canceled. To calculate the distribution of such an influence, trends at each of the 144 U.S. stations were simulated with an annual cycle calculated from observed daily data (the first five harmonics captured most of the variance in the annual cycle) as well as the autocorrelation and variance of the standard monthly means. An auto-regressive model (5) of order 1 (AR-1 model) was fit to the residuals of the daily temperatures minus the value of the sum of the harmonics, and the variance of each month was calculated in the same manner. The data at each station were simulated with the use of the mean appropriate for the day of the year calculated from the harmonics and the perturbation about this mean from the AR-1 model. Trends were then calculated using the same calendar offset as calculated from precession of the Earth’s orbit, as described above, and subtracted from the trends without the offset. The results were stratified by the magnitude of the persistence and variance term in the AR-1 model. A 2 × 2 contingency table was developed with class limits based on the median value of persistence and variance for all stations and all months. A significant portion of the difference in trends was found to be a result of the vagaries of weather and had nothing to do with precession of the orbit (Fig. 1). We show the result for the minimum temperature (Fig. 1), but results are similar for the maximum and mean temperature.

The effect of perihelion should be most apparent in the longest daily data set available, the CET. After incorporating the perihelion dates into the CET data set, spring (March, April, and May) warmed relative to the standard trends by 0.42°C over the 219 years and autumn cooled by 0.46°C. Using standard monthly data, we found that winter warmed relative to summer over 1772 to 1990 by 1.1°C; allowing for perihelion reduced this difference to 1.0°C. For the last 100 years (1891–1990), trend differences for the CET series are within the ±0.25°C range, falling in the center of the U.S. distributions (Fig. 1).

Inspection of the differences in trends calculated with and without the shift in calendar dates indicated that a bias was introduced during the transition seasons. It averaged between 0.05° and 0.10°C per century, with a positive bias during spring and a negative one during the autumn. This was due to shifting the calendar to later in the season. During summer and winter the slight shift of 2 days showed little bias, and even a 5-day offset in the CET time series produced only small differences.

In sum, we find Thomson’s concerns about the manner in which climatologists have calculated trends on monthly and annual time series to be of little consequence during the instrumental climate record.

Thomas R. Karl  
National Climate Data Center,  
National Oceanographic and Atmospheric Administration,  
Asheville, NC 28801–5001, USA

Philip D. Jones  
Climate Research Unit,  
University of East Anglia,  
Norwich, Norfolk NR4 7TT, United Kingdom

Richard W. Knight  
National Climate Data Center,  
National Oceanographic and Atmospheric Administration, Asheville, NC

REFERENCES AND NOTES


2. T. R. Karl, C. N. Williams, F. T. Quinlan, T. A. Boden, United States Historical Climatology Network (HCN)  
Searial Temperature and Precipitation Data, ORNL-CDIAC-30, N0P-019/R1 (Oak Ridge National Laboratory, Oak Ridge, TN, 1996).


4. For example, the days used to calculate trends of May’s temperature would consist of the days 3 May through 2 June if the perihelion date shifted by 2 days, but the anomaly of each day is still based on the mean temperature between 1 to 31 May, using all years of available data.


6. June 1995; accepted 28 August 1995

Are warming effects that result from man’s activity detectable in the subtle phase changes in the seasonal temperature cycle found by Thomson (1)? Given this important question, we raise specific issues for discussion.

1) Misidentification of the anomalistic year signature in temperature time series. The precession constant, 50.256° per year, is the rate at which the Earth’s rotation axis precesses, and it can be computed as a difference in the rate of change of phase between oscillations with a period of the sidereal year (365.26360 days per year) and those with the period given by the tropical year (365.242194 days per year) (2). It is not the rate of change of the phase between oscillations with periods defined by the lengths of the tropical year and the anomalistic year (365.259644 days per year), as is apparently assumed in Thomson’s analysis. Therefore, his finding of a phase rate difference of about 50° per year does not identify the anomalistic year as a property of terrestrial temperature data.

We see no explanation of his rate estimates of 50° per year, derived from the data shown in figures 1, 2, and 4 of his report unless Thomson can detect the sidereal year in his analysis. The sidereal year has no physical relevance in the seasonal temperature cycle. If the changes due to the anomalistic year and the cited capture effect really occur, he should find a phase rate difference of 61.9° per year because this is the phase rate difference between oscillations with periods of the tropical and anomalistic years. His stated significance tests on the Central England time series (99.999%) indicate sufficient accuracy to detect the 61.9° per year phase rate difference if it is present. A mechanism analogous to the capture effect cited by Thomson requires resonances of sufficiently narrow bandwidth to separate a frequency difference of 1/20000. Such resonances do not appear to exist in the climate engine.

The appearance of epochs with zero frequency difference [figures 2 and 3 of the article by Thomson (1)] is not unexpected, as we expect the temperature variation to be in phase with the tropical year at temperate latitudes. Near the equator, the solar driver has a phase rate twice that of the tropical year, superposed on the phase change due to the anomalistic year; but the amplitude of the anomalistic year component is weaker than that from the tropical year.

2) Decrease in amplitude of seasonal temperature variation. We confirm the decrease in the amplitude of the annual temperature cycles shown in figure 9 of (1) for both hemispheres. Thomson appears to assume, without discussion of the underlying processes and latitudinal dependencies, that an increase in solar irradiance necessarily leads to an increase in the amplitude of the seasonal temperature cycle. He then points out that the observed amplitude decrease argues against solar forcing because the trend of solar activity is increasing over the entire period. We expect the effects of increased solar irradiance or increased greenhouse gas concentrations to be quite complex due to the many feedback mechanisms in the climate system. For example, increased circulation due to global warming may well reduce the seasonal amplitude variation in higher latitudes. Detailed calculation of the effects of both solar and greenhouse forcing on the annual temperature cycle using the current general circulation models (GCMs) is needed to resolve the issue.

3) Variability in the phase curves from different locations. The discussion of figures 1, 2, 3, and 4 in Thomson’s article (1) needs substantial revision to remove the anomalistic year references, but the data themselves show intermittence in the occurrence of even the tropical year frequency in surface-temperature records. However, the 12 locations around the world exhibit phase shifts with much larger amplitudes than expected. Thomson links these differences between individual stations to “local topography, heat storage, and albedo” in each case, but not to latitude. Without established physical relationships
between the observed phase-shift patterns and these effects, conclusions concerning solar and greenhouse forcing are premature. Again, the issue calls for calculations with current GCMs with sufficient spatial resolution to understand regional differences as functions of latitude.

4) Post-1930 epoch: Phase and CO2 level correspondence. We find Thomson’s discussion of figures 6 and 12 of his article (1) misleading, as he implies that the phase change of the annual temperature variation in both hemispheres is caused by the slow increase of the atmospheric CO2 content over the last 130 years. Thomson does carefully point out in the captions that his suggested relationship comes from a regression of the logarithmic CO2 variation with his computed phase rates. From a purely analytical point of view, the superposition of a slowly increasing temperature due to greenhouse warming by CO2 with a sinusoidal signal representing the seasonal cycle does not give the phase shifts seen in either his figures 6 or 12. We simulated such a composite signal with a 1-year sinusoid with a 6 K amplitude superimposed on a hyperbolically growing temperature increase of 0.7 K—a symbol to that expected if the temperature increase is a result of greenhouse warming. Calculation of the variation of the phase with time shows a phase shift of less than 0.001° per year. Without an internal mechanism linking temperature of CO2, the cause of the unprecedented change in phase of the annual surface temperature since A.D. 1940 remains a mystery.

The Northern Hemisphere temperature data [figure 5 in the article (1)] show the abrupt change in slope of the phase variation at about A.D. 1940. This relatively abrupt change in phase of the seasonal cycle has no counterpart in the monotonically increasing CO2 record. Interestingly, at this same time such a counterpart exists in the instantaneous frequency of the solar cycle as expressed by 10Be radioisotope record (3). The absence of a physical mechanism linking sunspot activity and solar cycle phase shifts to surface temperature variations leaves the entire matter unclear. The origin of the intermittent 50° per year shift found by Thomson remains unknown.

Oran R. White
National Center for Atmospheric Research,
Boulder, CO 80307–3000, USA
E-mail: orw@hao.ucar.edu

Werner Mende
Institut für Meteorologie,
Freie Universität,
D-12165, Berlin, Germany

Juerg Beer
Eidgenössische Anstalt für Wasserversorgung,
Abwasserreinigung und Gewässerschutz,
8600 Zurich-Dieburg, Switzerland

Response: I thank Karl et al. and White et al. Their comments confirm many of my basic observations (1), so that disagreement seems limited to interpretation and terminology. Karl et al. confirm my observation (1) that the temperature data is accurate enough to distinguish the effects of precession. I disagree, however, that the changes are of little consequence and do not require correction. Proving or disproving the existence of a greenhouse warming signal is a statistical detection problem, characterized by the probabilities of false alarms and of missing a real signal. Uncorrected bias terms, such as precession, increase the probability of both kinds of error. Setting acceptable limits for such terms depends on three factors: First, allowing such biases to degrade the detection error probability by a factor of 2 implies (2) that these biases must be cumulatively less than 5.2% of the noise variance. Second, when filtered to have a time resolution of 1 year, the Jones-Wigley global temperature series has a residual standard deviation (SD) less than 32.1 mK for the interval 1854 to 1920 (3). Taking 5.2% of this variance leave 7.3 mK. Third, there are at least 20 identifiable effects, plus an unknown number of effects yet to be discovered, that might influence climate data. Allowing an equal share of the variance for each of these implies that one should attempt to eliminate individual bias terms that exceed 1.6 mK in a global series at annual resolution.

The seasonal bias from the precessional shift of 1.4 days per century has a root-mean-square value of 0.087 AT mK, where A is the amplitude of the annual cycle in kelvins and T the length of the record in years. Thus, if precession were the only problem, as Karl et al. have shown, standard anomaly series would be acceptable where the amplitude of the annual cycle is low and the records are short.

A worse problem with anomaly series, not addressed by Karl et al., is caused by rapid variation of the phase of the annual cycle during the reference period. To see the effects of phase changes during the reference period, consider a “half-artificial” temperature series

$$x(t) = A \cos[2\pi t + \theta(t)]$$

where \(\theta(t)\) is the measured phase from Williston, North Dakota (typical of central North America) (Fig. 1), and A is the average amplitude, 16.71 K. In such a climate, the summer temperatures always reach exactly 16.71°C, the winter temperatures ~16.71°C, the annual maxima and minima occur within a span of ±24 days over the duration of the record, and the extreme annual average temperature would be 0.39°C. There are no trends in minimum, maximum, or average temperature. The standard deseasonalizing procedure, however, produces an anomaly series with extremes of −1.63°C and +1.56°C and an SD of 0.337 K. This squared-error is a factor of 44,000 larger than \(1.6 mK)^2\). This series also has apparent seasonal trends of +0.561 K per century in April and −0.622 K per century in October. The apparent annual trend is only −0.0188 K per century and the SD of the monthly trends is 0.44 K per century. As the apparent trend in temperature attributed to anthropogenic greenhouse gases is about 0.6 K per century, the seasonal bias in the anomaly series could be a significant cause of confusion or misattribution.

While such bias terms nearly vanish when averaged over a full year, they will contribute substantially near points where records have gaps, begin, or end, and will also be largely coherent over continental scale areas, so spatial averaging will be of limited help.

Thus, I see at least four problems with the standard deseasonalizing procedure: (i) There are components of temperature at both the tropical and anomalistic year; the process cannot handle both simultaneously and, as Karl et al. have shown, the data are

**Fig. 1.** Phase of the annual cycle at Williston, North Dakota, and a simple approximation using (Eq. 2) with different logarithmic dependences for both the direct and transport amplitudes. Influence of CO2 suppresses the amplitude of the annual cycle on both terms, but the effect is larger on the direct radiation component than it is on the transport term; overall amplitude decreases and the phase changes rapidly in response to CO2.
Testing for Bias in the Climate Record
Oran R. White, Werner Mende and Juerg Beer

Science 271 (5257), 1880-1881.
DOI: 10.1126/science.271.5257.1880