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EVALUATION OF VEGETATION EFFECT ON URBAN CLIMATE BY COUPLED SIMULATION OF SATELLITE REMOTE SENSING AND LOCAL METEOROLOGICAL MODEL

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Abstract

The purpose of this study is to elaborate the urban climate simulation by use of the satellite remote sensing (RS) data and to evaluate the urban vegetation effect on mitigation of urban heat island. Urban heat island is simulated in Tokyo Metropolitan Area by application of Colorado State University Mesoscale Model (CSU-MM). By comparing simulation results with observed data of the ground monitoring system, it is confirmed that the simulation accuracy is improved by applying remotely sensed vegetation cover ratio (VCR) data to the ground surface of the mesoscale model. The results show that air temperature during daytime decreases by 1.5 degree Celsius due to vegetation on a typical summer day.

Key words: urban climate simulation, satellite remote sensing, vegetation

1. INTRODUCTION

In urban areas, the vegetation has the restraining effect for urban heat island phenomenon and it plays a significant role on improvement of the thermal environment in the summer time. Especially, under the Japanese climate condition, the mitigation of urban heat island in the summer time is the important issue related to the amenity of residential environment, the energy saving and peak-cut of electric power for air-conditioning.

A lot of numerical studies have been carried out to simulate the urban heat island by use of mesoscale meteorological models. In the most of the previous studies, physical characteristics of the ground surface are generally represented in meteorological models by use of land-use data. However, small vegetation-covers such as roadside trees and garden trees, which are excluded in land-use data, can not be represented through this method. As the practical technique for the representation of the actual ground surface, the satellite remote sensing (RS) has been developed recently. The purpose of this study is to propose a new method for elaborating surface boundary condition of urban climate simulation by use of RS data and to evaluate the urban vegetation effect on mitigation of urban heat island.

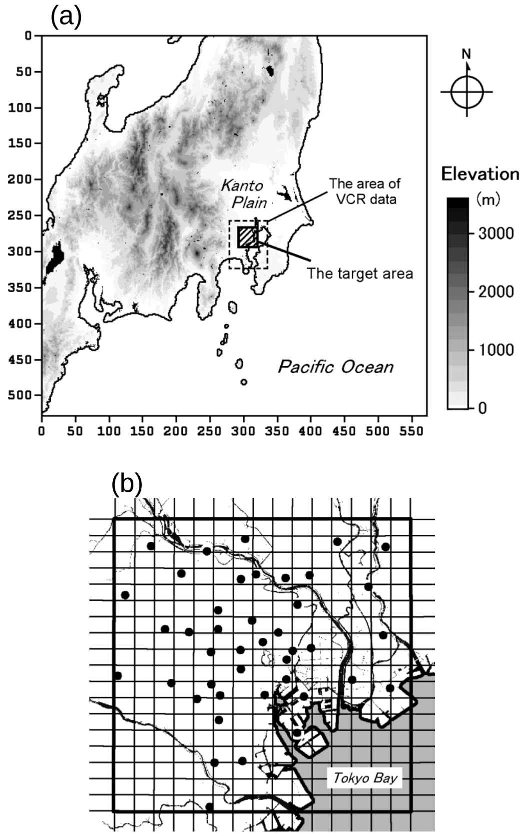

Fig. 1. (a) Computational domain (variable interval grid) and (b) the target area (2km grid). Solid circles (shown in (b)) indicate the observation points of High-density Urban Climate Observation Network.

2. MODEL DESCRIPTION

The mesoscale meteorological model used in this study is the Colorado State University Mesoscale Model (CSU-MM) developed by Pielke (1974) and after improved by Urickson and Mass (1990), Kessler and Douglas (1992). This model has been already used for the urban climate simulation (e.g., Ichinose *et al*. 1999, Urano *et al*. 1999, Taha 1996). The target area, which includes Tokyo Metropolitan Area, is shown in Figure 1b, and divided into 15 grid for the east - west direction, and

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18 grid for the north - south direction through the configuration of 2 km x 2 km mesh. To simulate local circulations developed around the target area, the computational domain is set as 500 km x 500 km (Figure 1a) with the variable interval grid system; the grid interval becomes larger, as the grid is far from the target area.

To simulate the typical summer weather days, the period under clear-sky conditions, 3-7 July 1998, which Japan Island was covered with the Pacific anticyclone, were selected. In this study, the initial values were given as a horizontally uniform. The simulation was started at the time of 0:00 Local Solar Time (LST), and carried out for 48 hours. The calculation results of the second day were analyzed in this study.

3. SIMULATION RESULTS

3.1. Simulation under Actual Conditions

The urban climate simulation under actual conditions was conducted in consideration of actual vegetation cover ratio (VCR) estimated from RS data (hereinafter Case RS). The distribution of VCR was estimated by using normalized difference vegetation index (NDVI) derived from visible and near-infrared band data acquired by Japanese Earth Resources Satellite-1 (JERS-1), as shown in Figure 2.

The method parameterizing the ground surface in meteorological model by using VCR data, which is proposed in this study, is schematically represented in Figure 3. To represent the land-use coverage in the meteorological model, in a general way, surface parameters, which represent physical characteristics of the land cover, such as albedo and specific heat, are set by each grid. In the previous studies, the distributions of surface parameters were usually derived by applying surface parameters of each land-use type to each grid of land-use data. On the other hand, for Case RS, the surface parameters were set through calculating the weighted mean by the area ratio of each land-use type and the VCR.

Figure 4 indicates the horizontal distribution of wind and temperature near the ground surface for Case RS at 15:00 LST. This figure shows that the southerly winds dominate over the whole region of target area. The high temperature area (of about 34 degree Celsius) appears in the northern part of the target area; it can most likely simulate the urban heat island in Tokyo Metropolitan Area. In addition, it is noteworthy that horizontal temperature gradients are large around the coastal areas of Tokyo Bay in the daytime, due to the penetration of the sea breeze front.

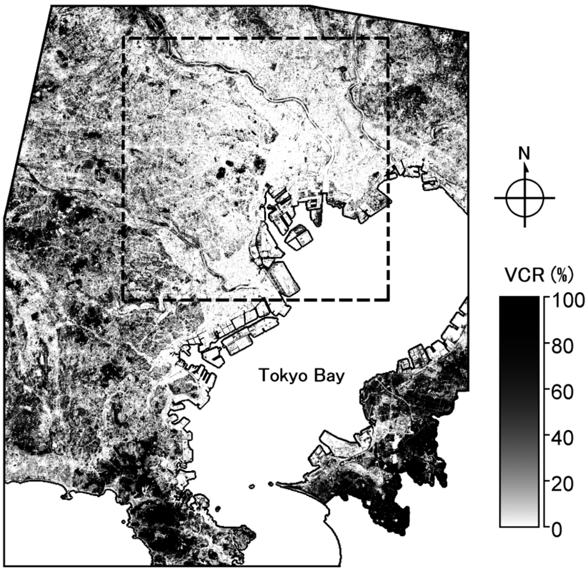

Fig. 2. The VCR data derived from RS data. The dashed-square indicates the target area of this study (see Fig. 1).

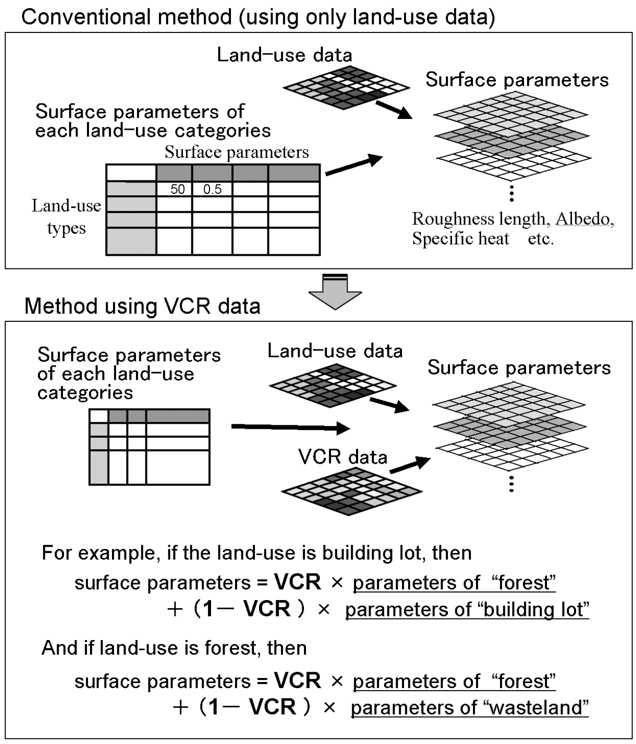

Fig. 3. Schematic diagram of the parameterization of the ground surface in meteorological model by using VCR data.

For the validation of new method, the simulation (the conventional method) was conducted using the surface parameters that are derived from only land-use data (hereinafter Case noRS). The initial conditions and the temporal and spatial distributions of anthropogenic heat are same as Case RS. To verify these simulation results, the calculated temperatures were compared with those observed by the ground monitoring system. The observational data used here is obtained from 42 points of High-density Urban Climate Observation Network (see Figure 1b), with the support of Japan Science and Technology Corporation. Figure 5 shows the scatter diagrams

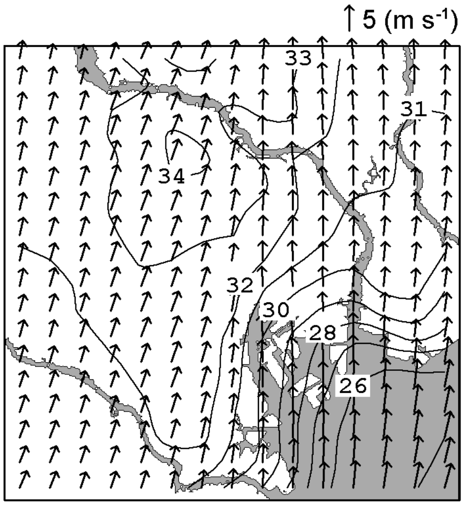

Fig. 4. Simulation result at 15:00 LST at 4.5 m above ground level.

of the calculated versus observed temperatures, and the root mean square errors (RMSE) and the correlation coefficients (R) for those. These figures reveal that the simulation results become more accurate by use of the RS data.

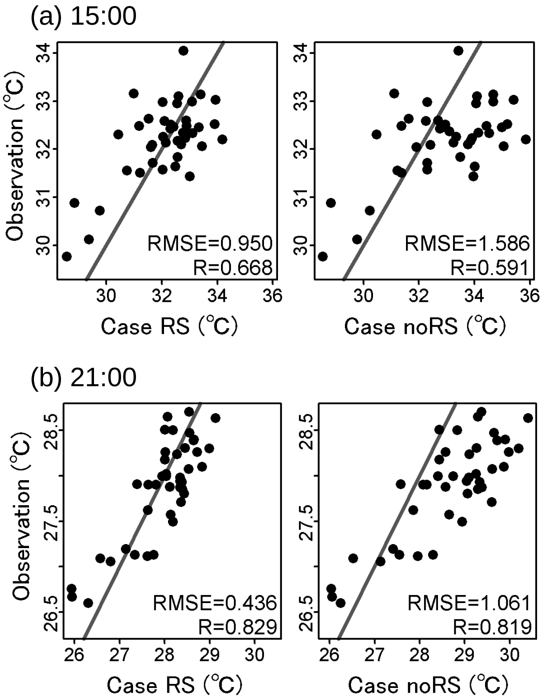

Fig. 5. Scatter diagrams of calculated temperature versus observed temperature at (a) 15:00 and (b) 21:00 LST.

3.2. The evaluation of the vegetation effect on the urban climate

The vegetation effect on mitigation of urban heat island is evaluated by comparing two cases: one is the actual vegetation case (i.e., Case RS) and the other is a no vegetation case (hereinafter Case VCR0). Surface parameters for Case VCR0 were generated by replacing the all meshes of VCR data by 0% and applying the method described previously (see Figure 3).

Figure 6 shows the horizontal distributions of the temperature difference between Case RS and Case VCR0 near the ground surface at 15:00 LST. As can be seen in this figure, the air temperature for Case RS is 1.5 degree Celsius lower than that for Case VCR0 in the western region of the target area. This results from the fact that the land-use of this region mainly consists of low-rise residential, and hence, there are a lot of garden-trees. Additionally, because this region exists at the inland of the target area, the arrival time of the sea breeze front delays. Therefore, the inland vegetation has a stronger effect on temperature than the coastal vegetation because the duration of supplying the sensible heat flux from ground surface to the atmosphere becomes longer. Vertical distributions of potential temperatures at Nerima (see Figure 6) for Case RS and Case VCR0 are shown in Figure 7. In the daytime, the air mass is diffused by development of the convective mixed layer, and the vegetation effect reaches to around the height of 400-600m. On the other hand, the vegetation effect reaches only about 100m at night because the inversion layer is formed and the atmosphere is stable. Figure 8 shows the comparison of the surface heat budgets between Case RS and Case VCR0 in the western region of the target area (the dashed-square

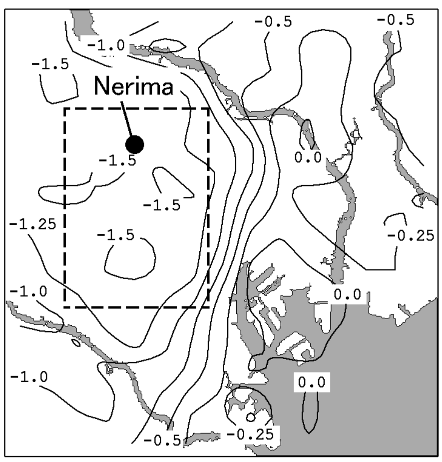

Fig. 6. Temperature difference (Case RS - Case VCR0) at 15:00 LST at 4.5 m above ground level.

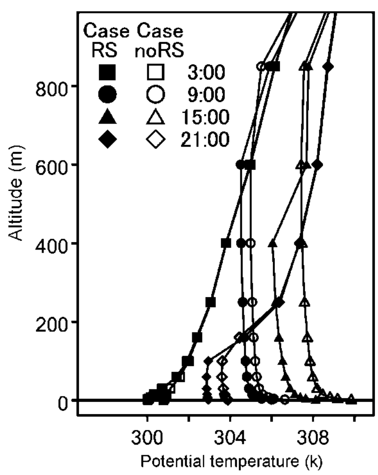

Fig. 7. Vertical profiles of potential temperature at Nerima (see Fig. 6).

area in Figure 6). This figure indicates the increase of latent heat flux and the decrease of sensible heat flux due to the vegetation are approximately 130 W m^{-2} and 100 W m^{-2}, respectively, at 13:00 LST.

On the other hand, in the eastern region, the air temperature is decreased by 0.5 degree Celsius (see Figure 6), which is smaller than the above difference in the western region. The reason for this is mainly that the VCR of the eastern region is relatively low in comparison with the surrounding areas due to the existences of the high-density urban districts, the densely residential areas and the reclaimed lands of Tokyo Bay.

4. SUMMARY AND CONCLUSIONS

The numerical simulations of urban climate were conducted in Tokyo Metropolitan Area in the summer by application of Colorado State University Mesoscale Model (CSU-MM). This paper emphasizes on making use of vegetation cover ratio (VCR) data derived from satellite remote sensing (RS) data, and it enables to assess the effect of small vegetation.

First, simulations are conducted for two cases: one is using vegetation cover ratio data (Case RS), and the other is using the land-use data as same as the previous studies (Case noRS). By comparing simulation results with observed data of ground monitoring system, it is confirmed that the simulation results become more accurate by use of the RS data.

Second, the vegetation effect on mitigation of heat island phenomenon is evaluated by comparing two cases: one is an actual condition case (Case RS) and the other is a no vegetation case (Case VCR0). The result shows that air temperature during daytime decreased by 1.5 degree Celsius due to vegetation on a typical summer day in Tokyo Metropolitan Area.

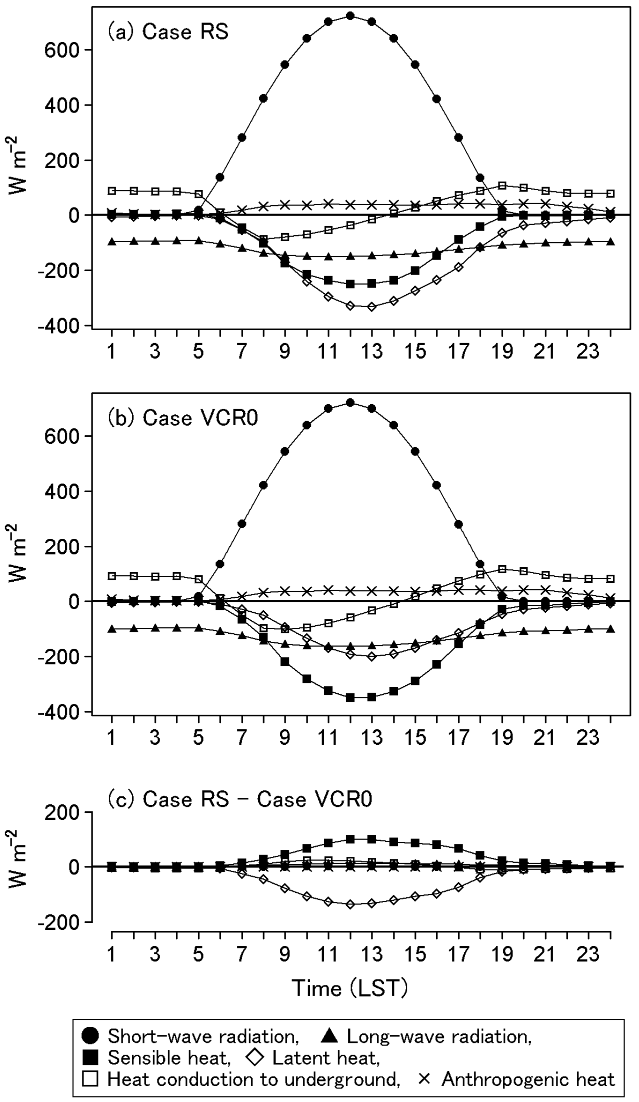

Fig. 8. Diurnal variation of surface heat budgets of (a) Case RS, (b) Case VCR0 and (c) the difference between Case RS and Case VCR0 (in the dashed-square area shown in Fig. 6).

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