Attractor Reconstruction of Spatiotemporal Interpsike Intervals with Application to a Coupled Human-Natural System

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Highly populated coastlines in many locations around the world represent some of the most glaring examples of geophysical systems with strong human interactions. Most commonly, these interactions take the form of altering the plan view position of the coastline through engineered placement of sand on the beach to counteract coastal erosion and enhance property value [1,2]. This process of beach nourishment makes human-occupied coastlines tightly coupled dynamical systems dominated by an array of feedbacks, thresholds, and emergent behaviors characteristic of complex systems [3-5]. While tools developed in nonlinear data analysis such as time series embedding for attractor reconstruction and forecasting [6,7] are becoming more prominent in the analysis of natural systems [8-10], they have yet to be used to analyze coupled human-natural systems. A primary difficulty in applying such data analysis techniques is the lack of data for variables that appropriately capture the long term dynamics of coupled human-natural systems. Furthermore, most embedding techniques tend to be focused on time series; aside from a few examples [11-13], they have not been adjusted for systems that evolve in both time and space. Here, we expand the attractor reconstruction and nonlinear forecasting technique for interspike intervals [14] to account for systems with integrate-and-fire dynamics that are linked in space, and apply this new technique to spatiotemporal data for beach nourishment. Because beach nourishment is often driven by a temporal integration of total net economic benefits for a given town, with a dependence on coastline position [2], we have collected the time between nourishment events in a range of towns that span a large portion of the U.S. East Coast as a data set representative of integrate-and-fire dynamics for a coupled human-coastal system. As an initial demonstration of the efficacy of applying attractor reconstruction to interpsike intervals in space and time, we apply the technique to generic integrate-and-fire data generated from a chaotic spatiotemporal map. We then show results illustrating the degree of nonlinear determinism in beach nourishment practices for different states along the U.S. East Coast as found from attractor reconstruction and forecasting of interspike intervals between nourishment episodes. We also explore using the attractor reconstruction of beach nourishment intervals to measure dynamical stability of the coupled human-coastal system. The implications of this analysis for large-scale management and prediction of human-occupied coastal systems will be discussed.

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