NOTES AND CORRESPONDENCE

An Extension of the Tahiti–Darwin Southern Oscillation Index

C. F. ROPELEWSKI

Climate Analysis Center, NMC, NWS, NOAA, Washington, DC 20233

P. D. JONES

Climate Research Unit, University of East Anglia, Norwich NR4 7TJ, England

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1. Introduction

The Southern Oscillation (SO) has been traditionally monitored by indices formed from surface pressure differences across the South Pacific (e.g., Chen, 1982; McBride and Nicholls, 1983; Trenberth, 1984). Several of the most-used indices of the SO are those based on Darwin and Tahiti pressures. Recently recovered station records for Tahiti have allowed us to more than double the length of the Tahiti–Darwin index time series to over 100 years. The purpose of this note is to make these data available to the climate research community and to suggest a rational scheme for identifying the positive and negative extremes of the SO.

2. Data

Although Tahitian meteorological observations have been taken since at least the 1870s, historical records have not been generally available for the period before 1935. The usefulness of SO indices based on Tahiti data for retrospective or long-term diagnostics studies has, therefore, been limited. Recently, we were fortunate to obtain copies of these, heretofore presumed lost, Tahitian pressure records from the French Meteorological Service. We were thus able to extend the Tahiti pressure series back to 1876 (Table 1) and to extend examples of the Tahiti–Darwin SO index back to the first year of available Darwin data (i.e., 1882). (Tahiti pressure data are listed for the 1876 to 1935 period only. Data after 1935 are available in the World Weather Records publications; e.g., U.S. Department of Commerce, 1981.) As with all such historical data, there are always questions regarding the quality and consistency of the record, especially at remote locations such as Tahiti. In order to minimize these concerns, we have provided some of the details of the observation practices in the Appendix. In addition, comparisons are made with data from other islands in the South Pacific to assess the long-term homogeneity of the record.

Monthly correlation coefficients were computed between the bias corrected data for Tahiti (see Table 2 and Appendix for details) and Santiago, Chile; Apia, Samoa; Suva, Fiji; and Darwin, Australia. The correlations are computed for two periods: 1890–1934 and 1935–85 (Table 3a). It is clear that these correlations have a different character for the two time periods, but that these differences are no greater than those observed for pressure correlations between other station pairs [e.g., we see comparable magnitudes of interperiod variations in the correlations when we repeat the exercise using Apia, Samoa, as the base station (Table 3b)]. Trenberth (1976) found similar secular variations in pressure correlations among pairs of stations in the Pacific basin. Thus, the correlation analysis does not identify any unique inconsistencies in the early Tahiti pressure data.

3. Discussion

In practice, the Tahiti–Darwin SO index has been computed in several different ways by different investigators (e.g., Chen, 1982; Trenberth, 1984). These various forms of the index yield the same qualitative description of the state of the SO. In this note, we show three different forms of the Tahiti–Darwin index but this by no means exhausts the indices used by various investigators. It turns out that two of the indices are numerically almost identical—the Climate Analysis Center's operational index and the "Troup" index (McBride and Nicholls, 1983). A third form of this index has a higher signal-to-noise ratio, as defined in Trenberth (1984), than the other two. In addition to the Tahitian bias corrections listed in Table 2, a one millibar adjustment in the Darwin data prior to August 1898 was made following the suggestions of Trenberth (1984) and Troup (1965).

As with all such indices, the annual cycle of pressure at each station is removed by forming anomalies, or differences, from the long-term monthly averages. These monthly anomalies are then normalized by the

TABLE 1. Tahiti monthly sea level pressure in millibars and tenths. (1000 millibars has been subtracted from the monthly values. Missing values are indicated by a −99.) Bias corrections have been applied (see text).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1876	116	122	104	117	134	154	144	164	157	126	111	117
1877	−99	−99	−99	−99	−99	−99	149	143	153	129	113	097
1878	094	094	094	110	125	132	151	168	155	139	134	121
1879	122	129	134	132	125	151	160	168	166	153	121	092
1880	110	130	133	130	135	147	153	169	162	153	138	113
1881	098	107	135	137	120	131	144	140	132	117	118	114
1882	094	107	123	110	120	119	109	108	117	126	128	112
1883	131	095	084	126	139	141	123	137	128	138	108	073
1884	092	109	131	117	130	148	137	134	134	144	118	084
1885	084	113	134	128	140	129	144	134	149	125	117	116
1886	121	106	130	120	129	140	139	150	154	149	126	107
1887	127	116	129	120	119	143	152	149	154	149	116	126
1888	092	112	116	100	116	124	123	138	133	127	108	118
1889	081	127	090	124	126	151	141	149	150	137	121	122
1890	128	133	134	120	129	134	131	134	144	133	124	110
1891	131	106	113	130	138	142	142	152	145	145	123	114
1892	114	105	121	130	147	154	153	148	−99	−99	−99	−99
1893	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99
1894	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99
1895	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99
1896	118	127	116	114	112	116	123	141	137	137	122	112
1897	096	104	107	110	120	137	145	150	142	140	108	112
1898	120	110	115	128	129	131	151	155	147	133	103	105
1899	126	136	126	120	122	131	136	130	146	158	151	110
1900	107	113	091	109	122	163	147	141	111	106	111	109
1901	108	120	132	127	131	158	164	164	126	098	114	106
1902	138	122	142	135	155	147	151	138	129	139	132	114
1903	106	109	130	136	138	140	134	146	150	138	116	120
1904	132	134	128	137	136	135	128	150	146	129	105	118
1905	103	088	092	080	081	102	116	140	131	122	110	094
1906	101	101	−99	−99	−99	129	139	166	159	142	133	−99
1907	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99
1908	−99	−99	−99	−99	−99	−99	−99	−99	172	144	118	095
1909	097	117	097	104	124	155	148	151	137	131	124	112
1910	110	129	131	111	129	151	160	151	154	151	130	124
1911	105	107	124	111	125	136	125	133	131	129	116	107
1912	099	100	104	113	125	129	128	137	129	128	121	104
1913	098	106	110	111	131	139	146	134	140	133	113	102
1914	118	135	132	−99	−99	−99	−99	−99	−99	150	−99	−99
1915	−99	−99	−99	−99	−99	−99	−99	−99	−99	−99	092	108
1916	107	099	103	121	123	128	161	164	139	130	122	106
1917	116	142	131	135	149	150	161	179	178	152	136	130
1918	129	135	124	135	137	131	127	145	152	133	122	100
1919	084	110	101	115	115	128	128	141	139	124	110	098
1920	099	110	120	112	121	122	136	144	144	124	114	108
1921	118	124	−99	−99	−99	−99	136	138	151	150	130	112
1922	115	116	118	112	115	134	138	144	147	144	130	119
1923	107	119	120	115	121	128	131	134	124	134	105	110
1924	108	116	119	100	136	144	153	162	156	137	128	103
1925	110	116	118	119	120	128	128	129	142	123	117	102
1926	081	084	094	101	109	116	121	118	125	118	110	095
1927	106	116	141	120	132	−99	−99	−99	148	134	112	121
1928	108	126	129	129	132	131	138	164	156	139	128	122
1929	108	128	124	124	120	148	151	149	148	150	127	110
1930	118	126	124	121	138	134	138	149	144	154	140	110
1931	123	099	135	129	148	160	156	−99	−99	−99	−99	−99
1932	−99	−99	−99	−99	−99	−99	−99	−99	124	124	113	105
1933	089	110	104	123	136	132	144	148	146	133	121	115
1934	116	121	111	119	122	144	139	117	135	144	134	105
1935	112	111	123	122	130	138	138	155	142	139	126	108

TABLE 2. Bias corrections to the Papeete, Tahiti and Darwin, Australia surface pressure in millibars.

Years	Bias correction
Tahiti	
1896	+1.0
1909–16	+0.5
1917–25	+2.0
1927–34	−1.6
Darwin	
1882–July 1898	+1.0

appropriate monthly standard deviations to produce standardized values, i.e., zero mean and unit variance. The 1951–80 period is used as the base period for computations of the means and standard deviations. In the CAC operational version of the index, the difference of these standardized values—standardized Tahiti minus standardized Darwin—is itself standardized.

In the Trenberth (1976) form of the index, the Tahiti and Darwin pressure anomalies are separately normalized by the mean of the 12-month standard deviations. This index tends to have smaller values than the other two indices during the Northern Hemisphere spring when correlations between Tahiti and Darwin are the weakest and conversely, higher values than the other two indices when the Tahiti–Darwin correlations are the strongest. Another difference between this index and the others presented here is that it does not have a standard deviation of one.

In the Troup form of the index, anomalies of monthly pressure differences, Tahiti minus Darwin, are standardized by the standard deviation of the Tahiti minus Darwin series. Time series plots of these three Tahiti–Darwin SO indices for the period 1882 to 1985 are given in Fig. 1. Since individual monthly values of each of these indices show large variability, the 5-month running mean (mrm) values are plotted. The CAC and Troup versions of the index (light and heavy solid lines in Fig. 1) are almost identical, while the Trenberth index shows considerably more amplitude. Table 4 lists the years during which the 5-mrm values of the CAC version of the Tahiti–Darwin index dip to the lowest 25% of its actual distribution for periods of five consecutive months or longer. These low-index years correspond very closely to the El Niño Southern Oscillation (ENSO) years in Rasmusson and Carpenter (1983). Also listed in Table 4 are the years during which the 5 mrm values of the CAC version of the Tahiti–Darwin index remained in the upper 25% of the distribution for five consecutive months or longer. Many of these years correspond to the "HIGH/DRY" years of van Loon and colleagues (e.g., van Loon and Madden, 1981). Years are listed in Table 4, irrespective of when during the annual cycle extremes occurred, and thus do not necessarily correspond to listings of ENSO or HIGH/DRY episodes. Although the years identified in Table 4 are formally based on the CAC version of

TABLE 3a. Monthly correlations (×100) between Tahiti and Santiago, Chile; Apia, Samoa; Suva, Fiji, and Darwin, Australia.

	J	F	M	A	M	J	J	A	S	O	N	D
Period 1930–85:												
Santiago	38	25	42	5	16	42	49	33	43	25	2	33
Apia	69	60	63	29	65	48	56	72	63	73	59	65
Suva	24	33	46	−5	15	28	23	51	35	24	12	13
Darwin	−29	−51	−48	1	−10	−38	−45	−31	−50	−43	−35	−32
Period 1890–1934:												
Santiago	0	18	10	−16	34	8	28	39	42	40	2	16
Apia	43	67	47	0	23	48	47	58	34	25	5	26
Suva	31	8	25	−22	−2	−3	12	22	25	27	8	−27
Darwin	−28	−33	−34	−30	1	−12	−28	−37	−24	16	−12	−42

TABLE 3b. Monthly correlations (×100) between Apia, Samoa, and Santiago, Chile; Suva, Fiji, and Darwin, Australia.

	J	F	M	A	M	J	J	A	S	O	N	D
Period 1930–85:												
Santiago	44	32	34	7	10	22	14	19	46	15	36	44
Suva	32	66	61	43	33	30	47	57	42	20	34	51
Darwin	−12	−28	−18	10	8	9	−14	2	−18	−21	12	9
Period 1890–1934:												
Santiago	24	51	35	14	32	48	44	53	43	9	49	35
Suva	35	56	22	33	45	11	57	50	56	21	53	5
Darwin	−36	−32	−10	−10	−10	−34	−39	−24	−10	−3	−2	−43

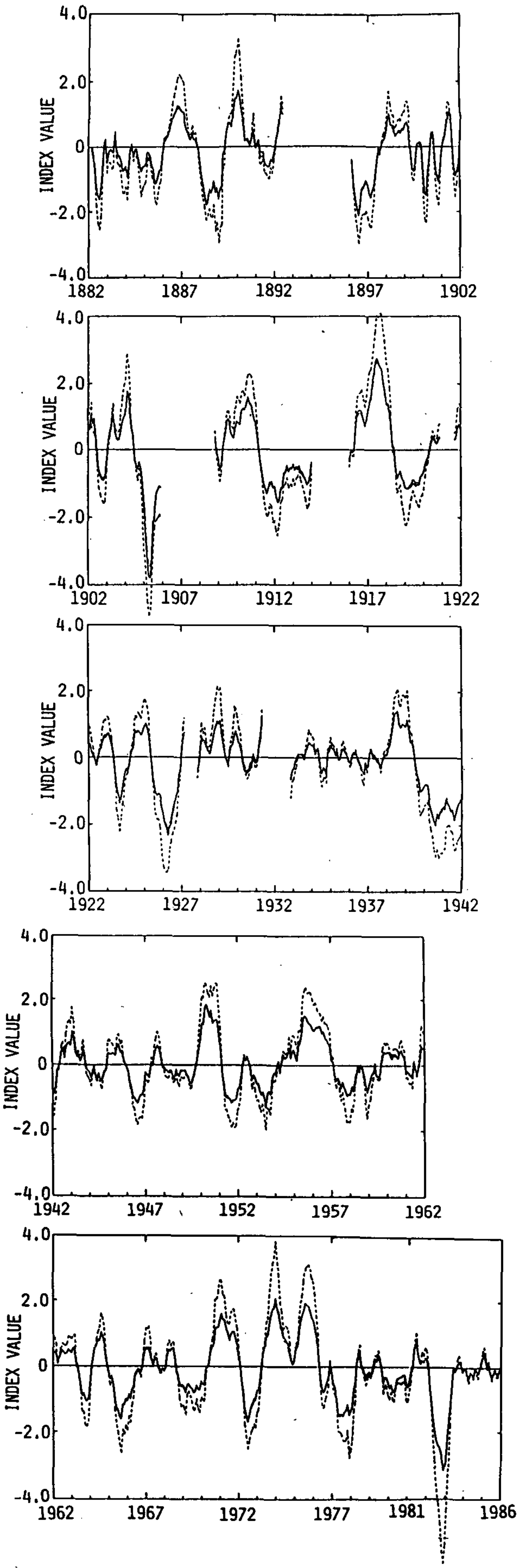

FIG. 1. Time series of three Tahiti–Darwin Southern Oscillation indices. An index with a high "signal-to-noise ratio," suggested by Trenberth (1984), is shown as a dashed line. Two other indices—the Climate Analysis Center operational index, heavy solid, and the "Troup" index, light solid—are virtually indistinguishable. See text for details.

TABLE 4. Years during which the Tahiti–Darwin index remained in the lower or upper 25% of the distribution for five months or longer.

Low index years	1888, 1896[a], 1900, 1902[a], 1905[a], 1911[a], 1913, 1918[a], 1919, 1923[a], 1925[a], 1926, 1939[a], 1940, 1941[a], 1946, 1951[a], 1953[a], 1957[a], 1963, 1965[a], 1969[a], 1972[a], 1977, 1982, 1983
High index years	1886, 1889, 1892, 1904[b], 1909, 1910[b], 1916[b], 1917[b], 1924[b], 1928, 1938[b], 1950[b], 1955[b], 1956[b], 1964, 1970[b], 1971[b], 1973[b], 1975[b]

[a] Warm Episode Years of Rasmusson and Carpenter (1983).
[b] High/dry years of van Loon and Madden (1981).

the Tahiti–Darwin SO index, it is clear from the time series plots of Fig. 1 that the other indices would yield essentially the same classification.

4. Conclusions

The quality of the early Tahiti data is considered to be sufficiently good for use as an SO index. It is probable that the pre-1935 data are slightly less reliable than the post-1935 data. Nonetheless, the pre-1935 data represent a useful extension to a widely used dataset. The 56-year extension of the Tahiti–Darwin SO index discussed here doubles the length of record previously available. It provides researchers with one means of identifying extremes of the SO over a much longer period. We have suggested a way of defining the High Index Phase of the SO consistent with the definition of the Low Index Phase and based on the distribution of Tahiti–Darwin SO index values.

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APPENDIX

Pressure Observations

The pre-1935 Tahiti sea level pressure dataset has been obtained from manuscript records held by the French Meteorological Service. All the 1875 to 1933 data for Tahiti were taken at the hospital in Papeete. These data are not available in Tahiti because of a fire, sometimes around 1930, which presumably destroyed the original manuscript records in Tahiti. However, because Tahiti was a French colony, copies or perhaps even the original records were sent back to France at periodic intervals.

Data from most French overseas meteorological stations were published in the annual volumes of the Central Bureau de Meteorologie de France until about 1914, normally, at least five years in arrears. All climatological data for Tahiti for the years 1876 to 1891 were republished by Krebs (1892) citing an "official Tahiti journal." For Tahiti, most volumes between 1892 and 1920 contain monthly mean temperature, humidity, precipitation and wind direction data, along with the station's location and observer's name. Pressure data are published for 1901, 1903 and 1904 as monthly means at 0800 and 1600 local time, the same observing hours as temperature. The monthly means given in this Note are based on the average of sea level pressures over these two observation times. In the 1909 volume of the Central Bureau de Meteorologie de France, the monthly mean Tahiti pressures were computed from the average of the 0600, 1200 and 1800 local time observations. Some of the data for Papeete and another island (Makatea) in the Society group were published in *Reseau Mondial* between 1910 and 1913 and again between 1932 and 1934. *Reseau Mondial* was a forerunner of *Monthly Climatic Data for the World* and contains data for about 1200 stations for 1910 to 1934. For the latter period of this record, 1932 to 1934, the monthly means are said to be calculated from the daily means formed from the average of the first and second maximum, and first and second minimum pressures, presumably in the two halves of the day.

The reason for the few missing years of observation between 1892 and 1932 is not known. Among the possibilities are that no data were collected in Tahiti during those years, replacements for malfunctioning barometers had to be sent for from France, or the manuscript data could have been lost in France or in transit. We believe that all months with data are made up of a full complement of daily observations and that no monthly means are based on only a few values.

Comparisons with records from the nearest islands (Apia, Samoa, and Suva, Fiji), albeit some distance from Tahiti, indicate that for the years 1896 and 1909 through 1925 the pressure at Tahiti appears to be relatively low, while for the 1927 to 1934 period the pressure appears to be relatively high. In order to insure agreement with these islands, the bias corrections listed in Table 2 were applied to the Tahiti data. The 1927 to 1934 correction is the exact difference between the *Reseau Mondial* data for the 1932 to 1934 period and our French Meteorological Service dataset and is confirmed by comparisons with the data for Apia, Samoa. The reasons for these and the other apparent biases can only be conjectured. An observation time change in 1909 and changes in the barometer elevation in 1917 and 1926 may have been responsible for some of the apparent biases.

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