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Statistical redundancy of instantaneous phases: theory and application to the seismic ambient wavefield

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In order to detect possible signal redundancies in the seismic ambient wavefield, we develop a new method based on pairwise comparisons among a set of synchronous time-series. This approach is based on instantaneous phase coherence statistics. The first and second moments of the pairwise phase coherence distribution are used to characterize the phase randomness. Both theory and synthetic experiments show that, for perfect phase randomness, the theoretical values of the mean and variance are equal to 0 and $1 - 2/\pi$, respectively. As a consequence, any deviation from these values indicates the presence of a redundant phase in the raw continuous signal. Using the ergodicity property of a random signal, we split an initial time-series into a set of synchronous signals. This allows us to detect and to quantify the repetitiveness of any possible temporally persistent and spatially localized source, during a given period of observation. In the case of the detection of a redundant phase, individual coherences (one trace against all others) quantify the contribution of each time-series independently.

A previously detected 26 s period microseismic source located near the Gulf of Guinea is used to illustrate one of the possible ways of handling phase coherence statistics. We use the continuous vertical component data recorded during the month of 2004 August by four broad-band stations of the Federation of Digital Seismography Network. To compute coherence statistics among a set composed of a sufficient number of synchronous traces, the raw seismic signal is split into 372 2-hr sliding time windows. Only the basic signal processing steps (including removing the mean, trend and the instrumental response) are applied. After bandpass filtering the data between 23 and 32 s periods, the 2-hr time-series are cross-correlated, leading to a set of 372 synchronous cross-correlations for each station pair. We observe that, for all station pairs, the mean overall coherence value is close to zero for most time lags, except for specific time windows in which a clear signal emerges. Converting mean overall coherences into geographical locations and using a standard 3.5 km/s group velocity value, the maximum coherence is obtained with a source located at $5.5°$N, $1.5°$E, in a very good agreement with previous locations found in the literature. This result demonstrates that our approach enables us to properly localize persistent sources, and to quantify their contribution to the overall seismic ambient wavefield.

The strength of the phase coherence statistics relies in its ability to quantify the redundancy of a given phase among a set of ambient noise cross-correlations without using classical amplitude normalization processing schemes. The method has various useful applications in seismic noise-based studies (tomography and/or source characterization). Depending on the application, the method may be used to exclude either poorly contributing traces for efficient signal extraction, or to exclude highly contributing traces to avoid contamination from a persistent signal.