

An update on model development

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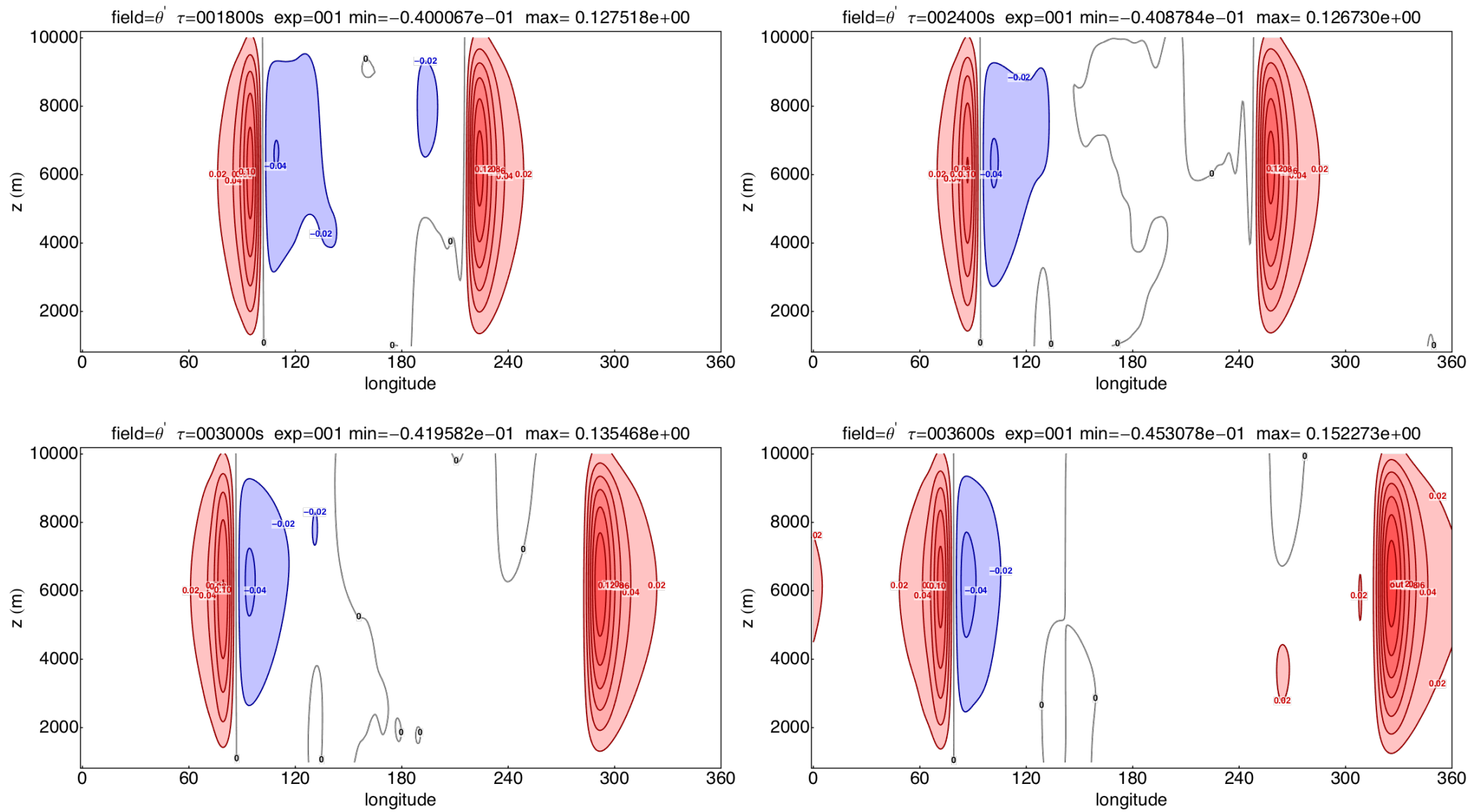
CMMAP summer meeting August 5, 2014



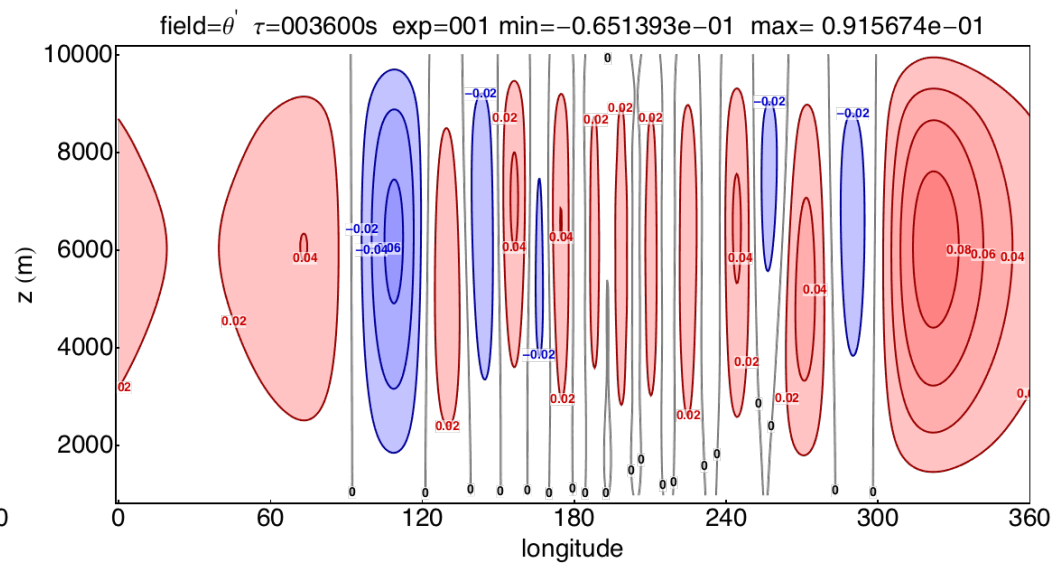
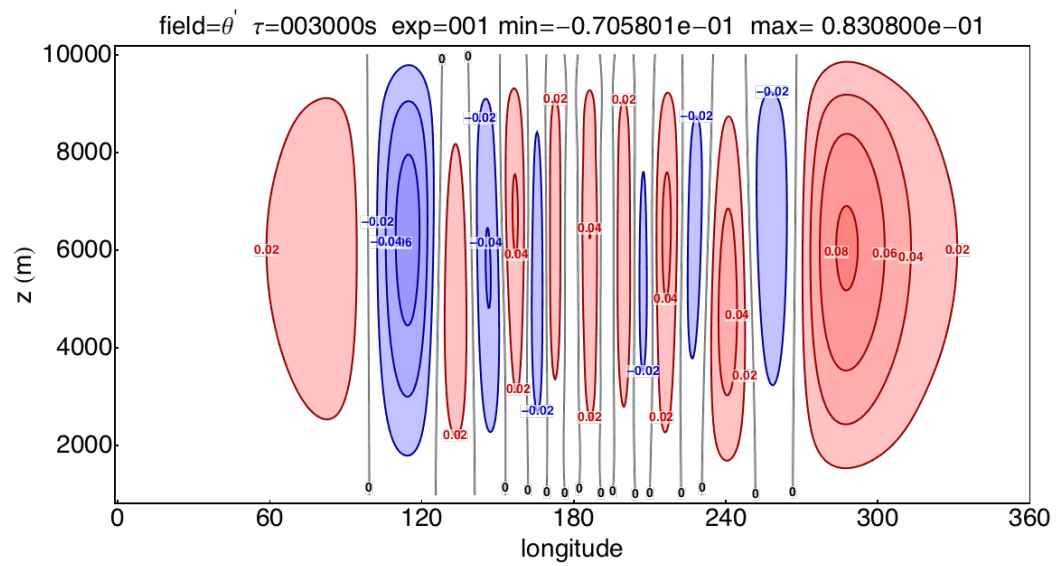
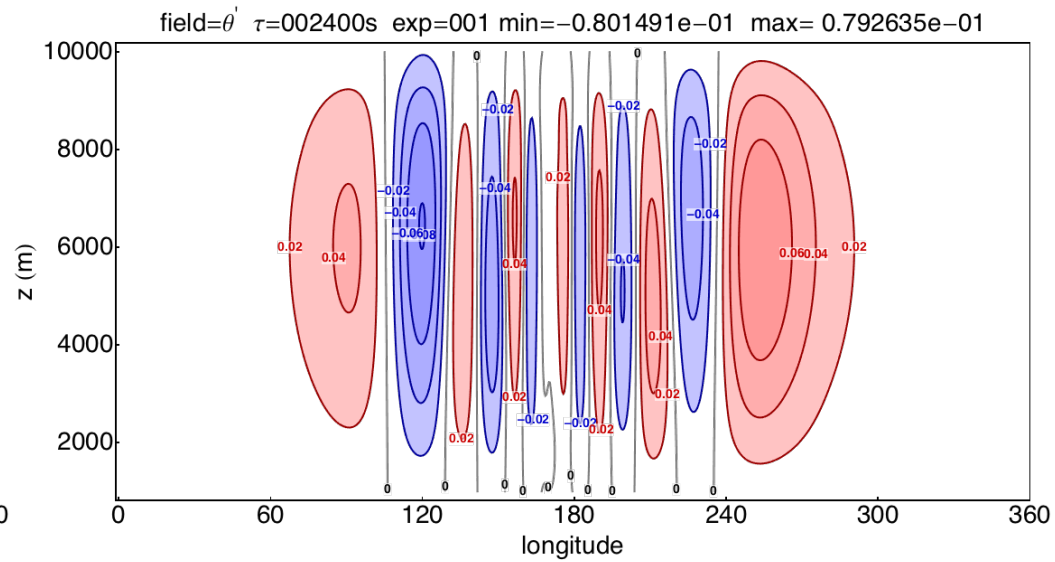
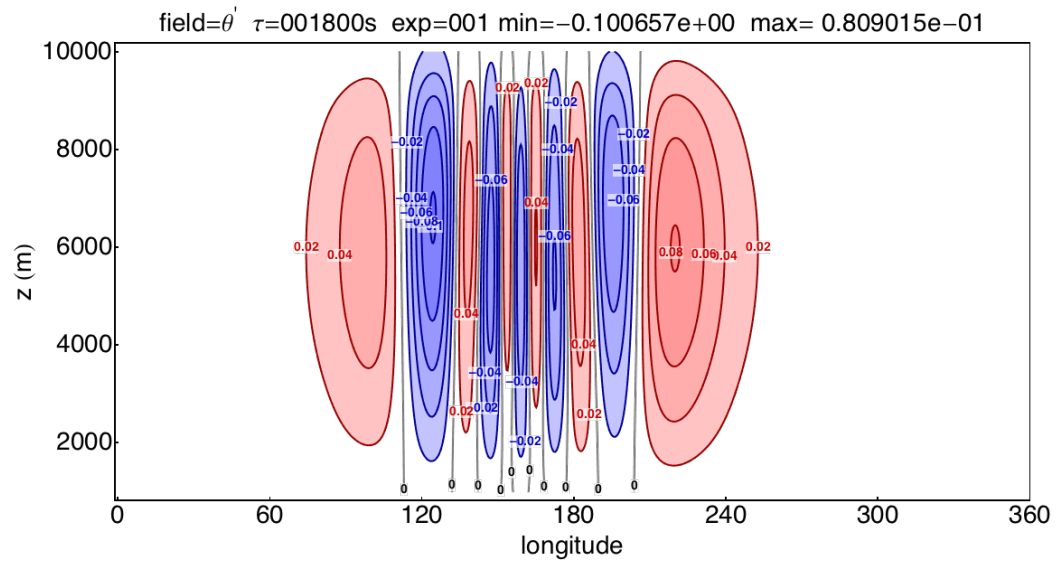
Outline

- 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

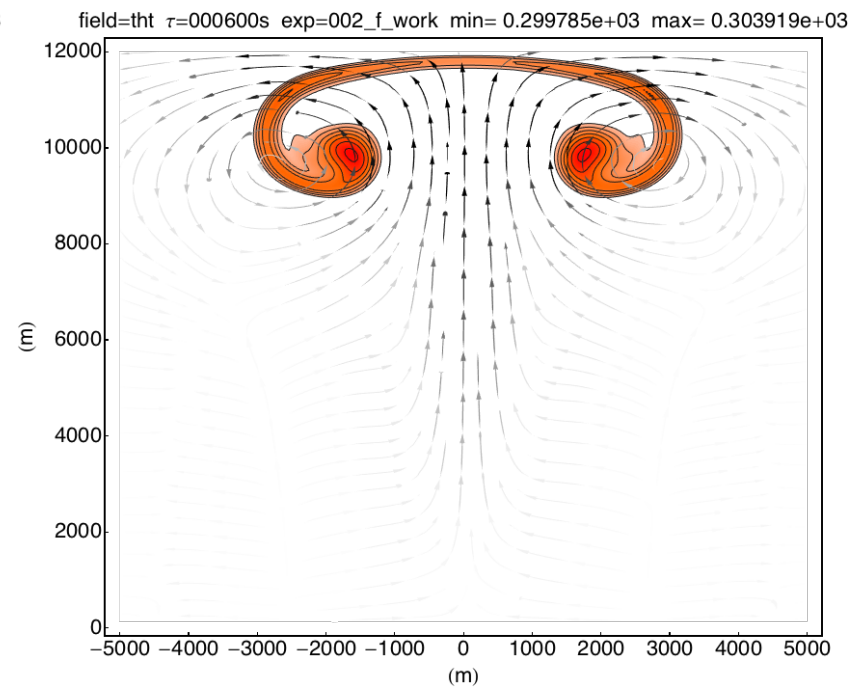
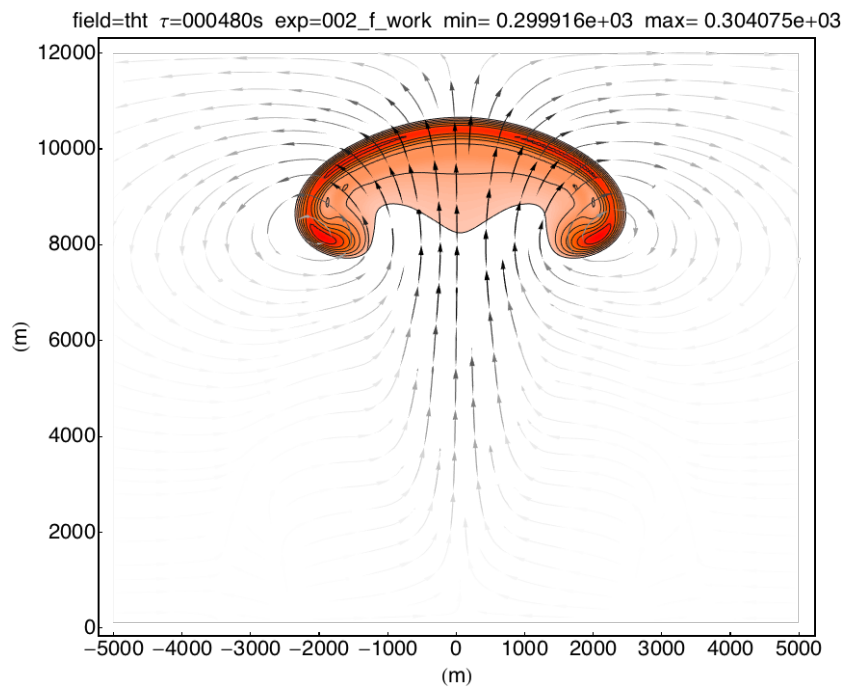
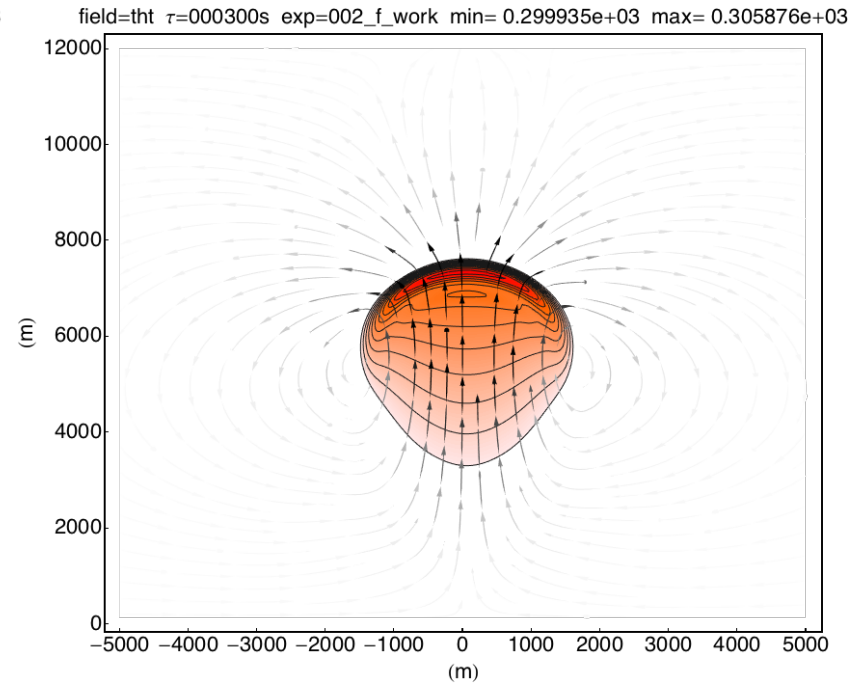
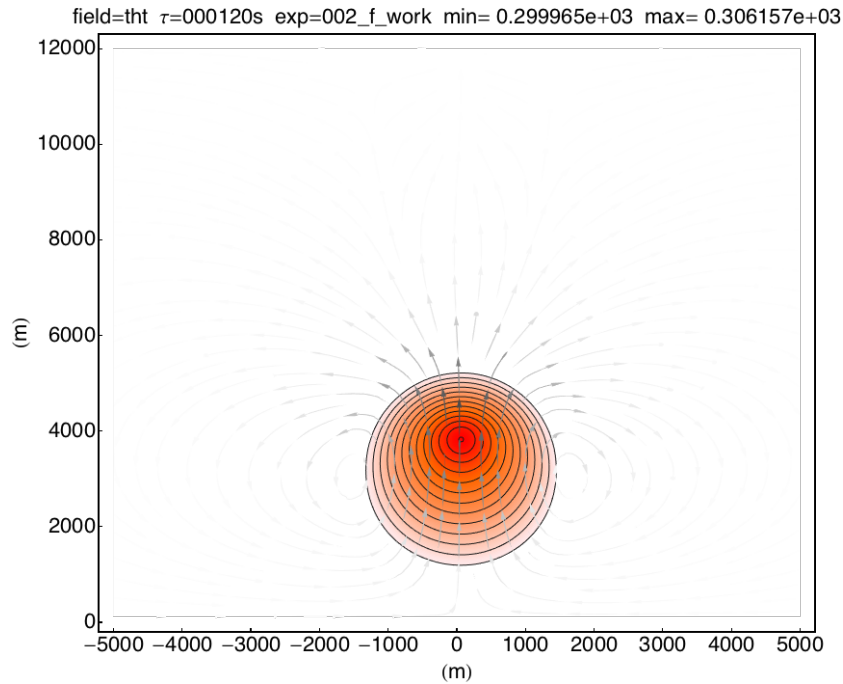
Height coordinate. Hydrostatic. Potential temperature perturbation.



Height coordinate. Nonhydrostatic. Potential temperature perturbation.

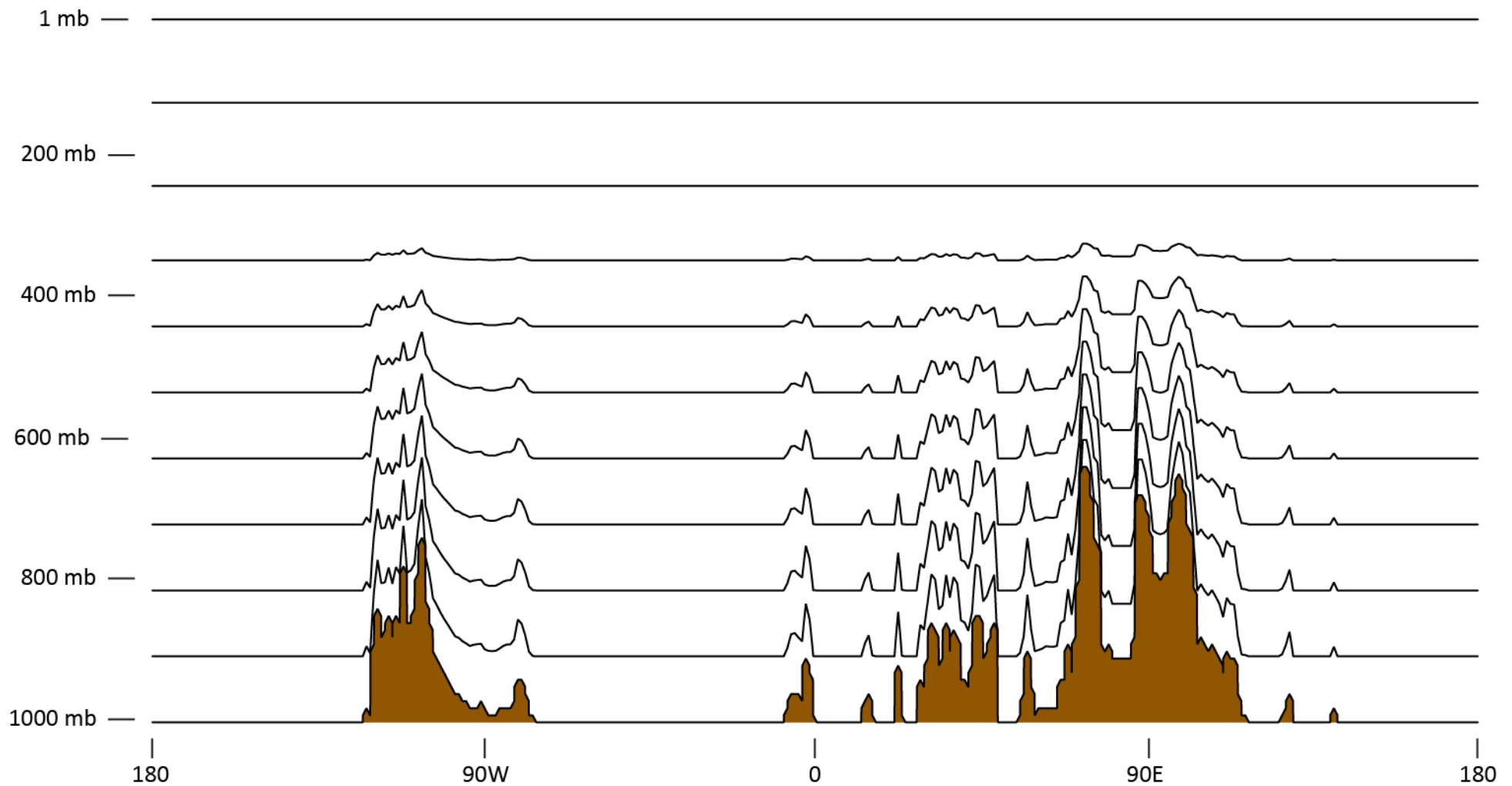


Height coordinate. Nonhydrostatic. Bubble.



Hybrid sigma-pressure coordinate

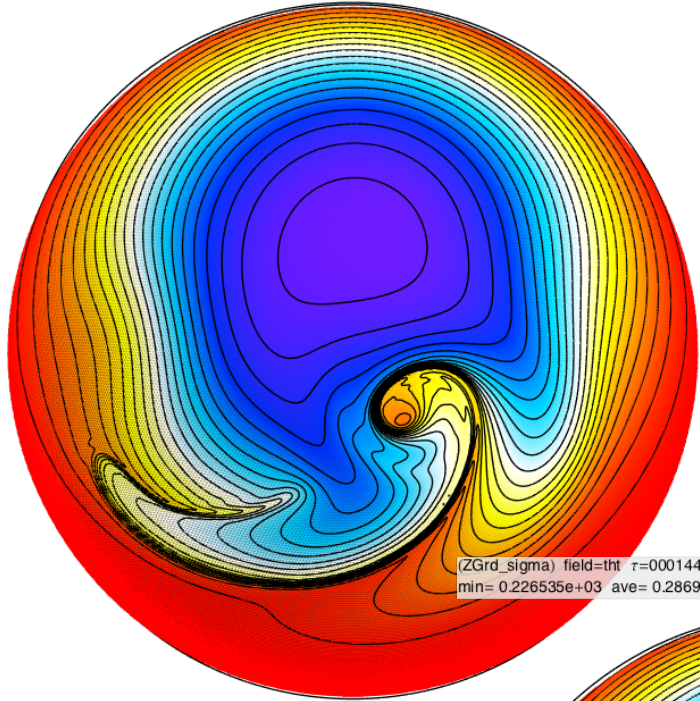
Surface topography and hybrid sigma-pressure coordinate surfaces at 39°N latitude circle



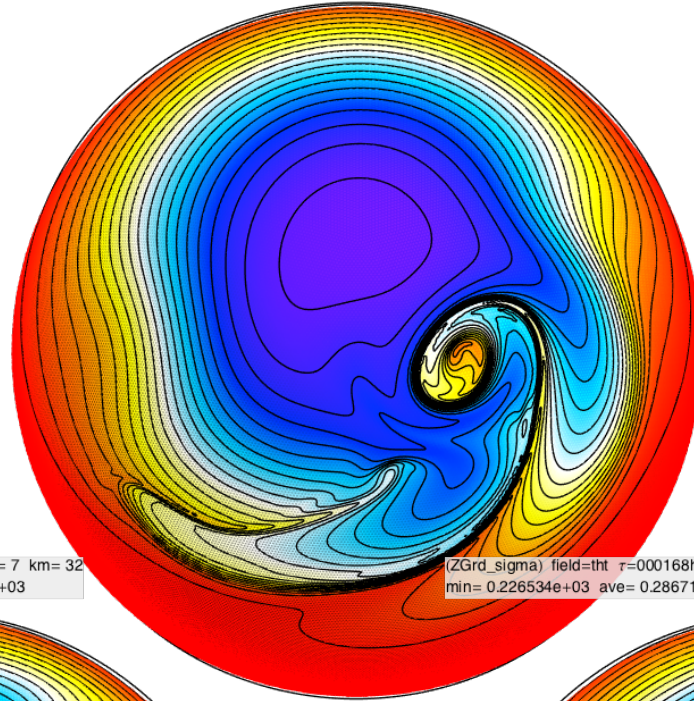
beta = 30.0_8
pC = 30000.0_8
pS0 = 120000.0_8
pT = 100.0_8

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

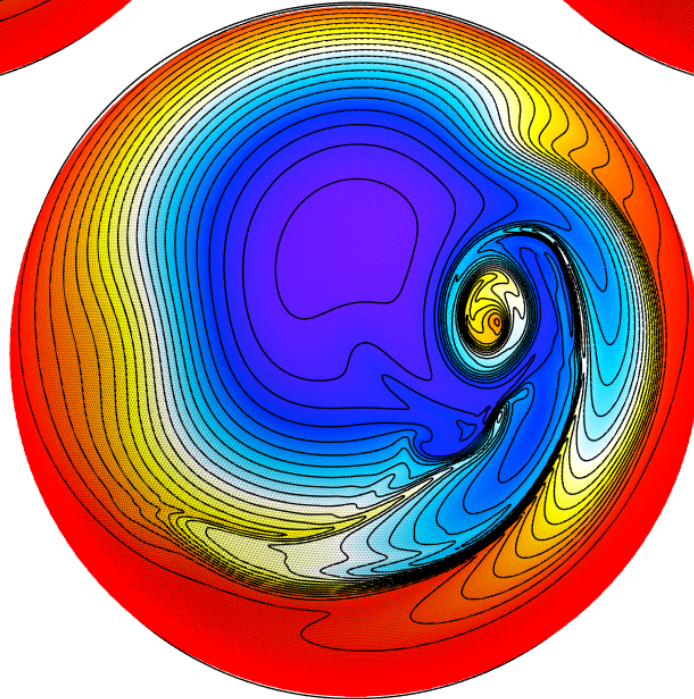
(ZGrd_sigma) field=tht $\tau=000096h$ k= 1 exp=006 lvmax= 7 km= 32
min= 0.226535e+03 ave= 0.287565e+03 max= 0.309948e+03



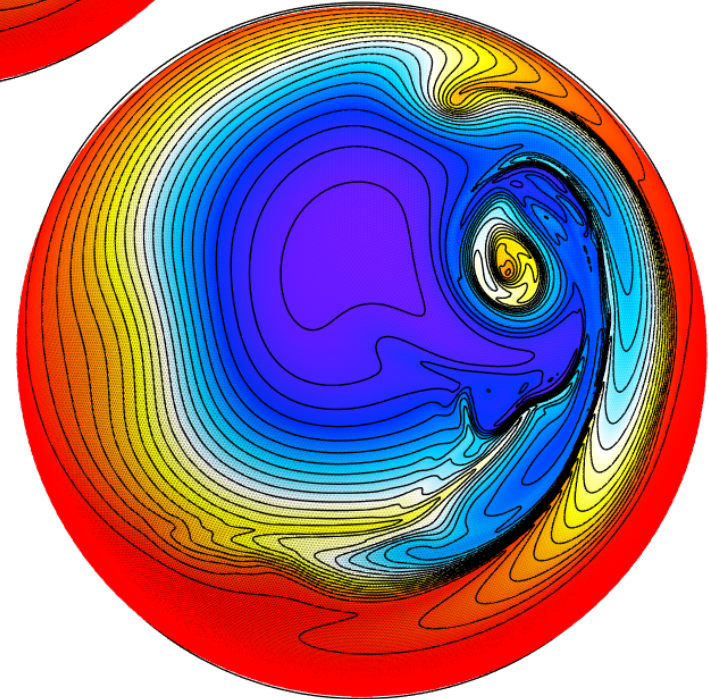
(ZGrd_sigma) field=tht $\tau=000120h$ k= 1 exp=006 lvmax= 7 km= 32
min= 0.226535e+03 ave= 0.287240e+03 max= 0.309948e+03



(ZGrd_sigma) field=tht $\tau=000144h$ k= 1 exp=006 lvmax= 7 km= 32
min= 0.226535e+03 ave= 0.286974e+03 max= 0.309948e+03

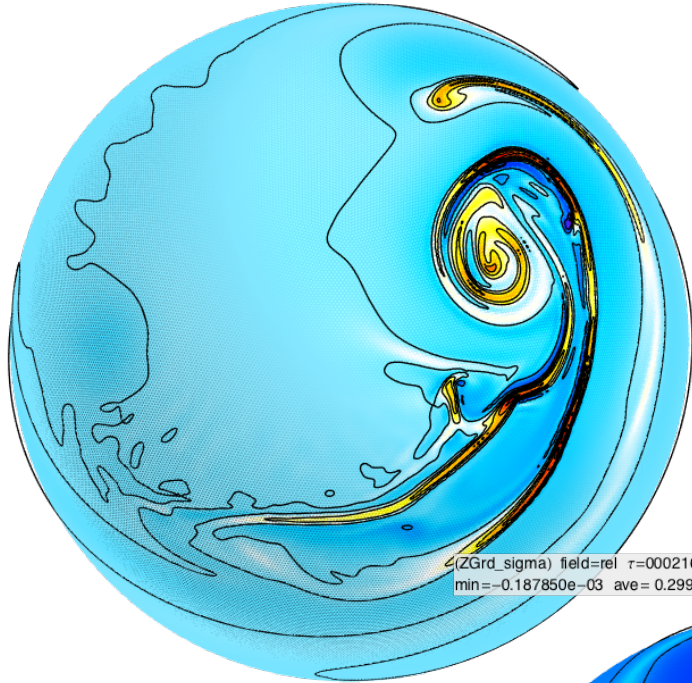


(ZGrd_sigma) field=tht $\tau=000168h$ k= 1 exp=006 lvmax= 7 km= 32
min= 0.226534e+03 ave= 0.286717e+03 max= 0.309948e+03

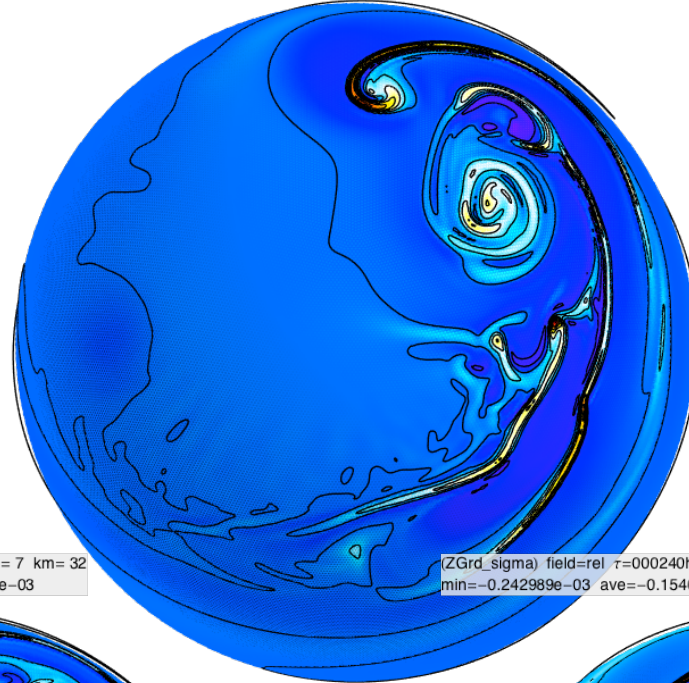


Hybrid sigma-pressure coordinate. Big mountain test. Surface relative vorticity.

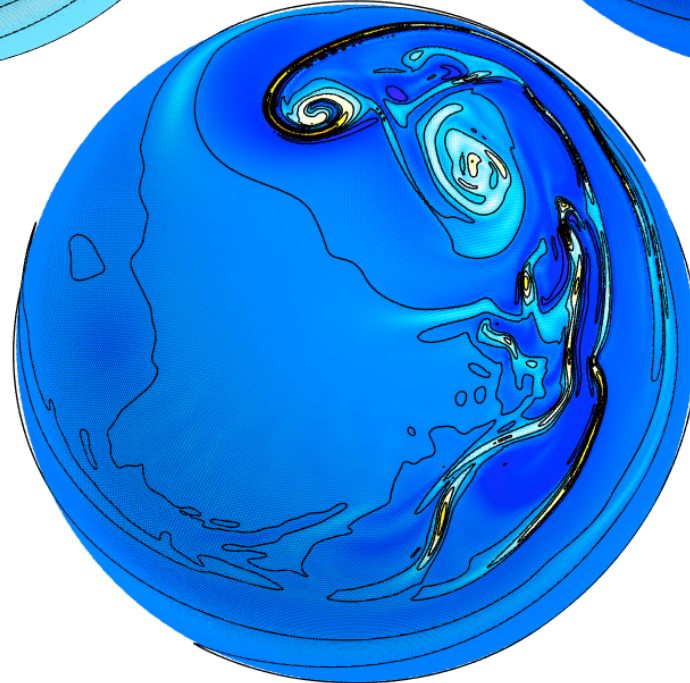
(ZGrd_sigma) field=rel $\tau=000168h$ k= 1 exp=006 lvmax= 7 km= 32
min=-0.253389e-03 ave=-0.935136e-09 max= 0.363863e-03



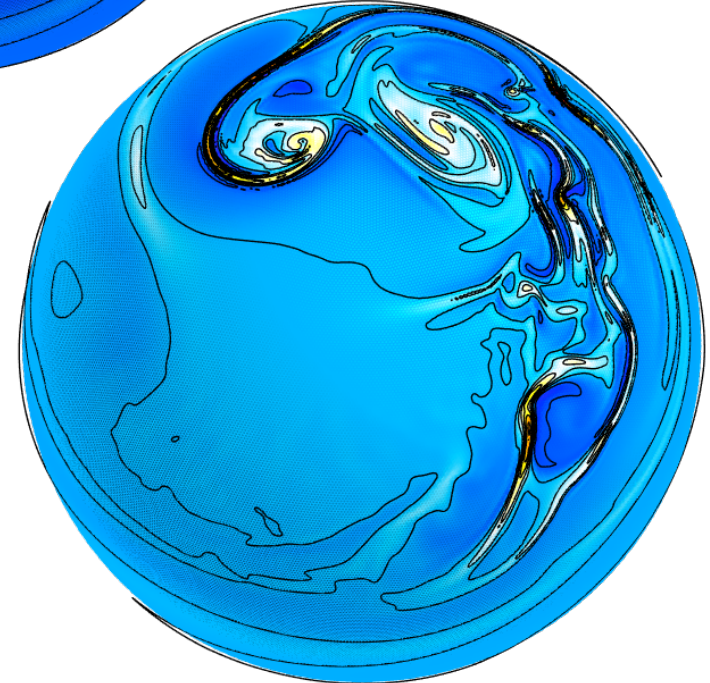
(ZGrd_sigma) field=rel $\tau=000192h$ k= 1 exp=006 lvmax= 7 km= 32
min=-0.141004e-03 ave= 0.580935e-08 max= 0.481793e-03



(ZGrd_sigma) field=rel $\tau=000216h$ k= 1 exp=006 lvmax= 7 km= 32
min=-0.187850e-03 ave= 0.299310e-08 max= 0.552506e-03

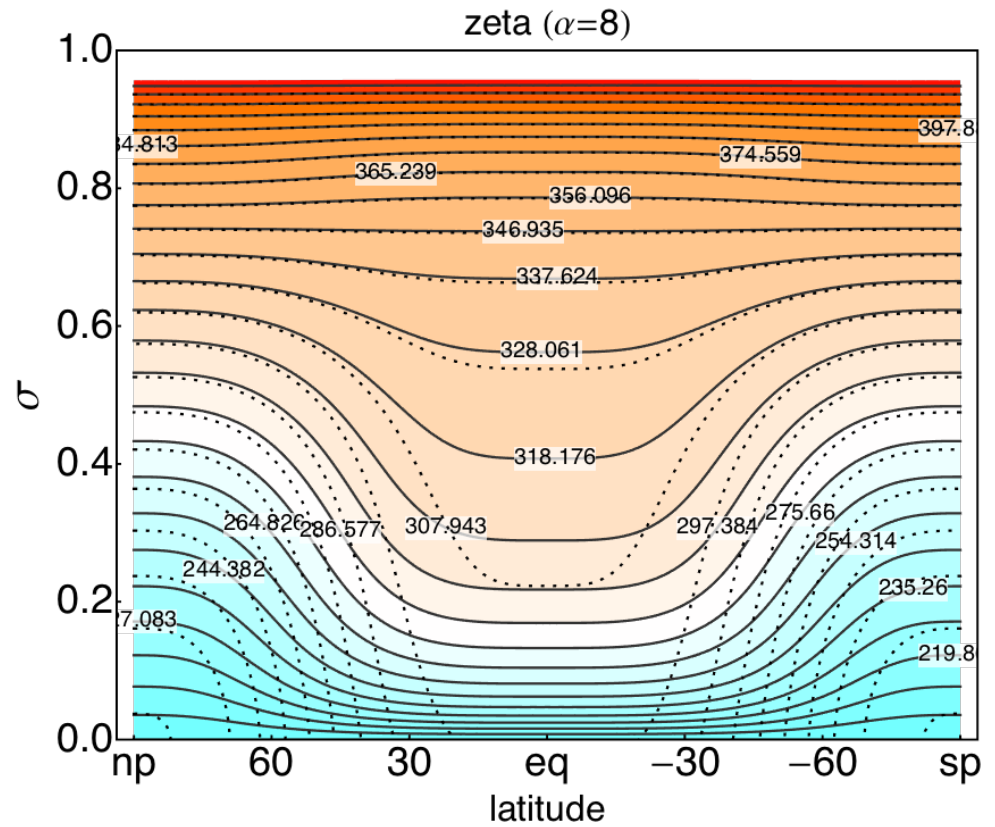
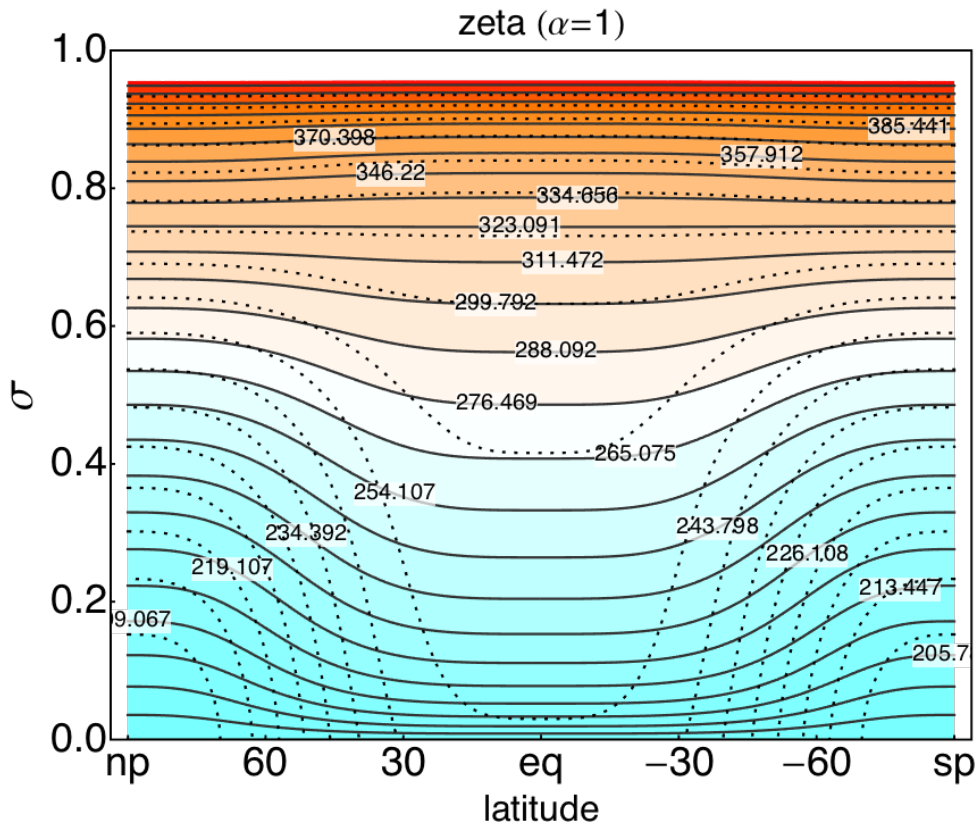


(ZGrd_sigma) field=rel $\tau=000240h$ k= 1 exp=006 lvmax= 7 km= 32
min=-0.242989e-03 ave=-0.154099e-08 max= 0.555997e-03



Hybrid sigma-theta coordinate.

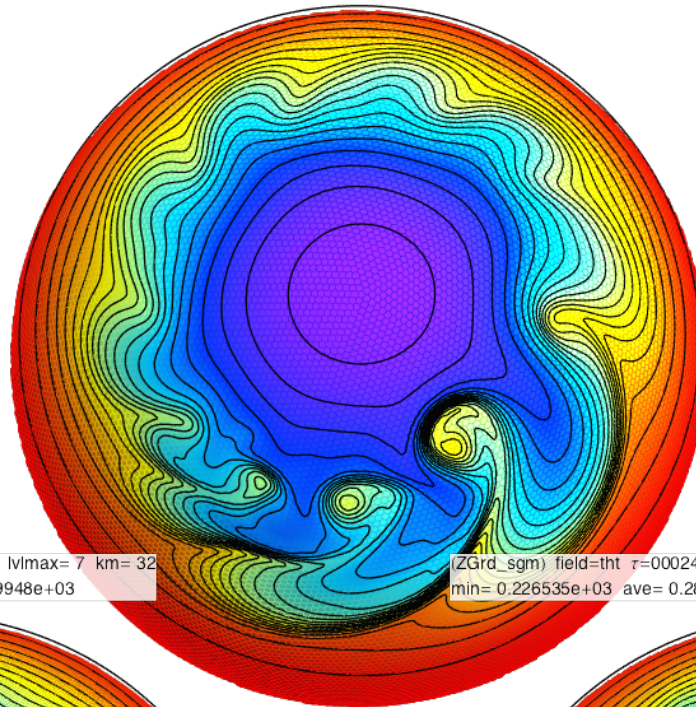
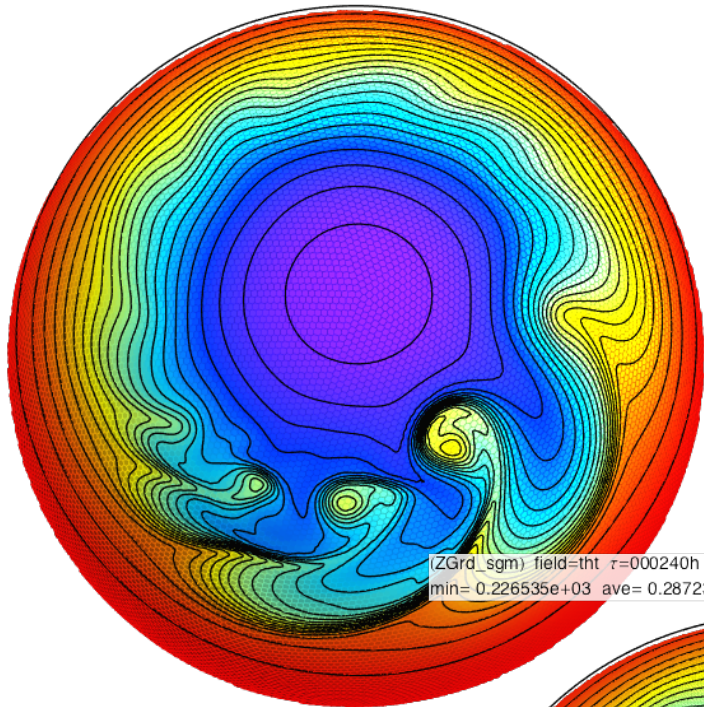
- Distribution of coordinate surfaces within Jablonowski-Williamson test case.
 1. $\alpha = 1$. Less isentropic
 2. $\alpha = 8$. More isentropic



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

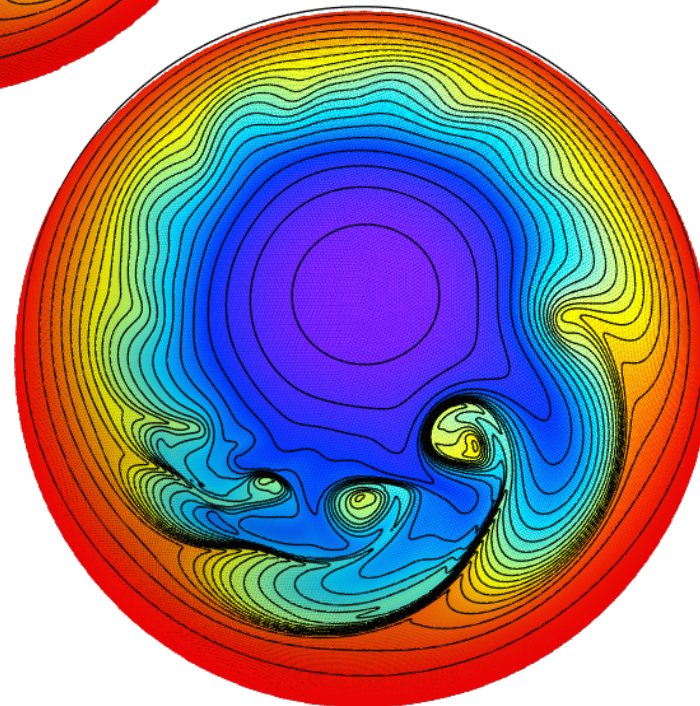
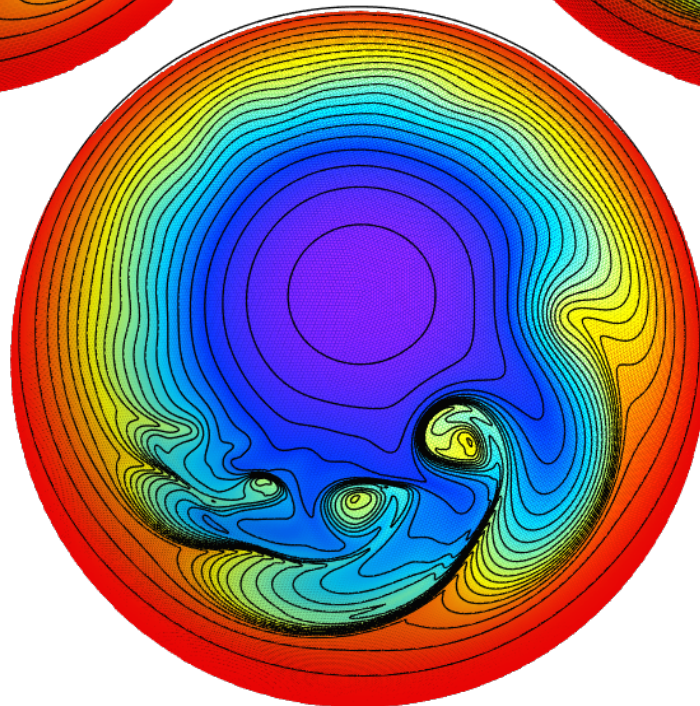
(ZGrd_sgm) field=tht $\tau=000240h$ k= 1 exp=900_01 lvmax= 6 km= 32
min= 0.226535e+03 ave= 0.287280e+03 max= 0.309947e+03

(ZGrd_sgm) field=tht $\tau=000240h$ k= 1 exp=900_08 lvmax= 6 km= 32
min= 0.226535e+03 ave= 0.287147e+03 max= 0.309947e+03



(ZGrd_sgm) field=tht $\tau=000240h$ k= 1 exp=900_01 lvmax= 7 km= 32
min= 0.226535e+03 ave= 0.287235e+03 max= 0.309948e+03

(ZGrd_sgm) field=tht $\tau=000240h$ k= 1 exp=900_08 lvmax= 7 km= 32
min= 0.226535e+03 ave= 0.287182e+03 max= 0.309948e+03



Axial angular momentum conservation in the icosahedral model

- Inspired by a paper in JAMES:

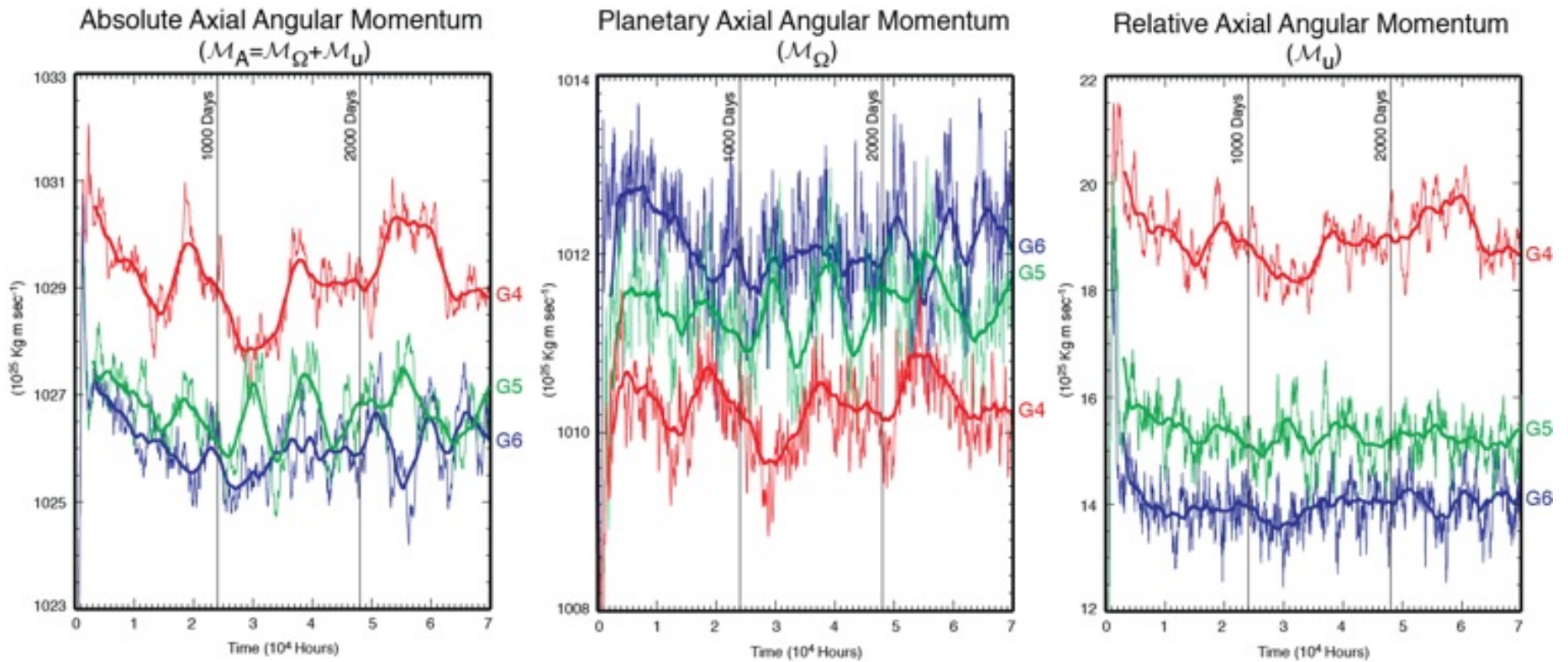
Held-Suarez simulations with the Community Atmosphere Model Spectral Element (CAM-SE) dynamical core: A global axial angular momentum analysis using Eulerian and floating Lagrangian vertical coordinates

Peter H. Lauritzen¹, Julio T. Bacmeister¹, Thomas Dubos², Sebastien Lebonnois^{3,4}, and Mark A. Taylor⁵

- 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)

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

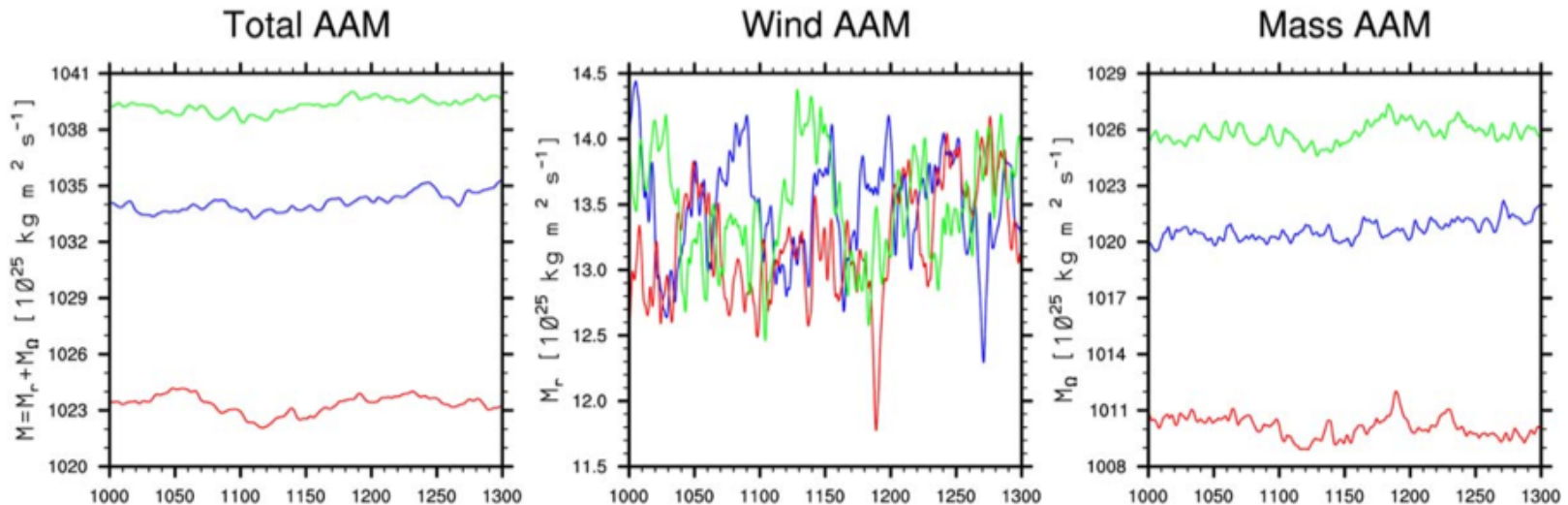
Axial angular momentum conservation in the icosahedral model



Axial Angular Momentum (AAM) diagnostics for CAM-SE

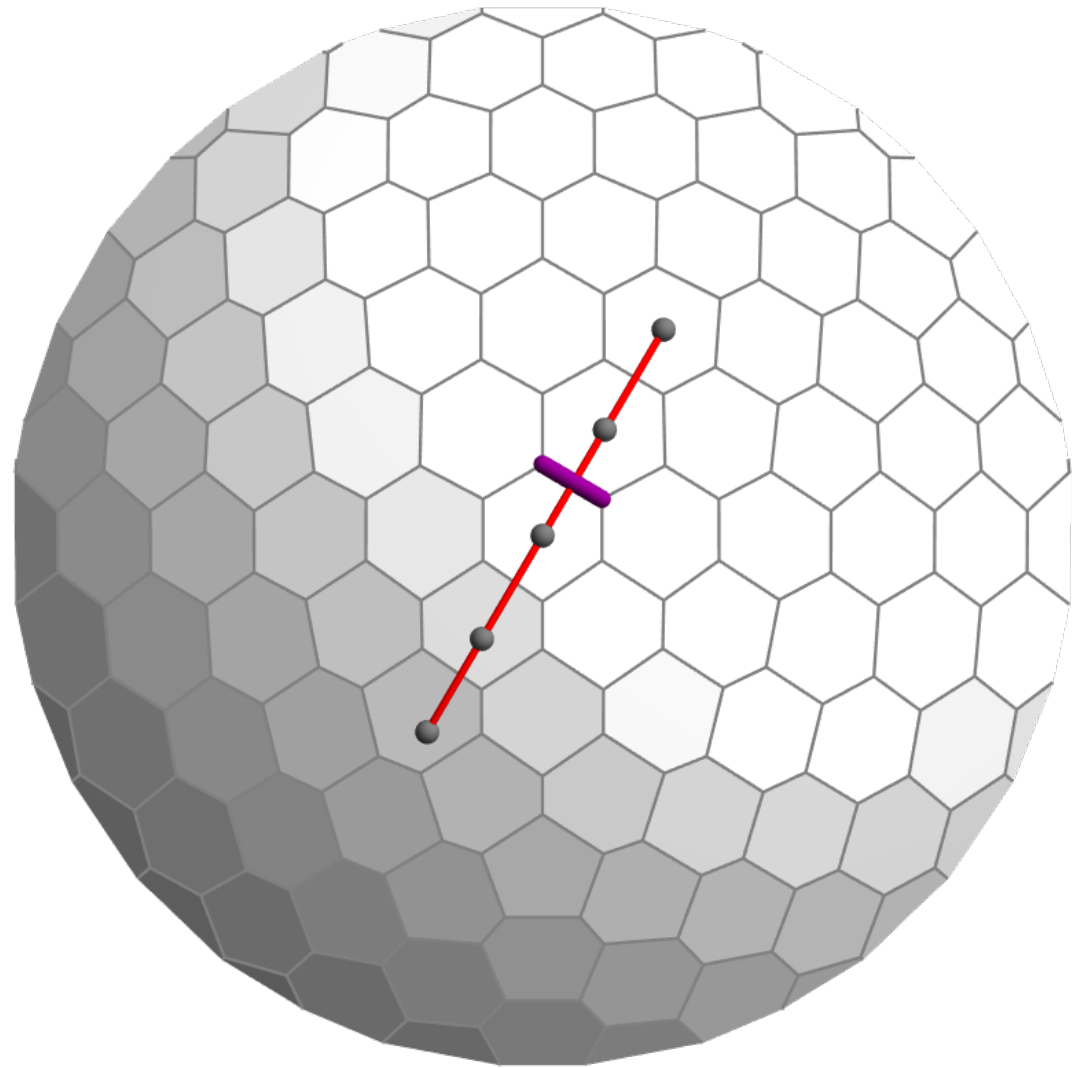
Colors show different polynomial orders for CAM-SE

- 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

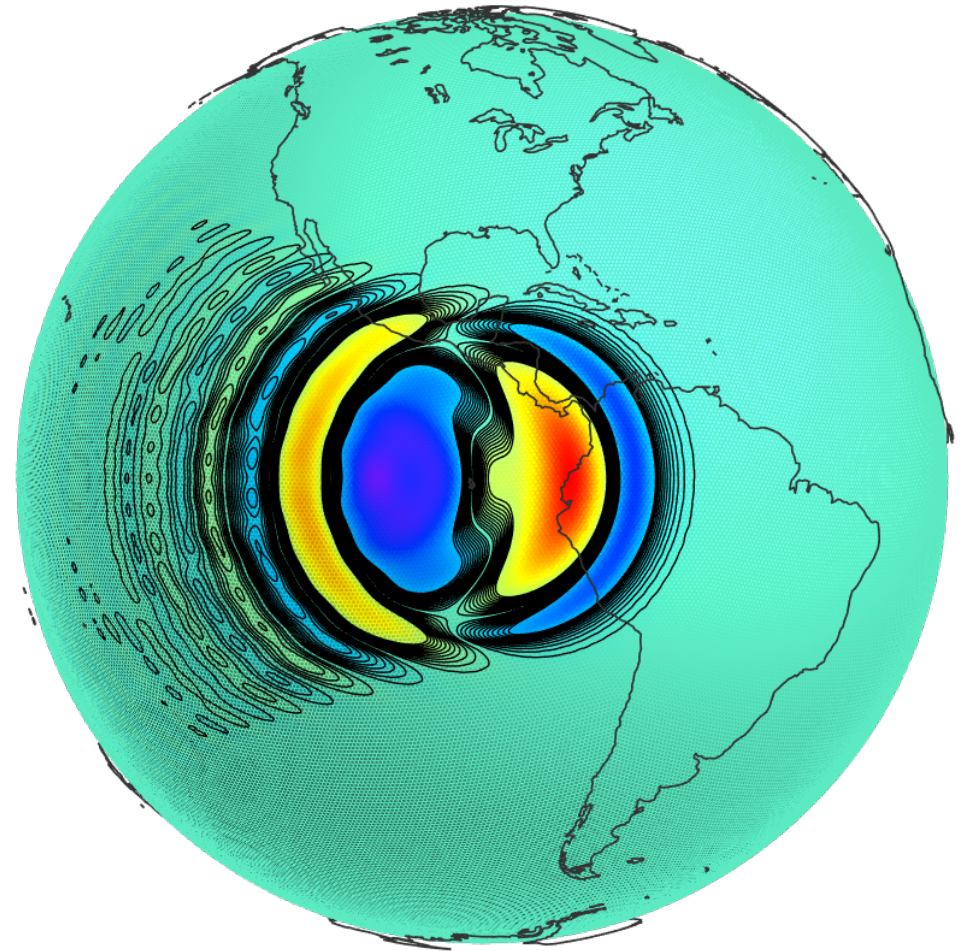
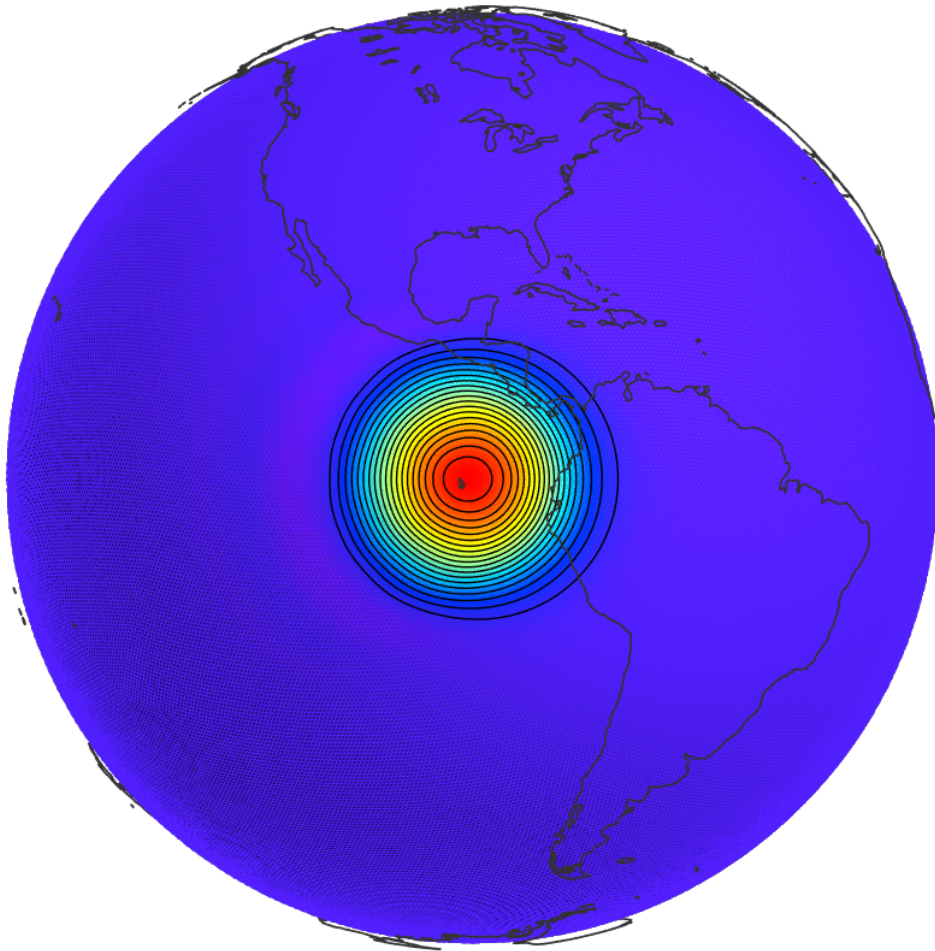


2nd-order. Williamson Test Case 2. Day 12.

maximum error is 56m

```
(swm) field=swm_IC001_mss_APPX  $\tau=000288h$  k= 1 exp=002 lvmx= 7 km= 1  
min=-0.341319e+02 ave= 0.829072e+01 max= 0.992771e+03
```

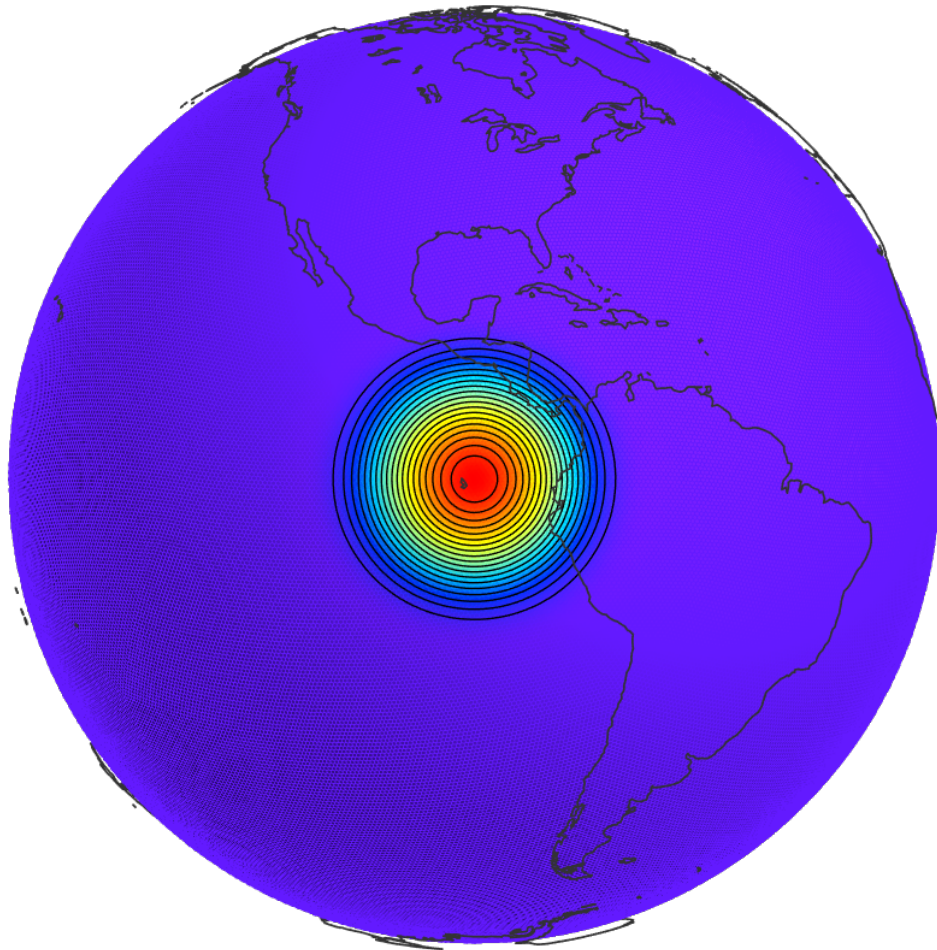
```
(swm) field=swm_IC001_mss_DIFF  $\tau=000288h$  k= 1 exp=002 lvmx= 7 km= 1  
min=-0.434330e+02 ave= 0.869191e-04 max= 0.569913e+02
```



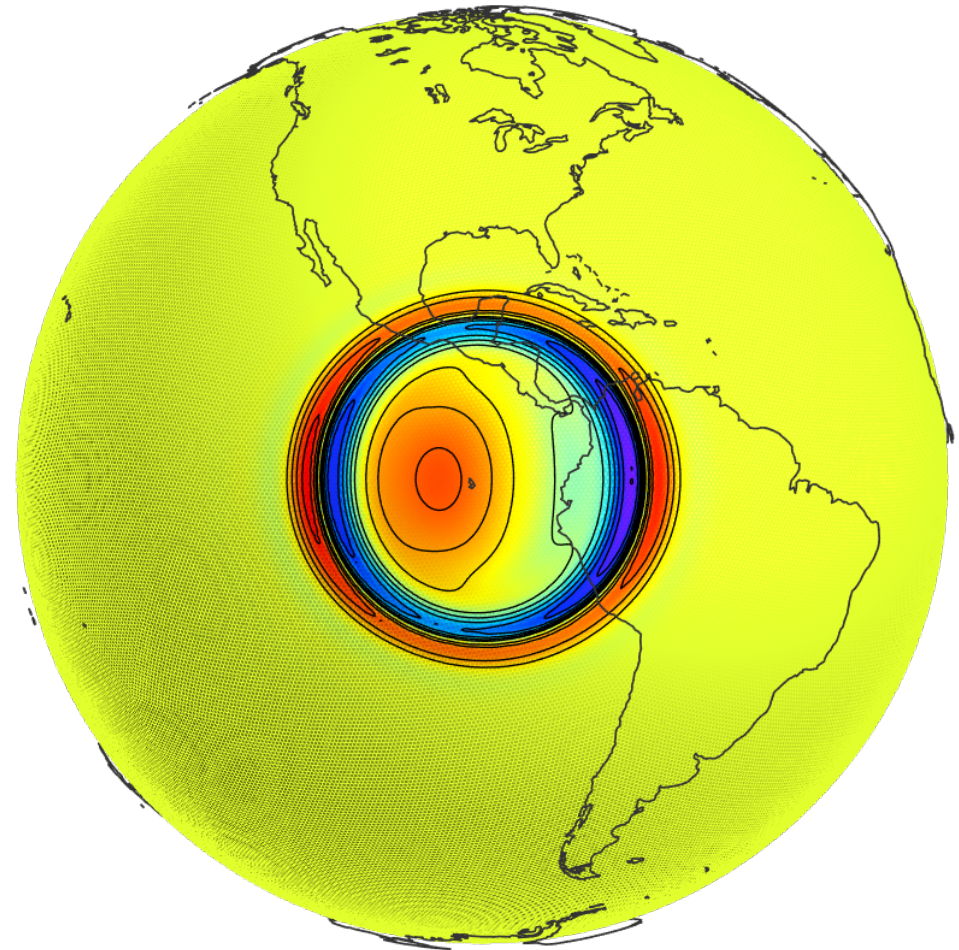
3rd-order. Williamson Test Case 2. Day 12.

maximum error is 7m

(swm) field=swm_IC001_mss_APPX $\tau=000288h$ k= 1 exp=003_wghts_csk lvlmax= 7 km= 1
min=-0.436593e+01 ave= 0.829069e+01 max= 0.997615e+03



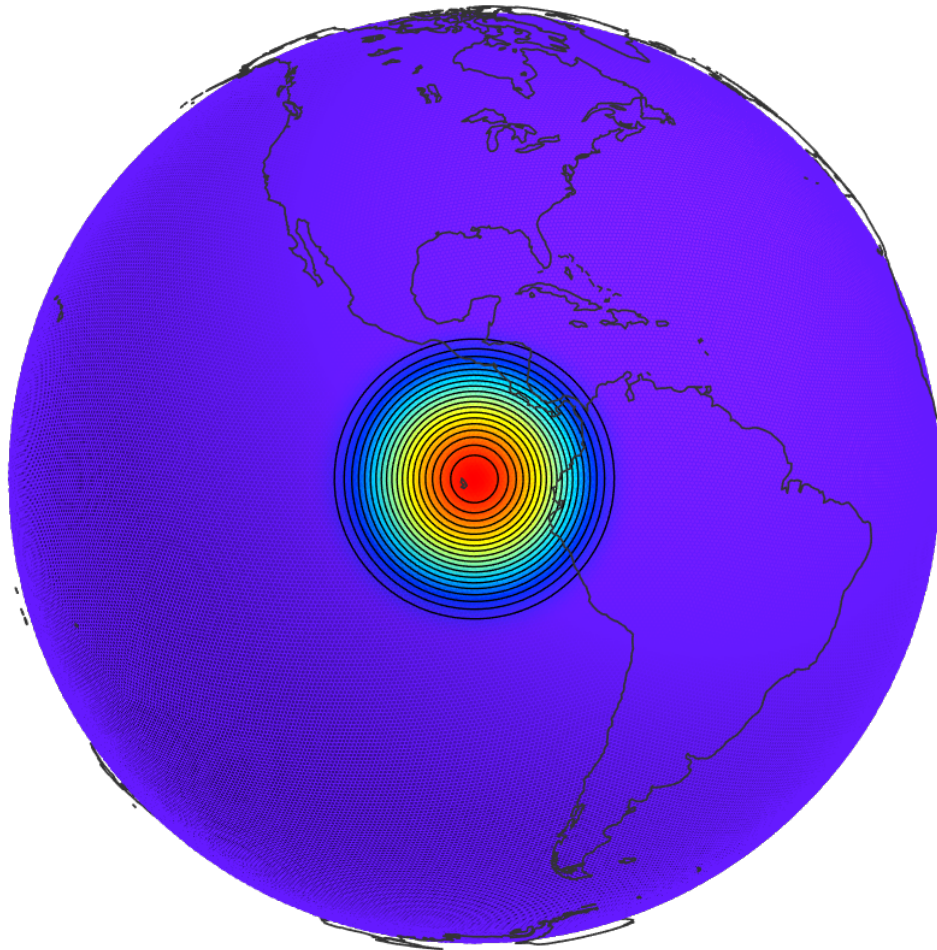
(swm) field=swm_IC001_mss_DIFF $\tau=000288h$ k= 1 exp=003_wghts_csk lvlmax= 7 km= 1
min=-0.703640e+01 ave= 0.117412e-03 max= 0.436593e+01



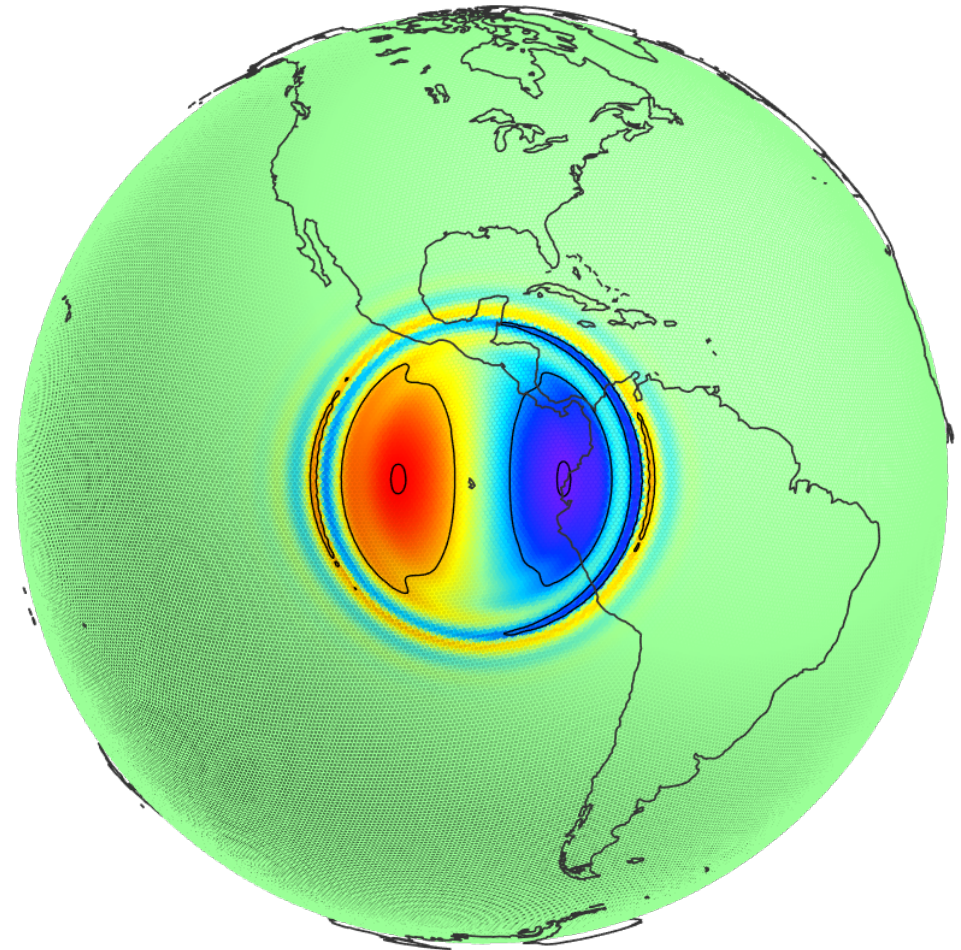
5th-order. Williamson Test Case 2. Day 12.

maximum error is 2m

(swm) field=swm_IC001_mss_APPX $\tau=000288h$ k= 1 exp=005 lvlmax= 7 km= 1
min=-0.127372e+01 ave= 0.829081e+01 max= 0.999997e+03



(swm) field=swm_IC001_mss_DIFF $\tau=000288h$ k= 1 exp=005_wghts_csk lvlmax= 7 km= 1
min=-0.203402e+01 ave= 0.190154e-06 max= 0.202028e+01



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

- Helmholtz decomposition

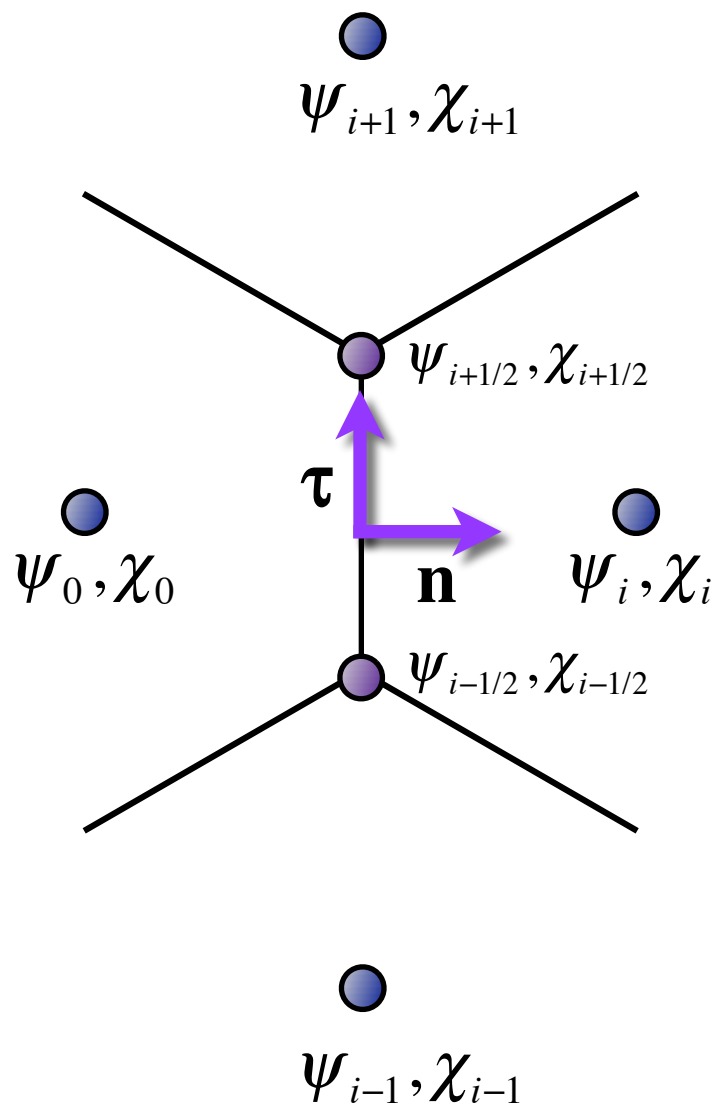
$$\mathbf{v} = \mathbf{k} \times \nabla \psi + \nabla \chi = \mathbf{v}_\psi + \mathbf{v}_\chi$$

- 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.



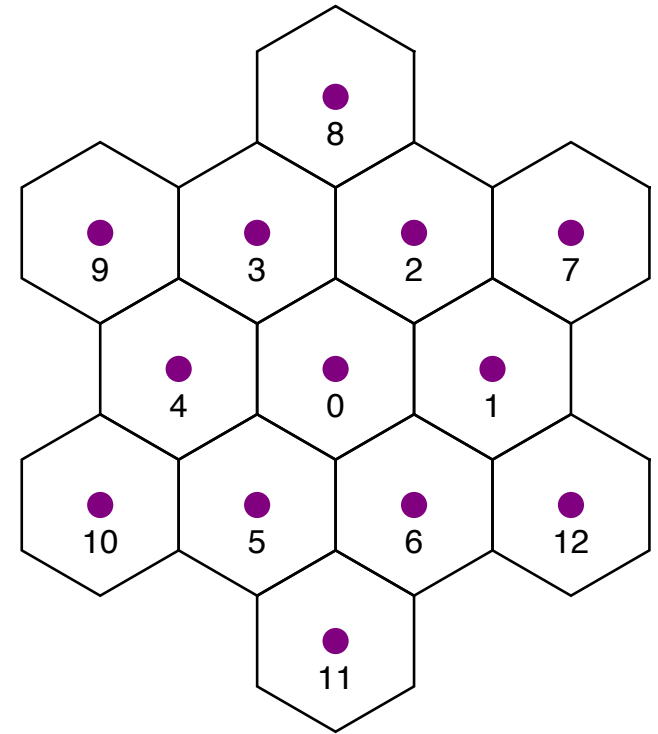
Perfect Hexagon Stencil 2 -- 3rd-order accurate

- The Laplacian can be written

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

- where the weights are given by

$$\left\{ \left\{ \begin{aligned} c_{00} &\rightarrow -\frac{16}{3\Delta^2}, & c_{01} &\rightarrow \frac{1}{\Delta^2}, & c_{02} &\rightarrow \frac{1}{\Delta^2}, & c_{03} &\rightarrow \frac{1}{\Delta^2}, & c_{04} &\rightarrow \frac{1}{\Delta^2}, \\ c_{05} &\rightarrow \frac{1}{\Delta^2}, & c_{06} &\rightarrow \frac{1}{\Delta^2}, & c_{07} &\rightarrow -\frac{1}{9\Delta^2}, & c_{08} &\rightarrow -\frac{1}{9\Delta^2}, \\ c_{09} &\rightarrow -\frac{1}{9\Delta^2}, & c_{10} &\rightarrow -\frac{1}{9\Delta^2}, & c_{11} &\rightarrow -\frac{1}{9\Delta^2}, & c_{12} &\rightarrow -\frac{1}{9\Delta^2} \end{aligned} \right\} \right\}$$

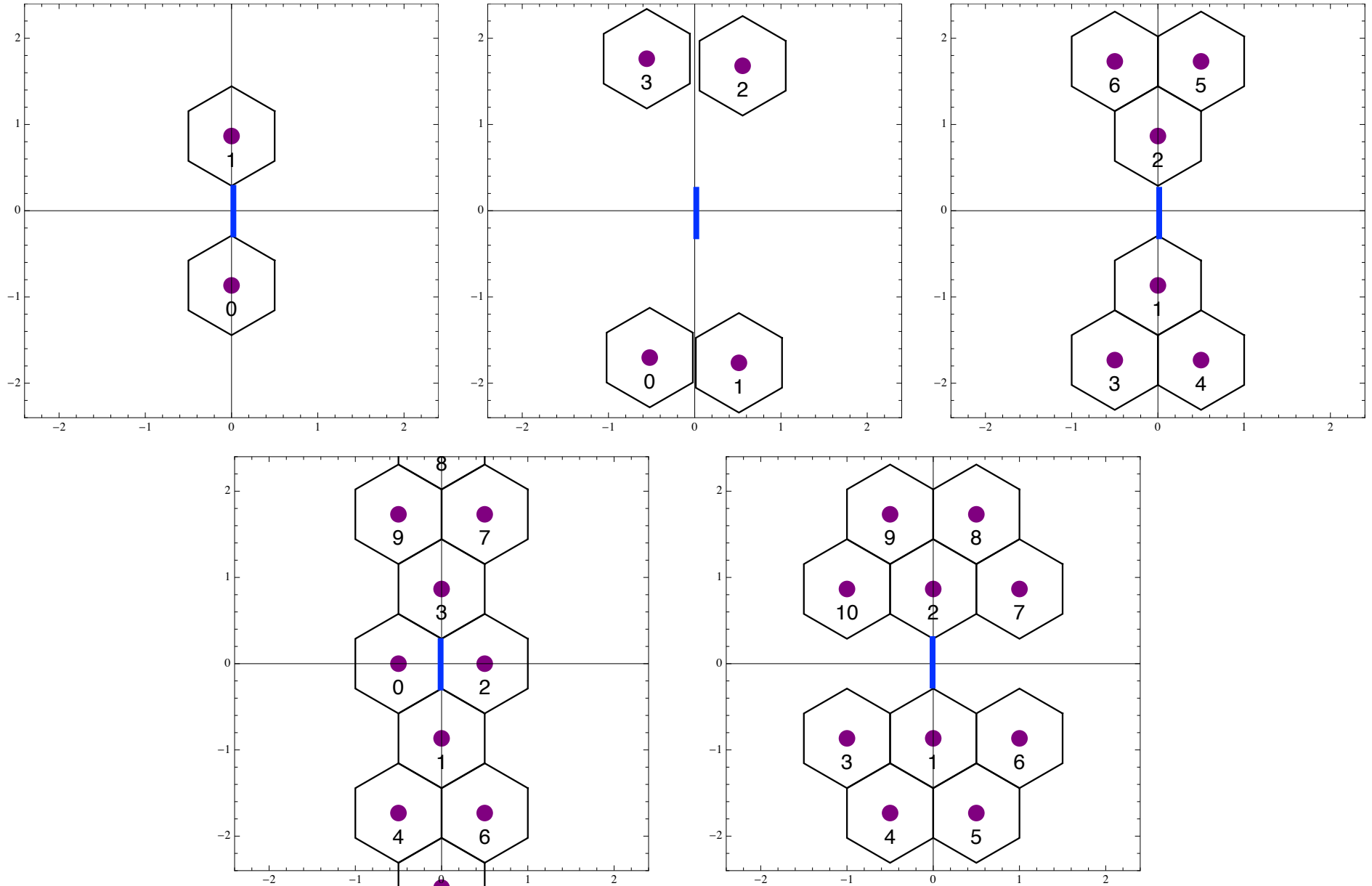


- The Taylor series becomes ($f^{(0,4)}$ is the lowest derivative)

$$\begin{aligned} & f^{(0,2)}[0,0] - \frac{1}{160} \Delta^4 f^{(0,6)}[0,0] - \frac{3\Delta^6 f^{(0,8)}[0,0]}{7168} + f^{(2,0)}[0,0] - \frac{1}{32} \Delta^4 f^{(4,2)}[0,0] - \\ & \frac{1}{512} \Delta^6 f^{(4,4)}[0,0] - \frac{\Delta^8 f^{(4,6)}[0,0]}{20480} - \frac{3\Delta^{10} f^{(4,8)}[0,0]}{4587520} - \frac{1}{240} \Delta^4 f^{(6,0)}[0,0] - \\ & \frac{1}{384} \Delta^6 f^{(6,2)}[0,0] - \frac{\Delta^8 f^{(6,4)}[0,0]}{6144} - \frac{\Delta^{10} f^{(6,6)}[0,0]}{245760} - \frac{\Delta^{12} f^{(6,8)}[0,0]}{18350080} - \frac{5\Delta^6 f^{(8,0)}[0,0]}{21504} - \\ & \frac{13\Delta^8 f^{(8,2)}[0,0]}{122880} - \frac{13\Delta^{10} f^{(8,4)}[0,0]}{1966080} - \frac{13\Delta^{12} f^{(8,6)}[0,0]}{78643200} - \frac{13\Delta^{14} f^{(8,8)}[0,0]}{5872025600} \end{aligned}$$

Series expansion approach to approximate the tangential derivative

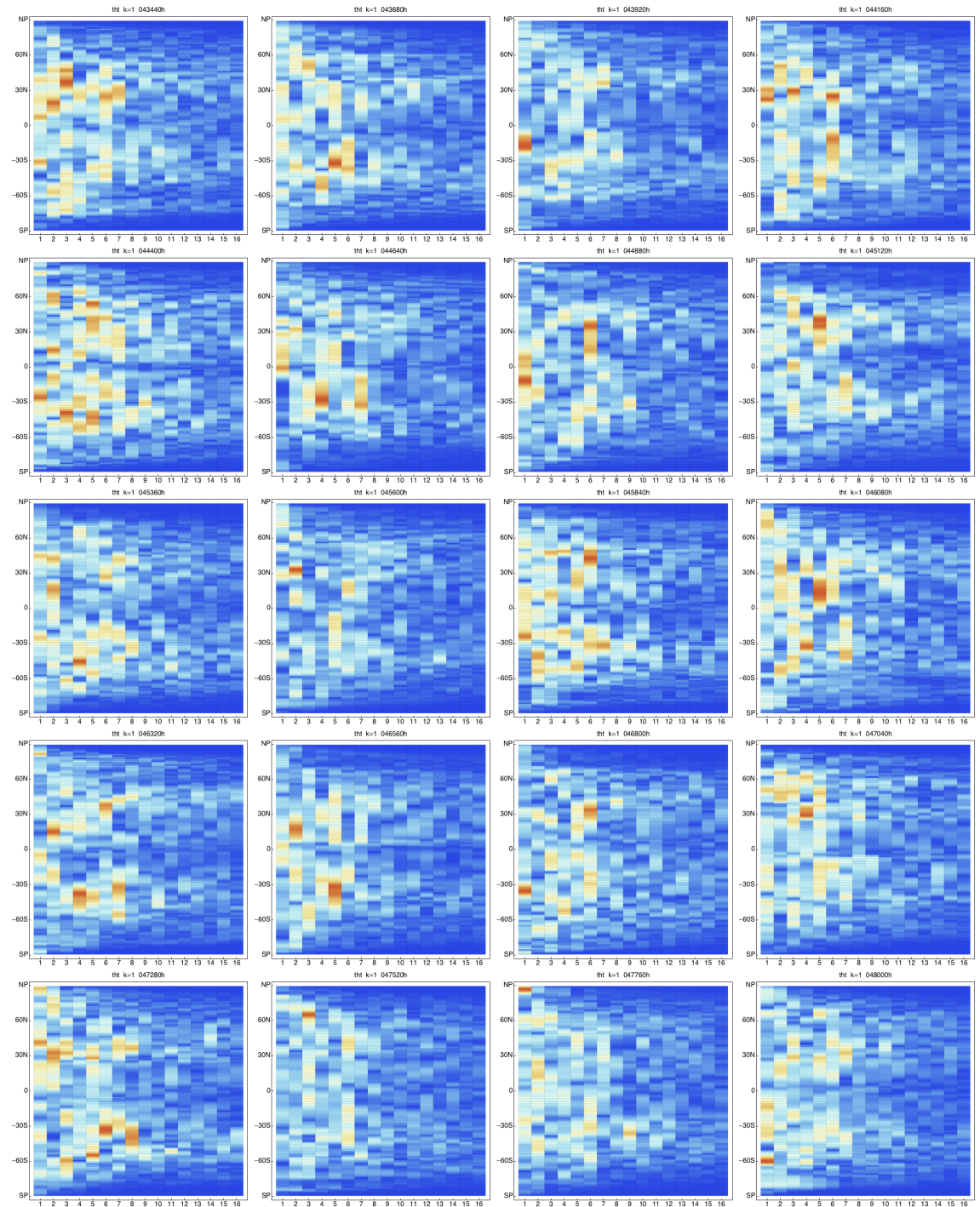
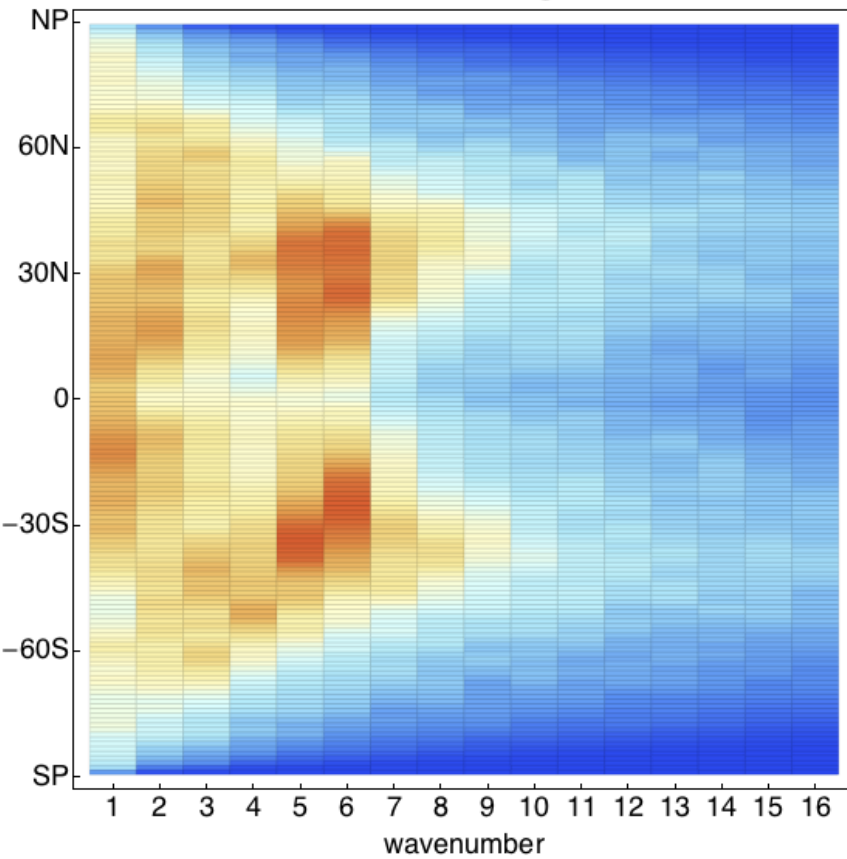
- Many stencils are possible



surface theta

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

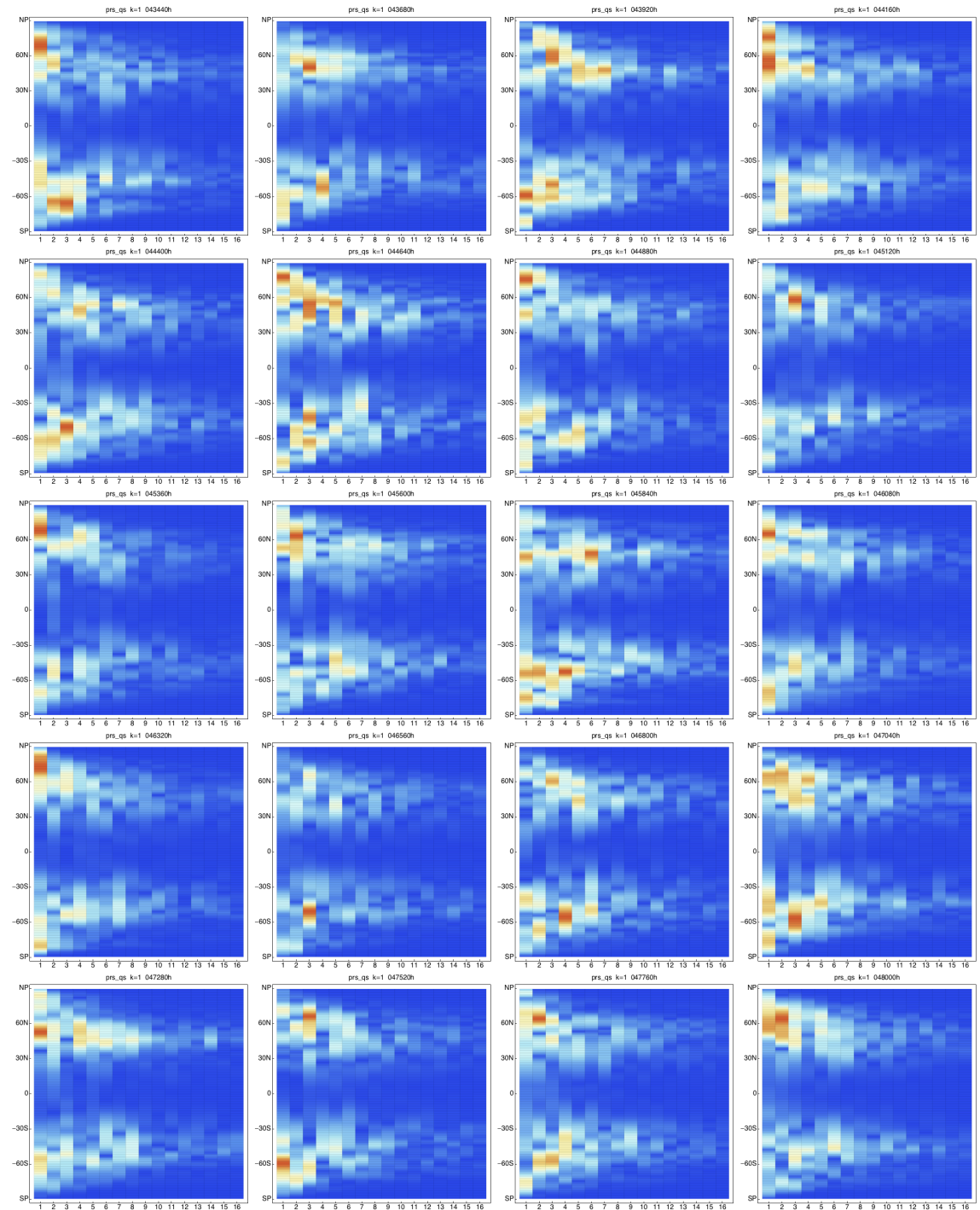
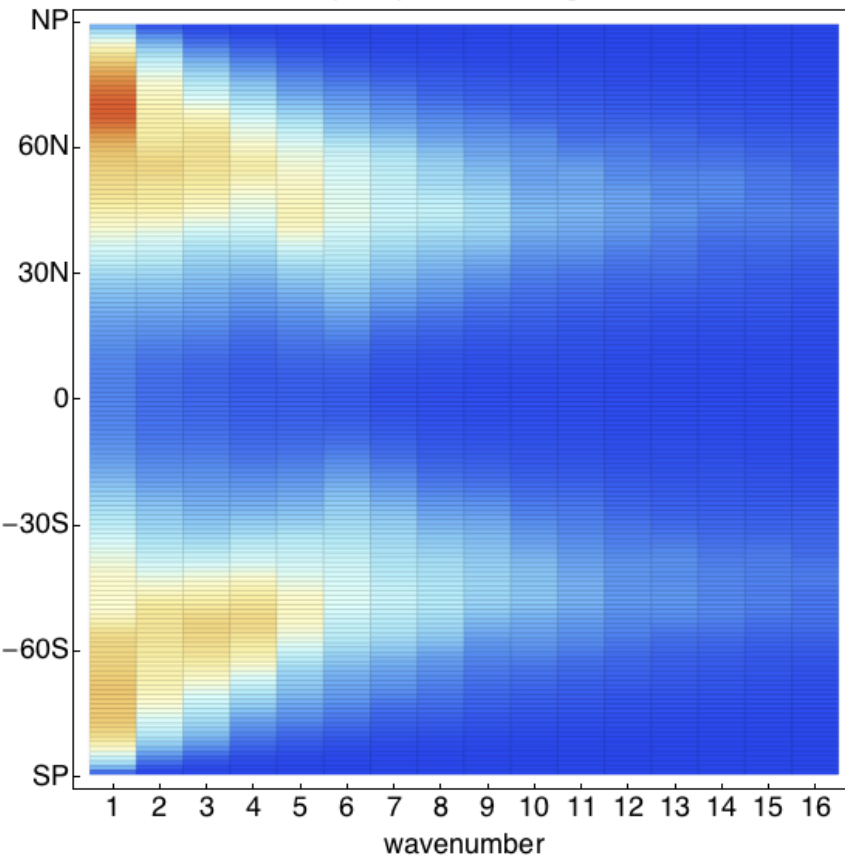
tht k=1 average



surface pressure

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

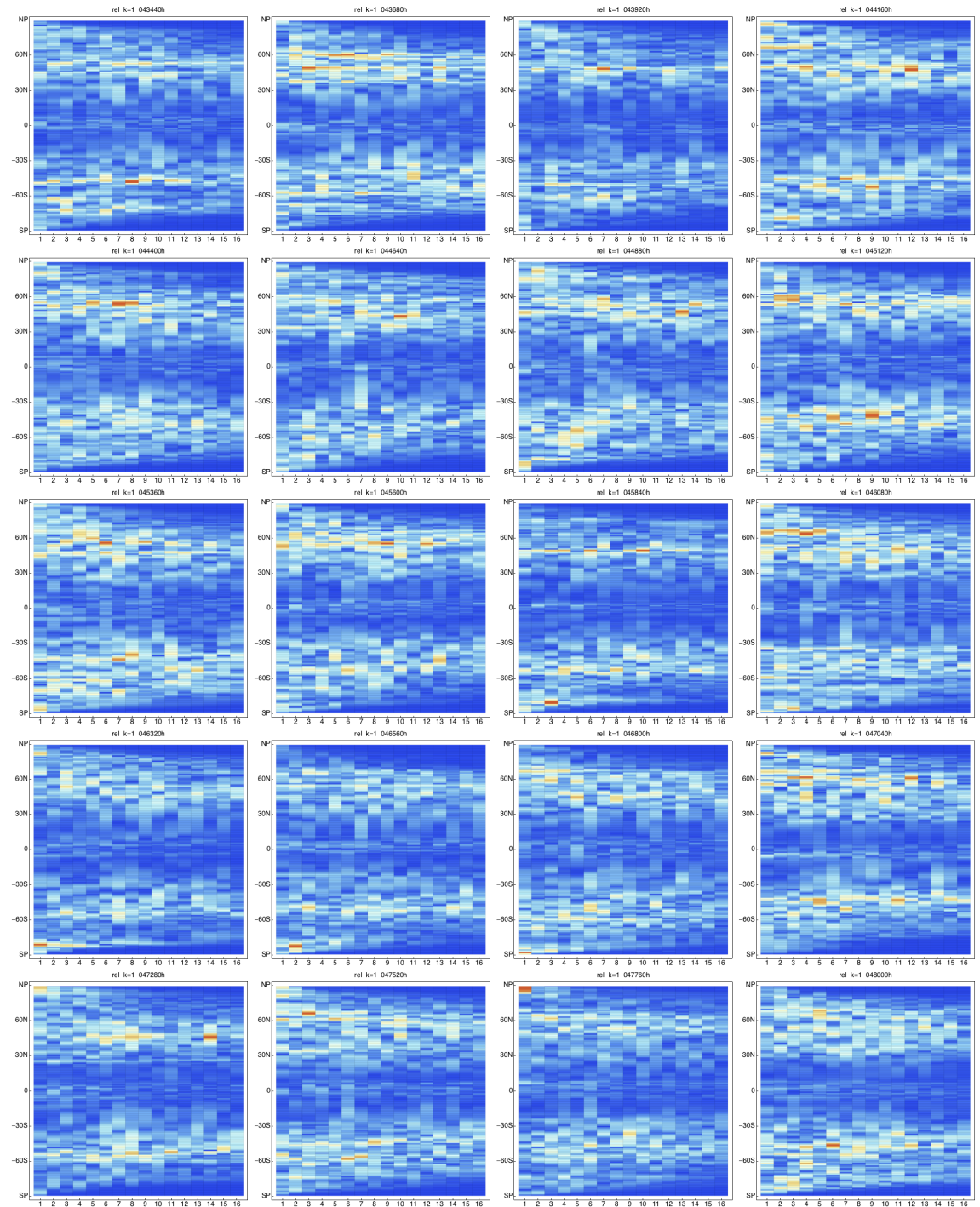
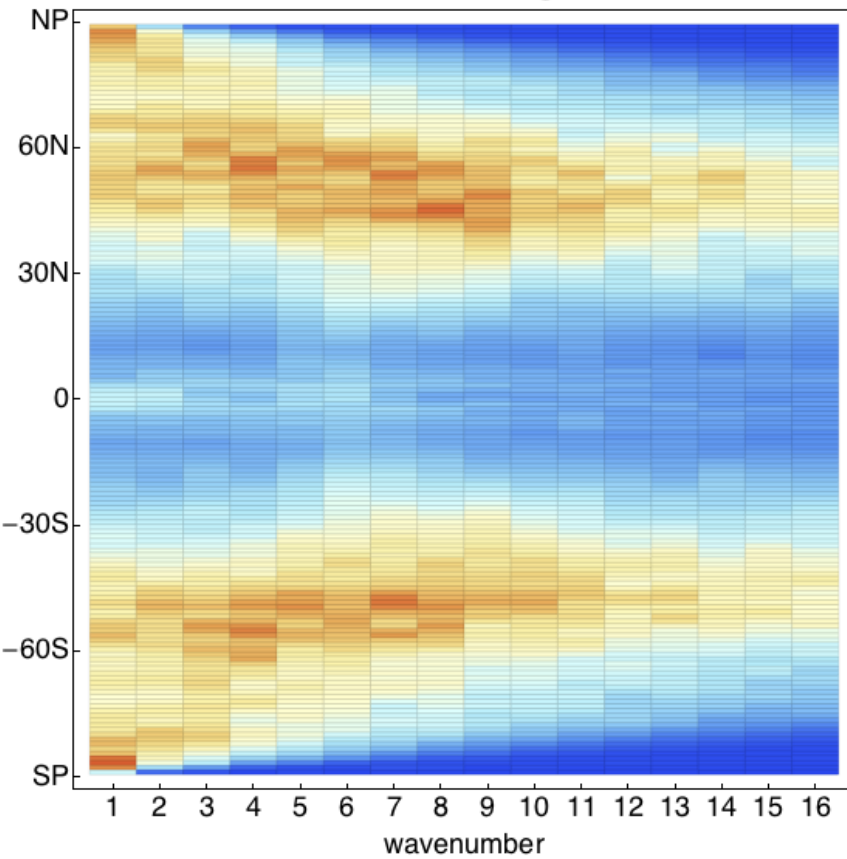
prs_qs k=1 average



relative vorticity

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

rel k=1 average



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

z k=12 average

