QUANTIFYING TIPPING BEHAVIOR: GEOMETRIC EARLY WARNINGS AND QUASIPOTENTIALS FOR A BOX MODEL OF AMOC

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A non-autonomous system can undergo a rapid change of state in response to a small or slow change in forcing, due to the presence of nonlinear processes that give rise to critical transitions or tipping points. Such transitions are thought possible in various subsystems (tipping elements) of the Earth's climate system. The Atlantic Meridional Overturning Circulation (AMOC) is considered a particular tipping element where models of varying complexity have shown the potential for bi-stability and tipping. We consider both transient and stochastic forcing of a simple but data-adapted model of the AMOC. We propose and test a geometric early warning signal to predict whether tipping will occur for large transient forcing, based on the dynamics near an edge state. For stochastic forcing, we quantify mean times between noise-induced tipping in the presence of stochastic forcing using an Ordered Line Integral Method (OLIM) of Cameron (2018) to estimate the quasipotential. We calculate minimum action paths (MAPs) between stable states for various scenarios. Finally, we discuss the problem of finding early warnings in the presence of both transient and stochastic forcing.