Experiments with MMF Coupling

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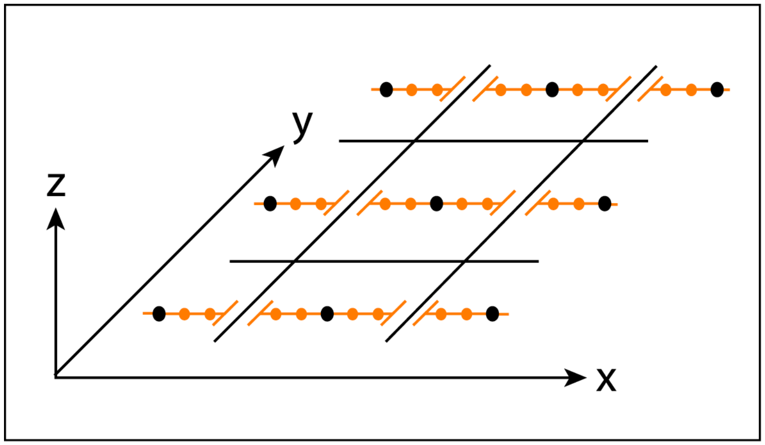
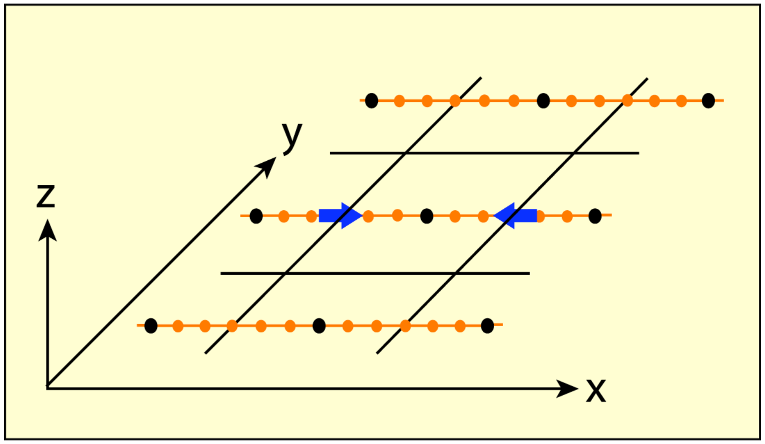
MULTI-SCALE MODELING FRAMEWORK

CRCP: original



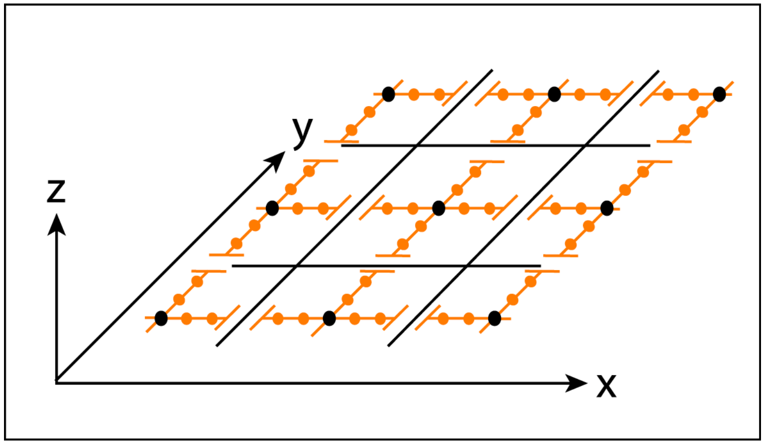
Grabowski and Smolarkiewicz (1999)

CRCP: extended



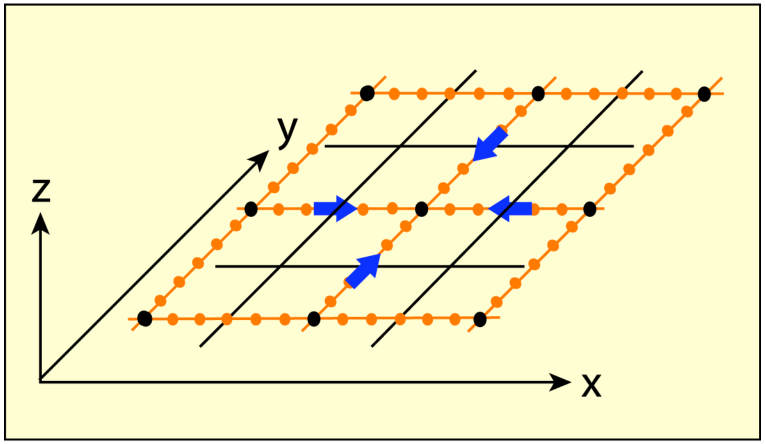
Jung and Arakawa (2003, submitted to MWR)

Two perpendicular CSRMs

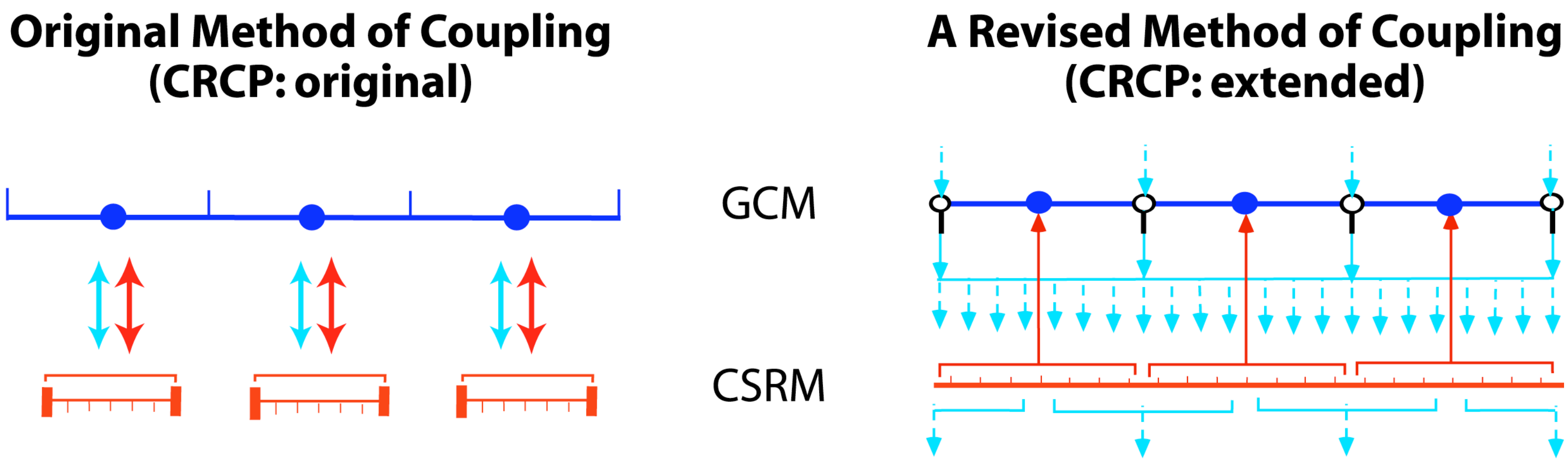


Arakawa (2003, submitted to J. Climate)

Quasi-3D MMF



Arakawa (2003, submitted to J. Climate)



In the revised method,

- CSRM is extended to the whole domain of GCM;
- communications between the GCM and the CSRM at the ● and ○ points.
  - The horizontal velocities of CSRM and GCM are coupled at the ○ points by relaxing one to each other on a finite time-scale (e.g. $\tau_m = 1$hr).
  - The thermodynamic variables of GCM are updated by horizontal averaging of the CSRM fields (e.g. $\tau_t \sim 0$).

GCM and CSRM share approximately the same fluxes of mass and other quantities at the borders of GCM grid boxes.

A Preliminary Test of Multi-scale Modeling in an Idealized Framework: Sensitivity to Coupling Methods
(Jung and Arakawa 2003, submitted to MWR)

The purpose of this study is to investigate the method of coupling between the GCM and CSRMs in the MMF.

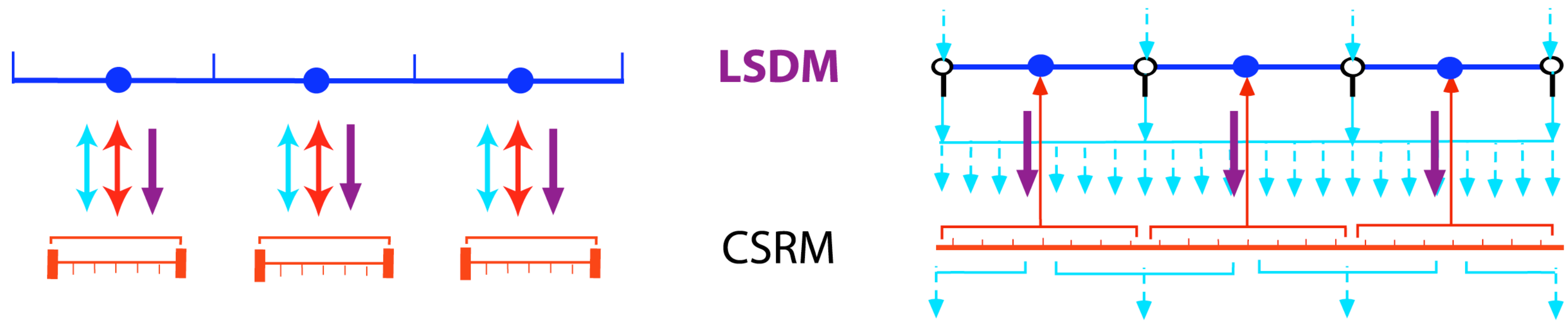
- We set up a two-dimensional framework that couples CSRMs with a lower-resolution version of the CSRM with no physics (large-scale dynamics model, LSDM), which mimics the role of a GCM in actual implementations of the MMF.

- Under idealized tropical conditions, we perform
  - CSRM runs (CONTROLs),
  - runs with the MMF using the original and revised methods of coupling for the selected realizations of CONTROL.

- The original and revised methods of coupling are tested in the 2D framework.
- The sensitivity to the strength of coupling represented by time scales for nudging the velocity and thermodynamic fields between the LSDM and CSRMs, are also tested.

Large-scale Forcing Given to the CSRM

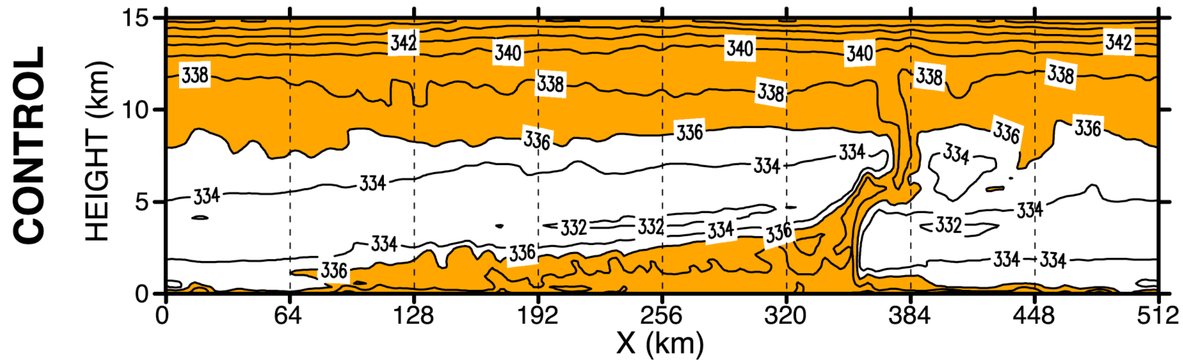
Original Method of Coupling (CRCP: original)	A Revised Method of Coupling (CRCP: extended)



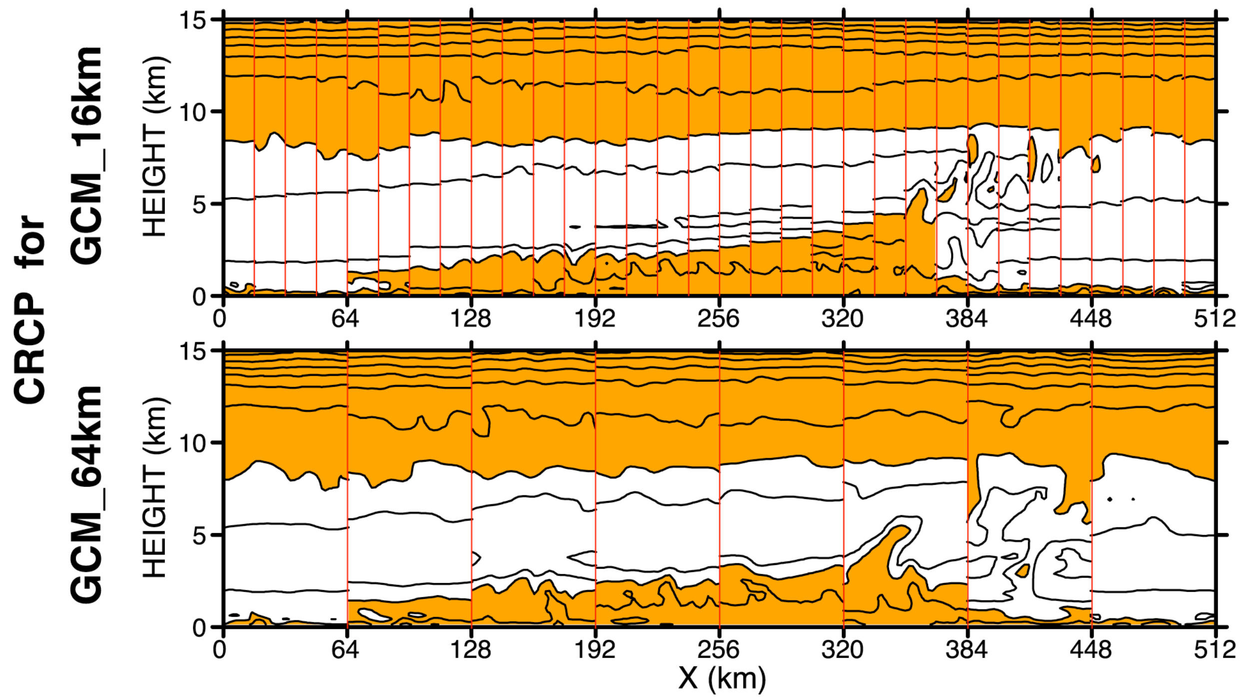
predicted advective tendencies of thermodynamic fields	predicted horizontal velocity
prescribed cooling and moistening rates (*representing climatological background)*	prescribed cooling and moistening rates (*representing climatological background)*

Moist Static Energy (K)

local time: 13 h

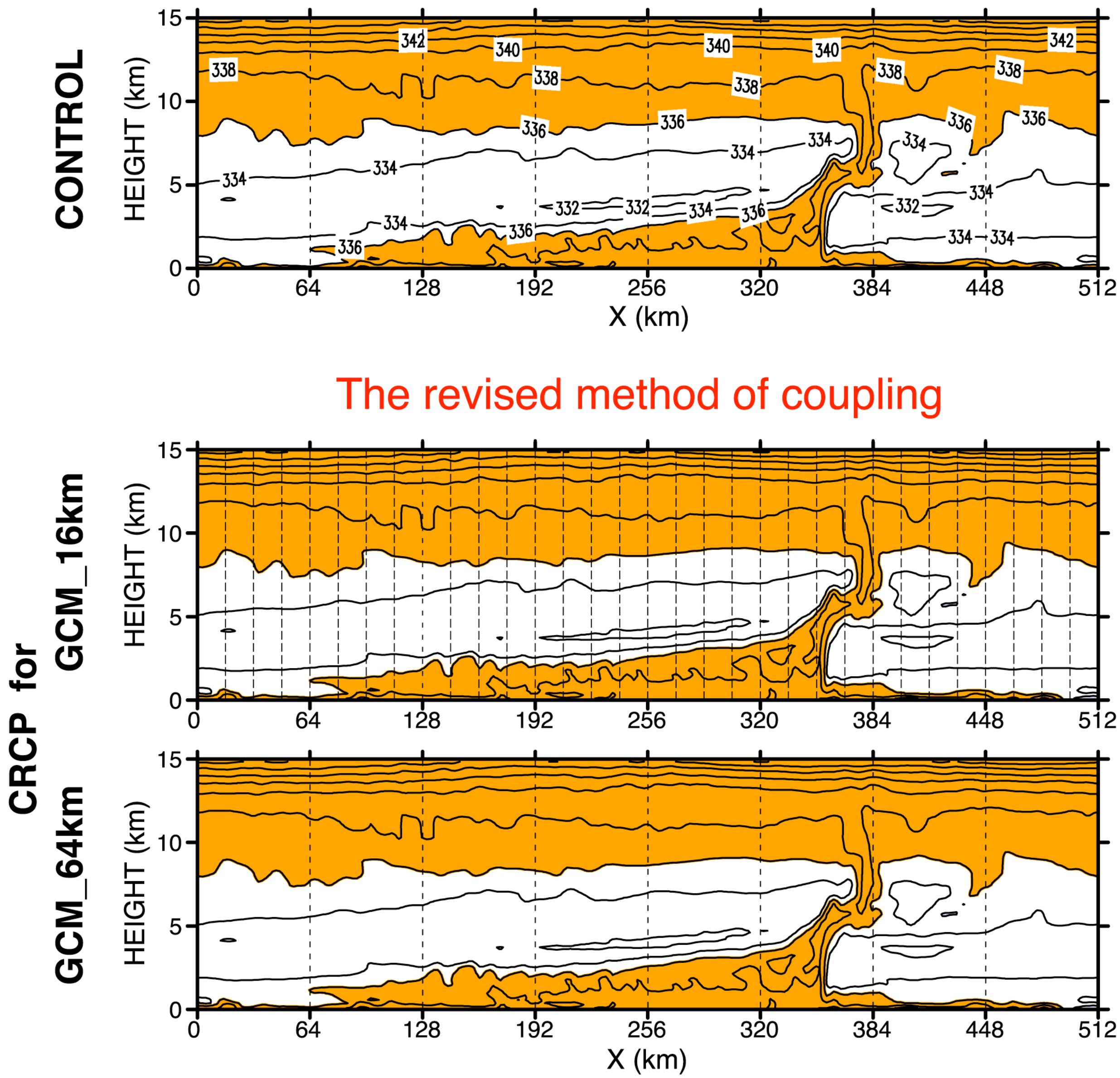


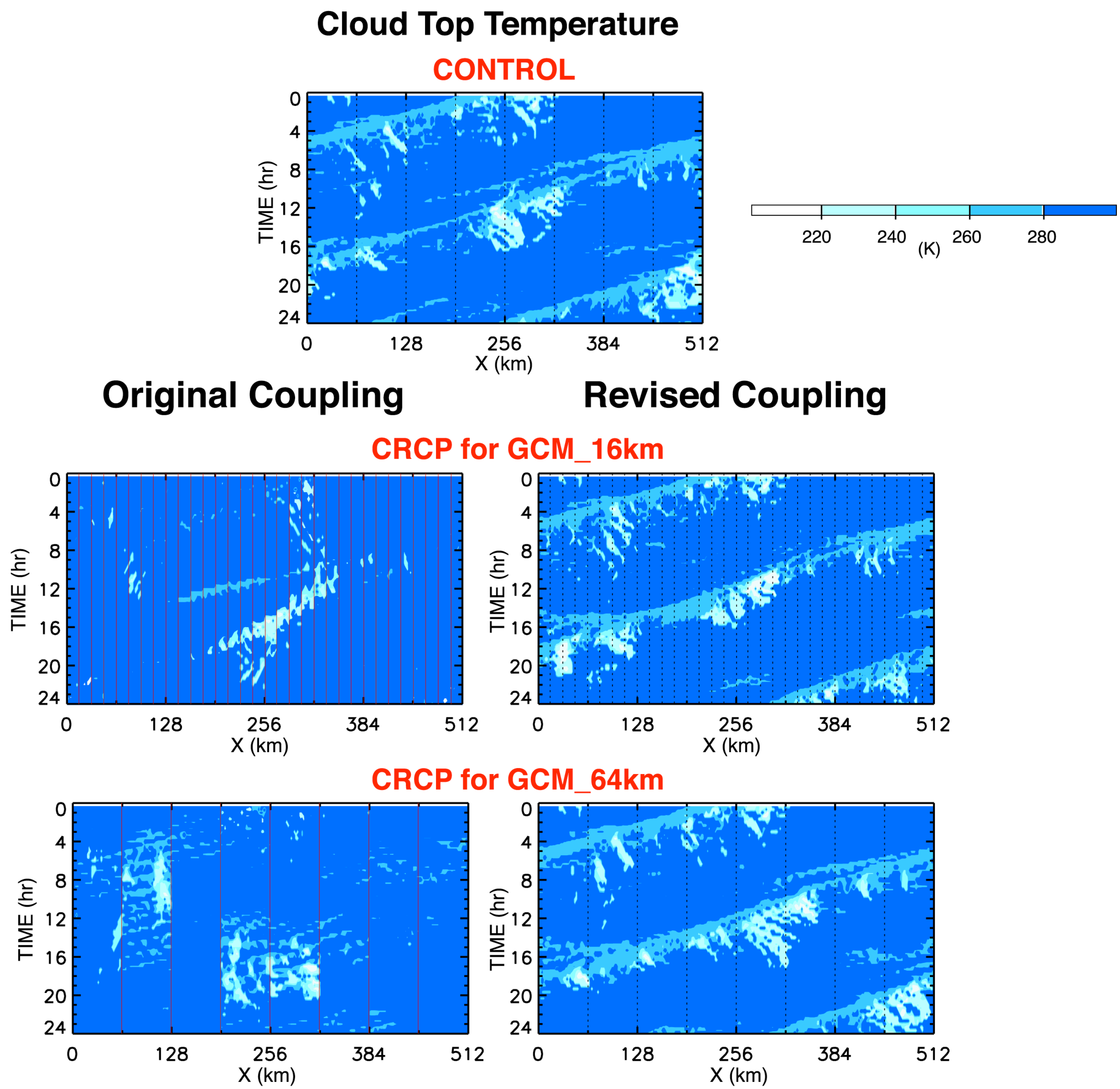
The original method of coupling



Moist Static Energy (K)

local time: 13 h



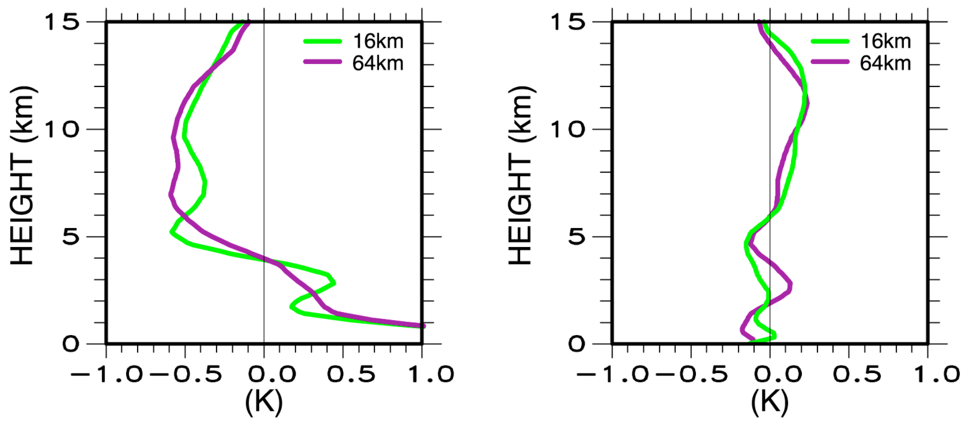


Cloud Top Temperature
CONTROL
TIME (hr)
X (km)
(K)
220
240
260
280
Original Coupling
Revised Coupling
CRCP for GCM_16km
CRCP for GCM_64km

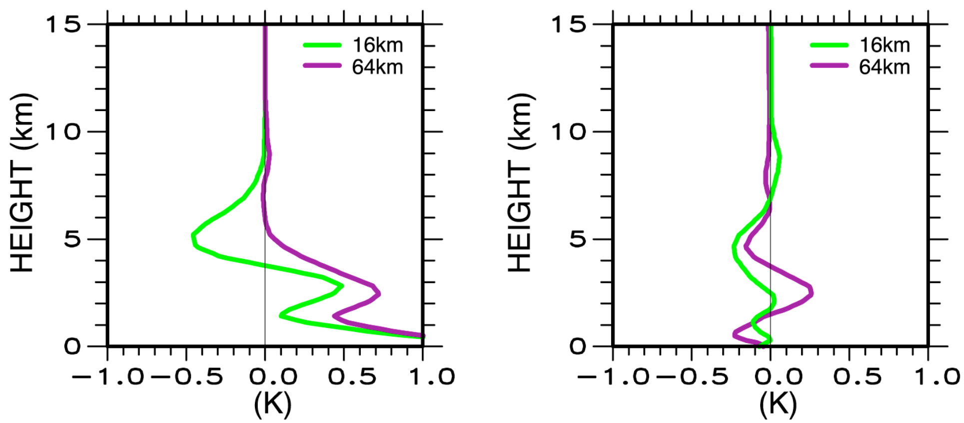
Errors of the Ensemble/Domain Averaged Profiles Predicted by GCM with CRCP

Original Coupling / Revised Coupling

Moist Static Energy

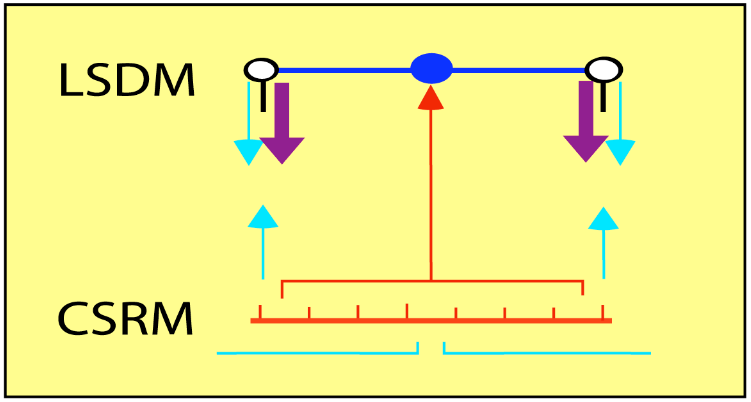


Total Water



Large-scale Forcing Given to the CSRM in the Sensitive Experiments Performed

A Revised Method of Coupling
(CRCP: extended)

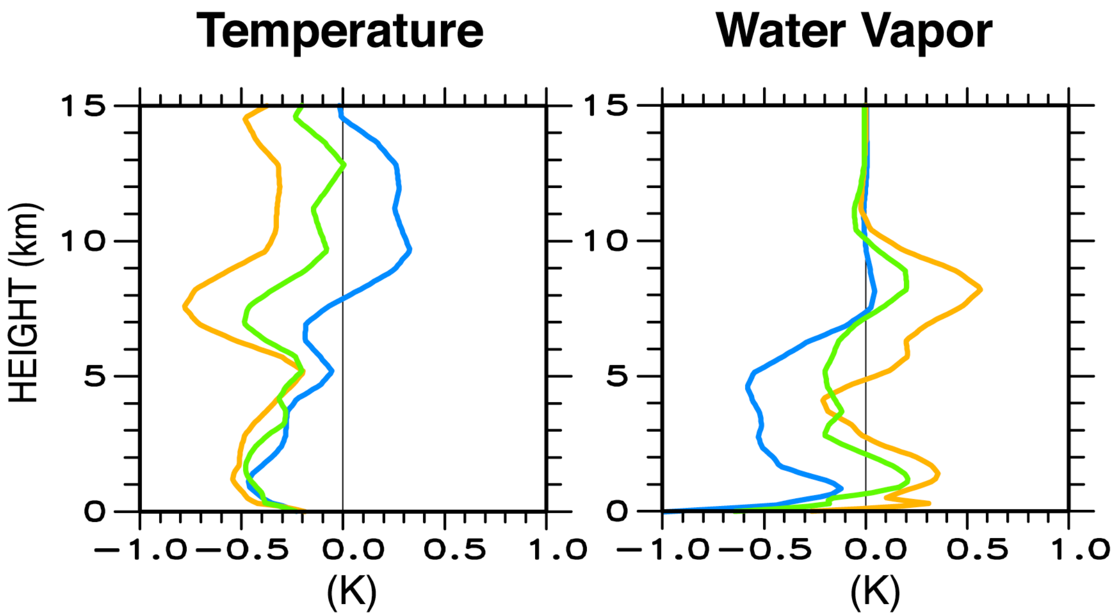


A combination of LSDM and prescribed vertical velocity substitutes a real GCM.

Errors of the Ensemble/Domain Averaged Profiles Predicted by GCM_16km with CRCP

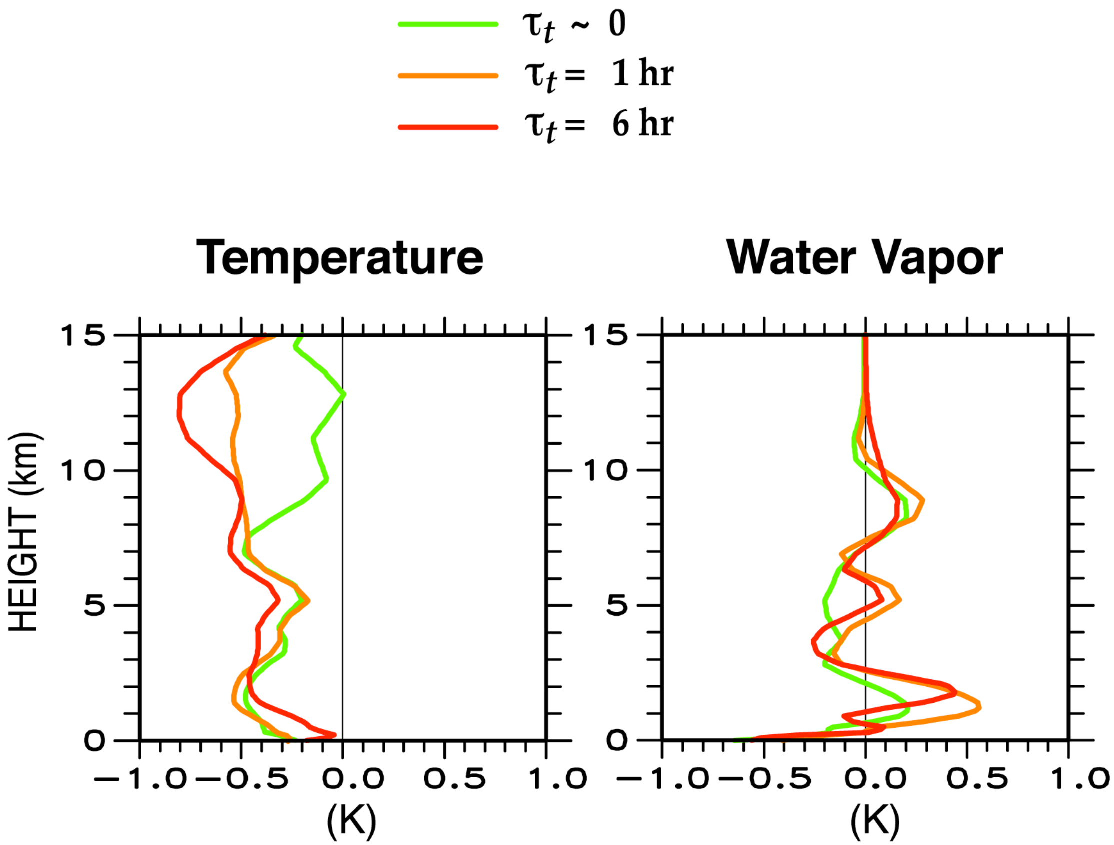
$(\tau_t \sim 0)$

- $\tau_m = 10$ min
- $\tau_m = 1$ hr
- $\tau_m = 6$ hr



Errors of the Ensemble/Domain Averaged Profiles Predicted by GCM_16km with CRCP

($\tau_m = 1hr$)



A Preliminary Test of Multi-scale Modeling in an Idealized Framework: Sensitivity to Coupling Methods
(Jung and Arakawa 2003, submitted to MWR)

Summary and Conclusions

With the original method of coupling,

- cloud systems can propagate only when the grid size of GCM is very fine,
- spurious effects are generated due to the cyclic lateral boundary condition,

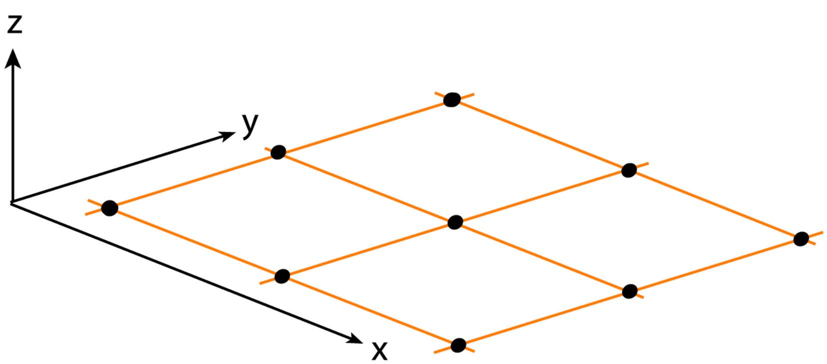
With the revised method of coupling,

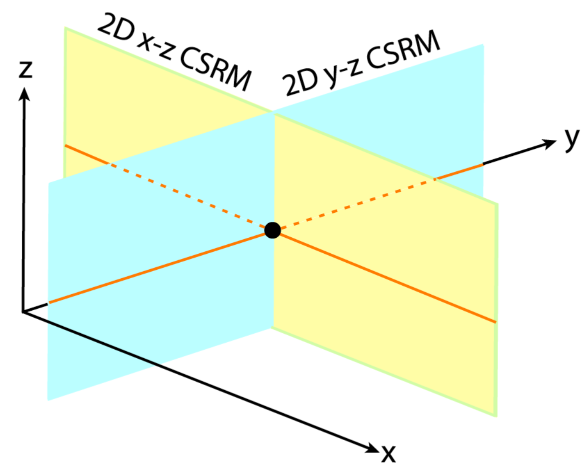
- cloud systems propagate properly,
- no spurious effects due to the cyclic lateral boundary condition exist,
- errors on large-scale thermodynamic fields are relatively small.

The errors are near the smallest when the velocity fields of the LSDM and CSRM are nudged to each other with the time scale of a few hours and the temperature field of the LSDM is instantaneously updated at each time step with the domain-averaged CSRM temperature field.

Future Work

Construction of a 3D CSRM using two sets of 2D CSRMs





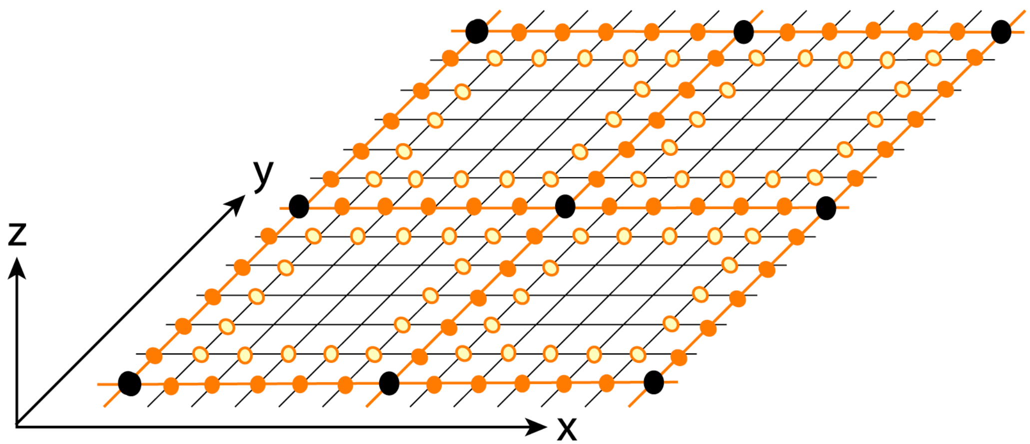
At the large dot points where the two perpendicular 2D CSRMs intersect, 3D variables are predicted by adding terms representing interactions between the two directions, which are missing in the 2D models.

e.g.

$$\rho_o \frac{\partial \eta}{\partial t} - \left(\frac{\partial \eta}{\partial x}\frac{\partial \psi}{\partial z} - \frac{\partial \eta}{\partial z}\frac{\partial \psi}{\partial x} \right) + \frac{\partial}{\partial x}\left(v \frac{\partial w}{\partial y} \right) + \frac{\partial}{\partial z}\left(\rho_o w_\phi \eta - v \frac{\partial u}{\partial y} \right) + f \frac{\partial v}{\partial z} = \frac{\partial F_w}{\partial x} - \frac{\partial F_u}{\partial z}$$

$$\rho_o \frac{\partial \xi}{\partial t} - \left(\frac{\partial \xi}{\partial y}\frac{\partial \phi}{\partial z} - \frac{\partial \xi}{\partial z}\frac{\partial \phi}{\partial y} \right) + \frac{\partial}{\partial y}\left(u \frac{\partial w}{\partial x} \right) + \frac{\partial}{\partial z}\left(\rho_o w_\psi \xi - u \frac{\partial v}{\partial x} \right) - f \frac{\partial u}{\partial z} = \frac{\partial F_w}{\partial y} - \frac{\partial F_v}{\partial z}$$

Quasi-3D CSRM in MMF



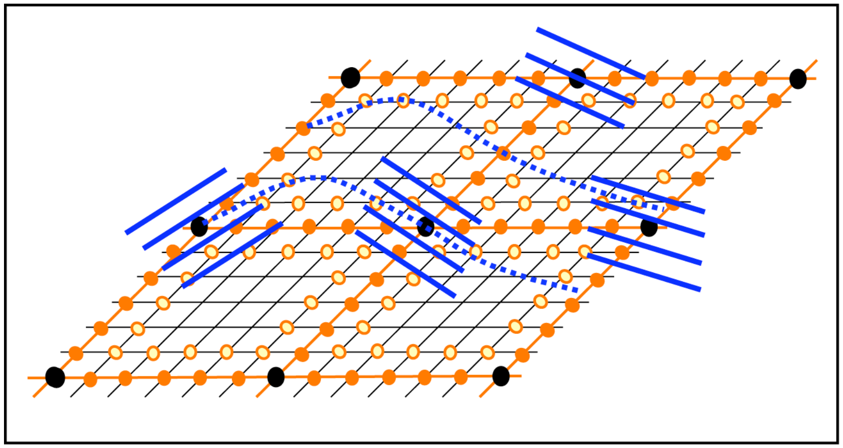
We need a regression/interpolation technique for determining values at bogus points near the grid-point axes (○ points in the figure).

After determining values at the bogus points, the 3D algorithm can be applied to all grid points (● and ● points in the figure).

Quasi-3D CSRM in MMF
(continued)

Two Types of Pattern Recognizable by the Quasi-3D CSRM

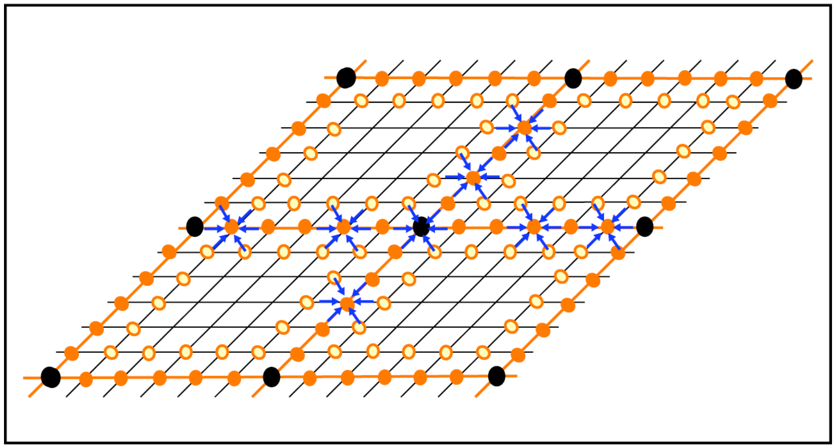
smooth 3D pattern



Regression analysis of the values at ● points

Interpolation of the regression coefficients

small scale features
that can be used as statistical samples



Deviation of explicitly predicted values from the smooth pattern