Model hierarchies and bifurcations in QE monsoon models

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The convective quasi-equilibrium (CQE) framework has been successfully employed in the past to build intermediate complexity models accounting for the interaction of convection and large-scale dynamics (Neelin and Zeng, 1999, JAS). As a consequence, these models find use in the study of monsoon circulations, which also experience abrupt onset among several other intriguing features. While some low-order simplifications of CQE based Quasi-equilibrium tropical circulation model (QTCM) yields insights into the mechanisms of monsoon dynamics, they are restricted in the range of processes accounted for. A hierarchy of models, on the other hand, would serve well to study monsoon dynamics and various influences. While the existence of bifurcations or 'tipping-points' in monsoon dynamics has been studied for certain simple models, a thorough investigation of this possibility across a hierarchy of models is absent. Such a hierarchy of models would provide an understanding of effects of different simplifying assumptions on dominant balances in the momentum and thermodynamic equations and resulting nonlinear dynamics, including the choice of precipitation parameterizations. This study explores a hierarchy of such models of varying complexity, based on the QTCM equations. The potential occurrence of bifurcation phenomena are considered, along with their sensitivity to various parameter changes, in the context of the role of different nonlinearities present in these models. The study builds on recent results interpreting the suppression of bifurcation phenomena in these models, as a result of shifts in equilibrium branches and consequently their physical relevance. The hierarchy of models approach, in this context, reconciles apparent contradictions between bifurcations being observed in the simplest models and the evidence from more complex models as well as observations, while identifying robust phenomena.