

**A Preliminary Test of Super-parameterization
in an Idealized Framework**

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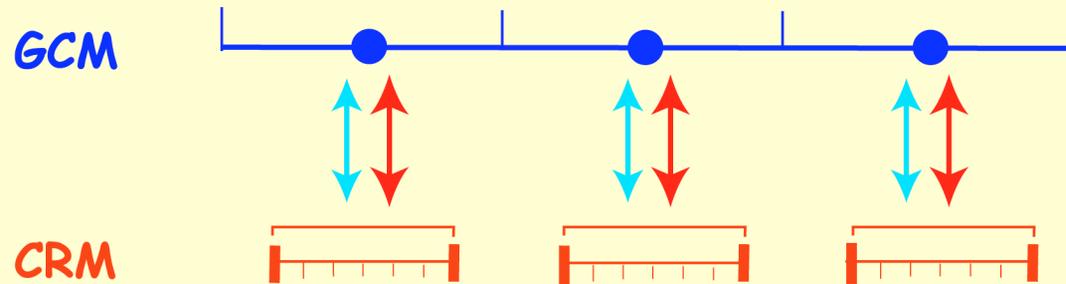
The purpose of the present study

To test and revise the method of coupling a cloud-resolving model (CRM) and a GCM in the "Super-parameterization".

- Lateral boundary conditions of the CRM
- Communications between the GCM and the CRM

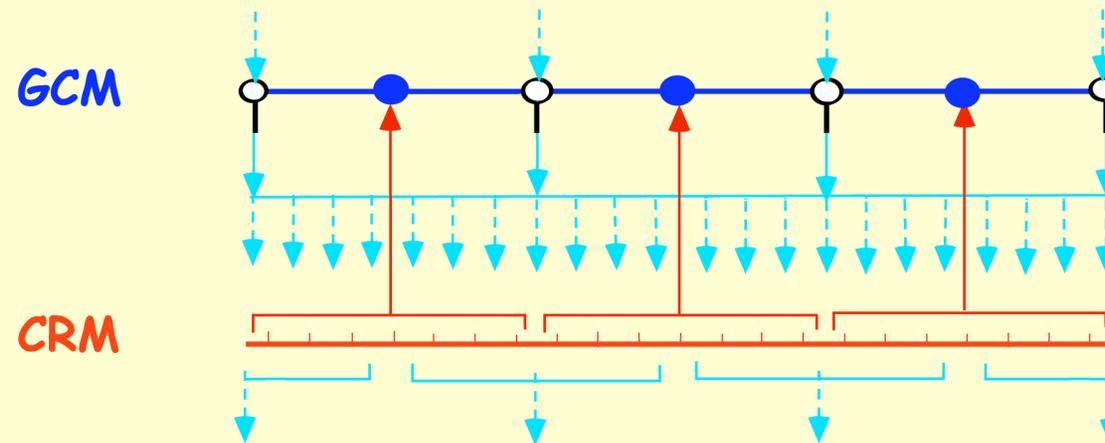
The Original Method of Coupling, 2D

Grabowski and Smolarkiewicz (1999); Grabowski (2001)



- CRM is **confined** to each column of a GCM with a cyclic lateral boundary condition. (no communication between CRMs)
- Communications between the GCM and the CRM at the ● points.
 - The E-W flows of CRM and GCM are coupled by relaxing one to each other on a finite time-scale (e.g. $\tau_m = 1$ hr).
 - The advective tendencies of thermodynamic variables (resolved by GCM) are given to CRM.
 - The thermodynamic variables of GCM are updated by horizontal averaging of the CRM fields (e.g. $\tau_t \sim 0$).

A Revised Method of Coupling, 2D



- CRM is **extended** to the whole domain of GCM.
- Communications between the GCM and the CRM at the ● and ○ points.
 - The E-W flows of CRM and GCM are coupled at the ○ points by relaxing one to each other on a finite time-scale (e.g. $\tau_m = 1\text{hr}$).
 - The thermodynamic variables of GCM are updated by horizontal averaging of the CRM fields (e.g. $\tau_t \sim 0$).

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

- CRM runs (CONTROLS),
- runs with the "Super-parameterization" using the original and revised methods of coupling for the selected realizations of CONTROL.

CRM RUN (CONTROL)

Domain size: 19km (height) × 512km (width)

Horizontal resolution: 2km

Vertical resolution: 34 layers with a stretched vertical grid

Lower-boundary: land surface with a fixed ground wetness
or ocean surface with a fixed temperature

Initial conditions: the GATE Phase-III mean sounding

Condition for solar radiation: diurnally changing over land or fixed over ocean

Large-scale forcing: based on the GATE Phase-III mean sounding

- prescribed advective tendency
- prescribed vertical motion

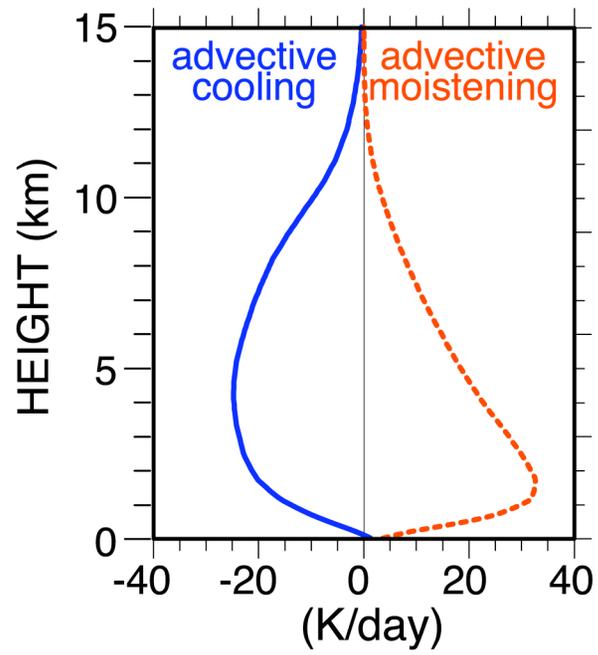
Perturbations: small, random temperature perturbations into the lowest model layer

GCM RUN

Horizontal resolution: 16 and 64km

Initial conditions: selected realizations of CONTROL

Prescribed Large-scale Advective Tendency

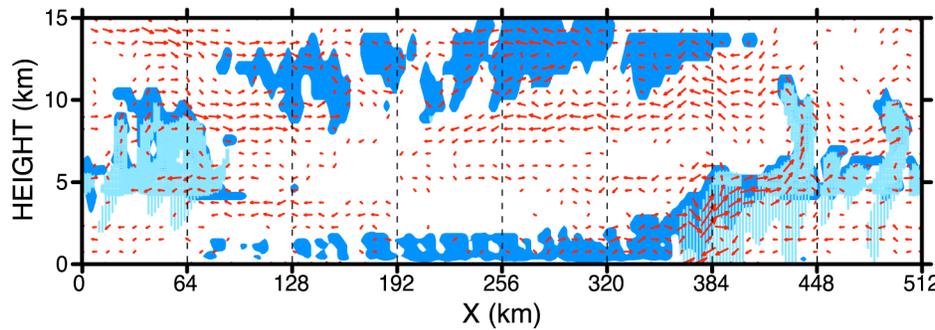


CONTROL (over land)

An example of the development of cloud systems for 1 hour period

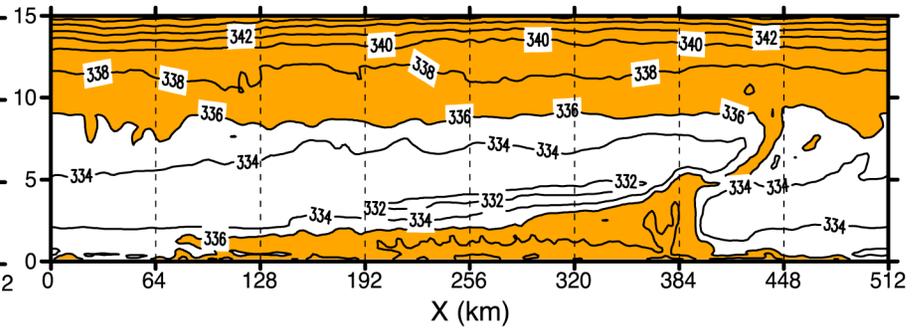
Clouds, precipitation and wind

local time: 12 h

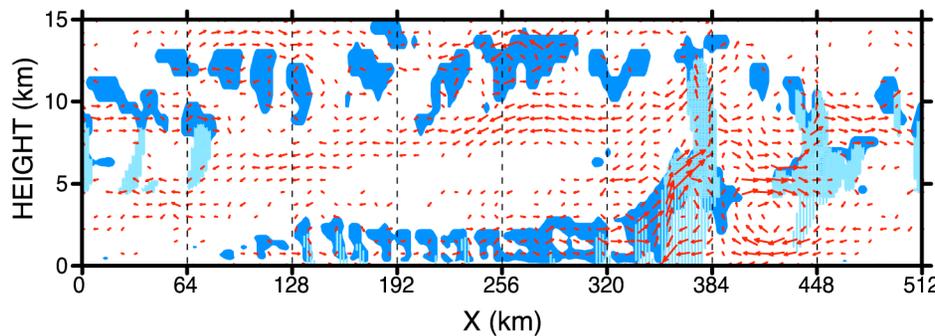


Moist Static Energy

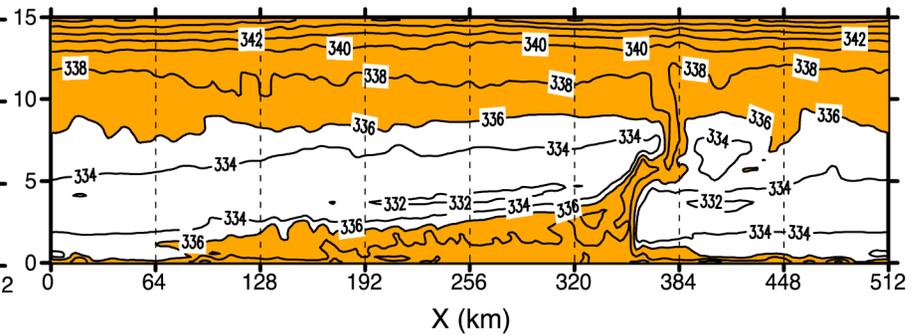
local time: 12 h



local time: 13 h

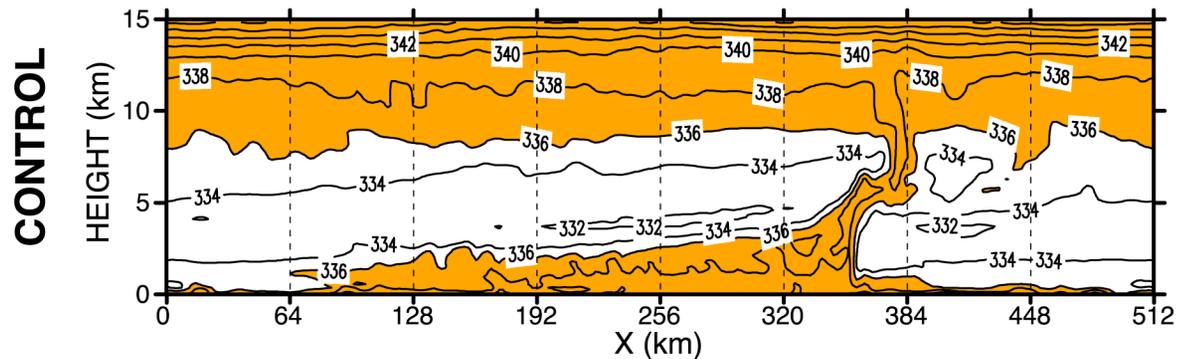


local time: 13 h

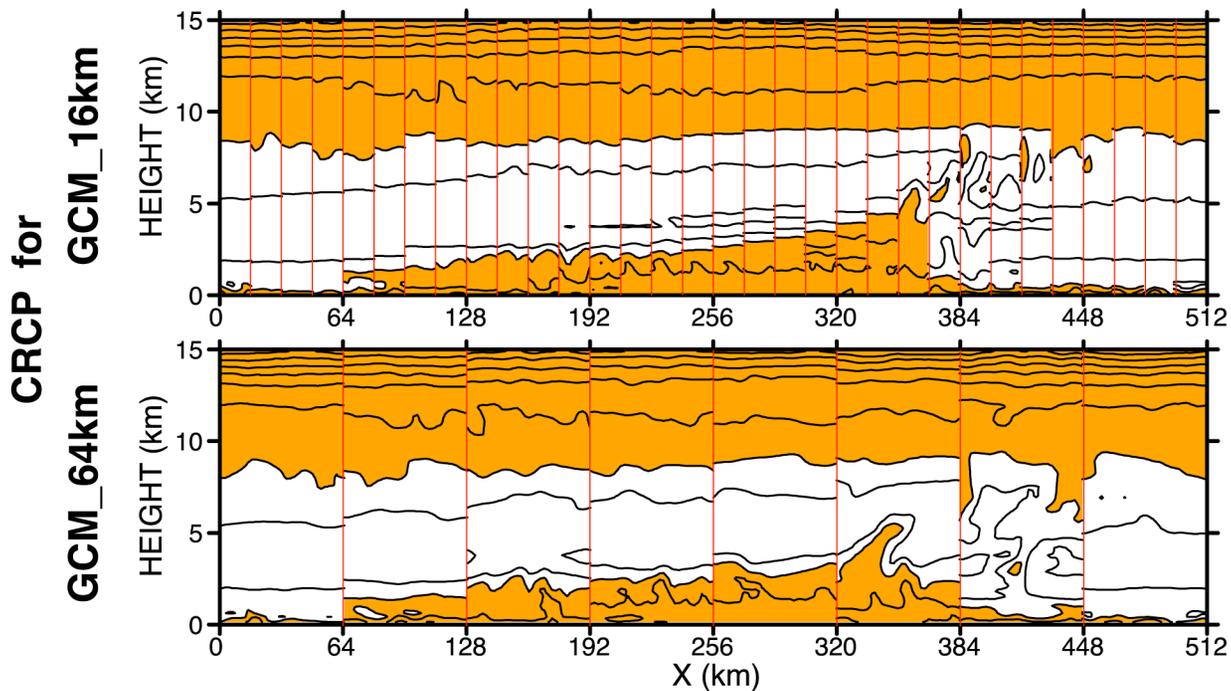


Moist Static Energy (K)

local time: 13 h

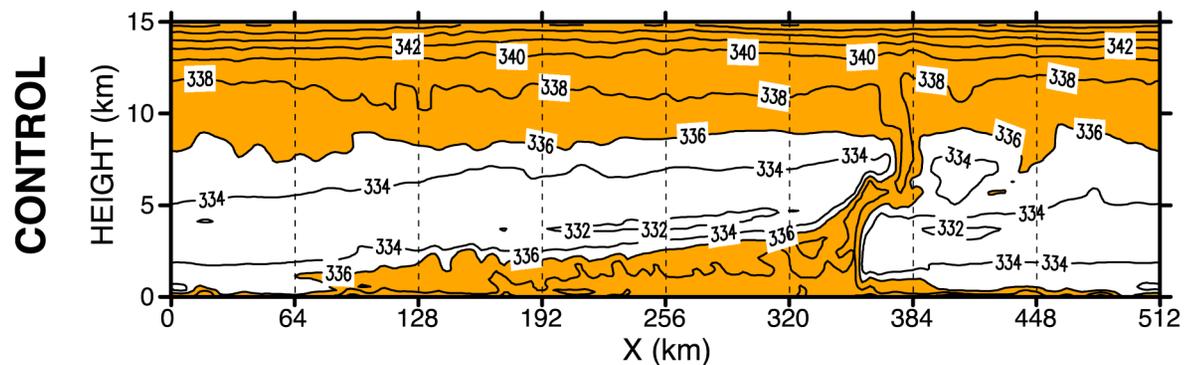


The original method of coupling

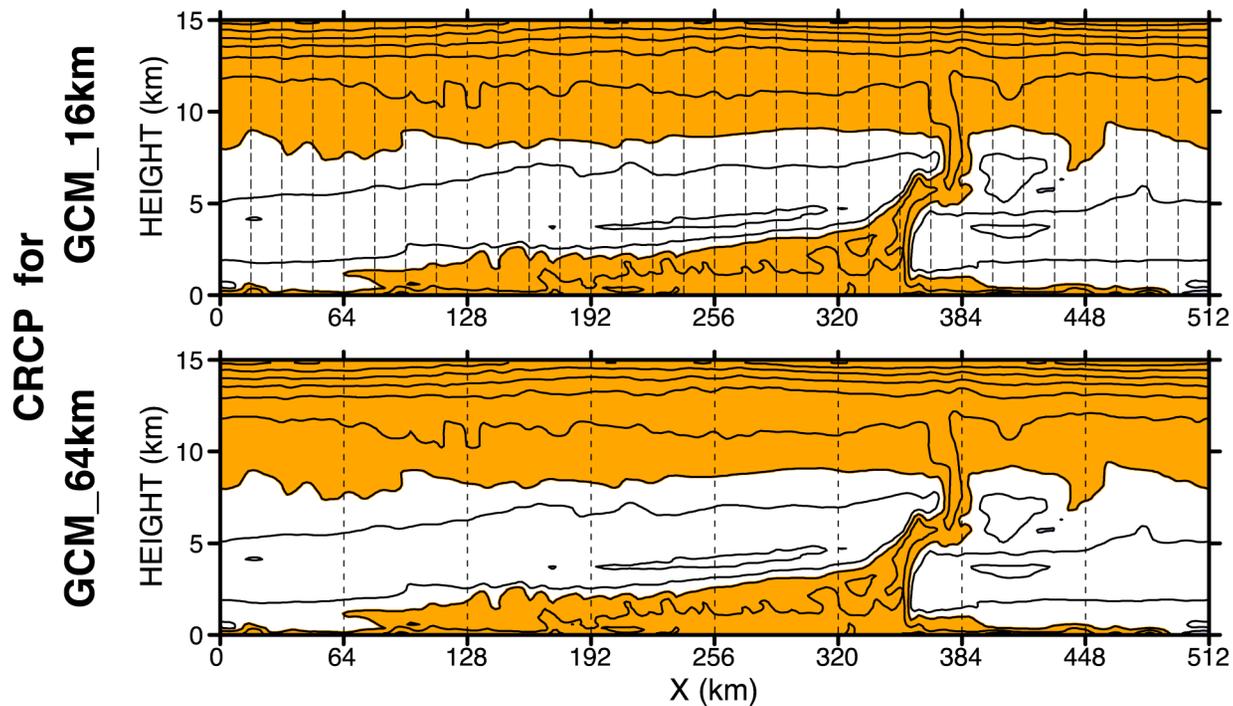


Moist Static Energy (K)

local time: 13 h

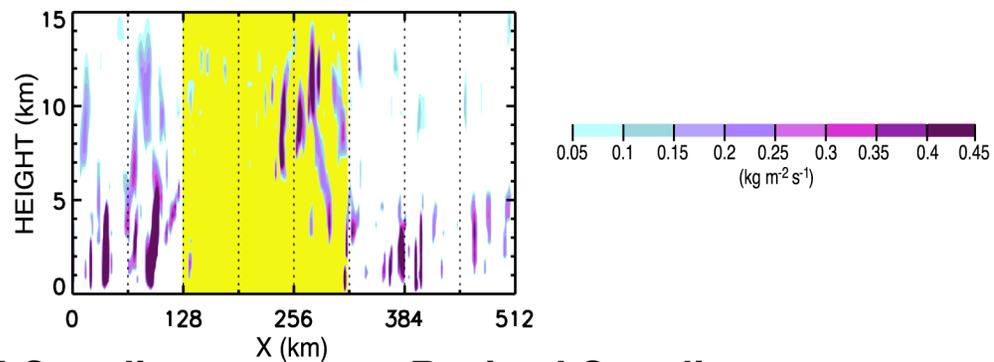


The revised method of coupling



Upward Mass Flux (after 20 min. integration)

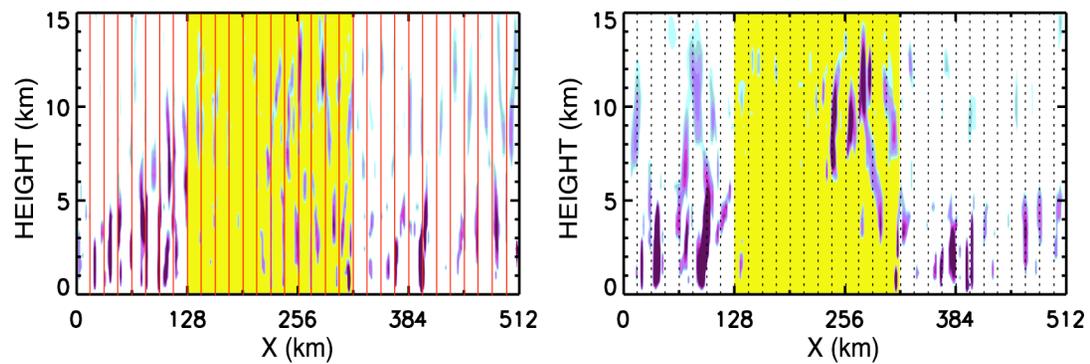
CONTROL



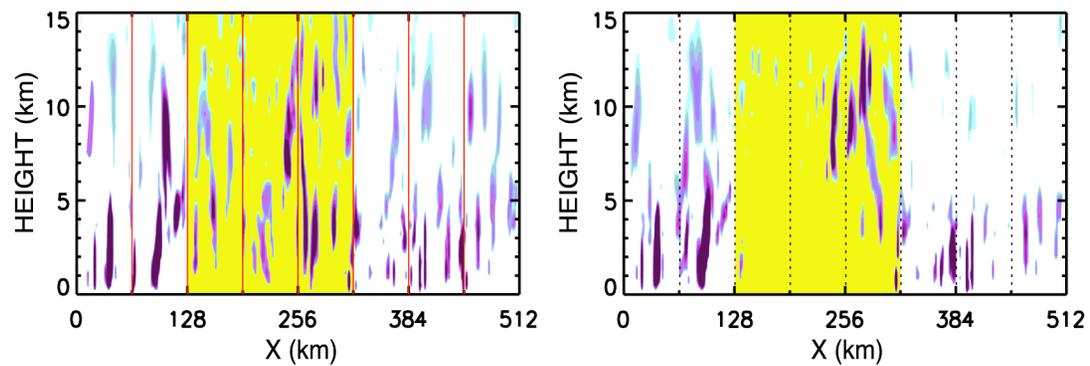
Original Coupling

Revised Coupling

CRCP for GCM_16km

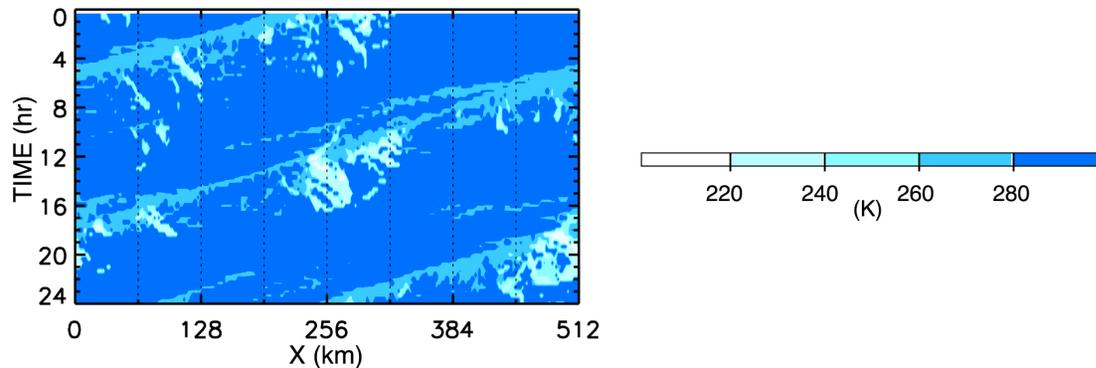


CRCP for GCM_64km



Cloud Top Temperature

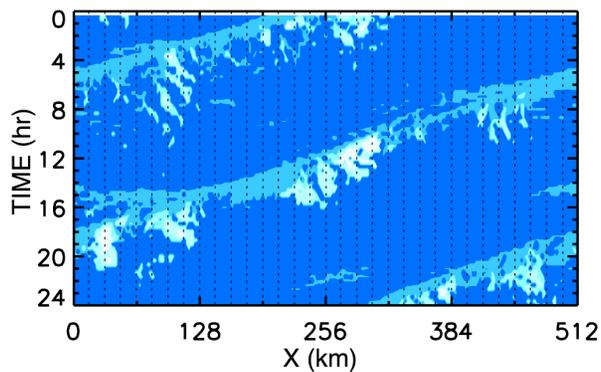
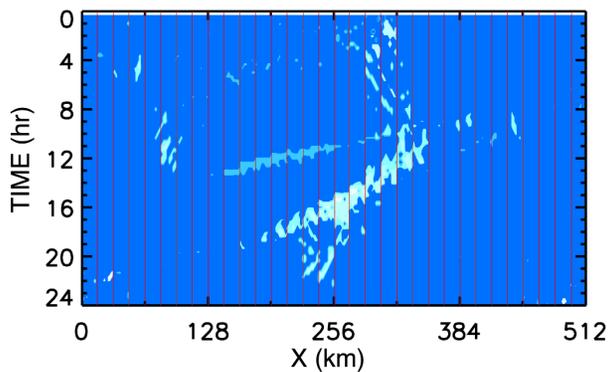
CONTROL



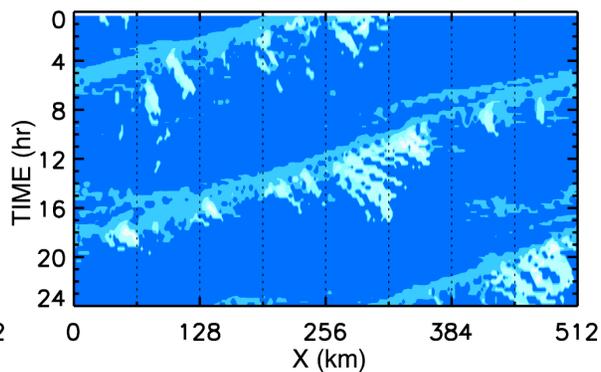
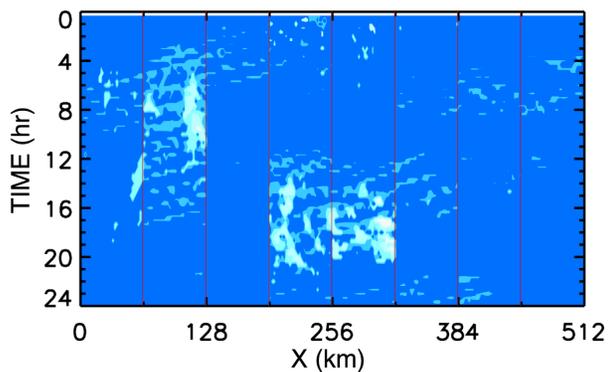
Original Coupling

Revised Coupling

CRCP for GCM_16km



CRCP for GCM_64km

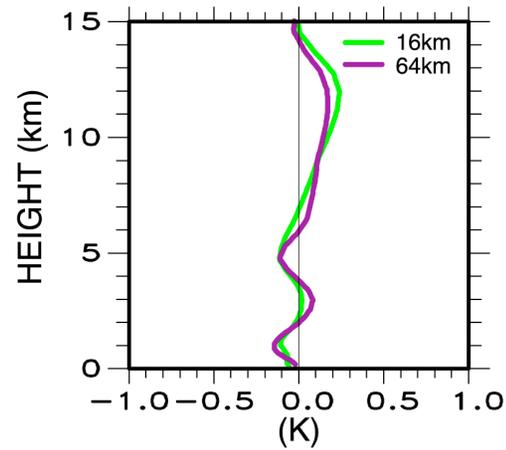
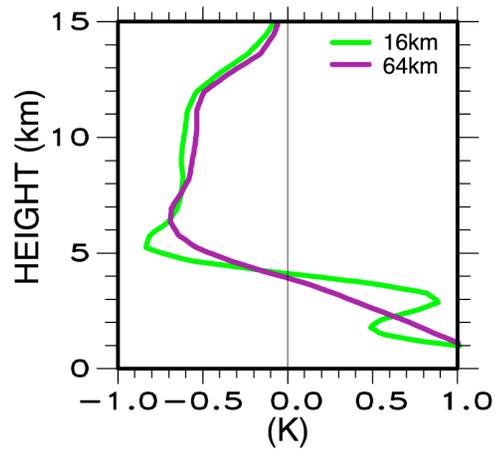


Errors of the Ensemble Time/Domain Averaged Profiles Predicted by GCM with CRCP

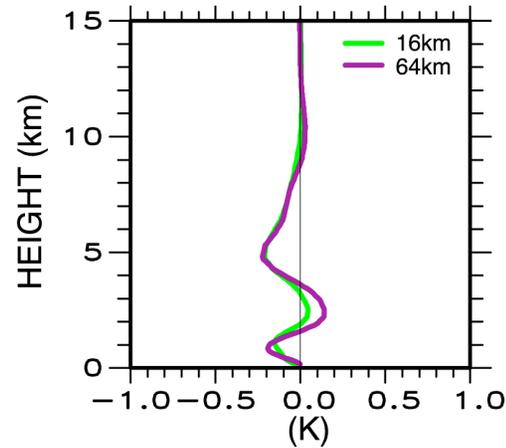
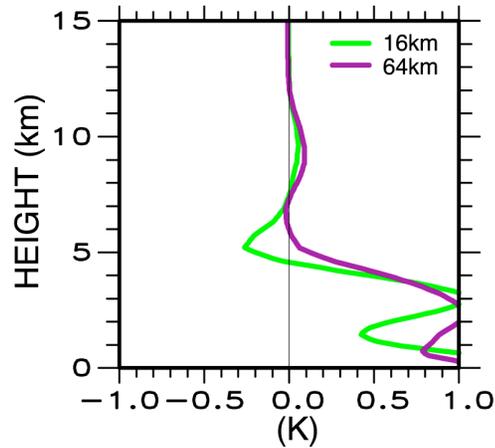
Original Coupling

Revised Coupling

Moist Static Energy

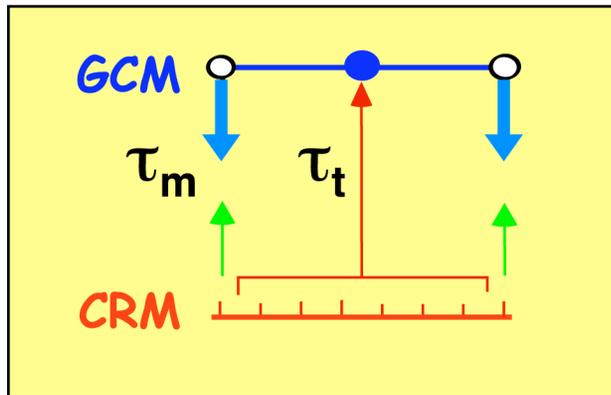


Total Water



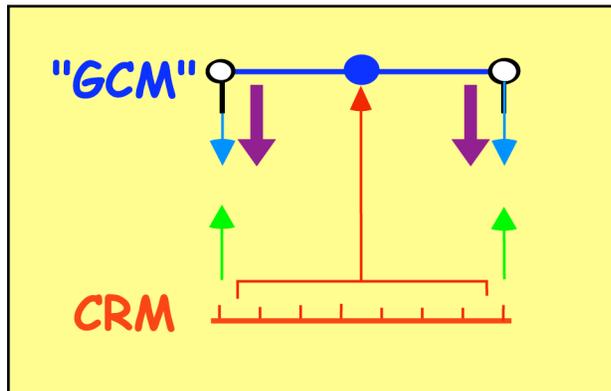
**Sensitivity to the Choice of Relaxation times
for momentum (τ_m) and thermodynamic fields (τ_t)
in the Revised Method of Coupling**

Revised Method of Coupling



- ↓ Predicted U by GCM
- ↑ Predicted u by CRM
- ↑ Thermodynamic field updating

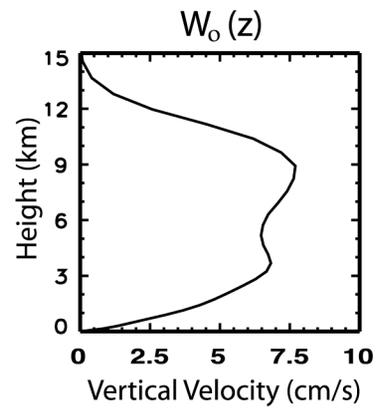
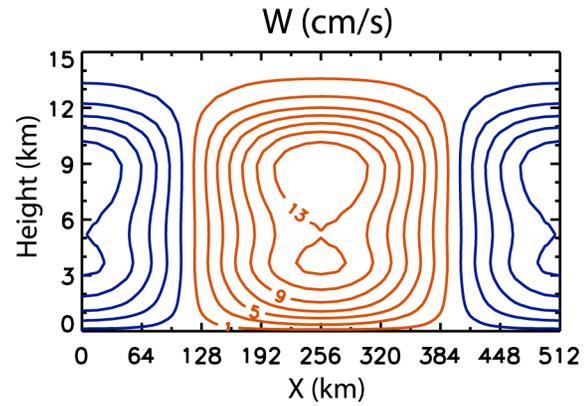
How to let the CRM recognize large-scale velocity field which can not be predicted by "GCM" ?



- ↓ Predicted U by "GCM"
- ↓ U associated with the prescribed vertical velocity

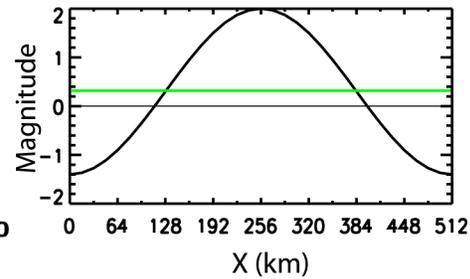
A combination of "GCM" and prescribed vertical velocity substitute a real GCM.

Prescribed Large-scale Vertical Velocity for CONTROL



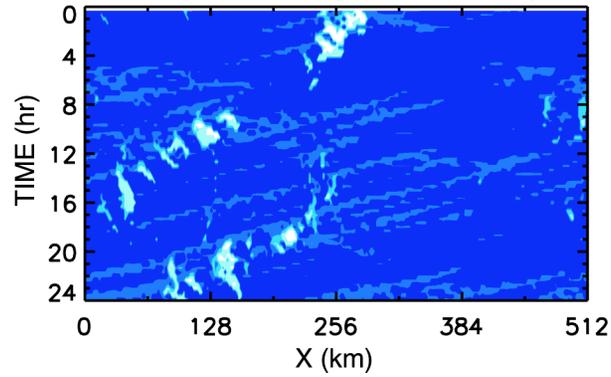
Zonal Variation Factor of W:

$$0.3 + 1.7 \cos 2\pi \left(\frac{x + \mathbf{X}/2}{\mathbf{X}} \right)$$



Cloud Top Temperature (day 12)

CONTROL (over ocean)

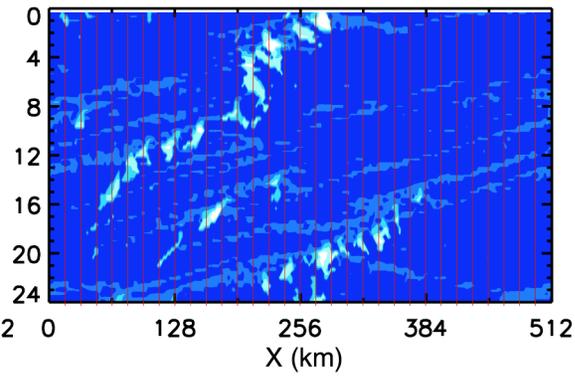
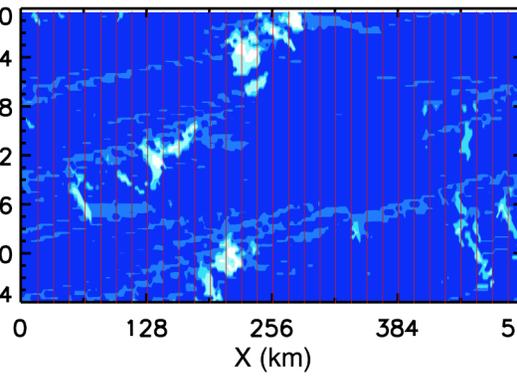
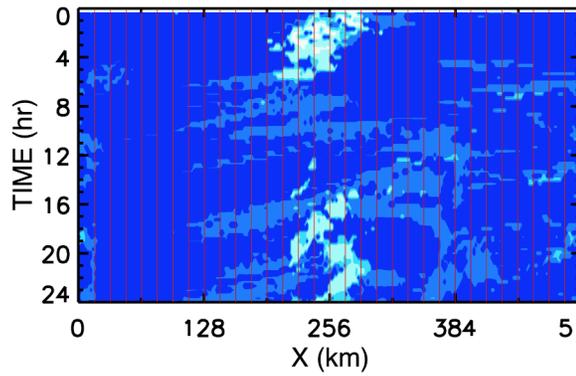


$\tau_m = 10 \text{ min}$

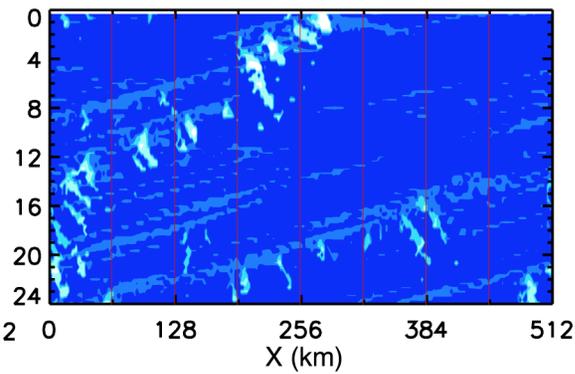
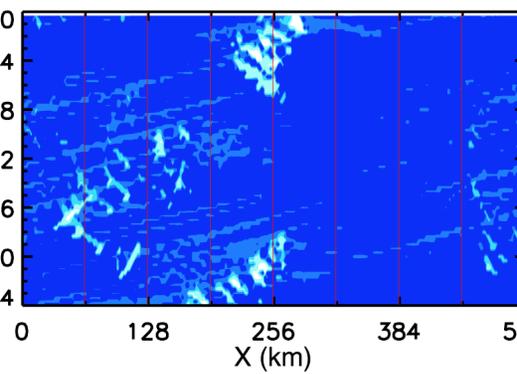
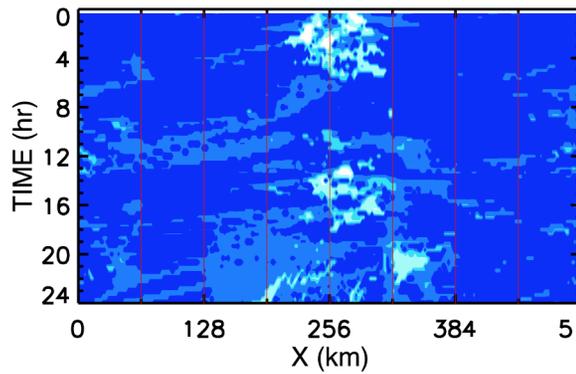
$\tau_m = 1 \text{ hr}$

$\tau_m = 6 \text{ hr}$

GCM_16km



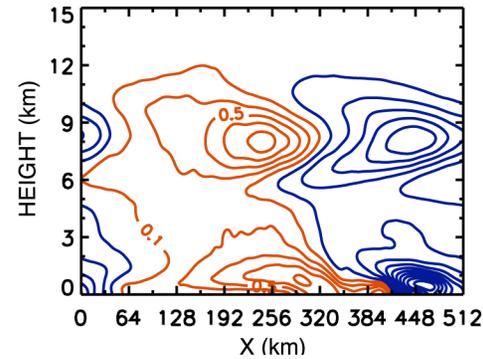
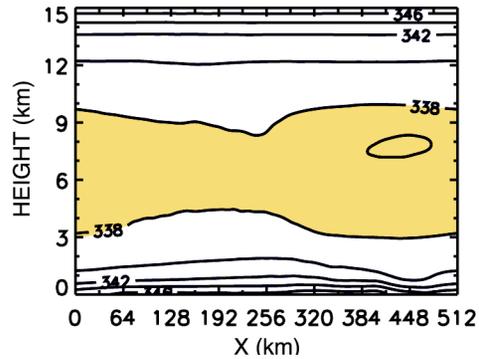
GCM_64km



Predicted with CRCP for

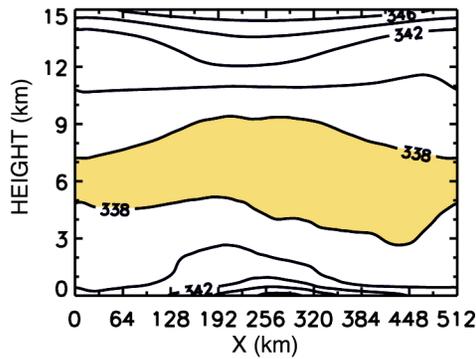
Ensemble Time Averaged Moist Static Energy and its Deviation from the Zonal Mean

CONTROL

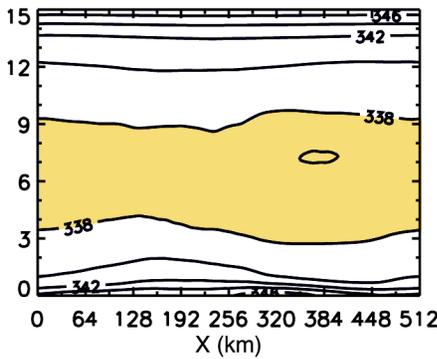


Predicted with CRCP for GCM_16km

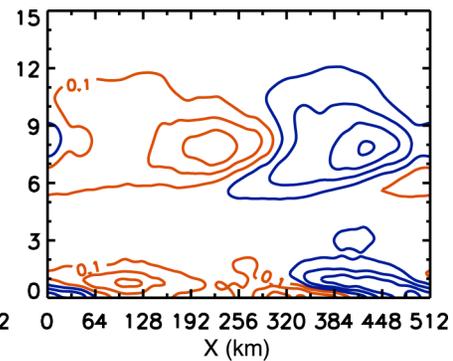
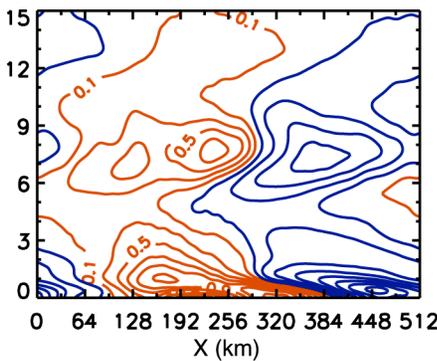
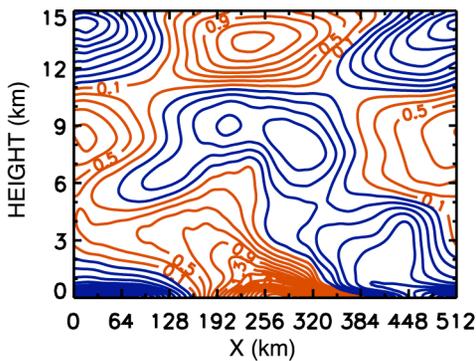
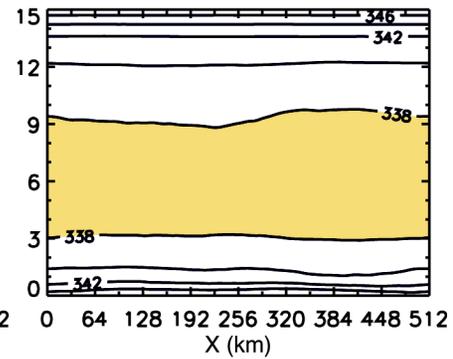
$\tau_m = 10$ min



$\tau_m = 1$ hr

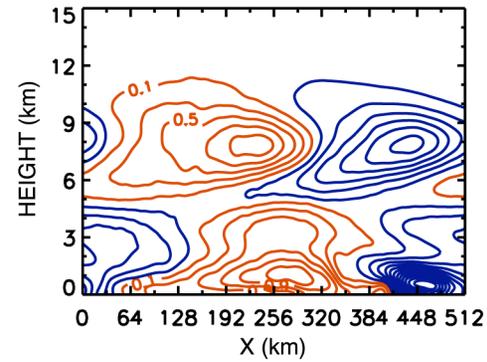
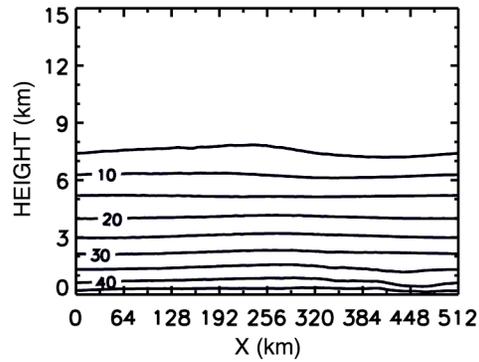


$\tau_m = 6$ hr



Ensemble Time Averaged Total Water and its Deviation from the Zonal Mean

CONTROL

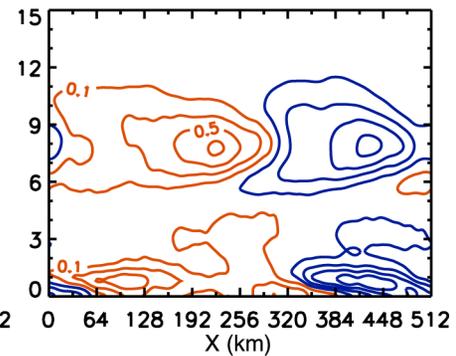
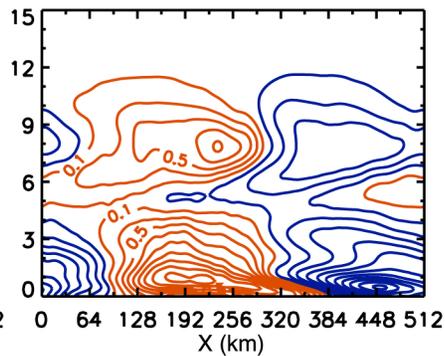
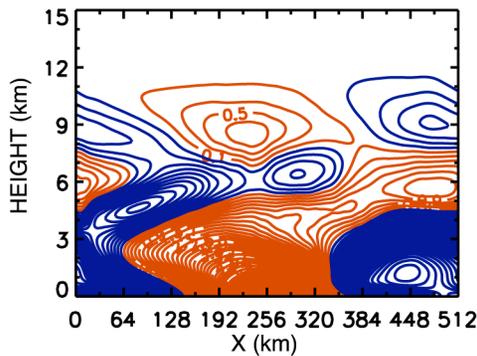
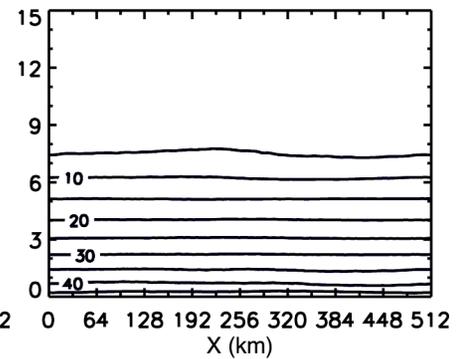
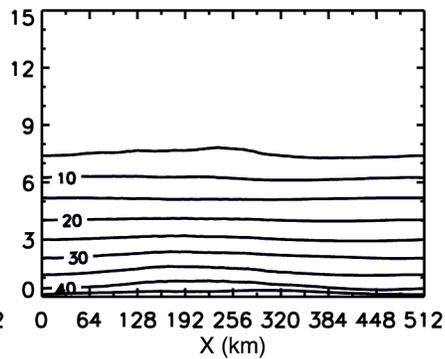
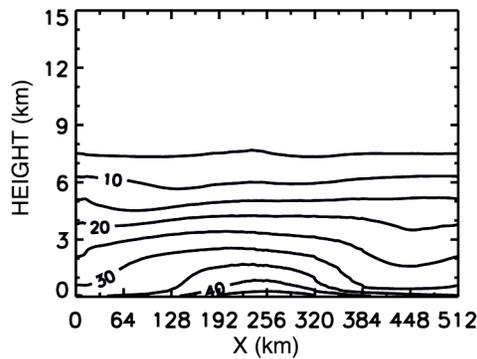


Predicted with CRCP for GCM_16km

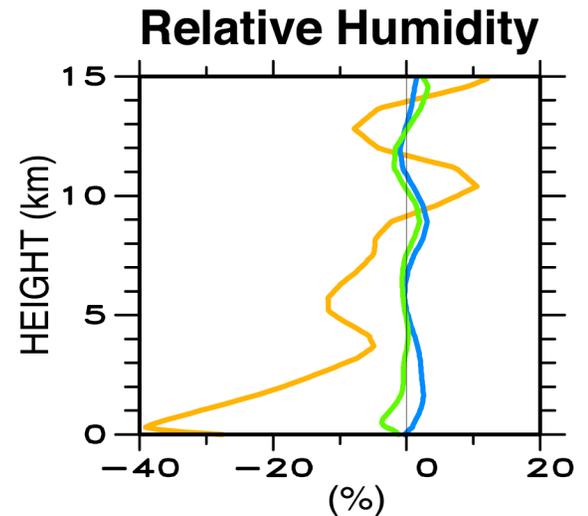
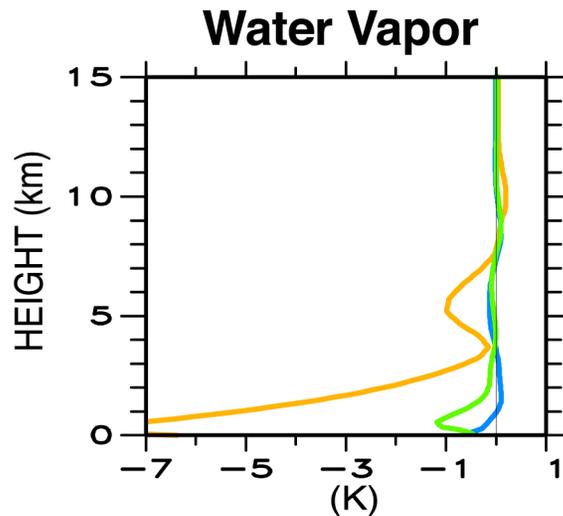
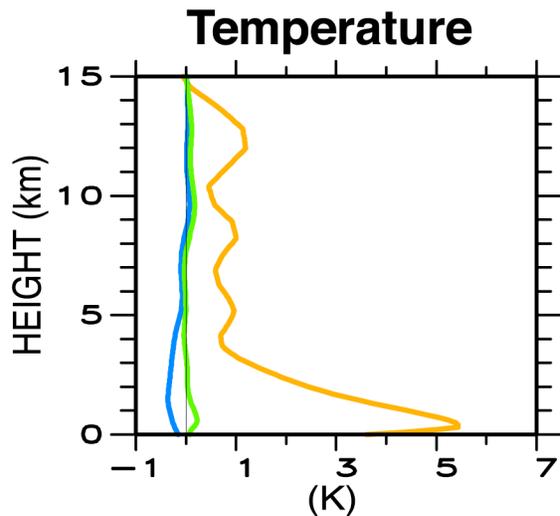
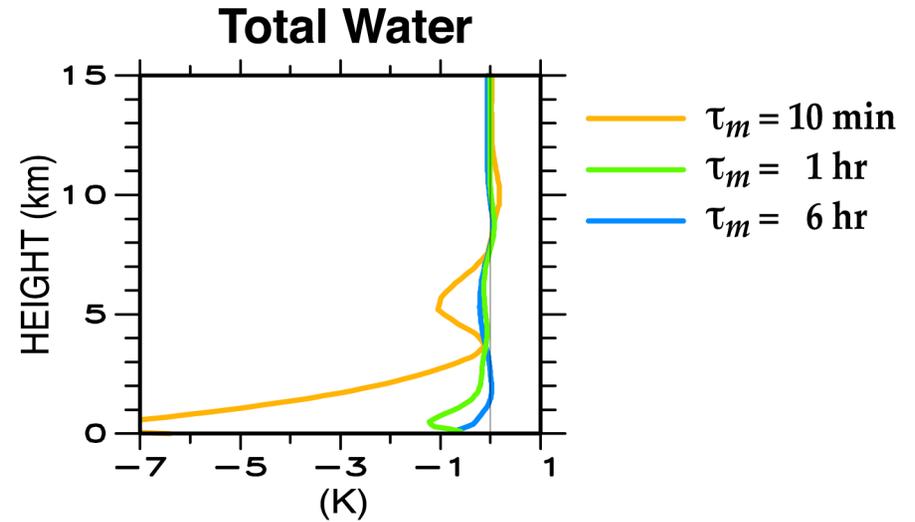
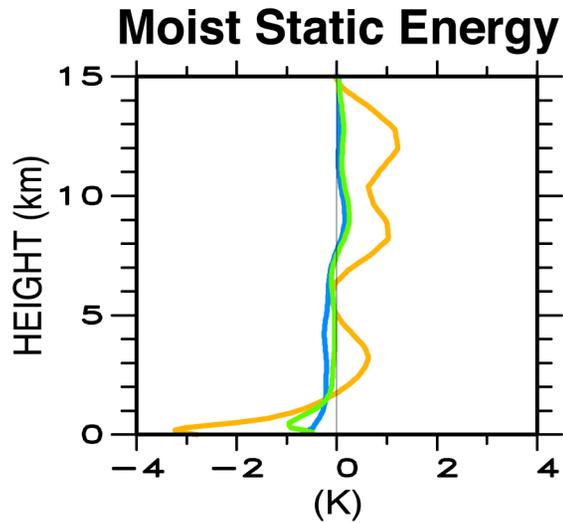
$\tau_m = 10 \text{ min}$

$\tau_m = 1 \text{ hr}$

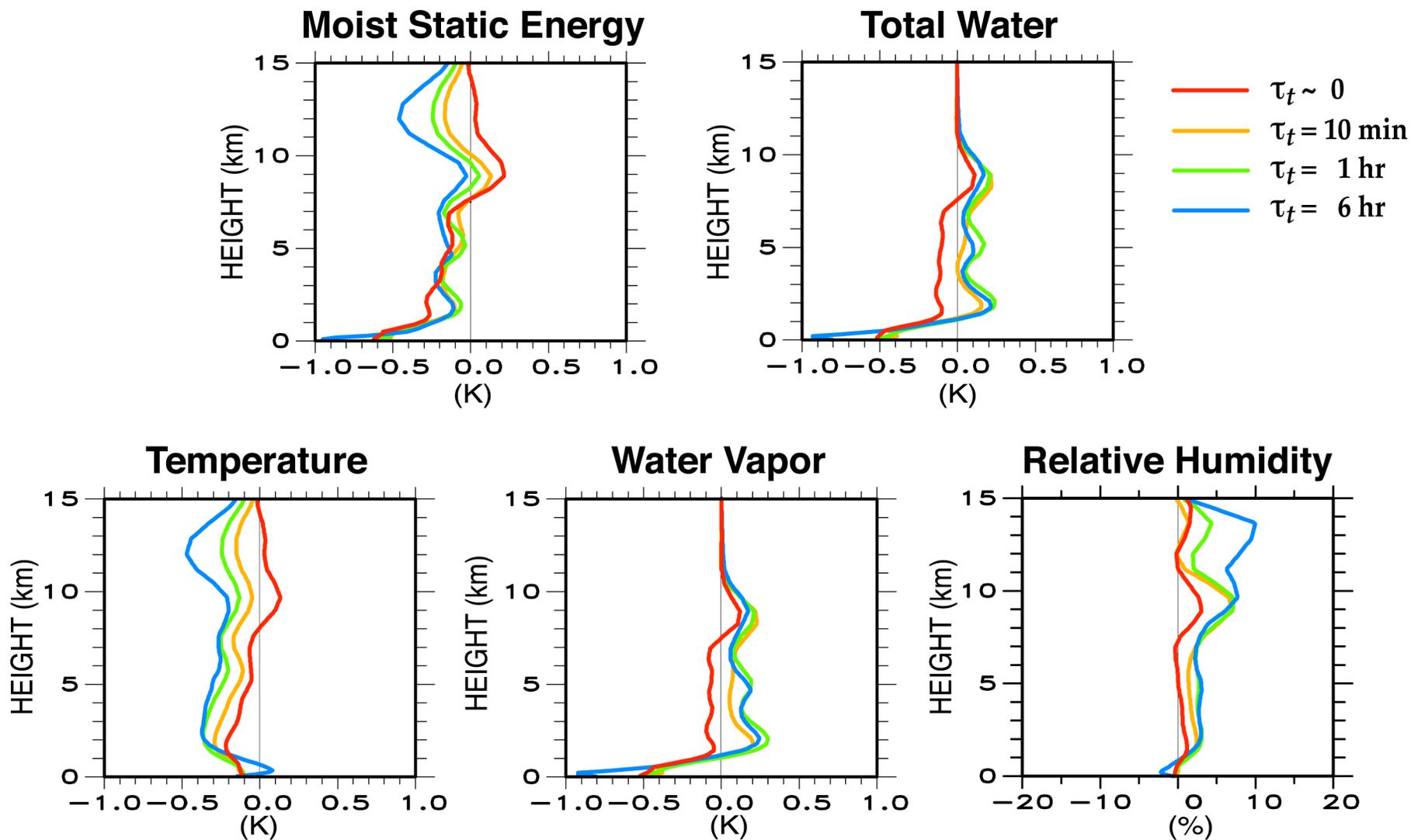
$\tau_m = 6 \text{ hr}$



**Errors of the Ensemble Time/Domain Averaged Profiles
Predicted by GCM_16km with CRCP
($\tau_t \sim 0$)**



Errors of the Ensemble Time/Domain Averaged Profiles Predicted by GCM_16km with CRCP ($\tau_m = 2$ hr)



SUMMARY AND CONCLUSIONS

- The original and revised methods of coupling a CRM and a GCM are tested in the two-dimensional framework.

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 sensitivity to the choice of relaxation times for momentum and thermodynamic fields in the revised method of coupling are also tested.

The coupling is more sensitive to the choice of relaxation times for momentum than that for thermodynamic fields.