An update on model development

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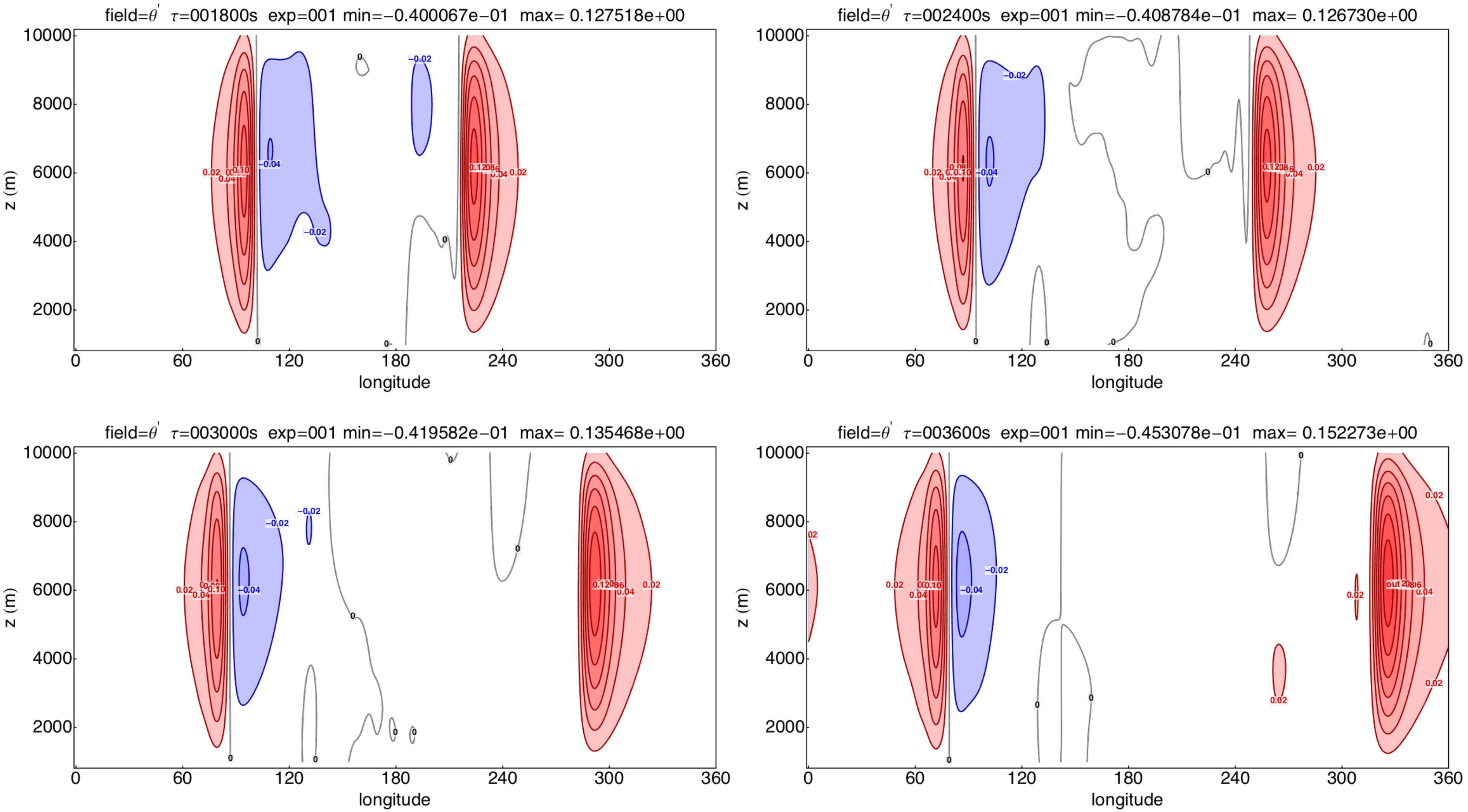
Outline

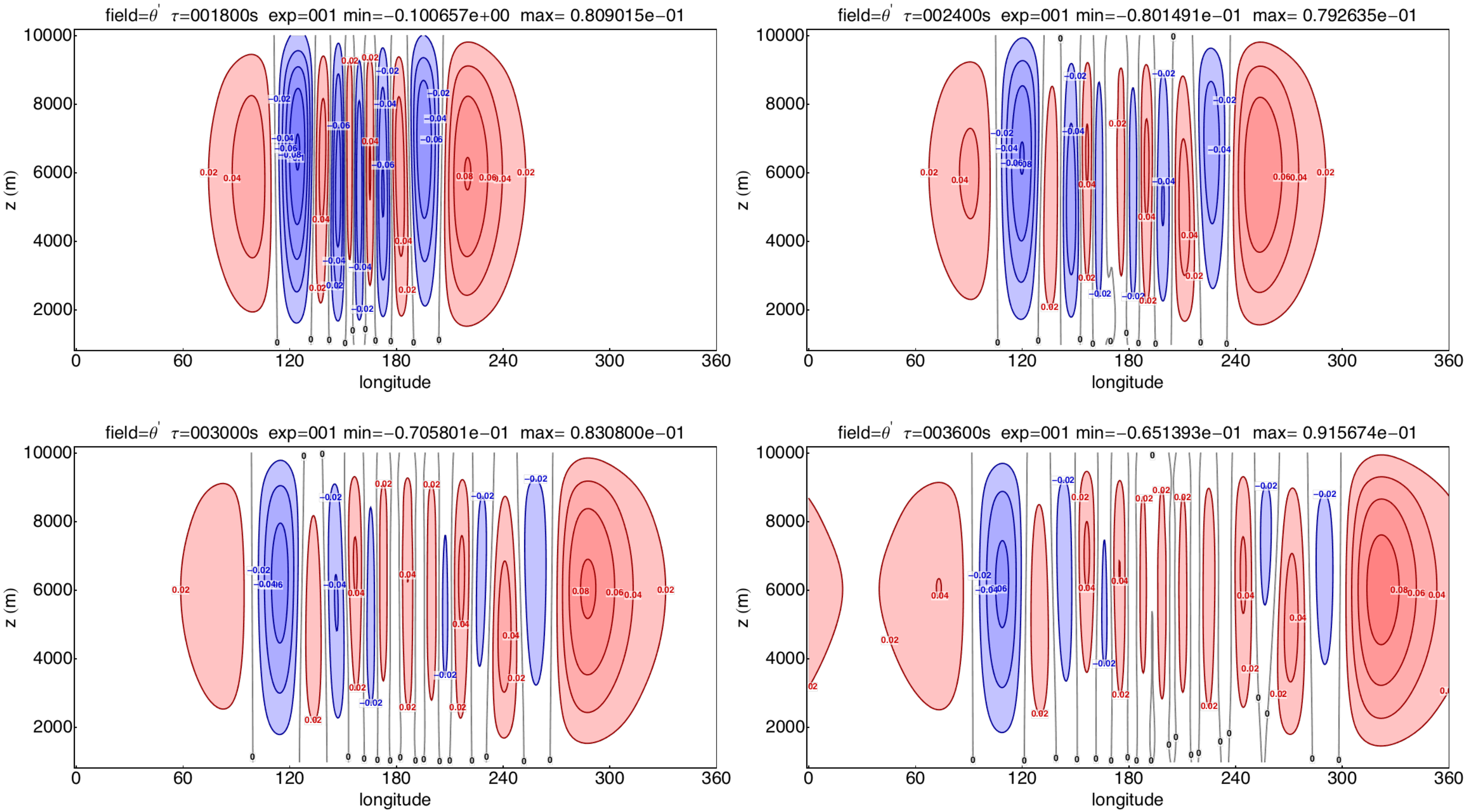
- Several unrelated little parts:

1. New vertical coordinates in the unified model
   a. height (Lorenz) *(NEW numerical tests)*
   b. terrain following (Charney-Phillips)
      - simple sigma (Phillips)
      - hybrid sigma-pressure coordinate *(NEW)*
      - hybrid sigma-theta coordinate *(NEW)*
2. Axial angular momentum conservation in the icosahedral model
3. 5th-order advection
4. More accurate winds

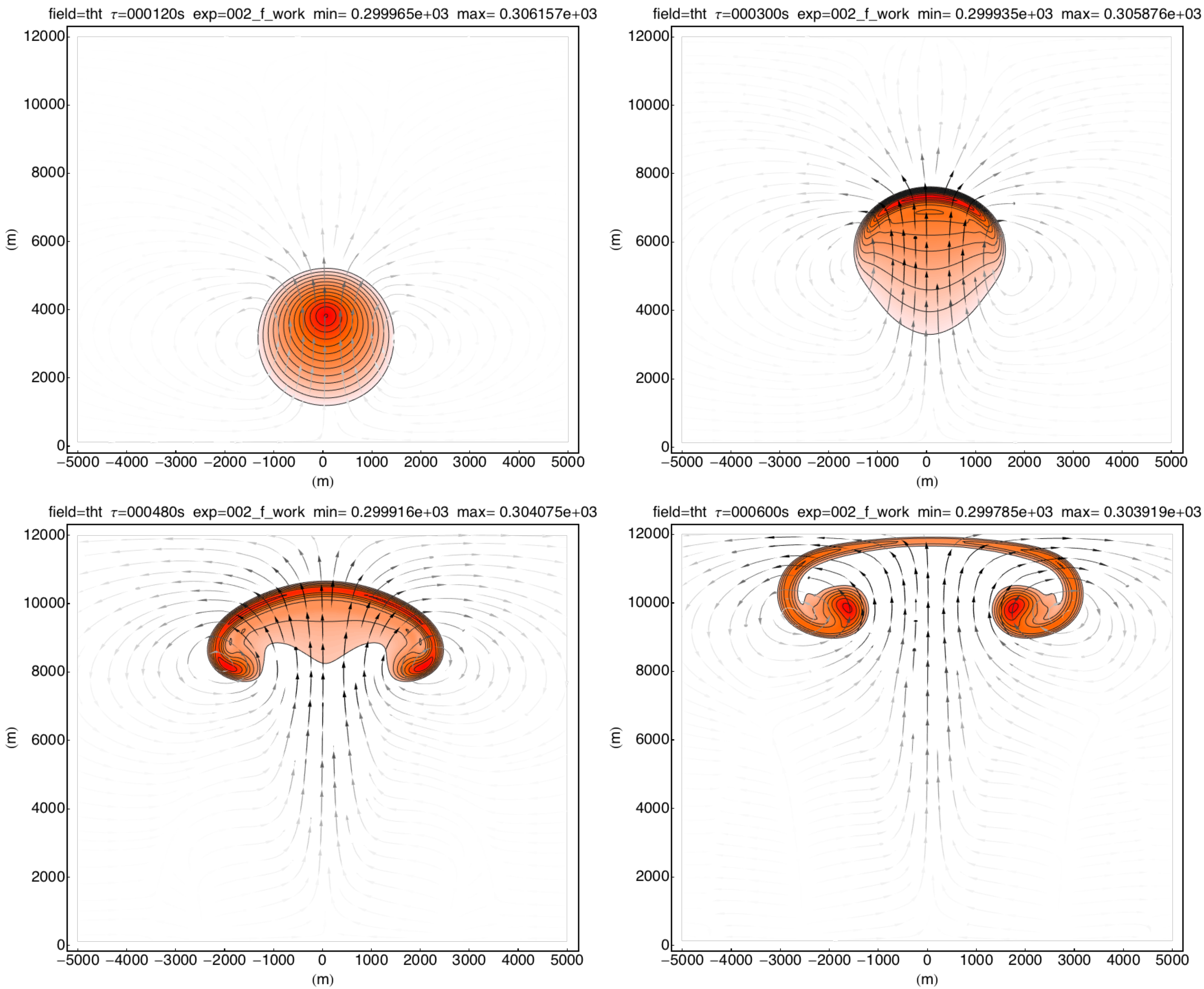
Height coordinate. Hydrostatic. Potential temperature perturbation.



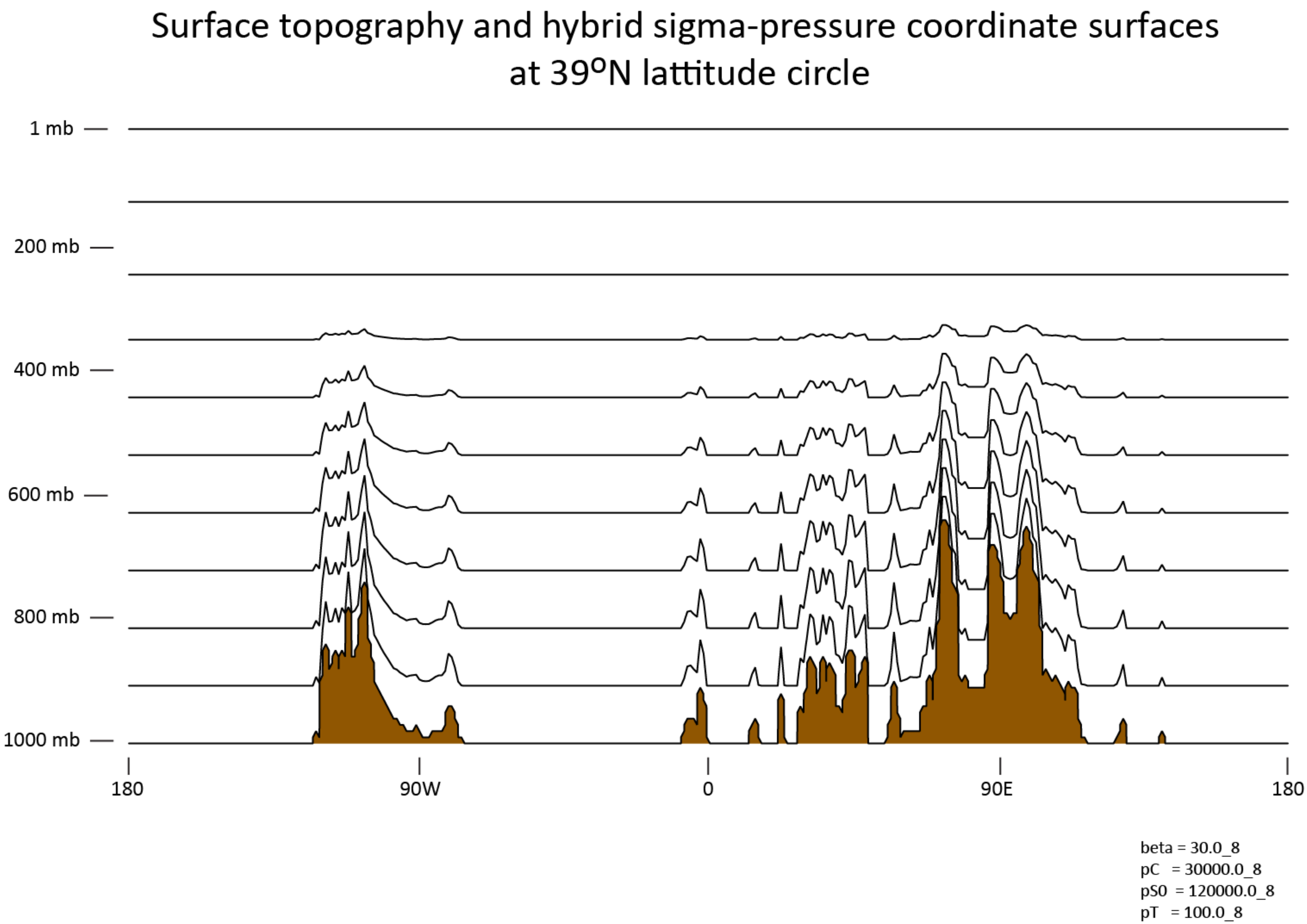
Height coordinate. Nonhydrostatic. Potential temperature perturbation.



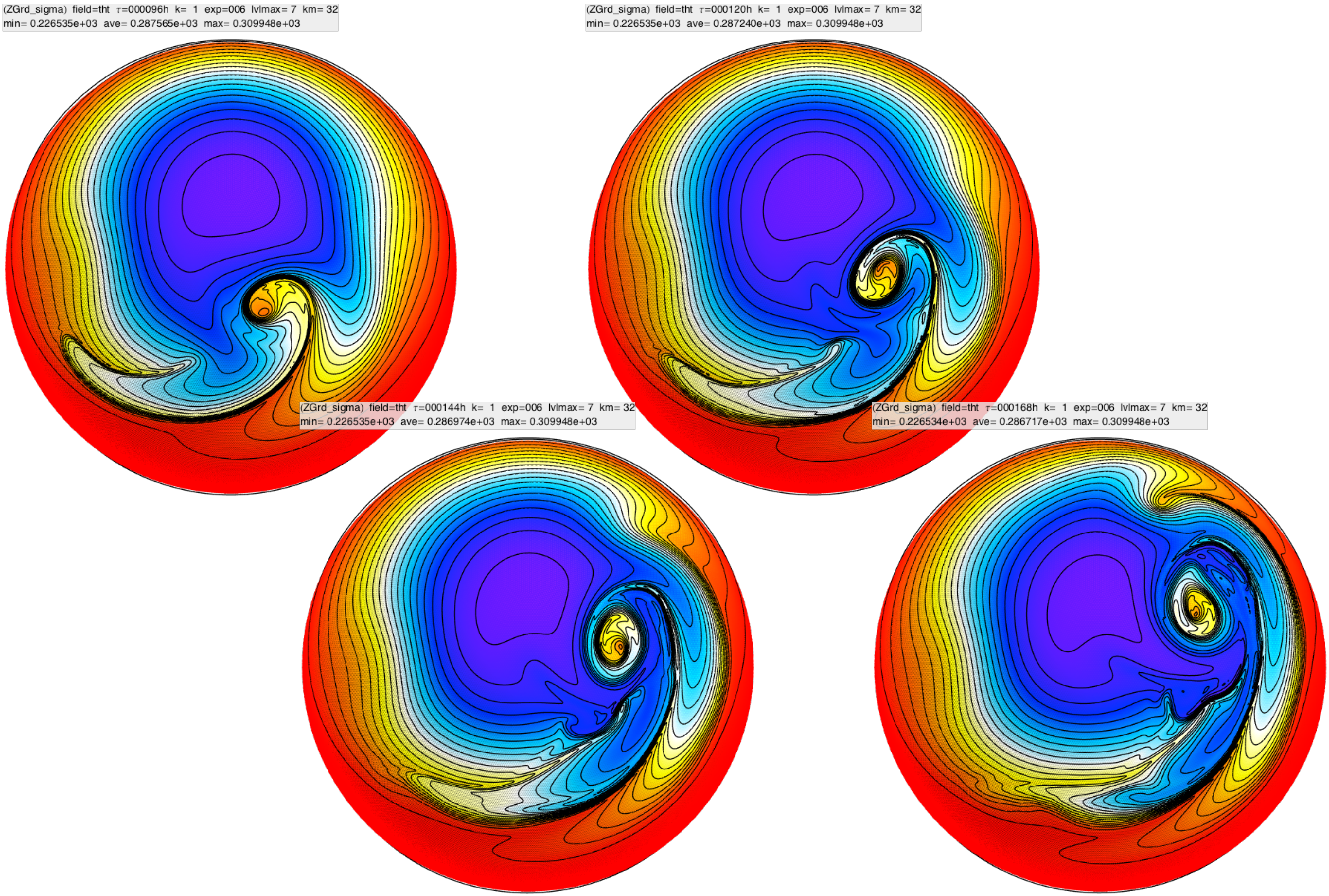
Height coordinate. Nonhydrostatic. Bubble.



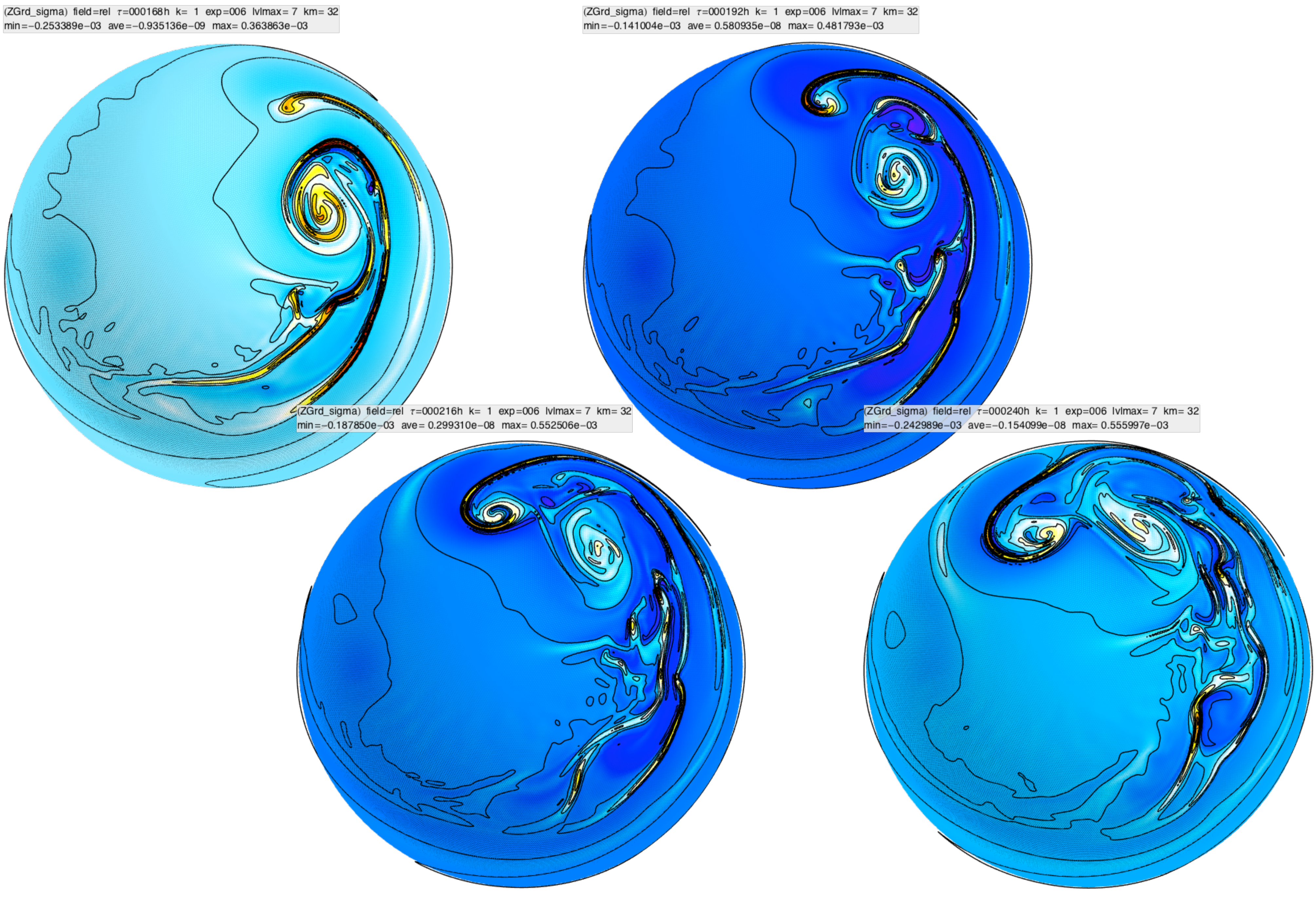
Hybrid sigma-pressure coordinate



Hybrid sigma-pressure coordinate. Big mountain test. Surface potential temperature.



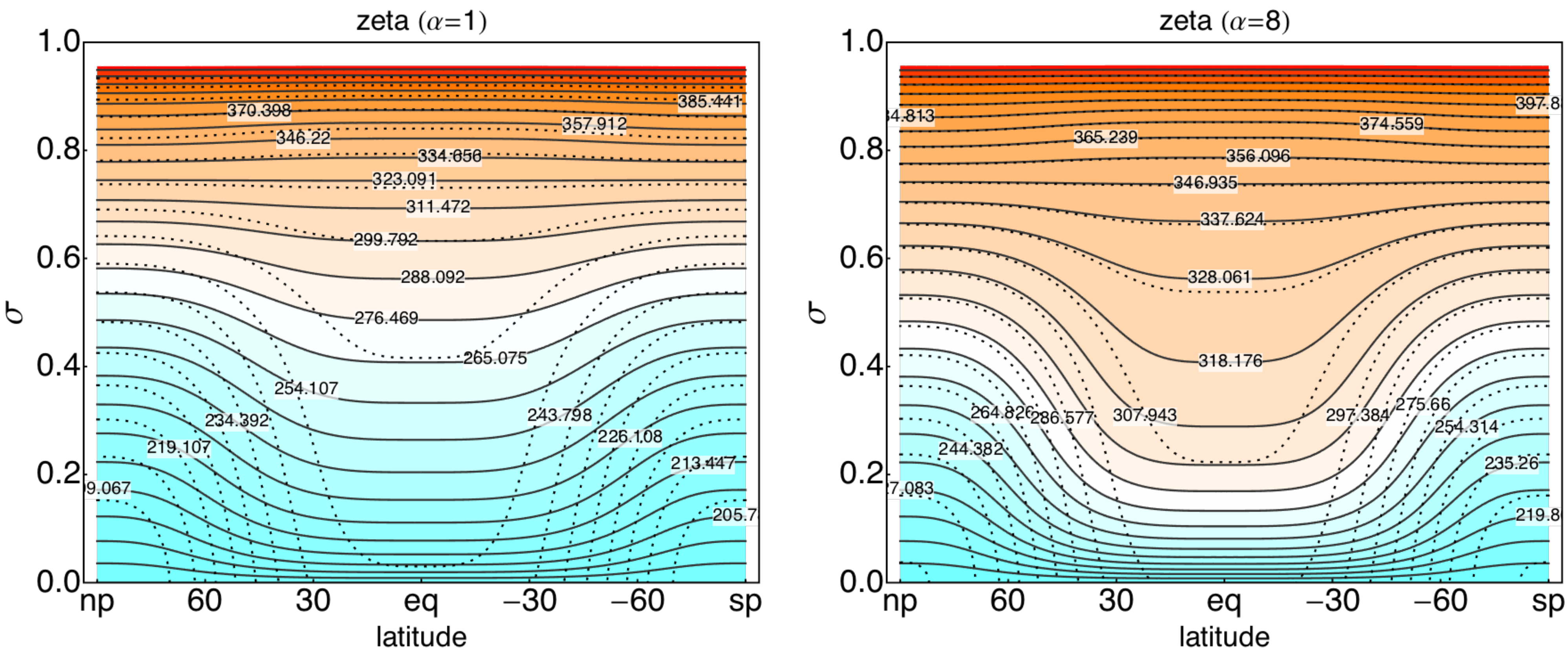
Hybrid sigma-pressure coordinate. Big mountain test. Surface relative vorticity.



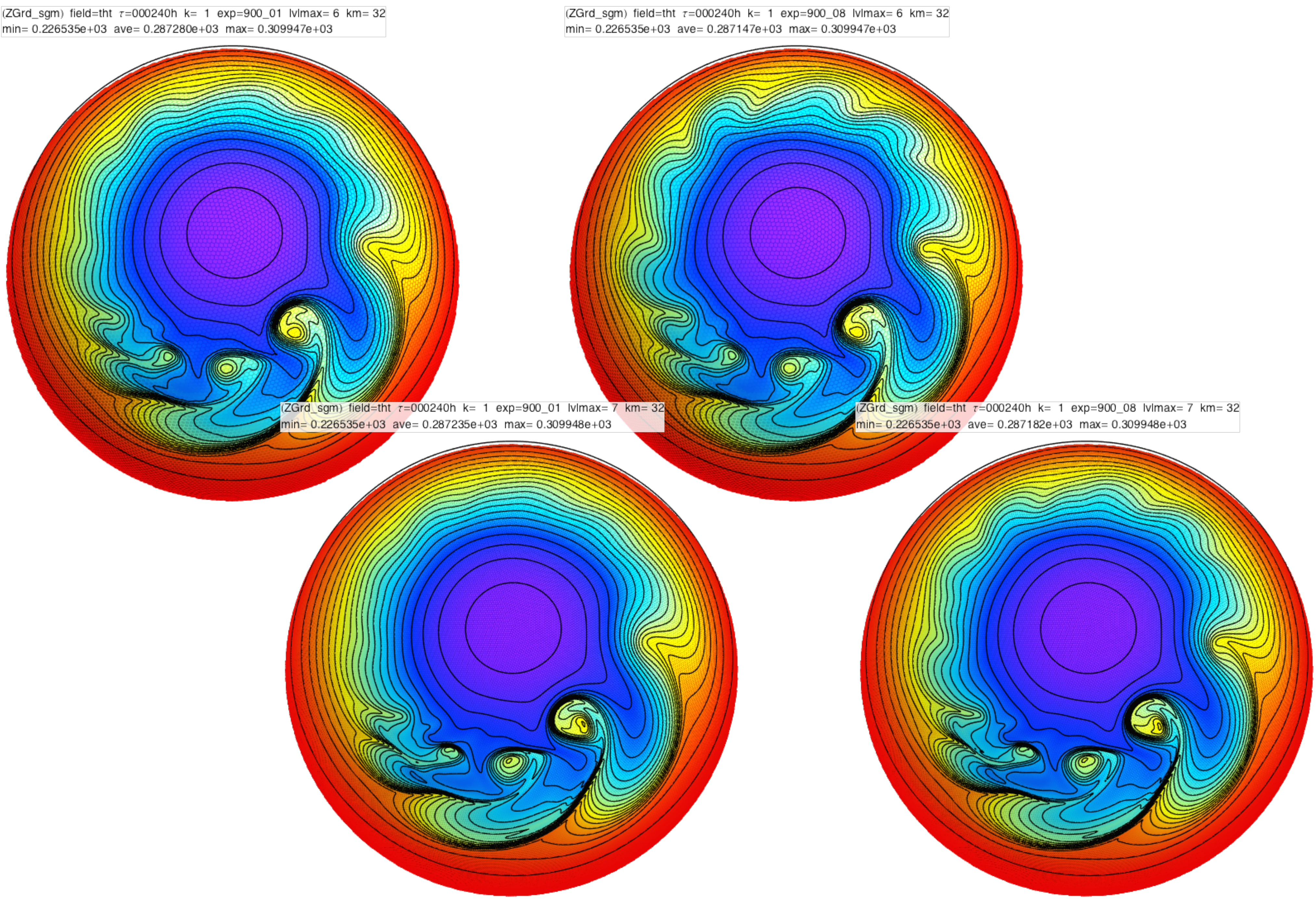
Hybrid sigma-theta coordinate.

- Distribution of coordinate surfaces within Jablonowski-Williamson test case.

    1. alpha = 1. Less isentropic
    2. alpha = 8. More isentropic



Hybrid sigma-theta coordinate. Jablonowski-Williamson. Day 10. Grid 6 and 7. α=1 and α=8.



Axial angular momentum conservation in the icosahedral model

- Inspired by a paper in JAMES:

Held-Suarez simulations with the Community Atmosphere Model Spectral Element (CAM-SE) dynamical core: A global axial angular momentum analysis using Eulerian and floating Lagrangian vertical coordinates

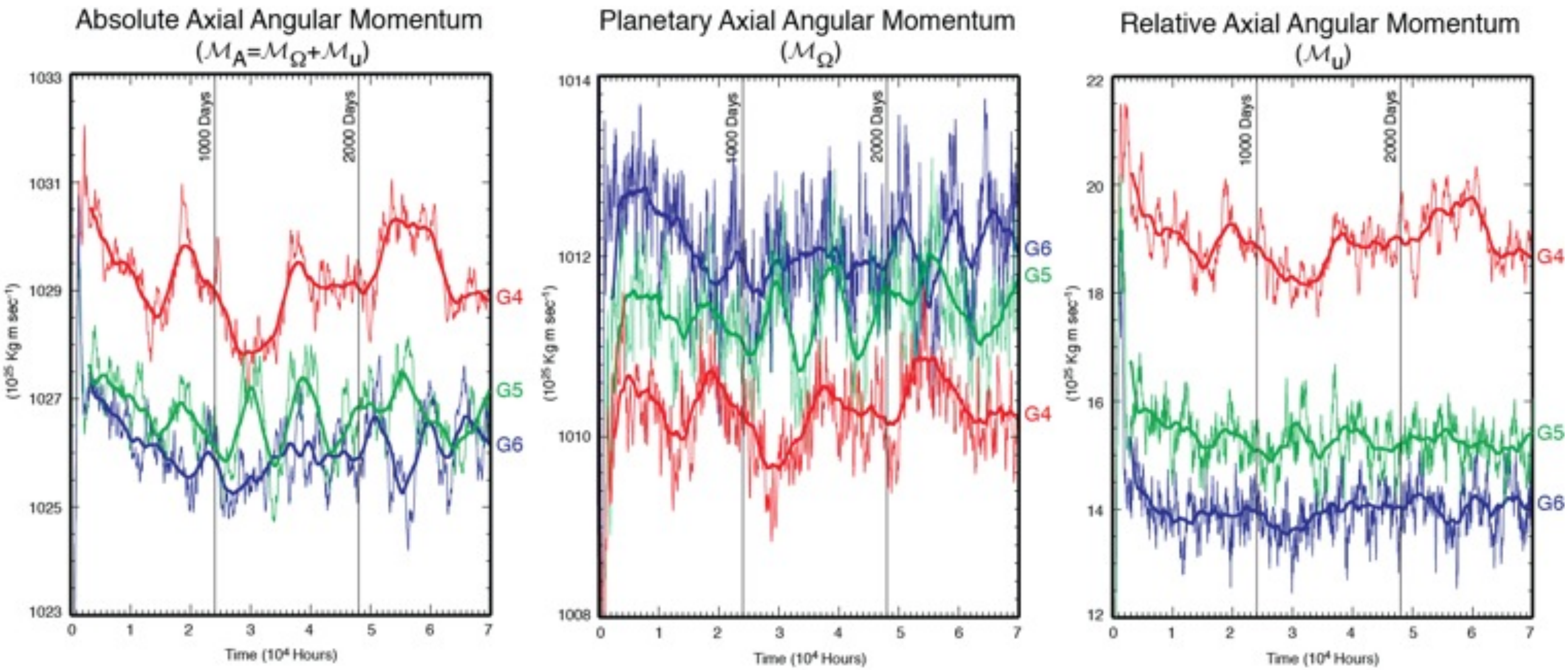
Peter H. Lauritzen[1], Julio T. Bacmeister[1], Thomas Dubos[2], Sebastien Lebonnois[3,4], and Mark A. Taylor[5]

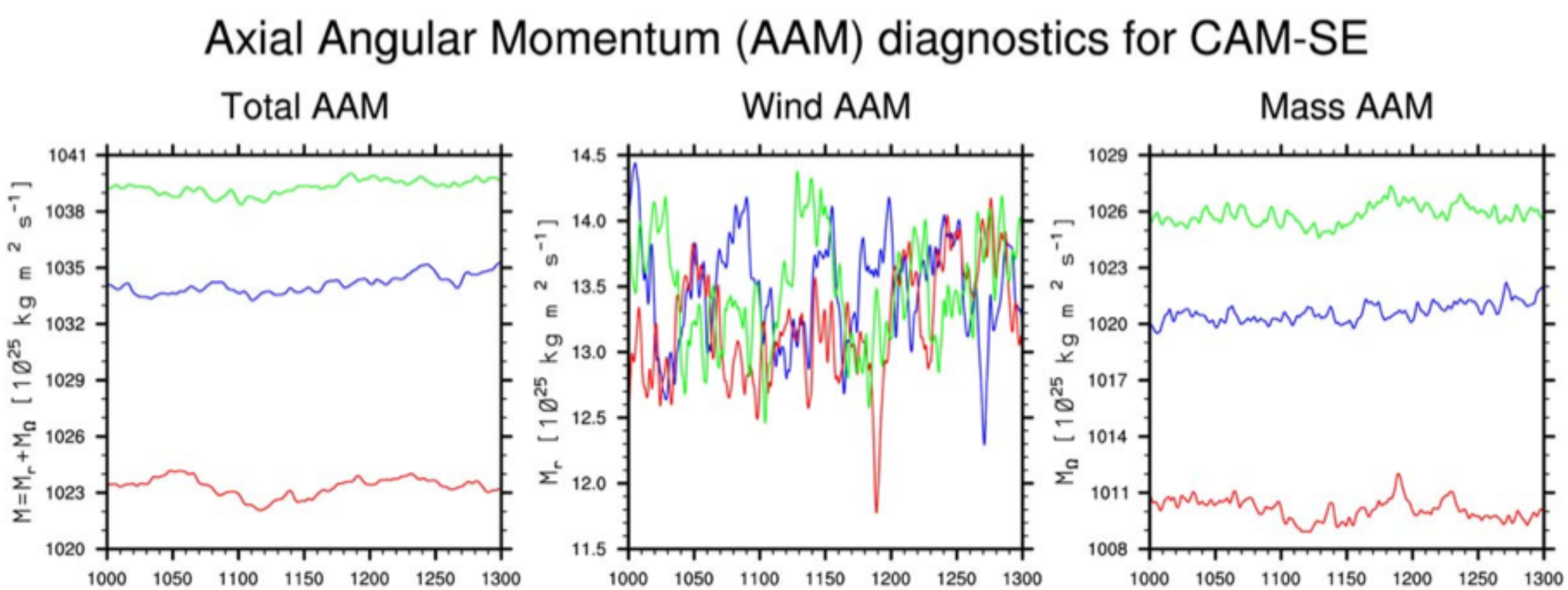
- The global axial angular momentum (AAM) can be separated into two parts:

  1. A part associated with the relative motion of the atmosphere with respect to the planet's surface. (wind AAM)
  2. A part associated with the angular velocity of the planet. (mass AAM)

$$M = M_r + M_\Omega = \int_D \rho u r \cos\varphi \, dV + \int_D \rho \Omega r^2 \cos^2\varphi \, dV$$

Axial angular momentum conservation in the icosahedral model



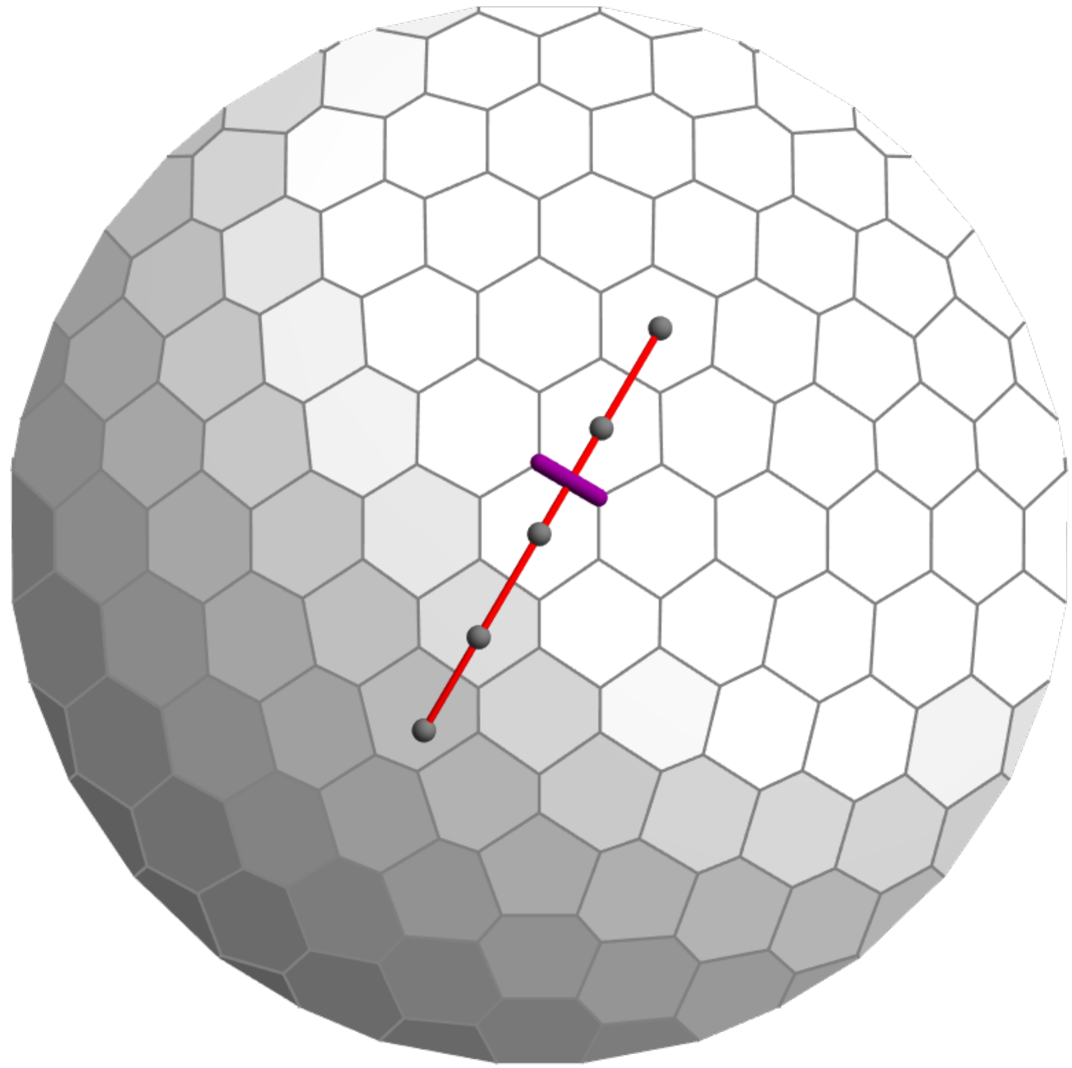


Colors show different polynomial orders for CAM-SE

- ne30np4 Lagrangian
- ne45np3 Lagrangian
- ne90np2 Lagrangian

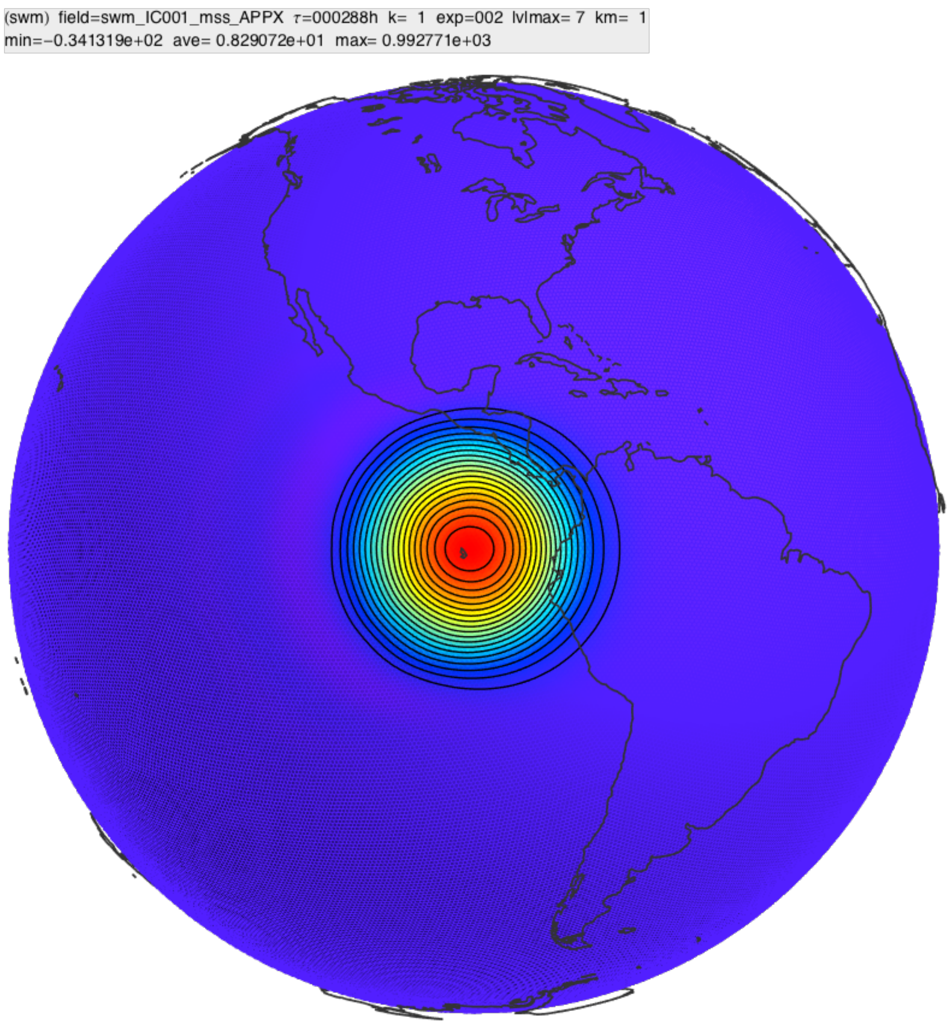
5th-order advection

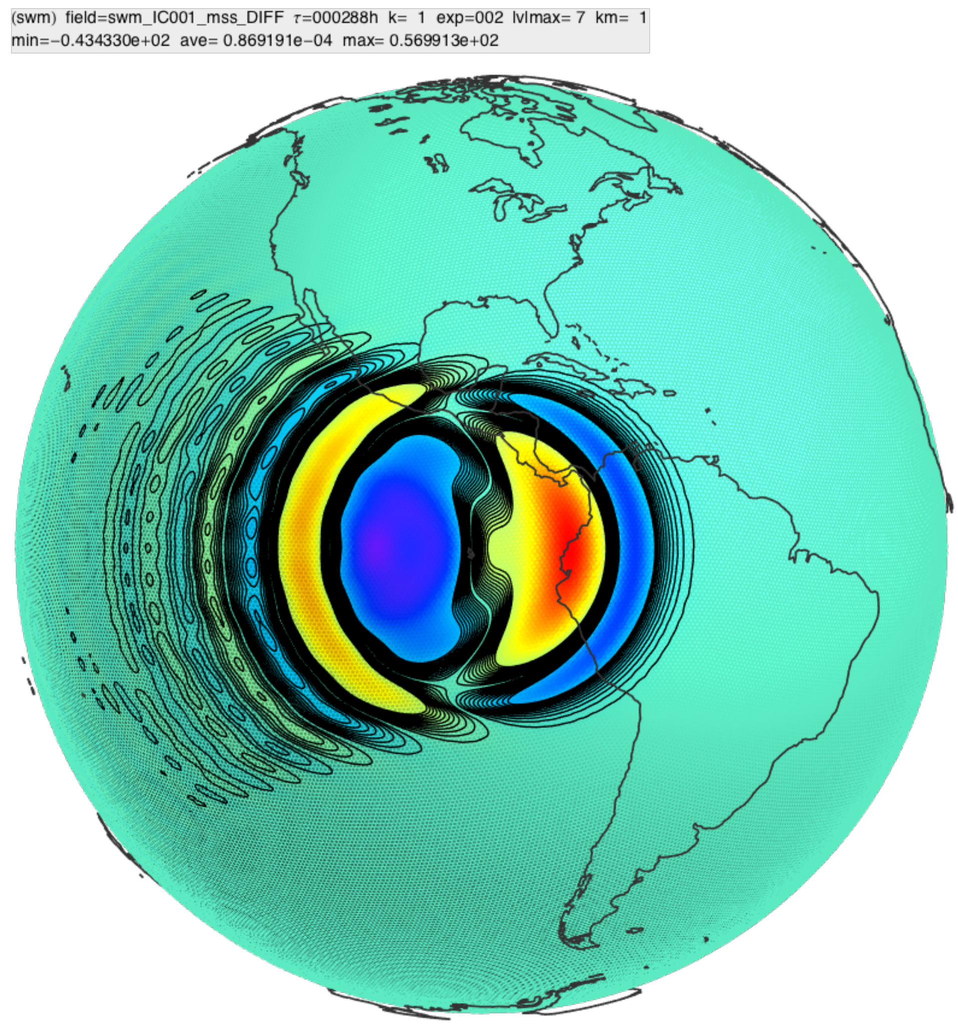
- In 5th-order advection the flux across a wall is determined by 3 points upstream and 2 points downstream



2nd-order. Williamson Test Case 2. Day 12.

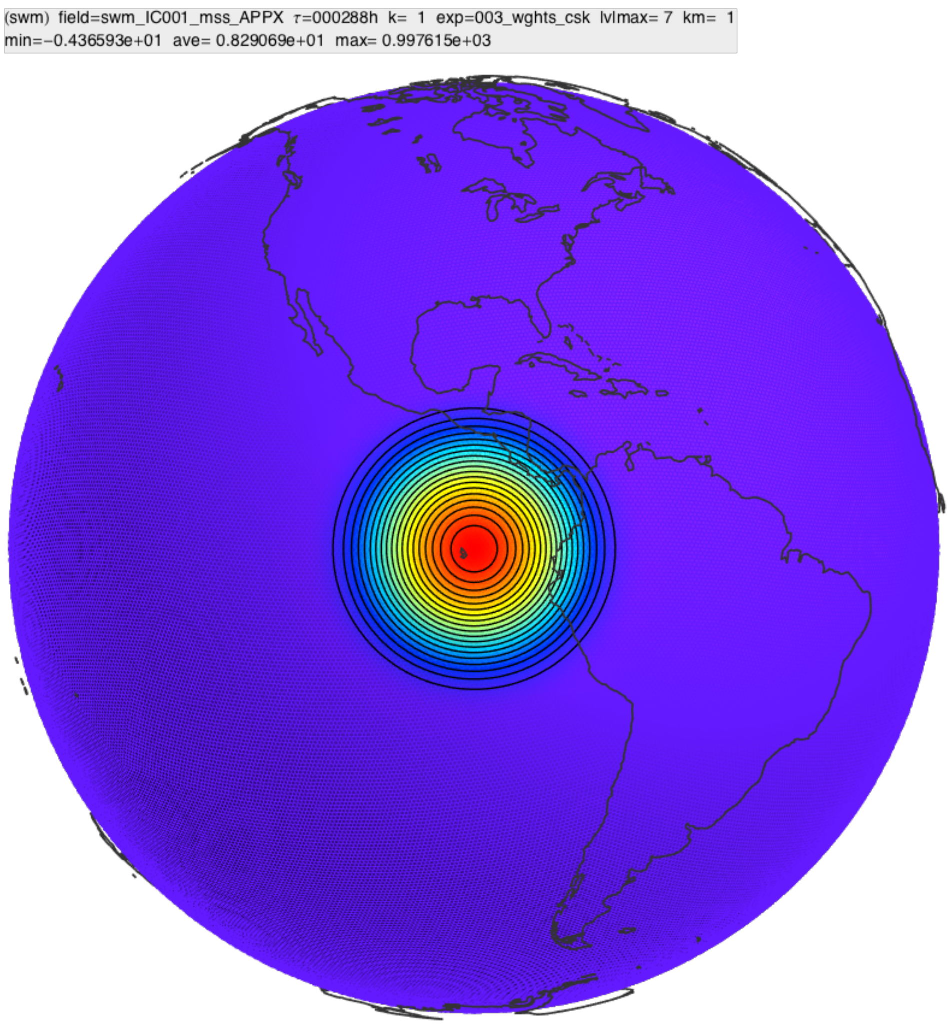
maximum error is 56m

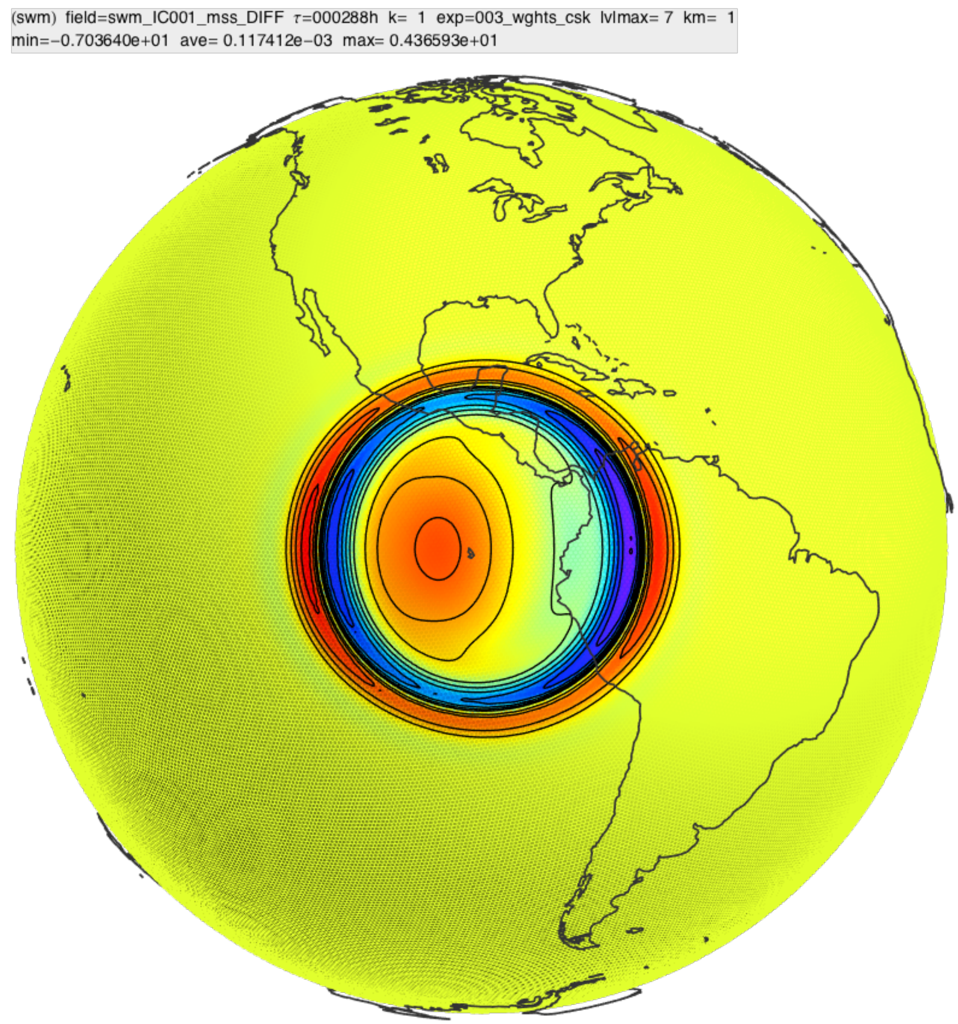




3rd-order. Williamson Test Case 2. Day 12.

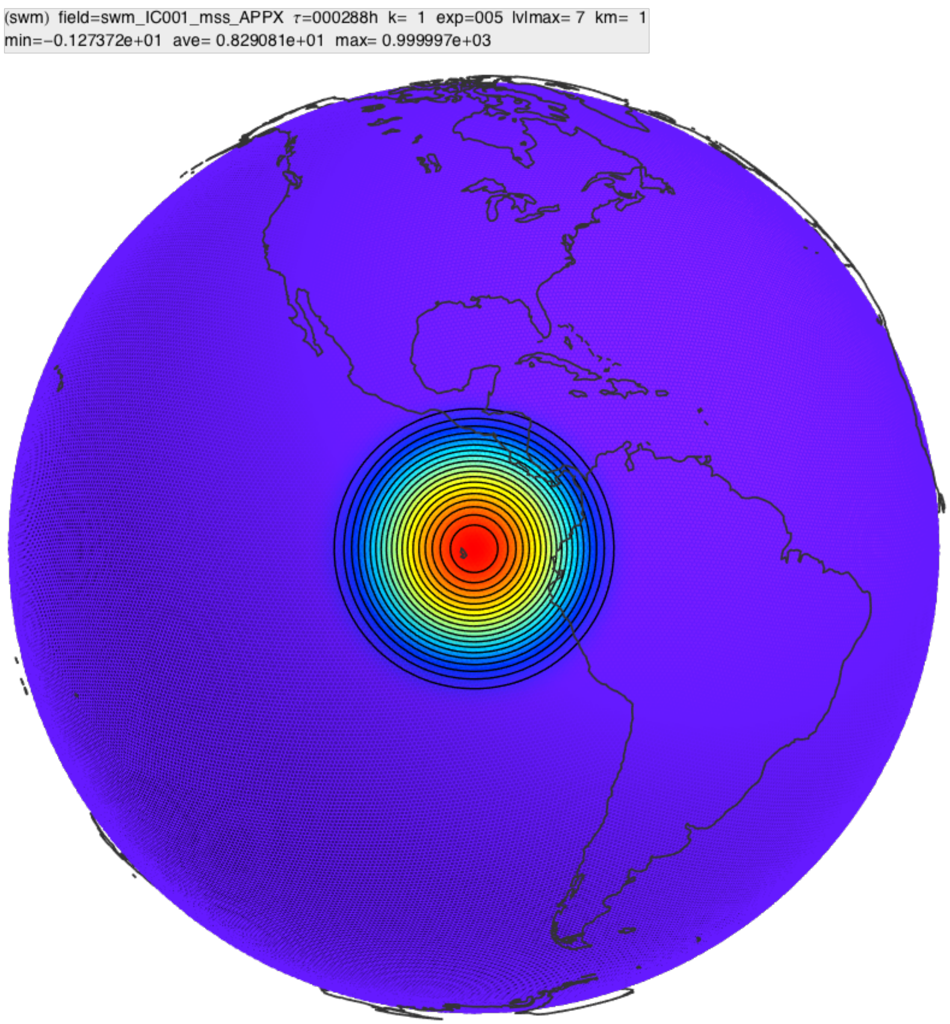
maximum error is 7m

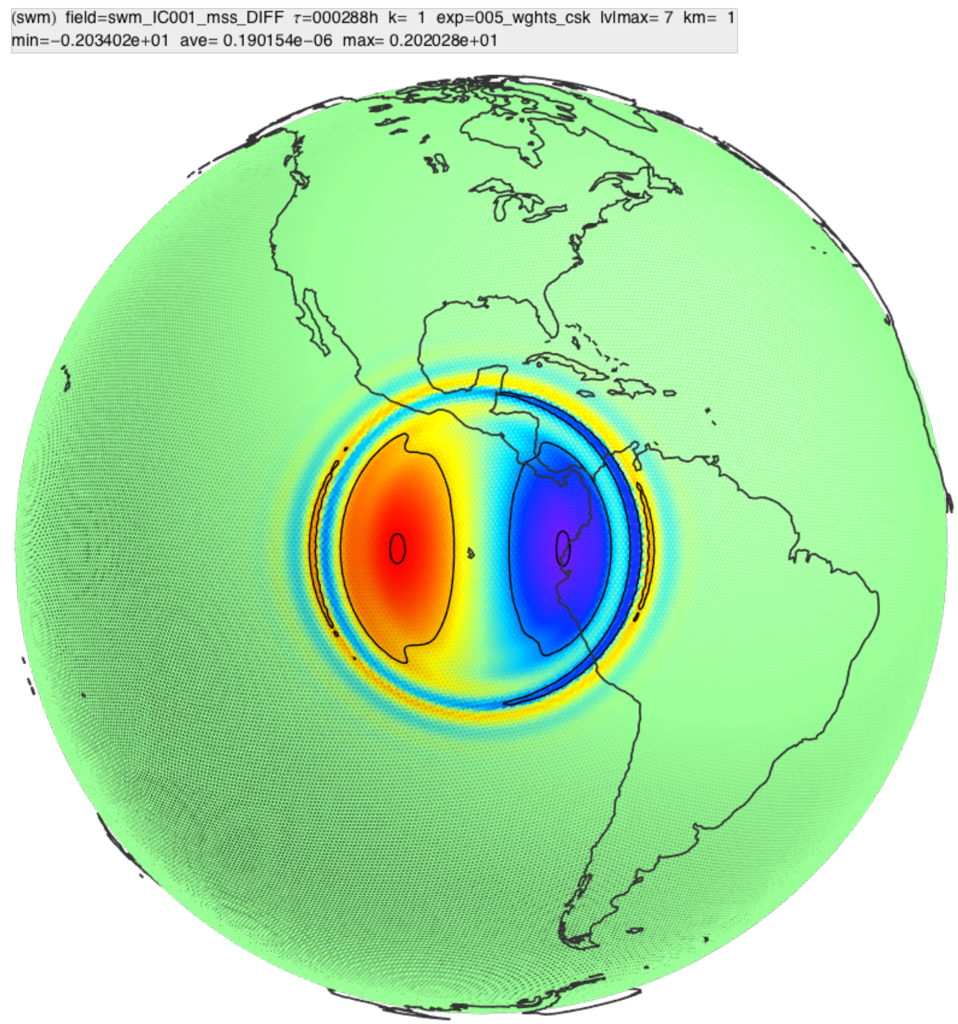




5th-order. Williamson Test Case 2. Day 12.

maximum error is 2m





Wind at edges as a function of stream function and velocity potential

- Helmholtz decomposition

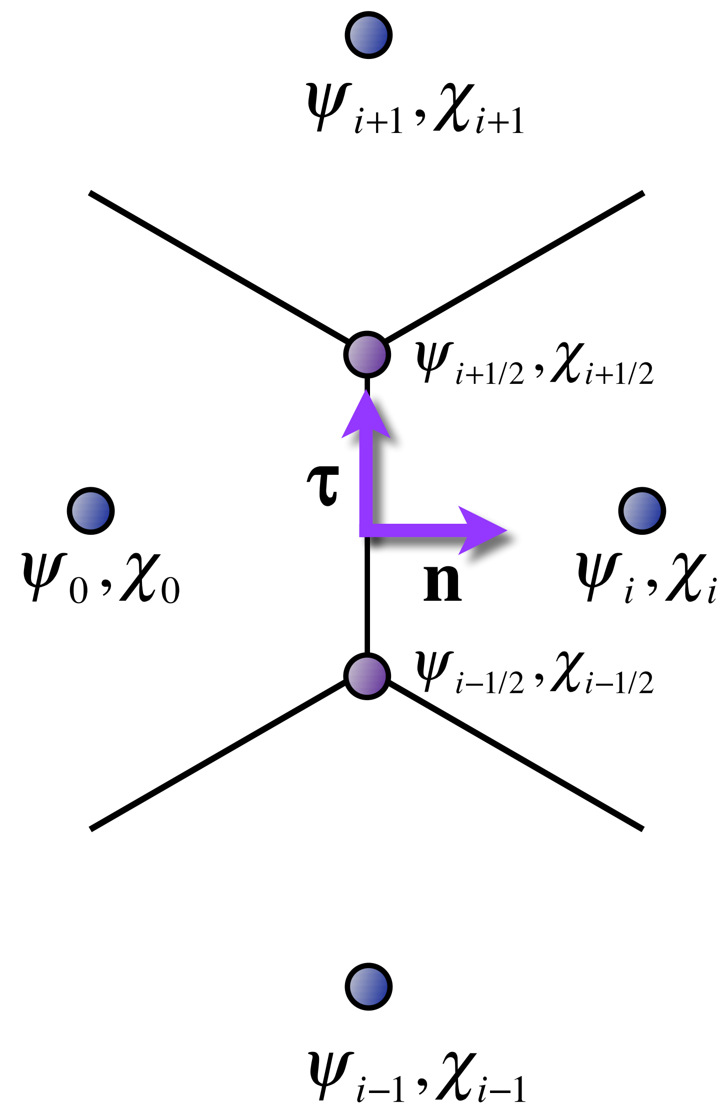
$$\mathbf{v} = \mathbf{k} \times \nabla \psi + \nabla \chi = \mathbf{v}_\psi + \mathbf{v}_\chi$$

- Interpolate $\psi_{i+1/2}$ and $\chi_{i+1/2}$ to cell corners from surrounding cell centers
- Vector wind at edges as a function of stream function and velocity potential

$$\left(\mathbf{v}_\psi\right)_i = \frac{\psi_{i+1/2} - \psi_{i-1/2}}{l}\mathbf{n} + \frac{\psi_i - \psi_0}{L}\boldsymbol{\tau}$$

$$\left(\mathbf{v}_\chi\right)_i = \frac{\chi_i - \chi_0}{L}\mathbf{n} + \frac{\chi_{i+1/2} - \chi_{i-1/2}}{l}\boldsymbol{\tau}$$

where l is the length of a cell wall and L is the distance between cell centers.



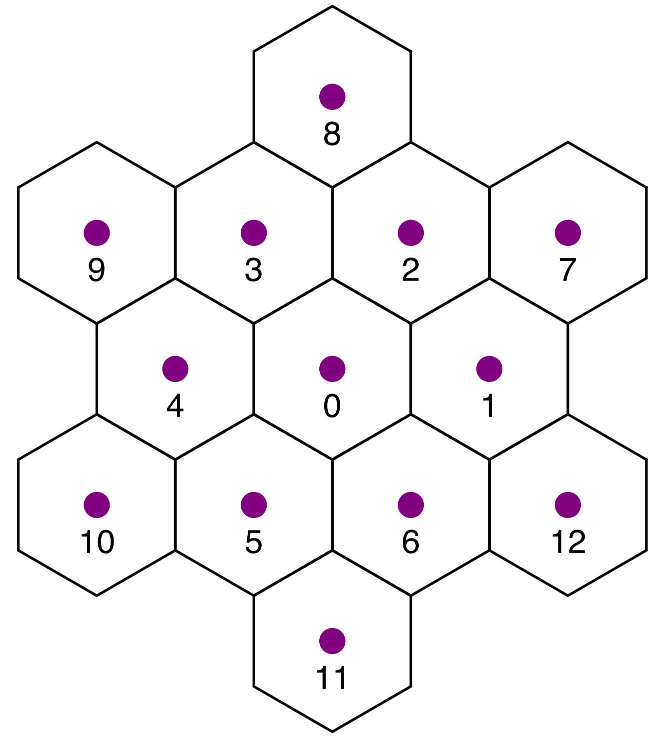
Perfect Hexagon Stencil 2 -- 3rd-order accurate

- The Laplacian can be written

$$\nabla^2 f \approx \sum_{n=0}^{12} c_n f\left(x_n, y_n\right)$$

- where the weights are given by

$$\left\{\left\{c00 \to -\frac{16}{3\,\Delta^2},\ c01 \to \frac{1}{\Delta^2},\ c02 \to \frac{1}{\Delta^2},\ c03 \to \frac{1}{\Delta^2},\ c04 \to \frac{1}{\Delta^2},\ c05 \to \frac{1}{\Delta^2},\ c06 \to \frac{1}{\Delta^2},\ c07 \to -\frac{1}{9\,\Delta^2},\ c08 \to -\frac{1}{9\,\Delta^2},\ c09 \to -\frac{1}{9\,\Delta^2},\ c10 \to -\frac{1}{9\,\Delta^2},\ c11 \to -\frac{1}{9\,\Delta^2},\ c12 \to -\frac{1}{9\,\Delta^2}\right\}\right\}$$

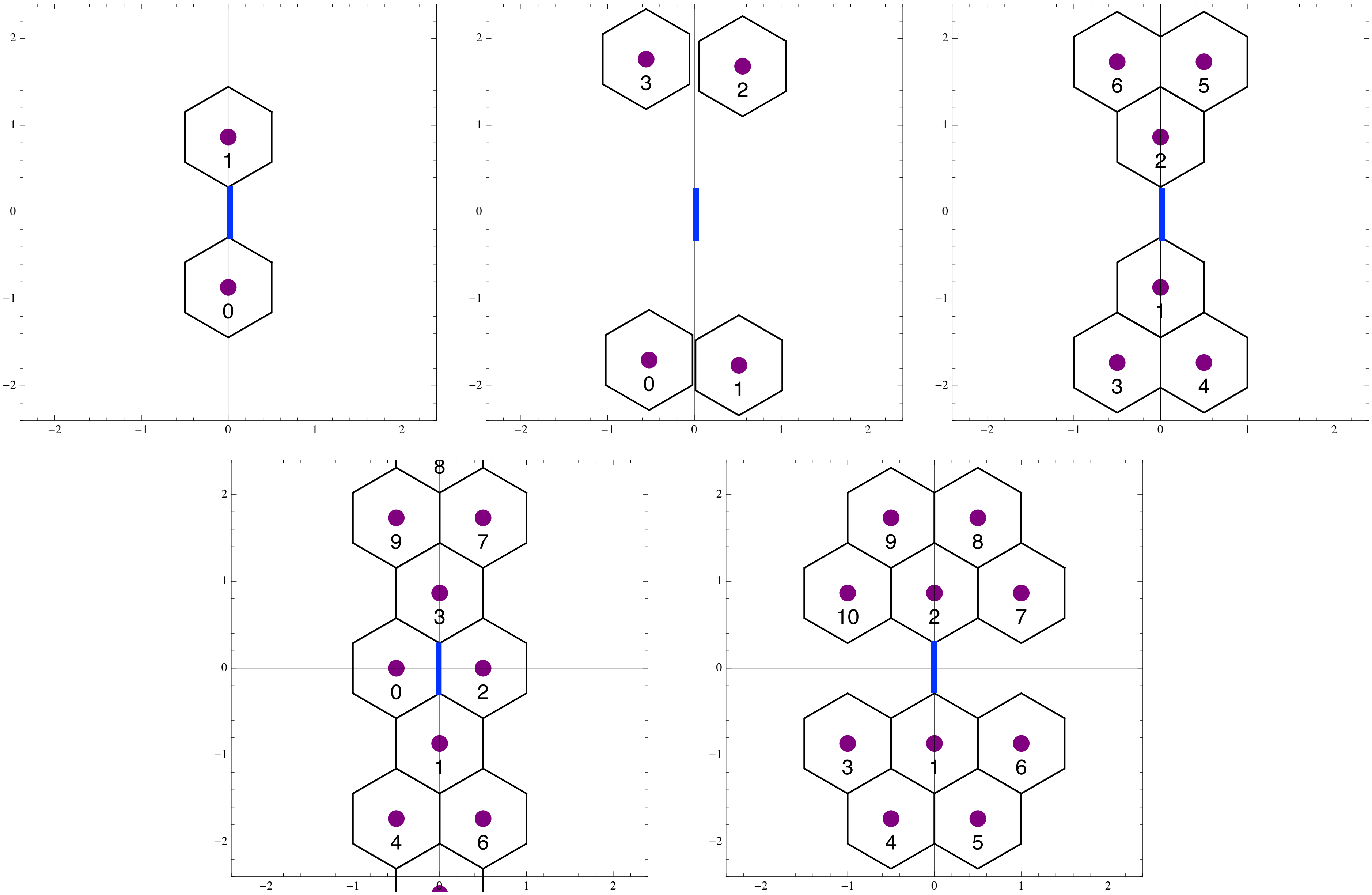


- The Taylor series becomes ($f^{(0,4)}$ is the lowest derivative)

$$f^{(0,2)}[0,0] - \frac{1}{160}\Delta^4 f^{(0,6)}[0,0] - \frac{3\,\Delta^6 f^{(0,8)}[0,0]}{7168} + f^{(2,0)}[0,0] - \frac{1}{32}\Delta^4 f^{(4,2)}[0,0] - \frac{1}{512}\Delta^6 f^{(4,4)}[0,0] - \frac{\Delta^8 f^{(4,6)}[0,0]}{20\,480} - \frac{3\,\Delta^{10} f^{(4,8)}[0,0]}{4\,587\,520} - \frac{1}{240}\Delta^4 f^{(6,0)}[0,0] - \frac{1}{384}\Delta^6 f^{(6,2)}[0,0] - \frac{\Delta^8 f^{(6,4)}[0,0]}{6144} - \frac{\Delta^{10} f^{(6,6)}[0,0]}{245\,760} - \frac{\Delta^{12} f^{(6,8)}[0,0]}{18\,350\,080} - \frac{5\,\Delta^6 f^{(8,0)}[0,0]}{21\,504} - \frac{13\,\Delta^8 f^{(8,2)}[0,0]}{122\,880} - \frac{13\,\Delta^{10} f^{(8,4)}[0,0]}{1\,966\,080} - \frac{13\,\Delta^{12} f^{(8,6)}[0,0]}{78\,643\,200} - \frac{13\,\Delta^{14} f^{(8,8)}[0,0]}{5\,872\,025\,600}$$

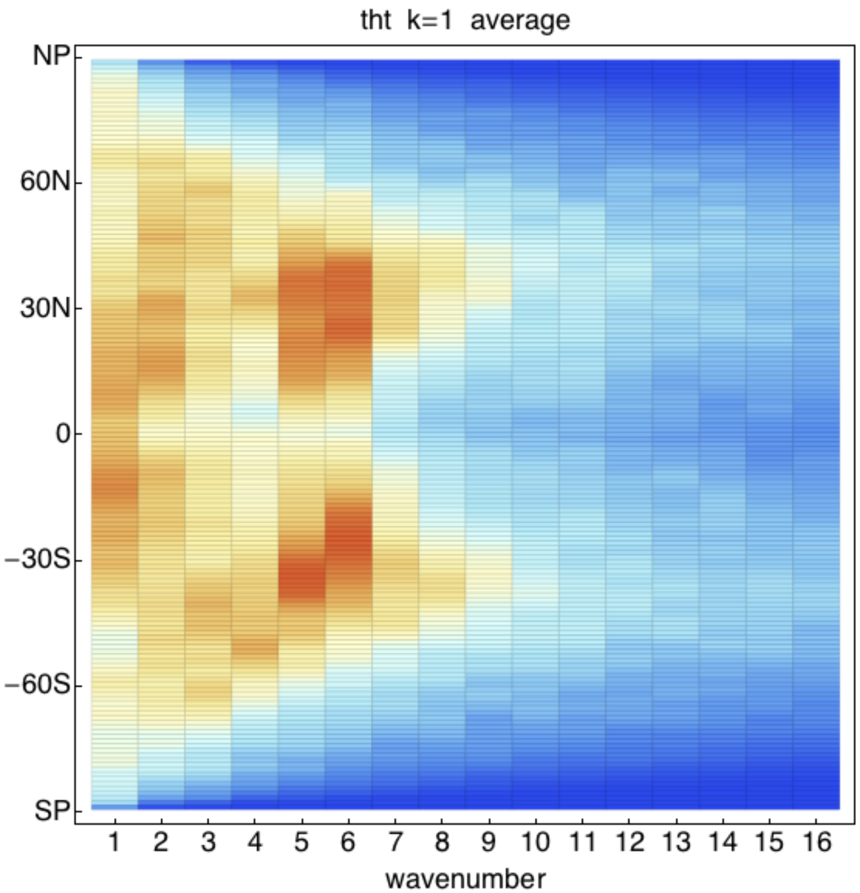
Series expansion approach to approximate the tangential derivate

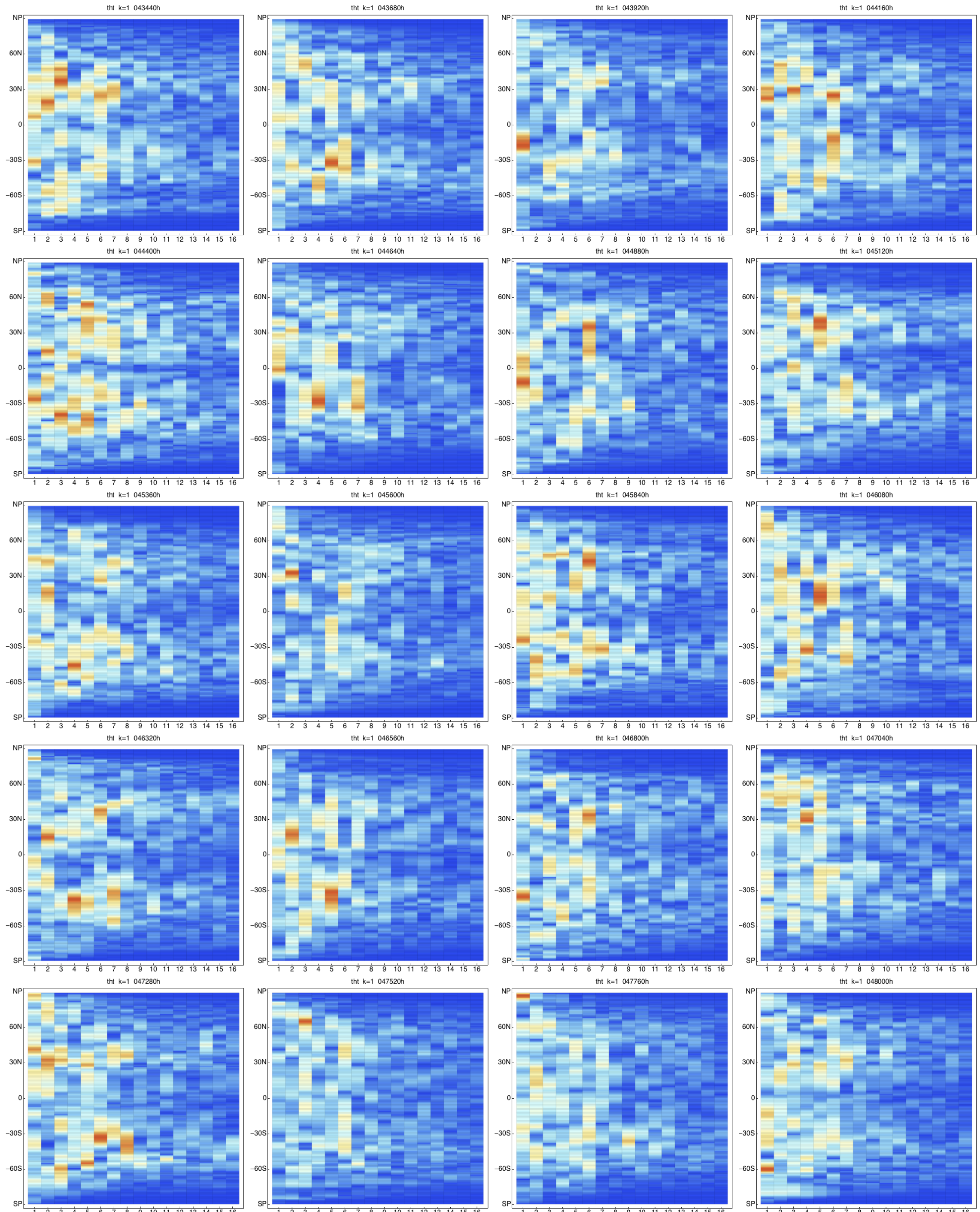
- Many stencils are possible



surface theta

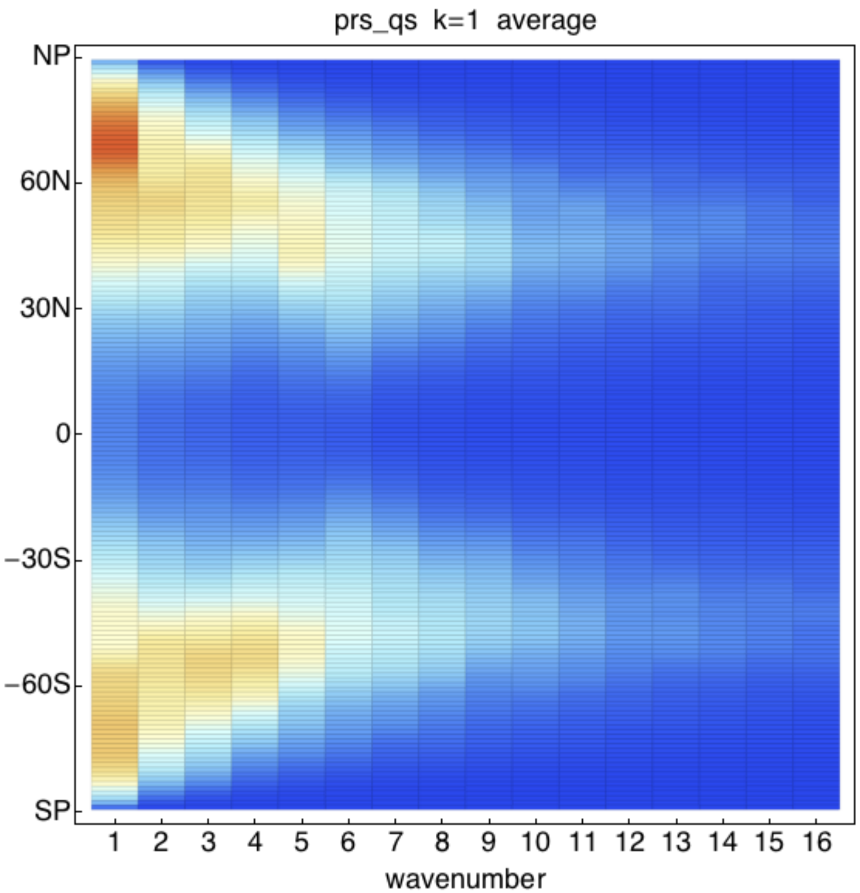
- Average from day 1500 to day 2000 every 10 days
- 20 snapshots from day 1810 to day 2000 every 10 days

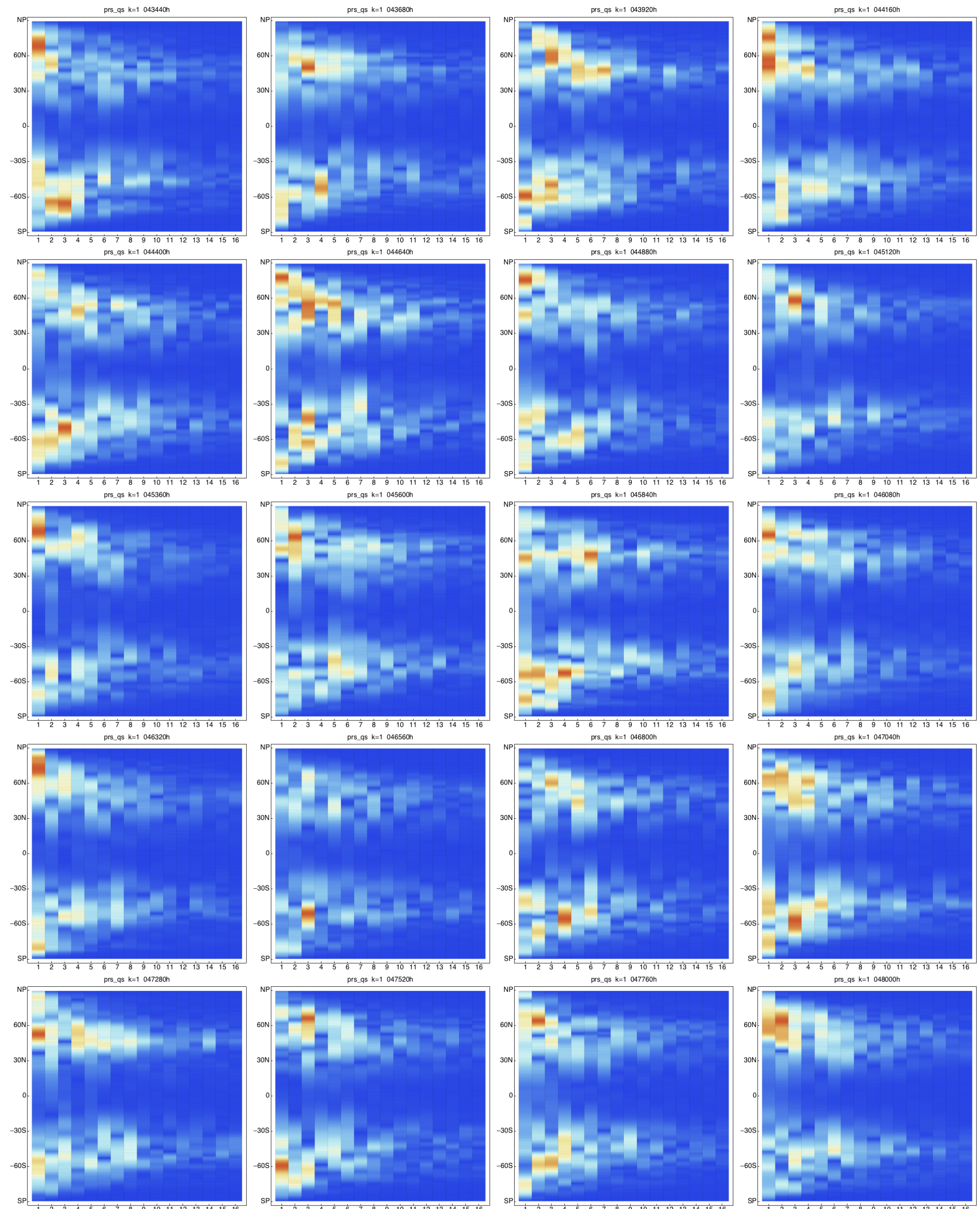




surface pressure

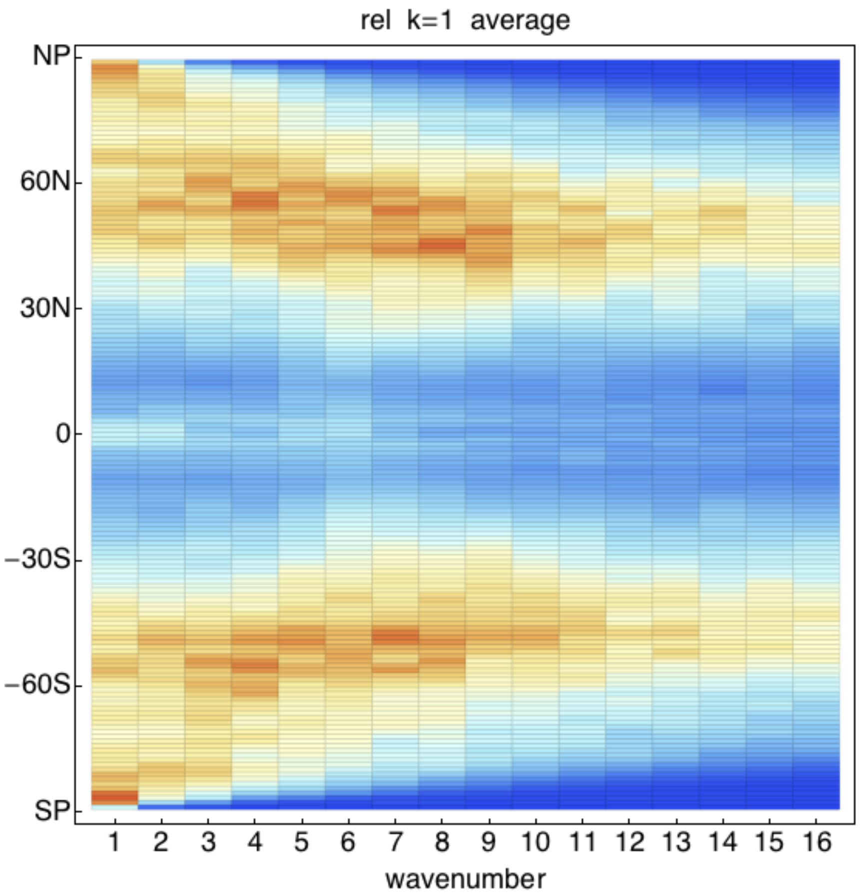
- Average from day 1500 to day 2000 every 10 days
- 20 snapshots from day 1810 to day 2000 every 10 days

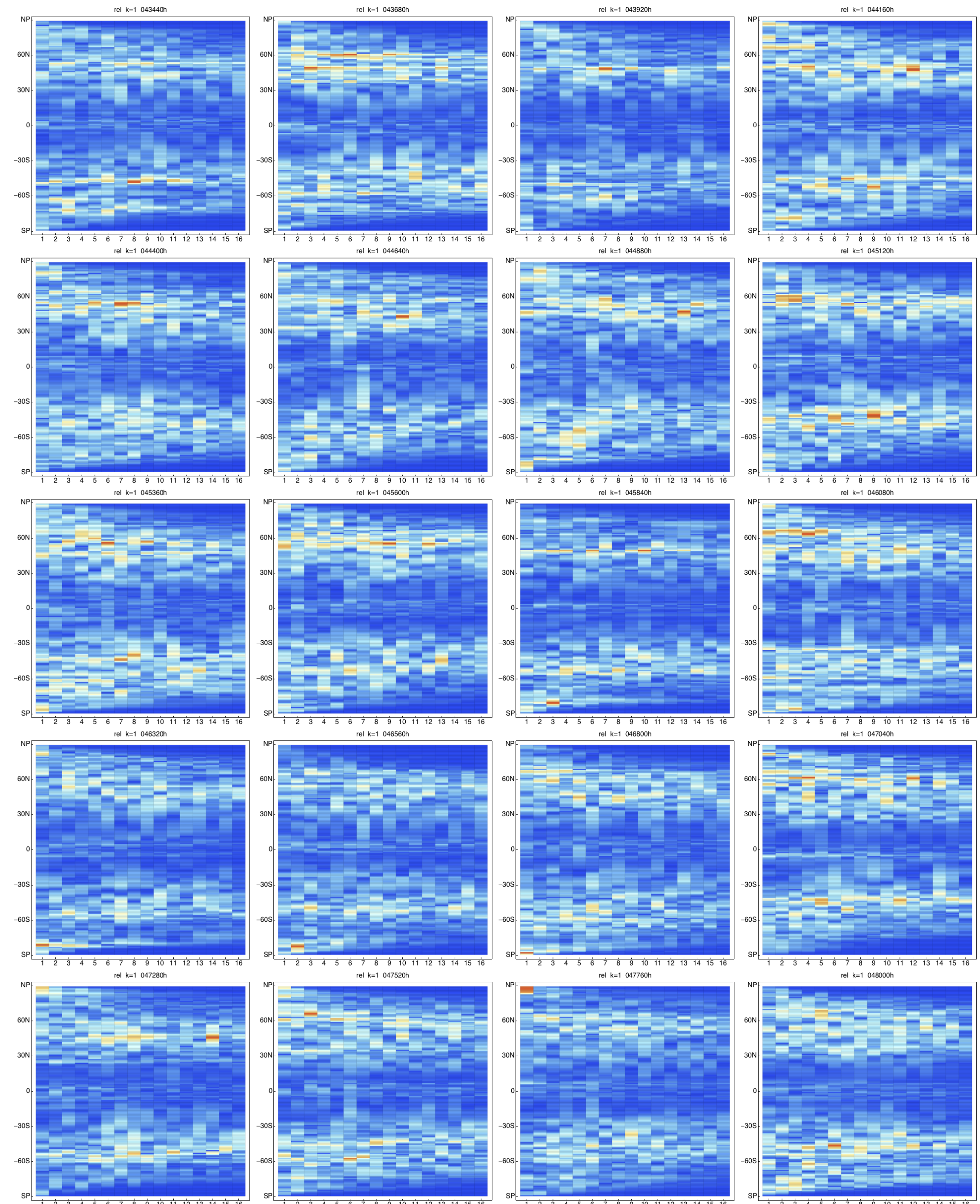




relative vorticity

- Average from day 1500 to day 2000 every 10 days
- 20 snapshots from day 1810 to day 2000 every 10 days





height at about 500hPA

- Average from day 1500 to day 2000 every 10 days
- 20 snapshots from day 1810 to day 2000 every 10 days