Stratospheric temperature anomalies in 1963 and 1966

By A. B. PITTOCK
C.S.I.R.O., Division of Atmospheric Physics, Aspendale 3195, Australia

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SUMMARY

The existence, statistical significance, and possible causes of stratospheric temperature anomalies observed at the 100 mb level in the Australasian region in 1963 and 1966 are discussed with reference to the so-called quasi-biennial oscillation, volcanic dust, and the general circulation. This discussion is facilitated by the use of the observed correlation between stratospheric temperatures and the mean latitude of the surface high pressure belt, in order to increase the sensitivity of a statistical test for anomalous temperatures.

1. INTRODUCTION

Sparrow (1965) and Newell (1970) have noted an apparently anomalous increase in stratospheric temperature of up to 5°C during 1963 in the Southern Hemisphere, centred around the 60 mb level at about 15 to 30°S. Newell attributed this anomaly to the presence of volcanic dust injected into the stratosphere by the eruption of Mt. Agung on Bali in March 1963. Sparrow (1965; 1971) asked whether the apparent break-down of the quasi-biennial oscillation (hereinafter referred to as the QBO) in 1963 (Kulkarni 1966) might also be an important factor.

McInturff, Miller, Angell and Korshover (1971) examined the temperature data in relation to trends and oscillations of longer period than the quasi-biennial. They concluded

(a) that if only data from stations within 10° of the Equator are considered, the 1963-64 temperature peaks may be merely the consequence of a long-term trend, but also
(b) that all equatorial stations and all Southern Hemisphere stations indicate an absolute maximum for their periods of record in late 1963 or early 1964, and that this suggests some influence of the observed volcanic dust (see e.g. Dyer and Hicks 1968) on stratospheric temperatures, particularly in the Australian region.

Climatic data above the 100 mb level are seriously limited since regular sounding data are not available, with the exception of a few individual stations, until the middle or late 1950’s. Thus Newell’s temperature deviations are given relative to monthly averages for only four years, 1958-62, prior to the volcanic eruption. As implied by McInturff et al. (1971) therefore, the statistical significance of the supposed anomalies in 1963, and their uniqueness, are not well determined.

In this note the statistical significance of the apparently anomalous stratospheric temperatures in the Australian region in 1963 are examined in relation to variations in an established parameter of the general circulation, viz., the mean latitude of the sub-tropical high pressure belt. In addition the investigation suggests that a comparable anomaly of opposite sign existed, centred at about 53°S in 1966.

2. STRATOSPHERIC TEMPERATURE AND THE GENERAL CIRCULATION

Information regarding atmospheric parameters and their anomalies can be obtained by looking at means, trends and possible periodicities. Additional information may be obtained from a consideration of the relationship between stratospheric temperatures and year to year variations in some parameter of the general circulation. Such a parameter, which can
be taken as representative of the general circulation in the Southern Hemisphere, at least in the Australasian sector, has recently been discussed by Pittock (1973).

Pittock found that the mean latitude of the surface high pressure belt, $L$, over Eastern Australia, which is related to the latitude of onset of baroclinic instability, is highly correlated on a year to year basis with such stratospheric parameters as total ozone content, winds, and temperatures. Year to year variations in $L$ thus reflect year to year variations in the strength of the mean Hadley circulation and of the meridional transport processes which determine late winter and spring ozone content, wind strength, and temperature in the middle and high latitude stratosphere.

**TABLE 1. Correlation coefficient $R_{T,L}$ between August-September-October mean 100 mb level temperatures, meaned for stations in the appropriate latitude belt in the Australasian region, and corresponding mean latitudes of the surface high pressure belt over the east coast of Australia. \( N \) is the number of years of data.**

<table>
<thead>
<tr>
<th>Latitude</th>
<th>$N$</th>
<th>$R_{T,L}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-8°N</td>
<td>10</td>
<td>+0.16</td>
</tr>
<tr>
<td>8°S</td>
<td>13</td>
<td>+0.32</td>
</tr>
<tr>
<td>12°S</td>
<td>18</td>
<td>+0.55</td>
</tr>
<tr>
<td>20°S</td>
<td>21</td>
<td>+0.06</td>
</tr>
<tr>
<td>31°S</td>
<td>13</td>
<td>−0.33</td>
</tr>
<tr>
<td>43°S</td>
<td>14</td>
<td>−0.71</td>
</tr>
<tr>
<td>53°S</td>
<td>13</td>
<td>−0.76</td>
</tr>
<tr>
<td>67°S</td>
<td>11</td>
<td>−0.53</td>
</tr>
<tr>
<td>85°S</td>
<td>12</td>
<td>+0.02</td>
</tr>
</tbody>
</table>

Table 1 gives the correlation coefficient, $R_{T,L}$ between August-September-October mean 100 mb level temperatures at stations in the Australasian region and $L$ in all available years. August–September–October was chosen because it shows the greatest year to year variability in $T$ and $L$, and the best correlations between them. Statistically significant correlations are found at 12°S (mean of Darwin and Cocos Is.), 43°S (mean of Hobart, Christchurch and Chatham Is.) and 53°S (mean of Macquarie Is. and Campbell Is.), and marginally at 67°S (mean of Mirny, Wilkes, and Mawson). The latter correlations account for from 30 per cent to in excess of 50 per cent of the total variance in $T$. Even the correlation at 31°S (Perth, Raoul Is., and Lord Howe Is.), while not statistically significant, accounts for some 10 per cent of the variance in $T$ (and more than 30 per cent of the variance if 1963 is excluded).

Where an appreciable correlation exists between $T$ and $L$, it can be used to reduce the residual variance of the temperature data, and so to increase the sensitivity of the statistical test applied to the significance of any apparent temperature anomalies which are not associated with corresponding changes in $L$. This should help to distinguish between year-to-year variations in $T$ which are related to variations in the general circulation (as represented by $L$), and variations which are essentially local or otherwise anomalous.

3. **Statistical analysis**

The scatter diagrams of $T$ versus $L$ for latitudes 31°S, and 53°S are shown in Fig. 1. Results of statistical regression analyses for these latitudes, and for 43°S, are given in Table 2. Following Bliss (1967) we may test outlying points, for instance those for 1963 at 31°S and 1966 at 53°S (see Fig. 1), and for 1963 and 1966 at 43°S (not shown in diagrams), for the probability of their occurrence by chance. The probability of a particular data point having a deviation, $d$, from the regression line, by chance, is given by Student’s $t$ test where
Figure 1. Scatter diagrams for August-September-October mean 100 mb level temperatures, $T$ (°C), at stations situated in the Australasian region at mean latitudes of 31°S and 53°S, plotted against corresponding mean latitudes, $L$, of the surface high-pressure belt along the east coast of Australia.

$t = d/S_d$, where $(S_d)^2$ is the variance of the regression line at that ordinate. This, however, is the probability for an independent or randomly chosen value rather than for an observation selected because it is the most discrepant. An approximate adjustment for this bias is to multiply the probability so obtained by $(N + 1)$, the number of observations which might have been selected as the outlier.

On this basis the probabilities of the above outlying points occurring by chance are approximately 0.14, 0.06, 0.8 and 0.7 respectively. These results suggest (apart from a 1 in 17 chance) that the 1966 value at 53°S could be anomalous. At 31°S, the chances of getting in a set of 13 values a deviation as large as the maximum one observed is 1 in 7; a not unreasonable event if one is testing purely on the selection of the largest deviate. However, the fact that 1963 was a year in which abnormal physical conditions prevailed in the stratosphere (viz., the presence of abnormally large quantities of volcanic dust, Dyer and Hicks 1968; Cronin 1971), would suggest that the occurrence of the largest deviate in that year may be more than a random occurrence. If we can postulate a priori that the 1963 value is the one that should be tested against the other data, then the probability of chance occurrence of so large a deviate is reduced by a factor $1/(N + 1)$ to the 1 per cent level. There would thus appear to be good grounds for supposing that at least some of the discrepancy
TABLE 2. Statistical analyses for the relations between 100 mb level mean temperatures, \( T \), and mean latitude of the surface high pressure belt, \( L \), assuming a linear relationship \( T = a + bL \), where \( R \) is the correlation coefficient between \( T \) and \( L \), \( N \) is the number of observations (years), and \( S^2 \) is the residual variance

<table>
<thead>
<tr>
<th>Latitude</th>
<th>( R )</th>
<th>Probability of chance occurrence</th>
<th>( a )</th>
<th>( b )</th>
<th>( N )</th>
<th>( S^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>31(^\circ)S</td>
<td>0</td>
<td>--</td>
<td>-62.39</td>
<td>0</td>
<td>13</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>-33</td>
<td>&gt;10%</td>
<td>-58.21</td>
<td>-0.14</td>
<td>13</td>
<td>1.67</td>
</tr>
<tr>
<td></td>
<td>-58</td>
<td>&lt;5%</td>
<td>-56.46</td>
<td>-0.21</td>
<td>12*</td>
<td>0.92</td>
</tr>
<tr>
<td>43(^\circ)S</td>
<td>0</td>
<td>--</td>
<td>-52.69</td>
<td>0</td>
<td>14</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>-71</td>
<td>&lt;1%</td>
<td>-43.05</td>
<td>-0.33</td>
<td>14</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>-88</td>
<td>&lt;0.1%</td>
<td>-42.09</td>
<td>-0.36</td>
<td>12*†</td>
<td>0.46</td>
</tr>
<tr>
<td>53(^\circ)S</td>
<td>0</td>
<td>--</td>
<td>-53.29</td>
<td>0</td>
<td>13</td>
<td>7.66</td>
</tr>
<tr>
<td></td>
<td>-76</td>
<td>&lt;1%</td>
<td>-34.51</td>
<td>-0.65</td>
<td>13</td>
<td>3.48</td>
</tr>
<tr>
<td></td>
<td>-87</td>
<td>&lt;0.1%</td>
<td>-34.38</td>
<td>-0.64</td>
<td>12†</td>
<td>1.66</td>
</tr>
</tbody>
</table>

* denotes omission of 1963 data. † of 1966 data. The first line for each latitude gives the variance in \( T \) alone.

in the 1963 temperatures at 31\(^\circ\)S can be attributed to some localized anomalous influence, most probably the presence of volcanic dust. This can only be supported or refuted if data from other similar events become available.

Note, in Table 2, the significant reductions in residual variance due to the omission of the outlying points, and in particular how this increases the significance of the correlation coefficient at 31\(^\circ\)S.

4. Discussion

McInturff and Miller (1972) note phase shifts between the wind and temperature fluctuations of the QBO in the equatorial stratosphere beginning before the eruption of Mt. Agung. They conclude that ‘it is most unlikely that the relatively small variations in temperature attributable to the Bali eruption can account for the very large fluctuations in kinetic energy required by the phase shifts. . . .’

Conversely, it seems unlikely that changes in the QBO around 1963 led to the observed temperature anomaly with respect to \( L \) in that year, since the QBO is clearly a mode of oscillation of the general circulation (Pittock 1973), so that changes in temperature due to variations in the QBO should have been reflected in other elements of the general circulation, and particularly in \( L \). Both Reed (1964), and McInturff and Miller (1972) believe, for example, that the QBO is in geostrophic balance. An examination of the \( L \) values (see Fig. 5 and Appendix I, Pittock 1973) indicates that a QBO existed in \( L \) from 1956 to 1965, but that it is not strongly in evidence outside those years. Further, the first really anomalous year since 1956, as far as the QBO in \( L \) is concerned, is 1966 rather than 1963, since the August–September–October mean \( L \) value was then relatively high whereas even years were relatively low from 1956 to 1964. This is also true, with opposite signs, for the Aspendale total ozone data.

Other unusual physical factors which might conceivably have influenced the 100 mb temperature in 1963 are the occurrence of the solar sunspot minimum, and the resumption of nuclear bomb tests in the atmosphere by the USSR and USA in 1962. The former, like the supposed breakdown of the QBO, would be expected to be reflected in \( L \) if there were any significant effect. The latter is at best unproven, and no plausible mechanism has been advanced.

The 1963 temperature anomaly at 31\(^\circ\)S is weakly in evidence also at 43\(^\circ\)S (see Table 2), but not at 53\(^\circ\)S. Total ozone data for Brisbane (28\(^\circ\)S) and Aspendale (38\(^\circ\)S) give no evidence.
of an anomaly in ozone amount with respect to $L$ in the spring of 1963 (see Fig. 2). This suggests not only that the temperature anomaly with respect to $L$ in 1963 is confined to middle and low latitudes, but also that it is not associated with even a local circulation anomaly, as the latter would be expected to have affected the ozone content.

It is therefore concluded that the statistical analysis suggests that the 1963 temperature anomaly may well be real, and that the part of the anomaly which does not correspond to a change in $L$ is probably a local effect due to the presence of volcanic dust in the stratosphere. At the 100 mb level at $31^\circ S$ the most probable magnitude of this local effect is an increase of about 3 deg C. This does not preclude other anomalous effects on the stratospheric temperature at that time due to changes in the general circulation (e.g. in the QBO) but it does suggest an upper limit of a degree or two to their contribution to the total anomaly as described for instance by Newell (1970).

As far as the 1966 temperature anomaly is concerned, it should be noted that if $L$ were lower (to fit in with the QBO), the 100 mb level temperatures at $53^\circ S$ would be even more anomalous (see Fig. 1).

Individual station data show greater variance than the mean data from stations grouped by latitude, and less data is available for levels above 100 mb. This makes a reliable picture
of the 1966 temperature anomaly difficult to obtain, particularly as it appears at latitudes where there are few stations. Nevertheless it is perhaps useful to indicate the order of magnitude of the anomalies observed at the various stations. Relative to regression lines between $T$ and $L$,

(a) the 100 mb level temperatures in August–September–October appear to be lower by

$\sim 2^\circC$ at Christchurch (43.5$^\circS$),
$\sim 2.5^\circC$ at Invercargill (46$^\circS$),
$\sim 4^\circC$ at Campbell Is. (53$^\circS$),
$\sim 3^\circC$ at Macquarie Is. (54$^\circS$).

(b) the 50 mb level temperatures appear to be lower by

$\sim 2.5^\circC$ at Auckland (37$^\circS$),
$\sim 4^\circC$ at Christchurch,
$\sim 6^\circC$ at Invercargill,
$\sim 7^\circC$ at Campbell Is.

In addition, there are indications that the corresponding mean total ozone amounts were lower by about 13 per cent at Macquarie Is. (see Fig. 2) and about 8 per cent at Wellington (41$^\circS$). Similar anomalies are not in evidence at Antarctic coastal stations, so the 1966 anomaly may be said to be most in evidence at about 50-55$^\circS$. The association of an anomaly in $T$ and in total ozone indicates a localized circulation anomaly.

5. CONCLUSION

A significant temperature anomaly may well have occurred at the 100 mb level in the lower latitudes of the Australasian region during 1963, and another temperature anomaly probably occurred at higher latitudes in the Australasian area during 1966.

The 1963 positive anomaly is statistically significant, on the present data, only if it is assumed to be present a priori; that is to say, the data does not support its existence on the basis of a null hypothesis. There is, however, strong a priori reason to expect that 1963 might have been anomalous, viz., the presence of large amounts of volcanic dust in the stratosphere. On that basis, the probable existence of a temperature anomaly in 1963 is supported. The anomaly was not obviously associated with any anomaly in the general circulation or in the QBO. It is therefore reasonable to associate the major part of the anomaly with the local influence in the stratosphere of the volcanic dust, although any causal connection has not been proven.

The negative temperature anomaly in the spring (August–September–October) of 1966 is most evident around 50-55$^\circS$ and is associated with lower total ozone content at Wellington and Macquarie Is. It is evidently a circulation anomaly of restricted latitude range, unusual in that it is not reflected in the latitude of the surface sub-tropical high pressure belt, which is a useful parameter of the general circulation.

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REFERENCES


