Atmos. Chem. Phys. Discuss., 11, C9186–C9197, 2011
www.atmos-chem-phys-discuss.net/11/C9186/2011/

Atmospheric
Chemistry
and Physics
Discussions

Interactive comment on "Solar response in tropical stratospheric ozone: a 3-D chemical transport model study using ERA reanalyses" *by* S. Dhomse et al.

S. Dhomse et al.

s.dhomse@see.leeds.ac.uk

Received and published: 21 September 2011

Anonymous Referee #1

This manuscript reports both model simulations and observational data analyses of the 11-year solar cycle response in tropical stratospheric ozone. The model simulations consist of calculations using an offline 3D CTM (SLIMCAT) forced with observed meteorology for 1978-2005. The observational data analyses consist of both composite (solar max minus min) and multiple regression analyses of several selected ozone profile datasets as well as use of a merged column ozone data set for model comparisons.

It is concluded (p. 13) that “simulated total ozone from the CTM shows quantitative agreement with the observed total ozone” but that “sometimes large differences between satellite and modelled total ozone highlight that there are still some inhomogeneities in ERA-40 reanalyses ...”. It is further concluded (p. 14) that “the simulated solar response from all the model runs seems to be in reasonable agreement with solar response from SBUV and SAGE in the low-mid stratosphere” but that the largest observation-model differences are found “in the upper stratosphere, where both SBUV and SAGE data show a much larger solar response ...”. Finally, it is concluded (p. 15) that model run CFIX (which used constant, annually repeating meteorology for a single year rather than temporally varying meteorology) “is in excellent agreement with the estimated solar response from SBUV and SAGE data” and that “at lower altitudes this implies that dynamics plays only minor role through downward transport below 30 km to give a secondary solar response in the TLS (tropical lower stratosphere).”

General Comments:

Overall, this is a useful comparison of model simulations with ozone observations for the purpose of better understanding the stratospheric ozone response to solar forcing on the solar cycle time scale. Among the most interesting results are (a) the lack of good agreement between the model simulations and the observational results in the upper stratosphere; and (b) the apparent ability of the model to simulate a second response maximum in the lower stratosphere, even for the case (CFIX) in which the meteorological fields did not change during the simulation. The TLS response for the latter case is attributed to “downward mixing of ozone-richer air (chemical solar response) to below 30 km, where the ozone photochemical lifetime increases rapidly from a few months to a few years” (p. 14, lines 18-20). This would imply that solar-induced dynamical transport is not important for producing the TLS ozone response. However, empirical evidence described below seems to contradict the latter implication. Also, if the stratospheric aerosol loading history was included in the CFIX simulation, there is a concern that much of the apparent TLS response in this simulation could be due to

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

an unrealistically large model aerosol chemical sensitivity rather than to solar forcing.

We thank the reviewer for his/her thorough and useful review which helped us to improve the manuscript. We have considered all the comments and the manuscript is modified accordingly.

These and other criticisms are detailed further below. A significant revision is needed before publication can be recommended.

Specific Comments:

1.There is fairly good empirical evidence that dynamical processes are important for producing the observed lower stratospheric ozone response to 11-year solar forcing. For example, Steinbrecht et al. (ACP, 2003) found that solar cycle response patterns for column ozone were very similar to those for 50 hPa temperature and had similar seasonal dependences, as was also the case for QBO and ENSO responses. At higher latitudes, response patterns tend to be zonally asymmetrical, again implying a role for dynamical processes. The observed ozone response in the lower stratosphere is significantly stronger during the east phase of the QBO than during the west phase (Labitzke, JASTP, 2004), again implying that dynamical processes are involved in producing the lower stratospheric response. The authors' final conclusion (p. 15) about dynamics playing only a minor role in producing the TLS response may therefore not be valid in this reviewer's opinion. It is certainly true that, in the model, dynamics plays only a minor role in producing the TLS response for run CFIX. However, there is a concern (see comment 2 below) that this apparent TLS response for run CFIX could be due to an unrealistically strong response of model chemistry to stratospheric aerosol loading following the Pinatubo eruption rather than to solar forcing.

Requested author revisions: Please add a paragraph with appropriate references to the Introduction summarizing empirical evidence given above that solar cycle changes in dynamical transport (e.g., tropical upwelling) contribute strongly to the solar cycle variation of ozone at low latitudes. Also, please revise the final paragraph of the paper

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

(now on p. 15) to state the possibility that the apparent TLS response for run CFIX may actually be due to aliasing from an unrealistically strong model ozone response to post-Pinatubo aerosol loading.

We agree with the reviewer about the solar-temperature-ozone relationship in mid-high latitudes and we suggest that much larger solar response in Runs A_E40 and B_EI may be partly due to component of this relationship in ERA-40 and ERA-Interim datasets. Appropriate discussion and references are added (e.g Steinbrecht et al, 2003, Labitzke and van Loon, 1987, Labitzke, 2004). In a revised version, we have included analysis of one additional run D_AFIX with constant dynamics and aerosols (time varying solar fluxes). This new run still shows up to 1% ozone change in the tropical lower stratosphere. We have added the discussion about the difference between runs C_FIX and D_AFIX concluding that the aliasing effects of the ozone loss after the volcanic eruption amplifies the solar response in the tropical lower stratosphere.

2. The conclusion that “simulated total ozone from the CTM shows quantitative agreement with the observed total ozone from TOMS/SBUV” is not consistent with what is shown in Figure 1. In addition to large model-observation differences during the late 1980’s and first few years of 1990’s that could be attributable to problems in the ERA-40 reanalysis data, there is a pronounced model decrease in 1992-93 using both reanalysis data sets that disagrees with the observed column ozone time series and apparently reflects an unrealistically strong model response to Pinatubo aerosol loading. This discrepancy is noted and attributed to a “model overestimate” on p. 7 (lines 14-16) and also on p. 14, lines 11-13. It seems likely that this anomalous model response contributes strongly to the modeled TLS “solar” response shown in Figures 5 and 6, if high aerosol loading years were not excluded from the analysis. The fact that the A and B runs show a stronger TLS response than the C run could be due to solar-induced dynamical transport forcing, which should be accounted for if the model is forced with observed meteorology (ERA-40 and ERA-Interim). The authors note this possibility also on p. 14, lines 14-16.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

Requested author revisions: Please change “quantitative agreement” to something like “approximate qualitative agreement” to be consistent with what is shown in Figure 1. Please add a conclusion to section 5 to the effect that anomalous model response to stratospheric aerosol loading is (or at least could be) an important cause (in addition to inhomogeneities in ERA-40 reanalyses) of the sometimes large differences between satellite and modelled total ozone shown in Figure 1. Also, please indicate whether this inferred anomalous model response is limited to the SLIMCAT model or whether it may occur in other CTMs as well. Revise the abstract accordingly.

We agree with the reviewer. We have highlighted these differences and also expanded the discussion about the aerosol effects with respect to satellite data. We have included detailed discussion about the differences in runs A_E40, B_EI, C_FIX and D_AFIX (constant aerosols and fixed dynamics). We also note that other CTM studies using ERA-40 data such as Sekiyama et. al do not discuss the aerosol effect in their simulations, whereas Flemming et. al., 2007 show less ozone loss that TOMS/SBUV data.

3. Why does Figure 1 not also include a curve showing the tropical total ozone results from run C? Since Run C did not include time-varying meteorology, it would seem that showing these results would be useful for distinguishing problems in the model simulations due to the meteorological analyses and due to the CTM itself. Requested author revision: Please add a curve for Run C to Figure 1 and discuss any deductions that may arise from this addition. To reduce the complexity of the figure caused by adding yet another model curve, I suggest removing the F10.7 curve and plotting it separately in black below the ozone curves in a (b) part of the figure.

We have modified the Figure 1 which includes ozone anomalies from all the four-runs. The curve for F10.7 solar flux is plotted separately.

4. P. 4, first full paragraph. The best observational estimates for the stratospheric ozone response to the solar cycle have been obtained using longer-term datasets such

as SBUV and SAGE, which have lengths up to 25 years (Soukharev and Hood, 2006; Randel and Wu, 2007; Tourpali et al. 2007). These analyses consistently show a positive response in the upper stratosphere, a small or negligible response in the tropical middle stratosphere (about 10 hPa), and a second significant response in the lower stratosphere (e.g., Figure 10 of Gray et al., 2010). In support of these results for ozone, similar analyses of long-term stratospheric temperature records (e.g., Frame and Gray, 2010; Gray et al., J. Atmos. Sci., 2009) also show an upper stratospheric solar cycle response, a lower stratospheric response, and a statistically insignificant response in the middle stratosphere. Results for the stratospheric ozone solar cycle variation reported by Fadnavis and Beig (2010) using the UARS HALOE data over the 1992-2004 period are uncertain because of the analytic techniques that were employed combined with limitations of the HALOE measurement technique. Specifically, they considered two latitude bands (0-30N and 0-30S) and analyzed sunset and sunrise events separately before averaging the results together to get a single regression coefficient for each band. Because of the very limited temporal and spatial sampling of this solar occultation instrument and the limited data record (< 13 years), the results for the two bands were quite different from one another: For 0-30N, a strong peak response of about 5% was obtained at 30 km altitude while for 0-30S, the response at 30 km was only about 1% and a maximum response of about 3% was obtained near 38-40 km.

These differences imply large uncertainties in their results. The analysis of HALOE data by Remsberg (2008) was much more comprehensive and attempted to account for the limited spatial and temporal sampling. According to his Figure 9a, the 11-year ozone response is similar to that derived from SBUV and SAGE data: There is an upper stratospheric response of 2.5-3.0%, a lower stratospheric response of 3 to 6% and a statistically insignificant response in the tropical middle stratosphere (15S to 15N, 10 to 20 hPa). However, his analysis also yields a significant response at latitudes higher than 15 degrees at 10 to 20 hPa. Consequently, the response averaged over 25S to 25N is positive at about 2% at 10 hPa (see his Figure 12). However, analyses f longer ozone records, including SAGE II, yields a negligible ozone response in the

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

middle stratosphere over a wider latitude range (20S to 30N; see Figure 10 of Gray et al., 2010). The bottom line of this comment is that our best estimates for the solar cycle response of stratospheric ozone come from the longer-term SBUV and SAGE records and are supported by analyses of long-term stratospheric temperature records. Analyses of the shorter HALOE record by Remsberg (2008) and Soukharev and Hood (2006) are generally consistent with the SBUV and SAGE results when the shorter time record is considered. In particular, the distinct response minimum in the tropical middle stratosphere near 10 hPa is almost certainly real because it is seen in all three satellite datasets: SBUV, SAGE, and HALOE (Soukharev and Hood, 2006; Remsberg, 2008, his Figure 9a). This is therefore a firm constraint on model simulations.

Requested author revision: Please revise this paragraph to summarize the above discussion and state that the balance of the observational evidence at this time favors an upper stratospheric response, a lower stratospheric response, and a statistically insignificant response in the tropical middle stratosphere. It may also be mentioned that there is a statistically significant response in the middle stratosphere but only outside of the tropics.

We removed the discussion about analysis by Fadnvis and Beig (2010). We also had a discussion with Dr E. E. Remsberg about the legends in his Figure 12. Apparently the legend in Figure 12 of Remsberg (2008) is slightly confusing. HALOE results shown in Figure 12 are not an average from 25S to 25N. In fact, that average is based only on the 20-degree wide latitude bins of 15S, 5S, 5N, and 15N, where each bin overlaps the adjacent one by 10 degrees. Because the width of the bin at, say, 15N extends from 5N to 25N, that is why the range of 25S to 25N was given for the average in Figure 12. However, we note that analysis of the shorter HALOE record by Remsberg (2008) and Soukharev and Hood (2006) are not consistent with the SBUV and SAGE (see Remsberg and Lingenfelser , 2010).

5. P. 5, lines 1-4. The general approach adopted in this work is to use an off-line 3D CTM forced using observed (analyzed) winds to specify the transport. Observed

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

aerosol data (SPARC 2006) are also used to specify the aerosol forcing. In effect, the chemistry model is being forced with observations. While computationally inexpensive, the comparison of model to observations is not really "clean" because the model also incorporates observations, which may themselves have a solar cycle component. In particular, if dynamical transport is actually the main driver of the TLS solar cycle response, as argued in Comment 1 above, then using observed winds sidesteps the fundamental issue of how solar forcing induces changes in dynamical transport, e.g., tropical upwelling.

Requested author revision: Please note these caveats in the Introduction.

We have modified the introduction accordingly.

6. Section 3 and P. 5, lines 12-16. It is stated that "two height-resolved satellite data sets" are analyzed to obtain the observed 11-year ozone response. These are referred to as "SBUV" and "SAGE" throughout most of the paper and in the figure labels. However, it would be much more accurate to say that these are "two height-resolved ozone profile data sets based on satellite measurements." The "SBUV" data set of McLinden et al. (2009) is a monthly zonal mean data set based on both SAGE and SBUV data over the 1979-2005 period. It is not independent of SAGE measurements because SAGE measurements largely determine interannual variability in the data set. So it is inappropriate in this reviewer's opinion to refer to it as an SBUV data set. It appears to be a valuable alternate data set and it is fine to use it in the present study but one must be careful in describing it. The "SAGE" data set of Randel and Wu (2007) can be described best as a time-dependent zonal mean ozone profile climatology because it is derived by combining the seasonal ozone climatology of Fortuin and Kelder (1998) with interannual variations derived from a multiple regression statistical analysis of SAGE I and II data and polar ozonesonde data. It is not actually "data" in the true sense of the word.

Requested author revisions: Please use "ozone profile data sets" in place of "satellite

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

ozone data sets" when referring to both data sets. Please point out that these two data sets are not independent of one another and are not the original satellite ozone measurements. Rather than referring to the McLinden et al. data set as "SBUV", it would be better to refer to it as "SAGE/SBUV" since interannual variability is mainly controlled by the SAGE data. Rather than referring to the Randel and Wu data set as "SAGE", it would be better to refer to it as "SAGE-based" since it does not include all information that was in the original SAGE data and it is based on a statistical analysis of the SAGE data and ozonesonde data as well as a seasonal ozone climatology

We agree with the reviewer. We have replaced SBUV with SBUV/SAGE and SAGE with SAGE-based. Appropriate references are included.

7. P. 6, lines 10-15. Please briefly explain the differences between the ERA-40 reanalysis, ECMWF operational analysis, and ERA-Interim dynamical fields with appropriate references.

In the revised manuscript, we included a paragraph about the differences between ERA-40 and ERA-Interim as well as corresponding references (Uppala et al, 2005 and Dee et al., 2011)

8. P. 7, line 11. Please explain "F10.7 solar fluxes". For example, you could say "Normalized 10.7 cm solar radio fluxes (hereafter F10.7), which are a good proxy for month-to-month and interannual solar UV variations, used in ...

Done

9. P. 7, lines 14-16. Here it is stated that the ozone loss after the Mt. Pinatubo eruption during 1992-1994 is being overestimated by the model. There is no discussion of why this is happening in SLIMCAT and whether it may also happen in other CTMs. Requested author revision: Please add some discussion of this. Also, please note elsewhere in the paper (e.g., the abstract) that some of the disagreement between observed tropical total ozone time series and the model simulations is due to this model

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

problem. (This comment may be redundant with Comment 2 above but it is worth emphasizing.)

See the reply to comment 2.

10. P. 8, lines 20-21. “In the upper stratosphere, ozone has a short photochemical lifetime and is strongly anti-correlated with temperature.” First, please replace “anti-correlation” with “inversely correlated” since anti-correlation suggests no correlation for at least some readers. More importantly, please add a brief explanation for this temperature dependence, e.g., “due to the strong temperature dependence of reactions that control the ozone balance.”

##We modified the sentence and added the Reference to Fig.2 from Dikty et al, 2010 (See reply to Reviewer 2).

11. Captions to Figures 4, 5, and 6. Please note the latitude range (25S to 25N) that is considered.

All the captions have been modified.

12. Figure 5. Again, please change the labels on the figures from “SBUV” to “SAGE/SBUV” and from “SAGE” to “SAGE-derived” with references to McLinden et al. and Randel and Wu, respectively on the figures. Please add (a), (b), (c), and (d) labels. Also, the A and B ozone model curves in the (a) part of the figure are different from those in the (b) and (c) parts of the figure. Why? Also, there are no error bars on the observationally estimated solar response curves. Can you add some error bars if known?

The labels are added. Ozone composites shown in panels (a) and (b) were in volume mixing ratio and Dobson Units, respectively. In revised version, all the composites shown in panels (a), (b) and (c) from all the model runs (A_E40, B_EI, C_FIX and D_AFIX) are in vmr. We have replaced SBUV and SAGE with SBUV/SAGE and SAGE-based. The references are added in the caption. We can not determine error

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

bars for composite analysis.

13. P. 12, lines 14-16. "... the exact cause of differences in estimated solar response from SBUV (Soukharev and Hood, 2006) and SAGE (Randel and Wu, 2007), with this present study is not clear." One other possible explanation for the differences is that these authors used the original SBUV and SAGE measurements rather than the derived data sets used in the present study. Please note this.

A discussion about these differences is included in the revised manuscript.

14. P. 13, lines 14-15. Which earlier studies are you referring to? Please add some references.

We have modified the sentence as "The results from .... ". We do not include any references for it.

15. P. 14, lines 18-20. "downward mixing". Presumably, this means effectively a diffusion of the increased ozone in the middle stratosphere downward rather than a change in mean upwelling rates. Please add a sentence making this clear.

This is combinations of diffusion, enhanced chlorine activation after the eruption and is discussed in the revised manuscript.

16. Figure 2. The colors for Run B and HALOE are nearly the same and are difficult to distinguish. Can you use a different color (e.g., green) for one of these?

We have changed the line color slightly. HALOE is shown in blue and green is used for RUN C.

Minor Comment:

There is a tendency to use the words "note" and "noted" too much in the description, e.g., "we note that ..." and "they noted ...". Please revise to minimize use of these phrases.

Appropriate changes have been done.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 13975, 2011.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper