

# Estimation of Return Level for Maximum Daily and Hourly Precipitation in Nagano Prefecture, Japan, Using the Extreme Value Theory

Fumio Maruyama

Department of Sports and Health Science, Matsumoto University, Matsumoto, Japan  
Email: fmaruya@nagoya-u.jp

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## Abstract

The weather in Nagano Prefecture, Japan, can be roughly classified into four types according to principal component analysis and k-means clustering. We predicted the extreme values of the maximum daily and hourly precipitation in Nagano Prefecture using the extreme value theory. For the maximum daily precipitation, the values of  $\xi$  in Matsumoto, Karuizawa, Sugadaira, and Saku were positive; therefore, it has no upper bound and tends to take large values. Therefore, it is dangerous and caution is required. The values of  $\xi$  in Nagano, Kisofukushima, and Minamishinano were determined to be zero, therefore, there was no upper limit, the probability of obtaining a large value was low, and caution was required. We predicted the maximum return levels for return periods of 10, 20, 50, and 100 years along with respective 95% confidence intervals in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. In Matsumoto, the 100-year return level was 182 mm, with a 95% CI [129, 236]. In Minamishinano, the 100-year return level was 285 mm, with a 95% CI [173, 398]. The 100-year return levels for the maximum daily rainfall were 285, 271, and 271 mm in Minamishinano, Saku, and Karuizawa, respectively, where the changes in the daily maximum rainfall were larger than those at other points. Because these values are large, caution is required during heavy rainfall. The 100-year return levels for the maximum daily and hourly precipitation were similar in Karuizawa and Saku. In Sugadaira, the 100-year return level for a maximum hourly rainfall of 107.2 mm was larger than the maximum daily rainfall. Hence, it is necessary to be careful about short-term rainfall events.

## Keywords

Extreme Value Theory, Maximum Daily and Hourly Precipitation, Principal Component Analysis, K-Means Clustering

## 1. Introduction

We predicted the extreme value of daily maximum precipitation in Nagano Prefecture, Japan, using extreme value theory. Japan has the highest precipitation in the world, but the basins in the northern and central parts of Nagano Prefecture have annual precipitation of less than 1500 mm, which is comparable to Hokkaido and the Seto Inland Sea. In particular, the area from the Nagano Basin to the Ueda/Saku Basin has the second-lowest precipitation after eastern Hokkaido. This is because it is far from the sea, is surrounded by mountains, and is relatively unaffected by typhoons and other fronts. The sunshine hours were highest in the central and southern parts of Nagano Prefecture, Japan. In a normal year, Nagano has 1969.9 h of sunshine, Suwa has 2164.8 h, and Matsumoto has 2134.7 h. The reason for the short hours of sunshine in the northern part of the prefecture is that there are many clouds due to the influence of the winter monsoon, and snow tends to fall.

Extreme value theory (EVT) has emerged as an important statistical discipline in applied science. Extreme value techniques are widely used in many other disciplines. Statistical approaches focused on extreme values have shown promising results in forecasting unusual events in earth sciences, genetics, and finance. For instance, EVT was developed in the 1920s [1] and has been used to predict the occurrence of events such as droughts and flooding [2] or financial crashes [3]. Extreme value modeling has been applied to the fields of ocean wave modeling [4], biomedical data processing [5], earthquake thermodynamics [6], and public health [7].

Applications of extreme value statistics for precipitation can be found [8] [9]. This study predicts the extreme values of maximum daily and hourly precipitation in Nagano Prefecture, Japan, using the extreme value theory.

## 2. Data and Analysis Methods

### 2.1. Data

Maximum daily and hourly precipitation in the Nagano Prefecture, Japan, Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano data from the Automated Meteorological Data Acquisition System (AMeDAS) provided by the Japan Meteorological Agency were used. The average annual precipitation, temperature, wind speed, and sunshine hours in Nagano Prefecture for 1991-2020 were also used. The precipitation, temperature, and wind speed data on October 12, 2019, in Nagano Prefecture were used. The latitude, longitude, and height above sea level at the AMeDAS observation points are listed in **Table 1** and are shown in **Figure 1**.

**Table 1.** Latitude, longitude, and height above sea level of the AMeDAS observation points.

	Latitude	Longitude	Height above sea level (m)
Iiyama	36°52.5'N	138°22.5'E	313
Nagano	36°39.7'N	138°11.5'E	418

## Continued

Omachi	36°31.4'N	137°49.9'E	784
Sugadaira	36°31.9'N	138°19.5'E	1253
Ueda	36°24.0'N	138°15.9'E	502
Karuizawa	36°20.5'N	138°32.8'E	999
Matsumoto	36°14.8'N	137°58.2'E	610
Saku	36°14.8'N	138°28.6'E	683
Suwa	36°2.7'N	138°6.5'E	760
Kisofukushima	35°50.4'N	137°41.3'E	750
Ina	35°49.5'N	137°57.3'E	633
Iida	35°31.4'N	137°49.3'E	516
Minamishinano	35°19.3'N	137°55.9'E	407

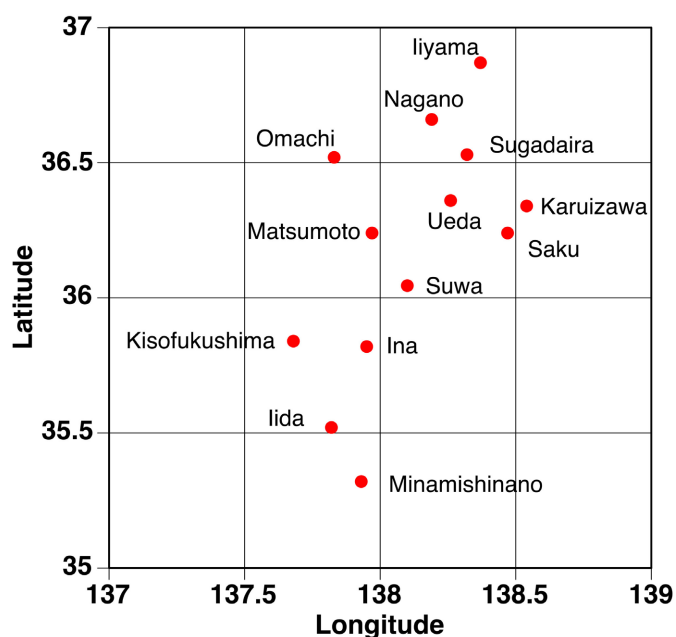


Figure 1. Latitude and longitude of the AMEDAS observation points.

## 2.2. Principal Component Analysis

Principal component analysis (PCA) attempts to recombine many original indexes with certain correlations into a new set of linearly independent comprehensive indexes to replace the original indexes. We performed PCA to derive climate indices that describe the main spatial features of the climate in Nagano Prefecture, Japan, using the average annual precipitation, temperature, wind speed, and sunshine hours for 1991-2020. PCA was calculated using Python.

## 2.3. k-Means Clustering

The k-means clustering method is widely used for weather classification because of its simplicity and speed. Here, k-means clustering was calculated using Python.

## 2.4. Extreme Value Theory (EVT)—Block Maxima Methods

### 2.4.1. General Extreme Value Distributions (GEV)

When data are taken to be the maxima (or minima) over certain blocks of time, as the annual maximum precipitation, it is appropriate to use the generalized extreme value (GEV) distribution as follows:

$$G(z) = \begin{cases} \exp\left\{-\left[1 + \xi\left(\frac{z - \mu}{\sigma}\right)\right]^{-1/\xi}\right\}, \xi \neq 0 \\ \exp\left\{-\exp\left[-\left(\frac{z - \mu}{\sigma}\right)\right]\right\}, \xi = 0 \end{cases} \quad (1)$$

where  $\mu$  is the location parameter,  $\sigma$  is the scale parameter, and  $\xi$  is the shape parameter.  $G$  is defined for all  $z$  values such that  $(1 + \xi(z - \mu)/\sigma) > 0$  for  $\xi \neq 0$  and all  $z$  values for  $\xi = 0$ . Three families of GEV distributions were defined depending on the value of  $\xi$ . For  $\xi > 0$ , we obtain the Fréchet distribution with a heavy tail,  $\xi = 0$ , the Gumbel distribution with a lighter tail, and  $\xi < 0$ , the Weibull distribution with a finite tail.

A classical method for modeling the extremes of a stationary time series is the block maxima method, in which consecutive observations are grouped into non-overlapping blocks of length  $n$ , generating a series of  $m$  block maxima,  $M_{n,1}, \dots, M_{n,m}$ , *i.e.*, to which the GEV distribution can be fitted for a large value of  $n$ . The usual approach involves considering blocks of a given time length, thus yielding maxima at regular intervals [1].

### 2.4.2. Return Levels

Once a GEV distribution has been fitted to empirical observations, it is possible to estimate the probability of an event that has not yet been observed. Estimates of the extreme quantiles of the annual maximum distribution were obtained by inverting Equation (1) as follows:

$$z_p = \begin{cases} \mu - \frac{\sigma}{\xi} \left[1 - \{-\log(1 - p)\}^{-\xi}\right], \xi \neq 0 \\ \mu - \sigma \log\{-\log(1 - p)\}, \xi = 0 \end{cases} \quad (2)$$

Here,  $G(z_p) = 1 - p$ . The return level  $z_p$  is associated with the return period  $1/p$ . Because of a reasonable degree of accuracy, the level  $z_p$  is expected to exceed on average once every  $1/p$  year. More precisely,  $z_p$  is exceeded by the annual maximum in any particular year with probability  $p$  [1].

Modeling was performed using the `evd` and `ismev` packages in R for GEV calculations.

## 3. Results and Discussion

### 3.1. The Weather in Nagano Prefecture

The explained variances and loadings of the first two principal components cal-

culated from annual average precipitation, temperature, wind speed, and sunshine hours data for 1991-2020 in Iiyama, Nagano, Omachi, Sugadaira, Ueda, Karuizawa, Matsumoto, Saku, Suwa, Kisofukushima, Ina, Iida, and Minamishinano are shown in **Table 2(a)**. The first and second principal components explained 74.7% of the variance. **Figure 2** shows a principal component analysis (PCA) biplot diagram for height above sea level, average sunshine hours, temperature, annual precipitation, and wind speed. The relationship between each principal component and each feature is indicated by an arrow. The larger the dot product between the axis corresponding to the principal component and the arrow corresponding to the feature, the greater the correlation between the principal component and the feature. In the PCA results, the sunshine hours and wind speed exhibit the same trend because the red arrows are close together. The red arrows are almost in the opposite direction, so precipitation and sunshine hours (wind speed) have opposite trends. Temperature and height above sea level have opposite trends. The lower the height, the higher the temperature, and the more precipitation, the shorter the sunshine hours. **Table 3(a)** shows a strong inverse correlation between height and temperature ( $r = -0.89$ ). There was an inverse correlation between annual precipitation and sunshine hours ( $r = -0.57$ ). There was a correlation between wind speed and sunshine hours ( $r = 0.42$ ).

**Table 2.** (a) Explained variance and loadings of the first two principal components calculated from height above sea level, average sunshine hours, temperature, annual precipitation, and wind speed for 1991-2020 in Iiyama, Nagano, Omachi, Sugadaira, Ueda, Karuizawa, Matsumoto, Saku, Suwa, Kisofukushima, Ina, Iida, and Minamishinano. (b) Explained variance and loadings of the first two principal components calculated from average annual precipitation, maximum daily precipitation, and maximum hourly precipitation for 1991-2020.

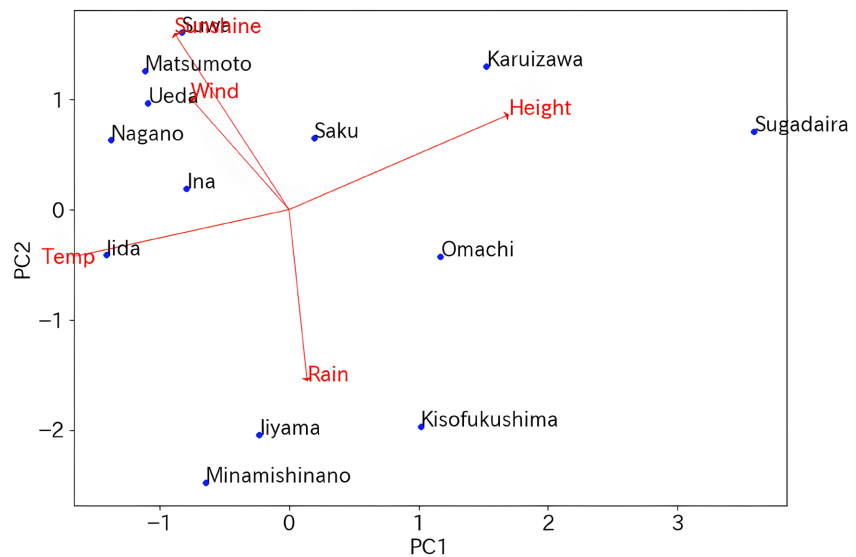
(a)		
	PC1	PC2
Height above sea level (m)	0.848	0.431
Average sunshine hours (h)	-0.443	0.802
Average temperature (°C)	-0.957	-0.246
Average annual precipitation (mm)	0.0701	-0.780
Wind speed (m/s)	-0.380	0.505
Proportion of variance	0.483	0.394
(b)		
	PC1	PC2
Annual precipitation (mm)	-0.896	-0.342
Maximum daily precipitation (mm)	-0.927	-0.190
Maximum hourly precipitation (mm)	-0.790	0.611
Proportion of variance	0.762	0.175

**Table 3.** (a) Correlation coefficient between features in **Table 2(a)**. (b) Correlation coefficient between features in **Table 2(b)**.

(a)					
Height	1	0.04	-0.89	-0.10	-0.01
Sunshine	0.04	1	0.28	-0.57	0.42
Temperature	-0.89	0.28	1	0.15	0.18
Precipitation	-0.10	-0.57	0.15	1	-0.11
Wind	-0.01	0.42	0.18	-0.11	1
	Height	Sunshine	Temperature	Precipitation	Wind

(b)			
Annual precipitation	1	0.80	0.51
Max daily	0.80	1	0.60
Max hourly	0.51	0.60	1
	Annual precipitation	Max daily	Max hourly

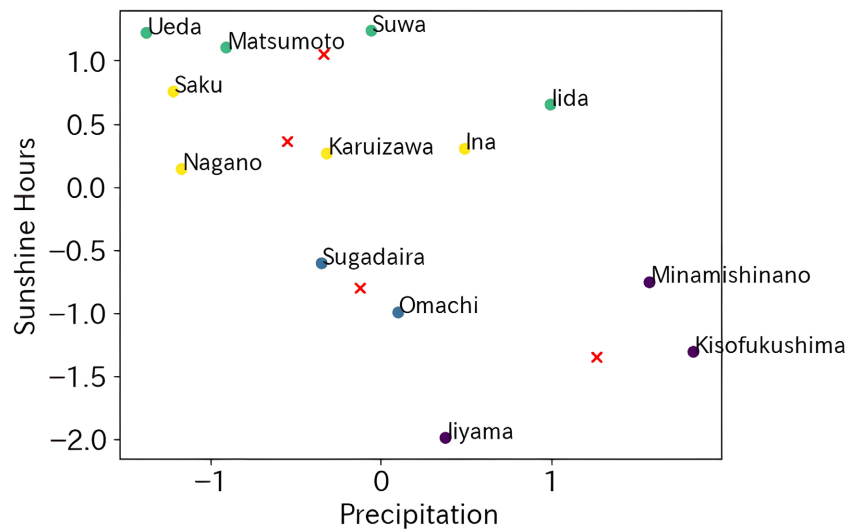


**Figure 2.** Principal component analysis (PCA) biplot diagram for average annual precipitation, temperature, sunshine hours, wind speed, and height above sea level for 1991-2020. The relationship between each principal component and each feature is indicated by an arrow. The larger the dot product between the axis corresponding to the principal component and the arrow corresponding to the feature, the greater the correlation between the principal component and the feature.

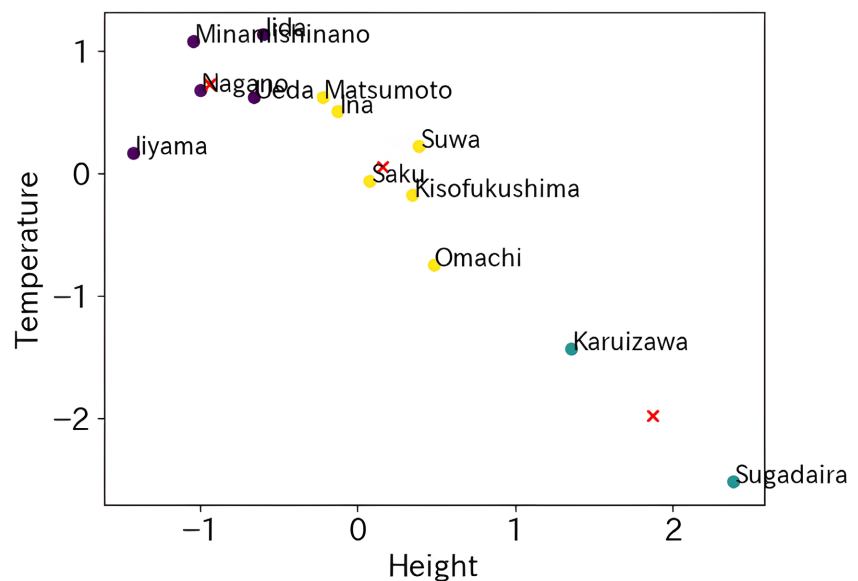
The k-means clustering of the annual precipitation and sunshine hours is shown in **Figure 3**. It can be classified into four types: high precipitation and low sunshine hours (Kisofukushima, Minamishinano, Iiyama), normal precipitation and low sunshine hours, low precipitation and high sunshine hours (Ueda, Matsumoto, Suwa, Iida), and low precipitation and normal sunshine hours.

The k-means clustering of the height above sea level and annual temperature is shown in **Figure 4**. It is clear that the higher the height, the lower the temperature. It can be classified into three types: high height and low temperature

(Sugadaira, Karuizawa), normal height and normal Temperature, and low height and high Temperature (Iiyama, Minamishinano, Nagano, Iida, Ueda).



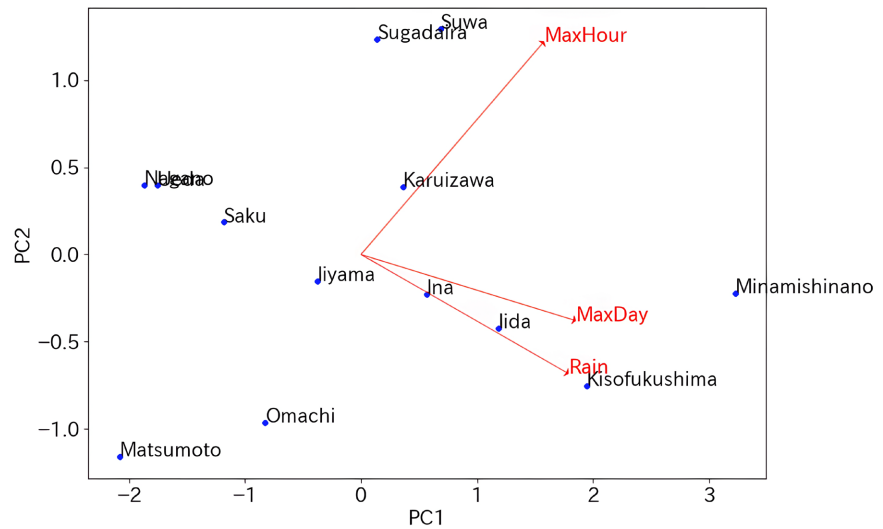
**Figure 3.** The k-means clustering of average annual precipitation and sunshine hours. x is the centroid of each cluster.



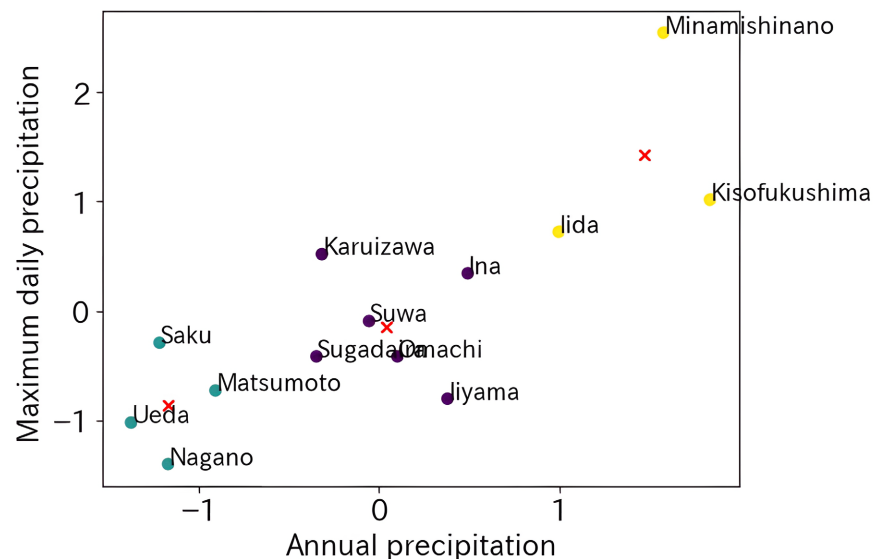
**Figure 4.** The k-means clustering of height above sea level and average annual Temperature. x is the centroid of each cluster.

The explained variances and loadings of the first two principal components calculated for average annual, maximum daily, and maximum hourly precipitation data for 1991-2020 in Iiyama, Nagano, Omachi, Sugadaira, Ueda, Karuizawa, Matsumoto, Saku, Suwa, Kisofukushima, Ina, Iida, and Minamishinano are shown in **Table 2(b)**. The first and second principal components explained 93.7% of the variance. **Figure 5** shows a principal component analysis (PCA) biplot diagram for the studied variables. The PCA results showed that the annual

and maximum daily precipitation tended to follow the same pattern, but the maximum hourly precipitation differed. Even if the annual precipitation is low, some places (Suwa, Sugadaira) have high maximum hourly precipitation, while others have low maximum one. In Minamishinano and Kisofukushima, both annual and maximum daily precipitation were large. **Table 3(b)** shows a strong correlation between annual and maximum daily precipitation ( $r = 0.80$ ). There was also a correlation between annual precipitation and maximum hourly precipitation ( $r = 0.51$ ). There was a correlation between maximum daily precipitation and maximum hourly precipitation ( $r = 0.60$ ).



**Figure 5.** Principal component analysis (PCA) biplot diagram for average annual (Rain), maximum daily (MaxDay), and maximum hourly precipitation (MaxHour) for 1991-2020. The relationship between each principal component and each feature is indicated by an arrow.

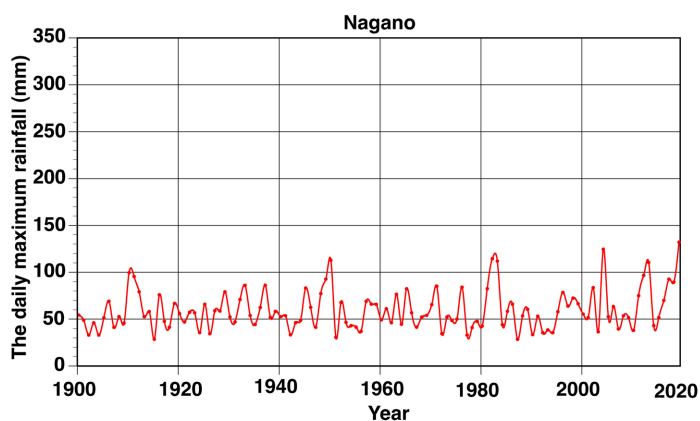


**Figure 6.** The k-means clustering of average annual and maximum daily precipitation. x is the centroid of each cluster.

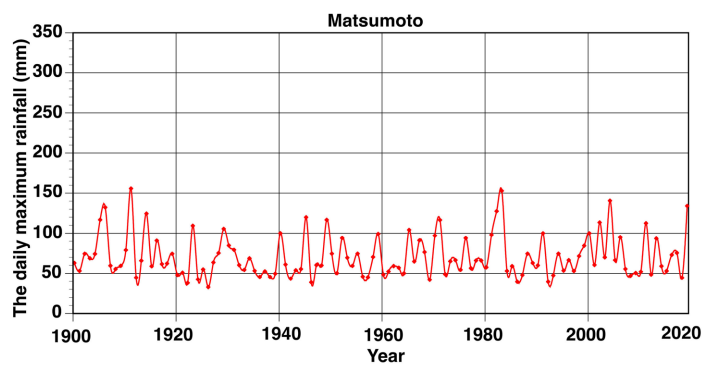
The k-means clustering of the annual and maximum daily precipitation data is shown in **Figure 6**. The greater the annual precipitation, the greater the maximum daily precipitation. The locations were classified into three categories: locations with high annual and maximum daily precipitation (Minamishinano, Kisofukushima, Iida), locations with normal annual and normal maximum daily precipitation, and locations with low annual and low maximum daily precipitation (Nagano, Ueda, Matsumoto, Saku).

### 3.2. The Maximum Daily and Hourly Precipitation

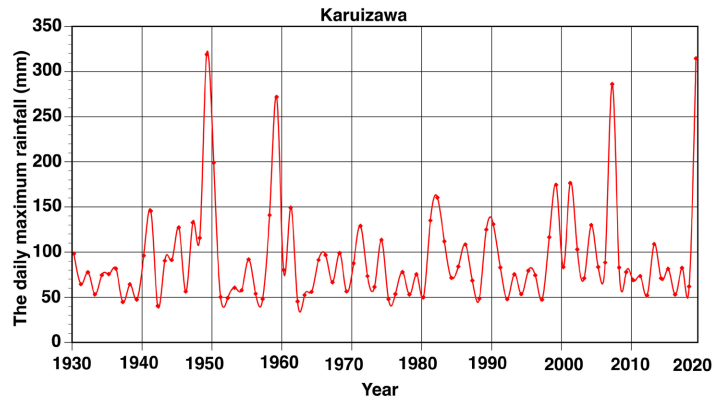
Maximum daily precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano are shown in **Figure 7**. The changes in Karuizawa, Saku, and Minamishinano were larger than those in the other points. The peak in 2019 was on October 12, when Typhoon HAGIBIS (T1919) occurred. **Figure 8** shows the daily precipitation versus average wind speed in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano on October 12, 2019. The weather at the seven locations can be roughly classified into four types based on the precipitation and wind speed. Saku and Sugadaira have high rainfall and low wind speed. Karuizawa have high precipitation and wind speeds. Minamishinano and Kisofukushima receive little precipitation and low wind speeds. Matsumoto and Nagano experienced little precipitation and high wind speeds.



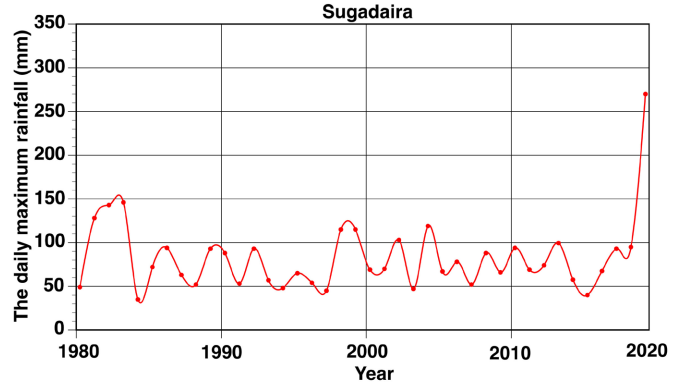
(a) Nagano



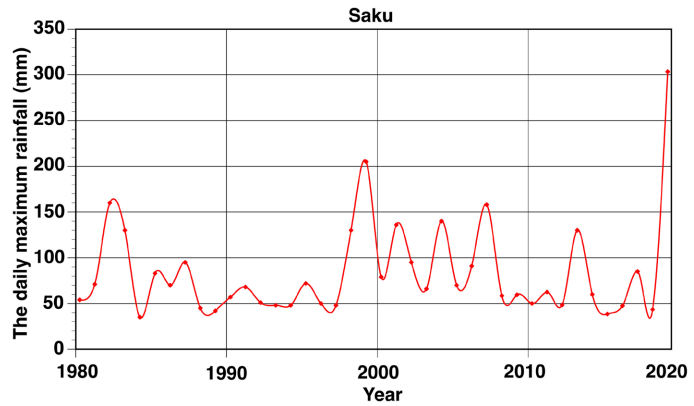
(b) Matsumoto



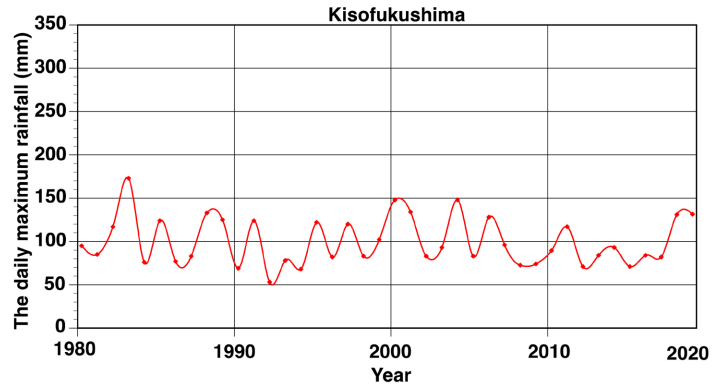
(c) Karuizawa



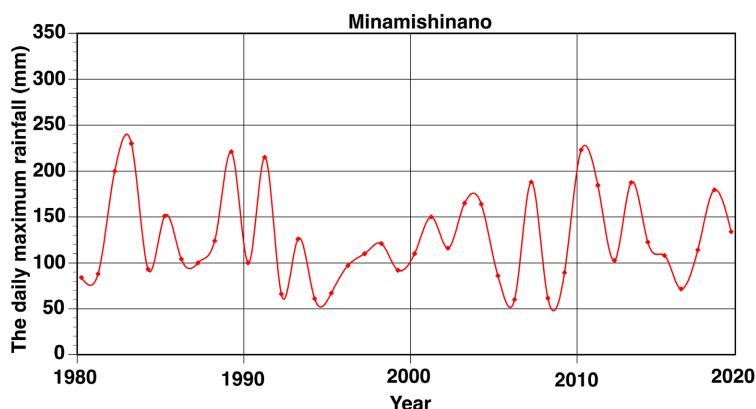
(d) Sugadaira



(e) Saku



(f) Kisofukushima



(g) Minamishinano

Figure 7. Plots of the maximum daily precipitation in Nagano (a), Matsumoto (b), Karuizawa (c), Sugadaira (d), Saku (e), Kisofukushima (f), and Minamishinano (g).

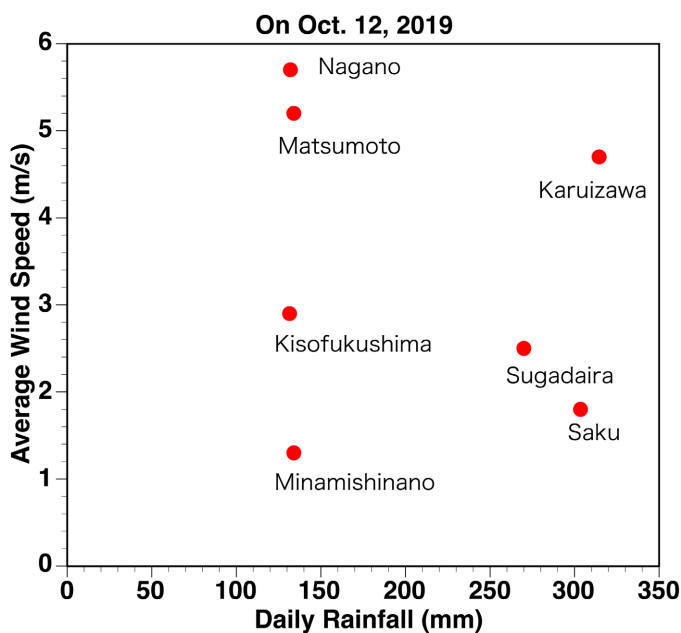
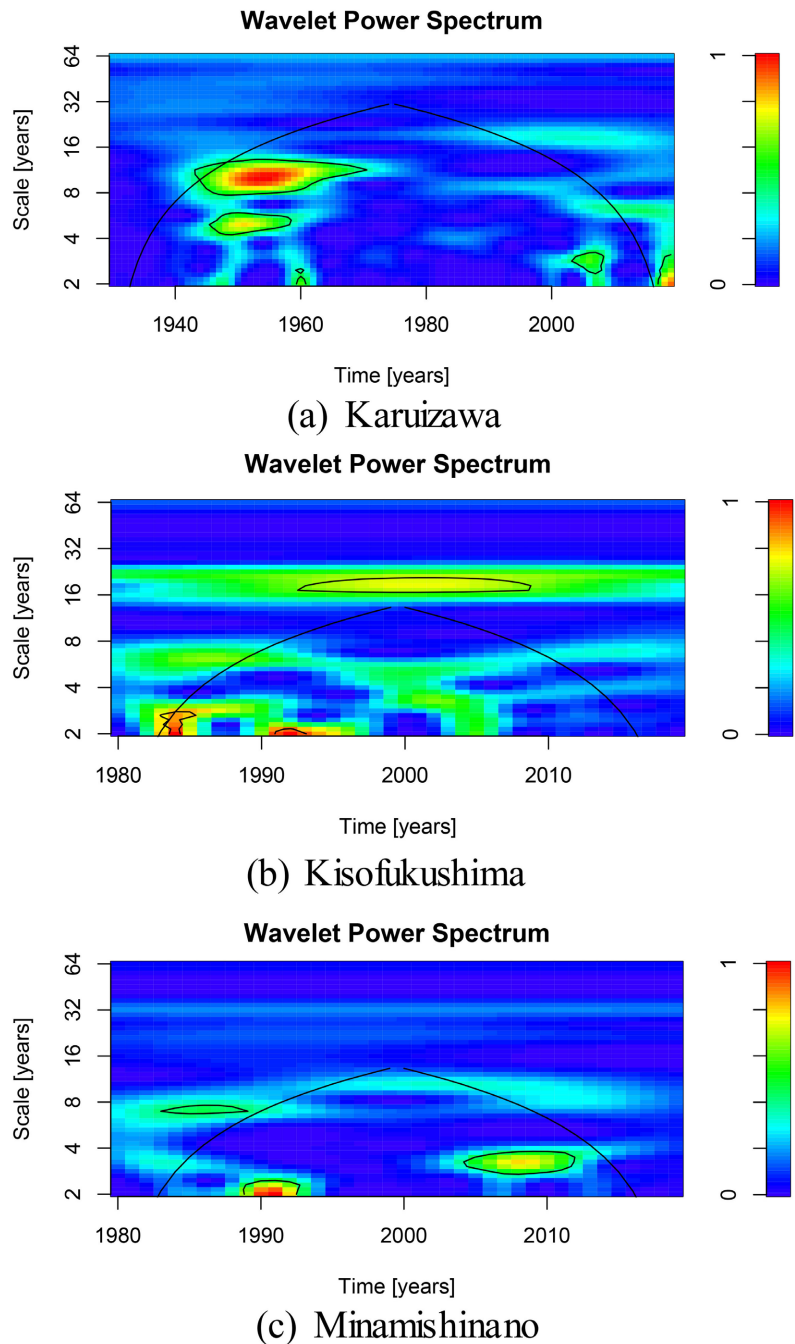


Figure 8. Daily precipitation versus average wind speed in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano on October 12, 2019.

Figure 9 shows the wavelet power spectra of the maximum daily precipitation in Karuizawa, Kisofukushima, and Minamishinano, where the characteristic periodicity was observed in some periods. In Karuizawa, for 1940-1960, a strong periodicity of eight years was observed. In Kisofukushima, for 1991-1992, two years were observed. In Minamishinano, two years were observed between 1990 and 1991.

Table 4 shows the results of GEV modeling for the maximum daily precipitation in Matsumoto using the block maxima method. The GEV parameters were estimated using maximum likelihood estimation (MLE). The model has three parameters: the location parameter  $\mu$ , scale parameter  $\sigma$ , and shape parameter  $\xi$ . As  $\xi$  was positive, the daily maximum rainfall did not have a finite upper limit.

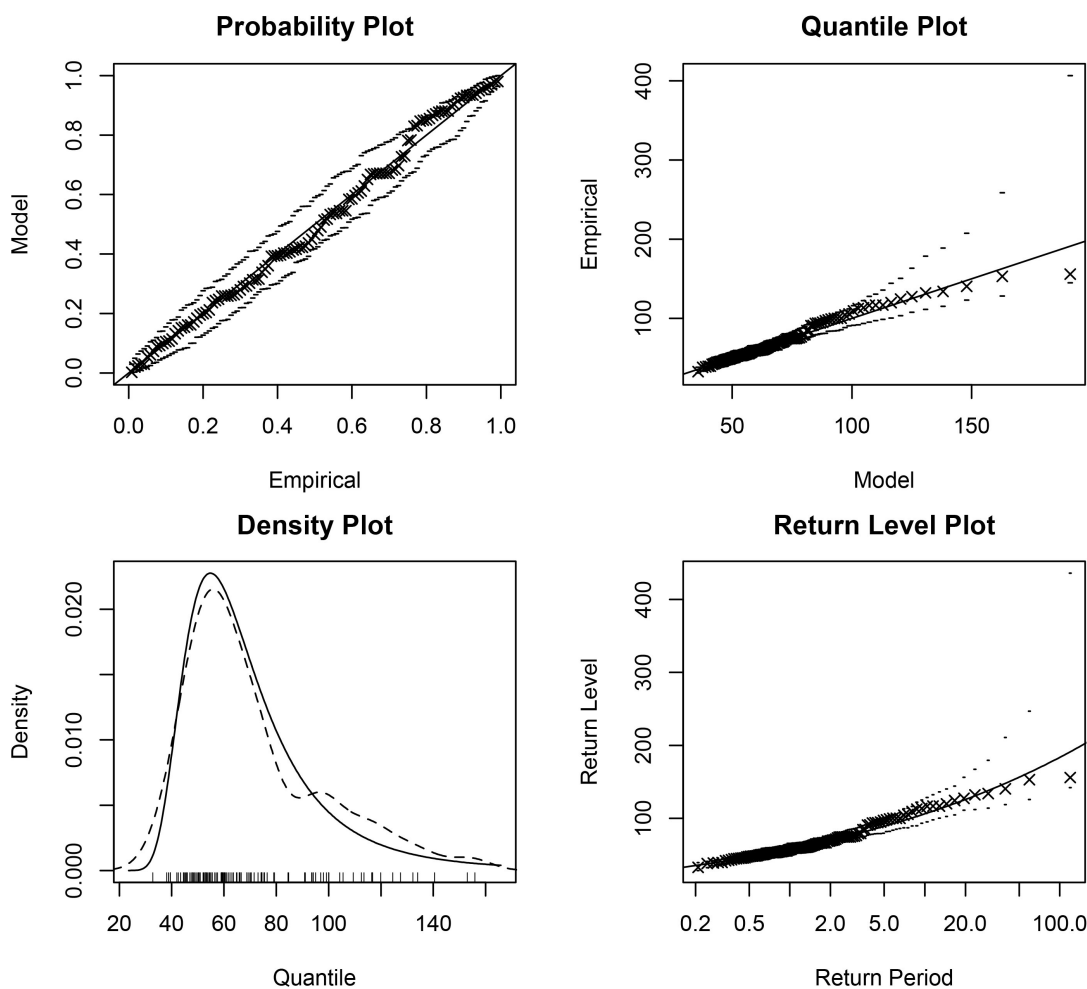
The various diagnostic plots for assessing the accuracy of the GEV model fitted to the daily maximum precipitation in Matsumoto are shown in **Figure 10**. Neither the probability plot nor the quantile plot doubts the validity of the fitted model: each set of plotted points is near-linear. In the return level curve, the estimated curve is not linear because  $\xi$  is not close to zero. Finally, the corresponding density estimates appeared to be consistent with the data. Consequently, all four diagnostic plots support the fitted GEV model.



**Figure 9.** Wavelet power spectra of the maximum daily precipitation in Karuizawa (a), Kisofukushima (b), and Minamishinano (c).

**Table 4.** GEV parameter estimates for the maximum daily precipitation in Matsumoto.

	$\mu$	$\sigma$	$\xi$
Parameter estimate	57.8	16.5	0.204
Standard errors	1.73	1.38	0.0804
95% CI	[54.4, 61.2]	[13.8, 19.2]	[0.0462, 0.361]

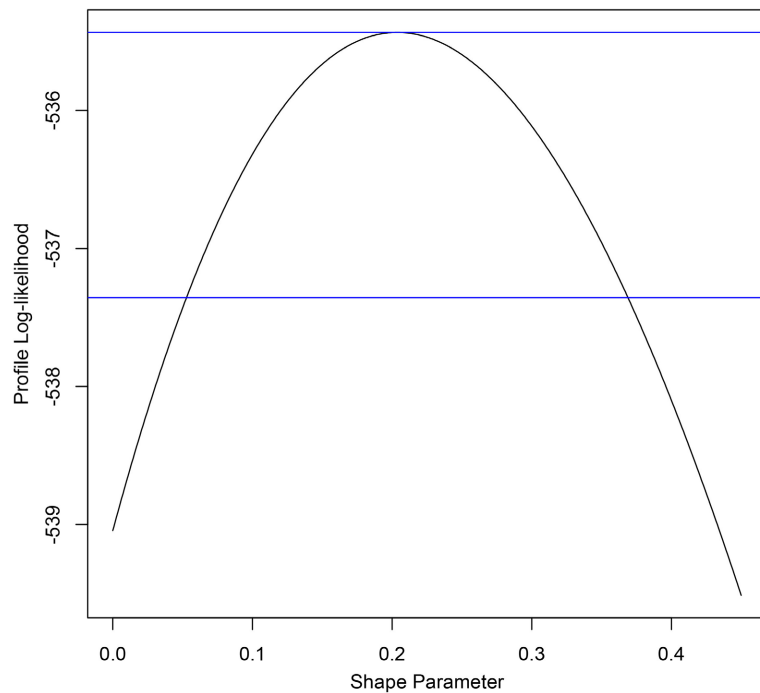


**Figure 10.** Diagnostic plots for GEV fit to the maximum daily precipitation in Matsumoto.

A greater accuracy of confidence intervals can usually be achieved using the profile likelihood. **Figure 11** shows the profile log-likelihood for  $\xi$  in Matsumoto, where  $\xi$  is estimated to be 0.203 with a 95% confidence interval (CI) [0.0514, 0.367], which is only slightly different from the earlier calculation, as shown in **Table 3**. Because  $\xi > 0$ , the maximum daily rainfall does not have a finite upper limit, and it is not useful to perform a detailed inference of the upper limit. Instead, we focus on the extreme return levels. **Figure 11** shows the symmetry of the profile log-likelihood surface.

**Table 5** shows the  $\xi$  for the maximum daily precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. The

values of  $\xi$  in Matsumoto, Karuizawa, Sugadaira, and Saku were positive, therefore, it has no upper bound and tends to take large values, which is dangerous, and caution is required. The values of  $\xi$  in Nagano, Kisofukushima, and Minamishinano were close to zero and included zero as a confidence interval, therefore, we determined it to be zero. Hence, there is no upper limit; thus, the probability of obtaining a large value is low, and caution is required.



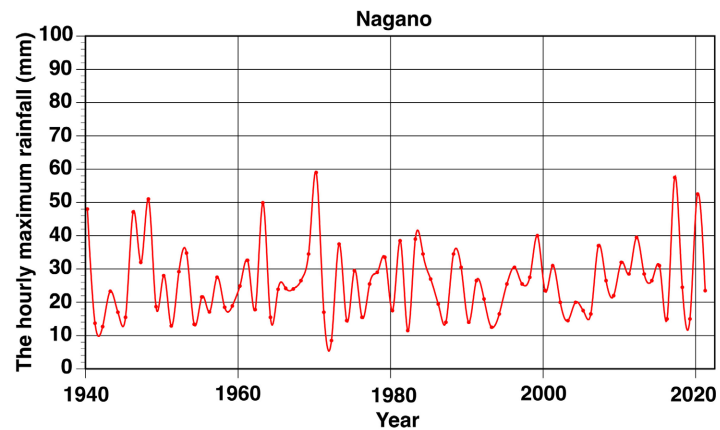
**Figure 11.** Profile likelihood for  $\xi$  in the maximum daily precipitation in Matsumoto.

**Table 5.**  $\xi$  for the maximum daily precipitation.

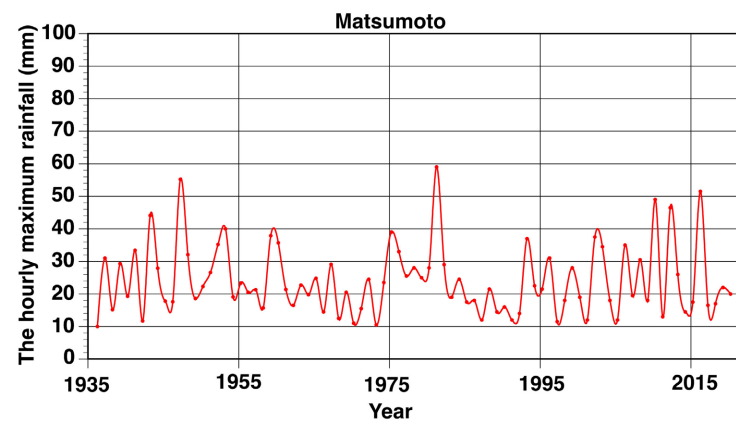
	$\xi$	Standard errors	95% CI
Nagano	0.0944	0.0817	[-0.0657, 0.2545]
Matsumoto	0.204	0.0804	[0.0462, 0.361]
Karuizawa	0.450	0.121	[0.212, 0.687]
Sugadaira	0.242	0.140	[-0.0319, 0.515]
Saku	0.514	0.172	[0.177, 0.852]
Kisofukushima	0.0139	0.158	[-0.296, 0.324]
Minamishinano	0.0400	0.175	[-0.303, 0.383]

Maximum hourly precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano are shown in **Figure 12**. **Table 6** shows  $\xi$  for the maximum hourly precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. The values of  $\xi$  in Matsumoto, and Sugadaira were positive, therefore, it has no upper bound and

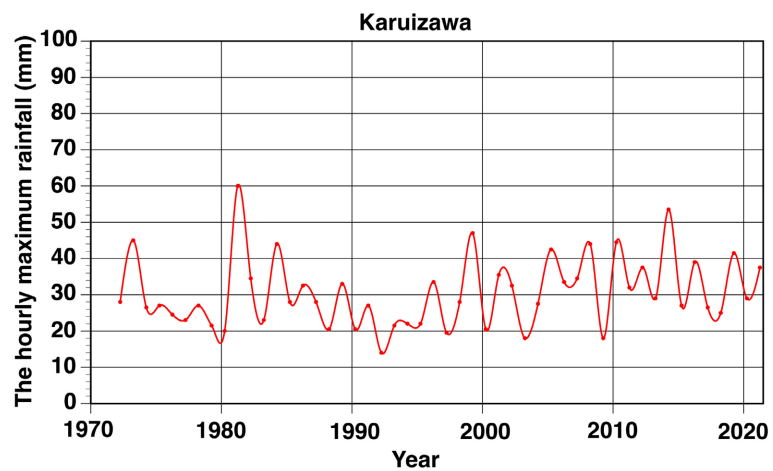
tends to take large values, which is dangerous, and caution is required. The values of  $\xi$  in Nagano, Karuizawa, Saku, Kisofukushima, and Minamishinano were close to zero and included zero as a confidence interval, therefore, we determined it to be zero. Hence, there is no upper limit; thus, the probability of obtaining a large value is low, and caution is required.



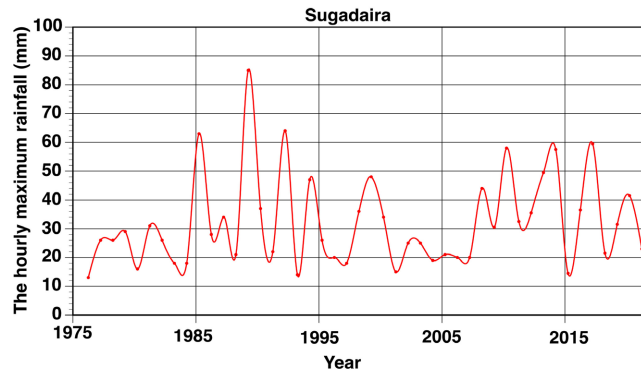
(a) Nagano



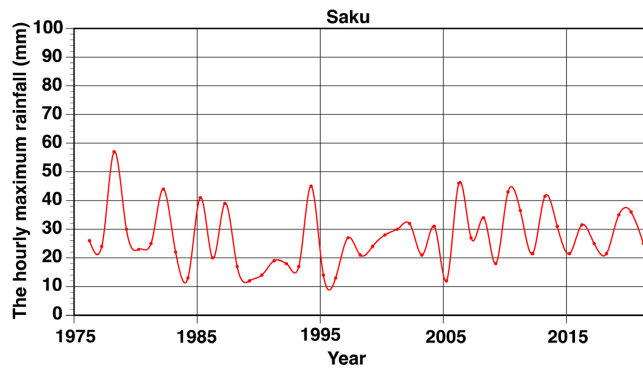
(b) Matsumoto



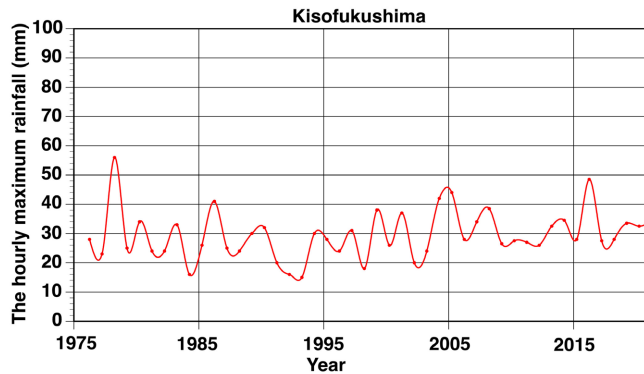
(c) Karuizawa



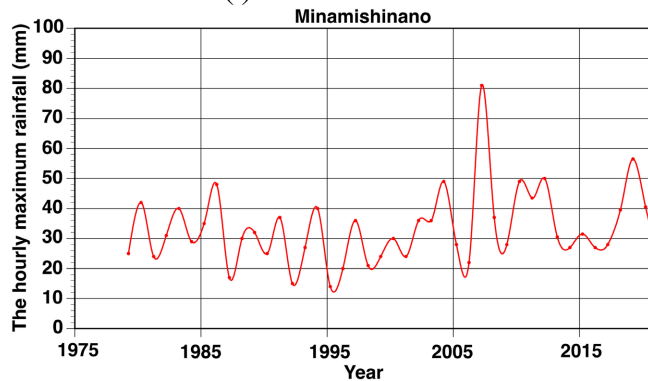
(d) Sugadaira



(e) Saku



(f) Kisofukushima



(g) Minamishinano

**Figure 12.** Plots of the maximum hourly precipitation in Nagano (a), Matsumoto (b), Karuizawa (c), Sugadaira (d), Saku (e), Kisofukushima (f), and Minamishinano (g).

**Table 6.**  $\xi$  for the maximum hourly precipitation.

	$\xi$	Standard errors	95% CI
Nagano	0.0591	0.0995	[-0.136, 0.254]
Matsumoto	0.163	0.110	[-0.0519, 0.378]
Karuizawa	0.00899	0.120	[-0.227, 0.245]
Sugadaira	0.291	0.166	[-0.0333, 0.616]
Saku	-0.0276	0.140	[-0.302, 0.247]
Kisofukushima	-0.0829	0.0932	[-0.265, 0.0997]
Minamishinano	0.00692	0.0979	[-0.185, 0.199]

**Table 7** shows the predicted maximum return levels for the maximum daily precipitation for return periods of 10, 20, 50, and 100 years along with their respective 95% CI in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. In Matsumoto, the 10-year return level was estimated to be 106 mm, with 95% CI [93.1, 119]. The 100-year return level was 182 mm, with 95% CI [129, 236]. Another way to interpret the plot is to say that there is approximately a 1% chance (1/100) each year that the magnitude of the maximum daily precipitation will exceed 182 mm. There is an approximately 10% chance (1/10) each year that the magnitude of the maximum daily precipitation will exceed 106.

**Table 7.** (a) GEV return level estimates for the maximum daily precipitation in Nagano. (b) GEV return level estimates for the maximum daily precipitation in Matsumoto. (c) GEV return level estimates for the maximum daily precipitation in Karuizawa. (d) GEV return level estimates for the maximum daily precipitation in Sugadaira. (e) GEV return level estimates for the maximum daily precipitation in Saku. (f) GEV return level estimates for the maximum daily precipitation in Kisofukushima. (g) GEV return level estimates for the maximum daily precipitation in Minamishinano.

(a)				
Return period (year)	10	20	50	100
Return level (mm)	87.6	102	121	136
Standard errors	4.43	6.90	11.8	16.4
95% CI	[78.9, 96.3]	[88.1, 115]	[98.0, 144]	[104, 168]
(b)				
Return period (year)	10	20	50	100
Return level (mm)	106	125	155	182
Standard errors	6.63	10.2	18.1	27.3
95% CI	[93.1, 119]	[105, 145]	[120, 191]	[129, 236]
(c)				
Return period (year)	10	20	50	100
Return level (mm)	157	202	272	271

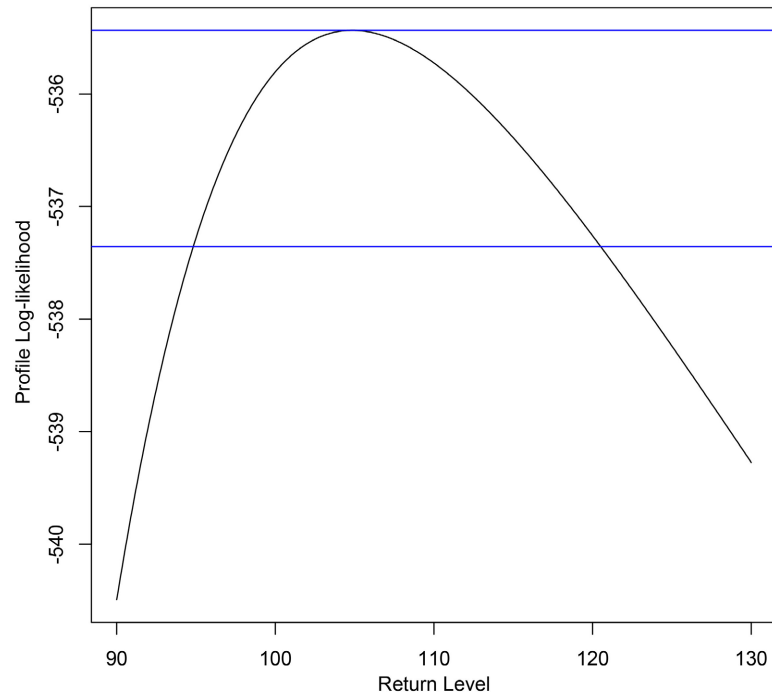
## Continued

Standard errors	18.2	29.8	53.0	39.9
95% CI	[121, 193]	[143, 260]	[168, 376]	[193, 349]
(d)				
Return period (year)	10	20	50	100
Return level (mm)	126	158	194	217
Standard errors	14.6	26.5	39.2	46.9
95% CI	[97.8, 155]	[106, 210]	[117, 271]	[125, 309]
(e)				
Return period (year)	10	20	50	100
Return level (mm)	150	191	249	271
Standard errors	30.0	43.2	60.8	69.7
95% CI	[91.1, 209]	[106, 275]	[129, 368]	[135, 408]
(f)				
Return period (year)	10	20	50	100
Return level (mm)	137	153	174	190
Standard errors	9.41	14.2	22.9	33.1
95% CI	[119, 155]	[125, 181]	[129, 218]	[125, 255]
(g)				
Return period (year)	10	20	50	100
Return level (mm)	193	221	259	285
Standard errors	17.2	25.2	43.0	57.2
95% CI	[159, 227]	[172, 270]	[175, 344]	[173, 398]

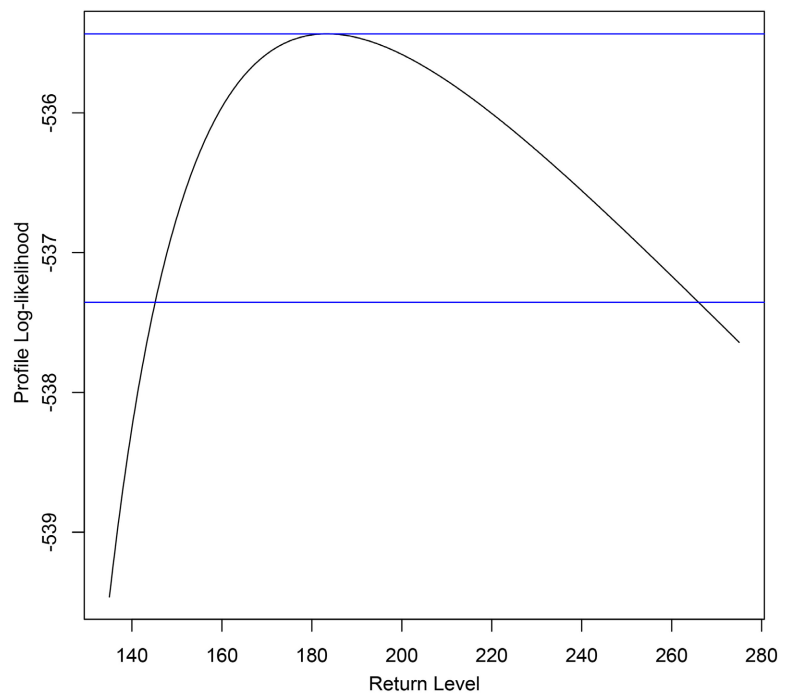
The better accuracy is due to the profile likelihood. **Figure 13** and **Figure 14** show the profile log-likelihood for the 10- and 100-year return levels for the maximum daily rainfall in Matsumoto, respectively. The surface is highly asymmetric, reflecting the greater uncertainty associated with large processes. From **Figure 12**, Matsumoto obtained the 10-year return level as 105 mm, with a 95% CI—obtained at the intercept with the drawn horizontal line—[94.5, 121]. As shown in **Figure 12**, the 100-year return level is 183 mm, with a 95% CI of [145, 266], which is similar to an earlier calculation. These results differ slightly from those of earlier calculations.

**Figure 15** shows the return period versus return level for Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. It can be divided into Minamishinano, Karuizawa, and Saku with high return levels, and Sugadaira, Kisofukushima, Matsumoto, and Nagano with low return levels. The 100-year return levels were 285, 271, and 271 mm in Minamishinano, Saku, and Karuizawa, respectively, where the changes in maximum daily precipitation were

large. The maximum daily precipitation in Japan was 922.5 mm in Hakone, Kanagawa Prefecture on October 12, 2019. Karuizawa's maximum 10-min rainfall was 38.5 mm on August 2, 1960, ranking tenth in Japan.



**Figure 13.** Profile likelihood for 10-year return level in the maximum daily precipitation in Matsumoto.



**Figure 14.** Profile likelihood for 100-year return level in the maximum daily precipitation in Matsumoto.

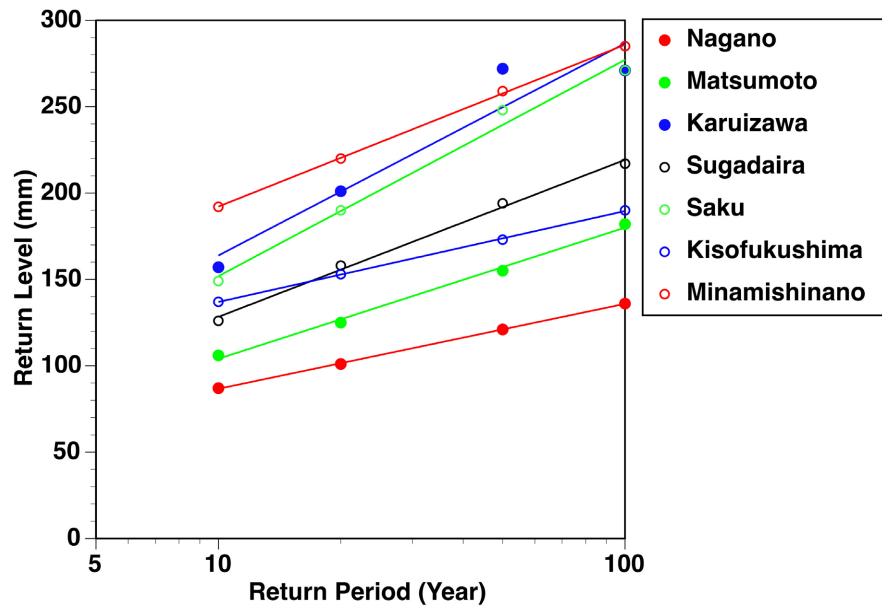


Figure 15. The return period versus return level for the maximum daily precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano.

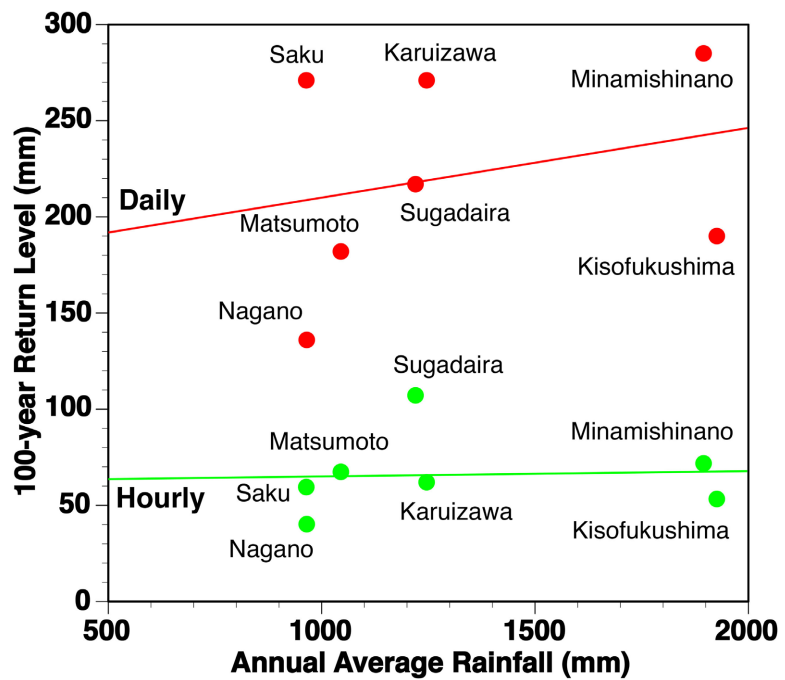


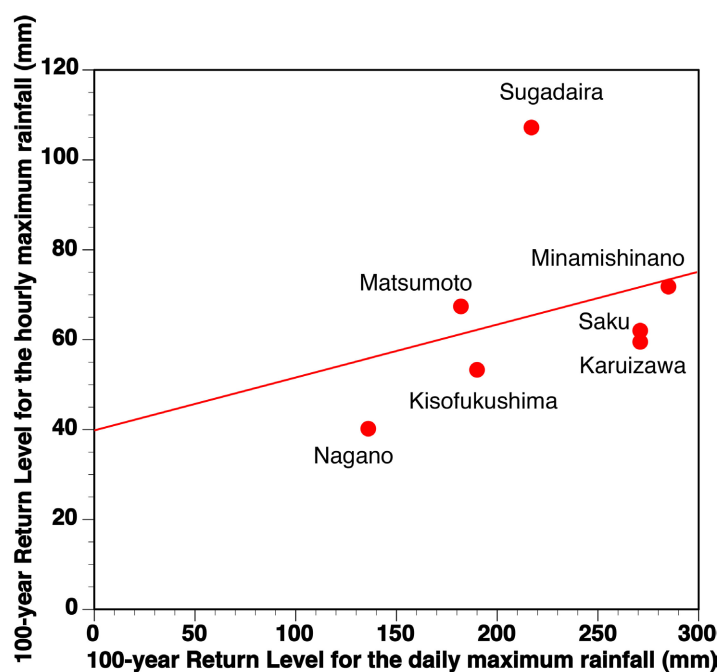
Figure 16. The average annual precipitation versus the 100-year return level for the maximum daily and hourly precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano.

Figure 16 shows the average annual precipitation versus the 100-year return level for the maximum daily and hourly precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. Regarding the average monthly precipitation, only in Minamishinano and Kisofukushima, precipitation in June and July (rainy season) is significantly higher than that in Sep-

tember and October (autumn rainy season). At the other five points, precipitation was almost the same in both seasons. These are some of the reasons why Minamishinano and Kisofukushima experienced high precipitation. Because Minamishinano, Karuizawa, and Saku have large 100-year return levels for the daily maximum rainfall, caution is required against heavy rainfall. Especially, in Saku and Karuizawa the annual average precipitation was low, but the 100-year return levels were high. The 100-year return levels for maximum hourly precipitation showed a smaller variance.

**Table 8.** The 100-year return level for the maximum hourly precipitation.

	100-year level (mm)	Standard errors	95% CI
Nagano	40.2	2.62	[35.1, 45.3]
Matsumoto	67.4	13.3	[41.3, 93.4]
Karuizawa	62.0	9.19	[44.0, 80.0]
Sugadaira	107.2	36.6	[35.6, 178.9]
Saku	59.5	10.1	[39.7, 79.3]
Kisofukushima	53.3	5.21	[43.1, 63.5]
Minamishinano	71.8	10.2	[51.8, 91.8]



**Figure 17.** The 100-year return level for the maximum daily precipitation versus the maximum hourly precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano.

**Table 8** shows the 100-year return levels for maximum hourly precipitation in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. The 100-year return level was 107.2 mm in Sugadaira, where the changes in maximum hourly precipitation were large. **Figure 17** shows the 100-year re-

turn level for the maximum daily precipitation versus the maximum hourly precipitation for Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. Both were almost proportional, and the values were similar for Karuizawa and Saku. In Sugadaira, the 100-year return level for the maximum hourly precipitation (107.2 mm) was larger than that for the maximum daily precipitation. Hence, it is necessary to be very careful about short-term precipitation. The maximum hourly precipitation in Japan was 153 mm on October 27, 1999, in Katori, Chiba Prefecture, and 153 mm on July 23, 1982, in Nagauradake, Nagasaki Prefecture.

#### 4. Conclusions

The weather in Nagano Prefecture, Japan, can be roughly classified into four types based on principal component analysis and k-means clustering. We predicted the extreme values of the maximum daily and hourly precipitation in Nagano Prefecture using the extreme value theory.

1) For the maximum daily rainfall, the values of  $\xi$  in Matsumoto, Karuizawa, Sugadaira, and Saku were positive; therefore, it has no upper bound and tends to take large values. Therefore, it is dangerous and caution is required. The values of  $\xi$  in Nagano, Kisofukushima, and Minamishinano were determined to be zero, therefore, there was no upper limit, the probability of obtaining a large value was low, and caution was required.

2) We predicted the maximum return levels for return periods of 10, 20, 50, and 100 years along with respective 95% CI in Nagano, Matsumoto, Karuizawa, Sugadaira, Saku, Kisofukushima, and Minamishinano. In Matsumoto, the 100-year return level was 182 mm, with a 95% CI [129, 236]. In Minamishinano, the 100-year return level was 285 mm, with a 95% CI [173, 398].

3) The 100-year return levels for maximum daily precipitation were 285, 271, and 271 mm in Minamishinano, Saku, and Karuizawa, respectively, and the changes in the maximum daily precipitation were larger than those at other points. Because these values are large, caution is required for heavy precipitation. The 100-year return levels for maximum daily and hourly precipitation were similar in Karuizawa and Saku.

4) In Sugadaira, the 100-year return level for a maximum hourly rainfall of 107.2 mm was larger than the maximum daily precipitation. Hence, it is necessary to be careful about short-term precipitation events.

#### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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