Attempts of Cloud Microphysics in a GCM

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Moisture equations & Reynolds averaging

- Governing equations for water vapor ($q$)

$$\frac{\partial q}{\partial t} + (\bar{u} \cdot \nabla)q = -C$$

- After Reynolds averaging (over a grid)

$$\frac{\partial \bar{q}}{\partial t} + \bar{u} \cdot \nabla \bar{q} = -\frac{\partial}{\partial p} \omega' q' - \bar{C}$$

- Convective parameterization equation

$$-\frac{\partial}{\partial p} \omega' q' = -g \frac{\partial M_c(q_c - \bar{q})}{\partial p} - C$$

- $C$: condensation-evaporation
- Sub-grid scale physics (Cloud)
- Large-scale condensation
- $C$: convective precipitation
35km GCM simulation

Simplified RAS

No cumulus parameterization
Parameterization is still needed for O(10km) models
But not as it is in O(100km) models
Current approaches

**Explicit Parameterization**

Aerosol Indirect Effect
- Global radiation budget change
- Climate change simulation
- Regional climate impact
  - Change monsoon circulation

**Multi-scale Modeling Framework (Superparameterization)**

Global Cloud Resolving Model

- NASA/GSFC, CSU
- NICAM (Japan)

*Horizontal Resolution of CRM: 4km

14, 7, 3.5km
Cloud Microphysics

No cumulus parameterization

Simplified RAS
Cloud Resolving Model

Hovmuller diagram of precipitation (No nudging of zonal wind)

Radiative-convective equilibrium experiment (self adjusted by energy balance) 3.82 mm day⁻¹, 3.77 mm day⁻¹, 3.85 mm day⁻¹, 3.95 mm day⁻¹
Vertical profile of moist static energy

- Last 15 days mean of radiative-convective equilibrium
Budget of microphysical processes (vertical integration)

Dominant processes having resolution dependency

- Rainfall rate
- Evaporation
- Condensation
- Sublimation
- Melting of graupel to make rain
- Melting of snow to make rain
- Deposition
- Accretion of cloud ice to make graupel
- Accretion of cloud water to make graupel
- Accretion of snow to make graupel
- Bergeron process of cloud ice
- Accretion of cloud water to make rain
- Accretion of rain to make snow
- Accretion of cloud water to make snow
- Freezing of cloud water to make ice

[10^{-2} \text{ mm h}^{-1}]
Modification of cloud microphysics in CRM

✓ Sub-grid concept of condensation process

- RH vs. amount of condensation

✓ Modification of autoconversion threshold value

\[
PRAUT = \alpha \rho (q_c - q_{c0})
\]

- \( \alpha \): rate coefficient (10^{-3})
- \( q_{c0} \): mass threshold value for autoconversion

\[
(\alpha) = CND + \alpha \cdot (EVP - \alpha)
\]

- Modify \( q_{c0} \) smaller from 1.5 \times 10^{-6} \text{ g g}^{-1} to 1.5 \times 10^{-4} \text{ g g}^{-1} (expect to the active conversion process from cloud water to rain water)
CRM result for condensation rate

(1) Sub-grid concept of condensation process

(2) Modification on autoconversion

Total modification (1) + (2)
The Impact of Modification of cloud microphysics

- Original microphysics (35km, Jan)
- Modified microphysics (35km, Jan)

PDF of precipitation
30S~10N, 45E~240E

- a) PDF of little prcp.
- b) PDF of middle prcp.
- c) PDF of heavy prcp.
- d) Diff. (new-old)
- e) Diff. (new-old)
- f) Diff. (new-old)
Toward High Resolution GCM with Microphysics

- Microphysics for convective cloud
- Microphysics for grid-scale condensation
- Subgrid-scale vertical transport

Advanced Moist processes for high resolution GCM

Convective parameterization

Cloud microphysics (GCE)
Parameterization vs Microphysics

Precipitation (Jan)

- TRMM Observation

- 35km GCM simulation

Convective parameterization (Bulk scheme Kim & Kang, 2011)
Large scale condensation parameterization

\[ \frac{\partial \tilde{q}}{\partial t} + \tilde{u} \cdot \nabla \tilde{q} = \frac{\partial}{\partial p} \left( \omega' q' \right) - \tilde{C} \]

Modified cloud microphysics (GCE)

Microphysics for grid-scale condensation only
Parameterization vs Microphysics

Precipitation (Jan)

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- 35km GCM simulation

Microphysics for grid-scale condensation only

> Adding convective parameterization for sub-grid scale condensation

Modified cloud microphysics (GCE)

\[
\frac{\partial \tilde{q}}{\partial t} + \tilde{u} \cdot \nabla \tilde{q} = \frac{\partial}{\partial p} \left( \omega' q' \right)
\]

Convective parameterization (Bulk scheme Kim & Kang, 2011)
Shallow convection vs Deep convection

- TRMM Observation
- 35km GCM simulation

Modified Microphysics
+ shallow convection
(non-precipitation, diffusion type
similar concept to Manabe scheme)

Modified Microphysics
+ shallow convection
+ Deep convection (BULK scheme)
Shallow convection vs Deep convection

Modified Microphysics

+ shallow convection
  (non-precipitation, diffusion type
  similar concept to Manabe scheme)

Modified Microphysics
+ Deep convection (BULK scheme)

35km GCM simulation

Precipitation (Jan, 3hourly)
Cloud microphysics

Non-hydrostatic vertical motion
Explicit turbulence
Cloud microphysics

Gobal CRM

Too much computational cost

High resolution GCM
Bulk & turbulence ensemble convection
Resolution dependent microphysics

Conventional GCM
Hydrostatic
Parameterized turbulence
Simple rain process

O(<1km)

O(100km)
Thank you
Influence of different type of microphysics in GCM

- Prcp. of Jun

TRMM

Lin scheme (1983), 35km

Rutledge-Hobbs scheme (1984), 35km