Uncertainties in Urban Climate Studies

Hiroyuki Kusaka[1]

[1] Associate Professor, Center for Computational Sciences, University of Tsukuba

Abstract

Urban climate studies have extensive history. However there remain large uncertainties in various aspects of urban climate studies. The following three issues are highlighted in this talk; uncertainties in observational methods, nonlinearity in numerical simulations of precipitation, and spreads in future projections from global circulation models. The author will discuss each of the above issues and presents on-going effort to reduce uncertainties.

1. Introduction

Urban climate studies have extensive history. However the author feels that uncertainties in observations and numerical simulations have not been taken into consideration at sufficient level.

The observed rapid increases in temperatures in urban areas are associated with urbanization and global warming. Evaluation of their individual impacts is of an importance. However, separation of warming effects from urbanization and global warming has been difficult due to uncertainties in today's commonly-used observational campaigns.

Heavy precipitation in urban areas poses a significant threat to human lives and social infrastructures. Studies based on numerical simulations have shown potential influence of urbanization in heavy precipitations, but numerical simulations of precipitation are highly nonlinear (chaotic) and thus significant uncertainties remain.

There is a high demand for urban climate projections for future urban planning. Urban climate projections largely depend on global circulation models (GCMs). GCM projections have large uncertainties in the magnitude of future temperature increases as well as in their interannual variabilities. Thus GCM uncertainties must be taken into consideration in urban climate projections along with uncertainties in urban scenarios.

This talk presents detailed discussions on the above three uncertainties and proposes solutions to each. The key here is to "think like a climatologist"; reduce uncertainties with employment of "ensembles".

2. Urban Heat Island Intensity (UHII)

Continuous observations of surface air temperature at a high spatial resolution in mid-sizes cities are important not only for researches in heat island but also for climate change and variability including global warming. As well known, the observed increasing trends in temperatures in urban areas are associated with both global warming and heat island phenomena. The Meteorological Agency of Japan reports that the observed temperature increase rate due to global warming alone is 1.1ºC per 100 years. This measure is based on 17 stations that are considered to be free of urbanization effects. However, these 17 stations include mid-sized cities with populations over 200,000 such as Cities of Mito and Nagano. Therefore it is difficult to conclude that this temperature increase rate is completely free of urbanization effects. Estimates of UHII in mid-sized cities would aid more accurate separation of warming impacts from global warming and urbanization.

In cases where daily, monthly, and yearly averaged values are called for, station-based observations (rather than mobile observations) are more helpful. In station-based observations, measurements must be taken with high-density observational network as the surrounding environment has a significant impact on air surface temperature measurements. However, it has been difficult to install extensive measuring equipment in urban cities with vigorous social activities with rapid changes.

With introduction of small and inexpensive equipment, high-density observation networks have recently been established in some of the major cities in Japan. Authors have been conducting a station-based observational campaign in City of Tsukuba, a mid-sized city with a population of 210,000 in Ibaraki Prefecture. The observed temperatures from the Tsukuba campaign will be presented in this talk. The preliminary results include relative impact of urbanization to global warming in City of Tsukuba.

3. Urban Precipitation

Changes in the precipitation pattern/amount in and around urban areas have been of general interest. Field experiments and numerical sensitivity experiments have been showing urban impact on the precipitation. However, there is a remaining problem. Simulating convective rainfall has high non-linear effect in general, and results from such simulations are extremely sensitive to the conditions of the experiment. Thus, a simulation based on single or a few cases can leave considerable uncertainty in its results. This is especially true in a place such as Tokyo where the influence of the ocean and mountains easily overweigh the urban effects in controlling precipitation (Fig. 1).

Figure 2 is the results from Kusaka et al. (2009) where urban sensitivity experiments are conducted for a certain event using the WRF model, with various model configurations. Their study concluded that model configurations have substantial impact on precipitation, so that they may change the sign of urbanization impact on precipitation. Kusaka et al. (2009) proposed that the sensitivity experiments based on the climate or ensemble simulations are available as a technique to mitigate such issues and improve reliability of results.

In this study, climatology of the precipitation will be simulated instead of a specific rainfall event, using the WRF model coupled with the single-layer urban canopy model developed by Kusaka et al. (2001) (hereafter, WRF_UCM). The simulation is conducted for eight consecutive years (2001-2008), referred to here as eight consecutive Augusts.

This study applies the ensemble experiment approach as well as climate simulation approach. Ensemble members are generated by using four different objective analysis datasets as initial and boundary conditions. Consequently, the eight consecutive Augusts simulations with four independent initial and boundary conditions provide virtual realization of 32-years worth of Augusts.

Figure 3 illustrates difference between experimental cases in monthly average precipitation amount in August for 2001-2008 as ensemble average. Figure 3a indicates that the precipitation amount is increased by 10-15% in the Tokyo Metropolis due to urbanization. Figure 3c is similar to Figure 3a, but the magnitude of urban effect is enhanced, compared to Figure 3a. Figure 3b shows the medium urban effects on the precipitation climatology. From these experiments, it is clear that there is a positive relationship between the urban effect and precipitation climate response.

From further analyses, it is found that precipitation is increased in the all intensity ranges. In particular, the heavy precipitation appears to be contributing to the increase of average precipitation amount in the Tokyo metropolitan area.

4. Urban Climate Projection: Dynamical Downscaling to the Future Climate

Greater Tokyo is the world's largest metropolitan area, with a population of about 32.5 million. Tokyo is already notable for its exceedingly uncomfortable summers, with an average August temperature of 27.4^{o}C, a humidity of 69%. As a result, heat stroke routinely hospitalizes people in Tokyo. Ambulances transported 4,245 people with heat stroke to the hospitals in Tokyo in 2010 summer. With such adverse effects from present summertime heat, how worse will the urban environment be in the future?

Recently, Oleson et al. (2010) and McCarthy et al. (2010) started work on these issues using GCMs with an urban canopy model. Although these climate models have improved the representation of urban surfaces, their spatial resolution is too coarse to describe Japanese metropolitan areas. Dynamical downscaling (DDS), in which GCM and regional climate models (RCM) are combined, is an effective approach to obtain a fine-scale climate projection. Here, it is preferable to use multiple GCMs in order to reduce uncertainties from spread in GCM projections.

Very recently, Kusaka et al. (2012) conducted downscaled urban climate projections in Tokyo metropolis in Japan using three GCMs (MIROC3.2-Medres, MRI-CGCM2.3.2, CSIRO-Mk3.0). The simulations used the WRF_UCM with 4-km horizontal resolution. As an ensemble average, August monthly average temperature is projected to increase by 2.3ºC in 2070s compared to 2000s. This temperature anomaly is comparable to that of record-breaking hot summer of 2010 (Fig 4). As a result, urban areas will experience uncomfortable sleeping nights every day in August. However, projected domain averaged August mean temperature ranges from 1.7-2.8 ºC by individual ensemble members.

In the latest experiment, my research team have projected urban climate under the RCP4.5 Scenario. Here, uncertainties in urban scenarios are evaluated by using three different urban planning scenarios; (i) status-quo city, (ii) compact city, and (iii) distributed city (Fig. 5). The results indicate that the compact city scenario can reduce the monthly mean temperature of 0.3ºC, whereas the distributed city scenario can increase the temperature of 0.6 ºC (Fig. 6). These urban planning impacts have two meanings; urban planning can reduce impact of global warming on resident’s health, and the magnitude of uncertainties in different urban scenario in the future is well comparable to that of the uncertainties in different GCMs.

References

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Authors' addresses
Hiroyuki Kusaka (kusaka@ccs.tsukuba.ac.jp)
Center for Computational Sciences, University of Tsukuba
1-1-1 Tennoudai, Tsukuba, 305-8572, Japan

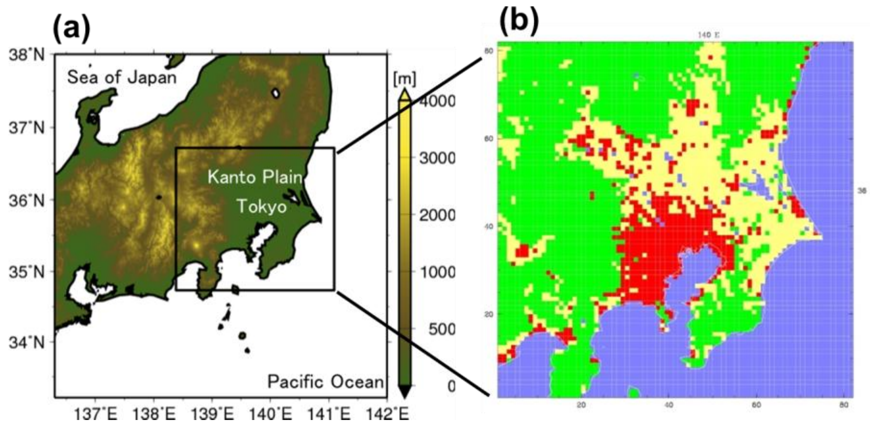

Fig. 1: (a) Topography of central Japan. (b) Land-use around the Tokyo Metropolitan area. Red, green, yellow, and blue indicate urban, forest, grassland, and water surfaces, respectively.

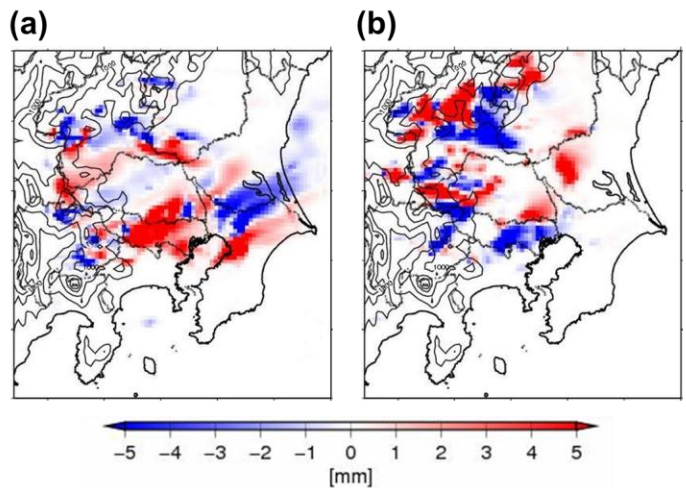

Fig. 2: Impact of the urbanization on convective rainfall simulation by the WRF model; the difference in the accumulated rainfall amount during the simulation period between the control experiment (with urban areas) and sensitivity experiment (without urban areas). Red shadings indicate the positive impact (urban areas increase rainfall amount) and Blue shadings indicate the negative impact. (a) WRF with WSM3 microphysics and Noah land surface schemes and (b) WRF with WSM6 microphysics and SLAB land surface schemes. (Kusaka et al. 2009, ICUC7 proceedings)

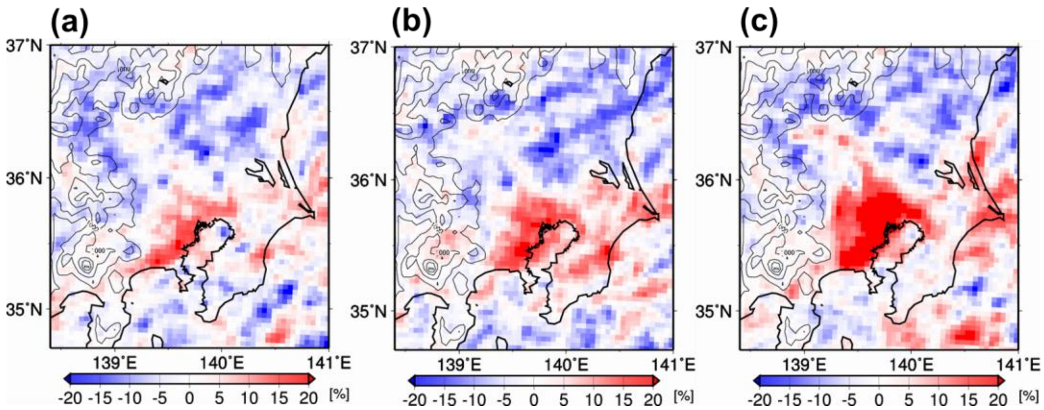

Fig. 3: Urban impacts on the monthly precipitation amount in August during the 8-year period (2001-2008). (a) Residential city scenario case. (b) Commercial city scenario case. (c) Commercial city with double anthropogenic heat scenario case. Red and blue indicate the increase and decreased precipitation amount by existence of the urban areas, respectively. All results are an ensemble mean from the four simulation members.

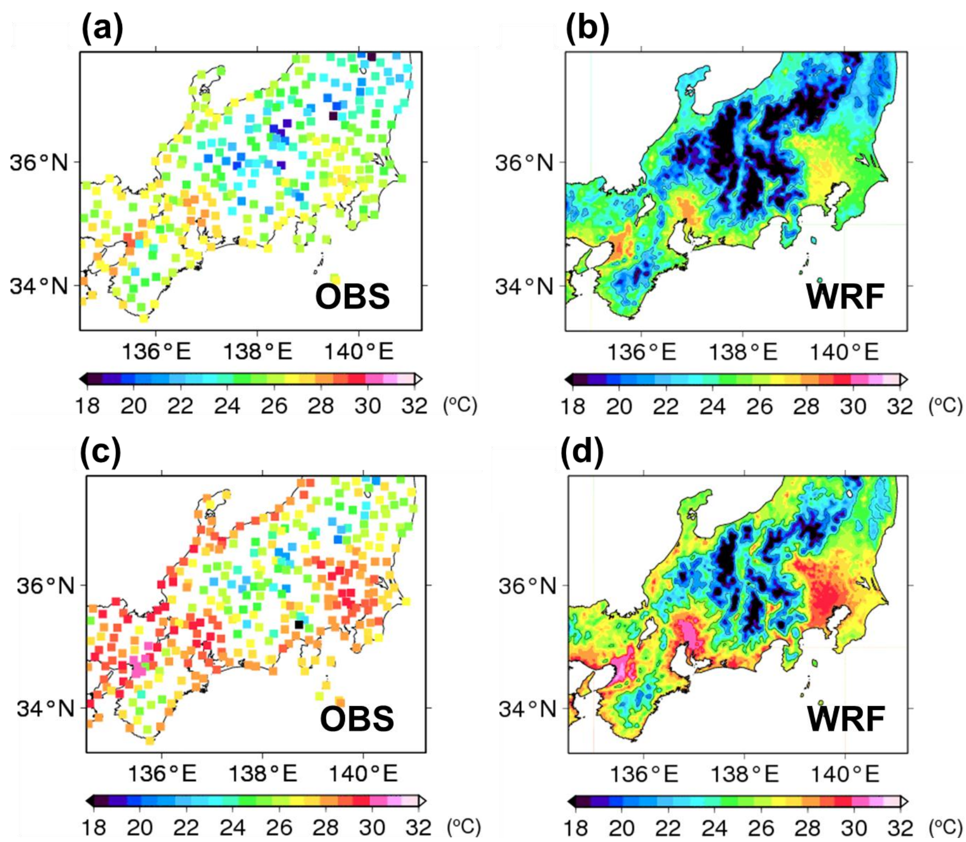

Fig. 4: August monthly mean surface air temperatures. (a) Climate in the 2000s (Observations). (b) Climate in the 2000s (WRF), (c) 2010 (Observations), (d) Climate in the 2070s (Ensemble mean from the three members).

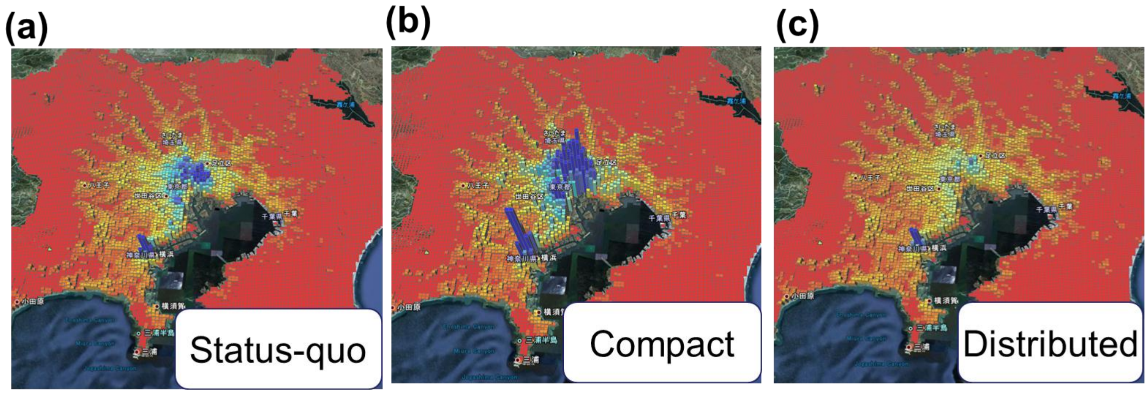

Fig. 5: Population distribution for the three urban planning scenarios. (a) Status-quo, (b) Compact-city, (c) Distributed-city.

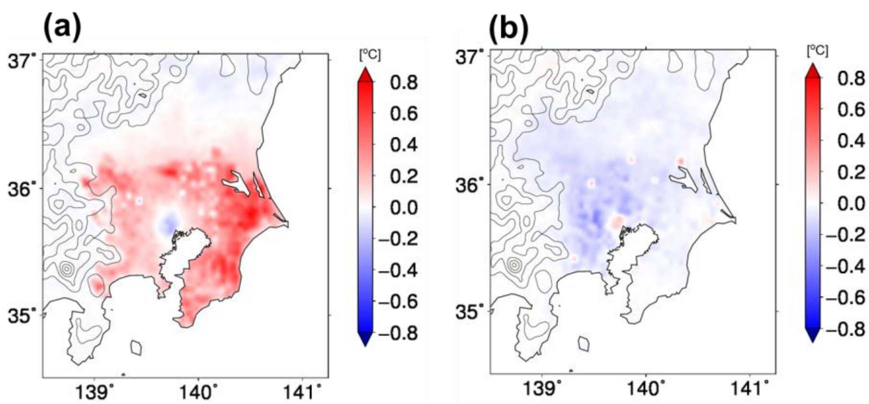

Fig. 6: Simulated temperature anomalies from status-quo for (a) distributed-city, and (b) compact-city.

Acknowledgements

The works presented in this talk are thanks to my research team and colleagues. I would like to thank Dr. Asuka Suzuki-Parker, Mr. Yuya Takane, Ms. Michi Komatsu, Ms. Keiko Nawata, Ms. Keiko Fujita of University of Tsukuba, and Dr. Sachiho A. Adachi and Mr. Masayuki Hara of JAMSTEC. This research was supported by the Research Program on Climate Change Adaptation (RECCA) of the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT), the Environment Research and Technology Development Fund (S-8) and Global Environment Research Fund (S-5-3) of the Ministry of the Environment, Japan. Numerical simulations for the present work were done under the "Interdisciplinary Computational Science Program" in the Center for Computational Sciences, University of Tsukuba.