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Detection of ENSO-influence on the monthly precipitation in South 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 and Japan. The influence of ENSO has also been studied in South Korea, but the estimated results are still qualitative and show an indirect relationship between ENSO and hydro-meteorological variables. In this study we use simple approaches to reveal the quantitative and direct correlation between SOI and the monthly precipitation at five stations distributed over South Korea. The monthly precipitation data are transformed into nonexceedance probability time series because the data cannot be normally distributed by applying the usual transformations. The SOI is classified into five categories according to their values. Additionally, to detect the nonlinear relationship between categorized SOI and nonexceedance probability of the monthly precipitation, we use Kendall's τ, a nonparametric test. Significant correlations between the categorized SOI and the transformed precipitation are detected. Generally, the monthly precipitation is influenced by a La Niña event with a lag time of 4 months for southern coastal areas and a lag time of 5 months for middle to high regions in South Korea. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS southern oscillation index (SOI); categorization; nonexceedance probability; Kendall's τ; South Korea

INTRODUCTION

El Niño results from a large-scale weakening of the trade winds and warming of sea-surface temperature in the eastern and central equatorial Pacific. The El Niño phenomenon typically lasts 12–18 months and occurs irregularly at 2–7 year intervals. In contrast, La Niña refers to the condition of lower than normal sea-surface temperature. There is an interannual seesaw phenomenon, which is called southern oscillation (SO), in tropical sea-level pressure between the eastern and western hemispheres. The features are collectively known as the El Niño–SO (ENSO) phenomenon.

During the latest several decades, research has revealed the influence of ENSO on regional and local hydro-meteorological variables, such as temperature, precipitation, streamflow and so on (e. g. McKerchar *et al*., 1996; Chiew *et al*., 1998; Gutiérrez and Dracup, 2001; Poveda *et al*., 2001). 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 researchers have also shown effects of ENSO on hydro-meteorology (e.g. Dracup and Kahya, 1994; Rodo *et al*., 1997; Xu *et al*., 2004).

A number of studies have also been carried out concerning the influence of ENSO on the hydrologic variables in South Korea (Lee, 1998; Kim and Lee, 2000; Shin, 2002). Various approaches were used and meaningful results obtained from the respective researches. However, there are few studies that show the direct

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and quantitative correlation between the influence of ENSO and hydro-meteorological variables in Korea and Japan.

On the other hand, we detected a quantitative and statistically significant correlation between the SO index (SOI) and precipitation and temperature in Japan, for the first time, 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 and temperature. The approach has also been utilized to reveal the relationship between SOI and precipitation in other studies (Kawamura *et al.*, 2001a; 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. For precipitation we transformed the data into nonexceedance probability time series, because monthly precipitation in South Korea cannot be readily normalized by the usual approaches, such as power transformation. For the estimation of correlation between SOI and precipitation, we used Kendall's τ, which is a nonparametric approach. Kendall's τ 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 τ for the correlation coefficient) are examined to investigate the relationship between SOI and precipitation in South Korea.

The remainder of this paper is organized as follows. The second section shows the location of the study area and provides the general properties of the monthly precipitation data in South Korea for the respective stations. The third section details the methodology applied. The penultimate section describes and summarizes the results drawn from this study. The final section gives the conclusions.

STUDY AREA

Annual mean precipitation in South Korea is 1274 mm. The precipitation varies from less than 1000 mm in the inland dry areas to above 1650 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 a Siberian air mass. More than half of the annual precipitation occurs during summer, whereas less than 10% of total annual precipitation falls during winter (Cha, 2000).

Five stations (Busan, Mokpo, Inchon, Daejeon, and Gangneung) in South Korea (Figure 1) were selected for the present study, not only because three of them (Inchon, Mokpo, and Busan) have the longest rainfall observations in South Korea, but also because these 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 each of the stations are shown in Table I.

The locations of the stations are depicted in Figure 1. Busan is located in the southeastern part of Korea. Frequent typhoons cause damage to the area in the summer season. Mokpo is located in the southwestern part of Korea. Inchon, Daejeon, and Gangneung stations have relatively short observations for the present study. Inchon has many missing values between 1904 and 1951 due to the 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 centre of South Korea and started to record precipitation in 1969. The last station, Gangneung is located in northeastern South Korea. It suffered great damage from Typhoon Rusa in 2002. It has the highest monthly precipitation (1137 mm) among the stations. The monthly precipitation time series for all stations are shown in Figure 2.

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

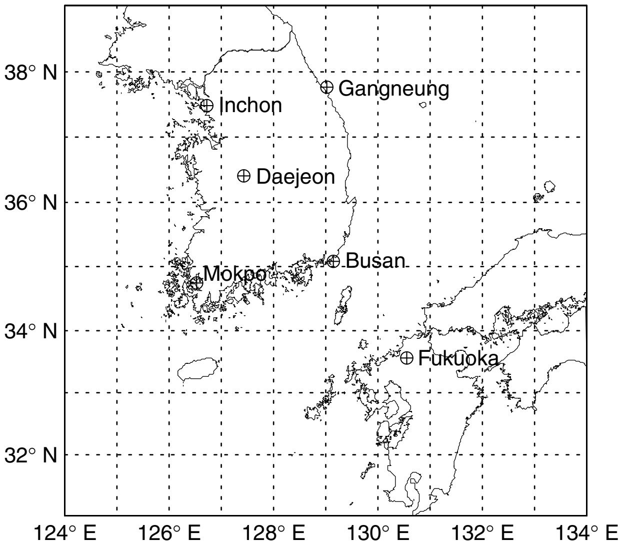

Figure 1. Location map of study area

Table I. 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

The monthly precipitation data at all stations are positively skewed rather than normally distributed (Jin *et al.*, 2002b). There are also several months with no precipitation (less than 0·1 mm) at Busan, Mokpo, Inchon, and Gangneung on a monthly basis, whereas Daejeon has no such data. The usual normalization methods, such as power transformations, are not suitable for series with a number of zero values.

METHODOLOGY

Categorization of SOI

The SOI, which is defined as the normalized difference in surface pressure between Papeete, Tahiti, in the central Pacific Ocean and Darwin in northern Australia, is a measure of the strength of the trade winds. The SOI is used by National Oceanic and Atmospheric Administration (NOAA) to judge whether El Niño and La Niña events are occurring (Japanese Study Group for Climate Impact & Application, 1999).

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 Center's method. The difference between the two methods is very small, as pointed out by McBride and Nicholls (1983), Ropelewski and Jones (1987) and Kawamura *et al.* (1998). In this study we used Troup's

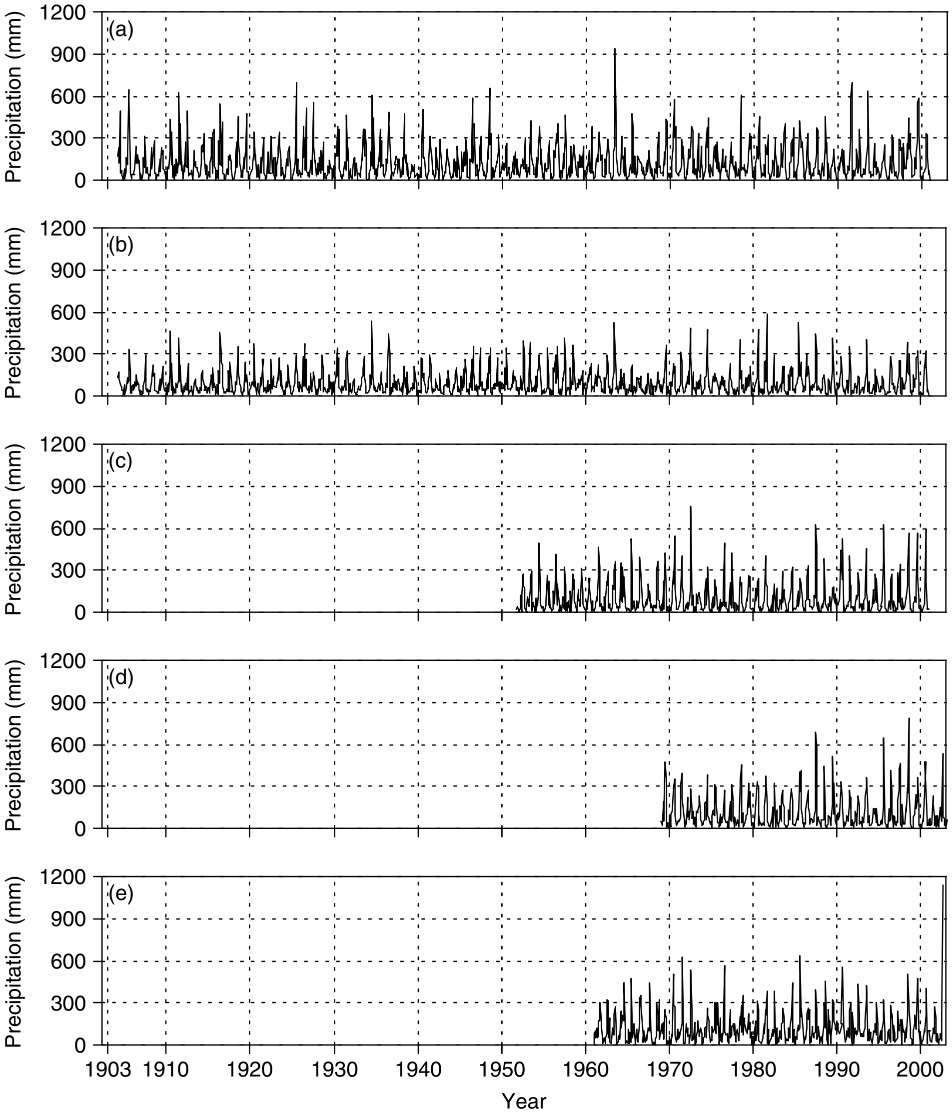

Figure 2. Time series plots for the monthly precipitation at (a) Busan, (b) Mokpo, (c) Inchon, (d) Daejeon, and (e) Gangneung stations in South Korea. Tick marks on the time axis refer to January

method (Troup, 1965). The SOI(y, m) in year y, month m ($m =$ January to December) is calculated thus:

$$\mathrm{SOI}(y, m) = \frac{[P_{\mathrm{T}}(y, m) - P_{\mathrm{D}}(y, m)] - M_{30}(m)}{S_{30}(m)} \quad (1)$$

Here, $P_{\mathrm{T}}(y, m)$ and $P_{\mathrm{D}}(y, m)$ are the MSLP (hPa) at Tahiti and Darwin respectively; $M_{30}(m)$ and $S_{30}(m)$ are respectively the mean value and the standard deviation of the MSLP difference between Tahiti and Darwin for the base period of 30 years (usually 1951–80). The SOI is expressed as the MSLP difference between Tahiti and Darwin, which is normalized to a mean of zero and a standard deviation of one. Figure 4 shows the time series of the monthly SOI values calculated using Equation (1) with the period from April 1902 to December 2002. Kawamura *et al.* (1998) used the same method to calculate the SOI data and investigated

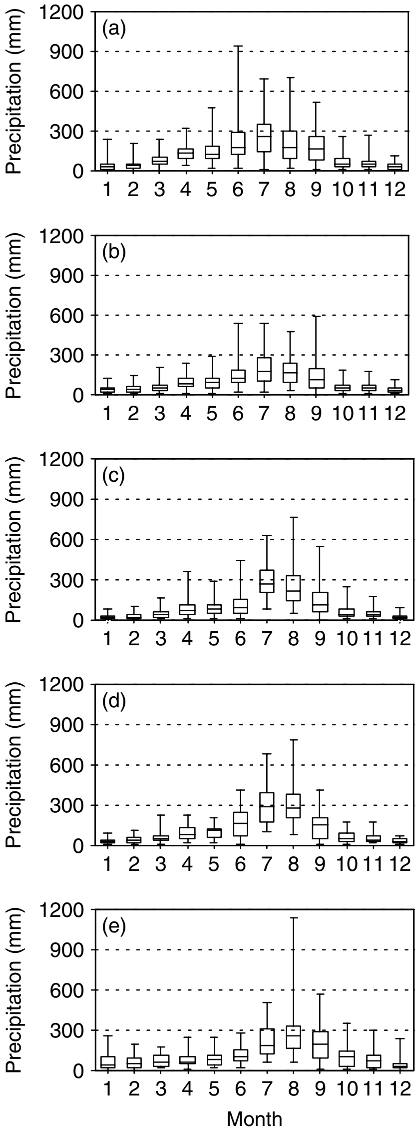

Figure 3. Box-and-whisker plots for each station in South Korea on a monthly basis: (a) Busan; (b) Mokpo; (c) Inchon; (d) Daejeon; (e) Gangneung

whether or not inherent chaotic characteristics exist in the data with a longer time span than that used in the present study.

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 τ, which are explained in following sections, were applied to reveal such correlation. Figure 5 shows the results with a lag time up to 12 months. 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: Strong El Niño (SOI < -2); Weak El Niño ($-2 \leq$ SOI < -1); Normal Condition ($-1 \leq$ SOI ≤ 1); Weak La Niña

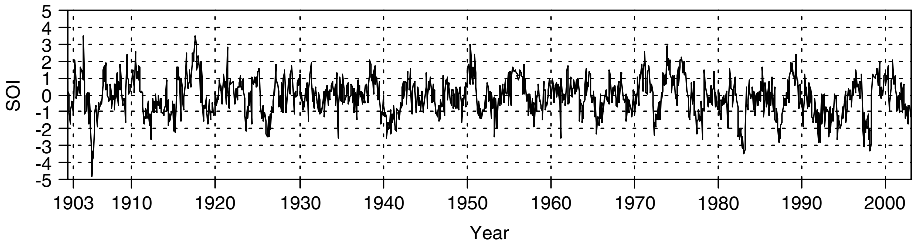

Figure 4. Time series plot for SOI (April 1902 to December 2002). Tick marks on the time axis refer to January

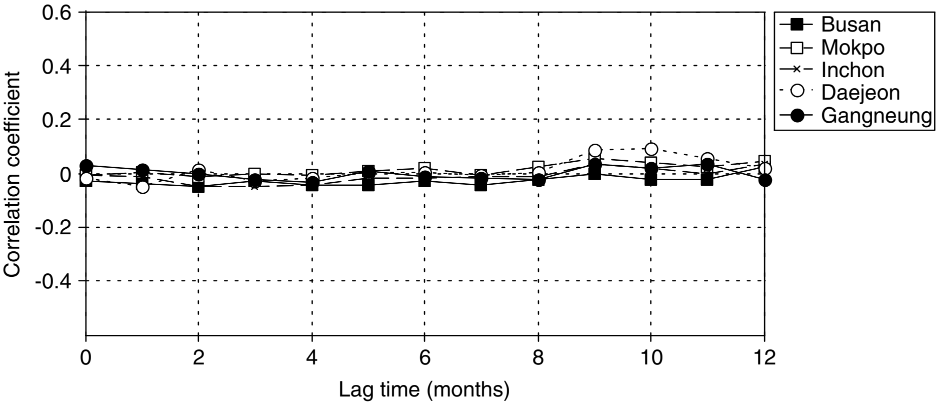

Figure 5. Cross-correlation between all of SOI data and nonexceedance probability time series at the five stations

(1 < SOI ≤ 2); Strong La Niña (2 < SOI). This naming for each category 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, are further described in the studies by Kawamura *et al.* (2001b, 2002).

Transformation of precipitation

The monthly precipitation data used 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. 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 monthly precipitation. As mentioned earlier, the precipitation typically shows positive skewness on a monthly basis, and this skewness should, therefore, be reduced. A usual method for this is cubic-root transformation, which 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; Jin *et al.*, 2002a). However, when using data that include zero values, like the precipitation in South Korea, the cubic-root transformation should be replaced. As an 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 q_i is the nonexceedance probability of the ith smallest precipitation, n is the number of data on a monthly basis, and α is a plotting position parameter.

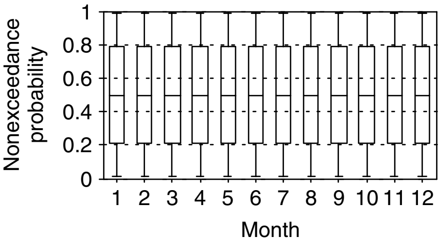

Figure 6. Box-and-whisker plot for nonexceedance probability time series on a monthly basis at Busan station

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

Cross-correlation

We applied a 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 and Wolfe, 1999).

We used Kendall's correlation coefficient in the cross-correlation analysis. Kendall's correlation coefficient, which is known as Kendall's τ, is a rank-based procedure and, therefore, is 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. A detailed procedure for Kendall's τ can be found in Hirsh *et al.* (1993).

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 (Figure 5). Even though some of them show a significance level higher than 5%, it was very difficult to say that there were significant tendencies from the weak correlation. Therefore, the results from the correlation of all data are ignored in this consideration. Henceforth, we focus only on the results by the categorization method.

Figure 7 shows the correlation coefficients with lag times up to 12 months at Busan. The figure shows only one correlation coefficient that is strong enough and statistically significant at the 1% level. In this and the following figures the significance levels are shown in parentheses next to the correlation coefficient. There is a correlation coefficient of −0·45 with a lag time 4 months under the 'Strong La Niña' category. The scatter plot is seen in Figure 8. From the significant coefficient with strong correlation, therefore, Busan has the tendency that the stronger the La Niña event, the lesser is the precipitation expected 4 months later. This tendency was revealed in our previous research (Jin *et al.*, 2002a) and, as described in the paper, it has the same trend with the same lag time of 4 months as the result at Fukuoka, which is in close proximity to Busan (Figure 1).

The next station, Mokpo, has some correlation coefficients at the 1% significance level under the 'Normal Condition' category, but the strengths of the correlations are very weak and negligible, so that no clear tendency can be drawn from the results. It is at the 5% significance level that tendencies can be detected

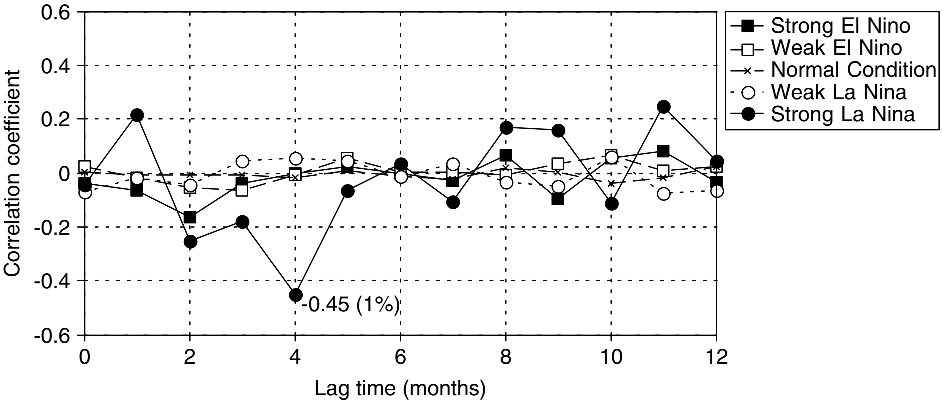

Figure 7. Cross-correlation between categorized SOI and nonexceedance probability time series at Busan station

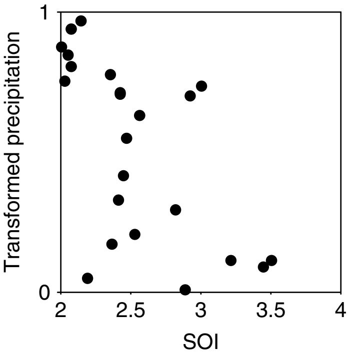

Figure 8. Scatter plot for lag time of 4 months under the 'Strong La Niña' category

under the 'Strong La Niña' category with lag times of 4 and 11 months (Figure 9). The tendencies are different according to the lag times. On the one hand, the correlation with a lag time 4 months shows the tendency that the stronger the La Niña event, the less the precipitation is at Mokpo, which is very similar to the correlation with the same lag time at Busan station (Figure 10a). On the other hand, the correlation for the lag time of 11 months reveals that the stronger the La Niña event, the more precipitation we can expect (Figure 10b).

The magnitudes of the most significant correlations with a lag time of 4 months are −0·45 at Busan and −0·37 at Mokpo. In addition, Fukuoka has the same tendency as the results at Busan and Mokpo, as mentioned above. These strengths are considerably higher than the correlation coefficients of SO in which the MSLP between Tahiti and Darwin are −0·26 with the long data period and −0·40 with the data from 1971 to 2001, although there is a very clear oscillation between them (Kawamura *et al.*, 2001b, 2002). Also, the southern coastal area in South Korea and Fukuoka in Japan was substantiated as being influenced by the 'Strong La Niña' condition with a lag time 4 months. The common results at the three different stations cannot be obtained by chance, and can be considered as clear evidence for the influence of the ENSO phenomenon.

Inchon station shows one correlation coefficient that has a 1% significance level with 5 months under the 'Weak La Niña' category and, in general, the variation of correlations according to lag times is fluctuating under the 'Strong La Niña' category (Figure 11). In addition, a strong correlation of 0·44 with the same lag time (5 months) was also revealed under the 'Strong La Niña' category, even though it had a low significance level due to the small number of data. This reveals that the La Niña event has a strong influence on precipitation at Inchon with a 5 months lag time.

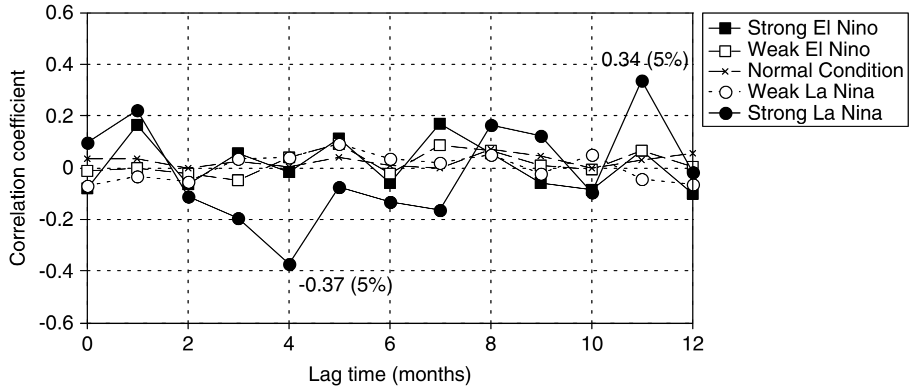

Figure 9. Cross-correlation between categorized SOI and nonexceedance probability time series at Mokpo station

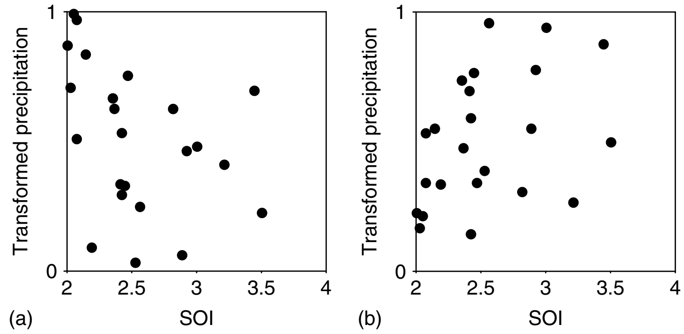

Figure 10. Scatter plots for lag times of (a) 4 months and (b) 11 months under the 'Strong La Niña' category

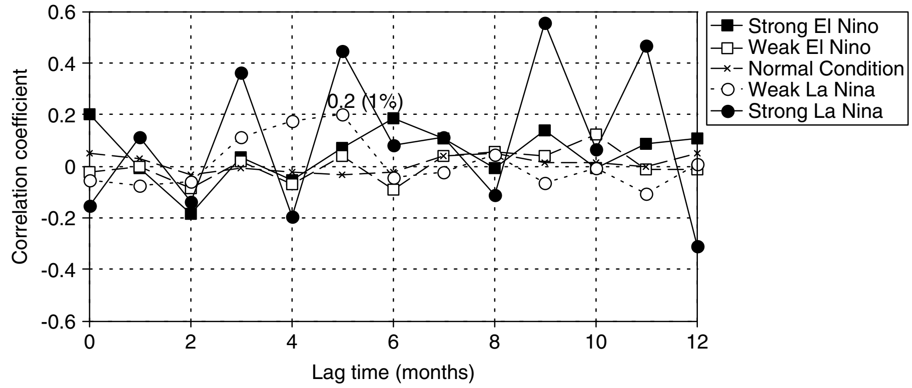

Figure 11. Cross-correlation between categorized SOI and nonexceedance probability time series at Inchon station

Figure 12 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 the 1% level under the 'Weak La Niña' category with a 5 months lag time and the 'Weak El Niño' category with a 10 months lag time. From the scatter plot of the correlation with a lag time of 5 months (Figure 13a), the tendency shows that the larger the SOI value, the more precipitation is expected. Also, the strong correlation with 5%

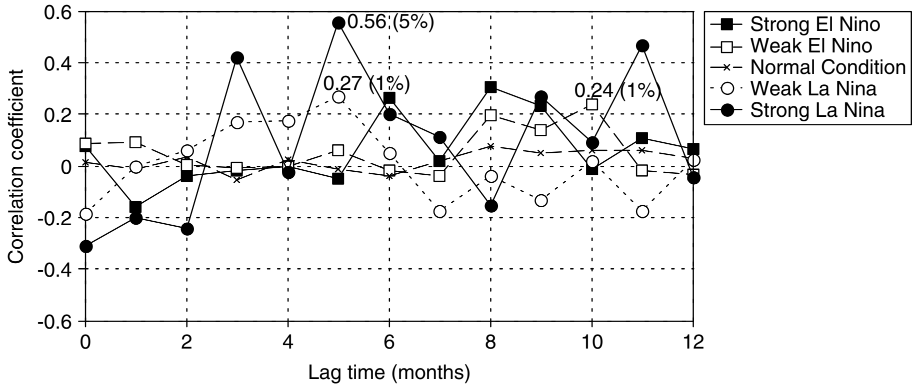

Figure 12. Cross-correlation between categorized SOI and nonexceedance probability time series at Daejeon station

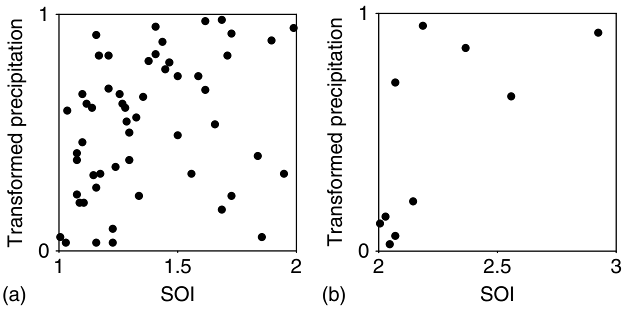

Figure 13. Scatter plots for lag time of 5 months under (a) the 'Weak La Niña' category and (b) the 'Strong La Niña' category

significance level was presented under the 'Strong La Niña' category with 5-months lag time (Figure 13b). The low significance level also resulted from the small number of data. The tendency is the same with the correlations under the weak condition above.

For the last station, Gangneung, there are two correlations that have a significance level higher than 5% (Figure 14). The correlations show the same lag time (5 months) as well as the same tendencies influenced by the La Niña condition. As is easily seen in Figure 15, the tendency reveals that the stronger the La Niña event, the greater the precipitation to be expected 5 months later. The two correlations at Gangneung have higher strength than those that show similar tendencies under the respective categories at Inchon and Daejeon.

Remarkably, the lag time of 5 months reveals the same tendency at Inchon, Daejeon, and Gangneung, which are located in middle to north region in South Korea. The tendency shows the stronger the La Niña event, the greater the precipitation to be expected 5 months later at the three stations. The most significant tendency is at Gangneung station.

CONCLUSIONS

A cross-correlation analysis was carried out with the primary objective of detecting the relationship between SOI and precipitation in South Korea. Monthly precipitation data were used from five stations distributed over South Korea with different data lengths, and 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, and the monthly precipitation data were

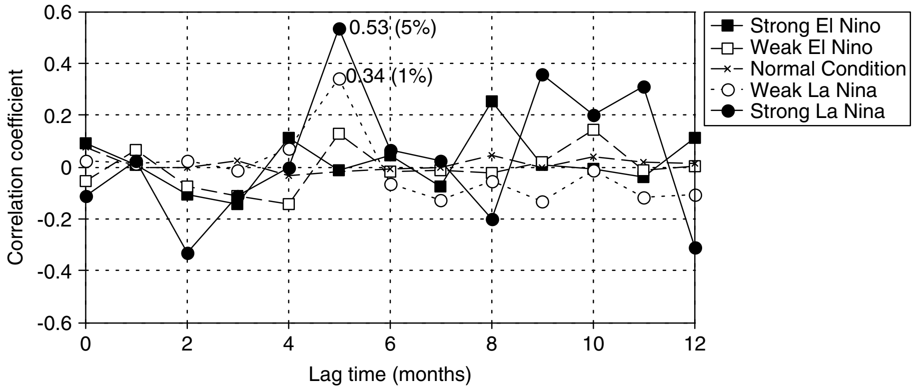

Figure 14. Cross-correlation between categorized SOI and nonexceedance probability time series at Gangneung station

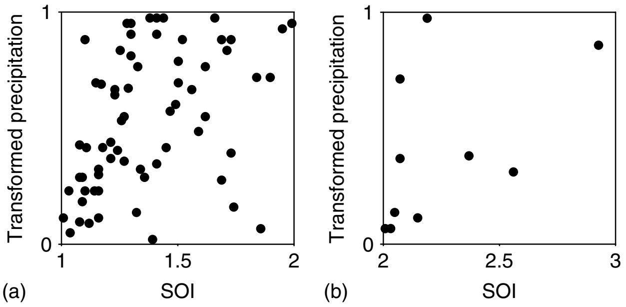

Figure 15. Scatter plots for lag time 5 months under (a) the 'Weak La Niña' category and (b) the 'Strong La Niña' category

transformed into nonexceedance probability time series. We used the nonparametric approach of Kendall's τ to estimate of the correlation coefficients.

From the cross-correlation analysis applied by the three methodological schemes above, we detected statistically significant correlations 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 significant correlation coefficients with lag times of 4 months under the 'Strong La Niña' category. Their tendencies revealed that the stronger the La Niña event, the less precipitation there is to be expected 4 months later. Inchon, Daejeon, and Gangneung showed a common lag time of 5 months, which had significant correlation coefficients, under La Niña events.

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

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