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CROSS-CORRELATION BETWEEN SOUTHERN OSCILLATION INDEX AND PRECIPITATION/TEMPERATURE IN FUKUOKA, JAPAN

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ABSTRACT

The impacts of Southern Oscillation on climate are widespread and extend far beyond the tropical Pacific. However, the concrete influence is not so clear, especially in middle to high latitudes, including Japan. In this study, the cross-correlation between monthly values of on one hand Southern Oscillation Index (SOI) and on the other hand normally standardized precipitation and temperature in Fukuoka, Japan, is investigated in detail using 109 years of data.

For the original time series, no significant direct correlation between SOI and precipitation/ temperature in Fukuoka is detected. However, statistically significant correlation coefficients are obtained when using SOI data categorized into five groups according to their magnitudes. In particular, the highest correlation coefficients, which are statistically significant at 1% level, are obtained for both precipitation and temperature data with lag time 4 months under the category which is referred to as "Strong La Niña".

From scatter plots and box-whisker diagrams for categorized SOI and the corresponding data which are detected as statistically significant by the above cross-correlation analysis, the following general tendencies of precipitation and temperature in Fukuoka under the influence of El Niño and La Niña events are also obtained: the stronger the La Niña event, the less precipitation and the lower temperature in Fukuoka 4 months later; the stronger the El Niño event, the more precipitation 2 months later and the lower temperature 12 months later are expected.

1 INTRODUCTION

The Southern Oscillation is a phenomenon which affects large-scale atmospheric and oceanographic features of the tropical Pacific Ocean. The oscillation can be characterized by indices based on either variations of sea surface temperature or differences in barometric pressure. Its best-known extremes are the El Niño and La Niña events. The impacts of Southern Oscillation on climate are widespread and extend far beyond the tropical Pacific, a phenomenon known as teleconnection. However, the concrete influence is not so clear, especially in middle to high latitudes, including Japan (Japanese Study Group for Climate Impact & Application, 1999; Sakurai, 1998; Yoshino, 1999). A general tendency of 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 on the one hand El Niño or La Niña events and on the other hand hydro-meteorological variables (e.g., precipitation and temperature) in Japan (Yoshino, 1999).

The overall purpose of the present project is to investigate in detail the direct cross-correlation between Southern Oscillation Index (SOI) and precipitation/temperature in Japan on a monthly basis. As the first step of this study, we focus on the precipitation and temperature data from Fukuoka City, which is located in the northern part of Kyushu Island, Western Japan. Fukuoka City is always exposed to potential drought and was actually struck by very severe droughts in 1978 and 1996 (for details refer to Kawamura and Jinno, 1996). Thus it is very important to reach an improved understanding of all climate features in the region.

In this study, we do not use any complicated methodology, but just ordinary cross-correlation coefficients are calculated. Nevertheless, we can detect statistically significant correlation between categorized monthly SOI and their corresponding normally standardized precipitation/temperature in Fukuoka. From these results, informative tendencies of precipitation and temperature under the El Niño and La Niña conditions are obtained. This paper reports on these results.

2 DATA

Several indices have been used to monitor the Southern Oscillation. One commonly used Southern Oscillation Index, SOI, is derived from values of the monthly mean sea level pressure difference between Papeete, Tahiti (149.6/W, 17.5/S.) and Darwin, Australia (130.9/E, 12.4/S). The database we maintain for the calculation of SOI consists of 133 years of monthly mean sea level pressure data at Tahiti and Darwin from January 1866 to December 1998. The data were obtained from Ropelewski and Jones (1987) and Allan *et al* (1991), who carefully infilled all missing values by correlation with data from other observation stations. Because of missing values, data from before about 1920 are

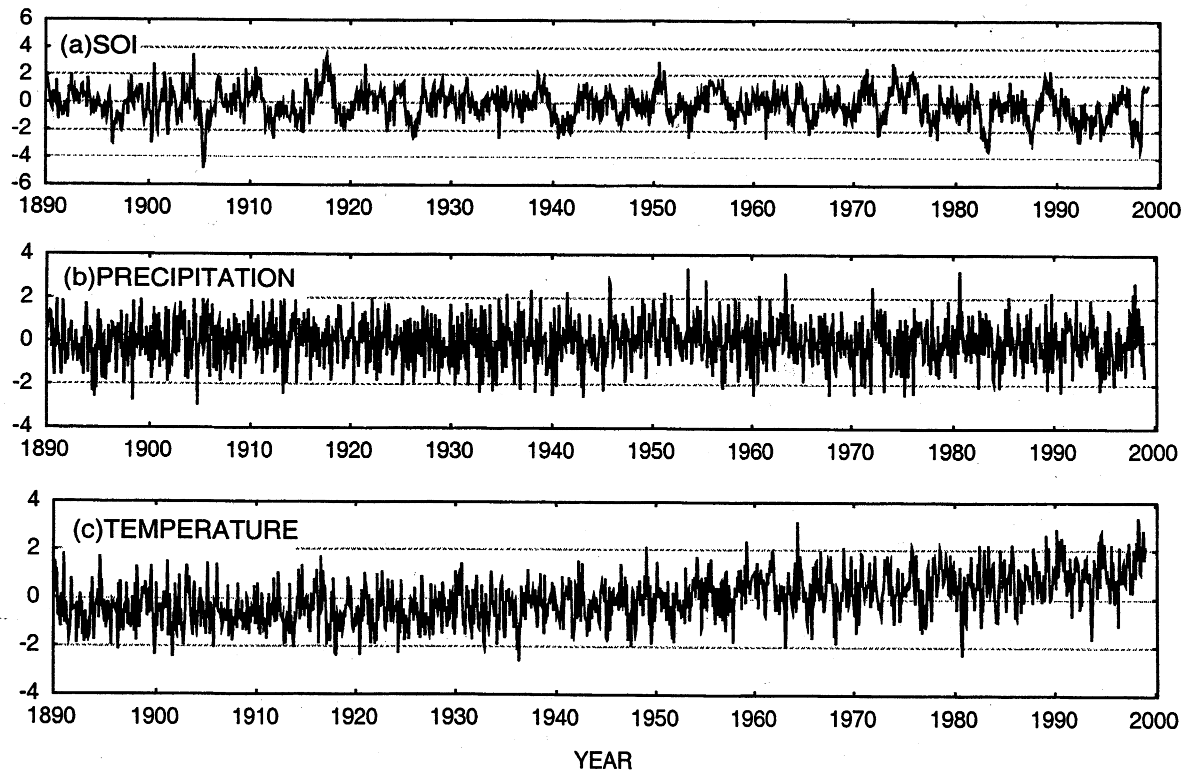

Figure 1. Monthly time series of (a) SOI, (b) standardized precipitation and (c) standardized temperature.

somewhat less reliable than the later values (Kawamura *et al.*, 1998). Some mean sea level pressure values after 1882, however, were revised using the data on the web site of NOAA (the National Oceanic and Atmospheric Administration) Network Information Center [http://www.nnic.noaa.gov/data/indices/].

To compute the SOI, in this study we use Troup's method (Troup, 1965; McBride and Nicholls, 1983), which first takes the difference between mean sea level pressures at Tahiti and Darwin. Then the difference series is standardized to a mean of zero and a standard deviation of one by subtracting the mean value and dividing by the standard deviation of each month (January-December), using the base period 1951-1980 for the computation of means and standard deviations (Kawamura *et al.*, 1998). Note that a standard deviation of ten is also commonly used (e.g. McKerchar *et al.*, 1998).

The precipitation data for each month (January-December) in Fukuoka are not normally distributed but positively skewed. Therefore, cubic root transformation is firstly carried out to normalize the data. Then the normalized monthly precipitation data are standardized to a mean of zero and a standard deviation of one by subtracting the normalized monthly mean values and dividing by the normalized monthly standard deviations, using the whole period for the computation of means and standard deviations. On the other hand, as the temperature data for each month (January-December) in Fukuoka are normally distributed, the original series are directly standardized to a mean of zero and a standard deviation of one using the same procedure as for the normalized precipitation data.

Precipitation and temperature data for Fukuoka exist since January 1890. Therefore, the data used in the following calculation of correlation comprise 109 years (1308 months; January 1890 - December 1998) of normally standardized monthly precipitation and temperature in Fukuoka, and SOI data for the same period, to conform to the period of available precipitation and temperature data in Fukuoka. These series, which form the basis for the analysis in this study, are shown in Figure 1.

3 CROSS-CORRELATION

As the first step in the analysis of cross-correlation between SOI and precipitation/temperature, ordinary cross-correlation coefficients between the original time series were calculated. Figure 2 shows the result of this. From this figure, correlations between SOI and precipitation/temperature for the original time series are almost zero for any time lag, which also has been found for other precipitation data in Japan (Yoshino, 1999).

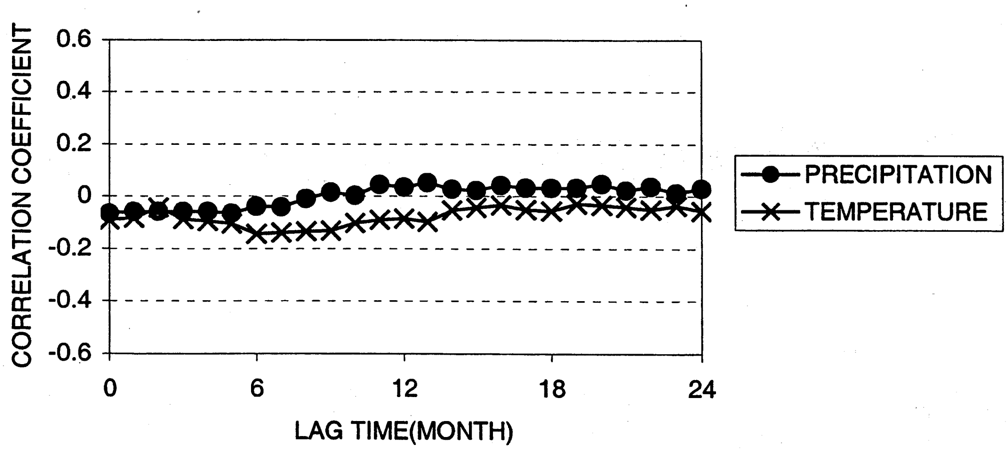

Figure 2. Cross-correlation between SOI and precipitation/temperature for the original time series.

In the next step, the SOI data are categorized into five groups A) to E) according to their magnitudes shown in Table 1. Hereafter, categories A) and B) are referred to as "Strong El Niño" and "Weak El Niño", respectively, for easy association with the phenomena in question. Similarly, categories D) and E) are referred to as "Weak La Niña" and "Strong La Niña", respectively. Category

C) is referred to as "Normal Condition". Figure 3 shows how frequently the five categories have occurred in each month during 109 years. From this figure, in spite of the small variation of the occurrence ratio of each category from month to month, it may be seen that El Niño and La Niña could occur in any month. Average occurrence ratios of category A) to E) are 4.3%, 15.8%, 65.4%, 12.4%, 2.1%, respectively. McKerchar *et al.* (1998) found a dependency of summer lake inflows and precipitation on spring SOI by adopting the idea of categorizing SOI.

Table 1. Classification of SOI.

Category	Magnitude of SOI	Referred to as
A	SOI<-2	Strong El Niño
B	-2□SOI<-1	Weak El Niño
C	-1□SOI□1	Normal Condition
D	1<SOI□2	Weak La Niña
E	2<SOI	Strong La Niña

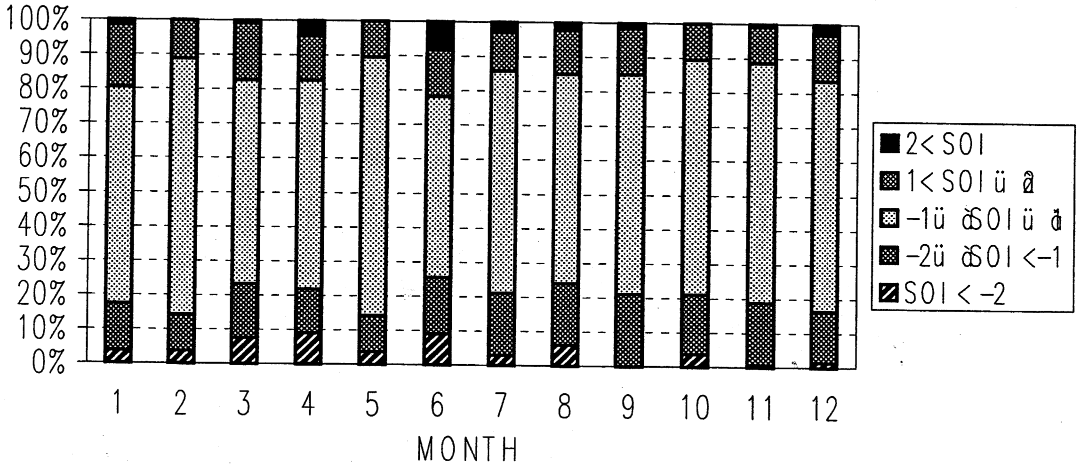

Figure 3. Occurrence ratio of each SOI category.

The cross-correlations between categorized SOI and corresponding precipitation/temperature data are calculated with various lag times. Figures 4 and 5 show the results of those correlations. From these figures, the correlations under the "Normal Condition" are almost zero at any lag time for both precipitation and temperature data, similarly to in Figure 2. The correlation increases with increasing SOI absolute values for both precipitation and temperature data. Generally, La Niña events are more strongly correlated to the precipitation data than El Niño events. For neither precipitation nor temperature data could statistically significant correlations at 5% level be detected under the categories of "Weak El Niño" and "Weak La Niña".

However, the highest correlation coefficient -0.49, which is statistically significant at 1% level, is obtained for the precipitation data with lag time 4 months under the category of "Strong La Niña" as shown in Figure 4. Significant positive correlations at 5% level are also obtained for the precipitation data with the lag time 8 and 16 months under the same category of "Strong La Niña". Under the "Strong El Niño" category, significant correlation at 5% level is detected only for the lag time 2 months for the precipitation data.

From Figure 5 for the temperature data, a statistically significant correlation coefficient at 1% level is obtained with lag time 4 months under the category of "Strong La Niña", and at 5% level with lag time 5 months under the same category. Significant correlation at 5% level is also detected with lag time 12 months under the category of "Strong El Niño".

As indicated above, we can successfully detect statistically significant cross-correlation between SOI and precipitation/temperature in Fukuoka by categorizing SOI data.

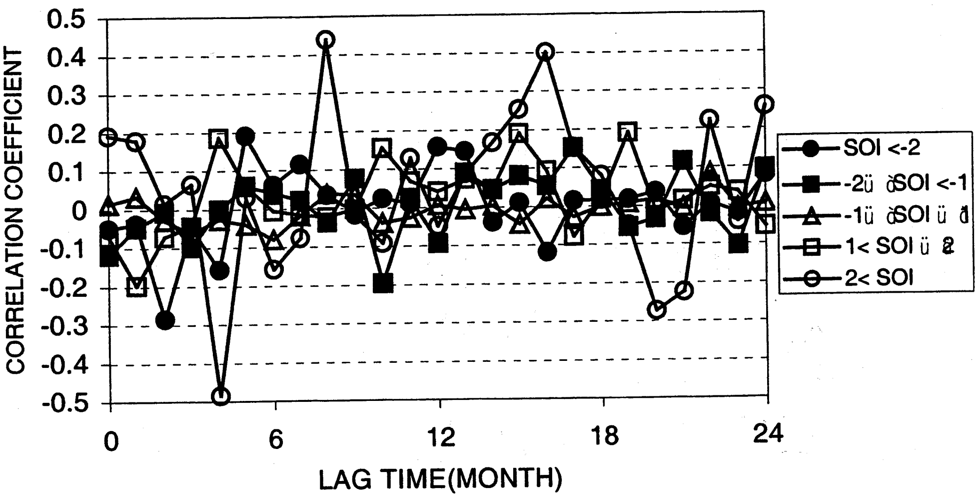

Figure 4. Cross-correlation between categorized SOI and corresponding precipitation.

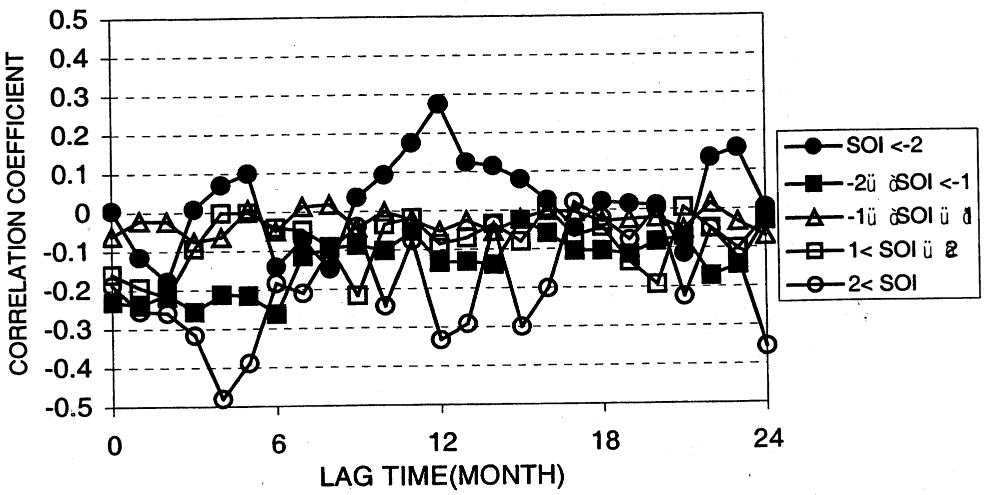

Figure 5. Cross-correlation between categorized SOI and corresponding temperature.

4 INFLUENCE OF EL NIÑO AND LA NIÑA EVENTS

We now focus on the data which are detected as statistically significant by the cross-correlation analysis carried out in the former section, to investigate in more detail the influence of El Niño and La Niña events on precipitation and temperature in Fukuoka.

First, precipitation data are examined. Figure 6 shows the box-whisker diagram of precipitation data for the lag time 4 months under the category of "Strong La Niña", which has the highest correlation as shown in Figure 4, compared with "Normal Condition". In the figure, small squares indicate median values, box parts indicate quartiles, and whisker parts indicate 10-90 percentiles. From this figure, the 90 percentile and upper quartile of "Strong La Niña" are almost the same as "Normal Condition", but median value and lower quartile are larger than "Normal Condition". On the other hand, the 10 percentile is much smaller than that of "Normal Condition". Thus, 4 months after "Strong La Niña", less precipitation is expected at 10 percentile, whereas slightly more precipitation is expected at median as compared with "Normal Condition". Figure 7 shows the scatter plots between SOI categorized as "Strong La Niña" and the corresponding precipitation with lag time 4 months. From this figure, we can see the tendency in which the stronger the La Niña event, the less precipitation in Fukuoka 4 months later.

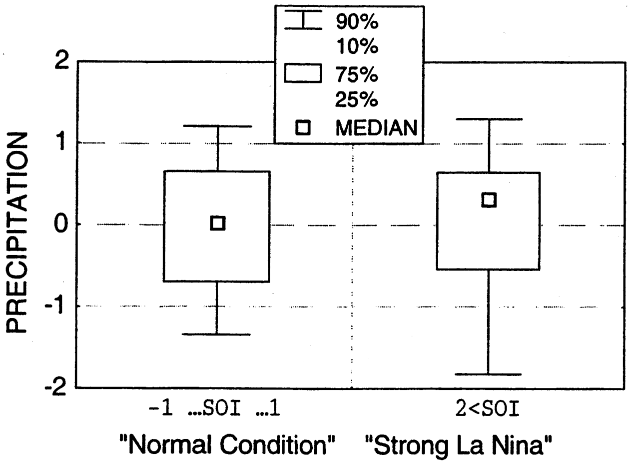

Figure 6. Box-whisker diagram of precipitation data for the lag time 4 months under the category of "Strong La Niña" compared with "Normal Condition".

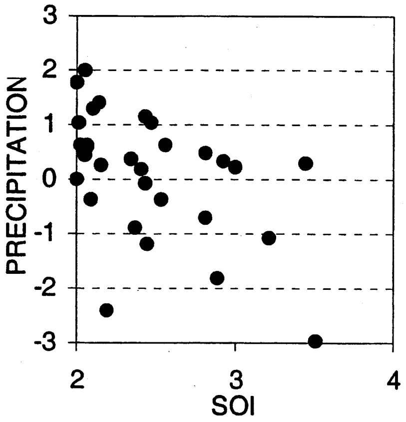

Figure 7. Scatter plots for the "Strong La Niña" in Figure 6.

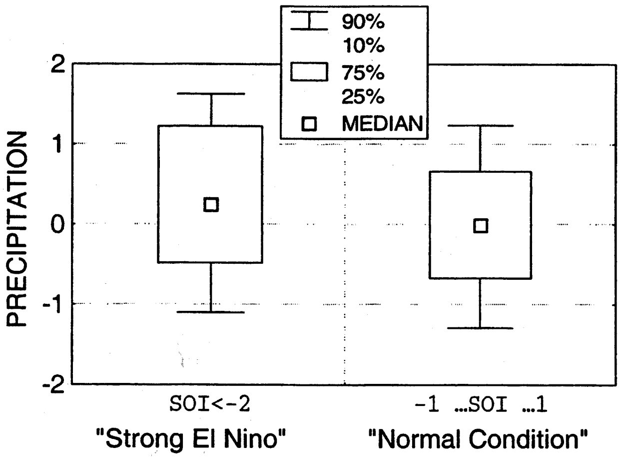

Figure 8. Box-whisker diagram of precipitation data for the lag time 2 months under the category of "Strong El Niño" compared with "Normal Condition".

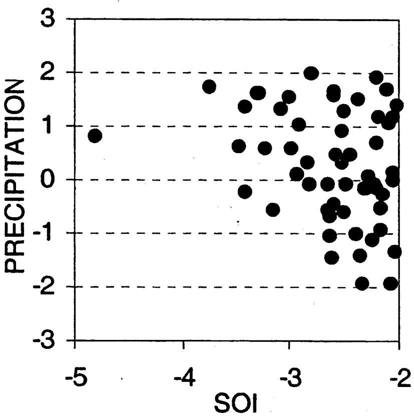

Figure 9. Scatter plots for the "Strong El Niño" in Figure 8.

Figure 8 shows the box-whisker diagram of precipitation data for the lag time 2 months under the category of "Strong El Niño", which has the only significant correlation under the El Niño category as shown in Figure 4, compared with "Normal Condition". From this figure, all values of median, quartiles and 10-90 percentiles of "Strong El Niño" are larger than those of "Normal Condition", in particular, the 90 percentile and upper quartile are much larger. Therefore, more precipitation than usual is expected 2 months after a "Strong El Niño" event occurs, and this tendency is more pronounced the higher the precipitation amount. Figure 9 shows the scatter plots for the "Strong El Niño" in Figure 8. From this figure, we can see the tendency in which the stronger the El Niño event, the more precipitation in Fukuoka 2 months later.

Next, temperature data are examined. Figure 10 shows the box-whisker diagram of temperature data for the lag time 4 months under the category of "Strong La Niña", which has the highest correlation as shown in Figure 5, and Figure 11 shows the scatter plots for the "Strong La Niña" in Figure 10. From these figures, the temperature in Fukuoka is significantly lower than usual 4 months after "Strong La Niña" happens. The stronger the La Niña event, the lower is the temperature.

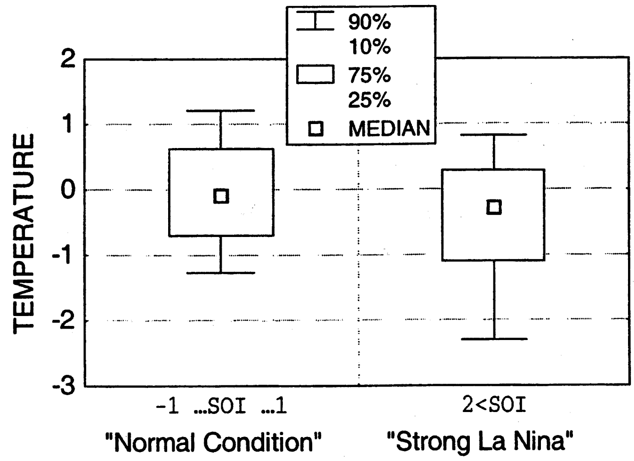

Figure 10. Box-whisker diagram of temperature data for the lag time 4 months under the category of "Strong La Niña" compared with "Normal Condition".

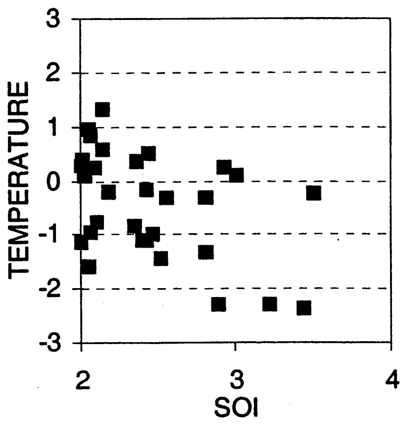

Figure 11. Scatter plots for the "Strong La Niña" in Figure 10.

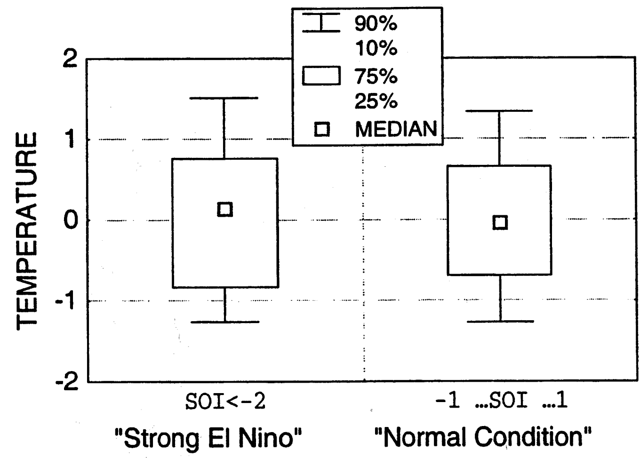

Figure 12. Box-whisker diagram of temperature data for the lag time 12 months under the category of "Strong El Niño" compared with "Normal Condition".

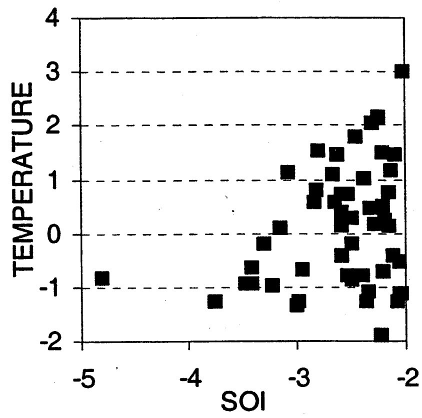

Figure 13. Scatter plots for the "Strong El Niño" in Figure 12.

Figure 12 shows the box-whisker diagram of temperature data for the lag time 12 months under the category of "Strong El Niño", which has the only significant correlation under this category as shown in Figure 5. In this figure, all percentiles of "Strong El Niño" are almost the same as those of "Normal Condition", although the median, upper quartile and 90 percentile are slightly higher and the lower quartile is slightly lower than those of "Normal Condition". Figure 13 shows the scatter plots for the "Strong El Niño" in Figure 12. From this figure, we can see the tendency in which the stronger the El Niño event, the lower temperature is expected in Fukuoka 12 months later.

5 CONCLUSIONS

In this study, the cross-correlation between monthly values of on one hand SOI and on the other hand normally standardized precipitation and temperature in Fukuoka, Japan, is investigated in detail using

109 years of data. Further, scatter plots and box-whisker diagrams of precipitation and temperature data are drawn for categorized SOI conditions, which are detected as statistically significant in the cross-correlation analysis, to find out general tendencies of precipitation and temperature in Fukuoka under the influence of El Niño and La Niña events.

The main conclusions obtained from this study are as follows. For the original time series, no significant direct correlation between SOI and precipitation/ temperature in Fukuoka is detected. However, statistically significant correlation coefficients are obtained when using SOI data categorized into five groups according to their magnitudes. In particular, the higher correlation coefficients, which are statistically significant at 1% level, are obtained for both precipitation and temperature data with lag time 4 months under the category which is referred to as "Strong La Niña". This may be the first time a significant cross-correlation has been detected between SOI and precipitation/temperature data in Japan.

From the results of the correlation analysis, scatter plots and box-whisker diagrams, the following tendencies are obtained: the stronger the La Niña event, the less precipitation and the lower temperature we expect in Fukuoka 4 months later; the stronger the El Niño event, the more precipitation 2 months later and the lower temperature 12 months later.

It might be possible to explain the physical reasons behind the above mentioned conclusions from the viewpoint of shifts of atmospheric pressure patterns. However, we have not yet found such clear physical explanations, but this point will be the focus of future research.

As the first step of this kind of study, the present results are valid only for the specific region in the middle latitudes, but we expect that the approach of this study can be easily extended and applied for other regions in order to evaluate the impacts of El Niño and La Niña events on climate.

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