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Low-frequency and intermittent variability of the North Pacific basin revealed through machine learning

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Extratropical atmosphere-ocean systems exhibit variability across a broad range of time scales, including seasonal, interannual, and decadal time scales. There is a strong interest among the climate community in extracting physically-meaningful information about such systems using data from models or observations, with the goal of enhancing our understanding of the underlying dynamics, and improving our predictive capabilities. Here, we develop methods based on machine learning that are able to analyze the strongly-nonlinear, multivariate time series generated by coupled atmosphere-ocean flows to reveal qualitatively-distinct and physically-meaningful spatiotemporal processes. The approach is based on Laplacian eigenmaps evaluated on high-dimensional data after suitable Takens-type embedding, yielding a set of reduced coordinates in which the observed complex signal is decomposed into well-separated families of processes. As an application, we study the variability of the upper-ocean temperature in the North Pacific sector of the CCSM3 model in an 800-year equilibrated control run. Imposing no a priori assumptions (such as periodicity in the statistics), our machine-learning technique recovers three distinct types of temporal processes: (1) the seasonal cycle; (2) decadal-scale variability with spatial patterns resembling the Pacific Decadal Oscillation (PDO); (3) intermittent processes associated with the Kuroshio extension and variations in the strength of the subtropical and subpolar gyres. The latter carry little variance (and are therefore not captured by classical singular spectrum techniques), yet they are expected to be crucial in generating the right dynamics. More generally, the methods presented here can be employed to reveal qualitatively-distinct temporal patterns in complex dynamical systems.