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Early warning of atmospheric regime transitions using transfer operators

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The existence of persistent midlatitude atmospheric regimes, such as blocking events, with time scales larger than 5-10 days and indications of preferred transition paths between them motivates the development of early-warning indicators of regime transitions.

Here, we use a barotropic model of the northern midlatitudes winter flow to study such meta-stable regimes. We look at estimates of transfer operators acting on densities evolving on a reduced phase space spanned by the first Empirical Orthogonal Functions of the streamfunction and develop an early-warning indicator of zonal to blocked flow transition.

The study of the spectra of transfer operators estimated for different lags reveals a multi-level structure in the flow as well as the effect of memory on the reduced dynamics due to past interactions between the resolved and unresolved variables. The slowest motions in the reduced phase space are thereby found to have time scales larger than 8 days and to behave as Markovian for larger lags. These motions are associated with meta-stable regimes and their transitions and can be detected as almost-invariant sets of the transfer operator.

The early-warning indicator is based on the action on an initial density of products of the transfer operators estimated for sufficiently long lags, making use of the semi-group property of these operators and shows relatively good Peirce skill score.

From the energy budget of the model, we are able to explain the meta-stability of the regimes and the existence of preferred transition paths as the manifestation of barotropic instability.

Finally, even though the model is highly simplified, the skill of the early warning indicator is promising, suggesting that the transfer operator approach can be used in parallel to an operational deterministic model for stochastic prediction or to assess forecast uncertainty.