Comment on: Stratospheric Ozone Depletion at northern mid-latitudes in the 21st century: The importance of future concentrations of greenhouse gases nitrous oxide and methane

M. P. Chipperfield and W. Feng
School of the Environment, University of Leeds, Leeds, UK

Received 27 September 2002; revised 6 March 2003; accepted 12 March 2003; published 8 April 2003.

INDEX TERMS: 0341 Atmospheric Composition and Structure: Middle atmosphere—constituent transport and chemistry (3334); 0325 Atmospheric Composition and Structure: Evolution of the atmosphere; 0340 Atmospheric Composition and Structure: Middle atmosphere—composition and chemistry; 1610 Global Change: Atmosphere (0315, 0325). **Citation:** Chipperfield, M., and W. Feng, Comment on: Stratospheric Ozone Depletion at northern mid-latitudes in the 21st century: The importance of future concentrations of greenhouse gases nitrous oxide and methane, *Geophys. Res. Lett.*, *30*(7), 1389, doi:10.1029/2002GL016353, 2003.

[1] Recently, *Randeniya et al.* [2002] (hereafter R2002) presented predictions of the future evolution of stratospheric O_3 over 2000–2100 based on two-dimensional (2D) model calculations. They investigated two IPCC scenarios covering high (A1F1) and low (B1) greenhouse gas (GHG) emissions, and a third based on A1F1 but with reduced CH_4 emissions. Among their results, they concluded that stratospheric O_3 may only partially recover towards pre-1980 values by around 2050 and argued that after this date it may again decline due to increases in stratospheric NO_x produced from increasing N_2O. However, R2002 did not include the coupled effects of GHG-induced temperature (T) changes on future O_3 trends. They did estimate the effect of future CO_2-induced stratospheric cooling on column O_3 using results of a single GCM simulation based on an unspecified scenario. When these GCM T changes were imposed on their 2D model the increase in column O_3 at northern mid-latitudes in 2100 was around 1%.

[2] Future cooling from increases in GHGs (most importantly CO_2) is a well-established feedback in the stratosphere [e.g. *Haigh and Pyle*, 1979]. We have performed similar 2D model calculations to R2002 but which include this feedback. This makes qualitative changes to the predicted future O_3 and we would therefore like to expand on the conclusions of R2002 by discussing our coupled calculations.

[3] We have used a global 2D dynamical-radiative model *Kinnersley* [1996] which extends from the ground to ~80km with a resolution of 9.5° (horizontal) and ~3.5 km (vertical). The model calculates its own temperatures using the model O_3, CO_2, CH_4, N_2O and NO_2. The model uses the stratospheric chemical module from the SLIMCAT 3D model [*Chipperfield*, 1999]. (Note that the model does not contain detailed tropospheric chemistry such as non-CH_4 hydrocarbons). Photochemical data is from *Sander et al.* [2000]. The model includes the effects of liquid aerosols in the lower stratosphere (LS) although in the runs presented here it did not include the effect of chlorine activation on cold solid/liquid particles as the model-calculated temperatures are not realistic enough to ensure a realistic timing/extent of polar stratospheric clouds (PSCs).

[4] Note that in the polar LS cooling may enhance PSC-induced O_3 loss, although stronger planetary wave activity may actually warm the Arctic vortex [e.g. *Austin et al.*, 2002]. However, 3D models are required to capture the interaction of the polar vortex and PSC chemistry realistically. Such 3D models are computationally expensive while 2D models are much cheaper but can still capture many of the chemical-radiative feedbacks of the global stratosphere.

[5] Six 2D model integrations were performed covering the period 1970–2100 (Table 1). These runs used either the A1F1 or B1 scenarios for GHGs. The model CO_2 (only used in the T calculation) was either time-varying (from the appropriate IPCC scenario) or fixed at the year-2000 value. The halogen scenario was taken from *WMO* [1999] scenario A3. The aerosol loading was taken from *WMO* [1999] for the period 1979–1995. Before 1979 and after 1995 the aerosol loading was held constant at these initial/final values.

[6] Figure 1 shows the evolution of column O_3 at 35°N–60°N from the six model runs. Over the period 1980–2000 the model produces a downward trend in O_3 and the enhanced loss after the eruption of Mt Pinatubo in June 1991. (Due the small modelled changes in the troposphere (see Figure 2), Figure 1 shows essentially only stratospheric O_3 changes). The model underestimates the extent of the overall decrease and early 1990s' dip due to the neglect of some polar processing and the inability of the model to capture dynamical effects [see *Hadjinicolaou et al.*, 1997]. However, the model performs reasonably over this period in line with other 2D models, though by 2000 our model indicates less column depletion than that of R2002.

[7] After 2000, the model runs with fixed CO_2 (and hence largely fixed T) show similar features to the calculations of R2002. Runs FA1, FB1 and FA1C all show an increase in O_3 towards the middle of the century followed by a decrease again. No run shows column O_3 returning to 1980 levels. Compared to R2002 our model shows only a slight enhancement of O_3 loss in run FA1 compared to FB1 in the year 2100, though our A1F1 run with low CH_4 (FA1C) also shows significantly more O_3 loss.

[8] The evolution of column O_3 changes dramatically when the T feedback effects of CO_2 are included. For all scenarios the O_3 recovery is initially more rapid and reaches

0094-8276/03/2002GL016353$05.00

Table 1. Two-Dimensional Model Experiments

Run	IPCC Scenario	CO_2
VA1	A1F1	369 ppmv in 2000 to 958 ppmv in 2100
FA1	A1F1	Fixed at 369 ppmv from 2000 onwards
VB1	B1	369 ppmv in 2000 to 548 ppmv in 2100
FB1	B1	Fixed at 369 ppmv from 2000 onwards
VA1C	A1F1 (B1 CH_4)	369 ppmv in 2000 to 958 ppmv in 2100
FA1C	A1F1 (B1 CH_4)	Fixed at 369 ppmv from 2000 onwards

larger values. For the low-GHG scenario B1 (run VB1) column O_3 returns to 1980 values while for the high-GHG scenario A1F1 (run VA1) column O_3 is predicted to exceed 1980 values by over 3% towards the end of the century. Note that in the high GHG scenario the T effect of CO_2 outweighs the chemical effect of increased NO_x from N_2O: the inclusion of the T feedback has reversed the order of which scenario gives the largest O_3 loss.

[9] The CO_2-induced stratospheric cooling increases column O_3 by reducing the rate of gas-phase loss processes. (Note that late in this century the stratospheric halogen loading will have returned to pre-1980 values and enhanced O_3 loss in the LS due to cooling and more PSCs should not be an important effect.) Model profiles of O_3, ΔO_3 and ΔT are shown in Figure 2. The model runs with fixed CO_2 also show a small cooling trend due to the increases in other GHGs, but the largest effect is from CO_2. The changes in the mid stratosphere from 2000–2050 in the coupled run VA1 are similar to the 5K cooling reported by *Rosenfield et al.* [2002] and this increases to a 12 K cooling by 2100. The runs with CO_2 feedback have more O_3 throughout the mid-upper stratosphere in 2100. The fixed CO_2 runs show a similar profile change from 2000–2100 as R2002, with a minimum near 10 hPa due to increase NO_x-catalysed loss. The effect of the stratospheric cooling is to increase O_3 throughout the mid-upper stratosphere in 2100 relative to 2000.

[10] There is also a small feedback of the cooling on a reduced yield of NO_x from N_2O [*Rosenfield and Douglass*, 1998], which further reduces the impact of increased N_2O. Figure 3 shows that by 2100 the high GHG scenario A1F1 has increased tropospheric N_2O with respect to B1 by 22%. In the runs with fixed CO_2 this increases mid-stratosphere NO_y by 18%. However, when the effect of CO_2-induced cooling is considered the increase in NO_y is only around 12%.

[11] In summary, for predictions of the future evolution of the O_3 layer it is essential to include the well-known feedback of stratospheric cooling caused by increasing GHGs [see also *Rosenfield et al.*, 2002]. Studies exploring different scenarios of chemically important species (e.g.

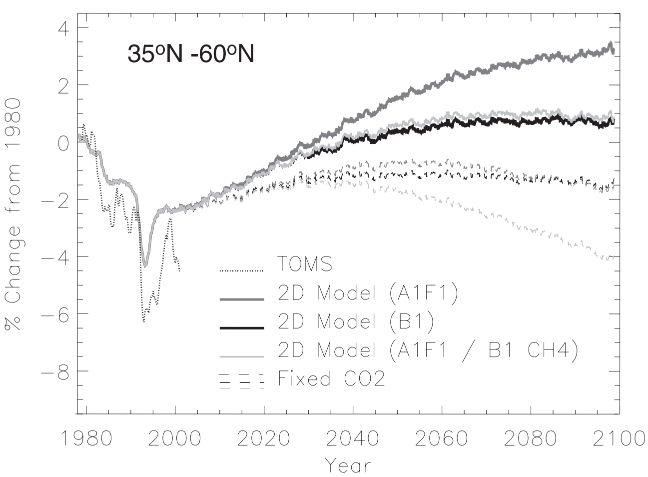

Figure 1. Variation in NH mid-lat. column O_3 (% change since 1980). Results of six 2D model runs are shown (see Table 1) with and without T feedback of CO_2 increases. Also shown are observed past changes from satellite data.

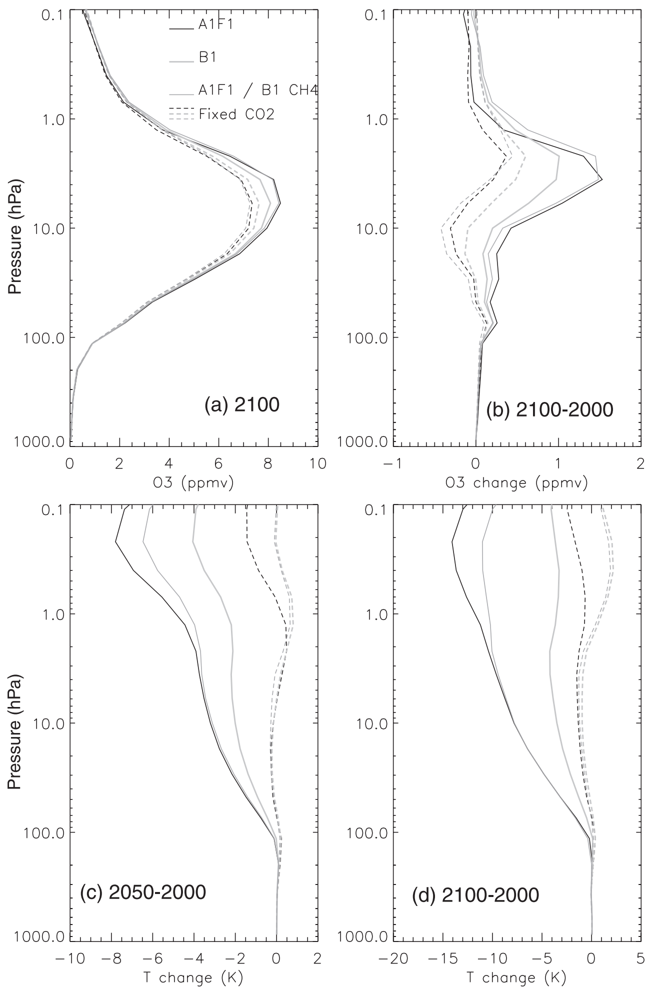

Figure 2. Profiles of (a) O_3 in 2100, (b) ΔO_3 from 2000–2100, (c) ΔT from 2000–2050 and, (d) ΔT from 2000–2100 from the model runs for 47°N in Sept. Note the modelled ΔO_3 and ΔT in the troposphere are essentially zero.

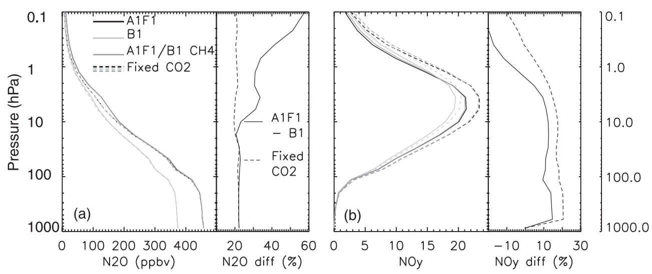

Figure 3. Profiles of (a) N_2O, and (b) NO_y at 47°N in 2100 from the 6 2D model runs (left) and the differences between runs with IPCC scenarios A1F1 and B1 (right).

CH_4, N_2O) also need to consider the possible future scenarios of CO_2. CO_2-induced cooling may cause stratospheric O_3 to recover to values greater than 1980 levels during this century.

References

Austin, J., et al., Uncertainties and assessments of chemistry-climate models of the stratosphere, *Atmos. Chem. Phys.*, *3*, 1–27, 2002.

Chipperfield, M. P., Multiannual simulations with a three-dimensional chemical transport model, *J. Geophys. Res.*, *104*, 1781–1805, 1999.

Haigh, J. D., and J. A. Pyle, A two-dimensional calculation including atmospheric carbon dioxide and stratospheric ozone, *Nature*, *279*, 222–224, 1979.

Hadjinicolaou, P., J. A. Pyle, M. P. Chipperfield, and J. A. Kettleborough, Effect of interannual meteorological variability on mid-latitude O_3, *Geophys. Res. Lett.*, *24*, 2993–2996, 1997.

Kinnersley, J. S., The climatology of the stratospheric THIN AIR model, *Q. J. R. Meteorol. Soc.*, *122*, 219–252, 1996.

Randeniya, L. K., P. F. Vohralik, and I. C. Plumb, Stratospheric ozone depletion at northern mid latitudes in the 21st century: The importance of future concentrations of greenhouse gases nitrous oxide and methane, *Geophys. Res. Lett.*, *29*, 10.1029/2001GL014295, 2002.

Rosenfield, J. E., and A. R. Douglass, Doubled CO_2 effects on NO_y in a coupled 2D model, *Geophys. Res. Lett.*, *25*, 4381–4384, 1998.

Rosenfield, J. E., A. R. Douglass, and D. B. Considine, The impact of increasing carbon dioxide on ozone recovery, *J. Geophys. Res.*, *107*, (No. D6), 10.1029/2001JD000824, 2002.

Sander, S. P., et al., Chemical kinetics and photochemical data for use in stratospheric modeling, Evaluation No 13, JPL Publication 00-3, Jet Propulsion Laboratory, 2000.

WMO, World Meteorological Organisation, Scientific assessment of ozone depletion: 1998, Global Ozone Research and Monitoring Project, No 44, 1999.

M. P. Chipperfield and W. Feng, School of the Environment, University of Leeds, Leeds, LS2 9JT, UK. (martyn@env.leeds.ac.uk)