Observing and Modeling the Urban Boundary Layer in Beijing

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National Center for Atmospheric Research

22 June 2012
Application needs

- Urban climate change
- Urban pollution
- Traffic/Emergency response
- Emergency response
- Urban planning assessment
- Urban weather forecast
- Atmos. Env./Human health
- Heat wave, heavy rainfall
- Urban climate change
- Urban planning assessment
Contents

1、Urban canopy model
2、Urban land surface model & land data assimilation system (HRLDAS)
3、Numerical modeling of UBL
4、Urbanization effects（effects on precipitation & monthly effects）
5、Dataset（GIS、SEB observation）
6、Operational applications（traffic、urban planning、emergency response、NWP）
7、Prospects
1. Urban canopy model

1) Improved latent heat flux modeling over urban surfaces
2) Improved surface wind
3) Optimizing UCM parameters

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

- Net radiation
- SH
- LH
- Storage

Worse
Taylor plot for every SEB components

- Overestimate $Q_H$
- Underestimate $Q_E$
- Worst performance of $Q_E$:
  $\text{RMSE}_S > \text{RMSE}_u$
1) Irrigation in urban area: Set SM from 0-1m (1-3 model layers) to SMREF (field moisture capacity) during 06-08 PM, from May to September.
### 2) Oasis effect

**Oasis coefficient:** \( \alpha_{oasis} = 1.5 \)

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.

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<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
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<td>23.9</td>
<td>65.1</td>
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<td>Cloudy</td>
<td>20.7</td>
<td>46.3</td>
<td>18.7</td>
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<tr>
<td><strong>Veg</strong></td>
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<td><strong>Veg_Diff (Clear-Cloudy)</strong></td>
<td>5.3</td>
<td>12.1</td>
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<tr>
<td><strong>Res</strong></td>
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<tr>
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<td><strong>11.3</strong></td>
<td>5.9</td>
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<tr>
<td><strong>Res_Diff (Clear-Cloudy)</strong></td>
<td>-2.1</td>
<td>6.6</td>
<td>1.3</td>
<td>1.3</td>
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<tr>
<td>1 + Res_diff / Veg_diff</td>
<td><strong>0.6</strong></td>
<td><strong>1.5</strong></td>
<td>1.4</td>
<td>7.5</td>
</tr>
</tbody>
</table>
3) LH from impervious surface

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

\[
\begin{align*}
\beta_G &= \begin{cases} 
1.0, & R \geq 10 \text{mm} \\
0.5, & 0 < R < 10 \text{mm} \\
\beta_{G,0} e^{-dt/5}, & \text{No rain}
\end{cases} \\
\beta_R &= \beta_W = \beta_G
\end{align*}
\]
4) **ALH**: Max. for Spr, Sum, Aut, and Win are 17, 42, 24, and 18 W m$^{-2}$
Old

Surface flux (W/m²)

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

New

Surface flux (W/m²)

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

- Obs
- BJ-RUC
- New
2. Urban land surface model & land data assimilation system (HRLDAS)

1) Setting up of u-HRLDAS

Land surface dataset
- Vegetation type
- Soil Texture
- Snow
- Leaf Area Index
- Terrain
- Vegetation Cover

Met. driving: GLDAS/obs/BJ-RUC
- Observed Precipitation, Radiation, T, Q, U, V

High-Resolution Land Data Assimilation System (HRLDAS)
- Soil moisture, soil temperature, snow cover, canopy water, skin temperature

Coupled WRF/Noah model
RMSE for skin temperature (°C)

- 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**

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

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**Rainfall**

- **aws**
- **gdas**

**New ET**

- After using urban cycle model
- Before using urban cycle model

**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** \( z = 384 \text{m} \)

**Horizontal Convective Rolls (HCRs)**

**Vertical velocity and horizontal wind vectors**

\(-z_i/L\)
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.
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

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

- Urbanization
  → Increasing CAPE, decreasing CIN
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 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°C and up
- Night: 200m, 1.4°C 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 116.34°E: Case CTRL and case U2C
- Urbanization increases rainfall in Haidian and Changping, and the frequency of heavy rainfall.

- UHIC→Wind rose

- WRF/Noah/UCM simulates this characteristics very well.

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

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

USGS : 1992-1993

LANDSAT-TM : 2009

Urban: Default     Low  Medium  High Density
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）

图8 京津冀地区2008年7月份NDVI分布图

图13 京津冀地区2008年7月份LAI分布图
AH for Jing-Jing-Ji area

Winter and summer human heat with time change

Yearly variation

Diurnal variation

AH for winter 2009, W/m²
5. Dataset

2）SEB observation in Beijing

- Tower: 325m
- Building height around tower: 50~70m
- Mean building height: ~19m
### Mean values of total daytime energy fluxes and flux ratios

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

<table>
<thead>
<tr>
<th>City location</th>
<th>Green space (%)</th>
<th>Building height (m)</th>
<th>Observation height (m)</th>
<th>Observation period</th>
<th>Frequency of days with rain (%)</th>
<th>Ratio</th>
<th>Qh/Q*</th>
<th>Qe/Q*</th>
<th>Qs/Q*</th>
<th>Qh/Qe</th>
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<tr>
<td>Vancouver,</td>
<td>4.0</td>
<td>8.6</td>
<td>/</td>
<td>Aug 1992</td>
<td>0.42</td>
<td>0.10</td>
<td>0.48</td>
<td>4.42</td>
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<td>(49° 16'N, 123° 06'W)</td>
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<td>Marseille,</td>
<td>11.0</td>
<td>20.0</td>
<td>/</td>
<td>Jun-Aug 1995</td>
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<td>4.27</td>
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<td>Basel,</td>
<td>10.0</td>
<td>14.0</td>
<td>32.0</td>
<td>Jun-Aug 2002</td>
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<td>3.0</td>
<td>Dec 2007</td>
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<td>0.11</td>
<td>0.80</td>
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<td>Tokyo, Japan</td>
<td>29.1</td>
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<td>Dec 2002</td>
<td>0.26</td>
<td>1.00</td>
<td>1.77</td>
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<td>(35° 34'N, 139° 07'E)</td>
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<td>Beijing, China</td>
<td>21.7</td>
<td>18.3</td>
<td>140.0</td>
<td>Dec 2009 – Feb 2010</td>
<td>5.0</td>
<td>0.28</td>
<td>0.07</td>
<td>0.66</td>
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<td>(39° 58'N, 116° 42'E)</td>
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<td>Chicago</td>
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<td>Dec 2009 – Dec 2010</td>
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<td>Mexico City,</td>
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<td>15.4</td>
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<td>0.18</td>
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<td>18.3</td>
<td>140.0</td>
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<td>Tokyo,</td>
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<td>Dec 2006</td>
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<td>Tokyo,</td>
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<td>Mediterranean climate: Sum: hot dry</td>
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**Beijing:** building, climate … → Different urban SEB characteristics
6、Operational applications

Road surface forecasting system → Traffic service
6、 Operational applications

UCM/UBL → urban planning

UNSM/UBL → emergency response

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
Contents

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7. Prospects

THANKS FOR YOUR ATTENTION &
HAPPY DRAGON BOAT FESTIVAL!

22 June 2012