CFD Simulation of Summertime Air Temperature Distribution of the Ten Kilo-meter Square Area of Center of Tokyo

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We have performed large-scale numerical simulations using the Earth simulator for the estimation of urban heat island phenomena considering detail locations of buildings and roads by means of CFD (Computational Fluid Dynamics). In this fiscal year, a ten kilo-meter square area of center of Tokyo was analyzed by using a horizontal grid spacing of 5 m to examine thermal construction in summer time. For the CFD simulation, building height, land use, anthropogenic heat etc. are databased by a 5 m mesh resolution. In addition, sun shade at each mesh and each time was analyzed considering complex 3D urban forms for the calculation of heat balance of urban surfaces. Numerical results showed air temperature is locally high along main streets at 8 o'clock. This situation may be caused by anthropogenic heat from automobiles of rush hour. In 14 o'clock, simulated air temperatures distributed uniformly except for cooling spots around sea shore and large parks.

Keywords: Heat island, Tokyo, CFD, Air temperature

1. Introduction

Recently, countermeasures against the urban heat island (UHI) effect, such as reduction of anthropogenic heat release and enhancement of urban ventilation, have become increasingly important in Tokyo. The evaluation of urban ventilation requires the construction of a high-resolution computational fluid dynamics (CFD) system, which takes account of complex urban morphology. The morphological complexity arises from multiscale geometry consisting of buildings, forests, and rivers superimposed on varying topography. Considering these backgrounds, we have developed a high-resolution CFD system and have performed simulations of wind and air temperature fields of Tokyo using a horizontal grid spacing of 5 m[1] [2]. It is necessary to accurately handle the heat transfer phenomenon of buildings or the ground prior to fluid analysis of an urban area.

In 2011, we improved the calculation method that grasps the surface temperature of a city in a three-dimensional nonsteady manner. We conducted a radiate calculation considering shadow and angle between sunbeam and building walls, and finally determined the surface temperatures of buildings and the ground. The simulation day is 10 August, 2007.

2. Location of analysis

A ten kilo-meters quare area of Tokyo is considered for analysis (Fig. 1). The computational domain extends vertically to a height of 500 m and is divided into grid cells that vary in height from 1 to 10 m with the smallest grid cells closest to the ground. The domain is horizontally divided into equally-sized 5-m grid cells. In order to obtain the boundary values of the CFD computational domain, the LOCALS-UCSS model [3] is run prior to the CFD analysis. The model is run for two domains with one-way nesting. The length of the sides of the domain and the grid spacing of the coarse grid model are 300 km and 5 km, respectively, and those of the fine grid model are 100 km and 1 km, respectively. The coarse grid model is run using initial and boundary values based on data from the Regional Spectral Model-Grid Point Value (RSM-GPV) provided by the Japan Meteorological Agency. The period of analysis is from 2100 LST on 9 August, 2007 to 2400 LST on 10 August, 2007. Figure 2 shows an example of simulation results by LOCALS-UCSS. Around 23 special wards of Tokyo, urban heat island are clearly formed.

3. Input data

To calculate the effective volume fraction and the open area ratio within each grid cell, the polygon data of each building is extracted from the GIS data of Tokyo. The height of each building is obtained using the aerial laser measurement data of the Geographical Survey Institute of Japan. Figure 3 shows the

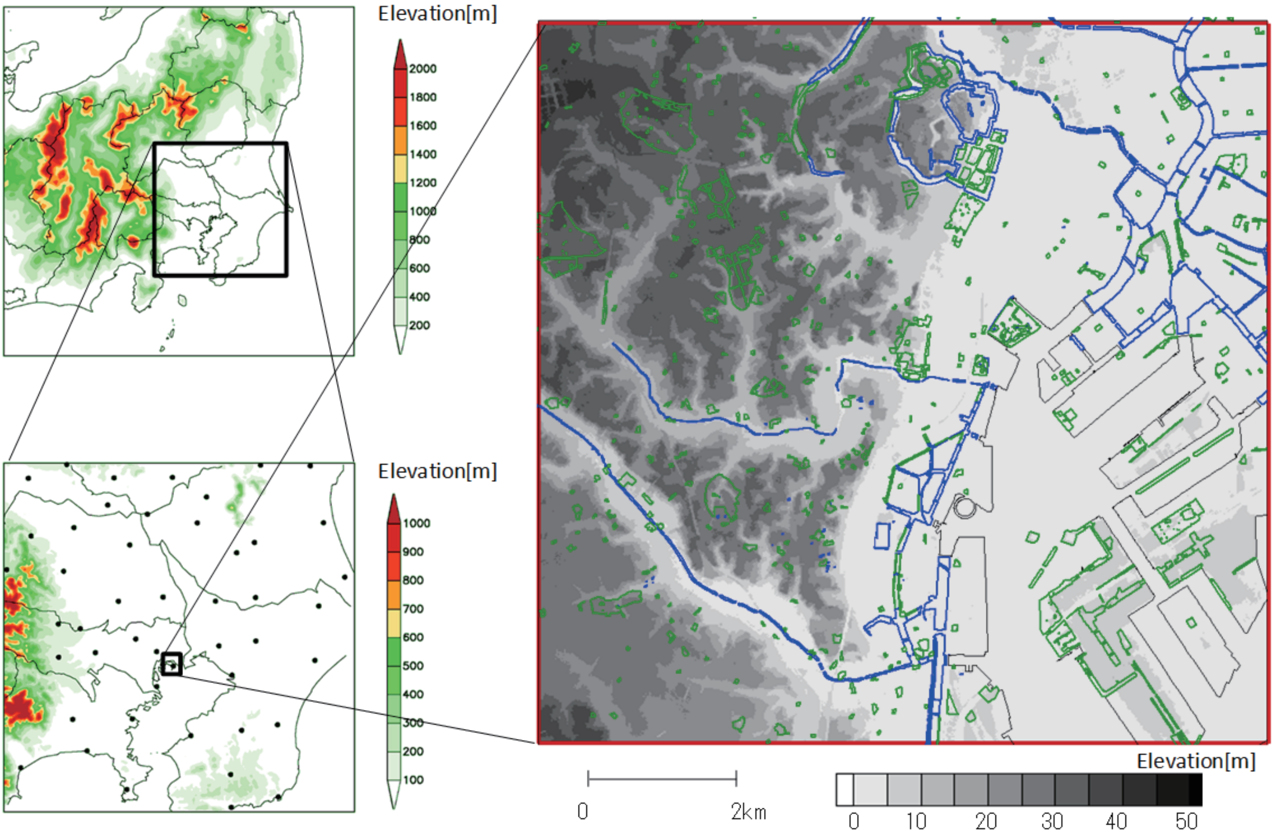

Fig. 1 Simulation domain.

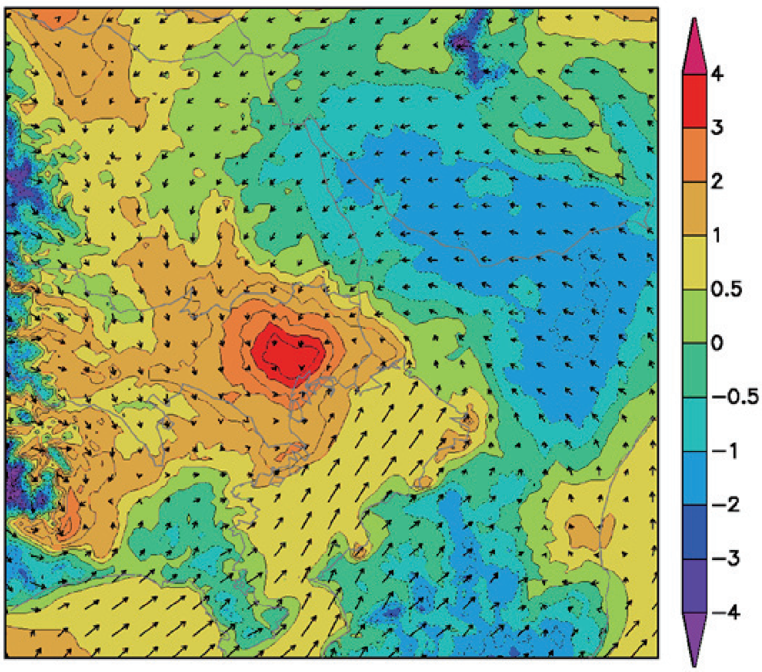

Fig. 2 Simulated air temperature distribution at 2:00 on 10 August, 2007.

distribution of building height in the computational area.

Anthropogenic heat can be classified into sensible heat and latent heat, and they are treated separately in the CFD model. Sensible heat includes heat released from buildings, traffic, and factories. The amount of anthropogenic heat released in individual grid cells for the time of simulation is estimated using the reported values in MLIT/MOE (2004)[4]. The estimation takes into consideration the location of anthropogenic heat releaseas well as the total area of rooftops, building walls, and road surfaces in each grid cell. Figure 4 shows the distribution of anthropogenic heat in the computational area.

4. Results

Air temperature and wind distribution at 8 o'clock are shown Fig. 5. Main wind direction is north, and air stream is formed from north region to Tokyo bay along Sumida-river. In addition, it is noticed that high air temperature areas are formed along main traffic roads. This is caused by anthropogenic heat from traffics. In the morning, sun radiation is not so large, and the heat amount by traffic is very large in rush hour.

As time goes by, high air temperature area extends over the land area especially north region. Figure 6 shows air temperatures and wind at 14 o'clock. Cool spots are seen around river, large parks and sea shores. This implies that anthropogenic heat of building and emitted heat from urban materials are important in the formation of air temperatures in the daytime.

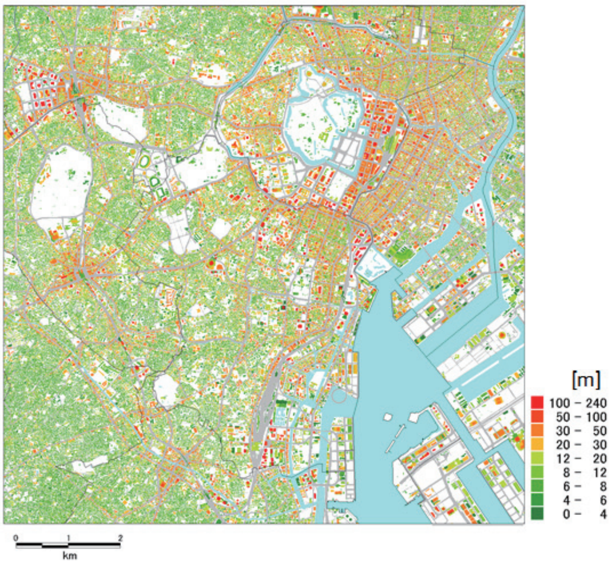

Fig. 3 building height.

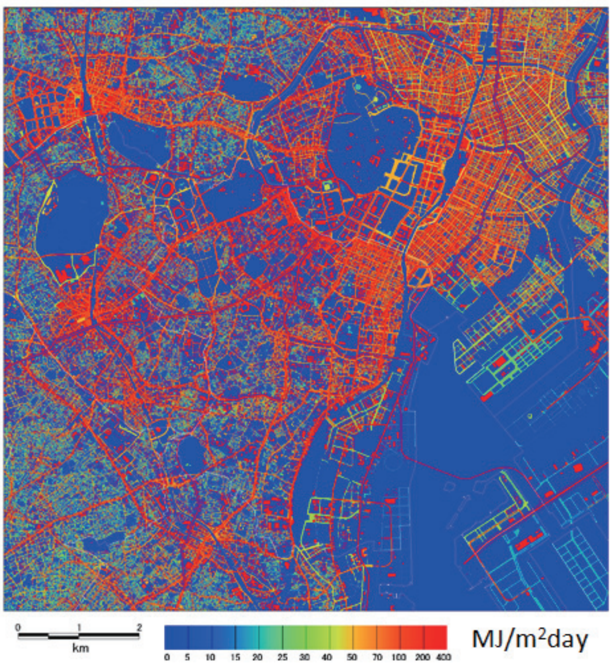

Fig. 4 Anthropogenic heat.

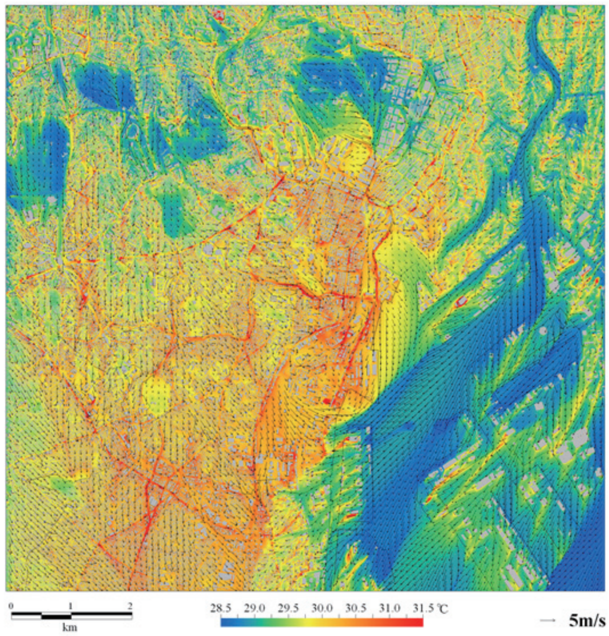

Fig. 5 Simulated air temperature and wind distribution (8:00, August 10, 2007).

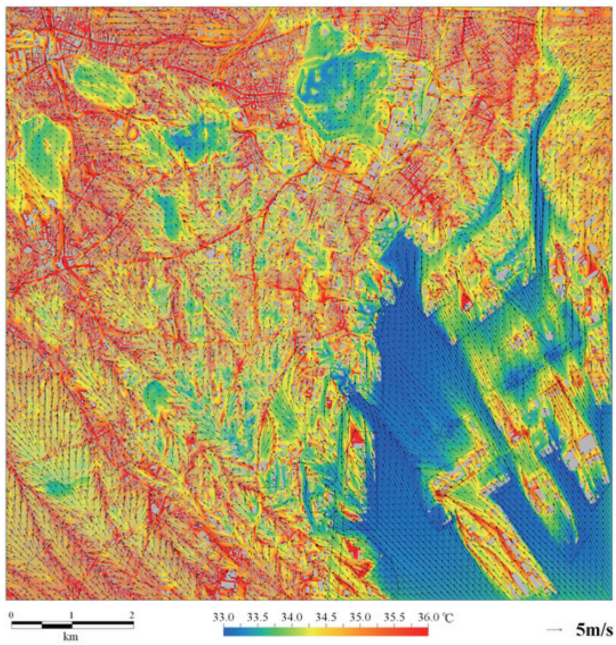

Fig. 6 Simulated air temperature and wind distribution (14:00, August 10, 2007).

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CFD による東京 10km 四方の夏季気温分布シミュレーション

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筆者らは CFD（数値流体力学）により街路や建築物を解像可能な詳細なメッシュ分割でヒートアイランド現象を検討してきた。本報では、都心エリア 10km 四方（5m メッシュ）を対象にして夏季の時空間変動のシミュレーションを実施した結果を示す。CFD 解析に当たって、都心 10km 四方の建物高さ、土地利用、人工排熱等を 5m メッシュで整備した。各時刻において都市空間の 3 次元的な日陰形成についてデータベース化し、熱収支計算に反映した。日射ビームの入射角度と建物壁の向きに対応して日射量は変化し、壁や地盤の蓄熱を考慮した熱伝導解析を実施した。その結果、朝 8 時では幹線道路沿いが高温化していることが分かった。日射の影響がそれほど大きくなく、ラッシュアワーであるため交通由来の人工排熱量が顕著である。時間が進むと、このような局所的な高温化傾向は薄れていき、日中 14 時においては都市域は全体的に（面的に）高温化する傾向が見られた。

キーワード: ヒートアイランド, 東京, CFD, 気温