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Adaptive wavelet for the detection of surface waves to predict Marine Sediments properties

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Summary

New data adaptive wavelet approach has been developed to study multimode surface wave propagation along the water-seabed interface. Our goal is to predict dynamic (shear velocity, attenuation) and physical properties (stiffness, density) of marine sediments from the surface waves records. Direct measurements of dynamic properties (shear velocity) from the time arrival data of seismic records are very difficult or impossible. Since surface wave velocities are directly linked with the shear strength (moduli) transformations as a function of depth and distance, we use the measurements of the surface wave velocities (group and phase) to invert their values into shear velocities. We use the wavelet cross-correlation technique to estimate and invert propagational parameters of surface waves (group and phase velocity) into shear velocity as a function of distance and depth. Wavelet analysis has been proven as the powerful tool in decomposing properties of surface seismic waves over a time and period (frequencies). However, successful differentiation between the modes in cases of their complex time and spatial variability requires time-scale images of considerably higher resolution than are possible with the wavelet analysis using standard wavelet kernels. In order to achieve a better resolution of imaging we developed a new data driven adaptive wavelet.

Method

Our approach is based on searching for coincident patterns of oscillations in a set of time records of surface waves. Time series are assumed to have zero means. First, we calculate covariance matrix, which is formed from the cross lag-correlation matrix with the minimum time-lag taken as the sampling interval. The matrix is then decomposed into the orthogonal components via the Karhunen-Loeve transform (**??**), also known as the Proper Orthogonal Decomposition Theorem (POD) or as Principal Component Analysis (PCA). Obtained eigenvalues, are the amplitude or energy content, they define the singular spectrum; the eigenvectors, are the oscillation forms – modes.

$$\int \phi(x,x')\psi_m(x')dx' = |\lambda_m|^2 \, \psi_m(x) \tag{1}$$

$\phi(x,x')-$ covariance matrix

λ_m- eigenvalues

$\psi_m(x)-$ eigenfunctions

We use only the few first eigenfunctions from the beginning of the singular spectrum which represents the surface wave oscillations (modes), and ignore the end of the spectrum where non-significant components (noise) are grouped. Calculated eigenfunctions have been regularized and checked for admissibility. Resulted basis becomes a new wavelet set which can be used for the decomposition of the original time series. This set is a discrete type wavelet set naturally adapted to particular data set, or record in case when an autocorrelation matrix is taken as an input data parameter.

Number of tests has been run to develop a new adapted wavelet to analyse surface wave synthetic records. The tests show that the adaptive wavelet gives much better images of the surface wave modes than standard wavelet kernels, especially in situations of a complex time-frequency overlapping between modes. The new basis has an optimal convergence in the sense of the least squares.

The approach is provided here with an additional test on the noise stability issues. The method differentiates efficiently between the coherent and non-coherent parts of the signal, thus, it is very stable to the non-coherent noise. Signal to coherent noise ratio is very sensitive to the number of eigenfunctions taken for the consideration. It increases with the decreasing number of eigenfunctions. This signal to noise ratio improvement, however, would come at significant resolution and the accuracy coasts. This problem is a topic of our current research.