PERFORMANCE OF THE WRF MODEL AS A HIGH RESOLUTION REGIONAL CLIMATE MODEL: MODEL INTERCOMPARISON STUDY

Hiroyuki Kusaka*, Fei Chen**, Mukul Tewari**, Michael Duda**, Jimy Dudhia**, Yukako Miya*, and Yuko Akimoto*
* University of Tukuba, Tsukuba, Japan; **National Center for Atmospheric Research, Boulder, CO, USA

Abstract

Recently, the performance of the WRF coupled to the single-layer urban canopy model (UCM, Kusaka and Kimura (2004a,b) has been evaluated in several case studies with regards to the urban heat islands (Miao et al., 2009). However, the results for the climate simulations have not been validated. In this study, we report the performance of the WRF as a regional climate model. Additionally, the results of an inter-comparison study of the land surface models are presented. As a result, we conclude that the WRF performed sufficiently well for an urban climate simulation if the Noah-LSM is used as a land surface model. It is clear that the UCM will improve the accuracy as the model has a tendency to reduce the diurnal range of the surface air temperature and produces a much similar frequency distribution to that of the observation.

Key words: Climate Simulation, WRF Model, Urban Canopy Model,

1. INTRODUCTION

The Weather Research and Forecasting (WRF) model has been developed as the next generation model after the MM5, which has been widely used globally. The number of urban climatologists who use WRF for urban climate study has been lately increasing. Recently, the performance of the coupled WRF-UCM has been evaluated in several case studies with regards to the urban heat islands (Lin et al.,2008; Miao et al., 2009) . However, the results for the climate simulations have not been validated. In this study, we examine the performance of the WRF as a local climate model using a massively parallel cluster computer. Additionally, an inter-comparison study of the land surface model is conducted.

2. DESIGN OF THE NUMERICAL SIMULATION

We conduct numerical simulations of the urban climate over the Tokyo metropolitan area in Japan to examine the performance of the WRF model as a local climate model. The numerical integration is conducted for 3 consecutive years from July 27st to September 1st for the control run (Table 1). Thereafter, some additional runs are carried out to perform an inter-comparison study for three land surface models; the Slab 5-layer model (Case Slab), Noah land surface model (Case Noah, Chen and Dudhia 2001) and Noah/UCM coupled model (Case UCM). Here, the UCM is the single-layer urban canopy model originally developed by Kusaka et al. (2001) and modified by Kusaka and Kimura (2004a, b), Chen et al. (2006), and Miao et al. (2009). The model domain is shown in Figure 1.

3. RESULTS

Figure 2 compares the diurnal variations of surface air temperature at Otemachi (downtown Tokyo) from the conventional surface observation network, the Automated Meteorological Data Acquisition System (AMeDAS) and the WRF model (Cases Slab, Noah, and UCM). Case Slab has a larger diurnal variation and error than the observation and the other two cases. Additionally, there is a one hour time lag in the phase. Throughout the day, the temperature for Case Noah is slightly higher than that of Case UCM; particularly in the early afternoon although the difference is less than 2°C.

Figure 3 characterizes quantitatively these features. At Otemachi, Case UCM produces the best performance score with 1.46 for the root mean square error (RSME) and 0.92 for the correlation coefficient. Case Slab has the worst score with 2.68 of RMSE and 0.77 of correlation coefficient. Case Noah results are close to that of Case UCM. These results are obtained for the other cities; including Nerima and in the other periods as well (Figure is omitted). The frequency distribution is given in Figure 4. Clearly, the frequency distribution from Case Slab is different from that of the observation. The shape of the distribution for Cases Noah and UCM are similar to that of the observation, but the latter seems closer except for around the maximum value.

Figures 5 and 6 show the distribution of the monthly mean surface air temperature at 1500 and 0500 Local Time (LT), respectively. For Cases Slab and Noah, the temperature in the northwestern inland areas is overestimated by about 3°C at 1500 LT, although the temperature distribution is qualitatively in agreement with the observations (Fig. 5a-c). The temperature from Case UCM is also overestimated for the area at this time, but the error seems to be only half of that of the other cases (Fig. 5d). On the other hand at 0500 LST, the temperature is underestimated in the Tokyo metropolitan area for Case Slab (Fig. 6a, b). In this case, the heat island observed in

Tokyo is not reproduced at all. When the Noah-LSM is used, a clear heat island is simulated (Fig. 6c). However, it is largely overestimated in the metropolitan area and the temperature pattern does not agree well with the observed one. When Cases Noah and UCM are compared, the latter case produces the temperature pattern better (Fig. 6c, d).

4. SUMMARY

In this study, we conducted a numerical simulation for 3 consecutive years, from July 27st to September 1st in order to examine the performance of the WRF as a local climate model. Additionally, the results of an inter-comparison study of the land surface model with different treatment of urbanization are presented. In general, the WRF model performs sufficiently well as an urban climate modeling system if the Noah-LSM is used as the land surface model. It is clear that the addition of UCM improves the model accuracy to mitigate the model tendency of reducing the diurnal range of the surface air temperature in urban areas and therefore produces more similar frequency distributions to that of the observation.

Acknowledgement
This work was supported by the Global Environment Research Fund (S-5) of the Ministry of the Environment, Japan.

References

[1] Chen, F., and J. Dudhia, 2001a: Coupling an advanced land-surface/hydrology model with the Penn State/NCAR MM5 modeling system. Part I: Model implementation and sensitivity. Mon. Wea. Rev., 129, 569-585.
[2] Chen, F., Tewari, M., Kusaka, H., and Bao, J., 2006. Effects of urban heat island on atmospheric boundary layer structures over the greater Houston metropolitan area, *Proc. ICUC-6*, in CD-ROM.
[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, *Bound.-Layer Meteor.*, 101, pp.329-358.
[4] Kusaka, H. and Kimura, F., 2004a. Coupling a single-layer urban canopy model with a simple atmospheric model: Impact on urban heat island simulation for an idealized case, *J. Meteor. Soc. Japan*, 82, pp.67-80.
[5] Kusaka, H. and Kimura, F., 2004b. Thermal effects of urban canyon structure on the nocturnal heat island: Numerical experiment using mesoscale model coupled with urban canopy model, *J. Appl. Meteor.*, 43, pp.1899-1910.
6) Lin, C-Y, F. Chen, J.C. Huang, W-C. Chen, Y.-A. Liou, W.-N. Chen and Shaw-C. Liu, 2008: Urban Heat Island effect and its impact on boundary layer development and land-sea circulation over northern Taiwan, Atmospheric Environment, 42, 5635-5649. doi:10.1016.
[7] Miao, S., Chen, F., LeMone, M. A., Tewari, M., Li, Q., and Wang, Y., 2009. An observational and modeling study of characteristics of urban heat island and boundary layer structures in Beijing, J. Appl. Meteor. Clim., 48, pp.484-501.

Table 1: Configuration of Numerical Simulations

Model	ARW-WRF V3.0.1
Radiation	Dudhia (short wave), RRTM (long wave)
Microphysics	WSM3
PBL	YSU
LSM	Slab (Case Slab), Noah (Case Noah), or Noah with UCM (Case UCM)
Initial / Boundary conditions	20-km JMA/RSM Analysis
Simulation period	00 UTC 27 July to 00 UTC 1 September 2002, 2003, 2004
Horizontal resolution	4 km

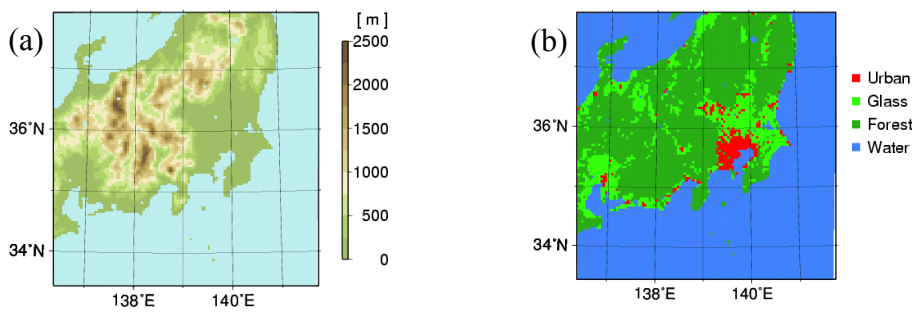

Figure 1: Domain of numerical simulation. (a) Terrain and (b) land-use.

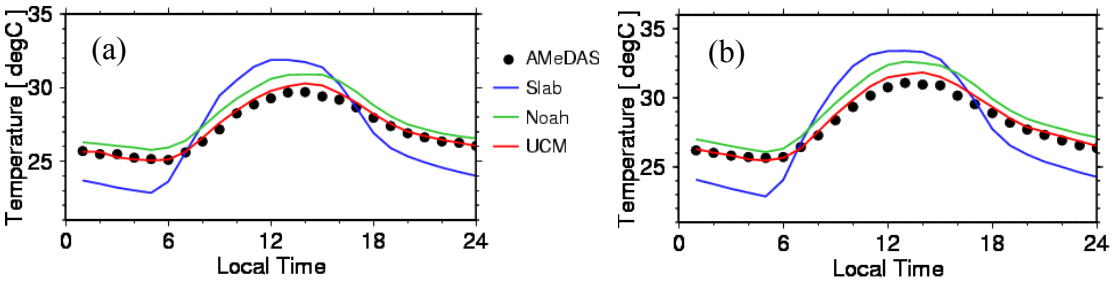

Figure 2: Diurnal variations of surface air temperature at Otemachi (Downtown Tokyo). Monthly mean temperature for each hour in August (a) 2004 and (b) 2002.The solid circle indicates the observation. Blue, green,and read solid lines are simulated results from Cases; Slab, Noah, and UCM, respectively.

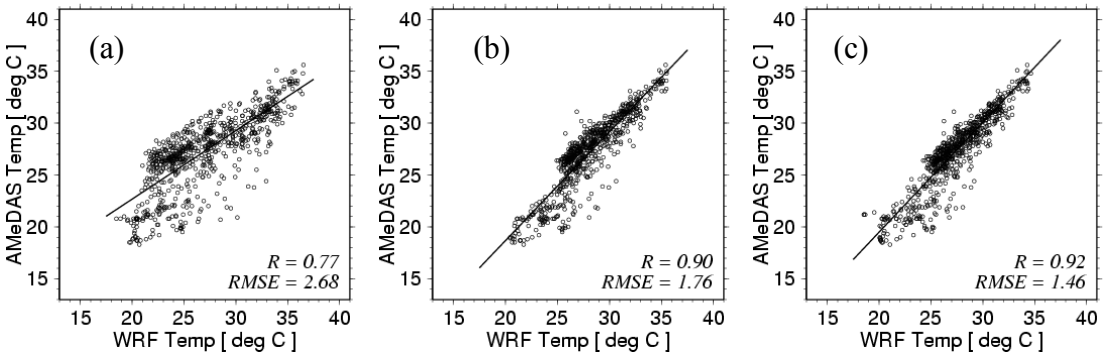

Figure 3: Scatter diagram of the observed surface air temperature versus simulated surface air temperature from (a) Case Slab, (b) Case Noah, and (c) Case UCM at Otemachi in August 2004. R indicates the correlation coefficient and RMSE is the root mean squre error.

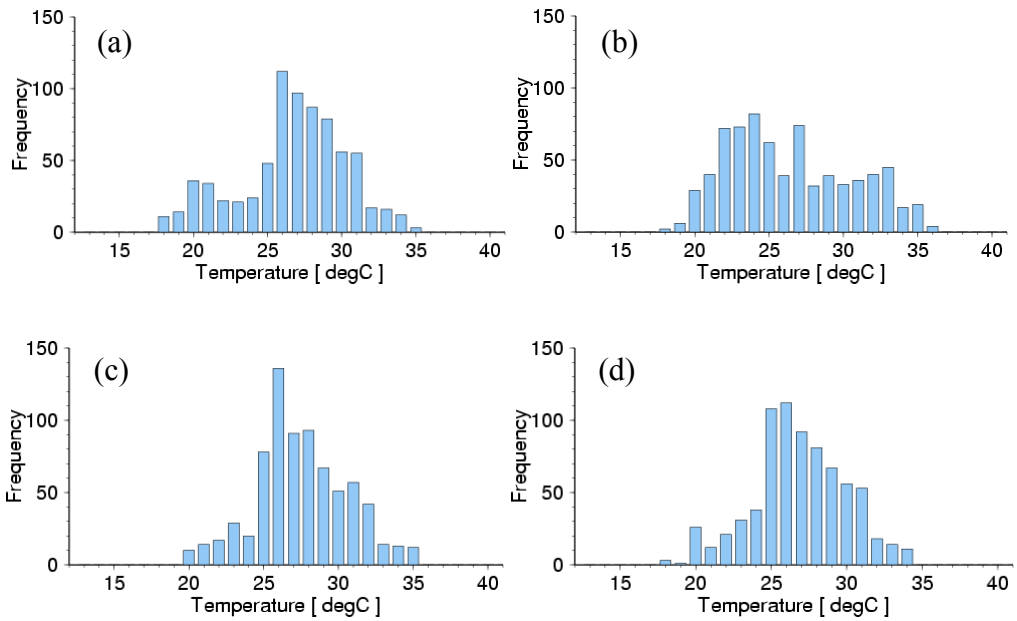

Figure 4: Frequency of surface air temperatures at Otemachi in August 2004. (a) AMeDAS observation, (b) Case Slab, (c) Case Noah, and (d) Case UCM.

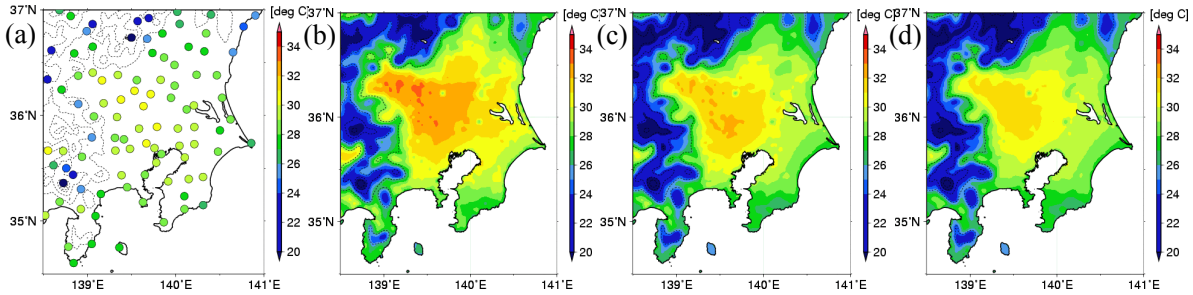

Figure 5: Distribution of monthly mean surface air temperature at 1500 Local Time in August 2004. (a) AMeDAS observation, (b) Case Slab, (c) Case Noah, and (d) Case UCM.

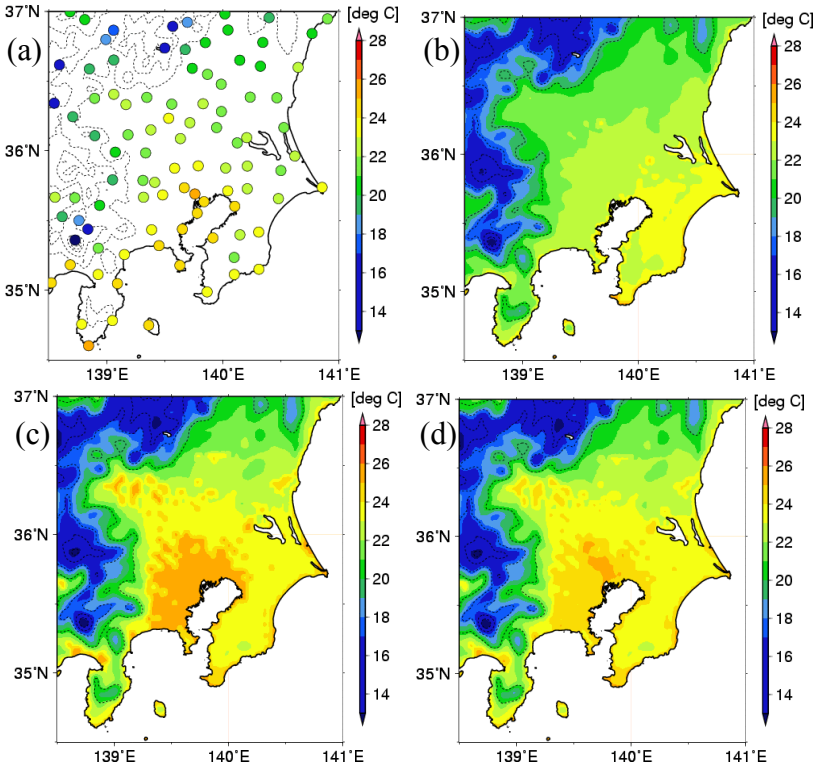

Figure 6: Same as Figure 5, except for at 0500 Local Time.