A semi-empirical approach to projecting the recovery of the Antarctic ozone hole using a range of emission scenarios

Stefanie Kremser[1], Petra Huck[2], Greg Bodeker[2], and Ulrike Langematz[1]

[1] Freie Universität Berlin, Berlin, Germany (stefanie.kremser@met.fu-berlin.de), [2]National Institute of Water and Atmospheric Research, Lauder, New Zealand

Introduction

This poster presents a computationally inexpensive approach to projecting Antarctic ozone recovery using semi-empirical models. These semi-empirical models link changes in temperature to changes in chlorine activation and ozone depletion. Chemistry Climate Models (CCMs) are traditionally used for such studies [Eyring et al., 2007]. However, CCMs are extremely computationally demanding and uncertainties due to uncertainty in future emission scenarios and model parameterisations cannot be accounted for. Future changes in Antarctic stratospheric temperatures were estimated from the UKMO HadCM3 and MPI-ECHAM5 global climate model output archived in the CMIP3 data base. In addition we present how Antarctic ozone recovery is likely to be influenced by the three different SRES emission scenarios A1b, A2 and B1.

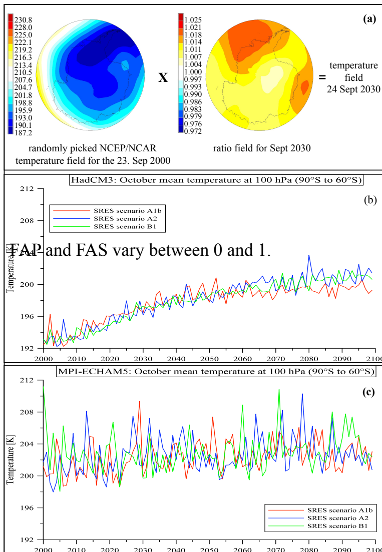

Figure 1: (a) Example of how we generate daily temperature fields (b) and (c) show the area weighted mean temperature for October at 100 hPa as simulated by HadCM3 (b) and MPI-ECHAM5 (c), respectively.

Method

Assumption: - the vortex area encompass the whole area between 60°S and 90°S

First semi-empirical model: - calculates the ClO_x time series in the Antarctic stratosphere using:

$$\frac{dClO_x}{dt} = \alpha \cdot (Cl_y - ClO_x) \cdot FAP \cdot FAS - \beta \cdot ClO_x \cdot (1 - FAP)$$

- α and β are the fit coefficients derived by optimally fitting the differential equation to satellite measurements of ClO_x obtained by the AURA MLS instrument
- Cl_y is the total stratospheric chlorine loading (Cl_y values were provided by P. Newman)
- FAP is the fractional area of the vortex covered with PSCs; FAS is the fractional area of the vortex exposed to sunlight
- FAP and FAS vary between 0 and 1.

Generate FAP: - the October mean temperature for the period 2000 to 2100 show a clear temperature rise in HadCM3 (Fig. 1b), but a very small temperature increase occurs in MPI-ECHAM5 (Fig.1c)

- future **daily** temperature fields are required
- we assume for a given day in the future that the temperature field will be similar to one of the temperature fields within 3 calendar days of that day in the period 2000 to 2007 but then scaled to accounted for a long-term transient change in the climate of the stratosphere
- therefore, for any year in the future we first randomly select a year in the period 2000-2007; within that year we randomly select a temperature field within 3 days of the current day → this field is then multiplied by the HadCM3 and MPI-ECHAM5 ratio field (Fig.1a), respectively:

$$\text{Ratio} = \frac{\text{model monthly mean temperature}}{\text{Climatological mean}}$$

- climatological mean refers to the mean temperature of the model monthly mean temperatures for the period 2000 to 2007
- 20 sets of daily FAP values were calculated, using the Monte Carlo method

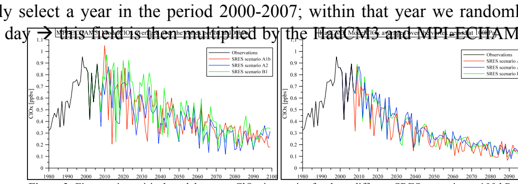

Figure 2: First semi-empirical model output: ClO_x time series for three different SRES scenarios at 100 hPa for the HadCM3 and MPI-ECHAM5 model, respectively.

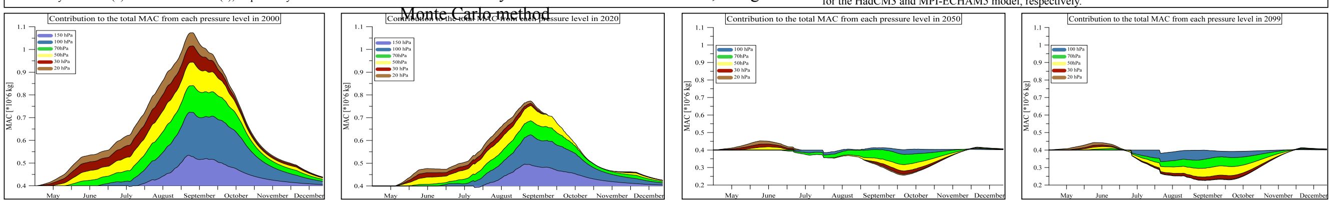

Figure 3: Example for the calculated Mass of Activated Chlorine (MAC). This figure shows the contribution from each pressure level to the total MAC for a selected number of years. To plot the MAC values, we added an offset to all calculated MAC values ($MAC_{offset} = 0.4 \cdot 10^6$ kg).

Second semi-empirical model: - relates the Ozone Mass Deficit (OMD) to the Mass of Activated Chlorine (MAC) and is given by:

$$\frac{dOMD}{dt} = (A \cdot MAC^2 + B \cdot MAC) \cdot \left(1 - \frac{OMD}{OMD_{150}}\right) - C \cdot OMD \cdot F_{act}$$

- A, B and C are the fit coefficients
- OMD_{150} is the value OMD would have if the total column ozone everywhere inside the vortex was 150 DU
- F_{act} is a measure of the actinic flux available to photolyze O_2 and form O_3
- we followed the OMD definition as described in Huck et al. [2007]
- MAC was calculated with respect to 1980 values; the contribution of each pressure level to the total MAC is shown in Fig. 3; in 2000 and 2020 the 100 hPa layer contributes the main amount to the total MAC
- afterwards, only the upper parts of the atmosphere contribute a significant amount to the total MAC, which shows a decrease from 2000 onwards
- OMD, averaged over the Antarctic vortex period (Fig. 4 and 5), decreases continuously after 2012
- with respect to 1980, ozone recovery, based on temperature fields from the HadCM3 model, occurs about 20 years earlier than based on temperature fields from MPI-ECHAM5 model

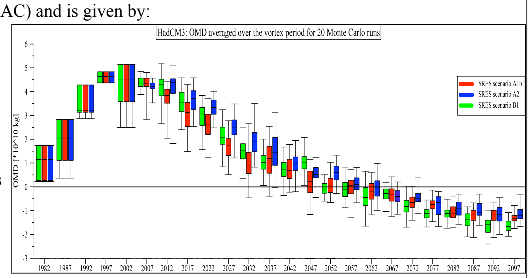

Figure 4: OMD comparison for three different SRES scenarios for HadCM3. The OMD values were averaged over the vortex period; negative values indicate that there is less OMD than in 1980 (referred as ozone recovery). The caps at the end of each box indicate the minimum and maximum, respectively. The box is defined by the lower and upper quartiles; the line in the center of the box is the median.

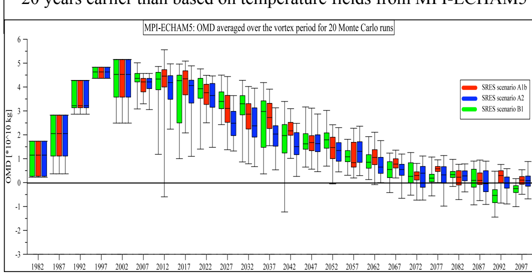

Figure 5: As Fig. 4 for the MPI-ECHAM5 model.

Conclusions

Our results show that the ozone feedback on future temperatures is very important. The stratospheric warming due to ozone recovery seems to work against the stratospheric cooling due to CO_2 increase.

As a result of the future decline in Cl_y, Antarctic ClO_x is also decreasing, but the intensity of the decline depends on the evolution of the future temperatures. Due to the high temperature variability in MPI-ECHAM5, there is also a high year to year variability in the ClO_x values.

Since the OMD responds to changes in ClO_x and thus to changes in temperature, the OMD in MPI-ECHAM5 returns to 1980 values about 20 years later than in HadCM3.

The time of the ozone recovery does not depend substantially on the different SRES scenarios.

References

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