Progress Report

Research Objective 1:
Development of a Q3D MMF

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From *"August 2011 CMMAP Team Meeting"*

Ongoing work:

- Prepare a new benchmark simulation with a large domain

- Test the new Q3D MMF code using a non-trivial GCM
  (Still using an idealized setting with a domain size of a few thousands km.)
  - Investigate the coupling strategy between GCM and CRM
  - Finalize the Q3D algorithm

An Idealized Benchmark Simulation

to be used for developing and finalizing the coupling algorithm for the Q3D MMF

Objective:

Produce physically-meaningful horizontal inhomogeneities that the GCM component can resolve their large scale behavior

Choice:

Simulate the transition of wave to vortices over the tropical ocean through the barotropic instability using an idealized setting

Model Configuration:

Model: 3D CRM (VVM developed by Jung and Arakawa)

Horizontal domain: 3072 km x 3072 km, Vertical domain: 18 km

Horizontal grid: 3 km, Vertical grid: 0.1 ~ 1 km (stretched grid)

f-plane, prescribed radiative cooling rate, SST = 302 K

Periodic boundary condition

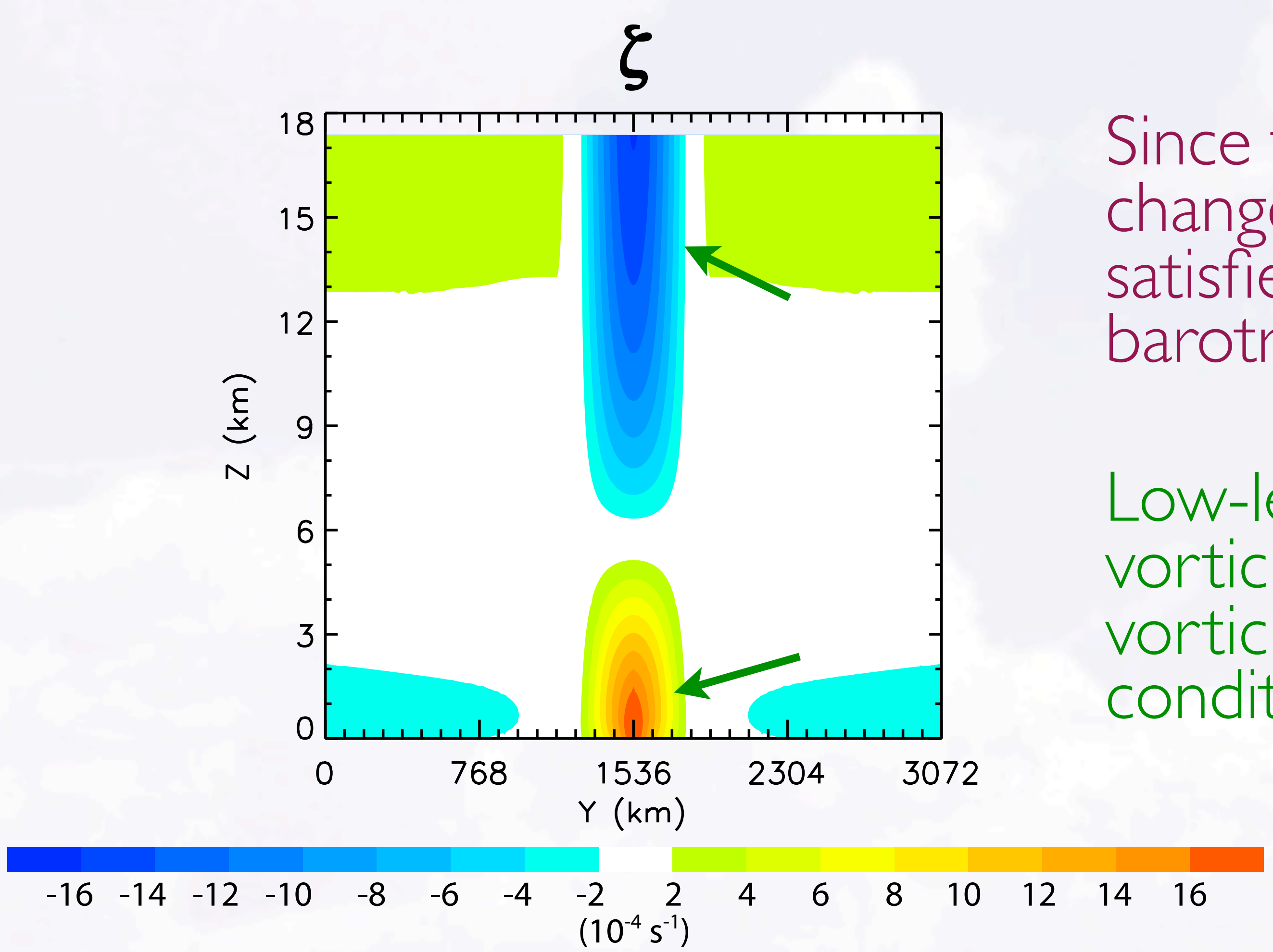
$f_0 = 1 \times 10^{-4}\ s^{-1}$

An Idealized Benchmark Simulation
(continued.)

Experimental Phases:

Phase 0 - Static adjustment for moist air

Prepare an analytical expression for the potential temperature satisfying the thermal wind balance with the prescribed motion field. Then, modify this motion field using the the virtual temperature effect with the prescribed mean relative hummidity.



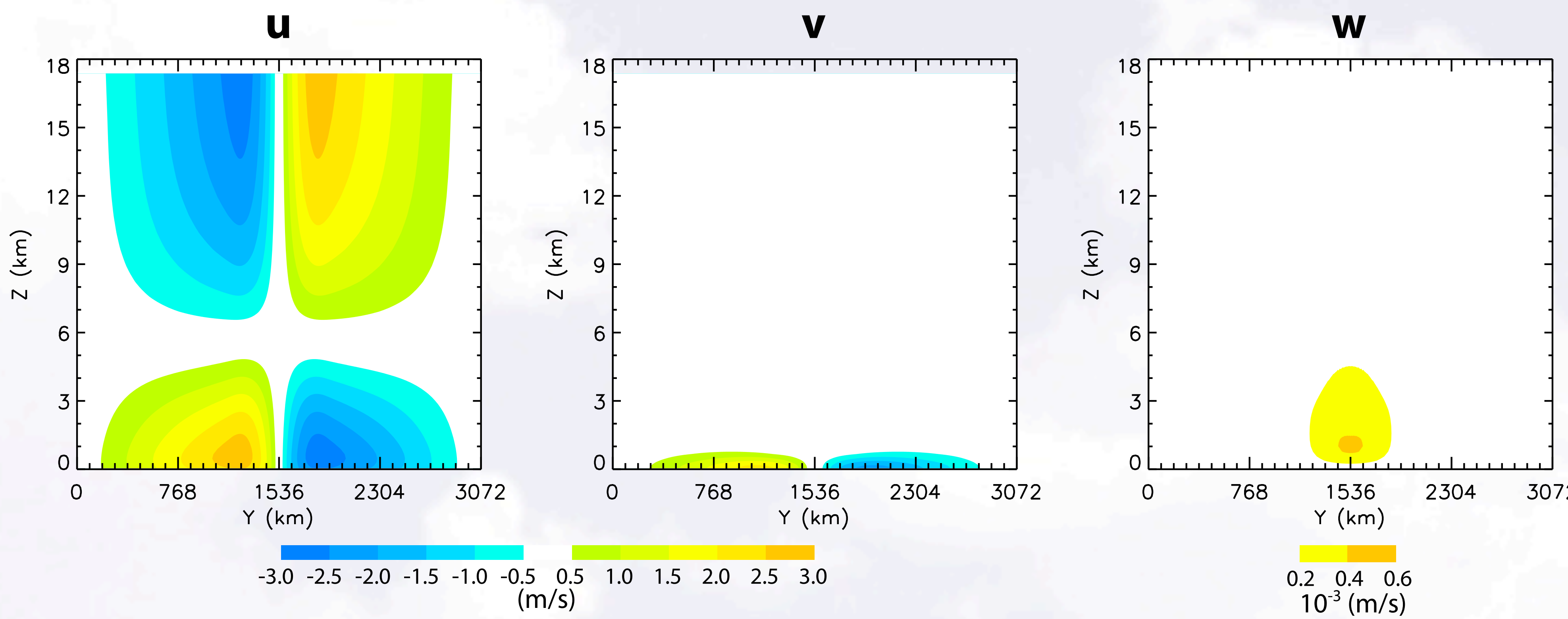
Since the meridional gradient of the vorticity changes sign at the center of the domain, it satisfies the necessary condition for barotropic instability.

Low-level, meridionally concentrated positive vorticity topped by upper-level negative vorticity is one of the important necessary conditions for the formation of tropical storms.

An Idealized Benchmark Simulation (continued.)

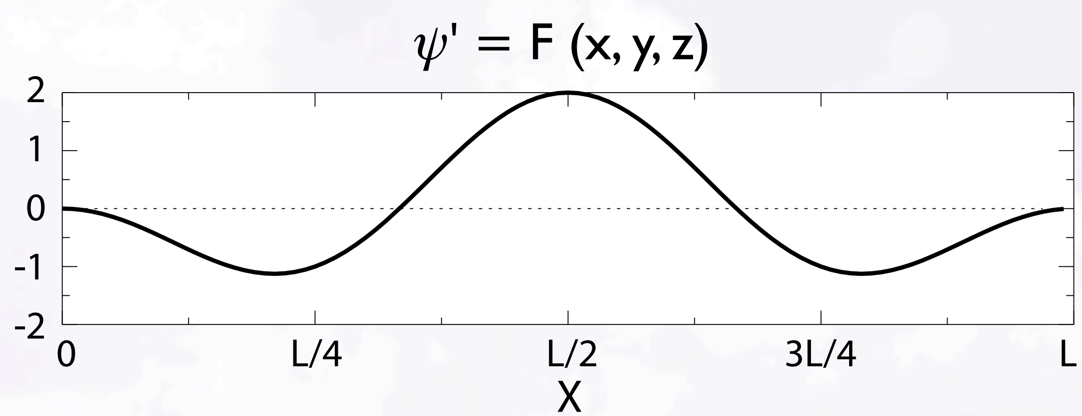
Experimental Phases:

Phase 1 - Dynamic adjustment through boundary-layer processes



Phase 2 - Thermodynamic adjustment through full physics

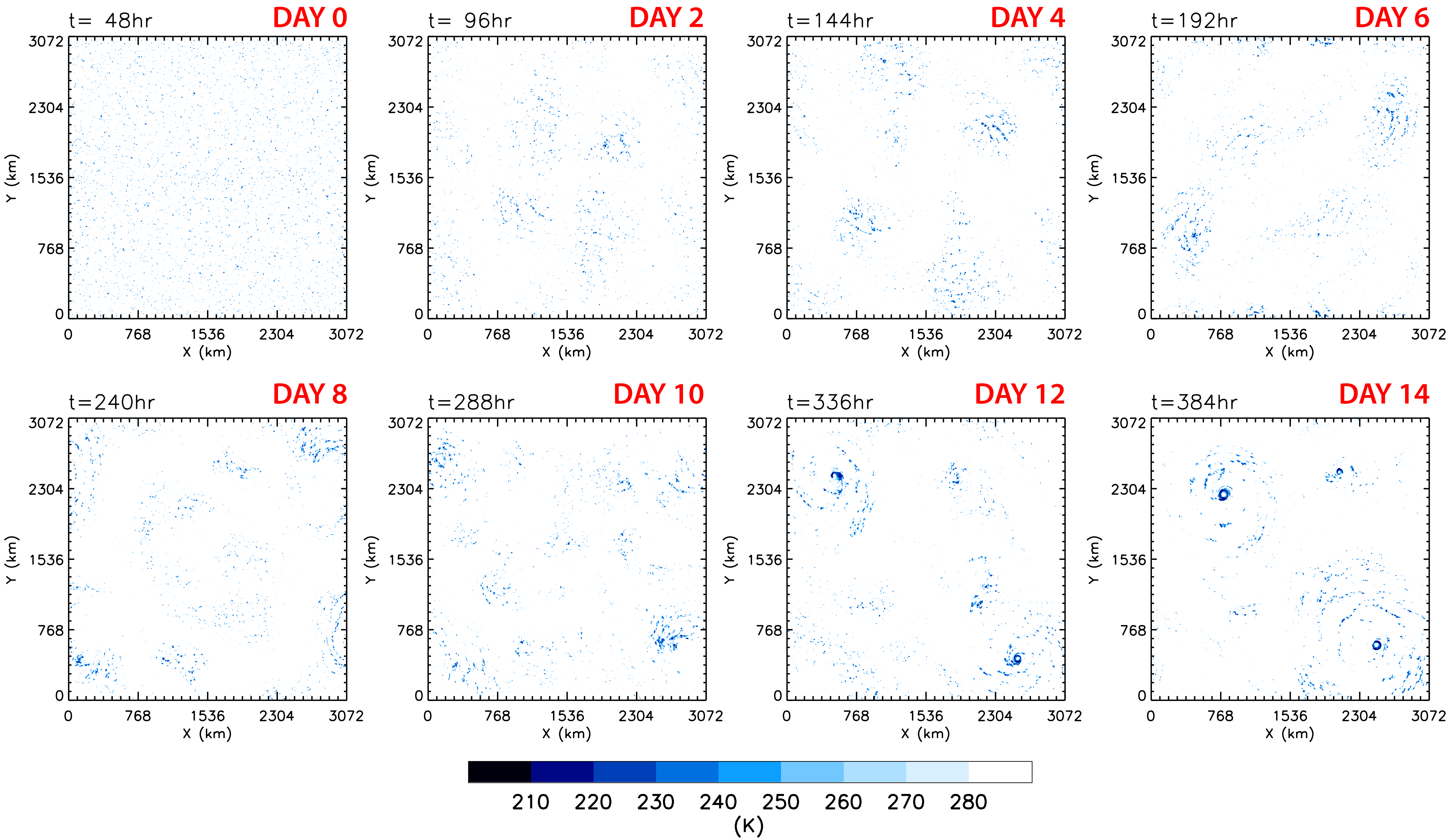
Phase 3 - Main simulation



A small amplitude wave is introduced into the motion field.

An Idealized Benchmark Simulation (continued.)

Cloud Top Temperature (Phase 3)

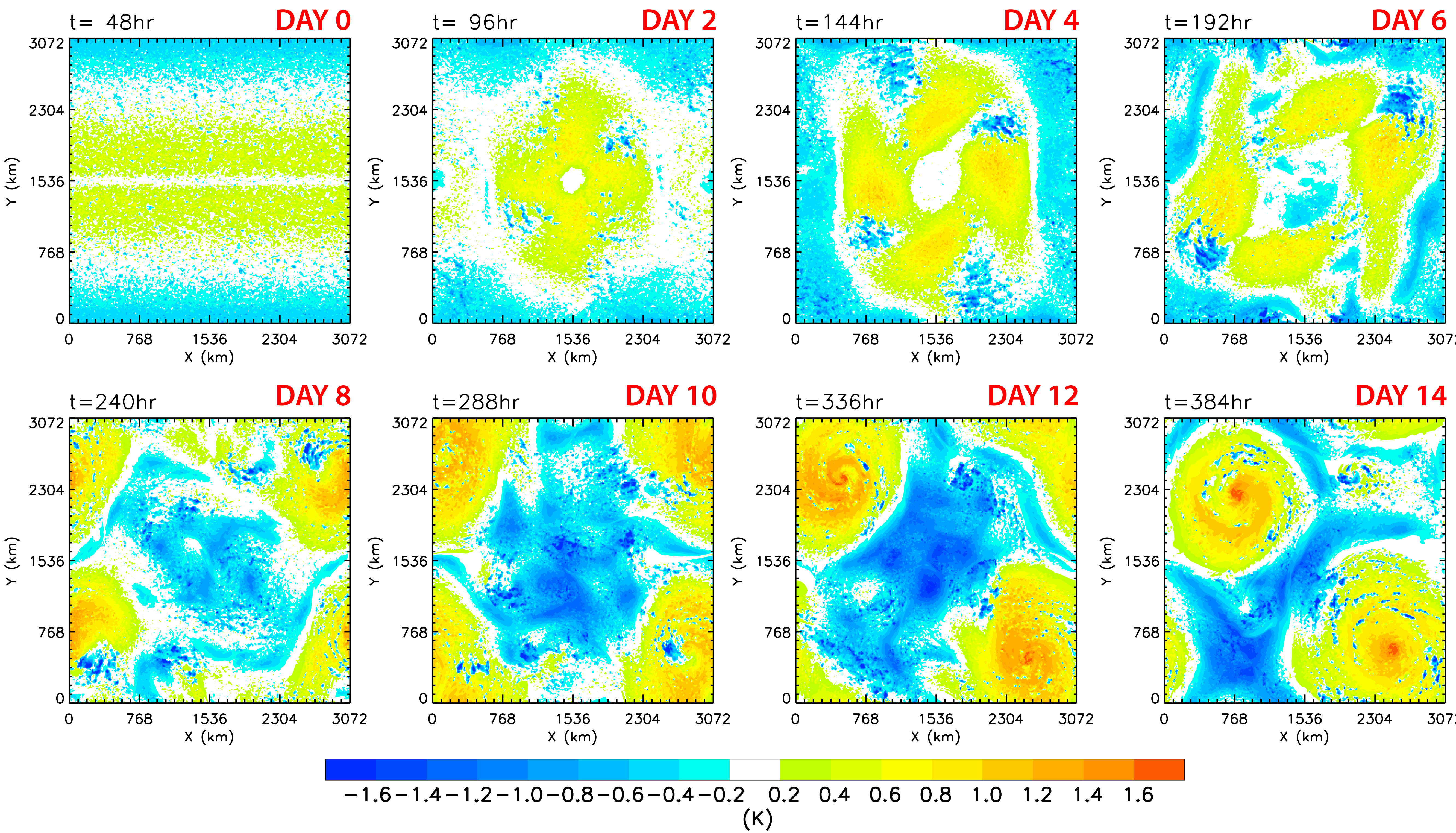


An Idealized Benchmark Simulation (continued.)

(Phase 3)

$\theta - \overline{\theta}$

(z = 46 m)

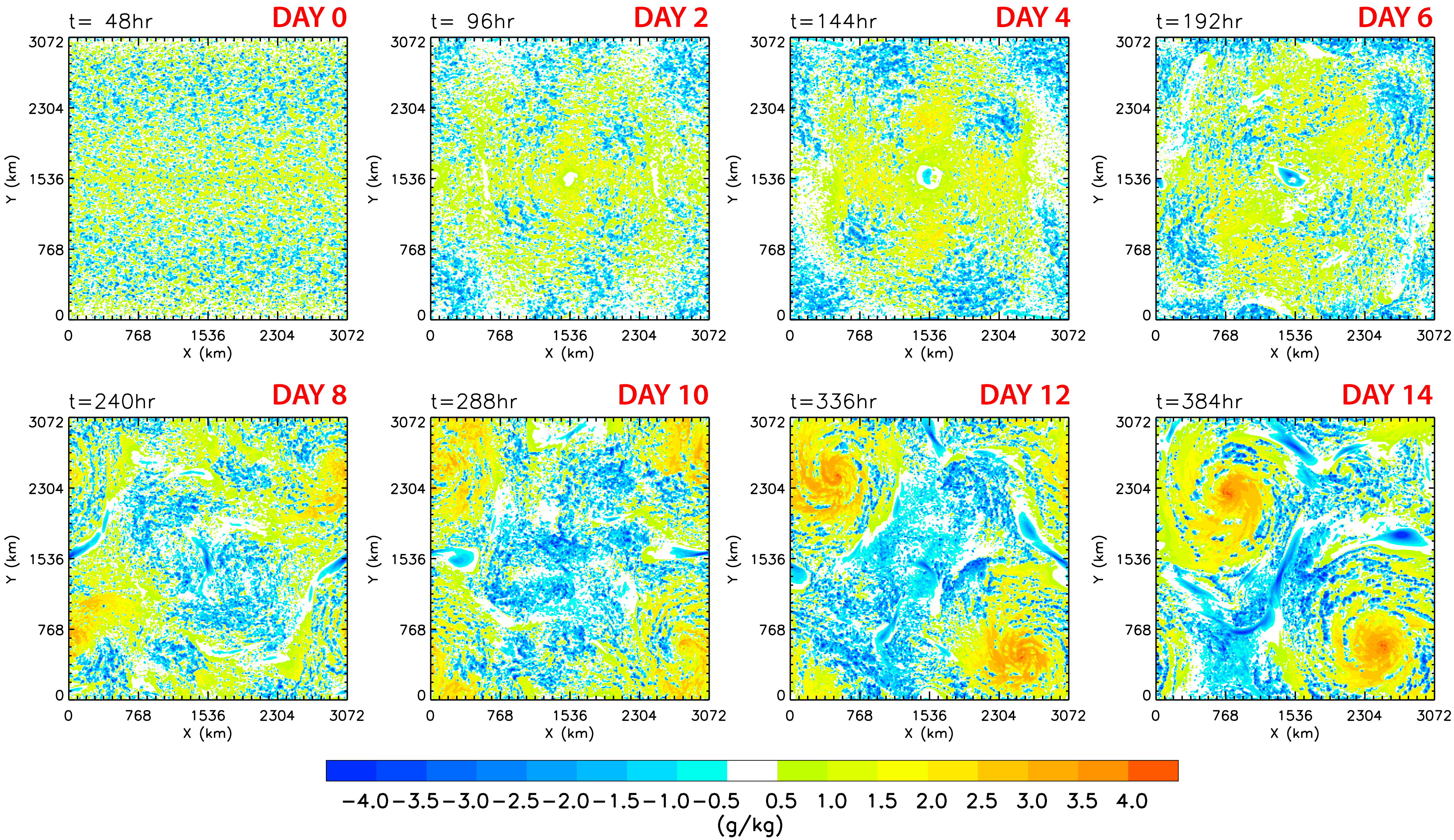


An Idealized Benchmark Simulation (continued.)

(Phase 3)

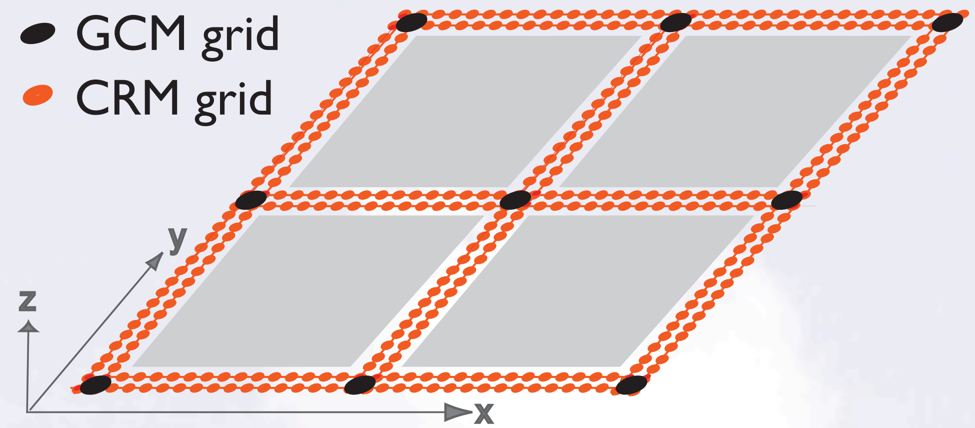
$$q_v - \overline{q}_v$$

(z = 46 m)



Test of Q3D Algorithm with a non-trivial GCM

The Q3D MMF introduces two perpendicular sets of channel domains, each of which contains a locally 3D array of grid points.



Shaded areas: gaps of the grid network

The lateral boundary condition for the channel domains consists of the sum of two parts: *one taken from smoothed background fields* interpolated from the gross features of GCM and *the other from cyclic conditions for deviations*.

In the earlier algorithm, the lateral boundary condition for solving the 2D elliptic equations (used in the determination of horizontal velocity at the uppermost layer) **was not consistent with the above. It has been modified in a consistent way.**

Smoothing of the background fields seems crucial to stable integration of the Q3D CRM. At present, a simple weighted average is used and it will be refined later.

Coupling Strategy

GCM effect on the CRM

The GCM effect on the CRM is simply through the boundary condition on the background field of CRM. This is parallel to the typical limited area modeling in which the large-scale model provides the boundary condition for the embedded small-scale model.

CRM effect on the GCM

As in the subgrid parameterization problems, the role of the CRM is to estimate the effects of eddies not resolved by the GCM. Thus, the CRM effect must be limited to the eddy effects by subtracting the non-eddy effects.

CRM effect on the GCM

Estimation of non-eddy effect:

Apply the Q3D prediction code to individual grid points after replacing the prognostic variables with their background fields. Since there is no possibility of double counting as far as physics is concerned, it is sufficient to estimate the non-eddy effect only for dynamics.

Eddy effect, R:

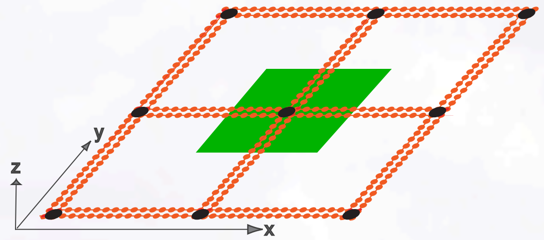
$$R \equiv \left(q_{t=t_0+\Delta T} - q_{t=t_0}\right) - \frac{1}{2}\left[\left(\frac{\partial q}{\partial t}\right)_{t_0}^{non-eddy} + \left(\frac{\partial q}{\partial t}\right)_{t_0+\Delta T}^{non-eddy}\right]\Delta T$$

$\left(\frac{\partial q}{\partial t}\right)_{t_0}^{non-eddy}$: time change of q per unit time due to the non-eddy effects diagnosed at $t = t_0$

ΔT : GCM time interval

The average of R over the net-size segment is added to $\hat{q}$ predicted by the GCM at each GCM time step.

$$q_{GCM} = \hat{q}_{GCM} + \varepsilon \cdot [R]$$

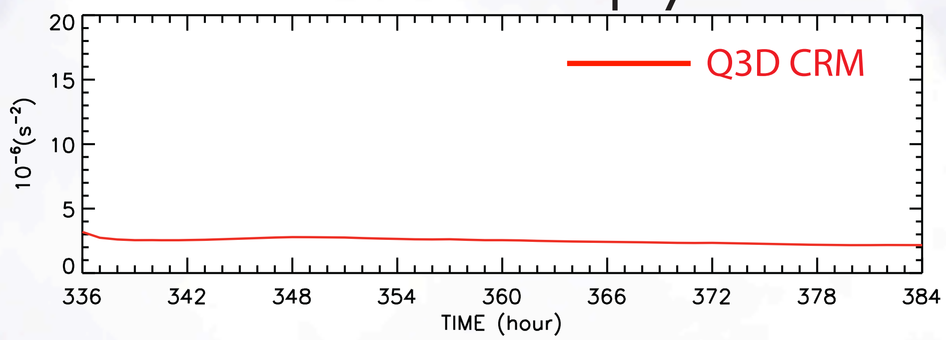


Test of Q3D Algorithm with a non-trivial GCM

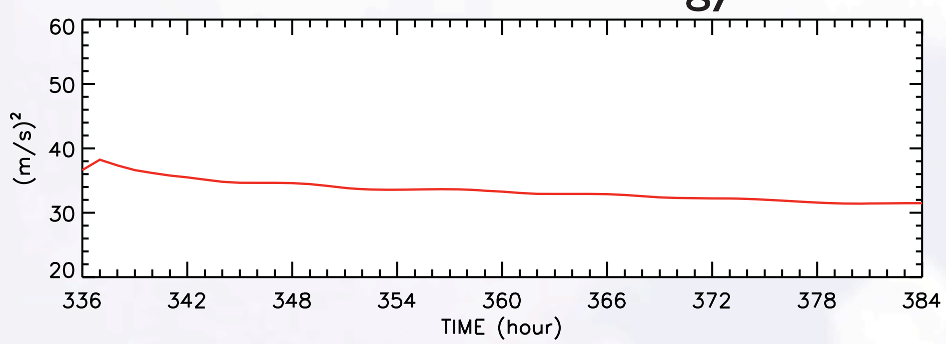
“One way coupling”

dGCM = 96km
dCRM = 3km

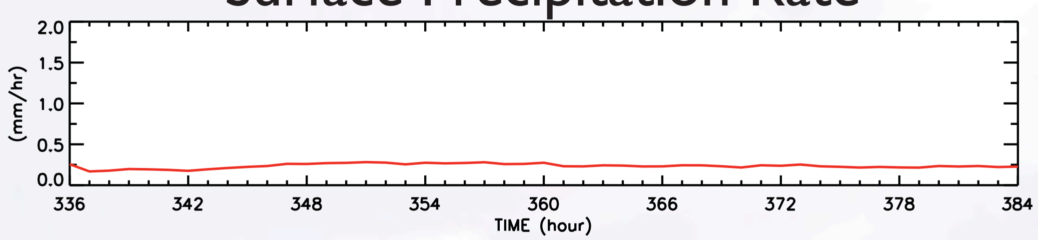
Mean Enstrophy



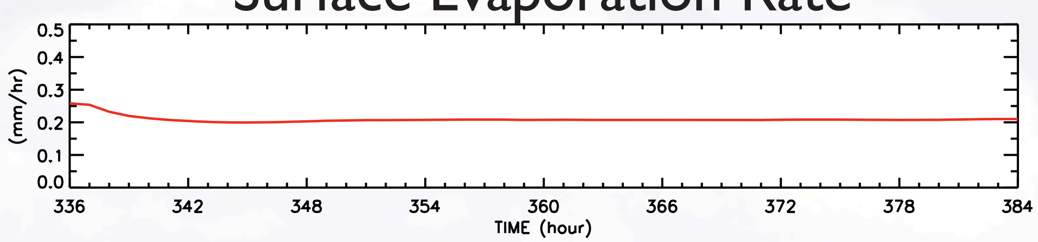
Mean Kinetic Energy



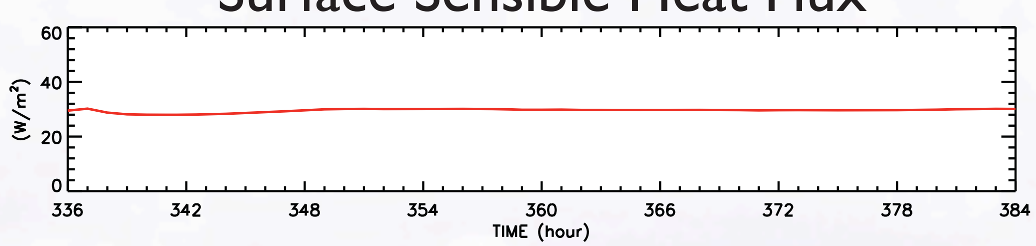
Surface Precipitation Rate



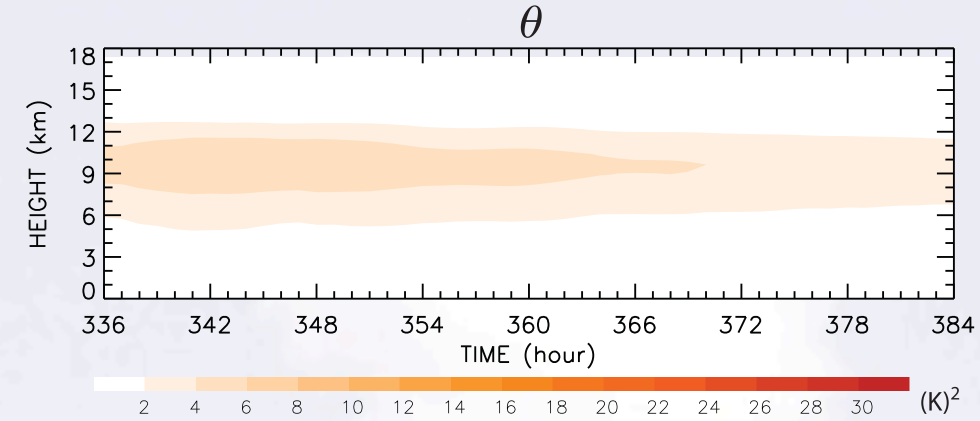
Surface Evaporation Rate

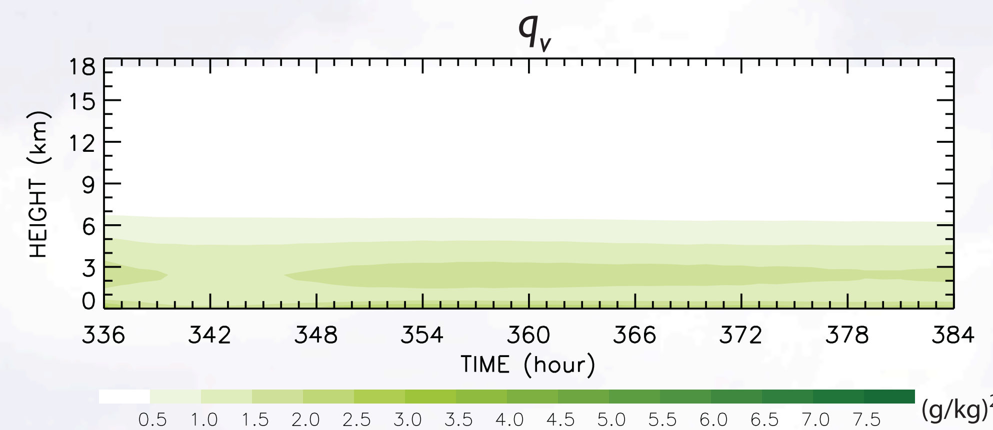


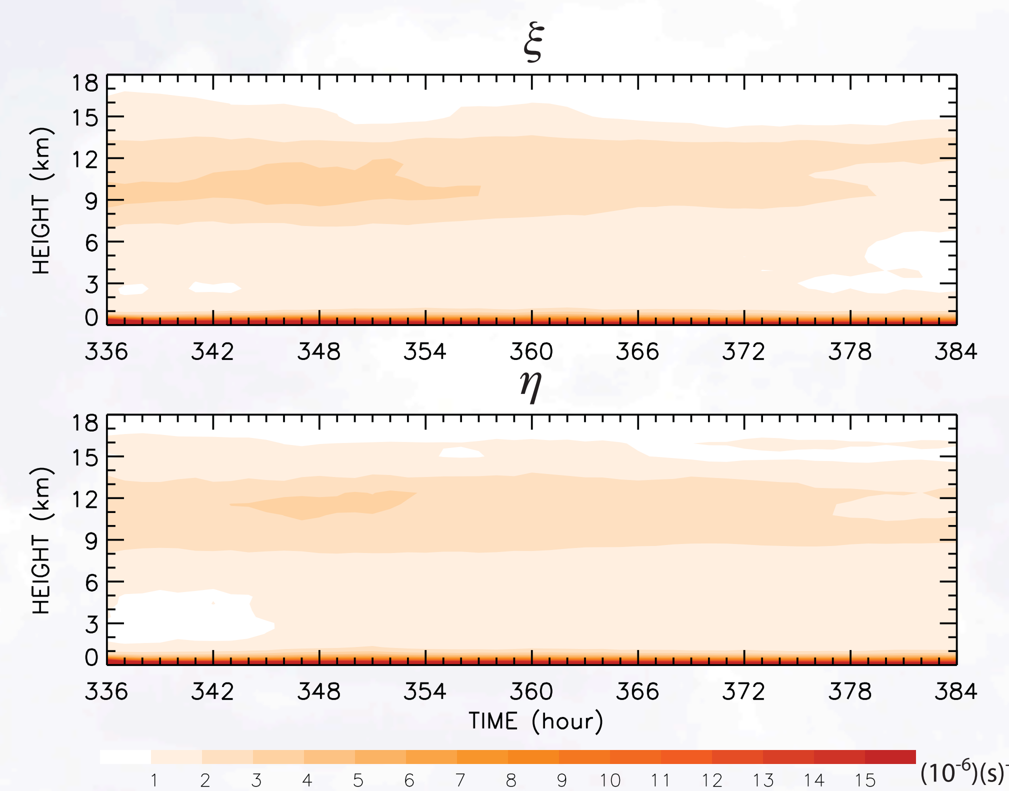
Surface Sensible Heat Flux



Variances





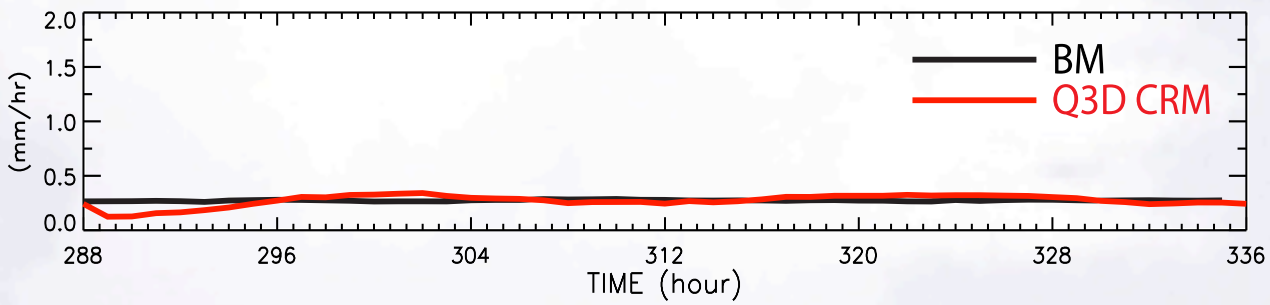


Test of Q3D Algorithm with a non-trivial GCM

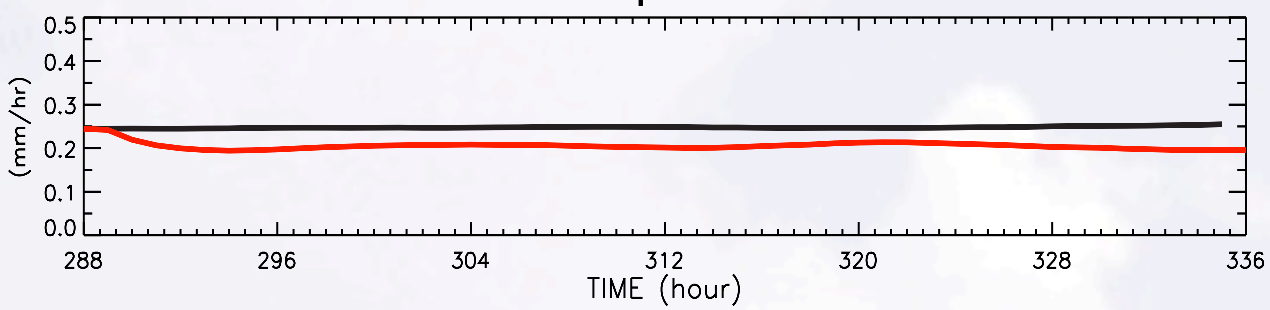
"Two way coupling"

$d_{GCM} = 96km \qquad d_{CRM} = 3km$

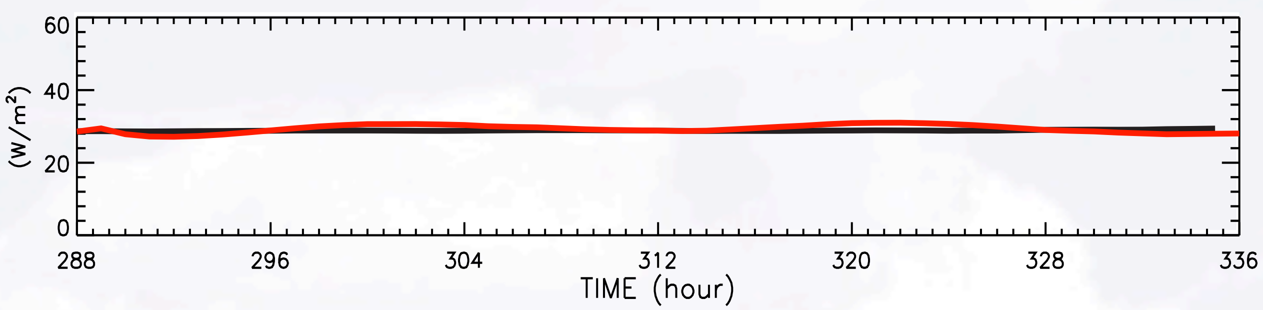
Surface Precipitation Rate



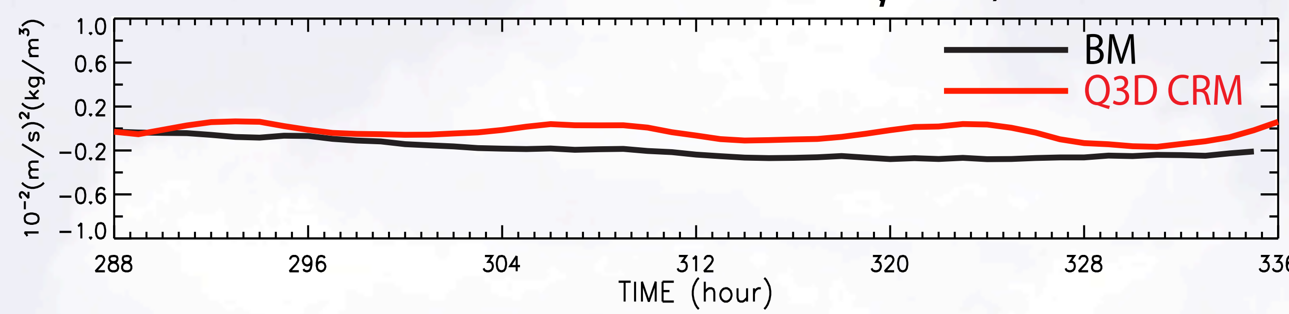
Surface Evaporation Rate



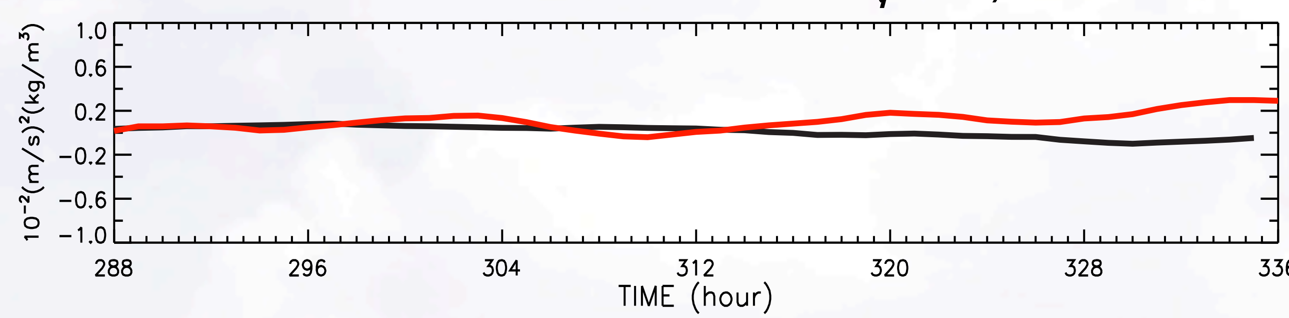
Surface Sensible Heat Flux



Surface Momentum Flux ($\rho\overline{u'w'}$)

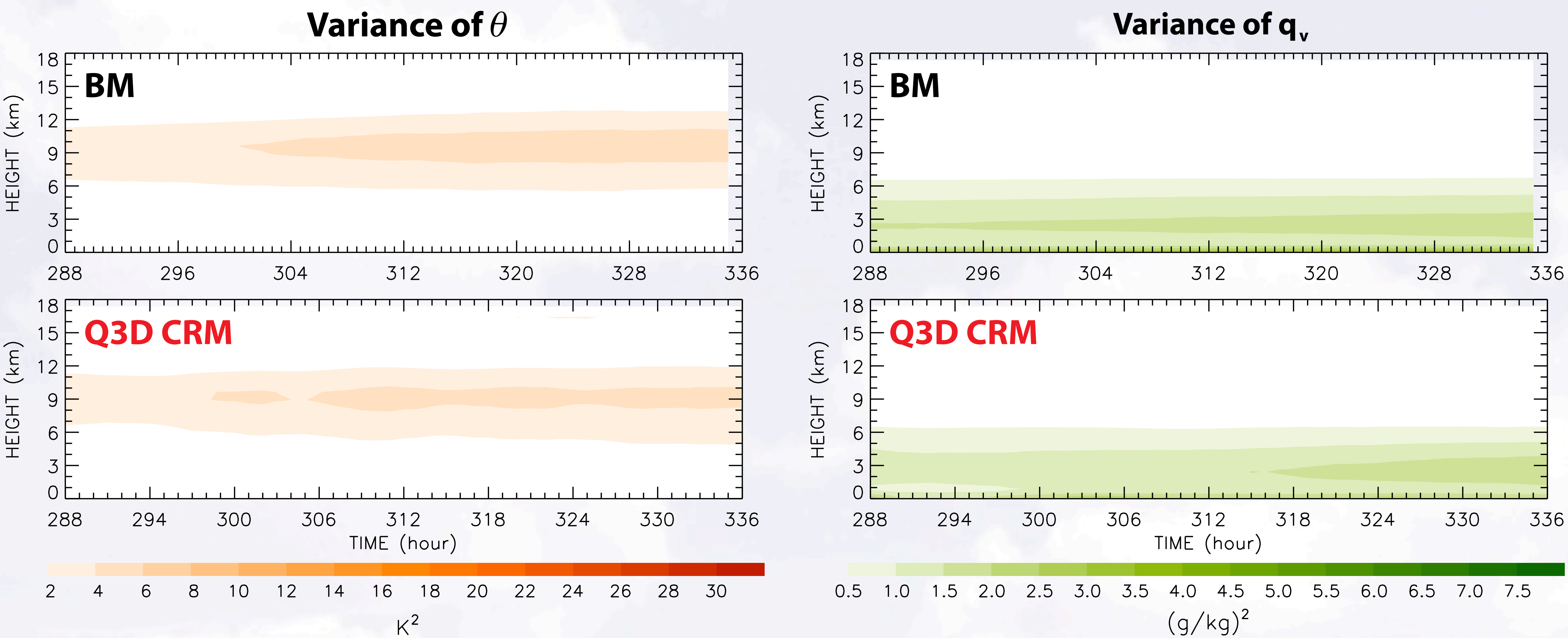


Surface Momentum Flux ($\rho\overline{v'w'}$)



Test of Q3D Algorithm with a non-trivial GCM

"Two way coupling"



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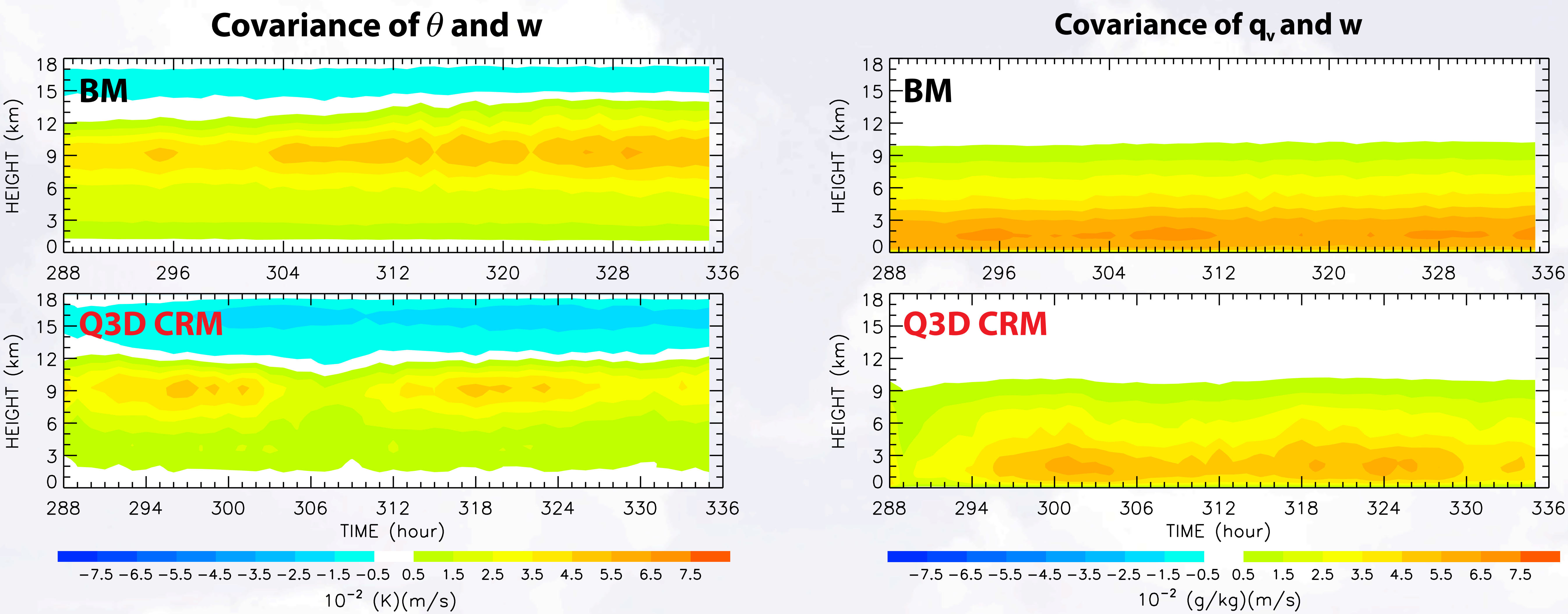

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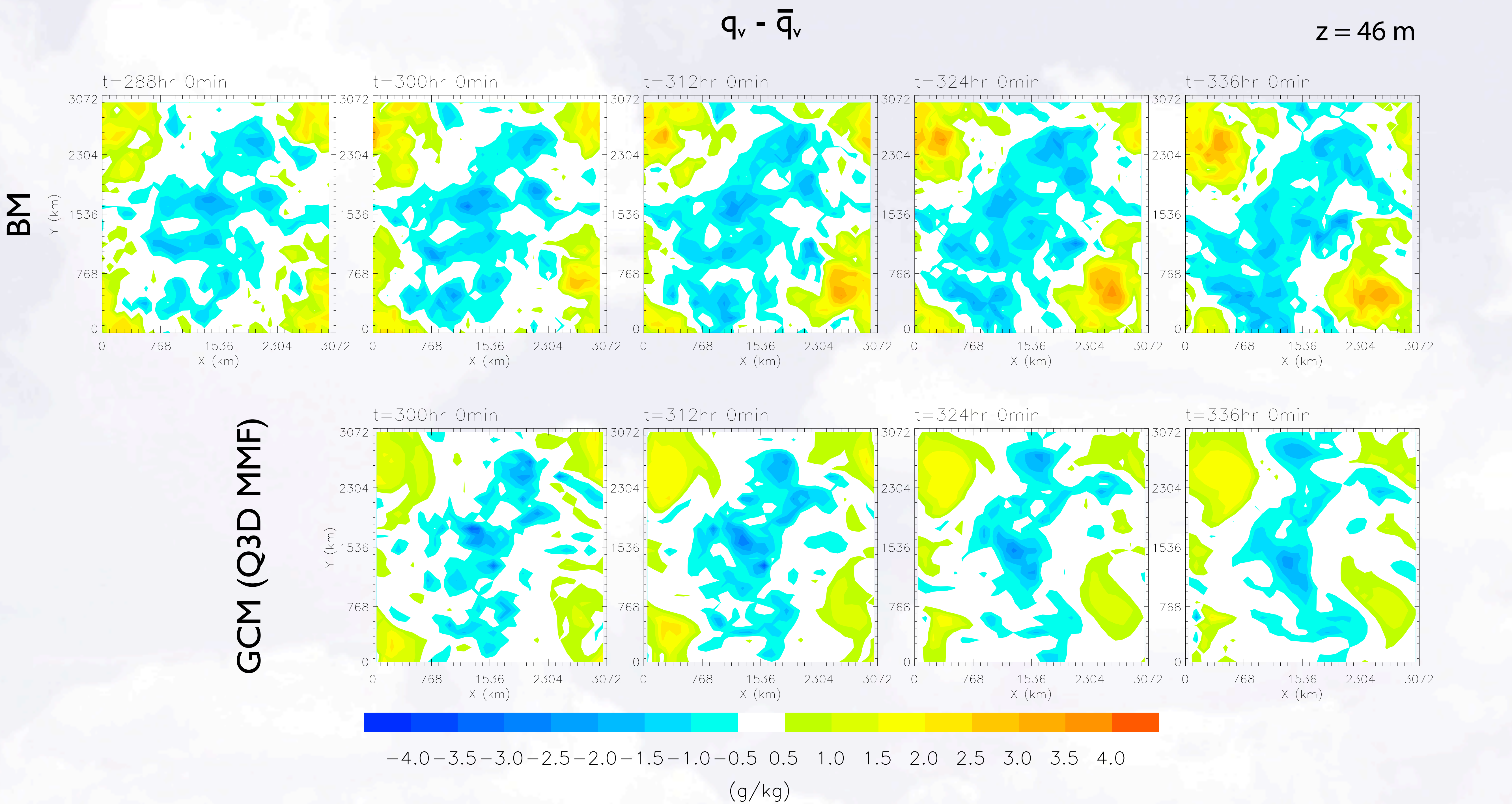

Test of Q3D Algorithm with a non-trivial GCM

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