Title: Multi-millennial-scale solar activity and its influences on continental tropical climate: Empirical evidence of recurrent cosmic and terrestrial patterns
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MS No.: esd-2015-30

You will find here:

Our final document with suggested and recommended changes, is attached. Supplementary Information (without changes).

Please Note that in the final document the following characters imply different objectives:

~~Period~~	**==>>**	**To be deleted**
Red Color text	**=>>>**	**To Referee 1**
Green Color text	**=>>>**	**To Referee 2**

Response to Referee 1.

Comments from Referee 1 (1)
The author does not produce any new dataset, nor presents any novel method either to interpret or to make future predictions based on proxy ice core data. Several workers used ice core data and discussed the role of solar activity on climate and its possible role on future climate. Sánchez-Sesma uses one of the ice core derived 10Be data as a proxy for solar activity and then makes prediction for the next few centuries. However, the choice of data may be questionable. He has taken data reported in Finkel and Nishiizumi (1997) which produced 10 Be data for the past 40,000 year albeit at coarse resolution (20-50 years during the Holocene). Another important drawback of this data set is the lack of data for the recent (last 3000) years.

Author's response
We have used ice core derived 10Be data from FN97 as a proxy for solar activity, however it was only used to detect the main recurrence period based on FS. In addition this recurrence period detected was verified with independent information from SS14.

Author's changes in manuscript.
We have tested the recurrence (going back in time) comparing the TSI (S04) record which is based on 14C, against another record of 10Be reconstructed by Adolphi et al. (2014). Results are shown in the new Figure 3.

Comments from Referee 1 (2)
Since the author makes prediction of SA for the next few hundred years, modeling of a dataset having long term variation but poor temporal resolution is not an ideal one. Steinhilber et al. (2009; also cited by the author) presented 10Be data for the last 9300 years with a high resolution of 5 years. This dataset would be a much better choice for the purpose of prediction for the next few hundred years.

Author's response
We have employed the S09, S04 and S12 records, that have decadal resolution, to extrapolate TSI forward in time. However only the longest record, S04 (based on 14C from tree-rings), allows a corroboration of the recurrence and a TSI forecast for the next centuries.

Author's changes in manuscript.
None

Comments from Referee 1 (3)
The author cites several studies that attempted to determine the effect of planetary motion and in turn torque exerted on the Sun and hence on the solar activity. These studies found a broad range of periodicities, starting from 50 yr to over 4.5 kyr. The effect of this kind of gravitational forcing on SA remains speculative, unless a rigorous analysis is done to identify which periodicities are actually affecting the SA. The conclusion "~9.5 kyr period recurrent pattern suggests that SA is characterized by solar dynamics with long tern patterns" seems to be unwarranted. ….

On page 1241, Line: 10-15; "finally we discuss….that suggests a possible planetary forcing of SA by an unknown mechanism." The author cites several works whereby gravitational forcing of the planets on solar activity has been discussed. The authors of

those papers have proposed several mechanisms, but the actual mechanism may not be identified yet. In that sense the author's claim of 'unknown mechanism' might be true, but the author neither proposes a new mechanism nor establishes the veracity of an existing mechanism.

Author's response

Thanks to the Horizon JPL/NASA solar system simulation we have analyzed the planetary gravitational influences over the Sun. The low-frequency similarities founded between the proposed gravitational forcing and the TSI support our proposed gravitational influence.

In Appendix B we show that: 1) Solar system dynamics generate lateral forces (enhanced by) with multi-millennia scale (~9500 yr) oscillations similar to those shown by solar activity (enhanced by); and 2) There is a suggested lagged response of around 67 centuries, of solar activity ( ) to the gravitational forcing (lateral force). The maximum forces F precede the maximum solar activity TSI, meaning that increases (decreases) of force F produce lagged increases (decreases) of TSI;

Author's changes in manuscript.

We have developed and aggregated the appendix B.

Comments from Referee 1 (4)

The solar dynamical behavior is expected to be controlled both by external factors, such as gravitational effect of the planets as well as the solar internal dynamics. The internal dynamics has not been discussed in the text. Consequently the statement "are possibly related to the Sun's rotation rate and impulses of the torque in the Sun's irregular motion" loses its credibility. 2

Author's response

In Appendix B we have also shown that:

1) Taking into account that the Sun's rotation axis is tilted by about 7.25 degrees from the axis of the Earth's orbit, the PGF are able to generate meridional forces and consequently meridional circulations in the Sun;

2) The lagged response appears to increase with forcing periods with a non-linear logarithmic function that implies temporal scale influences and possible connections with meridional circulations in different deep layers of the Sun;

3) The similarity of the ~9500yr TSI with the average SSN 10.5yr cycle, with scales differing at almost three orders of magnitude, suggests a self-similar process with a mechanism possibly linked to recurrent PGF in different scales.

Author's changes in manuscript.

We have developed and aggregated the appendix B.

Comments from Referee 1 (5)

The testing of the forecasting model relied on one of the tropical continental climate records, basically the Congo River Basin Surface Air Temperature (CRB-SAT) record. According to the author this record is isolated from the ocean influences and thus subjected to solar forcing. Despite this assumption the author goes on discussing the

influence of the THC (acronym not defined by the author, understandably the thermohaline circulation) on tropical climate. This raises an important question. If the role of ocean on the CRB-SAT is minimal then it means that this temperature record merely represents a local or regional scale climate and not the global/tropical climate, as global climate change is greatly influenced by ocean circulation. If that be the case, then the forecast of 'continental tropical temperature cooling of around 0.5oC for the rest of the 21st century' and similar other prediction on temperature would represent the temperature change on local/regional scale only. On the other hand, if the role of ocean through THC seems to be significant on CRB-SAT then the role of solar effect could be less or relatively insignificant. If that be the case then the purpose of this work itself becomes irrelevant.

Author's response

In order to analyze the importance of tropical climate (with the CTC, CRB-SAT record) in the Earth´s climate system (ECS), we have analyzed: a) the lagged responses of the ECS, and b) one of their possible climate consequences.

A) In Appendix C we have shown that the Climate & Sea-level (C&SL) responses to different climate forcing (CF) variability, over the Phanerozoic and the last glacial-interglacial cycles follows a non-linear law. Four lags are jointly analyzed based on previous studies. Our analysis suggests that C&SL responses are forced by different processes with different lagged responses through mechanisms possibly associated with the crustal movements and thermohaline currents that move mass (soil, water and salt) and energy against the thermal-rheological-mechanical (TRM) inertias of continents, oceans, glaciers and ice-sheets. The non-linear response appears to be frequency dependent and is verified twice, based on published data of multi-annual and centennial SL lagged responses. Our power law model suggests, for the ~9500 yr detected solar oscillation, a millennial-scale climate lagged response, which is verified with an oceanographic record of iron deposition in the south-western Pacific [SWP] that lags ~1500 yrs solar activity.

B) In the Appendix D, we have: 1) analyzed that the sea level SL reconstructed records, 2) proposed and applied a model for SL variations in term of the lagged influences of CTC variations, 3) developed their verifications with recurrences, and 4) discussed these results.

Author's changes in manuscript.

We have developed and aggregated Appendix C and D.

Comments from Referee 1 (6)

In the beginning the statement: 'the main signals of climate long term forcings have not been well described, neither forecasted…" seems to have underestimated the solar insolation variation on Earth which is considered one of the most important long term forcings on Earth's climate, based on which the Milankovitch theory has been

developed. The solar insolation variations can precisely be calculated and hence its values can be predicted (i.e http://bugle.imcce.fr/langues/fr/presentation/equipes/ASD/insola/earth/online/index.php) . According to this calculations the solar insolation will keep increasing, in general in most of the latitudes including the equatorial region of Africa. Increased insolation is expected to rise the global temperature for the next 5-6 thousand years, which does not conform to the author's prediction of cooling in foreseeable future.

Author's response

Firstly, it must be mentioned that the forecasted CTC cooling, shown in Figure 6, only covers the next century and is followed by a warming during the next seven centuries. This warming could be considered part of a longer warming process, that began 5 centuries ago with a total length of more than 1000 years. This warming is showing the influence of the orbital forcing in the CTC.

Secondly, it should be also noted that In the appendix C we have shown that the Milankovith theory is working, but the ECS (non-tropical, sea level) is responding in a lagged form. For instance, Shackleton (2000) has detected three different lags of 15, 7.6 and 3.7 Kyr of the ocean volume and climate responses to orbital forcing periodicities of 100, 41 and 21 Kyr (eccentricity, tilt or obliquity, and precession), respectively. Thus, the mentioned insolation increases that are coming will produce effects, at least in 3.7 Kyr later. For instance if you take into account the SL lagged response to the solar recurrent pattern (SRP) detected, with ~9.5 Kyr, the associated lag, in the Appendix D, is demonstrated to be around 1500 yrs.

Author's changes in manuscript.

We have developed and aggregated Appendix C and D to better understand the ECS responses to the detected Solar recurrent patterns.

Page 1240:

Line 5: Replace 'Eemian peiod' by the Eemian, similarly in pg 1244 line 24

Author's changes in manuscript.

A detailed comparison with the 10Be SS14 record (in 5 parts) coming from Greenland and the Eemian ~~period~~is displayed in Figure 2c.

Line: 20-21. '…at the center of tropical Africa, generates isolation from the ocean influences '. How does the author arrive at this conclusion; i.e, isolation from the ocean influences?

Author's changes in manuscript. (See page 3, line 29)

This tropical climate variable is very important because its location, at the center of tropical Africa, generates a relative isolation fromto ocean influences and thus enhances solar influences. This influence is known as continentality.

Page 1241

THC – should be explicitly defined.

Author's changes in manuscript. (See page 4, line 9)

thermo-haline circulation (THC) that increased during the present interglacial (Piotrowski et al., 2004)

Line 5: '…by considering reconstructed records of related SA…"
What is meant by 'related SA'?

Author's changes in manuscript. (See page 4, line 13)

In this paper, we attempt to advance our knowledge of solar variability by considering reconstructed records of variables related with SA over the last glacial cycle, from isotopic information coming from ice-cores and tree-ring layers, reanalyzing them with a linear modelling of oscillations with recurrent influences.

Line 18: if the data were taken from the literature then 'presented' should be replaced by 'used'.

Author's changes in manuscript. (See page 5, line 3)

In order to analyze solar/climate recurrent oscillatory patterns, six different reconstructed forcing (five) and climate (one) proxy records of these oscillations are ~~presented~~used.

Line 25: the calculation of variance between S04 & S09, S04&SO12 etc should be described.

Author's changes in manuscript. (See page 5, line 9)

The variance explanation (obtained as the square of the correlation coefficient multiplied by 100) between S04&S09, S04&S12, and S09&S12 for decadal average records are of 52.7, 82.9 and 59.3 %, respectively.

Page 1242:

Line 2 'Greenland ice' should be 'Greenland ice core'
+Line 3 – English problem: 'located at the Eemian…' located refers to space. Since Eemian represents a temporal domain 'located' is not appropriate here. Better use 'belonged to the Eemian'.

Author's changes in manuscript. (See page 5, line 13)

Secondly, there are three interesting and useful solar-related, 10Be isotope concentration records from Greenland ice core, one covering the past 40 Kyrs (FN97)~~and the~~, another covering only 20 Kyrs but ~~located at~~belonging to the Eemian (SS14), and another covering 20-10 Kyrs BP (A14).

Line 8: '…climate record obtained with a novel and promising molecular technique' – reader should have some idea about the novel and promising molecular technique that has been used to get the climate record.

Author's changes in manuscript. (See page 5, line 20)

it is a continental tropical climate record obtained with a novel and promising molecular technique (W07), based on changes in lipids associated with surface temperatures.

Line 9- Improper presentation: '….more influenced by the solar than the rest of the world...' what is the meaning of 'than the rest of the world'?

Author's changes in manuscript. (See page 5, line 22)

This CRB-SAT record (W07), or Tcrb, is relatively more solar-influenced than ~~the rest~~non-tropical areas of the world, because the latitudinal distribution of solar influences shows its maximum in the tropics.

Line 11: 'relatively less influenced by the ocean' –the author should give evidence in support of this statement.
The following argument viz. '…because its signal is coming from the central tropical zone of Africa' is a weak argument as the atmospheric tele-connections can work remotely.

Author's changes in manuscript. (See page 5, line 24)

Moreover, this record is also relatively less influenced by the ocean than in coastal regions, because its signal is coming from the central tropical zone of Africa, which is also isolated by topography.

Line 15 'response to SA should be modulated during the interglacial differently due to the increasing intensity of THC...' contradicts the statement given in line 11. 4

Author's changes in manuscript. (See page XX, line XX)

Although oceanic influences on the Tcrb are minimal, Tcrb responses to SA should be modulated during the interglacial differently due to the increasing intensity of THC that has been reconstructed by Piotrowski et al. (2004),…..

Line 23: Anthropogenic Global Warming: by coining this term does the author mean that the current warming has a natural component also?

Author's changes in manuscript. (See page 4, line 1)

In addition to solar influences on climate, recent studies have highlighted the importance of human activities, and suggest that anthropogenic influences on global warming (GW) are currently active, imposing a projected change of 4 ± 2 °C by 2100 AD that seems to exceed the maxima values estimated for the past millennia (IPCC, 2013).

Page 1243

The author uses three different models to simulate the solar/climate variability. While the first model is a well known Fourier series expansion, the second and third are not. For example, how the equation 2 and 3 have been derived is not clear. If they are taken from the literature then the reference should be given, otherwise the author should show the derivation and their verification. For example, how the values of M in Eqn. 2 have been determined should be explained. How the values of M chosen differently?

Author's changes in manuscript. (See page 6, line 13)

Based on Piotrowski et al. (2004), and the changes of amplitude in the detrended CRB record, the model for the lagged and modulated linear contribution of a proxy variable is proposed as follows:

Author's comment:

Models proposed are simple linear transformations of a lagged input variable, to provide an output variable. Parameters are estimated using linear regression equations. M values and their changes was, based on Piotrowski et al. (2004), proposed and accepted after its application.

Whether the iterative process (line 18) converges or not should be tested.

Author's changes in manuscript. (See page 7, line 3)

Taking into account both the dating limitations and the approximated values provided by proxy reconstructions, and instead of to developing statistical analysis, as convergence and confidence level estimations, we prefer in this stage of research about climate recurrences, to apply verification/replication of all of our findings with independent information in our estimation processes and results. Future climate reconstructions with more accurate information will provide further and refined statistical analysis.

Do the all three models yield consistent result?

Author's comment:

The FS model (Eq.1) was applied to FN97 10Be data to detect and verify the recurrences. The modulation & lagged model (Eq. 2) was applied to justify the solar recurrent influences in the CTC CRB record. The lagged model (Eq. 3) was applied to test the solar recurrent processes with independent information (SSN[S04] vs. 10Be[A14]). All they provide consistent results.

Page: 1244

Line 4: 10Be – it is a solar proxy variable and available over longer periods than SA records. Give reference.

Author's changes in manuscript. (See page 7, line 12)

In order to detect multi-millennia-scale recurrences and/or persistent oscillations in SA, we need to analyze 10Be information since it is a solar proxy variable and it is available over longer periods than SA records (SS14).

Inconsistency:
Line 10: FN97 but in line-17 it is written as NF97.
Line 18: What is NF? Is it NFS?

Author's changes in manuscript. (See page 7, line 25)

The statistically detrended 10Be FN97 record was modeled with a periodic FS function with $N_{FS}=10$ that employed Eq. 1. After a minimization processes, a 9390 yr period, P, was found and the corresponding model **that explain 49.2 % of variance** is displayed in Figure 2a.

Calculation of 9390 yr periodicity is not clear. Method of calculation with significance level should be shown.

Author's comment:

The FS model (Eq.1) was applied to FN97 10Be data to detect and verify the recurrences. A minimum of variance was obtained with P=9390yr. It was corroborated with the test of recurrences shown in Fig.3 that shows a match of 14C and 10Be based records, with recurrence of 9400yrs.

Line 19: how the number 49.2% is achieved?
+(Page 1245 Line 24): how 61.4% variance was explained is not clear.

Author's changes in manuscript. (See page 5, line 9)

The variance explanation (obtained as the square of the correlation coefficient multiplied by 100)…

Page 1245

Line 8: Normalization process – needs to be defined in the main text. How does it confirm the 9.5 kyr recurrence?

Author's changes in manuscript. (See page 8, line 21)

Our normalizations, which are devoted to eliminating high-frequency local climate influences on the 10Be signal, have provided elements (records) to confirm the previous results for the ~9.5 Kyr recurrence and a consequent increase and diminishing of the 10BeA and TSI signals, respectively, for the following centuries, as also shown in the SI-3.

Line 11: 'verification' should be preceded by 'application', not the other way round.

Author's comment:

We have taken into account this recommendation. We have put first a verification process (2.2) and later an application process (2.4) (See these reordered sections)

Line 12: wavelet analysis is problematic. It does not show the 'cone of influence' used to examine the edge effect; hence some observed periodicities which fall beyond the cone could become insignificant. A 'significant' period (9000 yr) as observed by the author is very likely to fall outside the cone of influence, casting doubt to its 'significance'. Line 13: Inconsistency: 'three main significant periodicities… ', but the very next line gives four periodicities (9000, 5000, 2400, 900 yrs)

Author's changes in manuscript. (See page 8, line 1)

Before extrapolating the 10Be ~9.5 Kyr recurrences to TSI, we applied a wavelet analysis to the three TSI records. The TSI spectral results (see **SI-4**) show three main, significant periodicities around 5000, 2400 and 900 years, and confirms the existence in solar activity of, at least around three harmonic periods of the ~9.5 Kyr oscillatory pattern.

Author's comment:

We have not taken into account the 9000 yr peak due to the cone of influence. It is obvious because their temporal length is around 10Kyr. However in order to eliminate doubts about the solar pattern and its persistence a comparison is developed and presented in Appendix A.

Line 17: why a lag of 9500 yr was applied? 5

Author's changes in manuscript. (See page 7, line 28)

It should be noted that the solar and climate recurrence periods evaluated with FS and analogue techniques (shown in SI) have shown values of 9500+/-100 yrs (~9.5 Kyr).

Did all three models Eq. 1, 2, and 3 yield consistent results when applied to a given 10Be record?

Author's comment:

The FS model (Eq.1) was applied to FN97 10Be data to detect and verify the recurrences. The modulation & lagged model (Eq. 2) was applied to justify the solar recurrent influences in the CTC CRB record. The lagged model (Eq. 3) was applied to test the solar recurrent processes with independent information (SSN[S04] vs. 10Be[A14], see Fig 3). All they provide consistent results.

Page 1246:

Line1: The Grand Minimum is defined as a deficit of TSI by about 0.5 W/m2. This should be compared with that of the Last Glacial Maximum, Little Ice Age etc.

Author's changes in manuscript. (See page 10, line 6)

Our model confirms a Grand minimum in the period from 2050 to 2200 AD forecasted by S13, ~~characterized by~~ showing a sustained deficit of 0.5 W/m2, similar to that shown in the Maunder Minimum, four centuries ago (see Fig. 4b).

Unusual terminology: THC deglaciation process- better term would be THC induced deglaciation process.

Author's changes in manuscript. (See page 10, line 15)

The modelling required a different modulation for the first (M=2.) and second (M=1.) halves to distinctly consider the decreasing THC induced deglaciation process until the stabilized Holocene periods (Piotrowski et al., 2004).

Line 13-14: 'these models of Tcrb ….explain for the 20-10 (10-0) kyr BP 30.0, 23.6, and 31.6 (6.5, 10.9 and 8.5) % of the reconstructed Tcrb record.' – Difficult to comprehend.

Author's changes in manuscript. (See page 10, line 17)

These models of Tcrb, which were based on S04, S09 and S12 records, explain 30.0, 23.6 and 31.6 % and 6.5, 10.9, and 8.5 % of the reconstructed Tcrb record for the periods from 20 to 10 and from 10 to 0 Kyr BP, respectively.

Line 17; "…when the THC was low and the advected heat from the tropics were also low". No evidence/reference cited in support of this statement.

Author's changes in manuscript. (See page 15, line 22)

This increasing THC implies greater oceanic heat transport from the tropics and a consequent lower thermal response of the CTC. About sudden climate changes during the interglacial, Clarke et al, (2001) have pointed out: "Studies of deep ocean sediments and ice cores as well as coupled climate model simulations have identified changes in the THC in the North Atlantic as the probable mechanism. The warm events are though to have occurred when the THC penetrated further into the Nordic sea, whereas the cold events coincided with times at which the THC has slackened, reducing the transport of warm water to the North Atlantic."

Page: 1247:

Line 4-5: uncommon language.

Line 5: 'we have found a ~ 9500 yr recurrence of SA…" But in page 1244 line 17 T=9390 yr was shown. If these two figures are considered statistically the same then the author should give the uncertainty levels in periodicity estimation.

Author's comment:
Besides to obtain the FS estimation (Figure 2) and the test based on 10Be and 14C (Figure 3) we have found also 9600yr lags for the 10Be (FN97) record after two standardization and normalization processes. For that reason we estimated a central value of 9500 and a range of +/-100 yrs to define the recurrent period

English: line 8; 'the following summarizes…' grammatical error.
Author's changes in manuscript. (See page 11, line 20)

In the following a summary of the tests and verifications of our findings is presented:

Line 19: where is the result of FFT?
Author's comment:
The FFT was employed to develop a forecast of TSI due to S13.

Line 20-21: difficult to comprehend.

the extrapolated models [TSI(S04), TSI(S09), and TSI(S12)], but backward in time (See Fig. 5), present an important match with independent CTC Tcrb (W07).

Page 1248

Line 4: 'increasing THC that has been reconstructed…'
Though the intensification of THC from the initiation of last deglaciation is widely known but the reader should get an idea how much THC was increased (without digging another citation) that is being used to explain the Tcrb record.
The mechanism given is also not very satisfactory. Unless the time scales of the CTC Tcrb match with that of the THC, the cause effect relationship becomes weak.
Author's comment:
The Hematite-stained grains measures by Bond et al (2001) show a decrease of around 50% during the early Holocene, which provide a lower limit for the THC decrease during last deglacial process.

Page 1249

Line 5: If the spectral characteristics of the torque exerted by the planets match with those of the proxies of SA, then the particular periodicities should be shown. How the high frequency (i.e. 50 yr) variability affects the SA and in turn the Earth's climate should be discussed.
Line 8: here the author cites other papers in which low frequency variability (~ 4.5 kyr) of planetary influence has been proposed. How it is possible that a wide spectrum of periodicities of planetary influence affect the SA and in turn the Earth's climate?

An spectral analysis of lateral forces, shown in Appendix B, displays important peaks of the 11, 22, 50-70, 180, 900 and 2400 yr period. We do not how these oscillations are influencing solar variability and later climate variability. However the lateral forces can induce meridional flows that affect the solar dynamo.

Solar variability is affecting the tropical climate as has been analyzed in our paper. Tropical climate is affecting (with a millennium scale lag) sea level variability by an unknown mechanism (that includes the THC). A final note: A 4670 yr peak in the spectral analysis developed by Bond et al. (1997) have shown the ECS one of the most important responses to solar forcing. It shows solar influences on climate, it is almost the half of the ~9500yr period, and it near the 4.5 Kyr associated with planetary forcing.

The last paragraph in Discussion is irrelevant and should be removed.

Author's comment:

This paragraph has been removed

Conclusion:

SA oscillations at 84, 178 and 2400 yr are possibly related to the Sun's rotation rate – remains a speculation.

Author's changes in manuscript. (See Appendixes page 5)

Finally, we also developed a spectral analysis of the analyzed lateral forces. This analysis is based on wavelets and is displayed in Figure B.9. It clearly shows important contributions to periods around of 8, 22, 60 (in a range of 50-80), 180, 650 (in a range of 400-800), 1000 and 2500 years.

Page 1251: there are several projections of cooling and warming ranging from 0.3 to 0.65°C for the next couple of hundred years without any error estimation. If the errors in periodicity estimations are quantified (which have not been done) then these temperature change estimates may not remain significant.

Author's comment:

The reviewer 1 is right. However our objective is present evidences (quantitative and qualitative) that promote further climate reconstructions and their analysis.
In this work, we have presented "clear" evidences of climate recurrences are affecting the tropics and sea level in its present trends. The challenge is to separate the climatic responses due to natural and anthropogenic causes. In order to do that we have also analyzed the time required for ECS to change. The lags found strongly suggests a major participation of the natural variability in the present climatic values and trends.

Response to Referee 1.

Comments from Referee 1 (1)

There has been a significant amount of work in recent times among the solar physics community regarding this issue and the author being a climatologist has missed some of these contributions, which would add greatly to the overall impact of the paper. I list here some of the important contributions that may be cited by the author to make a much more convincing case. For example, Janardhan, Bisoi and Gosain, Sol. Phys., 267, 267-277 were one of the first to report a steady and systematic decline in solar polar magnetic fields starting from around 1995. Later work, (Janardhan, et al., (2011) Geo. Res. Lett, 38, L20108) showed that the decline in solar magnetic fields was mirrored in the solar wind, by a similar decline in solar wind micro-turbulence levels. A study of the consequences of this decline on the earth's ionosphere showed that itsignificantly reduced the ionospheric cut-off frequency to radio waves, normally about 30 MHz, to well below 10 MHz (Janardhan et al. (2015) Sun
and Geosphere (in press)). The most recent report (Janardhan et al., (2015) J. Geo. Res. 120, 5306-5317) has shown that the decline in solar activity has to continue at least until 2020 and there is a good posibility of the onset of a Grand solar minimum from solar-cycle 26 onwards (2031). In addition, Choudhuri, and Karak (2012), Phys. Rev. Lett., 109,171103, and Karak, and Choudhuri (2013), Res. Astron. Astrophys., 13, 1339, used 11000 years of sunspot data derived from carbon 14 records in tree rings and showed that gradual changes in solar surface meridional flow velocity lead to a gradual onset of grand minima while abrupt changes lead to an abrupt onset. In addition, these authors also showed that one or two solar cycles before the onset of grand minima, the cycle period tends to become longer. It is noteworthy that surface meridional flows over Cycle 23 (Hathaway, and Rightmire (2010), Science, 327, 1350) have shown gradual variations and Cycle 24 started _1.3 years later than expected. There is also evidence of longer cycles before the start of the Maunder and Sporer minimum.

Author's changes in manuscript. (Page 14, line 9)

We have found and tested a recurrence of ~9500 yrs of SA that implies a solar Grand-minimum for the next one and a half centuries. However, we can also support our findings with other studies. For instance, the existence of different solar modes of activity (Grand minima, Regular, and a possible Grand maxima), which have also shown important temporal variations with asymmetries (Grand maxima significantly less often experienced than Grand minima) during the Holocene (Usoskin et al., 2014), would be considered expressions of our detected recurrent pattern of ~9500yrs.
In this work, we have forecasted a continuation of the solar decline for the next decades, which is supported through precursory signals during recent decades:
a) A steady and systematic decline in solar polar magnetic fields, starting from around 1995, which is well correlated with changes in meridional-flow speeds (Janardhan P., Bisoi, S. K., Gosain S., 2010)
b) A decline in solar wind micro-turbulence levels. Based on extensive interplanetary scintillation (IPS) observations at 327 MHz, obtained between 1983 and 2009, a steady and significant drop in the turbulence levels in the entire inner heliosphere, starting from around 1995, was detected (Janardhan et al., 2011).
c) A significant reduced ionospheric cut-off frequency to radio waves, normally about 30 MHz, to well below 10 MHz (Janardhan et al., 2015a).

Also, in this work, we have forecasted a Grand solar-minimum, with sustained low solar activity for the next two centuries, which has been supported through a number of recent studies and their findings:
a) The continuation of this decline in solar activity is estimated to continue until at least 2020, and there is a good possibility of the onset of a Grand solar minimum from solar-cycle 26 onwards (2031) (Janardhan et al., 2015b).
b) Based on the S04 SA record, it has been shown that gradual (abrupt) changes in solar surface meridional flow velocity lead to a gradual (abrupt) onset of grand minima, and that one or two solar cycles before the onset of grand minima, the cycle period tends to become longer (Choudhuri and Karak, 2012; Karak and Choudhuri. 2011). It is noteworthy that surface meridional flows over Cycle 23 (Hathaway and Rightmire, 2010) have shown gradual variations, and Cycle 24 started 1.3 years later than expected.

Comments from Referee 1 (2)

I would also like to point out that 10Be is a much better proxy for solar activity than Carbon 14 as it has a very short residence time in the atmosphere compared to carbon 14 and therefore it is good that the author has used 10Be records rather than Carbon 14 which is prone to larger errors. However, it must be noted that the abundance of 10Be in polar ice is also affected by local climate processes and atmosphere air mass mixing (Kocharov et al. 1989; Radiocarbon, 31, 163; McHargue & Damon 1991, Rev. Geophys., 29, 141). The climatic effect though is minor for polar sites (particularly for the South Pole) where 10Be most closely retains cosmic ray signal (Raisbeck et al. 1981, Geophys. Res. Lett., 8, 1015; Bard et al. 1997, Earth Planet. Sci. Lett., 150, 453). My concern therefore is regarding the reconstructions made from different reservoirs, eg. ice cores from Greenland will be greatly affected by climatic changes especially during the Holocene. Also, the interior of Greenland experiences mostly "dry" gravity aided deposition of 10Be carrying aerosols while in the coastal belt the deposition processes is wet deposition. Have the authors taken these constraints into consideration while looking at the data ? Could they comment on this.

Author's comment. (SI)

In the Supplementary Information we have developed a statistical detrending and demodulation of the solar proxy (10Be) record of FN97 10Be is a proxy of SA.
We have taken into account that, this record is produced by the impacts of galactic cosmic rays on Earth (SS14) in a known process of cosmogenic nucleosynthesis. Cosmic rays are highly energetic charged particles that impact Earth's upper atmosphere and terrain surface, that produce 10Be, and that are modulated by the variation in the strength of the geomagnetic field, as well as by solar magnetic shielding (SS14).

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