556: Improvement of the single-layer UCM in the WRF model

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Abstract

This study modifies the WRF/UCM to incorporate the gridded urban parameters into the model and reproduce the urban effects to local climate caused by inhomogeneity in an urban area. The simulations of heat island in summer and winter in Tokyo metropolitan area are conducted using the original WRF/UCM and the modified one.

The reproducibility of heat island in Tokyo metropolitan area is improved in the modified WRF/UCM compared with the original one. The urban fraction shows large impact on the nighttime surface air temperature in summer and winter. The anthropogenic heat (AH) affects on the nighttime surface air temperature in winter, while impacts of AH is small in summer. The differences in surface air temperature between the simulations with the spacially-uniform urban data and the gridded urban data are small during daytime in both seasons. The difference of surface wind speed is large in early evening in summer because of the difference in the speed of decline of the mixing layer between urban and other land-use areas.

Keywords: urban canopy model, urban parameters, WRF

1. Introduction

Anthropogenic heat, urban fraction, and building height (roughness length, displacement height) are major urban parameters expressing the urban characteristics such as human activity, land use, and urban geometric structure in an urban model.

To reproduce the urban effects to local climate caused by inhomogeneity in an urban area, this study modified the WRF/UCM to incorporate the gridded urban parameters into the model and conducted the preliminary sensitivity analysis of spatially inhomogeneous urban texture to the local climate.

Table 1: Model settings

Boundary data	NCEP/NCAR reanalysis I
Resolution	20km, 4km (Horizontal) 31 levels (Vertical)
Land surface scheme	Noah land surface model
Urban scheme	Single-layer urban canopy model (Kusaka et al., 2001)
PBL scheme	Mellor-Yamada-Janjic TKE scheme
Surface layer scheme	Monin-Obukhov (Janjic) scheme

2. Methodology

2.1 Model settings

The version used in this study is WRF version 3.3.1 (Skamarock et al., 2008). The applied schemes and model setting are listed in Table 1. The outer domain covers the most part of main islands in Japan, while the inner domain covers the central part of Japan including the Tokyo metropolitan area (TMA) (Fig. 1).

The grid of the inner domain has 126 x 126 grid cells with the horizontal resolution of 4 km. The sensitivity simulations are conducted in winter and summer. The summer case is conducted from July 25, 2010 to September 1, 2010, the output only in August is used for analysis. The winter case is integrated from January 25, 2008 to March 1, 2008, the output only in February is used for analysis.

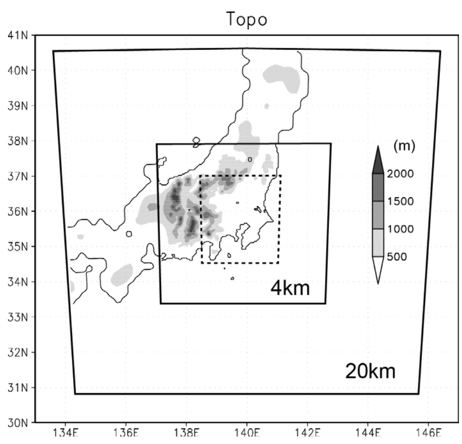

Fig 1. Model domains. The dashed square indicates the analyzed area (Tokyo metropolitan area).

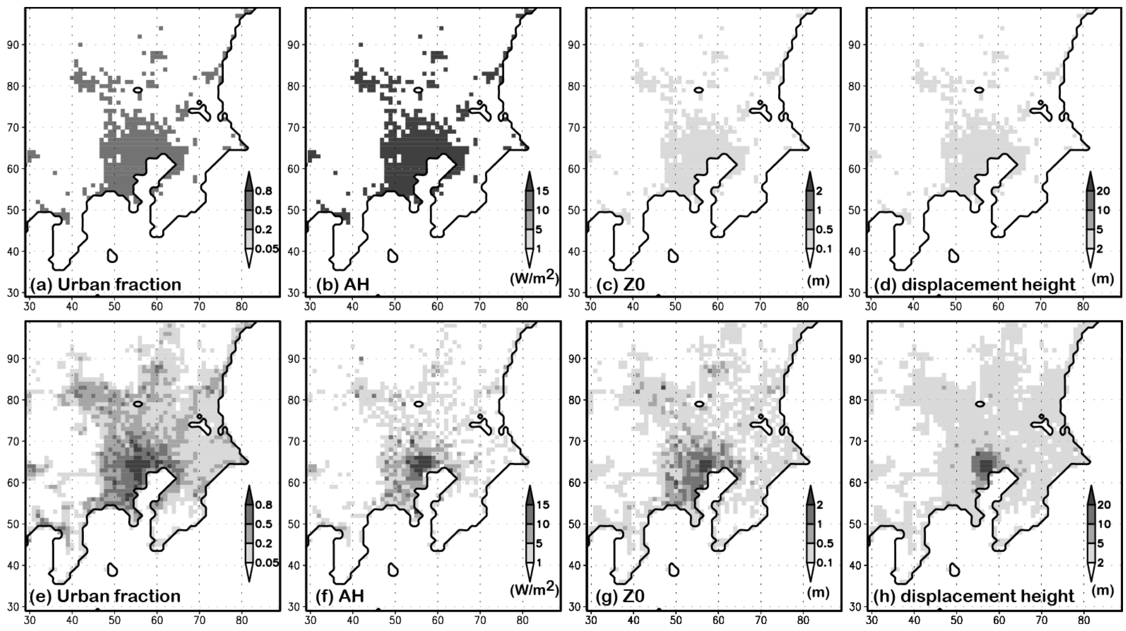

Fig 2. Distributions of (a) urban ratios, (b) anthropogenic heat flux, (c) roughness length, and (d) displacement height in ctl_org run. (e)-(h) are same as (a)-(d), but for exp_all run.

2.2 Experimental design

The four urban parameters are given as the gridded data in new WRF/UCM: (1) urban fraction, (2) anthropogenic heat (AH), (3) momentum roughness length, and (4) displacement height. The gridded urban parameters used in this study are illustrated in Fig 2.

The urban fraction is defined as a ratio of urban area to an entire grid cell, and created using the fine land cover data (FLCD) from the Digital National Land Information (DNLI) dataset, published by the Ministry of Land, Infrastructure, Transport, and Tourism. The FLCD categorizes land use into 11 or 12 types for every 100-m square. These 11 or 12 land-use types were reclassified to eight land-use types used in USGS land-use types in the WRF model. The anthropogenic heat release is based on the AH value in August reported in NIRE (1997), which is estimated using energy consumption rates. The momentum roughness length above canyon and the displacement height are calculated according to empirical equations set up based on a number of large eddy simulations in the Tokyo metropolitan area (Kanda et al., 2012).

To evaluate the impacts of the gridded data to urban climate, the sensitivity analyses are conducted. The experimental design was shown in Table 2. The fixed value in Table 2 means the urban parameter is spatially homogenous, namely, it is provided as constant value. On the other hand, “map” means the urban parameter is given as the gridded data.

Table 2: Experimental design.

Simulation	Urban fraction	AH (W/m^2)	Z0 (m)	Zd (m)
ctl_org	0.7	17.5	0.286	4.31
ctl_LU	0.7	0	0.286	4.31
exp_LU	map	0	0.286	4.31
ctl_AH	map	17.5	0.286	4.31
exp_AH	map	map	0.286	4.31
exp_all	map	map	map	map

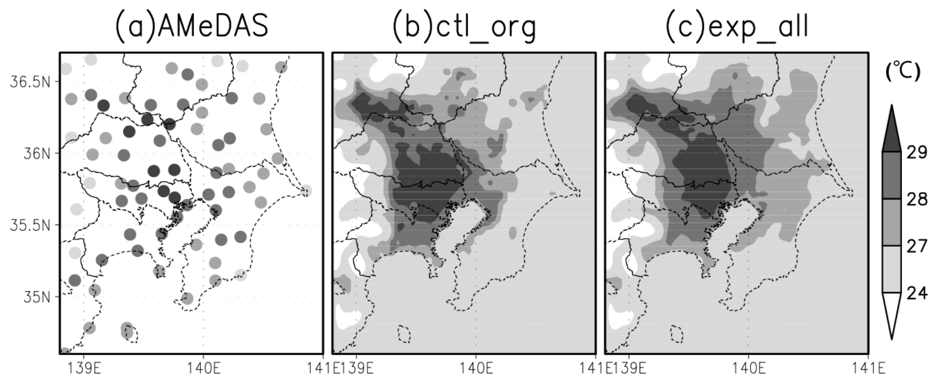

Fig 3. Monthly mean surface air temperature: (a)observation, (b) ctl_org run, (c) exp_all run.

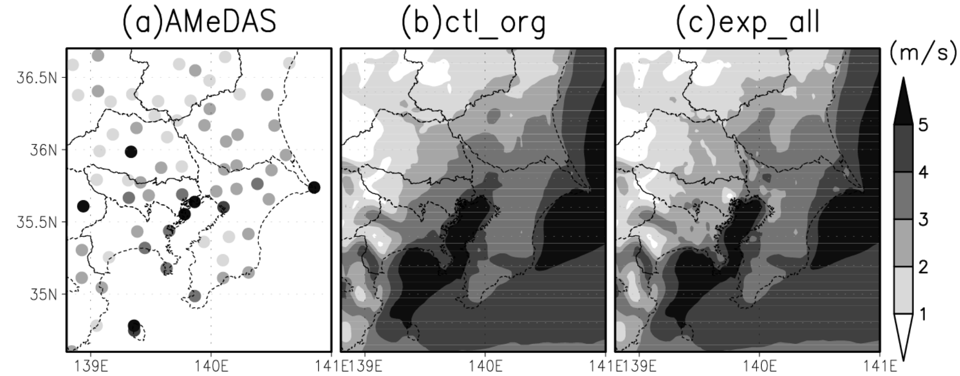

Fig 4. Monthly mean surface wind speed: (a)observation, (b) ctl_org run, (c) exp_all run.

3. Results

3.1 Comparison with Observation

The summertime surface air temperature and wind velocity simulated by the current WRF/UCM and new WRF/UCM are compared with observation to evaluate the model performance. Figure 3a shows the observed monthly mean surface air temperature (Tsa). The Tsa in August, 2010 exceeds 29 degree in the central part of TMA. The simulated Tsa in exp_all run captures well the feature in observation, although the simulated temperature is slightly overestimated in the center part of TMA and coastal areas (Fig. 3c). The Tsa in ctl_org run also shows the observed feature of Tsa. However, the temperature is overestimated in the center part of TMA more than that in exp_all and underestimated in the east area of TMA (Fig. 3b).

The surface wind speed is strong in the coastal area more than in the inner area (Fig. 4a). The model results can also reproduce the characteristics in observation (Figs. 4b and 4c), although the simulated wind speed overestimates about 1 m/s. The distributions of wind speed are almost same between ctl_org run and exp_all run, except for that around Tokyo. The wind speed weak around Tokyo in the exp_all run, because the sea breeze from south-west is weaken by the large friction due to the high buildings.

3.2 Sensitivity analysis of gridded urban parameters

The impacts of the gridded data of the urban fraction and the anthropogenic heat on summertime surface air temperature are indicated in Fig. 5. Figure 5a shows the surface air temperature differences between ctl_LU run and exp_LU run, while Fig 5b is that between ctl_AH and exp_AH. Tsa is strongly affected by the land use. The difference of about 20% in urban fraction corresponds to the difference of about 0.6℃ in surface air temperature. The temperature difference due to anthropogenic heat data is larger than 0.2℃. The effects of urban fraction to surface air temperature in winter is smaller than that in summer, while the AH has larger impacts on the Tsa in winter (Fig.6).

The diurnal variations of sensitivities of gridded urban parameters are shown in Fig.7 and Fig.8. For analysis of the sensitivity, mean difference is defined as spatial average of the absolute value of the difference in two simulations.

Mean difference in Tsa in summer between the exp_all run and the ctl_org run is large during the night time from 17LT to 04LT. The temperature difference in night time is mainly caused by the different urban fraction. This is because the difference in surface air temperature between the urban area and other land-use areas, such as grassland, irrigated cropland, and pasture, is dominant in the night time. In wintter, the urban fraction and the AH have a large impact on Tsa in the evening and in the nighttime, respectively. Especially, the AH has strongly affects on the Tsa in the early morning in wintter; the mean difference is about 0.2 ℃.

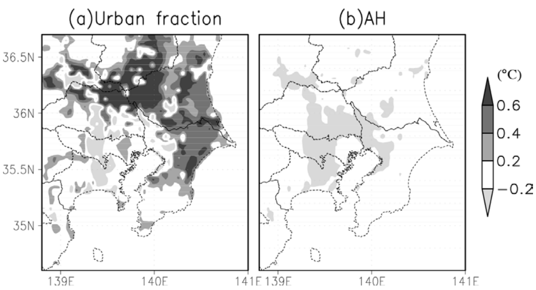

Fig 5. Difference in monthly mean surface air temperature in summer between (a) exp_LU and ctl_LU (exp_LU - ctl_LU), and (b) exp_AH and ctl_AH (exp_AH - ctl_AH).

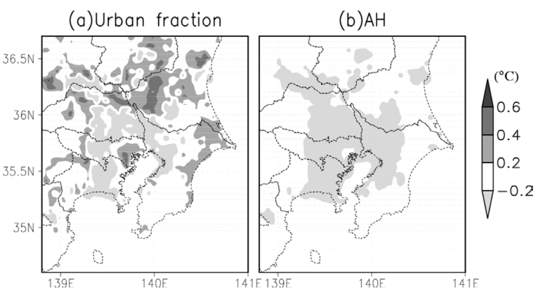

Fig 6. Same as Fig.5, but in winter.

The diurnal variations of mean differences in surface wind speed are smaller than that in Tsa. In the summer, mean difference peaks in early evening around sunset. The analysis of wind profile suggests that the large difference in surface wind speed is caused as a result of the difference in the decline speed of mixing layer. In winter, the diurnal variation of mean difference in surface wind speed is small.

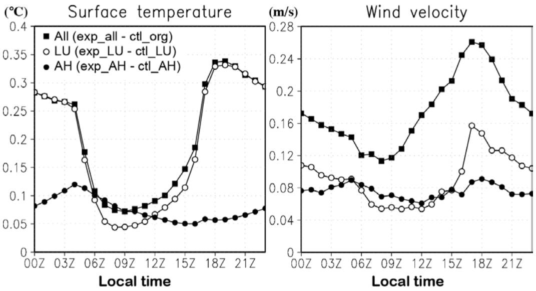

Fig 7. Diurnal change of mean difference in monthly surface air temperature ad monthly surface wind speed in summer.

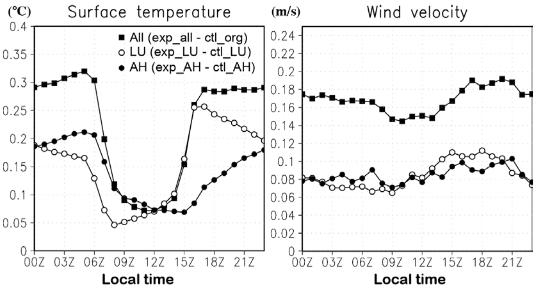

Fig 8. Same as Fig. 7, but in winter.

4. Conclusion

The simulations of heat island in summer and winter in Tokyo metropolitan area are conducted using the original WRF/UCM and the modified WRF/UCM.

The reproducibility of heat island in Tokyo metropolitan area is improved in the modified WRF/UCM compared with the original one. The modified WRF/UCM represent the weakness of sea breeze as a result of the large roughness length around Tokyo. The urban fraction shows large impact on the nighttime surface air temperature in summer and winter. The anthropogenic heat affects to the nighttime surface air temperature in winter, while it is small in summer. The differences in surface air temperature between the original WRF/UCM (the spacially-homogeneous data) and the modified one (the gridded urban data) are small during daytime in both seasons. The difference of surface wind speed is large in early evening in summer because of the difference in decline speed of the mixing layer between urban and other land use areas.

The modified WRF/UCM seems to be better than the original WRF/UCM. However, the quantitative evaluation due to the modification is additionally required.

5. Acknowledgements

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6. References

1. Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Duda, M.G., Huang, X.-Y., Wang, W. and Powers, J.G., (2008): A description of the advanced research WRF version 3. NCAR/TN-475+STR, 113p.
2. Kanda, M., A. Inagaki, T. Miyamoto, M. Gryschka, S. Raasch, (2012): New aerodynamic parameterization for real urban surfaces. Boundary-Layer Meteorology, submitted.
3. Kusaka, H., Kondo, H., Kikegawa, Y. and Kimura, F., (2001): A simple single-layer urban canopy model for atmospheric models: Comparison with multi-layer and slab models. Boundary-Layer Meteorology, 101, p.329-358.
4. NIRE, 1997: Development of a verification method of warming provision technologies within metropolitan cities (in Japanese). National Institute for Resources and Environment Rep., 311 pp.