# NOTES AND CORRESPONDENCE

## Latitudinal Variation in the Change of Sea Surface Temperature from 1880 to 1977

G. W. PALTRIDGE

*CSIRO Division of Atmospheric Research, Aspendale, 3195, Australia*

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Paltridge and Woodruff (1981, hereafter referred to as I) analyzed historical sea surface temperature (SST) data and some land-station temperature data in order to derive from the combination the change of global surface temperature over the years 1880–1977. A number of people have asked about the purely SST component of that change—in particular about the differences between tropical and higher latitudes and whether there is a difference between the long-term trends of summer and of winter SST.

Figure 1 gives zonal averages from 50°N to 50°S of the change in annual mean SST over the 98-year period. The analysis was performed in the same way and on the same basic data as developed in I except that no land-station information was included and that the screening of SST information was slightly more rigorous (see below). The basic data of I consisted of seasonal means (December–February and June–August) of the SST of 10° latitude by 10° longitude "boxes". Annual mean in the present context refers to the simple average of these two extreme seasons. The number of boxes containing data varied from one latitude zone to another. However, each point of the graphs of Fig. 1 is made up of data from the equivalent of between 80 and 100 boxes if one regards the extreme-season means of a given box as independent. The points are of pentad (i.e., five-year) averages of zonal temperature and were calculated as deviations from the 98-year mean.

Boxes were deleted from the analysis in I if, in the total 98-year period, they contained no data for more than 10 successive years. This 10-year "gate" was applied so as to allow inclusion of the many boxes which had no data during the two world wars. As a consequence, there were a few pentads apart from those covering the world wars where particular zonal averages were derived from significantly less than the normal number of boxes. (The world war pentads were totally excluded from the analysis.) In this note, the number of boxes $N$ was defined as significantly less than the normal number $N_0$ if

$$(N_0 - N) \times (\delta/2)/N_0 > 0.45, \qquad (1)$$

where $\delta$ was the maximum range of box temperatures about the particular zone as quoted in Table 1. The idea was to define the minimum number of boxes $N_0 - N$ which, if they should all have extreme values $\delta/2$ away from the zonal mean, would significantly alter that mean. The 0.45 was a fairly arbitrary choice of "significant alteration." It was simply the standard deviation of all the pentad averages of the 50–30°N zone before 1930.

In a number of cases (all before 1900), the criterion of Eq. (1) was seriously exceeded and the relevant zonal averages were deleted. For the rest, the zonal averages were adjusted by assuming the missing $N_0 - N$ boxes to have the same temperatures as the corresponding boxes in the adjacent pentad. The adjustments so made are recorded by the vertical dashed lines of Fig. 1. The ×'s are the unadjusted temperatures derived from the $N$ boxes.

In most respects, the results of Fig. 1 are similar to those of the earlier analysis of I. There appears to have been a minimum in global temperature somewhere

TABLE 1. Range of pentad-average box temperatures about each latitude zone in the given season together with the number of boxes ($N_0$) in each zone. The range is simply the difference between the box of highest temperature and the box of lowest temperature of the zone for the season and the figures quoted are actually the average of all those ranges over the 98 years.

| | Latitude: Degrees North 50–40 | 40–30 | 30–20 | 20–10 | 10–0 | Degrees South 0–10 | 10–20 | 20–30 | 30–40 | 40–50 |
|---|---|---|---|---|---|---|---|---|---|---|
| Jun–Aug: Range (K) | 12.3 | 11.6 | 8.5 | 5.7 | 4.9 | 6.1 | 9.9 | 7.2 | 8.8 | 3.4 |
| No. Boxes | 21 | 21 | 16 | 25 | 26 | 29 | 24 | 26 | 31 | 16 |
| Dec–Feb: Range (K) | 9.8 | 9.6 | 5.8 | 5.6 | 2.0 | 4.8 | 7.8 | 7.7 | 6.2 | 5.7 |
| No. Boxes | 17 | 23 | 15 | 25 | 21 | 26 | 22 | 26 | 30 | 25 |

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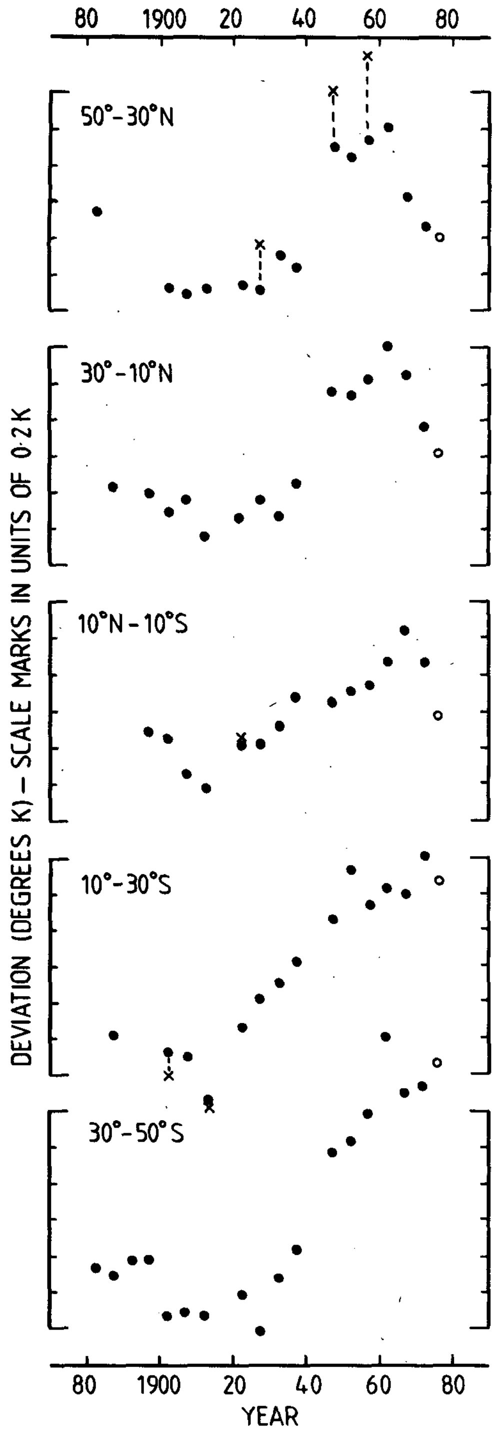


FIG. 1. Five-year (pentad) averages of the deviation of zonal average temperature from the long-term 98-year mean as a function of time. The final point (the open circle) for each zone is only a 3-year average (1975–77).

between 1900 and 1925, with the suggestion of a maximum (at least in the Northern Hemisphere) somewhere between 1945 and 1970. The change $\Delta_M$ of the mean from the first of these 25-year periods (1900–25) to the second (1945–70) is plotted as a function of latitude in Fig. 2. Each of the pair of means which were subtracted to give the change $\Delta_M$ ($x_1$ and $x_2$ say) has an associated standard deviation ($S_1$ or $S_2$) of the pentads of zonal temperature which make up the mean. The sum of $S_1$ and $S_2$ gives some idea of the face value significance of the information.

The main point shown in Fig. 2 is that the equatorial rise in temperature is considerably less than that of higher latitudes. This is not an artifice of the averaging process. It is a fairly obvious feature of the data from the individual seasons, is relevant to both hemispheres and appears just as obviously in all plots at a higher resolution of latitude (i.e., 10° instead of the 20° in the figure). It was also a feature of the analysis in I. However, there the apparent rise in tropical temperature was even smaller (0.28 K) and was less than the corresponding $S_1 + S_2$ (0.45 K). The rise was therefore regarded as insignificant in that paper.

One of the major difficulties associated with the use of SST data in the present context is the gradual change over the years from measurement of "bucket" temperatures to measurement of "condenser intake" temperatures. The SSTs of the present analysis derive from the dataset of the Historical Sea Surface Temperature (HSST) project which supposedly consists only of bucket measurements. However, there is some doubt about whether the screening process to remove condenser intake temperatures from the HSST data was effective (Barnett, 1984) and, unfortunately, it is unlikely the question will ever be satisfactorily resolved since the type of measurement was not recorded along with the data itself. Various comparisons (e.g., James and Fox, 1972) indicate that if the screening process

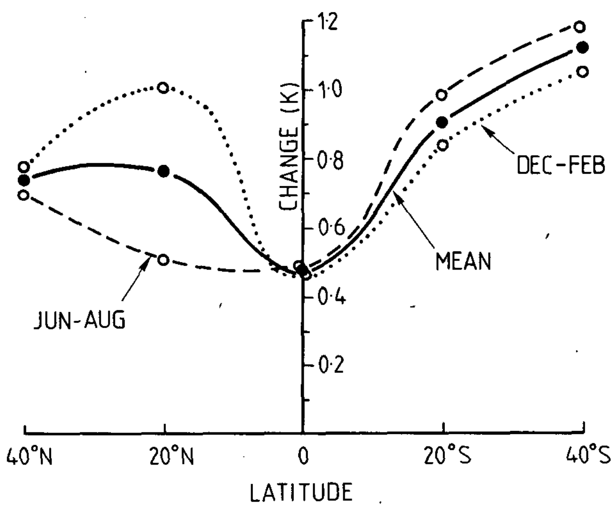


FIG. 2. The change of zonal average temperature between two 25-year periods (from 1900–24 to 1945–69) as a function of latitude. The solid line is the "annual mean"—simply the average of the two extreme seasons.

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was *completely* ineffective then the gradual change of measurement technique could contribute an apparent 0.3 K to the observed rise of temperature over the years. In that case (and there is no direct evidence to make the assumption), the main point of Fig. 2 is presumably still valid: the temperature rise at higher latitudes has been larger than that of equatorial regions.

An attempt to confirm the reality of the small rise in tropical surface temperature by comparison with land-station data failed. Records from eight long-term land stations between 10°N and 10°S were available from the U.S. National Center for Atmospheric Research compilation of monthly-averaged temperatures. Visual inspection was enough to show that for one reason or another, all of them were highly unreliable measures of long-term change and no amount of averaging would yield even an indication of the sign of the change, let alone the magnitude.

There may be a number of reasons why equatorial temperatures should rise less than those of higher latitudes. One of them concerns the possible upper limit to equatorial temperatures set by the rapidly increasing evaporation from water surfaces as the temperature rises (Newell and Dopplick, 1979). Table 2 gives among other things the actual zonal mean temperatures $T$ associated with the long-term changes $\Delta_M$ as given in Fig. 2. If one plots $\Delta_M$ as a function of $T$, the spread of points is too large to suggest a specific relation between them. Qualitatively, the plot of $\Delta_M$ as a function of $T$ supports the general proposition of an upper limit of tropical ocean temperature somewhere between 30 and 33°C.

The separate long-term trends of winter and summer temperatures corresponding to the annual means of Fig. 1 are not displayed here. It is sufficient to say that, to the extent that the phase of long-term change can be identified (see the discussion of I), there is no evidence of a phase difference between temperatures at any of the latitude zones between 50°N and 50°S.

TABLE 2. Zonal average temperature and the change $\Delta_M$ of the 25-year mean temperature from the period 1900–24 to 1945–69.

| Latitude zone | Season | Zonal average temperature (°C) | $S_1 + S_2$ (see text) | $\Delta_M$ (°C) |
|---|---|---|---|---|
| 50–30°N | Jun–Aug | 19 | 0.36 | 0.70 |
| | Dec–Feb | 13 | 0.30 | 0.77 |
| | Annual | | 0.17 | 0.74 |
| 30–10°N | Jun–Aug | 26 | 0.20 | 0.51 |
| | Dec–Feb | 23 | 0.32 | 1.01 |
| | Annual | | 0.18 | 0.77 |
| 10°N–10°S | Jun–Aug | 27 | 0.41 | 0.49 |
| | Dec–Feb | 27 | 0.20 | 0.48 |
| | Annual | | 0.29 | 0.48 |
| 10–30°S | Jun–Aug | 22 | 0.36 | 0.98 |
| | Dec–Feb | 25 | 0.24 | 0.84 |
| | Annual | | 0.29 | 0.91 |
| 30–50°S | Jun–Aug | 12 | 0.32 | 1.19 |
| | Dec–Feb | 15 | 0.53 | 1.07 |
| | Annual | | 0.34 | 1.13 |

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