ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

Volume 80, May 2012, Pages 296-311

Multi-scale harmonic model for solar and climate cyclical variation throughout the Holocene based on Jupiter–Saturn tidal frequencies plus the 11-year solar dynamo cycle

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https://doi.org/10.1016/j.jastp.2012.02.016

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Abstract

The Schwabe frequency band of the Zurich sunspot record since 1749 is found to be made of three major cycles with periods of about 9.98, 10.9 and 11.86 years. The side frequencies appear to be closely related to the spring tidal period of Jupiter and Saturn (range between 9.5 and 10.5 years, and median 9.93 years) and to the tidal sidereal period of Jupiter (about 11.86 years). The central cycle may be associated to a quasi-11-year solar dynamo cycle that appears to be approximately synchronized to the average of the two planetary frequencies. A simplified harmonic constituent model based on the above two planetary tidal frequencies and on the exact dates of Jupiter and Saturn planetary tidal phases, plus a theoretically deduced 10.87-year central cycle reveals complex quasi-periodic interference/beat patterns. The major beat periods occur at about 115, 61 and 130 years, plus a quasi-millennial large beat cycle around 983 years. We show that equivalent synchronized cycles are found in cosmogenic records used to reconstruct solar activity and in proxy climate records throughout the Holocene (last 12,000 years) up to now. The quasi-secular beat oscillations hindcast reasonably well the known prolonged periods of low solar activity during the last millennium such as the Oort, Wolf, Spörer, Maunder and Dalton minima, as well as the 17 **115-year** long oscillations found in a detailed temperature reconstruction of the Northern Hemisphere covering the last 2000 years. The millennial three-frequency beat cycle hindcasts equivalent solar and climate cycles for 12,000 years. Finally, the harmonic model herein proposed reconstructs the prolonged solar minima that occurred during 1900–1920 and 1960–1980 and the secular solar maxima around 1870–1890, 1940–1950 and 1995–2005 and a secular upward trending during the 20th century: this modulated trending agrees well with some solar proxy model, with the ACRIM TSI satellite composite and with the global surface temperature modulation since 1850. The model forecasts a new prolonged solar minimum during 2020–2045, which would be produced by the minima of both the 61 and 115-year reconstructed cycles. Finally, the model predicts that during low solar activity periods, the solar cycle length tends to be longer, as some researchers have claimed. These results clearly indicate that both solar and climate oscillations are linked to planetary motion and, furthermore, their timing can be reasonably hindcast and forecast for decades, centuries and millennia. The demonstrated geometrical synchronicity between solar and climate data patterns with the proposed solar/planetary harmonic model rebuts a major critique (by Smythe and Eddy, 1977) of the theory of planetary tidal influence on the Sun. Other qualitative discussions are added about the plausibility of a planetary influence on solar activity.

Highlights

► Holocene-to-now solar dynamics is hindcast with Jupiter/Saturn/Schwabe harmonics. ► Holocene-to-now climate variability is reconstructed with the same harmonics. ► Major natural beat harmonics with period 61, 115, 130 and 983 years are discovered. ► Oort, Wolf, Sporer, Maunder and Dalton solar grand minima (ice-ages) are explained. ► A new grand solar minimum (climate cooling?) is expected to occur in 2020–2045 A.D.

Introduction

It is currently believed that solar activity is driven by internal solar dynamics alone. In particular, the observed quasi-periodic 11-year cyclical changes in the solar irradiance and sunspot number, known as the Schwabe cycle, are believed to be the result of solar differential rotation as modeled in hydromagnetic solar dynamo models (Tobias, 2002, Jiang et al., 2007). However, solar dynamo models are not able of hindcasting or forecasting observed solar dynamics. They fail to properly reconstruct the variation of the solar cycles that reveal a decadal-to-millennial variation in solar activity (Eddy, 1976, Hoyt and Schatten, 1997, Bard et al., 2000, Ogurtsov et al., 2002, Steinhilber et al., 2009).

Ogurtsov et al. (2002) studied the power spectra of multi-millennial solar related records. These authors have found that in addition to the well-known Schwabe 11-year and Hale 22-year solar cycle, there are other important cycles. They found that: (1) an ancient sunspot record based on naked eye observations (SONE) from 0 to 1801 A.D. presents significant frequency peaks at 68-year and 126-year periods; (2) a ^{10}Be concentration record in South Pole ice data for 1000–1900 A.D. presents significant 64-year and 128-year cycles; (3) a reconstruction of sunspot Wolf numbers from 1100 to 1995 A.D. presents significant frequency peaks at 60-year and 128-year periods. Longer cycles are present as well. The 50–140 year band is usually referred to as the Gleissberg frequency band. The Suess/de Vries frequency band of 160–260 years appears to be a superior harmonic of the Gleissberg band. Periodicities of 11 and 22 years and in the 60–65, 80–90, 110–140, 160–240, ~ 500, 800–1200 year bands, as well as longer multi-millennial cycles are often reported and also found in Holocene temperature proxy reconstructions (Schulz and Paul, 2002, Bard et al., 2000, Ogurtsov et al., 2002, Steinhilber et al., 2009, Fairbridge and Shirley, 1987, Vasiliev and Dergachev, 2002). In particular, Ogurtsov et al. (2002) also found that mean annual temperature proxy reconstructions in the northern hemisphere from 1000 to 1900 present a quite prominent 114-year cycle, among other cycles.

None of the above cycles can be explained with the models based on current mainstream solar theories, probably because solar dynamics is not determined by internal solar mechanisms alone, as those theories assume, and further the physics explaining the dynamical evolution of the Sun is still largely unknown.

An alternative theory has been proposed and studied since the 19th century and it was originally advocated even by well-known scientists such as Wolf (1859), who named the sunspot number series. This thesis was also advocated by many solar and aurora experts (Lovering et al., 1868) and by other scientists up to now (Schuster, 1911, Bendandi, 1931, Takahashi, 1968, Bigg, 1967, Jose, 1965, Wood and Wood, 1965, Wood, 1972, Dingle et al., 1973, Okal and Anderson, 1975, Fairbridge and Shirley, 1987, Charvátová, 1989, Charvátová, 2000, Charvátová, 2009, Landscheidt, 1988, Landscheidt, 1999, Hung, 2007, Wilson et al., 2008, Scafetta, 2010, Wolff and Patrone, 2010, Scafetta, 2010, Scafetta, 2012, Scafetta, submitted for publication).

Indeed, the very first proposed solar cycle theory claimed that solar dynamics could be partially driven by the varying gravitational tidal forces of the planets as they orbit the Sun. However, since the 19th century the theory has also been strongly criticized in many ways. For example, it was found that Jupiter's period of 11.86 years poorly matches the 11-year sunspot cycle: see the detailed historical summary about the rise and fall of the *first solar cycle model* in Charbonneau (2002).

In the following we will see how some of the major critiques can be solved. If planetary tidal forces are influencing the Sun in some way, their frequencies should be present in solar dynamics, and it should be possible to reveal them with high resolution data analysis methodologies. Of course, planetary harmonics would only act as an external forcing that constrains solar dynamics to an ideal cycle around which the Sun chaotically fluctuates. A planetary theory of solar dynamics should not be expected to describe every detail manifested in solar observations. It can only provide a schematic and idealized representation of such a dynamics.

There are two major planetary tidal frequencies within the Schwabe frequency band. These are the sidereal tidal period of Jupiter (about 12 years) and the spring tidal period of Jupiter and Saturn (about 10 years). If solar activity is partially driven by these two tidal cycles, their frequencies should be found in the solar records. Indeed, the variable Schwabe 11-year solar cycle could be the product of synchronization of the solar dynamics to these two tidal cycles. However, the solar dynamo too should actively contribute to the process and the final solar dynamical output.

Moreover, if solar dynamics is characterized by a set of quasi-periodic cycles, complex interference and beat patterns should emerge by means of harmonic superposition. Sometimes these cycles may generate constructive interference periods, and sometimes they may give origin to destructive interference periods. Thus, multi-decadal, multi-secular and millennial solar variations may result from the complex interference of numerous superimposed cycles. For example, we may expect that during the periods of destructive interference the Sun may enter into prolonged periods of minimum activity, while during the periods of constructive interference the Sun may experience prolonged periods of maximum activity. If solar dynamics can be partially reconstructed by using a given set of harmonics, forecasting it would also be possible with a reasonable accuracy.

The above results would be important for climate change research too. In fact, solar variations have been associated to climate changes at multi-temporal scales by numerous authors (Eddy, 1976, Sonett and Suess, 1984, Hoyt and Schatten, 1997, Bond et al., 2001, Kerr, 2001, Kirkby, 2007, Eichler et al., 2009, Soon, 2009, Scafetta and West, 2007, Scafetta, 2009, Scafetta, 2010; and many others). Thus, forecasting solar changes may be very useful to partially forecast climate changes too, such as, for example, prolonged multi-decadal, secular and millennial climate cycles.

In the following, we construct a simplified version of a harmonic constituent solar cycle model based on solar and planetary tidal cycles. It is worth to note that the harmonic constituent models that are currently used to accurately reconstruct and forecast tidal high variations on the Earth are typically based on observed solar and lunar cycles and made of 35–40 harmonics (Thomson, 1881, Ehret, 2008). In comparison, what we propose here is just a basic simplified prototype of a harmonic constituent model based on only the three major frequencies revealed by the power spectrum of the sunspot number record. We simply check whether this simplified model may approximately hindcast the timing of the major observed solar and climate multi-decadal, multi-secular and multi-millennial known patterns, which will tell us whether planetary influence on the Sun and, indirectly, on the climate of the Earth should be more extensively investigated.

We will explicitly show that our simplified harmonic model suffices to rebut at least one of the major critiques against the plausibility of planetary influence on the Sun, which was proposed by Smythe and Eddy (1977). These authors, in the early 1980s, convinced most solar scientists to abandon the theory of a planetary influence on the Sun. Their critique was based on a presumed geometrical incompatibility between the dynamics revealed by planetary tidal forces and the known dynamical evolution of solar activity, which presents extended periods of low activity such as during the Maunder minimum (1650–1715). We will show how the problem can be easily solved.

We also add some qualitative comments concerning recent findings (Wolff and Patrone, 2010, Scafetta, submitted for publication), which may respond to other traditional critiques such as the claim that planetary tides are too small to influence the Sun (de Jager and Versteegh, 2005 and others).

It is not possible to accurately reconstruct the *amplitudes* of the solar dynamical patterns. Such exercise would be impossible also because the multi-decadal, multi-secular and millennial amplitudes of the total solar luminosity and solar magnetic activity are extremely uncertain. In fact, several authors, and sometimes even the same author (Lean), have proposed quite different amplitude solutions (Lean et al., 1995, Hoyt and Schatten, 1997, Bard et al., 2000, Krivova et al., 2007, Steinhilber et al., 2009, Shapiro et al., 2011). We are only interested in determining whether the frequency and timing patterns of the known solar reconstructions reasonably match with our proposed model. Indeed, despite that the amplitudes are quite different from model to model, all proposed solar activity reconstructions present relatively similar patterns such as, for example, the Oort, Wolf, Spörer, Maunder and Dalton grand solar minima at the corresponding dates.

For convenience of the reader, an appendix and a supplement data file are added to describe the equations and the data of the proposed solar/planetary harmonic model.

Section snippets

The 9–13 year Schwabe frequency band is made of three frequencies at about 9.93, 10.87 and 11.86 years

We use the Wolf sunspot number record from the Solar Influence Data Analysis Center (SIDC): see Fig. 1. This record contains 3156 monthly average sunspot numbers from January 1749 to December 2011 and presents 23 full Schwabe solar cycles, whose length is calculated from minimum to minimum. Table 1 reports the approximate starting and ending dates of the solar cycles and their approximate amplitude and length in years.

Fig. 2 shows two probability distributions, $P(x)$, of the lengths of the 23…

Analysis of the beats of the three frequencies measured in Schwabe's frequency band

Fig. 3A indicates the existence of three dominant cycles with periods: P_1=9.98, P_2=10.90 and P_3=11.86 years. We observe that the superpositions of these three cycles generate four major beat cycles. If P_i and P_j are the periods of the two cycles, the beat period P_{ij} is given by $P_{ij} = \frac{1}{1/P_i - 1/P_j}$.Assuming a 0.5% error, which would correspond to about one month resolution of the sunspot record herein used, we have the following beat cycles: P_{13}=63±3 years; P_{12}=118±10 years; P_{23}=135±12 years. Finally, …

The three-frequency solar-planetary harmonic model based on the two Jupiter-Saturn tidal harmonics plus the central Schwabe cycle

Our proposed three-frequency harmonic model is simply made of the function $f_{123}(t) = \sum_{i=1}^{3} A_i \; \cos\left(2\pi \frac{t-T_i}{P_i}\right)$.See the appendix for the full set of equations. For simplicity, we set the above function to zero when $f(t) < 0$ to approximately simulate the sunspot number record, which is positive defined: see Eq. (14) in the appendix.

The parameters of our model are chosen under the assumption that the measured side frequencies at approximately 9.98 and 11.86 years correspond to the two major tidal frequencies…

Multi-scale hindcast and forecast of solar and climate records throughout the Holocene

The proposed model needs to be tested by checking whether the time series built from it, once extended far before 1749 A.D. (in fact, we are using the sunspot record since 1749 for estimating some of the parameters of the model), is able to approximately hindcast the timing of the major known solar secular patterns and the quasi-millennial cycle. Some of the multi-decadal low solar activity patterns are named as Oort, Wolf, Spörer, Maunder and Dalton grand solar minima. We also need to test…

Rebuttal of the critique by Smythe and Eddy (1977)

The empirical results presented above clearly support a theory of planetary influence on solar dynamics. In fact, all major observed solar activity and climate modulations from the 11-year Schwabe solar cycle to the quasi-millennial cycle throughout the Holocene can be reasonably well reproduced by a model based on the frequencies and timings of the two major Jupiter and Saturn planetary tides, plus the median Schwabe solar cycle at 10.87-year period. Of course, the usage of a larger number of…

Conclusion

High resolution power spectrum analysis of the sunspot number record since 1749 reveals that the Schwabe frequency band can be split into three major cycles. The periods of the measured cycles are about 9.98, 10.9 and 11.86 years. The result suggests that the Schwabe solar cycle may be the result of solar dynamo mechanisms constrained by and synchronized to the two major Jupiter and Saturn's tidal frequencies at 9.93-year and 11.86-year. The central cycle is about the average between the two,…

Acknowledgment

The author thanks the ACRIMSAT/ACRIM3 Science Team for support.…

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…Hung (2007) observed that an 11-year planetary alignment cycle approximately matched the sunspot cycle, supporting the idea that planet–Sun tides affected solar activity. Scafetta (2012a) suggested that the Schwabe frequency of the sunspot record consists of three major periods with cycles of 9.98, 10.9, and 11.86 years. These cycles seem to be closely related to the spring tidal periods of Jupiter and Saturn (9.93 years) and the tidal sidereal period of Jupiter (11.86 years).…

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