ISSN : 0974 - 7451 Volume 9 Issue 6

Environmental Science
An Indian Journal

Current Research Paper

ESAIJ, 9(6), 2014 [203-210]

May the variable Sun weather and irradiance affect the climate on Earth?

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ABSTRACT

Although it is assumed that our primary source of energy began as a homogeneous ball of hydrogen (H) with a steady, well-behaved H-fusion reactor at its core, with a behaviour fully described by the simple Standard Solar Model (SSM), observations instead reveal a very heterogeneous, dynamic Sun. There is evidence our Sun is everything but stable and this variability may possibly have an impact on life on earth that is much larger than the expected.

KEYWORDS

Sun irradiance;
Sun weather;
Earth climate.

INTRODUCTION

The Standard Solar Model (SSM) is a mathematical treatment of the Sun as a spherical ball of gas with the hydrogen in the deep interior being completely ionized plasma. The spherically symmetric quasi-static stellar model is described by several differential equations derived from basic physical principles and it is constrained by boundary conditions as luminosity, radius, age and composition. The SSM provides estimates for the helium abundance and mixing length parameter by forcing the stellar model to have the correct luminosity and radius at the Sun's age and provides a way to evaluate more complex models with addition of rotation, magnetic fields and diffusion or improvements of convection. The SSM may change over time in response to relevant new discoveries but only within the narrow limits of the underlying theory. There are many sign the standard solar model may not be correct, there may be condensed matter in the Sun, and the Sun may have a variable output that may affect the climate on Earth. The paper tries to address all these issues.

MAY THE SUN BE COMPRISED BY CONDENSED MATTER?

The standard solar model (SSM) assumes the Sun is a sphere of gas in variable states of ionisation with the hydrogen in the deep interior entirely ionised plasma. The latest paper by Robitalille[26] provides evidence the core of the Sun is instead a condensed form of matter.

Despite the overwhelming evidence that the Sun is comprised of condensed matter, the SSM continues to be anchored on the gaseous plasma. The endurance of this model is due to the mathematical elegance of the equations for the gaseous state, the apparent success of the mass-luminosity relationship, and the long-lasting influence of the leading proponents of this model. However, no direct physical finding actually supports the notion that the solar body is gaseous. All observations are indeed most easily explained by recognizing that the Sun is primarily comprised of condensed matter.

There is a predominant belief in solar science that the problems with the gaseous model are not many and irrelevant. In reality, the gaseous equations of state have introduced more problems than solutions. Many of the conclusions inferred from the SSM have very likely led solar physics to accept deductions which exhibit little or no relationship to the actual nature of the Sun. Forty "presented by Robitalille[26] that the solar body is comprised of and surrounded by condensed matter. The "*lines of evidence*" are divided into seven broad categories: Planckian, Spectroscopic, Structural, Dynamic, Helioseismic, Elemental and Earthly.

The solar spectrum, limb darkening, and the directional emissivity of many structures, from sunspots to granules, from faculae to magnetic bright points, from spicules to the K-corona and the coronal structures, all highlight the presence of metallic and non-metallic material within the Sun. Molecular hydrogen and the metal hydrides imply that the chromosphere flash spectrum reveals condensation reactions in the solar atmosphere. An activated helium cycle in the chromosphere harvests hydrogen atoms and it enables them to re-join the solar surface. The cool-liquid-metallic hydrogen-containing K-corona recycles electrons contributing to preserve solar neutrality. The surface activity and the orthogonal arrangement of the photosphere and coronal flows are only compatible with condensed matters. The coronal rain and loops, the spicular velocities and the splash-down events all require condensed matters. The slow and fast solar winds also suggest a dynamic condensed matter Sun is constantly endeavouring to eject material. The Sun oscillations, the mass displacements, the shape, the internal layers, from the convection zone to the tachocline and the core, and the atmospheric waves all imply the presence of solids and liquids in addition to gases.

IS THE SUN STABLE?

Peter Toth questioned in 1977 if the Sun was a pulsar[1] finding periods which seem to describe the Sun's oscillation, an observed period of 2.65 h very close to 2.78 h the predicted radial mode fundamental oscillation of the homogeneous model of the Sun and an effect of magnetospheric origin was reported to have pulsations with period of 2 h 40 min.

Many other signs of failure of the SSM have been observed over the last 35 years. Although the SSM assumes that our primary source of energy began as a homogeneous ball of hydrogen (H) with a steady, well-behaved H-fusion reactor at its core, there have been observations revealing instead a very dynamic Sun[2-19].

As examples, the upward acceleration and departure of H ions from the surface of the quiet Sun and abrupt climatic change, including geomagnetic reversals and periodic magnetic storms that eject material from the solar surface are unexplained by the SSM.

The present magnetic fields are deep-seated remnants of ancient origin, probably generated by Bose-Einstein condensation of iron-rich, zero-spin material into a rotating, superfluid, superconductor surrounding the solar core, and/or super-fluidity and quantized vortices in nucleon-paired Fermions at the core.

Neutron repulsion energizes neutrons in cores of heavy elements, those that burned on Earth ~ 2 Gyr ago[8], planets[9], ordinary stars, and galaxies.

Linked variations between abundances of light elements and certain isotopes of heavy elements[10,11] provided early evidence that the Sun birthed the entire Solar System.

Ron Cowan[12] reports the Voyager 1 spacecraft may be approaching the edge of the Solar System, about 18 billion km (18 Gkm) from the Sun where the heliosphere, the bubble of electrically charged particles blown outwards by the Sun, gives way to interstellar space. About ten billion, billion (~10^{19}) Earths could fit inside this gigantic sphere of influence filled with waste products from the Sun's pulsar core[2].

Recently, it has been discovered that the Sun induces abrupt changes in Earth's Van Allen radiation belts[13] and is a driver of these systems more than the expected. The two donut-shaped regions of high-energy and hazardous particles named for their discoverer Van Allen are created by our planet's magnetosphere. Throughout the brief early life of the two-year mission of the twins Van Allen probes, energetic events and ejections of plasma from the sun caused dramatic changes in the radiation belts that, for the first time, were observed within the belts. In 2012, observations from the Van Allen Probes showed that a third belt can sometimes appear[14]. The eruption of a giant prominence on the sun of Aug. 31, 2012 sent out particles and a shock wave that travelled near Earth. This was possibly one of the causes of a third radiation belt that appeared around Earth a few days later.

Since their discovery, Van Allen radiation belts have been considered to consist of two distinct zones of trapped, highly energetic charged particles; the outer zone is composed mostly of MeV electrons increasing and reducing intensity on time scales ranging from hours to days; the inner zone is composed of high energy electrons and very energetic positive ions the latter being stable in intensity levels over years to decades[15]. In situ spacecraft observations reveal an isolated third ring of high-energy electrons that formed on 2 September 2012 and persisted largely unchanged for more than 4 weeks before being disrupted by a powerful interplanetary shock wave passage[15].

The sun seems static, placid, and constant. But our sun gives us more than just a steady stream of warmth and light bathing Earth and the rest of our solar system of light, electrically charged particles and magnetic fields[16]. The Sun is a variable star driving the space environment of the planets in our solar system[16]. The distance of the Sun from the Earth is at light travelling speed 8 minutes and 19 seconds. The Sun has a diameter of about 109 times that of Earth, a mass of about 330,000 times that of Earth, and it accounts for about 99.86% of the total mass of the Solar System. This variable star fluctuates on times scales ranging from a fraction of a second to billions of years. Solar flares, coronal mass ejections, high-speed solar wind, and solar energetic particles are all forms of solar activity.

A solar flare is an intense burst of radiation coming from the release of magnetic energy associated with sunspots. Flares are seen as bright areas on the sun and they can last from minutes to hours. A solar flare releases photons at most every wavelength of the spectrum and is also a site where particles (electrons, protons, and heavier particles) are accelerated. A solar prominence is a large is a bright feature extending outward from the Sun's surface. A prominence forms over timescales of about a day, and stable prominences may persist for several months. How and why prominences are formed is still a mystery.

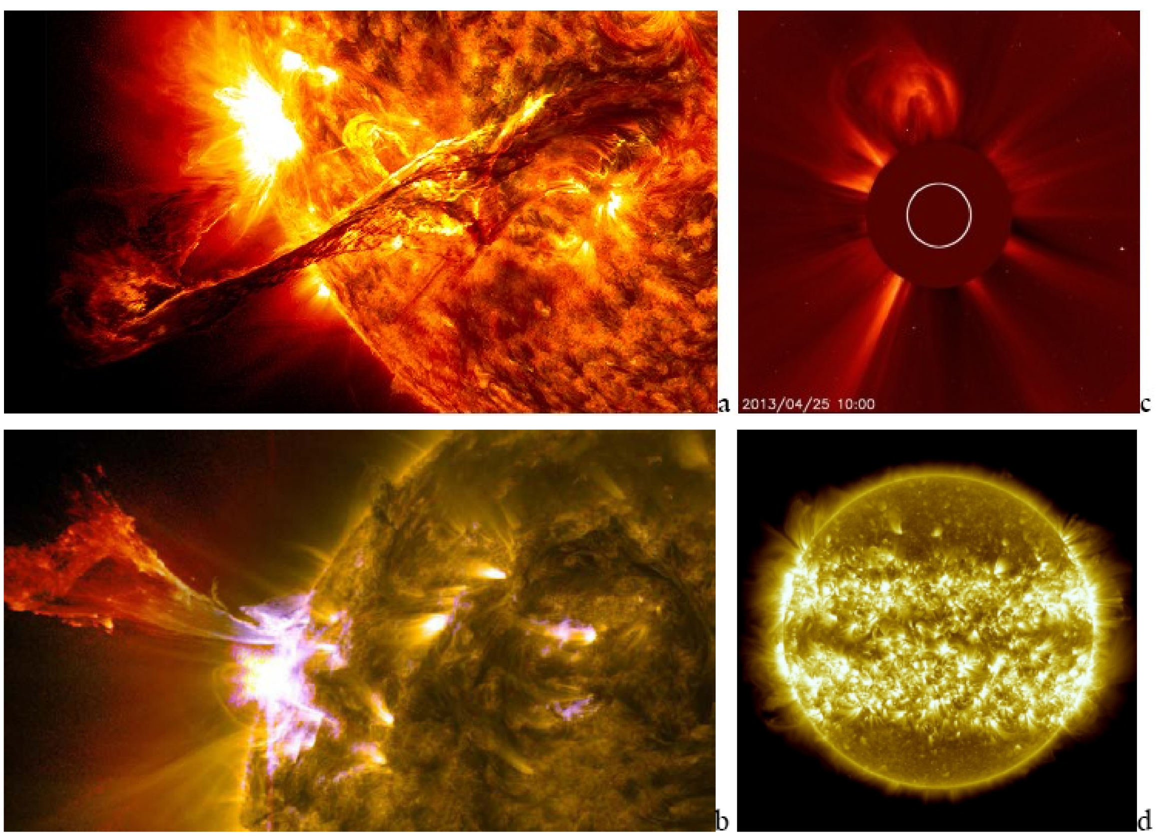

Figure 1 : Sun weather: a - Giant prominence on the Sun erupted on Aug. 31, 2012 (from[20]) Credit: NASA/SDO/AIA/goddard space flight center; b - Prominence eruption captured on May 3, 2013 (from[21]) Credit: NASA/SDO/AIA; c - Coronal mass ejection (CME) escaping the Sun on April 25, 2013 (from[22]) Credit: ESA&NASA/SOHO; d - Full year composite picture of the Sun April 16, 2012, to April 15, 2013 (from[23]) Credit: NASA/SDO/AIA/S

Figure 1.a presents a picture of the giant prominence on the sun erupted on Aug. 31, 2012 sending out particles and a shock wave that traveled near Earth. This event may have been one of the causes of a third radiation belt that appeared around Earth a few days later, a phenomenon that was observed for the very first time by the newly-launched Van Allen Probes.

Figure 1.b presents a burst of solar material leaps off the left side of the sun in a prominence eruption captured on May 3, 2013, just as an M5.7 class solar flare from the same region was subsiding.

The corona is structured by strong magnetic fields. Coronal mass ejections occur where these fields are closed the confined solar atmosphere can suddenly and violently release bubbles of gas and magnetic fields.

High-speed solar wind streams come from areas on the sun known as coronal holes formed anywhere on the sun. Solar energetic particles are high-energy charged particles, primarily thought to be released by shocks formed at the front of coronal mass ejections and solar flares. Coronal holes are variable solar features that can last for weeks to months. These holes are rooted in large cells of unipolar magnetic fields on the sun's surface; their field lines extend far out into the solar system. These open field lines allow a continuous outflow of high-speed solar wind.

Figure 1.c presents a coronal mass ejection (CME) escaping the sun on April 25, 2013, the second of two CMEs in the space of 12 hours, both heading away from Earth toward Mercury. Figure 1.d presents a full year composite picture of the Sun. This image is a composite of 25 separate images spanning the period of April 16, 2012, to April 15, 2013. It uses the SDO AIA wavelength of 171 angstroms and reveals the zones on the sun where active regions are most common during this part of the solar cycle. Figures 1.a, b, c and d are only a few qualitative examples of apparently far from stable and homogeneous hydrogen Sun.

IS THE SOLAR IRRADIANCE VARIABLE?

Sunspots contain strong magnetic fields that are constantly shifting and form and dissipate over periods of days or weeks. Over the last 300 years, the average number of sunspots has regularly oscillated in an 11-year (on average) solar sunspot cycle that is considered the main solar cycle. However, the 11-year cycle is actually part of a 22-year cycle of the Sun's magnetic field polarity also acknowledged. It is the general understanding that the brightness of the Sun changes throughout the sunspot cycle following the number of sunspots. However, measurements of total and spectral irradiance are only available since recently, with many instrumental issues still unresolved, and also the cyclic regular changing brightness may be questioned.

There is a consensus the total solar irradiance may change by about 0.1% during a cycle, but certain wavelengths of sunlight such as ultraviolet vary more[19], while there is disagreement about whether the last three solar cycles have gotten successively brighter[19]. If the general understanding is that irradiance cycles have been about the same in the last three sunspot cycles, one group reported an increasing trend whereas another group reported a decreasing trend over the entire 30-year record.

Only continuous, highly accurate, and stable long-term measurements may clarify if and how much the Sun irradiance is changing. In addition to the measure of the changes in the overall irradiance, also a measure how specific parts of the spectrum are changing is relevant.

The Solar Irradiance Monitor (SIM) aboard the SORCE satellite measures how individual parts of the spectrum vary. Figures 2.a to 2.h present the sunspot number (data from[17]) and the spectral irradiance at different wavelengths (data from[18]). While the spectral irradiance at some wavelengths as 20.5 and 120.5 nm correlate to the sunspot number, the spectral irradiance at other wavelengths as 300.5, 500.08, 685.95, 897.83 and 1097.55 does not correlate at all. Figures 2.i and 2.j present the sun total irradiance (data from[18]). The correlation with the sunspot number is much less than the claimed even considering only one cycle. During 2003 the number of sunspots was significantly larger than in 2012 but the total solar irradiance was smaller.

Instrumental errors are substantial and the period covered is too short to prove the claimed existence of a good correlation in between the number of sunspots and the solar irradiance. Actually, Figure 2 more likely shows the underestimated variability of the sun.

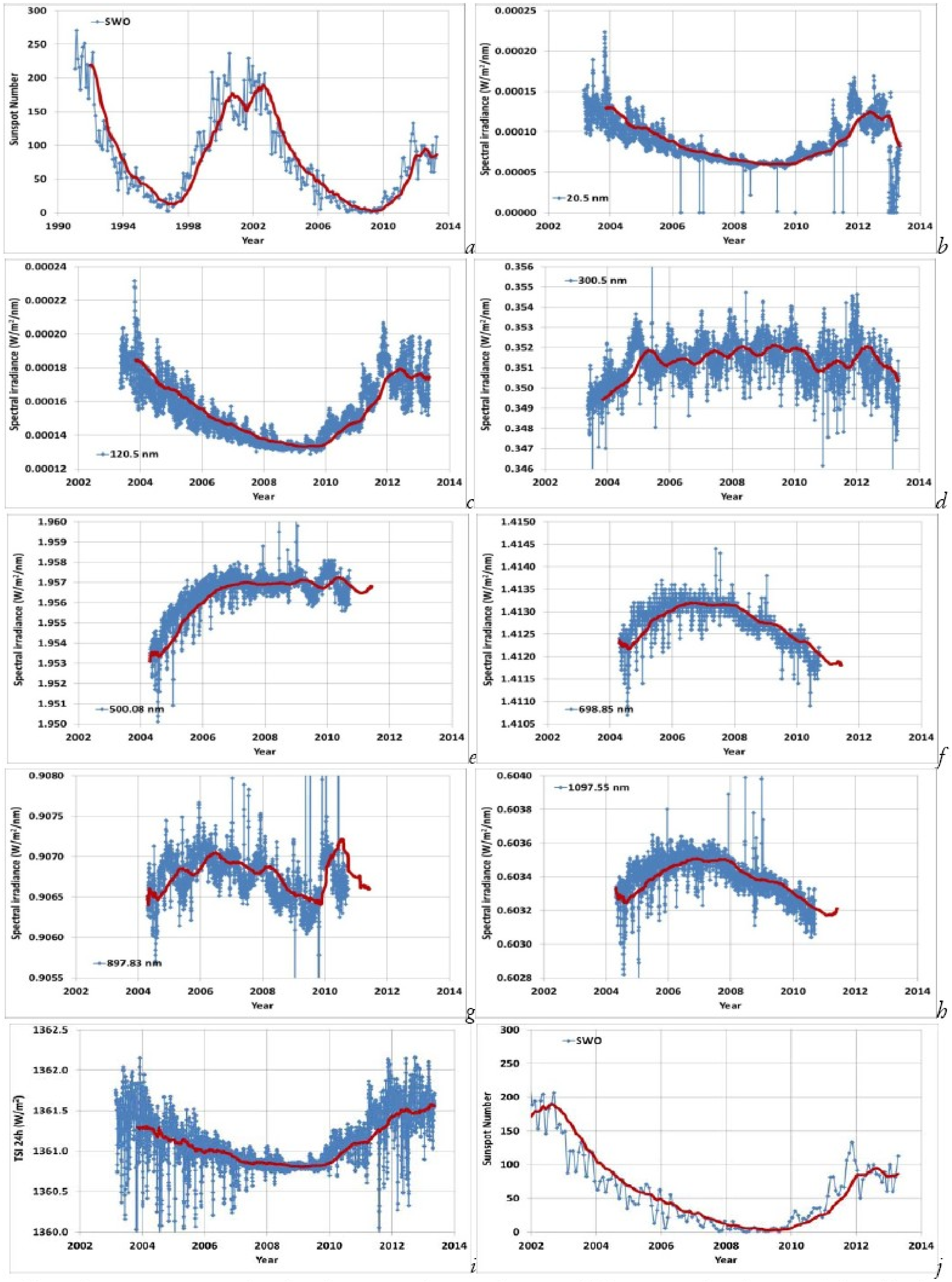

Figure 2 : (a): sunspot number; (b) to (h): measured Sun radiance at different wavelengths over the last decade (from[17,18]). One year moving averages superimposed. The sun radiance at different wave length does not follow the sunspot number in the same way; (i): measured total solar irradiance (from[17,18]); (j): sunspot number over the same time window. One year moving averages superimposed. During 2003 the number of sunspots was larger than in 2012, but the total solar irradiance was smaller.

MAY THE SUN BE RESPONSIBLE OF THE RECENT CLIMATE CHANGE?

The Total Solar Irradiance (TSI) measurements made by the SORCE mission since February 2003 and the historical reconstructed annual TSI values from the year 1611[18] do not support the theory that the Sun is responsible of the "*hiatus*" in the warming hypotetically caused by the increasing heat uptake because of the changed composition of the atmosphere. Nonetheless, the Sun output data show interesting similarities between the surface air temperatures – or at least the reconstruction made of these temperatures - and the solar output.

The output from the Sun tends to wax and wane on an 11-year cycle. This natural cycle is currently approaching its peak, but even if the present sun spot number is low for a peak, the actual measurements of the total solar irradiance incident upon Earth's atmosphere over all wavelengths is about the same values of 11 years ago, with differences that are within the accuracy of the measurement[18].

If we do consider the historical reconstructed total solar irradiance from 1850 to present[18], and the Berkeley Earth[25] global sea and land air surface reconstructed temperatures since same year, the Sun output has been increasing similarly to the global average air sea and land reconstructed temperatures, even if the correlation in between the two parameters seems reduced especially over the last 50 years.

Figure 3 is the total solar irradiance reconstructed as well as the reconstructed global sea and land air surface temperature. The Sun output is clearly not responsible for the missing heat uptake since the beginning of this century, but may account at least in part for the past increased heat uptake. The total solar irradiance is in-

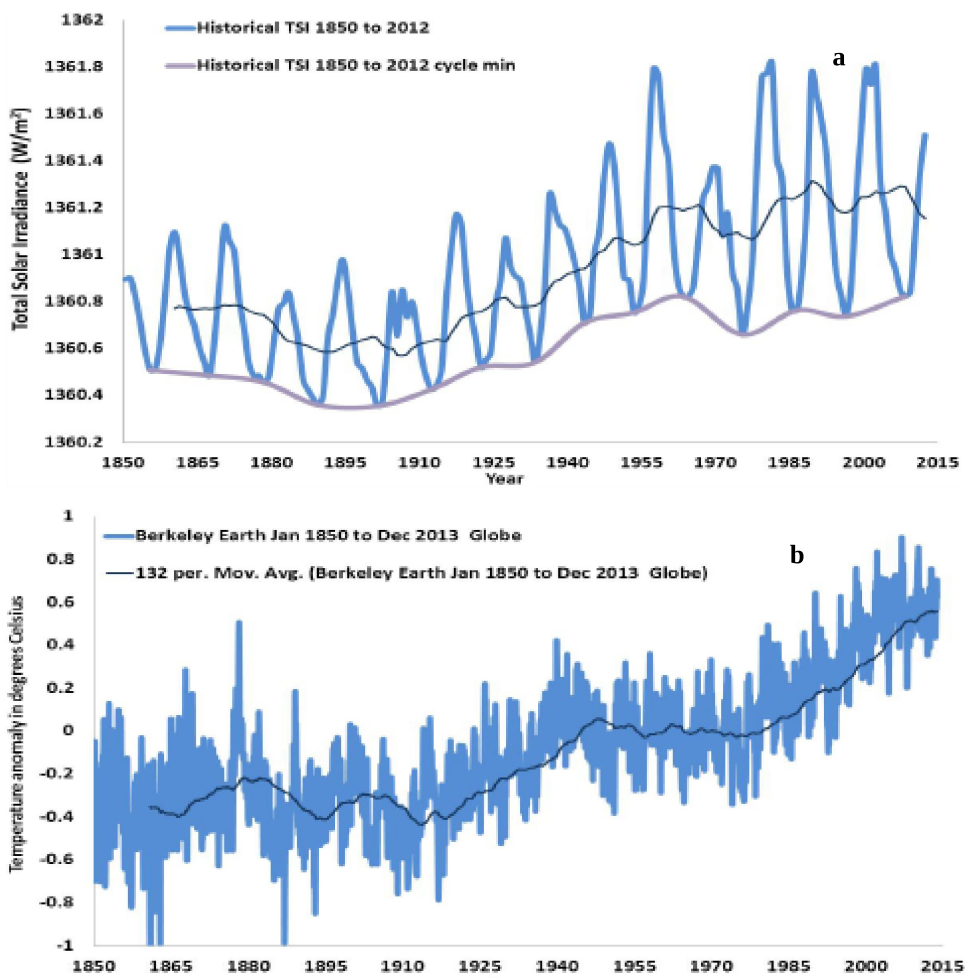

Figure 3 : (a): Reconstructed total solar irradiance (data from[18]); (b): reconstructed global land and sea air surface temperatures (data from[25])

creased of only 0.691 W/m^2 over the last 100 years, corresponding to a minimal +0.05 %. The Berkeley Earth data set suggests for the period 1910 to present the presence of a quasi-60 years oscillation about an almost constant warming trend totalling 0.77 °C over 100 years. Therefore, the Sun is certainly more responsible for the warming since the year 1910 than the "*hiatus*" since the year 2000, even if the contribution in terms of total solar irradiance seems minimal.

Over very long time scales, variations in Earth's orbit have been very likely the main cause of ice ages, with the Sun output being practically stable. However, the Sun has certainly produced more Sun spots in recent decades than in the 1800s. The increment of Sun spots may also reflect an increase in the ultraviolet range of sunlight, and the actual impact of changes in the Sun output at different wave lengths or the impact of the Sun weather is basically unknown. Changes in the radiative output of the Sun clearly affect the energy balance of the Earth's surface, but changes in the solar spectrum, in particular in the UV, may amplify this influence by affecting stratospheric chemistry. The Sun may influence the Earth's climate also in other complicated ways by modulating the flux of cosmic rays and similar.

CONCLUSIONS

Our Sun is not exactly stable, and there is certainly much more to understand in the behaviour of the Sun that what is represented in the SSN or what is guessed from counting the number of Sun spots.

There is evidence that this variable Sun may produce constantly changing climate conditions on our very close Earth, and these effects may be much larger than what is expected.

More than simple theories, high quality complex measurements are needed to better understand the behaviour of our Sun and our climate.

The Sun irradiance is not responsible for the global warming "*hiatus*" since the beginning of this century. The increased Sun irradiance over the past century may have contributed to the warming, but it is not certainly the only driving for the warming movement of the last century.

More research is certainly needed to understand our Sun and the mechanism the Sun influences the climate on Earth.

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