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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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Authors' Reply to Referee #1

General Comments

The referee's comments here address the general scope of the present study. Three main points are made, which we address in turn

1. What is the Aim of this New System?

By "system," we are not sure whether the reviewer refers to NOGAPS-ALPHA as a whole, or the new prognostic ozone capability specifically. We address both possibilities. The point of the new NOGAPS-ALPHA model, as stated both in the Introduction (pages 4229-4230) and in the Summary (page 4255), is to provide a completely new prognostic middle atmosphere capability in the Navy's operational global numerical weather prediction model (NOGAPS), in common with similar initiatives being undertaken at the world's major weather centers. In addition to providing entirely new global middle atmospheric forecasting products for high-altitude operations by the U.S. Department of Defense, it also improves tropospheric forecast skill through improved operational assimilation of satellite radiances. For more details and background (particularly the U.S. Navy relevance), see Eckermann et al. [2004b]. See also point 2 below. For the ozone component, a realistic ozone layer is of course an essential component to a prognostic stratosphere. More specifically, three-dimensional prognostic ozone fields improve shortwave radiative heating rates, provide new forecast fields such as surface UV-index forecasts, and can correct complex biases in some longwave satellite radiance channels due to ozone absorption [e.g., Derber and Wu, 1998], thereby improving operational data assimilation. All these improvements are directed towards the overarching goal of any NWP model - to continually improve overall forecast skill at all altitudes over periods from 0 days out to 5-10 days into the future.

2. Why Short-Term rather than Long-Term Integrations and What is the Relation to ECMWF Products?

NOGAPS is an operational NWP model that issues 0-5 day forecasts. The ultimate purpose of NOGAPS-ALPHA is to provide a high-altitude spectral forecast model with a middle atmosphere capability that can ultimately replace the current spectral model running operationally with a top forecast level of 10 hPa. An important part of NOGAPS-ALPHA development is to objectively validate its forecasting performance against observations, particularly for new prognostic features such as the ozone forecasts. The SOLVE2 mission's primary focus was to acquire stratospheric ozone data from aircraft sorties that could help validate ozone measured by the SAGE III satellite. The purpose of this paper is to use such measurements to validate ozone from a NOGAPS-ALPHA hindcast run to assess this prototype forecast model's initial performance. While we completely agree that long-term simulations are important for assessing the mean climate and stability of the NOGAPS-ALPHA middle atmosphere

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(see Figures 4 and 5), this is not our primary purpose here and will be reported elsewhere [e.g., Eckermann et al., 2004b]. Within the context of the SOLVE2 special issue of ACP that this paper has been submitted to, we feel it is far more appropriate to conduct short-term ozone forecast validation studies within the January 2003 time period of the SOLVE2 mission, rather than contributing a paper based on free-running multi-month or multi-year runs that have little direct relevance to SOLVE2.

As regards benefits and improvements relative to ECMWF, again, it is not the purpose of this paper to advocate one system over the other. Our primary purpose in comparing with ECMWF is to compare with a state-of-the-art NWP model. Furthermore, ECMWF IFS has an operational ozone forecasting capability that we had access to during SOLVE2, and thus, within the overall ozone validation context of SOLVE2, it is highly relevant to compare our results with these operational ozone products as well. Certainly, as the reviewer states, a "real comparison" between NOGAPS-ALPHA and ECMWF requires a much more methodical study involving skill scores and assessments of meteorology and impact of operational analyses. But we are not trying to make general conclusions about the relative merits of each models' skill. Our purpose is to show that the new NOGAPS-ALPHA prognostic ozone product: (1) compares at least favorably with ECMWF's more mature operational product; (2) compares well with satellite ozone and SOLVE2 aircraft data; (3) yields fairly reliable chemical transport and stratospheric meteorology for the two case studies considered.

3. Inaccuracies of DAS Winds

We are aware of recent work highlighting some of the weaknesses of data assimilation system (DAS) winds in offline chemical transport model (CTM) simulations of stratospheric ozone and tracer transport [e.g., Douglass et al., 2003; Schoeberl et al., 2003; Tan et al., 2004] over monthly and seasonal time scales, which yield excessive numerical diffusion of tracer distributions across the vortex edge and subtropical transport barrier and excessively "young" stratospheric age of air [Schoeberl et al., 2003]. A major finding of Douglass et al. [2003] is that using winds specified from the

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internal dynamics of a general circulation model (GCM) substantially reduced these biases, and that event- based hindcasts should use GCM winds. The ozone forecasts provided here are generated "internally" within NOGAPS-ALPHA using the core GCM prognostic meteorological fields and transport schemes, and thus should not suffer the problems encountered by offline diagnostic models driven by DAS wind fields. Note in particular that the +0 hour fields from the MVOI operational assimilations are first filtered within NOGAPS-ALPHA using a nonlinear normal mode initialization (NNMI) procedure [Errico et al., 1988] that yields a higher-order balanced initial state that will not radiate spurious gravity waves during the first few hours of a forecast. Thus, NOGAPS uses balanced GCM winds at all times during its integrations, and so should not suffer from the recently highlighted shortcomings in DAS winds raised by the reviewer. We have confirmed this in some multi-year simulations in which our chemical fields develop and maintain a sharp subtropical transport barrier and do not show numerical diffusion across it as DAS-based transport calculations appear to do [Tan et al., 2004].

More specifically, our reading of the reviewer's comments lead us to suspect that he/she is under the mistaken impression that NOGAPS-ALPHA is also a data assimilation system. It is not at present, though it will be once we interface the high-altitude spectral model with the Navy's "NAVDAS" operational data assimilation system [Daley and Barker, 2001] to yield a complete high-altitude NWP system that includes real-time operational data assimilation. To avoid the potential for confusion, we will make it clear in the revised version that for our purposes "NOGAPS-ALPHA" refers to the GCM component of the Navy's NWP and data assimilation system.

Reply to Specific Comments

Abstract

Part of the referee's concerns raised in the General Comment may be due to the following sentence at the end of the abstract (page 4228, lines 17-19) where we originally stated: "In general, these results demonstrate that the spectral advection component in

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NOGAPS-ALPHA is well-suited for middle atmosphere tracer transport." As the referee rightly points out, we have not fully demonstrated the suitability of the model transport based on the short-term ozone forecasts presented here. To provide the proper context for the present work, we offer the following revision: "In general, these results demonstrate that the ozone photochemistry parameterization, ozone initialization, and spectral transport code in the new NOGAPS-ALPHA NWP model can provide reliable short-range stratospheric ozone forecasts."

Section 2.6

The Cariolle and Déqué (1986) (hereafter CD86) and LINOZ schemes each have their own individual ozone mixing ratio, temperature, and ozone column climatologies. On page 4238, line 9, we state that the ozone mixing ratio climatology, r_o, is replaced with values from Fortuin and Kelder (1998). The climatology of the overhead ozone column amounts is based on values from the individual schemes. So yes, the three different ozone parameterizations use the same ozone mixing ratio climatology. This is done for two reasons. First, using an observationally based ozone mixing ratio climatology is in keeping with the ECMWF's ozone photochemistry parameterization that uses an observationally-based ozone mixing ratio climatology. Second, this allows the NOGAPS-ALPHA prognostic ozone to relax back to a zonally averaged climatological distribution identical to that used for the radiative heating calculations. This is done so that in the future, when we use prognostic ozone in the radiative heating code, there will be no major inconsistencies in the upper stratosphere. As we have implemented them in NOGAPS-ALPHA, it is the reference temperature (T_o) and reference ozone column (Σ_0) values that differ between the CD86 and LINOZ schemes.

We have not encountered any numerical instabilities associated with large values of the temperature deviation term $T-T_o$, so it is difficult for us to suggest where the problems identified in the reviewer's experiences with these schemes might originate. The photochemistry algorithms in NOGAPS-ALPHA apply the tendency carefully using either a numerically safe Euler backward method or the McLinden et al. (2000) exponential

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method. Both methods are based on relaxation to the "steady state" mixing ratio defined in McLinden et al. (2000). Before implementation in NOGAPS-ALPHA, these schemes were tested in offline single column runs. Neither method generated numerical instabilities.

One additional factor to consider is the size of the model time step: our Eulerian spectral model must use quite short time steps (300-450 s) to avoid numerical instabilities in the meteorology, whereas the semi-Lagrangian ECMWF IFS dynamical core allows much longer time steps. It's possible we might not be seeing instabilities from the temperature term in the photochemistry scheme due to our smaller model time steps.

Section 4.1

By "updated" we are referring to the most recent values of the CD86 photochemical coefficients, kindly provided by H. Teyssedre of Meteo-France. Our understanding is that the coefficients have been recalculated from time to time since the original Cariolle and Deque (1986) parameterization was first published. The version we are using is the same as the one currently used in the ECMWF IFS. More details are given in Dethof (2003). We will try to make this clearer in final revision.

Section 4.2

We thank the referee for bringing these facts to our attention. We were not aware that ozone observations poleward of 40° latitude are not being assimilated in the ECMWF system. In light of this, the large differences between the GEOS4 and ECMWF ozone analyses evident in Figure 9 can be seen as a result of the ECMWF system not capturing the unusually low ozone values near 65°N over the Atlantic sector (e.g., Figures 9 and 10). Where the ozone values are closer to climatology (e.g., Figure 11), both the GEOS4 and ECMWF analyses agree quite well. We have modified the text in Section 4.2 to reflect this. As we originally stated in Section 4.2, large differences between the GEOS4 and ECMWF ozone analyses are only evident during the SOLVE2 period at high latitudes, e.g. 60°N-90°N. At lower latitudes both systems produce very similar results. However, since this paper focuses on the SOLVE2 campaign, further examination of lower latitude regions would not be directly relevant (e.g., no SOLVE2 aircraft validation data were acquired at these lower latitudes).

Section 4.3

Figures 10 & 11

In Figure 10, the ozone profiles are located at or near Kiruna, Sweden (68°N, 20°E). This lies in a wider region where stratospheric ozone is unusually low. As mentioned above, the GEOS4 ozone analyses used to initialize the NOGAPS-ALPHA hindcast capture this feature much better than the ECMWF analysis. In this case, the consequence of a poor initialization is a poor forecast throughout the 5-day period. In Figure 11, the profiles are located near a region of near-normal ozone values, so there are no large differences between the GEOS4 and ECMWF analyses. However, Figure 11 shows that there are noticeable differences between the NOGAPS-ALPHA hindcast using the CD86 scheme and the other schemes (CHEM2D, LINOZ) in the lower stratosphere after 120 hours. All three schemes in NOGAPS-ALPHA are using the same ozone mixing ratio climatology (r_o), but they have different values of the coefficient $\partial(P-L)/\partial r$. Comparison of this coefficient between the 3 different schemes shows the CD86 values differ from the other two in the sense that the effective ozone relaxation time (the negative reciprocal of $\partial(P-L)/\partial r$) is much shorter in the CD86 scheme. The contribution from the $(P-L)$, $\partial(P-L)/\partial T$, and column sensitivity terms are fairly small here, so we can be reasonably sure that the differences between the three NOGAPS-ALPHA hindcasts result from differences in the $\partial(P-L)/\partial r$ term in each of the three photochemistry schemes. Taken together, Figures 10 and 11 illustrate one central conclusion of this work: that the short-term ozone simulations for these specific case studies appear to be (roughly) equally dependent on BOTH initialization procedures and the photochemical parameterizations.

ECMWF and SAGE III agreement 50-150 hPa

While it is difficult to determine exactly why the ECMWF and SAGE3 profiles appear to agree so well over Kiruna between 100-50 hPa (Figure 10), it is possible to rule out downward transport suggested by the referee. Since this feature persists over the entire simulation period (0-120 hours), it is likely due to the ozone initialization itself. Time scales for downward transport due to the residual meridional circulation are too slow to explain this lower stratospheric feature. Furthermore, in our description of the synoptic conditions for the case 1 period (11-16 January 2003), we note that this region is influenced by unusually strong adiabatic cooling related to uplift associated with the passage of a upper tropospheric anticyclone. We should also note that the information content of the SAGE3 retrieval is fairly low here since this region lies below the peak in the ozone profile. Based on these facts, we suspect that both the SAGE3 profiles and the ECMWF analyses are using similar ozone climatologies in the lower most stratosphere. We have revised the discussion in section 4.3 to clarify this point.

Using same ozone climatology in ECMWF and NOGAPS-ALPHA

Note that all three NOGAPS-ALPHA hindcasts use the same ozone mixing ratio climatology, e.g. Fortuin and Kelder (1998). This climatology is similar, but not necessarily identical, to the Fortuin and Langematz climatology used in the ECMWF IFS. Therefore, it is not expected that the ECMWF operational forecasts and the NOGAPS-ALPHA hindcasts using CD86 should exhibit the same tendency, since identical climatologies are not being used. The fact that we get this similar tendency leads us to conclude that it is due to the identical photochemical coefficients being used, and in particular the $\partial(P-L)/\partial r$ term.

Figure 12

The author is correct that by itself Figure 12 does not present a direct comparison between the CHEM2D and CD86 schemes necessary to justify are conclusion. Therefore we have added a new panel to this figure showing a T239L54 NOGAPS-ALPHA hindcast that employs the CD86 photochemistry scheme and the GEOS4 ozone analyses for initialization of the prognostic ozone fields. In this new Figure 12, comparison of the NOGAPS-ALPHA hindcasts using the CHEM2D (Fig 12a) and CD86 (Fig 12c) schemes reveals that the CD86 scheme produces zonal variations in total ozone that are smaller than observed. This feature is consistent with the shorter ozone relaxation times previously noted in the CD86 scheme.

Section 5.4

Figures 19 & 20

The ECMWF archives its T511L60 IFS operational forecast fields on a reduced N256 Gaussian grid. While in the spectral model there are 1024 longitude points around every latitude when transformed into gridpoint fields, on the reduced grid this is thinned out significantly at high latitudes, such that there are only 360 longitude points at 70°N (1° zonal resolution) and 192 longitude points at 80°N (1.875° zonal resolution) on this N256 reduced grid. This plays a big part in the smoother look of these ECMWF forecast fields in Figure 20. The contours, which show changes from gridpoint to gridpoint, still seem to suggest higher resolution than the NOGAPS-ALPHA fields in Figure 19, but this is a little deceiving. This is because the latitudinal resolution of the reduced N256 grid remains unchanged, retaining the full 512 latitude points at the original 0.35° meridional resolution.

While this data thinning undoubtedly contributes somewhat to the smoother look of these fields, it does not explain the overall large-scale lack of variability, as the reviewer points out. To test this, we performed an additional NOGAPS-ALPHA experiment that initialized the ozone fields using the ECMWF operational ozone analysis fields for 17 January, 2003 at 0Z, rather than the GMAO ozone analysis fields, again using CHEM2D ozone photochemistry scheme. This allows us to compare two NOGAPS-ALPHA ozone simulations in which the only difference is the ozone initialization, to see whether the shortcomings at high latitudes of the ECMWF ozone analysis may help explain the lack of structure noted by the reviewer in Figure 20.

This additional model run shows that the ECMWF-initialized NOGAPS-ALPHA ozone hindcasts at 114 hours over DC-8 flight segment 2 closely resemble the operational ECMWF ozone forecast in the original Figure 20. In the revised paper we have added an additional panel to Figure 20 comparing the operational ECMWF 114-hour ozone forecast along FS2 with this NOGAPS-ALPHA simulation using the ECMWF ozone for initialization. Thus our conclusion, based on this additional run, is that the lack of structure in Figure 20 is due to a lack of initial structure built in to the 0 hour ECMWF ozone initialization. This in turn appears to be a consequence of the fact that ozone observations used in the ECMWF ozone analyses are confined to latitudes equatorward of ±40°N, as the reviewer has pointed out.

Another factor that may contribute even further to the lack of structure in Figure 20 is the Cariolle-Déqué photochemistry scheme used in the ECMWF model, which has much faster photochemical relaxational time scales and thus pushes the hindcast back towards the reference 2D ozone climatology more rapidly than the CHEM2D scheme, for instance.

Hindcast vs. forecast

We have made changes throughout the manuscript so that the two terms are now used consistently. "Hindcast" refers to all NOGAPS-ALPHA runs. "Forecast" refers to the ECMWF results from archived operational forecasts generated during the SOLVE2 period from January-February 2003.

REFERENCES

Daley, R., and E. Barker (2001), NAVDAS: formulation and diagnostics, Mon. Wea. Rev., 129, 869-883.

Derber, J. C., and W.-S. Wu (1998), The use of TOVS cloud-cleared radiances in the NCEP SSI analysis system, Mon. Wea. Rev., 126, 2287-2299.

Douglass, A. R., M. R. Schoeberl, R. B. Rood, and S. Pawson (2003), Evaluation of

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transport in the lower tropical stratosphere in a global chemistry and transport model, J. Geophys. Res., 108(D9), 4259, doi:10.1029/2002JD002696.

Schoeberl, M. R., A. R. Douglass, Z. Zhu, and S. Pawson (2003), A comparison of the lower stratospheric age-spectra derived from a general circulation model and two data assimilation systems, J. Geophys. Res., 108(D3), 4113, doi:10.1029/2002JD002652.

Tan, W. W., M. A. Geller, S. Pawson, and A. da Silva (2004), A case study of excessive subtropical transport in the stratosphere of a data assimilation system, J. Geophys. Res., 109, D11102, doi:10.1029/2003JD004057.

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