# RELATIONSHIP BETWEEN ATMOSPHERIC-OCEANIC INDICES AND PRECIPITATION DURING HEAVY RAIN SEASON IN FUKUOKA, JAPAN

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**Abstract**

Climate change and extreme weather have affected human beings. One of the most crucial issues of global climate change is its affect on water resources. In particular, evaluation of the relationships between climate change and rainfall is indispensable in order to minimize the harm of droughts and heavy rains.

The conditions of climate can be represented by atmospheric-oceanic indices, those are for example Southern Oscillation index (SOI), Pacific Decadal Oscillation Index (PDOI), North Pacific Index (NPI) and Dipole Mode Index (DMI).

This study investigates the relationship between the four atmospheric-oceanic indices and the precipitation during heavy rainfall season in the city of Fukuoka, located in the northern part of Kyushu, Western Japan. Correlation analysis showed August rainfall had rather high correlation with June SOI and February NPI. Above and below normal amount of August rainfall appeared to have some relationship with the phase of SOI and NPI.

*Keywords*: August rainfall; SOI; PDOI; NPI; DMI; Cross-correlation

## 1. INTRODUCTION

The latest years have displayed a considerable interest in the relationships between global atmospheric-oceanic phenomena and local water resources. Qualitative and quantitative analyses of these phenomena and their influence on local hydro-meteorological events are important to predict future available water resources. Global atmospheric-oceanic phenomena can be represented using atmospheric-oceanic indices. Some of them are Southern Oscillation Index (SOI), Pacific Oscillation Index (PDOI), North Pacific Index (NPI), and Dipole Mode Index (DMI) (see e.g. Kawamura *et al*., 2003 and 2004). Especially, the impacts of El Niño Southern Oscillation (ENSO) phenomenon on climate are widespread and beyond the tropical

Pacific, a phenomenon known as teleconnection. There are many studies on the relationship between SOI and local hydro-meteorological phenomena. However, much less studies about the influence of the other proposed indices on local events have been carried out, especially ones aiming at Japan region.

The rainfall data in Fukuoka city, which is located in the northern part of Kyushu Island in Japan, is used in this study. Fukuoka city is vulnerable to drought and the city has been affected by severe droughts in 1978 and 1996 (for details refer to Kawamura and Jinno). Therefore the analysis of rainfall in this city is vitally important.

The objective of this study is to investigate the statistical relationship between four indices mentioned above and rainfall in Fukuoka city. Cross correlation analyses between those four indices and the rainfall during heavy rain season in Fukuoka city are conducted in this study.

## 2. DATA

In this study, Southern Oscillation Index (SOI), Pacific Decadal Oscillation Index (PDOI), North Pacific Index (NPI) and Dipole Mode Index (DMI) are used as global climate change indicators to investigate the relationship between global climate change and precipitation in Fukuoka city.

### 2.1 PRECIPITATION IN FUKUOKA

Precipitation in Fukuoka has been recorded since January 1890. Fig. 1 shows average precipitation, standard deviation, maximum, and minimum monthly precipitation (January – December). From Fig. 1, we can see that June, July, August and September have notably high precipitation. Accordingly, precipitation from June to September is comparatively important in term of the reliable supply of water. Hence the summed rainfall from June through September was firstly used for this study. Monthly rainfall and the summed rainfall are not

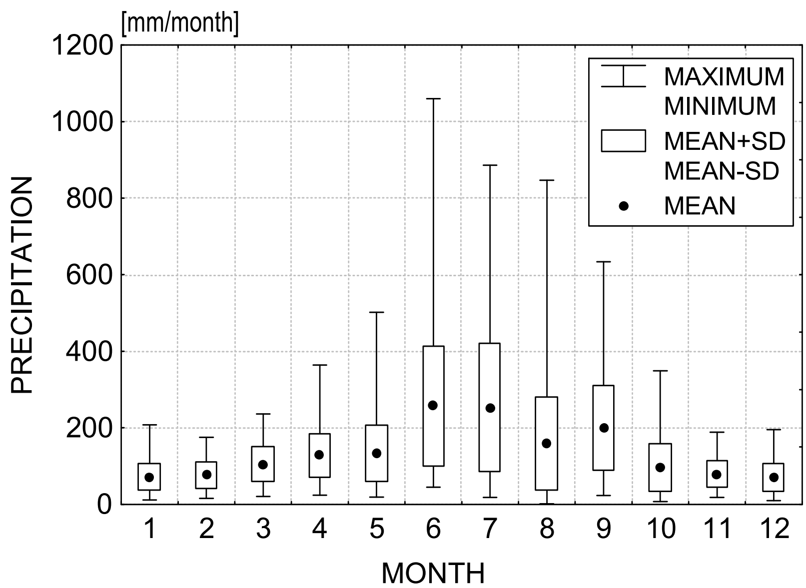


Fig. 1 Mean, standard deviation, maximal and minimal monthly precipitation in Fukuoka, Japan (1=January, 12=December)

normally distributed but skewed. Thereby, cubic root transformation was firstly conducted to normalize the data. Then, the normalized rainfall was standardized to a mean of zero and a standard deviation of one.

### 2.2 SOI

Southern Oscillation (SO) is one of the well known atmospheric phenomenon. The SO is an atmospheric see-saw process in the tropical Pacific sea level pressures between the eastern and western hemispheres associated with the El Niño and La niña oceanographic features. The oscillation can be characterized by a simple index, the Southern Oscillation Index (SOI). (e.g. Kawamura *et al*., 1998). The feature is known as the El Niño Southern Oscillation (ENSO) phenomenon.

The SOI was derived from 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 had carefully filled 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).

### 2.3 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].

### 2.4 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 were normalized on the monthly basis and the normalized NPI (denoted as $NPI_z$) were used in this study. The NPI data since 1899 were obtained from the website of UCAR (University Corporation for Atmospheric Research) [http://www.ucar. edu/ucar/index.html].

### 2.5. DMI

Saji et al (1999) have reported a dipole mode in the Indian Ocean: a pattern of internal variability with anomalously low sea surface temperatures off Sumatra and high sea surface temperatures in the western Indian Ocean, with accompanying wind and precipitation anomalies. The intensity of the dipole mode can be defined using the Dipole Mode Index, which index describes the difference in the sea surface temperature anomaly between the tropical Indian Ocean (50°E-70°E, 10°S-10°N) and the tropical south-eastern Indian Ocean (90°E-110°E, 10°S-Equator).

## 3. RESULTS AND DISCUSSIONS

### 3.1 CROSS-CORRELATIONS FOR THE TOTAL RAINFALL FROM JUNE TO SEPTEMBER

Firstly, cross-correlations between SOI, PDOI, $NPI_z$, DMI and the summed rainfall from June to September for lag -1 to -12 months were conducted (Fig. 2). For example, the correlations for lag -1 month in figure 2 shows the correlation coefficients between each index in May and the summed rainfall from June to September. While the total rainfall showed the correlation coefficients larger than 0.2 for June NPI of the previous year and May SOI in the same year, there was no data which manifested the significance level less than 1%.

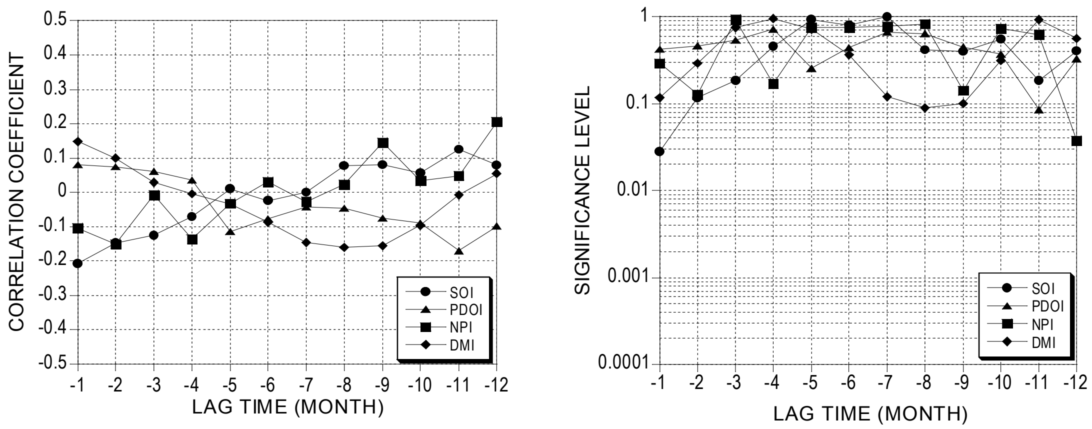


Fig. 2 Cross-correlation between the summed rainfall from June through September and corresponding SOI, PDOI, $NPI_z$ and DMI with its significance level

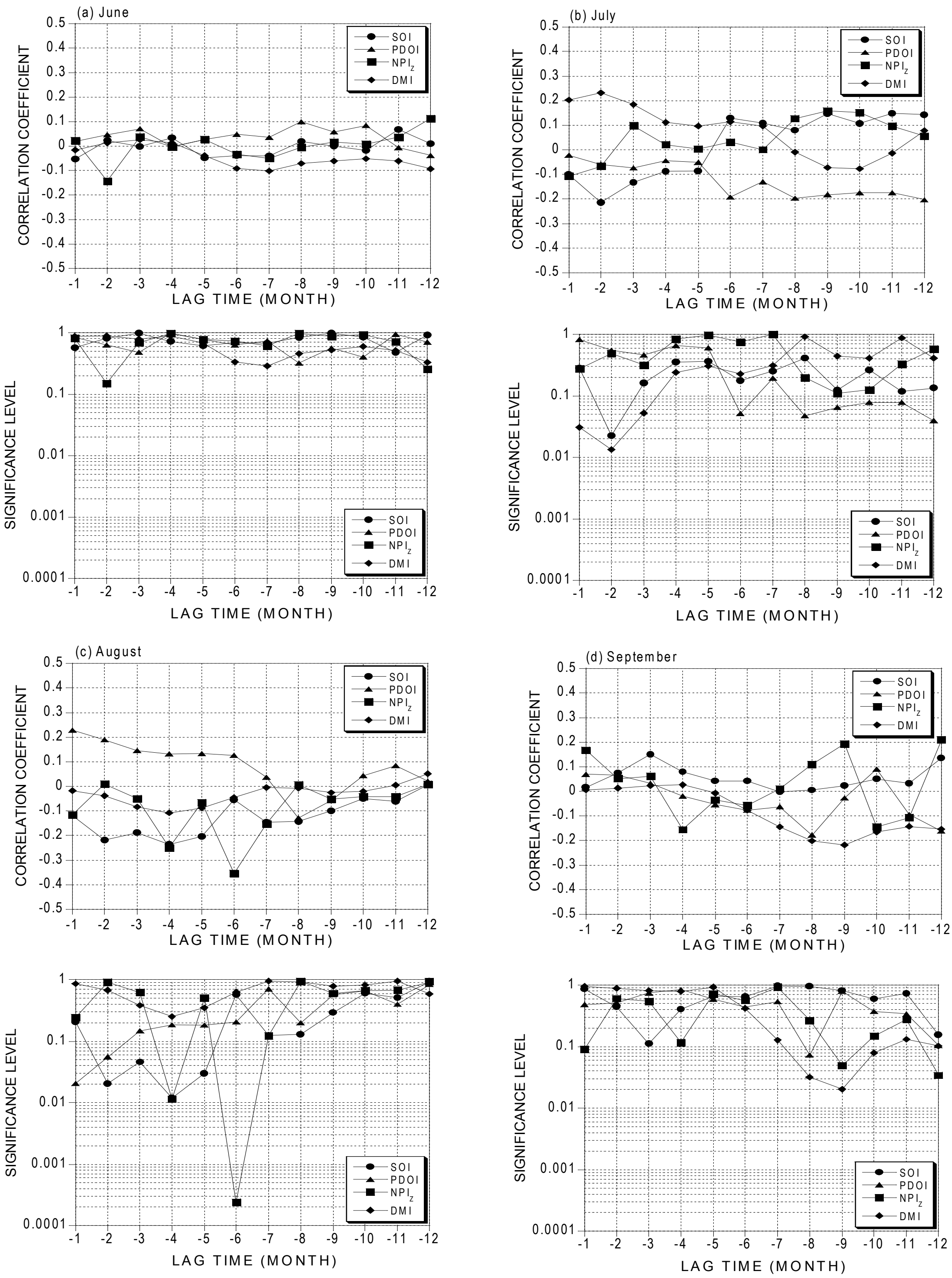


Fig. 3 Cross-correlation between rainfall in (a) June, (b) July, (c) August, (d) September and SOI, PDOI, $NPI_z$, DMI with its significance level

## 3.2 CROSS-CORRELATIONS FOR MONTHLY RAINFALL

Secondary, cross-correlations between the four indices (SOI, PDOI, NPI and DMI) and monthly rainfall from June to September were computed. Fig. 3 shows cross-correlation between rainfall in (a) June, (b) July, (c) August, (d) September and corresponding SOI, PDOI, NPI and DMI. As is seen from the figure 3, most of the correlation coefficients did not satisfy 1% significance level. However, August rainfall showed the correlation coefficient of

-0.35 for February NPI, satisfying 1% significance level. Also, correlation between August rainfall and June SOI (r= -0.21), April SOI (r=-0.23), April NPI (r=-0.24) showed the fairy high negative correlations, which were less than -0.2.

### 3.3 PARTIAL CORRELATION FOR AUGUST RAINFALL

The above analysis showed that correlation coefficients between August rainfall and SOI, NPI have higher correlation coefficients compared with the correlation for June, July and September rainfall. As the next step, stepwise partial correlation was conducted for August rainfall and SOI, PDOI, NPI and DMI. 48 data, which are lagged data ($\tau$=-1 to -12) of the four indices, were used for stepwise correlation analysis against rainfall in August. Partial correlation coefficients for step 1 through step 15 are shown in Fig. 4. The results of stepwise partial correlations reveals that NPI lagged by 6 months and SOI lagged by 2 months, which data are inputs for step 1 and 2, have partial correlation coefficients of -0.35 and -0.23 satisfying nearly 1% significance level, respectively.

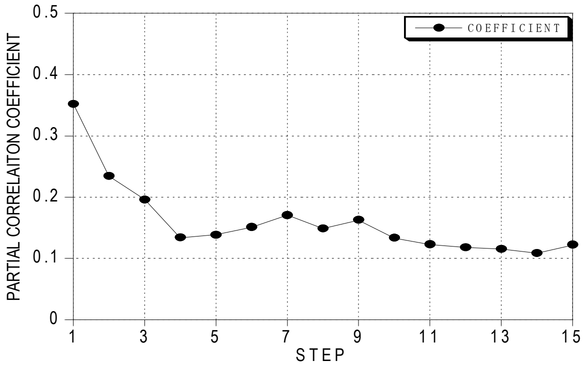


Fig. 4 Stepwise partial correlation between August rainfall and lagged SOI, PDOI, $NPI_z$ and DMI (48 inputs)

### 3.4 SOI AND NPI FOR ANOMALOUS RAINFALL IN AUGUST

Fig. 5 and 6 show scatter plot for August rainfall and June SOI, February NPI, which showed high correlation coefficients for stepwise partial correlation analysis. Fig. 5 and 6 represent the inverse relationship between August rainfall and June SOI, February NPI

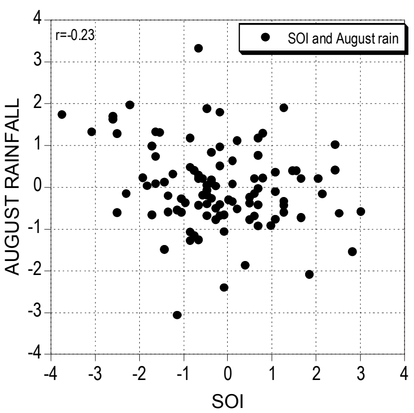


Fig. 5 scatter plot for August rainfall and June SOI

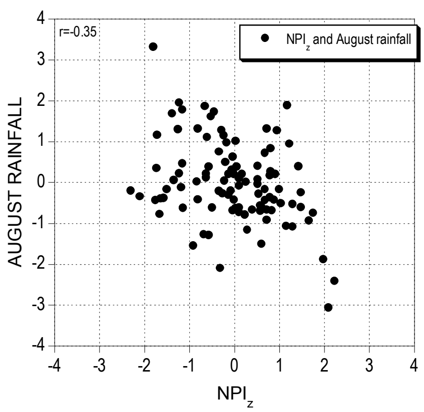


Fig. 6 scatter plot for August rainfall and February $NPI_z$

respectively.

Because our interest is not in usual amount of rainfall, but rather in the anomalous amount of rainfall, here we determined the normalized cube root August rainfall greater than 1 as above normal and less than -1 as below normal. Fig. 7 shows the scatter plot for June SOI and February NPI under the condition that August rainfall is greater than 1.0. It should be noted that the data under the condition that August rainfall is greater than 1.5 is colored in black. As is shown in Fig. 7, when the amount of August rainfall is above normal, both SOI in June and NPI in February tend to have negative value. Fig. 7 implies when August rainfall is greater than 1.5, both June SOI and February NPI are more likely to have negative values. Fig. 8 shows the scatter plot for June SOI and February NPI under the condition that August rainfall is less than -1.0 (below normal). It should be noted that the data under the condition that August rainfall is less than -1.5 is colored in black. Fig. 8 suggests when the amount of August rainfall is unusually low (less than -1.5), either SOI in June or NPI in February tend to have extremely high value.

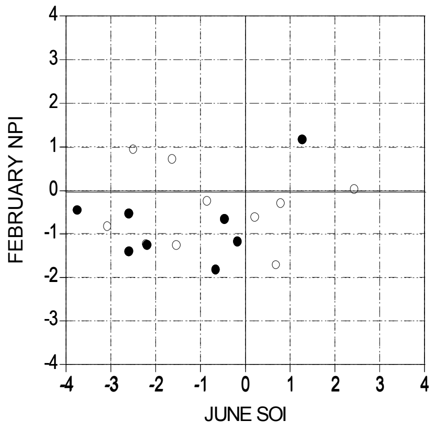


Fig. 7 The scatter plot for June SOI and February NPI when normalized cube root August rainfall is greater than 1.0 (The data under the condition that August rainfall is less than 1.5 is colored in black)

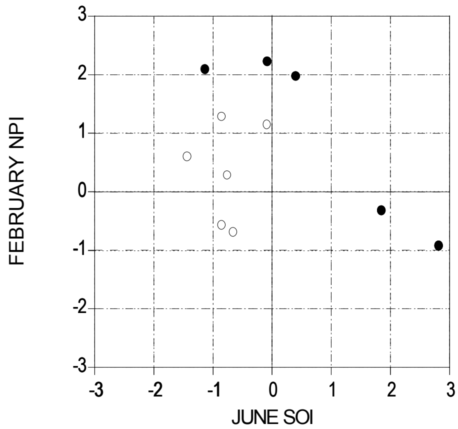


Fig. 8 The scatter plot for June SOI and February NPI when normalized cube root august rainfall is less than -1.0. (The data under the condition that August rainfall is less than -1.5 is colored in black.)

## 4. CONCLUSIONS

In this study, cross-correlation analyses between normally standardized monthly rainfall from June to September and four atmospheric-oceanic indices were conducted using up to 113 years of precipitation data. Summed rainfall from June through September did not show any significant correlations for four indices. Correlation between June, July, September rainfall and four indices showed no significant relationships. However, August rainfall showed rather high negative correlations with April SOI, June SOI and February NPI.

It was implied that when August rainfall is greater than usual years, both June SOI and February NPI tend to have negative values. When the amount of August rainfall is severely low, either June SOI or February NPI in the same year is likely to have remarkably high values.

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