응용통계연구제 5권 2호
1992년 pp 123-137

Statistical Nature of the Dry and Wet Periods defined in the Time Series of Annual Precipitations (1771-1990) of Seoul

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< ABSTRACT >

We analyzed a time series composed of the annual precipitations of Seoul based on the measurements of a Korean raingage and a modern raingage. The precipitations measured with a Korean raingage for the period of 1771 to 1907 are followed by the precipitations with a modern raingage for the period of 1908 to 1990. The latter part of the time series of annual precipitations were obtained from a book for annual precipitations of Korea by Korea Meteorological Administration and the former from Wada's table 1 for monthly precipitations reproduced from the daily rainfall measurements by a Korean raingage for the period of the Yi Dynasty.

In our analysis three different precipitation regimes clearly stand out of the entire period. In order to define objectively the period of each precipitation regime we made a time series of 9 year moving averages from the above time series. By taking into account the shapes of the moving average time series and by using a threshold value of annual precipitation 1050 mm, we defined three precipitation regimes of wet period 1(WP1), dry period (DP), and wet period 2 (WP2). The WP1 and WP2 show very similar characteristics in our statistical analyses. On the other hand, DP is very different from the two periods in many statistical aspects.

The strong similarities of the WP1 and WP2 regimes in the magnitudes of statistical parameters and in the shapes of their power spectrum distribution are supporting very positively the soundness of precipitation amounts measured with a Korean raingage in spite of numerous conceivable errors which might have

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been introduced into measurements of precipitation due to changes of observation site and environment, the scale of units employed, and urbanization of Seoul, etc. However, the annual precipitation amounts are not enough to examine throughly the characteristic of precipitation variations during the two regimes. It is definitely necessary to recover the daily amounts of precipitation, based on two or three times measurements of rainfall with a Korean raingage, scattered in various ancient documents such as the official diary of 'Seungjeong-weon'

1. Introduction

Among the many meteorological parameters, the longest records may be found for rainfalls. This might be due to the importance of the amount of precipitation for the agriculture in the human life. As Korea was a farming country, our ancestors would be very interested in measuring the amount of precipitation quantitatively. In the beginning period of the Yi Dynasty, King Sejong invented the Korean raingage[2] pronounced as 'Chukwookee' in Korean. Due to the invention of the gage, Korea has one of the most extended time series of the precipitation amounts measured with a scientific raingage in the world.

Kim and Ha (1987) analyzed the monthly precipitation amounts for the period of 1771-1986. In their analysis the precipitation amounts measured by Korean raingage was continued with the time series of precipitation values measured with a modern raingage[3]. In Korea the conventional modern method of measuring precipitation has been adopted since 1908. When considering differences of measurement between the two different raingage systems, if any, we might expect a discontinuity in the time series of precipitation amount around the year of 1907. But their figure 1 does not show any clear jump in precipitation

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[2] Although 'Chukwookee' should be preferred phonetically for designating the rainage invented by *King Sejong* , we will use this terminology instead of 'Chukwooke'. When the word 'Chukwookee' in Korean is written in Chinese character, it means any type of gage for measuring rainfall. Our choice of the terminology would somehow reduce confusions between measuring tools for rainfall used in our country and in other countries before the introduction of conventional modern raingages.

[3] Recently many kinds of raingages are used. This term will be used to denote any kinds of raingages employed nowadays in contrast with Korean raingages employed in the period of Yi Dynasty.

amounts at about the years of 1907-8. We think this suggests the annual precipitation amounts at Seoul are not so sensitive to the differing methods of measurement. In other words this suggests that the natural variability in the annual amounts of precipitation at Seoul is much larger than that resulting from a change of measuring instruments.

The above fact somewhat contrasts the findings of Groisman et al. (1991), in which they show that the amount of precipitation was significantly changed by the different types of raingage and also measuring frequency per day. According to their analysis more frequent measurement results in an increase of the measured amount of precipitation by 5 % to 40 %. The contrast of their results to the analysis of Kim and Ha(1987) may be attributed to the locality of characteristics of precipitation.

The time series of the annual precipitations may be enough to examine the climate changes of the amount of precipitation. Dealing with the annual record of precipitation will greatly reduce time and energy for processing data. Data description will be given in Section 2 which is followed by the result of analysis presented in Section 3. In Section 4 we will summarize our results and give suggestions for further analysis of the precipitation data.

2. Data

The entire data period extending from 1771 to 1990 may be divided according to their origin into two time periods with different length of 1771 ~ 1907 and of 1908 ~ 1990. The annual precipitation amounts for the latter part of the time series were obtained from a book of 'Climatological Extremes of Korea' for the period of 1904 to 1989 (KMA[4], 1990). The amount of the annual precipitation of 1990 is estimated based on the monthly precipitations in the 'Monthly Report'(KMA, 1990).

The former part of our data are based on the Table 1 of Wada's book (1917). But our annual data are not based on his converted monthly precipitation amounts given in his Table 2. The reason is that we want to look at an unconverted time series which was reproduced from the daily amounts of

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precipitation measured with a Korean raingage and which were modified by only taking into account the scale of units employed in the modern and premodern era of Korea. It seems not clear to us how much reasonable Wada's method of estimating his monthly coefficients. But in this paper we will not address the correctness of his monthly coefficients.

However, we think, it must be understood by all the people who are concerned with precipitations in the old times of Seoul that up to the present all the published precipitation data by KMA are, without exception, based on the converted data with the aid of Wada's monthly coefficients. Also all the works on the precipitation amounts of Seoul for the premodern era are based on the converted data originated from the table 2 of Wada(1917). Many literature about the secular trend of precipitations of Seoul pointed out that Seoul gets drier as time goes on slowly or in a stepwise like pattern (Kim and Ha, 1987; Cho, 1976).

3. Results

a) Unconverted time series

The unconverted time series of the annual amounts of precipitation are displayed in Fig. 1, in which the missing data for the Korean war are simply omitted. Except for the period near 1900 with apparently smaller amounts of annual precipitations, there are no significant long term variations in annual precipitations over the entire period of the time series. It should be worthwhile to note that we have not any clear discontinuity between the years of 1907 and 1908, when the two time series of the annual precipitation amounts are connected without any adjustment. On the other hand we could locate larger differences in the annual precipitation amounts near the years of 1890 and 1913, separately.

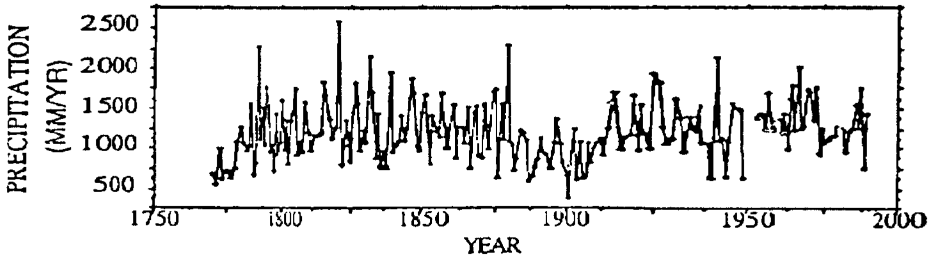

Fig. 1. Time series of the unconverted annual precipitations in millimeter from 1771 to 1990. Missing values during the Korean War 1950-1953 are omitted.

The smaller amounts of precipitation during the years before and after 1900 stands out clearly the general trend of increase in a cumulative amount of annual precipitations shown in Fig. 2. Near the beginning of the time series there is another period with a very slow increase of the cumulative precipitation amount but rather short. These smaller annual precipitations appearing in the beginning part of the time series shown in Figs. 1 and 2 will be excluded hereafter in our analysis even though they are supposed to be very interesting feature of the series.

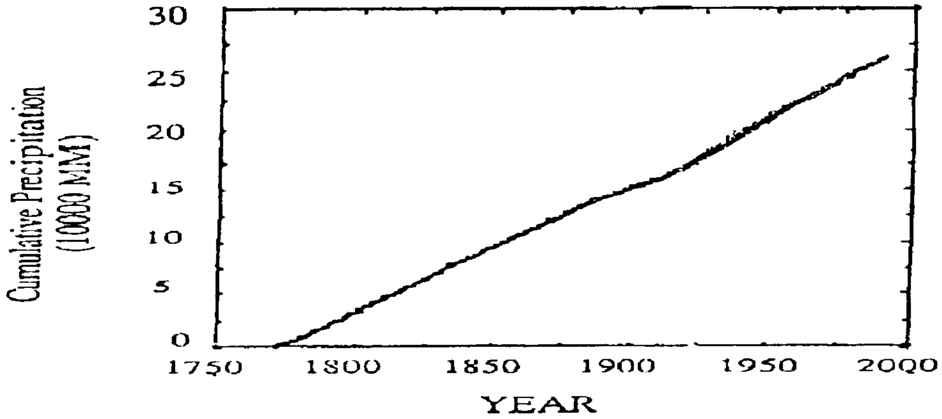

Fig. 2. Cumulative amounts of annual precipitation derived from the unconverted annual precipitations shown in Fig. 1. Missing values were linearly interpolated in the time domain.

b) 9 year moving averages

In order to delineate any decadal or interdecadal variations in the annual precipitation amounts, we made 9 year moving averages from the unconverted time series and displayed them in Fig. 3. Clearly, it is admissible to categorize the time series into three different periods. We partitioned the entire period into a wet period 1 (WP1), a dry period (DP), and a wet period 2 (WP2). The WP1 and WP2 are rather wet periods compared with the DP period. The total number of years belonging to the three different periods is 101 years for WP1, 27 years for DP, and 79 years for WP2, as in Table 1.

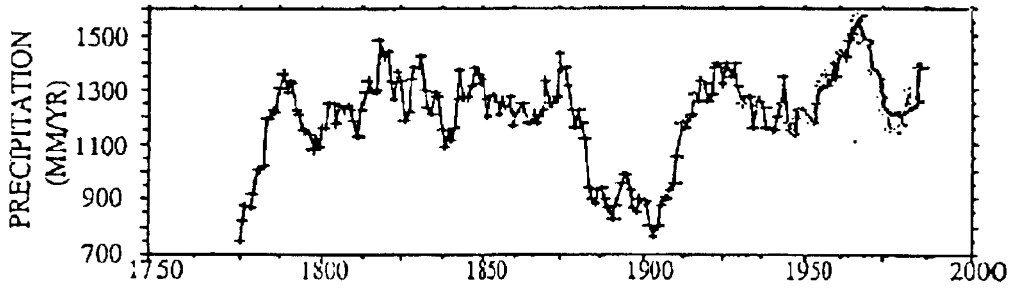

Fig. 3. Time series of 9 year moving averages reproduced from the unconverted time series of annual precipitations. The time series were used for the definition of the three different precipitation regimes of WP1, DP, and WP2.

Parameters	WP1 (1783-1883)	DP (1884-1910)	WP2 (1912-1990)
Numbers of years	101	27	79
Mean (mm/yr)	1256.5	898.0	1308.1
STD (mm/yr)	385.5	242.3	334.1
Skewness	.86	-.71	.53
Kurtosis	1.00	-.97	.43

Partitioning the entire period is very straightforward in the time series of the 9 year moving averages shown in Fig. 3. However, we are not so much concerned with the statistical characteristics of the time series of moving averages themselves. So we will come back to the unconverted time series again in order to examine the statistical characteristics of the time series for each period, separately.

We estimated statistical parameters such as means and standard deviations of annual precipitations for individual periods and exhibit them in Table 1. When we test the significance level of the parameters for the three periods given in Table 1, the means and variances for WP and DP are different with a level of confidence less than 0.5% irrespective of WP1 and WP2. On the other hand the means and variances for WP1 and WP2 are considered to be same with a level of confidence of 5%. In other words WP1 and WP2 are basically composed of samples from the same population.

In the case of the moments of skewness and kurtosis, the wet periods have much larger values than the dry period does. The frequency distribution of annual precipitations during DP should be negatively skewed and platykurtic, while during WPs an opposite pattern of frequency distribution is expected. The values of kurtosis shown in Table 1 are computed by subtracting the kurtosis value 3 for the normal distribution from the moment coefficients of kurtosis of annual precipitations. In order to examine the representativeness of statistical parameters given in Table 1, we plotted in Fig. 4 the frequency distribution of annual precipitations for the different periods. It seems very clear that the actual frequency distributions of annual precipitations during each period are very close to those which could be idealized based only on the values of statistical parameters for the corresponding period.

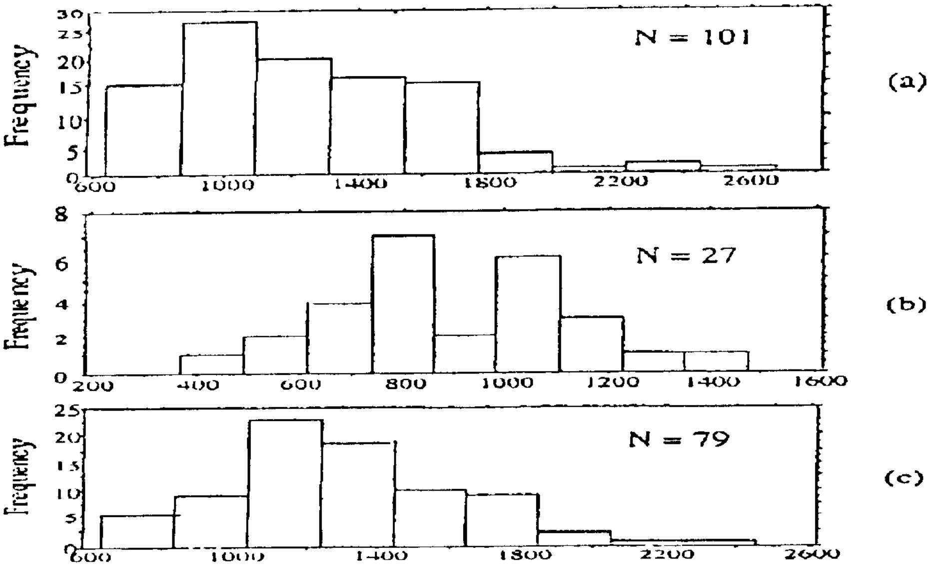

Fig. 4. Frequency distributions of the three different precipitation regimes of (a) WP1, (b) DP, and (c) WP2. The N values shown in the upper right corner of each panel are the total number of years for each regime.

In order to find any differences in the spectrum of the precipitation time series, we prepared Figs. 5 and 6 for the unconverted time series of the entire period and of each precipitation regime, respectively.

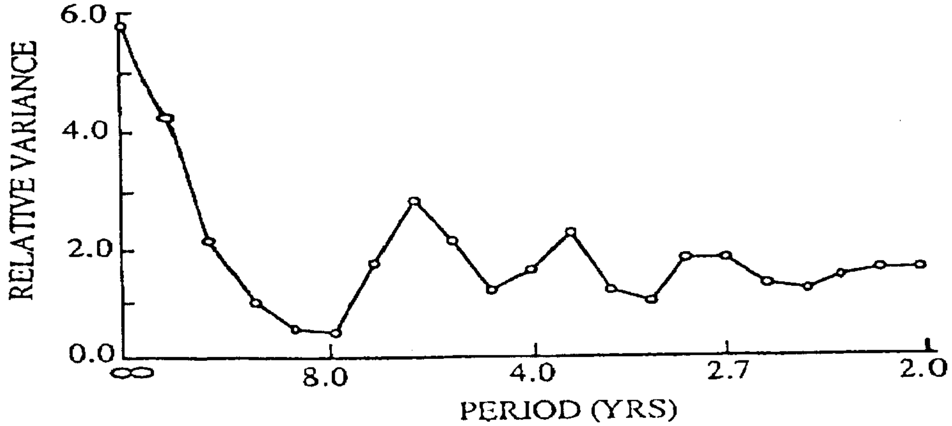

Fig. 5. Power spectrum of the time series shown in Fig. 1. Ordinate is relative variance. Variance is normalized by the total variance of the series. Area under curve is one.

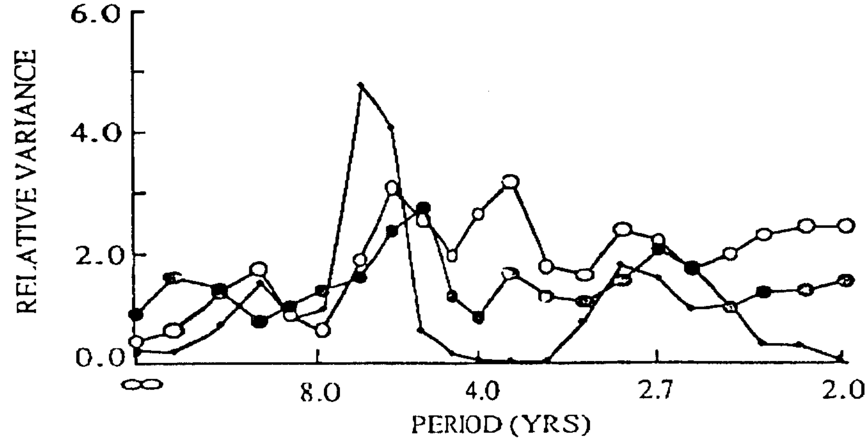

Fig. 6. As in Fig. 5, but for the three different precipitation regimes. The small right rectangle dots (◆ are for DP, the empty circles (o) for WP1, and the solid circles (●) for WP2.

The power spectrum for the entire period shown in Fig. 5 has very large variance near the low frequency regions except for the other four minor peaks at other frequency bands. But no signature of the power peak in a low frequency region of Fig. 5 is found in power spectra for each precipitation regime shown in

Fig.6. The relatively large power in a low frequency region are clearly related to the jump like transitions between the wet and dry periods which is very clear in Fig. 3. In Fig. 6 we want to point out differences in the distribution of power in the frequency domain between DP and WPs. The DP shows spectral peak near 6 years periodicity and 3 years periodicity while WPs manifest more or less a white noise spectrum.

c) Tendencies of annual precipitation

In order to examine any tendency of continuity in the annual amounts of precipitation between consecutive years, we made differences of precipitations between a year and the following year and displayed them in Fig. 7. The standard deviation of this time series is 492mm/yr. The larger value of the standard deviation of annual precipitation tendency time series compared with that of the time series of annual precipitations means that there exists a nature such as the amount of precipitation of a year does not say anything about the amount of next year precipitation. In other words there are relatively very strong high frequency components in the time series of annual precipitations. Such a nature is somewhat in contrast with the general redness of the meteorological parameters (Gilman et al., 1963). When looking at the unconverted time series shown in Fig. 1, it is also possible to note a big power associated with the high frequency components of fluctuations in the time series of annual precipitations.

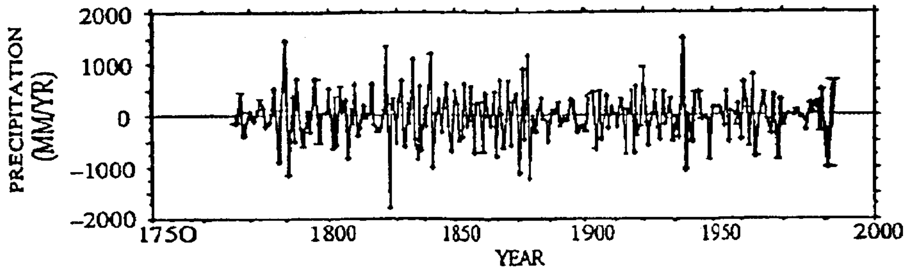

Fig. 7. Time series of the annual precipitations of difference between consecutive two years.

4. Discussion

We analyzed the time series of annual precipitations reproduced from monthly precipitations by a Korean raingage and a modern one. From the comparison of statistical parameters for the two wet periods defined in our analysis, we have not found any significant change in the magnitude of various statistical parameters between annual precipitations for 1783–1883 measured· by a Korean raingage and for 1912–1990 measured by a modern one. This is consistent with the results of Bradley et al. (1987). In their analysis South-East Asia shows almost stationary state in the annual amounts of precipitation with increasing year. In contrast, Soviet Union shows a slight increase of annual precipitation from 1850 through 1985. When considering the location of our country in their analysis, it seems much more plausible to expect a slight increase of precipitation rather than a decrease during the period of our data analysis. In our time series WP2 shows larger amount of annual precipitation than WP1 does (refer to Table 1).

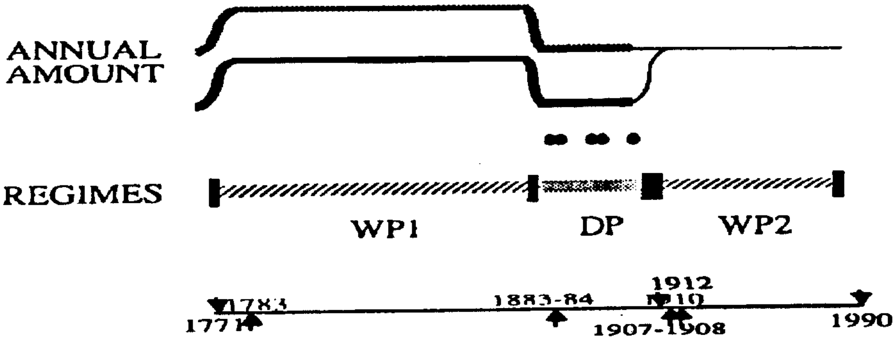

Fig 8. A schematic for the annual precipitations of Seoul.

In Fig. 8, we summarized schematically a long term or secular change of annual precipitations. The cross hatched thick curve followed by a thin straight line in the right side of the figure shows an interdecadal change of annual precipitations with increasing time based on Table 2 of Wada (1917) and also based on the precipitation amounts in 'Monthly Precipitation Records' for 1770 to 1960 published by KMA, which were basically reproduced from those in Wada's table 2. Because we have not processed the converted annual precipitations given in the Table 2 of Wada(1917), we depicted the curve by taking into account the shape of the time series of the low pass filtered annual precipitationsof Seoul for 1771 to 1975 appeared in the Fig. 4 of Cho (1976). According to these precipitation data sets we have not a dry period discussed in our analysis of the unconverted precipitation data set. The corresponding solid thick curve for the annual precipitations from 1771 to 1907 is configured based on the Table 1 of Wada (1917) of which annual precipitations are used with little modification in this study. The straight line of dashed and shaded patterns signifies the time span of each precipitation regime defined by us. The thin bottom line with arrow heads of marking starting and ending years of periods shows the progress of year from left to right. The five black dots denote the five years of which monthly precipitation amounts by a Korean raingage and a modern raingage were compared by Wada for making his monthly coefficients. The amounts of annual precipitations are represented in a relative sense in this schematic illustration.

Although we can show clearly the distinguished pattern of annual precipitation amounts in the time domain, we have to admit that there exist many limitations in studying of the statistical characteristic of each precipitation regime by using only annual precipitations. The unconverted monthly precipitation data available to us at present should be analyzed for further studying of the effects of the detailed methods of measuring, the frequency of measurement, and the change of observing sites. At present, however, we are not sure that the monthly precipitation amounts will be enough to address the above questions. If possible, the time series of daily precipitation amounts of a Korean raingage should be recovered and reanalyzed for its characteristics of variability in order to examine the climatic change in the amounts of precipitation and also to clarify an underground idea and effect of using Wada's monthly coefficients for conversion.

Actually Cho and Na (1979) had recovered daily precipitations of 24 years from the diary for the period of King Youngjo and compared them with the converted monthly precipitation values by Wada. They recognize the exactness of the precipitation amounts recorded in the diary with a slight disagreement in their comparison of the two precipitation amounts. In fact they questioned the reliability of the Wada's reproduced precipitation data. The difference they indicated would be much smaller if they used Wada's unconverted data rather than his converted data. In their study they compared their recovered data (in a certain sense this is very much like our unconverted data for daily precipitations) with the converted precipitations reproduced by multiplying Wada's monthly coefficients to the unconverted precipitations (personal communication with Dr.

Cho, 1992). Therefore, we think, it should be done restoring the daily precipitation amounts for the entire period from the diary without regard to the existence of discontinuities in the records.

We are very impressed with the work of Kim (1988). When thinking of his argument, it seems very important to make people, especially foreigners, know the fact about the Korean raingage. In addition, we should investigate the precipitation amounts by the Korean raingage for its own sake. Of course before analyzing data, we should convince ourselves and others as regards the quality of the data to be employed. Without increasing the validity of our precipitation data by a Korean raingage and without illuminating the mysteries of the monthly coefficients of Wada, the importance and invaluableness of our precipitation data set will be severely underestimated than it has to deserve.

We suggest that there might be involved many probable shortcomings in the conversion of the monthly amounts of precipitation by a Korean raingage into the corresponding ones by a modern raingage by using the monthly coefficients estimated for five years falling into our dry period isolated from the other period in statistical character (look at Fig. 7). Therefore, we should investigate these valuable records with a variety of different viewpoints and methods. In order to reduce the uncertainties in the calculation of the monthly coefficients and to recover the daily amounts of precipitation by the Korean raingage, works on this topic should be continued.

Acknowledgements

This paper is based on one of the lectures presented in a spring time symposium held at Young-Nam University for the topics of statistical methods in meteorology. Comments and questions of reviewers improved greatly the contents of the first version of the paper. The author wants to express many thanks to members of Korean Statistical Society.

< References >

[1] Bradley, R. S., Diaz, H. F., Eischeid, J. K., Jones, P. D., Kelly, P. M., & Goodess, C. M. (1987) "Precipitation fluctuations over Northern Hemisphere land areas since the mid-19th century", *Science*, 237,

171-175.

[2] Cho, H. K. (1976) "Secular variation of the rainfall in South Korea", ***Climatic Change and Food Production,*** Ed. by Takahashi, K. & Yoshino, M. M., University of Tokyo Press, 25-39.

[3] Gilman, D. L., Fuglister, F. J. & Mitchell, J. M., Jr (1963), "On the power spectrum of 'Red Noise'". ***Journal of Atmospheric Sciences,*** 20, 182-184.

[4] Groisman, P. Ya., Koknaeva, V. V., Belokrylova, T. A. & Karl, T. R.(1991), "Overcoming biases of precipitation measurement, A history of the USSR experience", ***Bulletion of American Meteorogical Society,*** 72, 1725 - 1733.

[5] Kim, S. S. (1988), ***Comments on the Chinese claim for the invention of Chukwookee,*** Selected Papers of Kim, S. S., Hakye-Sa, 427-440. (In Korean.)

[6] Kim, J. W. & Ha, K. J. (1987), "Climate changes and interannual fluctuations in the monthly amounts of precipitation at Seoul", ***Journal of Korean Meteorological Society,*** 23, 54-69.

[7] Korea Meteorological Service (1990), ***Climatological Extremes of Korea, Monthly and yearly values of meteorological parameters for 1904-1989.*** Dong-Jin Press Co., 507 pp. (In Korean.)

[8] ______ (1990), ***Monthly Weather Report, Issues of January to December, 1990.*** Each volume contains 38 pages. Gong-Myeung Press Co., 456pp. (In Korean.)

[9] Spiegel, M. R. (1961), ***Statistics,*** McGRAW-HILL, 359 pp.

[10] Wada, Y. (1917), ***Chosen Kodai Kansoku Kiroku Chosa Hokoku,*** (Reports on the survey of the ancient records of observation in Korea), 200 pp. (In Japanese.)

서울의 연 강수량

임규호1)

<요 약>

측우기와 근대 우량계로 관측한 서울의 연강수량 시계열을 분석하였다. 측우기로 관측된 1771년 부터 1907년 사이의 강수량과 1908년 이후부터 1990년까지의 근대 우량계에 의한 강수량 시계열을 특별한 보정없이 연결하여 사용하였다. 근대 우량계에 의한 후반부 자료는 기상청 발표자료이며 전반부의 고대 관측 자료는 와다(ワタ)가 측우기 자료를 이용하여 계산한 월별 강수량을 단위 환산후 수록한 그의 저서 내부의 표1을 이용하였다.

전 분석기간을 3 부분으로 분리가능하였으며 이를 객관화하기 위하여 원시 계열을 9년 이동평균하여 구한 시계열과 년강수량 1050mm를 기준으로 사용하였다. 우리는 분석기간의 대부분을 습윤시기1, 건조시기, 습윤시기2 로 분리 명명하였다. 통계적인 특성상 습윤시기1 과 2는 동일집단으로 간주 가능하나 습윤시기와 건조시기는 그렇지 못하다.

통계적인 특성상 습윤시기1 과 2의 강한 동질성은 측우기 자료의 신빙성을 높이는 것으로 해석할 수 있다. 이러한 결과는 고대 측우기 관측에 동반 되었을지 모르는 여러가지 제약들, 예를 들면 관측 장소와 측정단위의 불명확성 그리고 서울의 도시화와 관련된 제반 기후 변화등을 고려하면 더욱 더 그러하다. 그러나 건조시기와 습윤시기의 강수 변동성을 정확하게 파악하기 위하여는 승정원 일기와 같은 고 문서에 산재하는 측우기로 관측된 일 강수량을 재 발굴하여 분석하는 것이 시급하다.

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