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Impacts of ENSO on monthly precipitation in South Korea and Fukuoka, Japan

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Abstract Simple but robust approaches were used to reveal the quantitative and statistically significant influence of the Southern Oscillation Index (SOI) on monthly precipitation at five stations distributed over South Korea and Fukuoka, Japan. The monthly precipitation data were transformed into non-exceedence probability time series. SOI is classified into five categories. Correlation between the categorized SOI and transformed precipitation was calculated by Kendall's τ. The results show significant correlations when using the above methodological schemes. The spatial distribution of ENSO influence is obtained from the correlation results. Fukuoka and the southern coastal area of South Korea showed very strong and significant correlation coefficients with a lag time of four months under the "Strong La Niña" category. The middle to northern area showed a significant correlation with the common lag time of five months under the "Weak La Niña" and "Strong La Niña" categories.

Key words categorization of SOI; El Niño; influence of ENSO; Japan; Kendall's τ; Korea; La Niña; non-exceedence probability; SOI

INTRODUCTION

A large scale weakening of the trade winds and warming of sea-surface temperature in the eastern and central equatorial Pacific Ocean defines El Niño, which typically lasts 12–18 months and occurs irregularly at 2- to 7-year intervals. The opposite situation, La Niña, refers to the condition when the sea-surface temperature is lower than normal. The two situations define an inter-annual seesaw phenomenon, called the Southern Oscillation (SO), in tropical sea-level pressure between the eastern and western hemispheres. This oscillation is characterized by a simple index, the Southern Oscillation Index (SOI) (Kawamura *et al.*, 1998). The features are known collectively as the El Niño/Southern Oscillation (ENSO) phenomenon. This phenomenon is a result of interactions between large-scale oceanic and atmospheric circulation processes in the equatorial Pacific Ocean.

During the last several decades there has been considerable interest in the influence of ENSO on global and regional meteorological/hydrological variables, such as temperature, precipitation, streamflow, etc. (see e.g. Chiew *et al.*, 1998; Gutiérrez & Dracup, 2001; Poveda *et al.*, 2001). These studies showed that the influence of ENSO on hydrometeorological variables in the lower to mid-latitudes appears evident. For middle to high latitudes, however, the impact of ENSO on hydrological variables is not clear. Some studies, however, have also shown effects of La Niña and SO on hydrometeorology (see e.g. Dracup & Kahya, 1994; Rodo *et al.*, 1997).

A general tendency for cool summers and warm winters during El Niño events has been found in Japan (Japanese Study Group for Climate Impact & Application, 1999), but no significant correlation has been presented between El Niño or La Niña events and hydro-meteorological variables (e.g. precipitation and temperature) in Japan (Yoshino, 1999). A number of studies have been carried out by Lee (1998), Kim *et al.* (2000) and Shin (2002) on the influence of ENSO on hydrological variables in Korea. They used various approaches and obtained the meaningful results (for details refer to Jin *et al.*, 2004). However, there are few research projects that show direct and quantitative correlations between the influence of ENSO and hydro-meteorological variables in either Korea or in Japan. However, Kawamura *et al.* (2000, 2001a) have detected quantitative and statistically significant correlations between SOI and precipitation and temperature in Japan, using a simple method in which SOI data were categorized into five groups according to their magnitude.

In this study, simple but robust approaches are used to reveal the quantitative and statistically significant influence of the SOI on monthly precipitation at five stations distributed over South Korea and Fukuoka, southwestern Japan, which is located close to the south of South Korea. The monthly precipitation data are transformed into non-exceedence probability time series, as proposed by Jin *et al.* (2004), because the data cannot be normally distributed by applying the usual transformations (such as a power transformation). SOI is classified into five categories according to their values. Additionally, to detect the nonlinear relationship between the categorized SOI and non-exceedence probability of the monthly precipitation, we use Kendall's τ, a nonparametric test. These three methodological schemes (i.e. categorization of SOI, transformation of monthly precipitation into non-exceedence probability time series, and application of Kendall's τ for the correlation coefficient) are applied to investigate the relationship between SOI and precipitation in South Korea and Fukuoka for evidence of the spatial distribution of the ENSO influence.

STUDY AREA AND DATA

Figure 1 shows the locations of the observation stations selected in this study. They are Fukuoka station in Japan and five stations (Busan, Mokpo, Inchon, Daejeon and Gangneung) in South Korea. Their monthly precipitation data were used for the following analyses. The data periods of the monthly precipitation used in this study and their annual mean precipitation are shown in Table 1. Fukuoka was selected not only because of its close proximity to South Korea but also because of its long and well-investigated record of precipitation observations. Fukuoka is always exposed to potential drought and was actually struck by very severe droughts in 1978 and 1996 (for details refer to Kawamura & Jinno, 1996). The five stations in South Korea were selected not only because three of them (Busan, Mokpo and Inchon) have the longest rainfall observation records, but also because the five stations are distributed over

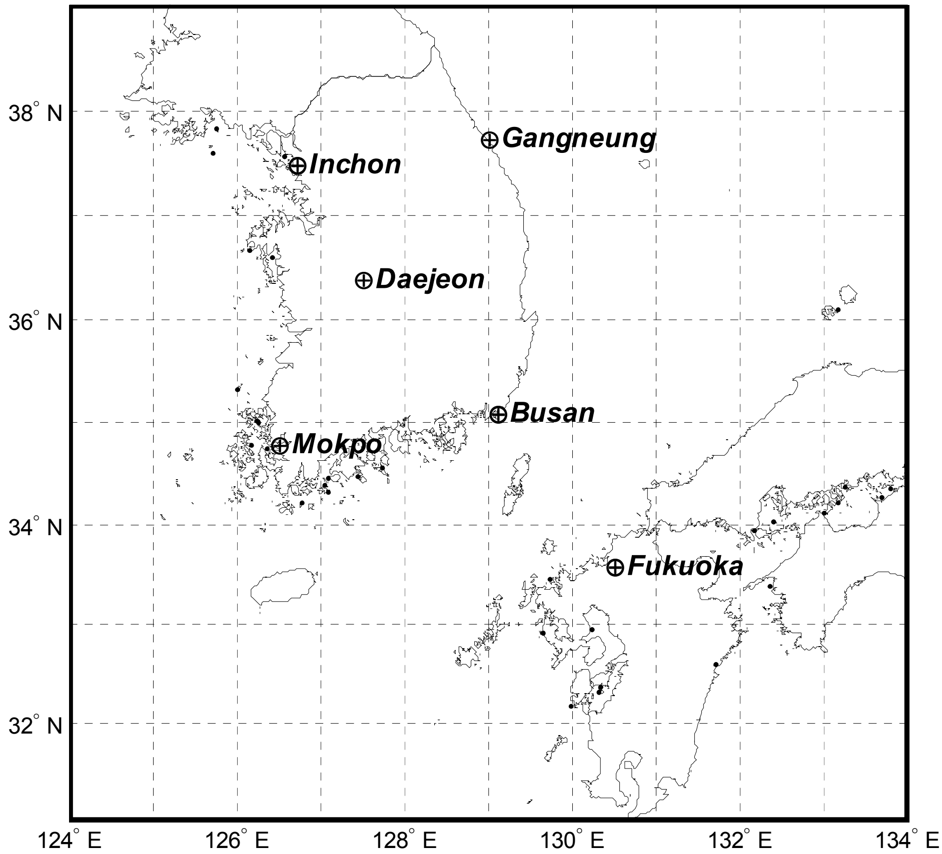

Fig. 1 Location map of study area.

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

Station	Data period	Annual mean precipitation (mm)
Fukuoka	January 1890–December 2000	1627
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

South Korea. Jin *et al.* (2002, 2004) describe the basic statistics of the data including correlation and spectral analyses. The monthly precipitation pattern differs considerably from station to station. The monthly precipitation data at all the stations were not normally distributed but instead positively skewed (Jin *et al.*, 2002). There are also several months that have no precipitation (<0.1 mm) at Busan, Mokpo, Inchon, and Gangneung on a monthly basis, while only Fukuoka and Daejeon have no such data. In the main it is the property of no precipitation on a monthly basis that causes the non-normal distribution after applying usual data transformations such as power transformations (Jin *et al.*, 2004).

METHODS

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). In the present study, we used Troup's method to calculate SOI, in which $SOI(y,m)$ in year y, month m (m = January to December) is calculated as:

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

Here, $P_T(y,m)$ and $P_D(y,m)$ are MSLP (hPa) at Tahiti and Darwin, respectively; $M_{30}(m)$ and $S_{30}(m)$ is the mean value (hPa) and its standard deviation (hPa) of the MSLP difference between Tahiti and Darwin for the base period of 30 years (usually 1951–1980), respectively. Kawamura *et al.* (1998, 2002) have analysed the statistical and chaotic characteristics of SOI in detail, and Jin *et al.* (2003b) presented the long-term variability of SOI.

The cross-correlation between SOI and monthly precipitation without categorization of SOI was calculated first, which indicated that the correlation coefficients are almost zero for any time lag at any of the six observation stations (Kawamura *et al.*, 2000, 2001a; Jin *et al.*, 2003a, 2004). Therefore, we categorized the SOI values into five groups according to their magnitudes:

Strong El Niño	$SOI < -2$	Weak El Niño	$-2 \le SOI < -1$
Normal condition	$-1 \le SOI \le 1$	Weak La Niña	$1 < SOI \le 2$
Strong La Niña	$2 < SOI$		

This naming of each category of SOI is for easy association with the El Niño and La Niña phenomena. Refer to the studies by Kawamura *et al.* (2001b) and Jin *et al.* (2004) for the frequency properties of the SOI categories.

Transformation of precipitation

To remove periodicities in the precipitation data, normalization was carried out. The cubic root transformation can usually be used to perform normalization. The data are then standardized to a mean of zero and a standard deviation of one (e.g. Salas, 1993). In this study, an alternative transformation was used since it was clear that the cubic root transformation did not work well for the monthly precipitation in Korea. Monthly precipitation data were transformed into non-exceedence probability time series for each month from January to December. The non-exceedence probability of the ith-smallest precipitation can be obtained using $\alpha = 0$ (known as the Weibull plot) from the general formula proposed by Cunnane (1978):

$$q_i = (i - \alpha) / (n + 1 - 2\alpha) \quad (2)$$

where q_i is the non-exceedence probability of the ith-smallest precipitation, n is the number of data in monthly basis from January to December, and α is a plotting position parameter. The comparison of the cubic root and non-exceedence transformations for the Fukuoka station data is described by Jin *et al.* (2004).

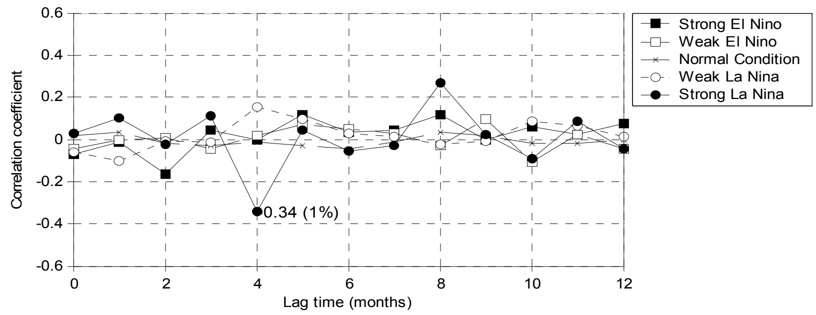

Fig. 2 Cross-correlation between categorized SOI and monthly precipitation at Fukuoka station.

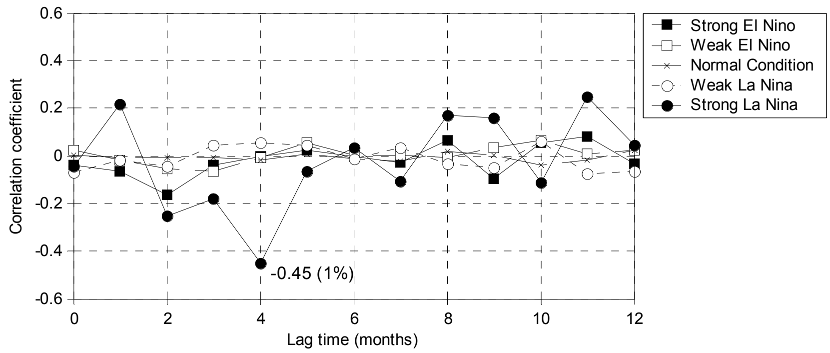

Fig. 3 Cross-correlation between categorized SOI and monthly precipitation at Busan station.

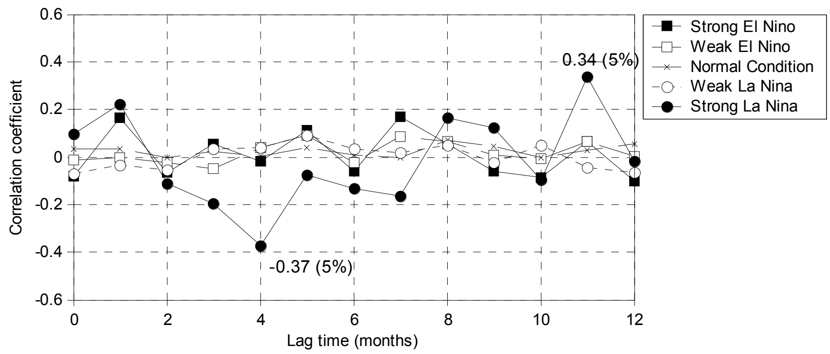

Fig. 4 Cross-correlation between categorized SOI and monthly precipitation at Mokpo station.

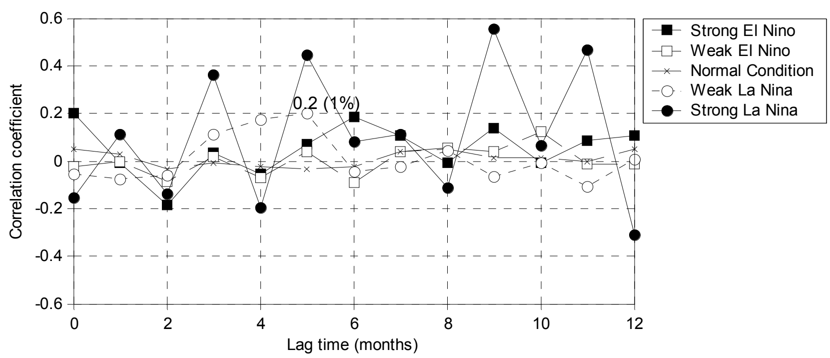

Fig. 5 Cross-correlation between categorized SOI and monthly precipitation at Inchon station.

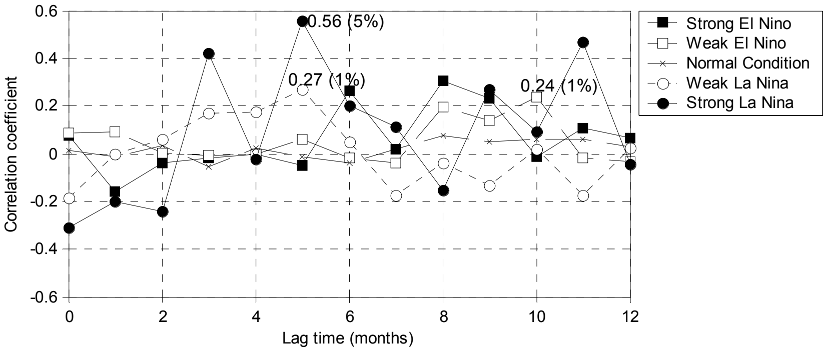

Fig. 6 Cross-correlation between categorized SOI and monthly precipitation at Daejeon station.

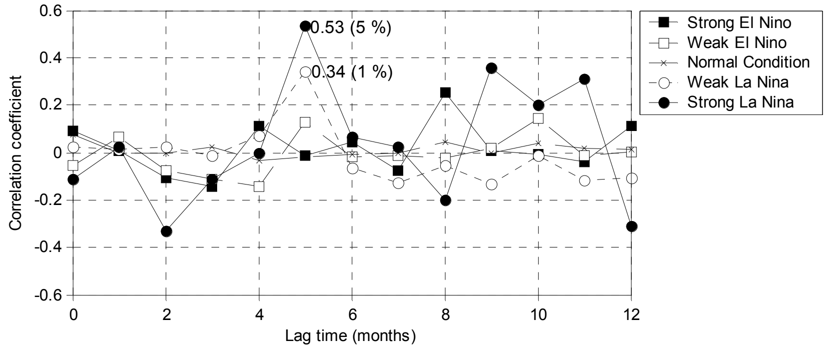

Fig. 7 Cross-correlation between categorized SOI and monthly precipitation at Gangneung station.

CROSS-CORRELATION ANALYSIS

We used Kendall's correlation coefficient, Kendall's τ, to investigate the influence of ENSO on the monthly precipitation at the six stations. Kendall's correlation is a rank-based procedure, and is therefore resistant to the effects of extreme values and to deviations from a linear relationship (Hirsh *et al.*, 1993). Figures 2–7 show the correlation coefficients with lag times of up to 12 months at Fukuoka, Busan, Mokpo, Inchon, Daejeon and Gangneung, respectively. The significance level is presented in parentheses next to the correlation coefficient in the figures.

From these figures, the correlations under the "normal condition" are almost zero at any lag time. However, statistically significant correlation coefficients are obtained under some other categories. From Figs 2–4, the highest correlation coefficients –0.34, –0.45, –0.37, which are significant at least at the 5% level, are obtained with the same lag time, four months, under the same category "Strong La Niña", at Fukuoka, Busan and Mokpo, respectively, shown in these figures. These correlations are considerably high compared with the correlation coefficients of the mean sea level pressure between Tahiti and Darwin, which show the very clear oscillation between known as the Southern Oscillation. In fact, that correlation is –0.26 with long period data, and –0.40 with the data from 1971 to 2001 (Kawamura *et al.*, 2001b, 2002). Figure 8 shows the scatter plot between SOI categorized as "Strong La Niña" and the corresponding monthly precipitation with a four-month lag time at Busan station. From

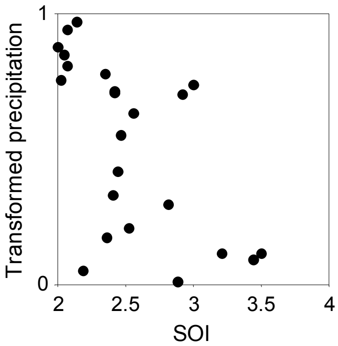

Fig. 8 Scatter plots between SOI categorized as "Strong La Niña" and monthly precipitation with lag time of four months at Busan station.

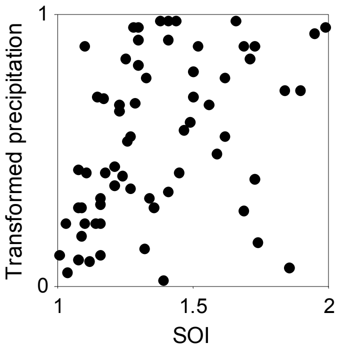

Fig. 9 Scatter plots for lag time of five months under the "Weak La Niña" category at Gangneung station.

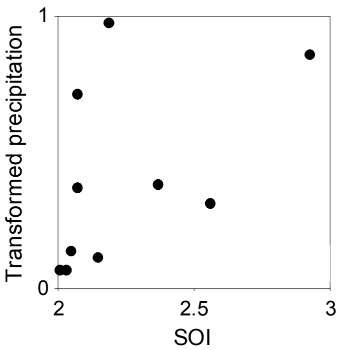

Fig. 10 Scatter plots for lag time of five months under the "Strong La Niña" category at Gangneung station.

this figure, we can see the tendency in which the stronger the La Niña event, the less the precipitation four months later at Busan. This tendency is exactly the same as that at Fukuoka and Mokpo with the same lag time and category. Therefore, the area that covers Fukuoka and the southern coastal area of Korea (Fig. 1) is influenced by "Strong La Niña" events with a lag time of four months.

In contrast, Inchon, Daejeon and Gangneung stations (Figs 5–7) show correlation coefficients with a five-month lag time under the "Weak La Niña" category that are statistically significant at the 1% level, although the values themselves are not so high. Also, Figs 5–7 show that there are quite a few higher correlation coefficients (>0.4) under the "Strong La Niña" category; however, these are not statistically significant due to the small number of data so categorized, except for just two points, i.e. those with a five-month lag time at Daejeon and Gangneung stations (Figs 6 and 7). Figures 9 and 10 show the scatter plots between the "Weak La Niña" and "Strong La Niña" SOI categories, respectively, and the corresponding monthly precipitation with a lag time of five months at Gangneung station. From these figures, we can see the tendency in which the stronger the La Niña event, the more precipitation that occurs five months later at Gangneung. This tendency is the same for Inchon and Daejeon with the same lag time and category. Consequently, the areas located in the middle to northern regions of South Korea (Fig. 1) can be influenced by La Niña events with a lag time five months.

CONCLUSION

The cross-correlation analysis was carried out with the primary objective of detection of relationships between the SOI and precipitation in South Korea and Fukuoka, Japan. When using all the data without any manipulation of the 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, while the monthly precipitation data were transformed into non-exceedence probability time series. For estimation of the correlation coefficient, we used the Kendall's τ, a nonparametric approach.

We successfully detected statistically significant correlations between the SOI and monthly precipitation using the above-mentioned schemes. Even though they have various lag times with different magnitudes, we could identify a spatial distribution of ENSO influence from the results. The southern coastal area, including Fukuoka, Busan and Mokpo, showed the very strong and significant correlation with a four-month lag time under the "Strong La Niña" category, even though the monthly precipitation pattern of each station differs considerably. Their tendencies revealed that the stronger the La Niña event, the less precipitation that occurs four-months later. On the other hand, the middle to northern areas of South Korea (Inchon, Daejeon and Gangneung) showed a common lag time of five months, which had a significant correlation coefficient at the 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, we conclude that the monthly precipitation in South Korea and Fukuoka, Japan is generally influenced by La Niña events. The influence has a four-month lag time in the southern coastal area, and a five-month lag for the middle to northern area of South Korea.

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