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New findings on Increasing Solar Trend That Can Change Earth Climate: Are We Entering a New Great Solar Minimum?

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Abstract. Studies of the Sun-Earth relationships during the past years have dramatically changed our view on Solar-Terrestrial Physics. Neither is the interplanetary medium unstructured or quasi-static, nor is it a simple magnetic stratified object. Thus, the interaction of the solar electromagnetic radiation (photons), hot plasma (electrons, protons and other ions), cosmic rays, microscopic dust particles, and magnetic fields (primarily from the Sun) with the upper environment of our Earth leads to a complex physics which is far to be understandable. This new science is growing rapidly, as well as for the physical problems which arise as for its growing impact on our societies. This last case is well illustrated by the emergence of the so-called Space Weather. In spite of a great number of papers and books written on this subject and on a broader one devoted to Solar-Terrestrial links, the different terms deserve to be clarified. In this paper, we will first establish a clear distinction between Space Weather, Space Climate, Space Physics, Sun-Earth connections, and Helioclimatology, this last word being introduced to describe the role of the Sun in the Earth's climate forcing. In a second step, we will emphasize the key role of the ranging time on which the effects may act. We will then underline the necessity to better predict solar activity showing the physical difficulties for such an exercise, yielding the extreme complexity for forecasting specific events. The three dataset, past Earth's temperature (since AD 630), solar shape variability (since AD 1600) and strength of umbral/sunspots magnetic field (since AD 1995) lead all to a Next Grand Minima predictable for 2015-2018. We will conclude by giving some imprints for the future.

Keywords: The Sun, solar cycle, solar irradiance, Indian rainfall, Indian surface temperature

Introduction

If it is obvious, since the highest Antiquity, that the Sun is the primary source for driving the Earth's climate system, it is not so evident since the middle of the 70's that the solar changes may have a corresponding response on the climate system. Two major arguments were developed to thwart the assertion that the Sun's output variability may play a key role. The first one concerns the anthropogenic effects and is today widely debated. The second is linked with the so-called *total solar irradiance* (TSI). Let us try to clarify this last point, the most objectively as possible, as new results are appearing.

The Earth receives at the top of the atmosphere a solar energy that was recognized as constant, and fixed at about 1366 W/m^2 up to the satellites era. Radiometers on board dedicated satellites record a

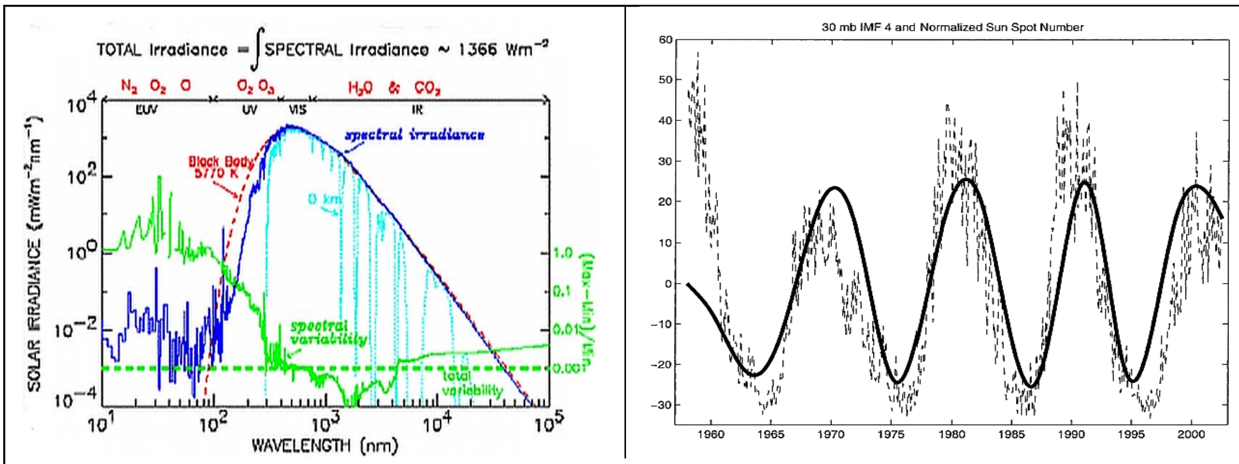

Fig. 1. Left. Wavelength dependence of the solar irradiance. The UV part of the spectrum clearly show a strong variability, ranging a factor of 2 (after, P. Brekke, 2005 [5]), whereas the IR part is relatively few affected.
Right: The dashed line is the normalized sunspot number. The thick solid line is decomposition 4 in the EMD method of the 30 mb geopotential height. The two time series are significantly correlated at 0.70 (after K. Coughlin, 2004 [6]).

fluctuation of ± 1.3 W/m^2 during a solar cycle, a value considered as too low to significantly affect the climate of the Earth [1]. Furthermore, if such an estimate of the "solar constant" may produce a climatic forcing, do its variations are of enough sensitivity to explain the differently equatorial, tropical or polar latitudes perturbations of the Earth's atmosphere? Even by admitting a modulation of the climatic signal on the top of the stratosphere, how changes can be reverberated on the lower layers, seat of our climate? An embryo of answer is suggested for example by Haigh [2] who suggested the role of the ozone destructive cycle, or more likely, through an amplification of the solar signal within the UTLS zone [3].

Recent works has significantly improved our knowledge on the TSI, mainly on the UV part of the spectrum (Fig.1, left). The most remarkable issue concerns its variability, reaching a factor 2 peak-to-peak that was addressed to cause a significant impact on the stratosphere. This finding was followed by a profusion of new studies, which are just beginning to be discussed in many symposia. This reinforce what Hansen wrote in 2000 [4]: "*Even if the solar forcing has been smaller than the anthropogenic forcing it is incorrect to assume that the Sun necessarily will be an insignificant player in climate change in the 21st century.*" As the interplanetary medium is neither unstructured or quasi-static, nor is a simple magnetic stratified object, thus, the interaction of the solar electromagnetic radiation (photons), hot plasma (electrons, protons and other ions), cosmic rays, microscopic dust particles, and magnetic fields (primarily from the Sun) with the upper environment of our Earth leads to a complex physics which is far to be understandable; their characterization deserves to be clarified.

Some Basic Definitions

The study of the Sun-Earth connections is a science in full effervescence, as well as for the physical problems raised that for its growing impact on our societies. This last case is illustrated by the emergence of a new field of research called "Space Weather". The launch of this new concept [1], deserves to be clarified in spite of a great number of papers and books devoted to this question. Weather first induces a brief temporal idea: *weather* is the state of the environment at a given time and place; it may be quiet or violent. Weather is currently associated with local parameters such as temperature, pressure, hygrometry or wind speed. On Earth, prior to the satellite era, such data have been widely recorded and were used, and still are, in meteorological reports. They have been used as time series for correlative studies with solar phenomena, and accompanied by a lot of skepticism among scientists due to a lack of physical mechanisms to account for these correlations. By contrast, *climate* refers to the long term, using data spanning more than one century and even more. Nowadays, climatic studies use a large variety of data other than «pure meteorological» parameters, such as cloud covering, albedo, extension of polar caps, tree leaves abundance, etc. Using the word "weather" must not be minimized. It must refer to specific conditions occurring in space, locally, and for which time-scales are of the order of minutes to hours, up to no more than some days (or a few months). Beyond is another field of research, space climate [8].

Sun-Earth connections (in French "Relations Soleil-Terre") refer on one hand to the structure of the solar plasma by the magnetic field and on the other hand to the structure of the magnetospheric plasma by the interplanetary medium. It is important here to stress the Sun's fundamental role in shaping the interplanetary space within the solar system, a region known under the name of "heliosphere". The physics of the heliosphere and its interactions with the Earth magnetosphere and ionosphere is the domain of Sun-Earth connections which can be extended to the interactions of the heliosphere with the magnetosphere and ionosphere of other planets, such as Jupiter (space physics). To conclude, we can say that - "Sun-Earth connections" deal with the "physics of the transport and energy conversion in the heliosphere", whereas, "Space Weather" are up to now described as "Conditions on the Sun and in the Solar Wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-born and ground-based technological systems and can endanger human life or health", following the definition made by US National Space Weather.

Some comments on this last definition can be made at this step. First, man-made pollution of space, such as debris or radio-pollution is not taken into account. Second, the life of a human has never been affected by plasma bursts arriving from the Sun on the Earth (at least during the last century where official recorded data are available). There is no direct reference to unspecified dangers but to impacts on the human activity and the living conditions on ground. At last, the word "meteorology" refers also to an operational system of forecasts. It results that "Space Weather" would be better defined as [2] - the science aiming at studying: (i) the composition and the dynamic of the upper layers of the atmosphere of the Earth (magnetosphere, ionosphere and thermosphere), the perturbations of which are due to solar events or man-made pollution (such as space debris or radio

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[1] Translated in French as ``météorologie de l'espace". It is not exactly the same, but meteorology is better appropriate than climatology, as it is written sometimes abusively. Space Climate is another new field of research, devoted to the study of impacts of solar outflows material in the environment of the Earth over long periods of time. The study of Space Climate thus involves both long-term average behavior and variations about those long-term averages [7].

[2] To our mind and according to other colleagues debating the question in forum such as the COST 724 "Developing the Scientific Basis for Monitoring, Modeling and Predicting Space Weather" whose conclusions can be found in http://cost724.obs.ujf-grenoble.fr.

waves); (ii) the effects that can endanger human life in space; (iii) the impacts on the performance and reliability of space-borne and ground-based technological systems, yielding economic upshots on our society.

By contrast, helioclimatology can be defined as the solar output variability which may influence our Earth's environment and more specially our climate [9, 10].

The Key Role of Time Ranging

From the core of the Sun up to the Earth, four main mechanisms generate a variability on the Earth global insolation [11]: (i) nuclear fusion in the core of the Sun; (ii) transport through the radiative and convective zone of the Sun; (iii) the emission of radiation from the photosphere towards the Earth; and, (iv) changes in the celestial mechanical parameters (eccentricity, nutation, inclination of orbits). These sources of variability act on different time scales, ranging from billion of years to seasons, sometimes to minutes or days.

The first case (in the range of 0 to 0.3 solar radius R) is studied through different models leading to high luminosity changes through very long periods of time (a doubling of the luminosity over the first 8 billions years, known as "the early faint Sun paradox").

The second case can be divided into two sub-groups: the first one concerns the energy transport through the radiative zone (0.3 to 0.7 R), likely to be stable, and the second one (0.7 to 1R) concerns the convective zone. Although the ultimate source of solar energy is the nuclear reactions taking place in the core, the immediate source of energy is the surface. Nuclear reactions are certainly steady on short time scale, but mechanisms which carry the energy in the convective zone may not be. If the central energy source remains constant while the rate of energy emission from the surface varies, there must be an intermediate reservoir, where the energy can be stored or released depending on the variable rate of energy transport [12]. The gravitational field (the virial theorem indicates that there is a connection between magnetic energy and gravitational energy), is one such energy reservoir. If energy is stored in this reservoir, it will result a change in the Sun's radius, at least in the uppermost layers of the Sun (the leptocline). Recent works show the compatibility of this theory with irradiance variations [13-15]. These mechanisms act at the level of days to several years (cyclic solar activity).

The third case is linked with the transport of the radiation from the photosphere up to the Earth. Changes in the global insolation are due on one hand to anistropic transport, and to the other hand, on changes in the UV part of the spectrum, for which certain spectral bands of the atmosphere are very sensitive (ozone layers for instance). The effects are also of the order of days and years. Finally, the variability due to movement of the Earth on its orbit and over its axis of rotation, leads to climatic changes that were first studied by Milankovich in 1930 [16]. The time scales involved here are of the order of thousands years.

The three last processes show cyclicities, and the question, which remains an *open question,* is: does exist resonant phenomena able to amplify changes in the global warming or cooling of our climate? In the same way, we are still ignorant of how feedbacks may act, but we know that such mechanisms may amplify a weak solar signal. In this scope, the UTLS (Upper-Troposphere-Lower-Stratosphere) region is a key-layer in the understanding of climatic phenomena. Changing chemistry in this region has lead us to better unravelling the dynamical feedback that can occur here. Undoubtedly, this effect, in conjunction with the solar irradiance changes, can influence the interannual variability of temperature in this zone [3, 17].

Emphasizing Forecasting Solar Activity

Pseudo-cyclicity of the solar activity is one of the most intriguing puzzles in solar physics. Why the Sun seems to beat regularly, at *around* 11-years, but also at *around* other specific periods, 80-yrs, 211-yrs, 400-yrs, even 2115-yrs [18], etc? This "around" is the core of the problem. We do not know why the lengths of the solar cycles vary from one cycle to the other, the differences being significant, of the order of 2 to 3-yr for the Schwabe 11-yr cycle for instance, more for other cycles. This renders the prediction difficult. However, planning for satellite orbits and space missions (especially for man-lived missions), often require knowledge of solar activity levels years in advance. The study of the Lyapunov exponent [19], for which the determination is between 3 to 4 years, shows that the solar cycle is not deterministic: it is thus impossible, in the solar case, to accurately determine the date and the level of intensity of the activity signal more than 3 or 4 years ahead. In other words, the *forecast* is good: the behaviour of a sunspot cycle is fairly reliable once the cycle is well underway, about 3 years after the minimum. For instance, in 2004 it is possible to forecast that the next solar maximum will take place around 2011. However the *prediction* is poor: inaccuracy on the date, inaccuracy on the estimate of the level of the signal. The *"observed"* is not enough to deduce what will be *"observable".*

There is a great lot of techniques (including neuronal networks), each of them showing advantages and drawbacks [3]. Predictions for solar cycle 24 has been made by several authors, leading to a large range of amplitude of the signal (15 papers are available on the subject for the single year 2008). In spite of the fact that some methods predict a relatively high cycle 24, three different analysis lead to about the same conclusion:

- Kilcik et al [20] reported that the maximum intensity of cycle 24, will be of 87.4 in December 2012; according to this forecast, the current solar cycle will have a magnitude far lower than any other since 1890-1910;

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[3] A comprehensive review can be found for instance in http://solarscience.msfc.nasa.gov/.

- Kitiashvili and Kosovichev [21] using a nonlinear dynamo model as described by Kleeorin and Ruzmaikin [22] which takes into account dynamics of the turbulent magnetic helicity, predict that the next sunspot cycle will be significantly weaker (by ~ 30%) than the previous cycle, continuing the trend of low solar activity;
- Using direct polar field measurements, now available for four solar cycles, Svalgaard et al. [23] predict that solar cycle 24 (2011 maximum) will have a peak smoothed monthly sunspot number of 75±8, making it potentially the smallest cycle in the last 100 years.

We need to improve the scientific way of predicting solar activity, both for a better understanding of the heliosphere and dynamo physics, as well as its usefulness to all space agencies interested in solar activity related phenomena, ranging from power grid spikes, to communication blackouts, to satellite orbital dynamics.

Understanding Dynamical Solar Internal Processes

A priori, it seems that understanding how the core of the Sun rotates is very far from the climatic research. It is not so sure, as one the key is the magnetism: the interplanetary medium is shaped by the solar magnetism. The solar magnetism is no more considered as a purely superficial phenomenon. If it has been shown that the length of the solar cycle depends on the transition region between radiation and convection, the internal solar magnetism is still poorly known.

To increase our knowledge on this difficult problem, a number of space missions are scheduled in the forthcoming years. Let us only mention some few ones: SDO (Solar Dynamics Observatory), which will focus on the convective zone; GOLF-NG, which aims to investigate the deepest layers of the Sun, and STEREO. All these missions will help us to get, at the horizon of 2009-2012, a 3-D. vision of the Sun. The heart of the complete project is, during the next solar cycle 2008-2017: (i) to follow the luminosity and radius variabilities; (ii) to measure constraints on the core dynamics; and (iii) to obtain a detailed analysis of the convective zone, both for the tachocline and the leptocline. Another mission, launched in 2018 near the solar poles or around the L1 Lagrangian point will allow to obtain all the necessary constraints to build a «predictable magnetic model" of the Sun and its relationship with our planet (and such a vision will be extended to other stars and planets). The road-map can be found in Turck-Chièze et al. [24].

Are We Entering a New "BLANK" Sun Era?

Space-based measurements reveal the existence of 11-year cycles in solar radiation upon which are superimposed larger and shorter term changes. Indirect proxies of solar activity [4] exhibit 11-year solar cycles as well as longer-term changes or cycles that exceed the amplitudes of their 11-yrs cycles. Comparisons of these proxy records with direct observations suggest that anomalously low solar activity have existed in the past. These periods are commonly known as the "Dalton", "Maunder", "Spörer, Wolf and Ort Minima" (which occurred from 1784 to 1829, from 1645 to 1715, from 1420 to 1535, from 1280 to 1340 and 1010-1050 respectively). By contrast, since about 1950, solar activity increased steadily, to amplitude never reached during the first half of the twentieth century. A crude analysis of the frequency at which appeared the above-mentioned minima together with this last remark, lead us to conclude that we are entering a new long solar minima, which will occurred around next cycle 25. If solar activity continues as low as it has been since 2007, 2008 would have rack up a whopping 290 spotless days by the end of December, making it a century-level year in terms of spotlessness [25]. At the end of January 2009, even if newly emerged Cycle 24 regions were recorded, plages were still of low probability of producing any activity.

Penn and Livingston [26] observed spectroscopic changes in temperature sensitive molecular lines, mainly in the magnetic splitting of Fe I line, and in the continuum brightness of over 1000 sunspot umbrae from 1990-2005. All three measurements show consistent trends in which the darkest parts of the sunspot umbra have become warmer (45K per year) and their magnetic field strengths have decreased (77 Gauss per year), independently of the normal 11-year sunspot cycle. A linear extrapolation of these trends may suggest that few sunspots will be visible after 2015. However, the long extrapolation could be of little statistical confidence.

Climate parameters of many types often exhibit cycles that are also common in solar activity proxies, such as near 11-, 22-, 80- and 210- years. It is well known that times of cooler climate in past millennia usually coincide with reduced levels of solar activity. For instance, during the Little Ice Age, which occurred from about 1450 to 1850, surface temperatures were from 0.6°C to 1°C colder than at present (depending on geographic location, as changes in solar radiation can often result in regional or local responses). Solar activity was lower than at present because of the occurrence of the above-mentioned Minima. Low-Frequency signals in long tree-ring chronologies have been used to reconstruct past temperature variability since the year 631 ([27]; see also Fig. 2 in [28]). Yearly data has been plotted in Fig.1a and a sinusoidal fit has been adjusted. In spite of the global warming which occurred these last few years, a general behaviour appears that would lead to a next minimum around the years 2018. The period found, of roughly 435-years, is this twice the powerful harmonic (212-yrs) considered as fundamental by Damon and Jirikowic [17].

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[4] Such proxies can be listed as: dendochronology, palynology, isotopic variations of marine sediments (foraminifers), ice analyzes (trapping of CO2, Be10), criticized study of old documents (parochial registers, ship's books, dates of harvests and vintages, wheat prizes, plum blossoming in Japan), glaciers advance and retreats, comets and auroras registers, C14 analysis, etc).

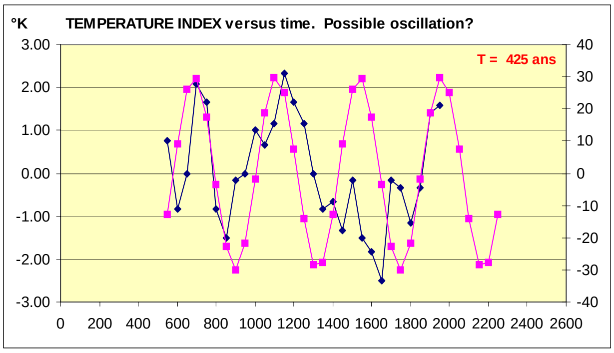

Fig.2a. Reconstruction of the past temperatures (blue line) according to Esper et al. [27]. The red curve is a straightforward sinusoidal fit. A periodicity of 425 years appears. An extrapolation to the next zero leads to 2017.

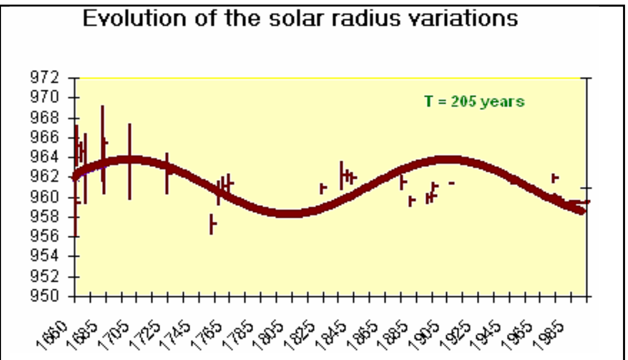

Fig 2b. A sinusoidal fit to observed solar radius variations since the Maunder Minimum leads to a next bigger Sun around 2018. Note that the solar shape is anti-phased with solar activity [29, 30].

Finally, an analysis of the solar radius variability, as it appeared for instance in [31] or [32] indicates that a modulation of amplitude can be seen, of about 205-years, which will lead to a next “bigger” Sun by 2018. As this variability must be taken with cautious, and as the data are certainly not all of the same quality, it can be noticed that this periodicity is about 212-yrs, i.e. the fundamental, as above stated.

The author is perfectly aware of the empirical character of the predictions made here. But it is rather striking, that the three parameters described, temperature index, solar radius variability and umbral-sunspots magnetic fields, lead to a new great Minima which might occur between 2015 and 2018.

Conclusions

It is extremely likely that we are just entering a new Minimum. The level of solar activity remained very low during several months in 2008. During that time, high-latitudes region of activity yielded frequently no flares, despite developing mixed-polarity areas indicating a new cycle difficult to start. A lot of predictions based of the past dataset point out that even if the maximum of solar activity has been increasing since the late 19th century, the next maximum will begin to decrease. By looking at all the past Minima deduced from historical records, it can be set forth that solar activity is certainly modulated over long periods of time. This modulation of amplitude is undoubtedly driven through dynamo processes, but the gravitational energy in the most outer layers certainly plays a key role (the “leptocline” shallow layer may be the cradle of turbulent pressure [30]). This gravitational energy expands or shrinks the solar envelope on an antiphasing process with the activity. Lastly, a magnetic field analysis conducted at Kitt Peak on spectral observations of temperature sensitive lines, show a possible long negative trend indicating a decline of solar activity, which could lead also to a suppressed activity in the forthcoming years.

The analysis over a long period of time of the deviation to the mean of the Earth’s temperature also shows a probable declining, the anthropogenic effect not taken into account. This can be done precisely because the study is conducted over several centuries, which smooth the recent ascending trend. We do not claim that this last effect does not exist, and we do not claim neither that the Earth's temperature follows the solar cycle. We merely said that a sinusoidal fitting of the data would yield a next temperature minimum in a few years. This would happen without strong effects on our climate, due to man's activity.

Cautiously, we can argue that the *next Grand Minima will occur by 2015-2018*. Prediction of long-term global effects from the Sun's influence over the climate is thus impinged in a new way.

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