Inclusion of Microphysics in Convection Parameterization in CAM5

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Motivation and Outline

Aerosol-cloud interaction

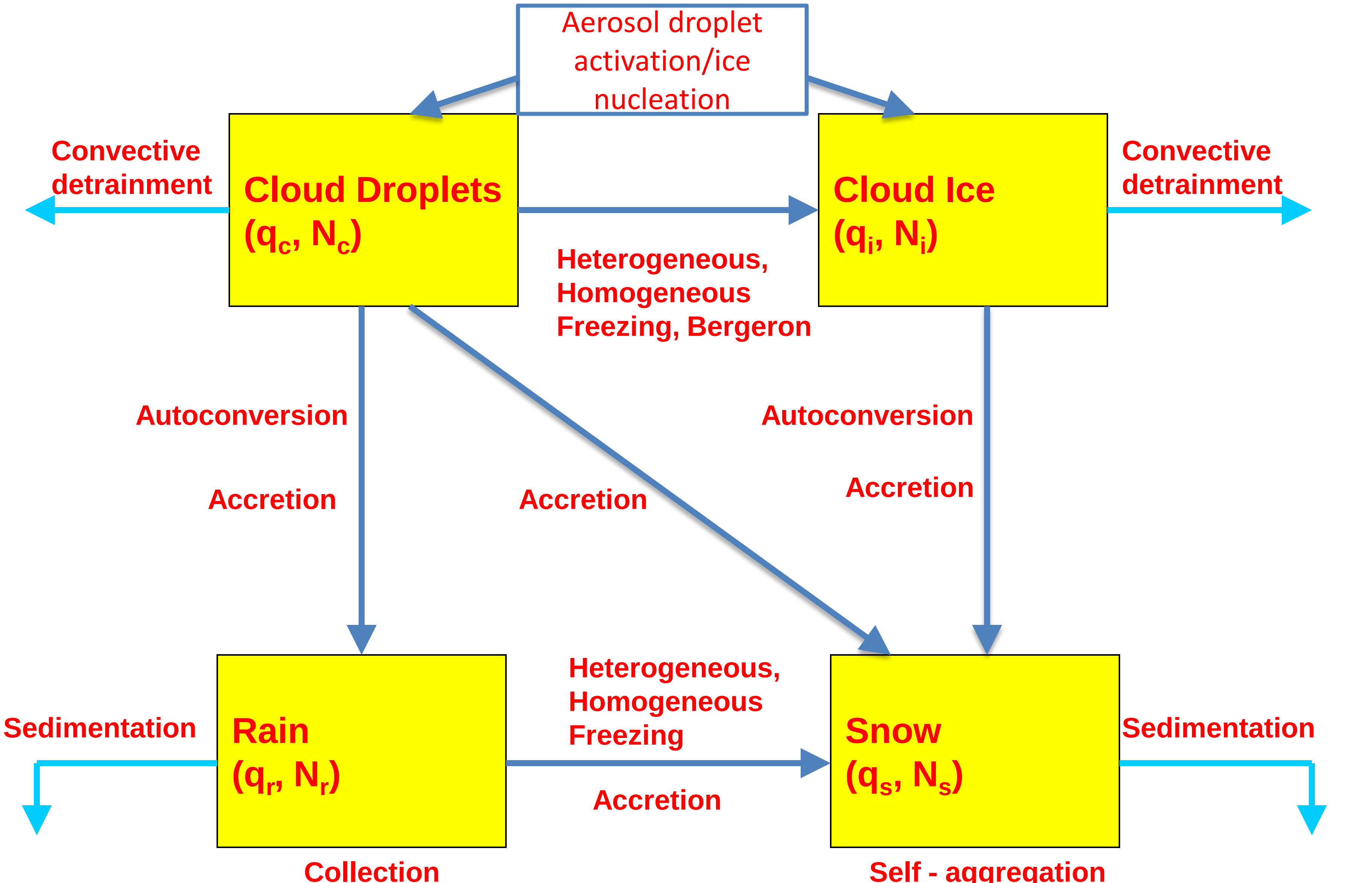
Convection-cloud interaction

- Brief description of a two-moment microphysics scheme
- Single-column model test at TWP
- CAM5 simulation

The Scheme

- Two-moment (mass and number concentration), 4-species (ice, liquid water, snow and rain)
- Based on the Morrison-Gettelman microphysics scheme for large-scale clouds, with heavy modifications to fit convective clouds
- All equations are diagnostic, as for other thermodynamic fields in a steady-state 1-D cloud model

Two-moment microphysics scheme for convective clouds



$$\frac{\partial}{\partial z}(M_u q_x) = -D_u q_x + \sigma_u S_x^q$$

$$\frac{\partial}{\partial z}(M_u N_x) = -D_u N_x + \sigma_u S_x^N$$

where x refers to c for cloud water, i for cloud ice, s for snow and r for rain, $\sigma = M_u/w_u$ is convective cloud fraction. S_x is the source/sink per unit cloud area.

$$\frac{\partial K_u}{\partial z} = -\frac{\nu_u}{M_u}(1+\beta C_d)K_u + \frac{1}{f(1+\gamma)} g \frac{T_{v,u} - T_{v,e}}{T_{v,e}}$$

$$K_u = \frac{w_u^2}{2}$$

$$S_c^q = P_{cond}^{q_c} - P_{auto}^{q_c} - P_{accr}^{q_c} - P_{accs}^{q_c} - P_{fhet}^{q_c} - P_{fhm}^{q_c} - P_{Berg}^{q_c}$$

$$S_c^N = P_{nuc}^{N_c} - P_{auto}^{N_c} - P_{accr}^{N_c} - P_{accs}^{N_c} - P_{fhet}^{N_c} - P_{fhm}^{N_c}$$

$$S_i^q = P_{cond}^{q_i} - P_{auto}^{q_i} - P_{accs}^{q_i} + P_{fhet}^{q_c} + P_{fhm}^{q_c} + P_{Berg}^{q_c}$$

$$S_i^N = P_{nuc}^{N_i} - P_{auto}^{N_i} - P_{accs}^{N_i} + P_{fhet}^{N_c} + P_{fhm}^{N_c}$$

$$S_r^q = P_{auto}^{q_c} + P_{accr}^{q_c} - P_{accs}^{q_r} - P_{fhet}^{q_r} - P_{fhm}^{q_r} - P_{fallout}^{q_r}$$

$$S_r^N = P_{auto}^{N_c} + P_{accr}^{N_c} - P_{accs}^{N_r} - P_{fhet}^{N_r} - P_{fhm}^{N_r} - P_{fallout}^{N_r} + P_{aggr}^{N_r}$$

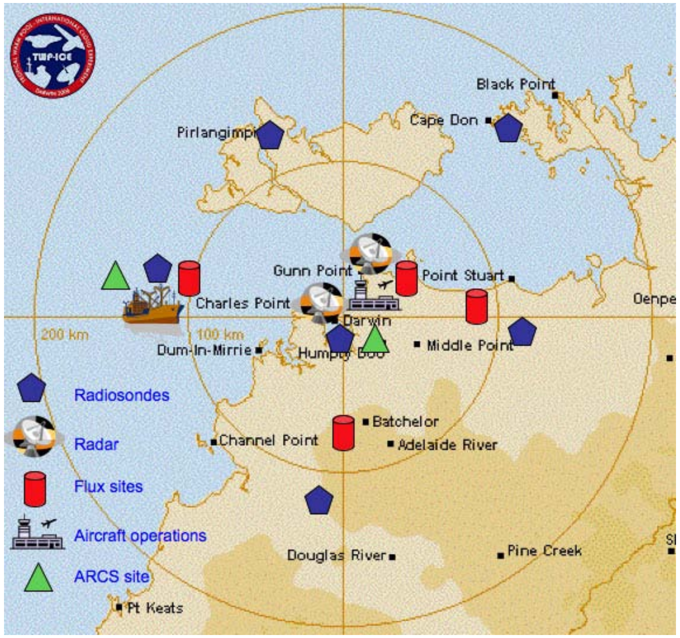
$$S_s^q = P_{auto}^{q_i} + P_{accs}^{q_i} + P_{accs}^{q_r} + P_{accs}^{q_c} + P_{fhet}^{q_r} + P_{fhm}^{q_r} - P_{fallout}^{q_s}$$

$$S_s^N = P_{auto}^{N_i} + P_{accs}^{N_i} + P_{accs}^{N_r} + P_{accs}^{N_c} + P_{fhet}^{N_r} + P_{fhm}^{N_r} - P_{fallout}^{N_s} + P_{aggs}^{N_s}$$

Song and Zhang (JGR, 2011)

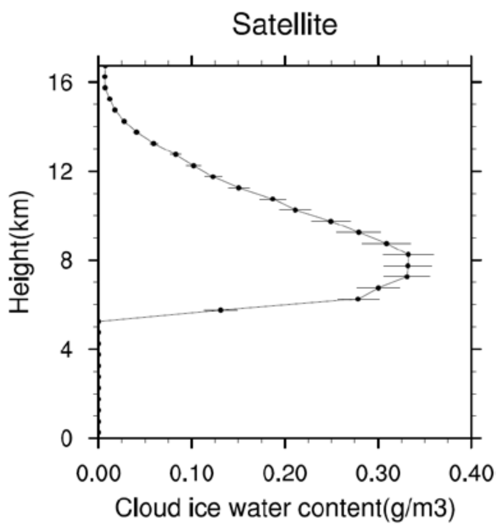
TWP-ICE SCM Simulation

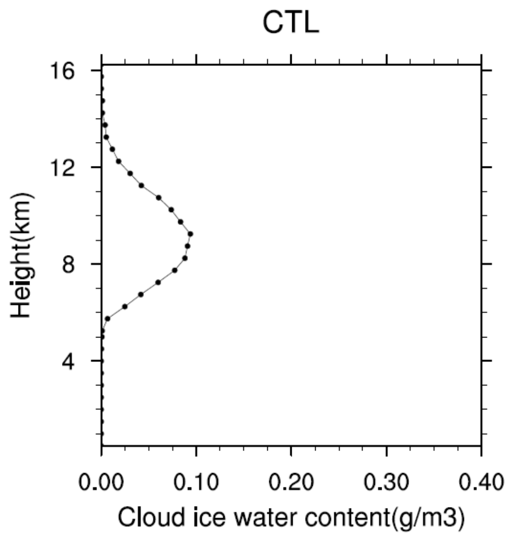
- Jan. 19-Feb. 12, 2006 at Darwin, Australia
- NCAR CAM3.5 SCM
- Large-scale Forcing Data by ARM (Shaocheng Xie)



Convective cloud ice during active monsoon period
TWP-ICE

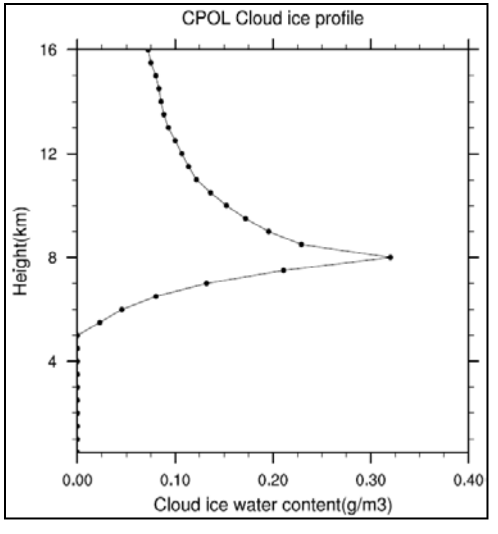
Satellite

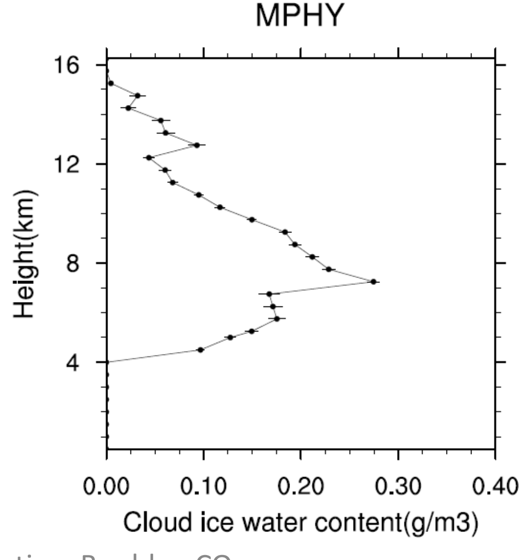




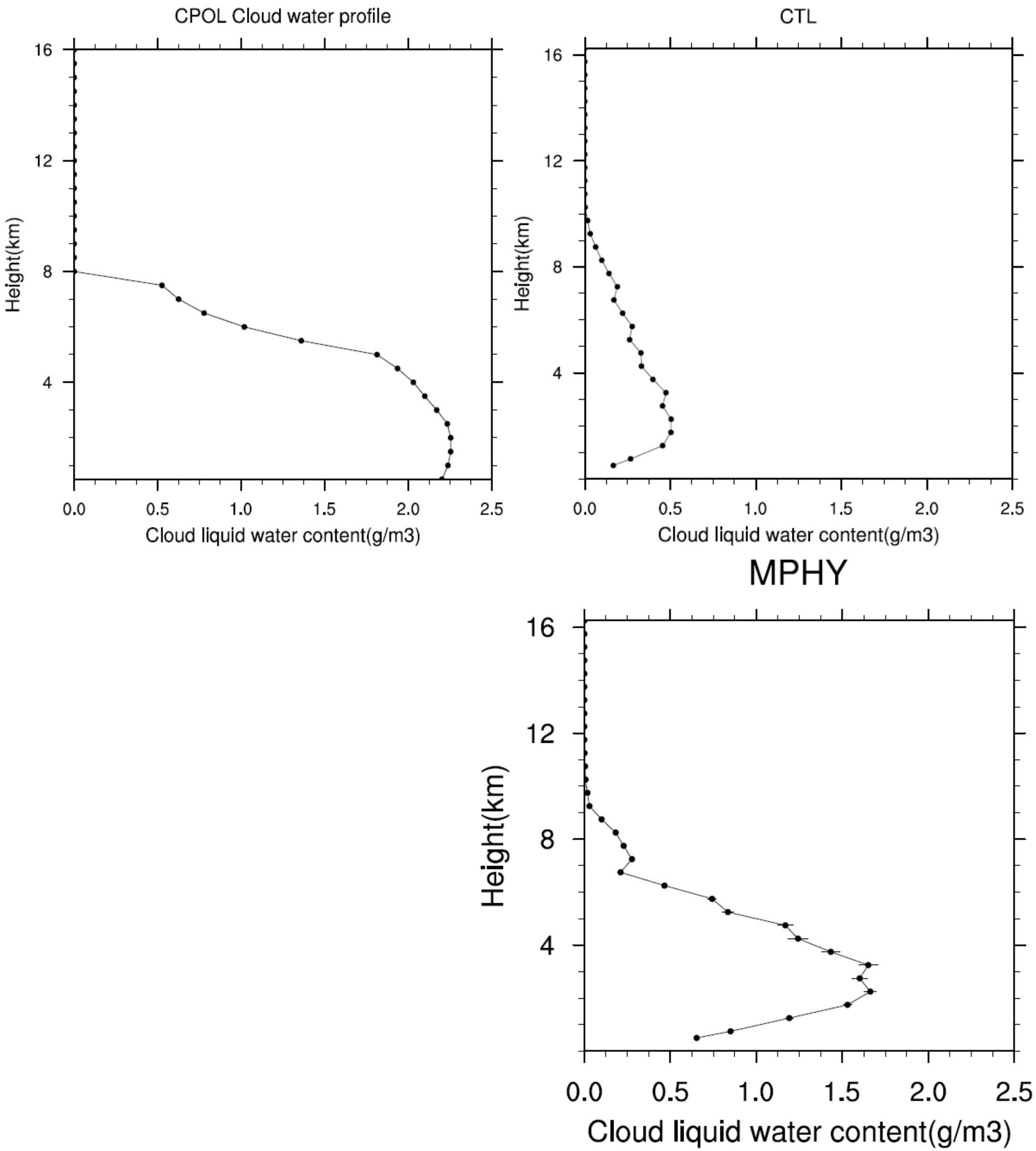
ZM

Radar

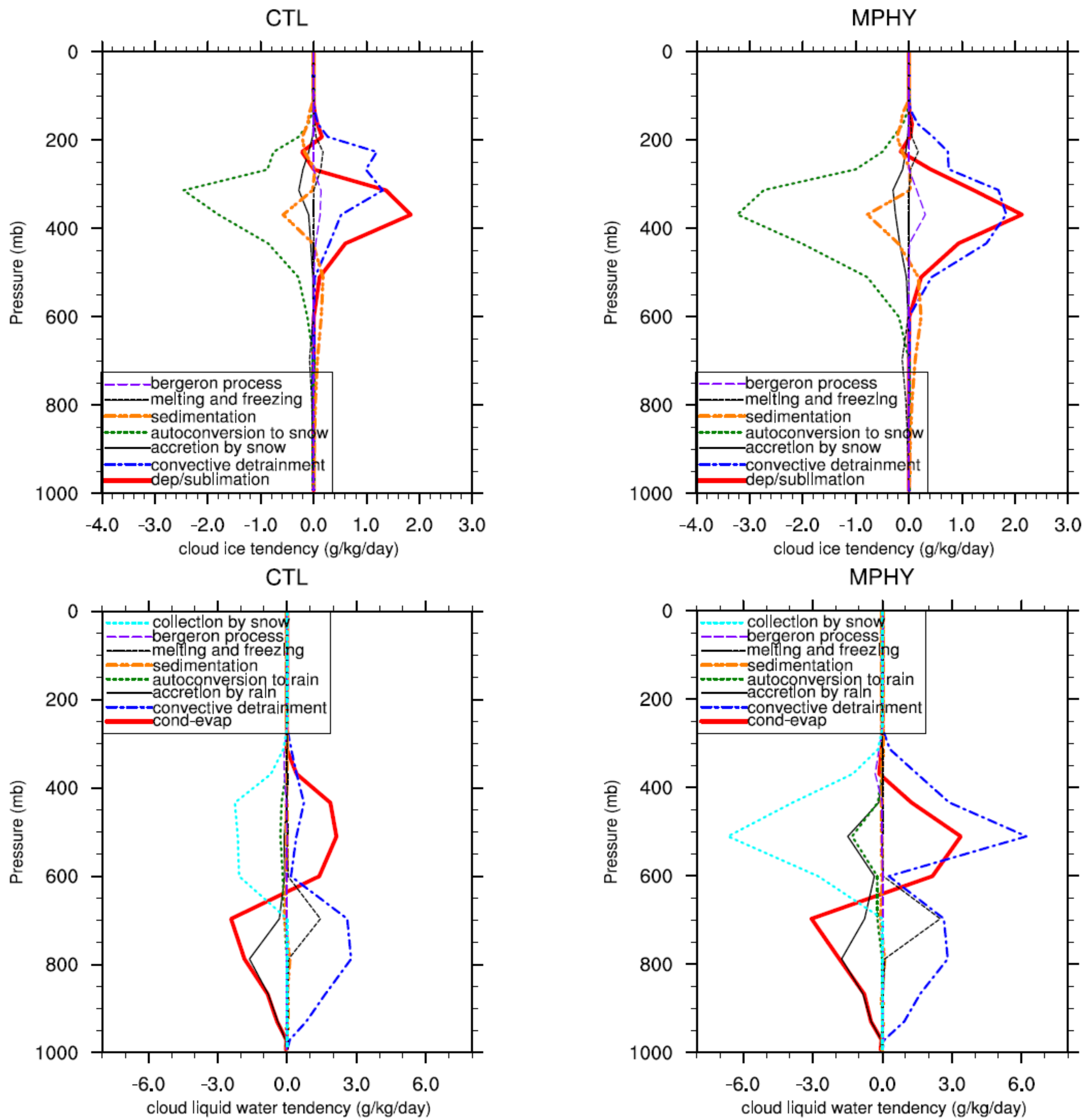




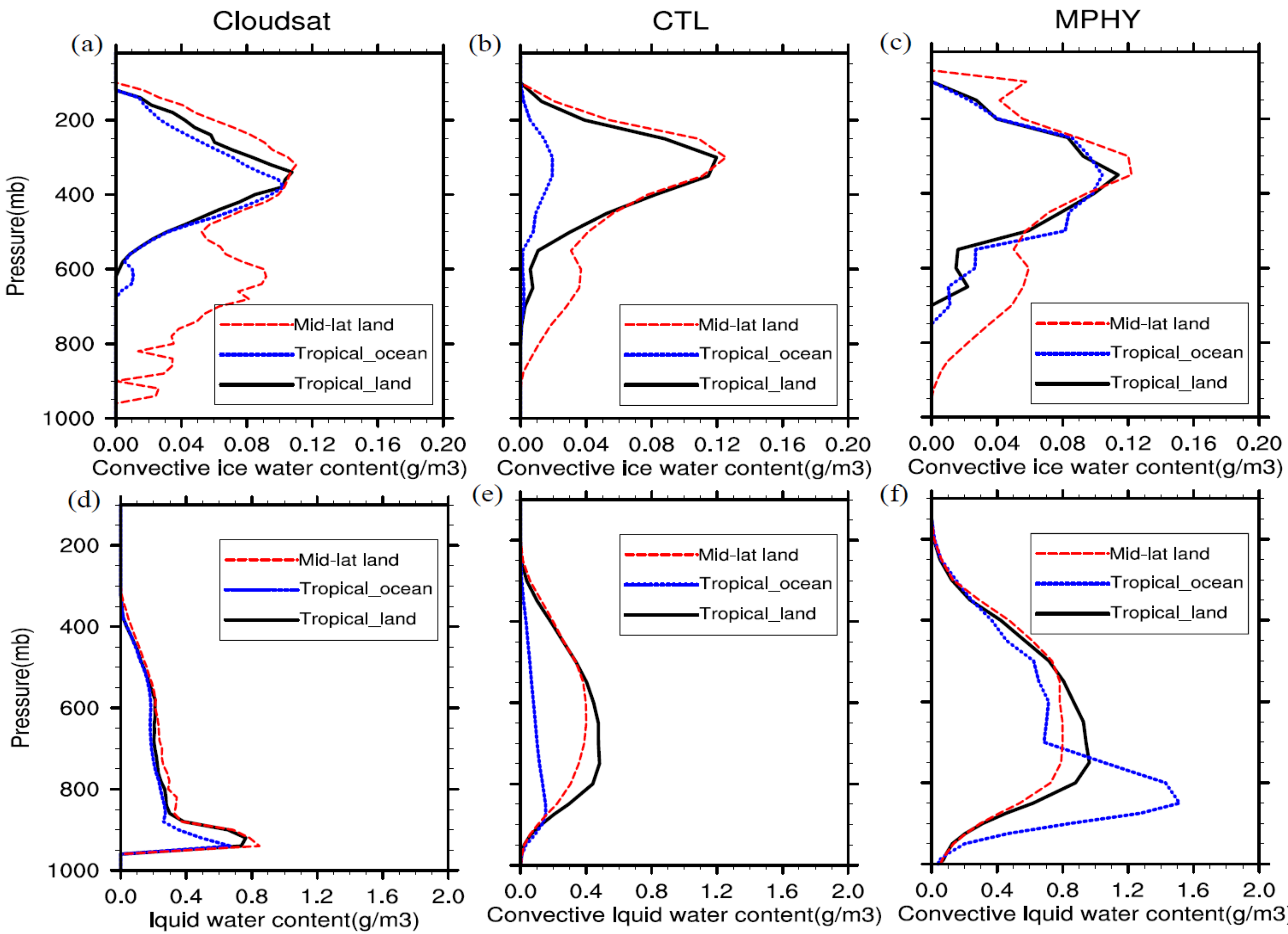
MPHY

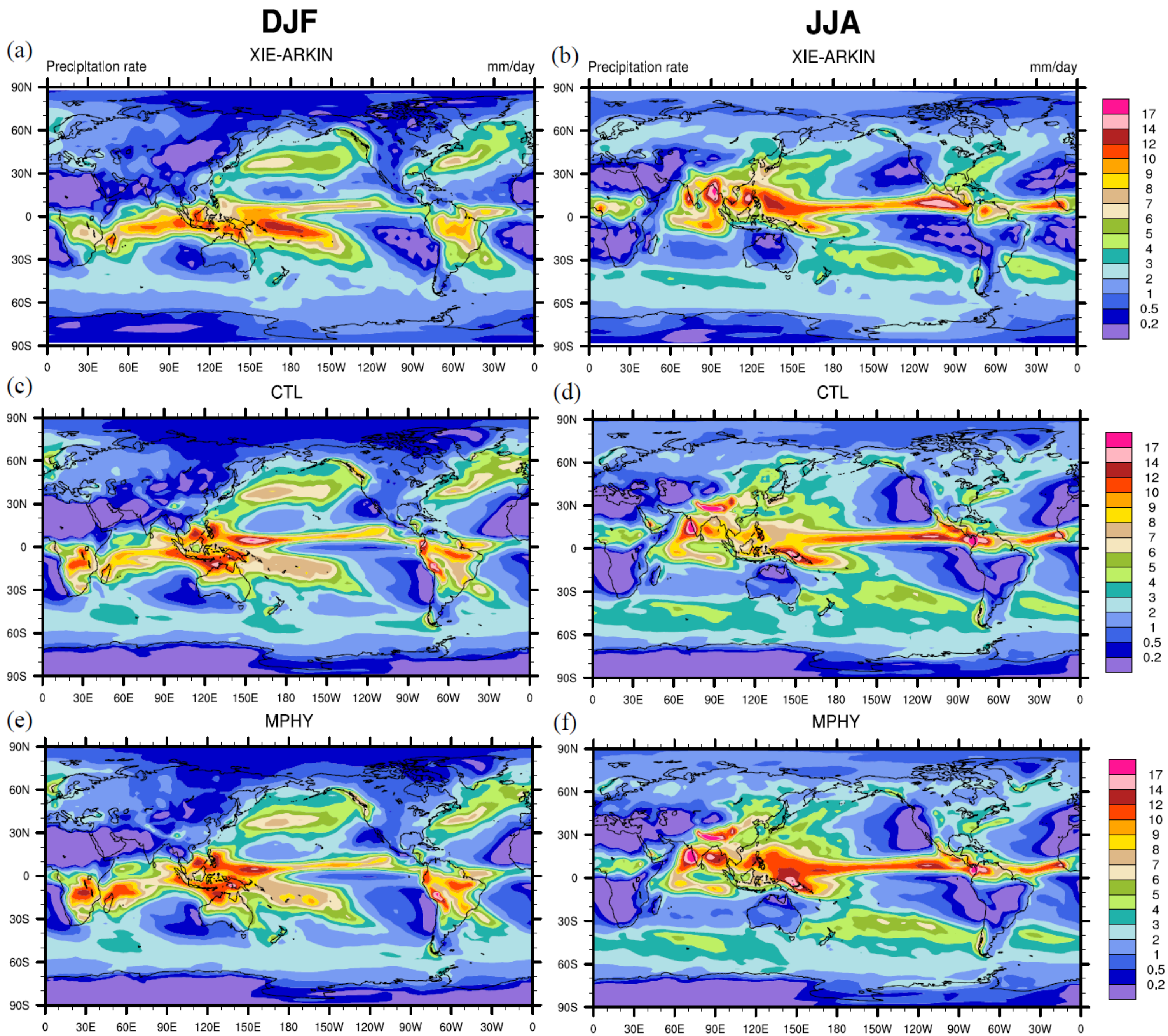


CPOL Cloud water profile
Height(km)
16
12
8
4
0.0 0.5 1.0 1.5 2.0 2.5
Cloud liquid water content(g/m3)
CTL
Height(km)
16
12
8
4
0.0 0.5 1.0 1.5 2.0 2.5
Cloud liquid water content(g/m3)
MPHY
Height(km)
16
12
8
4
0.0 0.5 1.0 1.5 2.0 2.5
Cloud liquid water content(g/m3)

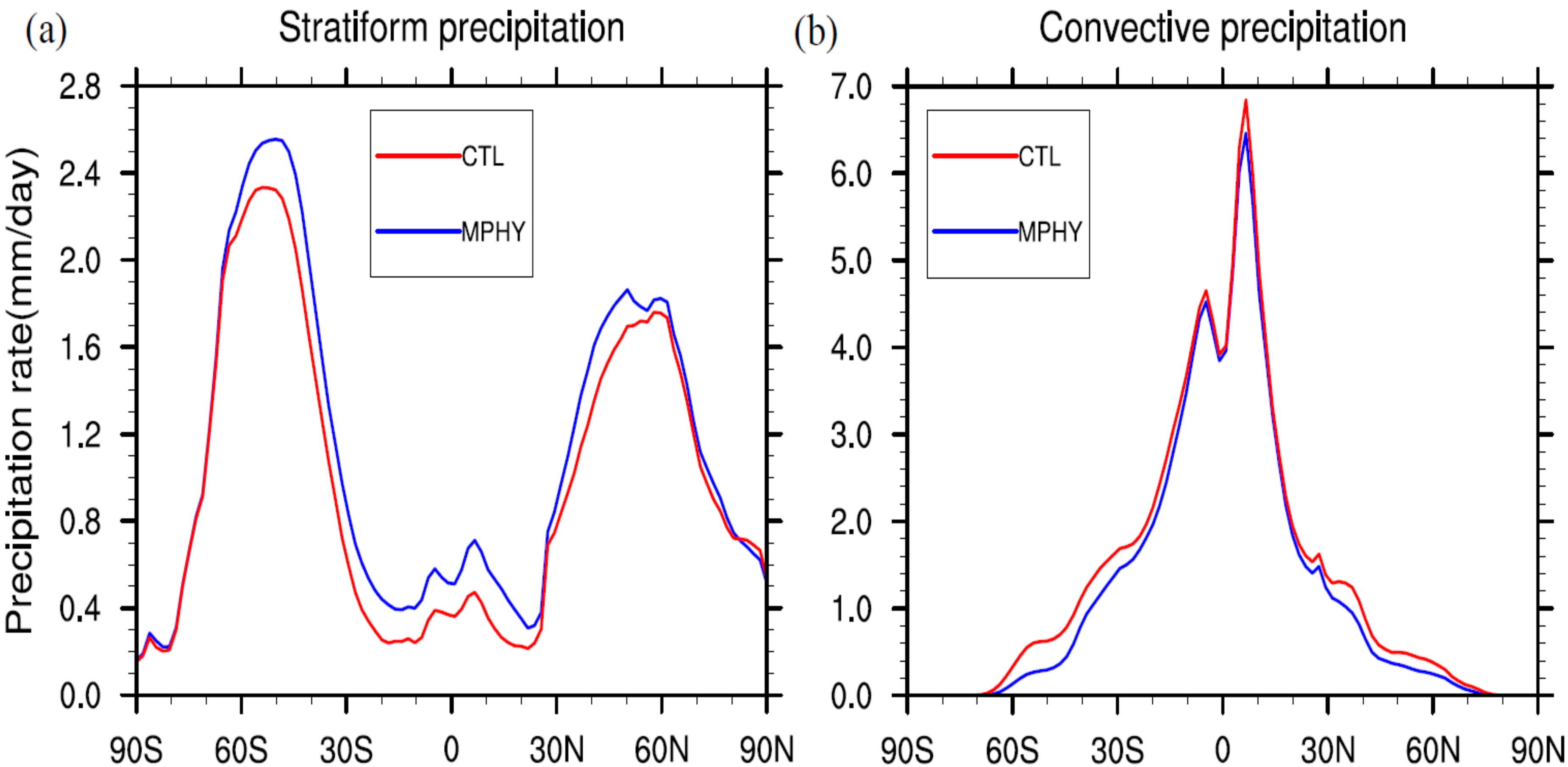

CTL
MPHY
Pressure (mb)
cloud ice tendency (g/kg/day)
bergeron process
melting and freezing
sedimentation
autoconversion to snow
accretion by snow
convective detrainment
dep/sublimation
cloud liquid water tendency (g/kg/day)
collection by snow
autoconversion to rain
accretion by rain
cond-evap

Results from CAM5

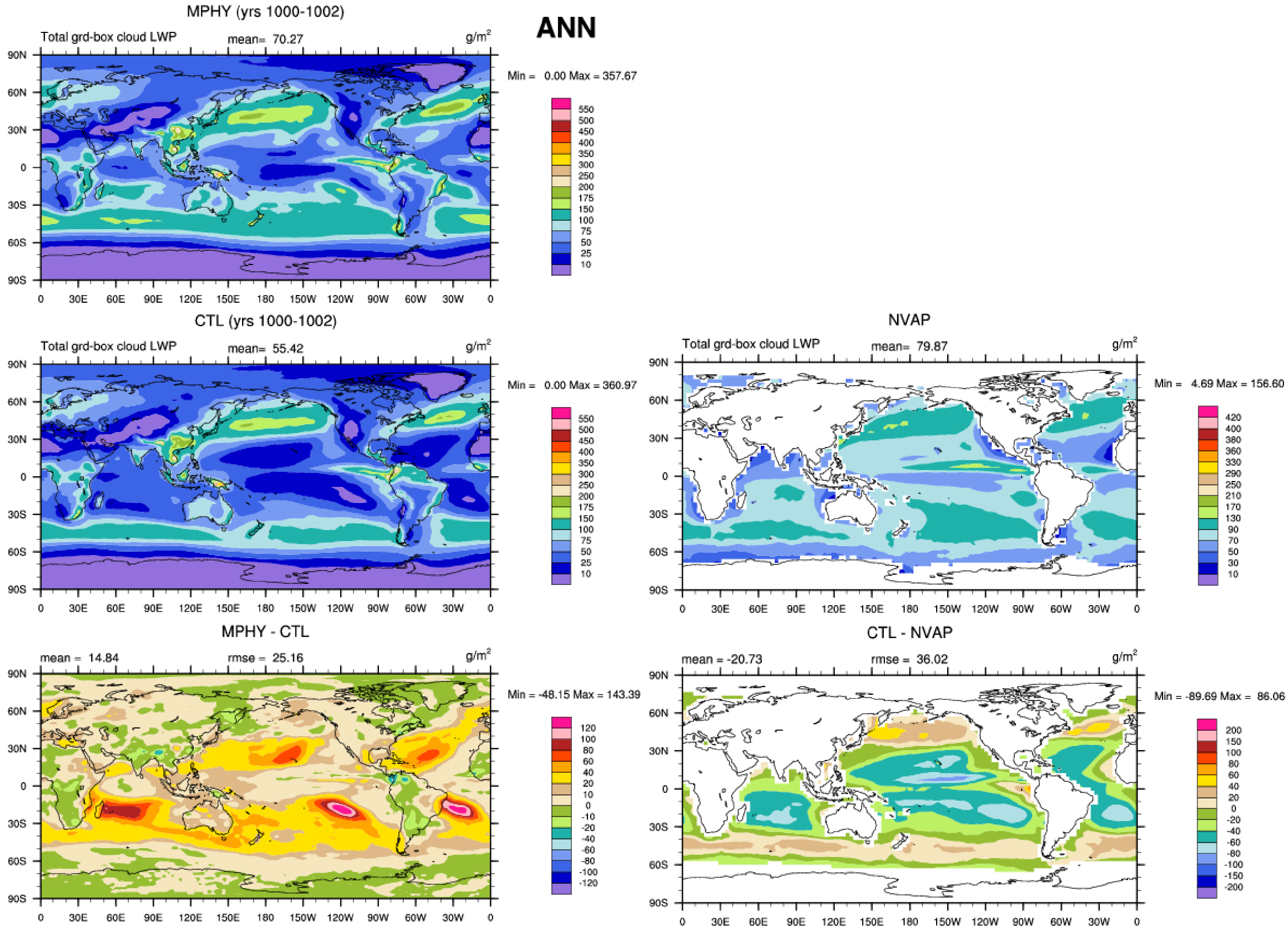

Cloudsat
CTL
MPHY
(a)
(b)
(c)
(d)
(e)
(f)
Pressure(mb)
200
400
600
800
1000
0.00
0.04
0.08
0.12
0.16
0.20
Convective ice water content(g/m3)
Mid-lat land
Tropical_ocean
Tropical_land
0.0
0.4
0.8
1.2
1.6
2.0
liquid water content(g/m3)
Convective liquid water content(g/m3)



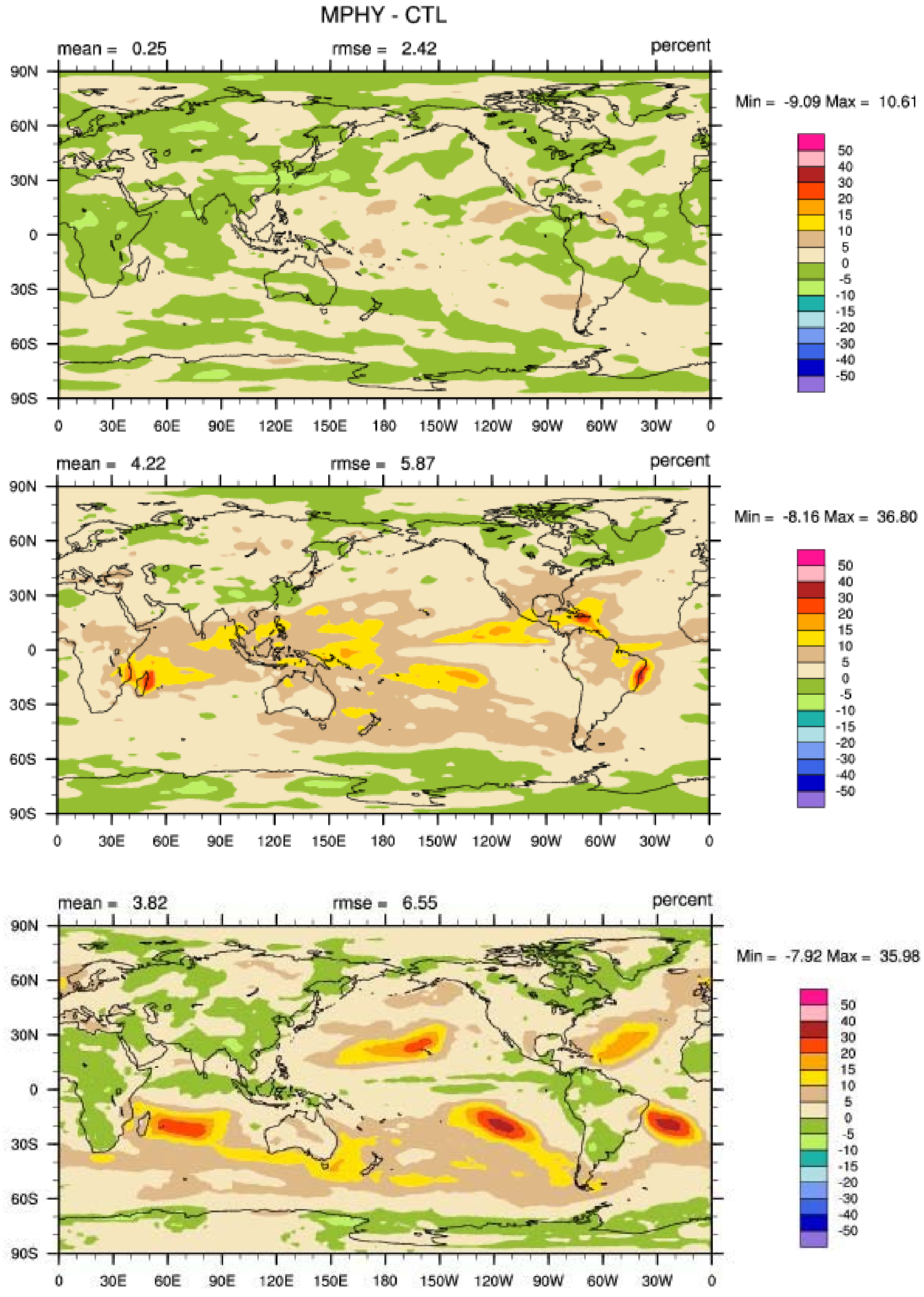
DJF
JJA
(a)
XIE-ARKIN
Precipitation rate
mm/day
(b)
XIE-ARKIN
Precipitation rate
mm/day
(c)
CTL
(d)
CTL
(e)
MPHY
(f)
MPHY
90N 60N 30N 0 30S 60S 90S
0 30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
17 14 12 10 9 8 7 6 5 4 3 2 1 0.5 0.2


(a)
Stratiform precipitation
Precipitation rate(mm/day)
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
CTL
MPHY
90S
60S
30S
0
30N
60N
90N
(b)
Convective precipitation
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
CTL
MPHY
90S
60S
30S
0
30N
60N
90N

ANN



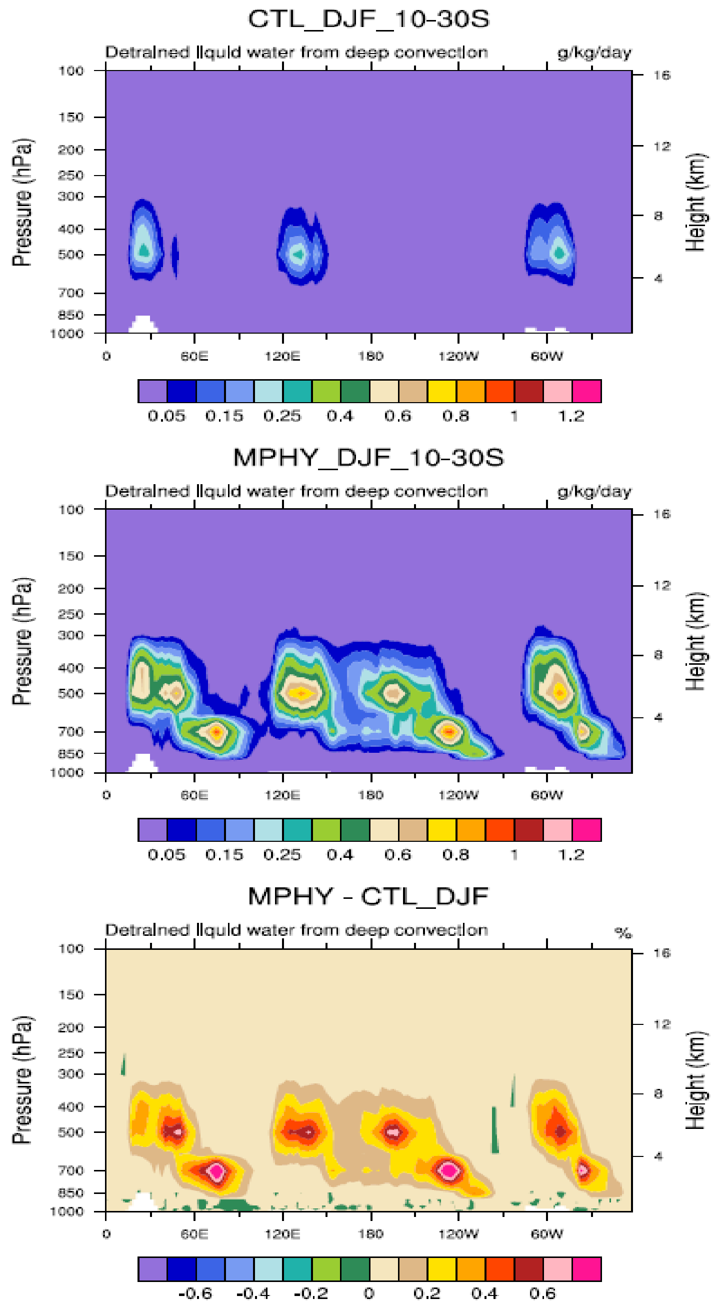
MPHY (yrs 1000-1002)
Total grd-box cloud LWP
mean= 70.27
g/m²
Min = 0.00 Max = 357.67
CTL (yrs 1000-1002)
Total grd-box cloud LWP
mean= 55.42
g/m²
Min = 0.00 Max = 360.97
NVAP
Total grd-box cloud LWP
mean= 79.87
g/m²
Min = 4.69 Max = 156.60
MPHY - CTL
mean = 14.84
rmse = 25.16
g/m²
Min = -48.15 Max = 143.39
CTL - NVAP
mean = -20.73
rmse = 36.02
g/m²
Min = -89.69 Max = 86.06



High Cloud

Mid-level Cloud

Low Cloud


CTL_DJF_10-30S
Detrained liquid water from deep convection
g/kg/day
Pressure (hPa)
Height (km)
100 150 200 250 300 400 500 700 850 1000
16 12 8 4
0 60E 120E 180 120W 60W
0.05 0.15 0.25 0.4 0.6 0.8 1 1.2
MPHY_DJF_10-30S
Detrained liquid water from deep convection
g/kg/day
Pressure (hPa)
Height (km)
100 150 200 250 300 400 500 700 850 1000
16 12 8 4
0 60E 120E 180 120W 60W
0.05 0.15 0.25 0.4 0.6 0.8 1 1.2
MPHY - CTL_DJF
Detrained liquid water from deep convection
%
Pressure (hPa)
Height (km)
100 150 200 250 300 400 500 700 850 1000
16 12 8 4
0 60E 120E 180 120W 60W
-0.6 -0.4 -0.2 0 0.2 0.4 0.6

Summary

- A new microphysics scheme is introduced in convection parameterization
- It produces a larger amount of cloud IWC and LWC in convective updrafts
- As a result, contribution to large-scale cloud ice and water budget is significantly enhanced, leading to more large-scale precipitation
- Results from CAM5 suggest likely improvement in model simulation of cloud microphysical properties and precipitation