CMAM projections of the dynamical and chemical effects on ozone through the 21st Century

David Plummer[1], John Scinocca[2], Ted Shepherd[3], Stephen Beagley[4] and Kirill Semeniuk[4]

e-mail: David.Plummer@ec.gc.ca

[1]Environment Canada, Montreal, Canada; [2] Environment Canada, Victoria, Canada; [3]University of Toronto, Toronto, Canada; [4]York University, Toronto, Canada

ABSTRACT: The Canadian Middle Atmosphere Model (CMAM) was used to produce a three-member ensemble of 'REF2' simulations covering 1950-2100 for the previous CCMVal model intercomparison (Eyring et al., 2007). Recovery of total column ozone projected by these simulations is not simply a result of decreasing stratospheric concentrations of ozone depleting substances (ODSs), but reflects additional effects of CO_2-driven cooling and changes in the Brewer-Dobson circulation as climate change acts simultaneously. The time series of column ozone is found to be well represented by regression onto a two-term expression accounting for changes in ODS concentrations and a linear trend term to account for secular changes. The contribution of these terms to changes in the ozone column, and the likely physical mechanism behind the trends, are analyzed below.

Long term trends in column ozone are fitted to: Oz(t) = a•EESC + b•t,

- EESC is the Equivalent Effective Stratospheric Chlorine from Newman et al. (2006).
- linear trends are chosen because both tropical upwelling and upper stratospheric temperatures show linear trends through the entire experiment

Trends in total column ozone are analyzed as resulting from changes over two vertical regions:

(1) Above 20 hPa: resulting from the EESC term (5-year age of air) and a linear term from long-term cooling

(2) From 400 to 20 hPa: resulting from the EESC term (3 year age of air) and a linear term, assumed to arise from dynamical effects

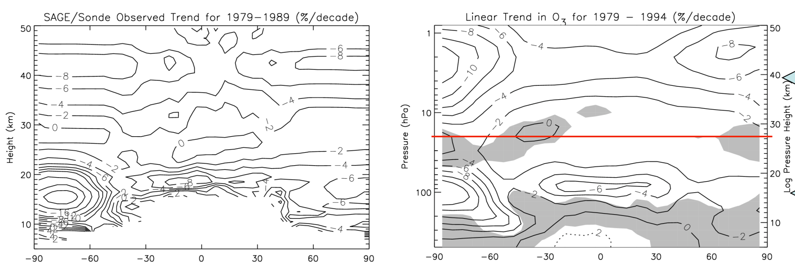

Figure 1. A comparison of the linear trends in ozone number density for the recent past from the Randel and Wu (2007) dataset (left panel) with CMAM (right panel).

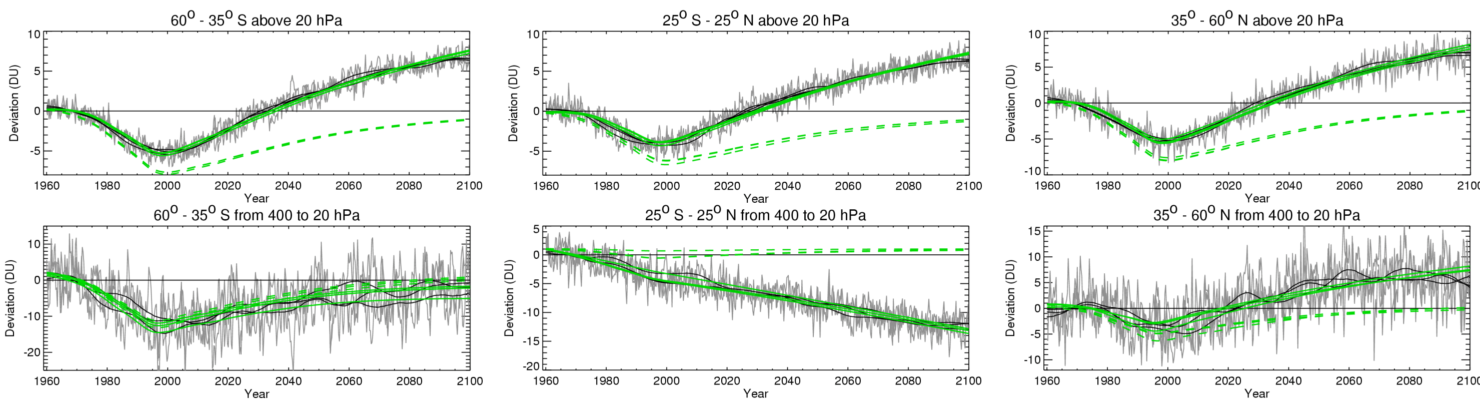

Figure 2. The evolution of the deseasonalized ozone column over different latitude bands and different height ranges (grey lines; black lines giving the smoothed time series). Also shown is the results from fitting the ozone column to the EESC and linear trend terms (green lines). The dashed green line shows only the EESC term, the solid green line shows the sum of the two terms. All quantities are plotted relative to the 1960-74 average.

Column ozone above 20 hPa: Temperature effects on chemical kinetics

All latitude bands show a strong 'super-recovery' driven by the effects of upper stratospheric cooling on the gas-phase chemical kinetics (Shepherd and Jonsson, 2008).

Column ozone between 400 and 20 hPa: increases in the B-D circulation

- the tropics show a strong decrease in ozone driven by a negative linear-trend component
- northern mid-latitudes show a super-recovery due to the positive linear trend component.
- the southern hemisphere mid-latitudes follow the EESC component with little additional linear trend.

Although not shown here, the increase in northern mid-latitudes is driven by changes in the spring-time buildup of ozone and likely related to increased northward transport of ozone. The loss in the tropics, most pronounced in the lower stratosphere, is believed due to a related cause - increased tropical upwelling bringing low O_3 concentrations from the troposphere.

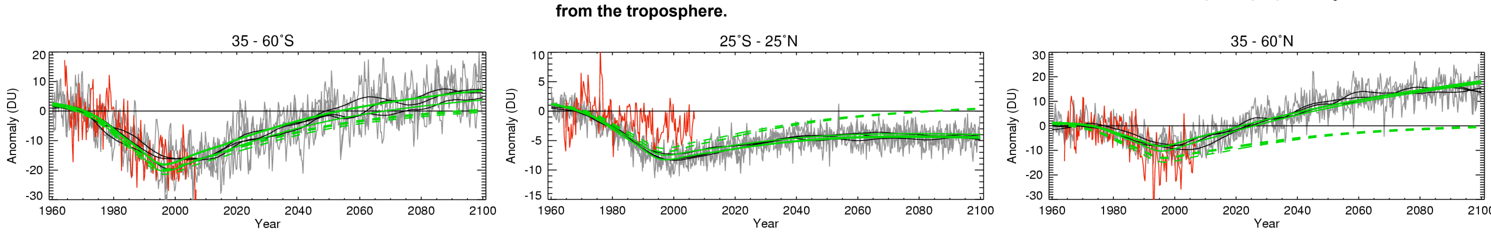

Figure 3. The evolution of the deseasonalized total column ozone over different latitude bands (grey lines; black lines giving the smoothed time series). Ground-based observations, with solar cycle, QBO and volcanic effects removed, are shown by the red lines (updated from Fioletov et al., 2002) Also shown is the results from fitting the total column ozone to the EESC (3 year age) and linear trend terms (green lines). The dashed green line shows only the EESC term, the solid green line shows the sum of the two terms. All quantities are plotted relative to the 1960-74 average.

Conclusion: Fitting secular trends in column ozone from the CMAM REF2 simulations to an EESC- and a linear-trend, the relative contributions to changes in column ozone can be attributed to declining ODSs, temperature effects in the upper stratosphere and dynamical changes. This analysis shows that approximately 50% of the increase in northern mid-latitude ozone after the year 2000 can be attributed to changes in ODSs, with the remainder attributed, approximately equally, to temperature effects on chemical kinetics in the upper-stratosphere and to increased poleward transport of ozone in the mid- to lower stratosphere.

Eyring, V. et al. Multimodel projections of stratospheric ozone in the 21st century, *J. Geophys. Res.*,112, doi:10.1029/2006JD008332, 2007.
Fioletov, V. E., G. E. Bodeker, A. J. Miller, R. D. McPeters and R. Stolarski, Global and zonal total ozone variations estimated from ground-based and satellite measurements: 1964-2000, J. Geophys. Res., 107, 4647, doi:10.1029/2001JD001350, 2002.
Randel, W. J. and F. Wu, A stratospheric ozone profile data set for 1979-2005: Variability trends and comparisons with column ozone data, *J. Geophys. Res.*, 112, doi: 10.1029/2006JD007339
Shepherd, T. G. and A. I. Jonsson, On the attribution of stratospheric ozone and temperature changes to changes in ozone-depleting substances and well-mixed greenhouse gases, Atmos. Chem. Phys, 8, 1435-1444, 2008.

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