Atmos. Chem. Phys. Discuss., 6, S3257–S3262, 2006
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Atmospheric Chemistry and Physics Discussions



# *Interactive comment on* "CHEM2D-OPP: A new linearized gas-phase ozone photochemistry parameterization for high-altitude NWP and climate models" *by* J. P. McCormack et al.

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Received and published: 20 September 2006

1. The aim of this study is to introduce a new linearized gas-phase ozone photochemistry parameterization for use in high altitude NWP and climate models. It is specifically designed for applications in which it is not computationally feasible to perform full photochemical calculations involving multiple reactions and numerous transported constituents.

As discussed in Section 2.1, there are a large number of theoretical and observational studies supporting our central thesis that this parameterization can provide an accurate, physically-based constraint on prognostic ozone fields in 3D models. Our assertion is that a linearized photochemistry scheme based on a 2D photochemical

model with fully interactive (or self-consistent) treatment of radiative, photochemical, and dynamical processes eliminates some of the systematic biases present in current operational applications (e.g., the GSFC1 results). Regarding the referee's suggestion that we compare the parameterized photochemistry performance with that of a full photochemical calculation, earlier studies referenced in this paper (e.g., Cariolle and Deque, 1986; McLinden et al., 2000) have already performed such comparisons. These studies have demonstrated that the parameterized approach is generally accurate to within 10% when conditions satisfy the assumed linear behavior, i.e., when the ozone and temperature perturbations are within acceptable ranges.

Specifically, the referee suggests we place the full CHEM2D photochemical code into NOGAPS-ALPHA for comparison with the parameterized ozone photochemistry results presented here. This is not feasible considering the time it would take to implement this change and the computational cost such model calculations would require. Rather than reproducing earlier published results comparing parameterized and full chemical simulations, the present study focuses on how best to implement a similarly formulated linearized ozone photochemistry parameterization in an NWP model.

The referee raises an important point about the role of model dynamics and transport issues affecting the performance of the model photochemistry. Ideally, the parameterized photochemistry improves model ozone forecast skill in regions where photochemical effects are important while preserving model forecast skill where transport effects dominate. We have attempted to illustrate this point with the diagnostic calculations in Figure 17, and with the discussion of the temperature climatology's impact on the zonal mean ozone fields in the 1-year simulation. To further illustrate this point, we are adding additional comparisons between the model prognostic ozone fields with parameterized photochemistry and without photochemistry (i.e., passive ozone). This allows us to more closely distinguish between the effects of transport and photochemistry on the ozone hindcasts. For this case study, our results indicate that CHEM2D-OPP offers the best overall results among the different schemes tested.



ACPD
6, S3257–S3262, 2006





EGU

2. We have cited several earlier studies (see Section 2.1) in which linearized ozone photochemistry is used to simulate the zonal structure in stratospheric ozone (Hartmann and Garcia, 1991; Douglass et al., 1985; Randel, 1990, 1993). In response to this comment and a similar comment from Referee 2, we are adding a figure to illustrate the zonal structure in the model prognostic ozone at 5 hPa over the Northern Hemisphere corresponding to Figures 12-15. A preliminary version of this figure can be found at http://uap-www.nrl.navy.mil/dynamics/html/chem2dopp/fig_r1.html. Our findings show that overall, the parameterized photochemistry is able to capture much of the zonal structure in the ozone fields at middle and high latitudes for the February 7 case studied here. While the values of (P-L) and its derivatives are based on output from a 2D model, it is the 3D structure in the model's prognostic ozone and temperature fields that accounts for the effects of zonally varying distributions of ozone-destroying radicals. In the Feb 7 case, for which the polar vortex is disturbed and there is considerable transport of mid-latitude air into the polar regions, our results show that an accurate treatment of photochemical effects at the lower latitudes is necessary to properly simulate the ozone distribution at the higher latitudes.

3. The referee's point is well taken. Ideally, we would carry out a proper significance test of our results through statistical analysis of an ensemble of ozone simulations produced by perturbing model initial conditions. Unfortunately, we do not currently have the personnel or computational resources to undertake this task in a rigorous manner. As an alternative to a formal ensemble approach, we have examined the ozone hindcast performance quantitatively through a comparison with the NASA GMAO ozone analysis for 12Z Feb 7 2005. For each photochemistry scheme (as well as passive ozone), we have computed the difference between the ozone analysis and the "forecast" ozone (denoted A-F) over the Northern Hemisphere at different altitudes for a range of initial conditions from 144-12 hours preceding the analysis time. As an example, values of (A-F) using the different photochemistry schemes at the 5 hPa level can be viewed at http://uap-www.nrl.navy.mil/dynamics/html/chem2dopp/fig_r2.html. The hemispheric mean and RMS values of (A-F) at 5 hPa can be viewed at http://uap-



ACPD
6, S3257–S3262, 2006





EGU

www.nrl.navy.mil/dynamics/html/chem2dopp_fig_r3.html.

These values of (A-F) provide a measure of typical forecast errors over the time periods relevant for the ozone profiles in Figures 12-15. Overall, we find that the differences between the CHEM2D-OPP, GSFC1, and CDV1.0 profiles in Figures 12-13 exceed typical forecast errors. Differences between the CHEM2D-OPP, GSFC2, and CDV2.1 profiles in Figures 14-15 are less than typical forecast errors. Overall, CHEM2D-OPP produces lower values of the mean and RMS (A-F) over the Northern Hemisphere on this date as compared to the other photochemistry schemes tested here. Our discussion of these results in the revised version will reflect these new findings.

4. The sentence should read "Ozone production occurs through a 3-body reaction involving molecular oxygen...". We have corrected this.

5. There are times when this assumption will not be completely valid, and we will be sure to note this in our revision. As the referee points out, this is possible in the vicinity of the terminator at high latitudes in winter, which may contribute to some of the errors in model ozone at high southern latitudes during the late winter/early spring period in the year-long simulation. We hope to develop an additional term to the linearized parameterization describing the effects of heterogeneous ozone loss due to chlorine activation, either through a separate chlorine loading term (Dethof and Holm, 2002) or through a 3D prognostic cold-tracer approach.

6. The values are small compared to the other coefficients in equation (1). We will correct this statement.

7. Yes, the full photochemical calculations are repeated with modified temperature/photolysis rates. These CHEM2D computations yield both control and perturbed (P-L) simultaneously.

8. Changes in overhead ozone column will affect both molecular oxygen photolysis (J2) and ozone photolysis (J3) but only the former (J2) has a net impact on the odd



ACPD
6, S3257–S3262, 2006

oxygen (Ox = O3 + O) distribution. Readjustment of the loss reactions through, e.g., NOx and HOx cycles, to the perturbed odd oxygen distribution is accounted for when we compute the perturbation values of (P-L). Carrying the full photochemical model perturbation calculations forward in time to allow the longer-lived members of the HOx and NOx families to readjust will result in a different profile for the column sensitivity term, but violates the underlying assumptions of the linear perturbation model.

9. The radiative heating and cooling rates are applied at every model time step (240 s) but the full radiation calculation is updated every two hours, due to the large computational burden of the the radiative heating/cooling calculations. We will revise the text to clarify this point.

10. Daily values are obtained by linear interpolation in time between monthly means at a given latitude and pressure level. The sentence should read "to the corresponding model location and day". The issue of using diurnally averaged ozone is discussed on page 6660 (line 25).

11. This was an oversight. We have corrected Figure 12-15 to only show the pressure range 200-0.4 hPa where the MLS ozone retrieval is valid.

12. The application of linearized ozone photochemistry for long-term runs to simulate the effects of ozone depletion is not justified without inclusion of an additional heterogeneous loss term. Thus we are not advocating this application with the present CHEM2D-OPP formulation, and we will revise our discussion to avoid giving this impression. Certainly, long-term climate simulations of ozone trends should have full chemistry, and there are several middle atmosphere GCMs with coupled chemistry that already do this. However, there are a number of NWP and climate applications that require accurate 3-D ozone fields but do not require a full treatment of ozone photochemistry. Possible examples would include be long-term climate simulations to test middle atmosphere gravity wave drag parameterizations, investigations of mean and planetary wave structures in the model, or intrinsic model interannual variability due to



ACPD
6, S3257–S3262, 2006

stratospheric warmings, etc. In addition, the LINOZ scheme of McLinden et al (2000) has been used to study solar cycle effects in the GISS GCM (Rind et al, 2004) and global chemical transport models (Sinnhuber et al., 2006). In these cases, use of a linearized ozone photochemistry parameterization can be justified if one wants to explore climate signal in a middle atmosphere GCM in the absence of ozone trends due to increasing chlorine.

13. We will take the referee's advice in our revision of the Conclusions, making sure to emphasize our new results and outlining future work without excessive detail.

14. Corrected.

Additional References:

Rind, D., et al. (2004): J. Climate, 17, 906-929.

Sinnhuber, et al.(2006): Atmos. Chem. Phys., 6, 1835-1841.

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Interactive comment on Atmos. Chem. Phys. Discuss., 6, 6627, 2006.