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Detecting clusters of irregular oscillations in the presence of colored noise: An application to climate records

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Over the last two decades, singular spectrum analysis (SSA) has became widely used in the identification of intermittent or modulated oscillations in geophysical and climatic time series; for an overview, see Ghil et al. (Rev. Geophys., 2002). SSA decomposes the delay-coordinate phase space of a given time series into a set of data-adaptive orthonormal components and allows one to reconstruct a robust "skeleton" of the dynamical system's structure and dynamics. The direct extension of SSA to multivariate time series — referred to as multivariate SSA (M-SSA) — found numerous applications in the extraction of common dynamical behavior from multivariate records. In this context, Feliks, Ghil and Robertson (J. Climate, 2011) have suggested the application of bivariate SSA to pairs of climatic variables in order to determine synchronization.

Groth and Ghil (Phys. Rev. E, 2011), however, have recently shown that classical M-SSA suffers from a degeneracy problem, with the eigenvectors not being well separated when the corresponding eigenvalues are similar in size. This problem is a shortcoming of principal component analysis in general, not just of M-SSA in particular. While both methods are good for signal compression purpose, they contribute little to the physical interpretation of the underlying system when this problem arises. For this reason, Groth and Ghil (Phys. Rev. E, 2011) have recently introduced a varimax rotation of M-SSA eigenvectors in order to improve the separation of distinct oscillations. In the present work, we demonstrate the effect of this M-SSA modification in an application to several climate records. We show that after this modification, M-SSA provides an excellent tool not only for the spectral analysis of multivariate time series but also for the identification of clusters of oscillations.

To prevent the misinterpretation of random fluctuations as oscillations in climate records, Allen and Smith (J. Climate, 1996) formulated a Monte Carlo test against a colored-noise null hypothesis. Although this test works quite well in case of a univariate SSA, its application to M-SSA becomes less and less discriminating as the number of variables increases. In order to improve the power of the test, we propose here the concept of Procrustes target rotation to overcome this dimensionality problem. With the proposed rotation, matching of M-SSA results from the time series and of M-SSA results from the null hypothesis' surrogate data is much improved.