MS No.: acp-2011-837: *'On the uses of a new linear scheme for stratospheric methane in global models: water source, transport tracer and radiative forcing.' Monge-Sanz et al. Atmos. Chem. Phys. Discuss., 12, 479-523, doi:10.5194/acpd-12-479-2012, 2012.*

Response to Reviewer #1

We thank the Reviewer for his/her comments and suggestions, which have raised points requiring improvement or clarification in the ACPD manuscript. The final manuscript for ACP will address these points as explained here below.

Please note that our responses to the Reviewer's comments are in bold font, while the original comments are in normal font**.**

Review of "On the uses of a new linear scheme for stratospheric methane in global models: water source, transport tracer and radiative forcing" by Monge-Sanz, Chipperfield, Untch, Morcrette, Rap, and Simmons.

The paper describes a new linear parameterization of stratospheric CH4 chemistry, CoMeCAT, which is designed for global models that resolve the stratosphere but do not include full photochemistry. The parameterization is similar in form to earlier linearized ozone photochemistry parameterizations, in that the loss rate is described in terms of a basic state value plus perturbation terms describing the effects of local variations in CH4 and temperature. The perturbation terms are evaluated using the TOMCAT box model, which is initialized using output from a fully interactive SLIMCAT model simulation that was forced with ERA-40 and ECMWF operational winds. The box model calculations were carried out for the period Jan-Dec 2004. The coefficients computed with the box model, and the reference climatologies for CH4 and T computed with the SLIMCAT model, are then used to specify a CH4 loss rate, which can be assumed to approximate a H2O production rate throughout the stratosphere where total hydrogen is constant. The COMECAT parameterization is then tested in both the SLIMCAT model and the ECMWF GCM, and differences in CH4, H2O, temperature, and radiative forcing are evaluated.

While I appreciate the level of work involved in carrying out and analyzing these simulations, in its present form the manuscript does not represent a substantial contribution to scientific progress within the field of NWP, data assimilation, or global modeling. This may be in part due to the nature of the problem (i.e., CH4 chemistry in the stratosphere), and in part due to the presentation of the material and methodology. My comments below address each part in turn.

Regarding the nature of the problem: The motivation for developing and implementing CoMeCAT is not clear. What scientific problem will this work address? The Introduction (p 481, lines 1-20) discusses the need for NWP/DAS models to accurately depict radiatively active trace gases such as H2O and CH3. This is not a disputed fact. However, the authors then claim that the description of such gases is “in many cases still too simple for current stratospheric purposes”. What does this mean? Are there studies that can be cited in support of this point? Further down, it is stated that “One of the current problems is the poor representation of CH4 found in most GCMs…”. Again, what references can be provided to support this statement? If by GCMs one means NWP models, this is probably true. If it means GCM’s such as coupled chemistry climate models, it is probably not true. For NWP purposes, one could argue that including CH4 chemistry is unnecessary because CH4 chemistry in the stratosphere (i.e. then net production of H2O due to CH4 oxidation) is very slow compared to transport times, for example. This can be seen in Figures 2, 3, and 4, where the photochemical lifetime of CH4 is on the order of years, and the sensitivities of the CH4 loss rate to changes in CH4 and temperature are extremely small. What exactly is the problem that CoMeCAT will address?

- The problem addressed by CoMeCAT is the improvement of the description of the stratospheric composition in models that consider the stratosphere but do not fully resolve chemistry in this region.

- The statements on the lack of detail in the description of stratospheric CH4 and H2O are mainly related to NWP models such as IFS (e.g. Bechtold et al., 2009), but not exclusively. Global climate models also show limitations in their description of stratospheric water vapour (Solomon et al., 2010). Regarding climate-chemistry models (CCMs), Gettelman et al. (2010) show that even if the models’ ability to simulate stratospheric water vapour has significantly improved in recent years, there are still discrepancies between models and not all of them are able to reproduce the annual cycle of water vapour in the lower stratosphere, there are also still some models that consider H2O to be fix throughout the stratosphere.

- The relevance of stratospheric CH4 and H2O for radiative forcing calculations has recently received a great deal of attention. In a study showing the links between stratospheric H2O and surface warming, Solomon et al. (2010) highlight the limitations in current global models regarding the description of these gases in the stratosphere.

- Even if stratospheric CH4 chemistry can be considered slow for short/medium-term weather prediction time scales, NWP models like IFS are also used to produce seasonal forecasts. Models with a realistic stratosphere are expected to improve seasonal prediction skill (e.g. Maycock et al., 2009), and an improved stratosphere is becoming essential for models aiming towards seamless prediction. CoMeCAT is an intermediate step previous to full chemistry, for two chemical species (CH4 and H2O) that affect forecasts at different time scales, from seasonal to climate.

- The distribution and evolution of CH4/H2O in the stratosphere affects temperature profiles in this region and, therefore, a realistic CH4/H2O stratospheric scheme linked to temperature has the potential to reduce model forcings and improve the assimilation of radiances sensitive to temperature.

- Another aspect that a scheme like CoMeCAT can address is the production of chemical reanalysis like those produced in the MACC project, where the stratosphere is not fully resolved yet. We will briefly mention this in the final manuscript as, although out of the scope of this paper, it is part of ongoing research.

- In the paper we also show how the CoMeCAT tracer enables the evaluation of transport within the GCM, in on-line runs, unlike the evaluations made by Monge-Sanz et al. (2007, 2012) which used off-line simulations. This is not only useful for internal GCM tests, but also for better understanding results from stratospheric off-line CTM simulations.

We will add/develop the discussion of all these points in the Introduction of the final manuscript.

Later in the Introduction (p 486, lines 5-18) it is mentioned that CoMeCAT has the potential to improve radiance assimilation and to provide a tracer for diagnosing transport in a GCM. If these two points are in fact the main motivations for developing CoMeCat, they should be discussed in more detail at the start of the Introduction. The results of the paper should also, consequently, clearly show how the CoMeCAT parameterization may contribute substantial new results in these areas of research.

The potential contributions of a scheme like CoMeCAT to stratospheric data assimilation and transport diagnostics will be discussed in more detail. The Introduction will be re-written to make these motivations clearer, as well as to clarify the other points discussed in the previous comment above.

Regarding the presentation of the results: The paper needs to be better organized around the main significant contributions of CoMeCAT. Currently, it lists the results of many different applications of CoMeCAT in different models, but the overall significance of the results is unclear. For example, Figs 8 and 9 discuss the differences in temperature between ECMWF GCM runs using with CoMeCAT or GEMS CH_4. Outside of the winter extratropics, the differences are small, and it is difficult to determine what, if any, relationship exists between the CH_4 differences in Fig. 9 and the temperature differences in Fig. 8. More importantly, it seems very likely that any differences in zonal mean temperature will be due to the radiation scheme using different zonal mean CH_4 distributions rather than any photochemical effects parameterized by CoMeCat. In this sense, Fig. 9 seems to be testing differences between GEMS and SLIMCAT CH_4 and could in fact have nothing to do with the linearized photochemistry scheme, which is the subject of this paper. The same seems to be true for Fig 12, which is really evaluating radiative forcing differences between an assumed global 1.8 ppmv CH_4 value and a reference CH_4 state (as a function of latitude, altitude, and season) determined from SLIMCAT.

We will edit the discussion of results to make clearer their significance within the context of current research in the field.

Regarding Figs. 8 and 9, the aim of the corresponding runs was to show that a more realistic stratospheric composition does have an impact on dynamical fields essential for data assimilation.

As for the magnitude of the temperature differences, two points regarding the comment above need clarification:

i) Even if the largest differences are found over the winter extratropics, for the length of the runs we use, differences outside the tropics, especially over the winter hemisphere, cannot be linked to CH4 differences due to the extent of the dynamical variability; we warn about that in the main text (page 496, lines 14-18).

ii) The differences of up to 2K found over the tropics cannot be characterised as 'small'. Research policy regarding ECMWF model changes rejects any model implementations that imply temperature differences over 0.5 K with respect to the corresponding previous IFS version. Thus, a stratospheric parameterisation that produces 2 K differences in temperature can be regarded as an important effect on the model temperature field. The fact that this difference is a persistent signal (not dynamical variability in one particular run) will be shown in the final manuscript, and the strength of the signal will be compared with the interannual variability in the default IFS model version used for our runs.

We agree that for a better evaluation of photochemical effects on temperature, longer runs with IFS would have been required; this has not been feasible due to project practicalities and allocation of resources at ECMWF.

Fig.12 evaluates the differences due to using a global constant value (1.8 ppmv) and the CoMeCAT tracer distribution, not the reference state determined from SLIMCAT. We will revise the text to avoid any confusion.

We will also include additional comparison of radiative effects between using the climatology and using the CoMeCAT tracer distribution in the E-S calculations.

It would help if the results presented in the paper could clearly show that (a) CoMeCAT CH4 chemistry can improve NWP/DAS treatment of radiance assimilation and (b) CoMeCaT CH4 helps diagnose transport in GCM's, as these seem to be the main motivations for developing CoMeCAT. As part of this, the paper should clearly show that CoMeCAT is producing CH4 or H2O tendencies (or increments) in the stratosphere that are large enough matter for these applications. As a start, one simple way to do this would be to plot the size of the tendencies from each of the individual terms in CoMeCAT (equation 16) as a function of altitude for a realistic profile of T and CH4.

Overall, I would recommend more effort in rewriting the Introduction section to motivate the research, and refocusing the analysis of model results to clearly show how the photochemistry in CoMeCAT has the potential to improve radiance assimilation for NWP and/or transport diagnosis in GCMs.

An analysis of tendencies for the individual terms in the parameterisation will be shown in the final manuscript.

We will rewrite the Introduction to show more clearly the motivation of this research, which focuses on these two main points: i) provide a more realistic stratosphere for models that do not fully resolve this region (as is the case of IFS), and ii) provide an internal tracer apt for stratospheric transport diagnostics in the GCM. The approach adopted by CoMeCAT allows us to tackle these two objectives with only one additional tracer in the model.

Testing to what extent the stratospheric CH_4 and H_2O distributions are improved using the new scheme is one main aim of the paper, however performing IFS runs including data assimilation was out of the scope of this paper, due to project restrictions (however, this remains as a future line of research). We will add a few lines to the main text to make this point clear in the final manuscript.

Specific Comments

1. The abstract is probably too long, and lacks focus. Rather than listing every result in detail, it would help to summarize the key results and their significance. If possible, reducing the number of acronyms in the abstract would improve its readability.

We will edit the Abstract focusing more on key results; we will also revise the use of acronyms and reduce it whenever possible.

2. The Introduction needs to be re-organized. As mentioned above, it seems as though the main motivations for CoMeCAT are not discussed until the very end of this section. It would help if these were discussed much sooner, and previous work on the subject should be cited where relevant in motivating the current research (i.e., why is CH_4 photochemistry needed, why are current methods unstatisfactory, etc.)

Yes, we will edit the Introduction to make the motivations clearer from the start, adding clearer references to previous studies.

3. Are longitudinal features in CH_4 really important (p. 482, line 18)?

Longitudinal features are important in the troposphere-stratosphere exchange, due for instance to longitudinal features in tropical convection (e.g. Fueglistaler et al. 2004; Berthet et al., 2007; Schoeberl and Dessler, 2011). A model resolving these features can include variations that are smeared out in 2D models.

4. Equations 2-6 are not really equations. The way this is written, it is very confusing. Can these be condensed and written as proper equations?

Yes, we will rewrite them.

5. Why do NWP models need CH_4 chemistry? (p 487, line 8) They need a good background CH_4 climatology, but do they need CH_4 chemistry unless they are assimilating CH_4?

The section of the manuscript showing impacts on the IFS temperature field tackles precisely this point. Fig. 8 shows the differences in temperature obtained with a good climatology (the GEMS climatology) and the CH_4 field from the parameterisation. Additional discussions will be added to the final manuscript on this point (see responses for comments above and also responses to Reviewer 2).
It needs to be taken into account that NWP models like the ECMWF IFS are now used not only for short/medium-term weather prediction, they also form the basis for seasonal prediction systems and long reanalyses production. For improving these applications, using accurate stratospheric methane and water vapour is necessary, not only the distributions of these constituents but also their evolution in time need to be realistically considered by the model. Also, improving the description of the stratosphere is becoming especially important if NWP models want to evolve towards seamless prediction systems.

6. As mentioned above, the entire discussion in section 6.2 seems inconclusive as to whether or not CoMeCAT CH_4 chemistry impacts temperature in long GCM simulations. I would recommend eliminating this section.

As we have indicated above, the aim of this section is to show that a more realistic stratospheric composition does have an effect on dynamical fields essential for data assimilation.
We don't agree with the reviewer's recommendation, instead we will edit and develop the discussion in this section to make its scientific relevance clearer. IFS ensemble runs we performed in a preliminary stage of our study back up the relevance of the impacts on temperature, we will discuss this in the final manuscript. We will also compare the magnitude of the obtained temperature differences with the model interannual variability in the corresponding region. Also, new testing with the GEMS climatology will be included to further help quantify these impacts to the possible extent (taking into account the limitations in the length of the runs we can perform with IFS).

7. Why do Figs. 6 and 7 plot these latitudes? It's not clear from these figures what the CH_4 chemistry is contributing.

Latitudes were chosen to show effects over high, mid and low latitudes in both hemispheres. The figures show results from the different simulations, both with the CTM and the GCM, compared against HALOE observations. At higher latitudes HALOE observations are not available.
In Fig.6 the contribution of the CoMeCAT CH_4 chemistry in the IFS model is shown by the line corresponding the 'fif4' run. In Fig.7 the contribution of the CoMeCAT scheme is shown by the lines from run 'fif6'.

We will revise main text to make all this clear.

8. I didn't follow the discussion on p. 498 regarding the nudged experiments. What exactly is CoMeCAT's role in helping to explain the differences here?

The purpose of this section is to show the effect that nudging a GCM to meteorological reanalysis has on stratospheric transport. Until now, published studies on GCM nudging had focused on nudging effects on dynamical fields (e.g. Telford et al., 2008; Douville, 2009), neglecting the effects it has on the distribution of chemical tracers in the stratosphere.
The role of CoMeCAT here is that of a long-lived stratospheric tracer for transport evaluation. Including a CH4 tracer like CoMeCAT in the GCM has therefore allowed us to evaluate, in on-line runs, the nudging effects on stratospheric transport of tracers; to the best of our knowledge, the present study is the first one tackling this aspect. The main advantage of using a CH4 tracer for transport diagnostics, over the use of e.g. an age-of-air tracer, is the availability of CH4 observations to compare with.

The experiments in this section show not only the potential of CoMeCAT as an internal tracer for stratospheric transport, but also provide an assessment of effects in a GCM nudged to the ERA-40 and ERA-Interim reanalyses. The assessment shows that the GCM nudged to these meteorological series exhibits similar features to the CTM runs driven by the same meteorological fields, exposing the limitations of nudged GCMs for tracers transport applications.

We will emphasise all this in the main text, and develop the discussion around the corresponding runs.

9. The Figure 1 caption should state that the CH4 and T reference terms come from SLIMCAT.

OK. We will edit the caption to clarify this.

10. The contour labels on Fig. 2, 3, and 4 are illegible for the most part. Please consider revising the units to make the plots easier to label (e.g., Fig. 2 could be plotted in years), and reducing the number of contour lines.

OK. We will re-plot these figures.

Additional references:

Berthet, G., J. G. Esler, and P. H. Haynes (2007), A Lagrangian perspective of the tropopause and the ventilation of the lowermost stratosphere, J Geophys Res, 112, D18102.

Gettelman, A., et al. (2010), Multimodel assessment of the upper troposphere and lower stratosphere: Tropics and global trends, J. Geophys. Res., 115, D00M08, doi:10.1029/2009JD013638.

Maycock et al. (2009), Stratospheric circulation in seasonal forecasting models: implications for seasonal prediction, Clim Dyn (2011) 36:309–321, DOI 10.1007/s00382-009-0665-x

Schoeberl, M. R. and Dessler, A. E. (2011), Dehydration of the stratosphere, Atmos. Chem. Phys., 11, 8433-8446, doi:10.5194/acp-11-8433-2011.