Study of Recent Variation in Weak Rainfall over Japan
Using 31-Year AMeDAS Dataset

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Abstract
Linear regression analysis was applied to the time series of hourly rainfall data between June and September for 31 years to elucidate the features of weak rainfall over Japan. Many stations exhibiting a significant positive trend in the frequency of weak rainfall (1–5 mm h\(^{-1}\)) were localized in the Hokkaido district. In contrast, there were only a few stations with a significant positive trend in weak rainfall over regions other than Hokkaido; however, many stations exhibited a significant positive trend in heavy rainfall exceeding 25 mm h\(^{-1}\). Thus, there existed a clear geographical contrast between the two regions.

1. Introduction
Recently, many climatological studies conducted from the view point of disaster prevention have shown that heavy rainfall events have exhibited a positive trend over the past 100 years (e.g., Iwashima and Yamamoto 1993; Karl and Knight 1998; Groisman et al. 2005; Fujibe et al. 2005). Many numerical studies have also pointed out that heavy rainfall events are expected to increase due to global warming (e.g., Meehl et al. 2005; Yoshizaki et al. 2005). However, since weak rainfall also contributes considerably to the total rainfall amount (see Fig. 1), it must also play an important role in large-scale water circulation; however, only a few studies have investigated the variation in weak rainfall.

Fujibe et al. (2005, 2006a and b) investigated a long-term trend in rainfall on the basis of historical rainfall data in Japan. The average amount of weak rainfall over Japan exhibited a distinct negative trend up to 2003 (Fujibe et al. 2005 and 2006b). The frequency of weak rainfall exhibited a negative trend from 1898 to 2003; however, it has remained almost constant over the past 30 years (Fujibe et al. 2006a).

It is well known that rainfall features depend on geographical features. Although previous studies have revealed some of the fundamental features of weak rainfall in Japan, the number of stations used in the analyses in these studies was not sufficient for elucidating the geographical distribution of the weak rainfall. In this study, we used Automated Meteorological Data Acquisition System (AMeDAS) data from 758 stations to elucidate the geographical distribution of weak rainfall. In particular, we focused on weak rainfall in the Hokkaido district.

2. Data
Approximately 1300 AMeDAS stations have been set up by the Japan Meteorological Agency (JMA) since 1976. Among these stations, AMeDAS stations whose location moved by more than 500 m and whose ratios of missing data were more than 1% (906 h/31 years) are excluded. As a result, data from only 758 stations were used. Although missing data are not corrected, we confirmed that missing data correction did not make much difference.

The hourly rainfall amount with a 1-mm resolution was used for analysis. Linear regression analysis was applied to the time series of hourly rainfall data so as to distinguish stations with a significant positive trend. A nonparametric rank-sum test was also applied to the same data; however, the conclusion was similar to that obtained from linear regression analysis.

The warm season (June to September) from 1976 to 2006 was selected as the analysis period.

3. Positive trend in weak and heavy rainfall

3.1 Definition of weak and heavy rainfall
For the sake of convenience, we defined “weak rainfall” and “heavy rainfall” as an hourly rainfall amount of less than 6 mm (1–5 mm h\(^{-1}\)) and more than 25 mm, respectively. Figure 1 shows the ratios of rainfall amount and rainfall frequency to the total rainfall amount and total rainfall frequency, respectively, at 1-mm interval. The ratios of rainfall frequency and rainfall amount corresponding to 1–5 mm h\(^{-1}\) of rainfall were found to be 83–91% and 46–65%, respectively; this implies that the variation in weak rainfall greatly contributes to that in the total rainfall.

Both the amount and the frequency of rainfall also exhibit a similar temporal variation (not shown). However, since the positive trend in the frequency is rather clear, we focus on the frequency of rainfall in this study.

3.2 Features of frequency of weak rainfall
Figure 2a shows the time series of the arithmetical
averaged frequency of weak and heavy rainfall over the Hokkaido district (n = 104) and regions other than Hokkaido (n = 654). The frequency implies the number of times weak rainfall was recorded in each year.

Correlation coefficients (r) of more than +0.46 and +0.36 correspond to 99% and 95% significance levels, respectively. Here, the horizontal stochastic independence of AMeDAS data was not considered. It is evident that the frequency of weak rainfall exhibits a positive trend over the Hokkaido district, and the correlation coefficient between the frequency and the year is +0.47; however, the frequency of weak rainfall over regions other than Hokkaido does not exhibit a significant variation (r = −0.10). On the contrary, although the frequency of heavy rainfall over the Hokkaido district does not exhibit any trends (r = +0.05), the frequency over regions other than Hokkaido exhibits a positive trend (Fig. 2b).

The features of the positive trend at other intensity levels are summarized in Fig. 3. Despite the significant trend in weak rainfall over the Hokkaido district, a rainfall amount of more than 5 mm h⁻¹ does not exhibit significant trends. On the other hand, the correlation coefficients increase with rainfall intensity over regions other than Hokkaido; this indicates that heavy rainfall events have exhibited a positive trend over the past 31 years, as shown in Fig. 2b and as confirmed in previous studies (e.g., Fujibe 2005).

Figure 4a shows the geographical distribution of the correlation coefficients of the frequency of weak rainfall. Many AMeDAS stations in the Hokkaido district have correlation coefficients of greater than +0.36. 61% of the stations in Hokkaido exhibit a significant positive trend. The ratio of increase in weak rainfall over a period of 31 years is 20–50% relative to the averaged frequency over 31 years (Fig. 4b).

In the Hokkaido district, the averaged rainfall amount over stations exhibiting a significant positive trend during the warm season is 450.6 mm, whereas, that over stations that do not exhibit a significant positive trend is 528.2 mm. In other words, the positive trend is a clear feature in the case of stations that receive a small amount of rainfall. In general, the topography affects the amount of rainfall even in the case of stratiform rainfall; however, there is no clear relationship between the marked positive trend and the topography/elevation of the stations.

It is noted that stations with a rather high correlation (indicated by green circles in Fig. 4a) are located in northern Honshu. The positive trend in weak rainfall does not appear to be restricted to the Hokkaido district; it also gradually weakens toward the south of Honshu.

The contribution of the increase in weak rainfall over the Hokkaido district is evaluated by comparing the total rainfall in the first and last 10 years (P1 and P2, respectively, in Fig. 2b). As shown in Fig. 5a, the rainfall amount in P2 (310.2 mm) is larger than that in P1 (413.4 mm). The increase in weak rainfall accounts for 63% (= 60.1 mm/96.8 mm) of the difference in the total rainfall amount between P1 and P2 (Fig. 5b); this implies that although the intensity of rainfall is weak, it affects the variation in the total rainfall amount over the Hokkaido district.

The positive trend in the weak rainfall over the
Hokkaido district exhibits a seasonal variation. The correlation coefficients for July and September exceed +0.36 (Table 1). According to JMA surface weather maps, weak rainfall was frequently observed over several stations simultaneously when cloud areas associated with fronts or synoptic-scale depressions passed near the Hokkaido district.

Figure 6 shows the diurnal variation of the frequency of weak rainfall for stations with and without a significant positive trend over the Hokkaido district. The frequency implies the number of times weak rainfall was recorded for each hour in a 10-year period. A comparison between P1 and P2 showed that the amount of weak rainfall increased regardless of the local time for both types of stations; however, the ratio of increase in weak rainfall was larger for stations exhibiting a positive trend.

3.3 Features of frequency of heavy rainfall

“Heavy rainfall” was defined as an hourly rainfall exceeding 25 mm; however, it is difficult to elucidate the geographical features on the trend of heavy rainfall using a uniform criterion over Japan. Therefore, a linear regression analysis is applied to heavy rainfall exceeding 25 mm h⁻¹ and the maximum correlation coefficient among them is adopted so as to distinguish the stations with a positive trend in heavy rainfall.

Figure 4c shows the distribution of the maximum correlation coefficients for heavy rainfall. The ratios of stations with a positive trend over the Hokkaido district and regions other than Hokkaido are 2.9% and 7.6%, respectively. In other words, heavy rainfall events exhibited a positive trend over regions other than Hokkaido in the past 31 years.

On the other hand, as mentioned above, weak rainfall exhibited a clear positive trend over the Hokkaido district. It is noted that a geographical contrast is evident between the features of the trends exhibited by the two regions.

4. Summary

Features of the frequency of weak rainfall (1–5 mm h⁻¹) during the warm season (June–September) over Japan were investigated using a 31-year AMeDAS dataset (1976–2006). The frequency of weak rainfall increased significantly over the Hokkaido district at a rate of 20–50% over 31 years. However, weak rainfall in regions other than Hokkaido did not exhibit any strong trend.

On the contrary, a positive trend in heavy rainfall (exceeding 25 mm h⁻¹) was dominant in regions other than Hokkaido. A distinct geographical contrast was evident between the features of the trends in the two regions.

In the past 31 years, weak rainfall has accounted for 60% of the increase in the total rainfall amount over the Hokkaido district; this implies that at least in the Hokkaido district, weak rainfall plays an important role in a large-scale water circulation. Considering the social impact and effect of the variation in rainfall on large-scale water circulation, it is evident that weak rainfall cannot be ignored.

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References


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SOLA: http://www.jstage.jst.go.jp/browse/sola/