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NUMERICAL SIMULATION OF SEA BREEZE ON HIGH RISE BUILDINGS TO REPRODUCE THE LOCALIZED HEAVY RAIN IN TOKYO

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Abstract

To evaluate the effect of high rise buildings in Tokyo Metropolis on the wind field which may trigger localized heavy rainfall in summer, the effect of the urban buildings was parameterized as the displacement height and implemented to WRF as a new terrain height, i.e, the sum of the displacement height and terrain height. The new simulation method resolved a convergence zone and strong upward flow around downstream region of high rise building in Sinjuku, corresponding to the actual localized heavy rain on August 10th in 2004. Without the consideration of the urban geometry, neither the convergence zone nor the strong updraft were not calculated. These results imply high rise building in Sinjuku is one of the factors to break out the localized heavy rain in Tokyo.

Key words: WRF, urban geometry, localized heavy rain, Tokyo

1. INTRODUCTION

Localized heavy rainfall in summer attracts attention in recent years in Tokyo. Rainfall sometimes reaches more than 20-50mm per hour and it can cause urban floods. These localized rainfalls are still difficult to be predicted. The urbanization is suspected to generate that rainfall. To investigate the urban effect on rainfall, it is needed to implement various urban parameters to weather forecast model. One of the urban parameters is urban geometry. Detailed urban geometry like building height and distribution of buildings should be included into weather forecast models. The explicit consideration of each building like CFD analysis, however, requires huge computational loads. Thus unrealistic urban geometry is still implemented in weather forecast models.

As one of the simplest approach, we considered urban geometry as the displacement height modification. Displacement height was calculated from detailed building information of Tokyo and thus represents the “bulk building landscape”. The detailed displacement height was added to the original terrain map.

At first, in this study, we statistically investigated the relationship between bulk urban geometry and amount of observed surface rainfall. Next, we simulated a rainfall day with (RUN1) and without (RUN2) considering detailed displacement height map. By comparing these results, the influence of urban geometry on the wind field which may trigger heavy rainfall was inspected.

2. URBAN GEOMETRY OF TOKYO

We calculated displacement height of Tokyo by using following equation (MacDonald 1998):

$$d = H(1 + 4.43^{-\lambda_p}(\lambda_p - 1)) \qquad (1)$$

Where H is average of buildings height and λ_p is building-to-land ratio. To calculate these parameters, we used information of floor space, floor number and use of building. Figure 1 shows estimated displacement height of Tokyo central part.

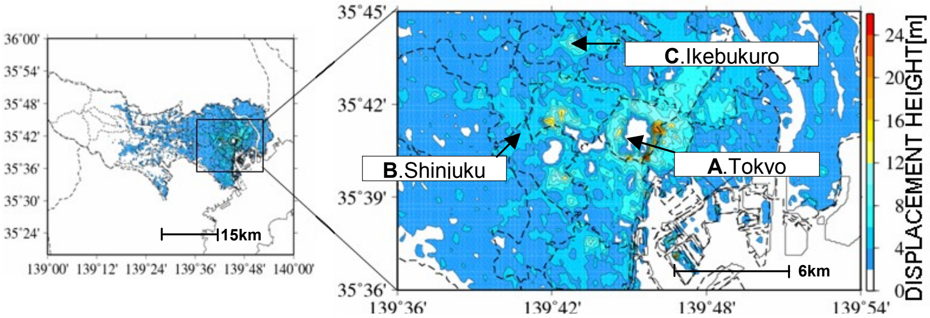

Figure 1: Displacement height of Tokyo central part

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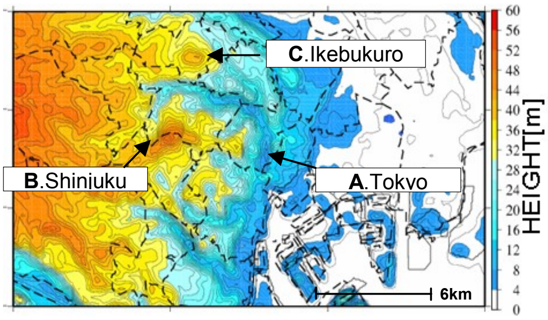

Figure 2: sum of displacement height and terrain height

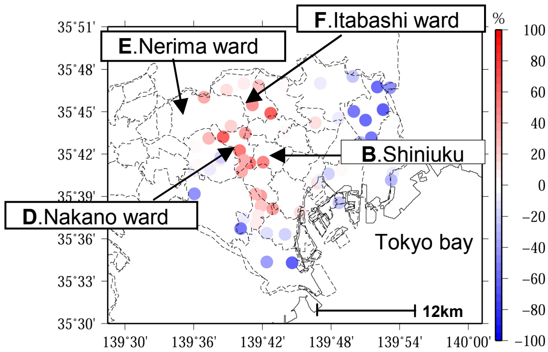

Figure 3: Anomaly of rainfall

Almost whole area is elevated more than 2m. Especially, large city areas (A, B and C in Figure 1) are elevated 12 - 26m. These towns have many closely packed high-rise buildings.

Sum of the displacement height and terrain height is shown in Fig.2. West part is elevated more than 30m because terrain height of West part is higher than east part. Around Shinjuku (B in Figure 2) area is more than 40m. Altitude within a 3km circuit of the center of Shinjuku looks like isolated mountain.

3. ANOMALY OF STRONG RAINFALL IN TOKYO

Ensemble-averaged rainfall was examined. This was to see the anomaly of strong rainfall and its relationship with the urban landscape. We extracted the day when localized severe rain occurred by using the rainfall data of the Tokyo Construction Bureau river department currently observed in 23 wards at 68 places. Analyzed period is the six summers (July - September) of 2001-2005. The followings are the extract conditions (Fujibe 2002) :

1) Maximum daily temperature is above 30 degrees C.
2) The day when rain starts from 12:00 to 21:00 and ends before 24:00.
3) 1-hour rainfall is more than 20 mm.
4) The rainfall events under the influence of the synoptic weather, such as a low pressure and a typhoon was discarded.

First, we summed up rainfall of each point. Second, we calculated average rainfall for every point. Finally, we plotted deviation from average to see the spatial anomaly of rainfall. Anomaly of rainfall was shown in Figure 3. Towns (D, E and F in Figure 3) on the north-west side of high rise buildings in Sinjuku (B in Figure 3) had more than 30% higher rainfall than other wards. The general see breeze in this area is coming from Tokyo Bay to north-west crossing the Shinjuku. Therefore, these three towns are located on the downstream of Sinjuku. This result implies a possibility that high-rise buildings can enhance the cumulonimbus cloud in downstream regions.

4. OVERVIEW OF NUMERICAL SETTINGS

We used WRF (Weather Research & Forecasting Model) to evaluate how urban geometry affected the atmosphere. Global Final Analyses data (space resolution is 1 degrees × 1 degrees, time resolution is 6 hours) released by NCEP was used for the initial condition. Land use and terrain height data was taken from digital national information 100 m and 50 m mesh data. Runs with (RUN1) and without (RUN2) considering detailed displacement height map were set up. Both cases used the urban canopy Model (kusaka et .al 2001) and Anthropogenic heat and vapor (Moriwaki 2009). A four-tier nested grid system was used. Fourth domain covers Tokyo central part. Domain information and Physics settings are shown in Table 1 and Table 2.

August 10, 2004 was chosen for analysis. Localized severe rain occurred around Shinjuku high-rise buildings area on this day. Details of this day are given in the following chapter. In order to take run-up time, initial time of numerical computation was made into 3:00 a.m. on August 8, 2004 (JST).

Domain	Grid number	Grid size	Time step
1	62×56×58	30 km	80s
2	171×171×58	6 km	20s
3	201×181×58	1.2km	4s
4	221×241×58	0.3km	1.3s

Table 1: Domain infomation

Microphysics	Thompson graupel scheme
Longwave Radiation	Rapid radiative transfer model
Shortwave Radiation	Dudhia Scheme
Land Surface	Noah Land Surface Scheme
PBL scheme	Mellor-Yamada-Janjic Scheme
Cumulus Parameterization	Kain-Fritsch Scheme

Table 2: Physics settings

5. METEOROLOGICAL FIELD OF AUGUST 10, 2004

The surface weather map is shown in figure 4. There were developing typhoon on the Pacific Ocean and the cold front extended north part of Japan. According to upper-air observation in Tateno (about 40km NE from Tokyo), level of free convection (LFC) at 9:00 was 3000 m (712 hpa). This suggests atmosphere over Tokyo area was a little unstable. If strong updraft occurred, Atmosphere tended to generate cumulonimbus cloud at this time.

Distribution of rainfall intensity and wind field is shown in Figure 5. At 12:00, rainfall was observed in southeast part of Saitama prefecture (H in figure 5). On the other hand, rainfall observed in Tokyo was very weak. In the wind field, sea breeze from Tokyo bay was observed up to the rainfall area. Updraft produced by sea breeze front might generate cumulonimbus and rainfall. Although rainfall became weaker all over the area at 12:30, severe rain was suddenly observed only around border of Toshima and Nakano ward (D and G in figure 5) after that. The peak of rainfall intensity was observed around 12:50. Rainfall in this time was about 20 mm/10min in Nakano ward.

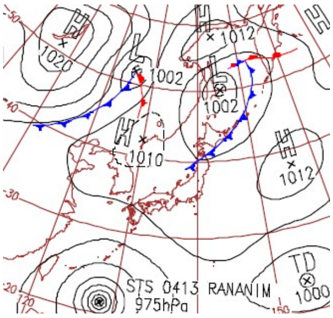

Figure 4: Weather map

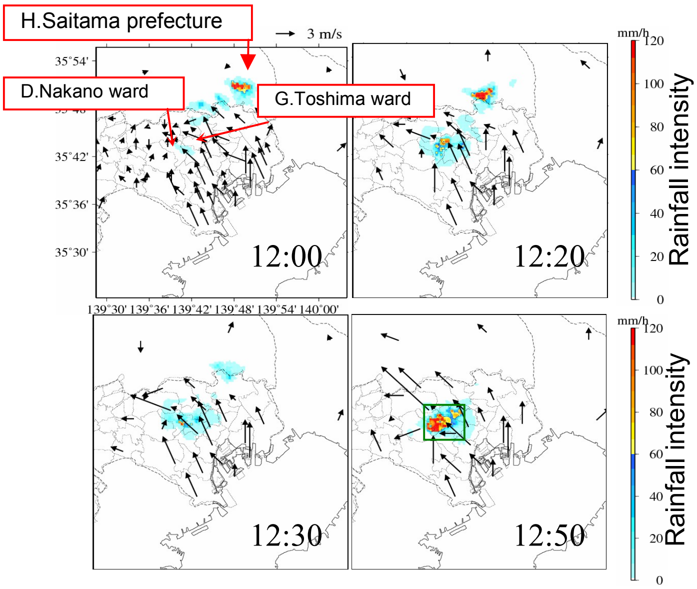

Figure 5: Distribution of rainfall intensity and wind

6. RESULT OF NUMERICAL SIMULATION

A conspicuous difference about the synoptic wind field was not seen between the observed and analysis result before 12:40. Here, we focused on around Shinjuku area to see weather wind was changed by high-rise buildings area. 10m above surface wind at 12:40 and 12:48 around Shinjuku high-rise buildings (I in figure6) is shown in figure 6 (RUN1) and figure 7(RUN2). Domain is green square in figure 5. Both RUN1 and RUN2, Sea breeze just passed through the Shinjuku high-rise buildings at 12:40. But only RUN1, a part of sea breeze changes a wind direction from south to southeast (Figure 6 red circle). It seems to blow along Kanda-river (J in figure6).

At 12:48, Southwest wind meet southeast wind generated at 12:40. There is a convergence zone (blue circle in figure 6) on the north side of Shinjuku high-rise buildings area. Although a convergence zone in RUN2 is also seen sporadically at some places, remarkable convergence region like RUN1 is not seen.

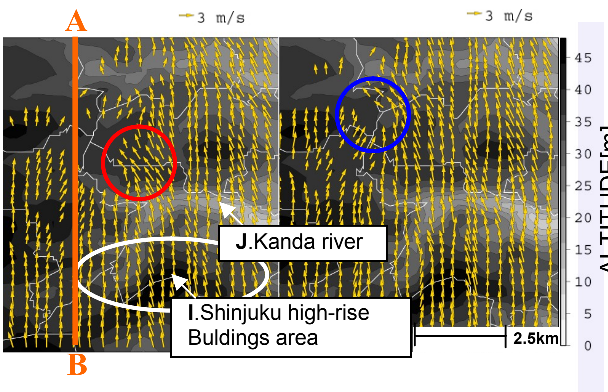

Figure 6: 10m above surface wind (RUN1)
(Left : 12:40 , Right : 12:48)

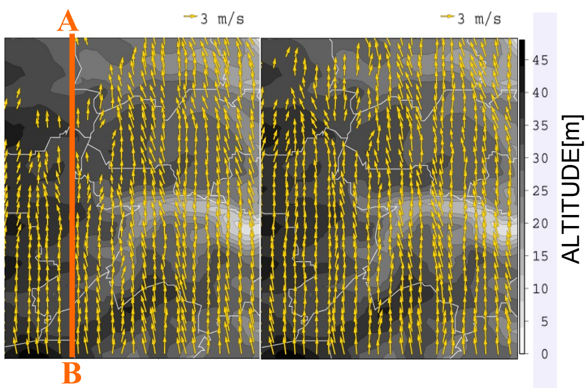

Figure 7: 10m above surface wind (RUN2)
(Left : 12:40 , Right : 12:48)

Figure 8 is the vertical cross section of vertical wind velocity along line A-B (figure 6 and 7 orange line). At 12:40, updraft is seen at central part in RUN1. Same feature is also seen in RUN2 though it is weaker than RUN1. Then, this updraft in RUN1 becomes strong gradually as a sea breeze intrude into inland. Finally, vertical wind velocity reached more than 6m/s between 800hpa and 900hpa at 12:50. On the other side, strong updraft like RUN1 is not resolved in RUN2.

The difference between RUN1 and RUN2 is at most tens of meters in displacement height. However, this little difference has had big influence on not only horizontal wind field but also vertical wind field. Although rainfall was not able to be reproduced in this simulation, Cloud water mixing ratio increased only RUN1 at the area corresponding to the strong updraft generated. These numerical simulation results show urban geometry has a potential to generate localized severe rain.

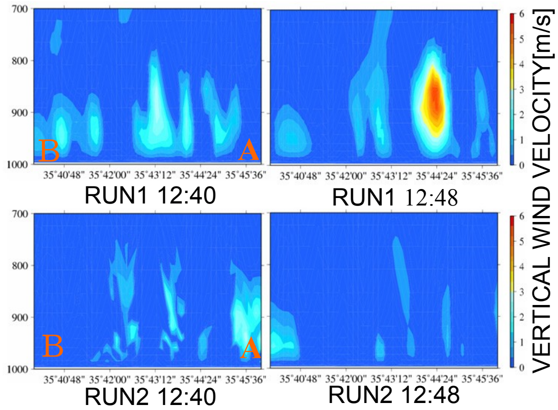

Figure 8: Vertical wind velocity

7. CONCLUTION

The conclusions of this study were summarized as follows:

1. New simple method to reflect urban geometry to weather forecast model was devised. This method is using displacement height calculated by building coverage and building height.
2. Localized severe rainfall day in the past was investigated statistically. On the north-west side of Shinjuku high rise buildings have more than 30% higher rainfall than other wards.
3. Weather simulation was performed in consideration of displacement height. Corresponding to the area where rain actually observed, strong updraft occurred and Cloud water mixing ratio increased.

These results imply high rise building is one of the factors to break out the localized heavy rain in Tokyo.

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