Simulation of the effects of increasing hygroscopic aerosols and rain embryos on precipitation: Focusing on warm-cloud seeding

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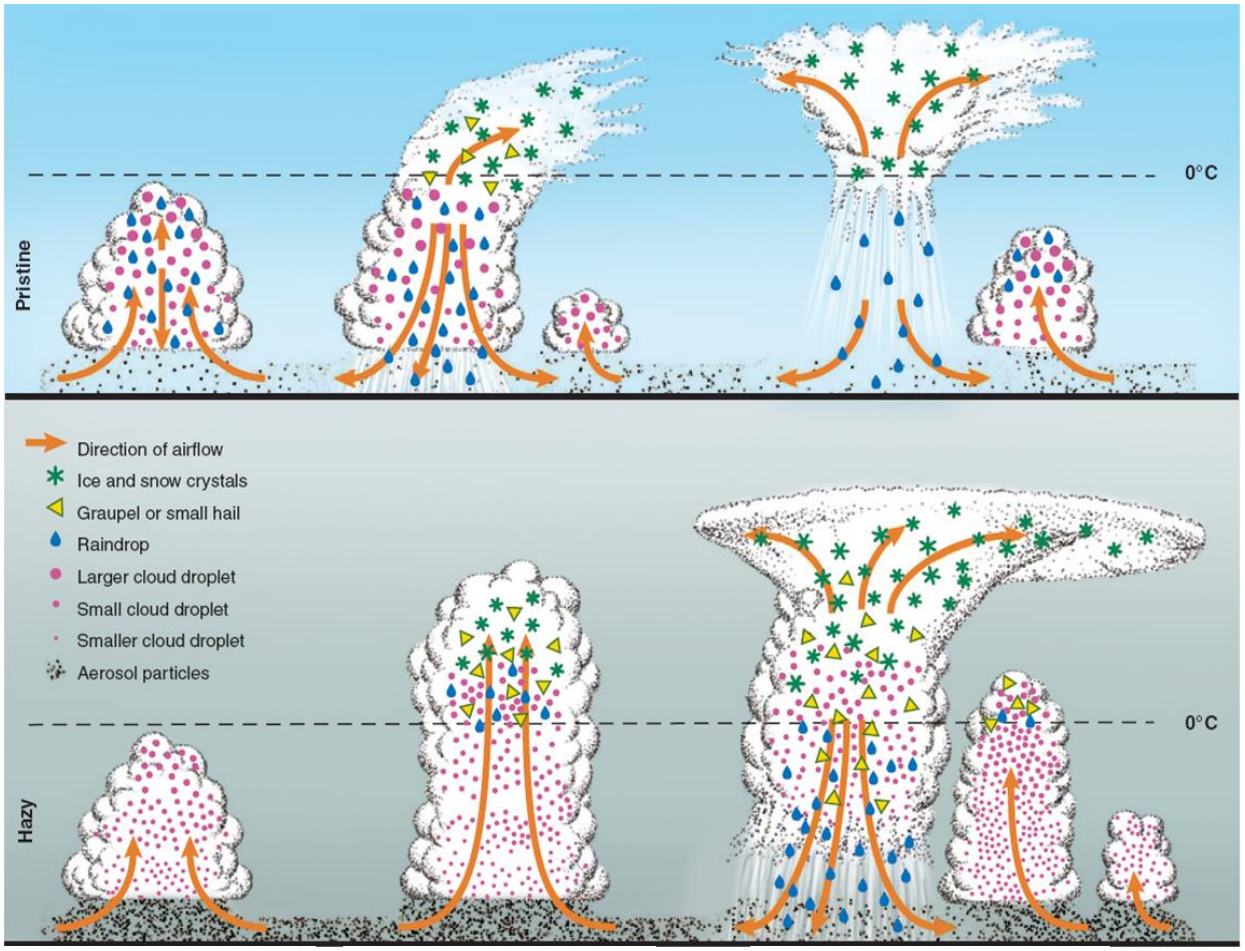
Motivation and Objectives

- To better understanding the effects of aerosols on cloud microphysics and the sequential effects on precipitation.

- To help constructing physically-based warm cloud seeding strategies that is applicable in Taiwan.

- To establish the cause-and-effect relationship between modified aerosol distribution and surface rainfall, especially on the effect of GCCN.

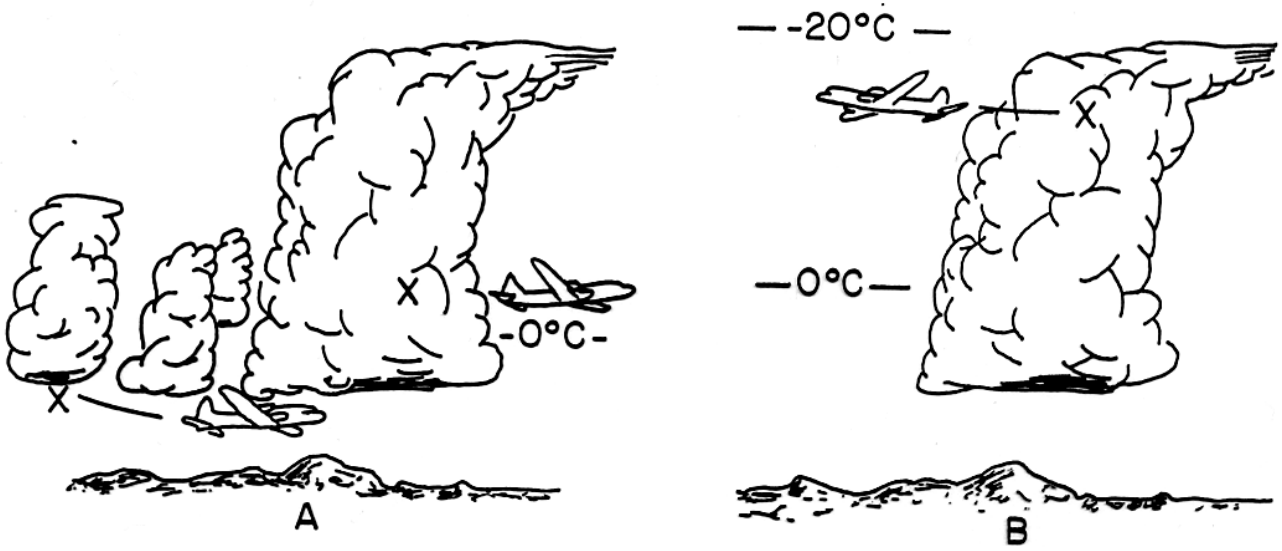
Convective cloud invigoration effect



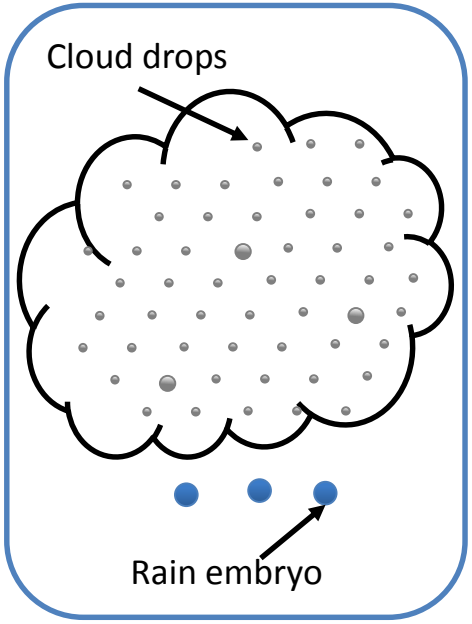
Growing Mature Dissipating

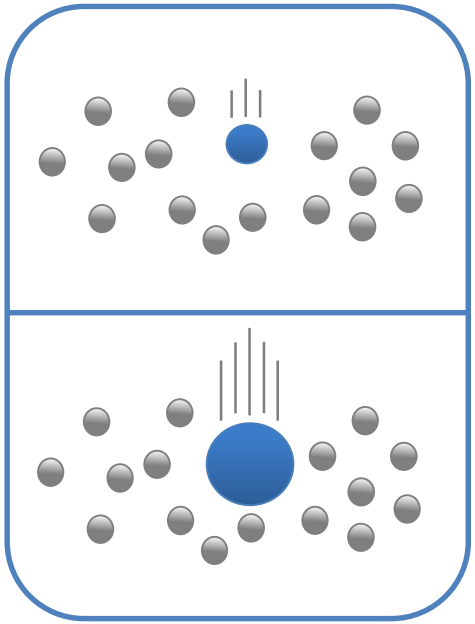
Rosenfeld et al. (2008)

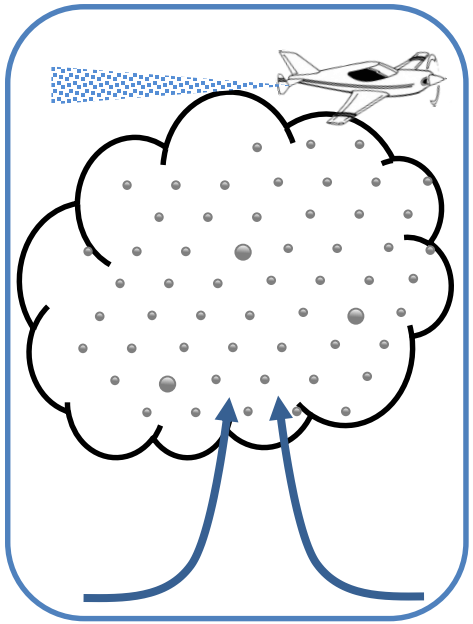
Initial aerosol distribution	Twomey (1959, 1977), Chen et al. (1998) (in Chinese), Rosenfeld (1999, 2008), Yin et al. (2000b), Khain et al. (2005), Jiang et al. (2006), Xue et al. (2010), Tao et al. (2012)
Presence of GCCN	Johnson (1982), Tzivion et al. (1994), Mather et al. (1997), Bruintjes (1999), Feingold et al. (1999), Yin et al. (2000a), Cheng et al. (2007), Rosenfeld et al. (2010), Xue et al. (2010)
Updraft velocity	Rokicki and Young (1978), Tzivion et al. (1994), Chen and Lamb (1999), Ramanathan et al. (2001), Seinfeld (2003), Khain et al. (2005), Lynn et al. (2007), Li et al. (2008), Kuba and Murakami (2010)

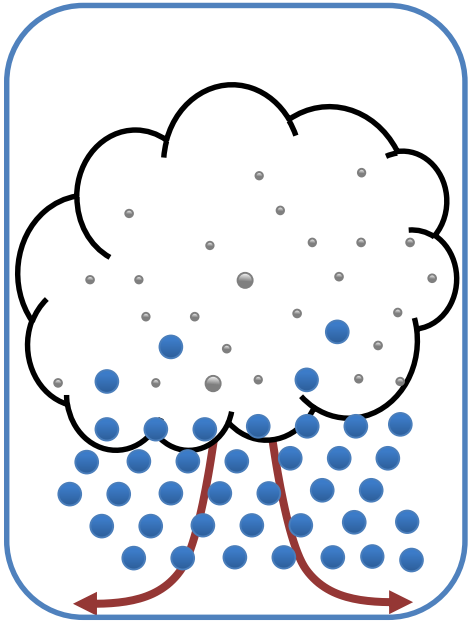

-0°C-
A
— -20°C —
—0°C—
B

Method 1: Spraying









1

Small cloud droplets produced by activation of naturally occurring CCN (i.e. continental type) produce very limited rainfall.

2

Cloud drops of size beyond the Hocking limit can grow efficiently by collision-coalescence process; that is, by colliding with other droplets and coalescing into a larger drop.

3

Sprinkling small water droplets or saline solution as rain embryos to accelerate collision-coalescence process.

Bowen (1952)
Biswas and Dennis (1971)
Murty (1989)
Czys and Bruitjes (1994)

4

Those rapidly growing rain embryos would breakup and induce chain-reaction to increase the rainfall amount.

Langmuir (1948)
Biswas and Dennis (1972)
Farley and Chen (1975)

The Bowen Model

Effective average value of collection efficiency

Rain embryo size

Cloud LWC (1 gm^{-3})

$$\frac{dR}{dz} = \frac{\bar{E}(R,r)M}{4r_L} \times \frac{u(R)}{U - u(R)}$$

Density of water

Terminal velocity of rain embryo

Updraft velocity

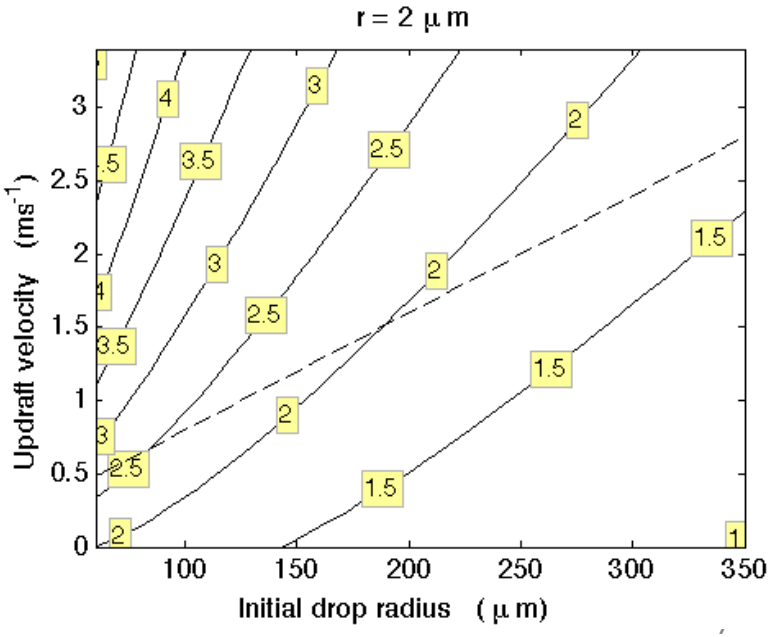
Prescribed monodisperse cloud drop size (r)

Discharge point (z_0)

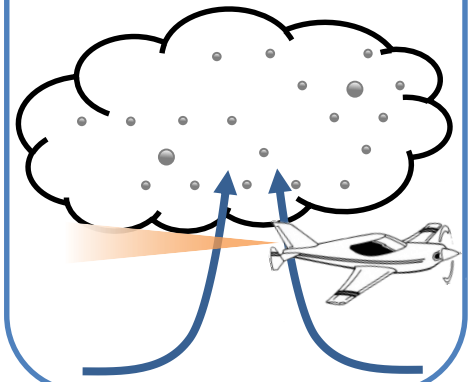
Cloud base (Z_{cb}): –4500 m from z_0

Cloud top (Z_{ct}): Unlimited until U ≤ u(R)

Contour: $\log_{10} \frac{(V_f)_{Z_{cb}}}{(V_i)_{Z_0}}$



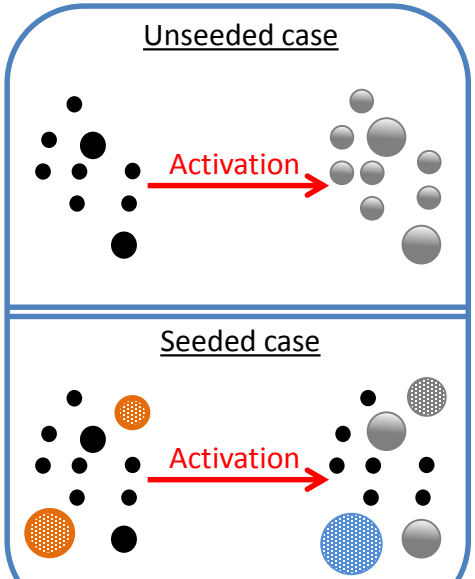
Method 2: Pyrotechnic flare seeding



1

Artificially release hygroscopic aerosol at the updraft region of a growing cloud with pyrotechnic flares.

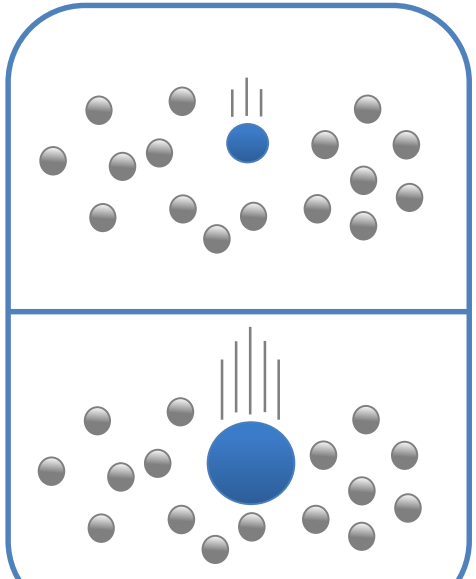
Mather et al. (1997)



2

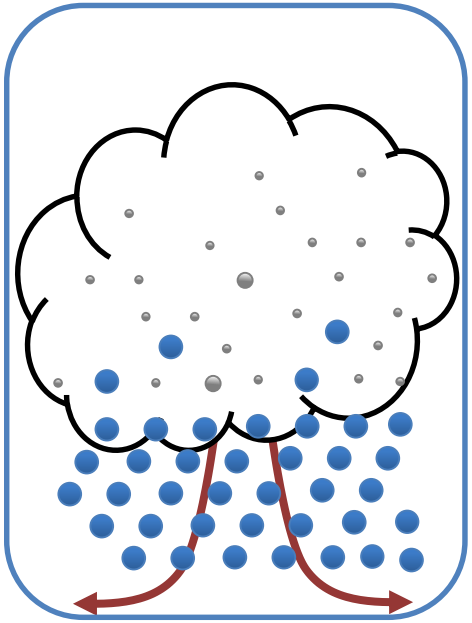
The relatively larger hygroscopic aerosol inhibit the activation of smaller ambient aero-sol, resulting broader droplet spectrum at cloud base.

Cooper et al. (1997)



3

The strong updraft rises those fewer but larger cloud droplets to near cloud top. The cloud drops then grow rapidly by collision-coalescence process.

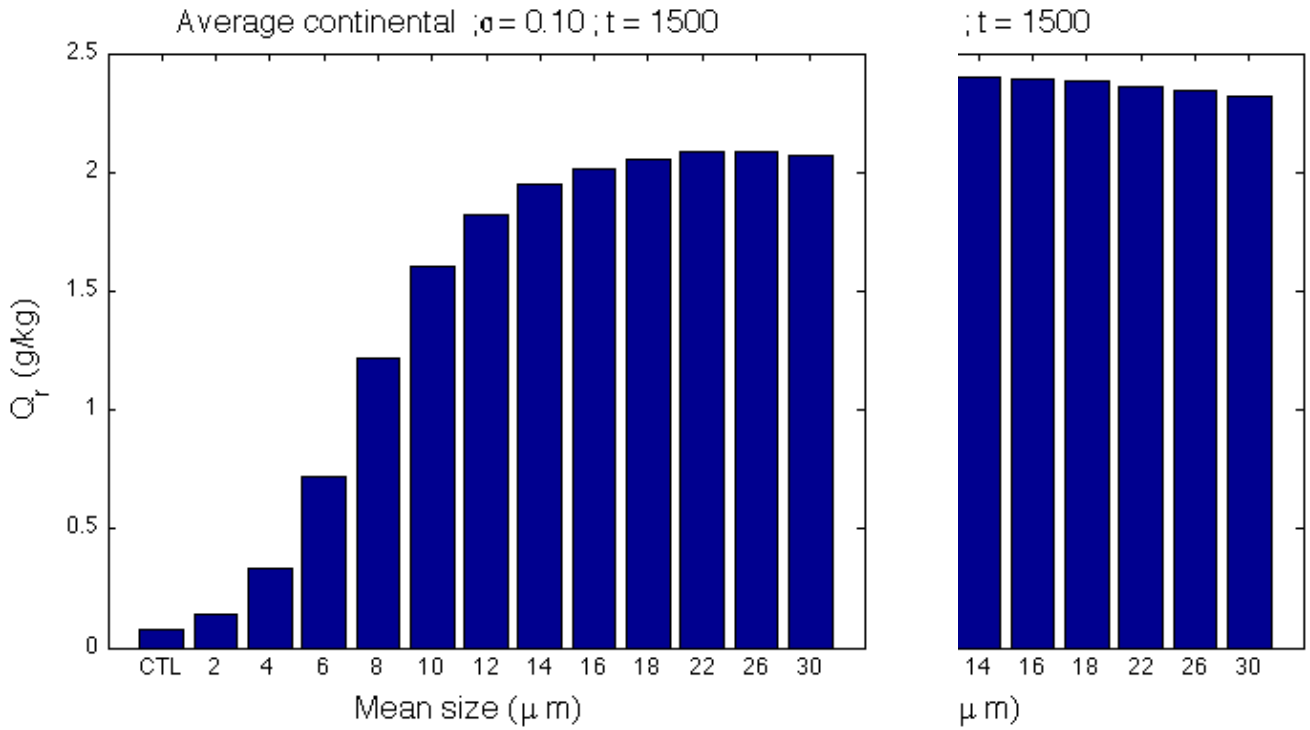


4

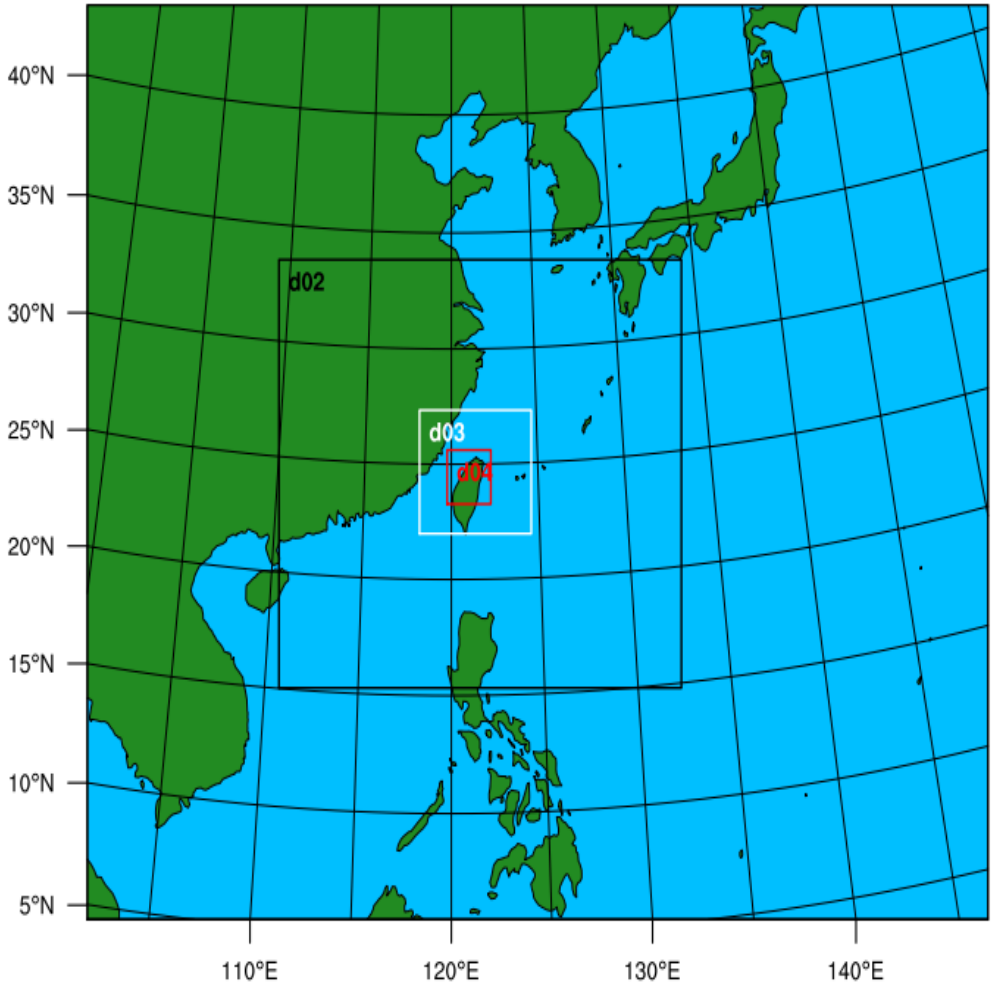
Those rapidly growing rain embryos would breakup and induce chain-reaction to increase the rainfall amount.

Langmuir (1948)
Biswas and Dennis (1972)
Farley and Chen (1975)

The parcel model (t=1500s)



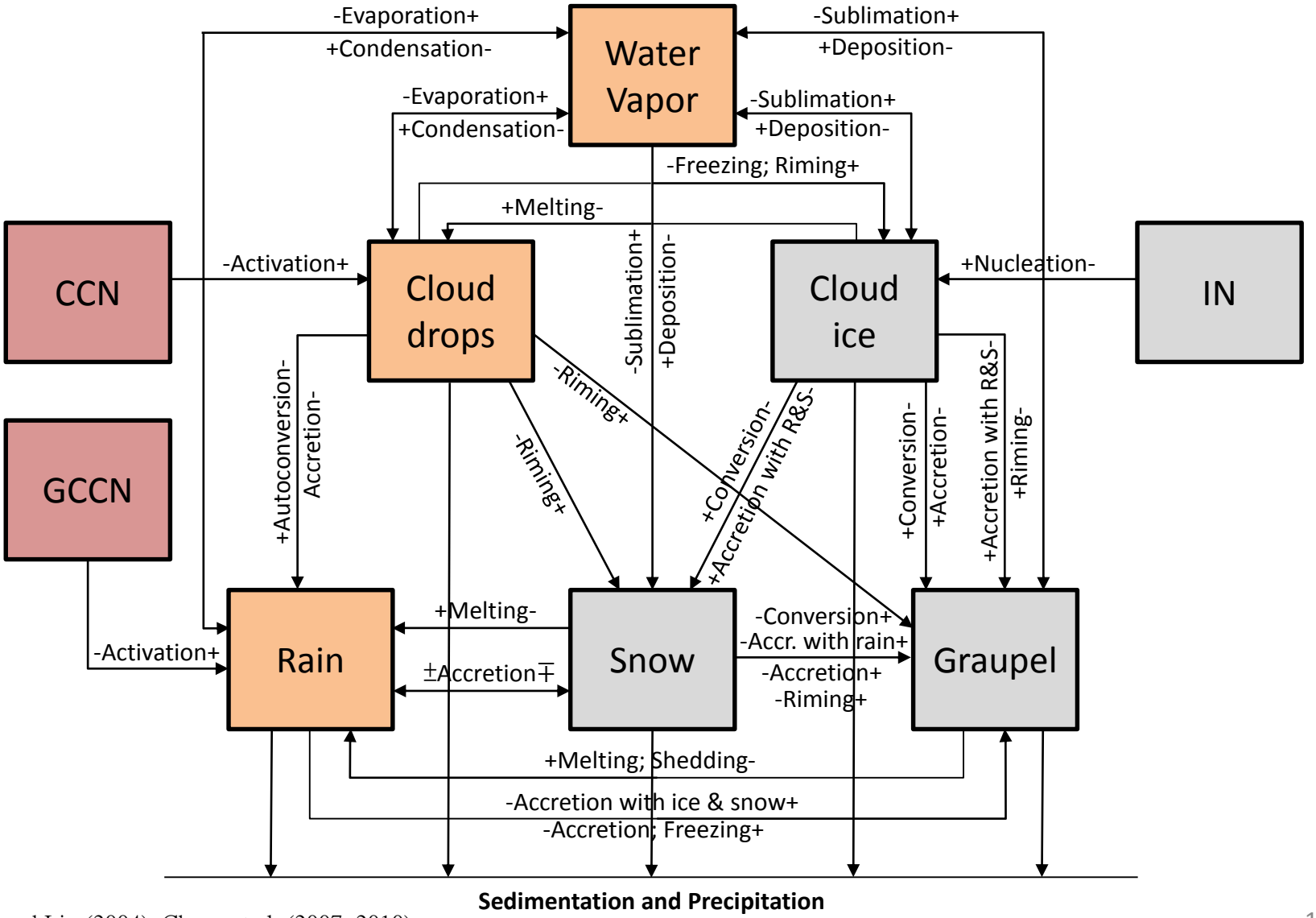
Model Configuration: WRF V3.3.1 with CLR2



D1 & D2: Averaged continental
D3 & D4: Averaged continental or Urban

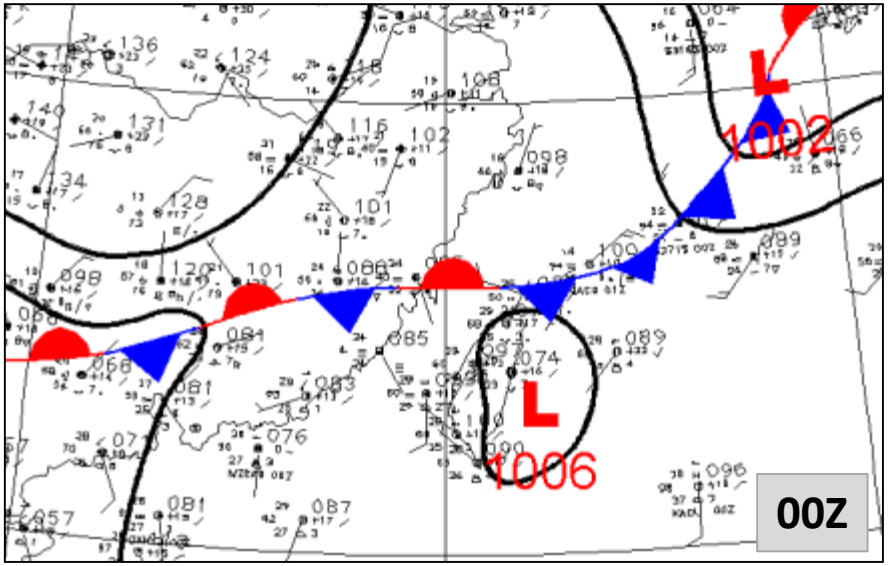
Simulation Period (48hrs)	
Case 1	2011/05/11 00Z ~ 2011/05/13 00Z
Domains setting	
Domain 1	95 ×80 (54 km)
Domain 2	127 × 112 (18 km)
Domain 3	106× 97 (6 km)
Domain 4	124× 127 (2 km)
Vertical	45 layers; P_{top} = 30 hPa
Physics Options	
Cumulus	New Grell (D1 & D2)
PBL	YSU
SW radiation	New Goddard
LW radiation	New Goddard
Surface layer	Monin-Obukhov
Land surface	Thermal diffusion
Microphysics	CLR2

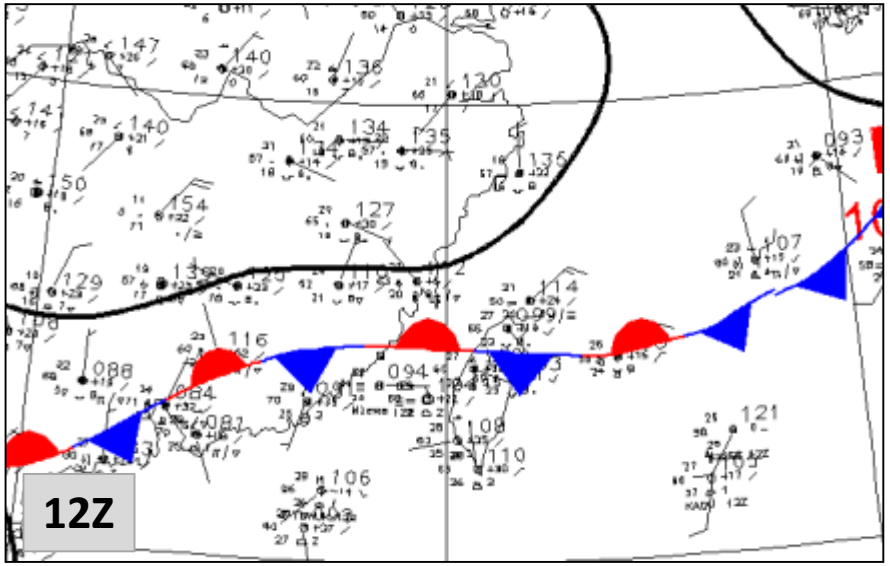
CLR2 cloud microphysics scheme (mixing ratio)

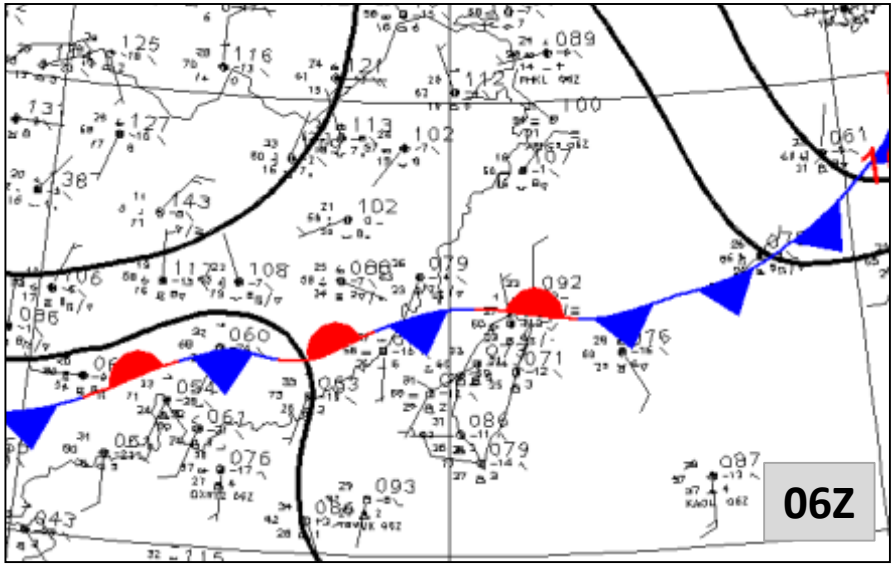


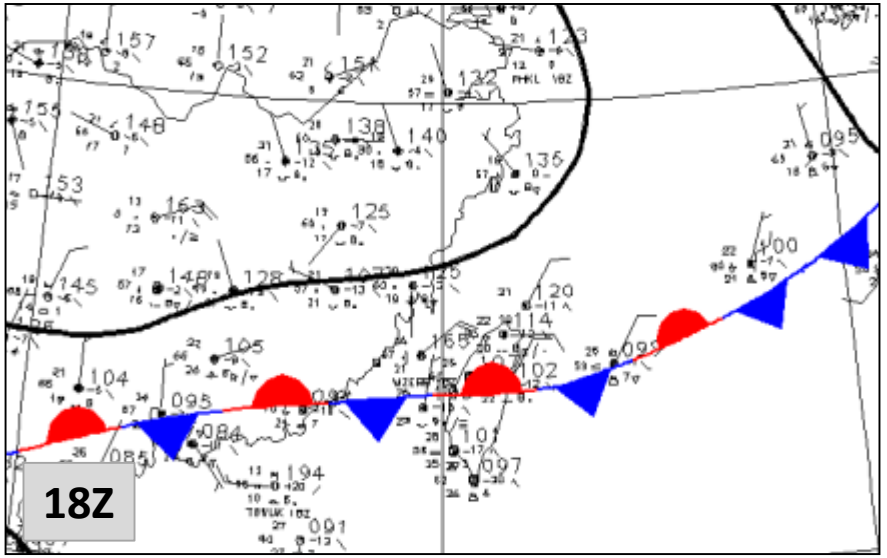
Chen and Liu (2004), Cheng et al. (2007, 2010)

Surface weather map (20110512)

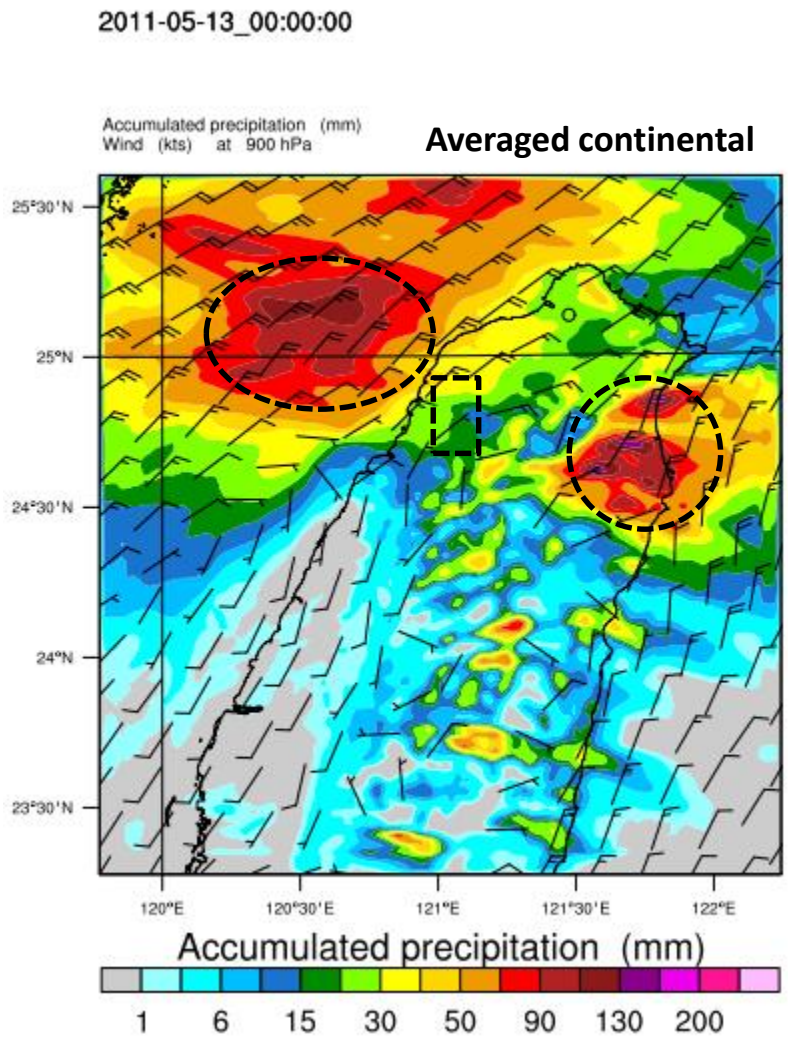


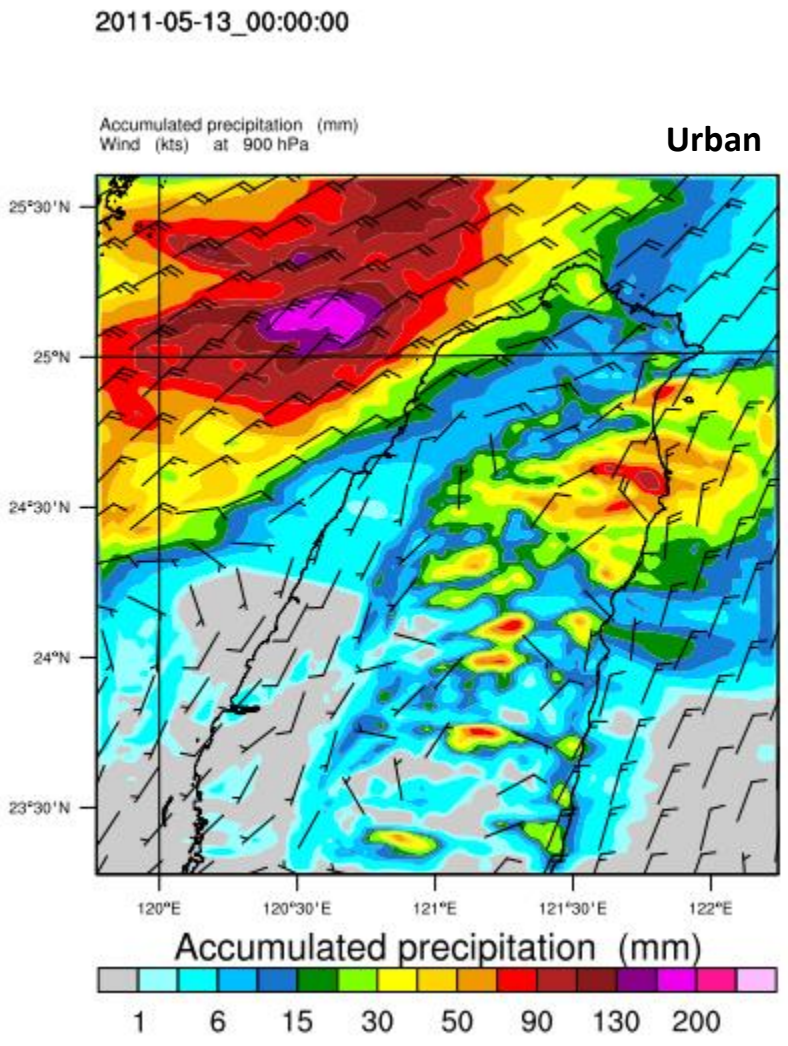




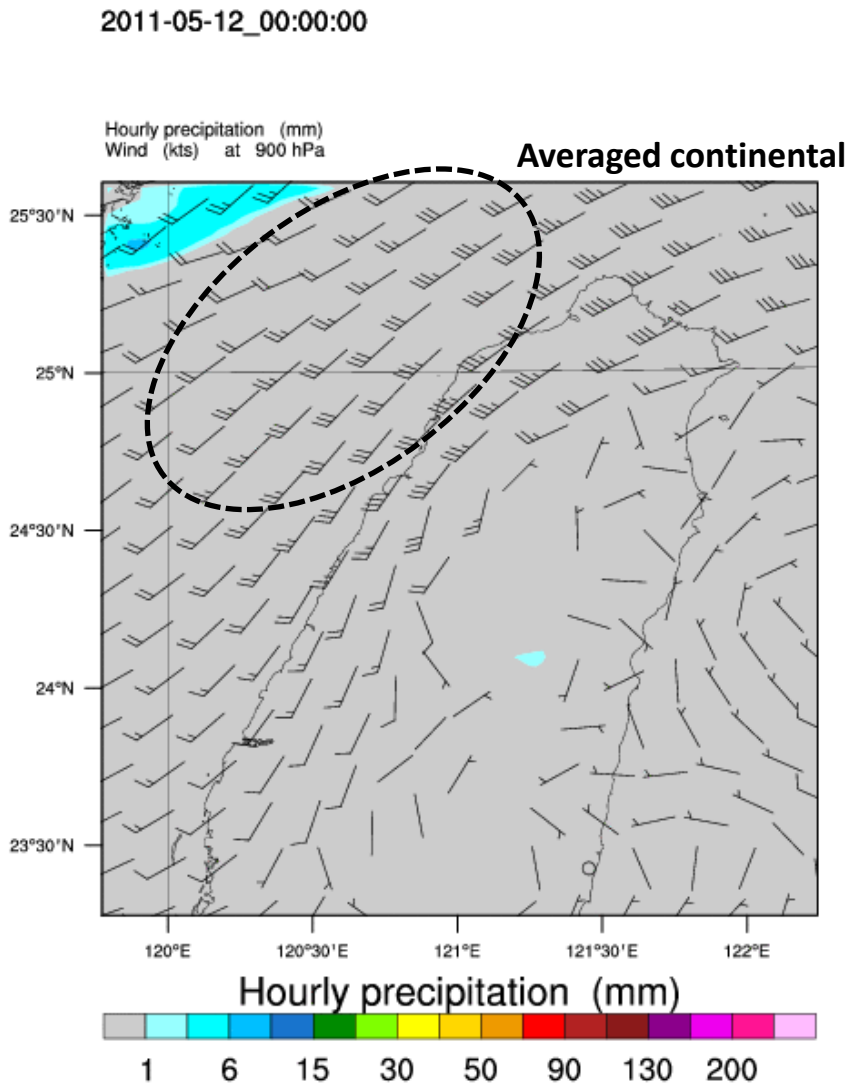


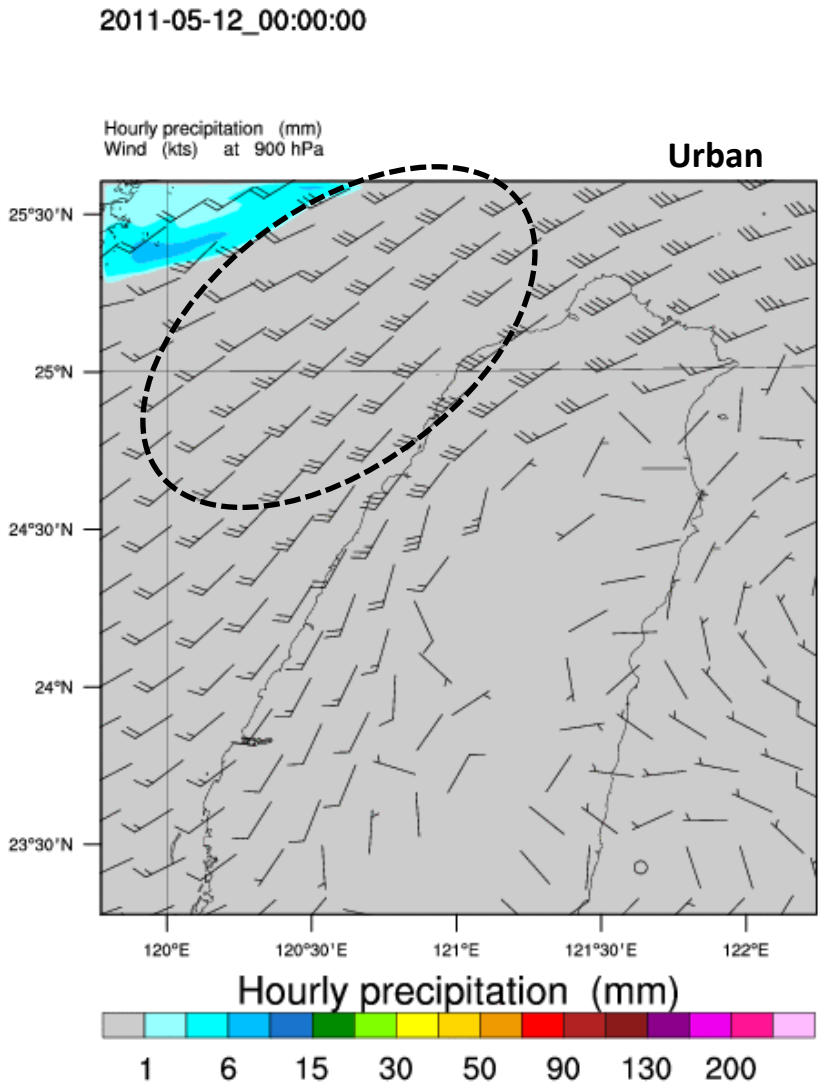
Effect of ambient aerosol type on accumulated rainfall

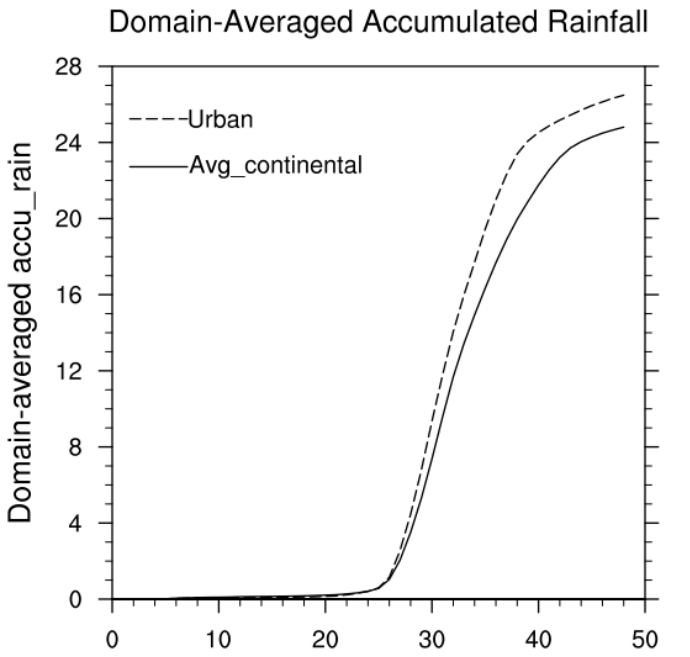


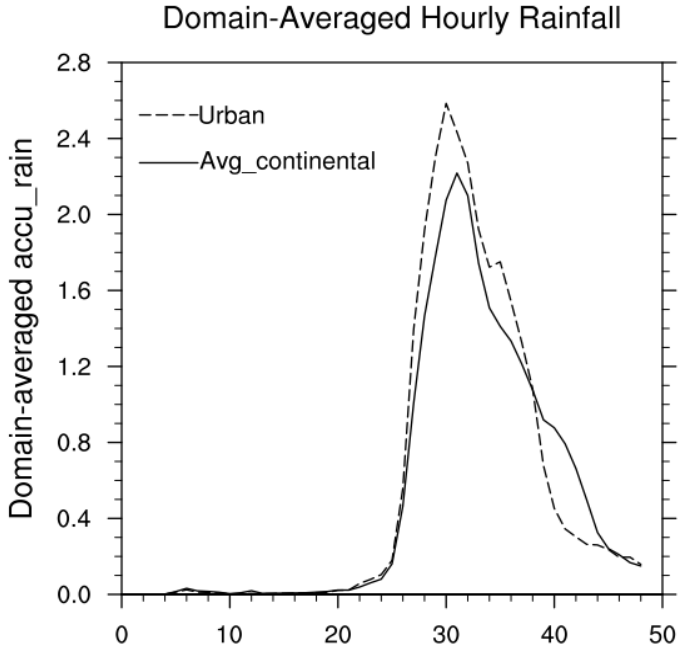


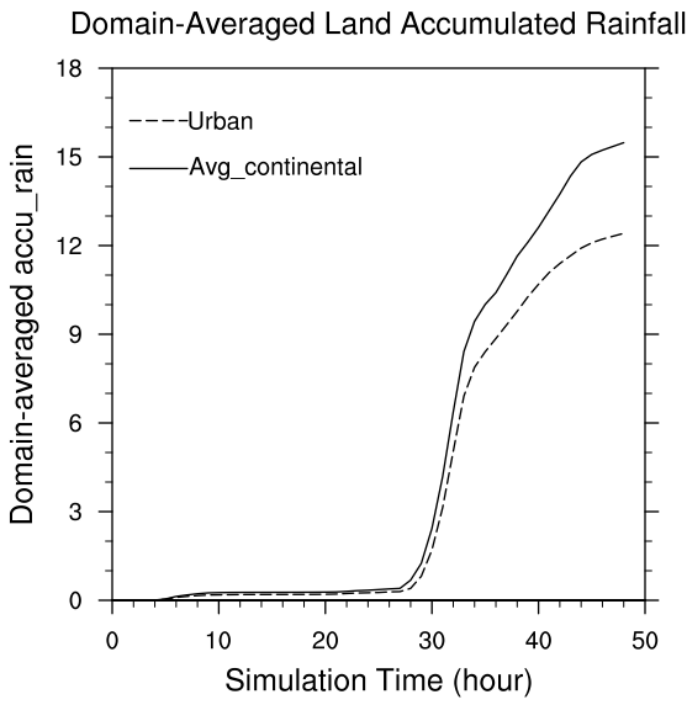
Sensitivity tests on ambient aerosol

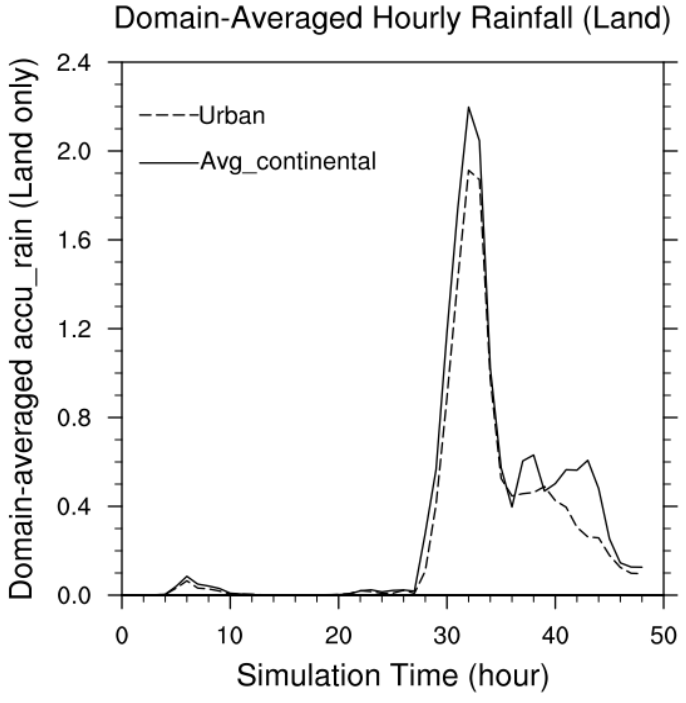


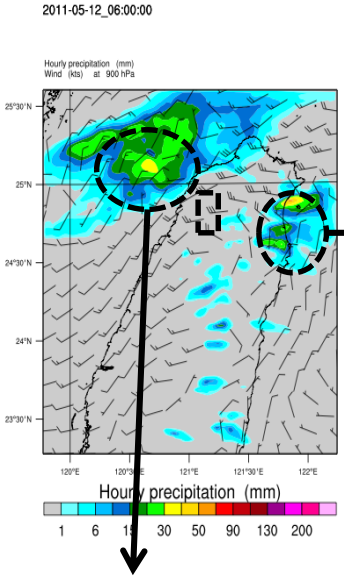


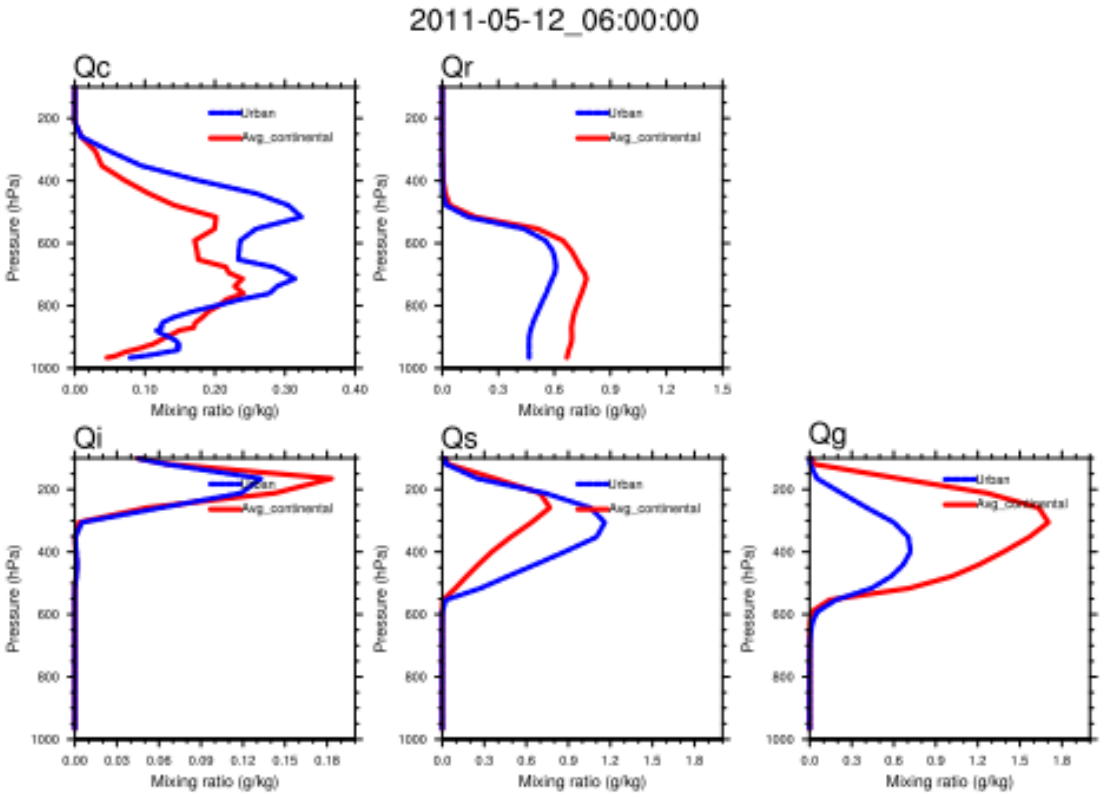

Domain-Averaged Accumulated Rainfall
Urban
Avg_continental
Domain-averaged accu_rain
0
4
8
12
16
20
24
28
0
10
20
30
40
50

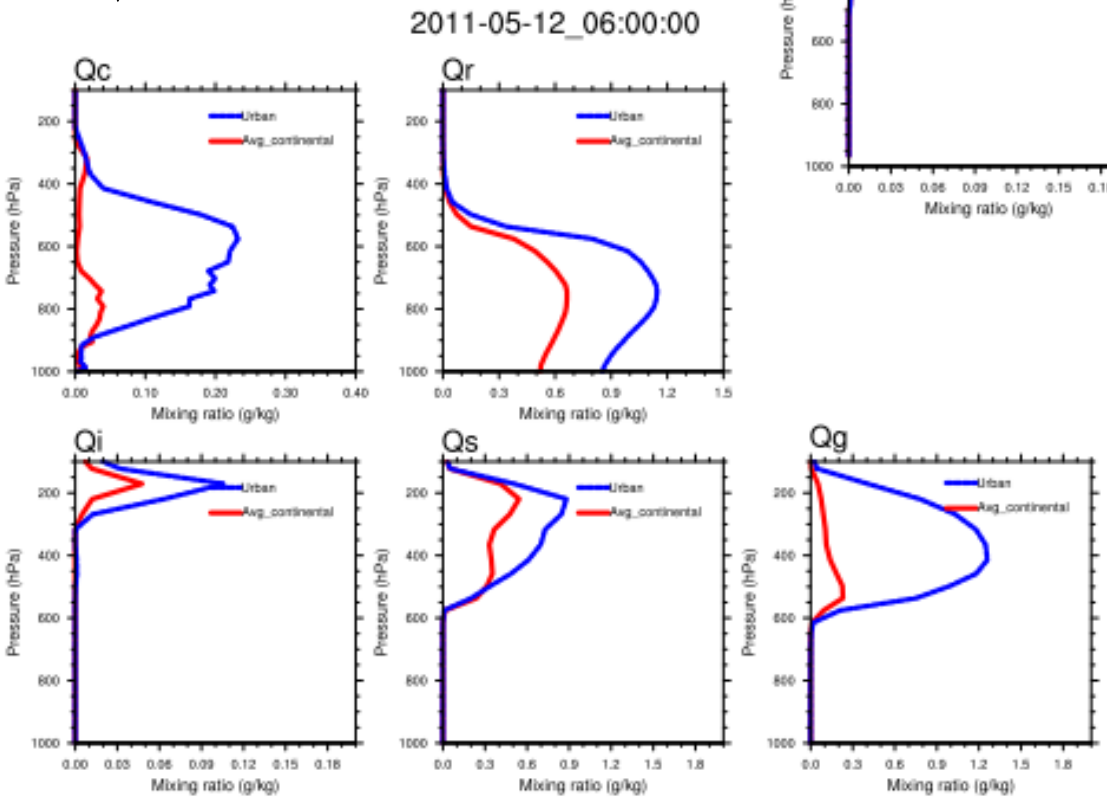

Domain-Averaged Hourly Rainfall
Urban
Avg_continental
Domain-averaged accu_rain
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
0
10
20
30
40
50


Domain-Averaged Land Accumulated Rainfall
Urban
Avg_continental
Domain-averaged accu_rain
0
3
6
9
12
15
18
0
10
20
30
40
50
Simulation Time (hour)


Domain-Averaged Hourly Rainfall (Land)
Urban
Avg_continental
Domain-averaged accu_rain (Land only)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
0
10
20
30
40
50
Simulation Time (hour)

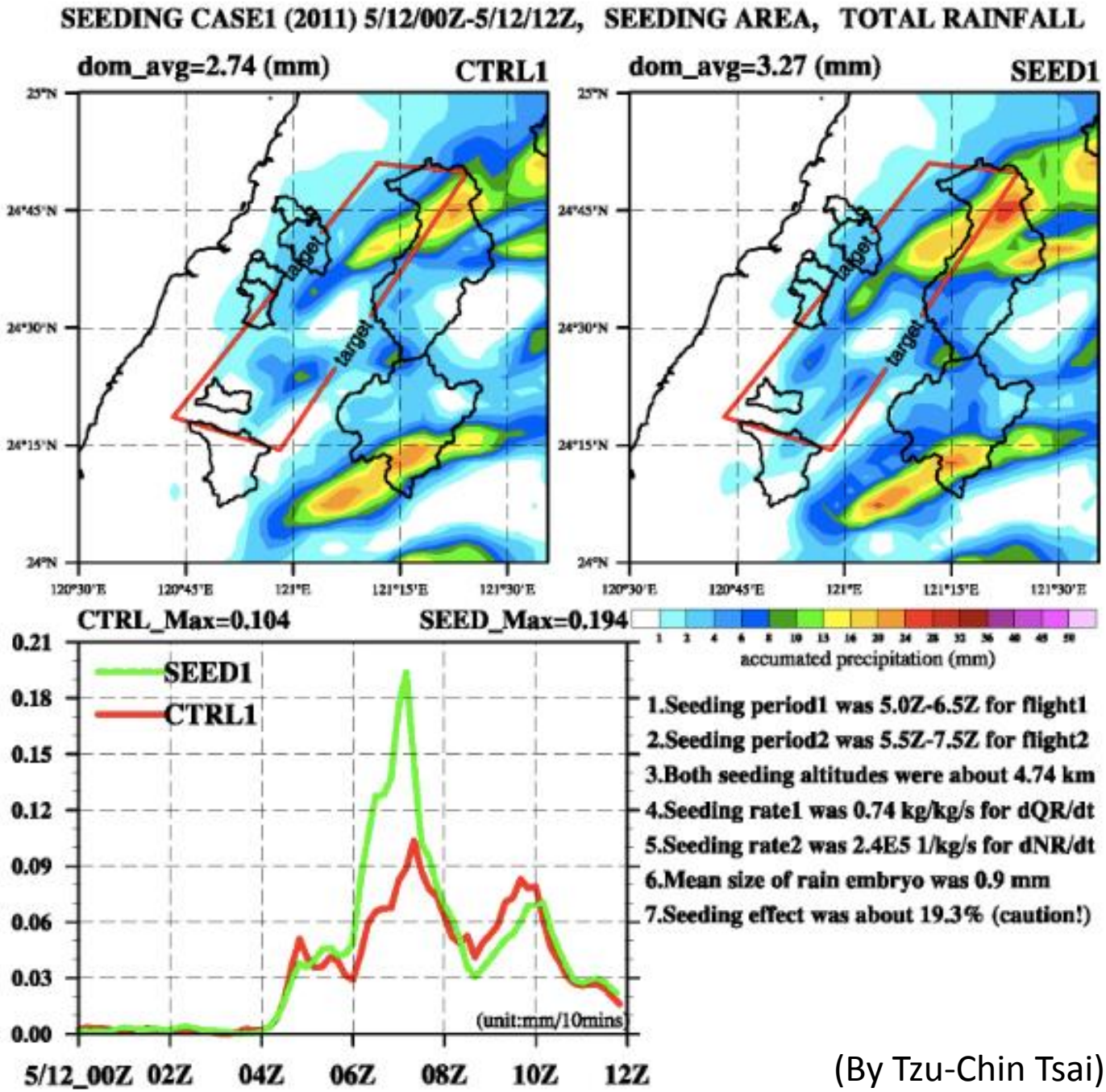






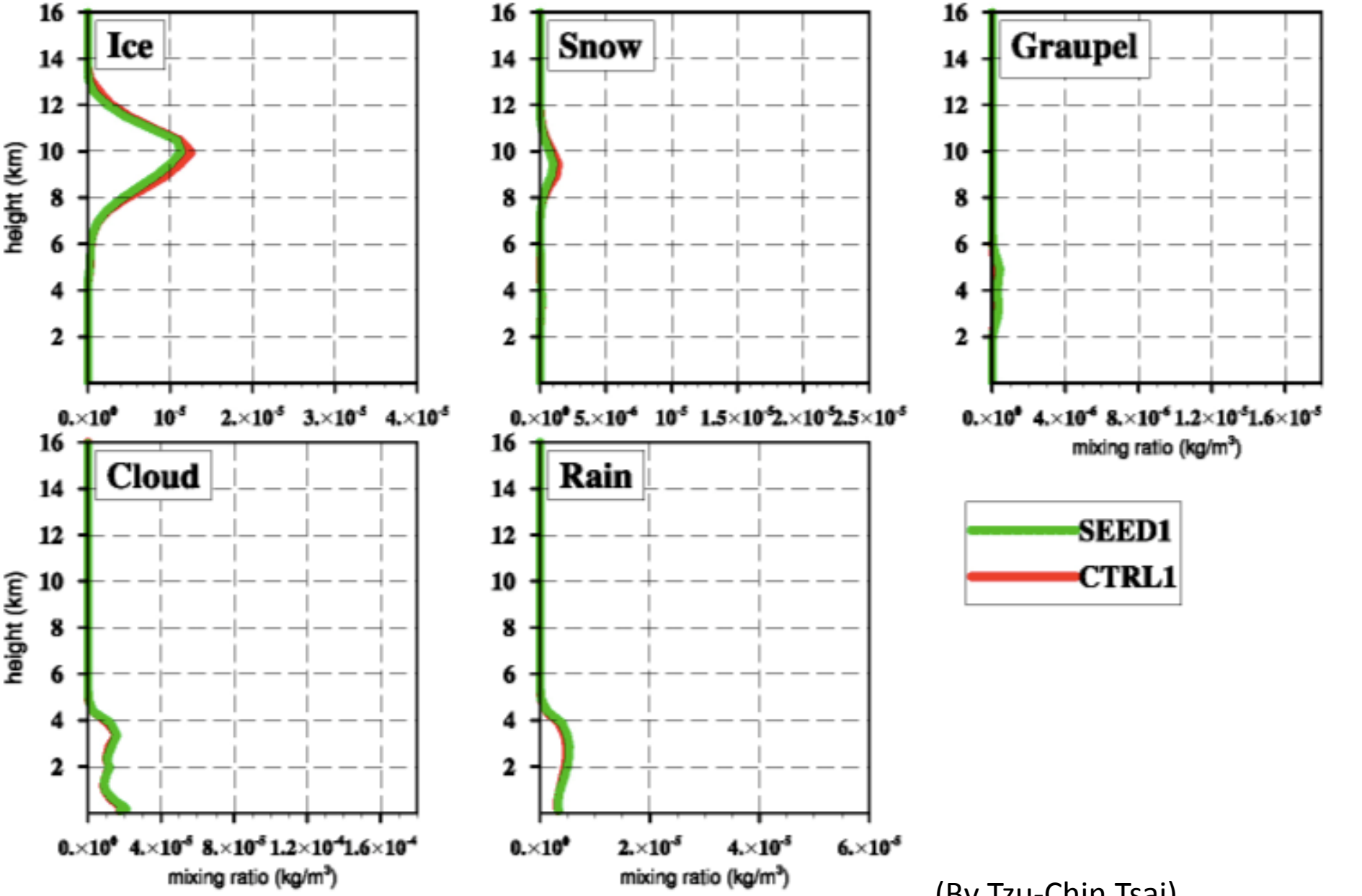
Urban

Averaged continental



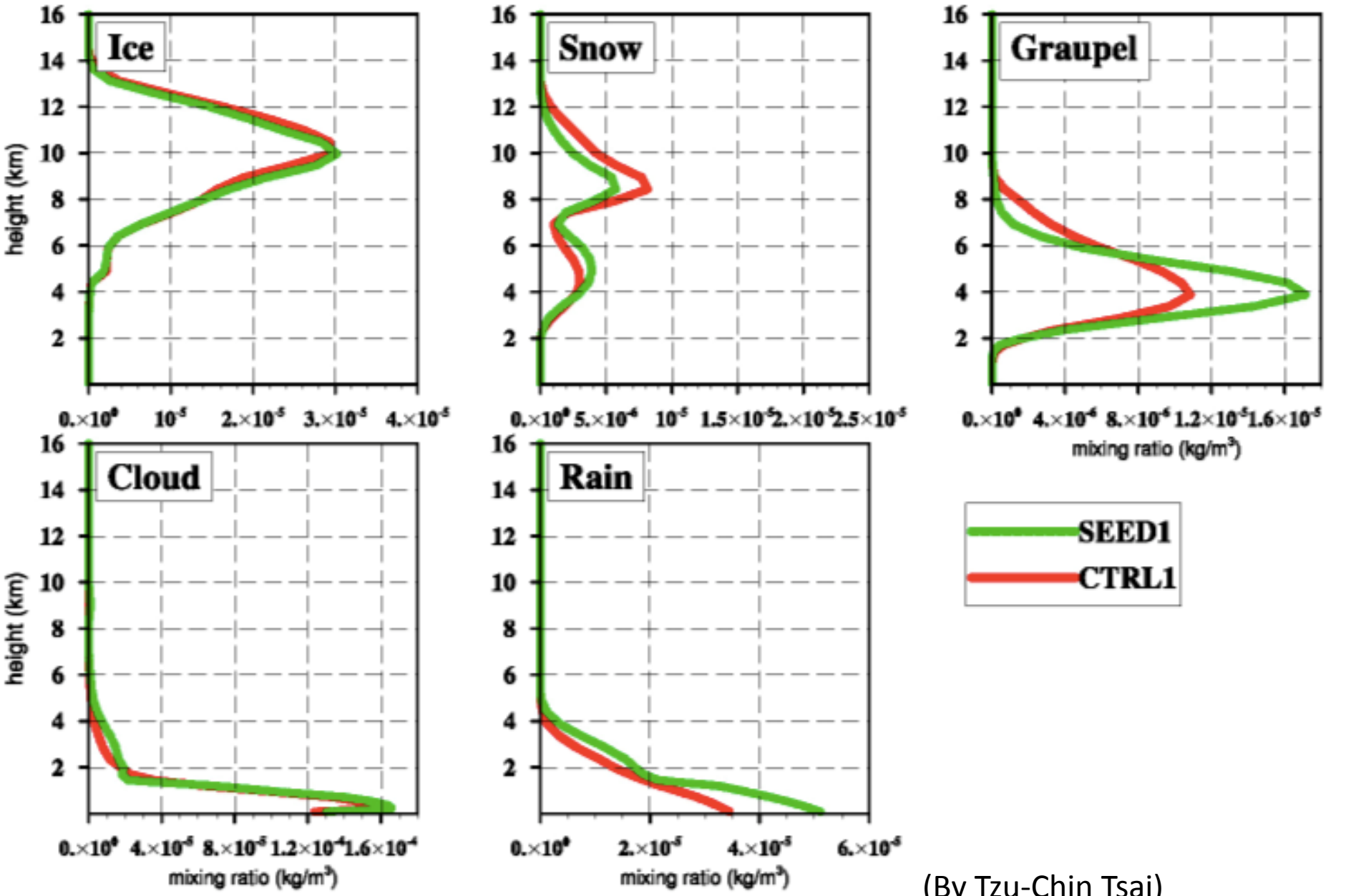
(By Tzu-Chin Tsai)

Case1 Before Seeding, 20011 5/11_12Z-5/12_05Z, targeted_area_avg (Mass)



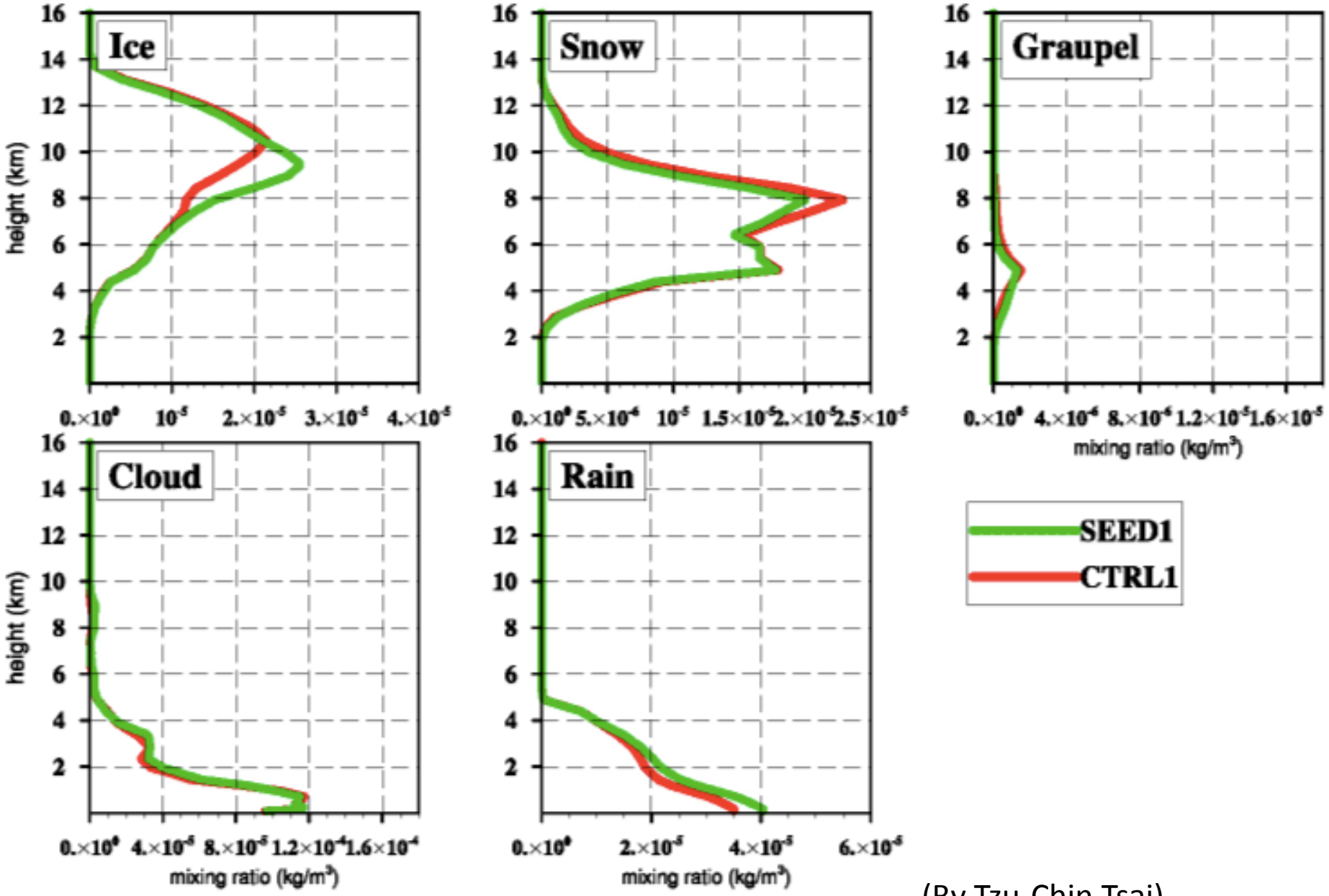
(By Tzu-Chin Tsai)

Case1 During Seeding, 20011 5/12_05Z-5/12_08Z, targeted_area_avg (Mass)



(By Tzu-Chin Tsai)

Case1 After Seeding, 20011 5/12_08Z-5/13_00Z, targeted_area_avg (Mass)



(By Tzu-Chin Tsai)

Conclusion and ongoing work

- Effect of different types of ambient aerosol:
  - Minor effect on precipitation pattern
  - Affect maximum rainfall amount
  - Major effect on distribution of hydrometeors
- Seeding effect by water spraying is about 19%

- Sensitivity tests on GCCN, seeding time and position
- Physical verification:
  - The microphysical processes involved
  - The seeding effect