A conceptual model for GHG-Temperature feedback in the climate system

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The climate system is inherently nonlinear, with coupling interactions playing a crucial role in shaping its dynamics. Such nonlinearity gives rise to complex behaviors, including chaos, multi stability, and tipping phenomena. Understanding these features is essential for assessing the stability of the Earth system under ongoing anthropogenic forcing. Scientific efforts approach this challenge from complementary directions, ranging from data-driven analyses to theoretical frameworks grounded in nonlinear dynamics. In this work, we focus on the latter perspective and investigate the coupled dynamics between global temperature and greenhouse gas (GHG) emissions. We conceptualize this interaction as a bidirectionally coupled system with reinforcing feedbacks: warming enhances GHG emissions through processes such as permafrost thaw, ice sheet melt, and biomass burning, while increased GHG concentrations further amplify warming. Within this framework, we analyze two distinct tipping mechanisms. We show that feedbacks can either drive accelerated warming beyond a trend-change point or give rise to multistability and tipping between alternative climate states. Moreover, we argue that these regimes are dynamically connected, such that gradual acceleration may increase the likelihood of crossing critical thresholds.

Spectral decomposition unlocks ascidian morphogenesis

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Describing morphogenesis generally consists in aggregating the multiple high-resolution spatiotemporal processes involved into reproducible low-dimensional morphological processes consistent across individuals of the same species or group. In order to achieve this goal, biologists often have to submit movies issued from live imaging of developing embryos either to a qualitative analysis or to basic statistical analysis. These approaches, however, present noticeable drawbacks as they can be time consuming, hence unfit for scale, and often lack standardization and a firm foundation. In this work, we leverage the power of a continuum mechanics approach and flexibility of spectral decompositions to propose a standardized framework for automatic detection and timing of morphological processes. First, we quantify whole-embryo scale shape changes in developing ascidian embryos by statistically estimating the strain rate tensor field of its time-evolving surface without the requirement of cellular segmentation and tracking. We then apply to this data spectral decomposition in space using spherical harmonics and in time using wavelets transforms. These transformations result in the identification of the principal dynamical modes of ascidian embryogenesis and the automatic unveiling of its blueprint in the form of scalograms that tell the story of development in ascidian embryos.

Self-similarity of mobility networks

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Mobility systems of people and goods are inherently multi-scale, spanning levels of organization from cities to regions and nations. Determining whether mobility networks exhibit similar patterns across these scales could reveal common organizing principles, allowing insights gained at one scale to inform the study of others. Renormalization provides a natural framework for studying this question. Here, we propose a Neighbor-Limited Box Covering method to renormalize undirected weighted mobility networks. This method iteratively selects box centers in descending order of node strength, merges each center with a fixed number of its highest-weight neighbors to form a renormalized node, and aggregates edge weights between renormalized nodes to construct the network at the next scale. We apply this technique to analyze real-world inter-city human mobility and freight trip networks in China and find that their topology, weighted structure, and dynamic processes all exhibit self-similarity, revealing common organizing principles across scales. Moreover, despite the absence of spatial information during renormalization, most renormalized nodes exhibit strong spatial cohesion, with their boundaries closely aligning with existing political and socio-economic regions. This alignment differs between mobility systems: human mobility aligns predominantly with provincial administrative regions, whereas freight mobility aligns predominantly with urban agglomerations, reflecting distinct patterns of spatial organization. Beyond their spatial cohesion, renormalized nodes form a hierarchy that further enables the identification of core cities across layers. The resulting hierarchy reveals the system-specific importance of cities and supports scale-sensitive planning and resource allocation across spatial scales.

Conditional stability and prediction performance in echo state networks and recurrent kernel machines

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Reservoir computing (RC) offers a natural meeting point of nonlinear dynamics and machine learning. In recent work on chaotic time-series prediction with finite echo state networks (ESNs), we showed that prediction performance is closely tied to generalized synchronization (GS) between the driving system and the reservoir, in particular to weak GS and bubbling phenomena. Here we connect this dynamical picture to the machine-learning description of RC. In the infinite-size limit, ESNs become recurrent kernel machines (RKMs), where the kernel is computed recursively from input time series and no evolving reservoir state remains; nevertheless, the boundary of conditional stability, i.e., the GS/no-GS transition, survives as an exactly computable edge of the kernel recursion. Comparing finite ESNs and RKMs for the Lorenz-96 system and other chaotic systems, we show that the parameters minimizing the prediction error do not coincide with this edge: a gap between the stability boundary and the forecasting optimum persists even in the infinite-width limit, and we discuss its origin in terms of weak GS and bubbling.

Complexity of the Earth's climate system

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Provide a summary of two studies on the complexity of the Earth's climate system based on methods from statistical physics.