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Atmospheric Chemistry and Physics Discussions

Interactive comment on "NOGAPS-ALPHA model simulations of stratospheric ozoneduring the SOLVE2 campaign" *by* J. P. McCormack et al.

J. P. McCormack et al.

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Reply to Interactive Comment: Anonymous Referee #2

Reply to General Comments

The referee's comments address two main points. The first point regards the role of heterogeneous chemistry in the ozone simulations presented here. The second point regards detailed comparisons between NOGAPS-ALPHA and ECMWF flow fields in the lower stratosphere. We address each of these in turn.

1. Heterogeneous Chemistry

Clearly heterogeneous chemistry plays a role, and it is certainly not our intention to argue that heterogeneous chemistry can be neglected. Rather, our intention here is to perform a first intercomparison of various gas-phase (homogeneous) ozone photo-

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chemistry parameterizations, prior to conducting subsequent investigations that include additional, more sophisticated, parameterizations of heterogeneous ozone losses (e.g., cold tracer advection schemes). In other words, we must first determine how well these basic homogeneous chemistry schemes operate in our new model under a range of different meteorological conditions before we can determine how to best simulate the additional effects of PSC-induced ozone loss. This type of comparison among different homogeneous ozone photochemistry schemes in an NWP model has, to our knowledge, never been performed and published before. Therefore, there was no way of knowing beforehand how these ozone simulations would compare with observations. As our results show, both the initial (+0 hour) 3D ozone fields and the details of the gas-phase photochemistry schemes can directly impact the performance of the model prognostic ozone over periods of 5 days throughout the Arctic stratosphere. These differences must be characterized and reconciled before additional effects like heterogeneous loss can be included with any confidence in an NWP system.

2. Flow Field Comparisons

While comparison of NOGAPS-ALPHA and ECMWF lower stratospheric flow fields is a useful, and ultimately necessary, test of NOGAPS-ALPHA model dynamics, the main goal of this paper is to test the new ozone initialization, photochemistry, and spectral transport schemes in NOGAPS-ALPHA. The ultimate goal is to develop a model capable of directly assimilating satellite radiance measurements, thus improving short-range forecasts. (A second NOGAPS-ALPHA paper, which has been submitted to Monthly Weather Review, focuses exclusively on differences between the ECMWF and NOGAPS-ALPHA prognostic meteorology/dynamics in simulating the 2002 Southern Hemisphere major warming event [*Allen et al., 2004*]).

While the lower stratospheric ozone fields in the present study are dominated by transport, as the reviewer states, our results demonstrate that the ozone forecast itself is more noticeably affected by differences in the GMAO-GEOS4 and ECMWF ozone assimilations, which we highlight and describe for the first time in this paper. To make this

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point more clearly, and to avoid the complication of possible differences in ECMWF and NOGAPS-ALPHA meteorology raised by the reviewer, we have conducted an additional set of NOGAPS-ALPHA hindcasts in which we initialized the ozone field using the ECMWF operational ozone analysis. The results from these additional simulations are now compared with the GESO4-initialized NOGAPS-ALPHA ozone hindcasts in order to isolate the changes due solely to differences in model initialization - i.e., the meteorology in these NOGAPS-ALPHA simulations are identical, the only differences are in the ozone initialization. This avoids the need for analysis of "psuedo-N_2O" fields, which were also questioned by the reviewer (see specific comments below). The additional results from these runs are added to Figure 20 (as new panel b), Figure 21 (as new panel c), and Figure 23 (as new panel b), and can be viewed at, respectively:

http://uap-www.nrl.navy.mil/dynamics/html/acp2004/draft_fig20_new.jpg

http://uap-www.nrl.navy.mil/dynamics/html/acp2004/draft_fig21_new.jpg

http://uap-www.nrl.navy.mil/dynamics/html/acp2004/draft_fig23_new.jpg

An excellent way to test and validate these schemes is to compare the NOGAPS-ALPHA model simulations with the satellite and aircraft ozone measurements obtained during SOLVE2. Since ECMWF forecast products provided invaluable guidance for flight planning during the field campaign, it makes sense to compare our new model results with the archived operational ECMWF forecasts.

Reply to specific comments

1. Yes, the stratospheric radiative heating is calculated using the zonally averaged (2D) ozone climatology based on Fortuin and Kelder (1998). NOGAPS-ALPHA can use either 2D climatological ozone values or the 3D prognostic ozone field to drive its radiative heating calculations. In the present study we have chosen to perform all NOGAPS-ALPHA hindcasts using the former method, i.e. we do not use prognostic ozone in the radiative heating calculations. We have made this choice in order that we may

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compare the performance of the different ozone photochemistry schemes (CHEM2D, LINOZ, and Cariolle-Déqué) under identical meteorological conditions. Running additional experiments with 3D ozone fed into the radiative heating can alter the model dynamics, and thus make it difficult to isolate the differences among various ozone schemes (see General Comment 2 above). For example, one obvious implication is that if an ozone photochemistry scheme produces unrealistically large ozone losses in the upper stratosphere (as is the case with the LINOZ scheme), this could introduce large errors in the model radiative heating rates and dynamics The net effect will be a combination of changes in ozone concentration, radiative heating, and circulation response. Certainly, when we ultimately develop a fully interactive prognostic ozone scheme for assimilation of satellite radiance measurements, the model radiative heating will utilize the 3D prognostic ozone, and we will the assess the impact then. We feel it is better not to comment on the possible implications of how the 3D ozone feeds back into model radiative heating and dynamics until we have a fully developed prognostic ozone scheme in NOGAPS-ALPHA. The goal of the present study is to help us determine the best way to do only the prognostic ozone component of the problem.

2. In theory, $(P - L)_o$ represents the net ozone tendency resulting from a balance between photochemical production/loss and transport. In practice, $(P - L)_o$ is computed in a zonally averaged (2D) model with full photochemistry and dynamics, and it is typically quite small ($<$0.1 ppmv per day) compared to the magnitude of the other photochemical coefficients. Note that in our formulation, the net ozone tendency is to be specified as $(P - L)_o$, not $(P - r_o\tau^{-1})$, where τ is the effective ozone relaxation time (for a definition see *Cariolle and Déqué*, 1986) and r_o is the photochemical model ozone mixing ratio. The difference is that in the former case, $(P - L)_o$ is always self-consistent, i.e. both the production and loss rates are based on the same photochemical model ozone distribution. This is not true of the latter formulation, used in the NCEP GFS model, where replacing r_o (the photochemical model ozone) with another ozone distribution can introduce serious biases.

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In the present formulation of NOGAPS-ALPHA, using values of $(P - L)_o$ for the first term and the ozone mixing ratio climatology of Fortuin and Kelder (1998) for the second term on the right hand side of equation (1) does not produce any significant errors. This formulation is consistent with the present ECMWF IFS ozone scheme. This approach also has the advantage that the photochemistry scheme will necessarily relax back to the same 2D climatological ozone distribution in the upper stratosphere that is used in the NOGAPS-ALPHA radiative heating calculations. This will be important when we eventually use prognostic ozone in the radiative heating calculations.

3. The reviewer raises a good point. Yes, the NOGAPS-ALPHA ozone simulations using the CHEM2D scheme only consider the first two terms in the ozone tendency. Note, however, that the NOGAPS-ALPHA simulations using either the CD86 or the LINOZ scheme use all four terms (i.e. temperature and column terms). Based on the ozone simulations during the warming event (Case 2), the implications of neglecting the temperature term in the 5-day simulations are negligible. Poleward of 50°N, the temperature coefficients in the LINOZ and CD86 schemes are extremely small. (For example, see the CD86 temperature coefficients for the month of January at :

http://uap-www.nrl.navy.mil/dynamics/html/acp2004/referee2_fig.jpg

Based on the CD86 values of $\partial(P - L)/\partial T$, at 60°N in January a 50 K temperature change would only produce a change in the ozone tendency of less than 0.1 ppmv per day near 30 km. The biggest implication of a warming event in the Arctic region for ozone would be through the perturbed transport and by prohibiting PSC formation. We note in passing that we hope in the near future to calculate temperature and column terms for the CHEM2D scheme as well, and will assess their impact when the these new coefficients are generated.

4. Based on input from Referee 1, we have learned that ECMWF only assimilates ozone observations between 40°N-40°S at present, whereas the NASA GEOS4 system assimilates ozone measurements poleward and equatorward of 40°N. We agree

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with the referee's impression that ECMWF is likely using climatology in this situation (see, e.g., Figure 9, and the smooth look to the ECMWF profiles in Figure 10). This poses a problem when the actual ozone distribution is significantly different from climatology (e.g., Figures 9 and 10), but not when the ozone distribution is less disturbed (see, e.g., Figure 11). Also, we do note that at lower latitudes the ECMWF ozone analyses closely match the GEOS4 analyses, so this is mostly a high latitude problem. As Figure 9 indicates, the ECMWF analyses do exhibit some zonal structure (albeit too smooth). The NOGAPS-ALPHA background ozone climatology is a zonal mean (2D), so no, they are not the same.

5. Because the temperature coefficients are so small here (see point 3), the improvement in the later ECMWF forecast is related to the higher resolution of the ozone analyses used to initialize the forecast. The coarse resolution of the GEOS4 ozone analyses used to initialize the NOGAPS-ALPHA hindcasts makes it difficult to reproduce the fine scale structure in the lower stratospheric ozone distribution observed during the DC8 flight. In response to the referee's comments, and to better illustrate our point, we have performed an additional simulation for the Jan 17-22 case in which we use the higher resolution ECMWF ozone fields to initialize the NOGAPS-ALPHA hindcast. We propose to add the results from this new simulation as a third panel (c) to Figure 21. The proposed draft figure can be viewed at

http://uap-www.nrl.navy.mil/dynamics/html/acp2004/draft_fig21_new.jpg.

The NOGAPS-ALPHA hindcast initialized with ECMWF ozone, Figure 21c, now shows a great deal of similarity to the archived operational ECMWF IFS +42 hour ozone forecast in Figure 21a. This demonstrates quite directly and persuasively that the differences between Figure 21a and Figure 21b are not due to differences in NOGAPS-ALPHA and ECMWF IFS meteorology, but are instead due to differences in the ozone initialization fields used in each case (ECMWF in panel a, GEOS4 in panel b). In this regard the high-resolution ECMWF forecasts are best for capturing this type of fine scale structure in lower stratospheric ozone.

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Interactive Comment

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6. We agree with the reviewer that the pseudo-N_2O tracer is not the best method to illustrate the results described above in item 5. The additional NOGAPS-ALPHA runs now initialized with ECMWF, rather than GEOS4, ozone analyses convey the importance of the initialization procedures more directly and more effectively than the "pseudo-N_2O" fields. Accordingly, in the revision we propose to remove the +42 hour pseudo-N_2O forecast field in Figure 22 and replace it with the +42 hour ozone field initialized using ECMWF ozone analysis, and incorporate it as Figure 21c (see discussion and web link listed in item 5). Therefore, in the proposed new Figure 21, the three ozone forecasts along FS2 can now be compared directly, and there is no need to include the "pseudo-N_2O" results.

REFERENCES

Allen, D. R., S. D. Eckermann, J. P. McCormack, L. Coy, G. L. Manney, T. F. Hogan, and Y.-J. Kim, 2004: NOGAPS-ALPHA simulations of the 2002 Southern Hemisphere stratospheric major warming, *Mon. Wea. Rev., (submitted)*, 2004.

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