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Study of thermal environment in Jingjintang urban agglomeration based on WRF model and Landsat data

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Abstract. In recent decades, unprecedented urban expansion has taken place in developing countries resulting in the emergence of megacities or urban agglomeration. It has been highly concerned by many countries about a variety of urban environmental issues such as greenhouse gas emissions and urban heat island phenomenon associated with urbanization. Generally, thermal environment is monitored by remote sensing satellite data. This method is usually limited by weather and repeated cycle. Another approach is relied on numerical simulation based on models. In the study, these two means are combined to study the thermal environment of Jingjintang urban agglomeration. The high temperature processes of the study area in 2009 and 1990s are simulated by using WRF (the Weather Research and Forecasting Model) coupled with UCM (Urban Canopy Model) and the urban impervious surface estimated from Landsat-5 TM data using support vector machine. Results show that the trend of simulated air temperature (2 meter) is in accord with observed air temperature. Moreover, it indicates the differences of air temperature and Land Surface Temperature caused by the urbanization efficiently. The UHI effect at night is stronger than that in the day. The maximum difference of LST reaches to 8-10ºC for new build-up area at night. The method provided in this research can be used to analyze impacts on urban thermal environment caused by urbanization and it also provides means on thermal environment monitoring and prediction which will benefit the coping capacity of extreme event.

1. Introduction

Generally, high temperature weather is mainly influenced by seasonal and weather systems, which is closed related with factors caused by atmospheric circulation anomalies, such as advection layer warming, insulation sinking warming and radiation warming in clear sky weather [1]. In addition to the above factors, its forming may be more closely related to combination of factors such as the underlying surface structure characteristics and anthropogenic heat emission. Some studies have indicated that warming caused by urban heat island (UHI) effect, can increase the happening of extreme high temperature weather [2][3]. In addition, UHI also has an effect on cloud, precipitation and air quality in urban area and its neighboring areas. And it even has a corresponding effect on global warming, thus it is necessary to carry out study of the problem [4].

In recent years, the Weather Research and Forecasting Model (WRF) model has become more and more mature and it has coupled with urban canopy model (UCM). It has become an important tool to study extreme weather quantitatively. Meng et al. [5] utilized WRF and UCM to study high temperature process under the influence of subtropical high pressure and the typhoon periphery airflow of Guangzhou. Zhang et al. [6] revised land use types of shanghai with WRF model using remote sensing data, and indicated that changes of land use and land cover (LULC) such as cultivated land into urban would result that horizontal wind speed decreased significantly and that the ground temperature and boundary layer height are closer to the measured values. Li et al. [7] carried out numerical simulation of summer climate effect for 5 years in mega-regions of the Yangtze River Delta and analyzed the UHI caused by urban agglomeration, land surface energy balance and its diurnal variation characteristics by the analysis of the contrast test of cities.

In order to analyze influence of rapid urbanization of Jingjintang urban agglomeration on meteorological elements, we carried out numerical simulation of one high temperature process on August in the area using WRF and UCM model. In the simulation, firstly the LULC data from the model was could be treated as former urban range in 1990s and a former simulation result was achieved according to it. Secondly, the current urban scope based on Landsat TM data could be used as new input and another simulation result was gotten. By the tests of high temperature weather processes, the influence of urbanization on air temperature and land surface temperature could be analyzed.

2. Study area and setting of simulation test

2.1. Study area

The Jingjintang urban agglomeration around Bohai Rim(38°30′~41°8′N; 115°17′~119°30′E) is surrounded by Yan Mountain in the north and Taihang Mountain in the west, covering approximately 42000 km^2 including Beijing, Tianjin and Tangshan (Figure 1).

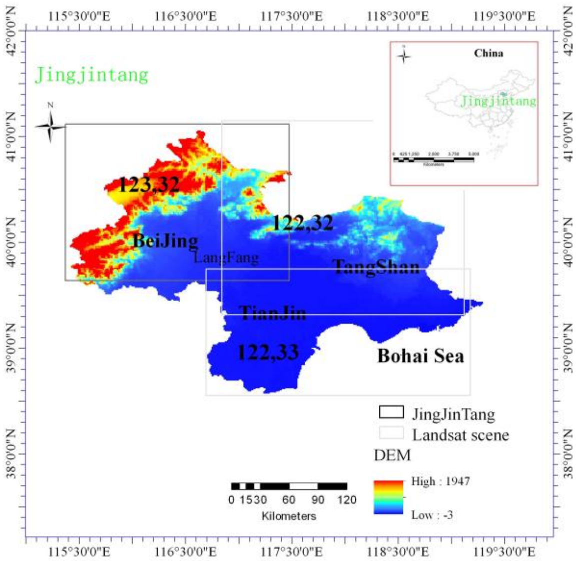


Figure 1. Location of the study area

2.2. Setting of simulation test

In the simulation tests, Beijing is taken as centre (116E, 40N). Two layer nested model is adopted. Outer lateral area has 302 grid points in horizontal direction and 272 ones in vertical direction with 6km spatial resolution. In the study, Landsat TM data are used to retrieve urban impervious surface of

Jingjintang urban agglomeration. Three Landsat footprints (path/row 122/32,122/33 and 123/32) cover entire urban agglomeration region (Figure 1). The urban scope in 1990s is given according to its own information of the model while current urban range is derived from Landsat TM on August, 2009 using SVM algorithm. Figure2 (a) and (c) indicates outer region while (c) and (d) illustrates inner region. The graph shows that model's own city coverage is small while the improved urban coverage is much larger. The two tests could reveal difference of thermal environment due to urban expansion. Under the condition of weak weather, UHI effect could be revealed fully. Therefore, we select a high temperature process on August 11-12, 2009 which has a low wind speed (4m/s).

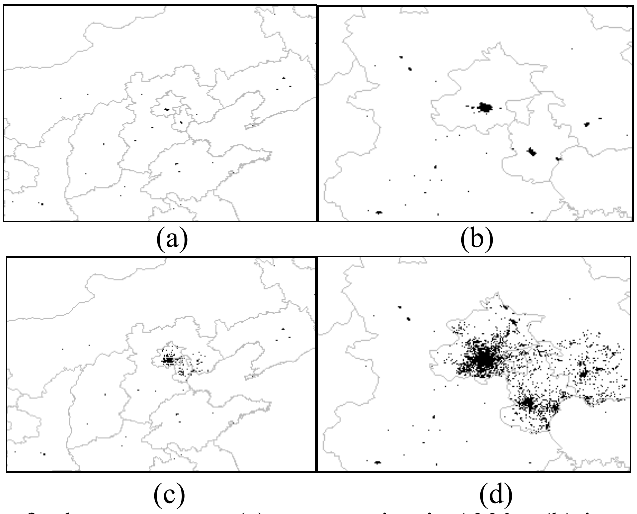


Figure 2. Difference of urban coverage: (a) outer region in 1990s; (b) inner region in 1990s; (c) outer region in 2009; (b) inner region in 2009

3. Methodology

Impact of urban thermal environment in the study area is analyzed by combination of satellite remote sensing and model simulation. Firstly, the new urban range is determined according to impervious surface percent which is derived based on SVM algorithm [8]. Secondly, WRF and the coupled UCM model are utilized using atmospheric environmental data of the selected high temperature process given by NCEP and the new urban information as inputs. In another test, it is simulated using the old LULC data and the same atmospheric field data. The flowchart is shown as Figure 3.

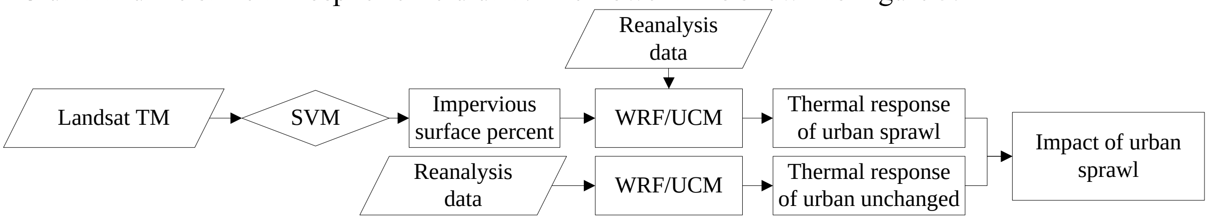


Figure 3. The processing flowchart

3.1. UCM model

UCM model is depicted using equation (1). The surface was grouped into three classes (roof, wall surface and road surface) by the model, and Land surface temperature (LST) and radiance are estimated by the following equation.

$$R_{n,i} = H_i + lE_i + G_i \quad (i = R, W, G) \tag{1}$$

where $R_{n,i}$ is downward net fluxes; H_i is upward sensible fluxes; lE_i is latent heat fluxes; G_i is underground thermal fluxes; and i is one of available surface types including roof, wall surface and road surface. Figure 4 illustrates schematic of UCM.

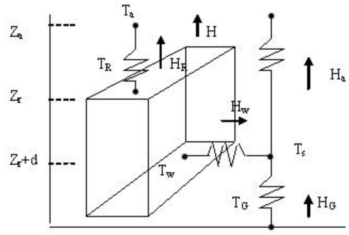


Figure 4. Schematic of UCM

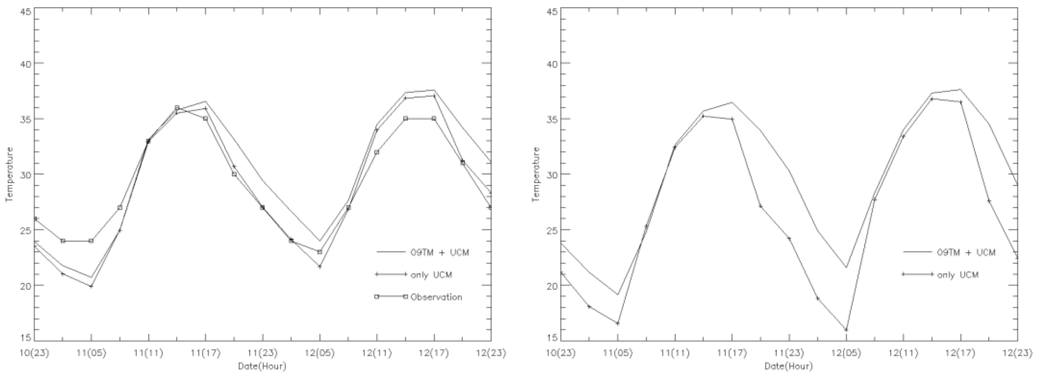
where Z_a is height of the lowest model level; T_a is air temperature at Z_a; H is aggregated sensible heat flux; Z_r is building height; Z_T is roughness length for heat; d is zero displacement height. T_R, T_W and T_G are surface temperature of roof, wall, and road, respectively; and H_R, H_a, H_w, and H_G are sensible heat fluxes from the roof, canyon, wall, and road, respectively.

3.2. *Impervious Surface Percent retrieval*

Impervious surface percent is derived according to V-I-S model using SVM algorithm. Detail information can be referred from references [8]. In the study, the pixel of percent larger than 50% could be thought as urban area.

4. Result

Figure 2 shows the urbanization extent of Jingjintang urban agglomeration which indicates that the urban have suffered manifest expansion. Figure 5 illustrates comparison of two simulation results and observation for air temperature at location of 2m high. Results show that the trend of simulated air temperature (2 meter) is in accord with observation air temperature except for the beginning due to 'spin-up' effect from both Figure 5 (a) and (b). The result of '09TM+UCM' is higher than that of 'only UCM'. Moreover, for urban centre, the difference is about 0.5 ºC in the day, while at night it turns to 2.5 ºC; And for new build-up area, the largest difference in the day is about 1 ºC -2 ºC at 17:00 while at night the difference becomes 5 ºC -7 ºC.



(a) (b)

Figure 5. Dynamic variation of average air temperature (8 pixels × 8 pixels) with time: (a) urban centre; (b) new build-up area

Figure 6 shows the dynamic variation of average LST for urban centre and new build-up area. It indicates that urbanization has less impact on urban centre (1 ºC ~2 ºC) than new urban area (8ºC ~10 ºC). It has stronger UHI effect at night than in the day.

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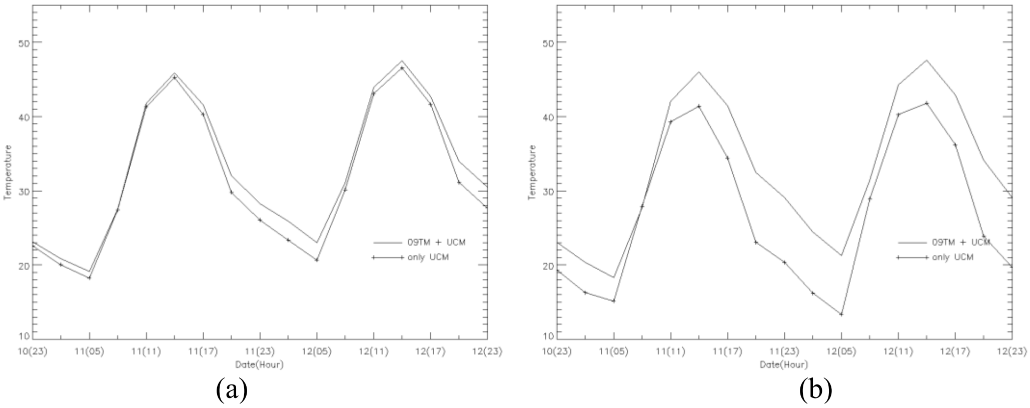

Figure 6. Dynamic variation of average LST (8 pixels × 8 pixels) with time: (a) urban centre; (b) new build-up area

Figure 7 (a) and (c) are the simulation results of 1990s while (b) and (d) are the ones of 2009. It efficiently indicates LST difference caused by the urbanization: the LST in 2009 is higher than that of in 1990s; the high temperature area in 2009 is larger than that of in 1990s and the trend is in accord with urbanization expansion. Meanwhile, Figure 7 (a) and (b) are the results in the day (14:00); Figure 7 (c) and (d) are the results at night (5:00). The graph shows that the UHI effect at night is stronger than that in the day.

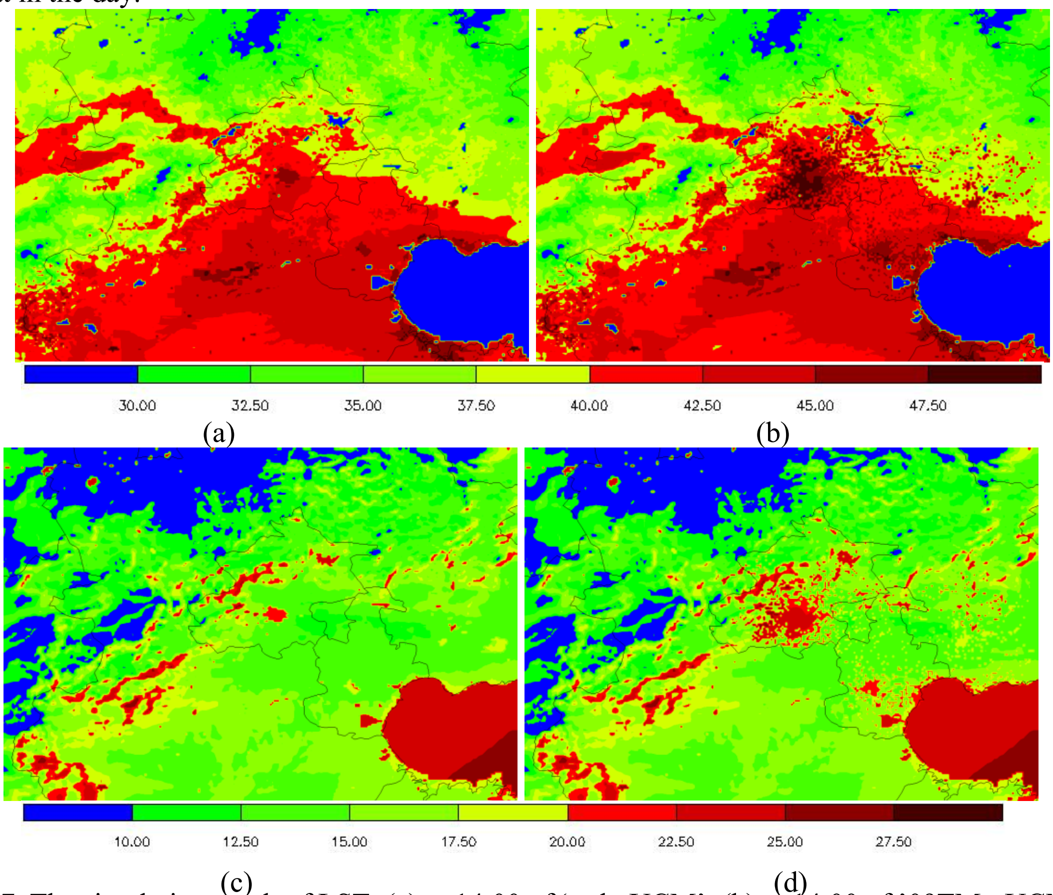

Figure 7. The simulation result of LST: (a) at 14:00 of 'only UCM'; (b) at 14:00 of '09TM +UCM'; (c) at 5:00 'only UCM'; (d) at 5:00 of '09TM +UCM'

Figure 8 (a) and (b) are difference value between 'only UCM' and '09TM +UCM' including in the day and night. From the graph, we can see that new build-up area has stronger UHI intensity than urban centre and at night it has stronger UHI intensity than in the day.

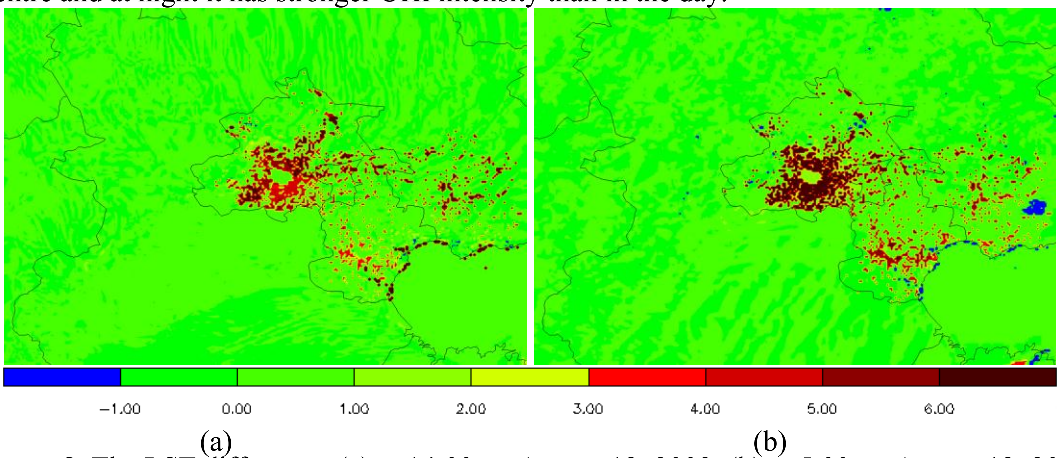

Figure 8. The LST difference: (a) at 14:00 on August 12, 2009; (b) at 5:00 on August 12, 2009

5. Conclusions

In the study, we carried out study of thermal response of extremely high temperature in Jingjintang based on WRF model. It is irreversible for urbanization. Therefore, we synthesize WRF model with remote sensing retrieval method to evaluate the influence of urbanization on thermal environment. Results showed there was less influence on urban centre. The UHI effect at night is stronger than the one in the day. The maximum difference of LST reaches to 8-10ºC for new build-up area at night. The simulation results are in accordance with observation. It is important to study the driving forces of urbanization. In the future, a comprehensive investigation should be considered.

6. Acknowledgement

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