Application of semi-empirical models to project the future of the Antarctic ozone hole in a changing climate

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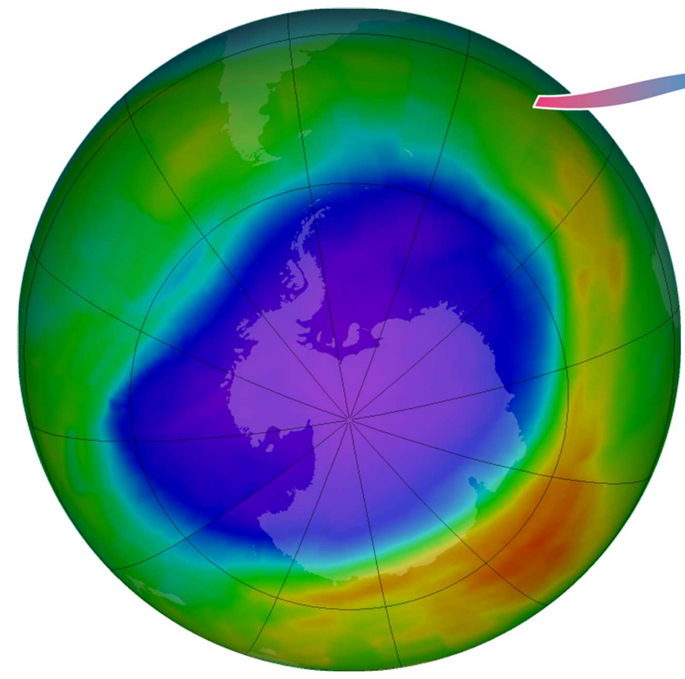
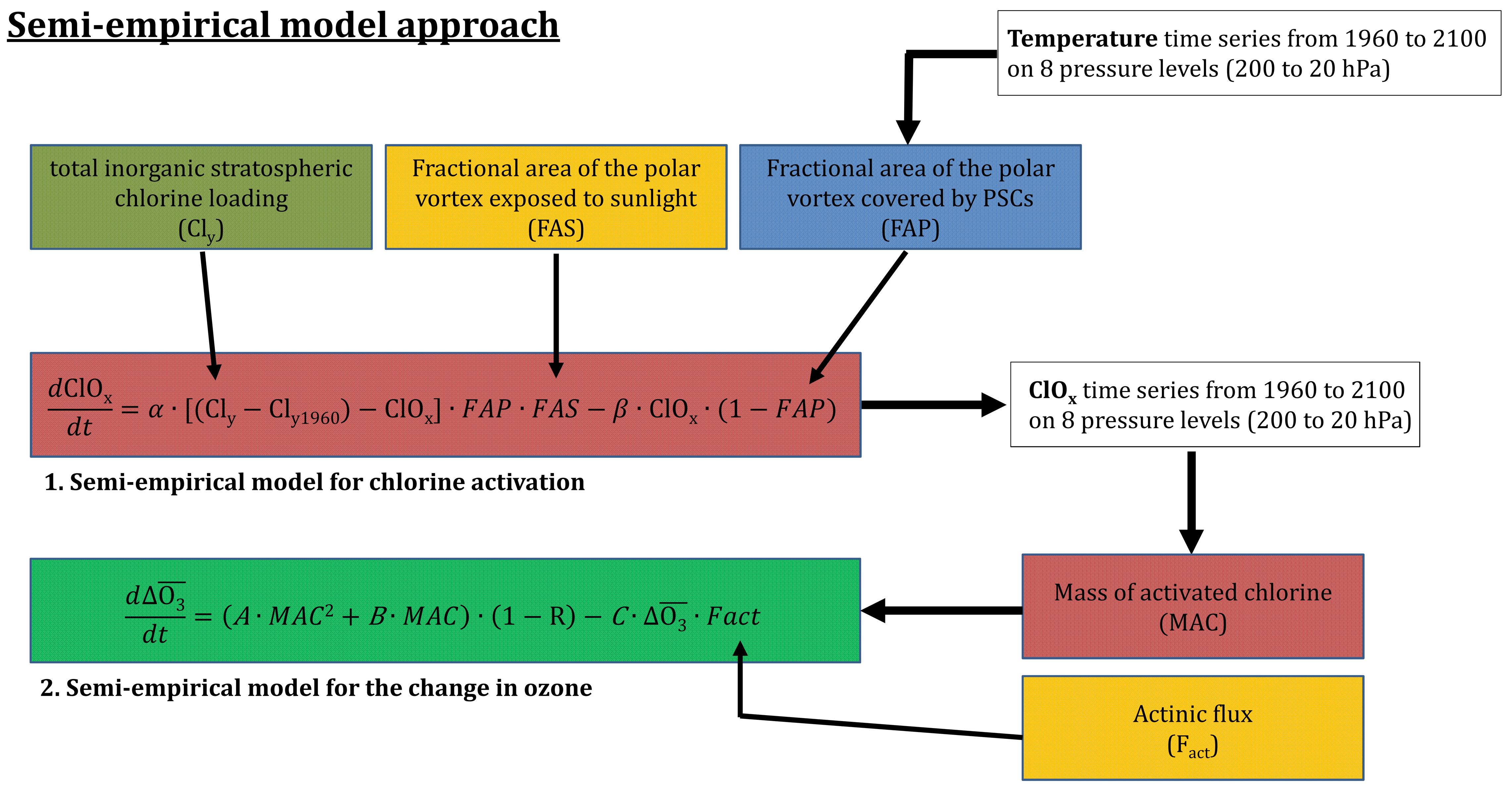


Introduction

- Establish a complementary approach to CCMs to project future Antarctic ozone levels.
- Use semi-empirical models (SEMs) of Antarctic ozone depletion – fast and inexpensive.
- SEMs take total inorganic stratospheric chlorine (Cl_y) and daily stratospheric temperature fields as input.
- Vortex average extent of polar stratospheric clouds (PSCs) and solar illumination are calculated within the model.
- Temperature trends taken from AOGCMS simulations from CMIP3 - specifically HadCM3.
- Three different greenhouse gas (GHG) emissions scenarios will be explored.
- All quantities are vortex averages and the area of the vortex is assumed to remain constant into the future.

Semi-empirical model approach



$$\frac{dClO_x}{dt} = \alpha \cdot [(Cl_y - Cl_{y1960}) - ClO_x] \cdot FAP \cdot FAS - \beta \cdot ClO_x \cdot (1 - FAP)$$

1. Semi-empirical model for chlorine activation

$$\frac{d\Delta\overline{O_3}}{dt} = (A \cdot MAC^2 + B \cdot MAC) \cdot (1 - R) - C \cdot \Delta\overline{O_3} \cdot Fact$$

2. Semi-empirical model for the change in ozone

- NCEP/NCAR stratospheric temperatures for the period 1960 to 2009 were used to estimate the vortex coverage by PSCs.
- NCEP/NCAR temperature fields from 2000 to 2009 were projected into the future by adding simulated temperature trends from HadCM3 for the period 2010 to 2100.
- Stratospheric temperature trends from three simulations performed by HadCM3, based on the IPCC Special Report on Emissions Scenario A1b, A2, and B1 were used.
- To account for future temperature variability, a Monte Carlo approach was employed to generate 1000 future temperature time series for each emissions scenario.
- The first SEM (equation 1) describes the vortex averaged time rate of change of activated chlorine (ClO_x) with respect to 1960 levels where α and β are fit-coefficients.
- Cl_{y1960} in equation 1, refers to the total stratospheric chlorine loading in 1960.
- The second SEM (equation 2) relates the total mass of activated chlorine (MAC) within a partial column extending from 200 hPa to 20 hPa to the vortex averaged time rate of change of ozone, where *A*, *B*, and *C* are fit-coefficients.
- A new metric is introduced ($\Delta\overline{O_3}$) as a direct measure of the change in ozone averaged over the Antarctic vortex core region, relative to 1960 ($\Delta\overline{O_3}^{year} = \Delta\overline{O_3}^{1960} - \Delta\overline{O_3}^{year}$).
- 1−R in equation 2, with R = $\Delta\overline{O_3}/(\Delta\overline{O_3}^{1960} - 150)$, accounts for saturation effects – it will be zero if ozone is destroyed completely within the partial column.

Determination of model fit-coefficients

- Assuming $ClO_x \approx ClO$, α and ß were derived by fitting equation 1 to day-time ClO measurements from the Microwave Limb Sounder (MLS) onboard the Upper Atmosphere Research Satellite (UARS).
- Derived fit-coefficients were used to calculate ClO_x abundances for the period 1960 to 2100.
- *A*, *B*, and *C* were derived by fitting equation 2 to ozone anomalies ($\Delta\overline{O_3}$) for the period 1980 to 2009 with respect to 1960 levels (Figure 2).
- A total column ozone baseline against which a return to 1960 values can be assessed was derived by employing a regression model together with satellite and ground-based observations (not shown).

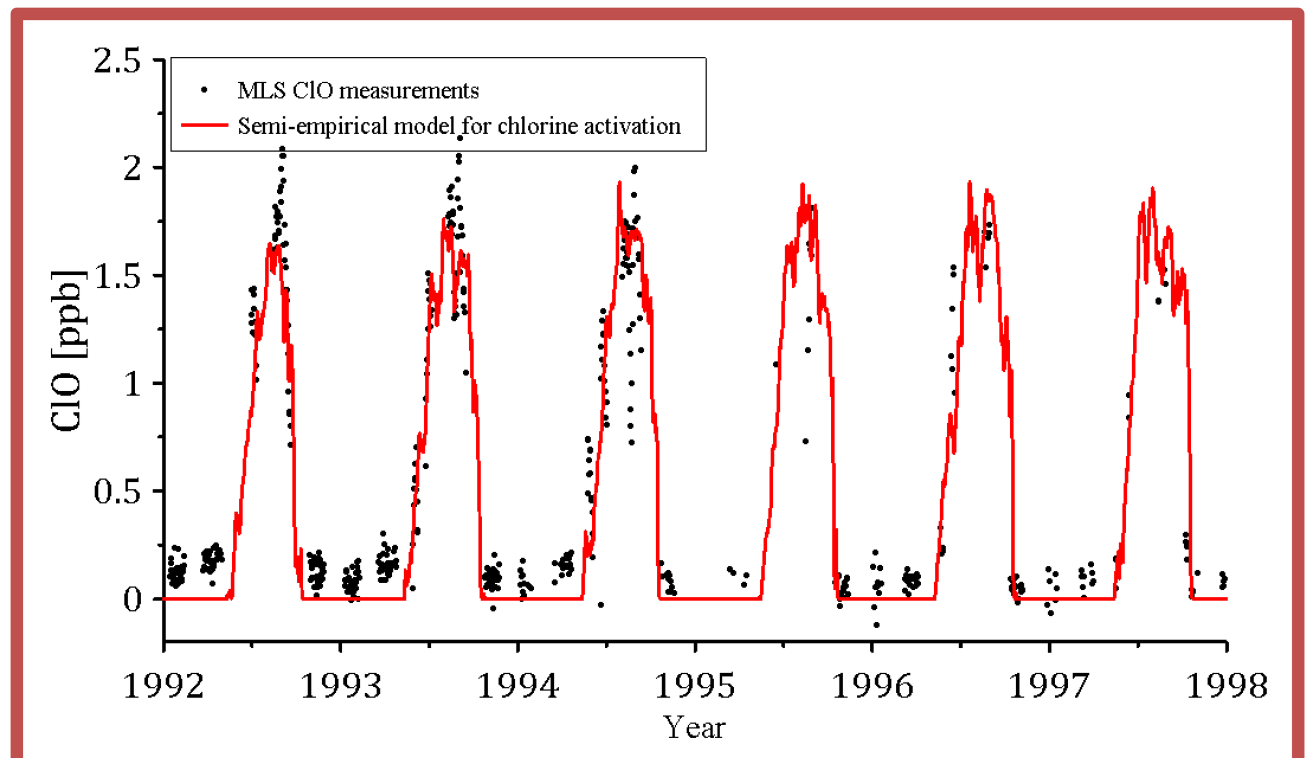


Figure 1 Semi-empirical model fit to the MLS ClO measurements

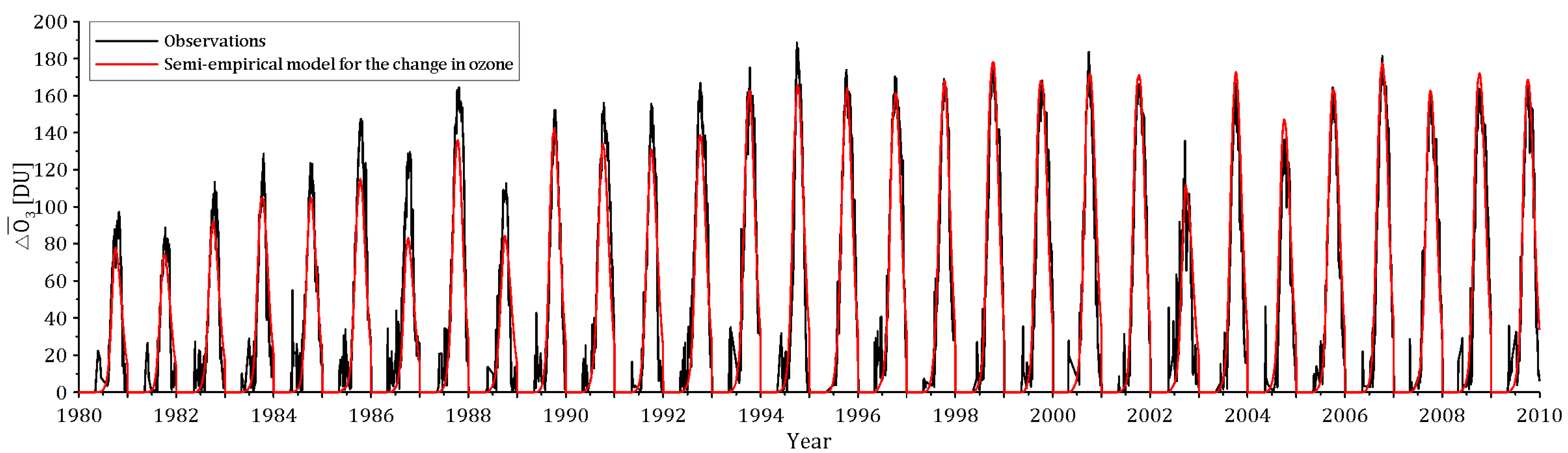


Figure 2 Vortex averaged total column ozone loss in DU as derived from observations compared to the semi-empirical model output for the period 1980 to 2009.

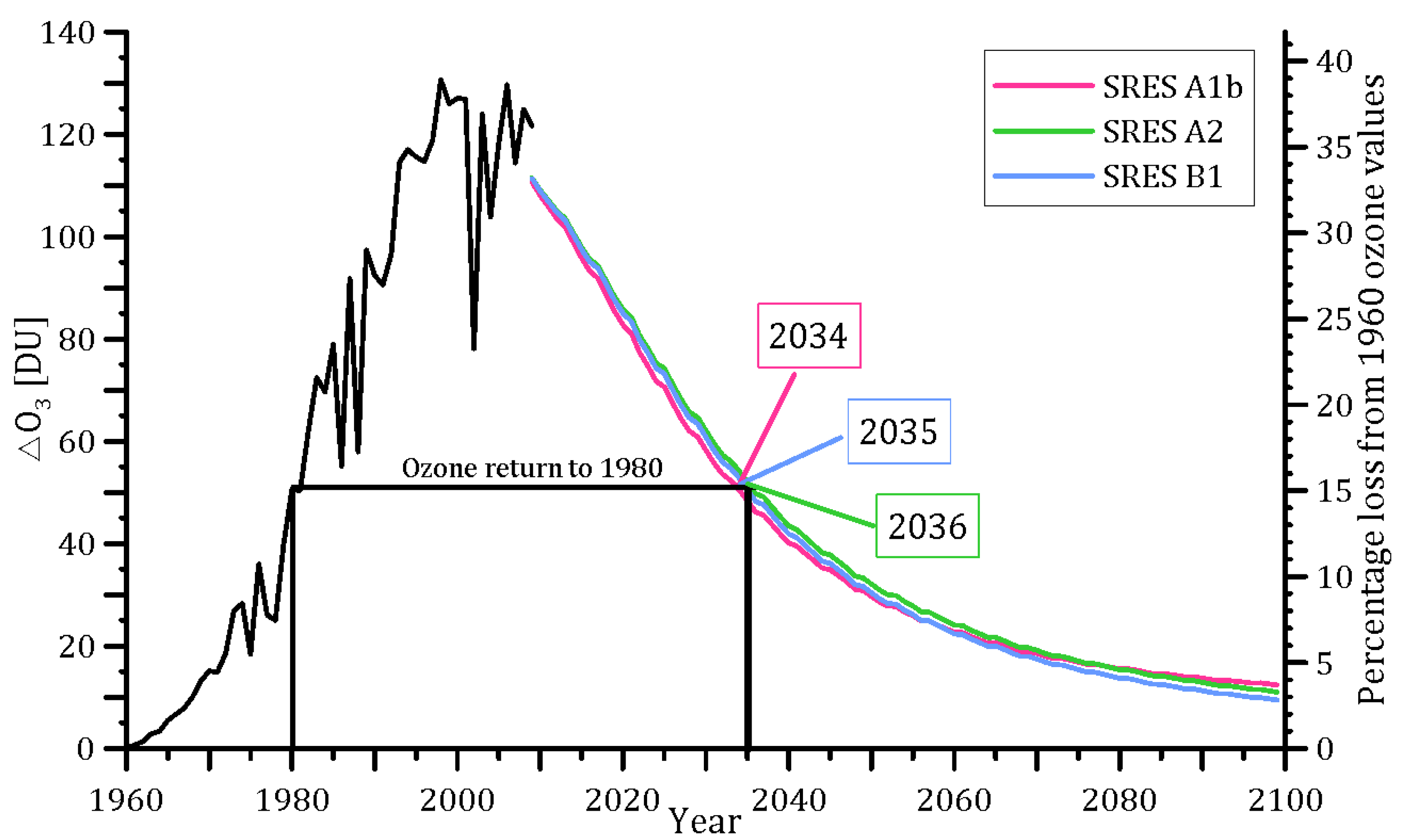


Figure 3 August to November averaged from $\Delta\overline{O_3}$ 1960 to 2100, where the August to November mean $\Delta\overline{O_3}$ from 2010 onwards are averaged over the 1000 Monte Carlo runs for each GHG emissions scenario.

Results & Conclusion

- $\Delta\overline{O_3}$ in the Antarctic stratosphere maximizes in the late 1990s and thereafter slowly decreases.
- Antarctic $\Delta\overline{O_3}$ returns to 1980 levels between 2030 and 2040 depending on the SRES scenario which is ~20 to 25 years earlier than derived from CCM simulations.
- Scenarios with greater GHG emissions have later return dates – A2 returns to 1980 about two years later than that for A1b.
- Antarctic ozone does not return to 1960 levels in the 21st century
- Results suggest that the missing temperature↔ozone feedback in HadCM3 accelerates return of ozone to 1980 levels in the Antarctic stratosphere.
- To reliably project future ozone levels the temperature↔ozone feedback has to be included in numerical models – CCM simulations or coupling AOGCM with SEMs interactively.

Acknowledgements
S. Kremser was supported through funding by the DAAD (Doktorandenstipendium), which allowed this work to be conducted. We acknowledge the modelling groups for making their model output available for analysis, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for collecting and archiving this data, and the WCRP's Working Group on Coupled Modelling (WGCM) for organizing the model data analysis activity. The WCRP CMIP3 multi-model dataset is supported by the Office of Science, U.S. Department of Energy. We would like to thank P. Newman for providing the Cl_y data.