Study on Influence of the Change of Land Cover Ratio on Urban Thermal Environment – No.2 Analysis by Mean of the Local Scale Numerical Simulation Model

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Abstract

The characteristics of land covers in the central part of Kyoto City are analysed by using the Ikonos data with 4m resolution. Albedo is presumed from panchromatic data. It is confirmed that albedo of the elementary school yard is high, and that of the tiled roof on the wooden house is low. It is confirmed from NVI image data that the green ratios in the imperial palace, the castle, parks, slopes, temples, and shrines are high. The parameters of ground surface heat budget are set by using Ikonos data, and the thermal environment in the central part of Kyoto City in summer is analysed using the local scale numerical simulation model. Based on an analytical result of the Ikonos data, it is calculated to improve albedo of the tiled roof on the wooden house, and the impacts on the thermal environment are analysed.

1. Introduction

We considered a characteristic of high-resolution satellite data (IKONOS, resolution 4m) of Kyoto City in previous study and examined possibility for applying to urban climate analysis (Takebayashi et. al. 2002). As a result, about distribution of green cover ratio and solar reflectivity (albedo), the possibility for using to surface boundary condition making of urban climate analysis was investigated. In this study, the central area of Kyoto City is considered to be a target area, surface boundary condition made by high-resolution satellite data is applied to the local scale numerical simulation model, and climate analysis is carried out. And the method to utilize the high-resolution satellite data to the climate analysis effectively is considered.

2. High-resolution satellite data

The data which observed by the high-resolution satellite IKONOS is provided from Japan Space Imaging Corporation. The wavelength of IKONOS data is as same as 1-4 bands of Landsat TM’s ones, and the resolution of each spectrum image is 4m. The data which used in this study is observed at 10:39 on October 19, 2000. Normalized vegetation index (NVI) is calculated by the following equation, and the distribution of NVI in calculation area is shown in figure 1.

\[
NVI = \frac{(\text{Band}4 - \text{Band}2)}{(\text{Band}4 + \text{Band}2)} \times 100
\]

Panchromatic value (Kpan) is calculated by the following equation using the brightness Ri of each band.

\[
Kpan = \Sigma Ri (i=1,4)
\]

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Albedo is supposed to be 0.03 for water surface, 0.10 for green surface, 0.15 for building surface, 0.30 for bare soil surface, from some reference documents (Oke 1987), (Kondo 1994), (Parlow 1996). A recurrence line is estimated and albedo is calculated. The distribution of albedo in calculation area is shown in figure 2.

Fig. 1: NVI distribution of calculation area (5km*5km)    Fig. 2: Albedo distribution of calculation area (5km*5km)

3. Outline of urban climate analysis model

Outline of urban climate analysis model with high-resolution satellite data is shown in figure 3. Ground surface boundary condition for heat budget model is made in 4m mesh which is resolution of satellite data. Observation data of August 2002 at Kyoto meteorological station are used for the weather condition. Heat budget is calculated every one hour from 1 to 31 on August 2002, and the calculation result of sensible heat flux distribution at 15:00 is input into the CFD model. Because of the computer memory limitation, a steady condition at 15:00 is assumed for CFD calculation.

Fig. 3: Outline of urban climate analysis model with high-resolution satellite data
4. Heat budget model

Ground surface heat budget model is shown in the following equation.

\[ R = V + lE + A \]

- **R**: Net radiation (W/m²), **V**: Sensible heat flux (W/m²), **lE**: Latent heat flux (W/m²), **A**: Conduction heat flux (W/m²).

\[ R = \left( 1 - \rho \right) S \downarrow + L \downarrow - \varepsilon \sigma T_s^4 \]

\[ V = \alpha c \left( T_s - T_a \right) \]

\[ lE = l \beta \left( \alpha c / Cp \right) \left( X_s - X_a \right) \]

\[ A = -\lambda \left( \partial T / \partial z \right) \big|_{z=0} \]

- **\( \rho \)**: Albedo (solar reflectivity) (-), **S \downarrow**: Downward short wave radiation (W/m²), **L \downarrow**: Downward long wave radiation (W/m²), **\( \varepsilon \)**: Emissivity (-), **\( \sigma \)**: Stephen Bolzman constant (=5.67*10⁻⁸W/(m²K⁴)), **T_s**: Ground surface temperature (K), **Ta**: Air temperature (K), **l**: Evaporation latent heat (=2,512kJ/kg), **\( \beta \)**: Evaporation ratio (-), **Cp**: Specific heat of air (=1.0kJ/(kgK)), **X_s**: Surface humidity (kg/kg), **X_a**: Air humidity (kg/kg), **\( \lambda \)**: Thermal conductivity (W/mK), **T**: Temperature (K), **z**: Distance to underground direction from surface (m). Conduction heat flux is calculated from following one dimensional heat conduction equation. Bottom boundary condition in the ground is assumed constant value 28°C at 50cm and the preparing run period is set for three days.

\[ \frac{\partial T}{\partial z} = \left( \lambda / CpG \gamma \right) \left( \frac{\partial^2 T}{\partial z^2} \right) \]

- **CpG \gamma** is thermal capacity of the ground (J/m³K), **\( \sigma \), \( l \), Cp** are constant values. **\( \varepsilon = 1 \)** is assumed. **L \downarrow** is estimated by Brandt equation using **Ta**, **Xa**, **cc**. **ac** is calculated by Jurges’s equation using wind velocity. **Xs** is estimated by **Ts**, **S \downarrow**, **Ta**, **Xa**, **u**, **cc** is given from the meteorological data as boundary condition. Ground surface parameter **Ts** is calculated from above equations as parameters **\( \rho \), \( \beta \), \( \lambda \), CpG\gamma**. Anthropogenic heat release **H** (W/m²), aerodynamic roughness parameter **z0** (m) are set as parameters of CFD model. Parameters **\( \rho \), \( \beta \), \( \lambda \), CpG\gamma**, **H**, **z0** are set by using high-resolution satellite data. Albedo \( \rho \) is shown in figure 2. The other parameters are calculated by the assumption such as figures 4, 5 using NVI.

Distribution of heat budget components estimated by heat budget model is shown in figure 6. Heat budget equation is calculated every hour from 1 to 31 on August, and only mean value at 15:00 is shown. Net radiation in the forest area and a part of building area is large, so much heat is absorbed there. At the place with many trees like the Imperial Palace, latent heat flux is about 200W/m², therefore sensible heat flux is controlled about 100W/m². In the central town area at the south side of the Imperial Palace, latent heat flux is almost 0 and conduction heat flux is small, therefore most of net radiation about 300W/m² are converted into sensible heat flux.

\[ \beta \]

\[ \lambda \ (W \ mK) \]

Fig. 4: Setting of evaporation efficiency \( \beta \) by NVI  Figure 5 Setting of thermal conductivity \( \lambda \) by NVI

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5. CFD model

Mesh size is 50m*50m for horizontal and inequality interval for vertical. Mesh numbers are 100*100*20. k-ε type equation model is used for a turbulence model. Buoyancy effect is incorporated to take the influence of atmosphere stability into consideration (Ca et. al. 2000). From the observation result of Kyoto meteorological station, mean values of air temperature and wind velocity, most frequency of wind direction are calculated, and the profiles are made by logarithm low. They are used for initial and upper boundary condition. Cycle boundary condition is used for side boundary.

Calculation result of air temperature and wind vector in normal condition is shown in figure 7. Air temperature and wind vector at the height of 1.5m and sections of air temperature are shown. Air temperature difference between green area and town area is recognized and a difference of the development of a thermal boundary layer is confirmed.

Calculation result of air temperature and wind vector when albedo in the south area of Imperial Palace is assumed 0.2 uniformly is shown in figure 8. It is assumed that high reflection paint is applied to the roof surface and high reflection or concrete pavements are used for the road surface. In the area that became the high reflection, air temperature dose not become same temperature to the green surface, but it becomes lower temperature slightly.
6. Conclusion

The central area of Kyoto City is considered to be a target area, surface boundary condition made by high-resolution satellite data is applied to the local scale numerical simulation model, and climate analysis is carried out. And the method to utilize the high-resolution satellite data to the climate analysis effectively is considered.

Outline of urban climate analysis model is shown, and ground surface heat budget model is introduced, and the setting method of heat budget parameter is explained. From the calculation results of ground surface heat budget, the distribution of heat budget components is considered.

From the calculation results of air temperature and wind vector in normal condition, air temperature difference between green area and town area is recognized and a difference of the development of a thermal boundary layer is confirmed.

From the calculation results of air temperature and wind vector when albedo in the south area of Imperial Palace is assumed 0.2 uniformly, the effect of becoming the high reflection to urban air temperature is considered.

Bibliography