# Numerical Simulation of Urban Heat Island in a Ten-kilometer Square Area of Central Tokyo

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To examine the detailed features of urban heat island phenomena, we have developed a thermal environmental analysis system, which can simulate the atmospheric environment considering urban effects such as artificial pavement, building height and anthropogenic heat. Our target area for the research is central Tokyo where the construction of high rise buildings is proceeding rapidly. We have utilized a five- meter mesh to resolve each building in urban areas. In this year, using the modified code which incorporates the Coriolis force and potential temperature, the thermal environment in a ten-kilometer square area of central Tokyo was simulated with 5m grid spacing. The distribution of air temperature and wind velocity near the ground was successfully simulated, and the computational results matched well with that of observation.

**Keywords**: urban heat island, CFD, airflow, temperature, urban area, observation

## 1. Introduction

In order to examine precisely the heat island phenomenon, a new thermal environmental analysis system which considers various urban effects such as the urban surface, building height and anthropogenic heat was developed and large-scale examinations were performed using the Earth Simulator. The Tokyo seaside area, where recently many buildings have been constructed, was selected as the target of this research. In this project, we have developed a numerical simulation system which can evaluate the urban heat island of a 5-kilometer square area, resolving individual buildings [1]. This paper reports the recent numerical results in a ten-kilometer square area of central Tokyo.

## 2. Numerical simulation model and data arrangement

The system developed on the Earth Simulator calculates outdoor thermal environmental factors such as air temperature, wind speed, and specific humidity to evaluate urban planning. In the system, mesoscale meteorological data is used for the boundary conditions in order to consider the regional climate characteristics. Detailed wind and temperature distributions in the computational area are calculated by the k-$\varepsilon$ turbulent model which is widely used in the engineering field. Accurate input data of the topography, land surface and building height were used. The CFD model is modified to consider effects such as Coriolis force, potential temperature and the buoyancy of vapor.

Various details of the district such as sea, river, high rise building and green area are prepared for input to execute the numerical simulation. Input mesh data of detailed topography, land surface, and building height is arranged in the computational area. The three-dimensional distribution of anthropogenic heat is also arranged considering the location of thermal sources such as automobiles, factories and buildings in the urban area. A distinction is made between sensible and latent heat.

## 3. Numerical simulation of the ten-kilometer square area

Fig. 1 is the computational domain for CFD analysis and shows altitude. The domain has a size of 10km*10km*500m, and covers central Tokyo and part of Tokyo bay. The population is about 4 million in the daytime and 0.8 million at night. The number of buildings is 165 thousand, with a total floor area of 14 thousand hectare. The domain was divided into 5m grids horizontally and 1m to 10m vertically. The total number of grid points is 0.5 billion including grids in the buffer zone. The date chosen for the simulation is July 31, 2005 since observations in the urban area were conducted on that day. The comparison between simulation and observation is described in the latter half of this report.

Numerical results for air velocity and temperature are as follows. Fig. 2 shows the vertical cross sections of wind speed and temperature distribution on two north-south lines (see the location of the two lines, "L1" and "L2" in Fig. 1).

Panels a and c show wind speeds. Wind is weakened in the leeward area of high rise buildings such as Sio-Site. On the other hand, open spaces like Akasaka Gosho are well-ventilated. Air temperature distribution is displayed in panels b and d. The temperature of panel d is lower than that of panel b because "L2" is located near the sea shore; the air is cooled by the sea breeze that reduces the development of a thermal boundary layer. In addition, the wind and temperature near the high rise buildings form similar distributions in that they curl up at same locations. In such areas, air might be mixed vertically by upstream heating due to building exhaust heat and by the circulation effects of building geometries.

Fig. 3 illustrates wind and temperature distributions of area "A" at the ten-meter height (location of area "A" is shown in Fig. 1). The wind blows along the meandering river. In area "C" (left side of Fig. 3), part of the wind flow along the river separates and cool air from the river penetrates into a residential area. In area "D" (right side of Fig. 3)

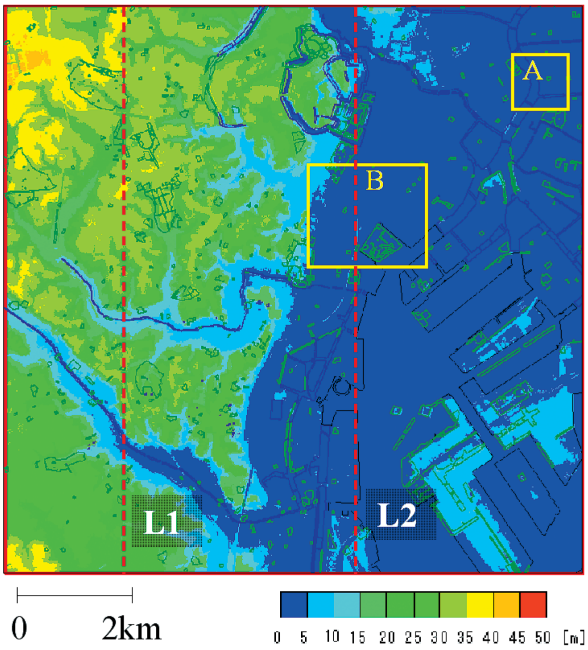



Fig. 1 Altitude in the 10km square area for computational domain.

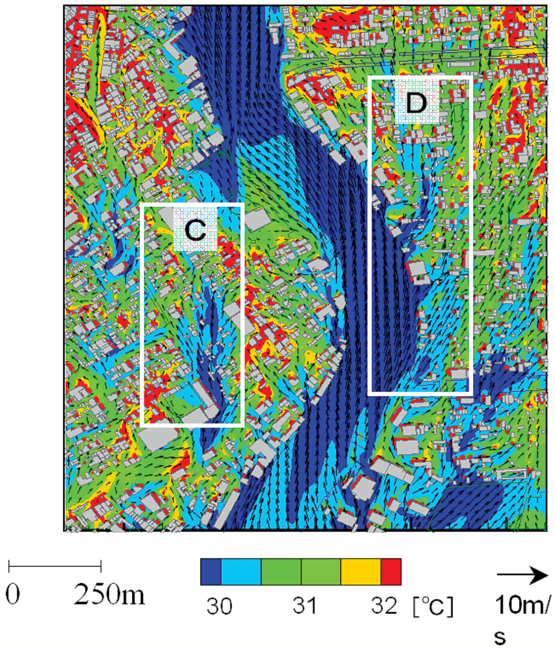



Fig. 3 Calculated wind and temperature distributions in area "A" (see Fig. 1) at 10m above the ground at noon on 31 July, 2005.

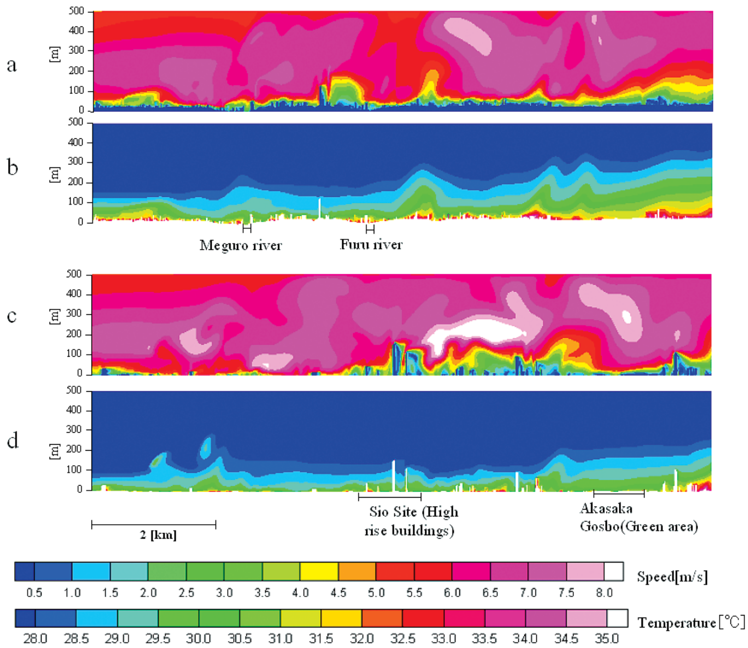



Fig. 2 Vertical cross section of wind and temperature for "L1" and "L2". Panel a is wind of "L1", panel b air temperature of "L1", panel c wind of "L2" and panel d air temperature of "L2". "L1" is a residential area including rivers, "L2"crosses high-rise building and green areas. The locations of "L1" and "L2" are shown in Fig. 1.

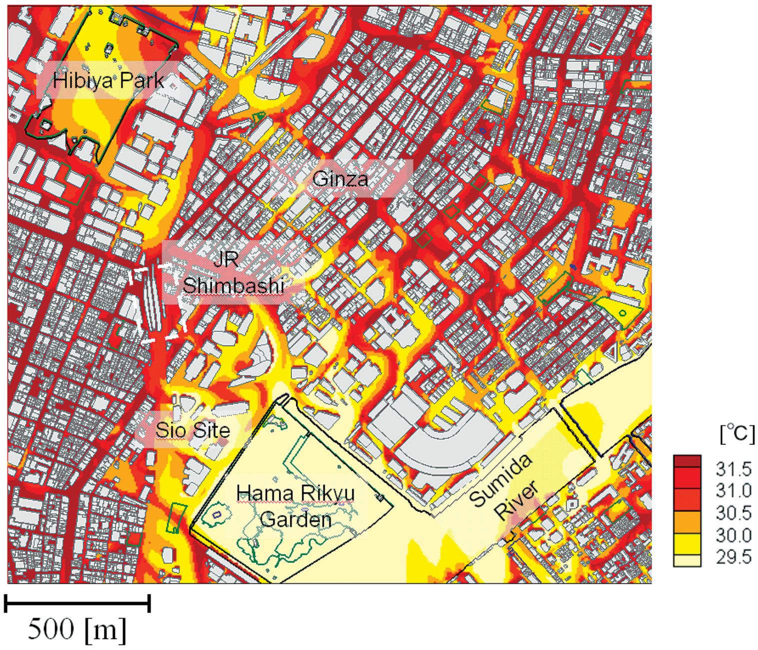



Fig. 4 Calculated temperature distribution at 5m above the ground in area 'B' (see Fig. 1) at noon on 31 July, 2005.

wind going upriver separates and penetrates a residential area on the opposite side by the inertia, when the wind path bends toward the west. Air temperature around the river is cooler than that around dense residential areas by 1-2˚C. The cooled area around the river extends inshore from one-hundred to two-hundred meters.

Fig. 4 illustrates the air temperature distribution of area "B" (see Fig. 1). Air temperature along each street is displayed in the figure, making it possible to study the urban heat island phenomena from the view point of urban district scales. Air temperatures around JR Shimbashi are extremely high. On the other hand, temperatures around Hama Rikyu Garden, the Sumida River, and Hibiya Park are low. In addition, the air temperature around the Sio-Site is low. This is because of the low value of building ratio in this area, which allows sea breezes to enter the gaps between buildings.

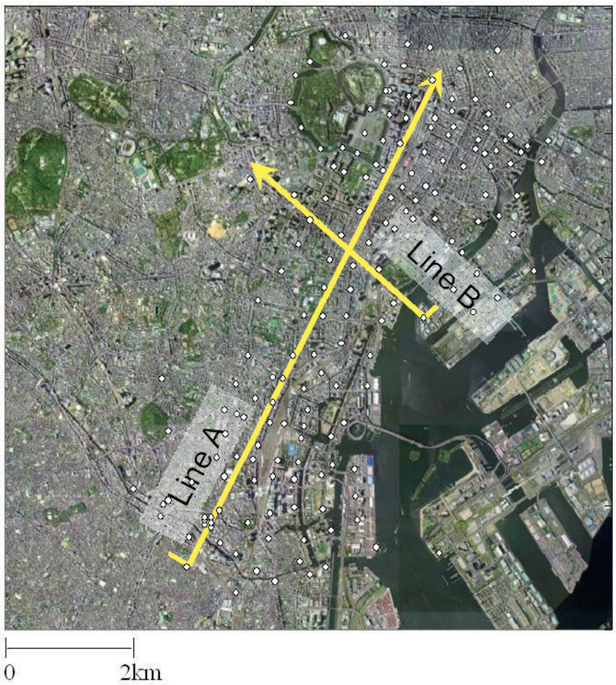
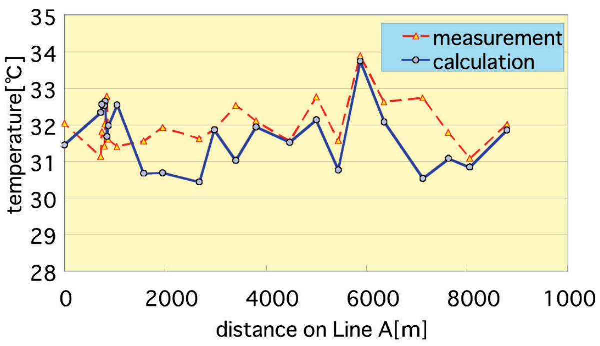



Fig. 5 Aerial photo of computational area with the plots of observation points (Aerial photo; Google map)

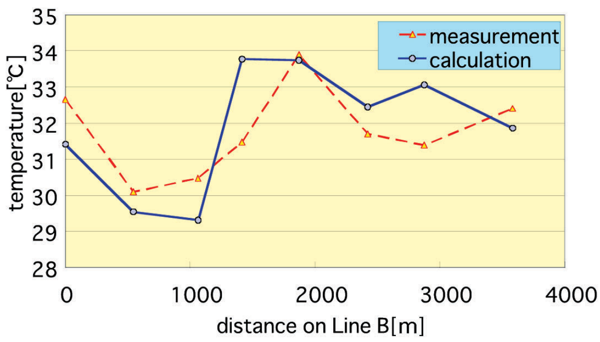
## 4. Comparison between observation and simulation

The thermal environment in central Tokyo was surveyed in the summer of 2005 using multiple data loggers attached to light poles to measure air temperature simultaneously over several days [2]. The measurement heights were from three to four meters above the soil surface. The number of observation points in the computational area is 173. Observation points are plotted in the aerial photo shown in Fig. 5. Numerical results of 3.5m above the soil surface are compared with observation data. The RMS error is 1.1˚ C. The location of Line "A", which is parallel to the sea seashore, and Line "B", which crosses it at right angles is displayed in the Fig. 5.

Fig. 6 shows the comparison between observation and numerical results. In the case of Line "A", it is difficult to find an obvious pattern of temperature fluctuation. Measured and simulated air temperature are both high at a distance of 6,000m. The pattern of temperature fluctuation is clear in Line "B". The temperature over the sea surface is low, temperatures inland are high. The temperature is especially high around Shimbashi (at a distance of 1,500–2,000m). The observations and simulation correspond well.




(a) Line "A"




(b) Line "B"

Fig. 6 Observation and numerical simulation results at noon on 31 July, 2005 (Locations of Lines "A" and "B" are shown in Fig. 5).

## 5. Summary

In this study we analyzed the distribution of temperature and airflow in a 10-kilometer square area in Tokyo by a numerical simulation system, resolving each building and topology explicitly. Numerical results show wind blowing along the meandering river and sometimes flowing into residential areas. Air temperature along each street is obtained by numerical simulation, and can be used to study the urban heat island phenomena from the view point of building scales. The computational results matched well with that of observation.

## Acknowledgement

In this report, we used the observation data of air temperatures in Tokyo central area in the summer of 2005, surveyed by National Institute for Land and Infrastructure Management and Waseda University.

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# 東京都心部の10km四方を対象にしたヒートアイランドの数値シミュレーション

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都市のヒートアイランド現象を詳細に検討するため、土地被覆、建物高さ、人工排熱等の都市的効果を分析可能な数値解析システムを地球シミュレータ上に構築した。本研究プロジェクトでは、再開発事業が急ピッチで進められている東京臨海部を研究の対象にしており、これまで5km四方の解析領域を水平5m解像度で数値シミュレーションを実施してきた。今年度は解析領域を10km四方に拡張して数値シミュレーションを実施すると共に、コリオリ、温位の効果を新たに方程式に組み込んで数値モデルの精度向上を図っている。計算結果より、河川から住宅地に流れ込む風の様子や街路空間の詳細な気温分布の状況など従来の解析では見られない、広域かつ詳細なヒートアイランドの状況を明らかに示すことが出来た。数値解析結果と観測結果を比較したところ、両者の地上近傍における気温分布は良く一致した。

キーワード：ヒートアイランド, CFD, 気流, 気温, 都市域, 観測