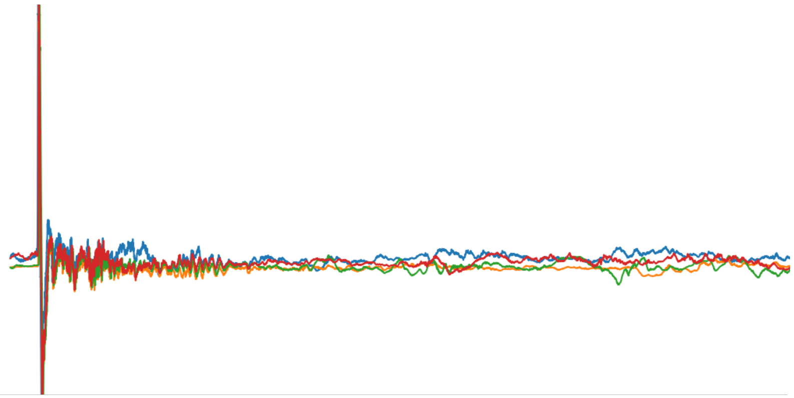
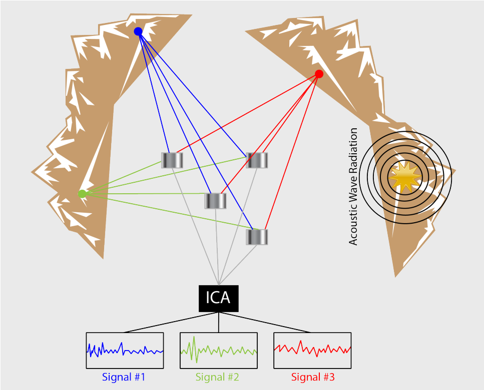
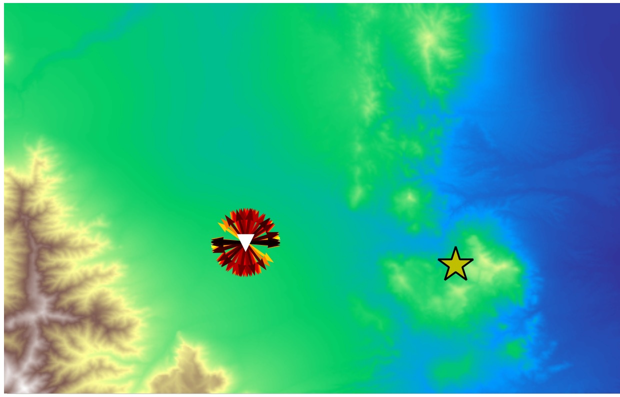
SAND2018-1380PE

Exceptional service in the national interest

Sandia National Laboratories







Tracking Scattered Signals in the Acoustic Coda Using Independent Component Analysis

Sarah Albert, Daniel Bowman

Sandia National Laboratories is a multimission 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

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

SAND 2018-XXXX

Independent Component Analysis

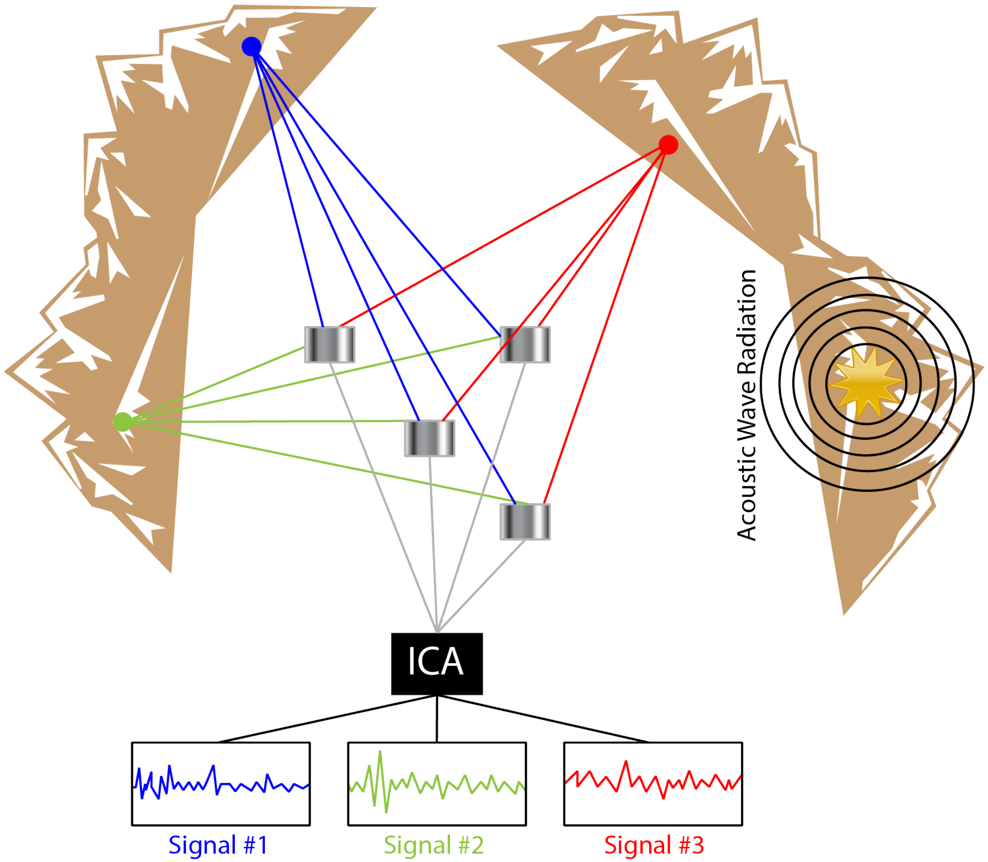


Image not to scale.

SAND 2018-XXXX

Independent Component Analysis

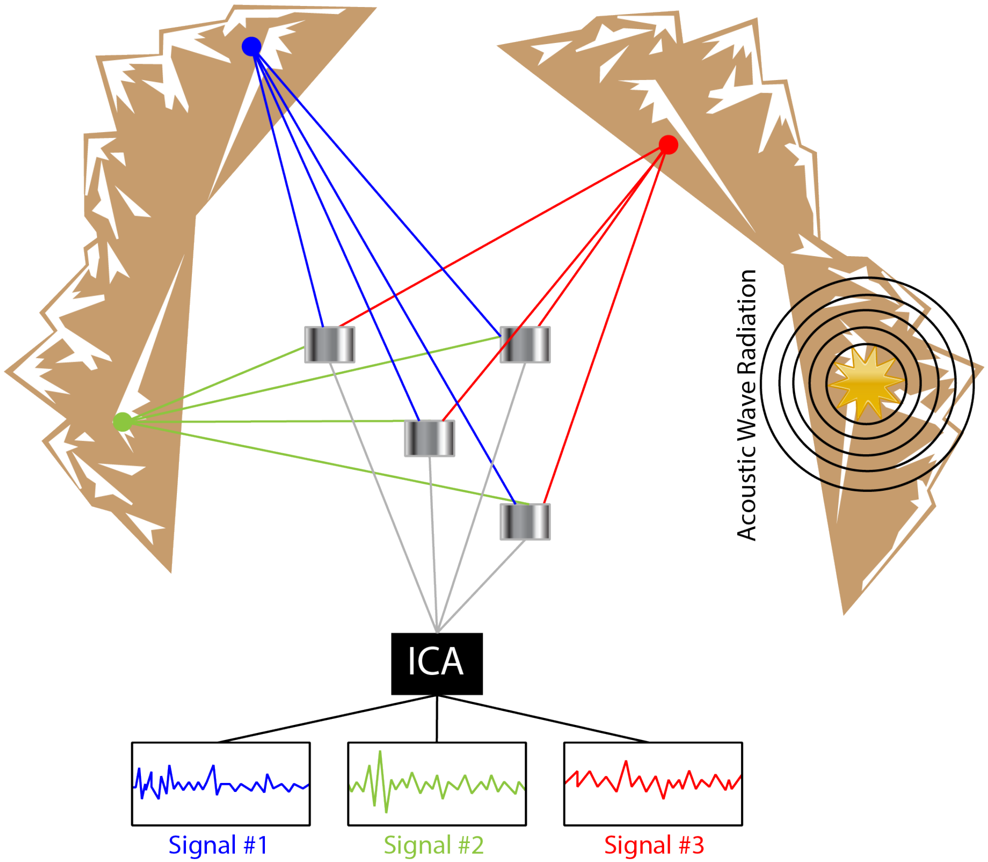


Image not to scale.

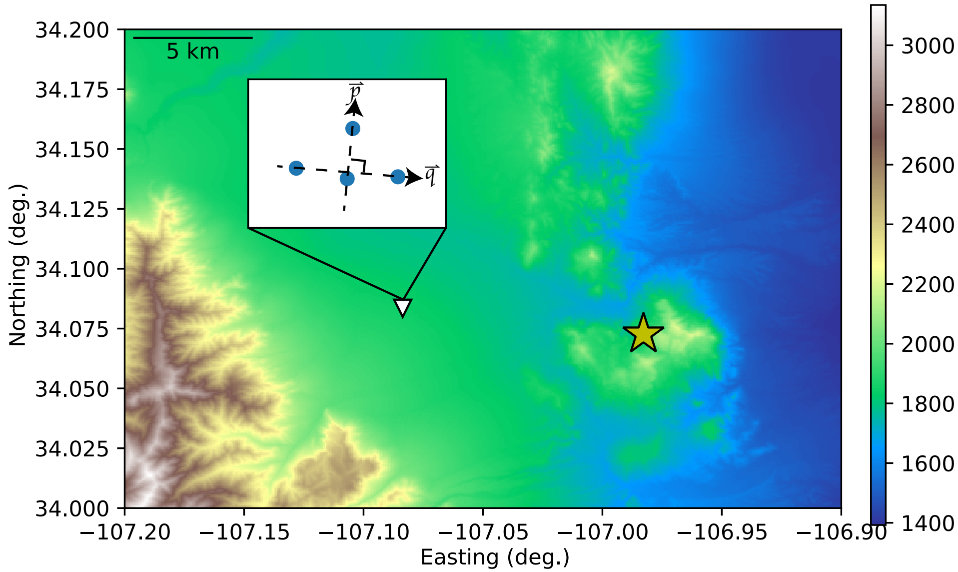
Mixed signal vector

Vector of source signals

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

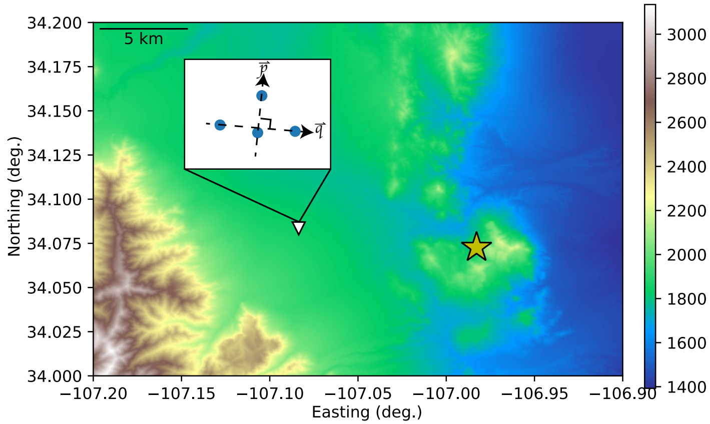
Weight vectors describing how signals are mixed (a.k.a "mixing" matrix)

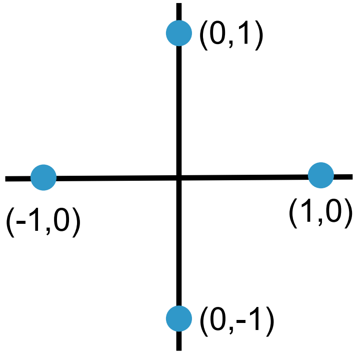
Gradient Flow ICA



- Closely-spaced array (10 m separation)
- Take spatial time derivatives of signal mixtures along position coordinates
  - Leads to backazimuth calculations
- Overcomplete ICA bases so we use symmetric quasi-decorrelation

Signal Backazimuth Calculation





- Spatial derivatives:

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

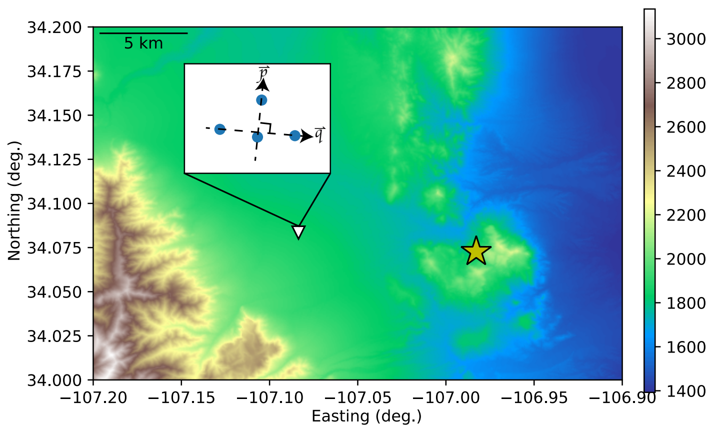
$$\xi_{10} \approx \frac{1}{2}(x_{1,0} - x_{-1,0})$$

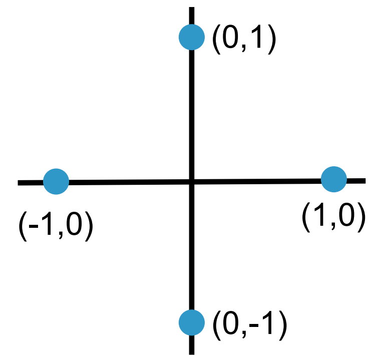
$$\xi_{01} \approx \frac{1}{2}(x_{0,1} - x_{0,-1})$$

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

Signal Backazimuth Calculation

Sandia National Laboratories





- Use inter-station time differences between sensors:

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

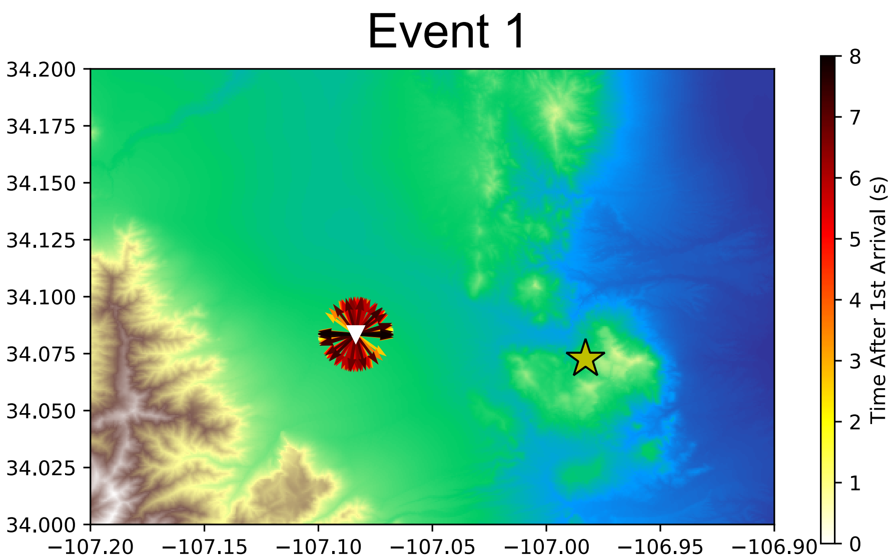
$$\tau_2^\ell = \frac{1}{c}\vec{p}\cdot\vec{u}_y^\ell$$

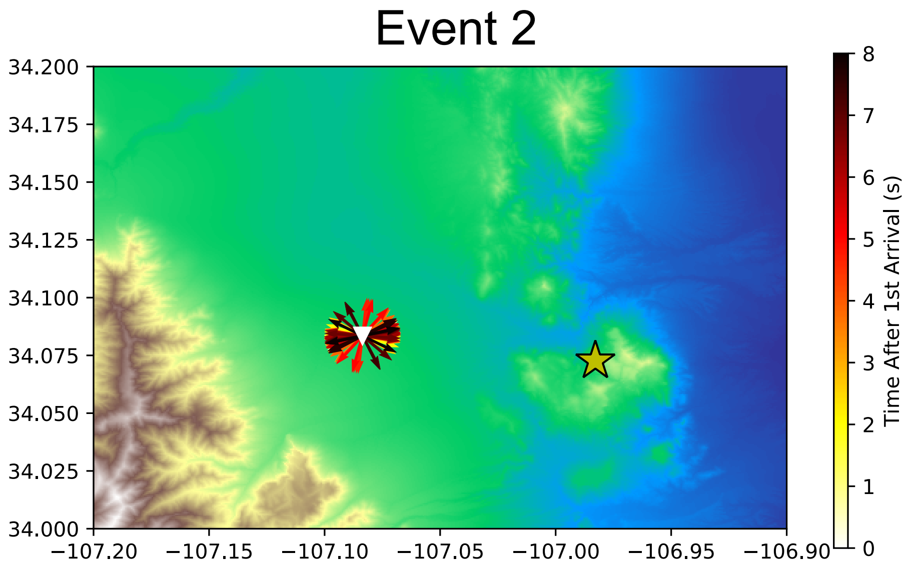
$$\tan^{-1}\frac{\vec{u}_x^\ell}{\vec{u}_y^\ell} = \theta$$

Direction vectors for source ℓ

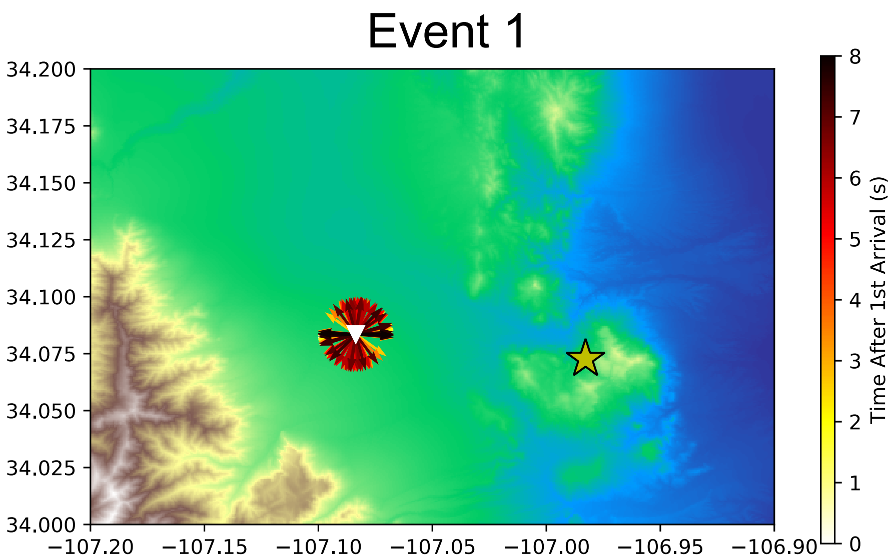
Signal backazimuth

Results (0 – 30 s after direct arrival)

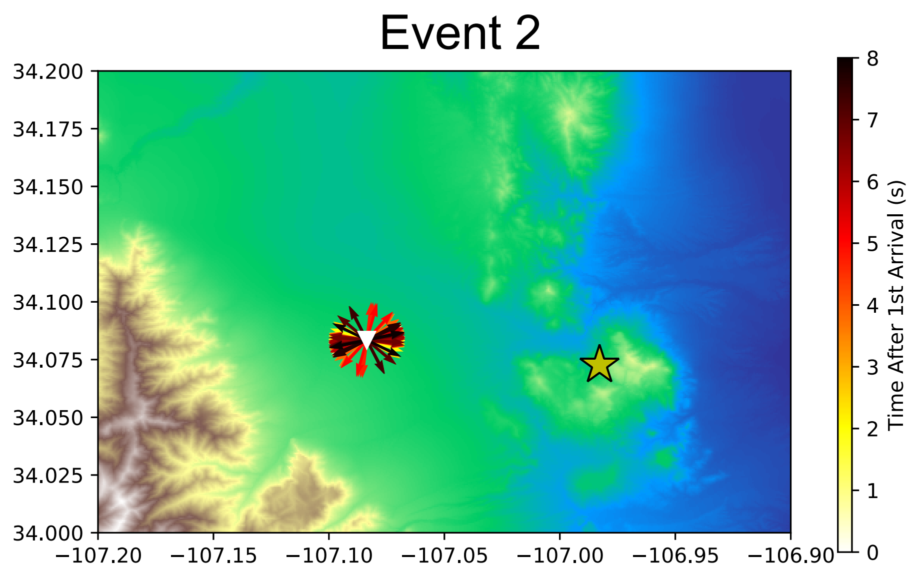




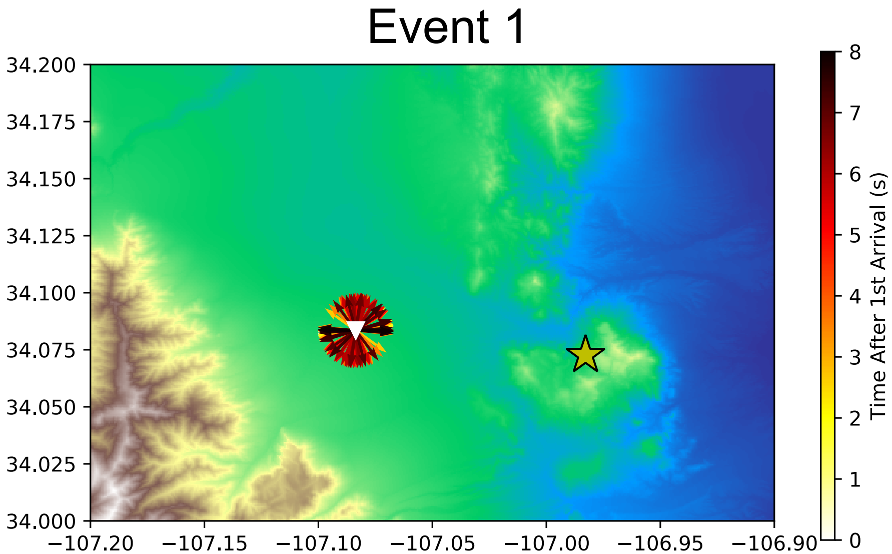
Results (0 – 30 s after direct arrival)



- Backazimuths point towards surrounding mountains
- Correct direct arrival backazimuth

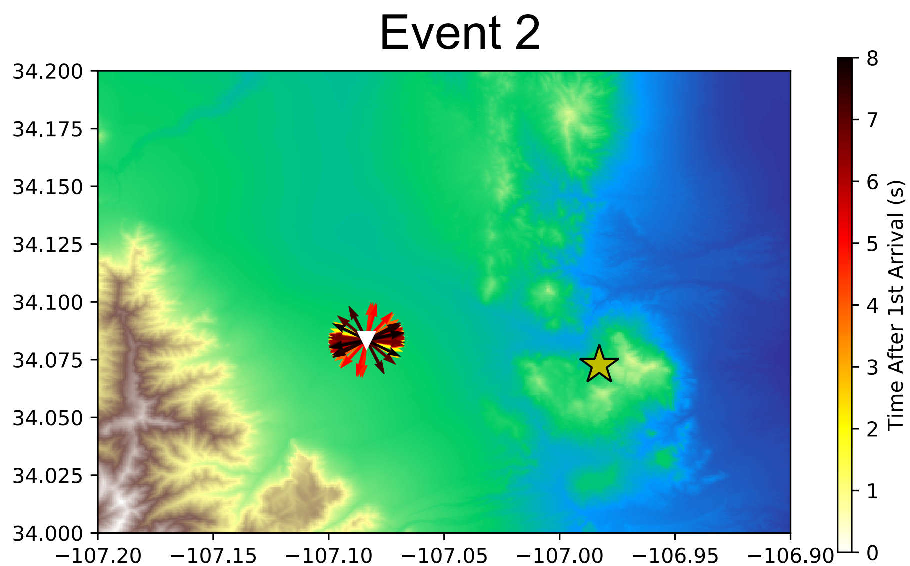


Results (0 – 30 s after direct arrival)



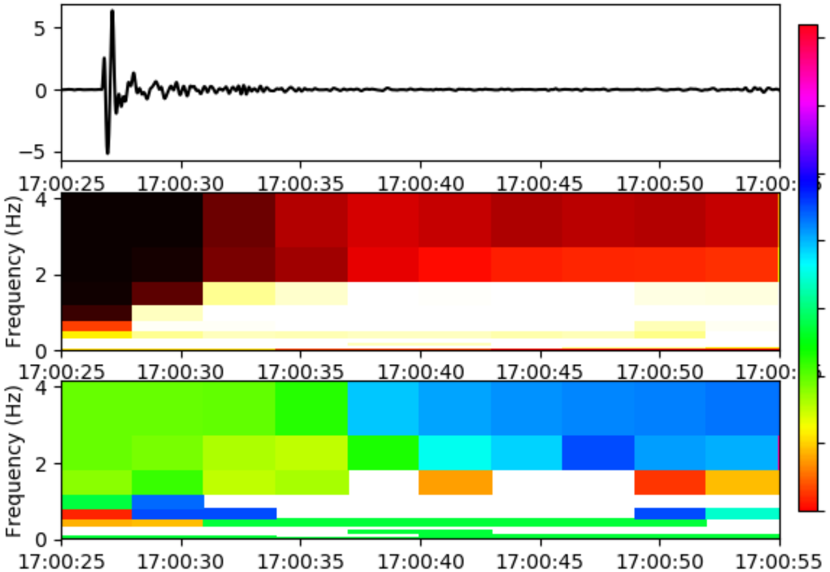
- Backazimuths point towards surrounding mountains
- Correct direct arrival backazimuth

- Backazimuths point towards surrounding mountains, but shifted
- Generally correct direct arrival backazimuth

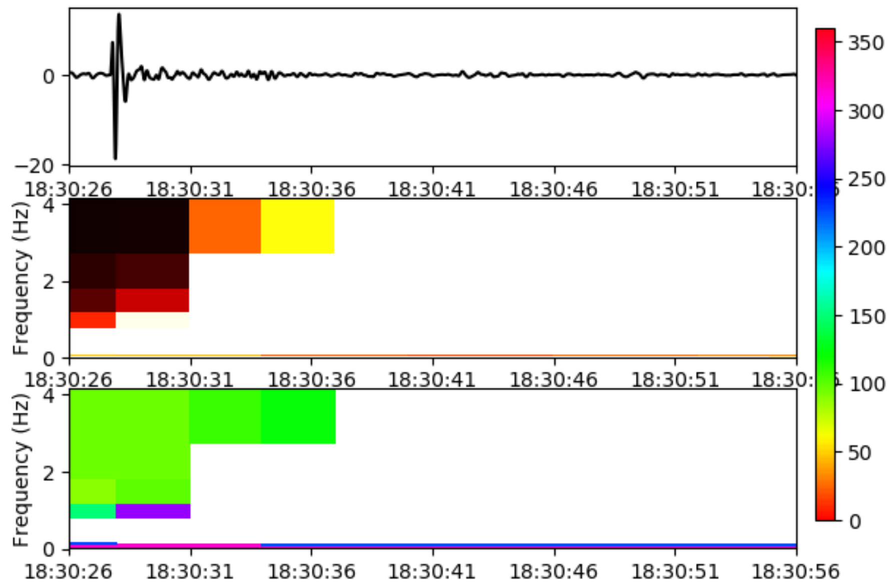


PMCC Comparison

Event 1



Event 2

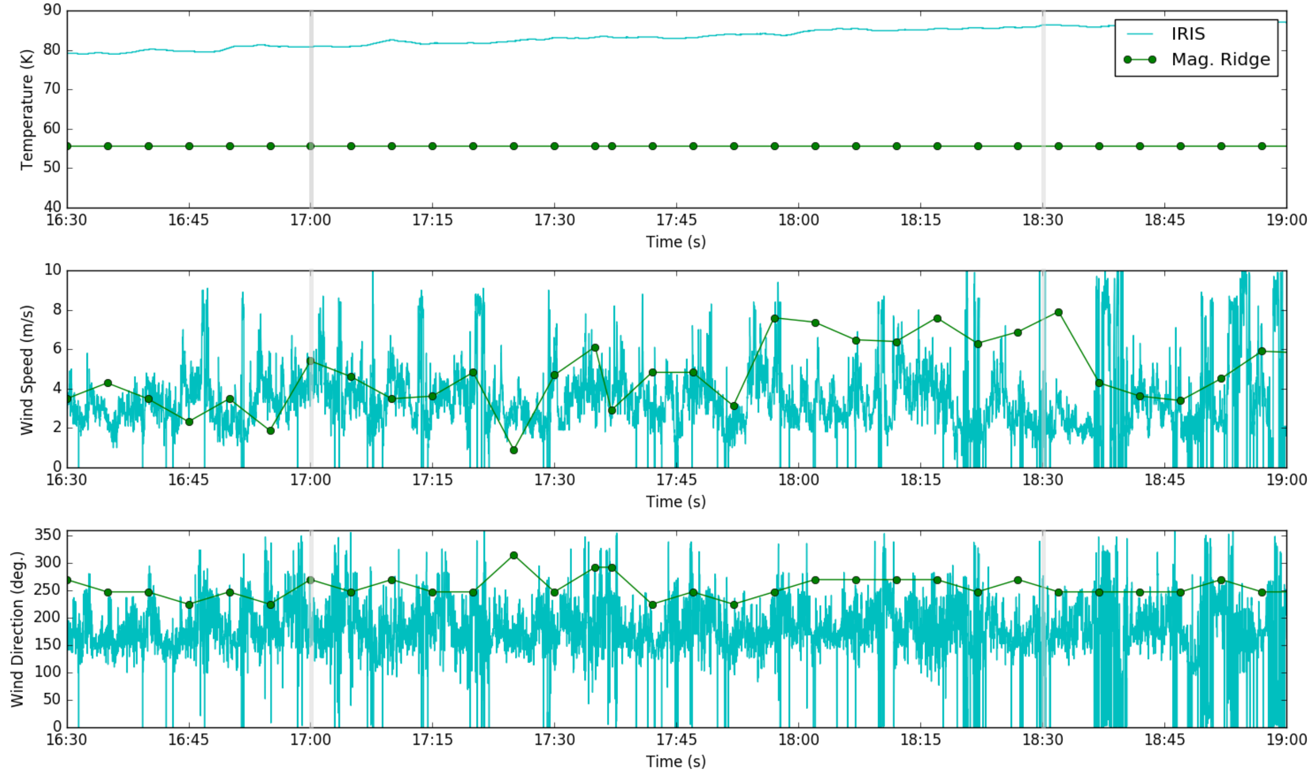


Conclusions

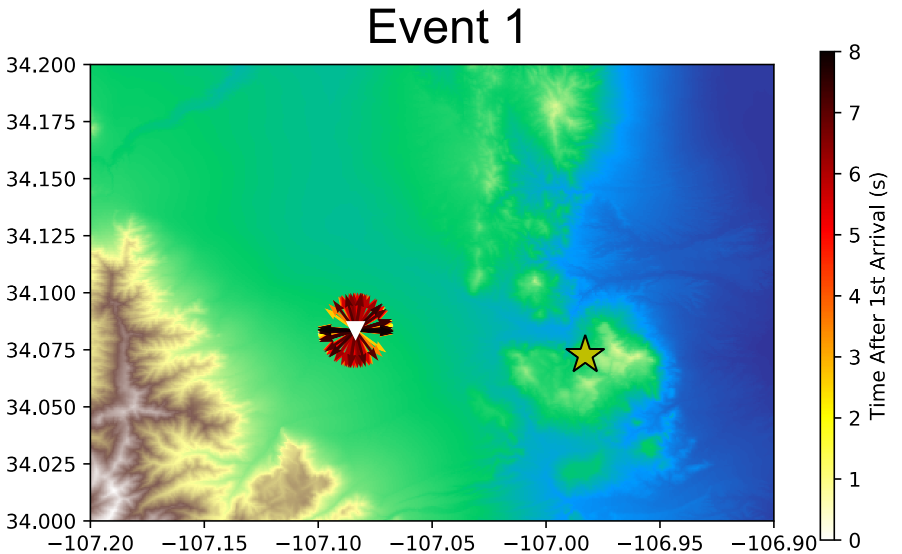
Strengths	Limitations
▪ Correctly identifies backazimuths from the direct arrival and scattered signals ▪ Only requires one explosion and four microphones ▪ Outperforms traditional methods in scattered signal identification	▪ Effectiveness with time decreases due to attenuation (30 s in our case) ▪ Must be done in an area with close, complex, topography (or other scatterers) ▪ Backazimuths are aliased, require analyst input

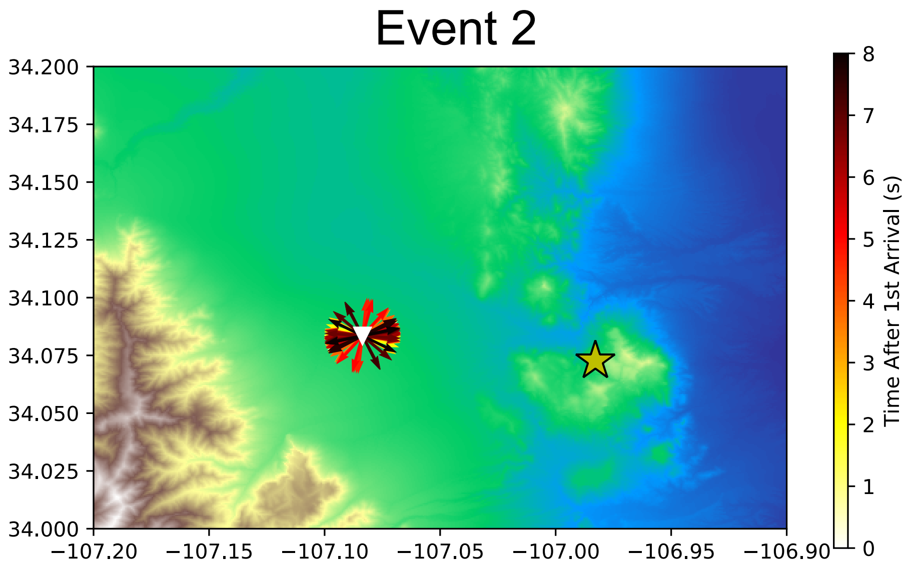
Future Work

- Publication in GRL or GJI
- Use this method with a larger array (50-100 sensors)
- Incorporate weather to explain "shifted" backazimuths during Event 2



Thank You


Event 1
34.200
34.175
34.150
34.125
34.100
34.075
34.050
34.025
34.000
−107.20
−107.15
−107.10
−107.05
−107.00
−106.95
−106.90
Time After 1st Arrival (s)
0
1
2
3
4
5
6
7
8


Event 2
34.200
34.175
34.150
34.125
34.100
34.075
34.050
34.025
34.000
−107.20
−107.15
−107.10
−107.05
−107.00
−106.95
−106.90
Time After 1st Arrival (s)
0
1
2
3
4
5
6
7
8