Progress Report

Research Objective:
Development of a Q3-D MMF

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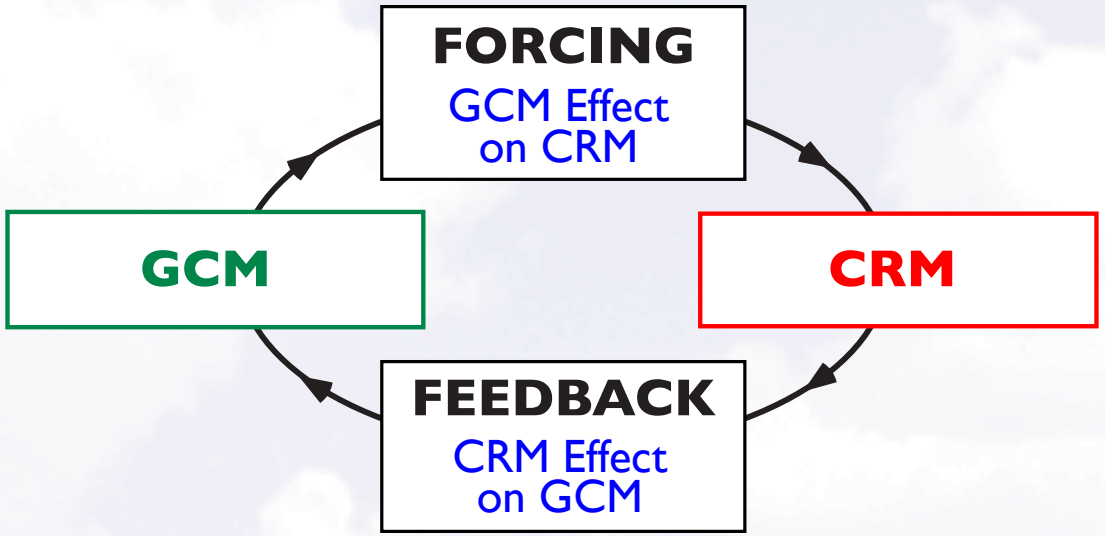
January 2013 CMMAP Team Meeting

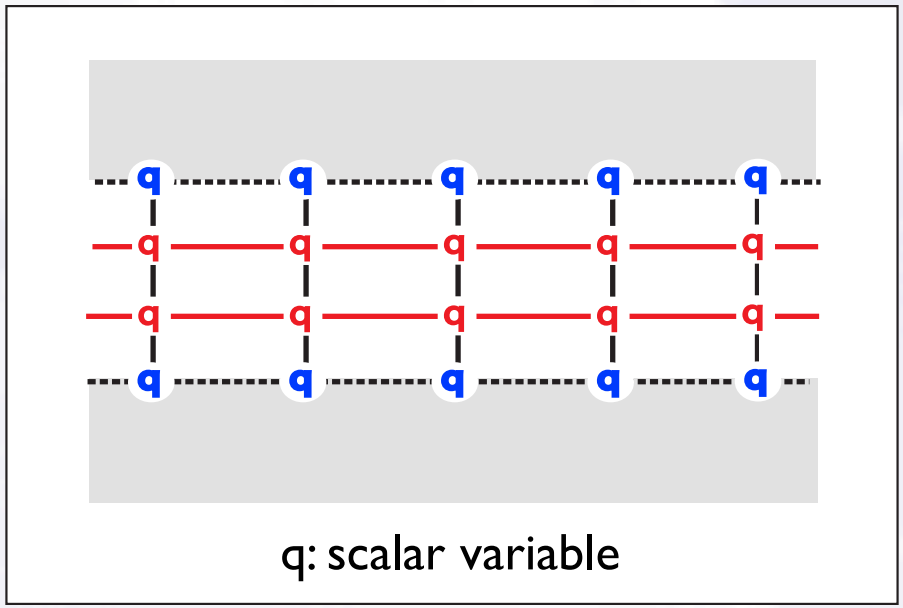
Coupling the GCM and CRM Components



MMF (Q3-D MMF) inherits the structure of the conventional GCMs, while the conventional cumulus parameterization is replaced with explicit simulations of cloud-scale processes.

Forcing: GCM effect on CRM

- Lateral Boundary Condition



Decomposition of variable: $q = \bar{q} + q'$

$\bar{q}$: interpolated from GCM

q' : cyclic across the channel

- Through the background field, CRM recognizes the horizontal inhomogeneity and anisotropy predicted by GCM.
- This feature is difficult to be achieved in the parameterization approach that responds to the vertical thermal structure predicted by GCM.
- Because of this feature, it is called "Quasi 3-D" framework.

Forcing: GCM effect on CRM (Continued.)

- Relaxation of q to $\bar{q}$:

  (maintains the compatibility of the GCM and CRM solutions)

  - When the GCM resolution is low, the relaxation time scale must be sufficiently *longer* than the typical time scale of cloud evolution.
  - When the GCM resolution is high, the relaxation time scale must be sufficiently *shorter* than the typical time scale of cloud evolution.
  - The choice of this time scale is important for the convergence of the Q3-D MMF to a GCRM.

    (Not fully explored yet. For the currently used GCM and CRM grid sizes of 96 km and 3 km, 12 hr is chosen.)

Feedback: CRM effect on GCM

Consists of the mean diabatic effects and the mean ***eddy effects*** of advective and dynamical processes simulated by the CRM

CRM effects from two intersecting channels are ***averaged***.

Test of Q3-D MMF

Transition of a wave to vortices over the tropical ocean in an idealized setting

(Horizontal domain: 3072 km x 3072 km, Vertical domain: 30 km)

Horizontal grid: 3 km (CRM) & 96 km (GCM)

When the channel width is 2-grid:

$$\frac{\text{\# of horizontal grid points of CRM in Q3-D MMF}}{\text{\# of horizontal grid points of 3-D CRM (BM)}} = 12.5\ \%$$

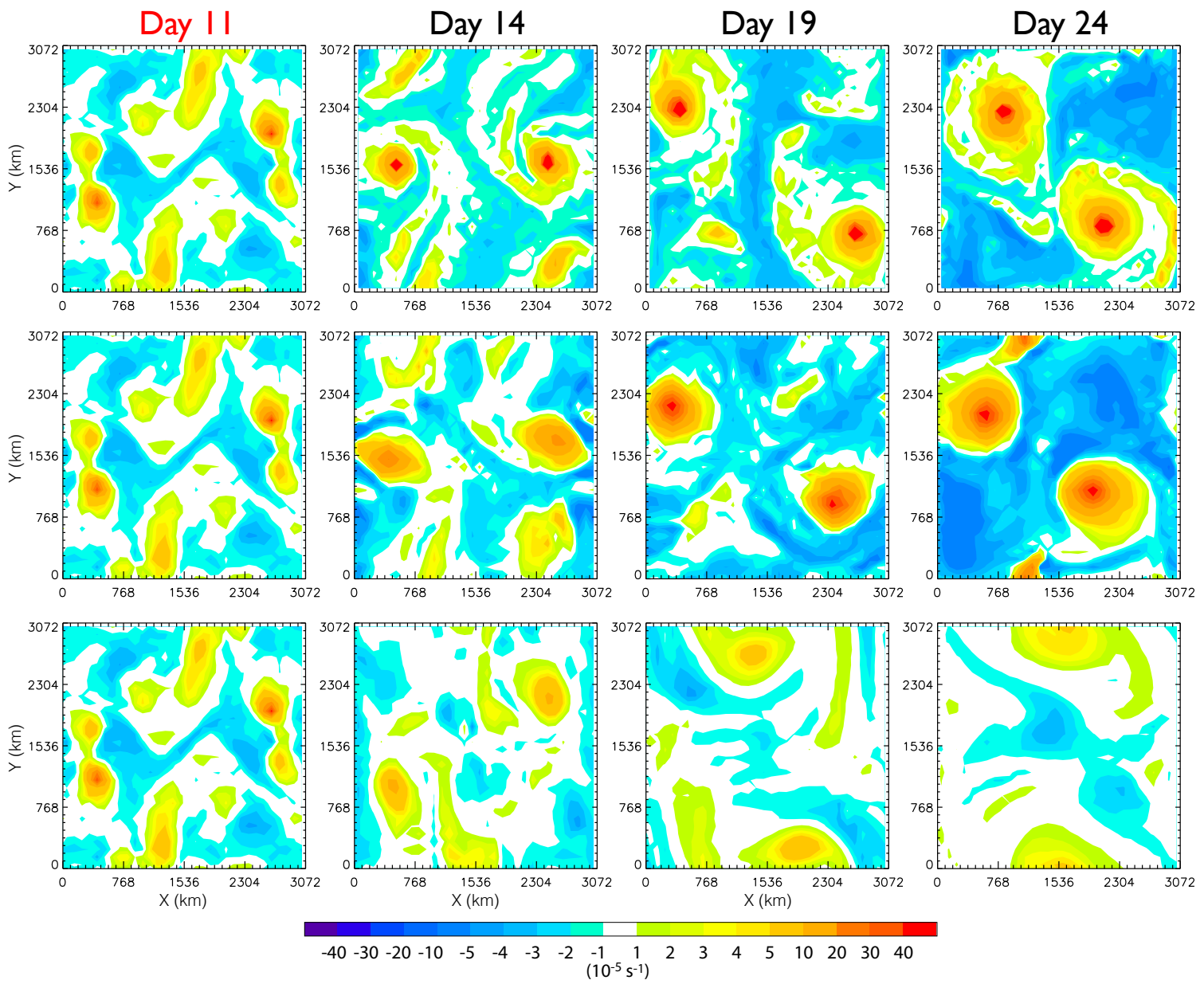
When the channel width is 1-grid:

$$\frac{\text{\# of horizontal grid points of CRM in Q3-D MMF}}{\text{\# of horizontal grid points of 3-D CRM (BM)}} = 6.25\ \%$$

This ratio becomes smaller if the GCM resolution is coarser or the CRM resolution is finer.

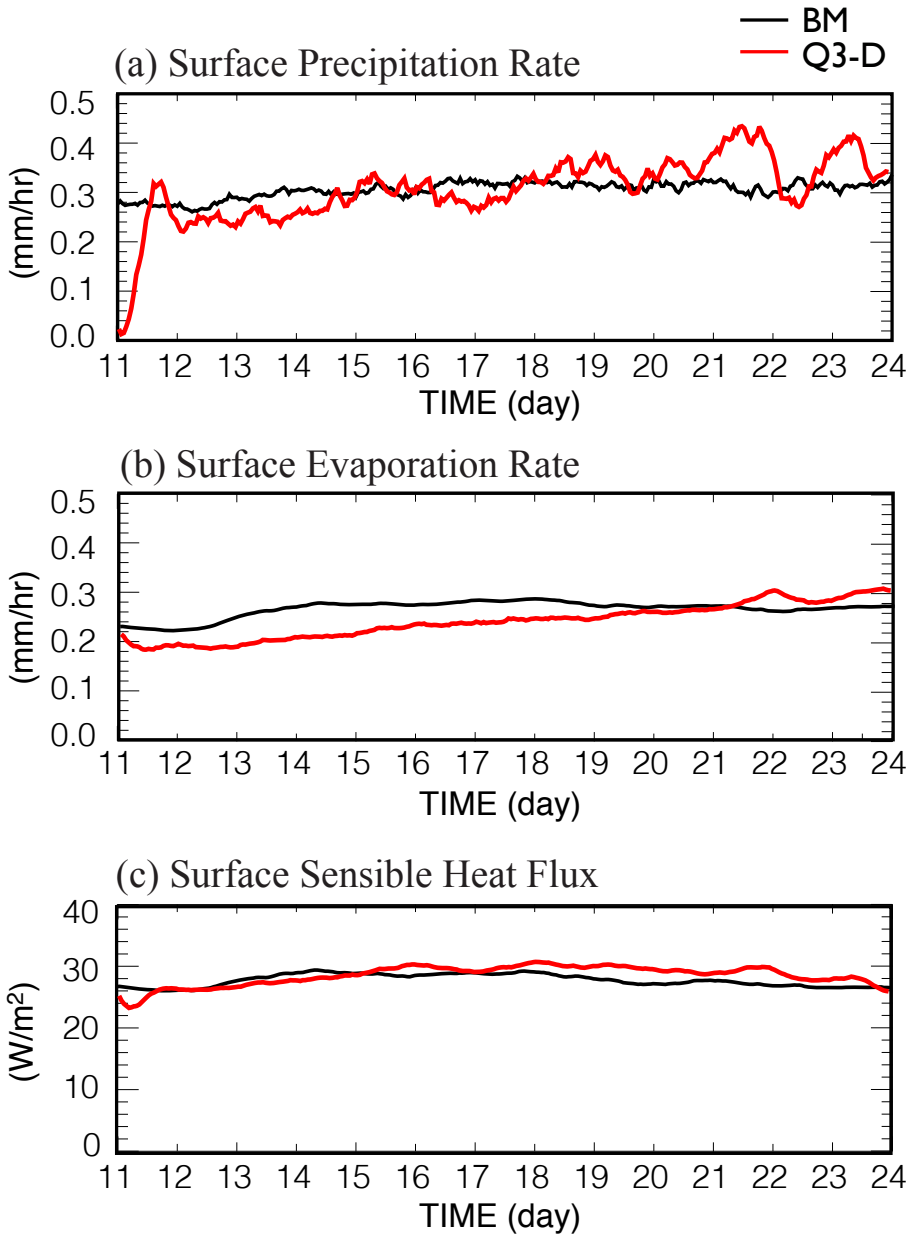
SIMULATED VERTICAL COMPONENT OF VORTICITY

(1.5 km height)



"Two intense vortices are developed and maintained in the Q3-D simulation"

Domain Averages



"Comparable in general"

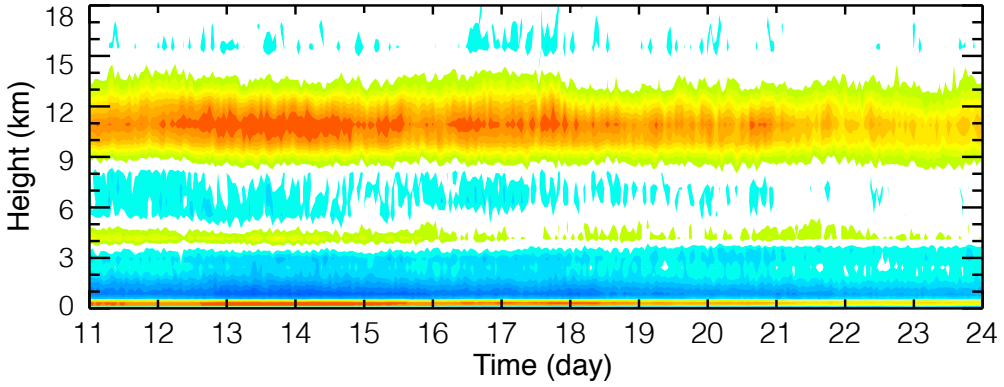
"Under-prediction during the earlier simulation days"

"Excellent prediction"

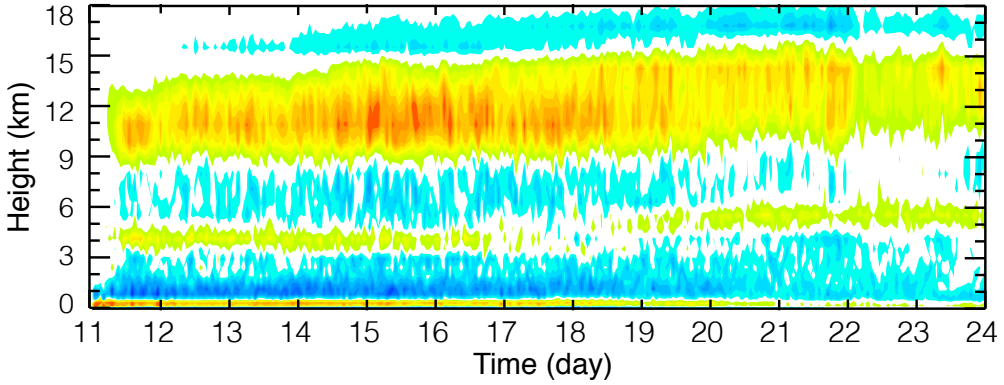
Eddy Transport Effects: $\Delta\theta$

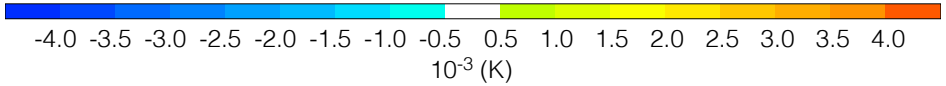
Potential temperature change due to the convergence of the vertical eddy transports over one GCM time step

BM (3-D)

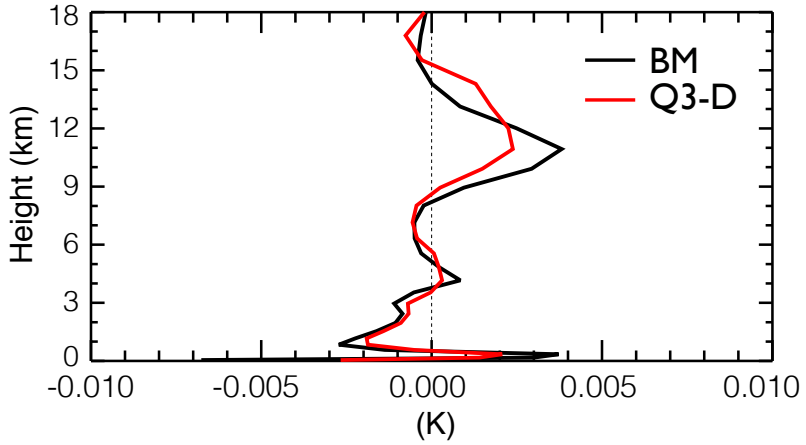


Q3-D





13 day average

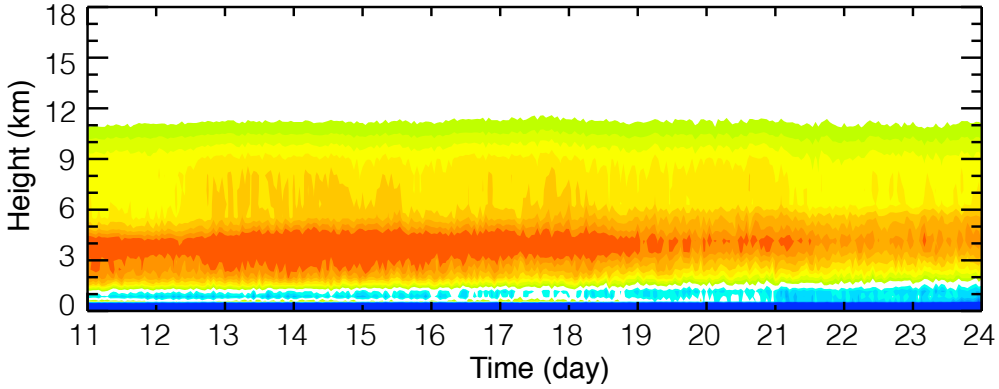


"Main features are qualitatively well captured, but upper-level maximum is under-predicted "

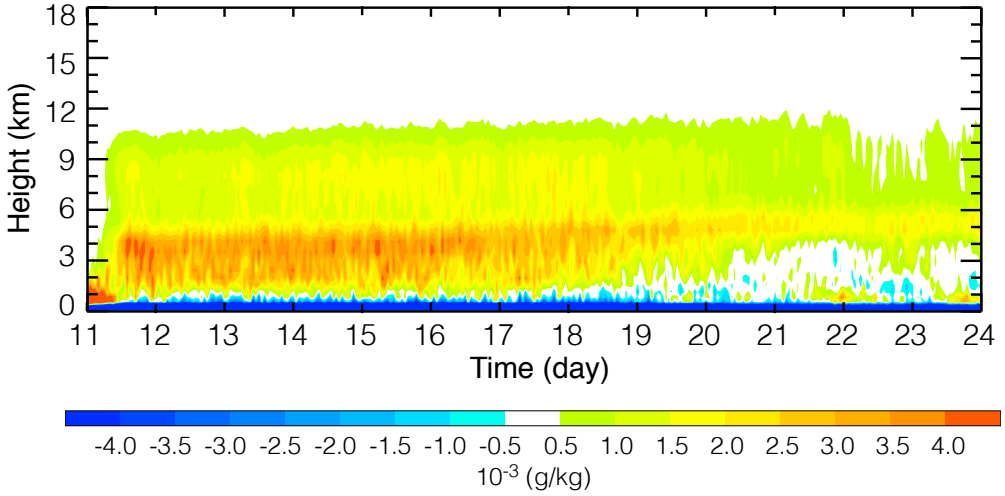
Eddy Transport Effects: Δq_v

Moisture change due to the convergence of the vertical eddy transports over one GCM time step

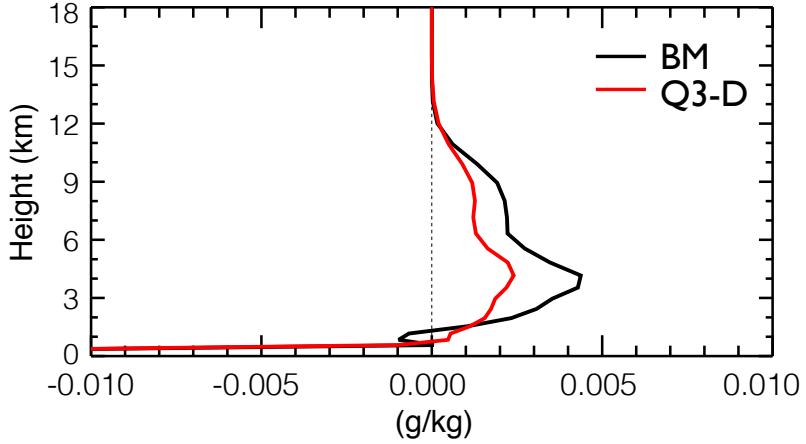
BM (3-D)

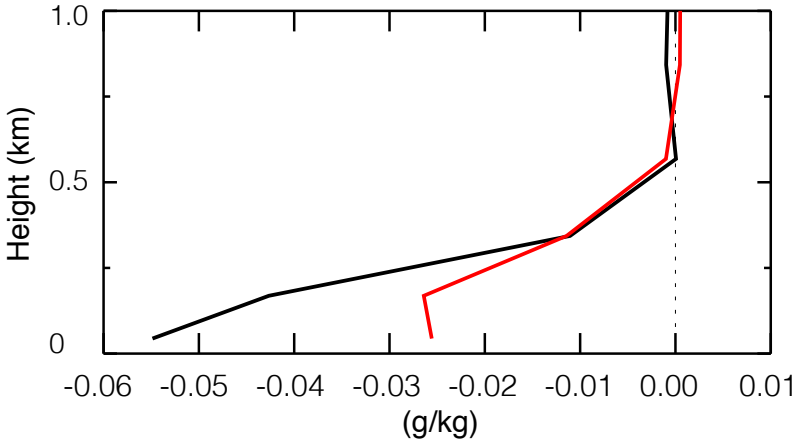


Q3-D



13 day average





"The intensity of the eddy transport effect is considerably weaker"

channel width=2, 3-D CRM

vs.

channel width=1, 3-D CRM

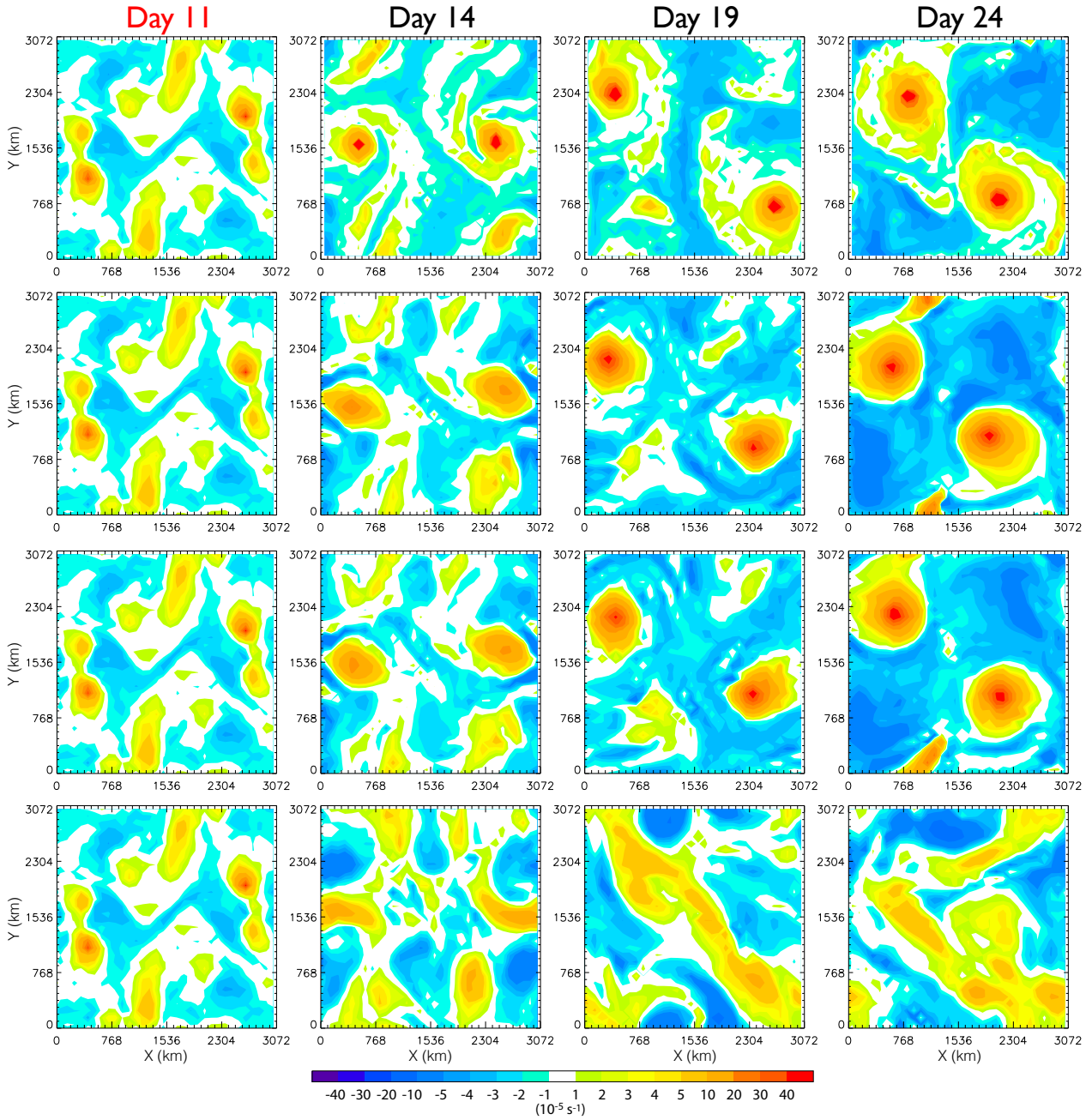
vs.

channel width=1, 2-D CRM

(Still uses two perpendicular sets of grid-point channels, but
does not recognize the gradient of background field across each channel)

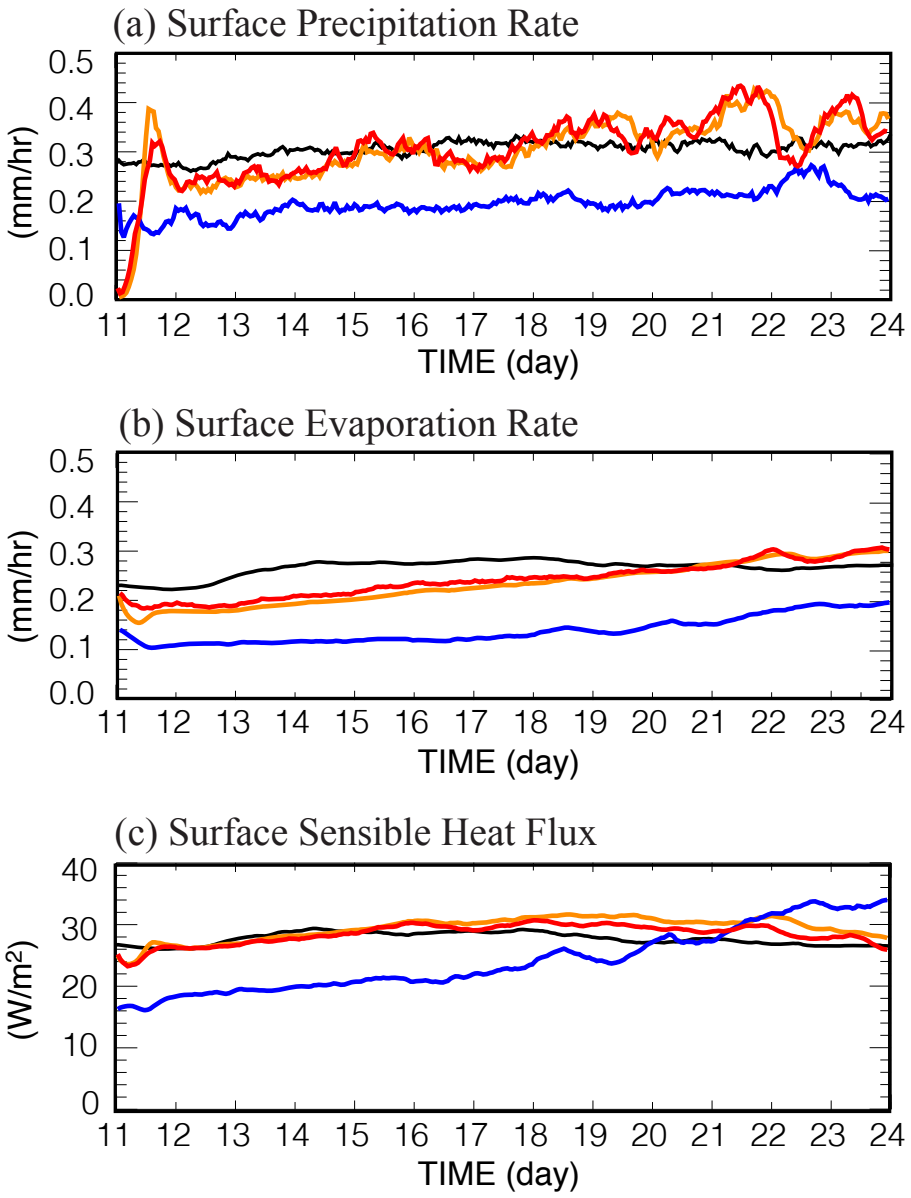
SIMULATED VERTICAL COMPONENT OF VORTICITY

(1.5 km height)



"The recognition of BG through the lateral boundary condition makes the difference"

Domain Averages



BM (3-D)

width=2, 3-D CRM

width=1, 3-D CRM

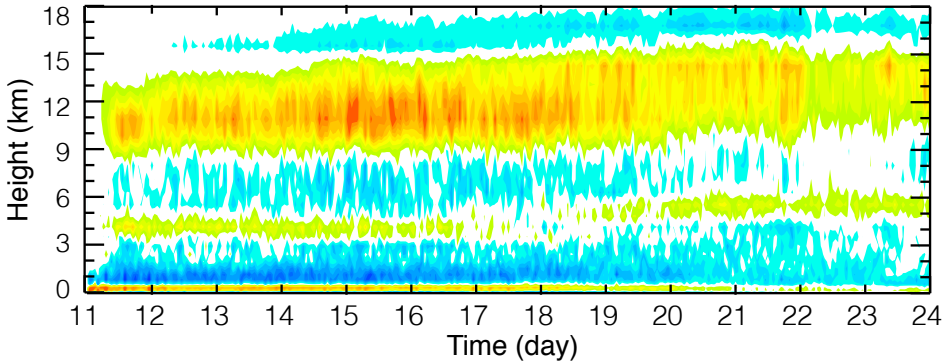
width=1, 2-D CRM

"Similar results from the cases with 1-grid and 2-grid widths"

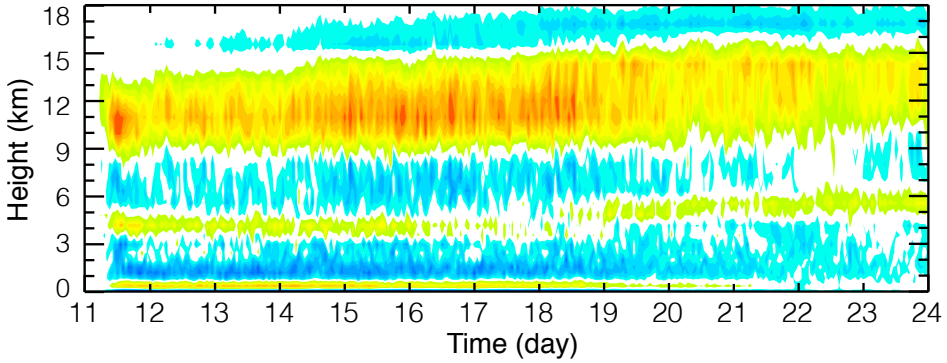
"Considerably under-predicted in the 2-D case"

Eddy Transport Effects: $\Delta\theta$

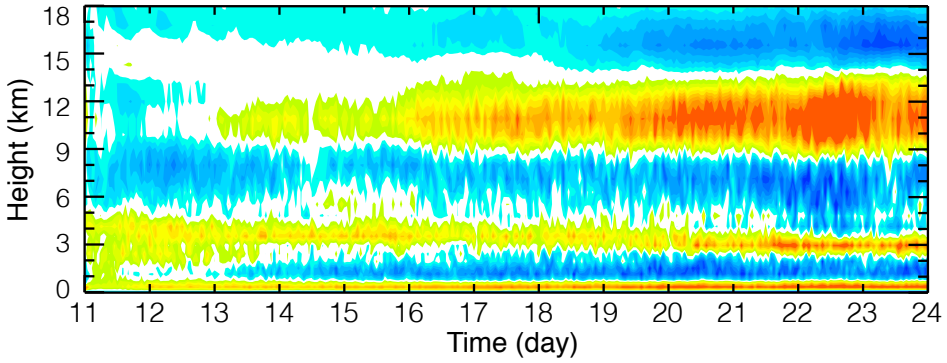
width=2, 3-D CRM



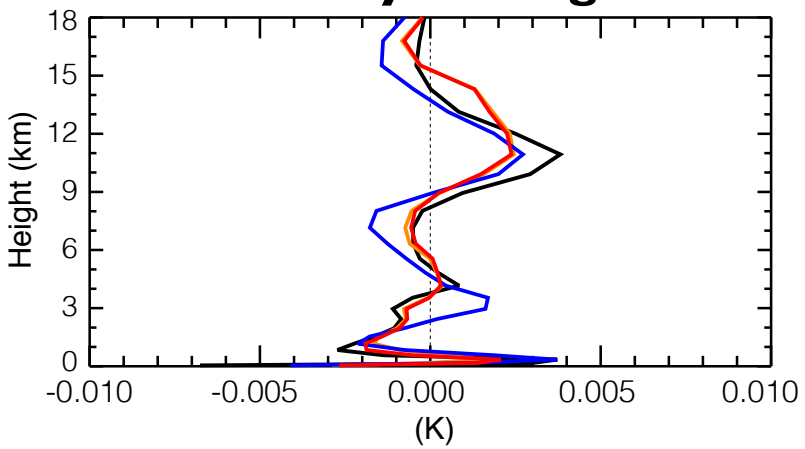
width=1, 3-D CRM



width=1, 2-D CRM



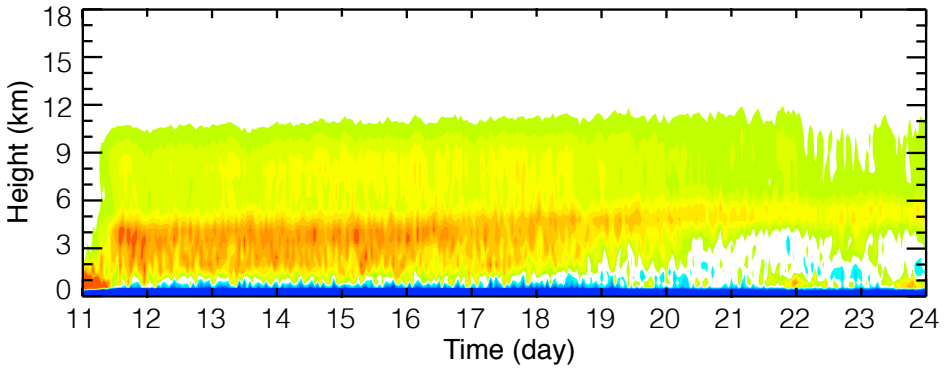
13 day average



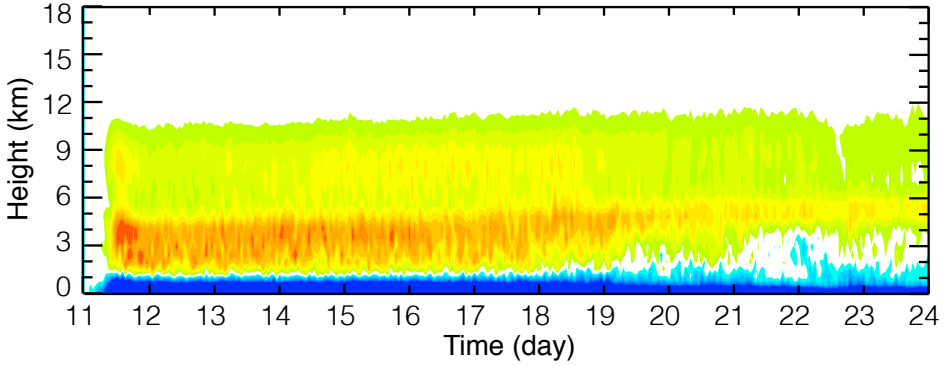
"Unlike in BM and other simulations, the eddy transport effects are increased near the end of simulation"

Eddy Transport Effects: Δq_v

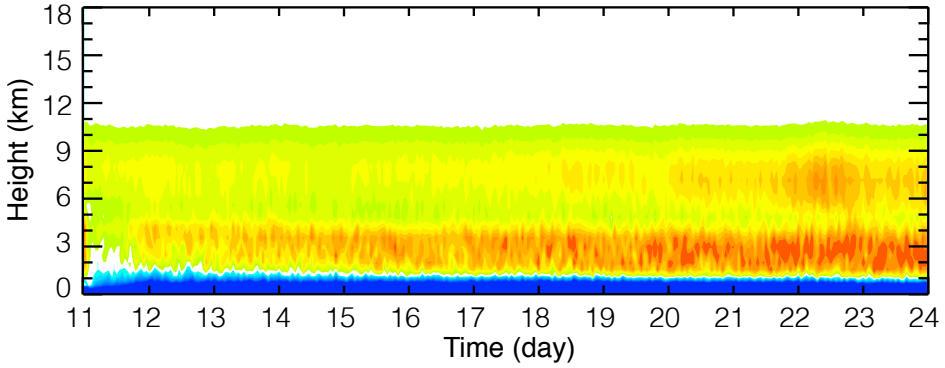
width=2, 3-D CRM



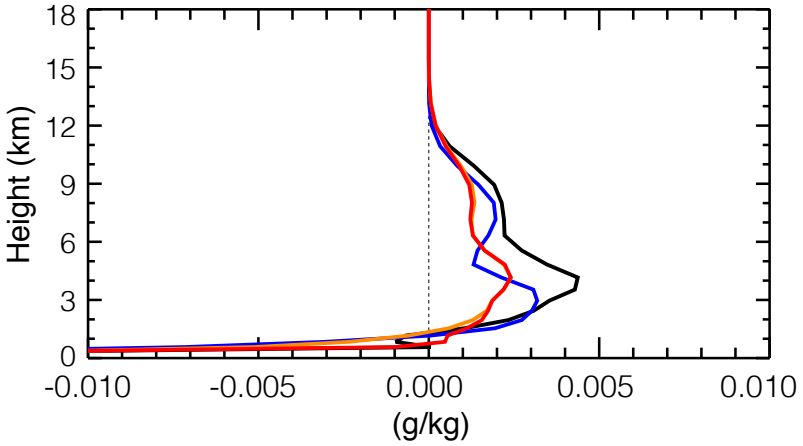
width=1, 3-D CRM



width=1, 2-D CRM



13 day average



"Unlike in BM and other simulations, the eddy transport effects are increased near the end of simulation"

Summary of the Test Results

- The encouraging results show the potential of the Q3-D MMF as the basic framework for future NWP and climate models.
- The Q3-D MMF using 1-grid channel width produces similar results with the one using 2-grid width.
- One of the major deficiencies is the under-prediction of the eddy effect of the moisture transport.

– This problem is mostly related to the degree of anisotropy in the organization of eddies.

If the organization is isotropic:
the ***eddy effects*** from two intersecting channels should be ***averaged***.
(because they give different samples for the same statistical effects)

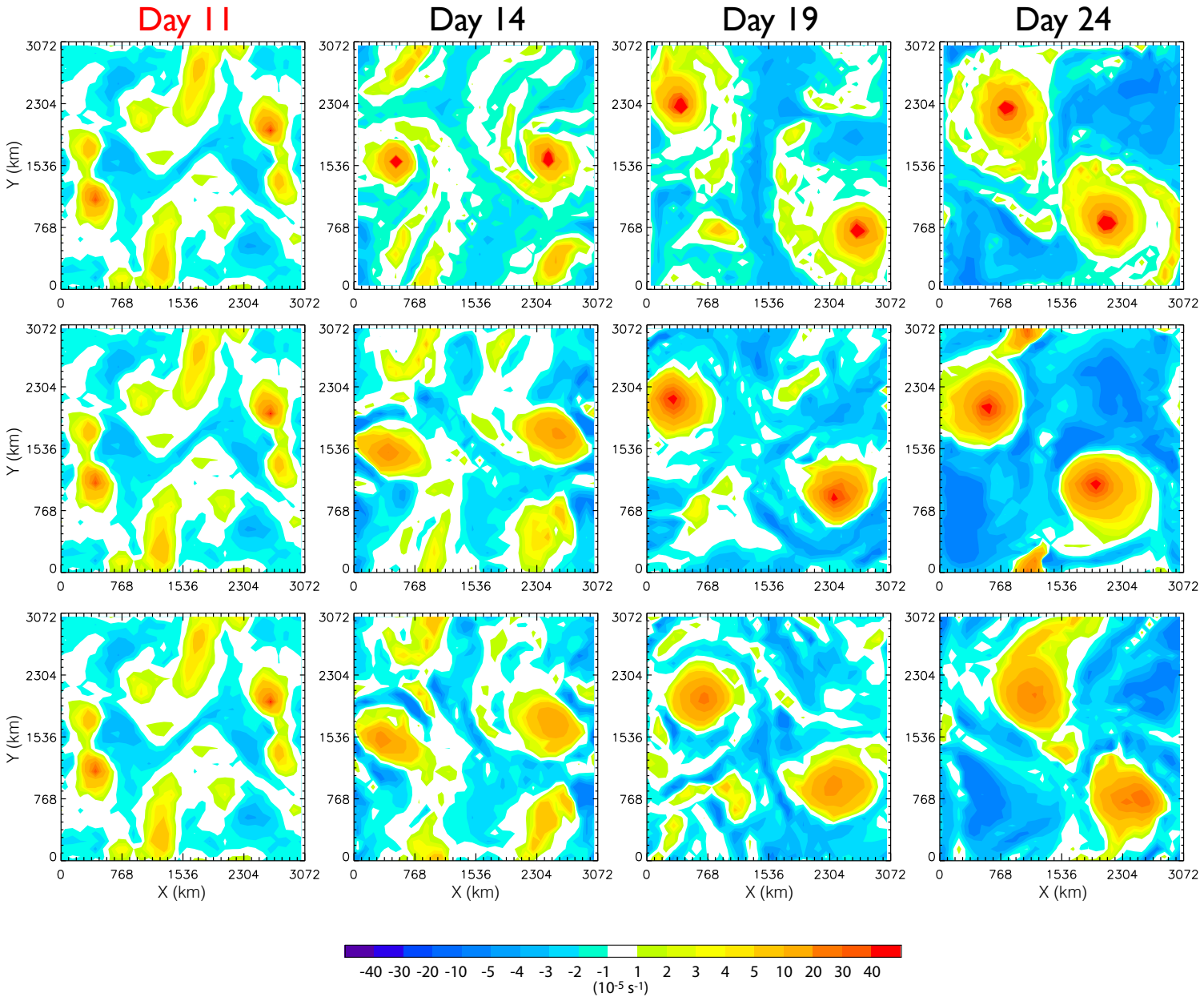
➡ Coupling used in the standard tests

If the organization is anisotropic:
the ***eddy effects*** from two intersecting channels should be ***summed***.
(because they give independent effects representing each direction)

➡ "Modified coupling"

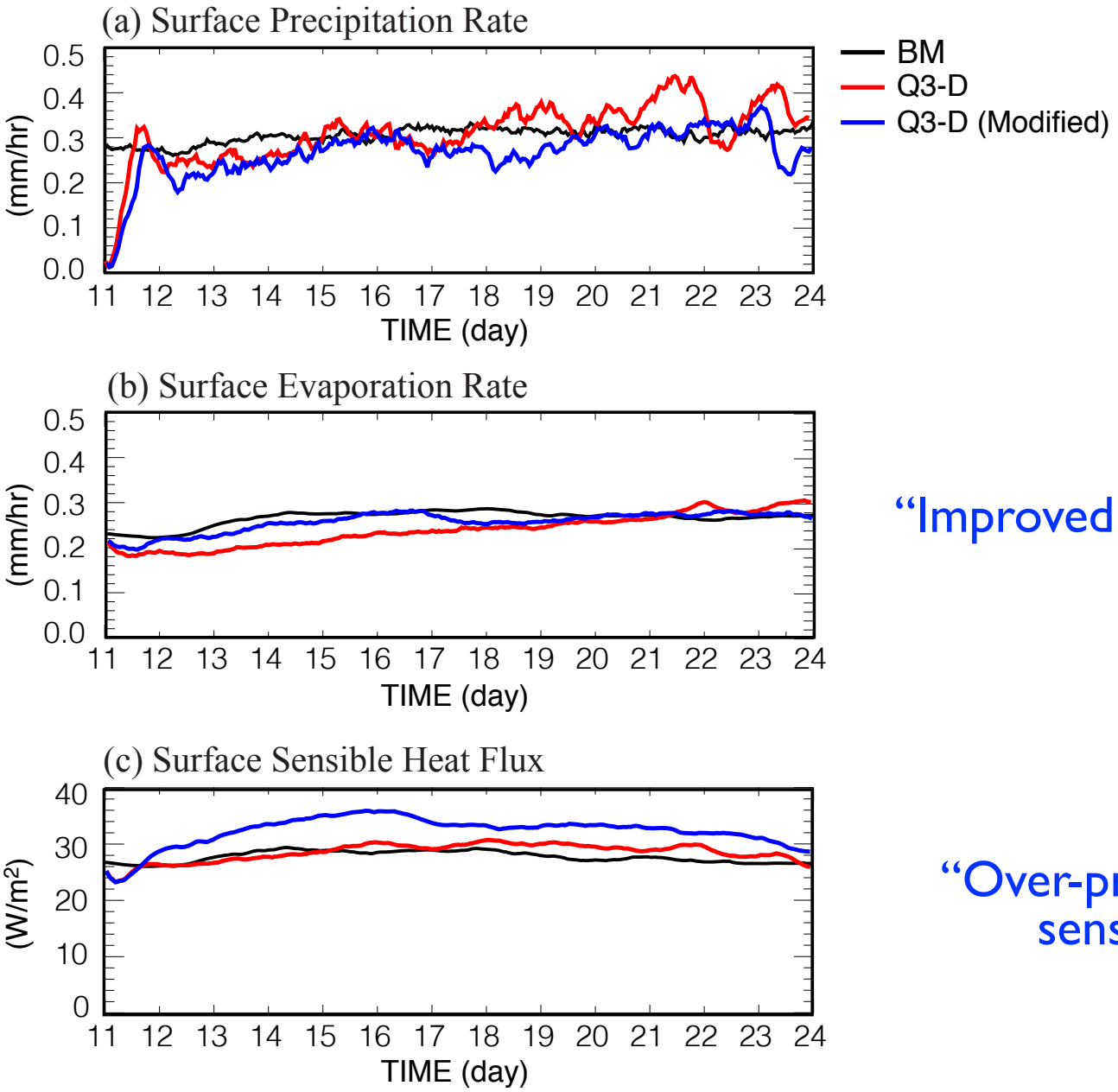
SIMULATED VERTICAL COMPONENT OF VORTICITY

(1.5 km height)



"Intensities of two vortices are reduced"

Domain Averages



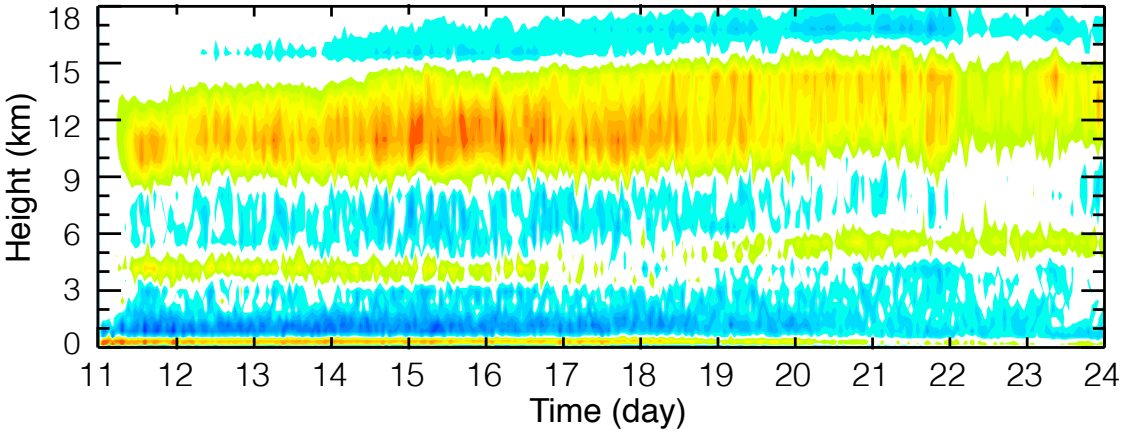
"Improved surface evaporation"

"Over-prediction of surface sensible heat flux"

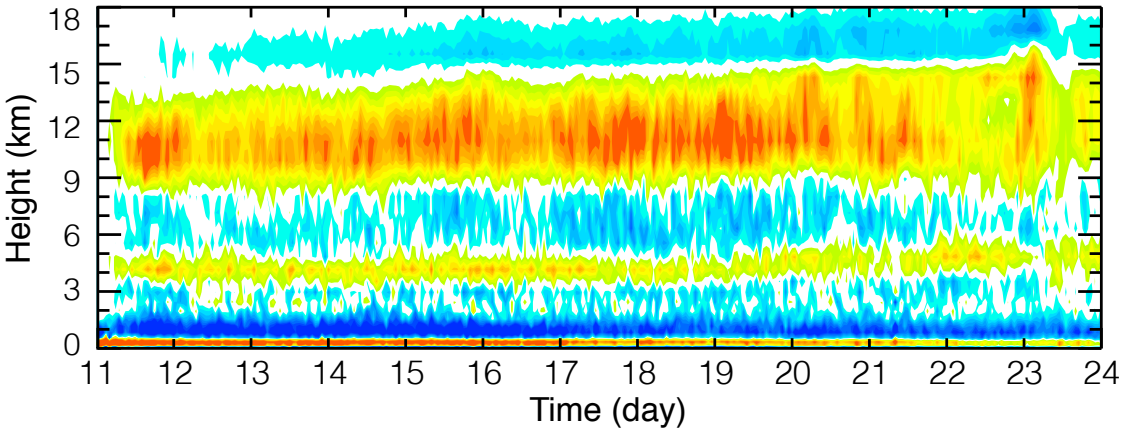
Eddy Transport Effects: $\Delta\theta$

Potential temperature change due to the convergence of the vertical eddy transports over one GCM time step

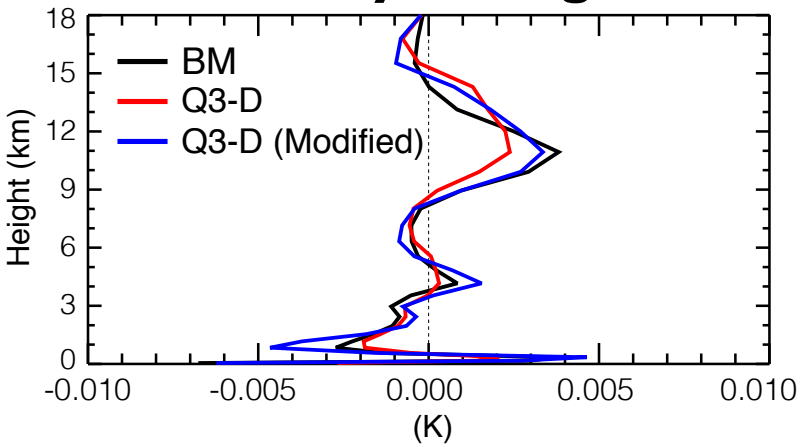
Q3-D

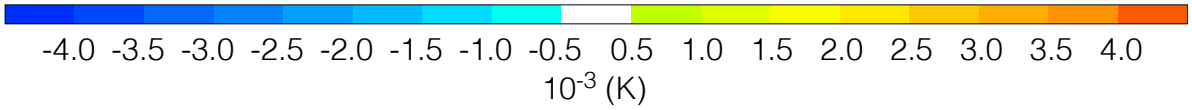


Q3-D (modified coupling)



13 day average



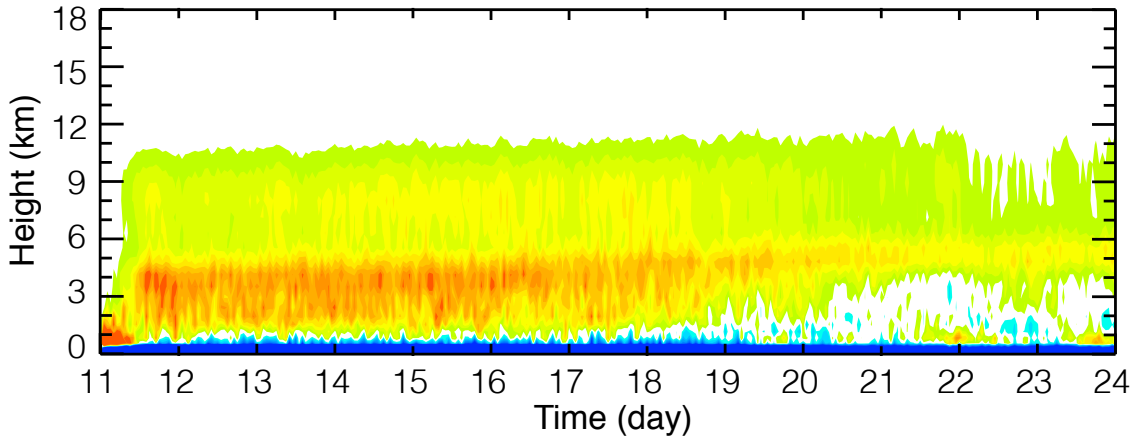


"Eddy transport effects are slightly over-predicted near the surface"

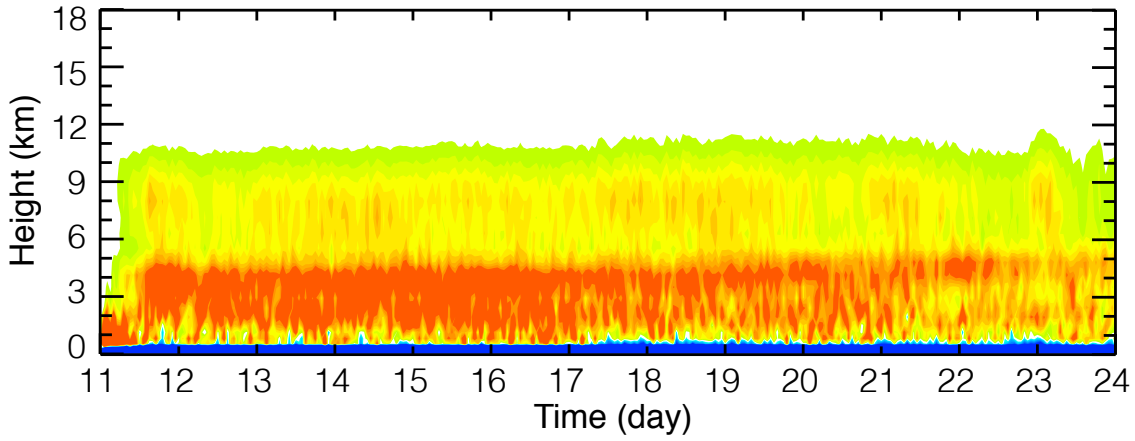
Eddy Transport Effects: Δq_v

Moisture change due to the convergence of the vertical eddy transports over one GCM time step

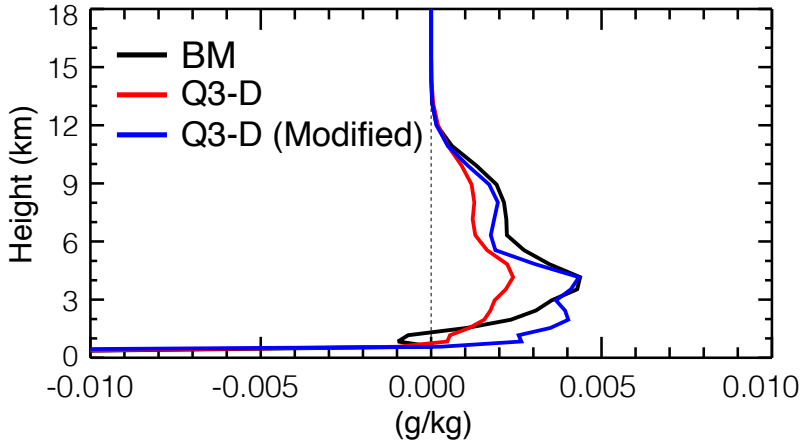
Q3-D

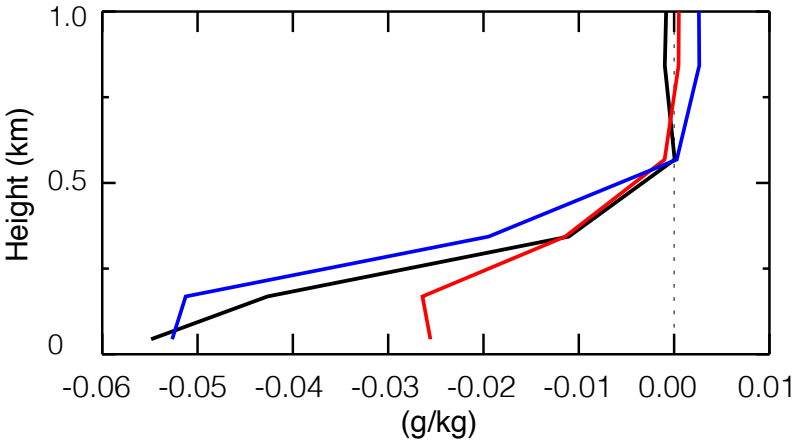


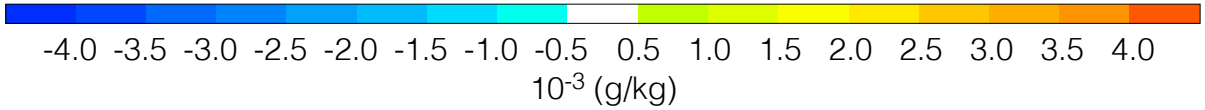
Q3-D (modified coupling)



13 day average

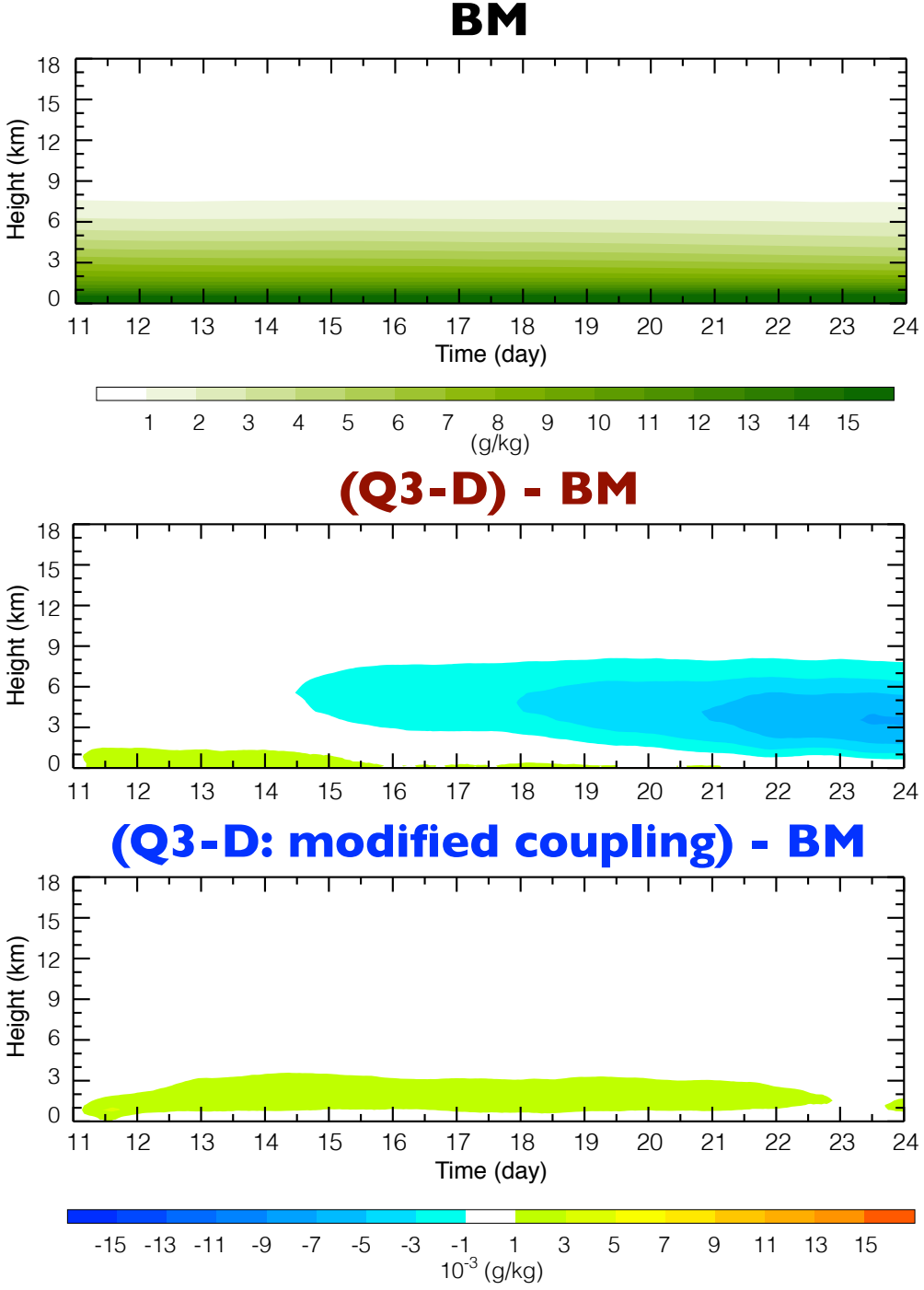






"Eddy transport effects are better-predicted"

Domain Average: q_v



"Dry bias in the middle atmosphere is removed"

Impact of the Modified Coupling

- Significantly improves the eddy transport effects on q_v, removing the dry bias.
- Slightly weakens the vortex intensity.
- Over-predicts the surface heat flux, indicating cold bias near the surface.

➡ For further improvement of the Q3-D MMF, a measure of anisotropy seems to be required in formulating the coupling. We plan to assess the degree of anisotropy by comparing the eddy statistics of the perpendicular channels.