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Interactive Comment

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.

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1 Introductory remark

The paper describes and analyses an experiment of atmospheric forcing by the 27-d period of solar irradiance employing the complex three-dimensional chemistry-climate model HAMMONIA. Regarding solar variability it is assumed that only a 27-day oscillation exists with amplitudes derived from observations during the period 1990 - 2000 (Lean et al., 1997, 2000). The response of the model atmosphere is studied using temperature and the mixing ratios of ozone (O3), atomic oxygen (O3P), water vapour (H2O), hydroxyl (OH), nitric oxide (NO), nitrogen dioxide (NO2) and nitric acid (HNO3) as model outputs. Various statistical methods are applied to investigate the relation between the forcing and the resulting variations of the chosen parameters at levels from 0 to 120 km altitude between -90 and +90 degrees latitude. Daily and longitudinally averaged model data are employed.

The basic findings of the paper are an intriguing, ambitious and novel contribution to the study of the impact of solar variability on the atmosphere. They offer insights into the behaviour of minor reactive constituents in the presence of the 27-day solar irradiance variation rarely discussed in the existing literature except for ozone. The paper presents results about the response of the whole atmospheric system up to 120 km in a consistent way, which can only be obtained with a tool like HAMMONIA. These facts alone would make the paper recommendable for publication. Yet it also provokes questions and some criticism regarding the method of analysis which should be taken into account in its final version.

2 Questions and comments

2.1 Application of statistics to the identification of the response of the model atmosphere to solar 27-day forcing

It is said (Section 3, first paragraph) that "the purpose of the analysis is not only to detect a 27-day signal in the atmosphere and calculate its amplitude and phase characteristics, but also to prove that the detected atmospheric response is related to solar forcing". The means chosen to prove this are statistical methods, namely correlation and filter techniques in the time domain and spectral methods in the frequency domain. After calculating the correlation of the 27-day forcing with filtered ozone and temperature oscillations around the period of 27 days in the tropics it is concluded: “The results of the correlation analysis suggest that the simulated ozone and temperature signals in the middle and upper atmosphere are closely related to the 27-day solar

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forcing. However, they provide no proof." (Section 5.1, last paragraph)

These statements provoke the question about sense and purpose of the statistical analysis carried out in the paper. The conditions for a modelled atmosphere are fundamentally different from that for the real atmosphere. The model experiment described in the paper provides detailed information about input (27-day solar forcing) to the model atmosphere and its output which can be studied in full complexity, in principle. Cause and effect are definitely known. In the real atmosphere one has to work with hypotheses about the nature of the possible causes and their possible effects. As regards possible causes (forcing) they are usually parameterized by observable parameters like sun spot number, 10.7-cm solar flux or the flux at selected wave lengths, for instance 205 nm, which directly affect atmospheric composition. It is hypothesized that they somehow represent the overall solar impact. The real atmosphere may be regarded as a black box acting on the input signal, whereas the model atmosphere is a prescribed system and therefore not black. In the case of the real atmosphere correlation and coherency estimates provide significance values or probabilities that our speculation about a certain effect or process may be true to a certain degree. Yet in the case of the model experiment no significance estimates are needed, because any deviation of a simulation with forcing from a simulation without forcing (base run) is an effect caused by the forcing (if the calculations are carried out properly). The most straightforward way to meet the purpose of the paper, namely to show the "effect of the solar rotational irradiance variation" on the atmosphere, is the comparison of disturbed runs with the base run employing relevant atmospheric parameters with or without statistical treatment. Such comparisons are shown in most figures with particularly interesting results for a larger period range (5 - 50 days) of ozone mixing ratio oscillations (Figs. 3 and 4) indicating a broad band response of the model atmosphere. Any large or small deviation of disturbed runs from the basic one (which could better be shown by difference plots) is a real effect of the cause "27-day forcing" in the model. It does not matter by which (statistical or other) methods the deviations are identified, if they are properly applied. Furthermore, considerations about the likelihood of forcing-response relations

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needing to exceed a certain threshold and specific form of the phase spectrum (Section 3, last paragraph) are irrelevant in case of the model experiment. A change after imposing a forcing on the model is a change caused by the forcing of the numerical system, may the coherence estimate be significant or not.

In conclusion, the correlation and spectral methods are analysis tools in the context of the paper and not tools for verifying or discarding a hypothesis about solar forcing of a certain periodicity. Any statement about "shortcomings of the frequently applied correlation (regression) method" (abstract, third sentence; also Section 6, 2nd paragraph) is therefore not approvable, if it is based on deviating responses of the model obtained with correlation and coherence methods. The assumption behind this statement seems to be, that cross-spectral analysis of time series is the more accurate and reliable method. Furthermore, one should not discard the wavelet transform method (Section 5.2), since it offers an illuminating view of the model's broad band response different from correlation and coherence analysis (again: a difference plot would be helpful).

2.2 Correlation versus coherence

"A comparison of the spectral coherences in Fig. 7a and b with the correlation coefficients reveals that e. g. in the case of ozone at altitudes below 30 km non-zero correlations can be calculated in regions of incoherent signals." This statement at the end of Section 5.4 is apparently intended to show the inferiority of correlation calculations in the sense that it one cannot rely upon their results. And in Section 5, 2nd paragraph, where agreement between spectral and regression results is discussed, the spectral approach is defended by stating "We believe that this correspondence is fortuitous and does not point to a deficiency of the spectral estimates for the standard forcing." On the other hand, correlation estimates obtained with atmospheric observations are used to verify the coherence estimates derived from the simulations. For dealing with this discrepancy of judgement about both methods it may be helpful to address a few basic features of correlation and spectral analysis of time series.

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Correlation coefficients measure the strength of the linear relation between data sets. They tell nothing about the strength of a "response" of one data set (signal) to the other. For instance, ozone variations are reasonable well correlated with the 27-day forcing around 30 km (Fig. 2a), while the sensitivity in this height range appears to be very low (Fig. 8a,b). Yet this does not mean that the forced oscillation does not exist, it just shows that it is a relatively pure sinusoidal signal (correlation near 0.5) with rather small amplitude (very low sensitivity value). By the way, the actual sensitive period range may be shifted and lie outside the bandwidth of the spectral estimates. Information about bandwidth is missing all over the paper. Therefore no definite judgement is possible for the moment. In addition the bandwidth of the band pass filter applied to ozone and temperature (Fig. 2) should be specified.

Scanning two time series with a sequence of narrow band pass filters and estimating the correlation between the filtered time series should theoretically yield a picture equivalent to the one obtained with cross-spectral analysis. This again demonstrates that the elegance of the direct method does not mean that it is superior to the correlation method. The authors actually apply a mixture of spectral and time domain analysis when they calculate sensitivities. Namely for calculating amplitudes and phases they use Fourier harmonic analysis if a dominating oscillation is revealed by spectral analysis. A consistent convenient and supplementary way would have been the derivation of gain spectra (Jenkins and Watts, 1968).

2.3 Sensitivity and model evaluation

Sensitivity estimates are used to investigate differences between the methods of analysis and to evaluate the simulations by comparing results based on modelled and observed time series. The results obtained with modelled data provide no evidence which statistical method is better. They just show different facets of the behaviour of the system. Findings for the mesopause region indicate higher sensitivities of the model atmosphere in the case of low instead of strong forcing when the spectral method is applied, but not for the regression method (Section 5.7, Fig. 12). This is interpreted

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as an indication of non-linear response of the model atmosphere to 27-day irradiance forcing. Referring to the remark about the larger bandwidth of the regression estimates (Section 5.7, 3rd paragraph) this statement should be checked with the cross-spectrum of forcing and atmospheric parameters, since it might be just a slight shift of periods not cached by the applied spectral method.

Sensitivities and time lags derived from satellite measurements of ozone and temperature are employed for model evaluation. They are compared with simulated values in Figs. 12 and 13. Satisfactory agreement is found at many levels, particularly between 30 and 60 km altitude, for most of the available observations. This is a nice indication that the model realistically reproduces features of the real atmosphere which are relevant for its response to solar rotation forcing. Yet it is only a qualitative indication, and deviations between model and observations are not a real proof that something is wrong with one or the other data set. The reason is, that observational data have been assembled in a way completely different from that used for the model data. Meaningful evaluation can only be achieved if the collection of observational data is realistically reproduced in the model atmosphere.

2.4 Dynamical response

The authors mention several times that dynamics may play an important role for the response of the atmosphere to solar forcing. The issue is addressed more explicitly in Section 5.9. No explanation of possible dynamical effects is given. They are left as an open question. In this context it seems that it was a misguided decision to analyse only daily and zonal averages. Parameters related to atmospheric dynamics (e.g. planetary wave amplitudes, EOFs of various variables) are easy to derive and would have been a promising addition to the study of the highly probable dynamical impact on the solar forcing effects. Planetary wave analyses may also provide a better picture of the 27-day response of the lower atmosphere. Applying cross-spectral analysis to temperature and geopotential height with the 10.7-cm solar flux as forcing function Ebel and Schwister (1983) showed that there is evidence of a response of the plane-

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tary wave field to solar rotational forcing at various periods (13.6 to 27.5 days) at all levels from the lower troposphere up to the middle stratosphere. The coherent part of the waves shows amplitudes increasing with height from the middle troposphere to the middle stratosphere similar to the amplitude of a free external wave in an isothermal atmosphere (Madden 1979). It is speculated that planetary wave modulation may be an efficient process of spreading the solar signal in the atmosphere. The model experiment offers an appealing opportunity to find out how such modulations are reflected by trace gas distributions in general in the lower and middle atmosphere.

3 Conclusions

The simulations of the 27-day solar rotation forcing of the Earth's atmosphere carried out with the HAMMONIA model experiment undoubtedly deserve publication. Straightforward discussion of the differences of the model output with and without forcing is recommended in addition to statistical analysis. The philosophy of applying statistical analysis to the model experiment should be reconsidered. More information about spectral properties, in particular bandwidth, is needed. It is regrettable that the authors did not include dynamical parameters in their analysis, so that they can only offer (acceptable) speculations about the dynamical response of the model atmosphere despite the fact that they have all data available for a comprehensive analysis of this aspect of solar-terrestrial relationships. Comparison of statistical results obtained with real and modelled data should be carried out with caution.

References

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Madden, R. A.: Observations of large-scale travelling Rossby waves, Rev. Geophys. Space Phys. 17, 1935 - 1949, 1979

Corrections

Section 5.5: Sensitivity is a dimensionless parameter. Figures with time lag: Indicate which time series is leading if the lag is positive. Fig. 3: (c,d) as (a,b) … (not As)

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