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Dynamical Landscape and Noise-induced Transitions in a Box Model of the Atlantic Meridional Overturning Circulation

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The multistability of the Atlantic Meridional Overturning Circulation (AMOC) challenges the predictability of long-term climate evolution. In light of an observed weakening in AMOC strength, it is crucial to study the probabilities of noise-induced transitions between the different competing flow regimes. From a dynamical systems perspective, the phase space of a multistable system can be characterised as a non-equilibrium potential landscape, with valleys corresponding to the different basins of attraction. Knowing the potential, one can infer the statistics and pathways of noise-induced transitions. Particularly, in the weak-noise limit, transition paths lead through special regions of the basin boundaries, called Melancholia states. Recent studies have applied these concepts to climate models of low and intermediate complexity. Here, we investigate the quasi-potential landscape of a three-box model of the AMOC, based on the popular model by Rooth. We analyse noise-induced transitions between the two stable circulation states and elucidate the role of the Melancholia state. Forcing the model with different noise laws, which represent fluctuations caused by different physical processes, we discuss how the properties of transitions change when considering non-Gaussian processes, specifically Lévy noise. Simulated transition rates are related to their theoretical values using the quasi-potential landscape. Our results yield a comprehensive picture of the dynamical properties of an inter-hemispheric three-box AMOC model under stochastic forcing. By relating the deterministic structure of this simple model to the statistics of critical transitions, we hope to build a basis for transferring this approach to more complex models of the AMOC.