B-53-3-2 Modeling of heat budget in urban canopy layer (Final Report)

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Total Budget for FY 1997-1999 7,428,000 Yen (FY 1999; 2,486,000 Yen)

Abstract In order to clarify heat budget in the urban canopy layer and to make parameterization it, following observations were carried out at towering building zone of the Shinjuku area. Those are several kinds of meteorological factors, short and long wave radiation, radiative temperature distribution on wall of building. And a series of aircraft observation was also carried out simultaneously with this ground based observation in order to obtain ground surface temperature distribution in the various types of land-use form. The temperature distribution on ground surface got by aircraft observation was checked with land-use form information in order to make ground surface initial value of the simulation of urban meteorology. The local meteorological model for verifying the quantification of ground surface heat budget in the urban area was improved. Some characteristics of surface temperature, fluxes of physical quantities at ground surface, and detailed structure of urban atmosphere are clarified by improved model.

Keywords heat budget, parameterization, ground surface, land-use, simulation

1. Introduction

The urban atmospheric environment is made to deteriorate by the artificial waste heat which originate from the increase in energy consumption with the progress of population concentration and by the restraint of the evapotranspiration by ground covering due to progress of urban development[1]. Many numerical models have expressed the heat island phenomenon, since the higher temperature at the urban area is pointed out. However, modeling of the heat budget which comprehend radiative and sensible heat fluxes, and its parameterizations in the urban canopy have not been done still. It is hard to seem to generalize the most important reason, since it has the structure in which it is complicated urban canopy. The elucidation in the urban canopy of the heat budget is a matter desired earnestly from not only field of the meteorological phenomenon but also fields of air pollution, climate and architecture.

The technique the most commonly done until now for this problem disregards the structure of the ground surface in the realistic urban area, and it has been handled that the flow of energy and mass are related to the height of the roof. However, on the other hand, the effort that intends to grasp the heat budget in limited space surrounded by the buildings has also been made. Munez and Oke[2] and Mills[3], Mills and Arnfield[4] investigated the detailed heat budget in the space surrounded by the buildings according to the numerical model. However, in order to expand these results to the whole urban area, the problem of the complexity of urban structure has been left still. Kobayashi[5] examined the effect of the arrangement of the building using a Monte Carlo method in upward radiation flux concerning area ratio and height of the building in urban area. On the other hand, Kimura[6] proposed simplified parameterization scheme of heat flux on mixtures of different land-use surface. Furthermore, Kimura and Takahashi[7] examined the effect of anthropogenic heating estimated from energy consumption in Tokyo metropolitan area using this parameterization, and they showed that the result is considerably better correspondence with observed value. On the other hand, Kurihara et al.[8] examined how artificial waste heat gives impact on the local wind circulation in the urban area, and they showed that the impact differs by the emission height of the artificial waste heat. The heat budget in the urban canopy is the most important element to form out the urban atmosphere. Therefore, the elucidation of the heat budget based on the observation in the urban canopy, and parameterization by observed results are very important matter for the progress of precise numerical model.

2. Objective

In order to clarify the heat island phenomenon, large number of local meteorological models has been developed until now. All of them expressed heat budget at ground surface taking average in a grid distance of several kilometers. However, the urban canopy has the complicated minute structure in the subgrid scale, and it is important that quantitatively grasps and clarifies the heat budget in the urban canopy. The artificial waste heat emission from individual building and heat budget are the subgrid scale problem, and it is impossible to take directly in the model. Then, the objective of this study is to get detailed expression of urban canopy layer in the meso-scale meteorological model. Therefore, the parameterization of heat budget in urban canopy is made based on field observation. And the ground surface heat budget of meso-scale meteorological model is improved according to land-use categories.

3. Method

In order to grasp the heat budget quantitatively, time variation of several meteorological variables, long wave radiation balance, temperature distribution on the wall of building and sensible heat flux, etc. were observed at limited space in urban canopy surrounded by the towering buildings. Owing to generalize the subgrid scale heat budget, the ground surface temperature on various land-use form was observed by the aircraft, and characteristics of the histogram of the ground surface temperature for every land-use category were obtained. The parameterization on the ground surface heat budget in a grid composed by various land-use categories was attempted, and precision of ground surface heat budget in the local meteorological model was carried out. The urban characteristics of the ground surface temperature, sensible heat, water vapor, and momentum fluxes distributions were clarified by using the local meteorological model which was improved on surface energy fluxes process.

4. Results

The high-temperature of the urban called the heat island phenomenon is greatly influenced not only by the anthropogenic heating in the urban area but also by the structure of the urban surface. Therefore, the sake is to estimate the heat budget at ground surface in the urban canopy at the good accuracy. Here, the ground surface means the surface that contact to the atmosphere including not only actual ground surface but also the wall surface of the building. However, buildings and houses, etc. have done the temperature control in the inside, and the waste heat is discharged in the atmosphere. The detailed mechanism on this artificial waste heat emitted from building to the atmosphere has evaluated by the Building Research Institute by using "thermal environment load estimating model of the architecture". Therefore, the observation, the model improvement and the simulation in this study were put the importance in the heat budget originated from urban structure.

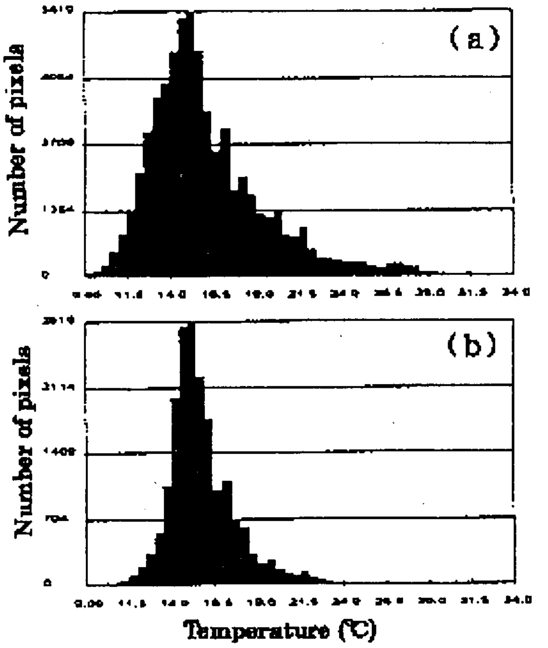

Fig. 1 Example of the surface temperature hitogram obtained by aircraft observation at 15:48 March 6, 1999. (a)is over Shinjuku, (b)over the forest of Meiji Jingu shrine.

(1) Observation of surface temperature

The observation of the grand surface temperature distribution by the aircraft reflects the complexity of urban structure. The histogram of surface temperature around the towering buildings in west Shinjuku in the stroke plane of about 500m × 400m of the thermal infrared image obtained by the *thermo-tracer* equipped on the aircraft shows the very wide temperature distribution, and the range has reached about 15 ℃ (see Fig. 1 (a)). However, in almost uniform ground surface condition (the leaves plane) such as forest of the Meiji Shrine, the surface temperature distribution is sharp, and the temperature range shows about 4 ℃ (see also Fig. 1(b)). The ordinate shows pixel number and the abscissa is temperature in ℃.

(2) Model improvement and simulation

Topographic contour line and ground surface roughness distribution in the model domain used in this study is shown in Fig. 2. As shown in Fig. 2, the model domain is mainly set at coastal region of the Tokyo Bay, and it covers 60km × 46 km region including downtown of Tokyo in the circumference by 1 km grid distance. The ordinate and abscissa are number of the grid node. The shadowed portion is occupied by large ground surface roughness such as the buildings. Topographic data set was made from the original data set with 50m grid interval. Two land-use data set of largest frequency and weighted mean were made using land-use data of the 100m grid in respect of the histogram on land-use categories occupied in 1km grid. Ground surface process of the local meteorological model (LAS) uses the method called force restore by

Deardorff[9]. In this method, the surface temperature is decided by potential temperature in the deep soil layer where the diurnal variation of soil temperature is ignored, specific heat, thermal conductivity in the soil, and as external force, short and long waves radiative fluxes, and latent heat and sensible heat fluxes on ground surface. The sensible heat flux is dependent on the ground surface condition, meanwhile, the latent heat flux depends on the wetness of the soil.

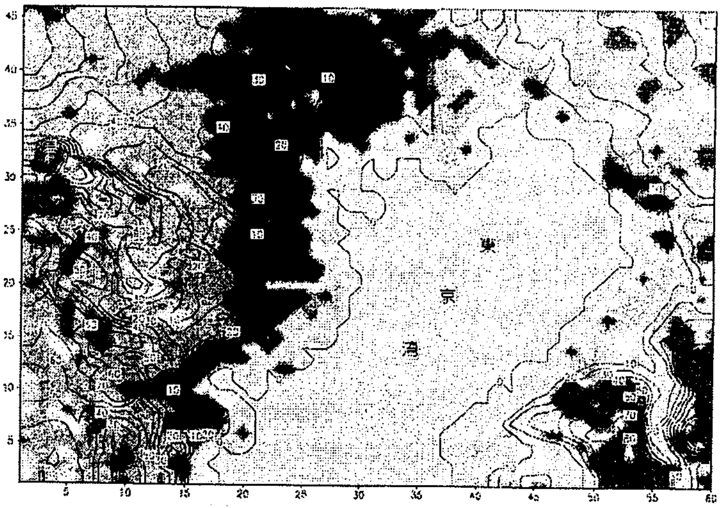

Fig.2 Topographic contoure and surface roughness in the model domain employed in this study.

It was improved in order to be correspondent ground surface process to the land-use form, and the sensitivity analysis on the effects of soil wetness and ground surface roughness on the time variation of surface temperature was carried out. The result showed that the amplitude of the time variation of surface temperature was high, as the soil wetness is generally lower, and as the ground surface roughness is smaller.

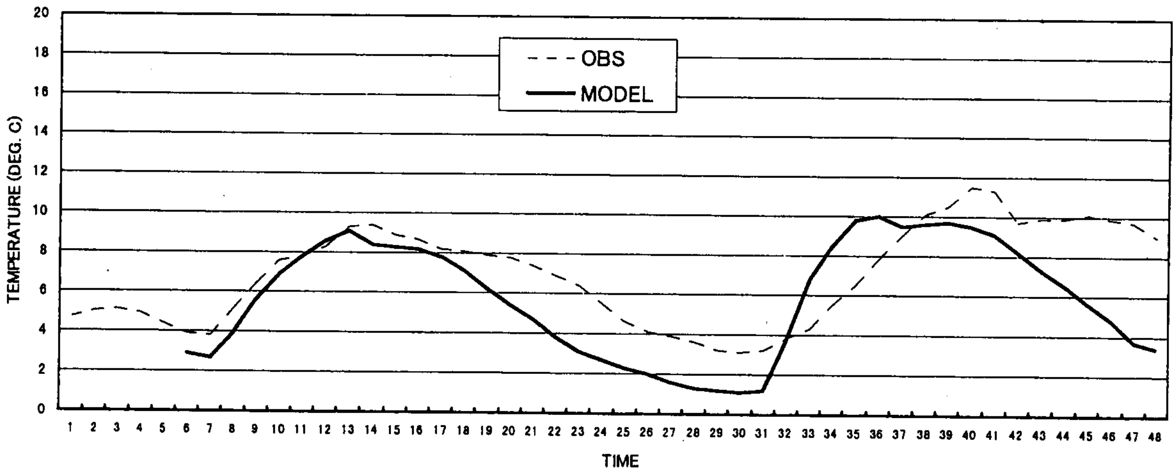

Fig. 3 Comparison of temperature time variation in respect of model result and observed value at Sinjuku.

The ground based observation of temperature and radiation fields in the urban canopy was carried out simultaneously by aircraft observation at the Kogakuin University in the towering buildings in Shinjuku in the middle of March, 1999. Meteorological simulation for the 48 hours was carried out since March 12th in this observation period. The comparison of time variation of the air temperature at Shinjuku by model result and observed value is shown in Fig. 3. The air temperature of the model is at the height of 15m above ground surface, and the observed value is the data at 25m above ground surface in the National Observation Station in the Shinjuku Gyoen park for general air environment. In the model result, temperature in the night and minimum temperature in the dawn have been evaluated low. This seems by the reason that the effect of artificial waste heat does not be considered probably. Actually, it seems to suppress the temperature decline in the urban lower atmosphere by artificial waste heat in the night. Oke and Maxwell[10] observedair temperature at Montreal and Vancouver by using motor vehicle, and they showed different cooling rate between urban and rural. Namely, temperature decline is restrainded by the artificial waste heat and urban structure. The consideration of detailed information of the artificial waste heat is necessary for better prediction of temperature. This problem is solved by the Building Research Institute.

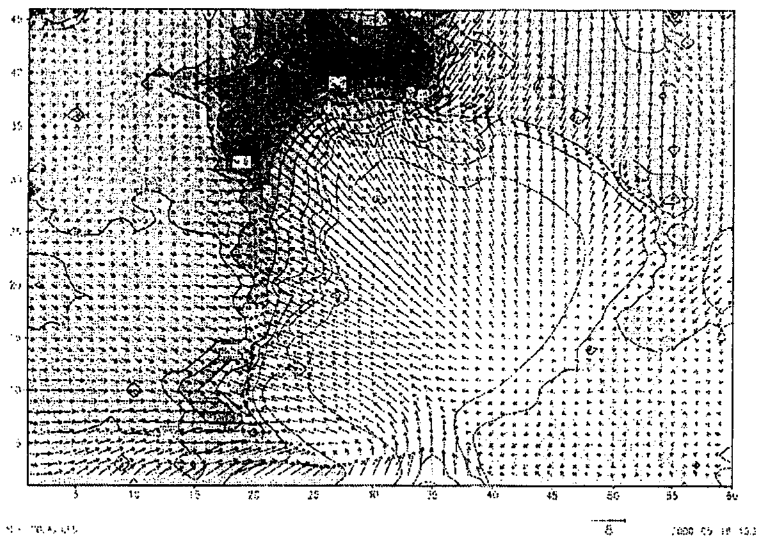

Fig. 4 The predicted temperature and wind distribution at 15m above ground surface.

Calculated temperature and wind fields at 15m above ground on 14:00 March 13th are shown in Fig. 4. The ordinate and the abscissa are also number of the grid node. It is seen that the temperature rises at the center of urban where is characterized as large surface roughness and low soil wetness due to a number of towering buildings. This high temperature disappears at night, and it appears at daytime of the next day again. However, it is actually expected that high temperature persists even in the night time due to the supply of artificial waste heat to the urban lower atmosphere. Southwesterly wind blows toward the place where the temperature is high, and strong sea breeze front has been formed here after southeasterly sea breeze close encounter to the southwesterly wind. The sea breeze is excellent at the east side of the front, and the thickness has reached about 800 ~ 1000m, and the northwest wind component dominates at the layer above sea breeze. The sea breeze advances from Tokyo Bay, and the front is reaching the center of Tokyo where the temperature is the highest around 14h. On the other hand, the sea breeze front at the northeast coast of the Tokyo Bay is standing still at coast line. It is supposed that high temperature induces the invasion of see breeze front. The geostrophic wind is the northwest on this day. Sea breeze does not go from here up north, and the front is disappearing with the progress in the time. Figure 5 shows latitudinal (northerly or southerly) wind component on the vertical cross-section plane at J=33 grid node on the north-south axis. The vertical structure of sea breeze front is clearly seen. The negative value on the contour is northerly component and positive is southerly. It has been also known that the wind blows toward the urban with the high temperature due to artificial waste heat. The circulatory system of the wind toward the urban area had been also recognized by Kurihara et al.[8]who examined impact by the effect of artificial waste heat to the regional wind circulation at the Kanto area by using nested numerical model. They gave uniform heat emission to the whole of urban area.

The particularities of this study are to express detailed surface process according to the urban structure by resolving into the smaller scale as possible, and to introduce the heat budget corresponding to this scale for the local meteorological model. And it can make to express the detailed wind and temperature fields in the urban area by the improved model.

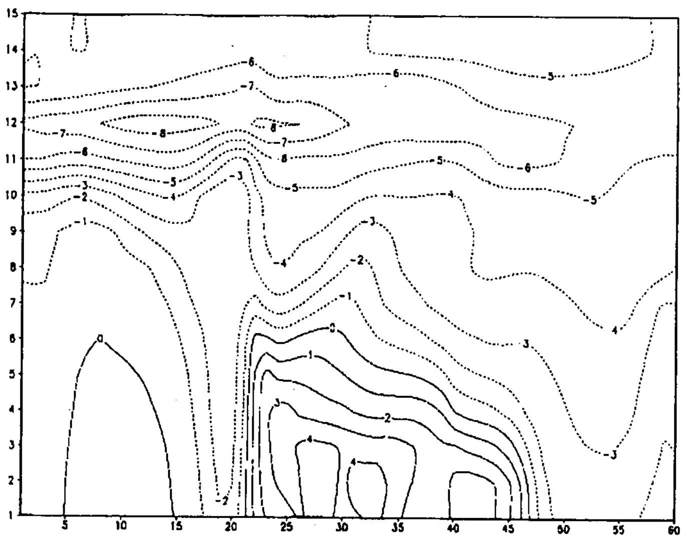

Fig.5 The vertical structure of the latitudinal wind component on the cross-section plane at J=33 grid node.

5. Concluding remarks

In order to parameterize heat budget on ground surface in urban canopy layer, the ground-based and aircraft observations of the ground surface temperature field was carried out. The local meteorological model was improved on the surface process that was parameterized according to various land-use categories. Numerical simulation of urban meteorology was performed. As the result, the detailed structures of wind and temperature fields in the urban area would be able to be expressed.

The problem left in this study in the future is to add the artificial waste heat, however, this can be easily solved by linking with the result of "thermal environment load estimating model of the architecture" by Bulding Research Institute.

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