Idealized Test Cases for Dynamical Core Experiments

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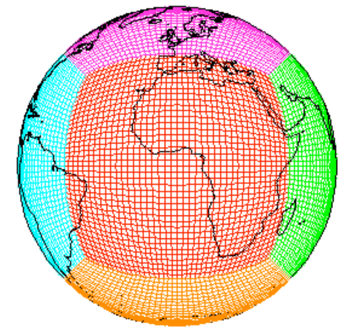
NCAR ASP Colloquium
June/2-13/2006

Motivation

- Test cases for 3D dynamical cores on the sphere
  - are hard to find in the literature
  - are often not fully documented
  - have (often) not been systematically applied by a large number of modeling groups
  - lack standardized & easy-to-use analysis techniques
- Idea: Establish a collection of test cases that finds broad acceptance in the modeling community
- Test suite that clearly describes the initial setups and suggests evaluation methods like the
  - Test suite for the SW equations (Williamson et al. 1992)
  - Proposed test suite for non-hydrostatic regional NWP dynamical cores (Bill Skamarock, NCAR, under development)

NASA/GFDL



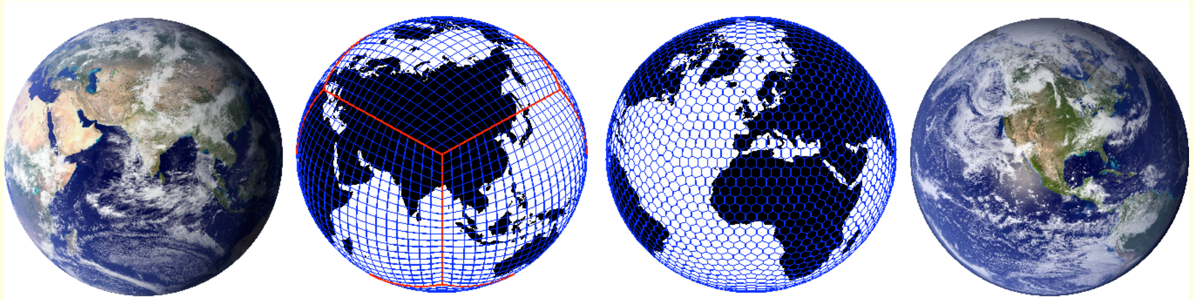
Goals of the Test Suite

Test cases should

- be designed for *hydrostatic* and *non-hydrostatic* dynamical cores on the sphere, for both *shallow* and *deep atmosphere* models
- be easy to apply: analytic initial data (if possible) suitable for *all grids*, formulated for different vertical coordinates
- be easy to evaluate
- be relevant to atmospheric phenomena
- reveal important characteristics of the numerical scheme
- have an analytic solution or converged reference solutions

Proposed Dynamical Core Test Suite for the 2008 NCAR ASP Colloquium

1. Steady-state test case
2. Evolution of a baroclinic wave
3. 3D advection experiments
4. 3D Rossby-Haurwitz wave with wavenumber 4
5. Mountain-induced Rossby wave train
6. Pure gravity waves and inertial gravity waves



Proposed Dynamical Core Test Suite for the 2008 NCAR ASP Colloquium

Family F	Test case	Test case F-x-y	Test case variant	Parameter choices
1	Steady-state	1-0-y	no rotation	$\alpha = 0$
		1-3-y	midlatitudinal flow	$\alpha = \pi/4$
		1-6-y	flow over the poles	$\alpha = \pi/2$
2	Baroclinic wave	2-0-y	no rotation	$\alpha = 0$
		2-3-y	midlatitudinal flow	$\alpha = \pi/4$
		2-6-y	flow over the poles	$\alpha = \pi/2$
3	Advection test solid body rotation	3-0-y	no rotation	$\alpha = 0$
		3-3-y	midlatitudinal flow	$\alpha = \pi/4$
		3-6-y	flow over the poles	$\alpha = \pi/2$
4	3D Rossby-Haurwitz wave	4-0-0		
5	Mountain-induced Rossby wave	5-0-0	wind amplitude	$u_0 = 20$ m/s
6	Pure gravity wave (non-rotating)	6-0-0	$\Omega = 0\ s^{-1}$	$N = 0.01\ s^{-1}$, $u_0 = 0$ m/s
		6-1-0	$\lambda_c, \varphi_c = (\pi, 0)$	isotherm, $u_0 = 0$ m/s
		6-2-0		isotherm, $u_0 = 40$ m/s
6	Inertio-gravity wave	6-3-0	Earth's rotation	isotherm, $u_0 = 0$ m/s

Test 1) Steady-State Initial Conditions

- Initial data required: u, v, T, p_s, Φ_s
- Find a steady-state, balanced solution of the PE Eqns: prescribe **u, v** and the surface pressure $\mathbf{p_s}$
- Plug prescribed variables into Primitive Equations (PE) and derive the
  - Geopotential field Φ: based on the momentum equation for v (integrate), calculate surface geopotential Φ_s

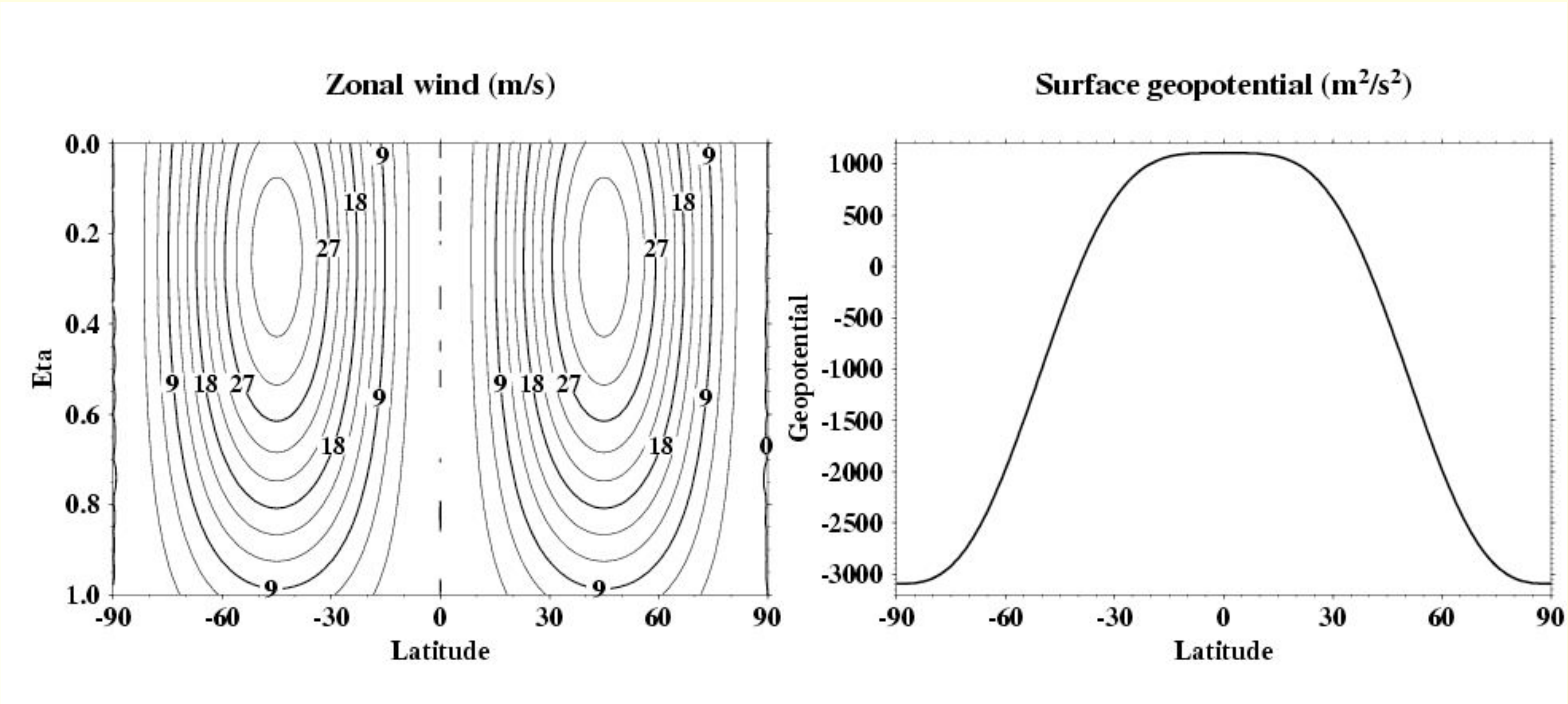
$$\frac{dv}{dt} + \frac{u^2 \tan\varphi}{a} = \frac{-1}{a}\left(\frac{\partial \Phi}{\partial \varphi} + R_d T \frac{\partial \ln p}{\partial \varphi}\right) - fu$$

  - Temperature field: based on the hydrostatic equation

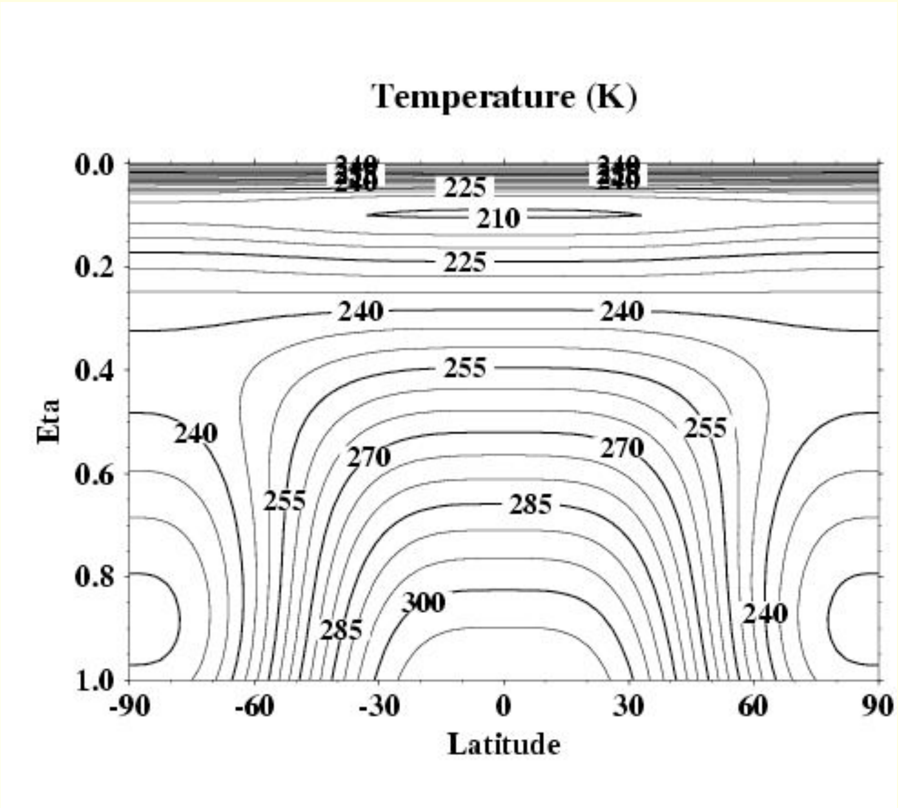
$$\frac{\partial \Phi}{\partial \eta} = -\frac{R_d T}{p}\frac{\partial p}{\partial \eta} \rightarrow \boxed{\frac{\partial \Phi'}{\partial \eta} = -\frac{R_d T'}{\eta}}$$

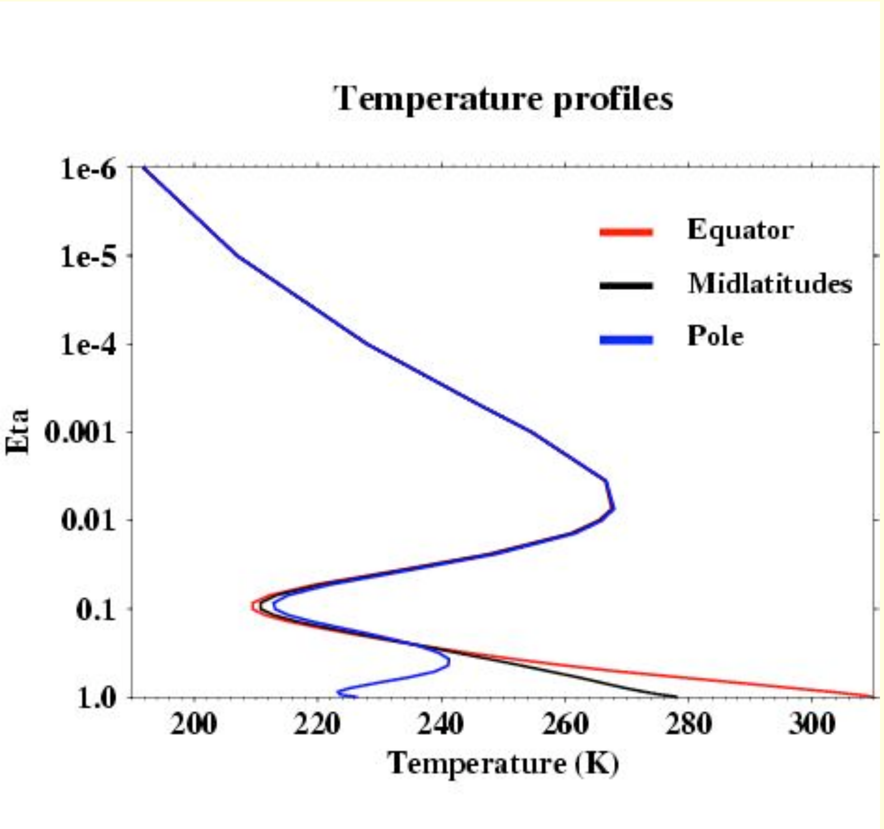
Steady-State Initial Conditions

- v = 0 m/s
- p_s = 1000 hPa
- u & Φ_s



Initial Temperature Field





Test Strategy

Test 1 (Steady-State):

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

Test 2 (Baroclinic Wave):

- Perturb the initial conditions with a small, but well-resolved Gaussian hill perturbation
- 30-day simulation: Evolution of a baroclinic wave over 10 days

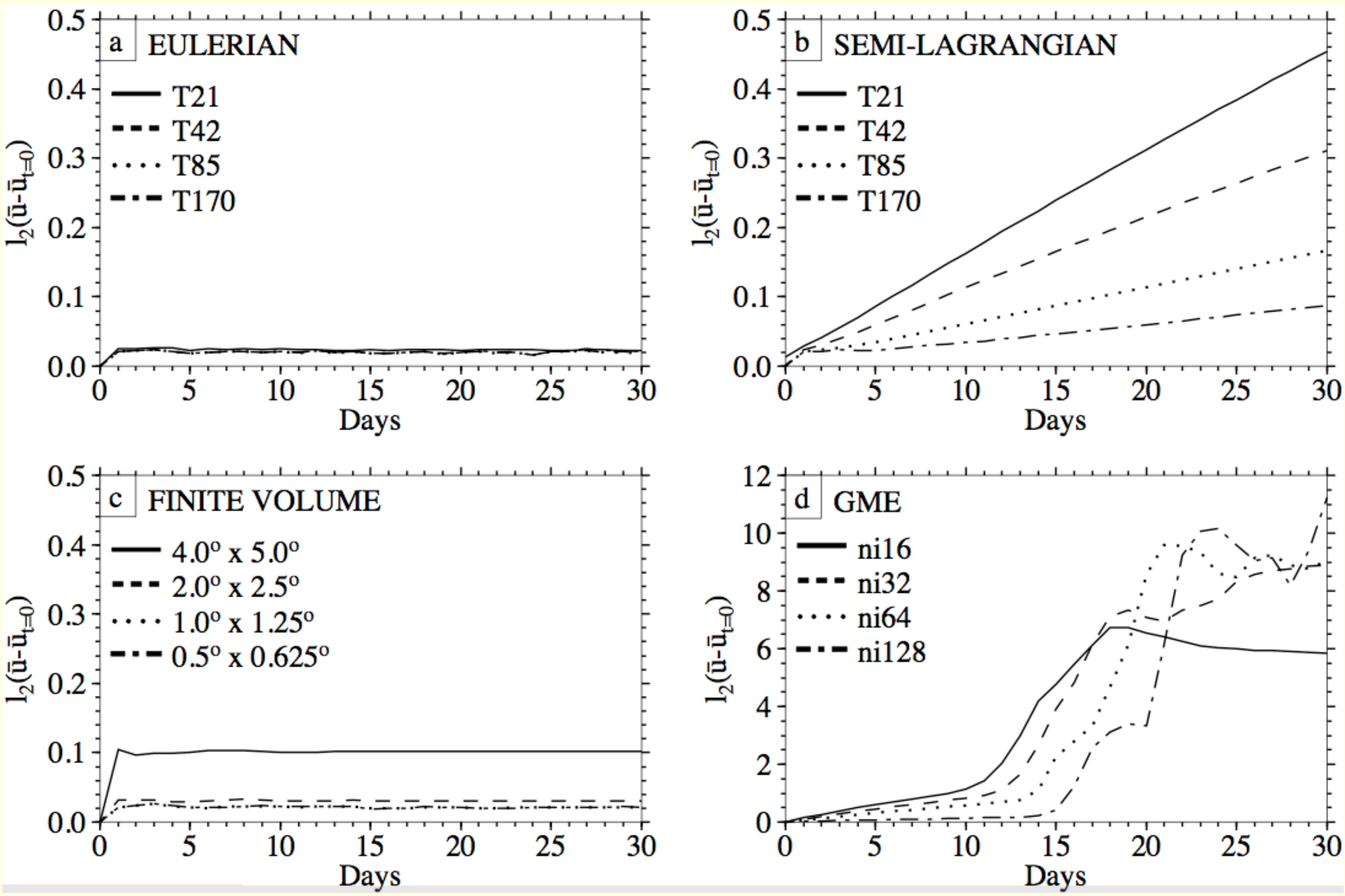
Example resolutions for convergence studies

EUL / SLD (truncation)	FV (lat x lon, in º)	GME (min. grid distance)
T21	4 x 4	≈ 440 km (ni = 16)
T42	2 x 2	≈ 220 km (ni = 32)
T85	1 x 1	≈ 110 km (ni = 64)
T170	0.5 x 0.5	≈ 55 km (ni =128)
T340	0.25 x 0.25	≈ 26 km (ni = 256)

- **Default: 26 vertical levels** with model top ≈ 3 hPa

Steady-State Test Case

- Maintenance of the zonal-mean initial U wind (Eqn. 18)

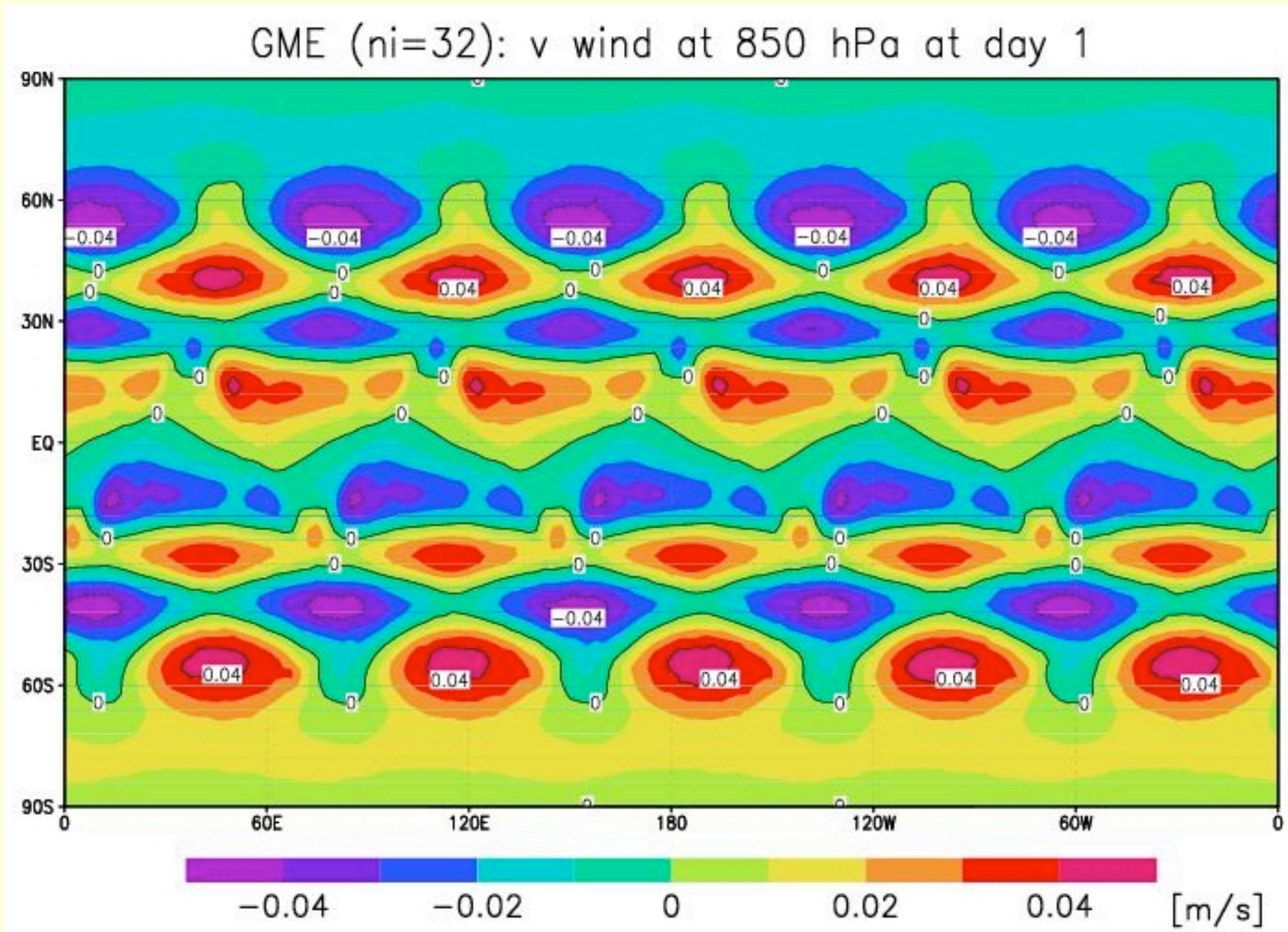


Decentering parameter effect

Wave number 5 effect

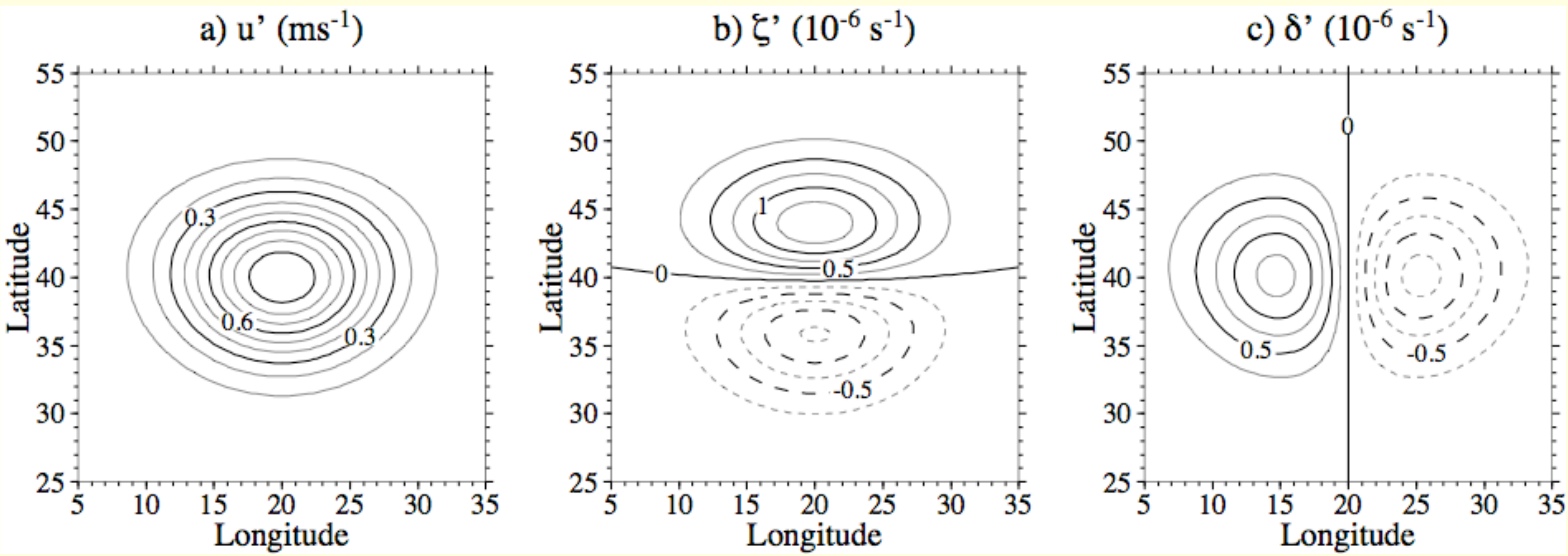
Steady-State Test Case: GME

- GME shows a truncation error with wave number 5
- Artifact of computational grid and numerical method

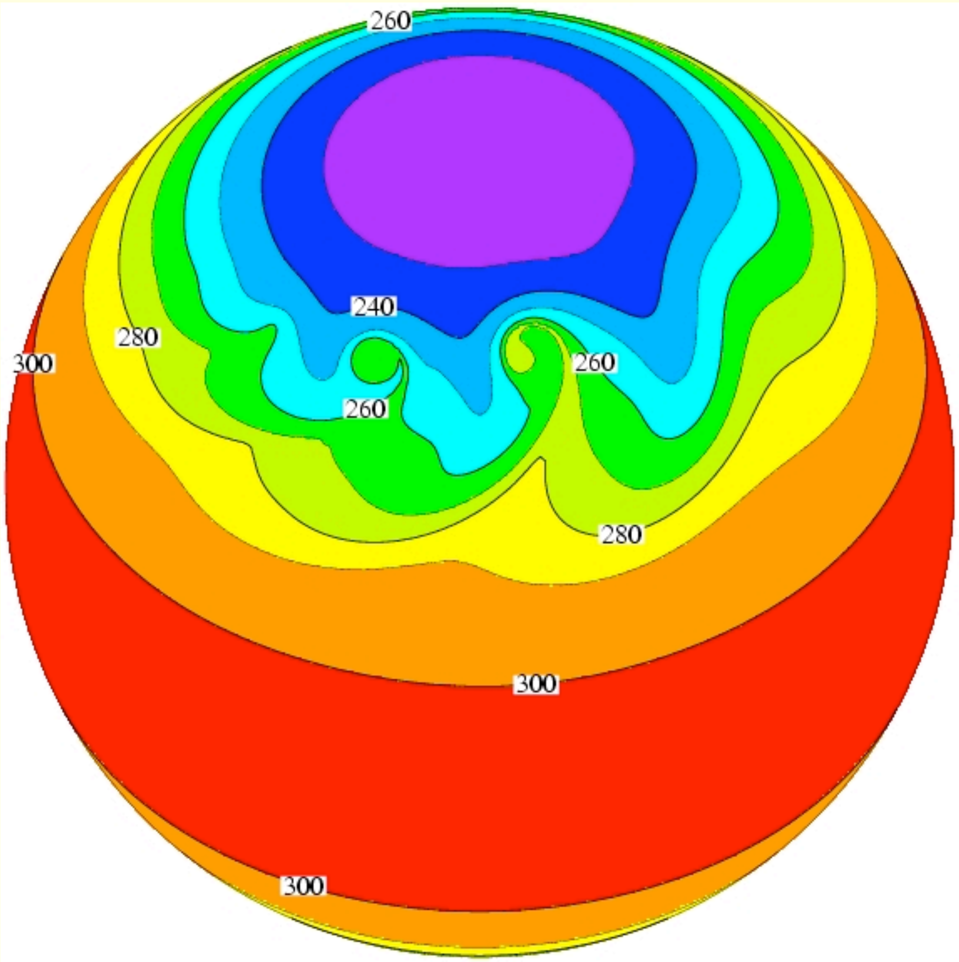


Test 2) Select Gaussian Hill Perturbation

- Overlaid perturbation (at each model level) triggers the evolution of a baroclinic wave over 10 days
- Suggested: pertubation of the zonal wind field ‘u’ or the vorticity and divergence (for models in ζ-δ form)



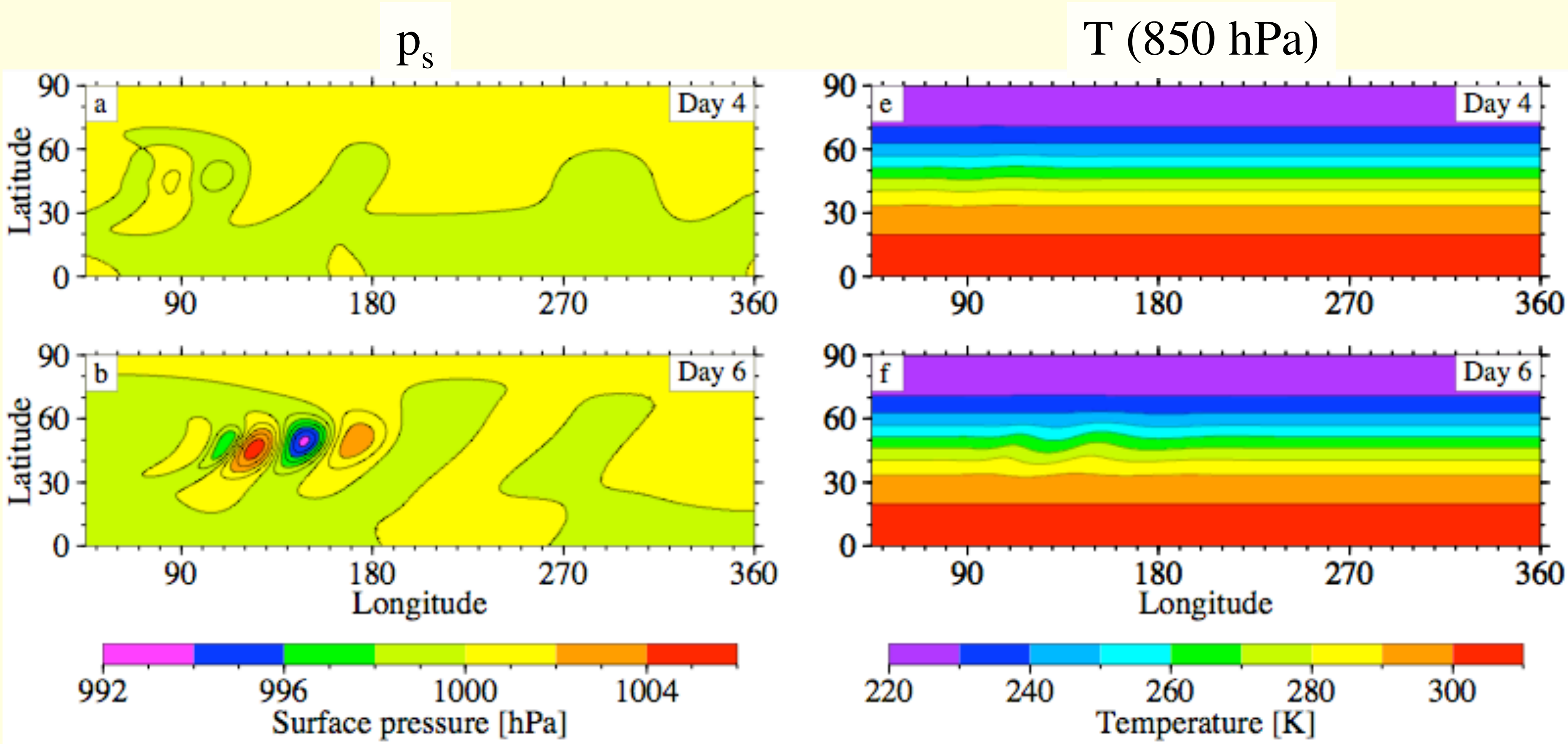
Test 2) Baroclinic Waves



- 850 hPa temperature field (in K) of an idealized baroclinic wave at model day 9.
- The initially smooth temperature field develops strong gradients associated with warm and cold frontal zones.

Evolution of the Baroclinic Wave

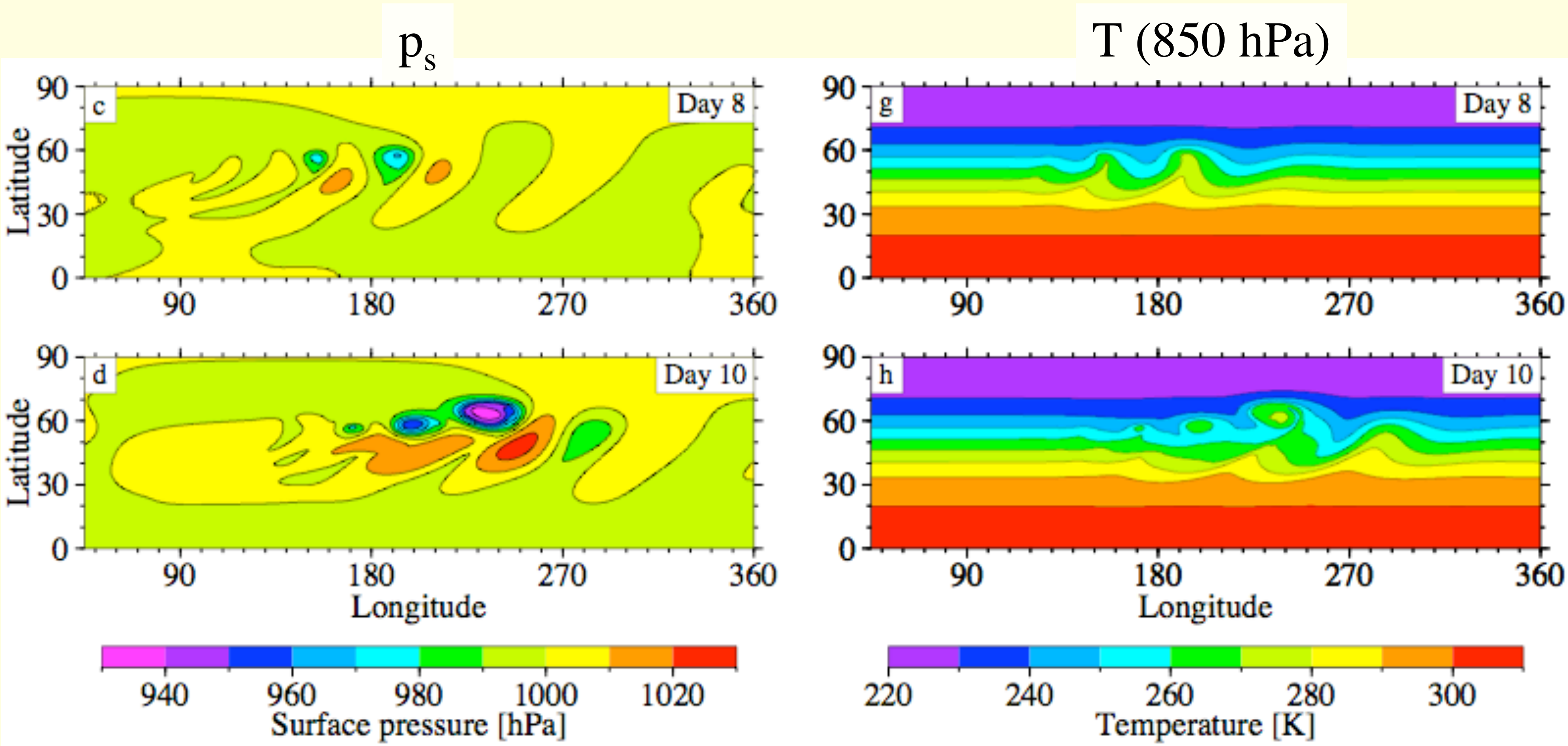
- Perturbation gets organized over the first 4 days and starts growing rapidly from day 6 onwards



FV 0.5 x 0.625 L26 dycore

Evolution of the Baroclinic Wave

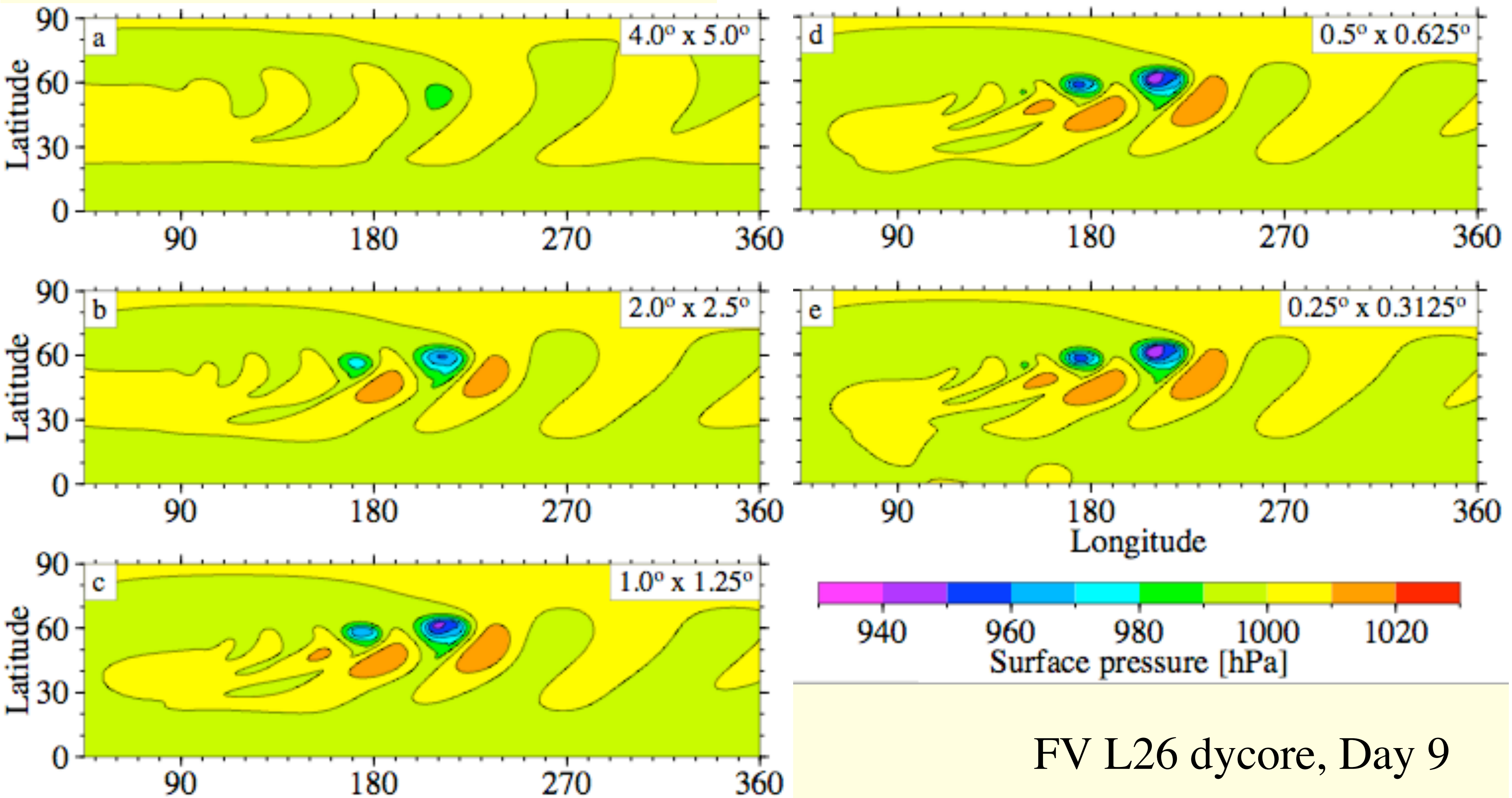
- Explosive cyclogenesis after day 7
- Baroclinic wave breaks after day 9



FV 0.5 x 0.625 L26 dycore

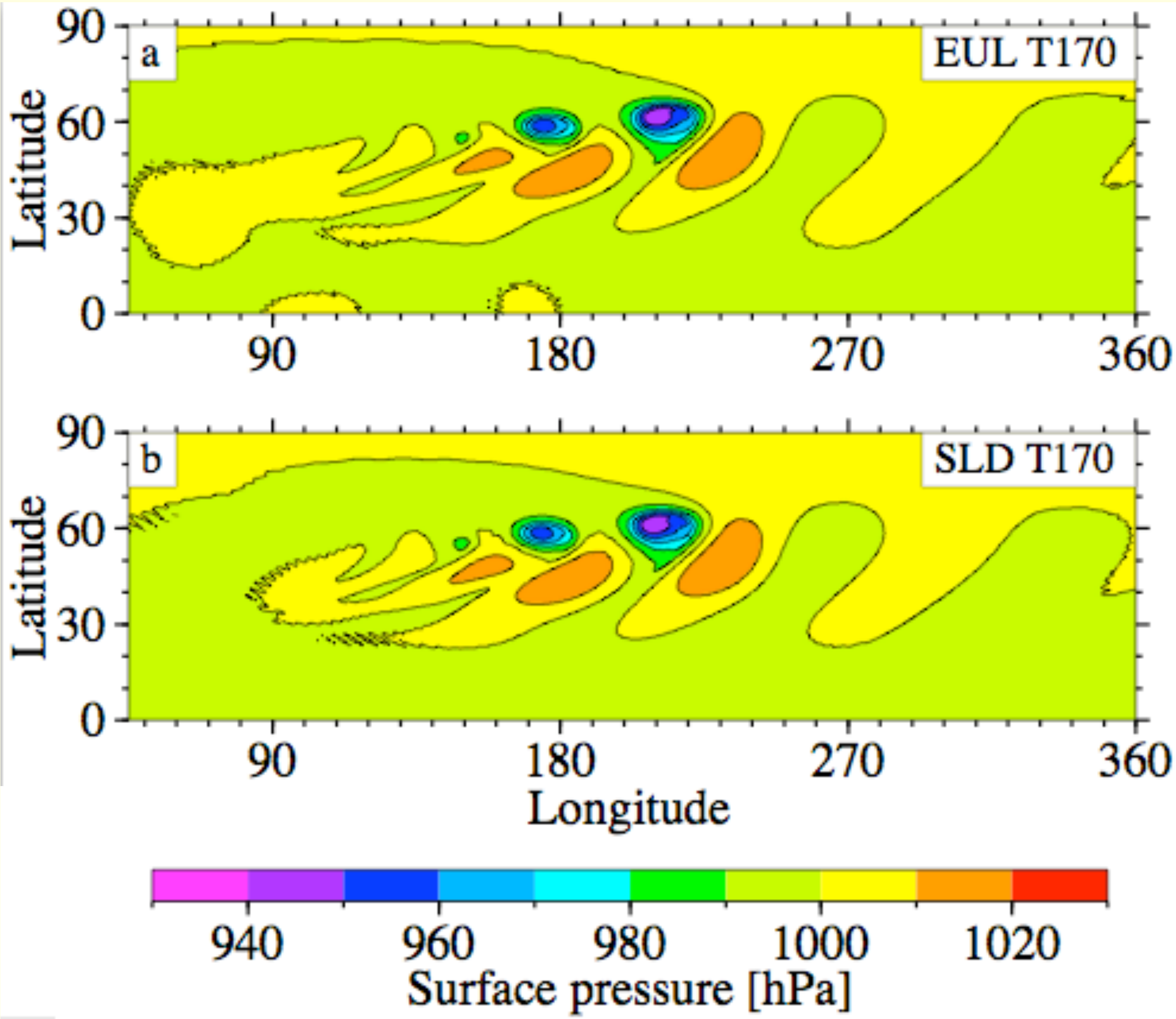
Convergence with Resolution

- Surface pressure starts converging at 1º x 1.25º



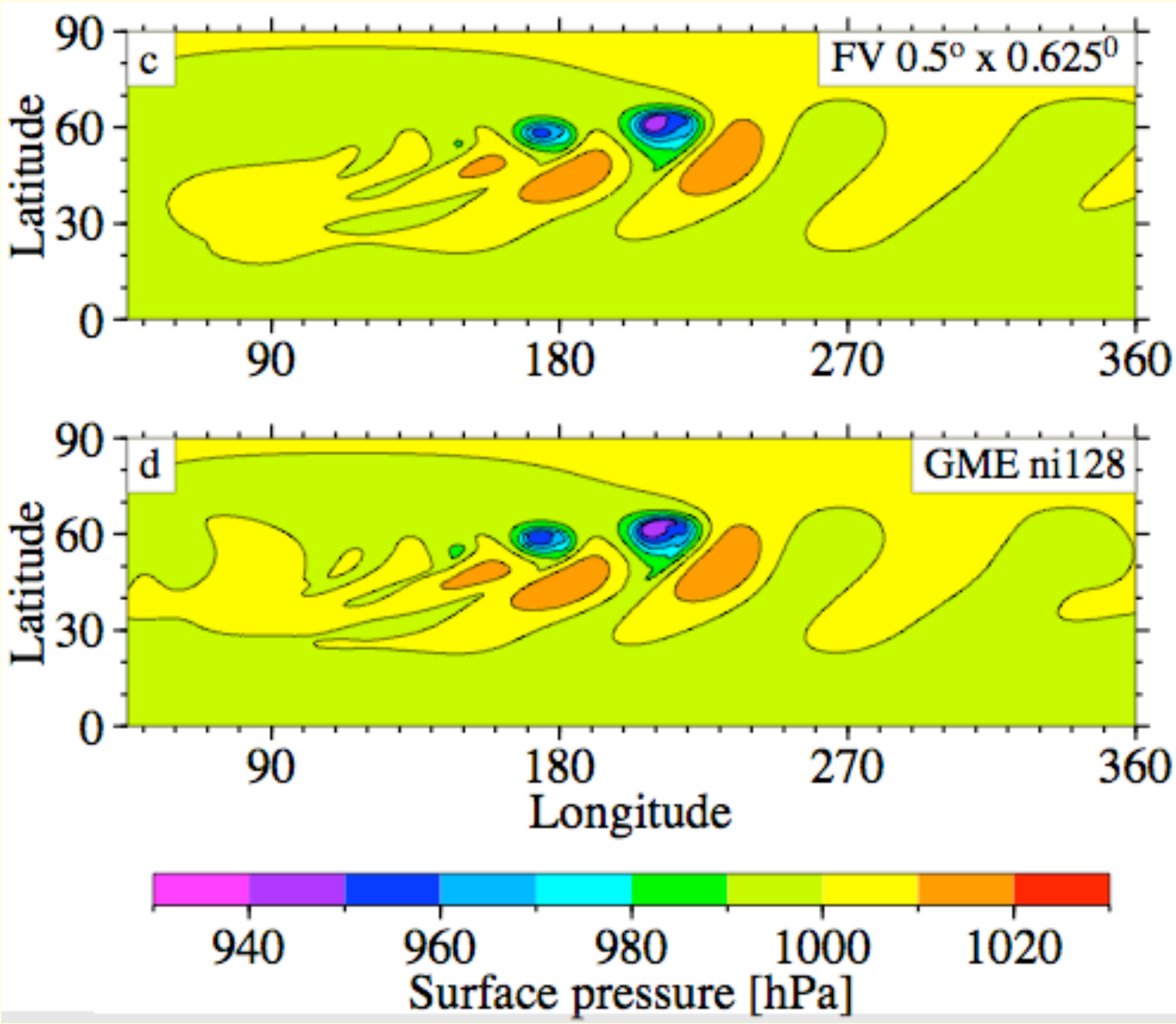
FV L26 dycore, Day 9

Model Intercomparison at Day 9



- Second highest resolutions, L26
- p_s fields visually very similar
- Spectral noise in EUL and SLD

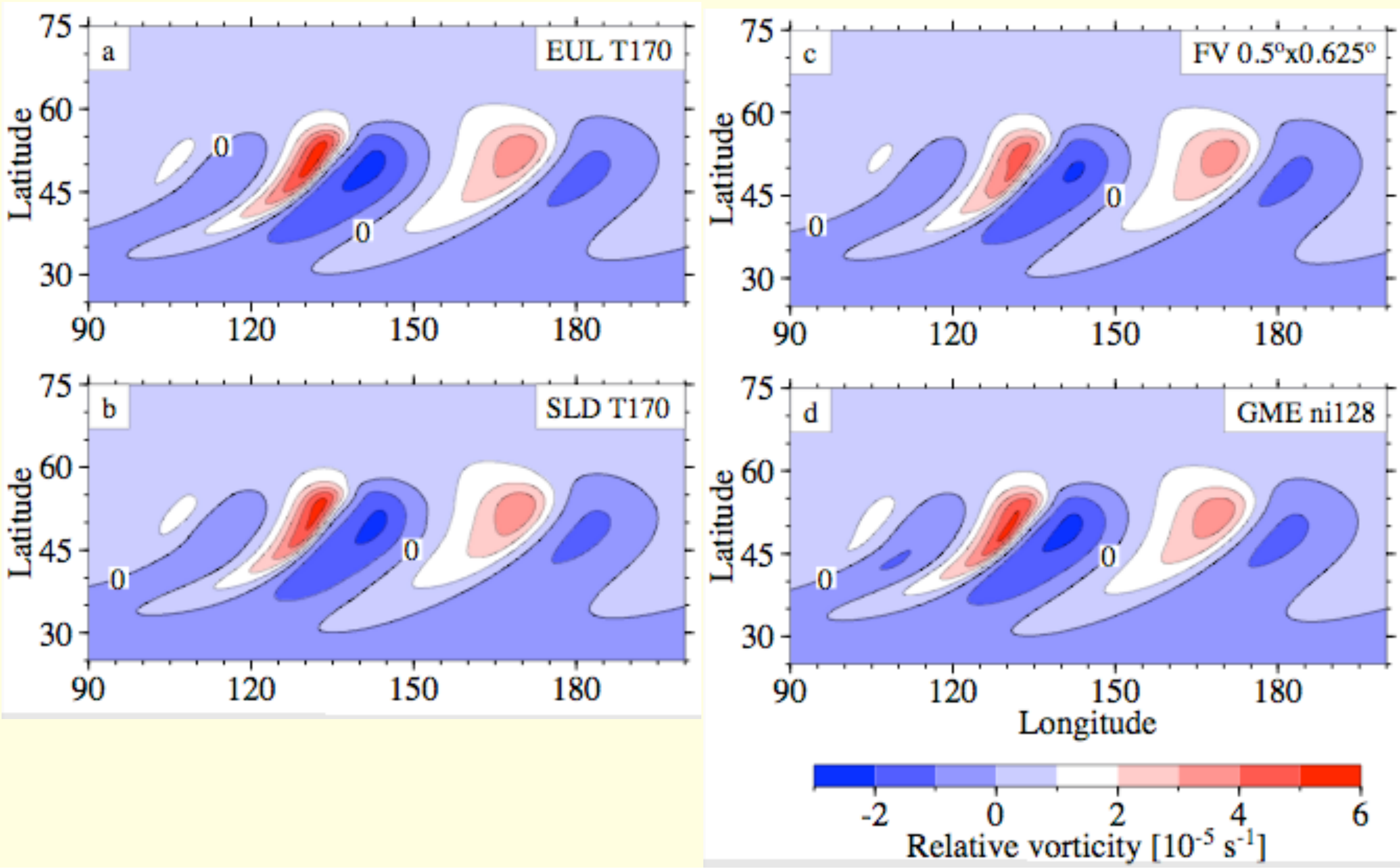
Model Intercomparison at Day 9



- p_s fields visually almost identical
- Differences only at small scales

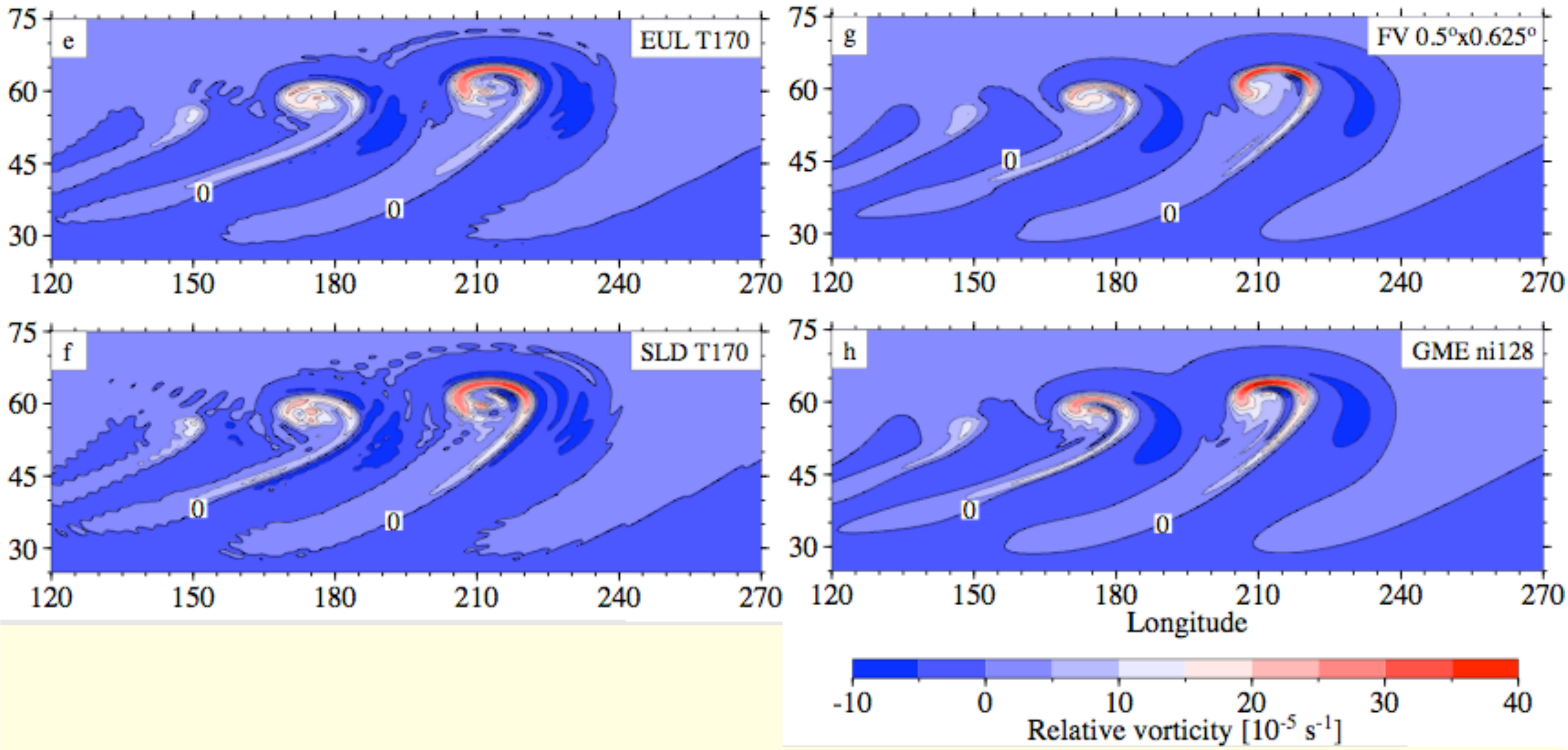
850 hPa Relative Vorticity at Day 7

- Differences in the vorticity fields grow faster than p_s diff.



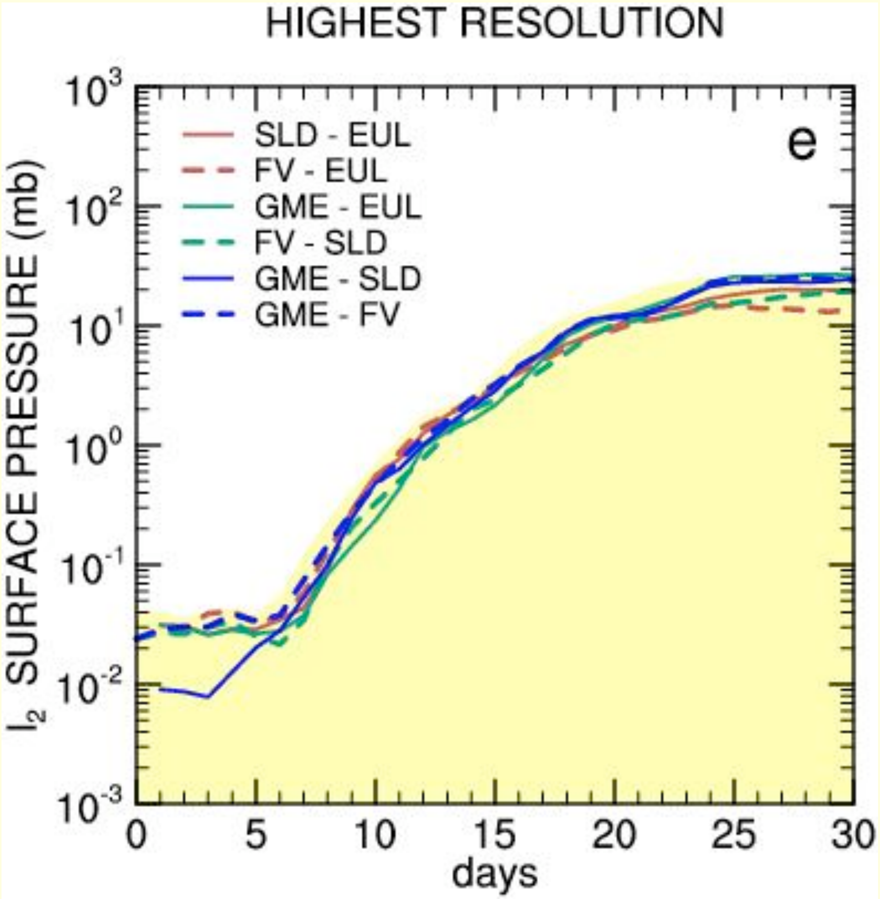
850 hPa Vorticity at Day 9

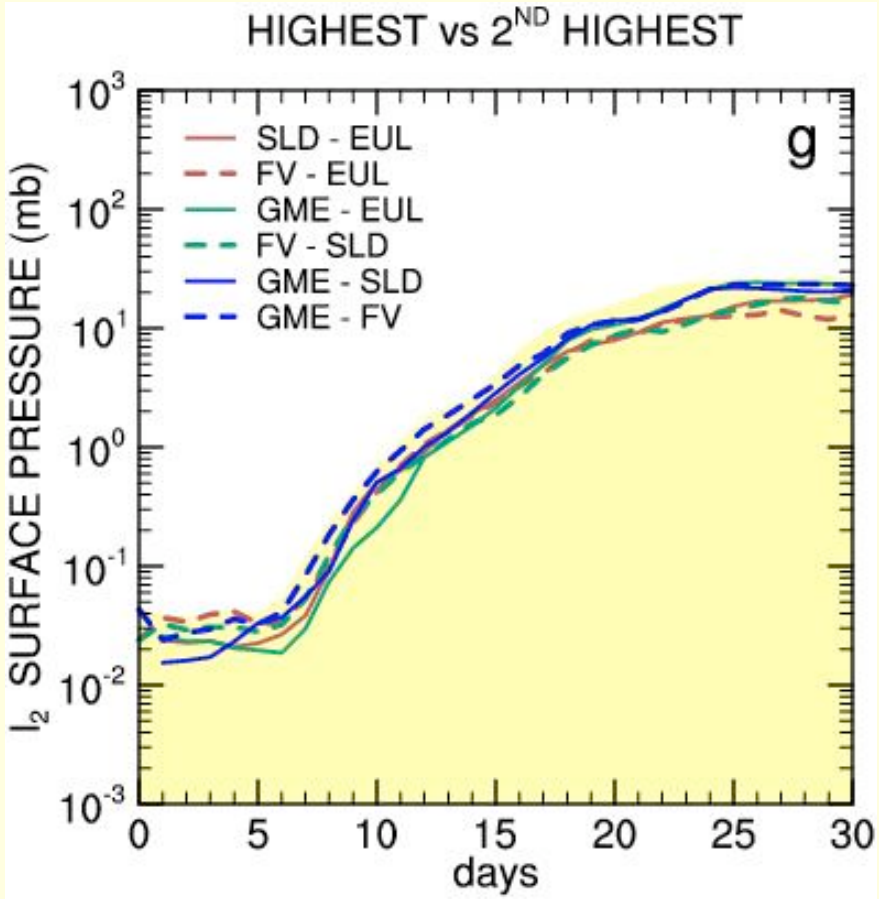
- Small-scale differences easily influenced by diffusion
- Spectral noise in EUL and SLD (L26)



Model Intercomparisons: Uncertainty

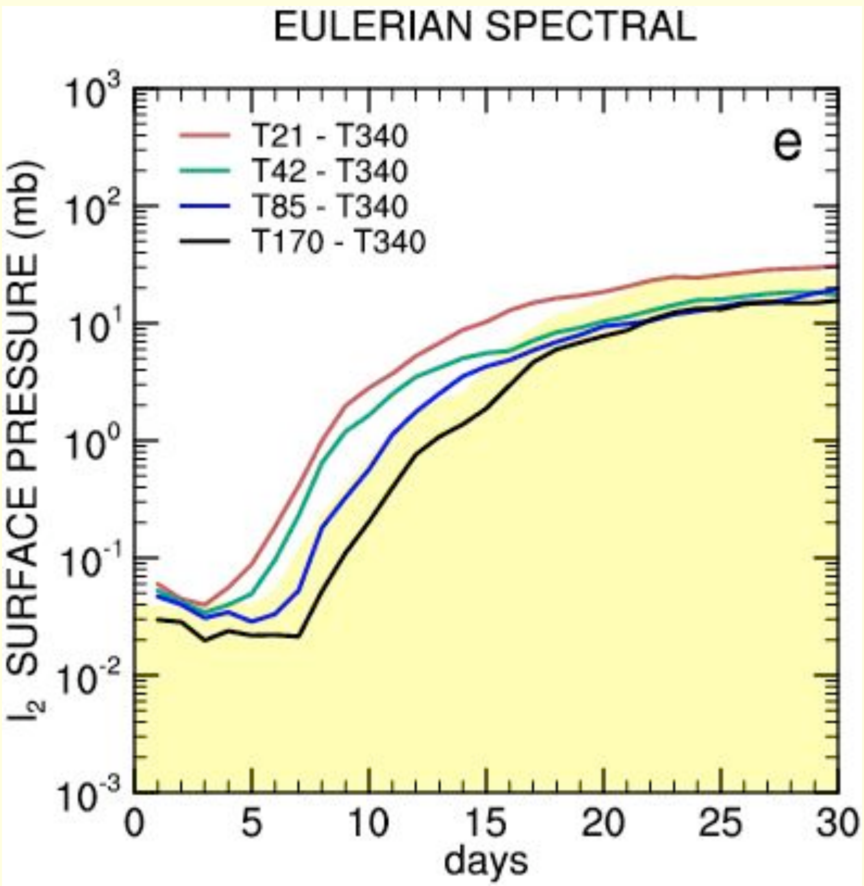
- Estimate of the uncertainty in the reference solutions across four models using $l_2(p_s)$
  (Jablonowski and Williamson, QJ(2006), NCAR Tech. Report 2006)

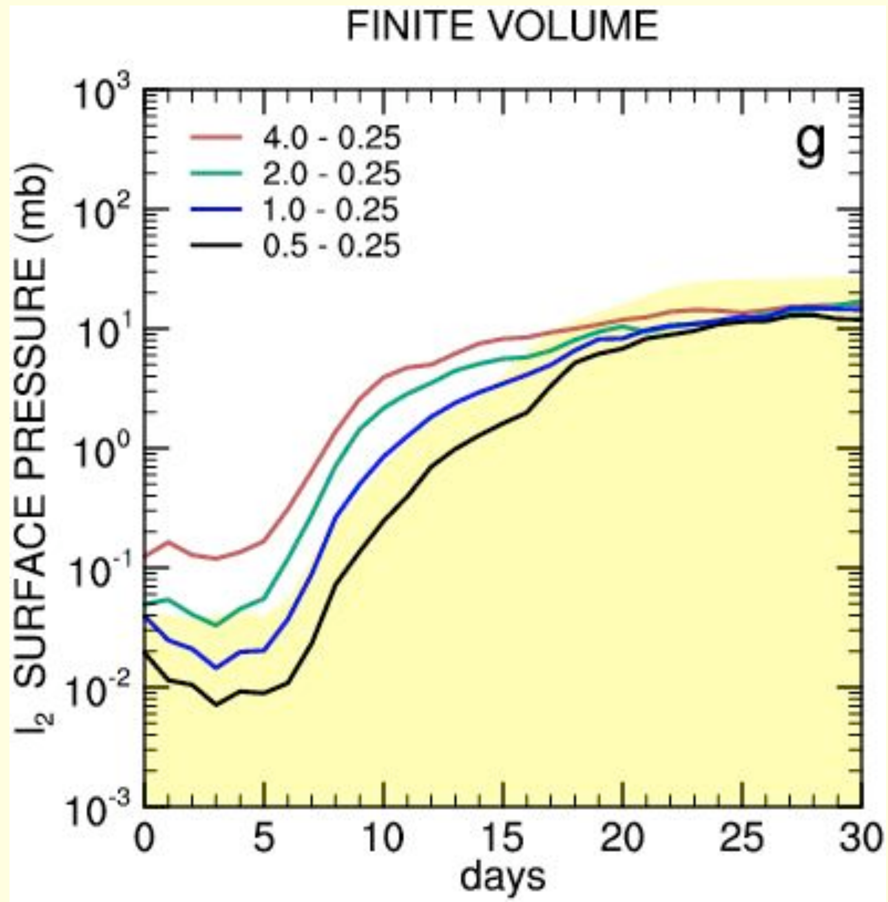




Single-Model Convergence

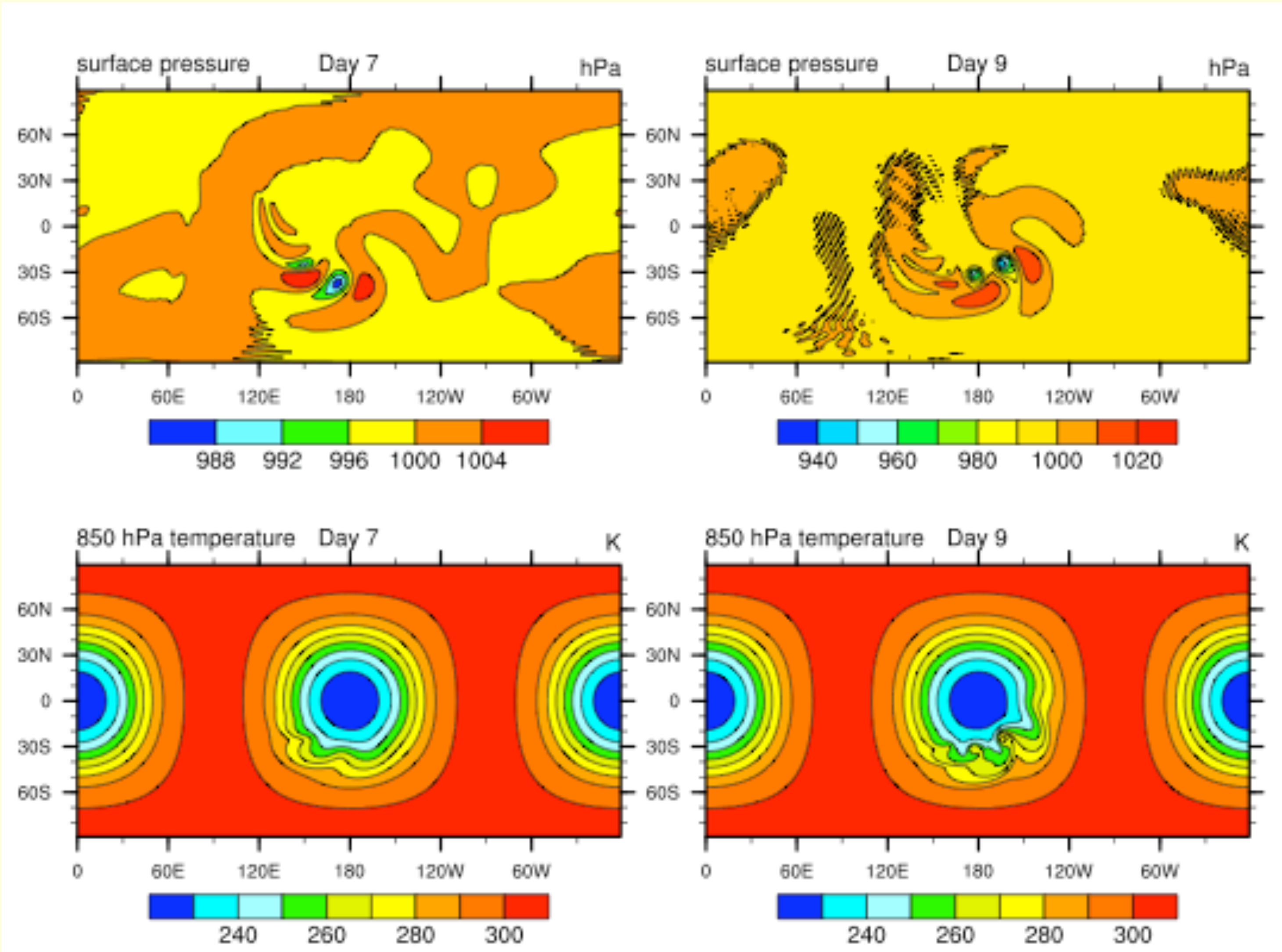
- Single-model uncertainty stays well below the uncertainty across models
- Models converge within the uncertainty for the resolutions T85 (EUL & SLD), 1x1.25 (FV), GME (55km / ni=128)





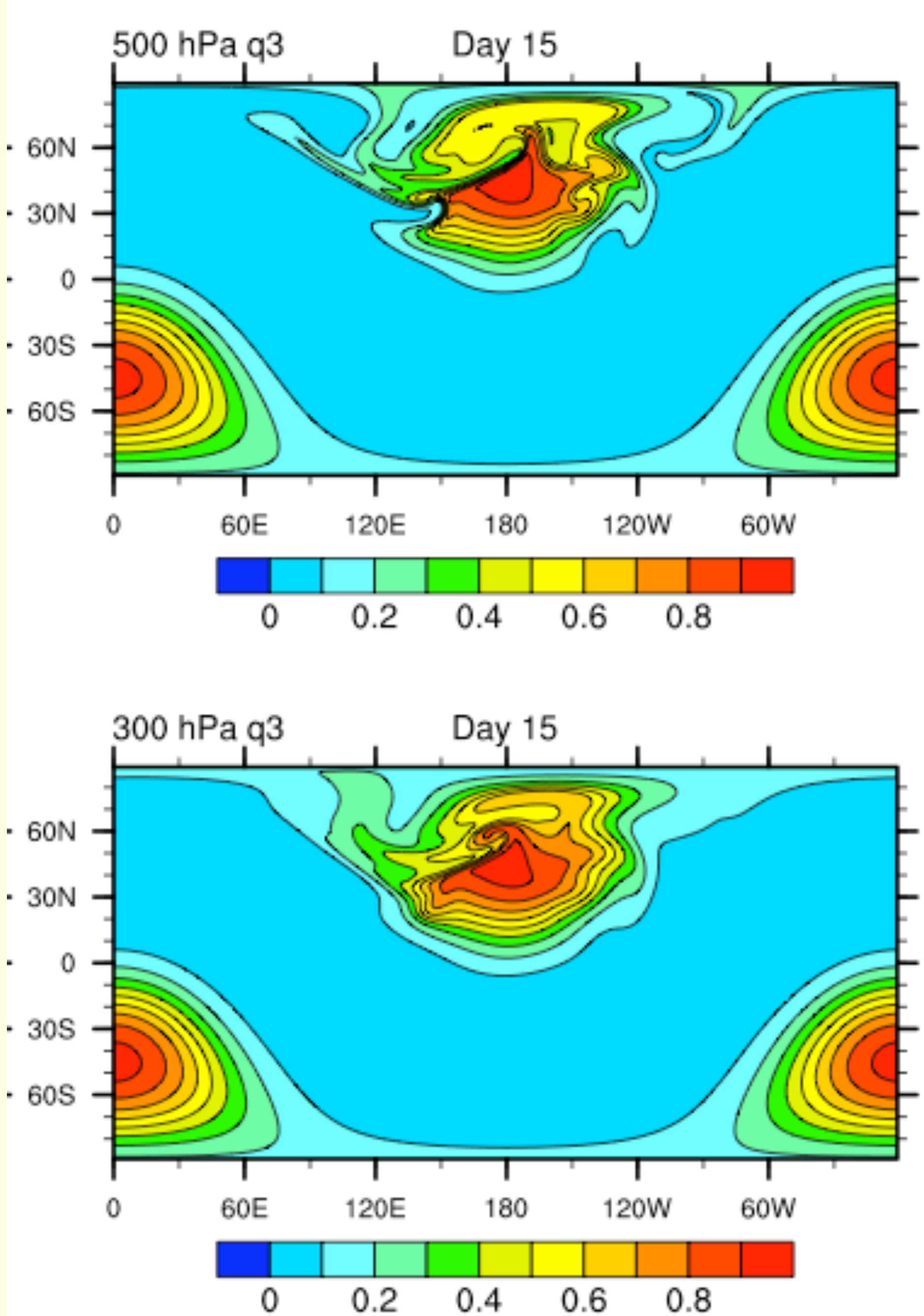
Test 2 with a rotation angle α=90°

- Increase the challenge for models with regular grids



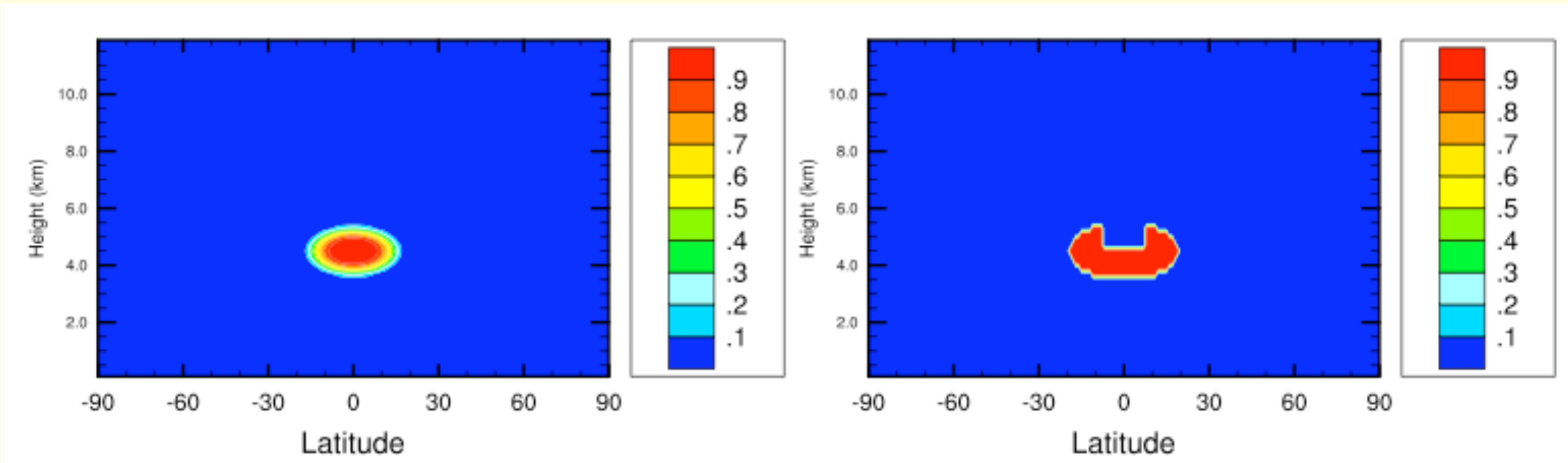
Test 2 with tracer q3 (α=45°)

- Explore the diffusive properties
- Mass conservation
- Over- and undershoots
- Consistency



Test 3) 3D Advection Tests

Prescribe two 3D tracer distributions:
Latitude-height cross sections



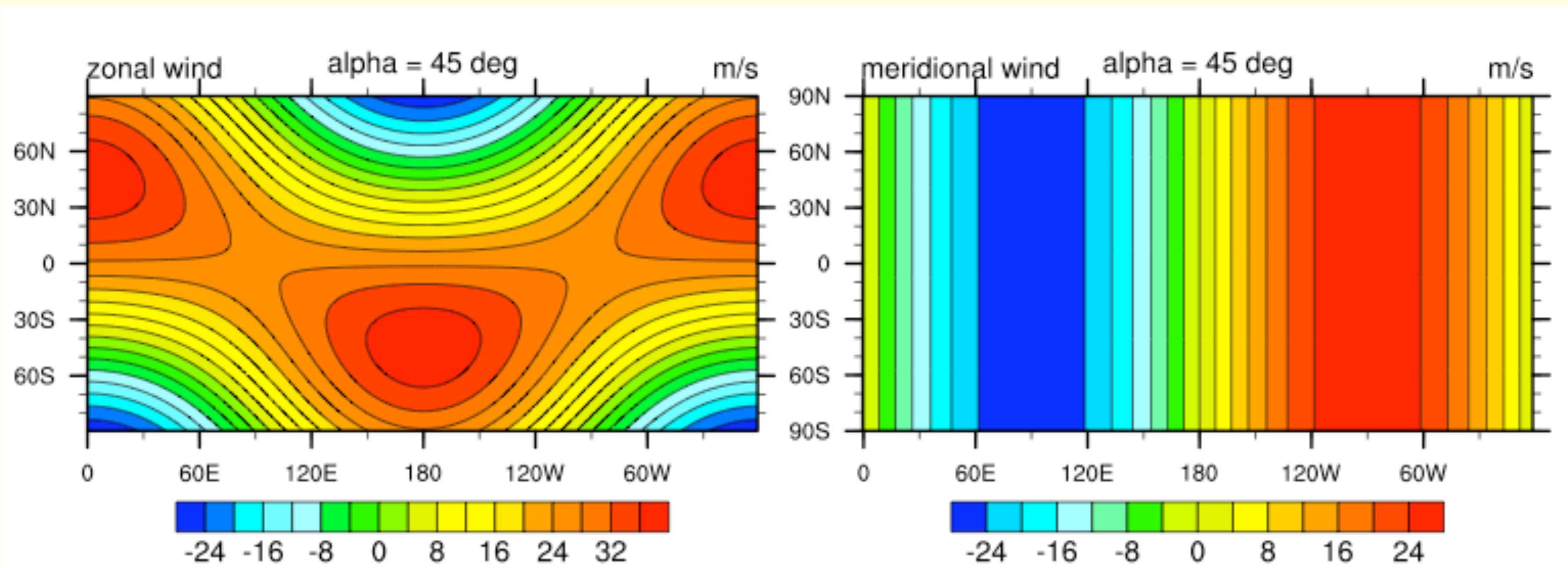
Smooth

Non-smooth: Slotted ellipse

Test 3) Advecting wind speeds

Prescribed horizontal winds with $\alpha = 45°$

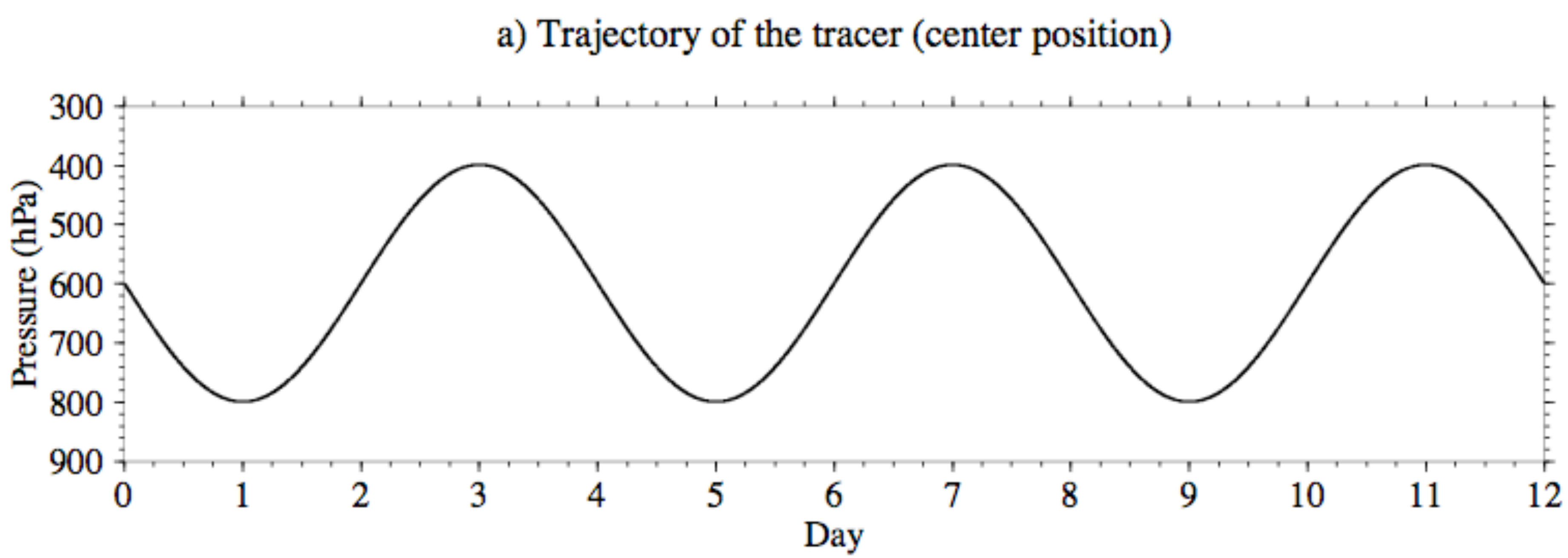
U **V**



Velocities transport the tracers once around the sphere within 12 days

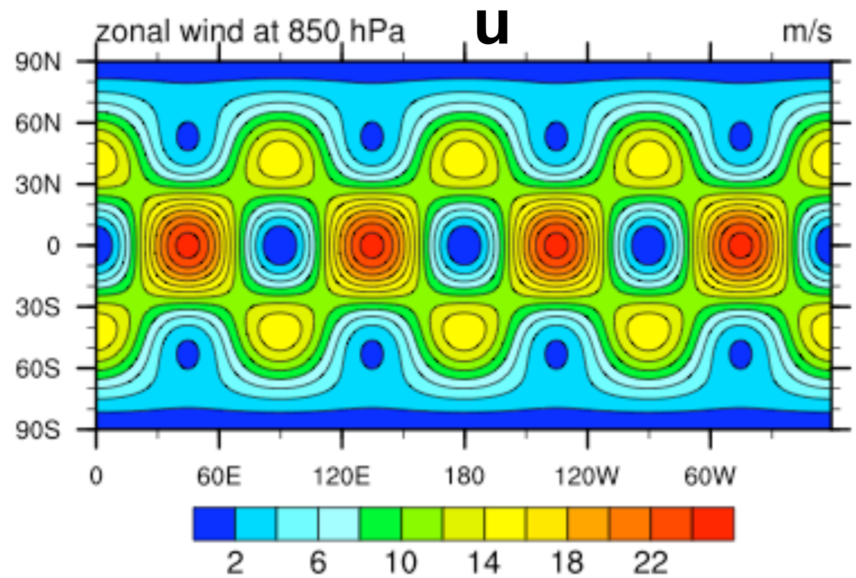
Test 3) Vertical advection

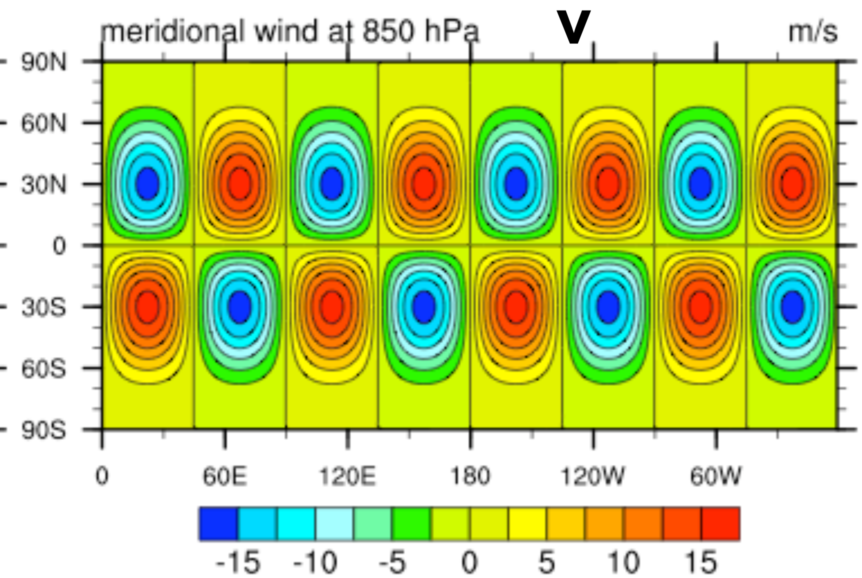
Tracers undergo 3 wave cycles in the vertical

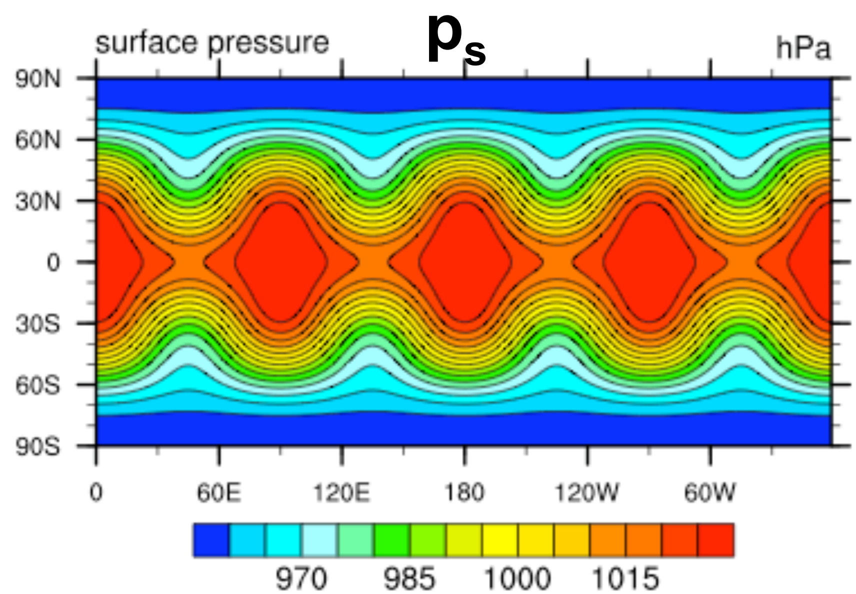


Tracers return to initial position after 12 days:
Allows assessment of the diffusion

Test 4) 3D Rossby-Haurwitz Wave



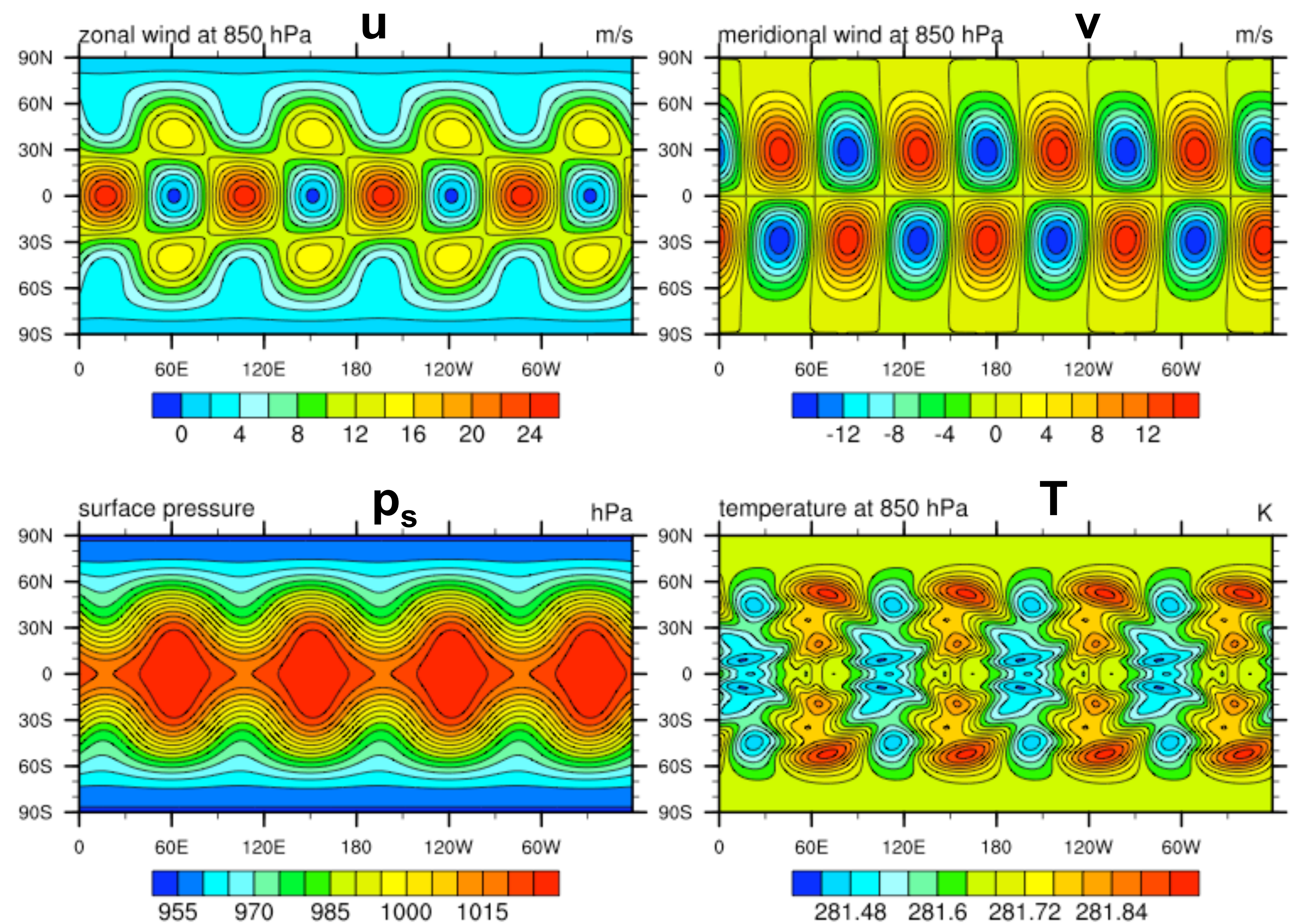




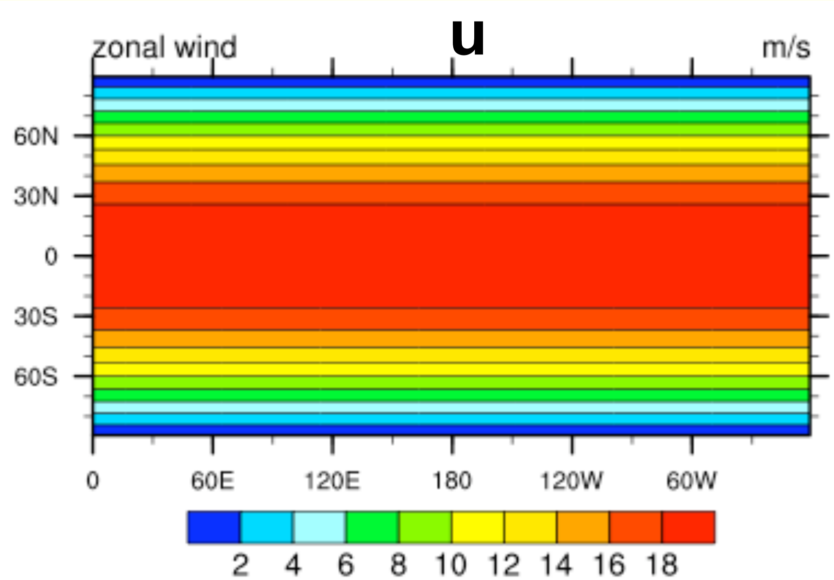
Wavenumber 4:
Initial u, v, p_s fields

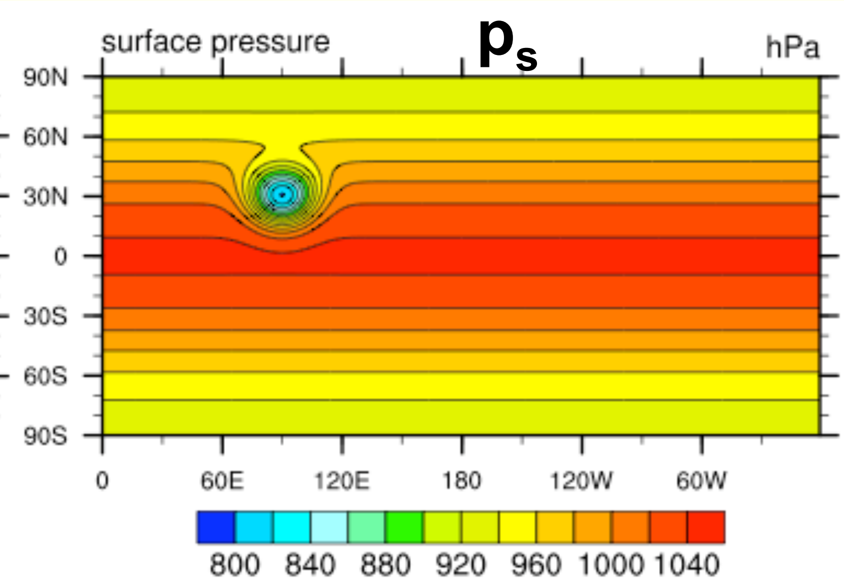
Pattern moves westward without change of shape (≈ -15.2° / day)

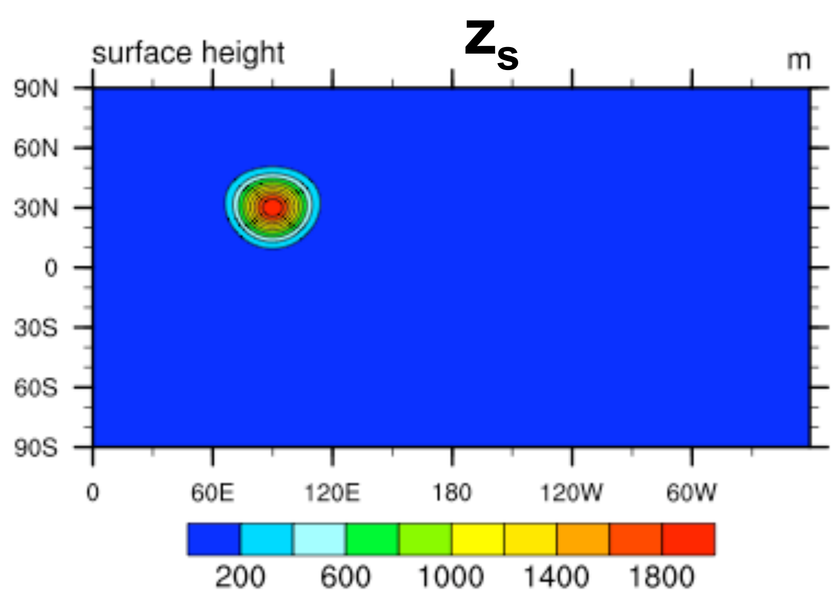
Day 15: Assess diffusion and symmetry



Test 5) Mountain-induced Rossby waves

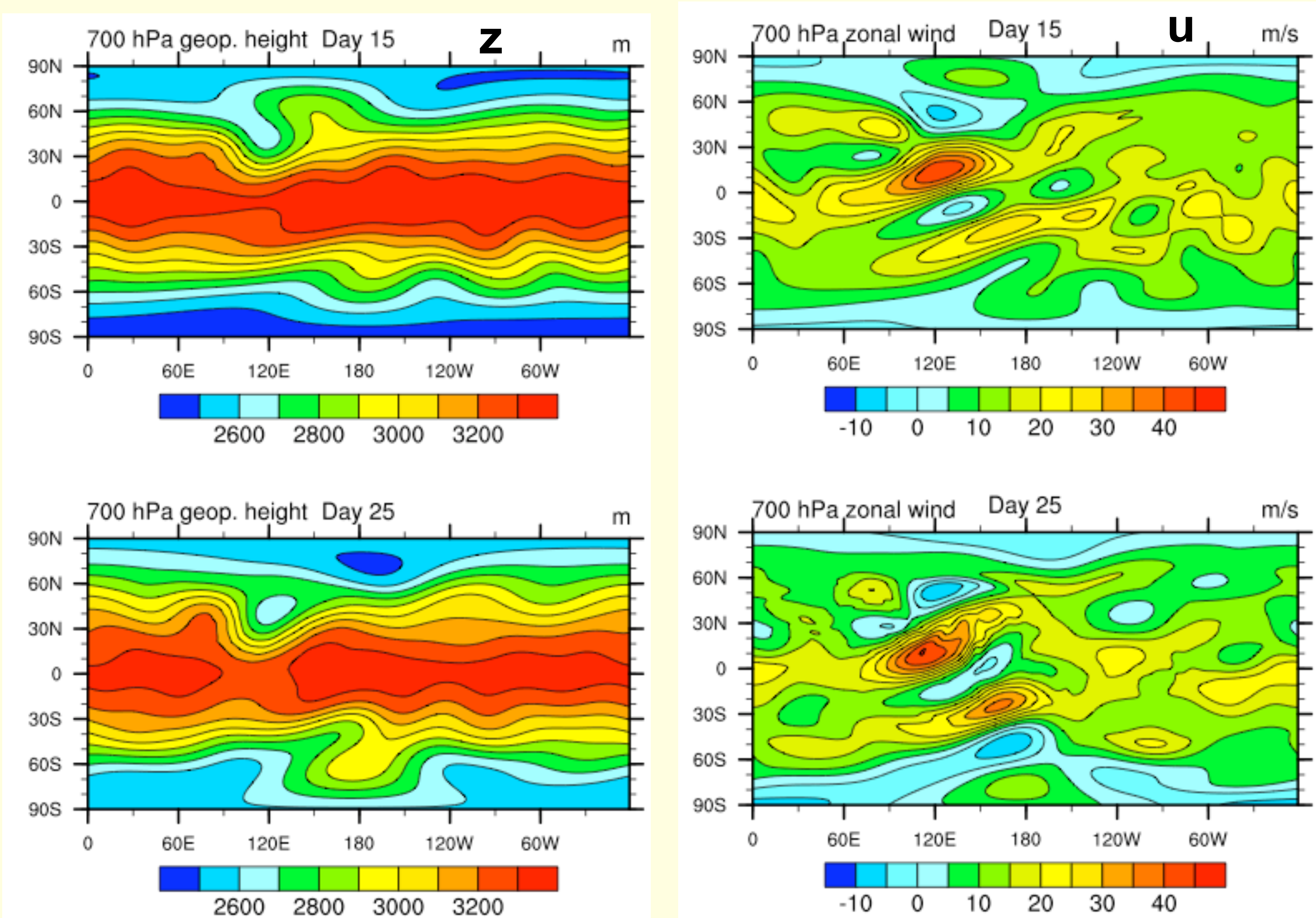






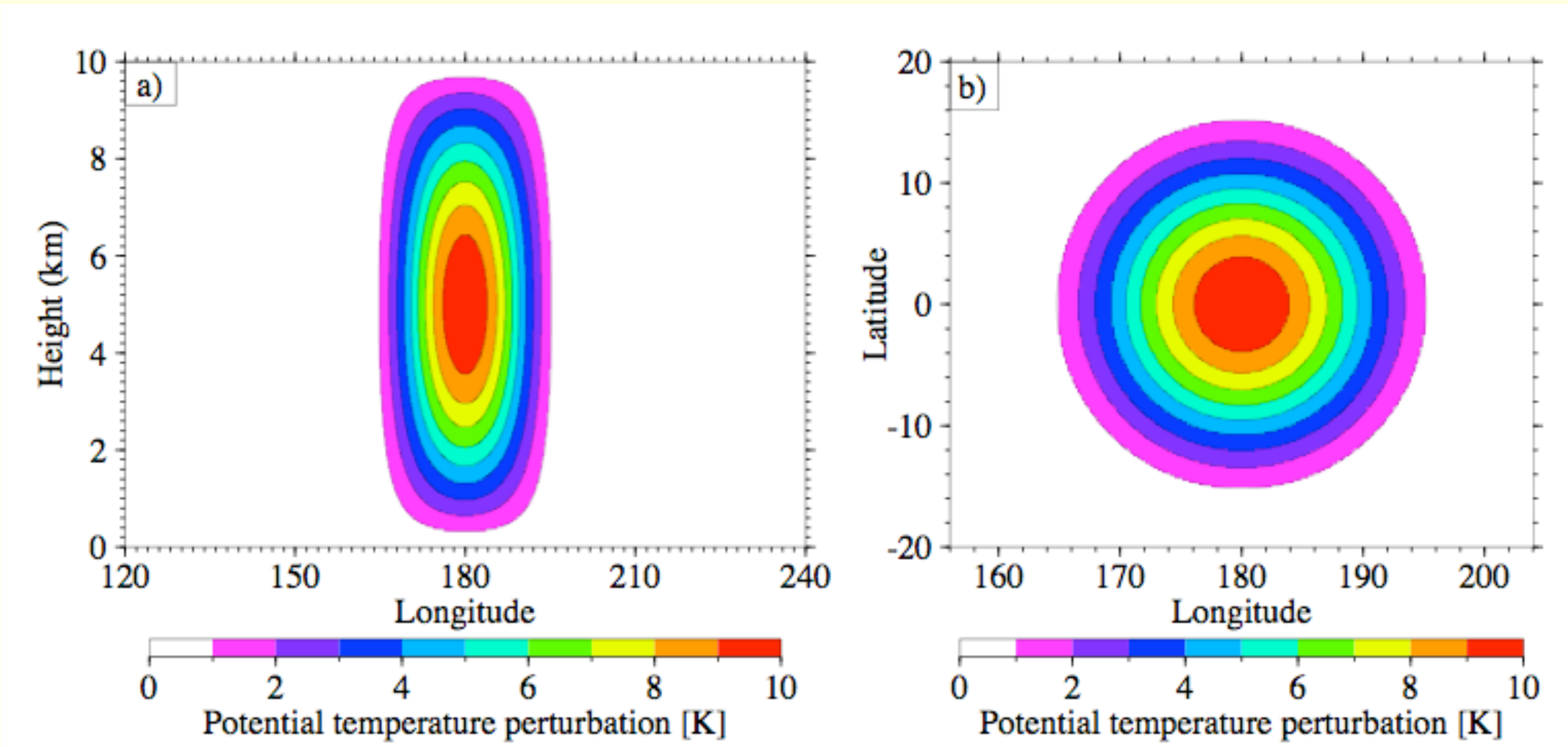
- Initial u, p_s, z_s fields, isothermal, v=0 m/s, balanced
- Mountain triggers the evolution of Rossby waves

Days 15 & 25: Mountain-induced waves

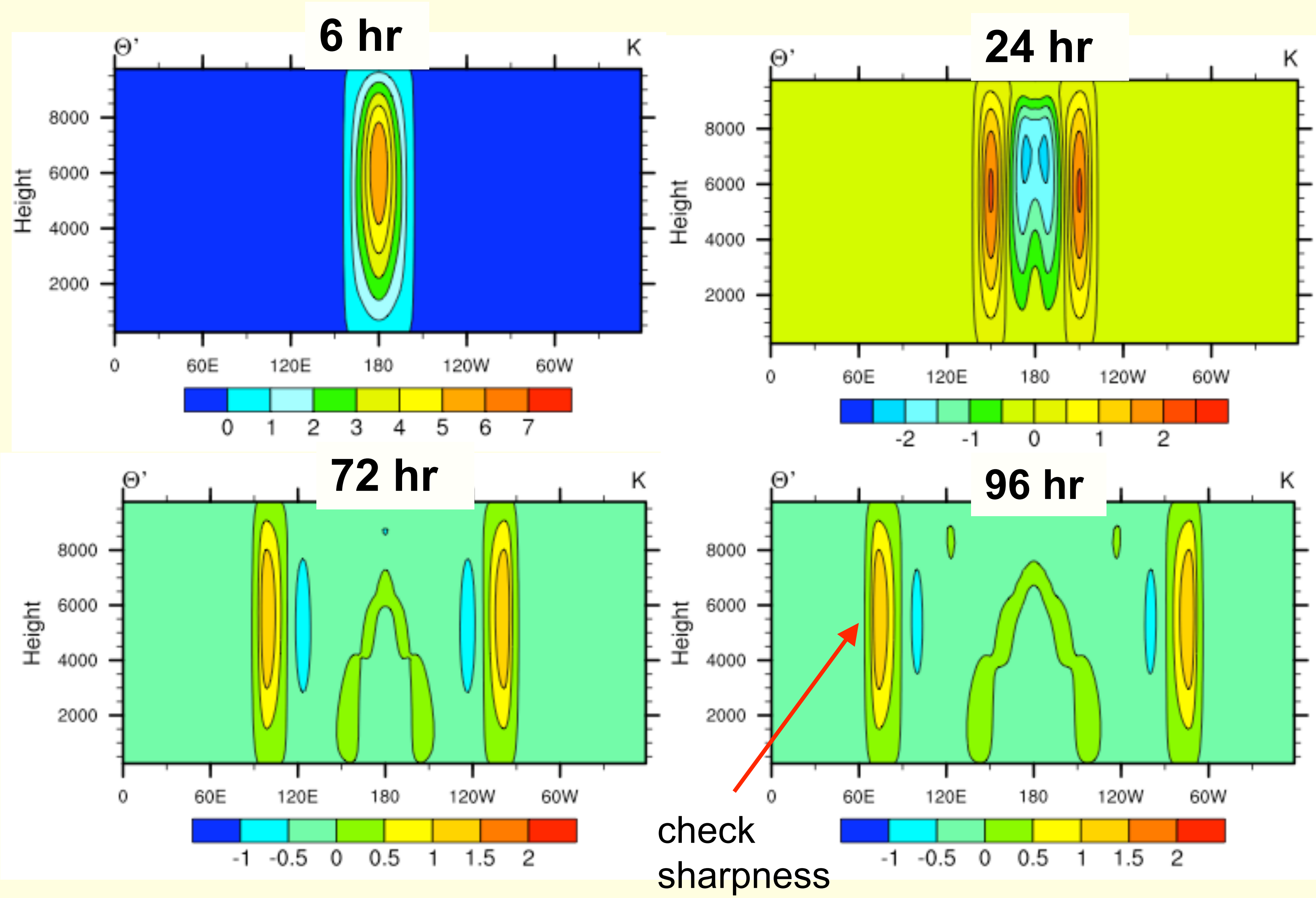


Test 6) Gravity waves

- No rotation in test [6-0-0], [6-1-0], [6-2-0]
- Balanced initial state with potential temperature perturbation
- Perturbation triggers hydrostatic gravity waves



[6-0-0]: Θ' cross section along the equator



Other tests we think about

6) 3D Mountain Waves (irrotational): hydrostatic & non-hydrostatic, linear & non-linear
7) Acoustic Waves
8) Dycore tests with real orography
9) Idealized tropical cyclone with simplified moisture processes:
   - Prescribed tropical vortex embedded in an easterly flow
   - Balanced initial data, ocean-covered surface
   - Specific humidity
   - Large-scale condensation with latent heat release
   - Simple boundary layer formulation (evaporation)

Practical tips for the next 11 days

- Use the GUI ncview for quick evaluations of your runs
- Use the NCL scripts for the in-depth analysis
- We will add more NCL scripts over the next few days
- We will need to tailor the scripts for some models
- Follow our suggested analysis techniques and feel free to add new ideas to it
- Feel free to play: e.g. explore different diffusion coefficients
- Remember Murphy's law
- Let your laptop survive for the next 2 weeks
- Most importantly: Have fun !

Resources

- Check the bluevista directory
  /homebv/cjablono/dycore_ncl
  for the newest versions of the NCL scripts
- Check the README_first file in this directory for practical tips on ncview and NCL
- ncview works with mouse-clicks, sometimes you also need to press the 'fn', 'ctrl', 'alt' or 'Apple' key to get the functionality you want, just explore it
- ncview is installed under
  /homebv/cjablono/ncview/bin/ncview
  /contrib/bin/ncview