Ambient Noise Correlation Amplitudes and Local Site Response

Shallow crustal features in Long Beach, CA

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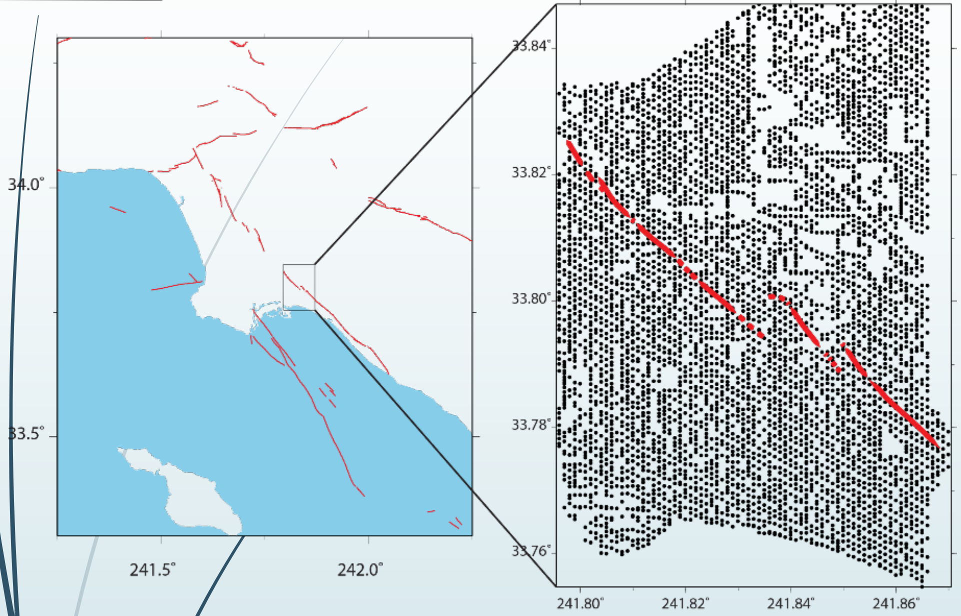
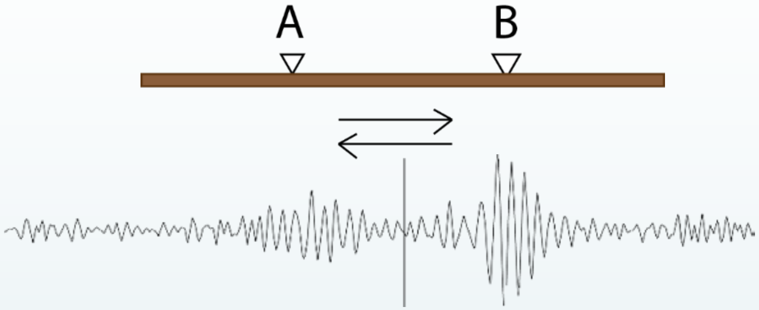
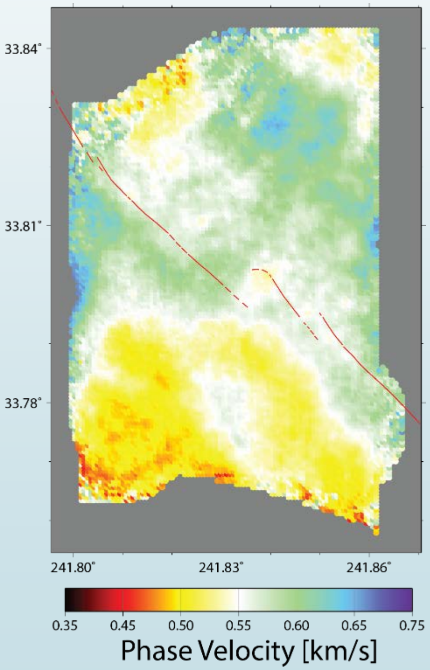
Long Beach Ambient Noise



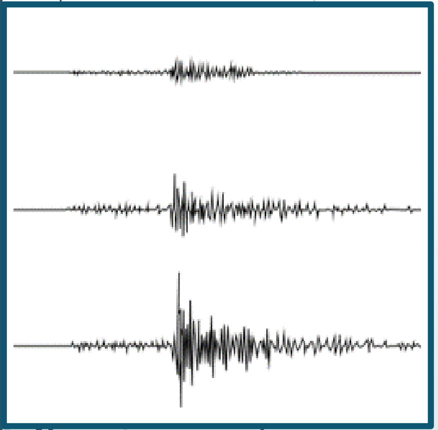


Phase velocity
at 1.67 Hz:
Lin et al 2013



- >5,000 stations
- Average 100m spacing
- Deployed by NodalSeismic

Three other crustal properties



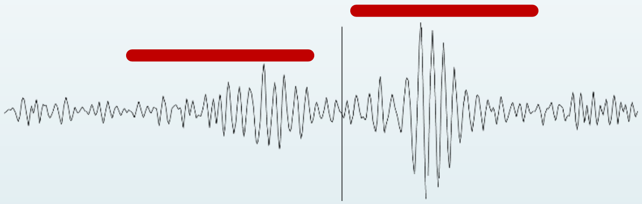
- **Site Amplification** (Site Response)

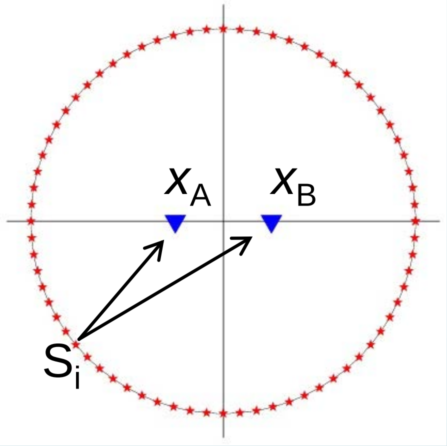
$$\boldsymbol{\beta}(\boldsymbol{x},\boldsymbol{y}) = \frac{A(x,y)}{A_0} = \frac{\text{Observed Amplitude}}{\text{Reference Amplitude}}$$

  - Important for engineers at > 1 Hz
- **(Intrinsic) Attenuation**
  - Inelastic loss of energy
- **Scattering or Sources**
  - Heterogeneities which redistribute energy

Ambient Noise Cross Correlations

- Amplitudes vary with source distribution



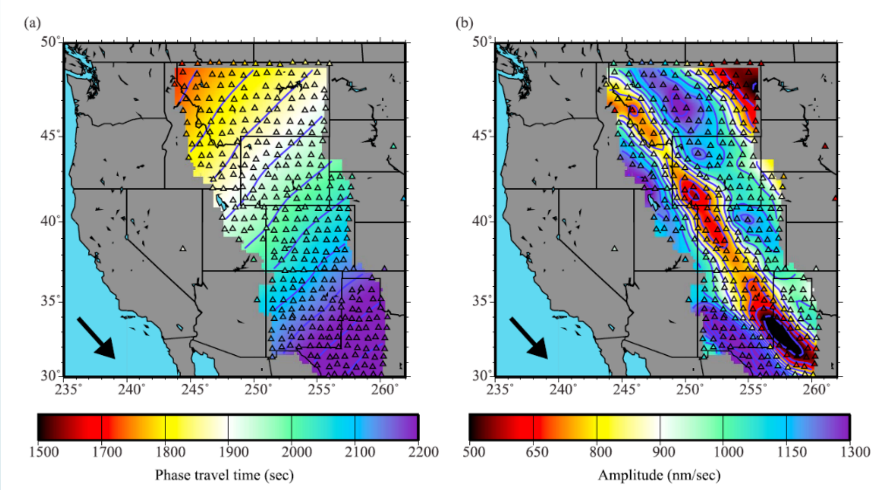


- What do we do?
  - Ignore the problem
  - Correct for known sources
  - Use some other method

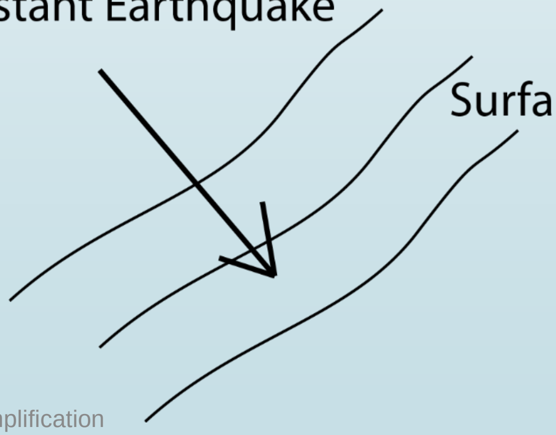
This study

Approach: Track wavefronts

Measure travel time τ, and amplitude, A



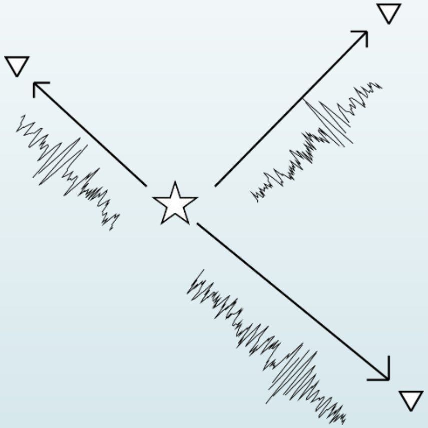
From Lin et al, 2012



Distant Earthquake

Surface wave-fronts

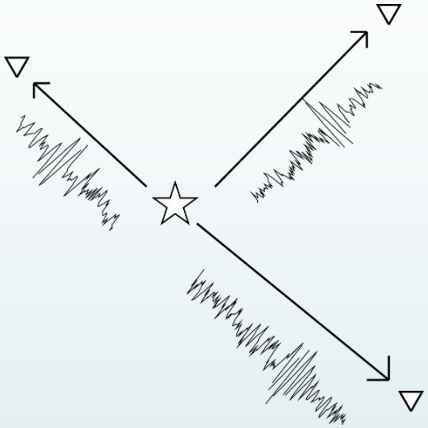
Track wavefronts of ambient noise



- Be careful with signal processing!

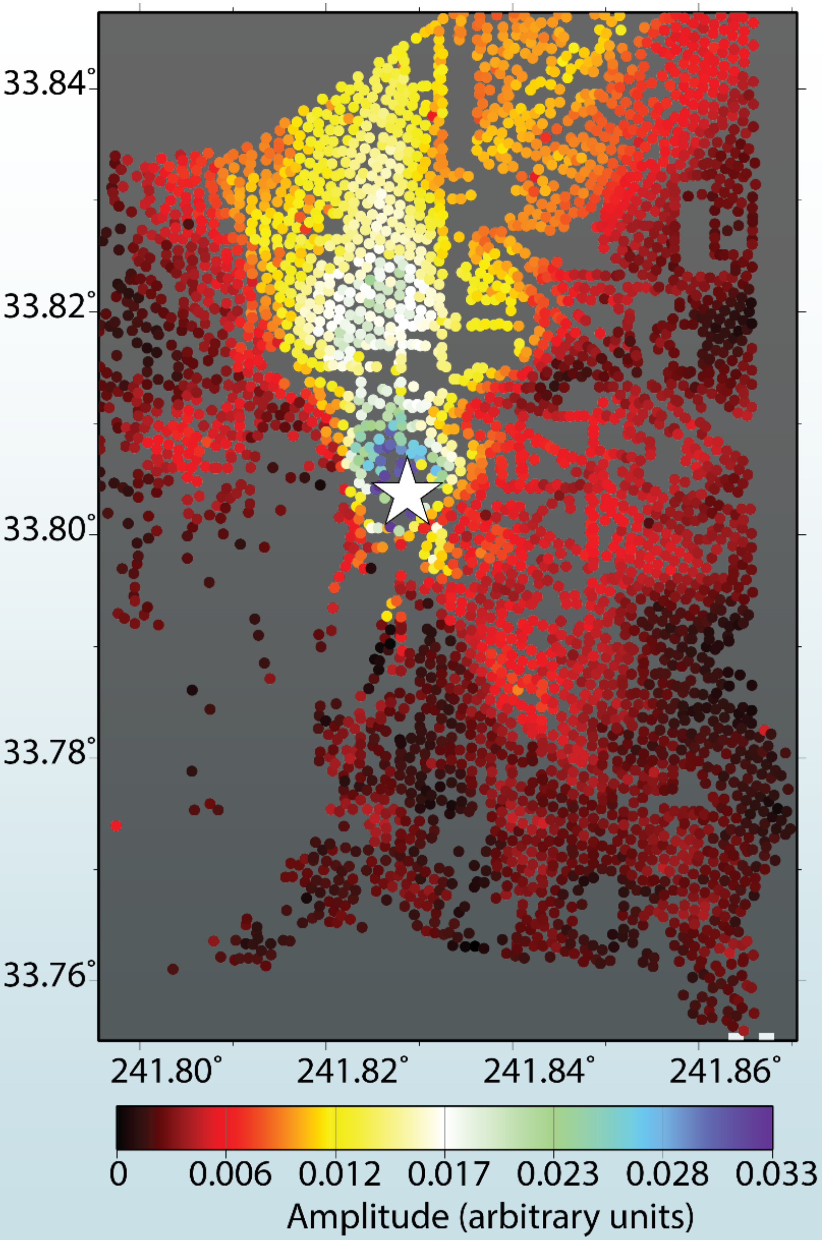
(Treat all stations equal)

Outgoing
Cross Correlations

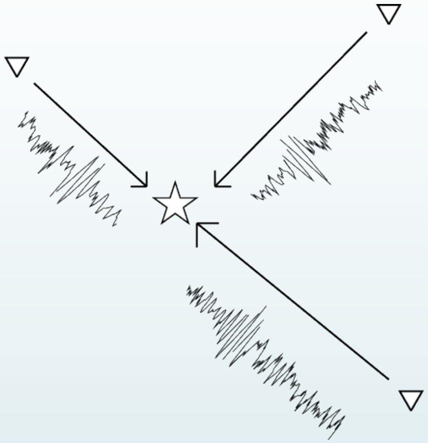


Incoming
Negative Lag

Outgoing
Positive Lag



Incoming
Cross Correlations



Incoming
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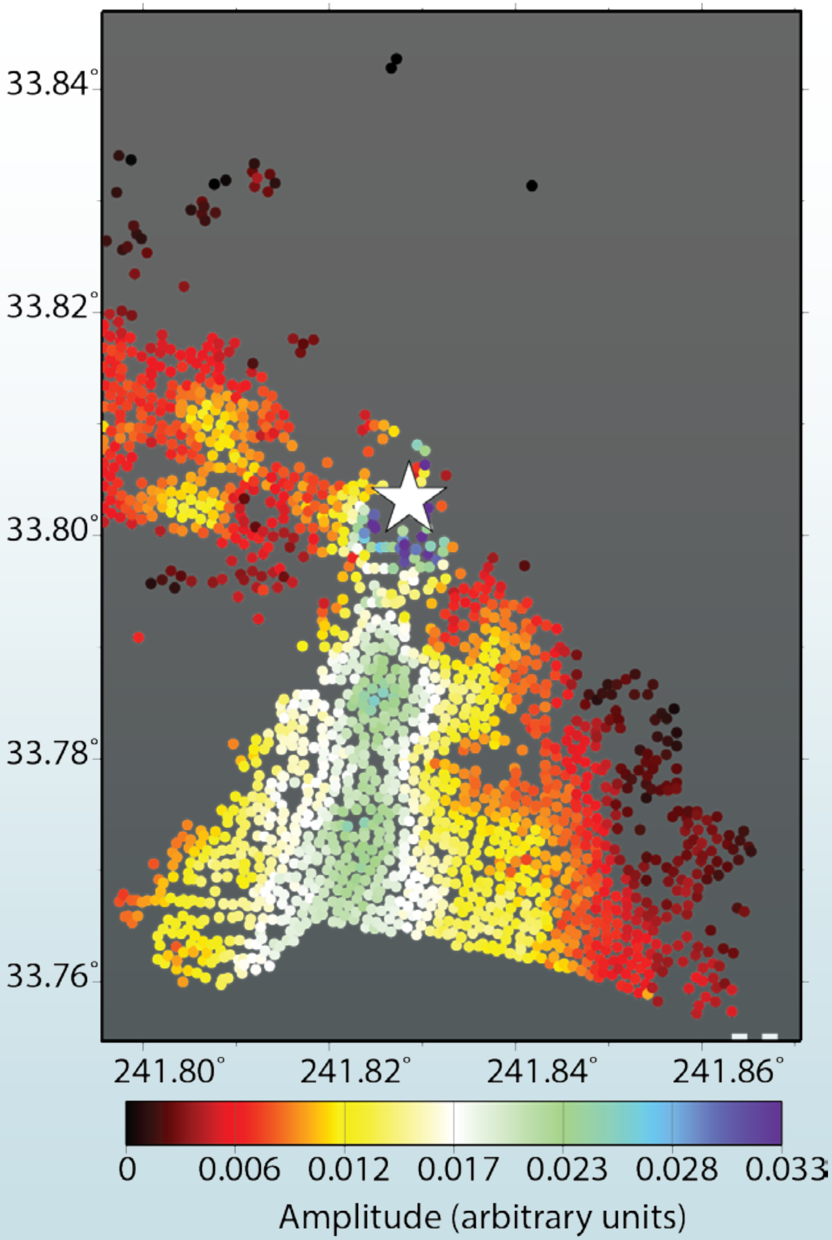


Helmholtz Wave Equation

$$S + \frac{2\nabla\beta\cdot\nabla\tau}{\beta} - \frac{2\alpha}{c} = \frac{2\nabla A\cdot\nabla\tau}{A} + \nabla^{2}\tau$$

Source + Amplification - Intrinsic Attenuation = Observed Amp Decay + Focusing, Defocusing

Desired ⋮ Directly measurable

β Site amplification factor
α Intrinsic attenuation factor

A Observed Amplitude
τ Observed Travel Time
c Phase Velocity

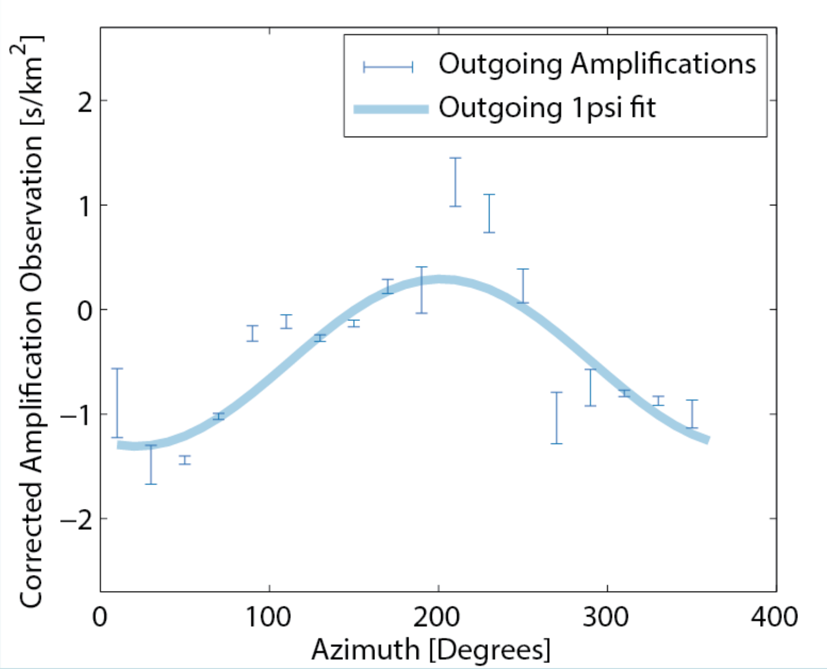
Left Hand Side:

Mean of the Sine Curve

$$S + \frac{2\nabla\beta\cdot\nabla\tau}{\beta} - \frac{2\alpha}{c}$$

Azimuthal Dependence!

Observe and Fit 360 Sine

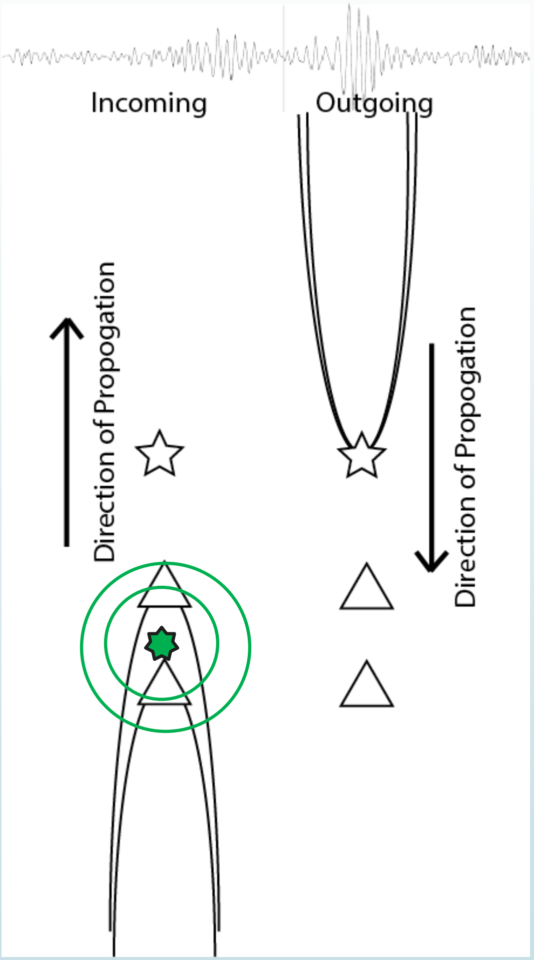


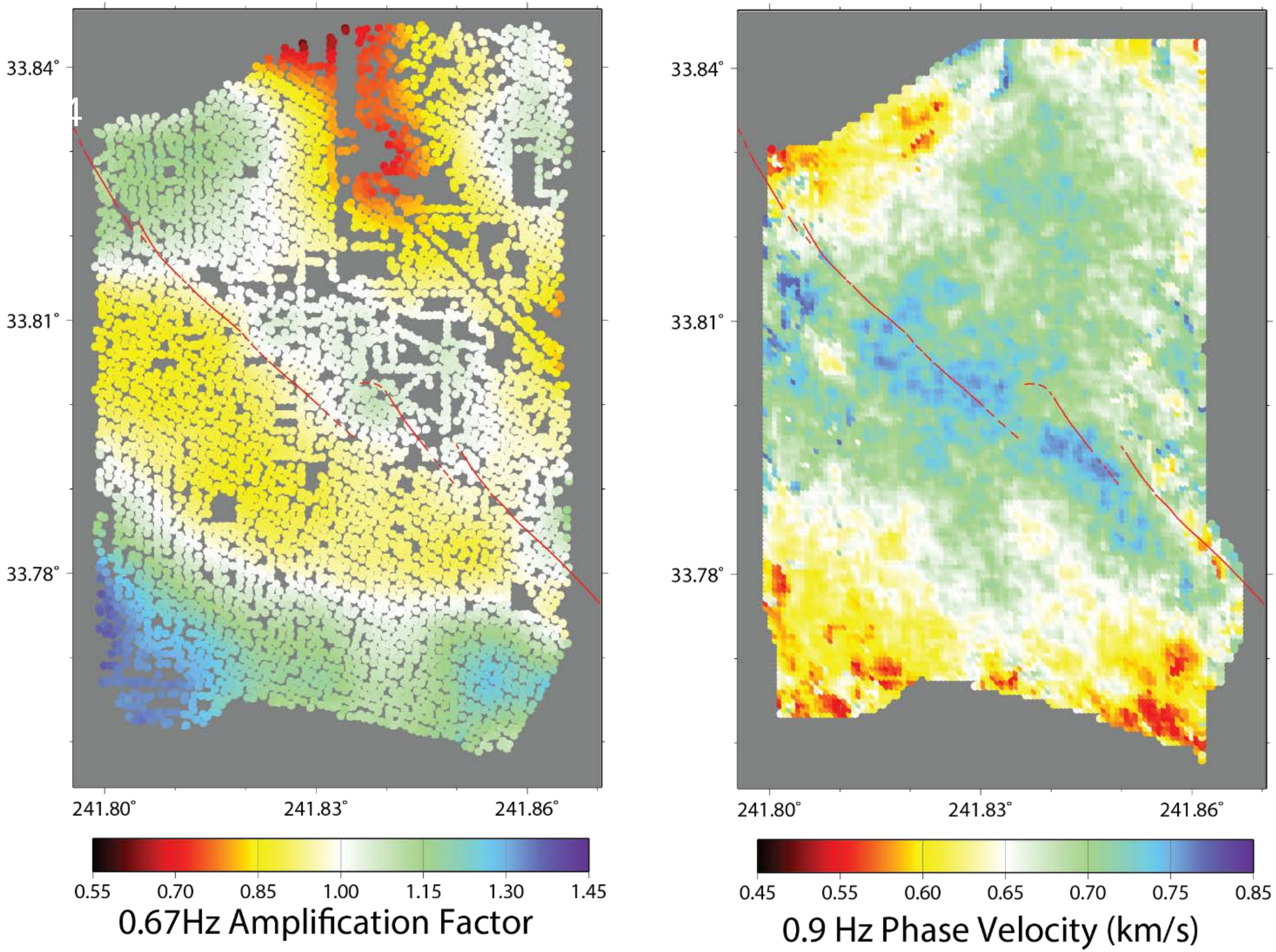
Attenuation and Scattering

Mean of the Sine Curve

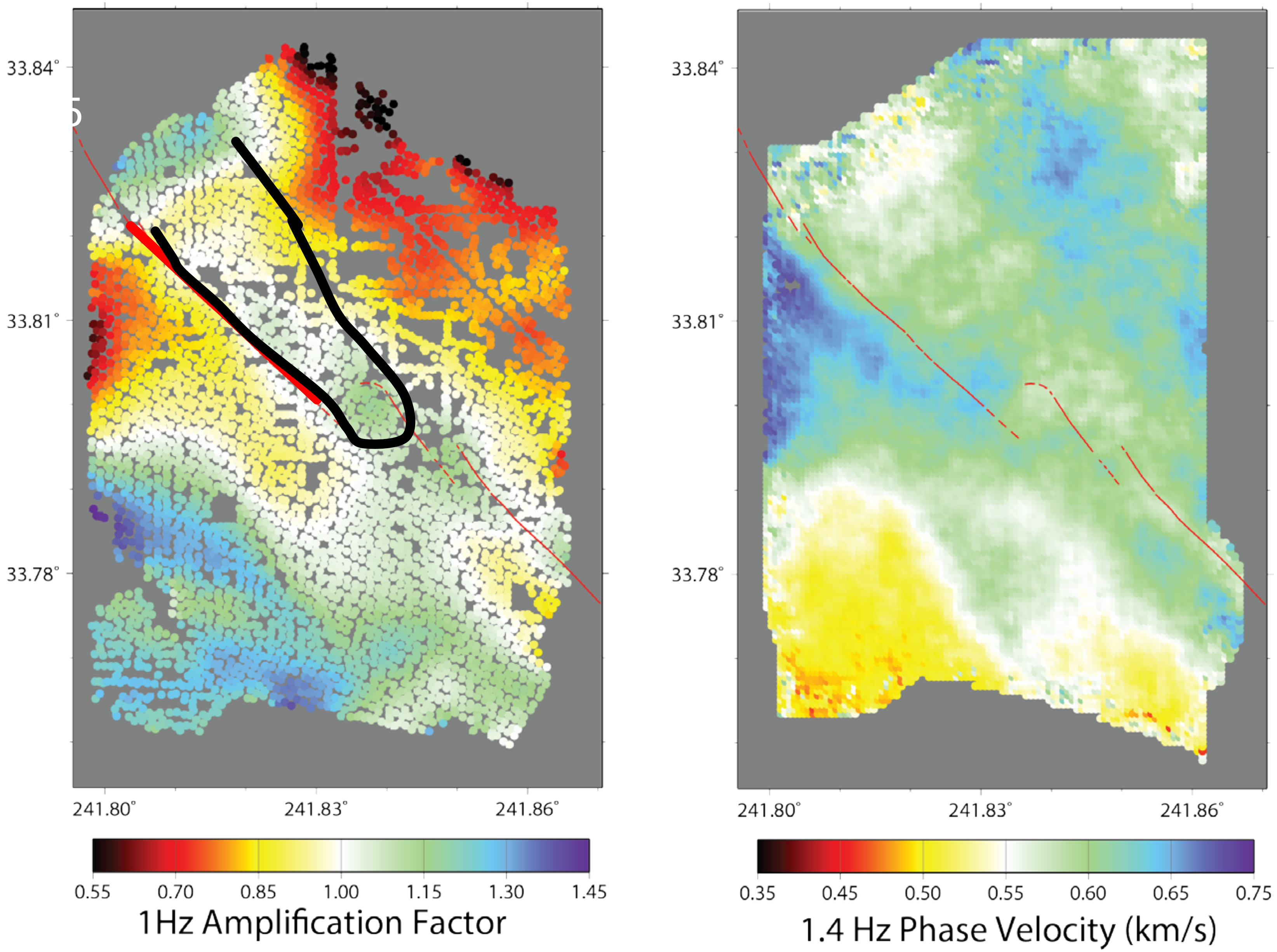
$$S+\frac{2\nabla\beta\cdot\nabla\tau}{\beta}-\frac{2\alpha}{c}$$

Incoming Waves Only!!





Lin et al 2013



Lin et al 2013

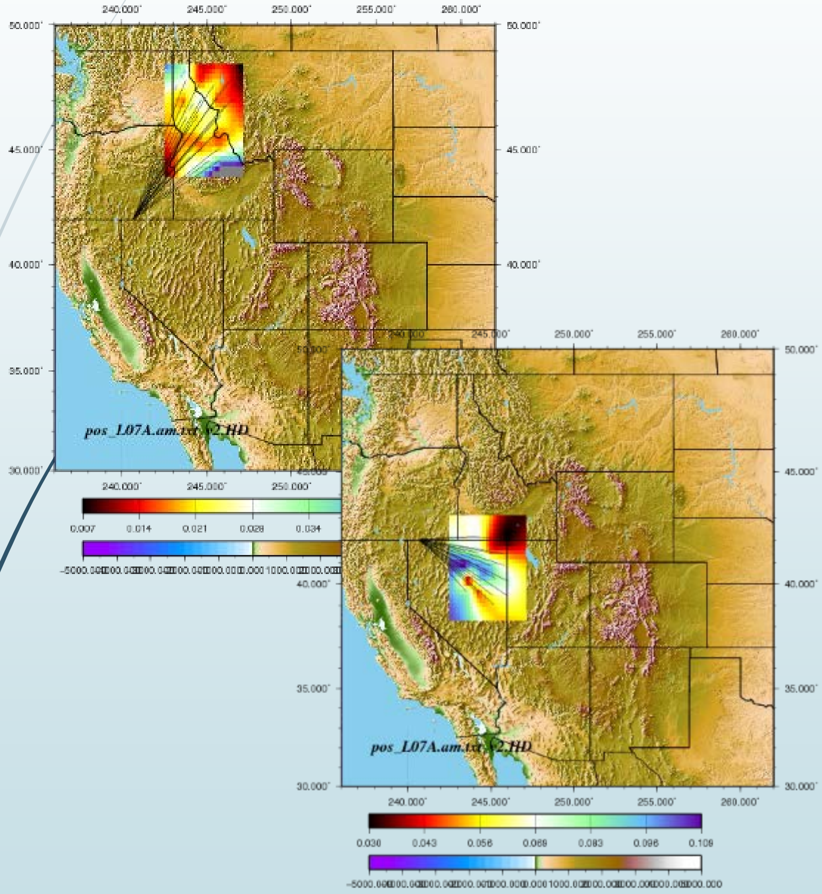
Conclusions

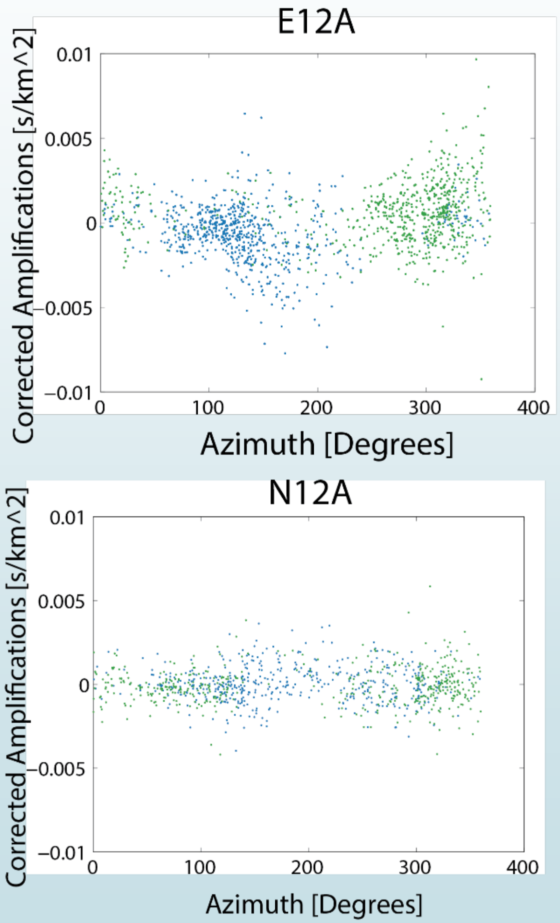
- In theory: Able to resolve all 3 properties:

Site Amplification, Attenuation, Sources/Scatt.

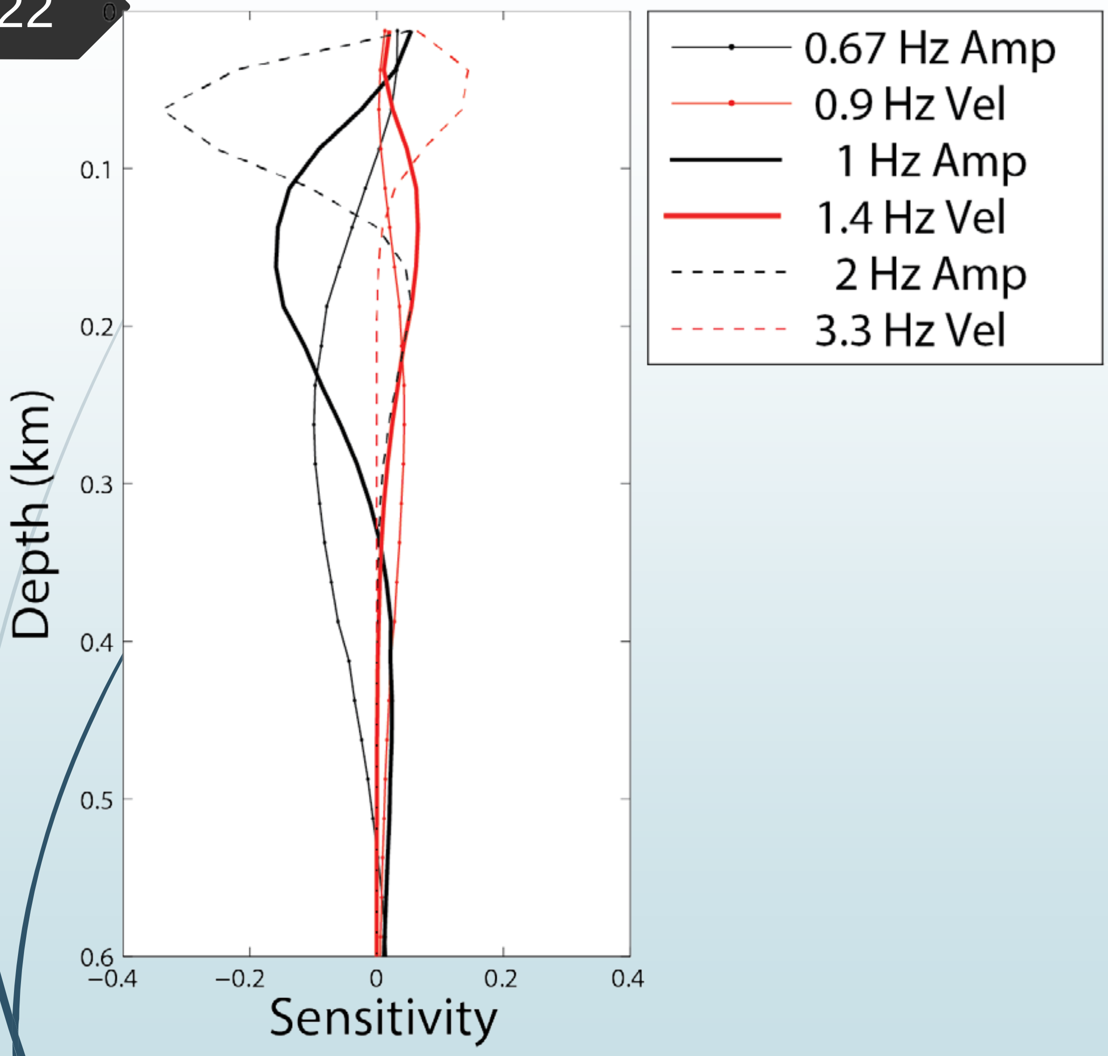
- Observations capture:
  - Velocity changes
  - Other effects we're interested in:
    - 3D geometry, resonances, topography, etc…

Future Work
UsArray --- compare to EQs



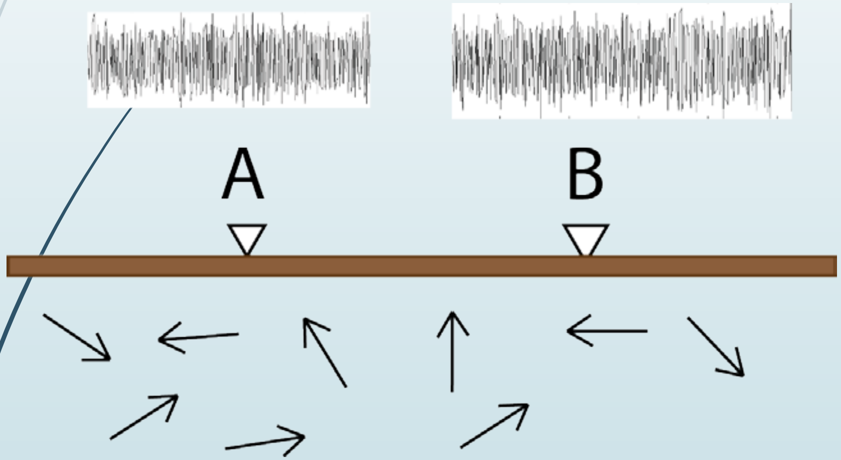


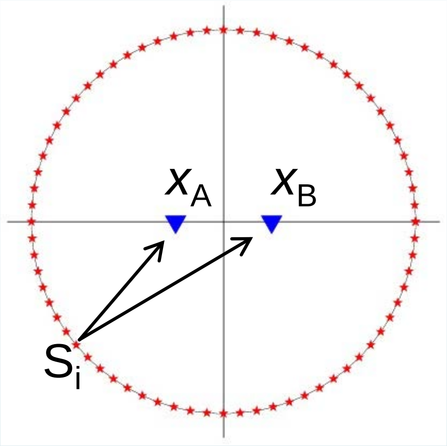
Sensitivity Kernels



Ambient Noise Cross Correlations

Random noise, recorded at two seismometers



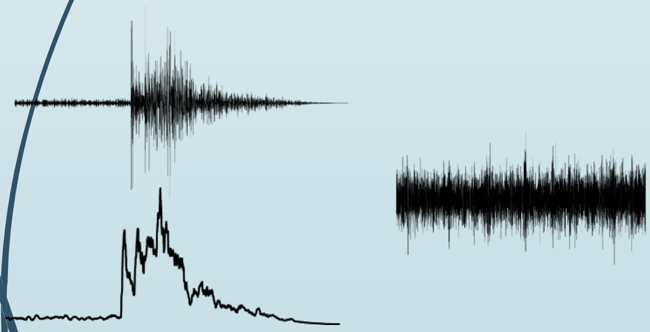


Ideally, homogeneous distribution of sources in time, space, and frequency…

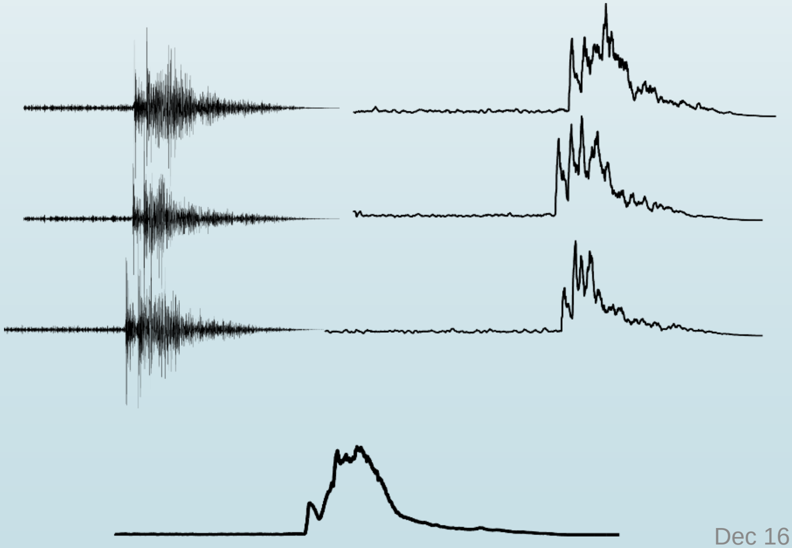
Data Processing

- Time Domain Normalization
- Spectral Whitening
- Pre-stack weighting

"Traditional" Running Mean
(as in *Bensen et al, 2007)*:

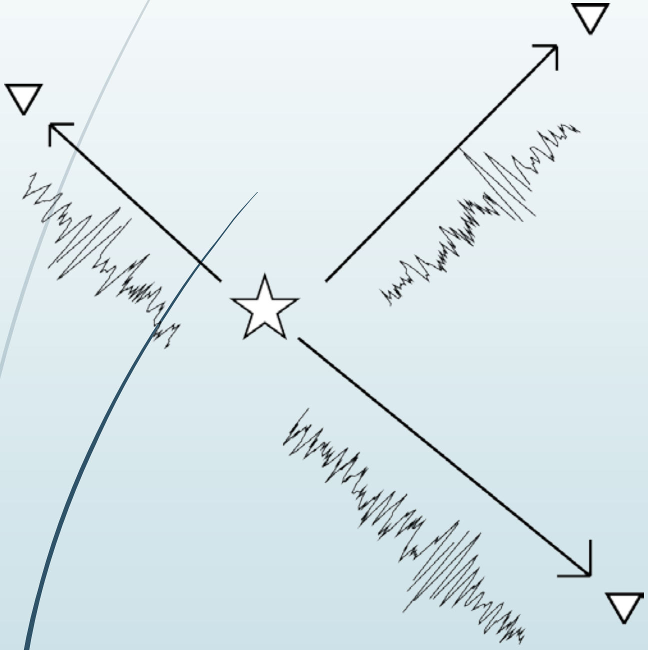


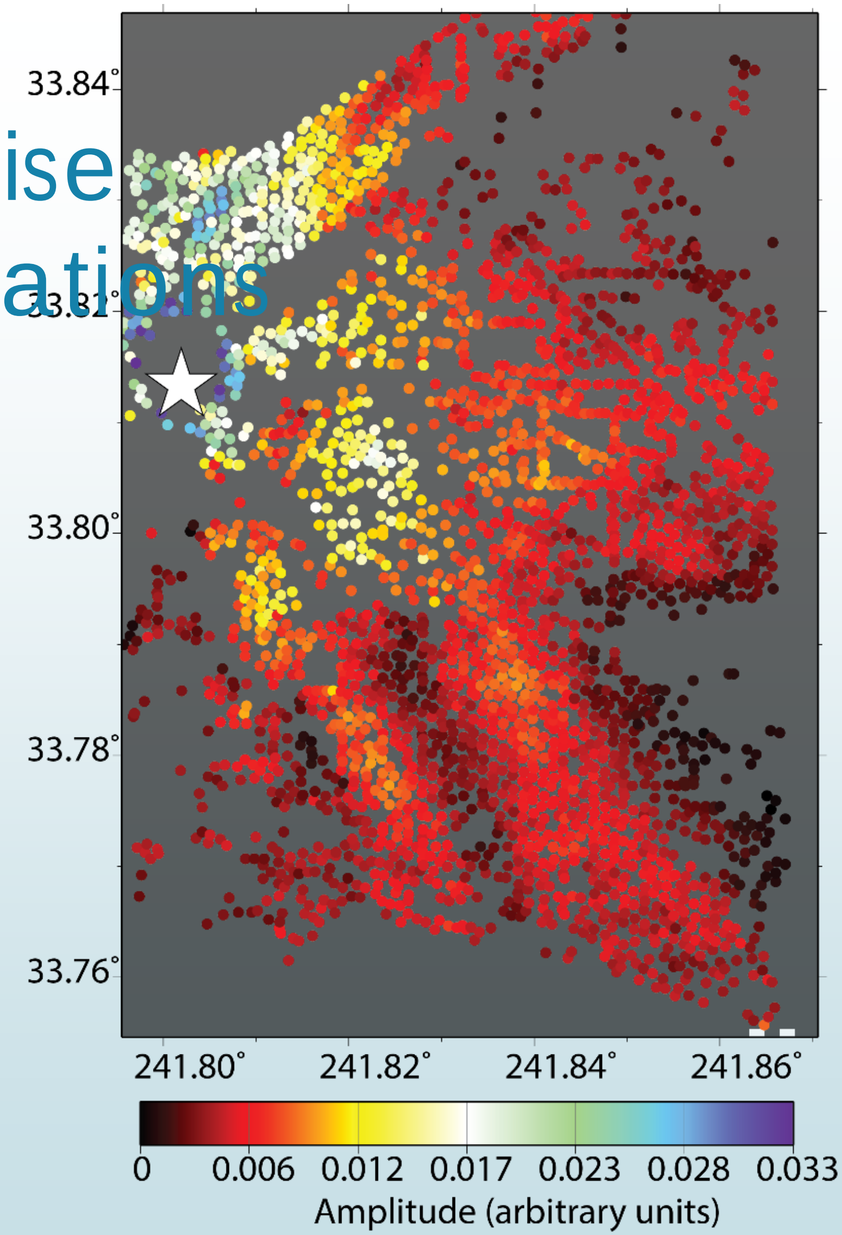
Find a Constant Envelope:



Ambient Noise Cross Correlations

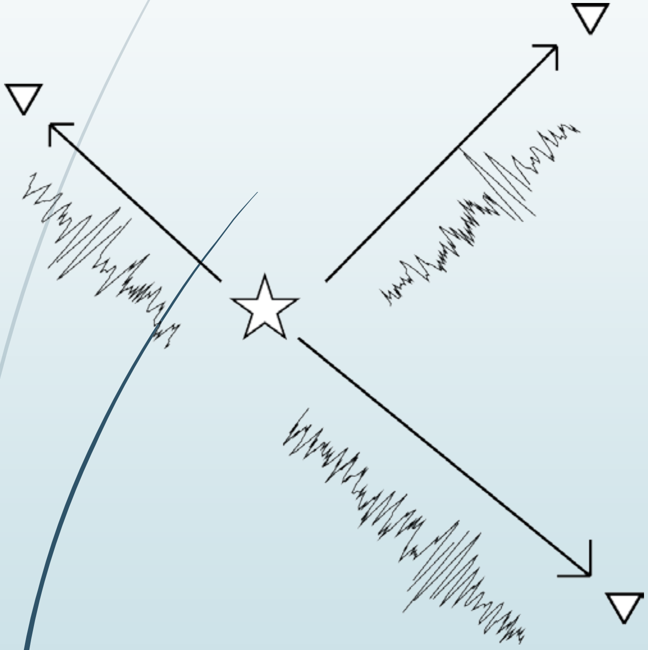
Constructing Wave-field maps

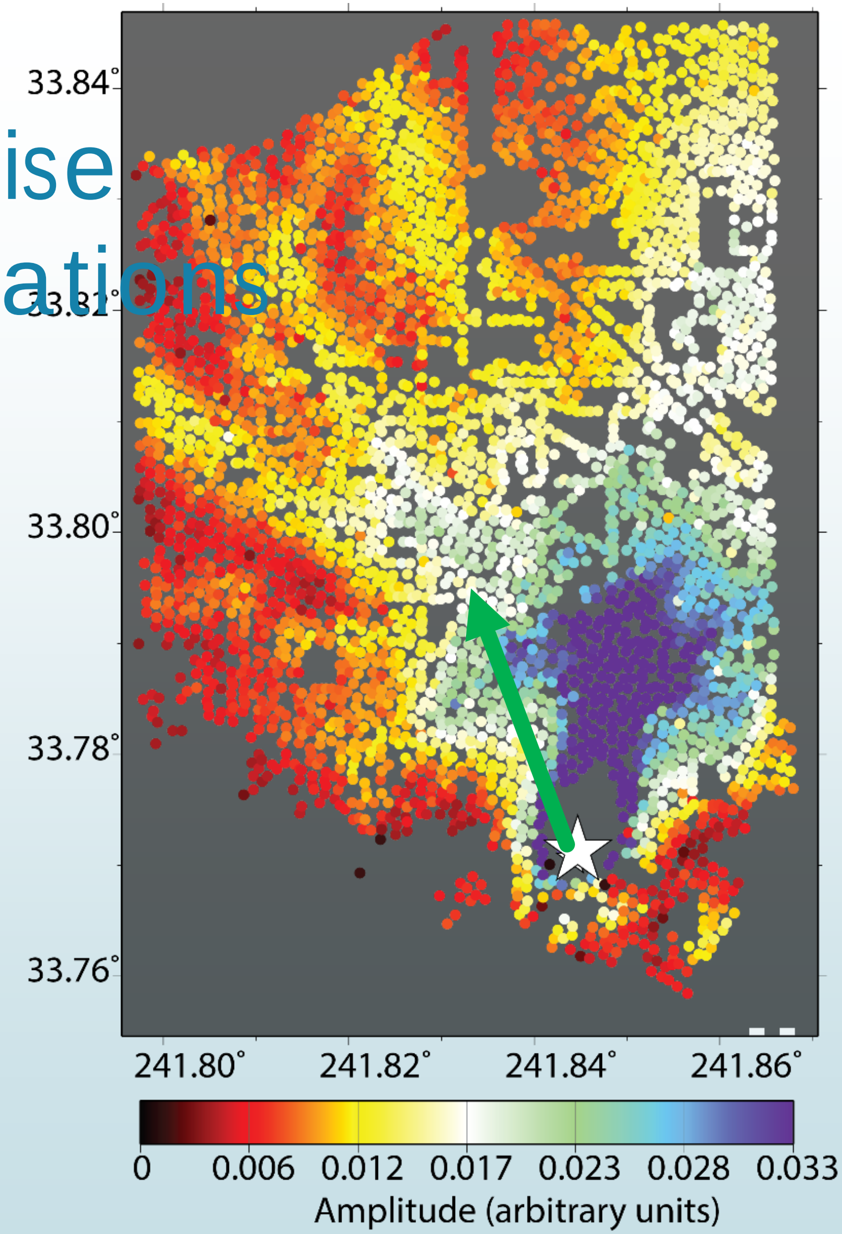




Ambient Noise Cross Correlations

Constructing Wave-field maps





Spatial Analysis of *Lin et al. 2012*

$$\frac{1}{c(r)^2}\frac{\partial^2\chi_{2D}(r,t)}{\partial t^2} = -\frac{2\alpha(r)}{c(r)}\frac{\partial\chi_{2D}(r,t)}{\partial t} + \nabla^2\chi_{2D}(r,t)$$

Wave Eq.

$$\chi_{2D}(r,t) = \frac{A(r)}{\beta(r)} e^{i\omega[t-\tau(r)]}$$

2D description of 3D wave

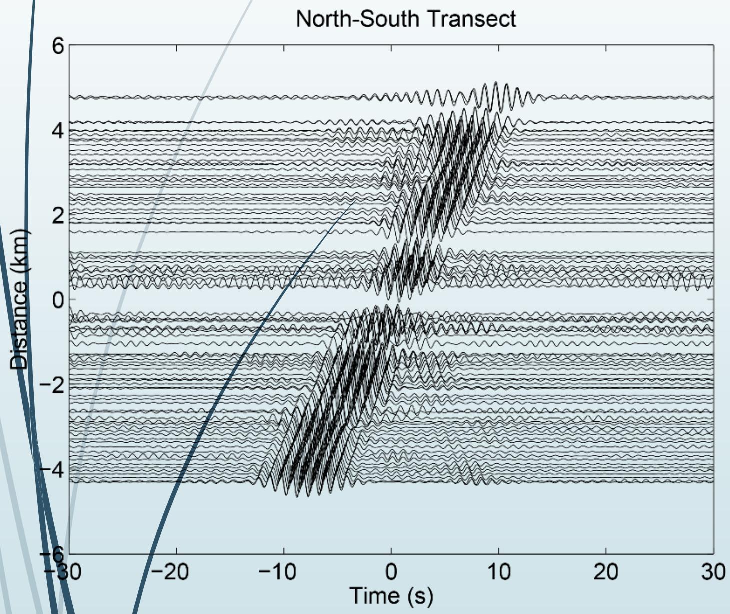
$$\frac{1}{c^2} = \nabla\tau\cdot\nabla\tau - \frac{\nabla^2(A/\beta)}{\omega^2(A/\beta)}$$

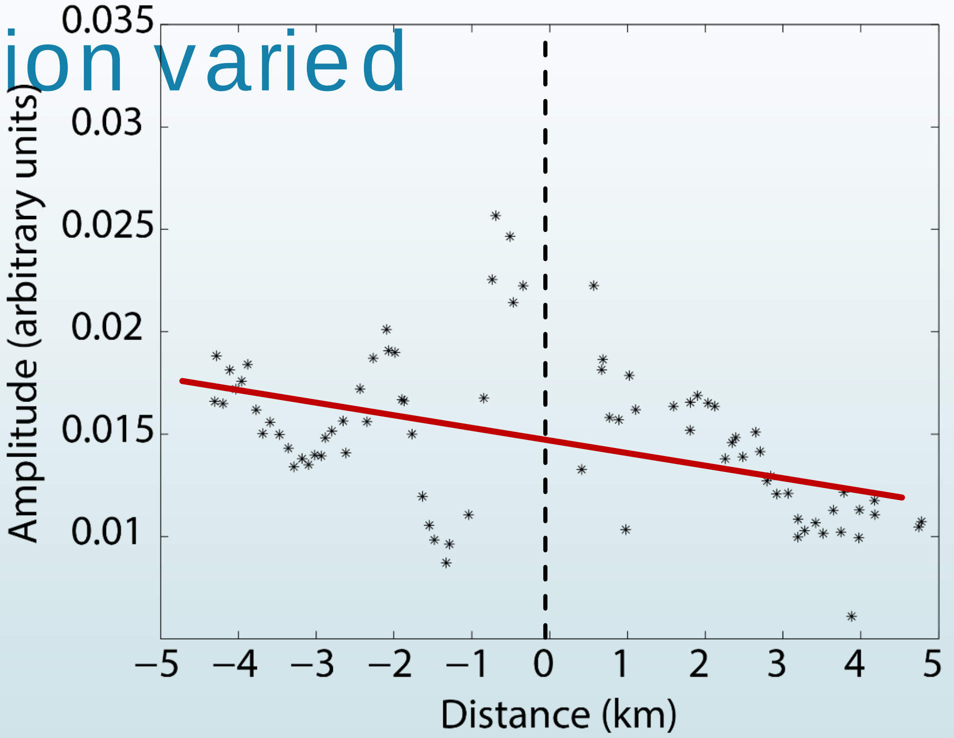
Real part (Eikonal)

$$\frac{2\nabla\beta\cdot\nabla\tau}{\beta} - \frac{2\alpha}{c} = \frac{2\nabla A\cdot\nabla\tau}{A} + \nabla^2\tau$$

Imaginary (Helmholtz)

Direction advantage: Attenuation constant, Amplification varied





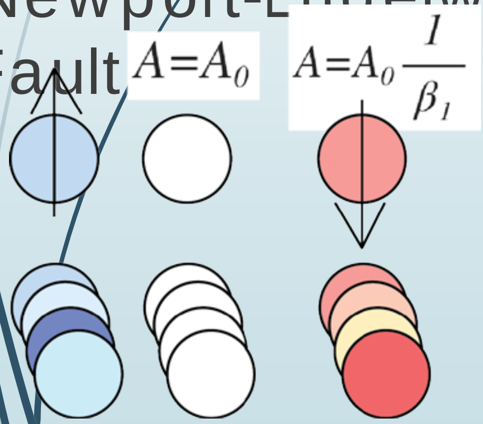
South (negative lag)
Incoming Energy

North (positive lag)
Outgoing Energy

An initial estimate of site amplificatio

Consider amplitudes only:

Striking correlation with Newport-Engelwood Fault


$A=A_0$

$A=A_0\frac{1}{\beta_1}$