The Chink in the Armor: Questioning the Reliability of Conventional Sensitivity Experiments in Determining Urban Effects on Precipitation Patterns

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Abstract

The present study discusses uncertainties of the conventional sensitivity experiment on a convective rainfall event over the Tokyo metropolitan area surrounded by complex terrain. Similar to previous studies, we obtain the positive impact of urbanization from the sensitivity experiment. However, negative or neutral impacts have also been found when the experimental design is marginally changed. Our results indicate that the conventional sensitivity experiment is not reliable due to the strong Chaos influence in rainfall simulation. Second, an approach similar to a climate simulation is attempted to decrease the characteristic of the initial value problem and instead strengthen the characteristic of the boundary value problem. Sensitivity experiments based on this method gives some indication of the possibilities of urban impact on the precipitation, although further research should be needed.

Key words: WRF Model, Uncertainties of Urban Rainfall Simulation, Chaos, Sensitivity Experiment, Climate Simulation

1. INTRODUCTION

Changes in the precipitation pattern and long term trend in and around urban areas have been of general interest since Changon (1968). This topic has recently been of focus in Japan due to the natural disasters connected to heavy rainfall events in the urban areas even though these occurrences are rare (e.g., Fujibe 1998; Sato et al. 2006; Fujibe et al. 2009). Fujibe (1998) and Fujibe et al. (2009) investigated the spatial distribution of precipitation in and around Tokyo using the data of the raingauge network and found a positive anomaly for precipitation in Tokyo in the afternoons during the warm season. Furthermore, it was confirmed that the anomaly tended to be enhanced in the early afternoon in the warm season, particularly with regarding heavy rainfall. Sato et al. (2006) used radar data and investigated precipitation frequency in Tokyo, which was remarkably higher than that of the surrounding areas. However, there have been several researches that question this idea. Kanae et al. (2004) pointed out that heavy rainfall over an urban area strongly depends on large-scale climate change.

Numerical experiment is generally considered as an effective method in order to determine the impact of several factors on a certain phenomenon. Indeed, with regards to the urban heat island phenomenon and low-level cumulus cloud lines, such an approach has been widely utilized (e.g., Kimura and Takahashi 1991; Kusaka et al. 2000; Kanda et al. 2001; Kusaka and Kimura 2004). Additionally, this approach has been successfully applied for rainfall events in the urban area on the idealized terrain or large plain in USA. In Japan, several numerical experiments have recently reported the positive impacts of urbanization on convective rainfall over the Tokyo metropolitan area (e.g., Moteki et al. 2005). From these factors, the influence of urban areas on precipitation has been heavily covered by the press. However, there is a remaining problem at least for the case of Tokyo. This is especially with regards to a place like Japan where the influence of the ocean and mountains easily overweigh the urban effects in controlling precipitation. As a result, a slight alteration of the land use may cause non-linear effects; i.e., Chaos, once the model produces rainfalls. In this case, it is difficult to determine if an increase in the rainfall amount is caused by the land use alteration or just by Chaotic nature.

In this study, we discuss whether the conventional sensitivity experiment is reliable in determining urban effects on a realistic convective rainfall event, analyzing several cases in the Tokyo Metropolitan area. Additionally, we propose alternative approaches and show the results from our study.

2. STANDARD APPROACH: SENSITIVITY EXPERIMENT FOR A SPECIFIC RAINFALL EVENT

Similar to previous studies, we first conduct the conventional sensitivity experiment (Figure 1, Table 1) using the Weather Research and Forecasting (WRF) model with 4-km horizontal resolution for a typical rainfall event (Figure 2); comparing the control run using the realistic land-use data to the sensitivity run using the land-use data without urban areas. The results show the positive impact of urbanization on the rainfall amount (Figure 3a). It seems that the existence of the urban areas enhances the rainfall intensity and increases the total rainfall amount. However, it is important to note that negative or neutral impacts have also been obtained when the experimental design had been marginally changed by adopting a different physics scheme (Figure 3b), spatial resolution or domain size. Furthermore, the enhancement of rainfall was unrelated to the location of the urban areas, i.e., the

precipitation pattern seems to be unorganized. Our results indicated that the conventional sensitivity experiment over the urban area surrounded by complex terrain is not reliable in determining the amount of precipitation due to the weak urban forcing and strong Chaos influence in rainfall simulation.

3. THREE APPROACHES TO OVERCOME THE ISSUE

Numerical simulation of convective rainfall in the urban areas is very sensitive to the changing initial condition and physics scheme as well as the surface boundary condition (land-use map).

One of the valuable methods used to overcome this problem is the ensemble sensitivity experiment which combines the ensemble forecast and the sensitivity experiment. However, when applying this method to a phenomenon with a strong non-linear tendency such as local heavy rainfall, it is very difficult to determine the correct members. Moreover, an enormous amount of ensemble member is required. For this reason, although this method is effective, it may be difficult to put into practice. In reality, we performed a sensitivity experiment using 10 ensemble members created by; a physical model ensemble, a parent model ensemble and a classic ensemble method based on the Lagged-Averaged Forecast (LAF) method, which consists of the initial times being altered but favorable results were not obtained. As a result, the ensemble average of the urban impact showed that the rainfall in the urban area was found to be inhomogeneous and unorganized.

Climate simulation should be recommended as a viable and efficient method. By using this method, we are able to decrease the characteristics of the initial value problem and instead strengthen the characteristics of the boundary value problem. Consequently, we are able to detect the impact of the surface boundary condition more clearly; i.e., the urban impact on rainfall simulation. In this study, an approach similar to a climate simulation is attempted. The numerical integration is conducted for 7 consecutive years from July 27st to September 1st for the control run (with urban areas) and the experimental run (without urban areas). Thereafter, the monthly accumulated precipitation in August for the 7 years from the control run is compared to that of the experimental run. Results from the numerical experiment shown in Figure 4 indicate that the existence of the urban areas increases the seven-month accumulated precipitation amount over the parts of the Tokyo metropolitan area. This sensitivity experiment based on a climate simulation gives some indication of the possibilities of the urban impact on precipitation, although there are some areas with negative and positive impacts where it is difficult to explain their reasons. Further research should be needed to conclude the positive urban impact on precipitation over the Tokyo metropolitan area.

4. Conclusions

The present study first examined uncertainties in the urban rainfall simulation using the WRF model, and showed that the conventional sensitivity experiment is not reliable due to the weak urban forcing and strong Chaos influence in rainfall simulation when it is performed over a case study with the urban area surrounded by complex terrain. Second, an approach similar to a climate simulation is attempted to decrease the characteristic of the initial value problem and instead strengthen the characteristic of the boundary value problem for the urban rainfall simulation. As a result, some indication of the possibilities of the urban impact on the precipitation was obtained, although further analysis should be needed to conclude the positive urban impact on the precipitation over the Tokyo metropolitan area.

5. Remarks

The third method may be to adopt a very high resolution, very accurate numerical model and an advanced data assimilation system. By using the urban-scale objective analysis data set, we could understand what happens in and around the convective rainfall system over the urban area. Very recently, the advanced data assimilation systems such as EnKF and 4DVAR have been utilized in the numerical weather prediction (NWP) field. Such advancement in technology will be utilized in the urban climate field in the near future.

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References

[1] Fujibe, F., 1998: Spatial anomalies and long-term changes of precipitation in Tokyo. Tenki, 45, 7-18. (in Japanese with English abstract).
[2] Fujibe, F., H. Togawa, and M. Sakata, 2009: Long-term change and spatial anomaly of warm season afternoon precipitation in Tokyo. SOLA, 5, 17-20.

[3] Kanda, M., Y. Inoue, and I. Uno, 2001: Numerical study on cloud lines over an urban street in Tokyo. Bound.-Layer Meteor., 98, 251-273.
[4] Kanae, S., T. Oki, and A. Kashida, 2004: Changes in hourly heavy precipitation at Tokyo from 1988 to 1999. J. Meteor. Soc. Japan, 82, 241-247.
[5] Kimura, F. and Takahashi, S., 1991: The effects of land-use and anthropogenic heating on the surface temperature in the Tokyo metropolitan area: A numerical experiment. Atmos. Environ., 25B, 155-164.
[6] Kusaka, H., F. Kimura, H. Hirakuchi, and M. Mizutori, 2000: The effects of land-use alteration on the sea breeze and daytime heat island in the Tokyo metropolitan area. J. Meteor. Soc. Japan, 78, 405-420.
[7] Kusaka, H. and Kimura, F., 2004. Coupling a single-layer urban canopy model with a simple atmospheric model: Impact on urban heat island simulation for an idealized case, *Journal of the Meteorological Society of Japan*, 82, pp.67-80.
[8] Moteki, Q., Y. Ito, K. Yorozu, K. Souma, A. Sakakibara, K. Tsuboki, T. Kato, K. Tanaka, and S. Ikebuchi, 2005: Estimation for effects of existence of urban on development of cumulonimbus clouds using atmosphere-land coupled model of CReSiBUC, Annuals of Disas. Prev. Res. Inst., Kyoto Univ., 48C.

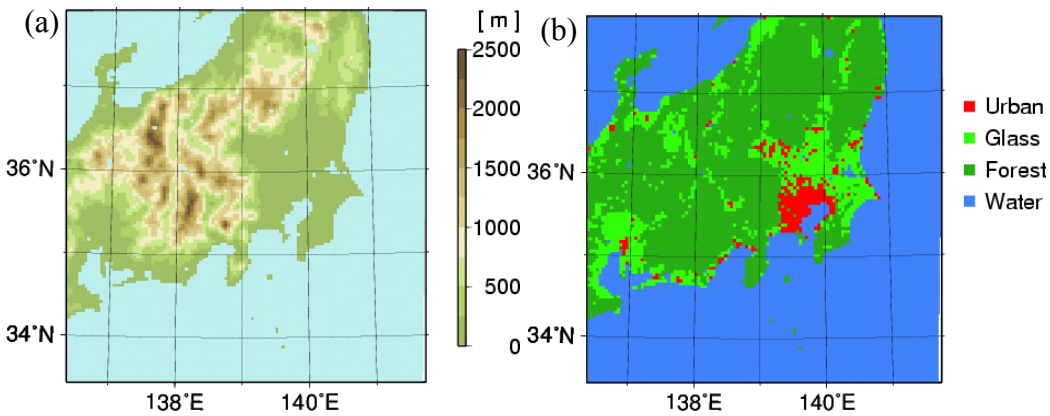

Figure 1: Domain of the model. (a) Terrain and (b) land-use. The largest urban area is the Tokyo metropolitan area.

Table 1: Configuration of Numerical Experiment (Case 1)

Model	ARW-WRFV3.0.1
Microphysics	WSM3
PBL	YSU
LSM	Noah
Initial time	12 UTC July 4, 2000
Period	48 hours
Initial/Boundary conditions	20-km JMA/RSM Analysis

In Case 2, the Microphysics and LSM options are changed.

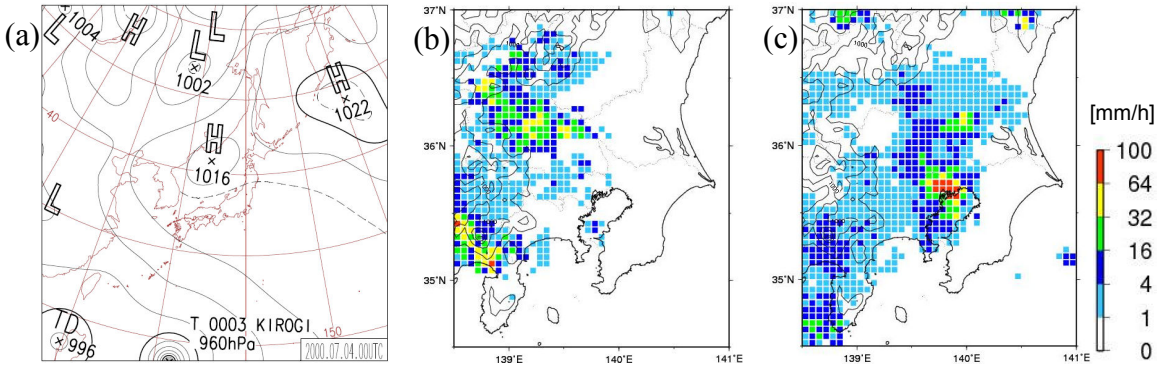

Figure 2: (a) Surface weather chart at 0900 Local Time July 4 2000. Hourly precipitation pattern observed by radar and rainguage at (b) 1500 and (c) 1800 Local Time.

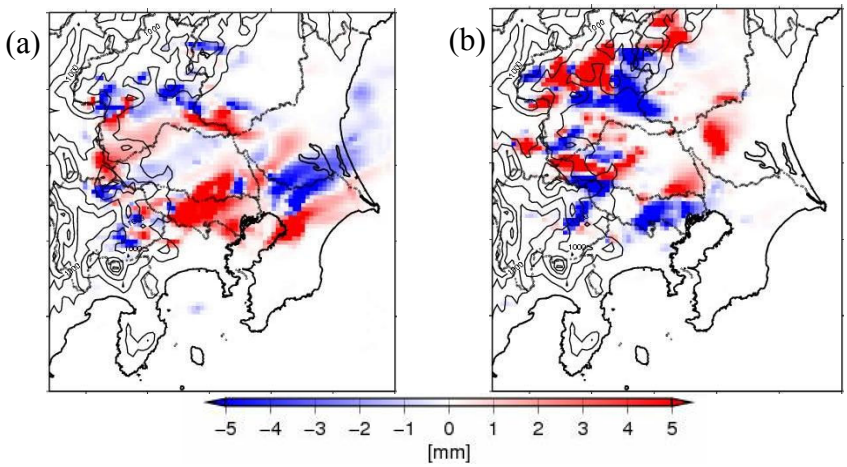

Figure 3: The impact of the urban areas on rainfall simulation; the difference in the accumulated rainfall during the simulation period between the control experiment (with urban areas) and sensitivity experiment (without urban areas). Red shadings indicate the positive impact (urban areas increase rainfall amount) and Blue shadings indicate the negative impact. (a) Case 1 and (b) Case 2.

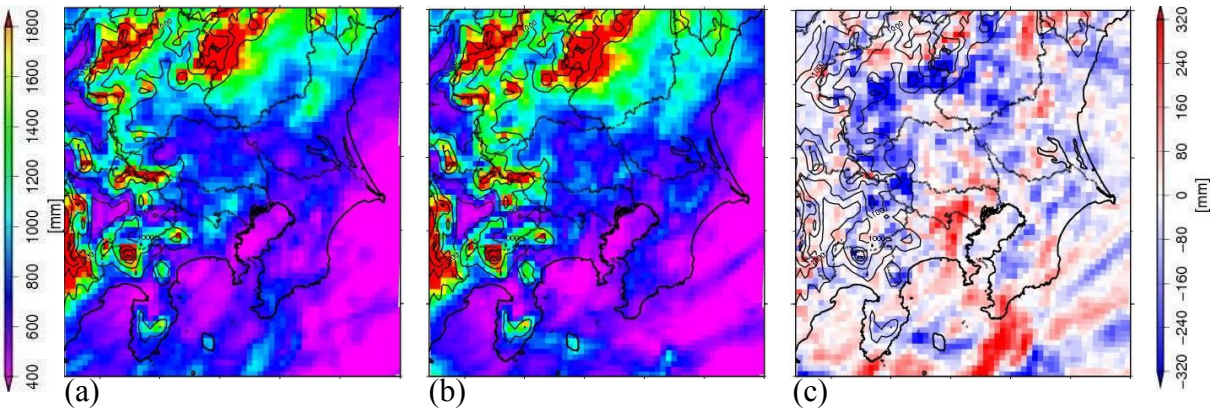

Figure 4: Accumulated rainfall amount in August 2001-2007 from (a) Control experiment (with urban areas) (b)Sensitivity experiment (without urban areas) and (c) the difference between the two experiments (Ctrl – Sens) but disregarding days with synoptic disturbances shown on surface weather charts; e.g. typhoons and extratropical cyclones.