Convective quasi-equilibrium and tipping points

- The onset of South Asian monsoon is a major research interest, and a range of models have been studied to address major questions, including presence or absence of tipping points.
- Interaction between convection in convective zones and large scale dynamics is a defining aspect of monsoon system.
- Quasi-equilibrium Tropical Convective Model (QTCM), a versatile model of intermediate complexity permits various simplifications via assumptions, leading to a hierarchy of models.
- QTCM PDES use convective approximations to simulate dynamics in the non-convective regions, using tailored basis functions for the momentum, thermodynamics, and moisture variables.
- Broadly, QTCM PDES relate radiative energy input to nonlinear advection of momentum, temperature, and moisture, thermal and moisture stratification effects, precipitation parameterization coupling the thermodynamic and moisture equations.

Model hierarchy

- Assumptions to yield a hierarchy of models- neglect of zonal velocity components, isolation of baroclinic components and neglecting barotropic ones, neglect of rotation, no nonlinear advection of momentum etc.
- Common elements to all models- baroclinic meridional velocity equation, thermodynamic and moisture equation with nonlinear advection of respective fields and stratification terms, and a Heaviside based precipitation formulation. → standard /minimal model used in the study.

- Use of Finite difference based single column framework yields various sets of ODEs (see Kumar S.K. and Seshadri A.K. 2022) A Land-Ocean-Ocean-Monsoon (LOOM) column is considered. Equilibria for the steady state form of equations found for two cases of the Heaviside function- zero precipitation (pink curves) and non-zero precipitation (red curves)- with different equilibria being indicated as:
  - Zero precipitation (pink curve).
  - Non-zero precipitation (red curve).
- Partial suppression of nonlinear advection still preserves the saddle-node structures, with lower a-only changing the equilibrium values quantitatively, and change in bifurcation points
- Inclusion of rotation in model also leads to only quantitative changes. Inclusion of rotation leads to a fourth ODE- zonal baroclinic velocity equations. The meridional velocity is only quantitatively affected due to the linear nature of the two momentum equations.

Nonlinear advection of temperature, changed boundaries

- The results are for a varied boundary condition, LOOM with non-zero zonal gradients. Consequently the zonal velocity could be stronger than for the LOO case.
- The panels show the bifurcation diagrams for change in nonlinear advection coefficient ($a_T$) in thermodynamic equation, reduced from 100 % of its default value to lower values. Note that the choice of boundaries (LOOM) leads to zero zonal gradients.
- Partial suppression of nonlinear advection still preserves the saddle-node structures, with lower a-only changing the equilibrium values quantitatively, and change in bifurcation points
- Inclusion of rotation in model also leads to only quantitative changes. Inclusion of rotation leads to a fourth ODE- zonal baroclinic velocity equations. The meridional velocity is only quantitatively affected due to the linear nature of the two momentum equations.

Nonlinear advection of Moisture, changed boundaries

- The appearance of third equilibrium (an unfolding of pitchfork bifurcation, see Kumar S.K. and Seshadri A.K., 2022) is also not affected by the changes, similar to case of change in $a_T$.
- Broadly, change in boundary conditions seems to have brought only a quantitative change
- Advection term in moisture equation seems to affect cubic term in the equilibrium equation and hence change in the qualitative form with change in $a_T$.

Summary

- QTCM based models can form a hierarchy of models which can be used to study monsoon dynamics at different levels of complexity
- The nonlinear advection of moisture seems to drive appearance of a third equilibrium, in addition to the saddle node equilibria. This is in contrast to nonlinear advection of temperature.
- It is seen that a change in model complexity does not seem to change dynamics qualitatively, chiefly due to linear nature of momentum equation used.
- Thus, a change in model complexity is closely dependent on included nonlinearities to exhibit a change in dynamics.

References:


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