Geophysical Research Abstracts
Vol. 13, EGU2011-6153, 2011
EGU General Assembly 2011

The unwanted amplification of monochromatic signals in seismic noise cross-correlation functions by spectral whitening

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The estimation of Green's functions based on seismic noise cross-correlation functions (CCFs) evolved to an important and widely used technique in seismology. It enables seismology to provide high-resolution tomography studies from local to continental scale and independent from earthquake seismicity or active seismic sources. Nevertheless, practical experience shows, that one has to use long time series (months to years) and to apply extensive normalisation to the seismic noise time series to obtain CCFs which are suitable to estimate Green's functions. The cross-correlation of non-normalised 'raw' seismic noise time series produces CCFs which are in general not suitable to estimate Green's functions due to disturbing dominant signals (e.g. earthquake waves, ocean-generated microseism) or instrumental irregularities. The important task of the processing is to provide an 'equalisation' of the signals contributing to the seismic noise in the time and frequency domain to be able to estimate the broad-band Green's function from the finally obtained seismic noise cross-correlation function.

The applied data processing is therefore critical and underwent an evolution in the last years. For practical reasons, only short time windows of seismic noise (typically several minutes to 24 hours) are normalised and cross-correlated. A large amount of 'short time window' CCFs is afterwards stacked to obtain a 'long time window' CCF which can be used to estimate the Green's function.

State-of-the-art is the normalisation of the seismic noise time series in the time and frequency domain prior to the cross-correlation. The task of the time domain normalisation of the time series is to suppress the effect of strong coherent transient signals (e.g. earthquakes) or instrument irregularities on the obtained CCF. The task of the frequency domain normalisation (spectral whitening) is to broaden the band of the seismic noise and to suppress the influence of dominating narrow-band signals (e.g. ocean-generated microseism) on the CCFs. Our presentation is focused on a critical aspect of the spectral whitening.

We demonstrate that the application of spectral whitening amplifies unwanted monochromatic signals in the stacked 'long time window' CCF under certain circumstances. The amplification occurs if a persistent localised source of a monochromatic signal exists and increases with decreasing length of the time window used for the cross-correlation due to the stacking. Such a persistent localised monochromatic source causes very reliably also a monochromatic signal in the 'short time window' CCFs, even if a short time window length (minutes to hours) is used. The emergence of this monochromatic signal in the CCF of seismic noise is significantly more efficient than the emergence of the Green's function. Such a persistent signal is significantly amplified in the stacked 'long time window' CCF even if its amplitude is very small in the original seismic noise time series due to the spectral whitening and stacking of the 'short time window' CCFs. This implies that the length of the time window used for the cross-correlation should not be selected for pure practical or technical reasons.

We use one year (2004) of seismic data of several stations of the Global Seismographic Network (GSN) in the United States of America to illustrate and discuss this effect on a continental scale. In this case the well known persistent monochromatic signal of ocean-generated microseism (period ∼26 s) originating from the Gulf of Guinea is amplified in the one-year CCFs of station pairs in the USA by the spectral whitening. We use time window lengths between 1 hour and 24 hours to illustrate the significant influence of the time window length on the magnitude of the amplification.