

Impact of urbanization on precipitation with
different strength
**城市化对北京地区不同强度降水影响的
机理研究**

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CONTENT



背景介绍



城市化对降水个例影响的机理研究



个例研究的不确定性分析



长期气候模拟中的城市信号



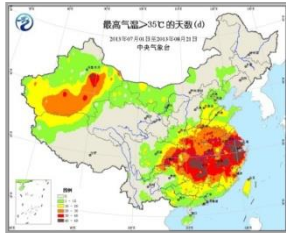
现有研究总结和研究计划



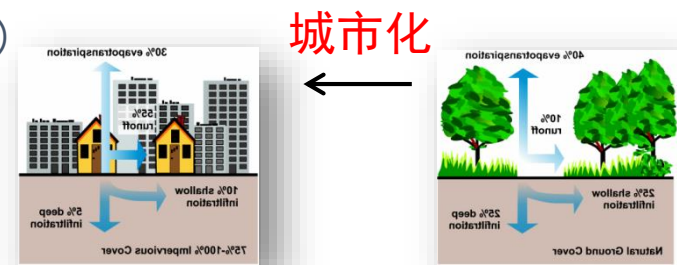


背景介绍

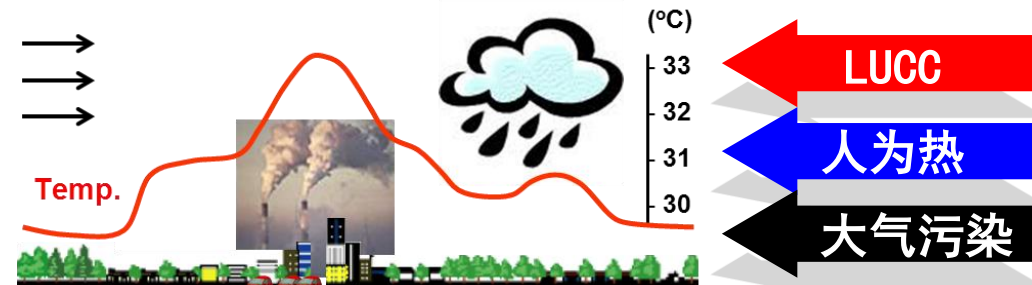
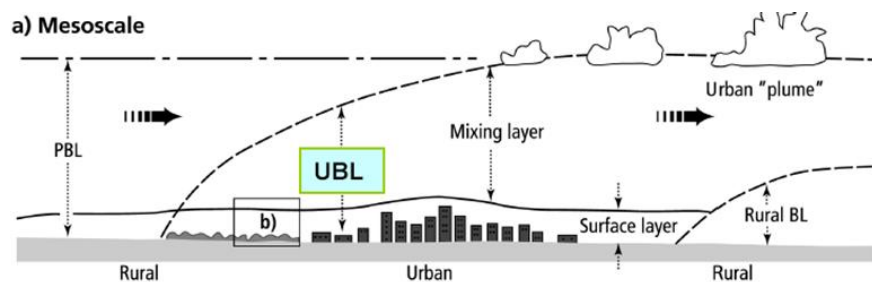
- 人口在城市聚集：
 1. 2007年, 世界城市人口: 50% (United Nations, 2007)
 2. 2050年, 预计超过>70%, 亚洲近一半
 3. 中国高速城市化, 人口在中国东部三大城市群聚集



- 全球变暖 ← 人类影响 (IPCC, 2013)
 1. 温室气体 (最激烈)
 2. LUC
 3. 气溶胶



- 城市化的气候效应：
 1. 全球尺度上的气候增暖 (存在争论)
 2. 区域尺度上有着复杂的气候效应





背景介绍

拟解决的主要问题

- 从观测中已经证实城市对降水影响

Changnon et al., 1981; Bornstein and Lin, 2000; Thielen et al., 2000; Wang et al., 2012; Shepherd et al., 2002; Shepherd and Burian, 2003; Yang et al., 2012

- 影响机制尚无定论（城市的热力作用，动力作用，云微物理CCN）

The surface roughness is increased by urbanization, leading to **enhanced convergence; Destabilization** is increased in the boundary layer; Precipitating systems are **bifurcated or diverted by the urban canopy** or related processes ; Increases in aerosols associated with urban land use lead to change in cloud condensation **nuclei (CCN)** sources

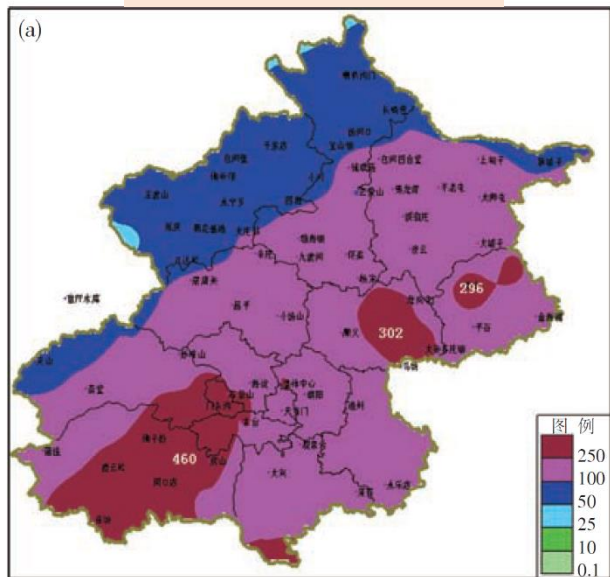
拟解决的主要问题

- 区域尺度，城市化对极端降水影响特征，贡献多大？影响机制如何？
- 城市的热力作用和动力作用的贡献多大？影响机制？多层城市冠层+人为热，
- 在不同大尺度环流形势下，城市是如何影响不同强度降水的？
- 长期气候模拟中，是否有城市影响降水的信号？

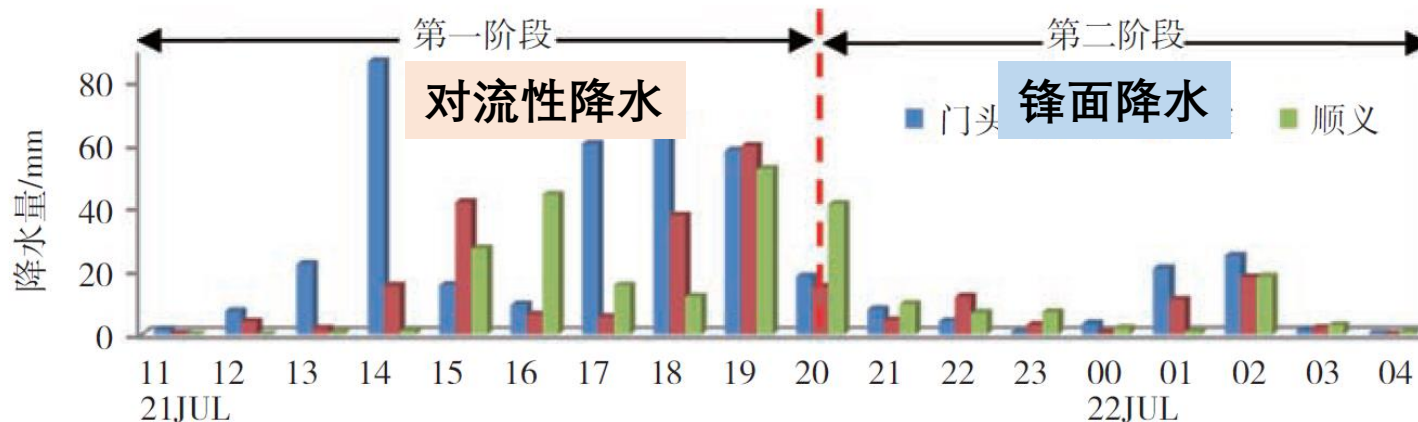


城市化对典型强降水影响的机理研究----20120721 观测分析

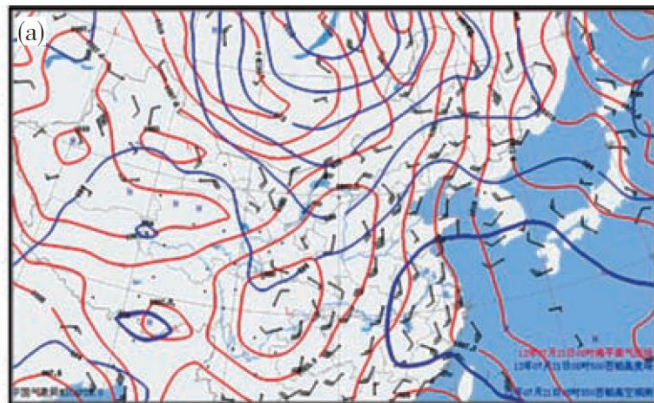
累积降水量mm



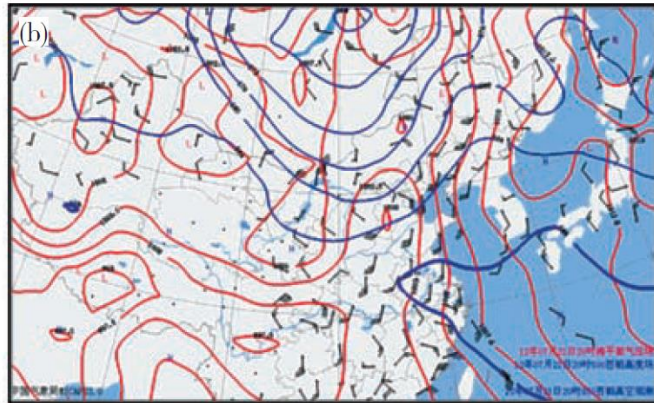
北京降雨量在**100毫米**以上的面积占北京市总面积的**86%以上**
 2012年7月21日10:00--22日6:00



500hPa



700hPa



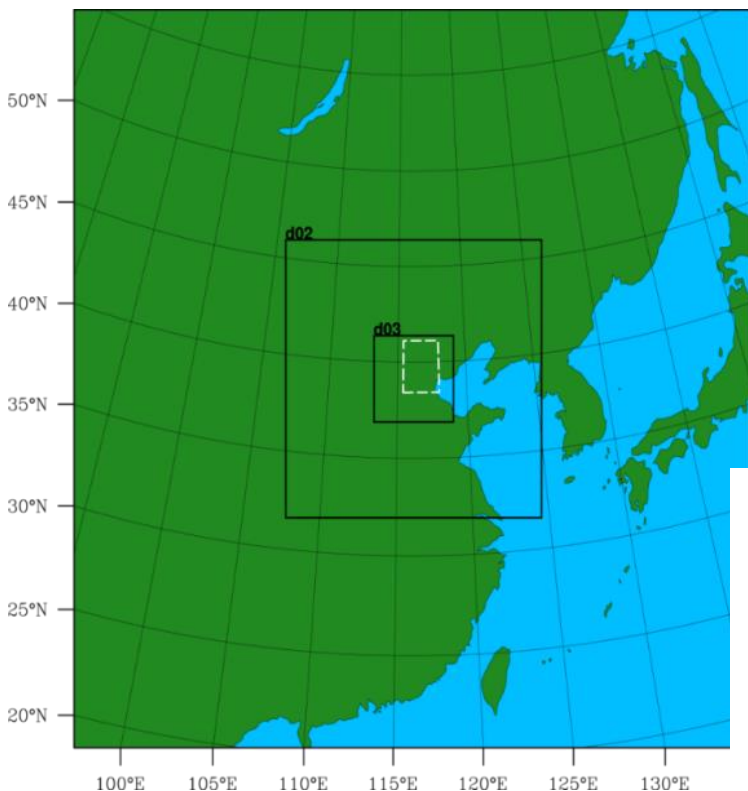
- 高空急流辐散与对流层中低层的低涡、切变线及地面倒槽等构成的深厚辐合系统形成强烈上升运动并一直维持;
- 副热带高压外围来自东部海洋的水汽通道与西南低空急流的水汽输送为暴雨发生提供了充沛的水汽条件



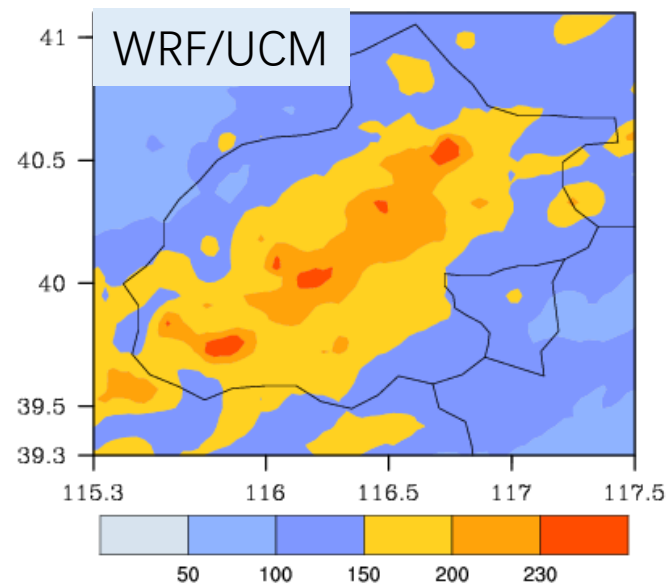
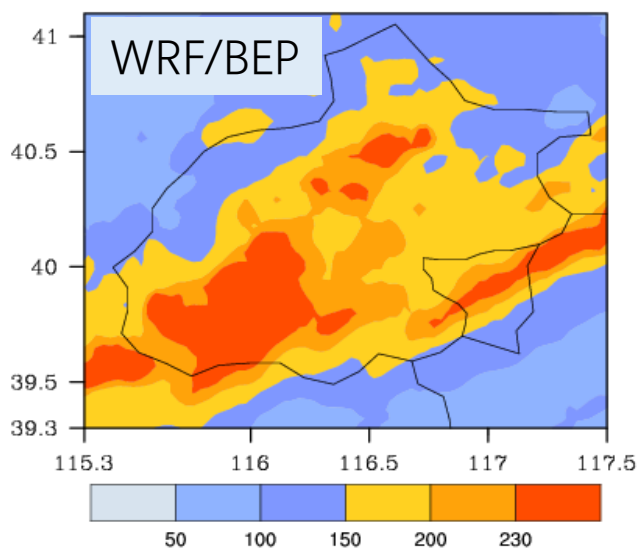
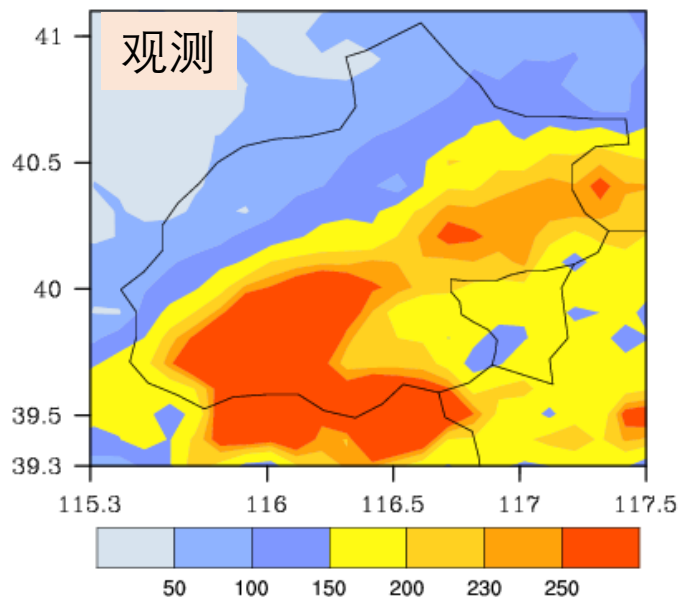
城市化对典型强降水影响的机理研究----20120721 模式验证

模式验证 总降水量

WRFV3.6.1/BEP

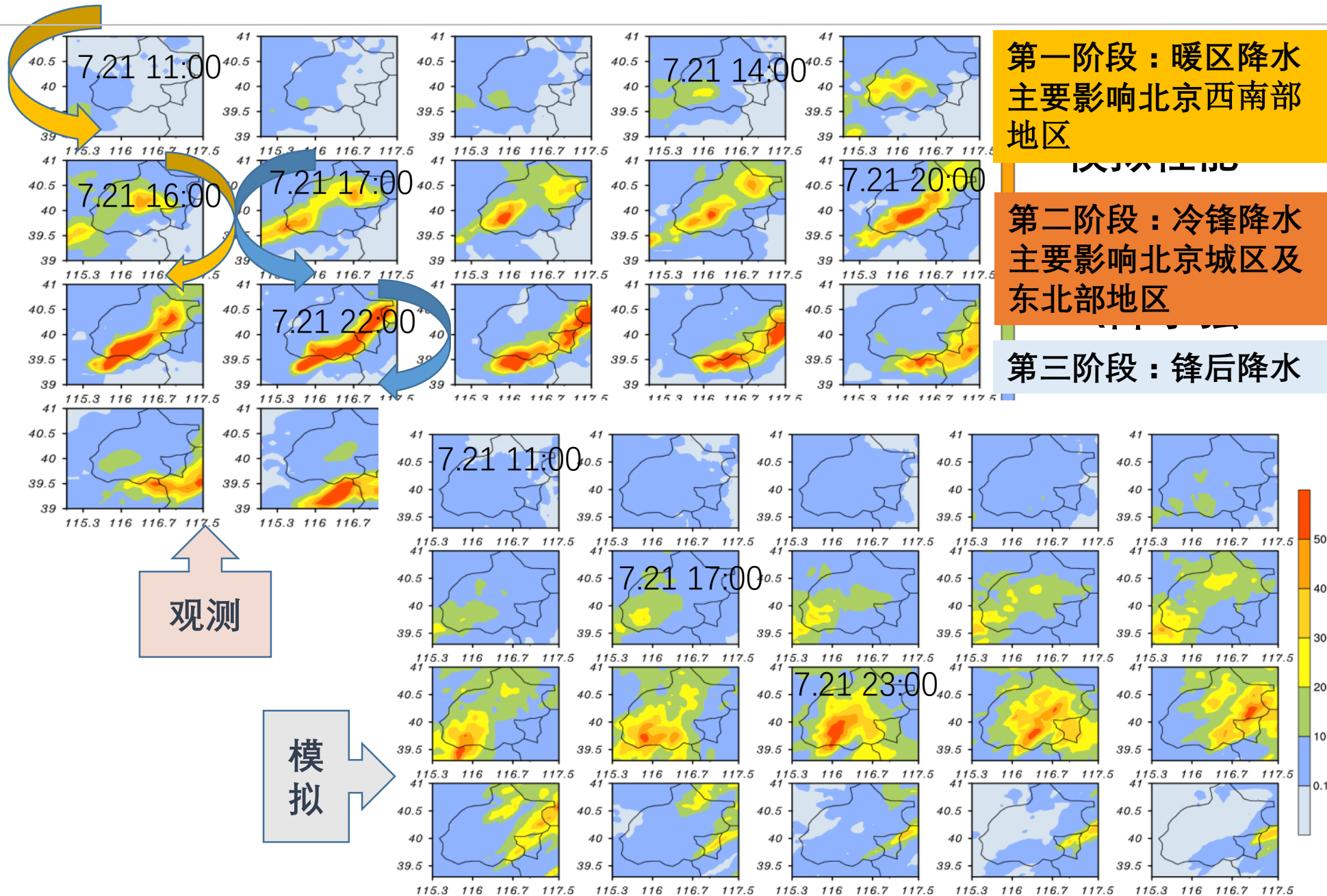


KF;RRTM;MYJ;Lin





城市化对典型强降水影响的机理研究----20120721 模式验证

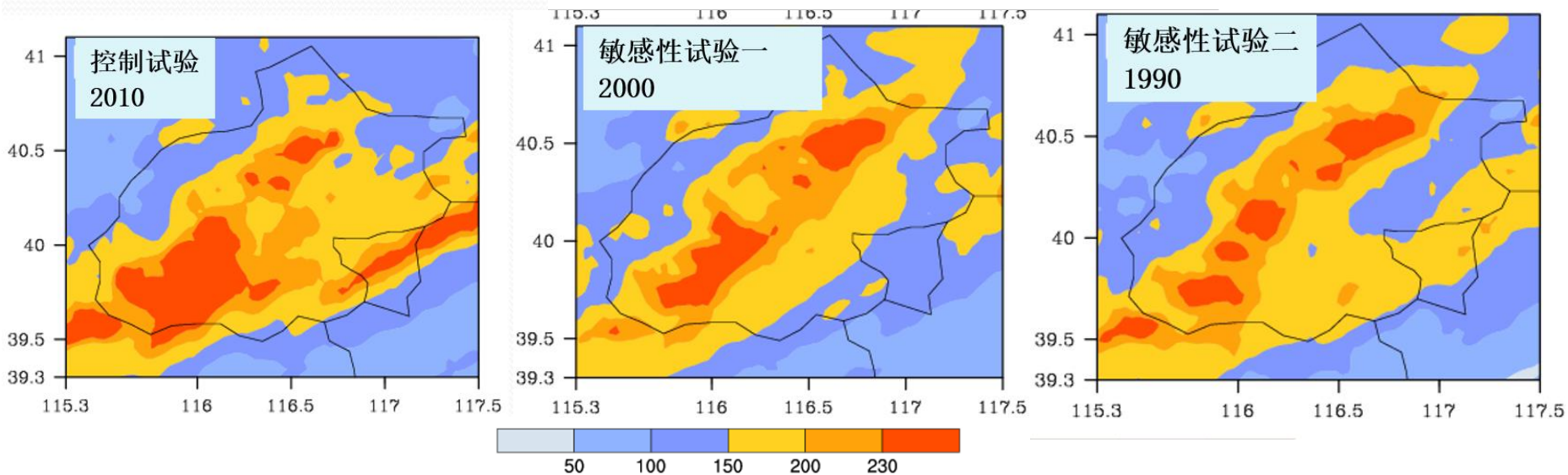
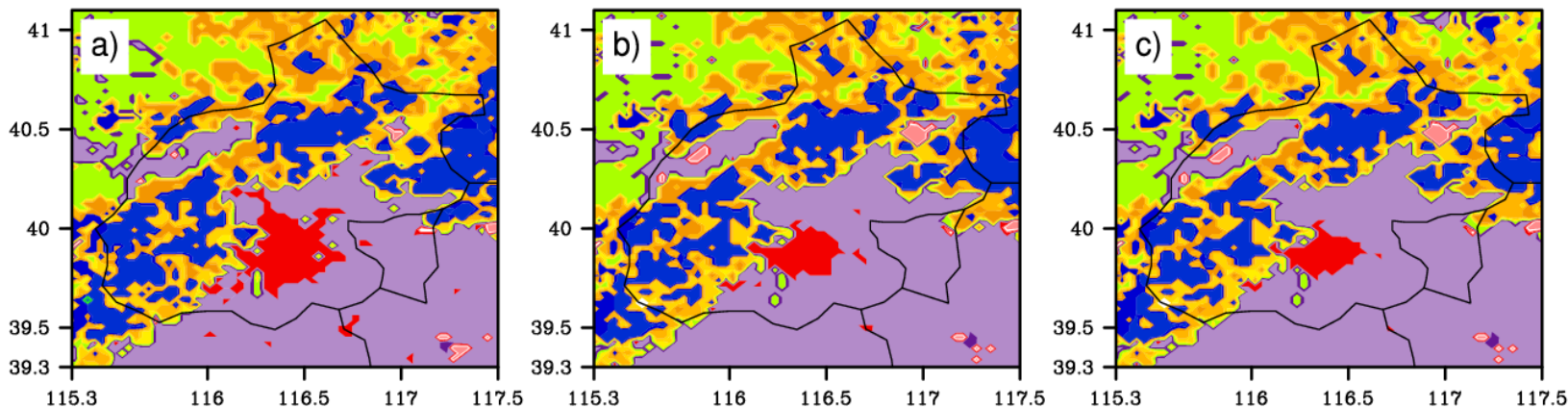




城市化对典型强降水影响的机理研究----20120721 试验设计

a) 控制实验 b) 敏感性实验一 c) 敏感性实验二

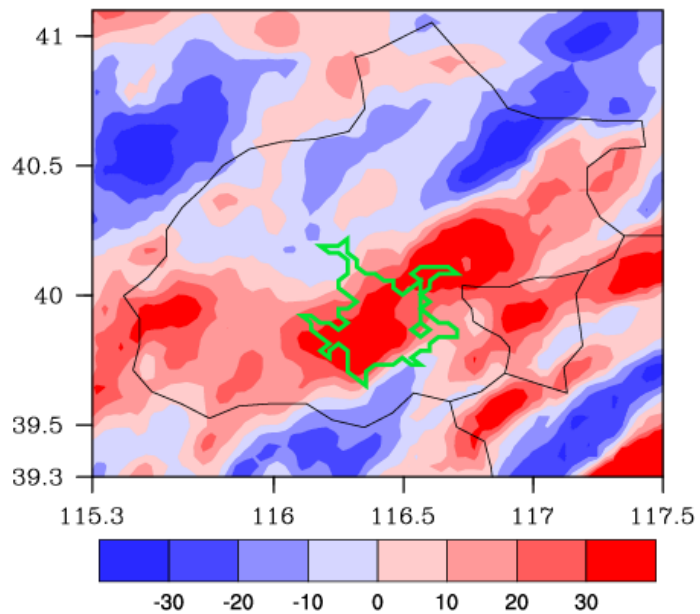
2010年地表利用地图 2000年地表利用地图 1990年地表利用类型



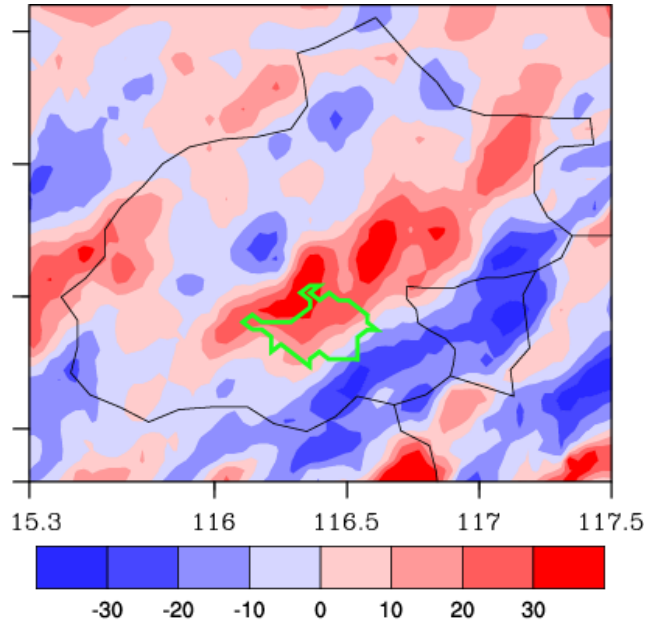


城市化对典型强降水影响的机理研究----20120721 结果分析

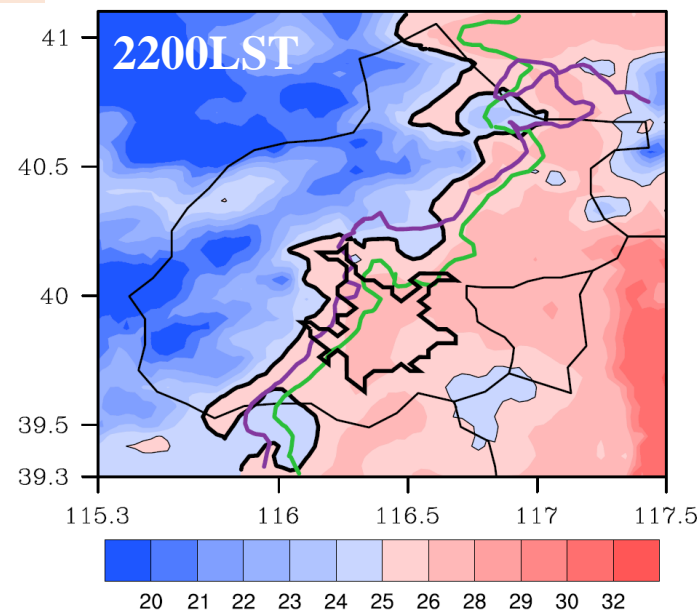
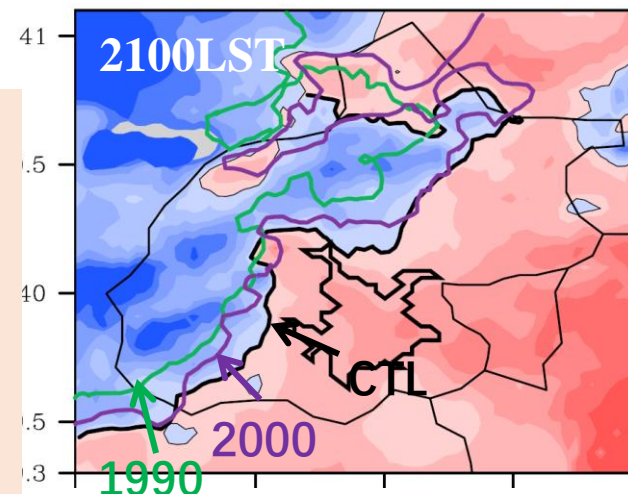
CTL试验-1990试验/CTL试验



2000试验-1990试验/2000试验



锋面两侧的温度梯度为
4-5C°/100 km
25°C isotherm
CTL-Black
2000-Purple
1990-Green



城市化对北京城区和“下风向”地区累计降水量的增加最显著。
推测：城市化很可能对锋面降水有重要影响

城市减缓了锋面的推进速度，延长了在北京城市停留的时间，
是北京城区降水增强的原因之一

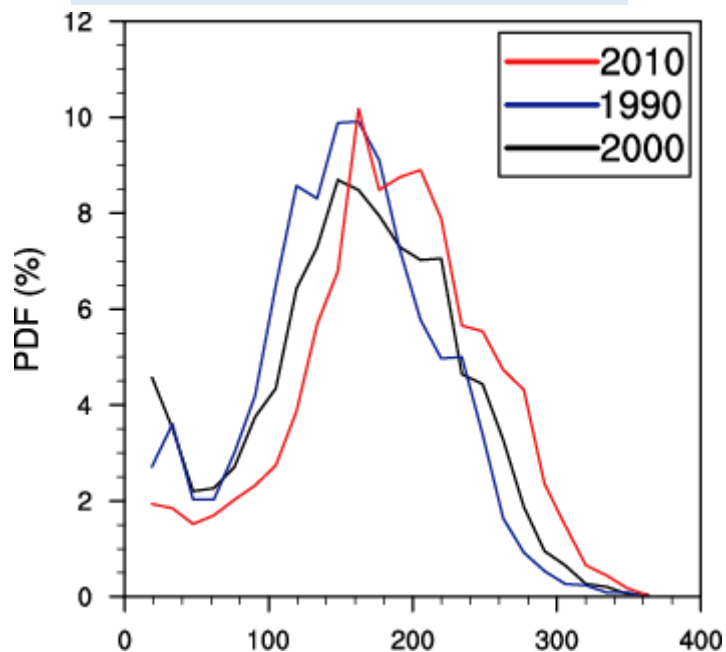


城市化对典型强降水影响的机理研究----20120721 结果分析

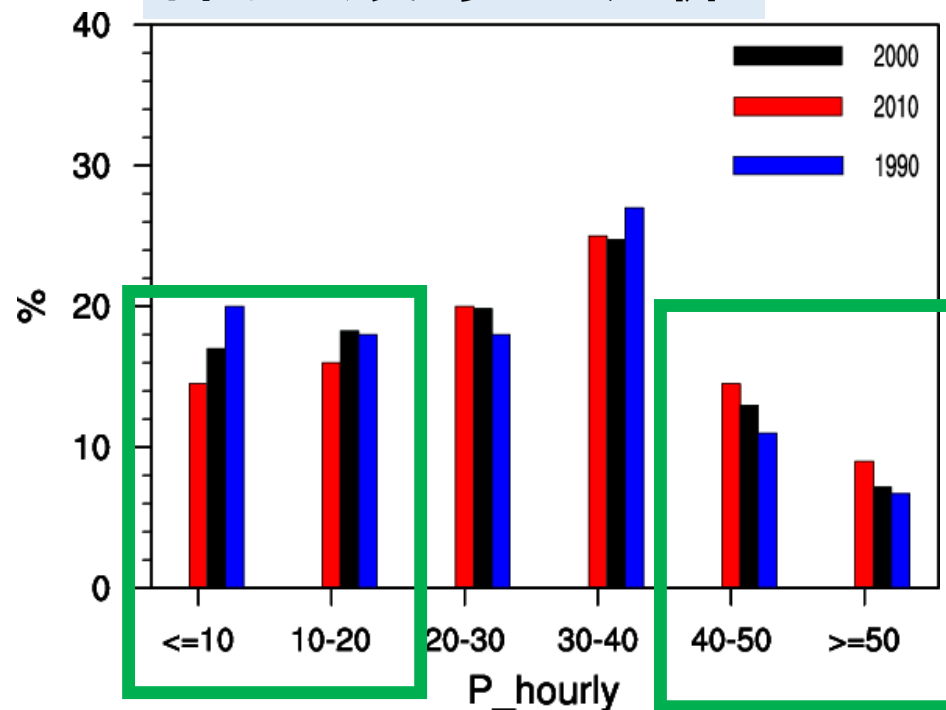
城市化对总降水量和降水强度的影响

- 控制试验**累计降水量**大于**200mm**的降水出现的频率明显高于两个敏感性试验。
- 控制试验**降水强度**大于**40mm**的降水出现的频率明显高于两个敏感性试验。

总降水的PDF分析



降水强度的PDF分析

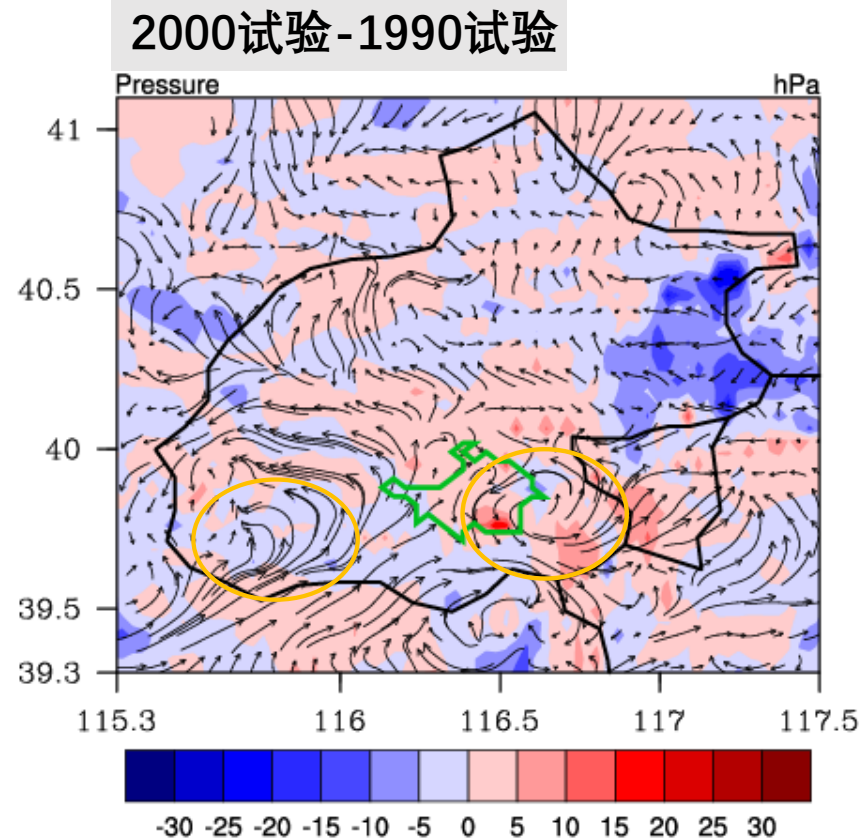
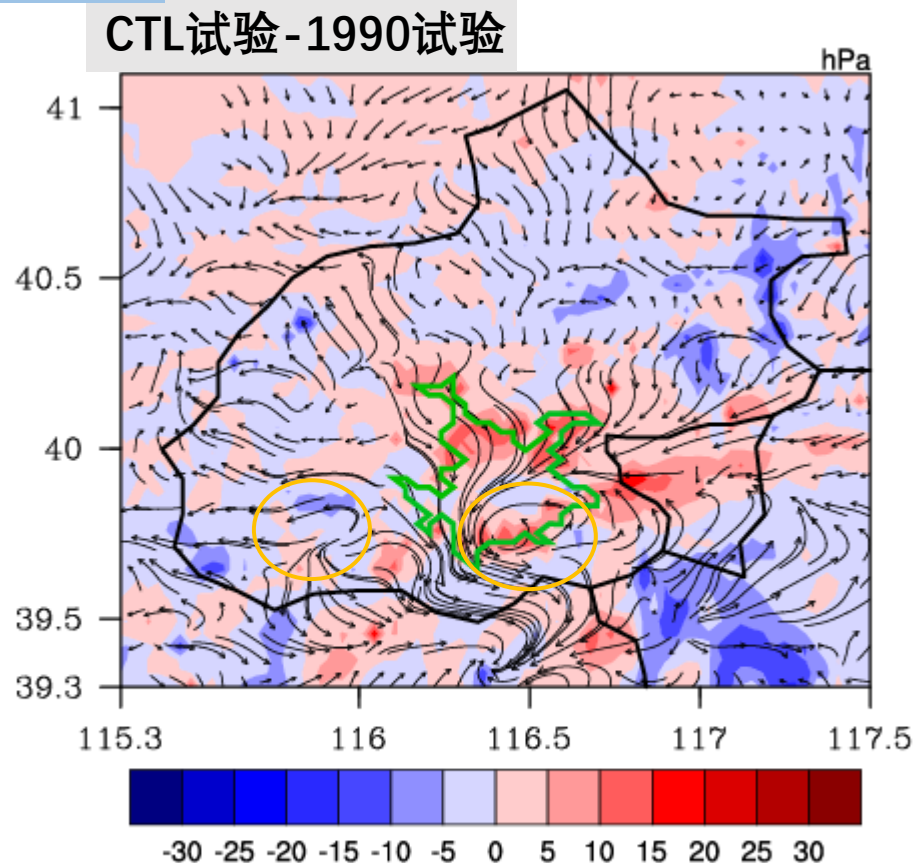




城市化对典型强降水影响的机理研究----20120721 机理分析

环流条件

平均感热通量（阴影）及850hPa环流场（矢量）



城市上下风向地区更容易形成气旋型环流

降水开始前（2012年7月21日8:00到12:00）平均感热通量差（阴影；瓦/平方米）
降水较大时（2012年7月21日22:00）850hPa环流场（矢量；米/秒）

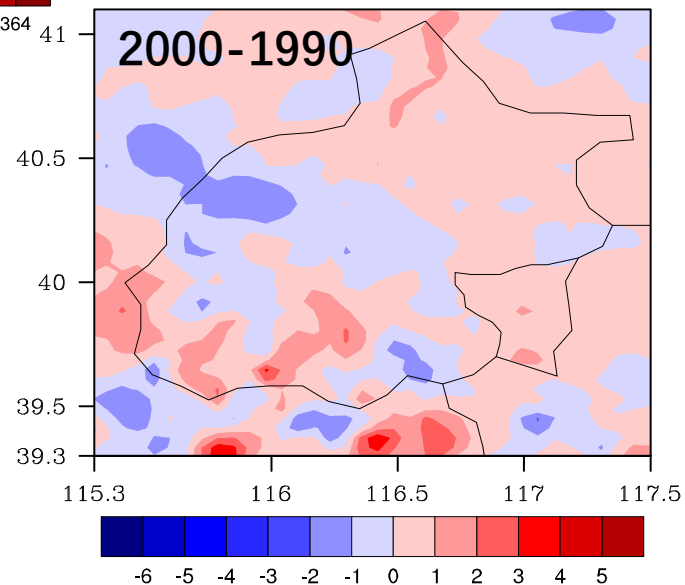
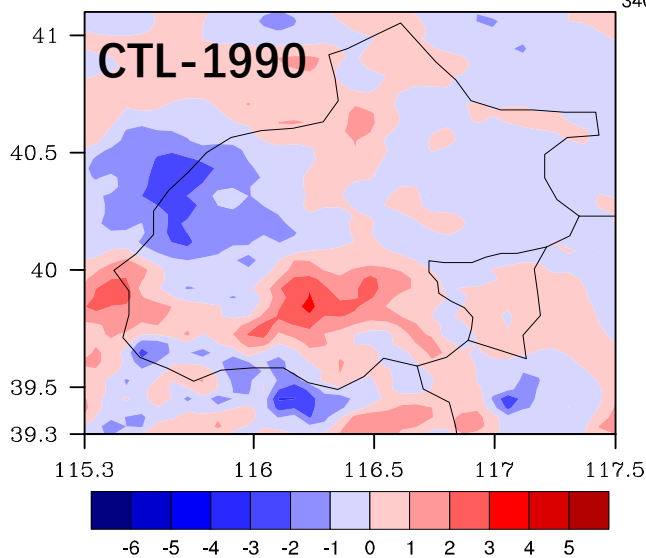
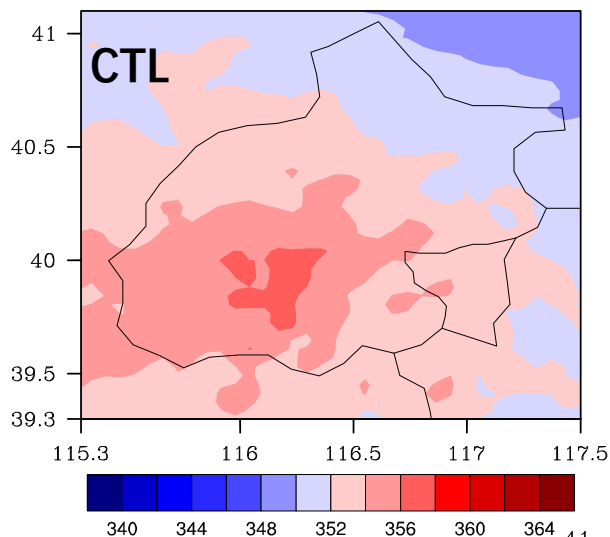


城市化对典型强降水影响的机理研究----20120721 机理分析

水汽条件

湿焓与总降水量分布相似
城市扩张导致城区及其上下风向地区湿焓增加

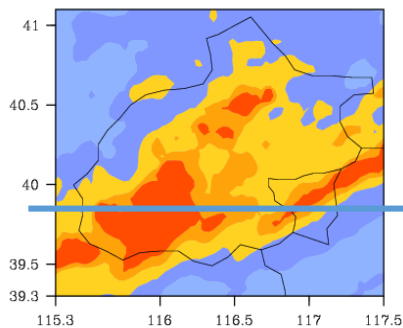
湿焓（假相当位温度），代表了系统可以转换成机械能的热力能





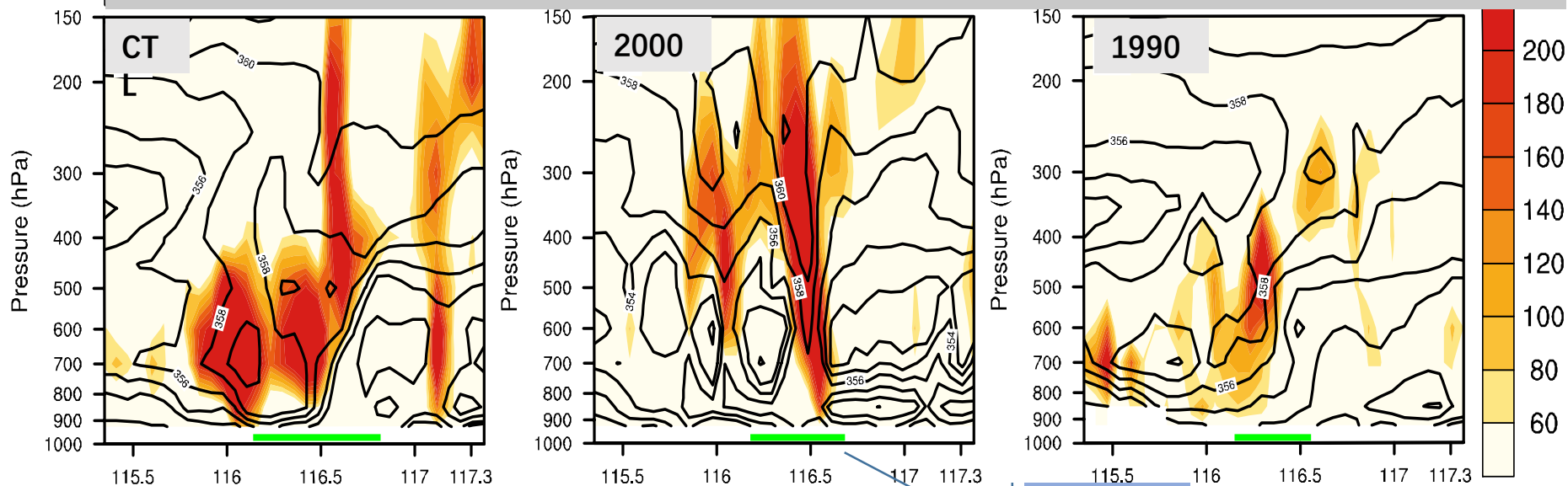
城市化对典型强降水影响的机理研究----20120721 机理分析

上升运动



城市及其上下风向地区的上升运动明显

W (cm/s) 及假相当位温(等值线 ; K) 沿39.7°垂直剖面



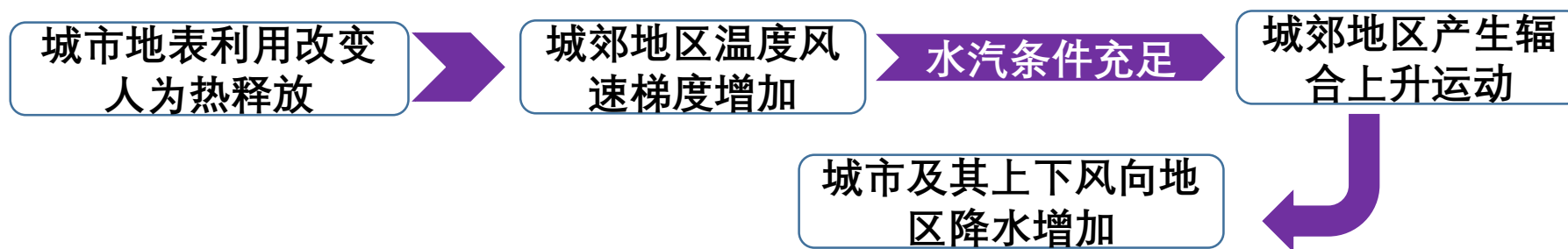
降水较大时7.21 23:00

城市区域



城市化对典型强降水影响的机理研究----20120721

- 城市化对强降水的作用不是决定性的，但使降水量增加30%，说明城市化的作用不可忽视。
- 城市化导致降水在城市区域及其“上下风方向”区域均有显著的增加。
- 城市化造成降水分布更加集中：累计降水量大于200毫米频率
降水强度大于40毫米频率 ↑
- 由于城市地表粗糙度的增加，对锋面的移动有阻碍作用，使得城区锋面降水时间延长。
- 城市化影响强降水的可能机制：



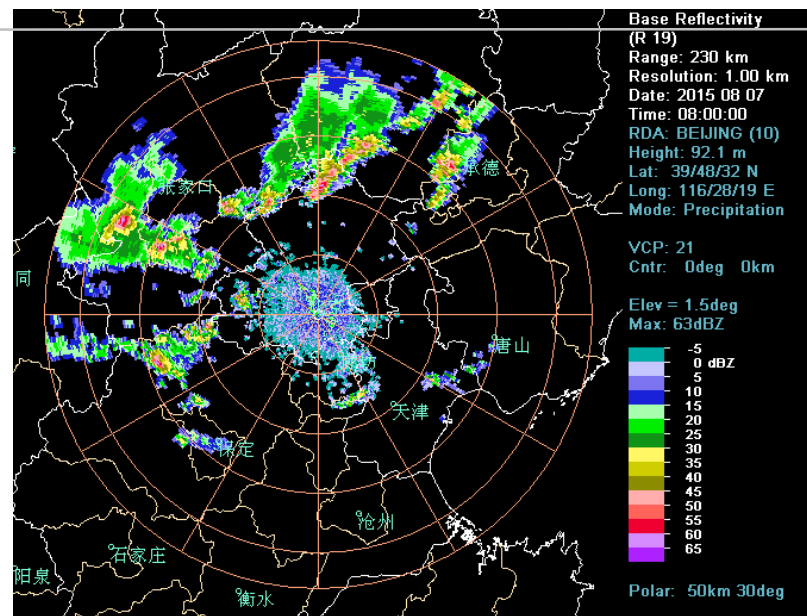


城市化对典型强降水影响的机理研究----20150807 观测分析

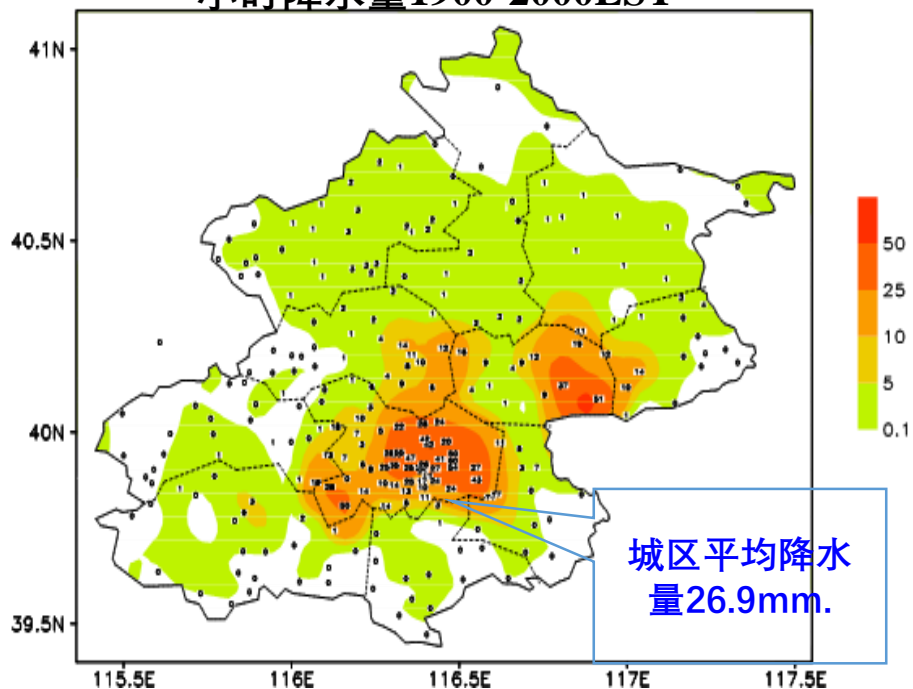
降水发生时间 201508071600 - 2100LST

降水中心位于朝阳，最大降水量84.2mm.

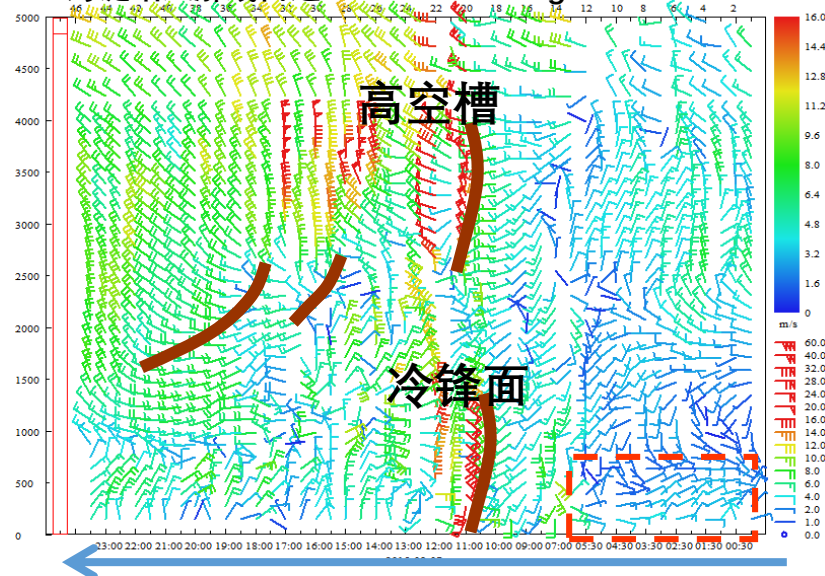
冷锋系统和局地风切变 是影响本次降水的主要天气系统。
这两个系统在到达城市后合并加强。



小时降水量1900-2000LST

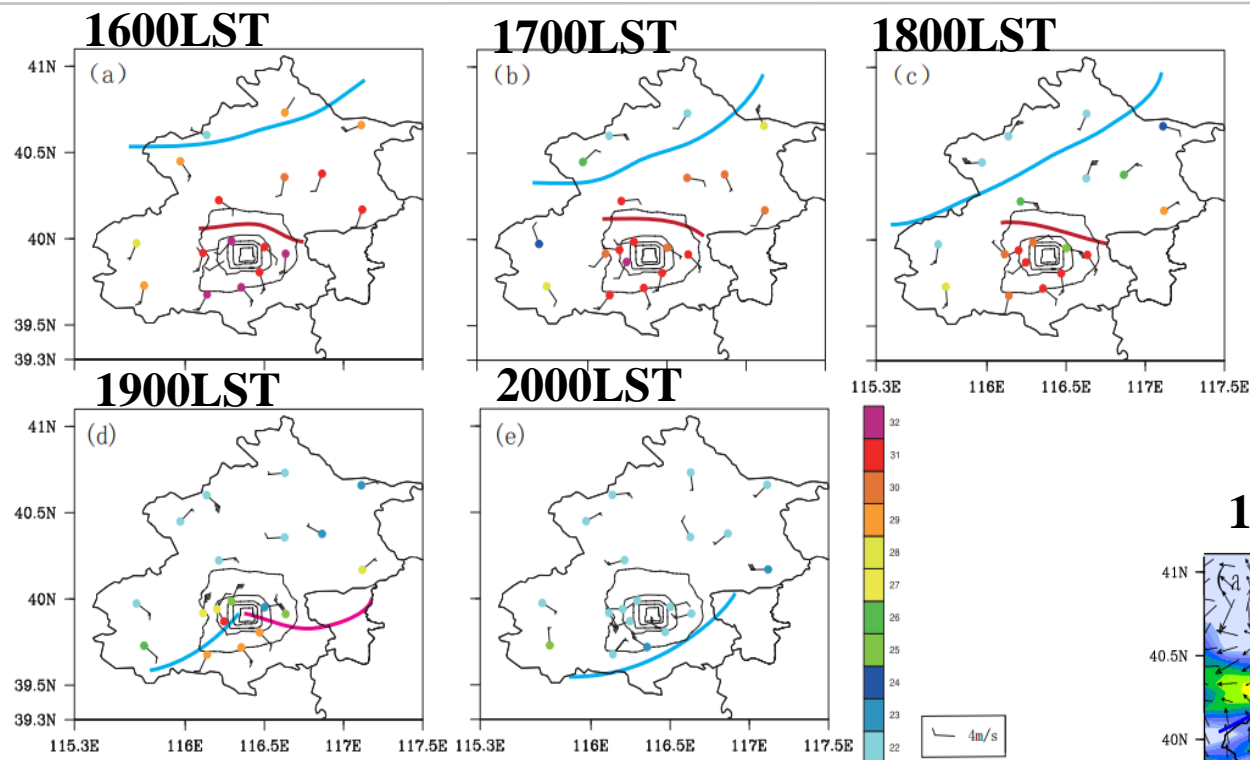


海淀站风廓线雷达 0800LST 7th Aug to 0700LST 8th Aug





城市化对典型强降水影响的机理研究----20150807 模式验证

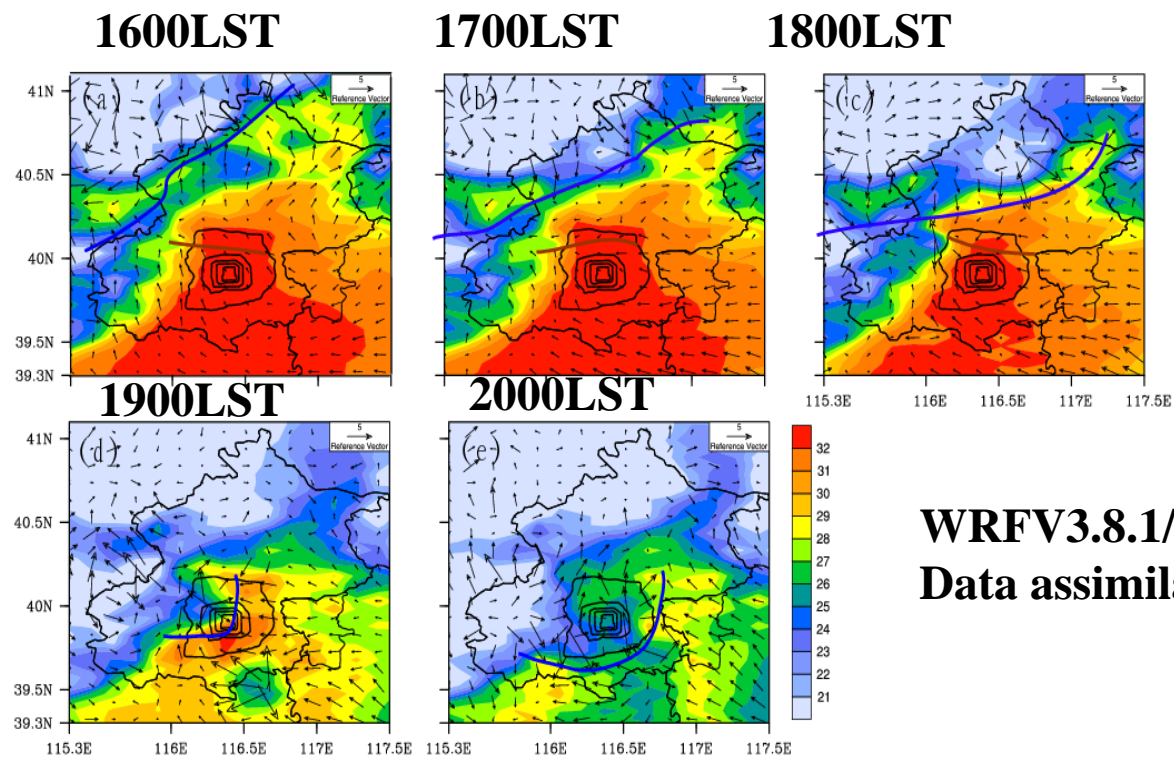


The blue lines show the cold front and the red lines show the convergence lines.

observation

CTL

CTL(urban scenario)
Sensitive test (replace urban to cropland)



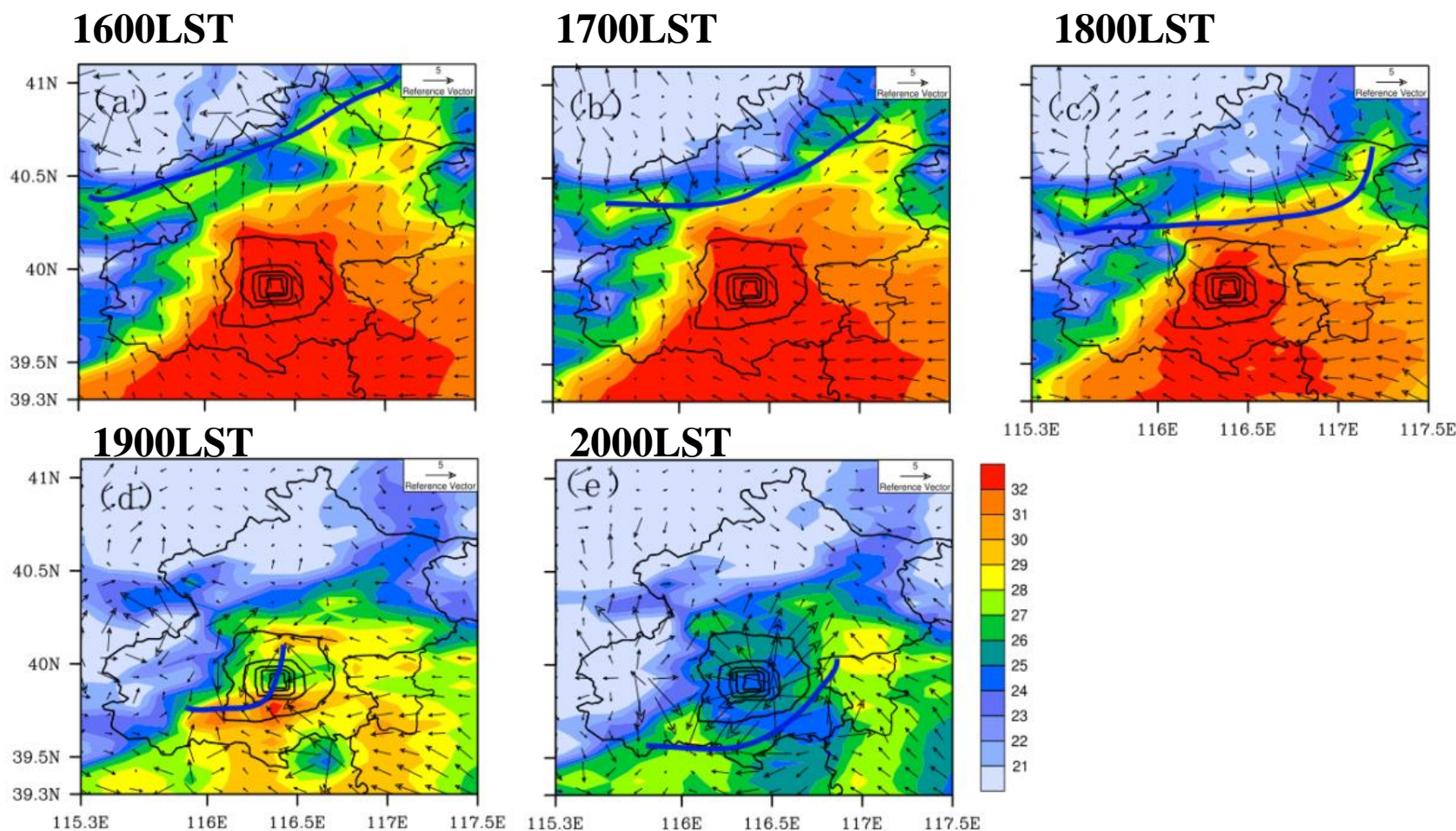
WRFV3.8.1/UCM
Data assimilation



城市化对典型强降水影响的机理研究----20150807 结果分析

2m temperature and 10m wind 1600-2300LST 7th Aug 2015

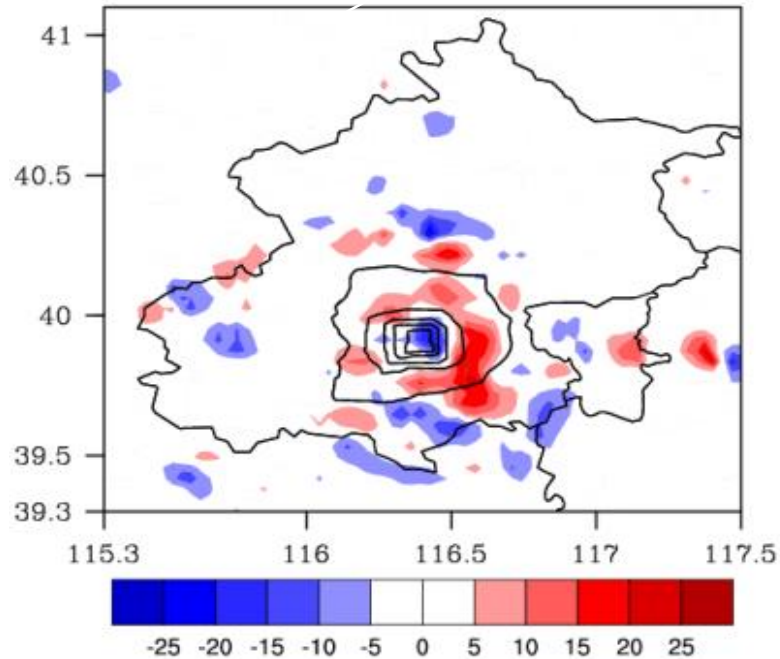
Convergence lines (local influence system) **can not be captured** by **Nourban** test



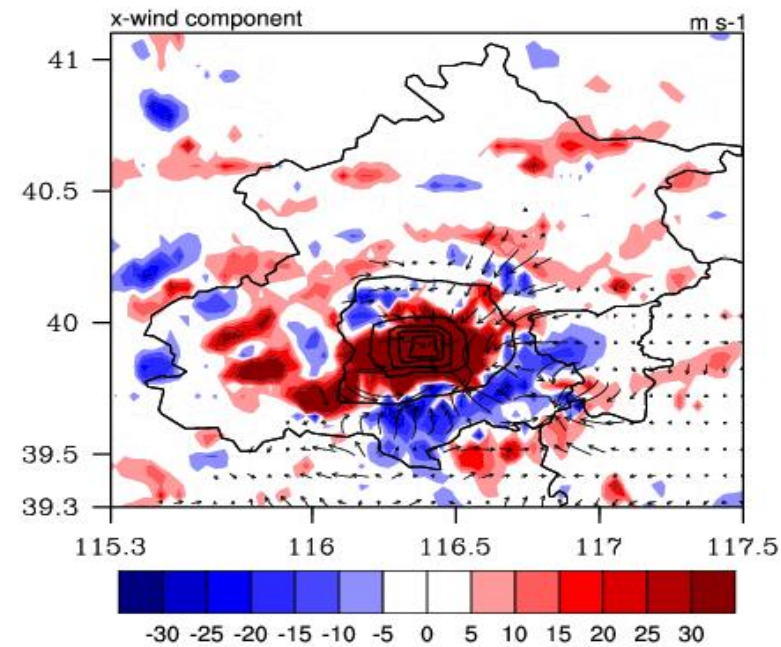


城市化对典型强降水影响的机理研究----20150807 机理分析

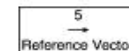
The urban induce the precipitation obviously increased **in downstream of suburban area** and little increased in upstream suburban area.



Urban makes the **sensible heat flux** increased which leads to the **gradient of temperature and wind** increasing in suburban area. When the rainfall system reached, **the convergence is enhanced in downstream** of urban area.



Difference between RUC and RUC_Nourban test: accumulated precip from 16-23 LST(left), Sensible heat flux and uv (850hpa) average from 08-12LST(right)





城市化对典型强降水影响的机理研究----20150807

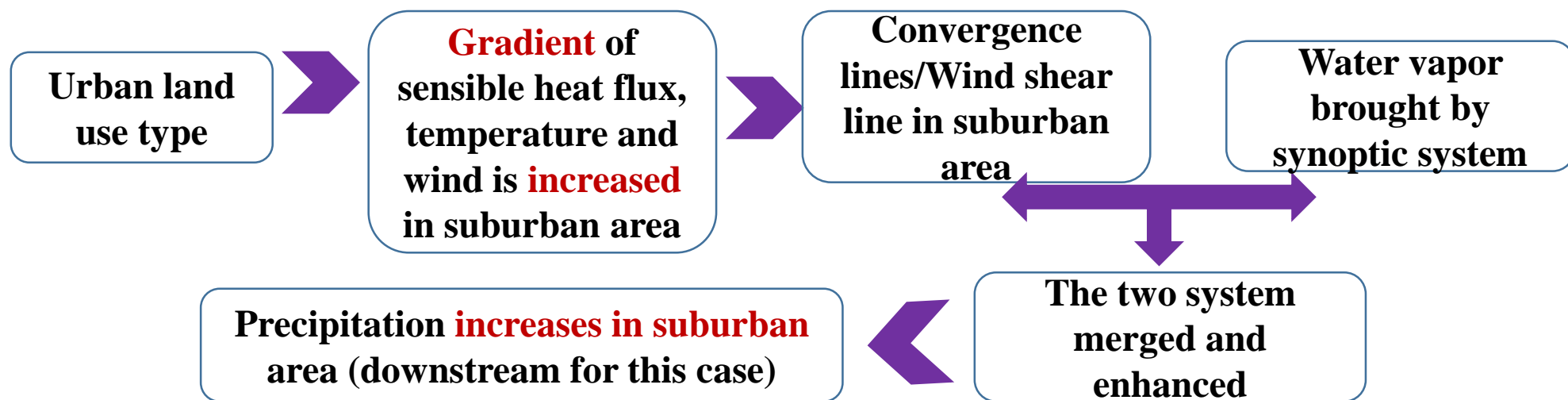
Main influence system : **Upper Trough** and **convergence line**

RUC model forecast shows a very well performance for this case

The impact of urban on precipitation:

1. Increasing the precipitation on **downstream of urban**.
2. **Extending the time** of the precipitation.

The possible mechanism of urbanization on precipitation





个例研究城市影响降水的不确定性分析

Part I 参数化方案的不确定性研究

9 Tests for Role of **MP** and **PBL** schemes using Urban land use maps (UE)

9 Tests for Role of **MP** and **PBL** schemes using Nourban land use maps (NUE)

	Test1	Test2	Test3	Test4	Test5	Test6	Test7	Test8	Test9
MP	①	①	①	②	②	②	③	③	③
PBL	①	②	③	①	②	③	①	②	③

Microphysics Options: ①Lin; ②WSM6; ③Thompson

PBL Physics Options: ①YSU; ②MYJ; ③Boulac

Part II 初始场不确定性研究

[Global Ensemble Forecast System](#) (GEFS) data including one control run and 20 members used and [downscale to the 6km](#) in uncertainty study for **initial fields**.

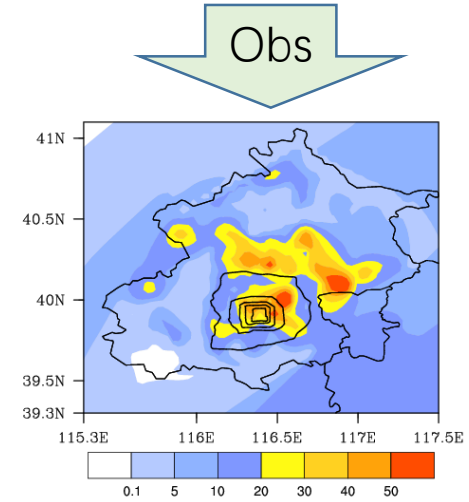
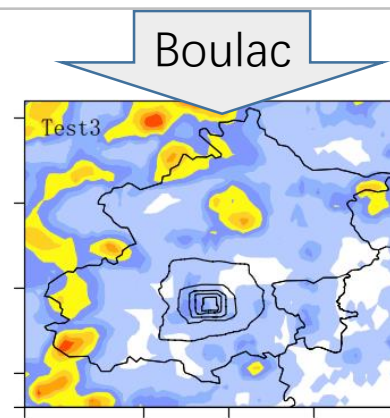
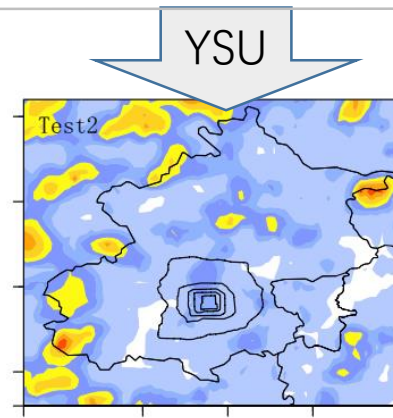
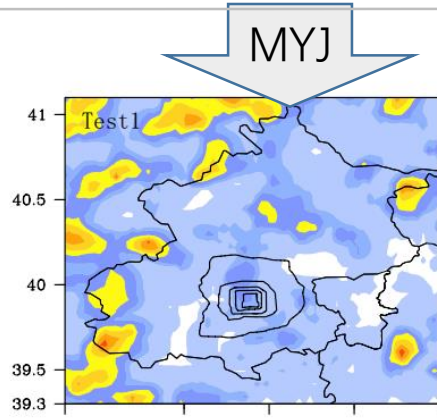
21 Tests for Role of **initial fields** using Urban land use maps (UEI)

21 Tests for Role of **initial fields** using Nourban land use maps (NUEI)

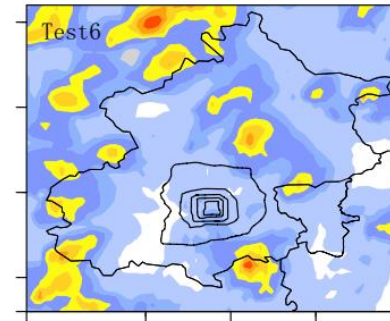
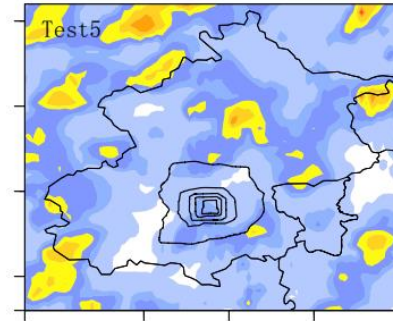
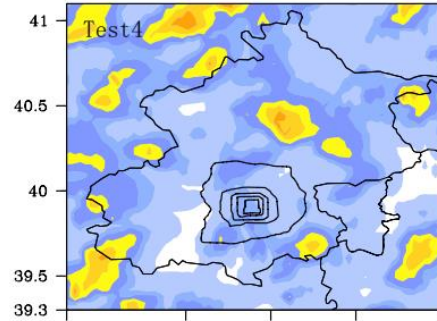


个例研究城市影响降水的不确定性分析 I 参数化方案

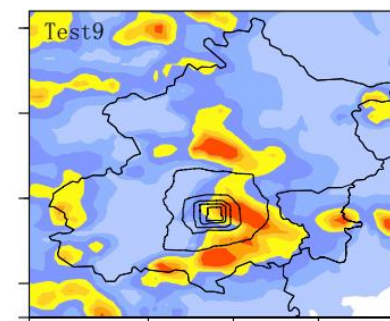
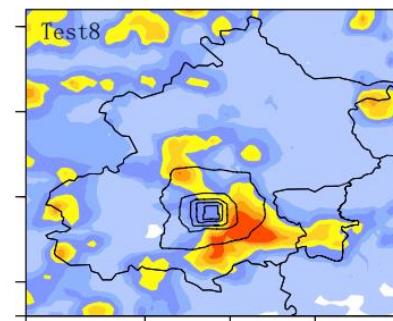
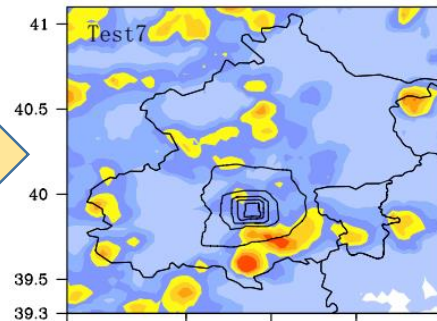
Lin



WSM6



Thompson



Results

- Circles = Beijing Ring Roads
- Boulac PBL: best for all MP schemes
- Thompson MP: best
- > Stats: next slide

Results: Accumulated precip (mm) model vs. obs, 16-23 LST, 7 Aug



个例研究城市影响降水的不确定性分析 I 参数化方案

- Bias (mm) & Threat score (TS, % correct at amounts > 0.1-50 mm)
- Boulac PBL (T3,6, 9) & Thompson MP (T7-9)

Test	1	2	3	4	5	6	7	8	9
Bias	4.38	4.24	4.74	4.40	4.31	4.52	4.35	4.26	4.12
TS \geq 0.1	77.07	78.19	80.69	80.73	78.11	80.10	79.26	79.26	80.70
TS \geq 10	4.67	5.1	4.08	8.79	9.72	7.27	10.12	10.80	12.75
TS \geq 25	0.90	0.20	0.47	1.73	0.545	1.67	2.45	4.67	9.38
TS \geq 50	0	0	0	0	0	0	0	0	1.55

➤ Results: not much variation in bias

The bias was not be improved by MP and PBL schemes

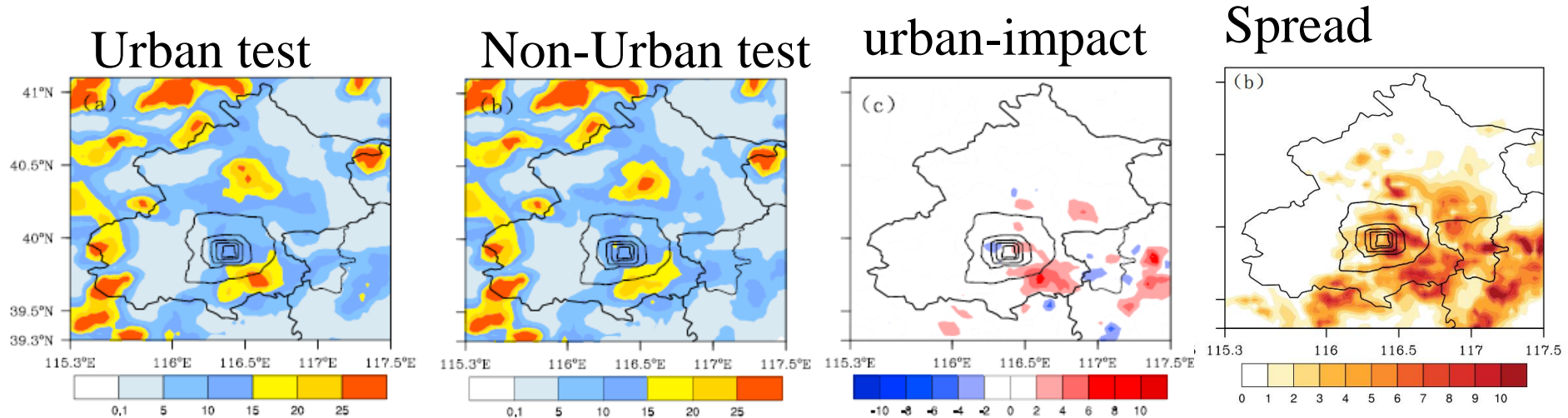
- Bias (about 4 mm) is small (about 16%), as mean is about 25 mm
- TS for capturing precip-occurrence: uniformly good at about 80%
- TS for correctly capturing higher accumulations: not good, but

BouLac PBL & Thompson MP together (test 9) is best (only combo to capture any extreme events)!



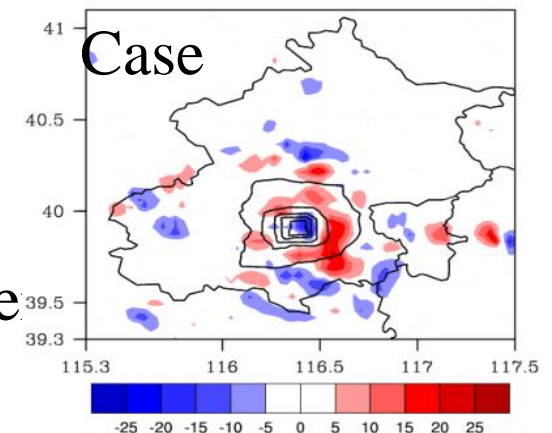
个例研究城市影响降水的不确定性分析 I 参数化方案

ensemble-mean & spread of precipitation



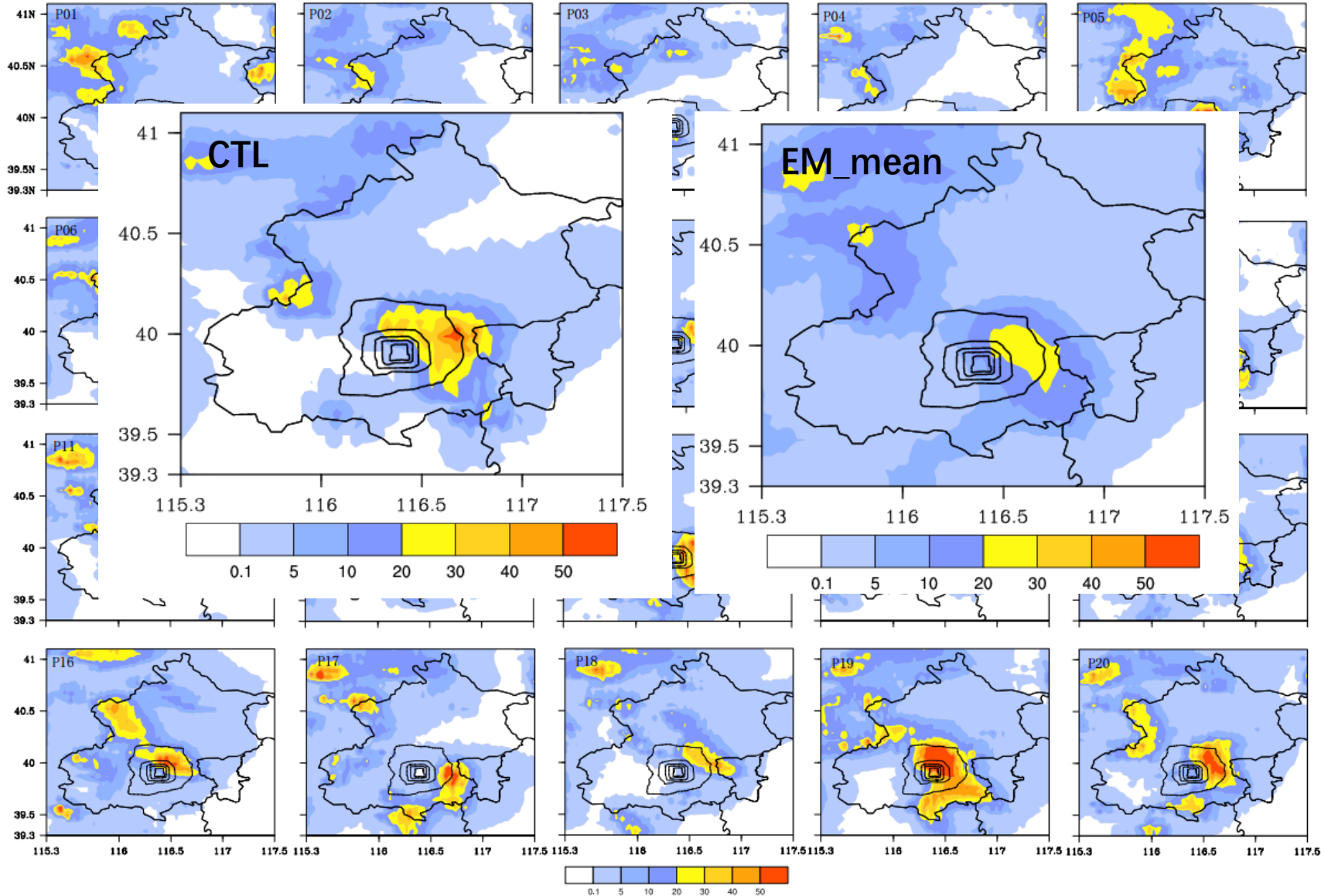
Results show that downwind urban max has

- Strongest ensemble mean (increased pp) signal (good result)
- Largest spread: ensemble means that mean is safer than guessing which result is best





个例研究城市影响降水的不确定性分析 II 初始场





个例研究城市影响降水的不确定性分析 II 初始场

	Bias pp	Bias U ₁₀	Bias V ₁₀	Bias T ₂	RMSE P	RMSE T	RMSE U	RMSE V
Control	3.94	-2.12	0.24	1.28	9.18	3.17	3.30	2.97
EM_mean	-1.15	-2.02	0.13	1.21	8.51	3.14	2.77	2.46

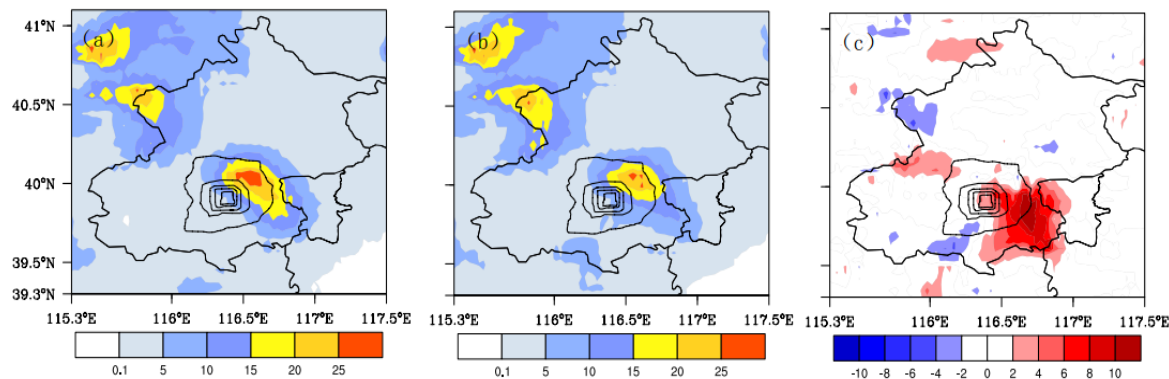
Threat score (TS, % correct at amounts > 0.1-50 mm)

	Control	EM_mean
TS ≥ 0.1	80.07	80.00
TS ≥ 10	12.75	9.90
TS ≥ 25	9.38	4.26
TS ≥ 50	1.55	0

- Bias & RMSE: obviously improved by ensemble mean
- TS for capturing precip-occurrence: uniformly good at about 80%
- TS for correctly capturing higher accumulations: not good, CTL is better than ensemble mean



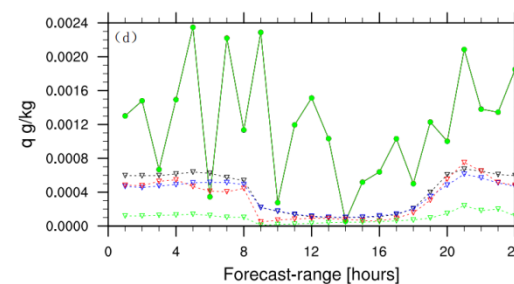
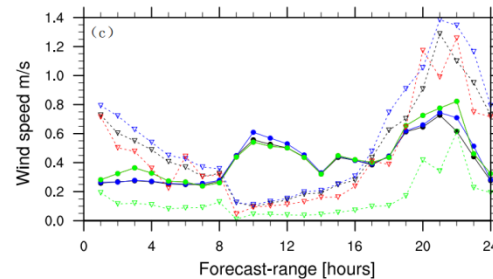
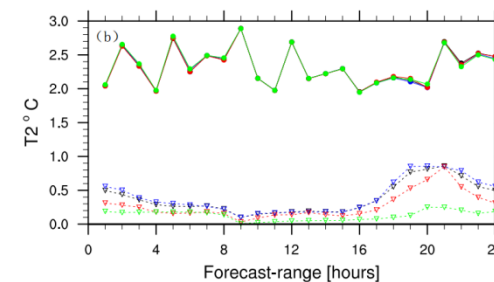
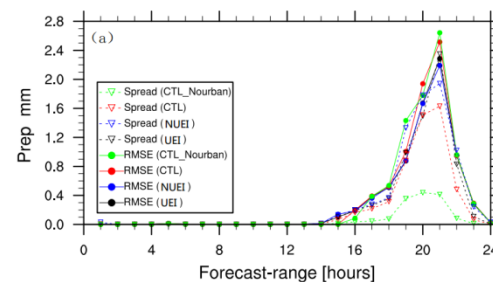
个例研究城市影响降水的不确定性分析 II 初始场



- 1) 集合试验结果显示：城市化增强了下风向降水和个例研究的结果一致。但是影响强度减少一半。
- 2) 虽然降水增加量小于个例试验的结果，但是城市影响的区域更加明确
- 3) 离散度与总降水量呈现正相关。

- 1) 有城市的试验RMSE优于无城市，预报效果提高。
- 2) 随着降水的增加，城市试验离散度明显增加。
- 3) 集合试验的离散度明显大于控制试验。

- 1) 有城市的试验对降水量和风速的模拟性能明显优于无城市的试验
- 2) 有无城市的试验对2m温度和湿度的模拟性能并无明显差异。





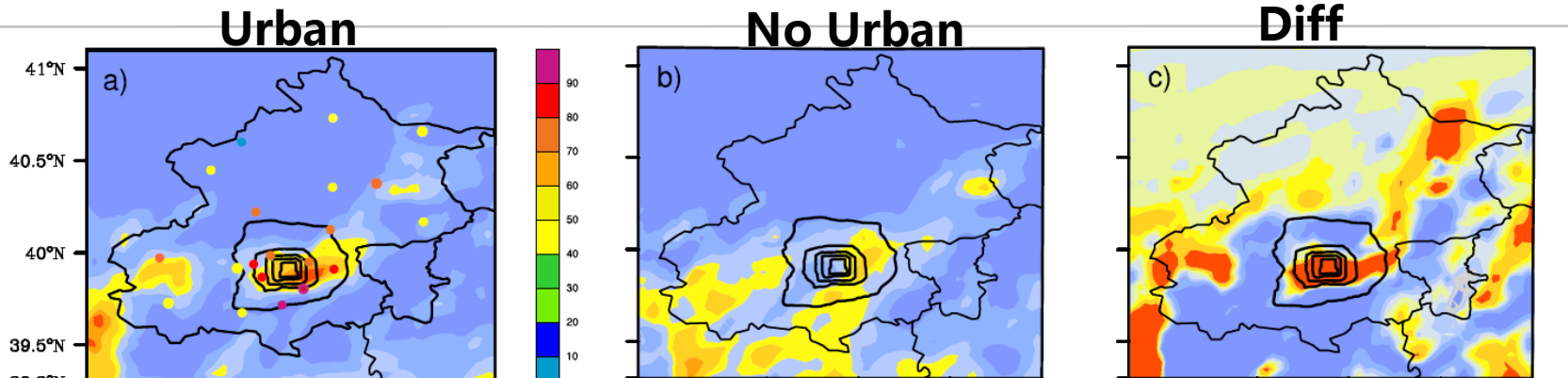
个例研究城市影响降水的不确定性分析 II 初始场

- Uncertainty of the **MP schemes** was greater than that of the **PBL schemes** for rainfall forecasting
- Bias and RMSE are obviously improved by **ensemble mean**.
- The uncertainties of the forecasting **temperature and wind field** were smaller than the uncertainty in **precipitation**. The ensemble mean can significantly improve the **forecasts of precipitation**, although some signals of extreme rainfall may be weakened.
- Studies of **urban impact on rainfall without ensemble runs probably overestimate urbanization effects on rainfall** (by **about 100%** because of model uncertainty). The ensemble approach made the spatial distribution of the urban impacts more obvious, although the **magnitude** was reduced.
- **The ensemble mean was valuable** in forecasting and studying the impact of urban land use because there was a **positive correlation** between precipitation and its spread.

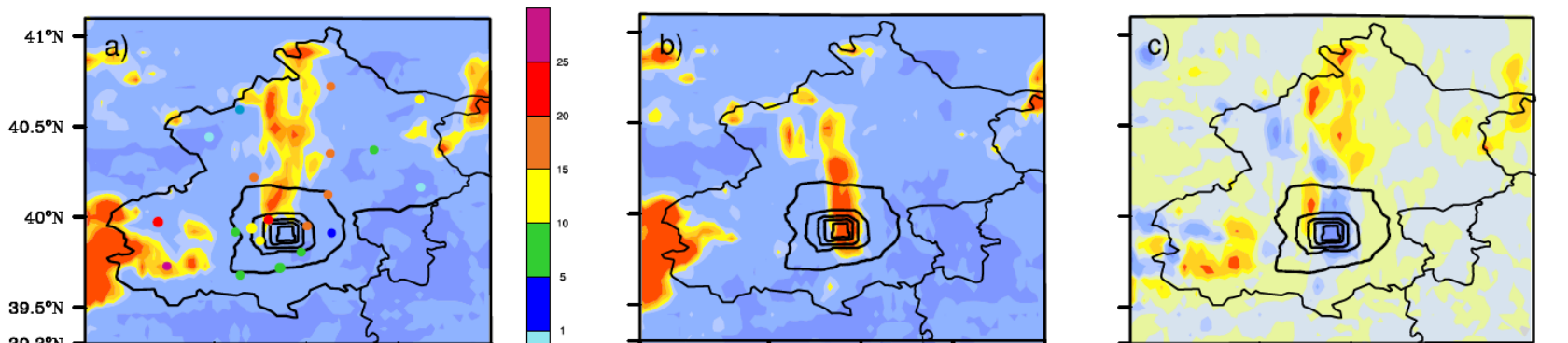


城市化对不同强度降水影响的特征和机理

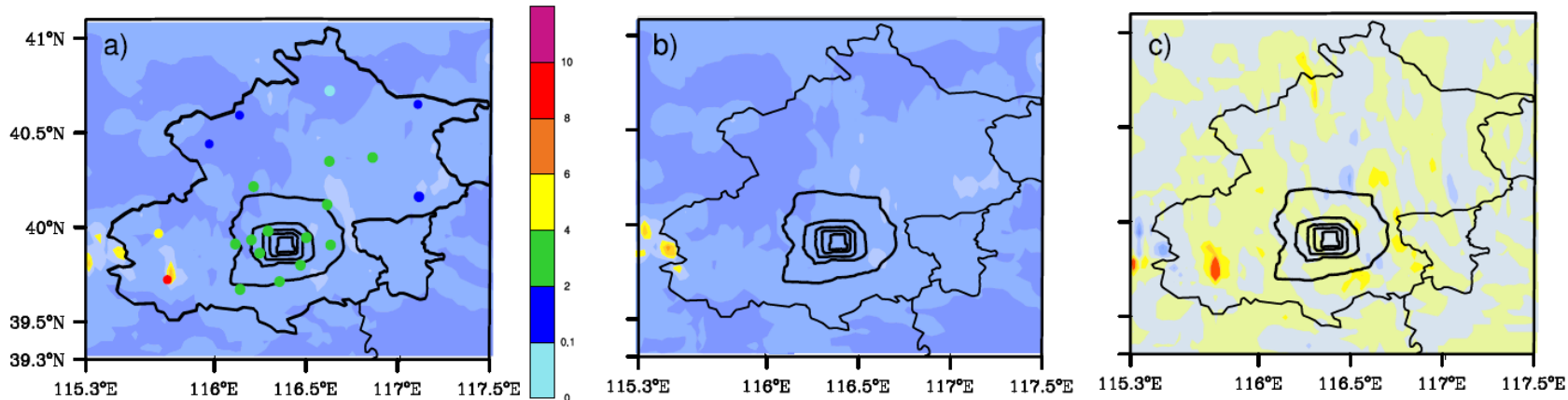
大雨



中雨



小雨





城市化对不同强度降水影响的特征和机理

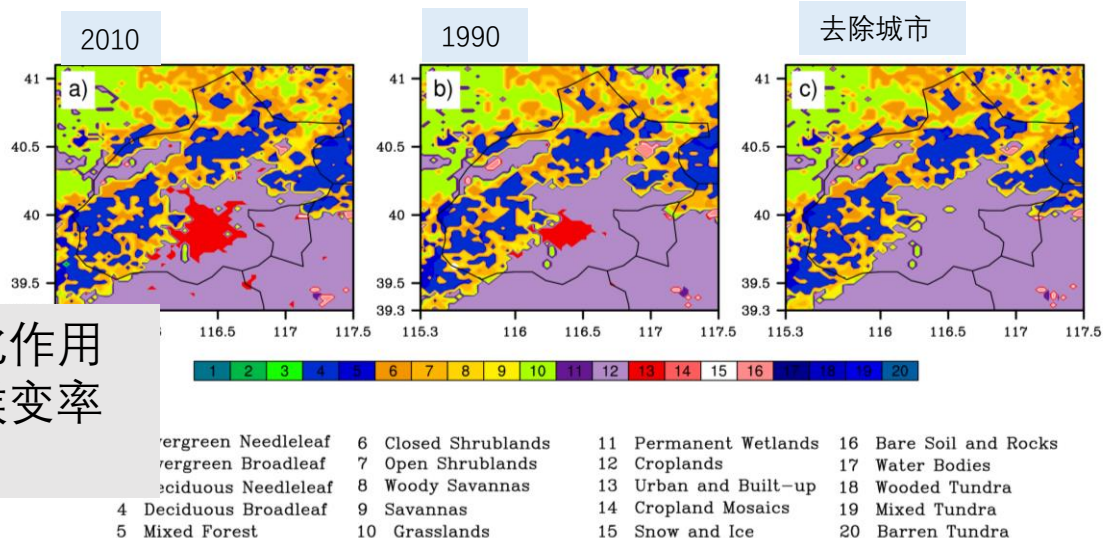
Urban impact characteristic	Total precipitation	Probability distribution of precipitation intensity	Sensible heat flux and wind field	Temperature	Moist enthalpy	Vertical velocity
Heavy rainfall	Increases the precipitation in urban and downwind areas	Increases frequency of precipitation greater than 6 mm	Sensible heat flux gradient increases with cyclonic circulation in suburban areas	The 2 m temperature is greater than 32°C, and the UHI intensity is greater than 2°C	The enthalpy increases in urban and suburban areas , and there are obvious differences between urban and rural areas	Vertical velocity increases in the urban area
Moderate rainfall	Increases precipitation in downwind suburban areas	Increases frequency of precipitation greater than 4 mm	Sensible heat flux gradient increases with cyclonic circulation in suburban areas	The 2 m temperature is greater than 30°C, and the UHI intensity is approximately 1.5-2°C	The enthalpy increases in urban and suburban areas , and there are obvious differences between urban and rural areas	No significant effect
Light rainfall	Urban impact on precipitation is not obvious	No significant effect	Sensible heat flux gradient increases , but there are no obvious features in the wind field	The 2 m temperature is greater than 25°C, and the UHI intensity is approximately 1.5-2°C	The difference in wet enthalpy of the suburban area is small	No significant effect



长期气候模拟中的城市信号

5个夏季长期模拟

试验设计



观测中提取的城市化作用包括除了大尺度气候变率以外的影响因子

模式中城市化作用主要包括地表利用的改变和人为热的作用

地表利用类型	北京 2010 年地表利用类型地图	北京 1990 年地表利用类型地图	北京去除城市的地表利用类型地图
初始场, 强迫场			
2008-2012年 6.15-8.01 FNL	控制试验 Landuse_2010	敏感性试验一 Landuse_1990	敏感性试验二 Landuse_nourban
1990年 6.15-8.01 ERA-interim		敏感性试验三 1990	敏感性试验四 Landuse_nourban_1990

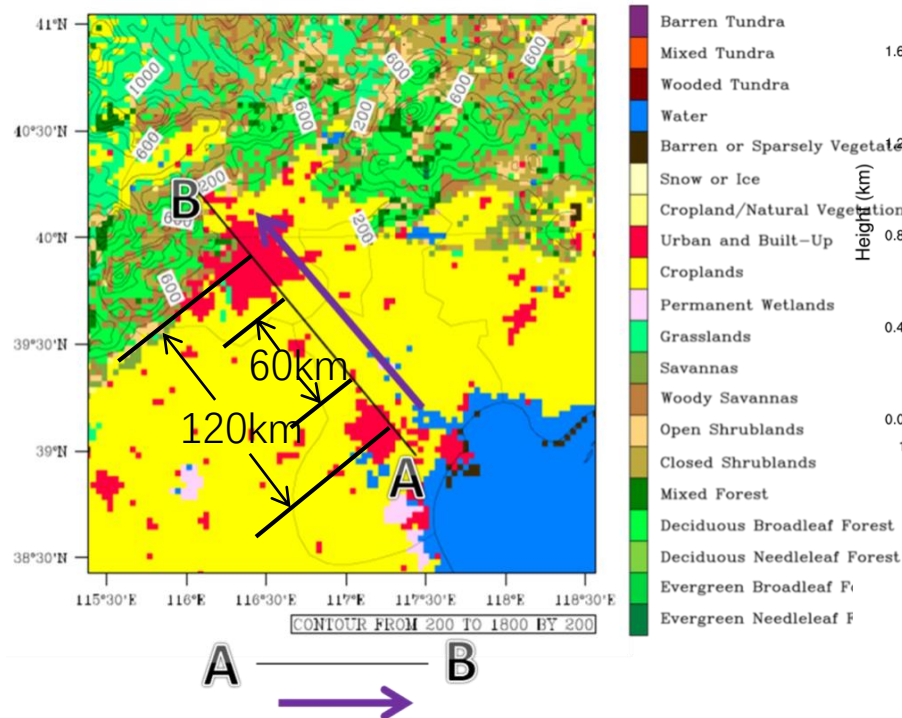
研究目的：揭示北京城市化进程的气候效应和不同年代大尺度气候强迫引发的城市化效应的差异



长期气候模拟中的城市信号

5个夏季长期模拟

W/m²



沿着主导风方向，从A到B做剖面

白天，天津和北京地表两个城市热岛，向下风向漂移10-40km左右。

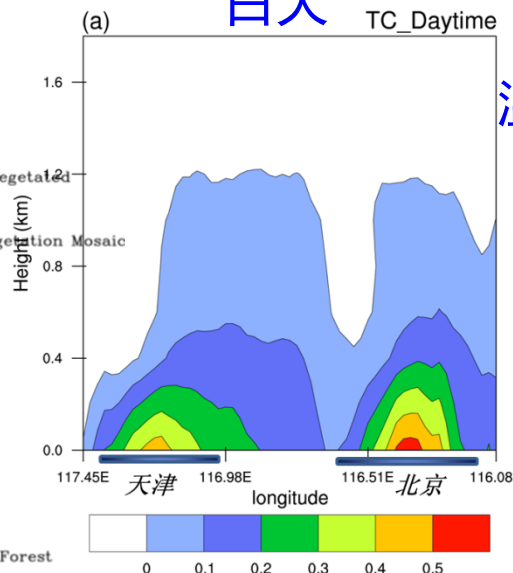
夜间，风速小，边界层稳定度大，局地热岛。

白天城市热力、动力湍流强烈，通过湍流向上

输送的水汽量很大，城市低层比湿降低，夜间，城市凝露量少，比湿比白天有所升高。

白天

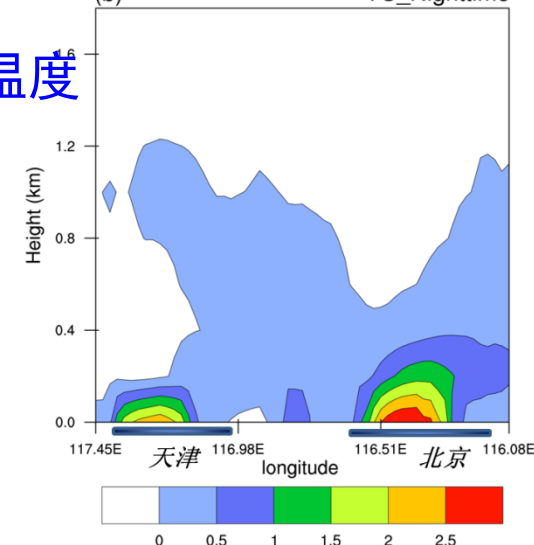
TC_Daytime



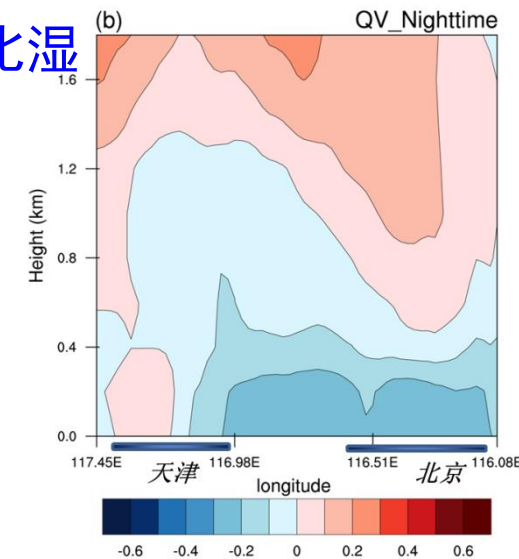
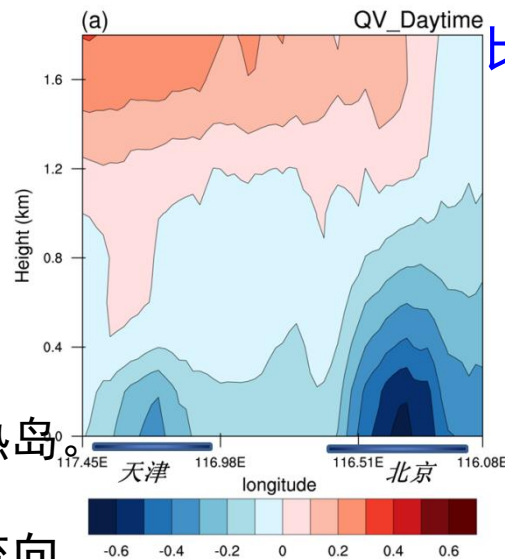
夜间

TC_Nighttime

温度



比湿

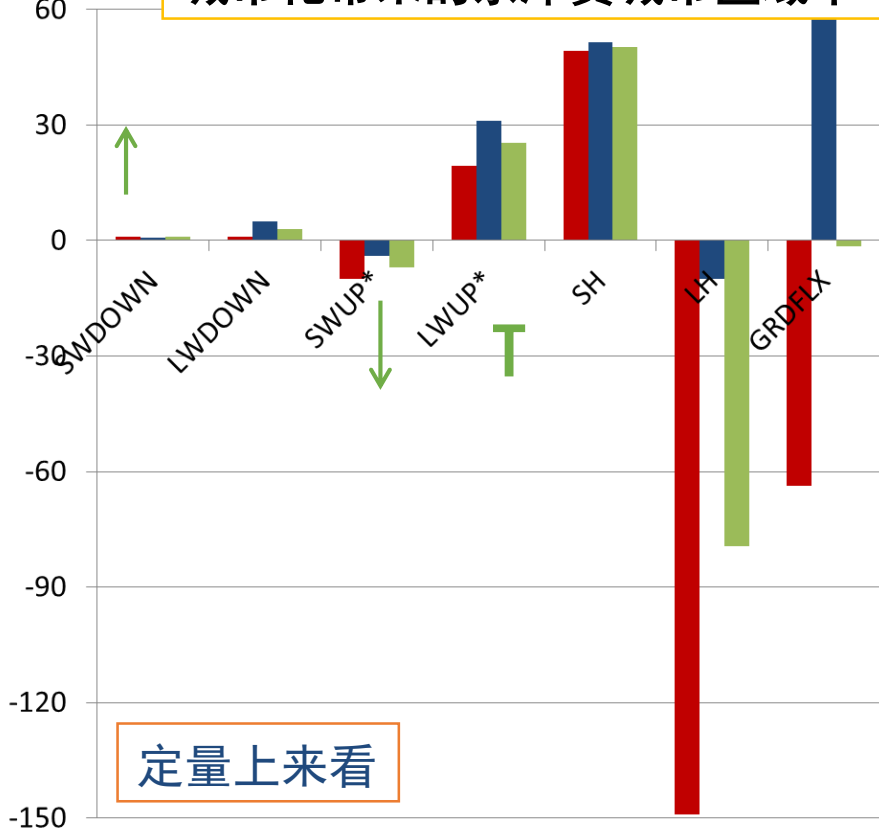




长期气候模拟中的城市信号

5个夏季长期模拟

W/m² 城市化带来的京津冀城市区域平均变化



地表吸收的净短波辐射增加（反照率减小）。

LWUP, 夜间增加幅度约为白天的1.8倍。

定量上来看

感热白天、夜间变化量：50W/m² 左右
感热夜间由负变正

白天潜热通量的减少幅度最大
接近150W/m²

土壤热通量变化：60W/m²

■ 白天
■ 夜间
■ 全天

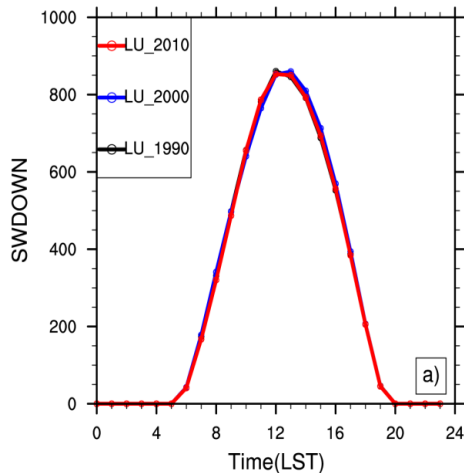
变量	UtoC		LU2010	
	白天	夜间	白天	夜间
TSK	305.66	296.13	307.86	300.62
T2	302.4	296.72	302.94	298.98
SWDOWN	520.57	29.09	521.65	29.87
LWDOWN	409.39	398.98	410.44	404.05
SWUP*	96.05	5.37	86.14	1.39
LWUP*	479.9	422.81	499.26	453.96
SH	138.58	-3.04	187.77	48.45
LH	168.49	11.75	19.48	1.77
GRDFLX	-34.56	21.12	-98.28	81.77



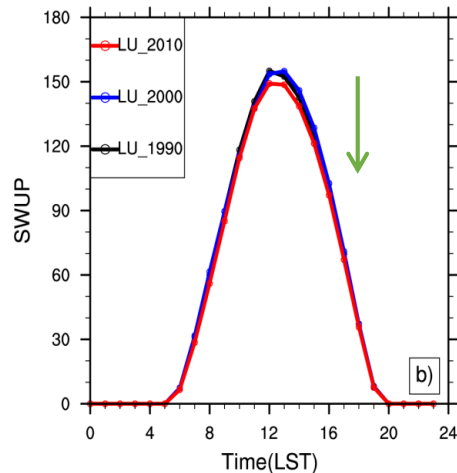
长期气候模拟中的城市信号

5个夏季长期模拟

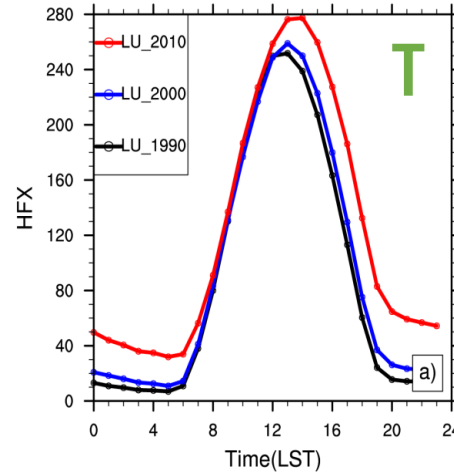
向下短波辐射通量



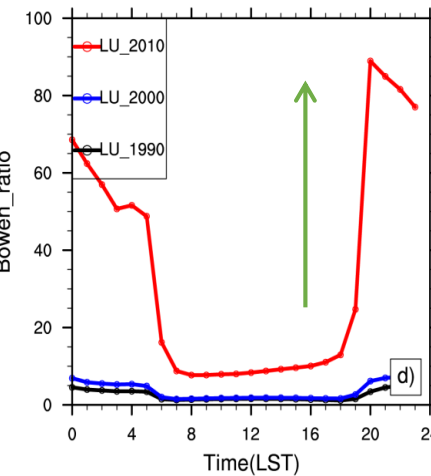
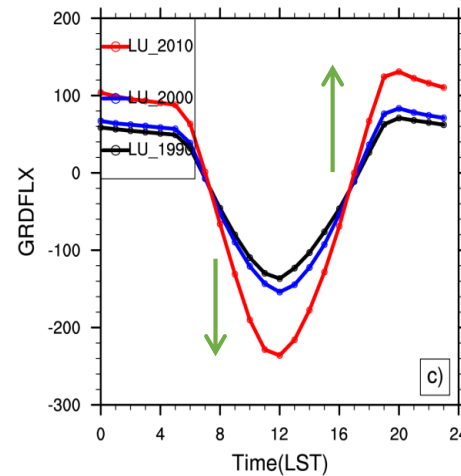
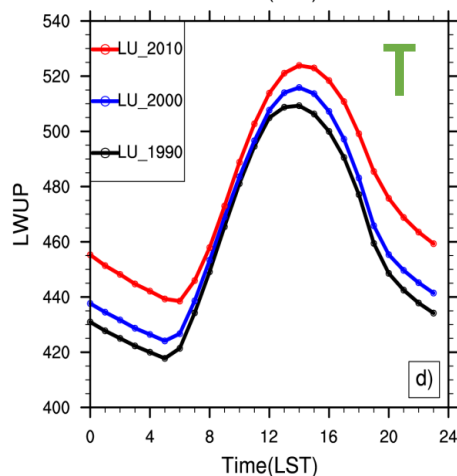
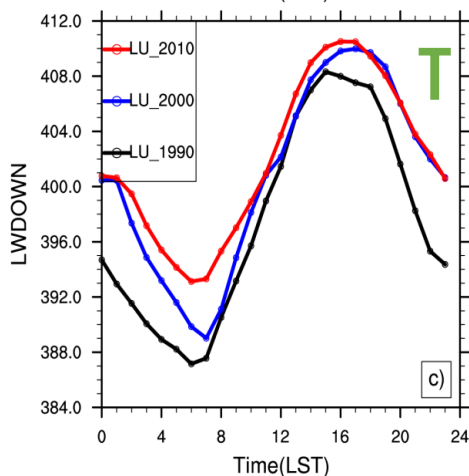
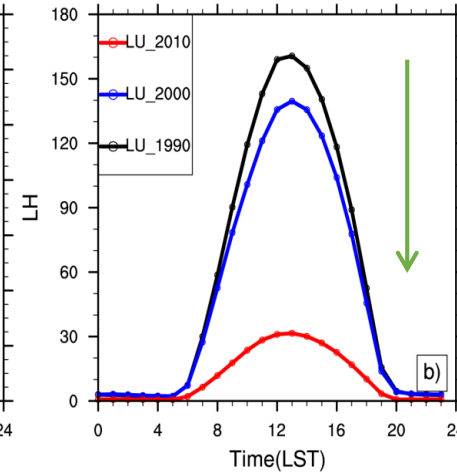
向上短波辐射通量



感热通量



潜热通量



向下长波辐射通量

向上长波辐射通量

土壤热通量

波文比

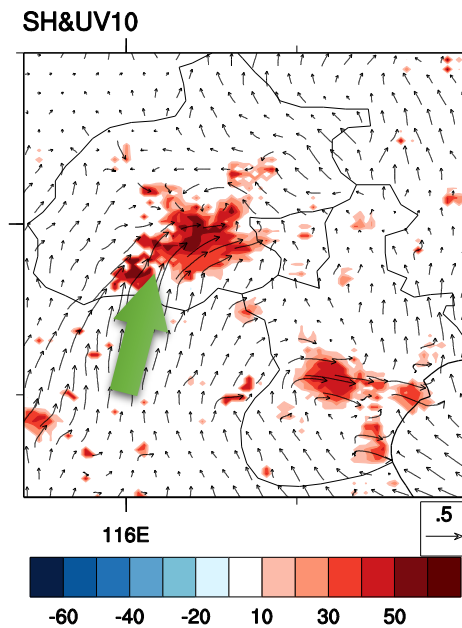
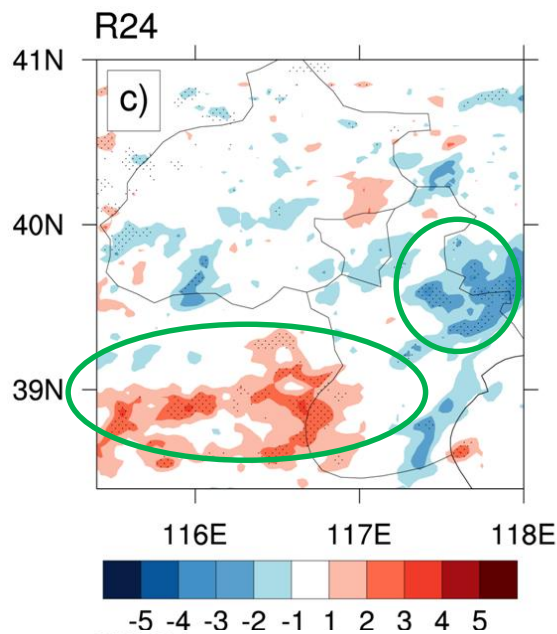


长期气候模拟中的城市信号

5个夏季长期模拟

对降水的影响

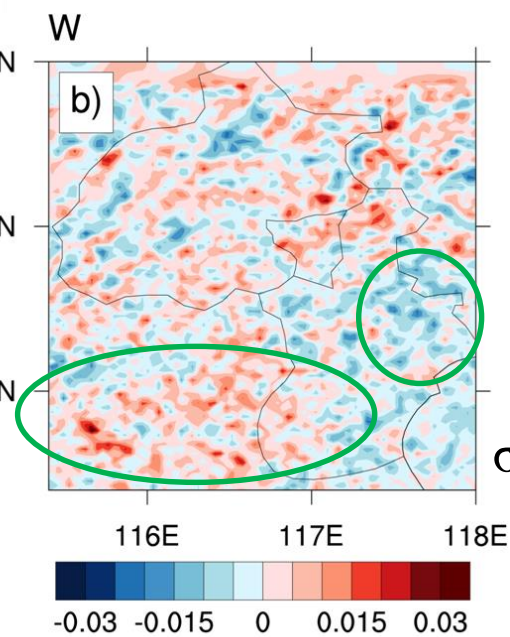
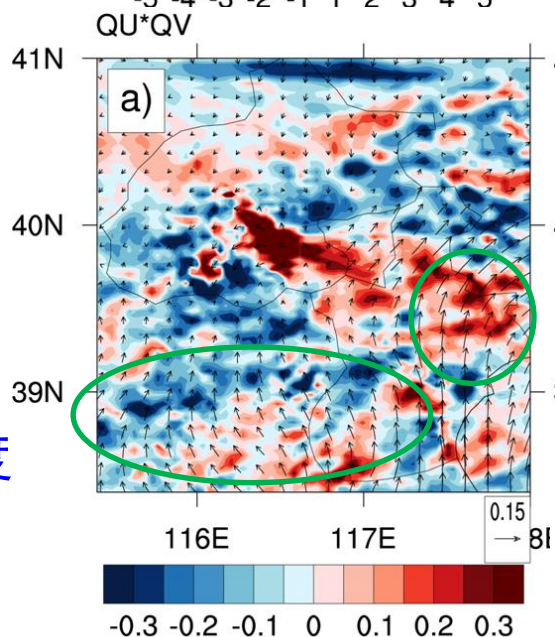
24h降水量



感热及地表风场
风向向着城市热岛地区辐合，对应着感热的增加
城市冠层的存在，使得降水系统分支或分散。

Baik et al., 2001

整层积分的水汽
通量输送及其散度



垂直速度
 $\sigma=0.46$ 约500hpa



长期气候模拟中的城市信号

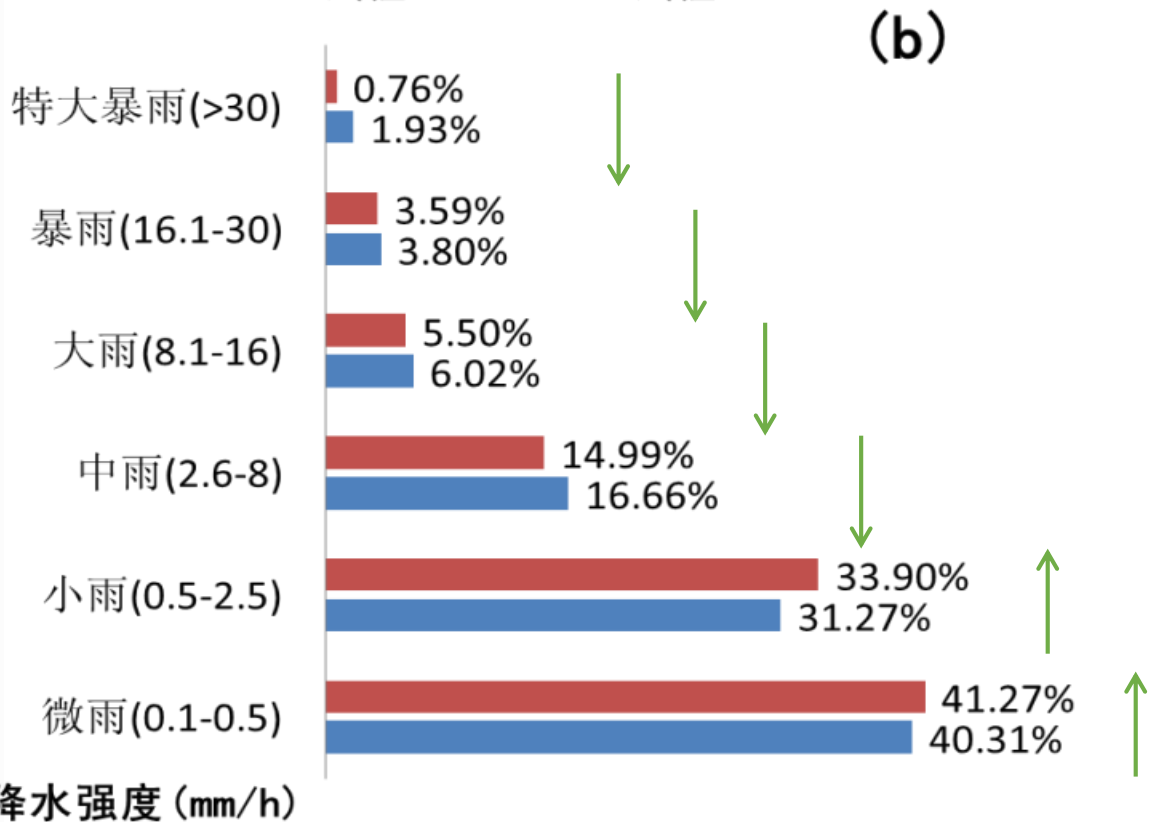
5个夏季长期模拟

京津冀城市区域
(2008-2012) 夏季

UtoC 试验: 3.12mm/h
LU2010 试验: 2.71mm/h

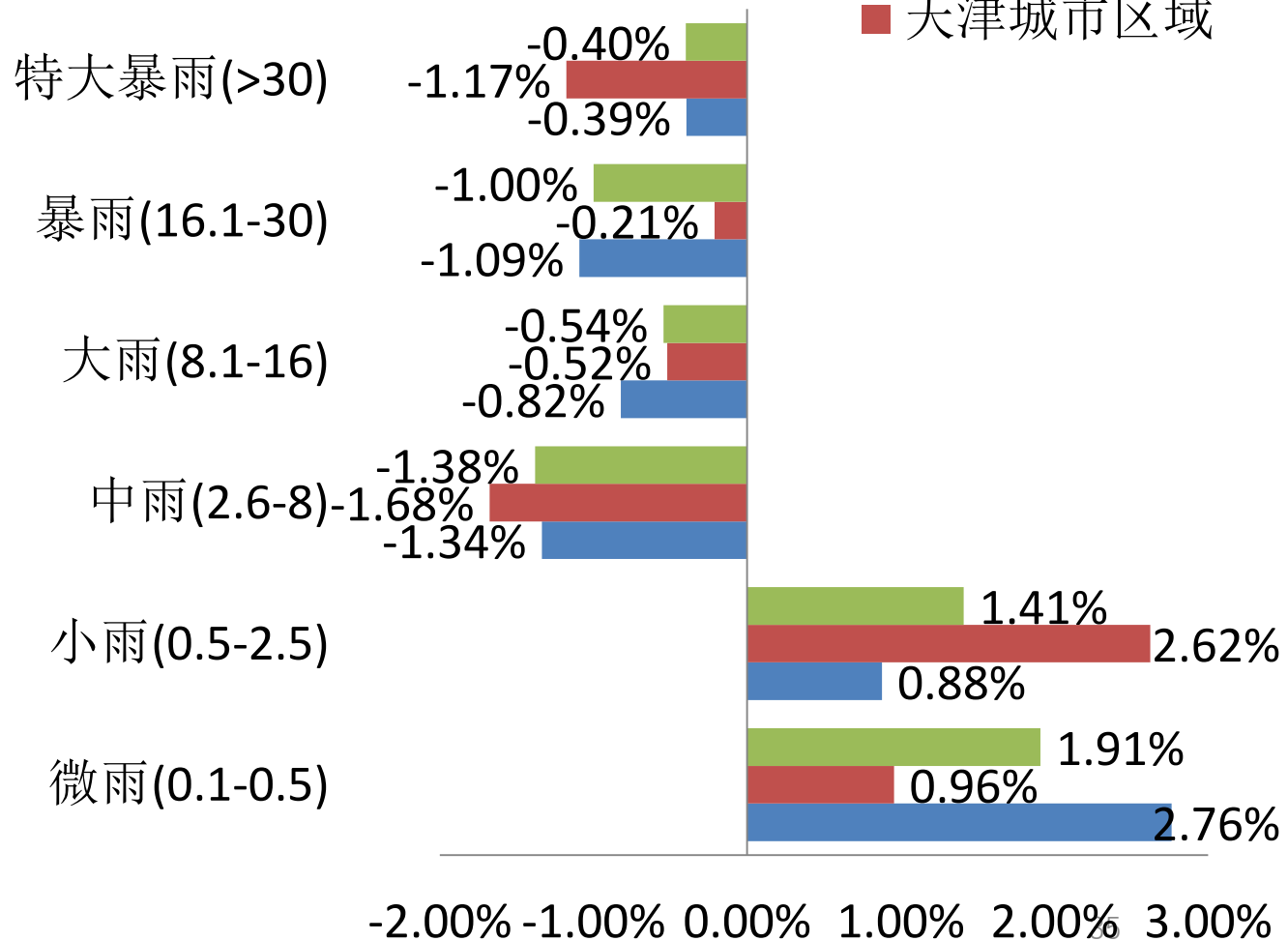
各降水强度所占比例

■ 试验LU2010 ■ 试验UtoC



城市化造成的各降水强度时数比例的变化

■ 京津冀城市区域
■ 天津城市区域



根据中国气象上对降水强度分类的规定



现有研究总结和 research 计划

Region	Cases	Synoptic Condition	Factors	Urban-impact	References
Beijing	2003 0604	convective cloud system	land cover change	precipitation become more concentrated and intensified	Guo <i>et al.</i> , 2006
Beijing	2006 0801	weak synoptic forcing	land cover change, anthropogenic heat	rainfall become more locally concentrated	Miao <i>et al.</i> , 2011
Beijing	2008 0627	cold frontal system	land cover change	modify the precipitation distribution; enhance the maximum intensity	Zhong and Yang, 2015
Beijing	2012 0721	vortices, troughs, cold fronts, low-level jets	land cover change, anthropogenic heat	Enhance urban and downwind precipitation ; spatial distribution become more concentrated	Yu and Liu, 2015
Beijing	2012 0721	the same as above	land cover change	weak (recent high urban development caused no significant change of precipitation)	Wang <i>et al.</i> , 2015
Beijing	2016 0719	cold vortex, low - level jet and monsoon system	anthropogenic aerosol emission	dispersion (suppressed precipitation intensity)	Guo <i>et al.</i> , 2019
Xiong'an	2016 0720	the same as above	land cover change	convective activity increased and rainfall in downwind area enhanced)	Xing <i>et al.</i> , 2019



现有研究总结和 research 计划

Region	Cases	Synoptic Condition	Factors	Urban-impact	References
Yangtze River Delta	2003 0705	southwesterly monsoon	land cover change	rainfall slightly increase in the downwind of the city belt and decrease in the upwind	Wan <i>et al.</i> , 2013
Yangtze River Delta	2006 0724	strong winds and large spatial convergence	land cover change, aerosol emission	dispersion (suppresses precipitation)	Zhong <i>et al.</i> , 2017
Yangtze River Delta	2006 0702	weak synoptic forcing	land cover change, aerosol emission	enhances the convergence of moisture fluxes; aggregation	Zhong <i>et al.</i> , 2017
Shanghai	2014 0913	convective process	land cover change	precipitation become more concentrated	Zhang <i>et al.</i> , 2017
Guangzhou	2017 0710	slowly evolving synoptic conditions with continuously transported moisture	land cover change	aggregation (but in a lesser extent than synoptic and topographic effect)	Huang <i>et al.</i> , 2019
Yangtze River Delta	2017 0710	convective cloud system	anthropogenic aerosol emission	precipitation become more concentrated ; the central value becomes stronger	Liu <i>et al.</i> , 2019



现有研究总结和 research 计划

不足和难点

个例研究

- 如何解决普适性？
- 不同影响因子（地表利用；人为热；气溶胶）的相互作用？
- 强降水的研究较多，中小降水的研究较少（气溶胶）

长期气候模拟

- 如何分离大尺度气候信号和城市化的贡献，量化城市化的贡献
- 机理分析？

研究计划

个例研究

- 解决模拟中的不确定性，多个例集合，集合同化技术
- 城市影响的客观平均标准 Lorenz et al. 2019
- 区分不同天气类型模拟 Shastri et al. (2015)
- 更先进的城市冠层模型
多层城市冠层的改进（人为热；水文）

长期气候模拟

- 机理分析？量化城市化贡献
- 未来气候变化情景下，城市热岛（城市化对降水效应）增强还是减弱？

A nighttime photograph of a city skyline, likely Beijing, featuring illuminated skyscrapers and a clear night sky with a crescent moon. A central white-bordered box contains the text.

谢谢大家

Q&A

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