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Nonlinear Dynamics of Complex Coevolutionary Systems in Historical Times

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A new theoretical paradigm for statistical-dynamical modeling of complex coevolutionary systems is introduced, with the aim to provide historical geoscientists with a practical tool to analyse historical data and its underlying phenomenology.

Historical data is assumed to represent the history of dynamical processes of physical and socio-economic nature. If processes and their governing laws are well understood, they are often treated with traditional dynamical equations: deterministic approach. If the governing laws are unknown or impracticable, the process is often treated as if being random (even if it is not): statistical approach.

Although single eventful details – such as the exact spatiotemporal structure of a particular hydro-meteorological incident – may often be elusive to a detailed analysis, the overall dynamics exhibit group properties summarized by a simple set of categories or dynamical regimes at multiple scales – from local short-lived convection patterns to large-scale hydro-climatic regimes. The overwhelming microscale complexity is thus conveniently wrapped into a manageable group entity, such as a statistical distribution.

In a stationary setting whereby the distribution is assumed to be invariant, alternating regimes are approachable as dynamical intermittence. For instance, in the context of bimodal climatic oscillations such as NAO and ENSO, each mode corresponds to a dynamical regime or phase.

However, given external forcings or longer-term internal variability and multiscale coevolution, the structural properties of the system may change. These changes in the dynamical structure bring about a new distribution and associated regimes. The modes of yesteryear may no longer exist as such in the new structural order of the system. In this context, aside from regime intermittence, the system exhibits structural regime change. New oscillations may emerge whilst others fade into the annals of history, e.g. particular climate fluctuations during the Little Ice Age.

Traditional theories of stochastic processes and dynamical systems are grounded on the existence of so-called dynamical invariants; properties that remain unchanged as the dynamics unfold, assuming structural invariance and ergodicity of the underlying system. However, such theories are no longer optimal when trying to understand and model long-term historical records of coevolutionary systems. A new paradigm is thus needed.

Therefore, we introduce a new class of dynamical systems that reinvent themselves as the dynamics unfold. Rather than only changing variables and parameters under a rigid framework, the governing laws are malleable themselves. The novel formulation captures and explains the coevolutionary dynamics of multiscale hydroclimatic systems, bringing along a physically sound understanding of their regimes, transitions and extremes over a long-term history.