Answer to anonymous Referee #1

We thank the Referee for her/his comments and suggestions. We answer point by point in the following with the Referee's comments added in *red/italics*. Text added to the revised version of the manuscript is included here in *blue/italics*.

This interesting and well written study addresses the impact of the choice of solar forcing model versus choice of CCM model through an ANOVA analysis of annual mean response rates. Although the study itself is performed under controlled conditions (no forcing from particles, no solar cycle, yearly means, ...) it sheds new light on the relative impact of the model choice and solar spectrum choice on heating rates, ozone, etc. In particular, the study highlights the influence of the CCM choice on the upper mesosphere and the impact of the prescribed solar forcing in the FUV on the response of the upper stratosphere and lower mesosphere. This excellent work is definitely worth publishing in ACP.

General comments

p3 line 10: the amplitudes are added... If the reference ATLAS3 spectrum underestimates the SSI in some spectral band, then this means that the departure from the true spectrum will affect all reconstructions, thus impacting the climatological state of the atmosphere. This effect may be significant in the visible and near-IR where Delta-SSI is relatively small as compared to the uncertainty on the reference spectrum. Although you briefly mention this in the conclusions I would recommend to address this issue (if it is one) here already because what follows heavily relies on the ATLAS3 reference spectrum.

In the introduction (page 2, lines 27–35; page 3 lines 1–4) the effect of differences in the spectral distribution between SSI data sets on the simulated temperatures are briefly discussed when the atmospheric state during solar mininimum is modelled:

Besides their solar cycle response on the thermal structure and dynamics of the middle atmosphere, the different spectral distribution of a SSI data set can also have an impact on the averaged middle atmospheric temperature, as was found in studies comparing different SSI data sets. It was shown that differences in the energy distribution during the solar minimum phases of individual SSI data sets may cause significant differences in the simulated temperatures in the middle atmosphere (e.g., Zhong et al., 2008; Oberländer et al., 2012). Even when scaled to the same TSI, the variable spectral distribution of energy within the SSI data sets can cause significant changes of the simulated climatological temperatures in the middle atmosphere. As shown in Matthes et al. (2017), climatological annual mean middle atmospheric temperatures in the tropics can be up to 1.6 K lower when using the CMIP6 recommended SSI data set instead of NRLSSI1.

This can be translated to the common solar minimum references state that is used as a base line for the maximum state of the five SSI data sets in this study.

p3 line 10: The SORCE dataset has received considerable attention (e.g. Haigh et al., 2010, https://doi.org/10.1038/nature09426) because of its anomalous solar cycle variability. Alas, it is implictly excluded from your analysis because of the considered time interval. Yet, I would still mention it here because of the continuing debate.

The SORCE SSI data are not included in our study, as it is not suited for modelling studies which usually span several decades. We have mentioned some studies using the SORCE SSI data in the introduction of the revision.

The deviant solar cycle behaviour of the SORCE measurements has motivated a number of CCM studies (e.g. Haigh et al., 2010; Merkel et al., 2011; Ball et al., 2011, 2016; Swartz et al., 2012) comparing simulations prescribing SORCE (Solar Radiation and Climate Experiment) SSI data and reconstructed SSI of the Naval Research Laboratory SSI (NRLSSI) or the

Spectral And Total Irradiance REconstructions (SATIRE) model.

p3 line 15: here it is important to give a physical flavour of why your ANOVA analysis can be useful, e.g. by mentioning that it is closely connected to regression analysis. Just saying that you're the first to use it does not help much in understanding what it is about.

The method of multiple linear regression and the ANOVA method are based on the same linear statistical model, assuming constant variances and a Gaussian distribution of the residuals. However, the purposes of the ANOVA as applied in this study and regression differ. Here, the ANOVA method is used to analyse whether there is a statistical significant difference between the mean values of a data set when grouped according to some kind of treatments. In our case two treatments are applied, and the data set (the annual mean solar responses) are grouped by SSI data set and CCM. The purpose of a regression analysis is to find relationships between a response (dependent) data set and independent data sets. Both methods have in common that they allow to estimate the portion of variance that can be explained either by the treatments or the independent data sets.
We have changed the sentence introducing the ANOVA in the Introduction, added some references, and have added a sentence that explains the main purpose of the ANOVA in our context.

To separate the influence of the SSI data sets and the CCMs on the solar responses in SW heating rates, temperature and ozone, a two-way analysis of variance (ANOVA) method (e.g Fisher, 1925; von Storch and Zwiers, 1999) has been applied. While the ANOVA is a well established method in many scientific fields, it is used rarely in the field of climate research (e.g Geinitz et al., 2015; Evin et al., 2019). Here we use ANOVA for the first time to quantify the uncertainty of the atmospheric response to decadal solar variability. The ANOVA-approach enables us to analyse if the usage of different CCMs or different SSI forcing datasets yields significantly different solar responses and to quantify which share of the total variance of the ensemble's solar response is related to either of the two factors (called treatment in the ANOVA-context).

p8 line 16: please replace "solar signal" by solar signature or similar because you are not really considering a signal, rather perpetual conditions.

To reflect the time slice character of our simulations, the term “solar signal" is replaced by "solar response” throughout the manuscript.

In this whole section the question that immediately arises is to what degree the modulation of that solar forcing by the 11-year cycle can affect your conclusions, e.g. through coupling with the NAO or, more generally, with the lagged ocean response. Please explain if and how these effects may impact your conclusions.

The 11-year solar cycle responses from transient simulations, which are usually extracted by multiple linear regression or composite analysis, as these simulations contain the full range of natural variability. However, the extracted solar signals are often quite similar compared to the solar responses from time slice simulations for solar maximum and minimum. We do not expect large differences of the 11-year solar cycle responses for transient simulations in the upper stratosphere to upper mesosphere.

p9 line 24: Here a brief rationale of why the ANOVA approach is pertinent is a must. Most readers are familiar with multilinear regression analysis, so that this analogy can be easily exploited. Please also give some adequate references (e.g. H. von Storch and F. W. Zwiers, Statistical analysis in climate research, Cambridge Univeristy Press, 2002) and above all, explain in more physical terms what you are trying to quantify with your https://www.overleaf.com/project/5e636cd609eeae000174ea02ANOVA analysis. I also recommend to cite some climate studies that illustrate the use of ANOVA analysis in climate studies, such as *the early https://doi.org/10.1357/0022240943076911 or the more recent https://doi.org/10.1002/joc.3991*

We have added some additional references, related to previous application of ANOVA in climate studies, in the introduction. To better motivate the usage of the ANOVA, we have added this short paragraph at the beginning of Section 5.

The averaged solar response discussed in Section 4 is supposed to be different with respect to the SSI data set prescribed and with respect to the CCM applied in each run. From the differences in the SSI amplitudes in the broad bands shown with Table 1 we expect the solar responses to be slightly different for each SSI data set, as we do for each of the CCMs. As the method of regression analysis can be used to calculate the fraction of the variance explained by a regressor, the ANOVA can quantify the fraction of explained variance by a certain factor.

One additional request: why a two-way analysis? Again, for those who are unfamiliar with ANOVA analysis, I recommend to motivate these choices here and then defer to the appendix for technical details.

The two-way ANOVA is a natural choice in light of our experimental setup where two CCMs apply five SSI data sets in the same way. This allows us to group the complete data set of annual mean solar responses by CCM and SSI data set. We have added an explanation to the manuscript.

The two-way ANOVA is used, as there are two treatments influencing the annual mean solar responses. As these treatments are not applied independently the interaction of CCMs and SSI data sets has to be taken into account.

p9 line 25: Why consider annual means only and not separate seasons (e.g. DJF) for which we know that the sensitivity may be higher ? Yearly averages tends to smear these seasonal differences.

The analyses of the seasonal differences is intended in Part II of the study which will focus on solar impacts on dynamical parameters of the atmosphere. This is now mentioned in the main text at the end of the introduction.

In this Part I of our study we concentrate on the annual mean solar response in heating rates, temperature and ozone, while Part II (in preparation) focuses on the dynamical solar and auroral responses in northern winter.

p17 I would suggest to mention as well the comparisons between the different spectral irradiance models and ozone observations (e.g. Ball et al., 2016, https://doi.org/10.1038/ngeo2640) which, broadly speaking, support your conclusions or at least do not contradict them.

We have cited the study of Ball et al. (2016) in a different Section, as it is not directly related to the solar response in total ozone.

p21 line 20: The investigation of more recent periods, instead of the 1989-1994 comparison would allow to better constrain the SSI variability (with SOLAR-ISS as you mention, but also other observational datasets such as AURA-OMI) and better overcome the main source of uncertainty in the solar forcing, which comes from the FUV range.

The motivation for selecting the solar amplitude 1989–1994 is now better motivated in Section 2. We have added a comparison of the selected solar amplitude with an averaged solar cycle amplitude over the satellite era, to show that it can serve as representative for recent solar cycles.

Compared to other solar cycle amplitudes in the satellite era (see Table S1 in the supplement) the one used in the paper is neither especially weak nor especially strong. The averaged ΔSSI is shown in Figure 2a with the error bars indicating the 95% confidence interval of the ΔSSI within each spectral region. The main characteristics of the solar amplitude chosen for the paper are also present in the averaged solar cycle amplitude. These are the small solar amplitude of SATIRE-T in the FUV and most of the ranking of the SSI data sets within the spectral regions. The deviations of the solar cycle amplitude from the averaged solar cycle amplitude is shown in Figure 2b. All deviations are within the range of the 95% confidence intervals. Therefore the selected solar cycle amplitude can be regarded as representative for most of the solar cycle amplitudes of the satellite era.

p23 line 15: Most ANOVA studies focus on the F ratio although one could also consider the coefficient of multiple determination R (e.g. von Storch and Zwiers, p. 176) which, arguably, gives a better physical picture. Did you consider it?

The F-statistics are used to estimate the probability (p value) that is plotted in Figure 1. The hatching denotes insignificant (i.e. p values larger than 0.05) differences between the solar responses when grouped according to CCM or SSI data set.

Technical corrections

Title: since this is part 1, what should we expect to find in part 2? The manuscript does not really tell this.

The study is entitled "Part I" and deals with annual mean quantities, as the "Part II" of the study is analysing the impacts on the dynamics especially in the winter seasons and also includes the impact of auroral forcing. Currently Part II, with the working title "Quantifying uncertainties of climate signals related to the 11 year solar cycle - Part II: Dynamical impacts of irradiance and auroral forcing", is in preparation. We have added the following sentence to Section 1:

In this Part I of our study we concentrate on the annual mean solar response in heating rates, temperature and ozone, while Part II (in preparation) focuses on the dynamical solar and auroral responses in northern winter.

p4 line 27: the appropriate reference for the Bremen MgII is Snow et al., 2014 (https://doi.org/10.1051/swsc/2014001)

The reference "Viereck et al. (2001)" is now replaced by "Snow et al. (2014)".

p6 line 10: observations

Done.

p35 Legend of Fig 4: does not pass → do not pass

Done.

References

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