New filtering options in CAM

Peter Hjort Lauritzen (NCAR)
Art Mirin (LLNL)
John Truesdale (NCAR)
Kevin Raeder (NCAR)
Jeff Anderson (NCAR)

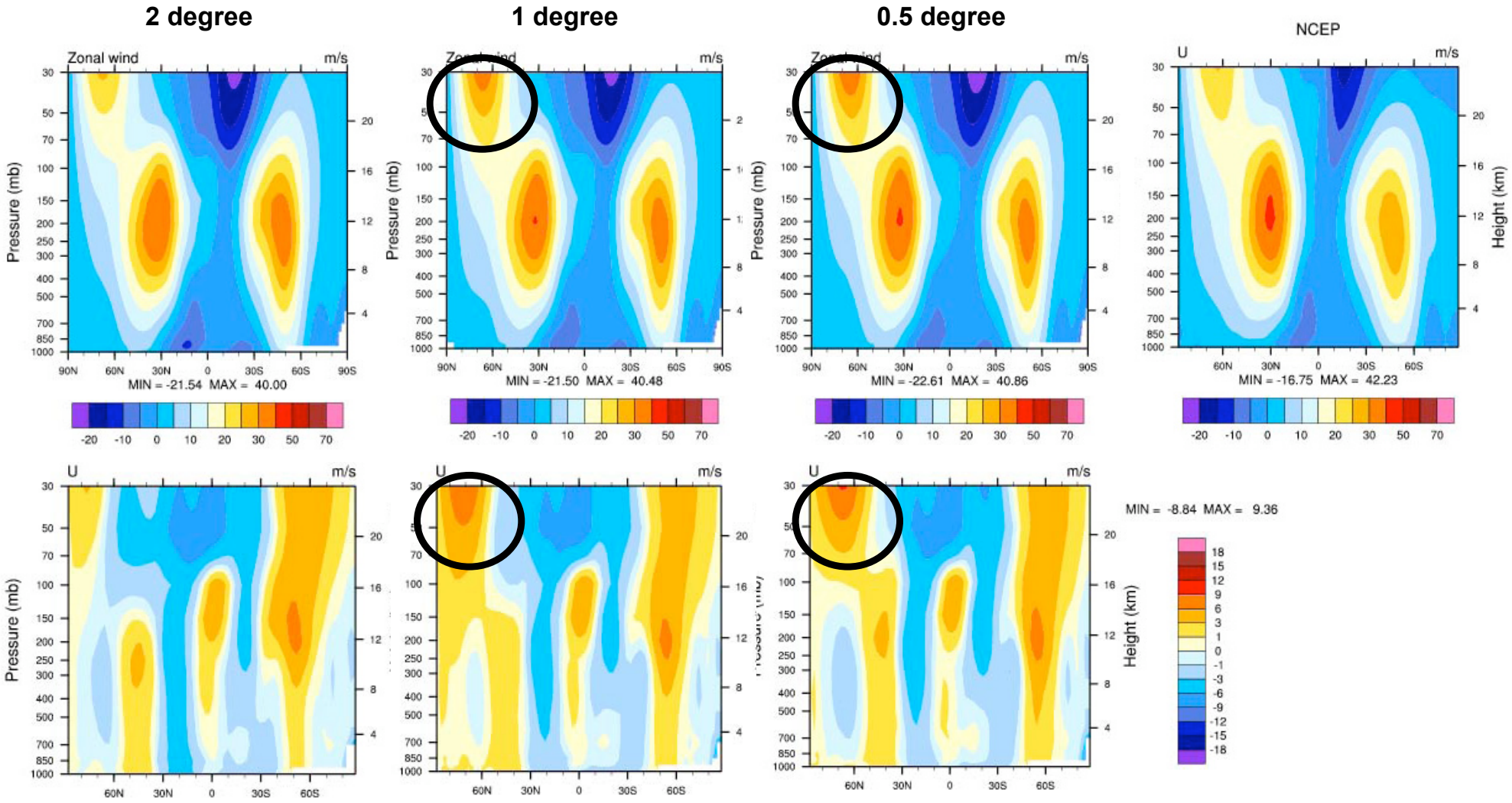
Why new filtering options in CAM4?

1. Excessive polar night jets at high resolution

2. Grid-scale noise

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

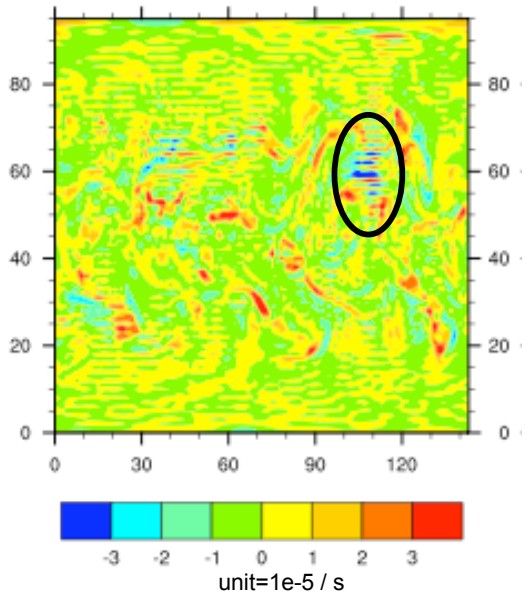
CAM4 (DJF zonal average over years 2-11)



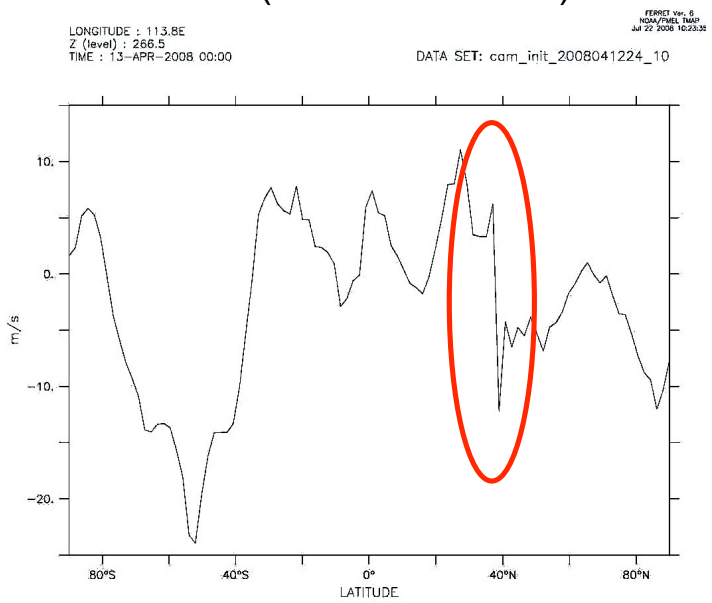
Has resulted in model execution failure at high resolution!

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)

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

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

where

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

and

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

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

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

$$\delta_\theta \psi_{ij} = \psi_{ij+1} - \psi_{ij}, \tag{7}$$

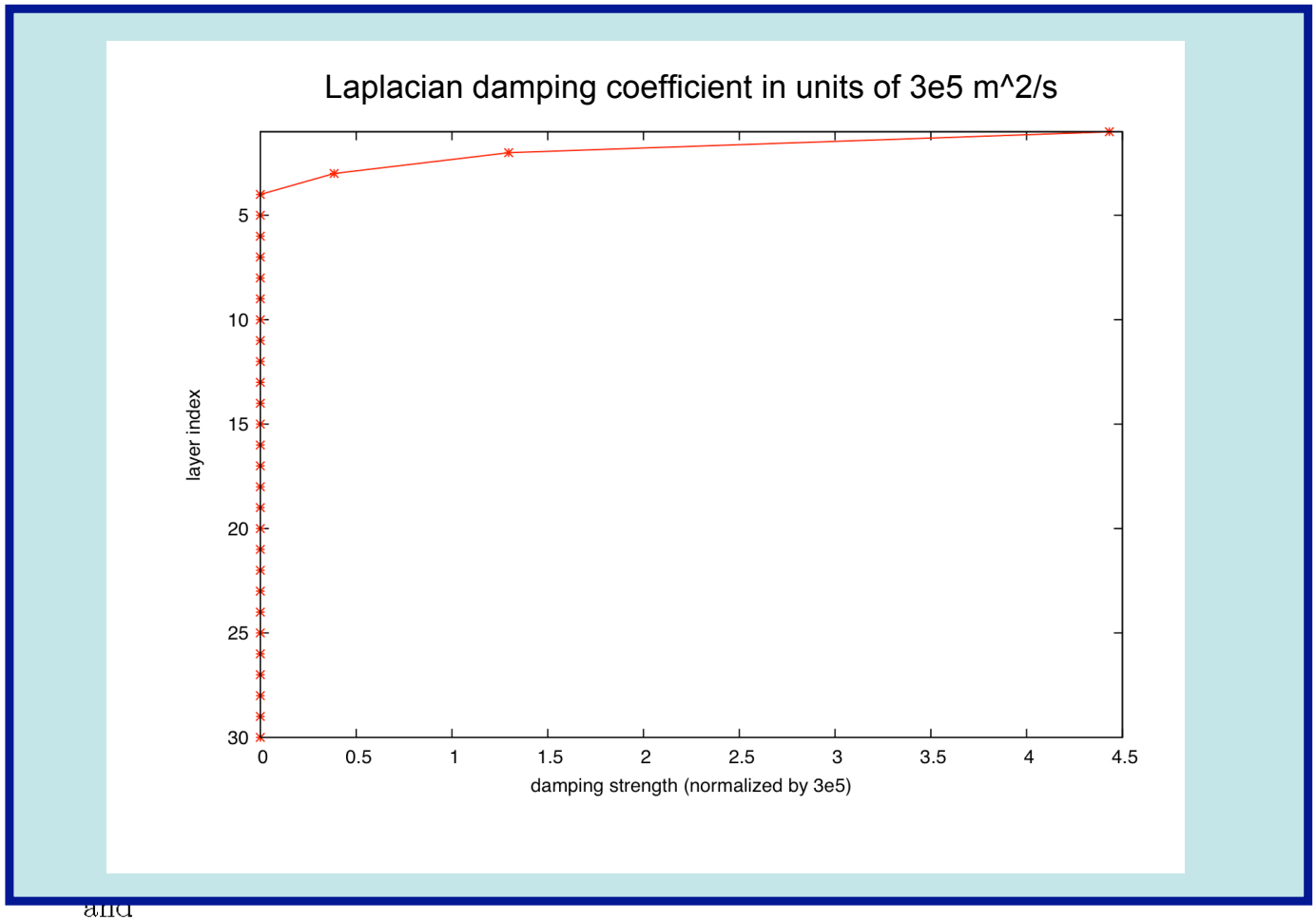
and

$$\nu_{del2} = 3 \times 10^5 \tag{8}$$

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

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

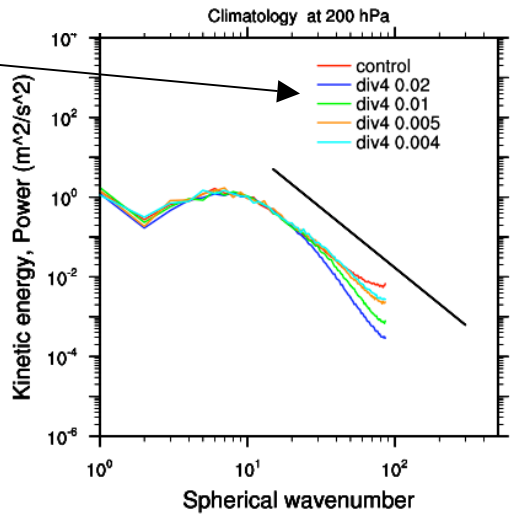
ν_{div4} is the damping coefficient

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

and τ_4 is set to 0.01.

Divergence damping coefficient is constant with height

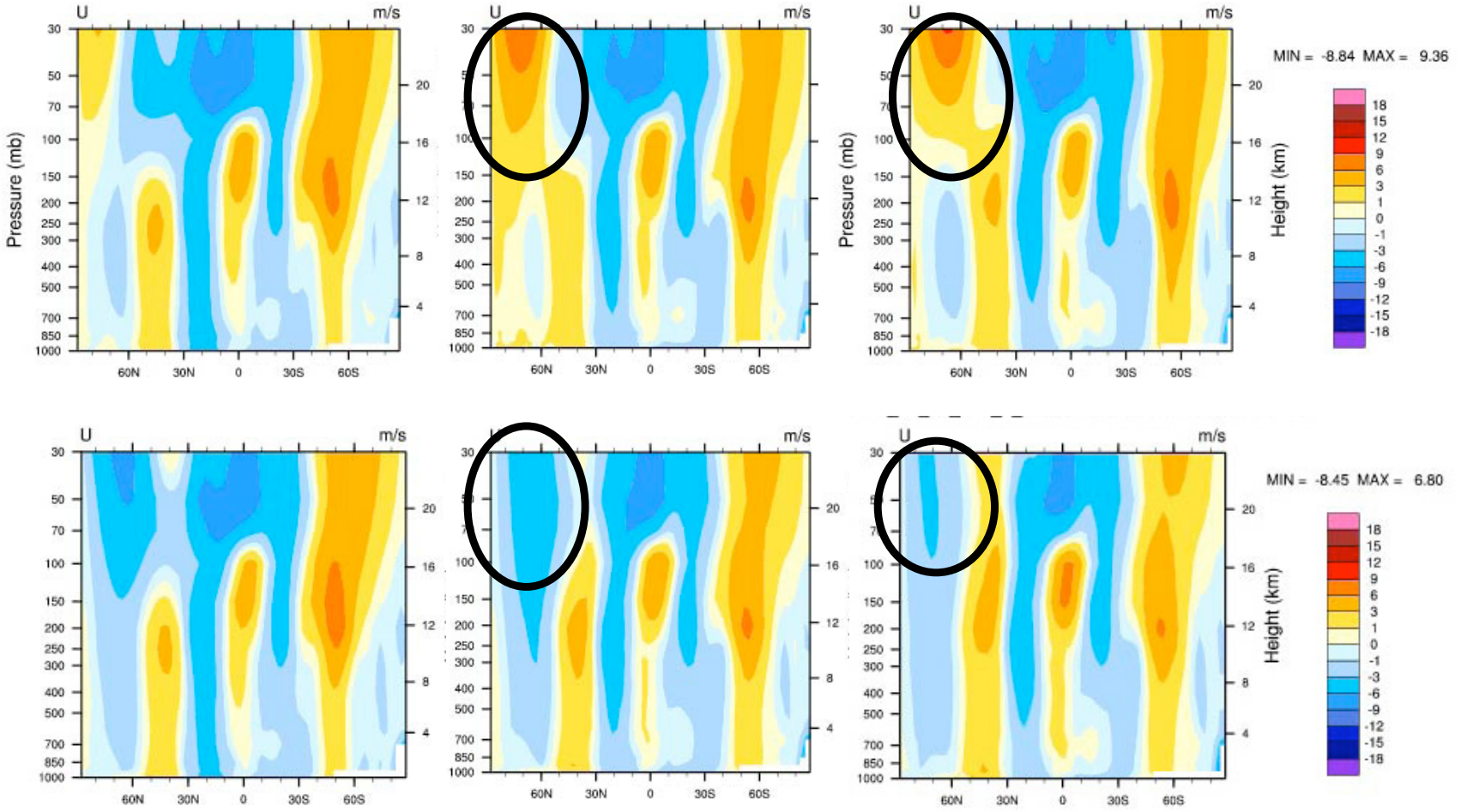
Divergent part of total kinetic energy



Zonal wind speed difference plots

CAM4 (DJF zonal average over years 2-11)

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



div2
= CAM4 (track 1)

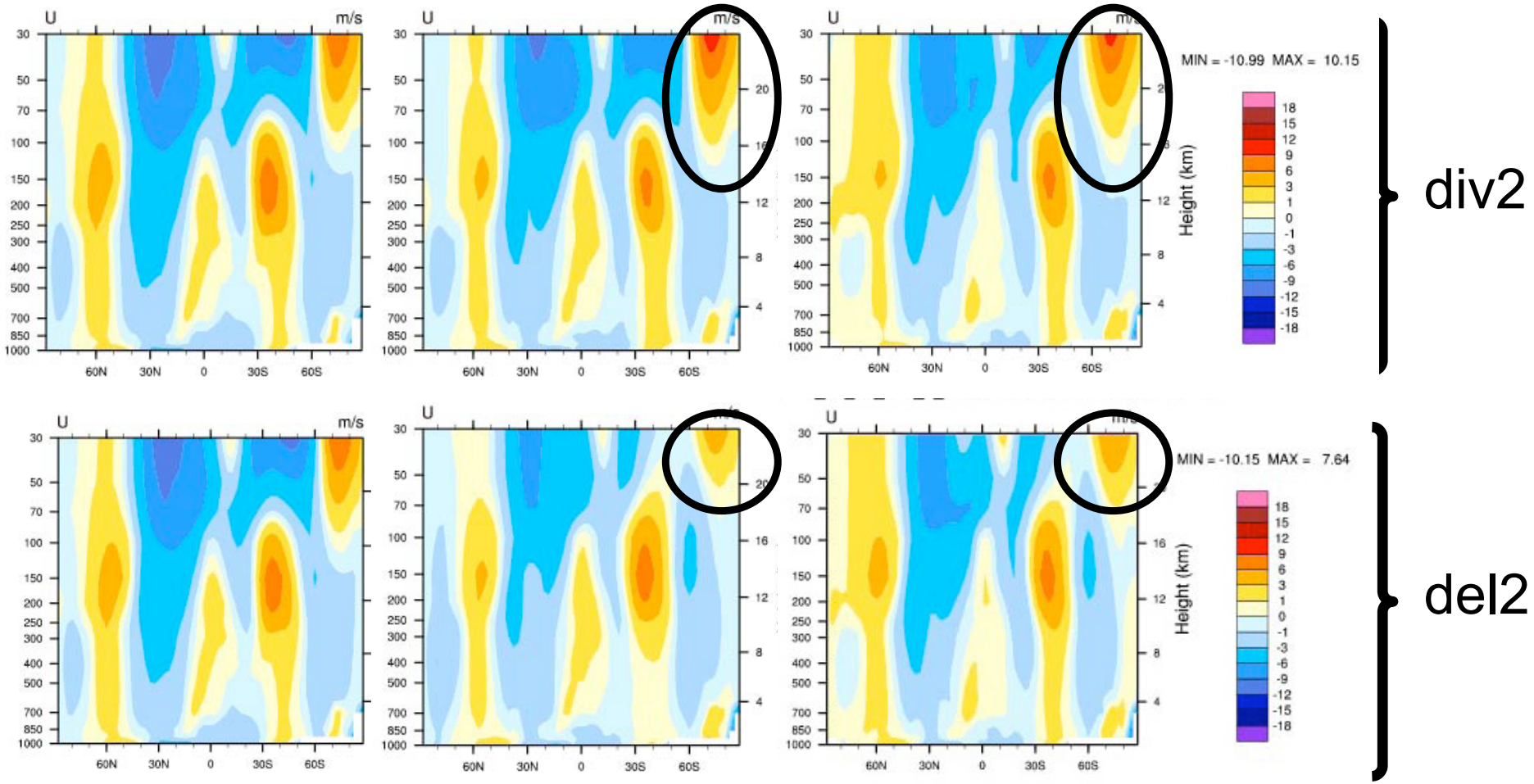
del2
= CAM4 (track 1) using Laplacian damping at model top & 4th-order divergence damping

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**

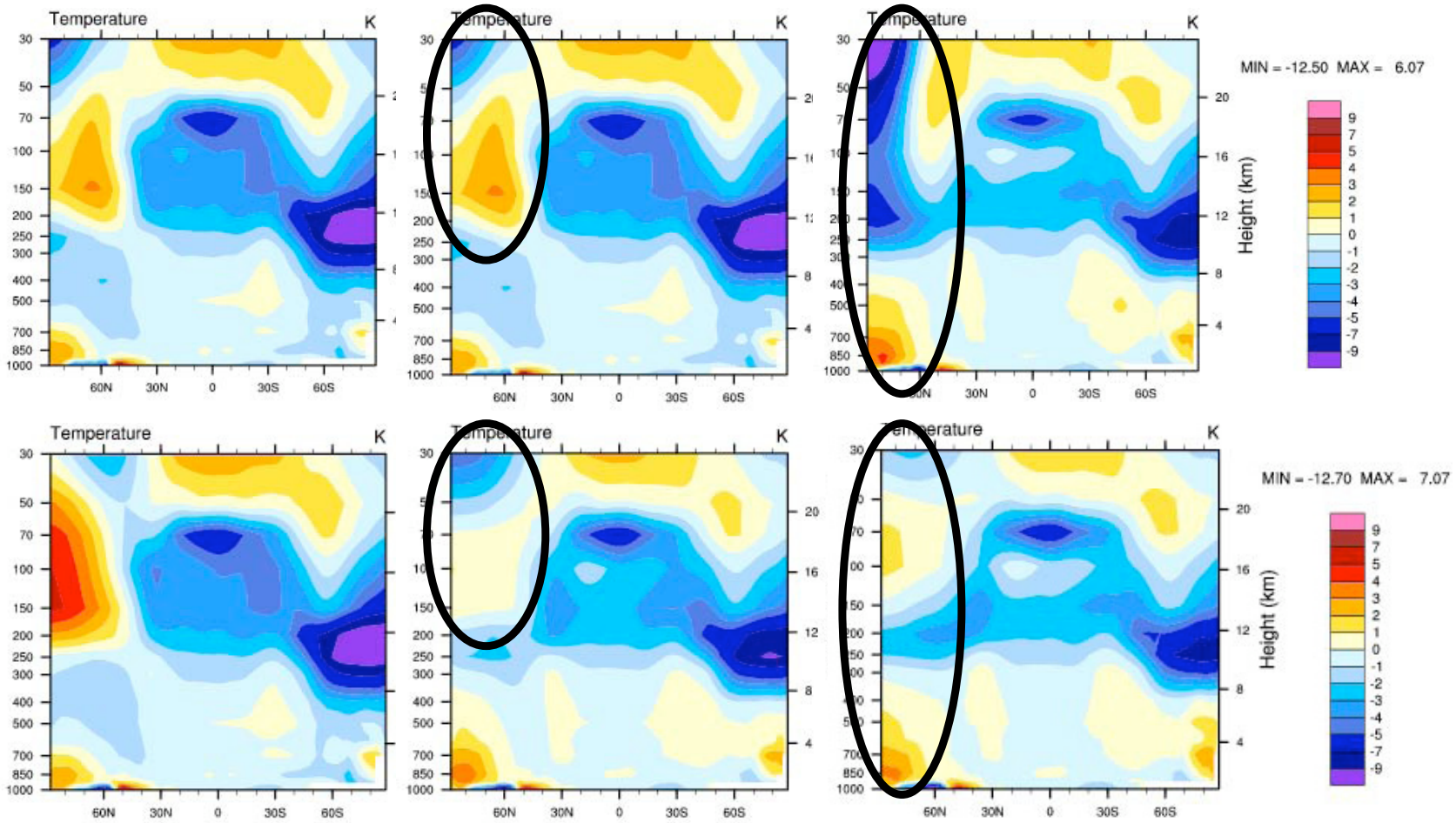


Representation of polar night jet improved at higher resolution

Temperature difference plots

CAM4 (DJF zonal average over years 2-11)

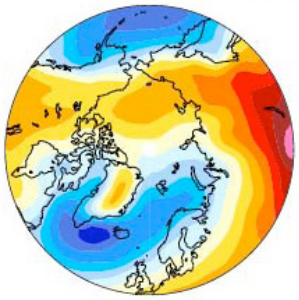
2 degree **1 degree** **0.5 degree**



Polar temperature biases reduced at higher resolution

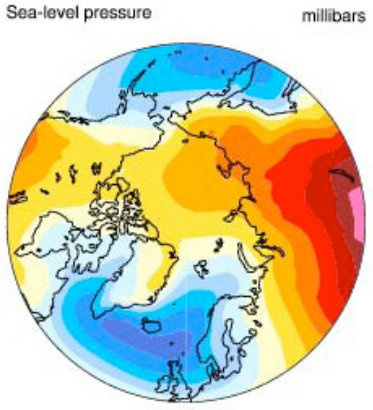
PSL for div2 (1st row) and del2 (2nd row)

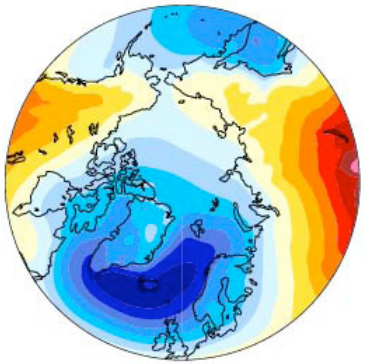
CAM4 (DJF zonal average over years 2-11)

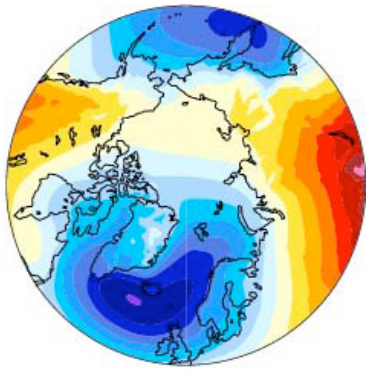


NCEP

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





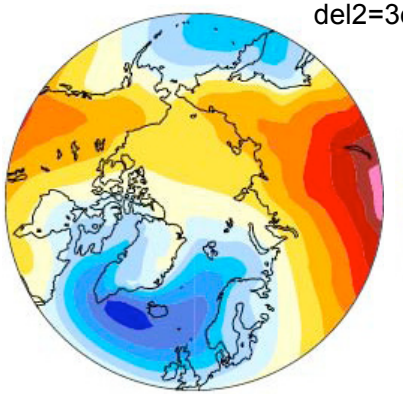


0.25 degree
"only" 2 year averages started from 6 year "spin-up" run using del2=4e5

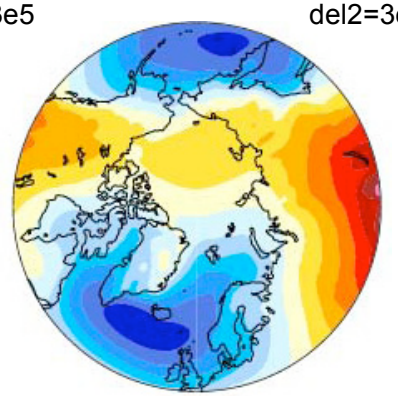
0.25 degree
(year 2-6)

del2 increased to 4e5

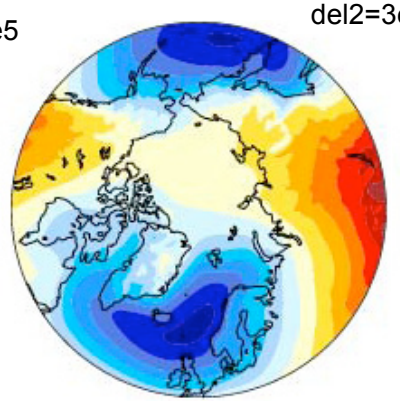
del2=3e5



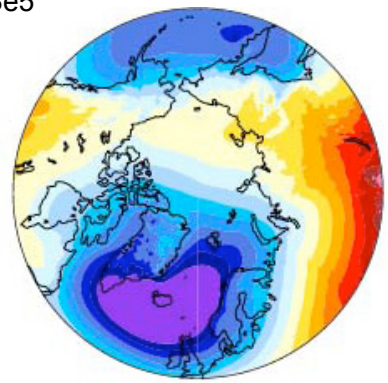
del2=3e5

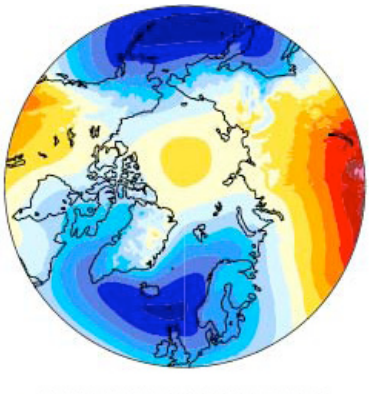


del2=3e5



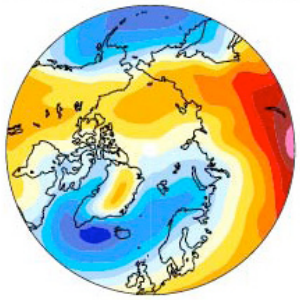
del2=3e5





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

CAM4 (DJF zonal average over years 2-11)



NCEP

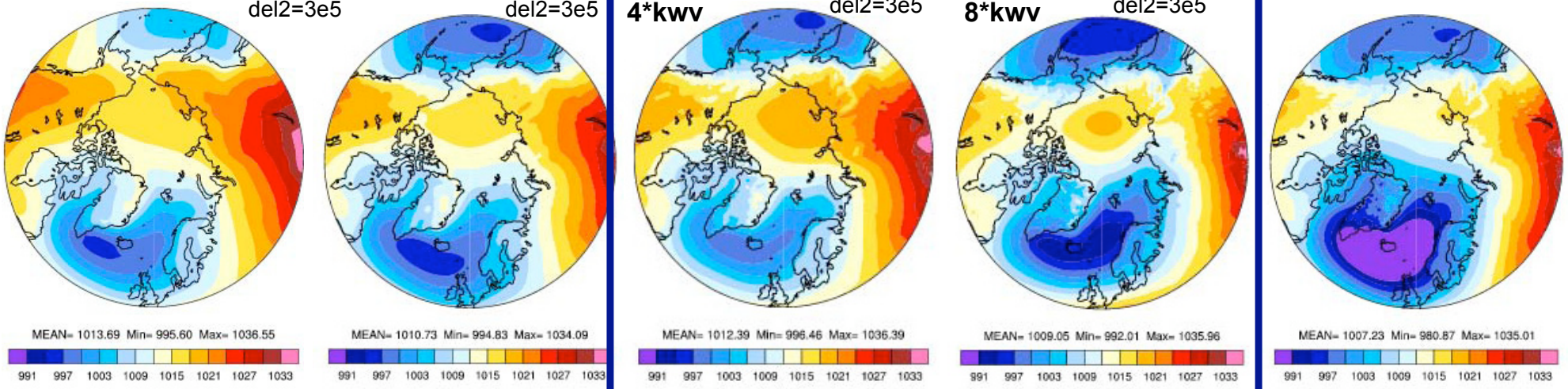
2 degree **1 degree** **0.5 degree**

Sea-level pressure millibars

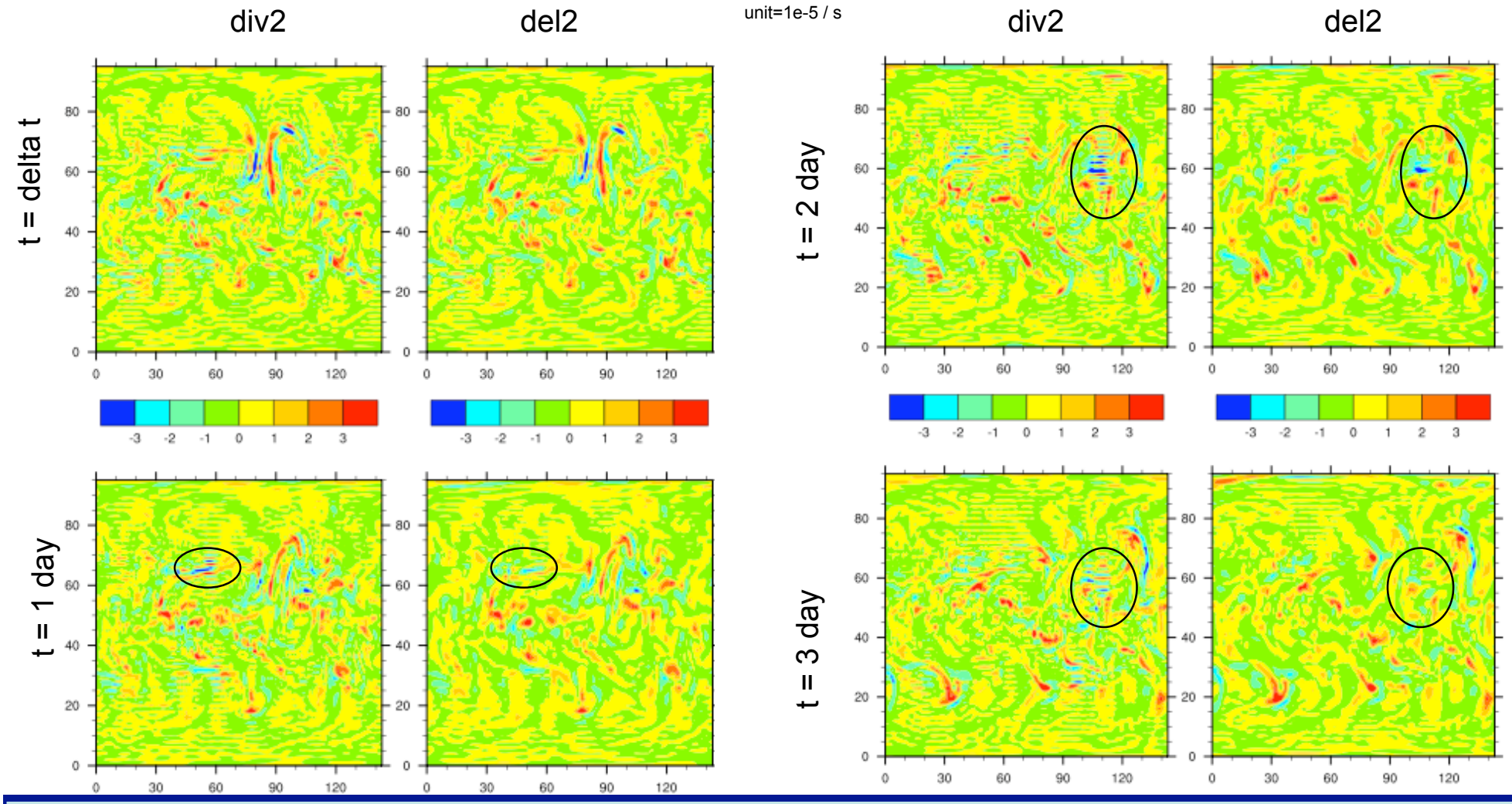
0.25 degree
(year 2-6)

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

del2=3e5 del2=3e5 **4*kwv** del2=3e5 **8*kwv** del2=3e5 del2=3e5



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



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

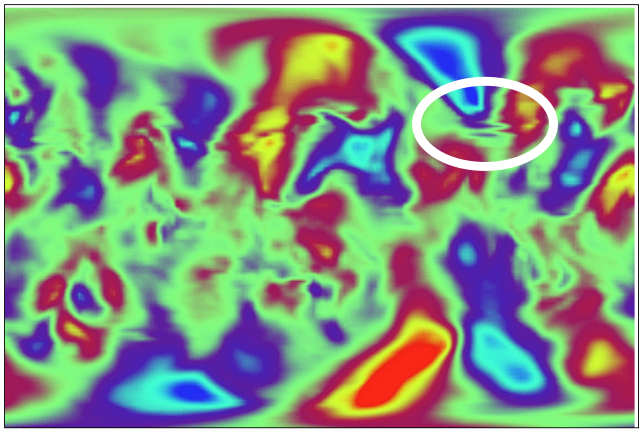
CAM-DART: An ensemble member, 6 hours after data has been assimilated

Track 5

Instantaneous meridional wind at level=103hPa

div2

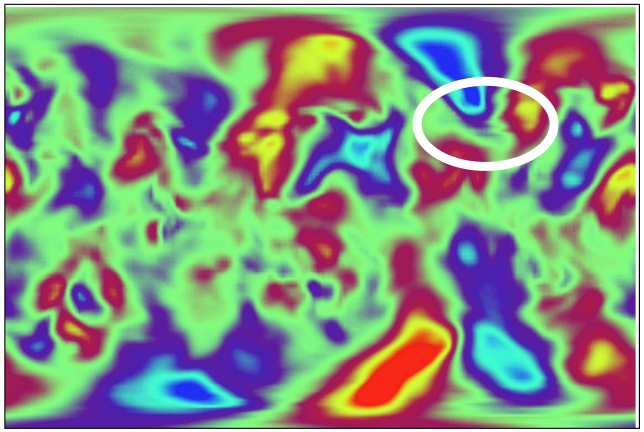
Meridional wind, staggered (m/s)



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

del2

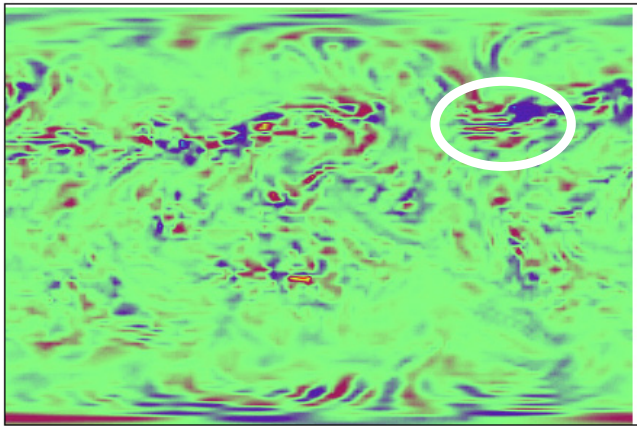
Meridional wind, staggered (m/s)



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

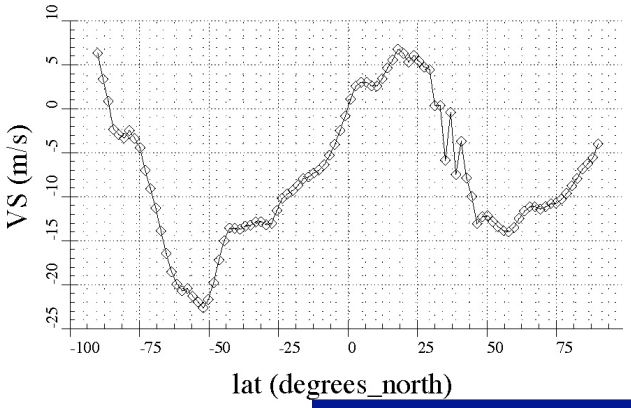
div2-del2

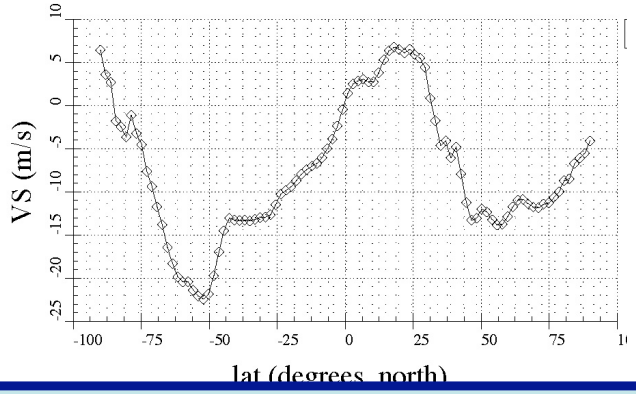
Meridional wind, staggered (m/s)

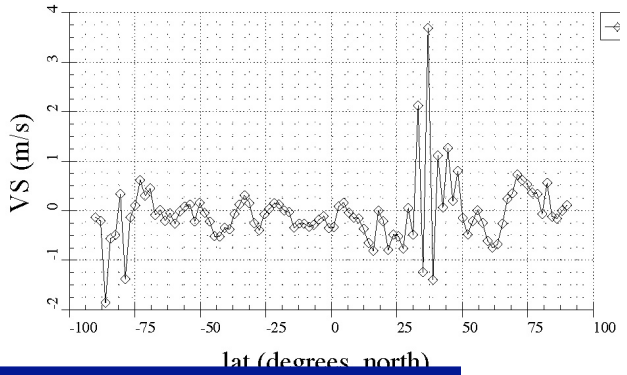


Contour range = [-6,6] m/s

Cross section at 271E







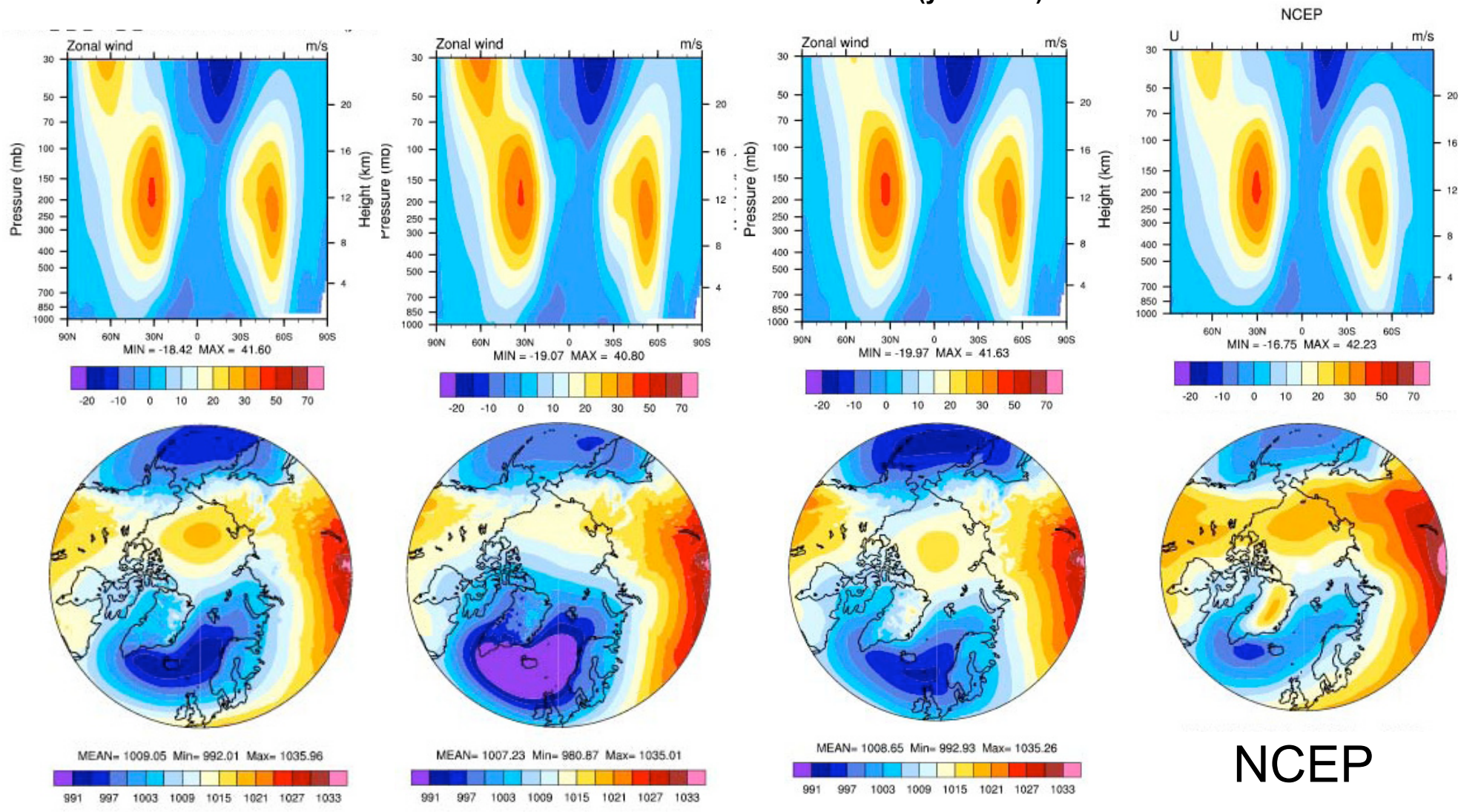
In general less grid-scale noise with 4th-order divergence damping!

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)** | NCEP



NCEP

Exploration of parameter space for del2

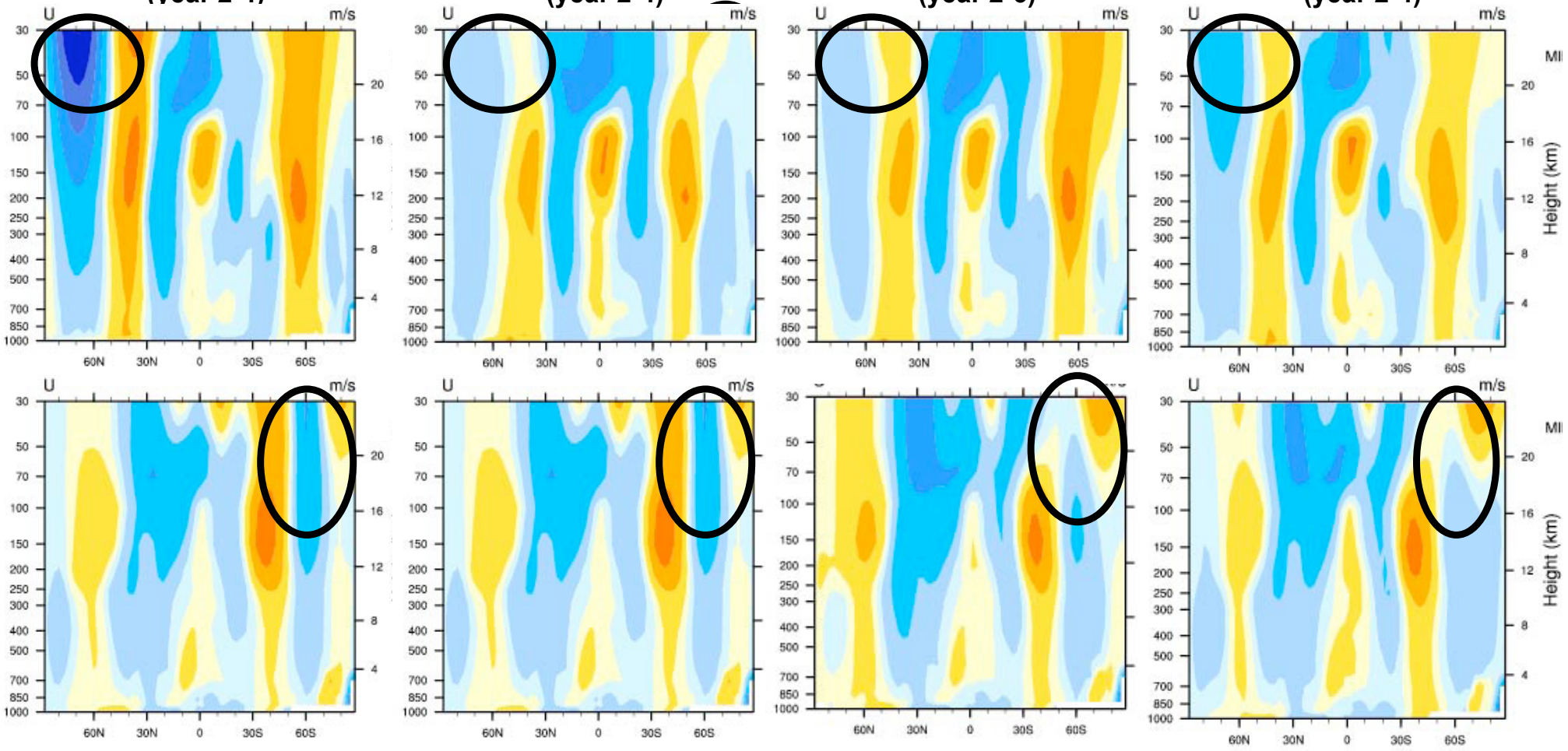
(plots are for 0.5 degree horizontal resolution)

del2 = 1e5 (year 2-4)

del2 = 2e5 (year 2-4)

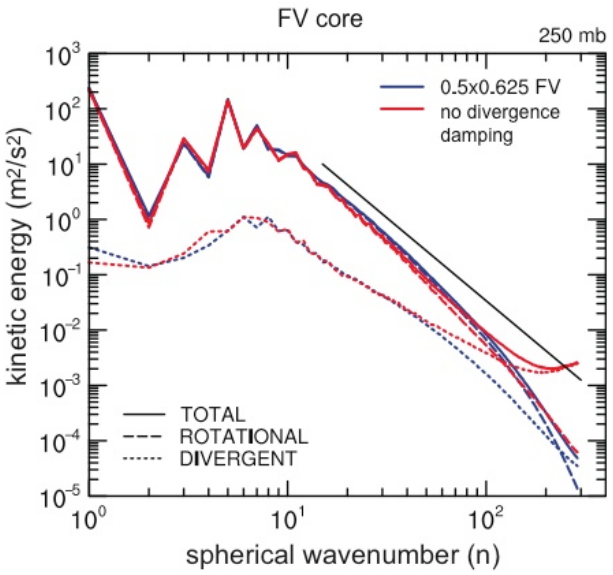
del2 = 3e5 (year 2-6)

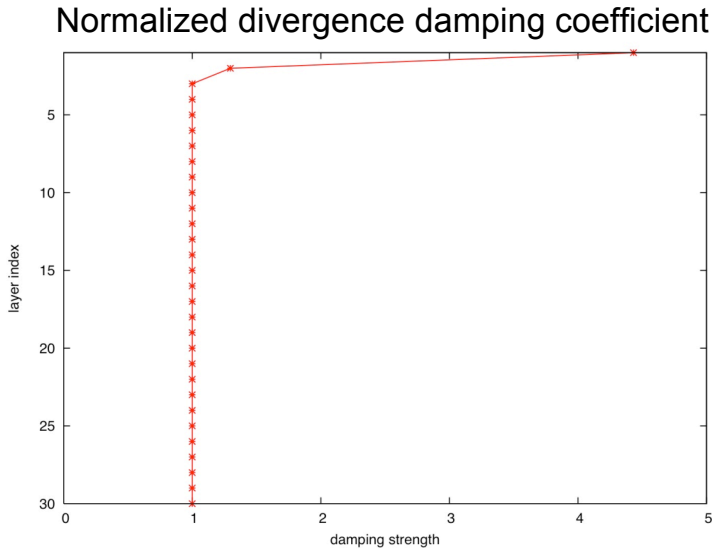
del2 = 4e5 (year 2-4)



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)

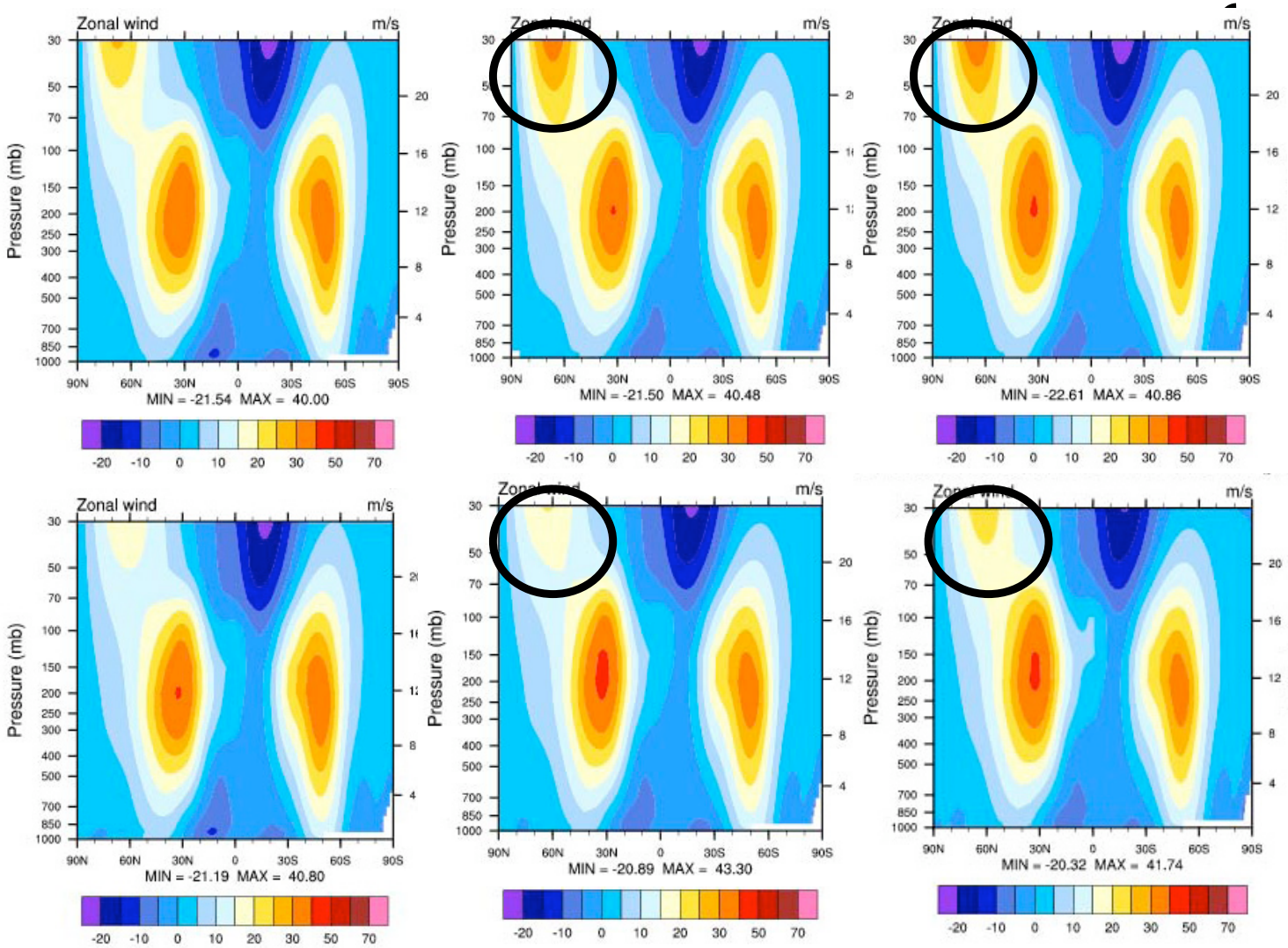




Zonal wind speed

CAM4 (DJF zonal average over years 2-11)

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



div2

= CAM4 (track 1)

del2

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