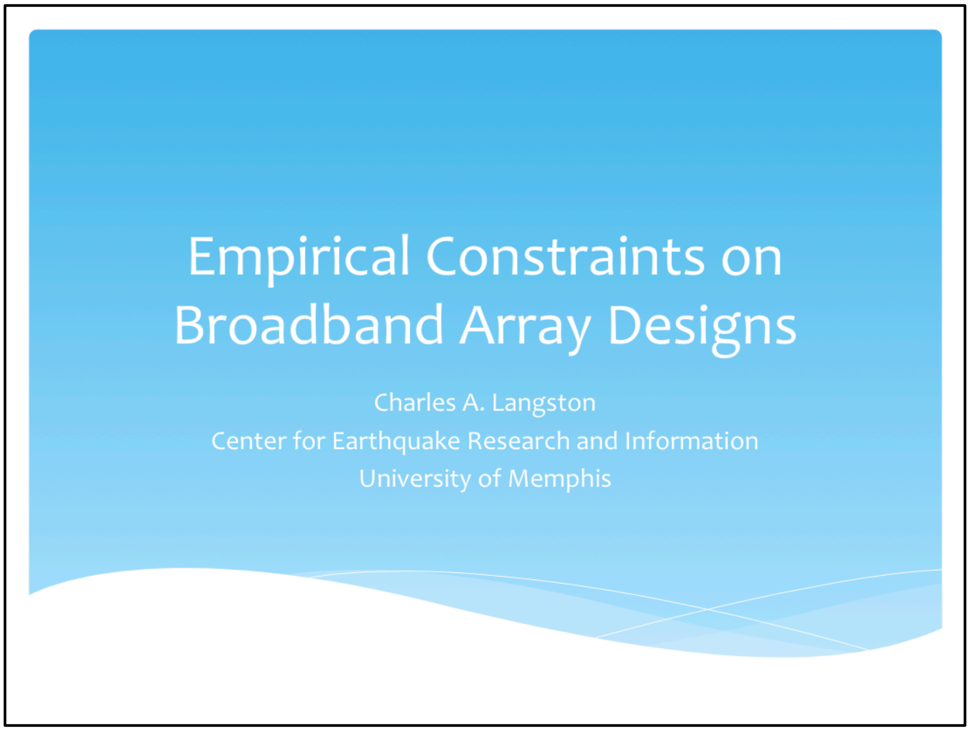
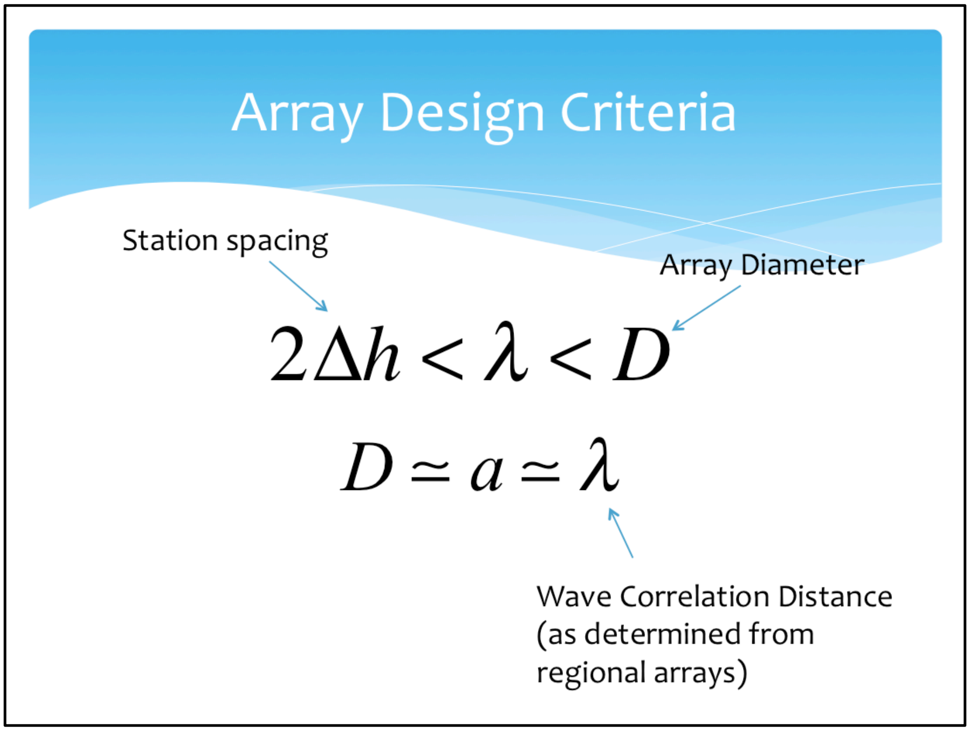


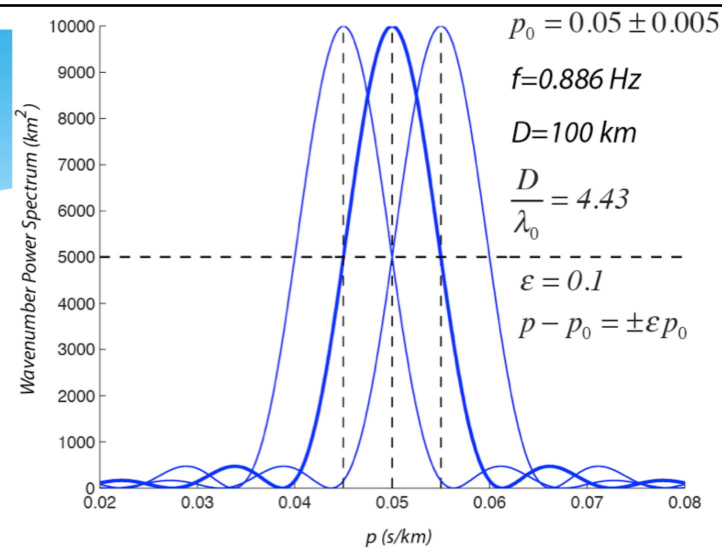
This is a presentation given at the GABBA Workshop held May 15 and 16, 2013, after the EarthScope National meeting in Raleigh, North Carolina.

Outline

- Broadband array designs – IRIS 2012 meeting
- Using TA to answer: How coherent are teleseismic body waves?

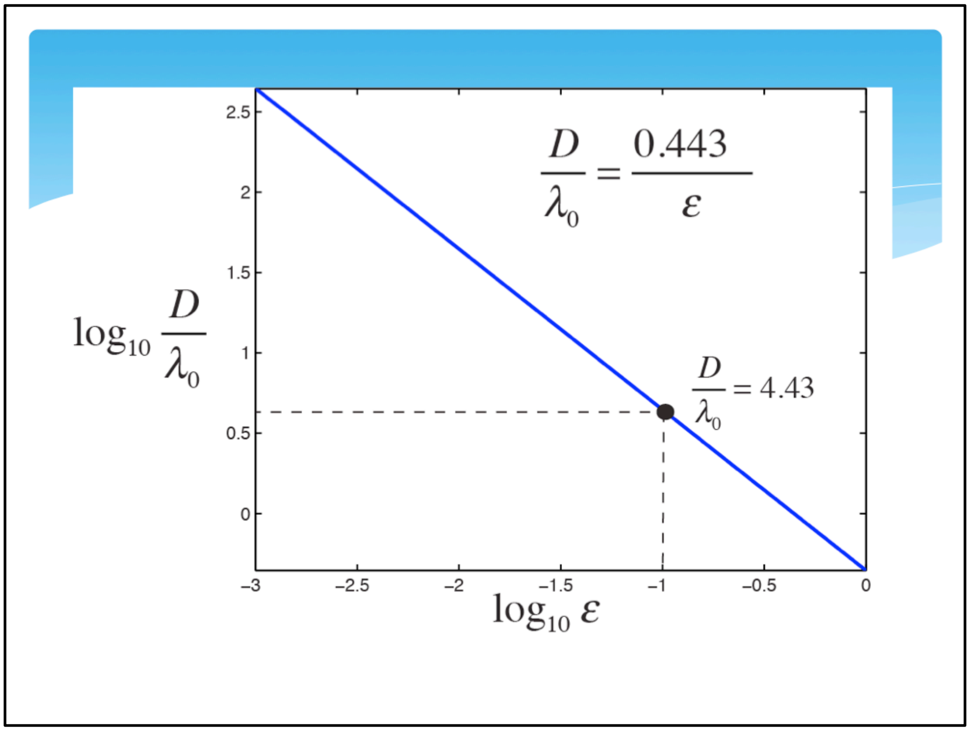


Array designs must sample the spatial wavefield at spatial frequencies less than Nyquist frequency, which is related to average sensor spacing. The array Diameter must be greater than a wavelength of the wave under study. Results from regional arrays show that crustal and upper mantle phases generally decorrelate over a distance, a, which is roughly a single wavelength. Thus, regional array resolution is limited by this degradation in correlation distance since beam forming implicitly assumes that the underlying wave signal is identical over all array elements.

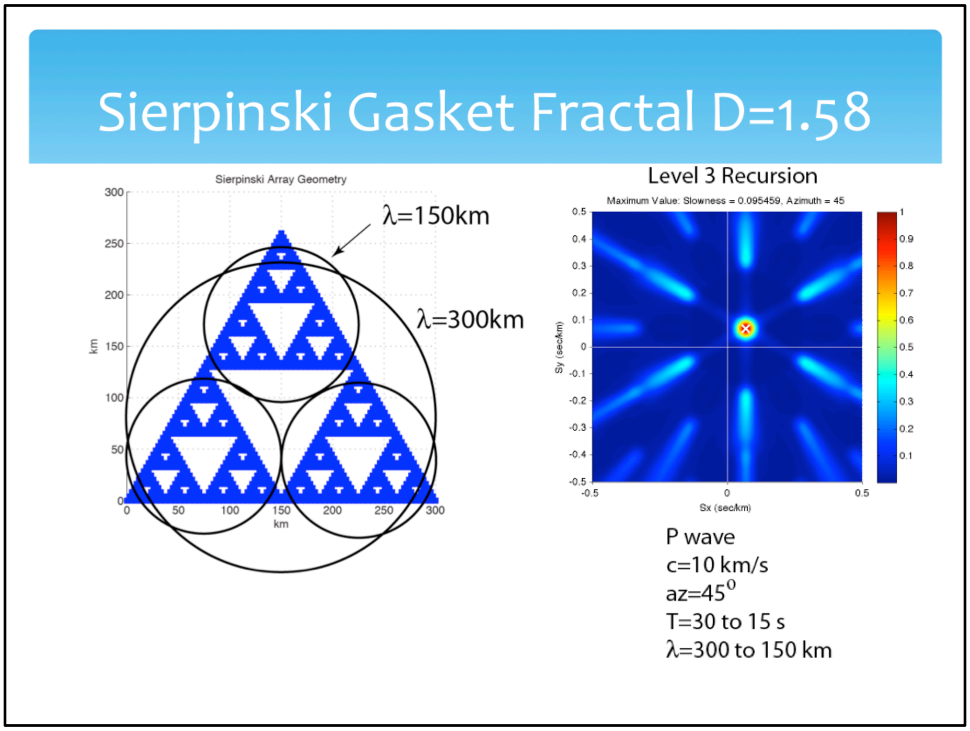


$$\left|\hat{\hat{u}}(k,\omega)\right|^2 = \frac{4\sin^2 \frac{\omega}{2}(p-p_0)D}{\omega^2 (p-p_0)^2}$$

The ability to resolve two signals can be estimated using a 1D line array that is D long. The frequency-wavenumber power spectrum is a sinc function to the second power. If resolution is defined as separation at the half-width of the signal peak, then a minimum array diameter, D, can be estimated for a given difference in the target slowness. Here it is assumed that we want to separate two signals with a 10% slowness difference. The array diameter must be greater than 4.4 times the horizontal wavelength to do so. Thus, it is difficult for regional arrays to perform at this level since signal correlation degrades significantly over a single wavelength.



This is a plot of of the needed array diameter to target wavelength ratio for different desired error thresholds. Smaller separations in slowness require greater array diameters.



If a broadband array is truly broadband, it must be able to resolve wavelengths at many scales. A fractal array is a self-similar arrangement of sensors that samples the wavefield uniformly in space. However, a large fractal array may be extravagant from two points of view. A fractal array may require an unrealistic number of seismometers (here there are 1095 array elements) and the extent of the array will be much larger than needed for shorter wavelengths, if signals decorrelate over a single wavelength.

Is

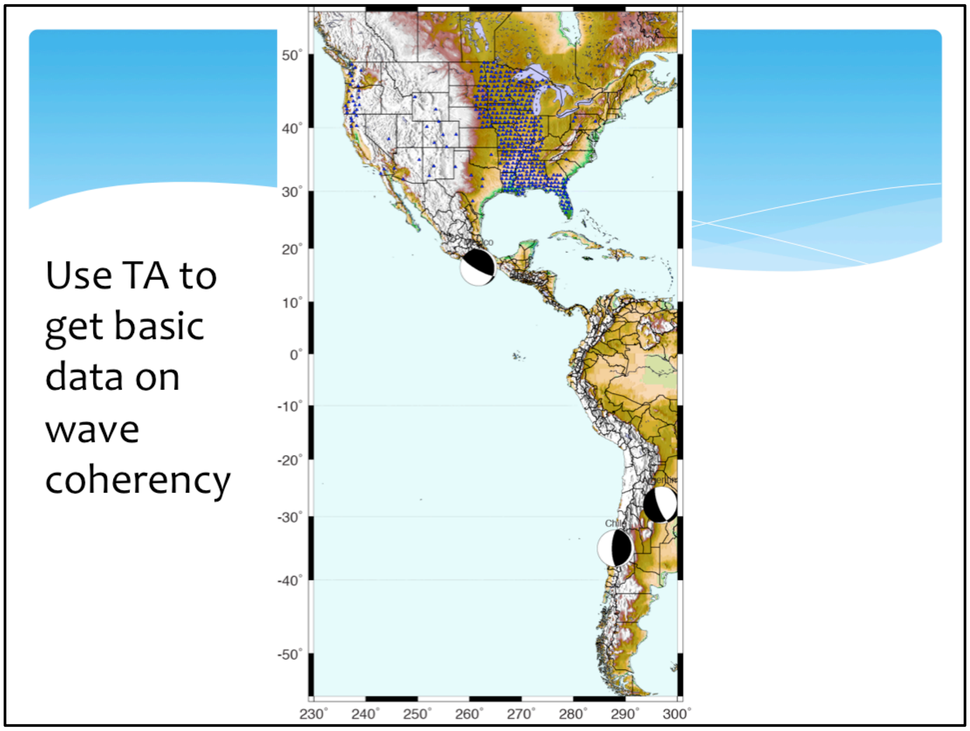
$$a \simeq \lambda$$

For teleseismic body waves?

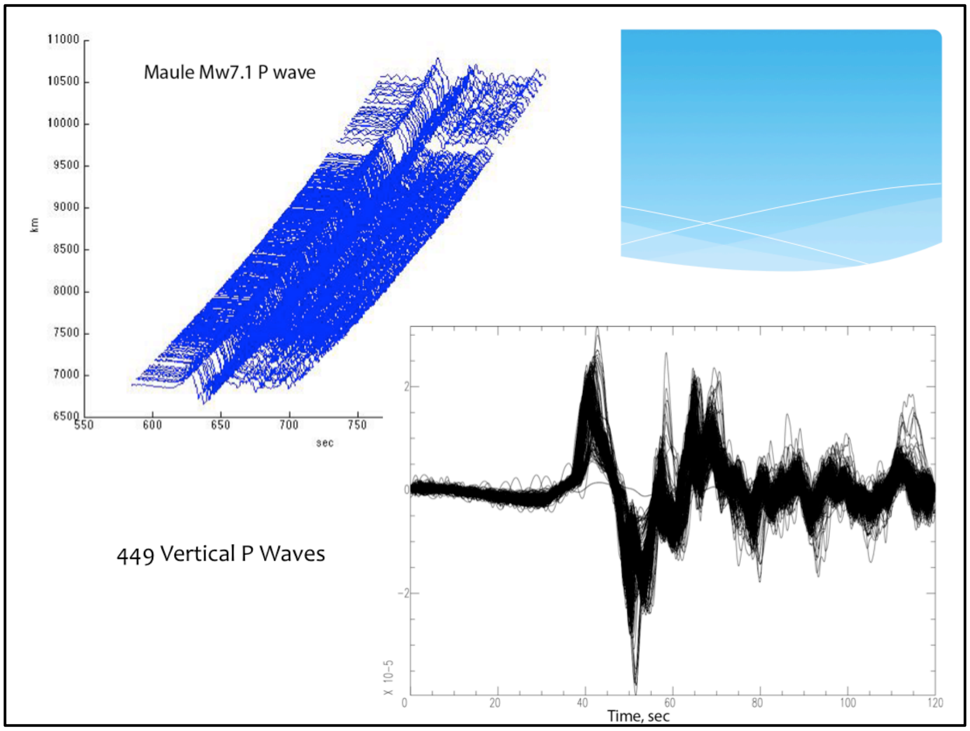
Important for:

- Array Design
- Transfer function analysis

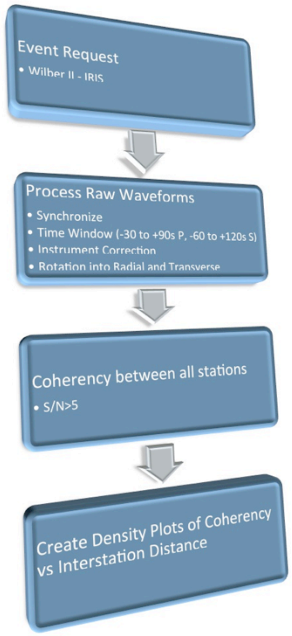
This is a fundamental question for teleseismic body waves. If signals decorrelate over a wavelength, then broadband array designs will be limited in utility. This question is also very important in transfer function analysis (i.e., P wave receiver functions) where an array-average of the vertical components of the teleseismic P wave is used to estimate the effective source function to be used in deconvolution. Is this true? Test the hypothesis using USArray TA data from large earthquakes.



Three earthquakes were chosen – A Maule, Chile, aftershock, A deep Argentina event, and a shallow Oaxaca, Mexico event recorded by the TA. The TA map shows the location of stations in March, 2012.



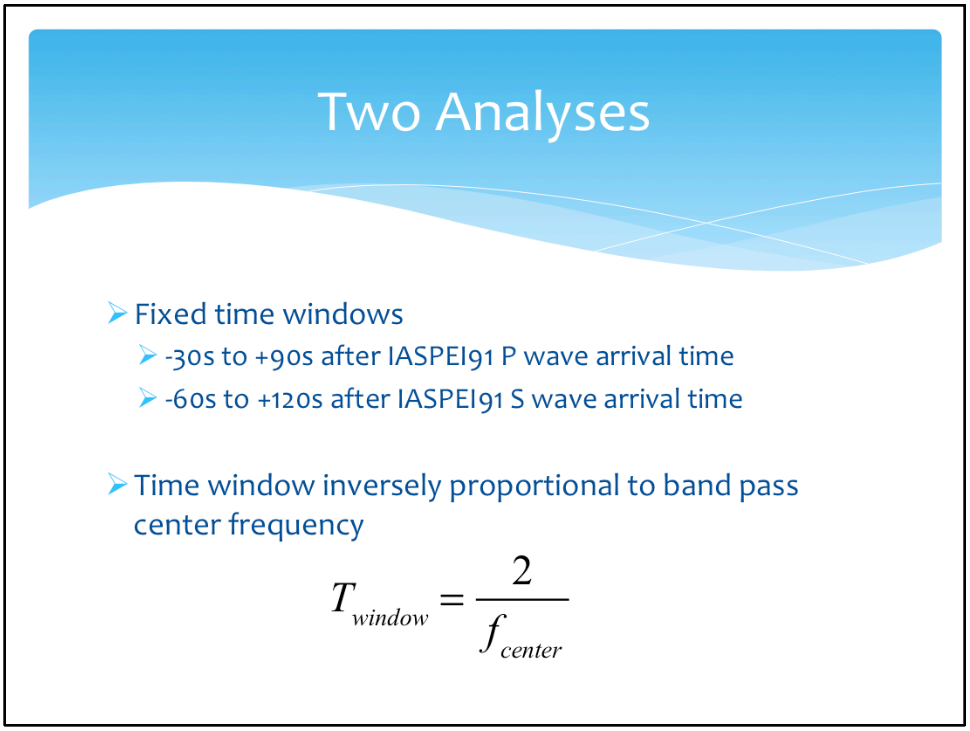
Waveforms from all three events visually correlate among themselves quite closely. Here is a pseudo profile of the Maule P wave (upper left) and with all waveforms plotted on top of each other relative to individual theoretical P wave arrival times.



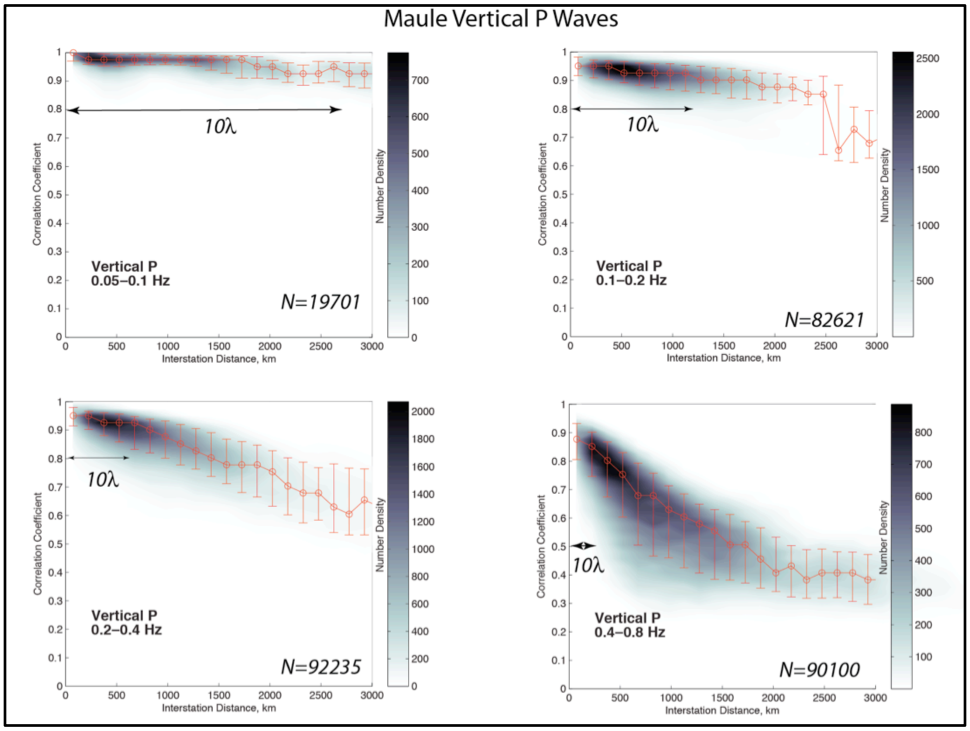
Oacaxa, Mexico	3/20/1012	Mw7.3
Maule, Chile	3/25/2012	Mw7.1
Santiago Del Estero, Argentina	5/28/2012	Mw6.7

$$C_{xy} = \max_{-\infty < \tau < +\infty} \frac{\int_{-\infty}^{+\infty} x(t)\, y(t+\tau)\, dt}{\int_{-\infty}^{+\infty} x^2(t)\, dt \int_{-\infty}^{+\infty} y^2(t)\, dt}$$

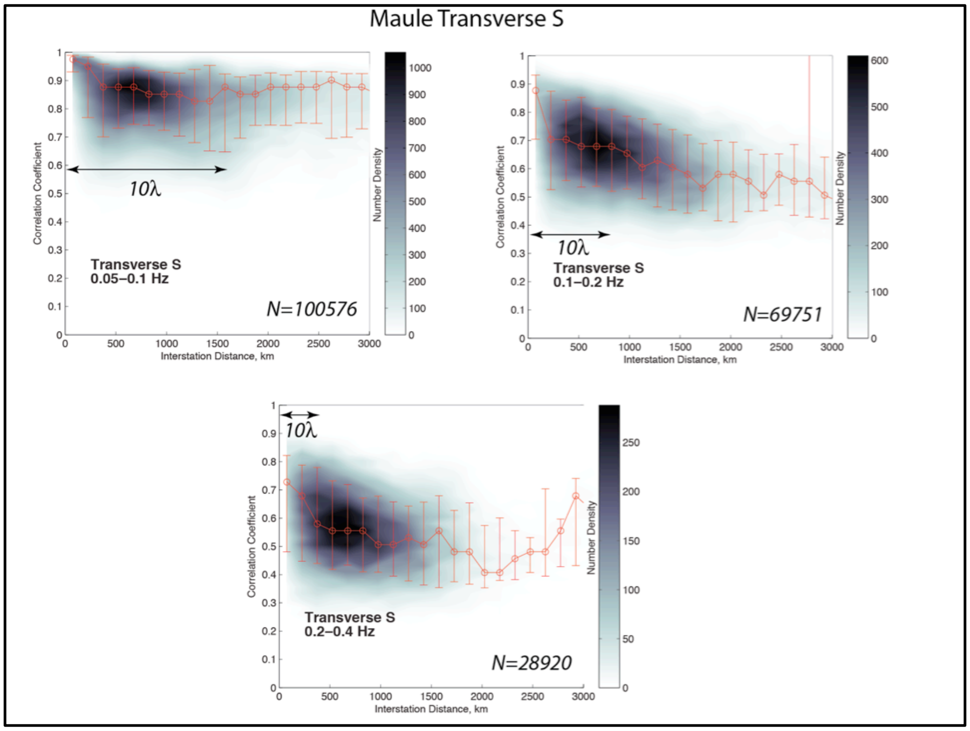
The data were processed in this manner. The maximum of the normalized correlation coefficient gives an estimate of waveform coherency of two waveforms. The coherency estimate is plotted with respect to interstation distance as the proxy for wavelength.



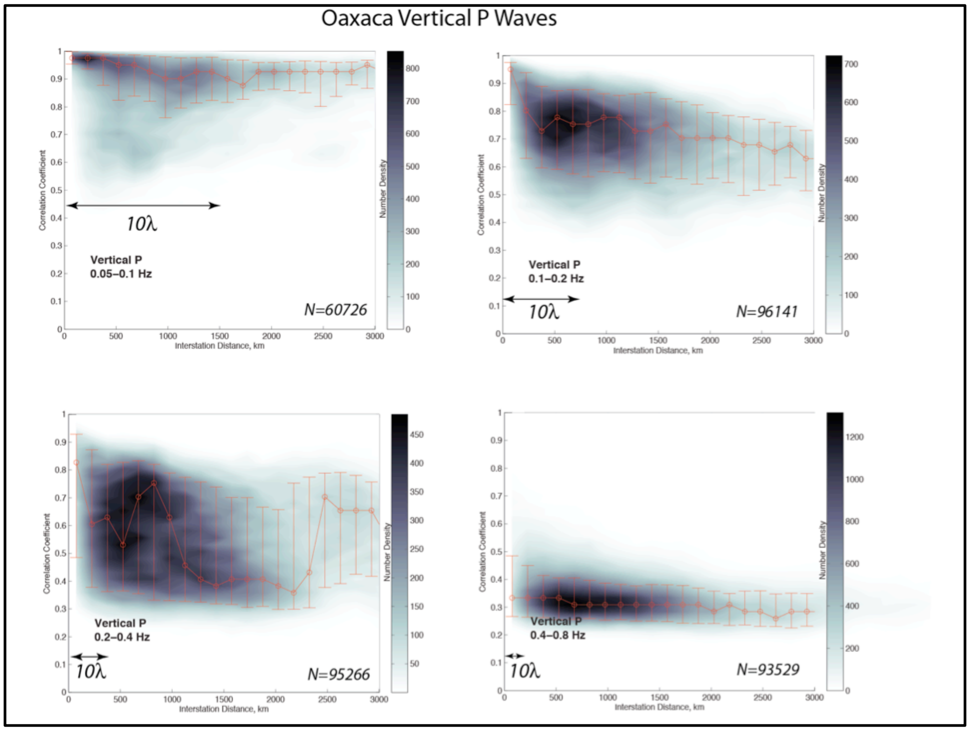
Two different analyses were performed – one with fixed time windows for the data and the other where the time window was twice the inverse center frequency of the bandpass.



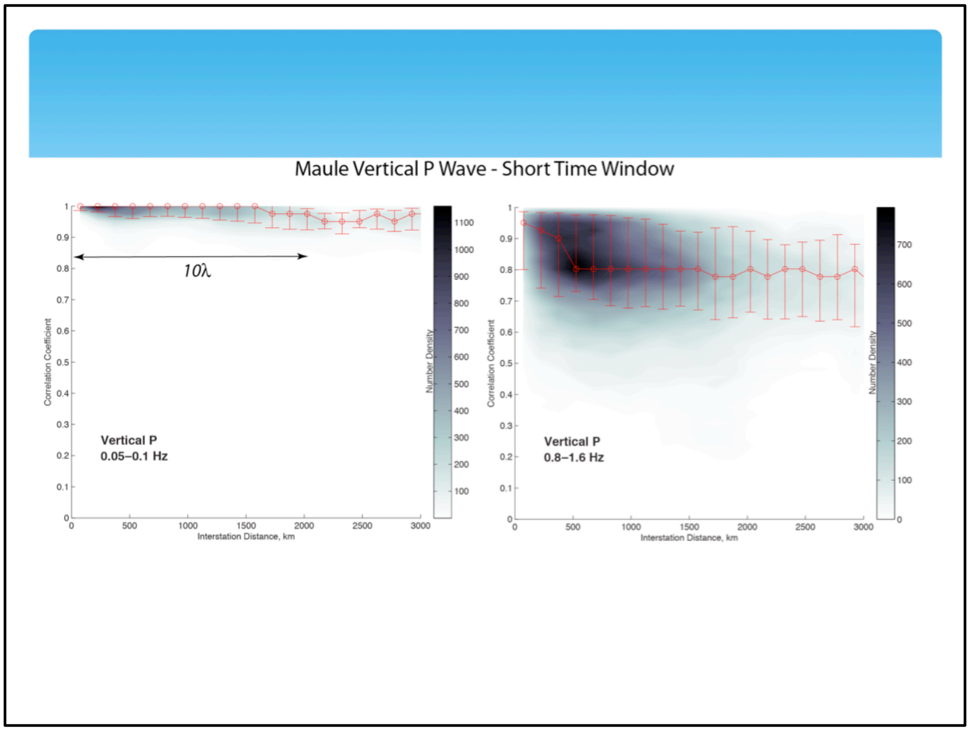
Here are the results for Maule P waves for 4 different bandpasses. The number density of coherency is plotted versus interstation distance. "N" is the number of coherency estimates. Note that P waves are highly correlated to distances greater than 10 wavelengths. The "error bars" show the width of the number density peak at half value.



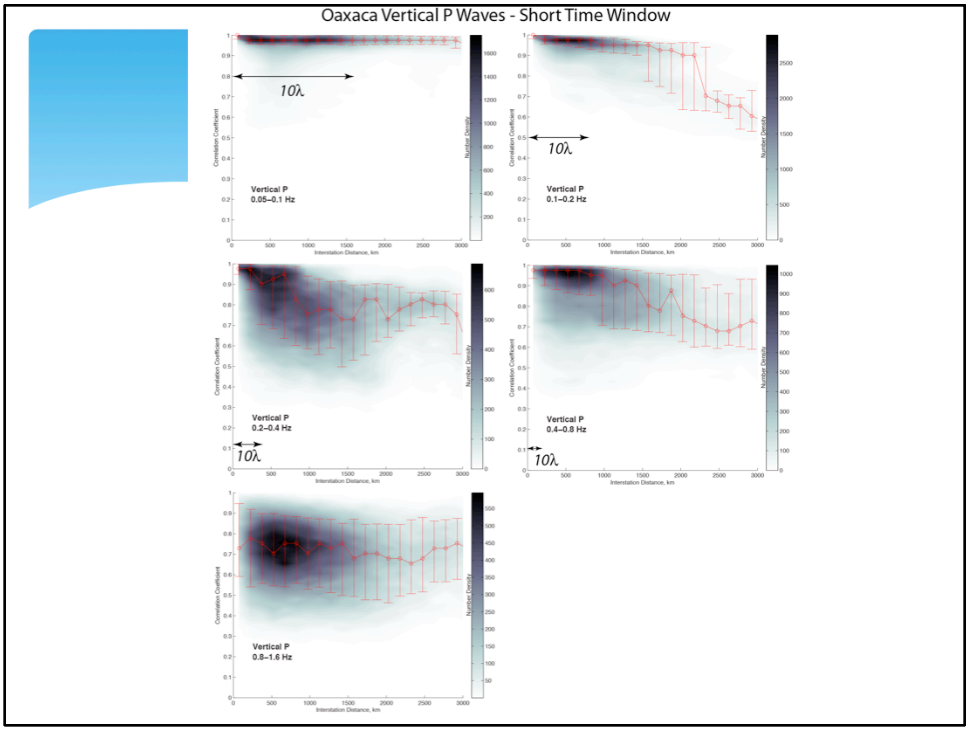
Results for Maule transverse S waves. Correlations are somewhat less than the P wave result but are still quite high.



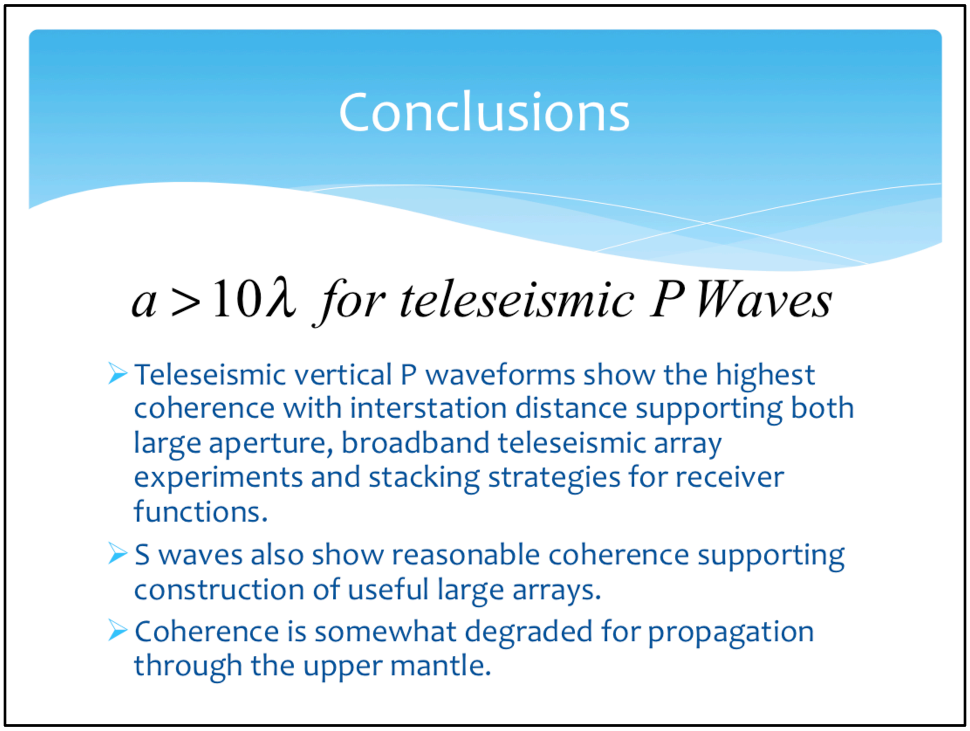
Correlations for Oaxaca P waves for the fixed time window. There is a large spread in the correlation density although peak values at low frequency are generally highly correlated. Decorrelation of most bandpasses may reflect the effect of upper mantle structure, e.g., P wave triplications.



Using a short time window inversely proportional to the bandpass center frequency necessarily increases the wave coherency. Here, even 1.2Hz P waves appear highly correlated across USArray (although there is large spread).



Similarly, coherency increases for Oaxaca P waves using short time windows.



The conclusions are straightforward. Teleseismic P waves (and S waves) can be highly correlated demonstrating that large broadband arrays can be built that can resolve very small variations in wave slowness. High correlations also support use of array stacking to obtain the best estimate of the teleseismic source function to be used in creating lithospheric transfer functions.