Characteristics of Monthly Precipitation in Korea and their relationship with SOI

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1. Introduction

The El Niño/Southern Oscillation (ENSO) results from the interactions between large-scale oceanographic and atmospheric circulation processes in the equatorial Pacific Ocean. There has recently been considerable interest in the El Niño/La Niña, which are known as extremes of Southern Oscillation.

The impacts of the phenomena have been studied in many countries. One of the studies describes the relationship between SOI and seasonal rainfall in Southern Europe and shows the correlation has increased towards the end of the 20th century[1). The potential for forecasting the hydroclimate variables in Australia was also investigated by assessing the lag correlations between rainfall, streamflow and ENSO several months earlier and the results shows that ENSO indicators can help to forecast the hydroclimate variables[2).

However, despite the global impact of the Southern Oscillation, there has been little evidence of El Niño/La Niña influence in middle to high latitude, especially at eastern part of Asia, including Japan and Korea. For the first time, the cross-correlation between SOI and precipitation in Fukuoka, Japan on a monthly basis was obtained when using SOI data categorized into five groups according to their magnitudes [3). Shin (2002) showed that the significant influences on flood and drought of El Niño and La Niña in Korea [4).

In this study, the method of categorization of SOI was also applied and revealed the cross-correlation between categorized SOI and precipitation in Korea. The results are compared to those in Fukuoka, Japan. Therefore, based on the above background, this study is aimed at evaluating the possible influence of ENSO in three stations (Inchon, Mokpo and Busan), Korea and in Fukuoka, Japan. Hence, using categorized SOI data and monthly precipitation data from the four stations in Korea and Japan, this study is able to detect statistically significant correlation between the categorized SOI and the corresponding precipitation.

Consequently, possible influences of El Niño and La Niña are assessed and presented in respect of the precipitation distribution pattern in the study area. The categorized SOI is used to investigate the relationship with monthly precipitation that are collected from the four stations.

2. Rainfall stations and precipitation data

The data used in this study were collected from three stations in Korea. The data are from modern observation stations at Inchon, Mokpo and Busan where were established in 1904 by the Chosen Governor-general Division [5).

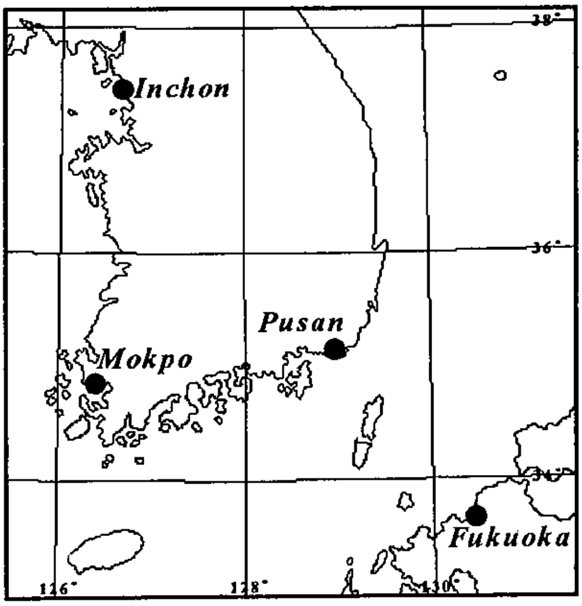
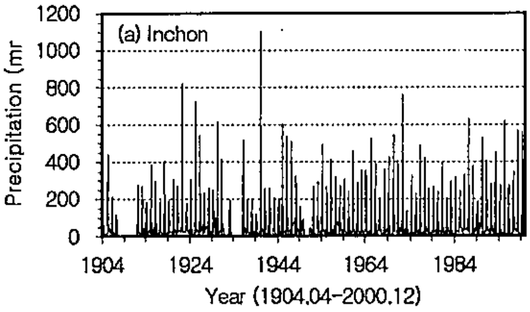


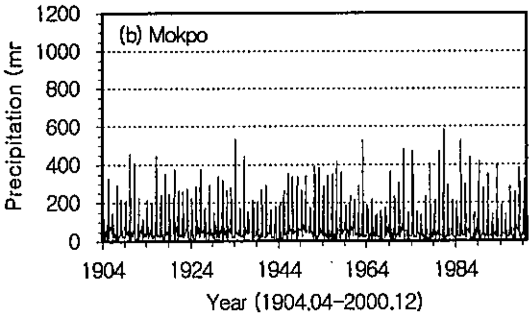
Fig. 1 Location of three stations in Korea and Fukuoka

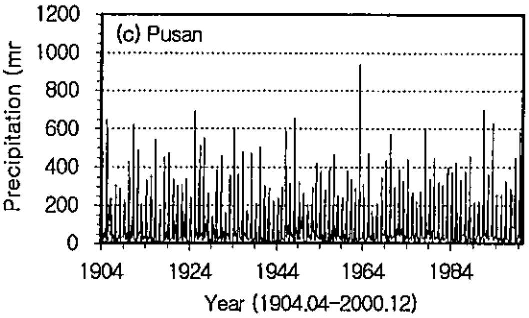
The three stations have the longest period of precipitation in Korea. First, Inchon station is located at the northwestern part of Korea and has a record of precipitation from 1904-2000. However, there are some missing values during the period of Korean War between 1950 and 1953 and, therefore, only data from 1952 were used in this study. Second, the Mokpo station (126.4°E, 34.8°N) is located at the southwestern part of Korea and also has a record of precipitation from 1904-2000. The Busan station (129°E, 35.1°N) is located at the southeastern part in Korea and has a record of precipitation from 1904-2000 like the other two stations. The datasets comprise monthly values with different periods for each station. The locations of the three stations are shown in **Fig. 1** and the periods of data used for the present study are shown in **table 1**.

Table 1 Data periods for each station in Korea

Station	Data Period	Month
Inchon	Oct. 1951 – Dec. 2000	591
Mokpo	Apr. 1904 – Dec. 2000	1161
Busan	Apr. 1904 – Dec. 2000	1161
Fukuoka	Jan. 1890 – Dec. 2000	1332







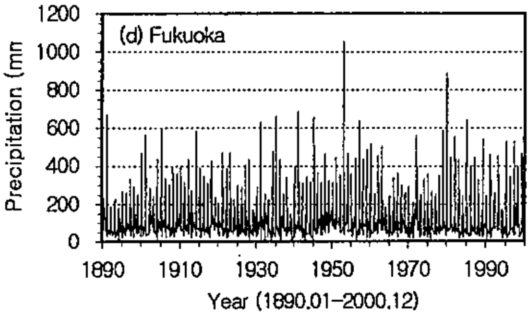


Fig. 2 Time series plots for each station

The monthly precipitation data from Fukuoka (130.4°E, 33.6°N) were also collected for the present study from January 1890 to December 2000. The station was selected for this study not only because it has long and well-investigated precipitation data but also because it is very close to Korea, especially to the Busan station which is one of the stations for the present study.

The monthly time series for the four stations are shown in **Fig. 2 (a) ~ (d)**. As is clear from the figure, Inchon has some missing values. Box-plots were used to show the statistical summary of the four stations where values of median, quartiles, maximum and minimum precipitations **(Fig.3 (a) ~ (d))**. The maximum mean precipitation was revealed in July for the three stations in Korea and in June for Fukuoka. Remarkably, some months with no precipitation (less than 0.1 mm) occurred at Busan between December and March, at Mokpo in September and at Inchon in February and September. However, there is no such precipitation (less than 0.1 mm) in Fukuoka.

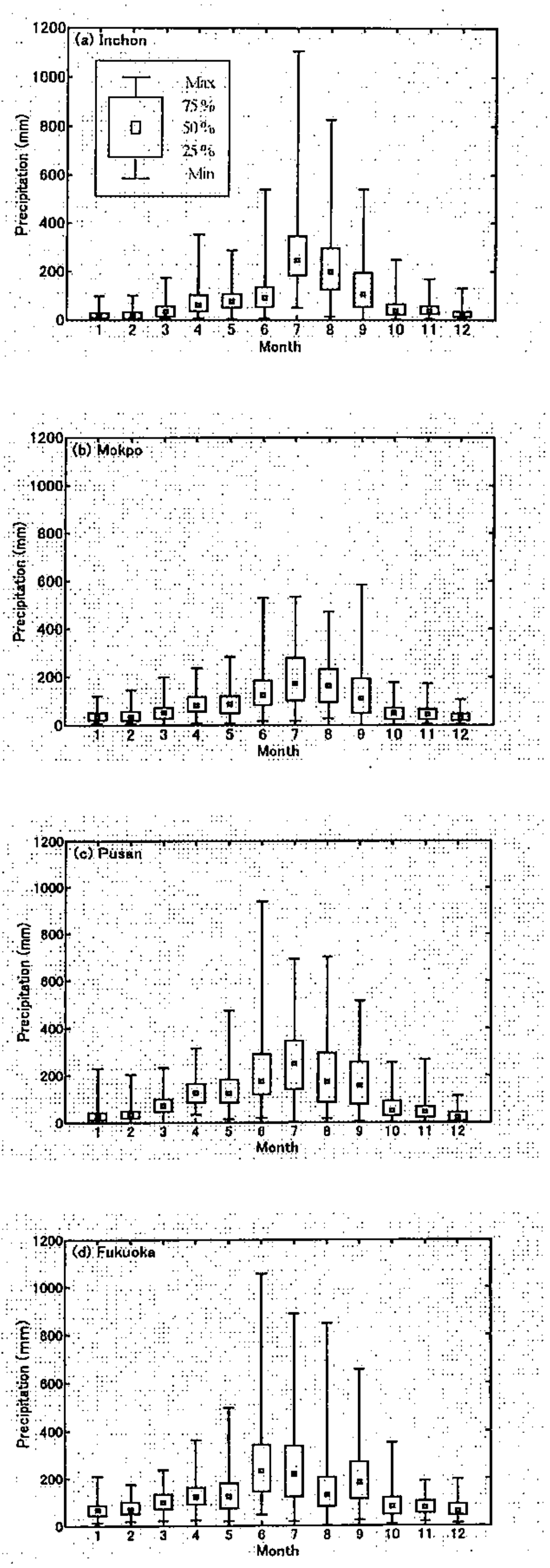


Fig. 3 Summary of basic statistics by box-whisker plot

3. Autocorrelation and spectrum analyses

To investigate the periodicity for each station, the autocorrelation and spectrum analyses were used in the present study. The analyses were applied to the monthly precipitation data period according to the **table 1**. The autocorrelation showed that the observed precipitation had one-year periodicity for all stations as shown in **Fig. 4**.

Spectrum analysis was performed to identify deterministic and periodic components in frequency domain. In the present study, the spectrum analysis is based on the maximum entropy method (MEM). In the spectrum analysis, four-, six-months and one-year periodicities were revealed for Inchon, while six-month and one-year for Mokpo, only one-year for Busan, and three-month and one-year for Fukuoka **(Fig. 5 (a) ~ (d))**.

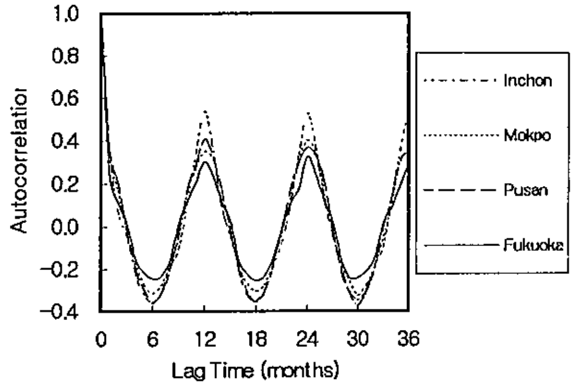
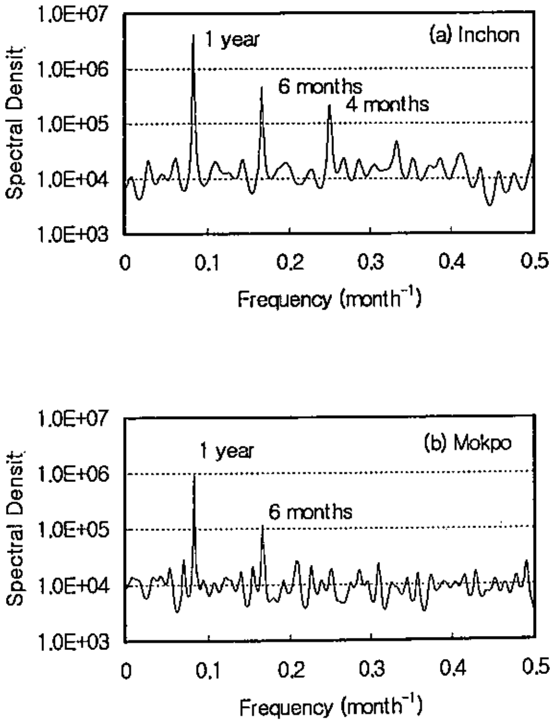


Fig. 4 Autocorrelation for each station



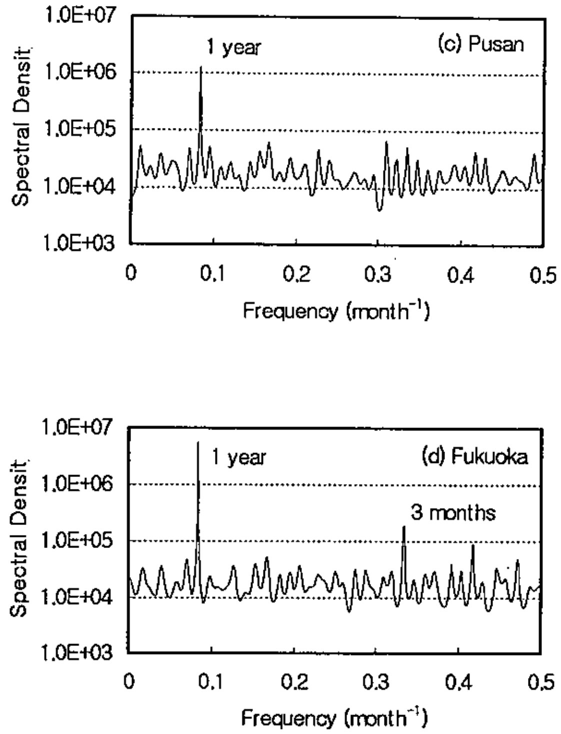
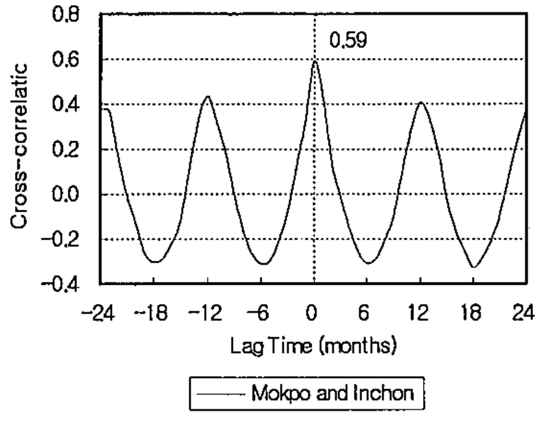


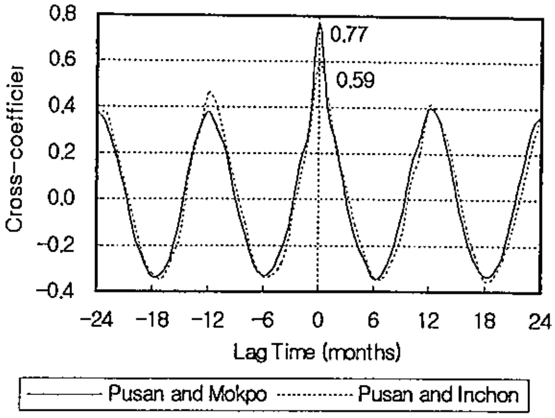
Fig. 5 Power spectrum for each station

4. Cross-correlation between stations

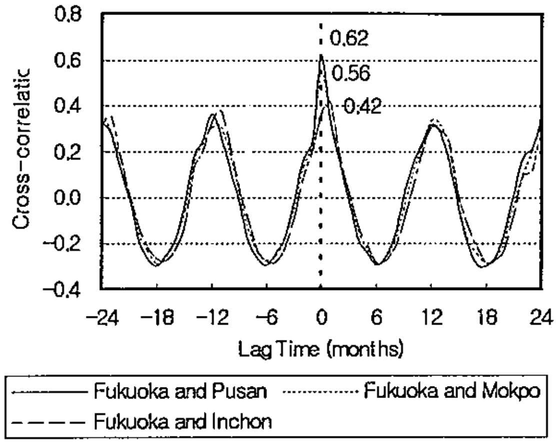
Results from the cross-correlation analysis are shown in **Fig. 6 (a) ~ (d)**. The analysis shows that the cross-correlation between all stations are high in general. The correlation between Inchon and Mokpo is 0.59 (**Fig. 6 (a)**). Notably, the highest cross-correlation is between Busan and Mokpo corresponding to 0.77 while Busan and Inchon are correlated at 0.59 as seen in **Fig. 6 (b)**. Inchon has the same correlation with Mokpo as with Busan (0.59).



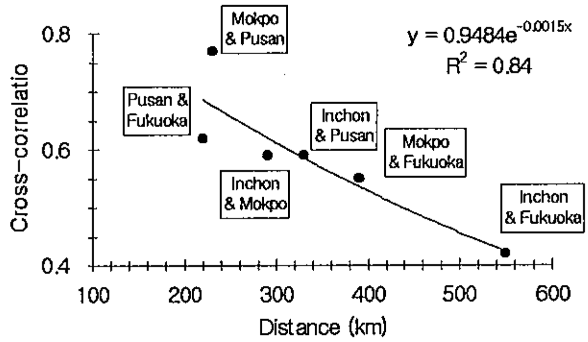
(a) Cross-correlation between Inchon and Mokpo



(b) Cross-correlation between Busan, Mokpo, and Inchon.



(c) Cross-correlation between Fukuoka and the three stations in Korea



(d) Cross-correlation with distance.

Fig. 6 Cross-correlation between stations

Notably, among the three stations in Korea, Busan shows the highest correlation with Fukuoka (0.62) as shown in **Fig.6 (c)**. 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 **Fig. 6 (d)**. We can see a clear relationship with distance.

5. Data transformations

Cubic root transformation was carried out to normalize the precipitation in all of the stations and then the normalized monthly precipitation values were standardized to a mean of zero and a standard deviation of one by subtracting the normalized monthly mean values from the monthly values and dividing by the normalized monthly standard deviations, using the whole data period for computation of means and standard deviations.

The Troup's method (Troup, 1965) was used for computation of SOI. First, the difference between mean sea level pressure at Tahiti (149.6°W, 17.5°S) and Darwin (130.9°E, 12.4°S) and then the differences are standardized to a mean of zero and a standard deviation of one by subtracting the mean value from the differences and dividing by the standard deviation of each month (January-December), using the base period of 1951-1980 for the computation of means and standard deviations. The SOI calculated by the above method are categorized into five groups according to their magnitudes such as "Strong El Niño ($SOI<-2$)", "Weak El Niño ($-2\leq SOI<-1$)" and "Normal Condition ($-1\leq SOI\leq 1$)" and "Weak La-Niña ($1<SOI\leq 2$)", "Strong La-Niña ($2<SOI$)". This categorization of SOI is for easy association with the El Niño and La Niña phenomena. **Fig. 7** shows cumulative frequency of categorized SOI for each month during the past 135 years.

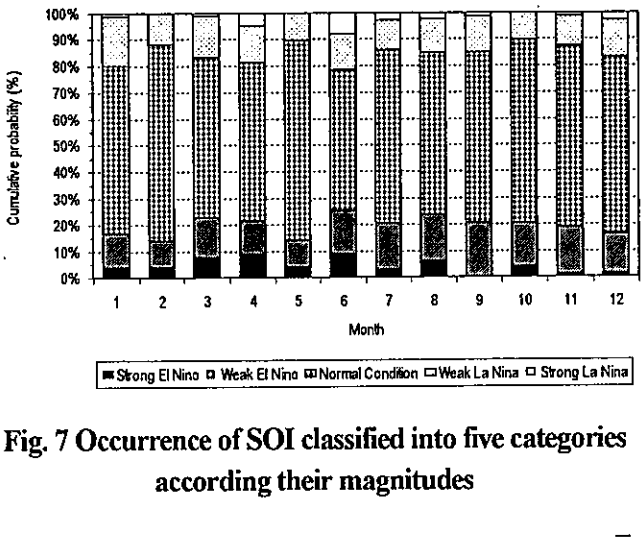


Fig. 7 Occurrence of SOI classified into five categories according their magnitudes

6. Cross-correlation between categorized SOI and precipitation

The statistically significant correlation between categorized monthly SOI and the corresponding precipitation can be detected from the results. The normally standardized precipitation was used for investigating the relationship with categorized SOI and the results are shown in figures below for each of the station. The cross-correlations between categorized SOI and corresponding precipitation were calculated with various lag times for each station. Generally, the correlations under the "Normal Condition" are almost zero at any lag time and La Niña events are more strongly correlated to the precipitation data than El Niño events for all of the stations.

(1) Inchon station

For the Inchon station, the result of cross-correlation between categorized SOI and normally standardized precipitation is shown in **Fig. 8**. The highest correlation coefficient among all the four stations was found in Inchon station under the category of "Strong La Niña" with a value −0.688 for time lag of 23 months and statistically significant at 5 % level **(Fig. 9)**. Even though the magnitude of the correlation is highest among all stations, the correlation is just significant at 5 % level, because the number of the data for the calculation of the correlation is less than those of the other two stations. In addition, correlation coefficient of −0.426 under the "Strong El Niño" category was also found at lag time of 17 months and significance level of 5 %, too **(Fig. 10)**.

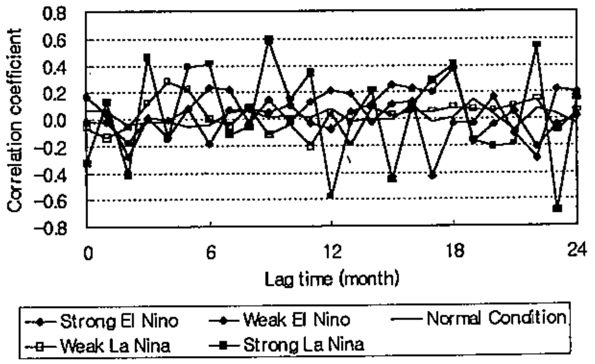


Fig. 8 Cross-correlation between categorized SOI and corresponding precipitation at Inchon

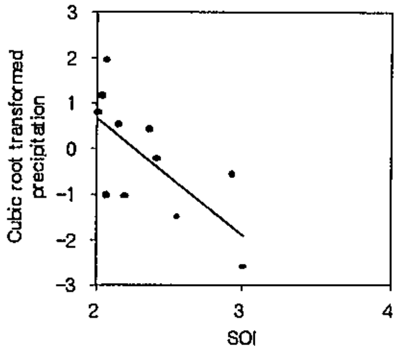


Fig. 9 Scatter plot for the "Strong La Niña" at Inchon (Lag Time = 23 months)

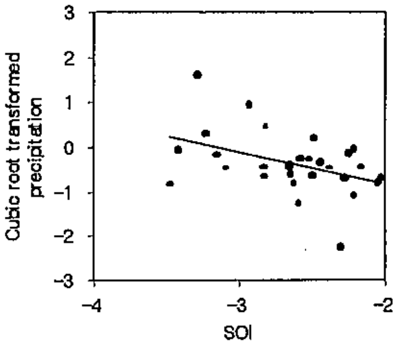


Fig. 10 Scatter plot for the "Strong El Niño" at Inchon (Lag Time = 17 months)

(2) Mokpo station

In the case of Mokpo station, the result of cross-correlation between categorized SOI and normally standardized precipitation is shown in **Fig. 11.** The highest correlation coefficient of 0.448 was observed at the lag time of 22 months under the "Strong La Niña" category with significance level of 5 % and the correlation of 0.418 was also detected at the lag time of 11 months with 5 % significance level under the same category. The scatter plots of these significant correlations are shown in **Fig. 12** and **Fig. 13**, respectively. **Fig. 12 (Fig. 13)** revealed a tendency which show that the stronger the La Niña event, the more the precipitation 22 months (11 months) later in Mokpo station with significance level of 5 %. However, no statistically significant value was found at any lag time under the category of "Strong El Niño".

(3) Busan station

For the Busan station, the result of cross-correlation between categorized SOI and normally standardized precipitation is shown in **Fig. 14.** The highest correlation of −0.607 with lag time of 4 months at significance level of 1 % was observed under the category of "Strong La Niña", while the correlation of −0.436 with lag time of 2 months for the same category was statistically significant at 5 % level (see **Fig. 15, 16**). However, no statistically significant value was found at any lag time under the category of El Niño. Therefore, the result shows the general tendency that the stronger the La Niña event, the less the precipitation at Busan 4 months later.

(4) Fukuoka station

The results of Fukuoka under the categories of "Normal Condition", "Weak El Niño" and "Weak La Niña" are similar with those of the Busan station and are shown in **Fig. 17.** That is, the correlations under the "Normal Condition" are almost zero at any lag time. La Niña events are also more strongly correlated to the precipitation data than El Niño events. The statistically significant correlations could not be detected at 5% level under the categories of "Weak El Niño" and "Weak La Niña".

However, the highest correlation coefficient −0.49, which is statistically significant at 1% level, is obtained with lag time 4 months under the category of "Strong La Niña. Significant positive correlations at 5% level are obtained with lag time 8 and 16 months under the same category. Under the "Strong El Niño" category, significant correlation at 5% level is revealed only for the lag time 2 months and the correlation coefficient is −0.28.

In the present paper, the scatter plots which show the highest correlation under the "Strong La Niña" and "Strong El Niño" categories are drawn in **Fig. 18** and **Fig. 19**, respectively. The figures show the general tendencies that the stronger the La Niña event, the less precipitation in Fukuoka 4 months later and the stronger the El Niño event, the more precipitation 2 months later.

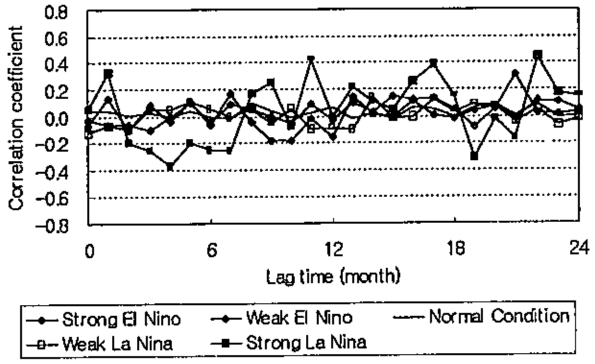


Fig. 11 Cross-correlation between categorized SOI and corresponding precipitation at Mokpo

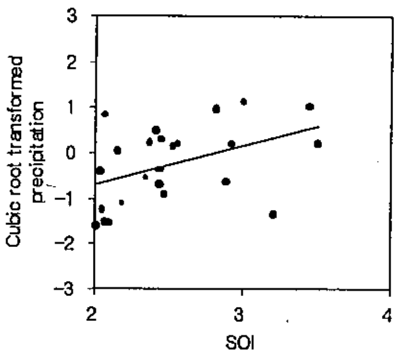


Fig. 12 Scatter plot for the "Strong La Niña" at Mokpo (Lag Time = 22 months)

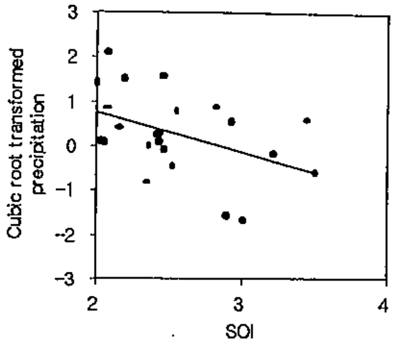


Fig. 16 Scatter plot for the "Strong La Niña" at Busan (Lag Time = 2 months)

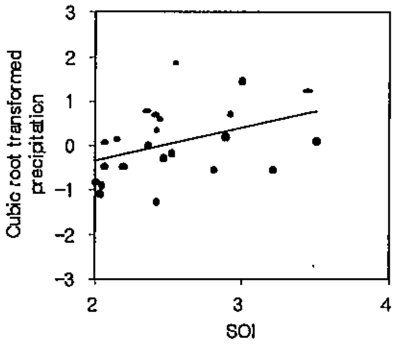


Fig. 13 Scatter plot for the "Strong La Niña" at Mokpo (Lag Time = 11 months)

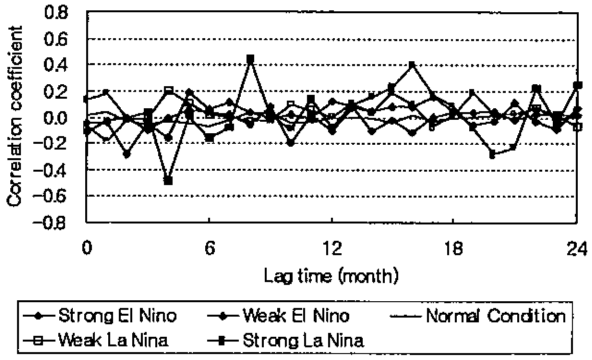


Fig. 17 Cross-correlation between categorized SOI and corresponding precipitation at Fukuoka

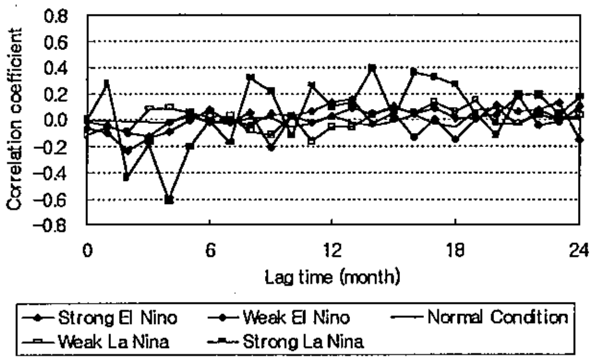


Fig. 14 Cross-correlation between categorized SOI and corresponding precipitation at Busan

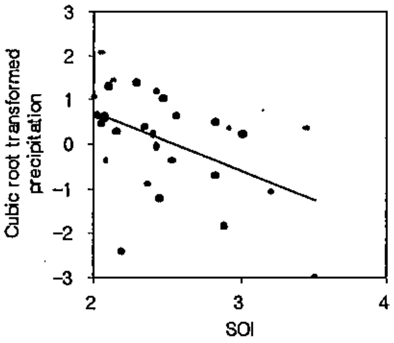


Fig. 18 Scatter plot for the "Strong La Niña" at Fukuoka (Lag time = 4 months)

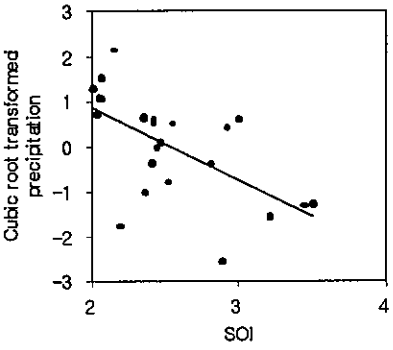


Fig. 15 Scatter plot for the "Strong La Niña" at Busan (Lag Time = 4 months)

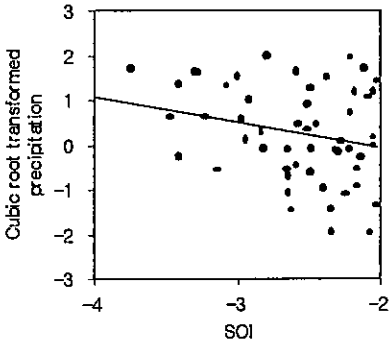


Fig. 19 Scatter plot for the "Strong El Niño" at Fukuoka (Lag time = 2 months)

7. Conclusions

In this study, the precipitation data of three stations that have the longest data records in Korea were collected. In addition, the precipitation data in Fukuoka, Japan was also collected from January 1890 to December 2000. The precipitation data from these four stations were statistically analyzed and the relationships with categorized SOI data were also evaluated with the primary objective of assessing the possible influence of the Southern Oscillation Index on the precipitation in Korea.

First, the results for Inchon station show a general tendency in which the stronger the La Niña event, the less the precipitation 23 months later. The highest absolute value of correlation coefficient with the lag time under the "Strong La Niña" category was observed for the Inchon station, comparing to the other stations. However, the physical interpretation of the lag time should be studied further. Second, in the case of Mokpo, the influence of La Niña was revealed and it should also be pointed out that there is the tendency that the influence under the "Strong La Niña" is associated with the precipitation in Mokpo as against the opposite trend in the other stations. Third, the results for the Busan station show a general tendency in which the stronger the La Niña event, the less the precipitation 4 months later. However, the statistically significant influence of El Niño was not detected at Busan and Mokpo. Finally, for Fukuoka station, the general tendency shows that the stronger the La Niña event, the less the precipitation 4 months later and the significant influence under the strong El Niño was detected at 5 % level, uniquely.

Conclusively, the significant correlations with the categorized SOI for each station were detected in the present study. Remarkably, the characteristics of precipitation between Busan and Fukuoka are different but the detected influence of SOI on the precipitation revealed the very similar pattern. In other words, Busan and Fukuoka stations might be considered that they are located in the same or very close influence area of SOI. However, the further studies are recommended for understanding the lag times physically that showed the significant correlation and evaluations of the possible factors that might be responsible for the observed varied trends.

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