DISTRIBUTION OF SUMMERTIME INTENSE RAINFALL FREQUENCY AND THE SURFACE ROUGHNESS IN THE TOKYO METROPOLITAN AREA

Hideo Takahashi*, Yasuko Nakamura**, Hiroto Suzuki***
*Tokyo Metropolitan University, Tokyo, Japan; **Tokyo Gakugei University, Tokyo, Japan, ***East Japan Railway Company, Chiba, Japan

Abstract

The localized high-frequency areas of summertime intense rainfall in the Tokyo Metropolitan Area appear to the leeward of high-rise buildings areas (e.g. Shinjuku, Ikebukuro). A simple estimation of ascending wind velocity based on the calculated aerodynamic parameters (\(z_0\) and \(z_d\)) representing 1 km\(^2\) areas by using DSM data suggests that large surface roughness created by high-rise buildings is a possible factor for localized high-frequency areas of intense rainfall in urban areas.

Key words: short-duration intense rainfall, surface roughness, high-rise buildings

1. INTRODUCTION

Recently, the frequent occurrence of ‘urban floods’ due to summertime, short-duration intense rainfall has been reported in the Tokyo Metropolitan Area. It was pointed out that the intense rainfall is likely to occur to the leeward of urban area by using observed rainfall data during METROMEX conducted in the 1970s (Changnon, 1978) and TRMM data in recent years (Shepherd and Negri, 2002). However, more detailed climatological spatial structure of intense rainfall within an urban area, such as the Tokyo Metropolitan Area has not been analyzed completely using high-density rainfall data. Here we present the spatial structure of the occurrence frequency of intense rainfall in the Tokyo Metropolitan Area based on detailed hourly rainfall data. In order to discuss the causal factors for the localized high-frequency area of intense rainfall, the distribution of surface aerodynamic parameters is calculated using surface elevation data, which can resolve individual buildings for simple evaluation of ascending wind velocity.

2. DATA AND PROCEDURE

2.1. Rainfall data

This study utilized hourly rainfall data of 90 stations in the Tokyo Metropolitan Area (Fig. 1a) recorded by the Japan Meteorological Agency (●), East Japan Railway Company (△), and the Bureau of Construction of the Tokyo Metropolitan Government (×). The target period covers the months of June to September in the years 1991 to 2002. In total, 226 cases were extracted where at least one station recorded an hourly rainfall of 20 mm or more in the central part of the Tokyo Metropolitan Area without being influenced by synoptic- or meso-scale disturbances.

2.2. Calculation of surface aerodynamic parameters

The heights of artificial constructions were determined as elevation difference between the 2.5 m interval elevation of a digital surface model (DSM) provided by the Pasco Corporation and the 2.5 m interval ground elevation interpolated from the 5 m interval DEM of the Geographical Survey Institute. The aerodynamic parameters (roughness length, \(z_0\), and zero-plain displacement, \(z_d\)), representing 1 km\(^2\) areas were calculated in the Tokyo Wards Area by method of Raupach (1992, 1994, and 1995) that obtained comparatively good evaluation by Grimmond and Oke (1999). One of the required parameters, the frontal area aspect ratio \(A_f\), was estimated by \(A_f = (\Sigma A_p ) / A_T\), where \(\Sigma A_p\) is the total area of roughness elements (buildings, plants and so on) seen by oncoming wind within plan area of \(A_T = 1\) km \(
\times\) km. In addition, average height of roughness elements, \(z_p\), was calculated by omitting the roughness elements lower than one-story houses, 3.5 m, since the plan area aspect ratio \(A_p\), though it did not use in calculation, was consistent with the analysis of independent GIS data. The \(z_0\) and \(z_d\) representing 1 km\(^2\) areas were calculated at the interval of 200 m to represent complicated urban structure.

*Corresponding author address: Hideo Takahashi, Department of Geography, Tokyo Metropolitan University, 1-1 Minamiosawa Hachioji Tokyo, 192-0397 Japan; e-mail: thideo@tmu.ac.jp
3. DISCUSSION

3.1. Localized high-frequency areas of intense rainfall

Figure 1(a) indicates the relative frequency distribution of intense rainfall among the 226 cases. High-frequency zones of intense rainfall are located along the boundary of the Tokyo and Saitama Prefecture, and the northwest region of the Tokyo Wards Area. Although the wind direction at Tokyo (Otemachi) varies between northeast and south-southwest during periods of intense rainfall, it is concentrated in the easterly and southerly directions 2-3 hours before the occurrence of intense rainfall. In the case of easterly winds (Fig. 1b), the occurrence increases toward the west from the center of Tokyo or Shinjuku; the highest frequency occurs in Nakano Ward (west of Shinjuku). For southerly winds (Fig. 1c), a relatively high-frequency zone appears along the boundary of the Tokyo and Saitama Prefecture; the maximum frequency occurs in the Itabashi Ward, located north of Ikebukuro. In addition, a high-frequency zone of intense rainfall also appears south of the Shibuya-Kasumigaseki area in the case of northerly winds (Fig. 1d). It is noted that the localized high-frequency areas of intense rainfall appear to the leeward of high-rise buildings such as Sinjuku and Ikebukuro.

Figure 1. Relative frequency distribution of intense rainfall (≥20 mm/hour) occurred in urban area of Tokyo (inside of the inner frame) for all cases (a: 226 cases), easterly wind cases (b: 105 cases), southerly wind cases (c: 77 cases), and northerly wind cases (d: 29 cases)

Relative frequency means the percentage ratio of number of intense rainfall cases at each station to that of all intense rainfall cases occurred within the inner frame. Abbreviations “SNJ”, “IKB”, “SBY”, and “TKY” in (a) indicate the place names and location of Shinjuku, Ikebukuro, Shibuya, and Tokyo Railway Station, respectively. The background figure and red arrows in (b)-(d) show the largest number of building floors in every 50 m x 50 m areas, and wind vectors at AMeDAS (Automated Meteorological Data Acquisition System) stations averaged for respective cases.

3.2. Preliminary estimation of ascending wind velocity due to surface roughness

Figure 2 shows the distribution of calculated $z_0$ (a) and $z_d$ (b) in the Tokyo Wards area. Areas with large $z_0$ and $z_d$
Figure 2. Distribution of calculated roughness length $z_0$ (a), and zero-plain displacement $z_d$ (b) by Raupach’s method.

Figure 3. Example of estimation of ascending wind velocity

(a) and (b) indicate the estimated vertical profiles of horizontal (southerly) wind velocity by applying the logarithmic rule using calculated $z_0$ and $z_d$ values assuming a wind velocity of 10 m/s at 250 m for 1 km windward (southward) of West-Sinjuku (b), and West-Sinjuku (a) where both of $z_0$ and $z_d$ indicate the largest, respectively. (c) indicates the difference in horizontal wind velocity between (a) and (b). (d) shows the estimated ascending wind velocity calculated from convergence of horizontal wind between (a) and (b).

are observed around Sinjuku, Ikebukuro, and the central Tokyo (vicinity of Tokyo Railway Station) where the government offices are located. To evaluate the effect of surface roughness on the occurrence of intense rainfall, the distribution of ascending wind velocity in the lower layer is estimated from the convergence of horizontal wind. The distribution of horizontal wind velocity at an arbitrary height for the three wind directions corresponding to Fig. 1(b)-(d) is evaluated by applying the logarithmic rule using calculated $z_0$ and $z_d$ values assuming a wind velocity of 10 m/s at 250 m (Fig.3). In the case of the southerly wind direction, a large ascending wind velocity of $>0.2$ m/s appears near both Shinjuku and Ikebukuro (Fig. 4a). A large ascending wind velocity of about 0.2 m/s appears near Shinjuku, although that around Ikebukuro is smaller in the case of the easterly winds (Fig. 4b). Moreover, the ascending wind velocity near Kasumigaseki (near the Tokyo Railway Station) is larger in the case of northerly winds (Fig. 4c) as compared with southerly winds (Fig. 4a). The distribution of estimated ascending wind velocity varies according to the wind direction, which corresponds to that of intense rainfall frequency for the respective wind directions. Thus, large surface roughness created by high-rise buildings is a possible factor for localized high-frequency areas of intense rainfall in urban areas.
In Fig. 4, areas with descending wind are suppressed.

4. CONCLUDING REMARKS

The localized high-frequency areas of summertime intense rainfall in the Tokyo Metropolitan Area appear to the leeward of high-rise buildings areas (e.g. Shinjuku, Ikebukuro). A simple estimation of ascending wind velocity based on the calculated aerodynamic parameters \(z_0\) and \(z_d\) representing 1 km² areas by using DSM data suggests that large surface roughness created by high-rise buildings is a possible factor for localized high-frequency areas of intense rainfall in urban areas.

References