Observing and Modeling the Urban Boundary Layer in Beijing

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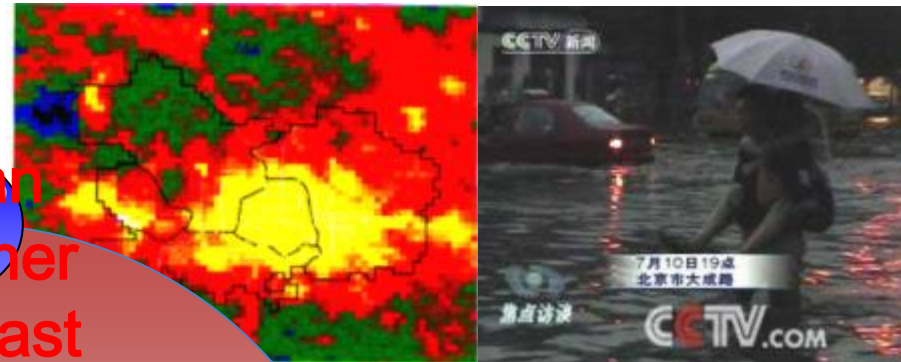
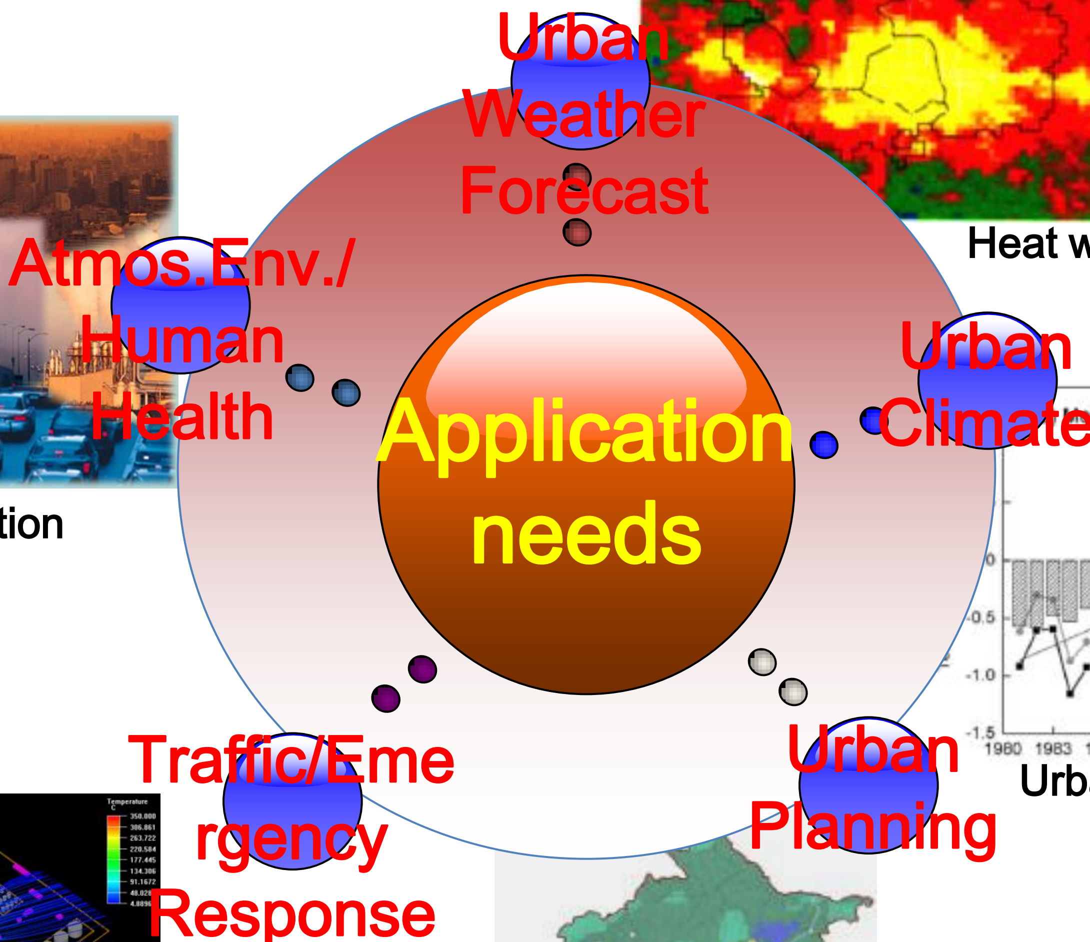
National Center for Atmospheric Research

22 June 2012

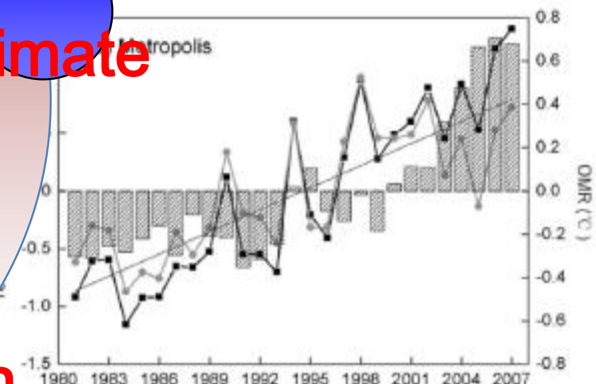
Application needs



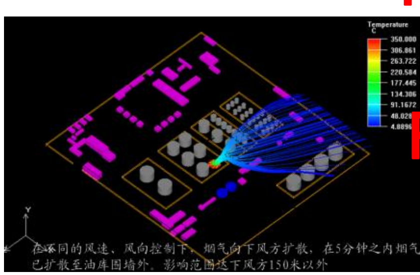
Heat wave, heavy rainfall




Urban pollution



Urban climate change



Emergency response


Urban planning accessment

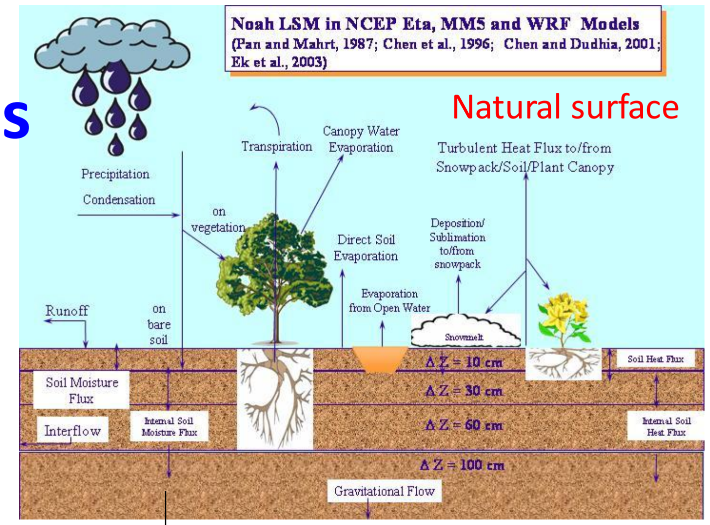
Contents

1、Urban canopy model

1） Improved latent heat flux modeling over urban surfaces

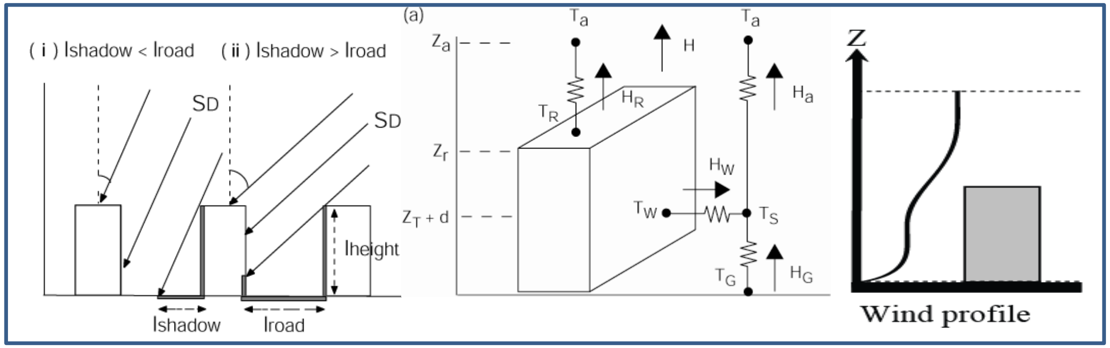
2） Improved surface wind

3） Optimizing UCM parameters



Coupled through 'urban fraction'

Urban canopy model: Man-made surface



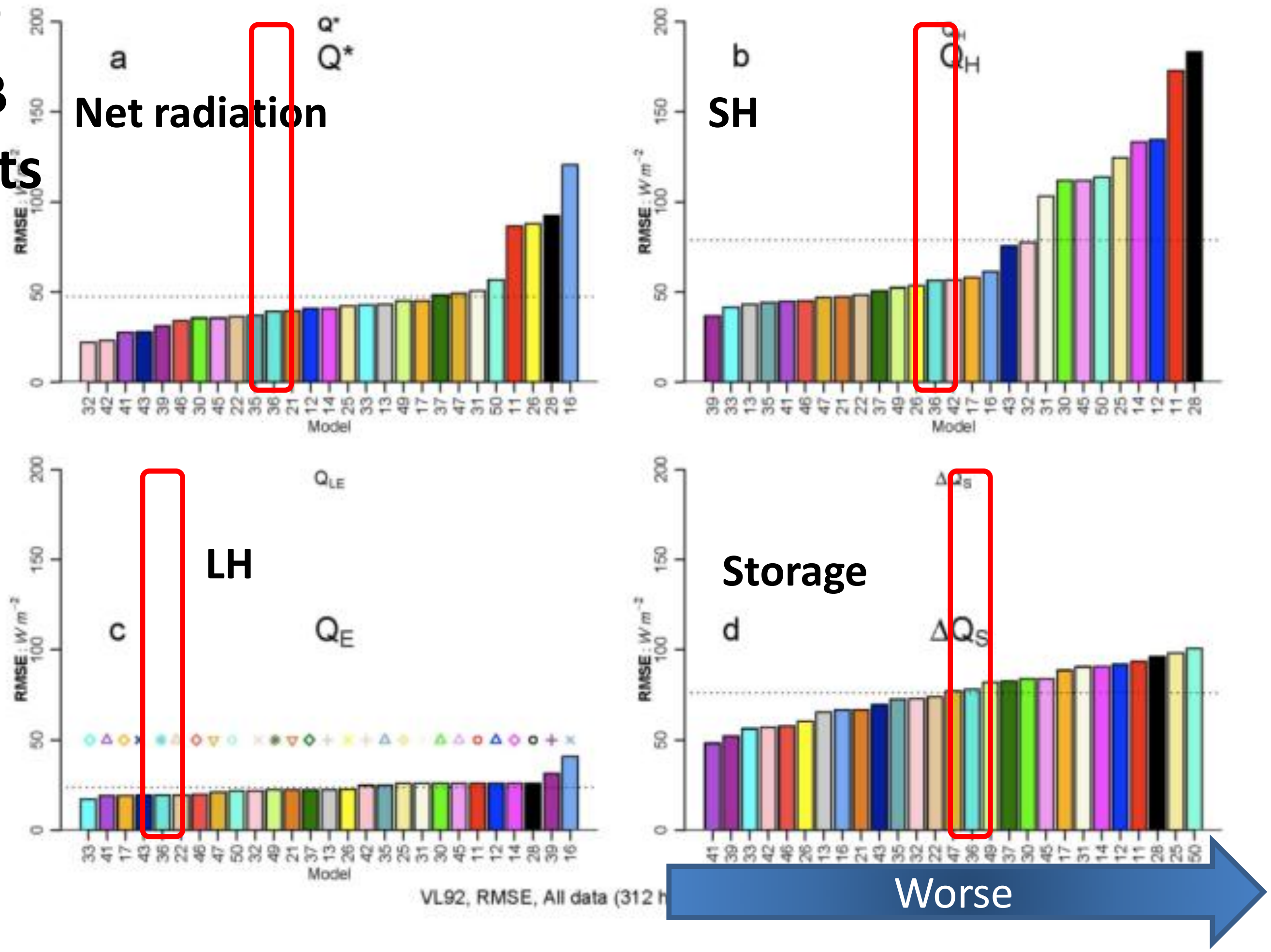
Noah/SLUCM (Kusaka 2001; Miao 2008, 2009,2011)

The International Urban Energy Balance Models Comparison Project

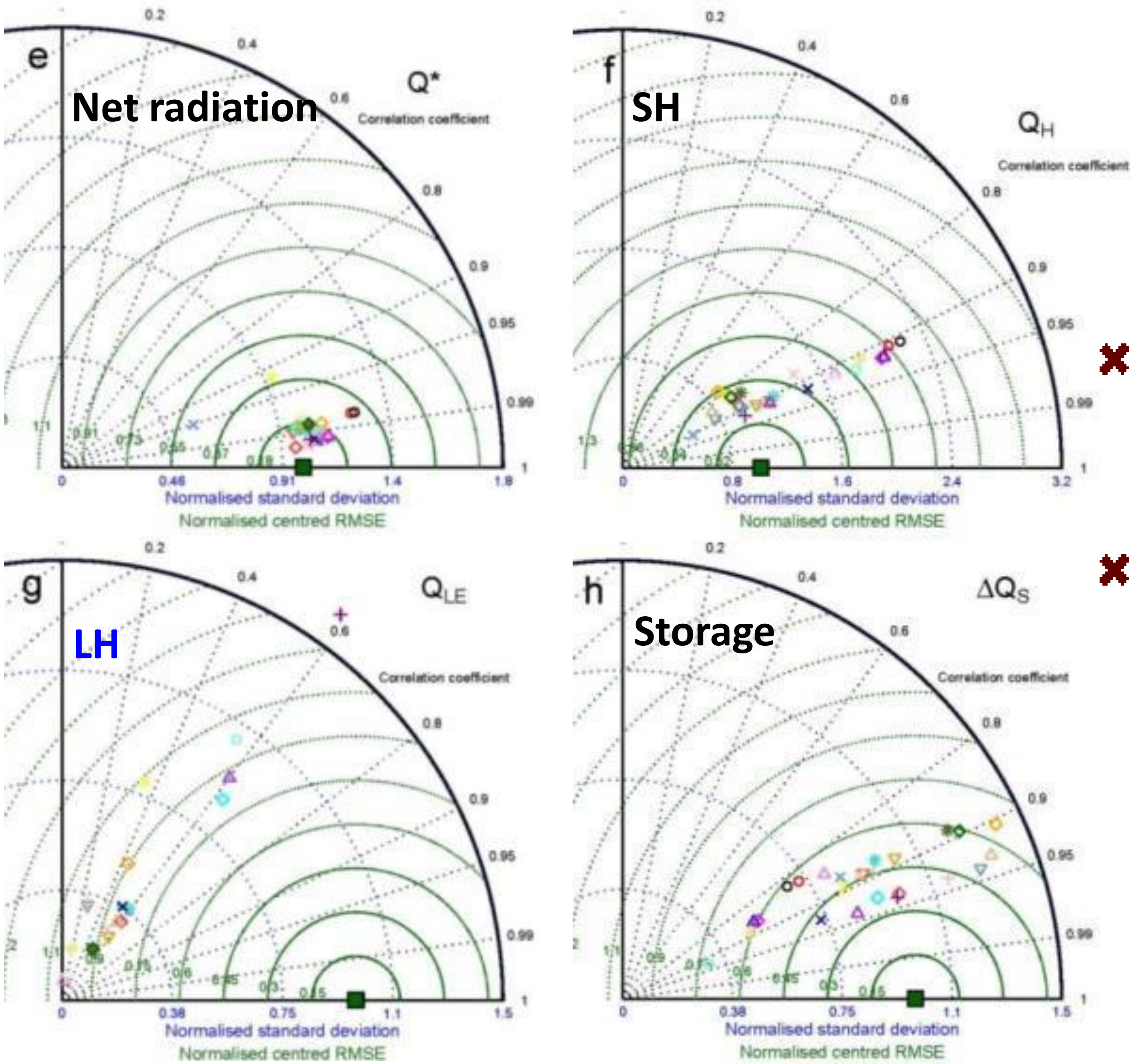
(CSB Grimmond)

33 UCMs: IUM/NCAR WRF/Noah/SLUCM (Miao and Chen， ～11)
NJU-UCM-S, NJU-UCM-M (Zhang and Jiang)

RMSE for every SEB components



Taylor plot for every SEB components



- Overestimate Q_H、 underestimate Q_E
- Worst performance of Q_E: $RMSE_s > RMSE_u$

1) Improved latent heat flux modeling over urban surfaces

1) **Irrigation in urban area:** **Set SM from 0-1m (1-3 model layers) to SMCREF (field moisture capacity) during 06-08 PM, from May to September.**

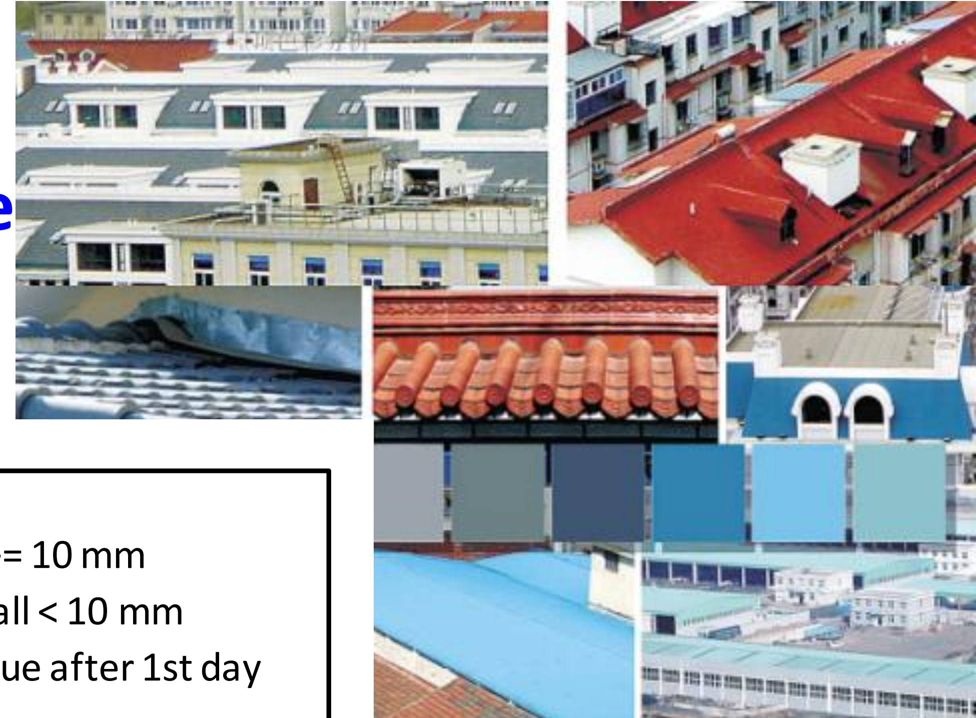
2) Oasis effect

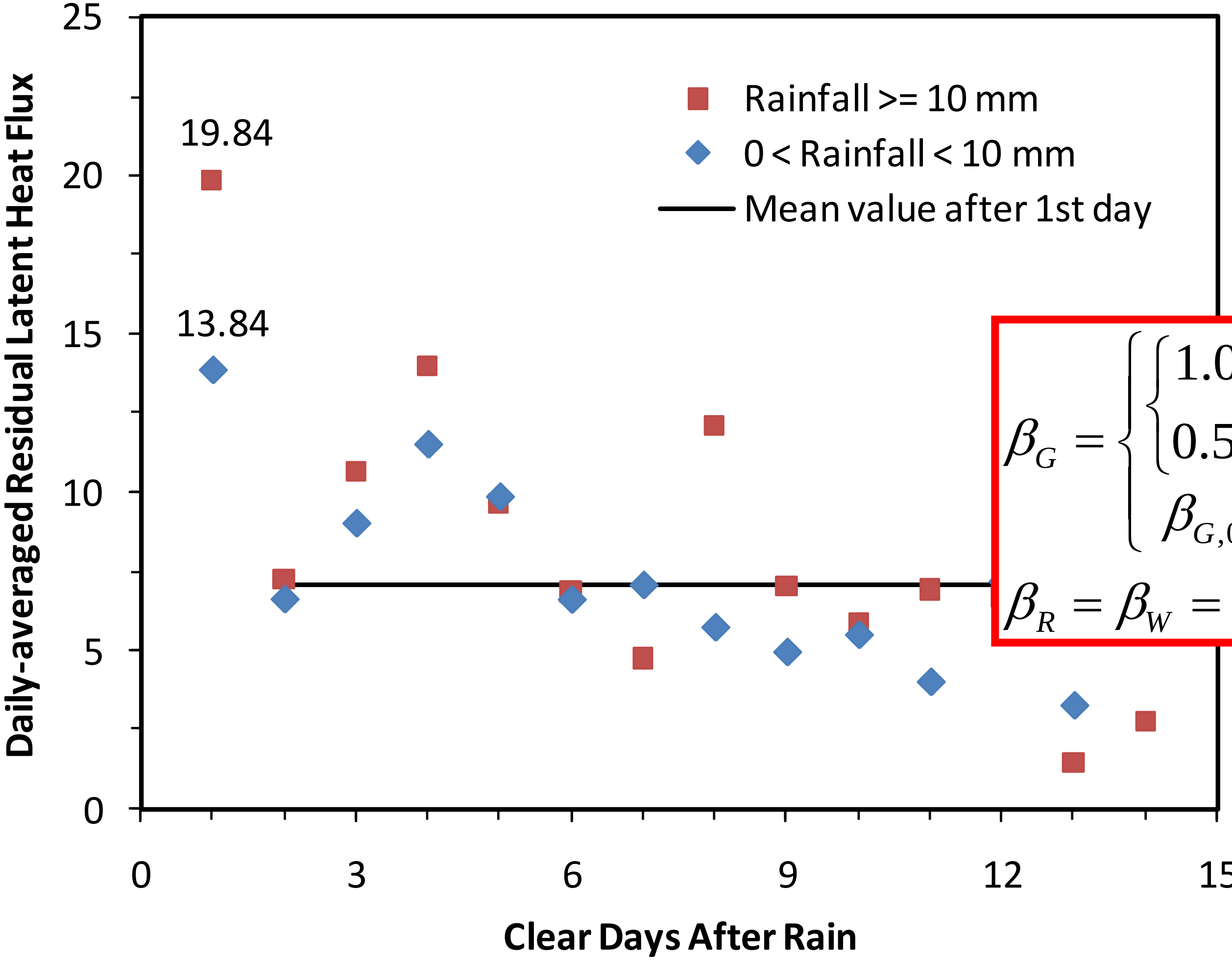
Oasis coefficient: α_{oasis}=1.5

Diurnal mean LH under different conditions for 4 seasons: Obs: observation, Veg: simulated LH for vegetation from case 2, Res: difference of these two values.

		Spring	Summer	Autumn	Winter
Obs	Clear	23.9	65.1	23.2	8.7
	Cloudy	20.7	46.3	18.7	7.2
Veg	Clear	15.6	36.0	10.6	1.5
	Cloudy	10.3	23.9	7.3	1.3
	Veg_Diff (Clear-Cloudy)	5.3	12.1	3.3	0.2
Res	Clear	8.3	29.0	12.6	7.2
	Cloudy	10.4	22.4	11.3	5.9
	Res_Diff (Clear-Cloudy)	-2.1	6.6	1.3	1.3
1 + Res_diff / Veg_diff		0.6	**1.5**	1.4	7.5

3) LH from impervious surface



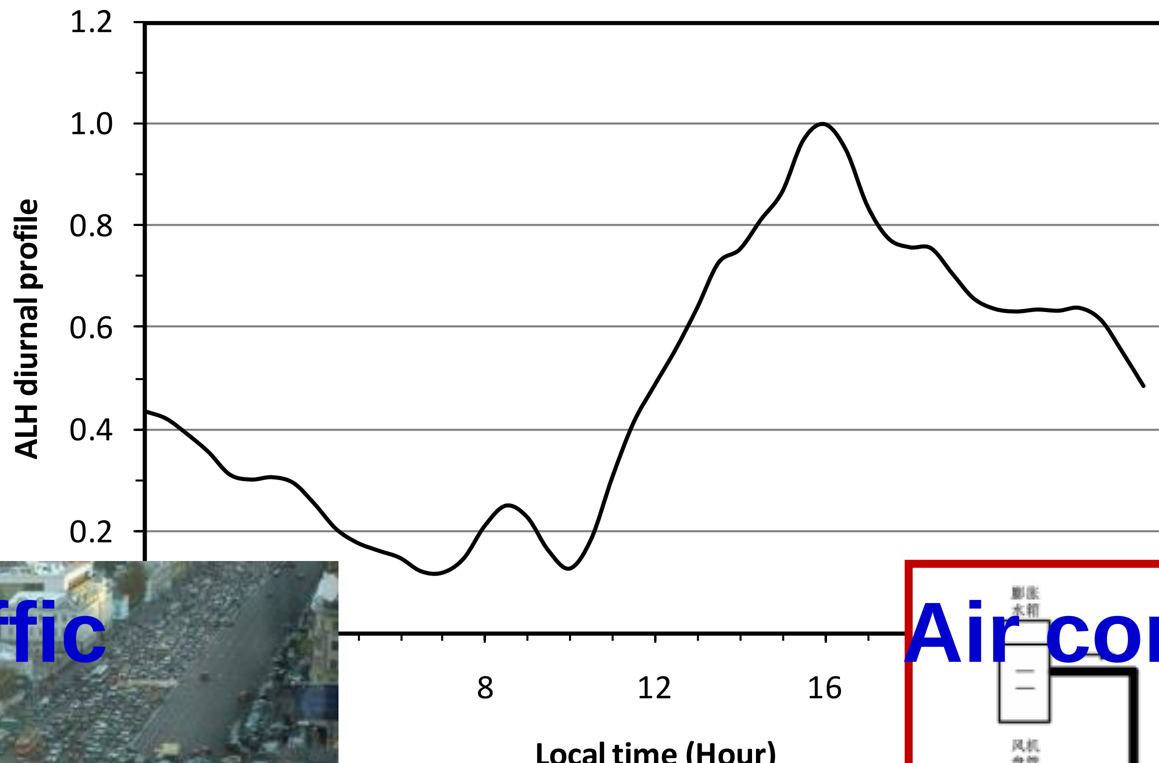


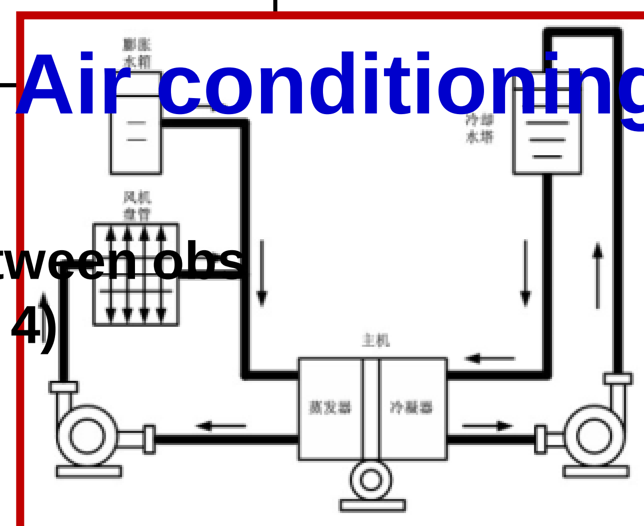
$$\beta_G = \begin{cases} \begin{cases} 1.0 \quad , & R \geq 10mm \\ 0.5 \quad , & 0 < R < 10mm \end{cases}, & Rain \\ \beta_{G,0} e^{(-dt/5)}, & No\,rain \end{cases}$$

$$\beta_R = \beta_W = \beta_G$$

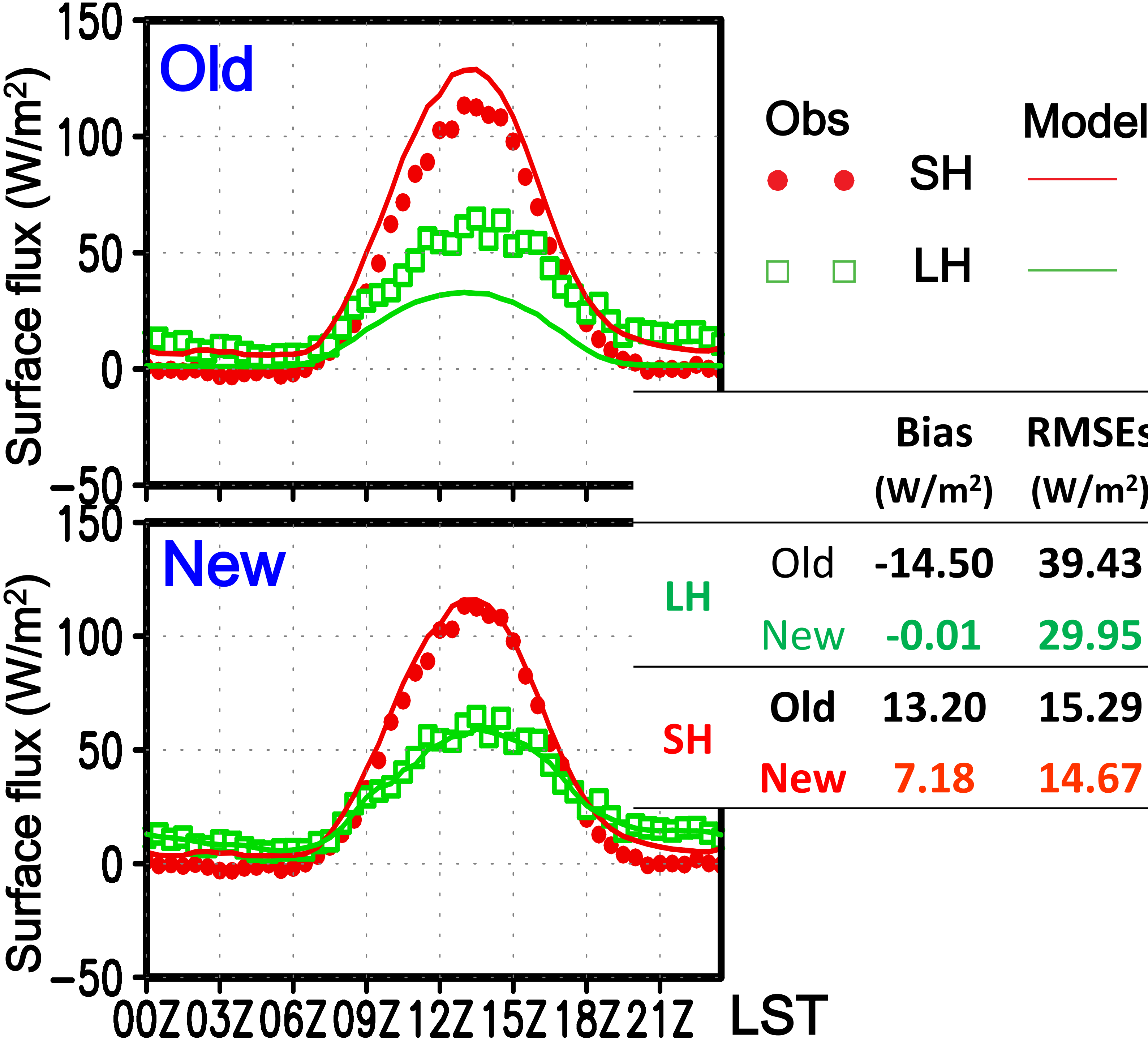
Variation of diurnal mean LH from impervious surface in summer (diff between obs and LH from veg in Case 3) with clear days after rain

4) ALH: Max. for Spr, Sum, Aut, and Win are 17, 42, 24, and 18 W m^{-2}



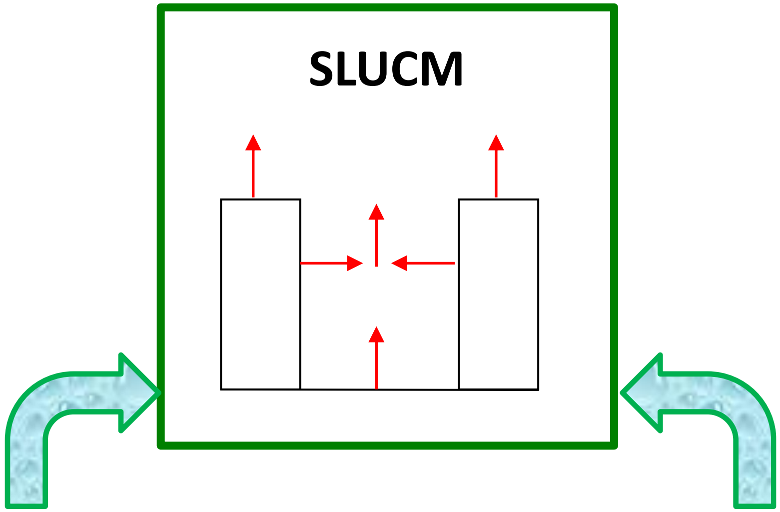


Diurnal variation of ALH (Diff. between obs and sim. value from Case 4)

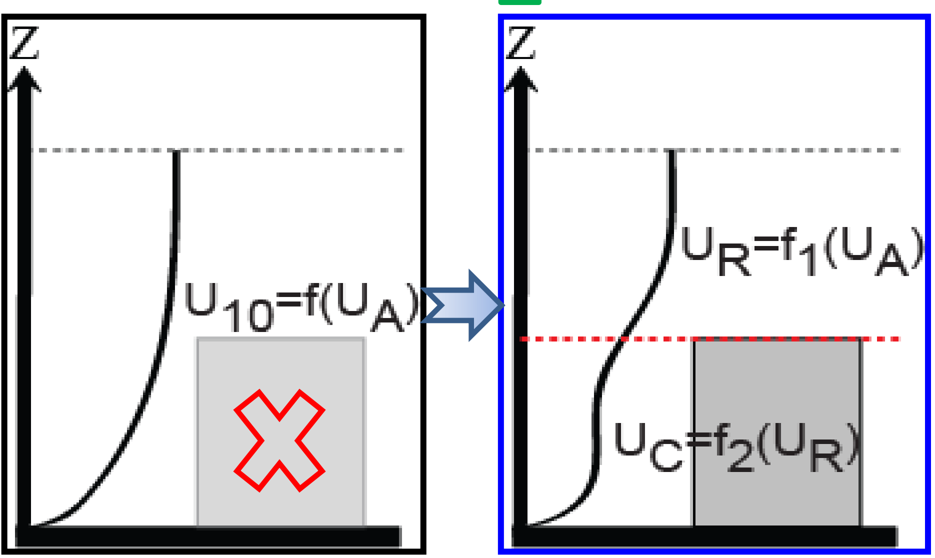


		Bias (W/m²)	RMSEs (W/m²)	IOA
LH	Old	-14.50	39.43	0.61
	New	-0.01	29.95	0.72
SH	Old	13.20	15.29	0.87
	New	7.18	14.67	0.87

2）Improved surface wind



3）Optimizing UCM parameters：

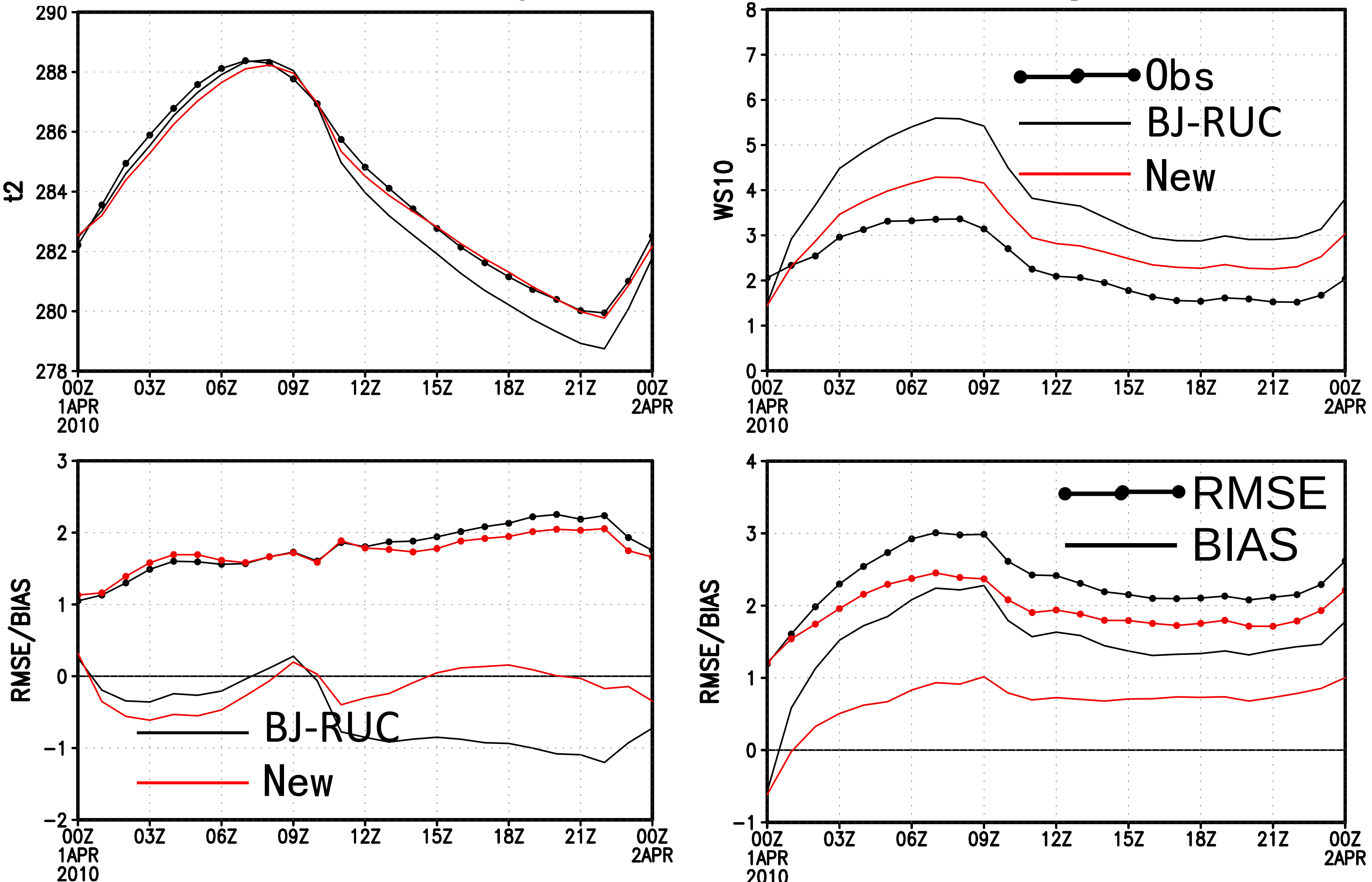


Morphological

Physical

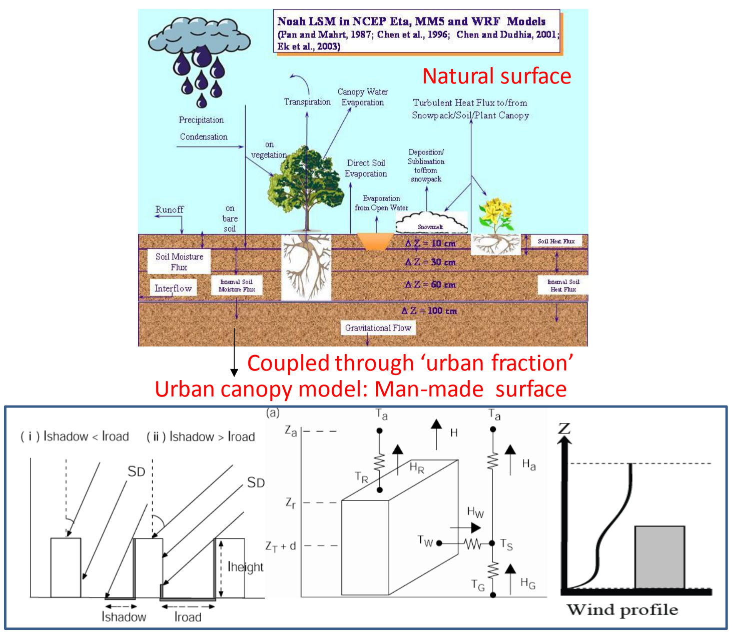
Evaluation:

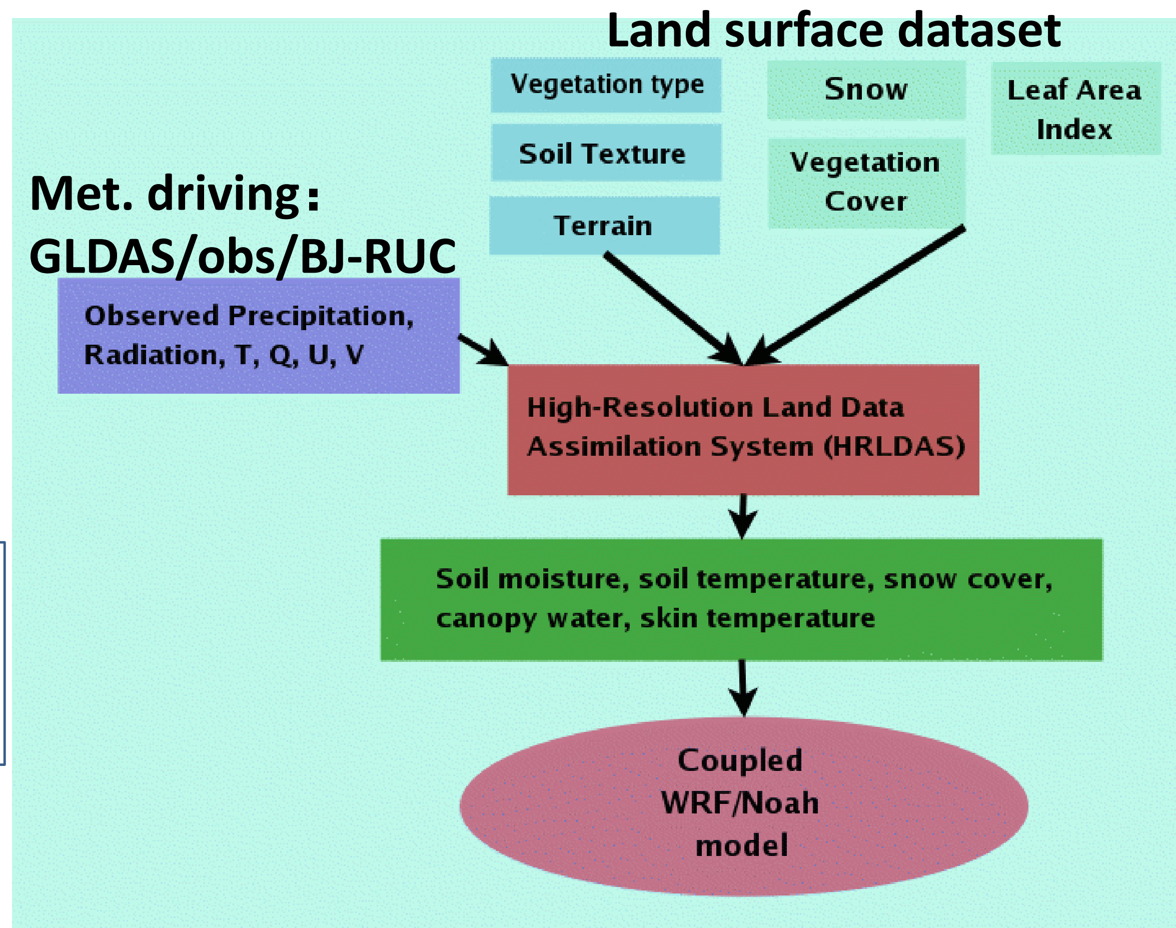
2m T、10m Wind Speed from BJ-RUC for April 2010）



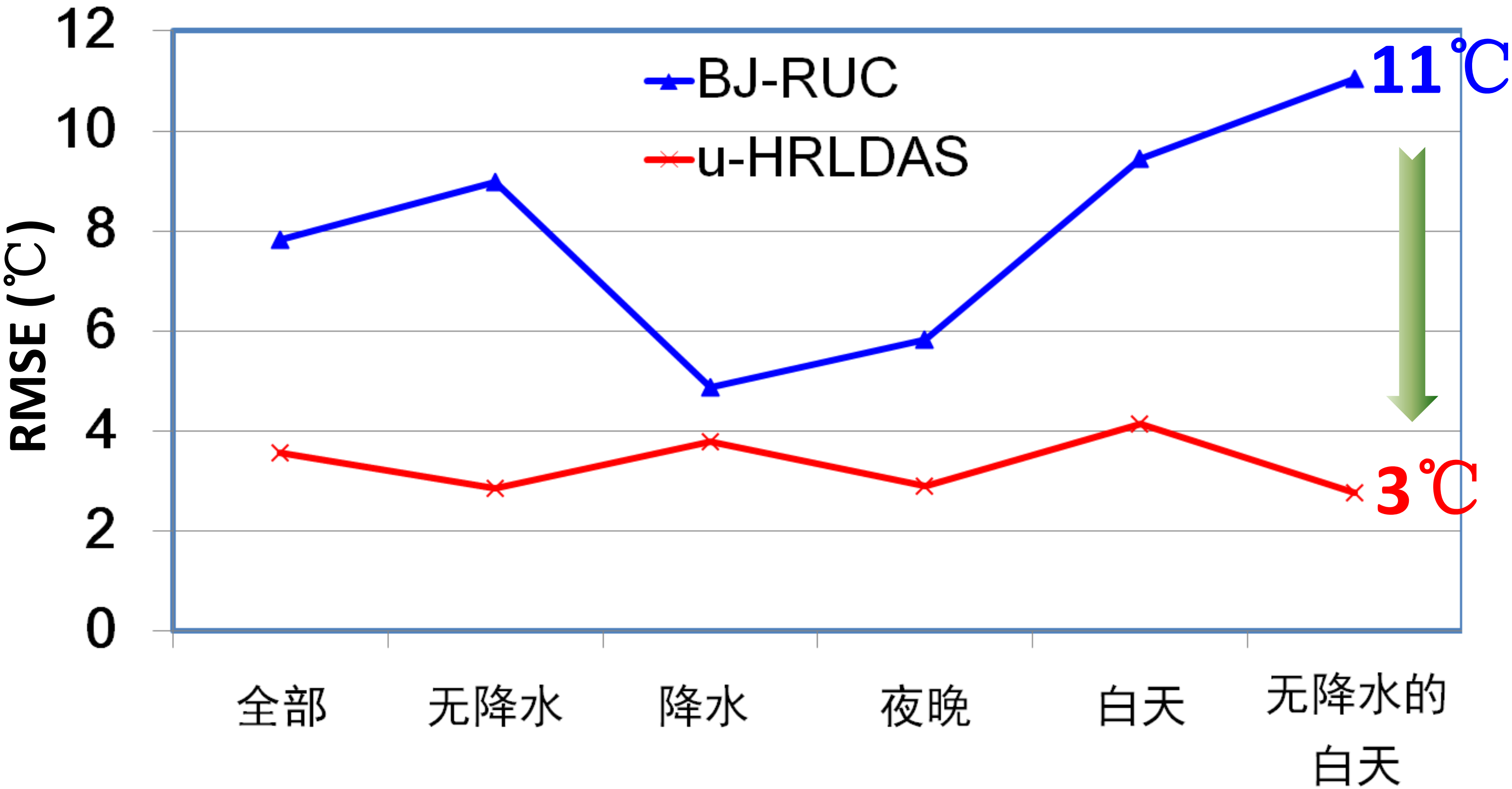
2、Urban land surface model & land data assimilation system (HRLDAS)

1）Setting up of u-HRLDAS





RMSE for skin temperature (℃)



◆Period： 1-31 Aug 2009

◆u-HRLDAS markedly improves skin T.， especially for no-rain daytime

2、Urban land surface model & land data assimilation system (HRLDAS)

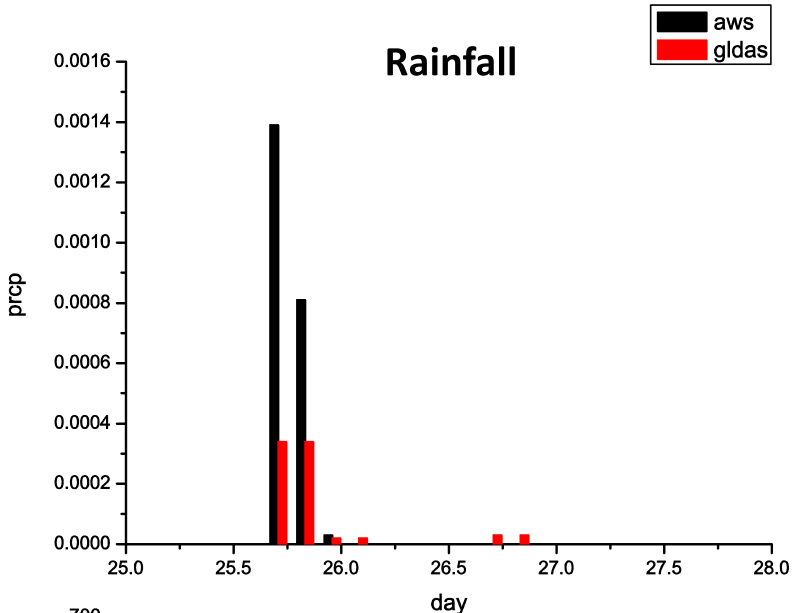
1）Setting up of u-HRLDAS

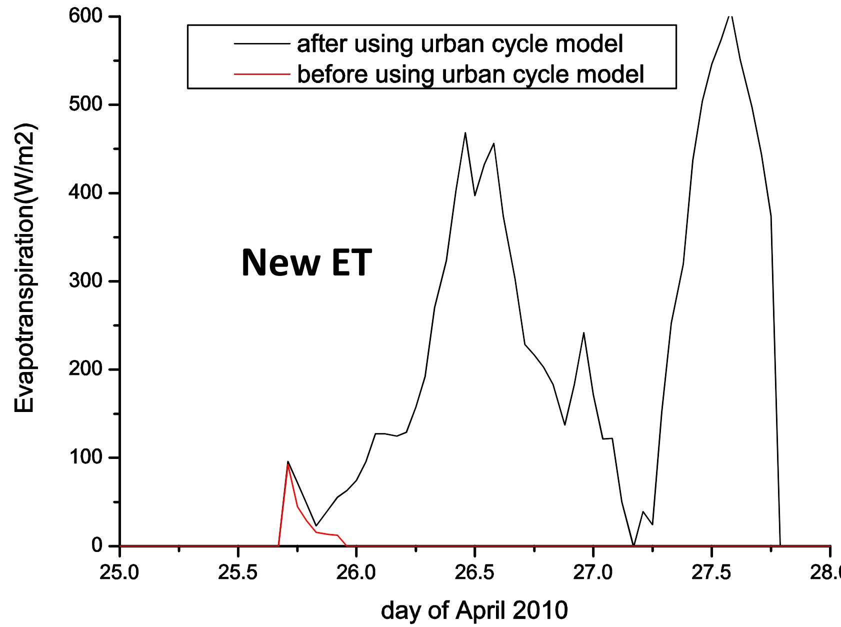
2）Improvements of u-HRLDAS

① **surface exchange coef., profiles for urban area**

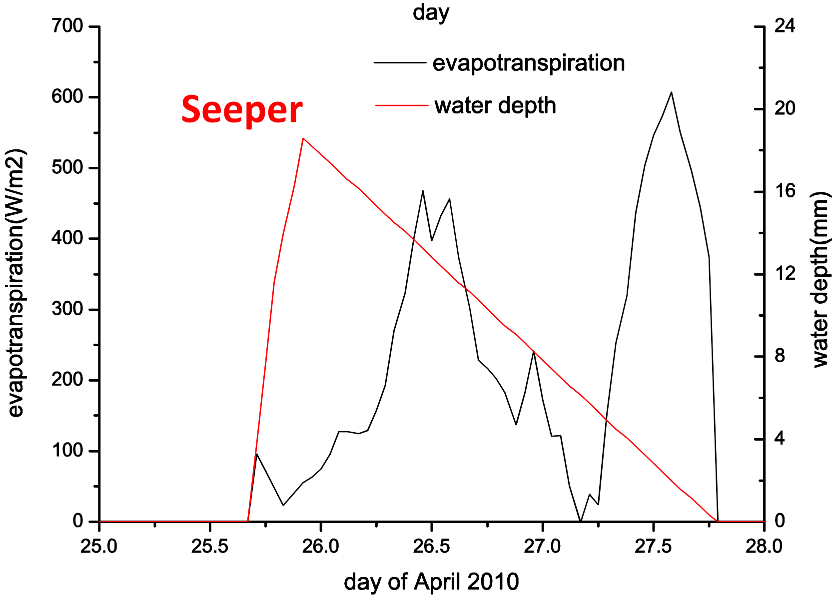
② **Evapotraspiration for impervious sfc., modeling the seeper depth**

• Evaluation





ET

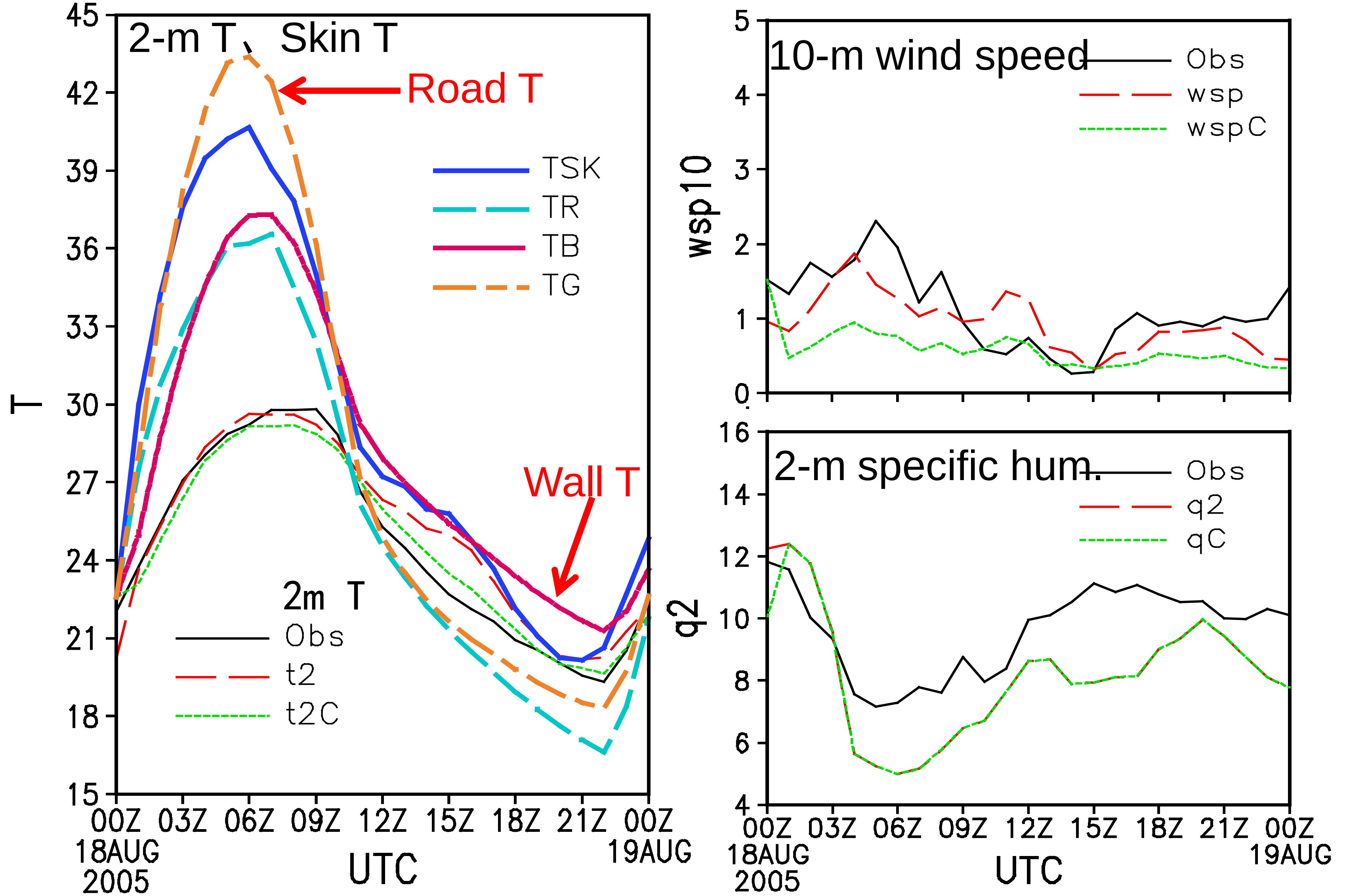


Seeper depth & ET

- ➢Seeper depth: better
- ➢ET: more， last longer

3、Numerical modeling of UBL

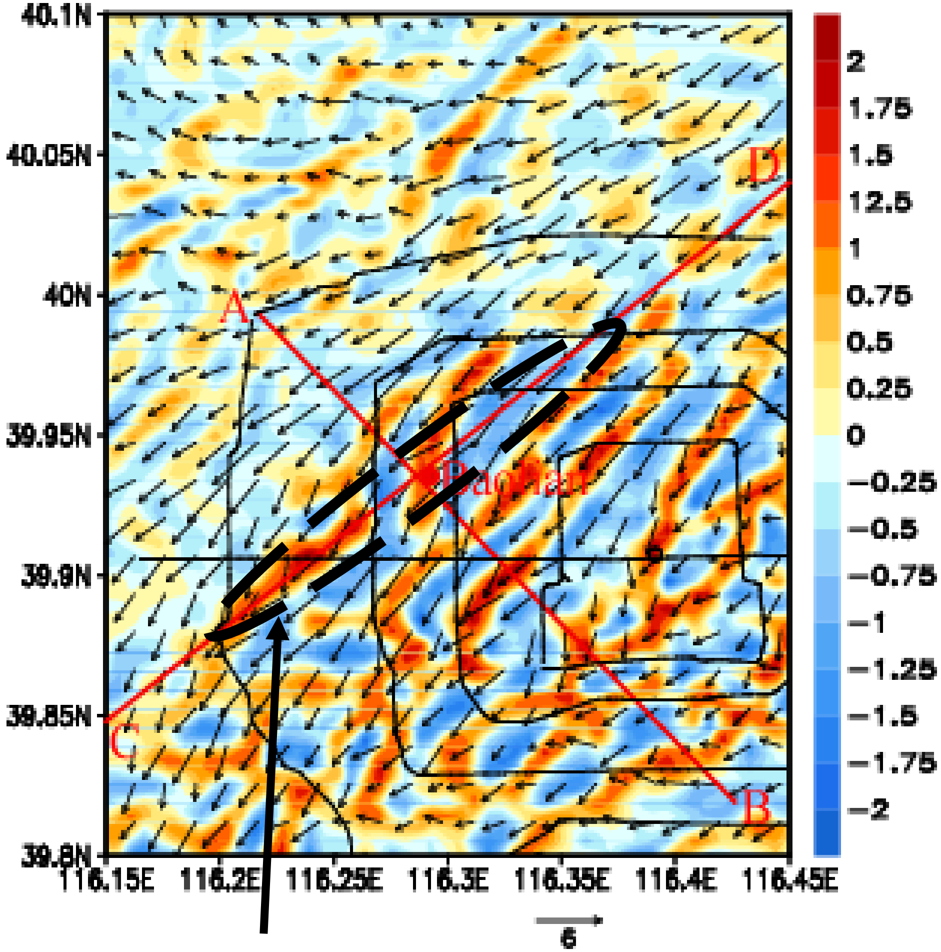
Diurnal variation of observed and simulated variables for high-density urban stations



UBL structures at 0600UTC (1400LST) 18 Aug 2005:

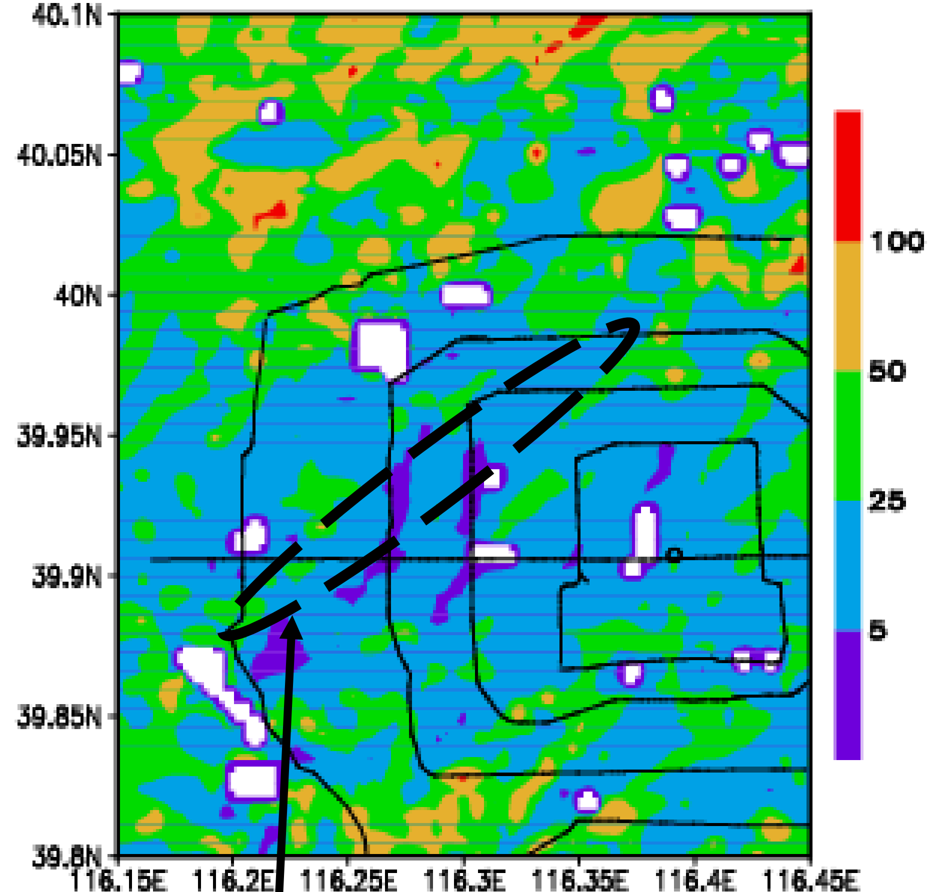
Horizontal distribution of (z = 384m)

Vertical velocity and horizontal wind vectors



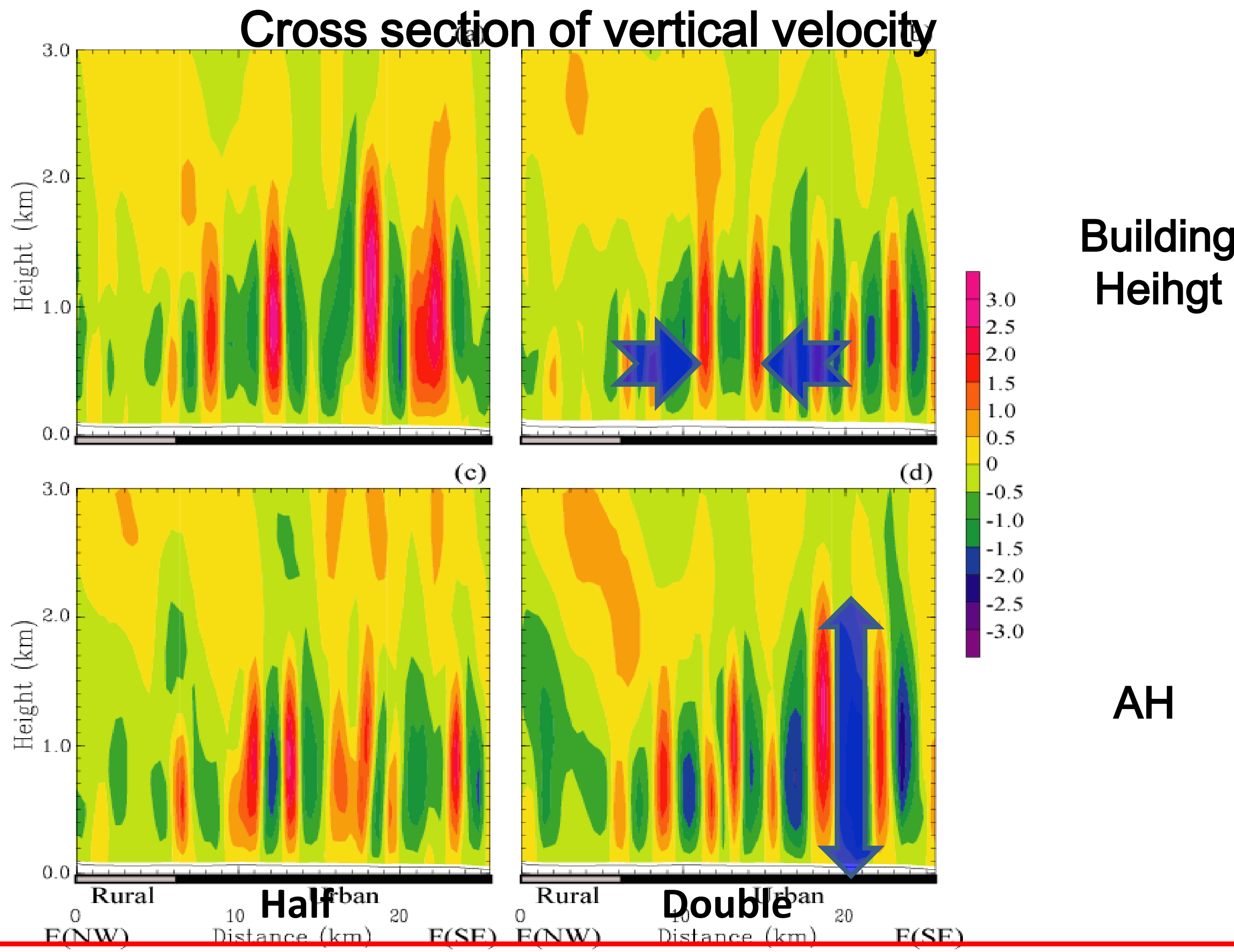
Horizontal Convective Rolls (HCRs)

$-z_i / L$



$-z_i / L < 25$

Aspect ratio of HCRs

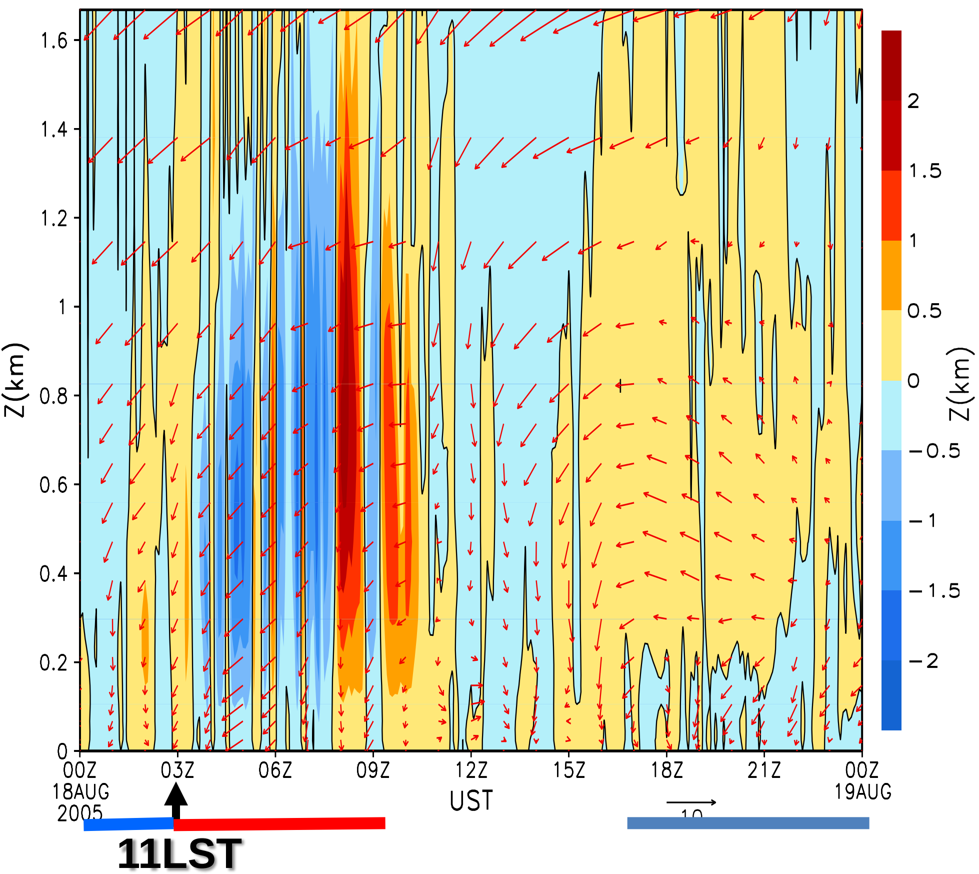


The aspect ratio of HCRs in urban areas (~1.5), due to the impacts of building height and AH, is smaller than the typical value over natural landscapes (2–15).

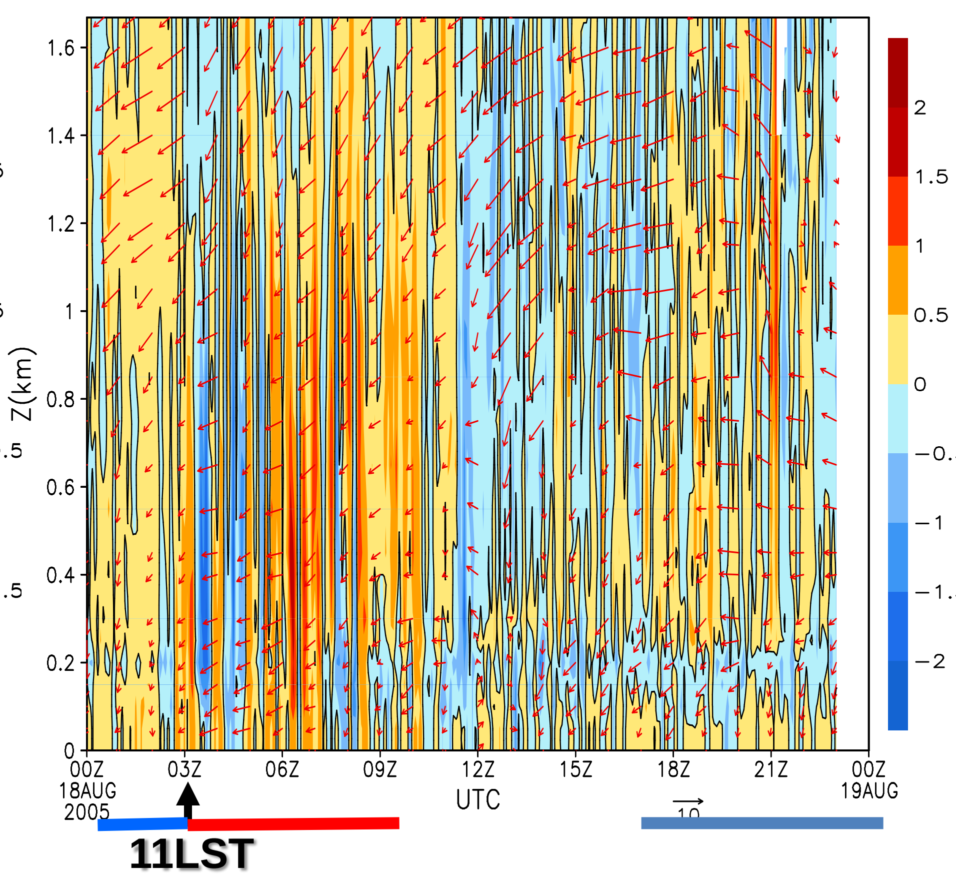
Diurnal variation of UBL structures (BaoLian)

(vertical velocity in shade, horizontal wind vectors in red)

WRF

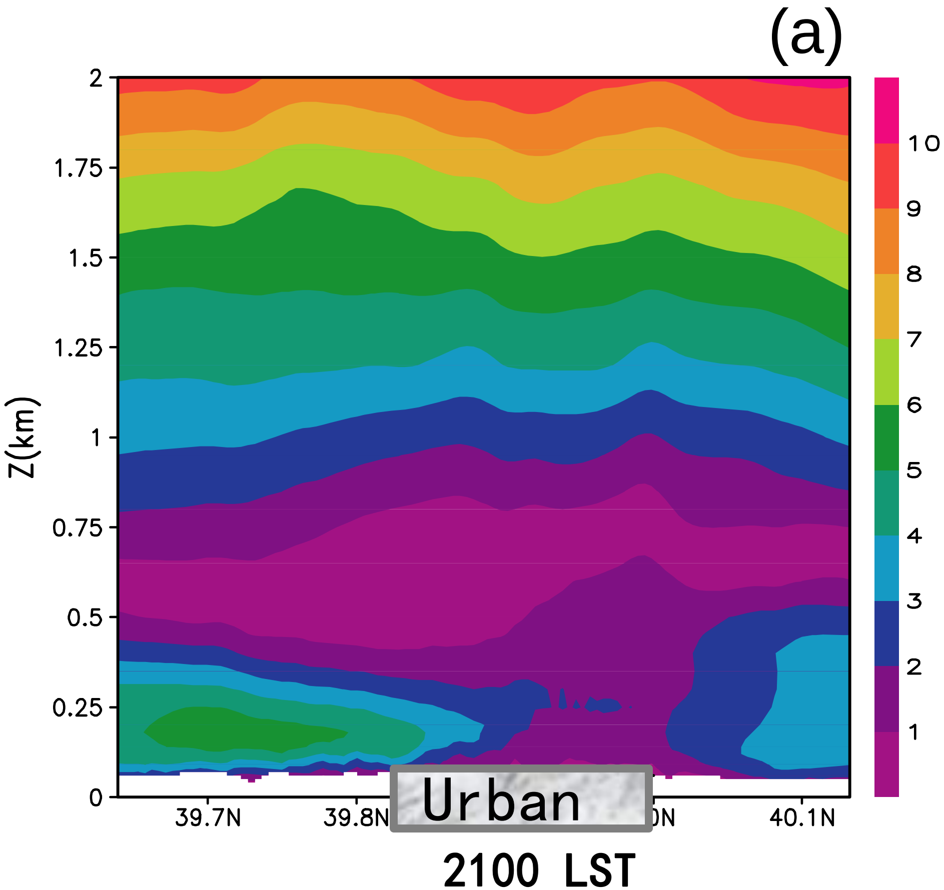


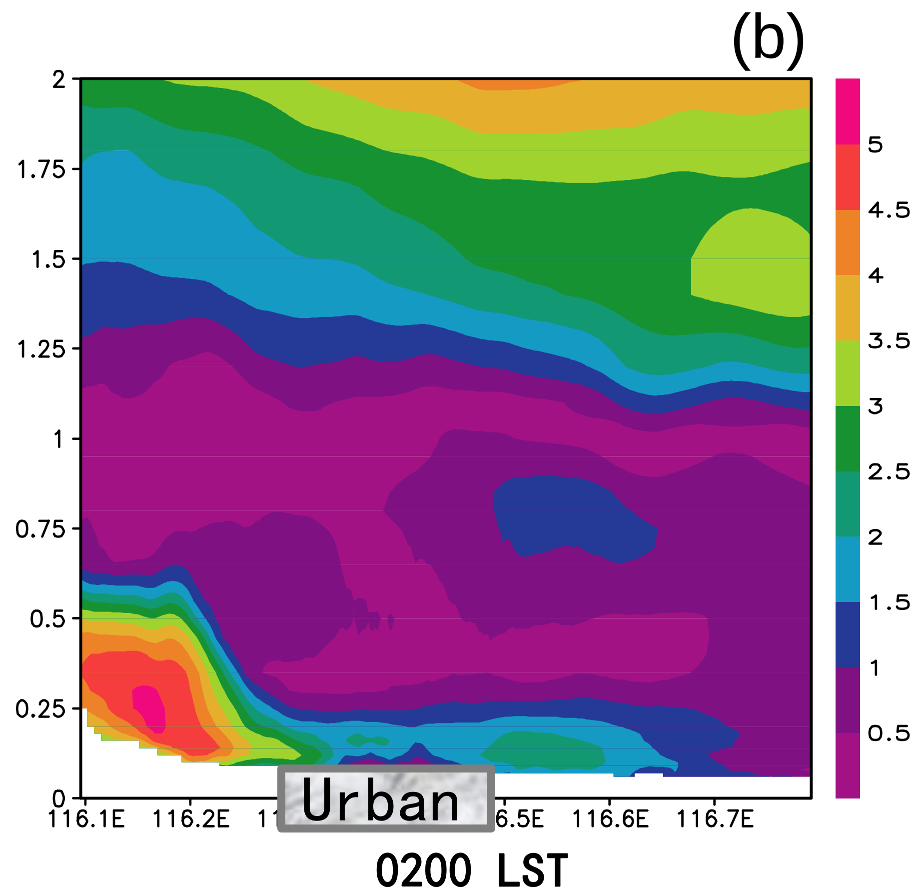
Obs from wind profiler



Impact of urban area on nocturnal BL LLJ

Cross-section of wind speed

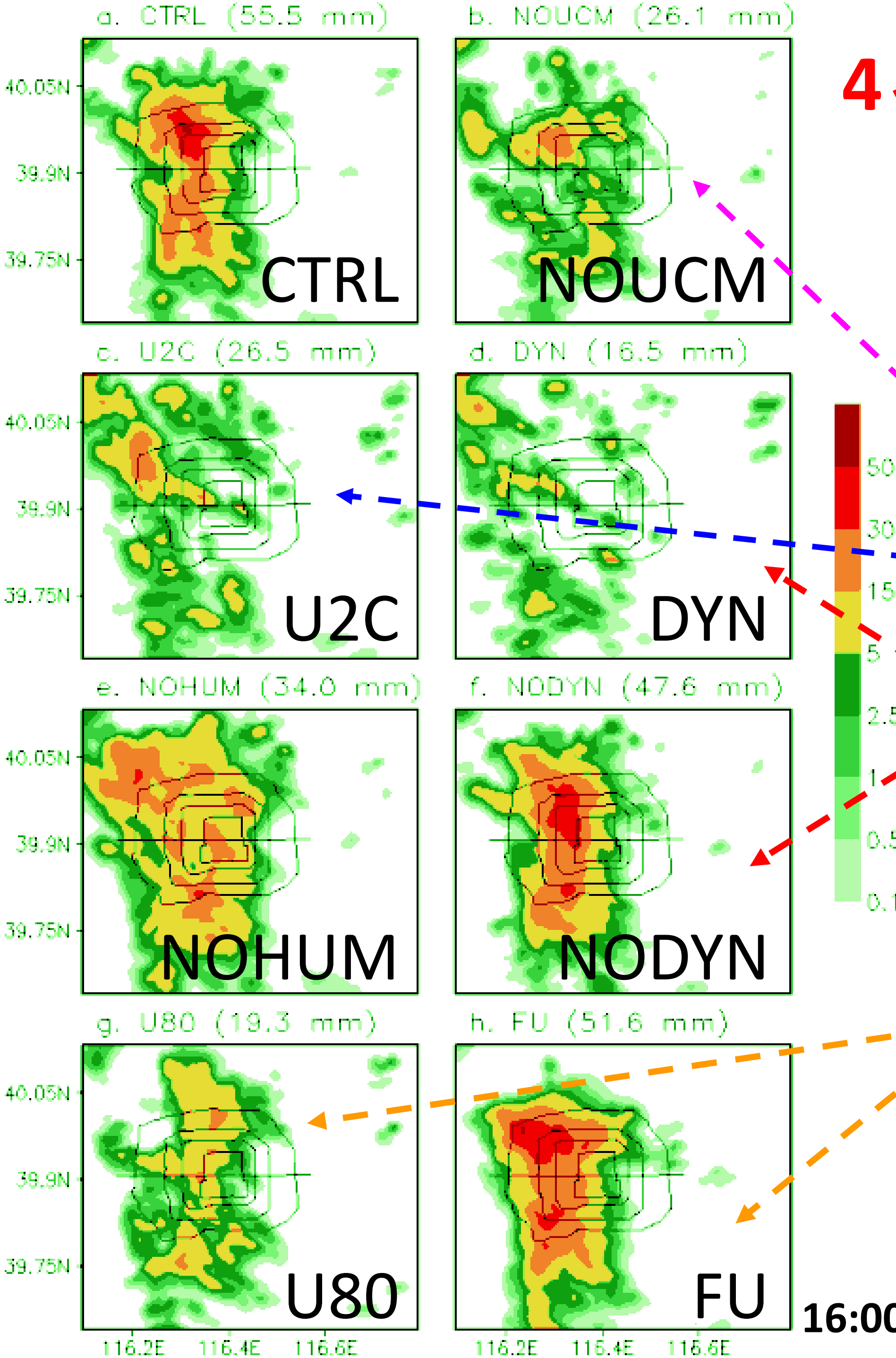




LLJ over urban areas: form later, located higher, and weaker intensity than that over rural areas.

4、Urbanization effects: on precipitation

A Case Study of Heavy Rainfall in Beijing on 1 August 2006

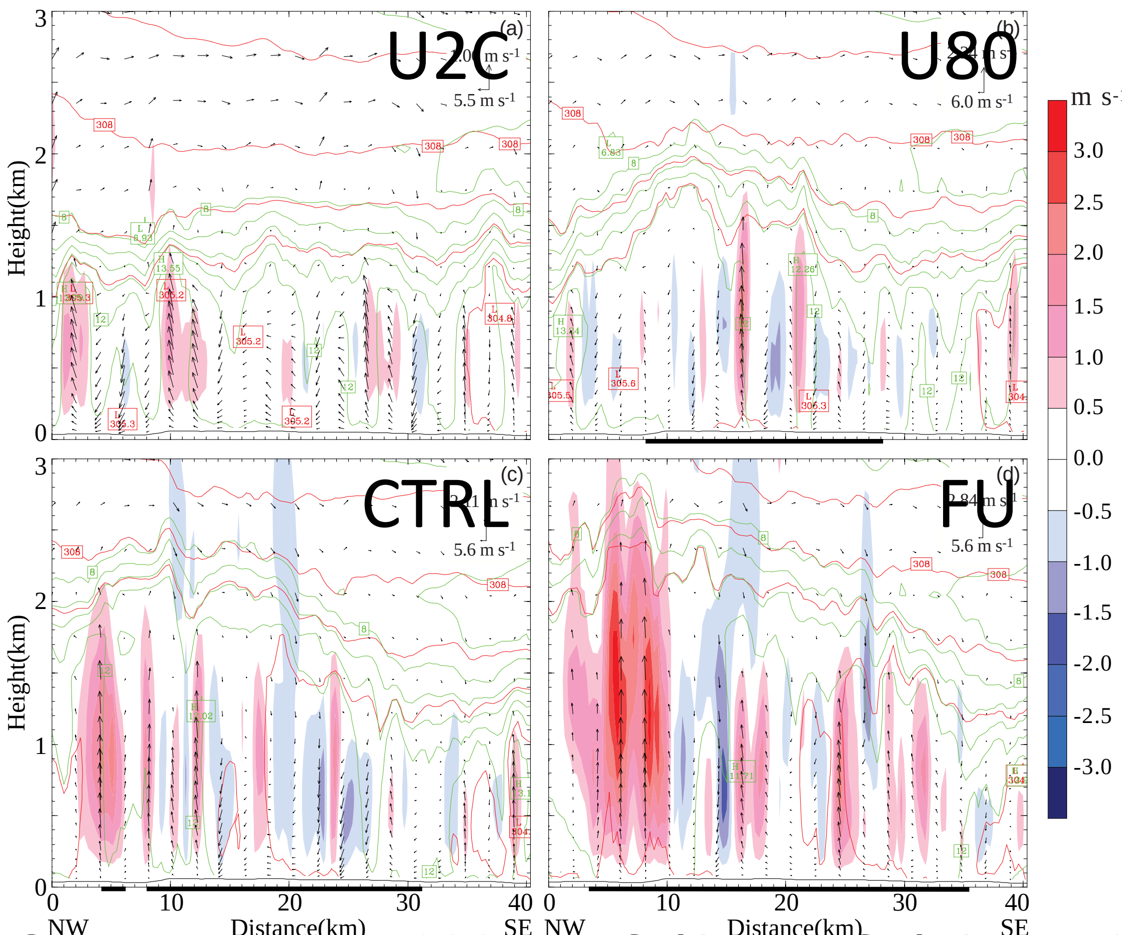


- The importance of UCM
- No urban
- Thermal impact vs. dynamic
- SH vs LH
- 1980s, FU

16:00-19:00 3-h accumulated rainfall (mm)

Urbanization effects: on precipitation

A Case Study of Heavy Rainfall in Beijing on 1 August 2006

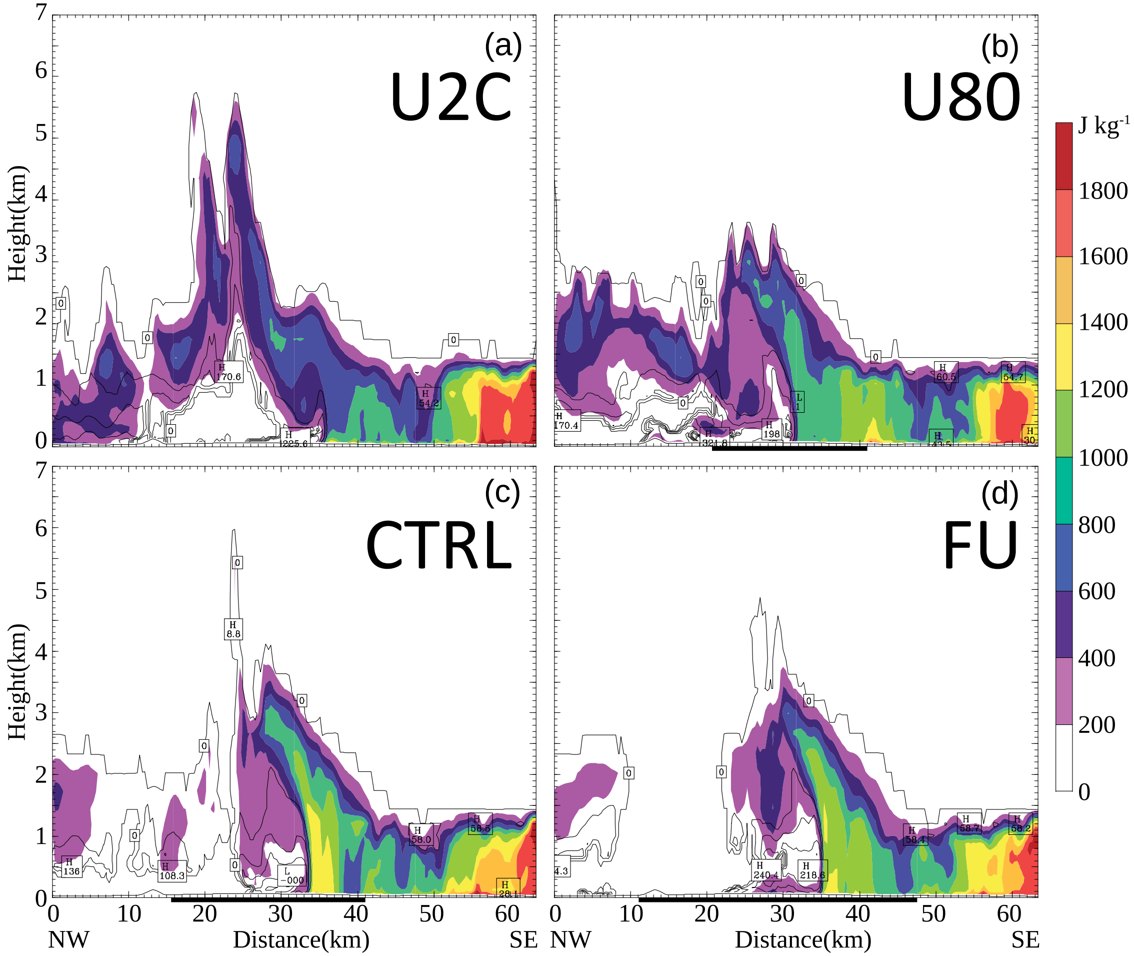


- Urbanization→Dry、hot →Stronger updrafts →higher PBL →Weaker capping inversion →Convection

Cross section at 0800 UTC (1600 LST) 1 Aug 2006 of vertical velocity (shaded), potential temperature (red contour), water vapor mixing ratio (green contour), and circulation vectors

Urbanization effects: on precipitation

A Case Study of Heavy Rainfall in Beijing on 1 August 2006



- **Urbanization**

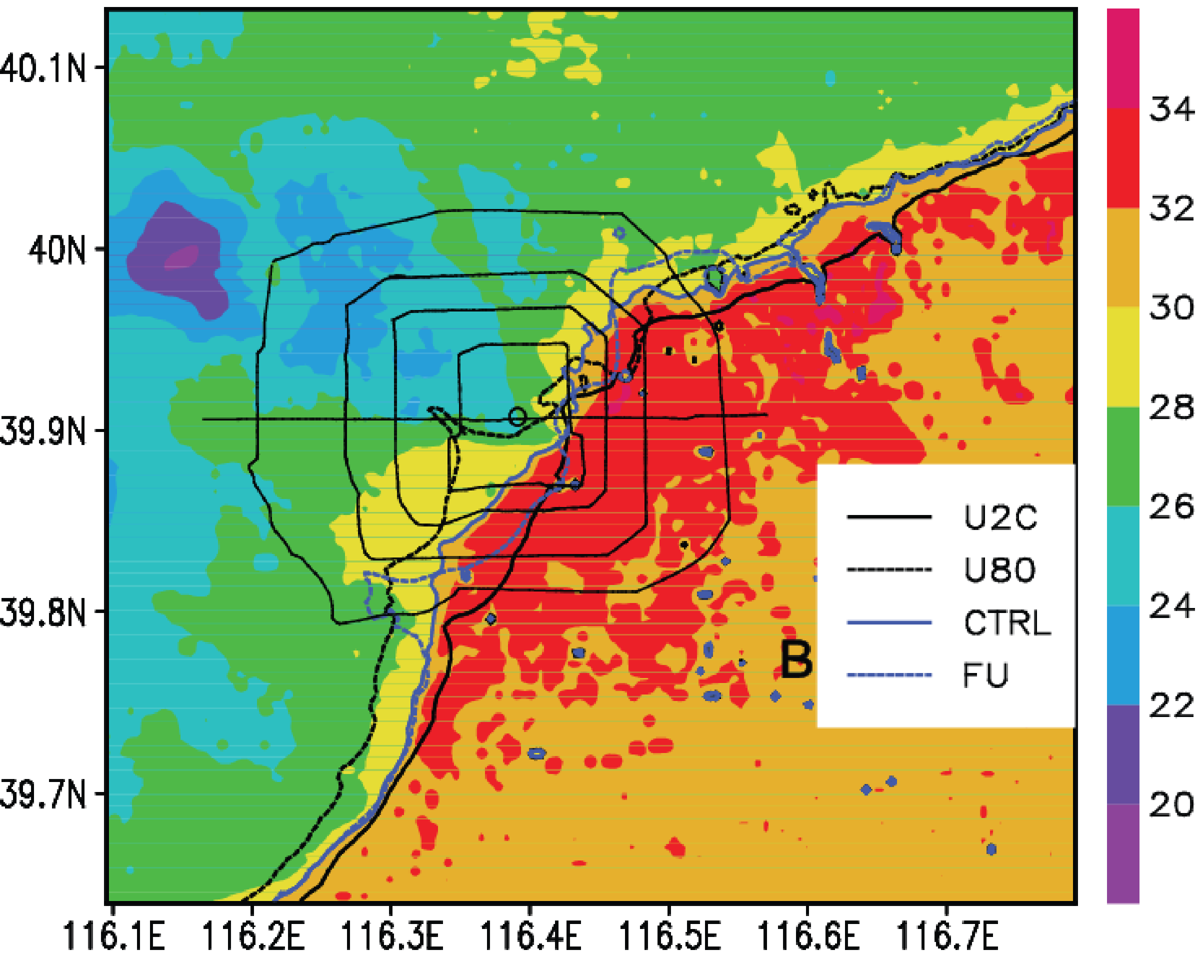
  →Increasing CAPE、

  decreasing CIN

Cross section at 0900 UTC (1700 LST) 1 Aug 2006 of CAPE (shaded), CIN (black contour)

Urbanization effects: on precipitation

A Case Study of Heavy Rainfall in Beijing on 1 August 2006

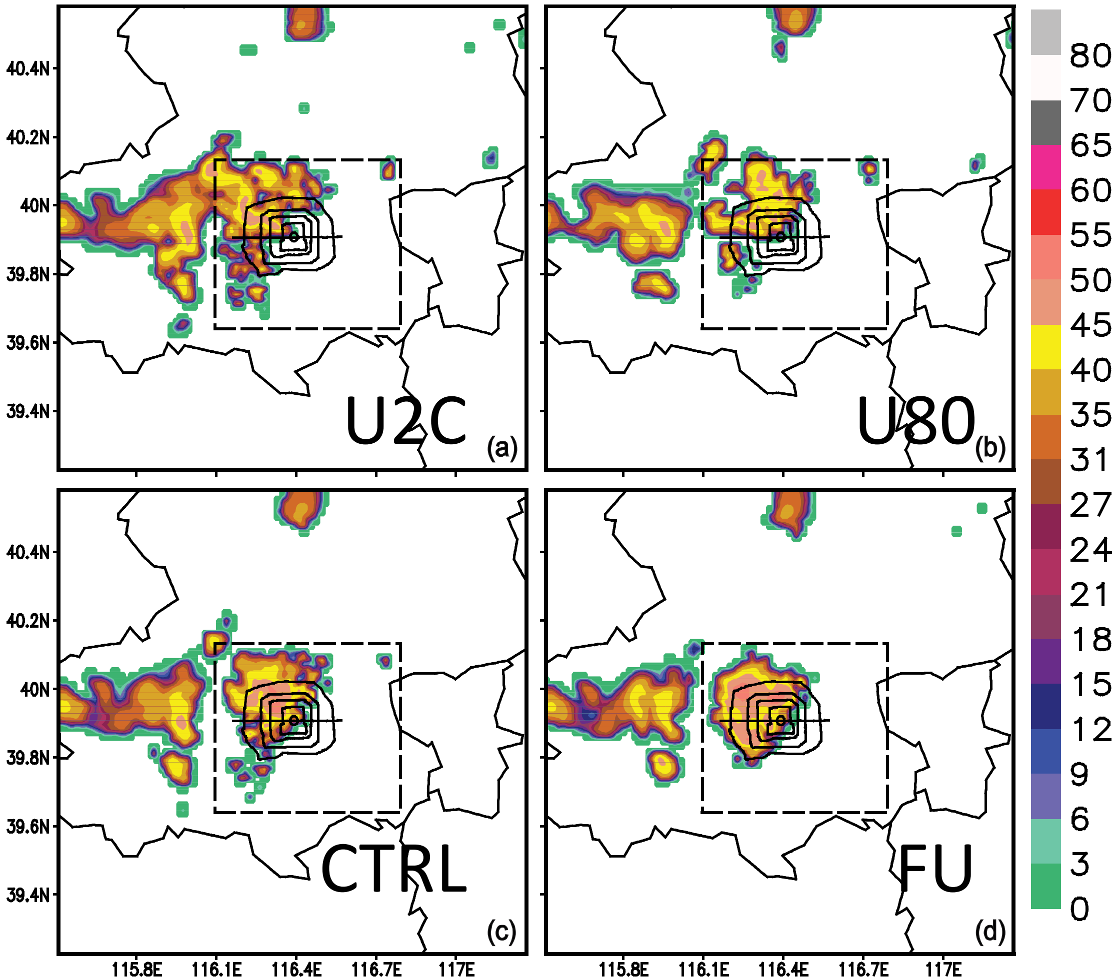


Horizontal distribution of 2-m T at 0900 UTC (1700 LST) 1 Aug 2006

- **Urbanization: thermodynamic →Thunderstorm movement**

Urbanization effects: on precipitation

A Case Study of Heavy Rainfall in Beijing on 1 August 2006

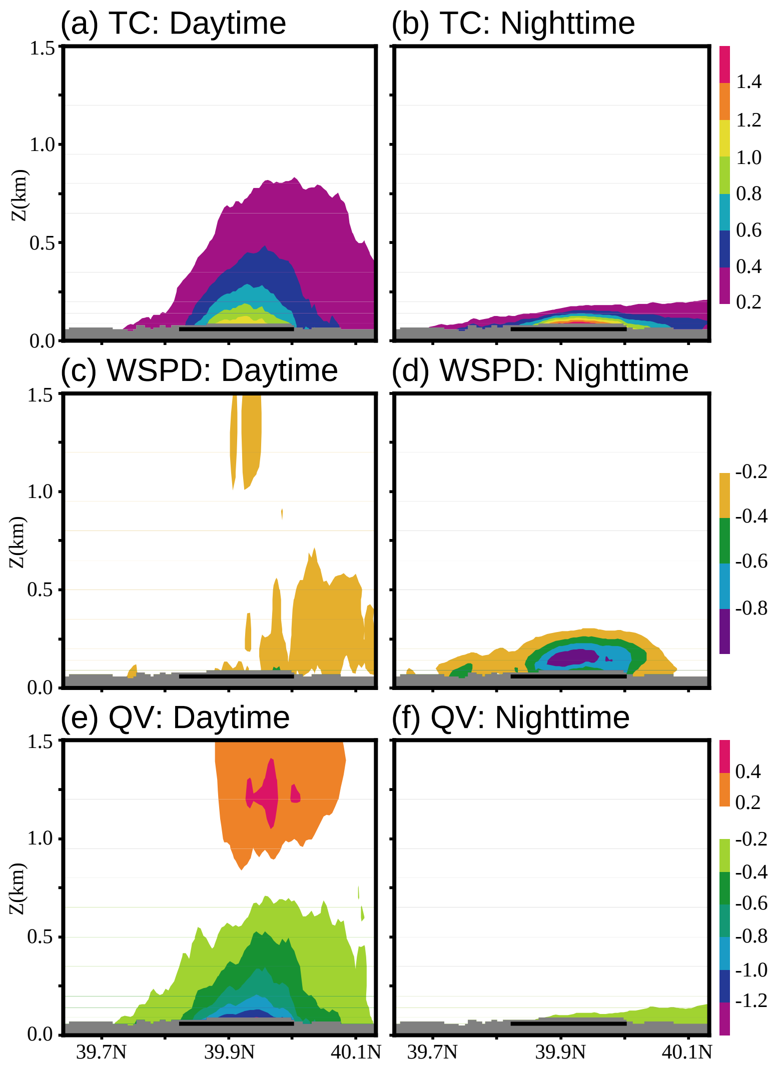


- **Urbanization**
  →separate, merge,
  →Rain: concentrated

Horizontal distribution of maximum reflectivity from WRF simulation at 0900 UTC (1700 LST) 1 Aug 2006

4、Urbanization monthly effects

Period: Aug 2006



Air T： Day： 800m， 1℃ and up

Night： 200m， 1.4℃ and up

Wind Speed： Day： slight decrease

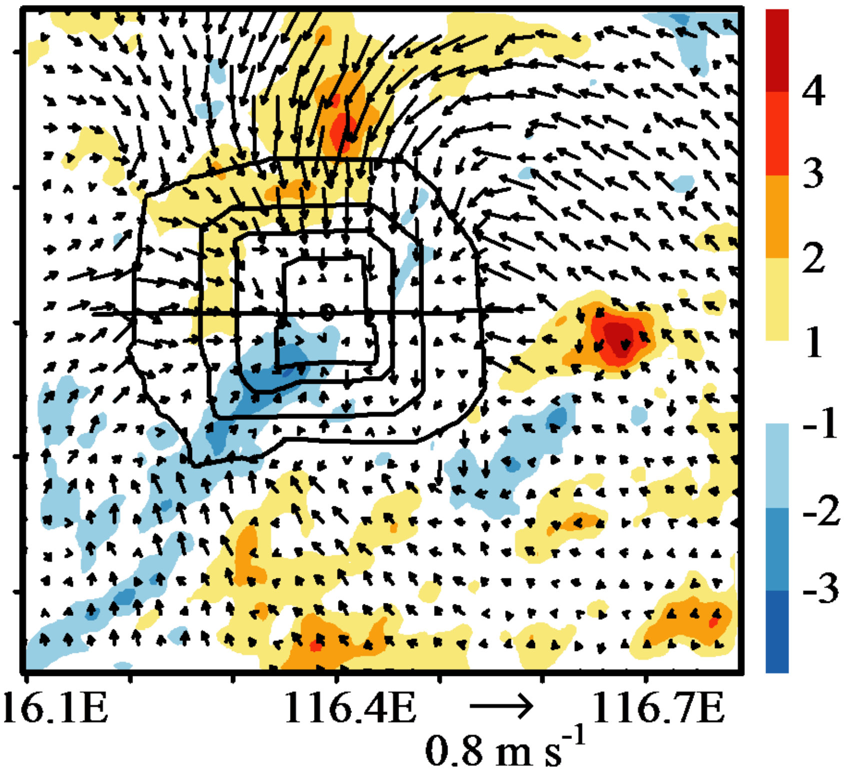
Night： 200m， 0.8m/s and up

Humidity： Day： 700m， 1.2g/kg and up

Night： slight decrease

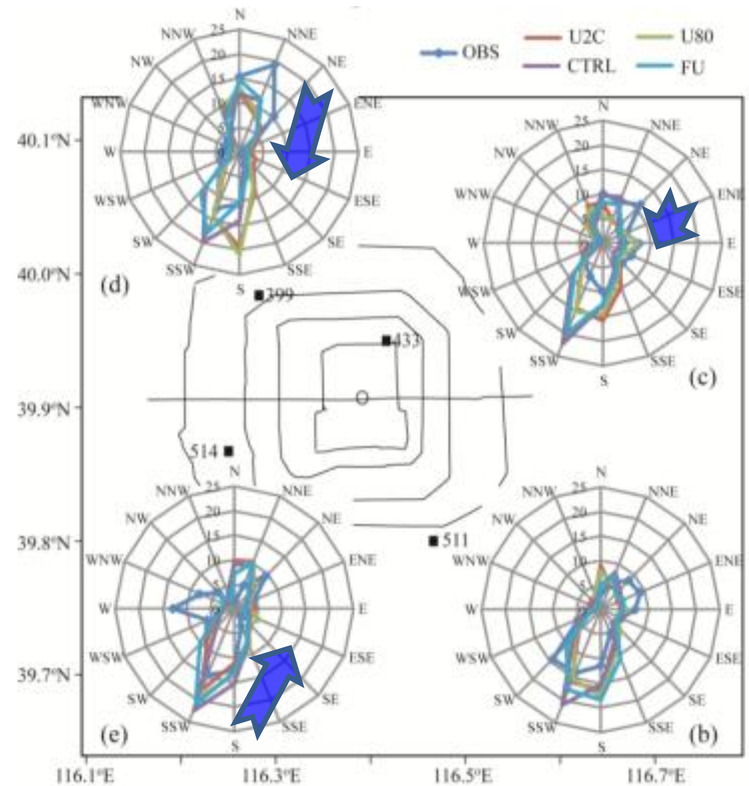
Cross-section of monthly mean diff. along 116.34ºE : Case CTRL and case U2C

- Urbanization increases rainfall in Haidian and Changping, and the frequence of heavy rainfall



Monthly mean daily rainfall and surface wind due to urbanization effects for Aug 2006

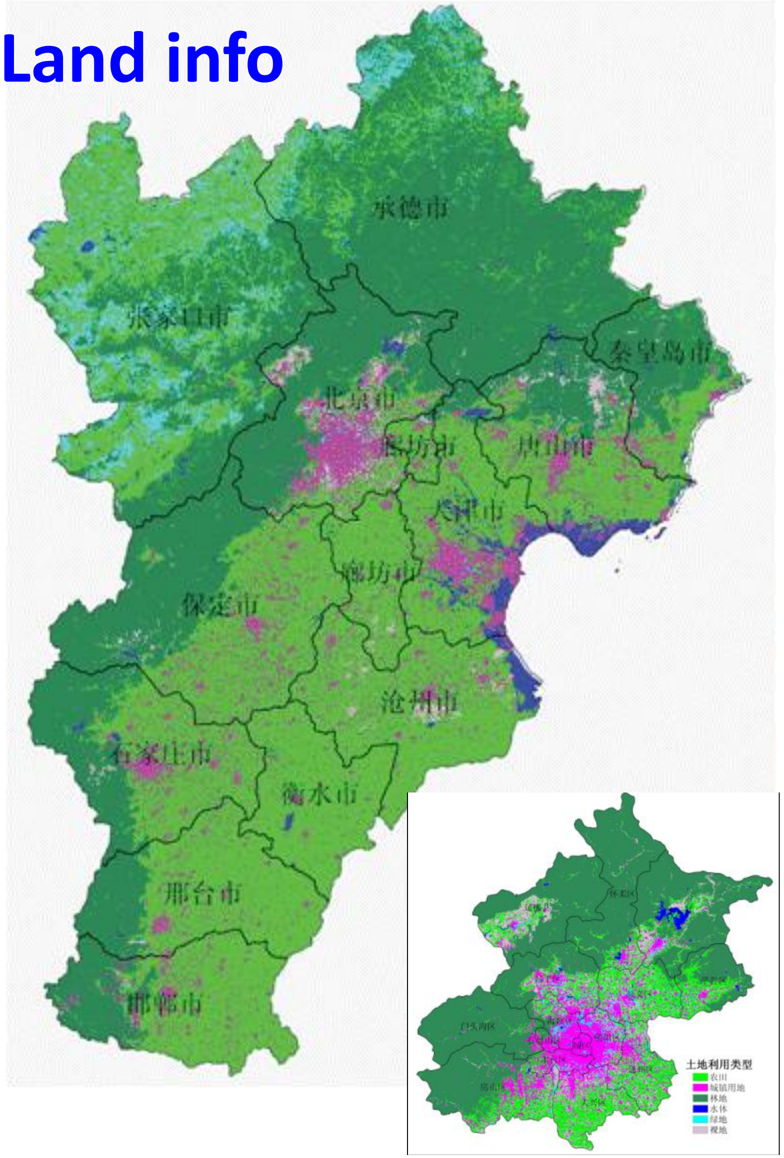
- UHIC→Wind rose
- WRF/Noah/UCM simulates this characteristics very well.

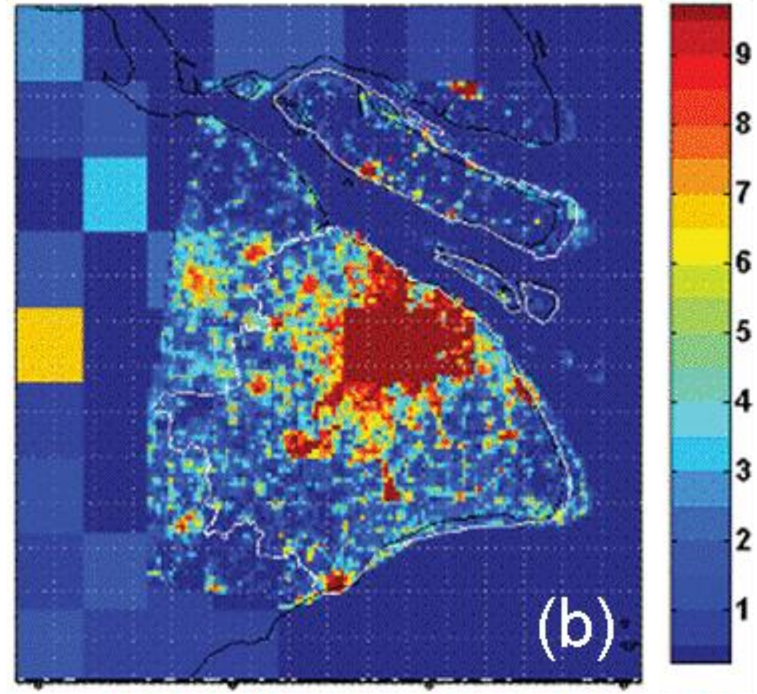


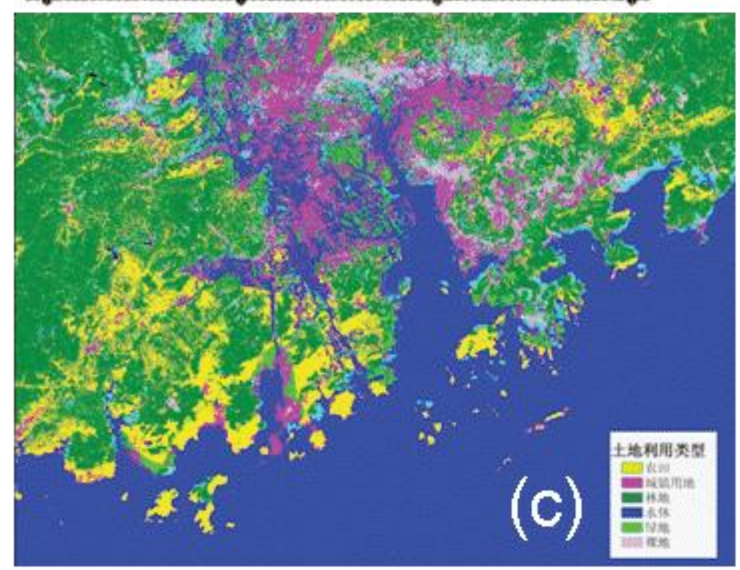
Wind rose at met. stations from obs. and modeling for Aug 2006

5、Dataset

1）Land info







(a) LU/LC in Jing-Jing-Ji area；(b)Emission inventory at 0.01° for Shanghai (PM10: g m^{-2} yr^{-1})；(c) LU/LC in PRD

LU/LC in Jing-Jing-Ji area

Urban area expands to 8 times

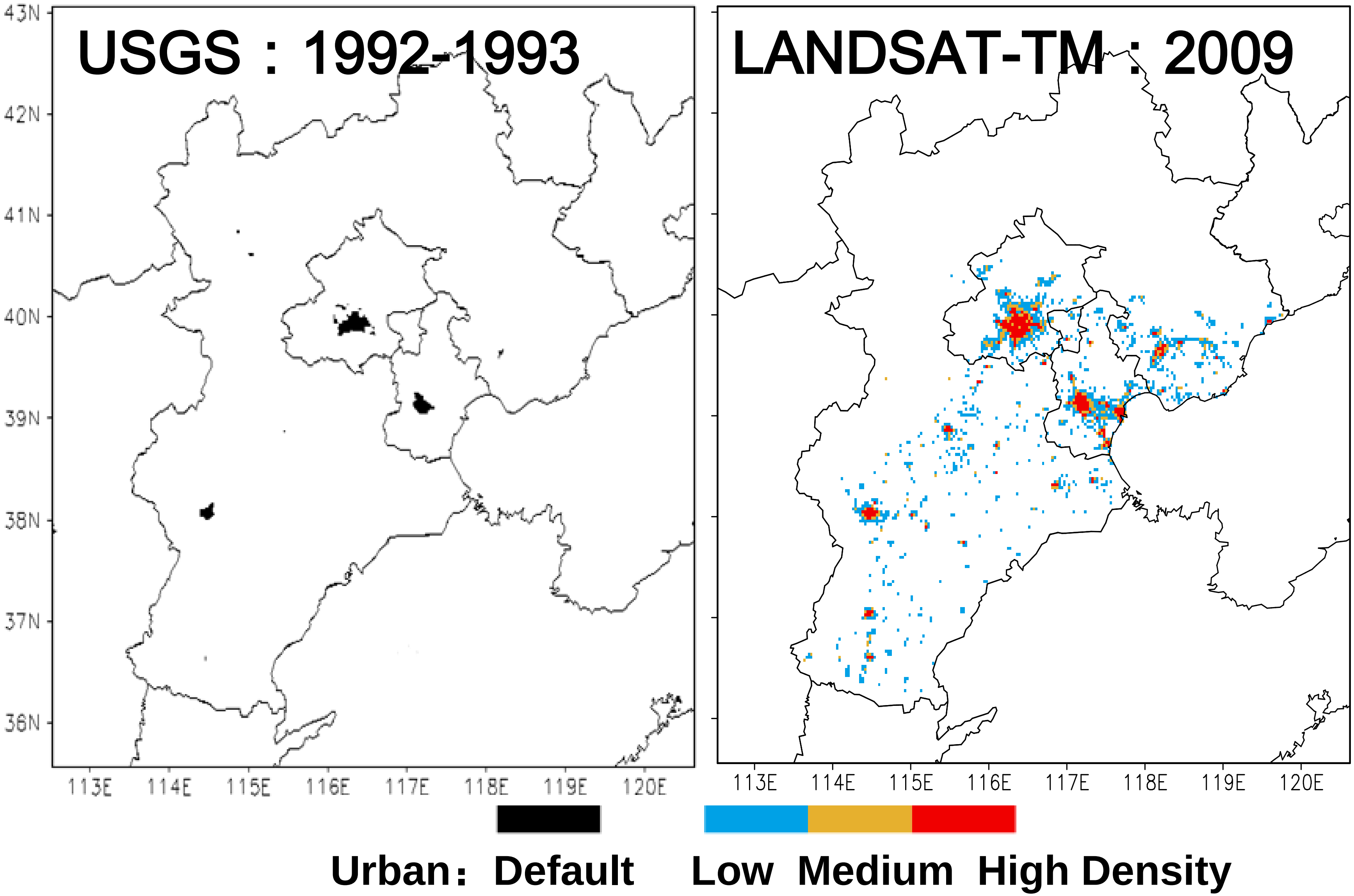


图 6 河北唐山地区地表反照率（2009年8月30日）

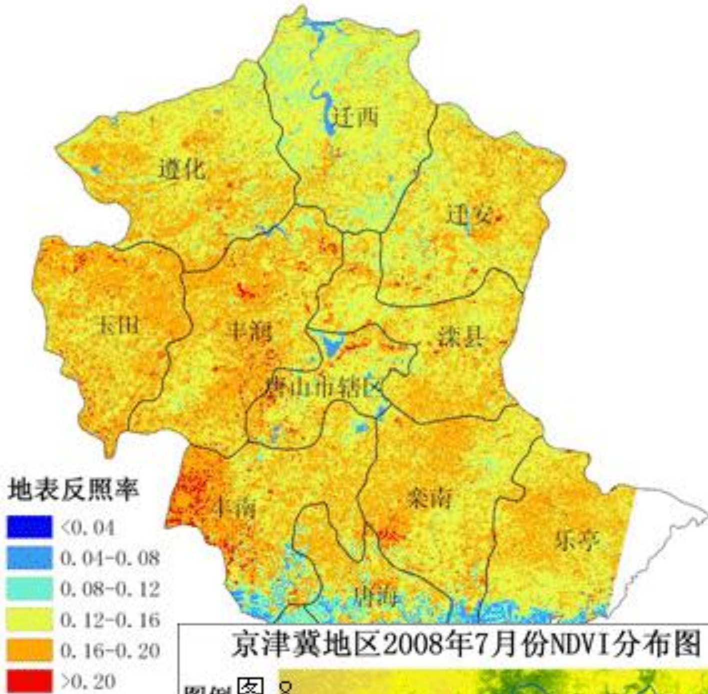
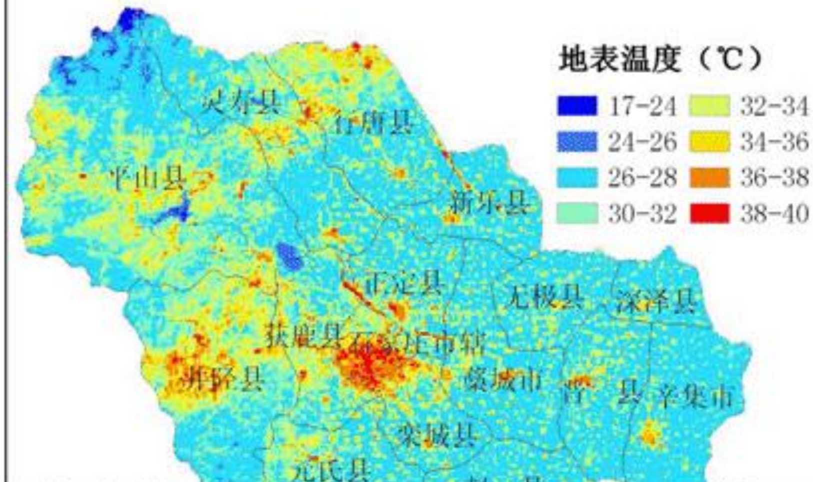
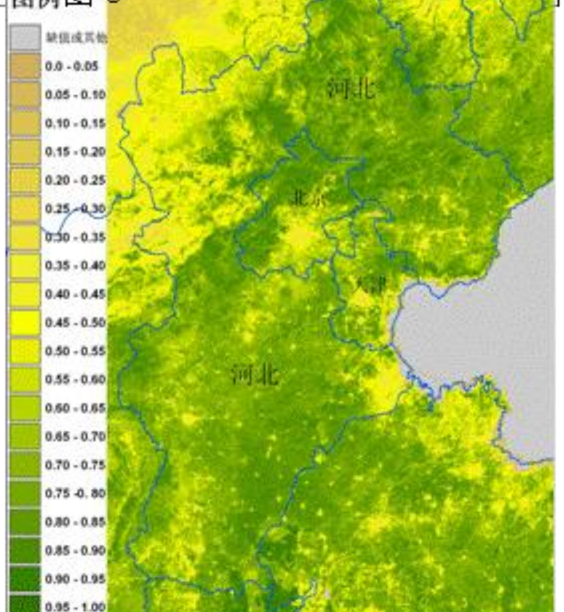


图 7 河北石家庄地区地表温度（2009年8月12日）



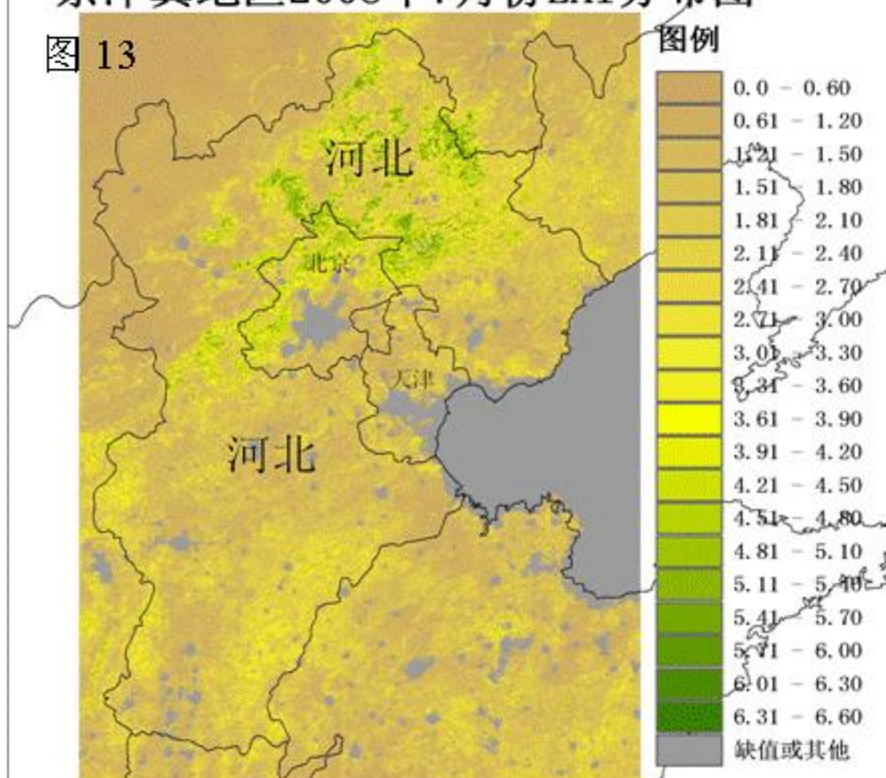
京津冀地区2008年7月份NDVI分布图

图 8

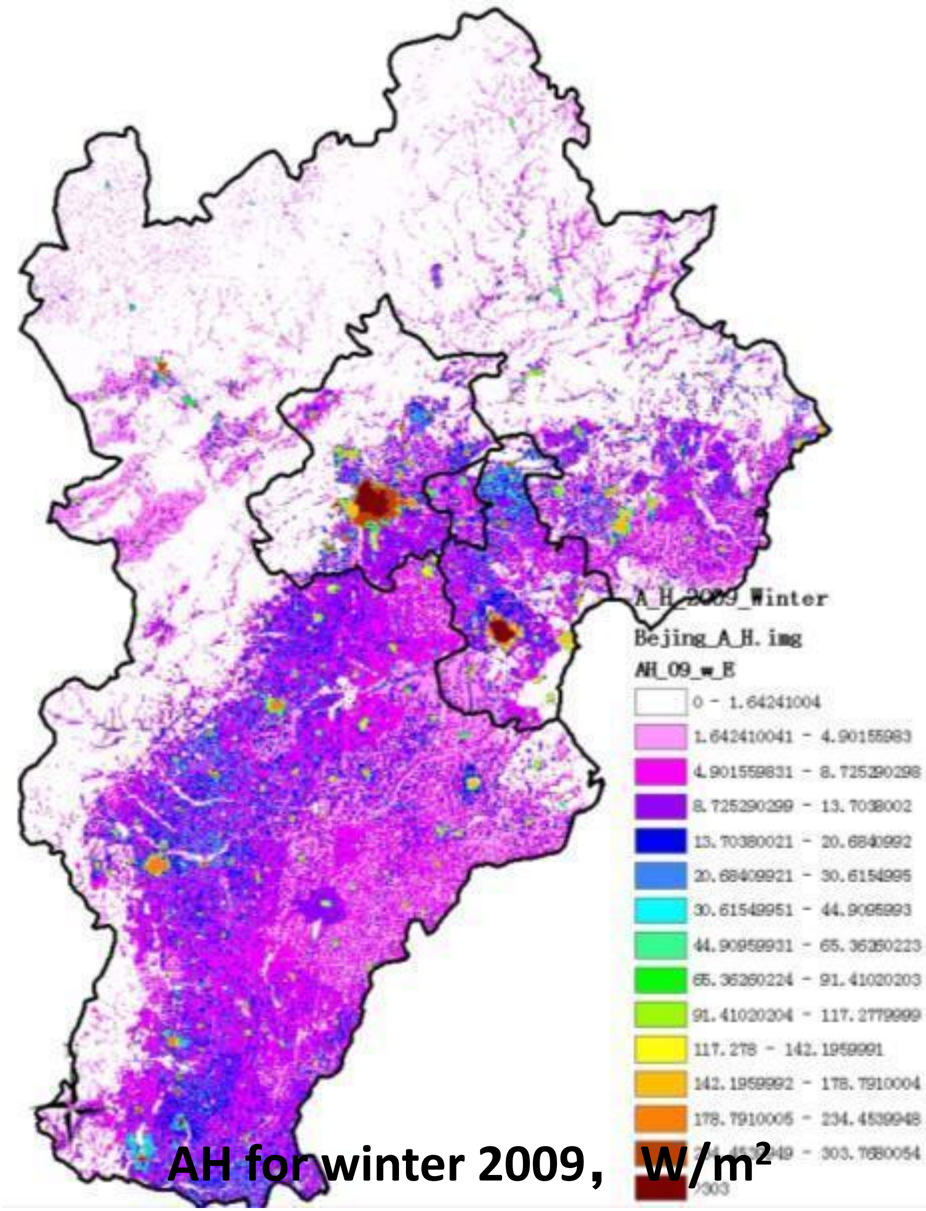


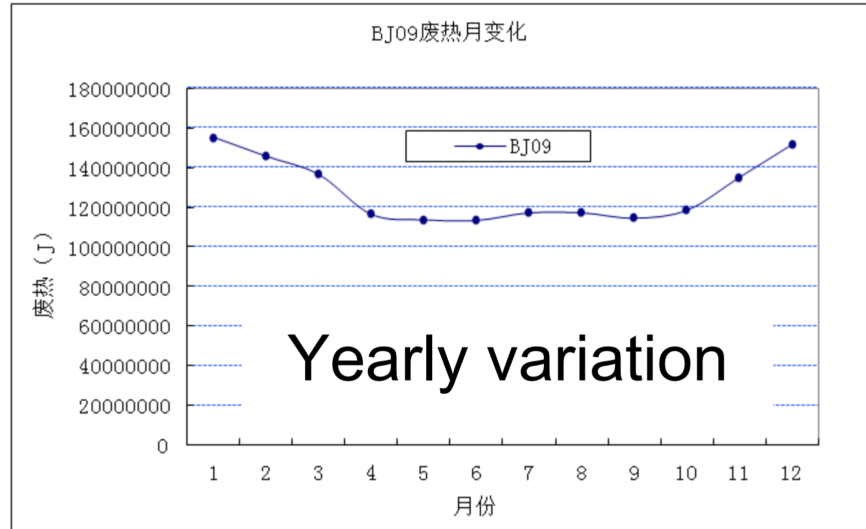
京津冀地区2008年7月份LAI分布图

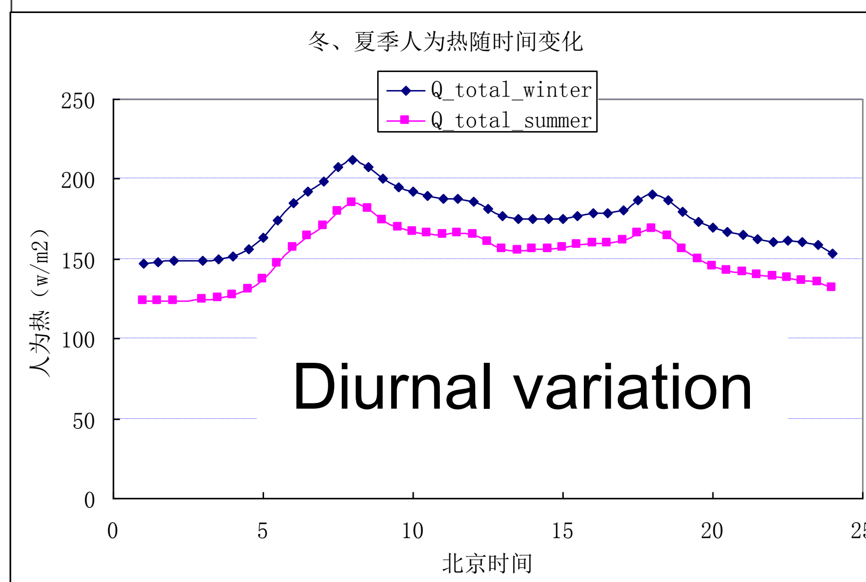
图 13



AH for Jing-Jing-Ji area

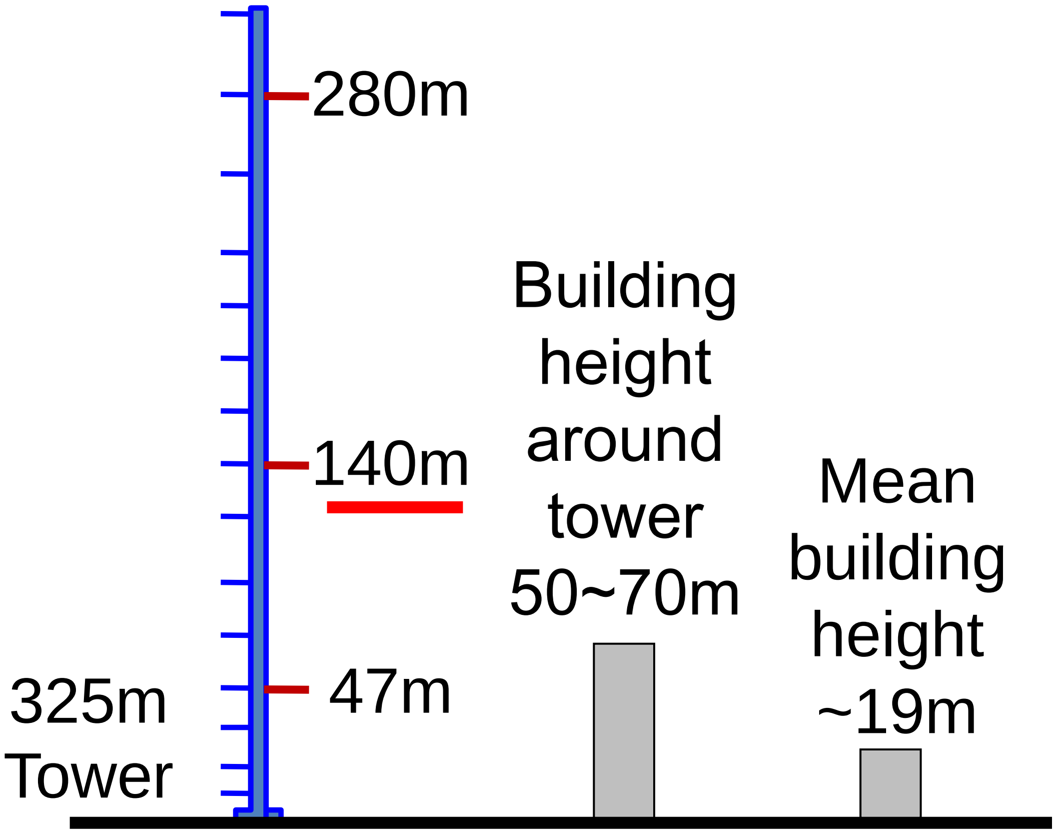






5、Dataset

2）SEB observation in Beijing



Mean values of total daytime energy fluxes and flux ratios

(Asian, European, American cities are in Black, Green, and Blue respectively)

City location	Green space (%)	Building height (m)	Observation height (m)	Observation period	Frequency of days with rain (%)	Ratio Qh/Q*	Ratio Qe/Q*	Ratio Qs/Q*	Ratio Qh/Qe
Vancouver, (49° 16'N, 123° 06'W)	4.0	8.6	/	Aug 1992	/	0.42	0.10	0.48	4.42
Marseille, (43° 17'N, 5° 23'E)	11.0								4.27
Basel, (47° 34'N, 7° 36'E)	16.0	14.6	32.0	Jun-Aug 2002	/	0.49	0.20	0.36	2.50
COSMO, (39° 04'N, 139° 07'E)									1.90
Tokyo, Japan (35° 34'N, 139° 41'E)	29.1							0.26	1.77
Beijing, China (39° 58'N, 116° 42'E)	21.7	[illegible]						0.51	0.82
Chicago, (41° 57'N, 87° 48'W)	44.2							0.26	0.78
Mexico City, (19° 25'N, 99° 10'W)	1.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.58	8.80
Beijing, (39° 58'N, 116° 42'E)	21.7	18.3	140.0	Dec 2009 – Feb 2010	5.0	0.28	0.07	0.66	4.16
Tokyo, (35° 34'N, 139° 41'E)									3.13
COSMO, (39° 04'N, 139° 07'E)	0.0	1.5	3.0	Dec 2006	16.1	0.25	0.11	0.63	2.29
Basel, (47° 34'N, 7° 36'E)									2.01

Mediterranean climate: Sum: hot dry

Beijing： building, climate …

→ Different urban SEB characteristics

Oceanic monsoon climate: Sum: cold dry

Mediterranean climate: Win: humid

6、Operational applications

Road surface forecasting system→Traffic service

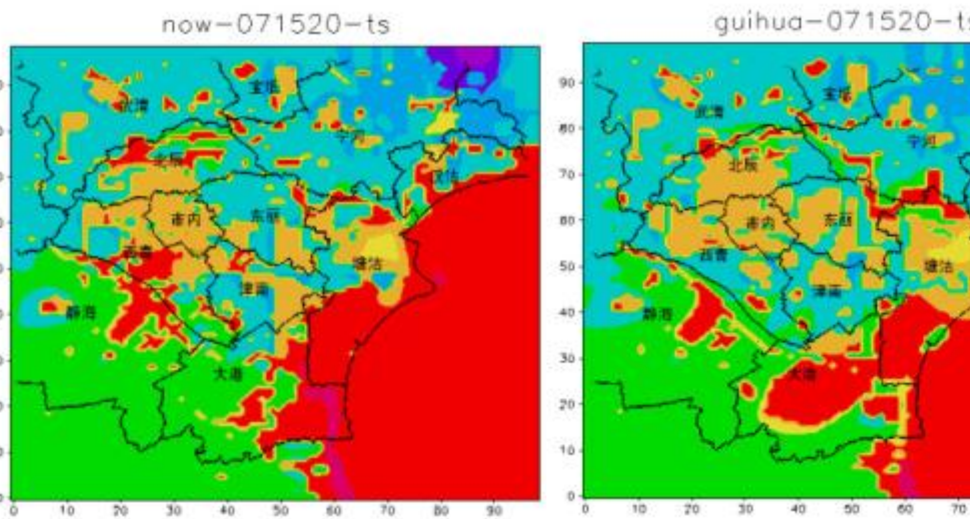
6、 Operational applications

UCM/UBL

→ **urban planning**

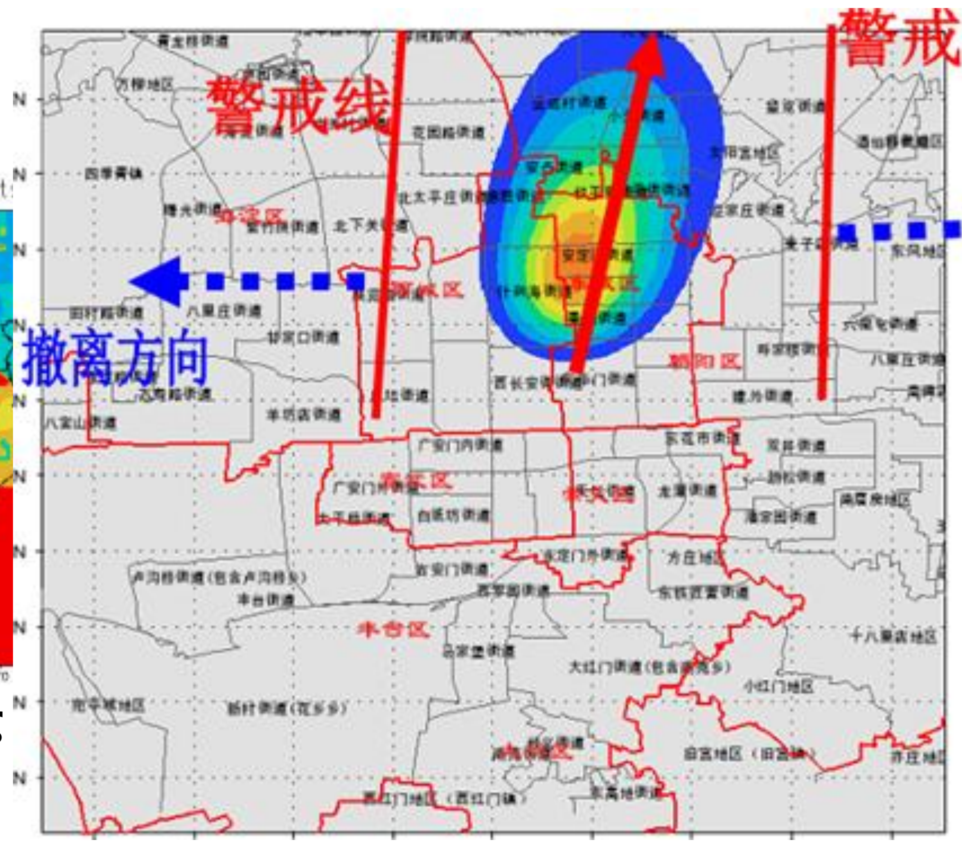
UNSM/UBL

→ **emergency response**



Now Planning

Nocturnal T in summer



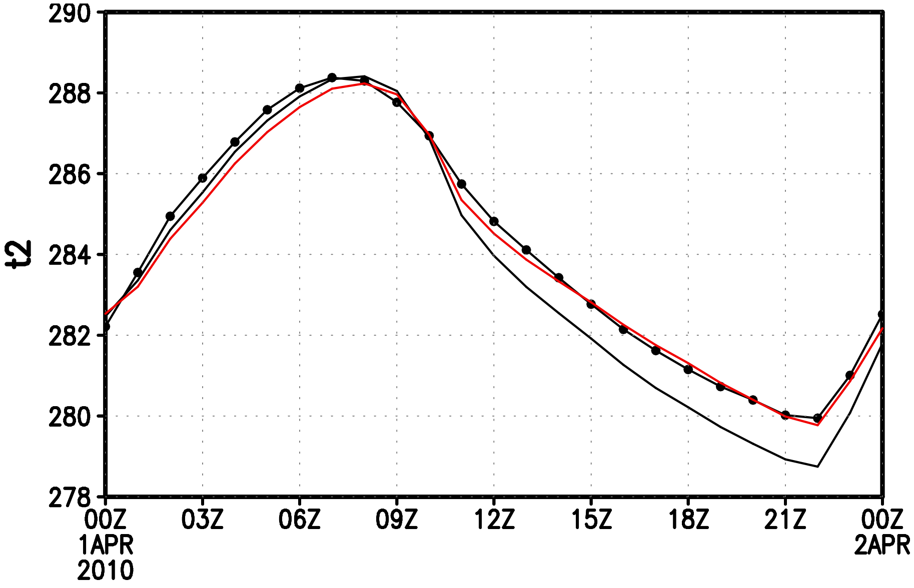
6、 Operational applications

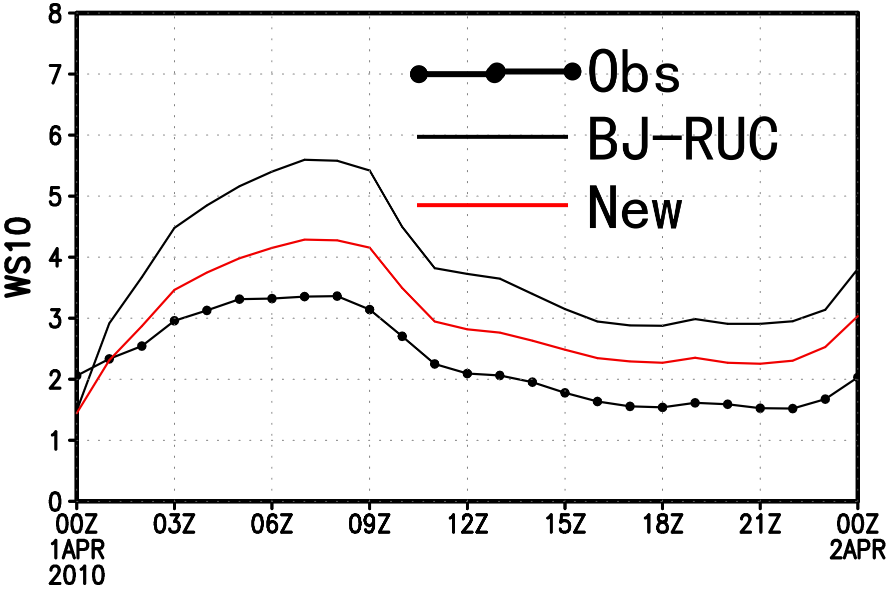
Dataset、UCM →

◆**BJ-RUC: improve the performance of surface forecast**

◆**Rainfall: in test**

Evaluation of T2 and WS10 from BJ-RUC for Apr 2010



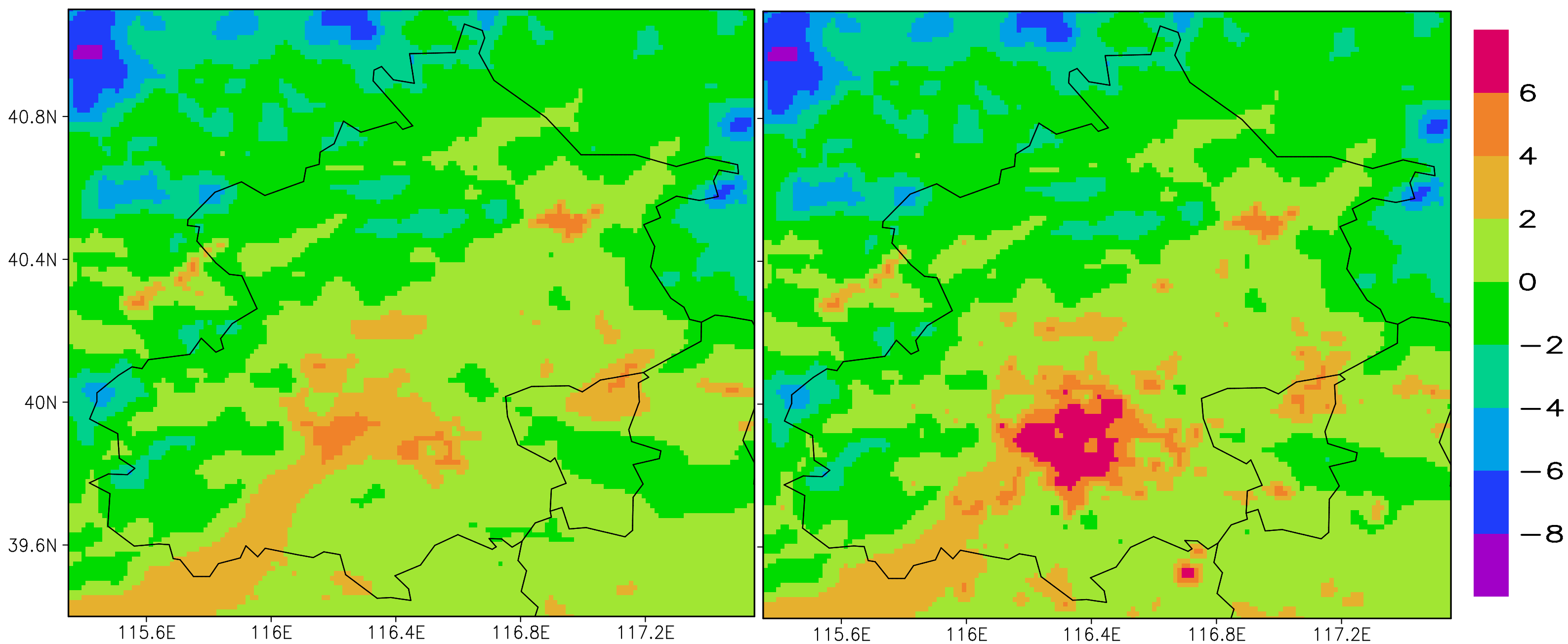


6、 Operational applications

◆UHI

◆More service products

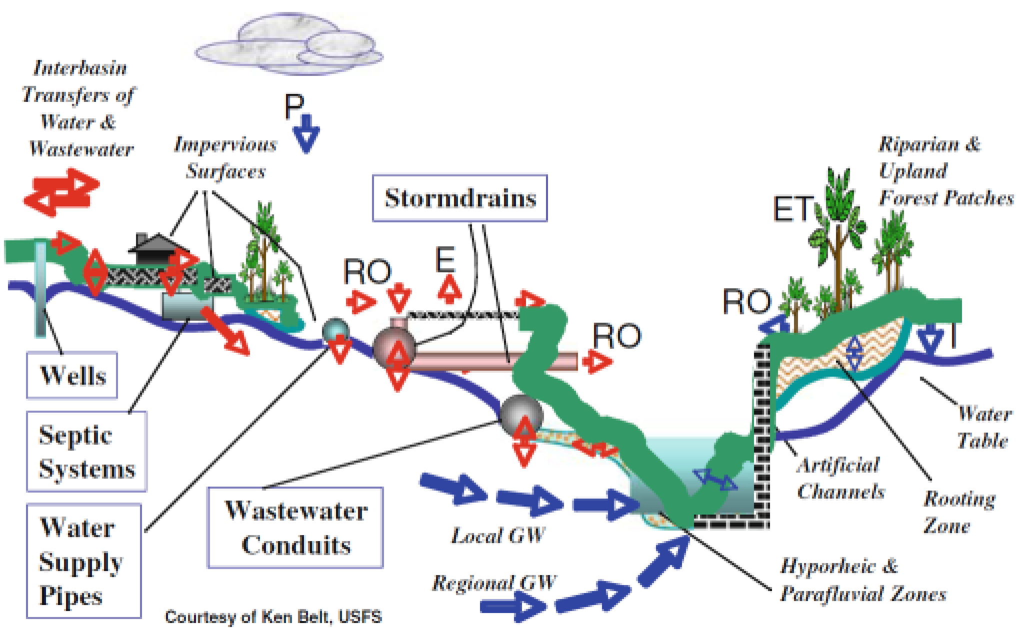
➢ **BJ-RUC** ➢ **New（LU+UCM）**



2m T.： 2010-04-03_0200LST (℃)

7、Prospects

1) **Urban land surface/canopy/BL model：**
   - **Heterogenity of urban surface: classification, characteristic length scale, MOST**
   - **Vegetation in urban**
   - **Hydrology in urban**
2) **Impacts on precipitation and for/haze**
3) **Impacts on regional climate & climate change**



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Contents

THANKS FOR YOUR ATTENTION &

HAPPY DRAGON BOAT FESTIVAL !

22 June 2012