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# Northern Hemisphere Surface Air Temperature Variations: 1851–1984

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ABSTRACT

A new compilation of monthly mean surface air temperature for the Northern Hemisphere for 1851–1984 is presented based on land-based meteorological station data and fixed-position weather ship data. This compilation differs from others in two ways. First, a considerable amount of new data, previously hidden away in archives, has been included, thus improving both spatial and temporal coverage. Second, the station data have been analyzed to assess their homogeneity. Only reliable or corrected station data have been used in calculating area averages. Grid point temperature estimates have been made by interpolating onto a 5° latitude by 10° longitude grid for each month of the 134 years. In the period of best data coverage, 58% of the area of the Northern Hemisphere is covered by the available data network. (The remaining area is mainly ocean too far from land-based stations to warrant extrapolation.) The reliability of hemispheric estimates is assessed for earlier periods when coverage is less than this maximum. Year-to-year estimates are considered reliable back to about 1875. Estimates earlier than this are judged sufficiently good to indicate trends back to 1851. This new land-based hemispheric temperature curve is compared with recent estimates of Northern Hemisphere temperatures based on marine data. The two independent estimates agree well on the decadal time scale back to the start of the century, but important discrepancies exist for earlier times.

## 1. Introduction

Many attempts have been made to combine station surface air temperature data into an average for the Northern Hemisphere (NH) (see Jones et al., 1982; Ellsaesser et al., 1985; and Wigley et al., 1985a for recent reviews of previous analyses). The agreement between these different analyses is extremely good on both the annual and monthly time basis. Of course, this agreement between datasets cannot be taken as confirmation of the reliability of the individual analyses, since most workers have used essentially the same data source, World Weather Records (WWR) (Smithsonian Institution, 1927, 1934, 1947 and US Weather Bureau, 1959–82, available in digitized form from the National Center for Atmospheric Research (NCAR), Jenne, 1975). The slight differences between different NH averages arise primarily from the use of different interpolation or averaging schemes and different reference periods.

Two major criticisms can be directed at previous work. First, the spatial coverage of the data is restricted, and hence, the representativeness of the hemispheric average is uncertain, particularly during the late nineteenth century. Second, the original station data may be affected by inhomogeneities and other errors in the station time series. Neither of these questions has been thoroughly studied by previous investigators, although all would have been aware of the problems.

Since the nineteenth century, the station temperature network has expanded considerably. At present, most of the land surface of the Northern Hemisphere is adequately covered. However, for periods prior to 1950, significant parts of the hemisphere are not represented. Prior to 1900, when land-based hemispheric estimates are based mainly on midlatitude (35°–60°N) data, the effects of reduced coverage may be substantial. The significance of such changes in coverage has not yet been properly assessed.

It has long been known that the basic source of long term station air temperature records (WWR) contains many station records that are not homogeneous (i.e., they contain changes that result from nonclimatic factors).[1] For example, values for individual months can be mispunched, misprinted or simply incorrect. More serious errors may arise from station moves, changes in observation times and the effects of environmental changes around the station. These factors may cause spurious discontinuities and trends that are not the result of climatic change and which may obscure or distort any climate-related change.

Bradley et al. (1985) and Jones et al. (1985) have supplemented the WWR dataset with a considerable

[1] The words "homogeneous" and "homogenous" are both used in this context. Although they have slightly different meanings, both are correct. We prefer "homogeneous."

amount of additional data from published and manuscript material in meteorological archives. This enhanced dataset is referred to below as the DOE (U.S. Department of Energy) data bank. The new data improve the spatial coverage significantly, particularly prior to 1920. Full details of these improvements, with maps showing the WWR Northern Hemisphere coverage and the new coverage, are given in Bradley et al. (1985). In addition, station history information is given indicating station moves, changes in observation times, and changes in the method of calculation of monthly mean temperatures (see also Goodess et al., 1985). Although detailed station history information is available for most countries, in some regions of the world, particularly the tropics, the available information is limited to the station location and altitude.

In this paper, we describe the use of this enhanced data bank to compile a new gridded hemispheric dataset. In the course of this, we assess the effects of the two main sources of possible error in estimating land-based surface air temperature over the Northern Hemisphere: errors in the individual station records used to compile hemispheric averages, and changes in spatial coverage. Changes in spatial coverage are potentially the more serious of the two problems. However, this effect cannot be assessed adequately before the problem of inhomogeneities in the station data has been resolved.

## 2. Reasons for station inhomogeneities

Although observers may take observations with meticulous care, nonclimatic influences can easily affect the readings. Some factors, such as the type of instrument, its exposure and the method of measurement, may be under the control of the observer; other factors, such as observation times and the station environment, may not.

Four major factors affecting station homogeneity have been identified (Mitchell, 1953; see also the summary by Bradley and Jones, 1985):

(i) changes in instrumentation, exposure and measurement techniques;

(ii) changes in station location (both in altitude and position);

(iii) changes in observation times and the methods used to calculate monthly means; and

(iv) changes in the environment around the station, particularly with respect to urban growth.

### *a. Changes in instrumentation and station location*

Instrumentation and instrument exposure changes have undoubtedly occurred in almost all regions where meteorological measurements are made. The degree of change varies from country to country and there is no simple way to quantify the magnitude of any effect. In one of the few studies to consider the effects of changes in instrumentation and exposure on the decadal time scale, Mitchell (1953) considers the effects on monthly mean temperature in the United States to be slight.

Information on site histories indicates that many stations have changed their locations on numerous occasions; Mitchell states that virtually every station is affected in some way. For the 120 stations used by him in one of the earliest NH temperature compilations, 157 changes of site were recorded. At the 16 stations in the United States, 95 important site changes had been recorded.

The effects of station moves must be assessed station by station using comparisons between data from the old and new sites and from neighboring stations. Ideally, simultaneous observations should be taken at both the old and new sites. It is rare, however, for a sufficient number of overlapping readings to be taken in order to evaluate possible seasonal differences in correction factors between sites.

### *b. Changes in observation times and the methods of calculation of monthly means*

Changes in observation time and the method of calculating monthly mean temperatures are a major potential source of error (Bradley et al., 1985). Bigelow (1909) gives factors necessary to adjust monthly means based on daily values computed using (max + min)/2 to those based on the average of 24 hourly values in map form for the United States. The seasonally varying adjustments range between $\pm 1.0°C$. Such adjustments were used in WWR for the United States up to 1940 or 1950 (depending on the station). Another observation time change has occurred in the United States over the most recent 20 years. At many non-first-order stations where mean temperature is computed using (max + min)/2, there has been an increase in the number of morning observations with a corresponding decrease in evening observations. The effects of such a change is considered to introduce a slight spurious cooling to monthly mean temperatures (Baker, 1975; Blackburn, 1983). Bradley et al. (1985) give a fuller discussion and a list of formulae used to calculate monthly mean temperature for each country in the Northern Hemisphere—where known! Few countries have used the same method of monthly mean calculation since the beginning of meteorological measurements (Alaska, Canada and India are noteworthy exceptions).

It is considered impossible to reduce all observations to the same standard (Bradley et al., 1985). Nevertheless, when compiling a NH temperature series, the problem is considerably reduced if all records are transformed to anomaly values from a common reference period. If individual site time series are *homogeneous*, then a time series of anomalies from a (max + min)/2 calculation is not likely to differ in any systematic way from a time series of anomalies from a mean based on a sensible set of fixed hours provided the same reference period is used. (Clearly if the time of observation of the maximum and minimum temperature changes, then the series will not be homogeneous.) That this is so is demonstrated every month by the contoured temperature anomaly maps published by Deutscher Wetterdienst (Die Grosswetterlagen Europas). Each European country uses a different system (different observation times and different methods of calculation), but, because anomalies are plotted with respect to a reference period, no discontinuities are ever apparent. Differences may arise if the variance of monthly mean temperature depended systematically on the method of calculating daily means, but this effect appears to be minor.

### *c. Urbanization effects*

Changes in the station environment, particularly in urban or industrial areas, are considered to have an important influence on station mean temperatures. The effect is undeniable on the daily time scale and many examples have been given in the literature (see Landsberg, 1981, for a thorough review). But is the urbanization effect sufficient to distort the average for the whole Northern Hemisphere? Dronia (1967) suggested that it was and that the early twentieth century warming was exaggerated by urban effects. Choosing 163 predominantly "greenbelt" stations to compute global temperature averages, he found a global cooling of 0.11°C between the 1870s and the 1950s, and a warming of 0.19°C between the 1900s and the 1950s. However, Dronia's data show large changes in coverage, particularly during the nineteenth century, and he made no attempt to assess the homogeneity of individual station records. His work contains a number of inconsistencies and methodological deficiencies, both in calculating the urbanization effect and in calculating global mean temperature changes. Poor coverage in high latitudes may further distort results. Both van Loon and Williams (1976) and Jones and Kelly (1983) have shown that the twentieth century warming was strongest in high latitude regions (particularly over Greenland and northern Siberia). We conclude that Dronia's results cannot be accepted at face value.

The contention that significant warming has occurred in high latitudes could be questioned. It is true that significant urban heat islands have been documented for some Arctic cities, particularly on the daily time scale (e.g., Fairbanks, Alaska; Weller, 1982). In general, however, our homogeneity analyses (next section) show that, at least for annual mean data, urbanization effects are small for most Arctic locations.

As will be demonstrated below, we do not consider urbanization effects to have caused any major distortion of large scale area average temperature changes. We have, nevertheless, removed suspect sites from our analysis. On smaller spatial scales (local to regional), however, data inhomogeneities caused by urbanization are undoubtedly important in some regions, especially the United States (Cayan and Douglas, 1984; Kukla et al., 1985).

## 3. Assessment of homogeneity

### *a. Method and examples*

From the available station history information given by Bradley et al. (1985) and Jones et al. (1985), it is apparent that there are many potential data inhomogeneities. For the United States, there have been, on average, six moves per station over the period 1873–1950 (Mitchell, 1953). For other countries, the average is much less than this, but almost every station has been affected at least once. At first sight, therefore, to homogenize all these data series appears to be an awesome task.

There are two possible approaches to this problem: either, all records must be exhaustively checked using station history information, when available, as a guide to likely errors; or inconsistencies between neighboring stations can be used as a guide to the major inhomogeneities in the dataset. The choice of approach depends upon the application. If a single station record is to be used in a study of local climatic change, the former approach is desirable, but, for many purposes, the latter will suffice.

Taking the more thorough approach first, one can start by assuming that all station air temperature records contain errors. The remedy would be to identify all potential errors from the station histories and apply corrections in a systematic manner station by station. Fortunately, such a pessimistic viewpoint (and the extremely laborious solution) is not warranted. Detailed examination of the accompanying notes to World Weather Records (Smithsonian Institution, 1927, 1934, 1947 and US Weather Bureau, 1959–82) reveals that the compilers were well aware of many of the problems. Homogeneity questions were addressed and many of the series entered into WWR have been corrected or homogenized. The degree of homogeneity testing varied from country to country and doubtless some countries were more diligent than others. Many of the longer European series have been thoroughly tested, although only scanty (but, nevertheless, adequate) detail of what was done is given in WWR. It is worth noting, however, that after 1950 when the publication was taken over under the auspices of WMO, [through the National Oceanic and Atmospheric Administration (NOAA), Asheville, North Carolina], the amount of station information that was published was reduced considerably. At the same time, the number of stations increased significantly (see Jones et al., 1982, Fig. 1).

As our concern is with the reliability of large-scale averages, we have used the second, cruder approach. To test homogeneity, we have compared records from neighboring stations. We have searched for discontinuities and trends in station differences, thereby identifying the major inhomogeneities, rather than assuming that all potential inhomogeneities have caused discontinuities in the station records. The discontinuities or trends can be caused by any of the problems discussed previously, site changes, instrumentation, urbanization, observation time changes (e.g., pm to am readings) and changes in the methods used to calculated monthly means [e.g., the use of fixed hours to the use of (max + min)/2]. We are only concerned with errors that are large enough to affect studies of large-scale climatic change. This method assumes that, within small areas, the effects of changes in climate will be similar. The size of the area within which station records were compared varied according to data availability and latitude (varying from $10^3$–$10^5$ km$^2$), with greater emphasis given to comparisons between stations that were closer together.

Records at four or five neighboring sites were compared on climatological time scales (of the order of 20 years), using the following procedure:

1) For each station, the entire record was first converted to anomalies from the appropriate monthly mean based on the entire station record length. Outliers were detected visually, and subsequently either verified, corrected, or replaced by a missing observation code. The use of statistical tests alone to identify outliers is not always effective because the outliers themselves can distort the statistics. A subjective decision must be made for each outlier identified by an objective statistical technique.

2) For all stations within an area, each annual temperature anomaly record was compared with all other records by plotting the differences between series as time series, a method proposed by Conrad and Pollak (1962). If abrupt changes in the difference time series are revealed, station moves or changes in observation times may be the cause. By comparing a number of station pairs, the erroneous station(s) become readily apparent. Confirmation of the cause of the inhomogeneity was then sought in the station history information given by Bradley et al. (1985) and Jones et al. (1985).

3) When a particular record showed a sudden jump or discontinuity, corrections were derived on a monthly basis and the errant data were adjusted (see below for details). Time series of differences between stations sometimes showed trends or gradual changes. Correcting such "errors" is much more difficult and, in most cases, it was necessary to remove that record from subsequent analyses: and flag it as "uncorrectable" in the data bank.

Four examples of the approach are shown in Figs. 1-4 and discussed in the figure captions. Only a small selection of the pair comparisons is shown in each of these examples. Full details of the comparison stations for each of the 2666 individual site time series, and of

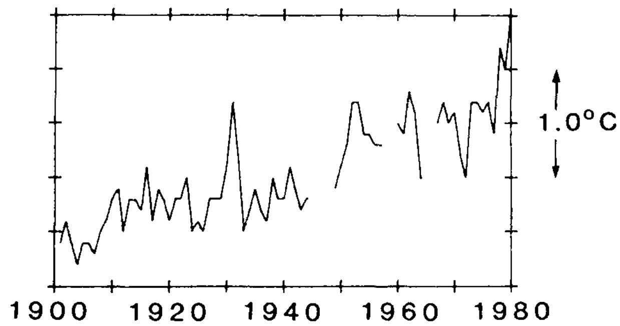


FIG. 2. Station temperature difference time series: Washington, DC (38.9°N, 77.1°W) minus Princess Anne (38.2°N, 75.7°W), 1901–80. The plot illustrates a nonclimatic warming trend associated with urban growth at the Washington DC station. Similar examples are evident from comparisons with other stations in rural areas within 200 km of Washington DC. The urbanization effect over the present century at Washington, DC is approximately 2°C in 80 years (0.025°C yr$^{-1}$).

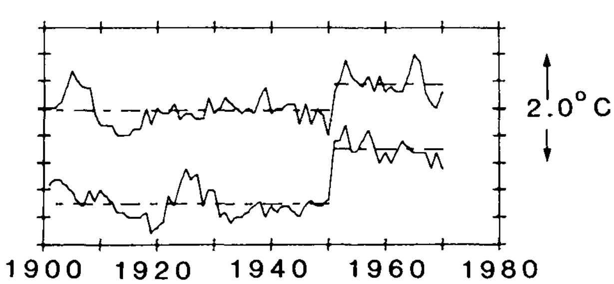


FIG. 1. Station temperature difference time series: (upper) New York (40.7°N, 74.0°W) minus New Haven (41.3°N, 72.9°W); (lower) Blue Hill (42.1°N, 71.2°W) minus New Haven, 1901–70. These plots identify New Haven as the errant station with a discontinuity in 1950/51. The result is confirmed by reference to the station history. Before 1950, the site was in or near to Yale University. After 1951, the station moved to the local airport. The straight lines are the mean station differences for the two periods, 1901–50 and 1951–70.

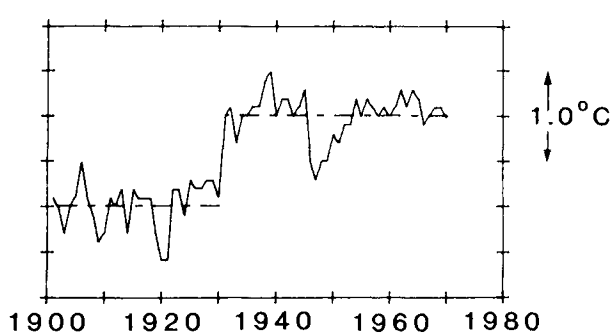


FIG. 3. Station temperature difference time series: Reykjavik (64.0°N, 22.0°W) minus Vestmannaeyjar (63.4°N, 20.3°W), 1901–70. The plot identifies Vestmannaeyjar as the errant station as a similar jump at 1931 also occurs when the station is compared with Stykkisholmur (65.0°N, 22.8°W). WWR station history data reveals a station move. The straight lines are the mean station differences for the two periods, 1901–30 and 1931–70.

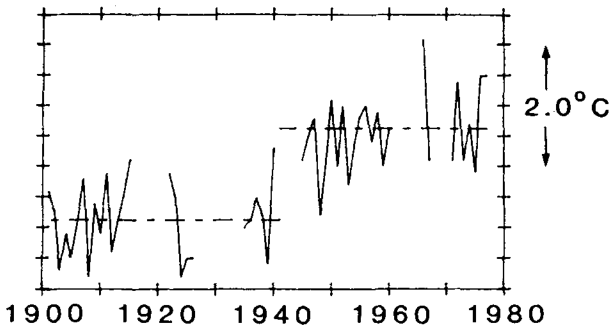


FIG. 4. Station temperature difference time series: Irkutsk (52.3°N, 104.3°E) minus Kirensk (57.8°N, 108.1°E), 1901–77. The plot identifies Kirensk as the errant station as a similar jump at 1941 also occurs when the station is compared with Cita (52.0°N, 113.5°E). Evidence in WWR indicates a change in station height. The straight lines are the mean station difference for the two periods, 1901–40 and 1941–77.

the results of the homogeneity analyses, are given in Jones et al. (1985).

### *b. Correcting errant station records*

When abrupt jumps in a station record occur, it is possible to derive correction factors in order to produce a homogeneous dataset. For the examples given here (Figs. 1–4), the New Haven, Vestmannaeyjar and Kirensk records were adjusted or "homogenized." The record for Washington, DC cannot be reliably corrected, so was flagged and was not used in further analyses. All stations showing nonclimatic warming trends were similarly flagged. In addition, station records which had numerous (generally more than two) discontinuities, and stations whose records showed nonclimatic cooling trends relative to their neighbors, were also flagged as uncorrectable and unusable.

Correction factors were obtained by differencing the mean temperature before and after the change at the errant station and comparing this with a similar difference at the "correct" neighbor station(s). Although errant stations were identified using annual data, corrections were derived on a monthly basis. The correction factor, in a particular month, is given by:

$$C = X_0 - X_1 - \frac{1}{N}\sum_{i=1}^{N}(Y_{i0} - Y_{i1}) \qquad (1)$$

where subscripts 0 and 1 refer to appropriate time periods before and after the discontinuity, $X$ is the monthly mean temperature at the errant site and $Y_i$ is the monthly mean temperature at the $i$th (of $N$) neighboring sites with a homogeneous record.

Station records were always adjusted to be compatible with the most recent part of the record. In the example illustrated for New Haven in Fig. 1, $N = 3$ (Blue Hill, New York and Trenton), period 0 covered the years 1901–50, and period 1 the years 1951–70. Full details for each homogenized site are given in Jones et al. (1985).

Of the 2666 stations in the DOE NH station temperature dataset, 249 records were homogenized in this way and 277 records were flagged as uncorrectable and hence, unusable in subsequent analyses. These numbers represent 12.3% and 13.7% of the 2021 records that could be examined (645 station records were either too short or there were no adjacent stations that could be used for comparative purposes). Although the correction procedure [Eq. (1)] is objective in its application, deciding which stations are in error, which stations to use in correction, and whether or not to correct, are subjective judgments. The corrections are meant to be general adjustments only, sufficiently reliable for continental or hemisphere-scale studies, but not necessarily for local studies. Such studies require a more detailed assessment of homogeneity, such as the first method mentioned above.

## 4. Results of the station homogeneity assessment

Full details of the homogenization analyses are given by Jones et al. (1985). Each station has been assigned a quality control code (correct, homogenized, not correct, not checked, or affected by urban warming). The stations used to assess this code for each station are listed (in Jones et al., 1985), together with any correction factor applied and the stations used in the calculation of the correction factor (Eq. 1).

The number of stations in each quality class are listed in Table 1 for seven regions of the Northern Hemisphere. The numbers in Table 1 include stations with relatively short records, and stations that could not be used in the estimation of the hemispheric average because they have insufficient data to calculate a reference period (1951–70) mean. These numbers, therefore, overestimate the amount of data that can be used for studies of hemispheric scale. Table 2 shows information for those stations with sufficient reference period data. In Table 3, this number is further divided to show only those stations in Table 2 that have data records commencing prior to 1900, tabulated decade by decade. Note that a few stations listed in column C of Table 2 have been used in our analyses even though their records were not rigorously tested for homogeneity (because of the absence of suitable records for comparison). This was necessary to minimise gaps in spatial average. These data were, however, evaluated subjectively in the light of insights gained during the overall homogenization process.

The most striking feature of these tables is that the large majority of the stations examined (56%) exhibited no major inhomogeneities. Although a fair proportion could not be tested (24%), the number correct or corrected (66%) far outweighs those with (possible) remaining problems. We conclude that the data bank

TABLE 1. Number of stations in each homogenization category for different regions of the Northern Hemisphere.*

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Europe (excl. USSR) | 290 | 12 | 170 | 58 | 7 | 537 |
| USSR | 188 | 8 | 0 | 7 | 0 | 203 |
| Asia (excl. PRC) | 149 | 30 | 91 | 7 | 0 | 277 |
| PRC | 42 | 0 | 70 | 10 | 0 | 122 |
| Africa (north of 2.5°S) | 160 | 39 | 144 | 16 | 0 | 359 |
| Americas (north of 2.5°S) | 588 | 160 | 136 | 131 | 31 | 1046 |
| Indonesia, Philippines, Pacific islands | 78 | 0 | 34 | 10 | 0 | 122 |
| All 7 regions | 1495 | 249 | 645 | 239 | 38 | 2666 |
| % of 2666 | 56 | 9.5 | 24 | 9 | 1.5 | |

* A: Stations correct after a specified year. (The specified year is not always the first year of record; in such cases, the early parts of the record were not used in any subsequent analyses.) B: Stations homogenized. C: Stations not examined (record too short or no adjacent stations for comparison). D: Stations incorrect (e.g., numerous jumps and/or trends including nonclimatic cooling trends). E: Stations with nonclimatic warming trends. F: Station totals.

can be considered generally reliable for studies of large-scale climatic change.

Nevertheless, there are difficulties in the earlier years. Table 3 is particularly informative. It shows that there are relatively few stations before 1880 over China, Africa (north of 2.5°S) and the Indonesia–Philippines–North Pacific Islands region. Overall, for the Northern Hemisphere (north of 2.5°S), there are 1584 usable records (i.e., those for which 1951–70 reference period means could be calculated), of which 509 commence before 1900.

Urban warming has been identified at 38 stations (~2% of the full set of stations), the majority of which (31) are located in the North American region. A complete discussion of reasons why most of the identified urban warming sites are in North America is beyond the scope of the paper. However, three possible reasons are worth further study. First, the growth of cities in North America has been much more rapid over the present century than in similar developed societies in Europe and northern Asia. Second, urbanization effects are greatest when minimum daily temperatures are considered. Any urbanization effect will, therefore, be reduced if monthly mean temperatures are calculated using fixed hour observations at, for example, 3, 4, 6 or 8 times a day. Most European countries, including the USSR, use fixed hour observations. Third, the density of stations in the United States and southern Canada is high and this may have facilitated detection. The density of stations is, however, also high for Europe and Japan.

All 38 identified stations have records extending back to at least the 1890s. If these stations are averaged, with no attempt at any weighting, the warming trend over the period 1881–1980 amounts to 1.20°C. This can be compared with a trend of 0.33°C resulting from an average series of 38 stations identified as correct, each of which is sited adjacent to the identified urban site. The trend of air temperature due to the urban effects is 0.0087°C yr$^{-1}$, comparable to many other estimates (Dronia, 1967; Kukla et al., 1985). The stations exhibiting urban warming have not been used in this new calculation of the hemispheric average.

TABLE 2. Stations with sufficient data in the reference period mean, 1951–70.*

| | A | B | C | D |
|---|---|---|---|---|
| Europe (excl. USSR) | 227 | 12 | 44 | 283 |
| USSR | 134 | 8 | 0 | 142 |
| Asia (excl. PRC) | 118 | 26 | 19 | 163 |
| PRC | 42 | 0 | 0 | 42 |
| Africa (north of 2.5°S) | 141 | 37 | 8 | 186 |
| Americas (north of 2.5°S) | 534 | 149 | 7 | 690 |
| Indonesia, Philippines, Pacific islands | 78 | 0 | 0 | 78 |
| All 7 regions | 1274 | 232 | 78 | 1584 |
| % of 1584 | 80.4 | 14.7 | 4.9 | |

* A: Stations correct after a specified year. B: Stations homogenized. C: Stations not checked. D: Totals.

TABLE 3. Number of stations with sufficient data in the reference period, 1951–70, and with records starting in the 19th century.

| | Stations with first reliable year before | | | | |
|---|---|---|---|---|---|
| | 1860 | 1870 | 1880 | 1890 | 1900 |
| Europe (excl. USSR) | 58 | 74 | 88 | 101 | 106 |
| USSR | 26 | 26 | 28 | 45 | 53 |
| Asia (excl. PRC) | 6 | 7 | 29 | 46 | 71 |
| PRC | 2 | 2 | 2 | 2 | 4 |
| Africa (north of 2.5°S) | 3 | 5 | 8 | 14 | 21 |
| Americas (north of 2.5°S) | 21 | 28 | 89 | 154 | 241 |
| Indonesia, Philippines, Pacific islands | 2 | 2 | 2 | 9 | 13 |
| All 7 regions | 118 | 144 | 246 | 371 | 509 |
| % of 509 | 23.2 | 28.3 | 48.3 | 72.9 | |

## 5. Gridding the station temperature data

In order to overcome the irregular distribution of the station data and to calculate large-scale spatial means, we have chosen to interpolate the data onto a regular grid (see Raper et al., 1984, for an alternative method). Previous analyses have accomplished this in a number of ways. Borzenkova et al. (1976) (updated in Vinnikov et al., 1980) used a subjective mapping technique: hand plotting the station data onto a map for each month over the period 1891–1980. The maps were contoured subjectively and grid point values extracted on a 5° latitude by 10° longitude grid. The grid point values were then averaged with cosine latitude weighting to produce hemispheric mean values. Further details of the methods are given by Jones et al. (1982) and Robock (1982). Hansen et al. (1981) divided the Northern Hemisphere into 40 boxes, the size of which depended on the "spatial correlation decay length," implying that the boxes were larger nearer the equator. The box values were areally weighted according to latitude to produce hemispheric mean values. Jones et al. (1982) interpolated temperature anomaly values onto the same grid used by Vinnikov et al. (1980), using an inverse-distance-weighted best fit plane fitted through the six nearest stations to each grid point. The grid point values were then averaged with cosine weighting to produce hemispheric mean values.

The only other recent set of long-term gridded land-based temperature data for the Northern Hemisphere is that produced by Yamamoto and co-workers (e.g., Yamamoto and Hoshiai, 1980; Yamamoto, 1981). They used optimum interpolation to estimate grid point values on a coarse network at 30° longitude spacing. Their results are not strictly comparable to the other three analyses as they assumed a zero anomaly value at all grid points where interpolation could not be made—effectively all the NH ocean areas. This step dramatically reduces the variance of their hemispheric average series compared with the other analyses discussed above.

The three independent analyses of Vinnikov et al. (1980), Hansen et al. (1981) and Jones et al. (1982) are compared in Wigley et al. (1985a,b). The different series have at least 95% variance in common. As the data sources used by the various workers are so similar (we estimate that there is around 95% data overlap among the three previously published analyses), the implication is that the method of gridding has little effect on annual hemispheric mean temperature estimates.

In Jones et al. (1985) we have identified some (relatively minor) practical disadvantages in the gridding method used in Jones et al. (1982). In order to make slightly better use of the available data, a new method of interpolating grid point temperatures will be used here.

It is not possible to use raw station data directly because of differing station altitudes and other aspects (e.g., differing observation times). Jones et al. (1982) overcame this using anomalies from a reference period mean (1946–60), the period with best data coverage. The WWR publications for the 1960s have now been fully published and the best period of data coverage is now 1951–70. We have, therefore, used this as a new reference period. For a station to be used in our analysis, at least 15 years of data are required between 1951–70. In some parts of the world, however, there were valuable long records that ended in 1950 or 1960. Clearly, it was desirable to retain these records in our analysis if at all possible. Fortunately, in most of these cases, reference period means could be estimated using data from nearby stations with accuracy better than 0.2°C.

The new method of gridding is as follows. Each station is first associated with its nearest grid point on a 5° latitude by 10° longitude network. For each grid point, all the available station anomaly values are averaged using inverse distance weighting

$$T_g = \sum_{s=1}^{M} \alpha_s T_s / \sum_{s=1}^{M} \alpha_s \qquad (2)$$

where $T_g$ is the interpolated grid point temperature anomaly, $T_s$ ($s = 1, M$) is the station temperature anomaly, $\alpha_s$ ($s = 1, M$) is the inverse of the great circle distance between station '$s$' and the grid point. (To avoid problems with stations very near grid points, $\alpha_s$ was never allowed to exceed $^1/_{50}$ n. m.)

The number of stations ($M$) varies through time at each grid point and from grid point to grid point. In some cases $M = 1$ and the station value itself was used as the grid point value. For each month, at each grid point, three quantities have been stored in our gridded data file: the grid point temperature anomaly ($T_g$), the number of stations used ($M$), and the quantity

$$\frac{1}{M} \sum_{s=1}^{M} \alpha_s$$

which is a measure of how close the stations are to the grid point.

The new method has some distinct advantages over the earlier method and is computationally simple and efficient. All the station data are used, but each record is used only at a single grid point. If new data become available or if a station is subsequently found to be incorrect, values can easily be reanalysed for the particular grid point affected.

We have used this method to calculate monthly grid-point anomalies, relative to 1951–70, back to 1851. A hemispheric average has been calculated using appropriate cosine weighting. The yearly values are plotted in Fig. 5 and the monthly values listed in the Appendix. The period of best coverage during the 1950s and 1960s allows interpolation to be made at points covering 58% of the surface of the Northern Hemisphere. This is

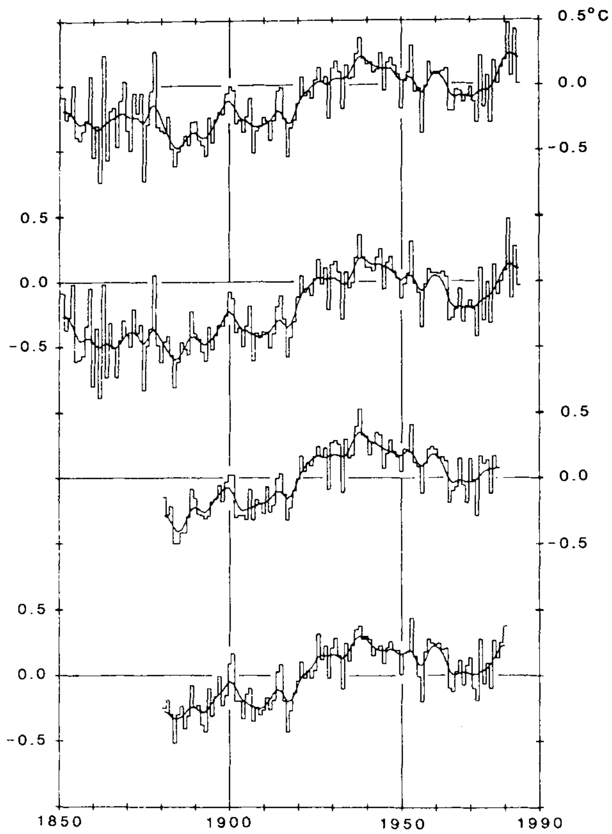


FIG. 5. Comparison of Northern Hemisphere land-based air temperature anomalies (from top to bottom): This paper, Kelley et al. (1985); Vinnikov et al. (1980); Hansen et al. (1981); and J. E. Hansen (personal communication). The filtered curve is a 13-term Gaussian filter designed to suppress variations on time scales less than 10 years. In order to estimate filtered values at the ends of each curve, six extra years are used at each end with values equal to the mean of the six years at the beginning/end of each curve.

slightly less than the 60% coverage achieved by Jones et al. (1982) because of a more stringent method of data interpolation. As station data can only be used at a single grid point, the number of grid points where interpolation can be made in high latitude regions is reduced. In the next section, we compare the results with other hemispheric analyses and assess the significance of the effects of changing spatial coverage, particularly for the nineteenth century.

## 6. Comparisons of Northern Hemisphere air temperature estimates

It would be most surprising if the new hemispheric temperature series differed markedly from other estimates, despite the more rigid station quality control techniques applied here. Of the 1584 stations used, over two thirds are in the World Weather Record station compilation used by others (Hansen et al., 1981; Jones et al., 1982), and most of these records contain only minor errors.

The degree of agreement can be judged from Table 4, where correlation coefficients between various published series are given, and from Figures 5 and 6. The series used in these comparisons are those of Vinnikov et al. (1980), Hansen et al. (1981) (Northern Hemisphere series, J. E. Hansen (personal communication, 1985); differs slightly from the published series, which covers 23.6°N–90°N), Jones et al. (1982) and Folland et al. (1984) (Northern Hemisphere averages, C. K. Folland and D. E. Parker, personal communication, 1985). In this last series, Northern Hemispheric mean surface temperature was estimated from marine rather than land-based data, either using sea surface (SST) or nighttime marine air temperature (NMAT). Although major data homogeneity problems arise using marine data, (see Barnett, 1984; Folland et al., 1984, for a thorough discussion), considerable effort has gone into the production of homogeneous records.

One further air temperature series has been included, referred to in Table 4 as JWK* (Kelly et al., 1985). This series is an extension of the Jones et al. (1982) series (JWK), incorporating additional data prior to 1921 (from Bradley et al., 1985, and regridded for the period 1851–1920 using the same interpolation scheme as in Jones et al., 1982). The reference period for this series is 1946–60. JWK* differs from JWK only over the period 1881–1920, but the differences are small (e.g., less than 0.02°C in the 1910s). Over the period 1881–1984, the JWK* versus JWK correlation is 0.995. The JWK* series can, therefore, be considered as an extension of the original Jones et al. (1982) series back to 1851.

For the period since 1881, all land-based Northern Hemisphere estimates are highly correlated. These high correlations result partly from the excellent agreement on time scales greater than 10 years. Correlations with the Folland et al. (1984) marine NH temperature estimates are smaller. This difference between land and marine data can be seen clearly in Fig. 6 where the present hemispheric estimate is compared with Folland et al. Although most of the longer term trends are in agreement after 1900, there is a marked divergence during the last century. The present work shows little overall trend in air temperatures over the period 1851–1900, but both marine temperature series show a cooling over the same period of about 0.5°C. Furthermore, both marine temperature series imply that conditions during the 1860s and 1870s were as warm as those in recent decades.

The similarity between the marine and land data after about 1900 can hardly be fortuitous, so we must assume that one or both datasets contain "errors" prior to 1900 or that a radical change in the climate system occurred around that time. The reason for the differences prior to 1900 obviously requires further work. It is, in fact, quite likely that both datasets contain errors (in the sense that they do not properly represent the large-scale area average): the land-based data because

TABLE 4. Correlation coefficients between various estimates of the Northern Hemisphere mean annual surface temperature. The various sources and periods of record are:

J et al. (this paper): 1851–1984
JWK (Jones et al., 1982): 1881–1982
JWK* (Kelly et al., 1985—i.e. JWK extended back to 1851, see text): 1851–1984.
VINN (Vinnikov et al., 1980): 1881–1978
HANS (Hansen et al., 1981: J. E. Hansen, personal communication): 1881–1980
SST (Folland et al., 1984, NH sea surface temperatures; C. K. Folland and D. E. Parker, personal communication): 1856–1983
NMAT (Folland et al., 1984, NH surface night-time marine air temperatures; C. K. Folland and D. E. Parker, personal communication): 1856–1981.

Period 1881–1984

| | J et al. | JWK | JWK* | VINN | HANS | NMAT |
|---|---|---|---|---|---|---|
| JWK | 0.973 | | | | | |
| JWK* | 0.975 | 0.995 | | | | |
| VINN | 0.933 | 0.955 | 0.953 | | | |
| HANS | 0.962 | 0.959 | 0.964 | 0.927 | | |
| NMAT | 0.524 | 0.514 | 0.540 | 0.510 | 0.566 | |
| SST | 0.508 | 0.483 | 0.505 | 0.480 | 0.570 | 0.898 |

Period 1851–1984

| | J et al. | JWK* | NMAT |
|---|---|---|---|
| JWK* | 0.957 | | |
| NMAT | 0.418 | 0.360 | |
| SST | 0.429 | 0.374 | 0.884 |

Period 1904–1984

| | J et al. | JWK | JWK* | VINN | HANS | NMAT |
|---|---|---|---|---|---|---|
| JWK | 0.971 | | | | | |
| JWK* | 0.969 | 0.997 | | | | |
| VINN | 0.925 | 0.950 | 0.952 | | | |
| HANS | 0.962 | 0.954 | 0.955 | 0.922 | | |
| NMAT | 0.728 | 0.720 | 0.737 | 0.711 | 0.765 | |
| SST | 0.623 | 0.600 | 0.615 | 0.587 | 0.695 | 0.904 |

of the limited coverage in early decades, and the marine data because of limitations in coverage and difficulties in homogenization. The potential error in the land-based data due to changing spatial coverage is discussed in a later section.

To illustrate the similarity between the land and marine data in the twentieth century, correlations using only data since 1904 are included in Table 4. The common variance between the present work and the Folland et al. NMAT curve doubles from 26% prior to 1904 to 52% thereafter. Although the land and marine series show vastly different long-term trends prior to 1904, they do, nevertheless, show many similarities on shorter time scales. This may help in unravelling the cause of the discrepancy.

To further illustrate both the similarities and differences between these different time series, Table 5 compares trends over selected periods. Over the longest interval for which we consider all data reasonably reliable (1904–78, the last year is controlled by being the last year for which data are available from the Vinnikov et al. series), all series show substantial warming with no significant trend differences. All land-based series show similar strong warming trends since 1965. However the SST series show a slight cooling reflecting a slightly later onset of the recent warming. If the SST trend is calculated to the end of the available record a slight warming trend is evident. The most interesting comparison is for the period 1938–65, for which all series except the SST average show a pronounced cooling. The strength of the cooling is, however, extremely dependent on the choice of starting and ending years. For this reason robust trend statistics have also been calculated for this period using methods outlined by Hoaglin et al. (1984) (see Table 5).

No satisfactory explanation of this cooling exists, and the cooling itself is perplexing because it is contrary to the trend expected from increasing atmospheric $CO_2$ concentration. Changing solar irradiance and/or changes in explosive volcanic activity have been suggested as causes (Hansen et al., 1981; Gilliland, 1982; Vinnikov and Groisman, 1981), but we suspect it may be an internal fluctuation possibly resulting from a change in North Atlantic deep water production rate

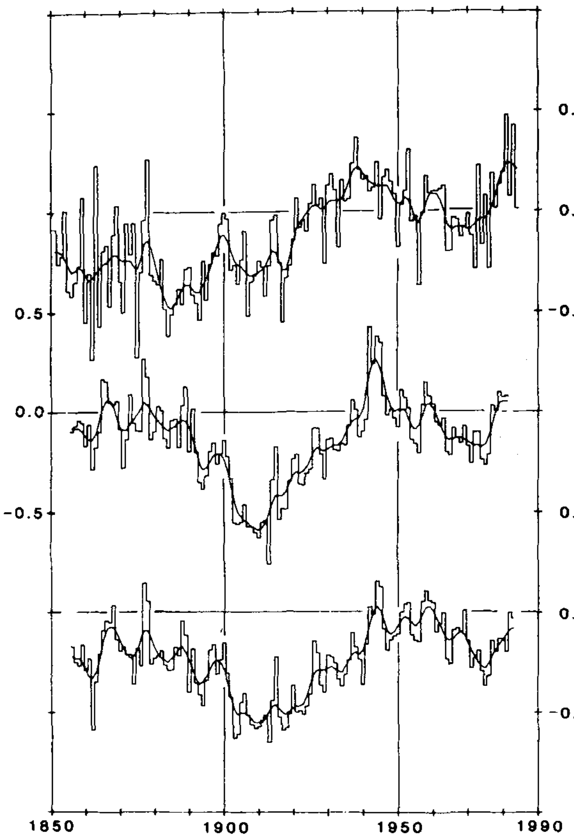


FIG. 6. Comparison of Northern Hemisphere land and marine air temperature anomalies (from top to bottom): This paper; Folland et al. (1984); nighttime marine air temperature, and Folland et al. (1984), sea surface temperature (C. K. Folland and D. E. Parker, personal communication). Filtered curve is as in Fig. 5.

(Wigley et al., 1985b). Southern Hemisphere marine data (Folland and Parker, personal communication, 1985) show a much smaller cooling, pointing to a hemispherically-specific cause. The data presented here, in fact, shows a somewhat smaller Northern Hemisphere cooling than in other Northern Hemisphere land records, partly due to the changed method of gridding and to the elimination or correction of station data which suffered from site moves to (cooler) airport locations in the 1950s. The present gridding method limited the amount of extrapolation into data-poor high latitude regions and so reduced the emphasis of these regions (which adjoin those that show the strongest 1938–65 cooling) in the overall average.

## 7. The effect of incomplete coverage during the early years

The relatively small and constantly changing number of stations used gives rise to some doubt concerning both the sign and magnitude of the area average temperatures prior to 1900, both for the Northern Hemisphere land area alone and for the hemisphere as a whole. Even today, the total coverage is only just over 50% of the area of the hemisphere.

The locations of the grid points used in the present analysis are shown in Fig. 7. Here, the figure at each grid point gives the decade when the grid point first has data for at least 80% of the monthly values. For example, 5 indicates 1851–1860, 6 indicates 1861–1870, and so on, up to 2 for the period 1921–30. Grid points entering the hemispheric average after the early 1920s are marked with an A. The time when each region of the Northern Hemisphere enters the analysis can be clearly seen.

In order to assess the effect of the incomplete data coverage during the earlier years, we compare results using the time varying grid (i.e., the data given in the Appendix) with results using a series of frozen grids. Frozen grids estimate the hemispheric average for all years using only those grid points that are operating 80% of the time during a particular decade. These estimates can then be compared with the estimate based on the more complete time-varying grid. Thus, the first frozen grid is based on the 1851–1860 period and a hemispheric average is computed using only those grid points coded 5 in Fig. 7. Similar frozen grid "hemispheric" temperature averages have been calculated for grids based on all decades up to and including 1921–30.

Figure 8 shows the differences between averages based on the time varying grid and on each of the frozen grids. As would be expected, the greatest differences occur for frozen grids based on coverage available in the earliest decades, particularly the 1851–1860, 1861–1870 and 1871–1880 periods. The pattern of these differences for some decades is similar because there is little effective change in coverage between some decades. The striking pattern evident in the early 1940s, which would indicate that estimates using the earliest three grids underestimate hemispheric mean temperature by up to 0.5°C, is simply due to the majority of grid points being in Europe. The early 1940s were well known in Europe as cold years, particularly the winters. Estimates of the hemispheric mean temperature in individual years using these first three frozen grids could be in error by as much as 0.5°C. Even so, taking time averages, none of the frozen grids seriously over- or under-estimates the hemispheric mean when results are compared over the period 1941–1980 (Table 6). The earliest frozen grids, however, explain less than 50% of the variance in the time-varying grid values (Table 7) because of the much larger interannual variability apparent for these grids. These results suggest that there is a marked increase in the reliability of hemispheric temperature estimates between the 1871–1880 and the 1881–1890 periods. The main reason for this can be seen in Figure 7, namely, the increasing

TABLE 5. Comparisons of the trends of surface air temperature estimates for the Northern Hemisphere from various sources for selected periods. (For sources and periods of record, see Table 4. TR = Trend coefficient × $10^3$ °C yr$^{-1}$; TOT = Total trend (°C) = TR × number of years; RTR = Robust trend coefficient × $10^3$ °C yr$^{-1}$).

| Period | J et al. | JWK | JWK* | VINN | HANS | NMAT | SST |
|---|---|---|---|---|---|---|---|
| 1904–end** | | | | | | | |
| TR | 3.95 | 3.40 | 3.59 | 2.80 | 4.03 | 6.56 | 6.02 |
| Tot | 0.32 | 0.27 | 0.29 | 0.21 | 0.31 | 0.51 | 0.48 |
| 1904–1938 | | | | | | | |
| TR | 16.39 | 17.72 | 18.92 | 18.20 | 17.30 | 17.34 | 10.83 |
| TOT | 0.57 | 0.62 | 0.66 | 0.64 | 0.61 | 0.61 | 0.38 |
| 1938–1965 | | | | | | | |
| TR | −9.64 | −11.27 | −11.27 | −11.67 | −7.11 | −8.30 | 1.94† |
| TOT | −0.27 | −0.32 | −0.32 | −0.33 | −0.20 | −0.23 | 0.05 |
| RTR | −4.05 | −4.86 | −4.86 | −9.73 | −1.35† | −6.49 | 2.70† |
| 1965–1978 | | | | | | | |
| TR | 9.82† | 12.75† | 12.75† | 11.34† | 10.37† | 4.42† | −11.91† |
| TOT | 0.14 | 0.18 | 0.18 | 0.16 | 0.15 | 0.06 | −0.17 |
| 1965–end** | | | | | | | |
| TR | 20.77 | 24.26 | 21.60 | 11.34† | 21.65 | 14.02 | 1.56† |
| TOT | 0.42 | 0.46 | 0.43 | 0.16 | 0.35 | 0.24 | 0.03 |
| 1881–end** | | | | | | | |
| TR | 5.09 | 5.57 | 5.31 | 4.70 | 4.97 | 2.90 | 3.12 |
| TOT | 0.52 | 0.55 | 0.55 | 0.46 | 0.50 | 0.29 | 0.32 |

** The number of years used for the various data sets differs (see Table 4 for the final year of each data set).
† These trends are not significant at the 5% significance level.

coverage over North America and Asia. The greatest increase in coverage occurs during the early 1870s.

In summary, therefore, it is clear that annual mean hemispheric temperature estimates after 1875 are more reliable than before 1875. Despite this, and despite the small area of coverage prior to 1875, the results of Table

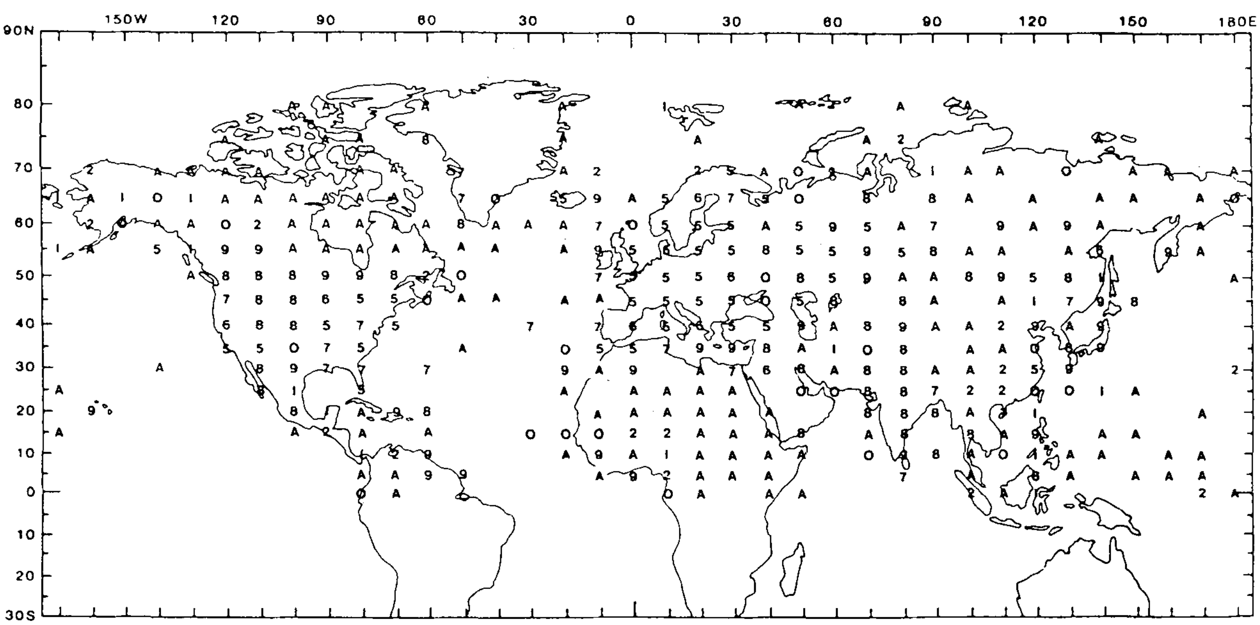


FIG. 7. Grid points where temperature estimates can be obtained. The number shown at each point indicates when that grid point entered the analysis. A 5 indicates that at least 80% of the monthly mean temperature anomalies were available during and subsequent to the 1850s: similarly, 6 (1860s), 7 (1870s), 8 (1880s), 9 (1890s), 0 (1900s), 1 (1910s), 2 (1920s). An A indicates that this grid point entered the analysis after the early 1920s.

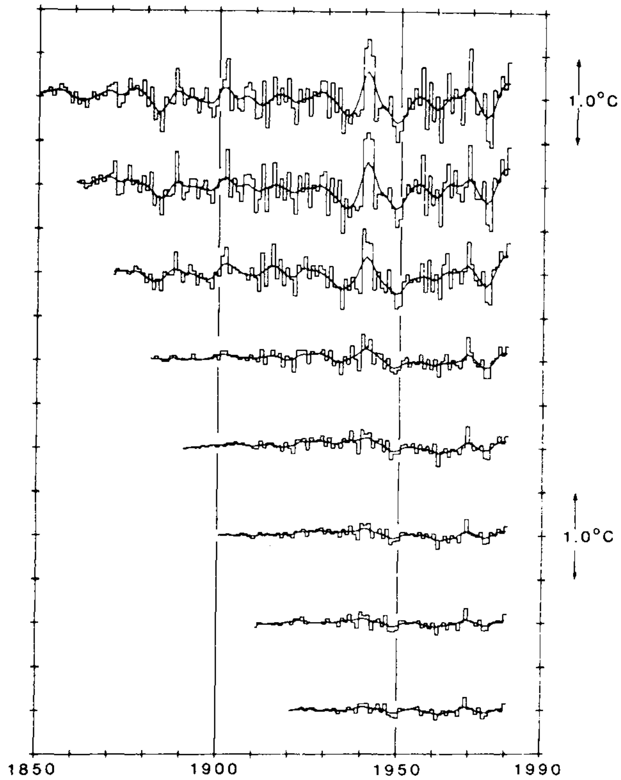


FIG. 8. Estimating the effect of incomplete coverage during the early years. Each curve depicts the difference between the result from the time-varying grid (the values plotted in Fig. 5a) and Northern Hemisphere averages based only on grid points with data during at least 80% of the decades (top to bottom): 1850s, 1860s, 1870s, 1880s, 1890s, 1900s, 1910s and 1920s. Filtered curves as in Fig. 5.

6 indicate that the estimated long-term mean temperature for the period 1851–1874 is reasonably reliable, and probably accurate to within 0.1°C. This suggests that there is either an error in the marine data of Folland et al. (1984) or that, during the late nineteenth century, the climate system was radically different from the present with the anomalies over the ocean areas in marked contrast to those over land areas. The former explanation seems more probable, although there are clearly residual uncertainties in the land-based data prior to about 1900.

## 8. Conclusions

The aim of this work has been to construct an objective and homogeneous series of monthly mean surface air temperatures which is representative of the land areas of the Northern Hemisphere. In order to ensure homogeneity of the final series, it has been necessary to assess, where possible, the homogeneity of all the potentially usable station records. This painstaking task resulted in some station records having to be corrected and some being flagged as unusable.

The correct and corrected stations were then interpolated onto a regular 5° latitude by 10° longitude grid by an objective, yet simple method for all months from 1851 to 1984. When the grid point values were areally weighted and averaged together, the resulting hemispheric series showed no major differences from previous analyses for the 1881–1980 period. Errors in the original station data (such as urban warming) cannot be held responsible for the trends in temperature seen in previous analyses. Some minor, but nevertheless, important, differences are noteworthy. In particular, the cooling between 1940 and 1965 evident in most earlier analyses appears reduced here (see Table 5).

The effects of the changing station network through time have been thoroughly examined and the magnitude of the possible bias during the nineteenth century due to stations being confined mostly to Europe and North America has been quantified. The hemispheric temperature series is probably reliable on a year-to-year basis after 1875. Prior to 1875, the year-to-year temperatures are subject to about twice the uncertainty present after 1875. However, the long-term mean for the period 1851–1874 appears to be a reliable estimate of the prevailing temperature of the land fraction of the Northern Hemisphere.

The nineteenth century data show a slight cooling between the late 1870s and the late 1880s. The mean temperature prevailing between 1851 and the late 1870s was similar to that of the 1900s and 1910s. The intervening decades of the 1880s and 1890s are the coldest of the entire record. The overall trend of hemispheric mean temperatures between 1851 and 1900 is in marked contrast to the marine data result given by Folland et al. (1984) and further analyses are required to either resolve or explain this difference. Around 1920, rapid warming took place culminating in the maximum warmth of the late 1930s. The land-based record shows more rapid warming than the marine record with some indication of a steplike change (Kelly

TABLE 6. Comparisons of means and standard deviations for the time-varying and frozen grids (°C).

| | Mean (1941–80) | Std dev (1941–80) |
|---|---|---|
| Time-varying grid | 0.03 | 0.16 |
| Frozen grid | | |
| 1851–60 | 0.04 | 0.33 |
| 1861–70 | 0.04 | 0.31 |
| 1871–80 | 0.04 | 0.25 |
| 1881–90 | 0.02 | 0.19 |
| 1891–1900 | 0.01 | 0.18 |
| 1901–10 | 0.02 | 0.17 |
| 1911–20 | 0.02 | 0.17 |
| 1921–30 | 0.02 | 0.17 |

TABLE 7. Estimating the effect of incomplete coverage. Correlation coefficients over the period 1941–80 are shown between annual means based on all available grid points (i.e., the series listed in the Appendix) and estimates based on the various frozen grids. Frozen grids use only those grid points that are operating 80% of the time during the specified initial decade.

| | Time-varying grid | 1850s | 1860s | 1870s | 1880s | 1890s | 1900s | 1910s |
|---|---|---|---|---|---|---|---|---|
| 1850s | 0.456 | | | | | | | |
| 1860s | 0.476 | 0.989 | | | | | | |
| 1870s | 0.534 | 0.961 | 0.966 | | | | | |
| 1880s | 0.795 | 0.848 | 0.859 | 0.891 | | | | |
| 1890s | 0.848 | 0.780 | 0.787 | 0.813 | 0.975 | | | |
| 1900s | 0.907 | 0.733 | 0.741 | 0.771 | 0.957 | 0.986 | | |
| 1910s | 0.920 | 0.716 | 0.724 | 0.767 | 0.948 | 0.969 | 0.992 | |
| 1920s | 0.936 | 0.684 | 0.691 | 0.724 | 0.928 | 0.957 | 0.989 | 0.993 |

et al., 1985). Over the period 1921–84, mean temperatures for the Northern Hemisphere were about 0.4°C warmer than those prevailing over the period 1851–1920.

Although this is the most comprehensive study of Northern Hemisphere surface air temperatures yet attempted, it must be recognized that uncertainties remain and these must eventually be resolved. There may be small residual data inhomogeneities in the individual station datasets, although the significance of these to the monthly hemispheric estimates will be minimized by the gridding method. The monthly estimates for the Northern Hemisphere presented in the Appendix are subject to spatial sampling uncertainty, particularly during the last century. The differences between this and other datasets (particularly the marine record) also indicate uncertainties. A detailed study of the land and marine surface temperature for both hemispheres should assist in determining the significance of these remaining problems.

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APPENDIX

Surface air temperature for the Northern Hemisphere: departures, in degrees Celsius, from the reference period (1951–70) mean. The figures in parentheses give the spatial coverage of the network as a percentage of the maximum possible area which includes ocean areas.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1851 | 0.58 | 0.44 | −0.62 | −0.55 | −0.30 | −0.14 | −0.11 | 0.04 | 0.10 | 0.28 | −0.36 | −0.36 | −0.08 |
| | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | |
| 1852 | −0.24 | −0.20 | −0.66 | −1.78 | 0.08 | −0.05 | 0.16 | −0.14 | −0.26 | −0.54 | −0.85 | 1.34 | −0.26 |
| | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (8) | (8) | (8) | (8) | |
| 1853 | 0.58 | −0.37 | −0.70 | −0.91 | −0.18 | 0.10 | 0.38 | 0.34 | −0.19 | −0.15 | −0.53 | −0.95 | −0.22 |
| | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (9) | |
| 1854 | −0.72 | −0.15 | 0.25 | −0.63 | 0.30 | −0.37 | 0.73 | 0.28 | −0.03 | 0.43 | −0.61 | 0.58 | 0.01 |
| | (9) | (8) | (8) | (9) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | |
| 1855 | −0.31 | −1.36 | −0.29 | 0.20 | 0.25 | 0.01 | 0.22 | −0.04 | −0.61 | −0.13 | −0.66 | −1.99 | −0.39 |
| | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | |
| 1856 | 0.27 | −0.55 | −1.26 | −0.40 | −0.40 | 0.47 | 0.04 | −0.32 | −0.54 | −0.83 | −1.61 | 0.05 | −0.42 |
| | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | |
| 1857 | −0.91 | −0.12 | 0.01 | −1.05 | −0.92 | −0.34 | −0.13 | 0.19 | −0.53 | −0.38 | −0.82 | 0.77 | −0.35 |
| | (7) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | |
| 1858 | −0.25 | −1.29 | −0.62 | 0.00 | −0.07 | 0.61 | 0.26 | −0.28 | −0.13 | 0.23 | −1.40 | −0.35 | −0.27 |
| | (8) | (9) | (9) | (9) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | |

APPENDIX (*Continued*)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1859 | 0.21 | 0.89 | 0.64 | 0.18 | 0.14 | 0.13 | 0.18 | 0.06 | −0.45 | −0.12 | −0.05 | −0.91 | 0.08 |
| | (8) | (8) | (8) | (8) | (9) | (9) | (9) | (8) | (9) | (9) | (8) | (9) | |
| 1860 | 0.09 | −0.83 | −1.39 | −0.30 | −0.02 | 0.04 | −0.32 | −0.04 | −0.10 | −0.33 | −1.30 | −2.11 | −0.55 |
| | (9) | (9) | (9) | (9) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | |
| 1861 | −2.50 | 0.45 | 0.66 | −0.93 | −0.83 | 0.09 | 0.38 | 0.44 | −0.19 | −0.33 | −0.30 | −0.48 | −0.30 |
| | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | |
| 1862 | −1.77 | −1.56 | −0.19 | −0.02 | −0.08 | −0.44 | −0.18 | −0.58 | −0.34 | −0.44 | −1.37 | −1.86 | −0.74 |
| | (8) | (8) | (8) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (8) | (8) | |
| 1863 | 1.91 | 0.88 | 0.62 | −0.05 | 0.35 | −0.30 | −0.14 | 0.09 | 0.15 | −0.29 | 0.02 | −0.31 | 0.24 |
| | (8) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | (7) | |
| 1864 | −1.62 | 0.11 | 0.50 | −0.59 | −0.54 | 0.51 | 0.00 | −0.28 | −0.52 | −1.32 | −1.37 | −1.70 | −0.57 |
| | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | (8) | |
| 1865 | 0.57 | −1.40 | −1.13 | −0.23 | 0.33 | −0.06 | 0.50 | −0.19 | 0.33 | −0.48 | 0.21 | −0.66 | −0.19 |
| | (9) | (9) | (9) | (9) | (9) | (8) | (8) | (8) | (8) | (8) | (9) | (9) | |
| 1866 | 0.78 | −0.15 | −0.43 | 0.05 | −0.74 | 0.14 | 0.23 | −0.33 | 0.21 | −1.09 | −0.59 | −0.01 | −0.16 |
| | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | |
| 1867 | −0.66 | 0.73 | −1.15 | −0.08 | −1.24 | −0.31 | −0.46 | −0.35 | −0.23 | −0.23 | −0.58 | −1.13 | −0.47 |
| | (9) | (9) | (9) | (9) | (9) | (9) | (8) | (9) | (9) | (9) | (9) | (9) | |
| 1868 | −1.15 | −0.83 | 0.10 | −0.28 | 0.52 | 0.32 | 0.72 | 0.41 | −0.20 | −0.10 | −1.13 | 0.29 | −0.11 |
| | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | |
| 1869 | −0.21 | 1.71 | −0.56 | −0.12 | 0.06 | 0.11 | 0.44 | 0.37 | 0.36 | −0.70 | −0.49 | −0.47 | 0.04 |
| | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (9) | (8) | |
| 1870 | 0.09 | −1.44 | −0.56 | −0.28 | 0.62 | 0.48 | 0.64 | −0.22 | −0.37 | −0.83 | −0.06 | −2.18 | −0.34 |
| | (9) | (9) | (9) | (9) | (9) | (9) | (10) | (9) | (10) | (10) | (10) | (10) | |
| 1871 | −1.20 | −1.39 | 0.66 | 0.06 | −0.63 | −0.35 | 0.27 | 0.31 | −0.71 | −0.53 | −1.10 | −1.34 | −0.50 |
| | (10) | (10) | (10) | (10) | (10) | (10) | (10) | (10) | (10) | (10) | (10) | (10) | |
| 1872 | −0.33 | −0.51 | −0.08 | 0.36 | 0.48 | 0.08 | 0.33 | 0.30 | 0.01 | −0.20 | −0.45 | −0.65 | −0.05 |
| | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | |
| 1873 | 0.20 | −0.20 | −0.04 | −0.94 | −0.62 | 0.13 | 0.28 | 0.17 | −0.53 | −0.50 | −0.58 | 0.17 | −0.21 |
| | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | |
| 1874 | 0.66 | 0.06 | −0.49 | −0.20 | −0.29 | 0.18 | 0.25 | −0.10 | 0.21 | −0.17 | −0.58 | −0.15 | −0.05 |
| | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (11) | (12) | (12) | |
| 1875 | −1.23 | −1.66 | −1.30 | −1.00 | 0.06 | 0.40 | −0.09 | −0.09 | −0.68 | −0.88 | −1.25 | −1.08 | −0.73 |
| | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | |
| 1876 | −0.16 | 0.21 | −0.10 | −0.12 | −0.76 | 0.38 | 0.36 | 0.17 | −0.13 | −0.50 | −1.18 | −1.70 | −0.30 |
| | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | |
| 1877 | 0.10 | 0.06 | −0.30 | −0.66 | −0.64 | 0.21 | 0.35 | 0.36 | −0.12 | −0.62 | 0.41 | 0.38 | −0.04 |
| | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | (13) | |
| 1878 | −0.33 | 0.84 | 1.22 | 0.69 | −0.20 | 0.33 | 0.27 | 0.29 | 0.33 | 0.21 | 0.21 | −0.63 | 0.27 |
| | (14) | (14) | (14) | (14) | (14) | (14) | (14) | (14) | (14) | (14) | (14) | (14) | |
| 1879 | −0.23 | 0.10 | 0.09 | −0.26 | −0.28 | −0.27 | −0.06 | −0.07 | −0.31 | 0.00 | −1.00 | −1.41 | −0.31 |
| | (15) | (14) | (14) | (15) | (15) | (14) | (15) | (15) | (15) | (15) | (15) | (15) | |
| 1880 | 0.00 | −0.35 | −0.07 | −0.19 | −0.05 | −0.21 | −0.07 | −0.03 | −0.18 | −0.83 | −1.14 | −0.91 | −0.34 |
| | (15) | (15) | (15) | (15) | (15) | (15) | (15) | (15) | (15) | (15) | (15) | (15) | |
| 1881 | −0.98 | −0.42 | −0.38 | −0.21 | 0.10 | −0.46 | −0.07 | 0.00 | −0.34 | −0.79 | −0.63 | −0.14 | −0.36 |
| | (17) | (17) | (17) | (17) | (17) | (17) | (17) | (17) | (17) | (17) | (17) | (16) | |
| 1882 | 0.85 | 0.41 | 0.71 | −0.49 | −0.62 | −0.51 | −0.39 | −0.02 | −0.18 | −0.79 | −0.79 | −0.97 | −0.23 |
| | (18) | (18) | (18) | (18) | (18) | (17) | (18) | (18) | (18) | (18) | (18) | (18) | |
| 1883 | −1.20 | −1.07 | −0.62 | −0.52 | −0.45 | −0.06 | −0.14 | −0.23 | −0.40 | −0.45 | −0.46 | −0.21 | −0.48 |
| | (18) | (18) | (18) | (18) | (18) | (18) | (18) | (18) | (18) | (18) | (18) | (18) | |
| 1884 | −0.31 | −0.23 | −0.67 | −1.08 | −0.63 | −0.64 | −0.51 | −0.75 | −0.66 | −0.46 | −1.02 | −0.46 | −0.62 |
| | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (18) | (18) | |
| 1885 | −1.36 | −0.50 | −0.09 | −0.59 | −0.79 | −0.47 | −0.15 | −0.66 | −0.48 | −0.74 | −0.44 | 0.21 | −0.51 |
| | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (19) | (19) | |
| 1886 | −0.96 | −0.18 | −0.76 | −0.30 | −0.28 | −0.54 | −0.14 | −0.21 | −0.12 | −0.47 | −0.61 | 0.01 | −0.46 |
| | (20) | (20) | (20) | (20) | (21) | (20) | (20) | (20) | (20) | (21) | (21) | (20) | |
| 1887 | −1.09 | −0.59 | −0.11 | −0.43 | −0.10 | −0.26 | −0.06 | −0.56 | −0.17 | −0.71 | −0.11 | −0.40 | −0.38 |
| | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | |

APPENDIX (*Continued*)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1888 | −1.01 | −1.04 | −0.76 | −0.04 | −0.34 | −0.32 | −0.23 | −0.37 | −0.31 | −0.33 | −0.35 | −0.43 | −0.46 |
| | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | (21) | |
| 1889 | −0.86 | −0.25 | 0.03 | 0.25 | 0.05 | −0.07 | −0.11 | −0.23 | −0.51 | −0.59 | −0.91 | −0.18 | −0.28 |
| | (21) | (21) | (21) | (21) | (21) | (22) | (22) | (22) | (21) | (22) | (22) | (22) | |
| 1890 | −0.05 | −0.16 | −0.16 | 0.05 | −0.50 | −0.19 | −0.21 | −0.30 | −0.16 | −0.32 | −0.65 | −0.56 | −0.27 |
| | (22) | (22) | (22) | (22) | (22) | (22) | (22) | (22) | (22) | (22) | (22) | (22) | |
| 1891 | −0.94 | −0.98 | −0.31 | −0.60 | −0.40 | −0.30 | −0.25 | −0.34 | 0.04 | −0.49 | −0.87 | 0.50 | −0.41 |
| | (23) | (24) | (24) | (24) | (24) | (24) | (24) | (24) | (24) | (24) | (24) | (24) | |
| 1892 | −0.74 | 0.00 | −0.73 | −0.57 | −0.44 | 0.01 | −0.25 | −0.31 | 0.02 | −0.24 | −0.85 | −1.29 | −0.45 |
| | (24) | (24) | (24) | (25) | (24) | (24) | (25) | (25) | (25) | (25) | (25) | (25) | |
| 1893 | −2.53 | −1.64 | −0.12 | −0.23 | −0.72 | −0.10 | −0.03 | −0.22 | −0.21 | −0.14 | −0.26 | −0.28 | −0.54 |
| | (25) | (25) | (25) | (25) | (25) | (25) | (25) | (26) | (25) | (25) | (25) | (25) | |
| 1894 | −0.74 | −0.12 | 0.32 | −0.23 | −0.22 | −0.30 | −0.07 | −0.15 | −0.32 | −0.22 | −0.39 | −0.41 | −0.24 |
| | (25) | (25) | (25) | (25) | (25) | (25) | (25) | (26) | (26) | (25) | (25) | (25) | |
| 1895 | −1.34 | −1.61 | −0.41 | −0.08 | −0.19 | −0.28 | −0.35 | −0.30 | 0.09 | −0.39 | −0.13 | −0.32 | −0.44 |
| | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | |
| 1896 | −0.29 | −0.24 | −0.57 | −0.63 | 0.03 | 0.14 | −0.06 | −0.22 | −0.21 | −0.13 | −0.74 | −0.26 | −0.26 |
| | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | (26) | |
| 1897 | −0.61 | −0.33 | −0.39 | −0.07 | 0.11 | −0.10 | 0.14 | −0.02 | 0.18 | −0.11 | −0.42 | −0.73 | −0.20 |
| | (27) | (27) | (26) | (27) | (26) | (26) | (26) | (26) | (26) | (26) | (27) | (26) | |
| 1898 | 0.56 | −0.46 | −1.25 | −0.47 | −0.35 | −0.11 | −0.15 | −0.01 | −0.02 | −0.38 | −0.08 | 0.06 | −0.22 |
| | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | |
| 1899 | 0.24 | −0.57 | −0.37 | −0.04 | −0.10 | −0.27 | −0.03 | 0.02 | 0.08 | 0.14 | 0.82 | −0.65 | −0.06 |
| | (27) | (27) | (27) | (27) | (27) | (26) | (27) | (27) | (27) | (27) | (27) | (27) | |
| 1900 | −0.51 | −0.42 | 0.06 | −0.19 | 0.00 | 0.05 | −0.12 | 0.08 | 0.04 | 0.50 | −0.01 | 0.49 | 0.00 |
| | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | (27) | |
| 1901 | −0.13 | −0.34 | 0.55 | 0.33 | −0.02 | 0.08 | 0.23 | 0.14 | −0.21 | −0.19 | −0.21 | −0.58 | −0.03 |
| | (29) | (29) | (29) | (29) | (29) | (28) | (29) | (29) | (28) | (29) | (28) | (29) | |
| 1902 | 0.33 | 0.18 | 0.19 | −0.44 | −0.53 | −0.44 | −0.45 | −0.21 | −0.28 | −0.52 | −0.56 | −0.79 | −0.29 |
| | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | |
| 1903 | 0.24 | 0.58 | 0.19 | −0.34 | −0.46 | −0.60 | −0.49 | −0.39 | −0.33 | −0.42 | −0.40 | −0.71 | −0.26 |
| | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | |
| 1904 | −0.62 | −0.39 | −0.39 | −0.53 | −0.34 | −0.40 | −0.48 | −0.31 | −0.54 | −0.30 | 0.05 | −0.13 | −0.36 |
| | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | (29) | |
| 1905 | −0.37 | −1.25 | −0.16 | −0.73 | −0.18 | −0.22 | −0.09 | −0.16 | −0.02 | −0.34 | 0.38 | 0.19 | −0.24 |
| | (30) | (30) | (30) | (30) | (30) | (30) | (30) | (29) | (30) | (30) | (30) | (30) | |
| 1906 | −0.04 | −0.67 | −0.16 | 0.21 | 0.04 | −0.04 | −0.09 | −0.03 | −0.09 | −0.10 | −0.33 | 0.27 | −0.09 |
| | (30) | (31) | (30) | (30) | (30) | (30) | (30) | (31) | (30) | (31) | (31) | (31) | |
| 1907 | −0.51 | −0.87 | −0.14 | −0.79 | −0.92 | −0.75 | −0.41 | −0.44 | −0.24 | −0.01 | −0.71 | −0.41 | −0.52 |
| | (31) | (31) | (31) | (31) | (31) | (31) | (31) | (31) | (31) | (31) | (31) | (31) | |
| 1908 | −0.18 | −0.17 | −0.62 | −0.37 | −0.30 | −0.21 | −0.34 | −0.41 | −0.12 | −0.45 | −0.66 | −0.32 | −0.35 |
| | (31) | (31) | (31) | (31) | (31) | (31) | (32) | (32) | (31) | (31) | (31) | (31) | |
| 1909 | −0.73 | −0.41 | −0.49 | −0.61 | −0.50 | −0.41 | −0.34 | −0.08 | −0.05 | −0.08 | 0.40 | −0.41 | −0.31 |
| | (31) | (31) | (32) | (32) | (32) | (32) | (32) | (32) | (32) | (31) | (32) | (32) | |
| 1910 | 0.14 | −0.15 | 0.21 | −0.16 | −0.29 | −0.36 | −0.17 | −0.30 | −0.34 | −0.25 | −0.64 | −0.58 | −0.24 |
| | (32) | (32) | (32) | (32) | (32) | (32) | (32) | (31) | (32) | (32) | (31) | (31) | |
| 1911 | −0.57 | −0.73 | −0.44 | −0.46 | −0.26 | −0.16 | −0.16 | −0.10 | −0.08 | −0.28 | −0.10 | 0.06 | −0.27 |
| | (32) | (33) | (33) | (32) | (32) | (32) | (32) | (33) | (33) | (33) | (33) | (33) | |
| 1912 | −0.42 | 0.10 | −0.24 | −0.22 | −0.11 | −0.03 | −0.61 | −0.83 | −0.83 | −1.04 | −0.55 | −0.31 | −0.42 |
| | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | |
| 1913 | −0.13 | −0.69 | −0.18 | −0.23 | −0.63 | −0.54 | −0.55 | −0.25 | −0.33 | −0.48 | 0.34 | 0.42 | −0.27 |
| | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | |
| 1914 | 0.69 | 0.28 | 0.22 | −0.30 | −0.02 | −0.19 | −0.20 | −0.21 | −0.24 | −0.09 | −0.27 | −0.19 | −0.04 |
| | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | |
| 1915 | 0.04 | 0.30 | −0.35 | 0.16 | −0.06 | −0.05 | −0.05 | −0.09 | −0.11 | −0.24 | 0.23 | 0.13 | −0.01 |
| | (32) | (32) | (32) | (32) | (33) | (32) | (32) | (32) | (32) | (32) | (32) | (32) | |
| 1916 | 0.32 | −0.06 | −0.37 | −0.18 | −0.30 | −0.33 | −0.07 | −0.22 | −0.44 | −0.25 | −0.16 | −0.88 | −0.25 |
| | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (32) | |

APPENDIX (*Continued*)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1917 | −0.46 | −1.15 | −0.89 | −0.57 | −0.99 | −0.28 | 0.00 | −0.10 | −0.06 | −0.61 | −0.06 | −1.46 | −0.55 |
| | (32) | (32) | (32) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | (33) | |
| 1918 | −0.61 | −0.33 | −0.09 | −0.66 | −0.70 | −0.45 | −0.25 | −0.29 | −0.15 | 0.25 | −0.23 | −0.51 | −0.33 |
| | (33) | (33) | (33) | (33) | (33) | (33) | (32) | (33) | (33) | (32) | (32) | (32) | |
| 1919 | −0.13 | −0.15 | −0.31 | −0.07 | −0.51 | −0.23 | −0.22 | −0.02 | 0.06 | −0.18 | −0.85 | −0.66 | −0.27 |
| | (31) | (32) | (31) | (32) | (31) | (31) | (32) | (32) | (32) | (32) | (32) | (31) | |
| 1920 | 0.11 | −0.30 | 0.50 | −0.15 | −0.05 | −0.20 | 0.02 | −0.05 | −0.06 | −0.40 | −0.52 | −0.58 | −0.14 |
| | (31) | (31) | (31) | (31) | (32) | (31) | (31) | (31) | (31) | (31) | (31) | (31) | |
| 1921 | 0.71 | −0.01 | 0.53 | 0.23 | 0.05 | 0.09 | 0.19 | −0.19 | −0.20 | −0.08 | −0.50 | 0.06 | 0.07 |
| | (33) | (33) | (33) | (34) | (34) | (34) | (34) | (34) | (34) | (34) | (34) | (34) | |
| 1922 | −0.51 | −0.39 | 0.18 | −0.04 | 0.18 | 0.12 | −0.07 | −0.06 | −0.18 | −0.16 | −0.04 | 0.00 | −0.08 |
| | (34) | (34) | (34) | (34) | (34) | (35) | (34) | (35) | (35) | (35) | (35) | (35) | |
| 1923 | 0.27 | −0.72 | −0.08 | −0.67 | −0.17 | −0.17 | −0.10 | −0.14 | 0.08 | 0.28 | 0.53 | 0.44 | −0.04 |
| | (35) | (35) | (35) | (35) | (36) | (36) | (36) | (36) | (36) | (36) | (36) | (35) | |
| 1924 | −0.34 | −0.22 | −0.07 | −0.20 | 0.03 | 0.03 | −0.03 | −0.01 | 0.00 | −0.06 | 0.09 | −0.44 | −0.10 |
| | (36) | (36) | (36) | (36) | (37) | (36) | (36) | (36) | (36) | (36) | (36) | (36) | |
| 1925 | −0.05 | 0.12 | 0.14 | 0.03 | −0.12 | −0.13 | −0.07 | 0.13 | 0.19 | −0.27 | 0.16 | 0.39 | 0.04 |
| | (37) | (37) | (36) | (36) | (36) | (36) | (36) | (36) | (36) | (37) | (37) | (36) | |
| 1926 | 0.78 | 0.66 | 0.53 | −0.23 | −0.19 | −0.08 | −0.09 | 0.02 | 0.16 | 0.08 | 0.28 | −0.23 | 0.14 |
| | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | |
| 1927 | −0.10 | 0.08 | −0.01 | −0.18 | −0.12 | 0.05 | 0.28 | 0.13 | 0.23 | 0.45 | 0.19 | −0.66 | 0.03 |
| | (37) | (37) | (37) | (36) | (37) | (37) | (37) | (37) | (36) | (36) | (37) | (37) | |
| 1928 | 0.55 | 0.23 | −0.19 | −0.29 | 0.02 | −0.28 | 0.24 | −0.05 | 0.02 | 0.10 | 0.30 | 0.22 | 0.07 |
| | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (37) | |
| 1929 | −0.62 | −1.54 | 0.02 | −0.37 | −0.08 | −0.20 | −0.10 | 0.02 | −0.08 | 0.14 | 0.22 | −0.51 | −0.26 |
| | (37) | (37) | (37) | (37) | (37) | (37) | (37) | (38) | (37) | (37) | (37) | (36) | |
| 1930 | −0.16 | 0.04 | 0.48 | 0.12 | −0.09 | −0.05 | 0.21 | 0.39 | 0.03 | −0.03 | 0.40 | 0.20 | 0.13 |
| | (37) | (37) | (37) | (37) | (37) | (38) | (37) | (38) | (38) | (38) | (37) | (37) | |
| 1931 | 0.27 | −0.39 | 0.10 | −0.07 | −0.05 | 0.25 | 0.31 | 0.30 | 0.28 | 0.46 | 0.40 | 0.42 | 0.19 |
| | (38) | (38) | (38) | (38) | (39) | (38) | (39) | (39) | (39) | (39) | (39) | (39) | |
| 1932 | 1.07 | −0.40 | −0.30 | 0.20 | 0.07 | 0.07 | 0.06 | 0.24 | 0.29 | 0.23 | −0.19 | 0.03 | 0.11 |
| | (39) | (39) | (39) | (39) | (39) | (39) | (39) | (39) | (39) | (39) | (39) | (39) | |
| 1933 | −0.39 | −0.52 | −0.26 | −0.11 | −0.16 | −0.18 | 0.24 | 0.09 | 0.09 | −0.01 | −0.20 | −0.80 | −0.18 |
| | (40) | (39) | (40) | (40) | (40) | (40) | (39) | (40) | (39) | (39) | (39) | (39) | |
| 1934 | −0.03 | 0.43 | −0.24 | −0.10 | 0.29 | 0.07 | 0.13 | −0.05 | −0.01 | 0.31 | 0.60 | 0.48 | 0.16 |
| | (39) | (39) | (40) | (40) | (40) | (39) | (40) | (40) | (40) | (40) | (40) | (40) | |
| 1935 | −0.37 | 1.14 | 0.43 | −0.22 | −0.34 | −0.02 | 0.10 | 0.05 | 0.12 | 0.35 | −0.49 | −0.19 | 0.05 |
| | (40) | (40) | (40) | (40) | (41) | (41) | (40) | (41) | (41) | (40) | (40) | (40) | |
| 1936 | −0.07 | −0.80 | 0.08 | −0.14 | −0.04 | 0.20 | 0.36 | 0.18 | 0.14 | −0.03 | 0.24 | 0.52 | 0.06 |
| | (41) | (41) | (41) | (40) | (40) | (41) | (41) | (41) | (41) | (41) | (41) | (40) | |
| 1937 | 0.02 | 0.42 | −0.09 | 0.11 | 0.23 | 0.29 | 0.30 | 0.42 | 0.50 | 0.52 | 0.34 | −0.17 | 0.24 |
| | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (39) | (40) | |
| 1938 | 0.44 | 0.35 | 0.83 | 0.44 | 0.18 | 0.10 | 0.25 | 0.43 | 0.48 | 0.63 | 0.45 | −0.14 | 0.37 |
| | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | |
| 1939 | 0.50 | 0.03 | −0.22 | 0.06 | 0.12 | 0.06 | 0.27 | 0.24 | 0.11 | −0.19 | 0.39 | 1.16 | 0.21 |
| | (41) | (41) | (40) | (40) | (41) | (41) | (40) | (41) | (41) | (41) | (41) | (40) | |
| 1940 | −0.56 | 0.18 | 0.22 | 0.31 | 0.06 | 0.08 | 0.21 | 0.14 | 0.36 | 0.18 | 0.24 | 0.51 | 0.16 |
| | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | (40) | |
| 1941 | 0.20 | 0.63 | 0.27 | 0.25 | 0.14 | 0.18 | 0.27 | 0.10 | −0.08 | 0.23 | −0.07 | 0.07 | 0.18 |
| | (42) | (43) | (42) | (43) | (43) | (43) | (43) | (43) | (43) | (43) | (43) | (42) | |
| 1942 | −0.13 | −0.35 | 0.38 | 0.22 | 0.06 | 0.23 | 0.06 | −0.08 | 0.12 | 0.41 | 0.19 | 0.08 | 0.10 |
| | (42) | (43) | (42) | (42) | (42) | (42) | (42) | (42) | (42) | (42) | (42) | (42) | |
| 1943 | −0.41 | 0.32 | −0.25 | 0.11 | 0.08 | −0.18 | 0.13 | 0.14 | 0.15 | 0.46 | 0.30 | 0.59 | 0.12 |
| | (43) | (42) | (42) | (42) | (42) | (43) | (42) | (42) | (42) | (42) | (42) | (42) | |
| 1944 | 1.06 | 0.46 | 0.28 | 0.10 | 0.23 | 0.07 | 0.12 | 0.15 | 0.41 | 0.37 | 0.06 | −0.30 | 0.25 |
| | (42) | (42) | (42) | (41) | (42) | (42) | (41) | (41) | (42) | (42) | (42) | (42) | |
| 1945 | −0.17 | −0.33 | 0.37 | 0.13 | −0.20 | −0.09 | −0.04 | 0.29 | 0.15 | 0.11 | −0.05 | −0.64 | −0.04 |
| | (41) | (41) | (41) | (41) | (41) | (41) | (41) | (41) | (41) | (41) | (41) | (41) | |

APPENDIX (*Continued*)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1946 | 0.52 | 0.32 | 0.44 | 0.53 | −0.05 | −0.02 | 0.06 | 0.09 | 0.27 | −0.07 | 0.27 | −0.31 | 0.17 |
| | (43) | (43) | (43) | (43) | (43) | (42) | (43) | (43) | (43) | (43) | (43) | (43) | |
| 1947 | −0.11 | −0.20 | 0.57 | 0.28 | 0.02 | 0.03 | 0.21 | 0.19 | 0.26 | 0.60 | 0.43 | 0.28 | 0.21 |
| | (44) | (44) | (44) | (44) | (45) | (45) | (45) | (44) | (44) | (45) | (45) | (45) | |
| 1948 | 0.74 | −0.09 | −0.26 | 0.06 | 0.36 | 0.18 | 0.04 | 0.13 | 0.24 | 0.21 | 0.25 | −0.07 | 0.15 |
| | (46) | (46) | (46) | (46) | (46) | (46) | (46) | (46) | (46) | (47) | (47) | (47) | |
| 1949 | 0.53 | −0.36 | 0.11 | 0.10 | 0.19 | −0.06 | −0.06 | 0.10 | 0.06 | 0.19 | 0.37 | −0.13 | 0.09 |
| | (47) | (47) | (47) | (46) | (47) | (47) | (47) | (47) | (48) | (48) | (48) | (47) | |
| 1950 | −0.77 | −0.49 | −0.17 | −0.05 | 0.11 | −0.06 | −0.22 | −0.22 | 0.01 | −0.08 | −0.46 | −0.06 | −0.18 |
| | (48) | (48) | (48) | (49) | (48) | (49) | (48) | (49) | (49) | (49) | (49) | (49) | |
| 1951 | −0.41 | −0.69 | −0.18 | 0.21 | 0.14 | −0.07 | 0.08 | 0.29 | 0.34 | 0.16 | 0.06 | 0.41 | 0.03 |
| | (54) | (55) | (55) | (55) | (54) | (54) | (55) | (55) | (55) | (55) | (55) | (55) | |
| 1952 | 0.23 | 0.16 | −0.17 | 0.30 | 0.21 | 0.22 | 0.24 | 0.09 | 0.15 | −0.08 | −0.25 | 0.09 | 0.10 |
| | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (57) | (56) | (57) | (57) | (56) | |
| 1953 | 0.29 | 0.52 | 0.51 | 0.51 | 0.28 | 0.29 | 0.27 | 0.24 | 0.18 | 0.30 | 0.08 | 0.29 | 0.31 |
| | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | |
| 1954 | −0.57 | −0.09 | −0.08 | −0.21 | −0.10 | 0.05 | −0.12 | −0.01 | 0.08 | 0.07 | 0.44 | −0.13 | −0.05 |
| | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | |
| 1955 | 0.65 | 0.01 | −0.54 | −0.13 | 0.00 | 0.04 | 0.01 | 0.13 | 0.04 | 0.14 | −0.27 | −0.28 | −0.02 |
| | (57) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (57) | (57) | (57) | (58) | |
| 1956 | −0.16 | −0.68 | −0.42 | −0.30 | −0.33 | −0.22 | −0.27 | −0.36 | −0.39 | −0.35 | −0.46 | −0.44 | −0.37 |
| | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (57) | (57) | (58) | (57) | (57) | |
| 1957 | −0.35 | −0.16 | −0.11 | −0.15 | −0.18 | 0.02 | 0.04 | 0.10 | 0.13 | −0.07 | 0.21 | 0.43 | −0.01 |
| | (58) | (58) | (57) | (58) | (58) | (58) | (58) | (58) | (57) | (57) | (58) | (58) | |
| 1958 | 0.79 | 0.35 | 0.32 | 0.14 | 0.19 | −0.08 | −0.04 | 0.04 | 0.03 | 0.00 | 0.14 | 0.25 | 0.18 |
| | (58) | (58) | (57) | (58) | (58) | (58) | (58) | (58) | (58) | (57) | (58) | (58) | |
| 1959 | 0.30 | 0.10 | 0.46 | 0.25 | 0.00 | 0.12 | 0.03 | 0.04 | 0.10 | −0.18 | −0.29 | 0.13 | 0.09 |
| | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | |
| 1960 | 0.19 | 0.79 | −0.52 | −0.18 | 0.02 | 0.25 | 0.05 | 0.10 | 0.10 | 0.01 | −0.06 | 0.47 | 0.10 |
| | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | (58) | |
| 1961 | 0.20 | 0.38 | 0.42 | 0.23 | 0.11 | 0.28 | 0.00 | 0.03 | −0.11 | −0.20 | 0.07 | −0.16 | 0.10 |
| | (56) | (56) | (57) | (56) | (56) | (56) | (56) | (55) | (56) | (56) | (56) | (56) | |
| 1962 | 0.23 | 0.39 | 0.19 | 0.17 | 0.10 | −0.19 | 0.03 | −0.01 | −0.08 | 0.24 | 0.12 | 0.13 | 0.13 |
| | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (57) | (56) | (56) | |
| 1963 | −0.04 | 0.55 | −0.15 | −0.04 | −0.06 | −0.10 | 0.11 | 0.08 | 0.20 | 0.56 | 0.52 | −0.05 | 0.13 |
| | (56) | (57) | (57) | (57) | (56) | (57) | (57) | (56) | (57) | (56) | (57) | (56) | |
| 1964 | 0.13 | −0.26 | −0.33 | −0.25 | −0.03 | −0.13 | −0.13 | −0.28 | −0.31 | −0.31 | −0.10 | −0.42 | −0.20 |
| | (57) | (57) | (56) | (57) | (57) | (57) | (57) | (56) | (56) | (56) | (56) | (56) | |
| 1965 | 0.05 | −0.56 | −0.04 | −0.37 | −0.13 | −0.19 | −0.22 | −0.38 | −0.29 | −0.12 | −0.17 | −0.01 | −0.20 |
| | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | |
| 1966 | −0.20 | 0.21 | 0.13 | −0.20 | −0.12 | 0.08 | 0.16 | 0.15 | 0.12 | −0.05 | −0.19 | −0.41 | −0.03 |
| | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (57) | (56) | (57) | |
| 1967 | −0.23 | −0.43 | 0.15 | −0.03 | 0.13 | −0.16 | −0.03 | −0.01 | −0.11 | 0.29 | 0.01 | −0.04 | −0.04 |
| | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (57) | (56) | (56) | |
| 1968 | −0.54 | −0.28 | 0.57 | −0.04 | −0.11 | −0.20 | −0.24 | −0.22 | −0.07 | −0.06 | −0.12 | −0.30 | −0.13 |
| | (54) | (57) | (55) | (55) | (56) | (56) | (56) | (56) | (56) | (55) | (56) | (56) | |
| 1969 | −0.66 | −0.74 | −0.11 | 0.10 | 0.01 | −0.11 | 0.00 | 0.00 | −0.05 | −0.02 | 0.21 | 0.46 | −0.08 |
| | (56) | (56) | (57) | (55) | (56) | (57) | (56) | (56) | (56) | (56) | (56) | (55) | |
| 1970 | −0.02 | 0.42 | −0.06 | 0.12 | 0.05 | 0.05 | −0.01 | −0.06 | −0.08 | −0.23 | 0.06 | −0.38 | −0.01 |
| | (56) | (56) | (56) | (56) | (56) | (56) | (56) | (55) | (55) | (56) | (56) | (56) | |
| 1971 | 0.02 | −0.25 | −0.33 | −0.20 | −0.13 | −0.22 | −0.17 | −0.20 | −0.07 | −0.02 | 0.18 | −0.04 | −0.12 |
| | (55) | (54) | (55) | (54) | (54) | (54) | (54) | (53) | (54) | (55) | (54) | (53) | |
| 1972 | −0.82 | −0.80 | −0.04 | −0.08 | −0.25 | −0.16 | −0.11 | −0.07 | −0.45 | −0.19 | −0.27 | −0.25 | −0.29 |
| | (54) | (53) | (53) | (53) | (53) | (53) | (54) | (53) | (53) | (53) | (52) | (52) | |
| 1973 | 0.25 | 0.65 | 0.59 | 0.36 | 0.33 | 0.26 | 0.12 | 0.08 | −0.02 | 0.05 | −0.09 | 0.19 | 0.23 |
| | (53) | (53) | (53) | (54) | (54) | (53) | (53) | (53) | (52) | (50) | (50) | (50) | |
| 1974 | −0.43 | −0.44 | 0.06 | 0.00 | −0.17 | −0.12 | −0.02 | −0.12 | −0.22 | −0.33 | −0.02 | −0.21 | −0.17 |
| | (51) | (52) | (53) | (52) | (52) | (53) | (51) | (51) | (51) | (50) | (51) | (50) | |

APPENDIX (*Continued*)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1975 | 0.28 | 0.28 | 0.39 | 0.33 | 0.17 | 0.09 | 0.04 | −0.04 | 0.05 | −0.06 | −0.20 | −0.33 | 0.08 |
| | (52) | (51) | (51) | (51) | (52) | (52) | (51) | (50) | (49) | (49) | (49) | (50) | |
| 1976 | 0.19 | −0.18 | −0.58 | 0.03 | −0.19 | −0.25 | −0.27 | −0.28 | −0.18 | −0.89 | −0.42 | −0.48 | −0.29 |
| | (49) | (51) | (51) | (51) | (51) | (51) | (51) | (49) | (49) | (49) | (48) | (49) | |
| 1977 | −0.45 | 0.36 | 0.81 | 0.48 | 0.31 | 0.27 | 0.04 | −0.11 | 0.11 | −0.03 | 0.65 | −0.12 | 0.19 |
| | (51) | (50) | (50) | (49) | (50) | (48) | (48) | (47) | (48) | (48) | (48) | (48) | |
| 1978 | 0.15 | 0.13 | 0.35 | 0.15 | −0.02 | −0.20 | −0.20 | −0.29 | −0.09 | −0.10 | 0.28 | −0.02 | 0.01 |
| | (49) | (50) | (50) | (48) | (49) | (49) | (49) | (49) | (48) | (47) | (49) | (48) | |
| 1979 | −0.04 | −0.54 | 0.48 | −0.16 | 0.11 | 0.18 | 0.04 | −0.03 | 0.13 | 0.25 | 0.27 | 0.91 | 0.13 |
| | (45) | (47) | (49) | (48) | (48) | (48) | (46) | (48) | (48) | (48) | (48) | (48) | |
| 1980 | 0.18 | 0.19 | 0.01 | 0.39 | 0.35 | 0.25 | 0.10 | 0.05 | −0.01 | 0.10 | 0.62 | 0.01 | 0.19 |
| | (47) | (46) | (46) | (46) | (47) | (46) | (46) | (45) | (47) | (46) | (44) | (43) | |
| 1981 | 0.98 | 0.90 | 1.18 | 0.52 | 0.12 | 0.29 | 0.17 | 0.24 | 0.11 | 0.11 | 0.39 | 0.77 | 0.48 |
| | (47) | (47) | (47) | (46) | (46) | (44) | (45) | (46) | (45) | (46) | (45) | (46) | |
| 1982 | −0.25 | 0.24 | −0.04 | 0.14 | 0.09 | −0.10 | 0.12 | −0.08 | 0.12 | −0.01 | 0.01 | 0.60 | 0.07 |
| | (44) | (46) | (45) | (44) | (45) | (45) | (44) | (45) | (44) | (44) | (45) | (46) | |
| 1983 | 1.03 | 0.61 | 0.68 | 0.46 | 0.06 | 0.02 | 0.27 | 0.42 | 0.37 | 0.21 | 0.88 | 0.19 | 0.43 |
| | (42) | (42) | (43) | (42) | (43) | (43) | (43) | (41) | (43) | (42) | (43) | (45) | |
| 1984 | 0.23 | 0.06 | 0.26 | 0.09 | 0.30 | 0.08 | −0.01 | 0.10 | −0.23 | 0.06 | −0.15 | −0.63 | 0.01 |
| | (43) | (43) | (43) | (44) | (42) | (44) | (42) | (43) | (39) | (41) | (41) | (42) | |

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