Relationship Between Atmospheric-Oceanic Indices and Precipitation in Fukuoka, Japan

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ABSTRACT: In these days, various global indices related to atmospheric-oceanic phenomena have been proposed in the world. The overall purpose of the present study is to investigate in detail the relationship between those indices and monthly precipitation in Japan. As the first step of this study, we focus on four atmospheric-oceanic indices and the 113-year long precipitation data from Fukuoka city, which is located in the northern part of Kyushu Island, Western Japan. In this study, the cross-correlations between four indices of SOI, PDOI, NPI, NAOI and normally standardized monthly precipitation in Fukuoka are investigated in detail. For the original time series, the correlations between those indices and precipitation are almost zero for any lag times. However, quite strong statistically significant correlations are obtained when using those indices data categorized into five groups according to their magnitudes. In particular, very high correlation coefficients at 1% significance level are obtained between precipitation and SOI, NPI with some lag times under some categories. From the scatter plots for the statistically significant data, the following general tendencies of precipitation in Fukuoka are obtained: the smaller the NPI, the more precipitation 6 months later; the stronger the La Niña event, the less precipitation 4 months later are expected.

Key words: SOI, PDOI, NPI, NAOI, precipitation, Fukuoka, cross-correlation, categorization

1 INTRODUCTION

Recent climatic changes and the occurrence of abnormal weather are concerned as the uncertainty factors from the viewpoint of future stable water resources management. Therefore, there has been considerable interest in the evaluation of influence of various global atmospheric-oceanic phenomena on water resources. Also, qualitative and quantitative analyses of those global phenomena and their influence on local hydro-meteorological events have become a very important task. Until now, various indices related to those global atmospheric-oceanic phenomena have been proposed in the world. They are Southern Oscillation Index (SOI), Pacific Decadal Oscillation Index (PDOI), North Pacific Index (NPI), North Atlantic Oscillation Index (NAOI) and so on.

As is well-known, the impacts of El Niño Southern Oscillation (ENSO) phenomenon on climate are widespread and beyond the tropical Pacific, a phenomenon known as teleconnection. There have been many reports of abnormal weather conditions worldwide considered caused by ENSO. There are many studies on the relationship between SOI and local hydro-meteorological phenomena. However, much less studies about the influence of other proposed indices on local events have been carried out, especially ones aiming at Japan region.

The overall purpose of the present study is to investigate in detail the relationship between various atmospheric-oceanic indices and monthly precipitation in Japan. As the first step of this study, we focus on the 113-year long precipitation 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, the cross-correlations between four indices of SOI, PDOI, NPI, NAOI and normally standardized monthly precipitation in Fukuoka are investigated in detail. We do not use any complicated methodology, but we just calculated cross-correlation coefficients for raw and categorized time series data. For the original time series, no significant strong correlations between those indices and precipitation in Fukuoka were detected. However, quite high statistically significant correlation coefficients were obtained when using those indices data categorized into five groups according to their magnitudes. From the results, informative tendencies of precipitation under some categorized atmospheric-oceanic conditions were obtained. This paper reports on these results.

2 DATA

2.1 SOI

One of the famous atmospheric phenomena is Southern Oscillation (SO). SO is an atmospheric see-saw phenomenon in tropical Pacific sea level pressure between the eastern and western hemispheres associated with the El Niño and La Niña oceanographic features. The oscillation can be measured by a simple index, the Southern Oscillation Index (SOI) (Kawamura et al., 1998) which is used by NOAA (The National Oceanic and Atmospheric Administration) to judge whether the El Niño and La Niña events occurring (Japanese Study Group for Climate Impact & Application, 1999). The features are known collectively as the El Niño Southern Oscillation (ENSO) phenomenon.

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 for the calculation of SOI in the present study consists of 137 years of monthly mean sea level pressure data at Tahiti and Darwin from January 1866 to December 2002. 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. The data from before about 1920 are somewhat less reliable than the later values (Kawamura et al., 1998). The details of statistical and long-term characteristics of SO, SOI and their barometric pressure data refer to Kawamura et al. (2002a and 2002b) and Jin et al. (2003a).

2.2 PDOI

Pacific Decadal Oscillation (PDO) is described as a long-lived El Niño-like pattern of Pacific climate variability. PDO has two phases, warm and cool phases, and each phase persisted for 20 to 30 years in the 20th century. The fingerprints of PDO are most visible in the North Pacific/North America sector. Several studies find evidence for just two full PDO cycles in the past century: cool phase occurred during the period of 1890-1924 and 1947-1976, while warm phase prevailed during the period of 1925-1946 and 1977 through the mid-1990 s (Mantua et al., 1997).

PDOI is the leading principal component of monthly sea surface temperature (SST) anomalies in the North Pacific Ocean poleward of 20°N (Zhang et al.,1997; Mantua et al., 1997). The PDOI data since 1900, which is used in this study, were obtained from website of JISAO (Joint Institute for the Study of the Atmosphere and Ocean) [http://tao.atmos. washington.edu/main.html].

2.3 NPI

Trenberth and Hurrell (1994) have defined the North Pacific Index (NPI) as the area-weighted sea level pressure over the region 30°N to 65°N, 160°E to 140°W to measure the decadal variations of atmosphere and ocean in the north Pacific. This index was highly correlated with the leading principal component of the 500 hPa geopotential height. NPI is also a good index for the intensity of the Aleutian Low pressure cell. The NPI data since 1899 were obtained from the website of UCAR (University Corporation for Atmospheric Research) [http://www.ucar. edu/ucar/index.html].

Original monthly NPI data have the unit of barometric pressure (hPa), and are not normally distributed but negatively skewed. However, NPI data for each month (January-December) are almost normally distributed (Iseri et al., 2003). Therefore, in this study original NPI data are standardized to a mean of zero and a standard deviation of one by subtracting the monthly mean values and dividing by standard deviation of each month (January-December), using the base period 1901-2000 for the computation of means and standard deviations. In this paper, this standardized NPI is defined as NPI_z, which is used for the following analysis.

2.4 NAOI

The North Atlantic Oscillation (NAO), originally defined as the difference in air pressure between Iceland and the Azores, and its related index (NAOI) is perhaps one of the most important climatic anomalies for the Northern Hemisphere (e.g., Wallace and Gutzler, 1981). The NAO provides a potential precipitation predictor for especially northern Europe. In this study, the recently published Gibraltar and south-west Iceland monthly mean sea level pressure (MSLP) by Jones et al. (1997) were used to obtain a measure of the NAO and to calculate NAOI (Jin et al., 2003b). The MSLP data from Gibraltar were used instead of the traditionally employed Azores station data due to the possibility to extend the time series analyses back to 1821.

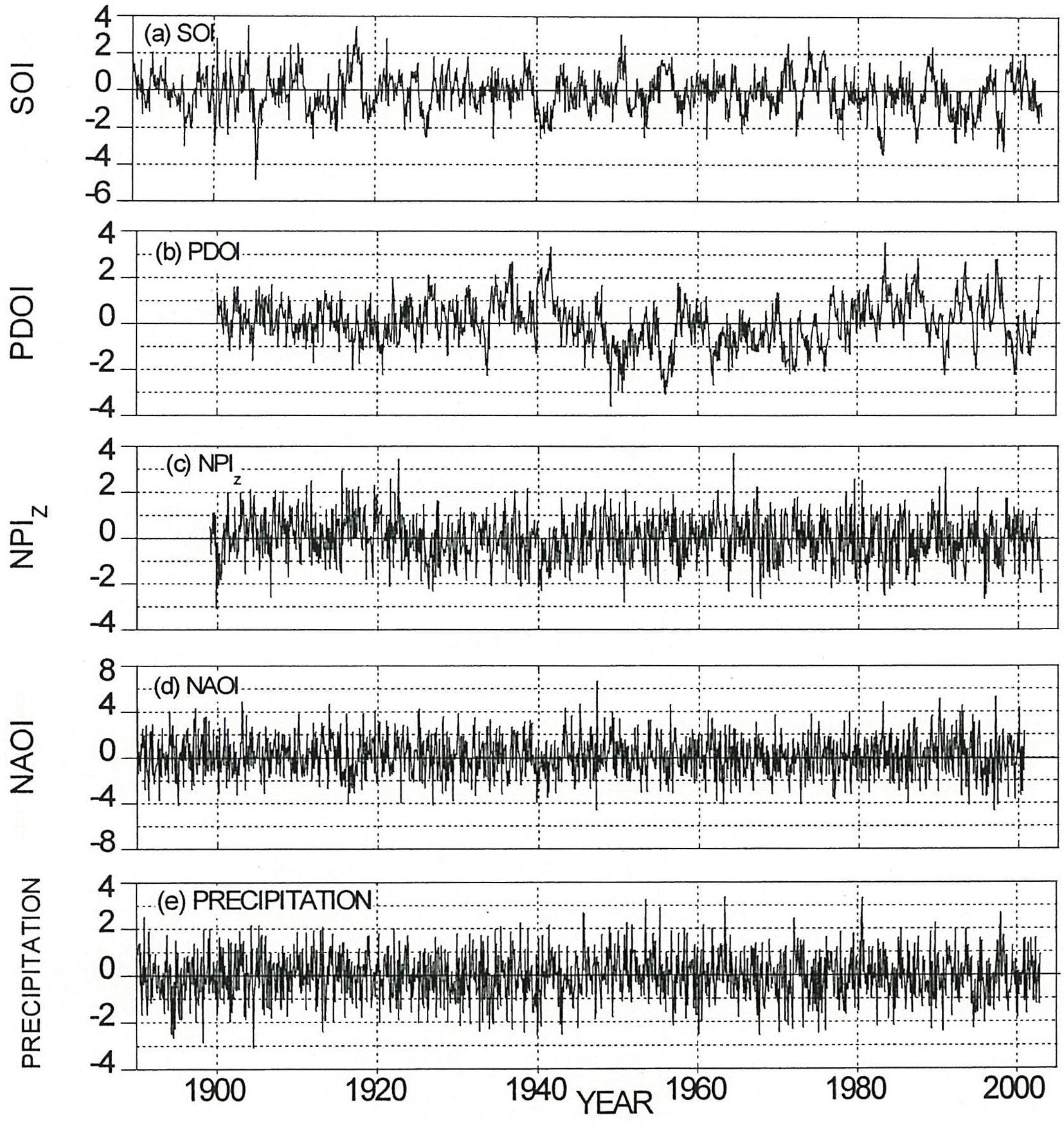

Figure 1. Monthly time series of (a) SOI, (b) PDOI, (c) NPI_z, (d) NAOI and (e) standardized precipitation.

2.5 Precipitation data in Fukuoka

Precipitation data for Fukuoka exist since January 1890. Therefore, the data used in the following calculation of correlation comprise 1356 months (January 1890 - December 2002, 113 years). 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 base period 1901-2000 for the computation of means and standard deviations.

Figure 1 shows the monthly time series of above-mentioned four atmospheric-oceanic indices and normally standardized monthly precipitation in Fukuoka. In the figure, each time series are drawn by existent data from January 1890 to December 2002. These time series data are the basis of all the following analyses.

3 CROSS-CORRELATION

As the first step in the analysis of cross-correlation between four atmospheric-oceanic indices (SOI, PDOI, NPI_z and NAOI) and precipitation in Fukuoka, ordinary cross-correlation coefficients between the original time series

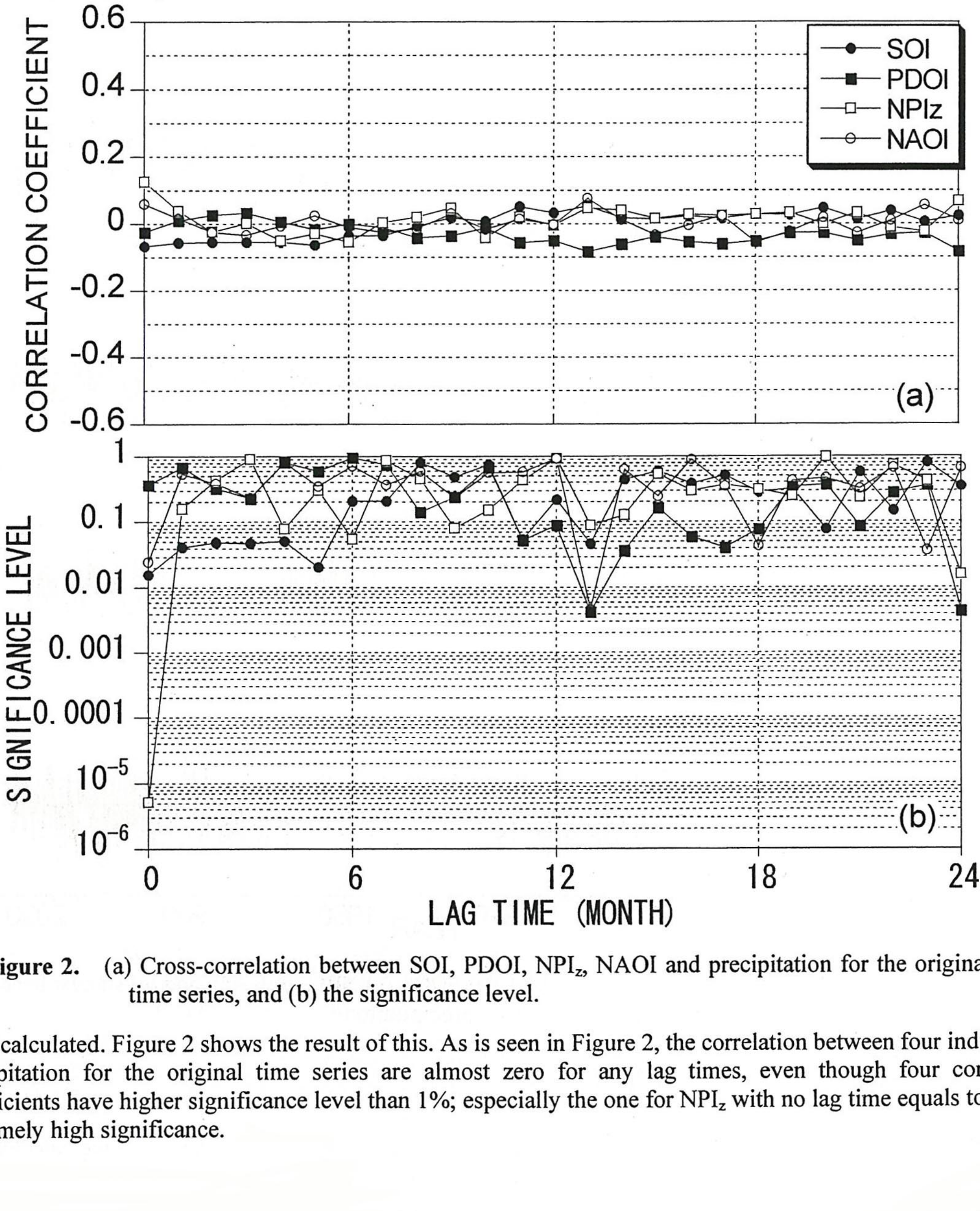

Figure 2. (a) Cross-correlation between SOI, PDOI, NPI_z, NAOI and precipitation for the original time series, and (b) the significance level.

were calculated. Figure 2 shows the result of this. As is seen in Figure 2, the correlation between four indices and precipitation for the original time series are almost zero for any lag times, even though four correlation coefficients have higher significance level than 1%; especially the one for NPI_z with no lag time equals to 1.13 at extremely high significance.

Table 1. Classification of atmospheric-oceanic Indices

Category	Magnitude of Index	Referred to as
A	Index < -2σ	Strong negative condition
B	-2σ <= Index < -σ	Weak negative condition
C	-σ <= Index <= σ	Normal condition
D	σ < Index <= 2σ	Weak positive condition
E	2σ < Index	Strong positive condition

σ : standard deviation ; σ = 1 for SOI, PDOI and NPI_z, σ = $\sqrt{2}$ for NAOI

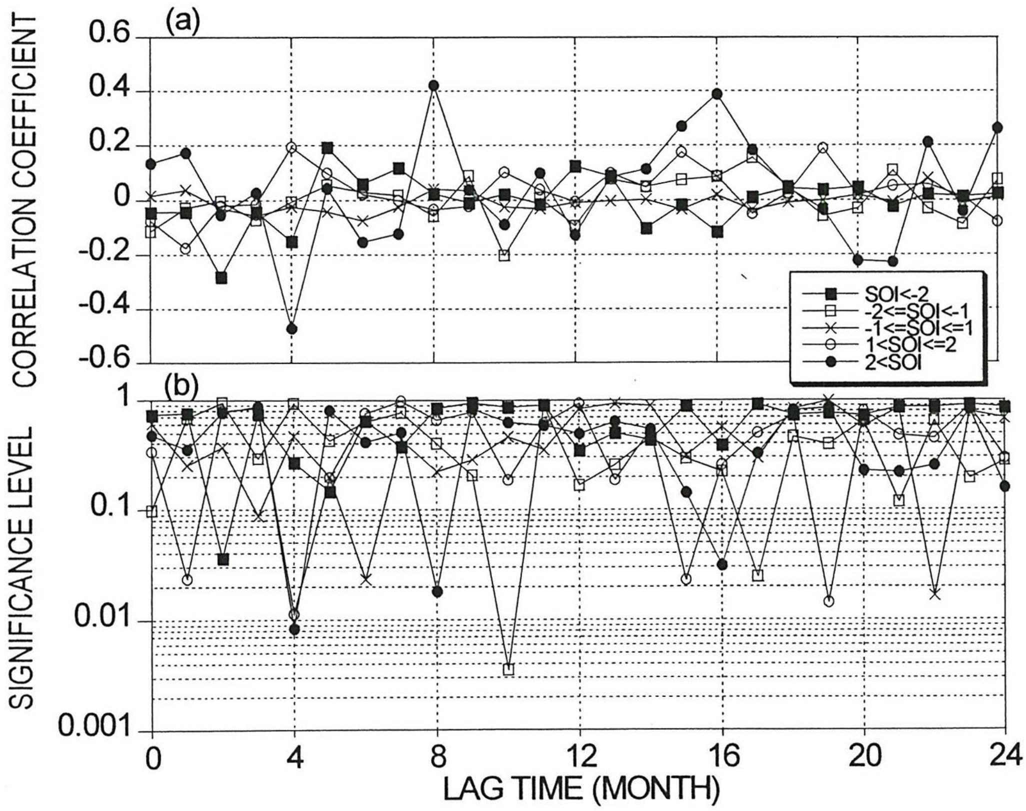

Figure 3. (a) Cross-correlation between categorized SOI and corresponding precipitation, and (b) the significance level.

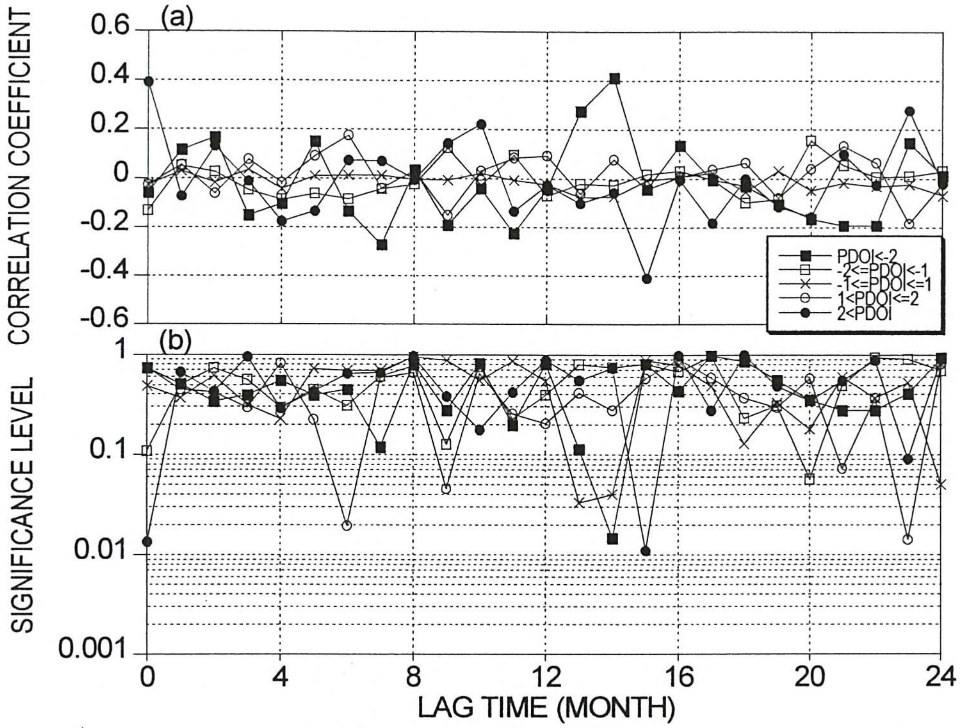

Figure 4. (a) Cross-correlation between categorized PDOI and corresponding precipitation, and (b) the significance level.

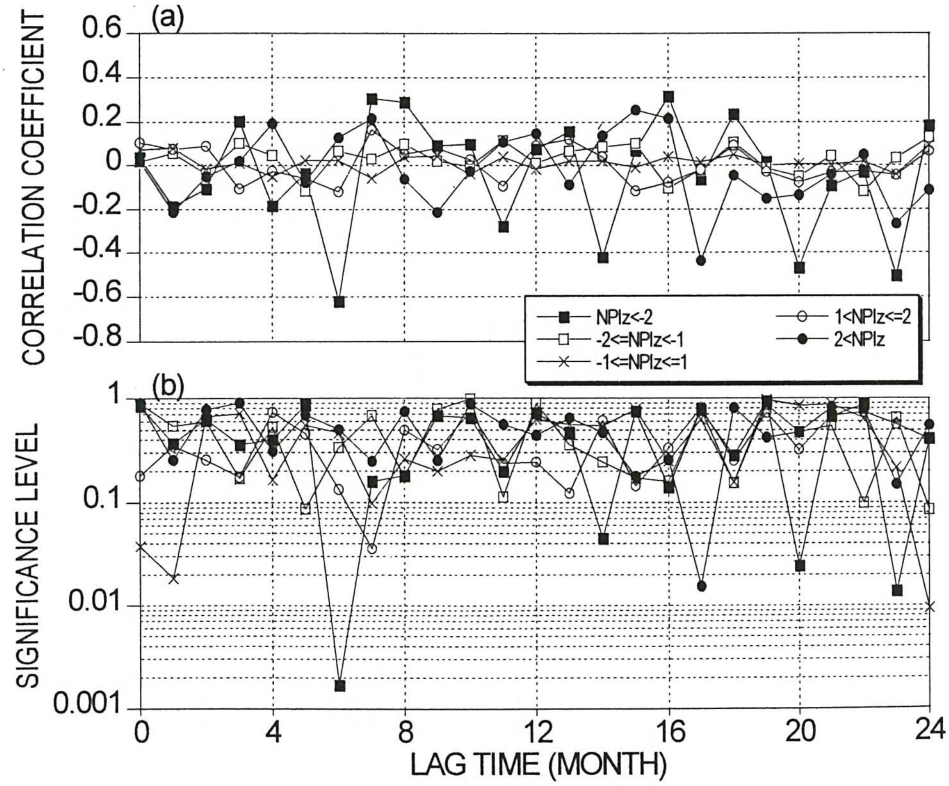

Figure 5. (a) Cross-correlation between categorized NPI_z and corresponding precipitation, and (b) the significance level.

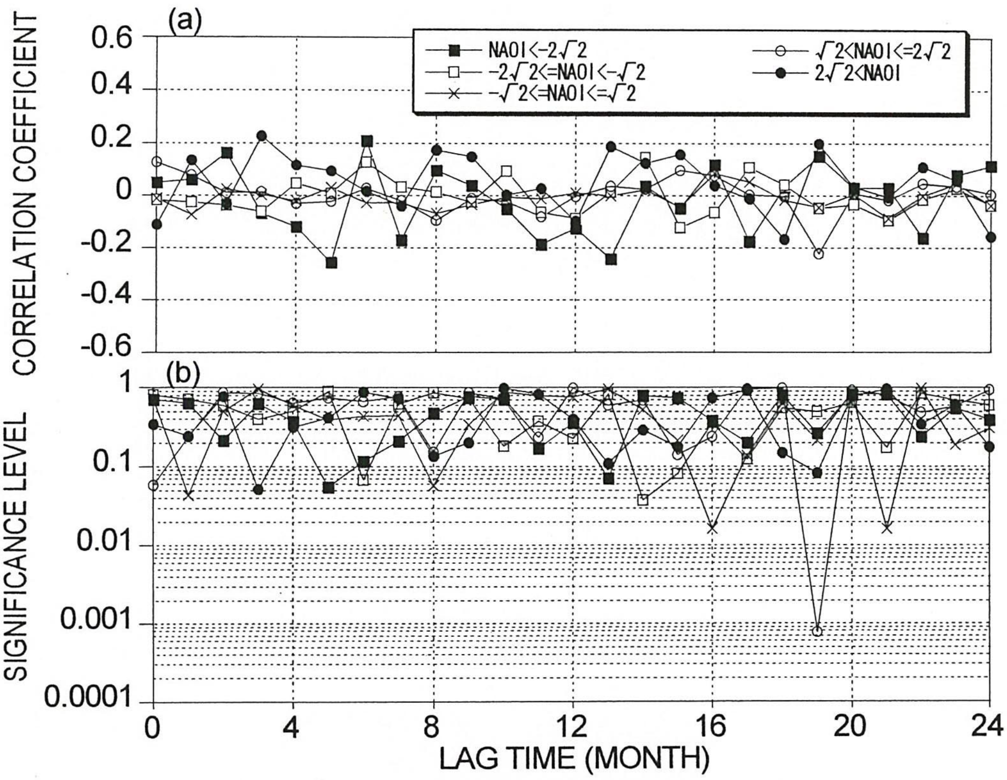

Figure 6. (a) Cross-correlation between categorized NAOI and corresponding precipitation, and (b) the significance level.

In the next step, the four indices 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 negative condition" and "weak negative condition", respectively. Similarly, categories D) and E) are referred to as "weak positive condition" and "strong positive condition", respectively. Category C) is referred to as "normal condition". The detail content of categorization for SOI refers to Kawamura et al. (2000, 2001) and Jin et al. (2003c).

The cross-correlation between categorized four atmospheric-oceanic indices and the corresponding precipitation data are calculated with various lag times. Figures 3 to 6 show the correlation coefficients and their significance levels. From these figures, the correlations under the "normal condition" are all less than 0.1 for any index and lag time, and just one point in Figure 5 exceeds 1% significance level. Under the "weak condition", positive or negative, almost all correlations are less than 0.2 and their significance levels are less than 1% for any index and lag time except for 2 points, which correspond to SOI with lag time 10 months and NAOI with lag time 19 moths. As an example, Figure 7 shows the scatter plot between NAOI categorized as "weak positive condition" and the corresponding precipitation with lag time 19 months, whose correlation coefficient is –0.22 with 0.1% significance level. From this figure, in spite of the high significance level, we cannot see any clear decreasing tendency.

Generally, the bigger the absolute value of the indices, the more the correlations fluctuate. For SOI and NPI_z, on one hand, there are strongest correlations between the indices under the "strong conditions" and precipitation, which are statistically significant at more than 1% level (Figure 3 and 5). The strongest correlation for SOI revealed the coefficient of –0.47 with lag time 4 months. Remarkably, the correlation between NPI_z and precipitation shows very high coefficient of –0.62 with lag time 6 months whose significance level is even higher than 0.2%. Under the same "strong conditions", relatively high correlations more than 0.4 at significance level 5% are also detected as shown in Figure 3 and 5.

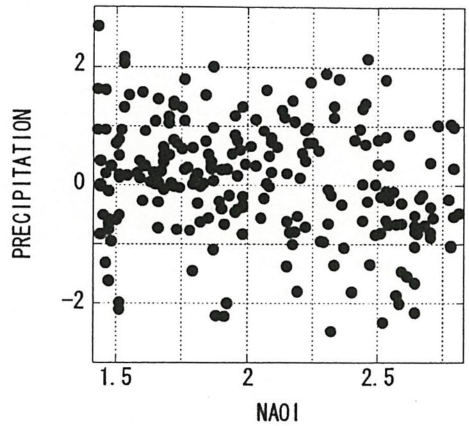

Figure 7. Scatter plot of NAOI and corresponding precipitation with lag time 19 months in "weak positive condition".

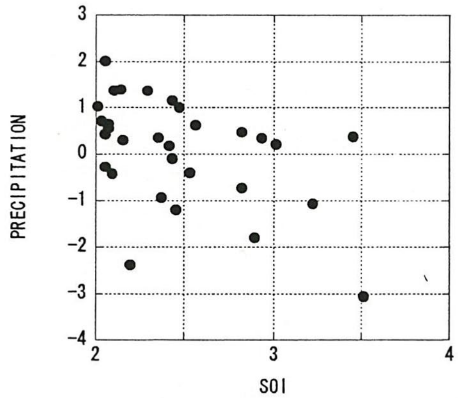

Figure 8. Scatter plot of SOI and corresponding precipitation with lag time 4 months in "strong positive condition".

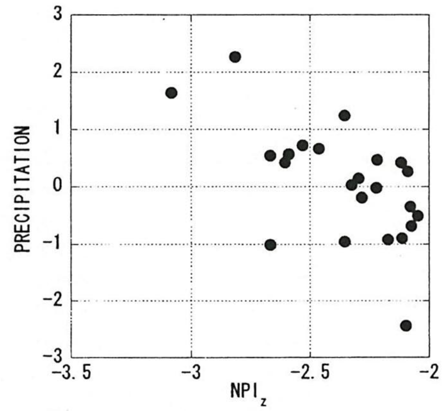

Figure 9. Scatter plot of NPI_z and corresponding precipitation with lag time 6 months in "strong negative condition".

On the other hand, for PDOI, relatively high correlations about 0.4 are detected with the lag times zero, 14, and 15 months under the "strong conditions", and their significance levels are around 1% (Figure 4). However, for NAOI there exist no high correlation coefficients more than absolute value 0.3 for any lag time and category (Figure 6).

We focus on the scatter plots for the correlations which represent the coefficients of –0.47 for SOI and –0.62

for NPI_z (Figure 8 and 9). There are definitely clear tendencies. The scatter plot in Figure 8 shows that the stronger the positive condition (La Niña event), the less precipitation in Fukuoka 4 months later we expect. From Figure 9, we can clearly see the tendency in which the stronger the negative condition of NPI_z, the more the precipitation in Fukuoka with 6 months lag time is depicted.

4 CONCLUSION

In this study, the cross-correlation between monthly values of the four indices (SOI, PDOI, NPI and NAOI) and normally standardized precipitation in Fukuoka, Japan is investigated in detail using 113 years of precipitation data. Scatter plots for very strong correlation with statistical significance level more than 1% were drawn to find out the general tendencies of precipitation in Fukuoka under the influence of various atmospheric-oceanic phenomena.

The main conclusions obtained from this study are as follows. For the original time series, the correlation between four indices and precipitation are almost zero for any lag times, even though some correlation coefficients have higher significance level than 1%. However, quite strong correlations with high significance level are obtained when using indices categorized into five groups according to their magnitudes. In particular, very strong correlations are detected between two indices (SOI and NPI_z) and precipitation in Fukuoka under the "strong condition" categories. The strongest correlation for SOI revealed the coefficient of –0.47 with lag time 4 months under the "strong positive condition". Remarkably, the correlation between NPI_z and precipitation shows very high coefficient of –0.62, whose significance level is even higher than 0.2%, for the lag time 6 months under the "strong negative condition".

For NAOI there exist no high correlation coefficients more than absolute value 0.3 for any lag time and category. This might results from the far distance between the region where the index is originated from and Fukuoka.

From the results of the scatter plots, the following tendencies are obtained: the stronger the positive condition for SOI (La Niña event), the less precipitation in Fukuoka 4 months later we expect; the stronger the negative condition of NPI_z, the more the precipitation in Fukuoka with 6 months lag time is depicted.

It may be possible to explain the physical reasons behind the above mentioned conclusions from the viewpoint of shifts of atmospheric pressure and oceanographic 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 area, Fukuoka in Japan, 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 atmospheric-oceanic phenomena on the local climate.

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