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Scale Separation of the Dominating Linear Instability Modes and the Background State in a Primitive Equation Model

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The classic linear mode theory explains the most important instability mechanism leading to the appearance of cyclones in the mid-latitudes atmosphere. It is typically based on quasi-geostrophic approximation and the expansion is performed around a fixed point corresponding to a stationary state. We study here the linear instability of an atmosphere described by primitive equations and consider a chaotic background state.
We use the PUMA model, describing a dry atmosphere driven by Newtonian cooling. Note that the leading instability is the first mode of a covariant basis - called the covariant Lyapunov vectors (CLVs) - which captures the full spectrum of linear stable and unstable linear perturbations of the chaotically evolving atmosphere.
We investigate three different horizontal resolutions (T21, T42, T84) without orography. By using classic diagnostic tools for the general circulation, e.g. the Lorenz energy cycle and spectral analysis, we quantify how the general circulation changes due to the increasing resolution. As expected, we find small adjustments of the properties of the flow but no major changes. For the leading instability mode we find that when reaching the highest considered resolution, a sudden jump into meso-scale regime is found, thus showing that the unbalanced dynamics becomes relevant. Instead, the climatology of the model is only weakly affected by the increase in the resolution, because it is mostly determined by quasi-geostrophic modes. The methodology proposed here allows for systematically testing the various dynamical instabilities occurring in the atmosphere at different spatial and temporal resolutions.