Impact of an Urban Land Surface Scheme on Local Climate Simulation for the Tokyo metropolitan area

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Introduction

The land surfaces take an important role to provide dynamical and thermal energy to the atmosphere above. For the more reproducibility on the climate simulation, the more sophisticated expressions of the land surface are needed. When the model grids are large with a broad view of the land surfaces, the land area is almost occupied by vegetation covers. Therefore, a sophisticated vegetation canopy model, the Simple Biosphere (SiB) model by Sellers et al (1986), has been adopted as the land surface model not only of the global climate models but also of the regional climate models. Also, our regional climate model, NHRCM (Non-Hydrostatic Regional Climate Model), has been shown good performances with the MJ-SiB (Meteorological Research Institute / Japan meteorological Agency's Simple Biosphere model, Ohizumi and Hosaka (2000)). However, non-vegetation but urbanized grids became obvious as the resolution of the model higher up to several km along with the rapid progress of dynamical downscaling technique and computational technology (Fig. 1). Reproducibility of the climatology on urban area seems to be insufficient even if the model devises treatment of the MJ-SiB as dried bare ground to express the so-called urban deserts. Sasaki et al. (2008) reported that the surface air temperature over urban area around Tokyo showed systematic negative biases in the present climate reproduction over Tokyo metropolitan area by the NHRCM with the grid spacing of 4km.

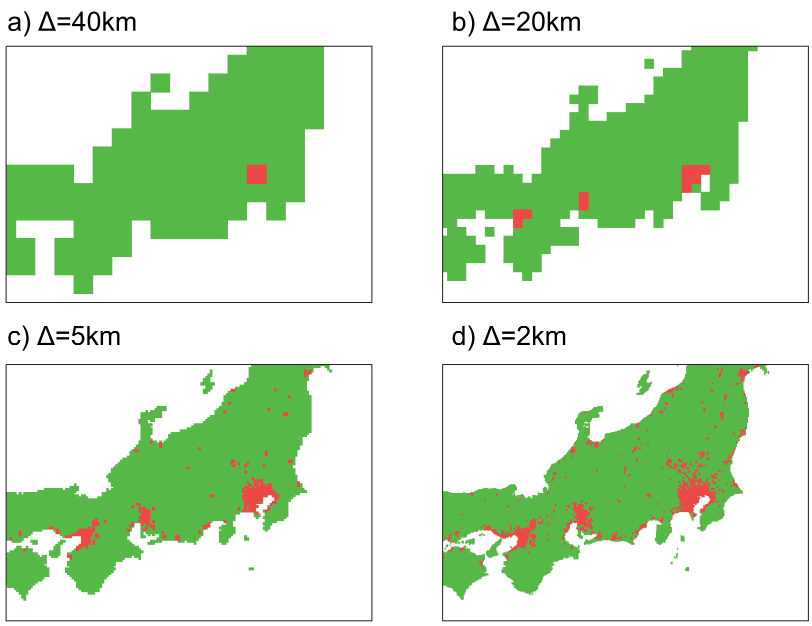

Figure 1. The model grid resolutions and the representative land use types. The land use types were binarized to vegetation grid (green) and urban grid (red), using the National Land Numerical Information database of Japan.

The concept of urban canopy had proposed as a sophisticated land surface scheme which can express the energy balances at the highly urbanized area. Some improved expressions of radiation and heat balances, which vary in time owing to the shadows of forest of high-rise urban buildings, are expected by them. In this study, an urban canopy parameterization scheme called SPUC (Square Prism Urban Canopy, Aoyagi and Seino (2011)), is applied to the 4km- resolution NHRCM. Using the SPUC- and SiB- coupled to the NHRCM, present climate (from 2001 to 2006) experiments is executed and the impact of the SPUC scheme to the climate reproducibility is evaluated.

2. Experimental Settings

The targeted area is Kanto-Koshin region including the Tokyo metropolitan area, which is one of the most urbanized cities in Japan. Reproduction term of the present climate is five years from September 2001 to August 2006. Time integration will be continuously executed throughout the 5 years. The JMA's regional analysis dataset (RANAL) will be used as initial and boundary conditions of the simulation. The RANAL will be downscaled once by NHRCM10km in order to produce water substances like clouds, ices, hails, etc. by NHRCM itself. The 10km resolution results will be also downscaled by NHRCM4km. The 4km experiments will be executed in two cases switching the land surface schemes on urban areas. One uses MJ-SiB scheme for all land grids (NHRCM-SiB). In this experiment, the urban area will be expressed as dried bare lands or bare ground with broadleaf shrubs. Another experiment (NHRCM-SPUC) uses MJ-SiB scheme at the grids of vegetation dominant and otherwise use an urban canopy scheme, SPUC, for urban dominant grids (Fig. 2).

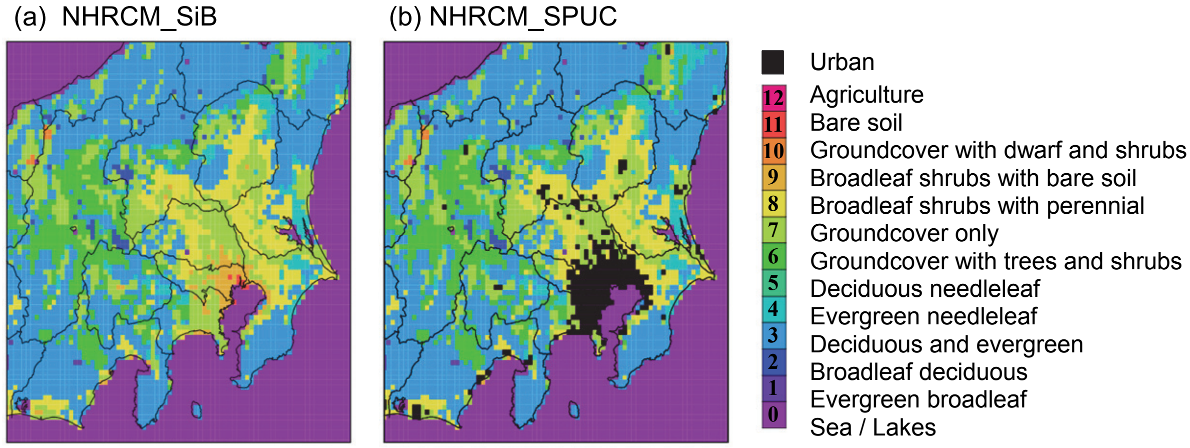

Figure 2. Horizontal distribution of land use types set in the NHRCM4km.

The urban grids are defined as the grids occupied over 50% by the land use of building area category calculated from the National Land Numerical Information dataset of Japan. The occupied area of buildings in the urban grids is estimated by assuming the building-to-land ratio be 60% of the area of building category. The shapes of buildings are derived from the GIS database provided by the Tokyo metropolitan government. We picked up the aspect ratio of each building in Tokyo from the GIS data, and averaged in each urban grid. The aspect ratio 0.25, which is the averaged value over Tokyo metropolis, will be applied to other prefectures. Skyview factors can be calculated from the building area fraction and averaged aspect ratio of the buildings. The skyview factor is one of the important parameters because it controls the shortwave radiation distribution onto the buildings and the grounds during the daytime, and also controls the effects on inhibition of radiative cooling at the ground owing to the downward longwave radiation from the high-rise buildings during the night. The physical parameters, such as albedo, volumetric heat capacity, and so on, are set uniform values of typical office buildings (Aoyagi and Seino 2012) for all urban grids. The anthropogenic heat is not considered at these experiments.

3. The impact on surface air temperature

Table 1 and Fig. 3 show the evaluated results of 5 years mean surface air temperature towards the observation acquired by the Automated Meteorological Data Acquisition System (AMeDAS) of JMA. The comparison was made with the AMeDAS value and the reproduced NHRCM's value of the nearest land grid point. The elevation corrections were applied with the temperature lapse rate of 0.006 K m^{-1}, as well.

Table 1 Evaluated bias and correlation coefficient of 5 years mean surface air temperature towards AMeDAS data in the domain.

	NHRCM_SiB	NHRCM_SPUC
Bias [°C]	1.30	1.55
Correlation coeff.	0.73	0.86

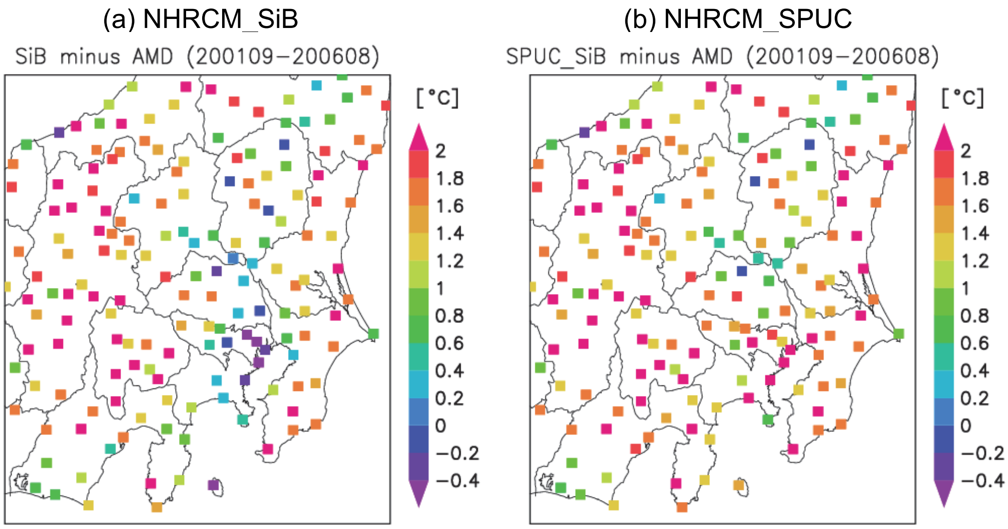

Figure 3 The differentials of 5 years mean surface air temperature towards AMeDAS.

Seeing the reproduction of NHRCM_SiB, we can see apparent negative biases around the urban area (urban area can be recognized in the Fig. 2), as indicated by the previous study of Sasaki et al. (2008). On the other hand in the NHRCM_SPUC experiment, the bias tendency was largely changed to positive. Then the area averaged bias seemed to get worse from 1.30 °C to 1.55 °C if the SPUC scheme would be applied. The area averaged correlation coefficient of the 5 years mean surface air temperature, however, was improved from 0.73 of NHRCM_SiB to 0.86 of NHRCM_SPUC. The reproduction skill was better when the SPUC was applied concerning to the horizontal distribution of the surface air temperature. Such the better reproduction of the temperature's horizontal distribution must result in the better reproduction of local circulations via the better reproduction of the barometric gradient.

Figure 4 shows the area averaged bias and correlation coefficients in each month. The impact of the application of SPUC scheme seemed to be large in winter. It is consistent with the fact that the heat island phenomenon, which is one of the famous features of urban climate, becomes obvious in winter season when the atmosphere tends to be more stable. Although the application of urban scheme SPUC made the reproduction of surface air temperature be worse at each observational points, the correlation, that is the reproduction of horizontal distribution of surface air temperature, was quite improved.

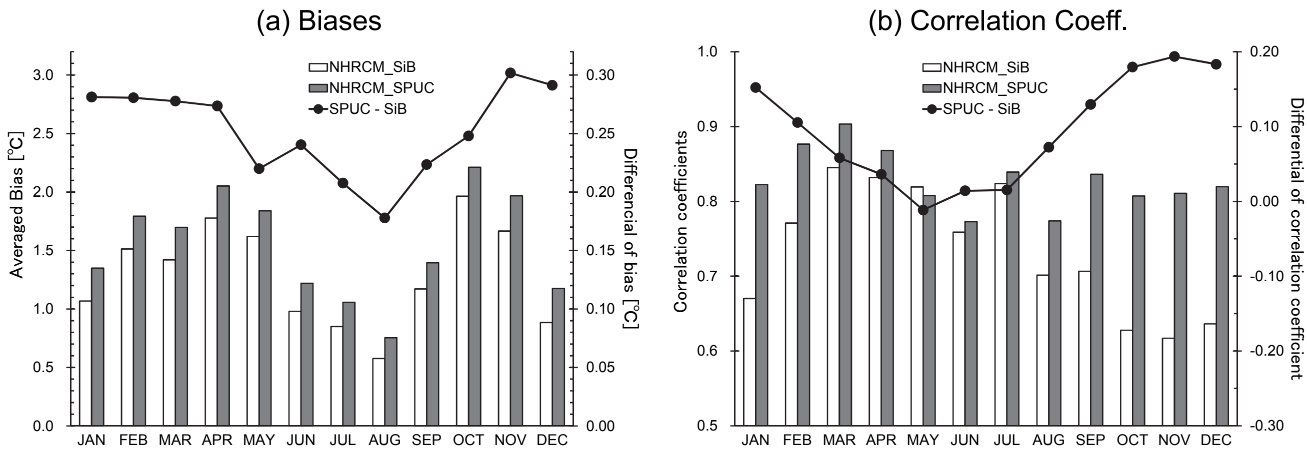

Figure 4 Annual variations of biases and correlation coefficients averaged over the domain.

Figure 5 shows the differences between the two experiments of monthly mean potential temperature profile in August and February around the urban grids. It represents how high the influence of switching the land surface scheme from MJ-SiB to SPUC (the influence of warmed up the lower atmosphere) reaches. The lower atmosphere was reproduced warmer throughout the day when the SPUC scheme applied. The warming effect was larger on February than August. During night, the affected area was limited below 200 m above the ground. On the other hand, the influence of the temperature increase by switching the land surface scheme reached around 1000 m during daytime. The atmospheric boundary layer grew higher by warming the lower layer. It also can be seen the situation that the upper part of the boundary layer (overshoot layer) got cooler, which is a typical pattern of so-called the crossover. The influence of the land surface modification reaches at 1800 m above the ground during the daytime of summer.

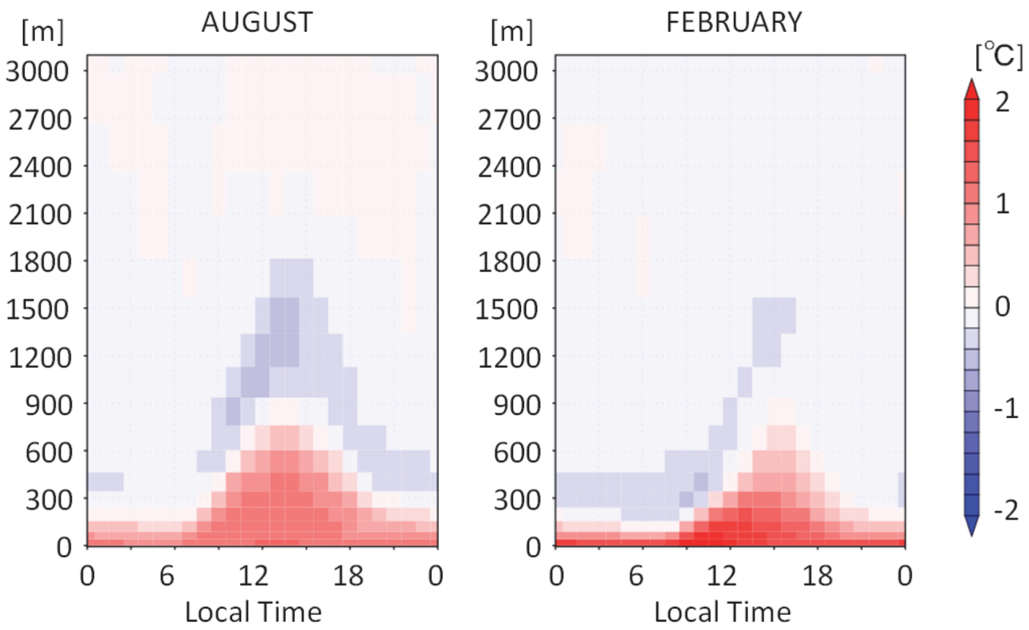

Figure 5 The daily variation of the difference of potential temperature profile around the urban area between NHRCM_SPUC and NHRCM_SiB.

4. The impact on precipitation field

The precipitation ratio, which is the ratio of the precipitation reproduced by NHRCM to the AMeDAS observation, is shown in Table 2 and Fig. 6. There is no significant difference of the precipitation reproduction around the urban area. Averaged precipitation ratio and correlation coefficient estimated over the analyzed domain were 119 % and 0.70 in both NHRCM_SiB and NHRCM_SPUC experiments. Although this result seems to conflict to the result on previous section that the temperature differences reach several km above, it can be acceptable if we consider that the influence of the land surface modification on the climatic precipitation field is quite little because of the limited influence of land surface modification on the weak solar insolation days, such as rainy days.

Table 2 Evaluated precipitation ratio and correlation of 5 years total precipitation amount towards AMeDAS data in the domain.

	NHRCM_SiB	NHRCM_SPUC
Precipitaion ratio [%]	119	119
Correlation coeff.	0.70	0.70

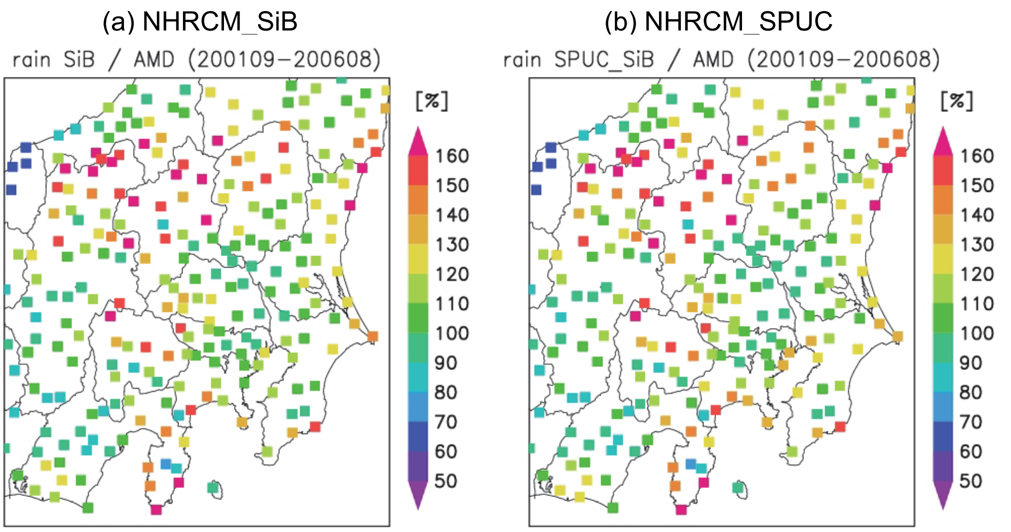

Figure 6 The ratio of 5 years total precipitation towards AMeDAS.

Then, were the temperature changes of lower atmosphere so small that the precipitation was not influenced at all? The difference of annual precipitation from September 2001 to August 2002 reproduced by NHRCM_SPUC and NHRCM_SiB is shown in Fig. 7. More precipitated area around coastal urban cities and less precipitated area in inland area can be seen although the amounts are very small just in several percent of the total precipitation amounts at each area. This can be explained as below: firstly, the atmosphere will be more unstable by the warming of lower atmosphere in urban area, then, the convection will be triggered easier and the precipitation increase in the area can be occur, as the result, the precipitation will be decreased in the downstream inland area. The cumulus convection parameterization scheme of the mesoscale atmospheric model estimates the atmospheric stability in the lower layer and triggers convection according with the stability. The parameterization scheme has an effect of bringing vapor to the upper layer estimating the entrainment/detrainment amounts. This behavior also affects the precipitation increase estimated by the cloud microphysics scheme. These are understandable qualitatively, but in quantitatively, this influence must depend on the parameter settings of the cumulus convection parameterization scheme. The image of the influence of land surface scheme on the precipitation changed drastically in the additional experiment of 2km-NHRCM without the cumulus convection parameterization scheme (Fig. 7b). This result is suggesting that the cloud resolving simulations by the higher resolution less than 2km NHRCM are needed in order to get more reliable reproduction of precipitations and estimation of the influence of urban land surfaces on the precipitation fields.

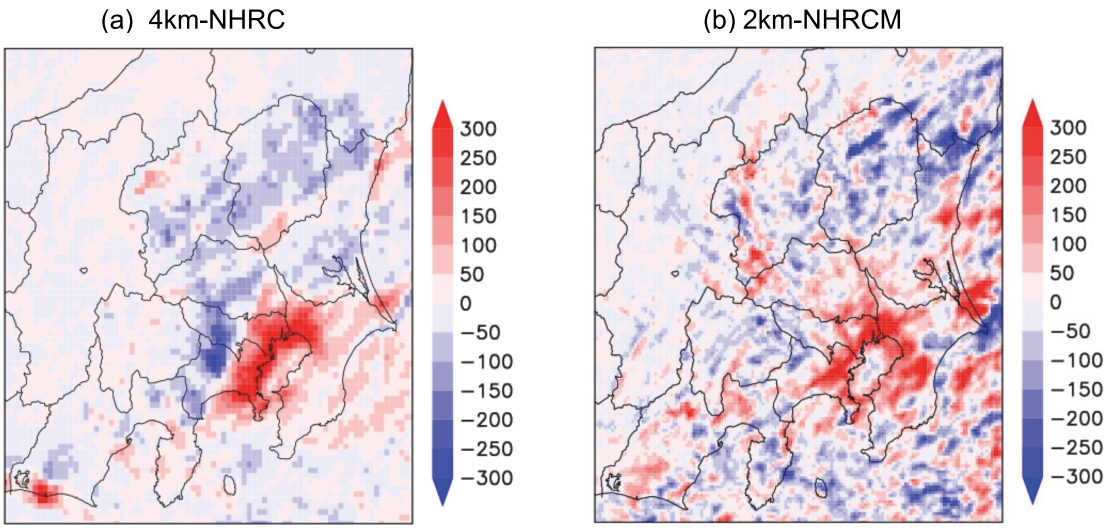

Figure 7 The difference between the annual precipitation (Sep. 2001 – Aug. 2002) reproduced by NHRCM_SPUC and NHRCM_SiB. (a) 4km-NHRCM with the cumulus convection parametrization scheme, (b) 2km-NHRCM without the cumulus convection parameterization scheme.

Acknowledgment

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