Cross-Correlation Between SOI and Monthly Maximum Daily Rainfall in Gangneung, Korea

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Abstract
In the present study, the influence of El Niño/Southern Oscillation (ENSO) which has been represented by Southern Oscillation Index (SOI) was evaluated with monthly maximum daily rainfall in Gangneung, Korea by categorizing the SOI according to their magnitudes. Statistical surveys on daily rainfall were carried out in the study area and frequency analysis was performed with yearly maximum rainfall. The monthly maximum daily rainfall data for cross-correlation analysis were transformed into two different dataset by cubic root transformation and nonexceedance probability. The correlation between the categorized SOI and the transformed monthly maximum daily rainfall was revealed with lag time 4-month under the strong La Niña category.

Introduction
El Niño is the condition in which sea surface temperature rises 1 to 2°C (sometimes 2 to 5°C) above normal in the eastern and central equatorial Pacific Ocean. It lasts typically 12-18 months, and occurs irregularly at the intervals of 2-7 years. On the other hand La Niña is a condition where the temperature becomes lower than normal. The Southern Oscillation (SO) is an atmospheric see-saw phenomenon in the tropical Pacific sea level pressure between the eastern and western hemispheres and is associated with the El Niño and La Niña oceanographic features (Sakurai, 1998; Japanese Study Group for Climate Impact & Application, 1999). This oscillation can be measured by a simple index, the Southern Oscillation Index (SOI) which is used by NOAA (National Oceanic and Atmospheric Administration) to determine whether the El Niño and La Niña events are occurring (Japanese Study Group for Climate Impact & Application, 1999). The oceanographic and atmospheric features are known collectively as the El Niño Southern Oscillation (ENSO) phenomenon.

The effects of ENSO on climate are widespread and extend far beyond the tropical Pacific, a phenomenon known as teleconnection (Sakurai, 1998; Japanese Study Group for Climate Impact & Application, 1999). There have been many reports of abnormal weather conditions worldwide which are thought to have been caused by ENSO. As the result, qualitative and quantitative analyses of SO and its influence on local hydro-meteorological phenomena have become very important areas of research and there are many research papers on the relationship between SOI and hydro-meteorological phenomena (Ropelewski and Halpert, 1987; Halpert and Ropelewski, 1992; Uvo et al., 1998; Yoshino, 1999).

In this study, the impact of El Niño/Southern Oscillation (ENSO) was studied with the rainfall data in Gangneung, Korea. The daily rainfall data was collected and the general characteristics of the data were investigated by using the box-whisker plot, the frequency of zero values in monthly basis, and the frequency analysis of annual maximum daily rainfall. Then the monthly maximum daily rainfall were extracted from the daily rainfall data and revealed the significant correlation with categorized SOI with several lag times. The cross-correlation analysis showed a couple of statistically significant correlations between the categorized SOI and the monthly maximum daily rainfall in Gangneung, Korea.

Study Area and Data Used

Gangneung station (128.89 °E, 37.75 °N) is located in the northeastern part of South Korea. This station had a severe flood in August 31, 2002 with 870.5 mm, which was the maximum rainfall since the observation at the station was started.

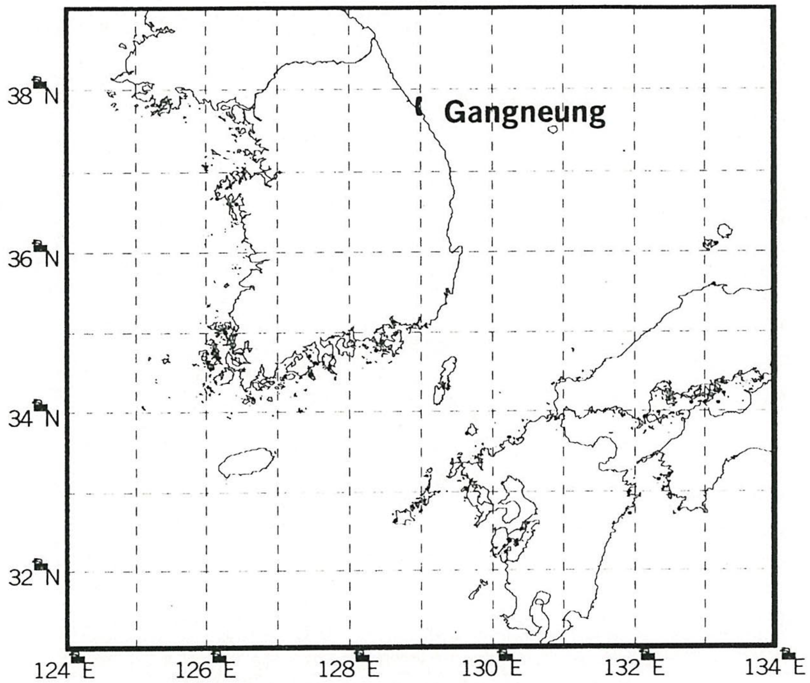

Fig. 1 Location of Gangneung in Korea

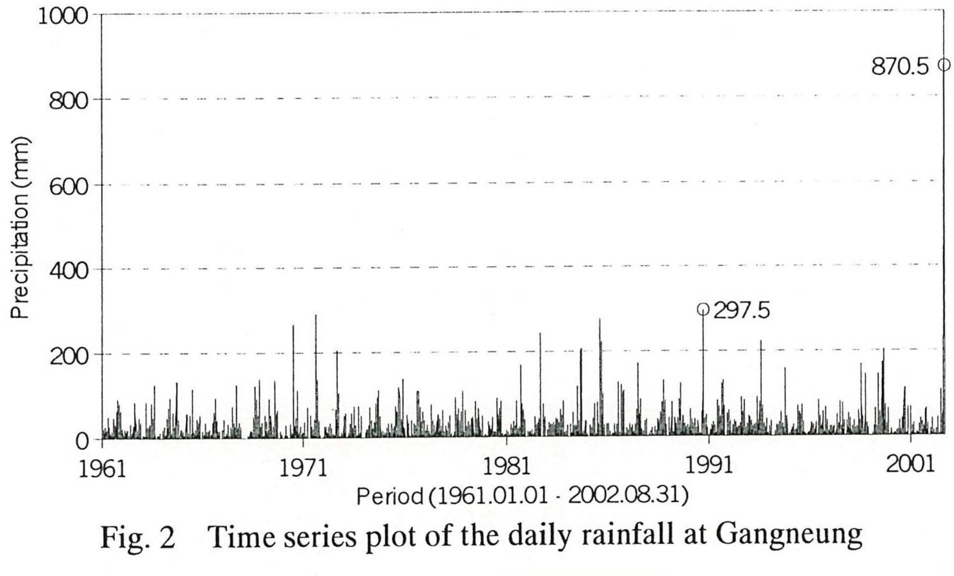

Fig. 2 Time series plot of the daily rainfall at Gangneung

Daily rainfall

The daily rainfall at Gangneung was collected from January 1, 1961 to September 2, 2002. The time series plot of the data is drawn in Fig.2. As is seen clearly, the rainfall with a hollow circle in August 31, 2002 is about three times larger than the past maximum rainfall record. The historic maximum rainfall is also seen in Fig. 3 with box-whisker plot on a monthly basis, which shows the maximum, minimum, quartiles, and median. However, the maximum median rainfall is displayed in September in Fig. 4, which is enlarged to focus on the quartiles and median. Fig. 5 shows the distribution of frequency of zero (less than 0.1 mm) daily rainfall on a monthly basis. It is very clear that the frequencies in July and August are much smaller than those in other months. On the other hand, December and January has the larger number of no rainfall days than other months.

Frequency analysis

This frequency analysis with the generalized extreme value (GEV) distribution was carried out with/without the historic maximum rainfall of 870.5 mm at Gangneung. The annual maximum daily rainfall data were extracted for each year. In the present study, the parameter estimation in the frequency analysis was performed by probability weighted moment (PWM) method (Japan Society of Civil Engineering, 2002).

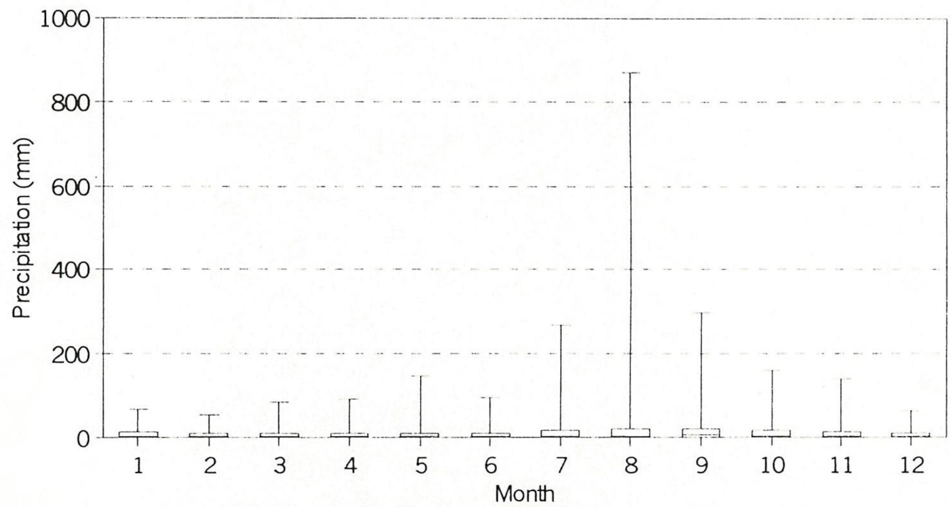

Fig. 3 Box-whisker plot of the daily rainfall at Gangneung

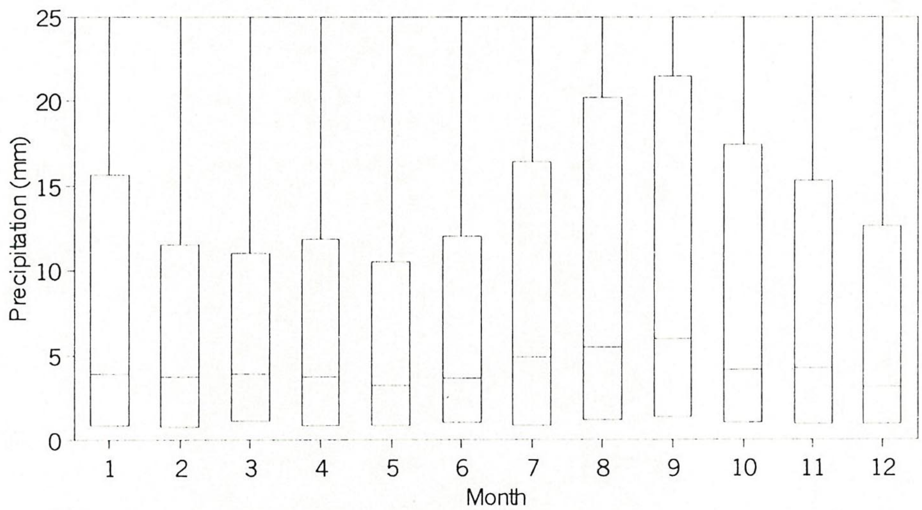

Fig. 4 Enlarged box-whisker plot to focus on quartiles and median

As is seen in Fig. 6 (lower line), the amount of 870.5 mm in August 31, 2002 has the return period of about 200 year when the amount was used for the frequency analysis. However, in the case excluding the amount of 870.5 mm, the return period of the amount is corresponding to around 4500 year (upper line in Fig. 6). This big difference between the results from including/excluding the maximum rainfall of 870.5 mm is very similar to the amount difference of rainfall between August 31, 2002 and the period before the day.

Monthly maximum daily rainfall and basic statistics

The monthly maximum daily rainfall data were extracted from the daily rainfall and the time series plot is shown in Fig. 7. The box-whisker plot was also used here to show the distribution of the monthly maximum daily rainfall (Fig. 8). The maximum median value for the monthly maximum daily rainfall was revealed in August. The spectrum analysis was carried out and the result shows the periodicities of 6- and 12-months (Fig. 9). These periodicities were removed by standardization in the following data transformation.

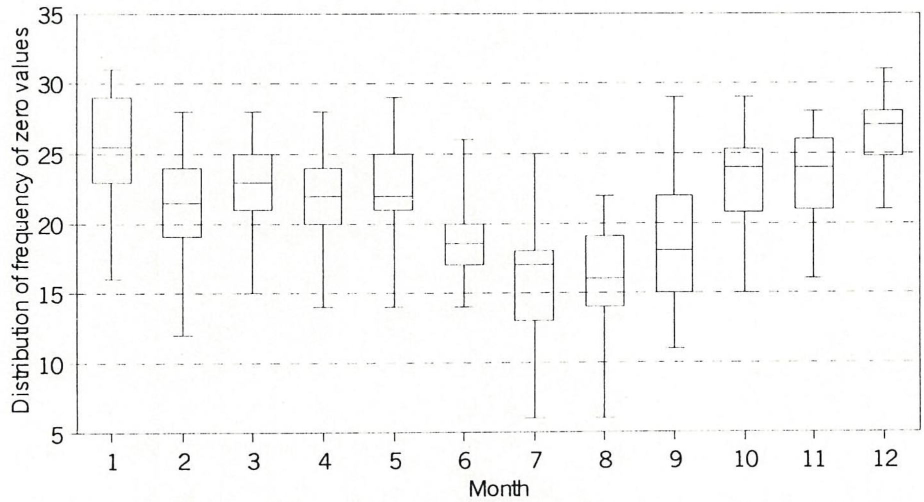

Fig. 5 Box-whisker plot for the distribution of zero rainfall

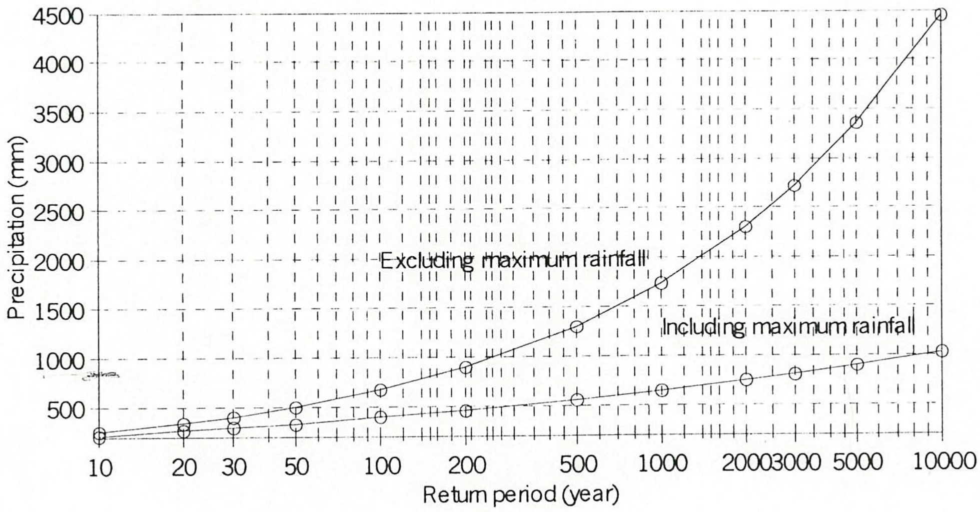

Fig. 6 Frequency analysis with generalized extreme value distribution; including/excluding the maximum rainfall in August 31, 2002.

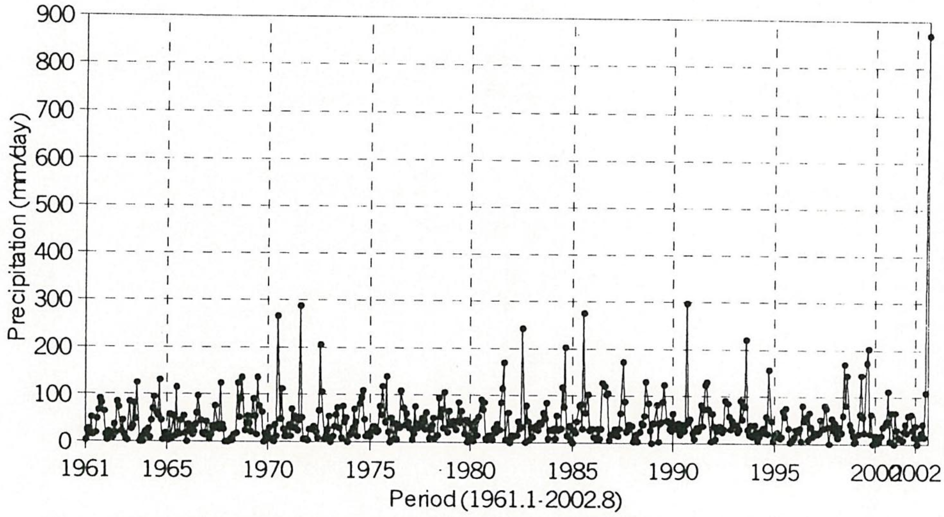

Fig. 7 Time series plot of the monthly maximum daily rainfall

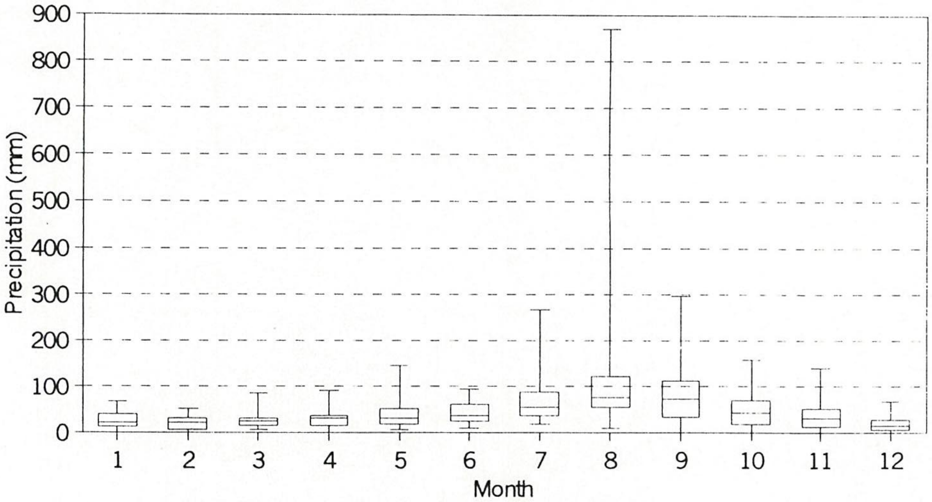

Fig. 8 Box-whisker plot for the monthly maximum rainfall

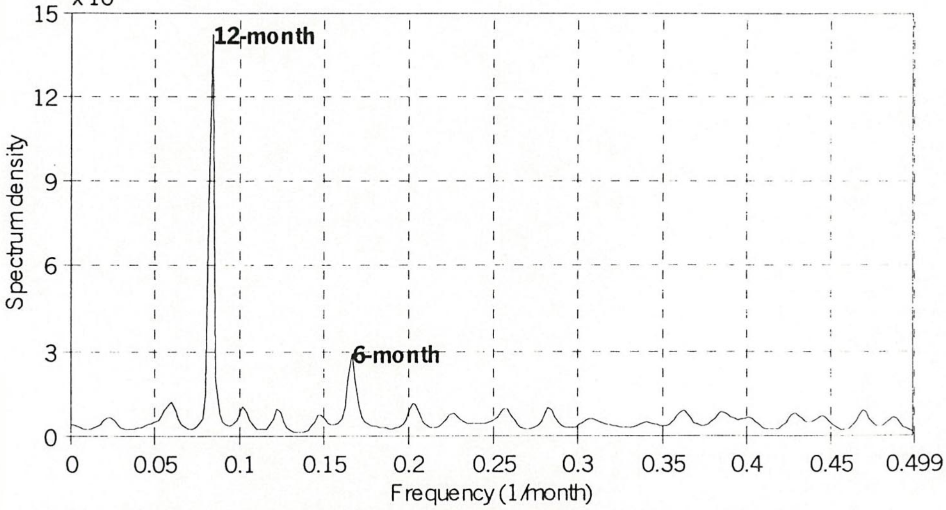

Fig. 9 Spectrum analysis of the monthly maximum rainfall

Cross-Correlation Analysis

Categorization of SOI

SOI values were classified into five groups according to their magnitudes because there was no statistically significant correlation with rainfall in middle to high latitudes when we used the SOI values without any manipulation (Kawamura et al., 2000a; 2000b; 2001; Jin et al., 2002). Fig. 10 showed the no significant correlations between SOI and raw monthly maximum daily rainfall in Gangneung with any lag times. In the present study, therefore, we applied the categorization method for SOI and extracted the corresponding monthly maximum daily rainfall. The categories are named as following; "Strong El Niño (SOI<-2)", "Weak El Niño (-2<SOI -1)", "Normal Condition (-1 SOI 1)", "Weak La Niña (1<SOI 2)", and "Strong La Niña (SOI>2)".

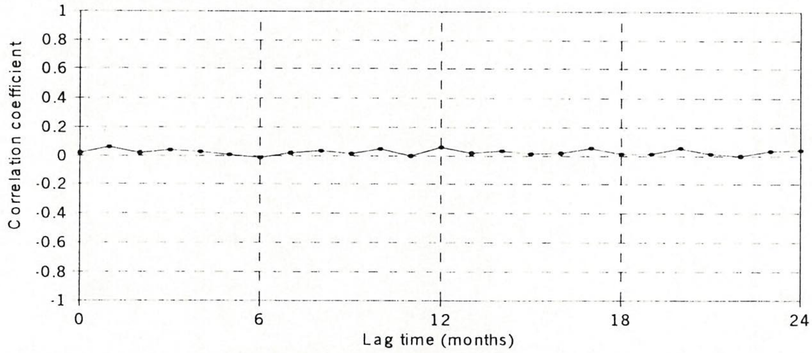

Fig. 10 Correlation coefficient between SOI and raw monthly maximum daily rainfall

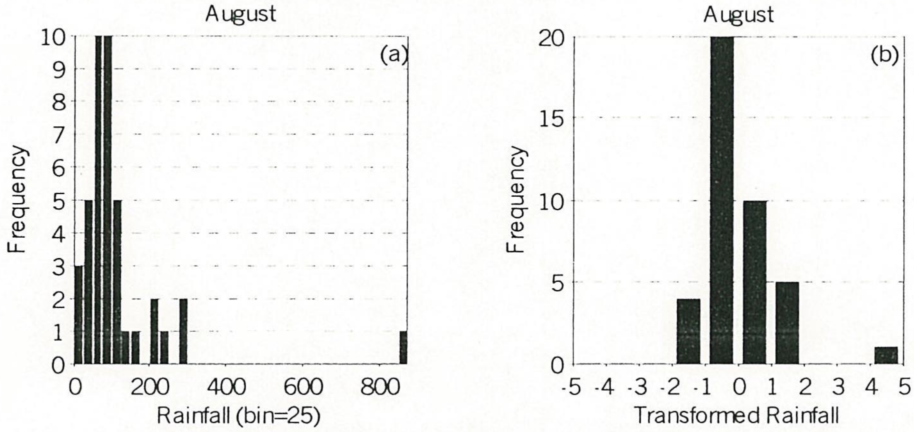

Fig. 11 Histograms for (a) monthly maximum daily rainfall and (b) cubic root transformed data in August

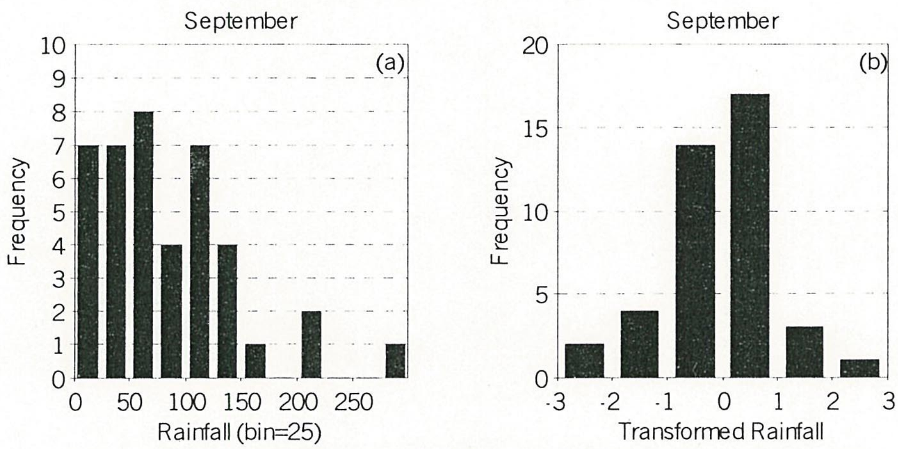

Fig. 12 Histograms for (a) monthly maximum daily rainfall and (b) cubic root transformed data in September

Transformation of the monthly maximum daily rainfall

The monthly maximum daily rainfall data were transformed by two methods. For the first method, the monthly maximum daily rainfall data are normalized with the cubic root transformation and then the normalized data are standardized with mean of zero and standard deviation of one on a monthly basis. In Fig. 11 and 12 showed the histograms in August and September which represent the frequency of raw monthly maximum daily rainfall (Fig. 11 (a) and Fig. 12 (a)), and that of cubic transformed data (Fig. 11(b) and Fig. 12 (b)). As is seen in Fig. 11, the histogram in August has the extreme value which is corresponding to 870.5 mm and it was difficult to normalize the data in August due to the value. For the data in September, however, it seems to be normalized well by the cubic transformation (Fig. 12).

For the second approach, the monthly maximum daily rainfall data are transformed into the nonexceedance probability time series on a monthly basis. This approach was applied for the first time to reveal the relationship between SOI and the precipitation in Busan and Fukuoka and showed applicability for the data which cannot be transformed into normal distribution with usual transformation method such as cubic root transformation (Jin et al., 2002). Therefore, in the present study, the nonexceedance probability tra nsformation is also exploited to reveal the correlation between SOI and precipitation at Gangneung. The nonexceedance probability of the *i*th-smallest value can be obtained using á = 0 from the general formula

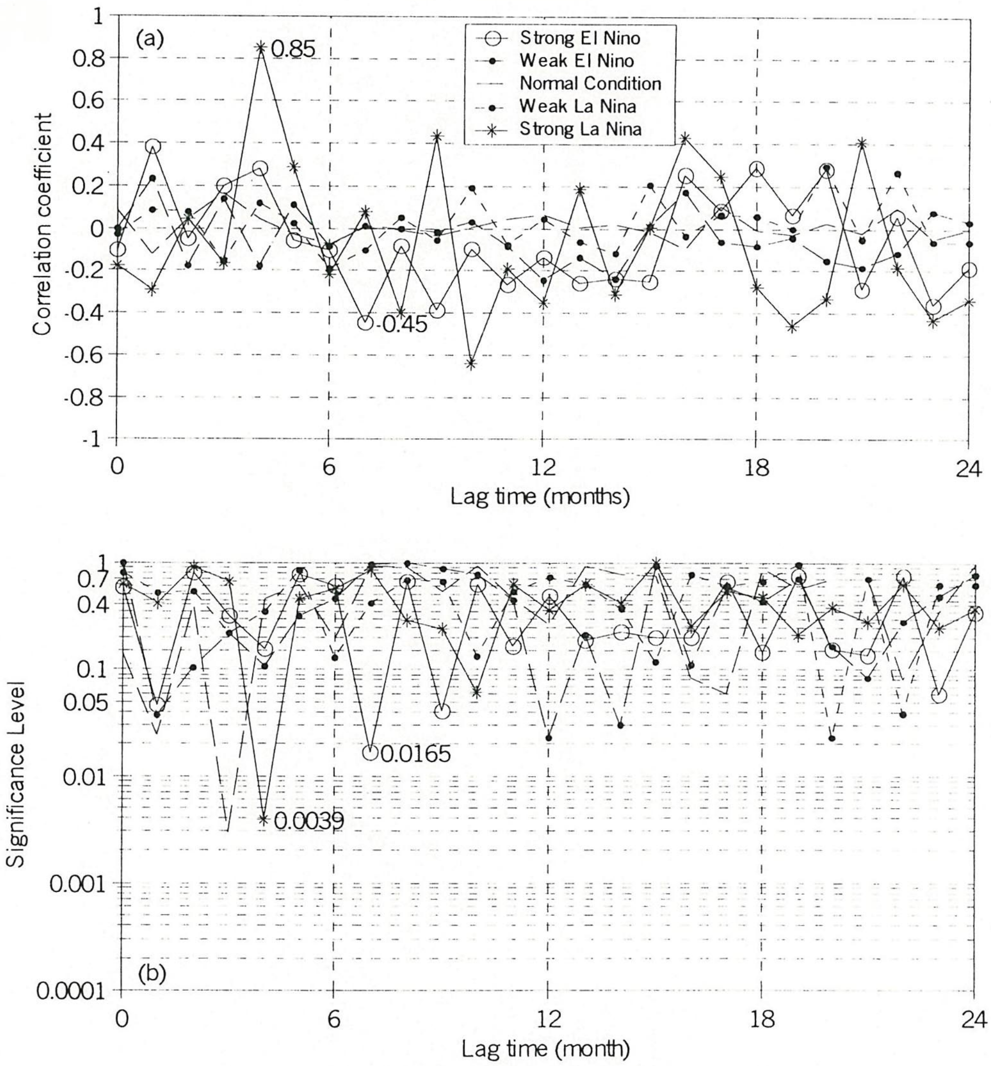

Fig. 13 (a) Cross-correlation between categorized SOI and cubic root transformed data of monthly maximum rainfall and (b) the significance level proposed by Cunnane (1978); $q_i = \dfrac{i-\alpha}{n+1-2\alpha}$, where q_i is the nonexceedance probability of the ith-smallest value, n is the number of data in monthly basis from January to December, and α is a plotting position parameter.

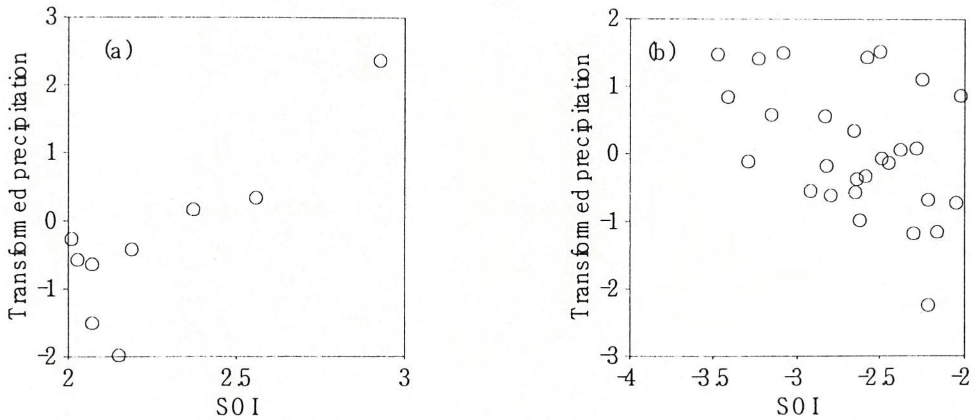

Fig. 14 Scatter plots of the statistically significant correlation ; (a) r = 0.85 with lag time 4-month under the strong La Niña category and (b) r = -0.45 with lag time 7-month under the strong El Niño category

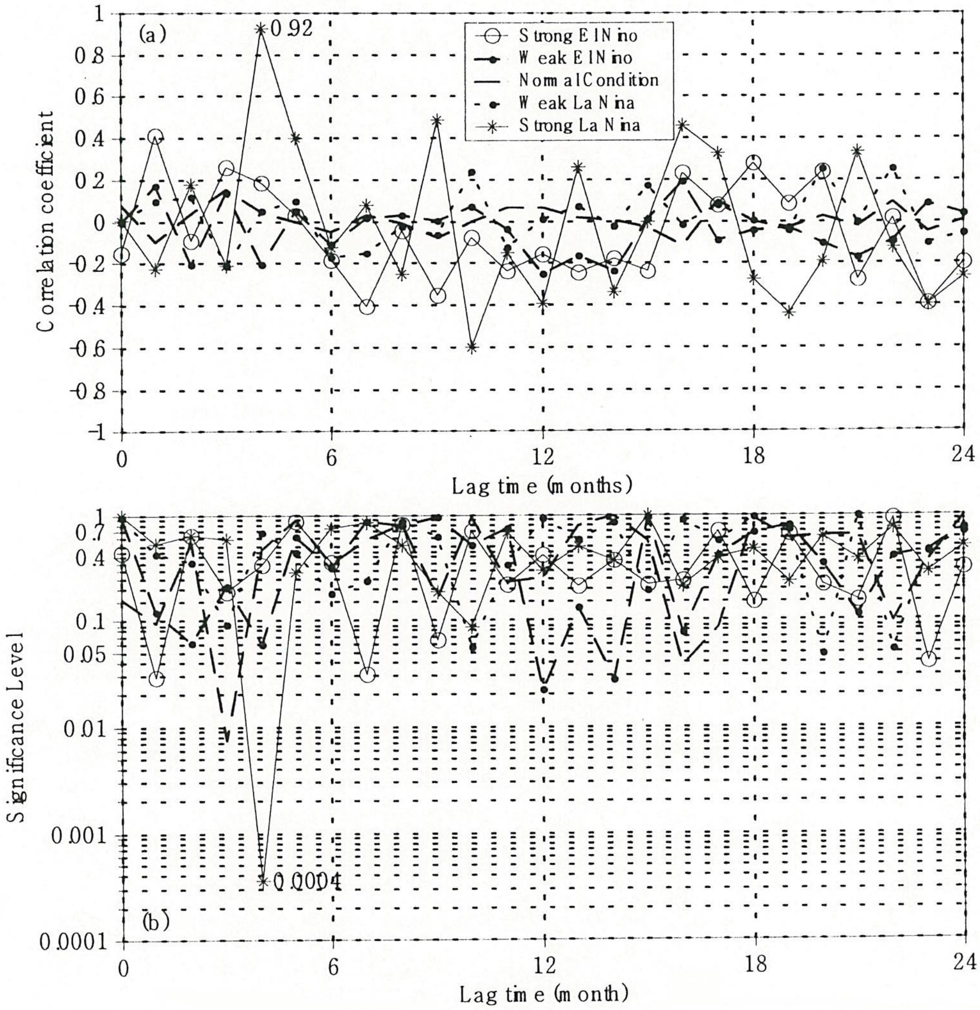

Fig. 15 (a) Cross-correlation between categorized SOI and nonexceedance probability of monthly maximum rainfall and (b) the significance level

Cross-correlation analysis
The cross-correlation analysis was performed with the categorized SOI and transformed rainfall with the two transformation approaches. Fig. 13 (a) shows the strength of correlation between the categorized SOI and the cubic root transformed data of the monthly maximum daily rainfall with lag times and Fig. 13 (b) displays the *p*-values (significance level) of the correlation. As are seen in the figures, there are two statistically significant correlation between SOI and rainfall. The highest significant correlation of 0.85 was revealed under the category of "Strong La Niña" with 1 % significance level and lag time 4-month.

The second significant was found under the "Strong El Niño" category with 5 % significance level and 7-month lag time. Two scatter plots are shown in Fig. 14 for the respective correlation, which are statistically significant. Fig. 14 (a) displays the stronger the La Niña, the more the rainfall at Gangneung four months later, while Fig. 14 (b) shows the stronger the El Niño, the more the rainfall seven months later.

As mentioned earlier, we transformed the monthly maximum daily rainfall into nonexceedance probability time series to avoid spurious correlation to be resulted from the assumption which the data is normally distributed. The cross-correlation between categorized SOI and nonexceedance probability of the monthly maximum daily rainfall shows the one statistically significant correlation of 0.92 under the "Strong La Niña" category with 1 % significance level and 4-month lag time as shown in Fig. 15 and the corresponding scatter plot is shown in Fig. 16.

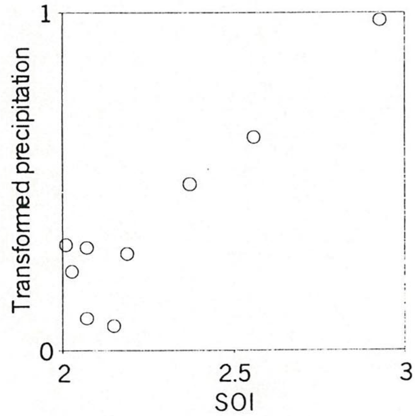

Fig. 16 Scatter plot of the statistically significant correlation; r = 0.92 with lag time 4-month under the strong La Niña category

Conclusion
In the present study, we started from the survey for the basic statistics of daily rainfall in Gangneung, Korea. Even though the historic maximum rainfall occurred in August 31, 2002, the maximum median of daily rainfall from the box plot was found in September. In the frequency of zero daily rainfall, July and August showed much smaller frequency than those in other months. The frequency analysis with generalized extreme value (GEV) distribution was carried out with the yearly maximum daily rainfall. The return period revealed about 200 years in the case including the historic maximum rainfall in August 31, 2002, while about 4500 year for excluding the maximum value. Spectral analysis was also performed using the monthly maximum daily rainfall and showed the two periodicities with 6- and 12- months. Cross-correlation analysis between categorized SOI and cubic root transformed monthly maximum daily rainfall displayed the strength of 0.85 with lag time 4-month and the 1 % significance level under the strong La Niña category, while –0.45 with lat time 7-month and the 5 % significance level was revealed under the strong El Niño category. In applying the

nonexceedance probability as the transformation for the rainfall data, the correlation showed the highest value of 0.95 with the lag time 4-month and the 1 % significance level. Consequently, the strong La Niña has strongly influenced on the monthly maximum daily rainfall in Gangneung with the tendency that the stronger the La Niña, the more the rainfall.

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