Secular Variations of the Rainfall in Japan

by

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Abstract

In order to study the secular variations of various rainfall amounts quantitatively, the next three methods are taken into consideration;

- a. Trend inspection based on rank correlational procedure.
- b. Fitting the orthogonal polynomials to secular variation.
- c. Statistical quantities showing variability and persistence.

Yearly, monthly and special rainfall amounts were statistically analysed by using the electronic computer, and we obtained the following main results through geographical comparison of the statistical quantities:

- (i) Over the whole area of Japan, there are more widely increasing regions than decreasing regions.
- (ii) Conspicuous increasing trends can be seen at Kyūshū and Shikoku districts.
- (iii) Both increasing and decreasing trends are seen disorder at Tōhoku and Hokuriku districts, and rather apparent increasing regions in snow-fall amount are scattered over these districts.
- (iv) Decreasing trend can be seen at Kantō district for any kinds of rainfall amounts on the whole.

As a result, the qualitative explanations hitherto put forward by several authors have been revised quantitatively and more in detail, and some of them are more or less corrected in this paper.

1. Introduction

In the study of secular variations, E. BRÜCKNER (1890) must be first mentioned as a forerunner. It was he who was the first to find out the so called "BRÜCKNER periodicity" indicating the 35.5 year periodical change by use of long range records of the water level observed at the Caspian Sea.

H. THIELEBEIN (1933) applied the method of G. HELLMANN (1908) for secular variation of annual rainfall amounts in Europe, and the various contributions due to W. KÖPPEN (1928), WAGNER (1928) and SCHERHAG (1936) etc. are mostly concerned with the verification of explanation possibility for climatic secular variation based on the idea of zonal index (large scale gradient of pressure field over the northern hemisphere), in view of the general circulation. These studies however didn't deal with the secular variation of rainfall directly but were considered as quite suggestive in investigating the mechanism of rainfall variation generally.

H.C. WILLET (1950) tried to explain the various periodicities noticed in secular

rainfall variations by annual change of both low index type and high-index type specified by the meteorological character of the general circulation, but consideration of geographical conditions was not always adequate in his study. On the other hand, in Japan, T. YAMAMOTO (1950) studied the long range variation of rainfall in the Far Eastern Asia mainly based on the collected reports of the older rainfall data at Keijō collected by Y. WADA (1907).

M. OGAWARA, T. OZAWA, E. SUZUKI, T. FUJITA and K. TOMATSU (1952) investigated somewhat systematically on the climatic variation since the commencement of routine observation (from 1900 to 1950) by use of several modern statistical procedures and the present author taking charge of statistical study of rainfall variations, and verifying the secular variations of monthly rainfall amounts at Sapporo, Tokyo and Fukuoka in January and August mainly by use of five year and ten year simple averages and orthogonal polynomials fitting to these averaged variations. However the author's results gained in this collaborative research (1952) are now considered inadequate in view of both the number of stations and the period observed.

H. ARAKAWA (1958) studied climatic variation based on the posthumous work of S. FUJIWHARA (1955) which he edited and sent to the world, but his study is hardly concerned with the secular variation within our period. K. TAKAHASHI (1956) took up several periodicities supposedly presented in secular variations of monthly amounts at representative points (Tokyo, Matsumoto and Niigata etc.) by use of periodogram analysis, but scarcely any permanently stable periodicities were found out after all, except 11 and 35.5- year periodic cycles.

Even if the numerous results he gained concerning periodicity are certainly suggestive for seasonal forecasting of climatic rainfall amount, they are not so for describing secular variation in reference to possible causes of climatic rainfall change.

Both the author (1957) and I. MORI (1959) independently discussed the secular variations of annual rainfalls caused by Bai-u and typhoon, and the former using the two statistical methods (rank correlation method and moving average) and the latter taking only a subjective view of diagrammatic secular variation at several points of Japan.

In these two studies, the data collected were not sufficient because only ten or so points came into consideration up till the year 1954. A reconsideration of the problem is now in order on the basis of recent data at as many observation points as possible.

Recently, T. SEKIGUCHI (1964) reported the systematic results of trend analysis on annual rainfall amounts in Japan by "Residual Mass Curve," and his study is quite suggestive to the present author as will be seen later. The author's approach is somewhat different from the various methods mentioned above in making use of the modern statistical method, and in taking into account the longest period and as many observation points as possible.

The numerous foregoing studies of secular variations of rainfall amounts may be summarized in the following condensed statement:

"Many statistical approaches to the study of secular variation have been developed such as successive variation ratio or width of fluctuation (der Quotient und die Weite

der Schwankung in German), moving or simple average, periodgram analysis, residual mass curve analysis, rank correlation method and polynomial fitting will be listed up here, and as a result, periodicities of 89-year (EASTON), 35.5-year (BRÜCKNER), 11-year (the same to the case of sun-spot number fluctuation), about 9-year (this periodicity is often noticed in secular variation of the high pressure zonal belt in middle latitudes), about 4-year (not yet known in relation to the other phenomena) etc. have been taken up and examined in detail and various tendencies (increasing, persistent and decreasing trends) have been locally verified and conjecturally explained."

In this paper, on the contrary, the author first proposes a rank correlation method which makes it possible to examine the statistically significant trend of the general tendency contained in secular variation, and secondly supplements the orthogonal or ordinary polynomial fitting to actual secular variation in order to clarify the cyclic up-and-down tendency in a wide sense. Moreover, several useful statistical quantities that can explain persistency or variation scale of secular variation are taken into account to complement the results obtained by the above two methods.

According to H. ARAKAWA (1955), periodgram analysis is not always suitable to analyse the irregular cyclic variation contained in actual secular variation of various rainfall amounts, so the author tried to fit several polynomials of the first, 2nd, 3rd and 4th orders, in order to clarify the cyclic character and to find out the time periods showing the maximum and the minimum year within the total range of observed periods.

The synthetic descriptions of trend characters are given after three such individual analyses to actual secular variations. From the necessity of obtaining as much stable result as possible, the author used the longest possible period (from the commencement year to the year of 1963 or 1964) for the 56 representative points as has often been done in the chapters of the author's previous paper (1967).

However, for convenience sake of geographical comparison, the range of observation period was adjusted to the longest commonly possible period between 1900 and 1963 (or 1964).

On the other hand, as regards the amount of rain caused by typhoons, the range had to be cut down to the period 1924-1964 in order to maintain the substantial homogeneity of data.

2. Statistical methods applied to the study of secular variation

(i) *Trend inspection based on rank correlational procedure*

Let $x_1, x_2, x_3, \dots, x_{N-1}, x_N$ be time series of successive rainfall amount obtained year by year, x_1 being the rainfall amount of the commencement year, x_2 that of the next year, $\dots$, x_N that of the most recent year respectively, and let $n_i (i=1, 2, \dots, N)$ be such a number showing the occurrence frequency of rainfall amounts which is greater than x_i behind the i -th value x_i in such a time series, then evidently, the next relations can be satisfied,

$$N-i \geq n_i \geq 0 \quad (n_{N-1}=1 \text{ or } 0, n_N=0)$$

and the summation of n_i , $P \equiv \sum_{i=1}^{N-1} n_i$ is a fundamental measure to denote the general situation of the secular trend in the following sense:

If the secular trend is monotone increase, then the inequality relations

$$x_1 < x_2 < x_3 < \cdots < x_{N-1} < x_N$$

is evidently satisfied and so we have

$$n_i = N-1, n_2 = N-2, \cdots, n_i = N-i, \cdots, n_{N-1} = 1$$

$$P \equiv \sum_{i=1}^{N-1} n_i = N(N-1)/2$$

If the secular trend is monotone decrease on the contrary, then the opposite inequality relation shown by

$$x_1 > x_2 > x_3 > \cdots > x_{N-1} > x_N$$

is also evidently satisfied and so we have

$$n_1 = 0, n_2 = 0, \cdots, n_i = 0, \cdots, n_{N-1} = 0, n_N = 0$$

$$P \equiv \sum_{i=1}^{N-1} n_i = 0$$

Consequently, the values of P are to be presented within the range $N(N-1)/2 \sim 0$.

Therefore, if we consider the modified measure S defined by

$$S = 2P - N(N-1)/2 \quad (2.1)$$

then the next correspondence relations are gained for a large number N

$$S = N(N-1)/2 \gg 0 \quad \text{for the completely monotone increasing trend}$$

$$S = -N(N-1)/2 \ll 0 \quad \text{for the completely monotone decreasing trend}$$

And moreover, S is close to 0 when the time series $\{x_1, x_2, \cdots, x_{N-1}, x_N\}$ is a random arrangement series having no increasing or decreasing trend. According to the statistical theory concerning to order statistics, as has been well known to the statistician, the quantity

$$I_T = S / \sqrt{N(N-1)(2N+5)/18} \quad (2.2)$$

is distributed approximately following the normal distribution with mean 0 and standard deviation 1 for a large number N under the assumption that the time series $\{x_1, x_2, \cdots, x_N\}$ is randomly arranged as was mentioned above. Accordingly, the author termed the quantity I_T as "trend index" to express the general tendency of secular variation, and assumed the next judgment criterions to denote quantitatively the non parametric trend:

$I_T \geq 2$	Conspicuous increasing trend (about 2% level)
$2 > I_T \geq 1$	Significant increasing trend (about 15% level)
$1 > I_T > 0$	Not significant but increasing trend
$0 > I_T > -1$	Not significant but decreasing trend
$-1 \geq I_T > -2$	Significant decreasing trend (about 15% level)
$-2 \geq I_T$	Conspicuous decreasing trend (about 2% level)

For example, in the case of $2 > I_T \geq 1$, the hypothesis of random arrangement is rejected at about 15% level of significance and the increasing trend is suggested with a rather large reliability. The analogous judgment holds for other cases of I_T as a rule.

(ii) *Fitting several polynomials to secular variation*

Let $x_1, x_2, \dots, x_N$ be a time series of size N as in (i), and let the polynomial of the p th order ($p=1, 2, 3$ and 4) to be fitted to this time series be

$$\left. \begin{aligned} x_t &= a_0 + a_1 \xi_1(t) + a_2 \xi_2(t) + \dots + a_p \xi_p(t) && \text{(orthogonal polynomial)} \\ &= b_0 + b_1 t + b_2 t^2 + \dots + b_p t^p && \text{(ordinary polynomial)} \end{aligned} \right\} \quad (2.3)$$

where $p \ll N$, then orthogonal coefficients $(a_0, a_1, a_2, \dots, a_p)$ can be generally determined by normal regression theory of modern statistics, and the ordinary coefficients $(b_0, b_1, b_2, \dots, b_p)$ are also derived easily from the set $(a_0, a_1, a_2, \dots, a_p)$, and these ordinary coefficients $(b_0, b_1, b_2, \dots, b_p)$ are completely the same as the results obtained by the least square method. Hereafter, the author will describe the computational procedure only as follows: In order to fit the orthogonal polynomial of the p th order, the author must pick up the value of $\xi_{i\alpha}$ ($i=1, 2, \dots, p$; $\alpha=1, 2, \dots, N$) for the given numbers p and N from a previously provided table, such as the one seen on p. 237 of the "Statistical Table" (New edition): published by Kawade Shobō (1952). And from combining the series $\{\xi_{i\alpha}\}$ and time series $\{x_\alpha\}$ ($\alpha=1, 2, \dots, N$), the following statistical quantities can be easily computed.

$$\left. \begin{aligned} a_{ij} &= \sum_{\alpha=1}^N \xi_{i\alpha} \xi_{j\alpha}, \quad a_{0i} = \sum_{\alpha=1}^N x_\alpha \xi_{i\alpha}, \quad a_{00} = \sum_{\alpha=1}^N x_\alpha^2 \\ &\quad (i, j=1, 2, \dots, p) \end{aligned} \right\} \quad (2.4)$$

Moreover, from the inverse $p \times p$ symmetric matrix $[a^{ij}] = [a_{ij}]^{-1}$ we have the following necessary orthogonal coefficients after all:

$$a_0 = \frac{1}{N} \sum_{\alpha=1}^N x_\alpha = \bar{x}, \quad a_i = \sum_{j=1}^p a^{ij} a_{0j} \quad (i=1, 2, \dots, p) \quad (2.5)$$

To verify the fitness extent of this polynomial, the quantity essentially equivalent to the residual sum of square

$$\chi^2_{N-p-1} \equiv N \sum_{\alpha=1}^N \left\{ x_\alpha - a_0 - \sum_{i=1}^p a_i \xi_{i\alpha} \right\}^2 / \sum_{\alpha=1}^N (x_\alpha - \bar{x})^2$$

is computed and the quantity χ^2_{N-p-1} is distributed as χ^2 -distribution with the degree of freedom $N-p-1$, so statistical significance can be tested by such χ^2 -distribution table as is well known to the statistician, and at the same time, the significance test of each orthogonal coefficient a_i ($i=1, 2, \dots, p$) is also similarly tested by changing the degree of freedom only.

In this case, the significant coefficient means that it is significantly different from 0 on each specified level of significance. Next, to have ordinary coefficients $(b_0, b_1, b_2, \dots, b_p)$ from the gained orthogonal coefficients the following well-known correspondence relations between them will be used

$$\left. \begin{aligned} \xi_1 &= t - \bar{t}, \\ \xi_2 &= (t - \bar{t})^2 - (N^2 - 1)/12 \\ \xi_3 &= (t - \bar{t})^3 - (3N^2 - 7)(t - \bar{t})/20 \\ \xi_4 &= (t - \bar{t})^4 + (3N^2 - 13)(t - \bar{t})^2/14 + 3(N^2 - 1)(N^2 - 9)/560 \\ &\dots\dots\dots \end{aligned} \right\} \quad (2.6)$$

where

$$\bar{t} = \sum_{\alpha=1}^N \alpha / N = (N+1)/2$$

These correspondence relations are also given on p. 238-239 of the "Statistical Table" (New edition): published by Kawade Shobō (1952) And in this paper, the cases $p=1, 2, 3$ and 4 are computed.

(iii) *Statistical quantities showing variability and persistence*

Among the various statistical quantities given in the authors previous paper (1967), mean difference M.D. (y) of annual rainfall amounts is the mean value of the possible absolute differences between any two values of annual rainfall amounts within a given time series ($x_1, x_2, \dots, x_N$) and is defined by $\sum_{j=1}^N \sum_{i=1}^N |x_i - x_j| / N(N-1)$. And Gini's concentration coefficient G.C. (y) of annual rainfall amounts is apparently a measure of relative variability to the mean square as is expressed by $G.C.(y) = M.D.(y) / \bar{y}^2$. So both M.D. (y) and G.C. (y) are considered as statistical quantities denoting variability of secular variation.

And, Goutereau ratio G. (y) is a mean ratio of absolute successive difference to absolute difference from mean value and is defined by

$$N \sum_{i=1}^{N-1} |x_{i+1} - x_i| / (N-1) \sum_{i=1}^N |x_i - \bar{x}| \sim \sum |x_{i+1} - x_i| / \sum |x_i - \bar{x}|$$

And so G. (y) shows a certain relative persistency and both positive and negative persistencies can be determined by knowing whether computed G. (y) is smaller or larger than $\sqrt{2}$, and absolute durability A.D. (y) is an expected value of absolute successive difference $\sum_{i=1}^{N-1} |x_{i+1} - x_i| / (N-1)$. So both Goutereau ratio G. (y) and A.D. (y) are considered as statistical quantities denoting the persistency of secular variation.

In the following section, computed results are shown for several cases.

3. Secular variation in annual rainfall amounts

The representative secular variations of annual rainfall amounts are graphically shown for Fukuoka, Tokyo and Sapporo in Fig. 1 as the examples. In this figure, the period marked by * means the significantly larger period of five or ten years than the standard initial period of 1901-1905 or 1901-1910 at 5% level, and the period marked by Δ means the significantly smaller period of five or ten years in the same sense.

For convenience of geographical comparison, the author adopted the unified period 1900-1963 ($N=64$) uniformly for all possible points, to compute trend index I_T .

Fig. 2 shows geographical distribution of I_T for annual rainfall amounts, and we have the next outline from this figure:

Number of points satisfying the inequality $I_T > 0 \dots \dots 33$

Number of points satisfying the equality $I_T = 0 \dots \dots 1$

Number of points satisfying the inequality $I_T < 0 \dots \dots 22$

And so, the number of increasing points is somewhat larger than that of decreasing points in Japan. In regional classification based on increasing and decreasing trends, the following results can be gained by Fig. 2:

Districts of increasing annual rainfall amounts—Kyushū, Chūgoku, Hokuriku, Tōhoku (Japan Sea side) and Hokkaidō.

Districts of decreasing annual rainfall amounts—Shikoku, Tōkai, Kantō and Tōhoku (Pacific Ocean side).

Fig. 1. Secular variations of annual rainfall amounts R_y at the three representative points in Japan.

Fig. 2. Geographical distribution of trend index I_T for annual rainfall amounts in Japan.

And among these districts, the central part of Kyushū, the northern Hokuriku district and Hokkaidō have significant increasing tendencies, while the northern Kantō district and the Pacific Ocean side of the Tōhoku district have significant decreasing tendencies. T. SEKIGUCHI (1964) considered that one extraordinary year with special heavy or light annual rainfall carries so much weight in the methods customarily used in the past (i. e. moving average, comparison of mean values between two different periods, etc.), that the real secular trends is liable to be hidden away from our eye. This induced him to use the method of Residual Mass Curve. The present writer generally concurs with SEKIGUCHI's point of view, but it must be pointed out the

Table 1 (a). Fitting results of several polynomials to the secular variations of annual rainfall amounts. b_0 is constant and b_i ($i=1, 2, 3, 4$) is coefficient estimated by maximum likelihood method.

Station	polynomial type	Mean (mm)	1st order		2nd order		
			b_0	b_1	b_0	b_1	b_2
Kagoshima		2294.7	2211.74	2.677*	2503.9	-26.068*	0.464*
Miyazaki		2571.6	2530.84	1.314	2585.6	-4.076	0.087
Kumamoto		1869.6	1854.75	0.479	2111.0	-24.732*	0.407*
Nagasaki		1985.5	1953.38	1.037	1989.0	-2.472	0.057
Izuhara		2220.1	2303.29	-2.683*	2437.7	-15.906	0.213
Saga		1854.0	1757.98	3.098**	1908.2	-11.675	0.238
Fukuoka		1660.5	1606.41	1.745	1750.0	-12.380	0.228
Ōita		1664.4	1647.89	0.532	1790.7	-13.521	0.226
Shimonoseki		1689.4	1664.38	0.808	1773.7	-9.945	0.173
Kōchi		2650.3	2674.26	-0.771	2832.2	-16.306	0.251
Tokushima		1663.1	1681.53	-0.595	1853.5	-17.510	0.273
Tadotsu		1144.8	1172.13	-0.881	1203.5	-3.969	0.050
Matsuyama		1370.9	1414.31	-1.400	1470.8	-7.349	0.096
Hiroshima		1567.6	1510.99	1.827	1616.3	-8.527	0.167
Okayama		1129.1	1029.75	1.172	1168.9	-6.326	0.121
Hamada		1667.1	1558.26	3.511**	1618.1	-2.377	0.095
Sakai		1970.8	1927.08	1.411	1973.0	-3.105	0.073
Kōbe		1340.4	1309.74	0.987	1386.9	-6.598	0.122
Ōsaka		1353.5	1347.88	0.181	1495.6	-14.351	0.234
Wakayama		1497.5	1518.78	-0.687	1699.7	-18.485*	0.287
Kyōto		1572.2	1536.81	1.143	1729.6	-17.820	0.306*
Hikone		1677.7	1642.02	1.153	1843.6	-18.683*	0.320*
Tsu		1757.9	1823.68	-2.122	1951.7	-14.716	0.203
Nagoya		1602.6	1715.88	-3.654**	1855.8	-17.418	0.222
Gifu		1917.4	2008.18	-2.930*	2219.5	-23.714*	0.335*
Takayama		1799.8	1822.78	-0.741	1928.6	-11.154	0.168
Hamamatsu		1963.5	2043.81	-2.592*	2154.3	-13.464	0.175
Yokohama		1687.1	1749.82	-2.024	1720.8	0.831	-0.046

Remark :

*, ** show the significant coefficients at 5% and 1% levels of significance respectively.

above effect is not completely eliminated in the residual mass curve since the annual rainfall ratio to the normal mean value is also utilized in this procedure.

In the rank correlation method used by the author in this paper, the special heavy or light annual rainfalls have no influence in the computation of trend index I_T since annual values themselves are not taken into account but their ordered rankings only are considered in the computation of I_T . Thus the disturbing effect mentioned by T. SEKIGUCHI is considered to be completely eliminated in trend analysis of secular variation. (For instance, the same results are attainable in any cases whether the

Table 1 (b). Fitting results of several polynomials to the secular variations of annual rainfall amounts. b_0 is constant and b_i ($i=1, 2, 3, 4$) is coefficient estimated by maximum likelihood method.

polynomial type Station	Mean (mm)	1st order		2nd order		
		b_0	b_1	b_0	b_1	b_2
Tokyo	1583.7	1642.85	-1.908	1587.7	3.515	-0.087
Chōshi	1713.5	1687.52	0.839	1716.9	-2.055	0.047
Mito	1438.7	1500.24	-1.983	1484.4	-0.423	-0.025
Utsunomiya	1538.8	1652.84	-3.678**	1634.1	-1.833	-0.030
Maebashi	1273.3	1310.70	-1.205	1338.1	-3.897	0.043
Kumagaya	1310.7	1336.86	-0.843	1358.3	-2.950	0.034
Kōfu	1234.3	1259.58	-0.816	1266.9	-1.537	0.012
Nagano	1002.9	997.28	0.181	1040.8	-4.092	0.069
Matsumoto	1083.4	1136.98	-1.726	1223.9	-10.281	0.138
Iida	1668.6	1740.17	-2.307	1959.9	-23.921*	0.349*
Tsuruga	2404.3	2205.86	6.401**	2202.7	6.717	-0.005
Fukui	2414.5	2371.52	1.387	2462.7	-7.575	0.144
Kanazawa	2569.1	2543.46	0.828	2741.7	-18.671*	0.314*
Fushiki	2261.3	2184.70	2.470	2310.7	-9.927	0.200
Niigata	1805.1	1804.18	0.030	1948.4	-14.160	0.229
Fukushima	1181.9	1222.86	-1.320	1226.9	-1.719	0.006
Ishinomaki	1121.6	1140.21	-0.602	1170.8	-3.612	0.049
Miyako	1324.8	1387.06	-2.010	1468.1	-9.978	0.129
Yamagata	1233.3	1223.75	0.309	1196.8	2.957	-0.043
Akita	1805.5	1811.63	-0.198	1861.4	-5.097	0.079
Aomori	1401.2	1394.56	0.213	1333.2	6.250	-0.097
Hakodate	1167.9	1176.14	-0.265	1079.5	9.243	-0.153
Obihiro	941.4	946.48	-0.163	917.5	2.684	-0.046
Suttsu	1252.7	1180.03	2.344	1056.7	14.475	-0.196
Sapporo	1094.4	1004.00	2.915*	947.1	8.507	-0.090
Asahikawa	1109.7	1039.96	2.250	1026.8	3.541	-0.021
Abashiri	847.5	833.60	0.450	750.1	8.662	-0.132
Nemuro	1028.9	920.46	3.500**	872.5	8.212	-0.076

Remark :

*, ** show the significant coefficients at 5% and 1% levels of significance respectively.

largest value of rainfall amount is quite much or slightly larger than the secondary value of rainfall amount in a given time series of secular annual rainfall amounts).

On the other hand, the rank correlation method has the following merits and demerits in actual application.

Merits—Each year has equal weight and I_T can be computed independent of the original value itself and the original frequency distribution of time series, and can be tested statistically for the significant or non-significant trend of secular variation.

Table 1 (c). Fitting results of several polynomials to the secular variations of annual rainfall amounts. b_0 is constant and b_i ($i=1, 2, 3, 4$) is coefficient estimated by maximum likelihood method.

Station	3rd order				4th order				
	b_0	b_1	b_2	b_3	b_0	b_1	b_2	b_3	b_4
Kagoshima	2621.0	-49.66**	1.421*	-0.010	2252.3	78.51**	-8.056*	0.229*	-0.0019
Miyazaki	2669.0	-20.89	0.711	-0.007	2459.8	51.84	-4.608	0.128	-0.0011
Kumamoto	2139.9	-30.56*	0.643	-0.003	1991.9	20.92	-3.164	0.094	-0.0008
Nagasaki	1941.4	7.142	-0.334	0.004	1795.1	57.99*	-4.095	0.099	-0.0008
Izuhara	2244.7	23.01*	-1.368*	0.017	2171.5	48.46	-3.251	0.064	-0.0004
Saga	1902.0	-10.43	0.189	0.001	1777.5	32.86	-3.014	0.081	-0.0007
Fukuoka	1821.8	-26.87*	0.816	-0.006	1637.9	37.11	-3.914	0.113	-0.0010
Ōita	1840.6	-23.56*	0.634	-0.004	1652.7	41.74	-4.195	0.117	-0.0010
Shimonoseki	1776.3	-10.47	0.194	-0.000	1549.8	68.28*	-5.629*	0.147	-0.0012
Kōchi	2920.0	-34.01**	0.970	-0.008	2794.1	9.781	-2.268	0.074	-0.0007
Tokushima	1821.8	-11.11	0.013	0.003	1628.1	56.22*	-4.967	0.128	-0.0010
Tadotsu	1200.6	-3.378	0.025	0.000	1112.8	27.13	-2.230	0.057	-0.0005
Matsuyama	1573.5	-27.27*	0.905	-0.009	1435.4	20.78	-2.647	0.081	-0.0004
Hiroshima	1638.8	-13.07	0.351	-0.002	1472.5	44.75	-3.925	0.106	-0.0009
Okayama	1184.7	-9.498	0.250	-0.001	1075.5	28.48	-2.559	0.069	-0.0006
Hamada	1496.7	-22.10	-0.900	0.010	1418.5	49.32	-2.912	0.061	-0.0004
Sakai	1897.4	12.14	-0.547	0.007	1843.0	31.04	-1.945	0.042	-0.0003
Kōbe	1324.5	5.970	-0.389	0.005	1265.6	26.45	-1.903	0.044	-0.0003
Ōsaka	1453.1	-5.778	-0.114	0.004	1366.3	24.41	-2.347	0.060	-0.0005
Wakayama	1699.1	-18.35	0.282	0.000	1538.7	37.40	-3.842	0.104	-0.0008
Kyōto	1670.2	-5.832	-0.181	0.005	1532.4	4.205	-3.723	0.095	-0.0007
Hikone	1719.7	6.329	-0.696	0.010	1669.5	23.75	-1.985	0.043	-0.0003
Tsu	1868.1	2.142	-0.482	0.007	1758.5	40.25	-3.301	0.078	0.0006
Nagoya	1833.2	-12.86	0.036	0.002	1734.5	21.45	-2.501	0.066	-0.0005
Gifu	2169.1	-13.56	-0.077	0.004	1991.0	48.37	-4.658	0.120	-0.0009
Takayama	1865.3	1.618	-0.351	0.006	1762.3	37.42	-2.999	0.072	-0.0005
Hamamatsu	2134.7	-9.500	0.014	0.002	1991.8	40.19	-3.661	0.094	0.0007
Yokohama	1665.7	11.92	-0.496	0.005	1420.8	97.13**	-6.798*	0.164*	-0.0013

Remark:

*, ** show the significant coefficients at 5% and 1% levels of significance respectively.

Demerits—The cyclic or periodic movement contained in secular variation cannot be examined since the original value is not directly used, and the various trend characters within the original secular values of annual rainfall amounts are not examined in detail.

Therefore, to eliminate such defects from the rank correlation method and to examine the cyclic movement of secular variation, the author tried fitting several polynomials to the secular variation of annual rainfall amounts and gave these numerous results in Table 1.

Table 1 (d). Fitting results of several polynomials to the secular variations of annual rainfall amounts. b_0 is constant and b_i ($i=1, 2, 3, 4$) is coefficient estimated by maximum likelihood method.

Station	3rd order				4th order				
	b_0	b_1	b_2	b_3	b_0	b_1	b_2	b_3	b_4
Tokyo	1548.3	11.45	-0.410	0.003	1382.7	69.03*	-4.667	0.111	-0.0009
Chōshi	1623.4	16.81	-0.720	0.008	1389.8	98.03**	-6.726*	0.159*	-0.0012
Mito	1394.1	17.79	-0.765	0.008	1261.1	64.04*	-4.186	0.094	-0.0007
Utsunomiya	1629.2	-0.857	-0.069	0.000	1486.4	48.82	-3.743	0.093	-0.0007
Maebashi	1273.7	9.079	-0.484	0.006	1092.5	72.09*	-5.144*	0.123	-0.0009
Kumagaya	1371.8	-5.680	0.145	-0.001	1182.3	60.23*	-4.729	0.122	-0.0010
Kōfu	1260.1	-0.164	-0.044	-0.001	1141.9	40.93	-3.803	0.077	-0.0006
Nagano	1021.3	-0.158	-0.090	0.002	922.9	34.06	-2.621	0.066	-0.0005
Matsumoto	1193.8	-4.211	-0.108	0.003	1056.8	43.44	-3.632	0.092	-0.0007
Iida	1927.6	-17.39	0.083	0.003	1787.2	31.41	-3.525	0.094	-0.0007
Tsuruga	2109.0	25.59*	-0.772	0.008	1945.8	82.37**	-4.971	0.114	-0.0009
Fukui	2352.0	14.72	-0.761	0.010	2262.2	45.96	-3.072	0.068	-0.0005
Kanazawa	2647.2	0.382	-0.460	0.008	2565.1	28.91	-2.570	0.062	-0.0004
Fushiki	2231.1	6.127	-0.452	0.007	2172.5	26.53	-1.961	0.045	-0.0003
Niigata	1910.2	-6.454	-0.084	0.003	1844.4	16.44	-1.777	0.046	-0.0003
Fukushima	1139.1	15.98	-0.713	0.008	982.9	70.27*	-4.728	0.109	-0.0008
Ishinomaki	1118.9	6.852	-0.376	0.005	1011.8	44.09	-3.131	0.074	-0.0006
Miyako	1391.0	5.558	-0.502	0.007	1240.4	57.95*	-4.377	0.105	-0.0008
Yamagata	1166.9	8.995	-0.288	0.003	1106.2	30.10	-1.849	0.042	-0.0003
Akita	1790.4	9.215	-0.502	0.006	1783.1	11.75	-0.691	0.011	-0.0000
Aomori	1345.5	3.752	0.004	-0.001	1190.5	57.68*	-3.984	0.100	-0.0008
Hakodate	1042.2	16.76	-0.459	0.003	1077.4	4.525	0.445	-0.019	0.0002
Obihiro	845.88	17.13	-0.633	0.006	801.6	32.51	-1.771	0.035	-0.0002
Suttsu	965.32	32.90*	-0.944*	0.008	1104.0	-15.32	2.622	-0.081	0.0007
Sapporo	906.35	16.73	-0.424	0.004	927.1	9.487	0.111	-0.010	0.0001
Asahikawa	981.11	12.76	-0.395	0.004	939.0	27.38	-1.476	0.031	-0.0002
Abashiri	675.51	23.70*	-0.743	0.007	650.5	32.41	-1.387	0.023	-0.0001
Nemuro	748.29	33.27**	-1.094*	0.011	781.0	21.90	-0.253	-0.010	0.0002

Remark :

*, ** show the significant coefficients at 5% and 1% levels of significance respectively.

In Table 1, "Mean" is short for the normal mean values of annual rainfall computed in the period range 1900-1963, so slightly different from the similar result shown in Fig. 22 presented at the previous paper of the author (1967), because the range of computed data is equivalent to possible maximum period length (from the commencement year to 1963) for each station in that Fig. 22.

However, these differences are so sufficiently small that are almost negligible for the computations in this chapter. The computed coefficients are shown by the same notation b_0 , b_1 and b_2 , etc. as population coefficients, and they are generally obtained by the maximum likelihood method. In Table 1, The symbols * and ** mean the statistically significant terms at the 5% level and 1% levels respectively, where

Table 1 (e). Fitting results of several polynomials to the secular variations of annual rainfall amounts. Computed values of variance.

Station	Var. R_y	Var. ε_1	Var. ε_2	Var. ε_3	Var. ε_4	$r(R_y, t)$
Kagoshima	213198	210829	192040	189673	168793	0.105
Miyazaki	215040	214470	213809	212606	205883	0.052
Kumamoto	124676	124600	110147	110002	106633	0.025
Nagasaki	147587	147231	146951	146558	143269	0.049
Izuhara	165531	163149	159174	152736	151909	-0.120
Saga	101668	98494	93531	93524	91141	0.177
Fukuoka	75023	74016	69479	68587	63385	0.116
Ōita	97339	97245	92754	92325	86905	0.031
Shimonoseki	75470	75254	72624	72623	64737	0.053
Kōchi	213724	213528	208040	206707	204271	-0.030
Tokushima	101612	101494	94989	94814	89049	-0.034
Tadotsu	36276	36019	35802	35801	34617	-0.084
Matsuyama	59770	59122	58317	56630	53697	-0.104
Hiroshima	80681	79577	77139	77051	72801	0.117
Okayama	39688	39234	37955	37912	36078	0.107
Hamada	110814	106738	105950	103402	102459	0.192
Sakai	62591	61933	61469	60480	60026	0.103
Kōbe	47700	47378	46069	45398	44864	0.082
Ōsaka	49989	49978	45176	44864	43705	0.015
Wakayama	97254	97098	89894	89894	85941	-0.040
Kyoto	73344	72912	64734	64124	61207	0.076
Hikone	69690	69251	60304	57644	57257	0.079
Tsu	88722	87233	83626	82418	80570	-0.130
Nagoya	68395	63978	59671	59582	58085	-0.254
Gifu	95414	92575	82752	82315	77436	-0.172
Takayama	82442	82261	79795	79101	77470	-0.047
Hamamatsu	124753	122532	119843	119777	116637	-0.133
Yokohama	87731	86376	86191	85668	76429	-0.124

Note :

$r(R_y, t)$ shows a sample correlation coefficient between R_y and year t .

the significance test is easily done by χ^2 -distribution as was already shown in the above section. The quantity $\text{Var. } R_y$ is the sample variance of annual rainfall amount showing the up-and-down variation scale around a normal mean value, and also the quantities $\text{Var. } \varepsilon_1$, $\text{Var. } \varepsilon_2$, $\text{Var. } \varepsilon_3$ and $\text{Var. } \varepsilon_4$ are the sample residual variances of annual rainfall amounts from the fitted 1st, 2nd, 3rd and the 4th order polynomials respectively.

Geographical distributions of these coefficients are shown in Fig. 3 in the summarized form.

Firstly, in fitting the linear trend $R_y(t) = b_0 + b_1 t$, the estimated coefficient b_1 has

Table 1 (f). Fitting results of several polynomials to the secular variations of annual rainfall amounts. Computed values of variance.

Station	Var. R_y	Var. ε_1	Var. ε_2	Var. ε_3	Var. ε_4	$r(R_y, t)$
Tokyo	72701	71496	70828	70559	66342	-0.129
Chōshi	80573	80340	80150	78637	70243	0.054
Mito	43142	41841	41785	40375	37653	-0.174
Utsunomiya	60619	56145	56067	56063	52924	-0.271
Maebashi	40218	39738	39573	38857	33805	-0.109
Kumagaya	49265	49030	48929	48897	43372	-0.069
Kōfu	62590	62370	62359	62351	60203	-0.059
Nagano	23640	23629	23214	23148	21659	0.021
Matsumoto	42299	41313	39649	39493	36605	-0.153
Iida	69056	67295	56672	56491	53463	-0.160
Tsuruga	113375	99828	99826	98311	94207	0.345
Fukui	76620	75984	74158	72044	70801	0.091
Kanazawa	96750	96524	87878	86335	85300	0.048
Fushiki	69390	67372	63877	62782	62252	0.171
Niigata	44786	44785	40206	39953	39287	0.003
Fukushima	33393	32817	32813	31480	27729	-0.131
Ishinomaki	36241	36121	35915	35449	33684	-0.057
Miyako	69587	68251	66807	65780	62287	-0.139
Yamagata	24437	24406	24246	24091	23524	0.036
Akita	59163	59150	58604	57734	57725	-0.015
Aomori	40388	40373	39544	39518	35819	0.019
Hakodate	23679	23656	21600	21360	21170	-0.031
Obihiro	28209	28200	28015	27128	26826	-0.018
Suttsu	36535	34718	31371	29928	26973	0.223
Sapporo	20442	17633	16921	16634	16567	0.371
Asahikawa	25806	24132	24094	23732	23460	0.254
Abashiri	20845	20778	19244	18283	18186	0.057
Nemuro	36098	32048	31542	28874	28710	0.334

Note :

$r(R_y, t)$ shows a sample correlation coefficient between R_y and year t .

Fig. 3 (a). Geographical distribution of coefficient b_1 in fitting linear trend $y = b_0 + b_1t$ (1960-1963, y : annual data, t : year).

Fig. 3 (b). Geographical distribution of b_1 in fitting quadratic trend $y = b_0 + b_1t + b_2t^2$ (1900-1963, y : annual data, t : year).

Fig. 3 (c). Geographical distribution of b_2 in fitting quadratic trend $y = b_0 + b_1t + b_2t^2$ (1900-1963, y : annual data, t : year).

Fig. 3 (d). Geographical type classification by the coefficients of $y = b_0 + b_1t + b_2t^2 + b_3t^3$ (1900-1963, y : annual data, t : year).

Fig. 3 (e). Geographical type classification by the coefficients of $y = \hat{b}_0 + \hat{b}_1 t + \hat{b}_2 t^2 + \hat{b}_3 t^3 + \hat{b}_4 t^4$ (1900-1963, y : annual data, t : year).

completely the same sign as I_T and the absolute value of b_1 is almost proportional to the absolute value of I_T over the whole domain of Japan, as is reasonably expected.

Secondly, in fitting the quadratic trend $R_y(t) = b_0 + b_1 t + b_2 t^2$, coefficients b_1 are of course different from coefficients b_1 of the linear trend and geographical distributions of b_1 and b_2 are also shown in Fig. 3. A somewhat different trend structure can be clarified for the same increasing regions of I_T . For example, a typical quadratic increasing trend is seen in the western part of Japan and a linear increasing trend at Hokkaido and the occurrence situations of maximum and minimum are evidently different between the Japan Sea side and the Pacific Ocean side of Japan. This is in agreement with the conclusion to be arrived at by T. SEKIGUCHI (1964).

Thirdly, in fitting the cubic and the 4th order polynomial, classified trend types are geographically shown in Fig. 3, since geographical distributions of various coefficient values are quite complicated and inconvenient for geographical comparison.

Lastly, in order to show the synthetic results of trend analysis, the author must compare Fig. 22 showing geographical distributions of variability and persistency by mean difference and Goutereau ratio etc. presented at the author's previous paper (1967) with Fig. 2 showing geographical distribution of trend index I_T and also with Fig. 3 showing polynomial fitting to secular annual rainfall variation in detail as far as possible. Thus the following summarized results are obtained:

- (a) Among the significant increasing regions due to primitive trend analysis performed by computing trend index I_T , the Kyushu district has a negative persistent tendency

(up-and-down tendency) and a quadratic (cyclic in a wide sense) trend with conspicuous variation, while the Hokkaidō district has the rather positive persistency and a linear increasing trend (monotone in a long range scale) with comparatively small variation.

Moreover, in the intermediate region between these two far distant districts, both Chūgoku and Hokuriku districts have neither positive nor negative persistency. These two districts have conspicuous or significant increasing trends but these increasing features are neither linear nor quadratic.

- (b) Among the significant decreasing regions shown by (a), the northern Kantō district has no apparent persistency and variability and has a linear decreasing trend with small variation, while both Tōkai and Chūbu districts have small positive

Table 2 (a). Estimated results of maximum and minimum years appearing in secular variation by fitting polynomials.

trend type Station	2nd Order		3rd Order			4th Order			
	Max.	Min.	Max.	Min.	Max.	Max.	Min.	Max.	Min.
Kagoshima		1928		1923	—	1909	1931	1955	
Miyazaki		1924		1918	1952	1908	1928	1952	
Kumamoto		1930		1929	—	1904	1930	1956	
Nagasaki		1922	1915	1938		1911	1932	1954	
Izuhara		1937	1910	1942		1910	1940	—	
Saga		1925		1925	—	1908	1929	1957	
Fukuoka		1927		1922	—	1906	1928	1953	
Ōita		1930		1925	—	1907	1929	1953	
Shimonoseki		1929		1928	—	1909	1931	1954	
Kōchi		1932		1925	1959	1902	1928	1953	
Tokushima		1932		1935	—	1908	1932	1955	
Tadotsu		1940		1941	—	1909	1932	1952	
Matsuyama		1938		1922	1947	1905	1928	1950	
Hiroshima		1926		1923	—	1908	1929	1954	
Okayama		1926		1924	—	1908	1929	1954	
Hamada		1913	1919	1938		1914	1934	1962	
Sakai		1921	1915	1938		1912	1936	—	
Kōbe		1927	1910	1937		1910	1933	1962	
Ōsaka		1931		1935	—	1907	1933	1960	
Wakayama		1932		1933	—	1906	1931	1955	
Kyōto		1929		1934	—	1908	1932	1959	
Hikone		1929	1905	1937		1908	1935	—	
Tsu		1936		1941	—	1908	1936	1959	
Nagoya		1939		1941	—	1905	1935	1956	
Gifu		1935		1938	—	1907	1933	1956	
Takayama		1933	1903	1940		1909	1934	1958	
Hamamatsu		1938		1941	—	1907	1933	1954	
Yokohama	1909		1916	1953		1911	1933	1951	

Remark :— denotes the year after 1963

Tabbe 2 (b). Estimated results of maximum and minimum years appearing in secular variation by fitting polynomials.

trend type Station	2nd Order		3rd Order			4th Order			
	Max.	Min.	Max.	Min.	Max.	Max.	Min.	Max.	Min.
Tokyo	1920		1918	1961		1912	1934	1950	
Chōshi		1922	1916	1942		1911	1933	1954	
Mito		—	1915	1949		1912	1937	1953	
Utsunomiya		—	—	—		1910	1934	1949	
Maebashi		1945	1912	1945		1911	1934	1953	
Kumagaya		1943		1933	1948	1909	1931	1952	
Kōfu		1963		1951	—	1910	1932	1952	
Nagano		1930		1936	—	1910	1932	1954	
Matsumoto		1937		1941	—	1908	1933	1954	
Iida		1934		1937	—	1906	1933	1957	
Tsuruga	—		—	—		1914	1929	1956	
Fukui		1926	1913	1940		1911	1935	—	
Kanazawa		1930		1937	—	1908	1934	—	
Fushiki		1925	1908	1935		1910	1933	—	
Niigata		1931		1935	—	1906	1933	1962	
Fukushima		—	1915	1947		1911	1935	1954	
Ishinomaki		1937	1912	1943		1911	1934	1954	
Miyako		1939	1906	1943		1910	1935	1955	
Yamagata	1935		1923	1950		1912	1934	1952	
Akita		1932	1912	1942		1911	1941	—	
Aomori	1932		1935	—		1912	1930	1950	
Hakodate	1930		1925	—		1928	1956	—	
Obihiro	1929		1919	1948		1915	1941	1958	
Suttsu	1937		1926	1952			1903	1930	1952
Sapporo	1946		—	—		1933	1948	—	
Asahikawa	—		1929	1937		1917	1931	1959	
Abashiri	1933		1923	1953		1920	1960	—	
Nemuro	1954		1923	1943		1926	1946	—	

Remark:— denotes the year after 1963

persistence and have a quadratic decreasing trend with slowly up-and-down variation.

- (c) The several maximum or minimum years that appeared in the secular variation of annual rainfall amounts are shown in Table 2 as a summarized result of polynomial fitting. Large scale cyclic movements can be described in this table. For example, the maximum year is easily seen in 1905–1915 and the minimum year is appeared in 1925–1935, and the maximum year is again noticed in the recent period 1952–1962 in the greater part of western Japan.

On the contrary, no systematic tendency can be seen at all and the Hokkaidō district shows a quite different tendency from the other districts of Japan.

Besides, several more detailed results may be derived from the authors work in

this field, and they will be explained by comparison with the foregoing past studies by other scholars: K. TAKAHASHI (1956) discussed the secular variations of annual rainfall amounts in relation to the sun-spot number at several points in Japan and T. YAMAMOTO (1958) studied the secular trend of annual rainfall through dividing annual rainfall into that of the warmer half year and that of the colder half year. However their studies were based on annual rainfall data obtained at only a small number of observation points as compared with the author's study, and consequently their results are not always satisfactory. And T. SEKIGUCHI (1964) performed synthetic investigation concerning the secular variations of annual rainfall amounts by use of the residual mass curve at about 70 observation points, and it will be meaningful to compare his synthetic results to the author's. The gists of the comparison will be given in an itemized form as follows:

(i) T. SEKIGUCHI divided the whole of Japan into three regions (Japan Sea side, Pacific Ocean side and Hokkaidō) with reference to the secular trend of annual rainfall amounts. In the geographical distribution of trend index I_T due to the author, the isoline showing the equality $I_T=0$ divides the whole of Japan into three regions which are practically the same as T. SEKIGUCHI, except for the treatment of Obihiro and Hakodate in Hokkaidō. Moreover, such rough trend characters have been clarified in detail by the other two approaches (polynomial fitting and computing of the statistical quantities of variability and persistency).

(ii) T. SEKIGUCHI took up the increasing trend of the Pacific Ocean side as a conspicuous character, and exemplified it by actual secular variations at Osaka, Gifu and Maebashi. However, according to analysis based on trend index I_T , the Pacific Ocean side of Japan is considered as a decreasing tendency region and the Japan Sea side of Japan is considered as an increasing tendency region on the contrary to his results. Moreover the southern part of the Chūbu district has a significant decreasing trend as is seen in the long range secular variations of annual rainfall amounts at Gifu, Nagoya, Iida and Kōfu. After all results contrary to what was pointed out by T. SEKIGUCHI are obtained for these observation points.

As the main reason for this discrepancy, the following must be noted:

T. SEKIGUCHI pointed out a recent increasing trend at Gifu, for example, but no such tendency is seen over the whole period, and in fact the significant decreasing trend is already indicated in the next two books already:

E. FUKUI: "General Climatology," published by Asakura Shoten (1961) p. 126.

K. WADATI (ed): "Climate of Japan" published by Tōkyō-dō (1958) p. 24.

In these books, the rainfall amount is shown to be generally larger in the summer season than in the winter season at Gifu, and has a remarkable decreasing tendency over the long period between 1900 and 1947. This tendency is never offset by the recent increasing period being pointed out by T. SEKIGUCHI.

(iii) T. SEKIGUCHI pointed out that the Japan Sea side has no apparent increasing or decreasing trend, but, seeing trend index I_T , the western part of the Hokuriku district, San-in district and the northern part of the Kyushū district, etc. have conspicuous or significant increasing trends and the details of such increasing trends are more clarified by polynomial fitting and analysis of variability or persistency referred to already.

As is shown in the above book written by E. FUKUI (1961), a heavy snowfall tendency appears rather clearly at the Hokuriku district in winter, and T. SEKIGUCHI pointed out a remarkable increasing tendency in the years after 1950

without mentioning the regions.

Then, the author would like to consider the western part of the Hokuriku district and the northern part of the Kyūshū district as the significantly increasing regions with conspicuous up-and-down variation.

4. Secular variation in monthly rainfall amounts

The author collected monthly rainfall amounts at 56 observation points where the commencement year of rainfall observation is 1900 or before, for each month of the year, and computed the trend index I_T for the period range 1900-1963 to uniformize the sample size of the stations in in Japan. The geographical distributions of the trend index I_T are given by Fig. 4.

No significant trend is seen to be predominant almost over half of the area of Japan in the general results shown by Fig. 4, since the regions satisfying two inequalities $0 \geq I_T > -1$, $1 > I_T \geq 0$ should be regarded as having no significant trends according to the judgement criterion based upon trend index I_T in section 1 of this chapter, so the appearance of significant trends different from month to month is summarized on the whole in Table 3 for every month.

As is apparently shown in Fig. 4, the conspicuous or significant trends of decreasing and increasing are rather complicated and different from month to month in Japan, but a substantial explanation of increasing and decreasing trends appearing in annual rainfall amounts will be to some extent possible to do from the various results of Fig. 4.

Therefore the author examined the monthly reason for the several significant

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

(j)

Fig. 4. Geographical distribution of trend index I_T for each month.

(a) January	(b) February	(c) March	(d) April
(e) May	(f) June	(g) July	(h) August
(i) September	(j) October	(k) November	(l) December

increasing and decreasing trends seen in annual rainfall data as follows:

- (i) The significant increasing trend of annual rainfall amounts appearing in the greater part of Hokkaidō will be due to the monthly significant increasing trend of snowfall data caused by the monsoon in January and February since the other months have no significant trend at Hokkaidō, and Hokkaidō district has negative persistency on its Japan Sea side in January, and show as very large fluctuation around the mean value as is seen in the values of M.D. (y) and A.D. (y) of Fig. 24 presented in the author's previous paper (1967).
- (ii) The significant increasing trend of annual rainfall amount seen in the western part of the Hokuriku district will be mainly due to the conspicuous increasing trend of monthly snowfall caused by the winter monsoon and secondly to the gradually increasing trend of monthly rainfall caused by Bai-u (June) and by typhoons and Shūrin (September and October), moreover secular variation of monthly rainfall amounts has the most apparent variability and no persistency in January as is shown in Fig. 24 (f) presented in the author's previous paper (1967).
- (iii) The significant increasing trend of annual rainfall amount seen over the western and the central Kyūshū district will be mainly due to rainfall increasing caused by typhoon in September, and secondly to the significant increasing tendency in February, since no stable persistency and variability is seen in the other

Table 3. Several regions having significant increasing and decreasing trends for every month.

Month	Increasing region	Decreasing region
January	Hokkaidō, Tōhoku, Hokuriku	West and Central part of Japan
February	Greater part of Japan	Kantō, Southern part of Hokkaidō
March	Hokkaidō and Hokuriku	Greater part of Japan
April	Hokkaidō, Tōhoku, Kantō and Kinki	West Japan, Central inner part of Japan
May	Japan Sea side, West Japan	East Pacific Ocean side of Japan
June	Greater part of Japan	A part of Hokkaidō and Kyushū
July	Japan Sea side of Japan, West Japan	Inner mountain range of Japan
August	Hokkaidō, West Pacific Ocean side of Japan	Tōhoku, Northern part of Kantō
September	Japan Sea side of Japan, Hokkaidō	Pacific Ocean side of Japan, Inner central part of Japan
October	Tōhoku, Hokuriku, Kantō and Chūgoku	A part of Hokkaidō, South-West Japan
November	Pacific Ocean side of Japan, West Japan	Tōhoku, Hokuriku and a part of Chūbu
December	West Japan Sea side, Kinki and Tōhoku	Central mountain range of Japan, A part of Kyushū and Shikoku

months.

- (iv) The significant decreasing trend of annual rainfall amounts seen over the southern part of the Chūbu district and the Tōkai district may be due to snowfall decreasing in January and to the significant decreasing tendency of monthly rainfall amounts in March. Moreover, persistency can hardly be noticed and variability is quite large in January in these districts.
- (v) The significant decreasing trend of annual rainfall amounts seen over the northern Kantō district and the Pacific Ocean side of the Tōhoku district may probably be due to the gradually decreasing though not significant tendency of monthly rainfall amounts in January, March, May and July mainly, and the significant decreasing trend of monthly rainfall amounts in September caused by typhoons and Bai-u. Variability and persistency are so small that they can not be seen, and in August variability is larger in the Kantō district than the Pacific Ocean side of the Tōhoku district in Japan. In these itemized descriptions, the trend characters of monthly rainfall are verified by addition of variability and persistency seen in the secular variations of monthly rainfall amounts in connection with the significant trend of annual rainfall amounts.

T. YAMAMOTO (1958) found the following three types of secular tendencies of rainfall amounts in summer season (from May to September) through his synthetic

graphical comparisons of secular changes in Japan:

A type: The northern and the central part of Japan (for example, Gifu)...Decreasing trend.

B type: The northern part of Hokkaidō district—No increasing or decreasing trend.

C type: Formosa and Okinawa districts...Increasing trend.

In this type classification, the whole domain of Japan is not covered in a mutually exclusive and exhaustive form. Fully aware of this deficiency, the author will try a comparison between his results with the above.

(α) *The northern and the central part of Japan*—According to the author's analysis due to the trend index I_T , no significant region is noticed in May and June, but decreasing trends are noticed in the several districts rather in July, while a not-significant increasing trend is seen in August and again in September significant decreasing trends appear almost everywhere and are likely to offset the not-significant increasing trend of the previous month.

After all, a conclusion which is practically the same as T. YAMAMOTO's is deduced generally as the summarized outline over May, June, July, August and September. In other words, T. YAMAMOTO's conclusions are refined and confirmed by the author's analysis.

Fig. 5 (a). Secular fluctuations of monthly rainfall amounts in January and August at the representative points. (1880–1963)

Fig. 5 (b). Fluctuations of the 5-year and 10-year moving averages in January and August.

(β) *The northern part of the Hokkaidō district*—As is seen in geographical distributions of trend indice I_T during May and September, not-significant decreasing and increasing regions are mixed together in a complicated form, so that a similar conclusion to T. YAMAMOTO's is well recognized for each month during May and September.

(γ) *The Formosa and Okinawa districts*—These districts are beyond the range of this study, and no comparative description is attempted here.

T. YAMAMOTO's study on the whole data obtained before 1950 at about fifteen observation points in Japan, while the author used all the possible data obtained before 1963 at 56 observation points of Japan for every month (from January to December). Consequently, the author's results are reasonably considered more precise and reliable on the whole.

Next, to bring out the actual secular variation patterns of monthly rainfall amounts, the author showed the several representative examples at Sapporo, Fukuoka and Tokyo in January and August in Fig. 5, where the period of the most conspicuous change period within ten successive years is indicated by a dotted line. Moreover, the symbols Δ and $*$, respectively, show the significantly different pairs of periods for five year mean and ten-year mean in this figure.

Note :

Solid and dotted lines show actual values and fitted curves respectively. (Origin: 1930)

Δ and $*$ show the significant coefficients at the level of 20% and 5% respectively, (according to normal regression theory)

Fig. 6. Actual mean values for five years (full lines) and the fitted polynomial trend curves (broken lines) of the third order for monthly rainfall amounts in August. (1900–1963)

Based on these simple comparisons, fitting of orthogonal polynomials was performed to the whole period that seemed to have any significant curvilinear trend; and transformation (2.6) was numerically given as was shown in Fig. 6, where the symbols Δ and $*$ denoted the significant coefficients ascertained at 10% and 5% levels on the relation (2.5), respectively.

As in the treatment of annual rainfall amounts, the results supplement suggestive informations for the various analyse due to trend index I_T .

In any case, Tokyo and Fukuoka have different curvilinear increasing trends, even though they have the same significant trend in trend index I_T . For example the former has a cubic curve type and the latter a quadratic curve type as was shown in Fig. 6.

It will be desirable that such a detailed analysis based on polynomial fitting be performed for all the stations over every month, but this is apparently impossible for any one man. Only some examples are therefore shown in this section.

5. Secular variation in the rainfall amounts caused by Bai-u

The rainfall caused annually by Bai-u or typhoon is rather important from a climatological point of view, generally occupying about fifty percent of the total annual amount. The author (1957) confirmed this fact at about twenty observation points in 1953, by categorically classified summation of daily rainfall amounts for nine causes, and moreover I. MORI (1959) reported a similar result for other years to the author.

Needless to say, rainfall amounts caused by Bai-u or typhoons are different for different regions and the above-stated fifty percent is an averaged amount over whole Japan.

Generally, the total rainfall amount of June and July is comparatively large in western Japan and rather less in northern Japan, and its ratio to annual rainfall amounts usually appear in averaged values within the range 15%-30% in Japan.

Therefore, in order to study the secular variation of rainfall amounts caused by Bai-u, the determination rule of the Bai-u period must be clarified in relation to the past several studies.

K. SAKATA (1952) and K. TAKAHASHI (1953) performed independently climatic seasonal classification and arrived at similar results in Japan. According to their studies the next statistical specification will be suitable for us to determine the Bai-u period:

beginning day of Bai-u—the 8th day ($\pm$ five days) in June.

ending day of Bai-u—the 13th day ($\pm$ six days) in July.

From climatological viewpoint, Bai-u starts earlier in southern Japan than in northern Japan and the Bai-u period is considered somewhat longer than that of the oriental calendar as is shown in "Climate of Japan" (1958) p. 59.

For example, the Bai-u period had the range between the 3rd day of June and the 24th day of July in 1953 according to the "Meteorological Review" (published by

CMO). On the other hand, M. YOSHINO (1965) pointed out four stages of Bai-u from the end of May to the middle decade of July, and the different types of Bai-u year by year.

The local heavy rainfall of Bai-u often appears in the middle of July, so T. MIZUNO (1958) considers July a rainy month of the Bai-u type.

From a synthetic consideration of the past studies mentioned above, the author considered the total rainfall amount of June and July as the rainfall amounts caused by Bai-u, and gave the representative examples of secular variations in Fig. 7.

Fig. 7. Secular fluctuations of rainfall data caused mainly by Bai-u at representative points. (1900-1963)

On the other hand, an example of geographical distribution was prepared for actual rainfall amounts caused by Bai-u in 1953 by Fig. 8. In this case the total number of days within the Bai-u period is about 52 as was previously indicated, and differences between actual rainfall amounts caused by Bai-u and the total rainfall amount of June and July are sufficiently small in comparison with the latter amount.

The geographical distribution of trend index I_T is shown in Fig. 9 for the total rainfall amount of June and July, and then the author should like to point out three reasons why this geographical feature is considered as invariant for small modifications of the Bai-u period.

- (a) The total rainfall amount of June and July is generally considered as a little larger than the exact rainfall amount caused by Bai-u, but the secular relative variation tendency itself will be almost unchanged even if the base line of variation

rainfall amount, as was mentioned in the previous section.

So in this section, the secular variations of rainfall amounts caused by typhoons are systematically verified, but in the first place, the method of determining the rainfall amount caused by typhoons accurately must be established in connection with the accuracy of the synoptic weather map.

As is well known to us, the synoptic weather map has regularly been made since the year 1902 in Japan, but the observation network was not extensive enough to catch typhoon in its initial stage. I. MORI (1959) computed rainfall amounts caused by typhoons from 1912 and 1955 for twelve representative points in Japan, and the author (1957) computed the same from 1924 to 1954 for eighteen points in Japan, and obtained the analysis result based on trend index I_T .

These two studies slightly differ from one another in the data used, since the present author took into account the following:

Rain caused by the activities of a front accompanying the approach of a typhoon near Japan.

Rain caused by a front extending south from the center of a deformed cyclone.

So, generally the author's summation results are systematically larger than those of I. MORI when compared year for year and point for point, but these differences hardly influenced the discussion of secular variations because the correlation coefficients between these two different original data exist actually within the range 0.94–0.99.

Then, the author supplemented the above results with the recent data (1955–1964) and recomputed the trend index I_T for each point appearing in either of the above two studies, by using of rainfall amounts caused by typhoon over the whole period 1924–1964.

For the following three reasons the year 1924 was made the starting year for investigating the secular variation of rainfall amounts caused by typhoons.

- (a) The observation network was pretty well established in the southern sea domain from about this year, so that typhoons came to be clearly caught in the synoptic weather map.
- (b) Meteorological and climatological knowledge concerning the typhoon, cyclone and front made rapid strides from about 1924 and these came into the synoptic weather map regularly.

For example, the front theory of J. BJERKNES appeared in 1919, the wave theory of the cyclone due to the Norway school was proposed in 1920 and 1921, and the 1st volume of the Second series of Journal of Meteorological Society of Japan was firstly published in 1924.

- (c) In the formidable report

The Collected Data of Typhoons in Japan: published by the River Department of the Construction Ministry in Japan (1949), the data of typhoons are summarized since the year 1924, and this report has been quite useful for the author.

Table 4. Total amounts of rainfall caused by typhoons and tropical cyclones in Japan.

Station No.	1	2	3	4	5	6	7	8	9	10	11	12
Year												
1924	337	227	369	331	299	383	175	254	307	89	259	364
25	226	180	574	305	612	688	179	349	301	316	485	685
26	85	58	144	62	128	131	129	53	87	107	112	148
27	451	340	552	229	271	353	68	194	323	208	219	416
28	186	141	210	66	666	581	104	207	176	243	339	438
29	482	256	343	95	624	634	150	189	164	431	611	777
1930	408	218	316	204	148	116	65	249	213	66	167	109
31	191	129	224	103	357	420	113	167	131	106	120	291
32	33	107	318	23	243	32	20	139	169	84	69	218
33	256	260	271	187	350	420	174	176	233	218	124	191
34	189	168	368	323	231	171	245	259	293	41	56	62
35	312	215	88	708	393	1048	521	168	138	628	489	339
36	403	264	389	106	290	373	45	115	174	89	232	167
37	206	143	124	268	138	339	136	119	191	73	59	54
38	212	72	189	70	227	116	212	54	60	225	263	749
39	127	187	200	123	260	198	24	68	88	121	160	103
1940	286	168	238	184	163	377	160	241	241	57	168	79
41	224	299	226	585	524	467	252	220	155	212	259	448
42	242	186	204	164	436	373	162	241	187	201	296	236
43	749	445	538	345	459	878	629	807	386	187	199	374
44	185	64	11	220	173	170	252	151	123	249	199	227
45	451	310	352	513	931	583	491	558	516	266	473	433
46	174	108	245	66	286	335	45	177	183	59	95	68
47	212	361	211	198	188	80	150	223	150	110	185	174
48	2	214	301	20	249	70	72	312	271	47	160	367
49	834	511	374	433	508	822	191	163	386	350	270	459
1950	706	583	438	189	654	620	88	267	259	279	411	544
51	289	135	218	297	331	652	163	243	224	128	179	268
52	252	348	306	158	511	213	65	236	241	123	197	127
53	35	183	156	6	407	227	79	287	227	238	220	56
54	484	335	426	427	518	669	232	264	425	190	310	203
55	466	253	210	247	330	411	120	213	163	163	213	263
56	196	256	267	188	287	610	92	132	126	203	148	118
57	347	119	250	202	305	698	141	230	117	436	300	274
58	114	133	111	102	504	343	183	79	120	259	379	784
59	502	381	337	228	599	620	213	264	86	412	537	422
1960	333	204	240	194	481	398	180	204	457	317	334	310
61	477	297	238	353	779	700	165	161	300	513	517	291
62	572	466	430	243	189	265	269	185	213	131	257	222
63	371	400	272	283	696	851	433	358	339	344	289	569
64	280	41	28	66	181	210	67	60	43	84	134	162

Remark: (I) Place name of each station number

1. Kagoshima

2. Kumamoto

3. Nagasaki

4. Fukuoka

5. Tokushima

6. Kōchi

7. Hamada

8. Hiroshima

9. Shimonoseki

10. Ōsaka

11. Nagoya

12. Tokyo

Station No. Year	13	14	15	16	17	18	19	20	21	22	23
1924	326	89	104	140	60	144	238	36	63	90	72
25	569	173	123	161	208	329	433	228	114	211	76
26	94	68	84	56	129	155	162	71	45	73	47
27	188	208	191	198	270	194	49	75	81	128	13
28	484	201	187	185	133	365	234	90	125	246	49
29	545	566	258	322	223	316	186	78	126	86	207
1930	139	54	116	29	177	138	3	76	1	100	2
31	233	110	87	172	114	134	144	94	95	127	67
32	486	77	170	95	201	272	58	166	52	204	64
33	168	96	115	182	153	192	103	201	64	294	121
34	174	40	83	96	164	58	247	134	61	193	62
35	215	289	150	213	129	329	195	251	127	254	130
36	147	83	94	141	155	126	94	108	98	141	119
37	112	37	42	53	39	112	166	122	37	—	157
38	612	199	146	203	162	504	149	58	229	—	48
39	213	40	168	13	223	193	62	162	14	73	34
1940	354	65	101	121	118	246	161	187	192	154	73
41	433	274	151	155	116	395	150	166	112	197	200
42	99	61	52	237	51	93	115	200	33	130	105
43	290	118	158	163	79	162	259	77	75	241	63
44	159	87	78	290	41	111	201	90	73	49	99
45	171	436	322	607	242	348	353	325	314	303	112
46	245	—	188	1	122	158	34	58	26	72	—
47	194	82	144	154	224	214	191	230	80	253	130
48	568	139	227	180	340	535	429	227	101	195	15
49	385	341	266	176	96	456	282	65	79	136	25
1950	353	165	215	302	281	226	293	263	135	316	119
51	233	141	95	125	74	105	88	86	162	77	34
52	517	119	389	97	272	302	56	198	39	176	32
53	273	172	288	298	348	341	170	224	66	179	162
54	243	75	90	153	87	125	70	156	100	80	120
55	319	125	195	191	124	198	150	149	144	121	102
56	35	109	108	180	106	72	32	42	73	92	189
57	457	151	115	296	156	136	138	142	199	134	191
58	422	295	301	305	379	525	540	520	529	297	220
59	280	453	309	580	157	271	320	111	142	101	152
1960	475	226	149	211	126	89	175	141	158	109	212
61	231	284	246	531	367	339	337	166	298	232	270
62	291	83	128	164	97	193	422	185	307	384	438
63	532	238	229	483	314	244	185	106	263	172	130
64	156	184	170	187	164	169	129	68	108	69	102

13. Chōshi 14. Matsumoto 15. Nagano 16. Kanazawa 17. Niigata 18. Fukushima
 19. Miyako 20. Aomori 21. Akita 22. Hakodate 23. Sapporo

(II) Unit: mm

In order to maintain the essential homogeneity of data, the author would like to take up 1924, as the starting point in this section, but it must be admitted that this is at any rate for the sake of convenience.

In Table 4 are shown the summarized results of rainfall amounts caused by typhoons during the period 1924–1964, for the twenty-three representative points of Japan.

This number is not considered as large enough for describing the general geographical character. However, it is beyond the competence of one man to increase the number of observation points further, since the daily weather map must be treated exactly for each station year by year over the long period (1924–1964). These twenty-three points may be considered almost satisfactory in representing the outline of the geographical features, seeing that one or two points are allocated at least to each of the regions classified by the rainfall character already in the author's paper (1967).

The geographical distribution of trend index I_T is given by Fig. 10 for such rainfall amounts caused mainly by typhoons in Japan, and the following geographical characters can be pointed out:

Fig. 10. Geographical distribution of trend index I_T for annual rainfall amounts caused mainly by typhoons. (1924–1964)

Fig. 11. Geographical distribution of trend index I_T for annual rainfall amounts caused by typhoons excluding June and July. (1924–1964)

- (i) Trend index I_T is generally positive over the whole of Japan, except at four points (Tokyo, Miyako, Shimonoseki and Nagasaki), and particularly, significant increasing trends are seen at a part of western Japan and the Hokuriku district.
- (ii) The number of points having a not-significant increasing trends is rather numerous in eastern Japan.

But the rainfall amount in June and July caused by typhoons certainly assumed as a part of rainfall amount due to Bai-u in the previous section, so this conventional classification may be doubtful.

Hereafter, the rainfall amounts caused by typhoons are again computed except for June and July for each point and trend index I_T is also computed by use of such rearranged secular variation. The geographical distribution of such corrected index I_T is shown in Fig. 11 in the same way as in Fig. 10.

Both Fig. 10 and Fig. 11 have analogous geographical features but have several differences in details. For example, the value of I_T at Tokyo is negative in Fig. 10 while conspicuously positive in Fig. 11 and in reverse, the Hokuriku district has a significant increasing trend in Fig. 10, but not in Fig. 11.

The fitting of polynomial and statistical analysis to compute variability and persistency indices is omitted in this section because it is considered unnecessary (significant trend is not so clear over the whole of Japan).

7. Synthetic considerations of the climatic change of rainfall and designs planning

In the four sections preceding this, the various geographical characters in the secular variation of rainfall amounts have been treated rather individually, and now a synthetic description will be desirable, even though the geographical features are quite complicated as were shown above.

The following results can be pointed out in summary after a synthetic consideration of the numerous figures concerning trend analysis mentioned in the previous sections:

- (a) In the geographical distribution of trend index I_T , the not-significant trend regions is somewhat more widely spread over Japan than the significant trend regions except for the secular variation rainfall amounts caused by Bai-u.
- (b) Both annual and monthly rainfall amounts have no remarkable persistency as a rule, and secular variability is comparatively large in the southwestern part and smaller in the northeastern part of Japan. Moreover, such variability is a little large on the Japan Sea side than on the Pacific Ocean side of Japan and is least in Hokkaidō.
- (c) A general significant increasing tendency is apparent over the Kyūshū, San-in and the western part of the Hokuriku district year by year in Japan, but the cause of this tendency is locally different.
Nevertheless, the increasing type is the very large up-and-down fluctuation form around the normal mean value, which is common to the three districts above.
The significant increasing tendency appearing in Hokkaidō is clearly different from that of the other districts as was pointed out by T. SEKIGUCHI (1964).
- (d) The general significant decreasing tendency is apparent over the Pacific Ocean side of the Tōhoku district, the northern Kantō district, the inner mountain range and the southern part of the Chūbu district and Tōkai district.

As the climatic cause of such a trend, the author would like to indicate the fact that the number of cyclones and fronts that move north eastward along the Pacific

Ocean side of Japan has relatively and gradually decreased year by year. This is responsible for the recent narrowing of the region suitable for skiing, but this tendency is not seen over the whole of Japan since an increasing tendency in snowfall is seen at the Hokuriku and San-in districts.

- (e) Secular variation of the rainfall amounts are very complicated in every district of Japan, but roughly speaking, the tri-partite division into the Japan Sea side, the Pacific Ocean side and Hokkaidō as proposed by T. SEKIGUCHI (1964) holds quite well, even though a few local anomalies are inevitable within each region.

Lastly, the author would like to point out the possible causes of the increasing or decreasing trend described above in this section.

A hypothetical explanation was proposed that the increasing tendency of annual mean temperature (its rate being about $1\sim 2^{\circ}\text{C}$ per 100 year at a large city and about $0.5\sim 1.5^{\circ}\text{C}$ per 100 year at the other regions in Japan) might be partly responsible for rainfall increasing, but this relation is so complicated since rainfall has a stronger locality than temperature, being apt to be affected by orographic conditions. The author therefore considers the synchronous relation as doubtful.

Large-scale variation of the zonal index type pointed out by H.C. WILLETT will give some suggestion as to secular change of rainfall, but no physical explanation of it which is convincingly clear has not yet been given. After all, the causes of secular variation is remained to be cleared up.

Nevertheless, prediction or extrapolation of secular variation is often urgently in climatological studies, so statistical inferences are to be performed by application of the time series analysis such as M. OGAWARA and his collaborators (1954) tried to do it for monthly rainfall amounts. The statistical extrapolation procedure of the secular trend itself is not yet established firmly enough to serve for actual purpose, even through the idea of the stochastic trend was recently proposed by M.H. QUENOUILLE etc.

In order to plan the feature utilization of untouched water resources, some operational foundations or safety prediction with a high reliability must be established statistically. A simple but suggestive proposal will be given as a final note in the following:

Suppose the operational planning during the future m years is desired from social activities under the past secular rainfall amounts with sample size N (N years is the whole length of the observation period)

Planning based on extreme value (maximum or minimum)

We can discuss only the maximum value without loss of generality, since the essential consideration is completely the same as for the minimum value.

Let the ordered annual sample of size N be

$$x_1 \leq x_2 \leq x_3 \leq \cdots \leq x_{N-1} \leq x_N$$

and let $x_{(m)}$ be an unknown maximum value in a future m year, then the probability $P(x_{(m)} > x_N)$ is equal to $m/(N+m)$ independently of the original frequency distribution,

so this probability is certainly suggestive to feature planning. Next, the author obtained the following relation by a slight deformation of the well known inequality derived by Tschhebyscheff.

$$P\{X \geq lX_N\} \leq 1/2 \{(lx_N - \bar{x})/s\}^2 \quad (7.1)$$

where $\bar{x}$ and s are the mean value and the standard deviation computed from the past sample with size N respectively. The relation (7.1) has the following sense.

"Suppose the case that $\bar{x}=100\text{mm}$, $s=20\text{mm}$, $x_N=300\text{mm}$, $l=1.5$ or 2 and $N=60$, then we can say that the new maximum record exceeding twice the past maximum 300mm will occur once during the sufficiently long period of 1350 years, and similarly that the new maximum record exceeding 1.5 times of the past maximum 300 mm will occur once during period of 600 year."

Further planning based on the relation (7.1) seems to be sufficiently safe but is accompanied with the following risk.

For example, an event occurring once in about 600 years might occurred the next year or the year after next. Generally speaking, the bank of Osaka Bay was destroyed by the overflowing of the Yodo river and the inundation by sea water due to the approach of the Ione typhoon, and such typhoon approaches western Japan once in ten years, statistically, so that the authorities reconstructed the bank to resist a typhoon approaching once in ten years. Then the 2nd Muroto Typhoon attacked Osaka Bay after ten years just, but as it was somewhat stronger than Ione, its bank was again destroyed.

This is an example of complete but accidental accordance between plan and executional results. Therefore, to obtain a safety planning with high reliability, no occurrence of such an event during successive future m years is desirable as a rule, so we will use the probability that the new maximum record exceeding the l times of the past maximum appears once in the successive future m years expressed by

$$P_{m,n}(l) = 1 - [1 - P\{X \geq lX_n\}]^m \quad (7.2)$$

This probability was theoretically discussed for several models by the author; it is equal to about $1/50$ in the case of

$$P\{X \geq lx_n\} = 1/600, \quad m=10.$$

In other words, the design planning of this case has a reliability of 98%.

What has been given here is only a part of the synthetic expository contributions proposed by the author recently.

8. Summary

The secular trends of annual, monthly and special climatic rainfall amounts were studied more in detail than ever over the whole domain of Japan by use of as much data as possible. Trend index I_T and polynomial fitting were mainly used to clarify the several characteristics of secular variations. Quantitative comparisons were also carried out to find the locality of secular variation. The main results obtained were shown in the preceding section and they will be helpful for long range forecasting of climatic rainfall amounts.

Several trials have hitherto been made by E. FUKUI, K. TAKAHASHI and others in Japan, but they were not always satisfactory in data and the number of observation points. In view of their deficiencies, the author tried to describe systematically the trend characters of rainfall in Japan. Even if the author's results in this paper might be more or less corrected by new data in future, they will furnish adequate basis for future studies of climatic change.

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日本における降水量の永年変動

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日本における降水量の永年変動の状態をまず、年降水量について調べ、つぎに月別の降水量について解析し、さらに年降水量のうち梅雨期雨量、台風による雨量についてその変動状態を統計的に解析した。解析の方法としては、順位相関によるトレンド検出、直交多項式およびそれを変換した通常多項式のあてはめ、変動状態を記述するいくつかの指数の計算の3つを採用し、増加または減少の実態を明らかにし、地域的な比較を行なった。資料は1900年以前から観測のなされている本邦全気象官署の1964年までの値である。

主な結果をあげると

- (i) 本邦全域としてみた場合、増加傾向になっている地点が多い。
- (ii) とくに九州、四国地方は顕著な増加傾向域となっているが、それは主として台風による雨量が増加しているからである。
- (iii) 東北、北陸地方では増加と減少の区域が入りみだれて存在し、とくに冬季降水量(降雪量)の明らかな増加域が点在しているが全般的には減少している。
- (iv) 関東地方はどの月別の降水量にも減少傾向の場合が多く、それが年降水量の明瞭な減少傾向となっていてあらわれている。

などである。

これまでの研究で定性的に知られていたことが数量的な結果として明らかにされ、資料補足によって若干訂正された結論が得られた。