The Sun has a significant influence on the climate

Introduction

According to the latest IPCC report, AR5, the influence of the Sun on our climate since pre-industrial times, in terms of radiative forcing, is very small compared to the variation of radiative forcing due to added anthropogenic greenhouse gases: 0.05 [0.00 to 0.10] W/m^2 vs. 2.29 [1.13 to 3.33] W/m^2. Thus, the IPCC message is that changes in solar activity are nearly negligible compared to anthropogenic ones. Can this interpretation be trusted?

In a famous lecture Feynman reminded us that scientific models must predict physical observations. If this crucial condition is not fulfilled, a physical model cannot be considered valid or complete, and the science cannot be considered “settled.” Indeed, it has been demonstrated that there are serious discrepancies between the general circulation climate model predictions and the data (e.g. Scafetta, 2013b). Thus, it is legitimate to question the science behind the IPCC interpretation and investigate alternative interpretations of climate changes.

Here I summarize how the scientific literature alternative to the thesis that the Sun contributes little to climate change has addressed the issue. Indeed, solar and global surface temperature records appear to be quite related to each other at both short and long time scales once the appropriate methodologies and solar models are adopted. It is necessary, however, to clarify a few concepts because no consensus on the solar contribution to climate changes exists. I believe that many people are somehow confused on this topic.

Understanding the data

The global surface temperature patters are evidently not determined exclusively by solar inputs. On time scales up to the millennial one, global climate averages are mostly regulated by volcano eruptions, anthropogenic forcings and numerous natural oscillations, which include solar, astronomical and lunar tidal oscillations. To avoid misleading conclusions, the different physical attributions need to be taken into account. In addition, the quality of solar and climatic records varies. Instrumental measurements are often processed through complex physical and statistical models and if direct measurements are missing, a low-quality solar and climate proxy reconstructions are adopted.

Many empirical studies (e.g.: Bond et al., 2001; Douglass and Clader, 2002; Eichler et al., 2009; Friis-Christensen and Lassen, 1991; Hoyt and Schatten, 1993; Hoyt and Schatten, 1997; Kerr, 2001; Kirkby, 2007; Loehle and Scafetta, 2011;Scafetta, 2012b; Scafetta, 2013a; Scafetta, 2013b; Scafetta, 2014; Scafetta and West, 2007; Scafetta and West, 2008; Shaviv, 2008; Soon, 2005; Soon, 2009; Steinhilber et al., 2012; White et al., 1997) have found a strong but *complex* solar signature in the climate system at multiple timescales once that specific models and records have been used. Some of these studies have claimed that the Sun could have contributed at least $\sim$ 50% of the post 1850 global warming. This conclusion contradicts the current analytical climate models, such as the general circulation models (GCMs) adopted by the IPCC that predict only a 5% or lower solar contribution to the warming observed during the same period (e.g. see the IPCC (2013)).

For example, Douglass and Clader (2002); Lean and Rind (2009); van Loon and Labitzke (2000); Scafetta (2009); Scafetta (2013c) evaluated the signature of the 11-year solar cycle on the temperature by simultaneously filtering off the volcano signature, the anthropogenic signature and the ENSO oscillations. These authors found that during the period from 1980 to 2000, which experienced very large 11-year solar oscillations, the 11-year solar cycle signature on the global surface temperature had an amplitude of about 0.1 K. At higher altitudes, however, the amplitude of the 11-year solar signature increases up to $\sim$ 0.4 K (e.g.: Scafetta, 2013c; van Loon and Labitzke, 2000; Svensmark and Friis-Christensen, 2007).

On longer time scales the solar influence on climate becomes clearer once appropriate solar proxy models are used (e.g.: Eddy, 1976; Hoyt and Schatten, 1997; Kirkby, 2007). Steinhilber et al. (2012) found an excellent correlation between a 9,400-year cosmic ray proxy model of solar activity from ice cores and tree rings and the Holocene Asian climate as determined from stalagmites in the Dongge cave, China. In particular, data show a strong millennial oscillation common to both solar and temperature records (e.g.: Bond et al., 2001; Kerr, 2001) that must have contributed significantly to the warming observed since 1850.

In fact, Christiansen and Ljungqvist (2012) showed that the extra tropical surface temperature of the northern hemisphere experienced significant warm periods during the Roman Optimum (100 B.C. - 300 A.D.), and during the Medieval Warm Period (900-1400 A.D.) and significant cool periods during the Dark Age (400-800 A.D.) and the Little Ice Age (1400-1800 A.D.) (Christiansen and Ljungqvist, 2012).

Thus, following this millennial cycle, since 1800 the temperature had to increase naturally: the millennial climatic maximum induced by the millennial solar maximum had to occur in the 21th century and could have contribute about 50% or more of the warming observed since 1850 (e.g.: Humlum et al., 2011; Scafetta, 2012a; Scafetta, 2013b). Numerous other climatic oscillations at the decadal, bi-decadal, 60-year and secular scales that could be solar-astronomically induced are also typically observed in a large number of data (e.g.: Scafetta, 2010; Scafetta, 2013b; Scafetta, 2014).

Empirical studies versus climate model studies

Thus, there is an apparent incompatibility between the empirical and analytical studies. This is likely due to (1) the different philosophical approaches used to address the problem and (2) to the current lack of scientific understanding of microscopic physical mechanisms regulating climate change. Let us understand the reason.

The empirical/holistic approach focuses on the macroscopic characteristics of the data that are interpreted using detailed cross-correlation pattern recognition methodologies. It does not require the microscopic identification of all physical microscopic mechanisms to recognize macroscopic patterns such as cycles, which can be directly modelled.

On the contrary, the analytical GCM approach focuses on the microscopic modelling of the individual physical mechanisms and their coupling: it uses Navier-Stokes equations, thermodynamics of phase changes of atmospheric water, detailed radiation budget of the Earth and atmosphere and ocean dynamics, specific radiative forcing functions as inputs of the model, etc. The GCMs depend on very numerous internal variables and are characterized by serious uncertainties such as those related to the cloud formation (IPCC, 2013), which regulate the important albedo index.

It is evident that the analytical models need to be physically *complete* to be meaningful. On the contrary, there are several reasons suggesting that the current analytical climate models are severely incomplete. This lack of detailed knowledge is manifest mostly in the large error bar that characterizes the climatic sensitivity to CO_2 doubling that, according to the IPCC, varies between 1.5 and 4.5^{o}C . Works suggesting a strong solar effect on climate would imply a climatic sensitivity to CO_2 doubling of about 1.5^{o}C . Note that this low climatic sensitivity to radiative forcing implies that the total solar irradiance varied significantly more than what currently used as total solar irradiance forcing in the current climate models and/or that solar forcings alternative to the radiative one are influencing the climate. Thus, the models may have used a wrong total solar irradiance input and/or they oversimplify the solar influence on climate.

Let us briefly summarize some of the arguments proposed in the referenced literature.

(1) The analytical models such as the CMIP5 GCMs adopted by the IPCC (2013) have used a solar forcing function deduced only from a specific total solar irradiance proxy record that shows only a

very small secular variability (e.g. Wang et al. (2005)), while alternative total solar irradiance proxy models showing a far greater secular variability and different details in the patters also exist (Hoyt and Schatten, 1997; Shapiro et al., 2011). These alternative solar models better correlate with the temperature patterns on multiple scales and reconstruct a large fraction of the warming observed since 1850 (Scafetta, 2013b; Hoyt and Schatten, 1997; Soon, 2009; Soon, 2005; Soon and Legates, 2013).

(2) The analytical models still assume that solar-climate interaction is limited to TSI forcing alone. However, other solar-climate mechanisms likely exist although still poorly understood. For example, the climate system may be particularly sensitive to specific radiations (e.g. ultraviolet light) and to cosmic ray or solar wind variations that could significantly modulate the cloud cover system (Kirkby, 2007). Other still unknown space weather and gravitational mechanisms may exist.

(3) The climatic records are characterized by numerous natural oscillations from the decadal to the millennial timescales that have been demonstrated to be not reproduced by the analytical models, but are present in specific solar, lunar and astronomical records (Scafetta, 2012b; Scafetta, 2013b; Scafetta, 2013a; Scafetta, 2010; Scafetta, 2012a). These oscillations, including the millennial cycle, stress the importance of solar and astronomical effects on the Earth's climate (Scafetta,2013b; Steinhilber et al., 2012).

In general, analytical models may theoretically be considered the best way to exploit the confirmatory analysis. However, the exploratory analysis - which is needed in order to envisage the primary physical drivers of phenomena - is a completely different gnoseologic concern. One cannot substitute the crucial stage of the exploratory analysis with any kind of complex confirmatory mathematics. Both stages are needed and, in general, to describe a complex system usually empirical/holistic approaches may be more satisfactory than an analytical ones. In the analytical modelling, mistakes can also be easily made when the original set of primary drivers and forcing functions is speculated.

For example, one of the reasons why the IPCC claims that the sun has not contributed to the warming observed since 1970s is because the adopted solar model (Wang et al., 2005) suggests that the average solar activity was quite constant or even decreased during this period. This interpretation follows the PMOD total solar irradiance satellite composite by Fröhlich (2006). However, Scafetta and Willson (2009); Scafetta and Willson (2014) have shown that PMOD used altered total solar irradiance satellite records based on hypotheses that appear contradictory. On the contrary, the unaltered total solar irradiance satellite records are combined in the ACRIM composite which suggests that solar activity increased from 1980 to 2000 and decreased afterward (Willson and Mordvinov, 2003). Even if the direct effect of the total solar irradiance may be small and the difference between ACRIM and the PMOD might be climatically negligible, the pattern shown by the ACRIM composite suggests a dynamics, for example a 60-year oscillation, regulated by astronomical forcings whose harmonics are found in the climate system as well (Scafetta, 2010; Scafetta, 2013b; Scafetta, 2012a; Scafetta,2014). See the difference between the ACRIM and the PMOD composite here http://acrim.com/TSI%20Monitoring.htm.

Significant correlation between solar-astronomical records and temperature records

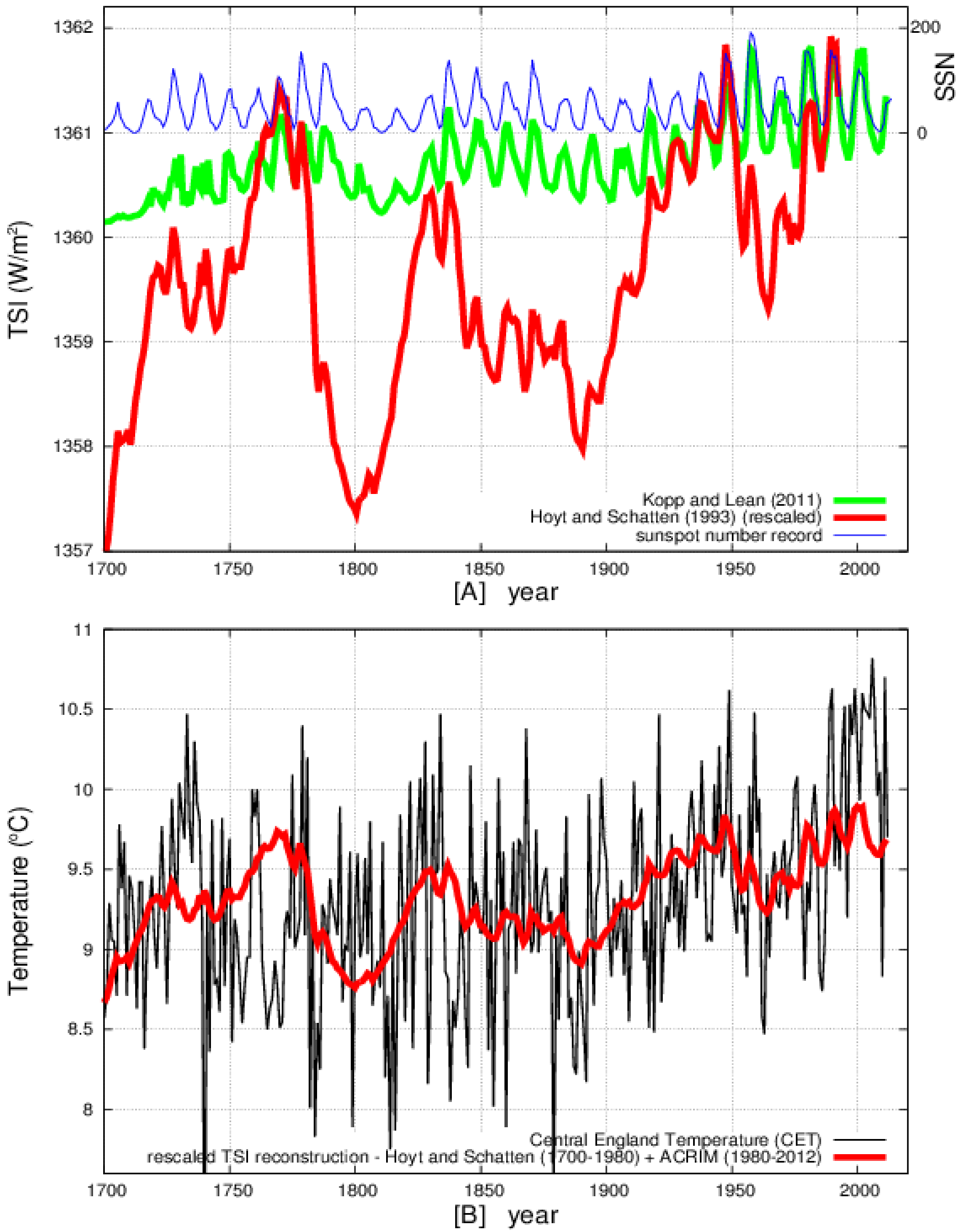

Figure 1a and 1b

Figure 1A compares the sunspot number record since 1700 (blue curve) versus two alternative total solar irradiance reconstructions (Wang et al., 2005; Hoyt and Schatten, 1997). The figure highlights that while the sunspot number is relatively flat, solar proxy models present a more significant secular variability that, however, depends greatly on the chosen proxy model. Some solar model predicts a variability significantly larger than others. Figure 1B simply compares the Central England Temperature record (Parker et al., 1992) and the solar reconstruction proposed by Hoyt and

Schatten (1997). A good correlation is noted for 300 years, which includes a significant portion of the warming observed since 1900.

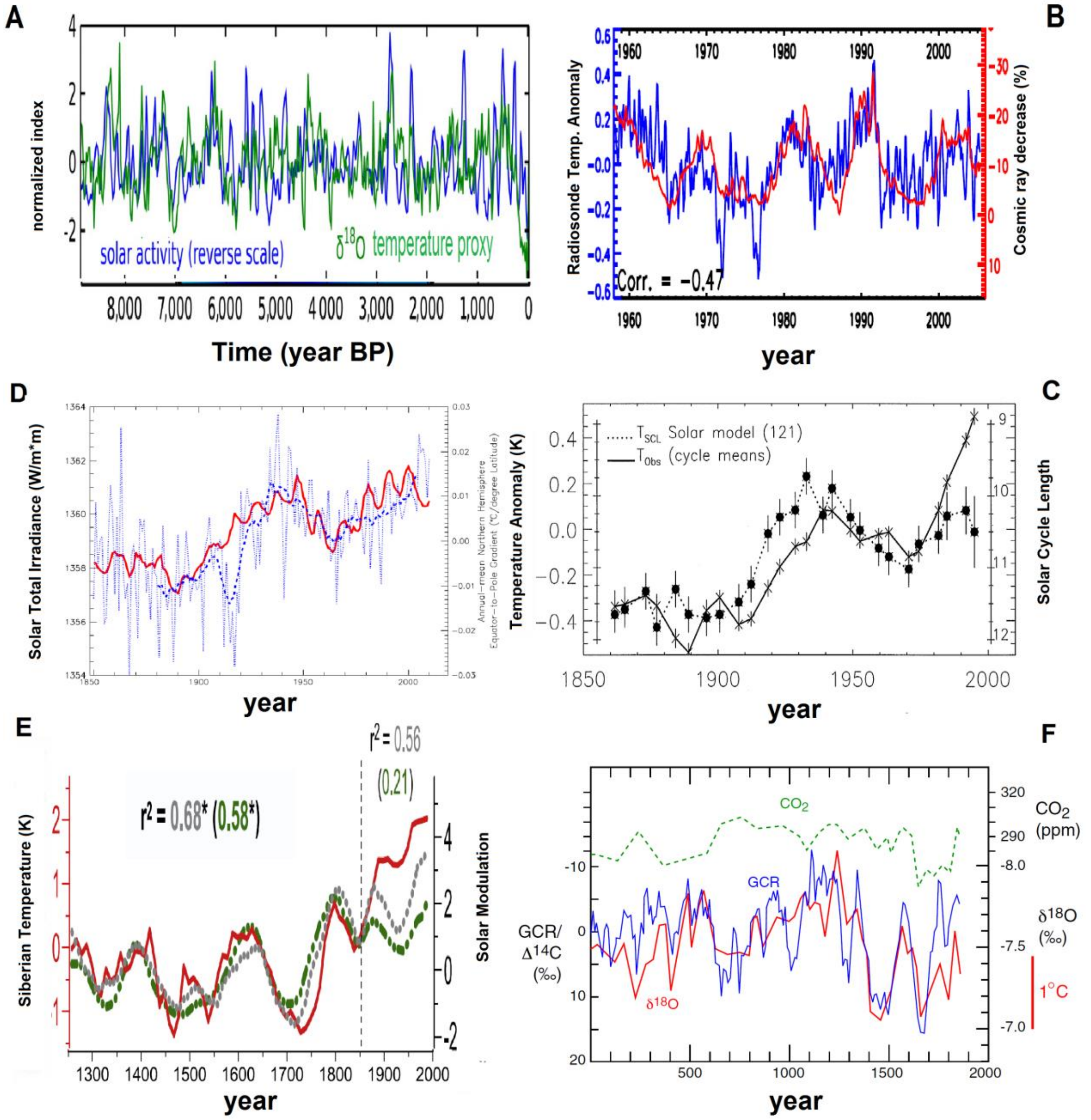

Figure 2

Figure 2 shows examples of solar-climate correlations taken from Steinhilber et al. (2012); Svensmark and Friis-Christensen (2007); Soon and Legates (2013); Thejll and Lassen (2000); Eichler et al. (2009) and Kirkby (2007). A good correlation between solar-astronomical records and climate records is evident at short and long time scales. Figure 2A compares a reconstruction of solar activity and a reconstruction of Asian climate during the Holocene (last 9000 years) (Steinhilber et al., 2012).

Figure 2B shows that the radiosonde temperature anomalies, after an appropriate filtering of other climatic factors, reveals a clear signature of the 11-year solar cycle reconstructed by the cosmic ray record (Svensmark and Friis-Christensen, 2007). Figure 2C compares the instrumental global surface temperature record versus a SCL121 solar cycle length model (Thejll and Lassen, 2000). Figure 2D compares the annual-mean equator-to-pole gradient over the entire Northern Hemisphere versus the estimated total solar irradiance record (red) of Hoyt and Schatten (1997) (red, with updates by Scafetta and Willson (2014)) from 1850 to 2010 (Soon and Legates, 2013).

Figure 2E compare a Siberian temperature reconstruction with solar activity proxies for 750 years (Eichler et al., 2009). Figure 2F depicts a temperature reconstruction for the Central Alps over the last two millennia, obtained from a $\delta^{18}O$ based temperature proxy model versus the variations of cosmic rays (^{14}C) and CO_2 over the same period (Kirkby, 2007). These empirical results clearly suggest that the Sun has a significant influence on the climate system.

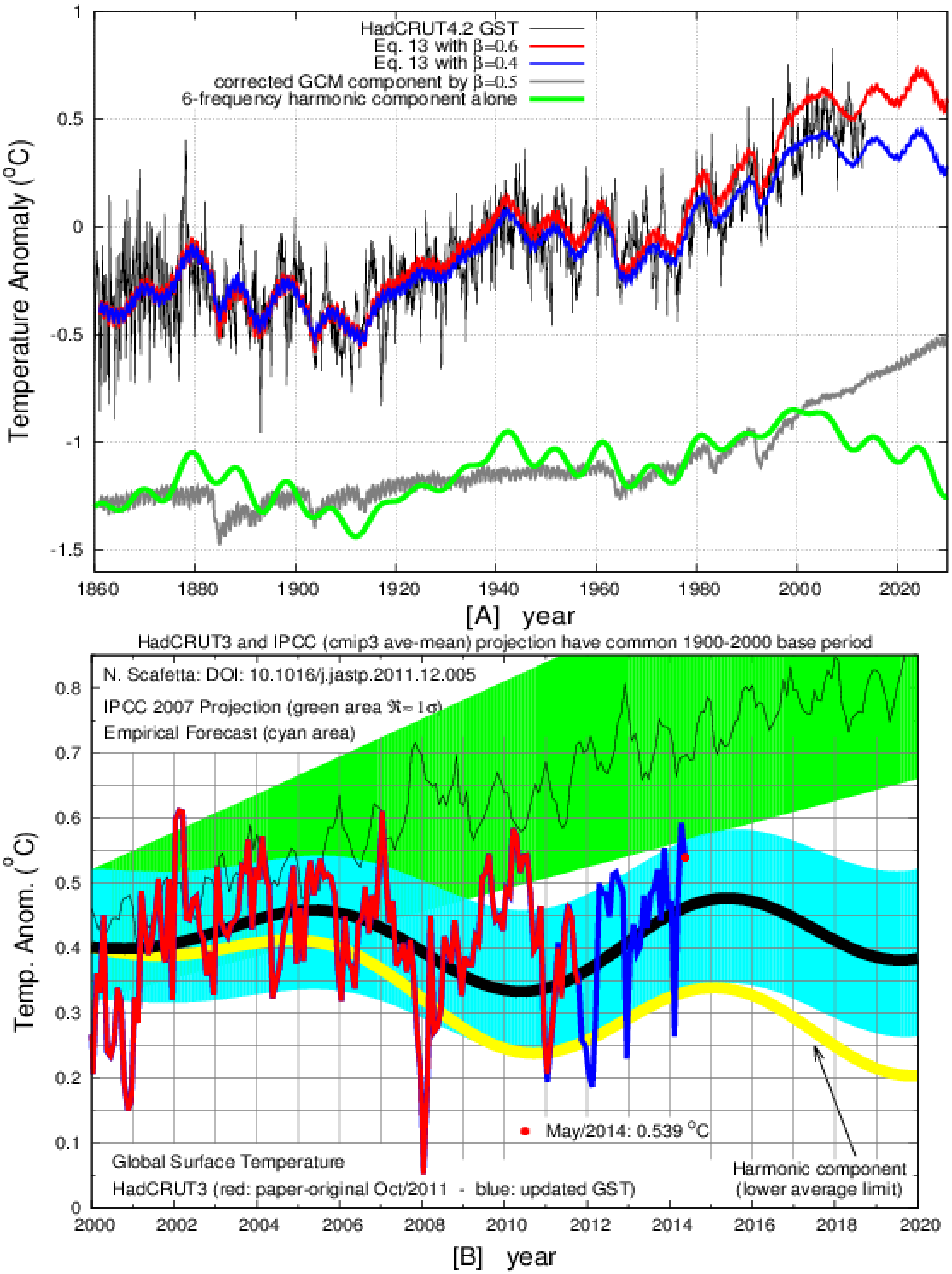

Figure 3

Figure 3A shows the good performance of an empirical model for the global surface temperature proposed by Scafetta (2013b). This model has the peculiarity of attempting a reconstruction of the climate variability using 6 identified solar-astronomical oscillations at periods of 9.1, 10.4, 20, 60, 115 and 983 year. Other harmonics are likely present. These oscillations are able to model the natural decadal-to-millennial natural climatic oscillations. To this harmonic component it is necessary to add an estimate of the anthropogenic and volcano components made by properly attenuating the CMIP5 general circulation model ensemble mean simulation by a factor β ≈ 0.5 to simulate a climate sensitivity to CO_2 doubling of about 1.5°C . Scafetta (2013b) showed that his model outperforms all CMIP5 general circulation models in reconstructing the global surface temperature record. Figure 3B shows a detail with an update of the semi-empirical astronomical model proposed by Scafetta (2012b) in 2011 against the HadCRUT3 global surface temperature record (Brohan, 2006). The red curve shows the original global surface temperature record published in Scafetta (2012b), which ended in October 2011. The blue curve shows the global surface temperature updated to the most current available month, which is May 2014. The back curve within the cyan 1-σ error area is the semi-empirical astronomical model forecast (which was modelled to start in 2000). The figure clearly shows that the proposed semi-empirical model outperforms the IPCC 2007 CMIP3 general circulation model projections (green area) and has successfully forecast the temperature trend from October 2011 to March 2014. Note that a simplified version of the same model was proposed by Scafetta since 2009 (Lorenzetto, 2009; Scafetta, 2010).

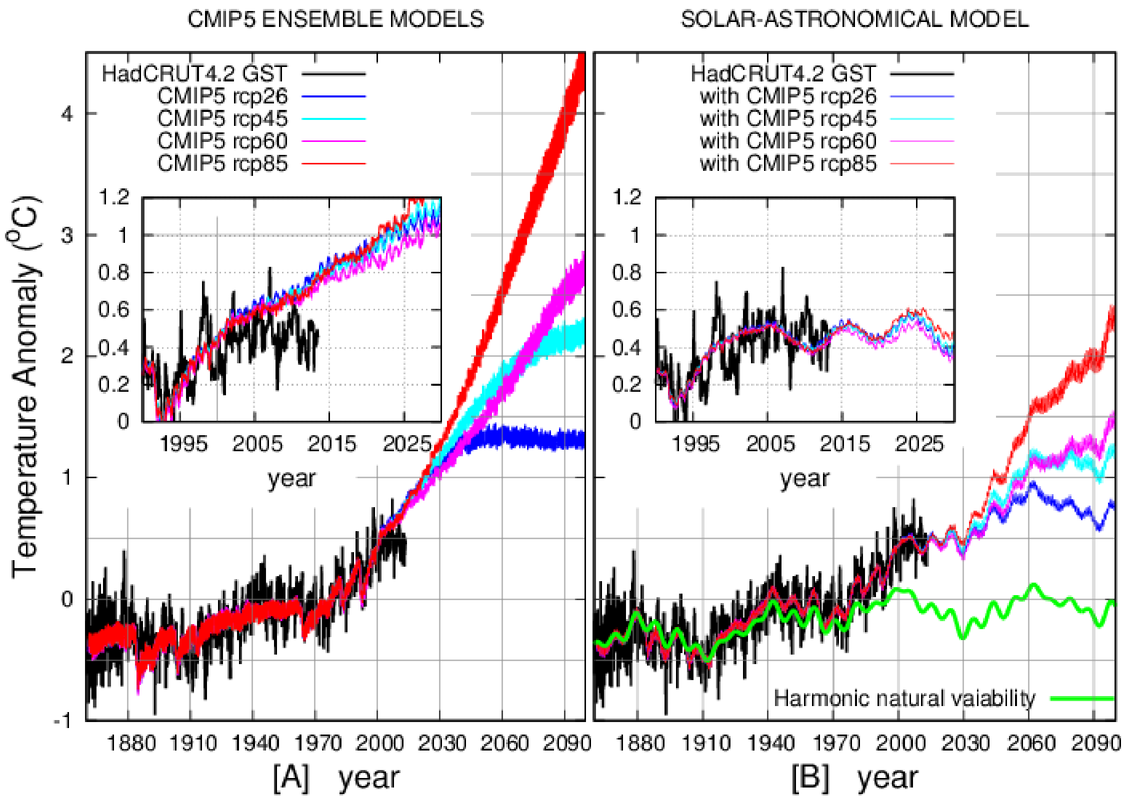

Figure 4

Finally Figure 4A compares the four CMIP5 climate model ensemble average projections versus the HadCRUT4 global surface temperature record. Figure 4B shows the solar–astronomical semi-empirical model against the HadCRUT4 GST record: a common 1900–2000 baseline is used. The figure highlights the better performance of the solar–astronomical semi-empirical model versus the CMIP5 models, which is particularly evident since 2000 as shown in the inserts.

As Figures 3 and 4 show, the proposed model has correctly predicted the observed continued standstill of the global surface temperature while the CMIP3 and CMIP5 general circulation models adopted by the IPCC in 2007 and 2013 predicted for the period 2000-2014 a strong warming of about 2°C/century, which has not been observed.

The solar–astronomical model projections for the 21st century look significantly less alarmist than those proposed by the IPCC. This is due to the fact that by taking into account the natural oscillations from the decadal to the millennial scales, the climate sensitivity to CO_2 doubling must be about 1.5°C while the CMIP5 climate models predict a climate sensitivity of about 3°C . See Scafetta (2013b) for details.

Conclusion

Figures 1-4 provide a strictly alternative message to the one proposed by the IPCC. The Sun must have contributed significantly to climate changes and will continue to do so.

After having noted that not even CO_2 and other greenhouse gases, either of natural or of anthropogenic origin, could be the cause, let alone the primary cause, of global climate changes, Quinn (2010) wrote: "*Evidence indicates that global warming is closely related to a wide range of solar-terrestrial phenomenon, from the sun's magnetic storms and fluctuating solar wind all the way to the Earth's core motions. Changes in the Solar and Earth magnetic fields, changes in the Earth's orientation and rotation rate, as well as the gravitational effects associated with the relative barycenter motions of the Earth, Sun, Moon, and other planets, all play key roles. Clear one-to-one correspondence exists among these parameters and the Global Temperature Anomaly on three separate time scales.*"

Biosketch

Nicola Scafetta graduated in Physics at the University of Pisa (Italy) and received his Ph.D. in statistical mechanics and complex systems at the University of North Texas (USA) in 2001. Since 2002 he moved to Duke University and collaborates with the Active Cavity Radiometer Irradiance Monitor (ACRIM) in several projects concerning solar dynamics and solar-climate interactions. He is currently proposing that the climate system is regulated by a significant natural component that appears to be regulated by solar and astronomical harmonics that the current climate models do not take into account.

References

Bond et al. (2001), Bond, G., B. Kromer, J. Beer, R. Muscheler, M. N. Evans, W. Showers, S. Hoffmann, R. Lotti- Bond, I. Hajdas, G. Bonani: Persistent solar influence on North Atlantic climate during the Holocene. Science 294 (2001) 2130–2136.

Brohan (2006), Brohan, P., Kennedy, J.J., Harris, I., Tett, S.F.B., Jones, P.D.: Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. Journal of Geophysical Research 111, (2006) D12106. doi:10.1029/ 2005JD006548.

Christiansen and Ljungqvist (2012), Christiansen, B., Ljungqvist, F.C.: The extra-tropical Northern Hemisphere temperature in the last two millennia: reconstructions of low-frequency variability. Clim. Past 8, (2012) 765–786.

Douglass and Clader (2002), Douglass, D. H., B. D. Clader: Climate sensitivity of the Earth to solar irradiance. Geophysical Research Letters 29 (16) (2002) 331–334.

Eddy (1976), Eddy, J. A.: The Maunder minimum. Science 192 (1976) 1189–1202.

Eichler et al. (2009), Eichler, A., S. Olivier, K. Heenderson, A. Laube, J. Beer, T. Papina, H.W. Gaggeler, M. Schwikowski: Temperature response in the Altai region lags solar forcing. Geophysical Research Letters 36 (2009) L01808.

Friis-Christensen and Lassen(1991), Friis-Christensen, E., K. Lassen: Length of the solar cycle, an indication of solar activity closely associated with climate. Science 254 (1991) 698–700.

Fröhlich (2006), Fröhlich, C.: Solar irradiance variability since 1978: revision of the PMOD composite during solar cycle 21. Space Sci. Rev. 125, (2006) 53– 65.

Hoyt and Schatten (1997), Hoyt, D. V., K. H. Schatten: The Role of the Sun in the Climate Change. Oxford University Press, New York (1997).

Humlum et al. (2011), Humlum, O., K. Stordahl, J.-E. Solheim: Identifying natural contributions to late Holocene climate change. Global and Planetary Change 79 (2011) 145-156.

Hoyt and Schatten (1993), Hoyt, D. V., K. H. Schatten: A discussion of plausible solar irradiance variations, 1700–1992. J. Geophys. Res. 98 (1993) 18895–18906.
Kerr (2001), Kerr, R. A.: A variable sun paces millennial climate. Science 294 (2001) 1431-1433.
Kirkby (2007), Kirkby, J.: Cosmic rays and climate. Surveys in Geophysics 28 (2007) 333–375.
IPCC (2013), IPCC (Intergovernmental Panel on Climate Change). Climate Change 2013: The Physical Science Basis: Fifth Assessment Report (2013). Available at http://www.ipcc.ch/
Lean and Rind (2009), Lean, J. L., D. H. Rind: How will Earth's surface temperature change in future decades? Geophysical Research Letters 36 (2009) L15708.
Loehle and Scafetta (2011), Loehle, C., N. Scafetta: Climate Change Attribution Using Empirical Decomposition of Climatic Data. The Open Atmospheric Science Journal 5 (2011) 74-86.
van Loon and Labitzke (2000), van Loon, H., K. Labitzke: The influence of the 11-year solar cycle on the stratosphere below 30 km. A review. Space Science Reviews 94 (2000) 259–278.
Lorenzetto (2009), Lorenzetto, S.: Se la Terra si surriscalda colpa del Sole: l'uomo non c'entra. Il Giornale, October 25, 2009. http://www.ilgiornale.it/news/se-terra-si-surriscalda-colpa-sole-l-uomo-non-c-entra.html
Parker et al. (1992), Parker, D. E., T. P. Legg, C. K. Folland: A new daily Central England Temperature Series, 1772-1991. Int. J. Clim. 12, (1992) 317-342.
Quinn (2010), Quinn, J. M.: Global warming. Geophysical counterpoints to the enhanced greenhouse theory. Dorrance Publishing Co., Inc., Pittsburgh, USA (2010).
Scafetta and West (2007), Scafetta, N., B. J. West: Phenomenological reconstruction of the solar signature in the NH surface temperature records since 1600. Journal of Geophysical Research 112 (2007) D24S03.
Scafetta and West (2008), Scafetta, N., B. J. West: Is climate sensitive to solar variability. Physics Today 3 (2008) 50–51.
Scafetta (2009), Scafetta, N.: Empirical analysis of the solar contribution to global mean air surface temperature change. Journal of Atmospheric and Solar-Terrestrial Physics 71 (2009) 1916–1923.
Scafetta (2010), Scafetta, N.: Empirical evidence for a celestial origin of the climate oscillations and its implications. Journal of Atmospheric and Solar-Terrestrial Physics 72 (2010) 951–970.
Scafetta (2012a), Scafetta, N.: 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. Journal of Atmospheric and Solar-Terrestrial Physics 80 (2012a) 296-311.
Scafetta (2012b), Scafetta, N.: Testing an astronomically based decadal-scale empirical harmonic climate model versus the IPCC (2007) general circulation climate models. J. Atmos. Sol. Terr. Phys. 80 (2012b) 124–137.
Scafetta (2013a), Scafetta, N.: Solar and planetary oscillation control on climate change: hind-cast, forecast and a comparison with the CMIP5 GCMs. Energy & Environment 24(3-4) (2013a) 455–496.
Scafetta (2013b), Scafetta, N.: Discussion on climate oscillations: CMIP5 general circulation models versus a semi-empirical harmonic model based on astronomical cycles. Earth-Science Reviews 126 (2013b) 321-357.
Scafetta (2013c), Scafetta, N.: Discussion on common errors in analyzing sea level accelerations, Solar Trends and Global Warming. Pattern Recogn. Phys. 1 (2013c) 37-57. http://dx.doi.org/10.5194/prp-1-37-2013
Scafetta (2014), Scafetta, N.: The complex planetary synchronization structure of the solar system. Pattern Recognition in Physics 2 (2014) 1-19. DOI: 10.5194/prp-2-1-2014.
Scafetta and West (2010), Scafetta, N., B. J. West: Comment on `Testing hypotheses about Sun-climate complexity linking'. Physical Review Letters 105 (2010) 219801.
Scafetta and Willson (2009), N. Scafetta, R. Willson: ACRIM-gap and Total Solar Irradiance (TSI) trend issue resolved using a surface magnetic flux TSI proxy model. Geophysical Research Letter 36, (2009) L05701. DOI: 10.1029/2008GL036307.
Scafetta and Willson (2014), Scafetta, N., R. C. Willson: ACRIM total solar irradiance satellite composite validation versus TSI proxy models. Astrophysics and Space Science (2014). DOI: 10.1007/s10509-013-1775-9.
Shapiro et al. (2011), Shapiro, A. I., W. Schmutz, E. Rozanov, M. Schoell, M. Haberreiter, A. V. Shapiro, S. Nyeki: A new approach to the long-termreconstruction of the solar irradiance leads to large historical solar forcing. Astron. Astrophys. 529 (2011) A67.
Shaviv (2008), Shaviv N. J.: Using the oceans as a calorimeter to quantify the solar radiative forcing. Journal of Geophysical Research 113 (2008) A11101.
Soon (2005), Soon, W.-H.: Variable solar irradiance as a plausible agent for multidecadal variations in the Arctic-wide surface air temperature record of the past 130 years. Geophysical Research Letters 32 (2005) L16712.
Soon (2009), Soon, W.-H.: Solar arctic mediated climate variation on multidecadal to centennial timescales: empirical evidence, mechanistic explanation and testable consequences. Physical Geography 30 (2) (2009) 144–148.

Soon and Legates (2013), Soon, W.-H., D. L. Legates: Solar irradiance modulation of Equator-to Pole (Arctic) temperature gradients: Empirical evidence for climate variation on multi-decadal timescales. J. Atmos. Sol. Terr. Phys. 93 (2013) 45-56.

Steinhilber et al. (2012), Steinhilber, F., J. A. Abreu, J. Beer, I. Brunner, M. Christl, H. Fischer, U. Heikkilä, P. W. Kubik, M. Mann, K. G. McCracken, H. Miller, H. Miyahara, H. Oerter, F. Wilhelms: 9,400 years of cosmic radiation and solar activity from ice cores and tree rings. PNAS 109 (16) (2012) 5967–5971.

Svensmark and Friis-Christensen (2007), Svensmark, H., E. Friis-Christensen: Reply to Lockwood and Frhlich - The persistent role of the Sun in climate forcing. Danish National Space Center Scientific Report 3/2007. Available at http://www.space.dtu.dk/english/research/reports/scientific_reports

Thejll and Lassen (2000), Thejll, P., K. Lassen: Solar forcing of the northern hemisphere land air temperature: new data. J. Atmos. Solar-Terrest. Phys. 62 (2000) 1207-1213.

Wang et al. (2005), Wang, Y.-M., J. L. Lean, N. R. Sheeley Jr.: Modeling the sun's magnetic field and irradiance since 1713. Astrophys. J. 625 (2005) 522–538.

White et al. (1997), White, W. B., J. Lean, D. R. Cayan, M. D. Dettinger: Response of global upper ocean temperature to changing solar irradiance. Journal of Geophysical Research 102 (1997) 3255–3266.

Willson and Mordvinov (2003), Willson, R. C., A. V. Mordvinov: Secular total solar irradiance trend during solar cycles 21–23. Geophys. Res. Lett. 30, (2003) 1199.