EVIDENCE OF A LUNISOLAR INFLUENCE ON DECADAL AND BIDECADAL OSCILLATIONS IN GLOBALLY AVERAGED TEMPERATURE TRENDS

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Image from NASA GSFC

Many WUWT readers will remember that last year we presented evidence of what we thought was a "solar imprint" in globally averaged temperature trends. Not surprisingly, given the strong interest and passion in the subject of climate change and global warming, our results were greeting with both praise and scorn. Some problems were pointed out in our original assessment, and other possible interpretations of the data were suggested. Some WUWT readers have wondered whether we would ever follow up on this.

We have been quietly working on this, and having learned much since our initial effort, we are as persuaded as ever that the basic premise of our original presentation remains valid. We have tried out some new techniques, and have posted some preliminary trials on WUWT in the past few months, here, and here.

However, questions remain. Since a lot of bright and capable people read WUWT, rather than wait until we thought we had all the answers, we have decided to present an update and let readers weigh in on where we are at with all of this. We have, in fact, drafted a paper that we might at some point submit for peer review, when we are more comfortable with some of the more speculative aspects of the matter. What follows is taken from that draft, with some modification for presentation here.

Introduction

Evidence of decadal and bidecadal variations in climate are common in nature. Classic examples of the latter include the 20 year oscillation in January temperature in the Eastern United States and Canada reported by Mock and Hibler [1], and the bidecadal rhythm of drought in the Western High Plains, Mitchell, Stockton, and Meko [2], and Cook, Meko, and Stockton [3]. Other examples include a bidecadal (and pentadecadal) oscillation in the Aleutian Low, Minobe [4]; rainfall and the levels of Lake Victoria, East Africa, Stager et al. [5]; and evidence from tree rings along the Russian Arctic, Raspopov, Dergachev, Kolstrom [6], and the Chilean coast, Rigozo et al. [7].

Evidence of decadal or bidecadal oscillations in temperature data, however, especially upon a global scale, has proven to be more elusive and controversial. Folland [8] found a spectral peak at 23 years in a 335 year record of central England temperatures, and Newell et al. [9] found a 21.8 year peak in marine air temperature. Brunetti, Mageuri, Nanni [10] have reported evidence of a bidecadal signal in Central European mean alpine temperatures. But the first to report bidecadal oscillations – of 21 and 16 years – in globally averaged temperature were Ghil and Vautard [11]. Their results were challenged by Eisner and Tsonis [12], but were later taken up and extended by Keeling and Whorf [13, 14].

No less unsettled is the issue of attribution. Currie [15], examining U.S. temperature records, reported spectral peaks of 10.4 and 18.8 years, attributing the first to the solar cycle, and the latter to the lunar nodal cycle. In the debate over the bidecadal drought cycle of the Western High Plains, Mitchell, Stockton, and Meko [2] concluded that the bidecadal signal was a solar phenomenon, not a lunar one. Bell [16, 17] and Stockton, Mitchell, Meko [18] attributed the bidecadal drought cycle to a combined solar and lunar influence, as did Cook, Meko, and Stockton [3]. Keeling and Whorf [13], working with globally averaged temperature data, reported strong spectral peaks at 9.3, 15.2, and 21.7 years. Eschewing a simpler combination of solar and lunar influences, they proposed a complex mechanism of lunar tidal influences to explain the evidence [14]. The past decade has seen only sporadic interest in the question of whether decadal and bidecadal variations in climate have a solar or lunar attribution, or some combination of the two. Cerveny and Shaffer [19] and Treloar [20] report evidence of tidal influences on the southern oscillation and sea surface temperatures; Yndestad [21, 22] and McKinnell and Crawford [23] attribute climate oscillations in the Arctic and North Pacific to the 18.6 year lunar nodal cycle. But interest in discerning an anthropogenic influence on climate has largely eclipsed the study of natural climate variability, at least on a global scale. There continue to be numerous reports of decadal or bidecadal oscillations in a variety of climate metrics on local and regional scales, variously attributed to solar and or lunar periods [3-7, 10, 19-27], but little has been done to advance the state of knowledge of lunar or solar periodic cycles on globally averaged temperature trends since the final decade of the 20th Century.

Besides the shift in interest to discerning an anthropogenic influence on global climate, the lack of agreement on any kind of basic physical mechanism for a solar role in climate oscillations, combined with the apparent lack of consistency in the relation between solar cycles and terrestrial temperature trends perhaps has made this an uninviting area of research. The difficulty of attributing temperature change to solar influence has been thoroughly surveyed by Hoyt and Schatten [28]. In particular, there are numerous reports of sign reversals in the relationship between temperature and solar activity in the early 20th century, particularly after 1920 [28, pp 115-117]. More recently, Georgieva, Kirov, and Bianchi [29] surveyed comprehensively the evidence for sign reversal in the relationship between solar and terrestrial temperatures, and suggested that these sign reversals are related to a long term secular solar cycle with solar hemispheric asymmetry driving the sign reversals. Specifically, they argue that there is a double Gleissberg cycle in which during one half of the cycle the Southern solar hemisphere is more active, while during the other half of the cycle the Northern solar hemisphere is more active. They argue that this solar hemispheric asymmetry is correlated with long term terrestrial climate variations in atmospheric circulation patterns, with zonal circulation patterns dominating in the 19th and early 20th century, and meridional circulation patterns dominating thereafter (see also [30] and [31]).

In our research, we pick up where Keeling and Whorf [13, 14] leave off, insofar as documenting decadal and bidecadal oscillations in globally averaged temperature trends is concerned, but revert to the explanation proposed by Bell [16] and others [3, 18], that these are likely the result of a combined lunisolar influence, and not simply the result of lunar nodal and tidal influences. We show that decadal and bidecadal oscillations in globally averaged temperature show patterns of alternating weak and strong warming rates, and that these underwent a phase change around 1920. Prior to that time, the lunar influence dominates, while after that time the solar influence dominates. While these show signs of being correlated with the broad secular variation in atmospheric circulation patterns over time, the persistent influence of the lunar nodal cycle, even when the solar cycle dominates the warming rate cycles, implicates oceanic influences on secular trends in terrestrial climate. Moreover, while analyzing the behavior of the secular solar cycle over the limited time frame for which we have reasonably reliable instrumental data for measuring globally averaged temperature should proceed with caution, if the patterns documented here persist, we may be on the cusp of a downward trend in the secular solar cycle in which solar activity will be lower than what has been experienced during the last four double sunspot cycles. These findings could influence our expectations for the future regarding climate change and the issue of anthropogenic versus natural variability in attributing climate change.

In our original presentation, we utilized Hodrick-Prescott smoothing to reveal decadal and bidecadal temperature oscillations in globally averaged temperature trends. While originally developed in the field of economics to separate business cycles from long term secular trends in economic growth, the technique is applicable to the time series analysis of temperature data in reverse, by filtering out short term climate oscillations, isolating longer term variations in temperature.

For the mathematically inclined, here is what the HP filter equation looks like, courtesy of the Mathworks

> The Hodrick-Prescott filter separates a time series y_t into a trend component T_t and a cyclical component C_t such that $y_t = T_t + C_t$. It is equivalent to a cubic spline smoother, with the smoothed portion in T_t.
>
> The objective function for the filter has the form

$$\sum_{t=1}^{m} C_t^2 + \lambda \sum_{t=2}^{m-1} ((T_{t+1} - T_t) - (T_t - T_{t-1}))^2$$

where m is the number of samples and λ is the smoothing parameter. The programming problem is to minimize the objective over all $T_1, \ldots, T_m$. The first sum minimizes the difference between the time series and its trend component (which is its cyclical component). The second sum minimizes the second-order difference of the trend component (which is analogous to minimization of the second derivative of the trend component).

For those with an electrical engineering background, you could think of it much like a bandpass filter, which also has uses in meteorology:

Outside of electronics and signal processing, one example of the use of band-pass filters is in the atmospheric sciences. It is common to band-pass filter recent meteorological data with a period range of, for example, 3 to 10 days, so that only cyclones remain as fluctuations in the data fields.

(Note: For those that wish to try out the HP filter on data themselves, a freeware Excel plugin exists for it which you can download here)

When applied to globally averaged temperature, the HP filter works to extract the longer term trend from variations in temperature that are of short term duration. It is somewhat like a filter that filters out “noise,” but in this case the short term cyclical variations in the data are not noise, but are themselves oscillations of a shorter term that may have a basis in physical processes.

This approach reveals alternating cycles of weak and strong warming rates with decadal and bidecadal frequency. We confirm the validity of the technique using a continuous wavelet transform. Then, using MTM spectrum analysis, we analyze further the frequency of these oscillations in global temperature data. Using sinusoidal model analysis we show that the frequencies obtained using HP smoothing are equivalent to what are obtained using MTM spectrum analysis. In other words, the HP smoothing technique is simply another way of extracting the same spectral density information obtained using more conventional spectrum analysis, while leaving it in the time domain. This allows us to compare the secular pattern of temperature cycles with solar and lunar maxima, yielding results that are not obvious from spectral analysis alone.

Using the Hodrick-Prescott Filter to Reveal Oscillations in Globally Averaged Temperature

We use the open source econometric regression software gretl (GNU Regression, Econometrics, and Time Series) [34] to derive an HP filtered time series for the HadCRUT3 Monthly Global Temperature Anomaly, 1850:01 through 2008:11 [35].

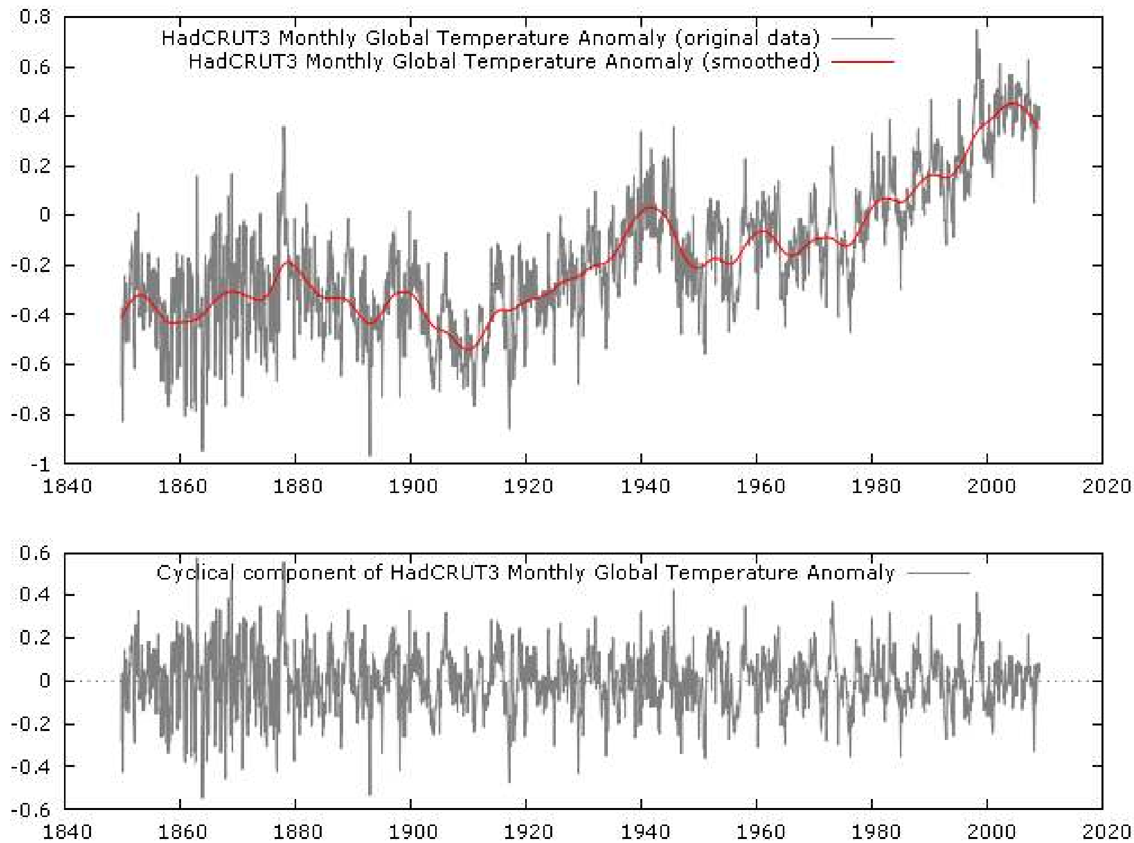
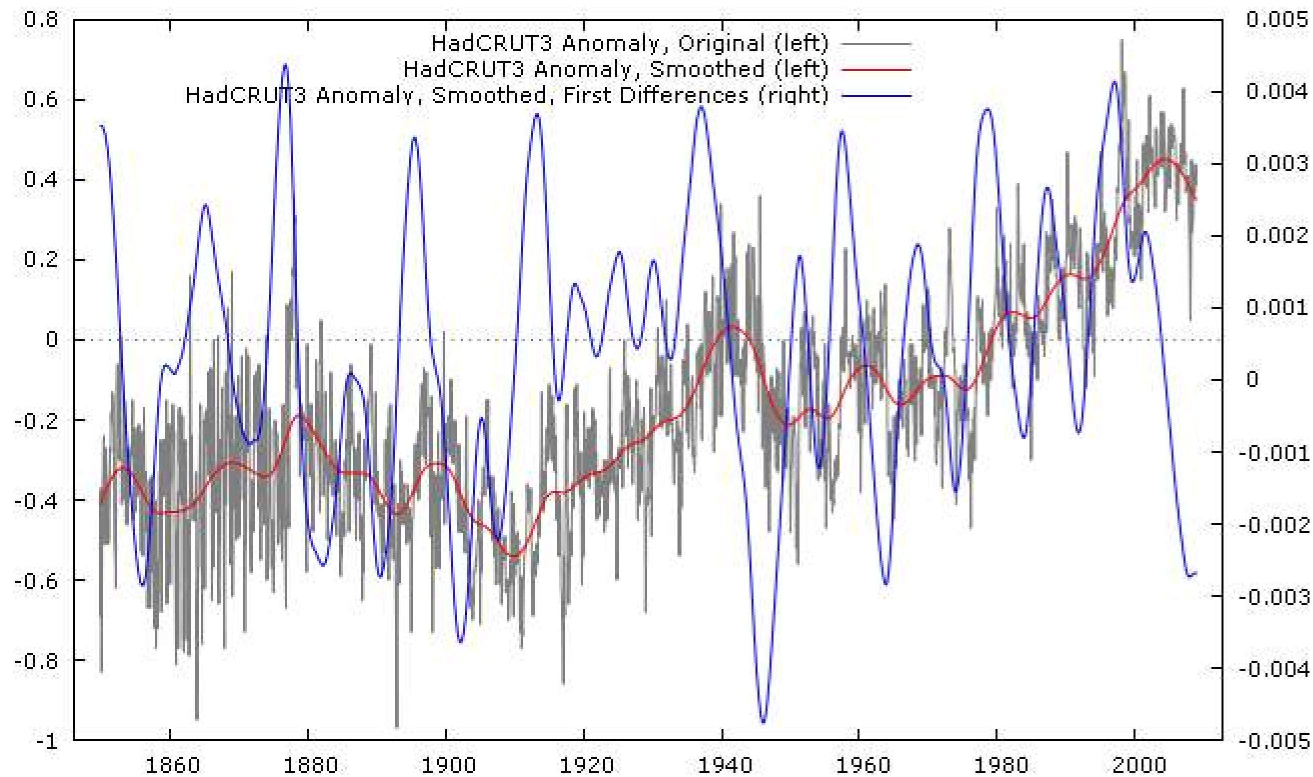
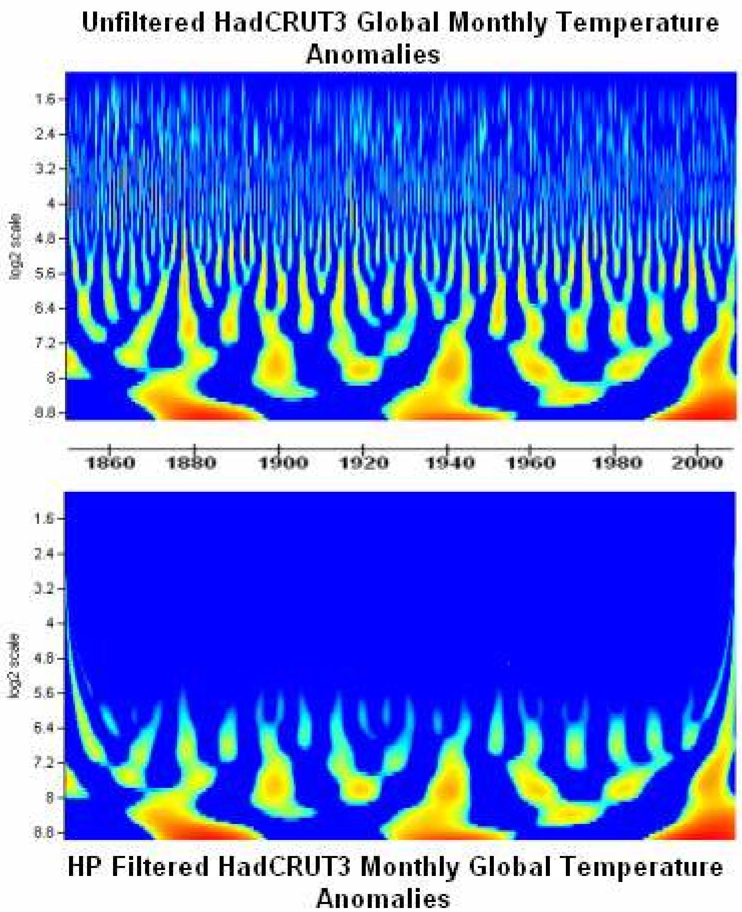


Figure 1 is representative output in gretl for a series filtered with HP smoothing (λ of 129,000). In the top panel is the original series (in gray), with the resulting smoothed trend (in red). In the bottom panel is the cyclical component. In econometric analysis, attention usually focuses on the cyclical component. Our focus, though, is on the trend component in the upper panel, and in particular the first differences of the trend component. The first differences of a trend indicate rate of change. By taking the first differences of the smoothed trend in Figure 1, we obtain the series (in blue) shown in Figure 2, plotted against the background of the original data (gray), and the smoothed trend (red).



What does this reveal? At first glance, we see an alternating pattern of decadal and bidecadal oscillations in the rate of warming, with a curious exception circa 1920-1930. We will return to this later. Concentrating for now on the general pattern, these oscillations in the rate of warming are representations, in the time domain, of spectral frequencies in the temperature data, with high frequency oscillations filtered out by the HP smoothing.

As evidence of this, Figure 3 presents the result of two Morelet continuous wavelet transforms, the first (in the upper panel) of the unfiltered HadCRUT3 monthly time series, and the second (in the lower panel) of results obtained with HP smoothing.. The wavelet transforms below a frequency of ~7 years ($2^{6.4} \approx$ 84 months) are visually identical; the HP filter is simply acting as a low pass filter, filtering out oscillations with frequencies above ~7 years, while preserving the decadal and bidecadal oscillations of interest here. In the next section, we investigate these oscillations in further detail, supplementing our results from HP filtering with MTM spectrum analysis, and a sinusoidal model fit.



Morelet Continuous Wavelet Transforms

Figure 3

Frequency Analysis

Figure 4 is an MTM spectrum analysis of the unfiltered HadCRUT3 monthly global temperature analysis. A feature of MTM spectrum analysis is that it distinguishes signals that are described as "harmonic" from those that are merely "quasi-oscillatory." In MTM spectrum analysis a harmonic is a more clearly repeatable signal that passes a stronger statistical test of its repeatability. Quasi-oscillatory signals are statistically significant, in the sense of rising above the background noise level, but are not as consistently repeating as the harmonic signals. The distinction between harmonic and quasi-oscillatory signals is well illustrated in Figure 4 by the two cycles that interest us the most – a "quasi-oscillatory" cycle with a peak at 8.98 years, and a "harmonic" signal centered at 21.33 years. Also shown are a harmonic, and a quasi-oscillatory cycle, of shorter frequencies, possibly ENSO related. The harmonic at 21.33 years in Figure 4 encompasses a range from 18.96 to 24.38 years, and the quasi-oscillatory signal that peaks at 8.93 years has sidebands above the 99% significance level that range from 8.53 to 10.04 years. These signals are consistent with spectra identified by Keeling and Whorf [13,14].

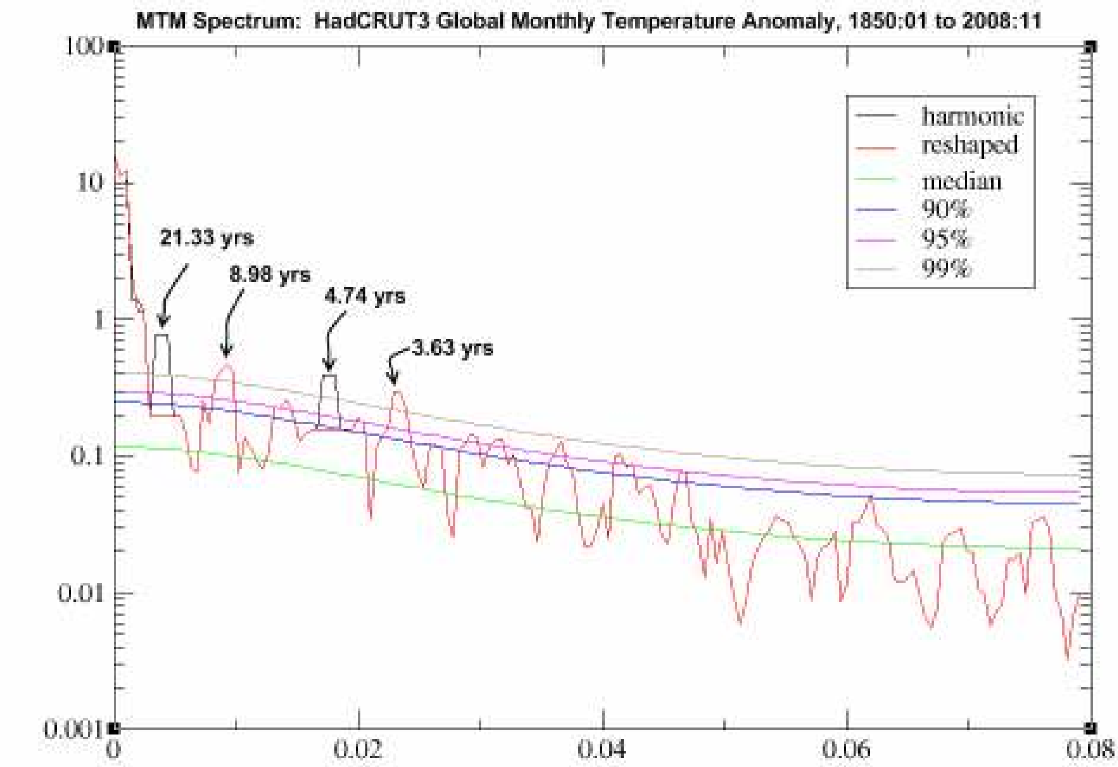


Figure 4

Figure 5 is an MTM spectrum analysis of the HP smoothed first differences. The basic

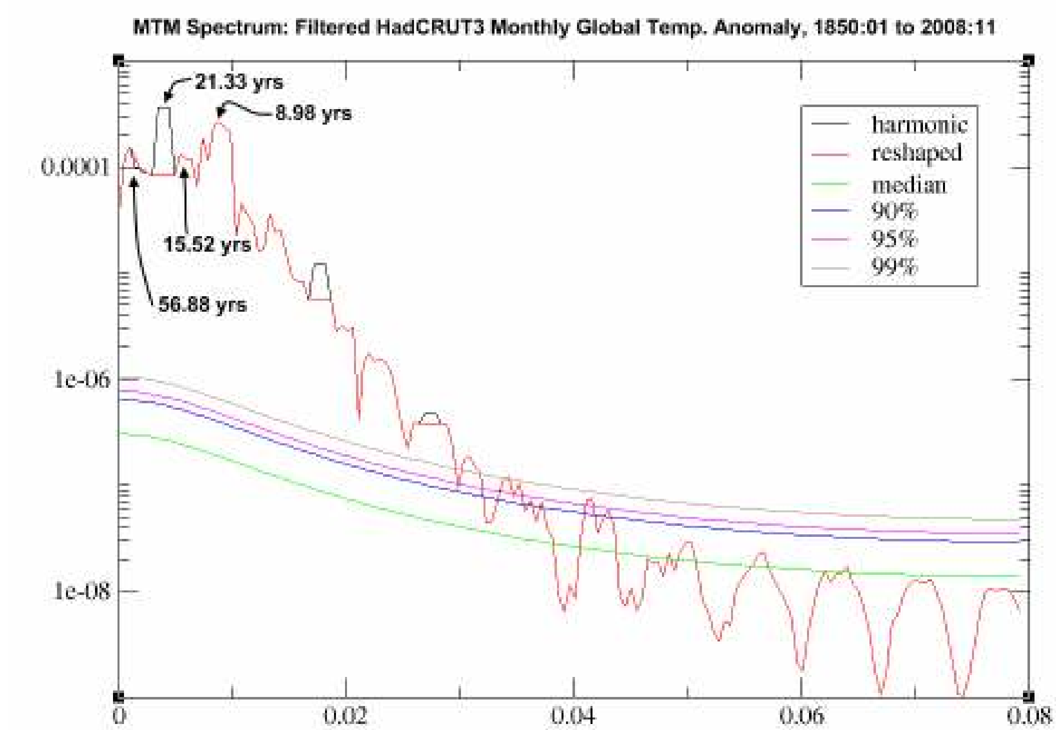


Figure 5

shape of the spectrum is unchanged, but it is now well above the background noise level because of the HP filtering. Attention is drawn in Figure 5 to four oscillatory modes or cycles because they correspond to the four strongest cycles derived from using the PAST (PAleontological STatistics) software [36] to fit a sinusoidal model to the HP smoothed first differences. Shown in Figure 6, the sinusoidal fit results in periods of 20.68, 9.22, 15.07 and 54.56 years, in that order of significance. These periodicities fall within the ranges of the spectra obtained using MTM spectrum analysis, and yield a sinusoidal model with an R^2 of 0.60.

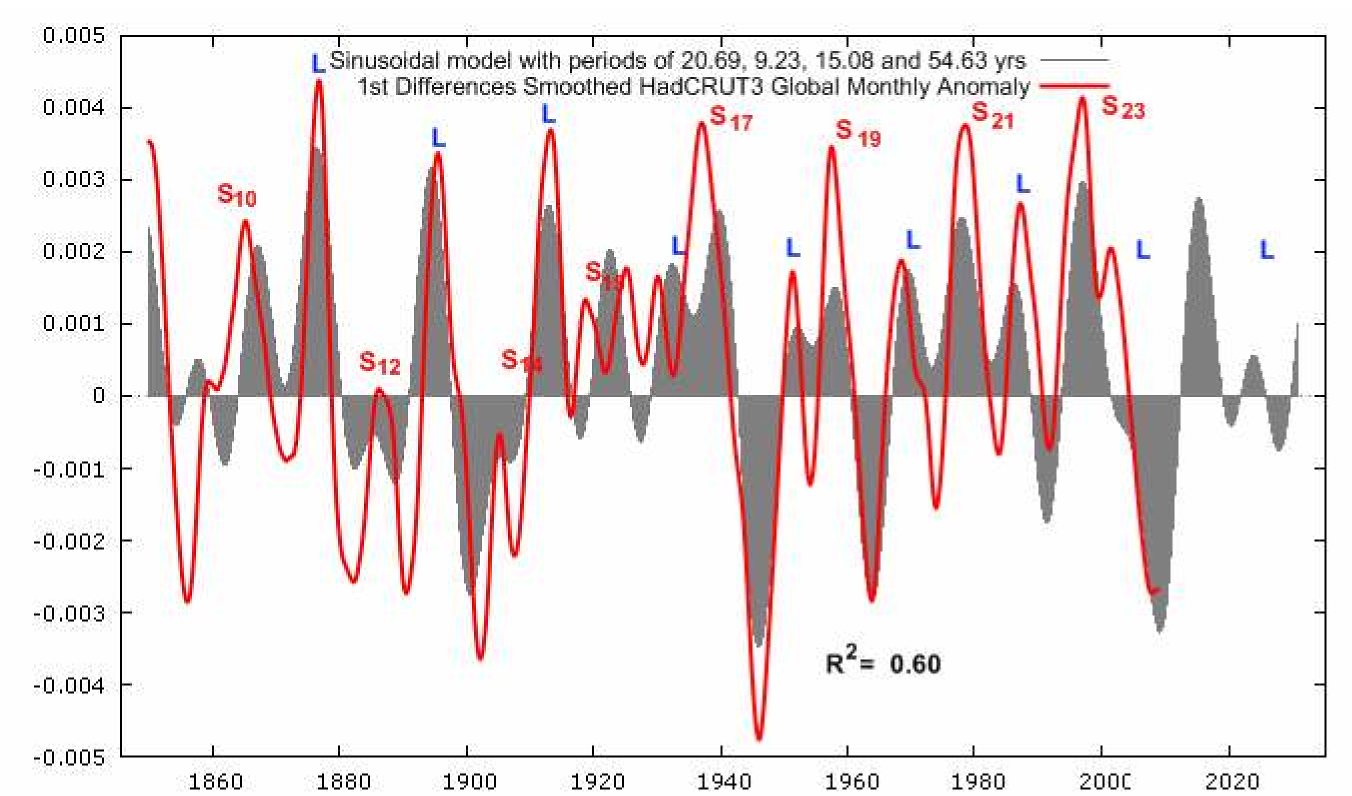


Figure 6

Discussion

The first differences of the HP smoothed temperature series, shown in Figure 2 and Figure 6, show a pattern of alternating decadal and bidecadal oscillations in globally averaged temperature. From the sinusoidal model fit, these cycles have average frequencies of 20.68 and 9.22 years, results that are consistent with the MTM spectrum analysis, and with spectra in the results published by Keeling and Whorf [13, 14]. But to what can we attribute these persistent periodicities?

A bidecadal frequency of 20.68 years is too short to be attributed solely to the double sunspot cycle, and too long to be attributed solely to the 18.6 year lunar nodal cycle. There is indeed evidence of a spectral peak at ~15 years, which Keeling and Whorf combined with their evidence of a 21.7 year cycle to argue for attributing the oscillations entirely to the 18.6 year lunar nodal cycle. But our evidence indicates that the ~15 year spectrum is much weaker, is not harmonic, and probably derives from the anomalous behavior of the spectra circa 1920-1930, something Keeling and Whorf could not appreciate with evidence only from the frequency domain. Especially in light of the evidence presented below, and because the bidecadal signal is harmonic, and readily discernible in the time domain representation of Figure 2 and Figure 6, we believe that a better attribution is the beat cycle explanation proposed by Bell [16], i.e. a cycle representing the combined influence of the 22 year double sunspot cycle and the 18.6 year lunar nodal cycle.

As for the decadal signal of 9.22 years, this is too short to be likely attributable to the 11 year solar cycle, but is very close to half the 18.6 year lunar nodal cycle, and thus may well be attributable to the lunar nodal cycle. Together, the pattern of alternating weak and strong warming cycles shown in Figure 2 and Figure 6 suggest a complex pattern of interaction between the double sunspot cycle and the lunar nodal cycle.

This complex pattern of interaction between the double sunspot cycle and lunar nodal maxima in relation to the alternating pattern of decadal and bidecadal warming rates is demonstrated further in Figure 6 with indicia plotted to indicate solar and lunar maxima. Since circa 1920, the strong warming rate cycles have tended to correlate with solar maxima associated with odd numbered solar cycles, and the weak warming rate cycles with lunar maxima. Prior to 1920, the strong warming rate cycles tend to correlate with the lunar nodal cycle, with the weak warming rate cycles associated with even numbered solar cycles. The sinusoidal model fit begins to break down prior to 1870. Whether this is a reflection of the poorer quality of data prior to 1880, or indications of an earlier phase shift, we cannot say, though the timing would be roughly correct for the latter. But the anomalous pattern circa 1920, when viewed against the shift from strong warming rate cycles dominated by the lunar nodal cycle, to strong warming rate cycles dominated by the double sunspot cycle, has the appearance of a disturbance associated with what clearly seems to be a phase shift.

These results agree with the evidence mustered by Hoyt and Schatten [28] and Georgieva, Kirov, and Bianchi [29] for a phase shift circa 1920 in the relationship between solar activity and terrestrial temperatures. However, we can suggest, here, that the supposed negative correlation between solar activity and terrestrial temperatures prior to 1920 rests on a misconstrued understanding of the data. As can be seen in Figure 6, the relationship between the change in the warming rate and solar activity is still positive, i.e. the warming rate is peaking near the peaks of solar cycles 10, 12, and 14, but at a much reduced level, indicative of the lower level of solar activity during the period. Indeed, for much of solar cycle 12, and all of solar cycle 14, the “warming” rate is negative, but the change in the warming rate is still following the level of solar activity, becoming less negative as solar activity increases, and more negative as solar activity decreases. Still, there is a strong suggestion in Figure 6 of a phase shift circa 1920 in which the relationship between solar activity and terrestrial temperatures changes dramatically before and after the shift. Before the shift, the lunar period dominates, and the solar period is much weaker. After the shift, the solar period dominates, and the lunar period becomes subordinate.

Speculating

To this point, we believe that we are on relatively solid ground in describing what the data show, and the likelihood of a lunisolar influence on global temperatures on decadal and bidecadal timescales. What follows now is more speculative. To what can we attribute the apparent phase shift circa 1920, evident not just in our findings, but as reported by Hoyt and Schatten [28] and Georgieva, Kirov, and Bianchi [29]? While the period of data is too short to do more than speculate, the periods before and after the phase shift appear to be roughly equivalent in length to the Gleissberg cycle. Since 1920, we've had four double sunspot cycles with strong warming rates ending in odd numbered cycles. Prior to 1920, while the results are less certain at the beginning of the data period, there is a reasonable interpretation of the data in which we see four bidecadal periods dominated by the influence of the lunar cycle. These differences may be attributable to the broad swings in atmospheric "circulation epochs" discussed by Georgeiva, et al. [30], characterized either predominantly by zonal circulation, or meridional circulation. With respect to the period of time shown in Figure 6, zonal circulation prevailed prior to 1920, and since then meridional circulation has dominated. These "circulation epochs" may have persistent influence on the relative roles of solar and lunar influence in warming rate cycles.

While the role of variation in solar irradiation over the length of a solar cycle on the broad secular rise in global temperature is disputed, we are presenting here evidence primarily of a more subtle repeated oscillation in the rate of change in temperature, not its absolute level. As shown in Figure 2 and Figure 6, the rate of change oscillates between bounded positive and negative values (with the exception circa 1920 duly noted). Variations in solar irradiance over the course of the solar cycle are a reasonable candidate for the source of this variation in warming rate cycle. As WUWT's "resident solar physicist" has pointed out, variations in TSI over a normal solar cycle can only account for about 0.07°C of total variation over the course of a solar cycle. The range of change in warming rates shown in Figure 2 and Figure 6 are <u>at most</u> only about one-tenth of this, or about ~0.006°C to ~0.008°C. If anything, we should be curious why the variation is so small. We attribute this to the averaging of regional and hemispheric variations in the globally averaged data. On a regional basis, analysis [not presented here] shows much larger variation, but still within the range of 0.07°C that might plausibly be attributed to the variation in TSI over the course of a solar cycle.

So variations in solar irradiance over the course of the solar cycle are a reasonable candidate for the source of this variation in warming rate cycle. At the same time, the lunar nodal cycle may be further modulating this natural cycle in the rate of change in global temperatures. As to the degree of modulation, that may be influenced by atmospheric circulation patterns. With zonal circulation, the solar influence is moderated and the lunar influence dominates the modulation of the warming rate cycles. With meridional circulation, the solar influence is stronger, and the warming rate cycles are dominated by the solar influence.

At this writing, we are in the transition from solar cycle 23 to 24, a transition that has taken longer than expected, and longer than the transitions typical of solar cycles 16 through 23. Indeed, the transition is more typical of the transitions of solar cycles 10 through 15. If the patterns observed in Figure 6 are not happenstance, we may be seeing an end to the strong solar activity of solar cycles 16-23, and a reversion to the weaker levels of activity associated with solar cycles 10-15. If that occurs, then we should see a breakdown in the correlation between warming rate cycles and solar cycles at bidecadal frequencies, and a reversion to a dominant correlation between temperature oscillations and the lunar nodal cycle.

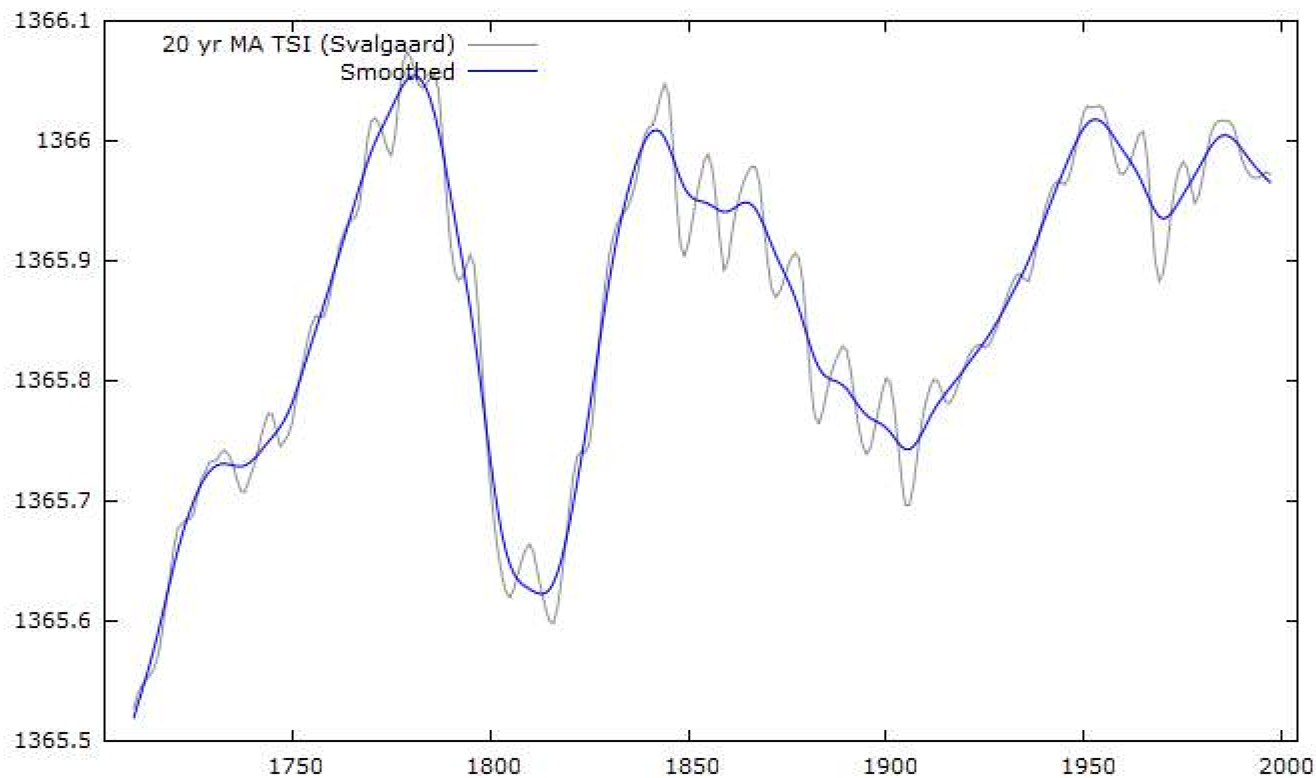
Interestingly, there was a lunar nodal maximum in 2006 not closely associated with the timing of decadal or bidecadal oscillations in globally averaged temperature. This could be an indication of a breakdown in the pattern similar to what we see in the 1920's, i.e. the noise associated with a phase shift in the weaker warming rate cycles will occur at times of the solar maximum, and the stronger warming rate cycles will occur at times of lunar nodal maximum.

Repeating, there appear to be parallels between our findings and the argument of Georgieva et al. [29] of a relationship between terrestrial climate and solar hemispheric asymmetry on the scale of a double Gleissberg cycle. Solar cycles 16-23, associated as we have seen with increased solar activity, and strong correlations with the strong terrestrial warming rate cycles of bidecadal frequency, represent 8 solar cycles, a period of time associated with a Gleissberg cycle.

While the existence of Gleissberg length cycles is hardly challenged, their exact length and timing is subject to a debate we will not entertain here at any length. Javariah [37] on the basis of the disputed 179 year cycle of Jose [38] believes that a descending phase of a Gleissberg cycle is already underway, and will end with the end of a double Hale cycle comprising solar cycles 22-25.

While it is true that solar activity, as measured by SSN, is already on the decline, we would include the double Hale cycle 20-23 in the recent peak of solar activity, and not necessarily expect to see the bottom of the current decline in solar activity that quickly.

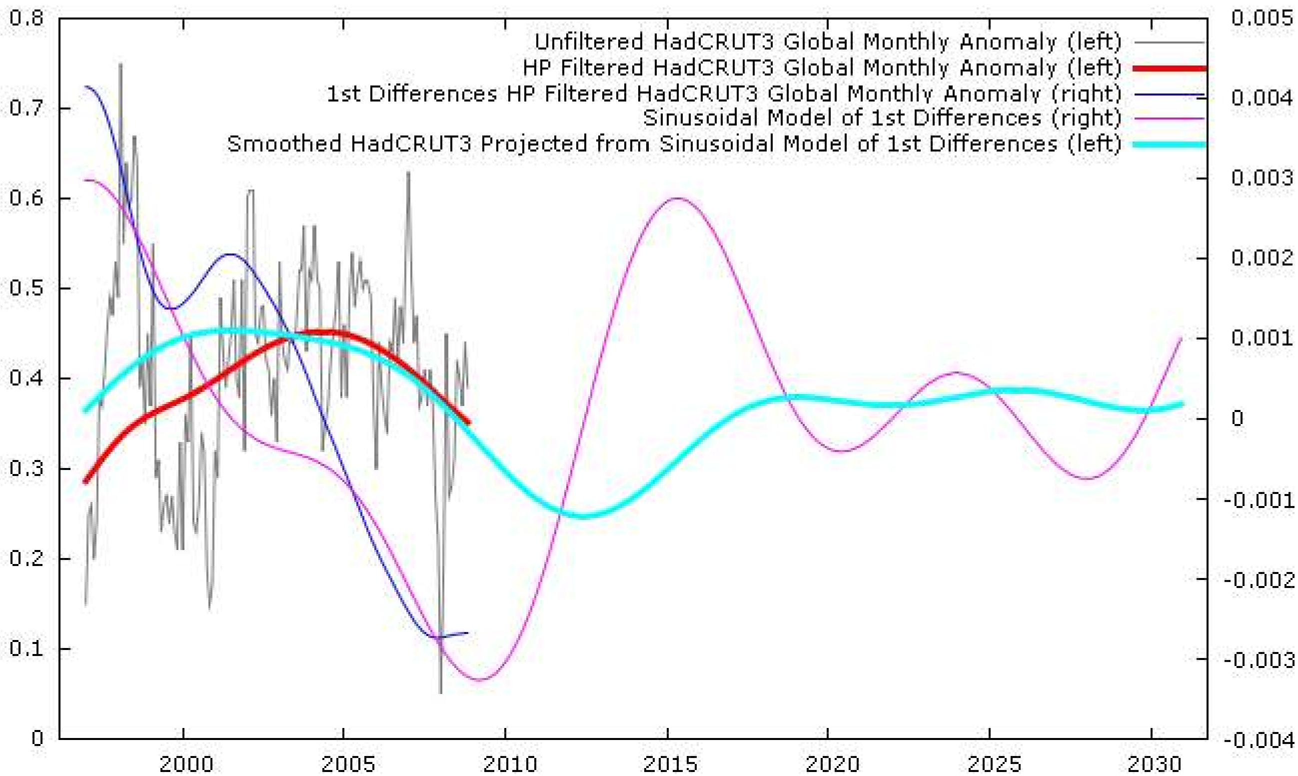
The issue here can perhaps be framed with respect to Figure 7 below:



Assuming we are on the cusp of a downward trend in solar activity that began circa 1990 according to Javariah, and will decline, say, to a level comparable to the trough seen in the early 1900's, will it be a sharp decline, like that seen at the beginning of the 19th Century, or a more moderate decline like that seen at the beginning of the 20th Century?

A naïve extrapolation might be to replicate the more gradual decline seen during the latter half of the 19th Century, suggesting a gradual decline in solar activity through solar cycle 31, i.e. for most of the 21st Century. And based on the prospect of a phase shift in the pattern of decadal and bidecadal warming rate cycles, the bidecadal cycle would come to be dominated by the influence of the lunar nodal cycle, and the influence of the solar cycle would be diminished, leading at least to a reduction in the rate of global warming, if not an era of global cooling. This is a prospect worthy of more investigation.

Finally, while we readily concede that multidecadal projections are at best little more than gross speculation, in Figure 6 we have carried the sinusoidal model fit out to 2030, and in Figure 8 we use the sinusoidal model of rate changes to project temperature



anomalies through 2030. Assuming a simple projection of the sinusoidal model of rate changes persists through 2030, there would be little or no significant change in global temperature anomalies for the next two decades.

Looking carefully at the sinusoidal model, what we are seeing projected for 2010-2020 are a return to conditions similar to what the model shows for circa 1850-1860, with the period 1853-2020 representing a complete composite cycle of the four combined periods of oscillation. That is, 1853 is the first point at which the sinusoidal model is crossing the x-axis, and at 2020 the model again crossing the x-axis and beginning to repeat a ~167 year cycle. In terms of solar cycle history, that corresponds to a return to conditions similar to solar cycles 10-15, with another phase shift reversing the phase shift of ~1920. If these broad, long term secular swings in solar activity and global atmospheric conditions and temperature anomalies are not random, but reflect solar-terrestrial dynamics that play out over multidecadal and even centennial time-scales, then the early 21st Century may yield a respite from the global warming of the late 20th Century.

Conclusion

There is substantial and statistically significant evidence for decadal and bidecadal oscillations in globally averaged temperature trends. Sinusoidal model analysis of the first differences of the HP smoothed HadCRUT3 time series reveals strong periodicities at 248.2 and 110.7 months, periodicities confirmed as well with MTM spectrum analysis.

Analyzing these periodicities in the time domain with the first differences of the HP smoothed HadCRUT3 time series reveals a pattern of correlation between strong warming rate cycles and the double sunspot cycle for the past four double sunspot cycles. Prior to that, with a phase shift circa 1920, the strong warming rate cycles were dominated by the timing of the lunar nodal cycle.

We suggest that this reversal may be related to a weaker epoch of solar activity prior to 1920, and that we may on the cusp of another phase shift associated with a resumption of such weakened solar activity.

If so, this may result in a reduction in the rate of global warming, and possibly a period of global cooling, further complicating the effort to attribute recent global warming to anthropogenic sources.

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