The Instrumental Precipitation Records During the Last 220 Years in Seoul, Korea

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Abstract : Statistical characteristics of precipitation in Seoul have been examined by using long-term observational data. Precipitation records from modern rain gauges were used for 1908-1999, together with the traditional Korean rain gauge (Chugugi) for 1777-1907.

Keywords: ARIMA Model, Intervention Model, Precipitation Records, Rain Gauge, Trend Analysis, Wavelet Analysis.

1. Chugugi

The Korean government has been measuring quantitative precipitation for a long period of time. In fact King Sejong, who was the fourth king of the Chosun Dynasty (1392-1910), invented *Chugugi*, the first rain gauge in the world in 1441 (Annals of King Sejong). The Korean people have relied heavily on agriculture, and crop yields depended on precipitation amount received during the growing season. Such an impact of precipitation amount on agriculture might have been much more serious due to the improper irrigation system. The social environments at the beginning period of Chosun Dynasty may have been related to the invention of the scientific rain gauge. *Chugugi*, made of iron and stone, remarkably resembles the modern rain gauges in shape and size (Kim, 1988) as shown in Figure 1. The height, diameter, and thickness of *Chugugi* are 30cm, 14-15cm, and 2.5mm, respectively. It is known that there is no change in shape (cylinder) and size over the years of 1770-1907. During the Chosun Dynasty, the network of *Chugugi* had been maintained over 8-9 places (including Daegu and Seoul) and the records were kept in the king's diary (Kim 1988). It has been located in the King's palace, in the case of Seoul. The status of the officers who have measured and recorded precipitation was the third place in the Ministry. Only the records in Seoul are found from currently available books. Korea has been keeping one of the world's longest time series of quantitative precipitation amounts measured by scientific rain gauge dating back to 1770.

Figure 1. Chugugi

In Korea, modern rain gauges were introduced in 1907. Since then, the modern gauges have been used for measuring the amount of precipitation. Recent analysis (Jung et al, 2001) suggested that there is a clearly discernable sudden increase of precipitation days around the year 1907, which resulted from the change of measuring unit from the traditional Korean rain gauge to modern ones. In contrast to the change in the number of precipitation days, it seems that there is no significant change in the monthly precipitation amount (see Figure 2).

The precipitation amount by the traditional Korean rain gauge was recorded with the Korean foot-rule such as *Pun*, *Chi* and *Cha*, which approximately correspond to 2 mm, 20 mm and 200 mm, respectively. For example, 1 *Pun* or more of precipitation was measured with the minimum resolution of *Pun* and the event with precipitation amount less than 2 mm was not measured. The events like snowfall and hail are not measured.

The earlier part of the data for 131 years (1777-1907) in this study was derived from the pseudo-hourly precipitation record in the *Seungjungwon-ilgee*, the official diary of the Chosun Dynasty. Unfortunately, observations before 1770 are not recorded in any of currently available books. Part of record is also found in the *Ilsong-rok*, but the record is very similar to that of the *Seungjungwon-ilgee*. The later part of the record for 92 years (1908-1999) was obtained from the Korea Meteorological Administration. The missing values during Korean War (1950-52) were interpolated. A time series plot of this data (annual precipitation) is given in Figure 2.

2. Statistical analysis

2.1 Trend analysis for Chugugi time series

Recent concern about the possibility of climatic change has focused on the climatic time series such as temperature and precipitation. A key question raised by these data is whether the temperature (or precipitation) rise is the start of a systematic change or simply an effect of natural variability. Here some statistical methods for detecting climate change or any trend over years are applied to Chugugi time series. Actually, testing hypothesis on correlation coefficient, regression method for testing the deterministic trend, and Brillinger's (1989) nonparametric method are used.

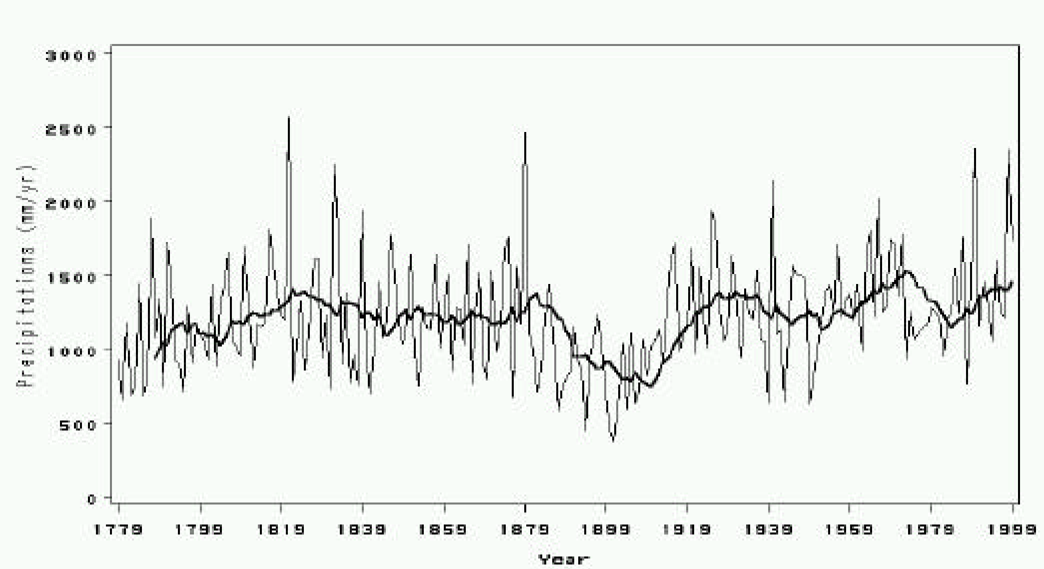

Figure 2. Time series plot of annual precipitation at Seoul from 1777 to 1999

For these purpose, time series of two months moving averages are constructed from 1771 to 1998. However, since snowfall was not measured by Chugugi, only the eight time series of two months (MA, AM, MJ, ..., SO, ON) are used for trend analysis. We applied the above methods to each of eight time series respectively.

Increasing trends for MA and AM are detected with 5% significance level by all of three methods. The monthly increments of MA and AM are 8mm-13mm and 14mm-16mm, respectively.

2.2 Wavelet analysis for Chugugi time series

Recently, wavelet transformation method with statistical analysis has been used many fields of applications including signal processing, image analysis, and data compression. It has been also applied to data analysis in the atmospheric sciences. A wavelet transform is a common and powerful tool for analyzing the localized variations of power within a time series. By decomposing a time series into time-frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time.

The results of wavelet transform of precipitation amount indicate the dominant 50-60 year oscillation during the dry period. In the case of the inter-decadal variations with periodicities longer than 20 year, the energy power maximum region shifts toward the shorter periodicities after the mid-1770s in the time and frequency analyses. The 20-30 day oscillation has a notable spectral peak. It seems to suggest the pass of typhoon and intensive cyclones. Also the spectral peaks with periodicities from 3 to 8 day mostly resulting from the synoptic-scale transients are dominant when 20-30 day oscillation is strong. See Jung (1999) for details.

2.3 Analysis using the intervention model

To determine whether it is necessary to recover the time series of annual precipitation amounts of a Korean rain gauge we analyzed the Chugugi data and the Wada's converted data using the intervention model.

One of the issues related to the precipitation amounts is the discontinuity in the time series around 1907 when the modern rain gauge was first used in Korea. To solve this discontinuity problem Wada (1917) reproduced the Chugugi data but many authors questioned the validity of Wada's method. In this paper we analyze the annual precipitation amounts in Seoul from 1777-1999 using the intervention model and show that Wada's method results in the overestimation of the annual precipitation amounts. Also we show whether there exist any discontinuities in the precipitation amounts due to the change in the measurement gauges and the methods.

To identify if there is any discontinuity in the precipitation time series we fit the ARIMA model to Chugugi data (model 1), Wada data (model 2), and the modern gauge data (model 3) separately. Our study implies that there might be a discontinuity problem between the Chugugi data and the modern gauge data owing to the change in the measuring method and gauge. Therefore, we have to be careful in using the combined precipitation data without any correction. This is one of the reasons why Wada made correction using his own method but recent studies show that his method is inconsistent.

To measure the effect of the change in the measuring method and gauge we fit the intervention model to the precipitation data using the change of the measurement method as an intervention.

$$I(t) = \begin{cases} 1, & 1777 \sim 1907 \\ 0, & 1908 \sim 1999 \end{cases}$$

Intervention model fitted to the converted data by Wada (1777-1999):

$$Z_t = \underset{(55.978)}{1327.0} + \underset{(72.306)}{194.58} \times I(t) + \frac{1}{1 - \underset{(0.0685)}{0.2308} B^{11}} e_t, \quad \hat{s} = 425.06 \tag{2.1}$$

Intervention model fitted to the unconverted data (1777-1999):

$$Z_t = \underset{(54.900)}{1332.1} - \underset{(70.493)}{188.93} \times I(t) + \frac{1}{1 - \underset{(0.0678)}{0.2925} B^{11}} e_t, \quad \hat{s} = 388.98 \tag{2.2}$$

In model (2.1), 194.58 is the intervention effect which means that Wada data records 194.58 mm more than the modern rain gauge data on the average. Standard errors of the estimates are given in the parenthesis. On the other hand the intervention effect of the model (2.2), -188.93, implies that Chugugi data records 188.93 mm lower than the modern rain gauge data on the average. The intervention effect in model (2.2) might be explained by firstly, Chugugi data does not record the precipitation amount less than the minimum unit of 1 pun ($\approx 2mm$) and secondly, the snowfall and hail are not measured for the Chugugi period. On the other hand the difference in the Wada data and the modern rain gauge data cannot be explained by the natural variation.

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