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12, C9795–C9806, 2012

Interactive Comment

Interactive comment on "Assessment of the interannual variability and impact of the QBO and upwelling on tracer-tracer distributions of N_2O and O_3 in the tropical lower stratosphere" *by* F. Khosrawi et al.

F. Khosrawi et al.

farah@misu.su.se

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We thank reviewer 2 for the constructive, helpful criticism. We followed the suggestions of reviewer 2 and revised the manuscript based on the comments made.

Overall comment:

There are several awkwardly constructed sentences in this manuscript. (there are too many for me to detail each one.) It needs editing by one of the native English speakers who are listed as authors. Here is an example of just one instance: Intro, second sentence starting on line 25. .

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

.missing a subject? This needs to be rewritten.
We have once again carefully checked the paper for awkwardly constructed sentences and made improvements throughout the paper.

Specific questions:
Page 22634 states "The atmospheric tape recorder is caused by the imprint of the tropopause temperature on trace gases as e.g. H2O, CO and HCN and their transport into the stratosphere with the upwelling branch of the Brewer-Dobson circulation." This is incorrect. Only the water seasonality is due to an imprint of tropopause temperatures, the others have to do with seasonality in tropospheric sources. A reference could be included here. I believe there is a paper by Schoeberl et al. that discusses this (in either GRL or JGR)
We agree and corrected this text part. It reads now: *The atmospheric tape recorder signature was first discussed using satellite-borne H_2O measurements in Mote et al., 1996 and is caused by the imprint of the tropopause temperature on H_2O and it's transport into the stratosphere within the upwelling branch of the Brewer-Dobson circulation. A tape recorder signature has also been found in other trace gases like CO, CO_2 and HCN is caused by the seasonal variability of tropospheric source gases (e.g. Schoeberl et al. (2006), Pommrich et al. (2010), Andrews et al. (1999)).*

Page 22635: How well do the satellite O_3/N_2O relationships agree with those derived from aircraft measurements at the levels of interest? Also, do uncertainties in temperature measurements from the satellite measurements play a role? Also, it appears that you are deeming Odin/SMR to be the most reliable or accurate measurement. Can you show that is the case? (Via a discussion of the validation exercises for each instrument considered.) If you are going to be combining different data sets, have you show there are not discrepancies between different O_3 and N_2O data sets considered?
We havn't done a comparison of the satellite derived N_2O/O_3 relationship from Odin/SMR yet. We agree that such a comparison would be quite interesting. However, to do such a comparison is beyond the scope of this study and has to be kept for future

ACPD
12, C9795–C9806, 2012

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

studies. This study already contains several data sets. Further, the paper is already quite long and complex. Uncertainties of temperature measurements of the satellite instruments play a role, but this is of minor importance for our study since all satellite data sets used in this study have thoroughly been validated. The discrepancies we see in our study agree with the discrepancies found in the validation studies. Further, we are not deeming Odin/SMR as the most reliable or accurate instrument. We solely use Odin/SMR as reference since this is the instrument we also used for the model evaluation described in Khosrawi et al. (2009). Since this is a follow-up study to our previous study it's only natural to use Odin/SMR also in this study as reference. To make this clear we changed the text on page 22635, line 22 as follows: *Here, monthly averages of N_2O and O_3 from different satellite data sets are derived and compared using Odin/SMR as a reference. Odin/SMR has been used as reference to facilitate with the results derived in Khosrawi et al. (2009).* The uncertainties of the Odin/SMR data sets as well as the uncertainties of the other satellite data sets are discussed in the paper (chapter 2 and section 5.3).

Page 22646 states and vertical velocities are overestimated by models in the lower tropical stratosphere (Ploeger et al., 2010); Is this really true for all models?
Atmospheric models have difficulties in correctly deriving vertical velocities in the tropical lower stratosphere. These do not need to be necessarily overestimated by the models. Vertical velocities in models can be both underestimated or overestimated as has e.g. shown recently by Schoeberl et al. (2012). We changed the sentence as follows to point this out: *On the other hand, transport processes in the tropical lower stratosphere are difficult to represent in models (e.g. Hegglin and Shepherd, 2007). This is due to the difficulties in deriving the vertical velocities in the tropical upper troposphere and lower stratosphere. Ploeger et al. (2010) and Schoeberl et al. (2012) have shown that vertical velocities in models can be both overestimated or underestimated resulting thus in faster or slower tropical upwelling compared to measurements. The model vs Odin/SMR differences could thus also be partly due to model deficiencies (Khosrawi et al., 2009).*

ACPD
12, C9795–C9806, 2012

Interactive Comment

Page 22646 also states "Though a satisfactory agreement between models and observations was found at 650 $\pm$ 25 K (differences generally within $\pm$20%) unusually (unrealistically high N_2O mixing ratios ($N_2O > 320$ ppbv) were found in the Odin/SMR data that were not found in the model simulations." Aren't those values unrealistically high not just relative to model simulations, but based on surface measurements? Should they not be thrown out before the analysis is even started?

We agree that these values are not only unrealistically high compared to model simulations but also to ground-based observations (and certainly also to aircraft and balloon observations). One could of course throw out these values. However, for our study showing that though the absolute values are unrealistic the inter-annual variability is caused by the QBO, we had to keep these values in the data set. The best alternative for future studies would be not to simply throw out these values but rather to derive a noise/bias correction for each satellite instrument. This is something we cannot do in the frame of this study. Note: In case of Odin/SMR the high N_2O values are cause by noise and a correction is not that easily done. This has to be considered in the retrieval routine and quality test of the specific data sets. For most of the instruments, however, the bias is not dependent on season, it is just a constant offset in a certain altitude range. Therefore, in our analysis, the position of the data points is shifted to the right, but neither the shape or the altitude/latitude/seasonal dependence of the correlation is affected. This allows us to perform the analysis as if the bias was not present.

Figures 3-6. . .it would be useful to be able to compare the o3/n2o relation for all instruments considered on the same plot. . .it looks like instrument differences are significantly larger than inter-annual differences.

We agree that instrumental differences are larger than the inter-annual variability of the monthly N_2O/O_3 averages derived from a specific instrument. A comparison as suggested by Reviewer 2 has already been done in the frame of this study. A com-

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

parison of all instruments considered in this study is provided in Figure 11-13 for the years 2003, 2006 and 2009 and the according differences found by this comparison are discussed in detail in section 5.3. The comparison showed that the data sets are generally in good agreement but that also known biases and uncertainties due to instrument noise of the satellite data sets are clearly visible in the monthly averages.

Page 22647: discussion of QBO. . .Given the variation between instruments, I have a hard time being convinced that you are actually seeing a QBO signal in the small variations at the ends of the n2o/o3 curves.

Uncertainties in satellite measurements cause biases in the absolute values of a species mixing ratio. In Odin/SMR these high values are not caused by a bias, but due to the instrument noise (see section 4.2. However, these uncertainties in satellite measurements do not cause a seasonal or an inter-annual variation. Thus, we can be sure that the inter-annual variability we see in the monthly averages of N_2O and O_3 and discussed in this study (section 5.2) are caused by a physical process as the QBO.

Page 22648: how do a greater number of observations lead to a lower standard deviation? (discussion of MLS data). Is the issue here really that Odin/SMR has a much lower precision than MLS? And how does coarser spatial resolution lead to lower inter-annual variability? I'd be more convinced if you could demonstrate this with synthetic data compared using different sampling and vertical weighting.

It is correct that a higher number of observations itself does not necessarily lead to a smaller standard deviation. However, a high number of measurements smooths out gradients in the measurements of trace gas distributions. Further, the high vertical resolution of Odin/SMR is accompanied with a higher noise of the Odin/SMR data compared to other data sets. These differences in sampling and vertical resolution do influence the standard deviation of the monthly averages but not the monthly averages itself. To be sure about the impact of the vertical resolution of the different data sets on our results we have performed several test that are also described in the paper (e.g.

p22653, l11ff and p22659, l16ff).

Page 22649 states "In the SD-WACCM simulation the QBO is realistically represented and arises solely from the nudging of the WACCM dynamics with GEOS5 meteorological fields. As in our recent model evaluation study the curves of monthly averages of N_2O and O_3 derived from SD-WACCM are at 500±25 K steeper (but not as steep as E5M1 and KASIMA) than the ones derived from the satellite data which can most likely be attributed to a stronger tropical upwelling in the model simulation than observed." Could you at least overplot the MLS curves on the WACCM (figure 6) curves? It looks like MLS has the 500 K relationship as steep as the model, whereas ODIN/SMR and MIPAS are not. I'm also having a hard time seeing that the curves extend to much lower N_2O values. . .picking one month and overplotting the model and satellite derived curves however may help in that demonstration. It may very well be that the real amount of in mixing is not well represented in the model; however, I find it hard to see that in the plots and discussion given here.

An overplot of the SD-WACCM curves with MLS (plus additionally Odin/SMR and MIPAS) are given in Fig 12 for every second month in 2006 and in Fig 13 for every second month in 2009. There it is shown what we already discussed on page 22649. The differences between WACCM and the satellite observations are not as large as the ones we derived when comparing KASIMA and E5M1 with Odin/SMR. Further, as stated on page 22649 the curves derived from WACCM are similar to the ones derived from e.g. MLS but still somewhat steeper which indicates an overestimation of upwelling as discussed in this study. To point out that this will be further discussed later in the paper we added a reference to section 5.3.

Page 22650 states "In the tropics, monthly averages of N2O values at 650±25 K were much higher derived from Odin/SMR observations (reaching up to 330 ppbv) than simulated by KASIMA and E5M1. These values are even higher than the highly accurate ground-based observations of N_2O (319 ppbv in 2005) derived in the troposphere (Forster et al., 2007). In the Odin/SMR data these high N2O mixing ratios occur solely in the tropics and with a seasonal

ACPD

12, C9795–C9806, 2012

Interactive Comment

cycle." Isn't this telling you there is a problem with the Odin/SMR measurements?
This is partly true. These high N_2O values and their occurrence with a seasonal and inter-annual variability are most pronounced in the Odin/SMR data. However, as we have shown in this study this is not a problem which concerns Odin/SMR alone but also all other satellite instruments. Though our study shows that the vertical resolution itself is not responsible it seems that a process related to the vertical resolution of the satellite instruments is responsible that these high values are most pronounced in the satellite instruments with a high vertical resolution like Odin/SMR which provide typically data with a larger noise error (precision) and consequently a wider statistical distribution of the single observation. Further, instrument biases do not tend to occur with a seasonal or inter-annual variation. Thus, the occurrence of higher values during certain seasons and years must be connected to a physical process as the QBO.

Figure 8: Do you really mean equivalent latitudes from 10N-10S? How do they differ from geographic latitudes and how were you able to calculate equivalent latitude for the tropics?
We are grateful for pointing this out. We accidentally wrote equivalent latitude though we meant latitude.

Page 22651: states "Further, the N2O fields for the stratosphere (Fig. 8 third panel) show that due to a stronger upwelling N_2O was transported higher up in 2002, 2004, 2006, 2008 and 2010 which is in agreement . . . . " This paper could use a simple description of how the secondary circulation varies according to phase of the QBO. . .to better explain why you are expecting a variation in upwelling. What might even be more useful is to see if you can determine what the QBO easterly vs westerly upwelling difference might be based on the N_2O measurements, and if it's consistent with theory.
We agree and added the following sentence at the end of the paragraph on p22650, l24: *Further, the QBO easterly (westerly) shear phase coincides with enhanced (reduced) upwelling (Punge et al., 2009)).*

ACPD
12, C9795–C9806, 2012

Interactive Comment

Page 22651 states "The fact that lower N_2O averages than Odin/SMR (330 ppbv) are found in the Aura/MLS observation is likely caused due to the coarser vertical resolution of Aura/MLS as can be seen from Fig. 9." Is that really the case, or is there a problem with Odin/SMR. As I noted previously, you can actually test this by using synthetic data at applying the appropriate averaging kernels. In regards to measurements in the stratosphere greater than 330 ppbv....are these even remotely realistic? I just looked at the NOAA GMD surface measurements (see http://www.esrl.noaa.gov/gmd/dv/hats/cats/cats_conc.html) and nothing is this high over the time period in question. If the tropospheric average is only 319 ppbv (as stated on page 22652) I question the value of discussing these high biased measurements in detail. It appears that these values are a result of a high bias, which therefore brings some of the analysis discussed in this paper in question.

We tried to make our point clear on several places throughout the paper and hope that we accomplished that now in the frame of the revisions. The high absolute N_2O values we are discussing are definitely incorrect. However, the signature in the inter-annual variability of N_2O values with higher or lower mixing ratios depended on which month is considered is definitely caused by a physical process as the QBO as can be seen from Fig. 8 for Odin/SMR or from same figures derived for other satellite instruments or e.g. models as WACCM (as well as in Fig 7 and the tables provided in the electronic supplement). Further, the fact that MLS has a low bias compared to other satellite instruments has been shown in several validation studies. The too high N_2O values found in Odin/SMR are smeared out in MLS due to the coarse vertical resolution as can be seen in the PDFs shown in Figure 9.

Page 22654: states "The QBO in SD-WACCM is realistically simulated and in good agreement with the QBO derived from Odin/SMR (not shown)." How is the QBO derived from Odin/SMR? Do you just mean the pattern in N2O, or some derived upwelling estimates?

Indeed, we refer here to the QBO signal as seen in the N_2O anomalies as shown for Odin/SMR in Figure 8. We changed the sentence on p22654, line 22 as follows to make this clear: *The QBO in SD-WACCM is realistically simulated and the QBO signature found in the N_2O anomalies is in good agreement (not shown) with the ones derived from Odin/SMR (Fig. 8).*

Page 22657: states "We found that the inter-annual variability is low and can easily be distinguished from model deficiencies." However, the inter-instrument variability does not appear to be low. Can it easily be distinguished from model deficiencies?

Yes, it definitely can though we agree that instrumental differences can not be neglected. That model deficiencies become distinguishable from instrumental differences e.g can be seen when comparing Figure 2 with Figure 11 to 13. Though Odin/SMR has too high N_2O due to instrument noise the much steeper correlation of the model data sets due to an overestimation of upwelling is clearly distinguishable from the uncertainties in O_3 and N_2O by Odin/SMR. As shown in Figure 11 to 13 the satellite instruments agree generally quite well with each other though there are slight differences in the absolute values between the instruments due to individual biases/instrument noise. However, these biases/instrument noises are in the order of approximately 20 ppbv) and thus, as discussed above, clearly distinguishable from model deficiencies. Of course, the uncertainties of a specific satellite data set must be taken into account when doing a model evaluation or satellite intercomparison. We added the following sentence to point this out, however somewhat later in the text, namely on p22658, line 22: *Thus, the results of model evaluation or satellite data intercomparison can be to some part be influenced by uncertainties in the satellite data used as reference for such a study and must be taken into account.*

Page 22658: states "We attribute the steeper correlation in the model simulations to a incorrect simulation of tropical upwelling which is due to a missing or incorrect simulation of the QBO." You should describe in detail what manner of incorrect tropical upwelling would change the O_3/N_2O correlations on a potential temperature surface, and in what manner. That has not been done clearly in this paper.

ACPD

12, C9795–C9806, 2012

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

If upwelling is stronger then high N_2O and low O_3 is brought up from the troposphere to the stratosphere and to higher altitudes as when upwelling is weak. This leads to a shift of the N_2O/O_3 correlation from slightly negatively correlated (increasing N_2O with decreasing O_3) to a strongly negatively correlated curve. Thus, in case of an overestimation of upwelling in a model simulation or strong upwelling in the atmosphere the correlation is steeper and in case of an underestimation of upwelling in the model simulation or weak upwelling in the atmosphere the correlation is flatter. We agree that we did not state this clearly in the paper. We added the following text on p22649, line 23 to make this clear: *In case of stronger upwelling low* O_3 *and high* N_2O *will be brought up to higher altitudes than during weak upwelling and thus increase the steepness of the* N_2O/O_3 *curves. Weak upwelling will have the opposite effect and cause a flattening of the curves.*

Page 22659 states "Such a high positive bias was not found in validation studies performed applying Odin/SMR N_2O *observations.." Where did validation data for 650 K in the tropics come from? Were there balloon tropical* N_2O *measurements?*
Most satellite validation studies were performed with comparing the satellites to each other. This was only natural due to the satellite data available during the last decade. Nevertheless also balloon or airborne data were applied for the validation of the satellite data employed in this study. A validation of the MIPAS high spectral resolution data (2004-2005) with airborne in-situ observations can be found in Baehr et al. (2005). Though not explicitly stated there a bias of 23 ppbv was found at altitudes between 6-25 km.

General assessment: It's difficult to understand the main point the authors want to make with this paper. If they want to do a detailed study of how the QBO impacts N_2O *and* N_2O/O_3 *correlations, it needs more work. It seems that currently the purpose of the manuscript is to attribute anomalously high values of* N_2O *observed in the tropical stratosphere to the QBO, and state that models are not doing it correctly. However, what the authors need to do is*

ACPD
12, C9795–C9806, 2012

demonstrate that those anomalously high values of N_2O are actually real.

We really tried our best to make our points clear in the paper and are sorry that we did not get our point through. However, we hope that we have accomplished this in the frame of the revisions we made due to the reviewer comments. The intention of this study is to show three things: (1) The inter-annual variability of monthly averages of N_2O and O_3 is low and can easily be distinguished from model deficiencies. Here, we address the criticism that has been made on earlier studies where we only applied one year of Odin/SMR or ILAS/ILAS-2 data. (2) Understanding the differences we derived between model simulations and Odin/SMR observations in Khosrawi et al. (2009). This includes the discussion on the anomalously high N_2O mixing rations and the seasonal and inter-annual variation of these values. Though the absolute values are unrealistic we could show that the seasonal and inter-annual variability in the occurrence of these values is caused by the QBO. (3) By comparing all data sets applied in this study we can show that this method is not only a valuable tool for model evaluation but also for satellite data intercomparisons. To make this clearer in the paper we added in the introduction the following sentence on page 22636, l1:*The main purposes of this study are:* and then use the numbers (1), (2) and (3) in the text as done above.

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ACPD

12, C9795–C9806, 2012

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 22629, 2012.