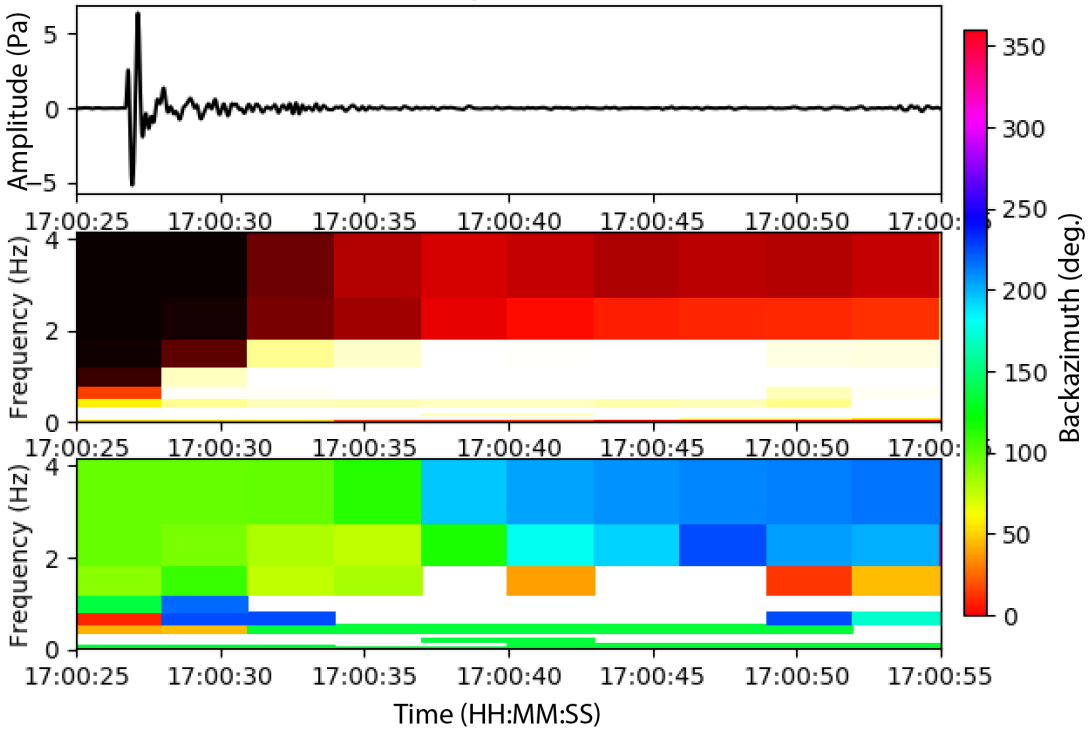
First arrivals

Signals from E-NE

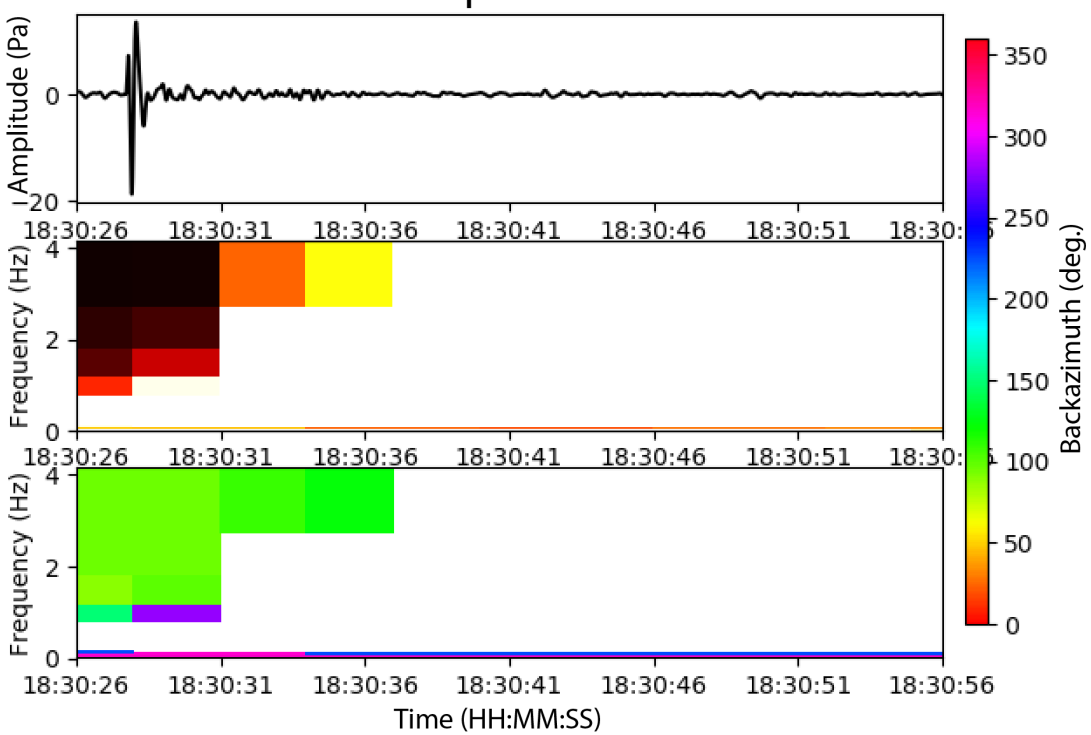
Signals from W-SW (and others?)

Progressive Multi-Channel Cross Correlation

Explosion 1

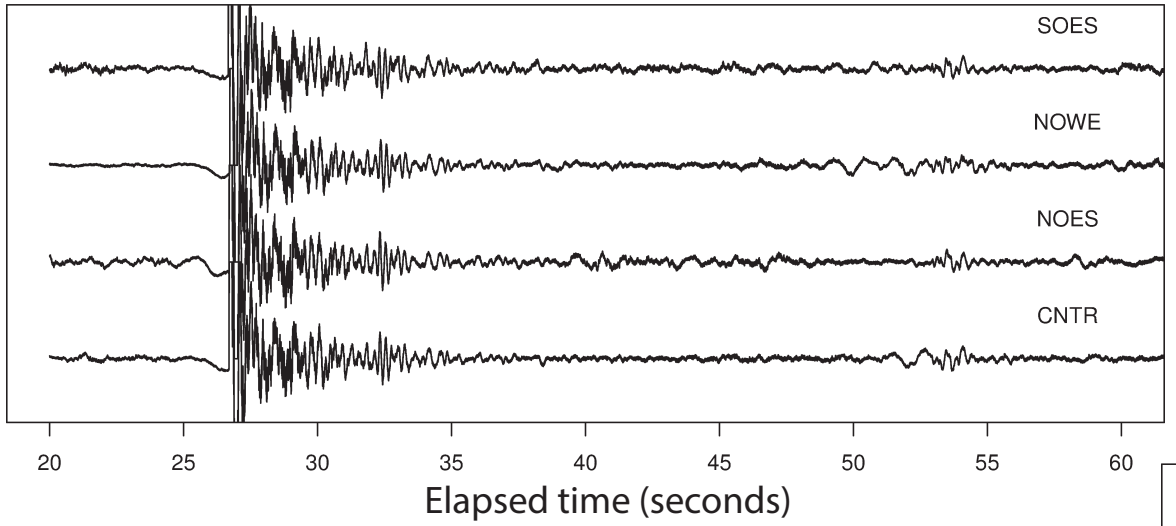


Explosion 2

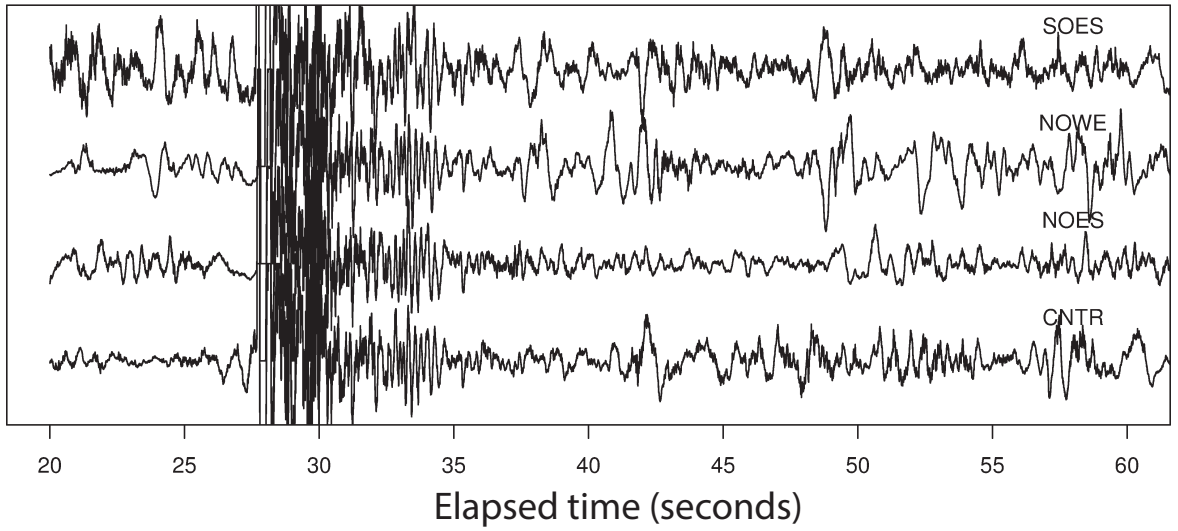


Amplitude Difference Between Explosions

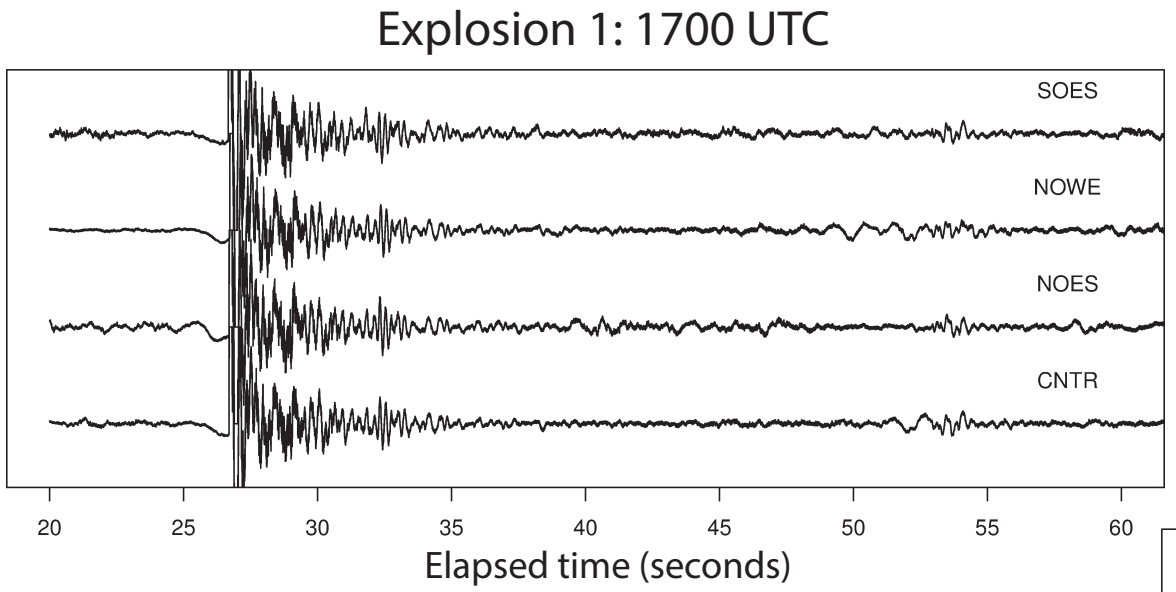
Explosion 1: 1700 UTC



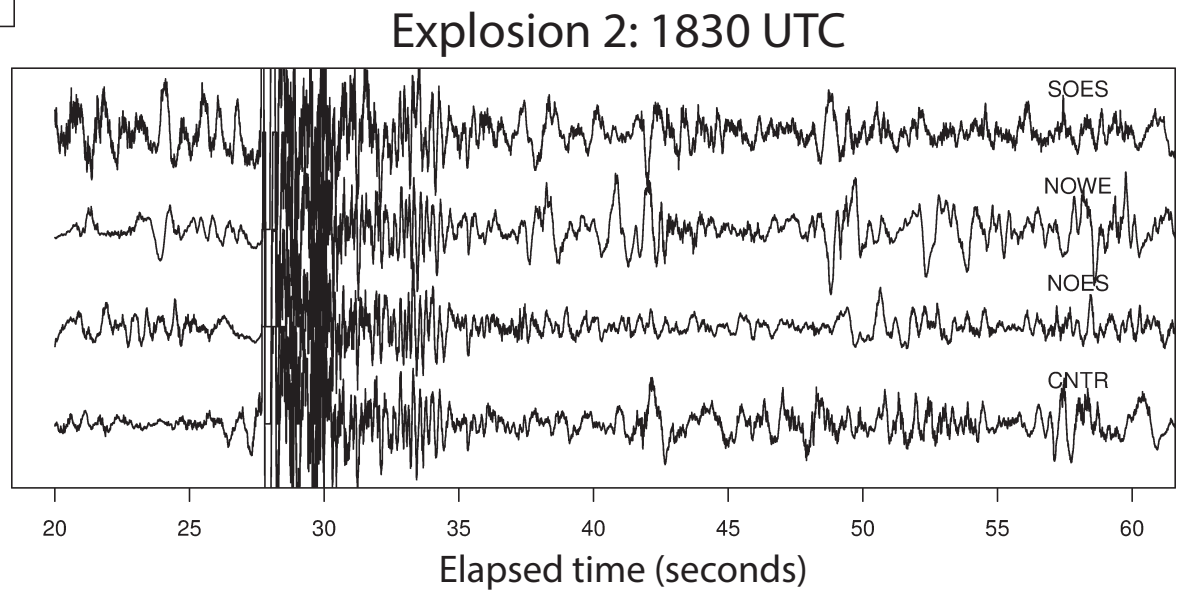
Explosion 2: 1830 UTC



Amplitude Difference Between Explosions

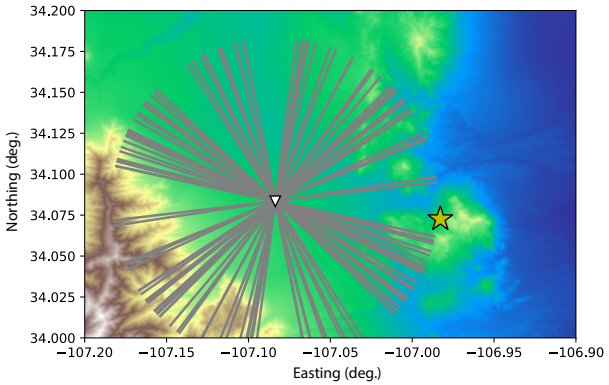


- Amplitudes 3.5 times greater for 2nd explosion
- Atmospheric or topographical ducting
- New atmospheric structure provides more accurate estimates < 25 seconds after first arrival

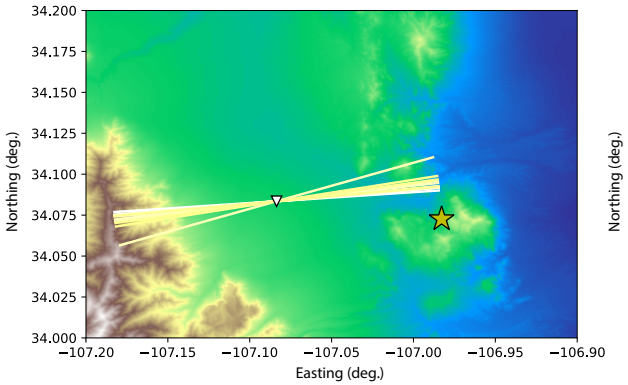


Results Refresher

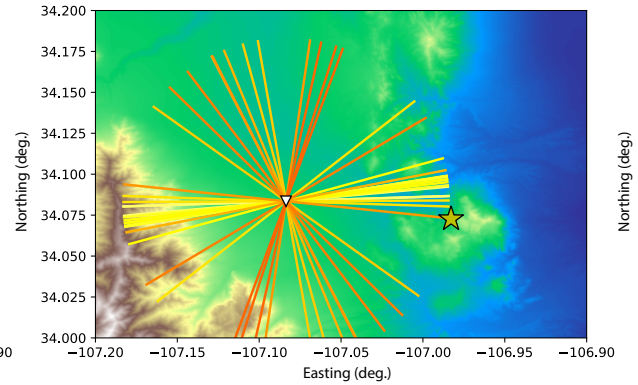
Explosion 1



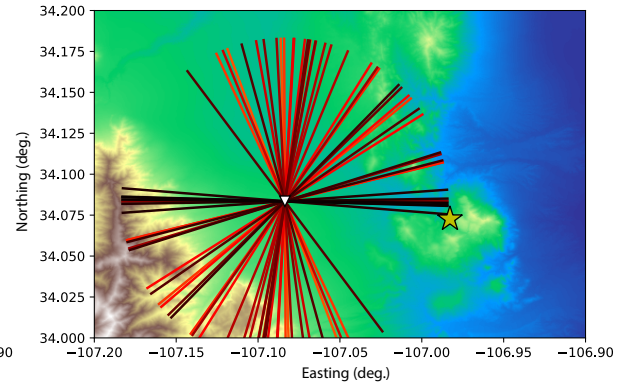
30 s prior to explosion



0 - 4 s

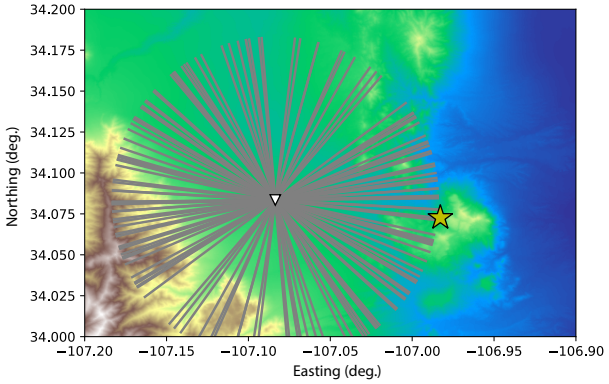


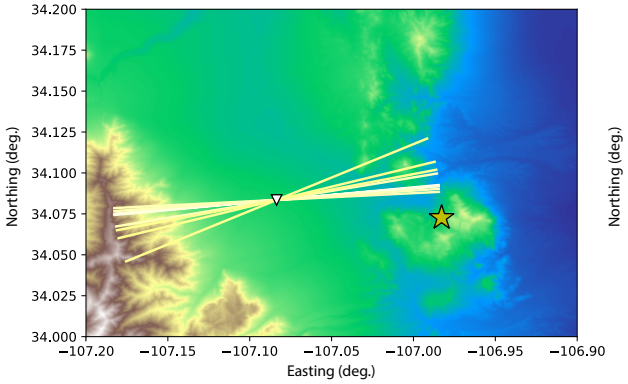
4 - 14 s

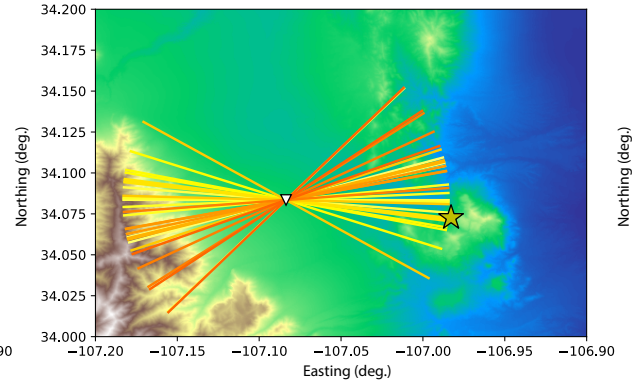


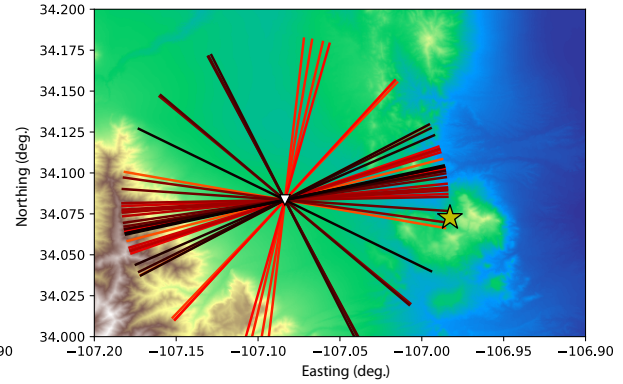
14 - 30 s

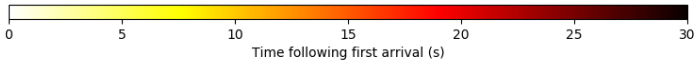
Explosion 2











No signals expected

First arrivals

Signals from E-NE

Signals from W-SW (and others?)

Conclusions and Future Work

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

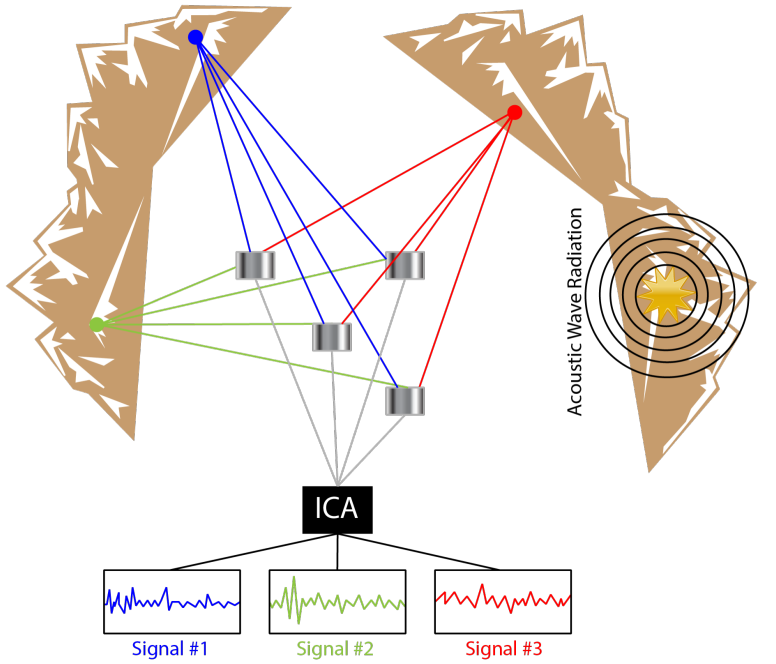


Image not to scale.