EGU General Assembly 2024

EGU24-14067, updated on 26 Jan 2025
https://doi.org/10.5194/egusphere-egu24-14067
EGU General Assembly 2024

A Forecast Test for Reducing Dynamical Dimensionality of Model Emulators

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The climate system can be numerically represented by a set of physically-based dynamical equations whose solution requires substantial computational resources. This makes computationally efficient, low dimensional emulators that simulate trajectories of the underlying dynamical system an attractive alternative for model evaluation and diagnosis. We suggest that since such an emulator must adequately capture anomaly evolution, its construction should employ a grid search technique where maximum forecast skill determines the best reference model. In this study, we demonstrate this approach by testing different bases used to construct a Linear Inverse Model (LIM), a stochastically-forced multivariate linear model that has often been used to represent the evolution of coarse-grained climate anomalies in both models and observations. LIM state vectors are typically represented in a basis of the leading Empirical Orthogonal Functions (EOFs), but while dominant large-scale climate variations often are captured by a subset of these statistical patterns, key precursor dynamics involving relatively small scales are not. An alternative approach is balanced truncation, where the dynamical system is transformed into its Hankel space, whose modes span both precursors and their subsequent responses. Constructing EOF- and Hankel-based LIMs from monthly observed anomalous Pacific sea surface temperatures, both for the 150-yr observational record and a perfect model study using 600 yrs of LIM output, we find that no balanced truncation model of any dimension can outperform an EOF-based LIM whose dimension is chosen to maximize independent skill. However, the dynamics of a high-dimensional EOF-based LIM can be efficiently reproduced by far fewer Hankel modes.