Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 57 (2016) 2121–2135

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

High resolution coherence analysis between planetary and climate oscillations

Nicola Scafetta *

Department of Earth Sciences, Environment and Georesources, University of Naples Federico II, Largo S. Marcellino 10, 80138 Naples, Italy

Received 23 October 2015; received in revised form 21 February 2016; accepted 28 February 2016
Available online 10 March 2016

Abstract

This study investigates the existence of a multi-frequency spectral coherence between planetary and global surface temperature oscillations by using advanced techniques of coherence analysis and statistical significance tests. The performance of the standard Matlab mscohere algorithms is compared versus high resolution coherence analysis methodologies such as the canonical correlation analysis. The Matlab mscohere function highlights large coherence peaks at 20 and 60-year periods although, due to the shortness of the global surface temperature record (1850–2014), the statistical significance of the result depends on the specific window function adopted for preprocessing the data. In fact, window functions disrupt the low frequency component of the spectrum. On the contrary, using the canonical correlation analysis at least five coherent frequencies at the 95% significance level are found at the following periods: 6.6, 7.4, 14, 20 and 60 years. Thus, high resolution coherence analysis confirms that the climate system can be partially modulated by astronomical forces of gravitational, electromagnetic and solar origin. A possible chain of the physical causes explaining this coherence is briefly discussed.

Keywords: Planetary oscillations; Solar oscillations; Climate oscillations; Coupling between planetary, solar and climate oscillations; Advanced method of spectral coherence analysis

1. Introduction

The planets and the sun generate the gravitational and electromagnetic fields present in our solar system. Because the orbital movements of the planets is periodic and highly synchronized (Scafetta, 2014a), a component of these forces varies harmonically. As a result, oscillations in the sun and, directly or indirectly, in the atmosphere–ocean system could emerge yielding specific climatic oscillations (cf.: Mörner, 2013; Mörner et al., 2013). A collective synchronization of coupled oscillators, where weak periodic forces can synchronize an entire system to specific internal or external forcing frequencies, may be involved in this complex process (cf. Strogatz, 2009).

Indeed, a planetary theory of solar and climate oscillations has been proposed since antiquity by a large number of authors such as Ptolemy et al. (1940), Ma'Sar (886) and Kepler (1979). All ancient civilizations advocated it based on their observations of the sky and understanding of geophysical and sociological phenomena (cf. Temple, 1998).

For example, the existence of a complex solar and lunar influence on the tidal system has been well-accepted since antiquity and today it is established science. The tidal phenomenon is studied in details at multiple time scales (cf. Wang et al., 2012). When in the 19th century the 11-year solar cycle was discovered, Wolf (1859) commented that the variations of the spot-frequencies could depend on the influences of Venus, Earth, Jupiter and Saturn.

* Tel.: +39 081 2538348.
E-mail address: nicola.scafetta@unina.it

http://dx.doi.org/10.1016/j.asr.2016.02.029
0273-1177/

Milankovitch (1930)'s orbital oscillations are today well-known to induce periodic climatic glaciations (cf. Roe, 2006). Numerous evidences for a solar influence on the climate at multiple scales are also well-known (e.g. Hoyt and Schatten, 1997). More recently, several authors have advocated a planetary theory of solar and climate oscillations on shorter scales (e.g. Abreu et al., 2012; Charvátová, 2009; Cionco and Soon, 2015; Hung, 2007; Jakubcová and Pick, 1986; Jose, 1965; McCracken et al., 2013, 2014; Mörner et al., 2013; Mörner, 2015; Puetz et al., 2014; Salvador, 2013; Solheim, 2013; Tan and Cheng, 2013; Tattersall, 2013; Wilson, 2013), which includes some of my studies (e.g. Scafetta, 2010; Scafetta, 2012a,b; Scafetta, 2014a; Scafetta and Willson, 2013a,b; Scafetta et al., 2013).

Several of the latter studies have pointed out that solar dynamics appears to be the result of interfering harmonic modes coherent to planetary harmonics. The proposed planetary-based solar harmonic models have reconstructed and hindcast several features of solar variability during the last 1000 years and during the entire Holocene. For example, these models have been able to approximately reconstruct the 11-year solar cycle variation using a combination of the orbits of Venus, Earth, Jupiter and Saturn (Hung, 2007; Salvador, 2013; Scafetta, 2012a,b; Wilson, 2013). By doing so, these models have hindcast the occurrence of grand solar minima such as the Maunder, Dalton and others, a quasi millennial solar oscillation, and have forecast a new grand solar minimum by 2030 (cf. Mörner, 2015). Also alternative studies (e.g. Shepherd et al., 2014) have argued that solar activity could be made of interfering harmonic modes that should yield a grand-minimum around 2030.

A coupling between planetary oscillations and climate change must necessarily involve a complex and long chain of physical mechanisms that are being investigated in the scientific literature. First, gravitational and electromagnetic planetary forces need to partially modulate solar activity: some authors have proposed how this can happen (e.g. Abreu et al., 2012; Scafetta, 2012b; Wolff and Patrone, 2010). The variation of solar activity would then modulate both total solar irradiance and, probably more importantly, the intensity and the dynamics of the solar wind and of the cosmic ray flux. The latter influence the ionization level of the atmosphere (e.g. Svensmark, 1998; Kirby, 2007) and the Earth's electric circuit and, consequently, modulate cloud formation and regulate the Earth's albedo (Tinsley, 2008; Svensmark et al., 2009; Svensmark et al., 2012). Finally, an astronomically induced albedo variation could easily induce climatic variations. In fact, if the Earth's albedo oscillates by just a few percent driven by astronomical forcings, the resulting oscillations should be sufficient to induce the observed climatic oscillations because these are of the order of a fraction of Celsius degree. The hypothesis that, together with the more traditionally accepted solar irradiance forcing (cf. Hoyt and Schatten, 1997), there might be a particle-based astronomical forcing of the atmospheric chemistry partially modulated by oscillations coherent to the planetary ones, is confirmed by the fact that planetary oscillations have been observed also in aurora's records since 1600 (Scafetta and Willson, 2013a).

However, evaluating the statistical significance of the empirical result is complicated. While basic astronomy determines accurately the major gravitational oscillations of the solar system due to the planetary revolution around the sun, the analysis of the climate is more problematic. Any coupling between astronomical and climate records could be masked by non-linearities, errors of measure and by a climatic variability driven by alternative internal and anthropogenic mechanisms, which are typically non-harmonic. To reduce the uncertainty, long and accurate global climatic records should be analyzed so that the non-harmonic climatic components could be filtered out and the hypothesized harmonic astronomical component could emerge more clearly. Yet, accurate global climatic records are short (about 165-year long) and, therefore, spectral coherence evaluations can be ambiguous (cf. Scafetta, 2014a).

Scafetta (2014a, Fig. 5) used the JPL's HORIZONS Ephemeris system to calculate the wobbling and the speed of the Sun from 12 December 8002 BC to 24 April 9001 AD to demonstrate that the major gravitational oscillations of the solar system are approximate harmonics of a 178.4-year base period: that is the period of the planetary harmonics is about $P_n \approx 178.4/n$ year with $n = 1, 2, 3\ldots$ (cf. Jakubcová and Pick, 1986). For example, two major oscillations of the solar system already noted since antiquity (Ma'Sar, 886; Kepler, 1606) are the quasi 20-year conjunction period of Jupiter and Saturn and their quasi 60-year trigon, which are the 9th and 3rd harmonic of the 178.4-year base period, respectively, while the orbital periods of the four Jovian planets (Jupiter, 11.86 year; Saturn, 29.46 year; Uranus, 84.01 year; and Neptune, 164.8 year) are roughly the 15th, 6th, 2nd and 1st harmonics of the 178.4-year base period. Thus, the climate could be expected to be modulated by a large number of close astronomically-induced frequencies, as already well-know to occur for the tidal system (cf. Wang et al., 2012).

A major statistical problem usually encountered in natural science is that spectral analysis is able to solve close frequencies and their beats only if the analyzed record has a minimum length of the same order of magnitude of the base period of the harmonic generating sequence. Therefore, because a relevant set of astronomical frequencies is made of harmonics of a 178.4-year base period, a minimum spectral resolution of about $1/178.4$ year^{-1} is required for a significant analysis. Unfortunately, the 165-year long climatic record is of the same order of magnitude of the 178.4-year base period. Thus, to determine unambiguously the statistical confidence of the spectral results could require the adoption of advanced techniques of analysis because such an outcome could be algorithm dependent.

Here I show that the popular Matlab magnitude squared coherence (MSC) mscohere algorithm (Welch et al., 1967) produces ambiguous results. This algorithm does find large spectral coherence peaks at about 20- and 60-year periods (cf. Holm, 2015), confirming the direct spectral analysis comparison first proposed in Scafetta (2010) and confirmed in (Scafetta, 2014a, Figs. 8 and 12), but their 95% significance level is ambiguous. I show that this result depends on the window function algorithm adopted for pre-processing the data. Generic arguments suggest that the most appropriate window function to be used to address this specific case could be the triangular one. However, the major problems appear to be (1) the disruption of the low-frequency component of the spectrum caused by the window function pre-processing itself and (2) the too low spectral resolution of the Matlab mscohere algorithm. Thus, the Matlab mscohere algorithm is inadequate for comparing the multi-decadal scales of the available 165-year long temperature sequence and of the astronomical record.

For the above reason, more advanced, high resolution coherence analysis methodologies were searched in the literature and, for the first time, were adopted to address astronomical and geophysical data. I will show that the canonical correlation analysis by Santamaria and Via (2007), which appears to be the most advanced technique of coherence analysis available, finds five coherent frequencies between planetary and climatic records at the 95% significance level at the following periods: 6.6, 7.4, 14, 20 and 60 years.

In conclusion, the empirical evidence about the existence of a coupling between astronomical and climate oscillations is statistically significant and, consequently, it is worth to further investigate the theory of a planetary modulation of solar activity and climate change.

2. Methods: alternative magnitude squared coherence (MSC) algorithms

The Matlab MSC mscohere algorithm is based on the Welch's averaged modified periodogram method (http://it.mathworks.com/help/signal/ref/mscohere.html) (Rabiner and Gold, 1975; Welch et al., 1967). The magnitude squared coherence estimate is a function of frequency that takes values between 0 and 1, which indicate how well a signal $x(t)$ corresponds to a signal $y(t)$ at each frequency. MSC is a function of the power spectral densities, $P_{xx}(f)$ and $P_{yy}(f)$, and of the cross power spectral density, $P_{xy}(f)$, of $x(t)$ and $y(t)$ that is defined as:

$$C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)} \tag{1}$$

Because the mscohere algorithm is based on the traditional Fourier periodogram algorithm, the uncertainty associated to a spectral peak is given by $\nabla f = \pm 1/2L$ or $\nabla p = \pm p^2/2L$, where L is the length of the record and $f = 1/p$ is the frequency associated to the detected spectral peak (cf. Scafetta, 2014a, Eq. (3)). Thus, lower the frequency of interest and larger is its uncertainty. For example, a low frequency peak is characterized by a large uncertainty lobe in a periodogram plotted in function of the period. The traditional Fourier periodogram is more optimized for higher frequencies detection than for lower frequencies detection. Moreover, if a signal contains two close frequencies, f_1 and f_2, they can be separated by the periodogram only if $|f_2 - f_1| \gtrsim 1/2L$ or, alternatively, if the length of the record is $L \gtrsim 1/2|f_2 - f_1|$. Thus, longer record are required to separate closer frequencies. Fourier based coherence functions such as Eq. (1) are characterized by the same uncertainty properties and statistical limitations discussed above.

Furthermore, in Fourier analysis a signal is also pre-processed using a window function such as, for example, the rectangular, the triangular, the Hann, the Hamming, the Blackman ones. These functions are zero-valued outside some chosen interval corresponding typically to the length L of the analyzed record or to a subset of it (cf. Press et al., 2007). The purpose of using window functions is to reduce the spectral leakage that could disrupt the periodogram. This problem is particularly relevant in experimental science when only short records of data are typically available.

However, the window function pre-processing severely alters the geometrical properties of the signal: see the Appendix A. Therefore, the periodogram function depends also on the adopted window function. For some applications (e.g. analyzing transient signals, self-windowing signal, pseudo-random noise excitation signal with period T, etc.) using window functions is not advised because they would disrupt the relevant information searched in the signal. Window functions heavily disrupt the very low frequency component of the spectrum too, because they introduce spurious very low frequencies that beat with the lower frequencies of the record disrupting them. Thus, using window functions when the scientific interest is in analyzing the low frequency component of the spectrum could yield misleading conclusions.

The Matlab MSC mscohere algorithm comes with 17 alternative window functions (http://it.mathworks.com/help/signal/ref/window.html). The choice of the window function depends on the expected signal frequency content. In this regards, Hongwei (2009) commented: *"If the signal contains strong interfering frequency components distant from the frequency of interest, choose a window with a high side lobe roll-off rate. If there are strong interfering signal near the frequency of interest, choose a window with a low highest side lobe level. If the frequency of interest contains two or more signals very near to each other, then frequency resolution is very important. It is best to choose a window with a very narrow main lobe. If the amplitude accuracy of a single frequency component is more important than the exact location of the component in a given frequency bin, choose a window with a wide main lobe. If the signal* *spectrum is rather flat or broadband in frequency content, use the Rectangle Window. In general, the Hanning Window has good frequency resolution and reduced spectral leakage. It is satisfactory in 95% of cases.*"

As explained in the Introduction, for the phenomenon herein under study the spectrum is not characterized by just a single frequency of interest. Several frequencies of interest span from the low to the high frequency components, and these harmonics are also beating among them. Thus, it is not evident how a window function should be preferred above another. For example, Holm (2015) used MSC algorithms with Kaiser window with parametric value $\beta = 6$, and claimed that the planetary theory of climate oscillation needs to be dismissed because, although the coherence analysis showed very strong peaks at 20 and 60-year periods, these peaks would not meet the 95% statistical confidence level. However, the Kaiser window with $\beta = 6$ is relatively narrow and, as shown in the Appendix A, it heavily disrupts the multidecadal scale of the temperature records that needed to be investigated. Thus, like other window functions, the Kaiser window is definitely not appropriate for our analysis. In general, the adoption of window functions could be safe if the scale of interest is at least 1 order of magnitude smaller than the window length. In this situation it is instructive to test several window functions using their Matlab default parameter values, which are the most commonly used, and study their performance to check whether common features emerge from multiple analyses and whether a specific window function provides clearer results. Some window functions are not parametric, others are parametric. In the latter case the Matlab default parametric values are herein used as

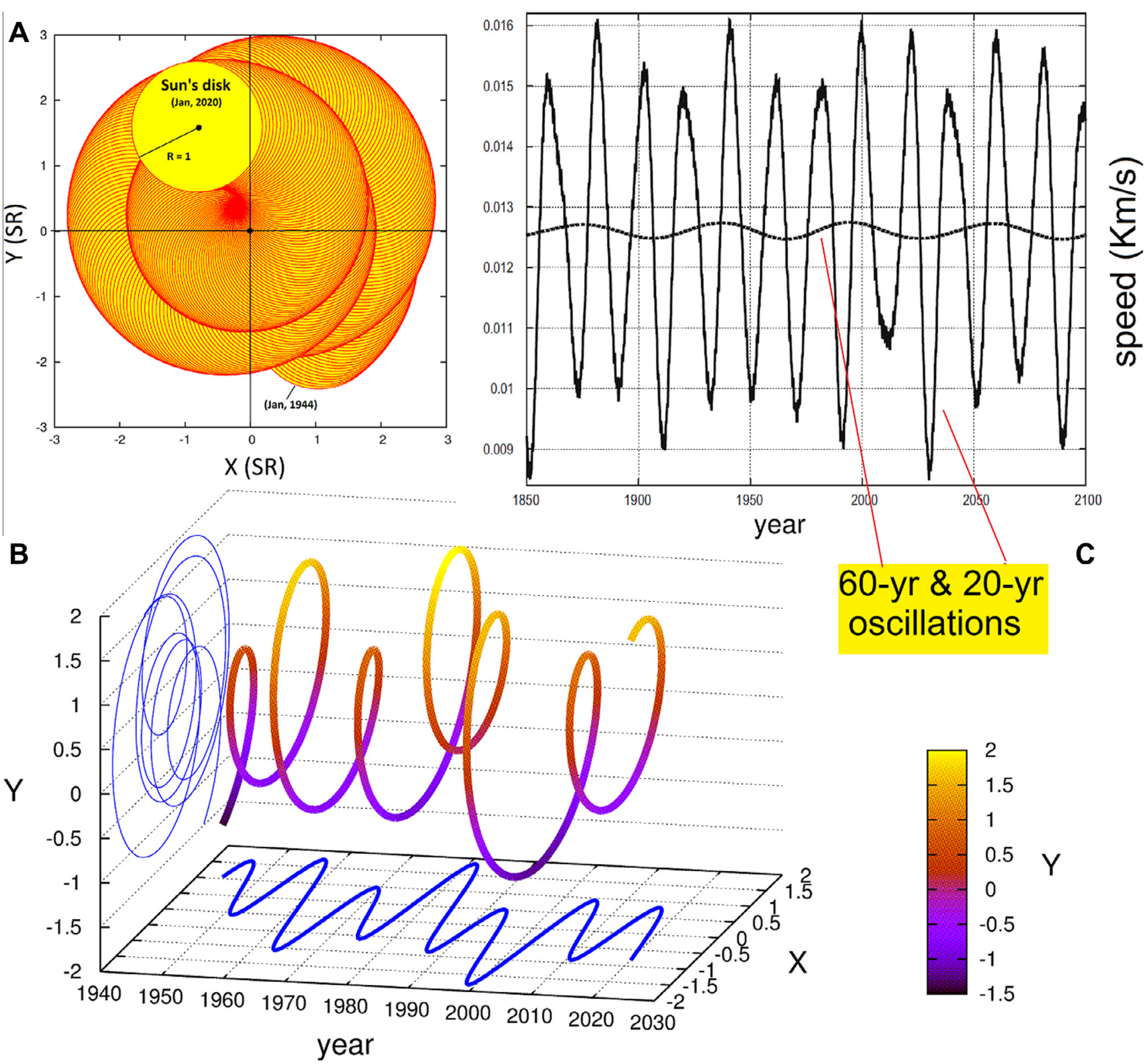

Fig. 1. (A and B) Wobbling of the Sun relative to the center of mass of the solar system. (C) The speed of the sun relative to the center of mass of the solar system, SCMSS. The quasi 20- and 60-year oscillations are highlighted. (From Scafetta, 2014a).

follows: Kaiser ($\beta = 0.5$), Tukey ($r = 0.5$), Chebyshev ($r = 100.0$ dB), and Taylor ($nbar = 4, sll = -30$ dB).

In any case, as Hongwei (2009) noted, the most important property that spectral analysis should fulfill to solve the spectrum is its spectral resolution. This ability cannot be improved significantly by simply changing the window function of the mscohere method. The spectral resolution can be improved only in two ways: (1) by increasing the length of the analyzed data that, unfortunately, is not an available option because the experimental global surface temperature record is available only since 1850; (2) by using alternative coherence algorithms that produce sharper and noisy free coherence peaks. Therefore, I looked for alternative methods of analysis that are characterized by a spectral resolution higher than what the mscohere method can offer.

To improve the spectral resolution of the Fourier periodogram at the lower frequency range of the spectrum the maximum entropy method (MEM) based on autoregressive models of the data has been developed (Press et al., 2007). Analogously, alternative MSC algorithms have been proposed such as the minimum variance

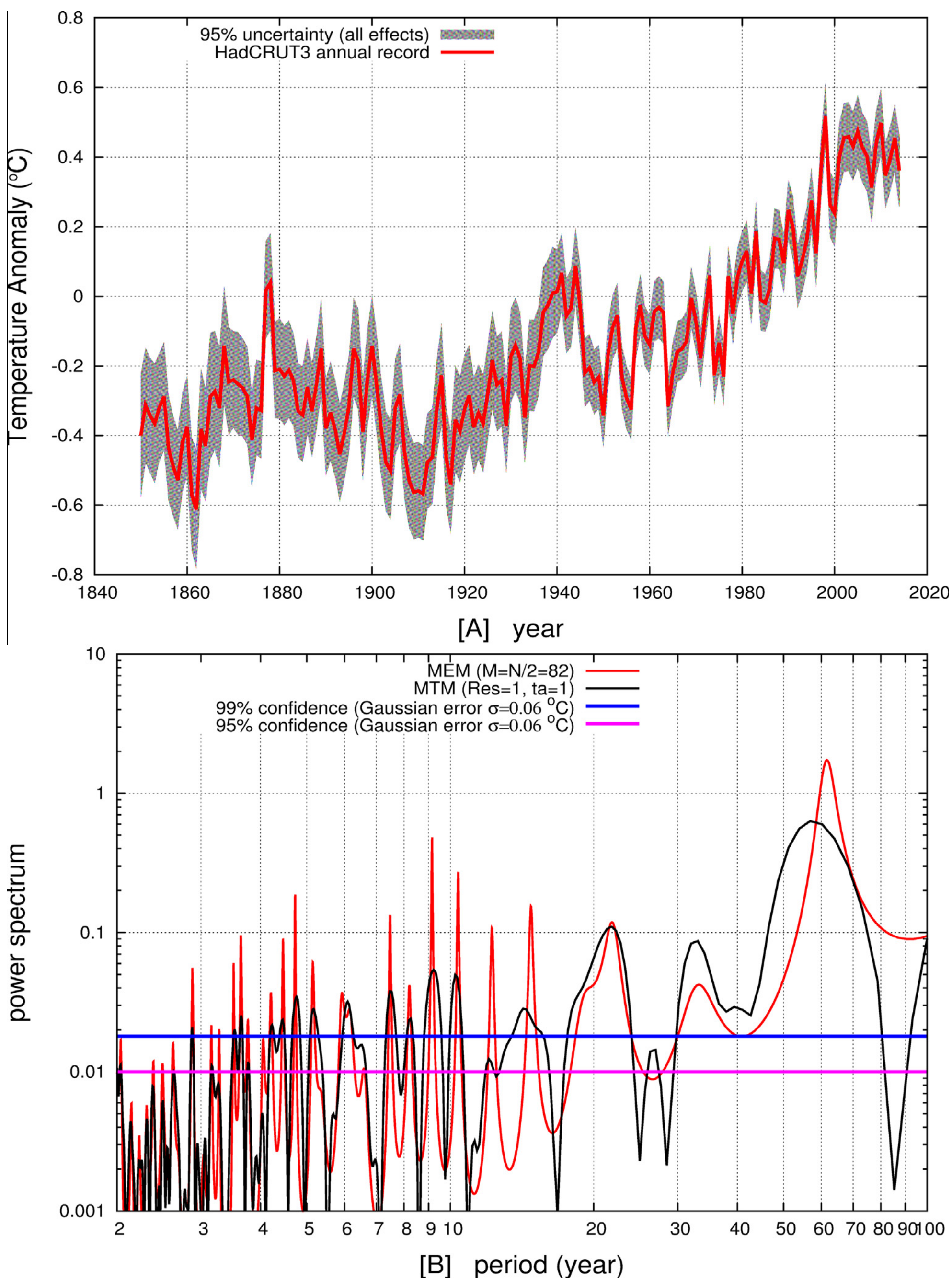

Fig. 2. (A) Annually resolved *HadCRUT* global surface temperature. (B) Power spectra (MEM and MTM) of the temperature record against the 99% and 95% statistical confidence levels. Note the quasi 20- and 60-year period spectral peaks. (From Scafetta, 2014a).

distortion-less response (MVDR) (Benesty et al., 2006) and a technique based on a reduced-rank approximation of the estimated coherence matrix using the canonical correlation analysis (CCA) (Santamaria and Via, 2007). The authors of both MSC methods have used several computer simulations to demonstrate that their proposed techniques perform significantly better than the Matlab mscohere algorithms. In particular, the CCA method was shown to provide sharper and noisy free MSC estimates also over the MVDR method (cf. Santamaria and Via, 2007).

MVDR-MSC is based on the evaluation of the following MSC equation:

$$\gamma_{xy}^2(\omega) = \frac{\left|S_{xy}(\omega)\right|^2}{S_{xx}(\omega)S_{yy}(\omega)} = \frac{\left|\mathbf{f}^H\mathbf{R}_{xx}^{-1}\mathbf{R}_{xy}\mathbf{R}_{yy}^{-1}\mathbf{f}\right|^2}{\left[\mathbf{f}^H\mathbf{R}_{xx}^{-1}\mathbf{f}\right]\left[\mathbf{f}^H\mathbf{R}_{yy}^{-1}\mathbf{f}\right]} \quad (2)$$

where $S(\omega)$ is the cross-spectrum and $\mathbf{R}$ is the cross-correlation $(L \times L)$ matrix between the input time series $x(t)$ and $y(t)$, and $\mathbf{f}$ is a vector made of the harmonics of $\omega, f_j(\omega) = e^{i\omega j}/\sqrt{L}$, with $j = 0, 1, \ldots L-1$, where L is the window length. By mathematical construction $0 \leqslant \gamma_{xy}^2(\omega) \leq 1$, and $\gamma_{xy}^2(\omega)$ theoretically approaches to 1 if the two original sequences present a common major harmonic at the frequency ω. CCA–MSC is based on the reduced rank coherence matrix as evaluated in the following equation:

$$\hat{S}_{x_1x_2}(\omega_k) = \mathbf{f}_k^H\hat{\mathbf{R}}_{x_1x_1}^{1/2}\tilde{\mathbf{C}}_{x_1x_2}\hat{\mathbf{R}}_{x_2x_2}^{1/2}\mathbf{f}_k, \quad (3)$$

where $\tilde{\mathbf{C}}_{x_1x_2}$ is the reduced-rank version of the coherence matrix and $\hat{\mathbf{R}}$ are the correlation matrices. Both techniques are able to produce very sharp coherence peaks and, therefore, are optimal to study the low-frequency range of a power spectrum.

The statistical significance of the MSC peaks are evaluated using Monte Carlo simulations based on the non-parametric random phase method for serially correlated data (cf. Traversi et al., 2012, Appendix). The method aims to compare the original coherence curve $C_{xy}(f)$ against synthetic coherence curves obtained with Monte Carlo simulations characterized by identical Fourier spectra with randomized phases yielding to curves with alternative geometrical patterns. The specific methodology proposed here is based on the following steps: (1) the FFT-transforms of the original $x(t)$ and $y(t)$ series are computed, the phases are randomized and the records are FFT-transformed back ($x \overset{FFT}{\rightarrow} f_x \overset{rand.phase}{\rightarrow} f'_x \overset{FFT^{-1}}{\rightarrow} x'$ and $y \overset{FFT}{\rightarrow} f_y \overset{rand.phase}{\rightarrow} f'_y \overset{FFT^{-1}}{\rightarrow} y'$); (2) coherence functions are calculated between the phase-randomized sequences and the original series ($C_{x'y}(f), C_{xy'}(f)$ and $C_{x'y'}(f)$); (3) steps 1 and 2 are repeated $N = 1000$ times to obtain three correspondent sequences of coherence functions, and for each frequency every sequence is sorted from the smallest to the largest value to obtain new coherence curves ($C_{x'y,i}(f), C_{xy',i}(f)$ and $C_{x'y',i}(f)$, with $i = 1, 2, 3, \ldots, N$); (4) Finally, in each case the statistical 90% and 95% significance level curves are defined by setting $i = 0.90N$ and $i = 0.95N$, respectively. A coherence spectral

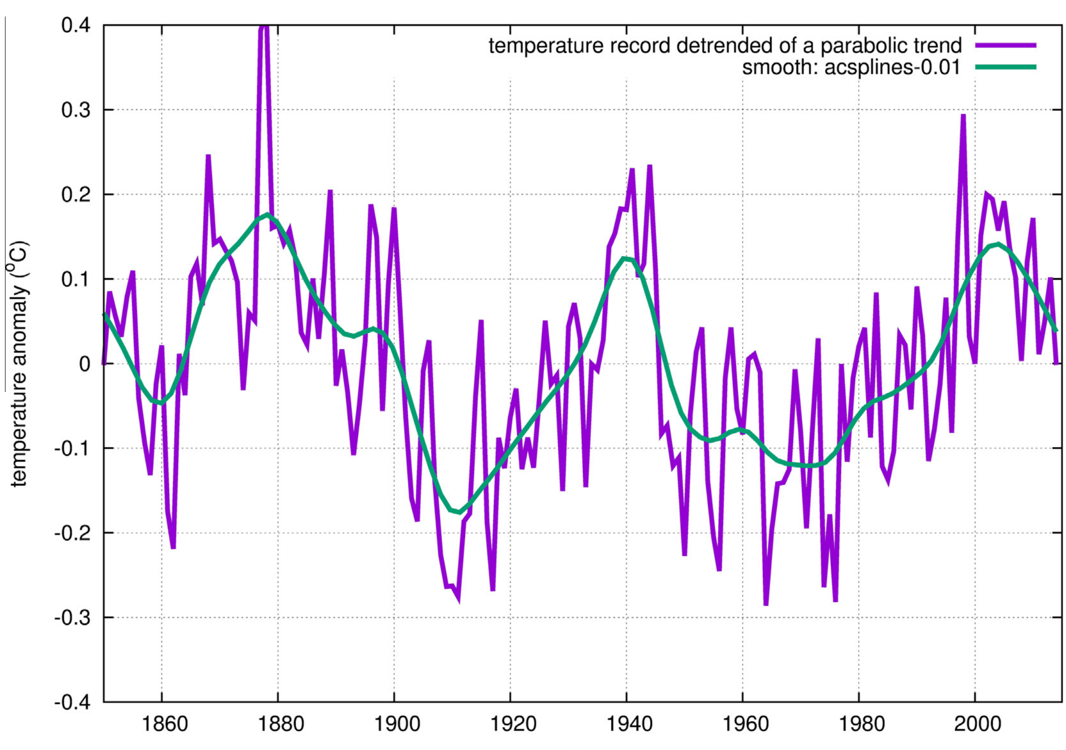

Fig. 3. (A) Annually resolved *HadCRUT* global surface temperature detrended of a parabolic trend of the type $f(t) = a(t-1850)^2 + b$, which highlights a quasi 60-year oscillation in the record with maxima around 1880, 1940 and 2000.

peak found in $C_{xy}(f)$ is 90% or 95% significant if it is higher than the obtained 90% and 95% significance level curves, respectively. The method evaluates which peaks in $C_{xy}(f)$ are likely not accidental within the chosen statistical confidence level.

3. Data analysis

Fig. 1 depicts the wobbling of the sun and its speed relative to the center of mass of the solar system. This record is used just as a proxy to calculate the internal gravitational oscillations of the heliosphere due to the movements of the planets. Other functions of the position of the planets could be chosen as well but all these functions share a common set of frequencies because they depend on the same periodic variables (cf. Bucha et al., 1985). The data were analytically obtained using the JPL's HORIZONS Ephemeris system (http://ssd.jpl.nasa.gov/?horizons). Fig. 1C highlights the quasi 20- and 60-year oscillations present in this record due to the combined orbits of Jupiter and Saturn.

Fig. 2A depicts the HadCRUT global surface annual temperature (Brohan et al., 2006) from 1850 to 2014. This record is used as a climate global index and it is preferred to other similar temperature records because it was used in previous works (cf. Scafetta, 2010, 2014a). Fig. 2B depicts two alternative power spectra (maximum entropy method -MEM- and the multi taper method -MTM-) against the 95% and 99% confidence levels of the experimental error of measure of the data highlighted in Fig. 2A, as done in Scafetta (2014a). Fig. 2B reveals the existence of quasi 20- and 60-year spectral peaks in the temperature record suggesting an evident spectral coherence with the astronomical record depicted in Fig. 1.

At first sight the records depicted in Figs. 1 and 2 look quite different from each other. However, the purpose of the present study is to check whether these two records are characterized by a common set of frequencies independently of their relative weight or amplitude. This comparison is properly achieved by MSC analysis.

Fig. 3 depicts the temperature record detrended of a quadratic fit function of the type $f(x) = a(t - 1850)^2 + c$, which is used to extract the accelerating observed warming, as first proposed in Scafetta (2010). This process is required to eliminate the evident non-stationarity of the global surface record that needs to be removed for improving the resolution of the coherence analysis. Scafetta (2014b)

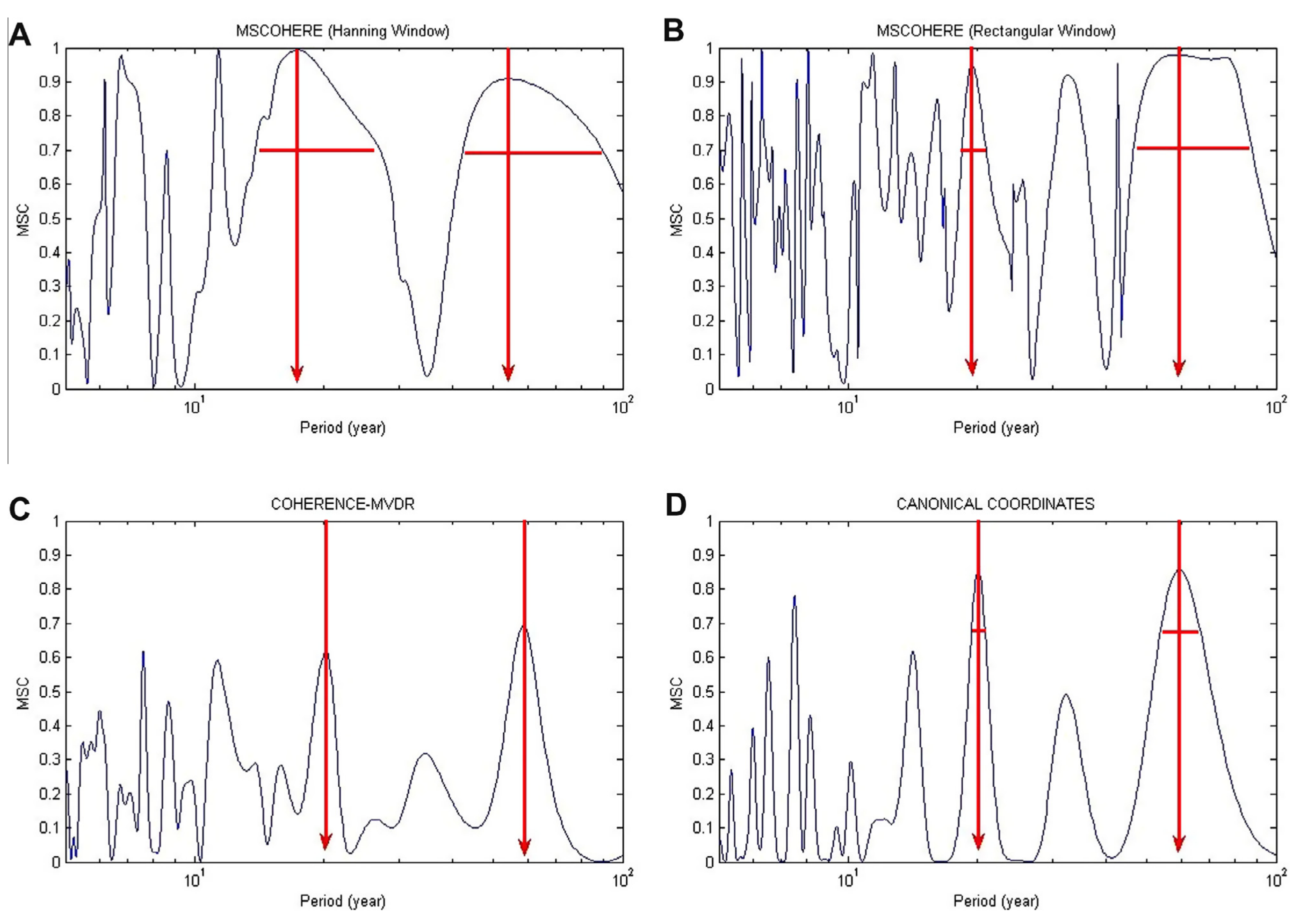

Fig. 4. Four alternative magnitude squared coherence measures between the global surface temperature record and the SCMSS record. 110-year segment windows were used. (A) the Matlab mscohere method with the Hanning window; (B) the Matlab mscohere method with the rectangular window; (C) the MVDR-coherence analysis; (D) the canonical correlation analysis. The 20- and 60-year oscillations are highlighted with their uncertainty bell width.

demonstrated that on 110-year or longer sequences a quadratic function is orthogonal to a 60-year or faster oscillations. Therefore, this detrending process does not disrupt the spectrum for 60-year or shorter periods, which is the range of interest of the present research.

The observed secular warming trend is typically associated with anthropogenic forcing and with long scale solar and other natural forcings (cf. IPCC, 2013; Scafetta, 2013). It can be treated as a climatic component independent from the 60-year and shorter scales herein of interest. As the figures shows, the adopted quadratic detrending clearly highlights that the surface temperature record is characterized by a quasi 60-year oscillation with maxima around 1880, 1940 and 2000, as first detailed in Scafetta (2010, Figs. 1 and 10) and demonstrated also using advanced Fourier filters (Scafetta, 2013). Indeed, the

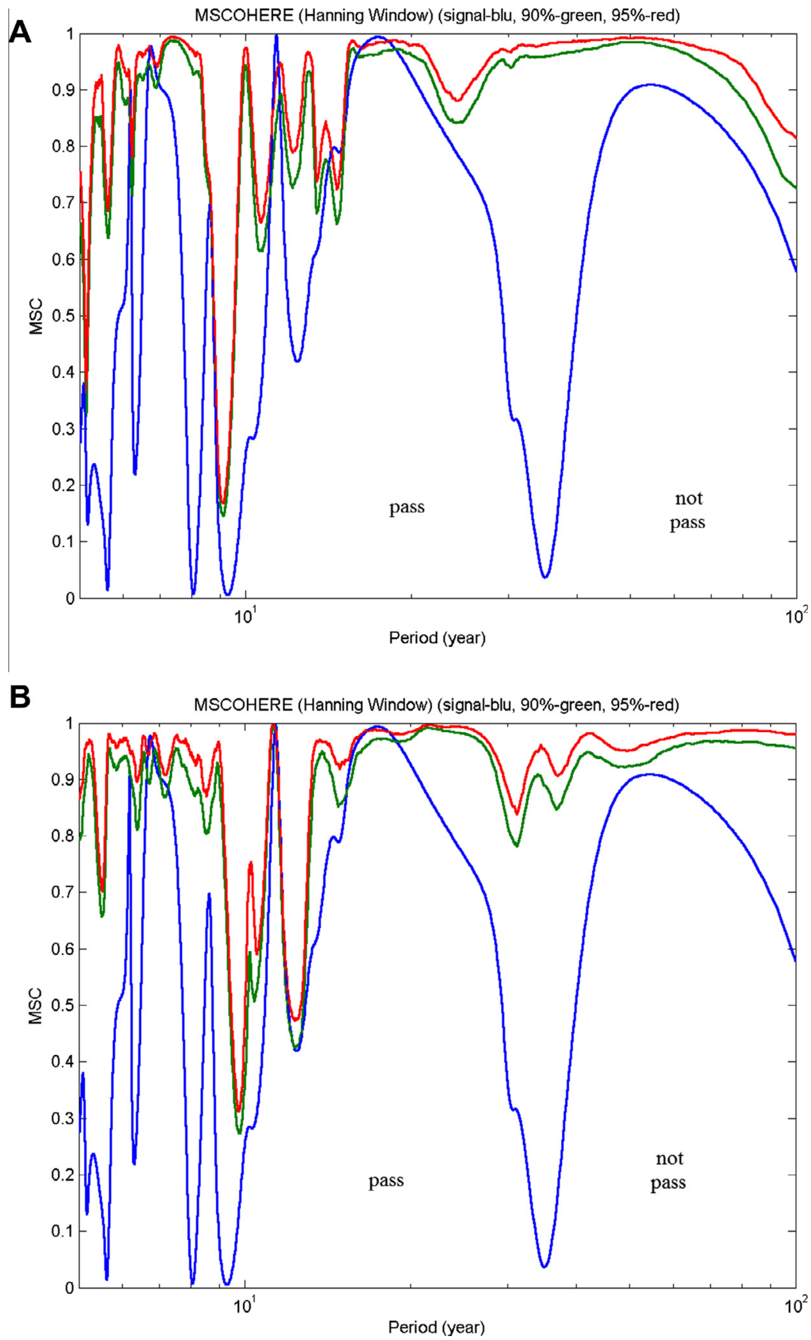

Fig. 5. Matlab magnitude squared coherence mscohere method with the Hanning window (blue) vs. 90% (green) and 95% (red) significance levels. (A) The Monte Carlo simulations based on the non-parametric random phase method is applied to the temperature record. (B) The Monte Carlo simulations based on the non-parametric random phase method is applied to the astronomical record. The "pass" or "not pass" labels refer to whether the quasi 20- or 60-year peak pass or not the 95% significance level. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

existence of a quasi 60-year oscillation since 1850 is confirmed by all major climatic indexes (cf. Scafetta, 2014b; Wyatt and Curry, 2014); it appears in the GISP2 Greenland ice core temperature record throughout the Holocene (cf. Davis and Bohling, 2001) where it is very clear since 1350 (Scafetta et al., 2013, Fig. 1), in Atlantic and Pacific temperature proxies since 1500 and in Indian monsoon records since 1830 (e.g. Scafetta, 2010), in the sea level and North Atlantic Oscillation (NAO) records since 1700 (cf. Scafetta, 2014b) and it is also present in global surface temperature proxy reconstructions since the medieval times (cf. Qian and Lu, 2010).

As explained in the Introduction, the coherence analysis is herein used with correlation matrices based on 110-year overlapping segments because this is the shortest segment necessary to solve the beats of the major frequencies of interest, as demonstrated in Scafetta (2014a, Table 1). Longer segments could be used, but the statistics of the MSC algorithms requires correlation matrices that need several segments and, on a 165-element long record, just 56 overlapping segments would be available using 110-year windows. Shorter windows such as 20- to 60-year long would increase the number of segments and make some of them also non-overlapping, but this choice would make the MSC techniques useless for our purpose. In fact, such short segments would have a so low spectral resolution that the MSC algorithm would be unable to detect the frequencies of interest, in particular the 20 and 60-year periods, as demonstrated in Scafetta (2014a, Fig. 11) and confirmed in Holm (2015).

For similar reasons also wavelet-based coherence methods, such as those also adopted by Holm (2015), should be

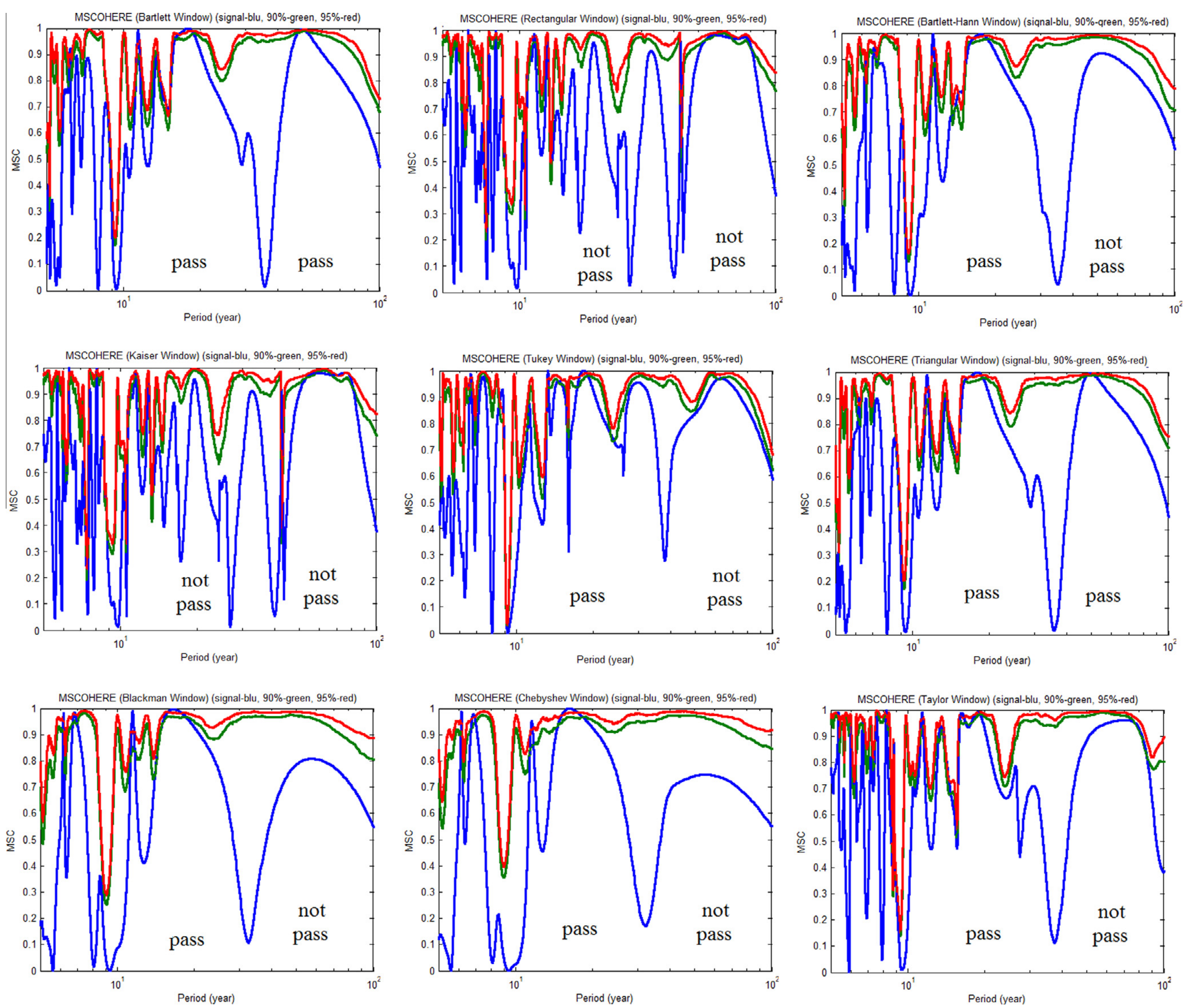

Fig. 6. Matlab magnitude squared coherence mscohere method with the 9 alternative window functions (blue) vs. 90% (green) and 95% (red) significance levels. The Monte Carlo simulations based on the non-parametric random phase method is applied to the temperature record. The “pass” or “not pass” labels refer to whether the quasi 20-year or 60-year peak pass or not the 95% significance level. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

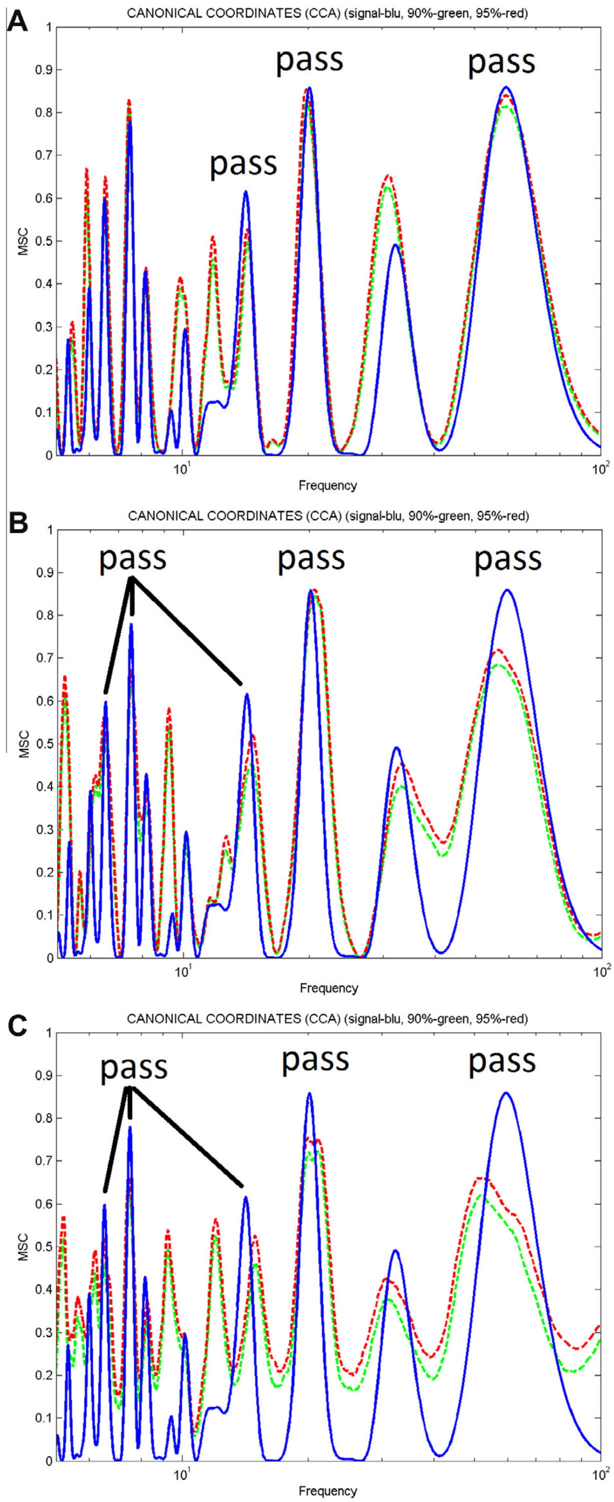

Fig. 7. The magnitude squared coherence canonical correlation analysis (blue) vs. 90% (green) and 95% (red) significance levels. (A) The Monte Carlo simulations based on the non-parametric random phase method when applied to the temperature record. (B) The Monte Carlo simulations based on the non-parametric random phase method when applied to the astronomical record. (C) The Monte Carlo simulations based on the non-parametric random phase method when applied to both the astronomical and the temperature records. Multiple peaks pass the 95% significance level at about 6.6, 7.4, 14, 20 and 60 years when $MSC > 0.5$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

avoided. In fact, these techniques adopt wavelets whose length scales with the analyzed period. In fact, a scale period p is usually analyzed by a wavelet with three oscillations, that is with a wavelet with a total length of about 3p (e.g. using the Morlet wavelet). Thus, with wavelets only chaotic beat patterns could be highlighted for most of the high frequency spectrum. On the contrary, for our purpose we need to solve the expected beats among the various expected harmonics and, therefore, the segment length should not scale with the frequency as required by the wavelet algorithm. As explained above, the segments must be kept at least at the same order of the 178.4-year astronomical base period (e.g. $L \gtrsim 110$ year). However, with wavelets this condition would not be met for scales smaller than 35 years, and for scales close to 60 years the number of available segments would be too small.

Finally, the fact that minimal windows of about 110-years need to be used to meet the spectral resolution requirements and significantly larger windows cannot be used for the shortness of the data, implies that windows functions used to pre-process the data in the mscohere method should be wide and not narrow. For example, Holm (2015) used segments of 109-year pre-processed with the Kaiser-Bessel window with $\beta = 6$, whose waveform attenuates by 80–100% about a third of the window record: see the Appendix A. Thus, using this window function on a 109-year long segment is approximately equivalent to use about 70-year long segments instead of the original 109-year long one; and 70-year long segments is too short for a significant analysis.

Fig. 4 compares four alternative magnitude squared coherence spectra: (a) the Matlab mscohere method with Hann window; (b) the Matlab mscohere method with the rectangular window; (c) the MVDR-coherence analysis; (d) the MSC canonical correlation analysis. Fig. 4A and B demonstrate that in our situation the Matlab mscohere method is unstable and produces poor quality diagrams. In fact, the coherence curves are quite different from each other demonstrating a strong dependency on the window function algorithm. In addition, the observed peaks at about 20- and 60-year periods are very wide and not well centered at the expected frequencies derived from direct spectral analysis comparison (Scafetta, 2014a). Using the Hann window, the 60-year peak is observed between 50 and 60 years while with the rectangular window the same peak ranges between 55 and 80 years. The two Matlab mscohere curves present peaks curve with heavily distorted bell patterns as one would expect from data too corrupted by the pre-processing of window functions. On the contrary, Fig. 4C and D demonstrate the good performance of the MVDR-coherence analysis and of the canonical correlation analysis. The two curves are coherent with each other and appear cleaner and smoother than those produced by the mscohere method. The expected peaks are sharper and very centered at the expected coherence frequencies such as at the 20- and 60-year periods. In particular, Fig. 4D also highlights coherence peaks at about 6.6, 7.4 and 14 years, which were already observed in the MEM-based time frequency comparison between the astronomical and the climatic records (Scafetta, 2014a, Fig. 8).

Figs. 5–7 depict alternative MSC results (blue) with added the evaluated 90% (green) and 95% (red) confidence statistical levels, as explained above. The Monte Carlo test was applied to the temperature record while the astronomical record was kept unaltered, and vice versa. Fig. 5 uses the Matlab mscohere method with Hann window function and shows that the 20-year MSC peak passes the 95% confidence level while the 60-year MSC peak does not pass it by a significant margin. Fig. 6 compares the Matlab mscohere method with nine alternative window function algorithms. The results are contradictory. In some case the 95% confidence level is missed by both the 20- and 60-year periods, as also found in Holm (2015). In other cases the 95% confidence level is passed by the 20-year period, but not by the 60-year one. Finally, in the remaining cases the 95% confidence level is passed by both the 20- and 60-year periods: e.g. using the Barlett window and the similar Triangular window. Clearly, the Matlab mscohere algorithm produces ambiguous results whose statistical significance depends on the window function.

Fig. 7 uses the canonical correlation analysis. The same Monte Carlo simulations based on the non-parametric random phase method for serially correlated data is applied for the significance test. As the figure shows, the 95% significance level is well met by both the 20- and 60-year MSC peaks either when the Fourier shuffling of the test is applied to only the temperature data (Fig. 7A), or to only the astronomical record (Fig. 7B) or to both records simultaneously (Fig. 7C). Also other coherence peaks at about 6.6, 7.4 and 14 years pass well the 95% significance level in Fig. 7B and C. The result depicted in Fig. 7C is sufficient to evaluate the 95% statistical significance of the five indicated coherence peaks because to fully randomize the test the Fourier shuffling should be applied simultaneously to both records. The results depicted in Fig. 7A and B are herein shown to demonstrate that the statistical results are quite robust for the 20-year and 60-year oscillations also when more stringent statistical conditions are used. In general, Fig. 7 fully confirms the significance of the coherence results revealed by the MEM time frequency analysis at multiple frequencies as done in Scafetta (2014a, Table 1 and Fig. 8). The observed MSC peaks are also very centered at the expected periods.

4. Conclusion

This study compares several MSC algorithms to determine the spectral coherence between climatic and astronomical records with their statistical confidence. I have shown that in the present case the Matlab mscohere function has a too low resolution and is statistically unstable. This methodology does find strong coherence peaks at the expected 20 and 60-year periods but their 95% statistical significance depends on the window function algorithm used to pre-process the data. According to the geometry of the adopted mscohere window function, the 95% significance level is met by both periods, is not met by both periods, or is met by one period (the 20-year long one) and not by the other (the 60-year long one). This result questions Holm (2015) because the mscohere technique is demonstrated to be too ambiguous and ultimately inadequate to convincingly dismiss (or support) the planetary theory of solar and climate variation suggested by a number of authors, as discussed in the Introduction.

As Hongwei (2009) noted, the window function needs to be carefully chosen according to the spectral property of the signal. In the present situation: (1) several frequencies at multiple scales with periods $P_n \approx 178.4/n$ and $n = 1, 2, 3 \ldots$ are expected; (2) the temperature record is just 165-year long; (3) the major expected coherence periods are at about 20- and 60-year periods and, therefore, they occupy the low frequency range of the spectrum. In this situation, it is not evident how to chose a window function above another. A window function should not be too rectangular to reduce the spectral leakage and should not be too narrow because such windows would significantly disrupt the low frequency component of the spectrum. The triangular windows could be a good compromise and, indeed, using these window functions, the mscohere coherence peaks at the 20 and 60-year are both 95% significant: see Fig. 6. In any case, the mscohere results depicted in Figs. 5 and 6 are unsatisfactory.

In the present case, the ambiguity of the mscohere method appears to be mostly due to its too low spectral resolution and the situation is worsen by the fact that this methodology requires the adoption of window functions. On the contrary, using alternative MSC algorithms characterized by a higher spectral resolution that, in addition, do not require any window function pre-processing, e.g. the canonical correlation analysis (Santamaria and Via, 2007), very sharp and high quality MSC curves are found. Repeating the same statistical test used in the mscohere method the 95% significance level is robustly met by both the 20- and 60-year MSC peaks. Also other MSC peaks at about 6.6, 7.4 and 14 years met the 95% significance level: see Fig. 7B and C.

The found coherence result confirms Scafetta (2014a) where a direct MEM power spectrum comparison was proposed. In fact, the astronomical harmonics can be calculated with a very high accuracy using several thousand year long records obtained with the JPL's HORIZONS Ephemeris system. On the other hand, periodogram and MEM power spectra of the temperature record show several peaks at the 99% confidence level, as shown in Fig. 2B that are coherent with several astronomical spectral peaks within their 99% confidence level (cf. Scafetta, 2014a).

However, MSC methods are more adequate for evaluating the spectral coherence between two records. The shortcoming of the method is that it requires correlation matrices using sub-window of the total record. Using sub-windows necessarily reduces the spectral resolution of the analysis. As demonstrated in this paper, a technical discussion has been necessary because the common mscohere method gives ambiguous results. To overcome the problem, higher resolution MSC methods have been needed to properly test our specific scientific hypothesis.

The result empirically suggests that the climate system is partially modulated by astronomical forces of gravitational and solar origin. The result appears robust also on a wider scale. In fact, although herein we have analyzed accurate global climate records, which unfortunately are available only since 1850, typical astronomical harmonics at 20- and 60-year periods have been observed also in a number of climate proxy records covering several centuries and millennia (cf. Chylek et al., 2011; Davis and Bohling, 2001; Jakubcová and Pick, 1986; Klyashtorin et al., 2009; Qian and Lu, 2010; Scafetta 2010, 2013, 2014b; Scafetta et al., 2013).

Critiques of the planetary theory of solar and climate variation have been published too, together with proper rebuttals. The most typical physical critique has been that the planets are too far from the sun to influence it in any meaningful way (e.g. Callebaut et al., 2012). However, this critique ignores the possibility that the small forcing induced by the planetary tides on the sun could be greatly amplified up to a four million factor by a nuclear fusion feedback yielding luminosity fluctuations of an order of magnitude compatible with the observations (cf. Scafetta, 2012b; Wolff and Patrone, 2010). In addition, this critique ignores that the planets-sun coupling could also be electromagnetic with the coupling signal traveling throughout the solar wind: such a mechanism would be far less sensitive to a r^{-3} distance attenuation factor as present in the gravitational tidal forcing. The existence of such a link appears supported by the fact that the side of the sun looking toward Jupiter appears brighter yielding to a quasi 1.09-year oscillation during solar maxima in the total solar irradiance records observed from the Earth (Scafetta and Willson, 2013b). In addition, there are numerous empirical evidences for a planetary modulation of solar activity, as

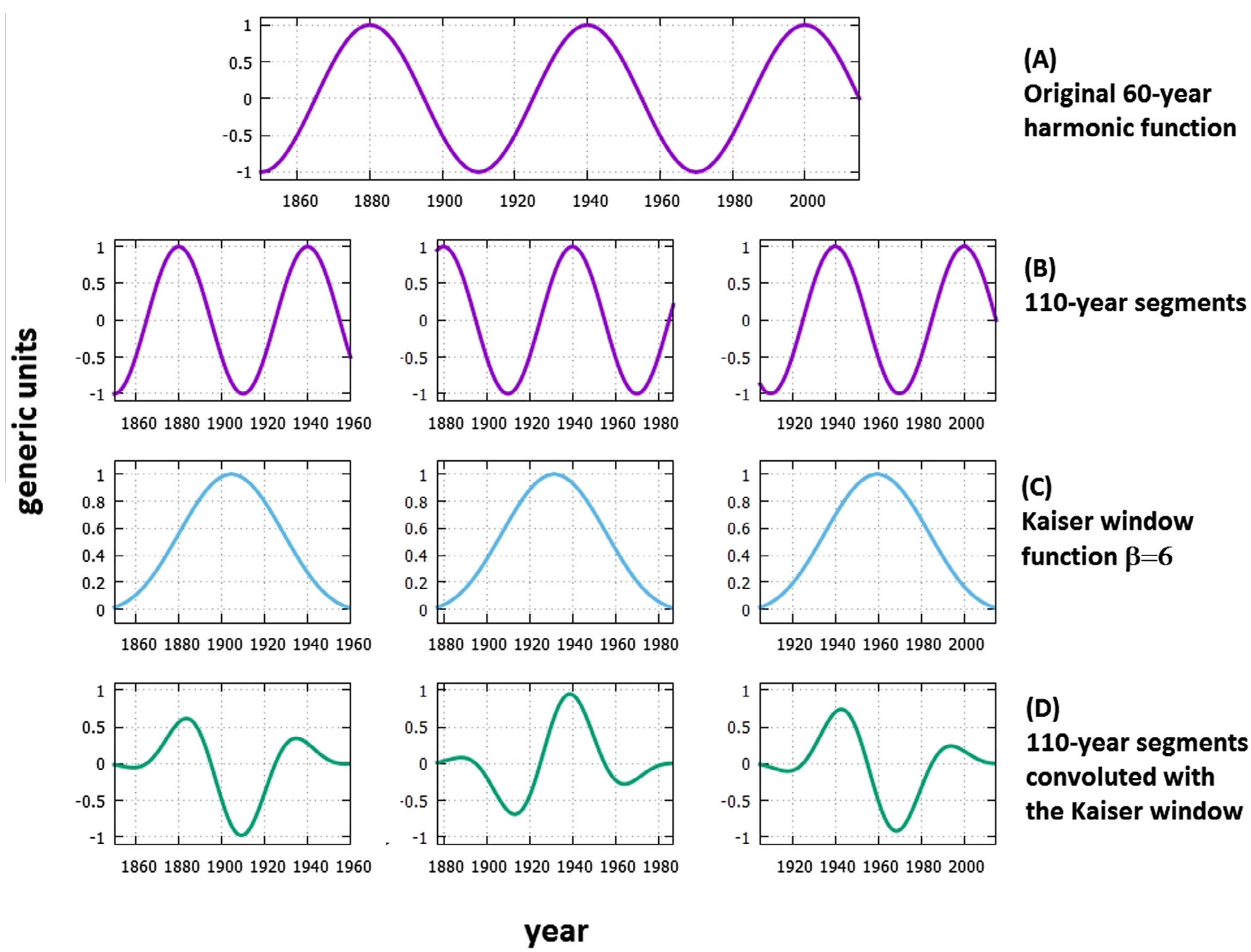

Fig. 8. Distortion of low frequency harmonics induced by a window-function. (A) 165-year long record of a 60-year period oscillation simulating the temperature record depicted in Fig. 3. (B) Three samples of 110-year segments to be processed in the covariance matrices of the coherence algorithms. (C) Example of a window-function: the Kaiser ($\beta = 6$) window is depicted. (D) The 110-year segments convoluted with the window-function to highlight the serious distortion of the 60-year oscillation caused by the convolution.

discussed and referenced in the introduction, even at the shortest time scales. For example, Hung (2007) reported that *"twenty-five of the thirty-eight largest known solar flares were observed to start when one or more tide-producing planets (Mercury, Venus, Earth, and Jupiter) were either nearly above the event positions (less than 10 deg. longitude) or at the opposing side of the Sun. The probability for this to happen at random is 0.039 percent."*

Critiques involving the statistical confidence of spectral results were also proposed. For example, Cameron and Schüssler (2013) and Poluianov and Usoskin (2014) critiqued the statistical analysis present in Abreu et al. (2012) showing an excellent agreement between the long-term cycles in proxies of solar activity and the periodicities in the planetary torque. This critique is not directly relevant for the present study because only specific long-term cycles in proxy records were analyzed while herein different oscillations and only accurate dynamical and experimental records were studied. However, McCracken et al. (2014) confirmed the evidence for a planetary forcing of the cosmic ray intensity and solar activity throughout the past 9400 years, which was also observed in Scafetta (2012a) using alternative data. Moreover, because herein I have demonstrated that a critique based merely on a statistical analysis could be ambiguous, it would be worthy in the future to address the issue using the advanced coherence methodologies herein adopted.

Cauquoin et al. (2014) also was critical of Abreu et al. (2012) by claiming that 330,000 years ago no evidence for a planetary influence on solar activity would exist. However, Scafetta (2014a) rebutted this claim highlighting that Cauquoin et al. (2014) observed solar oscillations at 103, 115, 130 and 150 year periods at the 95% confidence level and demonstrated that these specific oscillations are planetary induced oscillations. In fact, they derive from non-linearity applied to the beats of the 9.96-year Jupiter-Saturn spring tidal period and the 11.86-year Jupiter orbital period with the 11-year solar cycle as predicted by a planetary model of solar variation (cf. Scafetta, 2012a, 2014a).

Finally, Holm (2014a,b) claimed that *"An estimate of the magnitude squared coherence shows instead that under certain conditions only coherence at a period of 15–17 years can be found in the data"* and, therefore, he claimed to dismiss the otherwise well observed and expected coherence between astronomical and climate records at the 20- and 60-year periods, which has been confirmed also herein. Scafetta (2014a, Section 3) rebutted the claim demonstrating that Holm's analysis was prejudiced by its too low spectral resolution due to Holm's adoption of too short Fourier windows. In his response, Holm (2015) acknowledged the validity of my rebuttal and that longer windows needed to be used. He also confirmed the existence of a spectral coherence peaks at 20 and 60-year periods when a 109-year long window is adopted. However, he added that the result did not meet the 95% confidence level and concluded that because *"none of the high values of coherence then turn out to be significant ...the planetary hypothesis is therefore dismissed."* The present study rebuts this claim demonstrating that Holm's result is an artifact of the low spectral resolution of the mscohere and wavelet methods that he adopted: see also the Appendix A. In fact, as explained in the present study, the data have specific characteristics (e.g. the shortness of the temperature data) that require the adoption of high resolution spectral coherence methodologies to perform a meaningful analysis of the spectral range of interest and of its significance evaluated with Monte Carlo simulation based on a non-parametric random phase method.

I have shown that a high resolution coherence analysis methodology needs to be used and this methodology confirms that the climate system can be partially modulated by astronomical forces of gravitational and solar origin with a 95% confidence level.

Appendix A

Herein I show how window functions disrupt the low frequency component of a spectrum making the mscohere algorithm unstable. This property explains well the poor results depicted in Figs. 5 and 6. Fig. 8 shows a simple example made of a sinusoidal function of the type

$$f(t) = cos(2\pi(t - 1880)/60), \tag{4}$$

which has a 60-year period and maxima in 1880, 1940 and 2000, as shown in the temperature record depicted in Fig. 3 (cf. Scafetta, 2010, Figs. 1 and 10).

In the paper the mscohere function constructs covariance matrices based on 110-year segments of the original record. Fig. 8B shows three of these segments in the period 1850–1960, 1877–1987 and 1905–2015, respectively. These three segments still reveal a quite recognizable 60-year oscillation.

The mscohere methodology, however, pre-processes the segments with a window function to reduce aliasing distortion in the spectrum. Fig. 8C depict the Kaiser window function with $\beta = 6$. This window function was herein chosen because it was explicitly adopted by Holm (2015) in his critical study. Other generic windows functions could be adopted but the logical result exposed in this appendix would remain the same.

Fig. 8D shows the segments depicted in Fig. 8B convoluted with the Kaiser window function depicted in Fig. 8C. These convoluted curves are those that are directly processed by the mscohere algorithm. It is evident that these curves show a very disrupted and almost unrecognizable 60-year oscillation compared to those depicted in Fig. 8B and to the original record depicted in Fig. 8A. In particular, the extremes are too dumped and the time distance between contiguous maxima, which is 60 years in the original record, is now quite variable and even reduced to about 50 years.

Because the curves depicted in Fig. 8D significantly depend on the particular window functions, this simple example qualitatively explains why the mscohere algorithm, by processing segments with disrupted patterns as those shown in Fig. 8D, provides result for the low frequency component of the spectrum that are both highly uncertain and window-function dependent, as Figs. 5 and 6 show. Thus, one would expect that in such a situation the coherence peaks at 20- and 60-year periods could be not fully statistically significant. However, this simple example clearly suggests that the failure of finding fully statistically significant results is due to the computational artifacts introduced by the window-function pre-processing algorithms adopted by the mscohere methodology.

On the contrary, the canonical correlation analysis, in virtue of its algorithm, is less sensitive to aliasing distortions and presents a higher spectral resolution at the low frequency range of the spectrum than the mscohere method. Thus, this methodology does not require any window function pre-processing. Consequently, it can directly process unaltered 110-year segments of data that, as implicit in Fig. 8B, would still conserve a sufficiently clear 60-year modulation. This property helps to find the 95% statistical significant results depicted in Fig. 7.

References

Abreu, J.A., Beer, J., Ferriz-Mas, A., McCracken, K.G., Steinhilber, F., 2012. Is there a planetary influence on solar activity? Astron. Astrophys. 548, A88.

Benesty, J., Chen, J., Huang, Y. 206. Estimation of the coherence function with the MVDR approach. In: Acoustics, Speech and Signal Processing. ICASSP 2006 Proceedings, vol. 3, 500–503.

Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B., Jones, P.D., 2006. Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. J. Geophys. Res. 111, D12106.

Bucha, V., Jakubcová, I., Pick, M., 1985. Resonance frequencies in the Sun's motion. Stud. Geophys. Geod. 29, 107–111.

Callebaut, D.K., de Jager, C., Duhau, S., 2012. The influence of planetary attractions on the solar tachocline. J. Atmos. Sol. Terr. Phys. 80, 73–78.

Cameron, R.H., Schüssler, M., 2013. No evidence for planetary influence on solar activity. Astron. Astrophys. 557, A83.

Cauquoin, A., Raisbeck, G.M., Jouzel, J., Bard, E., 2014. (ASTER Team): No evidence for planetary influence on solar activity 330 000 years ago. Astron. Astrophys. 561, A132.

Charvátová, I., 2009. Long-term predictive assessments of solar and geomagnetic activities made on the basis of the close similarity between the solar inertial motions in the intervals 1840–1905 and 1980–2045. New Astron. 14, 25–30.

Chylek, P., Folland, C.K., Dijkstra, H.A., Lesins, G., Dubey, M.K., 2011. Icecore data evidence for a prominent near 20 year time-scale of the Atlantic multidecadal oscillation. Geophys. Res. Lett. 38, L13704.

Cionco, R.G., Soon, W., 2015. A phenomenological study of the timing of solar activity minima of the last millennium through a physical modeling of the Sun-Planets. New Astron. 34, 164–171.

Davis, J.C., Bohling, G., 2001. The search for patterns in ice-core temperature curves. In: Gerhard, L.C., Harrison, W.E., Hanson, B.M. (Eds.) Geological Perspectives of Global Climate Change, pp. 213–229.

Holm, S., 2014a. On the alleged coherence between the global temperature and the Sun's movement. J. Atmos. Sol. Terr. Phys. 110–111, 23–27.

Holm, S., 2014b. Corrigendum to on the alleged coherence between the global temperature and the sun's movement. J. Atmos. Sol. Terr. Phys. 119, 230–231.

Holm, S., 2015. Prudence in estimating coherence between planetary, solar and climate oscillations. Astrophys. Space Sci. 357 (106), 1–8.

Hongwei, W. 2009. Evaluation of various window functions using multi-instrument. Virtins Technology. Available at <http://www.multi-instrument.com/doc/D1003/EvaluationofVariousWindowFunctionsusingMulti-InstrumentD1003.pdf>.

Hoyt, D.V., Schatten, K.H., 1997. The Role of the Sun in the Climate Change. Oxford Univ. Press, New York.

Hung, C.-C. 2007. Apparent relations between solar activity and solar tides caused by the planets. NASA report/TM-2007-214817. Available at <http://ntrs.nasa.gov/search.jsp?R=20070025111>.

Intergovernmental Panel on Climate Change (IPCC), 2013. Climate Change 2013: The Physical Science Basis: Fifth Assessment Report. Available at <http://www.ipcc.ch/>.

Jakubcová, I., Pick, M., 1986. The planetary system and solar-terrestrial phenomena. Stud. Geophys. Geod. 30, 224–235.

Jose, P.D., 1965. Sun's motion and sunspots. Astron. J. 70, 193–200.

Kepler, J. 1606. De Stella Nova in Pede Serpentarii.

Kepler, J., 1979. 1601. Johannes Kepler's on the more certain fundamentals of astrology, Prague 1601. In: Brackenridge, J.B., Rossi, M.A. (Eds.), Proceedings of the American Philosophical Society, 123(2), pp. 85–116.

Kirby, J., 2007. Cosmic rays and clouds. Surv. Geophys. 28, 333–373.

Klyashtorin, L.B., Borisov, V., Lyubushin, A., 2009. Cyclic changes of climate and major commercial stocks of the Barents sea. Marine Biol. Res. 5, 4–17.

Ma'Sar, A., 886. On the great conjunctions. Edited and translated by K. Yamamoto, C. Burnett. Brill, 2000.

McCracken, K.G., Beer, J., Steinhilber, F., Abreu, J., 2013. A phenomenological study of the cosmic ray variations over the past 9400 years, and their implications regarding solar activity and the solar dynamo. Sol. Phys. 286, 609–627.

McCracken, K.G., Beer, J., Steinhilber, F., Abreu, J., 2014. Evidence for planetary forcing of the cosmic ray intensity and solar activity throughout the past 9400 years. Sol. Phys. 286 (2), 609–627.

Milankovitch, M., 1930. Mathematische Klimalehre und Astronomische Theorie der Klimaschwankungen, Handbuch der Klimatologie, Band I, Teil A. Berlin, Verlag von Gebr?der Borntraeger.

Mörner, N.-A., 2013. Planetary beat and solar–terrestrial responses. Pattern Recognit. Phys. 1, 107–116.

Mörner, N.-A., 2015. The approaching new grand solar minimum and little ice age climate conditions. Nat. Sci. 7, 510–518.

Mörner, N.-A., Tattersall, R., Solheim, J.-E., 2013. Pattern in solar variability, their planetary origin and terrestrial impacts. Pattern Recognit. Phys. 1, 203–204.

Poluianov, A., Usoskin, I., 2014. Critical analysis of a hypothesis of the planetary tidal influence on solar activity. Sol. Phys. 289, 2333–2342.

Press, W.P., Teukolsky, S.A., Vetterling, W.T., Flannery, B.P., 2007. Numerical recipes 3rd edition: the art of scientific computing, third ed. Cambridge University Press.

Ptolemy, C., 1940. 2nd century. Tetrabiblos. In: Robbins, F.E. (Ed.). Harvard University Press, Cambridge, MA (Loeb Classical Library 1940).

Puetz, S.J., Prokoph, A., Borchardt, G., Mason, E.W., 2014. Evidence of synchronous, decadal to billion year cycles in geological, genetic, and astronomical events. Chaos, Solitons Fractals 62–63, 55–75.

Qian, W.-H., Lu, B., 2010. Periodic oscillations in millennial global-mean temperature and their causes. Chin. Sci. Bull. 55, 4052–4057.

Rabiner, L.R., Gold, B., 1975. Theory and Application of Digital Signal Processing. Prentice-Hall, Englewood Cliffs, NJ.

Roe, G., 2006. In defense of Milankovitch. Geophys. Res. Lett. 33 (24), L24703.

Salvador, R., 2013. A mathematical model of the sunspot cycle for the past 1000 yr. Pattern Recognit. Phys. 1, 117–122.

Santamaria, I., Via, J., 2007. Estimation of the magnitude squared coherence spectrum based on reduced- rank canonical coordinates. In: IEEE International Conference on Acoustics, Speech and Signal Processing. ICASSP 2007, pp. III-985 - III-988. DOI: 10.1109/ICASSP.2007.366847.

Scafetta, N., 2010. Empirical evidence for a celestial origin of the climate oscillations and its implications. J. Atmos. Sol. Terr. Phys. 72 (13), 951–970.

Scafetta, N., 2012a. 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. J. Atmos. Sol. Terr. Phys. 80, 296–311.

Scafetta, N., 2012b. Does the Sun work as a nuclear fusion amplifier of planetary tidal forcing? A proposal for a physical mechanism based on the mass-luminosity relation. J. Atmos. Sol. Terr. Phys. 81–82, 27–40.

Scafetta, N., 2013. Discussion on climate oscillations: CMIP5 general circulation models versus a semi-empirical harmonic model based on astronomical cycles. Earth Sci. Rev. 126, 321–357.

Scafetta, N., 2014a. Discussion on the spectral coherence between planetary, solar and climate oscillations: a reply to some critiques. Astrophys. Space Sci. 354, 275–299.

Scafetta, N., 2014b. Multi-scale dynamical analysis (MSDA) of sea level records versus PDO, AMO, and NAO indexes. Clim. Dyn. 43, 175–192.

Scafetta, N., Willson, R.C., 2013a. Planetary harmonics in the historical Hungarian aurora record (1523–1960). Planet. Space Sci. 78, 38–44.

Scafetta, N., Willson, R.C., 2013b. Empirical evidences for a planetary modulation of total solar irradiance and the TSI signature of the 1.09-year Earth-Jupiter conjunction cycle. Astrophys. Space Sci. 348 (1), 25–39.

Scafetta, N., Humlum, O., Solheim, J.-E., Stordahl, K., 2013. Comment on The influence of planetary attractions on the solar tachocline by Callebaut, de Jager and Duhau. J. Atmos. Sol. Terr. Phys. 102, 368–371.

Shepherd, J., Zharkov, S.I., Zharkova, V.V., 2014. Prediction of solar activity from solar background magnetic field variations in cycles 21–23. ApJ 795, 46.

Solheim, J.-E., 2013. Signals from the planets, via the Sun to the Earth. Pattern Recognit. Phys. 1, 177–184.

Strogatz, S.H., 2009. Exploring complex networks. Nature 410, 268–276.

Svensmark, H., 1998. Influence of cosmic rays on the Earth's climate. Phys. Rev. Lett. 81, 5027–3030.

Svensmark, H., Bondo, T., Svensmark, J., 2009. Cosmic ray decreases affect atmospheric aerosols and clouds. Geophys. Res. Lett. 36, L15101. http://dx.doi.org/10.1029/2009GL038429.

Svensmark, J., Enghoff, M.B., Svensmark, H., 2012. Effects of cosmic ray decreases on cloud microphysics. Atmos. Chem. Phys. Discuss. 12, 3595–3617.

Tan, B., Cheng, Z., 2013. The mid-term and long-term solar quasiperiodic cycles and the possible relationship with planetary motions. Astrophys. Space Sci. 343, 511–521.

Tattersall, R., 2013. The hum: log-normal distribution and planetary–solar resonance. Pattern Recognit. Phys. 1, 185–198. http://dx.doi.org/10.5194/prp-1-185-2013.

Temple, R., 1998. The sirius mystery (Destiny Books), Appendix 3, Why Sixty Years? <http://www.bibliotecapleyades.net/universo/siriusmystery/siriusmysteryappendix03.htm>.

Tinsley, B.A., 2008. The global atmospheric electric circuit and its effects on cloud microphysics. Rep. Progress Phys. 71, 066801.

Traversi, R., Usoskin, I., Solanki, S., Becagli, S., Frezzotti, M., Severi, M., Stenni, B., Udisti, R., 2012. Nitrate in polar ice: a new tracer of solar variability. Sol. Phys. 280 (1), 237.

Wang, Z., Wu, D., Song, X., Chen, X., Nicholls, S., 2012. Sun-Moon gravitation-induced wave characteristics and climate variation. J. Geophys. Res. 117, D07102.

Welch, P.D., 1967. The use of fast fourier transform for the estimation of power spectra: a method based on time averaging over short, modified Periodograms. In: IEEE Transactions on Audio and Electroacoustics. AU-15, pp. 70–73.

Wilson, I.R.G., 2013. The Venus–Earth–Jupiter spin–orbit coupling model. Pattern Recognit. Phys. 1, 147–158.

Wolf, R., 1859. Extract of a letter to Mr. Carrington. Mon. Not. R. Astron. Soc. 19, 85–86.

Wolff, C.L., Patrone, P.N., 2010. A new way that planets can affect the Sun. Sol. Phys. 266, 227–246.

Wyatt, M., Curry, J., 2014. Role of Eurasian Arctic shelf sea ice in a secularly varying hemispheric climate signal during the twentieth century. Clim. Dyn. 42, 2763–2782.