Urban impact on summertime precipitation in Tokyo: Numerical simulation using NHM and the Square Prism Urban Canopy scheme

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1. Background

Precipitation modification due to increasing urbanization is one of the key topics in the urban climate research. Recently, Fujibe et al. (2009) showed that precipitation amounts observed in central Tokyo had statistically significant increasing trend and positive spatial anomaly to those in surrounding areas in the afternoon of warm season. However, the detected change in precipitation can be influenced by factors other than urbanization, such as global warming and associated regional climate change. For the better understanding of urban impact on precipitation, numerical modeling with a high-performance urban scheme is a useful approach. In the present research, numerical simulations for August in recent eight years have been conducted to investigate how increasing heat island intensity in Tokyo affects precipitation in the metropolitan area and its vicinities.

2. Experimental design

The Non-hydrostatic Model (NHM) of Japan Meteorological Agency (JMA) is utilized in the simulations (Saito et al., 2007). Horizontal grid interval is 2km and the model domain covers central Japan including Tokyo metropolitan area (Fig. 1). The Square Prism Urban Canopy (SPUC) scheme (Aoyagi and Seino, 2011) is incorporated in NHM. SPUC is a kind of single-layer urban canopy scheme. In contrast to the slab land surface scheme used in the operational version of NHM, SPUC takes into account heat and radiation exchanges by urban canopy elements in the surface heat budget. Spatial distribution of time-varying anthropogenic heat in the metropolitan area (Senoo et al., 2004) is also considered in SPUC. Area fractions of buildings and other land use categories in each model grid are determined from the 100m-mesh Digital National Land Information Dataset.

Comparative experiments have been done with and without SPUC for August from 2006 to 2013. In the SPUC experiment, SPUC scheme is applied in highly urbanized grids mainly in the central Tokyo area where area fraction of building lots is higher than 80%. On the other hand, in the SLAB experiment, slab land surface treatment is applied in the entire domain with urban surface parameters representing moderate urban conditions. Time integrations for 27 hours starting at 21 JST (Japan Standard Time, UTC+9hr) are repeated in both experiments. Initial and boundary conditions are given from operational mesoscale analyses of JMA. Simulation results in the two experiments from forecast time FT=3 to FT=27 (from 00 to 24 JST) are compared.

3. Results

Difference in the monthly mean surface temperature between the SPUC and SLAB experiments is shown in Fig. 1; simulated mean surface temperature of the SPUC experiment was higher up to 0.8K in the area where the surface scheme is changed. At Ohtemachi (business district) and Nerima (residential area) both located in Tokyo, simulated temperatures in the SPUC experiment were higher especially in the night-time, which agreed in general with observations (figure not shown). This indicates that realistic temperature field was simulated in the SPUC experiment in both diurnal temperature variation and heat island intensity.

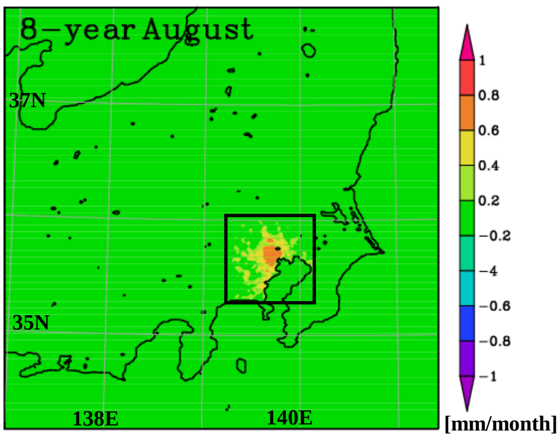

Fig. 1 Model domain and simulated 8-year August surface temperature difference between the SPUC and SLAB experiments. A rectangle indicates the reference urban area.

Monthly precipitation amounts were reasonably well simulated in both the SPUC and SLAB experiments. Difference in monthly precipitation between the experiments (SPUC-SLAB) is shown in Fig.2. Changes in rainfall distribution appear scattered in a wide area compared to the reference area where the urban surface scheme is replaced. We can also see that the precipitation increase is often coupled with its decrease nearby. Thus we evaluated area-averaged precipitation amounts in several rectangles with (k*10 + 1) km length (k=1-11) of each side, centered at the most urbanized area.

A larger amount of monthly precipitation in the SPUC experiment was found in domains with k ≦6 for the 8-year August mean. In domain 1, the most highly urbanized area, monthly precipitation amount was more than 10% larger in the SPUC experiment than in the SLAB experiment (Fig. 3). The normalized precipitation difference between the experiments decreases as the domain size increases. The differences were statistically significant by one-sided t-test at a significance level of 95% for domains 2 – 6, and 90% for domain 1.

Next, we examined daily maximum precipitation amount defined as the maximum value of the simulated daily precipitation among the grids in the domain every day. Figure 4 shows the scatter diagram of daily maximum precipitation in the SPUC and SLAB experiments in the reference urban area (domain 4). The linear regression line indicates that the SPUC experiment gives larger daily maximum precipitation amounts in domain 4 as well as the monthly precipitation amounts. It should be noted that the difference between the experiments were remarkable in some limited number of cases.

The present simulation results suggest that the temperature increase less than 1 °C in Tokyo area is likely to cause slight increase in summertime precipitation amounts in and around the area. However, differences in daily precipitation amounts and spatial distribution between the SPUC and SLAB experiments largely varied case by case. To examine the differences in more detail and obtain sufficiently meaningful features, additional simulations should be further conducted.

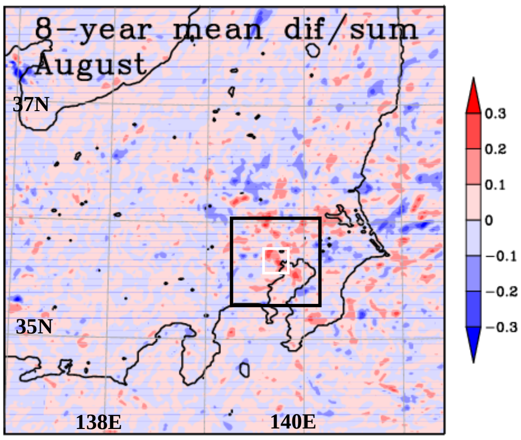

Fig. 2 Difference in monthly precipitation between SPUC and SLAB, defines as (SPUC-SLAB)/(0.5*(SPUC+SLAB)). A black rectangle indicates reference urban area (domain 4) and a white rectangle domain 1.

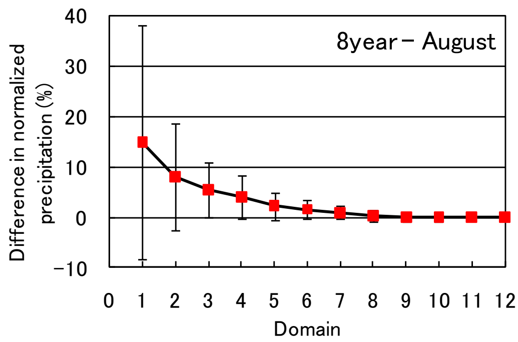

Fig. 3 Difference in normalized monthly precipitation between the SPUC and SLAB experiments (8-year August mean). Error bars denote standard deviations for 8 years.

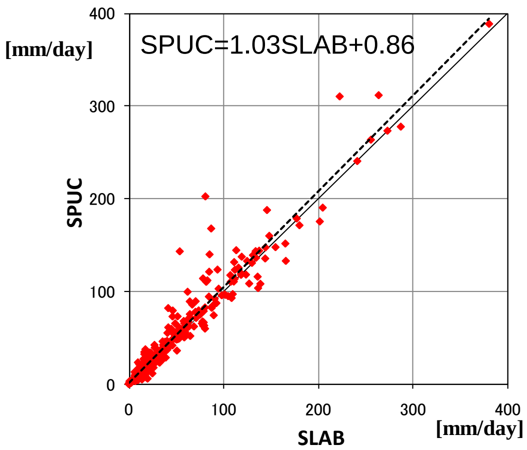

Fig. 4 Daily maximum precipitation amounts of the SPUC and SLAB experiments in the reference urban area (domain 4).

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