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Atmospheric
Chemistry
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Discussions

Interactive comment on "Parameterization of middle atmospheric water vapor photochemistry for high-altitude NWP and data assimilation" *by* J. P. McCormack et al.

J. P. McCormack et al.

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Reply to Referee 2 (Anonymous)

The referee raises two main points requiring clarification. First, the referee would like to see an improved discussion of the equivalent photochemical lifetime τ^* and the underlying assumptions involved. Second, the referee rightly points out that the background reference state r^o in CHEM2D-H2O is a tunable parameter (dependent on altitude, latitude, and season), which we have adjusted. This is done in order to demonstrate the sensitivity of CHEM2D-H2O to the assumed values of r^o. The referee points out that no similar type of adjustment of the ECMWF scheme is performed, so that in the comparison of the different methods the ECMWF scheme is possibly being "disadvantaged".

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We address each of these points in turn.

(1) The referee asks about the equivalence between the time scale for the ECMWF scheme and the effective lifetime τ^* in the CHEM2D-H2O parameterization. First, we should clarify the distinction between the CHEM2D model, which is a complete photochemical model, and the CHEM2D-H2O parameterization. The net photochemical rate of change of H_2O (P-L) in the CHEM2D model, plotted in Figure 3, is computed from the complete set of reactions. The most important of these reactions are illustrated in Figure 1. The CHEM2D-H2O parameterization expresses the net photochemical rate of change as an expansion of (P-L) about a background reference state r^o, as given in equation 6.

As Figures 1 and 2 illustrate, the relevant reactions and time scales for H_2O production via CH_4 loss in the stratosphere are distinct and essentially separable from the relevant reactions and time scales for H_2O loss in the mesosphere via photolysis. This fact is represented by the use of the coefficients k_1 and k_2 in the ECMWF scheme, whose values are based on estimates of CH_4 and H_2O and lifetimes, τ_{CH4} and τ_{H2O}, from full photochemical model calculations at a single latitude and season reported by Brasseur and Solomon (1986). The CHEM2D-H2O parameterization takes a similar approach, but now accounts for the full latitude and seasonal dependences of the τ_{H2O} and τ_{CH4}, as illustrated in Figure 2. Equations 7-9 demonstrate the equivalence of $(k_1 + k_2)$ and τ^{*-1}.

The source of the confusion may be in the way the effective photochemical lifetime τ^* is defined in equation (3). We should have mentioned explicitly that only values of τ_{CH4} between 100-0.1 hPa were used to calculate τ^*. It is in this region where CH_4 loss leads predominantly to H_2O production, as the referee states (see also Figure 1a, reactions 4-6). This is the reason for the shading in Figures 2a and 2b, which is meant to show regions where τ_{CH4} is excluded from the computation of τ^*. The use of τ_{CH4} between 100-0.1 hPa in computing τ^* is also shown graphically in Figure 5. Clearly, we did not describe this adequately in the text. We will address this in the revised manuscript, specifically in the discussion of Figure 2 and Figure 5 and in the definition of τ^* in equation (3).

(2) The referee is correct that the choice of r^o in CHEM2D-H2O represents a free, tunable parameter. This could be seen as an advantage or disadvantage over the ECMWF scheme, depending on the application. We will address this in our discussion of the results in the Conclusion section of the revised manuscript.

One of the main goals of this study is to quantify the sensitivity of CHEM2D-H2O to the choice of r^o. Only a very large change in r_Q would have much of an effect on the performance of the ECMWF scheme in these 10-day simulations, and there is no observational basis to motivate such a change. On the other hand, past experience with a linearized ozone photochemistry parameterization (e.g., Coy et al., 2007) in our forecast model has demonstrated that the choice of a background reference state has a significant impact on the performance of the parameterization. This earlier work showed that an ideal reference state is one that resembles the broad spatial and temporal characteristics of the assimilated observations. This was the main motivation for attempting EXP2, where the original choice for r^o (a combination of UARS MLS and HALOE climatologies plus CHEM2D model output) was replaced with a monthly zonal mean H_2O distribution based on NOGAPS-ALPHA assimilated MLS measurements for June 2007.

Based on comments from both referees, we recognize that the choice of r^o in EXP2 can be problematic, since in operational applications the reference state would not contain information from the present (or future) state of the H_2O distribution, as is the case in EXP2. To rectify this, we constructed a new r^o field based on 4 years of Aura MLS Level 2 data (i.e., not assimilated measurements). This provides a more objective comparison of the different H_2O photochemistry schemes than before. The revised manuscript will include results from an additional set of forecast runs using this new climatological r^o. The basic result, however, remains the same in that the lowest values of A-F are obtained when the CHEM2D-H2O scheme employs an observationally-based

r^o distribution that closely matches the overall characteristics of the assimilated H_2O measurements.

Reply to Minor Points:

(1) McCormack et al (2006), contains a detailed review of the development of linearized ozone photochemistry parameterizations, on which CHEM2D-H2O is based. We will refer the reader to this in the revised manuscript. Our revisions will also include more discussion of linearized photochemistry schemes and their past usage in atmospheric models (e.g., Cariolle and Déqué, 1986; McLinden et al., 2000) in the Introduction.

(2) This assumption is limited to the levels between 100-0.1 hPa (see reply to Main point 2 above). We will clarify this in the revised manuscript.

(3) CHEM2D values of r_Q peak between 100-1 hPa, but the variations are extremely small throughout the entire stratosphere. For example, June values of r_Q over the equator at 100, 10, and 1 hPa are 6.99, 6.95, and 7.10 respectively. There is a relatively small peak in r_Q seen near 50 hPa over the South Pole in December, but this is likely an artifact of the model and will not affect the CHEM2D-H2O parameterization since the effective lifetime (Figure 7b) is in excess of 500 days in this region.

(4) Values of τ_{CH4} above 0.1 hPa are omitted because they are not part of the CHEM2D-H2O parameterization, as stated in response to Main point 1 above. We did not make this clear in the original manuscript. We will address this in the revision. To avoid further confusion, we are considering only plotting values of τ_{CH4} computed from the loss reactions 4-6 listed in Figure 1a.

(5) We will change "giving" to "with".

(6) This is justified since we are limiting the effects of H_2O production via CH_4 loss to the 100-0.1 hPa region as indicated in Figure 5. We will clarify this in the revised manuscript.

(7) We will modify the wording as suggested by the referee.

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(8) We will explain this better in our revision. As Figures 1, 2, and 3 illustrate, the net photochemical tendency can be represented by two separate processes, i.e., production via CH_4 loss (100-0.1 hPa) and loss via photolysis (above the 0.1 hPa level). These processes have distinct time scales defined by τ_{CH4} and τ_{H2O} which can be combined to give an effective time scale for parameterized H_2O photochemistry, as shown in equations (7) and (8).

(9) Yes, "NOGAPS-ALPHA analyzed H_2O" refers to the assimilated H_2O fields generated from the combined NOGAPS-NAVDAS assimilation system. This is separate from the free-running NOGAPS-ALPHA forecast model simulations which comprise EXP1-3. NOGAPS-ALPHA refers to the entire system. NAVDAS is the data assimilation component of the system. The other component is the forecast model. The analyses are generated every 6-hours using NAVDAS combined with the forecast model. The free-running forecast model simulations (EXP1-3) are initialized with the analyses from NAVDAS, and the forecast model results at day 10 are compared to the analyses at that time. The referee is correct that using June 2007 analyzed H_2O to specify r^o in EXP2 introduces some problems since we are really adding *a posteriori* information through this choice of r^o. To address this, we have undertaken an additional set of forecast model runs using r^o derived from a 4-year climatology of Aura MLS zonal mean H_2O for June.

(11) This sentence fragment was a typographical error and has been corrected.

(12) It was not clear from the outset how well the original CHEM2D-H2O configuration in EXP1 would perform. The choice of r^o in EXP1 was based on an earlier version of NOGAPS-ALPHA used prior to the availability of our high-altitude assimilation system. We feel that comparing the results of EXP1 with EXP2 gives a good picture of how sensitive the parameterization can be to the choice of r^o. This knowledge may be useful to others considering the implementation of such a parameterization in their models.

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(13) Again, since we limit the effect of H_2O production via CH_4 loss to the 100-0.1 hPa region, CHEM2D-H2O specifies H_2O loss via photolysis only in the MLT region, which is a valid assumption.

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