An Index of the Southern Oscillation

P. B. Wright

1975

Climatic Research Unit
School of Environmental Sciences
University of East Anglia

Climatic Research Unit Research Publication 4
(CRU RP4)
About the Climatic Research Unit

The Climatic Research Unit (CRU) is widely recognised as one of the world's leading institutions concerned with the study of natural and anthropogenic climate change. CRU is part of the School of Environmental Sciences at the University of East Anglia in Norwich. The aim of the Climatic Research Unit is to improve scientific understanding in three areas:

- past climate history and its impact on humanity;
- the course and causes of climate change;
- prospects for the future.

About Climatic Research Unit Research Publications

The majority of CRU’s research output is published in the peer-reviewed science literature (journals and books), listed in full on our publications webpage. CRU Research Publications (CRU RPs) are occasional research reports that, due to various factors such as length, style or intended audience, are not suitable for publishing in the science literature. The first nine CRU RPs were originally published in hard copy form but are now available in electronic form, while from CRU RP10 onwards they are available only from our website in electronic form.

CRU Research Publications series

CRU RP1 (1973) Lamb HH
*The seasonal progression of the general atmospheric circulation affecting the North Atlantic and Europe.*

*Mapping the atmospheric and oceanic circulation and other climatic parameters at the time of the Last Glacial Maximum, about 17000 years ago.*

CRU RP3 (1974) Lamb HH
*The current trend of world climate – a report on the early 1970s and a perspective.*

CRU RP4 (1975) Wright PB
*An index of the Southern Oscillation.*

CRU RP5 (1977) Lamb HH
*Understanding climatic change and its relevance to the world food problem.*

*A meteorological study of July to October 1588: the Spanish Armada storms.*

CRU RP6a (1979) Douglas KS & Lamb HH
*Weather Observations and a Tentative Meteorological Analysis of the Period May to July 1588.*

CRU RP7 (1980) Perry AH & Fearnside T
*Northern Hemisphere pentad (5-day) mean sea level pressure values for the period 1951–70 and comparisons with earlier epochs.*

CRU RP8 (1985) Jones PD, Ogilvie AEJ & Wigley TML
*Riverflow data for the United Kingdom: reconstructed data back to 1844 and historical data back to 1556.*

CRU RP9 (1988) Santer BD
*Regional validation of General Circulation Models.*
An Index of the Southern Oscillation

by

P.B. Wright

Climatic Research Unit
School of Environmental Sciences
University of East Anglia
Norwich, NR4 7TJ
AN INDEX OF THE SOUTHERN OSCILLATION

by P. B. Wright

Climatic Research Unit
School of Environmental Sciences
University of East Anglia
Norwich

CRU RP4 1975
SUMMARY
An index of the Southern Oscillation for each season from 1851 to 1974 is presented. The index may be used for investigations into the spatial and temporal patterns of the SO. Full details of the method of construction of the index are given.

INTRODUCTION
The Southern Oscillation (SO) is a fluctuation of the atmospheric circulation with irregular period. It involves pressures, winds, rainfall, air temperatures and sea surface temperatures in many parts of the world, but especially the tropical zone in the Pacific and Indian Ocean sectors. It is the most important single mechanism responsible for climatic variations on time scales from a year to fifty years, and therefore deserves detailed study.

The behaviour of the SO may be briefly described as follows. A semi-permanent feature of the general circulation is the 'Walker cell' which consists of a circulation over the equator in a zonal plane involving ascent over the Indonesia sector, subsidence over the east Pacific, and surface easterlies and upper westerlies over most of the equatorial Pacific. Sometimes this circulation is stronger than usual (high index) and then it is associated with increased upwelling of cold water, clear skies and low rainfall in the equatorial east Pacific, and relatively cloudy rainy conditions in Indonesia, east Australia and India. At other times the Walker cell is weaker than usual (low index) and then the oceanic upwelling is also weak, associated with warmer, wetter weather in the equatorial east Pacific and relatively dry conditions in the Indian Ocean sector. The fluctuation between these states is the Southern Oscillation.

More information about the behaviour of the SO has been given by TROUP (1965) and BOER and KYLE (1974). Investigations are now in progress at the Climatic Research Unit with the aims of comprehensively mapping and explaining the mechanisms of the SO. In order to document the pattern of influence of the SO accurately, it is necessary to devise an index to represent it. The present paper describes how this was done, and presents seasonal values of the index for the period 1851-1974.
INDEX

The aim of this paper is to devise an index whose magnitude represents the strength of the Walker circulation and whose fluctuations represent the Southern Oscillation.

A good index should be:

(a) representative of some real physical feature
(b) reproducible
(c) homogeneous in time
(d) easy to calculate
(e) able to be extended in time outside the period for which it was calculated, using readily available data.

Several authors have devised indices of the SO. WALKER and BLISS (1924-36) used an index based on a combination of pressure, temperature and rainfall, different parameters being used in different seasons. This was effective but rather more complex than necessary. BERLAGE (1956), in contrast, used Batavia (now Djakarta) pressure alone. This is certainly simple and surprisingly good (eg annual values are correlated -0.8 with pressure at Easter Island); however data for Djakarta since 1945 are difficult to obtain or of doubtful quality, and during part of the year Djakarta is not at a 'centre of action' of the pressure balance (TROUP 1965). A combination of pressures at several stations, widely spaced, has seemed the best solution, as this could cater for the change of pattern with the season and also reduce the effect of local influences. The index presented here satisfies the above criteria quite well.

PRINCIPLES

It was decided:

(1) To follow WALKER'S principle of using different combinations of parameters in different seasons, because the regions of influence of the SO are observed to be different in different seasons.

(2) To use only pressures; this makes the index easier to interpret in physical terms.

(3) To use the season as the time unit, and not to apply any time smoothing.
(4) To use the grouping of months: Season 1 = FMA, 2 = MJJ, 3 = ASO, 4 = NDJ. This grouping is in principle no better or worse than either of the other possible groupings. (See also below.)

DEFINITION OF INDEX

The Index of the Southern Oscillation for season \(s\) \((s = 1, 2, 3, 4\) representing respectively the months February to April, May to July, August to October, November to January) in year \(y\) is denoted by \(C(ys)\) and defined by:

\[
C(ys) = \sum_{j=1}^{8} \left[ P(jys) - M(js) \right] W(js)
\]

where \(j\) denotes the station number according to Table 1, \(P(jys)\) is the seasonal mean pressure (as defined in Table 1a) for station \(j\), year \(y\), season \(s\), expressed in millibars minus 1000, and \(M\) and \(W\) are given by Table 1b.

For the period 1896-1945 pressure data are available in World Weather Records (WWR). After applying the corrections listed in Table 2, these data conform to the specification of Table 1. These data series were assumed to be homogeneous, although Table 2 suggests some uncertainties. The values of \(M\) and \(W\) were calculated by the method described in Appendix 1 and have the property that, over the period 1896-1945, the mean value of the index for each season was zero and the standard deviation was 1.

INDEX FOR STANDARD SEASONS

The original values of the index are for what will be referred to as the SO seasons - FMA, MJJ, ASO, NDJ. These have the advantage that, when combined in pairs (4 and 1, 2 and 3) they represent the year in two halves most conveniently (eg for correlating with rainfall in places where rain occurs predominantly in summer or winter). (Results showed that this is indeed an appropriate pairing, in that the autocorrelation from season 1 to season 2 is appreciably less than across other pairs.) They have the disadvantage of not agreeing with the more commonly used standard seasons - DJF, MAM, JJA, SON. A set of values of the index for the standard seasons may be prepared by parabolic interpolation according to the following example.
Denote the seasons FMA, MJJ and ASO by $T_1$, $T_2$ and $T_3$ respectively and the corresponding values of the index by $C_1$, $C_2$ and $C_3$. We fit a parabola to the three values, then interpolate at time

$$T_2 + \frac{(T_3 - T_2)}{3}$$

which corresponds to the standard season JJA. This is equivalent to using the formula for $C$ (the index for JJA):

$$C = \frac{-C_1 + 8C_2 + 2C_3}{9}$$

It must be noted that for the SO seasons each value of the index was derived from independent data. The time series has experienced no time smoothing. However for the standard seasons the consecutive values are not entirely independent, so this series may have certain statistical properties due to its method of calculation. This should be borne in mind in analysis.

**HOMOGENISING**

Much time has been spent in this study in trying to ensure that the pressure series used were homogeneous. Inhomogeneities can arise due to:

(a) Different methods of observation
(b) Different times of observation
(c) Different formulae used for standardisation
(d) Change of position of the barometer

All such changes, if known, can be corrected for. Some have been so corrected before publication, others may be corrected afterwards. But if there are unknown changes, they may be difficult or impossible to detect. A letter to the Meteorological Service of the country concerned is sometimes helpful, but information about changes in the early years may be lost for ever. Thus it is not possible to guarantee that the series of the Index is homogeneous. Empirical methods, in particular comparison of the trends in several stations, may detect some inhomogeneities, but the possibilities of genuine climatic changes must not be overlooked. It is considered that the series presented here is adequately homogeneous for most purposes, but it should not be relied on to investigate trends or to compare extreme values widely separated in time.
Table 3 lists some errors which have come to my notice but which have not been corrected in the values of the index presented here.

INDEX OUTSIDE THE BASIC PERIOD

Values of the index may be calculated for seasons outside the period 1896-1945 used in the initial analysis. If data for all eight stations are available and can be assumed to form a homogeneous series including the period 1896-1945, then the index is calculated using Table 1b. This procedure is valid provided only that the 'region of action' of the SO was not greatly different in the two periods of years.

If the set of parameters available is other than the original 8 pressures, then the analysis detailed in Appendix 2 is used to obtain an appropriate set of means and weights. The parameters must include data for at least part of the period 1896-1945, and the series must be homogeneous. The correlation of the 'new' index so calculated with the 'true' index should be greater than some suitable threshold value (eg 0.60) for the 'new' index to be acceptable.

DATA USED FOR OTHER PERIODS

For the periods 1851-95 and 1946 to date, various combinations of the 8 stations were available. The methods of Appendix 2 were used to determine the best combination for each season, and the appropriate weights. In most cases a combination was found which gave a correlation of at least 0.83 with the basic index. The combinations used are given in Table 4, with the correlation coefficients. (In a few cases marginally higher correlations could have been obtained with an extra station, but interests of economy were considered.) For recent years, Djakarta appeared to be not available or unreliable, and Honolulu showed difficulties with homogeneity, but it was found possible to leave out these stations and still keep correlations of 0.97 or more with the basic index.

For the period 1851-95, the data available were obtained from World Weather Records and satisfied the criteria of Table 1 after applying the corrections of Table 2. For the period 1946 to date, data were obtained from the sources given in Table 5b and corrected as described; they were then assumed to
conform to Table 5a. The appropriate set of means and weights is given in Table 5c. Appendix 3 gives some additional notes about corrections made. Values of the index for the period 1851 to date are given in Appendix 4. The reader may calculate values of the index for later years using the information in Table 5.

TEMPORAL ANALYSIS

The time series of the index is shown in Figure 1. From a scrutiny of this the reader may draw preliminary conclusions about the temporal behaviour of the SO. A complete statistical analysis is not presented here, but the following are a few features of interest.

1. There is no suggestion of any appreciable trend (although any positive conclusion would need careful examination in view of the method of construction of the index).

2. The series exhibits persistence (autocorrelation) of 0.67. Persistence is significantly least between February-April and May-July, ie across the northern spring.

3. There is no regular periodicity, but 3 to 5 years is a common cycle length. During 1881-1912 the dominant period was 3 years, whereas during 1911-42 the main peak of the power spectrum lay near 5 years.

MAPPING OF THE OSCILLATION

One of the most valuable uses of the index is to map the spatial pattern of the Southern Oscillation. Work to this end is now in progress. As an example of the maps being prepared, Figure 2 illustrates the pattern of correlation of the index with temperatures in the Northern Winter (December to February) over the world.
FURTHER EXTENSIONS OF SERIES

It would be of interest to extend the series of the index back in time as far as possible, for several reasons. For example, one could investigate variations in the periodicity of the SO, and (by correlating with other parameters) one could discover whether the spatial pattern remained the same. A knowledge of the state of the SO in any given season would also contribute to the work of the Historical Mapping Project of the Climatic Research Unit (mapping the seasonal weather patterns as far back in time as possible). It might also be possible to study trends, which could be done if the series used were known to be homogeneous. It may also be feasible to subtract the effect of the SO from a time series in order to study other oscillations more easily. It should be possible to extend the series back with reasonable confidence because there are many parameters which show significant correlations with the index. The mapping work now in progress suggests the following as regions from which early data might be utilised:

Temperatures over North America in winter and spring, especially the temperature gradient from NW to SE.

Temperatures in many equatorial regions, Chile, Australia and India.

Pressures in many parts of the Pacific and Indian Ocean regions.

In addition, for earlier years, non-instrumental and proxy data might be utilised, at least to give qualitative estimates of the index. For example, a series of quintiles of rainfall in Chile is available for the period 1535-1959; for the period 1860-1959 this is correlated -0.50 with the index for May-July, so this series should be valuable for estimating the index in earlier years, although it is not homogeneous and is probably less reliable in the earlier decades. A series of Java tree ring widths is correlated 0.29 with the index for November-January over the period 1851-1949, and that series dates back to 1514.
ACKNOWLEDGEMENTS

I am indebted to the Director, Environmental Data Service, NOAA, USA, and to the Deputy Director General of Observatories (Climatology and Geophysics), Poona, India, for providing pressure data and for advice about collating series for different periods. I would also like to acknowledge the help of the staff of the Computing Centre, University of East Anglia, and also Professor Lamb and other members of the Climatic Research Unit for their helpful comments.
REFERENCES


WORLD WEATHER RECORDS

Smithsonian Institution, Miscellaneous Collections, publications 2913, 3218, 3803; and U.S. Department of Commerce, 7 volumes.


MONTHLY CLIMATIC DATA FOR THE WORLD 1961 to date

U.S. Department of Commerce, Asheville N.C., U.S.A.
TABLE 1. Definition of Index

(a) Station specifications for pressure data

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Level</th>
<th>Averaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cape Town</td>
<td>Sea</td>
<td>Mean of 24 hours</td>
</tr>
<tr>
<td>2</td>
<td>Bombay</td>
<td>Sea</td>
<td>08.39 Indian Standard Time</td>
</tr>
<tr>
<td>3</td>
<td>Djakarta</td>
<td>Station</td>
<td>Mean of 24 hours</td>
</tr>
<tr>
<td>4</td>
<td>Darwin</td>
<td>Sea</td>
<td>Mean of 09.00 and 15.00</td>
</tr>
<tr>
<td>5</td>
<td>Adelaide</td>
<td>Sea</td>
<td>Mean of 09.00 and 15.00</td>
</tr>
<tr>
<td>6</td>
<td>Apia</td>
<td>Sea</td>
<td>Mean of 24 hours</td>
</tr>
<tr>
<td>7</td>
<td>Honolulu</td>
<td>Station</td>
<td>Mean of 08.00 and 20.00</td>
</tr>
<tr>
<td>8</td>
<td>Santiago</td>
<td>Sea</td>
<td>Mean of 24 hours</td>
</tr>
</tbody>
</table>

(b) Means and weights for each season

<table>
<thead>
<tr>
<th>Season</th>
<th>Station</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Means</td>
<td>14.83</td>
<td>12.38</td>
<td>8.70</td>
<td>7.82</td>
<td>8.94</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(FMA) Wts</td>
<td>-0.31</td>
<td>-0.44</td>
<td>-0.48</td>
<td>-0.27</td>
<td>0</td>
<td>+0.29</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Means</td>
<td>6.12</td>
<td>8.87</td>
<td>12.08</td>
<td>20.04</td>
<td>11.23</td>
<td>15.75</td>
<td>17.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(MJJ) Wts</td>
<td>0</td>
<td>-0.36</td>
<td>-0.70</td>
<td>-0.38</td>
<td>-0.11</td>
<td>+0.31</td>
<td>+0.20</td>
<td>+0.22</td>
</tr>
<tr>
<td>3</td>
<td>Means</td>
<td>9.03</td>
<td>9.53</td>
<td>11.80</td>
<td>17.58</td>
<td>11.64</td>
<td>14.50</td>
<td>17.32</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(ASO) Wts</td>
<td>0</td>
<td>-0.29</td>
<td>-0.51</td>
<td>-0.30</td>
<td>-0.07</td>
<td>+0.29</td>
<td>+0.25</td>
<td>+0.24</td>
</tr>
<tr>
<td>4</td>
<td>Means</td>
<td>14.64</td>
<td>14.40</td>
<td>8.48</td>
<td>7.36</td>
<td>13.94</td>
<td>8.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(NDJ) Wts</td>
<td>-0.37</td>
<td>-0.37</td>
<td>-0.40</td>
<td>-0.29</td>
<td>-0.18</td>
<td>+0.28</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
TABLE 2. **Corrections and Doubts**

1. The Bombay values for station level in WWR were corrected to sea level by adding 1.2 mb.

2. The Santiago values for station level in WWR were corrected to sea level by adding:
   
   61.4 mb in season 2
   60.8 mb in season 3

3. The Darwin values for 1941-45 were for the mean of 08.30 and 14.30 at the time of 142°E. It is not clear if these are homogeneous with the earlier series, but homogeneity has been assumed.

4. The Santiago values for 1941-45 were for the mean of 08.00, 14.00 and 19.00. Homogeneity with the earlier series has been assumed.

5. The Santiago values for 1972 August and September were given in MCD as 956.2 and 955.6. It was assumed that these were the station-level pressures, and they were corrected by adding 60.8 mb.

---

TABLE 3. **Errors which should be investigated**

1. Pressures for Djakarta for 1866-1930 should be 0.67 mb lower (World Weather Records 1921-30).

2. TROUP (1965) made a correction (details unspecified) to Darwin pressures.

3. DR D. J. SCHOVE has advised me that errors exist in the WWR data for Cape Town.

4. Bombay pressures should be 0.3 mb lower during 1881-90, and have errors (unspecified) in 1911 and 1919. (SCHOVE and BERLAGE, 1965.)
TABLE 4. (a) Stations used to obtain index during various periods (according to numbering in Table 1).

(b) The correlation coefficients of the index so obtained with the basic index (x 100).

<table>
<thead>
<tr>
<th>Season</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>1847-56</td>
<td>1, 2</td>
<td>1, 2</td>
<td>2</td>
<td>1, 2</td>
<td>92</td>
<td>59</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>1857-60</td>
<td>1, 2, 5</td>
<td>2, 5</td>
<td>2, 5</td>
<td>1, 2, 5</td>
<td>93</td>
<td>88</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>1861-65</td>
<td>1, 2, 5</td>
<td>2, 5, 8</td>
<td>2, 5, 8</td>
<td>1, 2, 5</td>
<td>93</td>
<td>90</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>1866-81</td>
<td>1, 2, 3, 5</td>
<td>2, 3, 5, 8</td>
<td>2, 3, 5, 8</td>
<td>1, 2, 3, 5</td>
<td>97</td>
<td>95</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>1882, 1890</td>
<td>1, 2, 3, 4, 5</td>
<td>2, 3, 4, 5, 8</td>
<td>2, 3, 4, 5, 8</td>
<td>1, 2, 3, 5</td>
<td>99</td>
<td>97</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>1883-89</td>
<td>1, 2, 3, 4, 5</td>
<td>2, 3, 4, 5, 8</td>
<td>2, 3, 4, 5, 8</td>
<td>1, 2, 3, 5</td>
<td>99</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>1946-73</td>
<td>1, 2, 4, 6, 8</td>
<td>2, 4, 5, 6, 8</td>
<td>2, 4, 5, 6, 8</td>
<td>1, 2, 4, 5, 6, 8</td>
<td>98</td>
<td>98</td>
<td>97</td>
</tr>
</tbody>
</table>
TABLE 5.  Calculation of index for period 1946 to date

(a) Station specifications for pressure data

<table>
<thead>
<tr>
<th>Station</th>
<th>Level</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Town</td>
<td>Sea level</td>
<td>Mean of 24 hours</td>
</tr>
<tr>
<td>Bombay</td>
<td>Sea level</td>
<td>08.39 Indian Standard Time</td>
</tr>
<tr>
<td>Darwin</td>
<td>Sea level</td>
<td>Mean of 08.30 and 14.30 (local time 142°E)</td>
</tr>
<tr>
<td>Adelaide</td>
<td>Sea level</td>
<td>Mean of 09.00 and 15.00 (local time 142°E)</td>
</tr>
<tr>
<td>Apia</td>
<td>Sea level</td>
<td>Mean of 24 hours</td>
</tr>
<tr>
<td>Santiago</td>
<td>Sea level</td>
<td>Mean of 08.00, 14.00 and 19.00</td>
</tr>
</tbody>
</table>

(b) Sources of data

(WWR = World Weather Records, MCD = Monthly Climatic Data for the World)

<table>
<thead>
<tr>
<th>Station</th>
<th>Year</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Town</td>
<td>1946-60</td>
<td>WWR</td>
</tr>
<tr>
<td></td>
<td>1961-date</td>
<td>MCD</td>
</tr>
<tr>
<td>Bombay</td>
<td>1946-50</td>
<td>WWR (converted by adding 1.1 mb) (1948 Mar : 1.0 mb added in addition)</td>
</tr>
<tr>
<td></td>
<td>1951-60</td>
<td>WWR</td>
</tr>
<tr>
<td></td>
<td>1961-72</td>
<td>Indian Meteorological Service</td>
</tr>
<tr>
<td></td>
<td>1973-date</td>
<td>MCD (converted by adding 1.6 mb in FMA, 1.1 in MJJ, 1.2 in ASO, 1.5 in NDJ)</td>
</tr>
<tr>
<td>Darwin</td>
<td>1946-60</td>
<td>WWR</td>
</tr>
<tr>
<td>Adelaide</td>
<td>1961-date</td>
<td>MCD</td>
</tr>
<tr>
<td>Apia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santiago</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(c) Means and weights for each season

<table>
<thead>
<tr>
<th>Season</th>
<th>Cape Town</th>
<th>Bombay</th>
<th>Darwin</th>
<th>Adelaide</th>
<th>Apia</th>
<th>Santiago</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.8</td>
<td>12.3</td>
<td>7.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(FMA)</td>
<td>-0.53</td>
<td>-0.70</td>
<td>-0.42</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>14.6</td>
<td>14.3</td>
<td>7.4</td>
<td>13.9</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>(NDJ)</td>
<td>-0.49</td>
<td>-0.43</td>
<td>-0.38</td>
<td>-0.25</td>
<td>0.36</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>8.9</td>
<td>11.8</td>
<td>17.6</td>
<td>11.6</td>
<td>17.3</td>
<td></td>
</tr>
<tr>
<td>(ASO)</td>
<td>-0.42</td>
<td>-0.41</td>
<td>-0.11</td>
<td>0.42</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6.0</td>
<td>12.1</td>
<td>20.0</td>
<td>11.2</td>
<td>17.8</td>
<td></td>
</tr>
<tr>
<td>(MJJ)</td>
<td>0</td>
<td>-0.47</td>
<td>-0.50</td>
<td>-0.14</td>
<td>0.44</td>
<td>0.31</td>
</tr>
</tbody>
</table>
TABLE 6. **Statistics of the 8 stations each season (see Appendix 1).**

<table>
<thead>
<tr>
<th>Station</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1014.83</td>
<td>1012.38</td>
<td>1008.70</td>
<td>1007.82</td>
<td>1017.11</td>
<td>1008.94</td>
<td>1015.85</td>
<td>available</td>
<td>0.64</td>
<td>0.63</td>
<td>0.61</td>
<td>0.97</td>
<td>1.08</td>
<td>0.65</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>-0.31</td>
<td>-0.44</td>
<td>-0.48</td>
<td>-0.27</td>
<td>+0.29</td>
<td>17.77</td>
<td>0.36</td>
<td>0.70</td>
<td>-0.38</td>
<td>-0.11</td>
<td>+0.31</td>
<td>+0.20</td>
<td>+0.22</td>
<td>0.36</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>1019.88</td>
<td>1006.12</td>
<td>1008.87</td>
<td>1012.08</td>
<td>1020.04</td>
<td>1011.23</td>
<td>1015.75</td>
<td>0.87</td>
<td>0.49</td>
<td>0.36</td>
<td>0.69</td>
<td>2.13</td>
<td>0.58</td>
<td>0.67</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>-0.36</td>
<td>-0.70</td>
<td>-0.38</td>
<td>-0.11</td>
<td>+0.31</td>
<td>+0.20</td>
<td>+0.22</td>
<td>0.36</td>
<td>0.45</td>
<td>0.47</td>
<td>0.80</td>
<td>2.04</td>
<td>0.64</td>
<td>0.71</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>1018.98</td>
<td>1009.03</td>
<td>1009.53</td>
<td>1011.80</td>
<td>1017.58</td>
<td>1011.64</td>
<td>1014.50</td>
<td>17.32</td>
<td>0.49</td>
<td>0.74</td>
<td>0.47</td>
<td>0.80</td>
<td>2.04</td>
<td>0.64</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>-0.29</td>
<td>-0.51</td>
<td>-0.30</td>
<td>-0.07</td>
<td>+0.29</td>
<td>+0.25</td>
<td>+0.24</td>
<td>0.36</td>
<td>0.45</td>
<td>0.47</td>
<td>0.80</td>
<td>2.04</td>
<td>0.64</td>
<td>0.71</td>
<td>0.65</td>
</tr>
<tr>
<td>4</td>
<td>1014.64</td>
<td>1014.40</td>
<td>1008.48</td>
<td>1007.36</td>
<td>1013.94</td>
<td>1008.26</td>
<td>1014.80</td>
<td>available</td>
<td>0.53</td>
<td>0.60</td>
<td>0.70</td>
<td>0.94</td>
<td>1.10</td>
<td>0.72</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>-0.37</td>
<td>-0.37</td>
<td>-0.40</td>
<td>-0.29</td>
<td>-0.18</td>
<td>+0.28</td>
<td>0.36</td>
<td>0.45</td>
<td>0.47</td>
<td>0.80</td>
<td>2.04</td>
<td>0.64</td>
<td>0.71</td>
<td>0.65</td>
<td>0.10</td>
</tr>
</tbody>
</table>

First line of each season: \( M \) (means)
Second line of each season: \( S \) (standard deviations)
Third line of each season: \( E \) (eigenvector values)
Fourth line of each season: \( W \) (weight)
APPENDIX 1 - How the index was constructed

A set of eight stations was chosen, for all of which monthly pressure data were available in World Weather Records for the complete period 1896-1945. The stations were chosen for being well spaced over the globe and because (according to the maps of BERLAGE and WALKER) their pressures are influenced by the SO in at least some seasons. These records appeared to be homogeneous, according to the information in World Weather Records which is not entirely unambiguous. The data were as specified in Table 1a. The monthly pressures were combined into seasonal values. An analysis was then done on each season in turn, using as variables the 8 seasonal pressures.

Notation. Let k denote the index number of the variable and i the year number. The basic data matrix for each season then consists of an array \( \{P(ik)\} \), where i runs from 1 to 50 and k from 1 to 8. Underlining denotes the 8-term vector consisting of some function of each variable, for example \( \underline{M} \) denotes the 8 mean values.

1. A principal component analysis was performed on the matrix \( \{P(ik)\} \). The correlation matrix was analysed. (See, for example, CRADDOCK and FLOOD 1969.) The first eigenvector, denoted by \( \underline{E} \), clearly represented the pattern of the Southern Oscillation as it is known from the work of WALKER and BERLAGE. The coefficient \( A(k) \) for a given year is given by

\[
A(i) = \underline{E} \cdot \underline{R}(i),
\]

where \( \underline{R} \) is the standardised pressure anomaly, ie

\[
R(ik) = \frac{P(ik) - \underline{M}(k)}{\underline{S}(k)}
\]

This coefficient may be used as an index. The values of \( \underline{E}(k) \), \( \underline{M}(k) \) and \( \underline{S}(k) \) are given in Table 6.
2. It was decided to ignore stations for which $E(k)$ was between \(-0.2\) and \(+0.2\). Denote by $F$ the vector $E$ in which all such components have been replaced by zero. Then calculate for each year

$$B(i) = F \cdot R(i)$$

and find $T$, the standard deviation of $B$. Then calculate

$$C(i) = \frac{-B(i)}{T}$$

and define $C$ to be the Index of the Southern Oscillation.

3. If we define

$$W(k) = \frac{-F(k) S(k)}{T}$$

then the index may be expressed as

$$C(i) = \sum_k \left[ P(ik) - M(k) \right] W(k)$$

Values of $W$ are given in Table 6.

4. This index has the property that, over the period 1896-1945, its mean value was 0 and its standard deviation 1.
APPENDIX 2 - How to calculate the index if a different combination of parameters is available.

1. It is assumed that a set of variables is available which, for a given season, are correlated with the SO index. It is also assumed that the values of each variable form a homogeneous series including at least (say) 20 years during 1866-1974, and preferably the whole period 1896-1945.

2. Form a data matrix \( \{ P \} \) consisting of values of the variables for all available years. (If one or more values are missing for a given year, that year must be omitted from the analysis.)

3. Do a principal component analysis using the matrix \( P \) together with the SO index \( I \) as an additional variable (number 0). Obtain \( M, S \) and \( E \) (notation as in Appendix 1).

4. Put \( E(0) = 0 \), denoting the resultant vector by \( E \). Calculate for each year

   \[
   A = E \cdot R
   \]

   and obtain \( T \), the standard deviation of \( A \).

5. Find the correlation coefficient \( Y \) of \( A \) with \( I \). If \( Y \) is less than some threshold value (I suggest 0.6), reject the set of variables as being unsuitable to represent the SO index.

6. The 'new' value of the index is given by \( \frac{A}{T} \) or alternatively by

   \[
   C = \frac{E}{k} \left[ P(k) - M(k) \right] W(k)
   \]

   where

   \[
   W(k) = \frac{E(k) S(k)}{T},
   \]

   the positive signs being taken if \( Y \) is positive, negative if \( Y \) is negative.

7. The values of \( M \) and \( W \) now define an index which can be calculated from these parameters over any period. The index so calculated has the property that, if used during 1896-1945, its mean value would be 0 and its standard deviation 1, and the accuracy of estimate it gives of the 'true' index is indicated by \( Y \).
APPENDIX 3 - Homogenising of Bombay pressures

1. Comparison of the values of sea level and station level pressure for 1941-50 (both in WWR) suggested a correction of +1.2 mb in all months to convert station level to sea level. This value was confirmed by the Indian Meteorological Service.

2. Because of the diurnal cycle of pressure, it was estimated that the pressure at 0830 is about 0.05 to 0.1 mb lower than that at 0839.

3. The Empirical corrections applied to the MCD values for 1973-date (Table 5b) were obtained by a comparison of MCD values and Indian Meteorological Service values during 1963-72.
APPENDIX 4 - Seasonal index of the Southern Oscillation for the period 1851-1974.

<table>
<thead>
<tr>
<th>Year</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1851</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1852</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1974</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Indicates data not available or not applicable.

STANDARD DEVIATION (SD) AND MAXIMUM (MAX) VALUES:

<table>
<thead>
<tr>
<th>Year</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>1851</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1852</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1974</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Indicates data not available or not applicable.

THE FIGURE SHOWS...
Figure 1. Graph of Southern Oscillation index from 1851 to 1974. Crosses denote values for season 1 (Feb-Apr) of each year.
Figure 2. Correlation of December - February temperature with simultaneous SO index. X indicates stations with at least 30 years' data, 0 those with less than 30 years.
Author

Peter Wright, Climatic Research Unit, School of Environmental Sciences, University of East Anglia.