Research Objective:

Development of a Q3D MMF

Progress towards a global Q3D MMF

Joon-Hee Jung

Thanks to professor Akio Arakawa for helpful comments.

August 4-6, 2015 CMMAP Team Meeting, Fort Collins

Progress Report

- The quasi-3D multi-scale modeling framework (Q3D MMF) is a second-generation MMF, in which the inherent deficiencies of the first-generation MMF have been eliminated or reduced.
- With the support of CMMAP, the algorithm of Q3D MMF has been developed and successfully tested in a limited-area model.

Publications:

A. Arakawa, J.-H. Jung, and C.-M. Wu, 2015: Multiscale modeling of the moist-convective atmosphere. AMS Monographs (in press).

Jung, J.-H., and A. Arakawa, 2014: Modeling the moist-convective atmosphere with a quasi-3d multiscale modeling framework (Q3D MMF). *J. Adv. Model. Earth Syst.*, 6, 185-205.

A. Arakawa, and J.-H. Jung, 2011: Multiscale modeling of the moist-convective atmosphere - A review. *Atmospheric Research*, 102, 263-285.

Wu, C.-M., and A. Arakawa, 2011: Inclusion of surface topography into the vector vorticity equation model (VVM). *J. Adv. Model. Earth Syst.*, 3, Art. M06002, 13pp.

A. Arakawa, J.-H. Jung, and C.-M. Wu, 2011: Toward unification of the multiscale modeling of the atmosphere. *Atmos. Chem. Phys.*, 11, 3731-3742.

Jung, J.-H., and A. Arakawa, 2010: Development of a quasi-3d multiscale modeling framework: motivation, basic algorithm and preliminary results. *J. Adv. Model. Earth Syst.*, 2, Art. #11, 31pp.

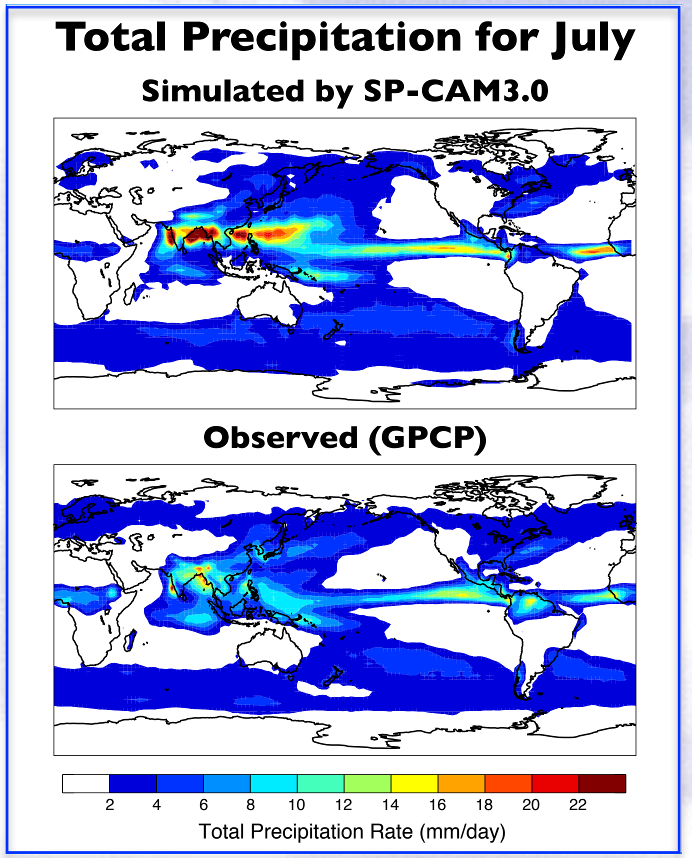
Jung, J.-H., and A. Arakawa, 2008: A three-dimensional anelastic model based on the vorticity equation. *Mon. Wea. Rev.*, 135, 276-294.

Expected Merits of the Q3D MMF as a Research Tool

- Improved simulation of tropical cloud clusters and their manifestations

Most GCMs (including SP-CAM) poorly simulate the surface precipitation in the Indian monsoon and adjacent regions.

As demonstrated by the idealized tropical cyclone generation experiment, a Q3D MMF can well simulate the interaction between the three-dimensional large-scale fields and cumulus convections.



(Prepared by Mark Branson)

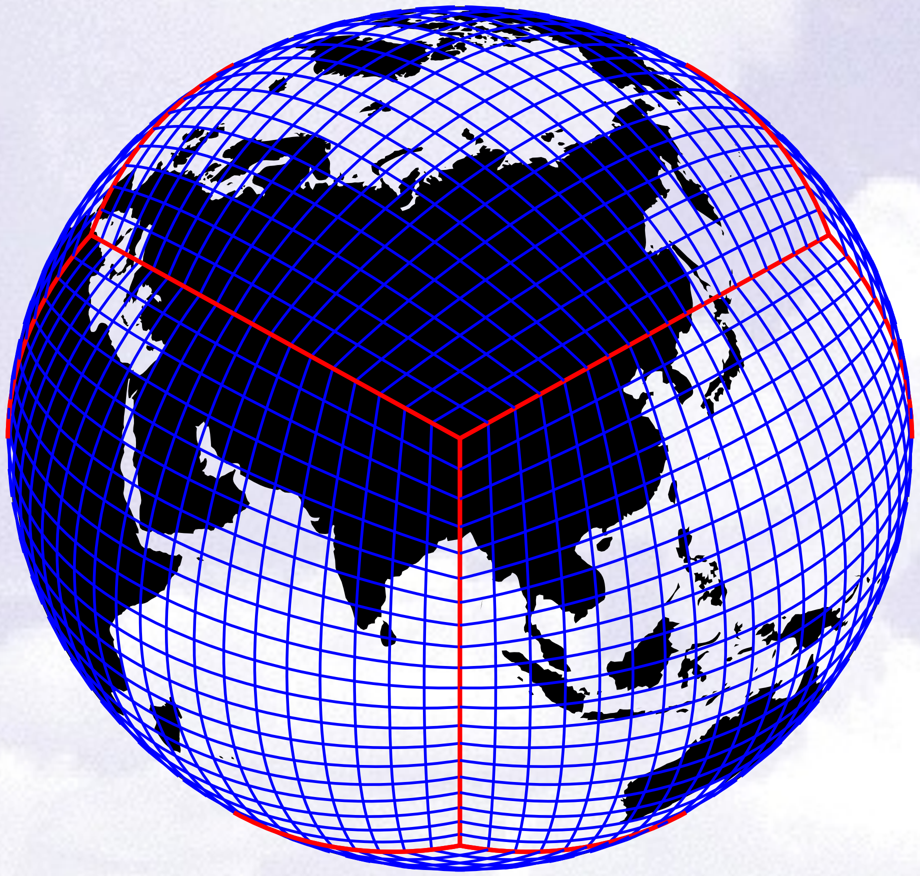
- Improved simulation of orographic precipitation

- Explicit simulation of momentum transports by convection and gravity waves

Development of a Global Q3D MMF

Joon-Hee Jung, Celal Konor, David Randall and Akio Arakawa (CSU/UCLA)
Peter Lauritzen (NCAR)

CRM developed at CSU/UCLA combined with Cubed-sphere dynamical core of the Community Atmosphere Model (CAM) developed at NCAR



Courtesy of Peter Lauritzen

Since the geometry of cubed-sphere grid logically assumes a square grid, it is more straightforward to extend existing regional models based on rectangular Cartesian coordinates to their global versions.

This makes the cubed-sphere grid a natural choice for the global Q3D MMF.

But, any GCM dynamical cores can be used. We will try various dynamical cores in the future.

Research Plans

- **Modification of the CRM for Use in the Global Q3D MMF**
  - Inclusion of surface topography
  - Implementation of the unified system
  - Extension of the CRM to curvilinear coordinates
  - Coupling with the land-surface model
  - Improvement of the code in terms of computational efficiency
- **Construction of a Global Q3D MMF**
  - Development of an interface for coupling the GCM and the CRMs that are independently developed
  - Construction of an optimized parallel code that allows efficient communications between the GCM and the CRMs
- **Evaluation of the Global Q3D MMF**
  - Aqua-planet tests and AMIP-style simulations

  (Tests and analysis will be designed to evaluate the model's performance with an emphasis on its merits as a new research tool.)

Ongoing Work
Inclusion of Surface Topography

Surface topography affects weather and climate by

- influencing the large scale flow through low-level flow blocking,
- generating vertically propagating internal gravity waves that influences the large scale flow through wave-breaking aloft,
- initiating atmospheric convection through forced lifting and surface heating by diurnal solar radiation on mountain slopes.

It is crucial to properly represent these topographic effects in the model for better simulation of weather and climate.

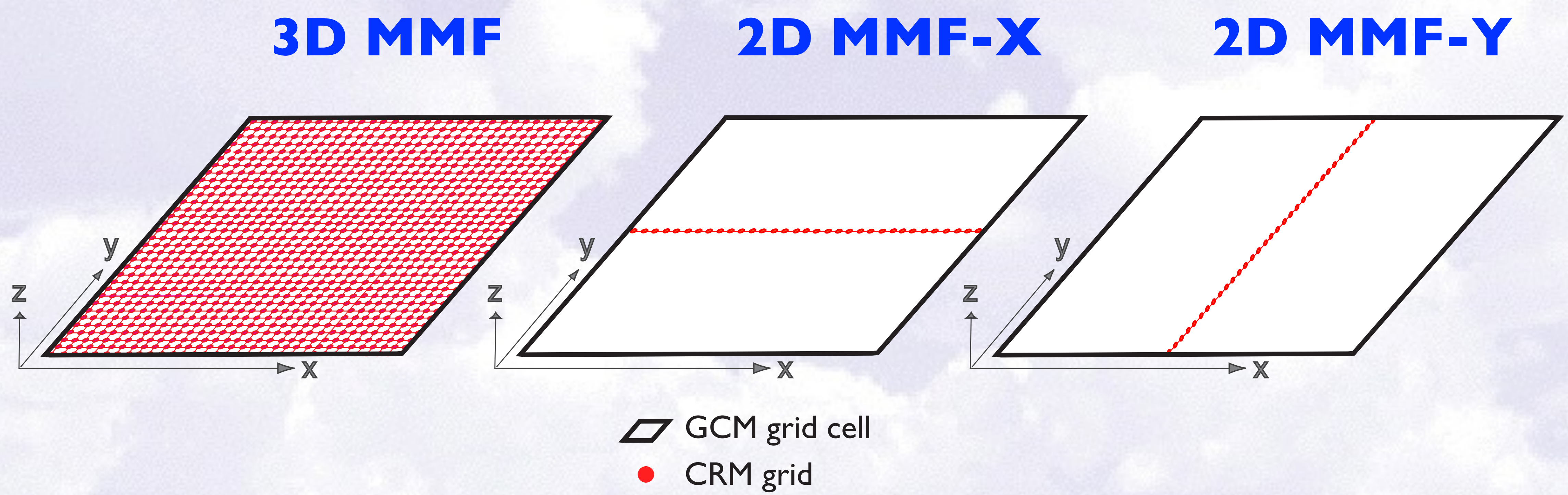
MMF has an advantage of explicitly resolving these effects.

Is it acceptable to use a 2-D CRM to simulate orographic precipitation due to complex 3-D topography even statistically?

Idealized 3D MMF (single-column GCM + 3-D CRM)

vs.

Idealized 2D MMF (single-column GCM + 2-D CRM)

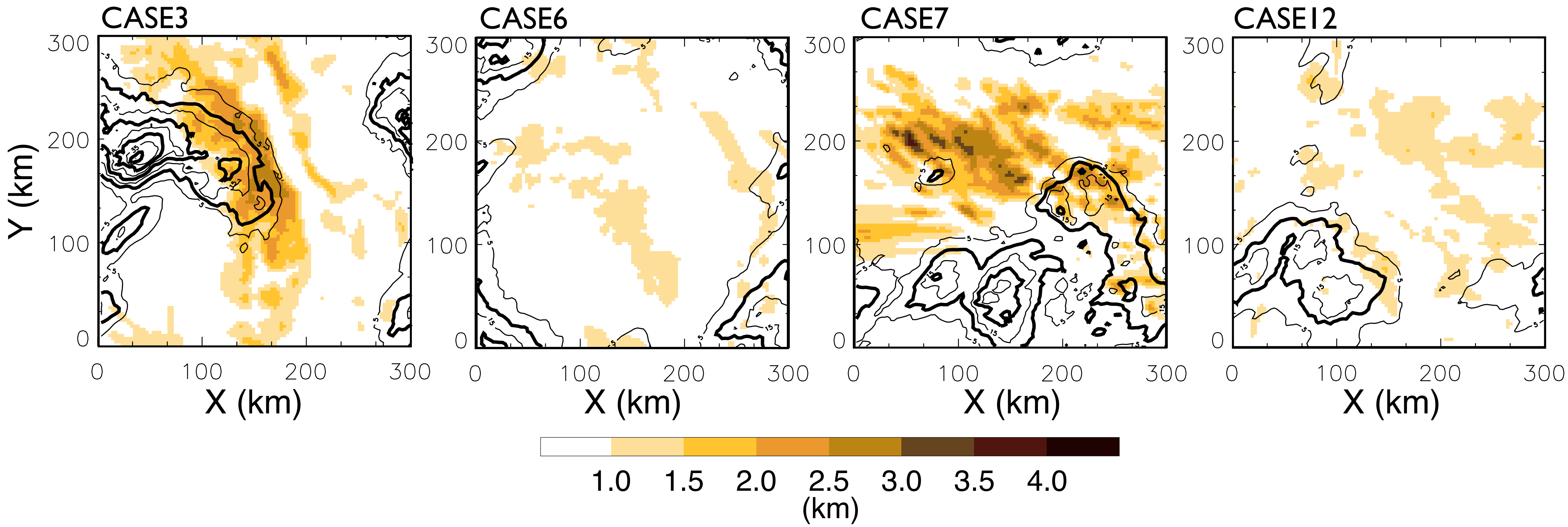


Idealized MMF Simulations

- **GCM cell size:** 300 km x 300 km
- **Vertical domain** of the GCM and CRM: 30 km
- **Initial Conditions:**
  - Vertical profiles of potential temp. and moisture are prescribed
  - Uniform southwesterly flow: U = V = 10 m/s
  - Initial state is maintained with time and regarded as the GCM state
- **In the CRM**
  - Horizontal grid: 3 km, Vertical grid: 0.1 ~ 1.7 km (stretched grid)
  - No radiation, No Coriolis force, No surface fluxes of sensible heat and moisture
  - Periodic boundary condition
- **The domain averages of CRM are nudged to GCM values**
- **Surface Elevation Data:**
  - 15 samples from high-resolution data of real topography
  - Domain averages of surface elevation are adjusted to a constant height of 1 km

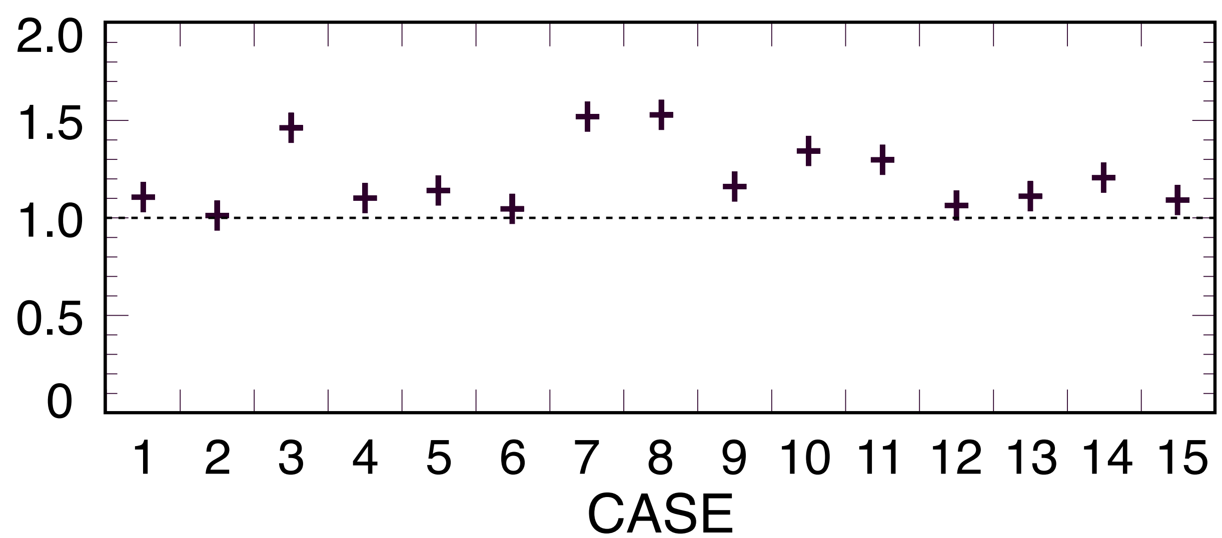
Simulated Results by the 3D MMF

Precipitation Intensity (24 hr average)



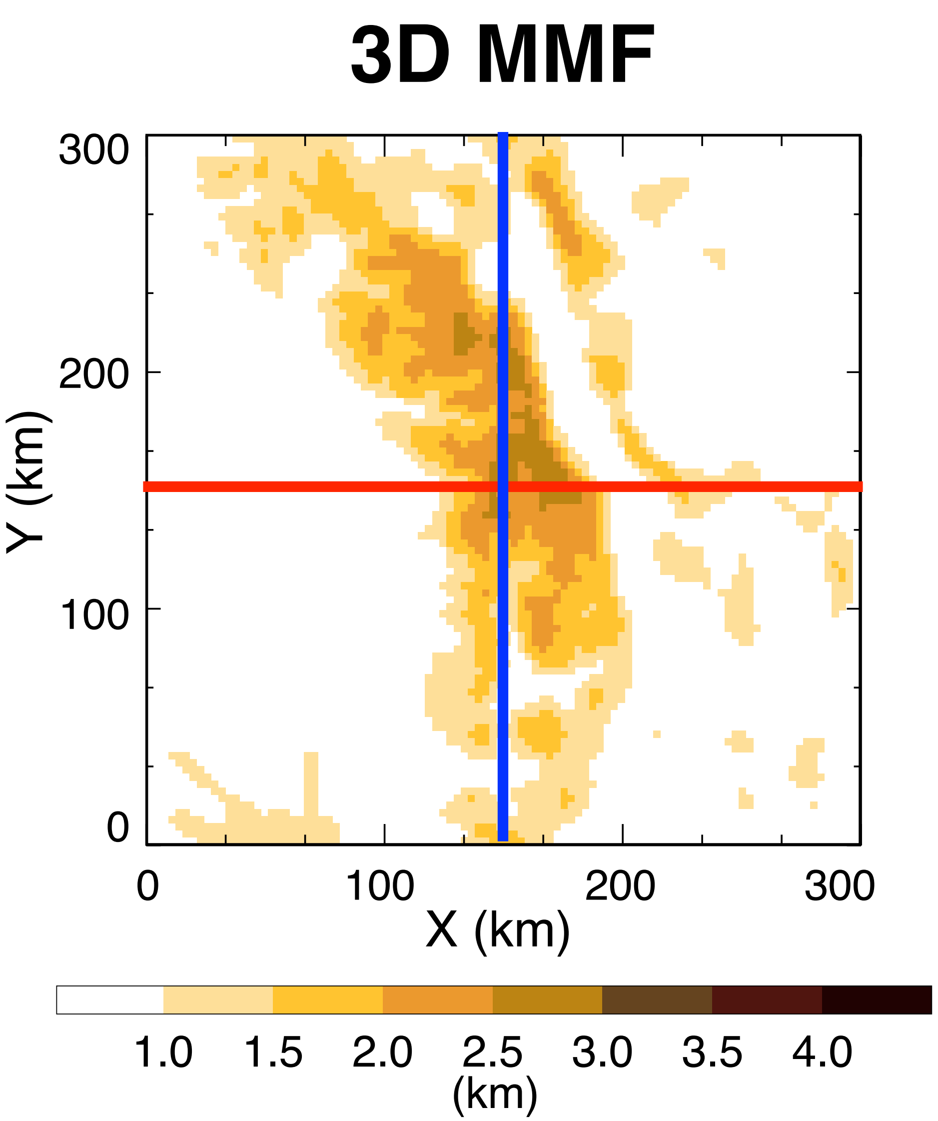
Mean Precipitation Intensity

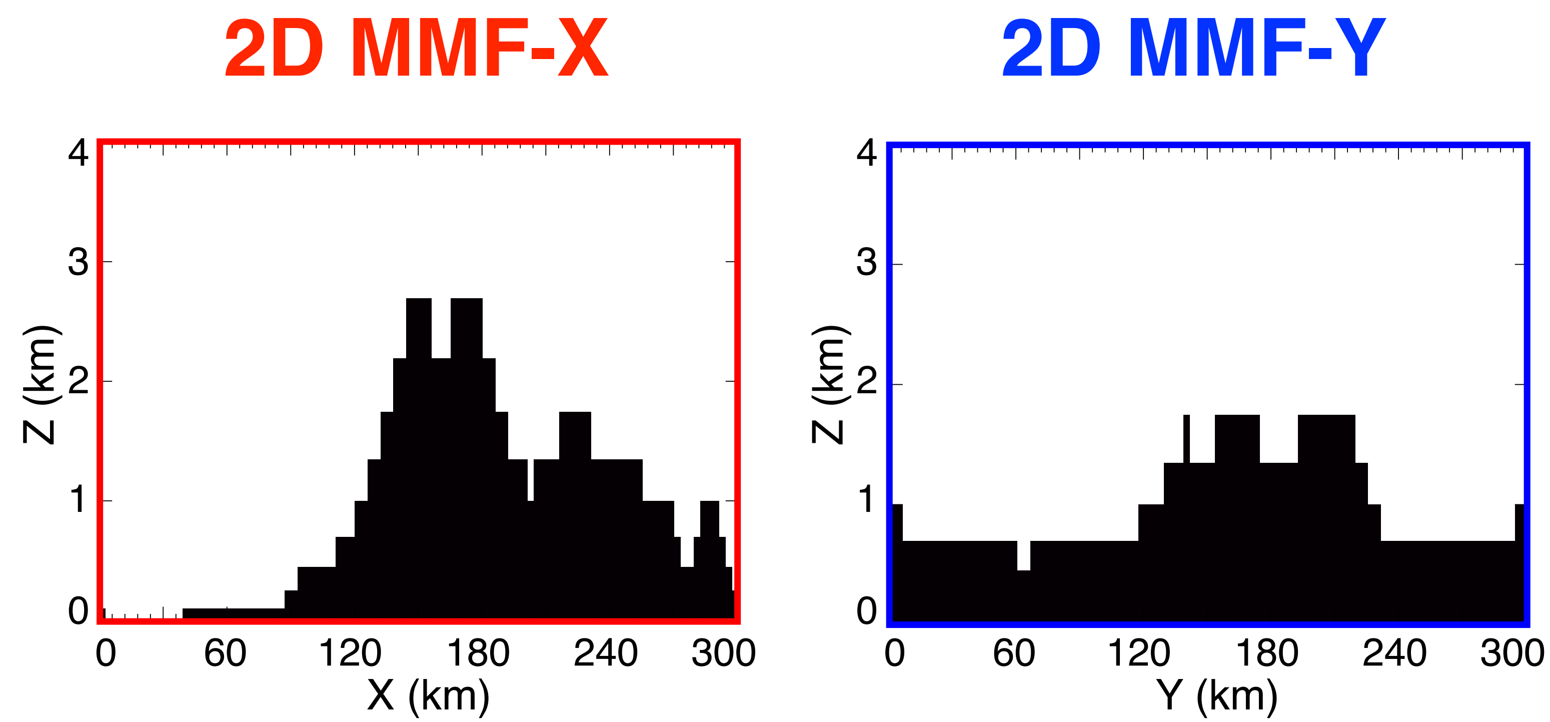
(Normalized by the one simulated with a flat topography)



Mean precipitation intensity generally increases due to the subgrid-scale inhomogeneity in topography.

Example of Surface Elevation Used in the Simulations of 3D & 2D MMFs



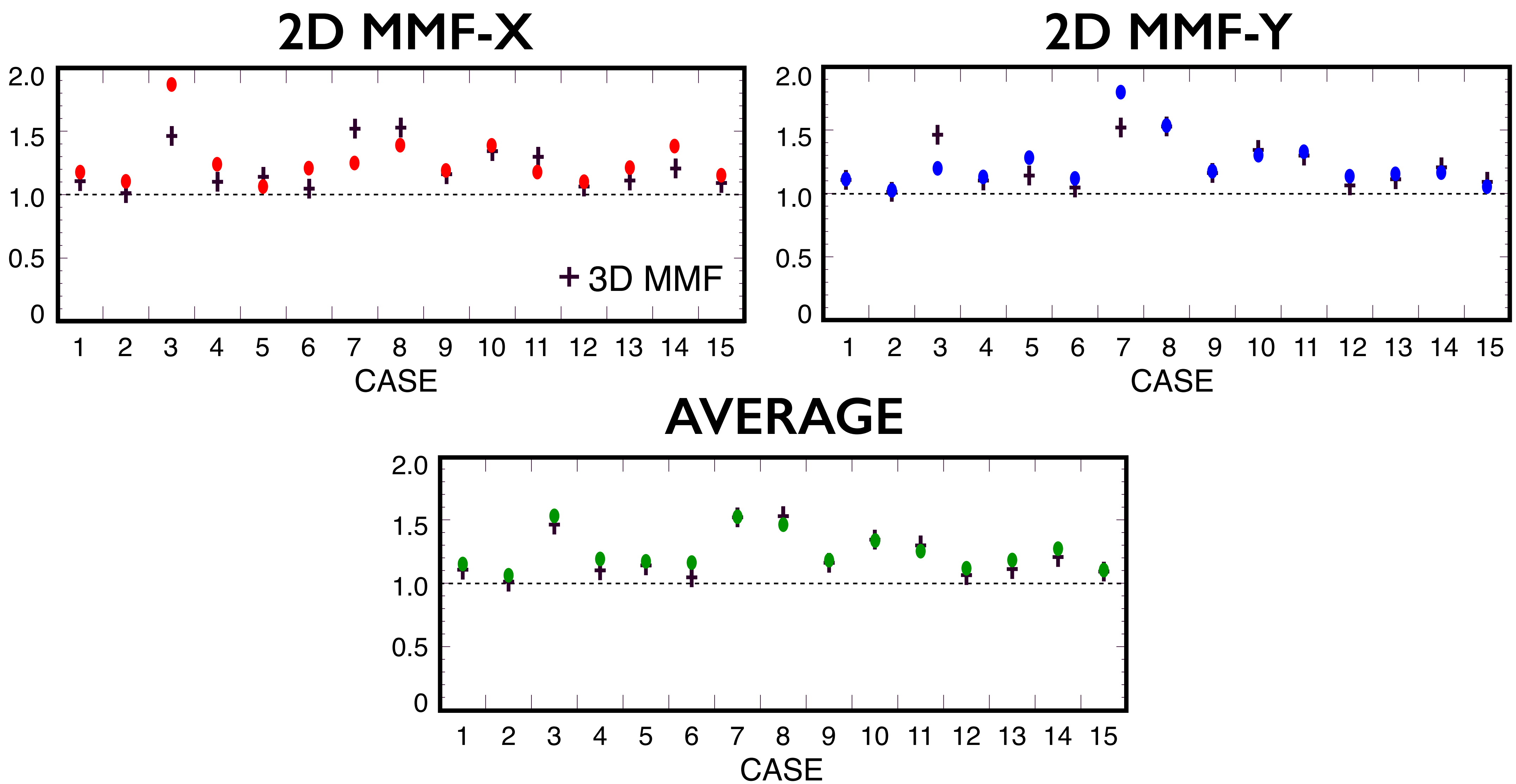


The CRM component recognizes only a cross section of the 3D topography.

The mean height is adjusted to that of the 3D topography.

Simulated Results by the 3D & 2D MMF

Mean Precipitation Intensity
(Normalized by the one simulated with a flat topography)



The embedded 2D CRM is able to predict the orographic precipitation reasonably well even with a sampled representation of topography.

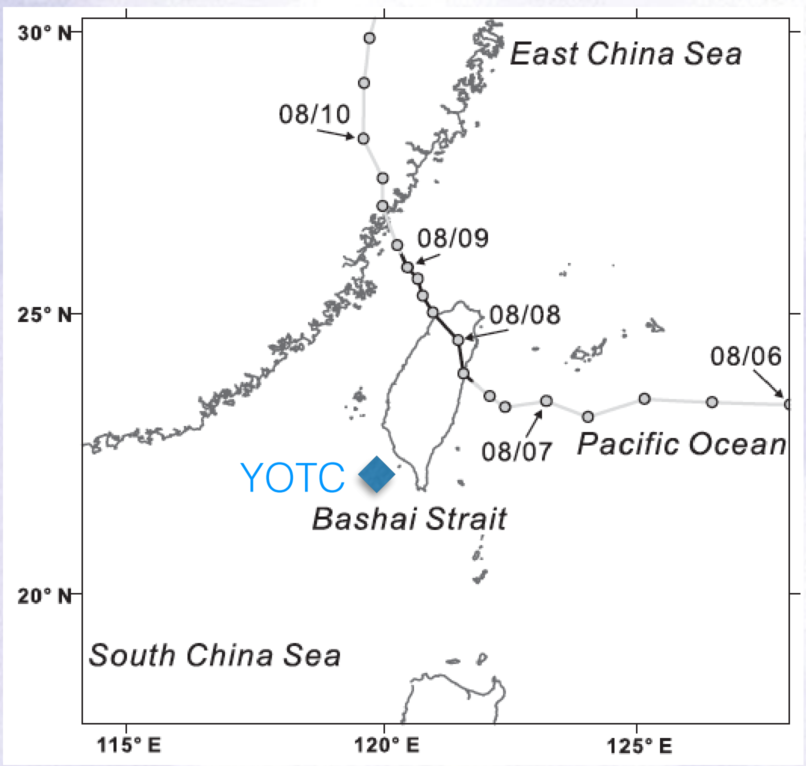
The error due to the sampling can be reduced by the use of two perpendicular CRM sets.

Benchmark for the Q3D MMF Test

Idealized Simulation of the Orographic Precipitation Associated with Typhoon Morakot (without the typhoon itself)

"Morakot": Taiwan's most severe weather event of the past 50 years

Track of Typhoon Morakot (2009)



Yu and Cheng, 2013 (JAS)

Strong southwesterly flow on the west slope of topography.

3D Simulation by VVM

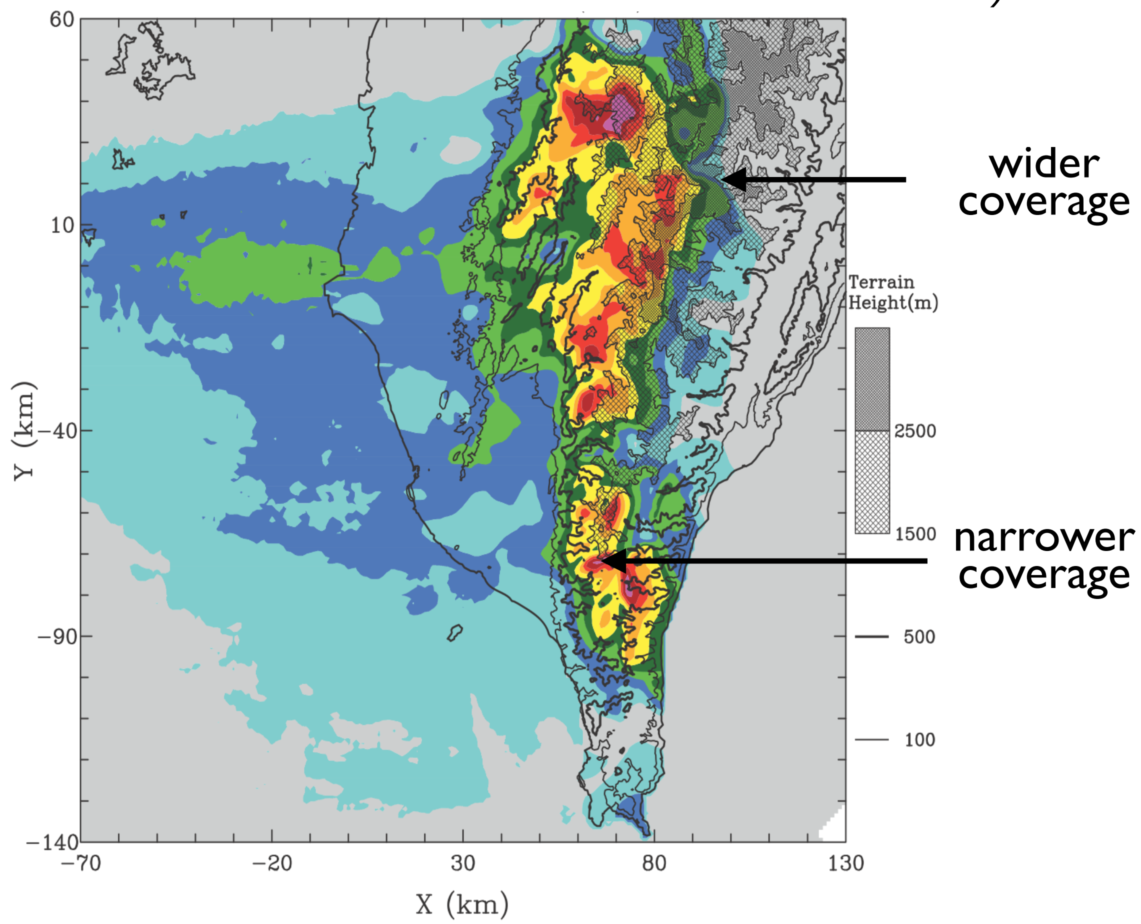
- **Initial soundings:** 36-hr averaged profiles during Morakot (The YOTC sounding)
- **Wind field:** 20 m/s southwesterly wind
- **Domain size:** 1024 km x 1024 km x 32 km
- **Horizontal resolution:** 2 km
- **Vertical resolution:** 200 m below 4-km & stretched up (50 levels)
- No radiation, No Coriolis force, No sensible heat flux

Model is integrated for 12 hrs.
This simulation is used as a benchmark for the Q3D MMF test.

Accumulated Precipitation

Observation

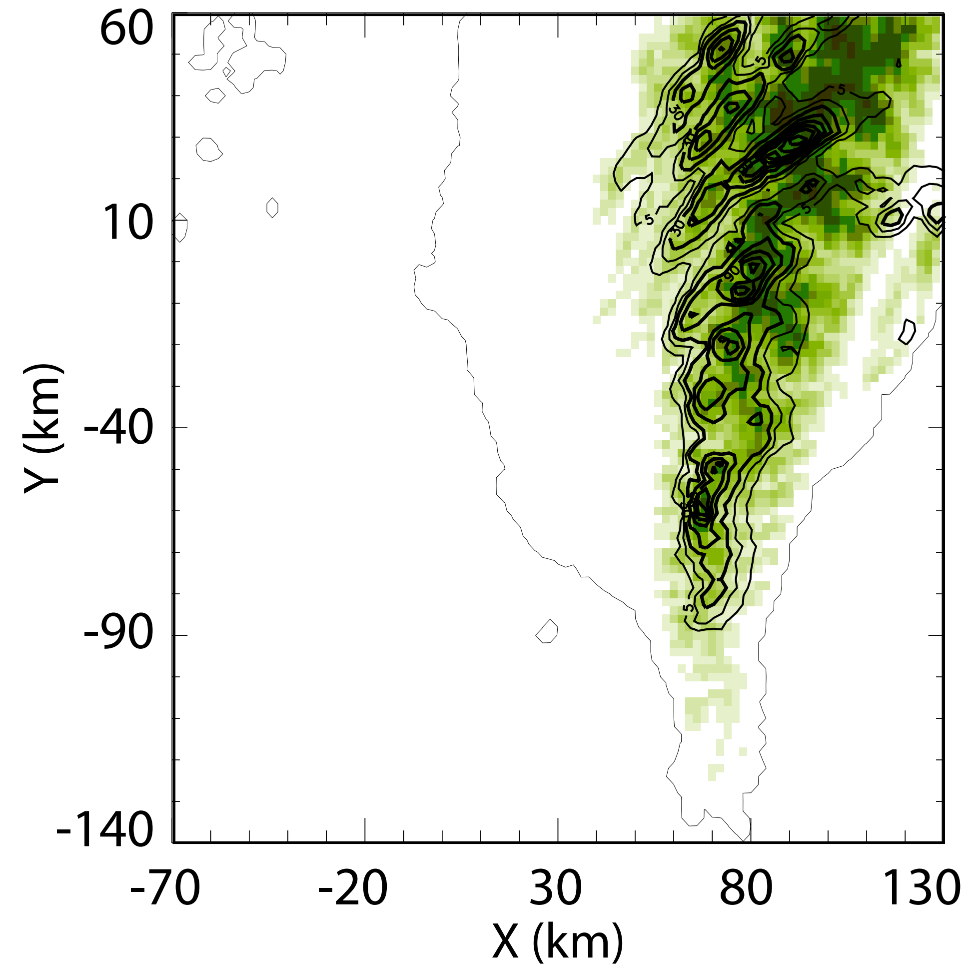
(Radar-derived accumulation for 36 hr)



Yu and Cheng, 2013 (JAS)

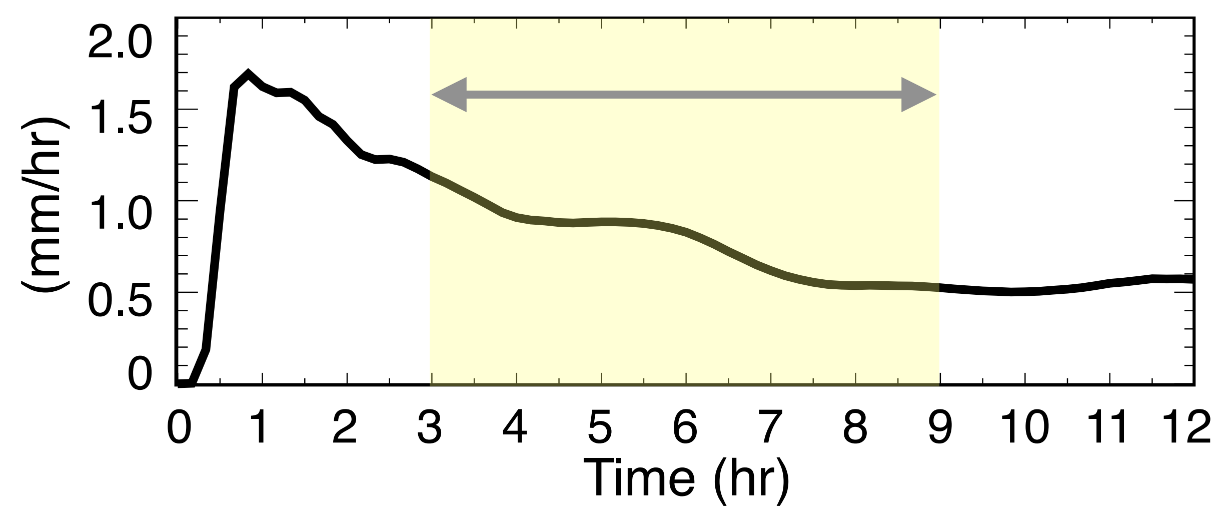
Simulated by the 3D CRM

(Accumulated for 6-hr)



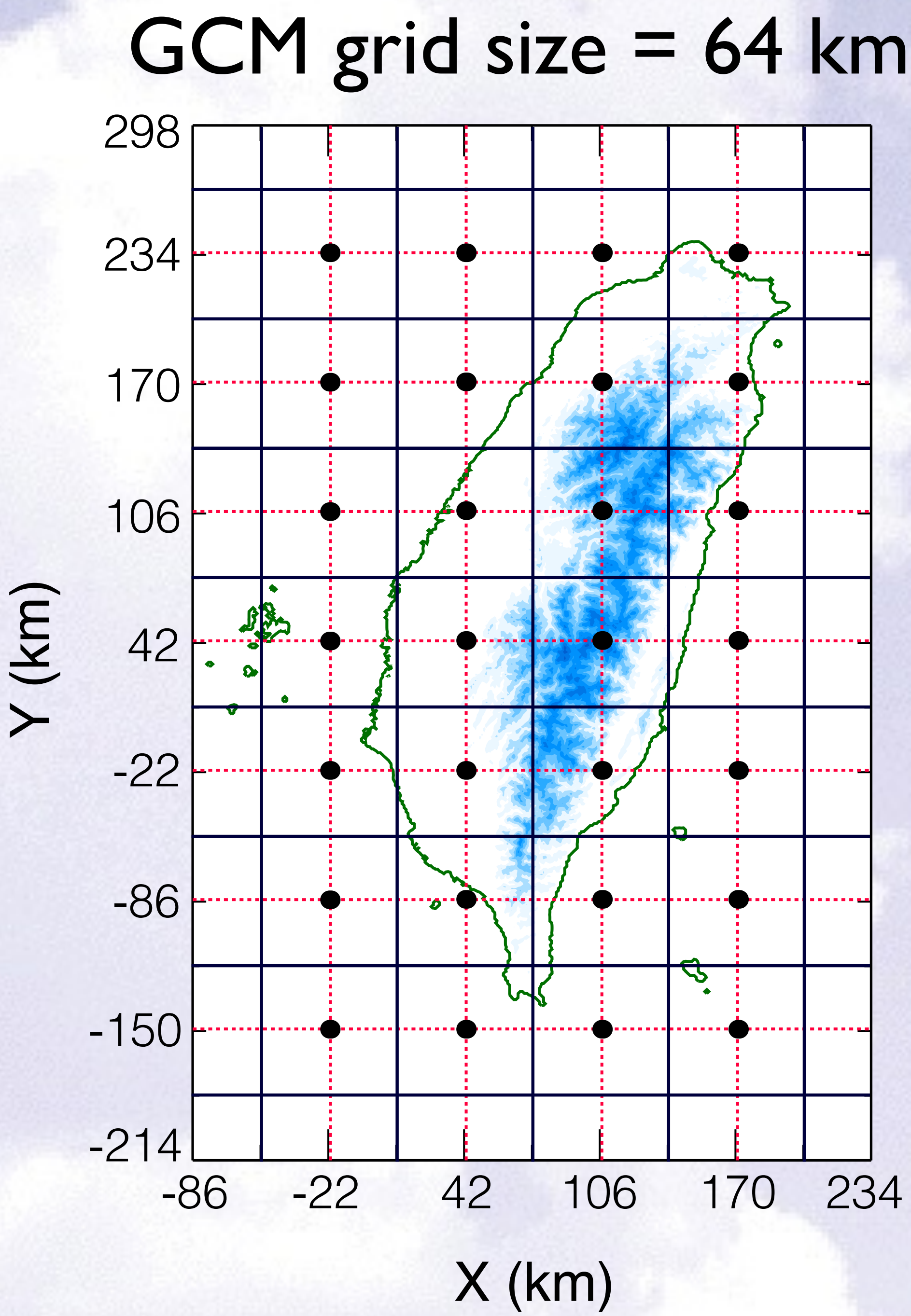
Stronger rainfall observed over the mountainous region

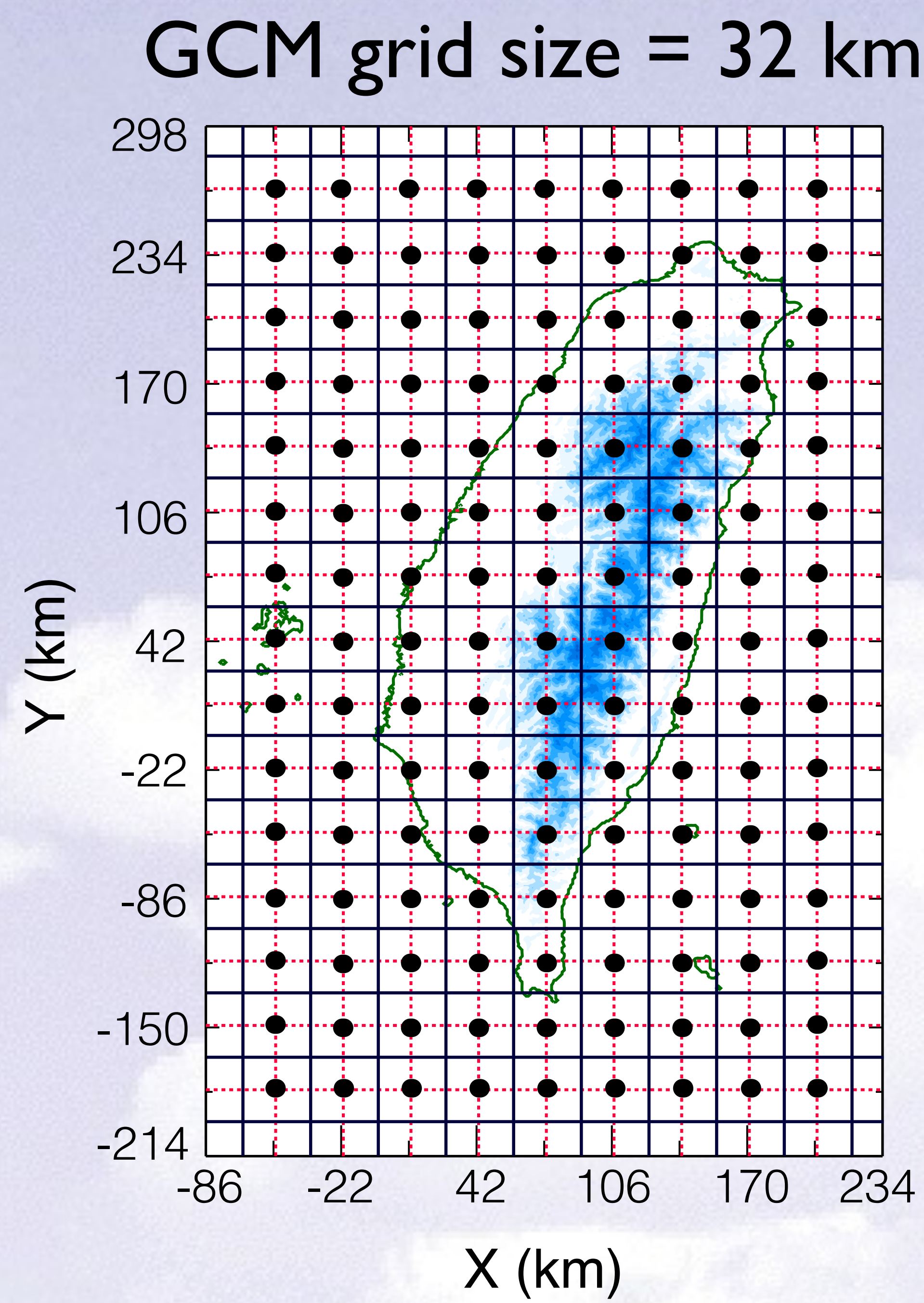
Precipitation Intensity



The 3D CRM is able to capture the characteristic orographic precipitation pattern.

Q3D MMF Simulation



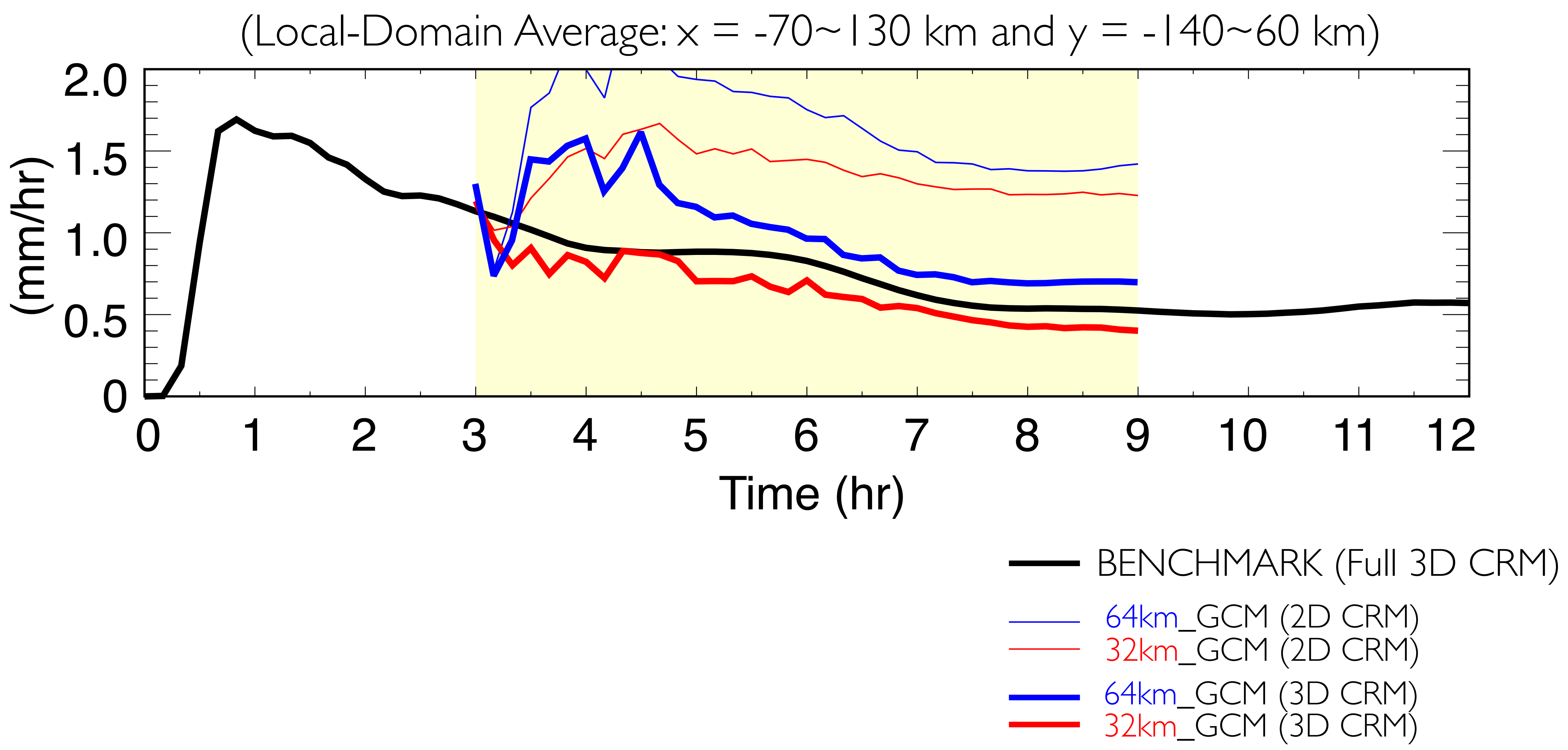


Q3D MMF simulation starts from the realization of Benchmark at t = 3hr.

Subgrid-scale inhomogeneity in topography is recognized by the CRM channels.

Q3D MMF Simulation Results

Precipitation Intensity



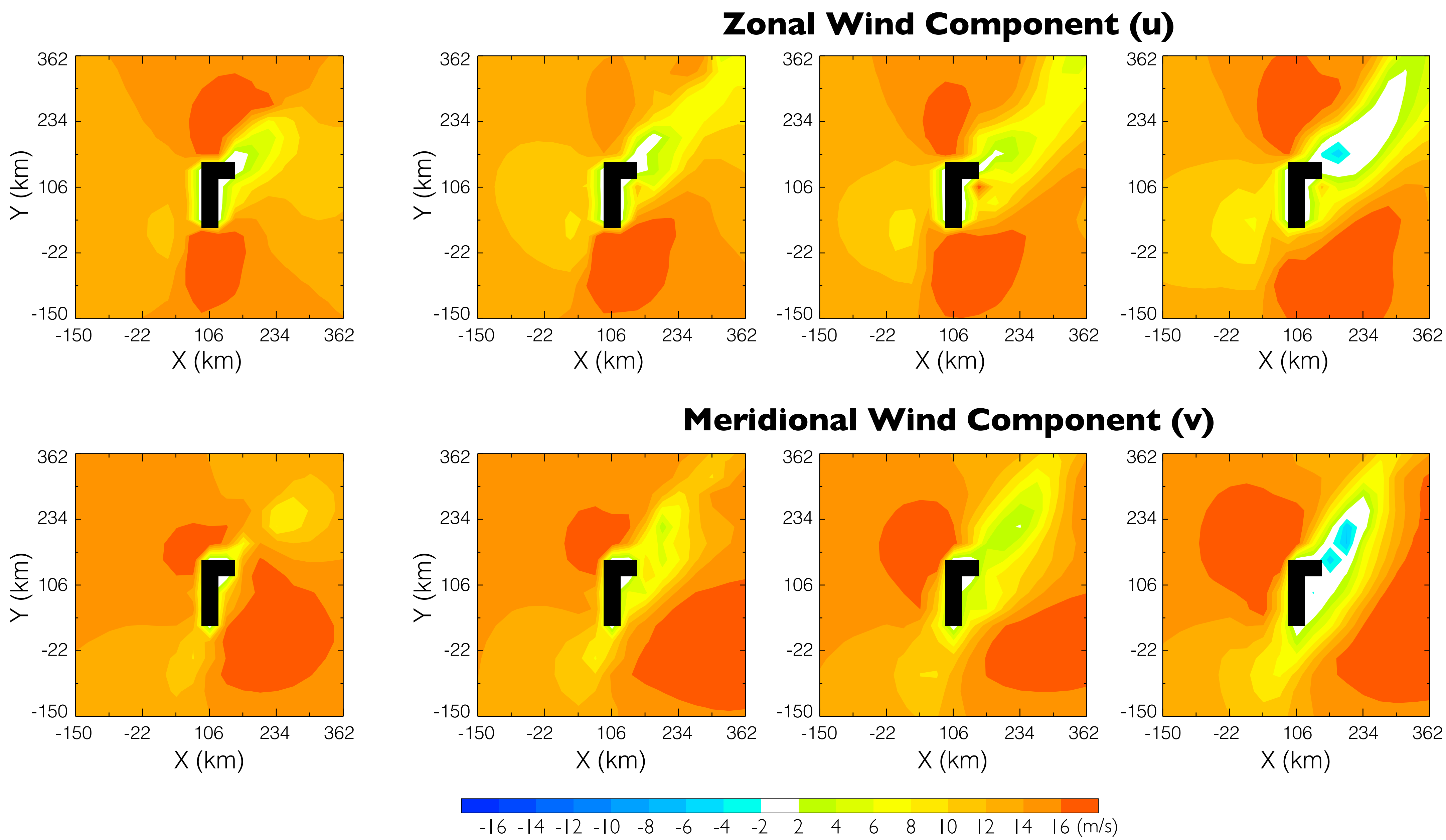
When 2D CRMs are used, the convective activity is much stronger over the mountain.

Q3D MMF Simulation Results (Continued.)

Horizontal Velocities
(GCM grid size = 32 km, Height = 1.7 km)

t = 0 hr **t = 6 hr**

	BENCHMARK	Q3D MMF (3D CRM)	2D MMF (2D CRM)

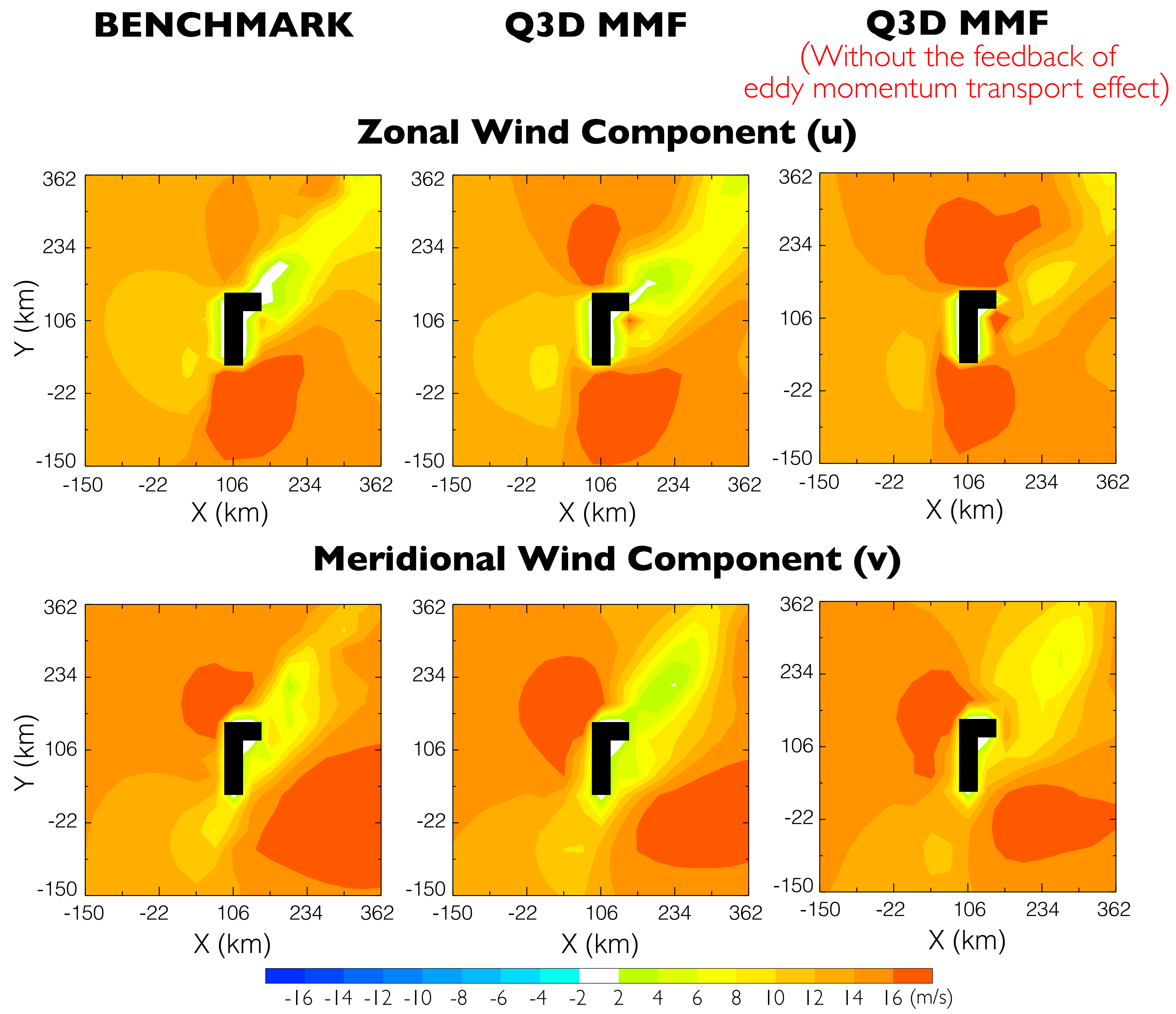


Q3D MMF captures the evolution of wind field reasonably well.

Q3D MMF Simulation Results (Continued.)

Horizontal Velocities

(GCM grid size = 32 km, Height = 1.7 km, t = 6 hr)



The eddy momentum transport feedback plays an important role to simulate the evolution of wind fields.