

Statistical Characteristics of Southern Oscillation and its Barometric Pressure Data

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ABSTRACT: The impacts of El Niño Southern Oscillation (ENSO) phenomenon on climate are widespread and extend far beyond the tropical Pacific. The phenomenon can be characterized by Southern Oscillation Index (SOI) which is derived from values of the monthly mean sea level pressure barometric difference between Tahiti and Darwin, Australia. Its best-known extreme is the El Niño event. In this study, general statistical characteristics of SOI and the data from which it is derived (i.e. mean sea level pressure data at Tahiti and Darwin) are presented as guidance when using SOI for other analyses. The characteristics include the availability of the barometric pressure data, statistics of monthly pressure data, correlation of SO intensity, frequency analysis of SOI by magnitude and by month (January-December), duration properties of SOI by run analysis.

1 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 interval of 2-7 years. In the opposite La Niña condition, the temperature is lower than normal. The impacts of these features on climate are widespread and extend far beyond the tropical Pacific (Sakurai (1998), Japanese Study Group for Climate Impact & Application (1999)). Southern Oscillation 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 (Sakurai (1998)). The oscillation can be measured by a simple index, the Southern Oscillation Index (SOI) (Kawamura et al. (1998)) which is used by NOAA (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. There are many research papers on the relationship between SOI and hydro-meteorological phenomena (e.g., Ropelewski and Halpert (1987), Halpert and Ropelewski (1992), Uvo et al. (1998), Yoshino (1999)). The authors have described the chaotic characteristics of SOI (Kawamura et al. (1998)) and the correlation between SOI and precipitation and temperature data in Fukuoka, Japan (Eguchi et al. (2000a, b), Kawamura et al. (2000a, b), (2001)). However, the properties of the barometric data from which SOI is derived (i.e. mean sea level pressure data at Tahiti and Darwin) and general statistical characteristics of SOI have not been published, as far as the authors know.

We have published autocorrelation and spectral characteristics of SOI (Kawamura et al. (1998)), so that in this study, other statistical characteristics of SOI and the barometric pressure data are presented. Firstly, the availability of the monthly mean sea level pressure data at Tahiti and Darwin, the statistics of the monthly pressure data, and the correlations between Tahiti and Darwin pressure anomalies are presented. Next, the characteristics of SOI, including frequency analysis of SOI by magnitude and by month (January-December), and duration properties of SOI by run analysis are discussed. We expect that these characteristics will offer useful background information when using SOI for other analyses.

2 AVAILABILITY OF THE PESSURE DATA AT TAHITI AND DARWIN

SOI values are calculated using the monthly mean sea level pressure (MSLP) data at Papeete, Tahiti (149.6°W, 17.5°S.) and Darwin, Australia (130.9°E, 12.4°S). Those MSLP pressure data since 1882 are available through web cites such as NOAA Network Information Center. However, some missing values exist for the Tahiti pressure data as shown in Table 1. Ropelewski and Jones (1987) infilled all missing values using newly found old pressure data in Tahiti. Furthermore, by supplementing and interpolating the data of Tahiti before 1882, they completed the pressure time series since 1866.

Allan et al. (1991) also infilled the pressure data in Darwin before 1882 by interpolating using the older records and by correlation with data from other observation stations. As the result, the pressure data in Darwin are also complete since 1866.

In this study, we use the monthly MSLP data of 134 years (1608 months) from January 1866 to December 1999 at Tahiti and Darwin, acknowledging that the reliability of the pre-1935 pressure data may be slightly less than the later data (Ropelewski and Jones (1987)).

Table 1. MSLP data missing periods at Tahiti.

Missing Period		Missing Months
From	To	
Sep 1892	Dec 1895	40
Mar 1906	May 1906	3
Dec 1906	Aug 1908	21
Apr 1914	Sep 1914	6
Nov 1914	Oct 1915	12
Mar 1921	Jun 1921	4
Jun 1927	Aug 1927	3
Aug 1931	Aug 1932	13

3 CHARACTERISTICS OF MSLP DATA

Fig. 1 shows the mean values and their standard deviations of monthly MSLP for each month (January-December) at Tahiti and Darwin for 134 years data. The mean values of MSLP are higher in the summer season of northern hemisphere and lower in the winter season for both sites. The difference between the highest and the lowest mean values is 6.8 hPa at Darwin, which is about twice as much as that (3.7 hPa) at Tahiti. The standard deviations are larger in January-March and smaller in April-June for both sites.

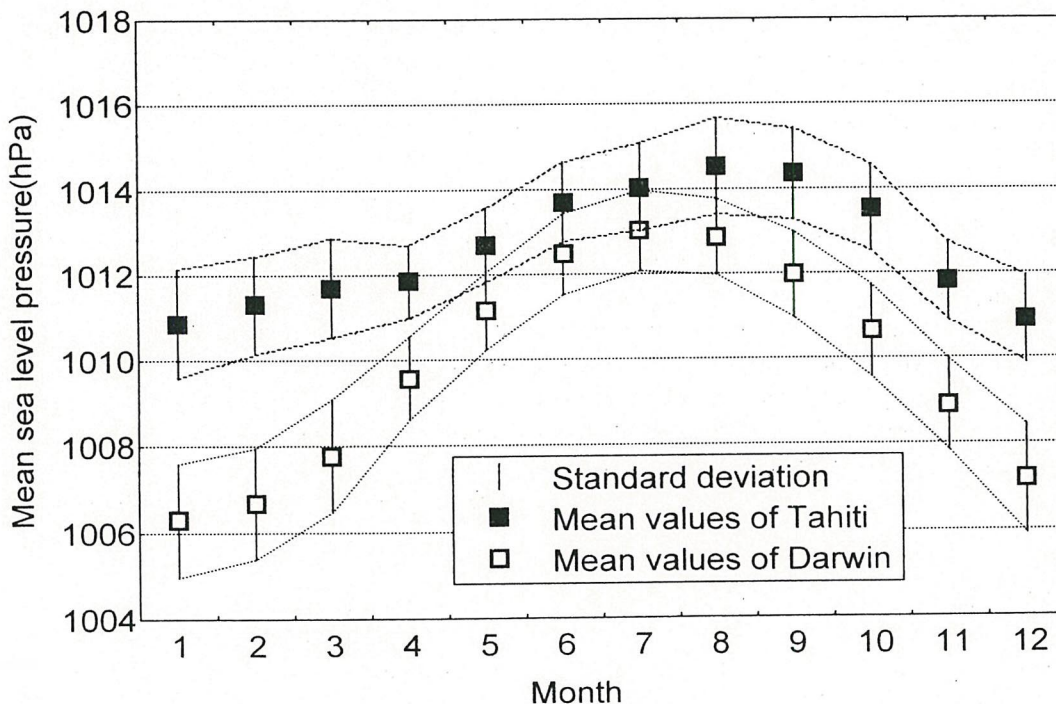


Fig. 1. The mean values and their standard deviations of monthly MSLP for each month (January-December) at Tahiti and Darwin for 134 years data.

Fig. 2 shows the average values, their standard deviations, maximum and minimum values of MSLP difference between Tahiti and Darwin for each month (January-December). From the figure, the average values of MSLP differences are positive for all months, but they are close to zero in the northern hemisphere summer. The mean minus standard deviation values are negative in June and July. The minimum values are negative for all months.

To check the reliability of the MSLP data, we divided the series into two groups, 1866-1934 (69 years), and 1935-1999 (65 years). The average values and their standard deviations for both groups are almost same. The mean value of the difference of monthly average values is 0.18 hPa, and the mean value of the standard deviations is 0.13 hPa.

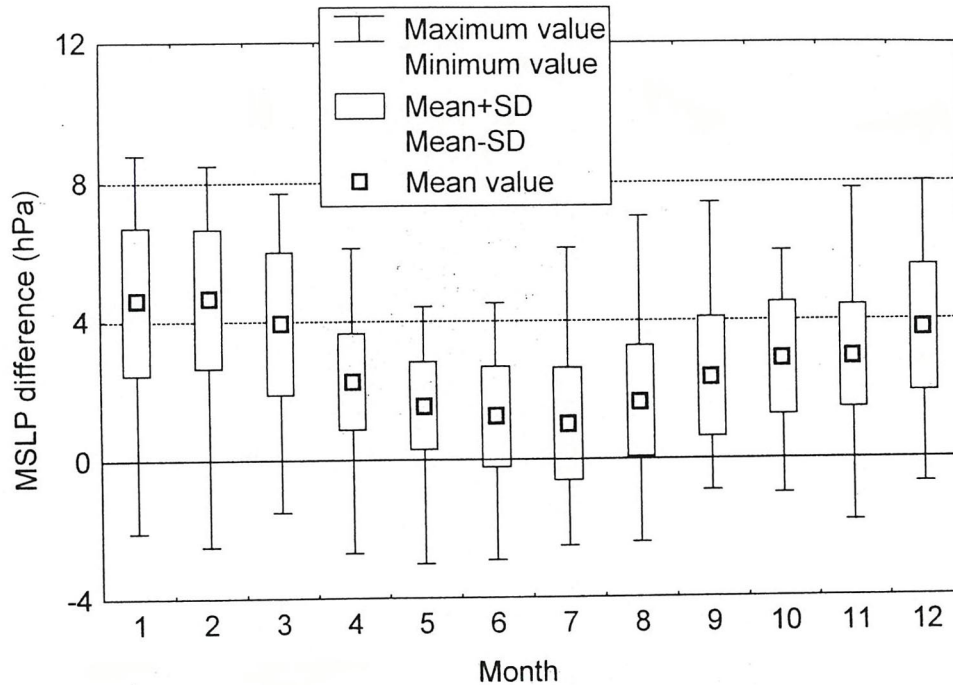


Fig. 2 Average values, standard deviations, maximum and minimum values of MSLP difference between Tahiti and Darwin for each month (January-December).

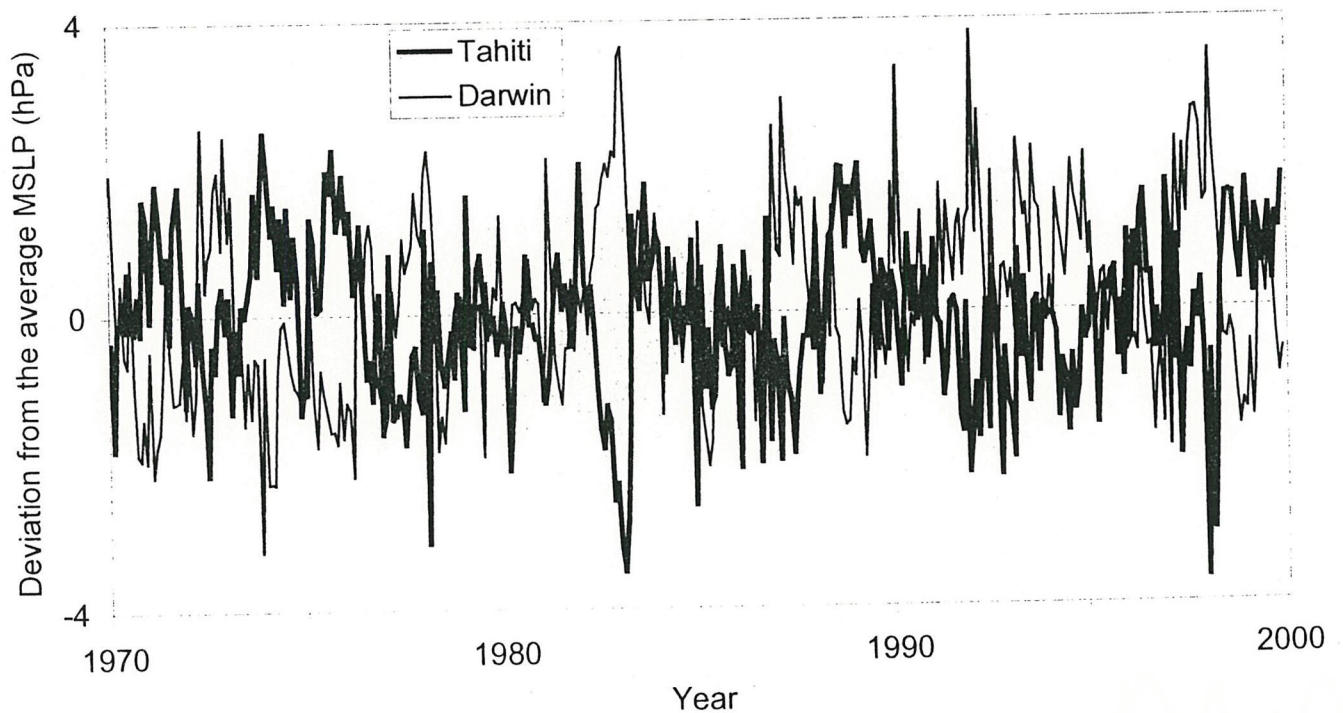


Fig. 3. Deviation time series from the average MSLP for the recent 30 years.

4 CROSS-CORRELATION OF TAHITI AND DARWIN PRESSURE DEVIATIONS

Deviation time series from the average MSLP of each month (January-December) are shown in Fig. 3 for the last 30 years. From this figure, we can see a clear tendency that when the pressure deviations rise above the monthly averages at Tahiti, the pressure deviations at Darwin fall below the monthly averages, and vice versa. This phenomenon was discovered by Sir Gilbert Walker for early in the 20th century, and it was named Southern Oscillation.

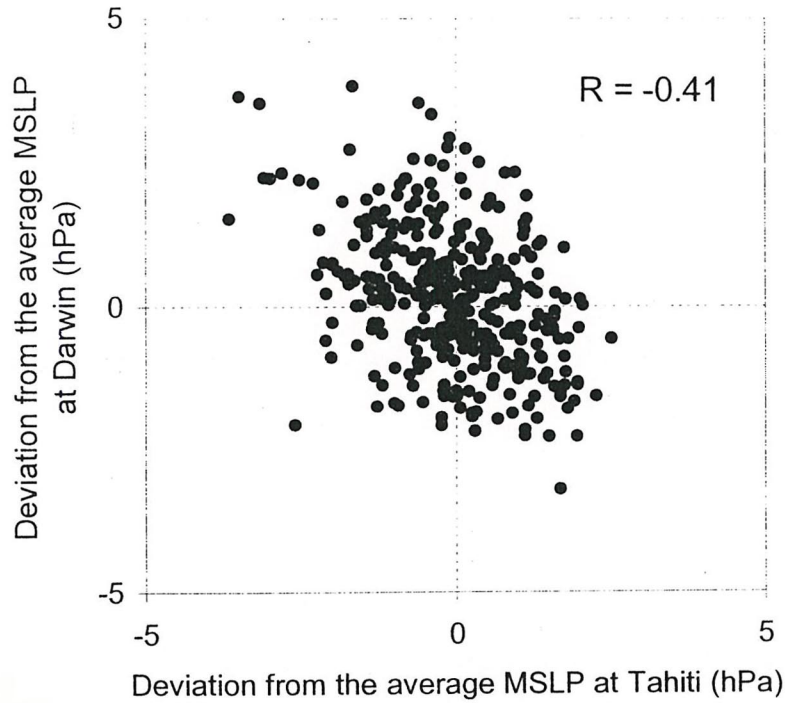


Fig. 4. Scatter plots for Fig. 3.

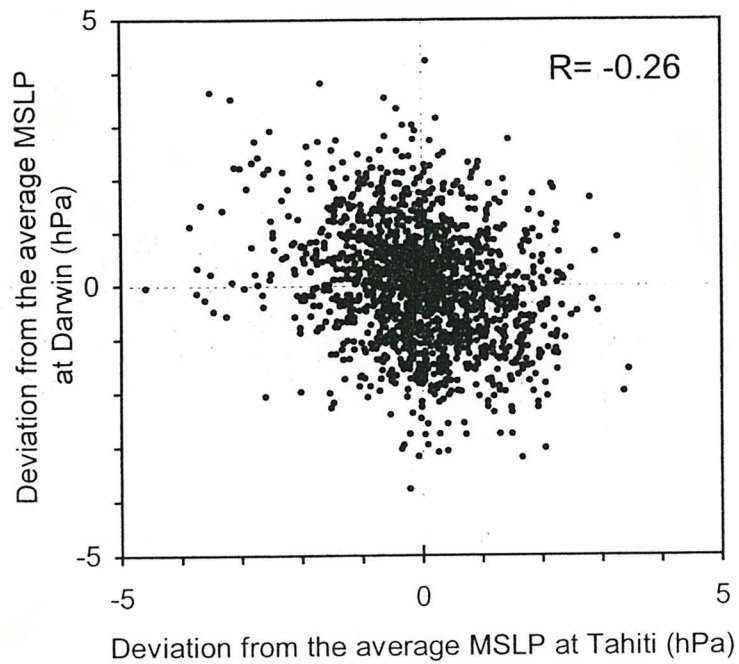


Fig. 5. Scatter plots of deviation from the average MSLP for the whole 134 years.

Fig. 4 shows the scatter plots for Fig. 3, i.e., the relationship between pressure deviations from the average MSLP at Tahiti and Darwin. From this figure, we can obtain the cross-correlation coefficient of -0.41 for the most recent 30 years. The correlation is not so high as we expect. For the whole series (Fig. 5), the correlation coefficient of pressure deviations is -0.26 which is even smaller. However, note that the significant level of those correlation coefficients is extremely high because of the large number of the data. In other words, when the statistical hypothesis test is executed, the null hypothesis of “correlation coefficient = 0” is easily rejected at the significant level of 0.001%. Also, the correlation coefficient becomes larger when the Darwin data are lagged by one month lag: it becomes -0.29 for the whole data.

5 CALCULATION OF SOI

Two commonly used methods to compute the SOI from the MSLP data at Tahiti and Darwin are Troup's method and the Climate Prediction Centre's method. The difference between two methods is very small as pointed out by McBride and Nicholls (1983), Ropelewski and Jones (1987) and Kawamura et al. (1998). In this study, we use Troup's method (Troup (1965)). The $SOI(y,m)$ in year y , month m (m =January to December) is calculated by the following equation;

$$SOI(y,m) = [\{P_T(y,m) - P_D(y,m)\} - M_{30}(m)] / S_{30}(m) \quad (1)$$

Here, $P_T(y,m)$, $P_D(y,m)$ = MSLP (hPa) at Tahiti and Darwin, respectively ; $M_{30}(m)$, $S_{30}(m)$ = the mean value (hPa) and its standard deviation (hPa) of MSLP difference between Tahiti and Darwin (cf. Fig.2) for the base period of 30 years (usually 1951-1980). As is indicated in Eq. (1), SOI is expressed as the MSLP difference series between Tahiti and Darwin which is normalized to mean zero and a standard deviation of one. Note that a standard deviation of 10 is also commonly used. Generally, El Niño conditions occur when the SOI is less than -1, and La Niña conditions when the SOI is more than 1. Strong El Niño/La Niña conditions prevail when the SOI absolute value exceeds 2. Fig. 6 shows the SOI time series for the recent 30 years. From this figure, strong El Niño events are found in 1982/1983 and 1997/1998.

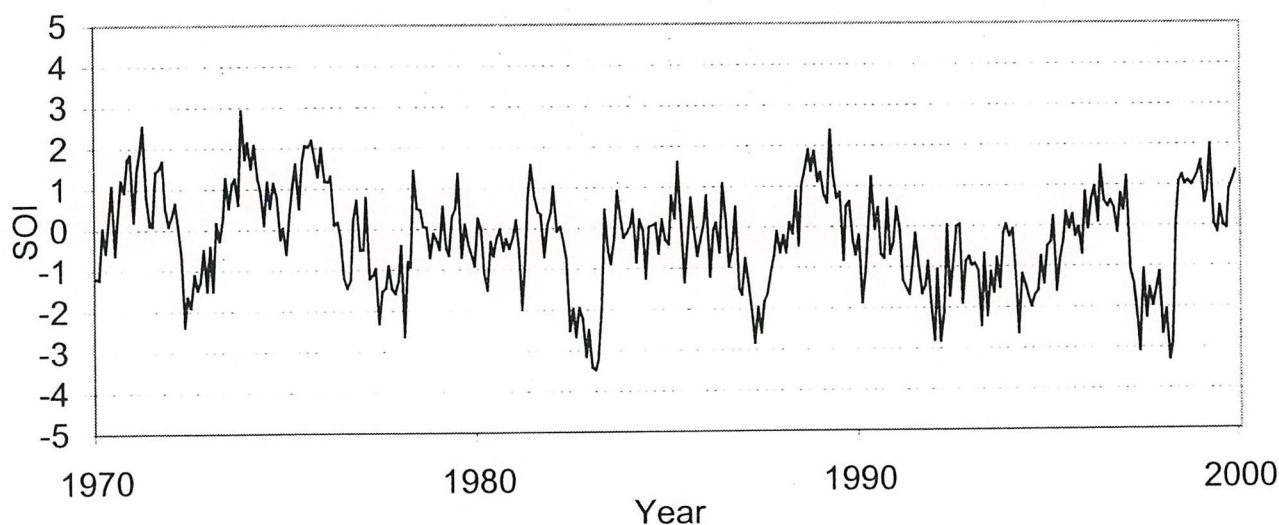


Fig. 6. SOI time series for the recent 30 years

6 FREQUENCY CHARACTERISTICS OF SOI

There are several papers in which SOI values are classified into some categories according to their magnitudes, and the relationship between the categorized SOI and hydro-meteorological elements are studied (e.g., Moss et al. (1994), McKerchar et al. (1998); Eguchi et al. (2000a, b), Kawamura et al. (2000a, b), (2001)) In this section, as the base of those research, frequency analysis of classified SOI is studied.

Fig. 7 shows the histogram SOI data of 1608 months. It looks normally distributed as expected. However, frequencies of the negative values are larger than those of positive values except for the case that the absolute values are less than 0.5. For example, the frequency less than -2 is 69, while the frequency more than 2 is 34, i.e., El Niño tendencies occur more frequently than La Niña tendencies. The tendency becomes more dominant when the SOI time series is smoothed. For example, in the histogram of 5 months moving average time series of SOI (Fig. 8), although the

frequencies themselves more than 2 absolute value decrease, the frequency more than 2 is 8, whereas the frequency less than -2 is 25. The reason using 5 months for moving average is because the Japan Meteorological Agency defines El Niño as the case when the 5 months moving average anomalies of sea surface temperature in the El Niño monitoring area exceed 0.5 degrees and they last more than 6 months. Similarly, La Niña is defined as the case in which the anomalies become less than -0.5 degrees.

Fig. 9 shows cumulative frequency of SOI classified into six categories for each month (January-December) during the past 134 years. From this figure, in spite of the small variation of the frequency of each category from month to month, it may be seen that El Niño and La Niña could occur in any month. However for June the frequencies of more than 2 and less than -2 are extremely high compared with those of other months. Also, the frequencies of more than 1 and less than -1 are much higher, whereas the ratio between -1 and 1 is very low. On the other hand, the frequencies of high absolute values are low in February and May, i.e., the frequency more than 2 for those months are zero, and the frequencies of values less than -1 are less than for other months. The reason for these features relates to seasonality in the evolution of El Niño and La Niña events (Trenberth and Shea (1987)).

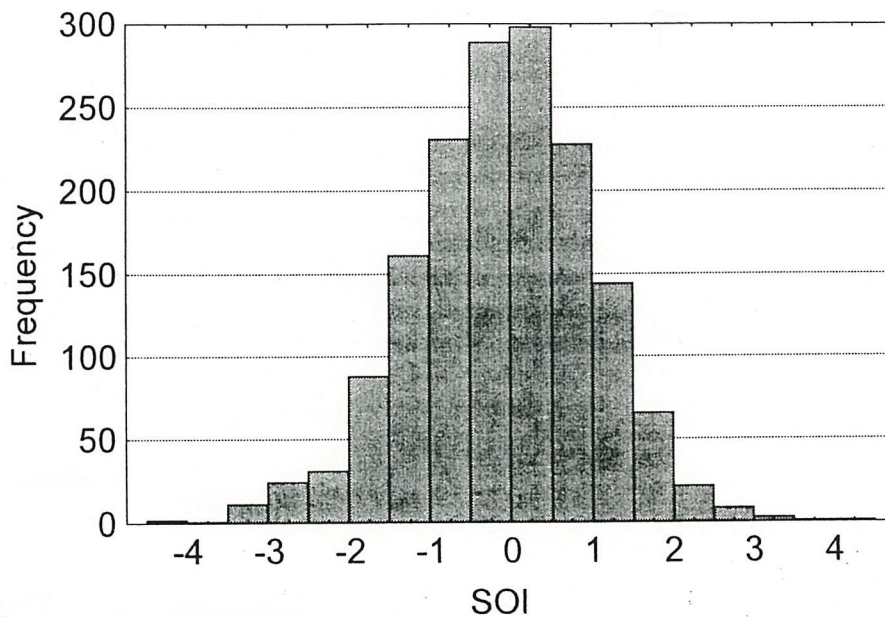


Fig. 7. Histogram of original SOI time series

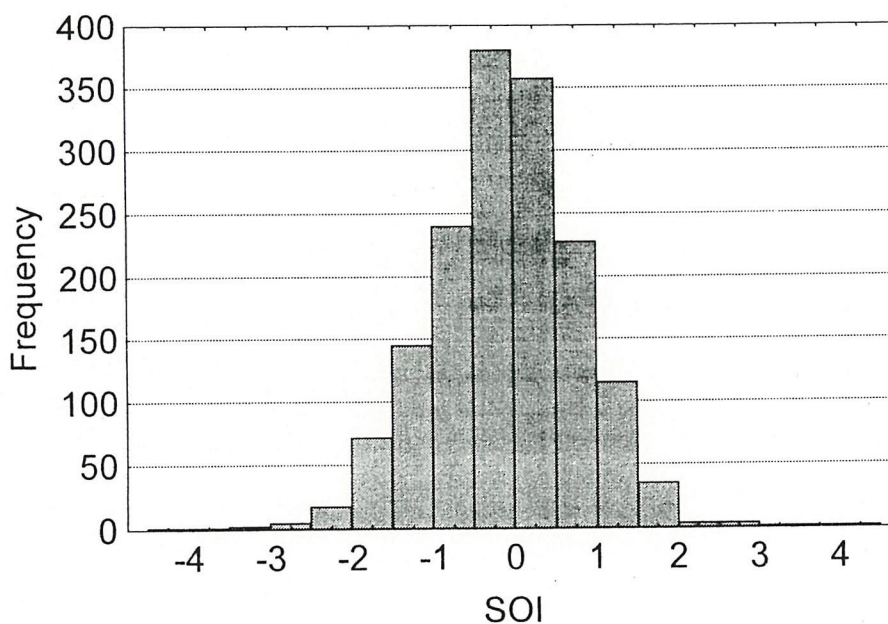


Fig. 8. Histogram of 5 months moving average time series of SOI

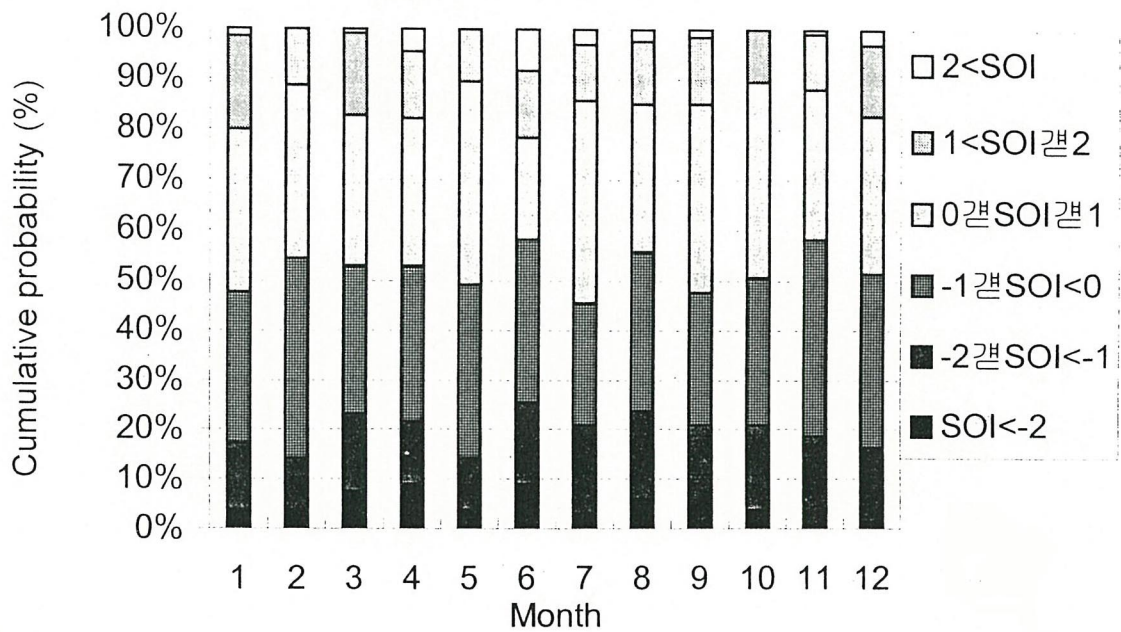


Fig. 9. Occurrence of SOI classified into six categories according to their magnitude

7 DURATION PROPERTIES OF SOI TIME SERIES

In order to investigate the duration properties of SOI, run analysis of the time series is carried out. Fig. 10 shows the histogram of positive run length (La Niña side) and negative run length (El Niño side). Positive run length is defined by the number of consecutive months in which the positive values of SOI continue, and similarly, negative run length is for the negative values. From Fig. 10, both positive and negative run length have the biggest frequency at one month, and the frequency decreases drastically with the increase of run length. The average of positive run length is 3.4 months, and 3.7 months for negative run length. The longest negative run length of 33 months is from August 1939 to April 1942. The negative run length for the large-scale El Niño event covering spring 1982 to summer 1983 is 13 months, and 14 months for another large-scale El Niño event covering spring 1997 to summer 1998.

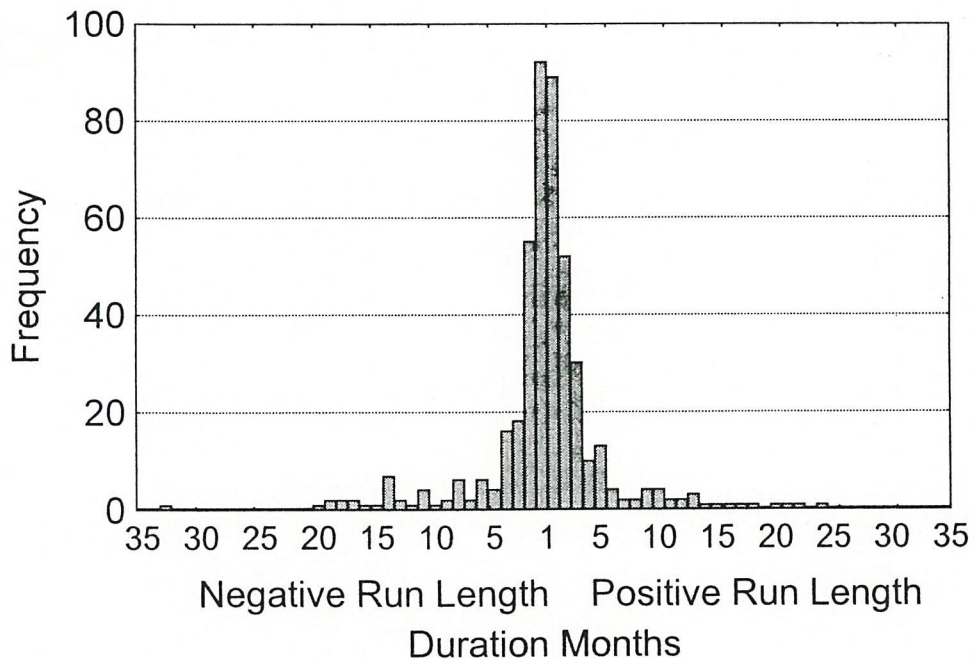


Fig. 10. Histogram of positive and negative run length for SOI time series

Next, the duration analysis is carried out for the case in which the absolute value of SOI is more than 1, which means how many months SOI time series is continuously above one or below minus one. The result is shown in Fig. 11. From this figure, the biggest run length is 14 months of negative side, which corresponds to the 1997/1998 El Niño event. The biggest positive one is 12 months which corresponds to the 1917 La Niña event. Average run lengths are 2.0 and 2.2 months for positive and negative, respectively, in which El Niño side tends to be a bit longer. The similar duration analysis (Fig. 12) is also carried out for the case in which the absolute value of SOI is more than 2, which corresponds to strong El Niño and La Niña. From Figure 12, the biggest run length is 6 months of negative side, which corresponds to 1982/1983 El Niño event, and the biggest positive one is 4 months which corresponds to the 1917 La Niña event. The same tendency of longer duration of El Niño side is obtained.

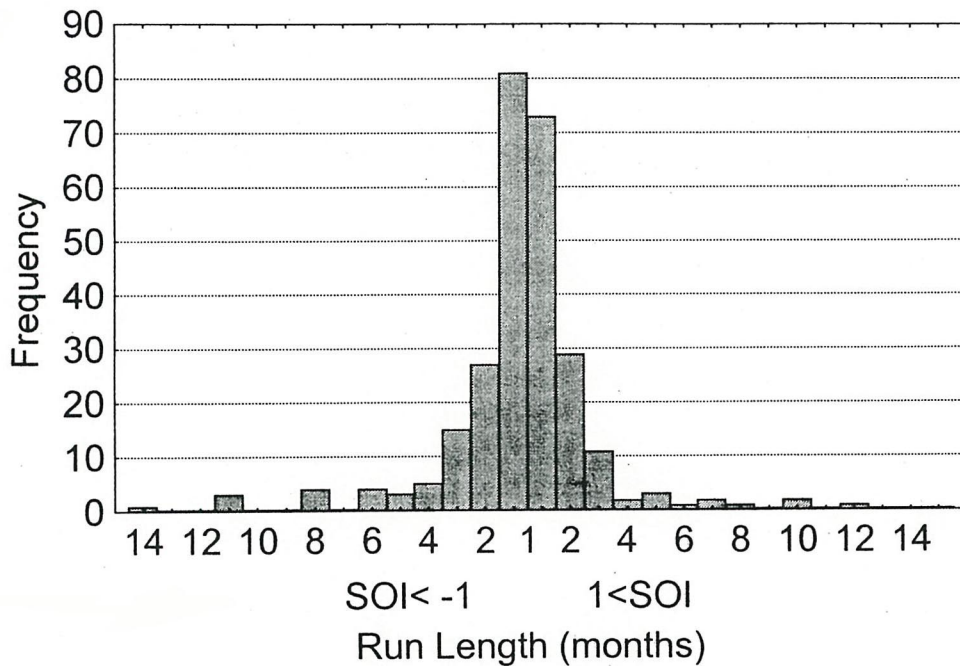


Fig. 11. Histogram of duration analysis result for the case in which the absolute value of SOI is more than 1

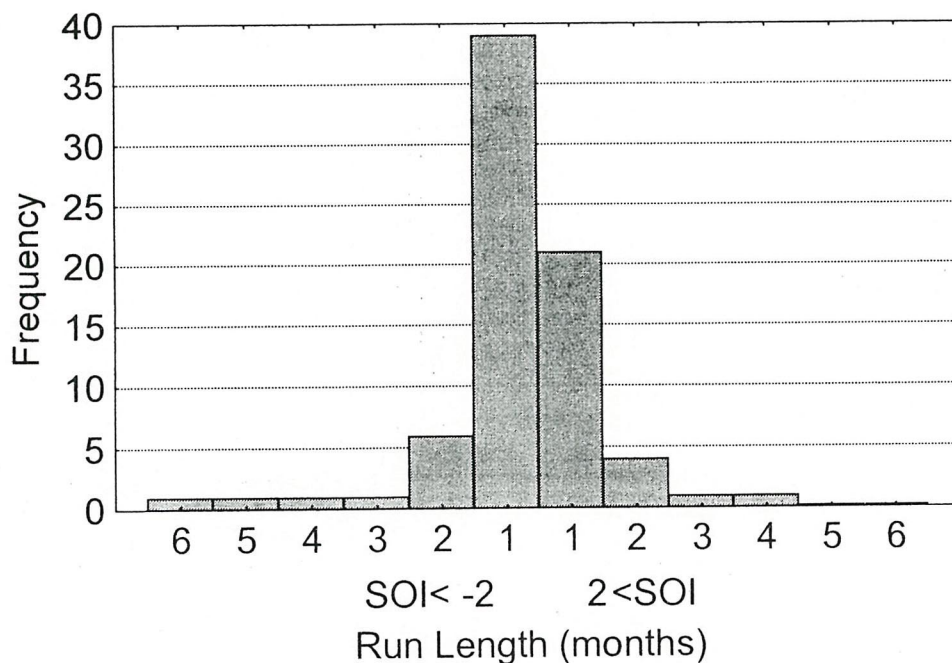


Fig. 12. Histogram of duration analysis result for the case in which the absolute value of SOI is more than 2

In addition, the similar run analyses are carried out for 5 months moving average SOI time series, and one of the results is shown in Fig. 13. From this figure (compared with Fig. 10), the biggest frequencies are obtained at one month for both positive and negative run length, which is the same result as in Fig 10. However, the frequencies themselves decrease especially for negative run length. The average lengths naturally become longer, and they are 9.6, 11.2 months for positive and negative run length, respectively, which indicates El Niño side becomes longer than that of Fig. 10.

In Fig. 13, the longest negative run length of 61 months started from August 1990, whereas the second longest negative begun in March 1911 and lasted 51 months. The longest negative run length of 33 months in Fig. 10 corresponds to 35 months in Fig. 13 with almost no increase of run length. As the result, the order of the run length periods does not correspond well between SOI time series (Fig. 10) and its 5 months moving average time series (Fig. 13).

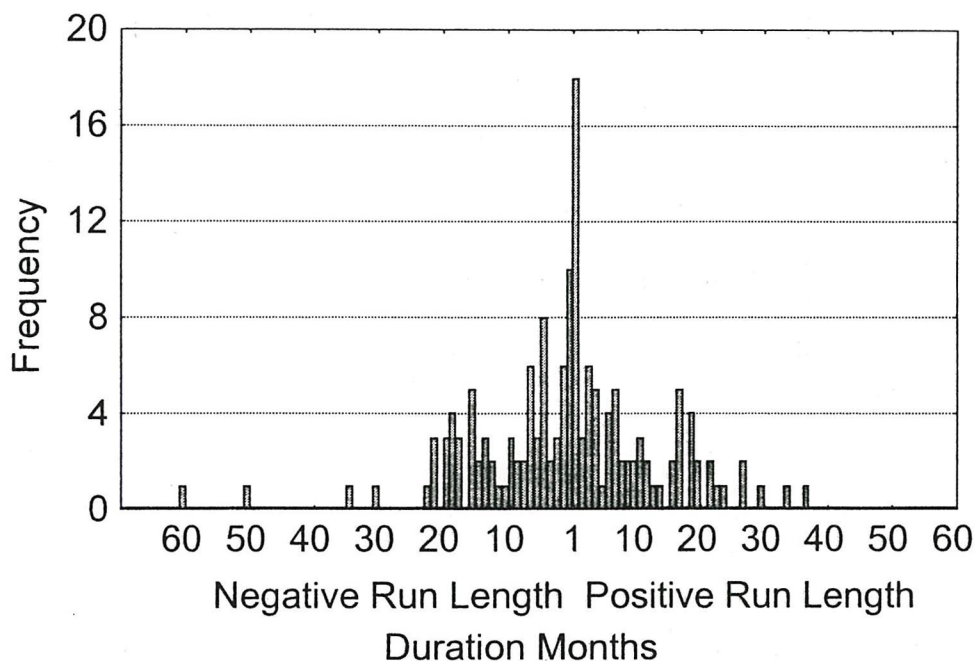


Fig. 13. Histogram of positive and negative run length for 5 months moving average SOI time series

8 CONCLUSIONS

In this paper, firstly the characteristics of MSLP data at Tahiti and Darwin as the base of SOI are investigated. Then, general statistical characteristics of SOI including frequency and duration properties are studied. The conclusions obtained in this study are as follows;

- 1. The consecutive SOI data are available since January 1866. The pre-1935 data may be slightly less reliable.
- 2. The MSLP is higher in the northern hemisphere summer season, and lower in winter season for both Tahiti and Darwin. The range of mean values of MSLP at Darwin is about twice as big as that at Tahiti. The standard deviations of MSLP are largest in January-March and least in April-June for both sites.
- 3. The average values of MSLP difference between Tahiti and Darwin are positive for all months, but they are close to zero in the northern hemisphere summer season.
- 4. Absolute value of the correlation coefficient of Southern Oscillation intensity for the whole period of 134 years is less than 0.3, which is not as high as we expect. However, the significant level of the correlation is extremely high according to the result of statistical hypothesis test. A higher correlation coefficient is obtained when one month lag is considered for the Darwin data.
- 5. The frequency of SOI less than -2 (strong El Niño) is about twice that of SOI more than 2 (strong La Niña).
- 6. The occurrences of SOI more than 2 and less than -2 are remarkably high in June compared with other months, and occurrences between -1 and 1 are relatively low. Extreme values of the SOI are least likely in February and May.
- 7. Both positive and negative run length of SOI time series have the biggest frequency at one month, and the frequency decreases drastically with the increase of run length. Negative run length is longer than positive run length on average. This tendency persists for the absolute values of SOI more than 1 and more than 2.
- 8 For 5 months moving average SOI time series, the frequencies of run length decrease compared with the original SOI time series especially for negative run length. The negative value run length is longer than the positive value run length.

-9 The order of the run length periods does not correspond well between original SOI time series and its 5 months moving average time series.

We expect the results, which are statistical characteristics of SOI, will contribute useful background information when using SOI for other analyses.

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APPENDIX – NOTATION

The following symbols are used in this paper :

- SOI(y,m) = value of SOI in year y, month m(m=January to December)
- PT(y,m), PD(y,m) = Mean Sea Level Pressure (hPa) at Tahiti and Darwin
- M₃₀(m), S₃₀(m) = the mean value (hPa) and its standard deviation (hPa) of MSLP difference between Tahiti and Darwin for the base period of 30 years