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The effects of a large city on heavy rainfall in Tokyo as revealed by ensemble simulation

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Many numerical studies have demonstrated that rainfall increased over cities and in their leeward areas in summer because of urban effects (e.g. Rozoff et al., 2003, J. Appl. Meteor.). However, several studies have produced the opposite conclusions. Trusilova et al. (2009, J. Appl. Meteor. Climatol.) have revealed that precipitation in urban areas decreased by 0.2 mm day^{-1} in summer because of the lack of surface evaporation. Kusaka et al. (2009, Proc. ICUC7) have pointed out that the results of these numerical studies arose from chaotic effects because precipitation is quite chaotic. Kusaka et al. (2009) have also suggested that one of the valuable methods used to overcome this problem is the ensemble simulation. This study is intended to investigate the effects of urban areas on precipitation during heavy rainfall occurring in central Tokyo, based on ensemble simulation of large members.
The ensemble simulation in this study consisted of simulations using various objective analysis data as the initial and boundary atmospheric field (RANAL, GANAL, JRA-25, NCEP-FNL and NCE/DOE-R2). Simulations were performed on 10 heavy rainfall events in central Tokyo during 1999–2007. An E-S wind system (convergence of easterly wind from the Pacific Ocean and southerly wind from Tokyo Bay and Sagami Bay in Tokyo; Fujibe et al., 2002, Tenki) has appeared at all these events. It often appears when a short-time heavy rainfall occurs in Tokyo.
Land use distributions of two types were prepared for numerical simulations; actual land use and virtual land use, in which all urban-type land use was converted to vegetation. Each member was simulated using actual land use and virtual land use. We used the Regional Atmospheric Modeling System (RAMS; Pielke et al., 1992, Meteor. Atmos. Phys.) Ver. 4.4 coupled with a single-layer Urban Canopy Model (Zhang et al., 2008, J. Appl. Meteor. Climatol.).
Results show no large differences in the E-S wind system of the Kanto plain (ca. 100 km $\times$ 100 km), even if cities were converted entirely to vegetation. However, the winds that blow to the urban area were strengthened because of the pressure decrease caused by the urban heat island. Consequently, the convergence leeward of the urban area was enhanced by the urban heat island. The updraft leeward of the urban area was also strengthened by the urban heat island.
In addition, the precipitation leeward of the urban area increased despite the decrease of vertical vapor flux from the land surface. The horizontal vapor flux from the southern sea of Tokyo increased because of the strengthening of the wind. When heavy rainfall occurs in Tokyo in an E–S wind system, much water vapor flows into the urban area from the southern sea of Tokyo. The precipitable water accordingly increases because of the surface wind enhancement.
We therefore concluded for the case of Tokyo that urban effects alter wind characteristics leeward of the urban area, and develop wind convergence and rainfall there.