Comparison of Correlation between Categorized SOI and Monthly Precipitation at Pusan in Korea and at Fukuoka in Japan

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1. Introduction

During the last decades there has been considerable interest in the influence of El Niño/La Niña, which are known as extremes of El Niño/Southern Oscillation (ENSO), on global and regional precipitation patterns. This phenomenon is a result from the interaction between large-scale oceanographic and atmospheric circulation processes in the equatorial Pacific Ocean.

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. However, a number of studies have used Southern Oscillation Index (SOI) to reveal relationships between the El Niño/La Niña phenomenon and precipitation and temperature in Korea. Lee (1998) applied harmonic analysis to identify region, magnitude, and season that showed monthly temperature and precipitation responses associated with El Niño/La Niña. Shin et al. (1998) investigated cross-correlation between the SOI and standardized monthly precipitation for twenty-five years at 22 stations in Korea, and showed that there was a significant correlation for a lag time of one year. They also showed that influence of SOI was stronger in southern as compared to central South Korea. In addition, using long-term data they showed that recent influence on drought of Korea from El Niño was increasing. The relationship between ENSO and drought in Korea was also investigated using Palmer Drought Severity Index (PDSI) and cross-correlation analysis (Lee, 1999). In the study, the link between ENSO and drought in Korea was shown to be statistically significant with 6% of the variance in PDSI explained by ENSO. Moon (2001) applied Multi-channel Singular Spectral Analysis (M-SSA) to identify coherent space-time patterns of low frequency harmonic element between SOI and the precipitation of Korea. Notably, Kawamura et al. (2001) has succeeded for the first time to detect statistically significant correlation coefficients using precipitation data in Japan by simple specific method in which SOI data categorized into five groups according to their magnitudes.

Therefore, based on the above background, in the present study we categorize the SOI according to their magnitudes while applying the cubic root transformation method to normalize the precipitation data at Pusan in Korea and at Fukuoka in Japan. The spectrum analysis is performed to identify deterministic and periodic components in frequency domain for each station. The cross-correlation analysis is also used to reveal the correlation between the categorized SOI and the transformed data, and the results are compared to each other.

2. Study area and Data used

The Pusan station (129°E, 35.1°N), which is very close to Fukuoka, is located in the southeastern part of Korea as shown in **Fig. 1**. The station is one of the stations that have the longest data (1904-2000) in Korea. Fukuoka

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(130.4°E, 33.6°N) in Japan was selected for the present study because of its close proximity to South Korea, especially the Pusan station, and also because of long (1890-2000) and well investigated precipitation statistics.

The monthly time series for the two stations are shown in **Fig. 2.** As is clear from the figure Fukuoka has the highest monthly precipitation equivalent to about 1060 mm. This is also seen in **Fig. 3**, which shows basic statistics in form of box-whisker plot (median, quartiles, maximum and minimum precipitation) for each station and monthly data. Maximum median values are seen in July for the Pusan, and in June for the Fukuoka station. A clear difference between the Pusan and Fukuoka stations is that months with no precipitation (less than 0.1 mm) occurred at Pusan between December and March, while no such record occurred in Fukuoka. As seen in the figure, the monthly data at the two stations are not normally distributed but instead positively skewed. This property is typical for data that is physically constrained to lie above a minimum value such as precipitation (must be non-negative; Wilks, 1995).

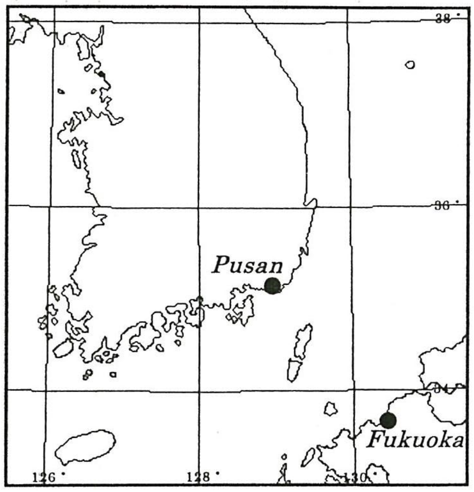

Figure 1 Map of study area

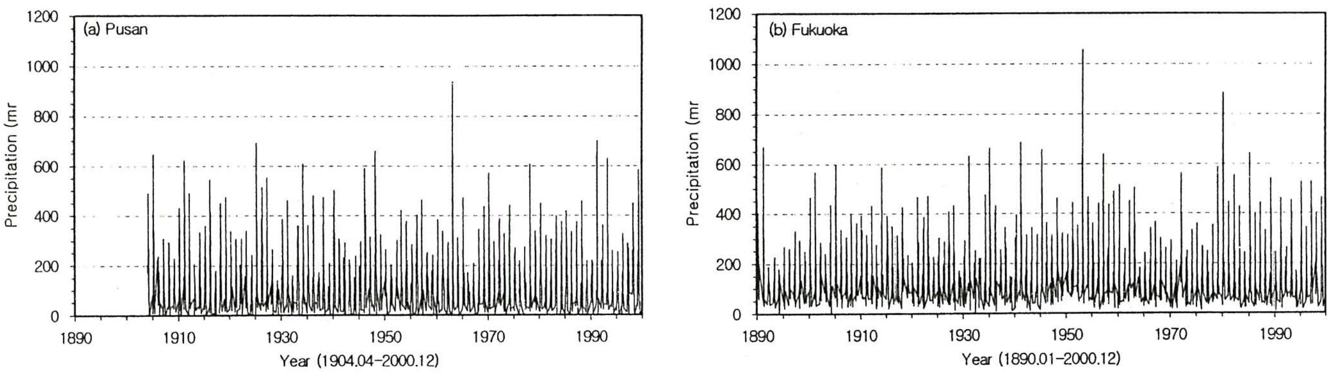

Figure 2 Plots of time series

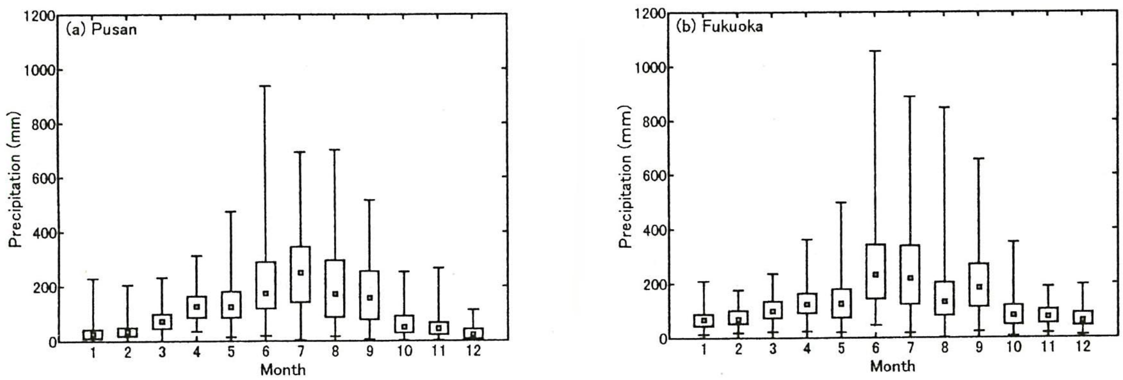

Figure 3 Box-whisker plots for each station

Therefore, in the present study the cubic root transformation was carried out to normalize the precipitation in both stations and then the normalized monthly precipitation values were standardized to a mean of zero and a standard deviation of one by subtracting the normalized monthly mean values from the monthly values and dividing by the normalized monthly standard deviations, using the whole data period for calculating of means and standard deviations.

The Troup's method (Troup, 1965) was used for calculating SOI. First, the difference between mean sea level pressure at Tahiti (149.6°W, 17.5°S) and Darwin (130.9°W, 12.4°S) and then the differences are standardized to a mean of zero and a standard deviation of one by subtracting the mean value from the differences and dividing by the standard deviation of each month (January-December), using the base period of 1951-1980 for the computation of means and standard deviations.

The SOI data are categorized into five groups according to their magnitudes mentioned above; "Strong El Niño (SOI<-2)","Weak El Niño (-2≤SOI<1)" and "Normal Condition(-1≤SOI≤1)" and "Weak La Niña (1<SOI≤2)", "Strong La Niña (2<SOI)". This naming for each categories of SOI is for easy association with the El Niño and La Niña phenomena. **Fig. 4** shows cumulative frequency of categorized SOI for each month during the past 135 years. From this figure, the frequencies of the "Strong La Niña" and "Strong El Niño" categories for June are extremely high compared with those of other months (Kawamura et al. 2001).

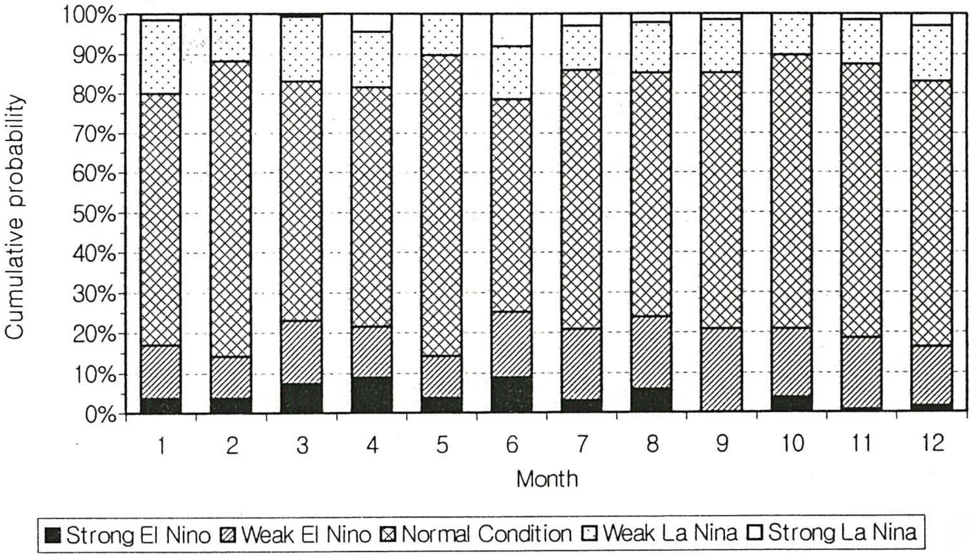

Figure 4 Occurrence of SOI classified into five categories according their magnitudes

3. Spectrum analysis

Spectrum analysis was performed to identify deterministic and periodic components in frequency domain. In the present study, the spectral analysis is based on the maximum entropy method (MEM). In the spectrum analysis only the one-year periodicity was revealed for the Pusan station while three-months and one-year periodicities were dominant for Fukuoka. The general pattern, however, is a clear similarity between Pusan and Fukuoka as shown in **Fig. 5**.

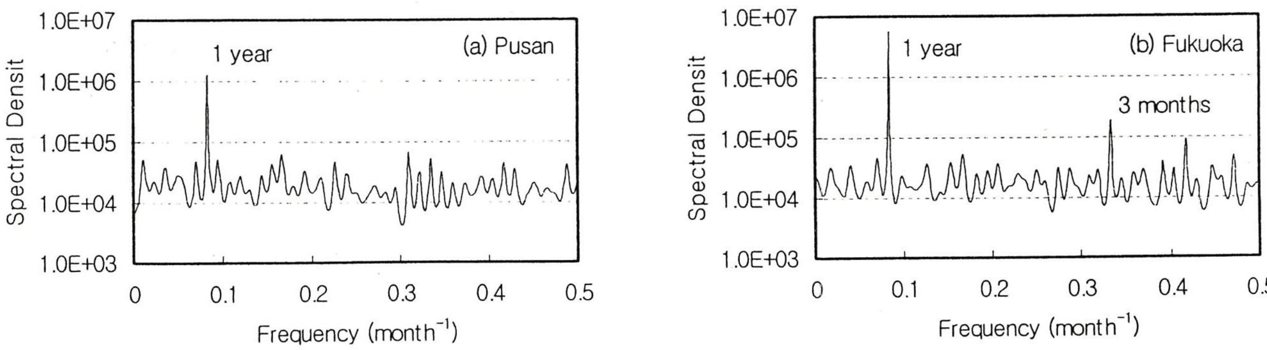

Figure 5 Periodogram for each station by spectrum analysis

4. Cross-correlation analysis

Cross-correlation between the Pusan and Fukuoka stations

Result from the cross-correlation analysis between the Pusan and Fukuoka stations is shown in **Fig. 6** and the scatter plot is shown in **Fig. 7**. The correlation reveals the high coefficient value of 0.62. The high correlation shows that the same rainfall processes are occurring at the two stations and that they can be used simultaneously to analyze regional precipitation patterns.

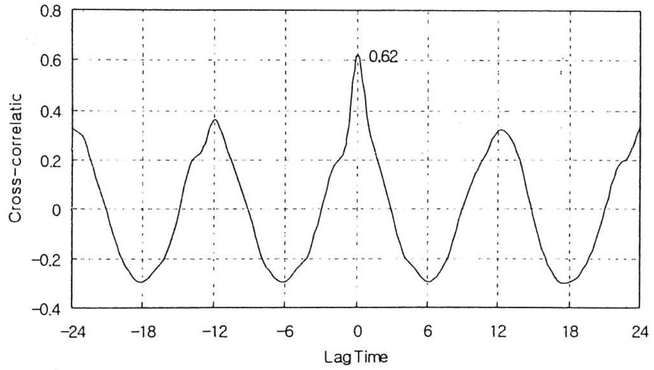

Figure 6 Cross-correlation between the Pusan and Fukuoka stations

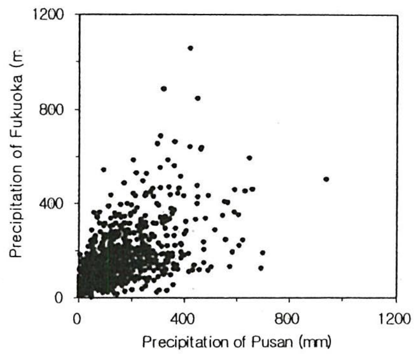

Figure 7 Scatter plot of precipitation at both stations

Cross-correlation between the categorized SOI and the precipitation at Pusan station

For Pusan station, the result of cross-correlation between the categorization and normally standardized precipitation is shown in **Fig. 8** to **Fig. 10**. Generally, the correlations under "Normal Condition" are almost zero at any lag time (see **Fig. 8 (a)**) and La Niña events are more strongly correlated to the precipitation data than El Niño events. The correlations under "Weak El Niño" and "Weak La Niña" are bigger than "Normal Condition" but not statistically significant (see **Fig. 8 (b)**).

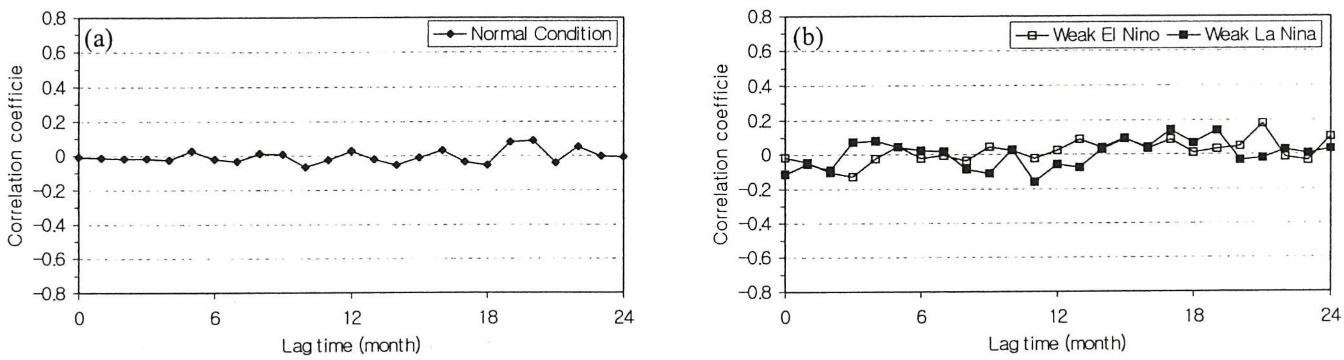

Figure 8 Cross-correlation between the SOI under the "Normal Condition" (a), "Weak El Niño and Weak La Niña" (b), and the precipitation of Pusan

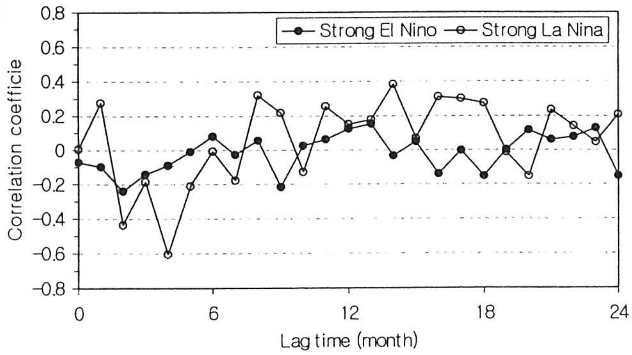

Figure 9 Cross-correlation between the SOI under the "Strong El Niño and Strong La Niña" and the precipitation of Pusan

The highest correlation of –0.61, which is significant at 1% level, was obtained with lag time 4 months and the correlation of –0.44, which is significant at 5% level, is obtained with lag time 2 months under the category of "Strong La Niña" as seen in **Fig. 9**. The highest correlation of –0.24 with lag time 2 months is obtained under the category of the "Strong El Niño" but the correlation is not statistically significant (see **Fig. 9**).

We now focus on the data which are detected as statistically significant by the cross-correlation analysis carried out in this study, to investigate in more detail the influence of La Niña on precipitation in Pusan. The scatter plot between the SOI categorized as "Strong La Niña" and the corresponding precipitation with lag time 4 months is shown in **Fig. 10**. From this figure, we can see the tendency in which the stronger the La Niña event, the less the precipitation at Pusan station 4 months later. The same general tendency is also seen in **Fig. 11**, which shows the scatter plot of the result with lag time 2 months.

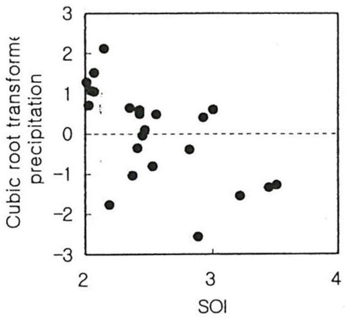

Figure 10 Scatter plot for the "Strong La Niña" with lag time 4 months

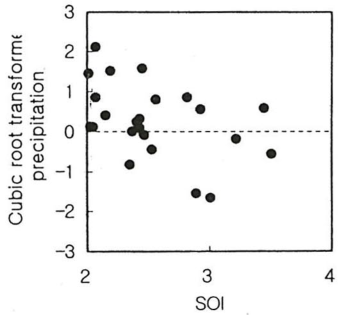

Figure 11 Scatter plot for the "Strong La Niña" with lag time 2 months

Cross-correlation between the categorized SOI and the precipitation at Fukuoka station

The results of Fukuoka under the categories of "Normal Condition", "Weak El Niño" and "Weak La Niña" are similar with those of the Pusan station and are shown in **Fig. 11**. That is, the correlations under the "Normal Condition" are almost zero at any lag time. La Niña events are also more strongly correlated to the precipitation data than El Niño events. The statistically significant correlations could not be detected at 5% level under the categories of "Weak El Niño" and "Weak La Niña".

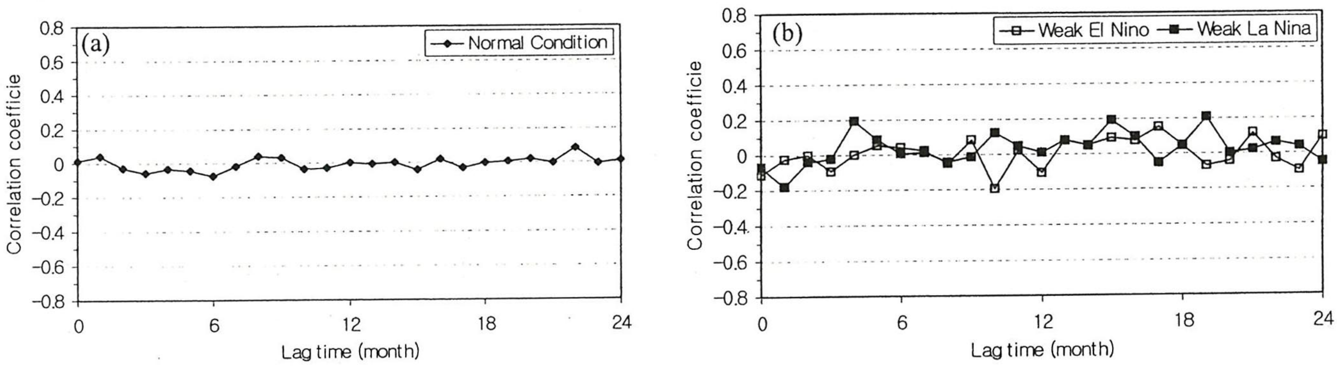

Figure 11 Cross-correlation between the SOI under the "Normal Condition" (a), "Weak El Niño and Weak La Niña" (b), and the precipitation of Fukuoka

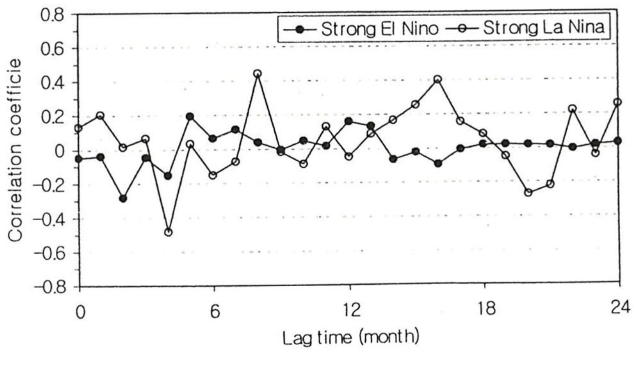

Figure 12 Cross-correlation between the SOI under the "Strong El Niño and Strong La Niña" and the precipitation of Pusan

However, the highest correlation coefficient –0.49, which is statistically significant at 1% level, is obtained with lag time 4 months under the category of "Strong La Niña" as shown in **Fig. 12.** Significant positive correlations at 5% level are obtained with lag time 8 and 16 months under the same category.

Under the "Strong El Niño" category, significant correlation at 5% level is revealed only for the lag time 2 months and the correlation coefficient is –0.28.

In the present paper, the scatter plots which show the highest correlation under the "Strong La Niña" and "Strong El Niño" categories are drawn in **Fig. 13** and **Fig. 14**, respectively. The figures show the general tendencies that the stronger the La Niña event, the less precipitation in Fukuoka 4 months later and the stronger the El Niño event, the more precipitation 2 months later.

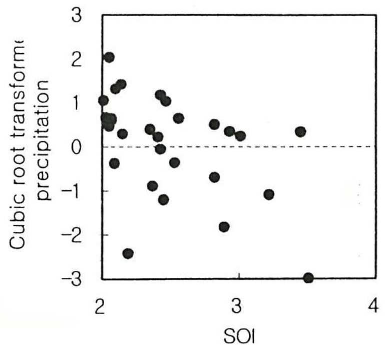

Figure 13 Scatter plot for the "Strong La Niña" with lag time 4 months

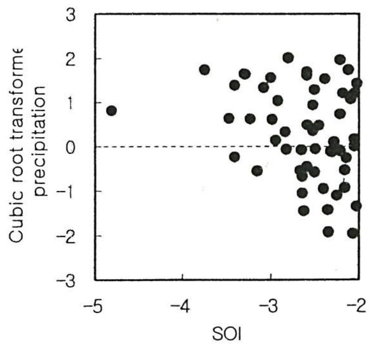

Figure 14 Scatter plot for the "Strong El Niño" with lag time 2 months

5. Conclusions

In the present study, we studied the cross-correlation between the categorized SOI and normally standardized precipitation at Pusan in Korea and at Fukuoka in Japan, using the cross-correlation analysis. Estimating relationships between SOI and the precipitation data of different areas is important to increase the knowledge on regional influence of SOI, temporally and spatially.

The general patterns of dominant periodicity for each station were revealed using spectrum analysis. Both stations showed a clear similarity of the general patterns. The correlation between the Pusan and Fukuoka stations was studied using cross-correlation analysis and showed a high correlation coefficient of 0.62. The cross-correlation analysis performed in the present study emerged the general tendency that the stronger the La Niña, the less precipitation in Pusan station 4 months later. Even though the highest correlation detected under the "Strong El Niño" category was not significant, the lag time of the result was 2 months. These lag times which are 2 and 4 months were also revealed in the results at Fukuoka station with same general tendencies.

Consequently, these results which are showing the similar periodicities, the high correlation and the same general tendencies can be attributed to the geographical proximity of the two stations. In this regard, a further cooperated research between Japan and Korea, especially for both stations is recommended for more in-sights into these observed trends.

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