Progress Report

Research Objective 2: **Development of a Q3-D MMF**

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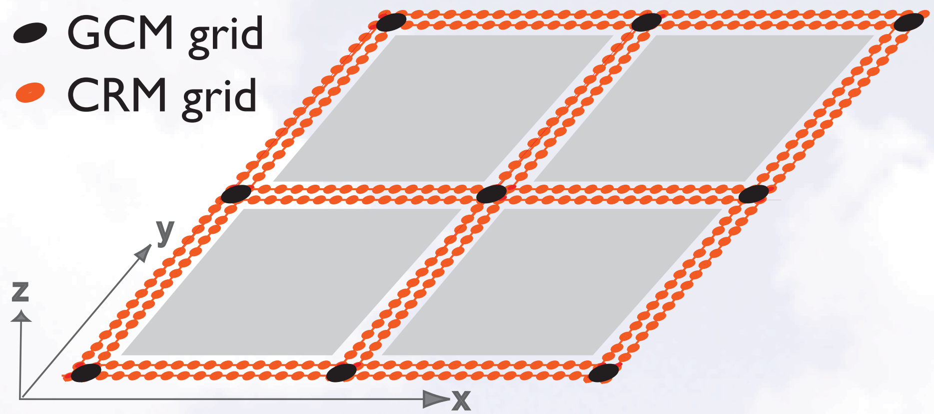
Grid System of Q3-D MMF



Shaded areas: gaps of the grid network

- A combination of a GCM grid and two perpendicular sets of cloud-resolving grid channels.
- Perpendicular channels are coupled only through the GCM to avoid singularity.
- The channel width is chosen to be a typical cloud size.

Coupling of the CRM and GCM components

GCM effect on CRM

- **Lateral boundary condition for the background field of CRM**

  CRM variables are separated into "background" and "deviation". The background is obtained from the GCM through interpolation while the deviation is assumed to be cyclic across the channel.

  The coupling through the lateral boundary condition is a key component of the Q3-D algorithm, which allows the CRM to recognize the three dimensionality of GCM through the background normal gradient.

- **Relaxation of CRM solution toward that of GCM**

  The main prognostic variables of CRM are relaxed to the background fields with a nonlinear formulation:

$$\left(\frac{\partial q}{\partial t}\right)_{relaxation} = -k\left(q-\overline{q}\right) \; ; \qquad k \equiv \frac{1}{\tau_1} + \frac{1}{\tau_2} \cdot \frac{\left|q-\overline{q}\right|}{STD\left(q_{GCM}\right)}$$

  Here, τ is a relaxation time scale and STD denotes the standard deviation.

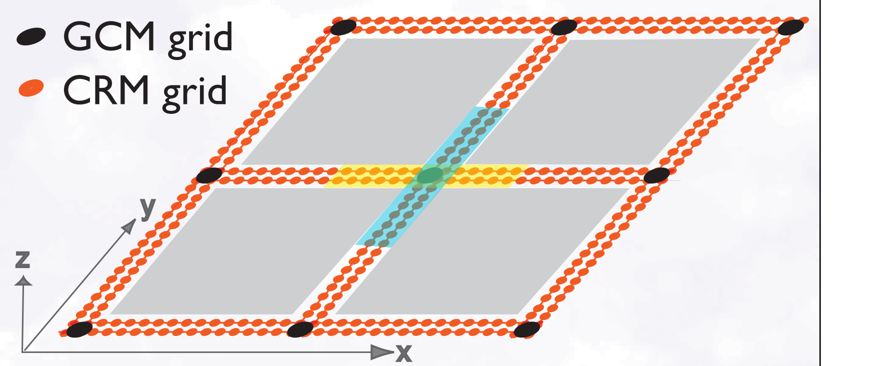
Coupling of the CRM and GCM components

CRM effect on GCM

- Diabatic and eddy transport effects

Diabatic and *eddy transport* effects are implemented in the GCM after averaging over
- channel segments (shown by ▬ and ╱)
- and neighboring channels.

$$\frac{\partial q_{GCM}}{\partial t} = \left(\frac{\partial q_{GCM}}{\partial t}\right)_{advection} + \left(\frac{\partial q_{GCM}}{\partial t}\right)_{LS-condensation} + F_q$$



$$F_q = \left(F_q^{x-channel} + F_q^{y-channel}\right)/2$$

$$F_q^{x-channel} \equiv \left(\overline{\overline{\frac{\partial q}{\partial t}}}\right)_{physics} - \frac{1}{\rho_0}\frac{\partial}{\partial z}\left(\rho_0 \overline{\overline{w'q'}}\right)$$

Here, the eddy q' is defined as $q' \equiv q - \overline{q}$.

$\overline{\overline{}}$ net size (GCM grid size) channel segment average

Benchmark Simulation

A straightforward application of the 3D CRM

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 dynamics-convection interaction using an idealized setting

Model Configuration:

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

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

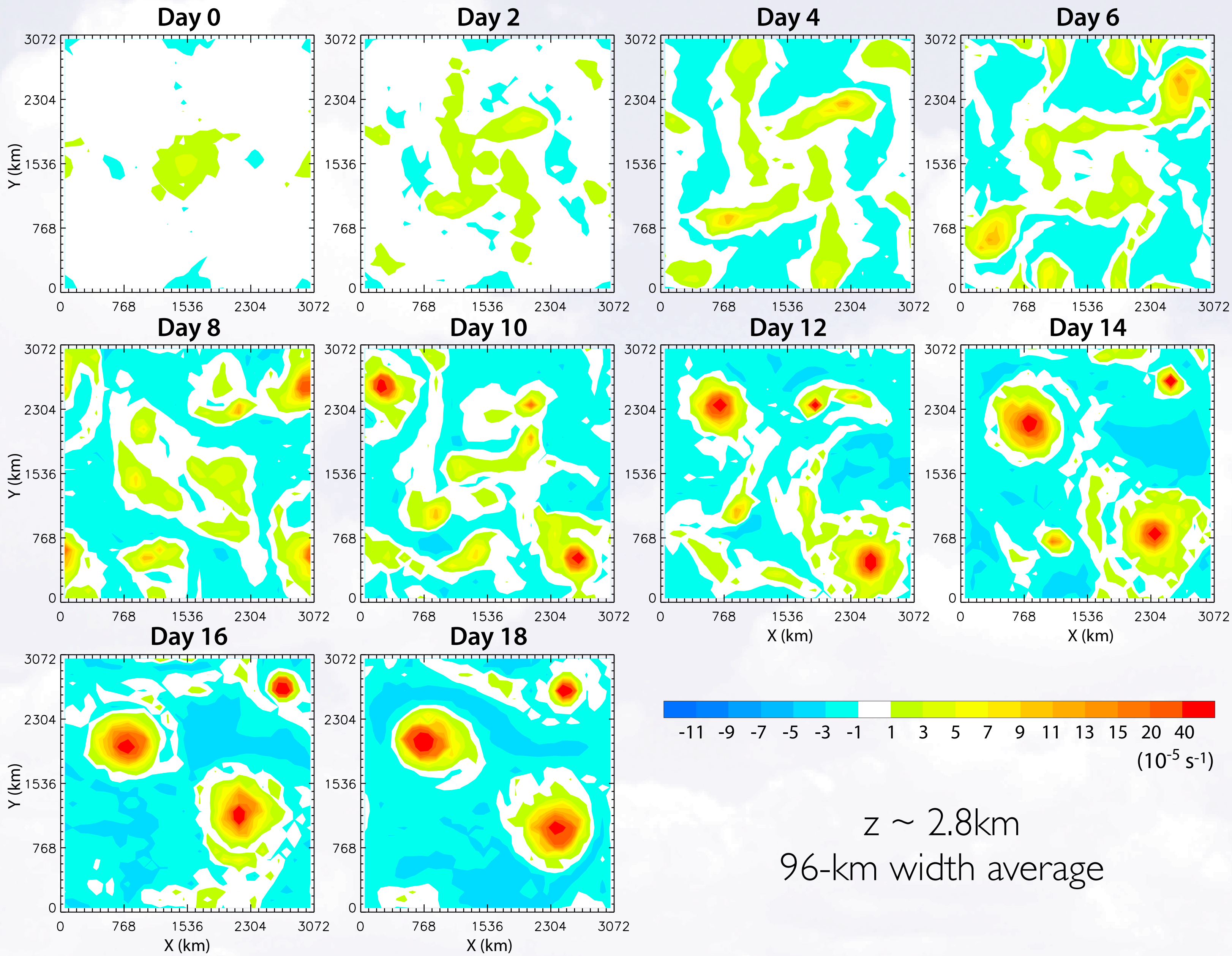
f-plane: $f_0 = 1 \times 10^{-4}\ s^{-1}$

Prescribed radiative cooling rate

SST = 302 K

Periodic boundary condition

Example of BM: Vertical component of vorticity



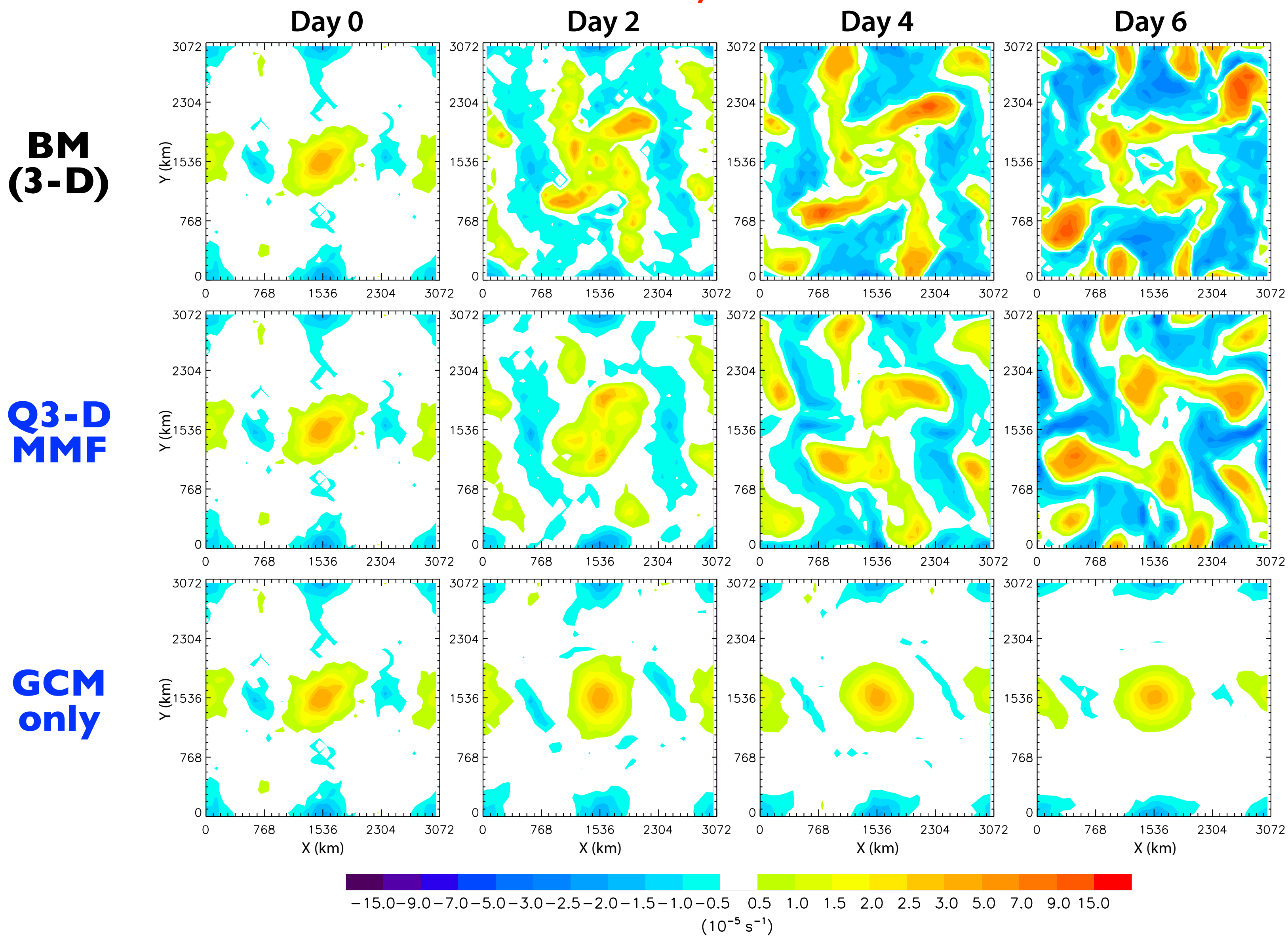
Q3-D MMF Simulation

Horizontal GCM grid = 96 km
Horizontal CRM grid = 3 km

$$\frac{\text{\# of horizontal grid points of Q3-D CRM}}{\text{\# of horizontal grid points of 3-D CRM}} \sim 13\ \%$$

Vertical component of vorticity

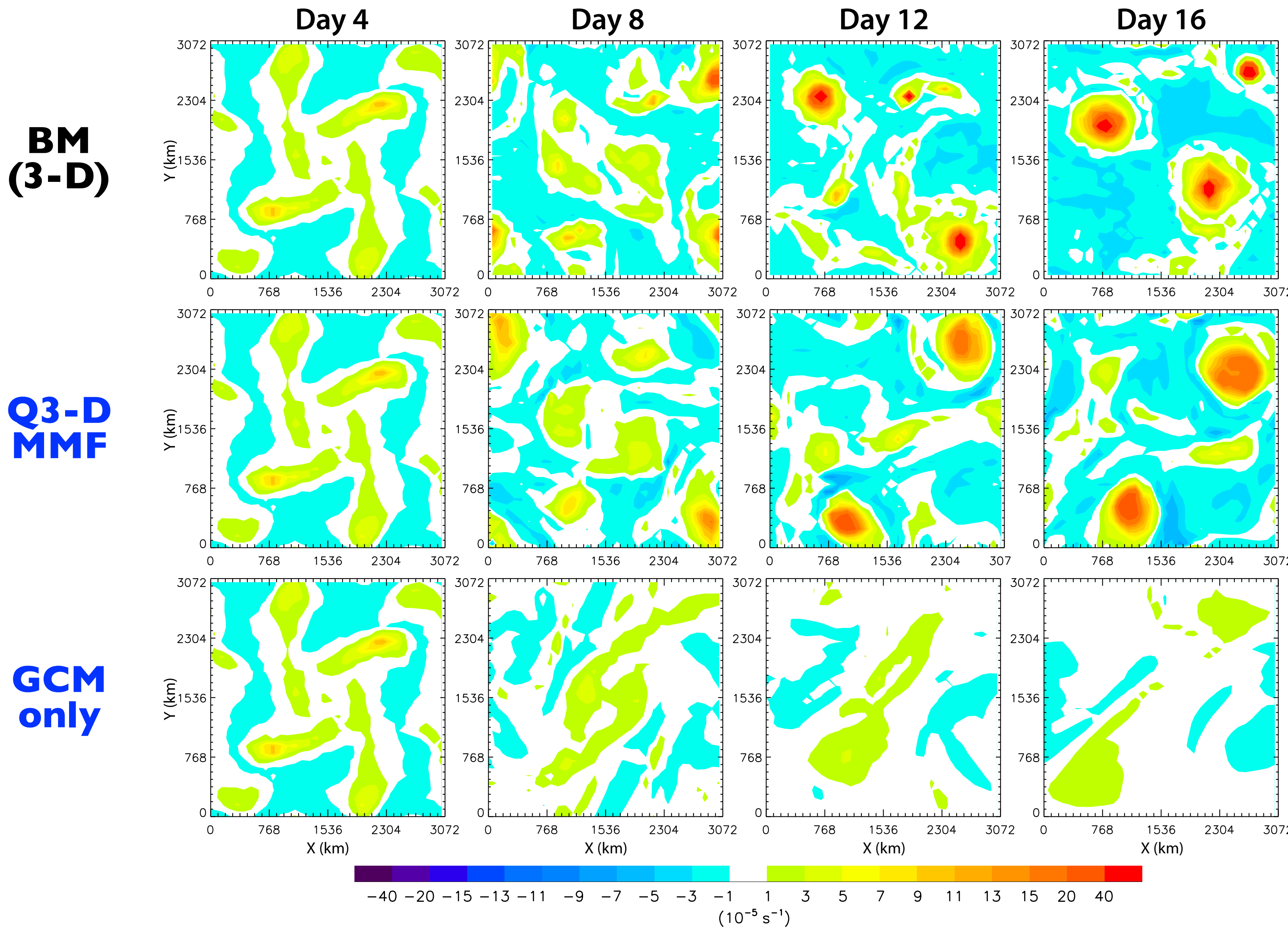
start from day 0 z ~ 2.8 km



"Breaking of the initial vorticity pattern to a fine-structured complex pattern"

Vertical component of vorticity

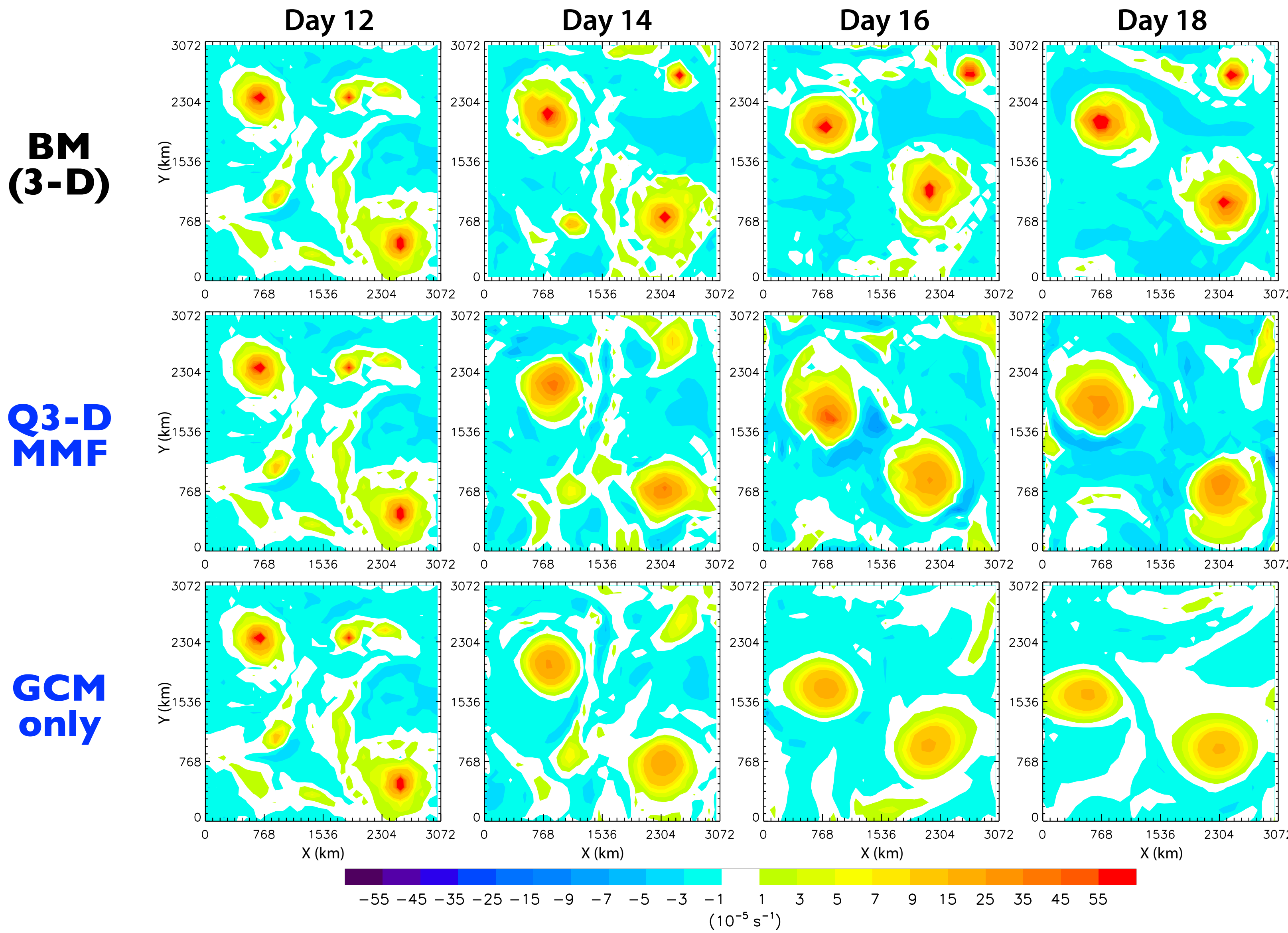
start from day 4   z ~ 2.8 km



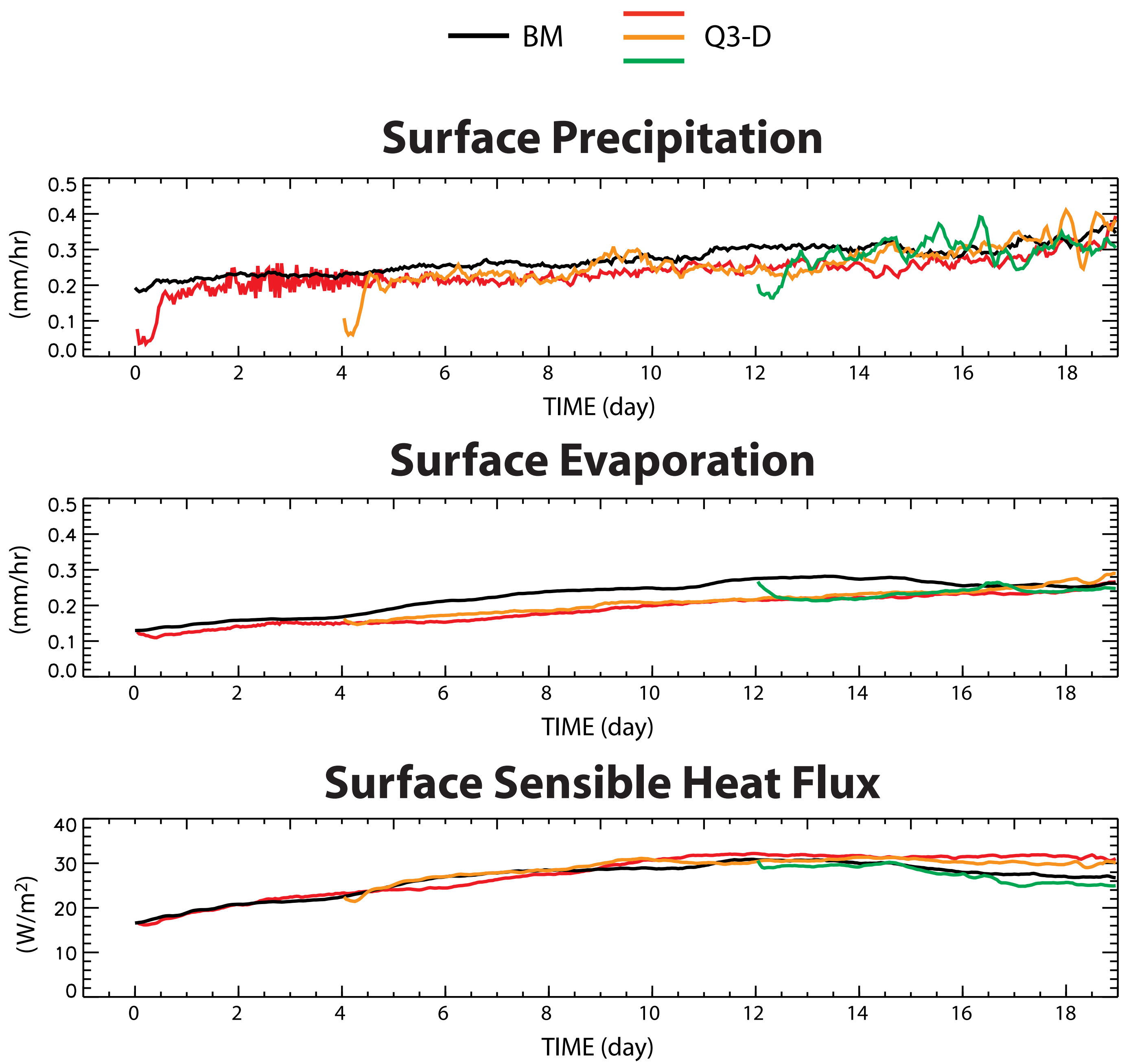
"Transition of the initial wavy disturbance to well-defined vortices"

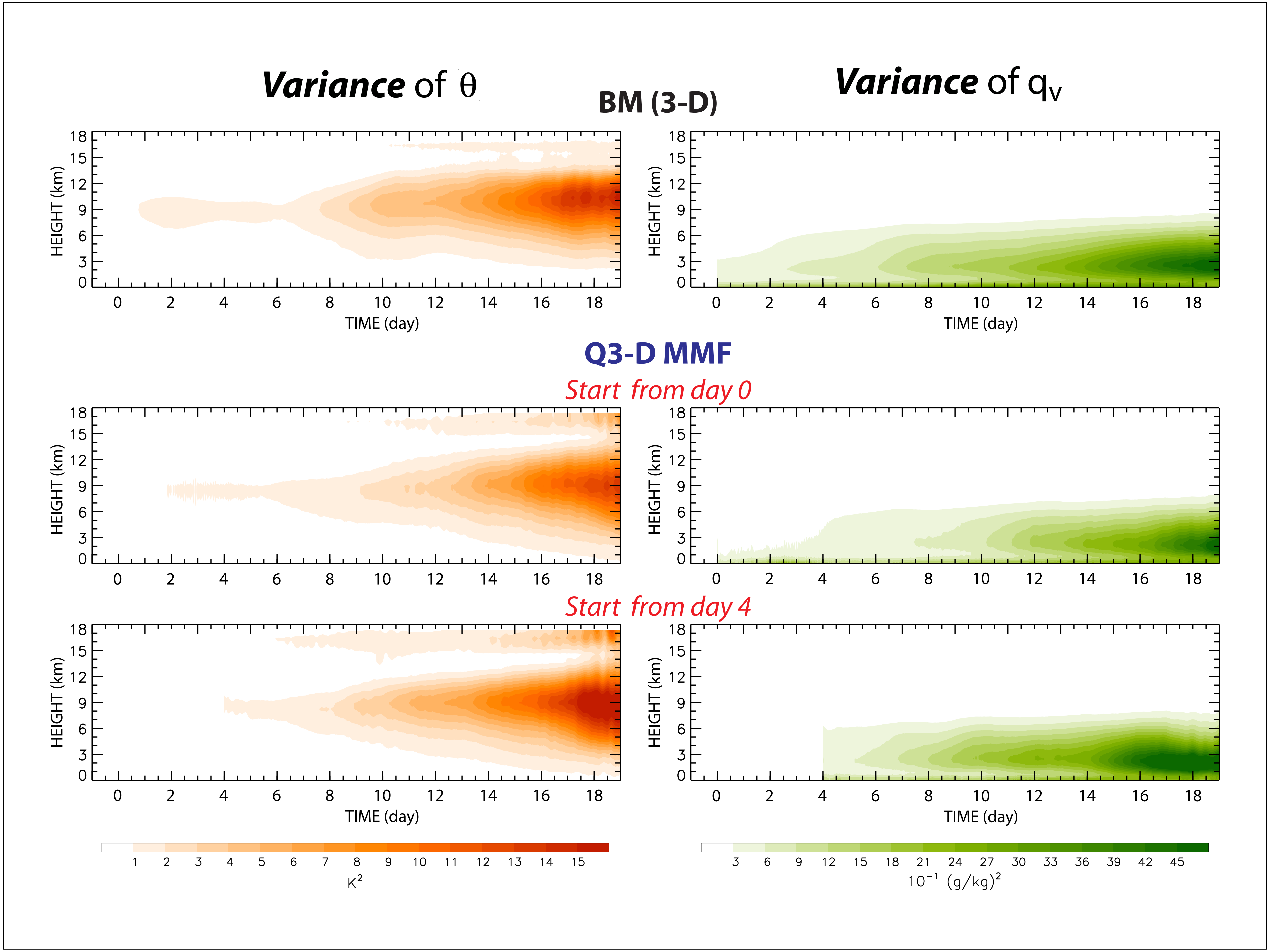
Vertical component of vorticity

start from day 12   z ~ 2.8 km

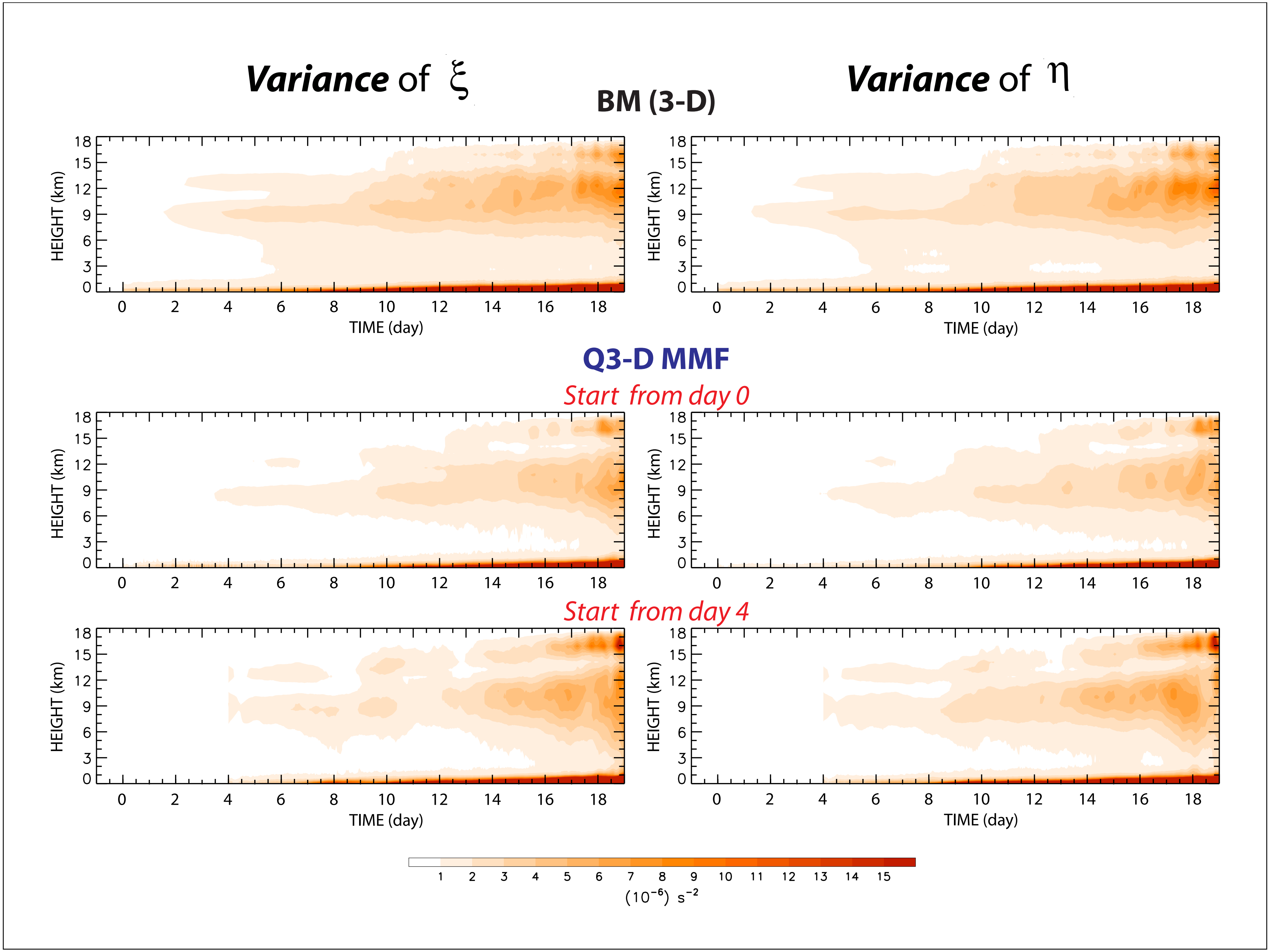


"Maintenance of the well-defined vortex pattern"

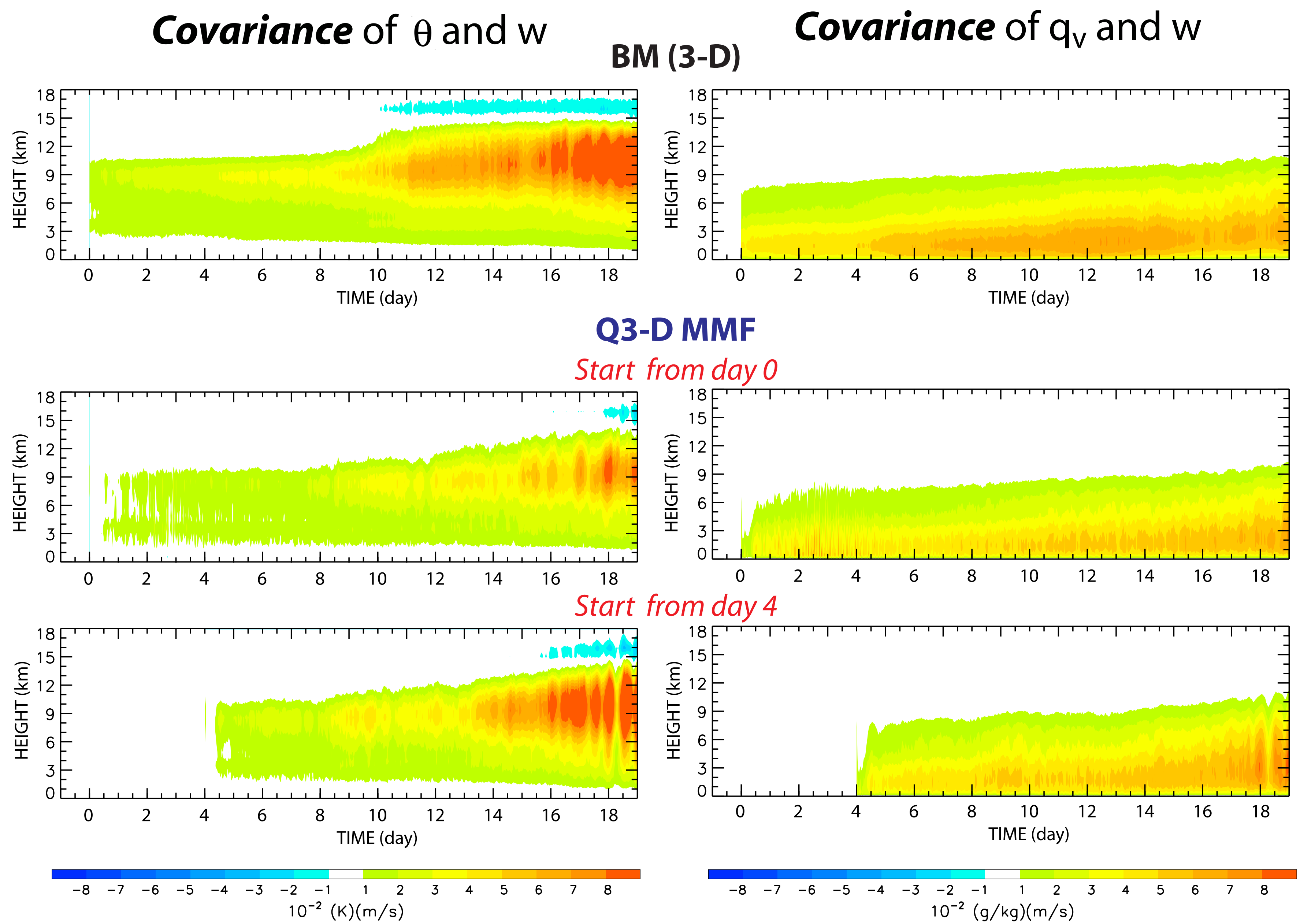

BM
Q3-D
Surface Precipitation
(mm/hr)
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
TIME (day)
Surface Evaporation
(mm/hr)
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
TIME (day)
Surface Sensible Heat Flux
(W/m2)
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
TIME (day)



Variance of θ
BM (3-D)
Variance of q_v
Q3-D MMF
Start from day 0
Start from day 4
HEIGHT (km)
TIME (day)
K^2
10^{-1} $(g/kg)^2$

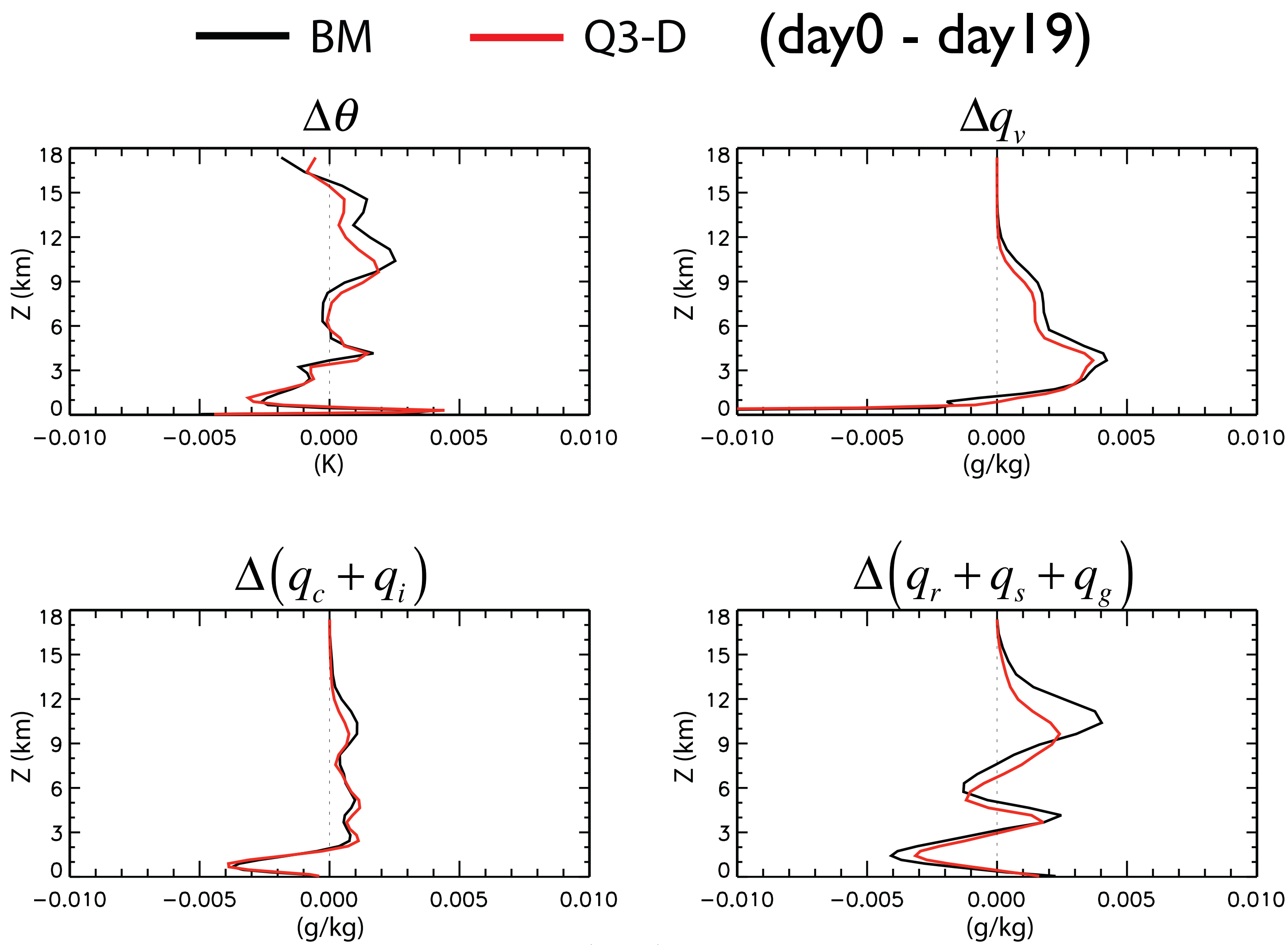


Variance of ξ
Variance of η
BM (3-D)
HEIGHT (km)
TIME (day)
Q3-D MMF
Start from day 0
Start from day 4
(10⁻⁶) s⁻²



Covariance of θ and w
BM (3-D)
Covariance of q_v and w
HEIGHT (km)
TIME (day)
Q3-D MMF
Start from day 0
Start from day 4
−8 −7 −6 −5 −4 −3 −2 −1 1 2 3 4 5 6 7 8
10^{-2} (K)(m/s)
10^{-2} (g/kg)(m/s)

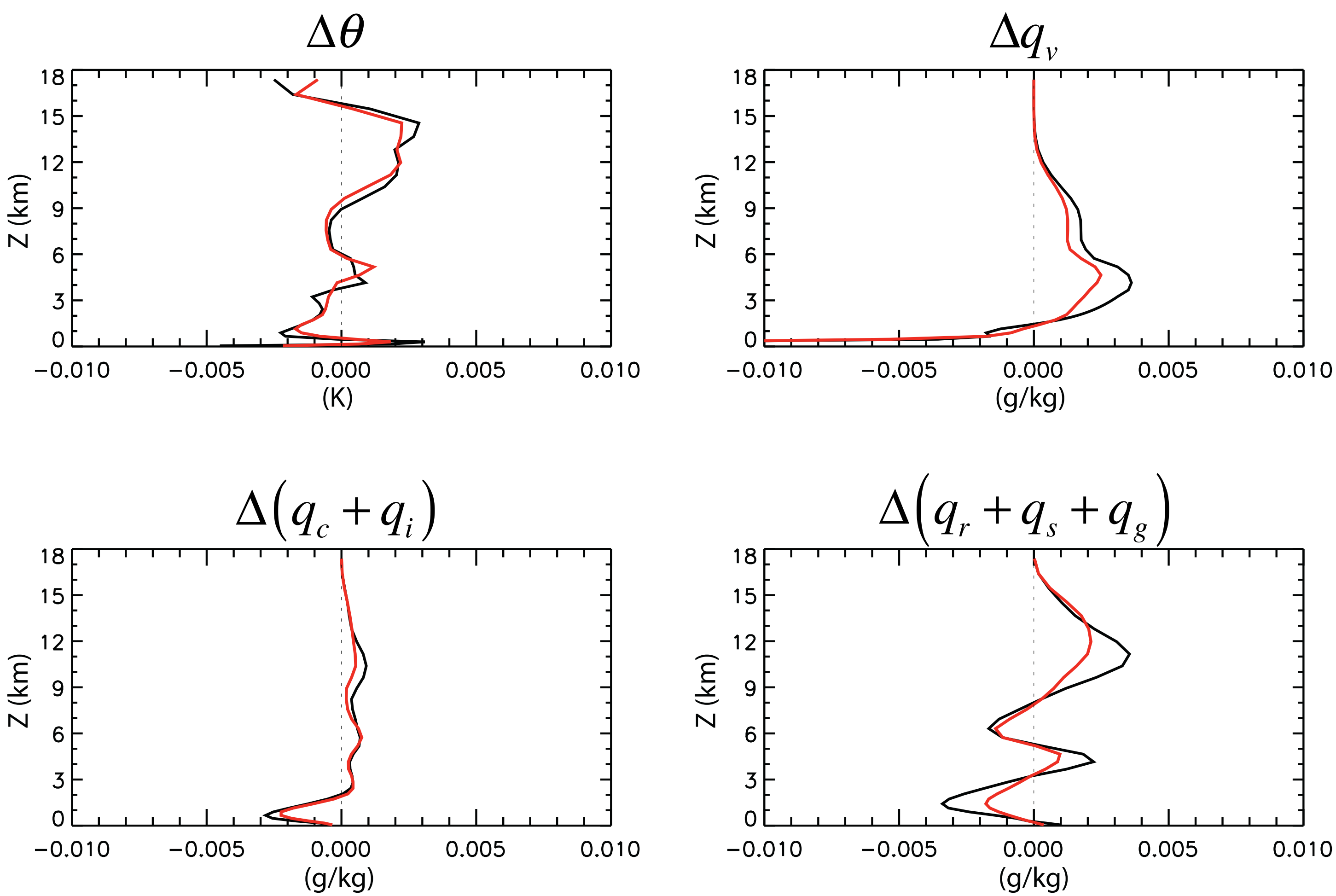
Time- and Domain-Averaged Eddy Transport Effect



$$\Delta q \equiv \left(\frac{\partial q}{\partial t} \right)_{eddy} \cdot dt_{GCM}$$

Time- and Domain-Averaged Eddy Transport Effect

BM Q3-D (day12 - day19)



$$\Delta q \equiv \left(\frac{\partial q}{\partial t}\right)_{eddy} \cdot dt_{GCM}$$

Completed Tasks

- Finalizing a Q3-D algorithm
- Constructing a parallelized code of Q3-D MMF
- Evaluating the new Q3-D MMF code

  The current Q3-D MMF reasonably predicts the transition of initial weak wave to vortices and most of the time evolution of variances and covariances appearing in BM.

Future Tasks

- Raising the upper boundary
- Preparing for publication
- Testing a simplified Q3-D MMF through climate-oriented simulations

For example,

Horizontal Domain = 3000 km x 3000 km

Horizontal GCM grid = 200 km

Horizontal CRM grid = 2 km

$$\frac{\text{\# of grid points of (simplified) Q3-D CRM}}{\text{\# of grid points of 3-D CRM}} \sim 6\ \%\ (2\ \%)$$

If horizontal CRM grid = 1 km ~ 6 % (1 %)