Reply
to the reviewer comments
To paper 3 in SR

The reviewers were presented with the outline of the concerns and the reply provided by Professor Zharkova (attached for reference). They advised that:

1. the concerns raised about the Earth-Sun distance and its variability are correct, that this section of the article is therefore invalid, and that your response does not address these concerns adequately. In particular, they note that rebuttal arguments build around previous papers misinterpret those studies (they commented specifically on the Shirley et al. paper referenced in your response, as well as the discussion around JPL ephemeris calculations;

   Answer 1.

   a) The distance between Earth and Sun is reduced by 0.004 au (see Fig.1 below which was sent in the previous reply) even in the current calculation of the Earth ephemeris considering the gravitational effect of Sun, Moon and only 3 planets as it currently stands in the JPL ephemeris.

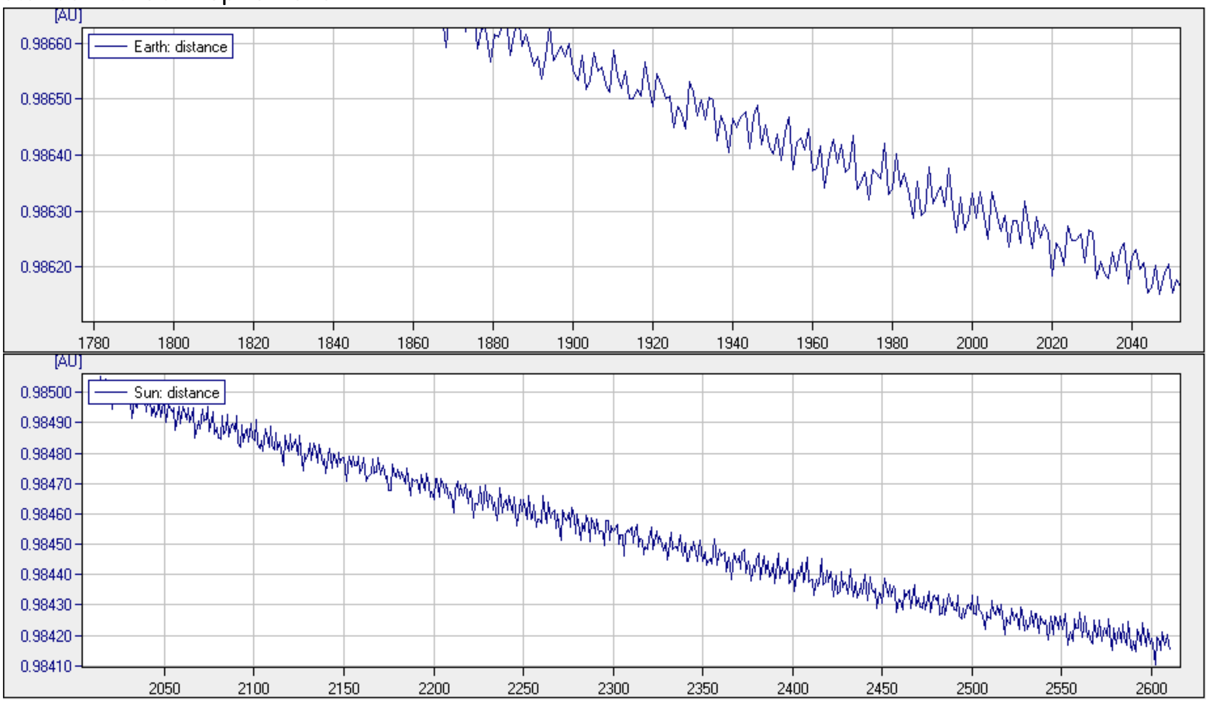


Fig. 1. Earth-Sun distance variations in time for the Earth rotation about Sun built from JPL ephemeris.

   Do the reviewers deny this obvious plot made from the current JPL ephemeris? If the other 3 large planets are included this decrease will be within the estimations we presented as we stated in the reply.

   b) However, recent simulations shown that if the Influence of all large planet included, the decrease of a distance between Earth and Sun can become twice larger than the current decrease of 0.004 au predicted by the JPL ephemeris only with Jupiter included (see the papers:

   a. Laskar et al, 2011, https://ui.adsabs.harvard.e...

   b. Fienga et al, 2011, https://ui.adsabs.harvard.e...

   c. And others https://ui.adsabs.harvard.e...)

The Observatory of Paris approach shows how the Earth orbit eccentricity and distance to the Sun can change if all 4 planets are considered so that the motion equations for large planets beside Jupiter are directly integrate and not integrated by averaging as they currently done in the JPL ephemeris. Laskar et al, 2011 in the paper even managed to find the proper terrestrial observations over the past millions of years confirming this effect.

The similar approach needs to be applied for a shorter timescale associated with period of 2100-2300 of solar inertial motion. This can clarify the variations of solar irradiance in the past 400 years and for the future 600-700 years.

In our case of SIM variations over the period of 2100 years the variations of the Earth orbit (as distance, so eccentricity) would be possibly smaller but still occurring on a smaller time scale of 2100 years, if the motion equations are not averaged but integrated directly as these authors did.

This gives JPL a viable route to improve the JPL ephemeris for the Earth orbit by applying the methodology by the French authors.

c) JPL launched the internal review to revise the calculation of JPL ephemeris for the Earth. Obviously, they appreciate the wisdom about the effect of large planets learnt from the papers on SIM as highlighted by our paper.
Do reviewer deny the text on the NASA website that all planets move about the barycentre of the planetary system and so does the central star?
https://spaceplace.nasa.gov/barycenter/en/
https://thegrandsolarminimum.com/wp-content/uploads/2019/07/doppspec-above.en_.gif
This wobbling star effects are used to detect stars with exoplanets. They work for other stars but the reviewers doubt it works for the Sun?

d) The paper **Shirley et al, 1990** is not listed in our reply to the pubpeer comments, it was not asked in the Editor query in July either.

However, we can answer this concern. In the paper we did not state that Shirley et al stated the increase of solar irradiance, but that he was the first who linked the solar luminosity with the SIM effect. Furthermore, we do not build our research about this paper by Shirley et al, 1990, it is not the key reference which affect any of our conclusions based on our own data and comparisons.

We made this estimation of the variations of solar irradiance based on the basic law of Physics for variations of luminosity with a distance. As the distance from a point source of radiation increases, the irradiance decreases.
https://www.bbc.co.uk/bitesize/guides/zh4qscw/revision/1

The relationship between irradiance, I, and distance, d, can be shown to follow an inverse square law.
$I = \frac{k}{d^2}$, or $I_1 {d_1}^2 = I_2 {d_2}^2$.
Then if the average solar irradiance of say, 1367 W/m^2 (Wolff and Hickey, 1987; Shirley, et al, 1990) at a distance of d_1=1 au and it should change when

the distance d_2 between the Earth and Sun decreased by 0.016 au (as SIM predicts) and becomes (d_2 =1-0.016=0.984 au). Then its square is 0.968256, so that the irradiance of 1367 divided by the square of the distance become 1366/0.968256= 1411.82.
The difference 1411.82-1367=44.82, that is 44.78/1367=0.0328 that is 3.3%.

Note the references:

1. Shirley, J. H., Sperber, K. R. & Fairbridge, R. W. Sun's inertial motion and luminosity. *Sol. Phys.* **127**, 379–392 (1990), https://ui.adsabs.harvard.edu/abs/1990SoPh..127..379S/abstract
2. Wolff, Charles L. and Hickey, John R., Solar Irradiance Change and Special Longitudes Due to γ –Modes, 1987, Science, Volume 235, Issue 4796, pp. 1631-1633 https://ui.adsabs.harvard.edu/abs/1987Sci...235.1631W/abstract.

In our estimate in the paper we used the distance d_2~0.02 au based on the estimation of Charvatova, 1998, 2000 and other sim authors, giving (by repeating the calculations above: 0.02→ 0.98→0.96. 1367/0.96=1423.9, 1423.9-1367=56.9, divide by 1367 gives 0.042=4.2%). This estimation gives the irradiance increase by about 4.2%.

Even with the current change of the distance between Sun and Earth of 0.004 au caused by Jupiter only as present in the current JPL ephemeris (see the answer 1), by 2600 the increase of solar irradiance on the Earth by 2600 will be by 0.8% of the initial irradiance occurred during Maunder minimum.

Therefore. **3.5% increase of solar irradiance owing to the SIM effect stated in our paper** while affected by 4 large planets **was a very conservative number of a potential solar irradiance increase during the whole cycle of 2000 years.** Even if Shirley et al. 1990 did not put this number in the paper, the above calculations prove this is easy to estimate.

e) Real variations of (restored and measured) TSI since Maunder Minimum.

According the restoration of TSI by Lean et al, 1995, 2000 shown in Fig. 2 below the solar irradiance has changed by 3 W/m^2.

Here is a table of restored and measured solar irradiance since Maunder Minimum:

	Maunder minimum:	2000-2012
Lean, 1995	– 1363	1366
Steinhilber, 2012	- 1364	1366
Shirley et al, 1990:		1370
Wolff and Hickey, 1987		1371

Hence the maximal variation of TSI since MM: 1371-1363= 8 W/m^2 (can be 1370-1363=7).

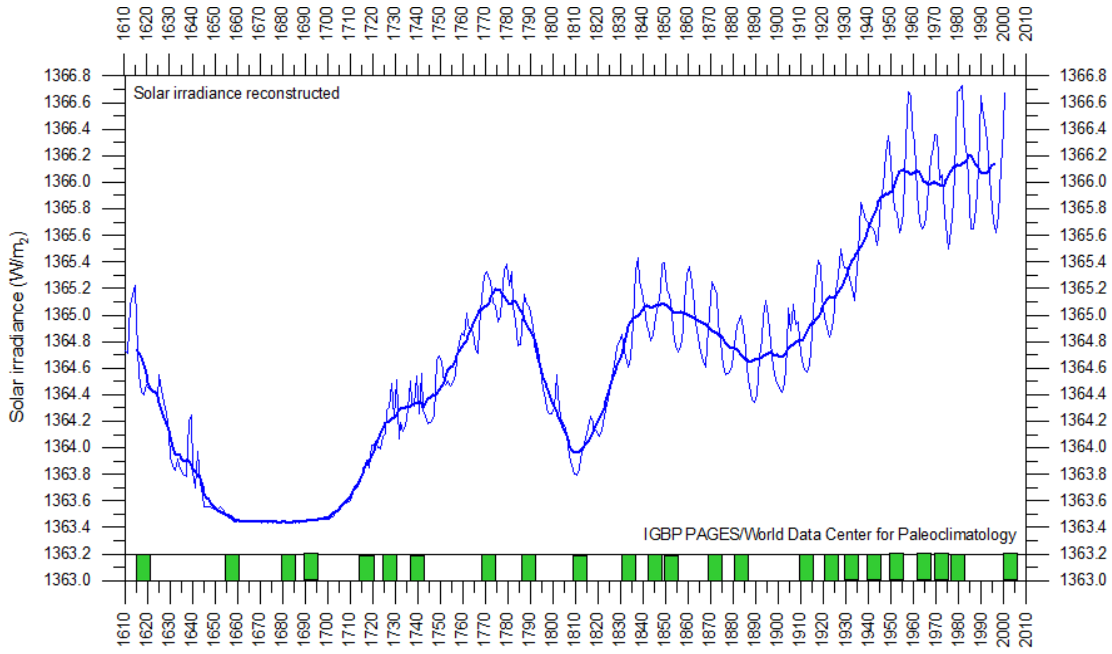


Fig. 2. *Solar irradiance since 1610 as reconstructed by Lean et al (1995) and Lean (2000). The thin line indicates the annual reconstructed solar irradiance, while the thick line shows the running 11 average.*

Let us **compare** this variation with that expected from **solar TSI affected by joint effects of grand solar minimum during MM and by changing distance** (and orbit eccentricity) between the Sun and Earth as derived from the current JPL ephemeris.

1. TSI variations owing to GSM is about 3 W/m^2, or 0.22% of TSI (following the curve by Lean et al, 1995 shown in Fig. 2 above).
2. TSI variations owing to the distance change would be 0.8% of TSI per 1000 years as calculated in item d) above. This would result in the TSI increase in the past 400 years after its minimum at MM as 4/10x0.8=0.32%.
3. Hence, the total increase of solar irradiance from MM to the current time caused by the joint effects 1+2 (of solar activity itself and by change of the distance owing to SIM) should be 0.2+0.32%=0.52%. This would give the increase of TSI 1363x0.0052= 7 W/m^2. Hence, the total irradiance in the present time should be 1363+7=1370 W/m^2 as reported by Shirley et al, 1990 or Wolff and Hickey, 1987. The latter even reports the TSI of 1371 W/m^2 that supports the suggestion of a larger decrease of the distance between the Sun and Earth.
4. Nowhere in the paper we do suggest that the decrease of the distance between the Earth and Sun will approach 0.02 au as it is estimated for the solar inertial motion. It could be much smaller, given the small size of the Earth.

f) Influence of green house gasses versus SIM

We wish to emphasize that we clearly stated in the paper that <u>we do not challenge the anthropogenic effects on temperature increase</u>, which have its own remits as indicated by one of the replies N38 by Dr. K. Rice.

Our prediction of temperature increase based on a straight line in the curve by Akasofu, 2010. Dr. Rice has shown in his reply to Pubpeer N38 (see Figure 3 below, blue line plotted by Ken Rice) that the terrestrial temperature increase above the baseline is higher than predicted by Akasofu, 2010 http://file.scirp.org/pdf/NS20101100012_47058306.pdf .

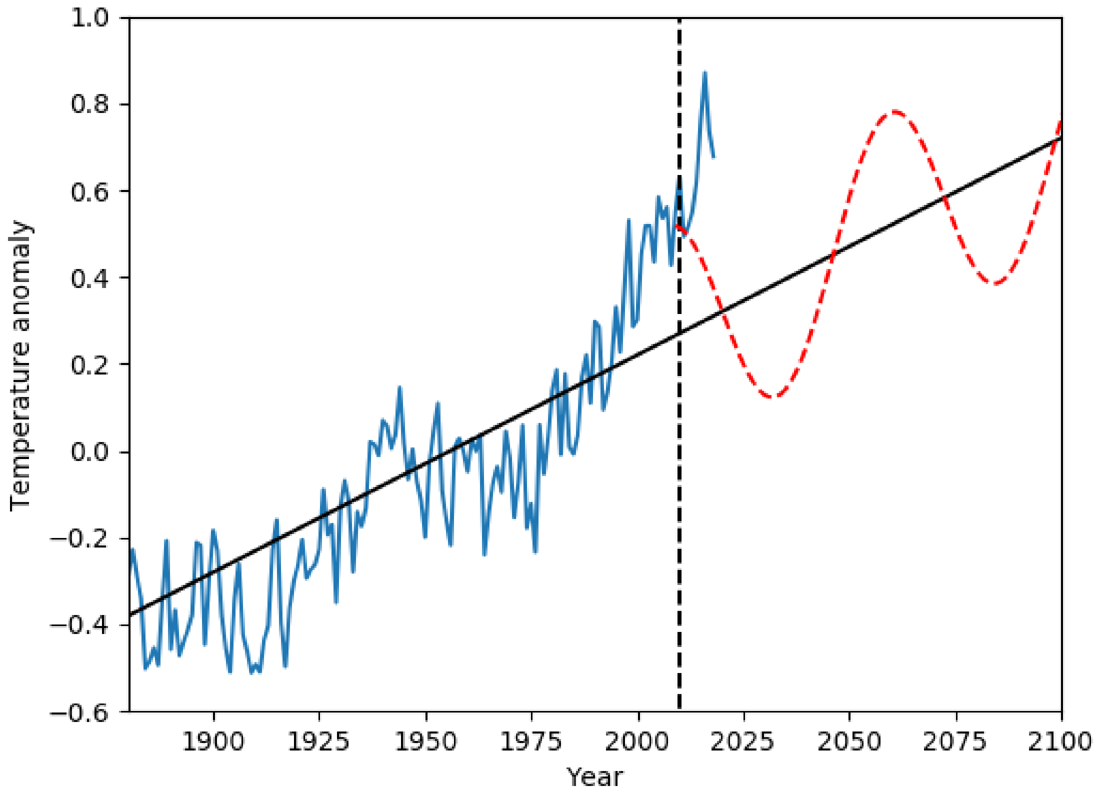


Fig. 3. Terrestrial temperature variations since 1875. Black solid line –baseline temperature, blue line – measurements provided by Ken Rice, red curve – the prediction from Akasofu's curve (Akasofu, 2010

Therefore, AGW people should not feel threatened by our findings, as they can benefit from these suggestions by fitting into their models of temperature increase the combined TSI variations. This can allow them to explain not only temperatures during regular solar cycles but also the temperatures during grand solar minima including the Maunder Minimum.

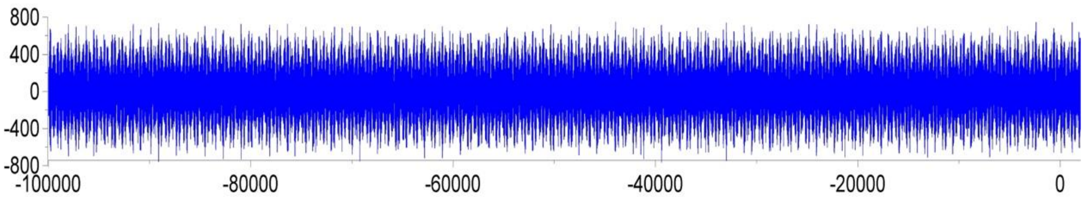
2. the concerns regarding reconstructions of the solar activity curves in Figures 1 and 3 are also correct.
    a. The reviewers point out the differences between the reconstructions in those figures, despite the fact that these are meant to show the same data - these differences significantly affect the interpretation of this data;
    b. they finally note that neither of the papers cited as source of this reconstruction provides it (one is a perspective article, the other is a review) and that the primary paper to which this reconstruction can be traced does not cover the period past year 1700. All of these concerns put conclusions of the first section of the paper in doubt.

Answer 2.

a) **Our answer:** The left axis in Fig. 1 in our paper Zharkova et al.,2019 contains the numbers for the summary curve (we can send this curve to the Editorial Board for verification, if they insist). And the Y axis in the summary curve in Fig. 3 (top figure) has slightly larger scale than in Fig. 1 because of smaller resolution (2 points per year in Fig. 3 and 13 points per year in Fig. 3), but the numbers are very close.

This difference between the summary curves in Fig.1 (top) and Fig.3 (cyan curve) is because the summary curve in Fig. 1 is obtained for 3000 (2000 AD and 1000 BC) years for 13 Carrington rotations per year using our formula, as it was in the original data from Wilcox Solar Observatory from which this formula was derived. Hence, we obtained 3000x13=39000 points of data this is the full dataset, which is possible to plot on a Fig. fitting a single page of A4.

When calculated the data for 100 thousand years, we would have 3900 thousand points which cannot be plotted on a single A4 page. Hence, we needed to find two average points per year and to use 200 000 points instead of 3.9x10^6 points, which would look as a thick solid curve as shown below), in which nothing can be seen. While by reducing the point numbers we could derive the long-term baseline oscillations.



The 100K summary curve (cyan line) was put as a background (cyan line) of the baseline oscillations in Fig.3. This background curve does not have any further role in the Fig. 3 besides from showing that the summary curve oscillation amplitude is more then 20 times higher than that of the baseline oscillations.

Furthermore, the baseline oscillation curve is plotted in Fig. 2 in our paper showing the same scale of these oscillations versus the summary curve (e.g. solar activity) similar to Fig. 3.

To demonstrate this point we can either explain why there is a difference between summary curve sin Fig. 1 and 3, or rebuilt Fig. 3 without the cyan curve (example 1) or with the same summary curve on background as in Fig. 1 (example 2). **The conclusions of the paper for this Fig. 3 (and Fig. 2) are done for navy blue curve, thus they do not change with a change of the background curve (cyan curve).**

b) **Our answer:** In Fig. 1 top plot the blue curve is our summary curve and the red curve is the curve of sunspots by Solanki et al, 2004 as per text file attached. The source of this reconstructed curve was correctly cited in our paper as suggested by the authors themselves in the file we used.

Solanki, S.K., I.G. Usoskin, B. Kromer, M. Schussler and J. Beer. 2004.
An unusually active Sun during recent decades compared to the previous 11,000 years. Nature, Vol. 431, No. 7012, pp.1084-1087, 28 October 2004. Their data stating explicitly which paper to cite can be found on the link
http://computing.unn.ac.uk/staff/slmv5/kinetics/solanki2004-ssn.txt.

However, the absolute numbers in Fig. 1 (top plot) of our paper are not essential because we compared the general trends of minima and maxima between these two curves (ours and Solanki) over a large period of time.

As the Editors can see, we have proven with data and text files that our figures 1-3 fully support our conclusions in the first part of paper about the baseline oscillations of solar background magnetic field and their link to the oscillations of solar irradiance at the Earth orbit and the baseline oscillations of terrestrial temperature.

As we explained above, this would not affect the conclusions from Fig.3, because we already have shown in Fig. 2 the scale of the baseline oscillations versus the summary curve.

We can issue the erratum of the paper explaining as above the difference between the summary curve (navy blue line) in Fig. 1 and in Fig. 3 (cyan line) and show the updated Fig. 3 with or without background curve on a background. ***But these are not the principal differences, which can affect in any ways the general conclusions of the paper.***

The rest of the paper and its conclusions are absolutely correct as a suggestion to work on this topic further.