A Vorticity-Divergence Dynamical Core based on the Nonhydrostatic Unified System of Equations on the Icosahedral Geodesic Grid

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Since last time...

- Celal and Dr. Arakawa revised the form of the elliptic equation for the non-hydostatic Exner pressure ($\partial\pi$)
- Revised elliptic solver to avoid the implicit vertical solve. This involved considerable (and ongoing) numerical experimentation.
- The new system works much better
- Show results from the modified non-hydrostatic system.
- Also show
  - improved tracer transport
  - inclusion of simple physics

New elliptic equation

$$\nabla_H \cdot \left(\rho_{qs} c_p \theta \nabla_H \delta\pi\right) + \frac{\partial}{\partial z}\left(\rho_{qs} c_p \theta \frac{\partial \delta\pi}{\partial z}\right) =$$

$$- \nabla_H \cdot \left(\rho_{qs} c_p \theta \nabla_H \pi_{qs}\right) + \mathcal{A}_D^* + \frac{\partial}{\partial z}\mathcal{A}_w + \boldsymbol{\nabla}_H \cdot \left(\mathbf{v}\frac{\partial \rho_{qs}}{\partial t}\right) + \frac{\partial^2 \rho_{qs}}{\partial t^2}$$

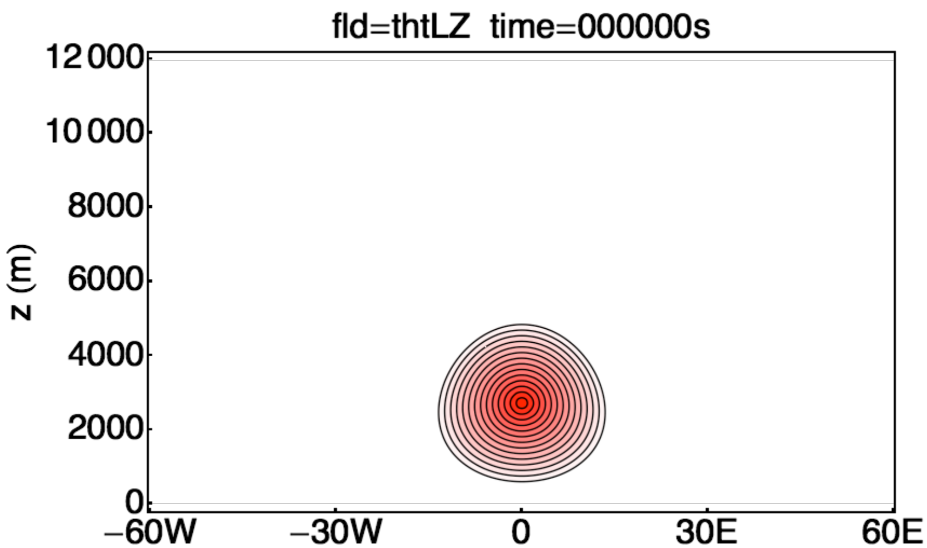
where

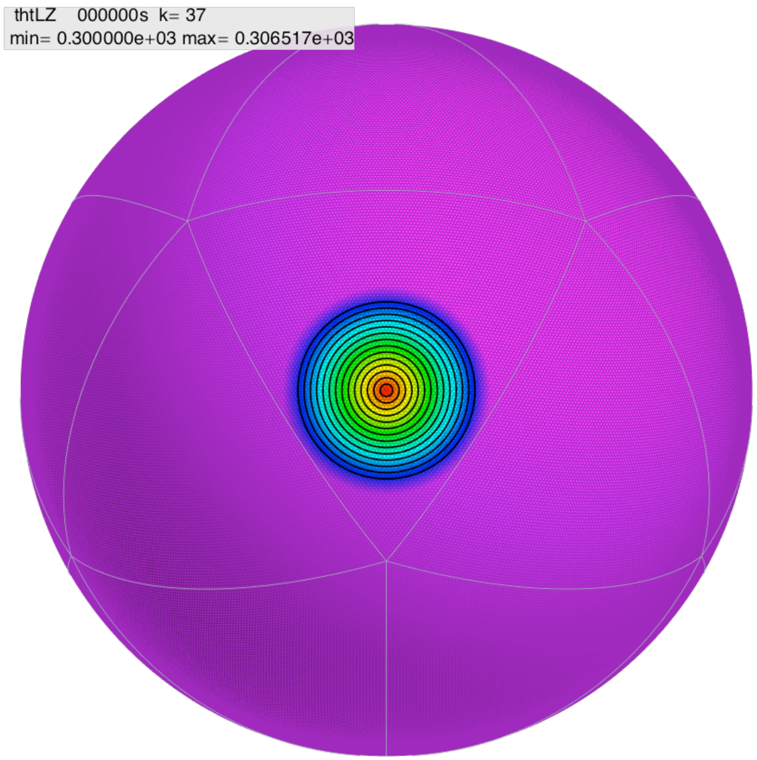
$$\mathcal{A}_D^* \equiv J\left(\rho_{qs}\eta, \chi\right) + \nabla_H \cdot \left(\rho_{qs}\eta \nabla_H \psi\right) - \nabla_H \cdot \left(\rho_{qs} w \frac{\partial \mathbf{v}}{\partial z}\right) - \nabla_H \cdot \left(\rho_{qs} \nabla_H K\right) + \boldsymbol{\nabla}_H \cdot \left(\rho_{qs} F_{\mathbf{v}}\right)$$

$$\mathcal{A}_w \equiv -\nabla_H \cdot \left(\rho_{qs} w \mathbf{v}\right) - \frac{\partial\left(\rho_{qs} w w\right)}{\partial z} + \rho_{qs} F_z$$

Warm Bubble Test

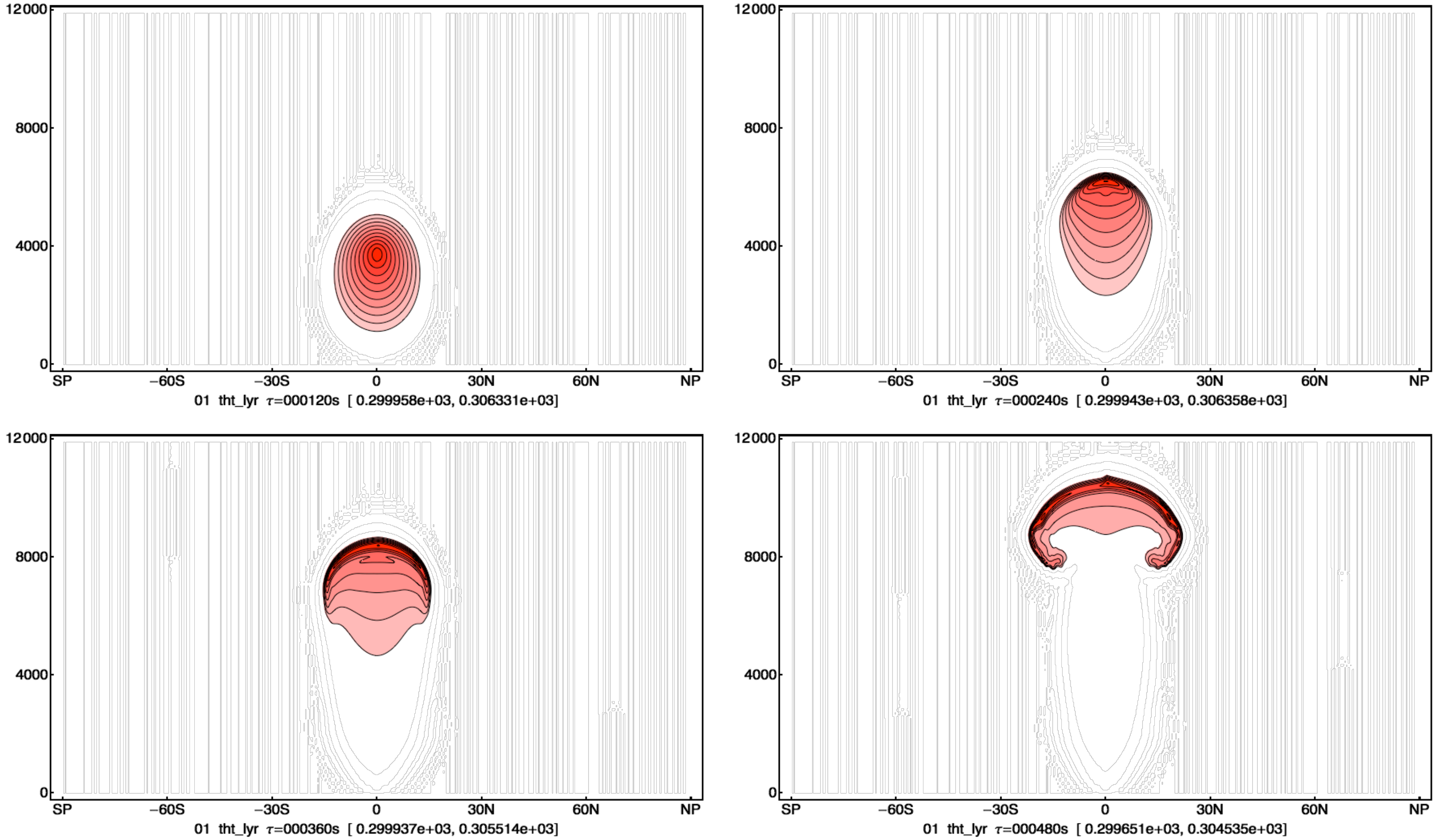
- Initial condition is the 3D version of Mendez-Nunez and Carroll (1994)
- The initial bubble is 6.6K warmer than the environment.
- The globe is 6.37km in radius (1000×smaller)
- The model resolution is
  - 163842 cells resulting in 63 m horizontally
  - 96 levels





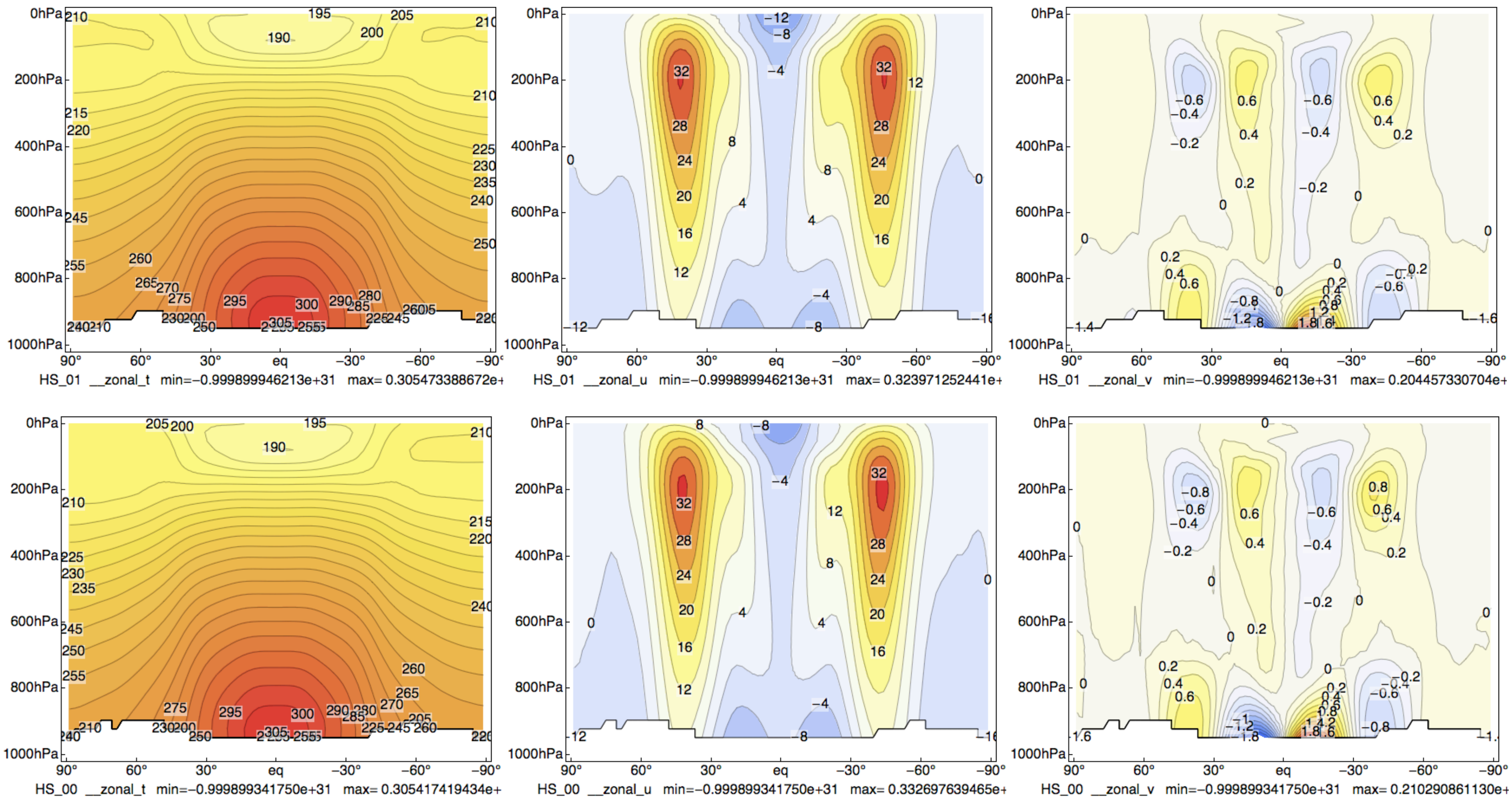
Warm Bubble Test

- Times are 120, 240, 360 and 480 seconds.



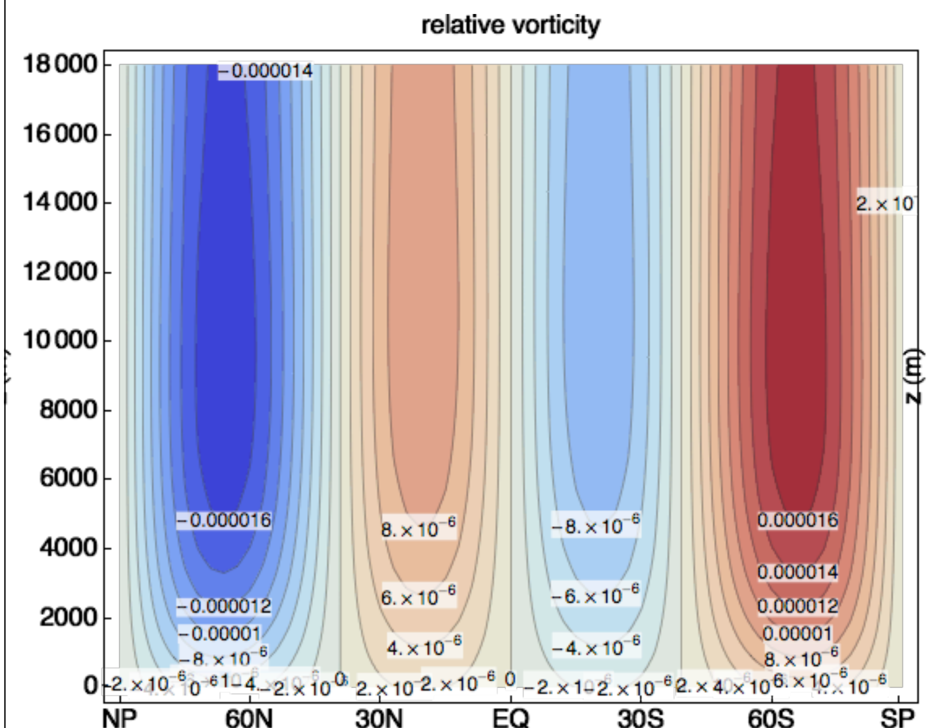
Held Suarez test case with grid 5 (250 km). 200 Days. 50 Samples

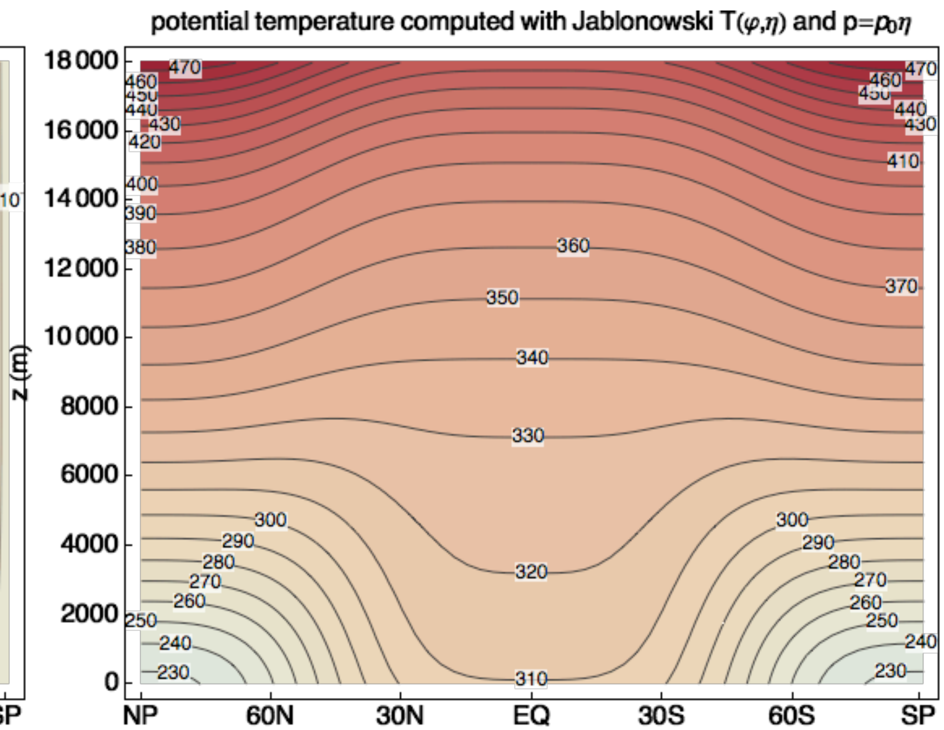
- Held-Suarez 1994. Newtonian relaxation toward prescribed temperature.
- Top row is non-hydrostatic. Bottom row is hydrostatic.
- Columns show temperature, zonal and meridional winds



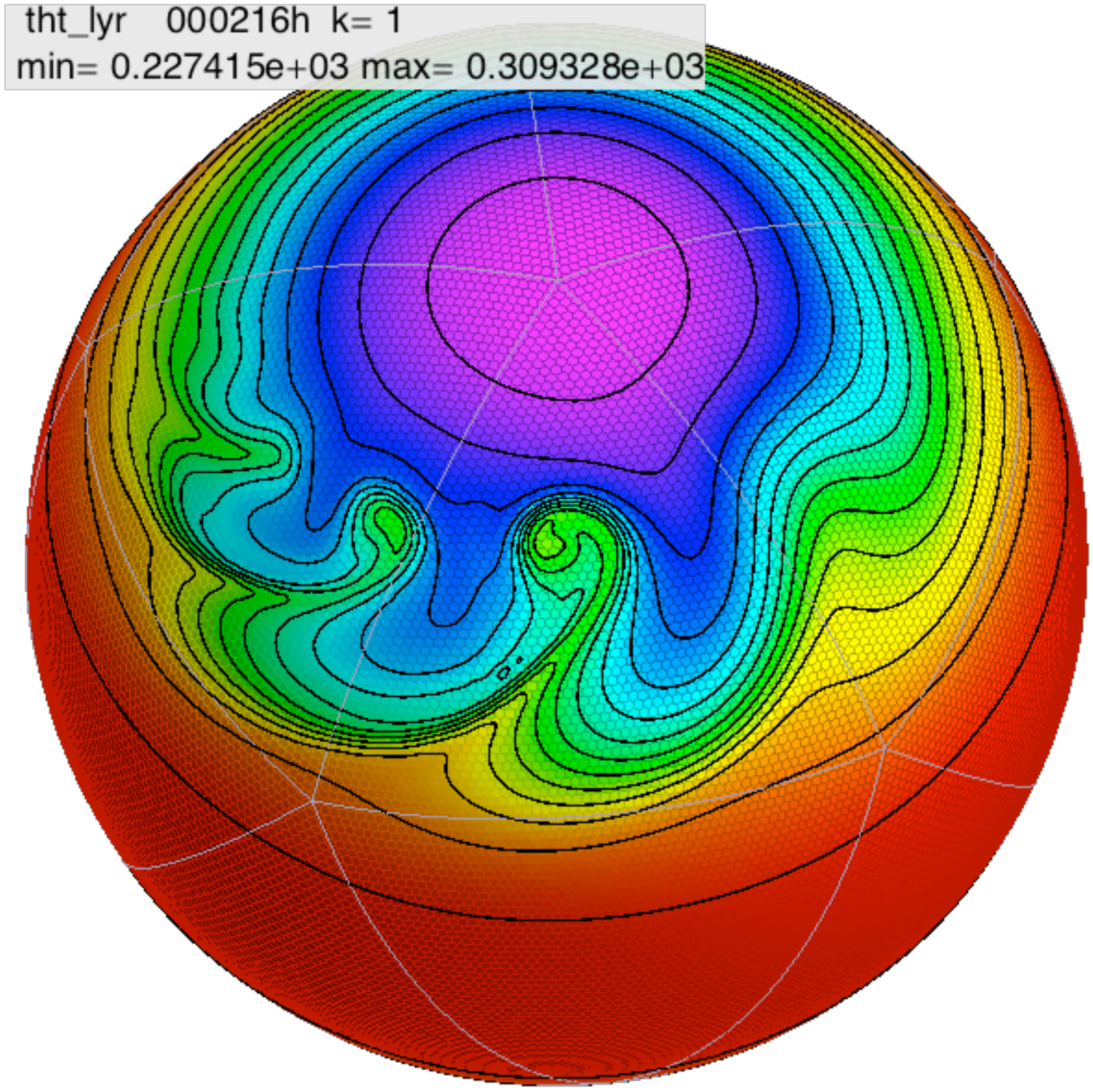
Extratropical cyclone

- Jablonowski and Williamson (2006) *Quart. J. Roy. Meteor. Soc.*, **132,** 2943-2975
- 40962 cells (125 km). 32 layers.



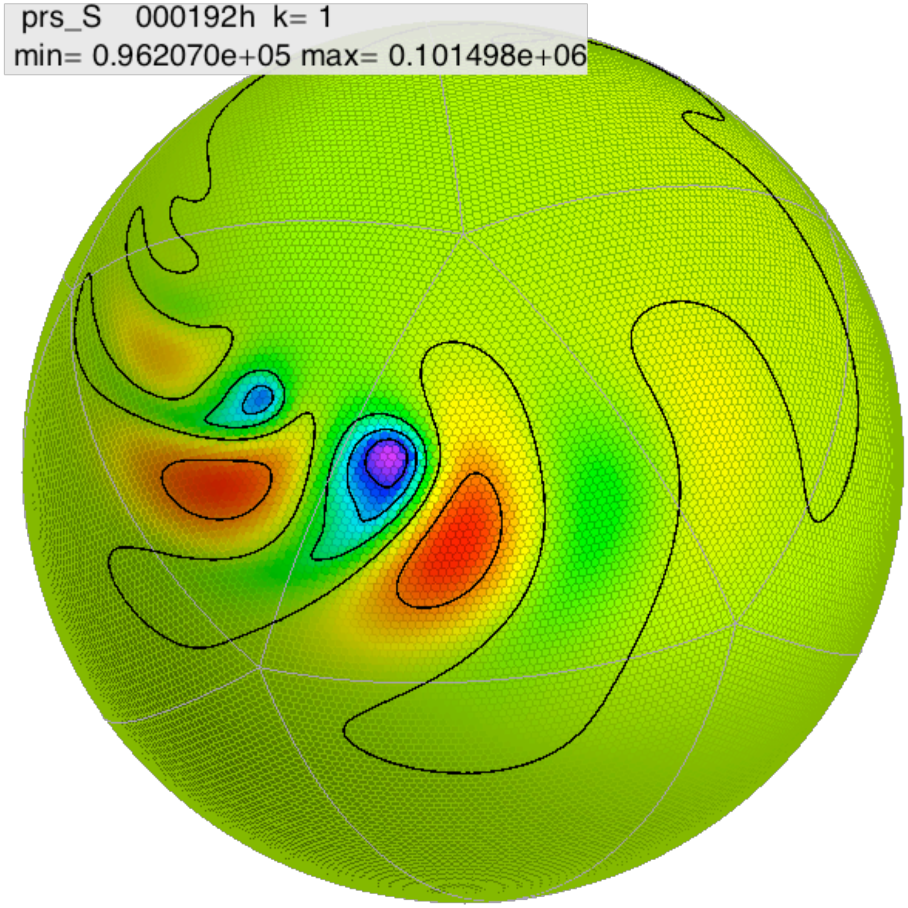


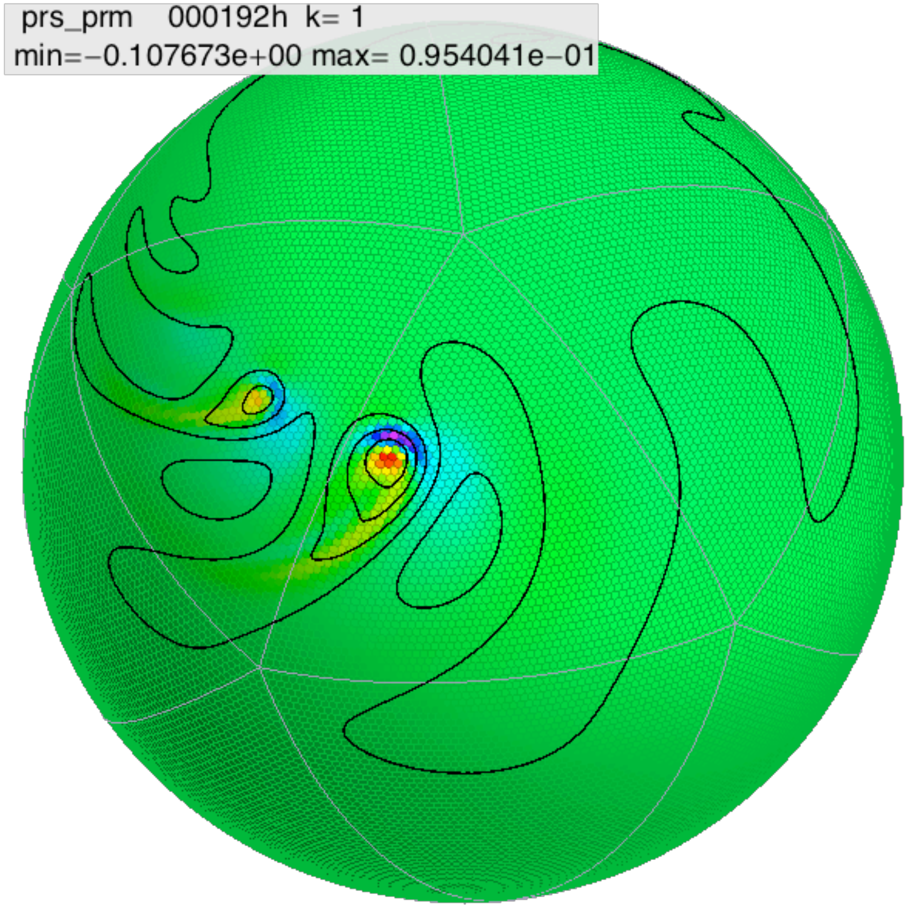
Extratropical cyclone



Extratropical cyclone

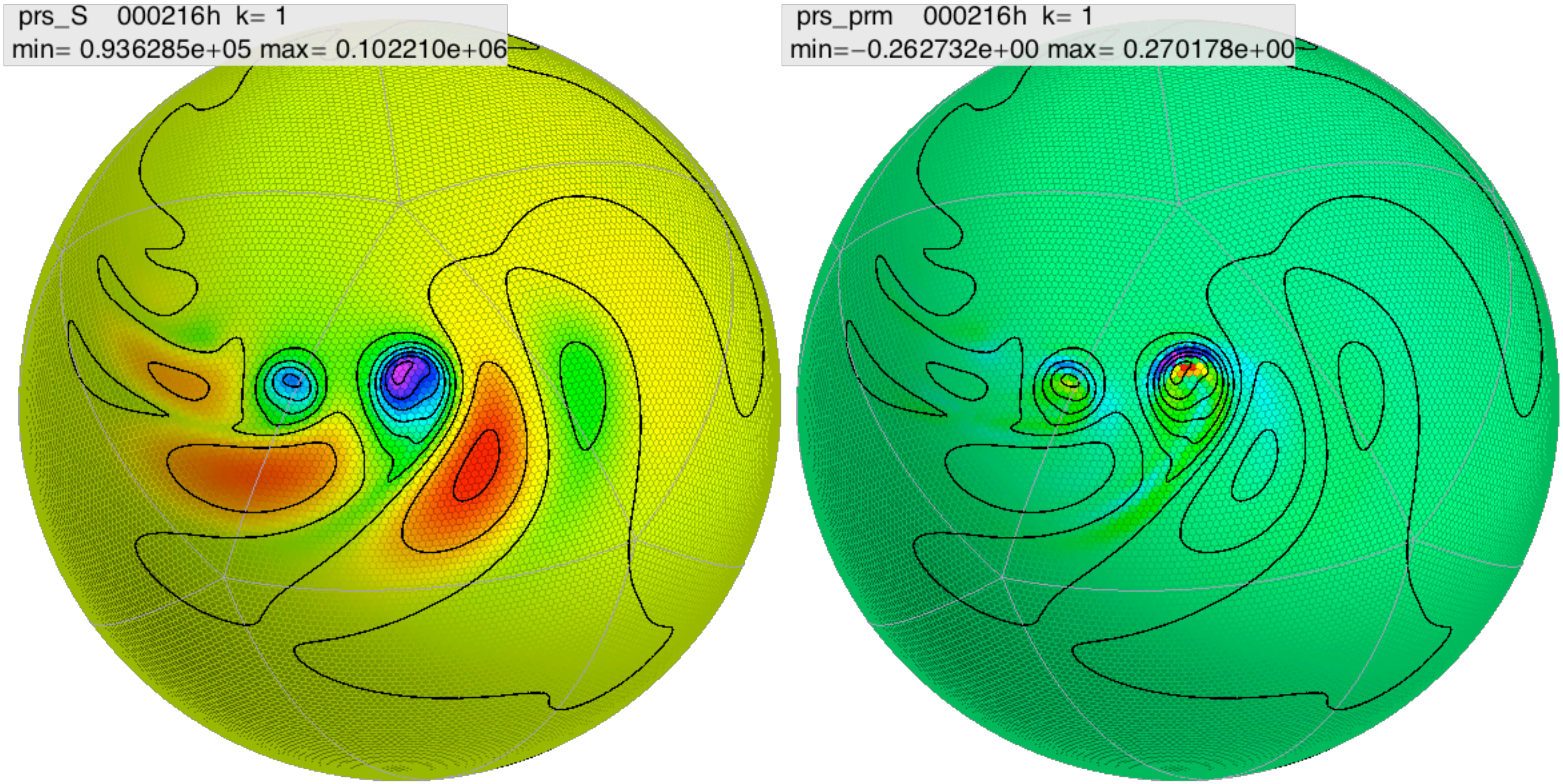
- Plots show total surface pressure and non-hydrostatic pressure (∂p) on day 8
- The non-hydrostatic ∂p works against the deepening low





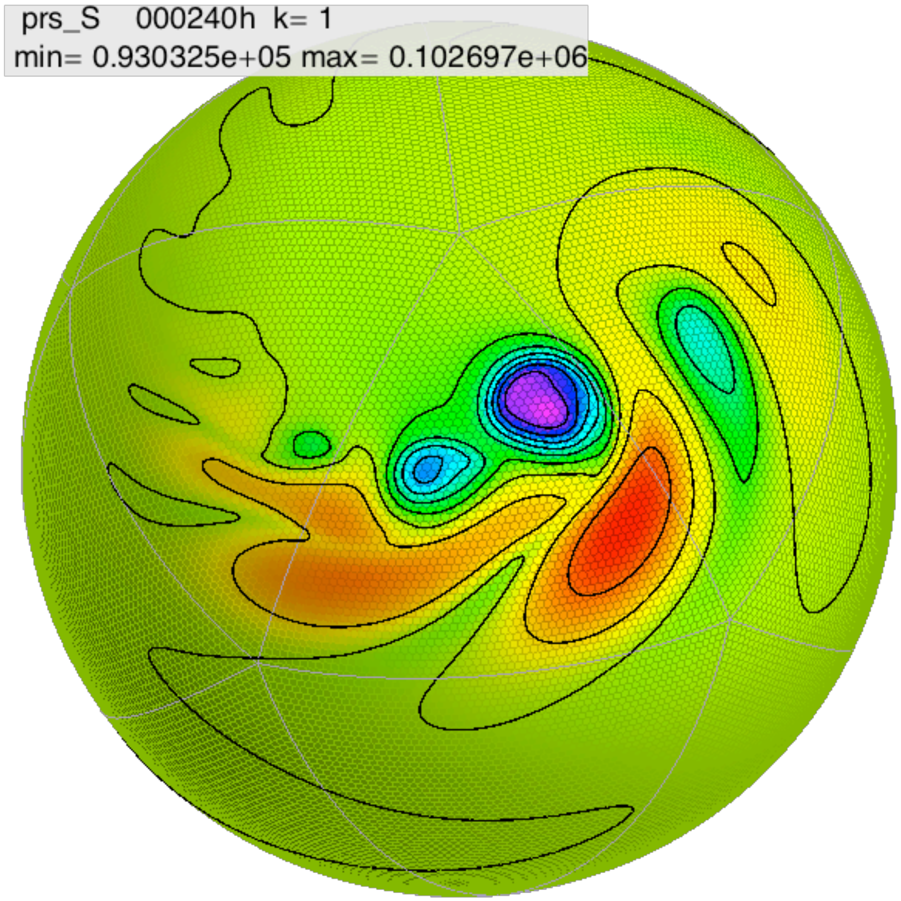
Extratropical cyclone

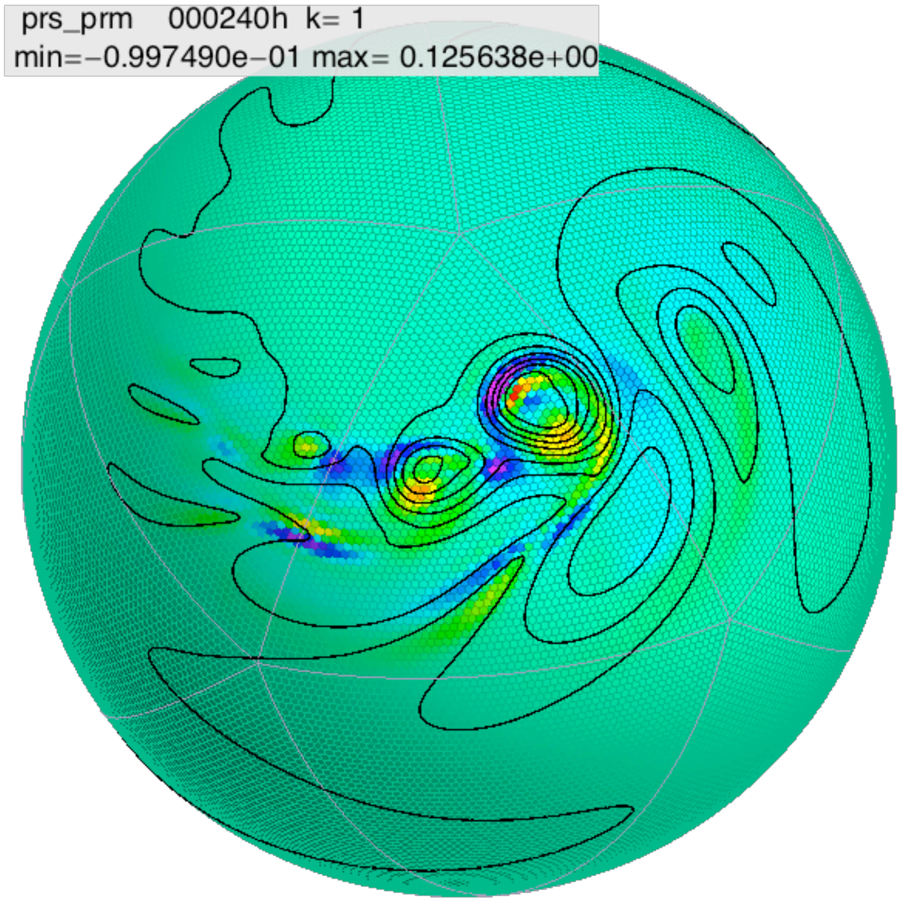
- Plots show total surface pressure and non-hydrostatic pressure (∂p) on day 9
- The non-hydrostatic ∂p works against the deepening low



Extratropical cyclone

- Plots show total surface pressure and non-hydrostatic pressure (∂p) on day 10
- The non-hydrostatic ∂p works against the deepening low



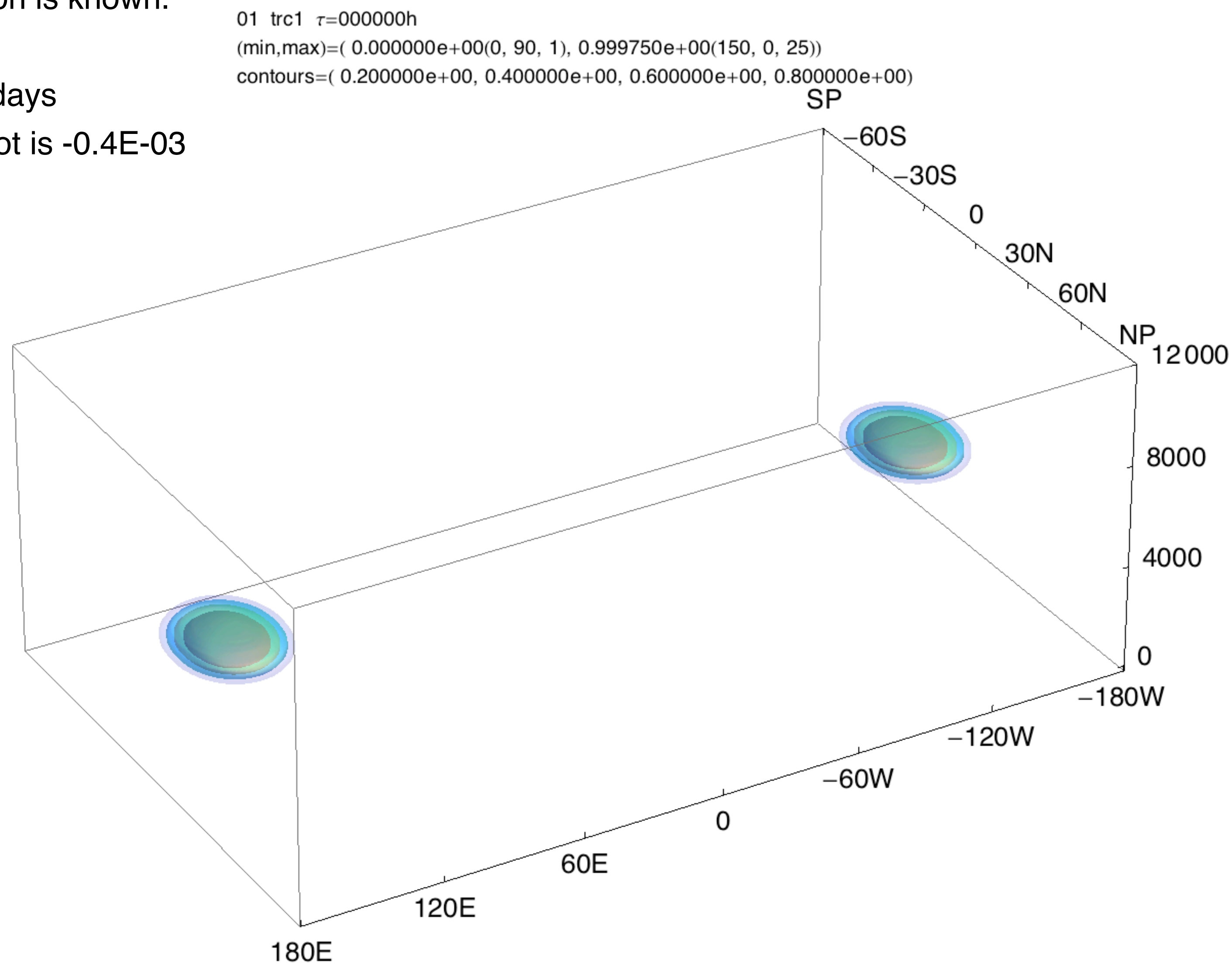


Improvements to tracer transport

- Horizontal advection of tracers
  - 3rd-order upstream biased interpolation to cell walls
  - positive-definite flux correction to avoid under-shooting
- Vertical advection of tracers
  - Lagrange polynomial, upstream biased interpolation to interfaces
  - positive-definite flux correction to avoid under-shooting
- The 3D deformational flow test is based on the 2D approach by Nair and Lauritzen JCP (2010)

Improvements to tracer transport

- The 3D deformational flow test is based on the 2D approach by Nair and Lauritzen JCP (2010)
- Time reversal ensures that the original profile is returned to its original position, so an analytic solution is known.
- Two cosine bells.
- Grid 7. 60 level. 12 days
- Minimum under-shoot is -0.4E-03



Inclusion of simple moist physics

- Idealized tropical cyclone simulation
- Reed and Jablonowski. JAMES (2012)
- Physical processes included in the *simple-physics* package:
  - Large-scale condensation defined to occur when the atmosphere becomes saturated.
  - Surface fluxes of horizontal momentum, evaporation (specific humidity) and sensible heat (temperature) from the ocean surface to the lower atmosphere.
  - Boundary layer turbulence of horizontal momentum, temperature and specific humidity.

Inclusion of simple moist physics

- Grid 6. 125 km resolution.
- This animation shows the winds at 2500 m
- Each frame is 4 hours
- 11 days
- Maximum wind 41 m/s