Synthetic Parameter Tests for Ambient Noise Tomography

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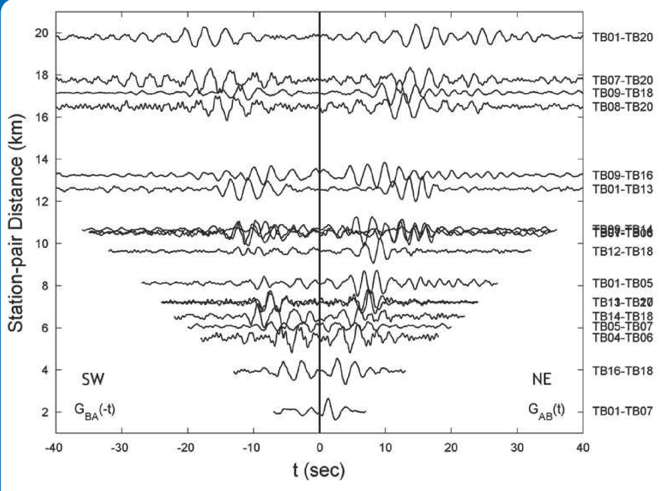
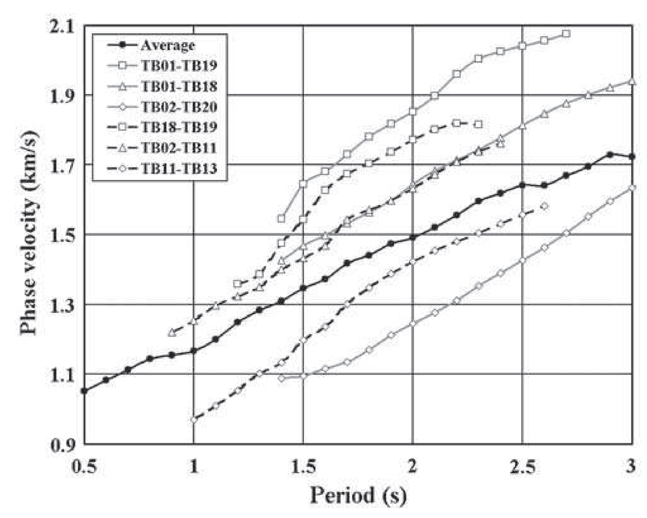
Introduction

Ambient noise tomography has rapidly become a powerful tool with which seismologist throughout the world study the velocity structure of the crust and uppermost mantle using ambient seismic noise instead of earthquake recordings. Typically the noise is recorded at periods ranging from 4 to 10 seconds, as the amplitudes are highest in that range. It is called the range is called the microseismic band, and contains the noise generated by ocean waves interacting with the coast and the seafloor. It is also well suited because the noise sources are fairly well distributed, and the methodology actually requires randomly distributed sources. Newer studies are now also using shorter periods (see figures to the right). However, these studies only go as far as determining the dispersion curves or inverting for phase or group velocity maps. We are therefore curios to see if it is possible to go beyond this and determine the S-velocity structure of the uppermost crust by inverting high frequency dispersion curves. To that end we present sensitivities and synthetic tests in the period range of 0.1 to 4 seconds, and compare them with the typically used 4 to 10 seconds band.

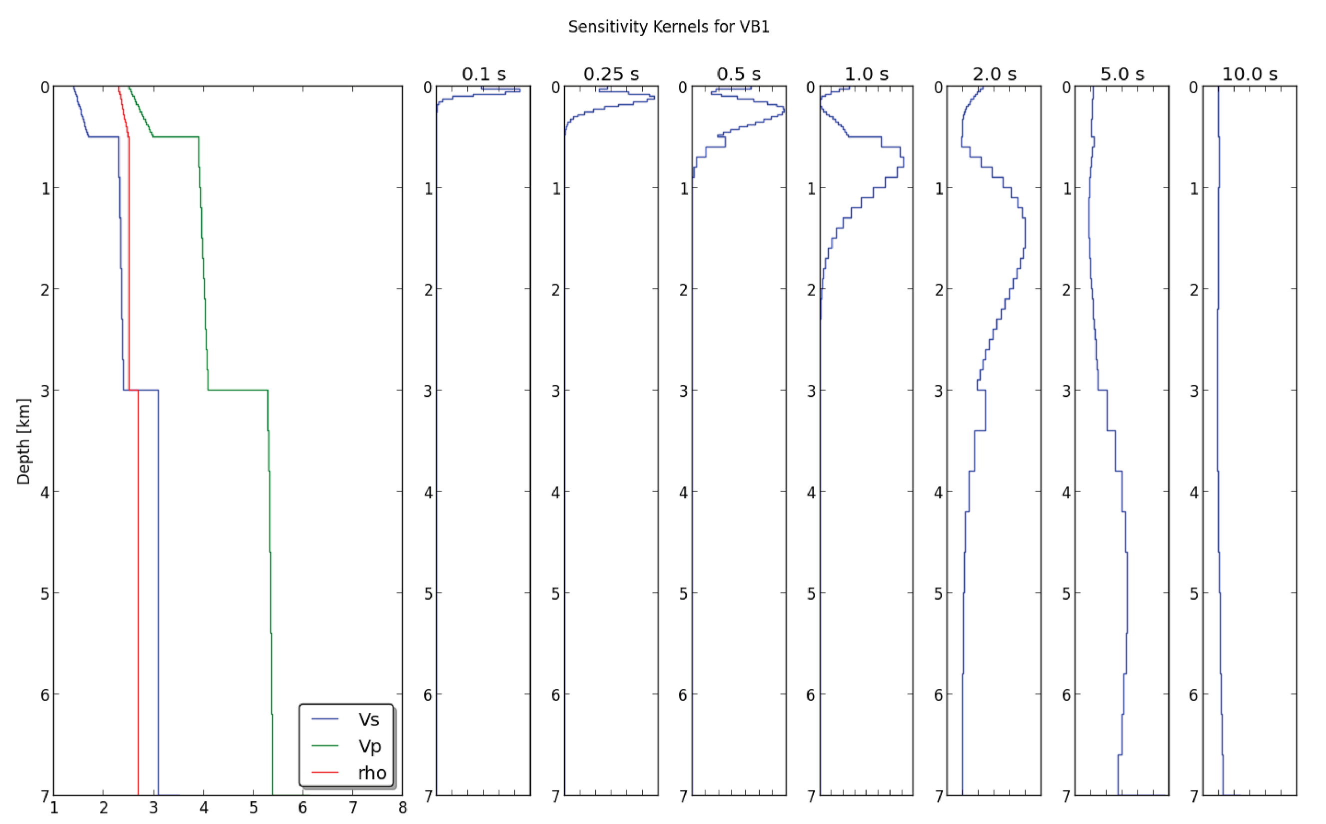


Huang et al. (2010) obtain Green's functions by crosscorrelating ambient noise recorede between 0.5 and 3 seconds period. These can be used to determind surface wave dispersion curves.



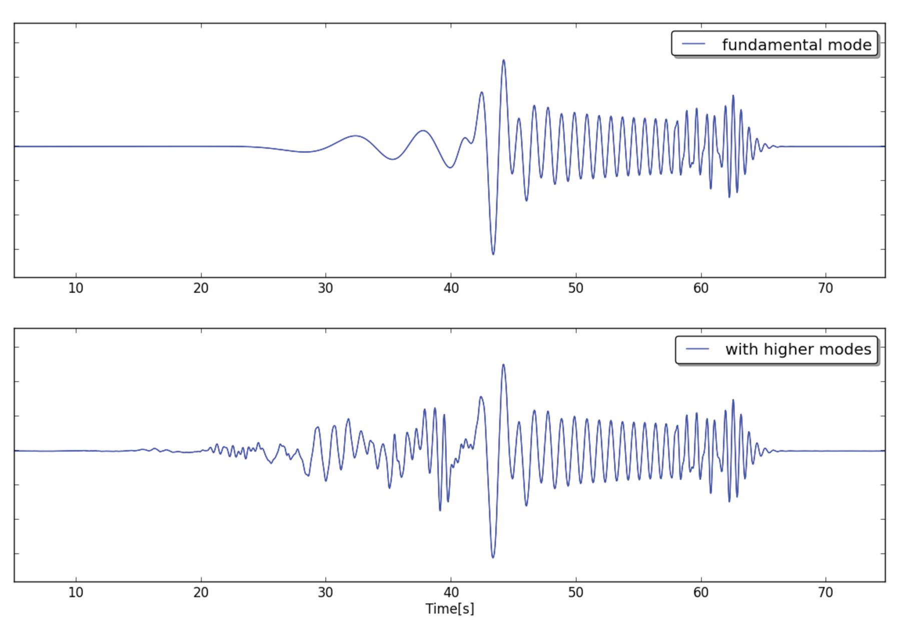
Analysing the the Green's functions yields phase velocity dispersion curves, which in turn provide insights into the crustal structure between two stations (Huang et al., 2010).

Sensitivity Kernels



We calculate fundamental mode Rayleigh wave phase velocity sensitivities to illustrate the dependence of measured phase velocities to S-velocities at depth. At short periods (0.1 to 1 second) phase velocity depends only on the top few hundred meters. For longer periods the phase velocity rapidly becomes more sensitive to the S-velocities of the mid- to lower crust. Therefore we must use the short peri-

Synthetic Waveforms



The sources of ambient noise recorded by seismometers are most likely generated at the surface. Hence we calculate synthetic seismograms assuming a vertical force acting on the free surface, recorded on the vertical component of seismic station at a distance of 75 km. The full waveform is obtained by modal summation.

However, a comparison of just the fundamental mode with the first 30 modes (including the fundamental) reveals that major differences exist only for the body waves arriving earlier. The surface waves are near identical so we proceed by using just the fundamental mode

References:
Yu-Chih Huang, Huajian Yao, Bor-Shouh Huang, Robert D. van der Hilst, Kuo-Liang Wen, Win-Gee Huang, and Chi-Hsuan Chen. Phase Velocity Variation at Periods of 0.5–3 Seconds in the Taipei Basin of Taiwan from Correlation of Ambient Seismic Noise Bulletin of the Seismological Society of America, October 2010, v. 100, p. 2250-2263

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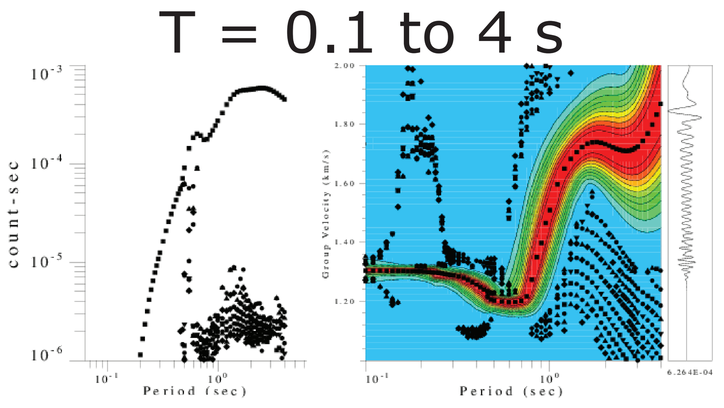
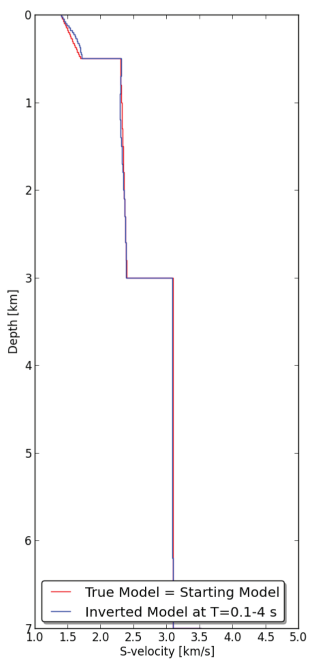
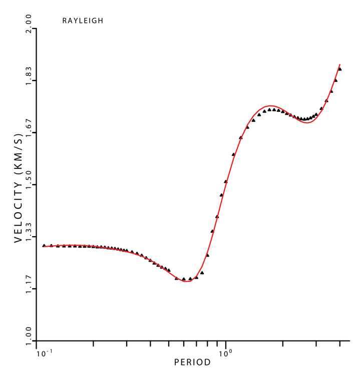
Inversion of Synthetic Data

With a real data set, crustal structure would be obtained by first measuring the surface wave group and/or phase velocities. The dispersion curve shows the frequency dependence of the surface wave velocities, and is then inverted for crustal structure at depth. The inversion of these data requires a suitable background model serving as a starting point for the inversion. This model should therefore be sufficiantly similar to the real velocity structure of the study region for the inversion algorithm to yield a realistic image of the subsurface. It is important to note that the suitability of the background model also is a function of the depth region we are interested in and the frequencies used. We show this by simulating a real world scenario using the synthetic waveforms calculated previously and as if they were real data. We perform the entire analysis in two period bands; one using only short periods ranging from 0.1 to 4 seconds and the commonly used macroseisic band ranging from 4 to 10 seconds.

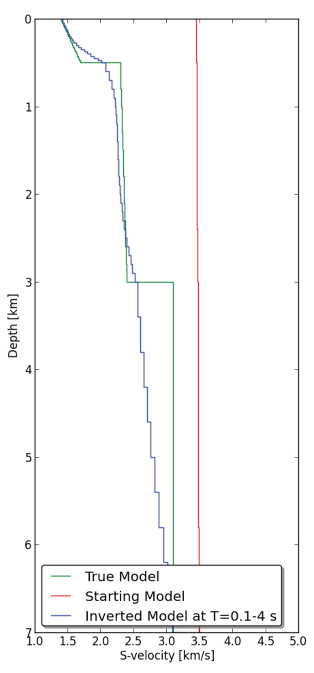
T = 0.1 to 4 s

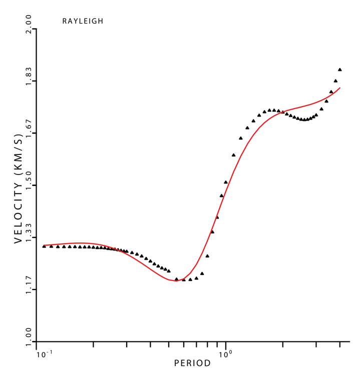






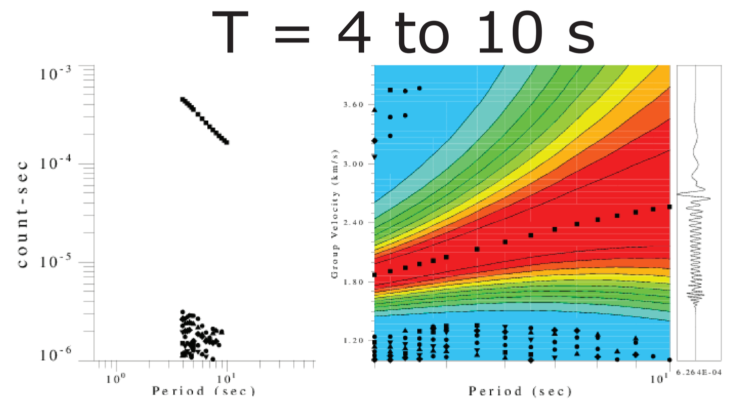
We first invert the measured dispersion curve using the same model used to calculate the synthetic waveforms as a starting model. Not surprisingly the true structure is well recovered by the inversion.

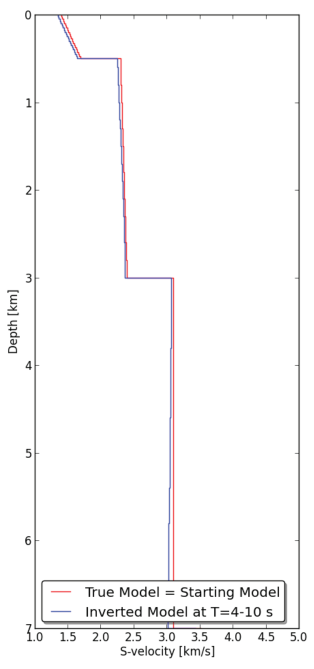


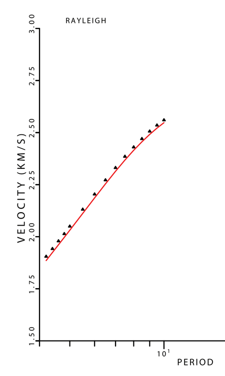


Using a simple starting model with a constant velocity in the upper crust the true structure is not recoverd as well. Importantly though, the slow velocities in the uppermost layers are seen in the inverted model.

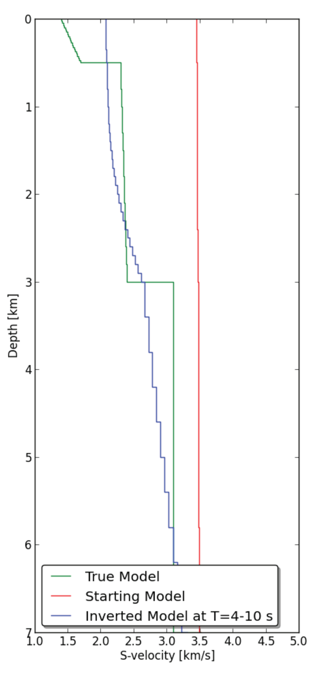
T = 4 to 10 s

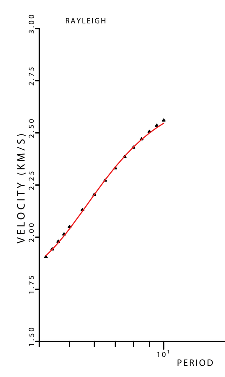






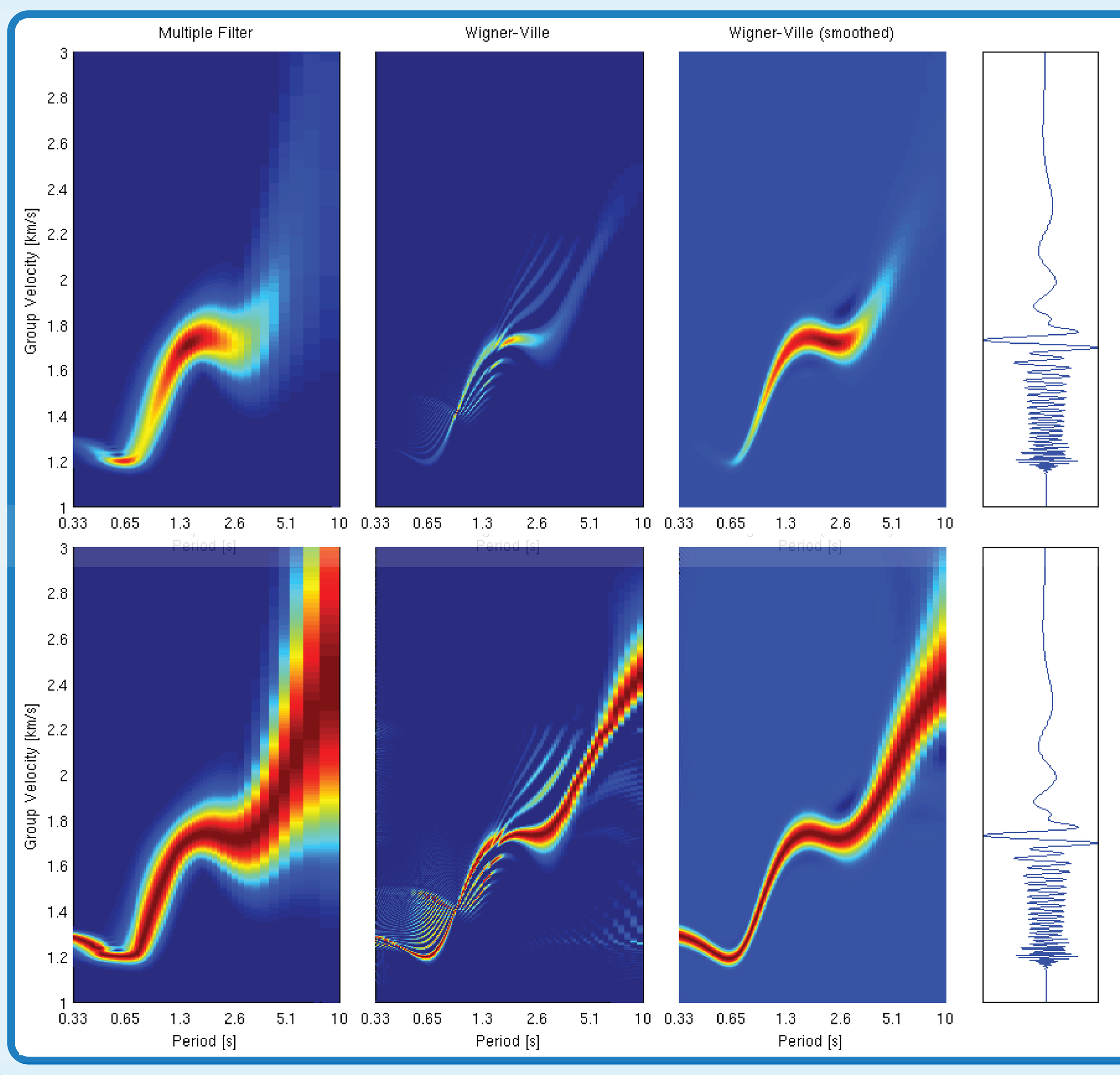
The longer periods also recover the true structure very well. The differnces between the inverted model and the true structure are a bit larger than for the shorter periods, however.





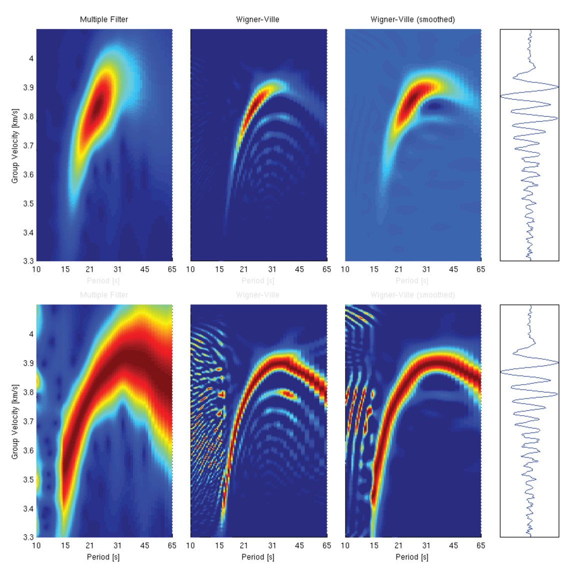
At a first glance the recovered model looks similar to the one obtained at shorter periods. However the inversion does not yield the shallow low velocities.

Dispersion from Wigner-Ville



Reliably determining the dispersion curve is crucial for investigating crustal structure from surface waves. Here we compare the traditionally used Multiple Filtering Technique (MFT, left) with the Wigner-Ville distribution (WV, center, smoothed on the right). The dispersion curves obtained are quite similar, however it is better constrained by WV across a broader frequency range. This becomes clear when normalising amplitudes for all periods (bottom).

Teleseismic Event



Example application of Wigner-Ville to a real teleseismic event recorded in Chile. Similar to the synthetic waveform the dispersion curve obtained from WV is near identical to MFT, but appears better constrained at all periods.

Conclusions

The main conclusions of this study are quite straightforward: (1) in order to seismically investigate the shallow structure of the crust using surface waves we must use high frequency data. By this we mean periods significantly shorter than the microseismic band of 4-10 secons. (2) If we manage to measure the dispersion at these short periods, we can reliably recover a realistic model through the inversion. In particular low velocities in the top few hundred meters are well recovered at 0.1 - 4 seconds.

Moving on, the intriguing questions and challenges that lie ahead of us now are on the one hand what influences velocity heterogeneity in the shallow crust. Can, for example, the range of expected velocities be compared to the lower crust/upper mantle, and thus be dealt with in the same way using the same methods? Moreover, actually getting that far could prove to be quite difficult, as the dispersion curve is not easily obtained at high frequencies: measuring group or phase velocity from a local earthquake is hampered by the high attenuation of the high periods, and ambient noise recorded will contain lots of man made cultural noise, which is likely not randomly distributed (a requirement for the cross-correlation to yield the nessecary Green's functions).