Geophysical Research Abstracts
Vol. 15, EGU2013-2104, 2013
EGU General Assembly 2013

A framework for evaluating model error using asymptotic convergence in the Eady model

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Operational weather forecasting requires the accurate simulation of atmospheric motions on scales ranging from the synoptic down to tens of kilometers. Weather fronts, ubiquitous of mid-latitude weather systems, are generated through baroclinic instability on the large scale but are characteristically “sharp” features in which temperature and winds can vary rapidly on the short scale.

The Eady model of baroclinic instability, Eady (1949), captures the important aspects of the frontogenesis process in an idealised system. Discontinuous solutions arise in finite time from an initially smooth, large scale flow. Long term solutions have been shown using the semigeostrophic equations and a fully Lagrangian model, Cullen (2007), which exhibit multiple lifecycles after the initial frontogenesis. Previous Eulerian solutions have relied on the addition of explicit viscosity to continue past the point at which the front collapses down to the scale of the grid spacing, e.g. Snyder et al. (1993), Nakamura (1994), but the artificial diffusion renders the subsequent lifecycles much less pronounced.

We present a framework for evaluating model error in terms of asymptotic convergence using the Eady model; by rescaling in one spatial dimension we are able to approach solutions of a balanced model, given by the semi-geostrophic equations, using the non-hydrostatic, incompressible Euler-Boussinesq Eady equations. Using this approach we are able to validate the numerical implementation and assess the long term performance in terms of solution lifecycles.

We present results using a finite difference method with semi-implicit time-stepping and semi-Lagrangian transport, and show that without any explicit viscosity we are able to proceed past the point of frontal collapse and recover the theoretical convergence rate. We propose that artificial diffusion of potential vorticity after collapse is detrimental to the long term evolution of the solution.