Rain reduction technology

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25/06/2019

outlines

1. Objective
2. AgI seeding with 3-D cloud model
3. Ice crystal seeding with MM5
4. AgI seeding with MM5 and WRF

1. Objective

As the opposite effect of artificial rainfall enhancement, artificial rainfall reduction has great significance in weakening heavy rain disaster, guaranteeing large-scale outdoor event, and more accurately performing artificial cloud dissipation or rain reduction.

- Studies on rain intensity reduction has been done by many scientists both in the laboratory or by using some models and also by field experiments.
- 1950s, Russian started overseeding with dry ice;
- Langmuir (1950s) suggested overseeding with dry ice to dissipate cloud;
- USA (Lovasich et al, 1971) overseeding AgI to reduce precipitation;
- Negative seeding effect of several rain enhacement experiments: Israel scientists found (Rosenfeld and Farbstein, 1992) that, in south Israel near desert, too many ice nuclea which compete with seeding agent, to suppress the seeding effect.
- Orville and Kopp (1974) to get 30% reduced precipitation with 2-D cloud model simulation
- Dennis and Koscielski (1996) to effect dynamic field to suppress the development of new convective cell;

- Inappropriate seeding clouds or unreasonable seeding can also cause negative effects of artificial precipitation (Ye Jiadong et al., 1998).
- The results of two-dimensional numerical simulation experiments on the warm rain process that changing the concentration of cloud condensation nuclei (CCN) can affect the warm rain process and the final rainfall and its distribution (Wang Chunming et al., 1996).
- Yin et al. (2000) states that based on numerical calculation of hygroscopic seeding impact on convective clouds, seeding agents with too small size could decrease about 22 – 30 % of precipitation.
- Givati and Rosenfeld (2004) showed that urban air pollution in California and Israel may reduce about 15 - 25% of yearly rainfall.
- According to Khain et al. (2005), small cloud condensation nuclei CCN may produce small droplets, which have small collision efficiency, thereby causing deep convective clouds decreasing precipitation.
- Weather Modification Technology Center (Indonesia) had carried out experiments in rain intensity reduction in order to overcome floods via competition method in Tuntang area – Central Java during the rainy season of 1995. The result showed that rainfall intensity was decreased to about 15 %.

Basic principles and methods for artificial rainfall reducation

Proper seeding to increase precipitation, before the original precipitation time

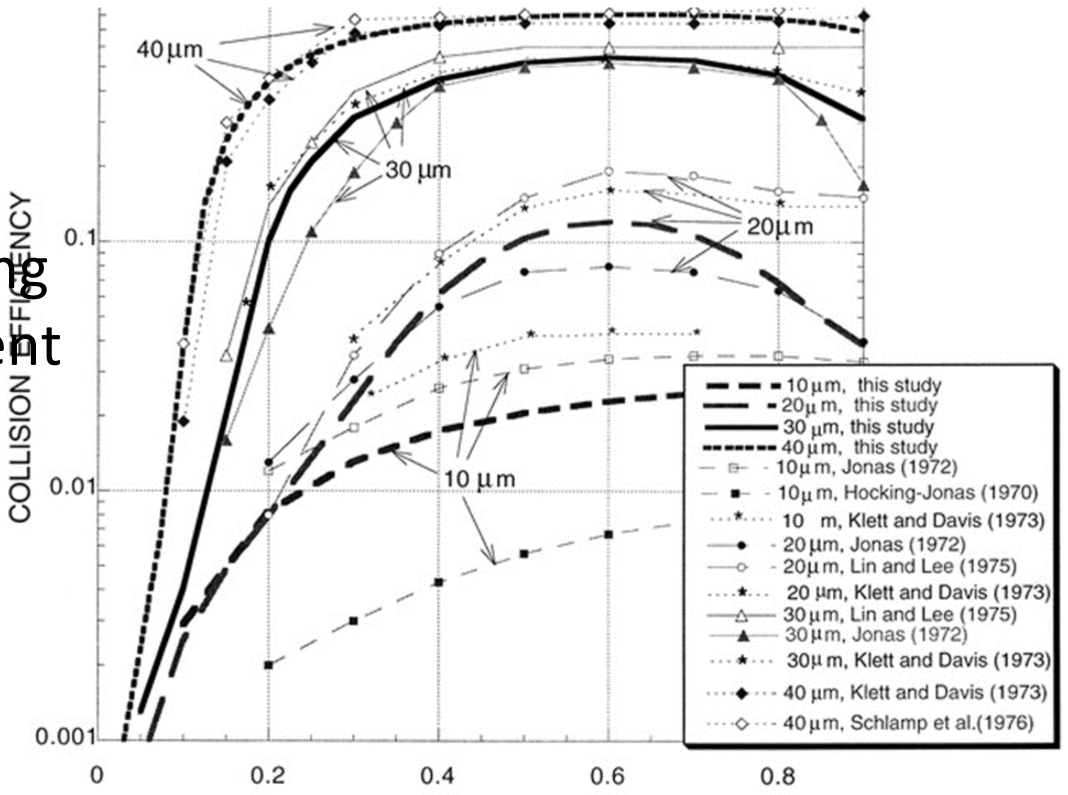
seeding large size particles, to suppress the development of cloud and precipitation

Over seeding to reduce or delay precipitation

- In the earliest stage, a cloud is an assembly of tiny droplets numbering in the order of 100 /cm3 and having radii of about 10 µm. Because efficiency of collision and coalecence is very low, this structure is of course extremely stable.
- Introducing super fine hygroscopic seeding agent into the clouds would then initiate the formation of small droplets that will act as competitor to the existing cloud droplets in the water vapor absorption process within the cloud.

This method may prevent development of cloud.

A good example of "competition mechanism" is during forest fires events. There are too many aerosol present (~2000/ cm3), which have sizes less than 2 µm, produced by forest fires, cumulus clouds barely developed over the fires.



2. To reduce strong convective precipitation with AgI seeding

3D cloud model, AgI seeding scheme,qv,qc,qr,qi,qg,qh,ni,nr,ng,nh,Fc

Dx=1200 m,Dz=700 m

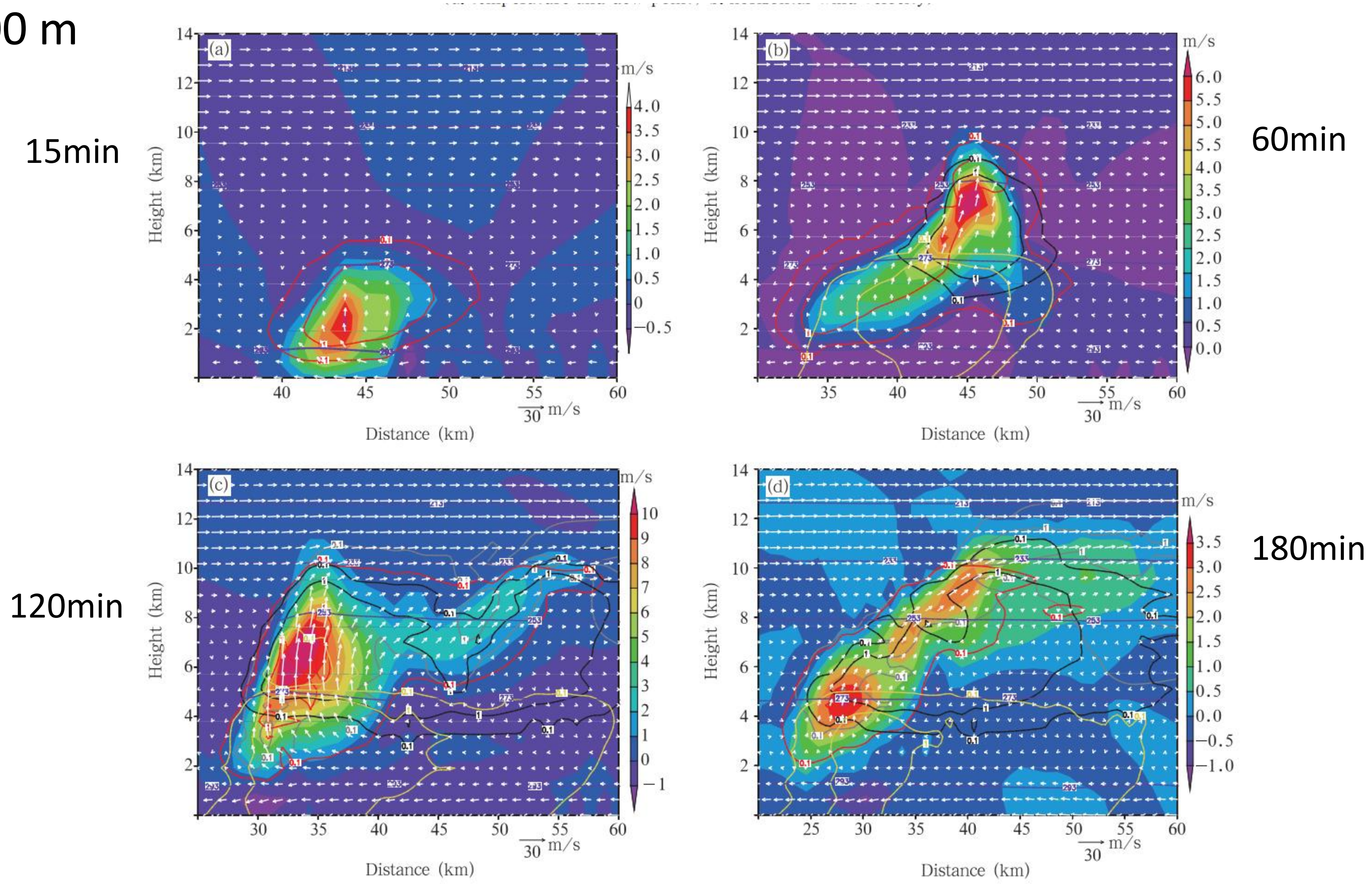


表 1　DeMott 等(1995)得出的 AgI 不同核化机制的核化效率

Table 1　The AgI nucleation rate given by DeMott (1995)

核化机制	AgI-AgCl(0.03 μm)	AgI-AgCl-4NaCl(0.03 μm)	条件
凝　华	$D_{dep}=a(S_i-0.65S_w-5)^b$		$T<-5$ ℃ $S_w>-8\%$
	$a=5.02\times10^5$	$a=5.86\times10^6$	
	$b=1.493$	$b=1.346$	
	$D_{dep}=a(S_i)^b$		$S_w<-8\%$
	$F_{dep}=1-\exp(-4\pi r_d^2 D_{dep})$		
接触冻结	$D_{cf}=a(S_i-0.055)^b$		$S_i>0.055$
	$a=1.198\times10^{12}$		
	$b=1.98$		
	$F_{cf}=1-\exp(-4\pi r_d^2 D_{cf})$		
	$F'_{cf}=F_{saw}F_{cf}$		
浸没冻结	$F_{imf}=p[T_0^{-1}(T+l)]^m$		$T<-5$ ℃
	$p=0.0337$		
	$l=5$		
	$m=3.2$		
	$T_0=-10$ ℃		
	$F'_{imf}=F_{imf}(F_{inc}+F_{ind})$		
凝结冻结	$D_{cf}=a[T_0^{-1}(T+d)]^b(S_w)^c$		$T<-5,-6$ ℃ $S_w>0\%$
	$a=2.36\times10^9$	$a=3.54\times10^{11}$	
	$b=4.836$	$b=4.730$	
	$c=2$	$c=2$	
	$d=3$	$d=6$	
	$T_0=-10$ ℃		
	$F_{cf}=1-\exp(-4\pi r_d^2 D_{cf})$		

Cloud fields and ice nucleation microphysical processes

$$\frac{\delta N_{\mathrm{aer}}}{\delta t} = -N_{\mathrm{aer}}\left(F_{\mathrm{scav}} + \frac{\partial F_{\mathrm{dep}}}{\partial t} + \frac{\partial F_{\mathrm{cdf}}}{\partial t} + \frac{\partial F_{\mathrm{imd}}}{\partial t}\right)$$

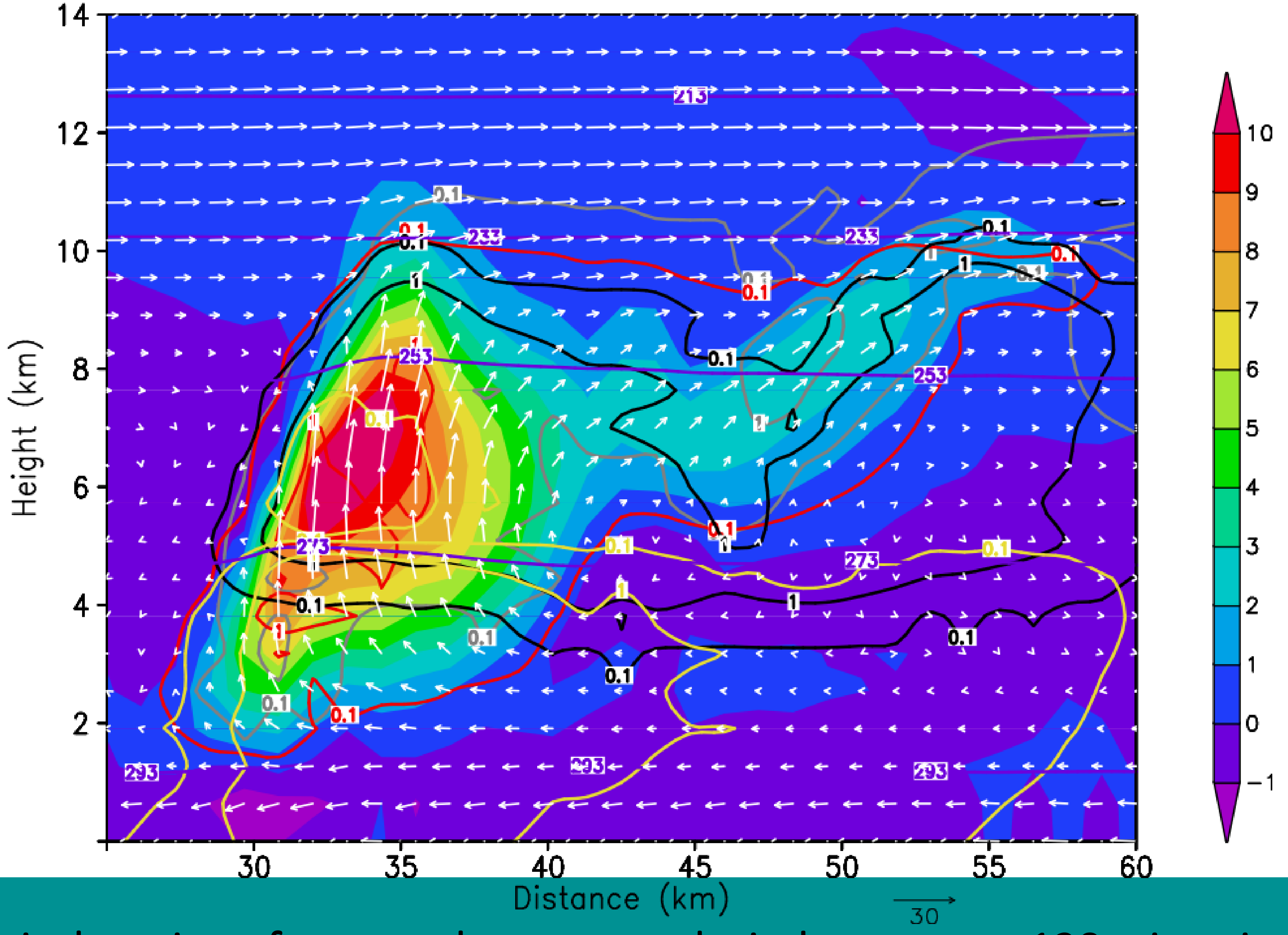
$$\frac{\delta N_{\mathrm{aim}}}{\delta t} = N_{\mathrm{aer}}\left[F_{\mathrm{scav}}(1 - F_{\mathrm{ctf}})(1 - F_{\mathrm{imf}}) + \frac{\partial F_{\mathrm{imd}}}{\partial t}\right] - N_{\mathrm{aim}}\frac{\partial F_{\mathrm{imf}}}{\partial t}$$

$$\frac{\delta Q_{\mathrm{v}}}{\delta t} = -N_{\mathrm{aer}}\left(\frac{\partial F_{\mathrm{dep}}}{\partial t} + \frac{\partial F_{\mathrm{cdf}}}{\partial t} + \frac{\partial F_{\mathrm{imd}}}{\partial t}\right)Q_0$$

$$\frac{\delta Q_{\mathrm{c}}}{\delta t} = \left[N_{\mathrm{aer}}\frac{\partial F_{\mathrm{imd}}}{\partial t} - N_{\mathrm{aer}}\left(F_{\mathrm{scav}}F_{\mathrm{ctf}} + F_{\mathrm{scav}}\left(1 - F_{\mathrm{ctf}}\right)F_{\mathrm{imf}}\right) - N_{\mathrm{aim}}\frac{\partial F_{\mathrm{imf}}}{\partial t}\right]Q_0$$

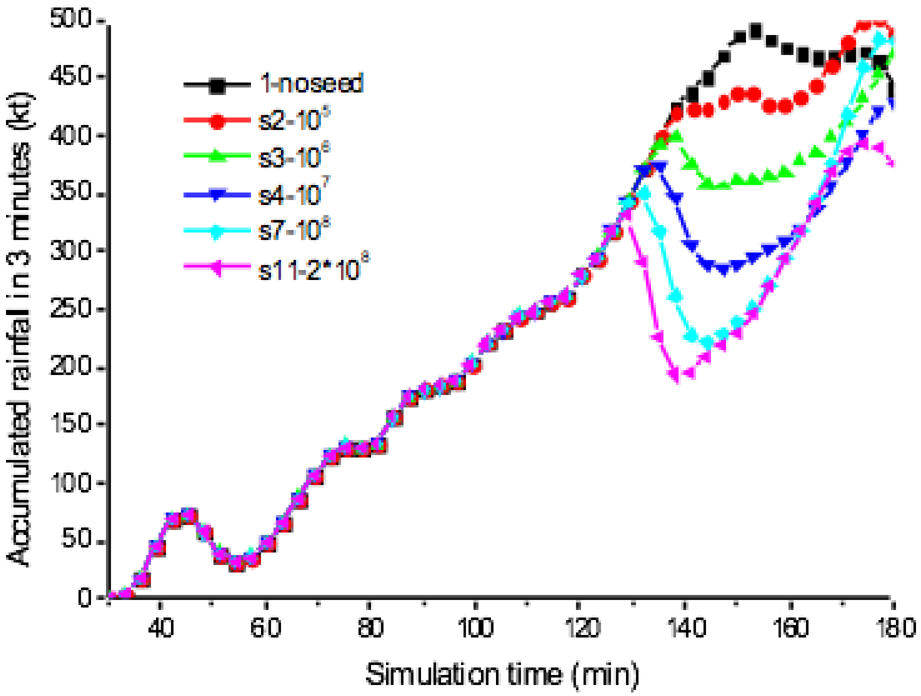
$$\frac{\delta N_{\mathrm{i}}}{\delta t} = N_{\mathrm{aer}}\left[\frac{\partial F_{\mathrm{dep}}}{\partial t} + \frac{\partial F_{\mathrm{cdf}}}{\partial t} + F_{\mathrm{scav}}F_{\mathrm{ctf}} + F_{\mathrm{scav}}\cdot(1 - F_{\mathrm{ctf}})F_{\mathrm{imf}}\right] + N_{\mathrm{aim}}\frac{\partial F_{\mathrm{imf}}}{\partial t}$$

$$\frac{\delta Q_{\mathrm{i}}}{\delta t} = \frac{\partial N_{\mathrm{i}}}{\partial t}\cdot Q_0$$

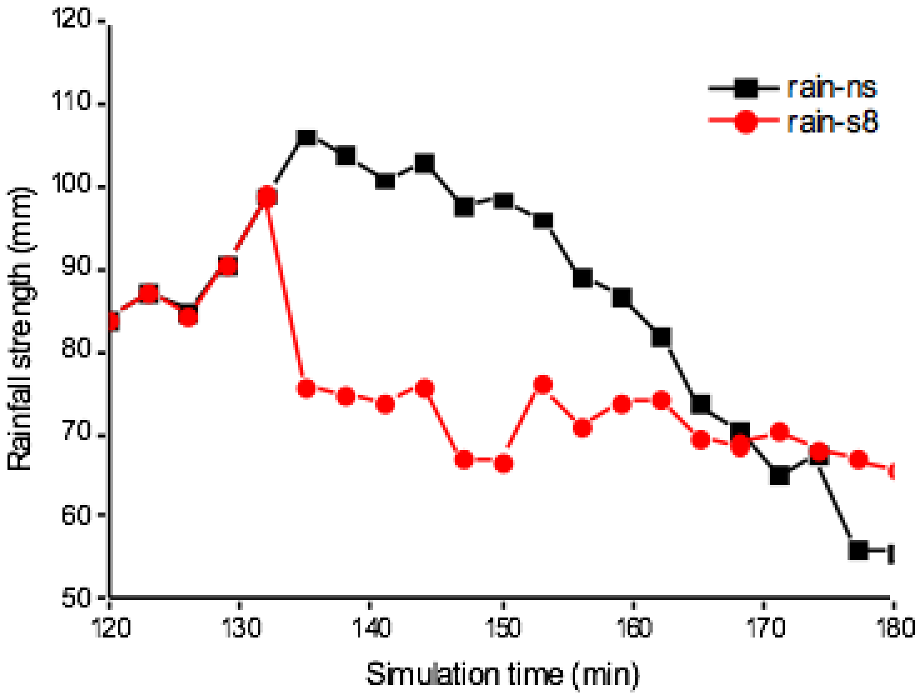


Vertical section of water substances and winds stream at 120 min, wind(shaded), cloud water (red), ice (grey) graupel(black), yellow (rain).

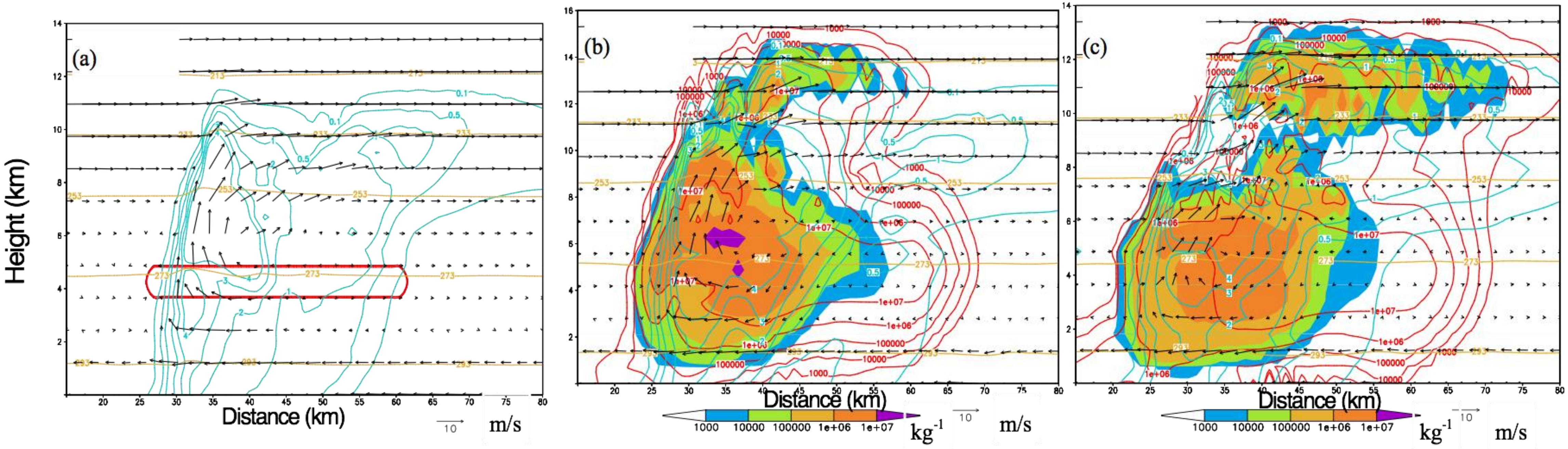
case	AgI播撒方案					Precipitation		AgI (kg)
	Seeding rate /kg	Seeding times	Seeding location			total（Kt）	changed（%）	
			z	x	y			
1		非播撒云				8713		
s2	1.0×10^5	15	8	20—50	35—50	8470	2.8	0.02
s3	1.0×10^6	15	8	20—50	35—50	7601	12.8	0.2
s4	1.0×10^7	15	8	20—50	35—50	6771	22.3	1.9
s5	5.0×10^7	15	8	20—50	35—50	6565	24.7	9.9
s6	1.0×10^8	15	7	20—50	35—50	6502	25.4	18.9
s7	1.0×10^8	15	8	20—50	35—50	6503	25.4	18.9
s8	1.0×10^8	30	8	20—50	35—50	6460	25.9	37.9
s9	2.0×10^8	15	8	20—50	20—50	6003	31.1	37.9
s10	2.0×10^8	15	9	20—50	20—50	6030	30.8	37.9
s11	2.0×10^8	30	9	20—50	20—50	5904	32.2	75.8



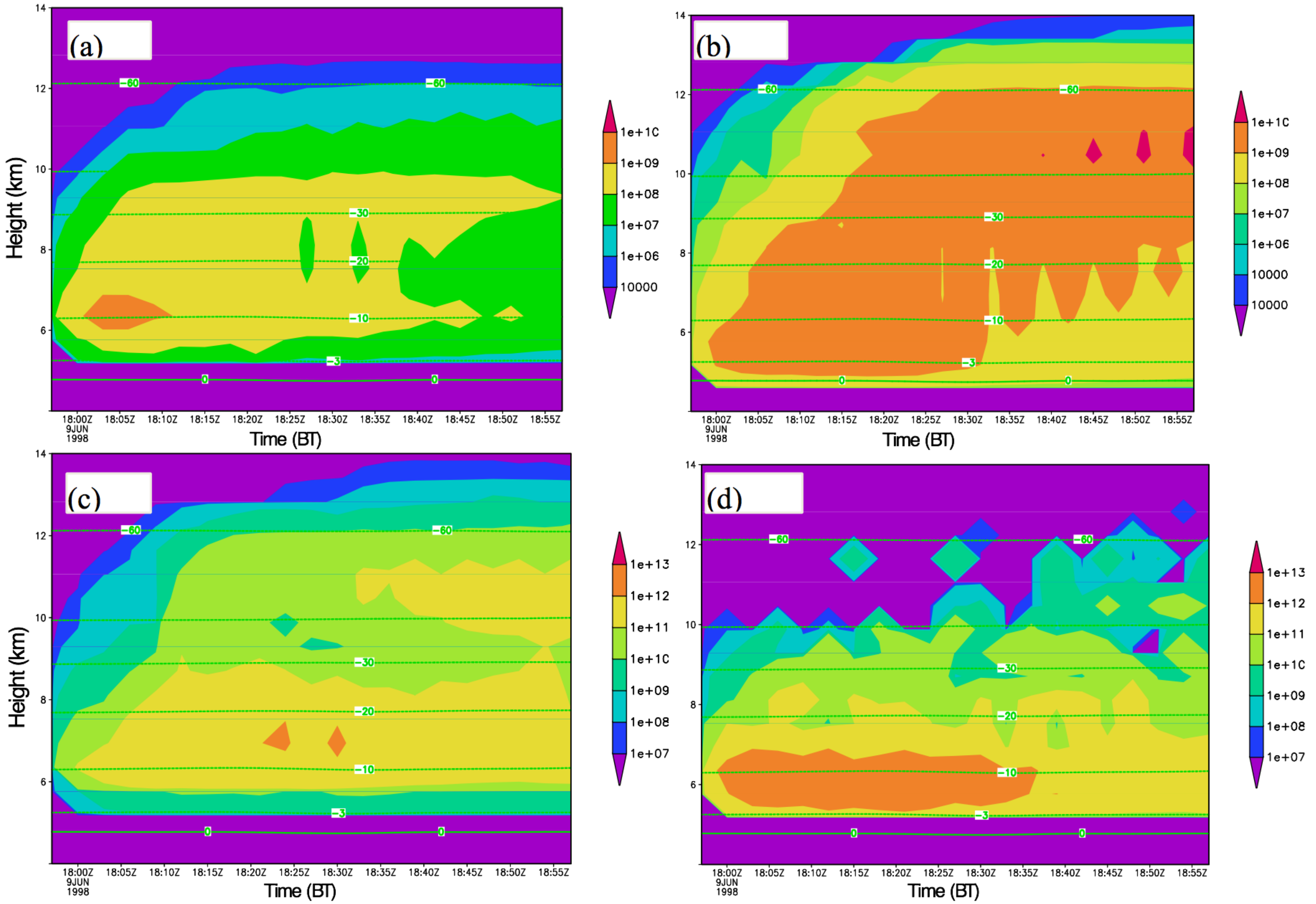
accumulated precipitation in 3 min



maxium grid precipitation

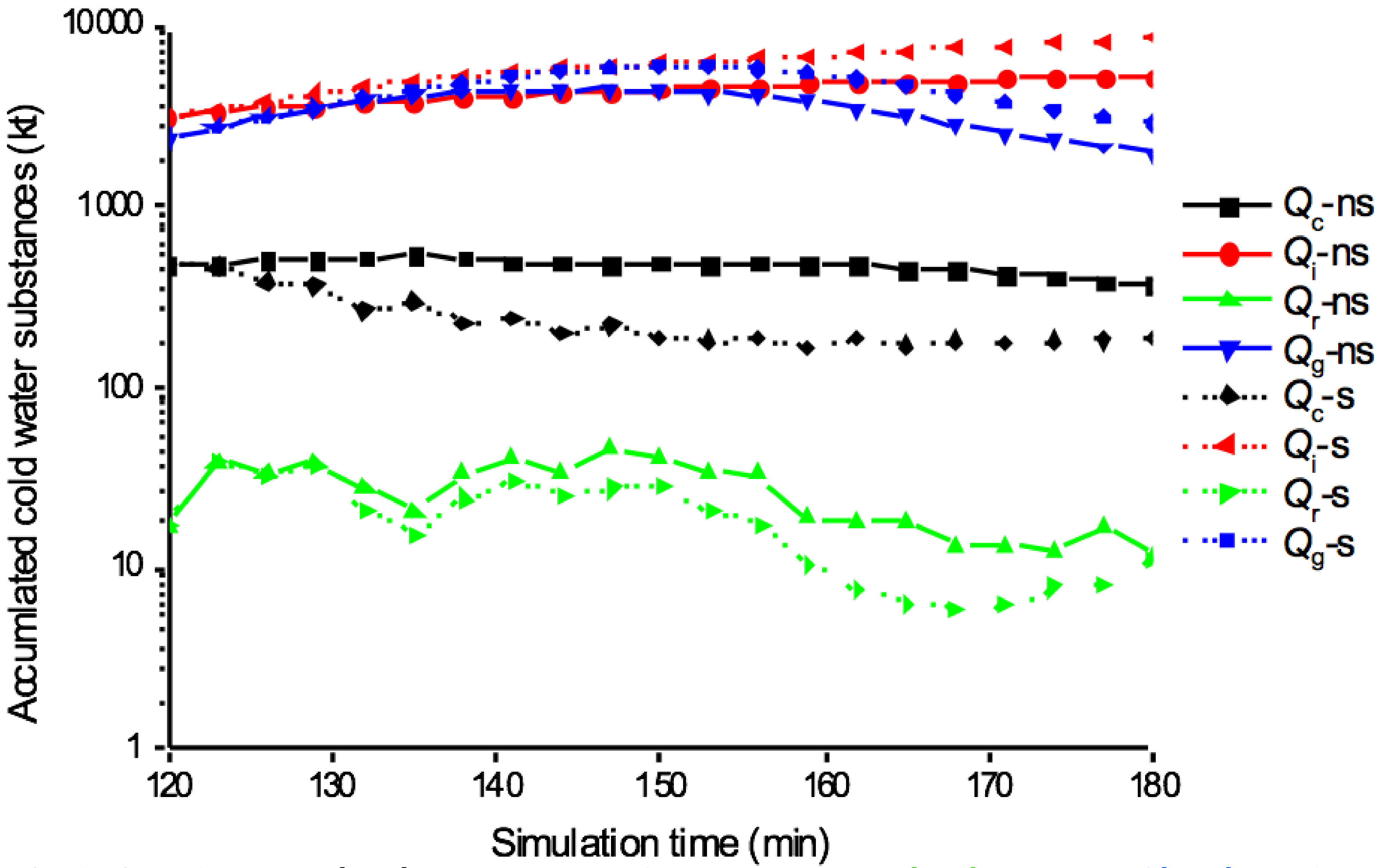


Vertical distribution of Naer and Naim、total water substance （g/kg） and wind vector in 120（a）、150（b）and 180 min（c）

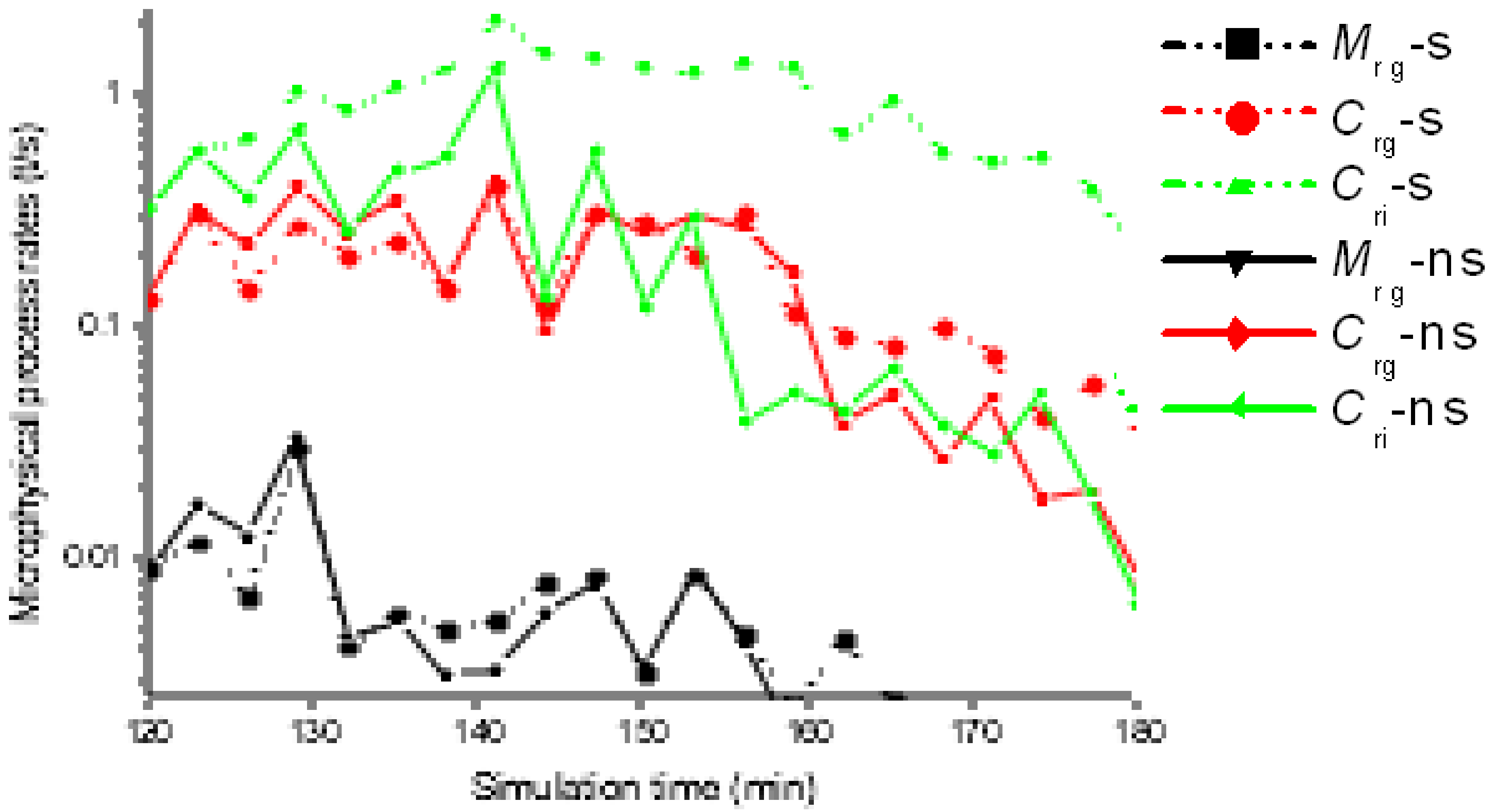


The condensation freezing and immersion freezing are the dominant nucleation modes in this convective cloud.

Four nucleation modes with time（s^{-1}）.a. F_{ctf}, b. F_{dep}, c. F_{imf}, d. F_{cdf} ）



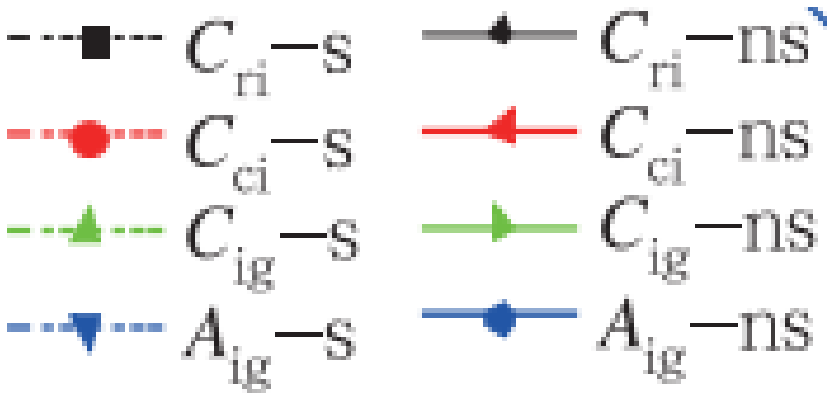
Supercooled cloud water(Qc)、supercooled rainwater(Qr), graupel(Qg) and ice(Qi) with time （solid line: unseeded, dotted line: seeded）

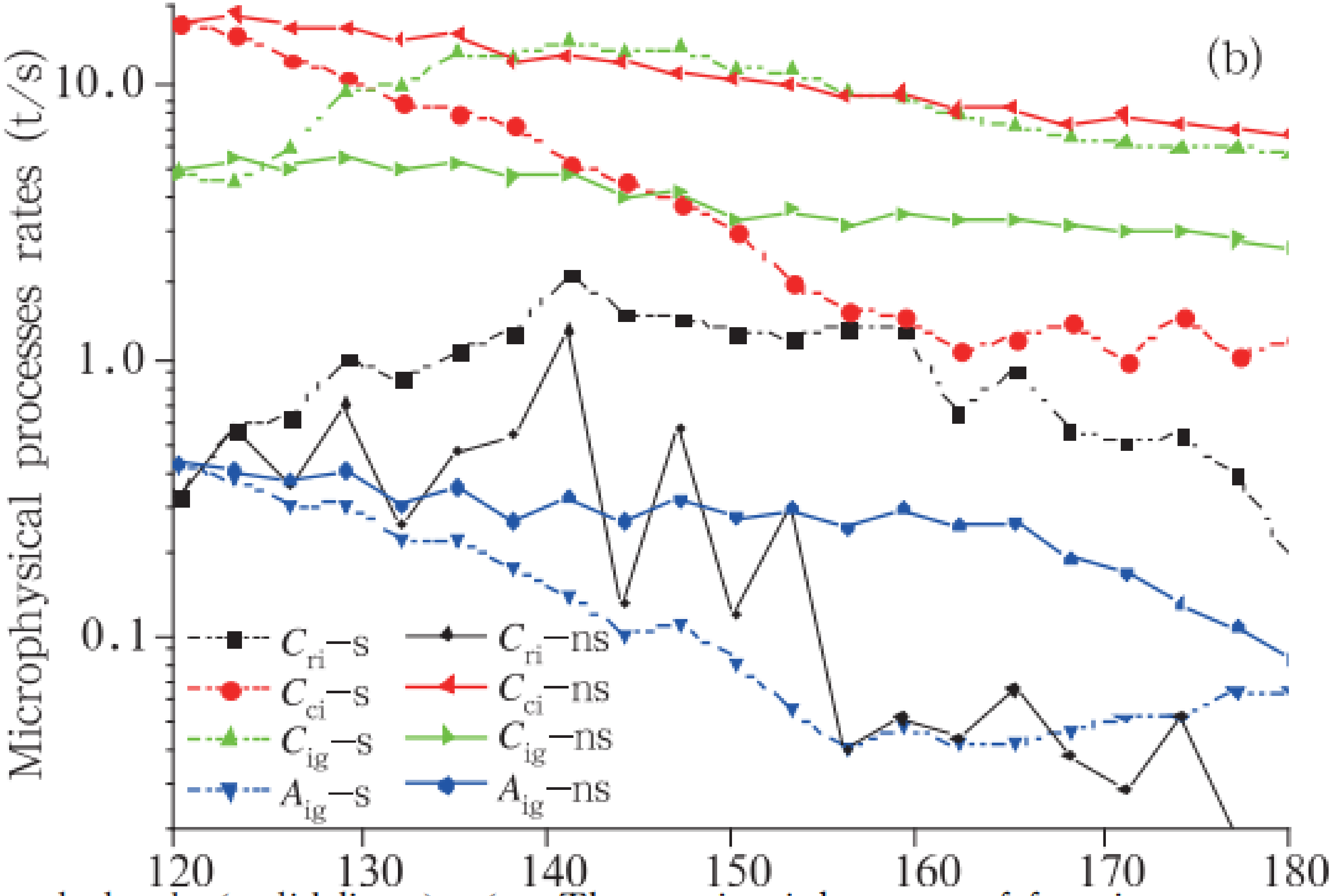


sink terms of supercooled rain water （solid line: unseeded, dotted line: seeded）

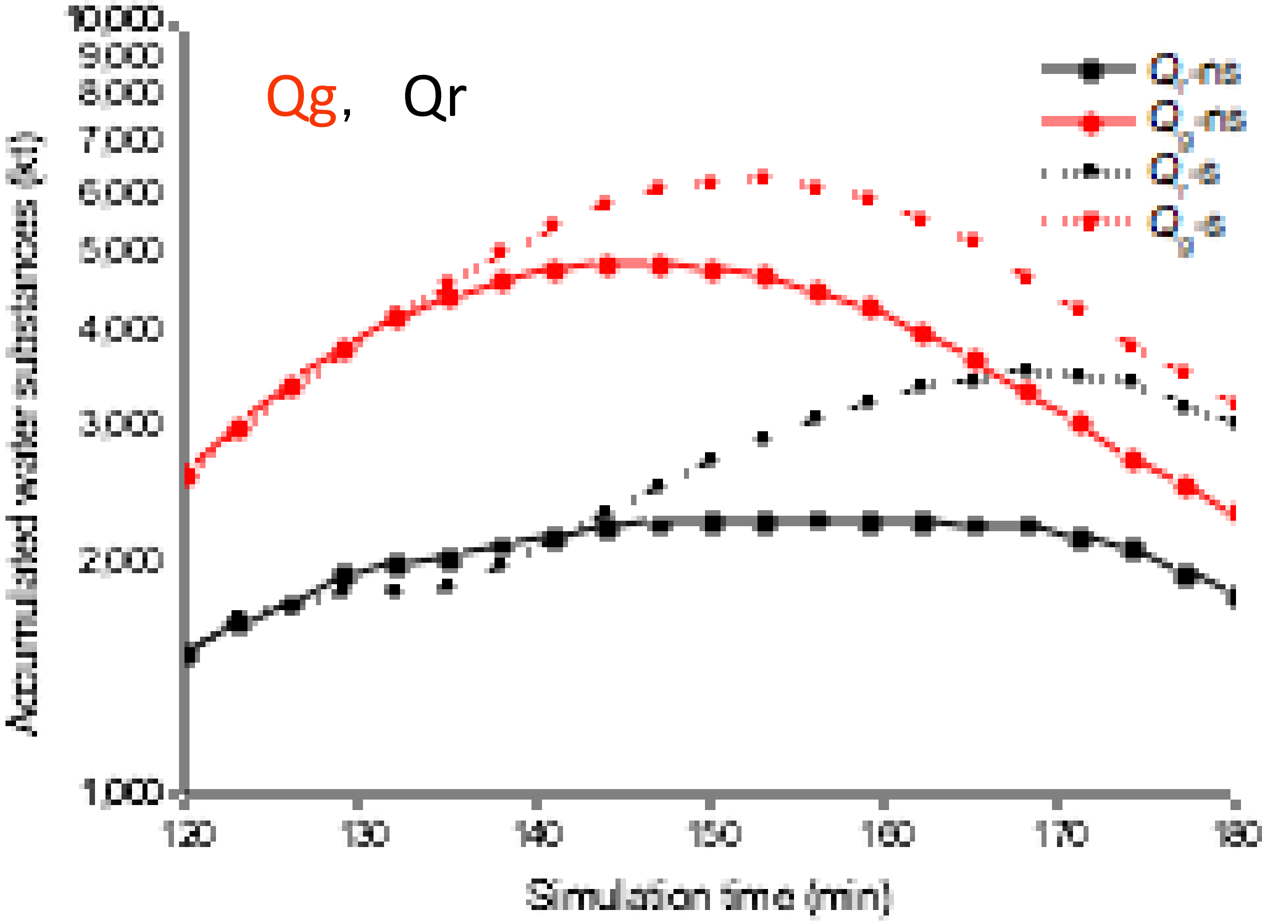
Ice source terms and sink terms in seeded (dot lines) and unseeded (solid lines)

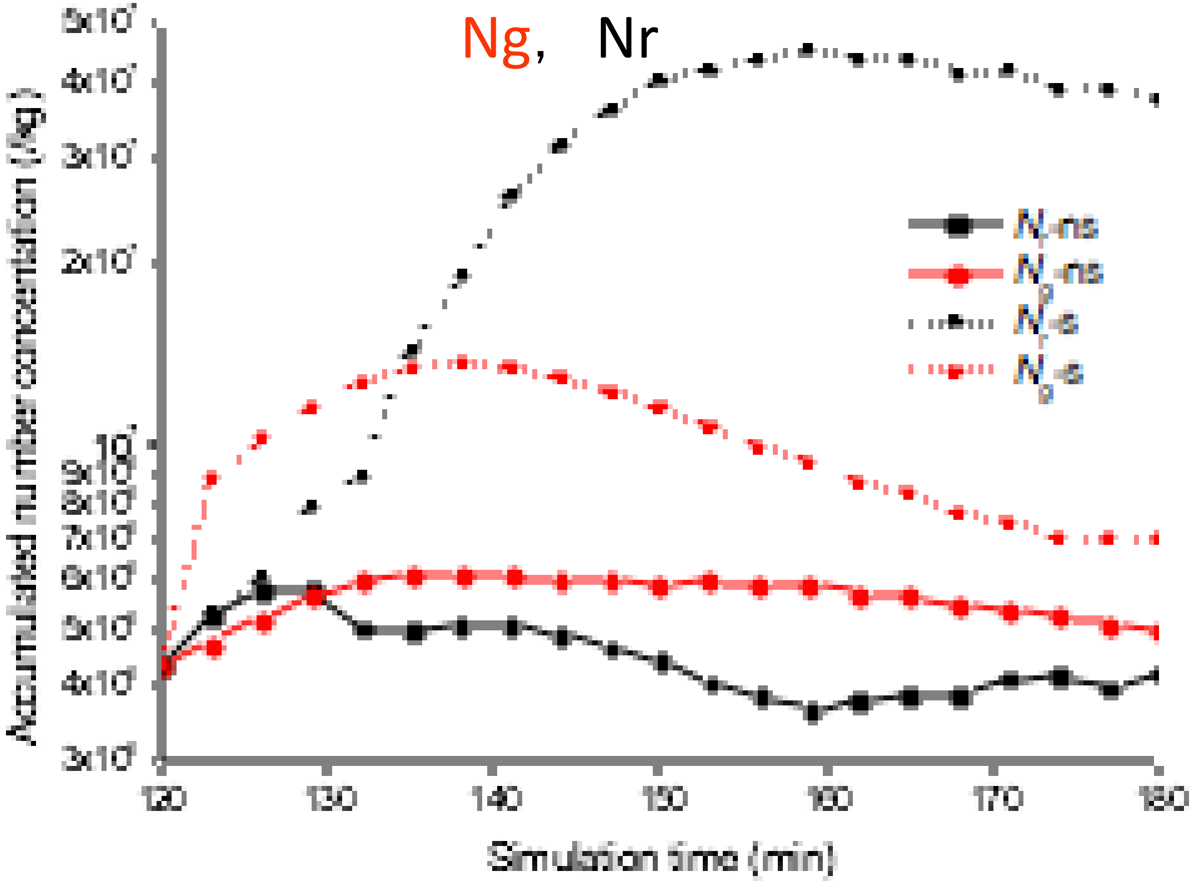
After seeding,
Cci, Aig decreased.
Cig, increased.



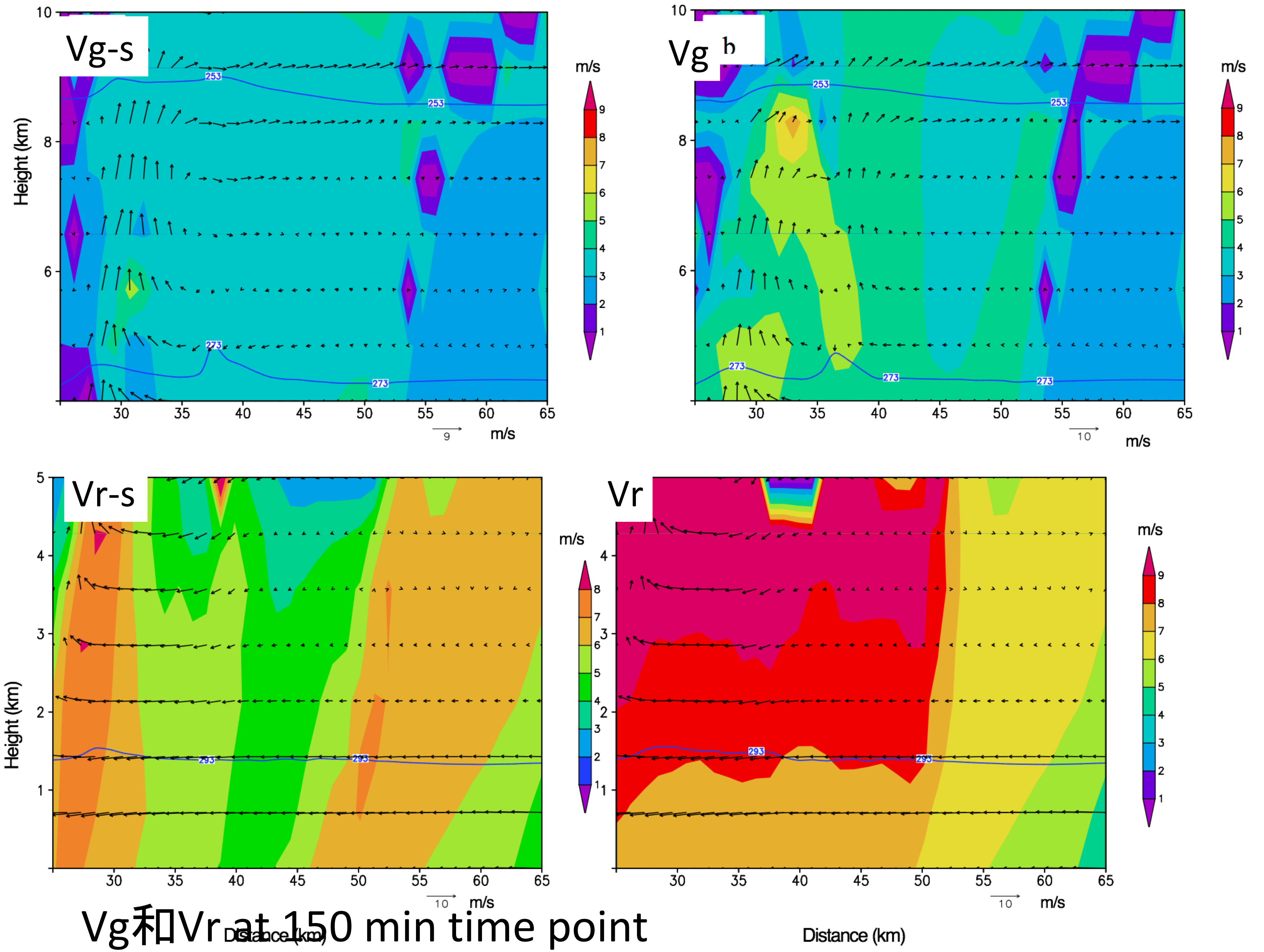


in seeded (dot lines) and natural clouds (solid lines). (a. Three rain sink terms of freezing to grauple M_{rg}, collection by ice C_{ri}, and collection by grauple C_{rg} in cold area; b. ice source terms of collection of cloud C_{ci}, ice sink terms of collection of rain C_{ri}, collection by grauple C_{ig} and autoconversion to graupel A_{ig})

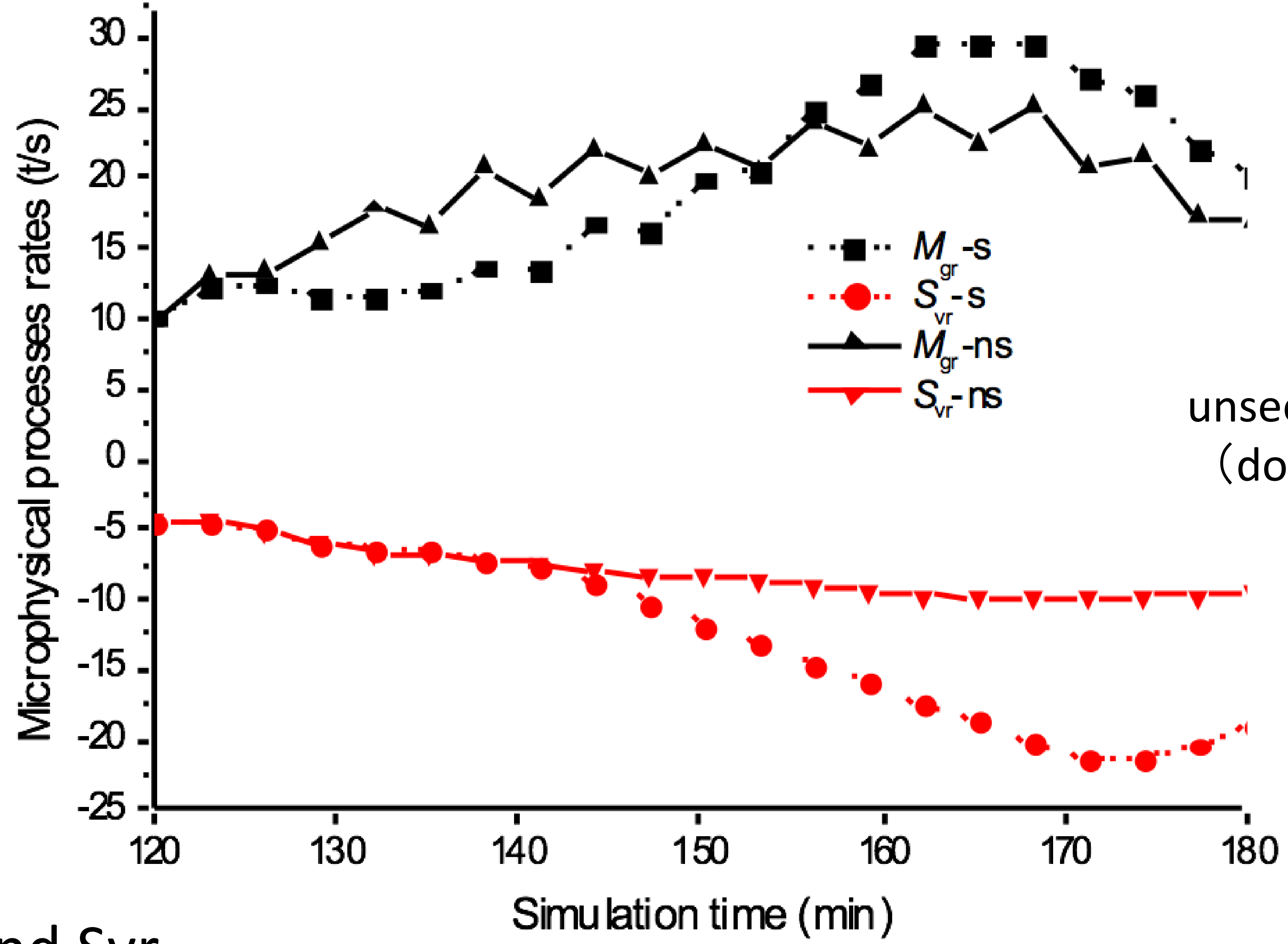




solid line: unseeded
dotted line: seeded



Vg和Vr at 150 min time point

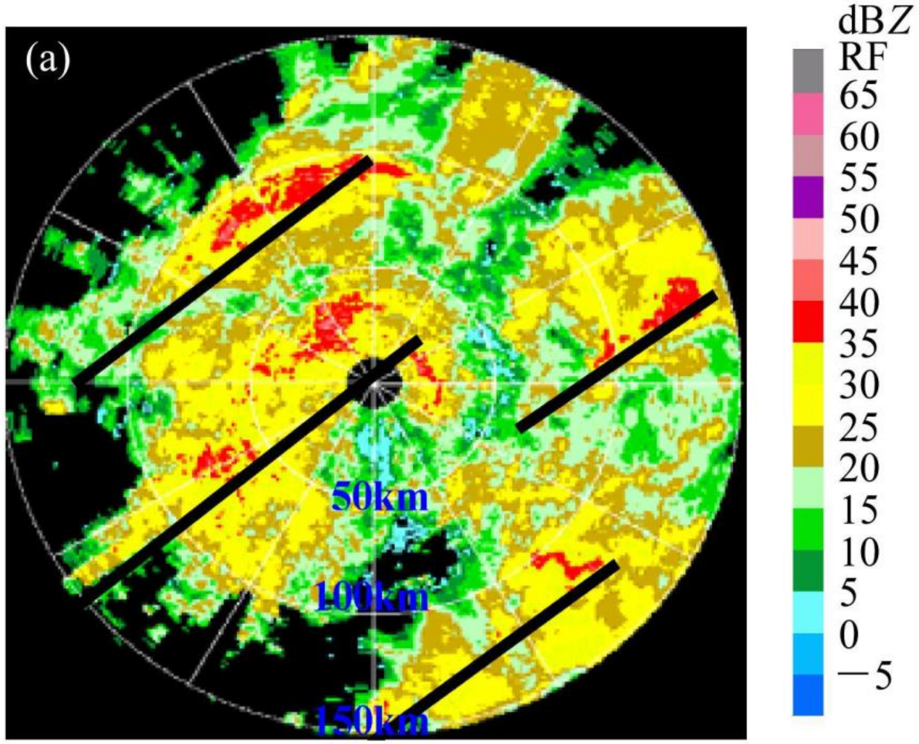


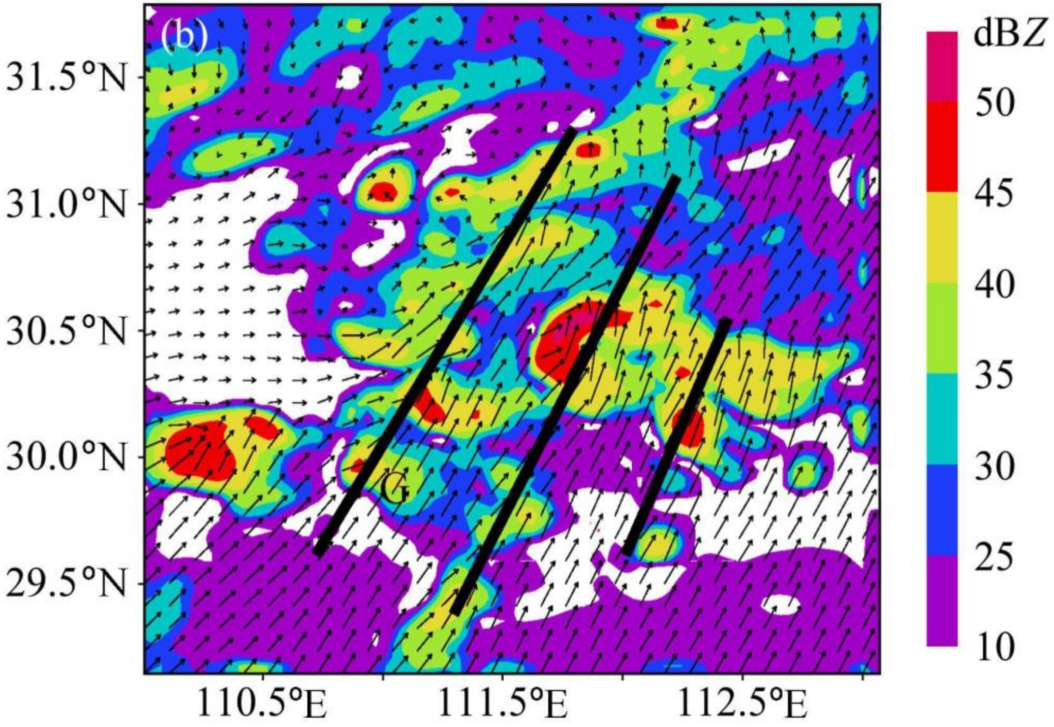
unseed（solid）seeded（dot）

Mgr and Svr

- Overseeding in updraft area with supercooled water can not only reduce the amount of rainfall, but also reduce the maximum rainfall strength. With large seeding concentration, rainfall amount can be decreased up to 32%, which greatly lowers the possibility of causing flood.
- After seeding, the falling speed of graupel and raindrops become weaker.
- The decrease of melting amount of graupel to rain in seeding cloud causes the decrease of rain amount, but later the much more rain evaporation causes less rainfall.
- The condensation freezing and immersion freezing are the dominant nucleation modes in this convective cloud.

2. MM5_CAMS seeding with artificial ice crystals to reduce Meiyu heavy storm （2002 年7 月22 ～ 23 ）





148mm in 24 h

Numerical experiments of adding ice crystals are conducted to study if there is any possibility to decrease the heavy rainfall.

表 1　不同催化试验的参数设置

Table 1　Parameters of different seeding tests

Case	seeding times	seeding height	seeding T	time to seed	seeding rate	cloud stage
1	单次播撒	5	−1～−4	21:20	10^3	Early 初生期
2	单次播撒	5.8	−6～−8	21:30	10^3	发展期
3	单次播撒	6.5	−8～−11	22:00	10^3	成熟期
4	单次播撒	6.5	−8～−11	22:00	10^4	成熟期
5	单次播撒	6.5	−8～−11	22:00	10^2	成熟期
6	10 分钟一次	6.5	−8～−11	21:30—22:00	10^4	Developing 发展期
7	10 分钟一次	6.5	−8～−11	22:00—22:30	10^4	成熟期
T8 8	10 分钟一次	6.5	−8～−11	22:00—23:50	10^4	mature 成熟期
9	10 分钟一次	6.5	−8～−11	22:00—23:50	10^3	成熟期
10	10 分钟一次	6.5	−8～−11	22:00—23:50	10^2	成熟期

In mature stage, seeding repeatedly, better rain reduction result.

one time seeding

11 times seeding

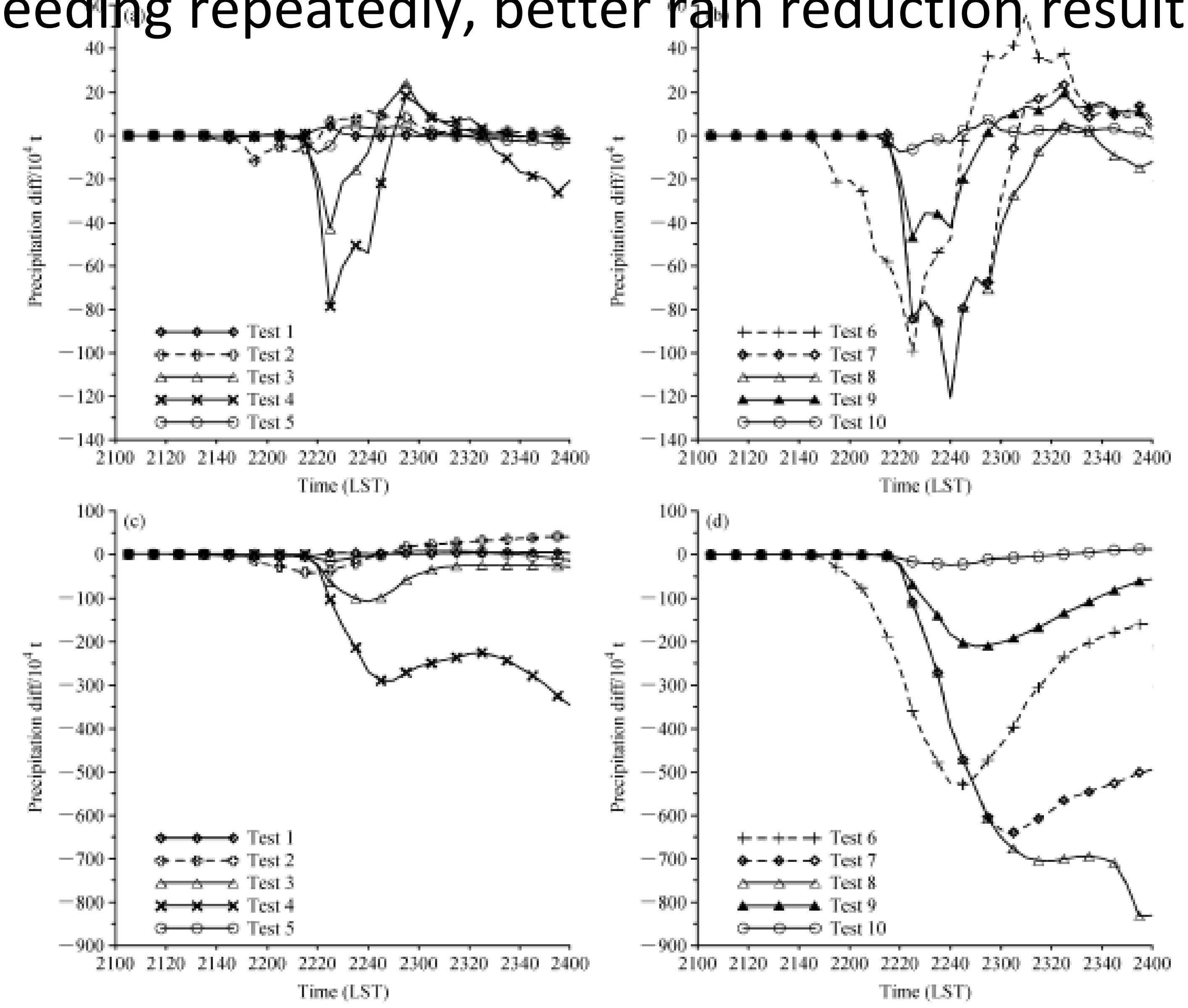


图 3　不同催化试验的区域（29.56°N－30.10°N，110.42°E－111.11°E）5 分钟累积雨量（a，b）和总累积降水量（c，d）减去未催化试验后的雨量变化随时间演变（单位：10^4 t）：（a、c）单次播撒；（b、d）多次播撒

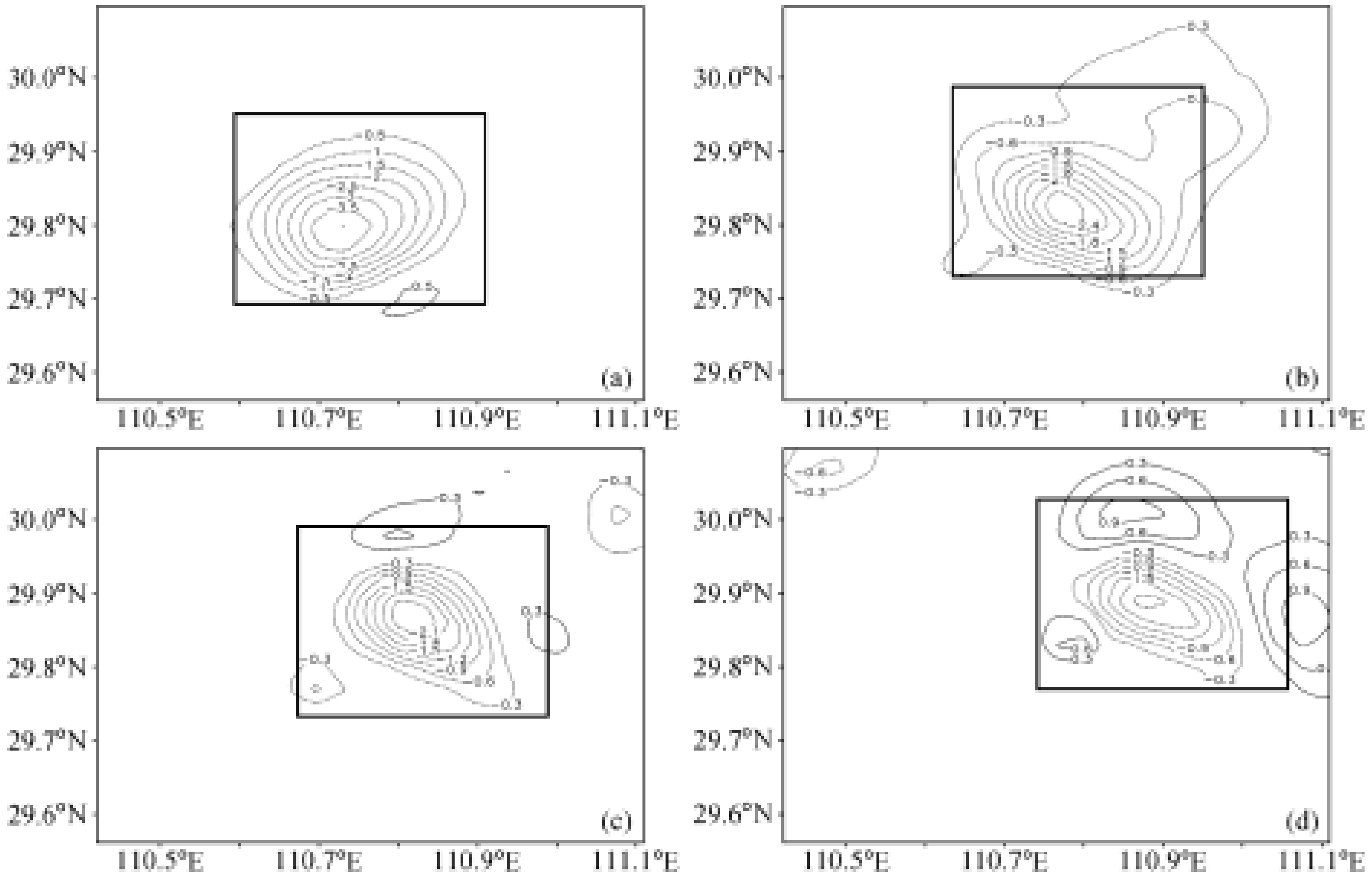


图 4　催化试验 8 的 5 分钟雨量与未催化试验的雨量差（单位：mm）：(a) 22:20；(b) 22:40；(c) 23:00；(d) 23:20。方框：播撒区

Fig. 4　The differences of accumulated 5 minutes precipitation (mm) between seeding test 8 and unseeding test: (a) 2220 LST; (b) 2240 LST; (c) 2300 LST; (d) 2320 LST. The rectangle depicts the seeding area

Unseeded precipitation (180min)　seeded precipitation (180min)　the difference after seeding

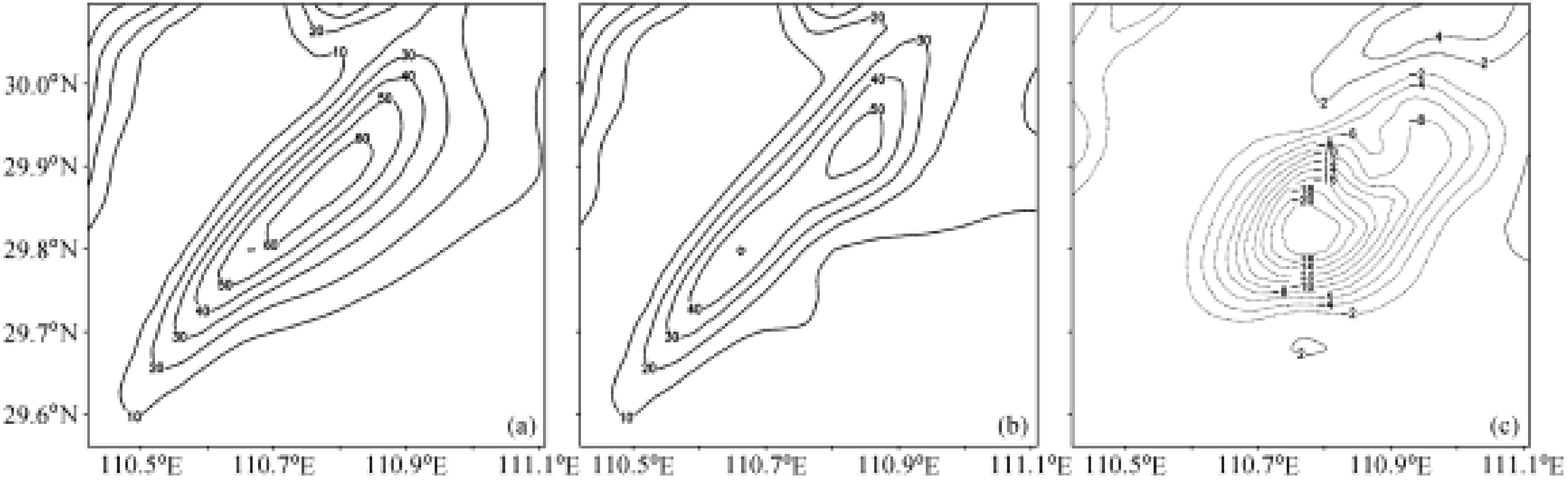


图 5　180 分钟内雨量分布（单位：mm）：(a) 未催化试验；(b) 催化试验 8；(c) 催化试验 8 减去未催化试验

Fig. 5　The accumulated 180 minutes precipitation (mm): (a) Unseeding test; (b) seeding test 8; (c) the difference between seeding test 8 and unseeding test

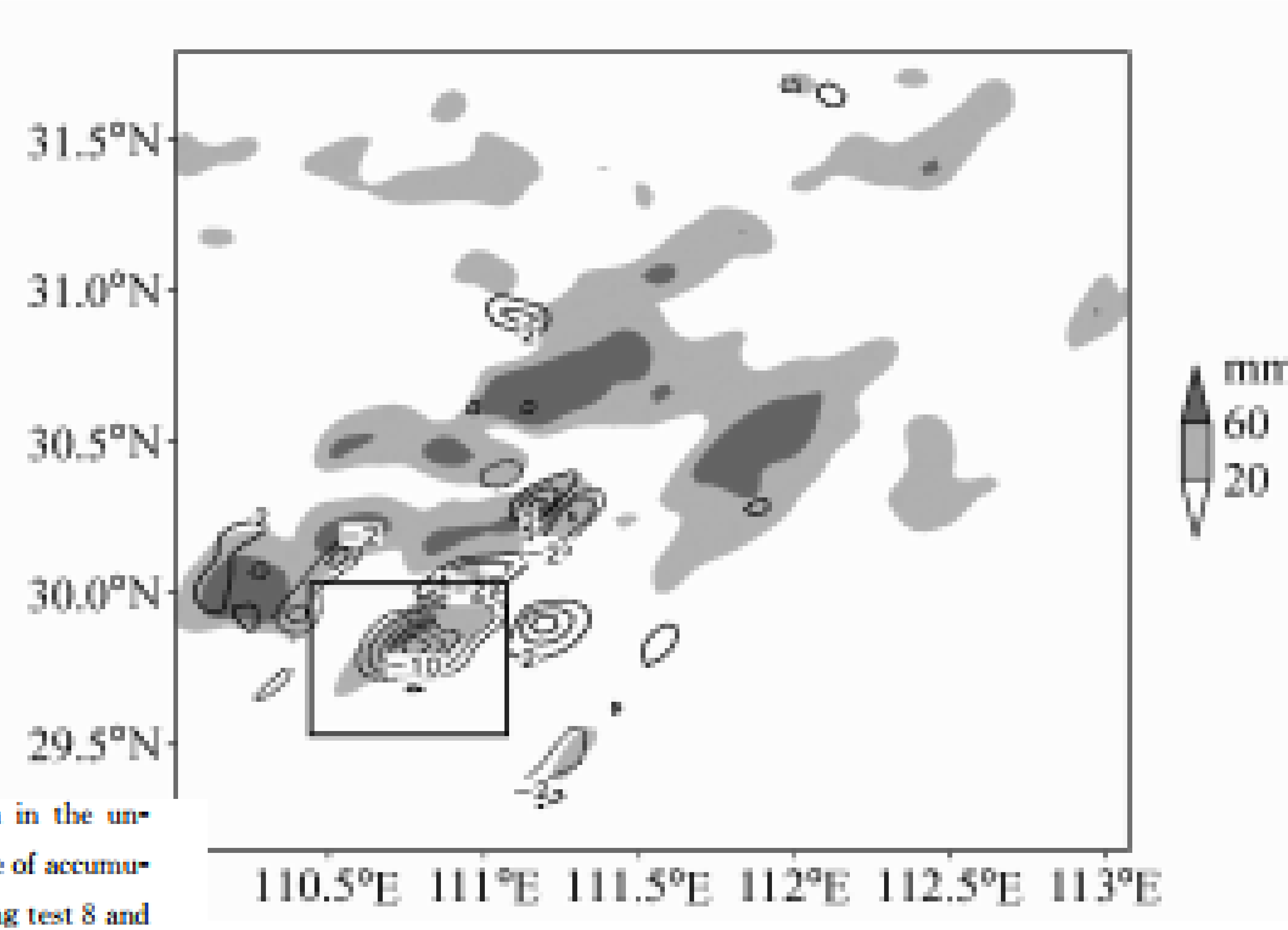


Fig. 6 The accumulated 180 minutes precipitation in the unseeding test for domain 3 (shaded) and the difference of accumulated 180 minutes precipitation (mm) between seeding test 8 and unseeding test (solid lines depict positive values, dashed lines depict negative values). The rectangle depicts the effect area of seeded echo G

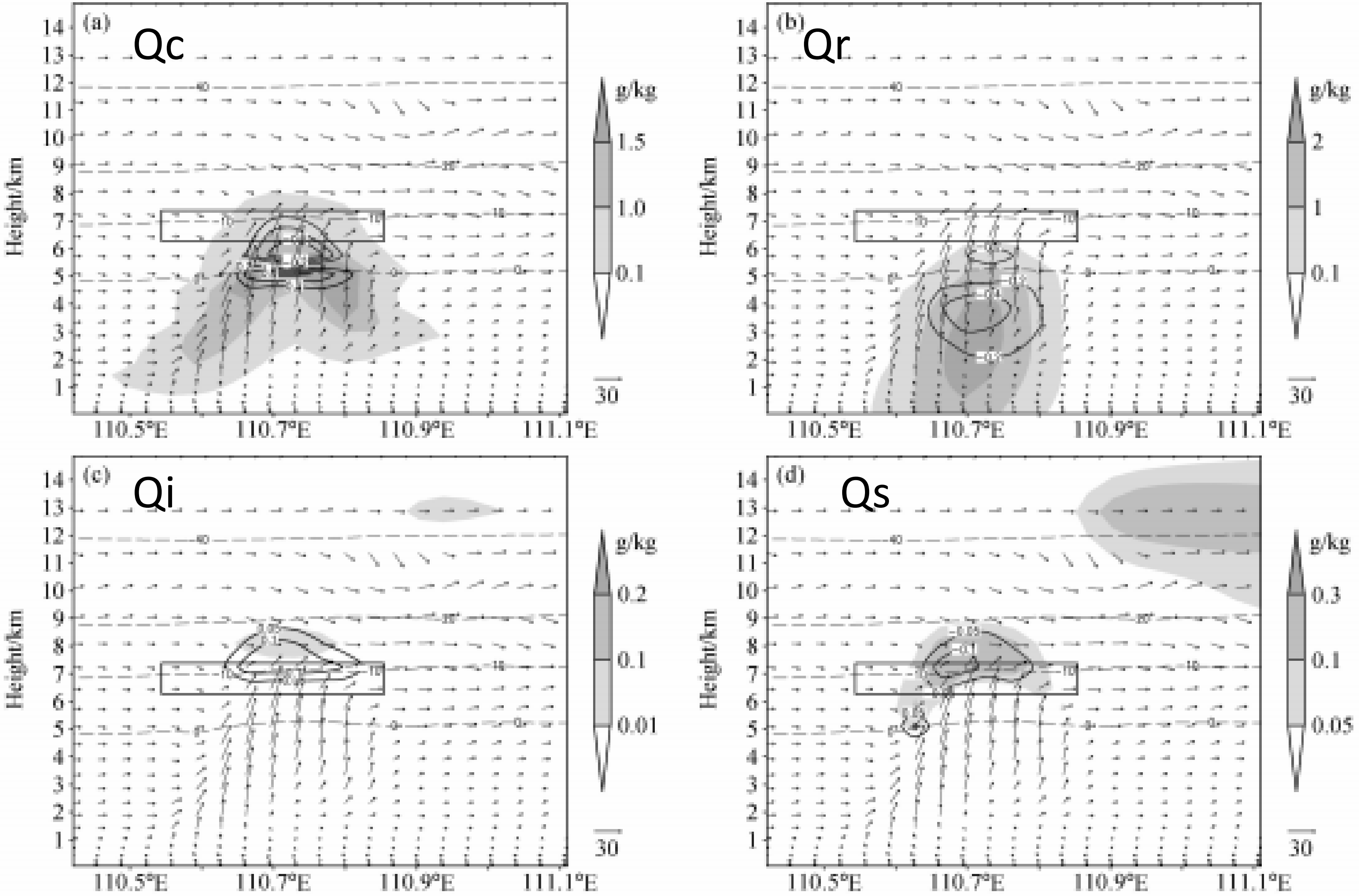


Fig. 7 The cross sections of physical quantities in unseeding test (shaded) and the differences between seeding test 8 and unseeding test (isolines) along 29. 82°N at 2205 LST 22 Jul 2002; Mass content of (a) cloud water, (b) rain water, (c) ice, (d) snow, (e) graupel; (f) vertical velocity (m/s); (g) temperature (℃). The rectangle depicts the seeding area at 2200 LST, the dashed lines depict 0℃, −10℃, −20℃, −40℃ isotherms in unseeding test, the arrows depict the synthesis of zonal wind (u) and vertical motion (w×10) in unseeding test

V and R at decreased rainfall cener

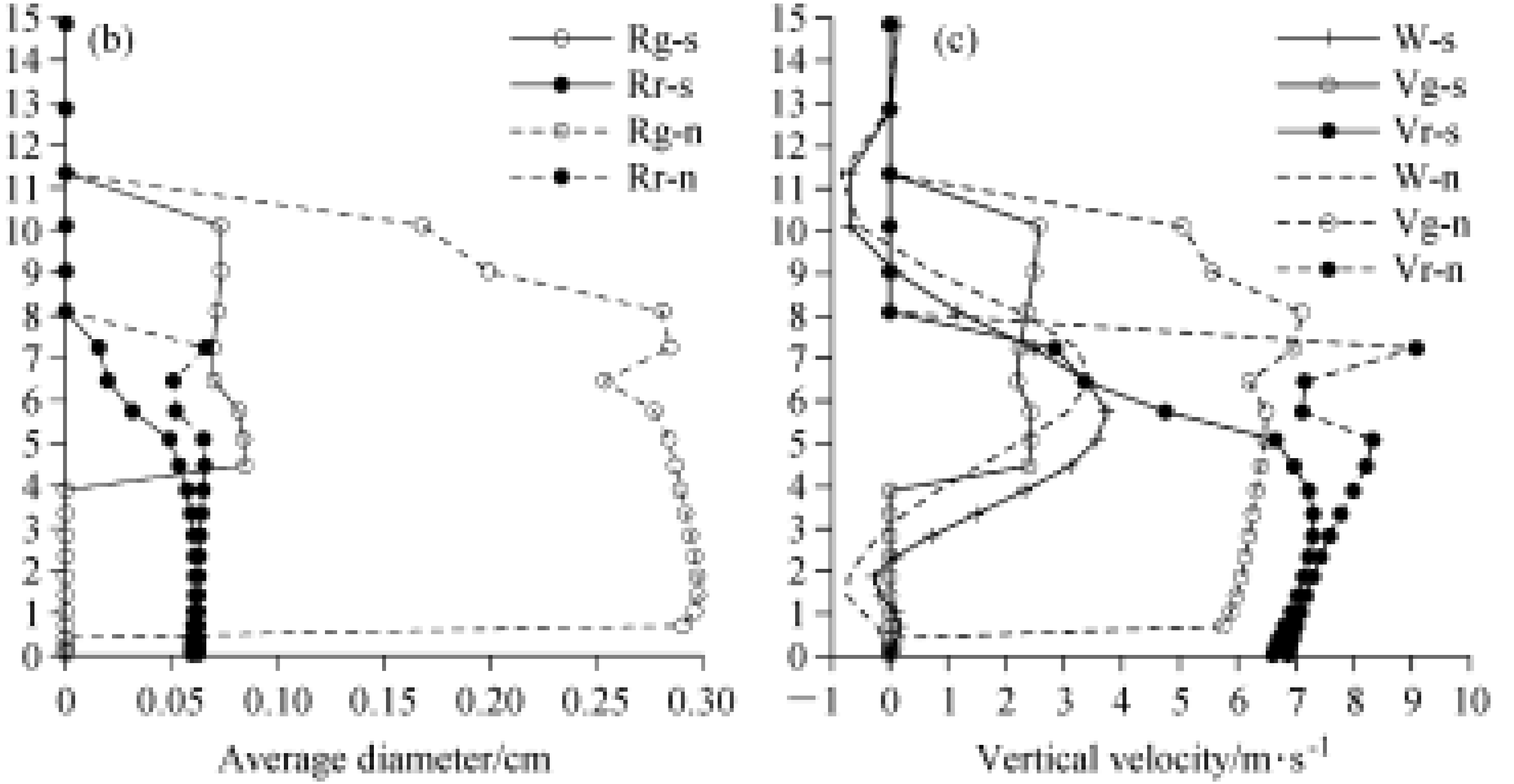


Fig. 11 The vertical profiles of physical quantities in unseeding test (n, dashed line) and seeding test 8 (s, solid line) at decreased rainfall center (29.85°N, 110.8°E) at 2300 LST 22 Jul 2002; (a) Conversion rates of rain water sources, Ccr: collection of cloud water by rain water, Ccg: collection of cloud water by graupel in the warm region, Mgr: the melting of graupel; (b) the averaged diameters of graupel (Rg) and rain water (Rr); (c) vertical velocity (W) and the fall speed of graupel (Vg) and rain water (Vr)

V and R at increased rainfall cener

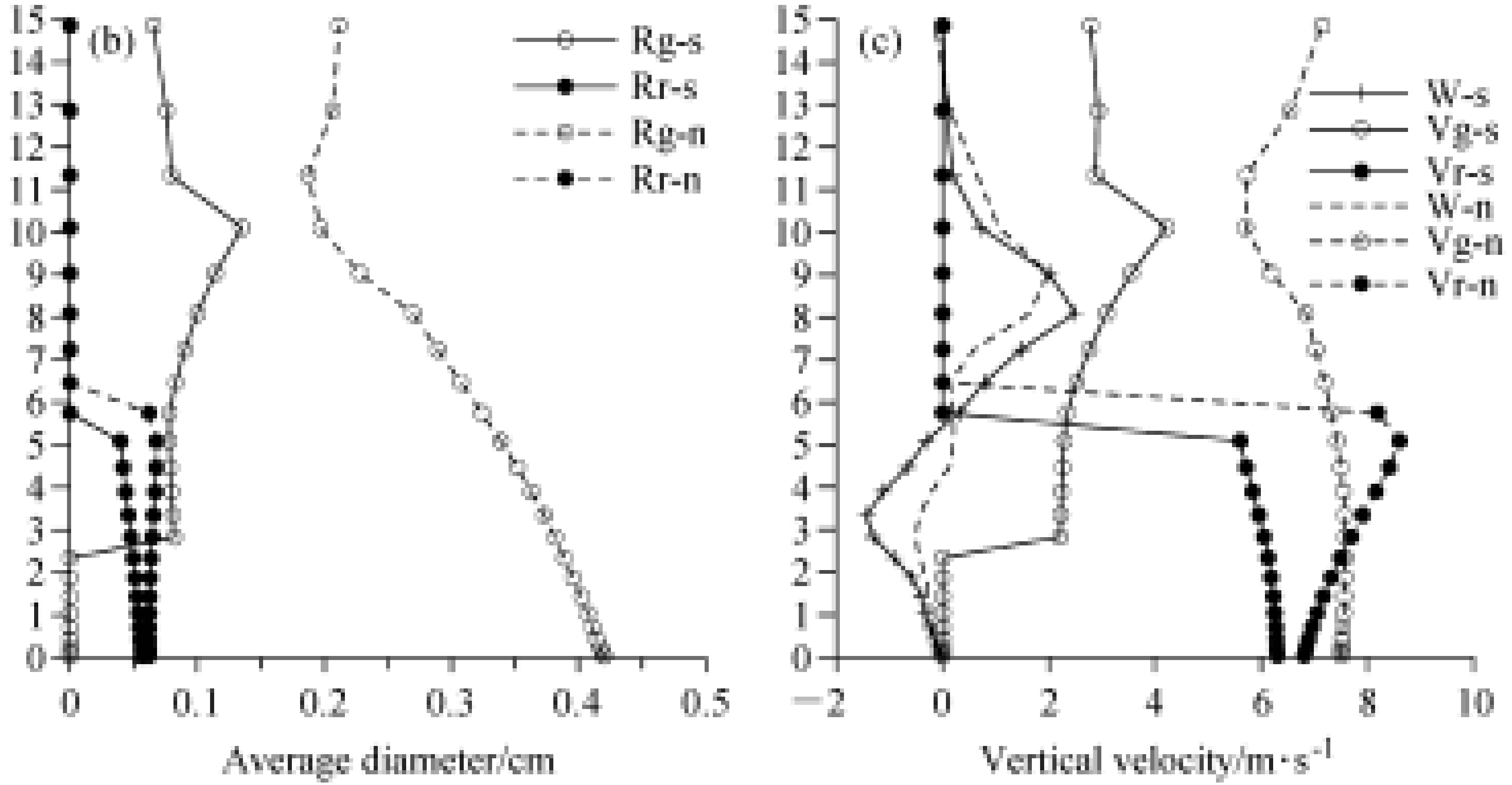


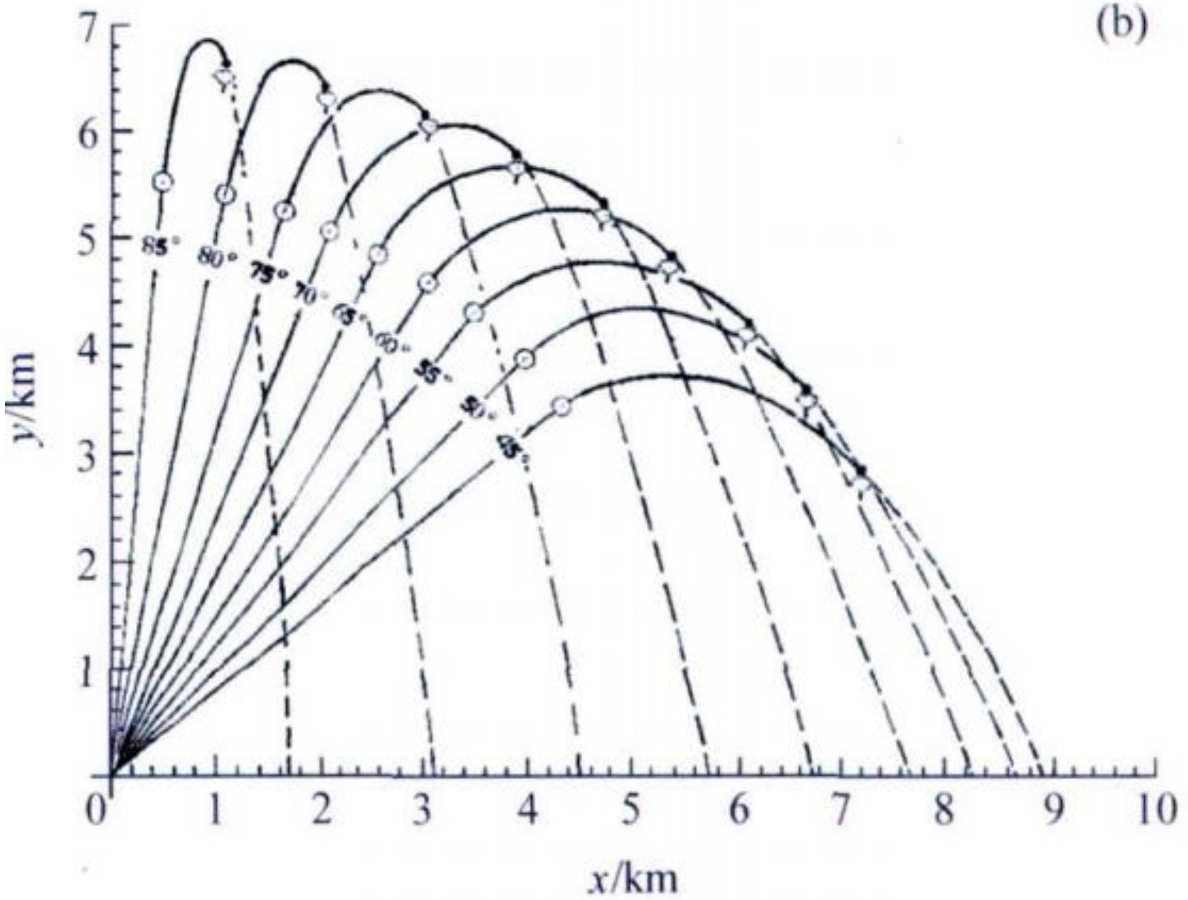
Fig. 12 Same as Fig. 11, but for the increased rainfall center (29. 85°N, 110. 97°E). (a) Msr: the melting of snow, Mgr: the melting of graupel

Overseeding with ice crystals, weakens the falling speed of gruapel, then reduce the melting to rain water.

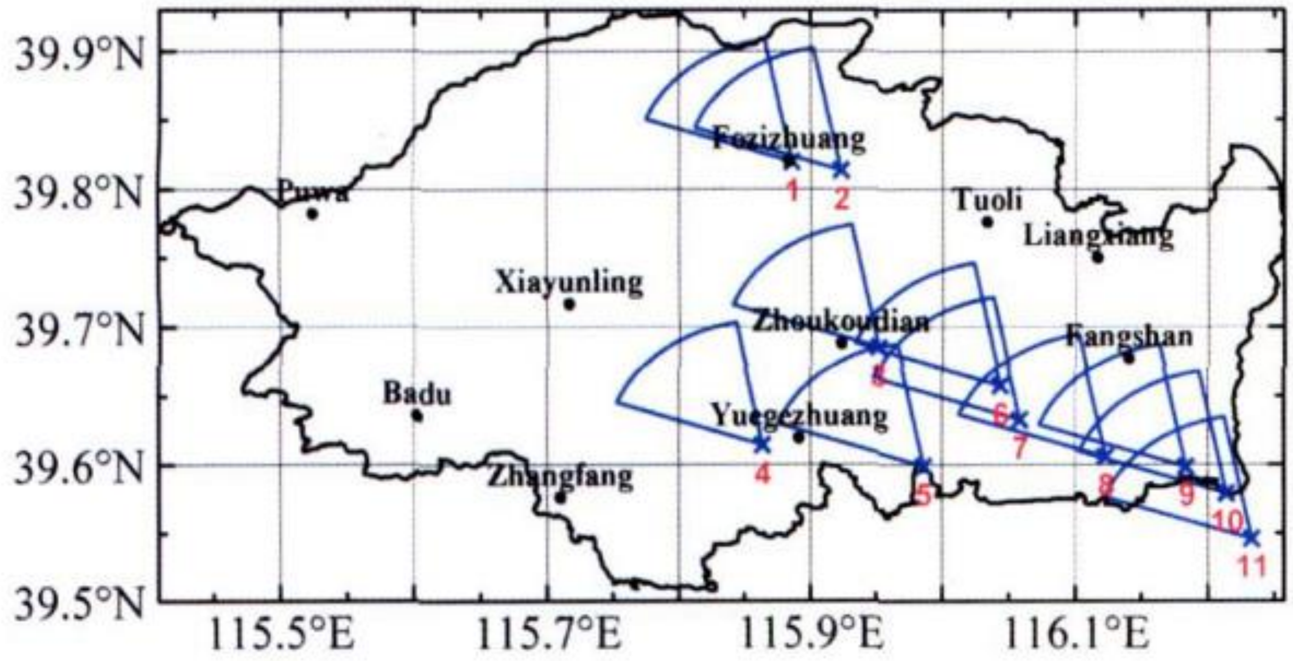
3. 2008 Beijing Olympic games

- Weather modification office of Beijing carried out cloud seeding operations by firing rockets to mitigate or suppress precipitation.

Ground based rocket launcher



(b) the trajectory curves for different shooting elevations



Seeding time: 20: 53~ 22: 45, this defense line shooted 435 rocket shells.

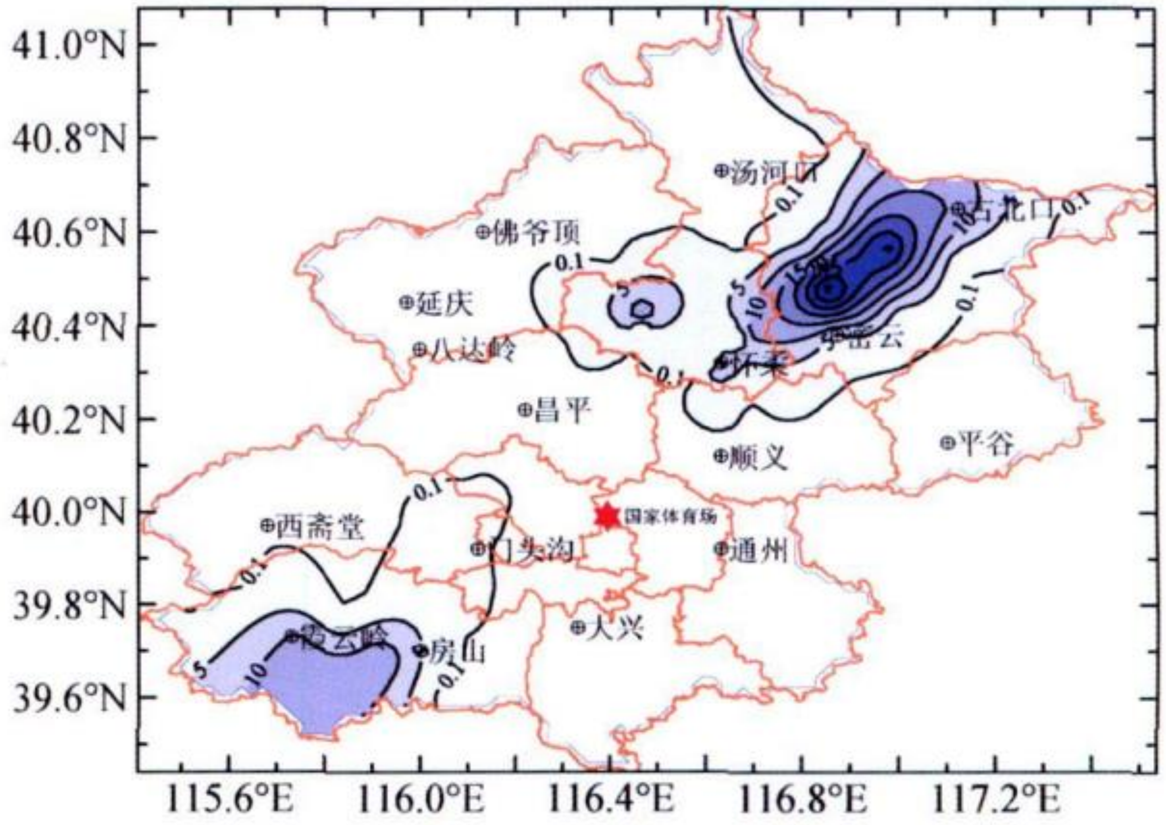
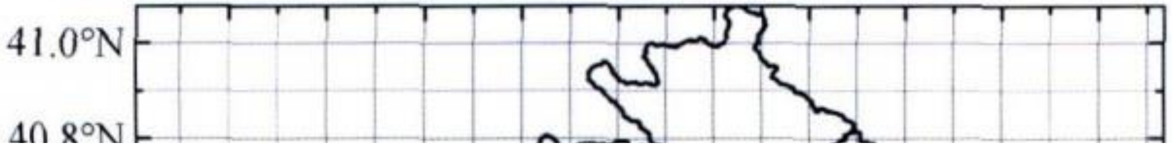


图 4 2008 年 8 月 8 日 18 时~ 8 月 9 日 00 时地面 6 小时累积降水量分布 (单位: mm)

Fig 4 Distribution of the 6-hour rainfall (mm) from 1800 LST 8 Aug to 0000 LST 9 Aug 2008



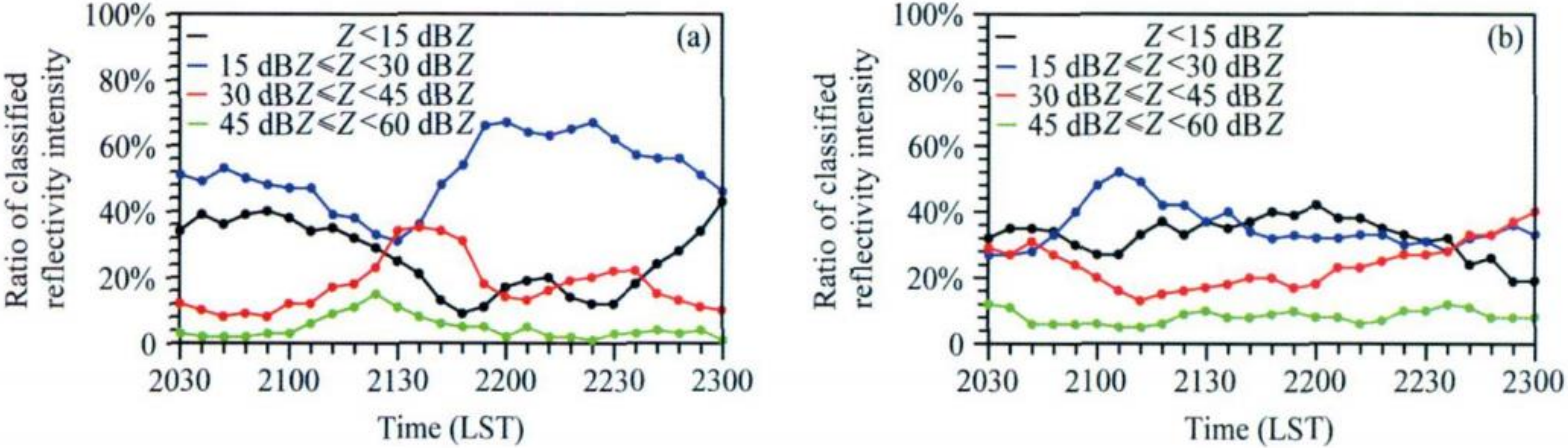


图 12　2008 年 8 月 8 日 20：30～23：00（a）目标区和（b）控制区内雷达反射率分级强度统计随时间变化

Fig. 12　Ratios of classified radar reflectivity intensity in the (a) target area and (b) control area defined in Fig. 9 from 2030 LST to 2300 LST 8 Aug 2008

area CA (blue line), and the operation sites (× shape) in Fangshan district

Rain mitigation simulation , MM5, Reisner + AgI seeding

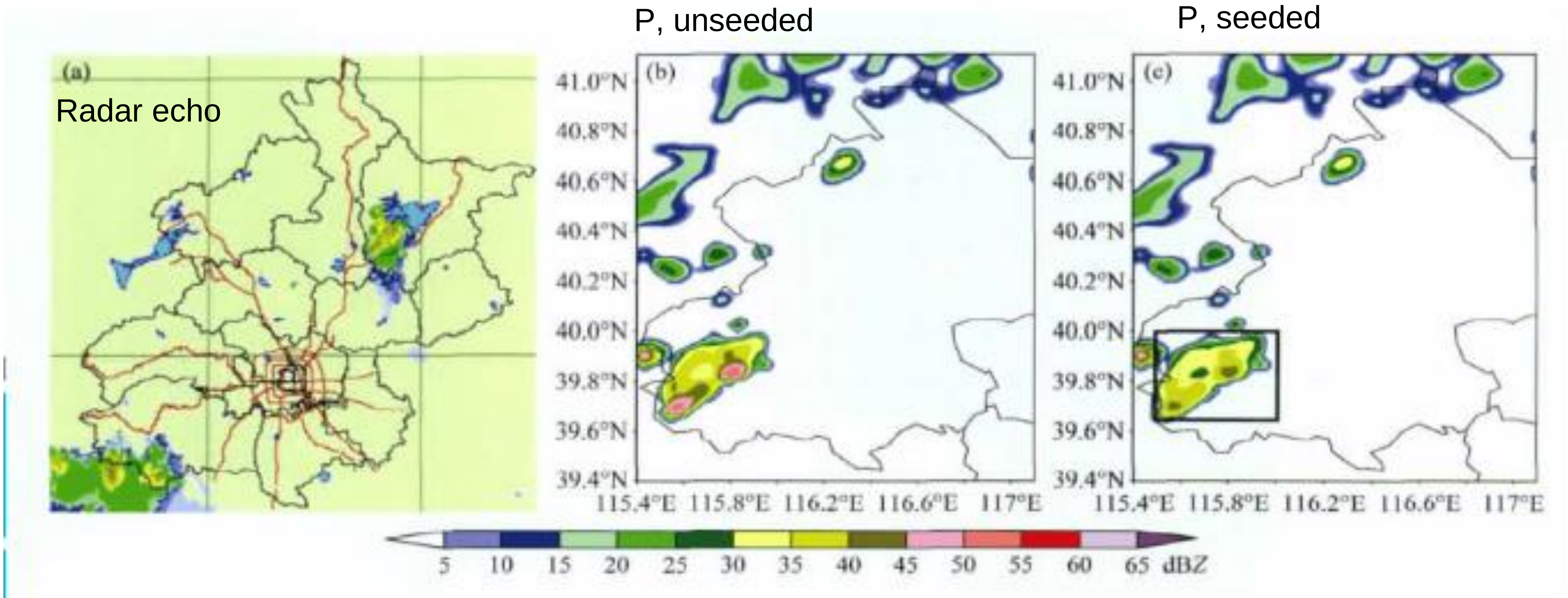


图7 2008年8月8日20:24 6 km高度的雷达回波：(a) 实况；(b) 未催化作业模拟；(c) 播撒作业（5 g·s^{-1}播撒率）催化模拟（方框为模拟的播撒作业区域）

Fig. 7 The radar echo at the height of 6 km at 2024 LST on 8 Aug 2008; (a) Observation; (b) natural model result; (c) seeded model result (5 g·s^{-1} seeding rate) (the rectangle denotes the seeding area)

5g/s, 6000-6500m, 90 rocket shells (25g), 7min

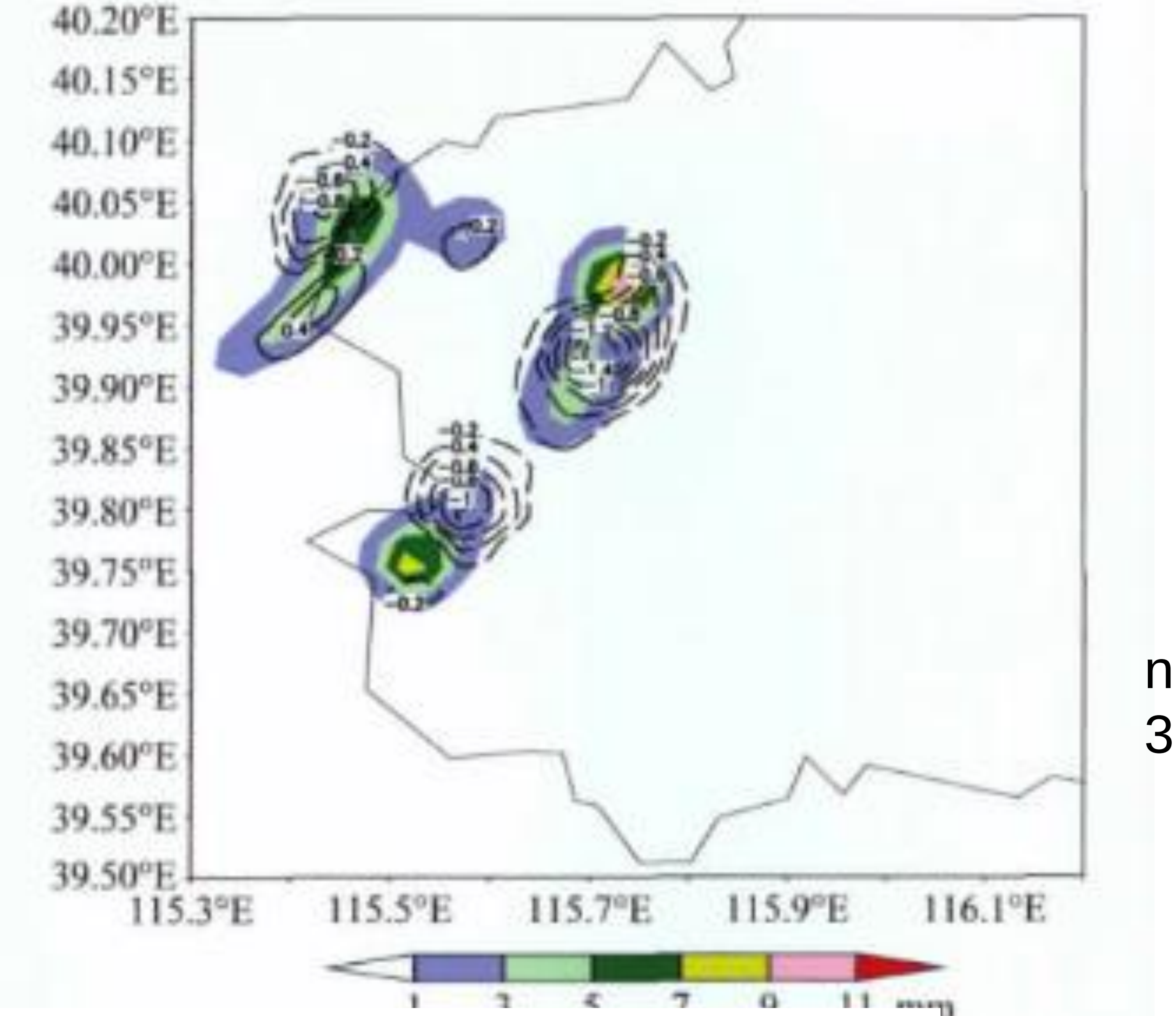


Fig. 8 Net surface rainfall increment in 30 min after seeding (shading: natural rainfall during 6 min; dotted line: decreasing rainfall)

net precipitation increment 30 min after seeding

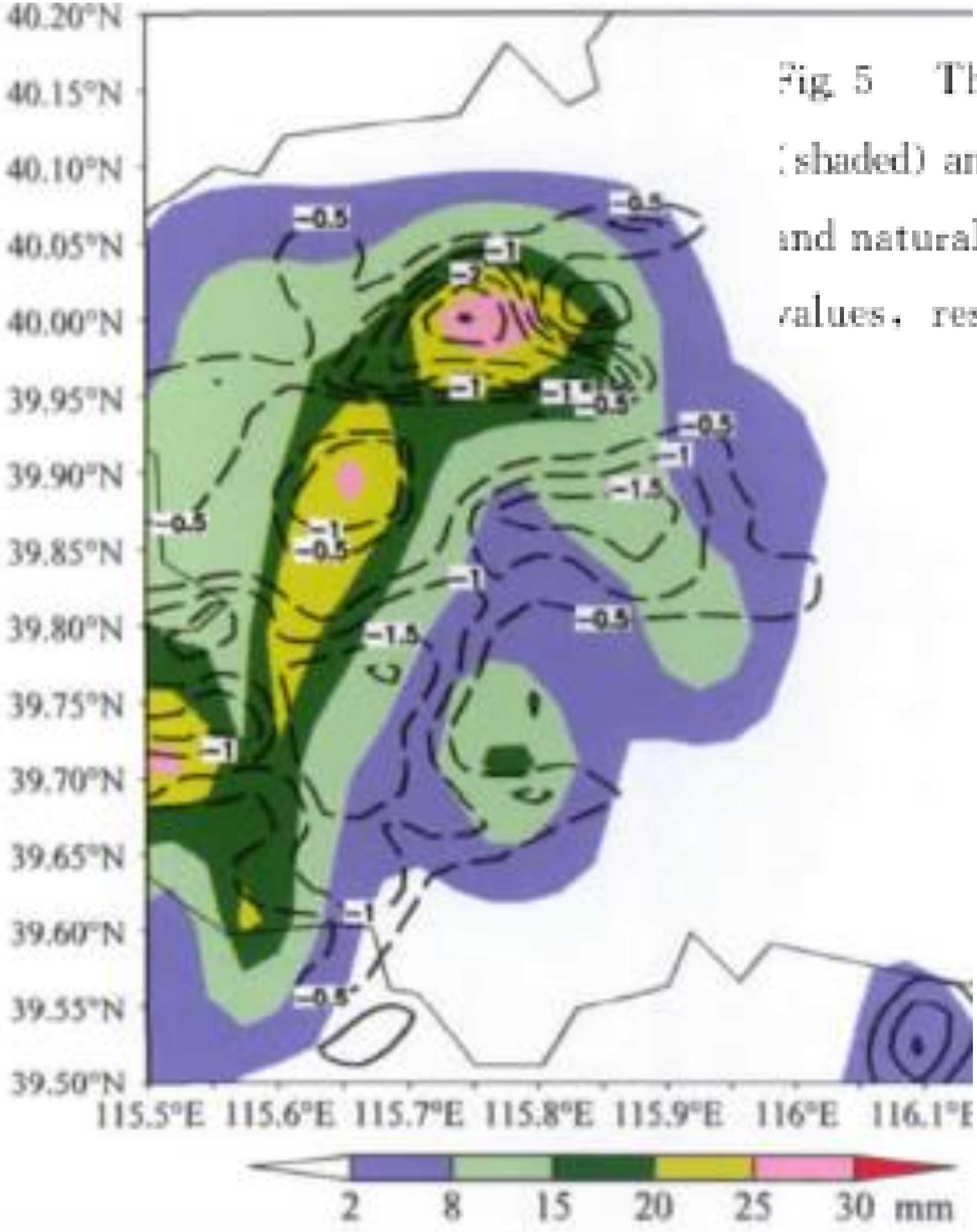


Fig 5 The accumulated 120-min precipitation in the natural test (shaded) and the difference between seeding test (5 g • s^{-1} seeding rate) and natural test (solid and dashed lines denote positive and negative values, respectively)

net precipitation increment
120 min after seeding

8-12% decreased precipitation

net P (kt)

net P (%)

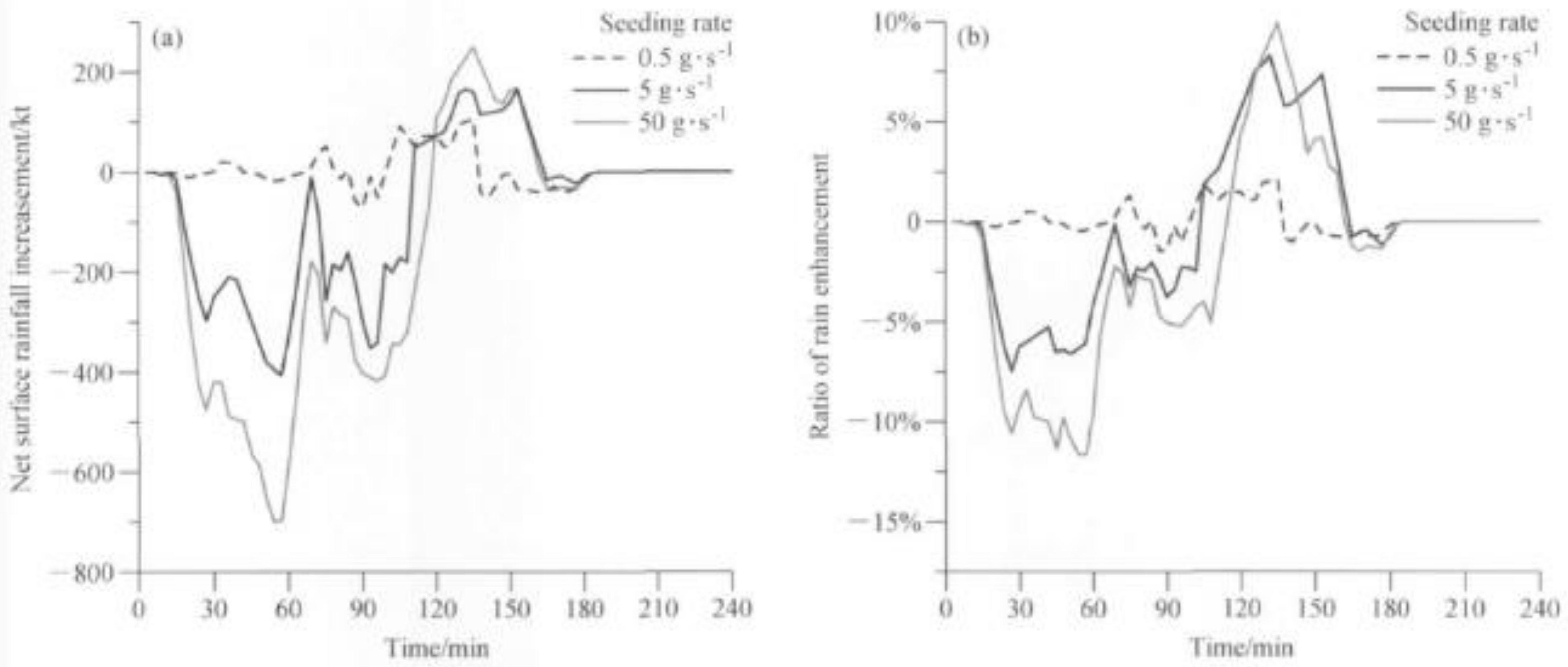
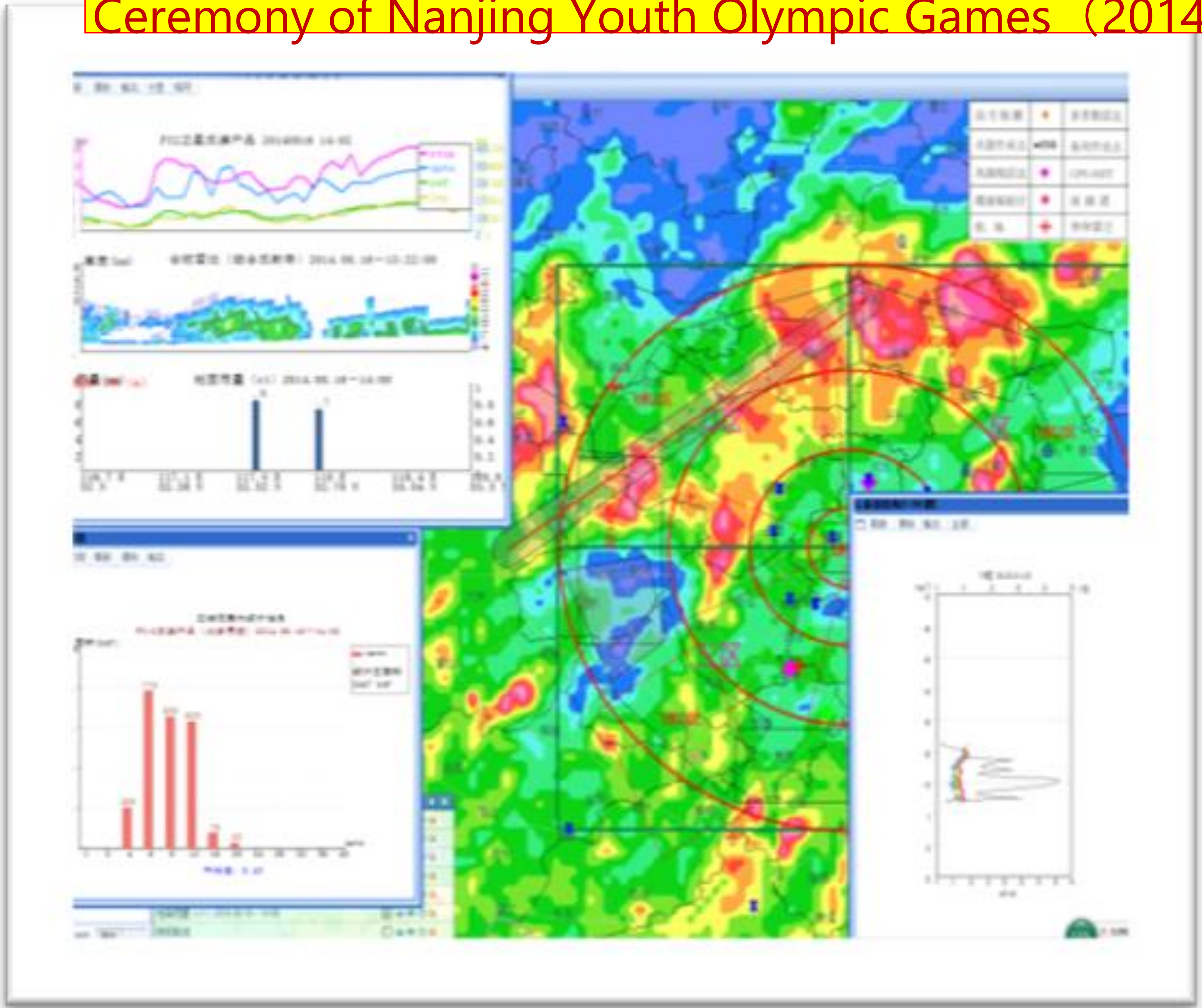


图 不同催化试验选择区域内（a）地面净增雨量总和及（b）增雨率

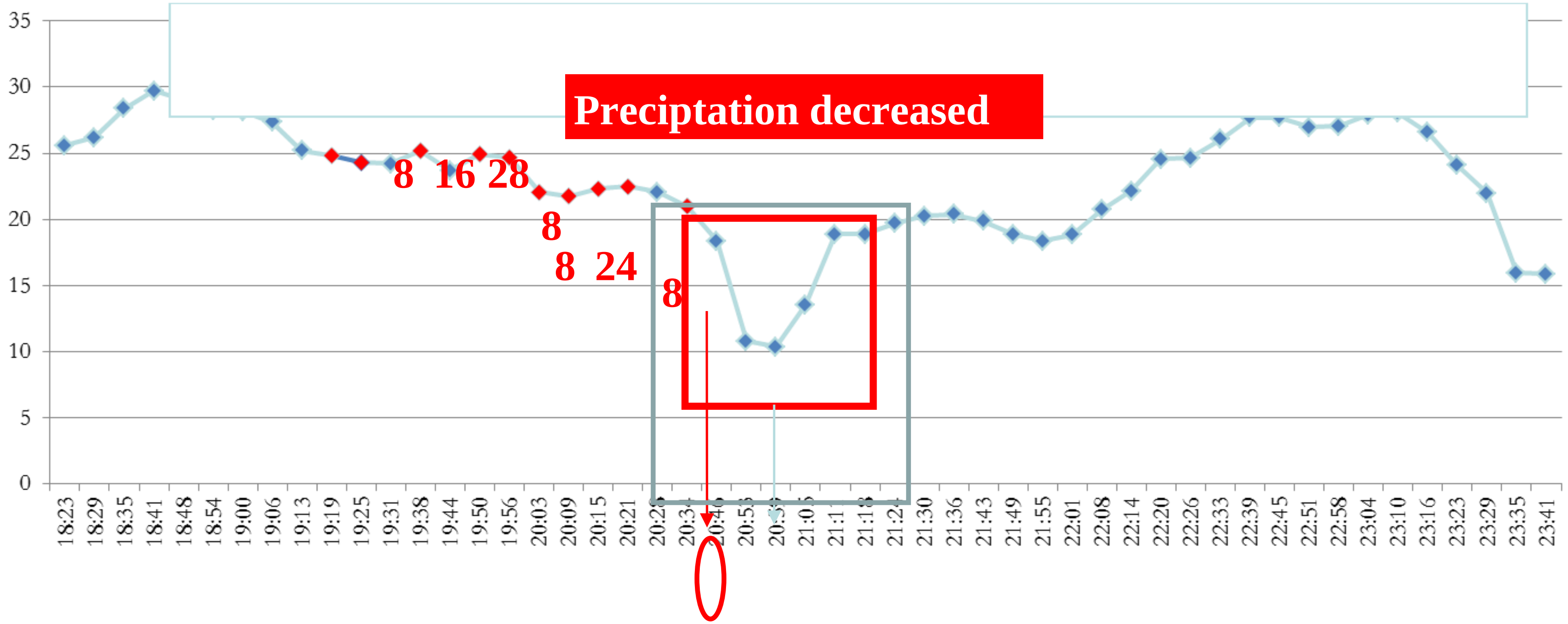
Fig. 4 （a）Accumulated surface rainfall and（b）the enhanced precipitation ratio within the selected area in different seeding experiments

4. Mitigating or Suppressing Precipitation by Cloud Seeding on Opening Ceremony of Nanjing Youth Olympic Games（2014， August 16， Nanjing）



◆**Model predict： cloud structure, moving direction**

Over-seeding by AgI, launching 701 rockets



Around 20:00, the precipitation is weakened

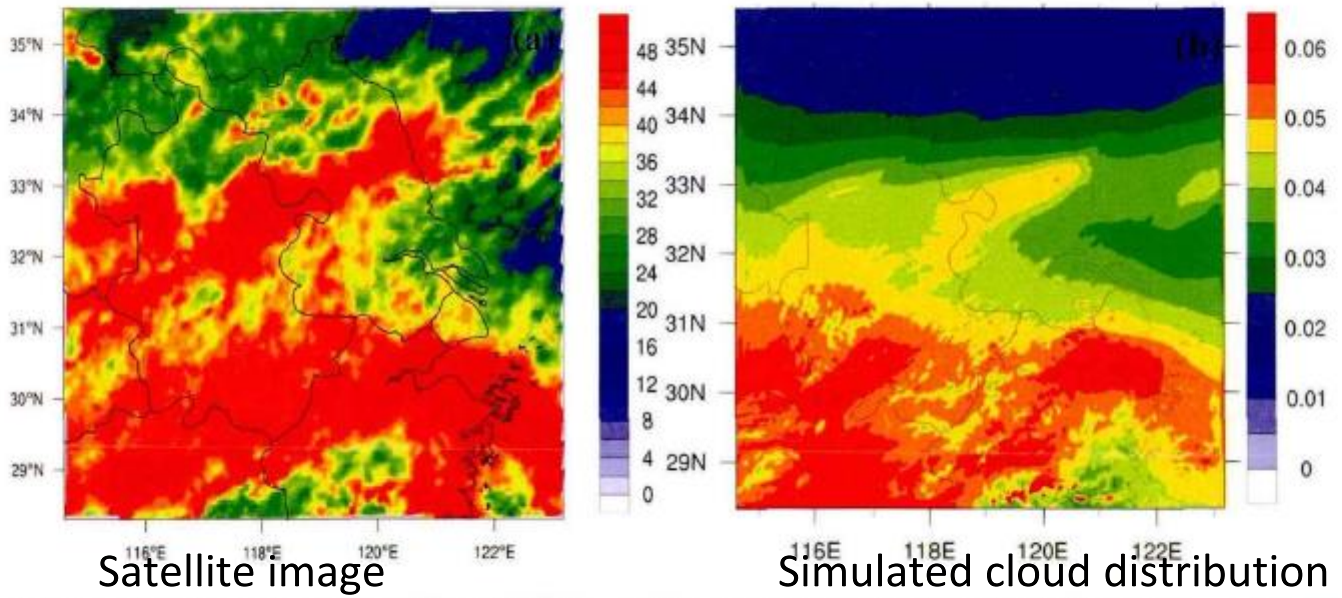


图 3.9 实况可见光云图与模拟云图对比，时间 2014/08/16/05 UTC（a）实况云图；（b）模

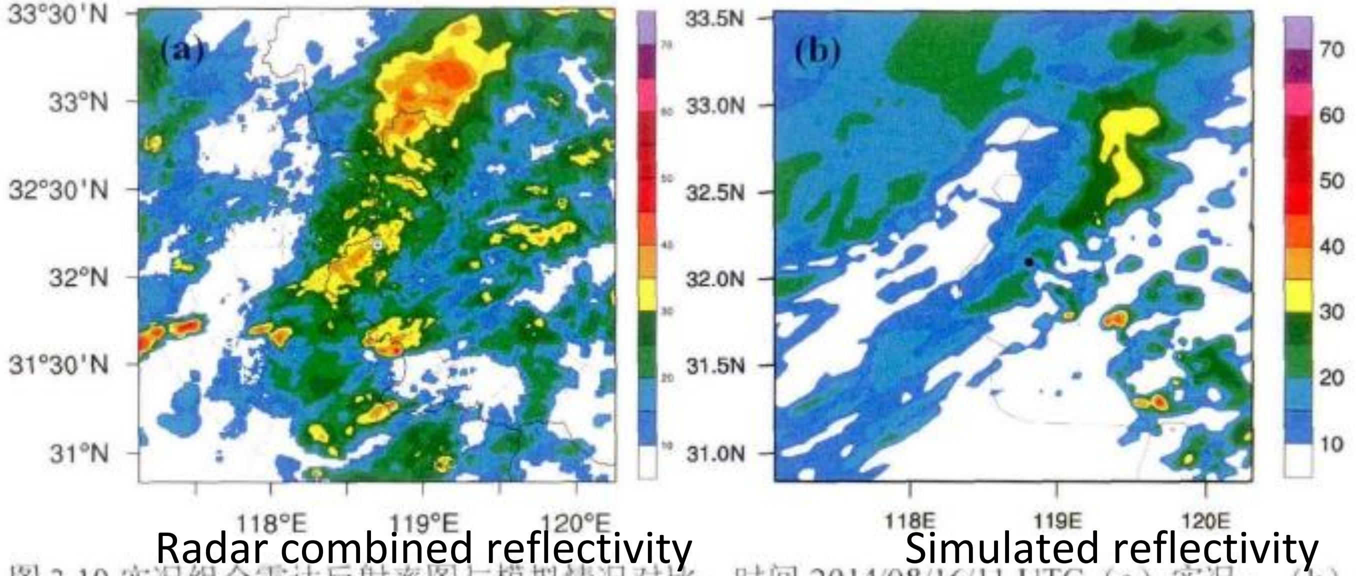
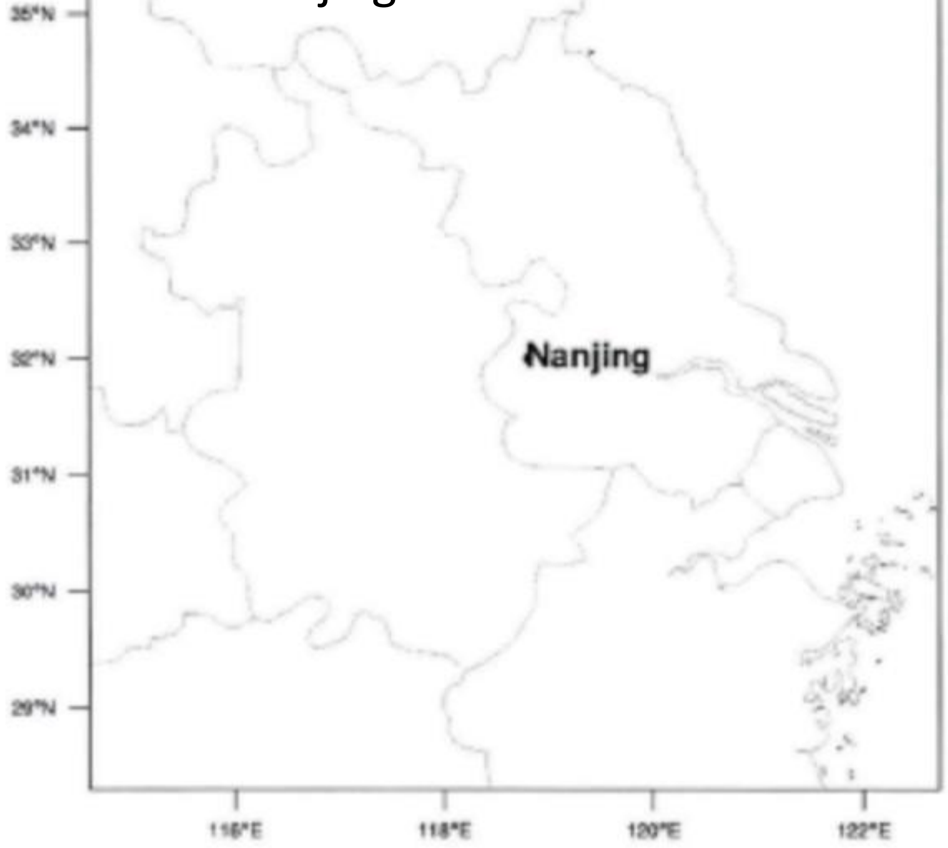
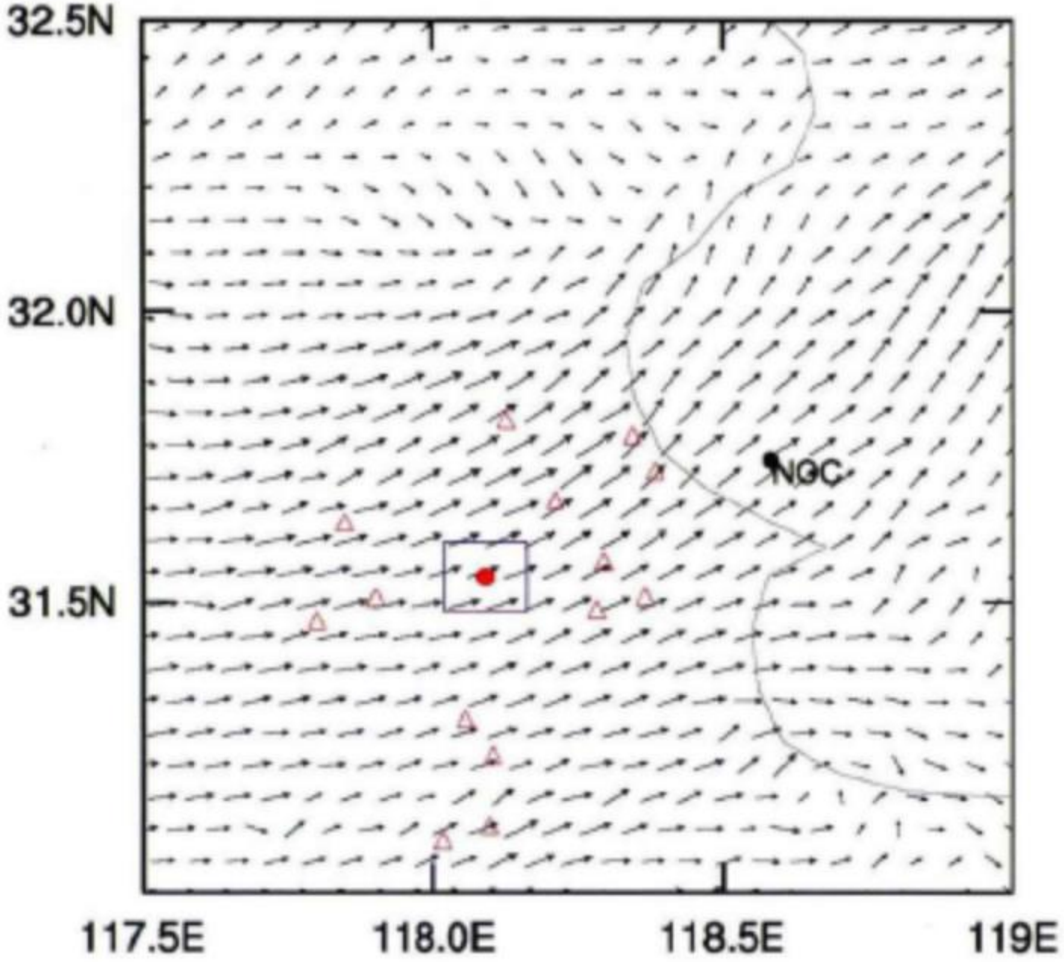


图 3.10 实况组合雷达反射率图与模拟情况对比，时间 2014/08/16/11 UTC（a）实况；（b）

WRF: Thompson +AgI Dx:1.33km, 601*601

The model simulation area with the center Nanjing.

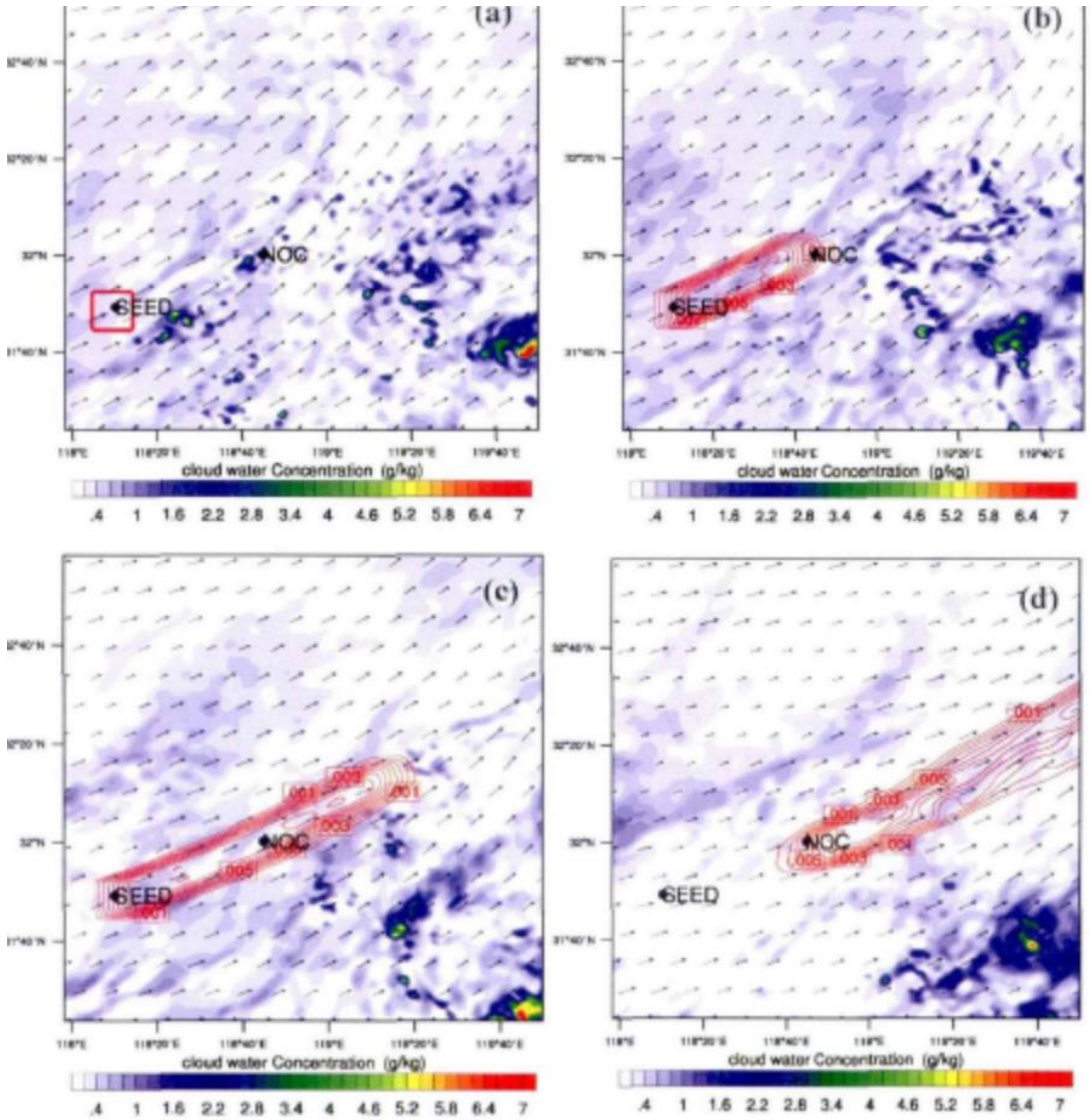




- Implemented ice nucleation mode by combining the silver iodide and cloud interaction in the Thompson microphysics scheme of the mesoscale WRF model, the feasibility, methods, and mechanisms for reducing rainfall are studied.

Seeding time : 2014/08/16/18:20,
Seeding height:6000m
one location, seeding2.5g/s

((a) 10:20 UTC ; (b) 11:10 UTC ; (c) 12:00 UTC ; (d) 13:30 UTC)



Vertical integration of cloud content (shaded) and AgI content (red contour)distribution at different time.

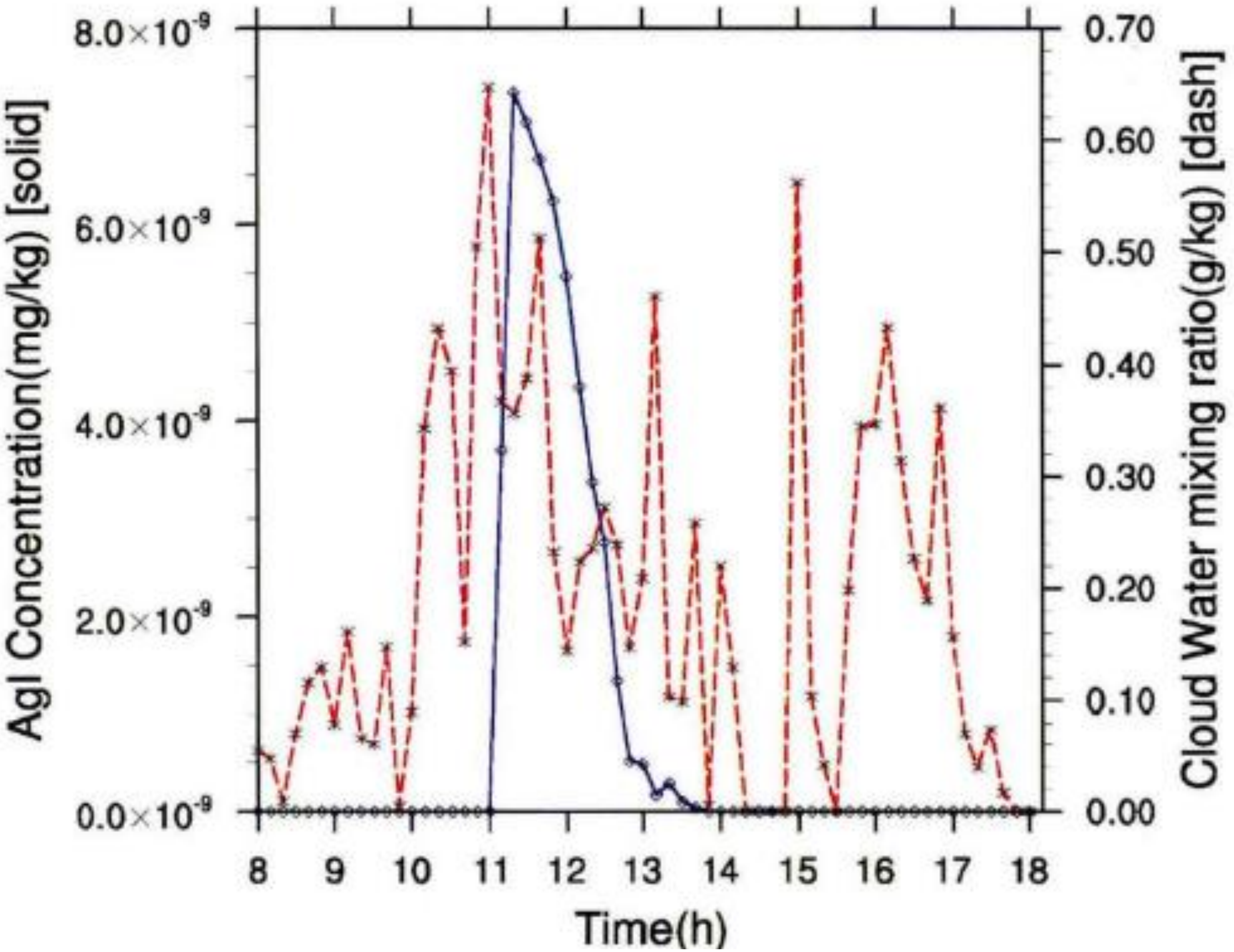


Fig. 4.3 Distribution of the vertical integration of cloud water content and silver iodide content in the Nanjing Olympic Stadium (118.67°E, 32.01°N) over the time. The blue solid line is the AgI content (unit: mg/kg) and the red dotted line is the cloud water content (unit: g/kg)

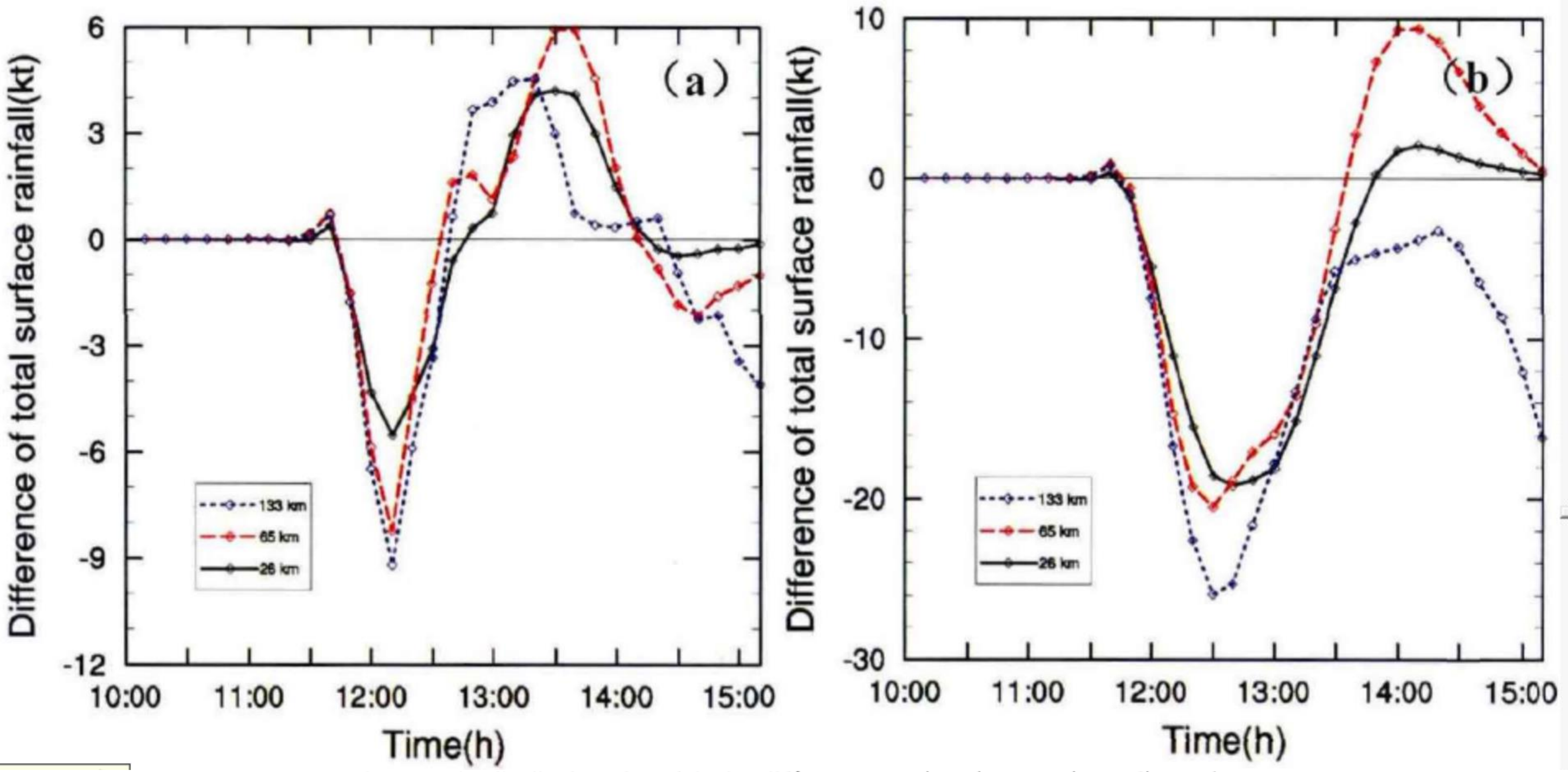


Fig. 4.12 The distribution of precipitation difference over times between the seeding and no-seeding around the Olympic Stadium. (a) the cumulative precipitation difference for ten minutes; (b) the cumulative precipitation difference over time. The blue line is the 133 km range near Olympic Stadium, the red line is 65 km, and the black line is 26 km

Summary and discussion

- Overseeding in updraft area with supercooled water can not only reduce the amount of rainfall, but also reduce the maximum rainfall intensity. With large seeding concentration, rainfall amount can be decreased up to 32%, which greatly lowers the possibility of causing flood.
- After seeding, the falling speed of graupel and raindrops become weaker.
- The decrease of melting amount of graupel to rain in seeding cloud causes the decrease of rain amount, but later the much more rain evaporation causes less rainfall.
- Both simulation and observation show the reduction of precipitation of 2008 and 2014 cases.
- Need Further field experiments and simulations to get more seeding results and seeding technique.

Thank you！

中国气象局人工影响天气中心
CMA Weather Modification Centre(WMC)