ON THE LONG-TERM VARIABILITY OF SOUTHERN OSCILLATION INDEX

Young-Hoon JIN
Graduate student, Institute of Environmental Systems, Kyushu University, Fukuoka, Japan

Akira KAWAMURA
Associate Prof., Institute of Environmental Systems, Kyushu University, Fukuoka, Japan

Kenji JINNO
Professor, Institute of Environmental Systems, Kyushu University, Fukuoka, Japan

Yoshihiko ISERI
Graduate student, Institute of Environmental Systems, Kyushu University, Fukuoka, Japan

Abstract: Recently, there has been considerable interest in the influence of El Niño/Southern Oscillation (ENSO) on a global scale. ENSO has been measured by a simple index called Southern Oscillation Index (SOI). The statistical characteristics of SOI have been also focused to reveal the influence of ENSO. The SOI trend shows that El Niño events are generally getting stronger and more frequently occurring than La Niña events. However, the variation of SOI has varied significantly in a long-term. The SOI values are computed using the mean value and its standard deviation of the base period from 1951 to 1980. In the present study, the different base periods are applied to compute the SOI values and the influence of the different base periods is investigated in detail to reveal the long-term variation of SOI. From the results, we could conclude that the present SOI should be carefully considered as a criterion to judge whether the El Niño and La Niña events are occurring.

1. INTRODUCTION

El Niño refers to the condition in which sea surface temperature rises 1 to 2°C (sometimes 2 to 5°C) above normal and trade wind becomes weak in the eastern and central equatorial Pacific Ocean on a large scale. It lasts 12-18 months typically, and occurs irregularly at the interval of 2-7 years. In the opposite La Niña condition, the temperature is lower than normal. Southern Oscillation (SO) is an atmospheric seesaw phenomenon in tropical Pacific sea level pressure between the eastern and western hemispheres associated with the El Niño and La Niña oceanographic features[1), 2)]. The oscillation can be measured by a simple index, the Southern Oscillation Index (SOI)[3)] which is used by NOAA (National Oceanic and Atmospheric Administra- tion) to judge whether the El Niño and La Niña events occurring[2)]. The features are known collectively as the El Niño Southern Oscillation (ENSO) phenomenon.

The effects of ENSO on climate are widespread and extend far beyond the tropical Pacific, a phenomenon known as teleconnection[1), 2)]. There have been many reports of abnormal weather conditions worldwide which are thought to have been caused by ENSO. These abnormal weather conditions and climatic changes have raised concerns about stable water resources management. As a result, qualitative and quantitative analyses of SO and its influence on local hydro-meteorological phenomena have become a very important research task.

There are many studies on the relationship between SOI and hydro-meteorological phenomena[4), 5), 6), 7)]. The authors have described the chaotic characteristics of SOI[3)] and the correlation between SOI and precipitation and temperature data in Fukuoka, Japan[8), 9), 10)]. The correlation between SOI and precipitation in Pusan, Korea has been also revealed and compared with the correlation in Fukuoka, Japan [11)].

However, the properties of the barometric data from which SOI is derived and general statistical and long-term characteristics of SO have unexpectedly not been published, as far as the authors know. Therefore, we have been researching on the characteristics of the barometric data[12), 13)]. The authors revealed SO intensity, which meant the cross-correlation of Tahiti and Darwin pressure deviations, had been increasing almost consistently since before 1900[13)]. In the present paper, we studied the long-term variability of SOI in which how the base period for calculation of mean value and its standard deviation was affecting.

In the researches mentioned above, the SOI data were computed by Troup's method[14)] by using the mean sea level pressure (MSLP) difference between Tahiti and Darwin. The differences are normalized to a mean of zero and a standard deviation of one by subtracting the monthly mean values and dividing by standard deviations for the base period between 1951 and 1980 in monthly basis (from January to December)[15]. The thirty-year-long base period has been used to obtain an index for the oscillation. As pointed out by Troup[14], the oscillation should not be characterized by any one period but should simply be regarded as an index. From the author's indication, the values for the oscillation can be computed using the mean and standard deviation by the base period, but should be carefully considered when judging whether it is classified into El Niño or La Niña event.

Based on the background described above, firstly, we calculate the MSLP difference between Tahiti and Darwin using the data from 1866 to 2000 in both stations and investigate the differences among the three periods; (1) the present base period, (2) the whole period from 1866 to 2000 and (3) recent thirty years (from 1971 to 2000). Secondly, the long-term variations for each calendar month are studied by surveying the long-term variation of the mean value and its standard deviation with thirty-year moving average. Finally, the results and conclusions drawn from the present study are represented.

2. VARIATION OF SOI BY DIFFERENT BASE PERIODS

SO phenomenon is expressed 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 [*http://www. nnic.noaa.gov/data/indices/*]. Totally 102 months missing values exist for the Tahiti pressure data. However, Ropelewski and Jones infilled all missing values using newly found old pressure data in Tahiti[16]. Furthermore, by supplementing and interpolating the data of Tahiti before 1882, they completed the pressure time series since 1866. Allan et al. also infilled the pressure data in Darwin before 1882 by using the older records and by correlation with data from other observation stations[17]. The pressure data in Darwin are also completed since 1866. As the result, in the present study, we use the long monthly MSLP data of 135 years (1620 months) from January 1866 to December 2000 at Tahiti and Darwin, acknowledging that the reliability of the pre-1935 pressure data may be slightly less than the later data[16].

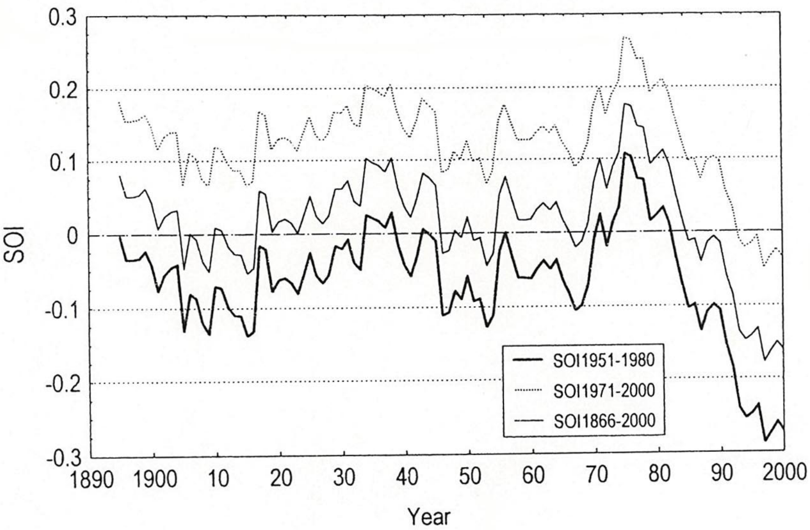

Fig. 1. Time series plot of thirty-year moving average of three different SOI values by the respective means and their standard deviation for the normalization. Thick solid line shows the SOI by the usual base period (1951-1980), while thin solid line for the SOI by the whole period (1866-2000) and dashed line for the SOI by the recent period. Tick marks on the time axis refer to January.

In the present study, we calculated SOI by different means and their standard deviations according to three different base periods, using monthly MSLP data. First, the *SOI(y,m)* in year *y*, month *m* (*m*=January to December) is calculated by the equation below:

$$SOI(y,m) = \frac{\{P_T(y,m) - P_D(y,m)\} - M_{30}(m)}{S_{30}(m)} \qquad (1)$$

Here, $P_T(y,m)$, $P_D(y,m)$ are MSLP data (hPa) at Tahiti and Darwin, respectively; $M_{30}(m)$, $S_{30}(m)$ are the mean value (hPa) and its standard deviation (hPa) of MSLP difference between Tahiti and Darwin for the base period of thirty years (usually from 1951 to 1980). The time series of thirty-year moving average of SOI calculated by the usual period was plotted in **Fig. 1**, which superposed on the plots of other values of SOI averaged for thirty years by the whole and recent periods (explained below). 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. It is generally known that 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 and La Niña conditions prevail when the SOI absolute value exceeds 2.

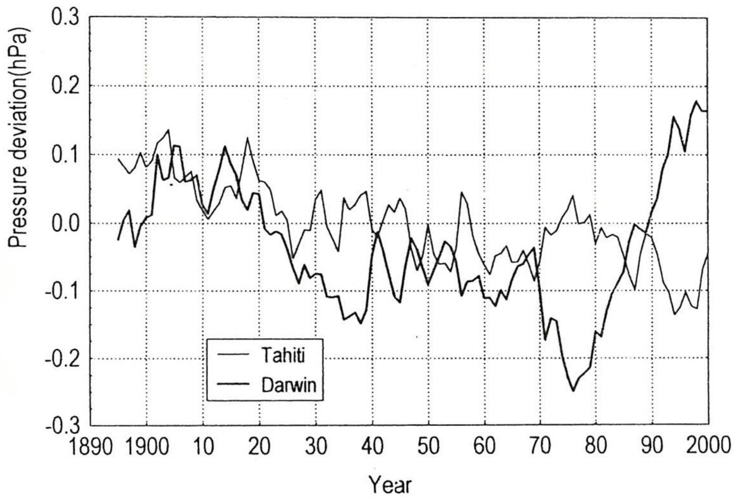

Fig. 2. Thirty-year moving average time series of pressure deviation

On the other hand, we computed the SOI using the means and standard deviations with the different periods for the normalization: the whole period from 1866 to 2000 and the recent thirty years from 1971 to 2000. The values averaged for thirty years were also plotted respectively in **Fig. 1**. As is seen clearly in the figure, the values of the thirty-year moving average of SOI by the whole and recent periods were shifted upward, comparing to the time series plot by the usual period. Especially, the time series of the averages of SOI by the recent period revealed the bigger difference from the values by the usual period than the time series by the whole period. This fact can be interpreted that the variation of the MSLP difference between Tahiti and Darwin is getting bigger with time. The steep descent is seen since mid-1970s and also seen in **Fig. 2**, which shows the thirty-year moving average time series of pressure deviation from the average MSLP of each month (January-December) at Tahiti and Darwin. On the one hand, the pressure deviation at Tahiti tends to decrease consistently. On the other hand, although the pressure deviation at Darwin had been fluctuating, it generally had been decreasing until the mid-1970s. However, it drastically changed to dominant increasing tendencies in the middle of 1970s.

For the better understanding of the steep descent since mid-1970s, we investigated the monthly MSLP data at Tahiti and Darwin. In the present paper, we show the mean values and their standard deviations for the usual (1951-1980: **Fig. 3 (a)**), whole (1866-2000: **(b)**) and recent (1971-2000: **(c)**) periods in monthly basis, respectively. As is seen in **Fig. 3**, the range and extent of months in which the standard deviations were superposed between Tahiti and Darwin are increased with the order of the usual, whole and recent periods. These more widely superposed months in the whole and recent periods produced the smaller values of MSLP difference between Tahiti and Darwin and occasionally negative values. Sequentially, the smaller or negative values made the values of anomalies (deviations from mean of the MSLP difference) smaller, too.

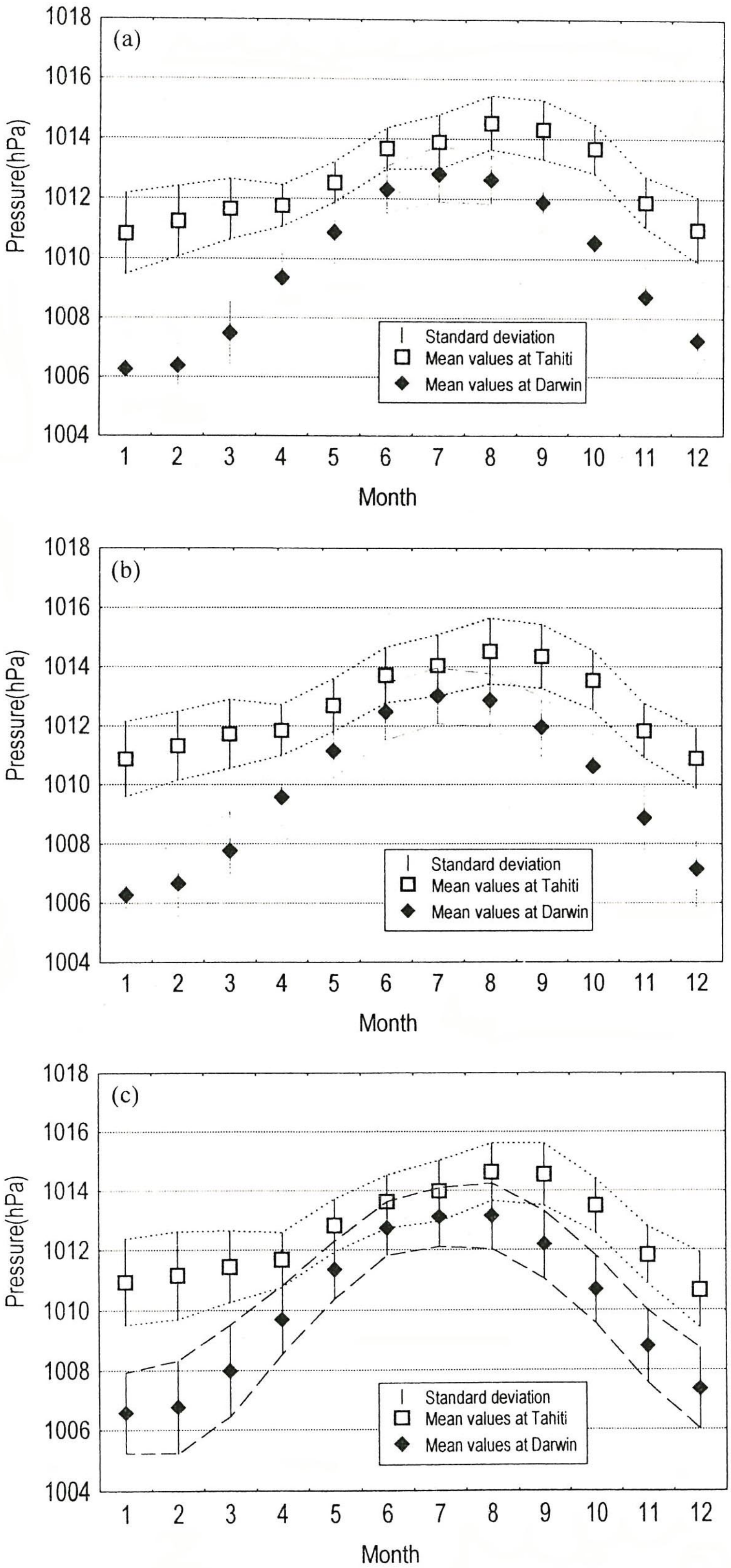

Fig. 3. Mean values and their standard deviations of monthly MSLP for each month (from January to December) at Tahiti and Darwin for each base period: (a) 1951-1880, (b) 1866-2000 and (c) 1971-2000.

In **Fig. 4 (a)** ~ **(c)**, we expressed the MSLP difference between Tahiti and Darwin according to the order with the usual, whole and recent periods for each month. As is seen in the figures, the monthly distribution of the

MSLP difference in **Fig. 4 (b)** and **(c)** is wider than that in **Fig. 4 (a)**. Additionally, the monthly mean values dotted in Fig. 4 are slightly decreased. From this wider distribution with the smaller mean values, the number of El Niño/La Niña events is expected to change.

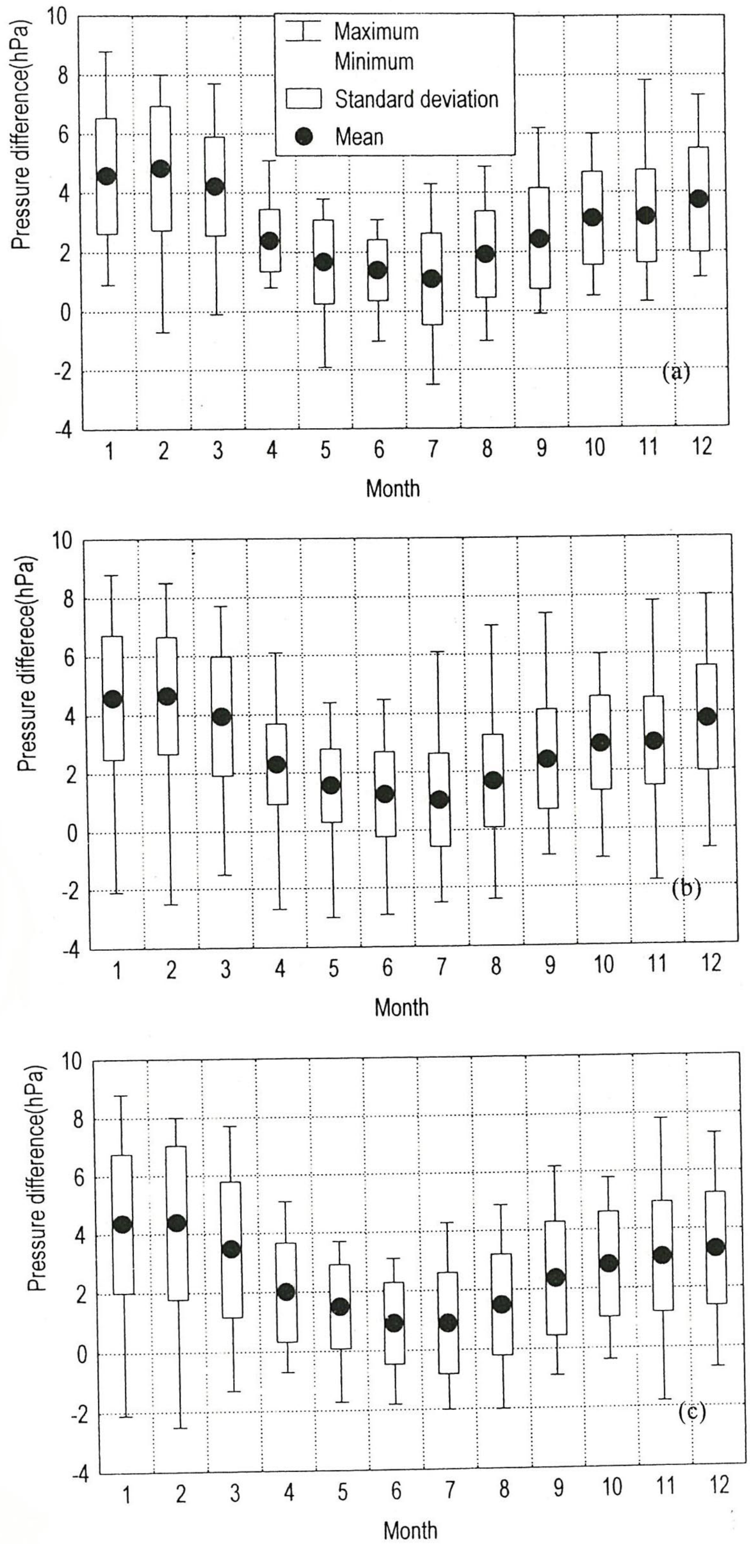

Fig. 4. Average values, standard deviations, maximum and minimum values of MSLP difference between Tahiti and Darwin in monthly basis (January-December) for each period: (a) 1951-1980, (b) 1866-2000 and (c) 1971-2000.

For the next step, we investigated the number of the El Niño/La Niña events according to the different periods and summarized it in **Table 1**. The values were classified into six groups according to their magnitudes. Focusing on the extreme events that refer to the strong El Niño and La Niña conditions (second and seventh rows in **Table 1**), the numbers of the events are gradually decreasing following the order with the usual, whole and recent periods. As mentioned earlier, the monthly mean values of the MSLP difference between the two stations according to the different periods were getting smaller and their distribution became wider. This fact resulted in that the number of each class of SOI was changed. Remarkably, the number of strong El Niño was changed drastically, comparing to the number of strong La Niña. From this result, we must consider carefully if an event that represents the strong El Niño by the usual classification is a real extreme event or not.

Hereafter, we focus on the monthly variation of the monthly MSLP difference between Tahiti and Darwin in detail using thirty-year moving average of the data and their standard deviations. The thirty-year moving averages are shown in **Fig. 5** for respective months and the trend with time shows the drastic decreasing since mid-1970s in the figures. Even though the long-term fluctuations for each month show the various and different pattern, the fluctuations after mid-1970s in the time axis emerge the decreasing tendencies commonly in all months. Remarkably, the steep descents after 1975 were detected in all months except May and September. Oppositely, the standard deviations for each month show the increasing trend after 1975, generally. These results in monthly moving average verified those mentioned above which referred to **Fig. 1** ~ **Fig. 4** and **Table 1**.

Table 1 Number of SOI classified into six groups according to their magnitudes.

	Base period (1951 -1980)	Whole period (1866 -2000)	Recent period (1971 -2000)
SOI > 2	37	25	22
2 ≥ SOI > 1	210	228	236
1 > SOI ≥ 0	533	590	659
0 > SOI ≥ -1	522	527	524
-1 > SOI ≥ -2	249	211	158
SOI < -2	69	39	21

3. RESULTS AND CONCLUSIONS

In the present study, we calculated SOI values using the three different periods as a base period to normalize the monthly sea level pressure (MSLP) difference between Tahiti and Darwin.

The first was the usual period from 1951-2000, which was used commonly to compute SOI, the second the whole period from 1866-2000 and the last the recent period from 1971-2000. The SOI values calculated by the different mean values and their standard deviations were investigated to reveal the variability of SOI and compared to each other. We showed the difference between the various SOI values using thirty year moving average. From this result, we could detect the significant variability between the SOI values used the usual, whole and recent periods. The drastic decreasing since mid-1970s was found in all time series of the thirty-year moving average of SOI by the various periods. Additionally, the variability was verified by the variability of the mean values and their standard deviations of MSLP difference between Tahiti and Darwin in monthly basis (from January to December).

From the results above, we could detect the number of extreme events such as strong El Niño/La Niña were changed with the different period for calculation of the mean and standard deviation. Consequently, it should, therefore, be paid attention to consider if an event can be classified into the extreme phenomenon or not.

REFERENCES

Sakurai, K. (1998). "Aiming at forecasting El Niño events." *Tropic Weather Affecting Japan*, Meteorological Society of Japan, Kansai Branch, the 20th Summer School Textbook, pp. 38-57.

Japanese Study Group for Climate Impact & Application. (1999). *El Niño & Global Environment*, Seizando, Japan.

Kawamura, A., McKerchar, A.I., Spigel, R.H. and Jinno, K. (1998). "Chaotic characteristics of the Southern Oscillation Index time series.", *J. Hydrol.*, Vol. 204, pp. 168-181.

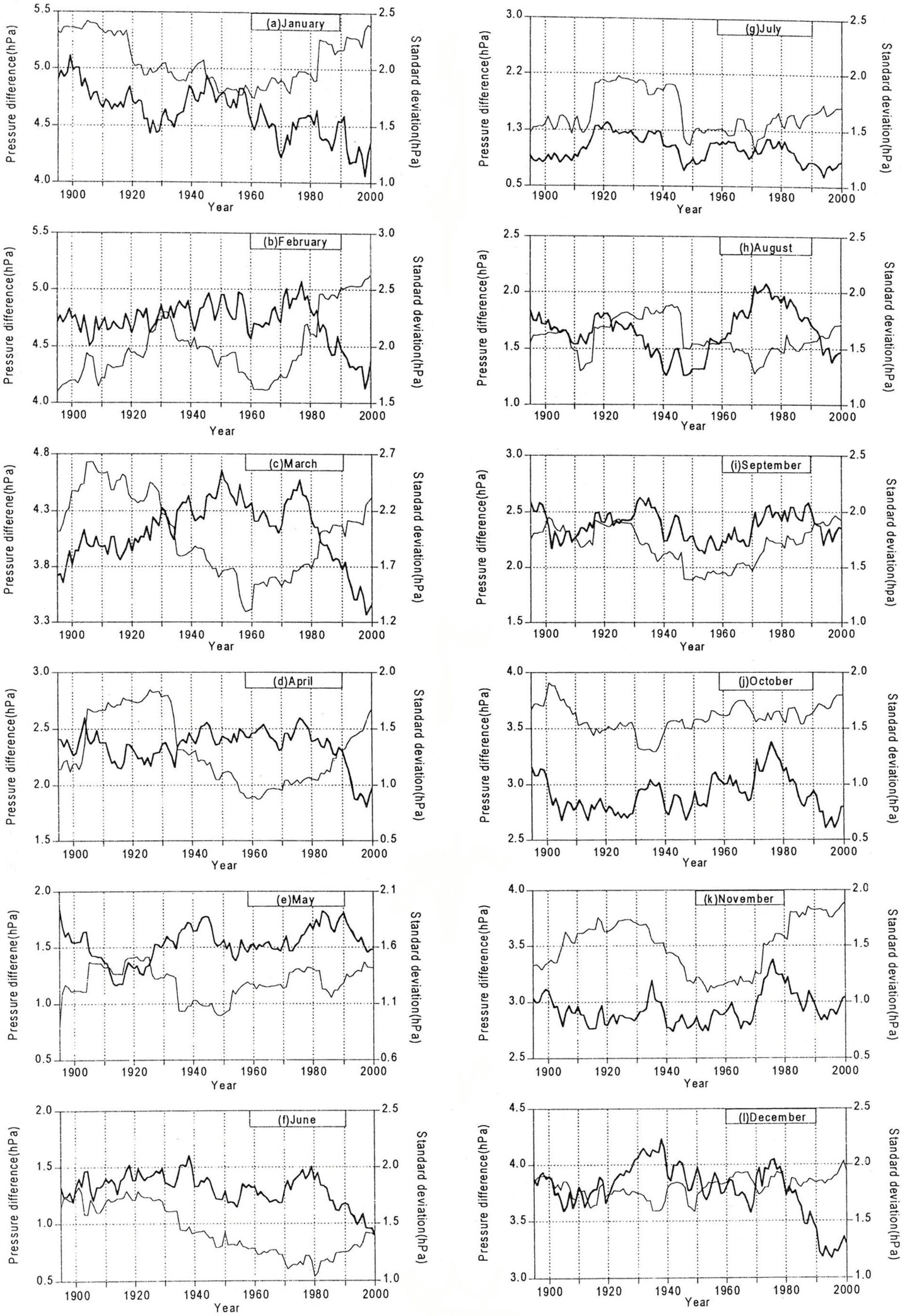

Fig. 5. Mean values of the difference of mean sea level pressure (MSLP) data between Tahiti and Darwin with thick line and the standard deviation with thin line for each month (from January to December). Tick marks on time axis refer to January.

Ropelewski, C.F. and Halpert, M.S. (1987). "Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation.", *Monthly Weather Review*, Vol. 115, pp. 1606-1626.

Halpert, M.S. and Ropelewski, C.F. (1992). "Surface temperature patterns associated with the Southern Oscillation.", *J. Climate.*, Vol. 5, pp. 577-593.

Uvo C.B., Repelli, C.A., Zebiak, S.E. and Kushnir, Y. (1998). "The relationships between tropical Pacific and Atlantic SST and northeast Brazil monthly precipitation.", *J. Climate*, Vol. 11, pp. 551-562.

Yoshino, F. (1999). "On the relation between the monthly rainfall in Shikoku island and the El-Niño event.", *Proc. of Fifth Symposium of Shikoku Branch of JSCE*, pp. 90-91.

Kawamura, A., Eguchi, S. and Jinno, K. (2000). "Cross-correlation between Southern Oscillation Index and precipitation in Fukuoka, Japan.", *Supplement to EOS*, American Geophysical Union, Vol. 81(2), WP57.

Kawamura, A., Eguchi, S. and Jinno, K. (2000). "Cross-correlation between Southern Oscillation Index and precipitation/temperature in Fukuoka, Japan.", *Proc. of Fresh Perspectives on Hydrology and Water Resources in Southeast Asia and the Pacific*, Christchurch, New Zealand, pp, 32-39.

Kawamura, A., Eguchi, S. and Jinno, K. (2001). "Correlation between Southern Oscillation and monthly precipitation in Fukuoka.", *Journal of Hydraulic, Coastal and Environmental Engineering, JSCE*, Vol, 691(-57), pp. 153-158.

Jin, Y.H., Kawamura, A. and Jinno, K. (2002). "Comparison of correlation between categorized SOI and monthly precipitation at Pusan in Korea and at Fukuoka in Japan.", *Proc. of Korea Water Resources Association*, pp. 1251-1256.

Kawamura, A., Eguchi, S. and Jinno, K. (2001). "Statistical characteristics of Southern Oscillation Index and its barometric pressure data.", *Annual Journal of Hydraulic Engineering, JSCE*, Vol. 45, pp. 169-174.

Kawamura, A., Eguchi, S. and Jinno, K. (2002). "Long-term fluctuation characteristics of Southern Oscillation.", *Annual Journal of Hydraulic Engineering, JSCE*, Vol. 46, pp. 103-108.

Troup, A.J. (1965). "The southern oscillation.", *Quarterly Journal of the Royal Meteorological Society*, Vol. 91(390), pp. 490-506.

McBride, J.L. and Nicholls, N. (1983). "Seasonal relationships between Australian rainfall and the Southern Oscillation.", *Monthly Weather Review*, Vol. 111, pp. 1998-2004.

Ropelewski, C.F. and Jones, P.D. (1987). "An extension of the Tahiti-Darwin Southern Oscillation index.", *Monthly Weather Review*, Vol. 115, pp. 2161-2165.

Allan, R.J., Nicholls, N., Jones, P.D. and Butterworth, I.J. (1991). "A further extension of the Tahiti-Darwin SOI, Early ENSO events and Darwin pressure.", *J. Climate*, Vol. 4, pp. 743-749.