New filtering options in CAM

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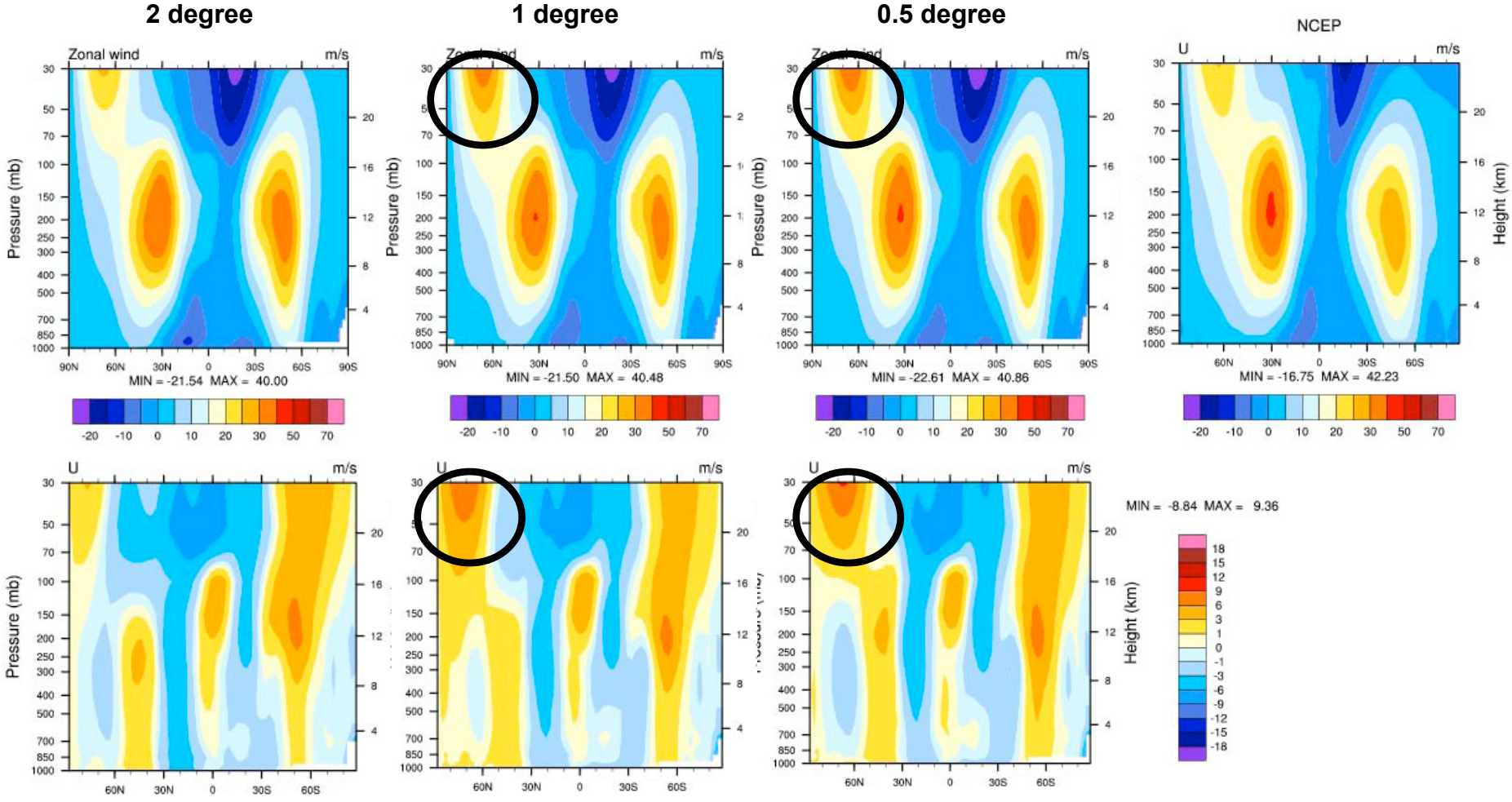
Why new filtering options in CAM4?

1. Excessive polar night jets at high resolution

2. Grid-scale noise

Zonal wind speed (1st row) & difference plots (2nd row)

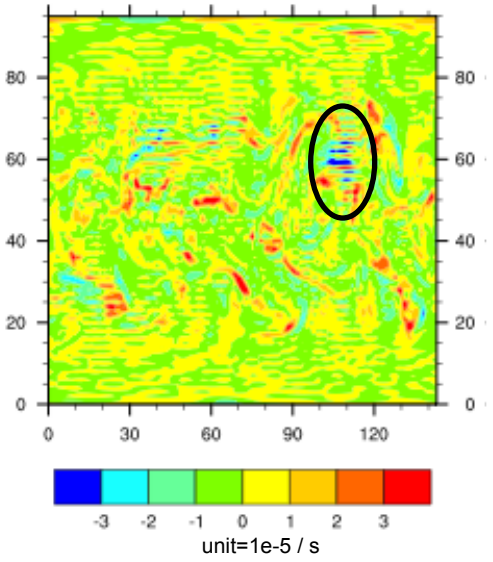
CAM4 (DJF zonal average over years 2-11)



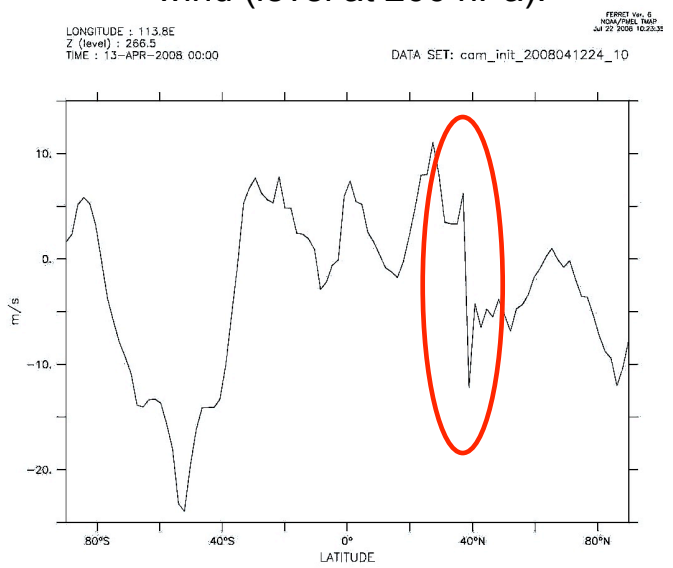
Has resulted in model execution failure at high resolution!

Some examples of grid-scale noise in "free-running" CAM

Instantaneous divergence (model level 13; 198 hPa):



Instantaneous meridional wind (level at 266 hPa):



see also Kevin Raeder's talk from the 2009 CCSM workshop in Breckenridge

A filtering solution

1. Excessive polar night jets at high resolution:

   Add Laplacian damping in model top layers using constant coefficients (regardless of resolution the same physical scale is damped equally much)

2. Grid-scale noise:

   Replace 2nd-order divergence damping with 4th-order divergence damping (which is more scale selective)

Implementation of Laplacian damping in CAM-FV

(controlled with `DIV24DEL2FLAG` namelist variable)

$$\frac{\partial u}{\partial t} = \ldots + \nu_{del2} \nabla^2 u_{ij} \quad (1)$$

$$\frac{\partial v}{\partial t} = \ldots + \nu_{del2} \nabla^2 v_{ij}, \quad (2)$$

where

$$\nabla^2 \psi_{ij} = \left(\nabla^2 \psi_{ij}\right)_\lambda + \left(\nabla^2 \psi_{ij}\right)_\theta, \quad (3)$$

and

$$\left(\nabla^2 \psi_{ij}\right)_\lambda = \frac{1}{A^2 \cos^2(\theta)} \frac{1}{\Delta\lambda^2} \delta_\lambda^2 \psi_{ij} \quad (4)$$

$$\left(\nabla^2 \psi_{ij}\right)_\theta = \frac{1}{A^2 \cos(\theta)} \frac{\delta_\theta \left[\cos(\theta) \delta_\theta \psi_{ij}\right]}{\Delta\theta^2}, \quad (5)$$

$$\delta_\lambda^2 \psi_{ij} = \psi_{i+1j} - 2\,\psi_{ij} + \psi_{i-1j}, \quad (6)$$

$$\delta_\theta \psi_{ij} = \psi_{ij+1} - \psi_{ij}, \quad (7)$$

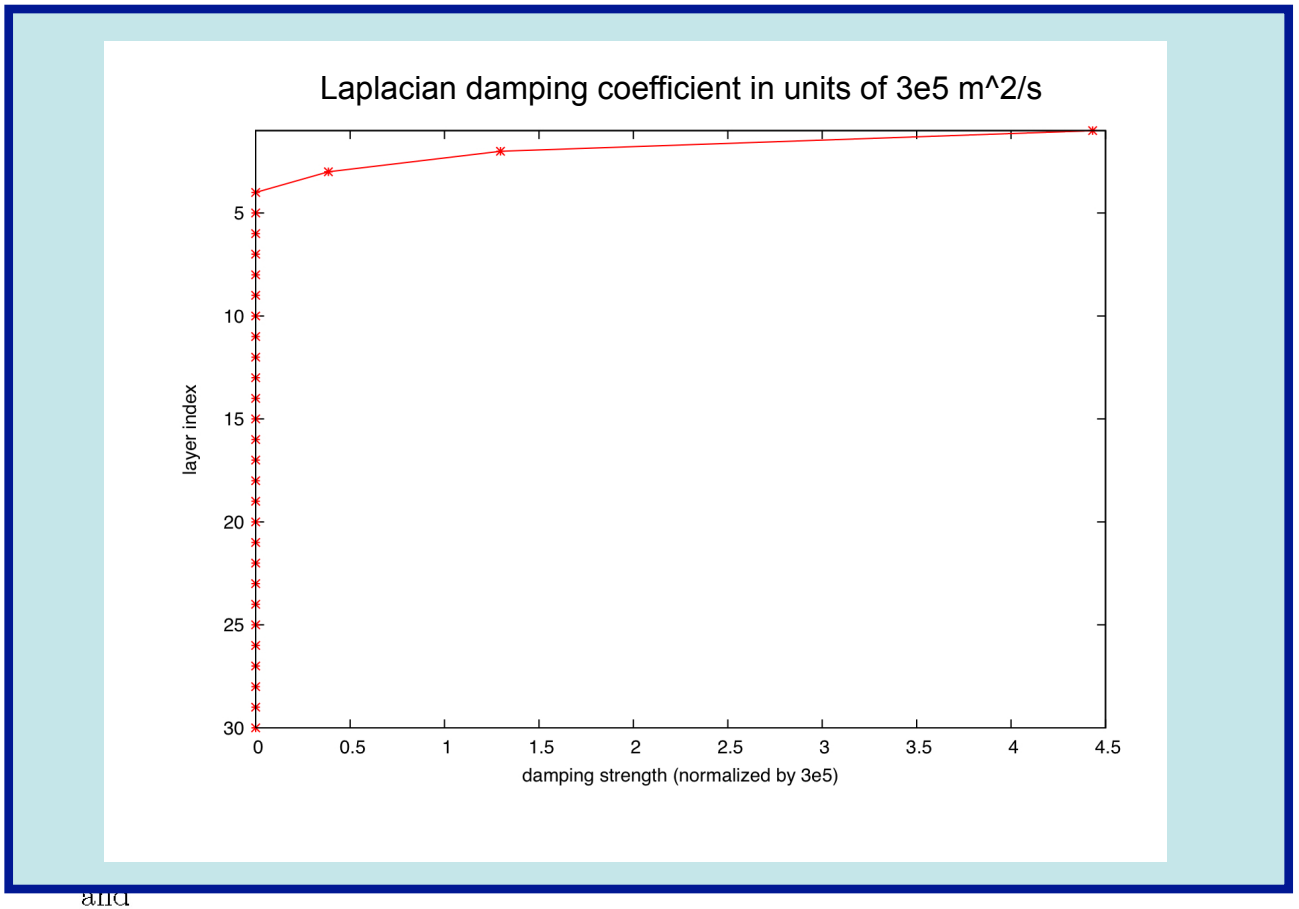
and

$$\nu_{del2} = 3 \times 10^5 \quad (8)$$

Indication that coefficient should increase (decrease) slightly with an increase (decrease) in resolution

Implementation of Laplacian damping in CAM-FV

(controlled with `DIV24DEL2FLAG` namelist variable)



and

$$\nu_{del2} = 3 \times 10^5 \qquad (8)$$

Indication that coefficient should increase (decrease) slightly with an increase (decrease) in resolution

Implementation of 4th-order divergence damping in CAM-FV

(controlled with `DIV24DEL2FLAG` namelist variable)

$$\frac{\partial u}{\partial t} = \ldots - \nu_{div4} \frac{1}{A \cos\theta} \frac{\partial}{\partial \lambda} \left(\nabla^2 D_{ij} \right) \quad (1)$$

$$\frac{\partial v}{\partial t} = \ldots - \nu_{div4} \frac{1}{A} \frac{\partial}{\partial \theta} \left(\nabla^2 D_{ij} \right), \quad (2)$$

where

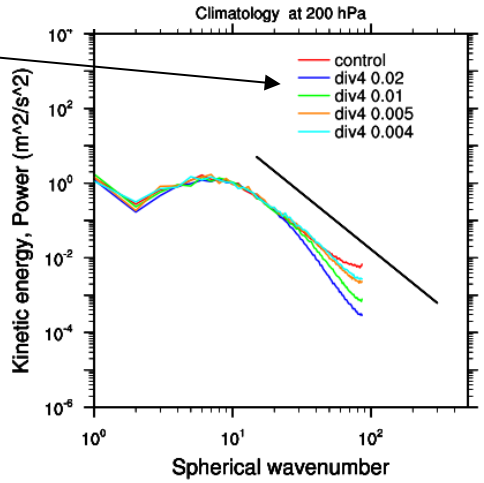
$$D_{ij} = \frac{1}{A \cos(\theta)} \left[\frac{1}{\Delta\lambda} \delta_\lambda u_{ij} + \frac{1}{\Delta\theta} \delta_\theta \left(\cos(\theta) v_{ij} \right) \right], \quad (3)$$

ν_{div4} is the damping coefficient

$$\nu_{div4} = \tau_4 \left(A^2 \cos\theta \Delta\lambda \Delta\theta \right)^2 / \Delta t. \quad (4)$$

and τ_4 is set to 0.01.

Divergent part of total kinetic energy

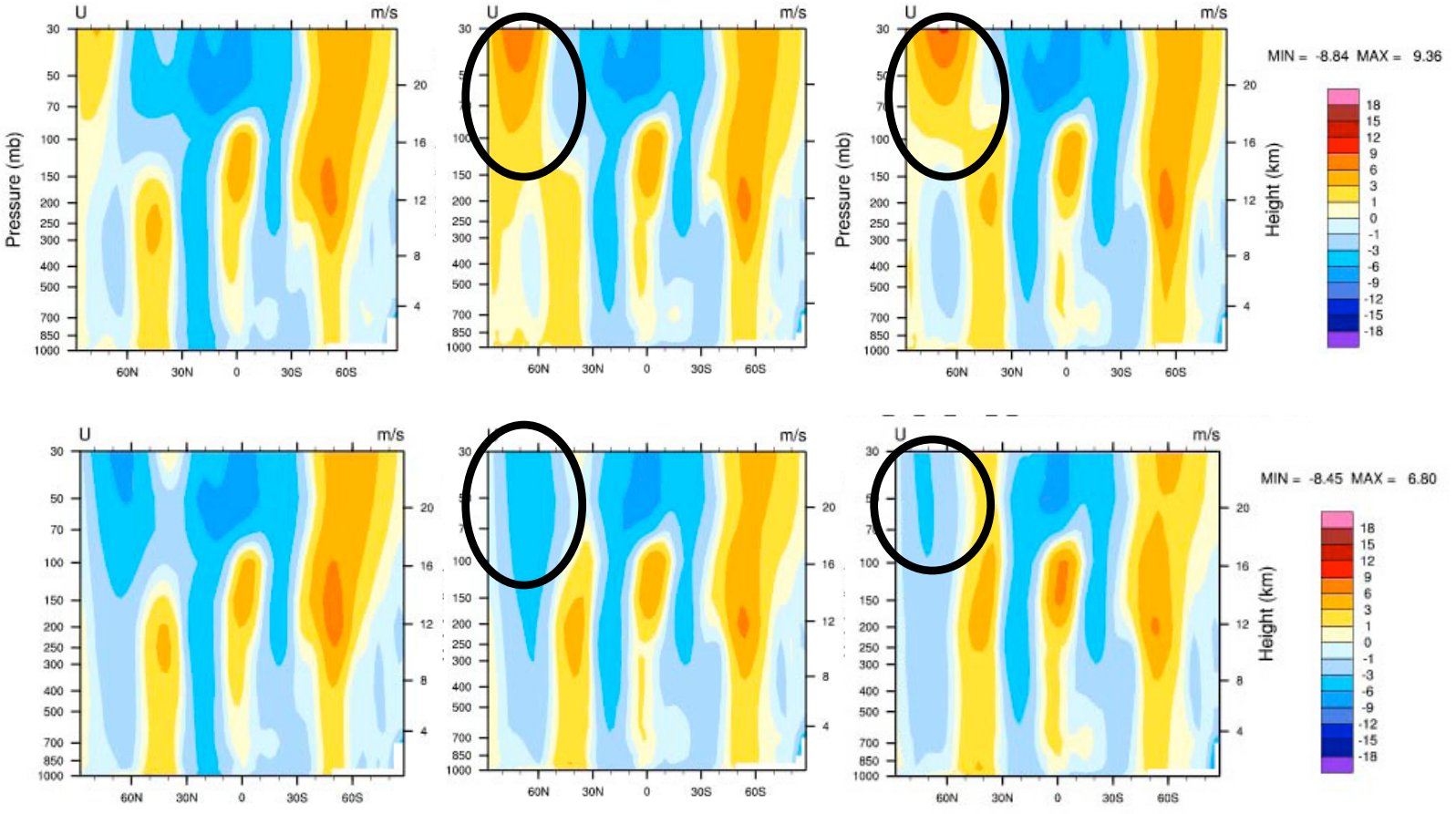


Divergence damping coefficient is constant with height

Zonal wind speed difference plots

CAM4 (DJF zonal average over years 2-11)

2 degree **1 degree** **0.5 degree**



div2
= CAM4 (track 1)

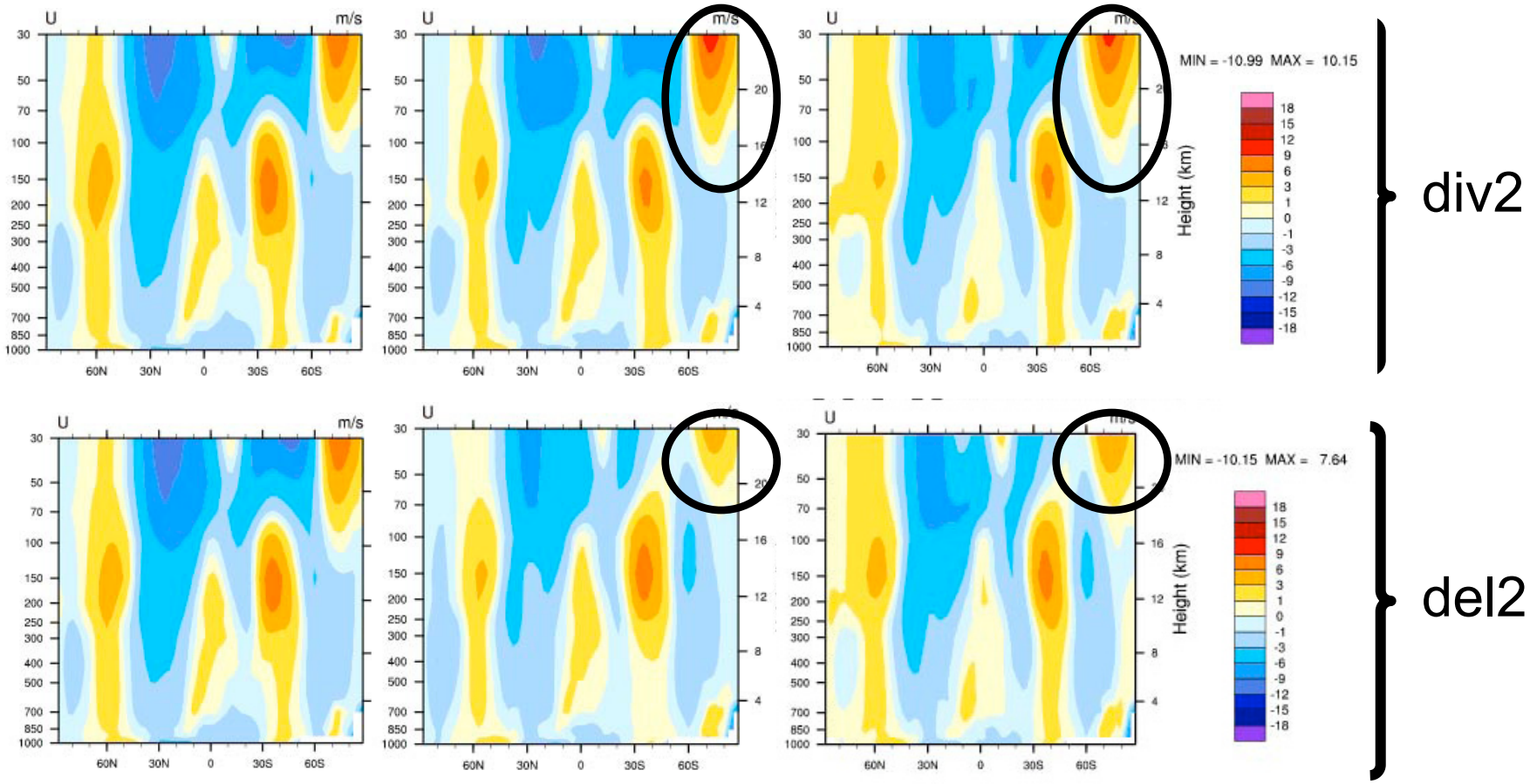
del2
= CAM4 (track 1) using Laplacian damping at model top & 4th-order divergence damping

Representation of polar night jet improved at higher resolution

Zonal wind speed differences

CAM4 (JJA zonal average over years 2-11)

2 degree **1 degree** **0.5 degree**

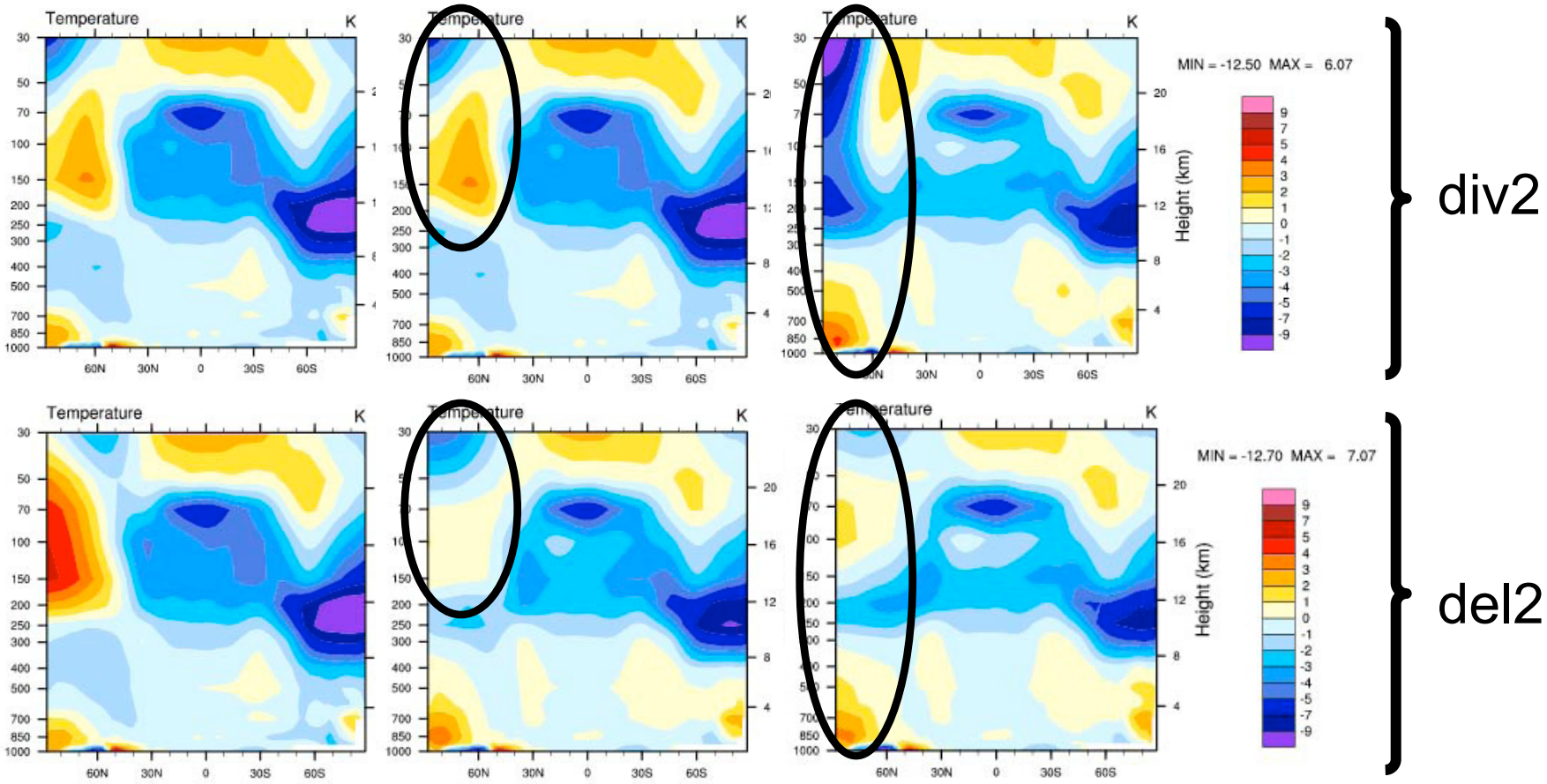


Representation of polar night jet improved at higher resolution

Temperature difference plots

CAM4 (DJF zonal average over years 2-11)

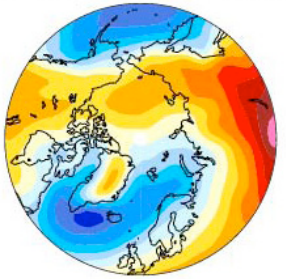
2 degree **1 degree** **0.5 degree**



Polar temperature biases reduced at higher resolution

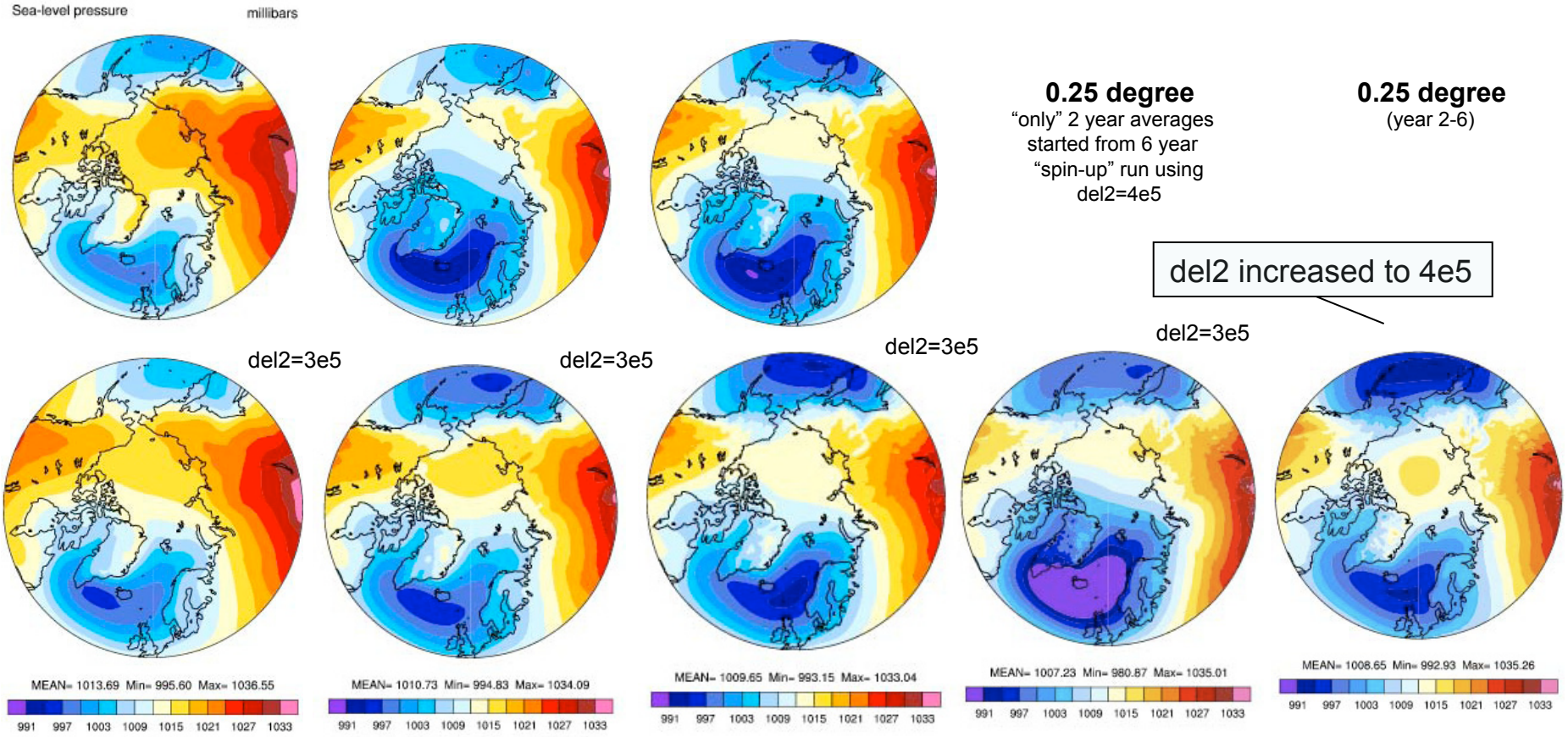
PSL for div2 (1st row) and del2 (2nd row)

CAM4 (DJF zonal average over years 2-11)



NCEP

2 degree **1 degree** **0.5 degree**



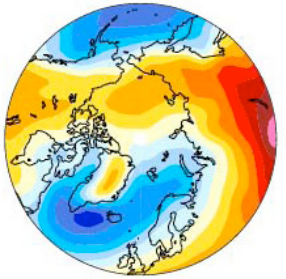
0.25 degree
"only" 2 year averages started from 6 year "spin-up" run using del2=4e5

0.25 degree
(year 2-6)

del2 increased to 4e5

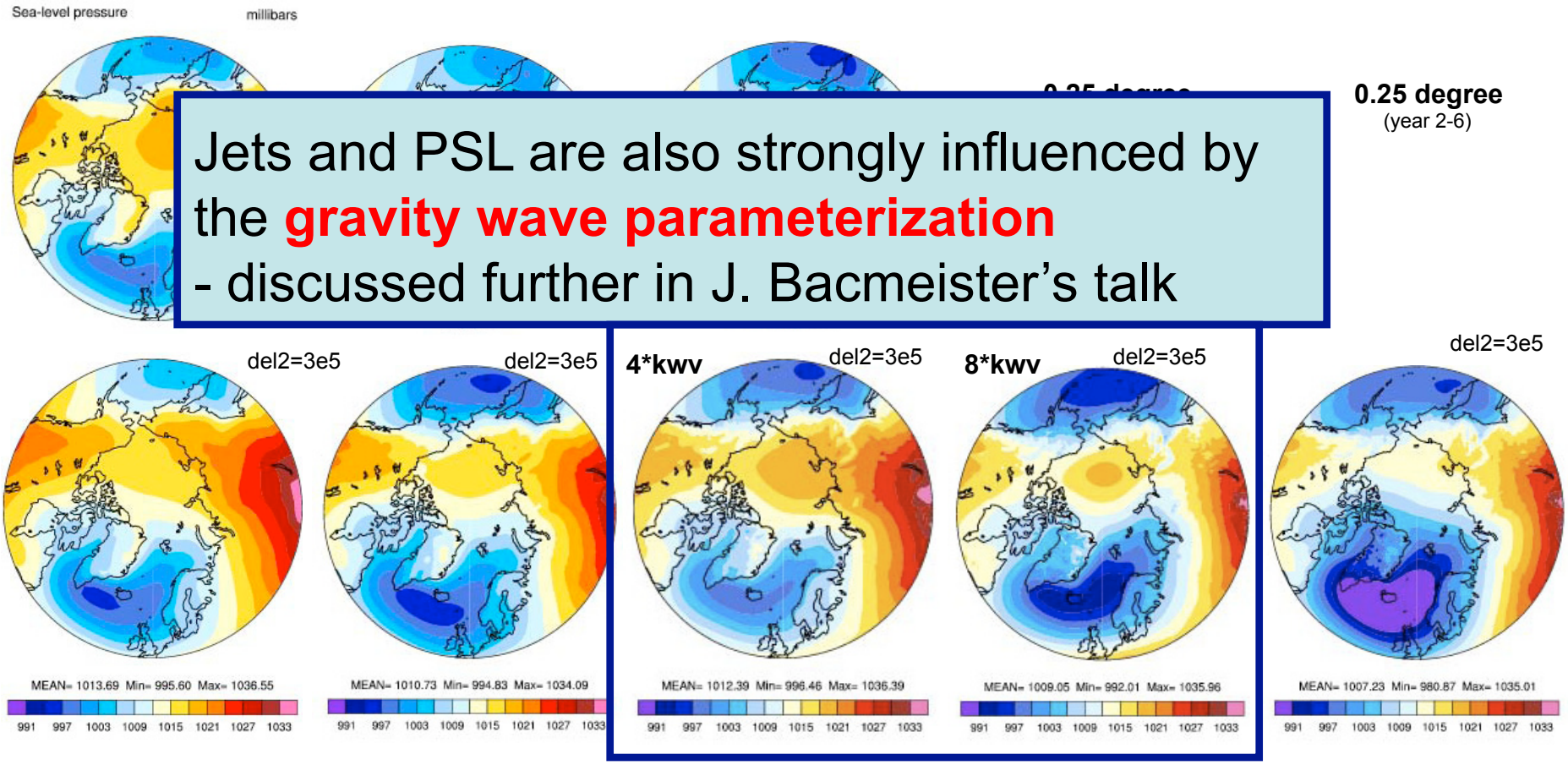
PSL for div2 (1st row) and del2 (2nd row)

CAM4 (DJF zonal average over years 2-11)



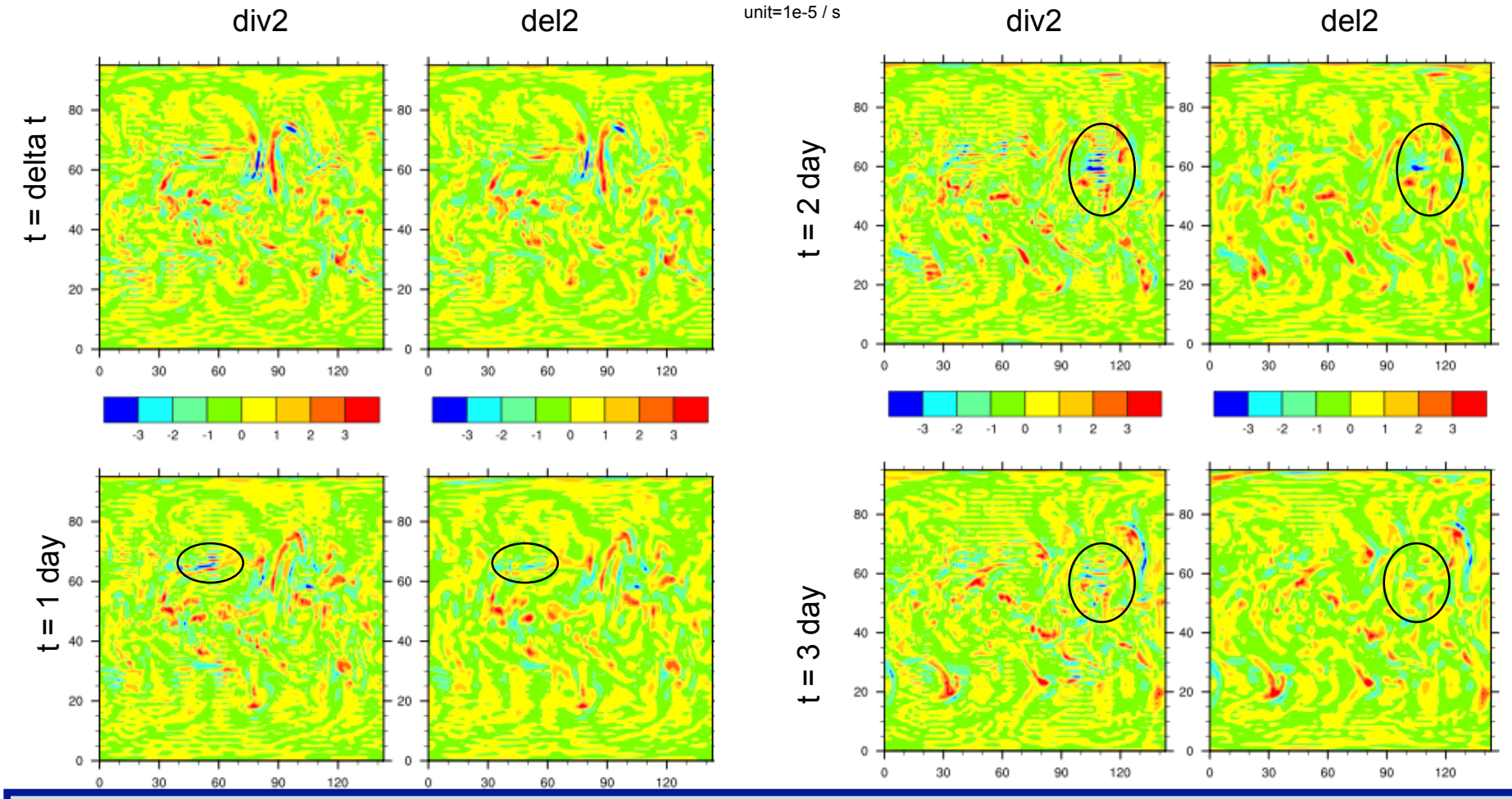
NCEP

2 degree **1 degree** **0.5 degree** **0.25 degree**
(year 2-6)



Jets and PSL are also strongly influenced by the **gravity wave parameterization**
- discussed further in J. Bacmeister's talk

del2 effects on instantaneous divergence fields in “free-running” CAM



Divergence associated with “physical” features seem preserved while grid-scale noise is alleviated

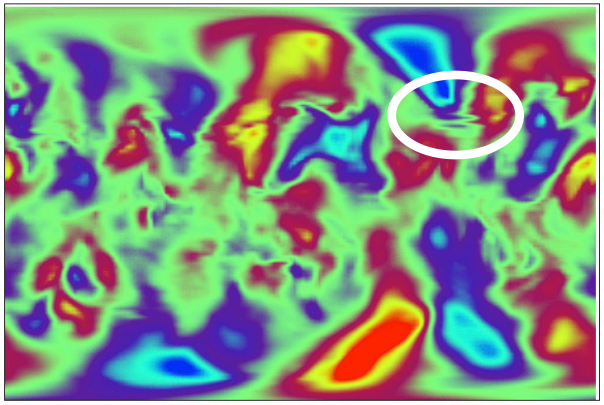
CAM-DART: An ensemble member, 6 hours after data has been assimilated

Instantaneous meridional wind at level=103hPa

Track 5

div2

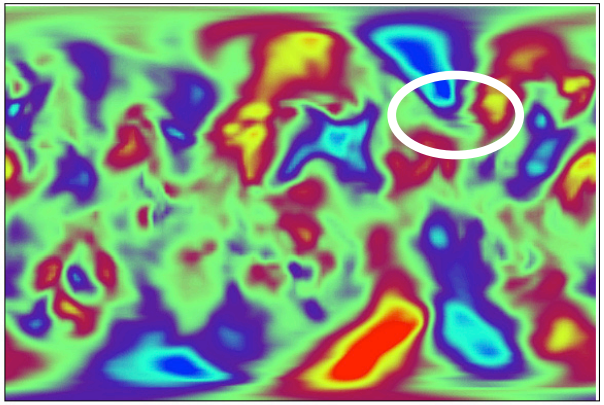
Meridional wind, staggered (m/s)



Contour range = [-6,6] m/s

del2

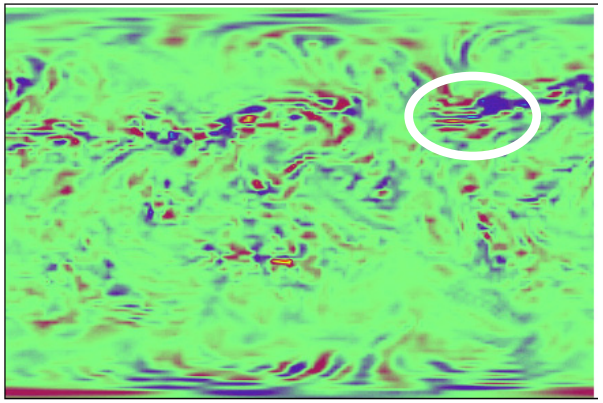
Meridional wind, staggered (m/s)



Contour range = [-6,6] m/s

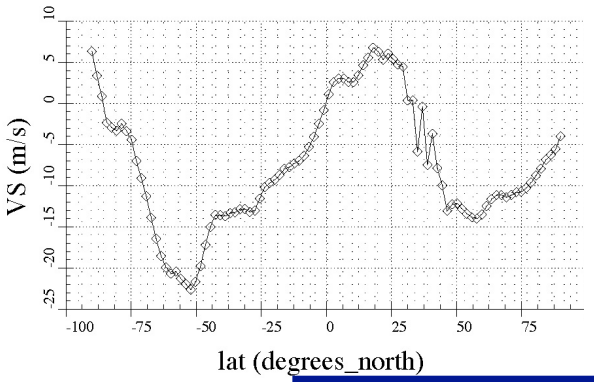
div2-del2

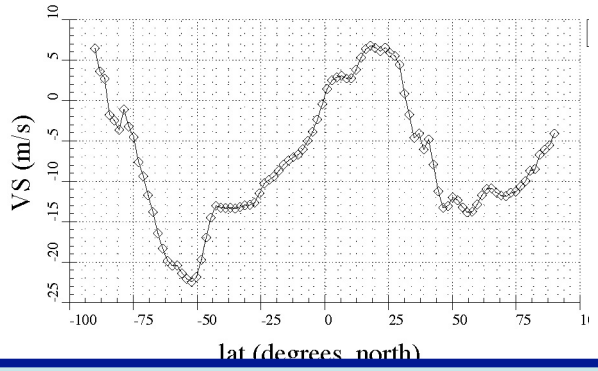
Meridional wind, staggered (m/s)

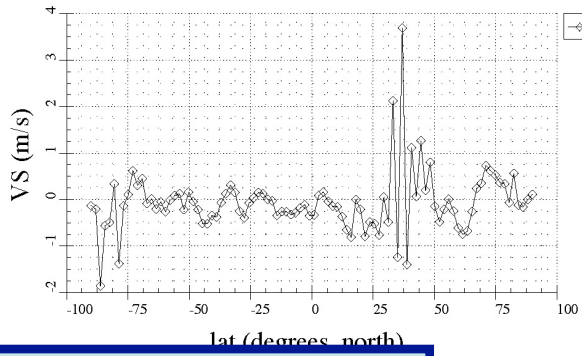


Contour range = [-6,6] m/s

Cross section at 271E







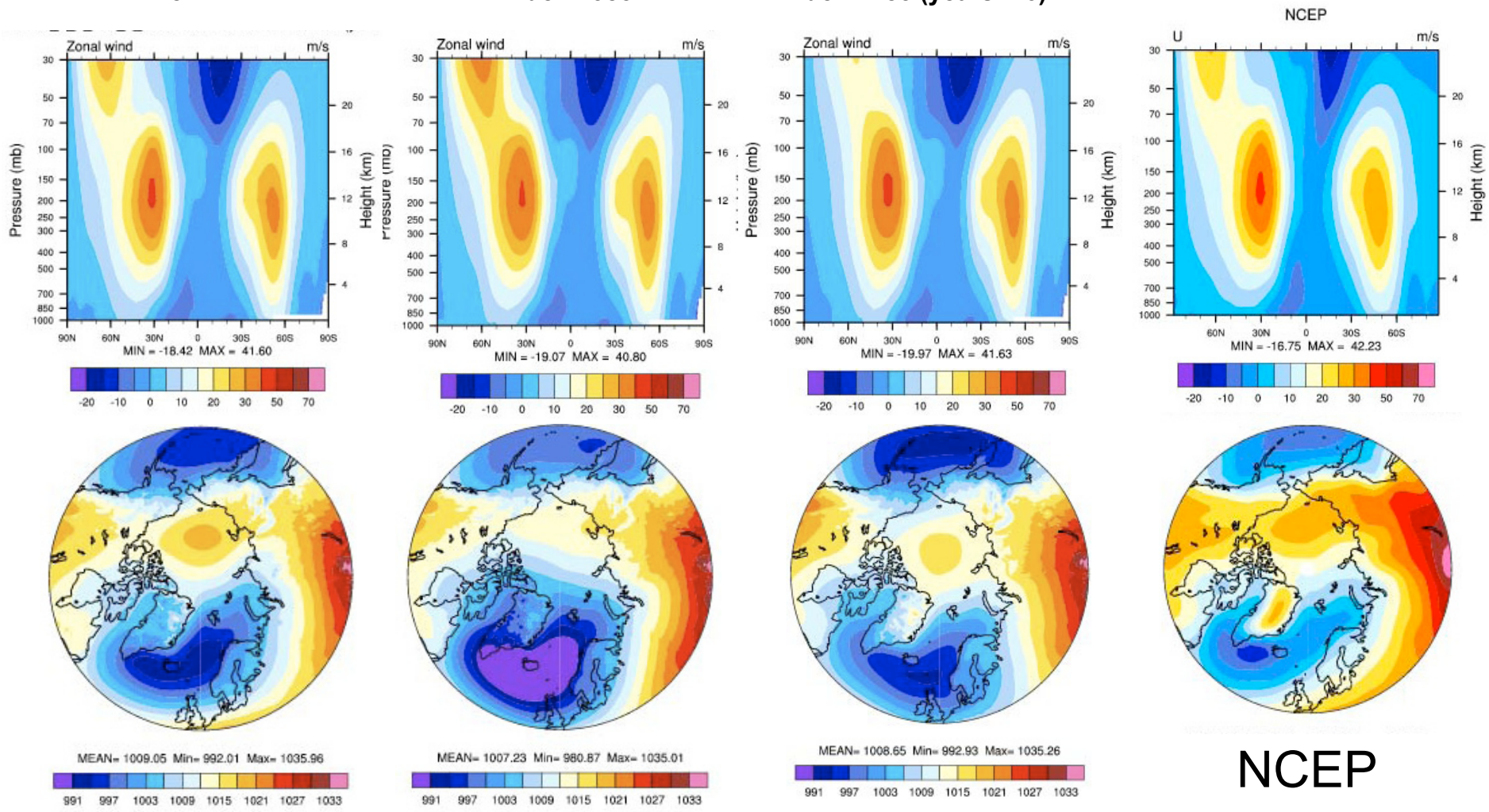
In general less grid-scale noise with 4th-order divergence damping!

Extra slides

0.25 degree resolution, del2 configuration: U & PSL

CAM4 (DJF zonal average over years 7-8; using "spun-up" initial condition from a 6 year del2 run with del2=4e6)

8*kwv **del2=3e5** **del2=4e5 (years 2-6)**



Exploration of parameter space for del2

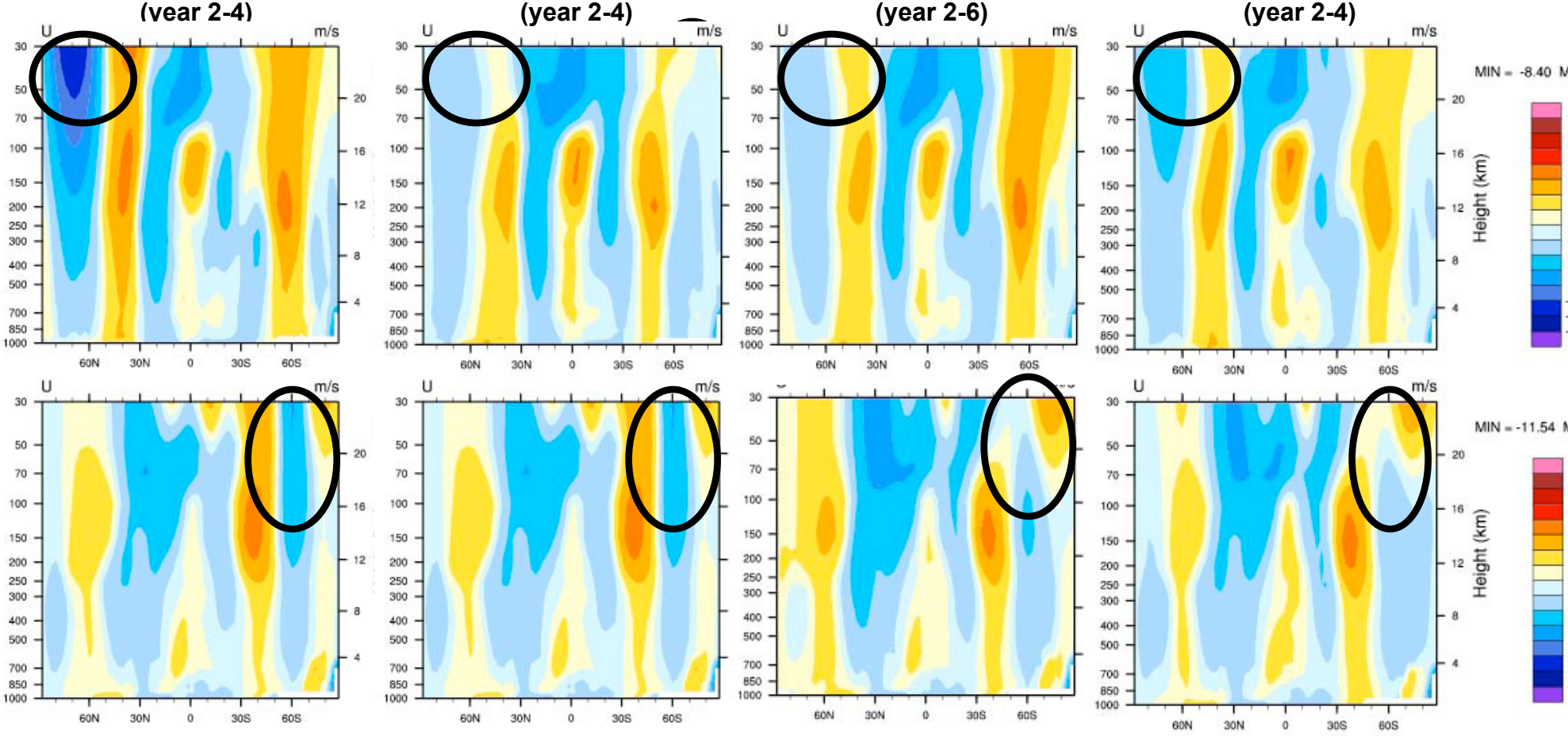
(plots are for 0.5 degree horizontal resolution)

del2 = 1e5 (vear 2-4)

del2 = 2e5 (year 2-4)

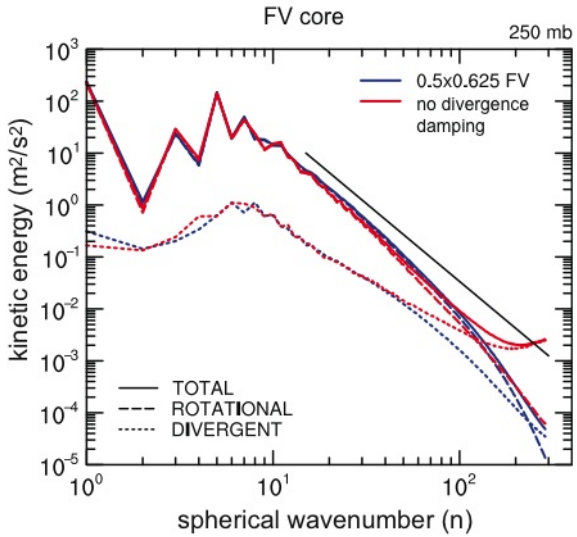
del2 = 3e5 (year 2-6)

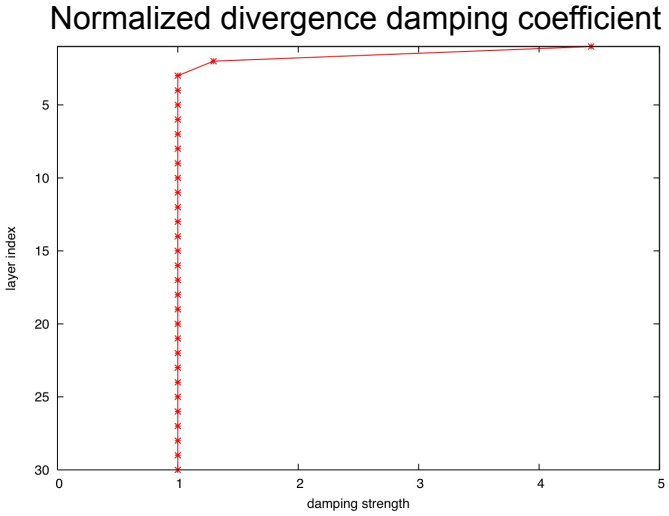
del2 = 4e5 (year 2-4)



Damping mechanisms in CAM

- **Vertical remapping** reduces to 1st order in top layers
- **Advection operators** reduce to 1st order in top layers and use limiters elsewhere
- **Divergence damping:** Constant throughout the atmosphere except for top layers (see below)

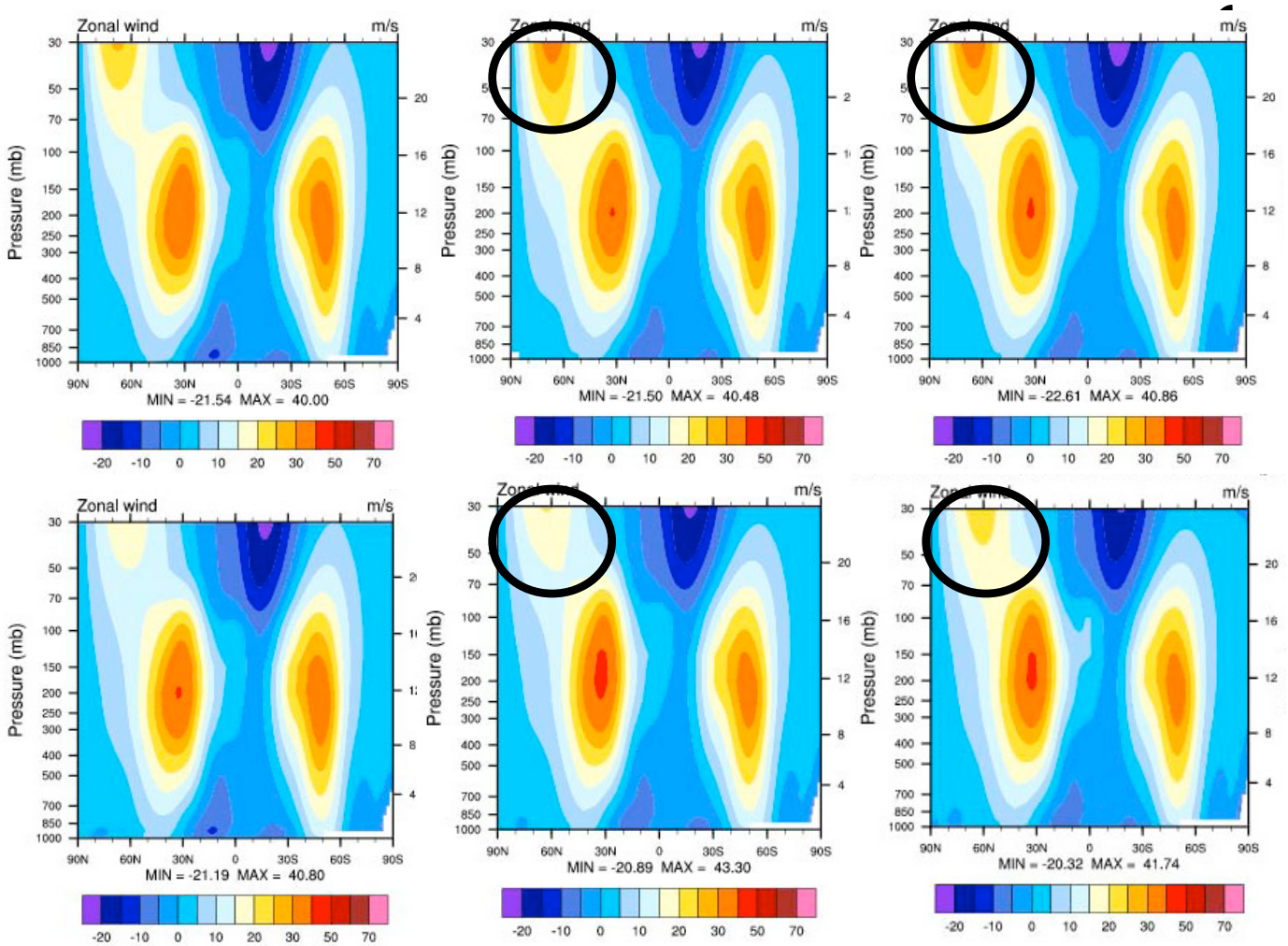




Zonal wind speed

CAM4 (DJF zonal average over years 2-11)

2 degree | **1 degree** | **0.5 degree**



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del2
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