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Pullback attractors of a low-order ocean model subject to deterministic and random forcing

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A low-order quasigeostrophic model captures key features of intrinsic low-frequency variability of the oceans' wind-driven circulation. This double-gyre model is used as a prototype of an unstable and nonlinear dynamical system with time-dependent forcing to explore basic features of climate change in the presence of natural variability. The present study relies on the theoretical framework of nonautonomous dynamical systems and of their pullback attractors (PBAs), namely the time-dependent invariant sets that attract all trajectories initialized in the remote past. Ensemble simula-tions help us explore these PBAs.

The chaotic PBAs of the periodically forced model are found to be cyclo-stationary and cyclo-ergodic. The model's response to periodic forcing turns out to be, in most cases, very sensitive to the initial state. We assess the convergence of trajectories to this PBA by computing the probability density function (PDF) of trajectory localization in the model's phase space. The dependence of the attracting sets on the choice of the ensemble of initial states is analyzed in detail. The extension to random dynamical systems is described and connected to the model's autonomous and periodically forced behavior. A standard Van der Pol oscillator is used to help explain the co-existence in the phase space of a quasi-periodic PBA and a chaotic PBA, for periodically forced systems that are close to a hamiltonian skeleton; this simple example shares key dynamical features with our low-order ocean model.