INVESTIGATION OF EFFECT OF BUILDING MORPHOLOGY ON SEA BREEZE ADVANCEMENT BASED ON MESO-SCALE SIMULATION

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1. INTRODUCTION

It has been generally recognized that the urban affects the various-scale weather condition, for example, street scale which is associated with the heatstroke, meso scale which is related with the localized heavy rainfall, synoptic scale which is associated with the global warming and so on.

In the 2000s, in order to confirm urban effects on weather and to improve the accuracy of urban weather numerical simulation, an urban canopy model had been developed that models complicated radiation processes between buildings and the atmosphere, and momentum and scalar transfer processes between cities and the atmosphere (Kusaka et al., 2002, Kanda et al., 2005).

Table 1 Calculation setting

Calculation span	From 1st August 9:00 AM
Grid number	202×3×70
Model top	20 km
Spatial resolution	1 km
Microphysics	Off
Cumulus parameterization	Off
Longwave Radiation	RRTM Scheme
Shortwave Radiation	MM5 shortwave (Dudhia)
Land Surface	Noah Land Surface Model
Urban physics	Single layer scheme
PBL Scheme	MUNN 3rd level TKE Scheme

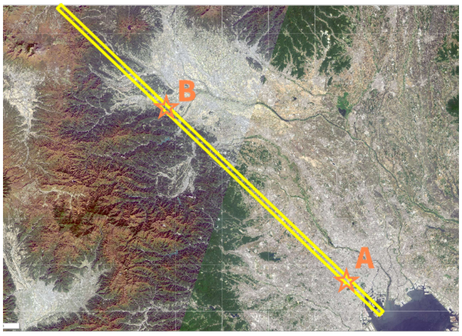

Figure 1 Calculation area

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Tokyo is one of top mega cities in the world and many kinds of unique meteorological phenomenon happens there. In order to forecast the urban-induced complex weather, understanding the effect of building morphology on the atmosphere is of great importance.

Recently, GIS data with high-spatial resolution made it possible to obtain precise urban morphology parameters such as roughness length Z_0, zero-plane displacement height Z_d, and sky view factor SVF and the parameters have already available (Makabe et al. (2014)). However, many numerical weather simulations still use the spatial-averaged uniform urban-morphological parameters even in highly urbanized area (Doan et al. (2016)) or incorporate only several types of urban forms in a simulation (Salamanca et al., 2011).

Varquez et al. (2015) pioneered urban weather simulation with distributed urban morphological parameters and reported the accuracy of calculation was improved if considered the actual distribution of the parameters.

Nevertheless, it should be emphasized that our understanding on those parameters are still limited. As for sea breeze advancement to urban areas, no one can answer correctly that whether Z0 slow down sea breeze or not. The higher Z0, the larger aero-dynamic drag will be produced, but on the other hand, enhancement of heat transfer could yield the large pressure gradient between land and sea, which may accelerate sea breeze advancement inland.

The purpose of this study is to evaluate the impact of urban morphological parameters on sea breeze behavior. Since numerical weather simulations have too strong non-linearly to evaluate those parameters' impact, we set up the calculations as follows: limiting to dry simulation, or cancel any phase change of H2O: conducting 2D simulation to erase circumvention and convergence of wind flow. Thanks to these setting, it is easy to evaluate and discuss about the effect of the morphological parameters.

2. CALCULATION SETTING

2.1 *Calculation Cases*

We performed 2D numerical simulations on sea breeze advancement over the Kanto plain with the Weather Research and Forecasting model (WRF). The simulation settings are described at **Table 1**. Simulated area was along the line from Tokyo harbor toward Shinjuku ward (Point A), which is one of the biggest commercial districts in Japan, extending to Saitama region (Point B, **Figure 1**), classified as a rural district. **Figure 2** shows the spatially averaged and distributed morphological parameters along the line in **Figure 1**. Initial and lateral boundary condition in the model was the ensemble average of radiosonde data at Tateno measured by Japan meteorological Agency (JMA) on sunny days in August during the 2000s, specifically, 22nd August, 2003, 5th August, 2005, 4th August, 2006, 6th August, 2007, 7th August, 2008, 18th August, 2010, 10th August, 2011, and 5th August, 2013.

Among various weather factors influenced by urban parameters, we focused on sea breeze advancement and compared sea breeze arrival time at Point A and Point B for 6 cases of simulations. The criterion for the arrival time of sea breeze is the increase of the amount of the water vapor ratio and the change of the wind direction toward land. The six cases considered are the following (**Table 2**).

- CNT: the spatially-averaged Z_0, Z_d, and SVF were assigned.
- CASE1: the actual distribution of Z_0 with the spatially-averaged Z_d and SVF were assigned.
- CASE2: the parameters' assignment was the same as CASE1 but the scalar transfer parametrization from the urban canopy was different from the other; the other adopted so-called top-down approach proposed by Kanda et al. (2005) but CASE2 followed the default method in WRF urban canopy model, or bottom-up approach (Kusaka et al., 2002).
- CASE3: the parameters' assignment was the same as CASE3 but the treatment of Z_d was different from the CASE3; Z_d was added to topography instead of using in "logarithmic method" (eq. 2-1).
- CASE4: the actual distribution of Z_d with the conventional approach of "logarithmic method" (eq. 2-1) with the spatially-averaged Z_0 and SVF were considered.

$$U = \frac{u^*}{\kappa} ln \frac{z - z_d}{z_0} \qquad (2\text{-}1)$$

where U is a horizontal wind speed, u^* is a friction velocity, and κ is the Karman constant.

- CASE5: the actual distribution of SVF, with the spatially-averaged Z_0 and Z_d were assigned.

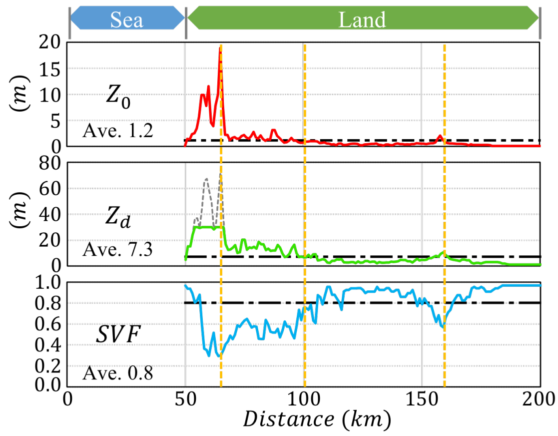

Figure 2 Domain setting and urban morphological parameters

Table 2 Calculation case
(Ave.: spatial averaged urban parameters,
Dist.: distributed urban parameters,
Topography: Z_d was added Topography,
Log: Z_d was used in logarithmic law.)

CASE	Z_0	Z_d	SVF	Z_0 scheme	Z_d scheme
CNT	Ave.	Ave.	Ave.	Top-down	Topography
CASE1	Dist.	Ave.	Ave.	Top-down	Topography
CASE2	Dist.	Ave.	Ave.	Bottom-up	Topography
CASE3	Ave.	Dist.	Ave.	Top-down	Topography
CASE4	Ave.	Dist.	Ave.	Top-down	Log
CASE5	Ave.	Ave.	Dist.	Top-down	Topography

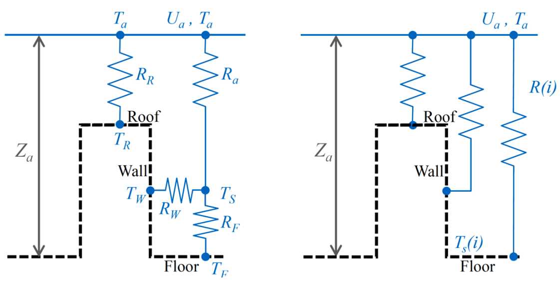

Figure 3 Bottom-up scheme & Top-down scheme

2.2 *Bulk Transfer Parametrization*

The all of cases except CASE2 incorporate the top-down (TD) scheme in scalar transfer parametrization proposed by Kanda (2005). **Figure 3** shows the resistance network in BU and TD where T is a temperature, U is a wind speed, Z is a roughness length, R is a resistance, and suffix of “R”, “W”, “F”, and “a” denote roof, wall, floor, and air, respectively.

TD approach first calculates bulk transfer resistance over entire urban canopy based on the conventional Monin-Obkhov theory with Z_0 and atmospheric stability. Then, the bulk value is partitioned to the local resistances on wall, roof, and ground considering weighted factors. On the other hand, in BU, the local resistances are first determined based on an experimental or a semi-theoretical manner. Z0 is used canyon resistance calculation. Because of a buffer effect in urban canyons, BU tends to emit smaller sensible heat flux than TD does.

3. RESULT AND DISCUSSION

3.1 *Result*

Sea breeze arrival time at Shinjuku (Point A) was the earliest in CNT, followed by CASE3 with CASE4, CASE2, and CASE1 with CASE5; CASE3 and CASE4, and CASE1 and CASE5 are simultaneously arrived there. But there were differences in arrival of sea breeze at Point B. CASE5 overtook the other cases and arrived there first, followed by CASE1, CASE3 with CASE4, and CASE2.

3.2 *Near Point A*

Figure 4 shows the diurnal change of the sensible heat flux at Point A. In comparison of CNT’s sensible heat flux result, CASE5 tended to have higher sensible heat flux and air temperature (**Figure 5**), thereby resulting in the higher pressure gradient between land and sea. Such high gradient contributed to accelerate sea breeze toward inland and it was expected that the sea breeze in CASE5 arrived at Point A faster than CNT, but in fact, CNT’s one arrived faster. At this time, the turbulent energy of CASE1 and CASE5 increased conspicuously near Point A. The mechanical drag by Z0 in CASE1 and the thermal effect due to high sensible heat flux in CASE5 increased the turbulent energy for each

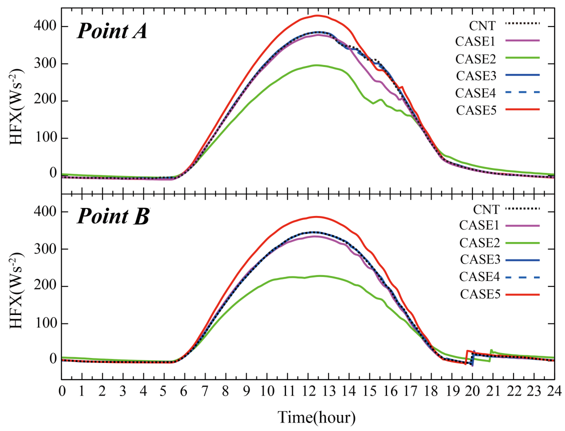

Figure 4 Sensible heat flux

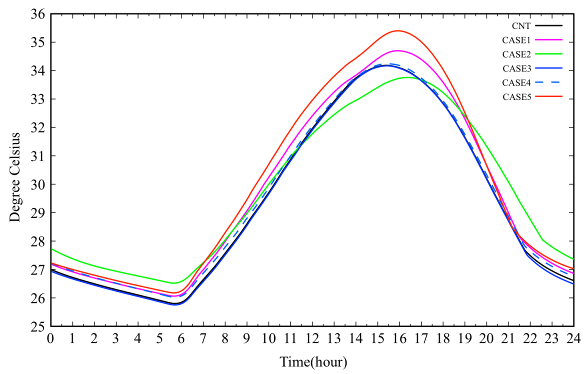

Figure 5 Land average temperature

case. In both cases, the momentum in the horizontal direction was used for vertical mixing, as a result the horizontal velocity in sea breeze was decelerated.

In CASE2 with distributed Z_0, the mechanical drag effect also made the high turbulent energy and the sea breeze delayed.

In CASE3 and CASE4 which have distributed Z_d, the effect of Z_d was NOT seen.

3.3 *Near Point B*

Sea breeze in CASE5 reached at the Point B 25 minutes earlier than CNT. Even at Point B, sensible heat flux of CASE5 was so high that the driving force of sea breeze penetration became strong.

Although sea breeze in CASE1, CASE3 and CASE4 arrived there simultaneously with that in CNT and the magnitudes of their sensible heat flux were almost same as that of CNT, the ~~land~~ first atmospheric temperature averaged over the

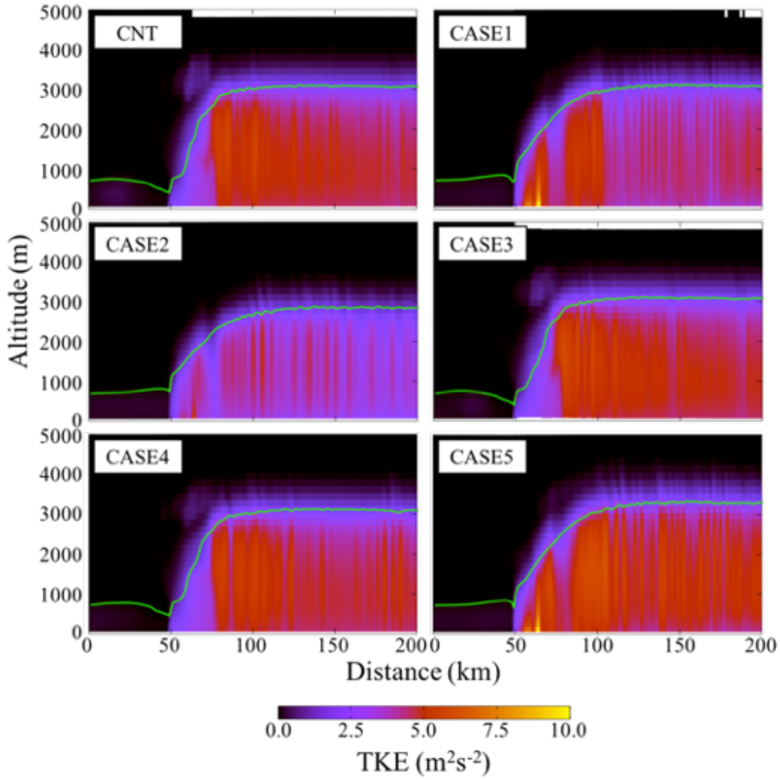

Figure 6 Turbulence Energy
(Green line: Planetary boundary layer height)

land in each case was different each other; CASE1 had the second highest temperature only after CASE5. In CASE1 and CASE5, the entrainment of air temperature from the free atmosphere seemed occurred by the strong atmospheric turbulence (**Figure 6**), which could increase the air temperature and enhance the pressure gradient between land and sea. At the rear side of Point A, such high gradient contributed to advancing the sea breeze over the land in corporation with he distributed Z_0 lower than spatially averaged one.

On the other hand, the sea breeze in CASE2 arrived at Point B later than any other cases. CASE2's sensible heat flux was the lowest and bottom-up scheme tended to store the heat within the urban canyon.

Sea breeze arrival time in CASE3 and CASE4 was the same as that in CNT and the effect of Z_d was not apparent.

3.3 *Relation Between Urban Morphology & Potential Temperature*

It seemed that the phase of diurnal pattern of the potential temperature in CASE2 was delayed in comparison with the other cases and the peak was smaller than any other. Furthermore, nighttime air temperature in CASE2 was the highest of all cases. Accordingly, BU could provide with clearer urban heat island phenomenon than TD.

Although the sensible heat flux of CASE1 was the same as that of CNT, the potential temperature of CASE1 was higher than that of CNT. It appears that the temperature within the atmospheric boundary layer increased because of the entrainment from the free atmosphere. Chiefly, high Z_0 is thought to enhance the heat exchange coefficient and heat the atmosphere but at the same time, the entrainment from the free atmosphere also plays an important role for reducing sensible heat flux from the surface by changing temperature gradient between urban surface and the above atmosphere.

In CASE5, in addition to the same entrainment mechanism as CASE1, the atmospheric boundary layer was heated more by the sensible heat from the ground surface.

Consequently, it is important to consider that method of urban canopy.

4. SUMMARY

- The effect on the sea breeze calculation depends greatly on a spatial arrangement of urban morphological parameters despite of the same average value.
- Z_0 and SVF had great influence on air temperature and wind field as well as sea breeze behavior.
- The difference in scalar transfer parameterization, BD and TD, yielded different sea breeze pattern by changing sensible heat emission from the surface.
- The effect of Z_d was not seen.

5. ACKNOWLEDGEMENT

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