**Atmospheric
Chemistry
and Physics
Discussions**

Interactive comment on "The effect of the solar rotational irradiance variation on the middle and upper atmosphere calculated by a three-dimensionalchemistry-climate model" *by* A. N. Gruzdev et al.
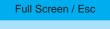
A. N. Gruzdev et al.

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We are very grateful to the three referees for the useful and comprehensive comments on our paper. Our response to the critical part of the comments follow.

Responses to comments by A. Ebel

Comment 2.1: We agree to the referee, that in principle, the atmospheric response to some forcing can be studied much easier with numerical experiments than in the real atmosphere because a) model output can be produced according to the needs of the analysis, and b) experiments with and without forcing can be compared as it is done

in our study. However, with climate models we are never sure if an apparent signal is a real response to a forcing or just due to some model variability which may lead to arbitrarily different model behavior in the cases with and without forcing. This will be clarified in the revised paper. From a purely technical point of view, we agree that any difference between our simulations with and without 27-day forcing is due to this forcing. But we need statistical techniques like the coherence analysis provided in this paper to estimate if a physical relation between forcing and model response is likely.

We prefer not to show difference plots for Figs. 3 and 4 that present time series because the difference between the disturbed and reference runs would be the response to the forcing superimposed by a signal related to the model variability. We like that in the current version of the figures the interannual variability of the response becomes visible.

Taking into account what was said above, cross-spectral analysis also helps to verify whether or not the detected signal is related to the forcing. As noted by the Anonymous Referee 3, this can be also done with the help of time progressive correlation analysis or correlation analysis applied to different sequent short time series. Additional and more local in time information can give the cross-wavelet analysis. This will be clarified in the revised paper.

Comment 2.2 will be taken care of in the revised paper.

Information on the band width of the band pass filter will be given. Although the prescribed forcing is a harmonic function, the model atmosphere exhibits the response within a broader frequency range that includes the forcing frequency. Therefore, the spectral coherence can be calculated.

Concerning the comment on the direct and the correlation method, they may be equivalent in the case of spectral analysis based on Fourier transform (which is linear). However, high resolution spectral methods (e.g. auto-regression methods) have nonlinear responses to regular components (e.g. the response to harmonic noiseless signal

looks like resonance). This feature results in a significant decrease of the response bandwidth that is unobtainable by band pass filters.

Concerning comment 2.3 see the second part of our comment to 2.2.

We agree to the comment that deviations between model and observations are not a real proof that something is wrong with one or the other data set. See also the answer to the comments by Anonymous Referee 3. The necessary changes will be made in the text of the revised manuscript.

Comment 2.4: Unfortunately, one paper cannot hold all things. The study of the dynamical response requires extensive additional analysis and should be the subject of future work.

Thank you for the useful reference to Ebel and Schwister (1983). It will help to concretize the discussion of the dynamical response.

Comment 3: See our answer to the comments in 2.1 and 2.2.

Concerning the comment on the non-inclusion of dynamical parameters, see the answer to the comment 2.4.

The comment on comparison of statistical results obtained with real and modelled data as well as similar comments of the other two reviewers will be taken into account.

We appreciate also the more technical remarks and will take care of them in the revised paper.

Response to comments by the Anonymous Referee 3

Comment 1: As the diurnal cycle of ozone is still relatively small in the stratopause region, we do not expect significant dependence of the O3 response on local times at these altitudes. However, we completely agree to the referee that this influence may be very important above, say, the mid-mesosphere. Therefore, we will perform an additional analysis of the ozone response for different local times. This will also allow a

better comparison to satellite observations which are, in general, performed for specific local times (see below).

The text concerning the comparison of simulated and observed data will be revised. Application of exactly the same analytic technique as used in various observational works would overload Section 5.8 which is not the main section in the paper. However, for the aims of comparison, the response sensitivities and time lags will be calculated with the use of the 35-day rectangular filter as suggested by the referee.

Concerning the suggestion of the referee to concentrate on very few observational data sets in the comparison, we believe that other observations are also noteworthy, not only those which are in better agreement with each other. However, the response sensitivities and time lags will be recalculated for local noon conditions with the use of the 35-day rectangular filter, in order to allow a closer comparison with results of the papers suggested by the referee. We will also comment on the possible influence of different local observing times (see above) and other possible differences between observations.

Comment: 8220;Since the observational sensitivities are annually averaged and were obtained for normal solar forcing, only model sensitivities for the full year period and for normal forcing should be shown in the figures. 8230;8221;

We will show model sensitivities for the full year period in the revised version.

We will follow the suggestions in comment (2) and (3) in the revised version.

Comment (4): Unlike harmonic (Fourier decomposition) analysis, spectral analysis gives a continuous spectrum. The spectrum of the real forcing is continuous and variable in time (see Fig. 1a). The spectra of atmospheric parameters are also continuous (see Figs. 4, 5). We used an idealized harmonic forcing with one harmonic component of constant amplitude. However, if the forcing has additional components and if the atmosphere has a response to this components, then coherency between the response

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and the forcing at these frequencies may be anticipated.

Comment (5): There are two groups of strong 27-day variations of solar flux in Fig. 3 of Hood, 1986, with largest amplitudes in December 1979 and July 1980. Although the amplitudes of the solar flux variations in these groups are close, the amplitudes of the corresponding ozone variations differ approximately by a factor of 2. Furthermore, this Figure shows also significant ozone variations at a weaker forcing, see especially two negative and one positive ozone deviations in January 1979 and a positive deviation in July 1979. Therefore, this Figure does not show unambiguously the direct relation between the forcing and response amplitudes. Nevertheless, our model results show that the amplitude of the response is larger for stronger forcing, but the sensitivity (i.e. the response amplitude per solar variations with an amplitude of 1

Comment (6): We will add the aim to assess whether the HAMMONIA model produces ozone and temperature responses to solar rotational UV forcing that agree with observations.

Comment (7): Our results show that the model atmosphere response to 27-day solar forcing is complex even in the case of idealized forcing represented by one harmonic of constant amplitude. One of the ideas in designing the experiments was to reduce the degree of complexity to better understand the response. And we think it is one of the important messages of the paper that the atmospheric response to 27-day forcing may be very variable even if an forcing of constant amplitude is assumed. Future simulations will, however, make use of the actually observed forcing.

Concerning comments 8, 9, 10, and 11, see our responses to comments 1, 2, and 8.

Comment (12): The paragraph will be revised.

Comment (13): The reference will be given. The method will be described in more detail. The wavelet transform method does allow to derive the phase information. However, for the sake of simplicity, we used the module of the wavelet transform.

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Comment (14): This sentence will be revised.

Comment (15): The meaning of the cross-correlation function presented by Hood, 1987, is different from that of the running power spectra in Fig. 4. The cross-correlation function shows changes in the degree of correlative relation of ozone variations to variations of the solar flux and in the time lag of the ozone response at varying solar forcing, while the power spectra in Fig. 4 show that the 27-day signal in the atmosphere is intermittent despite of constant and continuous forcing (see also our answer to comment (7).

Comment (16): This will be done, see the answer to comment (2).

Comment (17): Separate figure will be constructed.

Comment (18): The response is statistically significant, see the capture to Fig. 12.

Concerning comment (19), see the answers to the comment (1).

Comment (20): This paragraph will be revised.

Comment (21): Figures 12 and 13 show that the typical scale of altitude changes of sensitivities and phases derived from both the observations and modeling is larger than the resolution of the SBUV observations. Therefore, the difference in vertical resolution should not affect significantly these characteristics of the response. Furthermore, we think that other results than those suggested by the reviewer in comment (1) are also noteworthy. As answered above, the exact comparison between the responses derived from modeling and various measurements is difficult (and is not the main goal of the paper) since each observational work uses different data and methods of analysis and, in particular, since periods of different amplitudes and spectral composition of the solar forcing were analyzed. Nevertheless, the agreement between the model and observed ozone responses in the stratosphere and lower mesosphere seems satisfactory to us. This agreement has also been emphasized by Adolf Ebel in his comment 2.3. In the revised paper, we will use the rectangular filter as was used in the majority of papers,

in order to allow a closer comparison with observations (see above).

Comment (22): Our statement should not be considered without the next sentences which say: 8220;The analysis of observational data should include not only periods with a significant amplitude of the 27-day solar variation, but also periods when this forcing is absent or relatively weak. This would provide information about the inherent variability of the atmosphere and thereby help to identify which part of the variability is related to the solar forcing.8221; The inherent variability of the atmosphere at 27-day period (in the absence of 27-day solar forcing) was not yet studied. Analysis of the 27-day variations based on observations was made for periods of pronounced 27-day variations in solar fluxes.

Comment (23): Yes, it is a mistake. We confused the sensitivities for Lyman alpha and 205 nm. This mistake will be fixed.

Response to comments by the Anonymous Referee 4

Major issues

Comment 1: We didn't apply a "sinusoidal solar forcing with the same properties for all considered wavelengths" as stated by the referee but we applied wavelength dependent amplitudes. Maybe, the referee means that we should have included possible phase differences. It is true that the phase of the short-term variability of the solar spectrum may depend strongly on the wavelength. However, at wavelengths below about 300 nm phase differences are observed to be small. And the effects that we are studying are mostly related to the variability of UV forcing this should not be important in our case. Probably, the referee also means that the real solar forcing is not purely sinusoidal (includes higher harmonics). The spectral technique can be also applied in the case of more complicated forcing. The requirements are the same: the response at the same frequency should be coherent with forcing. If the forcing has significant higher harmonics, the responses at corresponding frequencies, if existing, is expected to be coherent with these harmonics as well. Furthermore, it is reasonably to expect

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in this case the same or close time lags of the responses at different frequencies. A comment on this issue will be added to the text of the paper.

Comment 2: Figures 12 and 13 will be reconstructed.

Comment 3: We are not completely sure to understand correctly all details of the referee8217;s comment. Concerning differences in the response to 11-year and 27-day solar forcing, this may be related to at least two issues: a) The temperature response does not only depend on the radiative forcing but may be influenced by changes in the dynamics (in particular in upwelling as mentioned by the referee which is influenced in the time-slice experiments whereas we didn8217;t analyze a significant response to the 27-day forcing, see also answers to A. Ebel); b) The relaxation time towards the equilibrium temperature (as also mentioned by the referee) which depends on altitude (Mlynczak et al., JGR, 1999). We will comment on the differences and on these two influence factors in the revised version. Consideration of a response with more complicated spectral properties requires additional and special analysis. In model simulations, it is possible, in principle, to analyze such a response (see comments by Adolf Ebel and our answer), but its interpretation is often involuntarily speculative. Moreover, such an analysis is usually impossible or problematic in the case of real observations. We did analyze the perturbations in the solar heating rate, the heating rate produced by the short wave part of solar spectrum (120-680 nm) exhibits a 27-day variation with local maximum of its power spectrum in the stratopause layer. However the temperature variations have not been revealed in this layer which may be related to the relaxation time. We don8217;t agree that this would lead to an 8220;underestimation of the signal8221; but that indeed the signal would not (or only weakly) appear when short-term forcing is applied.

Minor issues

Minor issues 1, 2, 4, 5, 7, 8, 9, 10, and 11 will be taken care of.

Comment 3: These sentences reflect our conclusion from the numerous observational

and numerical studies cited in the following. This will be made clear in the revised version of the paper.

Comment 6: Molecular diffusion is considered to play an important role in the response of O3 at the mesopause to solar variability. Atomic oxygen produced by photolysis of O2 in the lower thermosphere may be mixed downward and increase the ozone mixing ratio around the mesopause. However, we can not assess the magnitude of this effect in our model as the necessary diagnostics are missing in the output. The influence of molecular heat conduction on the energy balance is presented by Schmidt et al., (J. Climate, 2006).

Comment 9: The coherence for OH is high. This will be noted in the text.

Comment 12: The correlation coefficient of about 0.5 is actually not large. It is intermediate between cases of no correlation and high correlation. It can speak in favor of the existence of the statistical relation between the two time series, but the strength of this relation is affected by ozone variations not related directly (in a statistical sense) to the forcing. These variations affect also the sensitivities. As said on page 1133, lines 27-28, and page 1134, lines 1-3, the difference between the spectral and regression sensitivity estimates is insignificant above 110-120 km.

Comment 13: The spectral analysis has not revealed any coherent response to the (fictitious) forcing in the no forcing case. This will be noted in the text.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 1113, 2008.

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