

Covariant Lyapunov Vectors of a Quasi-geostrophic Baroclinic Model: Analysis of Instabilities and Feedbacks

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The classical approach for studying atmospheric variability is based on defining a background state and studying the linear stability of the small fluctuations around such a state. Weakly non-linear theories can be constructed using higher order expansions terms. While these methods have undoubtedly great value for elucidating the relevant physical processes, they are unable to follow the dynamics of a turbulent atmosphere. We provide a first example of extension of the classical stability analysis to a non-linearly evolving quasi-geostrophic flow. The so-called covariant Lyapunov vectors (CLVs) provide a covariant basis describing the directions of exponential expansion and decay of perturbations to the non-linear trajectory of the flow. We use such a formalism to re-examine the basic barotropic and baroclinic processes of the atmosphere with a quasi-geostrophic beta-plane two-layer model in a periodic channel driven by a forced meridional temperature gradient ΔT . We explore three settings of ΔT , representative of relatively weak turbulence, well-developed turbulence, and intermediate conditions. We construct the Lorenz energy cycle for each CLV describing the energy exchanges with the background state. A positive baroclinic conversion rate is a necessary but not sufficient condition of instability. Barotropic instability is present only for few very unstable CLVs for large values of ΔT . Slowly growing and decaying hydrodynamic Lyapunov modes closely mirror the properties of the background flow. Following classical necessary conditions for barotropic/baroclinic instability, we find a clear relationship between the properties of the eddy fluxes of a CLV and its instability. CLVs with positive baroclinic conversion seem to form a set of modes for constructing a reduced model of the atmosphere dynamics.