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

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***Abstract*— The estimation of the Green's function between two points on the Earth's surface by the cross-correlation of seismic noise time series requires, in general, very long time series (months to years) as well as massive normalisation. Spectral whitening is a widely used powerful normalisation to improve the emergence of broad-band signals in seismic noise cross-correlations. Nevertheless, we observe spectral whitening to depend strongly on the time window length necessarily used to fragment very long time series. An unwanted amplification of a persistent microseism signal is observed on the continental scale with time windows shorter than 12 hours.**

I. Introduction

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 normalization to the seismic noise time series to obtain CCFs which are suitable to estimate Green's functions. The cross-correlation of non-normalized 'raw' seismic noise time series produces CCFs which are in general not suitable 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 'equalization' 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.

II. Data Processing

The applied data processing underwent an evolution in the last years [1]. For practical reasons, only short time windows of seismic noise (typically several minutes to 24 hours) are normalized 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 normalization of the seismic noise time series in the time and frequency domain prior to the cross-correlation [1]. The task of the time domain normalization of the time series is to suppress the effect of strong coherent transient signals (e.g. earthquakes, instrument irregularities) on the obtained CCF. The task of the frequency domain normalization (spectral whitening) of the time series or CCFs 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. Alternatively, all normalization can be done after the cross-correlation by applying time and frequency domain normalization procedures to the CCFs prior to the stacking [2]. This presentation is focused on a critical aspect of the spectral whitening.

III. Effects of Spectral Whitening

We demonstrate (see also [2]) 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 localized 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 localized 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 [3] is amplified in the one-year CCFs of station pairs in the USA by the spectral whitening (Fig. 1). 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. We state that the time window length should be at least 12 hours if spectral whitening is used for noise interferometry on a continental scale.

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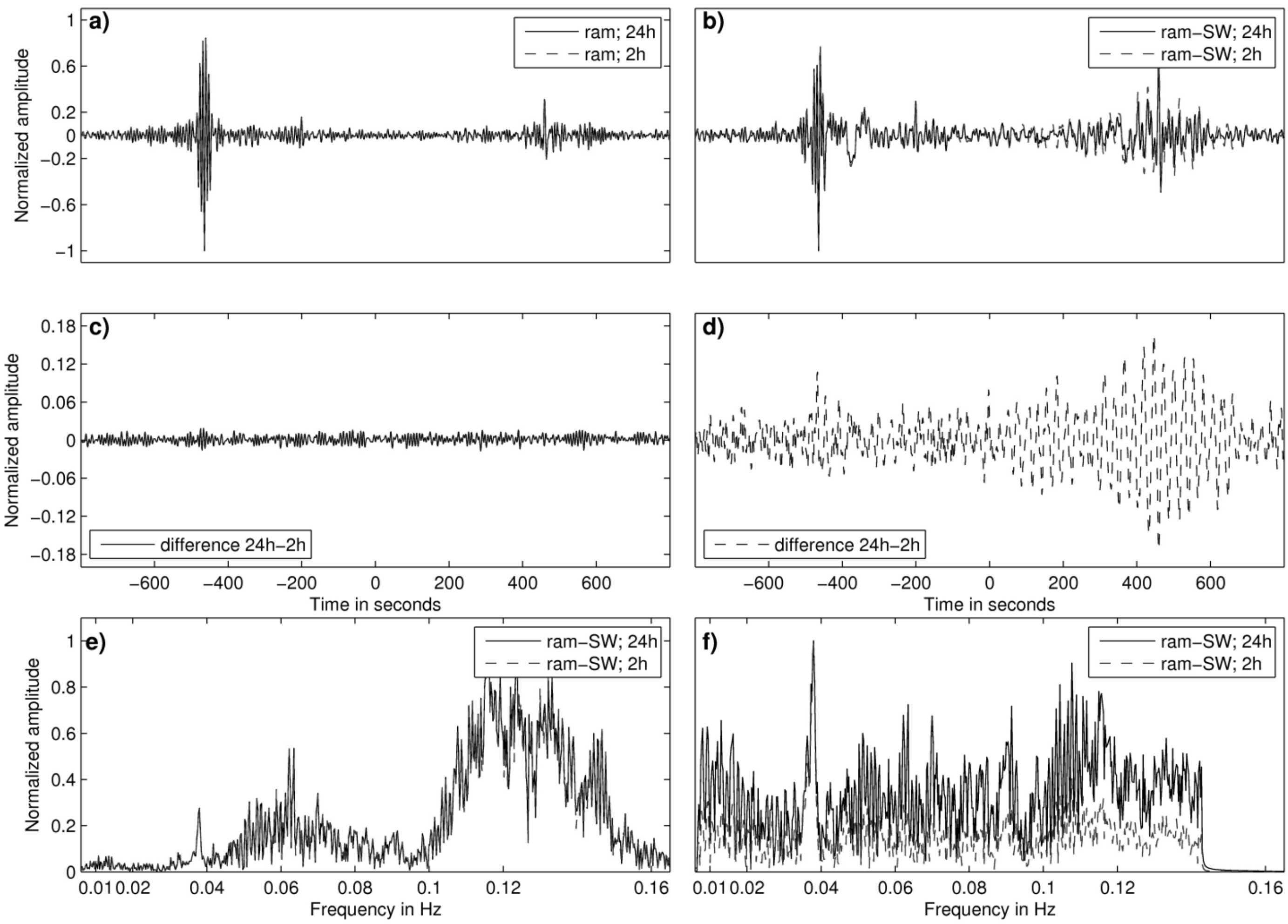

Fig. 1. Comparison of stacked 12-month CCFs (ANMO-CCM, 7-150 s, distance 1404 km) obtained with different normalization schemes and time window lengths. (a) CCFs obtained with the running absolute mean (ram) time domain normalization [1] with a time window length of 24 hr (black line) and 2 hr (grey dashed line). The differences between the CCFs are rather small and can be hardly seen in (a). (b) the same as in (a) for CCFs obtained with the ram time domain normalization and consecutive spectral whitening (SW). The CCFs differ in their causal parts. (c) and (d) are the waveform differences between the 2 hr CCF and the 24 hr CCF in (a) and (b), respectively. The 26 s microseism signal from a localized source in the Gulf of Guinea [3] emerges in the causal part of 12-month CCFs obtained by the spectral whitening and stacking of the CCFs obtained by cross-correlating 2 hour time windows of seismic noise (d). (e) and (f) corresponding amplitude spectra of the CCFs in (a) and (b). The spectra of the CCFs in (a) are nearly the same. The spectra of the CCFs in (b) show the unwanted amplification of the 26 s microseism signal in the CCFs obtained with spectral whitening due to the short time window length of 2 hours.