Measurement of Rayleigh-Wave Phase and Group Velocity from Ambient Noise recorded on Land and Ocean-Bottom Seismographs

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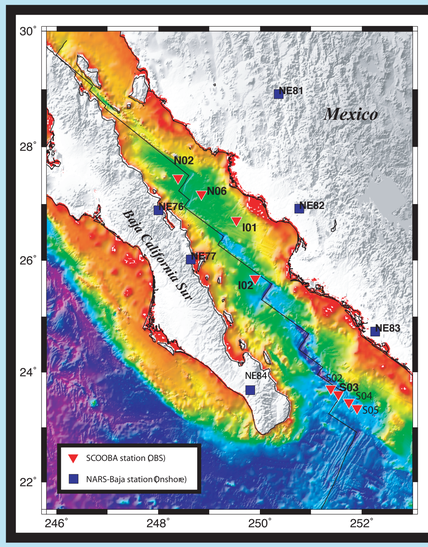


What are we studying? The Pacific-North America plate boundary, an oblique rift system in this area, runs lengthwise along the Gulf of California. The overall rate of spreading is fast (~48 mm/yr), making this one of the best modern examples of how continents break up and drift apart [Lizarralde et al, 2007].

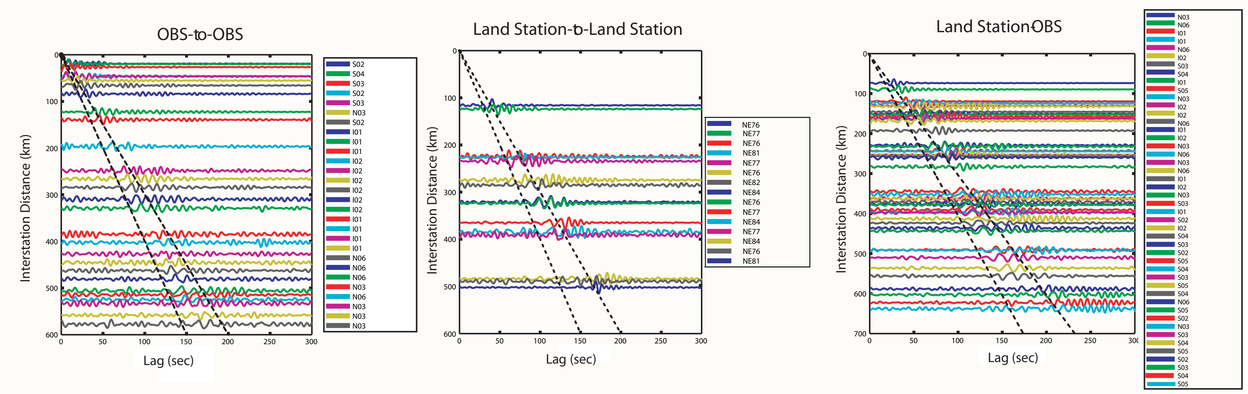
What are we looking for? We are looking for mantle melt because it has been theorized that partial melt in the upper mantle leads to deformation of the lithosphere. Studies on the lithosphere indicate that when it is exposed to strain, any melt present weakens the lithosphere further, resulting in highly localized deformation and rupture [Buck, 1991]. Why is this important? Studying this young rift has the potential to tell us about the large-scale tectonic processes and cycles, such as the Wilson cycle, that cause the formation and closure of ocean basins.

Abstract.

Using the data from eight ocean-bottom seismometers, part of the 12-month-long deployment of the Sea of Cortez Ocean-Bottom Array (SCOOBA) seismic experiment, and the data from six onshore seismometers, part of the NARS-Baja experiment, we have used ambient seismic noise to estimate the phase and group velocity of surface waves propagating through the crust and the upper mantle beneath the Gulf of California. We cross-correlated the continuous data from 91 station pairs in 6-hour time windows and stacked it. As inter-station distance decreases, the coherence, or the similarity of the noise recorded between each station pair and the signal-to-noise ratio, increases. The cross-correlations were most successful, as measured by high signal-to-noise ratios, for stations 50 km to 400 km apart. We then used two methods to determine the surface-wave velocity. We found the phase velocity using a spectral method based on Aki's [1957] original expression for the cross-correlation of stochastic surface waves. Using an independent technique, frequency-time analysis, we also estimated group velocity, from which we plan to extract the phase velocity. We inverted the group velocity and created maps at a number of different frequencies.

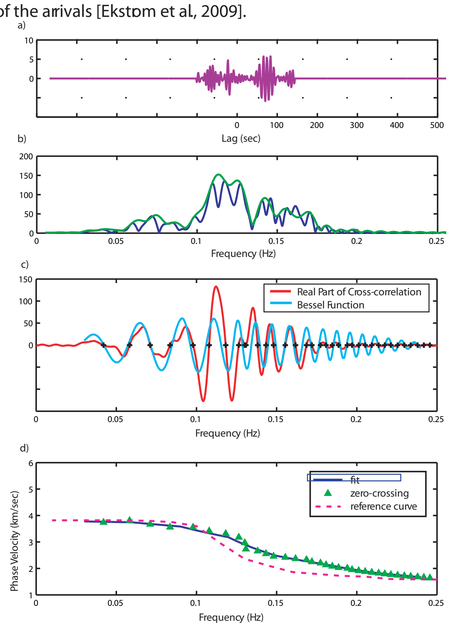
1. Noise Cross-Correlations Plotted by Distance

Each colored trace is a time series that represents year-long stacks of cross-correlation of ambient seismic (ground motion) noise between two stations. The cross-correlations approximate a Rayleigh surface wave traveling between the two stations. When the two stations are close together, the impulse occurs close to the y-axis, because the stations are recording very similar data (meaning the signal lag time is minimal). When the stations are farther apart, the impulse occurs farther from the y-axis (meaning the signal lag time is greater). Also, notice that as the inter-station distance increases, there is more noise on either side of the impulse, thus the signal-to-noise ratio decreases. The dotted black lines provide reference arrival times for a wave traveling with a constant group velocity -- the left-hand one represents a wave traveling at 4 km/sec whereas the right-hand one represents a wave traveling at 3 km/sec.



2. Measuring Phase Velocity Using Aki's Spectral Method

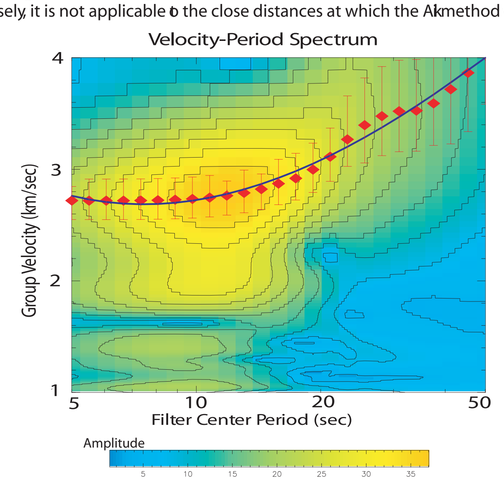
We determined the surface-wave phase velocity using a recently developed algorithm that is based on Aki's [1957] original expression for the cross-correlation of stochastic surface waves. In the frequency domain, the real part of the noise cross-correlation spectrum can be described by a Bessel function that is a function of phase velocity. The algorithm identifies the zero crossings of the real part of the cross-correlation spectrum and associates these zero crossings with those of the Bessel function. The algorithm determines phase velocities at discrete frequencies and then forms a dispersion curve, which is used to estimate phase velocities at other, arbitrary, frequencies. This easily automatable method can be used with shorter inter-station distances than are allowed for by traditional methods, methods based on measuring group velocity of the arrivals [Ekstrom et al, 2009].



a) Stacked cross-correlation of two OBS stations (I01-I02) with an inter-station distance of 123 km. The data was filtered to include periods of 6-50 seconds. The SNR is 43.76, a low to intermediate value for our data set.
b) Amplitude spectrum.
c) The real part of the cross-correlation function (red) is plotted against the best-fitting Bessel function (blue). The zero crossings of the cross-correlation are plotted as black plus signs.
d) The estimated phase velocity is plotted (dark blue) along with the zero-crossings of the cross-correlation (green triangles). The reference curve (pink dotted line) for phase velocities in oceanic crust with approximately 3 km of water (Harmon et al, 2007).

3. Measuring Group Velocity Using Frequency-Time Analysis

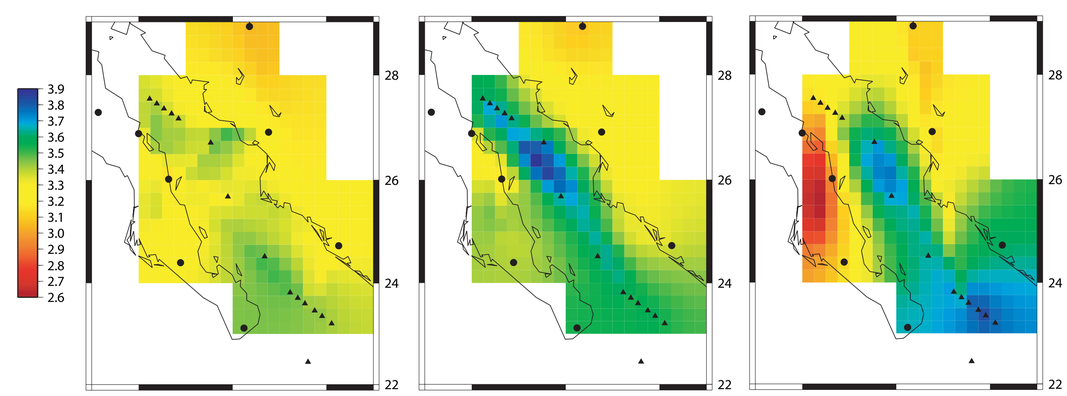
We measured the group velocity of the cross-correlation Rayleigh waves at all inter-station distances greater than 100 km using a time-frequency analysis [Ammon et al, xxxx]. This method estimates the amplitude of the correlagram as a function of period and arrival time (group velocity); for correlation functions with a well-isolated Rayleigh wave, the peak amplitude will map out the surface-wave dispersion, even in the case of substantial noise. This method thus works well for the long-distance, low signal-to-noise observations that were not suitable for the Aki analysis; conversely, it is not applicable to the close distances at which the Aki method worked well.



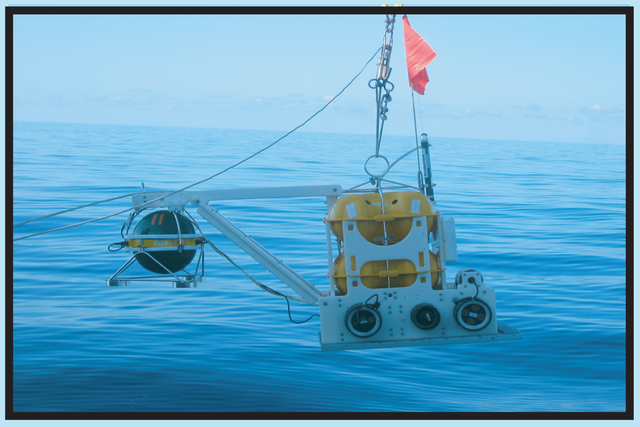
This curve shows the group velocity at different periods. The coloring shows that the data is the most stable at intermediate periods.

4. Group Velocity Maps

Using a simple tomographic algorithm, we inverted our inter-station group velocity dispersion curves for 2D maps of group velocity at a range of periods (10 sec, 14 sec, 16 sec., 18 sec, 20 sec, and 24 sec). The short period maps (10- and 14-second) are limited to the crust, even in oceanic regions. The longer period (18-, 20-, and 24- second) maps (shown below) sample the mantle in the midgulf, where crustal thickness is less than 10 km. The slower velocities in the northern gulf may be explained by the thick sediment layer there, whereas the faster velocities in the southern gulf could be explained by the thinner sediment layer there [Lizarralde et al, 2007].



18-second period. 20-second period. 24-second period.



Deployment of an OBS in the Gulf of California. The seismometer is housed in the green sphere. Instrument sinks to seafloor (1-3 km depth) due to its own weight. After recording for 1 year, the anchor (bottom plate) is released, and instrument returns to surface, driven by buoyancy of glass spheres housed in the yellow cases.

Conclusions and Future Work

- The noise cross-correlations of our data were most successful for stations 50 km to 400 km apart.
- For several of the cross-correlation functions, the Aki spectral phase-velocity analysis provided estimates that were unfeasible. This appears to be due to two factors: (1) very low signal strength in the long-period (T>20s) band; and (2) high noise levels in the correlation function, especially for the longer inter-station distances.
- We conclude that the Aki spectral method works best when there is an inter-station distance of 50 km to 200 km and an intermediate to high SNR.
- The frequency-time technique complements our study well, as it works best with inter-station distances above 200 km and can work with a low SNR.
- As a future step, we will extract phase velocities from the group velocities that we obtained from the frequency-time technique. We will compare and combine the phase velocities obtained from the two different methods.

References and Acknowledgements

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