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Journal of Hydrology 301 (2005) 54–65
Journal of Hydrology
www.elsevier.com/locate/jhydrol

Quantitative relationship between SOI and observed precipitation in southern Korea and Japan by nonparametric approaches

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Received 23 December 2002; revised 20 May 2004; accepted 15 June 2004

Abstract

Several studies have tried to link southern oscillation index (SOI) and observed precipitation in Korea and Japan. However, so far no clear relationship between the SOI and the precipitation in the area has been found. In the present study, categorized SOI are used to reveal quantitative and statistically significant influence on monthly precipitation at Busan in Korea and at Fukuoka in Japan. Monthly precipitation data were transformed to cubic root and nonexceedance probability time series. Correlation between the categorized SOI and transformed precipitation was calculated by Kendall's τ and Pearson's r. The results show that significant correlation is at hand when using both approaches. Significant correlation at the 1% level was obtained with lag time of 4 months under the 'Strong La Niña' category (SOI > 2) at both stations. The results show that southern Korea and southern parts of Japan are located in the same or very close influence range of SOI.

Keywords: Southern oscillation index (SOI); Categorization of SOI; Nonexceedance probability; Kendall's τ

1. 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 2–7 year intervals. The opposite situation, La Niña, refers to the condition when 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 eastern and western hemispheres. This oscillation is characterized by a simple index, the southern oscillation index (SOI) which is used by National Oceanic and Atmospheric Administration (NOAA) to judge whether the El Niño or

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doi:10.1016/j.jhydrol.2004.06.026

the La Niña event is occurring (Japanese Study Group for Climate Impact and Application, 1999). The features are known collectively as the El Niño/southern oscillation (ENSO) phenomenon. This phenomenon is consequently a result from the interaction between large-scale oceanographic and atmospheric circulation processes in the equatorial Pacific Ocean.

During the latest 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. Poveda et al., 2001; Gutiérrez and Dracup, 2001; 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, however, the impact of ENSO on hydrological variables is not clear. In particular, a wide study area from low to high latitudes was used to investigate the correlation between ENSO and hydro-climate in South-east Asia and Pacific region and the weaker evidence with higher latitudes was revealed (Xu et al., 2004). Some studies, however, have also shown effects of La Niña and SO on hydrometeorology also here (e.g. Dracup and Kahya, 1994; Rodo et al., 1997).

For South-east Asia several studies have been made. Yoshino (1999) studied relationships between SOI and precipitation in the Philippines/Malaysia and Japan, respectively. Although no quantitative relationship between SOI and precipitation was calculated, a clear pattern similarity between SOI and precipitation in the Philippines and Malaysia could be found. However, no clear relationship between SOI and precipitation in Japan was found. Kawamura et al. (1998, 2001a), on the other hand, detected quantitative and statistically significant correlation 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.

Several studies have presented relationships between the El Niño/La Niña phenomena and hydrological variables in Korea. Lee (1998) revealed response of temperature/precipitation to El Niño/La Niña in Korea using harmonic analysis. Kim and Lee (2000) applied composite analysis to investigate the relationship between SOI and streamflow patterns at two gauging stations in Korea and showed that seasonal flow from September of El Niño year to February of the following year was smaller than its mean. Moon (2001) used multi-channel singular spectral analysis to identify coherent space-time patterns of low frequency harmonic elements between SOI and precipitation in Korea. Shin (2002) revealed significant influence of El Niño/La Niña on floods and droughts in Korea, applying statistically robust cross-correlation analysis.

As seen from the above, various approaches have been applied to reveal relationships between SOI and hydro-meteorological variables. Evaluating various methods to reveal influence of SOI in middle to high latitudes is important because there is little evidence of El Niño/La Niña phenomena for these regions. Alternative techniques should, therefore, be evaluated in order to reveal hidden patterns and covariance in data. From this viewpoint, an appropriate pre-processing of raw data is essential. Normalization of raw data is usually performed because of skew data. However, when normalization is not possible with the usual transformations, an alternative transformation should be performed instead and verified.

In the present paper, a nonparametric approach to reveal nonlinear relationships between SOI and precipitation was used. Besides the commonly used Pearson's r (Pearson product moment correlation coefficient), also the Kendall's τ was used. This method is robust with regard to effects of extreme values and deviations from a linear variation (Hirsh et al., 1993; see also e.g. Kendall, 1938; Kendall and Gibbons, 1990; Hirsh et al., 1982; Hirsh et al., 1991; and Gan, 1998).

Two approximately 100-year monthly precipitation time series observed in southern Korea and south Japan were analyzed to reveal co-variation with SOI. After showing the location of the study area and providing general properties of data used two different transformation techniques are applied to the monthly precipitation data. The results are analyzed in comparison with categorized SOI. In other words, the applicability of the nonparametric methods is verified through the results from Fukuoka, south Japan and the methods are applied to the monthly precipitation data in Busan, southern Korea. We close with a discussion of practical aspects of results obtained.

2. Study area, data, and methods

2.1. Study area

Two precipitation stations with observed long time series were selected for the study, Busan in Korea and Fukuoka in Japan. Busan is located in the southeastern part of the Korean peninsula at 129°E and 35.1°N, as shown in Fig. 1. This station has the longest period of precipitation observations in South Korea (1904–2000). The Fukuoka station is located in the northern part of Kyushu Island at 130.4°E and 33.6°N, southern Japan (Fig. 1). The Fukuoka station has observations during 1890–2000. The Fukuoka precipitation station has several well-recorded droughts during its period of observation, notably some of the worst in 1978 and 1996 (Kawamura and Jinno, 1996). The two stations were selected not only because of the long records but also due to that the two stations represent a meteorological and climatic area that is spanning across the strait between South Korea and Japan. This area is important for the understanding of the climatic features of the region. Consequently, by studying stations representing this area a more complete and spatially correct understanding of the effects of ENSO can be achieved.

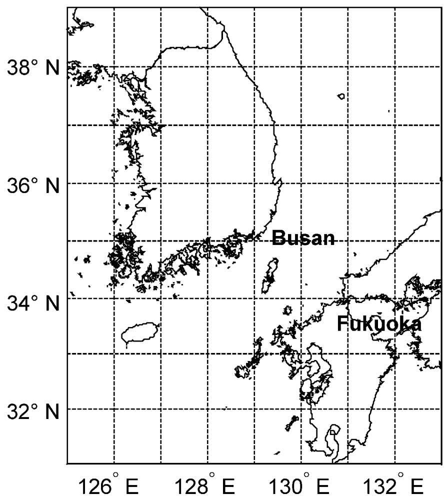

Fig. 1. Location of study area; Fukuoka in Japan and Busan in Korea.

2.2. Categorization of southern oscillation index (SOI)

The SOI data were calculated using the monthly mean sea level pressure (MSLP) at Papeete, Tahiti (149.6°W, 17.5°S) and Darwin, Australia (130.9°E, 12.4°S). The MSLP data starting from 1882 are available through web sites such as NOAA Network Information Center. However, some missing values exist for the Tahiti pressure data. Ropelewski and Jones (1987) filled in all missing values using newly found pressure data for Tahiti. Furthermore, they completed the pressure time series since 1866 by supplementing and interpolating the data of Tahiti before 1882. Allan et al. (1991) also augmented the pressure data at Darwin before 1882 by using older records and by correlation with data from other observation stations. As a result, the pressure data at Darwin were also completed since 1866. We describe below the process of calculation for SOI values in detail because we used the interpolated and extended MSLP data from the two stations, which were not readily obtained from web sites.

Two commonly used methods to compute SOI from MSLP data at Tahiti and Darwin are Troup's method and the Climate Prediction Centre'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). Kawamura et al. (2001b) presented general statistical characteristics of SOI.

In the present study, we use Troup's method (Troup, 1965). The SOI(y,m) in year y, month m (m= January to December) is calculated by the following equation:

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

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 MSLP difference between Tahiti and Darwin for the base period of 30 years (usually 1951–1980), respectively. The SOI is expressed as the MSLP difference between Tahiti and Darwin which is normalized to zero mean and a standard deviation of one. Note that a standard deviation of 10 is also commonly used.

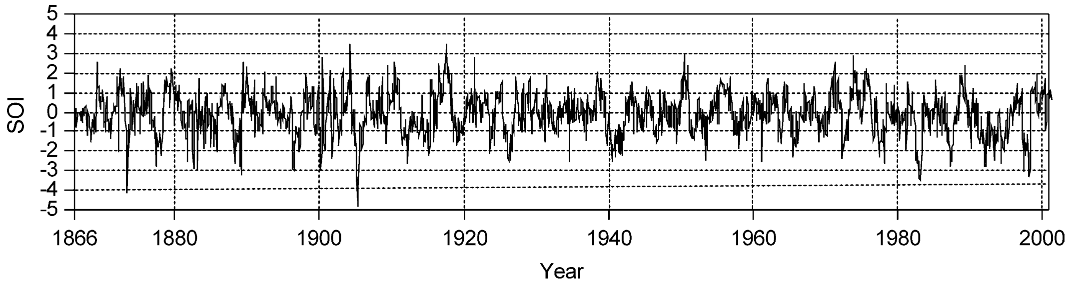

Fig. 2. Time series of SOI by Troup's method from January 1866 to December 2000. Tick marks on the time axis refer to January.

Generally, El Niño conditions occur when the SOI is less than -1, and La Niña conditions when the SOI is more than 1. Strong El Niño/La Niña conditions prevail when the SOI absolute value exceeds 2. Fig. 2 shows the SOI time series since January 1866.

The categorization method for SOI is conceptualized as data classified into five groups according to their magnitude, such as 'Strong El Niño ($SOI < -2$)', 'Weak El Niño ($-2 \leq SOI < -1$)', 'Normal Condition ($-1 \leq SOI \leq 1$)', 'Weak La Niña ($1 < SOI \leq 2$)', and 'Strong La Niña ($2 < SOI$)'. The boundary values between categories are based on the standard deviation of SOI data. For further details on statistical characteristics of SOI using the present categorization see Kawamura et al. (2001b, 2002).

2.3. Precipitation data

Monthly precipitation at Busan and Fukuoka were used to investigate effects of SOI on the precipitation climate of the area. The data at Busan are from April 1904 to December 2000 (1161 months) and from January 1890 to December 2000 (1332 months) for Fukuoka.

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

$$q_i = \frac{i - \alpha}{n + 1 - 2\alpha} \quad (2)$$

where, q_i is the nonexceedance 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.

3. Correlation between SOI and monthly precipitation

Apparent for both precipitation data series is the skew data for all months. This is clear from the box-whisker plots for both stations shown in Fig. 3.

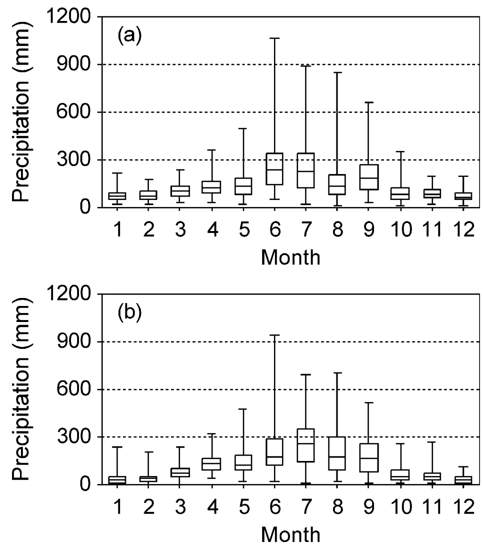

Fig. 3. Box-whisker plots with median, quartiles, maximum, and minimum of the monthly precipitation in (a) Fukuoka and in (b) Busan.

Cross-correlation between the two stations is 0.62 which indicates a high degree of similarity. An initial analysis of the monthly precipitation data also included spectrum analysis (maximum entropy method) identifying deterministic and periodic components in frequency domain. In the spectrum analysis, 3-month and 1-year periodicities were dominant for Fukuoka (Fig. 4(a)), while only 1-year periodicity was revealed for Busan (Fig. 4(b)).

The result of the cubic root transformation is shown in Fig. 5. As seen from the figure the cubic root transformation worked well for the Fukuoka precipitation (Fig. 5(a)) but not the Busan precipitation (Fig. 5(b)). Because of this, the nonexceedance probability for the monthly precipitation was calculated as shown in Fig. 6(a) and (b). Distributions of the nonexceedance probability were depicted by the box-whisker plot (Fig. 7). The transformed data are uniformly distributed in all months so as to the data are standardized by removing hydrological components, such as periodicity and seasonality. These nonexceedance probabilities were used for calculating the cross-correlation with the categorized SOI. Fig. 8 shows the cumulative frequency of SOI classified into five categories for each month (January–December) during the past 135 years ('Strong El Niño (SOI < −2)', 'Weak El Niño (−2 ≤ SOI < −1)', 'Normal Condition (−1 ≤ SOI ≤ 1)', and 'Weak La Niña (1 < SOI ≤ 2)', and 'Strong La Niña (2 < SOI)'). From the figure, it may be seen that even though El Niño and La Niña could occur in any month, there are some general preferences for different months. Strong El Niño or Strong La Niña has some preference to occur during spring and summer months. Strong La Niña appears to occur mainly in April or June while Strong El Niño appears to occur mainly in March to August.

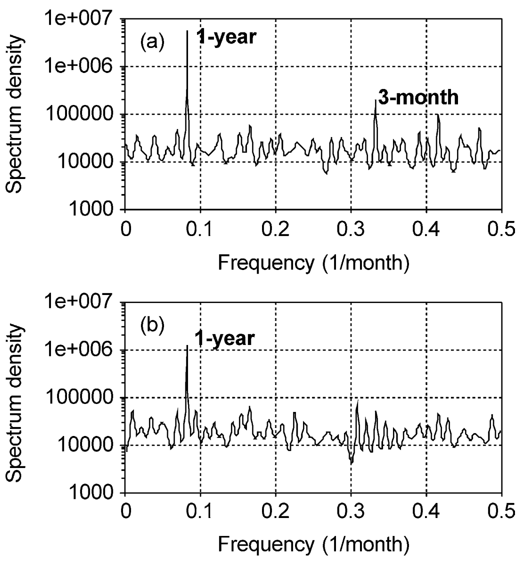

Fig. 4. Power spectrum for (a) Fukuoka and for (b) Busan.

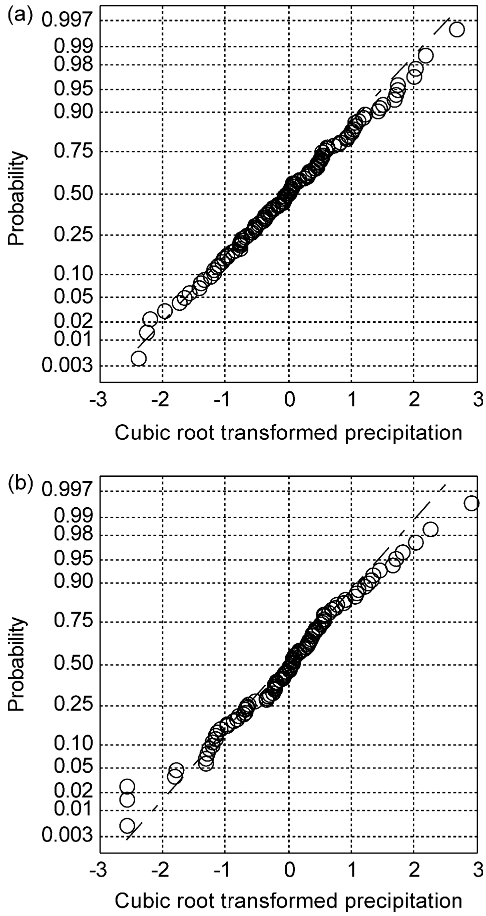

Fig. 5. Normal probability plot of the cubic root transformed precipitation at (a) Fukuoka for October which represents a straight line and the normal distribution and at (b) Busan for January in which the months with no precipitation (less than 0.1 mm) were plotted in the lower-left side and the distribution in non-normal.

When using the raw SOI without categorization and transformed precipitation, no significant correlation was found. The Pearson correlation coefficient between the categorized SOI and transformed precipitation, on the other hand, displayed significant

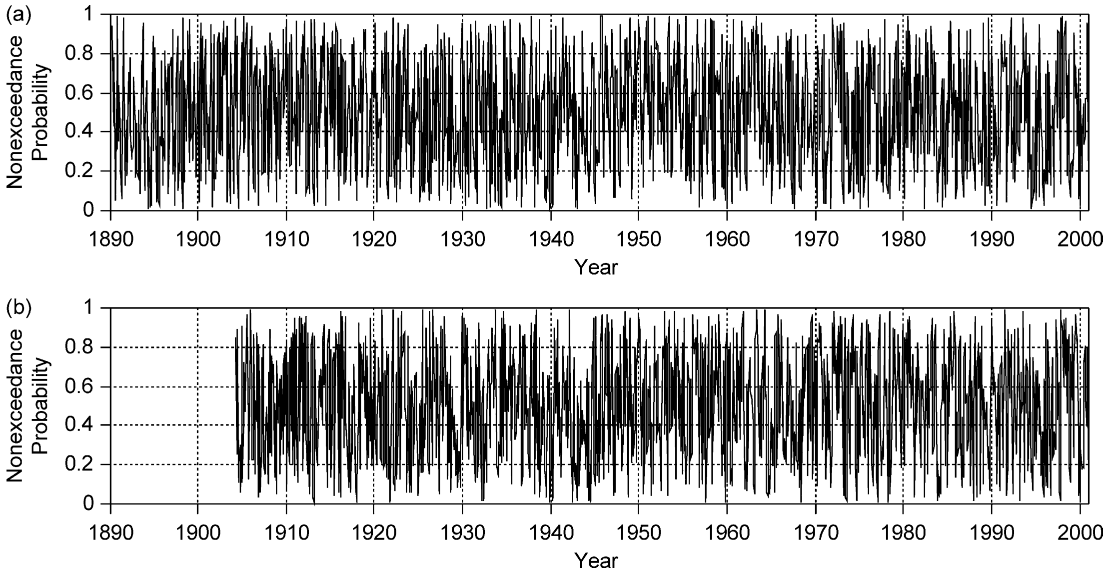

Fig. 6. Time series of the nonexceedance probability of the monthly precipitation at (a) Fukuoka from January 1890 to December 2000 and at (b) Busan from April 1904 to December 2000. Tick marks on time axis refer to January.

relationships for the Fukuoka station. Fig. 9 shows that there are three lag times that display significant correlation coefficients between the categorized SOI and the cubic root transformed precipitation data. Correlation coefficients are plotted in Fig. 9(a) and significance levels in Fig. 9(b). A correlation of −0.49 is significant at 1% level with a lag time of 4 months, under the 'Strong La Niña' category. Two correlation coefficients of 0.21 (lag $t=4$ months) under the 'Weak La Niña' and −0.2 (lag $t=10$ months) under the 'Weak El Niño' category were detected at the same significance level of 1%.

Correlation coefficients between the categorized SOI and the nonexceedance probability revealed similar strengths and the same lag times with those obtained above (Fig. 10), even though the significance level under the 'Strong La Niña' category showed a lower one than 1% level. Consequently, this confirmed that the transformation of precipitation data into nonexceedance probabilities was an efficient method that could be compared to the traditional cubic root transformation. Therefore, the nonexceedance probability method was used to transform the precipitation at Busan. The cross-correlation between the categorized SOI and the nonexceedance probability time series of precipitation at Busan are shown in Fig. 11. A significant correlation coefficient under the 'Strong La Niña' category was detected according to the figure. The correlation coefficient of −0.61 was revealed at the 1% significance level with lag time 4 months.

We now focus on the data, which were detected as statistically significant at 1% level with strong

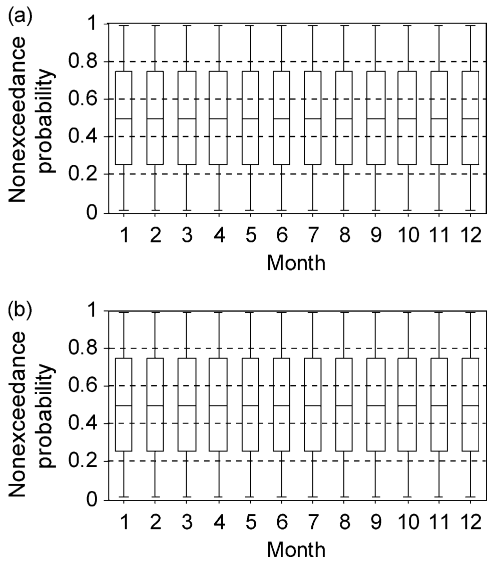

Fig. 7. Box-whisker plots with median, quartiles, maximum, and minimum of the nonexceedance probability time series at (a) Fukuoka and at (b) Busan.

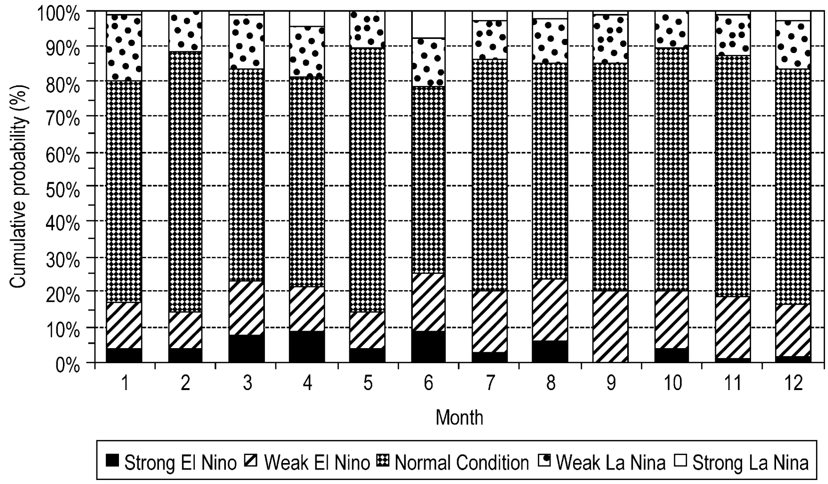

Fig. 8. Occurrence of SOI classified into five categories according to their magnitude.

correlations by the cross-correlation analysis above to investigate in more detail the influence of SOI on precipitation at both stations. Fig. 12(a) shows the scatter plot with lag time 4 months with high correlation under the 'Strong La Niña' category at Fukuoka (e.g. Kawamura et al., 2000, 2001a). The correlation with lag time of 4 months has the significance level of 1% when using the cubic root transformed precipitation, while 5% with non-exceedance probability time series. For comparison with the correlation at Busan, the nonexceedance probability time series was used to depict the scatter

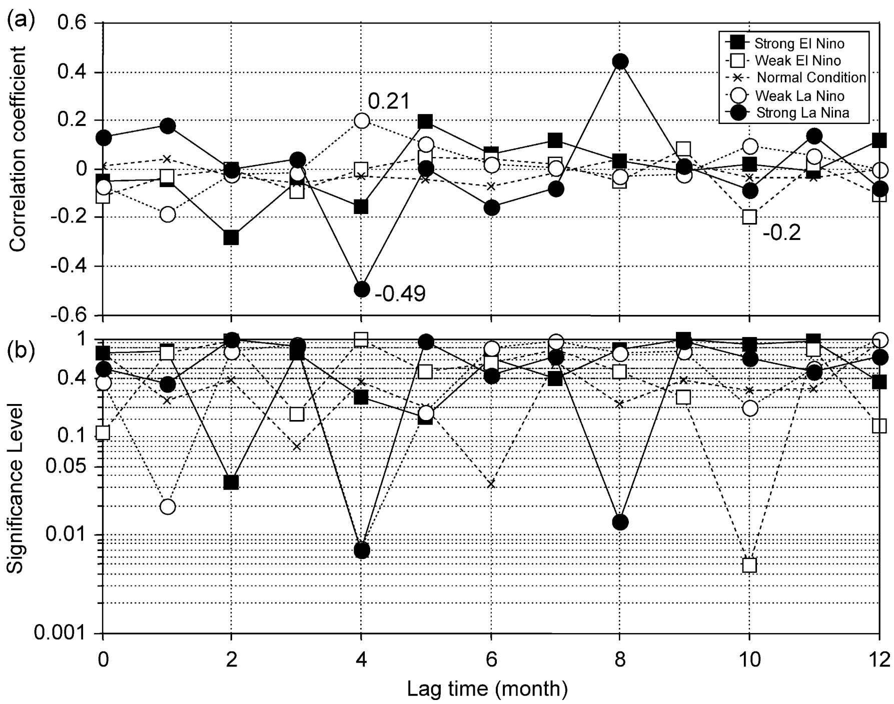

Fig. 9. Variation of (a) cross-correlation by Pearson's r between the categorized SOI and the cubic root transformed precipitation, (b) significance level up to lag time of 12 months at Fukuoka.

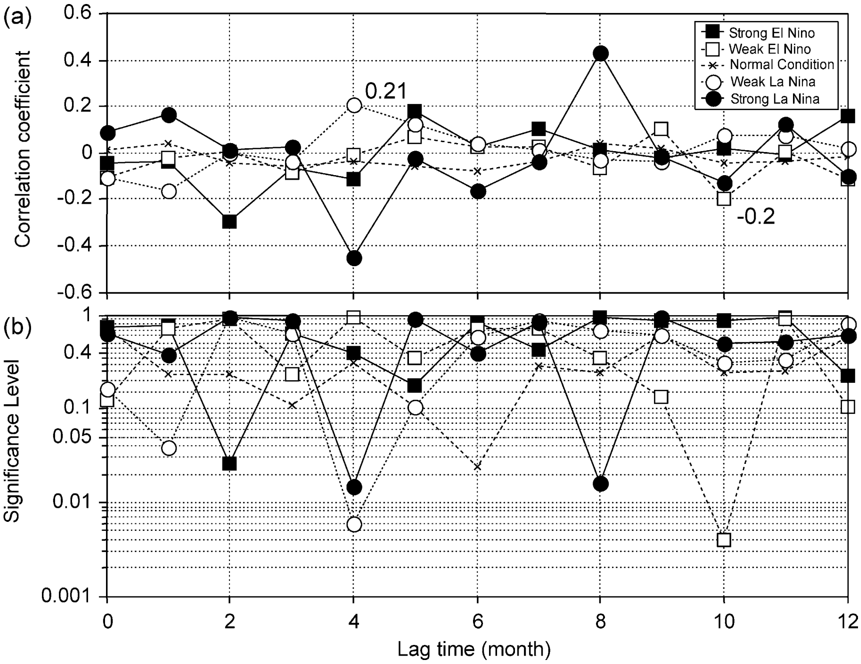

Fig. 10. Variation of (a) cross-correlation by Pearson's *r* between the categorized SOI and the nonexceedance probability time series, (b) significance level up to lag time of 12 months at Fukuoka.

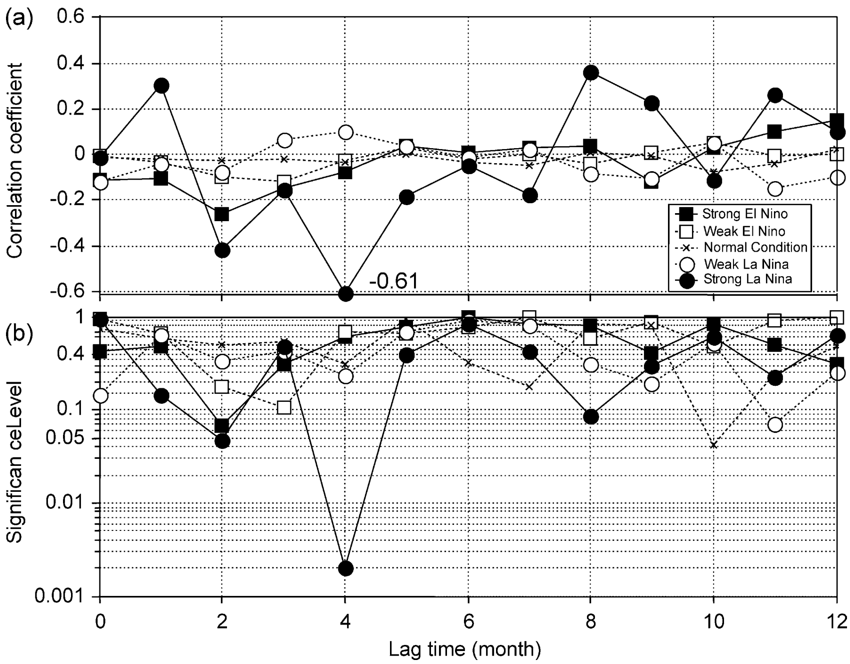

Fig. 11. Variation of (a) cross-correlation by Pearson's *r* between the categorized SOI and the nonexceedance probability time series, (b) significance level up to lag time of 12 months at Busan.

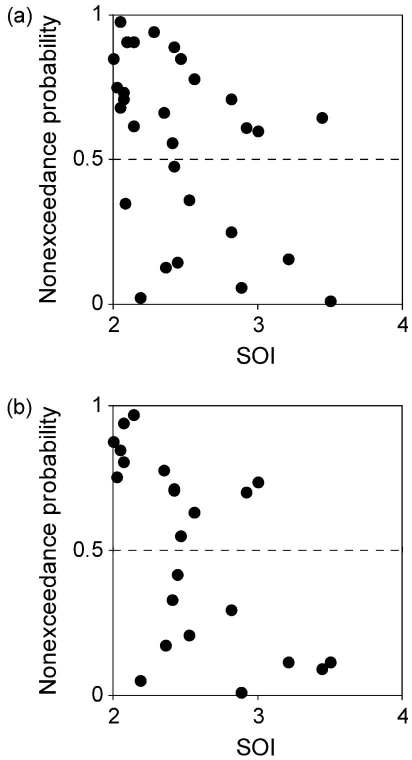

Fig. 12. Scatter plots between the SOI categorized into the 'Strong La Niña' and the nonexceedance probability time series of precipitation with 4 months lag time at (a) Fukuoka and (b) Busan.

plot. There is a clear tendency that a 'Strong La Niña' event will lead forward to less precipitation in Fukuoka 4 months later. The scatter plot between the SOI categorized as 'Strong La Niña' and the corresponding nonexceedance probability of precipitation with lag time 4 months at Busan is shown in Fig. 12(b). Here, the same tendency is seen for Busan as that for Fukuoka. Consequently, the correlation between the SOI and monthly precipitation at the two stations show similar results.

Also, Kendall's τ cross-correlation between the categorized SOI and precipitation was calculated to confirm the above results. This correlation coefficient is not based on the magnitude of the data but instead on the rank. 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 (Hirsh et al., 1993). Usually, the objective in applying Kendall's τ is to test the null hypothesis (H_0) that two variables (x, y) are independent and the distribution of y does not change as a function of x (which implies $\tau=0$). This null hypothesis is against one of the following alternatives (H_1): $\tau \neq 0$, $\tau > 0$, or $\tau < 0$. The first alternative means that there is an association between the two variables, while $\tau > 0$ indicates a direct association between the variables and $\tau < 0$ an inverse association (Daniel, 1978).

The results of these calculations are shown in Fig. 13 when using the cubic root transformed precipitation and in Fig. 14 for the nonexceedance probability time series at Fukuoka. Generally, the strengths of the correlations by Kendall's τ are weaker than that of Pearson's r. Significant correlations at the 1% were detected for lag time of 4 months under La Niña condition for Kendall's τ at Fukuoka with both transformed data. However, no statistically significant correlation under the 'Strong El Niño' category could be found.

A significant correlation at 1% level under the 'Strong La Niña' category revealed the same lag time of 4 months as that of the Pearson's r at Busan. The cross-correlation between the categorized SOI and the nonexceedance probability time series of precipitation at Busan is shown in Fig. 15.

The strong negative correlation coefficient with the same lag time of 4 months at both stations were significant at the 1% level, under the 'Strong La Niña' category, in common. The general tendency is that the stronger the La Niña event, the less simultaneous precipitation at both stations 4 months later.

4. Conclusion and discussion

As mentioned earlier, although the ENSO has influence on a global scale, there has been little evidence of El Niño/La Niña influence in middle to high latitudes, including Korea and Japan. Two stations (Busan and Fukuoka) which represent the climatologic region covering southern parts of Korea and Japan were selected for an investigation of SOI influence on monthly precipitation patterns. Categorized SOI and monthly precipitation data transformed to nonexceedance probability time series displayed statistically significant correlation at both stations. The results for Pearson's r and Kendall's τ were

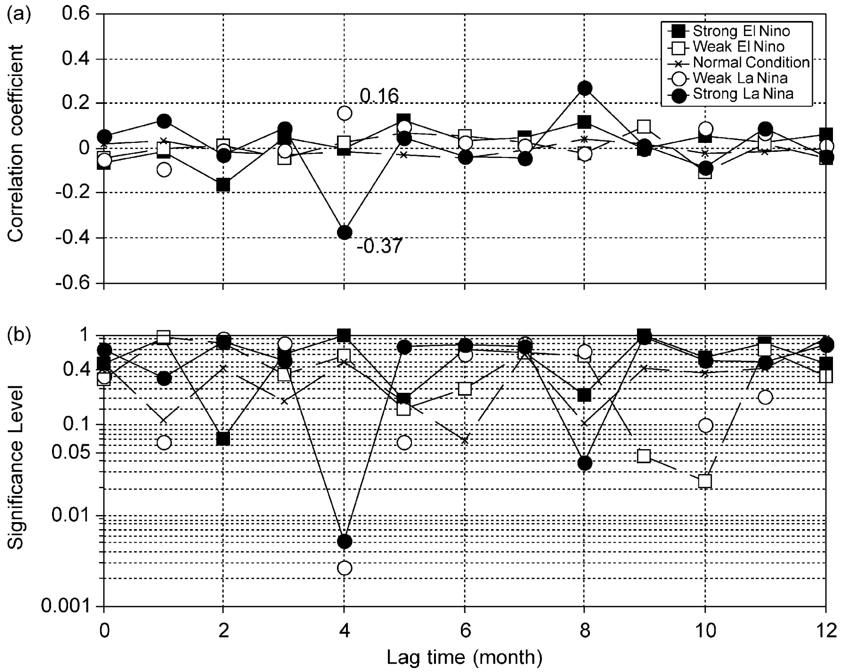

Fig. 13. Variation of (a) cross-correlation by Kendall's τ between the categorized SOI and the cubic root transformed precipitation, (b) significance level up to lag time of 12 months at Fukuoka.

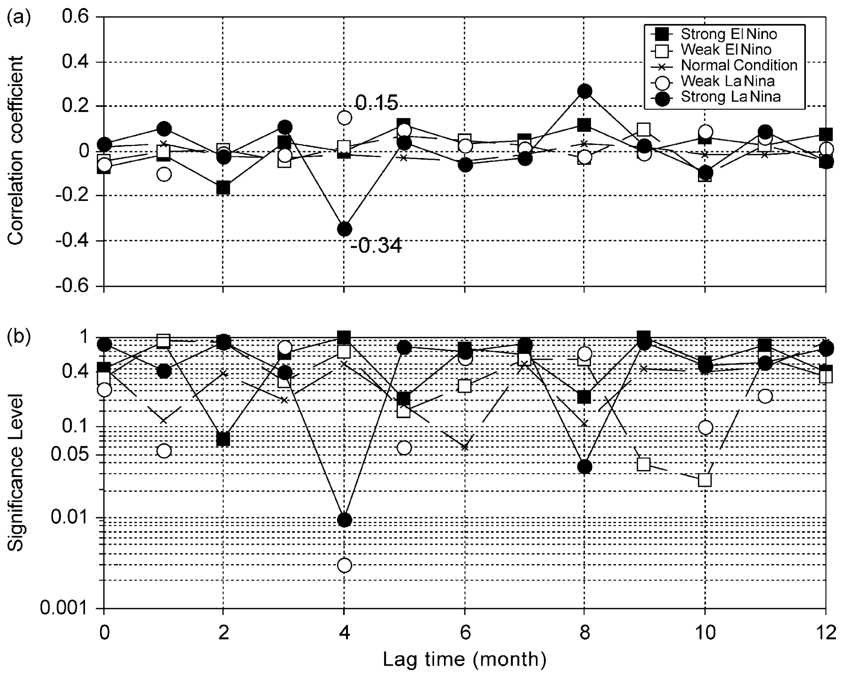

Fig. 14. Variation of (a) cross-correlation by Kendall's τ between the categorized SOI and the nonexceedance probability time series, (b) significance level up to lag time of 12 months at Fukuoka.

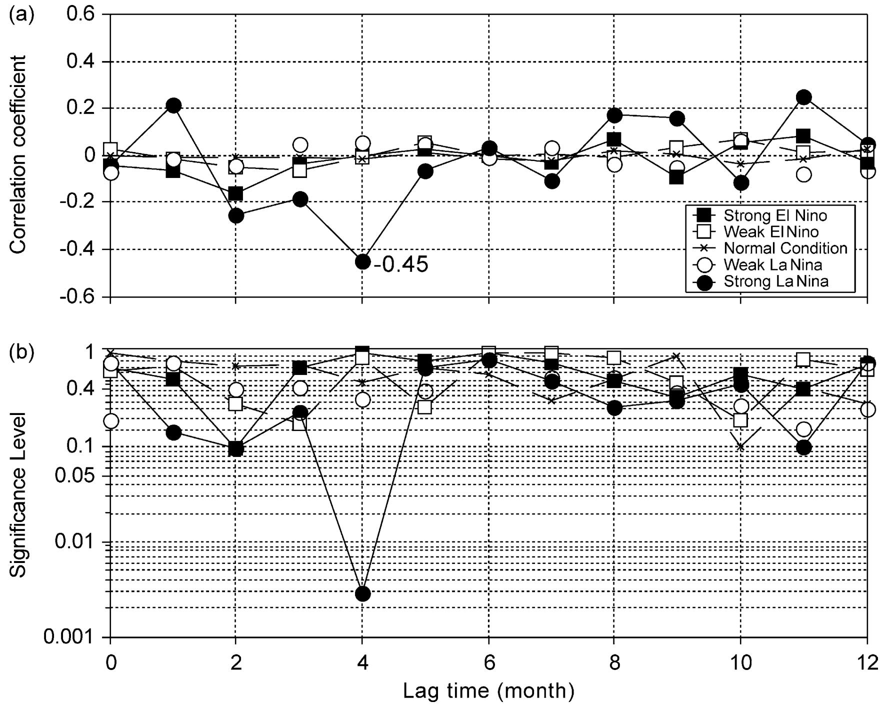

Fig. 15. Variation of (a) cross-correlation by Kendall's τ between the categorized SOI and the nonexceedance probability time series, (b) significance level up to lag time of 12 months at Busan.

slightly different though confirming a general tendency. The results indicated that the stronger the La Niña event, the less precipitation at Fukuoka and Busan with lag time 4 months. In general, both stations showed a strong similarity on the influence of ENSO, even though the stations have different patterns for the respective precipitation data. It may be concluded that the entire area which the stations represent has a similar reaction to SOI.

The above results on the ENSO-influence were detected by using distribution-free methods: the data transformation into nonexceedance probability time series and Kendall's correlation coefficient. The former was verified as an alternative for common transformation methods. This method is independent of distribution of raw data. In addition, the latter can be applied to obtain nonlinear relationships between SOI and precipitation. These distribution-free approaches may be proposed as a practical application for detection of relationship between SOI and hydrological variables. It should be further studied to develop prediction models of rainfall as influenced by SOI.

Acknowledgements

R. Berndtsson gratefully acknowledges the financial support of the Swedish Natural Science Research Council and the Sweden–Japan Foundation for this study.

References

Allan, R.J., Nicholls, N., Jones, P.D., Butterworth, I.J., 1991. A further extension of the Tahiti-Darwin SOI, early ENSO events and Darwin pressure. J. Clim. 4, 743–749.

Chiew, F.H.S., Piechota, T.C., Dracup, J.A., McMahon, T.A., 1998. El Niño/Southern Oscillation and Australian rainfall, streamflow and drought: links and potential for forecasting. J. Hydrol. 204, 138–149.

Cunnane, C., 1978. Unbiased plotting positions—a review. J. Hydrol. 37, 205–222.

Daniel, W.W., 1978. Applied Nonparametric Statistics. Houghton Mifflin, Boston.

Dracup, J.A., Kahya, E., 1994. The relationships between US streamflow and La Niña events. Water Resour. Res. 30 (7), 2133–2141.

Gan, T.Y., 1998. Hydroclimatic trends and possible climatic warming in the Canadian Pairies. Water Resour. Res. 34 (11), 3009–3015.

Gutiérrez, F., Dracup, J.A., 2001. An analysis of the feasibility of long-range streamflow forecasting for Colombia using El Niño-Southern Oscillation indicators. J. Hydrol. 246, 181–196.

Hirsh, R.M., Slack, J.R., Smith, R.A., 1982. Techniques of trend analysis for monthly water quality data. Water Resour. Res. 18 (1), 107–121.

Hirsh, R.M., Alexander, R.B., Smith, R.A., 1991. Selection of methods for the detection and estimation of trends in water quality. Water Resour. Res. 27 (5), 803–813.

Hirsh, R.M., Helsel, D.R., Cohn, T.A., Gilroy, E.J., 1993. Statistical analysis of hydrological data, in: Maidment, D.R. (Ed.), Handbook of Hydrology. McGraw-Hill, New York, pp. 28–30. Chapter 17.

Japanese Study Group for Climate Impact and Application, 1999. El Niño and Global Environment. Seizando, Japan in Japanese.

Kawamura, A., Jinno, K., 1996. Integrated water resources management in Fukuoka metropolitan area. Environ. Res. Forum 3&4, 97–109.

Kawamura, A., McKerchar, A.I., Spigel, R.H., Jinno, K., 1998. Chaotic characteristics of the southern oscillation index time series. J. Hydrol. 204, 168–181.

Kawamura, A., Eguchi, S., Jinno, K., 2000. Cross-correlation between Southern Oscillation Index and precipitation/temperature in Fukuoka, Japan, Proceedings of the Fresh Perspectives Symposium 2000, Christchurch, Newzealand.

Kawamura, A., Eguchi, S., Jinno, K., 2001a. Correlation between Southern Oscillation and monthly precipitation in Fukuoka. J. Hydraul. Coastal Environ. Eng., JSCE, No. 691/II-57 2001;, 153–158 (in Japanese with English abstract).

Kawamura, A., Eguchi, S., Jinno, K., 2001b. Statistical characteristics of Southern Oscillation Index and its barometric pressure data. Annu. J. Hydraul. Eng., JSCE 45 (169), 174.

Kawamura, A., Eguchi, S., Jinno, K., 2002. Long-term fluctuation characteristics of Southern Oscillation. Annu. J. Hydraul. Eng., JSCE 46, 103–108.

Kendall, M.G., 1938. A new measure of rank correlation. Biometrika 30, 81–93.

Kendall, M.G., Gibbons, J.D., 1990. Rank correlation methods, fifth ed. Griffin, London.

Kim, Y.-O., Lee, H.-S., 2000. Korean streamflow patterns in relation to El Niño/Southern Oscillation. Wat. Eng. Res. Int. J. KWRA 1 (2), 107–117.

Lee, D.-R., 1998. Relationships of El Niño and La Niña with both temperature and precipitation in South Korea. J. KWRA 31 (6), 807–819 (in Korean with English abstract).

McBride, J.L., Nicholls, N., 1983. Seasonal relationships between Australian rainfall and the Southern Oscillation. Mon. Weather Rev. 111, 1998–2004.

Moon, Y.I., 2001. Harmonic element analysis between precipitation in South Korea and Southern Oscillation Index, Japan–Korea Joint Seminar on Hydrology and Water Resources.

Poveda, G., Jaramillo, A., Gil, M.M., Quiceno, N., Mantilla, R.I., 2001. Seasonality in ENSO-related precipitation, river discharge, soil moisture, and vegetation index in Colombia. Water Resour. Res. 37 (8), 2169–2178.

Rodo, X., Baert, E., Comin, F.A., 1997. Variations in seasonal rainfall in Southern Europe during the present century: relationships with the North Atlantic Oscillation and the El Niño-Southern Oscillation. Clim. Dynamics. 13, 275–284.

Ropelewski, C.F., Jones, P.D., 1987. An extension of the Tahiti–Darwin southern oscillation index. Mon. Weather Rev. 115, 2161–2165.

Salas, J.D., 1993. Analysis and modeling of hydrologic time series, in: Maidment, D.R. (Ed.), Handbook of Hydrology. McGraw-Hill, New York, p. 20. Chapter 19.

Shin, H.-S., 2002. Do El Niño and La Niña have influences on South Korean hydrologic properties?, Proceedings of the 2002 Annual Conference, Japan Society of Hydrology and Water Resources, pp. 276–282.

Troup, A.J., 1965. The southern oscillation. Quart. J. Royal Meteo. Soc. 91 (390), 490–506.

Xu, Z.X., Takeuchi, K., Ishidaira, H., 2004. Correlation between El Niño-Southern Oscillation (ENSO) and precipitation in Southeast Asia and the Pacific region. Hydrol. Process. 18, 107–123.

Yoshino, F., 1999. On the relation between the monthly rainfall in Shikoku island and the El Niño event, Proceedings of the Fifth Symposium of Shikoku Branch of JSCE, pp. 90–91 (in Japanese).