Progress Report

Research Objective 1:
Development of a Q3D MMF

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Objective

Develop and finalize the coupling algorithm for the GCM and CRM

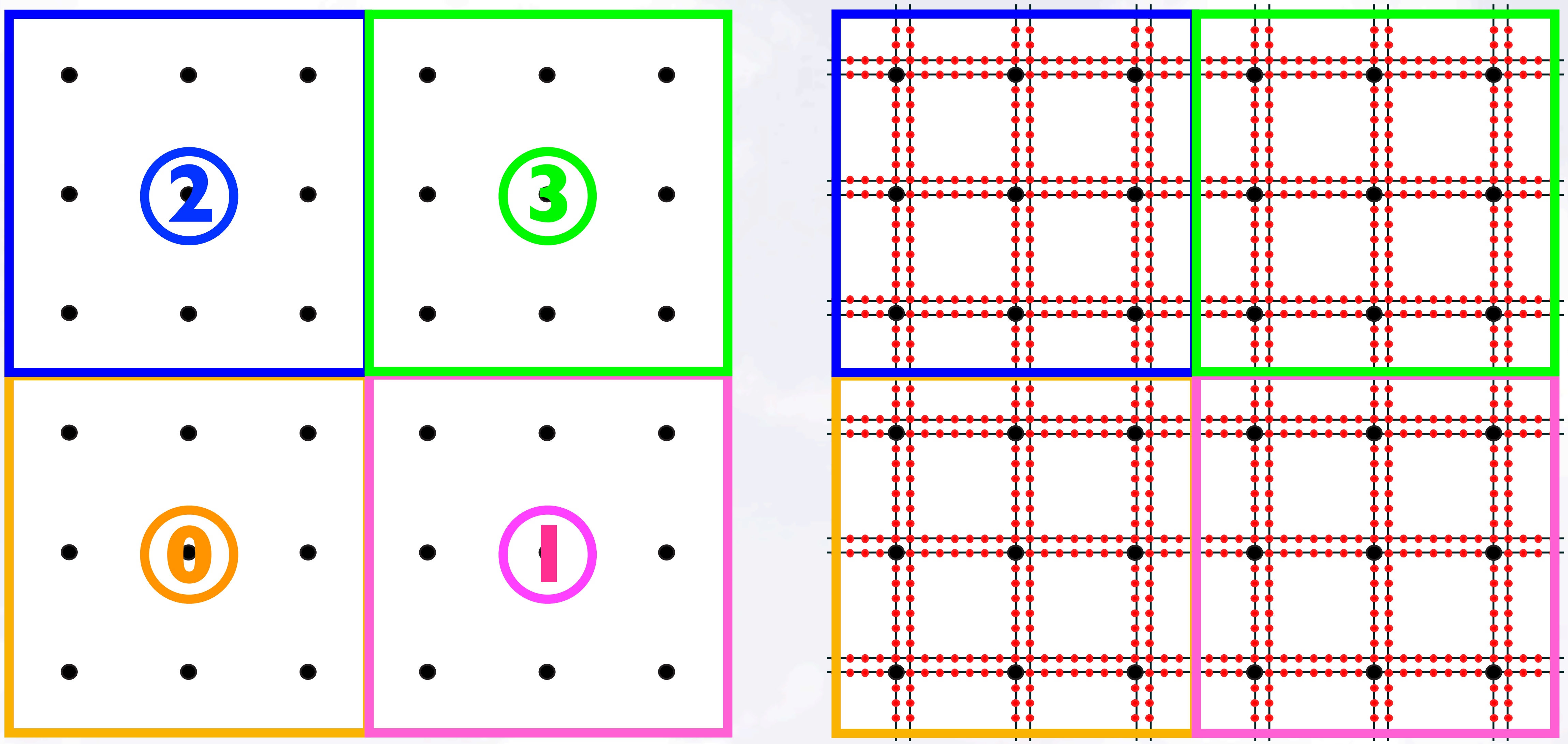
Completed Tasks:

Developing a new parallelized code of the Q3D MMF
(Fortran 77/serial ⟶ Fortran 90/parallelized)

- Forming a structure of Q3D MMF:
  - GCM: active dynamics, saturation adjustment, and I/O
  - Q3D CRM: active dynamics, full physics, I/O, and Q3D algorithm (channel structure, background field and ghost point calculations, channel coupling, solving elliptic equations, etc.)
  - Interface between GCM and Q3D CRM
  - Preparation of initial conditions from BM (3D CRM) data
  - All I/O data are in machine-independent data formats (netCDF)

Global horizontal domain is divided into rectangular subdomains of equal size

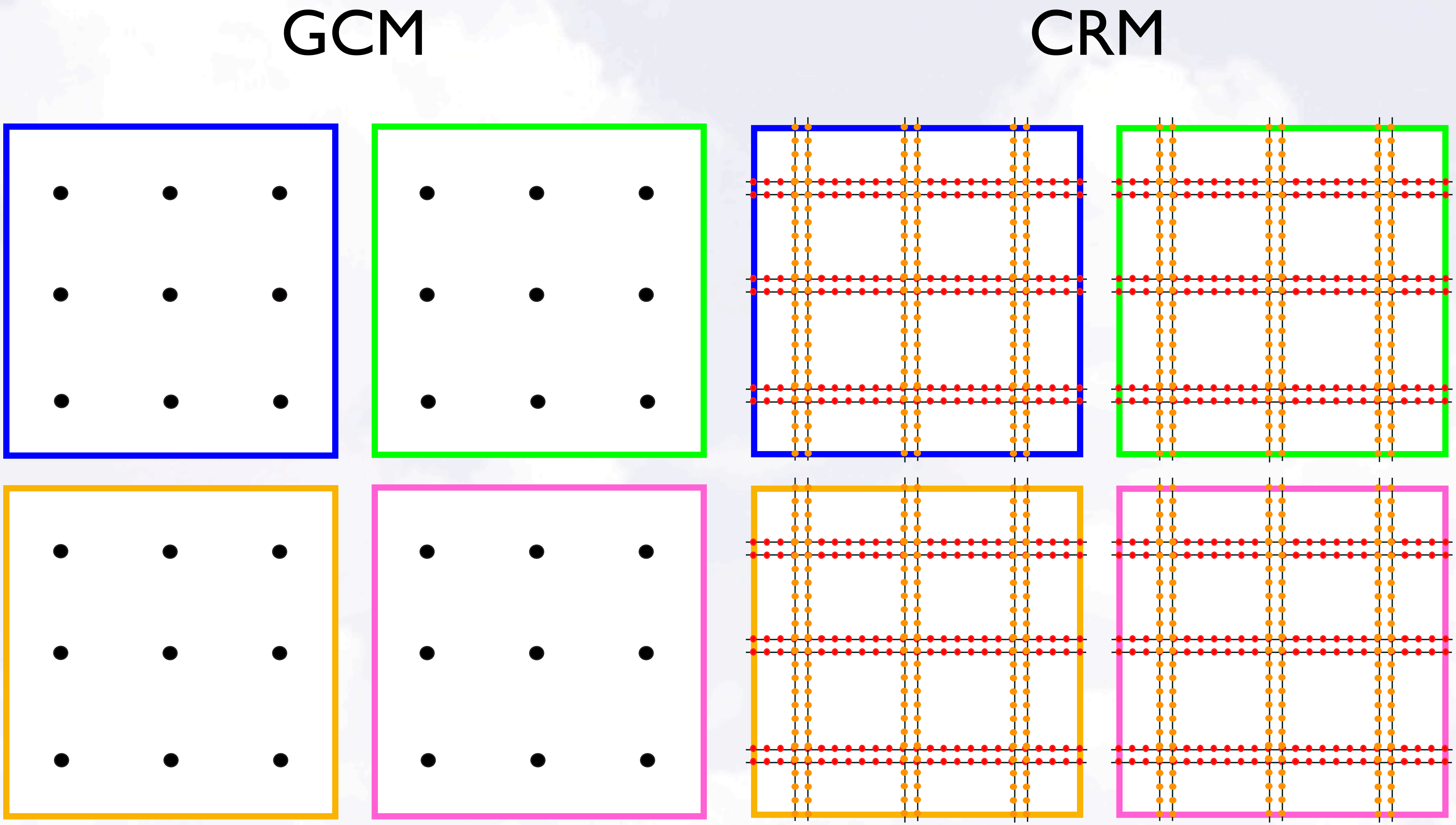
Subdomains are distributed among computer processors



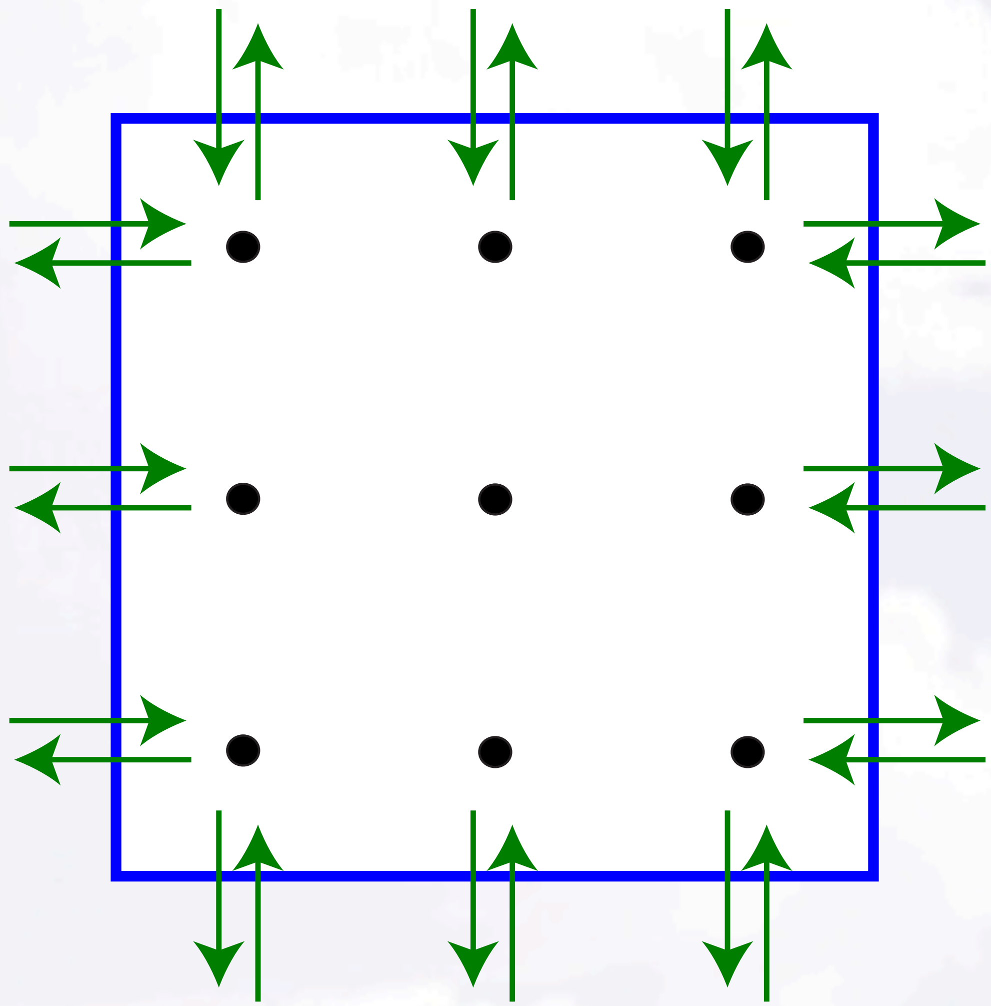
● GCM grid point

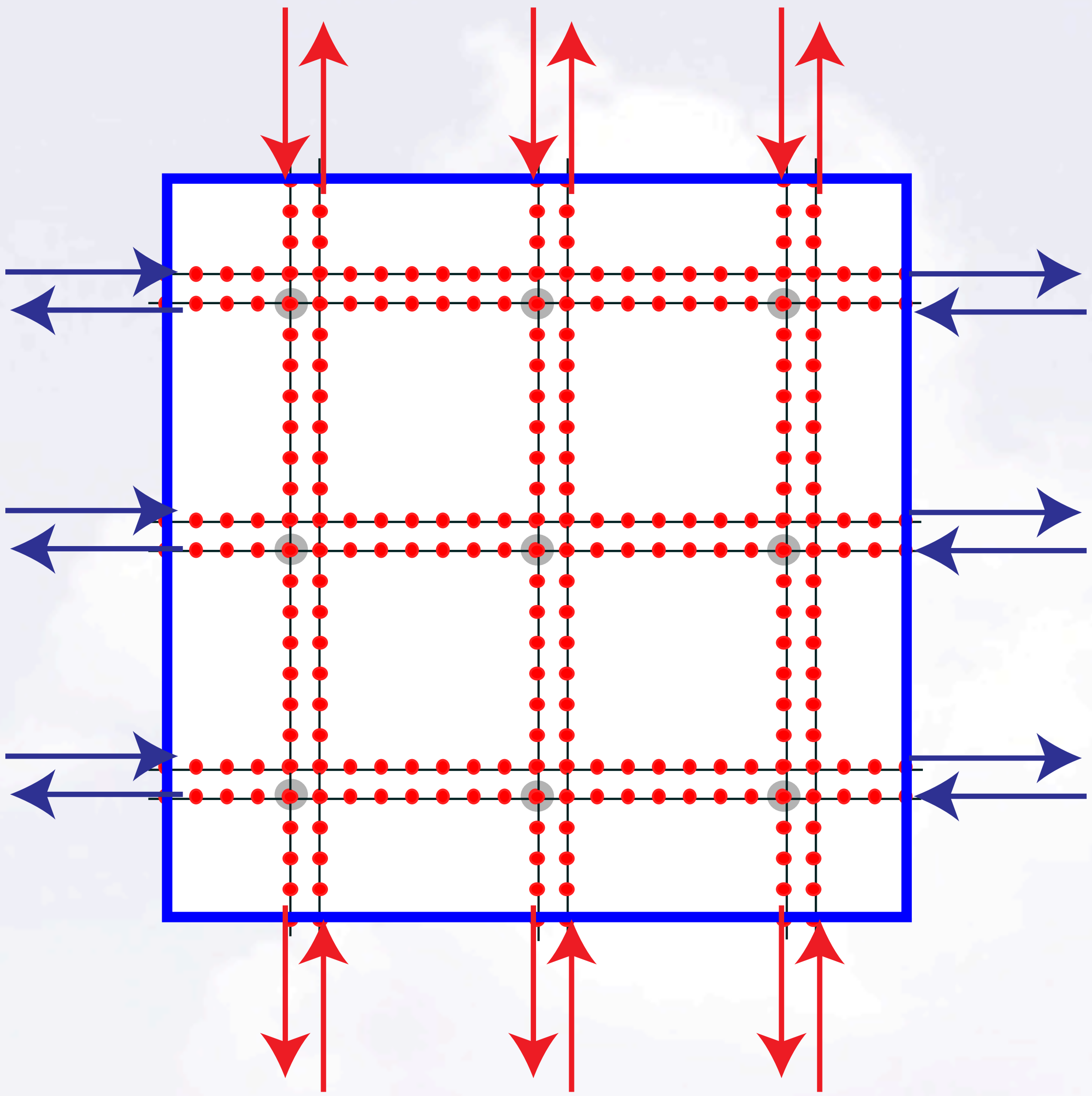
● CRM grid point

Each process simultaneously performs own calculation



Communication between Neighboring Domains by Message Passing Interface (MPI)



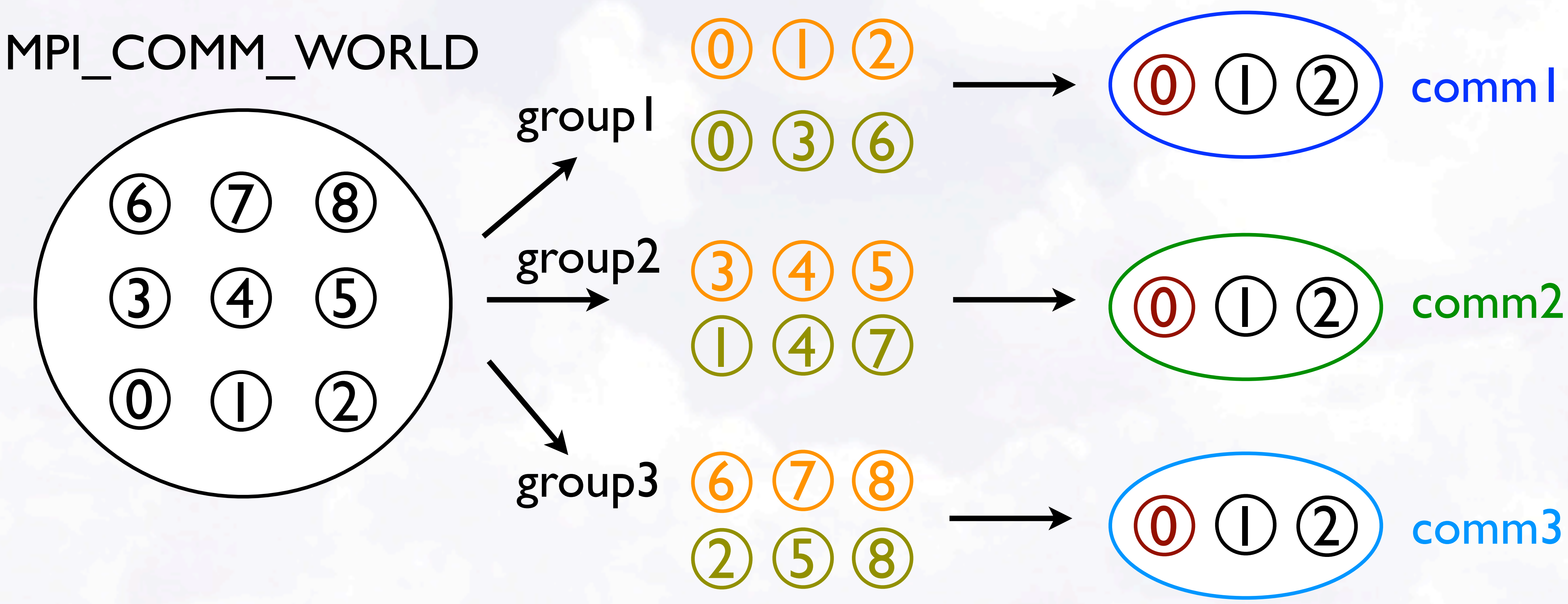


For GCM calculation, message passing involves two directions (e/w *and* s/n).

For Q3D CRM calculation, message passing involves only one direction (e/w *or* s/n).

Parallelization Exceptions

- I/O - gathered to one process into global size array.
- Elliptic Solver: A relaxation procedure is used to solve the w-eq, which is based on an iteration method.
  - New groups are formed as subsets of global group.
  - One process of each group performs the relaxation procedure.



Completed Tasks (continued.):

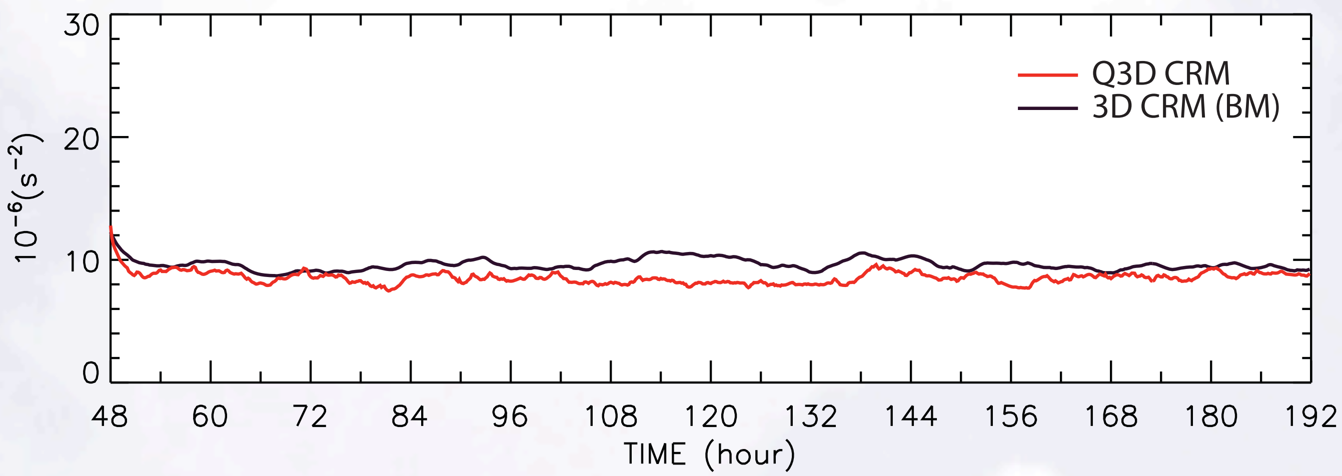
- Test the new Q3D MMF code following Jung and Arakawa (2010): small horizontal domain & trivial GCM

  - Horizontal Domain Size: 384 km x 384 km
  - Horizontal grid size: dx=dy=3 km (CRM), 192 km (GCM)
  - GCM values are obtained from the averages of BM data (the case with well organized convective activity)
  - No coupling between the GCM and CRM: The role of GCM is to provide the background fields for CRM
  - 4 computing processors are used

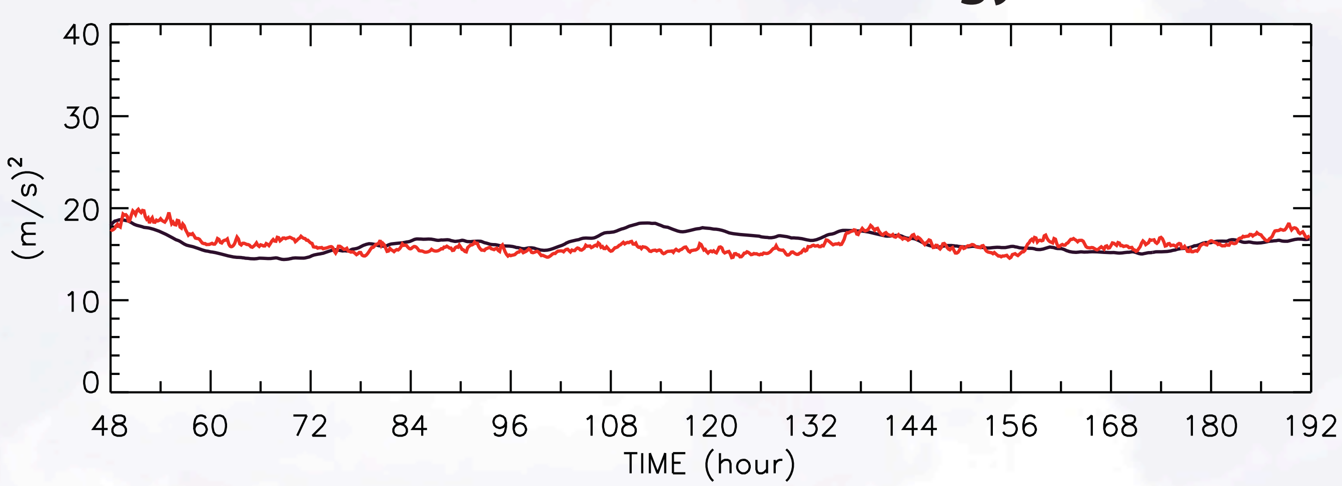
Small Domain Test

(trivial GCM & no coupling between GCM and CRM)

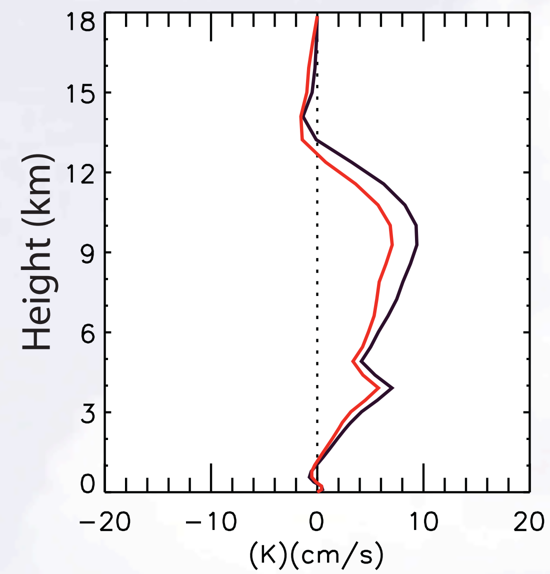
Mean Enstrophy



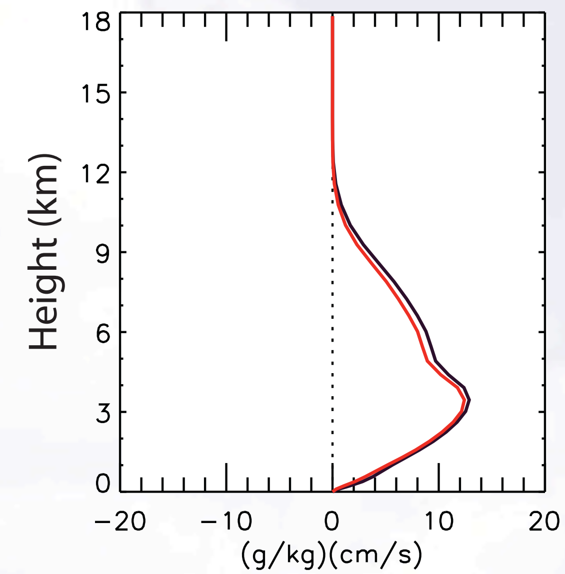
Mean Kinetic Energy



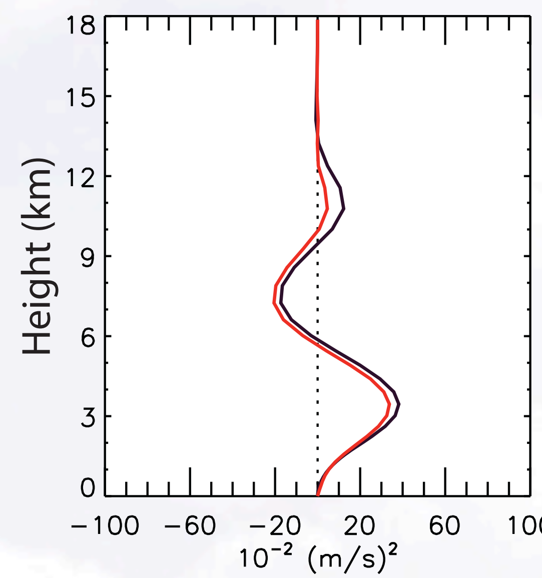
Covariance of θ and w



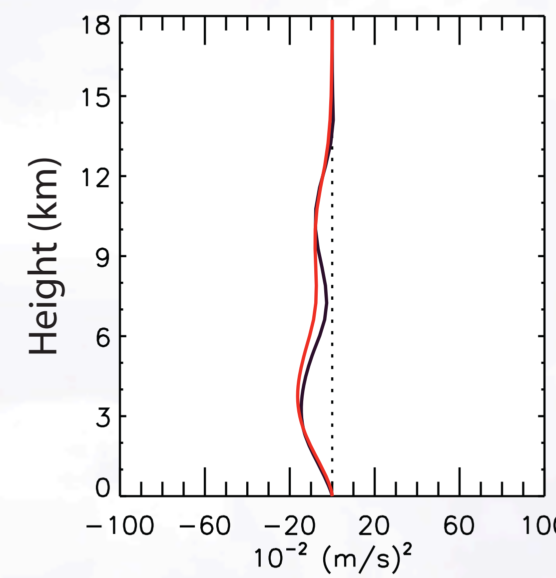
Covariance of q_v and w



Covariance of u and w



Covariance of v and w



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

An Idealized Benchmark Simulation

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

Goal:

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)

$f=3.8 \times 10^{-5} s^{-1}$, prescribed radiative cooling rate, SST=302 K

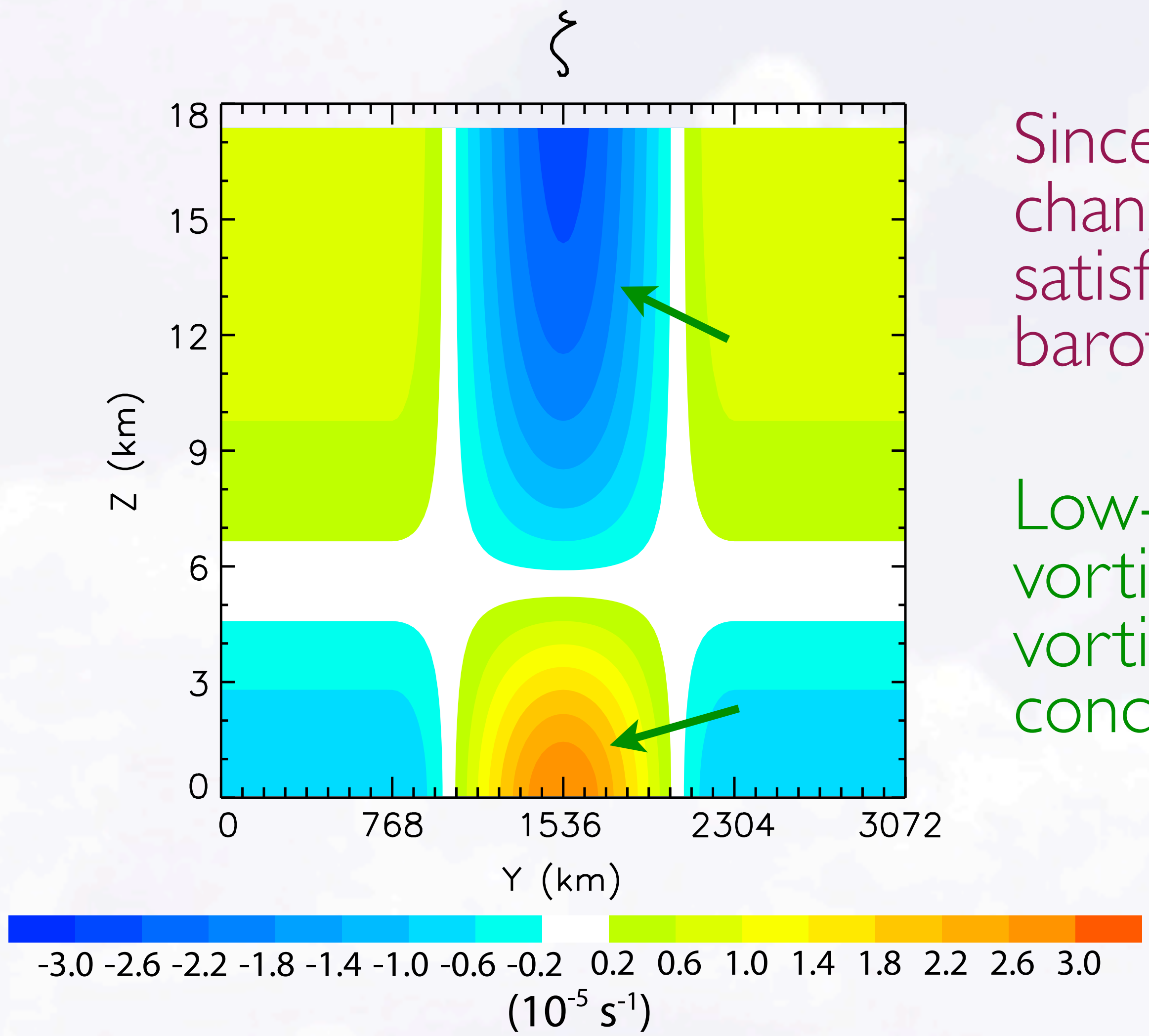
Periodic boundary condition

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.



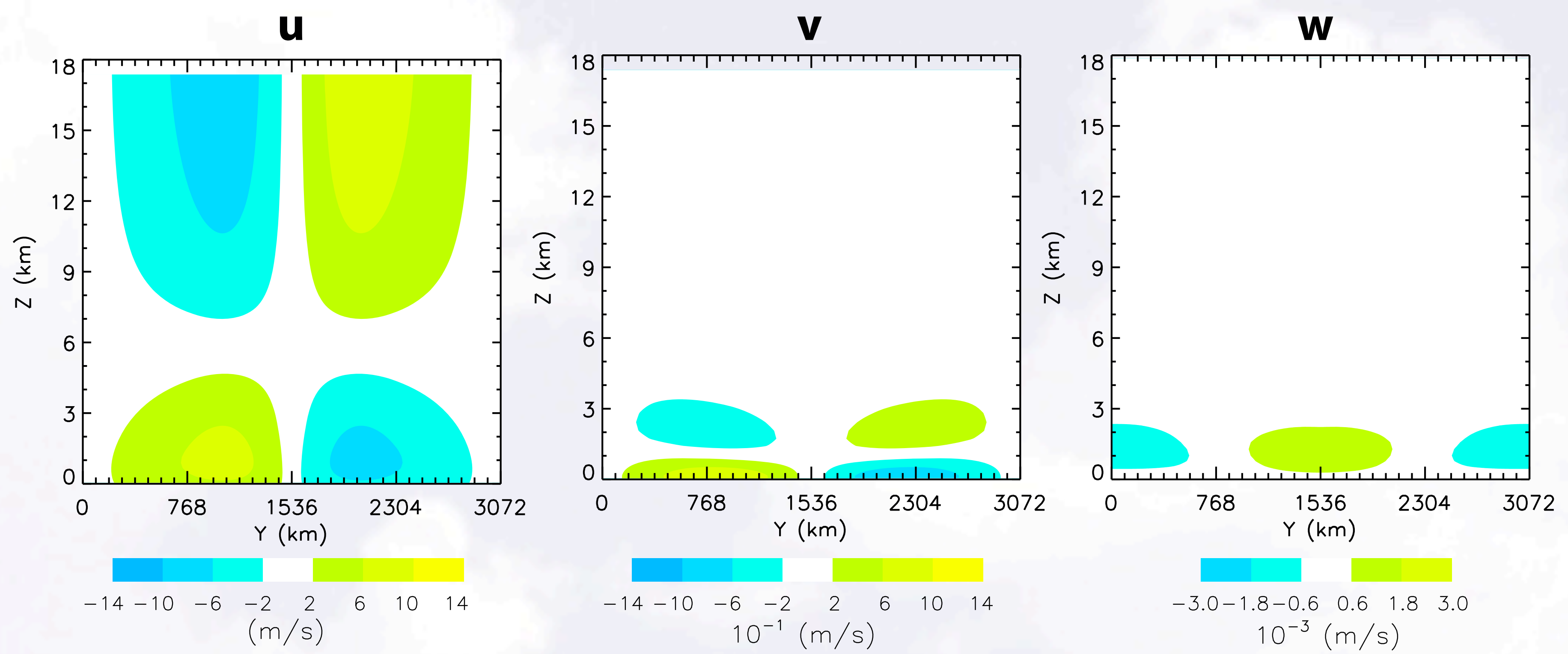
Since the meridional gradient of the vorticity changes sign at the center of the domain, it satisfies the necessary condition for barotropic instability.

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.)

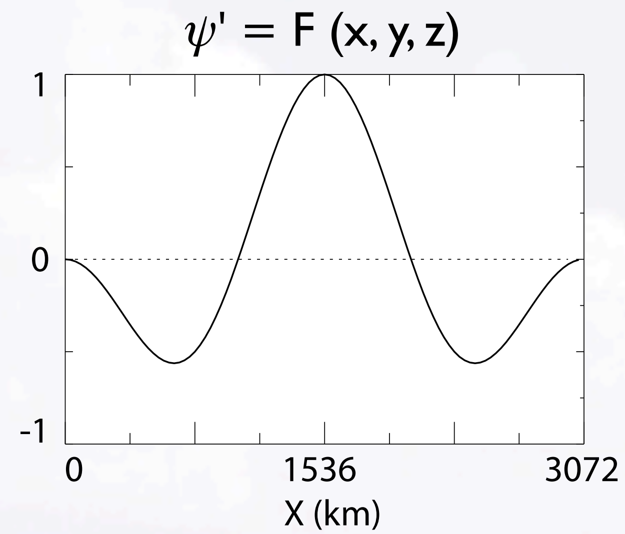
Experimental Phases:

Phase 1 - Dynamic adjustment through boundary-layer processes



Phase 2 - Thermodynamic adjustment through full physics

Phase 3 - Main simulation

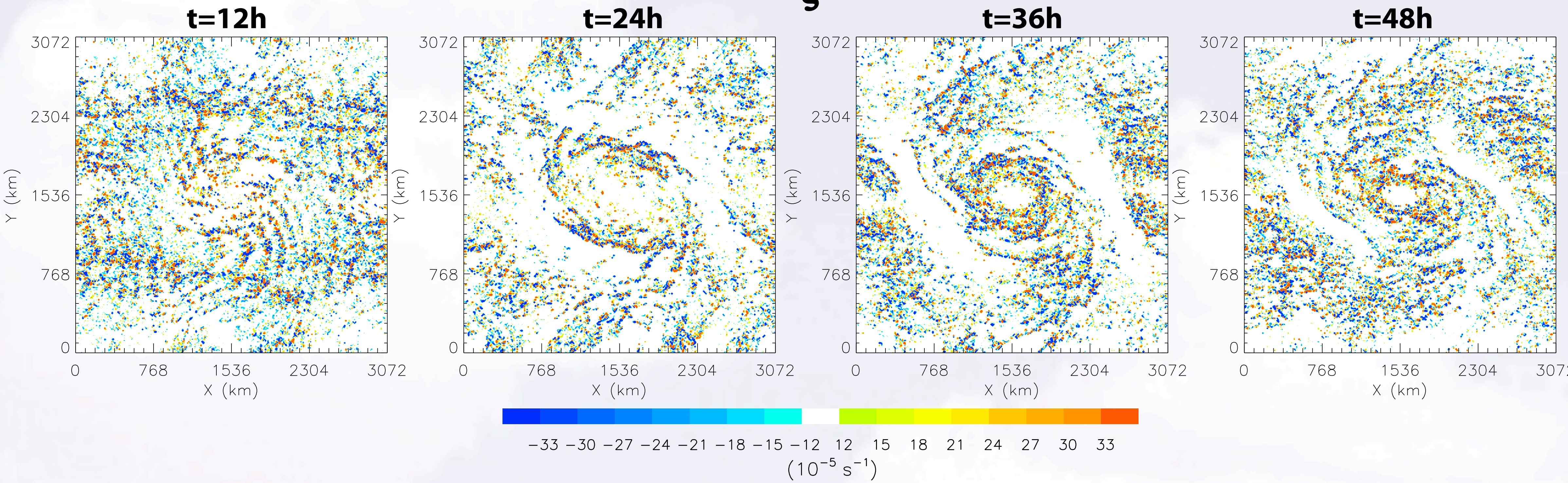


A small amplitude wave is introduced into the motion field.

Phase 3

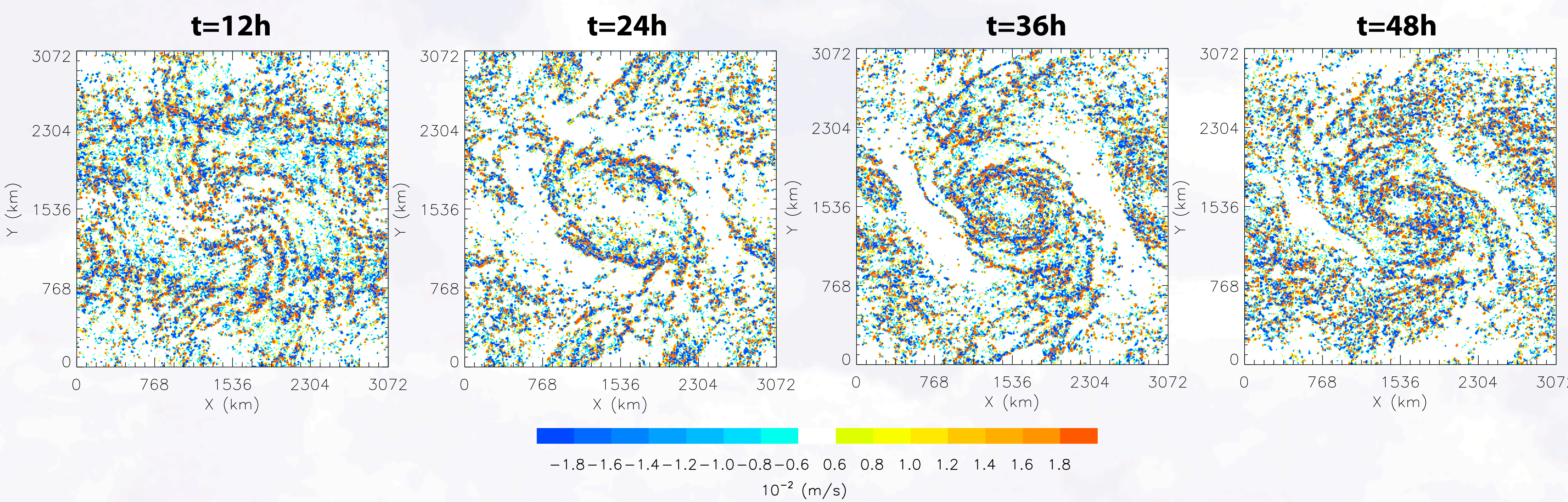
z = 46 m

ζ



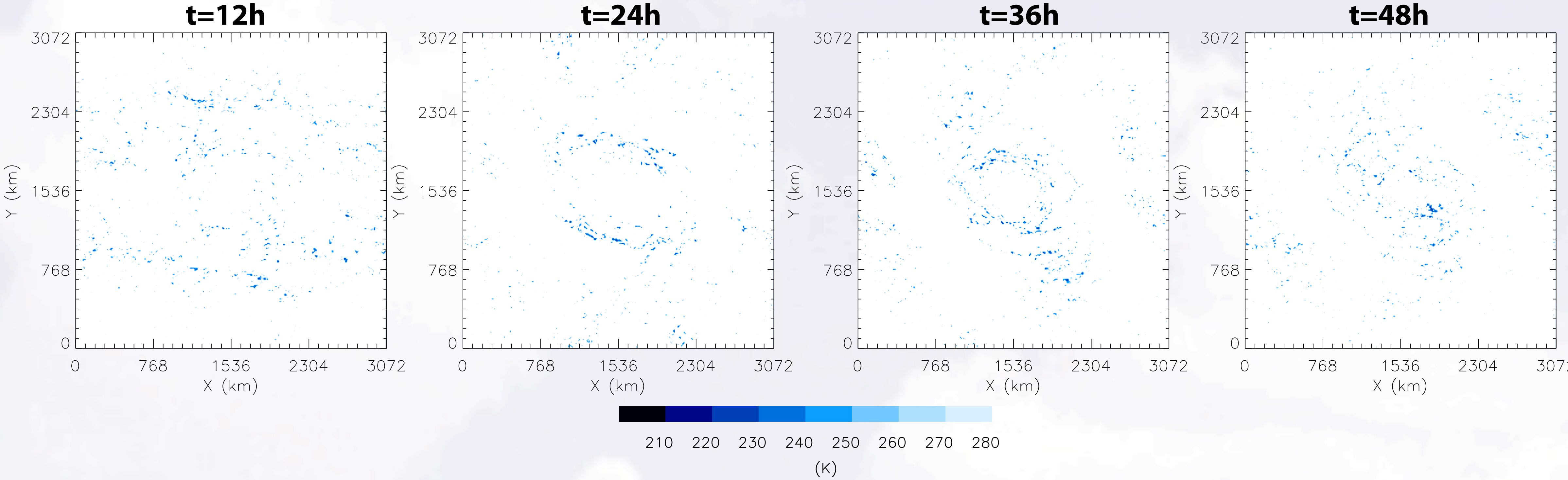
z = 100 m

Vertical Velocity

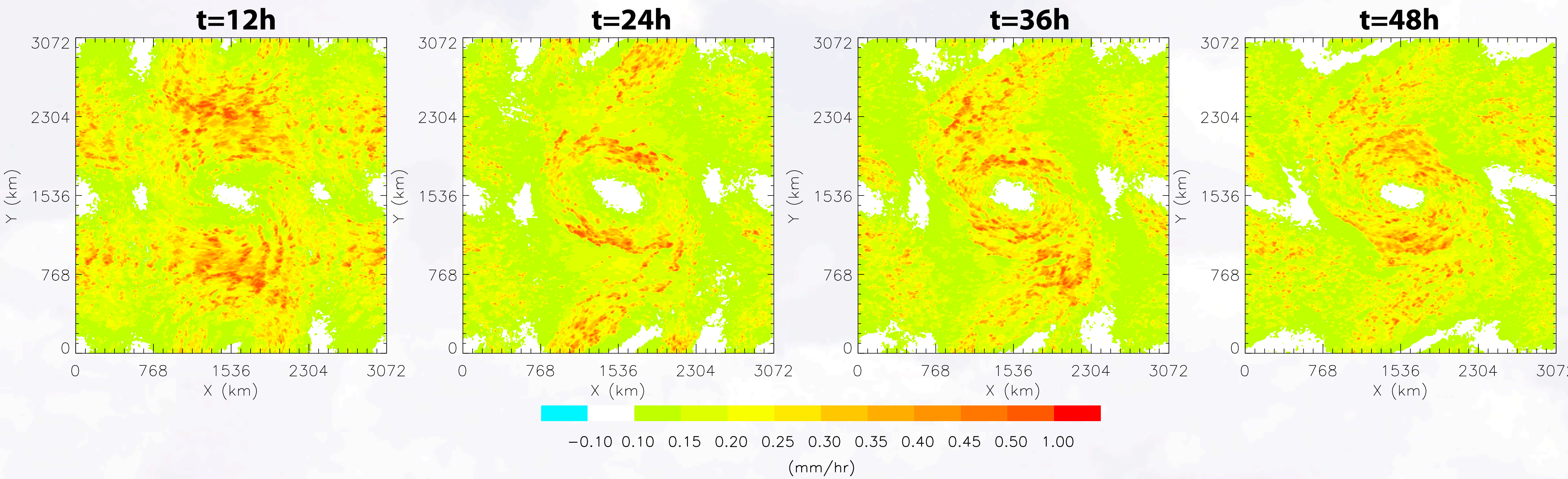


Phase 3

Cloud Top Temperature



Surface Evaporation Rate



Coupling Strategy

GCM effect on the CRM

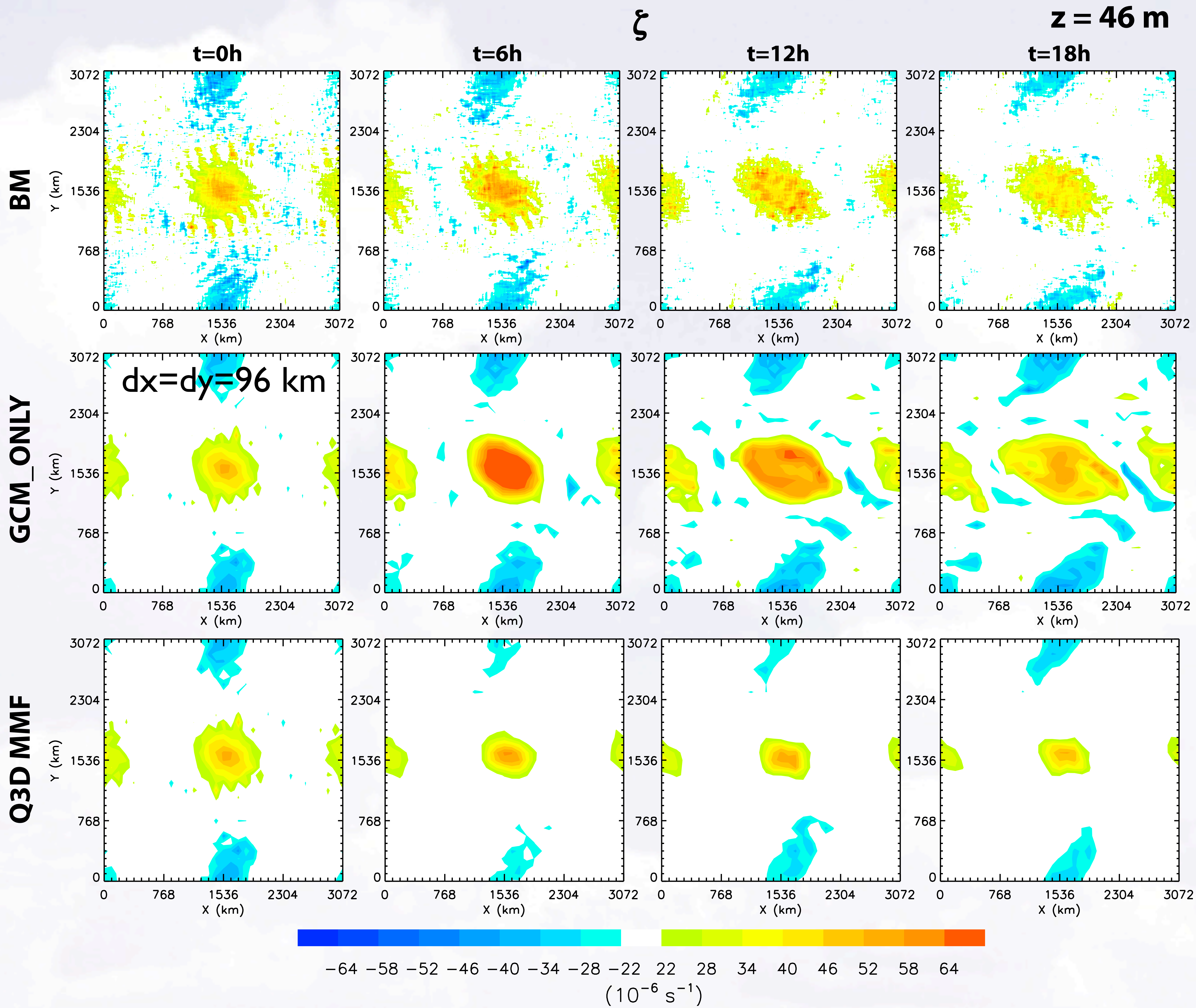
Since the Q3D CRM can partially represent large scale dynamics, it should not be forced by the GCM to avoid "double counting" in the coupled system. However, it is important that large scale fields recognized by the CRM should be sufficiently close to the GCM fields.

CRM effect on the GCM

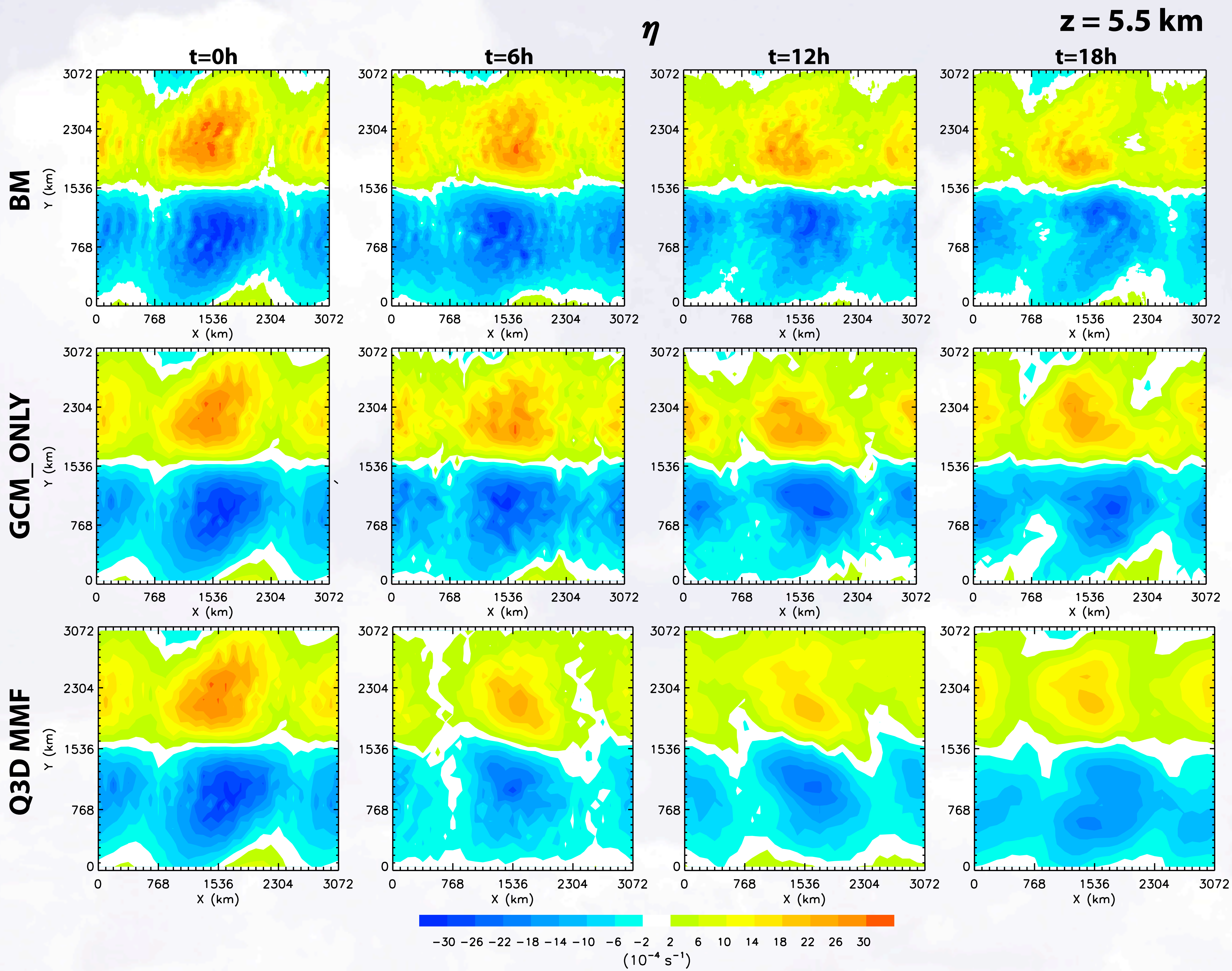
As in the subgrid parameterization problems, the role of the CRM is to estimate the effects of eddies not resolved by the GCM. Thus, the CRM effect must be limited to the eddy effects by subtracting the non-eddy effects.

Not tested yet!

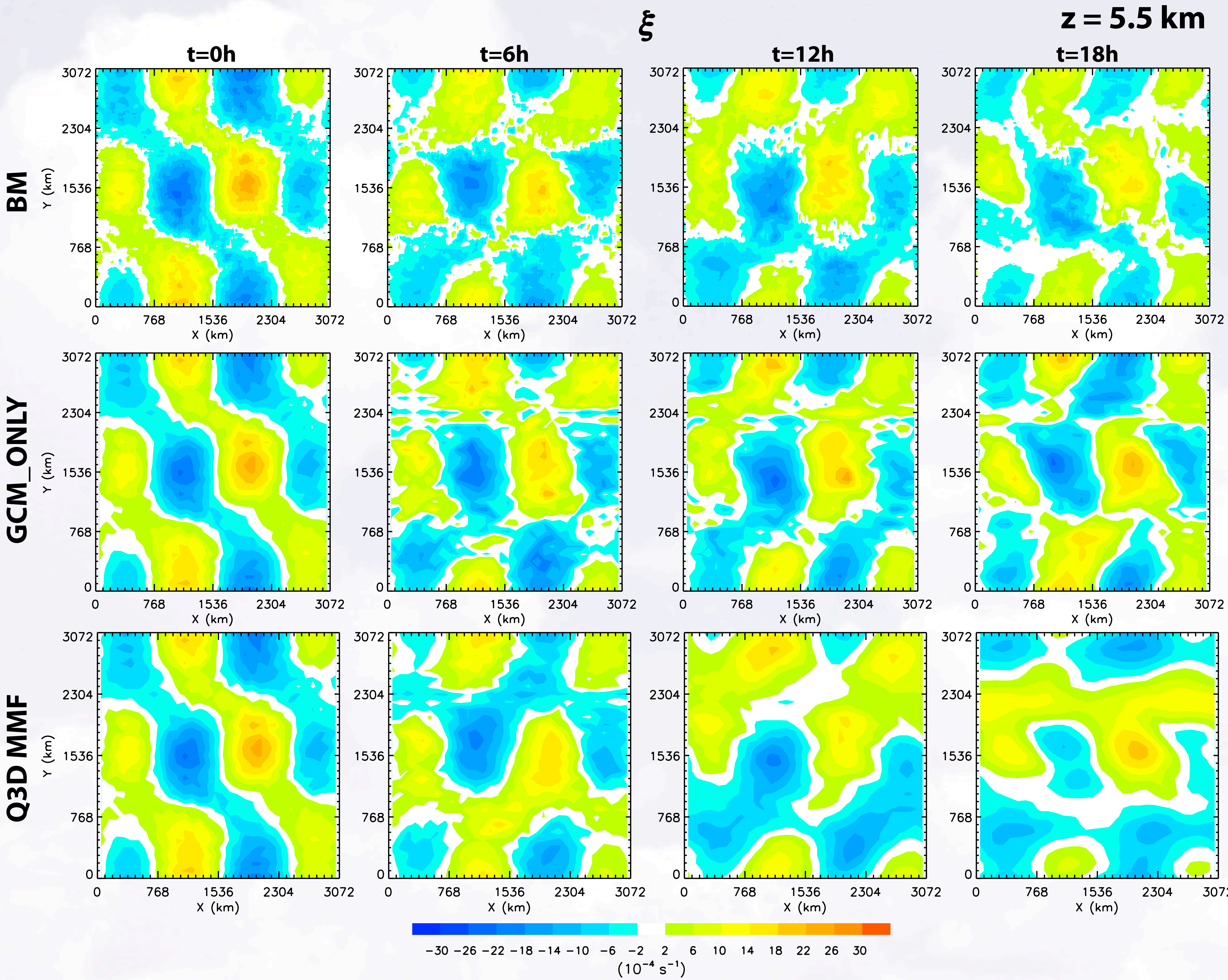
Instead, we tried a mutual relaxation through nudging.



ζ
z = 46 m
t=0h
t=6h
t=12h
t=18h
BM
GCM_ONLY
Q3D MMF
dx=dy=96 km
Y (km)
X (km)
0
768
1536
2304
3072
−64 −58 −52 −46 −40 −34 −28 −22 22 28 34 40 46 52 58 64
(10^{-6} s^{-1})



η
z = 5.5 km
t=0h
t=6h
t=12h
t=18h
BM
GCM_ONLY
Q3D MMF
Y (km)
X (km)
0
768
1536
2304
3072
−30 −26 −22 −18 −14 −10 −6 −2 2 6 10 14 18 22 26 30
$(10^{-4}\ s^{-1})$


ξ
z = 5.5 km
t=0h
t=6h
t=12h
t=18h
BM
GCM_ONLY
Q3D MMF
Y (km)
X (km)
0
768
1536
2304
3072
−30 −26 −22 −18 −14 −10 −6 −2 2 6 10 14 18 22 26 30
(10⁻⁴ s⁻¹)