Attempts of Cloud Microphysics in a GCM

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Moisture equations & Reynolds averaging

❖ Governing equations for water vapor (q)

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

• C: condensation-evaporation

❖ After Reynolds averaging (over a grid)

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

Sub-grid scale physics (Cloud)

Large-scale condensation

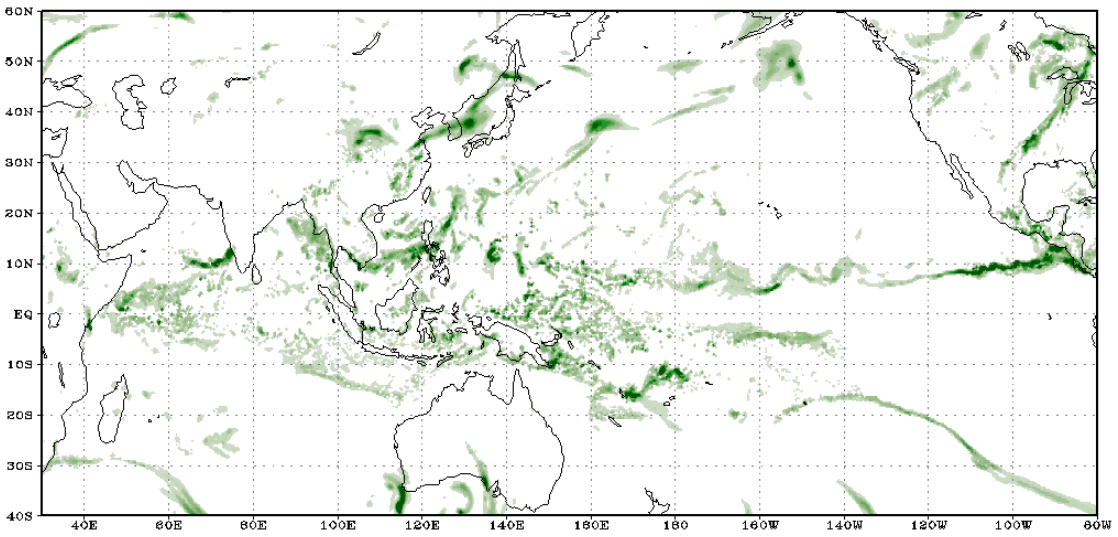
❖ Convective parameterization equation

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

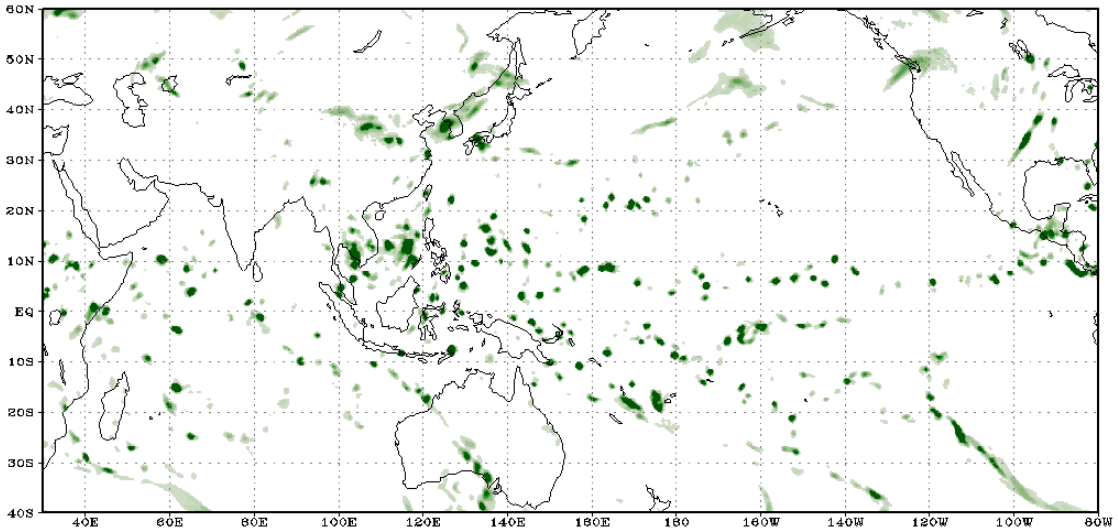
• C: convective precipitation

➢ 35km GCM simulation

Simplified RAS



No cumulus parameterization

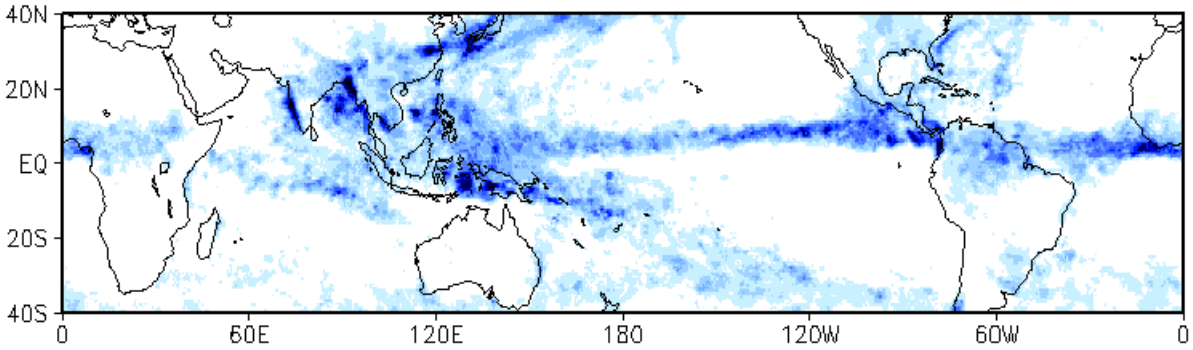


Monthly Mean

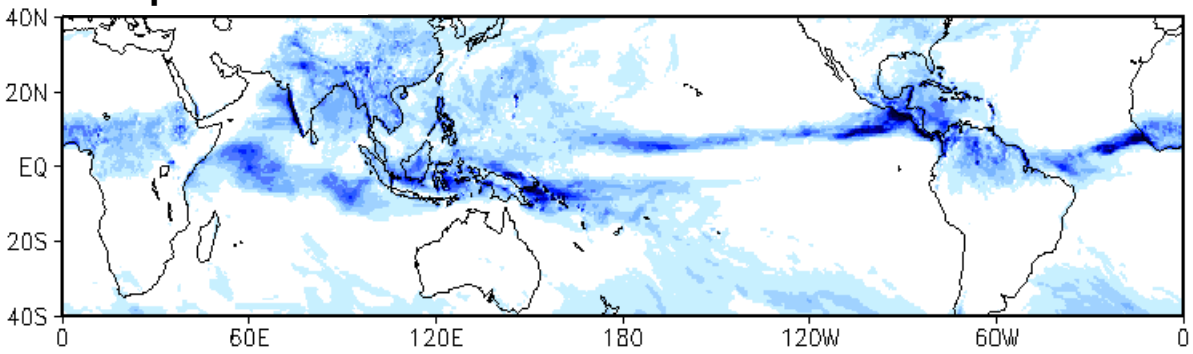
1999
June mean

precipitation

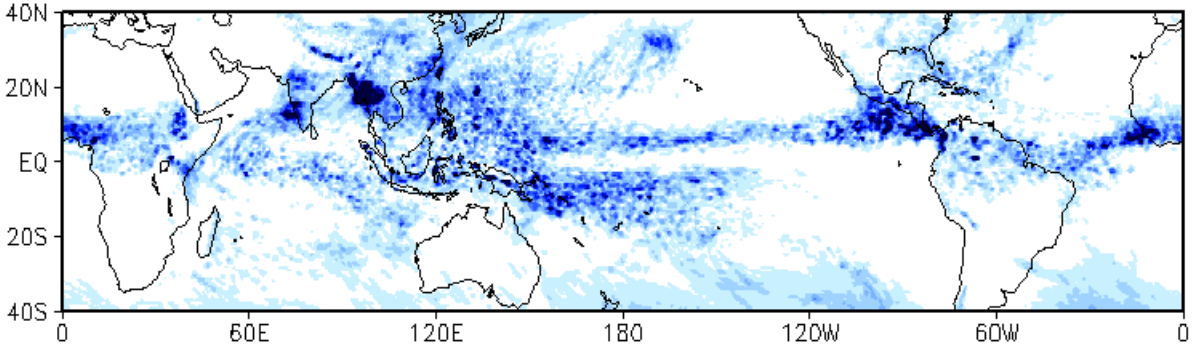
TRMM



Simplified RAS

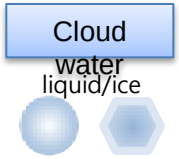


No cumulus parameterization



Parameterization is still needed for O(10km) models
But not as it is in O(100km) models

Conventional GCM

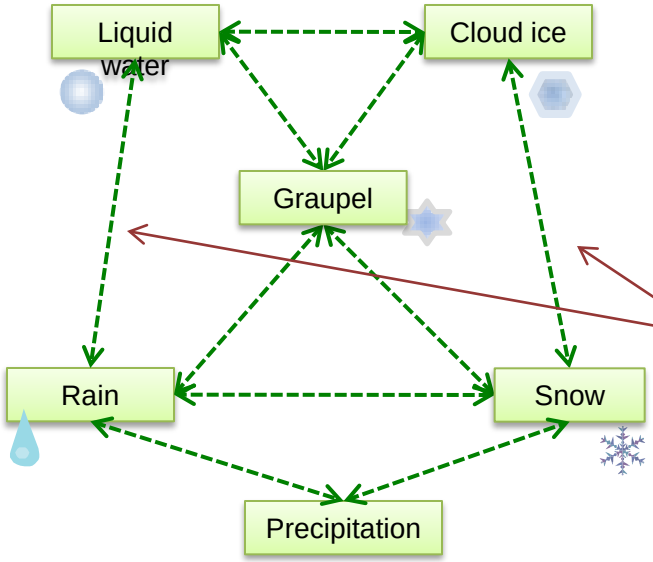


Implicit Parameterization

Autoconversion
Accretion…

:removed in 1 step

CRM Cloud Microphysics



Explicit Parameterization

Aerosol Indirect Effect

- **Global radiation budget change**

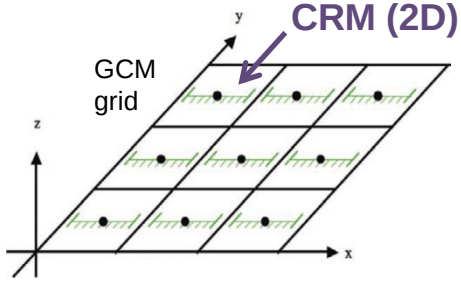
→Climate change simulation

- Regional climate impact

→ Change monsoon circulation

❖ Current approaches

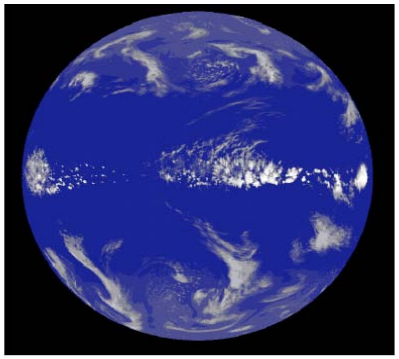
Multi-scale Modeling Framework (Superparameterization)



NASA/GSFC, CSU

***Horizontal Resolution of CRM: 4km**

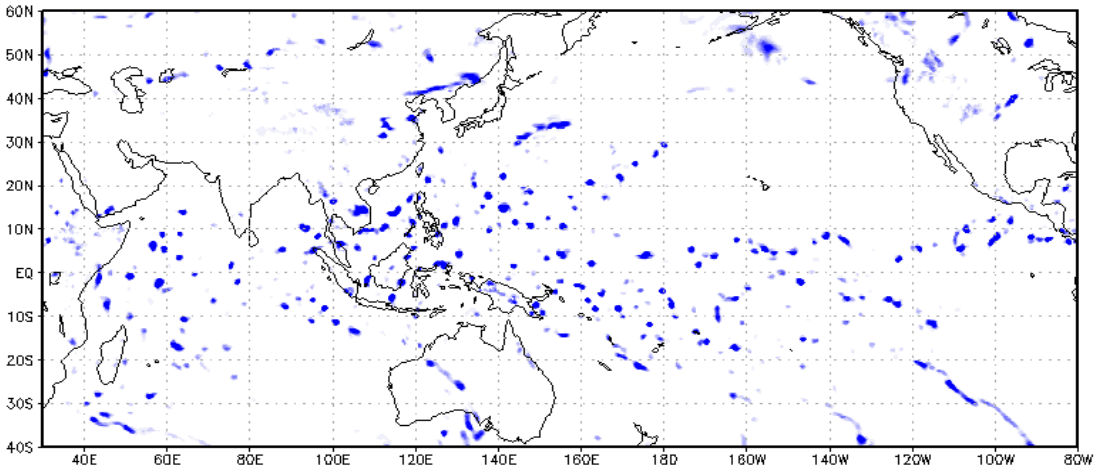
Global Cloud Resolving Model



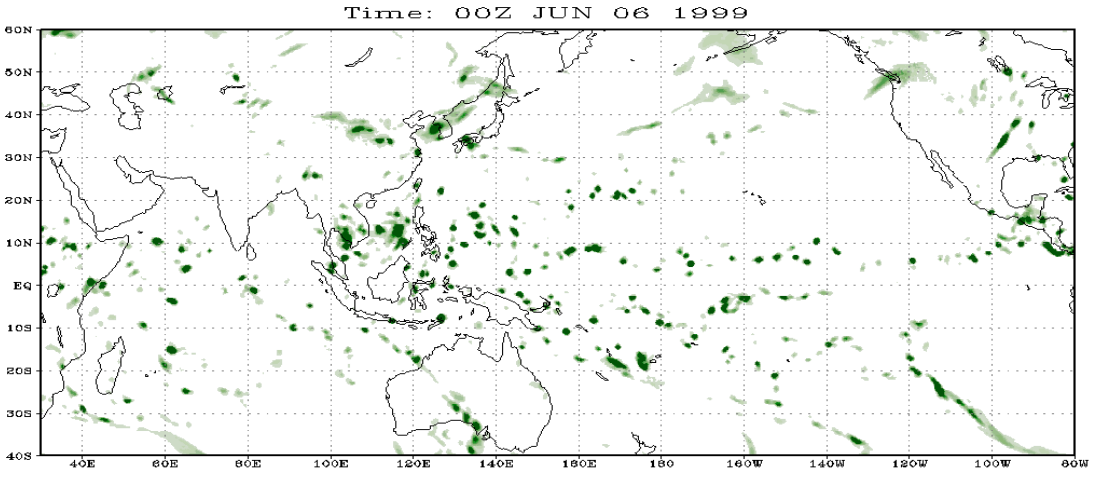
NICAM (Japan)

14, 7, 3.5km

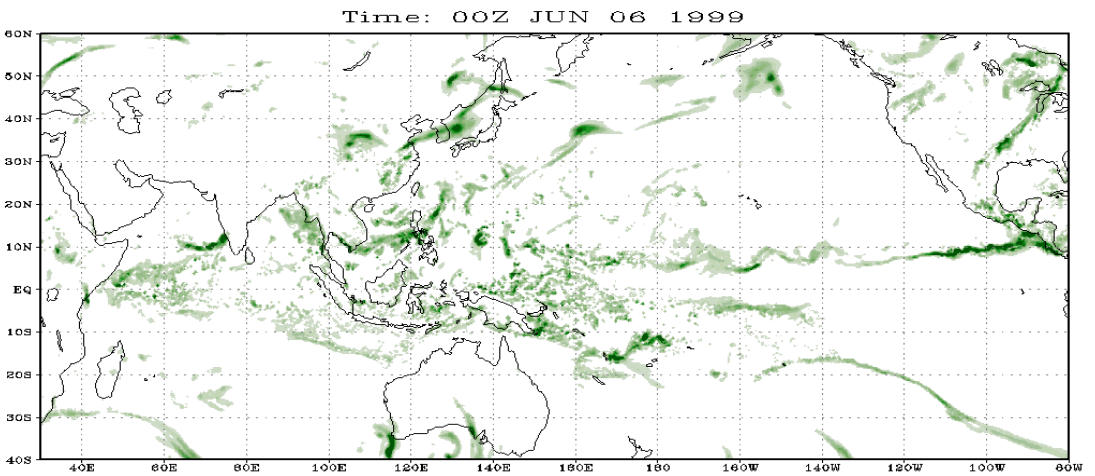
Cloud Microphysics



No cumulus parameterization

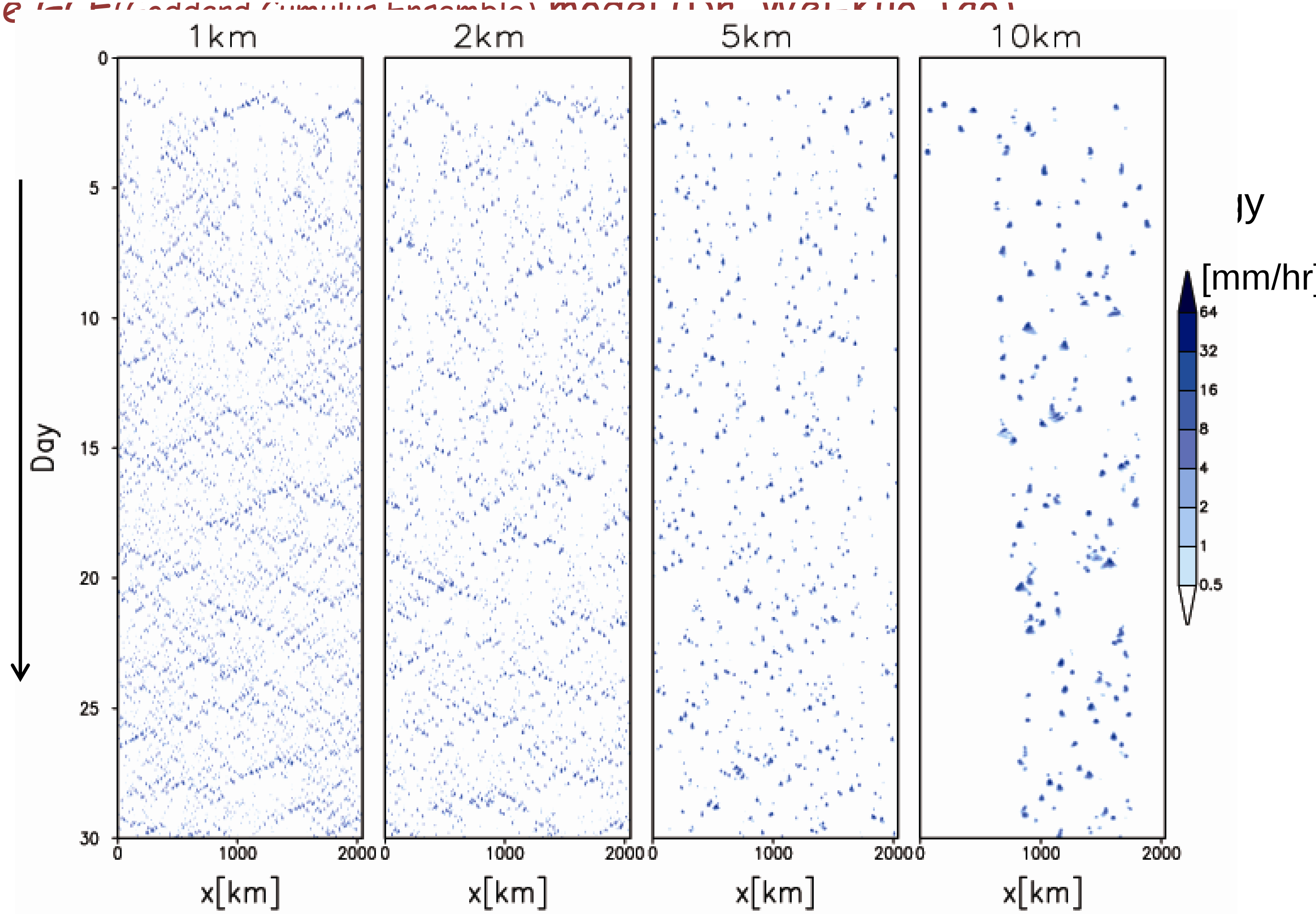


Simplified RAS



Cloud Resolving Model

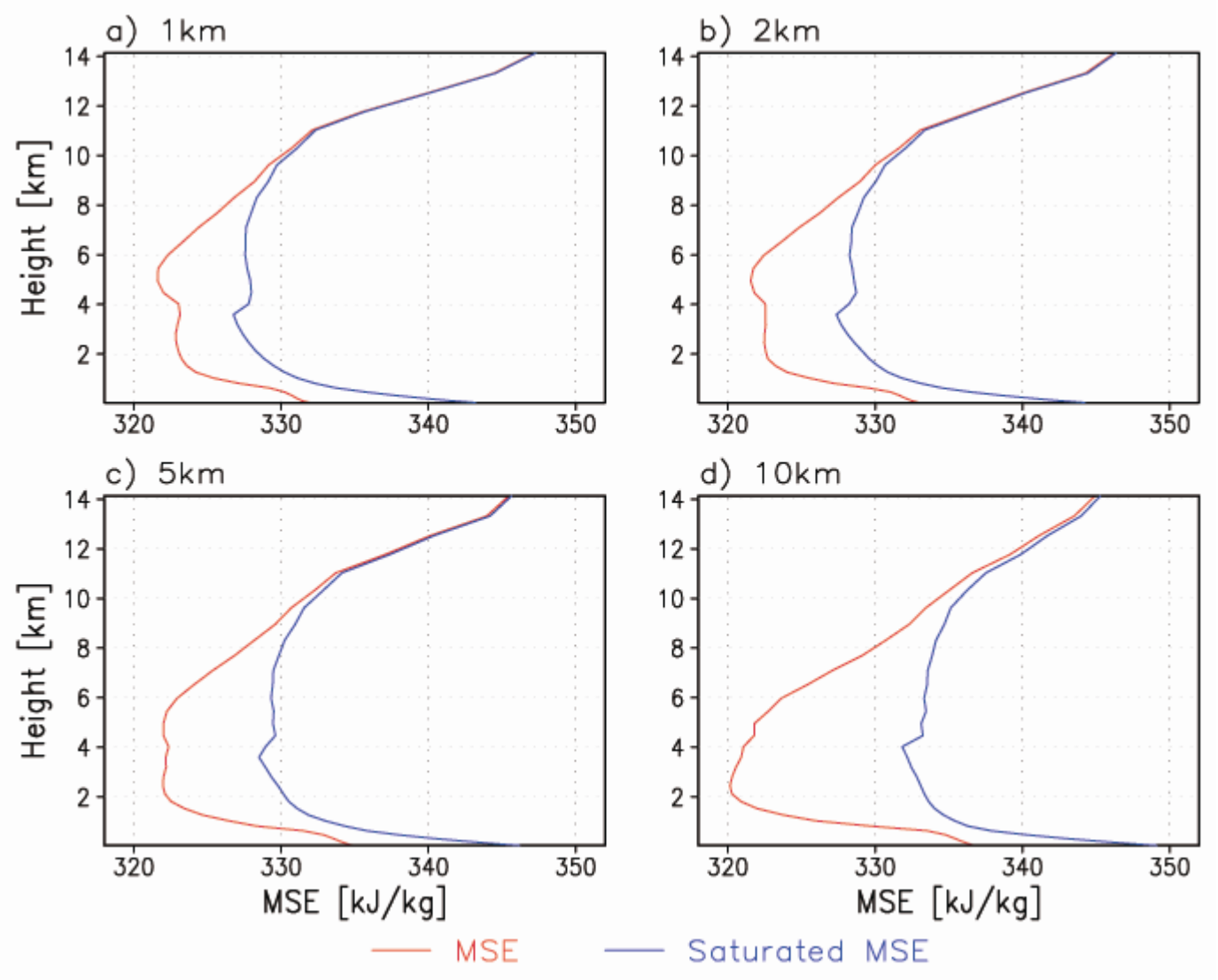
Hovmuller diagram of precipitation (No nudging of zonal wind)



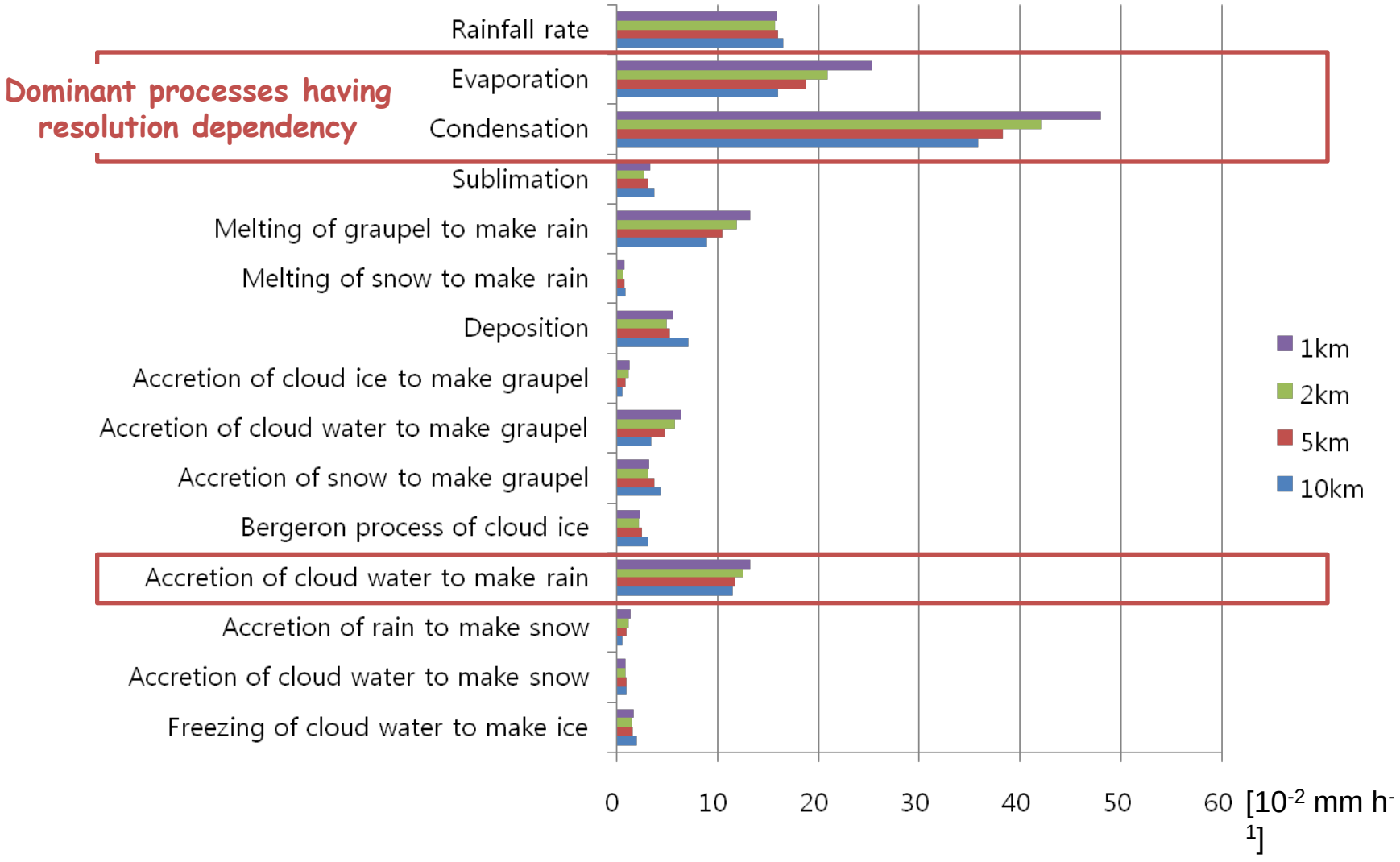
1km	2km	5km	10km
3.82 mm day^{-1}	3.77 mm day^{-1}	3.85 mm day^{-1}	3.95 mm day^{-1}

Vertical profile of moist static energy

- ✓ Last 15 days mean of radiative-convective equilibrium

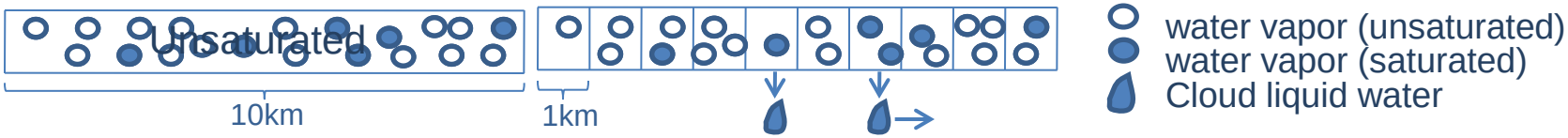


Budget of microphysical processes (vertical integration)

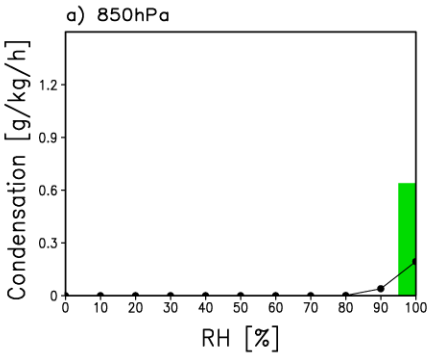


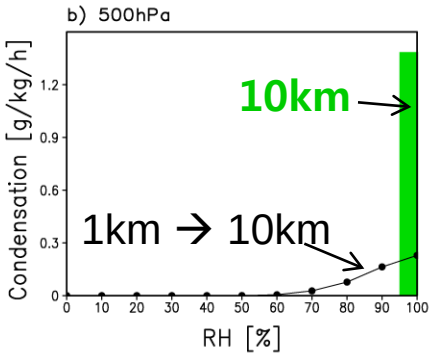
Modification of cloud microphysics in CRM

✓ Sub-grid concept of condensation process

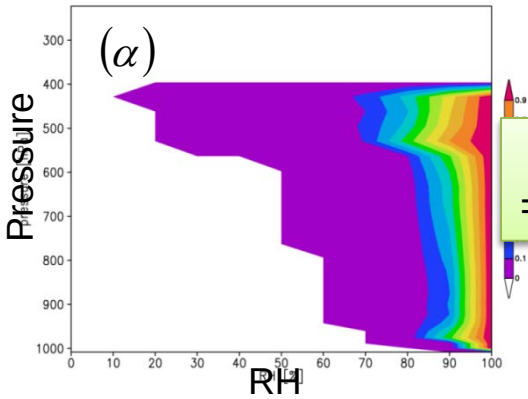


- RH vs. amount of condensation





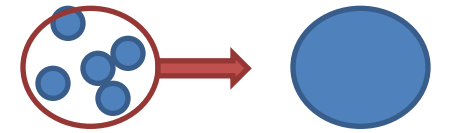
Fraction of condensation area



Modification of CND

= CND × α + ENV (1 − α)

✓ Modification of autoconversion threshold value



$$P_{RAUT} = \alpha\rho(q_c - q_{c0})$$

α : rate coefficient (10^{-3})

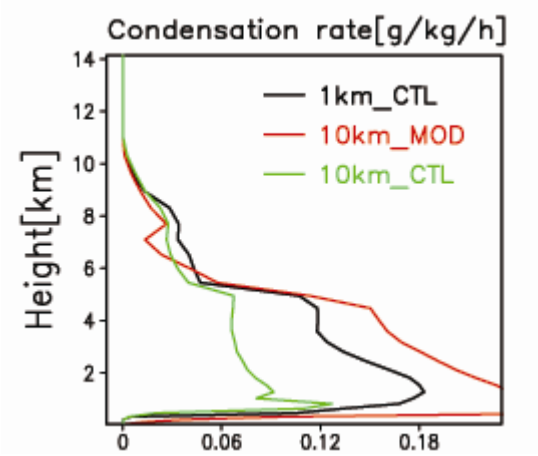
q_{c0} : mass threshold value for autoconversion

→ If $q_c < q_{c0}$ (no process to make rain water)

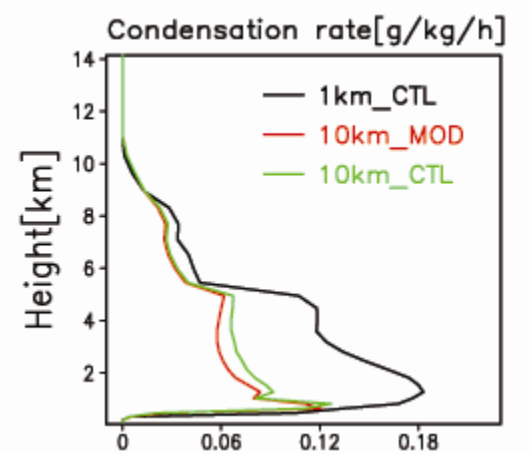
- Modify q_{c0} smaller from 1.5×10^{-3} g g^{-1} to 1.5×10^{-4} g g^{-1} (expect to the active conversion process from cloud water to rain water)

CRM result for condensation rate

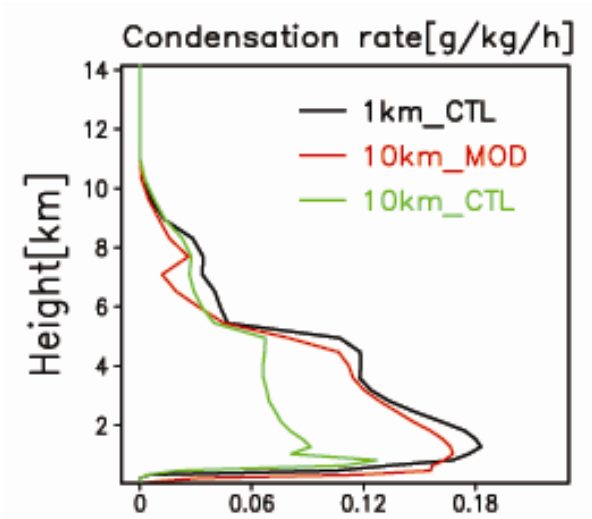
(1) Sub-grid concept of condensation process



(2) Modification on autoconversion

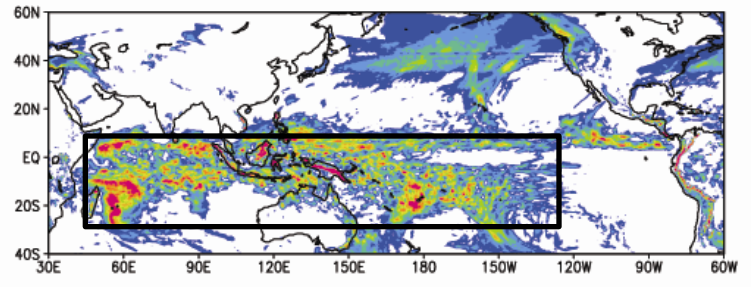


Total modification
(1) + (2)

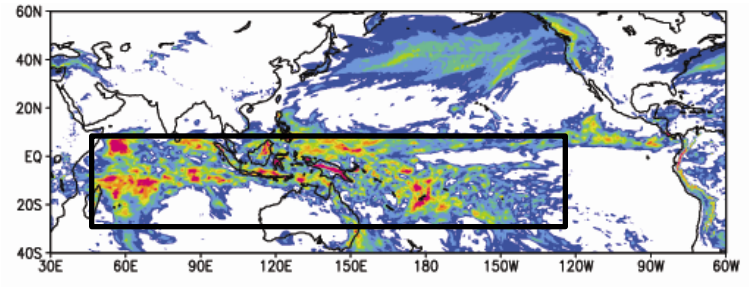


The Impact of Modification of cloud microphysics

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

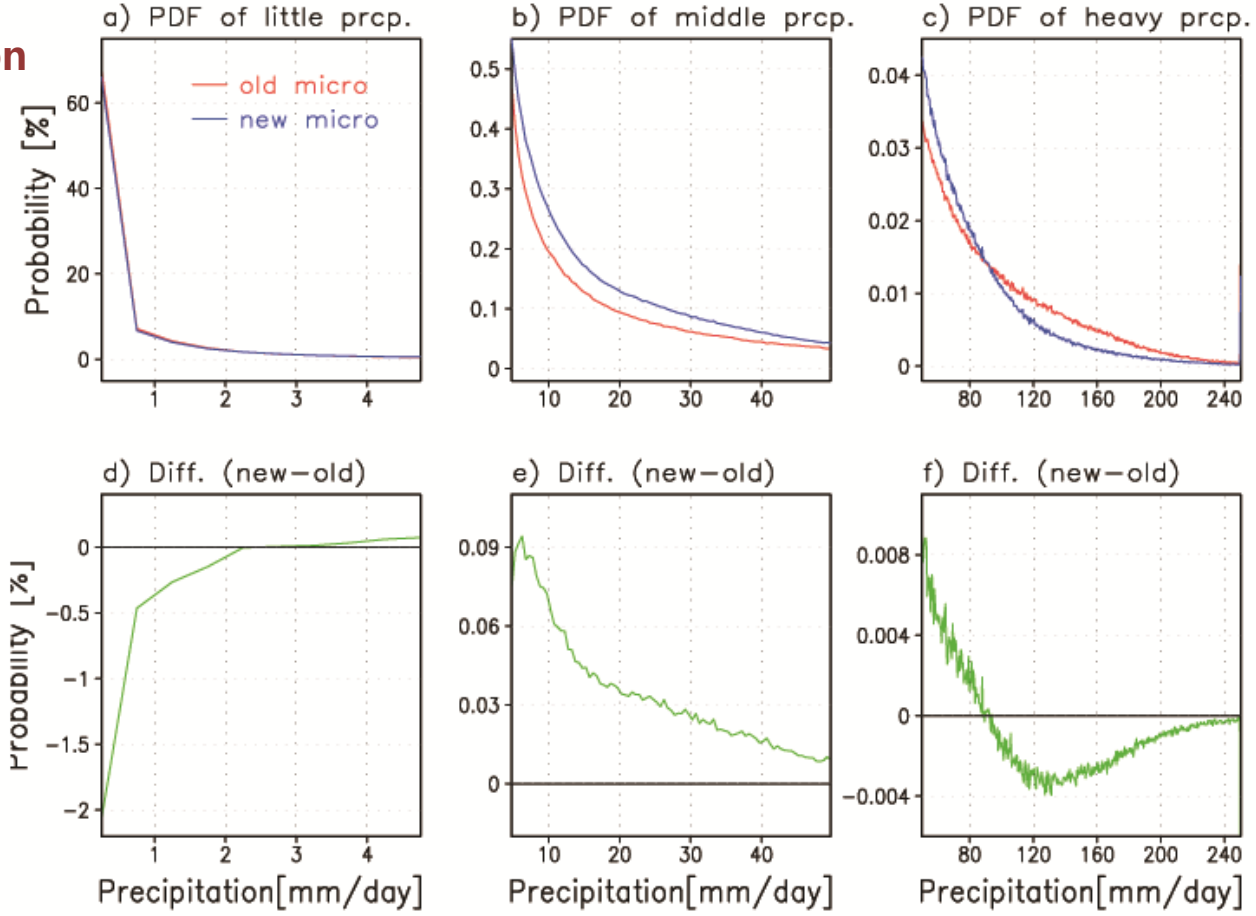


- **Modified microphysics (35km, Jan)**

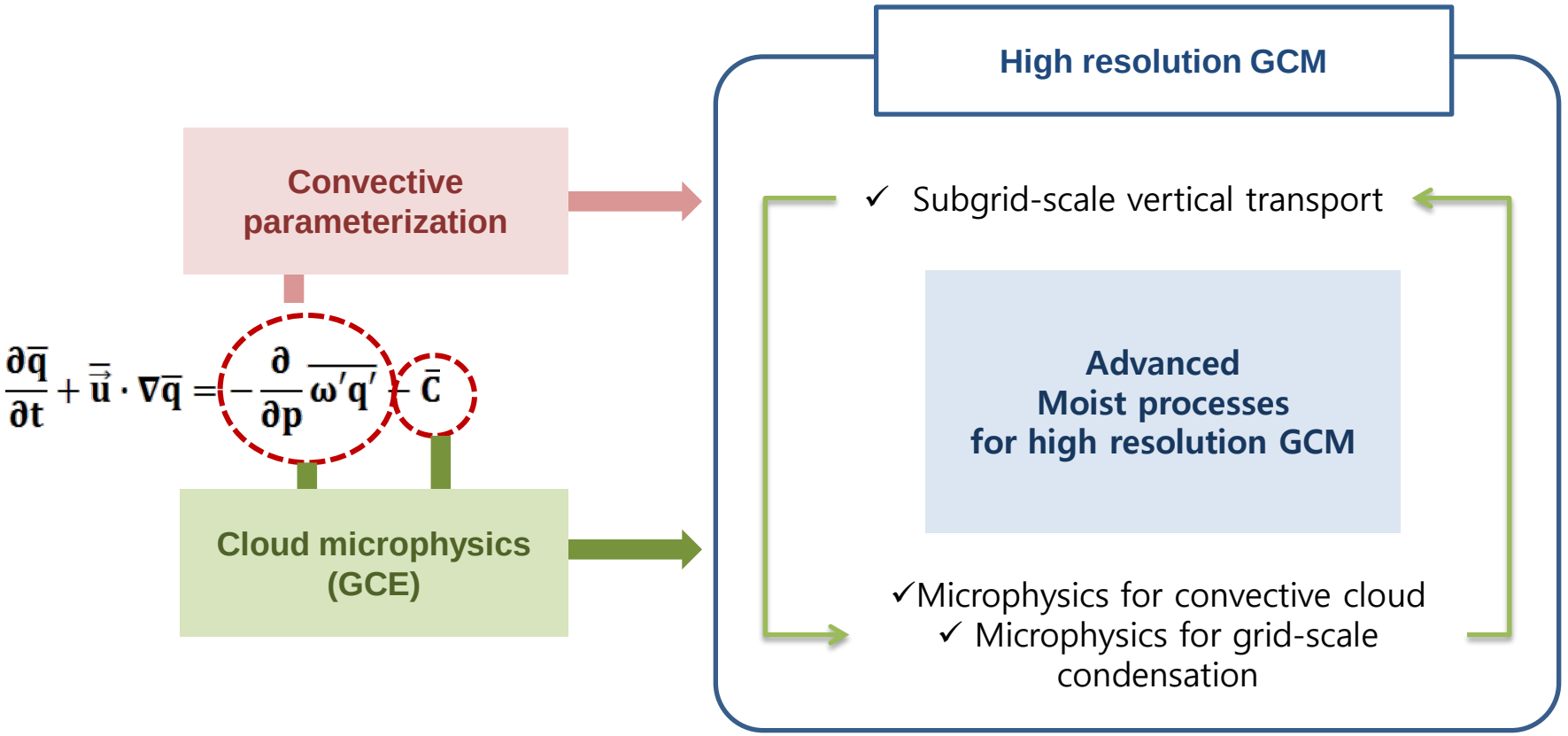


- **PDF of precipitation**

30S~10N,
45E~240E



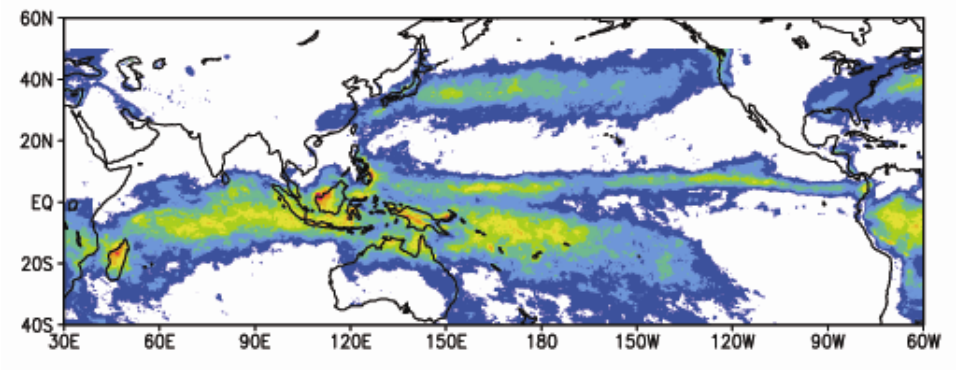
Toward High Resolution GCM with Microphysics



Parameterization vs Microphysics

Precipitation (Jan)

- **TRMM Observation**



- **35km GCM simulation**

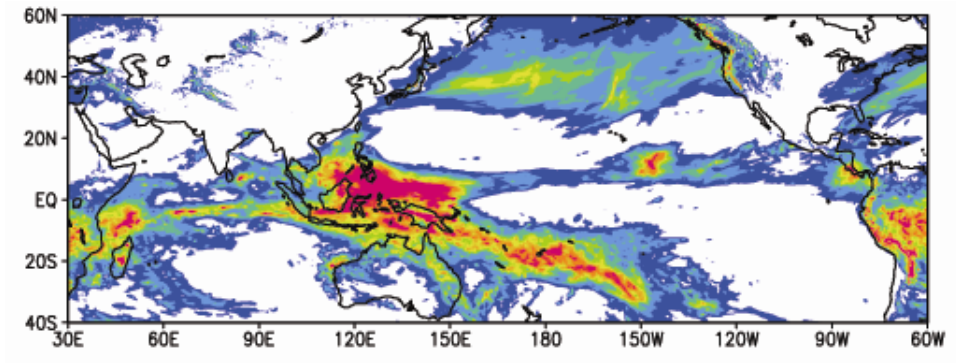
Convective parameterization (Bulk scheme Kim & Kang, 2011)

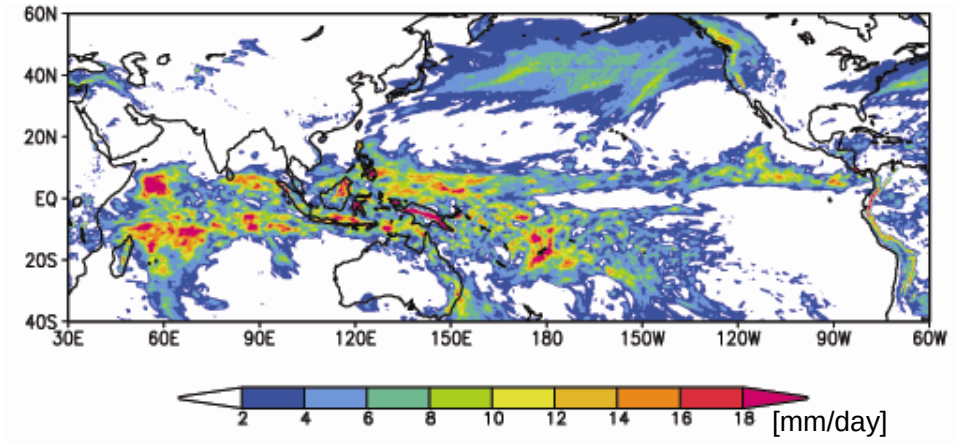
Large scale condensation parameterization

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

Modified cloud microphysics (GCE)

Microphysics for grid-scale condensation only

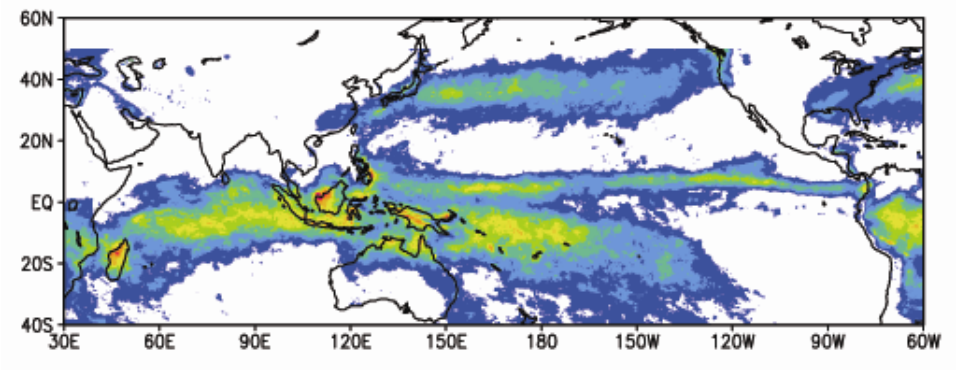




Parameterization vs Microphysics

Precipitation (Jan)

- **TRMM Observation**



- **35km GCM simulation**

Microphysics for grid-scale condensation only

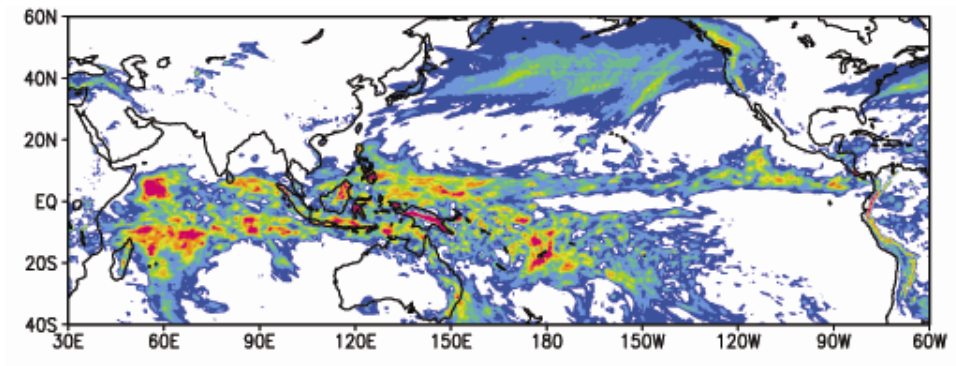
Modified cloud microphysics (GCE)

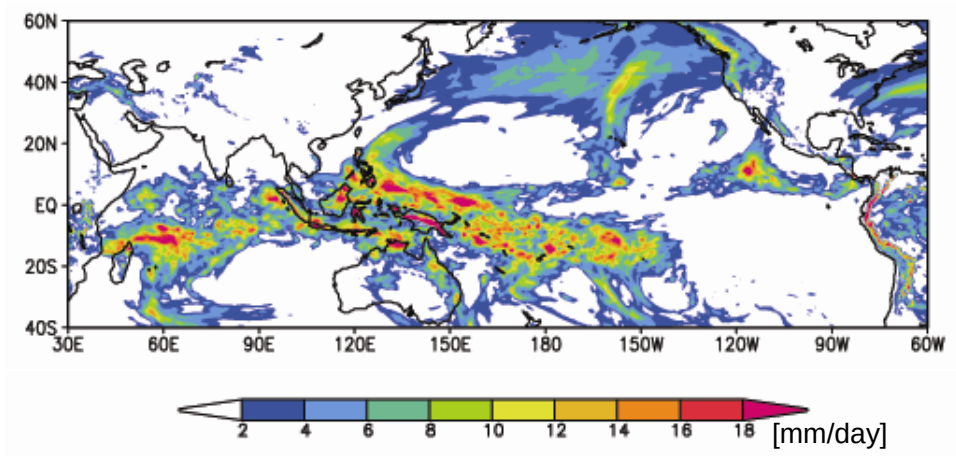
$$\frac{\partial \bar{q}}{\partial t} + \vec{\bar{u}} \cdot \nabla \bar{q} = -\frac{\partial}{\partial p}\overline{\omega' q'} + \bar{C}$$

Convective parameterization (Bulk scheme Kim & Kang, 2011)

Modified cloud microphysics (GCE)

Adding convective parameterization for sub-gird scale condensation

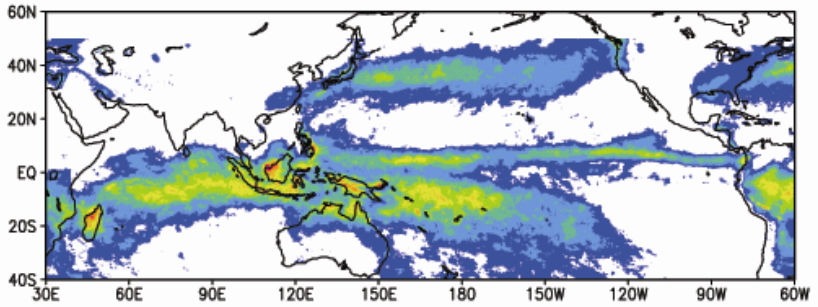




Shallow convection vs Deep convection

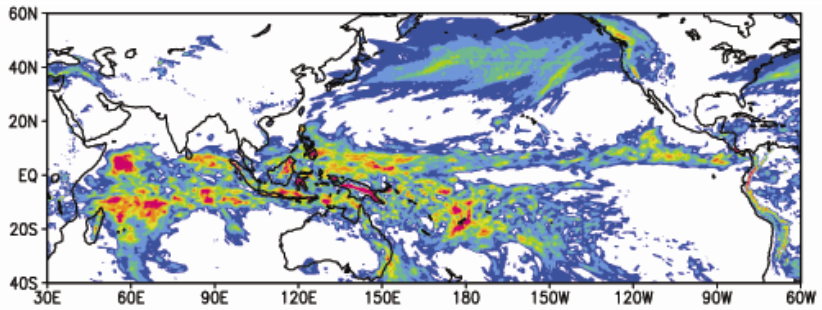
Precipitation (Jan)

- TRMM Observation

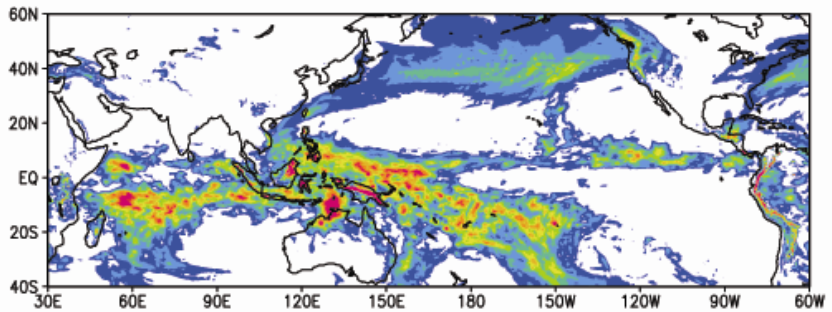


- 35km GCM simulation

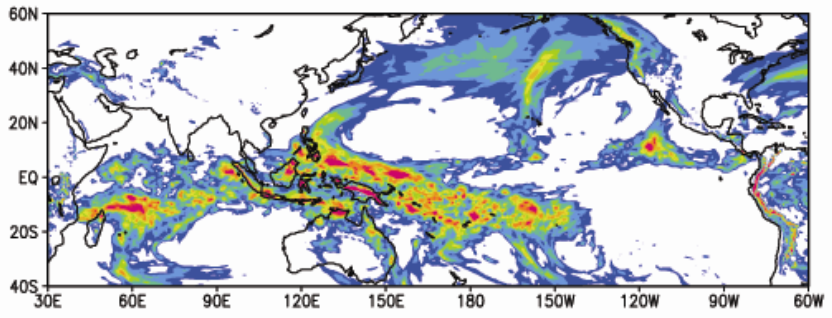
Modified Microphysics



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

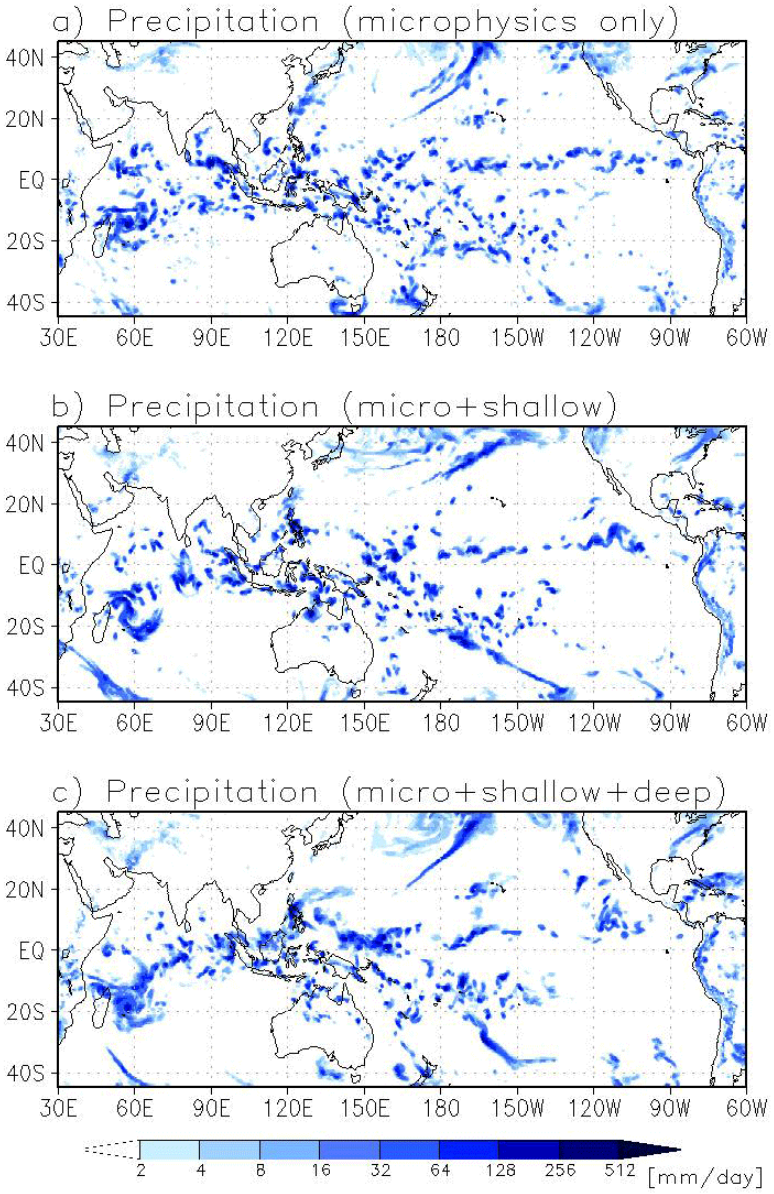
Precipitation (Jan, 3hourly)

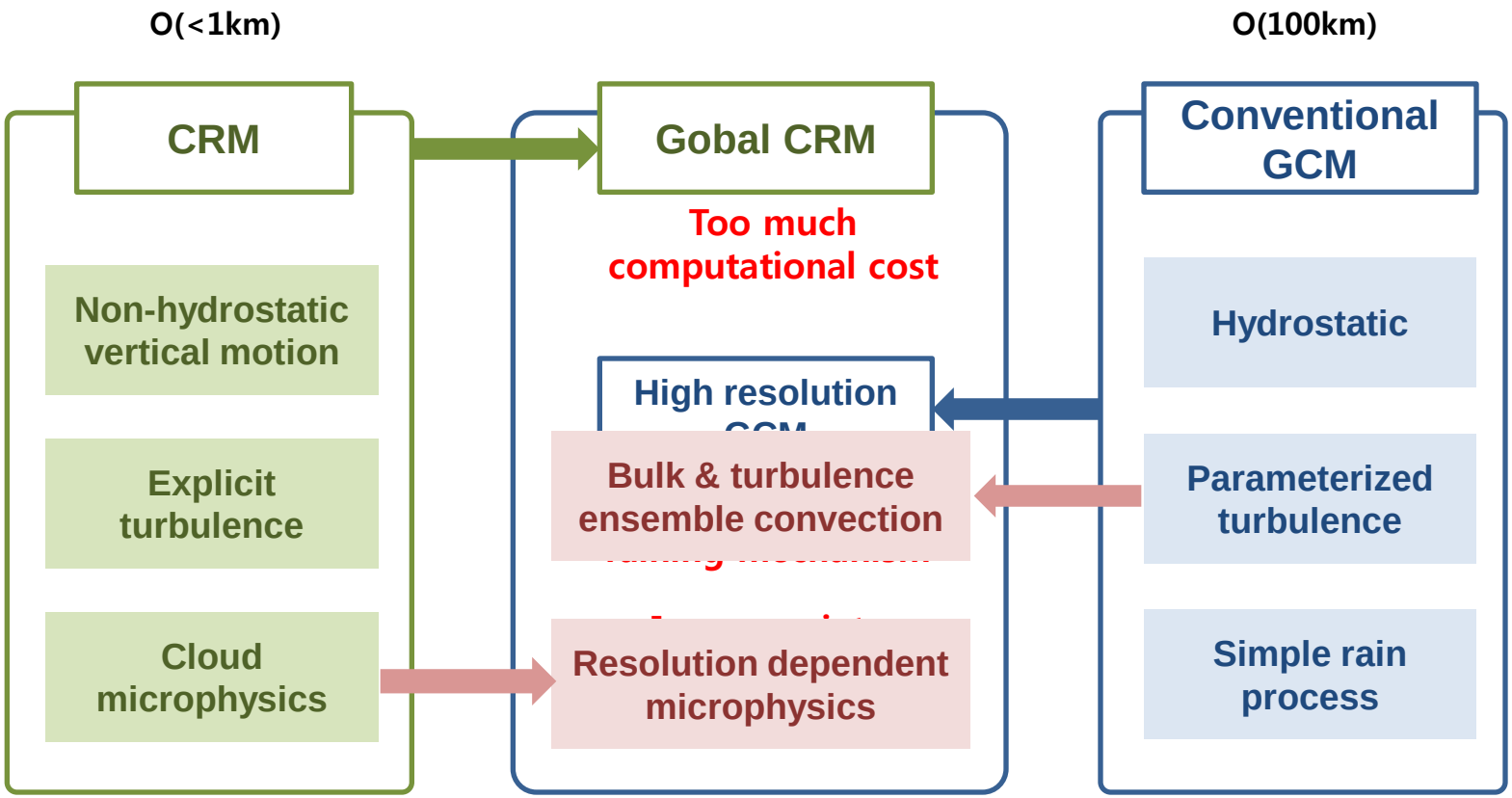
➢ **35km GCM simulation**

Modified Microphysics

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

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



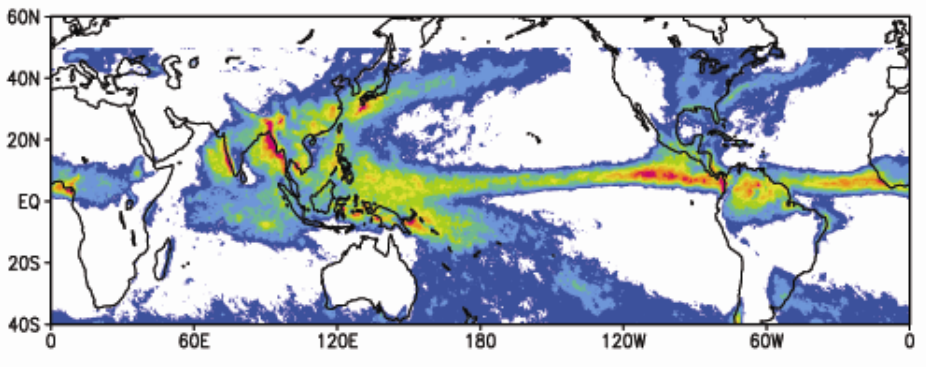

O(<1km)
O(100km)
CRM
Gobal CRM
Conventional GCM
Too much computational cost
Non-hydrostatic vertical motion
Explicit turbulence
Cloud microphysics
High resolution
Bulk & turbulence ensemble convection
Resolution dependent microphysics
Hydrostatic
Parameterized turbulence
Simple rain process

Thank you

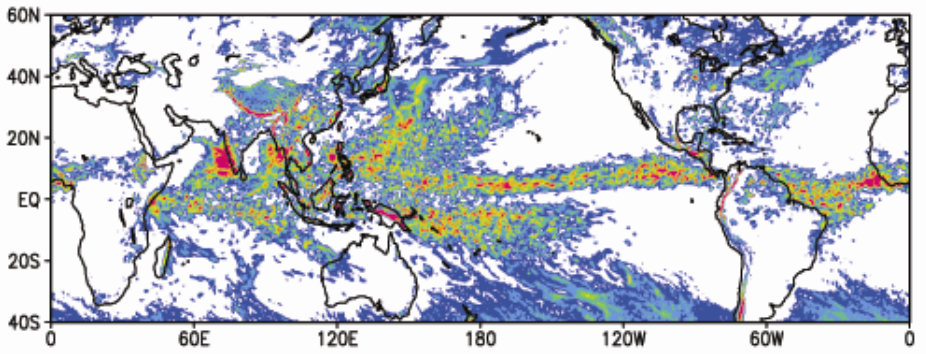
Influence of different type of microphysics in GCM

➢ Prcp. of Jun

TRMM



Lin
scheme (1983), 35km



Rutledge-Hobbs
scheme (1984), 35km