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Transition Probabilities of Wind-driven Ocean Flows

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The quasi-geostrophic wind-driven double-gyre ocean circulation in a midlatitude rectangular basin is a multi-stable system. Under time-independent forcing, the number of steady states is controlled by the Reynolds number. For a specific range of Reynolds numbers, at least two stable steady states exist. In the quasi-geostrophic model, sub-grid scale processes are usually heavily parameterised, either by deterministic or stochastic representation. In the stochastic case, noise-induced transitions between the steady states may occur.

A standard method to determine transition rates between different steady states is a Monte Carlo approach. One obtains sufficient independent realisations of the model and simply counts the number of transitions. However, this Monte Carlo approach is not well-suited for high-dimensional systems such as the quasi-geostrophic wind-driven ocean circulation. Moreover, when transition probabilities are rare, one needs long integration times or a large number of realisations.

Here we propose a new method to determine transition rates between steady states, by using Dynamically Orthogonal (DO) field theory. The stochastic dynamical system is decomposed using a Karhunen-Loéve expansion and separate problems arise for the ensemble mean state and the so-called time-dependent DO modes. Each DO mode has a specific probability density function, which represents the probability in that direction of phase space. In the case of two steady states, at least one of the DO modes has a bimodal distribution. We analyse transition probabilities using this specific DO mode, which is more efficient compared to the ordinary Monte Carlo approach. We will present the general method and show results for transition probabilities in the quasi-geostrophic wind-driven double-gyre ocean circulation.