Seasonal patterns of deaths in Matlab, Bangladesh

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Background

Deaths exhibit a seasonal pattern in most parts of the world. Analyses of deaths for the years 1972–1974 from the vital registration system of Matlab, Bangladesh, published in this journal 17 years ago, showed sinusoidal seasonal patterns. As death rates have declined in other nations, the seasonal pattern is attenuated. Death rates have declined substantially in Bangladesh in the past two decades. Thus, the present study examines monthly counts of deaths from Matlab data for a period 15 years later and tests the hypothesis of a decrease or shift in seasonality over time.

Methods

Trigonometric regression models were fit to monthly data by age and cause of death from the Matlab vital registration system for the years 1982–1990. A total of 20,328 death records were available for analyses.

Results

In the recent period significant sinusoidal seasonal patterns are found in all but one of the age and cause of death groups. Total deaths peak in the winter as do neonatal deaths but post-neonatal and child deaths are maximum in April and July respectively. Among cause groups, injury deaths (mostly attributed to drowning) show the greatest seasonal swing. The time of peak has only shifted for one age group—neonates—since the 1972–1974 period. The magnitude of the seasonal swing has declined significantly only for the neonatal age group and injury cause of death group.

Conclusion

Marked seasonal patterns of deaths persist in the Matlab area of Bangladesh even as the level of mortality has declined.

Keywords

Seasonal pattern, mortality, Matlab Demographic Surveillance System, Bangladesh

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The same has been documented for one developing country—Costa Rica—where an analysis of data for the period 1851-1921 showed a peak of deaths in the rainy season which declined over time as the mortality level declined.11

In the developed nations there was also a shift in the pattern from a summer peak in the early part of the century, due mostly to deaths attributed to enteric diseases, to a winter peak now which is due largely to increased fatalities at that time from cardiovascular and respiratory infections.12-14 In Matlab in the 1970-1974 period the maximum of deaths was already in the winter.

Given this background, the purpose of the present research is to test the following hypotheses with data for a recent period from the same vital registration system in Matlab, Bangladesh.

1. That the seasonal patterns of mortality in Matlab by age and cause are still described well by a sinusoidal curve.

2. That the times of peaks of deaths for age and cause groups have remained the same.

3. That the magnitudes of the seasonal patterns have declined as mortality has declined.

Data and Methods
The International Centre for Diarrheal Disease Research, Bangladesh (ICDDR,B) has maintained a registration system of births, deaths and migrations in Matlab since 1966. In 1990, 142 villages with a population of over 200,000 were under demographic surveillance. The Matlab area is located about 40 miles southeast of Dhaka; it is a densely populated riverine area with monsoon rains and flooding of much of the land area between June and September. Three seasons can be distinguished: hot-dry (March-June); hot-wet (July-September) and cool-dry (October-February). Rice cultivation is the major occupation with fishing the second most common livelihood. Islam is the majority religion and literacy is low. A detailed description of the area, the people and Matlab health and family planning research and programme activities is given by Fauveau.15

Field staff of ICDDR,B record demographic events during fortnightly visits to households. Information on date of death, age at death and cause of death is recorded. Interviewers write descriptive information given by relatives of the deceased—an unstructured ‘verbal autopsy’. This information is evaluated by medically trained staff who assign a cause of death code. The cause of death data have been assessed by Zimicki and Fauveau16 by medically trained staff who assign a cause of death code. The cause of death data have been assessed by Zimicki16 and Fauveau et al.17 The latter compared the cause of death coded independently by three physicians for the same 1008 verbal autopsy records for child deaths; there were disagreements in 35% of the cases of neonatal deaths but this declined to 22% for deaths of children above one year of age.

The data are computerized, edited, and tabulated by the Centre. This paper uses data for the years 1982-1990 for the analysis of seasonal patterns—a total of 20,328 deaths. These results are contrasted with those found previously in the vital registration data for 1972-1974. The coding for cause of death changed twice during the study period, so to avoid problems in comparisons, only major groupings are used. For the purpose of this study the following large groups of causes are defined: respiratory, diarrhoea, injury, and all other causes combined. Age groups for this analysis are: neonatal, post-neonatal, 1-4 years, 5-14 years, 15-44 years, 45-64 years, and ≥65. In the analyses of data from 1972-1974 there were fewer age groups: neonatal, post-neonatal (actually age group 2-12 months was used), 1-4 years, 5-14, 15-44, and ≥45. We were unable to compare diarrhoeal deaths in the two time periods since in the latter period both chronic and acute diarrhoea were grouped together but in the earlier period only chronic diarrhoea was tabulated. To adjust for differing deaths in the months, the monthly counts were multiplied by the factor (365/12)x where x is the number of days in the given month.

Counts of deaths were deemed satisfactory for analysis rather than rates, since in general the population sizes varied only slightly over the time period—less than 5% in any age group (not shown). An exception is neonatal deaths; because of the birth seasonality, there is a large variation (nearly twofold between winter and summer months) in the number of infants exposed to the risk of death. Thus neonatal mortality rates were calculated using standard demographic techniques of the Lexis diagram with births tabulated by 2-week calendar intervals and deaths cross-tabulated by 2-week intervals of age at death as well.18

Three progressively more complicated statistical models were fit to the adjusted monthly counts of deaths for each age and cause group. Model I is simply linear regression on time, i.e. \[ Y_t = \beta_0 + \beta_1 t \] where \( t \) is the number of ordinal months since January 1982 (\( t = 1,2,...,108 \)) and \( Y_t \) is the adjusted number of deaths in month \( t \).

Model II is the simple trigonometric regression model:

\[ Y_t = \mu + \beta_0 \cos(wt + \theta) + \gamma \] where \( \gamma \) is the amplitude of the curve, \( \theta \) is the phase angle and \( w = 2\pi/12 \), so the cycle is one year.

Model III expands Model II and was derived after exploratory data analysis showed a large spike of deaths in late 1983. Epidemiologists at ICDDR,B have described an outbreak of Shigella dysenteriae I at that time.19 Model III allows a spike during those months. The Appendix gives details of the models including estimation of the relative magnitude and time of peak (a linear function of \( \theta \)). These models were fit rather than the more general time series models which allow multiple periodicities, both because we wanted to fix the periodicity at 12 months and to allow direct comparisons with the 1972-1974 results.

The fit of each model was assessed by examination of the regression values. Differences in fits of Models I & II and Models II & III were tested with the F-statistic. If a more complex model did not significantly improve the fit, then the more parsimonious model was taken as the final model.

To test the hypotheses that the differences in magnitude and time of peak between 1972-1974 and 1982-1990 were zero, z-tests were done using the variances derived for \( \theta \) and \( \tau \) from the regression results.

Residuals from the regression fits were examined for possible patterns. For each model with a significant fit, standardized residuals were calculated and averaged across all years for a given month and then plotted by month.

Data on daily temperature and rainfall from the meteorological station in Dhaka were obtained from the US National Climate Data Center for the same time period.20 These daily values were summarized first within a month and then across years by mean monthly maximum temperature, mean monthly minimum temperature and mean monthly rainfall (in mm). To
highlight possible associations these were plotted with the residuals from the trigonometric regressions. Selected linear regressions of residuals on the temperature variables were also done.

Results
The observed data and best-fitting model for each age and cause of death group are shown in the panels of Figures 1, 2 and 3; the $r^2$ statistics are given in Table 1, and the parameter estimates are given in Table 2. For total deaths, the seasonal pattern has a peak in late November with 11% variability above and below the mean. The spike of deaths in November–December 1983 is apparent in many of the panels.

Age groups
For neonates the peak of the number of deaths is in November and the magnitude of the seasonal pattern is 47% above and below the mean value; the trigonometric regression (Model II) explains 69% of the variation in the monthly series. With adjustment for the number of births, the risk of neonatal death peaks earlier—at the end of September—has 15% seasonal change around the mean level and the regression explains 38% of the variation. Thus counts of neonatal deaths have much

Figure 1 Number of total, neonatal and post-natal deaths and neonatal mortality and fitted trigonometric regression estimates by month for selected age groups, Matlab DSS 1982–1990
greater seasonal variation than neonatal mortality since the former are affected by birth seasonality. Though the relative oscillations of both curves appear to be approximately of the same magnitude in the figures, the measure $t/m$ is larger for the counts of deaths because the mean of the counts is much lower than the corresponding mean for the rates. The poorer fit of the curve for neonatal mortality is also apparent from the figures.

In the post-neonatal group the seasonal pattern has a 28% variability above and below the mean and a peak in the hot-dry season. Mortality of 1–4 year olds is maximum in the hot-wet season with 19% variation above and below the mean, while the deaths of those age 5–14 years of age peak still later in the year (October). There was no significant seasonal pattern for the age group 15–44 years. After neonatal and post-neonatal deaths, the age group with the largest magnitude of seasonal pattern is the group ≥65 years with a variability of 26% above and below the average level. In this group 51% of the variation in the monthly series is explained by the fit of Model III.
Causes of death

Injury deaths have the greatest variability (as measured by t/m) of any cause of death group with a peak in mid-July and a variation of 45%. Sixty-four per cent of these deaths are due to drowning. For the entire time period both the number of injury deaths and the percentage of those due to drowning peak in September (data not shown). In that month 78% of injury deaths were drownings while in January only 25% of injury deaths were so attributed.

Diarrhoeal deaths also peak in the hot-wet season, but with only an 8% seasonal variability. Deaths due to respiratory disease and all other causes peak in the cool-dry season and have magnitudes of variability of 20% and 15% respectively.

Analyses of residuals

Figure 4 shows standardized residuals by month for each age group (4a) and cause of death group (4b). The trigonometric fits consistently underestimate the actual number of deaths in April and December and overestimate the deaths in February. The high residual for injury deaths in September corresponds with the peak of drowning deaths; thus the pattern of drowning deaths has greater variation than sinusoidal. In Figure 5, the residuals for the various groups have been averaged and plotted on the same scale as the temperature and rainfall variables. To allow this comparison the values of the weather variables by month (Yj) were standardized as

\[ Y_j - \frac{\text{median of } Y}{\text{range of } Y} \]

From Figure 5 we draw the following conclusions. The residuals from the trigonometric fits of deaths are unrelated to the rainfall curve. However, the two largest residuals in deaths (in April and December) correspond to the months with the highest maximum temperature and the next to lowest maximum temperature respectively. Thus, excesses in deaths (beyond the trigonometric
fit) are found in months with temperature extremes, and this holds for all the age groups examined irrespective of the times of their zeniths. This V-shaped pattern of the residuals with temperature is missed by regression and correlation techniques—the correlations between the two series are not significant (not shown) because high death residuals correspond with both the high and low temperatures.

**Comparison with 1972–1974 results**

Table 3 summarizes the comparison of seasonal patterns between the early 1970s and the 1980s in Matlab; significant differences between the periods are starred. The only significant shift in time is for neonatal mortality for which the peak is nearly a month later in the 1982–1990 period.

With respect to magnitude of the seasonal patterns, among the six groups with significant patterns that can be compared between the two time periods, two showed a significant decline by the later period: neonatal mortality and injuries. The sharpest decline was for neonatal mortality with a 48% reduction (48% = 100*(29-15)/29) in the magnitude of the seasonal swings. The oscillations of injury mortality decreased by 27%. Total deaths actually had a slight increase in the magnitude of the pattern. One might posit that this is due to a greater percentage of deaths in the recent period in the age groups with the highest seasonal variation. However, the percentages of deaths of infants or people over 45 were very similar in the two time periods (64% for 1970–1974 and 61% for 1982–1990).

**Discussion**

Both births and deaths have striking seasonal patterns in Bangladesh and both are quite closely fit by a trigonometric curve; the hypothesis of such a seasonal pattern of deaths is supported for all age groups except 15–44 and for the four cause of death groups studied. This is despite the fact that the weather pattern is not really sinusoidal but rather has three phases as described above.

In many tropical developing nations, the peak of deaths is in the summer. Also, in nations in temperate climates which are now considered as developed, the seasonal pattern of deaths shifted from a summer to a winter peak as mortality declined. But in Matlab, the peak of deaths was already in winter in the 1970–1974 period. In this regard it is noteworthy that a report on seasonality of deaths from India in the previous century also did not show a peak in the summer but rather in October–November.

### Table 1 Values of $r^2$ ($\times 100$) and change in $r^2$ using three models for monthly deaths (1982–1990) in Matlab, Bangladesh

<table>
<thead>
<tr>
<th>Group</th>
<th>$r^2$ ($\times 100$)</th>
<th>Change ($\times 100$) in $r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model I</td>
<td>Model II</td>
</tr>
<tr>
<td>All deaths</td>
<td>38</td>
<td>54</td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neonatal deaths</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neonatal</td>
<td>8</td>
<td>69</td>
</tr>
<tr>
<td>mortality</td>
<td>16</td>
<td>38</td>
</tr>
<tr>
<td>Post-neonatal</td>
<td>22</td>
<td>49</td>
</tr>
<tr>
<td>1–4 years</td>
<td>50</td>
<td>53</td>
</tr>
<tr>
<td>5–14 years</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>15–44 years</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>45–64 years</td>
<td>8</td>
<td>32</td>
</tr>
<tr>
<td>&gt;65</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>Cause of death</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury</td>
<td>1</td>
<td>38</td>
</tr>
<tr>
<td>Diarrhoea</td>
<td>35</td>
<td>36</td>
</tr>
<tr>
<td>Respiratory</td>
<td>45</td>
<td>56</td>
</tr>
<tr>
<td>Other causes</td>
<td>15</td>
<td>38</td>
</tr>
</tbody>
</table>

* Values rounded to nearest integer; values of differences can be off by up to 1% due to rounding of original $r^2$ values.

Model I: Simple linear regression, Model II: Simple trigonometric regression, Model III: Adjusted trigonometric regression

**Discussion**

Both births and deaths have striking seasonal patterns in Bangladesh and both are quite closely fit by a trigonometric curve; the hypothesis of such a seasonal pattern of deaths is supported for all age groups except 15–44 and for the four cause of death groups studied. This is despite the fact that the weather pattern is not really sinusoidal but rather has three phases as described above.

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### Table 2 Results of trigonometric regression for deaths in Matlab, Bangladesh, 1982–1990, by age at death and cause of death

<table>
<thead>
<tr>
<th>Group</th>
<th>Parameter</th>
<th>$r^2$</th>
<th>m</th>
<th>$\beta$</th>
<th>$\Theta_1$</th>
<th>$t_1/m$ ($\times 100$)</th>
<th>$t_2/m$ ($\times 100$)</th>
<th>Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>All deaths</td>
<td>Model I</td>
<td>69</td>
<td>188</td>
<td>-0.97</td>
<td>0.41</td>
<td>11</td>
<td>41</td>
<td>Nov. 21</td>
</tr>
<tr>
<td>Age at death</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neonatal deaths</td>
<td>Model I</td>
<td>69</td>
<td>25</td>
<td>-0.11</td>
<td>0.52</td>
<td>47</td>
<td>47</td>
<td>Nov. 7</td>
</tr>
<tr>
<td>Neonatal mortality</td>
<td>Model I</td>
<td>38</td>
<td>56</td>
<td>-0.00017</td>
<td>1.33</td>
<td>15</td>
<td>15</td>
<td>Sept. 29</td>
</tr>
<tr>
<td>Post-neonatal</td>
<td>Model I</td>
<td>32</td>
<td>32</td>
<td>-0.15</td>
<td>1.99</td>
<td>12</td>
<td>12</td>
<td>Apr. 9</td>
</tr>
<tr>
<td>1–4 years</td>
<td>Model I</td>
<td>67</td>
<td>36</td>
<td>-0.50</td>
<td>2.56</td>
<td>19</td>
<td>19</td>
<td>Jul. 18</td>
</tr>
<tr>
<td>5–14 years</td>
<td>Model I</td>
<td>40</td>
<td>9</td>
<td>-0.08</td>
<td>1.12</td>
<td>11</td>
<td>11</td>
<td>Oct. 11</td>
</tr>
<tr>
<td>15–44 years</td>
<td>Model I</td>
<td>17</td>
<td></td>
<td></td>
<td>no significant seasonal pattern</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45–64 years</td>
<td>Model I</td>
<td>42</td>
<td>28</td>
<td>-0.07</td>
<td>0.04</td>
<td>14</td>
<td>14</td>
<td>Dec. 37</td>
</tr>
<tr>
<td>&gt;65</td>
<td>Model I</td>
<td>51</td>
<td>40</td>
<td>-0.006</td>
<td>0.03</td>
<td>26</td>
<td>26</td>
<td>Dec. 37</td>
</tr>
<tr>
<td>Cause of death</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury</td>
<td>Model I</td>
<td>38</td>
<td>10</td>
<td>0.1217</td>
<td>2.70</td>
<td>45</td>
<td>45</td>
<td>July 10</td>
</tr>
<tr>
<td>Diarrhoea</td>
<td>Model I</td>
<td>52</td>
<td>43</td>
<td>-0.398</td>
<td>2.42</td>
<td>8</td>
<td>8</td>
<td>July 26</td>
</tr>
<tr>
<td>Respiratory</td>
<td>Model I</td>
<td>56</td>
<td>25</td>
<td>-0.186</td>
<td>0.53</td>
<td>20</td>
<td>20</td>
<td>Jan. 13</td>
</tr>
<tr>
<td>Other causes</td>
<td>Model I</td>
<td>46</td>
<td>83</td>
<td>-0.349</td>
<td>-0.04</td>
<td>15</td>
<td>15</td>
<td>Dec. 36</td>
</tr>
</tbody>
</table>

* For groups with a significant $\beta$, m is equal to $\alpha + \beta_0(54.5)$ where 54.5 was the midpoint of the time interval in months.
The attenuation of the seasonal pattern of mortality in developed nations mentioned in the introduction occurred over 30–50 years. For example, Momiyama\(^9\) found that the coefficient of variation of monthly series of infant deaths declined in 12 of 24 European and North American countries by an average of 48% between 1920 and 1966 while mortality itself declined by 68–80% in all these countries. By contrast the more modest decline in magnitude of seasonality in neonatal mortality documented here occurred over a period of only a decade during which infant mortality declined by 40% (and neonatal by 37%)\(^{4,5}\). The declines are therefore of a similar order of magnitude in both sub-tropical and temperate climates but they are occurring more rapidly in developing nations as mortality itself has declined more rapidly there.

The birth peak in Matlab is in November\(^{25}\) and the peak of neonatal deaths is also in that month. However, the risk of neonatal death is highest several months before the birth peak. In the last decade the peak of neonatal mortality has progressed one month later in the year and simultaneously there has been a significant dampening of the pattern. Over the time span neonatal mortality has declined from 78 to 49 per 1000. The oscillation in neonatal mortality is marked, with much higher rates in the months before the fall rice harvest. Thus for the neonatal group both the level and seasonality of mortality have declined. For post-neonatal deaths the time of the peak and the magnitude of the seasonal swing have not changed significantly even though the level of post-neonatal mortality has declined from 60 per 1000 to 31 per 1000 over the period.\(^{4,5}\)
Aside from neonates, in all age and cause groups the time of the death peak is not significantly different in the later period from that in the earlier period. Thus, with one exception (neonatal mortality), hypothesis 2 is supported. The third hypothesis (that the magnitude of the pattern will decline) is supported only for neonatal mortality and injury deaths. The greatest magnitudes of seasonal swings in deaths are found in the youngest and oldest age groups—the most vulnerable ages.

As observed in other populations, diarrhoeal deaths in Matlab peak in the hot-wet season and respiratory deaths in the cool-dry season. Respiratory deaths are maximum in the cold months, a pattern that is found in many nations.  

No seasonal pattern was found for deaths in the 15–44 years age group. Could this be due to different seasonal patterns by cause which counterbalance each other when aggregated? To assess this, deaths in this age group were tabulated by cause of death by month across all years (not shown). The associated \( \chi^2 \) test for independence did indicate significant seasonal changes in the cause of death distribution. In particular injury accounts for 16% of the deaths in September but only 8% in February, but numbers of deaths were too few to allow separate trigonometric analyses.

The trigonometric regressions explain part of the variation in the monthly series—from a low of 38% for neonatal mortality to a high of 69% for total deaths. The analyses of residuals showed that for all age groups, regardless of the time of the seasonal peak, the largest residuals were in the months of highest or lowest temperatures. This "V" pattern with temperature has been observed in other populations.

Those who administer health intervention programmes, such as the Maternal and Child Health/Family Planning project in Matlab, need to be cognizant of these underlying patterns of deaths. A previous study in Matlab showed a seasonal pattern in a proximate determinant of infant and child mortality—malnutrition. The worst nutritional status was found in the late summer, coinciding with the highest rice prices and the highest risk of neonatal mortality. Researchers have also shown that September is the month of poorest nutritional status of...
Maternal malnutrition bodes poorly for newborns dependant on breastmilk. Nutritional supplementation to new mothers in those months could be an appropriate intervention.

Appendix

The models and their estimation

Estimation in Model I is via simple linear regression techniques. Model II is \( Y_t = \mu + \beta_1 t + \beta_2 \cos(\omega t + \theta) \). This can be rewritten as

\[
Y_t = \mu + \beta_1 t + \beta_2 x_{1t} + \beta_3 x_{2t},
\]

where \( x_{1t} = \cos(\omega t) \) and \( x_{3t} = \sin(\omega t) \). With this re-expression, multiple linear regression techniques can be applied. For Model III, \( Y_t = \mu + \beta_0 t + \beta_1 x_{1t} + \beta_2 x_{2t} + \beta_3 x_{3t} + \beta_4 x_{4t} \) where \( x_{1t} \) to \( x_{4t} \) are defined as follows:

\[
\begin{align*}
x_{1t} &= \begin{cases} 
\cos(\omega t) & \text{if } t < 23 \text{ or } t > 25 \\
0 & \text{otherwise}
\end{cases} \\
x_{2t} &= \begin{cases} 
\sin(\omega t) & \text{if } t < 23 \text{ or } t > 25 \\
0 & \text{otherwise}
\end{cases} \\
x_{3t} &= \begin{cases} 
2\cos(\omega t) & \text{if } 23 \leq t \leq 25 \\
0 & \text{otherwise}
\end{cases} \\
x_{4t} &= \begin{cases} 
2\sin(\omega t) & \text{if } 23 \leq t \leq 25 \\
0 & \text{otherwise}
\end{cases}
\]

Note that \( t = 24 \) corresponds with December 1983.

From the estimated regression parameters in Models II and III (an estimate \( \hat{\theta} \) for each \( \beta \)), values of the amplitude \( (\gamma) \) and phase angle \( (\theta) \) of the trigonometric fit are derived. In particular, \( \hat{\gamma} = \sqrt{\hat{b}_1^2 + \hat{b}_2^2} \) and the relative magnitude of the seasonal swing is then estimated as \( \gamma/m \) where \( m = \mu + 54.5*\hat{b}_0 \). Also the estimate of the phase angle is:

\[
\hat{\theta} = \begin{cases} 
\pi + \arctan\left(\frac{-\hat{b}_2}{\hat{b}_1}\right) & \hat{b}_1 < 0, \ \hat{b}_2 < 0 \\
\arctan\left(\frac{-\hat{b}_2}{\hat{b}_1}\right) - \pi & \hat{b}_1 < 0, \ \hat{b}_2 > 0 \\
\arctan\left(\frac{-\hat{b}_2}{\hat{b}_1}\right) & \hat{b}_1 > 0 \\
-\pi/2 & \hat{b}_1 = 0, \ \hat{b}_2 > 0 \\
\pi/2 & \hat{b}_1 = 0, \ \hat{b}_2 < 0
\end{cases}
\]

To determine the exact time of the peak we then solve the equation \( \cos(\omega t + \theta) = 1 \) (or \( \omega t + \theta = 0 \)) for \( t \) and compare this to \( t = 1.0 \) which corresponds to 15 January in our formulation. The SAS Statistical software\(^{31}\) and STATA software\(^{32}\) were used for the regressions and to examine the residuals and temperature data. For comparison of the trigonometric fits between the two time periods, variances of the estimates of \( \theta \) and \( \tau \) (and also \( \gamma/m \)) were approximated, using the delta method, as:

\[
\hat{V}(\theta) = \left(\frac{\hat{b}_1}{\hat{b}_1^2 + \hat{b}_2^2}\right)^2 \hat{V}(\hat{b}_1) + \left(\frac{\hat{b}_1}{\hat{b}_1^2 + \hat{b}_2^2}\right)^2 \hat{V}(\hat{b}_2)
\]

\[
\hat{V}(\gamma) = \frac{\hat{b}_1^2}{\hat{b}_1^2 + \hat{b}_2^2} \hat{V}(\hat{b}_1) + \frac{\hat{b}_2^2}{\hat{b}_1^2 + \hat{b}_2^2} \hat{V}(\hat{b}_2)
\]

Estimates of variances for the 1970–1974 period were unavailable so we substituted the variance estimates from the later period.

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