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A Luni-Solar Connection to Weather and Climate
III: Sub-Centennial Time Scales

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Abstract

The best way to study the changes in the climate "forcings" that impact the Earth's mean atmospheric temperature is to look at the first difference of the time series of the world-mean temperature, rather than the time series itself. Therefore, if the Perigean New/Full Moon cycles were to act as a forcing upon the Earth's atmospheric temperature, you would expect to see the natural periodicities of this tidal forcing clearly imprinted upon the time rate of change of the world's mean temperature.

Using both the adopted mean orbital periods of the Moon, as well as calculated algorithms based upon published ephemerides, this paper shows that the Perigean New/Full moon tidal cycles exhibit two dominant periodicities on decadal time scales.

The first is 10.1469 years, which is half of the 20.2937-year Perigean New/Full moon cycle. This represents the time required for the resynchronization of the phases of the Moon with the epochs when the perigee of the lunar orbit points directly towards or directly away from the Sun.

The second is 9.0554 years, which closely matches the 9.0713-year Lunar Tidal Cycle (LTC). This is the harmonic mean of the prograde 8.8475-year Lunar Anomalistic Cycle (LAC) and half of the retrograde 18.6134-year Lunar Nodal Cycle (LNC).

Hence, if the Perigean New/Full moon tidal cycle were to act as a "forcing" on the world's mean temperatures, you would expect to see periodicities in the first difference of the world's mean temperature anomaly (WMTA) data that were a simple sinusoidal superposition of the two dominant periods associated with the Equinox(/Solstice) spring tidal cycles (i.e. 9.1 and 10.1469 tropical years).

This paper makes a comparison between two times series that describe these phenomena. The first time series represents the lunar tidal forcing (LTF) curve. This curve is a superposition of a sine wave of amplitude 1.0 unit and period 9.1 tropical years, with a sine wave of amplitude 2.0 units and a period 10.1469 (= 9 FMC's) tropical years, that is specifically aligned to match the phase of the Perigean New/Full moon cycle. The second time series represents the difference curve for the HadCRUT4 monthly (Land + Sea) world mean temperature anomaly (DSTA), from 1850 to 2017.

A comparison between the LTF and DSTA curves shows that that the timing of the peaks in the LTF curve closely match those seen in the DSTA curve for two 45-year periods. The first going from 1865 to 1910 and the second from 1955 to 2000. During these two epochs, the aligned peaks of the LTF and the DSTA curves are separated from adjacent peaks by roughly the 9.6 years, which is close to the mean of 9.1 and 10.1469 years. In addition, the comparison shows that there is a 45-year period separating the first two epochs (i.e. from 1910 to 1955), and a period after the year 2000, where the close match between the timing of the peaks in LTF and DSTA curves breaks down, with the DSTA peaks becoming separated from their neighbouring peaks by approximately 20 years.

Hence, the variations in the ***rate of change*** *of the smoothed HadCRUT4 temperature anomalies closely follow a "forcing" curve that is formed by the simple sum of two sinusoids, one with a 9.1-year period which matches that of the lunar tidal cycle, and the other with a period of 10.1469-years that matches that of half the Perigean New/Full moon cycle. This is precisely what you would expect if the natural periodicities associated with the Perigean New/Full moon tidal cycles were driving the observed variations in the world mean temperature (about the long-term linear trend) on decadal time scales.*

1. Introduction

Wilson and Sidorenkov (2018), hereafter referred to as **paper I**, shows that the epochs when the lunar line-of-apse points directly towards/away from the Sun, at times that are very close to the Equinoxes and Solstices (i.e. seasonal boundaries), exhibit distinct periodicities at 28.75, 31.00, 88.50, 148.25, and 208.00 years. In addition, this paper notes that these specific periodicities only arise when the close lunar alignments are viewed in a frame of reference that is fixed with respect to the perihelion of the Earth's orbit.

The full significance of the 208-year repetition pattern observed in the lunar alignments in **paper I** only becomes apparent when these periodicities are compared with the amplitude spectrum of a proxy for the maximum daytime temperatures (T_m) on the Southern Colorado Plateau for a 2,264-year period from 266 BC to 1997 AD (Salzer and Kipfmueller 2005) [N.B. T_m is derived from the tree ring widths of Bristlecone Pines (P. aristata) located near the upper tree-line of the San Francisco Peaks (3,536 m). These trees were chosen because it is believed that their growth is primarily limited by the daily maximum temperature at these locations.]. The close matches that are observed between the periodicities seen in the lunar alignments and most prominent peaks in the amplitude spectrum of T_m, indicate that a factor associated with the times when the lunar line-of-apse points directly towards/away from the Sun near seasonal boundaries must have an influence on the Earth's mean temperature.

A Luni-Solar Model is outlined in **paper I** that proposes that it is the periodicities associated with the long-term alignments between, the times when the Perigee of the lunar orbit points directly towards or directly away from the Sun, and the seasonal boundaries, that produce synonymous long-term periodicities in the zonal wind speeds of the Earth's atmosphere. The model further proposes that it is these wind speed changes that produce the long-term variations in the amount of regional cloud cover that influence the efficiency with which the Earth warms and cools. Finally, the model concludes that it is these changes in the cooling and heating rates of the Earth's atmosphere that control the long-term variations in the world's mean temperature (Sidorenkov 2009 and 2016).

Wilson and Sidorenkov (2019), here after referred to as **paper II**, shows that the long-term periodicities exhibited by the alignments of the lunar line-of apse with the seasonal boundaries have effectively the same periodicities as the alignments of the Perigean New/Full moons with the seasonal boundaries (provided both are viewed in a frame of reference that was fixed with respect to the Perihelion of the Earth's orbit).

In addition, **paper II** shows that selecting the times when the lunar line-of-apse points directly towards or away from the Sun, at times that are very close to Equinoxes (/Solstices), is equivalent to selecting the times when strongest spring tidal peaks are crossing (/furthest from) the Earth's equator. These are called the Equinox (/Solstice) spring tides since they are the strongest spring tidal events that take place nearest to the dates of the nominal Equinoxes (/Solstices).

Finally, **paper II** shows that the Equinox and Solstice spring tides correspond to the times when the lunar-induced rotational acceleration of the Earth changes sign. This raises the question, can these lunar induced changes in the sign of the Earth's rotational acceleration be link to any atmospheric/oceanic phenomenon that is known to influence changes in the Earth's global mean temperature? Further investigate shows that the phenomenon that best meets these requirements is the starting dates for moderate to strong El Nino events.

The strongest spring tidal events that occur close to either the nominal Vernal Equinox (i.e. 0.00 UT March 21st) or the nominal Autumnal Equinox (i.e. 0.00 UT September 21st) that have peak tides at latitudes that are close to the Earth's equator are selected in **paper II**. In like manner, the strongest spring tidal events that occur close to either the nominal Summer Solstice (i.e. 0.00 UT June 21st) or the nominal Winter Solstice (i.e. 0.00 UT December 21st) that have peak tides at latitudes that are close to those of the lunar standstills are selected, as well.

The selected sample shows that the tidal events closest to the Vernal Equinox naturally divides into five 31-year epochs that start in the years 1870, 1901, 1932, 1963, and 1994. The three lunar tidal epochs that start in 1870, 1932, and 1994 begin with a Perigean Full moon, so they are designated as Full Moon epochs. Similarly, the remining two epochs that start in 1901 and 1963 begin with a Perigean New moon, so they are designated as New Moon epochs.

Paper II makes a comparison between the starting dates for moderate to strong El Nino events and the times when the strongest spring tides are near to the Earth's equator [i.e. Equinox spring tides]. This comparison shows that there is an alignment between the two phenomena during Full Moon epochs (i.e. for those starting in 1870, 1932, and 1994). Additionally, **paper II** makes a comparison between the starting dates for moderate to strong El Nino events and the times when the strongest spring tides are at their furthest distance from the Earth's equator [i.e. Solstice spring tides]. This second comparison shows that there is an alignment between the two phenomena during the New Moon epochs (i.e. for those starting in 1901 and 1963).

Hence, **paper II** concludes that, during the Full Moon epochs, there is a significant alignment between the starting dates of moderate to strong El Ninos and the times when Equinox spring tidal events occur and that, during New Moon epochs, there is a significant alignment between the starting dates of moderate to strong El Ninos and the times when Solstice spring tidal events occur. This means that there must be a connection between the occurrences of strongest Equinox/Solstice spring tidal events and the onset of El Ninos.

The conclusions of **paper II** concerning the link between the starting dates for moderate to strong El Nino events and the strongest Equinox/Solstice spring tidal events needs to be considered in the light of the work of Wilson (2013), Tisdale (2012), and de Freitas and McLean (2013). These authors show that whenever the relative strength and/or frequency of the El Niño events are greater than that of the La Niña events [i.e. the cumulative Extended Multivariate ENSO index (MEI) is trending positive] then global mean temperatures increase, and that whenever the relative strength and/or frequency of the La Niña events are greater than that of the El Niño events (i.e. the cumulative MEI is trending negative) then global mean temperature decreases. This means that there is a prima facie case for a link between the strongest Equinox/Solstice spring tidal events [or the Perigean New/Full moons that are nearest in time to the dates of the nominal Equinoxes and Solstices] and the times when the world's mean temperature is either increasing or decreasing.

In this paper (i.e. **paper III**), we investigate if there is a link between Perigean New/Full moons and the rate of change of the world's mean temperature on decadal to inter-decadal time scales. In the next paper (i.e. **paper IV**), we investigate how spring tidal moons are responsible for the onset of Pacific-Penetrating Madden Julian Oscillations, which are believed to play an important role in the triggering of El Nino events. This leads to a final discussion about how spring tidal events lead to changes in the world's mean temperature on sub-decadal time scales.

The Moon's mean orbital periods are used in section 2 of this paper to show that Perigean New/Full moons exhibit two prominent repetition patterns, one at 9.1 years and the other at 10.1469 tropical years. In section 3, more accurate lunar ephemeris data is used to confirm the existence of these two repetition patterns. Evidence is present to support the claim that the Perigean New/Full moon cycle is responsible for the quasi-decadal and bi-decadal oscillatory components in the world's mean temperature anomaly, in section 4. Finally, in section 5, we present the analysis and conclusions

2. The Perigean New/Full Moon Cycle and the 9.1-Year Lunar Tidal Cycle – Determined from the Mean Orbital Periods of the Moon.

a. The Adopted Mean Orbital Periods

It is important to note that the monthly lunar orbital periods used in this paper are those for J2000.0 (= 1 January 2000 12:00 TT). The fact that orbital periods are averages allows us to quote them to the level of precision stated. However, in many cases there can be significant variation of the orbital periods about the quoted values of their means. Hence, using the average values only become meaningful if we are considering time intervals that are long compared to the monthly orbital period of the Moon.

The four monthly lunar periods that are used in this paper (Simon et al. 1994) include (for J2000.0):

i. **the sidereal month** (**SidM**) = 27.321662 days. This is the time required for the longitude of the Moon to complete one revolution with respect to the stars (as measured by the fixed J2000.0 Vernal Equinox);

ii. **the tropical month (TM)** = 27.321581 days. This is the average time for the longitude of the Moon to return to the Vernal Equinox of date;

iii. **the anomalistic month** (**AM**) = 27.554550 days. This is the time required for the Moon to return to the perigee of its orbit;

iv. **the draconic month** (**DM**) = 27.212220 days. This is the time required for the Moon to move from the ascending node of its orbit back to the ascending node.

In addition, the three yearly periods used in this paper include (for J2000.0):

i. **the sidereal year** (**SidY**) = 365.2563630 days. This is the time for the Earth to complete one orbit of the Sun with respect to the stars (IERS 2010).

ii. **the tropical year** (**TY**) = 365.2421897 days. This the time required for the mean ecliptic longitude of the Sun to increase by 360^{O} and

iii. **the anomalistic year** (**AY**) = 365.259636 days. This the time required for the Earth to go from Aphelion/Perihelion to Aphelion/Perihelion (which is roughly 4.71 minutes longer than the sidereal year because of a prograde precession of the apsides of the Earth's orbit – Meeus and Savoie 1992, using Laskar's expression).

b. The Six Fundamental Lunar Cycles

There are six fundamental lunar cycles. These are the lunar synodic month (SynM), the Full Moon Cycle (FMC), the Lunar Anomalistic Cycle (LAC), the Draconic Year (DY), the Lunar Nodal Cycle (LNC), and the (modified) Lunar Evection Period (LEP).

The timing of these lunar events is determined by four orbital periods: The Earth's sidereal year (SidY); the lunar sidereal month (SidM); the lunar anomalistic month (AM); and the lunar Draconic month (DM).

New and Full moons take place at the beat period of the lunar sidereal month with the Earth's sidereal year, with a New/Full moon reoccurring once every **lunar synodic month (SynM** = 29.5305889 days):

$$\frac{\mathbf{1}}{\mathbf{SidM}} - \frac{\mathbf{1}}{\mathbf{SidY}} = \frac{\mathbf{1}}{\mathbf{SynM}}$$

The Full Moon Cycle (**FMC** = 411.7844303 days = 1.12738 sidereal years) is the time required for the Perigee-end of the lunar line-of-apse to realign with the Sun. The length of the FMC is determined by the beat period of the AM with the SynM, such that:

$$\frac{\mathbf{1}}{\mathbf{AM}} - \frac{\mathbf{1}}{\mathbf{SydM}} = \frac{\mathbf{1}}{\mathbf{FMC}}$$

The Lunar Anomalistic Cycle (**LAC** = 3232.6054406 days = 8.85024 sidereal years) is the time it takes for the lunar line-of-apse to rotate once around the Earth with respect to the stars, in a pro-grade direction. The length of the LAC is determined by the beat period between the FMC and the SidY, such that:

$$\frac{1}{\mathbf{SidY}} - \frac{1}{\mathbf{FMC}} = \frac{1}{\mathbf{LAC}}$$

The Draconic year (**DY** = 346.6200760 days = 0.94898 sidereal years) is the time it takes one end of the line-of-nodes (i.e. either the ascending or descending node) of the lunar orbit to re-align with the Sun. The length of the DY is determined by the beat period between DM and the SydM, such that:

$$\frac{1}{\mathbf{DM}} - \frac{1}{\mathbf{SydM}} = \frac{1}{\mathbf{DY}}$$

The Lunar Nodal Cycle (**LNC** = 6793.4770631 days = 18.5992 sidereal years) is the time require for the lunar line-of-nodes to precess once around the Earth with respect to the stars in a retrograde direction. The length of the LNC is determined by the beat period between the DY and the SidY, such that:

$$\frac{1}{\mathbf{DY}} - \frac{1}{\mathbf{SidY}} = \frac{1}{\mathbf{LNC}}$$

The (modified) Lunar Evectional Period (LEP) - Technically, this period is the shortest time interval between a new(/full) moon at a close perigee-syzygy alignment and the next new(/full) moon at a close perigee-syzygy alignment (Wood 1985). By convention, this period is taken as the average of 14 SynM (= 413.428245 days) and 15 AM (= 413.318250), which is 413.373247 days (Wood 1985). However, for the purposes of this paper, we adopt a slightly modified Lunar Evectional Period (MEP), with a value of 14 SynM (= 1.131885 sidereal years).

c. The 20.2937-year Perigean New/Full Moon Cycle

Perigean New/Full moons occur whenever a New or Full moon takes place at a date that is very close to the Perigee of the lunar orbit.

It takes 1.0 FMC for the perigee-end of the lunar line-of-apse to realign with the Sun. Therefore, 1.0 FMC falls short of one LEP (= 14 SynM) by roughly 1.64 days and 15 AM by about 1.53 days. Hence, it is possible for the lunar line-of-apse to point directly at the Sun at times when the phase of the moon is not New or directly away from the Sun when the moon is not Full. This means that some Perigean New/Full moons induce tidal forces that are noticeably more extreme than others.

It turns out that after 18 FMC's, the difference between 18 FMC's and 18 x LEP's (= 18 x 14 x Synodic months) is almost exactly one synodic month (since 18 x 1.64 = 29.52 days) and the difference between 18 FMC's and 18 x (15 x anomalistic months) is also almost exactly one anomalistic month (since 18 x 1.53 days = 27.54 days). [N.B. Another reason for the re-alignment is that 18 FMC's (= 7412.119745 days) is 1.4 hours less than 252 synodic

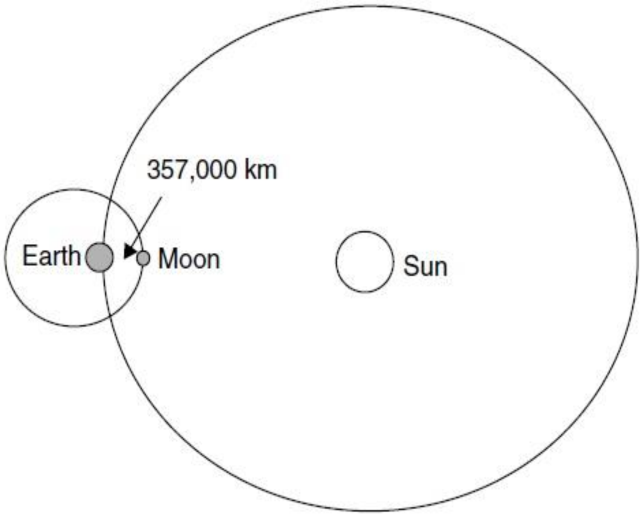

Figure 1. Once every 20.29371 tropical years there is an Extreme Perigean New moon.

months (= 7412.177802 days) which, in turn, is only about 5.6 minutes more than 269 anomalistic months (= 7412.173950 days)].

Thus, if you start out with a New/Full moon that is extremely close to Perigee, you get back a New/Full moon that is also extremely close to perigee 18 FMC's (= 20.29371 tropical years = 20.29292 sidereal years) later. Hence, the 20.2937-year Perigean New/Full moon cycle just represents the time required for the resynchronization of the phases of the Moon with the epochs when the perigee of the lunar orbit points directly towards or directly away from the Sun (Treloar 2002).

d. The 9.1-Year Lunar Tidal Cycle

If the lunar tides were to act as a "forcing" upon the Earth's climate system, you would expect the period of this "forcing" (i.e. the Lunar Tidal Cycle - **LTC**) would operate at the harmonic mean of the prograde Lunar Anomalistic Cycle (LAC = 3231.4956309 days = 8.84754 tropical years) and half of the retrograde Lunar Nodal Cycle ((LNC/2) = 3399.1918853 days = 9.30668 tropical years). [N.B. Both the LNC and LAC must be converted to their values with respect to the tropical year rather than the sidereal year, since most factors associated with the climate system vary with the seasonal cycle.]. Hence:

$$\left(\frac{\mathbf{1}}{\boldsymbol{LNC/2}} + \frac{\mathbf{1}}{\mathbf{LAC}}\right) = \frac{\mathbf{2}}{\mathbf{LTC}} = \frac{\mathbf{2}}{\mathbf{9.07130\ trop.\ yrs}} \cong \frac{\mathbf{2}}{\mathbf{9.1\ trop.\,yrs}}$$

[N.B. The value of LTC is very close to (but not precisely the same as) 8 x LEP's (= 8 x 14 x SydM) = 9.05543 tropical years (with the difference being 0.01587 tropical years).]

Hence, if the seasonal luni-solar alignments influence the world's mean temperature on sub-centennial times scales, they are likely to do so at a rate that is a simple superposition of the 9.1-year lunar tidal cycle and the 10.1469 (= (20.29371)/2)-year half Perigean New/Full moon cycle.

3. The Perigean New/Full Moon Cycle and the 9.1-Year Lunar Tidal Cycle – From Calculated Algorithms

The y-axis for figure 2 shows the time difference (in hours) between when a Perigean New/Full moon takes place and the time when it reaches perigee. The dates and times of perigee are those calculated using the algorithms that are published by Meeus 1998, while the dates and time of the phases of the Moon are those calculated using the algorithms of Meeus 1988. The accuracy and precision of these lunar dates and times are more than adequate for the purposes for which they are used in this study (Chapront-Touz, M. and Chapront, J. 1991).

The sample of Perigean New/Full moons displayed in figure 2 is limited to those New/Full moons near perigee that are closer to perigee than the Full/New Moon at perigee that follow them. All Perigean New/Full moons that meet this criterion are displayed over the 164.6 years between March 6-7th, 1856 and October 16th, 2020. A positive time difference on the y-axis means that the moon becomes New/Full after it has passed through perigee.

The first near-vertical line on the left-hand side of figure 2, shows the nine New moons that were closest to perigee between March 6-7th 1856 and March 27th, 1865. Each New Moon at perigee is separated from its predecessor by one LEP (= 14 Synodic months), as you move from the bottom to the top of this line [N.B. This means that, on average, the near-vertical lines in figure 2 span a time period equal to eight x LEP = 8 x 14 Synodic months = 9.055 tropical years, which is very close to the period of the 9.07130-year LTC.

In the year or so after March 27th, 1865, the New moons near perigee are no longer closer to perigee than the Full moons near perigee that follow them. It is not until November 22nd, 1866 that we start getting a series of (nine) Full moons near perigee that are closer to perigee than the New moons near perigee that follow them. For reference, this is the second near-vertical line from the left-hand side of figure 2. The pattern, of nine New moons nearest perigee, followed by nine Full moons nearest perigee, is repeated as you move from left to right across figure 2. Again, for reference, the near vertical lines that correspond to sequences of New moons near perigee are marked on this figure with the symbol NM.

Figure 2 can be used to make a preliminary measurement of the average spacing between Perigean New moon sequences, at equivalent time misalignments with Perigee. Highlighted in figure 2 are three Perigean New moon pairs that have one member of the pair separated from the other by seven New moon sequences i.e. (1865.241 and 2007.297), (1861.839 and 2003.896), and (1856.183 and 1998.243). The average spacing per New moon sequence for these three pairs is 20.2940 ± 0.0002 tropical years, which is effectively equal to 18 FMC's (= 20.2937 tropical years) to within the margin of error (1.5 sigma).

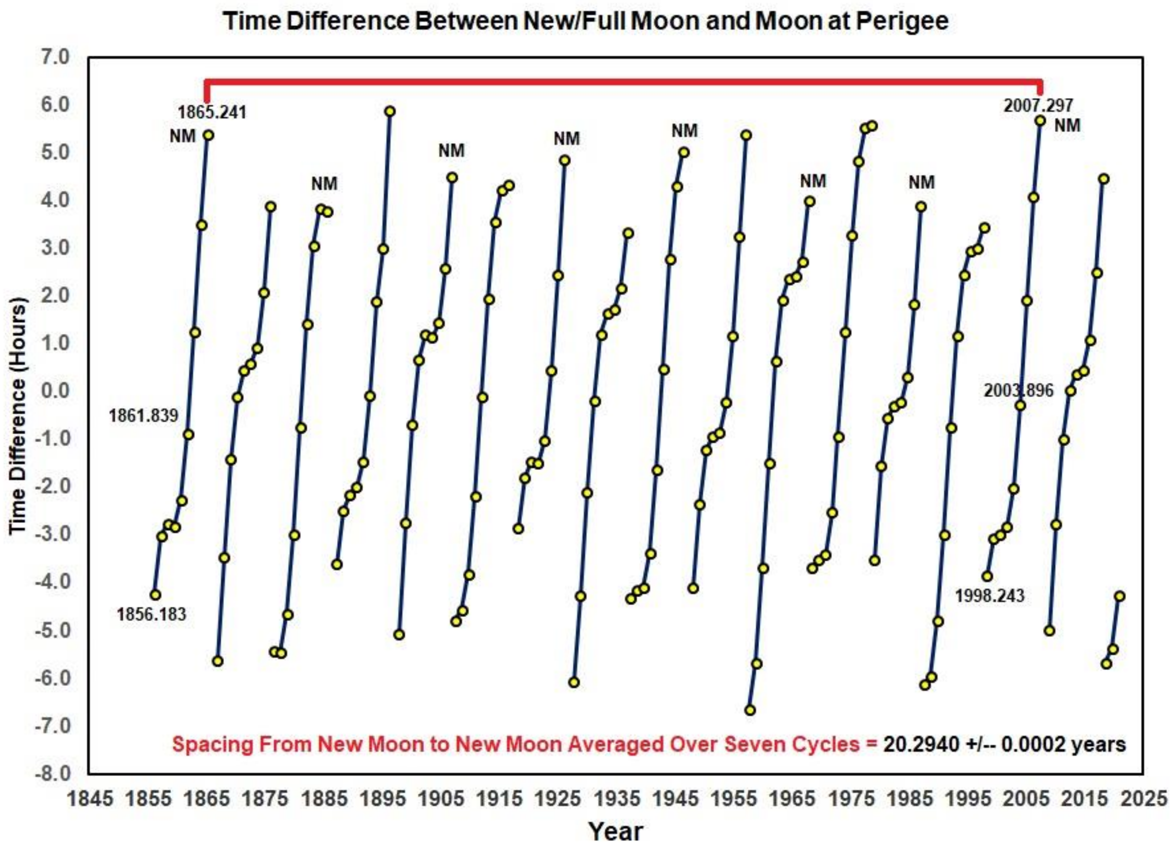

Figure 2.

Table 1

Sequence	FM	NM	Delta1	NM	FM	Delta2	Σ Deltas
1	1866.894	1876.474	**9.580**	1876.474	1887.191	**10.717**	**20.297**
2	1887.191	1897.899	**10.708**	1897.899	1907.485	**9.586**	**20.294**
3	1907.485	1918.200	**10.715**	1918.200	1927.777	**9.577**	**20.292**
4	1927.777	1937.361	**9.584**	1937.361	1948.071	**10.710**	**20.294**
5	1948.071	1957.652	**9.581**	1957.652	1968.366	**10.714**	**20.295**
6	1968.366	1979.077	**10.711**	1979.077	1987.530	**8.453**	**19.164**
7	1987.530	1998.243	**10.713**	1998.243	2008.950	**10.707**	**21.420**
Averaged Over Seven Cycles							**20.2937**
N.B. All but one of the spacings fall close to either a value of 9.5816 or 10.7119 years							

Another way to measure the mean spacing between lunar sequences is to determine the mean spacing between the start of one Perigean Full moon sequence and the start of the next. The results of these measurements are shown in Table 1. They indicate that the mean spacing between the start of adjacent Full sequences is 20.2937 years = 18 FMC's. This is because the spacing between the start of one Perigean New/Full moon sequence and the next Full/New moon sequence oscillates between 9.5 LEP and 8.5 LEP − SydM/2 = 10.71290 and 9.58097 tropical years, respectively, leading to a long-term average between the sum of the two spacings (i.e. Delta1 + Delta2 = Σ Deltas in table 1) that is equal to 18 FMC's ≈ 18 LEP – SynM = 20.2939 tropical years.

Each near-vertical line in figure 2 that is annotated with an "NM" is a Perigean New moon cycle. A detailed analysis of the spacing of the New moons that make up these cycles shows that they follow a pattern like the one shown in figure 3. This is a pattern where the long-term average length of the Perigean New moon cycles is 8 LEP's = 9.055 tropical years, the spacing between the end of one New moon cycle and the start of the next is (10 LEP − SynM) = 11.2384 tropical years, and the spacing between the start of one New moon cycle and the start of the next is 18 FMC ≈ 18 LEP − SynM = 20.2939 tropical years.

Each near-vertical line in figure 2 that is **not** annotated with an "NM" is a Perigean Full moon cycle. A detailed analysis of the spacing of the Full moons that make up these cycles shows that they follow a pattern that closely matches that shown in figure 3 for the Perigean New moon cycles. The main difference is that the Full moon cycles are shifted in time with respect to the New moon cycles by 9 FMC ≈ 9 LEP – ½ SynM = 10.1469 tropical years. This ensures that both lunar cycles remain in almost perfect antiphase with each other.

Hence, our analysis of the data in figures 2 and 3 show that the Perigean New/Full cycles not only exhibits a natural periodicity of 10.1469 years (= 9 LEP – ½ SynM) but that they also have a periodicity at 9.0554 years (= 8 LEP) that closely matches the 9.0713-tropical year lunar tidal cycle (LTC). This makes the Perigean New/Full moon cycles a good

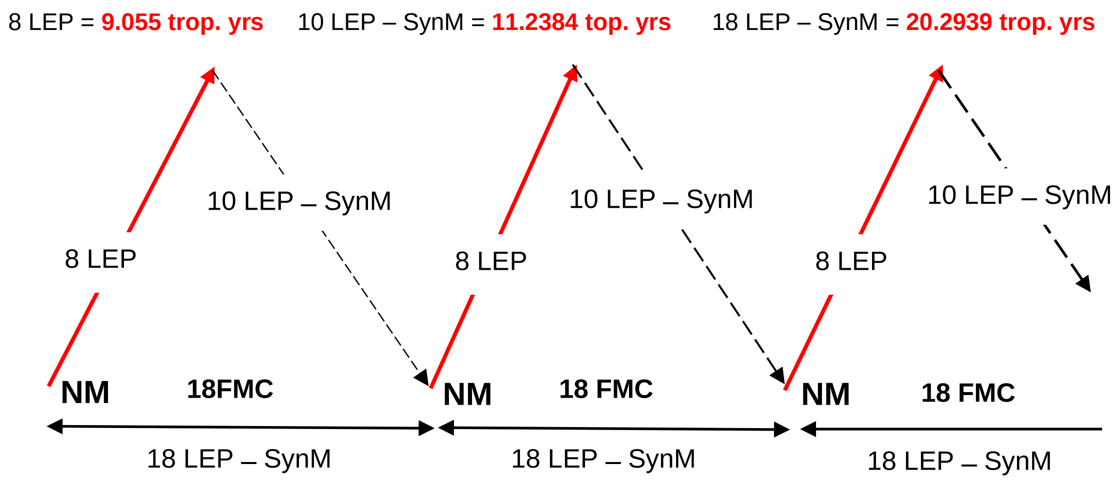

Figure 3

candidate for investigating the connection between the short-term decadal lunar tidal cycles and the long-term luni-solar seasonal alignment cycles discussed in paper I.

4. Evidence that the Perigean New/Full Moon Cycle Influences the Rate of Change of the World's Mean Temperature Anomalies.

a) The World (Land + Sea) Mean Monthly Temperature Anomaly Data.

The instrumentally-derived world (i.e. land + sea) mean monthly temperature data can only be traced back for 169 years (e.g. HadCRUT4 – covers from 1850 to 2019). One consequence of the relatively short length of the instrumental temperature record is that if there are any oscillatory cycles present in the data, their periods can only be determined to a reasonable level of precision if they are ≤ 20 – 30 years. This can be seen from the fact that, even under ideal circumstances (i.e. a spectral resolution of ± 0.5 frequency channels), a 20.0-year (bi-decadal) signal can only be determined to a precision of ± 1.36 year and a 30.0-year signal can only be determined to a precision of ± 3.6 year.

Spectral analysis of the world's mean monthly temperature anomaly data reveals that there are at least three prominent quasi-stationary temperature cycles present in the temperature data:

i. The first clearly identified periodic signal is the quasi-decadal oscillation near 9.1 years. This is often attributed to the effects of lunar tidal cycles upon temperature (Holm 2014, Scafetta 2010 & 2014). Spectral analysis shows that this 9.1-year period is present prior to 1915 and that it reappears again after 1955. However, it is noticeably absent during the forty-year period between 1915 and 1955 (Holm 2014).

ii. The second periodic signal is the bi-decadal oscillation near 20 years. This cycle is present over most of the 169-year temperature record. Various values have been attributed to the length of this cycle, including: 21 and 16 years (Ghil and Vautard 1991); 21.7 years (Keeling and Whorf 1996, 1997); 21.7 ± 1.2 years (Scafetta 2014), 20.68 years (Copland and Watts 2009); 21 ± 1.4 years (Scafetta 2010) and 15 – 20 years or 21 years (Holm 2014 - depending upon the spectral analysis method used).

    Copland and Watts (2009) noted that a period of 21 ± 1.4 years is too long to be attributed to the 18.6-year Lunar Nodical Cycle (LNC), though it is consistent with the 22-year Hale solar magnetic cycle and the 20.2937-year Perigean New/Full moon cycle, given the quoted uncertainty.

iii. Finally, there is a relatively strong oscillatory signal with a period around 60 years (Scafetta 2010, 2014), although the exact value of this spectral feature is poorly defined given the relatively short length of the instrumental temperature record.

b. The Difference Curve for the Trend Component of the World's Mean Temperature Anomaly Data.

Figure 4 shows the raw HadCRUT4 monthly (Land + Sea) world mean temperature anomaly (**WMTA**) data from 1850 to 2017 (grey line – Climatic Research Unit, University of East Anglia, 2017).

[This data can be accessed at: https://crudata.uea.ac.uk/cru/data/temperature/.]

Following the method used by Copeland and Watts (2009), a Hodrick Prescott filter (Hodrick and Prescott 1981 - using λ = 129,0000) is applied to the raw WMTA data to produce a smoothed temperature anomaly curve (Excel Plugin 2019). The resulting smoothed anomaly curve is superimposed upon the raw WMTA data in figure 4 (red line).

The Hodrick Prescott filter is designed to separate a time series data into a trend component and a cyclical component using a technique that is equivalent to a cubic spline smoother. It acts as a low-pass filter that smooths out short-term temperature fluctuations, leaving behind the unattenuated long-term oscillatory signals (Copland and Watts 2009). Given the specific value of λ used here, this effectively translates to a band-pass that eliminates all the oscillatory temperature signals that have periods ≤ 7.0 years (Copland and Watts 2009).

Investigations of climate change generally involve the study of "forcings" upon the climate system. These are expressed in power terms that are measured in W m^{-2}. This means that the best way to study temporal changes in these "forcings" is to look at time series of the first differences in the total energies that are associated with each forcing. Similarly, the mean temperature of the Earth's atmosphere is a measure of its total energy content. Thus, the best way to study the changes in the climate "forcings" that impact the mean temperature of the Earth's atmosphere is to look at time-series of the first difference in world-mean temperature, rather than time series of the temperature itself [Goodman 2013].

Following this train of logic, the first difference curve of the smoothed trend component of the WMTA time series is calculated in degrees Celsius per month. The resultant first difference curve (multiplied by an arbitrary factor of 150) is plotted in figure 5 (blue curve). Superimposed upon this is the raw temperature anomaly data (light-grey curve) and the smoothed trend component (red curve), displayed in units of degrees Celsius.

c. Evidence for a Luni-Solar Influence Upon the Decadal and Bi-decadal Oscillations in WMTA Data.

Hence, if the Perigean New/Full moon tidal cycle were to act as a "forcing" on the world's mean temperatures, you would expect to see periodicities in the first difference of the WMTA data that were a simple sinusoidal superposition of the two dominant periods associated with this lunar cycle i.e. 9.1 and 10.1469 tropical years.

The red curve in figure 6 shows a superposition of a sine wave of amplitude 1.0 unit and period 9.1 tropical years with a sine wave of amplitude 2.0 units and period 10.1469 (= 9 FMC's) tropical years. Note that the units used are degrees Celsius per month times 1000. The actual function that used in figure 6 is:

$$F(t) = 1.0 \times \sin\left(\frac{2\pi(t - 1894)}{9.100}\right) + 2.0 \times \sin\left(\frac{2\pi(t - 1894)}{10.1469}\right)$$

where t is the date expressed in decimal Gregorian years [N.B. For the purposes of this study, this curve will be referred to as the lunar tidal forcing curve – i.e. **LTF** curve].

It is evident from figure 6 that the combined oscillatory function is modulated by an 88.2-year envelope that is formed by the beat period between 9.1 and 10.1469 years [N.B. the curves displayed in figure 6 are plotted in Gregorian years rather than tropical years. The error produced by this approximation is imperceptible to the eye over the time period considered].

In order to highlight how this red curve is aligned with the Perigean New/Full moon cycle, a dotted blue curve is plotted in figure 6 that peaks whenever a sequence of Perigean New(/Full) moons changes to a sequence of Perigean Full(/New) moons (see figure 2). The dotted blue curve is just the absolute sequential difference curve (measured in hours per data point spacing) for the data points displayed in figure 2 [N.B. values in the absolute sequential difference curve that are ≥ 6.0 hours per data point spacing have been arbitrarily set to 6.0 and the resulting curve has been displaced downward by 5.0 hours per data point spacing to facilitate the comparison between these two curves]. A comparison between the blue and red curves in figure 6 show that the two curves are almost perfectly synchronized in phase with each other.

Figure 7 shows a reproduction of figure 6, with the red curve (in figure 6) representing the superimposed LTF is replotted as a blue dashed curve in figure 7. Overlaying this (in figure 7) is a red curve which is simply a reproduction of the difference plot of the smoothed component of the WMTA from figure 4 [N.B. For the purposes of this study this curve will be referred to as the difference of the smoothed temperature anomaly curve – i.e. **DSTA**. It has units measured in degrees Celsius per month. In addition, the DSTA curve values have been scaled-up by a factor of 1000 to roughly match the variance of the LTF curve. This is done to aid the comparison between these two curves.

The comparison DSTA and LTF curves shows that that the timing of the peaks in the LTF curve closely match those seen in the DSTA curve for two 45-year periods. The first going from 1865 to 1910 and the second from 1955 to 2000. Note that these years are delineated by the black vertical lines in figure 7. During these two epochs, the aligned peaks of the LTF and the DSTA curves are separated from adjacent peaks by roughly the 9.6 years, which is close to the mean of 9.1 and 10.1469 years. This is in stark contrast to the 45-year period separating these two epochs (i.e. from 1910 to 1955), and the period after the year 2000, where the close

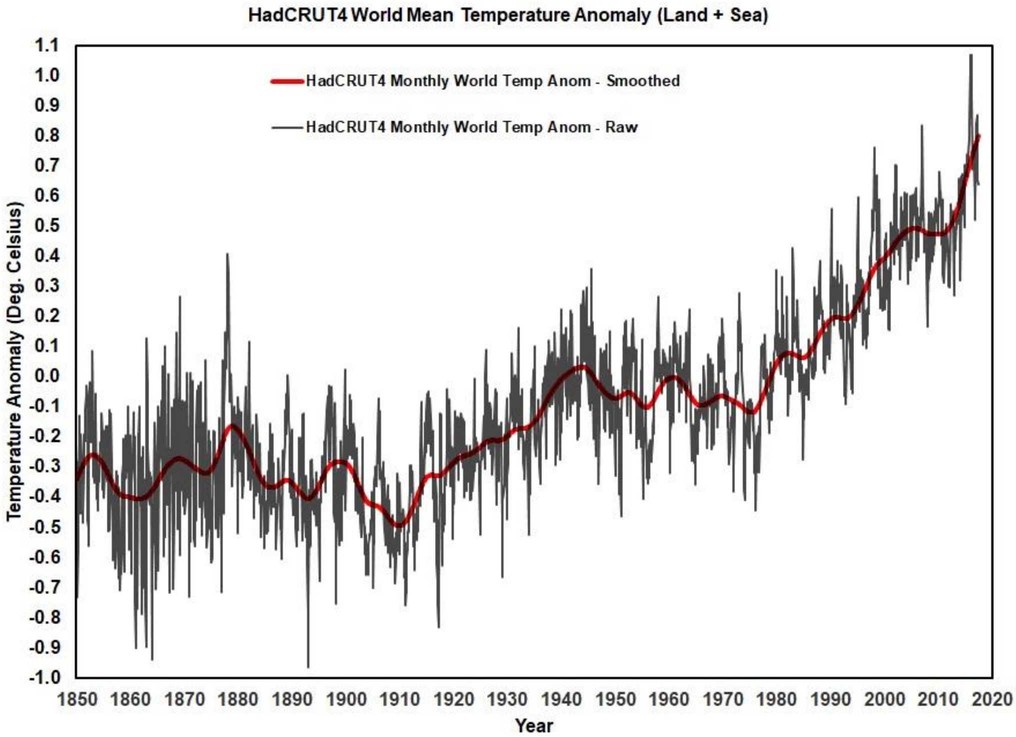

Figure 4

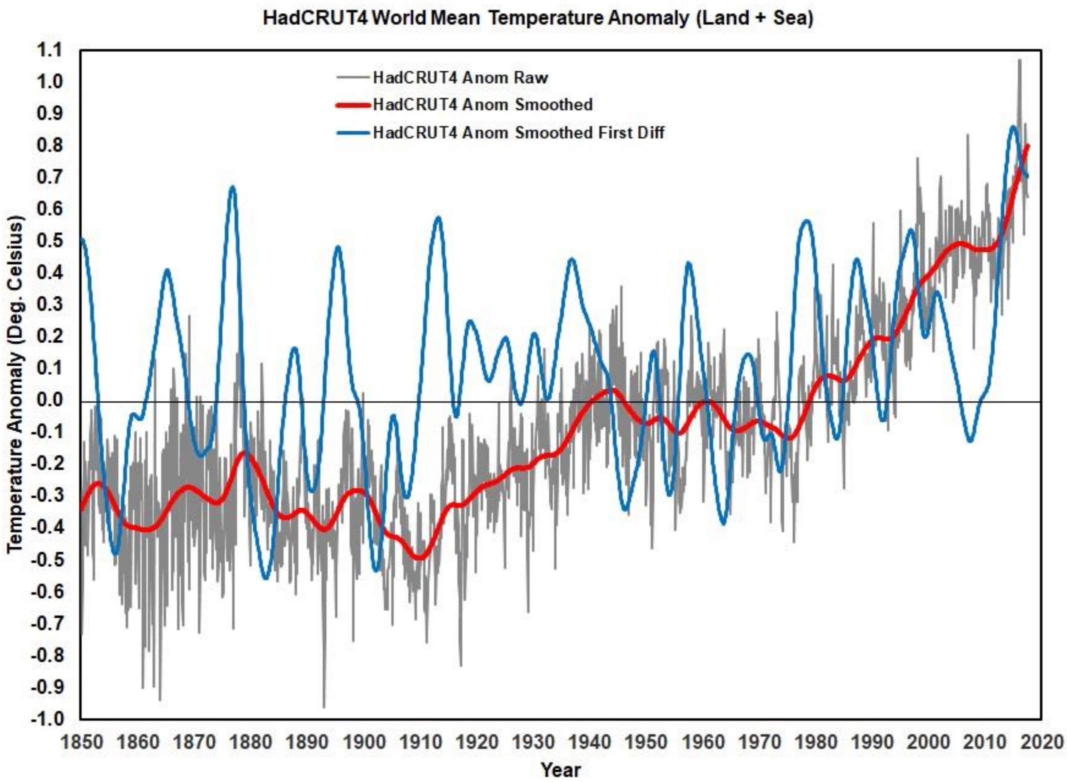

Figure 5

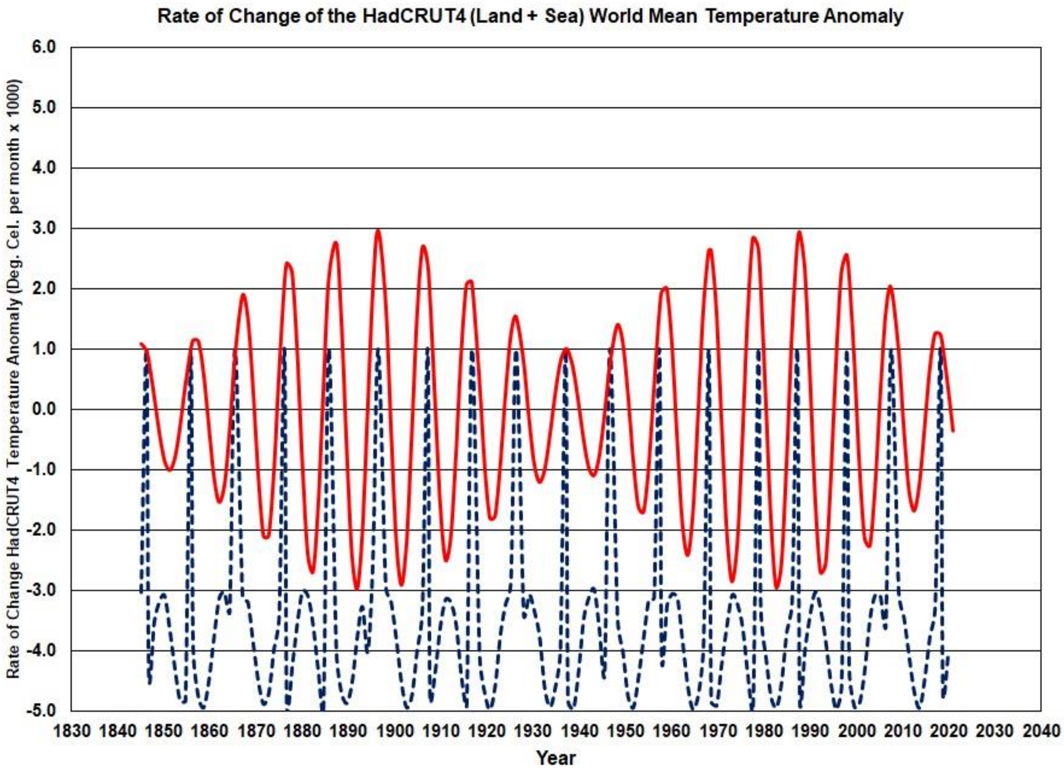

Figure 6

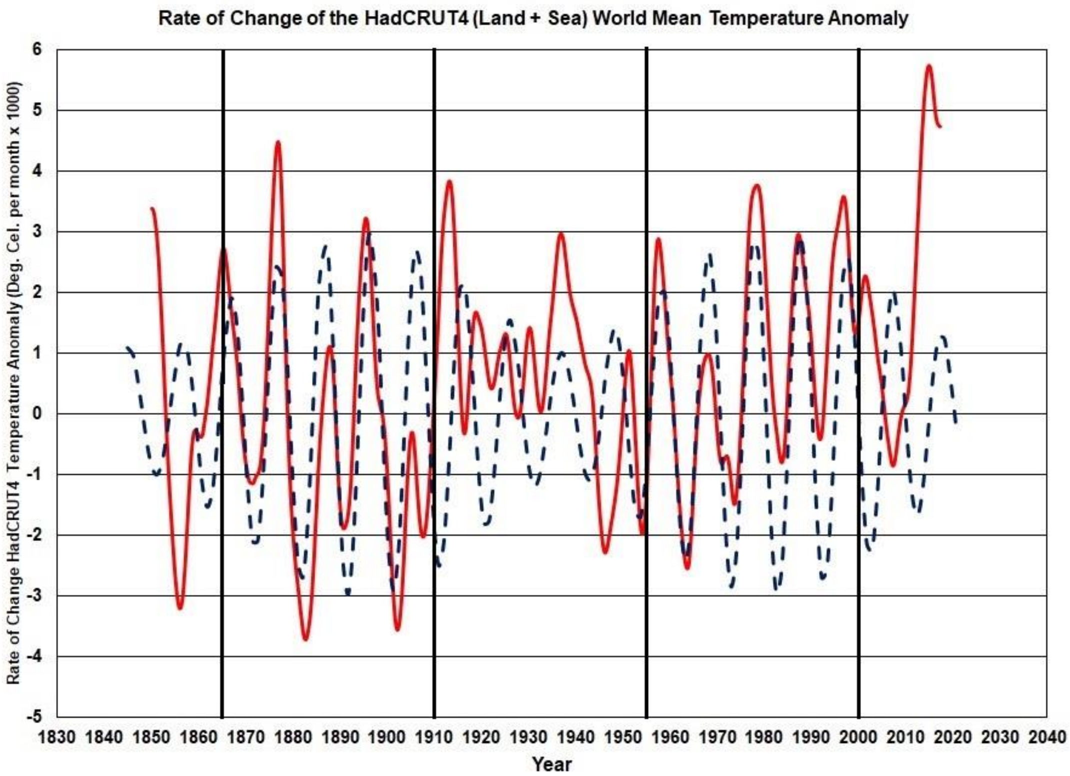

Figure 7

match between the timing of the peaks in LTF and DSTA curves breaks down, with the DSTA peaks becoming separated from their neighbouring peaks by approximately 20 years.

Hence, the variations in the **rate of change** of the smoothed HadCRUT4 temperature anomalies closely follow a “forcing” curve that is formed by the simple sum of two sinusoids, one with a 9.1-year period which matches that of the lunar tidal cycle, and the other with a period of 10.1469-year that matches that of half the Perigean New/Full moon cycle. This is precisely what you would expect if the natural periodicities associated with the Perigean New/Full moon tidal cycles were driving the observed changes in the world mean temperature on decadal time scales.

5. Discussion and Conclusions

Paper II shows that selecting the times when the lunar line-of-apse points directly towards or away from the Sun, at times that are very close to Equinoxes (/Solstices), is equivalent to selecting the times when strongest spring tidal peaks are crossing (/furthest from) the Earth’s equator. These are called the Equinox (/Solstice) spring tides since they are the strongest spring tidal events that take place nearest to the dates of the nominal Equinoxes (/Solstices).

In addition, Paper II establishes that the Equinox (/Solstice) spring tides are a good candidate for investigating the connection between the centennial-scale luni-solar seasonal alignment cycles discussed in paper I, and the lunar tidal cycle forcing on the world’s mean temperature, at decadal to sub-decadal time scales.

The Equinox spring tidal events that are closest to the Vernal Equinox naturally divides into five 31-year epochs that start in the years 1870, 1901, 1932, 1963, and 1994. The three lunar tidal epochs that start in 1870, 1932, and 1994 begin with a Perigean Full moon, so they are designated as Full Moon epochs. Similarly, the remining two epochs that start in 1901 and 1963 begin with a Perigean New moon, so they are designated as New Moon epochs.

Hence, paper II concludes that, during the Full Moon epochs, there is a significant alignment between the starting dates of moderate to strong El Ninos and the times when Equinox spring tidal events occur. It also concludes that, during New Moon epochs, there is a significant alignment between the starting dates of moderate to strong El Ninos and the times when Solstice spring tidal events occur. This means that there must be a connection between the occurrences of strongest Equinox/Solstice spring tidal events and the onset of El Ninos.

Wilson (2013), Tisdale (2012), and de Freitas and McLean (2013) show that whenever the relative strength and/or frequency of the El Niño events are greater than that of the La Niña events [i.e. the cumulative Extended Multivariate ENSO index (MEI) is trending positive] then global mean temperatures increase, and that whenever the relative strength and/or frequency of the La Niña events are greater than that of the El Niño events [i.e. the cumulative MEI is trending negative] then global mean temperature decreases.

Hence, the conclusion of paper II about the onset of El Niño events, combined with the conclusions of Wilson (2013), Tisdale (2012), and de Freitas and McLean (2013) about the role that the ENSO plays in heating and cooling the Earth's atmosphere, supports a prima facie case that there is some factor that links the Equinox/Solstice spring tidal events, with the times when the world's mean temperature either increases or decreases

Goodman (2013) proposes that the best way to study the changes in the climate "forcings" that impact the Earth's mean atmospheric temperature is to look at the first difference of the time series of the world-mean temperature, rather than the time series itself. Therefore, if the Perigean New/Full Moon cycles were to act as a forcing upon the Earth's atmospheric temperature, you would expect to see the natural periodicities of this tidal forcing clearly imprinted upon the time rate of change of the world's mean temperature.

Using both the adopted mean orbital periods of the Moon (see section 1), as well as calculated algorithms based upon published ephemerides (see section 2), this paper shows that the Perigean New/Full moon tidal cycles exhibit two dominant periodicities on decadal time scales.

The first is 10.1469 years (= 9 LEP's – ½ SynM), which is half of the 20.2937-year Perigean New/Full moon cycle. This represents the time required for the resynchronization of the phases of the Moon with the epochs when the perigee of the lunar orbit points directly towards or directly away from the Sun.

The second is 9.0554 years (= 8 LEP's), which closely matches the 9.0713-year Lunar Tidal Cycle (LTC). This is the harmonic mean of the prograde 8.8475-year Lunar Anomalistic Cycle (LAC) and half of the retrograde 18.6134-year Lunar Nodal Cycle (LNC).

Hence, if the Perigean New/Full moon tidal cycle were to act as a "forcing" on the world's mean temperatures, you would expect to see periodicities in the first difference of the world's mean temperature anomaly (WMTA) data that were a simple sinusoidal superposition of the two dominant periods associated with the lunar tidal cycles (i.e. 9.1 and 10.1469 tropical years).

This paper makes a comparison between two times series that describe these phenomena. The first time series represents the lunar tidal forcing (LTF) curve. This curve is a superposition of a sine wave of amplitude 1.0 unit and period 9.1 tropical years, with a sine wave of amplitude 2.0 units and a period 10.1469 (= 9 FMC's) tropical years, that is specifically aligned to match the phase of the Perigean New/Full moon cycle. The second time series represents the difference curve for the HadCRUT4 monthly (Land + Sea) world mean temperature anomaly (DSTA), from 1850 to 2017.

A comparison between the LTF and DSTA curves shows that that the timing of the peaks in the LTF curve closely match those seen in the DSTA curve for two 45-year periods. The first going from 1865 to 1910 and the second from 1955 to 2000. During these two epochs, the aligned peaks of the LTF and the DSTA curves are separated from adjacent peaks by roughly the 9.6 years, which is close to the mean of 9.1 and 10.1469 years. In addition, the comparison shows that there is a 45-year period separating the first two epochs (i.e. from 1910 to 1955), and a period after the year 2000, where the close match between the timing of the peaks in LTF and DSTA curves breaks down, with the DSTA peaks becoming separated from their neighbouring peaks by approximately 20 years.

Hence, the variations in the **rate of change** of the smoothed HadCRUT4 temperature anomalies closely follow a "forcing" curve that is formed by the simple sum of two sinusoids, one with a 9.1-year period which matches that of the lunar tidal cycle, and the other with a period of 10.1469-year that matches that of half the Perigean New/Full moon cycle. This is precisely what you would expect if the natural periodicities associated with the Perigean New/Full moon tidal cycles were driving the observed changes in the world mean temperature (about the long-term linear trend) on decadal time scales.

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CONFLICT OF INTEREST

No outside funding was used to conduct this work. No conflicts of interest are involved.

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