# Relationship between Southern Oscillation Index and Monthly Precipitation in Korea

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ABSTRACT: During the latest several decades, there has been considerable interest in revealing the relationship between El Niño/Southern Oscillation (ENSO) and hydro-meteorological variables. The oscillation is characterized by a simple index, the Southern Oscillation Index (SOI). However, thus far, there is little evidence for the influence of ENSO in Korea. The influence of ENSO has been studied also in Korea but the estimated results are still qualitative and show an indirect relationship between ENSO and hydro-meteorological variables. In the present study, we used simple but significant approaches to reveal the quantitative and direct correlation between SOI and the monthly precipitation at five stations which are distributed over Korea. The monthly precipitation data are transformed into nonexceedance probability time series because the data cannot be normally distributed by applying usual transformations such as cubic root transformation. SOI is classified into five groups according to their values. In addition, to detect the nonlinear relationship between categorized SOI and nonexceedance probability of the monthly precipitation, we used the Kendall's $\tau$, a nonparametric test. Statistically significant correlations between the categorized SOI and the transformed precipitation were detected. Generally, the monthly precipitation is influenced by La Niña event with lag time four-months for southern coastal area and lag time five-months for middle to high regions in Korea.

## 1 INTRODUCTION

El Niño results from a large scale weakening of the trade wind and warming of sea surface temperature in the eastern and central equatorial Pacific. The phenomenon of El Niño lasts typically 12 ~ 18 months and occurs irregularly at 2 ~ 7 year intervals. In the opposite, La Niña refers to the condition, which shows the lower sea surface temperature than normal. There is an interannual seesaw phenomenon, which is called Southern Oscillation (SO), in tropical sea level pressure between eastern and western hemispheres. The Southern Oscillation Index (SOI), which is defined as the normalized difference in surface pressure between Papeete at Tahiti in central Pacific Ocean and Darwin in northern Australia, is a measure of the strength of the trade winds. The SOI is used by NOAA (National Oceanic and Atmospheric Administration) to judge whether the El Niño and La Niña events are occurring (Japanese Study Group for Climate Impact & Application, 1999). The features are collectively known as the El Niño/Southern Oscillation (ENSO) phenomenon.

During the latest several decades, considerable researches have been progressed to reveal the influence of ENSO on regional and local hydro-meteorological variables, such as temperature, precipitation, streamflow and so on. (see e. g., Poveda et al., 2001; Gutiérrez et al., 2001; and Chiew et al., 1998). These studies showed that the influence of ENSO on hydro-meteorological variables in the lower to mid-latitudes appears evident. For middle to high latitudes, some researches have also shown effects of La Niña and SO on hydrometeorology (e.g Dracup et al., 1994 and Rodo et al., 1997).

A number of studies have also carried out by Lee (1998), Kim at el. (2000) and Shin (2002) about the influence of ENSO on the hydrologic variables in Korea. They used various approaches and obtained the meaningful results from the respective researches. However, there are few researches that show the direct and quantitative correlation between the influence of ENSO and hydro-meteorological variables in Korea as well as in Japan.

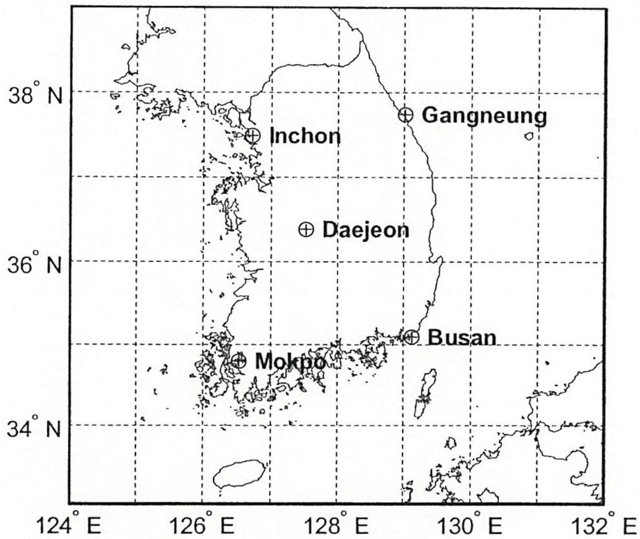

Fig. 1. Location map of study area

Table 1. Data periods of monthly precipitation and annual mean precipitation at the respective stations for the present study.

| Station | Data Period | Annual mean precipitation (mm) |
|---|---|---|
| Busan | April 1904 ~ December 2000 | 1440 |
| Mokpo | April 1904 ~ December 2000 | 1100 |
| Inchon | October 1951 ~ December 2000 | 1170 |
| Daejeon | January 1969 ~ December 2002 | 1330 |
| Gangneung | January 1961 ~ August 2002 | 1380 |

On the other hand, we detected the quantitative and statistically significant correlation between SOI and precipitation/temperature, for the first time in Japan, using the categorization method of SOI (Kawamura et al., 2000). The categorized monthly SOI data were used to detect the direct correlation with monthly precipitation/temperature. The approach was also utilized for the objective to reveal the relationship between SOI and precipitation in other studies (Kawamura et al., 2001a and Jin et al., 2002a).

In this study of the influence of SOI on precipitation in South Korea, we apply the categorization method for the detection of significant correlation. The categorization of SOI values is classified into five groups according to their magnitudes. We transform the monthly precipitation data with an appropriate method. Because monthly precipitation in Korea cannot be readily normalized by usual approaches such as power transformation, we propose the new data transformation, which change the data into nonexceedance probability time series. The approach of monthly precipitation into nonexceedance probability can be an alternative for the usual data transformations. This approach shows meaningful results, which are drawn in the present study and described later. For the estimation of correlation between SOI and precipitation, we used Kendall's $\tau$ which is a nonparametric approach. Kendall's $\tau$ is robust with regard to effects of extreme values and deviations from a linear variation (Hirsh et al., 1993).

These three methodological schemes (i.e. categorization of SOI, transformation of monthly precipitation into nonexceedance probability time series, and application of Kendall's $\tau$ for the correlation coefficient) are examined to investigate the relationship between SOI and precipitation in South Korea.

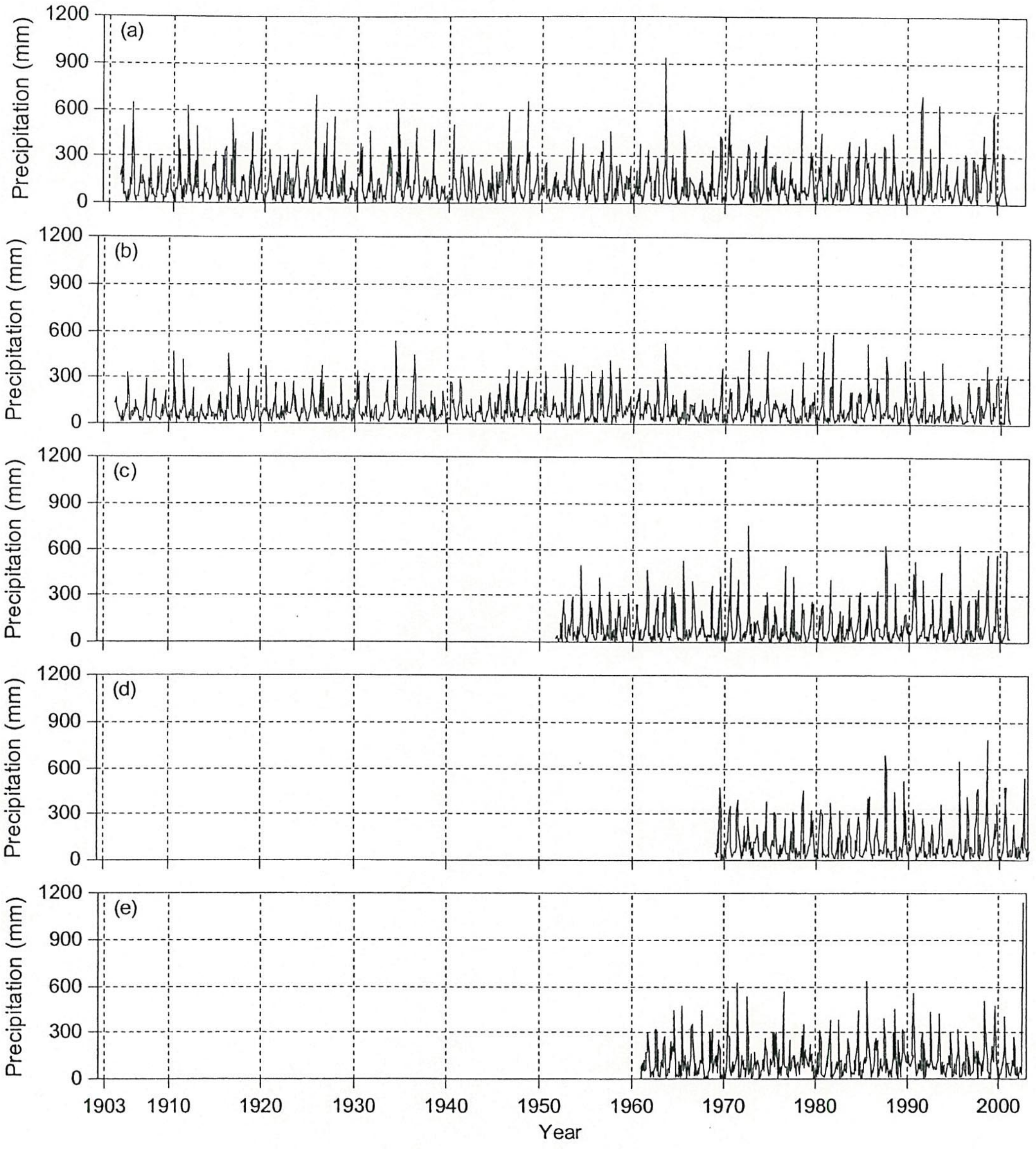

Fig. 2. Time series plots for the monthly precipitation at (a) Busan, (b) Mokpo, (c) Inchon, (d) Daejeon, and (e) Gangneung stations in South Korea. Tick marks on the time axis refer to January.

## 2 STUDY AREA

Annual mean precipitation in South Korea is 1,274 mm. The precipitation varies from less than 1,000mm in the inland dry areas to above 1,650 mm in the southern coastal areas. The climate from June to August is hot and humid with frequent heavy rainfalls associated with the East-Asian Monsoon. Meanwhile, December to January is cold and dry under the dominant influence of Siberian air mass. More than half of the annual precipitation occurs during summer, while less than 10 % of total annual precipitation falls during winter (Cha, 2000).

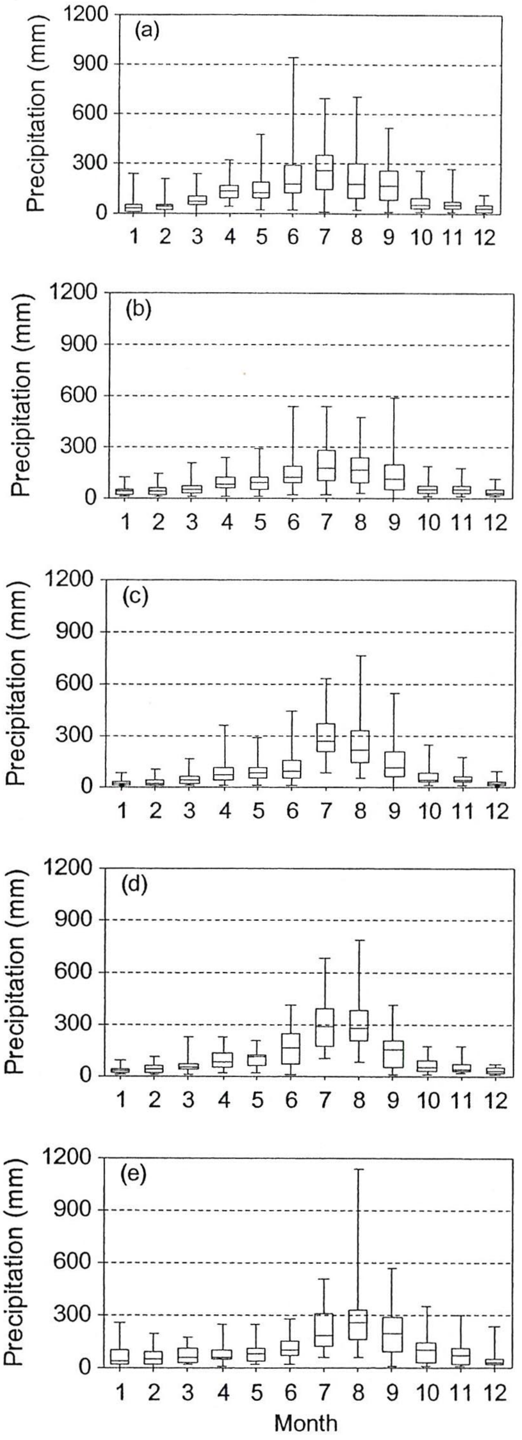

Fig. 3. Box-whisker plots for each station on a monthly basis: (a) Busan, (b) Mokpo, (c) Inchon, (d) Daejeon, and (e) Gangneung stations in South Korea.

Five stations (Busan, Mokpo, Inchon, Daejeon, and Gangneung) in Korea (Fig. 1) were selected for the present study not only because three (Inchon, Mokpo, and Busan) of them have the longest rainfall observation in Korea but also because the five stations can represent the whole area of South Korea. We used the monthly precipitation data from the five stations. The data periods and annual mean precipitation values for the respective stations are shown in Table 1.

Locations of the stations are depicted in Fig. 1. Busan is located in the southeastern part of Korea. Frequent typhoons cause damage to the area in summer season. Mokpo is located in the southwestern part of Korea. Inchon, Daejeon, and Gangneung stations have relatively short observation for the present study. Inchon has many missing values between 1904 and 1951 due to Korean Wars. We use the consecutive precipitation data at this station from October 1951. For statistics of the monthly precipitation at Busan, Mokpo and Inchon, see Jin et al. (2002b). Daejeon station is located in the center of South Korea and has started to record precipitation since 1969. For the last station, Gangneung is located in the northeastern part in South Korea. It had great damage from Typhoon Rusa in 2002. It has the highest monthly precipitation of 1137 mm among the stations. The monthly precipitation time series for all stations are shown in Fig. 2.

Fig. 3 shows basic statistics in the form of box-whisker plots (median, quartiles, maximum and minimum precipitation) for each station on a monthly basis. Maximum median values are seen in July for all stations but August for Gangneung. Relatively high median values in a year are found between June and September.

The monthly precipitation data at all stations are not normally distributed but instead positively skewed (Jin et al. 2002b). This property is typical for data that lie above a minimum value. There are also several months which have no precipitation (less than 0.1 mm) at Busan, Mokpo, Inchon, and Gangneung on a monthly basis, while only Daejeon has no such data. The typical property of precipitation and several no precipitation data on a monthly basis cause the non-normal distribution after applying usual transformation method for obtaining data normalization such as power transformations.

## 3 METHODOLOGY

### 3.1 Categorization of SOI

SOI values are calculated using the monthly mean sea level pressure (MSLP) data at Papeete, Tahiti (149.6 °W, 17.5 °S) and Darwin, Australia (130.9 °E, 12.4 °S). There are two commonly used methods to compute the SOI from the MSLP data at Tahiti and Darwin: Troup's method and the Climate Prediction Centre's method. The difference between two methods is very small as pointed out by McBride and Nicholls (1983), Ropelewski and Jones (1987) and Kawamura et al. (1998). In the present study, we used Troup's method (Troup, 1965). The SOI(y,m) in year y, month m (m=January to December) is calculated by the following equation;

$$SOI(y,m) = [\{P_T(y,m) - P_D(y,m)\} - M_{30}(m)] / S_{30}(m) \tag{1}$$

Here, PT(y,m), PD(y,m) = MSLP (hPa) at Tahiti and Darwin, respectively; M30(m), S30(m) = the mean value (hPa) and its standard deviation (hPa) of MSLP difference between Tahiti and Darwin for the base period of 30 years (usually 1951-1980). SOI is expressed as the MSLP difference between Tahiti and Darwin which is normalized to mean of zero and a standard deviation of one. Fig. 4 shows the time series of the monthly SOI values calculated by the above equation with the period from April 1902 to December 2002.

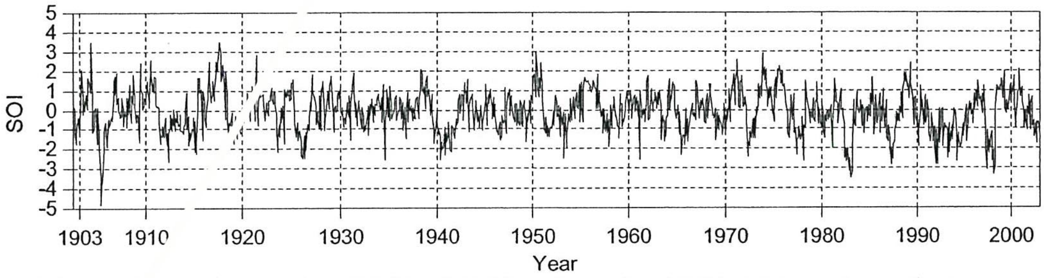

Fig. 4. Time series plot for SOI (April 1902 to December 2002). Tick marks on the time axis refer to January.

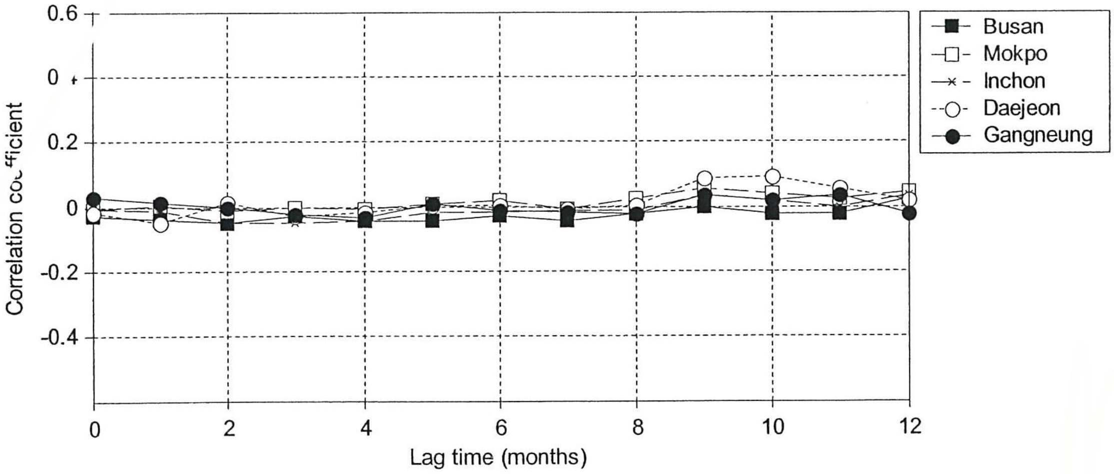

Fig. 5. Cross-correlation between all of SOI data and nonexceedance probability time series at five stations.

We tried to find a significant and strong correlation between SOI and monthly precipitation without any manipulation such as categorization. Nonexceedance probability time series of monthly precipitation and Kendall's $\tau$ which are explaining in following sections were applied to reveal such correlation. Fig. 5 shows the results with lag time up to 12-month. There is no strong correlation coefficient with significance for all lag times at the five stations.

Therefore, we categorized the SOI values into five groups according to their magnitudes, such as "Strong El Niño (SOI<-2)", "Weak El Niño (-2 SOI<-1)", "Normal Condition (-1 SOI 1)", and "Weak La Niña (1<SOI 2)", "Strong La Niña (2<SOI)". This naming for each categories of SOI is for easy association with the El Niño and La Niña phenomena. The statistical characteristics of SOI such as the categorical occurrence and long-term fluctuation can refer to the study by Kawamura et al. (2001b, 2002).

### *3.2 Transformation of precipitation*

The used monthly precipitation data from the five stations should be normalized and standardized to avoid spurious correlation before cross-correlation analysis is carried out by calculating the usual correlation coefficient such as Pearson's r. The standardization on a monthly basis is used for removing hydrological components, e.g. seasonality and annual periodicity. The normally standardized data can be used to investigate the relationship between ENSO and the monthly precipitation. As mentioned earlier, the typical property of precipitation shows positive skewness on a monthly basis and this skewness should, therefore, become smaller. As a usual method for this, cubic root transformation was carried out and the transformed data were then standardized to a mean of zero and standard deviation of one (Kawamura et al., 2000; 2001a and Jin et al., 2002a). However, when using the data which are including zero values like the precipitation in South Korea, the cubic root transformation should be reconsidered and altered by a proper method. For the alternative, we transform the monthly precipitation data into nonexceedance probability time series. We applied this approach to the monthly precipitation data on a monthly basis from January to December so as to remove hydrological components. The nonexceedance probability of the ith-smallest precipitation can be obtained using $\alpha = 0$ from the general formula proposed by Cunnane (1978);

$$q_i = \frac{i-\alpha}{n+1-2\alpha} \tag{2}$$

where, qi is the nonexceedance probability of the ith-smallest precipitation, n is the number of data on a monthly basis, and $\alpha$ is a plotting position parameter.

A box-whisker plot represents the distribution of transformed data on a monthly basis at Busan as an example (Fig. 6) and this can be compared with the plot for the raw precipitation data (Fig. 3). The nonexceedance probability time series is uniformly distributed and unbiased on a monthly basis, while the raw precipitation data show positively skewed distributions from January to December.

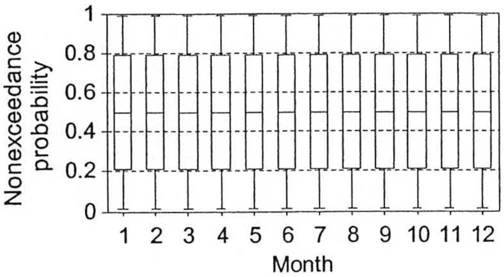

Fig. 6. Box-whisker plot for nonexceedance probability time series on a monthly basis at Busan station.

### *3.2 Cross-correlation*

We applied nonparametric technique to investigate the influence of ENSO on the monthly precipitation at the five stations. Nonparametric techniques have several advantages. In particular, nonparametric procedures require few assumptions about the underlying populations from which data are obtained and are relatively insensitive to outlying observations. Many nonparametric procedures require just the ranks of the observations, rather than the actual magnitude of the observations, whereas the parametric procedures require the magnitudes (Hollander et al, 1999).

We used Kendall's correlation coefficient among nonparametric techniques instead of Pearson's r in the cross-correlation analysis. Kendall's correlation coefficient, which is known as Kendall's $\tau$, is a rank-based procedure, and is therefore resistant to the effect of extreme values and to deviations from a linear relationship. Thus, it is well suited to use with dependent variables for which the variation around the general relationship exhibits a high degree of skewness or kurtosis and the detail procedure for Kendall's $\tau$ can be referred to Hirsh et al. (1993).

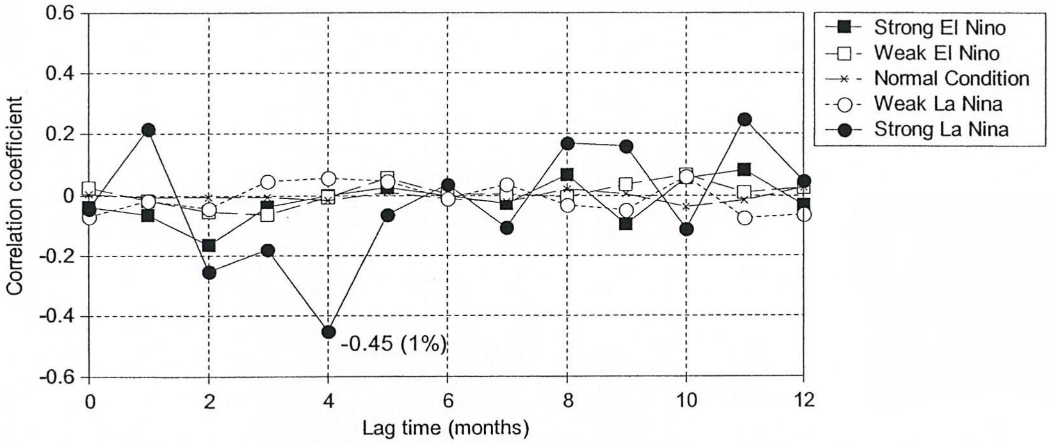

Fig. 7. Cross-correlation between categorized SOI and nonexceedance probability time series at Busan station.

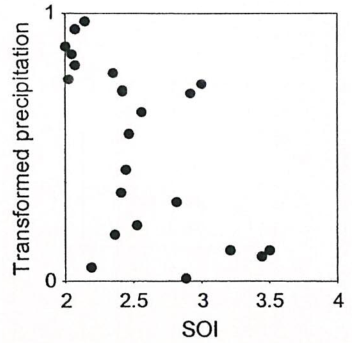

Fig. 8. Scatter plot for lag time four-months under the "Strong La Niña" category.

## 4 RESULTS

When using all data of both SOI and nonexceedance probability time series of monthly precipitation without categorization, all of the correlation coefficients with various lag times were very weak (Fig. 5). Even though some of them show the significance level higher than 5 %, it was very difficult to say there were significant tendencies from the weak correlation. Therefore, the results from the correlation of all data are ignored in this consideration. Henceforth, we are focusing only on the results by categorization method. Fig. 7 shows the correlation coefficients with lag times up to 12-month at Busan.

The figure shows only one correlation coefficient, which are strong enough and statistically significant at 1 % level. The significance level is presented with parenthesis in the next to the correlation coefficient in the figure. It has the correlation coefficient of –0.45 with lag time 4-month under the "Strong La Niña" category. The scatter plot is seen in Fig. 8. From the significant coefficient with strong correlation, therefore, Busan has the tendency that the stronger the La Niña event, the less precipitation four months later we expect.

The next station, Mokpo has some correlation coefficients with the 1 % significance level under the "Normal Condition" category but the strengths of the correlation are very weak and negligible so that no clear tendency can be drawn from the results. It is the 5 % significance level that the tendency can be detected under the "Strong La Niña" category with lag time 4- and 11-months (Fig. 9). Their tendencies are different according to the lag times. On one hand, the correlation with lag time 4-month shows the tendency that the stronger the La Niña event, the less the precipitation at Mokpo which is very similar to the correlation with the same lag time at Busan station (Fig. 10 (a)). On the other hand, the correlation for lag time 11-month reveals that the stronger the La Niña event, the more precipitation we expect (Fig. 10 (b)).

The magnitudes of the most significant correlations with lag time 4-month have –0.45 at Busan and –0.37 at Mokpo. These strengths are considerably high comparing with that the correlation coefficients of the mean sea level pressure between Tahiti and Darwin are –0.26 with long data period and –0.40 with the data from 1971 to 2001, although there is a very clear oscillation between them (Kawamura at al., 2001b and 2002). Also, the south coastal area in South Korea was substantiated to be influenced by La Niña event strongly with lag time 4-month.

Inchon station shows one correlation coefficient which has 1 % significance level with 5-month under the "Weak La Niña" category (Fig. 11). The scatter plot shows the tendency which the stronger the La Niña event, the more precipitation we expect with the lag time 5-month (Fig. 12). In addition, the strong correlation with the same lag time (5-month) was also revealed under the "Strong La Niña" category, even though it had a low significance level. La Niña event has strongly influenced on the precipitation at Inchon with 5-month lag time.

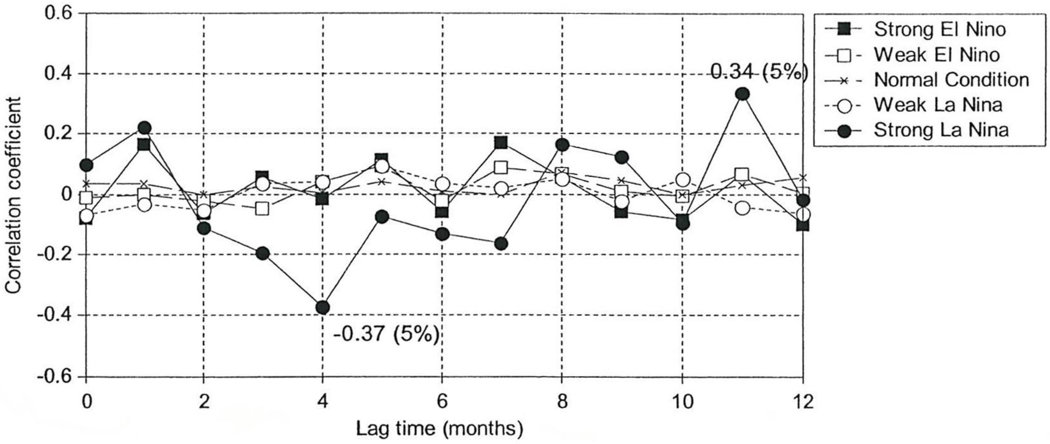

Fig. 9. Cross-correlation between categorized SOI and nonexceedance probability time series at Mokpo station.

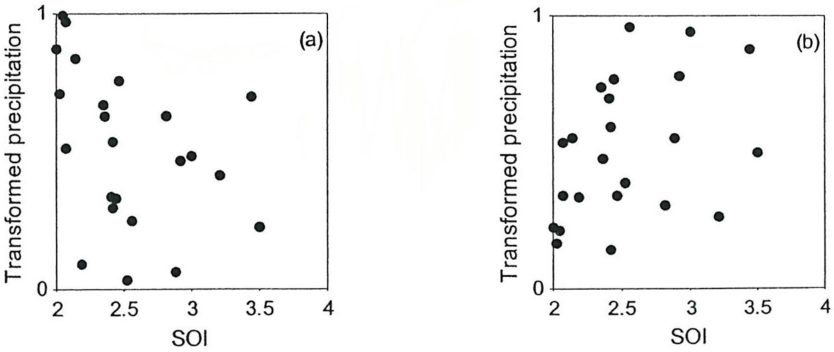

Fig. 10. Scatter plots for lag time (a) 4-month and (b) 11-month under the "Strong La Niña" category.

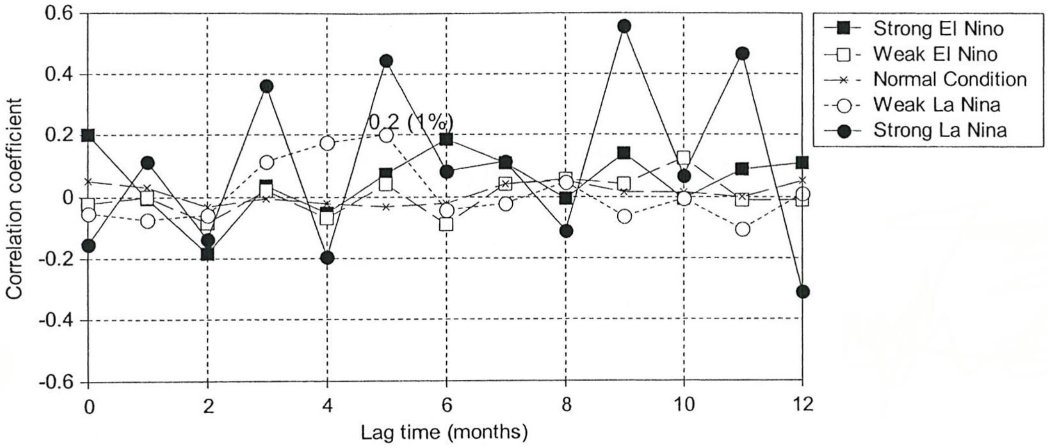

Fig. 11. Cross-correlation between categorized SOI and nonexceedance probability time series at Inchon station.

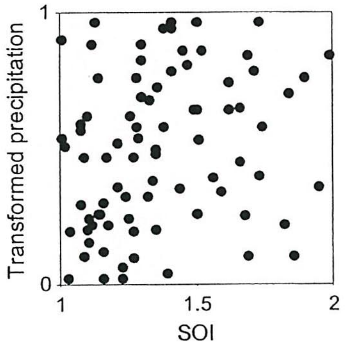

Fig. 12. Scatter plot for lag time five-months under the "Weak La Niña" category.

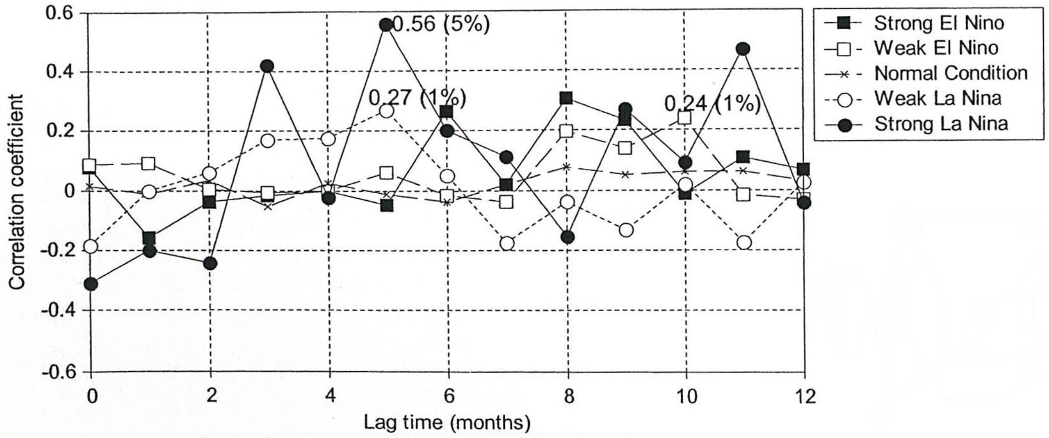

Fig. 13. Cross-correlation between categorized SOI and nonexceedance probability time series at Daejeon station.

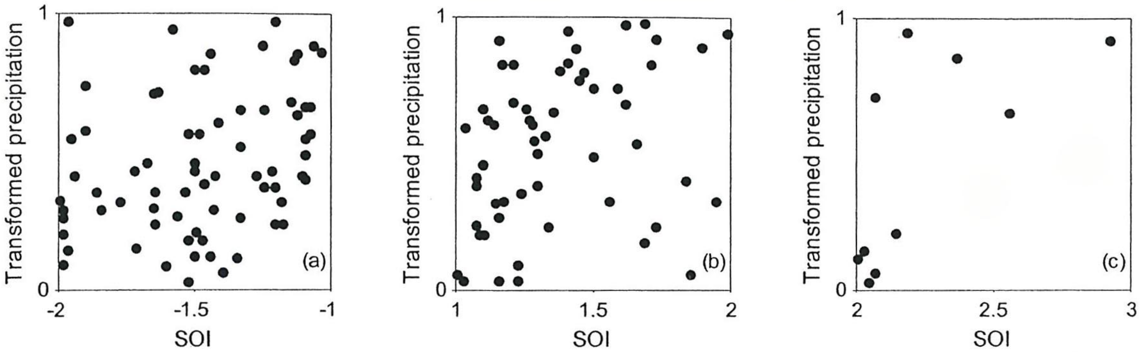

Fig. 14. Scatter plots for lag time (a) 10-month under the "Weak El Niño" category, (b) 5-month under the "Weak La Niña" category, and (c) 5-month under the "Strong La Niña" category.

Fig. 13 depicts the correlations between SOI and precipitation at Daejeon station, which has the shortest period for the present study. From the figure, we can see two significant correlations at 1 % level under the "Weak El Niño" category with 10-month and the "Weak La Niña" category with 5-month lag time, respectively. From the two correlations, the tendencies show the larger the SOI value, the more precipitation with the two lag times is expected. Also, the strong correlation with 5 % significance level was presented under the "Strong La Niña" category with 5-month lag time. The tendency is the same with the correlations under the weak condition above. The respective scatter plots for the significant correlations at Daejeon are shown in Fig. 14.

For the last station, Gangneung has two correlations which have significance level higher than 5 % (Fig. 15). The correlations show the same lag time (5-month) as well as the same tendencies influenced by La Niña condition. As is easily seen in Fig. 16, the tendency reveals that the stronger the La Niña event, the more precipitation 5-month later we expect.

Remarkably, the lag time of 5-month reveals the same tendency at Inchon, Daejeon, and Gangneung which are located in middle to high region in South Korea. The tendency shows the stronger the La Niña event, the more precipitation five month later is expected at the three stations.

## 5 CONCLUSIONS

The cross-correlation analysis was carried out with the primary objective for the detection of relationship between SOI and precipitation in South Korea. The monthly precipitation data were used from five stations, which are distributed over South Korea with different data length, while SOI values are calculated by Troup's method. When using all data without any manipulation of SOI such as categorization, no clear relationship between SOI and precipitation was found. Therefore, when applying the cross-correlation analysis, we categorized the SOI values into five groups according to their magnitudes and named respective categories, while the monthly precipitation data were transformed into nonexceedance probability time series. For estimation of correlation coefficient, we used the Kendall's $\tau$, a nonparametric approach.

From the cross-correlation analysis applied by the three methodological schemes above, we detected statistically significant correlation between SOI and precipitation in South Korea. Even though they have various lag times with different magnitudes, we could find a spatial distribution of ENSO influence from the results. Busan and Mokpo showed the very strong and significant correlation coefficients with lag time 4-month under the "Strong La Niña" category. Their tendencies revealed that the stronger the La Niña event, the less precipitation 4-month later we expect. Inchon, Daejeon, and Gangneung which have short data periods showed that the correlation coefficients with lag times were variable. However, from the results, they showed a common lag time of 5-month which had a significant correlation coefficient at 1 % level, under the "Weak La Niña" category. In addition, strong correlations were revealed with the same lag time under the "Strong La Niña" category at three stations.

Consequently, the monthly precipitation in South Korea is generally influenced by La Niña event. The influence has a 4-month lag time for southern coastal area and a 5-month for the middle to northern area in South Korea.

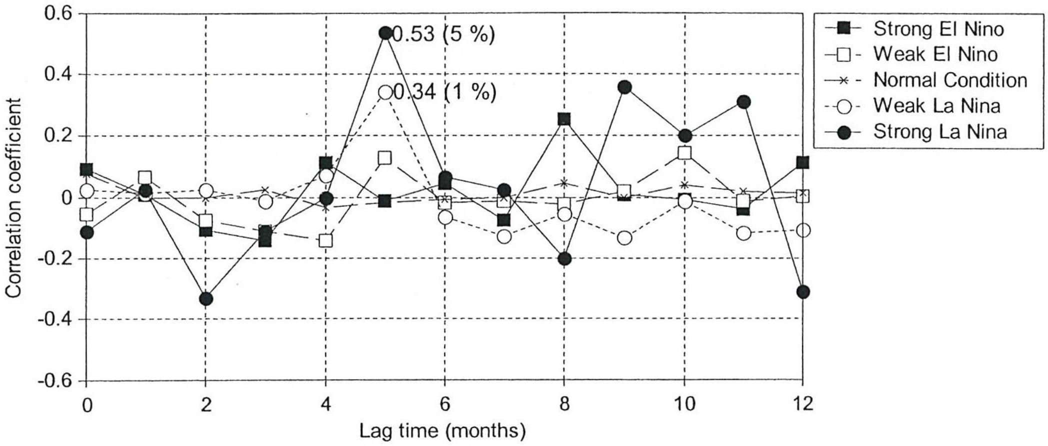

Fig. 15. Cross-correlation between categorized SOI and nonexceedance probability time series at Gangneung station.

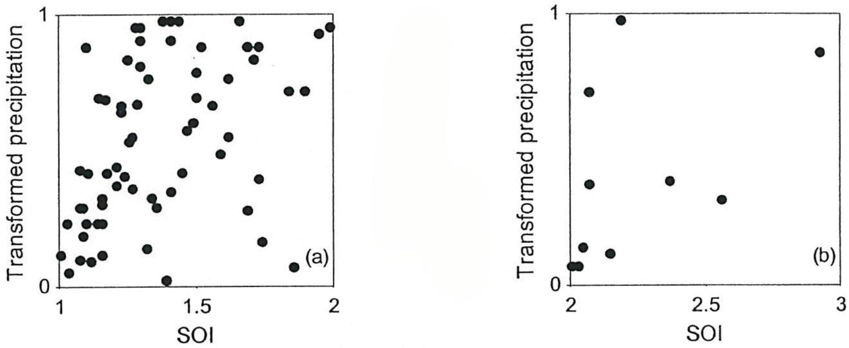

Fig. 16. Scatter plots for lag time (a) 5-month under the "Weak La Niña" category and (b) 5-month under the "Strong La Niña" category.

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