Some Considerations Relevant to Computing Average Hemispheric Temperature Anomalies

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(Manuscript received 25 June 1986, in final form 15 December 1986)

ABSTRACT

Three data bases of gridded surface temperature anomalies were used to assess the sensitivity of the average estimated Northern Hemisphere (NH) temperature anomaly to: 1) extreme gridpoint values and 2) zonal band contributions. Over the last 100 years, removal of either the top or bottom 10% of the gridpoint anomalies in any year changes the estimated NH average anomaly by 0.1–0.2°C. Excising extensive zonal bands also produces root-mean-square changes in the estimated NH anomaly of approximately 0.1°C. The estimated NH average anomaly appears to be robust to such perturbations.

1. Introduction

Hemispheric or global temperature anomaly curves such as those developed by the Climate Research Unit (Jones et al., 1986a) are widely quoted in the literature, particularly with regard to global warming due to "greenhouse" gases. Such curves are commonly created using surface temperature anomalies calculated from data interpolated on a regular grid. This study examines aspects of this averaging process with particular emphasis directed to the "robustness" of the estimated hemispheric average to the presence of possible spurious observed data. A primary question addressed is: How sensitive are the estimated Northern Hemisphere (NH) average anomalies to the selection of gridpoints?

In this work, three extensive gridded temperature data bases are used (see Table 1). Detailed descriptions of these data bases are found in the primary references: Climate Research Unit (CRU): Jones et al. (1986b); Soviet: Robock (1982); Comprehensive Ocean-Atmosphere Data Set (COADS): Slutz et al. (1985). Because the first two datasets cover primarily the Northern Hemisphere (COADS has global coverage), the focus here will be on the NH. An excellent recent summary of these (and many other) data bases appears in Bradley and Jones (1985).

2. Calculation of hemispheric temperature anomalies

In computing an average hemispheric (or any other areal) temperature anomaly series, one generally starts with estimated monthly temperature series at a number of fixed gridpoints. In the case of the CRU, Soviet, and COADS compilations, these monthly data are available on regular grids (either 5° × 10° or 2° × 2°) for periods of a century or more. The COADS data are not gridded in the sense of the other two. For the COADS data, rather than interpolating values to a regular grid, statistics are developed for data collected in 2° × 2° "boxes." Here, the average coordinates of this box are considered as a "gridpoint." The COADS surface air temperature will be used here.

The development of a gridded monthly dataset is fraught with many difficulties. These factors have received widespread attention in the literature and have recently been discussed in detail by Jones et al. (1986b) and Bradley and Jones (1985). Among the many problems are: widely changing coverage and measurement techniques, changing locations of stations (Mitchell, 1953), inadequate sampling, particularly over ocean areas (Mobley and Preisendorfer, 1985), variable times of day or month at which the measurements were taken (Bradley and Jones, 1985), and possible effects of urban growth (Dronia, 1967). Jones et al. (1986b) have attempted to assess the homogeneity of individual temperature records by intercomparing the temperature data from neighboring stations.

With sea surface temperature data, the inhomogeneity of the record due to bucket or intake sampling poses a particularly serious problem (Barnett, 1984). Although the effects of each of these changes may individually be small, it is important to remember that the total observed change in the average NH land temperature during the last 100 years is only about 0.6°C.

As Jones et al. (1986b) have emphasized, there are significant areas of the hemisphere not represented in their historical temperature record. Even today, the CRU NH gridded dataset covers only about one-half of the hemispheric area. To estimate the effect of incomplete coverage (particularly before 1900) Jones et al. (1986b) have compared their time varying grid with those for a series of "frozen" grids which use only those gridpoints with data available for 80% of the time start-

TABLE 1. Summary of data sources.

Data source	Coverage	Areal extent	Temporal extent	Grid
CRU	Land only	NH	1851–1984	5° × 10°
Soviet	Land + water	NH	1891–1979	5° × 10°
COADS	Water only	Global	1854–1981	2° × 2°

ing during a particular decade. They found that the differences in estimated NH average temperature anomalies between the time varying grid and the frozen grids beginning after about 1880 are very small.

Here we take a somewhat different approach, focusing on the possible influence of available individual gridpoint values on the estimated average hemispheric temperature anomaly. These methods were developed initially to identify suspect data values in these data bases and they have served successfully in that role. The techniques were expanded to show how one can more precisely assess the sensitivity of areal averages to the presence (or absence) of individual measurements.

a. Distribution of gridpoint values for a given year

To compute a desired regional, zonal, hemispheric or global area average temperature anomaly, individual gridpoint anomalies are averaged over the area of interest, generally using area-weighting (cosine of the latitude). The many details involved in obtaining these gridded temperature anomalies from station records are discussed in the primary references accompanying each of the data bases. If

T_{iy} temperature anomaly at gridpoint i for year y,

ϕ_i latitude of gridpoint i,

then the average area-weighted temperature anomaly T_{awy} for any desired area in year y, is calculated as

$$T_{awy} = \frac{\sum T_{iy} \cos\phi_i}{\sum \cos\phi_i}. \quad (1)$$

Let us first examine the computations leading to an estimate of the annual NH average temperature curve using the CRU NH gridded dataset (Jones et al., 1986). Each individual gridpoint temperature anomaly can be normalized as

$$\hat{T}_{iy} = T_{iy} \cos\phi_i \Big/ \frac{1}{N_y} \sum \cos\phi_i, \quad (2)$$

where N_y is the number of gridpoints with "sufficient" data in year y. For any year, the denominator in Eq. 2 is the average cosine of all gridpoints used. The expected value of this area-weighted variable, $\hat{T}_{iy}$, is the conventional area-weighted average curve shown in Fig. 1. Also shown in Fig. 1. are the 26 000+ individual annual anomalies, $\hat{T}_{iy}$, that were used to compute the NH average anomaly over the period 1851–1984.

In estimating an annual average anomaly at any gridpoint in any year, the available monthly anomaly values must first be averaged. With the CRU gridded anomaly data, three different NH average annual anomalies were estimated using only those gridpoints containing at least 3, 6 or 12 months of data in a given year. Over the last 100 years, it was found that the average absolute difference in the estimated annual NH anomaly between the 3 month minimum requirement and the complete dataset was negligible, being only 0.02°C. Thus, for this study, a gridpoint is included if the annual average can be derived by averaging at least six monthly data values for the particular year. Jones et al. (1986b) use a different inclusion criterion, but their results are virtually identical to those obtained here. The COADS dataset also contains boxes with measurements commonly taken only during certain months of the year. Nevertheless, calculations with these data show that the average absolute difference in the NH average air temperature anomaly from 1875–1979 calculated using 25% and 90% monthly data content is <0.09°C.

It is important to realize that, for each year of the record, the area-weighted average curve of Fig. 1. is, in fact, the average of a rather broad distribution of anomaly values. We will examine several characteristics of these distributions and see how they change with time over the course of the record. These parameters permit better understanding of the sensitivity of the estimated average to the selection of gridpoints used.

Figure 2 shows the histograms of the cosine-weighted anomalies ($T_{iy} \cos\phi_i$) for all of the gridpoints used to

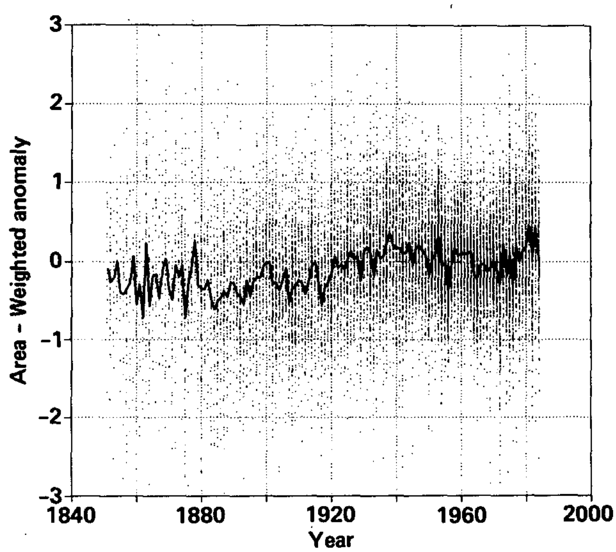

FIG. 1. CRU area-weighted NH average temperature anomaly from 1851 to 1984. The 26 000+ individual gridpoints used to estimate the area weighted average (solid curve) are also shown.

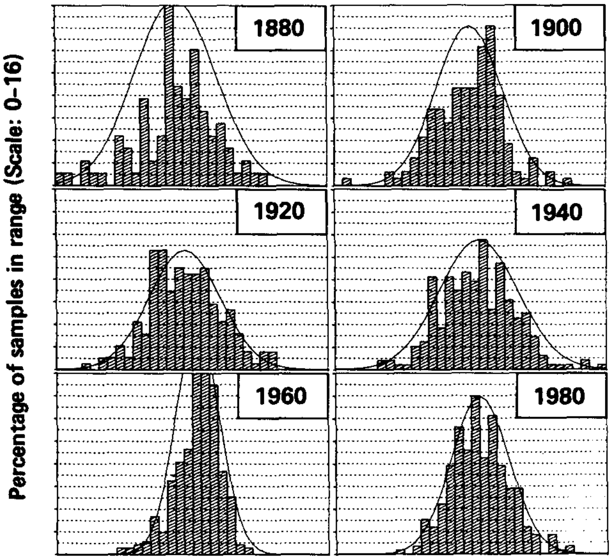

FIG. 2. Histograms of the distribution of area weighted CRU anomalies for different years in the period 1880 to 1980. (All subplots are scaled identically.)

compute the NH average for each of the years: 1880, 1900, 1920, 1940, 1960 and 1980. The smooth curve above the hatched area is that for a normal distribution with the same estimated mean and standard deviation as these data. Qualitatively, at least, these distributions appear to approximate a normal distribution for at least most of these particular years.

A more objective test of normality can be obtained by examining the cumulative distribution and testing for normality using the well-known Kolmogorov–Smirnov test (K–S) based on the maximum deviation of the observed distribution from that of a true normal with the same estimated mean and standard deviation (Lilliefors, 1967). Figure 3 shows one such cumulative distribution for the area-weighted CRU data for 1920. The K–S test shows these data to be normal. If one examines the distribution of $T_{iy} \cos\phi_i$ for each of the years: 1880, 1885, 1890 . . . 1980, using the K–S test one finds approximate normality for years examined for the period 1885 to 1955, with generally non-normal behavior after that.

The K–S test is predicated on the assumption that the observations in the distribution are uncorrelated. For these temperature data, there is spatial correlation, although this is, on the average, small for the grid sizes used. Calculations of all pairwise cross-correlations of the CRU annual data at 146 gridpoints with nearly complete coverage over the last 100 years give an average cross correlation of 0.14. However, the correlations between many adjacent gridpoints is often high, effectively reducing the number of independent gridpoints in the set. Thus, the attribution of normality must be considered tentative and only approximate. Although the assumption of normality is not rigorously necessary for what follows, normality considerations do provide a useful framework for understanding the robustness of the hemispheric average anomaly.

b. Time variation of the parameters in the distribution of temperature anomalies

For both the CRU and the COADS data bases, the number of gridpoints used in computing the NH average increases markedly from the beginning of the record to the end. Figure 4 shows the variation of the number of gridpoints used in computing the NH average for the COADS, CRU, and Soviet data bases. Over the extent of the CRU data, the increase in gridpoints has been nearly an order of magnitude, from only 45 grid points in 1851 to a peak of more than 300 in the 1960s. Although the Soviet data appear virtually complete, they have extrapolated their land-based data over the oceans giving a false impression of high data coverage (Bradley et al., 1985).

It is also important to recall that the number of individual station records incorporated into each gridpoint value has also changed over time (Jones et al., 1986b). The striking decrease in the amount of data in the COADS maritime data base during the two World Wars is particularly evident in Fig. 4.

Let us first examine the variation of the area weighting factor, AWF = average $\cos\phi_i$, for the CRU NH data. In Fig. 5 the mean cosine of the latitude of the CRU NH gridpoints is plotted from 1851 to 1984. Over the last 100 years, 1880–1980, there is little variation

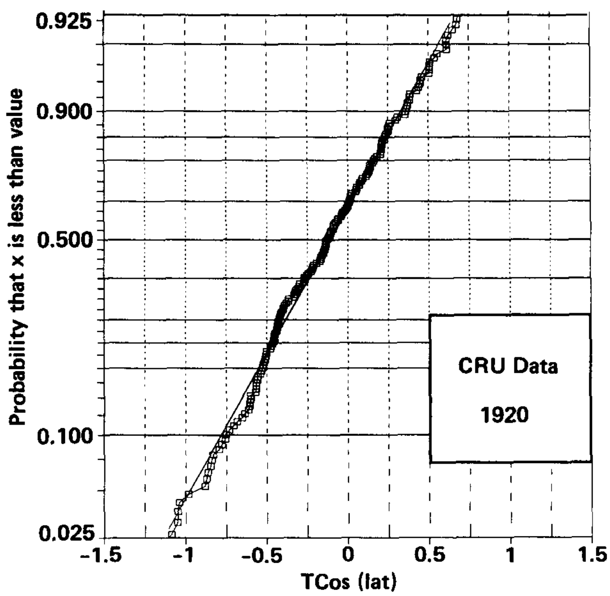

FIG. 3. Cumulative distribution of the area-weighted anomalies for CRU NH data for 1920. (A truly normal distribution would plot as a straight line.)

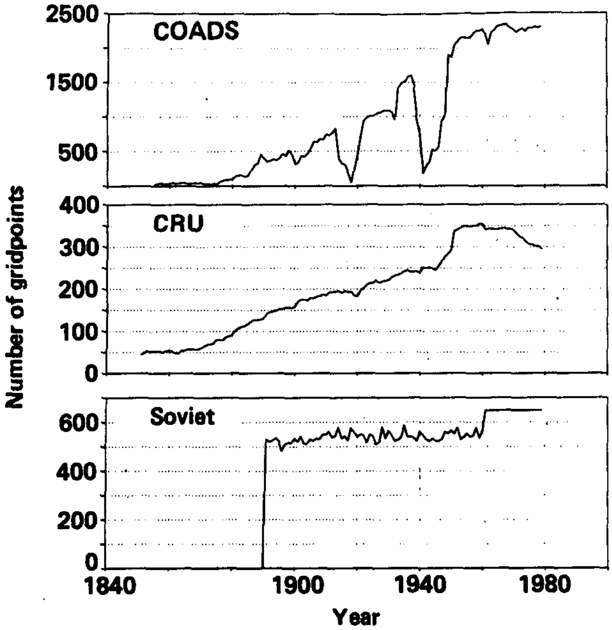

FIG. 4. Numbers of gridpoints used to compute NH averages for COADS, CRU, and Soviet data bases. 1840–1980. Note different ordinate scalings.

in this average, which ranges from 0.69–0.73. This is equivalent to an average latitude range of only 43° to 46°N. This initially surprising result is largely due to the fact that we are dealing here with a uniform grid, rather than a more random ensemble of stations. When entirely filled, a land-based 5° × 10° uniform grid such as the CRU set would have a mean AWF of 0.66 for the NH. Additionally, with the CRU grid, a substantial number of midlatitude European and North American gridpoints present throughout the record serve as an effective flywheel, preventing strong variation of this factor. This constancy results in an average absolute difference between the weighted and the simpler unweighted temperature anomaly series of only 0.047°C for the entire period of record, 1851–1984 (Fig. 6). In other words, when using the CRU gridded anomaly data to compute a NH "average," it makes little practical difference whether area weighting is used or a simple unweighted average is calculated. This may not, however, continue to be true as the climate changes.

These calculations were repeated for the NH using the COADS air and sea surface temperature data. Over the last 100 years, with the exception of the two World Wars when the data content dropped precipitously, both records show a virtual constancy in the mean value of $\cos\phi$: 0.81 to 0.85 (corresponding to mean latitudes of 32°–36°N). Here again, the area-weighted and the unweighted NH curves are virtually indistinguishable. For the COADS air temperature data, the average absolute difference between the area-weighted and the unweighted NH average annual anomaly is only 0.01°C over the last 100 years.

A normal distribution can be completely characterized by its mean, μ, and standard deviation, σ. We next examine the time variation of the estimated mean and standard deviation for the area-weighted NH anomaly: T_{awy}. Figure 7 shows the variation in the estimated standard deviation of T_{awy} for the CRU NH land record. (The corresponding mean is the curve in Fig. 1.) From about 1890 to 1945, the standard deviation remained substantially constant at about 0.7°C. During the period 1945–80 there has been some variability of

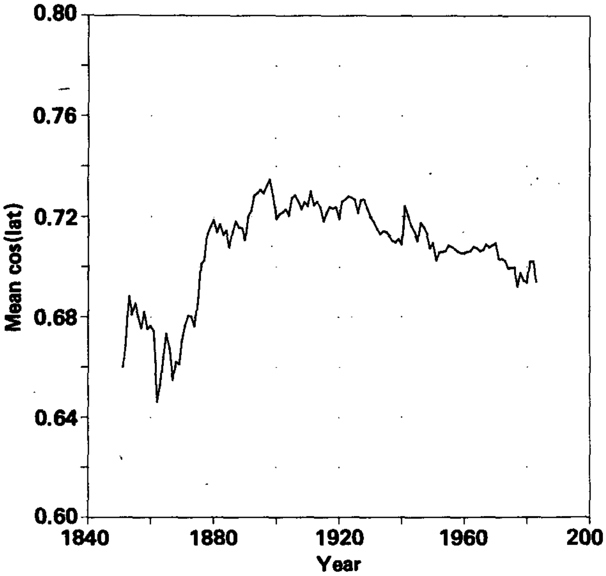

FIG. 5. Average $\cos\phi$ for NH CRU gridpoints from 1851–1984.

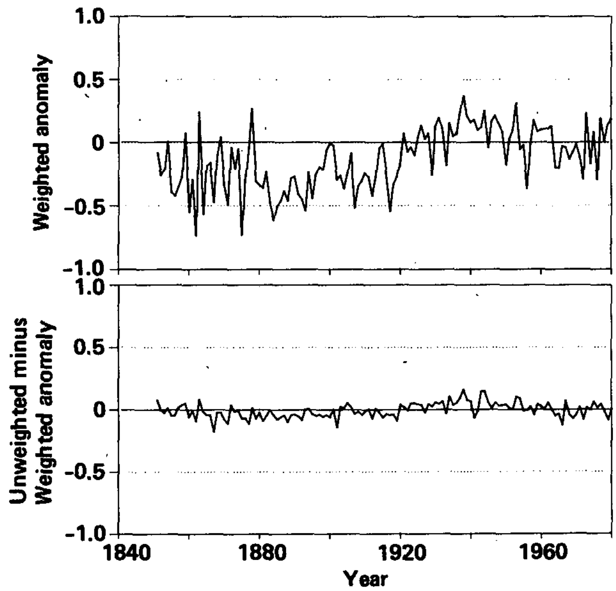

FIG. 6. Area-weighted average and difference between area-weighted and unweighted NH temperature anomaly curves for CRU data, 1840–1980. Both plots are drawn with the same scaling.

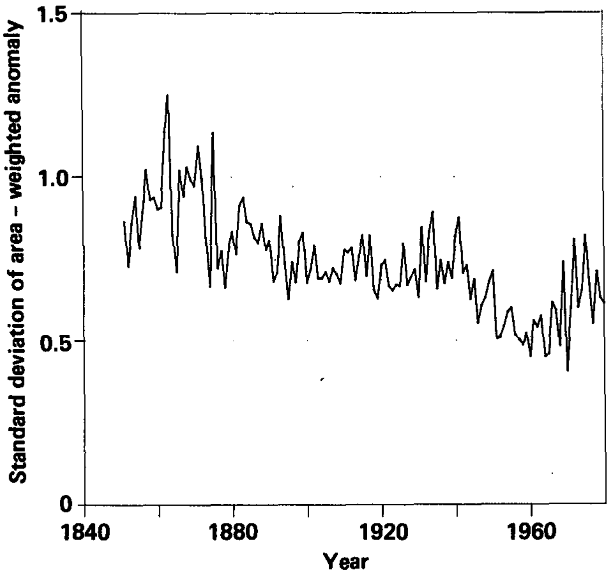

FIG. 7. Estimated standard deviation for the area weighted temperature anomaly T_{awy} for the CRU NH data, 1851–1984.

the standard deviation, which dropped to a minimum of about 0.45 in 1970 and rose again to the previous level.

The corresponding means and estimated standard deviations for the COADS NH marine air temperature data are seen in Fig. 8. The standard deviation has been nearly constant during most of the last 100 years. For these marine air data, the standard deviation is approximately one-half that of the land-based CRU record (cf. Fig. 7), which is to be expected considering the much smaller gridpoint variability of the marine data. The differences seen between the estimated average anomalies of the CRU data (Fig. 6) and the COADS estimates (Fig. 8) have been discussed recently by Jones et al. (1986b) and are thought to be due largely to inhomogeneties in the marine record.

The time-varying nature of these distributions can also be visualized by using three dimensional plots. Figure 9 shows the three dimensional histograms of the CRU NH area-weighted temperature anomalies plotted for the period 1851–1910 and from 1910–76. In generating these plots, it is assumed that the area weighted anomaly is normally distributed for each year, with a mean and standard deviation estimated from the results given in Figs. 1 and 7. On the lower surface in each plot, the mean value of the distribution (the conventional area-weighted curve) is shown as a heavy solid line and that $\mu \pm 2\sigma$ are indicated as two lighter lines. For a truly normal distribution, 95% of the area weighted temperature anomalies would lie between these two lines. Because the total area under each curve is, by definition, 1.0, the highest peaks occur when the standard deviation is smallest. We can see that, in spite of widely different areas of coverage, both the means and the standard deviations for these data do not change markedly over more than a century. This near constancy will be important in explaining the results found in the next section.

3. Robustness of the NH average

Let us now consider the questions: How stable is the estimated area-weighted NH average temperature anomaly to the selection of gridpoints? Might this average be particularly sensitive to only a few gridpoints, particularly early in the record where few data points are available? Could relatively few extremal anomalies (either real or spurious) significantly affect the estimated hemispheric average? How much would the removal of data from entire latitudinal zones change the estimated hemispheric average anomaly?

a. Stability of the NH average anomaly

One can quantitatively calculate the change, ΔT_{jy}, in the area-weighted average temperature anomaly T_{awy}, which would result from the addition of a single gridpoint, j during year y. Let the raw anomaly at the gridpoint be T_{jy} and let f_{jy} be the fractional area represented by point j ($=\cos\phi_j/\Sigma \cos\phi$). Then

$$\Delta T_{jy} = (T_{jy} - T_{awy}) \times \frac{f_{jy}}{1 + f_{jy}}. \qquad (3)$$

The change in area-weighted temperature is the product of two factors: 1) the difference between the temperature anomaly at point j and the original area-weighted average, and 2) the fractional area represented

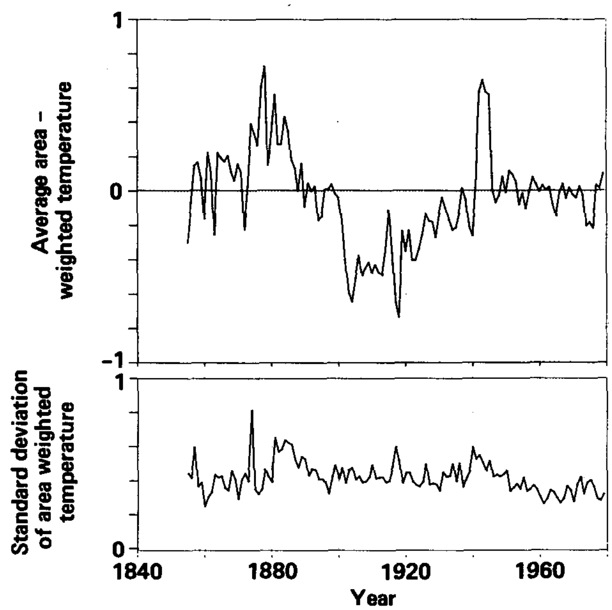

FIG. 8. Estimated mean and standard deviation of the COADS NH air temperature anomaly for the period 1851–1979.

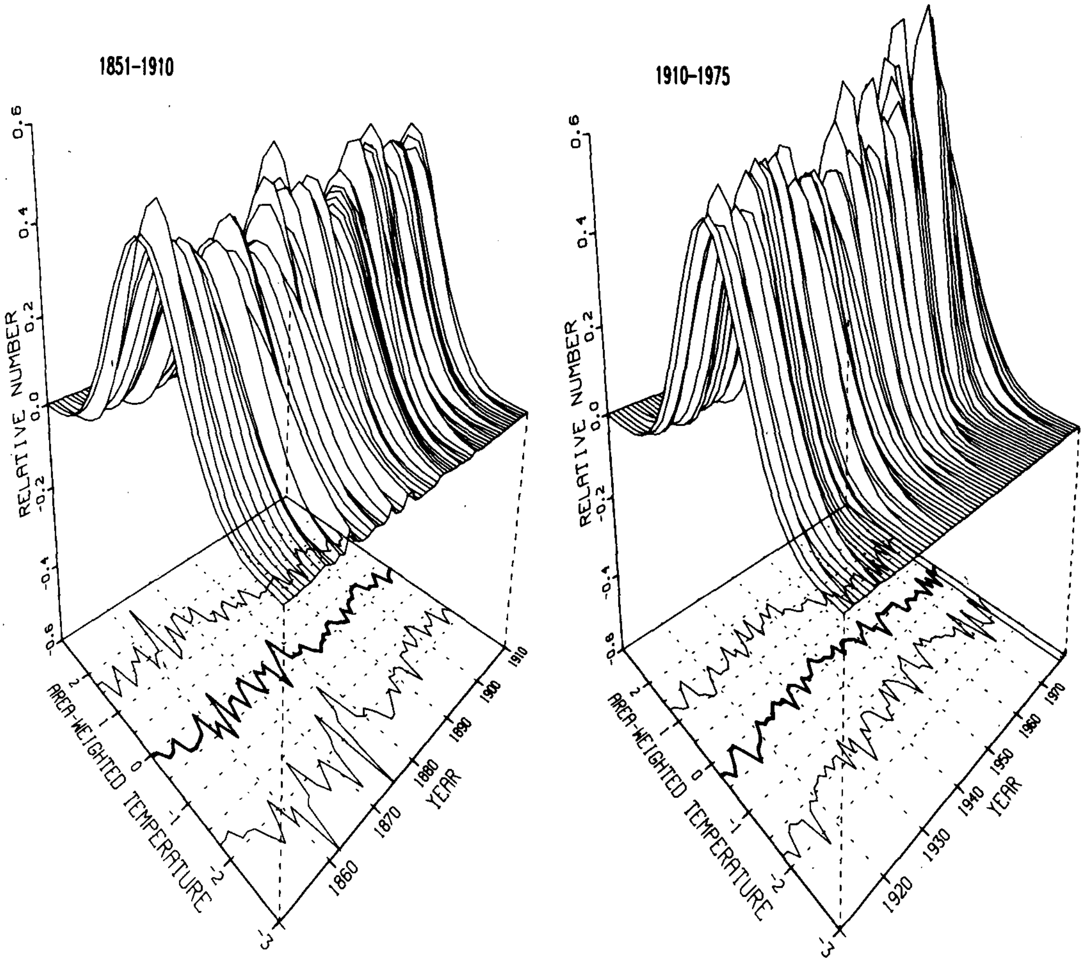

FIG. 9. Three-dimensional histogram of the distribution of area weighted temperature anomaly over time. (CRU data 1851–1976.) The values for each year are assumed to be normally distributed. On the lower surface, the estimated average anomaly is drawn as a heavy solid line and the $\pm 2\sigma$ estimates are shown as lighter lines.

by gridpoint *j*. Thus, any point added or removed which has a temperature equal to the area weighted average will cause no change in the average. Those points furthest from the average (factor 1), and those closest to the equator (factor 2) will obviously have the greatest effect.

To assess the consequences of removing extremal points, the following calculations were performed using the CRU and COADS data bases. For each year of the record, all gridpoints with six or more months of data present for the year were used to estimate an annual area-weighted NH anomaly. (As mentioned previously, calculations using the CRU data and COADS data show that virtually identical NH annual averages are obtained if at least 3 months of data are present.) For each year, the values of $T_{iy} \cos\phi_i$ at all eligible gridpoints were first sorted. New hemispheric averages were then recalculated after either 10% or 25% of the gridpoints were removed, separately, from either the lower or the upper range of the sorted data. These extremal gridpoints, if removed ("trimmed") would cause the greatest change in the estimated average. [In the development of the COADS data base (Slutz et al., 1985), "trimming" was applied in terms of a robust estimate of the standard deviation; here we remove a fixed percentage of the total number of samples.]

Figure 10 shows the resultant changes of the average NH hemispheric temperature anomaly for the CRU data due to this trimming. For a given percentage of extremal gridpoints removed, the change produced in the NH average temperature varies only slight during most of the last 100 years. Over the period 1880–1980, removing either the most positive or negative 10% of the points during any year, would change the mean NH temperatures by an average of 0.14°C (positively, if the lower 10% were removed; negatively if the upper 10% were removed). Correspondingly, removing the most influential 25% of the points during each year would change the estimated average temperature anomaly by about 0.3°C. Since the change produced

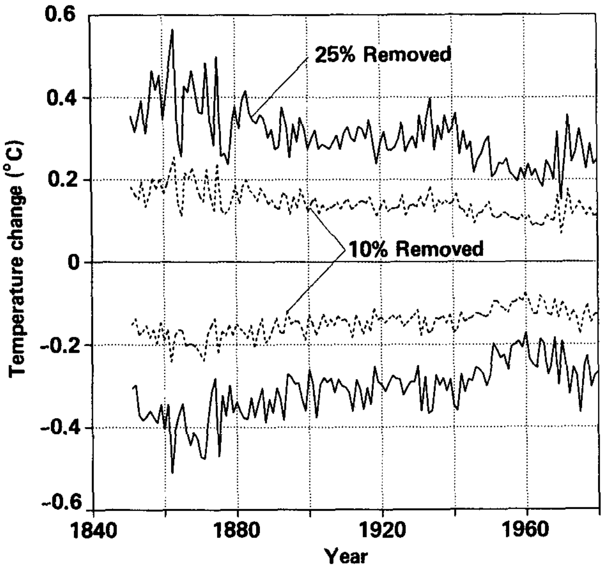

FIG. 10. Resultant change in area-weighted average temperature anomalies for CRU NH data after removing maximum or minimum 10% or 25% of the area weighted gridpoints anomalies during each year.

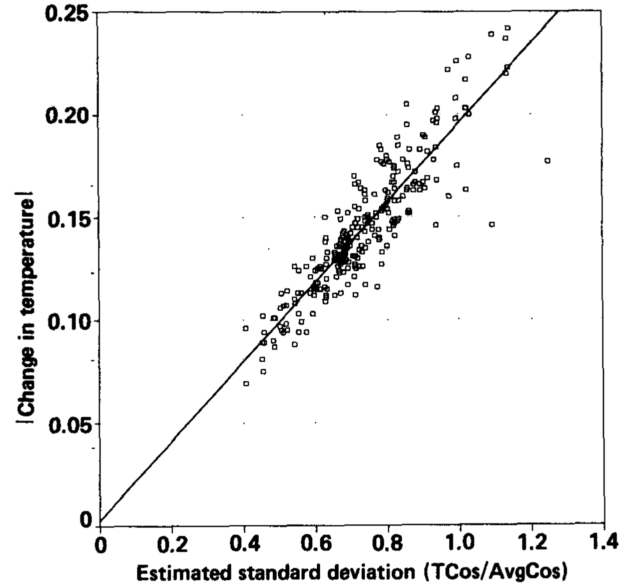

FIG. 11. Absolute value of the change in the estimated average NH temperature anomaly for the CRU NH data after removing the extreme 10% of the gridpoints vs the estimated standard deviation of the area-weighted temperature T_{awy}.

in the average is approximately symmetrical, simultaneously removing both the highest and the lowest 10% (or 25%) gridpoints would have very little effect on the estimated NH average temperature anomaly, and consequently on trends or cyclic variations that some suggest are present in the record. Similarly, removing any randomly selected ensemble of these gridpoints should produce virtually no change in the average.

The near constancy of the change in average temperature anomaly with a constant trimming during the last 100 years may appear, at first, surprising, considering the widely varying coverage in the CRU data during this period. However, this result may be explained as follows. In Fig. 11, for the entire CRU NH record, the absolute difference in the average NH temperature anomaly, due to trimming either the lower or the upper 10% of the points, is plotted versus the estimated standard deviation of $\hat{T}_{iy}$ (Eq. 2) for the same year. These variables are highly correlated ($R^2 = 0.90$).

To estimate the truncation effect on a truly normal distribution, a Monte Carlo procedure was adopted. One thousand normal distributions were generated with means in the range -1 and $+1$ and σ between 0.3 to 0.7 (corresponding approximately to the estimated bounds for the CRU data, as shown in Figs. 1 and 7). These distributions were then sorted and truncated in a similar manner to the anomaly data and the changes in means noted. Multiple linear regression shows that over these ranges of μ and σ, the change in the estimated mean caused by removing the upper or lower 10% of the points is well approximated by the simple linear relationship:

$$\Delta T = 0.19\sigma. \tag{4}$$

Because the average value of the standard deviation is, in this instance, about 0.7°C (Fig. 7), the corresponding change in the 10% trimmed average temperature is approximately 0.13°C which agrees well with the results seen in Fig. 10. Analogous results pertain in the 25% trimming situation. Thus, the result that the trimmed

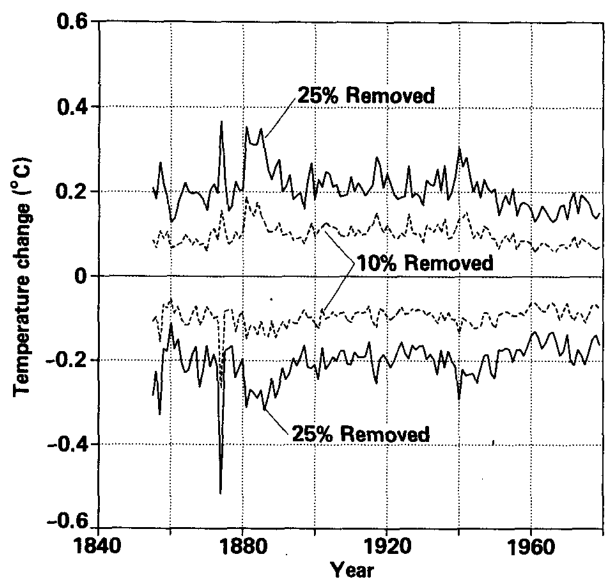

FIG. 12. Resultant change in area-weighted average hemispheric temperature anomalies for COADS NH marine air temperature data by removing extreme 10% or 25% of the area weighted gridpoints.

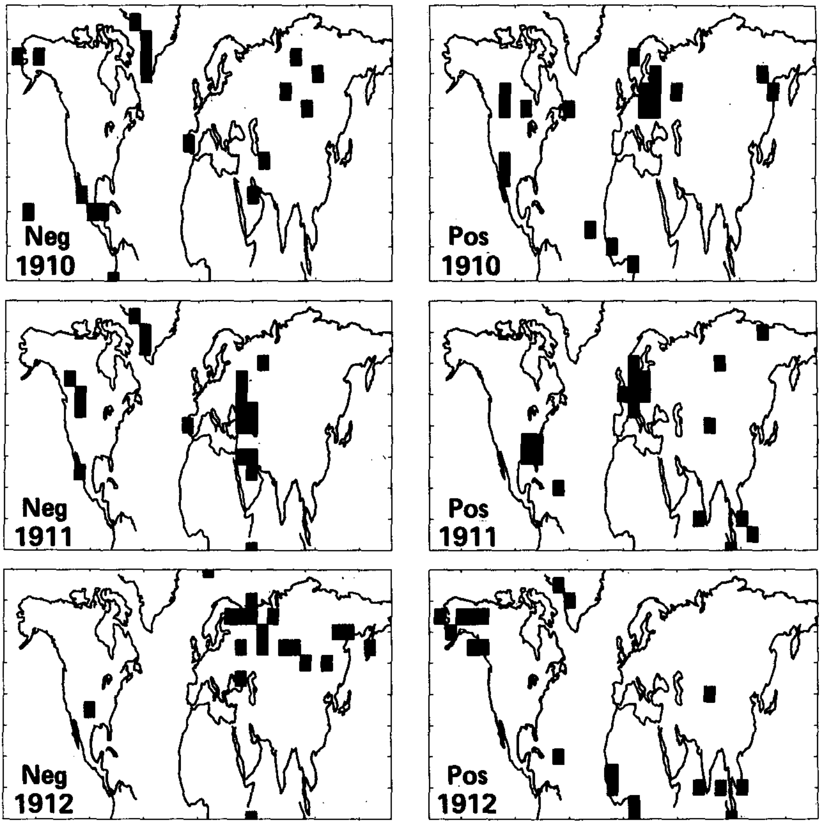

FIG. 13. Locations of the 10% most positive and negative gridpoints in computing the CRU NH average anomaly for the individual years 1910–12.

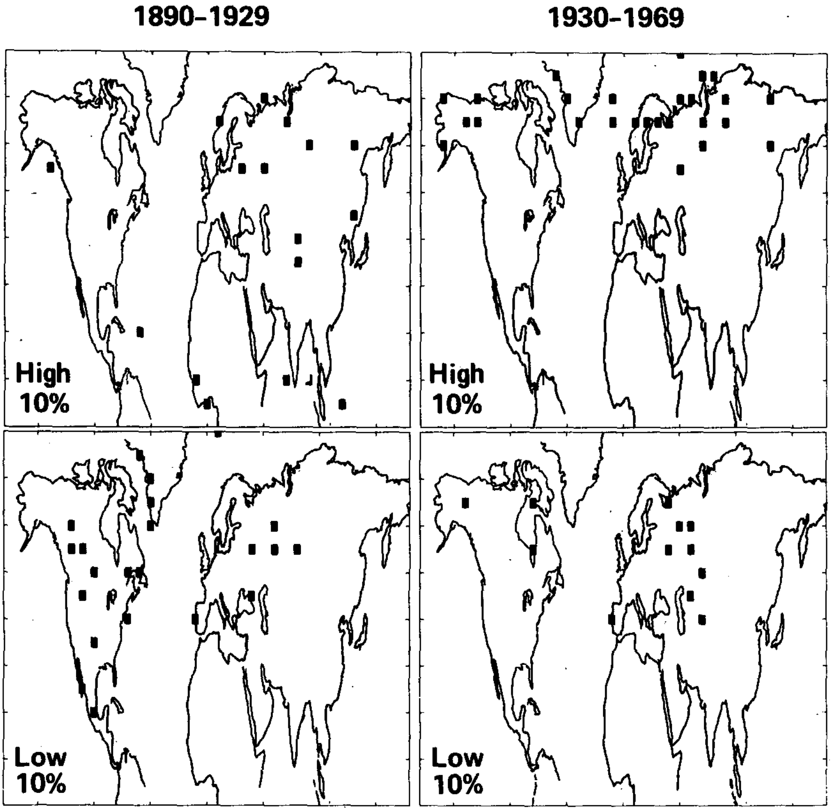

FIG. 14. Locations of the most persistent extreme anomalies (highest and lowest 10%) in the CRU record in two, 40 year periods, 1890–1929 and 1930–69.

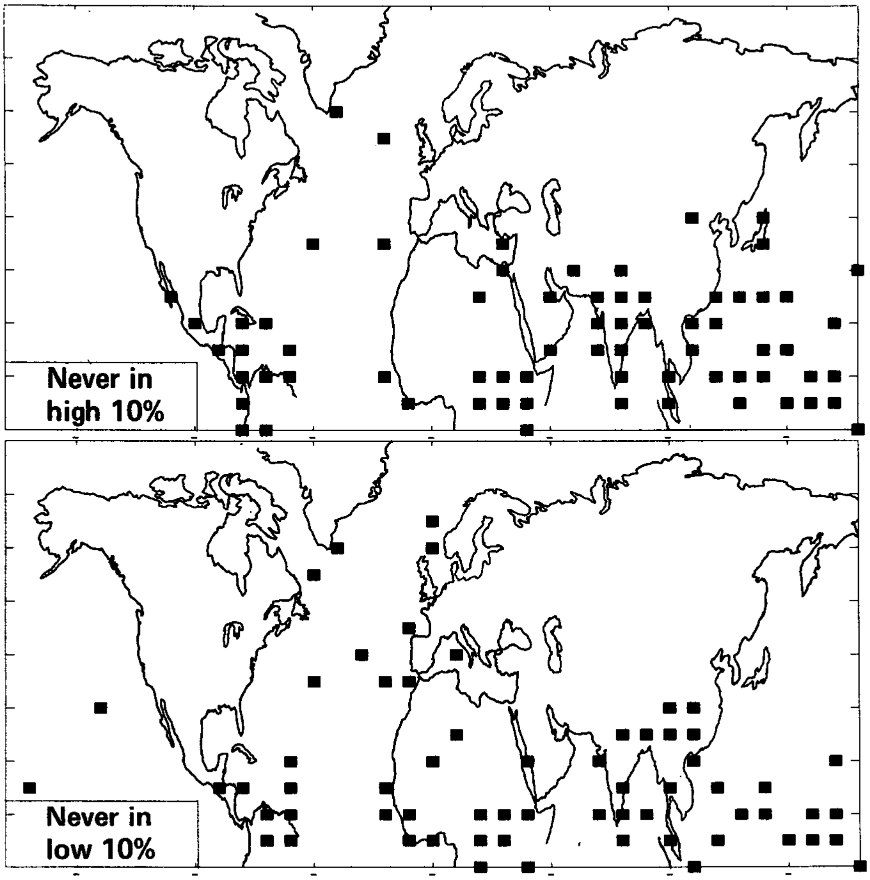

FIG. 15. Locations of those gridpoints which never appeared in the top 10% or the bottom 10% during the period 1890–1969.

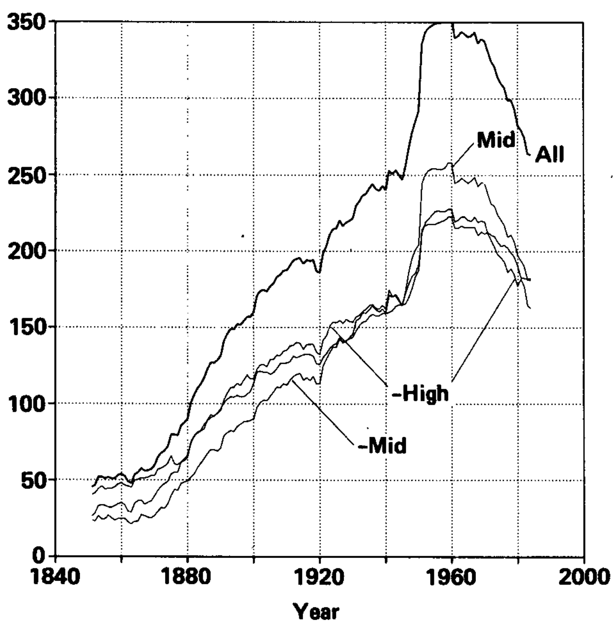

FIG. 16. The number of gridpoints remaining after removing low (0–30°), middle (35–50°), and high (>50°) latitude bands from the CRU NH data.

average value of the NH temperature anomaly changes by a nearly constant value over the extent of these data may be ascribed to:

1) The empirical result that $T\cos(\phi)$ appears to be distributed approximately normally over the majority of the record.

2) The means and standard deviations of this distribution change only slight with time, despite an order of magnitude change in data coverage over the past 100 years.

3) For truly normal distributions with $-1 < \mu < +1$, and $0.3 < \sigma < 0.7$, the change in the trimmed mean

TABLE 2. Difference in CRU NH average 1851–1984 after excluding particular zonal bands.

Band removed	Rms temperature difference (°C)	Average absolute temperature difference (°C)	Remaining linear trend (°C/century)
Low	0.11	0.085	0.44
Middle	0.10	0.075	0.37
High	0.09	0.072	0.30

is approximately proportional to the standard deviation.

The analogous trimming results using the COADS data base in computing the NH maritime air temperature average are shown in Fig. 12. They are similar to those of the CRU data, and, because the standard deviation here is more stable (Fig. 8), there is an even greater constancy seen after 1900. The average change in the NH temperature found in trimming the highest or lowest 10% of the anomalies is only about 0.1°C since 1890. The corresponding change in the hemispheric average for trimming the top or bottom 25% is about 0.15–0.25°C. Once again, the changes are nearly symmetrical and the comments made previously for the CRU data apply.

b. Locations of the most influential gridpoints

In computing the above statistics, sorted lists of the area-weighted temperature anomalies were determined for the period of the record. Knowing the locations of these gridpoints, we can identify where the largest contributors to the NH average anomaly are located, and how these locations change over time. The locations of the top and bottom 10% of the CRU NH gridpoints are shown on maps typified by Fig. 13, for the years 1910–12. In examining time sequences of such plots, it was difficult to find consistent patterns of points which persisted for more than, at most, 5 years.

We can, however, examine the persistency, on the average, of individual gridpoints in the extrema of the anomalies. Using the CRU data, and examining two 40 year periods, 1890–1929 and 1930–69, we can determine which gridpoints most consistently appeared in the top or bottom 10% of the raw anomalies. Here, to permit high latitude points to appear, the unweighted, or raw anomalies are examined. Fig. 14 shows that 17 gridpoints appeared ten or more times in the top 10% during the 1890–1929 period and 26 gridpoints were present at least ten times in the second 40 year period. The striking appearance of only high latitude (>50°N) gridpoints in the high 10% is apparent in the second period. The fact that 22 gridpoints appear in the low 10% in the early period, and only half that number are present in the last period is due to the generally increasing trend of the average anomaly curve with time.

The lack of appearance of specific gridpoints in the extrema can also be determined, as is seen in Fig. 15 which shows the locations of the gridpoints never present in either the top or the bottom 10% in the period 1890–1969 are shown. As one might expect, the great majority of the points are found at low latitudes, and the remaining gridpoints at higher latitudes are all maritime locations. In these areas, the temperatures are relatively stable and never reach the extrema of the distributions.

c. The effect on the NH average of removing zonal regions

In the previous sections, the effect on the NH average of removing the extremal gridpoints during each year was examined, with the resultant changes found to be nearly constant over time and surprisingly small. As Jones et al. (1986a) along with many others have pointed out, for periods prior to 1950, significant areas of the NH are not represented in the record. Because we cannot test the effect of this by adding new measurements to the data, we will consider what would happen if extensive zonal bands are removed from the existing record before computing the average. Would the estimated NH average anomaly change markedly with the removal of any particular band? Once again we find, even when a large fraction of the data is removed, the resultant change in the estimated NH average is generally small.

Consider first the CRU land-based NH record from 1851 to 1984. Three different latitude bands will be removed during each year, A: low latitudes (0°–30°N), B: midlatitudes (35°–50°N), and C: high latitudes (>50°N). Figure 16 shows the effect of this removal on the number of area-weighted gridpoints as a function of time for the three zonal deletions. During the last 100 years, the change in areal coverage is largest for the low latitude band, with nearly one-half the data being excluded, on the average. For midlatitudes, 30–40% of the data are removed, and for high latitudes, about 20% would be excluded.

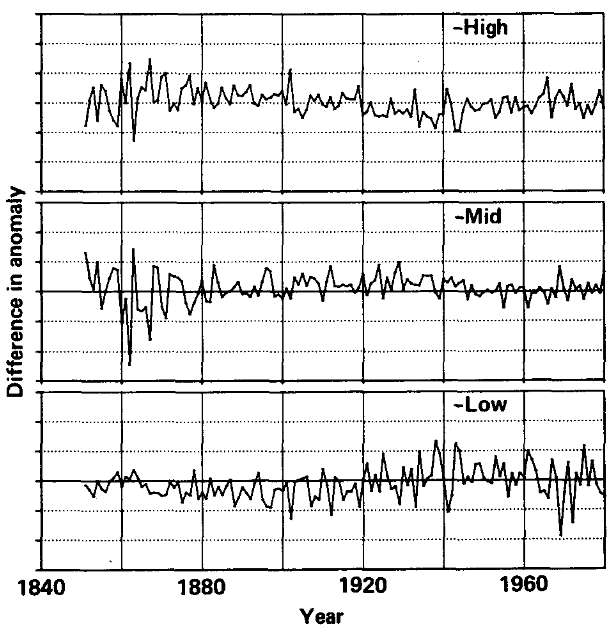

FIG. 17. Difference in computed NH averaged anomalies obtained after removing low (0–30°), middle (35–50°), and high (>50°) latitude bands from the CRU NH data. The range of the temperature axis in each subplot is ±0.4°C and each plot covers the period, 1851–1980.

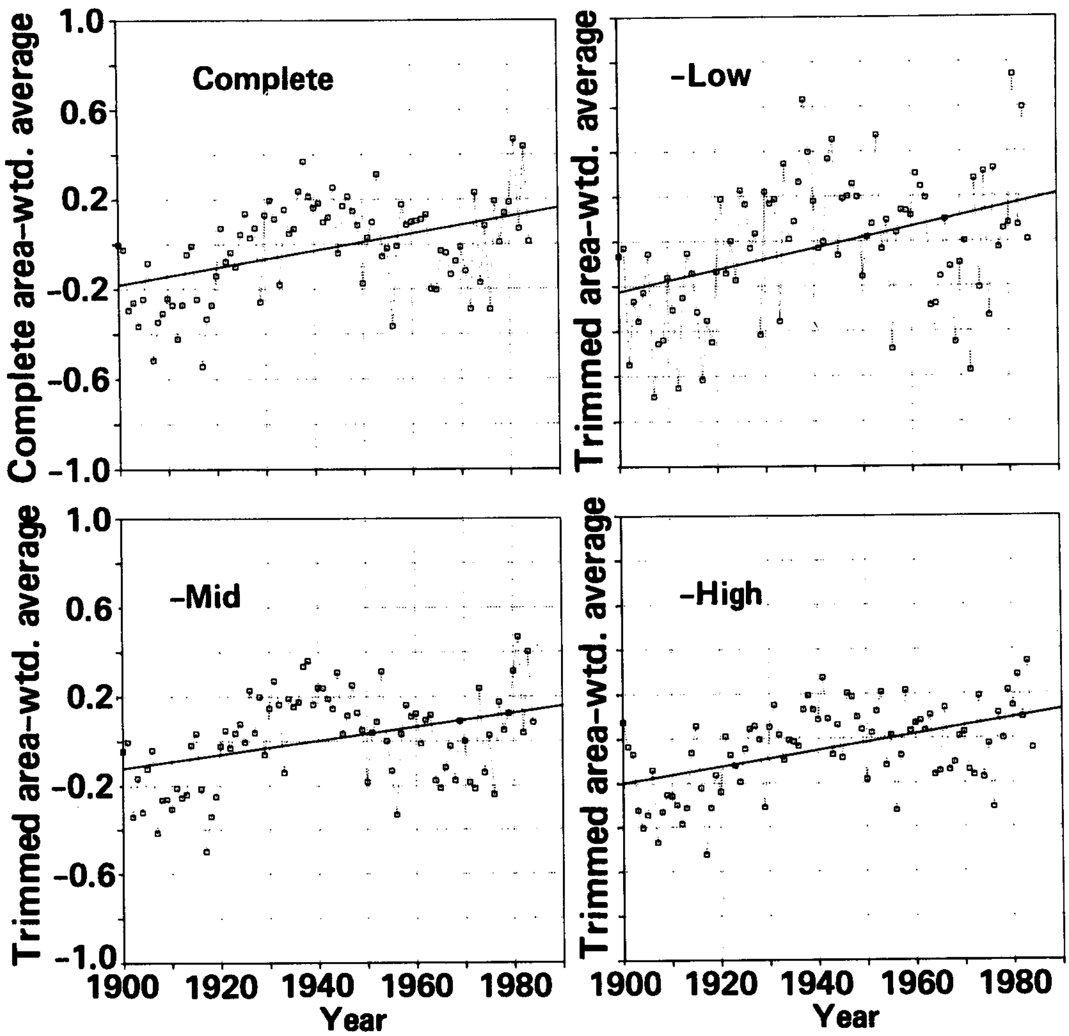

FIG. 18. CRU NH anomaly data, 1900–80; complete, after removal of low (0–30°), middle (35–50°) and high (>50°) latitude bands. Linear least-squares fits are shown in each case.

If we recalculate the NH average anomaly excluding these zonal bands one at a time, the different statistics that result are summarized in Table 2. Once again, the differences are relatively small, considering the rather substantial reduction in areal coverage involved. A more detailed view as a function of time is seen in Fig. 17 where the difference plots (modified series minus original full NH series) are shown. For the removal of the middle and high latitudes, relatively large changes occur before about 1880, with generally a small positive change from midlatitude removal from about 1880 to about 1950. The effect of low latitude removal is small and generally negative until about 1920, after which the changes become both larger and generally more positive.

Figure 18 shows the original CRU data and the resultant average anomaly data after zonal removal. The slopes of the linear least-squares fits found after removing the middle and high latitude bands are virtually the same: 0.37 and 0.30°C/century and are also very close to the original NH result, 0.36°C/century. The slope after removing the low latitudes is higher, 0.44°C/century, and its "average" curve is also noisier than are the other two.

These calculations were repeated using the Soviet gridded dataset (land + water) over the period 1891–1979. Here, because the gridded data were substantially complete (see, however, earlier comments regarding their oceanic data), the changes in content with band removal over time were more nearly constant, and proportional to the area reduction: about 50% for removal of the low latitude band, about 30% exclusion for middle latitudes, and about 20% exclusion for high latitudes. Quantitatively, the average changes observed

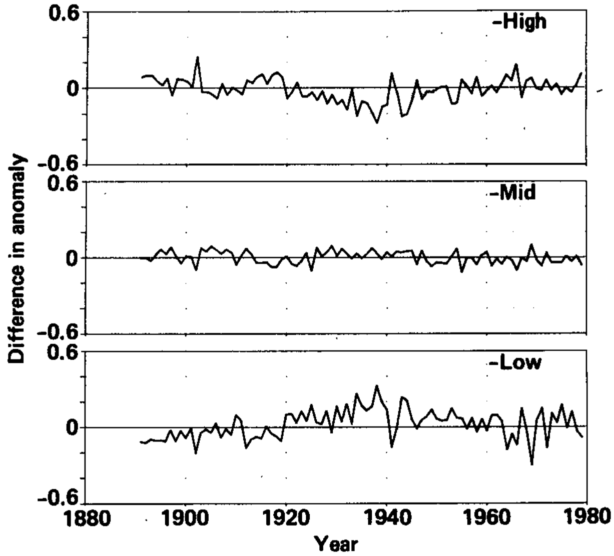

FIG. 19. Difference in computed NH average anomalies obtained after removing low, middle and high latitude bands from the Soviet NH data.

in removing the low and high latitude bands with the Soviet data were nearly identical to those found using the CRU NH dataset whereas removal of the midlatitudes had an effect only one-half that found with the CRU data.

If we compare the detailed difference curves, Figs. 17 and 19, we see more obvious difference patterns with time for the Soviet set than for the CRU data. For the Soviet data shown in Fig. 19, excluding the midlatitudes has virtually no effect on the estimated NH average (rms difference = 0.05°C). However, excluding low latitudes has a generally positive effect from about 1920 to 1965, whereas excluding high latitudes has virtually the opposite effect over the same time period. In fact, these two differences are virtually mirror images of one another until the late 1960s. For the Soviet data: 1) the midlatitudes show essentially the same behavior as the average of low and high latitudes, 2) for the central two-thirds of the record, low latitudes tended to be colder than the NH average anomaly and high latitudes warmer, by nearly the same amount.

In treating the COADS air temperature dataset over the NH in the same manner, the generally small changes in the average hemispheric temperature are again evident. Figure 20 shows the number of boxes (2° × 2° areas) that remain after removal of the different latitude bands. Because large drops in data content occurred in both World Wars, in the following discussion we will exclude the years 1914–19 and 1939–45. For the complete COADS record, Fig. 21 shows the resultant changes in estimated NH temperature anomalies after excluding the three zonal bands and the war years. Large differences occur during the period before 1900. The insignificant change resulting after high latitude removal is probably due to the lack of high latitude maritime data in the COADS record (see Fig. 20). The temperature changes seen after removing either the middle or high latitudes are small and generally comparable to the other data bases. Because the low latitudes constitute nearly half of these data, their removal has the most profound effect, but even this is

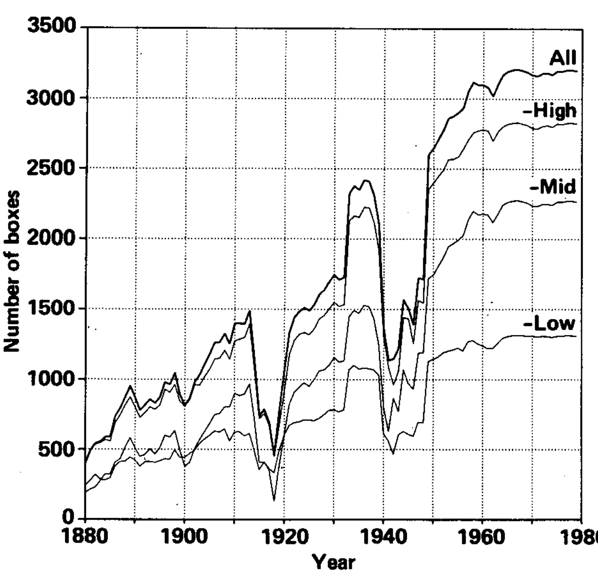

FIG. 20. Boxes remaining in COADS air temperature data after removal of three zonal bands: low (0–30°), middle (35–50°), high (>50°).

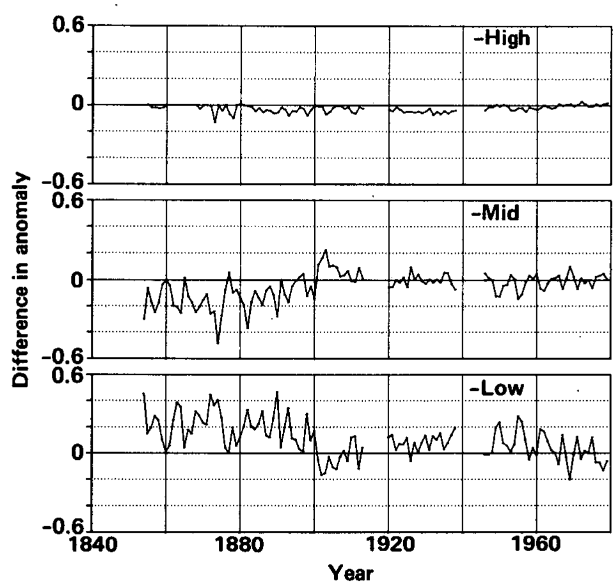

FIG. 21. Temperature differences resulting from removal of three latitude bands for COADS air temperature data, low (0–30°), middle (35–50°), high (>50°).

small with an rms value of 0.11°C for the years since 1900.

These zonal removal studies using these three data bases show that the NH average anomaly curves are quite robust to the exclusion of data on a strictly latitudinal basis. Even when substantial regions of the data are excised, the change in the average anomaly in any year is found to be of the order of 0.1°C.

4. Conclusions

Calculations using three extensive gridded data bases show that the NH average temperature anomaly is surprisingly robust to both the presence of extreme values and even to the exclusion of latitudinal bands. For the CRU dataset, removing the highest or the lowest 10% of the gridpoints will shift the estimated hemisphere average temperature anomaly in any year during the last century by about 0.10°C. These results can be explained assuming a simple model of normally distributed area weighted anomalies with limited ranges of means and standard deviations. Excluding complete latitudinal bands, involving data reductions of as much as 50%, similarly produces changes in the average NH temperature anomaly of about 0.10°C. As a final note of caution, it is comforting to note that both this study and that of Jones et al. (1986b) have found the estimated average NH anomaly to be robust to the presence or absence of individual measurements. However, this provides no guarantee as to the accuracy of these data in estimating the true NH temperature anomalies.

Acknowledgments. The constructive criticisms of my colleagues at the Lawrence Livermore National Laboratory and of the two referees and editor are gratefully acknowledged.

This work was performed under the auspices of the Carbon Dioxide Research Division, U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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