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Extracting and predicting ENSO through Koopman operator analysis

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Koopman operators are a class of operators in dynamical systems theory that govern the temporal evolution of observables. They have the remarkable property of being linear even if the underlying dynamics is nonlinear, and provide, through their spectral decomposition, natural ways of extracting intrinsic coherent patterns and performing statistical prediction. Here, we employ a recently developed framework for data-driven approximation of Koopman operators to extract and predict ENSO from model and observational Indo-Pacific SST data. We show that Koopman eigenfunction analysis recovers the fundamental component of ENSO as a coherent oscillator, as well as a multiscale hierarchy of internal and forced modes of variability on seasonal to decadal timescales. We discuss the modulating relationships between ENSO and other modes in this hierarchy, including the annual cycle, the tropospheric biennial oscillation, and decadal modes in the Indo-Pacific. Using this framework, we perform data-driven probabilistic forecasts of ENSO and its impacts on the hydroclimate, and assess the skill of these forecasts in the presence of climate change.