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Signals from the planets, via the Sun to the Earth

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Abstract. The best method for identification of planetary forcing of the Earth's climate is to investigate periodic variations in climate time series. Some natural frequencies in the Earth climate system seem to be synchronized to planetary cycles, and amplified to a level of detection. The response by the Earth depends on location, and in global averaged series, some planetary signals may be below detection. Comparing sea level rise with sunspot variations, we find phase variations, and even a phase reversal. A periodogram of the global temperature shows that the Earth amplifies other periods than observed in sunspots. A particular case is that the Earth amplifies the 22 yr Hale period, and not the 11 yr Schwabe period. This may be explained by alternating peak or plateau appearance of cosmic ray counts. Among longer periods, the Earth amplifies the 60 yr planetary period and keeps the phase during centennials. The recent global warming may be interpreted as a rising branch of a millennium cycle, identified in ice cores and sediments and also recorded in history. This cycle peaks in the second half of this century, and then a 500 yr cooling trend will start. An expected solar grand minimum due to a 200 yr cycle will introduce additional cooling in the first part of this century.

1 Introduction

The near similarity of the length of the 11 yr sunspot cycle and the 11.8 yr orbital period of Jupiter has led to speculations about a possible connection between the planets and solar activity periods. This is discussed in other papers in this issue (Mörner, 2013a; Scafetta and Willson, 2013b; Solheim, 2013; Tattersall, 2013; Wilson, 2013).

The general argument against the hypothesis that the planets may have some control on the Earth's climate is that the effect of gravity on the Earth or the Sun from the planets is too small to have any direct effect (de Jager and Verdsteegh, 2005). In addition, the giant planets may be too far away to interact with the magnetic fields of the Earth or the Sun. In order to have an effect, the weak signal from the planets needs to be amplified, maybe of the order of 10^4–10^5. Recently two possible mechanisms for amplification in the Sun have been proposed.

Abreu et al. (2012) propose that tidal torque from the planets may introduce deformation of a non-spherical tachocline and change its capacity for storage of magnetic flux tubes, which may develop into sunspots. The amplification can be the result of a resonance effect meditated by gravity waves. A non-spherical tachocline is consistent with helioseismological observations.

Another mechanism proposed by Scafetta (2012a) is that the nuclear burning in the solar core is modulated by tidal interaction from the planets. From mass–luminosity relations for solar type stars, he calculates that the amplification can be of the order of 4×10^6, which is enough to explain the TSI (total solar irradiance) variations observed. The cyclic variation in nuclear burning is assumed to be transferred to the surface of the Sun by gravity waves.

These amplification mechanisms are not proved, but strongly supported by similarities in periodicities calculated from planetary orbits and observed in ^{10}Be, ^{14}C and other solar activity indicators (Scafetta, 2010; Abreu et al., 2012).

In the following we will assume that an amplification of a tiny planetary signal takes place in the Sun, and that this signal is imbedded in the solar wind or in TSI variations. We will investigate the response to some of these planetary signals in our climate system. There are many processes between the Sun and the climate system, which may modify the frequency, amplitude and phase of a planetary–solar signal (Mörner, 2013a, Fig. 6). The response to a solar signal may differ at various places on the Earth, and the response may

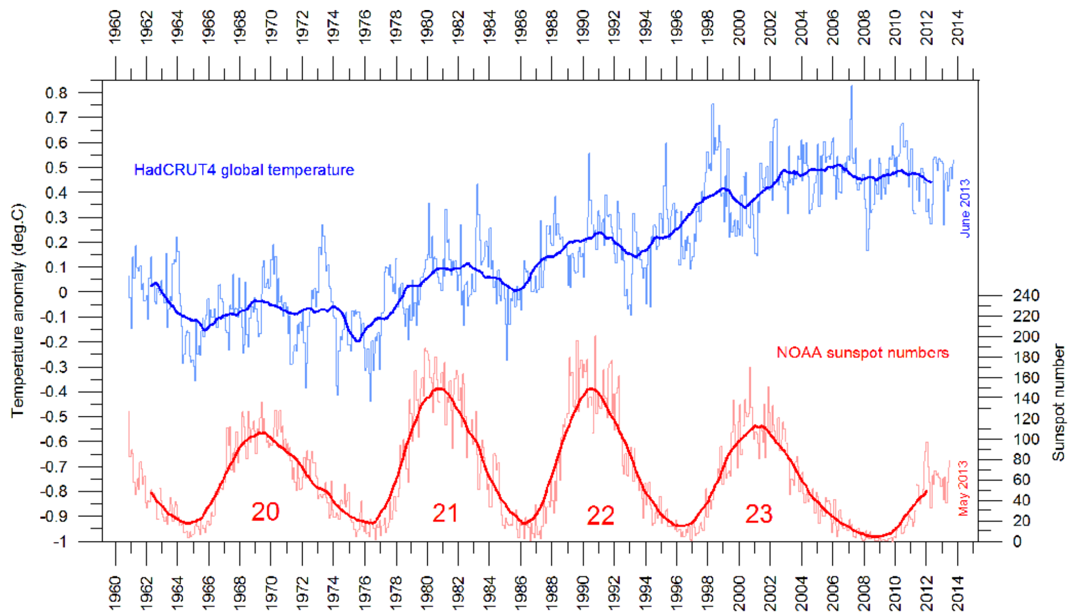

Figure 1. The thin lines show monthly sunspot numbers (red) since 1960 and HadCRUT4 monthly values of global temperature (blue). The thick lines are 3 yr running averages. Sunspot cycle numbers for SC20–23 are indicated (graph provided by Ole Humlum).

be phase-shifted due to the thermal inertia and heat transported by air and ocean or other processes. We may therefore not expect to find the same response everywhere, and in global averages some signals may be below detection. On the other hand, if we find phase-locked solar periods, it is a high probability that they are from the Sun. In addition there may be natural frequencies in the Earth's climate system that respond to external periodic forcing. Scafetta (2010) found 11 periods between 5 and 100 yr in global temperature series, corresponding approximately to periods calculated from the orbits of the planets (see Fig. 7).

In this investigation we will first compare global temperature and solar activity (Sect. 2), then sea-level change and solar activity (Sect. 3). In Sect. 4 we will investigate if periods between 5 and 80 yr observed in the Sun, with assumed planetary origin, also are present in global temperature series, and show how cosmic rays may modulate the signal. In Sect. 5 we look for solar signals in the climate on centennial and millennial timescales, including historical evidence of solar activity-related climate periods. Finally, in Sect. 6 we discuss our findings, and what this may tell us about the Earth's future climate.

2 Global temperature and solar activity

A comparison of the variations of sunspots numbers with the global temperature is shown in Fig. 1. The general picture is that the temperature roughly follows the sunspot variations up and down, indicating a heating and cooling sequence. The effect is of the order of 0.1–0.2 °C in a solar cycle (SC) and largest in SC21. In SC21–23, it looks as if the global temperature does not return to the same level as in the previous minima. One explanation may be that the cycle is too short for a complete cooling, and the temperature increase in 1980–2000 is a result of the higher solar activity in SC21–22 compared to SC20 and 23. Another possibility is that a warming trend started in about 1976 and leveled off after 2000. We shall later (Fig. 3) see that this warming trend may be interpreted as part of a 60 yr warming/cooling cycle.

A detailed analysis of the relation between the cycle-averaged sunspot number and global temperature in the same interval, delayed 3 yr, shows a correlation of $r = 0.77$ for SC10–21, and $r = 0.975$ if SC16–19 are excluded (Stauning, 2011). In this period (1923–1964) solar activity increased significantly, and the temperature variations were for a while leading the sunspot number variations. The maximum temperature increase during one cycle was 0.05 °C, which corresponds to about 0.1 % irradiance increase over a cycle. He concludes that changes in terrestrial temperatures are related to sources different from solar activity after 1985 (SC22).

A much stronger response is observed by comparing the sea surface temperature (SST) global ocean heat content (OHC) and Atlantic OHC variations folded over solar cycles since 1950. The correlations between the reconstructed solar flux and SST, OHC global and OHC Atlantic are $r = 0.83$, 0.79 and 0.86, respectively (Shaviv, 2008), and the peak-to-peak sea surface temperature varies from 0.08 to 0.10 °C over a solar cycle. This is a factor of five larger than that calculated from the TSI variations, and requires an amplification mechanism, which is not identified, but could be low cloud cover modulated by the galactic cosmic ray (GCR) variations (Shaviv, 2008, Fig. 3).

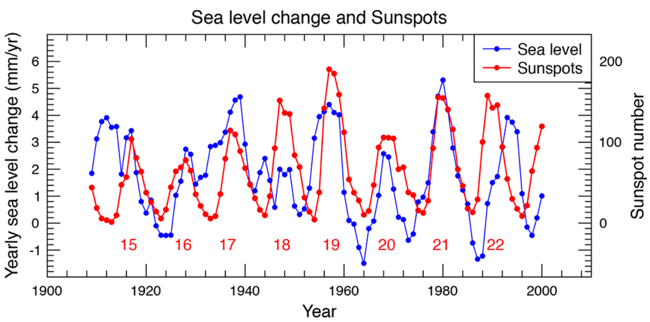

Figure 2. A comparison of yearly sea level change (Holgate, 2007) and yearly averaged sunspot numbers.

3 Sea level change and solar activity

A stronger effect related to solar cycles is seen in Fig. 2, where the yearly averaged sunspot numbers are plotted together with the yearly change in coastal sea level (Holgate, 2007). The sea level rates are calculated from nine distributed tidal gauges with long records, which were compared with a larger set of data from 177 stations available in the last part of the century. In most of the century the sea level varied in phase with the solar activity, with the Sun leading the ocean, but in the beginning of the century they were in opposite phases, and during SC17 and 19 the sea level increased before the solar activity.

The coastal sea level variation cannot be explained as due to expansion/contraction of the oceans due to heating/cooling during a solar cycle as proposed by Shaviv (2008) simply because, near the shore, the thermal expansion becomes zero since the expansion is proportional to the depth (Mörner, 2013b). The good correlation and nearly in-phase response between solar activity and sea level indicates that this is a direct mechanical response – and not a thermal response that needs time to heat up and cool, and therefore shows delayed response. This may be seen comparing Figs. 1 and 2.

An explanation for the sea level variations is found in the extremely good correlation between sunspots and rotation of the Earth expressed as semi-annual length of day (LOD) variations (Le Moël et al., 2010, their Fig. 1). The sunspot numbers are leading approximately 1 yr, and the correlation coefficient is $r = 0.76$ after detrending. They attribute the 10.5 yr modulation of LOD through a modulation of the excitation function of the zonal wind, and also show that GCR (see Fig. 5) correlates extremely well with the semi-annual LOD variations. This indicates that the GCR may act as a link between solar activity variations and the Earth rotation through various proposed mechanisms such as seasonal cloud variations, variations in the Earth's electric circuits or atmospheric aerosols, which again are modulated by the solar wind (Svensmark and Friis-Christensen, 1997; Svensmark et al., 2013; Tinsley et al., 2007). If the solar wind carries signals from the planets, either from their control of the solar activity by tidal effects or by direct electro-magnetic interaction, this signal may be transferred to the Earth's climate system.

4 The strong 60, 22 and 9 yr periods, but weak 11 yr period in the global temperature

A periodogram of sunspot number variations since 1850 shows that the strongest periods are in the 10–12 yr Schwabe band (Fig. 3a), while the Hale period at 22 yr is quite weak. Figure 3b shows a periodogram for the same period for the HadCRUT4 global temperature. Here the dominant periods are 155, 66, 21.6 and 9.14 yr. The difference means that the Earth as a whole does not respond to the dominant solar periods. This will be discussed later.

The global temperature variations since 1850 can be modeled with a linear trend of +0.0047 °C yr^{-1} and the four dominant periods: 155, 66, 21.6 and 9.14 yr as shown in the periodogram in Fig. 3b. The resulting temperature curve with this model is shown in Fig. 4.

We had expected a strong signal at $P = 10$–12 yr, where the sunspot variation is strongest, as shown in Fig. 3a, but instead we observe a strong 22 yr period, and an even stronger 66 yr component. The differences between Fig. 3a and b may tell us something about filtering and amplification of solar signals in our climate system.

The dominance of a 22 yr period compared with a 10–12 yr period can be explained by GCR variations. The 22 yr Hale period is the Sun's magnetic period, and represents a polarity change in the two hemispheres of the Sun. This is observed in the GCR variations as shown in Fig. 5. During solar cycles with negative polarity of the Sun's northern polar field, the GCR variation has a peaked form. In the other phase it has a plateau. This is an effect of the differences in cosmic ray drift in the positive and negative phases of the magnetic cycle. Integrated GCR counts are higher in plateau cycles compared with peak cycles (Ogurtsov et al., 2003), and this may be the reason for the amplification of the 22 yr component in the global temperature curve.

The difference between 11 and 22 yr climate response is also seen in the latitudinal difference in the rhythm of growth in pine trees, as shown in Fig. 6, where the 20 yr period dominates north of 65 degrees latitude, while the 10 yr period dominates at lower latitudes. This may be a result of differences in atmospheric circulation or effects of cosmic rays of lower energies reaching deeper at higher latitudes. For Svalbard at 78° N, an analysis by Humlum et al. (2011) shows that periods 17 and 26 yr are much stronger than those at 10–12 yr.

The filtering, phase changes, and response of natural frequencies make it difficult to find exact correspondence between the solar and planetary periods in the Earth's climate system. One possibility is to search for quasi-periodic oscillations in the same frequency bands as forced by the

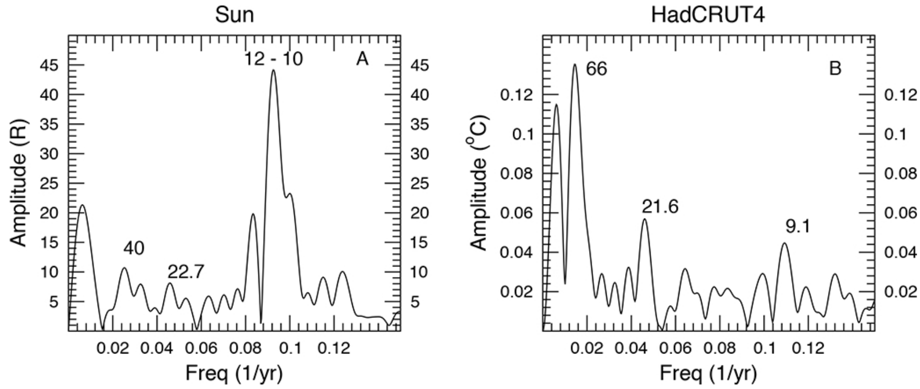

Figure 3. Periodogram of the sunspot record from 1850 **(A)** and the global temperature for the same period **(B)**. The periods (in yr) of the strongest peaks are indicated. R is the average yearly sunspot number. The strongest periods (in yr) are shown.

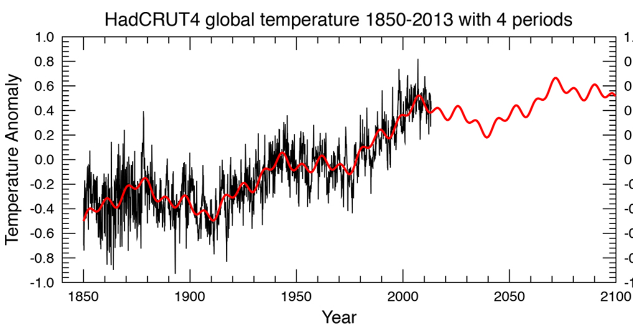

Figure 4. HadCRUT4 monthly averages of global temperature anomalies compared with a simple model consisting of a linear trend (0.0047 °C yr^{-1}) and four harmonic components with periods 155, 66, 21.6 and 9.14 yr.

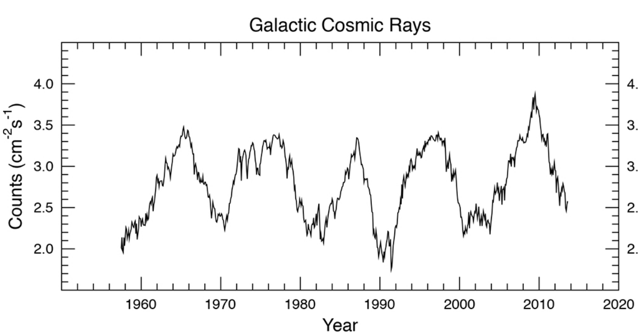

Figure 5. Monthly values of cosmic ray intensity measured in the Murmansk region, 1965–2013 at an altitude of ≈ 25 km, with a cut-off of 0.6 GV (Stozhkov et al., 2007, 2009).

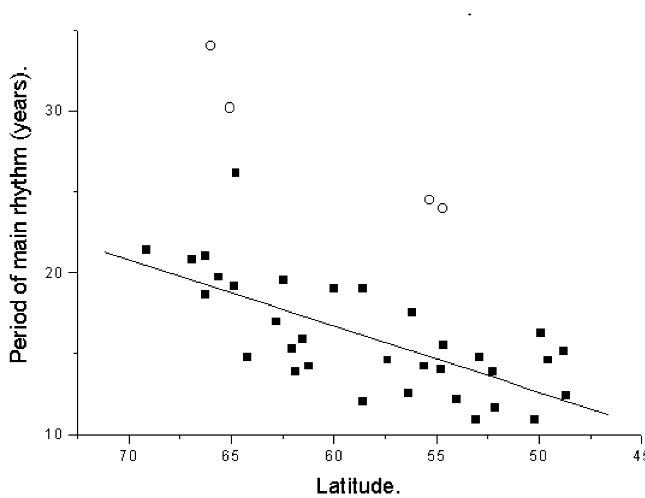

Figure 6. Latitudinal dependence of the rhythmic periods of pine growth along the Murmansk–Carpathians profile (Konstantinov et al., 1986). Squares – normal conditions, open circles – bog conditions.

planetary system. This is done by Scafetta (2010, 2012a, b, c, 2013a, b). One example is his power spectra analysis of the HadCRUT4 temperature series (Fig. 7), which show six peaks present in the Northern and Southern hemispheres, land and ocean separately (Scafetta, 2010). The same peaks can be found in power spectra of the velocity of the Sun relative to the solar system center of mass (SSCM). In the temperature series there is also a strong component of a 9.1 yr lunar cycle. The 20 and 60 yr modulations may be explained as a signal due to the orbits of Jupiter and Saturn (Scafetta, 2010, 2013b).

The 60 yr cycle is clearly present in the Pacific decadal oscillation (PDO) and the Atlantic multi-decadal oscillation (AMO), with phases coherent with a planetary signal since at least 1650. This is also the case for the Indian summer monsoon variations and many other climate series (Scafetta, 2012b, c).

Yndestad et al. (2008) have shown that a 74.4 yr sub-harmonic of the lunar 18.6 yr nodal tide cycle controls the decadal temperature and salinity of the North Atlantic Water current, which has a major influence on the climate in northern Europe. The lunar 74 yr period may also contribute to the global average temperature's 60 yr cycle.

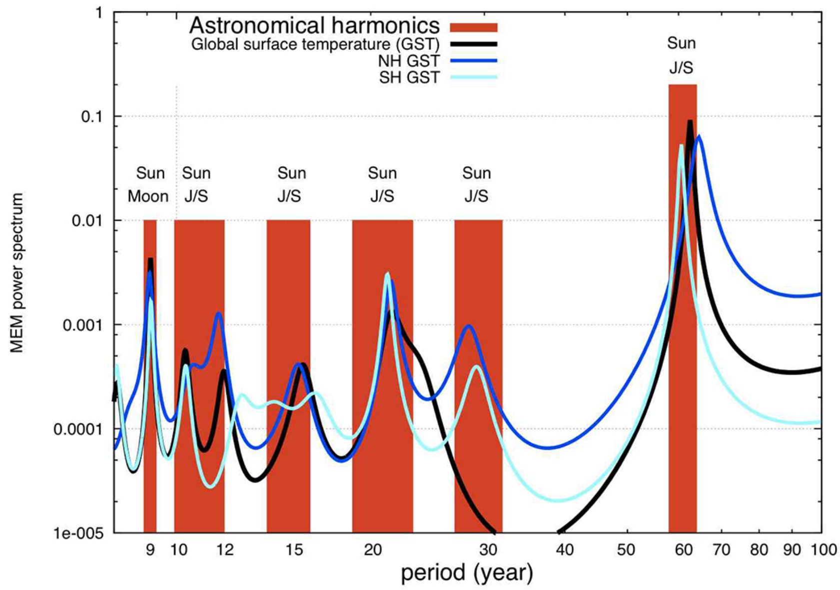

Figure 7. Power spectra of the HadCRUT4 global surface temperature (GST) (1850–2012) (black) and of the Northern Hemisphere and Southern Hemisphere GSTs using the maximum entropy method (MEM); red boxes represent major astronomical oscillations associated with a decadal solilunar tidal cycle (about 9.1 yr), and the major heliospheric harmonics associated with Jupiter and Saturn (from Scafetta and Willson, 2013a).

5 Sun and planets control the climate on centennial and millennial timescales

Galactic cosmic rays are modulated by the magnetic field transported from the Sun to the Earth by the solar wind. The variation of GCR can be determined from dating of ^{14}C abundances in tree rings, and ^{10}Be in ice cores. Two 9400 yr long ^{10}Be data records from the Arctic and the Antarctica, and a ^{14}C record of equal length, have been analyzed by McCracken et al. (2013). They determined 15 significant periodicities between 40 and 2320 yr. The oscillations may either originate in the Sun, or be imprinted in the solar wind by other members of the solar system.

If we look at the relative amplitude of the 15 periods (McCracken et al., 2013, Fig. 4), the periods 2310, 976, 708, and 208 yr are strongest, while the periods 1768, 1301, 1125, 508 and 351 yr are weaker. Also periods 65, 87.3, 104.5, 129.8, 148 and 232 yr are detected.

Many of these periods may be related to the planets (Abreu et al., 2012). Scafetta (2012b) has constructed a simple harmonic model based on three periods in the Schwabe sunspot cycle 11 yr band: 9.93, 10.87 and 11.86 yr, and the beat cycles between them. The 9.93 yr period is the Jupiter/Saturn spring period (half the synodic beat period), 11.86 yr the Jupiter orbital period, and 10.87 yr a quasi-11 yr solar dynamo period theoretically deduced. From these three periods, four beat periods of 63, 118, 135 and finally 970 yr are created. Solheim (2013) shows that the 10.87 yr dynamo period splits into two periods (11.01 and 10.66 yr) when sunspot series back to 1700 are analyzed. He also finds modulation periods of 440, 190 and 86 yr in the length of solar cycles.

The amplitudes of the climate periods in Scafetta's harmonic model were determined from the relative amplitudes in the sunspot power spectrum, and the phases were determined from the perihelion date for Jupiter and the date for the strongest spring tide of the Jupiter–Saturn conjunction. The phase of maximum amplitude for the combined beat period (T_{123} = 970 yr) was determined from the beat of the other two beat periods, and its amplitude from two reconstructions of total solar irradiance since 800 AD (Bond et al., 2001; Steinhilber et al., 2009). The result is quasi-periodic regular periods of about 120–140 yr plus a quasi-millennium cycle, which has a maximum around 2060. The quasi-millennium cycle could also be forced on the Sun by the rotation of the Trigon, the great conjunctions of Jupiter and Saturn with a period of 960 yr (Scafetta, 2012b).

Another interesting period is a combination of the synodic period of the Uranus–Neptune conjunction of 171.44 yr and the 9× Jupiter–Saturn conjunction period of 178.787 yr, which has a beat period of 4200 yr, which means that the four giant planets create quarter cycles about 55× Jupiter–Saturn synodic periods, which is 1100 yr, for the motion of the Sun around the solar system center of mass or SSCM (Charvátová, 2000).

The connection between solar activity and climate on secular and millennial timescales is documented in many studies comparing solar activity and climate. The most famous is perhaps Bond et al. (2001), who compared ice debris outside

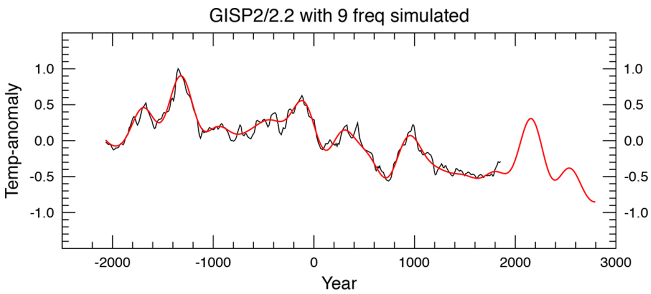

Figure 8. A simple harmonic model for the GISP2 temperature variations, with extension to 2800 AD.

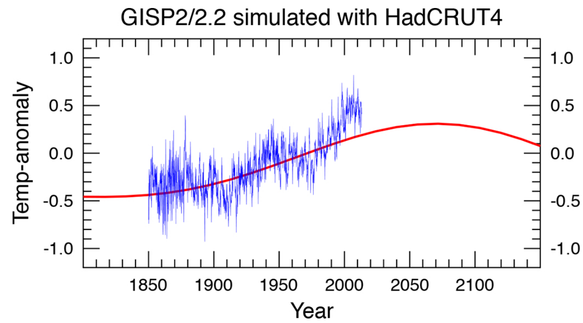

Figure 9. The red curve is the harmonic model based on the GISP2 series (Fig. 8) shifted 85 yr (earlier) and compared with the HadCRUT4 monthly global temperatures including June 2013 (blue).

Greenland with ^{14}C abundances, and found a very good correlation during 12 000 yr.

Analysis of a temperature reconstruction from the Greenland ice core GISP2 the last 4000 yr by Humlum et al. (2011) showed dominant periods of 1130, 790–770, 560 and 390–360 yr. The last period was strong in the beginning of the record, but has since weakened. In order to compare this temperature series with modern global temperatures, we compute the average and divide by 2.2, which is the relation between Arctic and global temperature variations. Figure 8 shows the resulting temperature record and a model based on nine periods where 2804, 1186 and 556 yr are the dominating in addition to a linear cooling trend since the Holocene maximum 7000 yr BP.

This simple harmonic model gives a fair reconstruction of historic warm periods – the Medieval Warm Period around 1000, the Roman Warm Period about 200 BC and the Minoan Warm Period about 1400 BC – and shows that the modern warm period is a result of periodic variations, which will have a peak in the near future.

We find that all the 10 periods observed in solar variations with $P > 200$ yr (McCracken et al., 2013) are present in the GISP2 temperature reconstruction, but that the Earth (or the Greenland ice) for some reason has amplified the period around 1000 yr and its harmonics at about 500 yr. In addition the periodogram of GISP2 temperature data shows periods of 189, 179 and 168 yr, which also are related to planets: the 178 yr period is the trefoil period where the pattern of the solar orbit around the SMMC repeats, and is also close to the 9× Jupiter–Saturn conjunction period (Jose, 1965). A 190 yr period is also found controlling the length of the sunspot cycle (Solheim, 2013).

The GISP2 may have a timing error of decades and/or show temperatures out of phase with the global temperature variation. In Fig. 9 we compare the simulation determined from the GISP2 data with the HadCRUT4 global temperature series, and find a good fit if we introduce a shift of 85 yr, which means the response in the ice core as shown in Fig. 8 is delayed 85 yr compared with the instrumental temperature record. This suggests that a modern temperature maximum will take place about 2070. This corresponds to the maximum determined by Scafetta (2012b) in his Jupiter–Saturn–Sun harmonic model discussed above. The reason for the shift we have introduced is at present unexplained, but should be investigated more closely.

If we are as close to the millennial temperature peak as indicated in Fig. 9, the global temperature will increase at most 0.2 °C due to this period in this century. The global temperature development will therefore be dominated by the shorter periods, in particular the 60 yr period as observed in Figs. 3 and 4b. Based on an analysis of the length of the solar cycle since 1610, it is concluded (Richards et al., 2009; Solheim, 2013) that a grand solar minimum is expected to occur in the first part of this century. The global temperature may then be lower than indicated by the millennium peak in Fig. 9, but still higher than during the the Little Ice Age of the Maunder Minimum (1640–1720), which happened during a minimum phase in the millennium period.

6 Conclusions

The orbits of planets represent stable periodic oscillations, which makes the Sun move in a complicated orbit around the SSMC. The variations in these orbits create periodic tides, which can be amplified by processes in the solar tachocline, which seems to have a controlling effect on the solar dynamo (Abreu et al., 2012). The tides may also modulate the nuclear burning rate in the solar center and create gravity waves, which may transmit a signal to the outer layers of the Sun (Scafetta, 2012a), which modulates the solar activity.

Luminosity variations and solar activity variations may be detected at the Earth either as TSI variations, where signals from the inner planets are detected (Scafetta and Willson, 2013a, b), or in the climate related to the Schwabe sunspot cycle or the Hale magnetic cycle. The temperature response to the Schwabe cycle is small, and may be restricted to certain geographic regions, while the Hale cycle response can be detected in the global average temperature. Since this is a magnetic cycle, and the magnetic field controls the influx of galactic cosmic ray particles, the amplification of the

Hale cycle is an indication of GCR influence on climate. The coastal sea level is strongly modulated by the Schwabe cycle, and this is explained by LOD variations modulated by zonal winds, which again are modulated by GCR controlled by the solar wind.

However, the 60 yr cycle is the dominating one in temperature measurements since 1850, and it is followed back to 1650 in the PDO cycle and the AMO cycle (Scafetta, 2012c). This period may be forced by a beat between the Jupiter orbital period and the Jupiter/Saturn spring period. The beat between these periods and the solar dynamo period creates other beat periods of 120–140 yr, which is also observed in solar activity indicators such as ^{14}C and ^{10}Be abundance variations. Of particular interest is the 178 yr SSMC variation created by a the four giant planets, which have an even stronger modulation with a period of 1100 yr, which is the period between temperature maxima the last 4000 yr.

Calibrations of the phase of the millennium cycle by two different methods give the same answer: we may expect the millennium temperature cycle to reach a maximum around 2060–2080, and then it will decline the next 5–600 yr. This means that an expected grand solar minimum this century, which is predicted to start in the period 2030–2050 due to the Sun's 200 yr cycle (Abdusamatov, 2007; Scafetta, 2010), will not result in as low temperatures as observed during the Maunder Minimum, which took place in the minimum phase of the millennial cycle. This is in line with the forecast by Mörner (2011, Fig. 6).

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