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. $\tau_m = 1$ 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) x 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

![Graph showing prescribed large-scale advective tendency with labels for advective cooling and moistening.](Image)
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
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 ($\tau_m$) and thermodynamic fields ($\tau_t$) in the Revised Method of Coupling
Revised Method of Coupling

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

A combination of "GCM" and prescribed vertical velocity substitute a real GCM.
Prescribed Large-scale Vertical Velocity for CONTROL

\[ W_0(z) = 0.3 + 1.7 \cos 2\pi \left( \frac{x + x/2}{X} \right) \]
Cloud Top Temperature (day 12)

CONTROL (over ocean)

$\tau_m = 10 \text{ min}$

$\tau_m = 1 \text{ hr}$

$\tau_m = 6 \text{ hr}$

Predicted with CRCP for

GCM_16km

GCM_64km
Ensemble Time Averaged Moist Static Energy and its Deviation from the Zonal Mean

CONTROL

Predicted with CRCP for GCM_16km

τ_m = 10 min

τ_m = 1 hr

τ_m = 6 hr
Ensemble Time Averaged Total Water and its Deviation from the Zonal Mean

CONTROL

Predicted with CRCP for GCM_16km

$\tau_m = 10$ min  $\tau_m = 1$ hr  $\tau_m = 6$ hr
Errors of the Ensemble Time/Domain Averaged Profiles Predicted by GCM_16km with CRCP

$(\tau_t \sim 0)$

Moist Static Energy

Total Water

Temperature

Water Vapor

Relative Humidity

- $\tau_m = 10$ min
- $\tau_m = 1$ hr
- $\tau_m = 6$ hr
Errors of the Ensemble Time/Domain Averaged Profiles Predicted by GCM_16km with CRCP

$\tau_m = 2 \text{ hr}$

- **Moist Static Energy**
  - HEIGHT (km)
  - (K)
  - Colors represent different time intervals:
    - $\tau_t \sim 0$
    - $\tau_t = 10 \text{ min}$
    - $\tau_t = 1 \text{ hr}$
    - $\tau_t = 6 \text{ hr}$

- **Total Water**
  - HEIGHT (km)
  - (K)

- **Temperature**
  - HEIGHT (km)
  - (K)

- **Water Vapor**
  - HEIGHT (km)
  - (K)

- **Relative Humidity**
  - HEIGHT (km)
  - (%)
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.