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The relation between spectral whitening and the attenuation of the ambient seismic field

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Measuring attenuation on the basis of interferometric, receiver-receiver surface waves is a nontrivial task: the amplitude, more than the phase, of ensemble-averaged cross-correlations is strongly affected by non-uniformities in the ambient wave field; in addition, ambient data are typically preprocessed in ways that affect the amplitude itself. Some authors have recently attempted to measure attenuation in receiver-receiver cross-correlations obtained after the usual processing of seismic ambient-noise records, including, most notably, spectral whitening. An alternative processing method involves Aki's spatial autocorrelation (SPAC). It has been suggested that these two approaches are equivalent. We explain that, instead, important differences exist. We find a formal relationship between the SPAC-based and spectral-whitening-based definitions of ensemble-averaged cross-correlations, by Taylor-expanding the latter around the former. We approximate the behavior of the whitened cross-spectrum up to the second order of the Taylor expansion. For the case of an isotropic source distribution and a lossless subsurface, we find that the real part of the whitened azimuthally-averaged cross-spectrum can be approximated analytically by three quarters of a Bessel function plus one quarter of a cubed Bessel function. We additionally find an approximate analytical formula for the whitened cross-spectrum over an attenuating subsurface for sources isotropically distributed in the far field. We validate our analytical results numerically, by comparison with the direct application of the spectral-whitening approach to a synthetic data set. We find that interpreting attenuation parameters estimated via whitened ambient-noise records as if they were obtained using the SPAC-method can lead to significant overestimation of seismic attenuation. Especially for short receiver-receiver distances with respect to the wavelength considered, this may result in large errors.