Sea-level records analysis with empirical mode decomposition and its variations: Boundary effect improvement and mode reconstruction method

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A common goal of most time-series analysis is to separate deterministic periodic oscillations in the data from random and aperiodic fluctuations associated with unresolved background noise (unwanted geophysical variability) or with instrument error. For many applications, the sea level records are treated as linear combinations of periodic or quasi-periodic components that are superimposed on a long-term trend and random high-frequency noise. The periodic components are assumed to have fixed or slowly varying amplitudes and phases over the length of the record. Fourier analysis is one of the most commonly used methods for identifying periodic components in near-stationary sea-level data. If the sea-level data are strongly non-stationary, then more localized transforms like Wavelet transform can be used. However, the sea-level is a naturally non-linear process and data with the non-linear interactions among the physical processes with different time scales causing sea-level changes.
Empirical Mode Decomposition (EMD) is an adaptive (data-driven) method to analyse non-stationary signals stemming from non-linear systems (Huang et al., 1998). It produces a local and fully data-driven separation of a signal in high and low frequency oscillations, called intrinsic mode functions (IMFs), and a monotonic trend (residual). Detailed information on EMD and EEMD are referred to Huang *et al.* (1998) and Wu and Huang (2009). The CEEMDAN is an important improvement of EEMD (Torres et al., 2011), achieving a negligible reconstruction error and solving the problem of different number of modes for different ensemble numbers with signal plus noise. The improved CEEMDAN is a further improvement of CEEMDAN for solving the problem of residual noise in modes and spurious modes (Colominas et al., 2014). For the sake of paper length, readers refer to the relevant literature above for detailed algorithms of EMD and its variations. For applications of EEMD, refer to Lee *et al.* (2012).
In this study, we illustrate two improvements in the signal decomposing and analysis process of EMD; the boundary effect and reconstruction method for decomposed intrinsic mode functions (IMFs). We use the mirror method for boundary effect and statistical significance test for reconstruction of IMFs to improve the statistical significance of each modes. The artificial signal test show that the proposed mirror method for boundary effect and the statistical significance test for reconstruction of IMFs improve the decomposing results dramatically compared to the original artificial signal components.

Keywords: empirical mode decomposition, boundary effect, mode reconstruction method, sea-level records

