Atmos. Chem. Phys. Discuss., 11, C16171–C16181, 2012
www.atmos-chem-phys-discuss.net/11/C16171/2012/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Stratosphere-troposphere ozone exchange from high resolution MLS ozone analyses" *by* J. Barré et al.

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Received and published: 22 March 2012

General comments

Comment 1:

Vertical resolution in the CTM: It says on p. 33423 l.9 that the vertical resolution in the UTLS is about 800m. Since it does not say that this resolution varies together with the horizontal resolution, I suppose that it is the same for both horizontal resolutions (2 and 0.2 degrees, respectively). The high horizontal resolution roughly corresponds to

a 20km grid cell in the horizontal. In this case, the ratio horizontal/vertical is around 20 for the grid while it is around 100 in the flow. Horizontal motions are over-resolved with respect to vertical motions. In a semi-Lagrangian advection scheme, this means that the advection will be overly diffusive in the vertical as compared to the horizontal. As a result, I am not convinced that the high resolution mode can accurately resolve the small scale filaments (and ozone STE), since these are usually developing along isentropes that are not following the model levels (especially around high PV anomalies). Why use such a configuration in the CTM?

The referee is correct when mentioning that the vertical resolution is the same in both configurations. We acknowledge the referee's point concerning the shortcomings in the configurations of the CTM we use. Nevertheless the CTM configuration we use is state of the art (we have around 50 publications in the peer-reviewed international literature), and we think it is appropriate for studying the problem at hand. This is because Pisso et al., (2009) has shown that in the troposphere with a vertical resolution of 800 m, realistic mixing processes require at least 40 km of horizontal resolution. Therefore, we think a 20 km horizontal resolution is appropriate. Furthermore, this 20 km resolution matches the resolution of the ARPEGE analyses we use for meteorological forcings in the CTM; also, the vertical resolution of the CTM is the same as that of ARPEGE. This choice of 20 km horizontal resolution can be seen as a trade-off between lower and upper model levels which differ in vertical resolution. We have added a reference to Pisso et al. (2009) and have clarified this point in the text (see section 2.1).

Reference added :

Pisso, I., E. Real, K. S. Law, B. Legras, N. Bousserez, J. L. Attié, and H. Schlager (2009), Estimation of mixing in the troposphere from Lagrangian trace gas reconstructions during long-range pollution plume transport, J. Geophys. Res., 114, D19301, doi:10.1029/2008JD011289.

Comment 2:

The vertical resolution in MLS is 3km in the UTLS, and therefore assimilation increments are likely to be blind to the detailed vertical structure in the ozone around the tropopause which the CTM produces. Since the CTM has a low bias in ozone in the lowermost stratosphere (see the peaks between 200 and 100 hPa in Figs. 8, 10, 13), it is most probable that these increments will erroneously add ozone below the tropopause as well, which will increase the background ozone in the free troposphere. I think this is what Fig. 1 suggests: With zero ozone increments below 215hPa (since no data is assimilated below this level), the analysis still sees a significant increase in the free tropospheric ozone concentration. At least part of it is due to artificial injection of ozone from data assimilation. Figs. 8, 10, 13 all show that this free tropospheric ozone is higher in the analyses than in the forecasts or in observations. Furthermore, this erroneous injection of ozone in the troposphere by way of assimilation increments is disconnected (and can not be estimated) from the ozone STE flux estimated using the Wei formula.

Please see our reply to comments 1 and 2 from referee 1.

Comment 3:

The Wei (1987) formula has been shown to lead to a problem of cancellation between the terms in equation (1), with the result being a small residual compared to individual terms. Since the estimates of individual terms are subject to errors (derivatives taken on finite spatio-temporal resolution data), the relative error on the residual is likely very large (e.g. Wirth and Egger, 1999). This is especially of concern with the low vertical and temporal resolutions used here. It would be good to show maps of the ozone STE fluxes to show how noisy your estimates are. In Fig. 11, error bars are

provided but there is no explanation in the manuscript about how they are calculated. A stratospheric tracer would give more reliable estimates than the Wei method.

Regarding the use of the Wei formula, please refer to our reply to comment 5 from referee 2. We have added the reference suggested by referee 2 (Wirth, V. and J. Egger, 1999). The text now discusses in more detail the limitations of the Wei formula. Finally, we agree with the referee that a stratospheric tracer would give a more reliable estimate than the Wei method but for our CTM configuration we think it is more practical to use the Wei method. Also, it is not straightforward to assess the impact of the assimilation of ozone data on the fluxes (which has two contributions: one directly from assimilation increments and the other one from the transport and mixing of increments ingested at all previous assimilation windows). The Wei formula allows one to distinguish between the "dynamical" part of the fluxes, which is fixed by meteorological analyses at the two different resolutions, and the "composition" part, which depends on the 3-d ozone field. For information, we have produced maps of the ozone STE fluxes for the two horizontal resolutions, 2^o and 0.2^o (left and right hand panels in figure 1 below). We propose to add a comment about the ozone STE fluxes in the paper, but not to show the figure immediately above. However if the editor thinks the figure should be added, we will include it. We have clarified the text regarding the description of how the errors in the STE fluxes are calculated. This is now detailed in the main text, and it has also been added to the caption of Figure 11.

Comment 4:

With these comments in mind, I conclude that the assimilation only helps to correct the low bias in the lowermost stratosphere (see the peaks between 200 and 100hPa in Figs. 8, 10, 13), but does not help with any laminae structures found in the profiles (would be better seen using mixing ratios in Figs. 8, 10 and 13), and produces a concerning positive bias in the free troposphere. It does not help either with ozone STE fluxes.

In the figures 8, 10 and 13 in the discussion paper (figures 6, 10, 13 in the revised paper) the assimilated profiles at low and high resolution are in better agreement with independent (i.e., non-assimilated) observations than the corresponding "free" model runs. This is in particular the case for the peaks in the ozone profile in the UTLS regionbetween 300hPa and 100 hPa. These "peaks" are called "laminae structures" in the literature (see, for instance, Stohl et al., 2003). We agree that the assimilation produces a positive bias in the troposphere, but in figures 10 and 13, the assimilation at high resolution is able to represent an ozone maximum layer/structure in the free troposphere which is not found in the other experiments. The term "laminae" is likely not appropriate for this feature and we have thus changed the wording. Regarding the STE ozone fluxes, the aim of the paper is to investigate how these fluxes are modified by the assimilation and the horizontal resolution. The aim is not to see whether these fluxes are improved by these modifications, due to a lack of a reliable independent reference to test this. We have clarified this aspect in the text.

Specific comments

p. 33421, l.5: How can an intrusion bring high PV in the troposphere if you use PV as the tropopause definition?

In this part of the text, no tropopause definition has been provided. The tropopause can have many definitions such as PV of potential temperature or a mixing layer between stratospheric and tropospheric tracers.

l. 11: PV is not quasi-conserved in the UTLS region.

It is mentioned in the literature (for instance: Appenzeller et al., 1996) that PV is quasi-conserved in the UTLS region at the time scale of a few days. The sentence is reformulated.

p.33424, l.11-15: There is an error with the 1 June 2009 date.

Fixed.

l.21-22: Needs to be clarified.

The text has been clarified.

p.33426, l.9-10: Needs to be clarified.

The text has been clarified.

l.15-19: Needs to be clarified.

The text has been clarified.

l. 20: Not only advection, but also includes artificial injection of ozone due to data assimilation (see comment 2 above)

The text has been clarified; see also our reply to comment 2 above.

p.33427, l.4: dynamical tropopause, not tropopause height estimation.

Fixed.

l.6: it is simplistic to say that STE is an irreversible isentropic process

The text has been clarified.

l.25: What is middle-scale?

“Middle“ has been changed to ”synoptic“.

Section 4.1: Does not belong to Results.

The plan has been changed for clarification: see our response to the specific comment of referee 2 on this matter.

p.33428 l.3: What is a PV height anomaly?

The text has been clarified.

l.17: What do you mean with ”high PV“?

The text has been clarified.

l.18: Clarify ”anticyclonic curve“

The text has been clarified.

l.23-25: Circular argument: In fact, a positive PV anomaly is associated with a cyclonic circulation

The term ”cyclonic” has been removed.

p.33429, l.9: What do you mean with ‘south tip’?

The text has been clarified.

Section 4.2.3 is trivial – could be removed.

We think it is important to highlight what the high resolution set up is able to represent and what the low resolution set up is unable to represent. This also gives some perspective for past or future work using global CTM or NWP running at similar resolutions (1^o-2^o). Furthermore, the plan has changed according to the comments from referee 2.

p.33430, l.12-14: Strange statement! I would expect the free forecast to have a better alignment between ozone and PV. How do you quantify this alignment? Why is that a representing an added value to the ozone distribution?

It has been said in the introduction that: ”that ozone fields and PV fields are strongly correlated in the UTLS layers of the atmosphere“. This statement has not been quantified, but is merely a qualitative statement based on a consideration of the figures. Please see also our reply to comment 1 and 2 from referee 1. In the new sections 4.2.4 and 4.3.4 a validation with independent data shows the added value to the ozone distribution itself.

l.20-23: Trivial.

Fully agreed, but we believe it is helpful for a better understanding.

p.33431, l.28: This conclusion is incomplete, a mention on the increased ozone bias in the free troposphere is needed.

Please see section 4.4.3 in the updated manuscript.

p.33433, l.21-22: I disagree with this statement. The horizontal resolution is not limiting here, but the vertical resolution is, and so is the vertical resolution of MLS observations.

We have clarified the text following this suggestion. Please also see our reply to comment 1.

p.33434, l.2: It is suggested that advection is responsible for the ozone bias in the troposphere, but the assimilation artificially injects ozone as well!

Please see our reply to comment 2 from referee 1.

l.11: The artificial injection of ozone by data assimilation is not included in the ozone flux estimates.

Please see also our reply to comment 2 from referee 1. We think that a significant part of the ozone flux actually takes place in the STE structures (see the additional figures provided in this document) where the dynamical tropopause is "low".

Caption to Figure 1:
Instantaneous ozone fluxes through the 2 PVU surface on 17 July 2009 15:00 UT for low resolution MLS analyses (left) and high resolution MLS analyses (right) in kg.m^{-2}.s^{-1}. Negative values are the downward fluxes and positive values are the upward fluxes.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 33419, 2011.

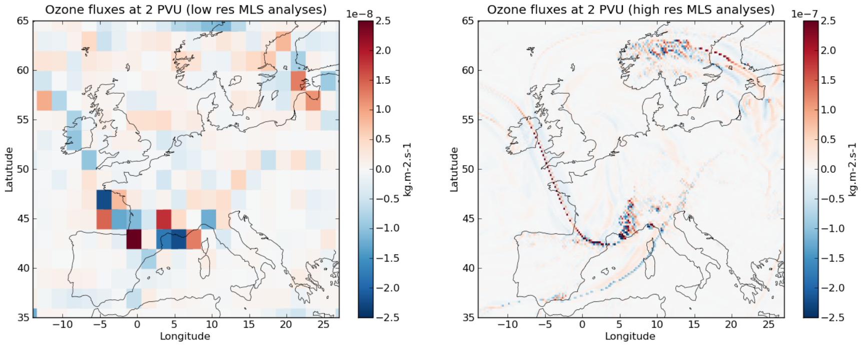
Ozone fluxes at 2 PVU (low res MLS analyses)
Latutude
Longitude
1e−8
kg.m-2.s-1
Ozone fluxes at 2 PVU (high res MLS analyses)
Latutude
Longitude
1e−7
kg.m-2.s-1

Fig. 1.