New idealized test cases for dynamical cores

Christiane Jablonowski (cjablono@umich.edu)
University of Michigan

PDEs on the Sphere Workshop, Toronto
8/12/2002

Overview

- Introduction of the test suite - basic ideas
- Initial data set
- Characteristics of the initial conditions
- Test strategy
- Results of the model intercomparison (4 models)
  - Balanced initial state
  - Baroclinic wave test
- Wrap-up

Basic idea & Design goals

- Goal: development of a new dynamical core test (without physics, dry & prescribed orography) that
  - is easy to apply
  - is idealized but as realistic as possible
  - gives quick results
  - starts from an analytic initial state, suitable for all grids
  - triggers the evolution of a baroclinic wave
- Designed for primitive equation models with pressure-based vertical coordinates (hybrid, sigma or pure pressure coordinate)

Derivation of the test case

- Initial data required: u, v, T, p_s, ϕ_s
- Find a steady-state, balanced solution of the PE equations: **prescribe the wind speeds u & v and surface pressure p_s**
- Plug prescribed variables into PE equations and derive the
  - **Geopotential field:** based on the momentum equation for v (integrate), calculate surface geopotential

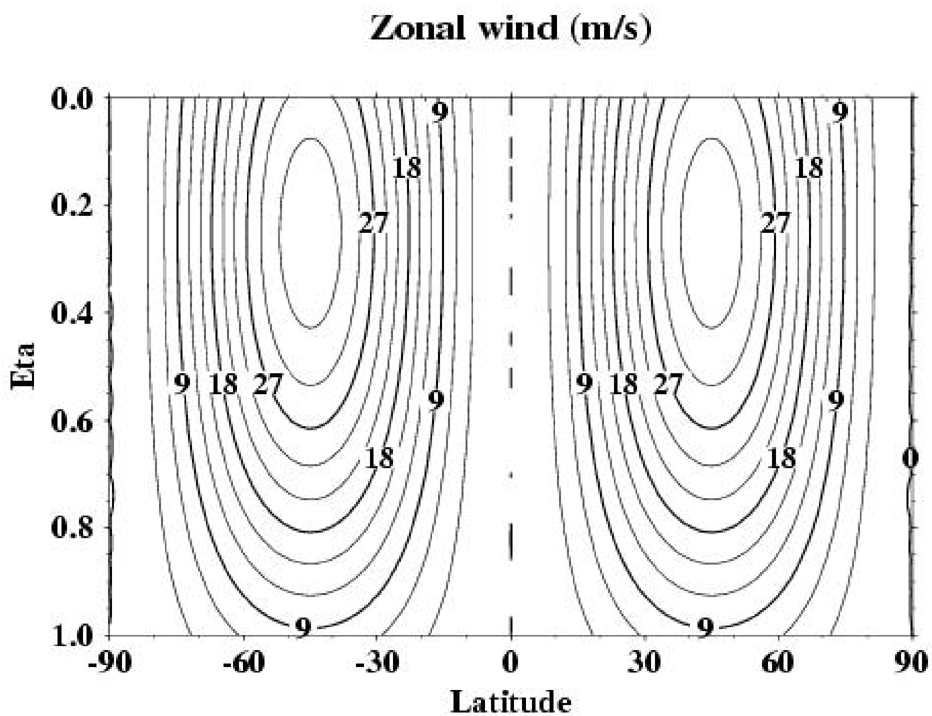
$$\frac{dv}{dt} + \frac{(u^2 \tan(\varphi))}{a} = -1/a\left(\frac{(\partial \phi)}{(\partial \varphi)} + RT\frac{(\partial \ln(p))}{(\partial \varphi)}\right) - fu$$

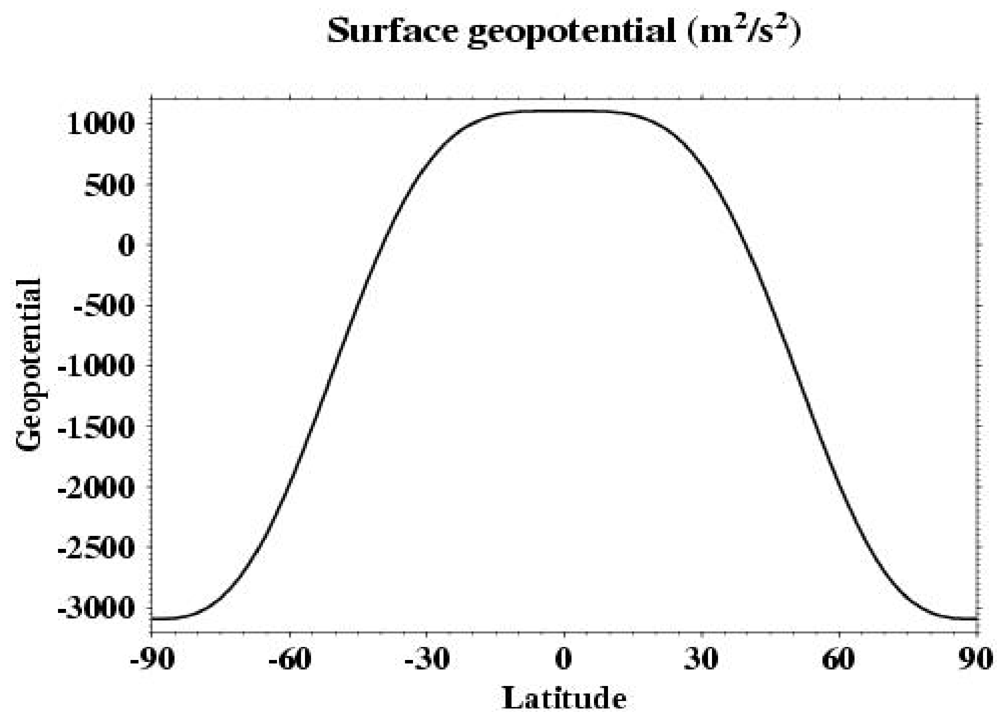
  - **Temperature field:** based on the hydrostatic equation

$$\frac{(\partial \phi)}{(\partial \varphi)} = -R\frac{T}{p}\frac{(\partial\ p)}{(\partial \eta)}$$

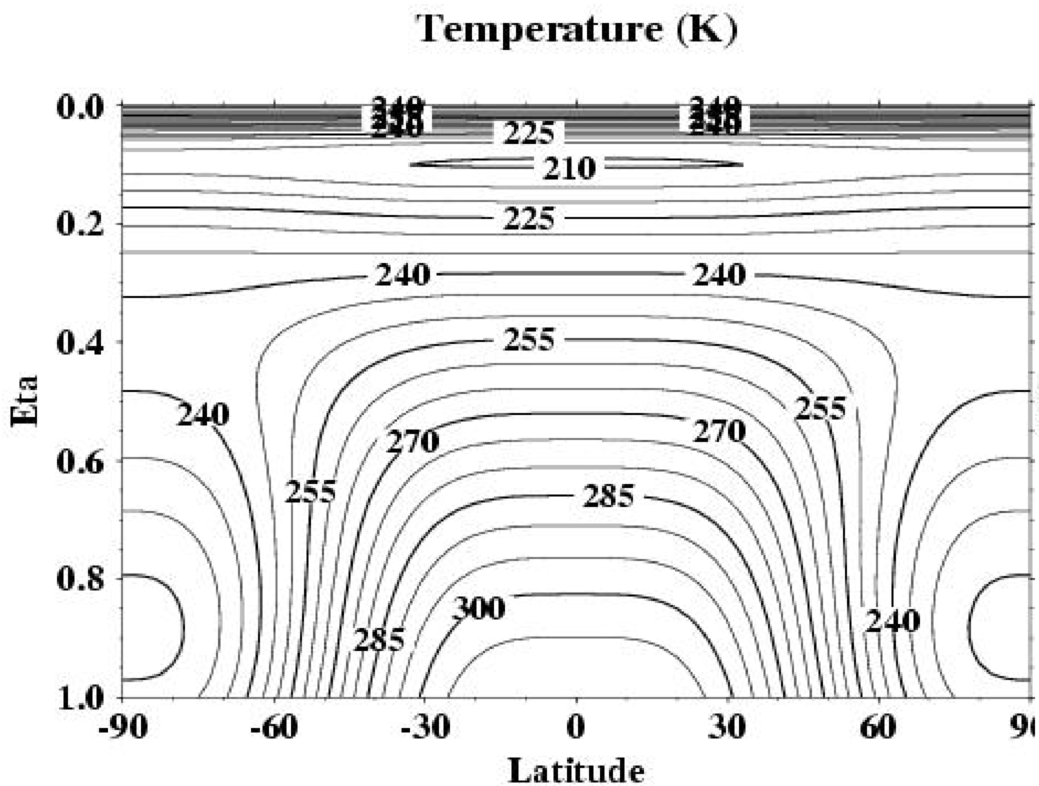
The initial data set

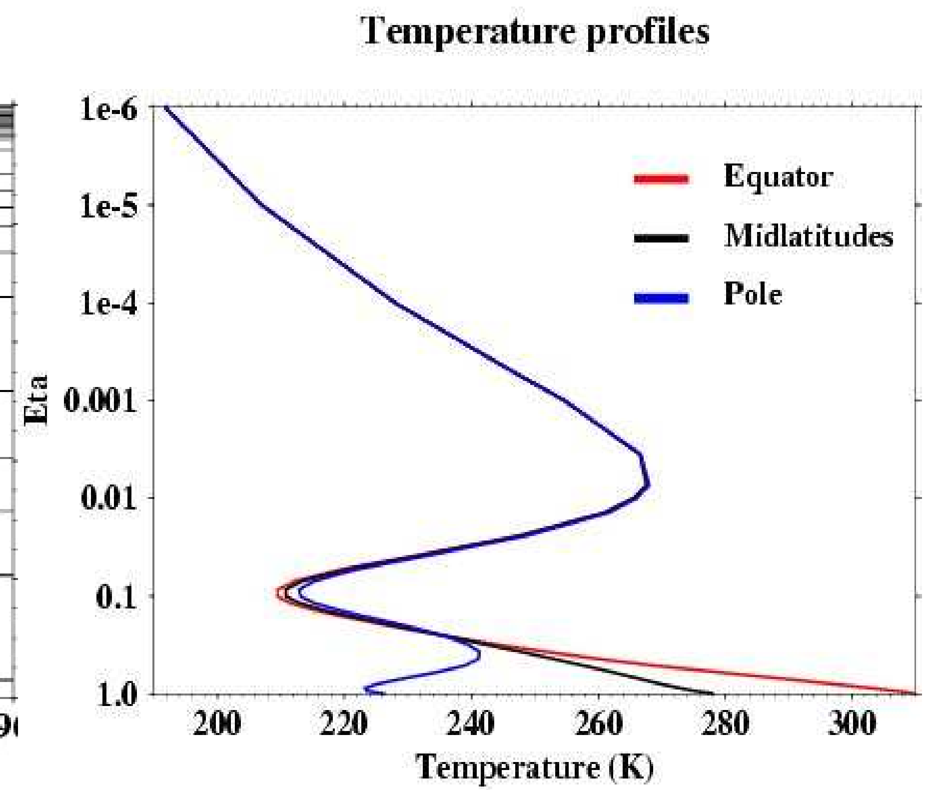
$v = 0$ m/s
$p_s = 1000$ hPa





Initial temperature profile





Characteristics of the initial conditions

Instability mechanisms:

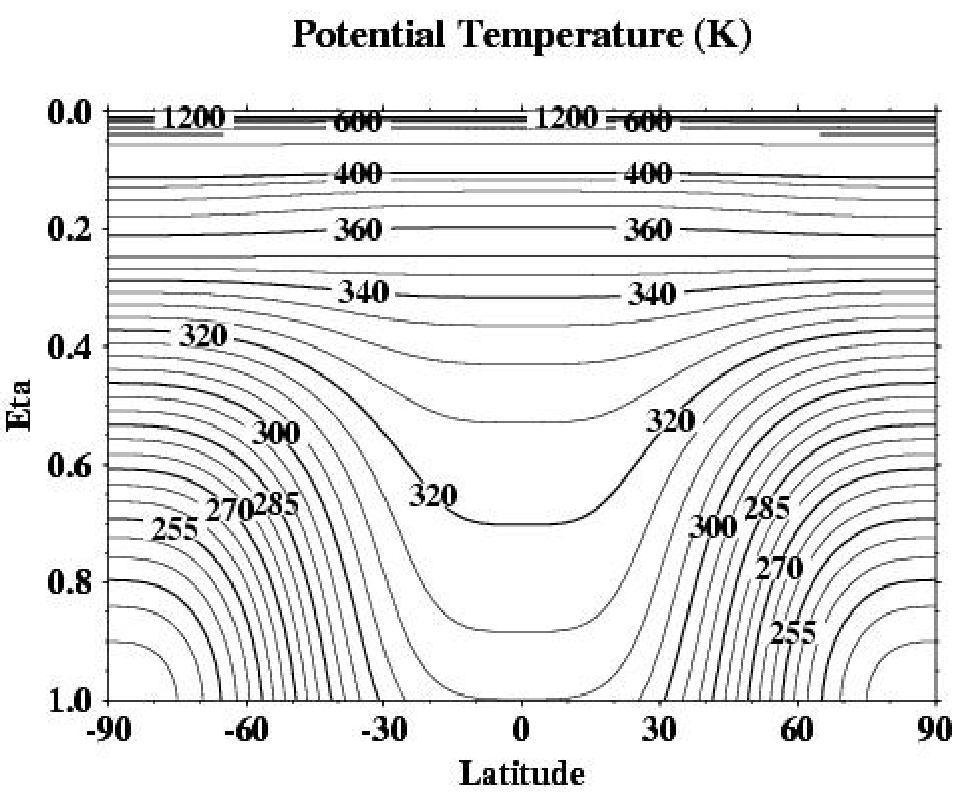
- Baroclinic instability - vertical wind shear
- Barotropic instability - horizontal wind shear

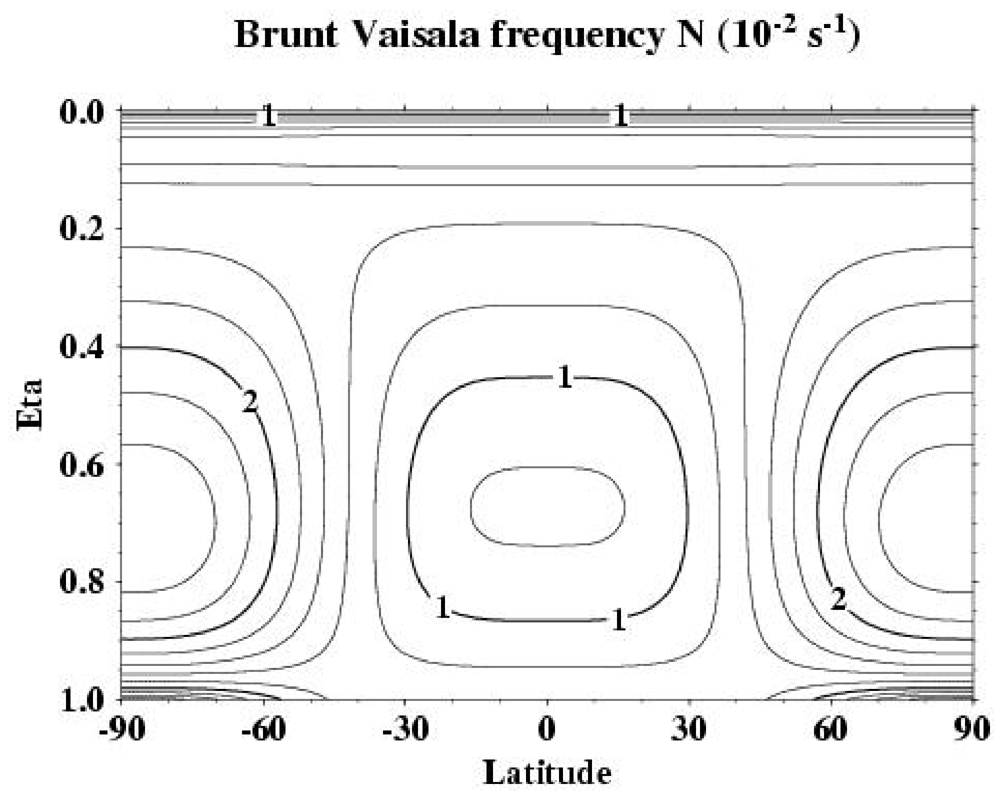
But:

- Statically stable
- Inertially stable
- Symmetrically stable

Characteristics of the initial conditions (IC)

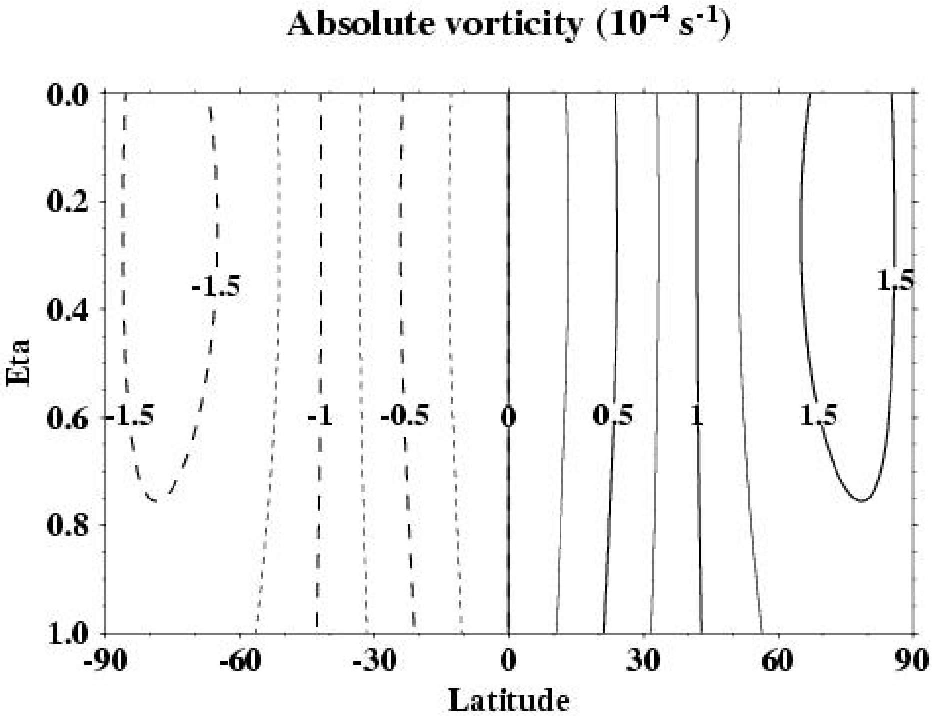
- **Static stability**



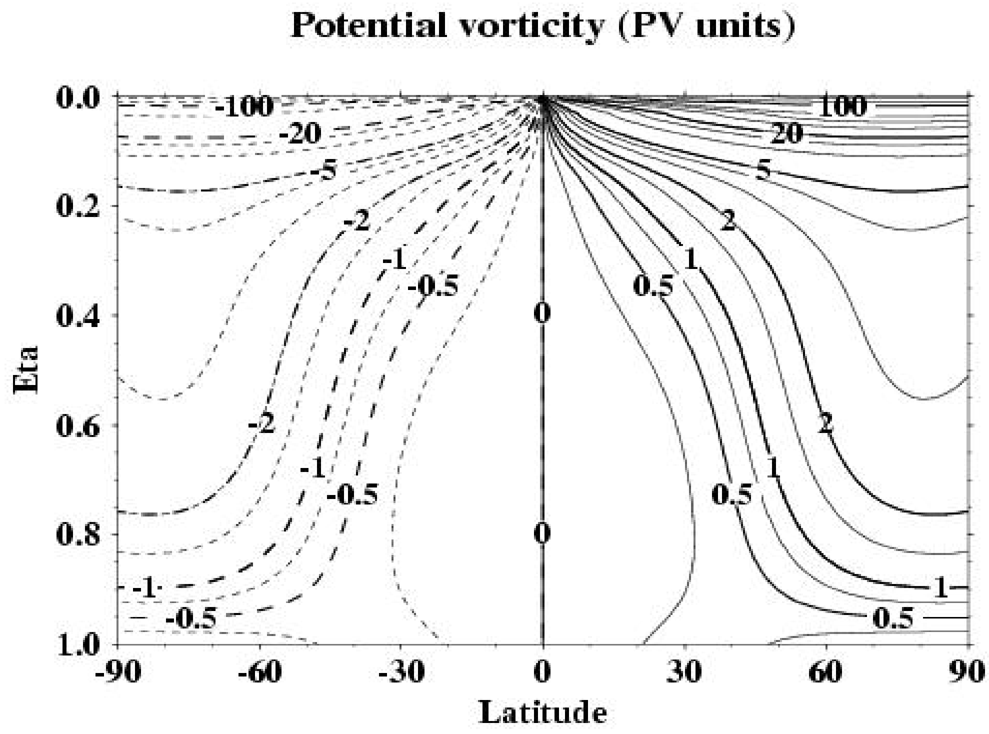


Characteristics of the IC: Stability properties

- **Inertial stability**



- **Symmetric stability**



Test strategy

Step 1

- Initialize the dynamical core with the analytic initial conditions (balanced & steady state)
- Let the model run over 30 days (if possible without diffusion)
- Does the model stay stable ?

Step 2

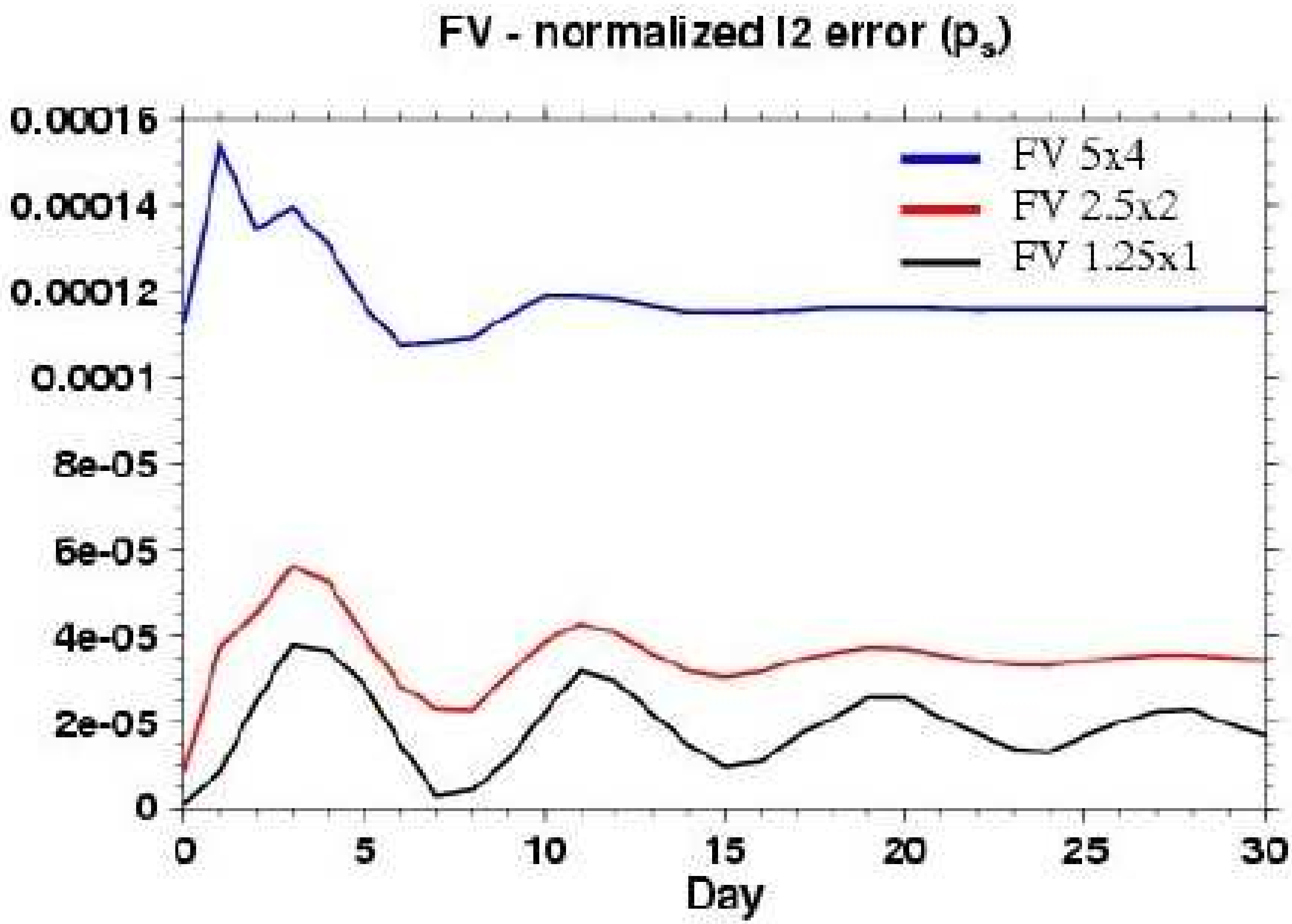
- Perturb the initial conditions with small, but well-resolved Gaussian hill perturbation
- 30-day simulation: Evolution of a baroclinic wave

Model intercomparison

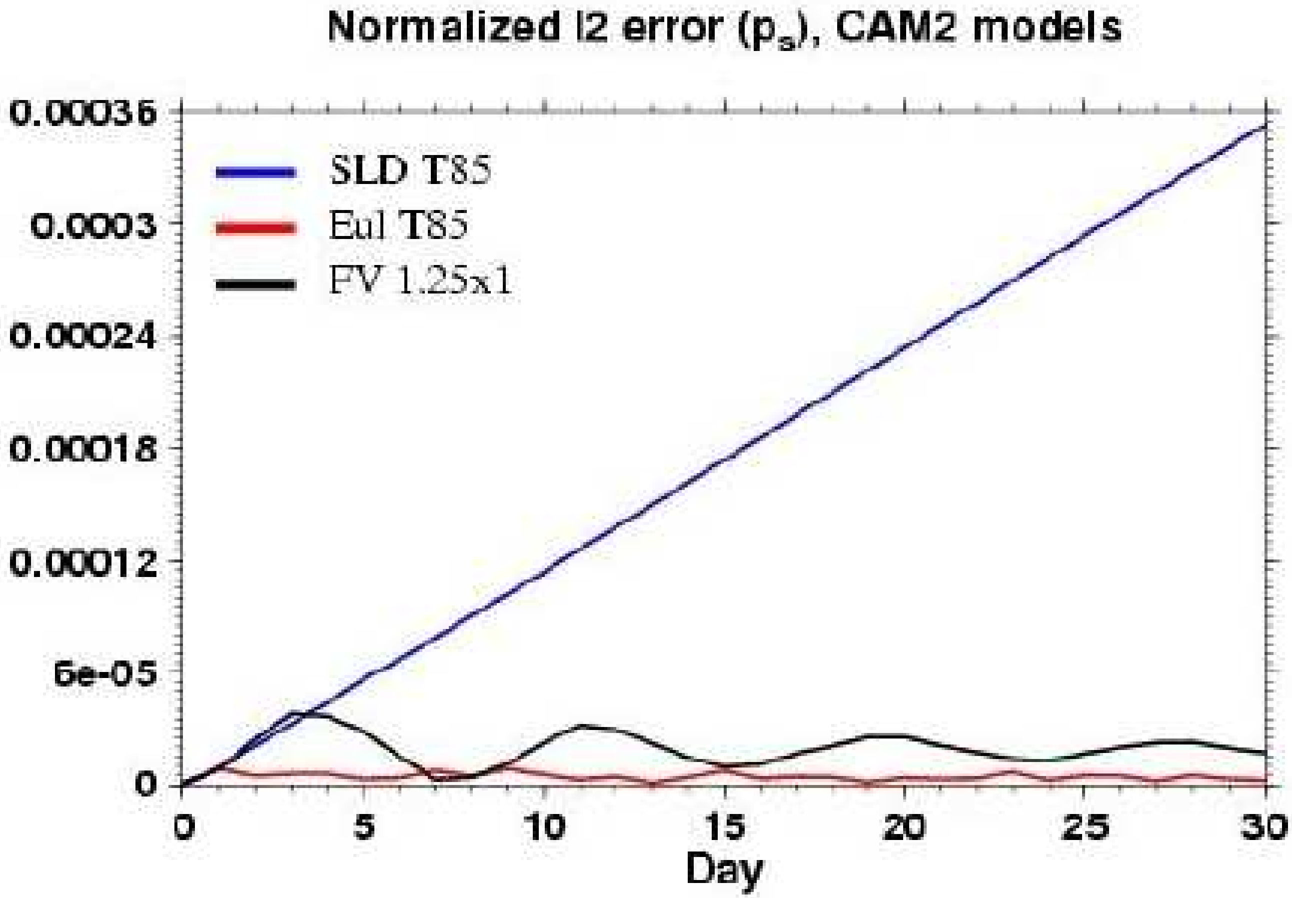
- **NCAR CAM2 framework:**
  - Eulerian dynamical core (Eul), spectral
  - Semi-Lagrangian (SLD), spectral
  - Finite Volume (FV) dynamical core (NASA/GSFC)
- **GME:**
  - Icosahedral model of the German Weather Service (DWD)
- **Resolutions:** T170, T85, T42, T21 with 26 hybrid levels

Balanced initial state: Convergence study

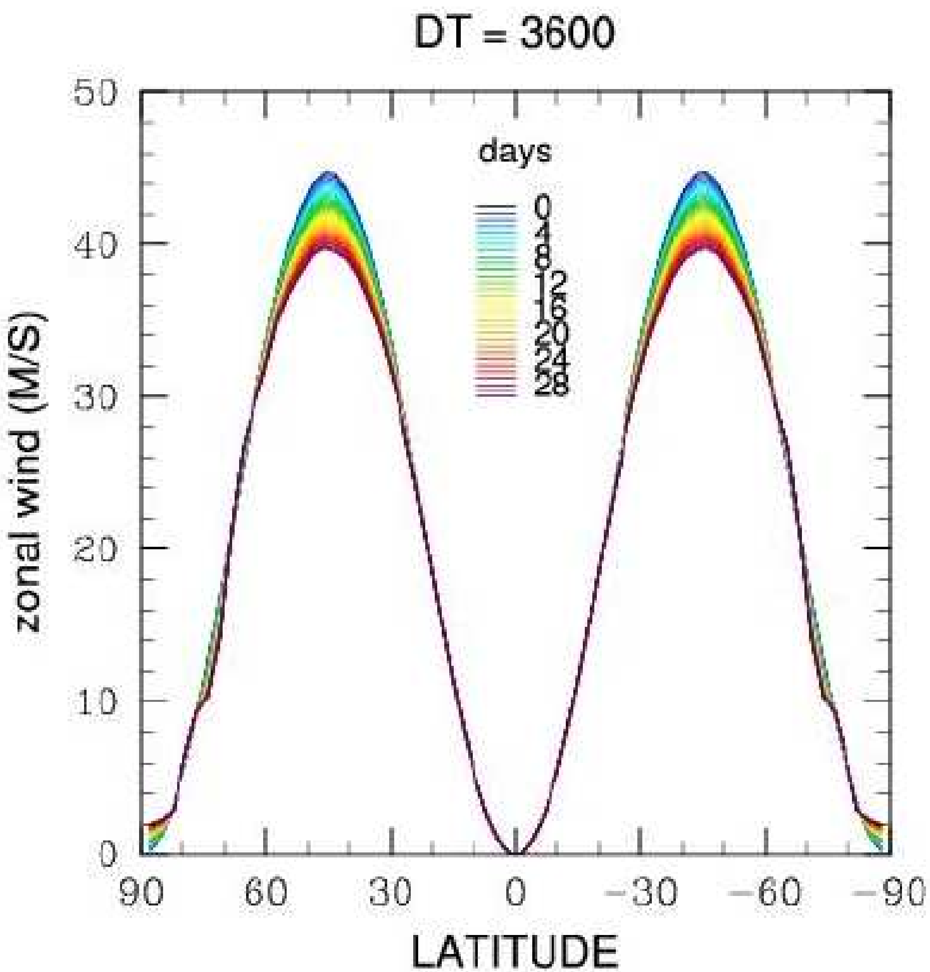
Initial state is the true solution:



Balanced initial state: Intercomparisons



Balanced initial state: Problem areas

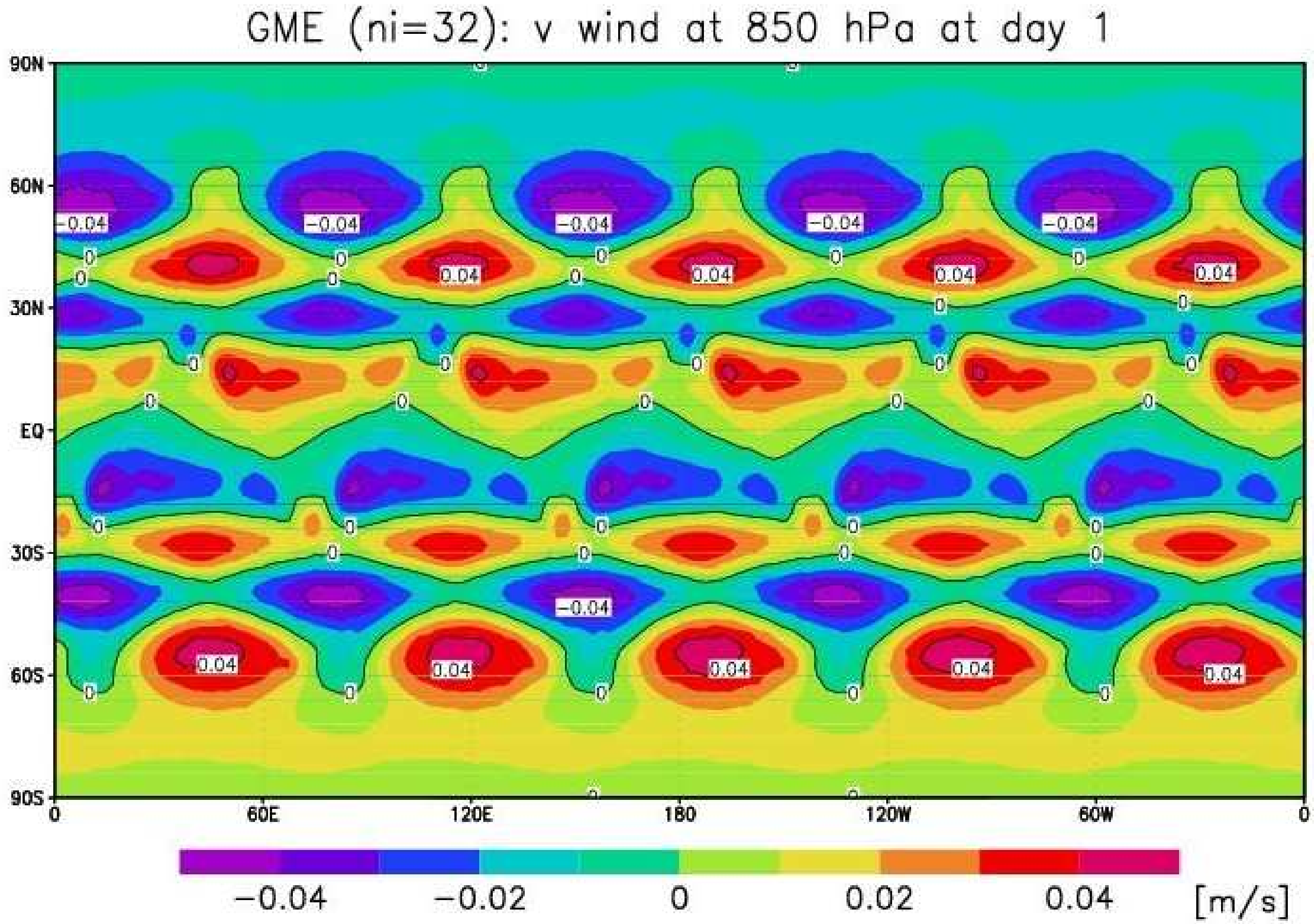


Zonal-mean **zonal wind u decreases over time** in an old version of the SLD dynamical core

(here at jet level 250hPa with different version of the test)

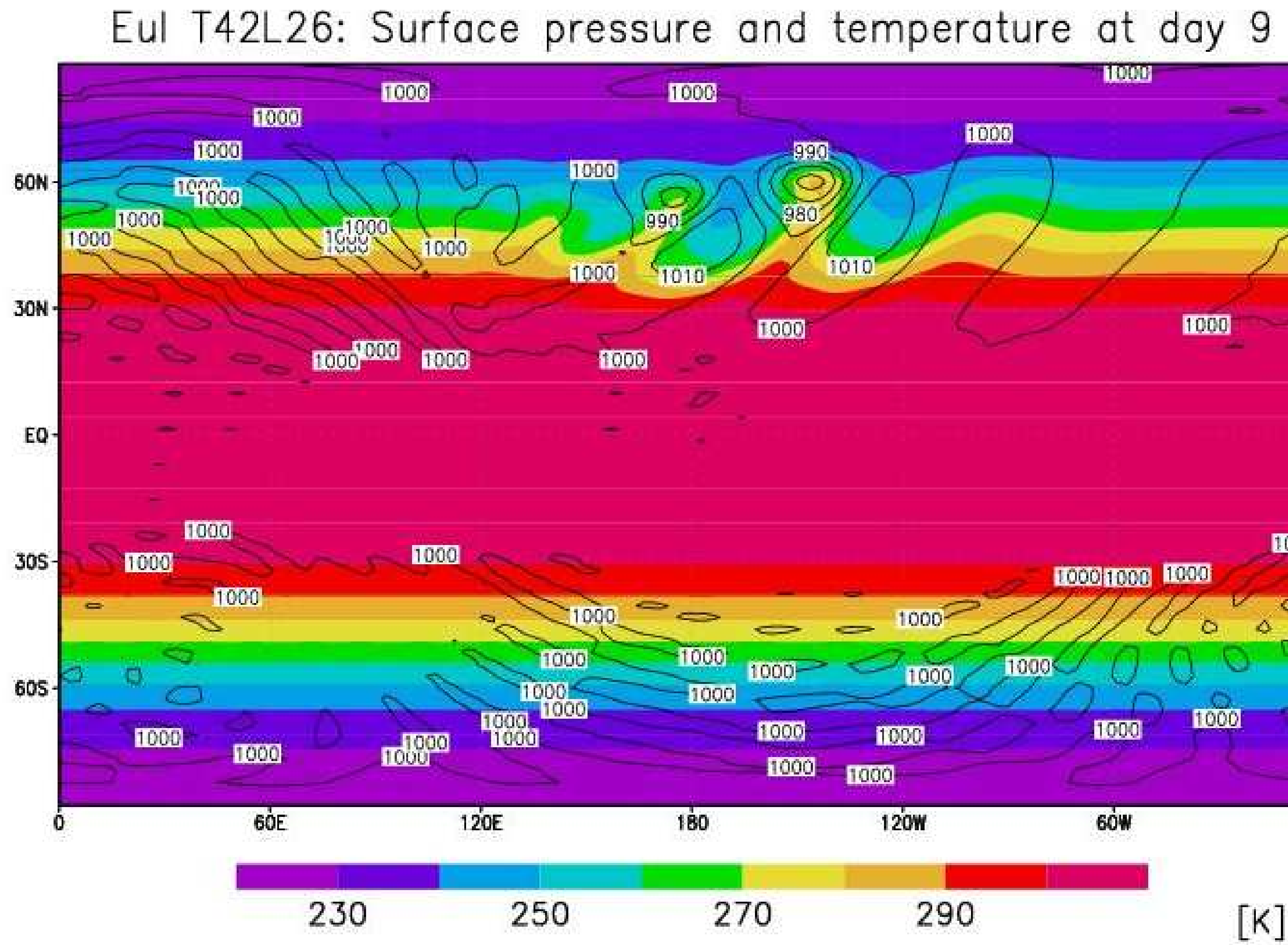
Balanced initial state: Special effects

GME shows a truncation error with wavenumber 5 structure



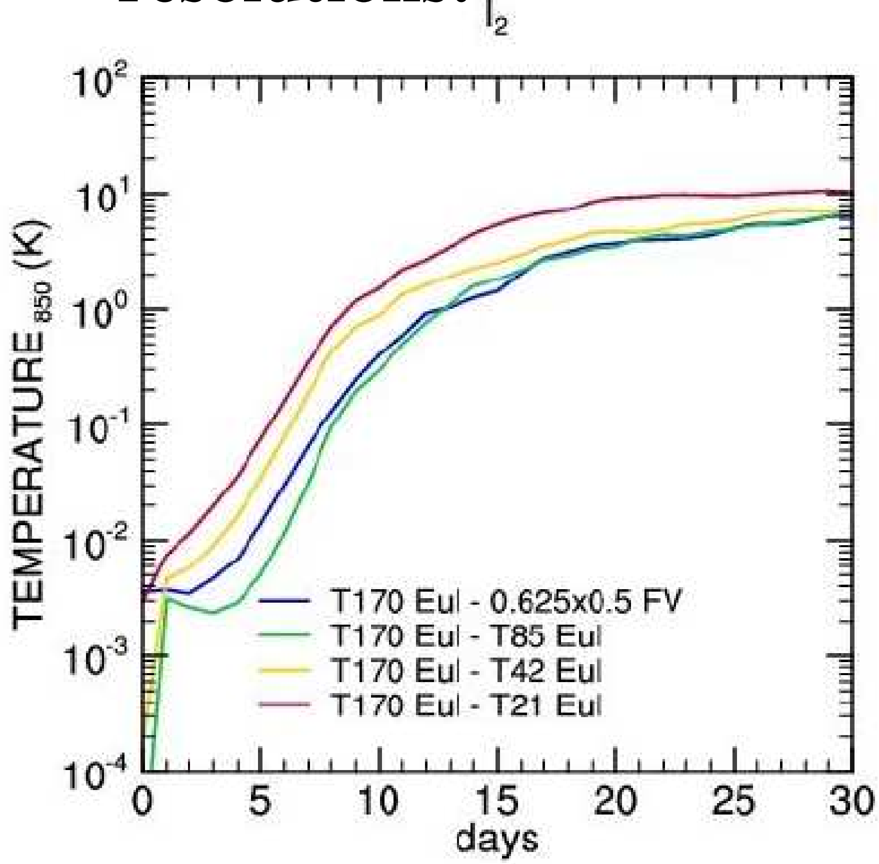
Baroclinic wave test

Strong temperature fronts, low and high pressure systems in the NH

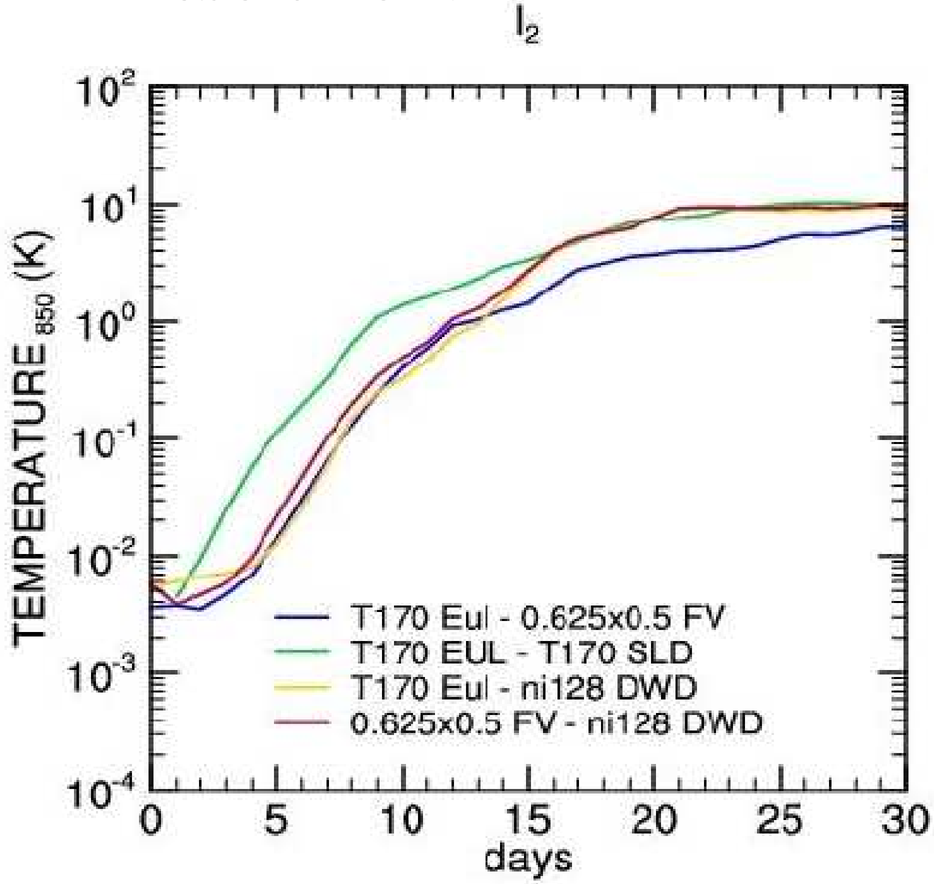


Baroclinic wave - Convergence & Uncertainty

Eulerian at different resolutions:

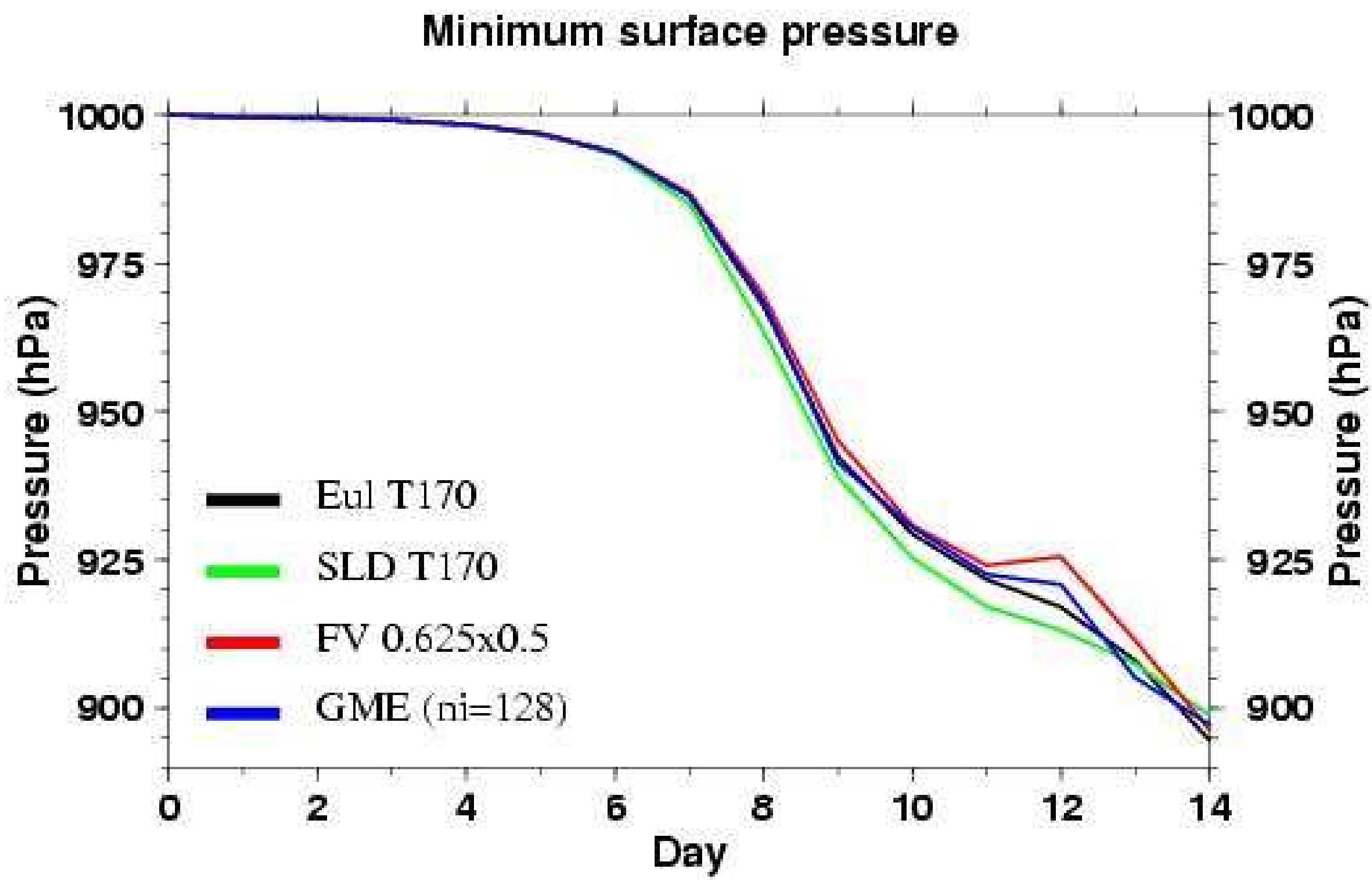


All models at highest resolution:

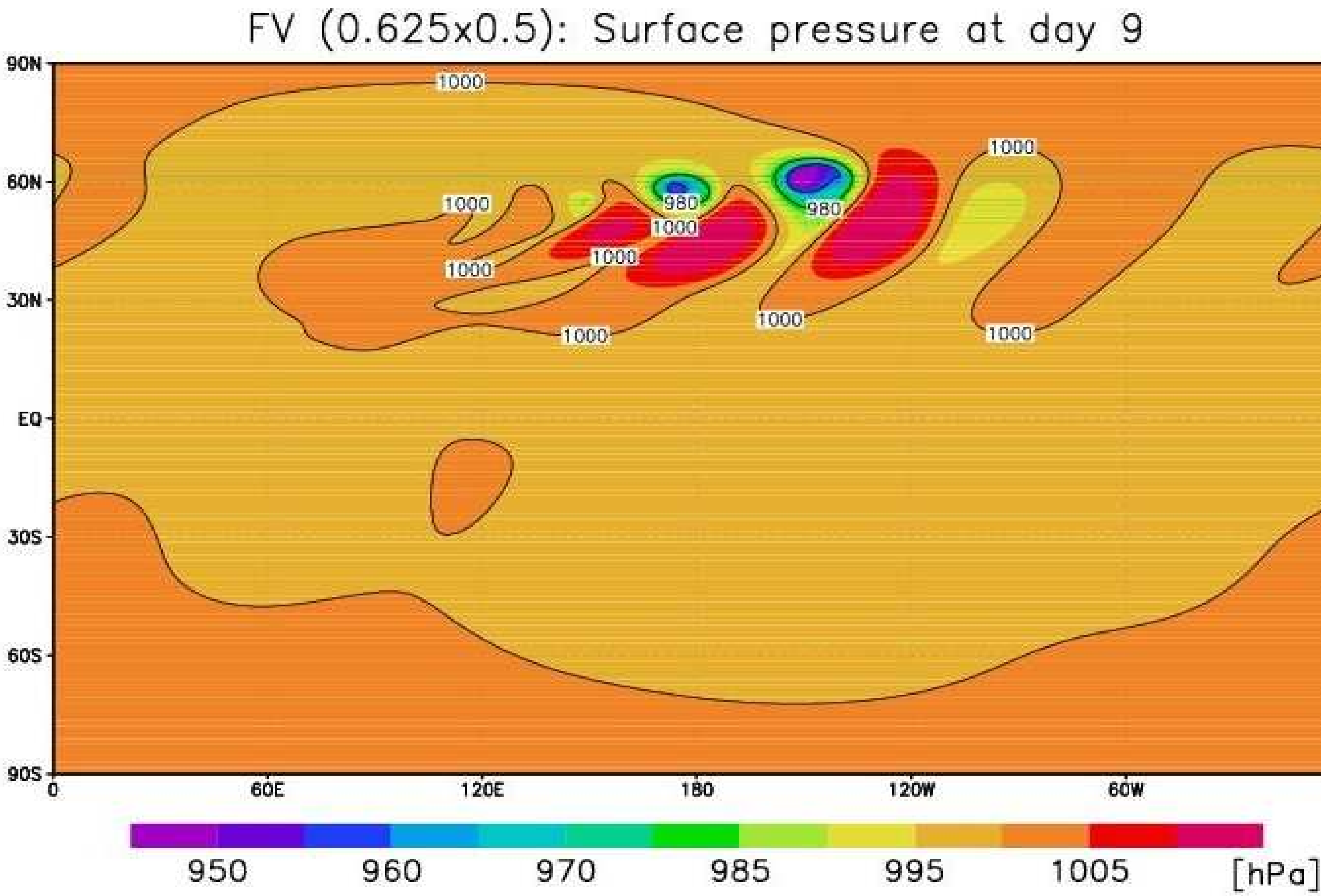


Baroclinic wave: Convergence

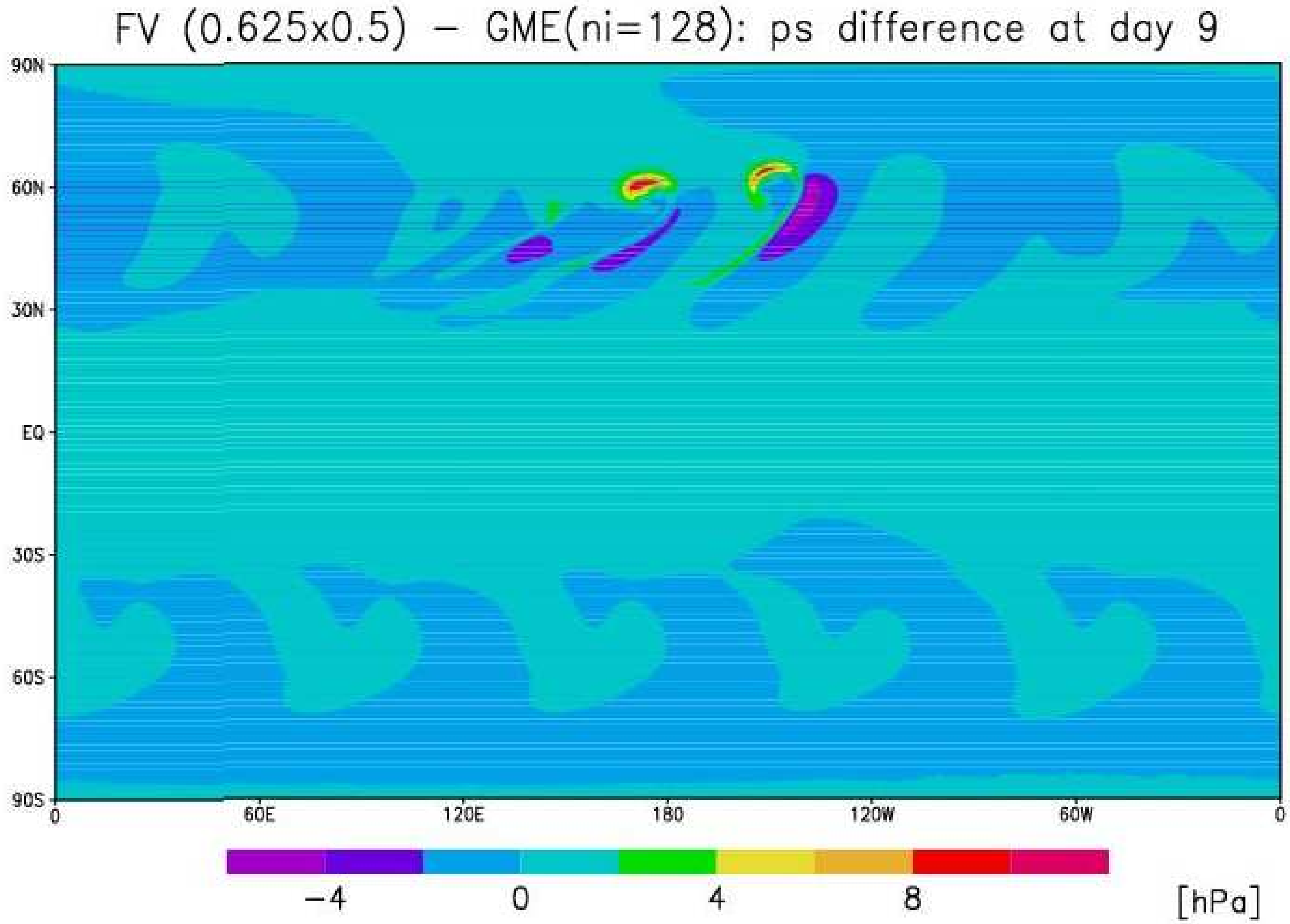
All models at highest resolution:



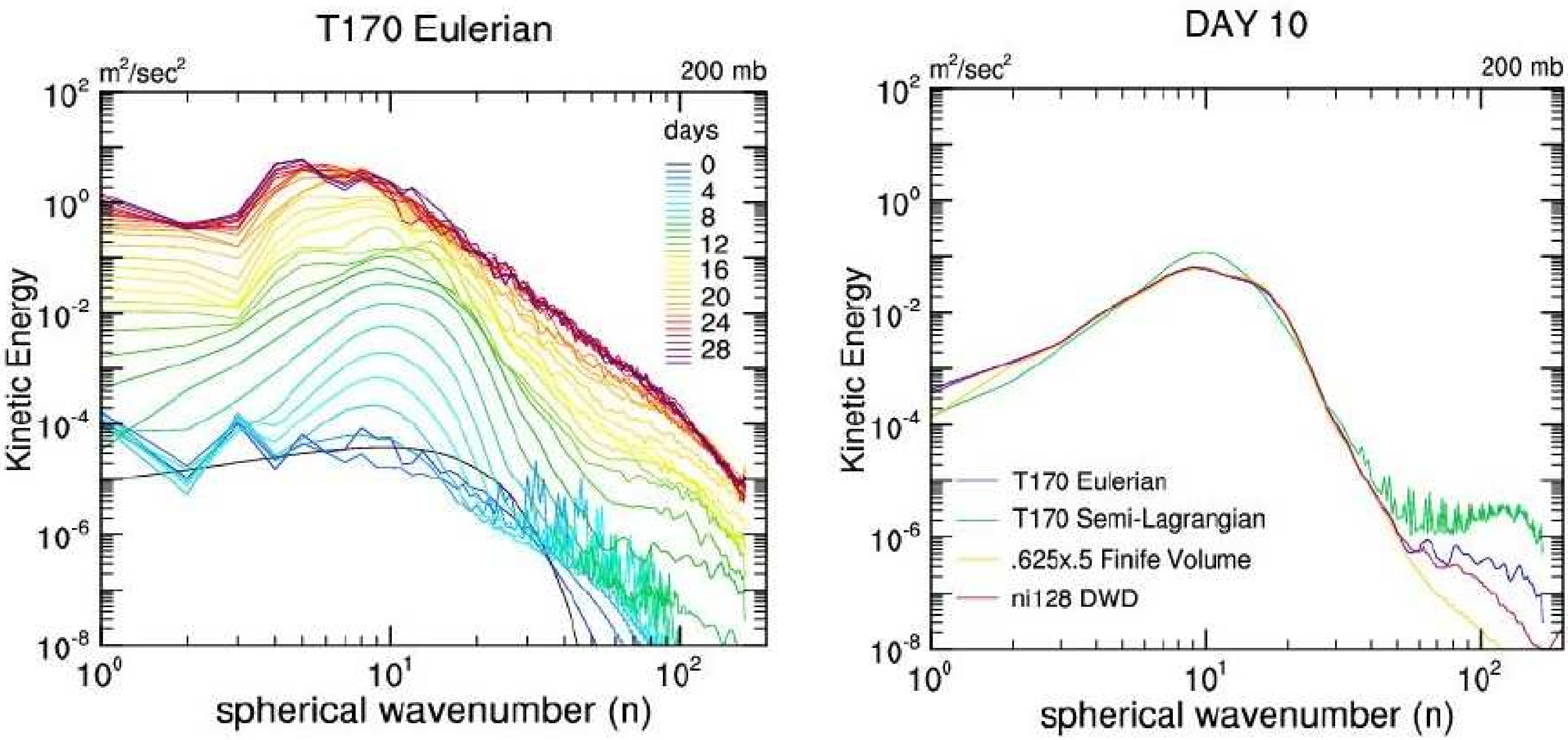
Baroclinic wave: p_s grid point data



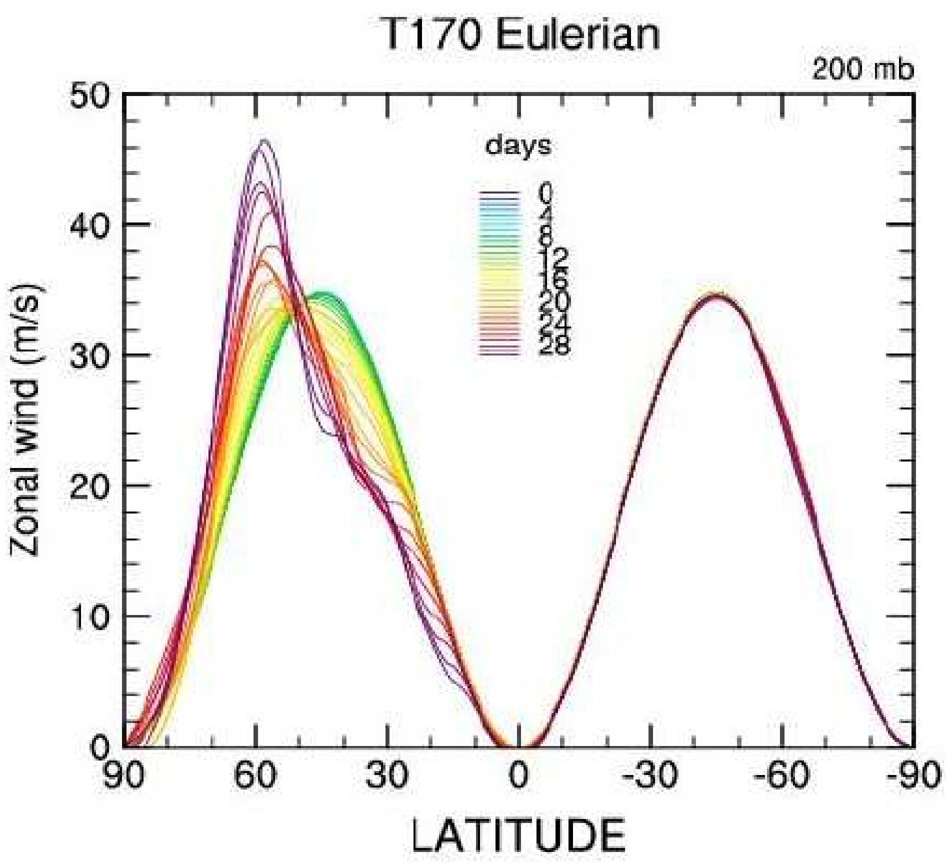
Baroclinic wave: p_s difference plot

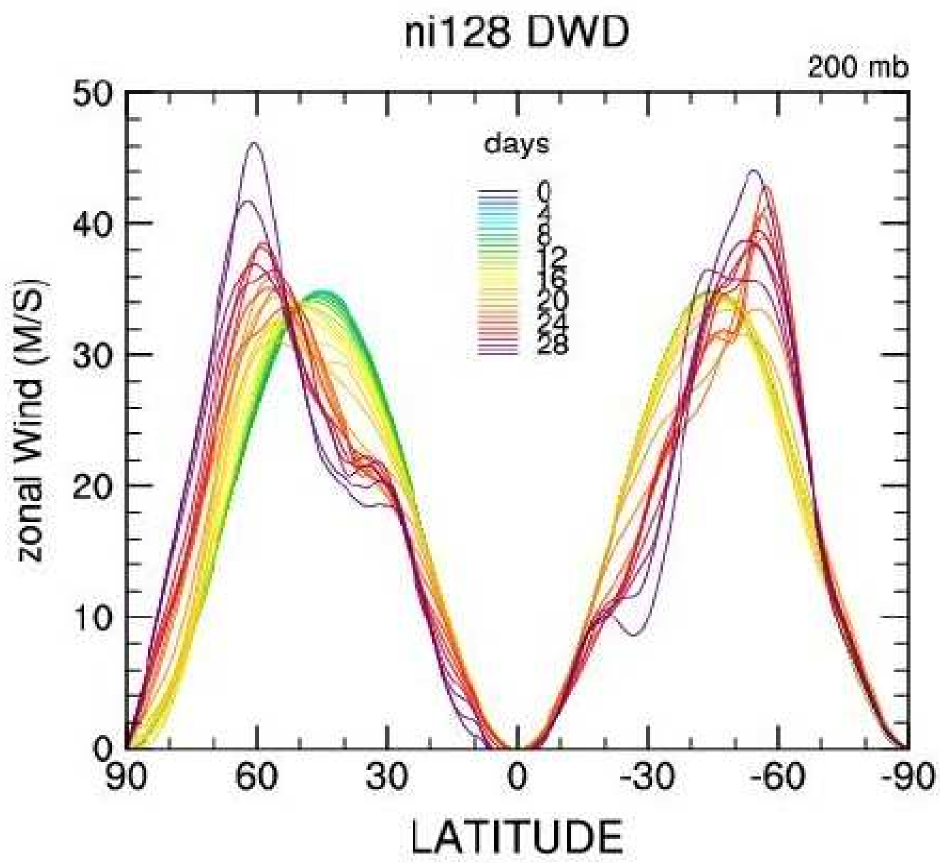


Baroclinic wave: KE spectra



Baroclinic wave: zonal-mean zonal wind





Wrap-up

- The steady state test can detect problems in the dynamical cores
- Baroclinic wave test:
  - convergence with resolution
  - 3 out of 4 models agree on the solution for 10 days
  - after 10 days we encounter predictability issues
  - Minimum resolution required: approx. T42
- Powerful test suite, easy to apply

Future application: Ideal test for Adaptive Grid GCMs