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Interactive comment on "Modelling the effects of (short-term) solar variability on stratospheric chemistry" *by* R. Muncaster et al.

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Author's reply to reviewers
Manuscript "Modelling the effects of (short-term) solar variability on stratospheric chemistry" by Muncaster et al.

We thank both reviewers for their comments. They have been very valuable and helped us make the manuscript more targeted. Overall, as a response to the reviewers' comments, we have re-written the introduction to make it much more focussed. We have re-written much of the abstract and conclusion from the same perspective. We have tried to clarify some parts of the other sections of the manuscript as well. We changed the title. We hope that in its new form, the manuscript is more focused, lighter and its scope clarified. In the following, we reply to each comment of the two reviewers and

describe what related changes we made to the manuscript. The reviewer's comment is written in italic font. Line and page numbers refer to the new version of the manuscript.

New Title:

A simple framework for modelling the photochemical response to solar spectral irradiance variability in the stratosphere

Reply to Reviewer 1

GENERAL COMMENTS:

1. I still do not see who can be interested in the proposed parametrization. The authors briefly said that the parametrization can be used in chemistry-climate models with simplified chemistry, but only one example was given (Taylor and Bourqui, 2005) and there are no comments on how the suggested parametrization can be applied and what benefits its application will give to the model.

This is a central aspect of this study and we agree that it was not clearly explained in the manuscript. Recent satellite observations of the solar spectral irradiance have shown that the irradiance does not vary homogeneously across wavelengths. As a result, if climate-chemistry models (CCMs) are to address the issue of solar irradiance variability, they have to allow for a spectral representation of the irradiance variability. Several CCMs (e.g. WACCM, HAMMONIA, CMAM) have been updated in this direction. As far as chemistry is concerned, the usual photolysis look-up tables need to include the irradiance for a number of spectral bands as inputs. This severely increases the dimensionality of look-up tables, which increases very substantially the computational cost of the CCM. Since the stratospheric response to solar irradiance variability is relatively small (a few percent on ozone), it is easily hidden by natural variability, and therefore long simulations are necessary to extract this signal in a robust manner (of the order of the century). The computational cost of CCMs is today the most severe limit to our capacity to extract a robust stratospheric response to solar variability with a three-dimensional CCM.

This study offers two useful elements that help overcome this barrier: (1) it provides a simple framework to study the photochemical effect of spectral irradiance on the stratosphere without having to use a CCM; (2) it is a first step towards a simple and low cost parameterisation of the solar variability which could be used in any CCM (and not only simplified chemistry CCMs, as stated in the first version of the manuscript). This study is really a first step in that it introduces the framework and makes a proof-of-concept of the parameterisation. It is not our intention to introduce a parameterisation for end-users in this manuscript. More work is needed to generalise the statistical models introduced here to arbitrary spectral irradiance variations. A subsequent study is being conducted, based upon this framework, to understand how the ozone response changes when using other "models" of spectral irradiance variability, such as a SOLSTICE-like variability, or with a semi-empirical model of the spectral irradiance variability (e.g. Bolduc et al., 2012). Further possible investigations include the study of the coupling of this pure photochemical response with the radiative heating effect on temperature of the varying solar irradiance.
The manuscript's abstract, introduction and conclusion have been re-written with these aspects clarified.

2. The developed parametrization is not properly explained and validated. The description of the on-line validation mode is not sufficiently clear. For example, the author stated that the memory term should be dropped in "on line" mode causing additional errors, but later on they still use 2(3)-predictor schemes. It is not clear why it can be called like this if one of two(three) predictors was dropped. Nothing is clearly said about additional errors. In general, the validation of the proposed parametrization should be done with a potential target model (i.e., CCM with simplified chemistry, but not with the simple photochemical model which is rather far from the real processes in the atmosphere). Such a procedure would clearly show the benefits and issues related the introduction of the proposed method.
The manuscript's abstract, introduction, and conclusion have been re-written to give the manuscript a better focus and to clarify this aspect. As mentioned above, it is

not our intention here to introduce an end-user parameterisation. This manuscript introduces a framework and makes a proof-of-concept for a new parameterisation. The statistical models (or parameterisations) are here compared with the photochemical model they originate from using statistically independent time series. This is the standard method to evaluate a statistical model. It is to be noted that the statistical models are developed to represent the photochemical *perturbation* due to solar variability. As parameterisation, they shall be incorporated in a CCM on top of the ordinary photochemistry scheme. They are of course not meant to replace a CCM.
Section 4.3, l.476-485 already contains an explicit discussion of these modes: "In the off-line mode, the statistical model takes care of the effect of the solar variability while the photochemical model simulates solar average conditions. The statistical model does not feed back into the photochemical model. While this mode provides the most direct evaluation of the predictive skills of the statistical models, it may not be appropriate when the feed back between radiation and photochemistry needs to be accurately resolved. In the on-line mode, the ozone perturbation generated by the statistical model is added to the ozone concentration in the photochemistry scheme when initialising the latter for the next day's calculation. However, since the photochemical model is initialised every day with the perturbed ozone concentration, it keeps memory of the previous day's perturbation in ozone. Thus, the memory term in the statistical model must be dropped in this mode, giving rise to potential additional errors."
The following clarification has been added to the manuscript:
Section 2.2, l.221: "More details and the results of these five simulations are presented in Sect. 4.3."

3. The applied 1-D model describes only photochemical process. But, is it enough to analyze the response to the spectral solar variability? The model does not take into account temperature changes produced by solar irradiance variability which can contribute to the ozone response. The model does not consider any other processes *in the real atmosphere which can contaminate, mask or enhance pure chemical response (e.g., Gruzdev et al., ACP, 2008). These issues and their implications for the presented results should be discussed in the manuscript. Otherwise it is not clear how the obtained results can be compared against observations.*

As noted above, this study focusses on the pure photochemical response only. Further investigations will focus on the coupled effect between the photochemical response and the temperature effect due to radiative heating changes caused by irradiance changes. In order to be able to compare the stratospheric response to observations, the statistical model will need to be incorporated to a CCM, so that all mechanisms can interact (photochemical, radiative and dynamical). This goes beyond the scope of this manuscript.

The introduction and conclusion have been re-written and this aspect has been clarified:

Introduction l.65-70: "We focus on the pure photochemical response of the stratosphere to short-term solar variability. This response can not be directly compared to observations since it does not take into account dynamical and radiative feed-back. However, this pure photochemical response is well constrained and should have a high degree of similarity among numerical models. It therefore represents a robust first step in the evaluation of SSI reconstructions from a stratospheric perspective."

Conclusion l.545-546: "This paper proposes a simplified modelling framework for characterising the effect of spectral solar irradiance variability on the stratosphere, focussing on the pure photochemical response."

Conclusion l.622-627: "This modelling framework can be easily extended to study the feed-back between photochemistry and temperature. A first step would be to allow the temperature to change according to the response of ozone by incorporating an interactive radiation calculation in the column forced with solar average. A second step would be to include SSI variability in the radiation calculation. This would allow to evaluate the importance of these two levels of feed-back on the ozone response to solar variability and results could be compared with Semeniuk et al. (2011) and

Gruzdev et al. (2009)."

4. The model set-up for the case with scaled spectral solar irradiance variability is not justified. The authors introduced uniformly distributed scaling factor which does not depend on the wavelength, while Haigh et al.(2010) showed that the difference between the SORCE data and Lean's parametrization is not spectrally homogeneous. Moreover, the postulated by the authors spectral homogeneity of the solar irradiance variability on the daily time scale has not been convincingly validated. It well could be that the variability of the spectral solar irradiance on the daily time scale is far from idealized case studied in the manuscript. This issue should also be carefully discussed.

We agree with the Reviewer that the spectral irradiance variability may not be homogeneous across the wavelengths. It is not our intention to suggest that it is homogeneous. We have made sure that the introduction and the conclusion make this clear (see below). In contrary, the framework proposed here is meant to allow the study of the effects of such homogeneities on ozone. The experiments using uniform scaling factors are only provided here as examples of extension of the study. They show that for homogeneous Lean type spectral irradiance variability, the linearity of the ozone response goes beyond the ordinary range of variability. But it also shows that this linear relationship only holds when there is homogeneity through the entire spectrum; it changes when only the wavelengths between 200 and 400nm are allowed to vary.

This aspect has been clarified in the Introduction, Section 4.4 and the conclusion:

Introduction l.100-105: "In a first step, we limit the study to the pre-defined solar maximum and minimum spectra from Lean (1997) and assume that the SSI varies homogeneously between these two spectra. This allows comparison with previous studies in the context of constant solar maximum / minimum simulations. This first application of this simplified modelling framework presented in this paper provides a reference for further studies that will apply this framework to more advanced SSI variability reconstructions."

Section 4.4 l.521-524: "Although it is beyond the scope of this paper to apply the method developed here to these new observations, we present additional experiments in this section that illustrate the sensitivity of the ozone response to differences in the SSI variability pattern."

Conclusion l.586-621: "The linearity of the O_x response, and thereby the validity of the statistical models, in an extended domain of solar variability was tested with solar maximum and solar minimum experiments. It was found that within the range tested here, extending the solar variability magnitude of Lean (1997) by a factor three uniformly through the spectrum, the response remains fully linear and the statistical models identical. In contrast, magnifying the solar variability within a limited range of wavelengths from 200 to 400nm led to a different linear relationship between response and solar variability magnitude.

The modelling approach presented here based on ensembles of transient photochemical simulations with linear regression analysis sets a simple framework to characterise the effect of SSI variability on stratospheric chemistry. In particular, it is proposed as an efficient framework which can be used to evaluate the implications on the stratosphere of using more complex SSI variability patterns as the still commonly used one based upon Lean (1997) solar maximum/minimum spectra. These include spectral time series from SIM or SOLSTICE, advanced reconstructions (e.g. Thuillier et al., 2012) or outputs from semi-empirical solar models (e.g. Bolduc et al., 2012). Haigh et al. (2010) suggest, based upon recent results from instruments SIM and SOLSTICE onboard satellite SORCE, that the variability in the ultra-violet range from 200 to 400nm may be underestimated by a factor 4 to 6 in Lean (1997). As shown in the present study, while the ozone response remains linear with a factor three applied uniformly through the spectrum, it changes if the factor three is only applied to the 200 to 400nm range. This illustrates the dependence of the ozone response to the particular wavelengths forced, including those outside the 200 to 400 nm range which dominates stratospheric photolysis processes. Furthermore, it is expectable that variable correlations between pairs of wavelengths through the spectrum will affect the ozone response. In particular, Bolduc et al. (2012) suggest that the pair of wavelengths 240 and 300nm may have

a correlation well below 1.0, which may specially affect the stratospheric chemistry through a decorrelation of photolysis processes for O_2 and O_3. CCMs are unquestionably necessary to study the interactions between photochemistry and dynamics in the stratosphere. However, in the current context where various data sets, reconstructions and empirical models of SSI variability need to be inter-compared with respect to their implications on stratosphere, a modelling framework such as the one proposed here presents two major advantages, aside from its minimal computational cost. First, it provides a complete picture of the SSI response, including its non-stationary component. CCM studies typically only include the statistically stationary component of the response to solar variability as a result of the necessity to perform temporal averages to remove the large unforced variability. Second, it provides a well-constrained and robust response. Here again, the large unforced variability present in CCM outputs limits the robustness of the results and may interfere with them where feed-back between photochemistry and dynamics are present. In addition, differences in the dynamical behaviour of different CCMs may affect their results and ranges of responses."

MINOR ISSUES:

1. page 32457, line 7: I think this fact was known long before year 2000.
Sentence and reference removed.

2. page 32458, line 27: Please, check. I recall the radiative relaxation time could reach 100 days in the lower stratosphere
Sentence and reference removed.

3. page 32459, line 27: Most of the models participating in CCMVal-2 campaign used monthly mean spectral solar irradiance. So, this statement is not correct.
Statement removed.

4. page 32460, lines 2-8: I guess, these statements are not correct either. Most of the CCMs use proper representation of solar irradiance variability.
Clarified in the new Introduction, see l.30-41: "The stratosphere is most sensitive to

the ultra-violet (UV) range of the solar spectrum. The magnitude of variability in the UV is wavelength-dependent and is between one and two orders of magnitude larger than the variability of the total solar irradiance (TSI). As a result, numerical models need to incorporate some spectral dependence in their representation of solar variability. Most past numerical studies have been performed with a representation of spectral solar irradiance SSI variability based upon two pre-defined solar irradiance spectra, such as the maximum and minimum spectra from Lean (1997), and variations between these two spectra were kept homogeneous throughout all wavelengths. With this assumption, the photolysis can be simplified in CCMs to a linear combination of two pre-calculated photolysis look-up tables representing solar maximum and solar minimum (e.g. Austin et al., 2007). This ignores any decorrelation or anticorrelation of variability between different wavelengths, and does not allow temporal changes in the SSI variability pattern."

5. page 32461, lines 9-29: I think this paragraph belongs to conclusions.
Paragraph removed.

6. page 32464: I have noticed that the authors consider the tine interval much shorter than 27-day cycle. Any implications for observed responses?
This aspect is clarified in the introduction. We use ensemble simulations to characterise the response and therefore do not need to perform 27-day simulations. The regression models we obtain contain the entire information of the response and are able to reproduce the response to the 27-day cycle.
Introduction l.78-92: "In order to characterise the effect of SSI variability on this time scale, we use an ensemble simulation approach. We perform large ensembles of 10-day simulations, each driven by an independent time series of daily-varying SSI. The number of simulations in the ensemble must be large to cover with enough detail the space of possible conditions. The effect of the SSI on stratospheric ozone is then captured statistically from the ensemble of simulations by using a multiple linear regression. Here, the multiple regression model needs to be carefully chosen such that it provides an as complete as possible characterisation of the ozone response. In

this study, we test two regression models with two and three predictors, respectively. The simplest one has as predictors the solar irradiance perturbation on the current day and the concentration of ozone on the previous day. The most accurate one has in addition the irradiance perturbation of the previous day as predictor. The coefficients of the regression model provide a characterisation of the response of stratospheric ozone to the type of SSI variability reconstruction chosen. Inter-comparison between different types of SSI variability reconstruction can then be done by simply comparing the regression coefficients and/or the results of the regression models in simple cases. For instance, the magnitude of the response to a 27-day cycle can be retrieved from the regression models alone."

7. page 32463, line 6: Reconstruction of spectral solar irradiance by Lean is based on satellite measurements but not identical to SOLSTICE. Please, refine what exactly was used.
Sentence changed into: "The solar spectrum comes from Lean (1997) and includes maximum, minimum, and average solar irradiance at each wavelength interval"

8. page 32467, line 21: I recall the water vapor life time is larger than 5 days. Does it have any implications for the results. I think 5 days should be better justified.
The lifetime of water vapour in the stratosphere is much longer than the length of our simulations and for this reason, it stays nearly constant throughout the 10-day simulations.
Sentence added in Section 2.2 l.149-151: "The temporal evolution of all chemical species is calculated with the exception of only N_2 and O_2 that are kept constant with time."

9. page 32468, HOx: Nothing is said about HOx production from H2O+O(1D) which also depends on solar irradiance. Is this reaction chain important?
This reaction is the oxidation of water vapour and is stated as important in the

manuscript on l.271-273.

10. Section 4.2: I think this section (compare to previous ones) is to short and therefore not clear. In particular, I do not understand why there is no sensitivity to NOx levels while the temperature dependency appears via oxidation by NOx?

This is a good point. The reason is that the temperature perturbation used here has a much stronger effect on ozone than the perturbation in NOx concentration used here. These perturbations are meant to be representative of the natural variability across seasons and longitudes at the equator. However, it is expected that the variability in NOx due to long-term N2O increases, or due to latitudinal variability would be larger than that used here. A subsequent generalisation of the statistical model to various latitudes and atmospheric compositions will need to include the effect of NOx as well as temperature.

A paragraph has been added in the Section 4.2 l.463-469: “It is interesting to contrast the significant effect of the temperature perturbation with the insignificant effect of the NOx perturbation. These perturbations are meant to be representative of the natural variability across seasons and longitudes at the equator, and the variability of NOx appears to be too small to be felt on odd oxygen. However, variability in NOx related to either anthropogenic emissions of N2O or to different latitudes, may be larger than that used here. A subsequent generalisation of the statistical model to various latitudes and atmospheric compositions will need to include the effect of NOx as well as temperature.”

11. page 32482, line 24: Is it allowed to refer to submitted papers?

This paper was accepted in the meanwhile and its reference was changed accordingly in the new version.

12. Table 1: CFC11 mixing ratio is for sure altitude dependent.

We agree of course that CFCs vary with altitude in the stratosphere. However, in this study we made the simplification of keeping it constant. The effect of including vertically varying profiles of CFCs would be negligible in this study. The reason is that

we start with a realistic profile of Clx and we limit ourselves to a 10 day simulation. A realistic vertically varying profile of CFCs would only slightly affect the rate with which Clx is produced along the simulation. Note that the change in Clx over the time scale of the simulations is smaller than 10% everywhere (table 2), and therefore the effect of a vertically varying profile of CFCs on Clx must be smaller than 10% at least. Furthermore, Clx is found to play a secondary role on the ozone response. Hence, the effect on the ozone response would be negligible in this study.

Sentence changed in Section 2.2 l.148-149: “Initial concentrations of long-lived species are taken constant with altitude and are listed in Table 1. This simplification does not affect the results on the time scale studied here. The vertical profiles of the other chemical species, along with temperature are given in Fig. 1.”

13. Figure 1: H2O profile is not instructive. It looks like H2O does not exist in the stratosphere.

H2O mixing ratios are known to be very small in the stratosphere (around 4 ppm) but increases strongly towards the upper troposphere. We have changed the scale in order to make the stratospheric part clearer.

14. Figure 5: I see no lines above stripped area.

We guess that the Reviewer points to the R2 lines. These lines are hard to see because they show a value very close to 1 everywhere.

A note has been added in Section 4.1, l.426-427: “(the lines are not distinguishable from the vertical axis on the graph)”

15. Figure 6. I see only red lines.

This is because all lines representing the different days are almost completely overlapping. A note has been added in Section 4.2, l.455-456: “The variability of the response with the day of the simulation is insignificant, with all lines overlapping each other.”

16. Figure 8: The magnitude of the ozone response is only 0.1%. In the text it is mentioned that typical response is around 3%. Please, explain why such an extreme case *was chosen.*

The ozone mixing ratio varies in the graph from around 8.5 to around 8.6. This corresponds to a 1.2% signal, which is not an extreme case. Furthermore, as shown in Fig. 9, the response is linear over a large domain, and therefore the statistical model is insensitive to the magnitude of the signal over a large range (from 0.1 to 3.0 times Lean sol max – sol min spectra).

17. Figure 9: No middle panel. Most of the lines are not visible.

Top, middle and bottom graph references have been corrected in the text and the caption. Some of the lines are not visible because they are overlapping. Notes have been added in Section 4.4:

l.528-529: "(all lines overlap to each other)"

l.533-535: "In the latter panel, results from the 3-predictor model (small symbols) overlap with those from the photochemical model (colour lines). The 2-predictor model gives results that are slightly high biased (large symbols)."

l.536-543: "Figure 9 (bottom) shows the responses in the photochemical and statistical models as a function of the magnifying factor at 37km altitude. Consistently, results from the 3-predictor model (red symbols) overlap with those from the photochemical model (dark blue line), whereas the 2-predictor model (green symbols) is slightly high biased. These results are compared on Figure 9 (bottom) with the response found in the photochemical model when the magnifying factor is applied only within the range 200 to 400 nm. In the latter case, the response remains linear through the entire range but with a smaller slope and non-zero intercept. This is explained by the ozone production outside the 200 to 400nm window which is kept constant in these experiments."

Reply to Reviewer 2

GENERAL COMMENTS:

a) the article should be shorter as the basic aim is the parametrization of the stratosphere composition, in particular in the introduction where is discussed the 11-year

and the 27-day rotation effects on the atmosphere. Going directly to the subject would be useful.

The introduction has been entirely re-written in a more focussed and shorter manner. The abstract and conclusion have been changed very significantly to reflect this refocus. It should be noted that this study proposes a simple framework to study the photochemical effect of spectral irradiance on the stratosphere without having to use a CCM. CCMs with a comprehensive representation of the spectral irradiance variability are very computationally expensive. Since they also include the dynamical effects, long simulations are necessary in order to extract a robust ozone response. In this context, simpler models and a step-by-step approach starting with the sole photochemistry is useful. This study also provides a first step towards a simple and low cost parameterisation of the solar variability which could be used in any CCM (and not only simplified chemistry CCMs, as stated in the manuscript). This study is really a first step in that it introduces the framework and makes a proof-of-concept of the parameterisation. It is not our intention to introduce a parameterisation for end-users in this manuscript. The manuscript has been reworked to clarify these aspects.

b) There are several numerical models of the SSI. The choice made here should be justified.

The choice is made here to use Lean (1997)'s "model" of SSI variability with a homogeneous variation between the two solar min and solar max spectra. We choose this because it is the simplest starting point, and because this representation has been widely used in CCMs. A subsequent study is being conducted, based upon this framework, to understand how the ozone response changes when using other "models" of spectral irradiance variability, such as a SOLSTICE-like variability, or with a semi-empirical model of the spectral irradiance variability (e.g. Bolduc et al., 2012).

Introduction l.100-105: "In a first step, we limit the study to the pre-defined solar maximum and minimum spectra from Lean (1997) and assume that the SSI varies homogeneously between these two spectra. This allows comparison with previous studies in the context of constant solar maximum / minimum simulations. This first application of this simplified modelling framework presented in this paper provides a reference for further studies that will apply this framework to more advanced SSI variability reconstructions."

Conclusion l.593-621: "The modelling approach presented here based on ensembles of transient photochemical simulations with linear regression analysis sets a simple framework to characterise the effect of SSI variability on stratospheric chemistry. In particular, it is proposed as an efficient framework which can be used to evaluate the implications on the stratosphere of using more complex SSI variability patterns as the still commonly used one based upon Lean (1997) solar maximum/minimum spectra. These include spectral time series from SIM or SOLSTICE, advanced reconstructions (e.g. Thuillier et al., 2012) or outputs from semi-empirical solar models (e.g. Bolduc et al., 2012). Haigh et al. (2010) suggest, based upon recent results from instruments SIM and SOLSTICE onboard satellite SORCE, that the variability in the ultra-violet range from 200 to 400nm may be underestimated by a factor 4 to 6 in Lean (1997). As shown in the present study, while the ozone response remains linear with a factor three applied uniformly through the spectrum, it changes if the factor three is only applied to the 200 to 400nm range. This illustrates the dependence of the ozone response to the particular wavelengths forced, including those outside the 200 to 400 nm range which dominates stratospheric photolysis processes. Furthermore, it is expectable that variable correlations between pairs of wavelengths through the spectrum will affect the ozone response. In particular, Bolduc et al. (2012) suggest that the pair of wavelengths 240 and 300nm may have a correlation well below 1.0, which may specially affect the stratospheric chemistry through a decorrelation of photolysis processes for O2 and O3. CCMs are unquestionably necessary to study the interactions between photochemistry and dynamics in the stratosphere. However, in the current context where various data sets, reconstructions and empirical models of SSI variability need to be inter-compared with respect to their implications on stratosphere, a modelling framework such as the one proposed here presents two major advantages, aside from its minimal computational cost. First, it provides a

complete picture of the SSI response, including its non-stationary component. CCM studies typically only include the statistically stationary component of the response to solar variability as a result of the necessity to perform temporal averages to remove the large unforced variability. Second, it provides a well-constrained and robust response. Here again, the large unforced variability present in CCM outputs limits the robustness of the results and may interfere with them where feed-back between photochemistry and dynamics are present. In addition, differences in the dynamical behaviour of different CCMs may affect their results and ranges of responses."

c) For choosing a model which property is mainly required for the present study? Value of precision and/or accuracy taking into account the wavelength domain to carry out the calculations of the stratosphere composition.

We are not sure about the meaning of this comment. Our best understanding of it is that it provides possible avenues for answering the previous comment. However, as mentioned in our previous answer, we did not choose the Lean (1997) SSI model for any other reason than that it is a good starting point since it has been commonly used with CCMs. We would like to underline here that the framework introduced here can be used with all types of SSI models and will be especially useful for comparing the impact of different SSI models on the ozone photochemical response. Naturally, the statistical models, or parameterisations, will be dependent on the SSI model used, unless it is generalised.

d) The conclusion points out that the results of the study are based on a unique SSI model (Lean). It is true that the results will have a more general validity if similar results were also obtained with another model or directly with SSI data.

Yes, we agree and that will be the focus of a subsequent manuscript.

e) In the introduction, several numerical simulations are listed using 1D, 2D and 3D models and providing different responses even in the tropical regions. Have you analysed the cause? Is it due to different solar inputs, or specific situations for example?

We have not analysed the causes and such an analysis would go well beyond the scope of this manuscript. Instead, we have re-focused the introduction and have strongly reduced this discussion of results from numerical simulations.

f) Section 4 deals with daily random variability, could you explain more clearly the aim of this section?

The goal of this section is twofold: (1) To map (or regress) the ozone response to solar variability with respect two the smallest and simplest parameters. They are here memory of the previous ozone perturbation and the current day's solar irradiance in the simplest case of the 2-predictor regression. This allows to see the ozone response as a linear function of these two parameters. (2) This regression leads to statistical models that can replace the photochemical scheme and be used onboard CCMs. The purpose of this section is now clarified in the introduction and recalled in the beginning of section 4.

Introduction l.78-92: "In order to characterise the effect of SSI variability on this time scale, we use an ensemble simulation approach. We perform large ensembles of 10-day simulations, each driven by an independent time series of daily-varying SSI. The number of simulations in the ensemble must be large to cover with enough detail the space of possible conditions. The effect of the SSI on stratospheric ozone is then captured statistically from the ensemble of simulations by using a multiple linear regression. Here, the multiple regression model needs to be carefully chosen such that it provides an as complete as possible characterisation of the ozone response. In this study, we test two regression models with two and three predictors, respectively. The simplest one has as predictors the solar irradiance perturbation on the current day and the concentration of ozone on the previous day. The most accurate one has in addition the irradiance perturbation of the previous day as predictor. The coefficients of the regression model provide a characterisation of the response of stratospheric ozone to the type of SSI variability reconstruction chosen. Inter-comparison between different types of SSI variability reconstruction can then be done by simply comparing the regression coefficients and/or the results of the regression models in simple cases. For instance,

the magnitude of the response to a 27-day cycle can be retrieved from the regression models alone."

Section 4, l.320-327: "In this section, the effect of short-term solar variability on Ox is approached from a statistical perspective using multiple linear regressions on ensembles of simulations. The goal is to develop the simplest statistical model which captures the odd oxygen response in a complete manner. This statistical model, through its coefficients, characterises the ozone response to the type of SSI variability considered here and can be used to predict the odd oxygen response to an arbitrary time series of SSI (e.g. a 27-day cycle). This provides a simple framework for inter-comparing different SSI variability reconstructions/models with respect to their effect on the stratosphere. It also gives an approach for developing a simple parameterisation of the odd oxygen response to SSI variability."

g) On line 41, the sentence starts by "The solar variability. . .eleven solar cycle. . . 27-day rotation period of the Sun." It is more correct to write "The solar irradiance variability. . . "as the irradiance varies with the 27-day periodicity due to rotation and not to an internal mechanism as the 11-year solar cycle.

Sentence removed.

Results

Table 2 gives the percentage change of composition for several species after 5, 10 days . . . . What was the initial SSI change for example at 200 nm?

This table is only meant to show that the stratospheric composition does not change dramatically over the first 10 days in our simulations and that we can therefore consider that over these first 10 days, the composition in our simulation remains of relevance to the stratosphere (despite the transient nature of our simulations).

Now, a reader wishing to use the numerical results of your study for a certain level of solar activity change, how, he will proceed? Is it possible to provide a percentage of composition change for a given SSI variability at a wavelength of reference (for example 200 nm)?

Figure 3 provides the photochemical response to the Lean (1997) solar max – solar min spectra. In these experiments, the 200nm irradiance is changed by 8.4%. The regression coefficients given in Figs. 4 and 5 together with formula 5 and 6 allow to predict the ozone response to an arbitrary time series of SSI variability following Lean 1997 spectra. Note however that the response discussed in this paper only includes the photochemical processes and is therefore not meant to be directly comparable with observations. Nevertheless, in the equator, where the dynamical variability is low, it compares reasonably well, as discussed in the conclusion.

MINOR DETAILS

The terms "on line and off line" (line 16) have to be explained as all readers are not expert in the field of simulation, but interested by the results.
These terms have been removed from the abstract and introduction to avoid difficulty understanding the purpose and scope of the paper. They are explained in detail in Section 4.3 (l.476-585).

Figures 4 and 5 are difficult to read as the lines are very close to each other. On lower Figure 9, the two colors are very close (on my copy!).
In Figure 4 and 5, the lines are overlapping in many regions. This shows that there is not a high sensitivity of the results on the particular day of the simulation. This has been clarified in the text: Addition in Section 4.1, l.437-439: "The day-to-day variability of the non-normalised regression coefficients is insignificant for both the 2- and 3-predictor models. This is seen on Figs. 4 and 5 by the fact that all lines of different colours overlap and can not be distinguished from each other."

Conclusion
The article is interesting, but it would be more attractive by being shorter and written for readers not especially expert in the field of numerical simulation. In particular, means to access to the composition variability as a function of SSI variability should be provided if possible. This being taken into account, the paper has to be published.

Thank you for your very valuable comments. The introduction has been re-written in the light of the two Reviewers comments, and the abstract and conclusion have been changed very significantly to reflect the refocus of the article. The Figure 3 provides a direct mean to compare our results with other studies. However, it should be noted that these results only show the photochemical component of the response.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 32455, 2011.