Proceedings of the International Symposium on Lowland Technology, Saga University, September 2002

COMPARISON OF MONTHLY PRECIPITATION AT PUSAN, MOKPO, AND INCHON IN KOREA AND AT FUKUOKA IN JAPAN

Y. H. JIN, A. KAWAMURA, K. JINNO
Institute of environmental systems, Kyushu University, Fukuoka, Japan
R. BERNDTSSON
Department of water resources engineering, Lund University, Lund, Sweden

ABSTRACT: Few studies of how the precipitation climate is co-varying over South Korea and southern Japan have been made. We fill this gap by studying the co-variation of long monthly precipitation records at three stations in South Korea and one station in Japan. Properties of precipitation at Pusan, Mokpo, and Inchon in Korea using monthly records since 1904 are analyzed in terms of basic statistics. Autocorrelation and spectrum analyses are performed to investigate the periodicity in the time series. Statistical characteristics and periodicities for each station are compared with those at Fukuoka in Japan and also the cross-correlation among these four stations are investigated. The general characteristics of precipitation in Korea are an annual mean of about 1,300 mm, of which more than half occur between June and September. The winter precipitation from December to February is usually less than 10% of total annual precipitation. Remarkably, there are several records of no monthly precipitation (less than 0.1 mm) at the three stations in Korea, while no such record has occurred in Fukuoka. Pusan and Fukuoka have similar spectrum patterns in which the annual periodicity and a shorter periodicity of about 3 months are dominant. Inchon and Mokpo have dominant annual and half-year periodicities. In general, cross-correlation between all stations are high. The highest correlation occurs between Mokpo and Pusan corresponding to 0.77 (lag $t = 0$). Pusan and Fukuoka have the second highest correlation corresponding to 0.56. Additionally, the highest correlation between Inchon and Fukuoka occurs uniquely for a lag time of one month with a value of 0.42.

INTRODUCTION

Observation of precipitation in Korea has been made since the rain gauge, which was called Chukwooki, was invented in 1441 (Ahn 2001). This rain gauge was 40 cm high and had a diameter of 16 cm. After improving the rain gauge the next year, 1442, the depth and diameter were modified to a height of about 30 cm and a diameter of 14 cm. Such rain gauges were installed all over the country and used until 1907. However, the precipitation data, which were recorded in the Diary of Seung Jeoung-Won, disappeared during the Japanese and Chinese invasions in the 16th and 17th centuries. Precipitation observations were restarted in 1770 in Seoul using the same type of gauge. Consequently, precipitation records exist from 1770 (Cha 2000).

A Chosen governor established and started operating modern precipitation observation stations in Inchon, Pusan, Mokpo, and Wonsan in 1904 (Wonsan is located in present North Korea). In 1907, the Kyeng-Sung climatological station was constructed. In 1916, 15 more rain gauges were established and 53 water level gauges introduced to observe runoff. Since then, hydrological stations have been increasing annually (Ahn 2001).

Many researchers have studied precipitation characteristics of Korea. Kim et al. (1988) studied the time variation of precipitation using long period data for main cities in Korea and showed changes of annual mean precipitation with time. Kim et al. (1997) showed the nonstationarity, trends, and persistence of annual precipitation at 38 stations in Korea.

There are also a number of studies using the precipitation data from 1770 and Chukwooki gauge observations. Kim et al. (1992) investigated the long-term precipitation and temperature characteristics for Seoul and showed that annual mean temperature is rising at a rate of 0.0185°C and that annual precipitation is fluctuating over a large range with no significant trend. Consequently, annual mean precipitation in Seoul revealed no statistically significant relationship with annual mean temperature. Jung et al. (1999) investigated the long dry period that emerged in Seoul before and after 1900 by applying wavelet analysis. They showed that the long dry period was not due to observational error from the Chukwooki gauge or missing data but due to a real natural variation in precipitation. Based on these studies, Yoo et al.

(2000) studied recurrence characteristics of wet and dry years for annual rainfall showed that the return period for wet years is about 5~6 years, and that for dry years about 6~7 years.

The above studies were results of extending precipitation data in time by including the Chukwooki gauge data. Equally important, however, is to extend the data spatially. By extending data spatially trans-nation wise a better understanding of regional precipitation processes can be achieved. Traditionally, regional precipitation studies are made within country limits. However, climate or precipitation follows no such borders. Instead, a more complete picture of the regionally varying precipitation process can be achieved by comparing data from several countries. In this sense, we investigate the connection between precipitation in South Korea and southern Japan. By establishing such relationships we can utilize connections for, e.g., spatial extrapolation as well as possibilities for prediction of precipitation. As a first step, we select three stations (Inchon, Mokpo, and Pusan) in South Korea because they have the longest modern precipitation time series (since April 1904), while Fukuoka in Japan is selected for because of the close proximity to Korea. In the following, we establish statistical relationships between the mentioned precipitation stations.

STUDY AREA AND DATA USED

The average annual precipitation in South Korea is 1,274 mm. The precipitation varies from less than 1,000 mm in the inland dry areas to above 1,650 mm in the southern coastal areas. From June to August, the climate is hot and humid with frequent heavy rainfalls associated with the East-Asian Monsoon, (Cha 2000). Meanwhile, the winter, from December to January, is cold and dry under the dominant influence of Siberian air mass. Therefore, more than half of the annual precipitation occurs when a stationary front lingers across the Korean peninsula during summer, while the winter precipitation is less than 10% of total annual precipitation (http://www.kma.go.kr).

Three stations with the longest period of precipitation observations (since April 1904) were chosen, Inchon, Mokpo, and Pusan. The data period for each station is shown in table 1.

The Inchon station (126.6°E, 37.5°N) is located in northwestern Korea as shown in figure 1 and has precipitation records from April 1904 except for some missing data between 1904 and 1951. The period and number of missing data at this station are shown in table 2. For this reason, the data periods used in this study are different with respect to the analyses for Inchon. Data from October 1951 to December 2000 were used for autocorrelation and spectrum analyses while the whole data period except missing values was applied in the cross-correlation analysis.

The Mokpo station (126.4°E, 34.8°N) is located in the southwestern part of Korea (figure 1) and the Pusan station (129°E, 35.1°N), which is closest to Fukuoka, is located in the southeastern part of Korea.

Fukuoka (130.4°E, 33.6°N) in Japan was selected for the present study because of its close proximity to South Korea, especially the Pusan station, and also because of long (1890-2000) and well investigated precipitation statistics.

Table 1 Data period for each station.

Station	Data Period	Months
Inchon	Apr. 1904 – Dec. 2000	1061
Mokpo	Apr. 1904 – Dec. 2000	1161
Pusan	Apr. 1904 – Dec. 2000	1161
Fukuoka	Jan. 1890 – Dec. 2000	1332

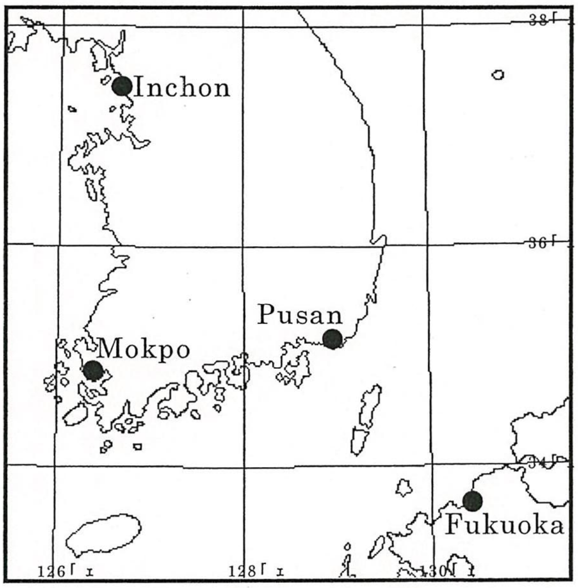

Figure 1 Map of study area.

Table 2 Periods with missing data at Inchon station.

Missing Period		Missing
From	To	Months
Jan. 1908	Dec. 1911	48
Jan. 1932	Dec. 1932	12
Jan. 1934	Dec. 1935	24
Jun. 1950	Sep. 1951	16

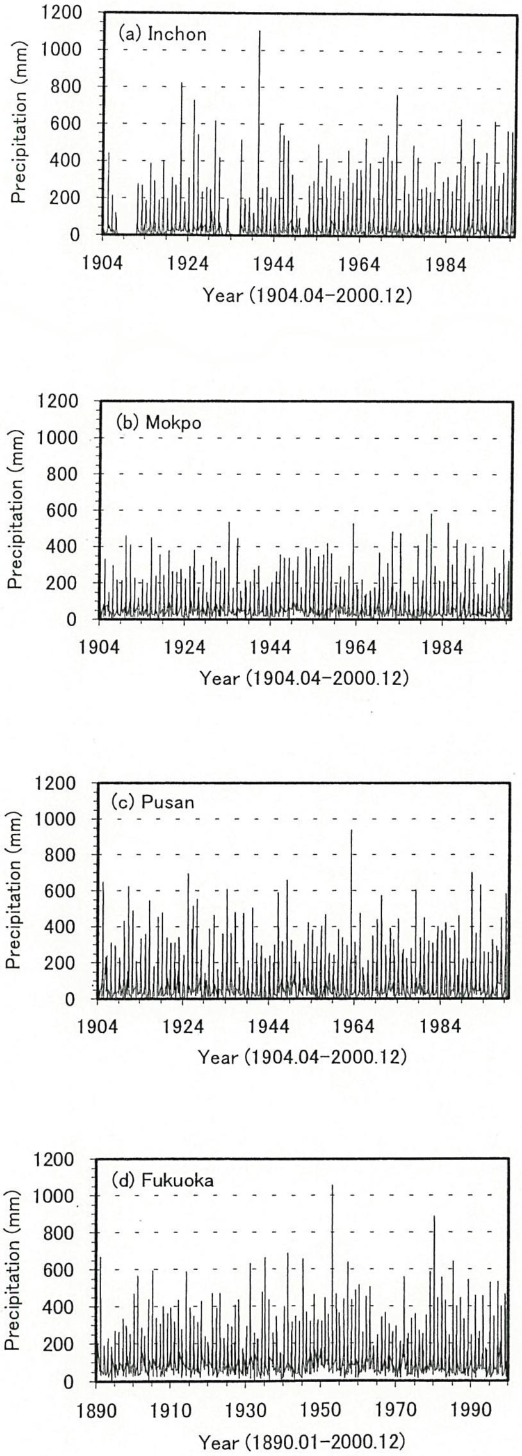

Figure 2 Plots of time series.

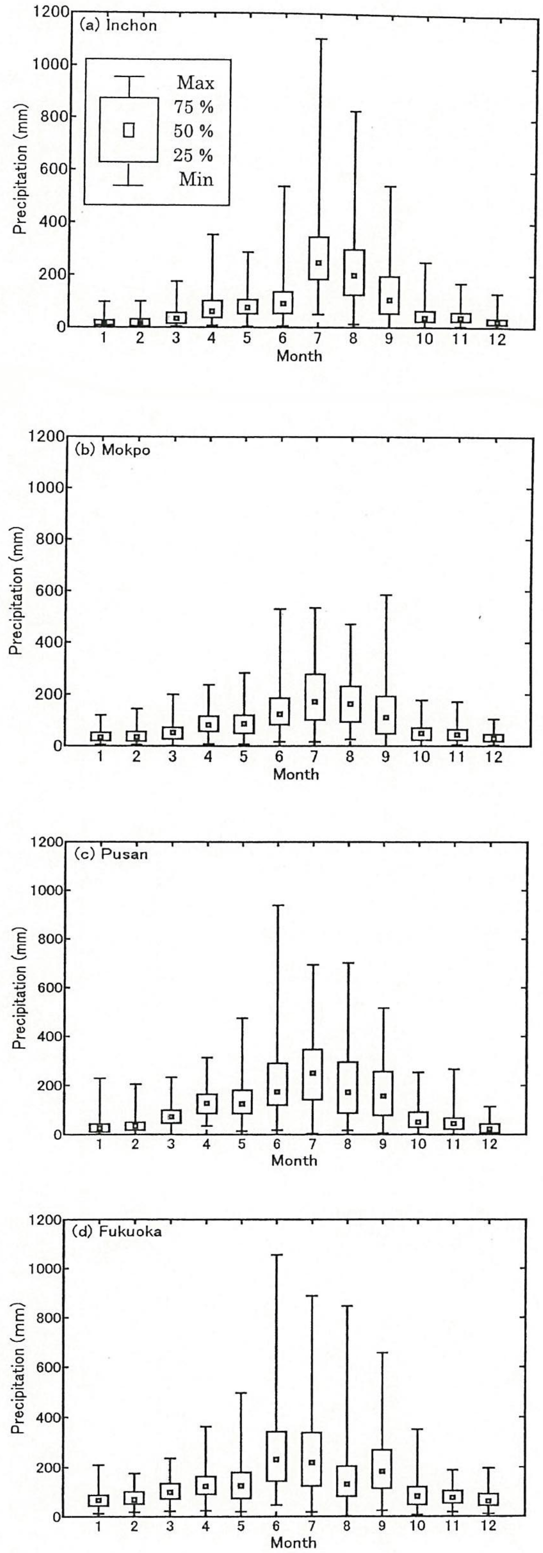

Figure 3 Box-whisker plots for each station.

BASIC STATISTICS

The monthly time series for all stations are shown in figure 2. As is clear from the figure Fukuoka has the highest annual precipitation equivalent to about 3000 mm and Inchon has the highest monthly precipitation of about 1100 mm. This is also seen in figure 3, which shows basic statistics in form of box-whisker plots (median, quartiles, maximum, and minimum precipitation) for each station and monthly data. Maximum median values are seen in July for the three Korean stations, and in June for the Fukuoka station. As seen in the figure, the monthly data at all stations are not normally distributed but instead positively skewed. This characteristic is typical for data that are physically constrained to lie above a minimum value such as precipitation (must be non-negative; Daniel, 1995). A clear difference between the Korean and the Japanese station is that months with no precipitation (less than 0.1 mm) occurred at Inchon in February and September, at Mokpo in September, and at Pusan between December and March, while no such record occurred in Fukuoka.

AUTOCORRELATION AND SPECTRUM ANALYSES

To investigate possible periodicities for the different stations, autocorrelation and spectral analyses were used. The analyses were applied using the entire period for Fukuoka, Pusan, and Mokpo but only September 1952 to December 2000 for Inchon due to missing data.

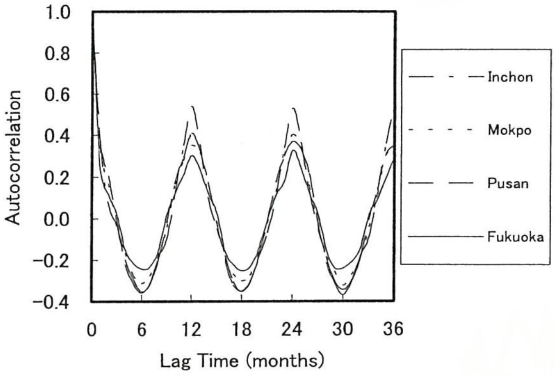

Figure 4 Autocorrelation for each station.

Autocorrelation analysis

The autocorrelation analysis shows a twelve-month periodicity as expected for all stations as shown in figure 4. Notably, the dependence is largest for Inchon showing a correlation of 0.54 at 12 months lag time.

Spectrum analysis

Spectrum analysis was performed to identify deterministic and periodic components in frequency domain. In the present study, the spectral analysis is based on the maximum entropy method (MEM).

In the spectrum analysis four-, six-months and one-year periodicities were revealed for the Inchon station, and six-months and one-year for Mokpo as seen in figure 5, (a)~(b). The patterns are similar for Inchon and Mokpo in that they both show six-months and one-year periodicities. For Pusan only the one-year periodicity was clear while three-months and one-year periodicities were dominant for Fukuoka. The general pattern, however, is a clear similarity between Pusan and Fukuoka as shown in figure 5, (c)~(d).

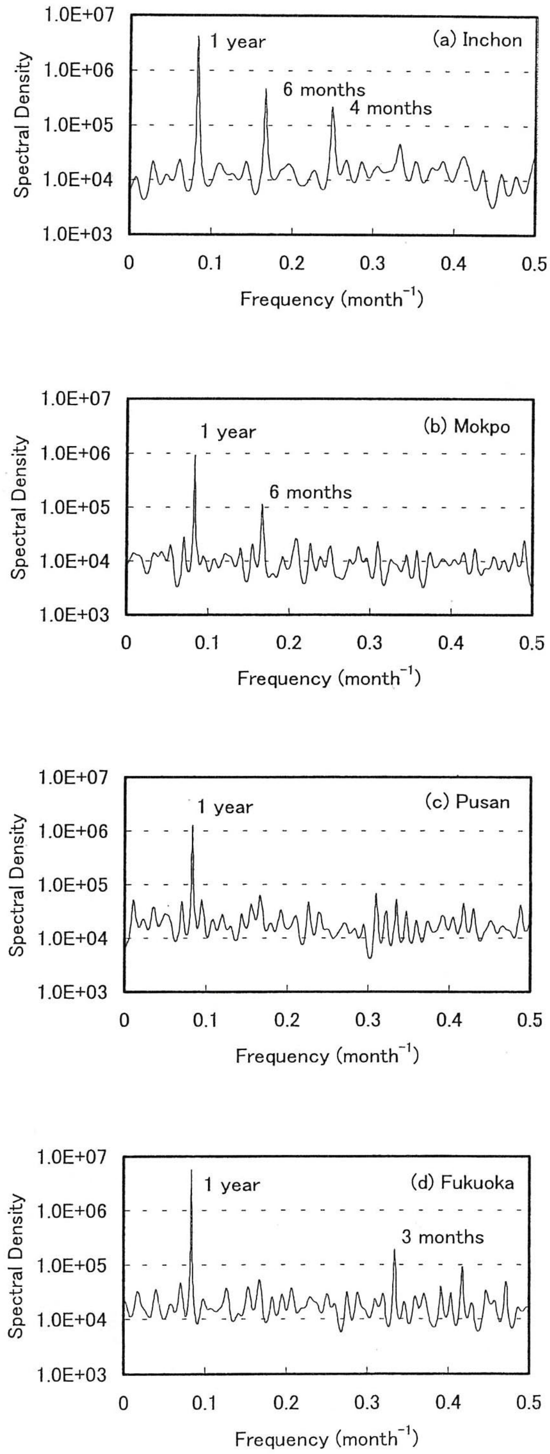

Figure 5 Periodogram for each station by spectrum analysis.

CROSS-CORRELATION ANALYSIS AND MOVING AVERAGE

Results from the cross-correlation analysis are shown in figures 6 to 9. The analysis shows that in general the cross-correlation between all stations are high. The correlation between Inchon and Mokpo is 0.59 (Figure 6). Notably, the highest cross-correlation is between Pusan and Mokpo corresponding to 0.77 while Pusan and Inchon are correlated at 0.59 as seen in figure 7. Inchon has the same correlation with Mokpo as with Pusan (0.59).

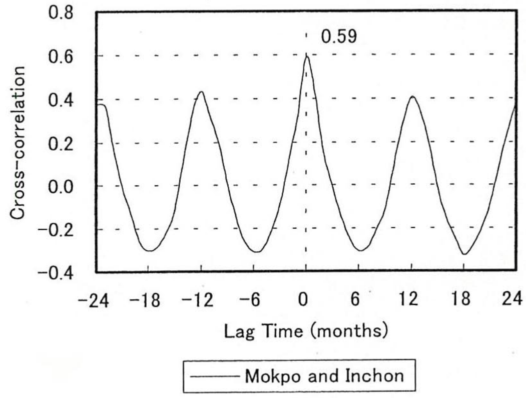

Figure 6 Cross-correlation between Inchon and Mokpo

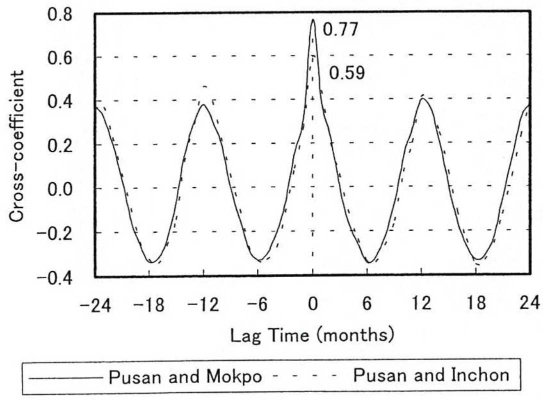

Figure 7 Lagged cross-correlation between Pusan, Mokpo, and Inchon.

Notably, among the three stations in Korea, Pusan shows the highest correlation with Fukuoka (0.62) as shown in Figure 8. The high correlation shows that the same rainfall processes are occurring at the two stations and that they can be used simultaneously to analyze regional precipitation patterns. The correlation is 0.52 between Fukuoka and Mokpo and 0.42 between Fukuoka and Inchon. Remarkably, the highest correlation between Fukuoka and Inchon was found for a lag time of one month. This indicates that also the relationships can be used to make predictions in time. The cross-correlation against distance between the paired stations is shown in figure 9. We can see a clear relationship with distance.

Annual mean precipitation and five-year moving averages were calculated as seen in figure 10. As seen in the figure, similar patterns emerges between Mokpo and Fukuoka, although the highest cross-correlation with Fukuoka was with Pusan.

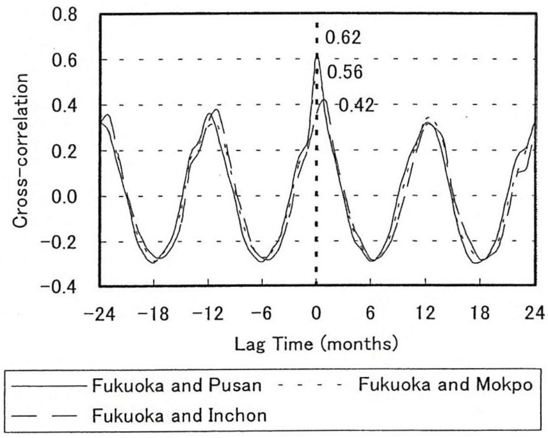

Figure 8 Cross-correlation between Fukuoka and the three stations in Korea

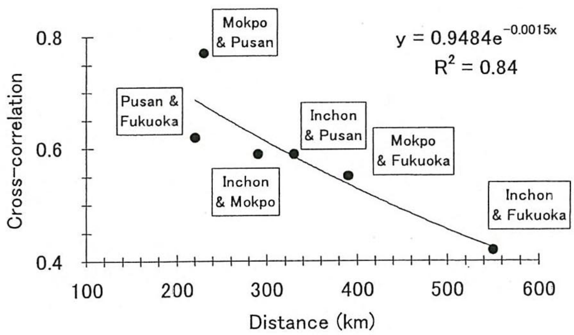

Figure 9 Cross-correlation with distance

CONCLUSION AND DISCUSSION

In the present paper, we studied basic statistical and co-variation of monthly precipitation time series from four stations in South Korea and southern Japan. Establishing statistical relationships between different areas is important to increase the knowledge on regional precipitation processes, temporally as well spatially. Besides basic statistics co-variation among the stations were studied using autocorrelation, spectrum and cross-correlation analyses.

In general, the investigated stations display an increasing annual rainfall gradient from northern South

Korea to southern Japan. Regarding autocorrelation of monthly data, the stations on the other hand display a decreasing gradient from north to south. Consequently, Fukuoka has the lowest autocorrelation and Inchon the highest. Besides the twelve-month periodicity in the autocorrelation, spectral analysis detected additional periodicities in the Inchon, Mokpo and Fukuoka stations. Notably, the patterns of spectrum are similar between Pusan and Fukuoka.

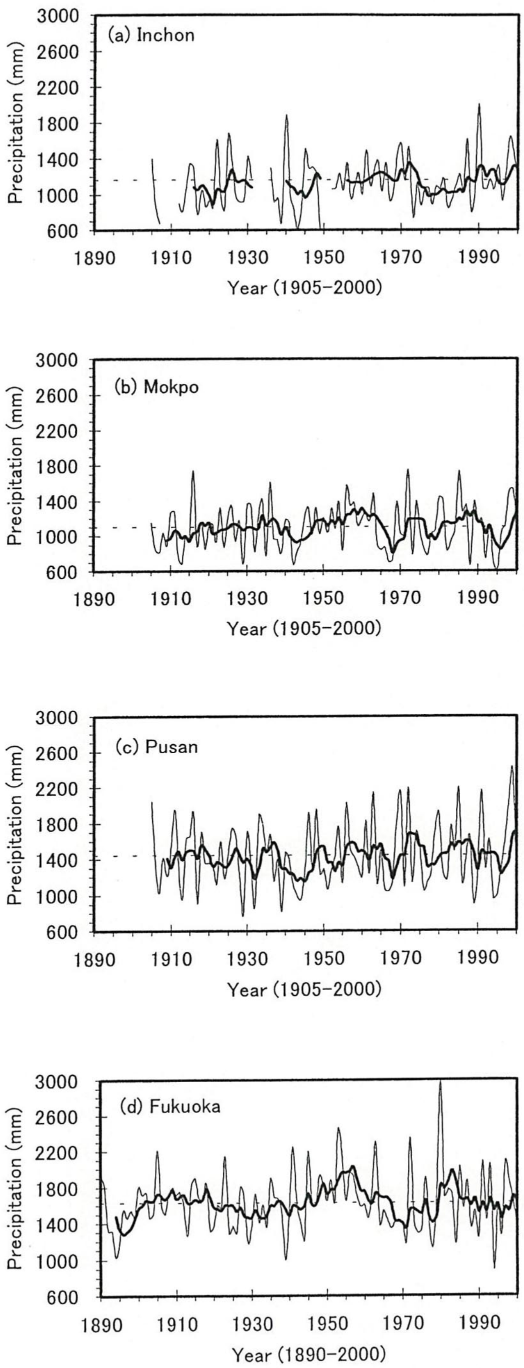

Figure 10 Annual precipitation, 5-Year moving average and annual mean precipitation

Second, the results of cross-correlation analysis show that the correlation between Mokpo and Pusan is highest compared to other station combinations. The highest cross-correlation with Fukuoka is Pusan with a correlation coefficient of 0.62 (zero time lag). Remarkably, the highest cross-correlation between Inchon and Fukuoka was for one month time lag. Besides, the long-term variation pattern was studied using five-year moving average to detect similarities among the stations. The result shows that similarities are at hand especially for Mokpo and Fukuoka.

Based on these results, we can conclude that monthly precipitation at Inchon, Mokpo, Pusan, and Fukuoka has similar characteristics. This similarity involves periodicity as well as cross-correlation and long-term variation patterns. Therefore, it can be said that the region involved display great similarities regarding spatial and temporal precipitation processes. Consequently, this can be exploited in, e.g., spatial extrapolation or prediction in time.

REFERENCES

Ahn, S. J. (2001). Master plan of water resources management in South Korea. *Proceedings of 2001 Annual Conference, Japan Society of Hydrology and Water Resources*. Yamanashi University: 88-95.

Cha, E. J. (2000). The origin of water resources in Korea. *Magazine of Korea Water Resources Association*. 33(4): 67-72.

Daniel, S. W. (1995). Statistical methods in the atmospheric sciences. Academic Press.

Jung, H. S., Lim, K. H. and Oh, J. H. (1999). The study on the dry period in Korean peninsula based on the precipitation measured by Chukwooki. *Proceedings of Korea Water Resources Association*. 41(25): 147-152.

Kim, B. S., Kang, K. S. and Seo, B. H. (1997). The analysis of characteristics of annual precipitation time series in Korea. *Proceedings of Korea Water Resources Association*. 39(44): 280-285.

Kim, S. and Shin, H. M. (1992). The statistical test for long term variation tendency of precipitation in Soeul. *Proceedings of Korea Water Resources Association*. 34(26): 264-272.

Kim, Y. S., Kim, G. H. and Kim, S., Seo, B. H. (1988). The study on the precipitation variation according to the period of record at main cities in Korea. *Proceedings of Korea Water Resources Association*. 30(19): 158-165.

Yoo, C. S., Kim, B. Y. and Roh, J. K. (2000). A study on the reoccurrence characteristics of wet and dry years appeared in Seoul annual rainfall data. *Journal of Korea Water Resources Association*. 33(3): 307-314.