ANALYSIS OF URBAN EFFECT ON LOCAL HEAVY RAINFALL IN TOKYO USING MESOSCALE MODEL
Toru Yamanaka*, Ryozo Ooka**
*KAJIMA Corporation, Tokyo, Japan; ** University of Tokyo, Tokyo, Japan

Abstract
Numerical simulations were performed on local heavy rainfall observed at Tokyo on August 15 2005. In this event, three wind systems were observed near ground level around Tokyo, dry cold northwesterly wind, warm southerly wind, cold northeasterly wind. And hourly rainfall amount of 58mm was recorded at an AMeDAS station. The mesoscale model (MM5) is successful in reproducing ground wind systems and the distribution of rainfall. It is found out that cold northeasterly wind mainly transported moisture into convective area. Furthermore the effect of urban area on local heavy rainfall is estimated.

Key words: local heavy rainfall, moisture transport, mesoscale

1. INTRODUCTION
Intense thunderstorms often occur in summer around Tokyo and produce local heavy rainfall which sometimes cause serious damages to urban infrastructure. In recent years, some studies pointed out that the convergence of low-level airflows and the moisture in the low-level air play significant roles to initiate and develop the thunderstorms. Yoshizaki et al. (1998) showed that the thunderstorms were generated on the convergence area of low-level airflows around Tokyo during a heavy rainfall event. Fujibe et al. (2003) examined the relation between precipitation distribution and surface wind patterns using statistical approach, and got the results supporting the above conclusion. Seko et al. (2007) examined the distribution of precipitable water vapor derived form global positioning system, and showed that the precipitable water vapor near the rainfall region was larger than those of the surrounding region. Kato (2006) noted that middle-level dry air maintains convective activity by maintaining the instability, despite suppressing the development of convective clouds. In this study, moisture transportation during local heavy rainfall is investigated using Mesoscale Model 5th generation (MM5). Numerical model is useful tool to reproduce such severe events. Furthermore the effect of urban area on local heavy rainfall is estimated.

2. LOCAL HEAVY RAINFALL EVENT AROUND TOKYO
On August 15 2005, local heavy rainfall was observed in central part of Tokyo. The maximum hourly rainfall amount of 58mm was recorded on an Automated Meteorological Data Acquisition System (AMeDAS). The rainfall around Tokyo concentrated on the small area within few kilometers. Many houses were flooded during this heavy rainfall event.

3. NUMERICAL MODEL DESIGN
Numerical simulations were performed by MM5. Two-way nested model domains with high resolution horizontal grid spacing is used (outer grid spacing is 3km and inner is 1km). The top level of model domain is 30hPa with 37 vertical levels. The outer domain covers the area of 540km 492km, and the inner domain covers the area of 264km 258km. The initial and lateral boundary values of outer domain are prepared by interpolating NCEP final analysis data (FNL). MM5 has three types of land-use datasets to define the lower boundary condition. These datasets are supplied by PSU/NCAR and USGS. Instead of these datasets, the digital national land information data provided by the ministry of land, infrastructure, transport and tourism (MLIT) of Japan is used in this study. To input the digital national land information data for lower boundary condition, MM5 and TERRAIN program modified by Kawamoto and Ooka (2008) are used. And anthropogenic heat data of 1km horizontal resolution in and around Tokyo (which is provided by Advanced Industrial Science and Technology (AIST), Japan) is given into model. The list of physical schemes used in this numerical simulation is shown in table 1.

Table 1: The model design

<table>
<thead>
<tr>
<th>Cumulus Parameterization</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBL Scheme</td>
<td>MRF</td>
</tr>
<tr>
<td>Explicit Moisture Scheme</td>
<td>Goddard Microphysics</td>
</tr>
<tr>
<td>Radiation Scheme</td>
<td>Cloud-radiation scheme</td>
</tr>
<tr>
<td>Surface Scheme</td>
<td>Five Layer Soil model</td>
</tr>
</tbody>
</table>

Four Dimensional Data Assimilation (FDDA) is not used in order to estimate the effect of lower boundary condition on local rainfall.
4. NUMERICAL ANALYSIS

4.1. Brief verification of numerical reproduced fields

Figure 1(a) shows surface wind fields and air temperature recorded on AMeDAS at 19 JST (=UTC+9h). It was two hours and a half before observing maximum hourly accumulated precipitation in Tokyo. There are three wind systems around Tokyo at a height of 10m: 1) northeasterly cold wind (under 28°), 2) southerly warm wind (over 30°) and 3) northwesterly wind. These three wind systems converged on Tokyo urban area indicated as open-dotted-ellipse in Figure 1(a). The model is successful in reproducing three wind systems, and the location of reproducing convergence line corresponds to the observed one (Figure 1(b)). Figure 2(a) shows hourly accumulated rainfall estimated from Radar-AMeDAS data at 21:30JST. Radar-AMeDAS data is the objectively analyzed weather radar rainfall data that are calibrated with AMeDAS. The reproduced peak rainfall amount and distribution of the rainfall region agree with those of Radar-AMeDAS data, except for an hour delay (Figure 2(b)).

4.2. Moisture transportation

Kowano et al (2008) analyzed 3D wind fields derived from dual doppler radar data during this rainfall event, and found out that the movement of convective clouds stagnated at Tokyo for a while. This is causing concentration of...
rainfall at small area (Kowano et al 2008). While Kowano et al (2008) had clarified the mechanism of the concentration of rainfall, it was not explained where was water vapor came into convective area.

The Moisture transport is examined from the reproduced distribution of water vapor mixing ratio ($q_{vp}$) and low-level wind (Figure 3). At 17 JST, There is low $q_{vp}$ air at Tokyo (S1 in Figure 3), however, high $q_{vp}$ air was transported to Tokyo by northeasterly wind with very clear front line. Figure 4 shows observed $q_{vp}$ at stations (in Figure 3). This Figure included reproduced $q_{vp}$. Observed $q_{vp}$ at NE1 in northeasterly wind is about 2g/kg greater than $q_{vp}$ in southerly wind. The model generally underestimates $q_{vp}$ comparing to the observed $q_{vp}$, however, the difference of amount of $q_{vp}$ between two wind systems, northeasterly and southerly wind systems, is almost same to observed one.

In Figure 5, the vertical distribution of $q_{vp}$ is investigated along the SW-NE bold line showed in Figure 3. The SW-NE line passes through S1 (in Figure 3) and local heavy rainfall region (in Figure 2(b)). High $q_{vp}$ air from northeasterly side and slightly high $q_{vp}$ air from southerly side converge at 18:30 JST. While two air masses are mixed on the convergent point, high $q_{vp}$ air from northeasterly side tends to go under the southerly air, because the northeasterly air is cooler and heavier than the southerly air. At 19:30 JST, the high $q_{vp}$ air is pushed by northeasterly cold outflow (open arrow in Figure 5(c)) associated with previous rainfall, and is forced to go up. This high $q_{vp}$ air is condensed at upper-level and discharged the latent heat. This latent heat may contribute to enhance the convective activity.

5. SENSITIVITY STUDY

In order to estimate the effect of urban area on the heavy rainfall, more two numerical experiments are performed: WITHOUT_AH case and NON_URBAN case. The WITHOUT_AH case has the same model design as the control experiment (mentioned above section, CONTROL case) except anthropogenic heat is not included. In the
The NON_URBAN case, the land-use index of urban area is replaced with the one of farmland. Figure 6 shows 12 hours accumulated rainfall reproduced in each case. During these 12 hours, most of rainfall in Tokyo was observed. In the WITHOUT_AH case, the distribution of heavy rainfall region is shifted easterly comparing to the CONTROL case. In the NON_URBAN case, amount of rainfall seems to be less than the other two cases.

The budget of $q_{vp}$ within a region is given by Eq. (1),

$$FV = SV + R + SFC_{without\_rainfall}$$

where $FV$ denotes flux convergence of $q_{vp}$ into the region, $SV$ denotes time increment of $q_{vp}$ in the region, $R$ denotes rainfall, $SFC_{without\_rainfall}$ denotes net time increment of condensate without rainfall (e.g. cloud water, rain water, ice, snow and graupel). Figure 7 shows the $q_{vp}$ budget within the volume which has the box shape in horizontal (Figure 6) of the height from surface to 20km. And Figure 7 also shows the horizontal convergence of the lower-level air of the height from surface to 1.5km. The positive value of convergence denotes inflow. In the WITHOUT_AH case, the $q_{vp}$ budget and low-level air convergence are almost same as those of the CONTROL case. This is suggested that anthropogenic heat affects the distribution of rainfall region (Figure 6), but has little affection to $q_{vp}$ budget. In the NON_URBAN case, the peak value of the low-level air convergence is less than those of the other two cases, and inflow of $q_{vp}$ ($FV$) is weaker than those of the other two cases.

6. CONCLUSION

Moisture transportation during local heavy rainfall event around Tokyo on August 15 2005 is investigated using mesoscale model. In this event, it found out that the moisture would be originated in northeasterly region, and that anthropogenic heat affects the distribution of rainfall region but has little affection to moisture budget.

References


