Impacts of Urban Morphology and Climate Change on Urban Heat Island over Beijing Metropolitan Area: Compact- Versus Dispersed-city

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1. Abstract

Background: Cities evolve in both size and shape (spatial pattern).
Objective: In this study, we examine the thermal environment (e.g., urban heat island) over Beijing metropolitan area with projected spatial patterns of urban coverage (compact-city and dispersed-city); we evaluate relative contributions of future climate and urbanization to regional warming;
Methods: We rely on state-of-art atmospheric modeling tools and in-situ observations to evaluate the range of dynamical and thermal behaviors under different scenarios (with both spatial patterns of urban coverage and climate forcing considered).
Results : The urban core region is cooler in the dispersed city and the urban-rural contrast is also narrower. However, Dispersed city produces a larger warming effect to regional climate than compact city. In terms of future impacts, the climate change signature is the dominant forcing and therefore dispersed city scenario appears to have an advantage. Note that the traffic patterns are not being considered in this assessment.
Conclusions: Other mitigation strategies should be employed along with city designs to enhance urban adaptability to future climate change.

2. Case Description

Time period: 1st July-10th July, 2010 (major regional heat wave);

Average 2m temperature during 4th July-6th July exceeds 33 degree C (Fig. 1);

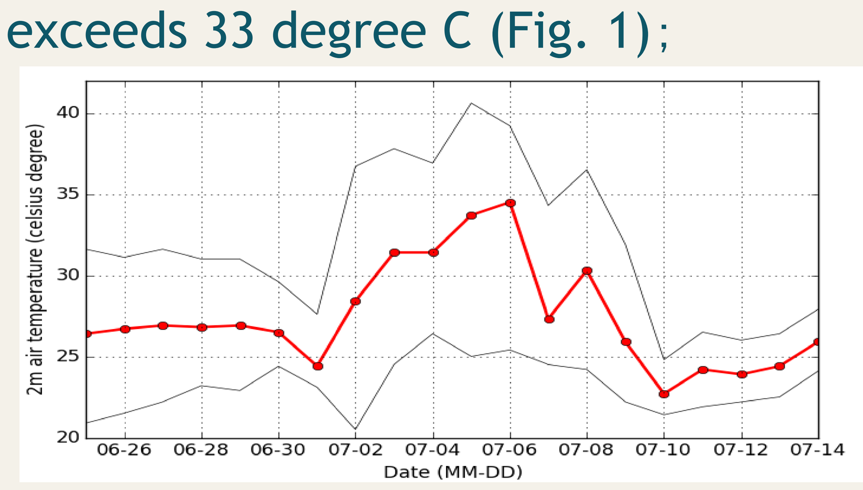

Figure 1. Time series of 2m temperature over Beijing urban core region

3. Model Configuration

We use the WRF coupled with Single-Layer UCM modeling system. Three one-way nested domains were configured over Beijing (Fig. 2). ERA-interim were chosen to provide boundary/initial conditions for all simulations.

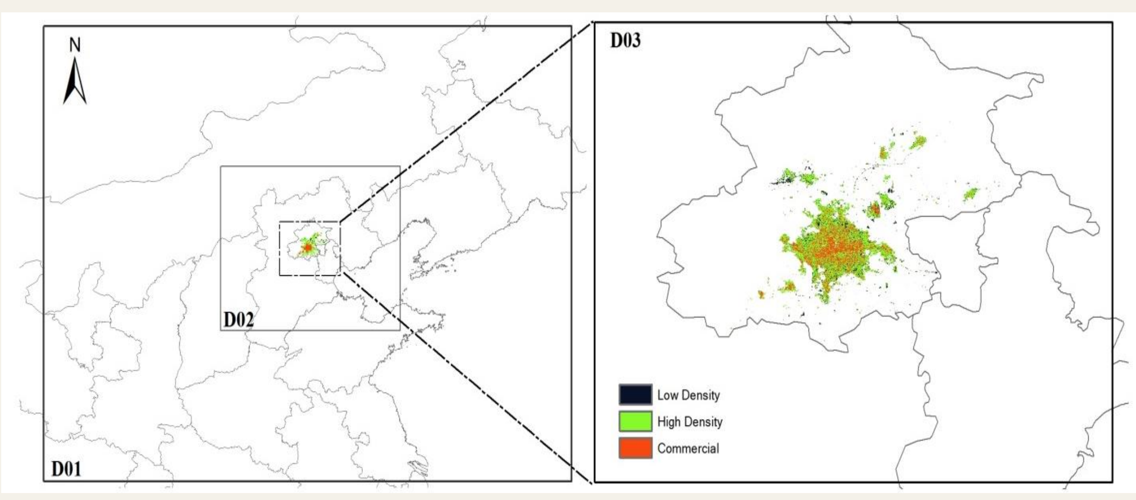

Figure 2. WRF domain configurations

Table 1. WRF physics options

Physics	Option
Long wave radiation	RRTM Scheme
Short wave radiation	Dudhia Scheme
Surface layer	Monin-Obukhov Scheme
Land surface	Noah LSM
Boundary layer scheme	Yonsei University Scheme (YSU)
Urban physics	Single Layer UCM (SLUCM)
Land Surface	Noah Land Surface Model (Noah LSM)
Land use	MODIS 30s

4. Experiments Setup

Both impacts of urbanization and future climate change are considered:

For urbanization: compact-city (Fig. 3c) versus dispersed-city (Fig. 3d), both scenarios have the same urban coverage (twice as large as the current urban coverage);

For future climate change: 2050s climate forcing from CCSM (RCP 8.5);

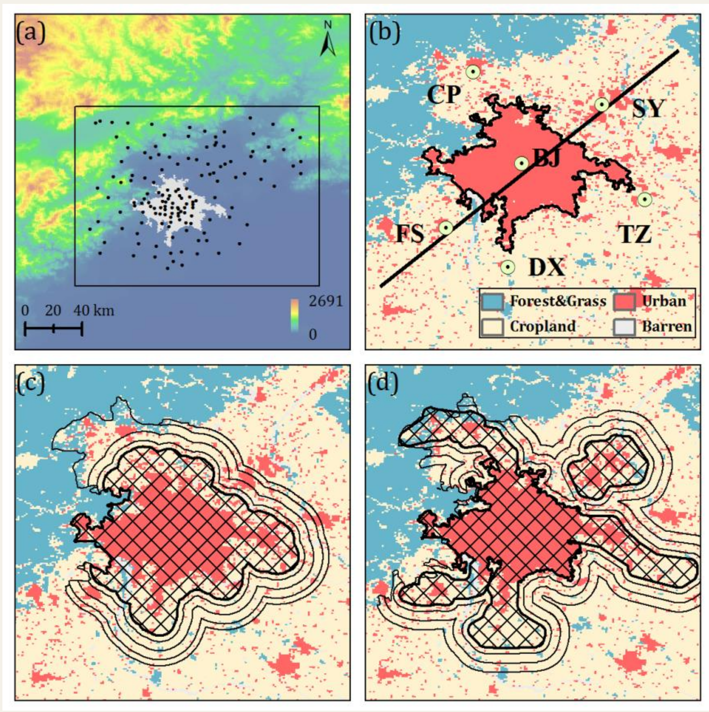

Figure 3. (a) Topographic features around Beijing; (b) current urban coverage; urban coverage for (c) compact-city scenario and (d) dispersed-city scenario. Urban boundaries are highlighted by black solid curves .

Table 2. Configuration of Experimental Runs (No.1 is control simulation)

NO.	Urban scenario	Climate Forcing
1	Current	Current (2010)/ERA-interim
2	Compact-city	Current (2010)/ERA-interim
3	Dispersed-city	Current (2010)/ERA-interim
4	Current	Future (2050s)/CCSM RCP8.5
5	Compact-city	Future (2050s)/CCSM RCP8.5
6	Dispersed-city	Future (2050s)/CCSM RCP8.5

5. Model Validation

Model results from control simulation were validated against in-situ observations (Fig. 4).

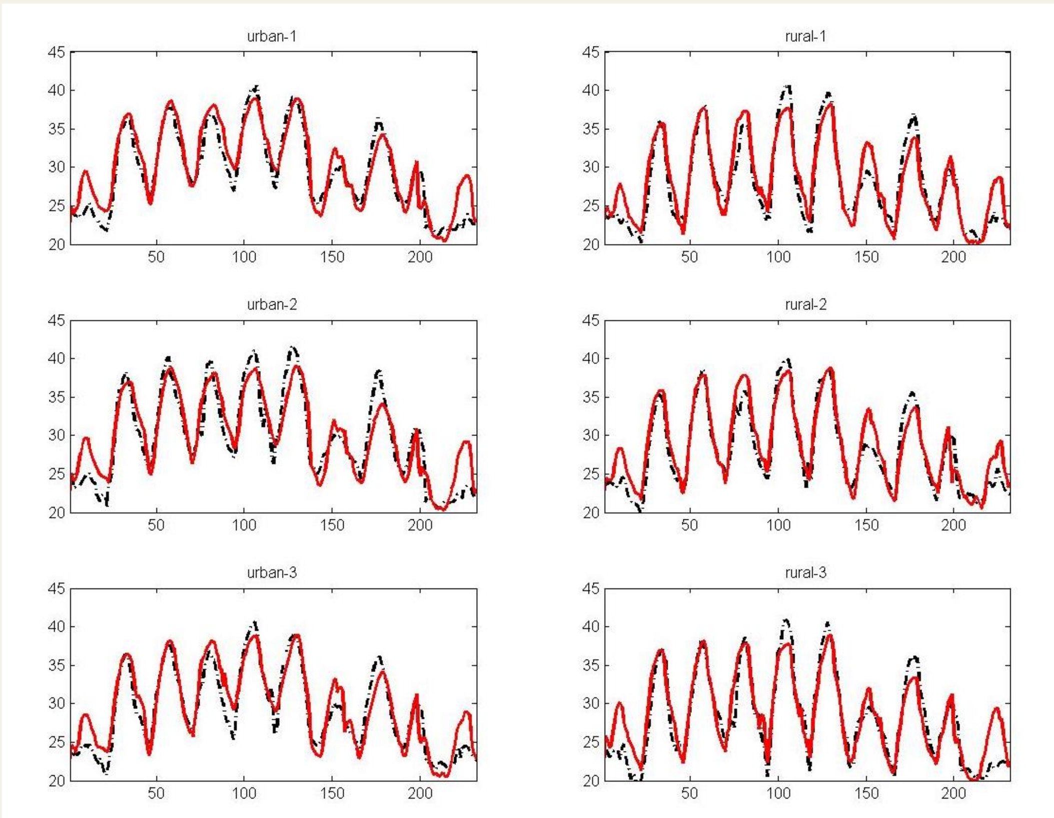

Figure 4. comparison of 2m temperature (red line is simulation)

6. Results: UHI Intensity

Definition of UHI intensity (UHII):

Average of 2m temperature difference between urban region and rural region.

Note 1: UHII is reduced by 0.5 C on average in dispersed-city scenario, while compact-city increase UHII (by ~0.1 C on average).

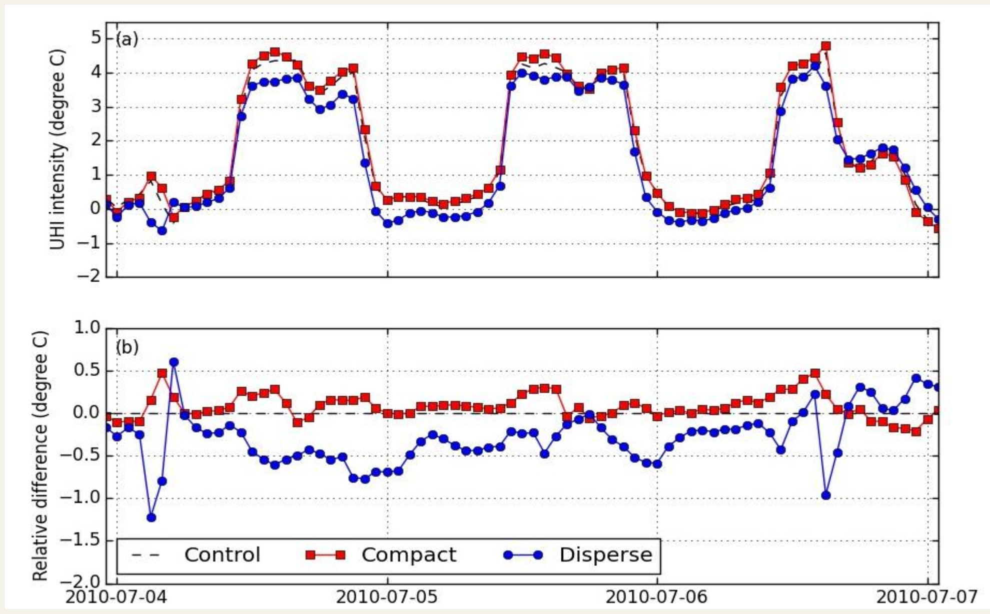

Figure 5. Time series of UHII and the difference between different runs

6. Results: UHI Footprint-horizontal

Definition of UHI footprint-horizontal:

Horizontal spatially averaged 2m temperature over and beyond the extent of urbanization.

Note 2: (a) Dispersed-city scenario produce a larger regional warming effect (by 0.1 K on average) than compact-city scenario;

(b) urban core region is cooler (by 0.15 K) in dispersed-city scenario than compact-city;

(c) The difference between two urban

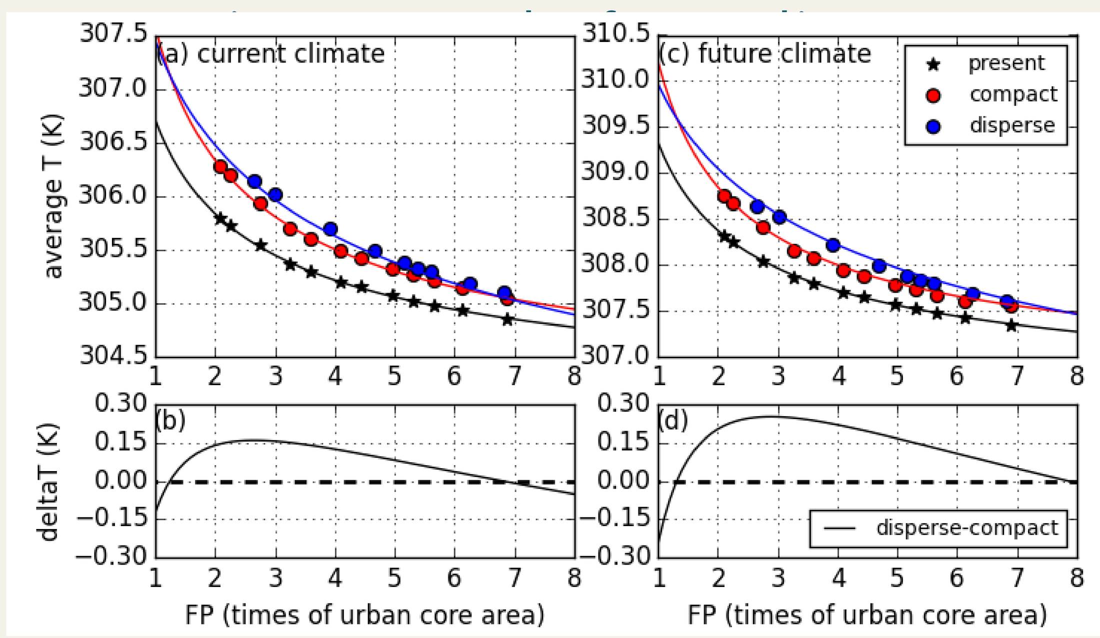

Figure 6. UHI footprint (horizontal) over different scenarios

6. Results: UHI Footprint-Vertical

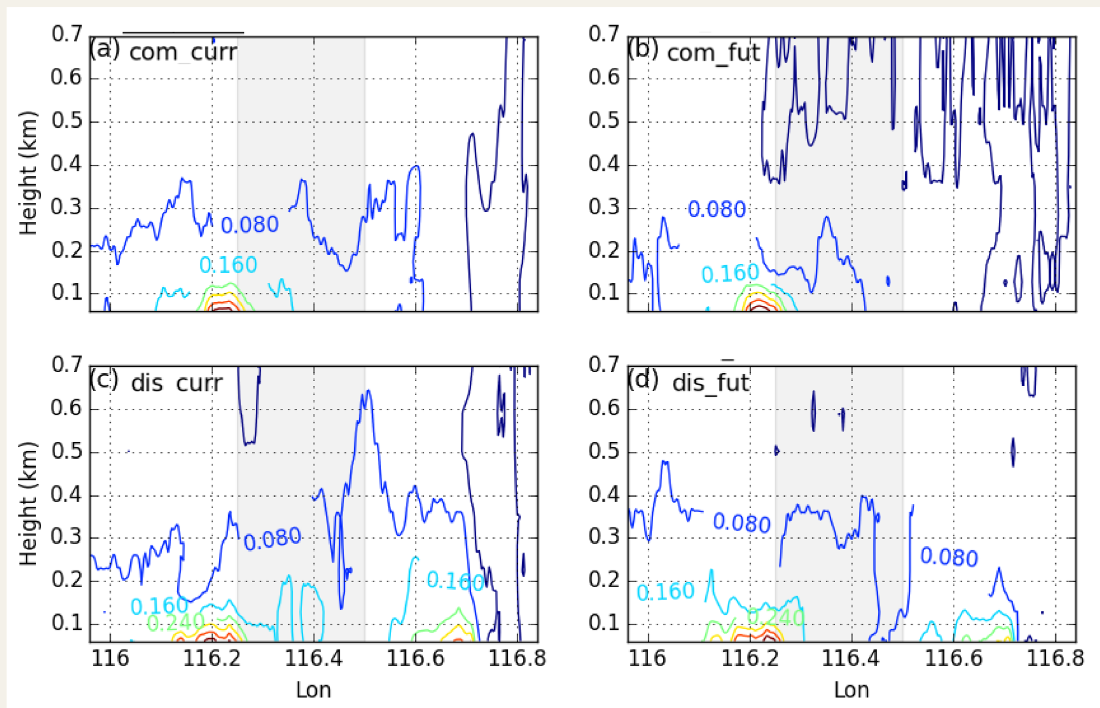

Figure 7. Vertical profiles of potential temperature difference along the black straight line in Fig. 1b

Note 3: Dispersed-city scenario tends to produce a deeper perturbation on potential temperature profile than compact-city.

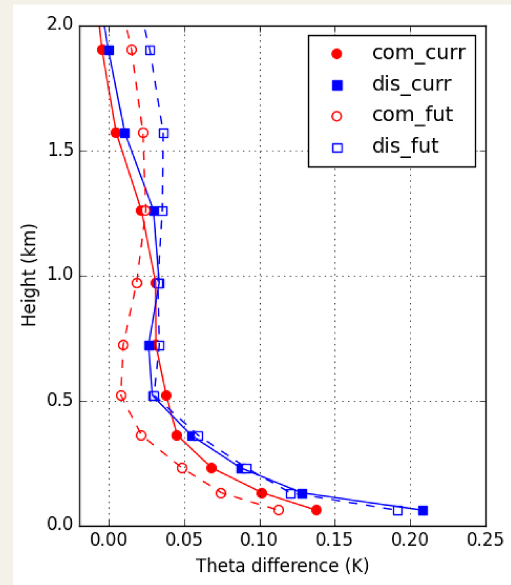

Figure 8. Vertical profiles of average potential temperature difference

6. Results: Relative contribution

Note 4: Climate change contributes more than 80% to the total warming over the urban core region in 2050s, while the contribution of urban coverage to warming is ~20% (assessed using interaction explicit factor-separation Analysis).

Table 3. Relative contributions to warming effect

Scenarios	Compact-city	Dispersed-city
Total increase (K)	2.98	2.89
Due to Climate (K)	2.44 (82%)	2.44 (85%)
Due to Urbanization (K)	0.50 (17%)	0.40 (13%)
Interactions (K)	0.04 (1%)	0.07 (2%)

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