Passive seismic imaging based on dense geophone arrays

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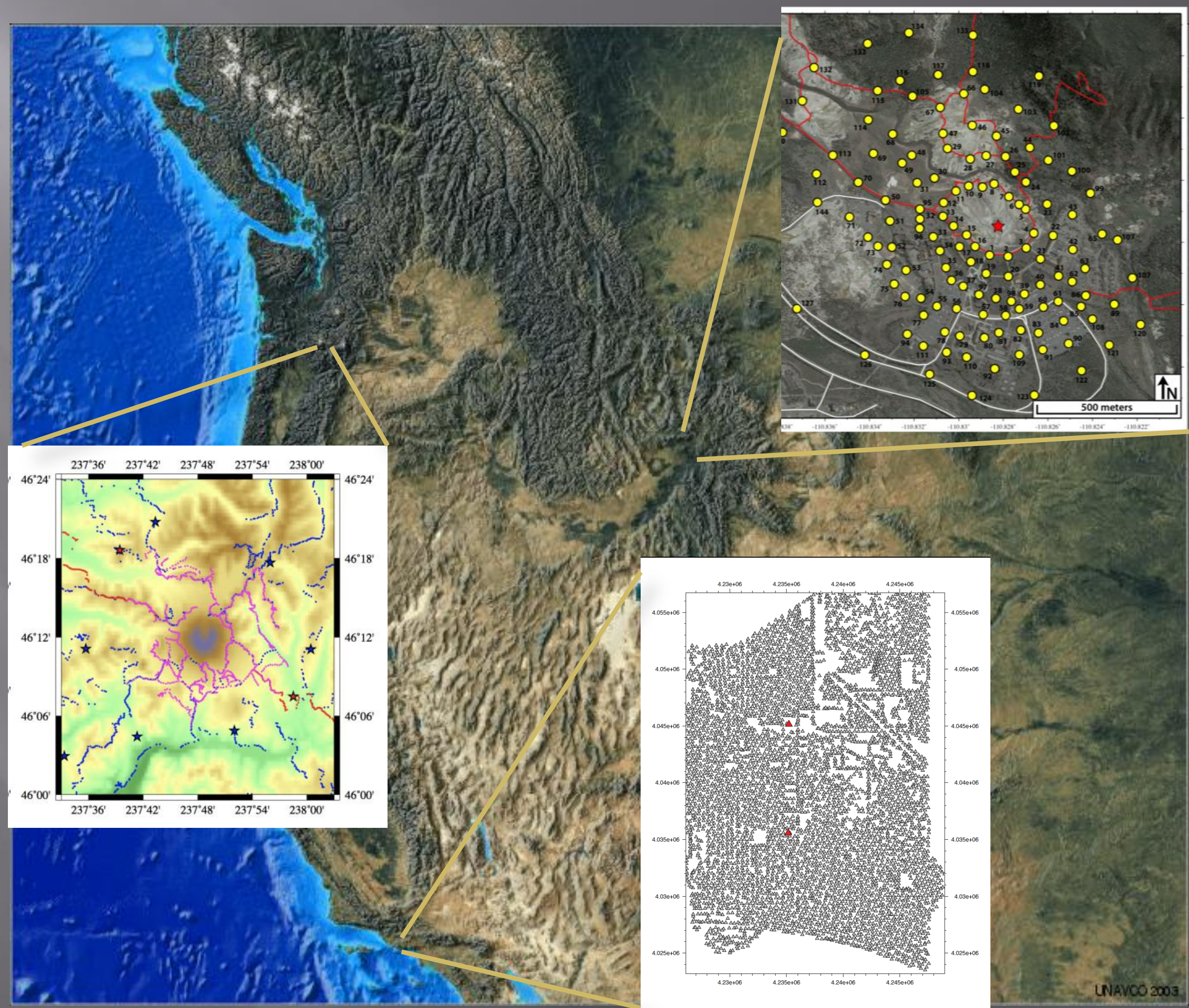
June 6, 2017

at Cargèse France



Acknowledgement

- Yadong Wang (Utah)
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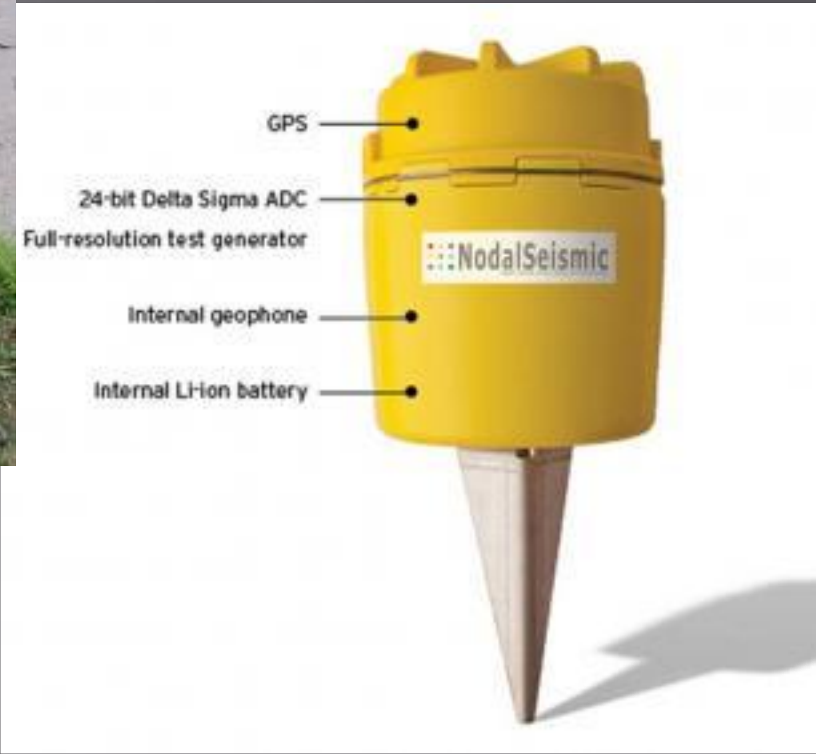
- Jamie Farrell (Utah)
- Kevin Ward (Utah)
- Brandon Schmandt (U. New Mexico)

Cableless geophone system

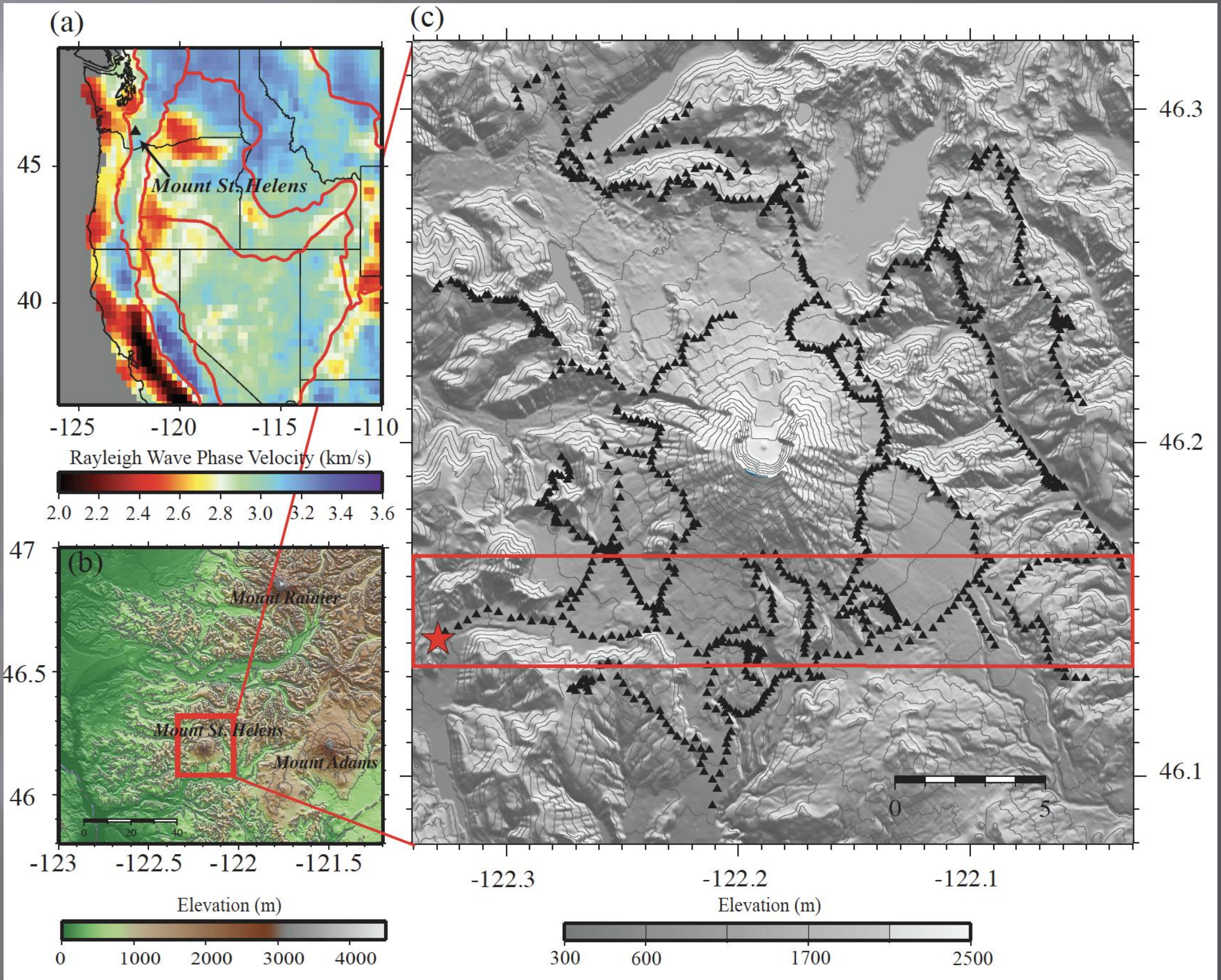
- Autonomous
- Cheap and easy to deploy
- 5 or 10 Hz corner frequency
- 14~30 days battery life
- 1 or 3 components



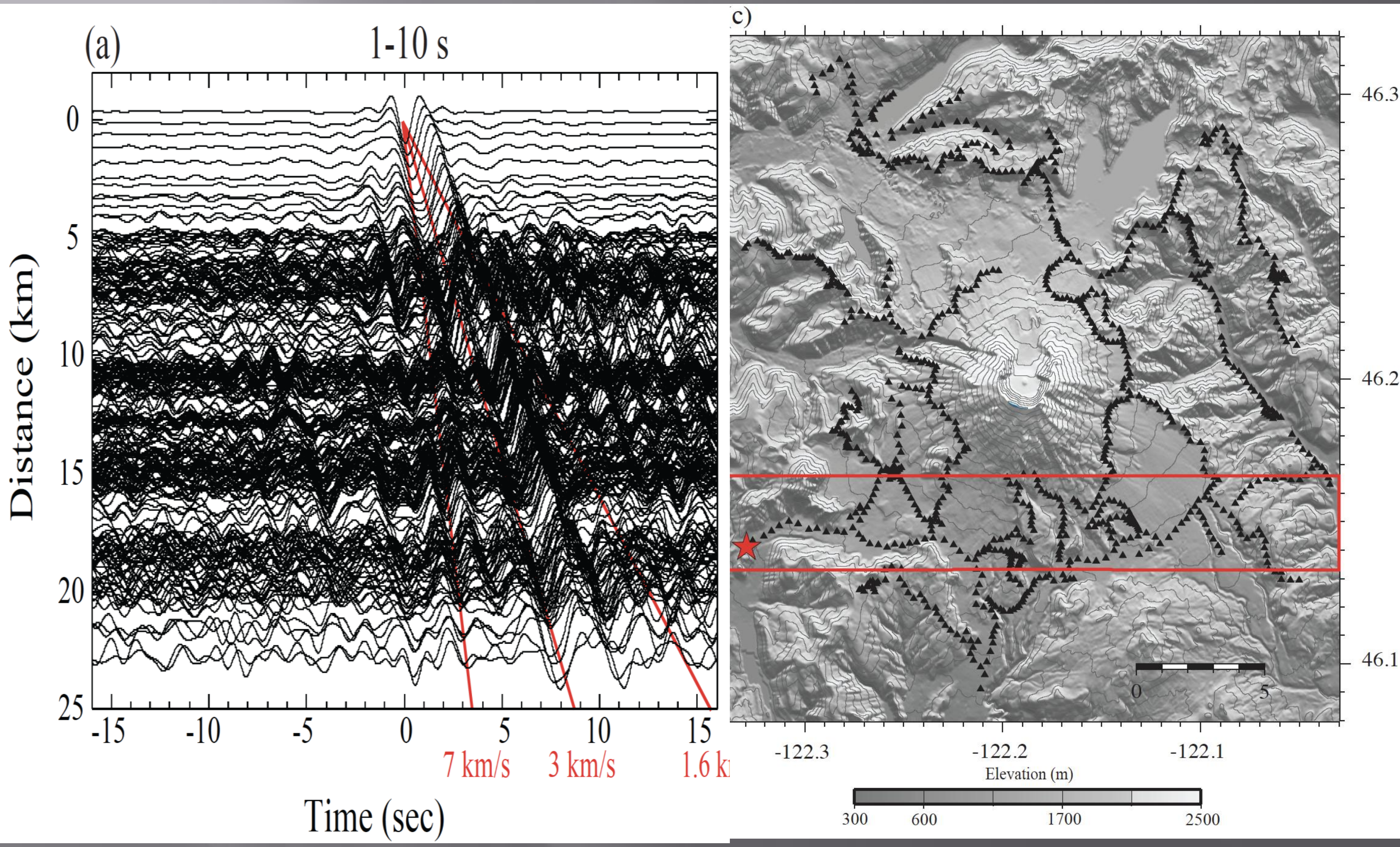
NODALSEISMIC
real cable free data acquisition

Mt St Helens

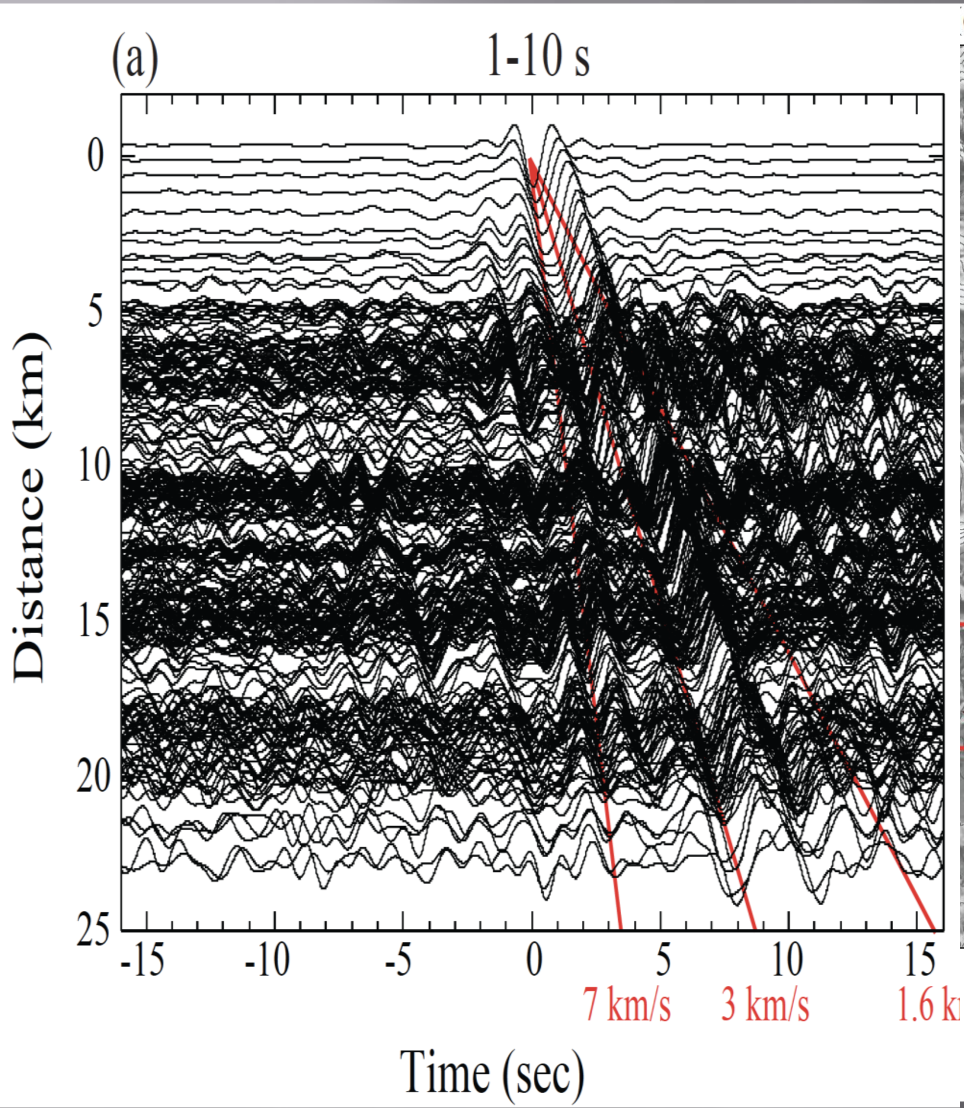
904 nodes deployed between 18 July 2014 and 5 August 2014



Mt St Helens


(a)
1-10 s
Distance (km)
0
5
10
15
20
25
-15
-10
-5
0
5
10
15
7 km/s
3 km/s
Time (sec)
c)
46.3
46.2
46.1
-122.3
-122.2
-122.1
0
5
Elevation (m)
300
600
1700
2500

Mt St Helens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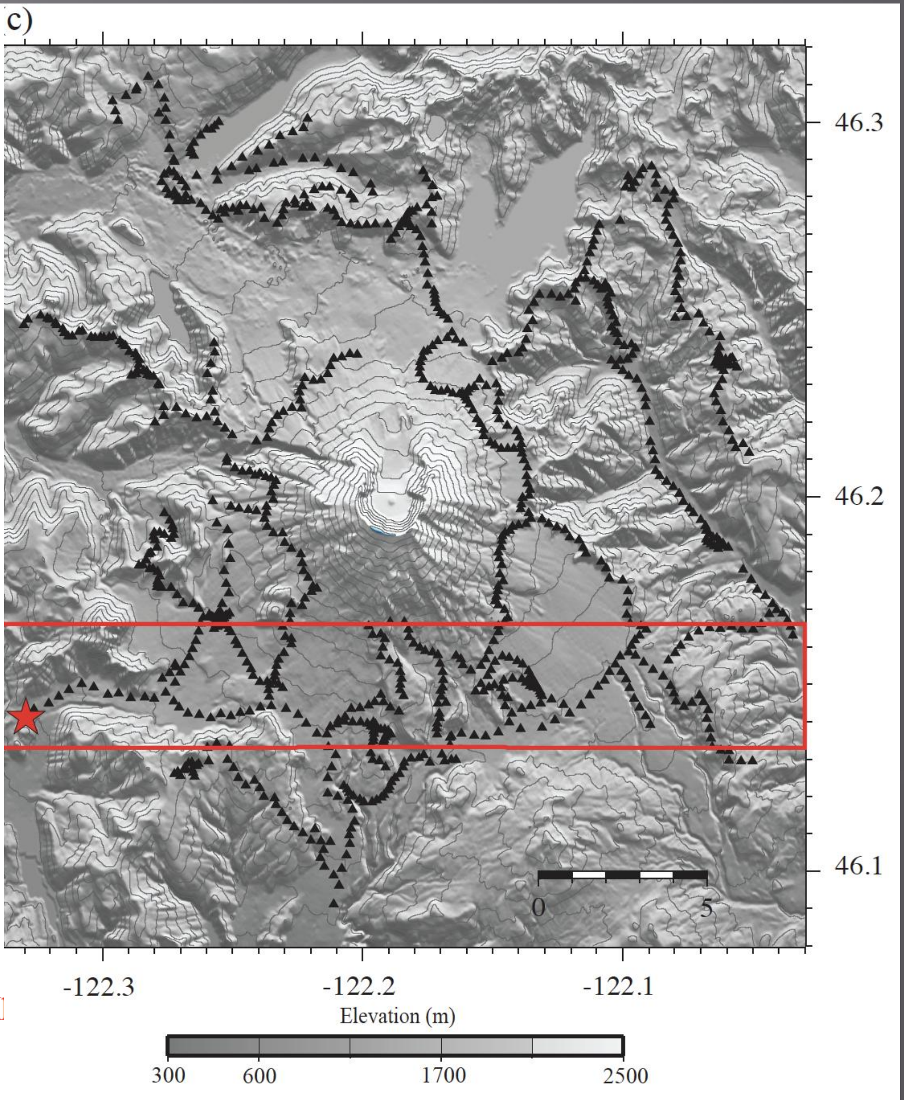
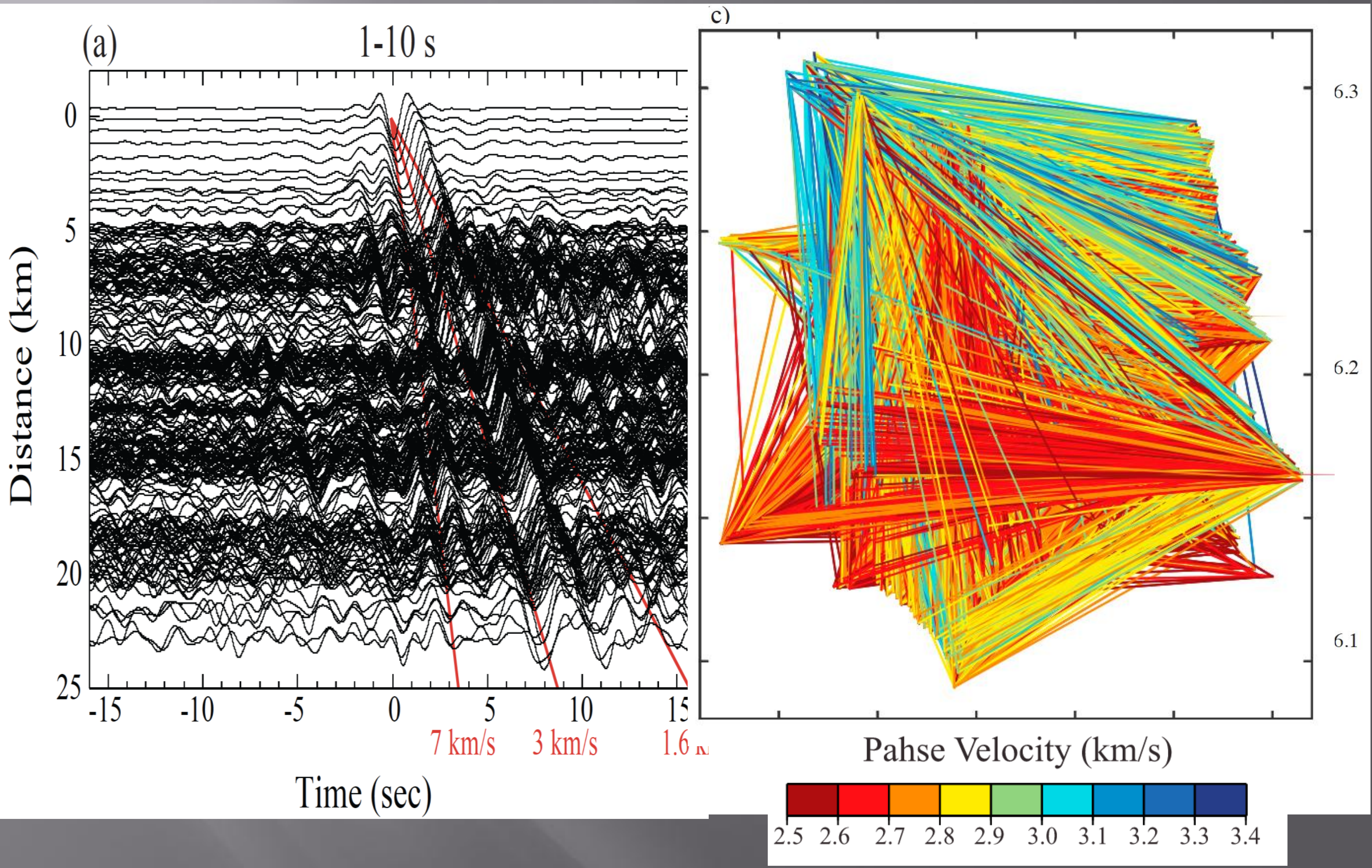
Time (sec)

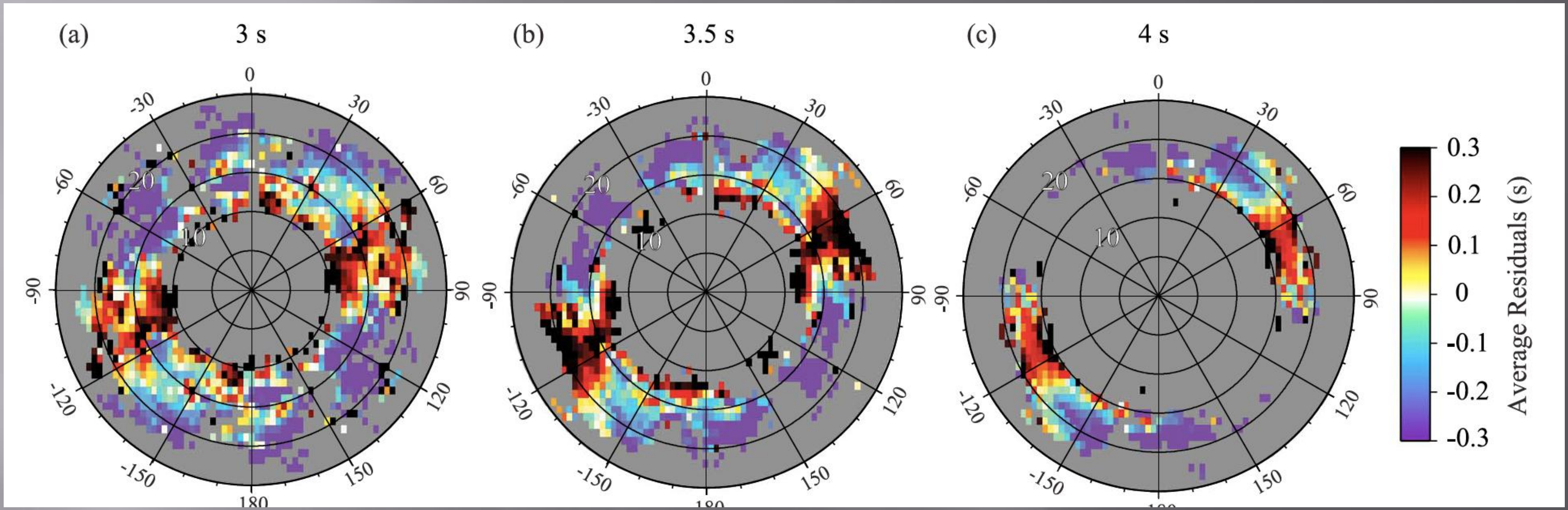

c)
46.3
46.2
46.1
-122.3
-122.2
-122.1
0
5
Elevation (m)
300
600
1700
2500

Mt St Helens

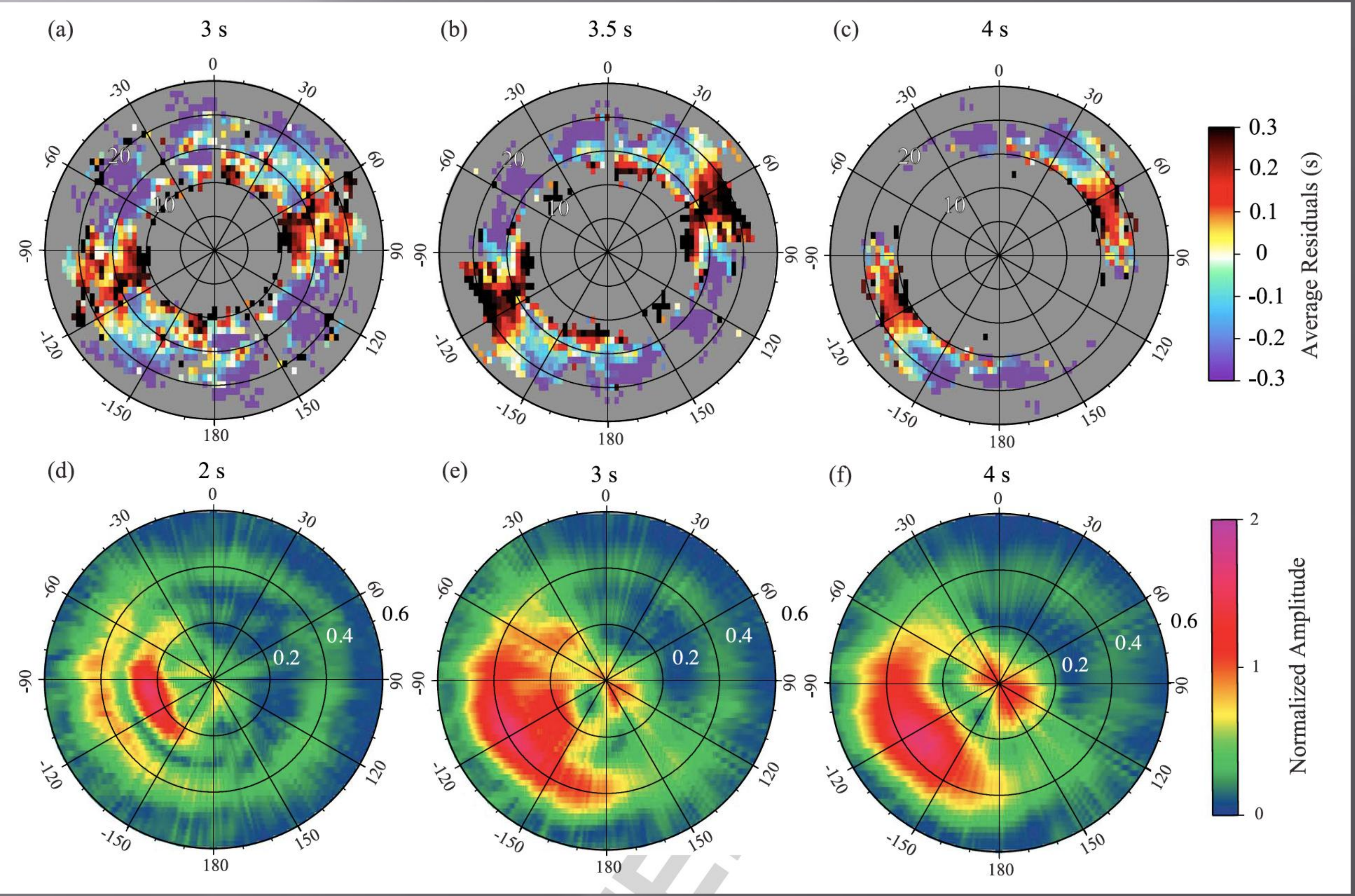
3s



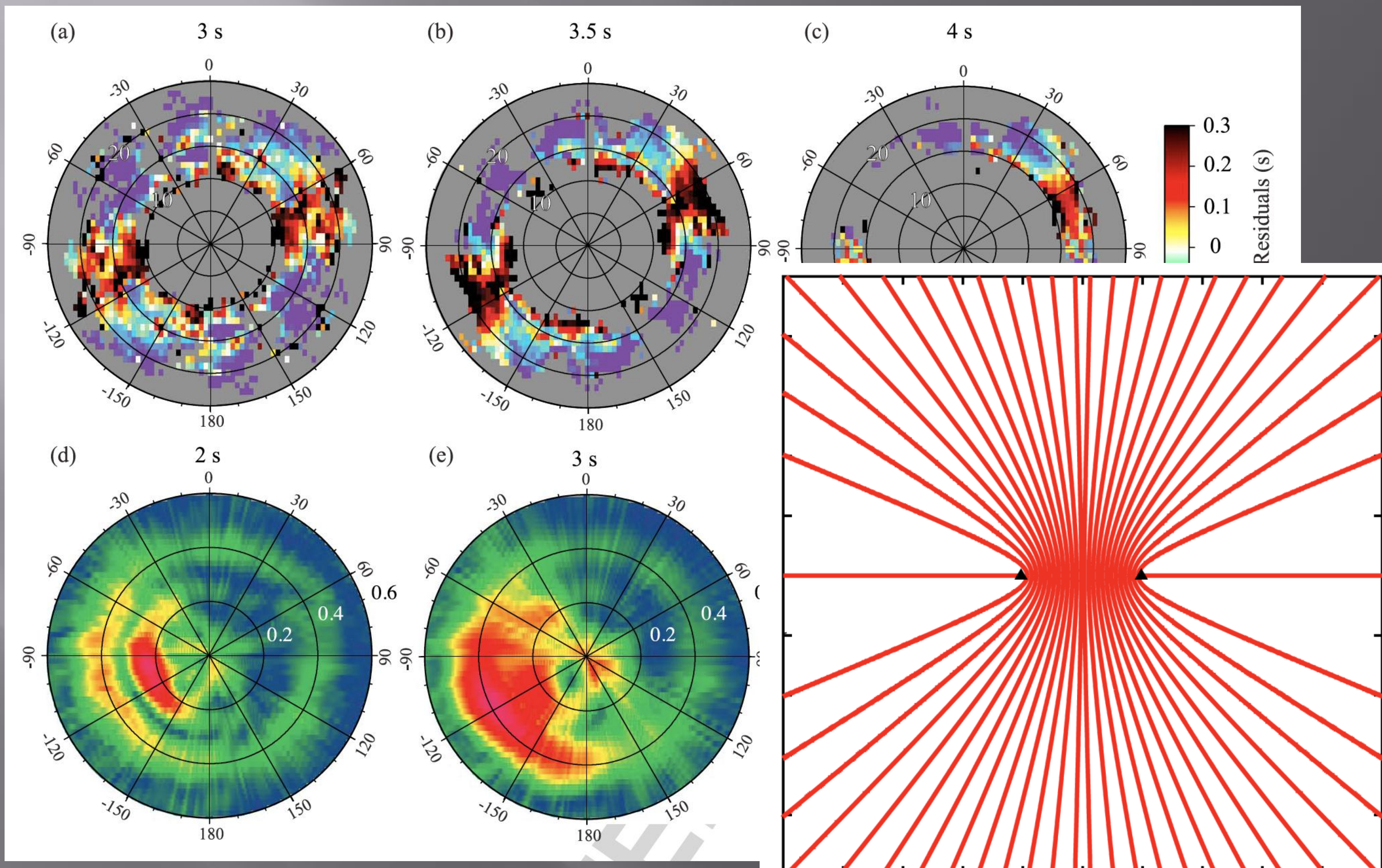
Systematic Traveltime Biases



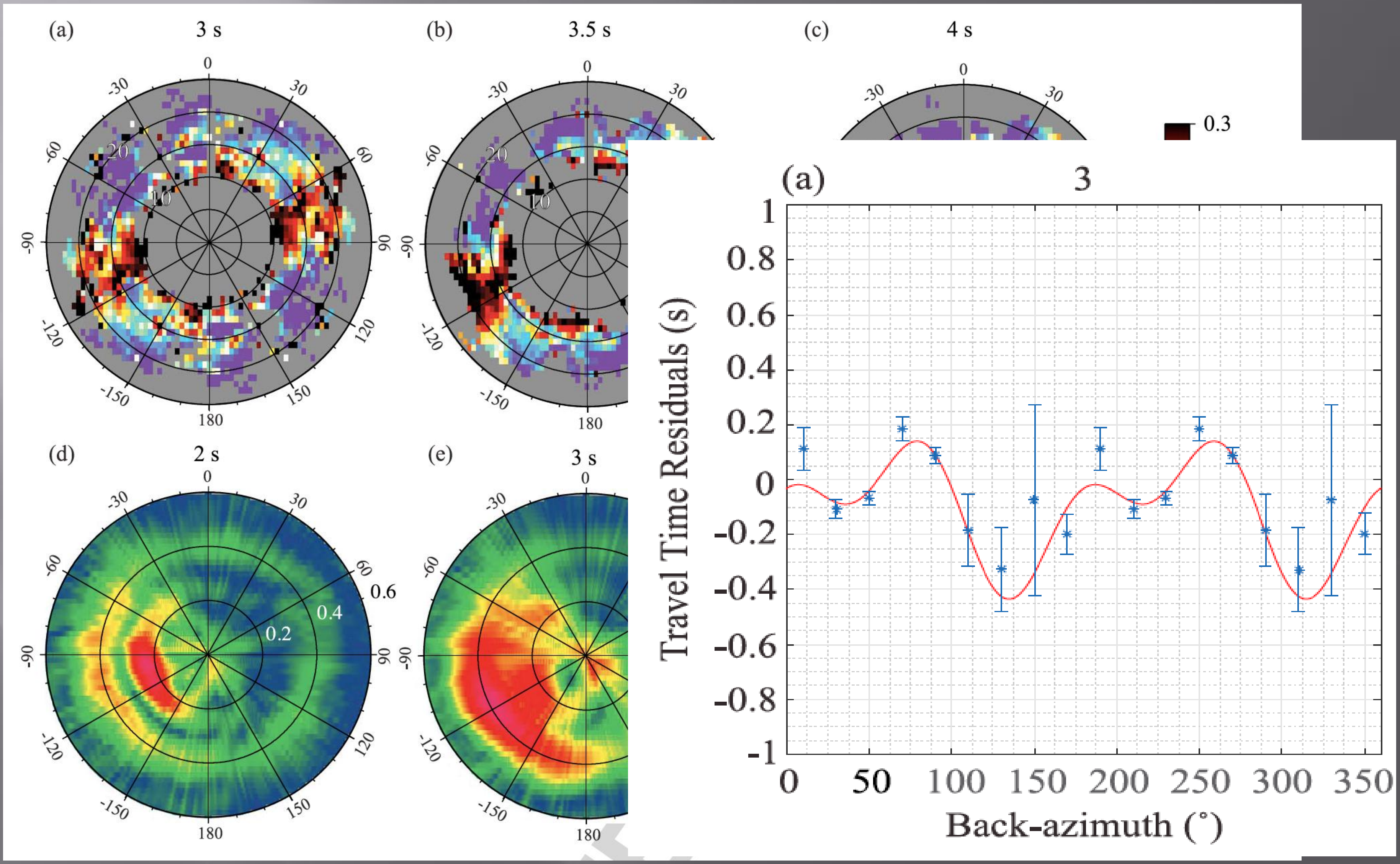
Systematic Traveltime Biases



Systematic Traveltime Biases



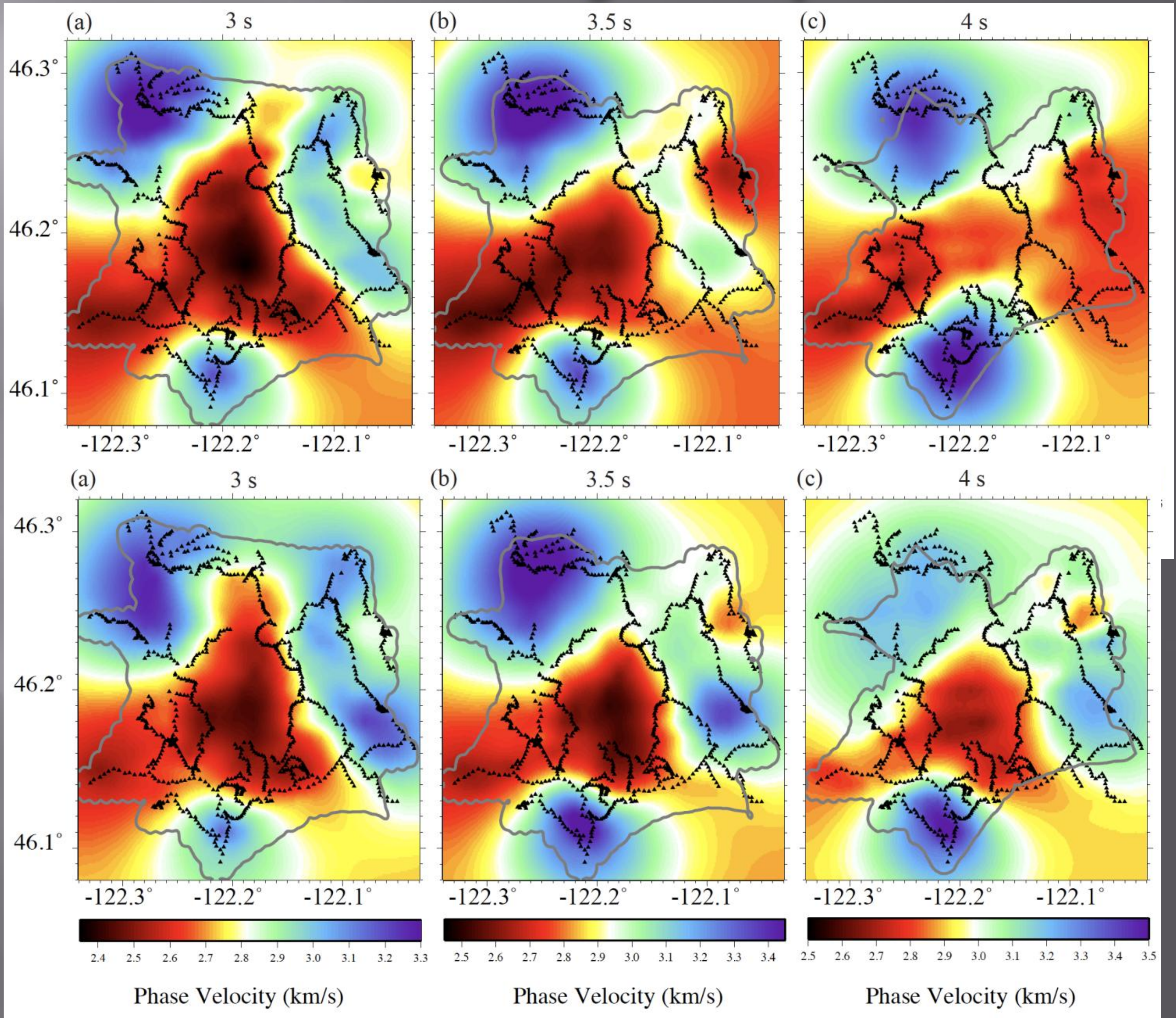
Systematic Traveltime Biases



Phase velocity maps

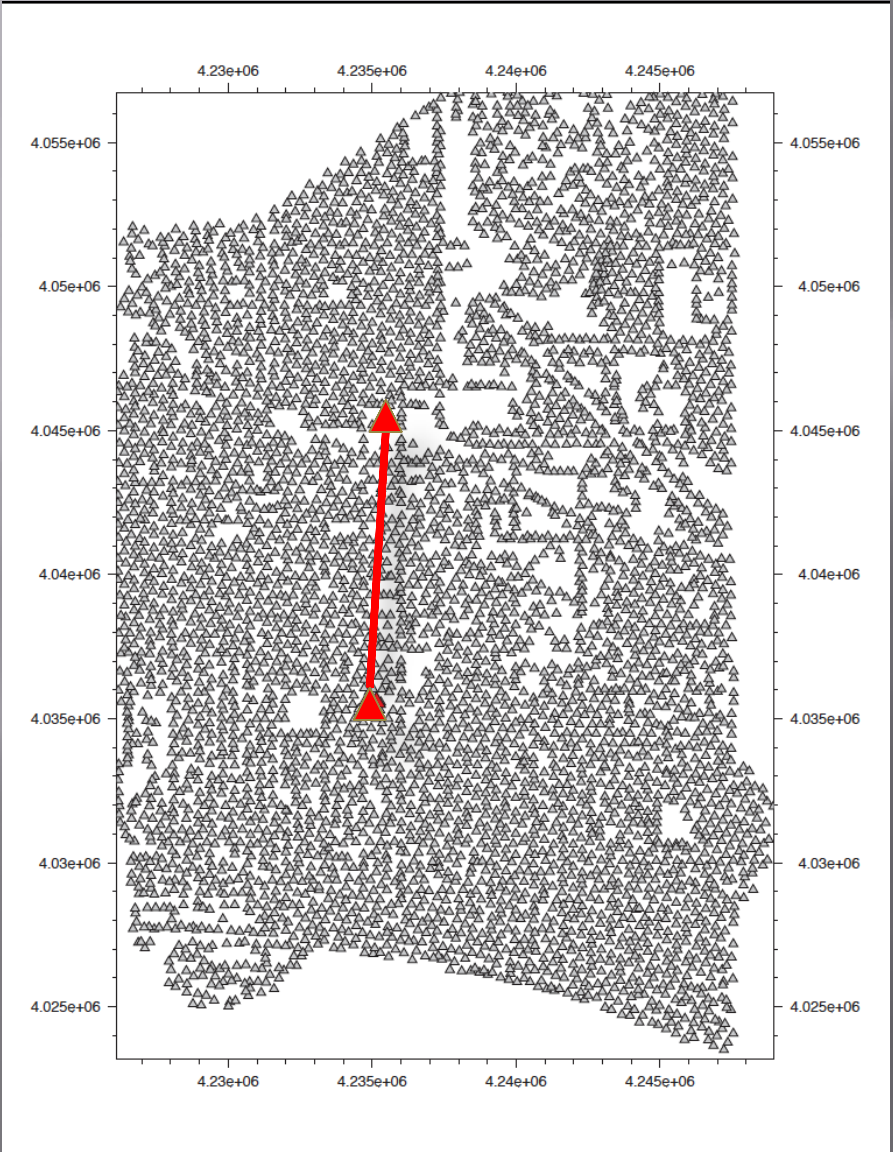
Before Correction

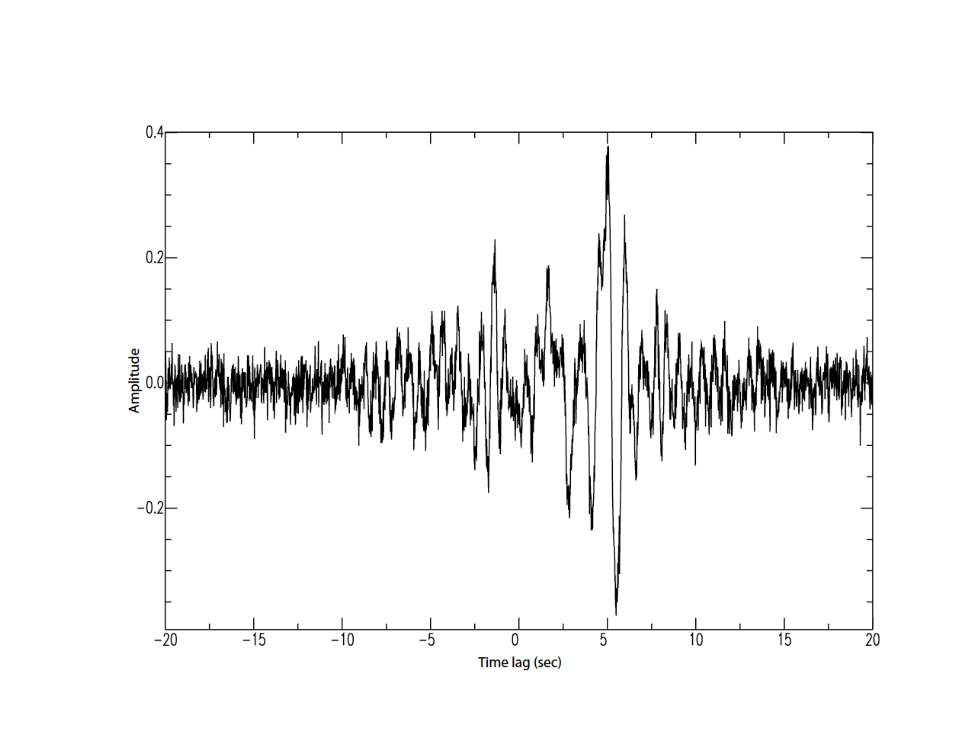
After Correction



Wang et al., 2017

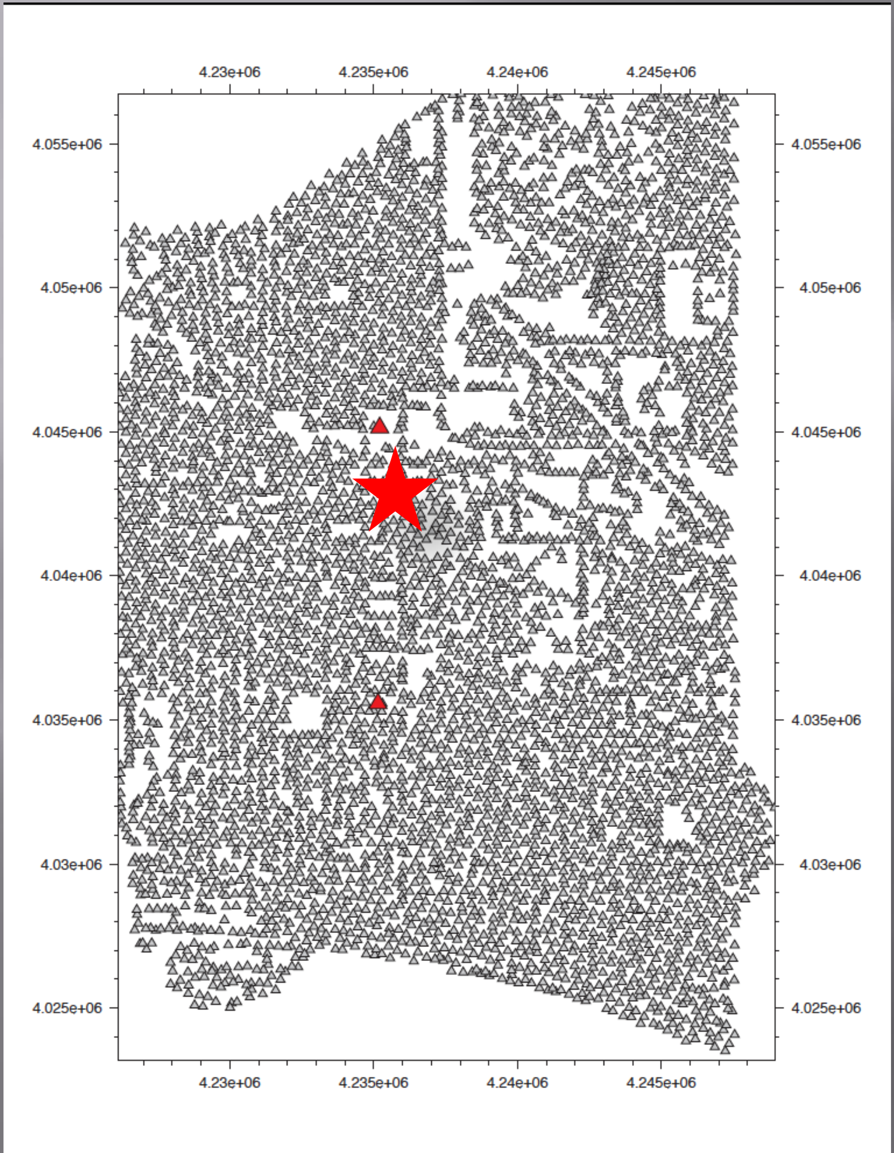
Long Beach Dense Array

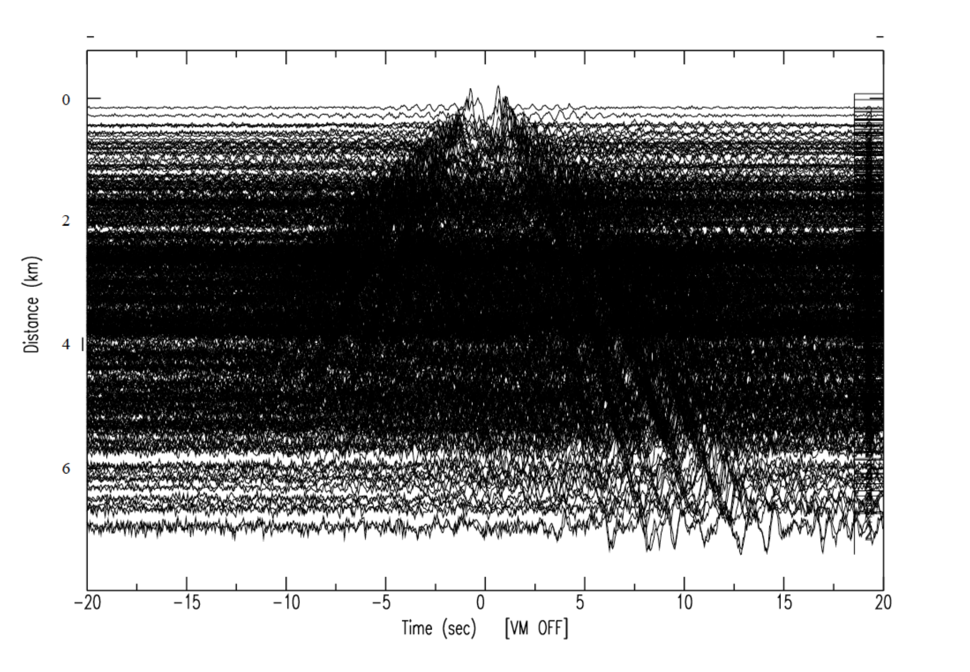




3 week of noise

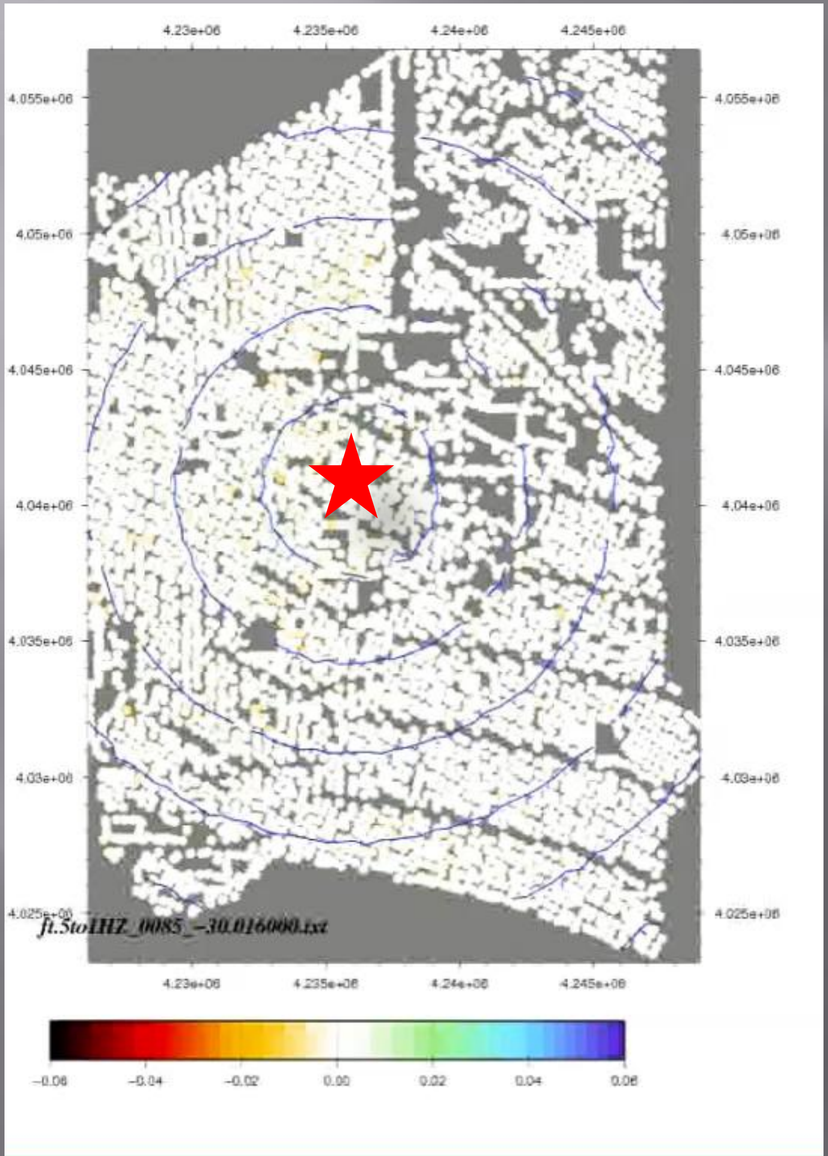
Long Beach Dense Array

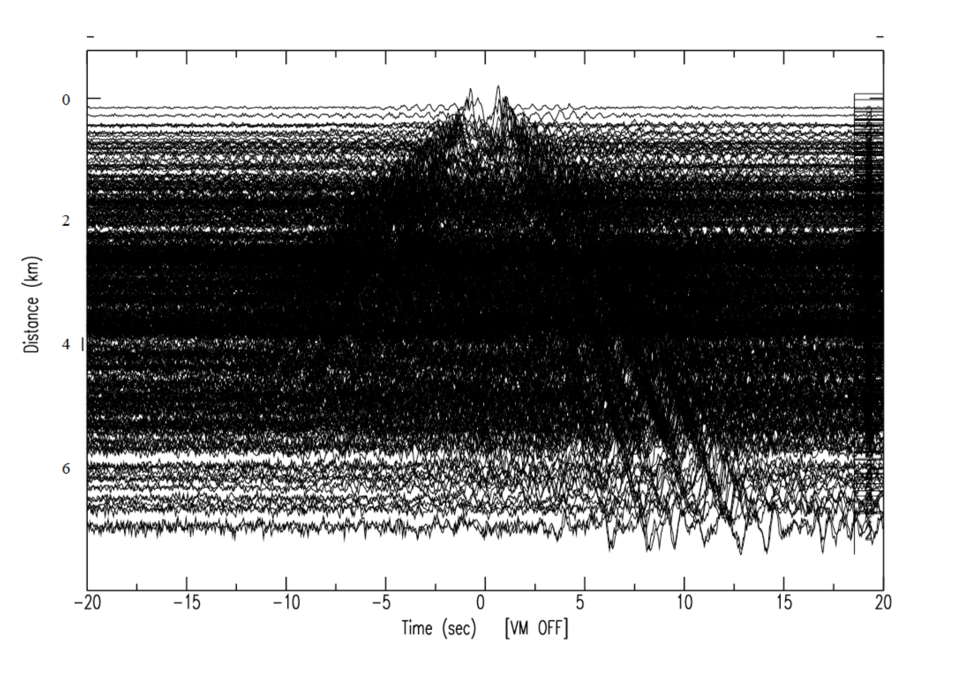




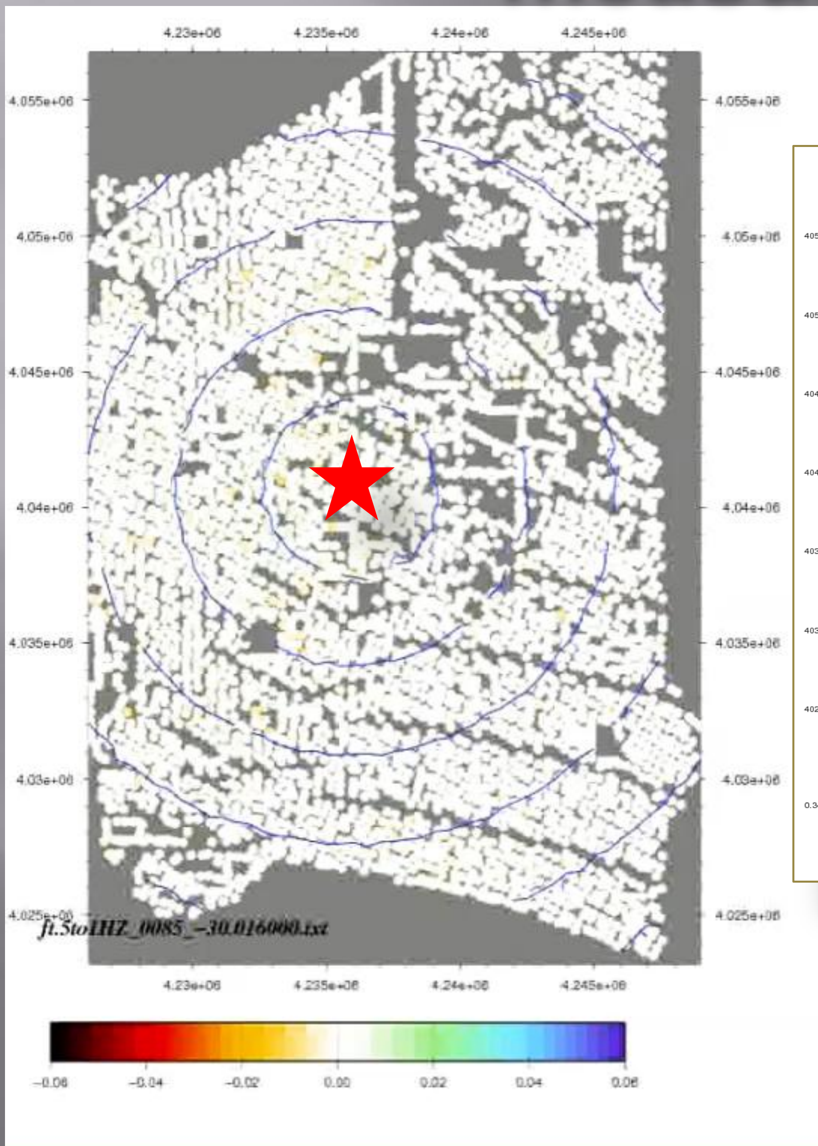
3 week of noise

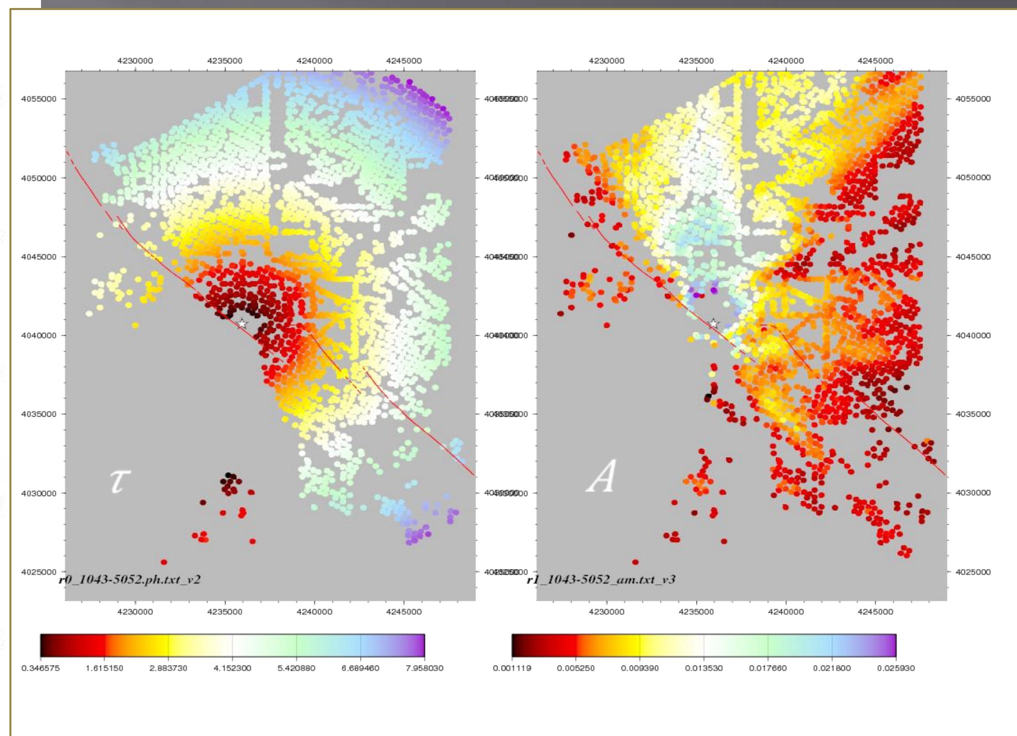
Long Beach Dense Array





Traveltime and amplitude measurements





Bowden et al., 2015

The cross-correlation wavefield

- Assume the noise wavefield *u(x,t)* satisfies the wave equation *L:*

$$Lu(x,t)=0$$

- The cross-correlation wavefield between a source station A and all other locations is:

$$C(x_A,x,t)=\int u^*(x_A,\tau)u(x,t+\tau)d\tau$$

- The cross-correlation wavefield satisfies the wave equation:

$$LC(x_A,x,t)=\int u^*(x_A,\tau)Lu(x,t+\tau)d\tau=0$$

Solution of the 2D wave equation

- Real part:

$$\frac{1}{c(\mathbf{r})^2} = \nabla t \cdot \nabla t - \frac{\nabla^2 (A/b)}{w^2 (A/b)}$$

Helmholtz tomography (Lin & Ritzwoller 2011, GJI)

- High-frequency approximation (ray-theory approach)

$$\frac{\hat{k}}{c} @ \nabla t$$

Eikonal tomography (Lin et al. 2009, GJI)

- Imaginary part:

Corrected amplitude decay

Apparent amplitude decay

Focusing/ defocusing

$$\frac{-2a}{c} + \frac{2\nabla b \cdot \nabla t}{b} = \frac{2\nabla A \cdot \nabla t}{A} + \nabla^2 t$$

A: observed amplitude

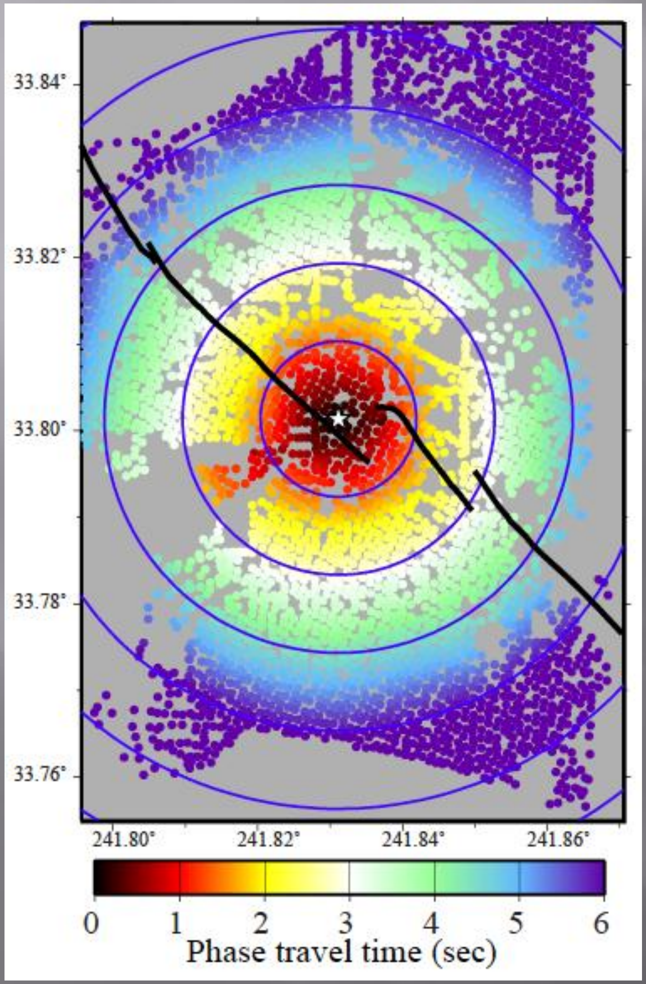
τ : observed phase travel time

β : local amplification factor

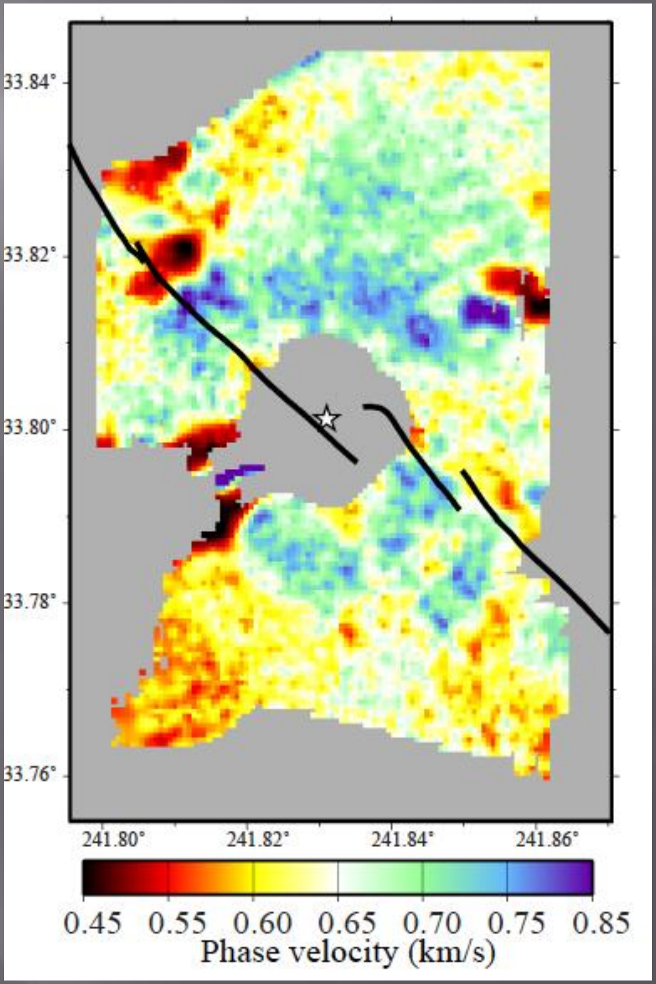
Amplification and attenuation (Lin et al. 2012, JGR)

Eikonal tomography

Travel time



Phase velocity

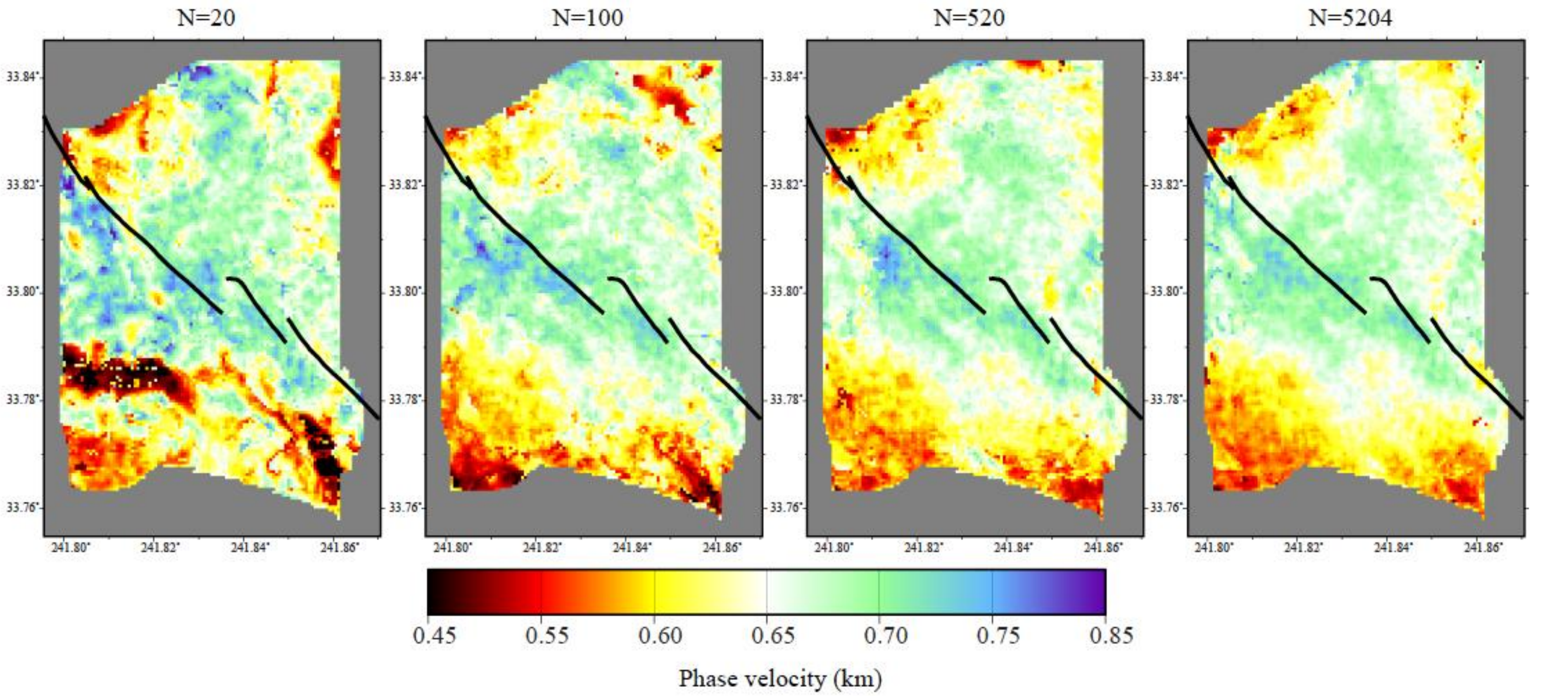


$$\frac{\hat{k}}{c} @ \nabla t$$

Eikonal Tomography

Eikonal tomography

N=20 N=100 N=520 N=5204



Azimuthal anisotropy

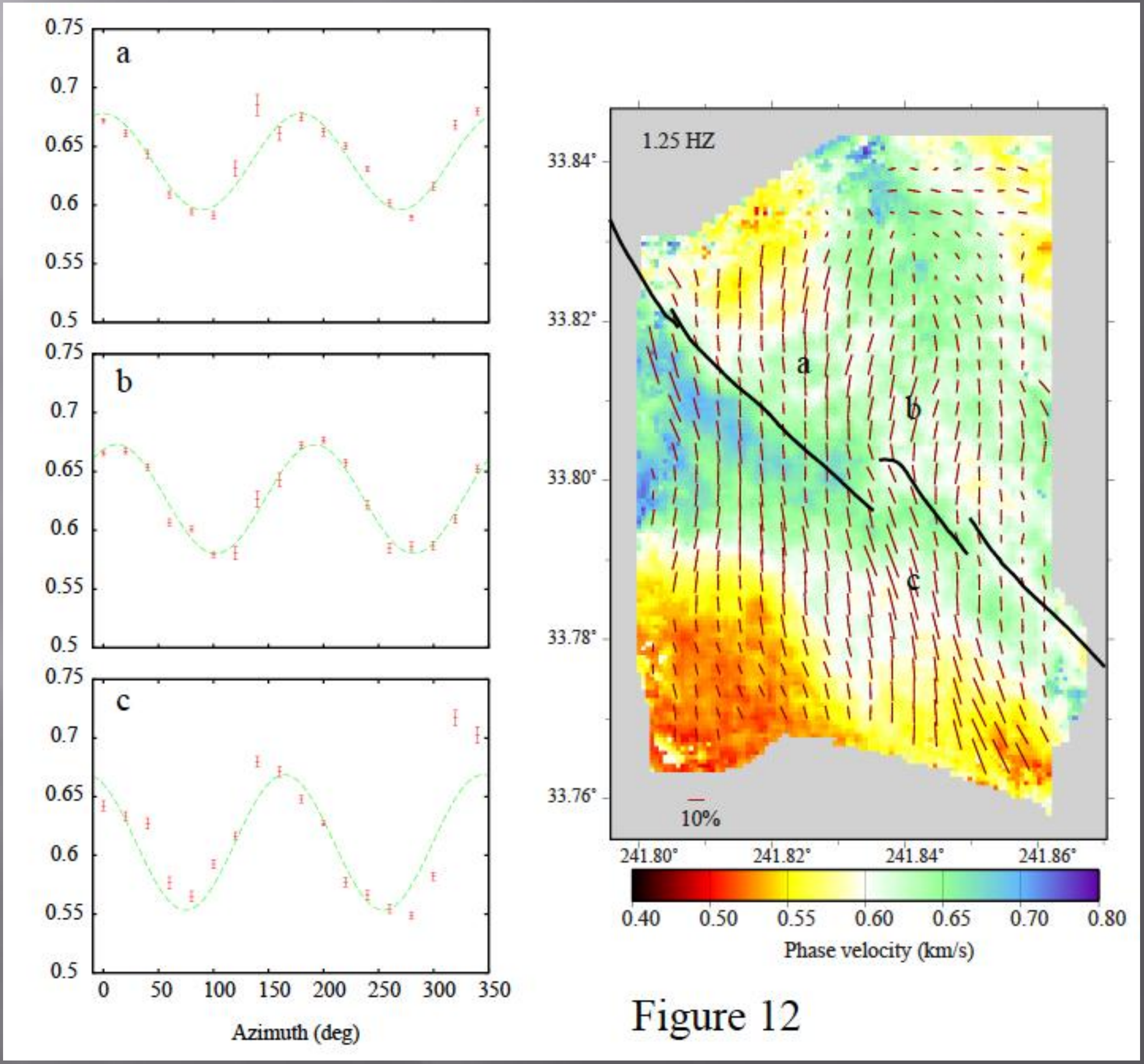
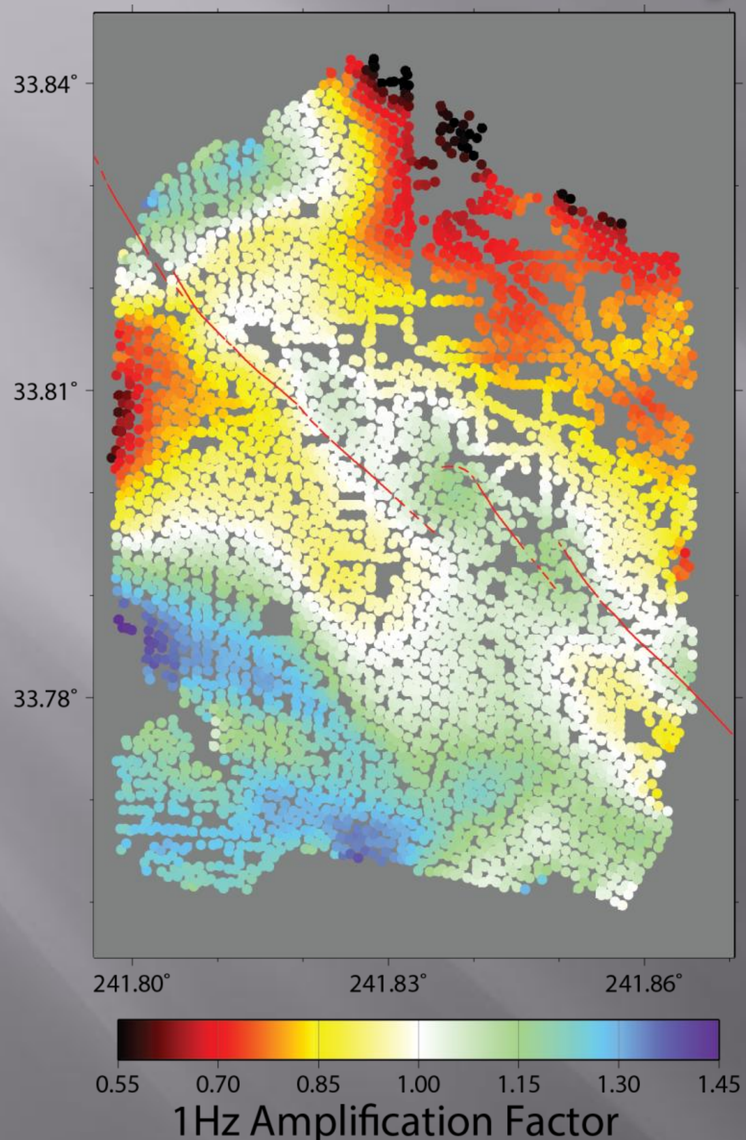
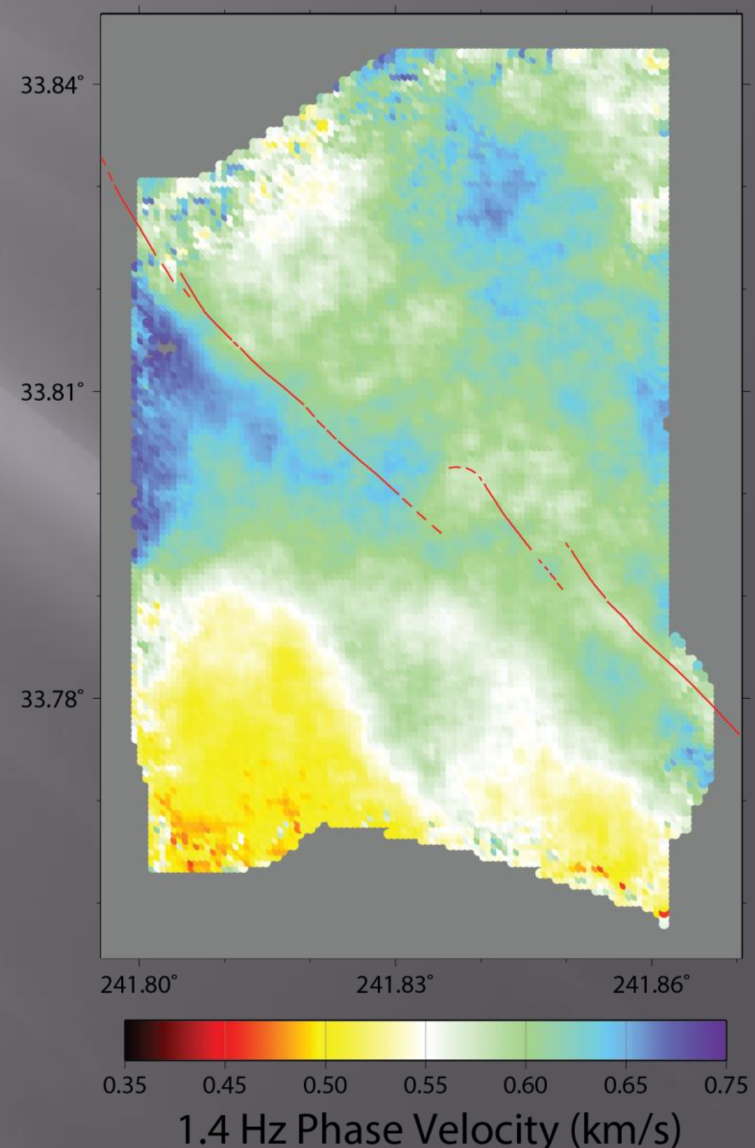


Figure 12

Amplification



Bowden et al., 2015



Lin et al., 2013

THE UPPER GEYSER BASIN IMAGING EXPERIMENT

University Of Utah
Seismograph Stations
The University of Utah

National Park Service

fairfieldnodal

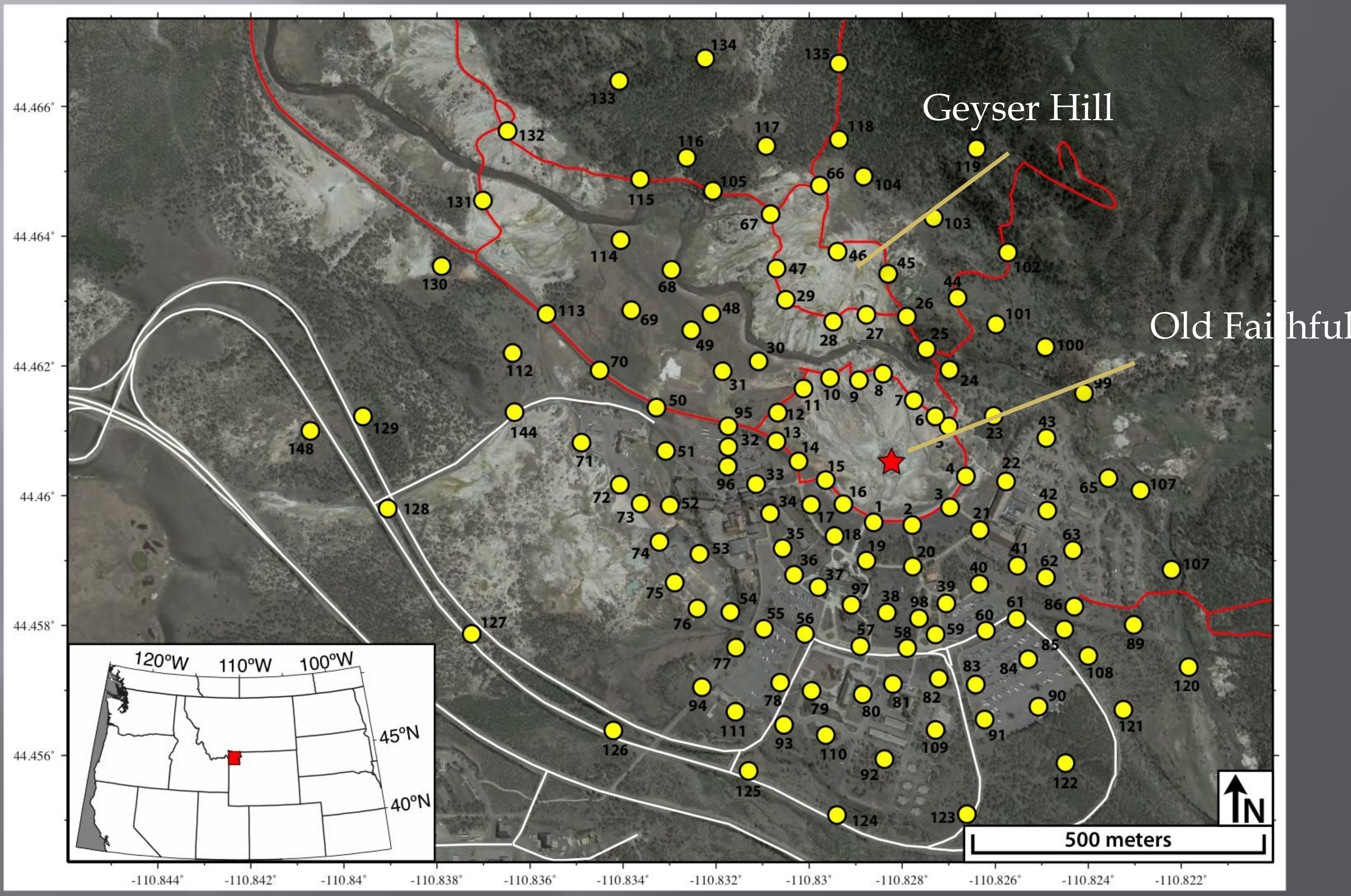
UTEP

Photo by Stephen Wilkes, National Geographic Magazine

3C geophones

Cableless 3C geophone system

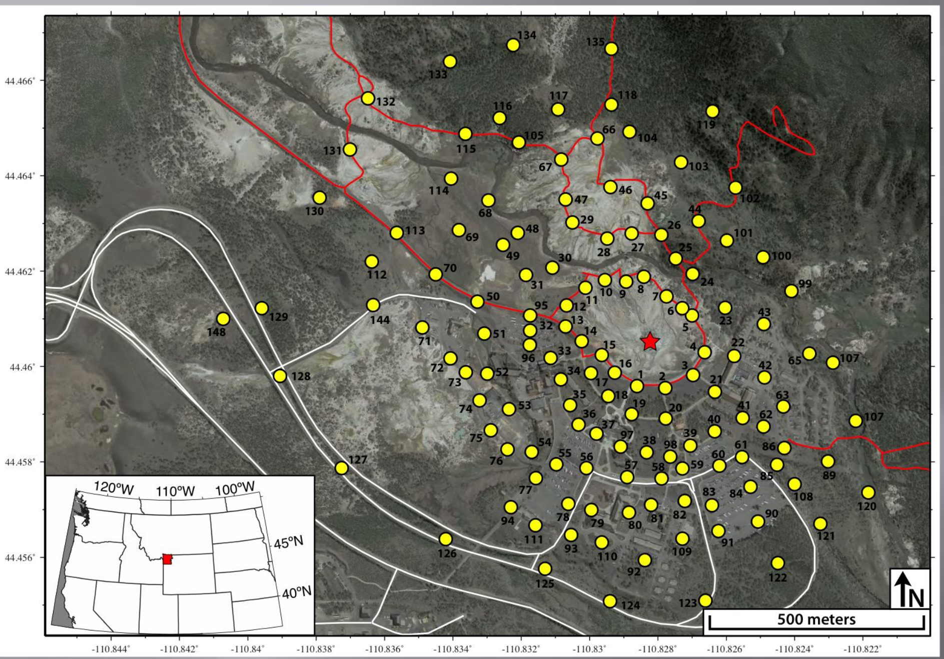
The Old Faithful Array



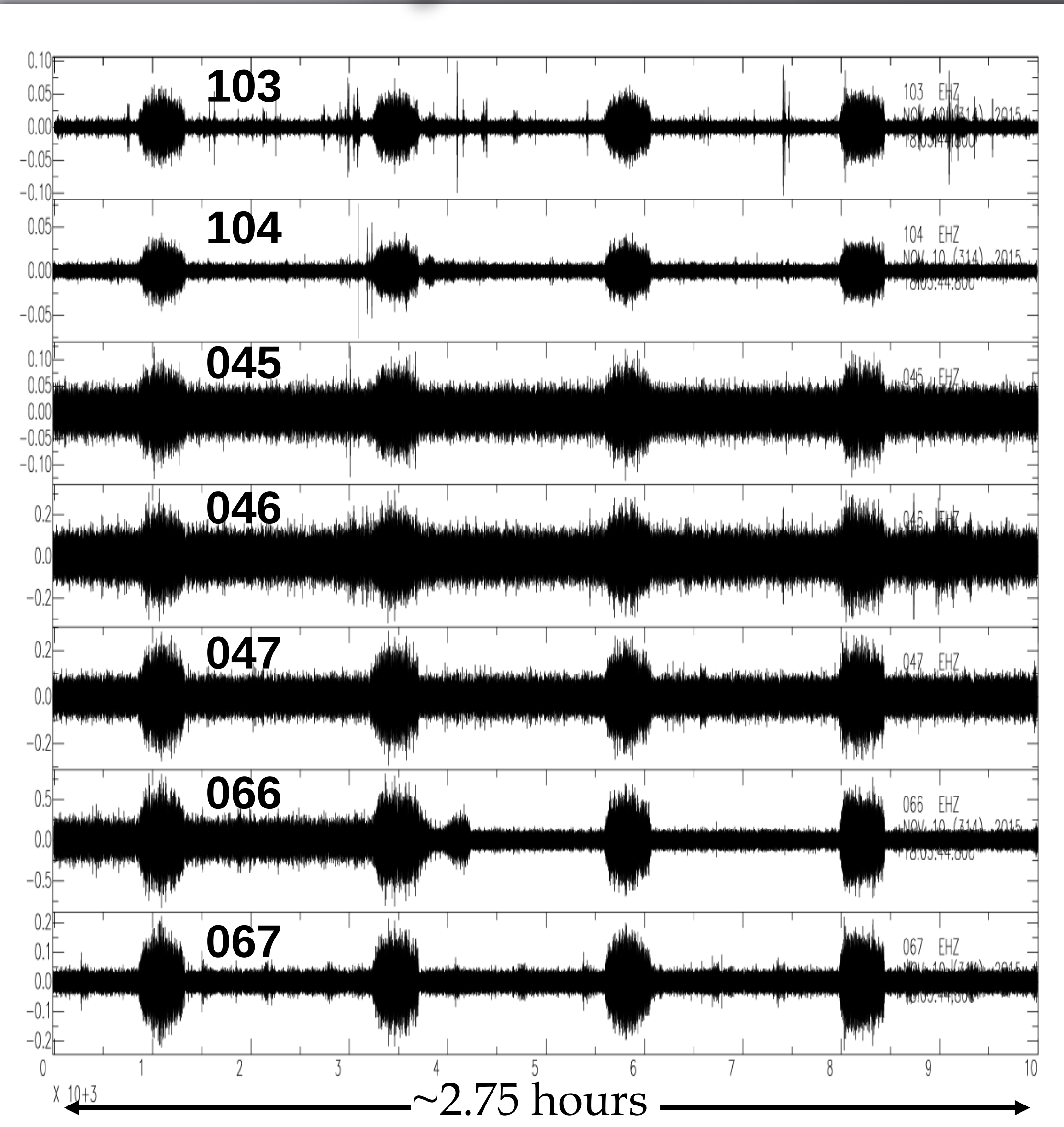
Old Faithful deployment

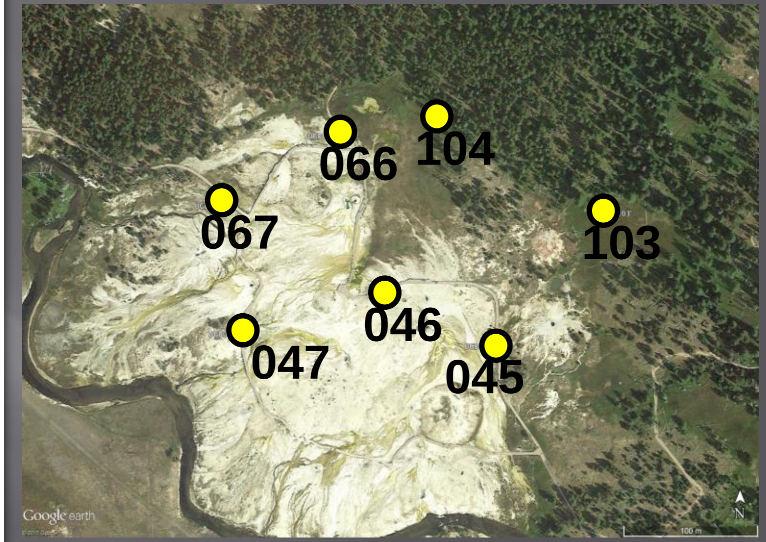

fairfieldnodal
0001083
ZLAND 3C 5Hz

Temporal Noise Variation

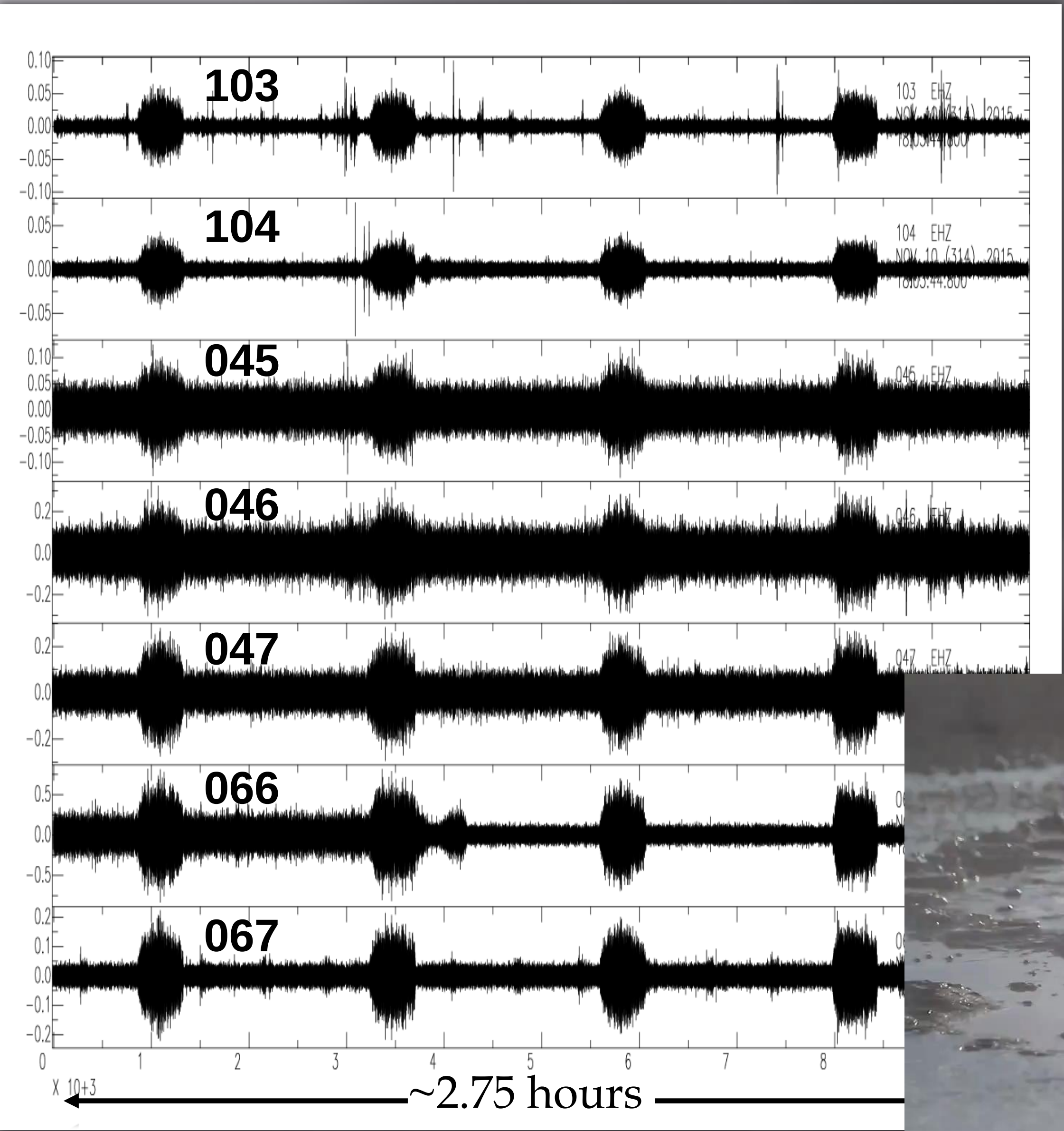


Hydrothermal Tremor



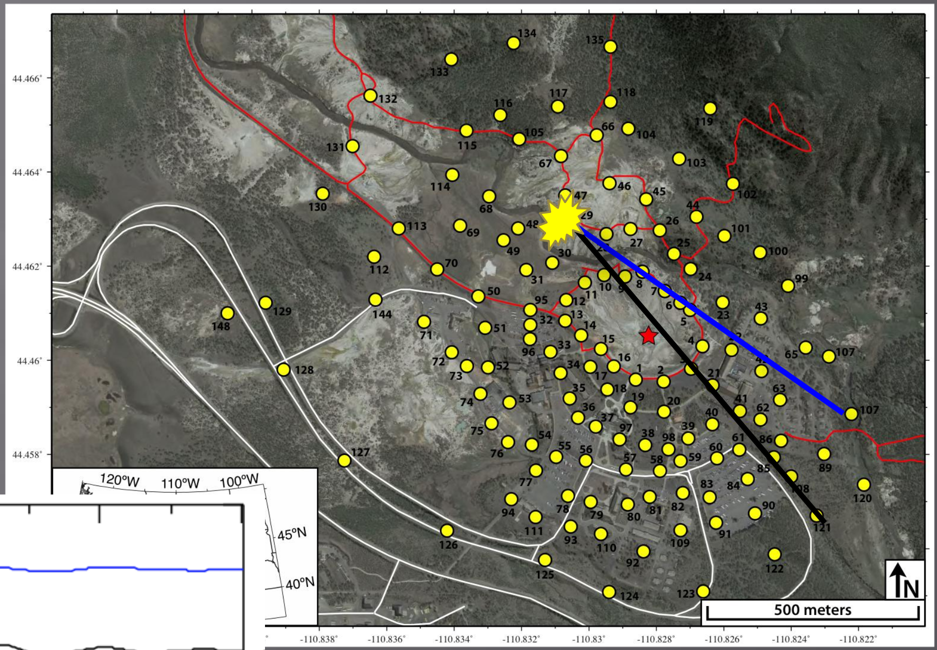


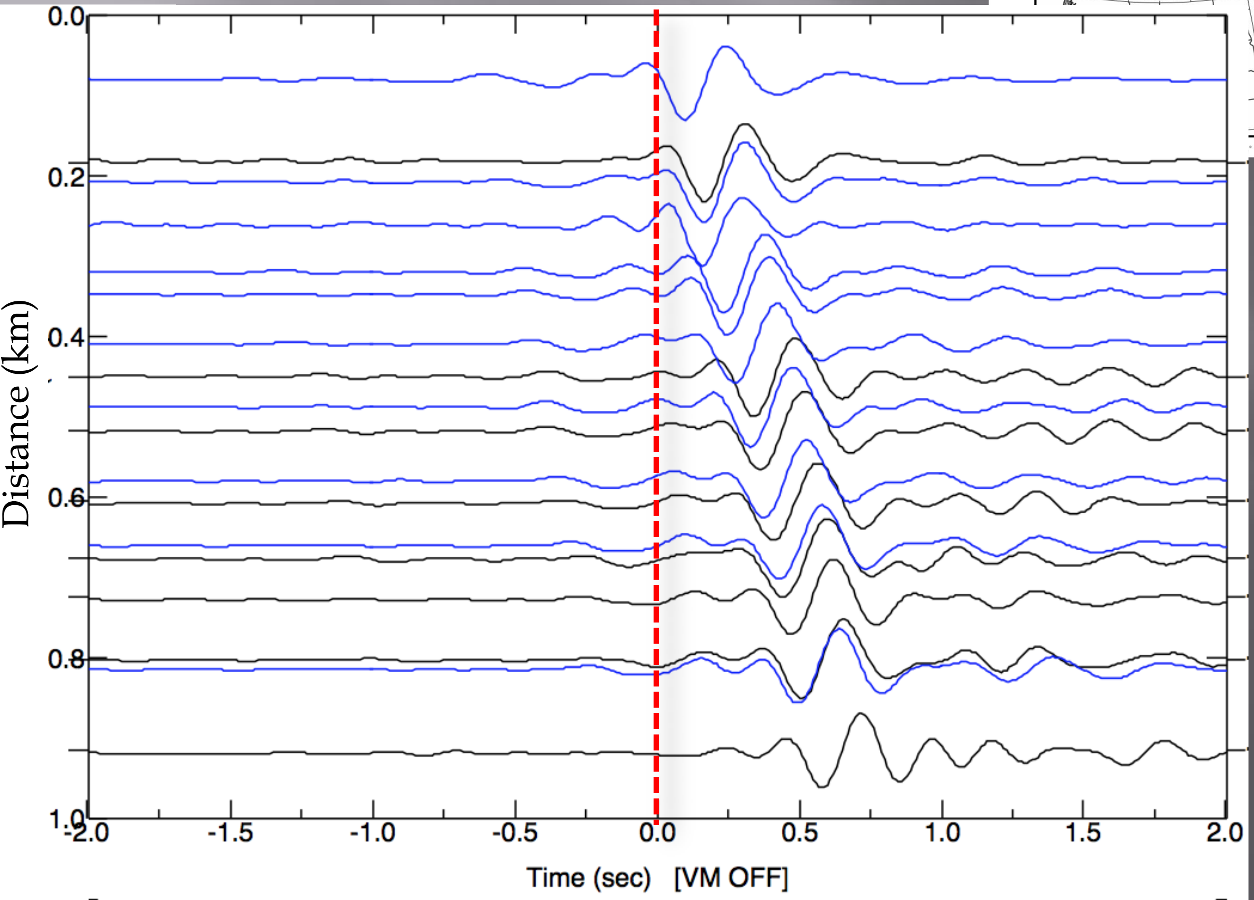
Raw seismic waveforms



Doublet Pool

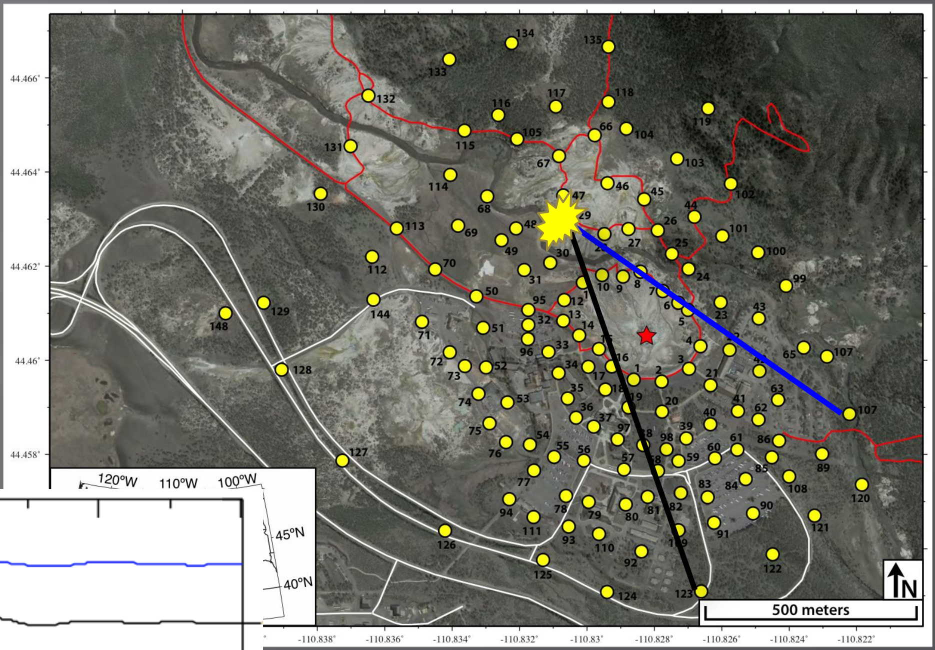
Virtual Record Section

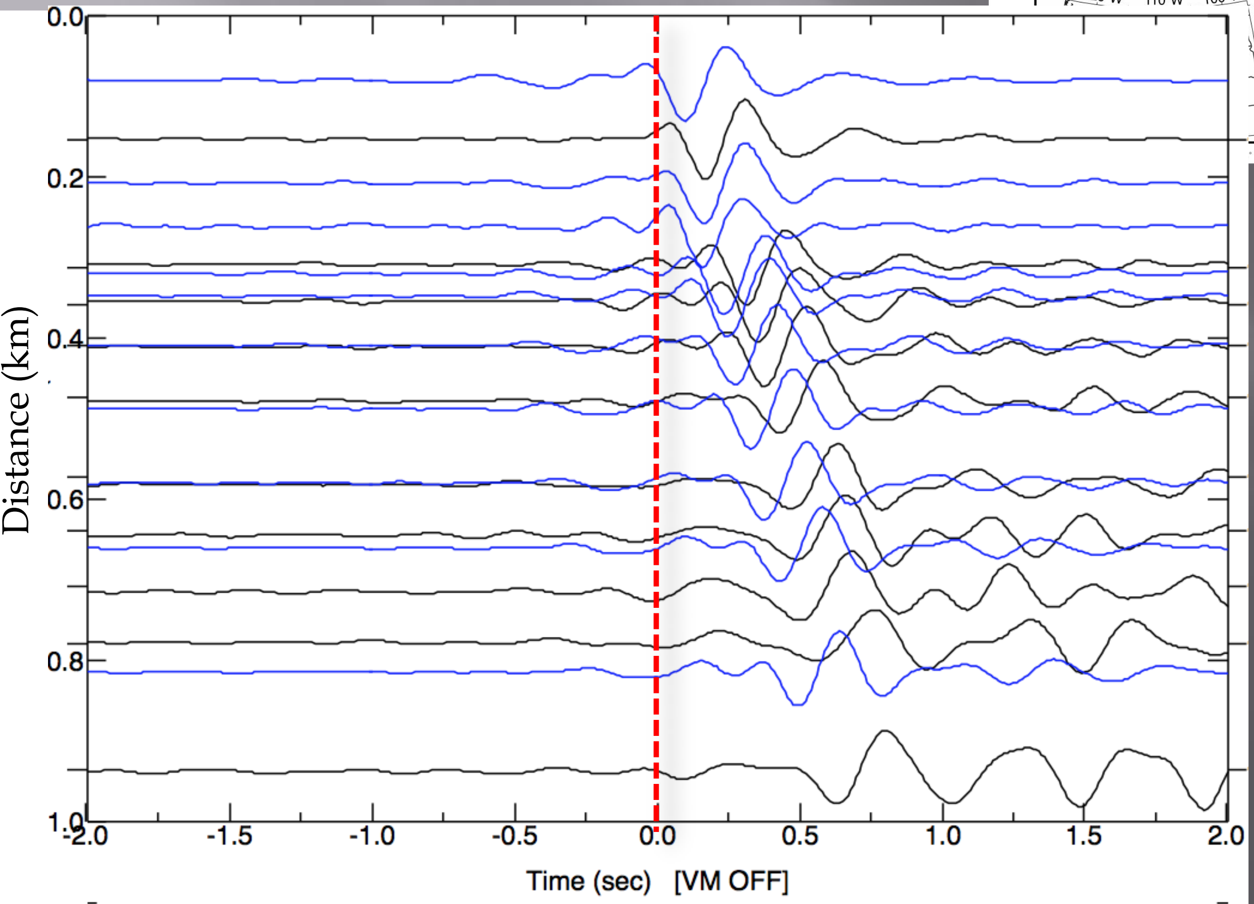




1-5 Hz

Virtual Record Section

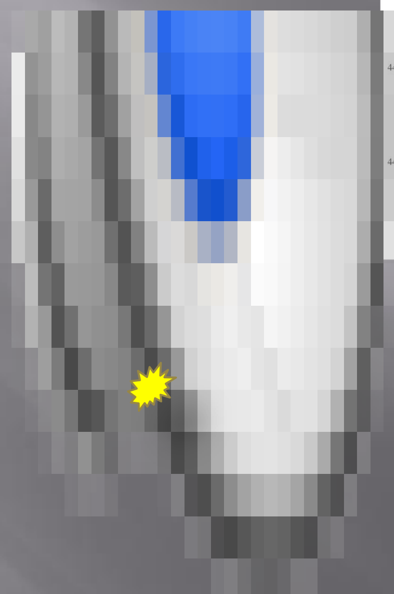


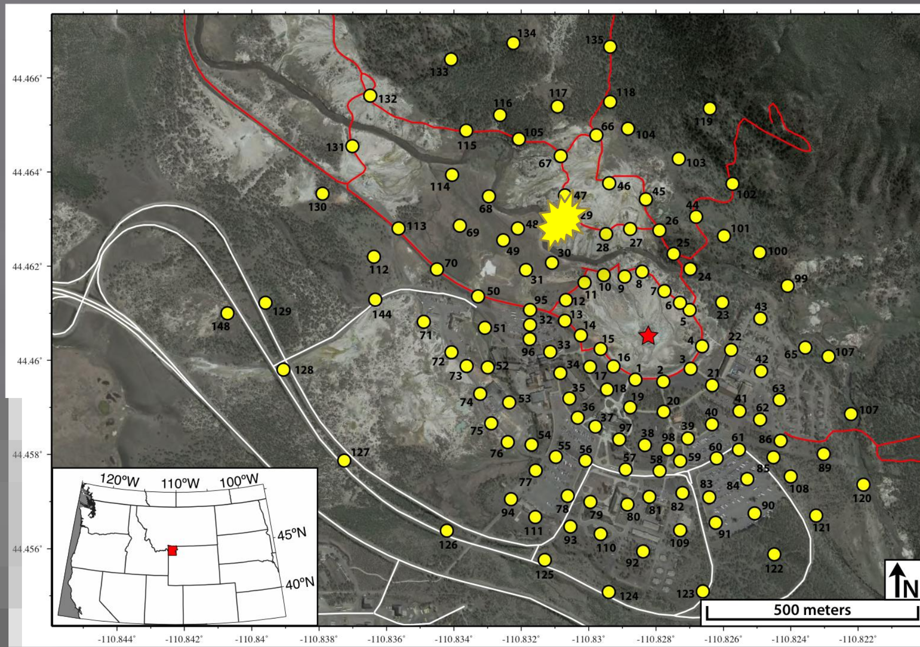


1-5 Hz

Cross-correlation wavefield

0.5 - 3 Hz





Conclusions

- The availability of low cost autonomous geophones has promoted the development of passive shallow imaging with dense geophone arrays.
- The noise source distribution can be highly heterogeneous at short periods and can affect the retrieval of the Green's function based on the noise cross-correlation method.
- 2D array analysis method can be used to mitigate the source effect and study both surface wave velocity and amplification structures.
- Seismic imaging in Yellowstone has now revealed new information on shallow structure associated with the Old Faithful hydrothermal system.


Questions?