Notes on the noise-correlation Green's function method

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Since its introduction to seismology by Campillo and Paul (2003), the noise-correlation Green function method has become quite popular. For example, it has been applied to tomographic studies for regional structure (Shapiro et al., 2004) and local structure (for example Southern California by Sabra et al., 2005, and many other regions by now). It has even been applied to Apollo data (Larose et al., 2005; Tanimoto et al., 2008) and was shown to be effective for recovering shallow lunar structure.

Examination of its theoretical foundation indicates, however, that there are many issues that need to be examined. This is especially true for some steps in data analysis such as pre-whitening and bit conversion. I will examine some aspects of this technique, using a simple normal mode theory.

First, I will discuss what is really recovered by this noise-correlation method, under the assumption that noise sources are uniformly distributed. Simple cross-correlation of data at two stations (without pre-whitening) produces a correlogram that is not exactly a Green function (Tanimoto, 2008). The differences from the Green function are found in four aspects; proportionality to noise-source spectra (thus source is not a delta function), proportionality to density of sources, a general trend (due to coefficients) in frequency to emphasize high-frequency portion and the time dependence contains one more integration in time in comparison to the Green function.

A pre-whitening procedure can turn the source term to the delta function and indeed as Weaver and Lobkis (2001) showed that this method can lead to a Green function for a flat (especially 2D) medium. However, it cannot correct for frequency dependence in amplitude coefficients, naturally contained in a Green function formula for the normal-mode theory. Also this procedure removes a geometrical spreading term, making comparisons of amplitudes at different distances rather difficult. Therefore, strictly speaking, what we get by cross-correlation are not Green functions, at least for long-period, normal-mode frequency range.

What is important, however, is the fact that these deviations from the Green function only appear in amplitude coefficients and not in phase; therefore, phase and group velocity measurements can be performed without any bias. It thus appears that structural studies, using surface-wave velocity measurements (e.g., Shapiro et al., 2004), are valid. However, since waveforms may be affected by differences in amplitude terms, detailed waveform modelling of the correlograms cannot be justified rigorously.