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# HOMOGENIZED LONG-PERIOD SOUTHERN OSCILLATION INDICES

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## ABSTRACT

Many research workers require indices of the Southern Oscillation that are continuous for a long period, homogeneous and easily updated. This paper aims to provide such indices. The method used is to compare indices based on sea-surface temperature (SST), rainfall and pressure, and thereby to make some corrections to improve homogeneity. To fill data gaps, substitutions are proposed based on regressions between indices over 1950–1979. Tabulations are presented of the recommended long-period indices: SST monthly 1872–1985; rainfall monthly 1893–1983; and pressure seasonal 1851–1984. The most extreme years according to the two monthly indices are listed.

KEY WORDS Southern Oscillation Climatic change Atmospheric circulation Data inhomogeneities

## 1. INTRODUCTION

The Southern Oscillation (SO) is the dominant pattern of short-term climate variation, and is therefore of great importance in climate studies. It has been the central focus of many studies related to the causes of climate anomalies in many regions (e.g. McBride and Nicholls, 1983; Cadet, 1985), of diagnostic dynamic studies (e.g. Wallace and Gutzler, 1981), and of attempts to model climate variations (e.g. Blackmon *et al.*, 1983; Latif, 1987). For all these purposes, an index of the state of the SO is needed; and for many studies, that index should be available for a long period (100 years or more).

Many indices have been developed. The first (Walker and Bliss, 1932), used several variables, namely pressure, rainfall, and temperature at various places. Most other indices, on the other hand, have been based on a single variable at one or several places. Pressure is the most commonly used variable; Berlage (1957) used pressure at Djakarta as an index, many authors have used Darwin and Tahiti pressures, Wright *et al.* (1985) used Darwin alone, and Wright (1975) used pressure at several stations. Another commonly used index is the sea-surface temperature (SST) anomaly averaged over 5°N–5°S, 180–90°W or some closely similar region (e.g. Angell, 1981; Pan and Oort, 1983), or a principal component of SST in which that region plays a major role (Weare, 1986). Rainfall in the Gilbert and/or Line Islands has been used as an index by Meisner (1976) and Wright (1984). Some long-period indices have been based on indirect evidence relating to fisheries and biological variables (see Quinn *et al.*, 1978).

For the period 1950 to date, several indices are available that are considered reliable and homogeneous. The statistical characteristics of some of them have been examined by Wright (1984). Pressure indices have the disadvantage that the month-to-month variability is large, so they are useful only when smoothed in time or averaged over seasons. Indices of SST do not have this disadvantage, and they are therefore more useful for many studies.

When one requires an index for a much longer period, however, one discovers that all the available indices have limitations. Sea temperature indices, for example, are subject to inhomogeneities due to changes in method of measurement (e.g. Barnett, 1984), and also to changes in the density of observations over time.

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Pressure series suffer from changes in station location, instrument or time of observation (Parker, 1983), or inhomogeneities due to having to combine records from different stations over different periods (Wright, 1975). The pressure index of Wright (1975), available for 1851–1974, has been used in numerous studies; unfortunately, this also has limitations due to its method of construction and to the fact that it cannot be readily updated.

The recent publication of data for Tahiti for most of the period 1876–1934 (Ropelewski and Jones, 1987) has made it possible to consider the use of a pressure index based on Darwin and Tahiti for a long period. Unfortunately this series has several gaps, there are some doubts about the reliability of the Tahiti data over part of the period (Trenberth and Shea, 1987), and the high month-to-month variability characteristic of pressure indices remains.

The purpose of this paper is to provide the best long-period SO indices currently available. The method employed is to take a number of potentially useful indices and to compile long-period series based on them, using comparisons between indices as an aid to identifying and removing inhomogeneities and filling data gaps.

## 2. DATA

### *2.1. Basis*

As the basis for the proposed indices, the present paper makes use of several data series (Table I) that exist for long periods, are highly correlated, are known to be good indicators of the SO, and have been used in previous studies. The series are described in sections 2.2 to 2.5. Wright (1984) presented statistics of some of these series; further statistics and justifications for the use of these series are given in section 2.6.

### *2.2. SST index ($S$) and air temperature index ($A$)*

The SST index is the index defined by Wright (1984) as the mean SST anomaly over the region 6–2°N, 170–90°W; 2°N–6°S, 180–90°W; 6–10°S, 150–110°W. It is recalculated here using the 'trimmed' (fully quality-controlled) version of the Comprehensive Ocean–Atmosphere Data Set (COADS) (Woodruff *et al.*, 1987), by averaging anomalies in the relevant 4° latitude by 10° longitude boxes. At least four observations in a 4° × 10° box, and at least two 4° × 10° boxes, were required in order to accept a monthly value. In months when less than two boxes were available, an average was calculated over the larger area 6–2°N, 170–80°W; 2°N–6°S, 180–80°W; 6–10°S, 150–80°W; if at least two boxes were available for this area, this average was used as the index. This substitution was used in at least two months in each of the years 1868, 1872, 1879, 1907, 1915–1921, 1938–1941, and 1946, and in 12 isolated months in other years during 1862–1899.

The time series of the index $S$ is likely to have several inhomogeneities due to changes in methods of measurement of SST (Wright, 1986). Jones *et al.* (1986) have attempted to quantify the inhomogeneities for global mean SST, and use will be made of their estimated corrections. The series also becomes more noisy the further back in time one goes, because of large variations in the number of observations made per month (Wright, 1986). The series is also noisy during parts of the World War periods.

Table I. Basic data series used in this paper

| Name of element | Region | Section |
|---|---|---|
| SST ($S$) | Central and eastern Equatorial Pacific | 2·2 |
| Air temperature ($A$) | Central and eastern Equatorial Pacific | 2·2 |
| Rainfall ($R$) | Central Equatorial Pacific islands | 2·3 |
| Pressure ($D$) | Darwin, Australia | 2·4 |
| Pressure ($T$) | Tahiti, south Pacific | 2·4 |
| Pressure ($DT$) | Darwin and Tahiti | 2·4 |
| Pressure ($W$) | Up to 8 stations in tropics | 2·5 |

The air temperature index, $A$, was defined in the same way as the index $S$ but using the COADS air temperature data. This index is also likely to have inhomogeneities, but different ones from those of $S$. Jones *et al.* (1986) also provided estimated corrections for global air temperatures. The noise variations with time are similar to those of $S$.

### 2.3. *Rainfall index (R)*

The rainfall index $R$ was defined by Wright (1984) as a mean over one to six stations in the central Equatorial Pacific. It contains an inhomogeneity in 1920 due to a change in the reference means, and other inhomogeneities are possible due to changes in the number and selection of stations available.

### 2.4. *Pressure indices (D, T, and DT)*

The pressure indices $D$ and $T$ are series of monthly mean pressure anomalies at Darwin ($D$) and Tahiti ($T$) as used by Wright (1984) and corrected as described there. In addition use is made of early Tahiti data for 1876–1934 supplied by P. Jones, and identical to those published by Ropelewski and Jones (1987) except that values for the year 1916 are 1·5 mb higher. These data are of uncertain quality, and many values are missing. Darwin pressure is believed to have an inhomogeneity in 1898 (Kidson, 1925). Also, there is conflicting evidence about possible inhomogeneities in and after 1939 (Wright, 1984).

The index $DT$, defined as $D-T$, is one version of a number of weighted differences of Darwin and Tahiti pressures that have been devised (see review in Ropelewski and Jones, 1987).

### 2.5. *Pressure index (W)*

The pressure index $W$ of Wright (1975) is based on pressures at up to eight stations in the global tropics, and has been used by several authors (e.g. Newell *et al.*, 1982; Hackert and Hastenrath, 1987) in correlation studies. This index was defined for the seasons February, March and April (FMA), May, June and July (MJJ), August, September, and October (ASO), and November, December, and January (NDJ), and each season standardized; it was then quadratically interpolated to a set of values in the standard seasons DJF, MAM, JJA and SON. The latter set is used here. It was attempted to make the series homogeneous, but some inhomogeneities may still be present. This index differs from the others in being defined only for seasons, and in its method of standardization; it therefore requires different treatment.

### 2.6. *Further statistics*

The series discussed here are all available for most of the period 1892–1980, and some for periods before and after. Within the period 1950–1979 it is reasonable to assume that each series is homogeneous. Table II shows the inter-series correlations for this period. A conservative approximate estimate of the effective number of degrees of freedom $n$ for the correlations of these highly autocorrelated series may be obtained by applying the following correction to the original number of degrees of freedom $N$:

$$n = N(1-r)/(1+r)$$

where $r$ is the lag-1 autocorrelation of the more highly autocorrelated of the pair (World Meteorological Organization, 1966). With this correction, all the correlations quoted in Table II, with the exception of those between monthly Tahiti pressure and the temperatures, are significant at well beyond the 1% level. More relevantly, they are also very high. Correlations between annual values of the series are even higher (Wright, 1984; see Table III). These high correlations imply that all the series, with the partial exception of monthly Tahiti pressure, may be treated as indices of the same phenomenon, namely the Southern Oscillation, and may be used as proxies for each other. For periods before 1950, the data series vary in quality, some markedly so, and they also possess known and, probably, some unknown inhomogeneities. The extent to which proxy relationships are valid for periods before 1950 is discussed in section 3.1.

Table II. Simultaneous correlations between the indices listed in Table I

| | A | R | D | T | DT | W |
|---|---|---|---|---|---|---|
| *Correlations between monthly data during 1950–1979* | | | | | | |
| S | 0·96 | 0·81 | 0·63 | −0·47 | 0·67 | |
| A | | 0·83 | 0·61 | −0·47 | 0·66 | |
| R | | | 0·61 | −0·44 | 0·65 | |
| D | | | | −0·34 | 0·83 | |
| T | | | | | −0·80 | |
| *Correlations between seasonal data during 1950–1979 (for W, 1950–1974)* | | | | | | |
| S | 0·98 | 0·87 | 0·78 | −0·67 | 0.82 | −0·82 |
| A | | 0·89 | 0·75 | −0·67 | 0·81 | −0·79 |
| R | | | 0·74 | −0·60 | 0.77 | −0·72 |
| D | | | | −0·58 | 0.91 | −0·74 |
| T | | | | | −0·87 | 0·61 |
| DT | | | | | | −0·77 |

## 3. METHOD

The high correlations between the indices over 1950–1979 imply that several physical aspects of the Southern Oscillation are closely related. The question then arises; have these physical relationships changed with time? There is abundant evidence that the general pattern of SO relationships has remained the same for at least a century (Berlage, 1957; Quinn *et al.*, 1978; Wright, 1984; Nicholls, 1988), although there is some suggestion that some of the pressure relationships may have varied between decades (e.g. Trenberth and Shea, 1987). The assumption is made here that, if an inhomogeneity is apparent in a time series that represents such a relationship, the inhomogeneity is due to data error and not to climatic change. According to this assumption, the proxy relationships are valid as a means of identifying such data errors.

The proxy relationship is used in two ways. First, one index ($A$) is used to make an estimate ($B_A$) of another ($B$), and the sequence of differences $B - B_A$ is examined to identify inhomogeneities, which are then attributed to data error. Second, gaps in the series of one index are filled using estimates based on another index. To obtain the required estimates, regressions are calculated between pairs of indices for the period 1950–1979, which is used as the reference period and within which the series are assumed to be homogeneous.

The sequence of steps used is as follows. First, the indices are regressed on each other for 1950–1979 (section 4). Annual data are used to obtain the regression coefficients, then these coefficients are treated as applicable both to annual means and to individual months. If the relationships between the indices are found, in the future, to exhibit a substantial seasonal variation, then a detailed seasonally stratified analysis will be necessary to improve the estimates.

Next, modifications are made to the series according to a priori evidence of probable inhomogeneities (section 5). Where the a priori evidence is quantitatively uncertain, further evidence is awaited before making modifications.

Next, the indices are related to each other in pairs (sections 6–8). This is done by using the regression coefficients derived in section 4 to form proxy series, then subtracting these from the actual series and examining the differences. From the series of differences, inhomogeneities are subjectively identified. Since the belief is that there may be many inhomogeneities, some of which are undetectable, it is not considered necessary to restrict attention only to those that can be demonstrated to be statistically significant. What is desirable, however, is that any suspected inhomogeneity be investigated for support by comparison with an independent data set. As a result of this study, a small number of inhomogeneities can be identified and corrected.

Next, a few isolated gaps, and some longer periods during the war years, are filled with estimates based on other series.

Finally, three long-term time series are presented (section 10). The first, denoted *S*-cap, is a monthly series of the homogenized *S* with gaps and two periods of poor data filled by estimates from *R*, *D*, and *A*, and is complete for 1881–1985. The second, *R*-cap, is a similar monthly series for *R* for 1893–1983, with gaps filled by estimates from *S*. The third, *DT*-cap, is a seasonal index representing Darwin minus Tahiti pressure, but based on *W* for the period 1851–1934; this is complete for 1851–1985.

A few final comments about the presented series are relevant. First, where gaps are filled by estimates, no time smoothing is used. Second, although the method assumes that the physical relationships between *S*, *R*, and the pressure field, insofar as they affect variations on time scales of several years, remained constant over the period 1850–1984, it does allow for the possibility that the relationships can vary in individual months, and even for as long as a year at a time (e.g. that the Equatorial Pacific SST could be consistently warmer for a year than would be expected from the state of Darwin pressure).

## 4. REGRESSION OF INDICES ON EACH OTHER

Annual means were formed from the monthly values of the series *S*, *R*, *D*, and *T* for 1950–1979, defining the year as April–March (e.g. 1951 refers to April 1951 to March 1952). With these annual means, each index was regressed on each other. The results are given in Table III. The equations given in Table III are used in the subsequent analysis for both annual and monthly data to calculate estimates of one index based on another. For example, rainfall estimated from Darwin pressure is denoted by $R_D$, and defined by $R_D = 0.329\ \mathrm{D} + 1.02$.

## 5. CORRECTION OF SERIES ACCORDING TO KNOWN INHOMOGENEITIES

### *5.1. The SST index*

A number of studies (Barnett, 1984; Folland *et al.*, 1984; Wright, 1986) have identified inhomogeneities in SST data sets. In one of the most recent studies, Jones *et al.* (1986) attempted to quantify these inhomogeneities. Their analysis assumed that data from land stations does not have systematic inhomogeneities, that the difference, SST minus air temperature (AT), is constant apart from small random fluctuations, and that SST and AT inhomogeneities were not coincident. From this analysis they concluded that, for the ocean regions as a whole and the year as a whole, SST and AT should be corrected by the amounts shown in Table AI to make them homogeneous with 1950–1979. Stratification by hemisphere showed that the errors were consistent between the two hemispheres, except only in 1941. It must be noted that these errors were determined empirically and cannot be treated as definitive. For the purpose of the present paper, it is

Table III. Regression of annual mean indices on each other for April 1950 to March 1980 (*S* in °C, *R* in per cent/100, *D*, *T* in mb)

| Index | Correlation Coefficient |
|---|---|
| $S = 2{\cdot}20\ R - 2{\cdot}26$ | 0·93 |
| $R = 0{\cdot}39\ S + 1{\cdot}02$ | |
| $S = 0{\cdot}80\ D$ | 0·90 |
| $D = 1{\cdot}00\ S$ | |
| $R = 0{\cdot}329\ D + 1{\cdot}02$ | 0·87 |
| $D = 2{\cdot}3\ R - 2{\cdot}4$ | |
| $R = -0{\cdot}395\ T + 1{\cdot}04$ | −0·78 |
| $T = -1{\cdot}5\ R + 1{\cdot}6$ | |

assumed that these errors apply to the Equatorial Pacific. The relevant changes are made to the index $S$, to form the resulting series $S^1$.

### 5.2. *The rainfall index*

The $R$ series is likely to have an inhomogeneity in 1920, because different stations and means were used for the pre- and post-1920 periods. For the two stations common to both periods, the means for 1900–1919 were higher than those for 1948–1967 in most months (table 1 in Wright (1984)). Assume that this difference represents a real climatic change between the two periods, and that this change was uniform spatially and through the year. Then the $R$ data for 1892–1919 should be increased by six percent units to make them homogeneous with the later period. Let this correction be made, and call the resulting series $R^1$.

### 5.3. *Darwin pressure*

According to Kidson (1925), Darwin pressures up to July 1898 should be increased by about 1 mb to make them homogeneous with the later period. This is not obvious from the time series of $D$ (see Figure 2A). No correction is made at this stage.

## 6. COMPARISON OF PAIRS OF INDICES

### 6.1. *Rainfall related to Darwin pressure*

Comparison between $R$ and $D$ is made by calculating $R^1 - R_D$ (Figure 1A). If the two series are both homogeneous, this quantity should be close to zero in all years. Visual inspection of Figure 1A suggests that 1931–1947 was a little lower than neighbouring periods, and that there were a few years with rather extreme values, especially 1891 and 1901. If the period is divided in accordance with known or suspected inhomogeneities in $R$ or $D$, the mean values of $R^1 - R_D$ are as shown in column (a) of Table IV.

Some months in several years, but especially during 1891–1901 and in 1920, were based on only one station. It is therefore quite likely that the values of $R$ for those months are unreliable. Two of the most extreme values of $R^1 - R_D$ occurred in those years. If those months are omitted and the analysis repeated, the mean values of $R^1 - R_D$ are as in Table IV column (b). The value of $R^1 - R_D$ is now close to zero throughout 1900–1982, except in 1931–1947. The mean value for 1931–1947 differs significantly at the 1% level from that for the reference period 1950–1979, by the $t$-test. If this is due to data error, it implies that either $R^1$ was too low by 11 per cent units or that $D$ was too high by 0·34 mb.

FIGURE 1

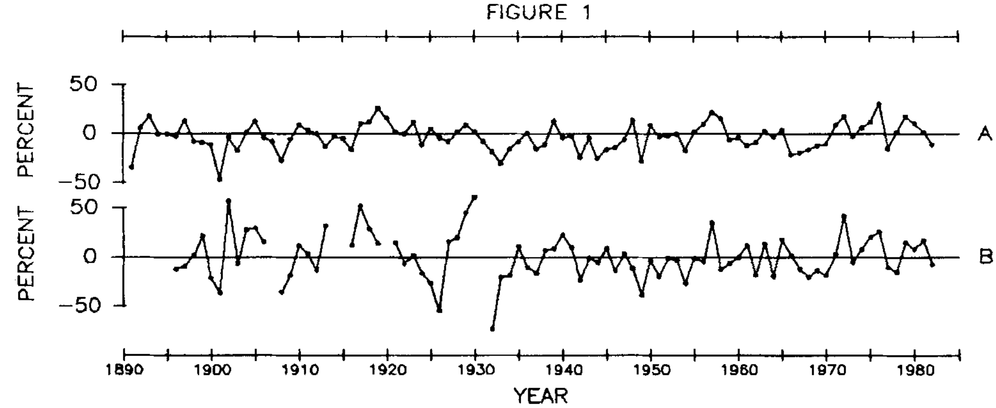


Figure 1. Annual (April–March) mean values of: (A) $R^1 - R_D$ (rainfall index corrected by six percent units during 1891–1919, minus estimate of rainfall based on Darwin pressure); (B) $R^2 - R_T$ (same rainfall index but with months based on only one station omitted, minus estimate of rainfall based on Tahiti pressure)

Table IV. Mean values of $R-R_D$ (rainfall index minus its estimate based on Darwin index) in several periods (per cent units). (a); using $R^1$ (original rainfall index increased by six per cent units during 1891–1919). (b); using $R^2$ (same but omitting months when rainfall index was based on only one station)

| Period (calendar years) | (a) | (b) |
|---|---|---|
| 1891–1897 | −1·9 | +5·0 |
| 1900–1919 | −4·9 | −2·9 |
| 1920–1930 | +3·1 | +0·5 |
| 1931–1947 | −11·1 | −11·3 |
| 1948–1982 | +0·7 | +0·7 |

The result for 1891–1897 in Table IV, column 6, really applies only to 1895–1897, and suggests that either $R^1$ was too high by 5 per cent units or that $D$ was too low by 0·15 mb. Such an error in $D$ agrees in sense with that already mentioned for periods before 1898 (section 5·3), but is much smaller. To investigate further, monthly values of both $D$ and $D-D_R$ (using $R^2$ as the reference rainfall series) are presented in Figure 2. No inhomogeneity stands out above the general level of variability of either of these quantities. Therefore, the results in this section do not provide much support for the supposed inhomogeneity in Darwin pressure in 1898.

The lack of a significant change across 1919 provides support for the correction already made to $R$ (section 5.2).

As a result of this comparison, months based on only one station will henceforth be omitted from the rainfall index $R^1$, and the resulting series called $R^2$.

### 6.2. *Rainfall related to Tahiti pressure*

We now compare $R$ with $T$, by calculating $R_T$ according to Table I. Figure 1B shows $R^2-R_T$. No inhomogeneity in 1931–1947 is in evidence. This suggests that the previously suspected inhomogeneity is either not real or is in $D$, not $R$. During 1900–1930, $R-R_T$ exhibits high amplitude fluctuations which were not present in $R-R_D$, or in data for 1933–1982. This suggests that the early Tahiti record may be less reliable than the later, and not sufficiently reliable for use as a proxy for the other series.

### 6.3. *SST related to Darwin pressure*

Figure 3 presents $S^1-S_D$. The series shows some substantial inhomogeneities, and also a few isolated extreme values. If the period is divided subjectively, taking account of known or suspected inhomogeneities in $S$ or $D$, the mean values of $S^1-S_D$ may be summarized as:

(1) 1882–1897, +0·39°C;
(2) 1899–1916, −0·07°C;
(3) 1921–1930, +0·06°C;
(4) 1931–1947, −0·27°C;
(5) 1948–1979, −0·01°C.

In section 6·1 the possibility was noted that $D$ was too high by 0·34 mb during 1931–1947. If $D$ is now corrected by this amount, then the value of $S^1-S_D$ for period 4 becomes zero. This makes the whole period 1899–1979 homogeneous in terms of period means. This result provides independent support for the Darwin correction, and that will henceforth be adopted. It must be noted nevertheless that the period for which this correction is being applied depends only on the statistical evidence of these comparisons with $R$ and $S$, and not on any specific knowledge about changes in observational practice at Darwin.

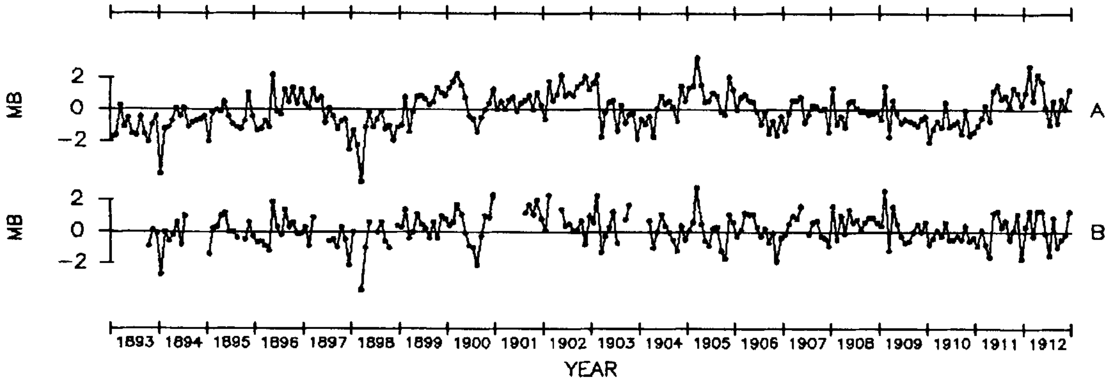


Figure 2. Monthly values of: (A) Darwin pressure; (B) $D-D_R$ (Darwin pressure minus estimate of Darwin pressure based on rainfall index $R^2$)

FIGURE 3

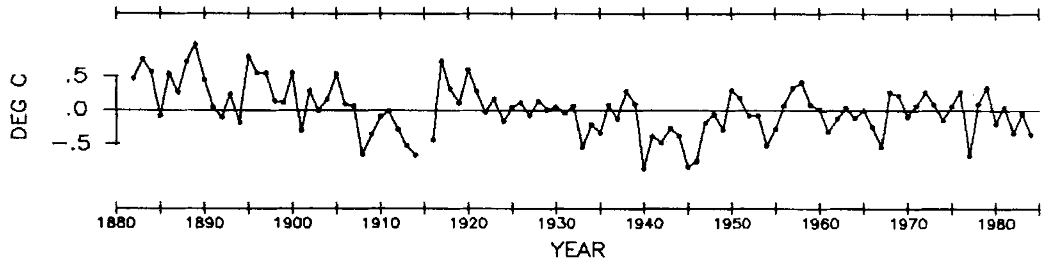


Figure 3. Annual (April–March) values of $S^1-S_D$ (SST index minus estimate of SST based on Darwin pressure)

The results of this section, indicating consistency between $S^1$ and the corrected $D$ from 1899 to 1979, provide encouraging support for the validity of the Jones *et al.* estimates over that period, and for their applicability to a limited region at least on an annual mean basis.

For the period before 1900 there are more uncertainties. The result for 1882–1897 implies that either $S$ is too high by about 0·39°C, or that $D$ is too low by about 0·5 mb. This estimate for $D$ compares with other estimates of 0·15 mb (section 6.1) and 1 mb (section 5.3). For the purpose of this paper, a compromise estimate of +0·7 mb will be adopted as the correction to be made to Darwin pressure for the period up to July 1898; but the uncertainty of this estimate is evident. The Darwin pressure series with the two corrections will be called $D^1$.

Alternatively, the error before 1898 could be in $S$. After the analyses described in this paper had been completed, Folland and Parker (personal communication) presented some results which suggest that the error in SST before 1940 was a function only of place and season, and did not vary with time as Jones *et al.* had proposed. They suggested that the correction for the central and eastern Equatorial Pacific should average through the year to about 0·35°C. If this correction were made to the period 1882–1897 in place of the values in Table AI, the value of $S^1-S_D$ would become +0·60, which would in turn result in a Darwin correction of 0·75 mb, nearer to Kidson's estimate. Further analysis of the pre-1900 period is necessary.

### *6.4. SST related to air temperature*

Wright (1986) noted the close correlation between monthly SST and AT anomalies in many areas of the Pacific. As illustration, the correlation between the present indices $S$ and $A$ using monthly data for 1950–1979 is 0·96. For a similar pair of indices defined over an area of the east Atlantic, the correlation is 0·95. This correlation reflects the tendency of the surface air to maintain a constant small temperature difference from the sea surface. It implies that one of the series $S$ or $A$ could be used as a reliable proxy for the other.

The COADS series of both SST and AT have inhomogeneities, but probably not at the same times (Jones *et al.*, 1986). Therefore, a comparison might make it possible to identify inhomogeneities in SST. Jones *et al.* made such a comparison using global means. If the series $S$ and $A$ are both corrected according to Jones *et al.*'s global values, the difference in the resulting annual means is given by Figure 4a. The strong autocorrelation of this $A-S$ series implies that some inhomogeneities still exist in either $S$ or $A$. Even within the last 25 years there is an appreciable fluctuation of $A-S$ that deserves attention as a possible inhomogeneity.

Repeating the analysis for the Atlantic area gives Figure 4b. In this case there are apparently few substantial inhomogeneities, and those are mostly before 1890. There is also no correlation between the $A-$S series for the two regions.

Thus there appear to be some inhomogeneities in either $S$ or $A$, or both, that are regionally dependent and not removed by the Jones *et al.* corrections. Unfortunately this analysis does not provide any guide to specific further adjustments to $S$.

When $S$ is missing, $A$ may be used as a proxy for $S$. There were 7 months during 1859–1881 when this was possible.

## 7. RELATIONS BETWEEN THE PRESSURE INDEX $W$ AND THE OTHER INDICES

The following analyses for $W$ compared with $S^1$, $R^2$, and $D^1$ were done for each season separately.

First, $W$ was regressed on $S^1$, $R^2$, and $D^1$ individually for the period 1946–1974. Using the regression coefficients, the series $W_S$, $W_R$, and $W_D$ were obtained for all available years. (Again, $W_S$ denotes '$W$ as estimated by $S$', etc.) Then $V \equiv$ the mean of $W-W_S$, $W-W_R$, and $W-W_D$ was calculated. The values of $V$ for the four seasons are shown in Figure 5.

There appear to be some systematic features in these time series. For example, they are relatively low around 1900 and around 1940. If $S$, $R$, and $D$ are assumed homogeneous, this implies that $W$ was too low in those periods. There is also a suggestion that $W$ was too low in the earlier years; the trend from 1882 to 1973 was upward in all seasons, significantly so in DJF and SON. The mean values of $V$ over several arbitrarily chosen periods were as in Table V. Based on this table, the following corrections to $W$ will be adopted: in 1850–1910, add 0·35 to $W$; in 1911–1946, add 0·18 to $W$. Since no specific cause of inhomogeneity has been identified, these corrections are somewhat arbitrary. It may be claimed only that the resulting series (called $W^1$) is likely to be more homogeneous than the series without the corrections.

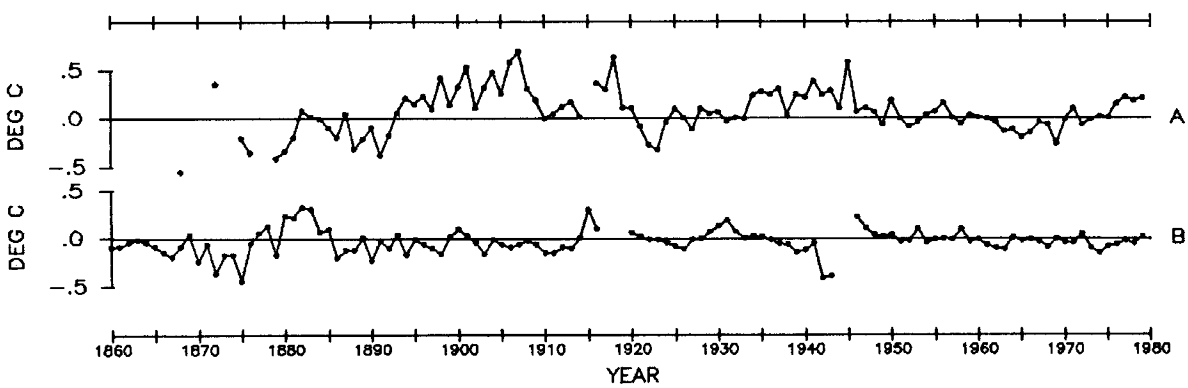


Figure 4. Annual (January–December) mean values of air temperature minus SST for; (A) Equatorial central and east Pacific; (B) Equatorial east Atlantic

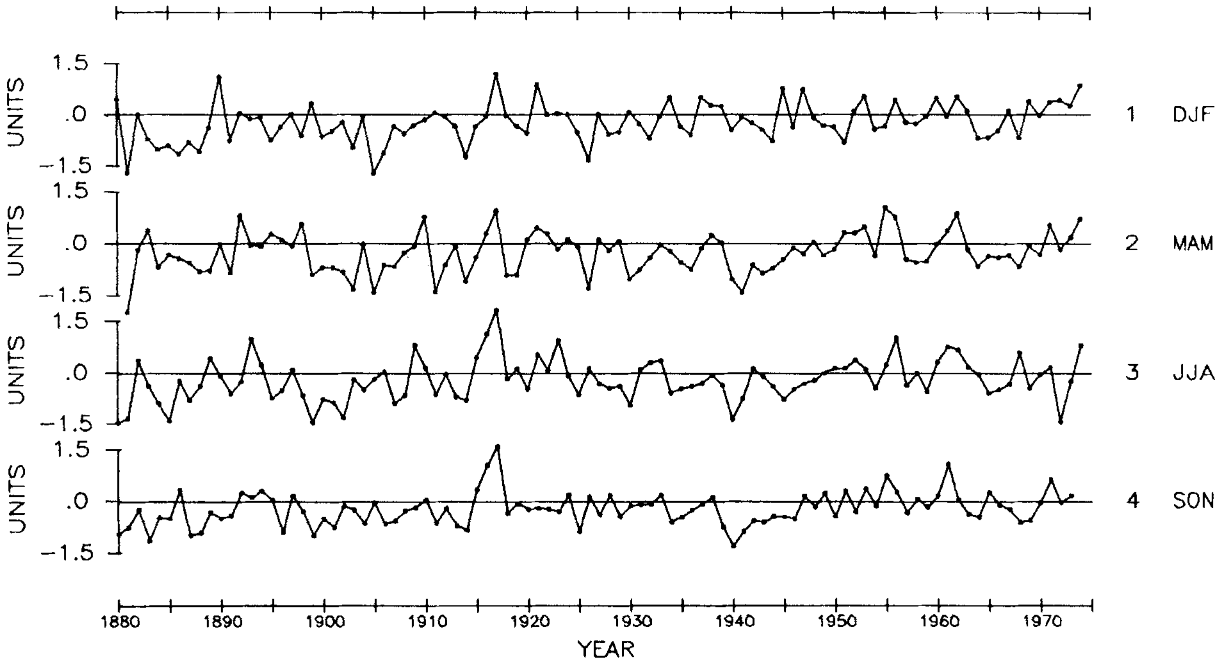


Figure 5. Values of $V \equiv$ 'error' in $W$ (see section 7) for each season separately

Table V. Mean values of $V$ ($\equiv$ 'error' in $W$) in each season over four periods

| | DJF | MAM | JJA | SON |
|---|---|---|---|---|
| 1882–1893 | −0·47 | −0·29 | −0·26 | −0·39 |
| 1894–1910 | −0·46 | −0·34 | −0·43 | −0·33 |
| 1911–1946 | −0·15 | −0·37 | −0·14 | −0·24 |
| 1947–1975 | 0·01 | 0·00 | 0·01 | 0·02 |

## 8. RELATIONS BETWEEN TAHITI PRESSURE $T$ AND OTHER SERIES

### *8.1. T related to R*

Relationships between $T$ and $R$ were discussed in section 6.2, where it was suggested that the early Tahiti record published by Ropelewski and Jones (1987) may be less reliable than the later record.

### *8.2. T related to D and S*

Table VI shows correlations of $T$ with $D^1$ and $S^1$ in each decade. The relations with Darwin pressure have also been noted by Trenberth and Shea (1987). The pattern is rather similar for the two indices.

The interdecadal variations in the correlations since 1940 suggest that natural variations in the physical relationships between $T$ and the other components of the SO are considerable. Nevertheless, the general level of correlation in the earlier decades was lower than in the later, supporting the suggestion that parts of the earlier $T$ record may be less reliable.

Table VI. Correlation of $T$ with $S^1$ and $D^1$, monthly values, all months

| | With $S$ | With $D$ |
|---|---|---|
| 1890–1899 | −0·08 | −0·11 |
| 1900–1909 | −0·21 | −0·13 |
| 1910–1919 | −0·39 | −0·41 |
| 1920–1929 | −0·40 | −0·18 |
| 1930–1939 | 0·15 | 0·05 |
| 1940–1949 | −0·33 | −0·35 |
| 1950–1959 | −0·52 | −0·36 |
| 1960–1969 | −0·34 | −0·16 |
| 1970–1979 | −0·54 | −0·45 |
| 1876–1934 | −0·19 | −0·15 |
| 1935–1984 | −0·43 | −0·36 |

### 8.3. *DT related to W*

The regression of $DT$ (using $D^1 - T$) on $W^1$ for 1935–1974 is as follows:

(a) for DJF, $DT = -0{\cdot}16W + 0{\cdot}04$ (correlation coefficient $= -0{\cdot}78$);
(b) for MAM, $DT = -0{\cdot}08W + 0{\cdot}01$ (correlation coefficient $= -0{\cdot}57$);
(c) for JJA, $DT = -0{\cdot}10W + 0{\cdot}02$ (correlation coefficient $= -0.80$);
(d) for SON, $DT = -0{\cdot}13W + 0{\cdot}03$ (correlation coefficient $= -0{\cdot}84$).

The two indices are related most poorly in MAM; however, this is the season when most of the SO relationships are weakest, and it may be that the SO pressure-anomaly pattern is itself poorly defined at this season. Figure 6 shows the time series of $DT$, together with the estimate of $DT$ based on $W$ according to these equations.

Table VII shows that in only two seasons were the correlations between the two indices substantially lower in the earlier period. Therefore, from this evidence it is by no means evident that the earlier Tahiti record is substantially less reliable.

### 8.4. *Summary*

The Tahiti record for the period 1876–1934 may be less reliable than that for 1935 to date. However, this characteristic is clearly apparent only in monthly data, and must be seen in the context of the inherent instability of all SO pressure indices used on a monthly basis. There also appears to be a considerable natural variation in the relation between Tahiti pressure and other features of the SO.

## 9. SUMMARY OF RESULTS

The series $R$, $D$, $S$, and $W$ have been assessed relative to each other. The following corrections have been proposed to make them more homogeneous.

(1) To $S$, change according to the estimates of Jones *et al.* (Table AI).
(2) To $D$, add 0·7 mb to all values from the start until July 1898; subtract 0·34 mb from all values during 1931–1947.
(3) To $R$, add six per cent units to all values during 1892–1919, and use only values based on at least two stations.
(4) To $W$, add 0·35 to all values during 1850–1910; and 0·18 to all values during 1911–1946.

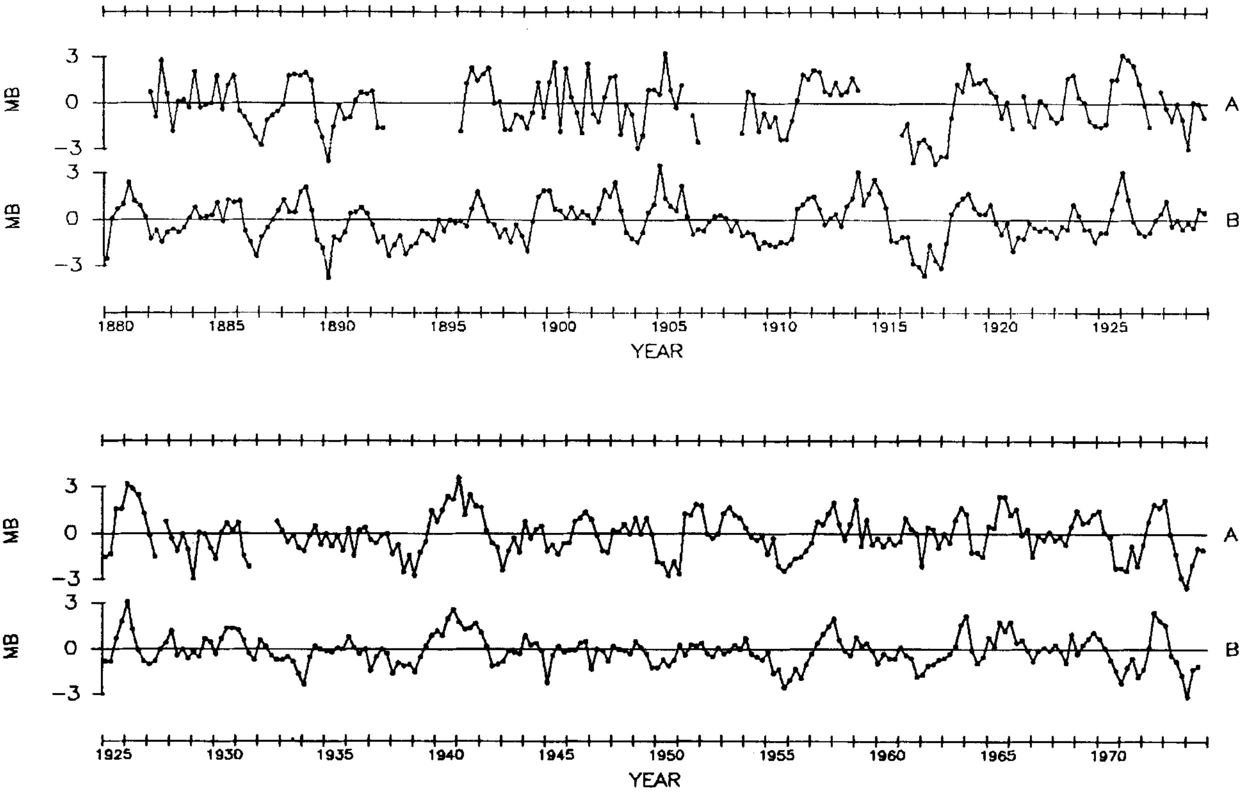


Figure 6. Seasonal values of: (a) $D^1$ minus $T$ (Darwin pressure corrected, minus Tahiti pressure); (B) Estimated value of Darwin minus Tahiti pressure index using regression on $W$

Table VII. Correlation between $DT$ and $W$ in different periods

| | DJF | MAM | JJA | SON |
|---|---|---|---|---|
| 1882–1934 | 0·76 | 0·63 | 0·60 | 0·73 |
| 1935–1974 | 0·78 | 0·67 | 0·80 | 0·84 |

The following qualifications apply:

(a) in all series except perhaps $D$, confidence in their reliability decreases as one goes back in time;
(b) $S$ is relatively unreliable and has several missing values during 1914–1918 and 1938–1941, because there were many fewer ship observations in those periods. $R$ is less reliable in various months during 1893–1915, 1919–1921, 1925–1927, 1941–1946 and 1981–1983 when it is based on only two stations;
(c) the Tahiti data for 1876–1934 are probably less reliable than those for the later period;
(d) no attempt has been made to homogenize the series with respect to variance.

## 10. COMPLETE LONG-PERIOD INDICES

### *10.1. Introduction*

The purpose of this work has been to provide the research worker with the best available indices of the SO with respect to homogeneity, length of series and ease of updating, for each individual month, season or year. To this end, the following indices are recommended to users.

### *10.2. Monthly indices*

The homogenized series of $S$ produced here is believed to be the best available, monthly, long-period index of the SO, because it is nearly complete from 1880 to date, it has high month-to-month autocorrelation and it represents a clearly defined physical entity. It is also easily updated from, for example, the CSM Monthly Bulletin (World Climate Program, 1984–present). This series is presented as the unbracketed values in Table AII, and its validity as an estimate of SST does not depend on the assumption that SO physical relationships have remained constant.

Users who desire a series without any gaps may use the complete series in Table AII, referred to as $S$-cap. The bracketed values are the regressed value of $R$, or, when not available, $D$. In two periods (1914–1918 and October 1938 to December 1941) the series for $S$ was clearly statistically inhomogeneous due to poor data, and the value of $S_R$ was chosen to be used for $S$-cap. Within the period 1854–1880, index $A$ was also used to fill a few gaps, but many gaps remain, especially before 1872 (not presented).

An alternative monthly index, and one that depends only on atmospheric information, is given by the homogenized $R$, presented as unbracketed in Table AIII for 1893–1983. The bracketed values are $R_S$, and the resulting series $R$-cap is complete from October 1893 to August 1983.

In both $S$-cap and $R$-cap the filling has been done using only data for the relevant month, so as to avoid introducing statistical characteristics such as autocorrelation. Nevertheless, since $R$ and especially $D$ are more variable than $S$, a better estimate of $S$ in missing months might be obtained by averaging the values of $S$ in adjacent months.

### *10.3. A long-period atmospheric index*

The user who requires an index based on atmospheric pressure must accept that only seasonal values may realistically be used, since intermonthly variability is large. Presently available long-period indices are: (i) $W$,

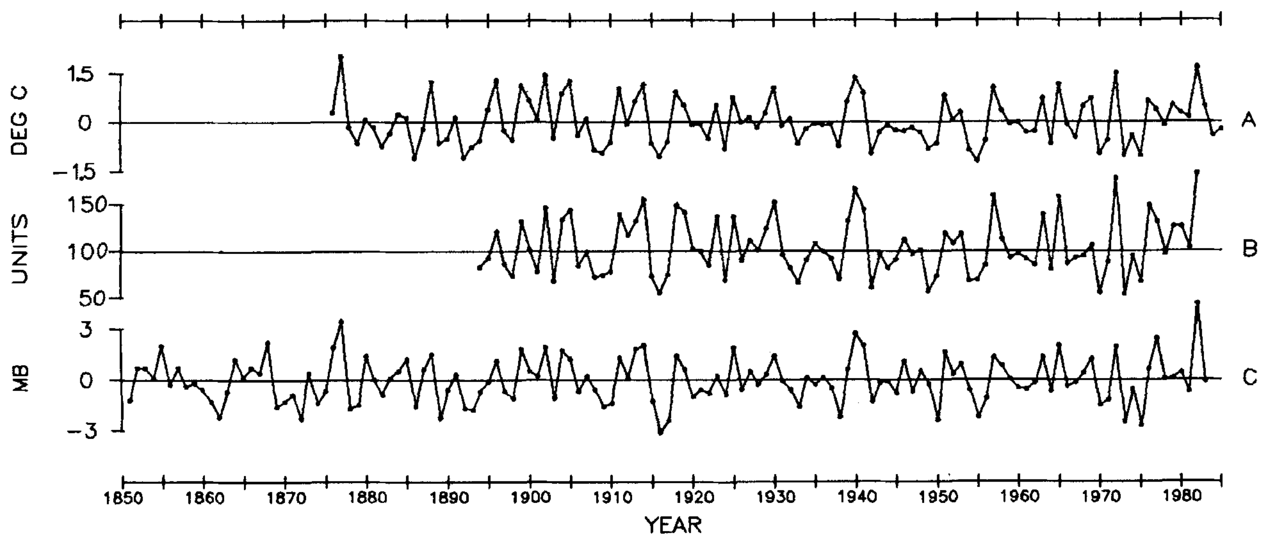


Figure 7. Annual (June–February) mean values of filled and homogenized series (see section 10). (A) $S$-cap; (B) $R$-cap; (C) $DT$-cap.

Table VIII. (a) The extreme decile years during 1872–1985, according to the filled homogenized SST index ($S$-cap). Years are defined as April of the given year to March of the next year. Left, warm years; right, cold years (b) Periods when successive years (April–March) were all relatively extreme. Left, warm events (each year at least 0·5°C); right, cold events (each year at most −0·5°C)

| (a) Year | Index (°C) | Year | Index (°C) |
|---|---|---|---|
| 1877 | 1·87 | 1874 | −1·13 |
| 1982 | 1·50 | 1955 | −1·08 |
| 1902 | 1·28 | 1916 | −1·07 |
| 1972 | 1·28 | 1886 | −1·00 |
| 1940 | 1·27 | 1875 | −0·99 |
| 1914 | 1·19 | 1892 | −0·96 |
| 1905 | 1·18 | 1909 | −0·91 |
| 1888 | 1·04 | 1873 | −0·88 |
| 1896 | 1·04 | 1975 | −0·88 |
| 1957 | 1·01 | 1973 | −0·86 |
| 1965 | 0·99 | 1954 | −0·84 |

| (b) Period | Mean | Years | Period | Mean | Years |
|---|---|---|---|---|---|
| 1982–1983 | 1·05 | 2 | 1872–1875 | −0·94 | 4 |
| 1904–1905 | 0·94 | 2 | 1954–1956 | −0·81 | 3 |
| 1939–1941 | 0·90 | 3 | 1916–1917 | −0·79 | 2 |
| 1913–1914 | 0·87 | 2 | 1908–1910 | −0·78 | 3 |
| 1899–1900 | 0·79 | 2 | 1892–1894 | −0·77 | 3 |
| 1918–1919 | 0·74 | 2 | 1970–1971 | −0·63 | 2 |
| | | | 1949–1950 | −0·59 | 2 |

complete for 1851–1974 but difficult to update; (ii) some linear combination of Darwin and Tahiti pressures, complete for 1935 to date, and now available also for 1882–1934 but with some gaps and some questions of reliability. To derive an ideal and complete pressure index would require a thorough analysis of the series for Darwin, Tahiti, Djakarta and Apia, comparing them to identify inhomogeneities and using some as substitutes for others when missing. Here is proposed, as a convenient long-period pressure index, the following series $DT$-cap: for the period 1935 to date, use $DT$, where $D$ has been corrected as described in section 9 (this may be updated from the CSM Monthly Bulletin); for the period 1851–1934, correct $W$ as described in section 9, then convert it to $DT$ using the regression formulae in section 8.3. The resulting seasonal series of $DT$-cap is presented in Table AIV.

### *10.4. Summary of final indices*

Figure 7 provides a summary of the three final indices, in the form of time series of annual values. The period June–February was used in this case for averaging because the relationships between the indices during March–May, especially those involving $DT$-cap, are less consistent. The correlations of the series in Figure 7 for 1893–1982 are: $S$-cap with $R$-cap, 0·92; $S$-cap with $DT$-cap, 0·89; $R$-cap with $DT$-cap, 0·88.

## 11. CONCLUDING REMARKS

By the time the present paper was ready for final submission, it was already evident that a number of further improvements were desirable and possible. These include: possible modifications to the period before 1900 based on new studies of SST errors; a more comprehensive analysis of related pressure stations (e.g. Djakarta, Apia) to investigate inhomogeneities in Darwin pressure further; and perhaps a seasonal stratification of the relationships. The claim is made here that the series presented are the most homogeneous long-period indices of the SO hitherto published, nevertheless they are capable of further improvement.

It is important for climatic-change studies to obtain homogeneous series not only of particular indices such as the SO, but also of data sets such as SST that are subject to systematic errors. The high correlation between indices based on different physical features can, as in the present paper, provide a valuable tool for helping to obtain independent estimates of such errors.

## 12. EXTREME EVENTS

As a simple application, the monthly indices will be used to identify extreme warm and cold events.

First, from *S*-cap, form annual values for April–March, requiring at least 6 months of data. This series is complete for 1872–1985. Table VIIa lists the 11 extreme warmest and 11 extreme coldest events according to this series. There is a clear bias towards higher amplitude extremes in the warm events than in the cold. According to these data, the recent 1982–1983 warm event was a little weaker than that of 1877–1878. Also listed (Table VIIIb) are the spells in which each year was above 0·5°C or below −0·5°C. Based on this statistic the 1982–1983 period was the warmest 2-year period in the record. Only one warm period spanned 3 years, but several cold periods did. This implies that extreme cold periods, though less intense than warm ones, often last longer. Table IX presents the same statistics based on *R*-cap, which is complete for 1893–1982.

Table IX. (a) The extreme decile years (April–March) during 1893–1982 according to the filled homogenized rainfall index (R-cap). Left, wet years; right, dry years. (b) Periods when successive years (April–March) were all relatively extreme. Left, wet periods (each year at least 120 per cent units); right, dry periods (each year at most 80 per cent units)

| (a) Year | Per cent units | Year | Per cent units |
|---|---|---|---|
| 1982 | 164 | 1916 | 54 |
| 1972 | 162 | 1973 | 60 |
| 1940 | 160 | 1949 | 63 |
| 1910 | 157 | 1893 | 65 |
| 1957 | 152 | 1942 | 65 |
| 1965 | 147 | 1970 | 65 |
| 1919 | 144 | 1924 | 69 |
| 1918 | 143 | 1938 | 69 |
| 1976 | 142 | | |

| (b) Period | Mean | Years | Period | Mean | Years |
|---|---|---|---|---|---|
| 1918–1919 | 143 | 2 | 1916–1917 | 67 | 2 |
| 1939–1941 | 143 | 3 | 1949–1950 | 67 | 2 |
| 1913–1914 | 142 | 2 | 1954–1955 | 71 | 2 |
| 1976–1977 | 135 | 2 | 1908–1909 | 72 | 2 |
| 1904–1905 | 133 | 2 | 1893–1894 | 73 | 2 |
| 1979–1980 | 125 | 2 | | | |

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## APPENDIX

Table AI. Corrections made to $S$ and $A$ (°C) as determined by Jones *et al.* (1986) for global means

| Period | Correlation to $S$ | Correlation to $A$ |
|---|---|---|
| 1861–1873 | +0·08 | −0·40 |
| 1874–1889 | +0·08 | −0·48 |
| 1890–1902 | linear | linear |
| 1903–1940 | +0·49 | +0·17 |
| 1941 | +0·34 | ±0·17 |
| 1942–1945 | −0·10 | −0·54 |

Table AII. Unbracketed values: homogenized *S* series. All values: *S*-cap (homogenized *S*, with gaps and periods of poor data filled with estimates based on *R*, *D*, or *A*). 'M' denotes missing data

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1872 | −4 | −69 | M | M | −71 | −110 | M | 14 | −117 | −99 | −115 | −80 |
| 1873 | −102 | −106 | [33] | M | M | M | −48 | −36 | M | −80 | −103 | −150 |
| 1874 | M | −124 | −78 | −186 | M | −36 | M | −147 | M | −124 | −127 | M |
| 1875 | M | −125 | −47 | −72 | −68 | M | −52 | M | −73 | M | −180 | −79 |
| 1876 | M | 99 | −172 | −156 | −46 | M | 21 | 9 | 15 | 21 | 11 | 21 |
| 1877 | 83 | 50 | M | M | 67 | [247] | M | 105 | 137 | 155 | M | 257 |
| 1878 | 319 | 207 | M | 101 | M | M | 41 | 0 | −27 | −57 | M | −63 |
| 1879 | M | 17 | −39 | −49 | −28 | −108 | 55 | −65 | −51 | −54 | −93 | −85 |
| 1880 | −160 | −20 | −9 | M | M | −37 | −68 | 10 | 15 | 72 | 6 | 36 |
| 1881 | 32 | 14 | 37 | 29 | −26 | [99] | 43 | −46 | 53 | −62 | −41 | −48 |
| 1882 | −65 | −74 | 7 | −5 | 2 | −82 | −71 | −122 | −36 | −102 | −68 | −87 |
| 1883 | −53 | −42 | 9 | 18 | 6 | −37 | −11 | 10 | −35 | −45 | −41 | −43 |
| 1884 | −51 | −42 | 33 | −21 | 5 | −46 | −13 | 5 | 6 | 96 | 66 | 74 |
| 1885 | 60 | −17 | −17 | −29 | 10 | 18 | −43 | −20 | 46 | 26 | 78 | 34 |
| 1886 | 13 | −37 | −46 | −152 | [−48] | −98 | −111 | −81 | −85 | −116 | −120 | −125 |
| 1887 | −108 | −139 | −16 | −80 | −39 | −67 | −53 | −68 | −45 | −18 | −18 | −11 |
| 1888 | 59 | 45 | 31 | 36 | 46 | 64 | 39 | 41 | 95 | 154 | 152 | 198 |
| 1889 | 205 | 170 | 48 | 85 | 44 | 14 | −28 | −65 | −74 | −139 | −134 | −74 |
| 1890 | −57 | −20 | −134 | −70 | −59 | −71 | −83 | −76 | −64 | −38 | −96 | −2 |
| 1891 | −7 | −20 | −19 | 54 | 43 | 18 | 14 | [160] | −40 | −3 | −3 | −3 |
| 1892 | −10 | 4 | −21 | −18 | −50 | −98 | −111 | −96 | −101 | −129 | −132 | −95 |
| 1893 | [−80] | −136 | −102 | −103 | −122 | −85 | −58 | −101 | −86 | [−105] | −89 | −92 |
| 1894 | −74 | 8 | −75 | −56 | −30 | −62 | −24 | −46 | −39 | −87 | −38 | −80 |
| 1895 | [−50] | −85 | −31 | −11 | 53 | 33 | −21 | 39 | 77 | 37 | 87 | 47 |
| 1896 | 53 | 10 | 37 | 6 | 11 | 33 | 84 | 153 | 114 | 110 | 165 | 176 |
| 1897 | 169 | 165 | 65 | −79 | 5 | −1 | 28 | −17 | 11 | −33 | −31 | −30 |
| 1898 | −26 | −134 | −52 | −48 | −33 | −43 | −58 | −67 | −24 | −50 | −71 | −63 |
| 1899 | −67 | −41 | −64 | −15 | −26 | −14 | 25 | 58 | 104 | 232 | 164 | 168 |
| 1900 | 163 | 137 | 91 | 98 | 108 | 92 | 78 | 83 | 98 | 80 | 19 | 68 |
| 1901 | 56 | 33 | −15 | 25 | −1 | 12 | −34 | −11 | −1 | 1 | 10 | 7 |
| 1902 | 52 | 51 | 41 | 70 | 61 | 70 | 146 | 110 | 176 | 177 | 172 | 169 |
| 1903 | 170 | 117 | 101 | 14 | 20 | −17 | −66 | −70 | −47 | −46 | −51 | −85 |
| 1904 | −52 | −5 | 0 | −21 | −16 | 19 | 80 | 87 | 68 | 118 | 100 | 119 |
| 1905 | 97 | 98 | 92 | 77 | 155 | 151 | 135 | 82 | 164 | 127 | 112 | 122 |
| 1906 | 142 | 95 | 48 | 110 | 23 | 2 | 15 | −67 | −38 | −67 | −90 | −20 |
| 1907 | −45 | −55 | −65 | −42 | 16 | 20 | −19 | 0 | 91 | −57 | 28 | 46 |
| 1908 | −58 | 42 | −23 | −32 | −43 | −95 | −84 | −47 | −117 | −71 | −59 | −77 |
| 1909 | −83 | −129 | −46 | −49 | −86 | −81 | −54 | −78 | −77 | −108 | −132 | −117 |
| 1910 | −117 | −82 | −107 | −123 | −78 | −82 | −48 | −52 | −83 | −36 | −67 | −55 |
| 1911 | −69 | −72 | −63 | −80 | −14 | 1 | 53 | 88 | 106 | 111 | 138 | 215 |
| 1912 | 122 | 87 | 58 | 91 | 37 | −24 | 19 | −58 | 26 | −7 | 29 | −18 |
| 1913 | −38 | 15 | 3 | −11 | −49 | 26 | 34 | 21 | 43 | 42 | 52 | 106 |
| [1914 | 139 | 106 | 168 | 93 | 141 | 93 | 67 | 53 | 86 | 207 | 161 | 148] |
| [1915 | 133 | 93 | 148 | 111 | 104 | 3 | −28 | −87 | −15 | −175 | −125 | −70] |
| [1916 | 9 | −101 | −57 | −109 | −107 | −79 | −85 | −94 | −96 | −96 | −127 | −125] |
| [1917 | −149 | −103 | −114 | −24 | −76 | 1 | −46 | −59 | 9 | −103 | −85 | −43] |
| [1918 | −125 | −96 | 25 | −8 | 16 | 16 | 58 | 139 | 82 | 133 | 82 | 106] |
| 1919 | [111] | 120 | [141] | [148] | 113 | 136 | 32 | 17 | 27 | 60 | −31 | 40 |
| 1920 | 76 | [111] | 52 | 41 | 57 | −29 | −91 | −13 | 27 | −14 | 13 | −13 |
| 1921 | 64 | −17 | −87 | −11 | −12 | 13 | 12 | 23 | 7 | 3 | −75 | 36 |
| 1922 | −53 | −18 | −9 | 31 | 31 | −97 | 33 | −25 | −52 | −84 | −94 | −17 |
| 1923 | −38 | −84 | 6 | 23 | 44 | 10 | 24 | 51 | 83 | 90 | 107 | 68 |
| 1924 | 36 | 8 | 26 | 1 | −64 | −58 | −97 | −69 | −63 | −98 | −99 | −51 |
| 1925 | −117 | −84 | −36 | −79 | 8 | 5 | 47 | 44 | 70 | 68 | 103 | 144 |
| 1926 | 120 | 89 | 82 | 88 | 45 | 8 | 42 | 22 | −4 | −47 | −55 | −50 |
| 1927 | 48 | 30 | −16 | −44 | 8 | 12 | −25 | 10 | 16 | 46 | 22 | 24 |
| 1928 | 15 | 5 | −10 | 0 | 8 | −29 | −23 | −2 | 12 | −8 | −10 | 1 |

Table AII. (*continued*)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1929 | −61 | −39 | 0 | 4 | −23 | 25 | 11 | 19 | 27 | 37 | 52 | 27 |
| 1930 | 25 | 20 | 18 | 28 | 29 | 20 | 70 | 60 | 102 | 129 | 164 | 153 |
| 1931 | 147 | 102 | 89 | 93 | 55 | 36 | 31 | 18 | −22 | −66 | −29 | −33 |
| 1932 | −22 | 1 | 54 | 21 | 67 | 41 | 9 | 17 | 18 | 27 | −5 | −8 |
| 1933 | −7 | 0 | −28 | 15 | −25 | −40 | −56 | −49 | −50 | −93 | −85 | −97 |
| 1934 | −48 | −90 | −48 | −16 | −9 | −5 | −12 | 14 | −18 | −12 | −23 | −48 |
| 1935 | −53 | −26 | −29 | −35 | −21 | −22 | −44 | 22 | −1 | 21 | −8 | −39 |
| 1936 | 7 | 16 | 1 | −7 | 8 | −28 | −5 | −18 | −4 | 50 | −6 | 6 |
| 1937 | −47 | −25 | 4 | −39 | −18 | −9 | 16 | −3 | 17 | −3 | 5 | 5 |
| 1938 | −56 | −39 | −40 | −13 | −39 | −60 | −58 | −69 | −78 | [−112] | [−46] | [−87] |
| [1939 | −63 | −92 | −79 | −21 | 31 | 5 | 47 | 38 | 40 | 69 | 93 | 133] |
| [1940 | 71 | 75 | 102 | 106 | 71 | 95 | 71 | 67 | 93 | 227 | 155 | 190] |
| [1941 | 166 | 181 | 104 | 84 | 80 | 89 | 58 | 60 | 159 | 82 | 146 | 126] |
| 1942 | 67 | 45 | 27 | 45 | −1 | −7 | −46 | −71 | −98 | −141 | −150 | −135 |
| 1943 | −126 | −102 | −110 | −68 | −19 | −35 | 5 | 1 | −8 | −61 | −66 | −39 |
| 1944 | −63 | −1 | 1 | 25 | 22 | 33 | 45 | 14 | 2 | −53 | −45 | −32 |
| 1945 | −33 | −19 | −95 | −135 | 4 | [7] | −51 | −68 | −32 | −60 | 5 | [−32] |
| 1946 | [3] | [5] | 10 | 32 | −40 | −127 | −38 | −54 | 37 | −8 | −36 | −26 |
| 1947 | −6 | 5 | 9 | 7 | 15 | 14 | −26 | −35 | −26 | −40 | −21 | −32 |
| 1948 | −2 | 21 | 39 | 34 | 24 | 4 | −81 | −36 | −66 | −70 | −5 | −1 |
| 1949 | −42 | 17 | −23 | 99 | 14 | −44 | −40 | −35 | −70 | −67 | −141 | −83 |
| 1950 | −104 | −148 | −25 | −54 | −115 | −71 | −85 | −59 | −77 | −45 | −110 | −79 |
| 1951 | −45 | −21 | −21 | 15 | 32 | 33 | 98 | 101 | 74 | 89 | 132 | 88 |
| 1952 | 69 | 53 | 12 | 56 | −6 | −20 | −10 | −10 | 19 | 23 | −3 | −30 |
| 1953 | 54 | 32 | 37 | 101 | 56 | 51 | 60 | 16 | 67 | 9 | 54 | 8 |
| 1954 | 4 | 5 | 12 | −95 | −73 | −101 | −110 | −92 | −86 | −106 | −87 | −101 |
| 1955 | −65 | −27 | −67 | −59 | −98 | −104 | −90 | −64 | −132 | −160 | −185 | −132 |
| 1956 | −139 | −64 | −67 | −62 | −57 | −53 | −60 | −72 | −73 | −52 | −84 | −63 |
| 1957 | −58 | 0 | 24 | 60 | 86 | 86 | 98 | 123 | 54 | 84 | 117 | 129 |
| 1958 | 141 | 132 | 98 | 69 | 50 | 54 | 42 | 33 | −2 | 20 | 22 | 54 |
| 1959 | 48 | 40 | 27 | 42 | 29 | −3 | −25 | −12 | −28 | 30 | 3 | −7 |
| 1960 | −9 | −7 | 7 | 23 | 23 | −10 | −1 | 22 | 18 | −17 | −23 | −20 |
| 1961 | −17 | 29 | 0 | 21 | 1 | 43 | −38 | −35 | −71 | −82 | −27 | −32 |
| 1962 | −22 | −16 | −37 | −44 | −35 | −21 | −7 | 0 | −26 | −30 | −33 | −63 |
| 1963 | −43 | −36 | 1 | 18 | 6 | 27 | 81 | 74 | 86 | 86 | 104 | 102 |
| 1964 | 68 | 26 | −17 | −37 | −83 | −92 | −46 | −82 | −75 | −58 | −94 | −95 |
| 1965 | −52 | −10 | −4 | 13 | 66 | 84 | 92 | 118 | 126 | 146 | 142 | 147 |
| 1966 | 110 | 82 | 62 | 39 | −15 | 24 | 22 | 10 | −2 | −7 | −27 | −33 |
| 1967 | −42 | −20 | −36 | −45 | −4 | 23 | −16 | −37 | −66 | −59 | −50 | −52 |
| 1968 | −76 | −87 | −72 | −34 | −46 | 1 | 38 | 43 | 28 | 33 | 65 | 75 |
| 1969 | 98 | 67 | 60 | 53 | 103 | 72 | 38 | 57 | 73 | 90 | 89 | 109 |
| 1970 | 89 | 48 | 17 | 41 | 1 | −45 | −90 | −86 | −87 | −86 | −116 | −133 |
| 1971 | −117 | −111 | −88 | −55 | −47 | −53 | −54 | −59 | −66 | −65 | −84 | −80 |
| 1972 | −38 | −6 | 4 | 48 | 82 | 84 | 113 | 154 | 143 | 174 | 204 | 207 |
| 1973 | 159 | 117 | 57 | −10 | −30 | −70 | −75 | −86 | −92 | −97 | −129 | −129 |
| 1974 | −144 | −98 | −69 | −54 | −51 | −27 | −32 | −26 | −25 | −60 | −64 | −63 |
| 1975 | −44 | −35 | −49 | −30 | −48 | −91 | −76 | −79 | −96 | −118 | −107 | −135 |
| 1976 | −137 | −86 | −49 | −28 | −9 | 29 | 48 | 70 | 70 | 96 | 86 | 66 |
| 1977 | 78 | 45 | 46 | 1 | 34 | 27 | 23 | 15 | 29 | 57 | 62 | 59 |
| 1978 | 67 | 23 | 6 | −23 | −12 | −49 | −27 | −42 | −18 | −8 | −5 | 35 |
| 1979 | 3 | 11 | 40 | 35 | 42 | 53 | 12 | 18 | 100 | 42 | 45 | 59 |
| 1980 | 47 | 40 | 24 | 28 | 39 | 58 | 24 | −14 | 18 | 7 | 35 | 53 |
| 1981 | −23 | −44 | −20 | −35 | −14 | 1 | −30 | −48 | 7 | 24 | −19 | 25 |
| 1982 | 31 | 29 | 22 | 37 | 76 | 98 | 70 | 97 | 136 | 184 | 192 | 250 |
| 1983 | 221 | 187 | 167 | 141 | 164 | 155 | 81 | 84 | 60 | −16 | −45 | −9 |
| 1984 | −24 | 31 | −14 | −5 | −5 | −33 | −2 | 2 | 23 | −35 | −31 | −42 |
| 1985 | −59 | −27 | −37 | −50 | −51 | −56 | −15 | −21 | −26 | −43 | −29 | −4 |
| 1986 | −38 | −9 | 5 | 14 | −5 | −7 | 47 | 43 | 53 | 61 | 104 | 127 |

Table AIII. Unbracketed values: homogenized $R$ series. All values: $R$-cap (homogenized $R$, with gaps filled with estimates based on $S$). 'M' denotes missing data

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1893 | M | M | M | M | M | M | M | M | M | 55 | 60 | 92 |
| 1894 | 47 | 54 | 81 | 83 | 84 | 122 | 67 | [84] | [87] | [68] | [87] | [71] |
| 1895 | 80 | 85 | 90 | 56 | 76 | 88 | 67 | 73 | [132] | 96 | 128 | 99 |
| 1896 | 79 | 78 | 115 | 107 | 119 | 86 | 101 | 101 | 114 | 137 | 128 | 166 |
| 1897 | 107 | 149 | 121 | [71] | [104] | [102] | 136 | 107 | 94 | 60 | 98 | 86 |
| 1898 | 46 | [50] | 70 | 100 | 69 | [85] | 79 | 73 | 78 | 104 | [74] | 41 |
| 1899 | 46 | 79 | 59 | 101 | 92 | 123 | 125 | 135 | 99 | 183 | 110 | 109 |
| 1900 | 149 | 157 | 130 | 125 | 142 | 127 | 122 | 134 | 95 | 60 | 81 | 62 |
| 1901 | [124] | [115] | [96] | [112] | [102] | [107] | [89] | 78 | 69 | 57 | 64 | 83 |
| 1902 | 73 | 81 | [118] | [129] | 140 | 128 | 129 | 140 | 166 | 149 | 229 | 119 |
| 1903 | 154 | 102 | 88 | 112 | 112 | 72 | 77 | [75] | 35 | 16 | [82] | [69] |
| 1904 | [82] | [100] | 56 | 72 | 107 | 94 | 105 | 130 | 136 | 126 | 154 | 150 |
| 1905 | 159 | 142 | 126 | 153 | 150 | 169 | 142 | 132 | 150 | 165 | 146 | 136 |
| 1906 | 119 | 135 | 97 | 84 | 80 | 88 | 77 | 92 | 69 | 78 | 117 | 103 |
| 1907 | 56 | 74 | 89 | 94 | 71 | [110] | 101 | 91 | 83 | 119 | 126 | 81 |
| 1908 | 95 | 86 | 45 | 60 | 65 | 105 | 76 | 95 | 72 | 53 | 55 | 76 |
| 1909 | 61 | 56 | 81 | 59 | 76 | 83 | 110 | 101 | 71 | 40 | 78 | 61 |
| 1910 | 53 | 69 | 71 | 71 | 102 | 78 | 89 | 87 | 63 | 88 | 62 | 61 |
| 1911 | 100 | 77 | 153 | 144 | 105 | 118 | 120 | 111 | 134 | 163 | 106 | 191 |
| 1912 | 137 | 171 | 144 | 146 | 125 | 117 | 129 | 90 | 115 | 155 | 117 | 105 |
| 1913 | 101 | 123 | 70 | 65 | 91 | 91 | 114 | 124 | 124 | 145 | 137 | 135 |
| 1914 | 166 | 151 | 179 | 145 | 167 | 145 | 133 | 127 | 142 | 197 | 176 | 170 |
| 1915 | 163 | 145 | 170 | 153 | 150 | 104 | 90 | 63 | 96 | 23 | 46 | 71 |
| 1916 | 107 | 57 | 77 | 53 | 54 | 67 | 64 | 60 | 59 | 59 | 45 | 46 |
| 1917 | 35 | 56 | 51 | 92 | 68 | 103 | 82 | 76 | 107 | 56 | 64 | 83 |
| 1918 | 46 | 59 | 114 | 99 | 110 | 110 | 129 | 166 | 140 | 163 | 140 | 151 |
| 1919 | 153 | 187 | 167 | 170 | 131 | 140 | 136 | 152 | 159 | 174 | 136 | 129 |
| 1920 | 92 | 153 | 156 | 104 | 113 | 150 | [67] | [97] | [113] | [97] | [107] | [97] |
| 1921 | 120 | 75 | 54 | 52 | 58 | 46 | 98 | 86 | 100 | 97 | 109 | 133 |
| 1922 | 115 | 114 | 68 | 98 | 110 | 109 | 121 | 101 | 89 | 36 | 93 | 74 |
| 1923 | 69 | 73 | 107 | 105 | 69 | 128 | 127 | 146 | 126 | 147 | 163 | 138 |
| 1924 | 147 | 112 | 103 | 52 | 90 | 84 | 86 | 81 | 63 | 103 | 50 | 25 |
| 1925 | 50 | 79 | 64 | 45 | 89 | 114 | 103 | 123 | 120 | 182 | 133 | [158] |
| 1926 | 148 | 151 | [134] | [136] | 134 | 120 | 109 | 138 | 94 | 84 | 126 | 47 |
| 1927 | 45 | 44 | 55 | 51 | 83 | 92 | 118 | 89 | 100 | 78 | 117 | 131 |
| 1928 | 151 | 126 | 64 | 81 | 54 | 75 | 90 | 83 | 113 | 98 | 113 | 112 |
| 1929 | 91 | 131 | 82 | 74 | 95 | 106 | 126 | 135 | 99 | 105 | 142 | 135 |
| 1930 | 133 | 138 | 139 | 83 | 84 | 115 | 137 | 152 | 191 | 169 | 177 | 146 |
| 1931 | 147 | 130 | 136 | 99 | 96 | 125 | 79 | 108 | 71 | 93 | 65 | 80 |
| 1932 | 117 | 126 | 129 | 104 | 107 | 100 | 107 | 107 | 101 | 33 | 59 | 43 |
| 1933 | 114 | 75 | 86 | 88 | 90 | 109 | 125 | 90 | 52 | 62 | 53 | 18 |
| 1934 | 43 | 46 | 75 | 68 | 78 | 119 | 109 | 93 | 63 | 68 | 76 | 90 |
| 1935 | 99 | 103 | 73 | 67 | 94 | 100 | 114 | 85 | 104 | 117 | 93 | 110 |
| 1936 | 119 | 128 | 113 | 91 | 86 | 74 | 96 | 99 | 96 | 76 | 155 | 103 |
| 1937 | 96 | 107 | 95 | 70 | 85 | 111 | 111 | 101 | 129 | 96 | 77 | 49 |
| 1938 | 87 | 65 | 55 | 65 | 63 | 85 | 74 | 85 | 52 | 52 | 82 | 63 |
| 1939 | 74 | 61 | 67 | 93 | 117 | 105 | 124 | 120 | 121 | 134 | 145 | 163 |
| 1940 | 135 | 137 | 149 | 151 | 135 | 146 | 135 | 133 | 145 | 206 | 173 | 189 |
| 1941 | 178 | 185 | 150 | 141 | 139 | 143 | 129 | 130 | 175 | 140 | 169 | 160 |
| 1942 | [128] | [120] | 111 | 90 | 86 | 83 | 42 | 85 | 42 | 53 | 55 | 56 |
| 1943 | 56 | 81 | 52 | 92 | 103 | 109 | 108 | 120 | 65 | 79 | 82 | 101 |
| 1944 | 121 | 90 | 92 | 101 | 118 | 114 | 102 | 85 | 84 | 91 | 59 | 86 |
| 1945 | 51 | 67 | 96 | 76 | 113 | 106 | 133 | 84 | 69 | 78 | 48 | 88 |
| 1946 | 104 | 105 | 117 | 118 | 123 | 133 | 126 | 127 | 79 | 119 | 135 | 79 |
| 1947 | 105 | 103 | 66 | 97 | 94 | 106 | 94 | 89 | 76 | 85 | 100 | 97 |
| 1948 | 107 | 120 | 140 | 147 | 143 | 132 | 93 | 97 | 74 | 72 | 123 | 117 |
| 1949 | 84 | 119 | 120 | 103 | 99 | 76 | 80 | 60 | 74 | 61 | 53 | 44 |
| 1950 | 22 | 42 | 42 | 65 | 51 | 79 | 73 | 90 | 60 | 56 | 60 | 60 |

Table AIII. (*continued*)

| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 94 | 82 | 97 | 112 | 138 | 136 | 120 | 140 | 123 | 129 | 92 | 131 |
| 1952 | 104 | 93 | 102 | 101 | 105 | 106 | 93 | 112 | 111 | 66 | 108 | 115 |
| 1953 | 113 | 144 | 122 | 130 | 155 | 119 | 116 | 125 | 138 | 144 | 119 | 116 |
| 1954 | 97 | 90 | 90 | 88 | 65 | 64 | 76 | 83 | 67 | 58 | 43 | 51 |
| 1955 | 107 | 61 | 91 | 82 | 77 | 90 | 89 | 69 | 99 | 52 | 42 | 55 |
| 1956 | 66 | 55 | 74 | 95 | 101 | 91 | 79 | 99 | 97 | 96 | 88 | 71 |
| 1957 | 72 | 75 | 89 | 104 | 140 | 144 | 134 | 105 | 146 | 175 | 201 | 190 |
| 1958 | 167 | 166 | 149 | 130 | 131 | 121 | 128 | 109 | 85 | 86 | 110 | 127 |
| 1959 | 120 | 135 | 113 | 101 | 95 | 92 | 81 | 69 | 82 | 85 | 108 | 87 |
| 1960 | 109 | 123 | 89 | 98 | 106 | 79 | 98 | 95 | 81 | 115 | 96 | 104 |
| 1961 | 104 | 103 | 103 | 101 | 108 | 117 | 113 | 118 | 92 | 100 | 98 | 57 |
| 1962 | 59 | 62 | 85 | 98 | 104 | 81 | 111 | 84 | 109 | 71 | 104 | 72 |
| 1963 | 67 | 68 | 74 | 79 | 69 | 94 | 108 | 129 | 151 | 180 | 136 | 158 |
| 1964 | 158 | 137 | 107 | 56 | 50 | 56 | 58 | 89 | 78 | 75 | 66 | 80 |
| 1965 | 105 | 117 | 114 | 107 | 101 | 124 | 132 | 149 | 178 | 189 | 182 | 159 |
| 1966 | 168 | 140 | 132 | 114 | 87 | 103 | 116 | 92 | 67 | 83 | 87 | 96 |
| 1967 | 75 | 68 | 66 | 87 | 74 | 96 | 100 | 85 | 85 | 102 | 84 | 113 |
| 1968 | 89 | 84 | 42 | 59 | 40 | 65 | 107 | 61 | 85 | 98 | 113 | 93 |
| 1969 | 114 | 115 | 124 | 129 | 118 | 106 | 86 | 90 | 111 | 100 | 114 | 109 |
| 1970 | 117 | 117 | 117 | 124 | 103 | 77 | 59 | 70 | 48 | 53 | 48 | 39 |
| 1971 | 41 | 61 | 52 | 87 | 84 | 110 | 87 | 90 | 69 | 87 | 60 | 107 |
| 1972 | 94 | 92 | 82 | 99 | 122 | 130 | 148 | 159 | 191 | 203 | 223 | 191 |
| 1973 | 181 | 173 | 124 | 92 | 108 | 83 | 37 | 79 | 69 | 57 | 16 | 41 |
| 1974 | 24 | 67 | 47 | 70 | 104 | 101 | 122 | 85 | 75 | 104 | 61 | 101 |
| 1975 | 106 | 102 | 120 | 94 | 93 | 101 | 80 | 66 | 72 | 45 | 45 | 55 |
| 1976 | 60 | 77 | 116 | 104 | 129 | 132 | 138 | 150 | 150 | 165 | 155 | 156 |
| 1977 | 156 | 135 | 132 | 128 | 119 | 105 | 131 | 119 | 115 | 126 | 160 | 161 |
| 1978 | 136 | 130 | 112 | 98 | 73 | 78 | 72 | 73 | 88 | 80 | 78 | 123 |
| 1979 | 138 | 141 | 128 | 99 | 111 | 120 | 99 | 108 | 117 | 173 | 141 | 136 |
| 1980 | 126 | 114 | 143 | 135 | 130 | 127 | 118 | 133 | 115 | 120 | 149 | 135 |
| 1981 | 116 | 120 | 120 | 110 | 112 | 128 | 69 | 103 | 146 | 121 | 90 | 135 |
| 1982 | 51 | 96 | 65 | 109 | 139 | 107 | 154 | 197 | 184 | 260 | 255 | 208 |
| 1983 | 181 | 97 | 73 | 93 | 160 | 142 | 142 | 106 | M | M | M | M |

Table AIV. *DT*-cap: 1851–1934 estimates of Darwin minus Tahiti pressure based on the index of Wright (1975); 1935–1985 homogenized Darwin pressure anomaly minus Tahiti pressure anomaly, calculated monthly and averaged over 3-month seasons

| | DJF | MAM | JJA | SON | | DJF | MAM | JJA | SON |
|---|---|---|---|---|---|---|---|---|---|
| 1851 | −999 | −999 | −21 | 2 | 1904 | −14 | −8 | 5 | 10 |
| 1852 | −16 | −10 | −3 | 11 | 1905 | 35 | 14 | 9 | 6 |
| 1853 | 12 | −4 | 12 | 13 | 1906 | 22 | 2 | −9 | −6 |
| 1854 | −3 | 3 | −5 | −8 | 1907 | −7 | −1 | 2 | 3 |
| 1855 | 15 | 9 | 15 | 15 | 1908 | 1 | −7 | −1 | −10 |
| 1856 | 31 | −3 | −11 | 9 | 1909 | −8 | −9 | −18 | −14 |
| 1857 | −8 | −8 | −6 | 14 | 1910 | −16 | −17 | −14 | −15 |
| 1858 | 12 | 0 | −9 | −1 | 1911 | −12 | 7 | 10 | 14 |
| 1859 | −2 | 5 | 4 | 4 | 1912 | 15 | 7 | −3 | 1 |
| 1860 | −13 | −4 | −3 | −1 | 1913 | 4 | −4 | 9 | 14 |
| 1861 | −15 | −11 | −16 | −3 | 1914 | 31 | 10 | 17 | 26 |
| 1862 | −20 | −11 | −11 | −23 | 1915 | 18 | 8 | −13 | −14 |
| 1863 | −32 | −17 | −15 | −6 | 1916 | −11 | −11 | −28 | −30 |
| 1864 | −1 | 6 | 11 | 7 | 1917 | −36 | −16 | −26 | −31 |
| 1865 | 19 | −2 | 5 | −3 | 1918 | −15 | 4 | 10 | 14 |
| 1866 | 1 | −1 | 2 | −1 | 1919 | 17 | 8 | 4 | 4 |
| 1867 | 21 | −1 | −8 | −7 | 1920 | 10 | −2 | −9 | −2 |
| 1868 | 28 | 11 | 18 | 18 | 1921 | −20 | −11 | −12 | −2 |
| 1869 | 29 | 7 | 0 | −7 | 1922 | −5 | −7 | −5 | −7 |
| 1870 | −40 | −11 | −9 | −15 | 1923 | −11 | −4 | −6 | 10 |
| 1871 | −14 | −3 | −5 | −7 | 1924 | 3 | −6 | −6 | 14 |
| 1872 | −16 | −9 | −15 | −20 | 1925 | −8 | −8 | 7 | 18 |
| 1873 | −33 | −6 | −11 | 7 | 1926 | 31 | 13 | −1 | −8 |
| 1874 | 17 | −5 | −14 | −20 | 1927 | −10 | −8 | 0 | 4 |
| 1875 | −7 | −9 | −4 | −5 | 1928 | 12 | −4 | 0 | −6 |
| 1876 | −13 | −4 | 12 | 18 | 1929 | −2 | −5 | 7 | 5 |
| 1877 | 27 | 14 | 40 | 43 | 1930 | −3 | 7 | 14 | 14 |
| 1878 | 20 | 8 | −7 | −27 | 1931 | 13 | 6 | −3 | −7 |
| 1879 | −16 | −4 | −12 | −8 | 1932 | 6 | 2 | −4 | −7 |
| 1880 | −25 | 1 | 7 | 10 | 1933 | −7 | −5 | −8 | −16 |
| 1881 | 24 | 12 | 9 | 2 | 1934 | −23 | −5 | 2 | 0 |
| 1882 | −12 | −7 | −14 | −8 | 1935 | 0 | −8 | −1 | −11 |
| 1883 | −6 | −8 | −5 | 1 | 1936 | 3 | −14 | 2 | 4 |
| 1884 | 8 | 1 | 2 | 3 | 1937 | −4 | −6 | −1 | 0 |
| 1885 | 11 | −1 | 13 | 11 | 1938 | −13 | −7 | −25 | −14 |
| 1886 | 12 | −7 | −14 | −23 | 1939 | −27 | −12 | −5 | 15 |
| 1887 | −11 | −5 | 0 | 6 | 1940 | 8 | 15 | 24 | 22 |
| 1888 | 13 | 5 | 5 | 18 | 1941 | 36 | 12 | 25 | 18 |
| 1889 | 21 | 6 | −13 | −18 | 1942 | 17 | 2 | −6 | −9 |
| 1890 | −37 | −11 | −13 | −8 | 1943 | −24 | −11 | −3 | −12 |
| 1891 | 4 | 5 | 8 | 4 | 1944 | 8 | −3 | 3 | 5 |
| 1892 | −3 | −14 | −11 | −23 | 1945 | −11 | −7 | −13 | −6 |
| 1893 | −16 | −10 | −22 | −17 | 1946 | −6 | 8 | 10 | 14 |
| 1894 | −15 | −7 | −9 | −13 | 1947 | 9 | −1 | −11 | −12 |
| 1895 | 0 | −7 | 0 | −2 | 1948 | 2 | 1 | 6 | 0 |
| 1896 | −1 | −4 | 7 | 18 | 1949 | 10 | 0 | 10 | 0 |
| 1897 | 9 | −1 | −3 | −11 | 1950 | −18 | −19 | −27 | −18 |
| 1898 | −6 | −14 | −3 | −10 | 1951 | −26 | 13 | 12 | 19 |
| 1899 | −20 | −1 | 15 | 19 | 1952 | 18 | 0 | −3 | 0 |
| 1900 | 19 | 7 | 6 | 1 | 1953 | 13 | 17 | 12 | 10 |
| 1901 | 8 | 1 | 5 | 3 | 1954 | 4 | −2 | −4 | −2 |
| 1902 | −2 | 7 | 19 | 15 | 1955 | −13 | −3 | −21 | −24 |
| 1903 | 24 | 6 | −8 | −12 | 1956 | −20 | −16 | −15 | −11 |

Table AIV. *(continued)*

| | DJF | MAM | JJA | SON | | DJF | MAM | JJA | SON |
|---|---|---|---|---|---|---|---|---|---|
| 1957 | −6 | 8 | 6 | 13 | 1971 | −22 | −24 | −8 | −21 |
| 1958 | 20 | 6 | −4 | 6 | 1972 | −7 | 8 | 19 | 17 |
| 1959 | 22 | −8 | 9 | −7 | 1973 | 22 | 0 | −13 | −28 |
| 1960 | −3 | −8 | −3 | −7 | 1974 | −35 | −20 | −9 | −10 |
| 1961 | −5 | 10 | 3 | 0 | 1975 | 1 | −14 | −26 | −28 |
| 1962 | −21 | 4 | 3 | −9 | 1976 | −27 | −8 | 14 | 2 |
| 1963 | 0 | −6 | 9 | 17 | 1977 | 1 | 15 | 23 | 21 |
| 1964 | 13 | −12 | −12 | −15 | 1978 | 29 | 1 | −5 | 5 |
| 1965 | 5 | 4 | 24 | 24 | 1979 | 1 | 4 | −5 | 4 |
| 1966 | 12 | 16 | −1 | 3 | 1980 | 4 | 13 | 4 | 6 |
| 1967 | −15 | −1 | −4 | 1 | 1981 | 3 | 10 | −11 | −1 |
| 1968 | −4 | −2 | −7 | 5 | 1982 | −8 | 4 | 32 | 39 |
| 1969 | 15 | 7 | 8 | 13 | 1983 | 61 | 23 | 7 | −6 |
| 1970 | 15 | 1 | −2 | −22 | 1984 | −3 | 2 | 3 | 1 |

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