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Frequency Distribution of Intense Rainfall in the Wards of Tokyo and Its Relationship with the Spatial Structure of Building Heights

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Abstract

This study presents the minute spatial structure of both the frequency of intense rainfall (data from the 1991 to 2002, except 1993, were used) and recent trends (15-25 years until 2002) in the special wards of the Tokyo Metropolis in summer (June to September), on the basis of hourly rainfall data from a dense rain-gauge network. As this is the first step in elucidating the relationship between the distribution of the frequency of intense rainfall and that of surface roughness in metropolitan Tokyo, the averaged number of building stories within a certain area, which is referred to as the smoothed building height (SBH), was assumed to be an alternative parameter when deciding surface roughness. The distribution of the ascending rate of SBH (hereafter, the ascending rate of SBH is referred to as ARS) for wind direction was calculated by varying the averaging area for SBH, in order to compare it to the distribution of intense rainfall frequency. The results are summarized as follows.

The high-frequency areas of intense rainfall appear in the western to northern parts of the area comprising the wards and along the boundary between the Tokyo Metropolis and Saitama Prefecture. The frequency of intense rainfall in these areas is two to three times as high as that in the eastern part of the area comprising the wards. Moreover, the maximum areas of intense rainfall frequency are localized in the western, northern to northwestern, and southern part of the area comprising the wards, corresponding to wind direction. These areas are situated 3-5 km from the leeward side of the area, where the ARS derived from the SBH at a 1-2 km scale is large, that is, the vicinities of Shinjuku (SNJ), Ikebukuro (IKB), and Shibuya (SBY). Accordingly, we suggest that the large surface roughness due to high-rise buildings in the western part of the area comprising the wards has the effect of increasing the frequency of intense rainfall.

The increasing trend of intense rainfall is clear in the western part of the area comprising the wards, whereas a decreasing trend, although not statistically significant, is seen in the eastern part of the area comprising the wards. It is noted that observational stations with large increasing trends of intense rainfall, such as Nakano (NKN) and Shinagawa (SNG), are located 3-5 km from the leeward side of SNJ and on the shore of Tokyo Bay in the southern part of the area comprising the wards, respectively, where the ARS for easterly winds derived from the SBH at a 1-2 km scale is large.

Key words : wards of Tokyo, frequency distribution of intense rainfall, hourly rainfall, surface roughness, building height, wind direction

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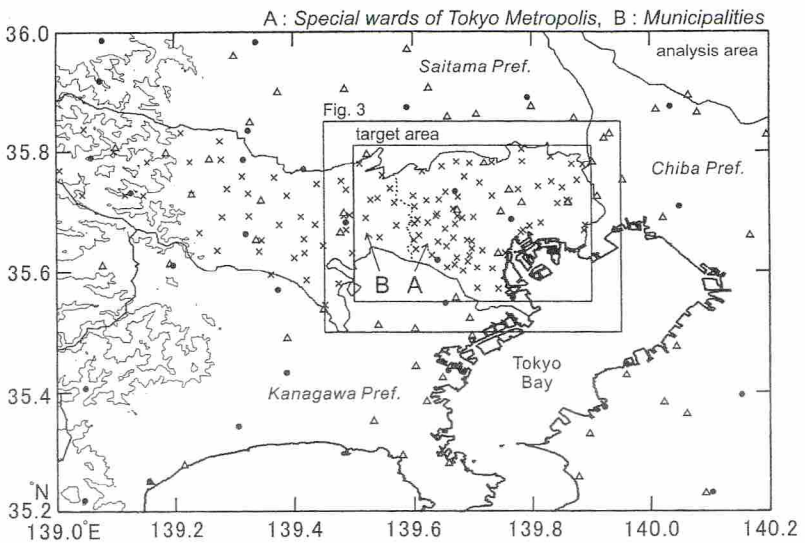

Fig. 2 Analysis area and distribution of rain-gauge stations. ●: AMeDAS station, △: JR station, ×: Tokyo metropolis station. Large and small boxes within the figure indicate the locations of Fig. 3 and the urban core area (target area), respectively.

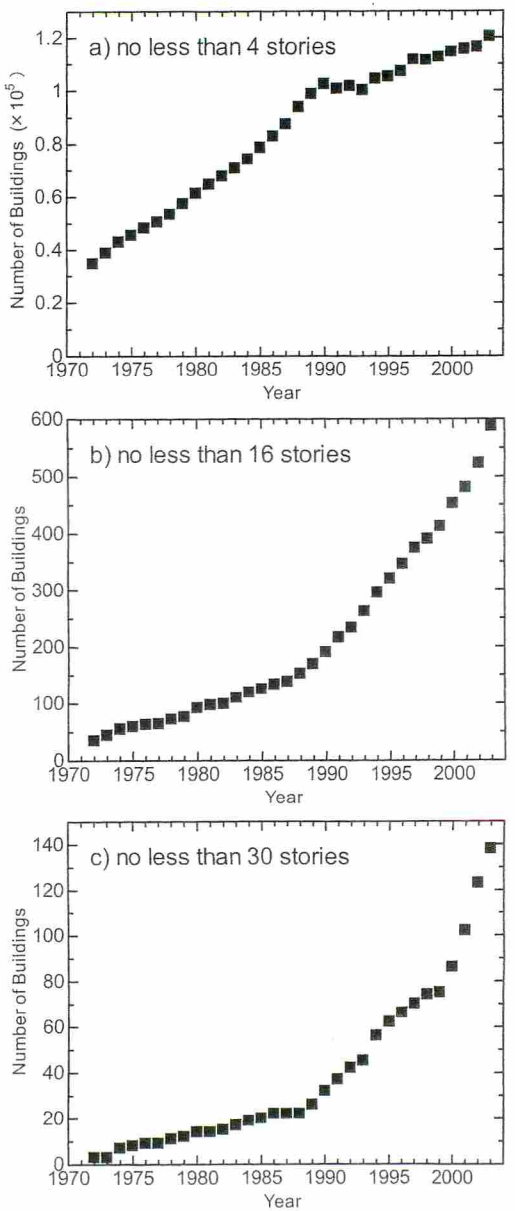

Fig. 1 Historical changes in the number of buildings with (a) no less than four stories, (b) no less than 16 stories, and (c) no less than 30 stories in the wards of Tokyo (from 1972 to 2003). Data from the statistics book of the Tokyo Fire Department published every year from 1973 to 2004.

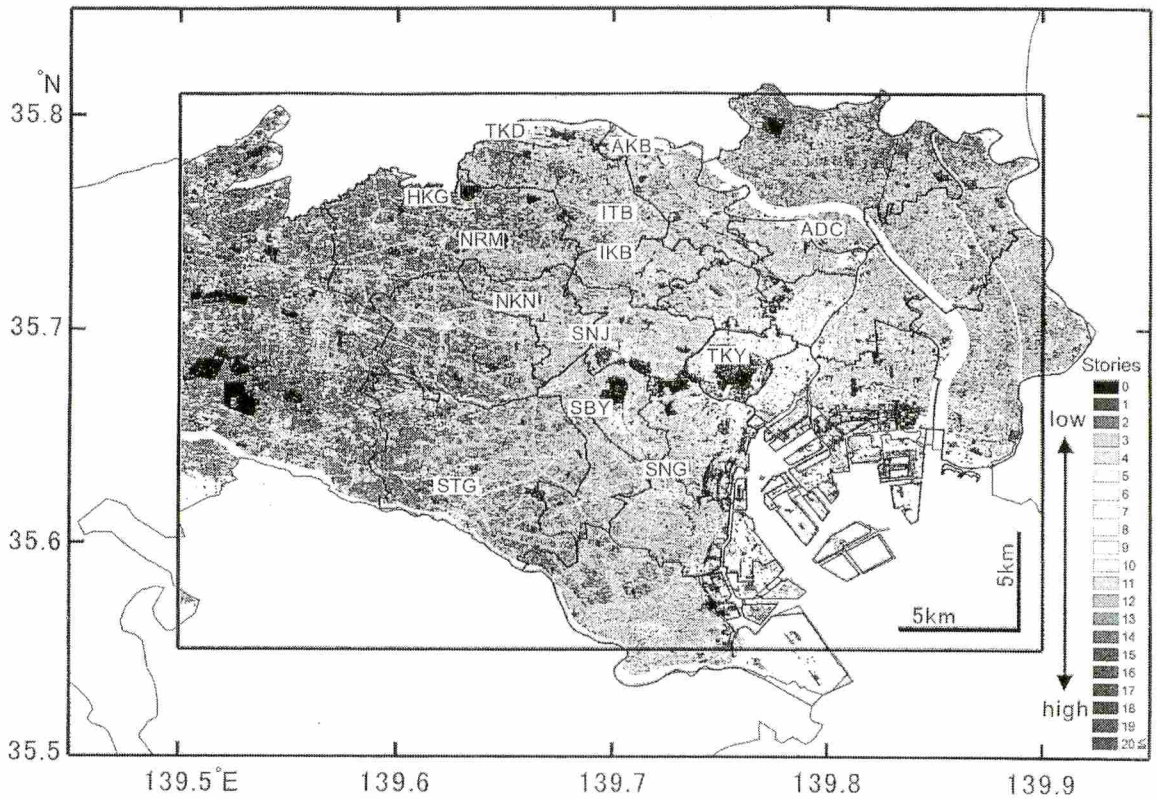

Fig. 3 Distribution of the building height (stories) in the urban core area of the Tokyo Metropolis. The number of building stories is shown by the maximum number of stories in the respective 50 m × 50 m grids. The names of major areas referred to in the text are shown along with their corresponding locations, which are situated just southeast of the area name labels (*railway station). ADC: Adachi, AKB: Akabane*, HKG: Hikarigaoka, IKB: Ikebukuro*, ITB: Itabashi, NKN: Nakano*, NRM: Nerima*, SBY: Shibuya*, SNG: Shinagawa*, SNJ: Shinjuku*, STG: Setagaya, TKD: Takashimadaira, TKY: Tokyo*.

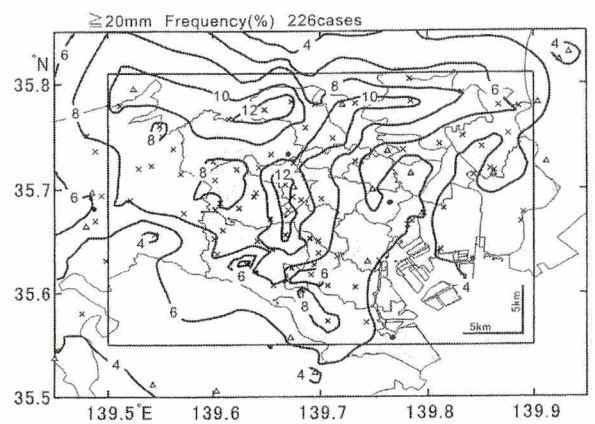

Fig. 4 Frequency distribution of intense rainfall (≧ 20 mm/h) in the urban core area of Tokyo. The values represent the percentage frequency calculated as a ratio of the number of cases of intense rainfall at each rain-gauge station to the total number of cases of intense rainfall that occurred in the target area (totaling 226 cases). The gray area indicates the area comprising the wards of the Tokyo Metropolis. The symbols of rain-gauge stations are the same as those in Fig. 2.

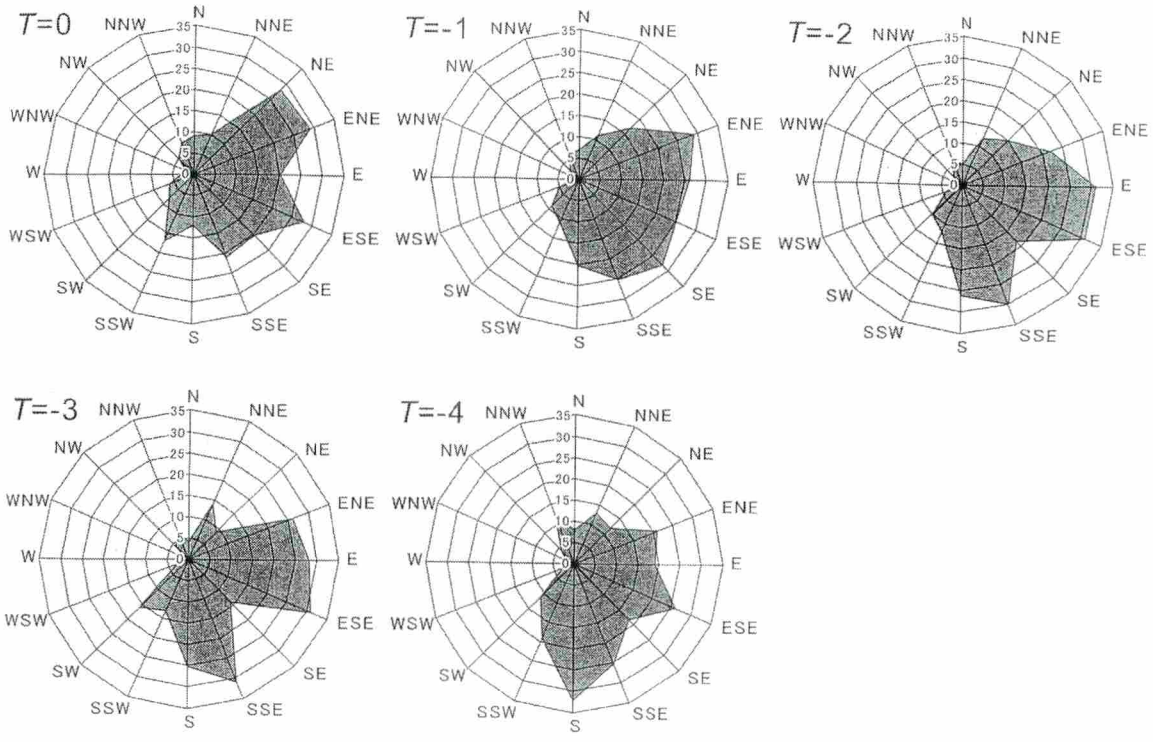

Fig. 5 Wind roses at Otemachi from occurrence time ($T=0$) to four hours prior to occurrence time ($T=-4$) of intense rainfall in the target area. Frequencies are indicated by the number of cases for the respective wind directions.

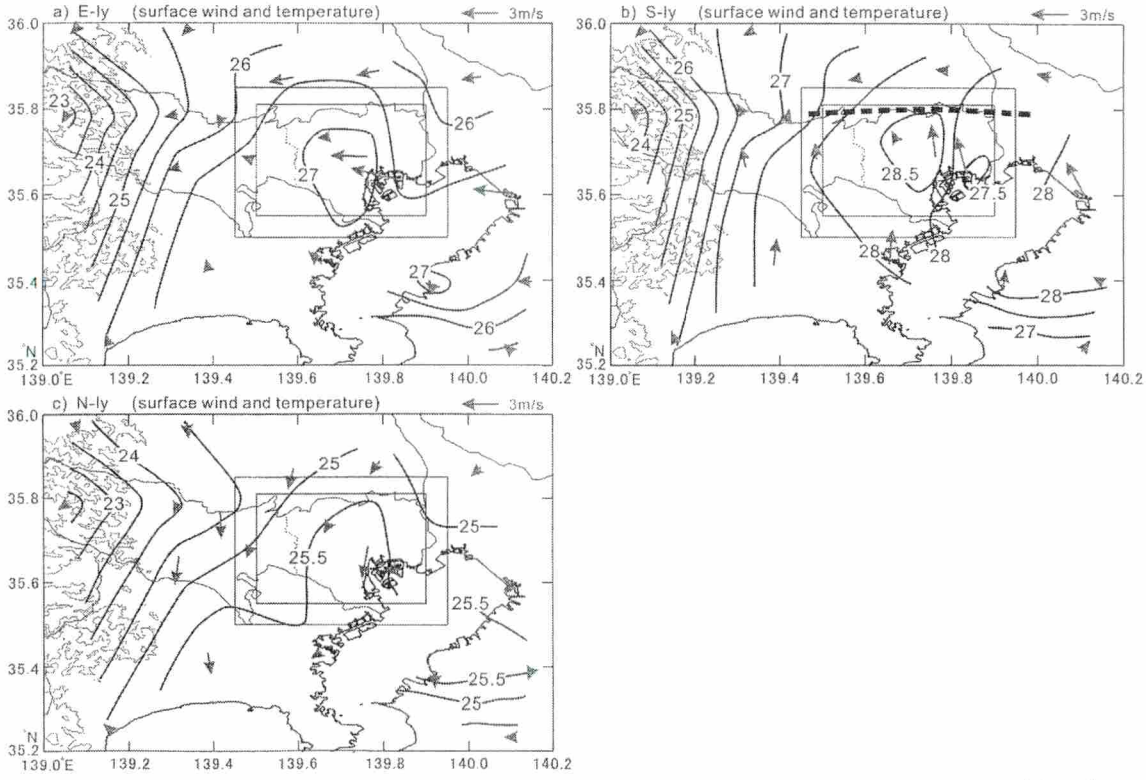

Fig. 6 Distribution of averaged wind vector and temperature for the respective wind directions at Otemachi two hours prior to the appearance of intense rainfall. The bold dashed line in the case of southerly winds (b) represents the discontinuity line of winds (convergence zone). Temperature contour lines are drawn at every 0.5℃.

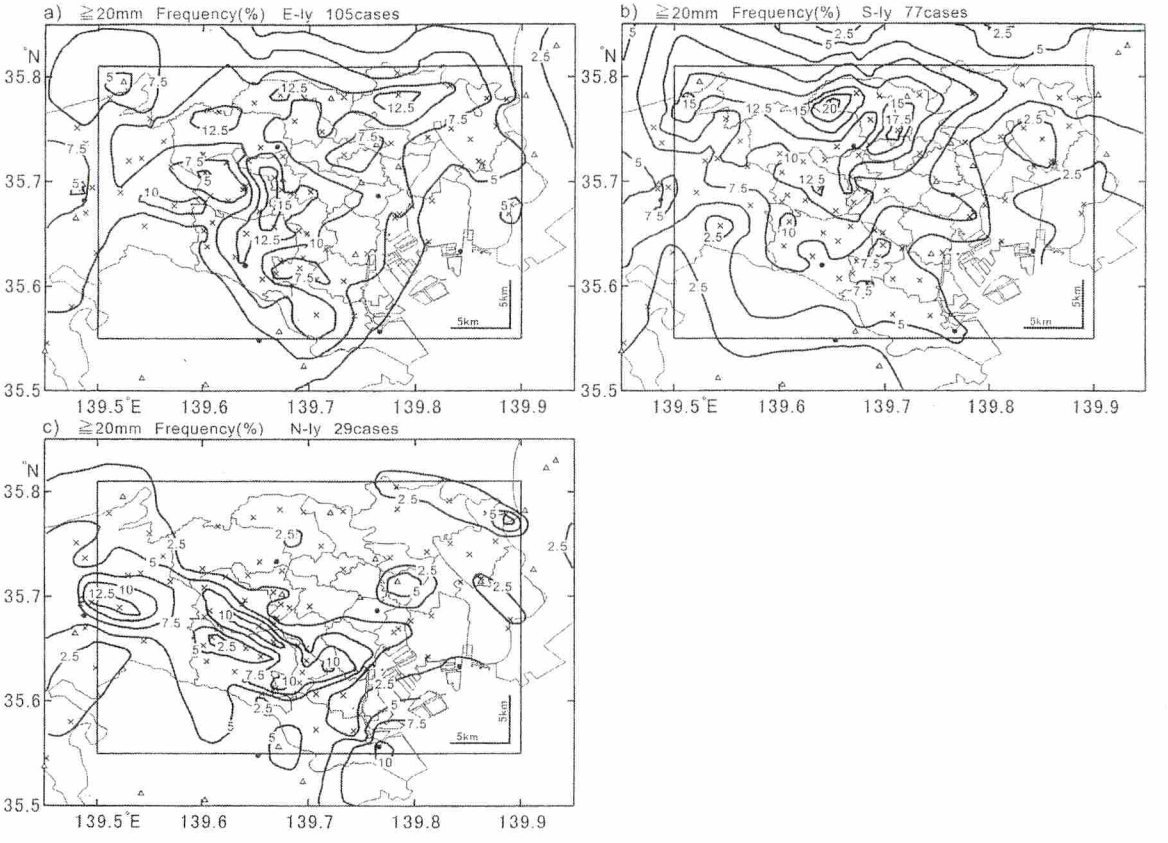

Fig. 7 Same as Fig. 4, except wind direction at Otemachi is (a) easterly (105 cases), (b) southerly (77 cases), and (c) northerly (29 cases). The values represent percentage frequency calculated as a ratio of the number of cases of intense rainfall at each rain-gauge station to the total number of cases of intense rainfall that occurred in the target area for the respective wind directions. The gray area indicates the area comprising the wards of the Tokyo Metropolis. The symbols of the rain-gauge stations are the same as those in Fig. 2.

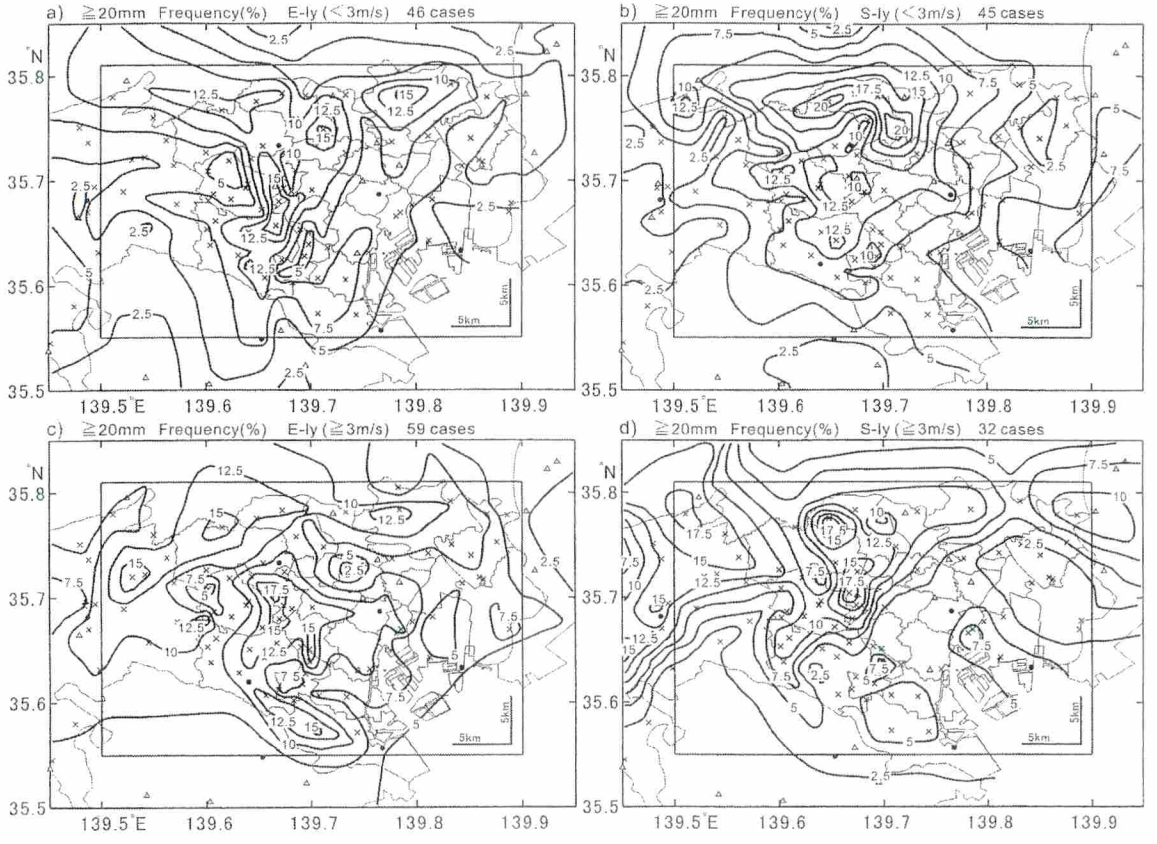

Fig. 8 Same as Fig. 4, but for cases of weak (<3 m/s) and strong (≧3 m/s) wind for easterly and southerly winds at Otemachi. (a) weak easterly winds (46 cases), (b) weak southerly winds (45 cases), (c) strong easterly winds (59 cases), (d) weak southerly winds (32 cases). The values represent percentage frequency calculated as a ratio of the number of cases of intense rainfall at each rain-gauge station to the total number of cases of intense rainfall that occurred in the target area for the respective categories. The gray area indicates the area comprising the wards of the Tokyo Metropolis. The symbols of rain-gauge stations are the same as those in Fig. 2.

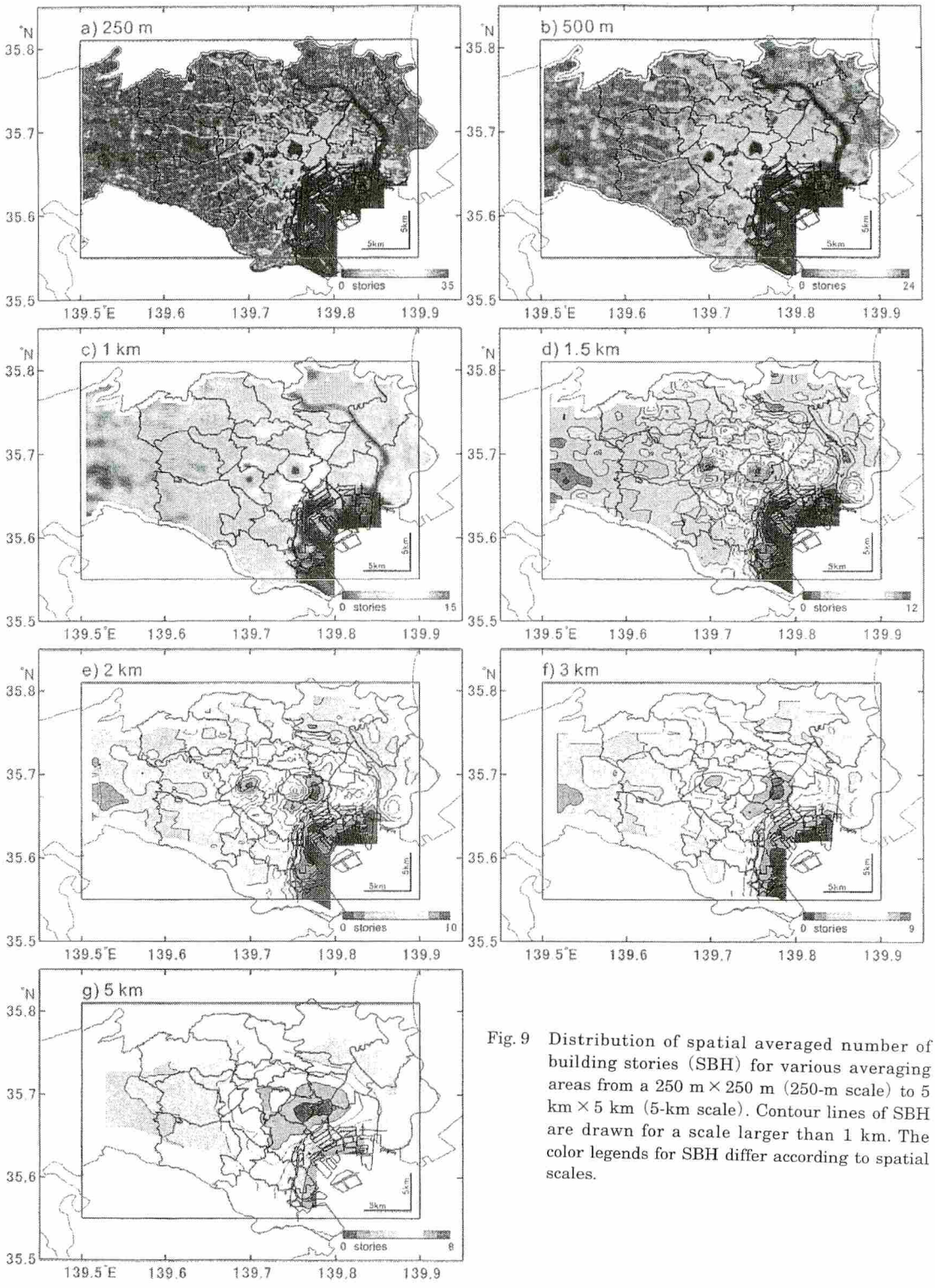

Fig. 9 Distribution of spatial averaged number of building stories (SBH) for various averaging areas from a 250 m × 250 m (250-m scale) to 5 km × 5 km (5-km scale). Contour lines of SBH are drawn for a scale larger than 1 km. The color legends for SBH differ according to spatial scales.

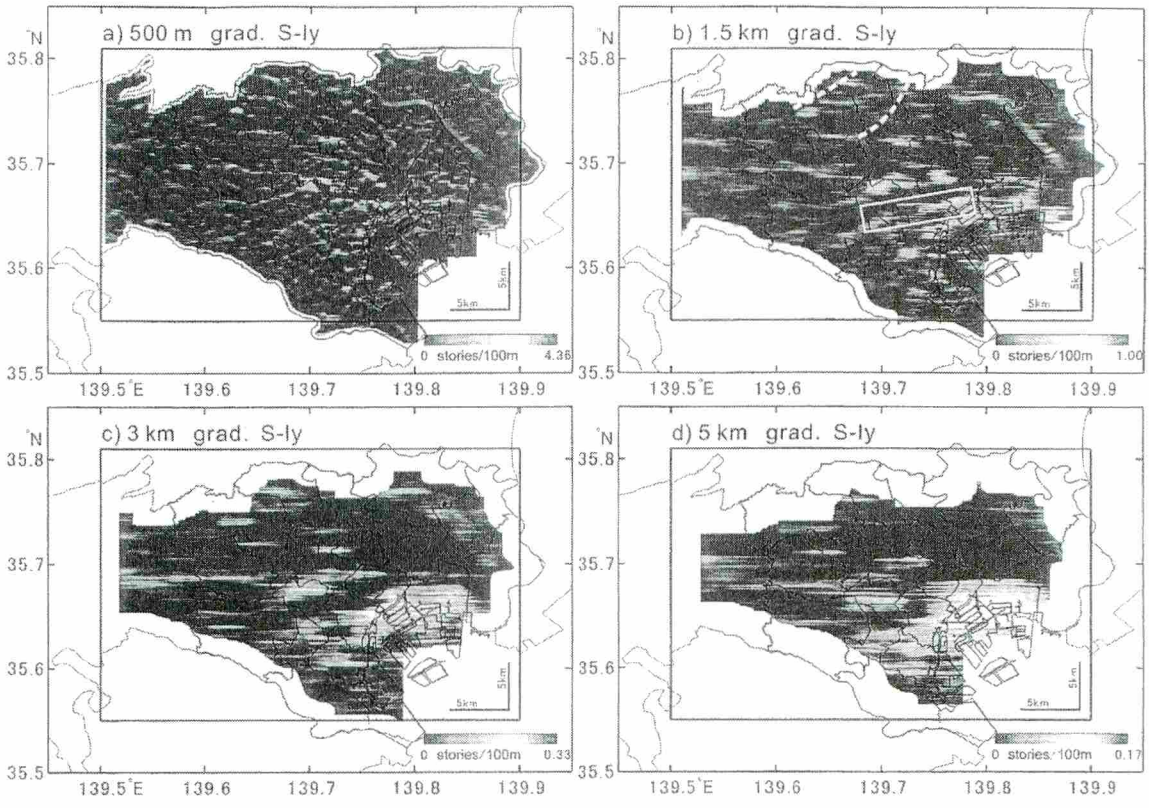

Fig. 10 Distribution of ARS (ascending rate of SBH) corresponding to southerly winds for various average areas. (a) 500 m × 500 m (500-m scale), (b) 1.5 km × 1.5 km (1.5-km scale), (c) 3 km × 3 km (3-km scale), (d) 5 km × 5 km (5-km scale). The color legends for ARS differ depending on spatial scales. The dashed line in (b) indicates the high-frequency zone of intense rainfall for cases of southerly winds (Fig. 7b). Refer to Fig. 11 for the white box in (b).

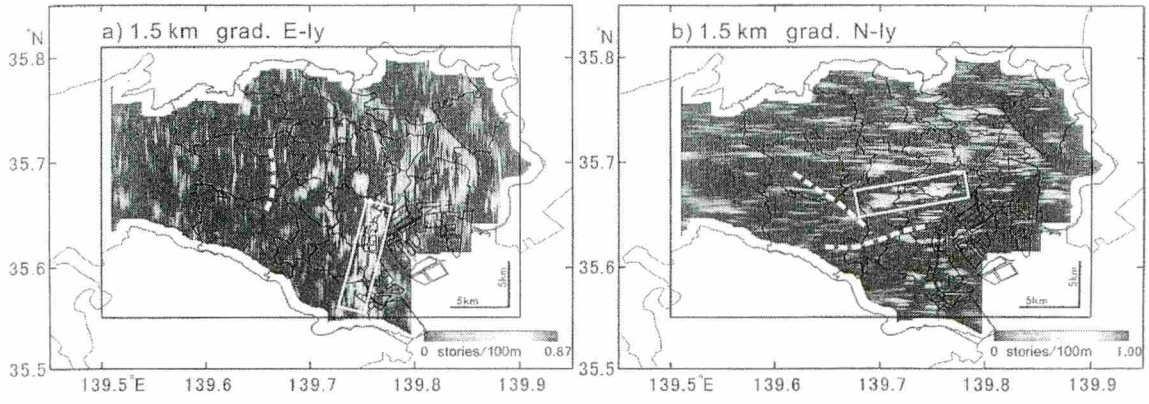

Fig. 11 Same as Fig. 10, but for (a) easterly and (b) northerly winds with a 1.5-km scale. The color legends for ARS between (a) and (b) differ. The dashed lines in (a) and (b) indicate high-frequency zones of intense rainfall for cases of easterly (Fig. 7a) and northerly (Fig. 7c) winds, respectively. Large ARS areas in white boxes in Figs. 10b and 11b are due to high-rise buildings in the same areas.

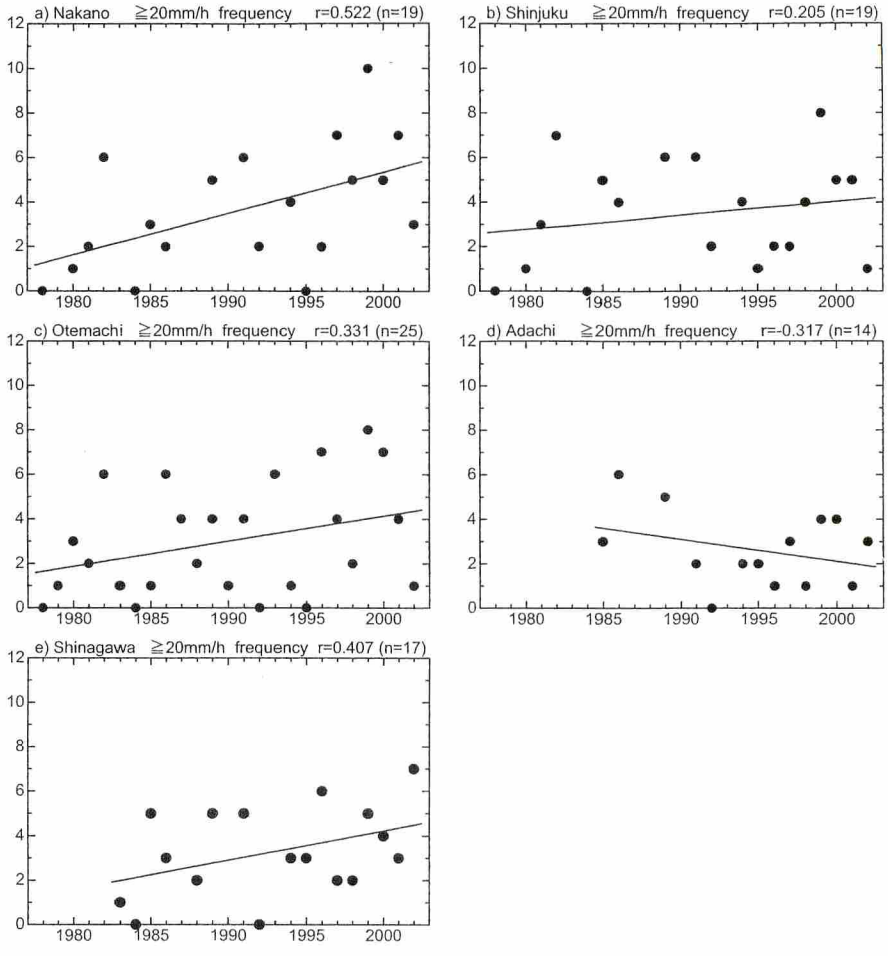

Fig. 12 Recent trends of occurrences of intense rainfall (≧20 mm/h) at five selected stations in the wards of Tokyo. Correlation coefficient (r) of regression line at the respective stations and the number of effective years (n) are shown above the figures. (a) Nakano (NKN), (b) Shinjuku (SNJ), (c) Otemachi (vicinity of TKY), (d) Adachi (ADC), (e) Shinagawa (SNG).

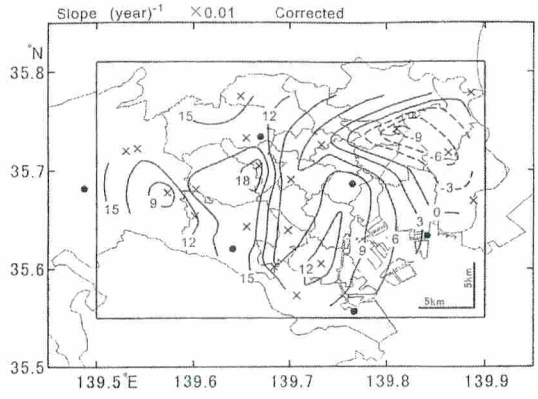

Fig. 13 Spatial difference in the recent trends of occurrences of intense rainfall (≧20 mm/h). The trend at each station is represented by the inclination of the regression line between the number of occurrences of intense rainfall and year. Positive and negative values indicate increasing and decreasing trends, respectively. The gray area indicates the area comprising the wards of the Tokyo metropolis. The symbols of rain-gauge stations are the same as those in Fig. 2.

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