Quantifying key sensitivities in the interaction between climate change and Antarctic ozone depletion

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Abstract A key process that links changes in climate to reductions in Antarctic stratospheric ozone is the heterogeneous activation of chlorine on polar stratospheric clouds (PSCs). Increases in greenhouse gases cool the Antarctic stratosphere, increasing the frequency and ubiquity of PSCs, and promote ozone destruction. On the other hand, increases in dynamical activity, for example increases in wave disturbances of the vortex edge and increases in the Brewer-Dobson circulation, would warm the Antarctic stratosphere and reduce ozone destruction.

Evaluating the ability of chemistry-climate models to adequately simulate this key process is central to their success in projecting the recovery of the Antarctic ozone hole.

To this end two semi-empirical models have been developed which capture key sensitivities in the interaction between climate change and Antarctic ozone depletion. The models are fitted to observations and/or model output of temperature, ClO and O3 and incorporate climate feedback effects and natural variability. By applying the semi-empirical models to both observations and CCMs, and by comparing the model coefficients between CCMs and observations, the CCMs can be subjected to a process oriented evaluation that disaggregates the effects of the chemistry and climate drivers of Antarctic ozone depletion.

Chlorine Activation Model

\[ \frac{d\text{ClO}}{dt} = \alpha \left( \text{Cl}_2 - \text{ClO} \right) \text{FAP} \cdot \text{FAS} \cdot \frac{1}{\tau} \text{ClO} \]

\( \alpha \): fit parameter
\( \tau \): chlorine deactivation half life (10 days)
\( \text{Cl}_2 \): total stratospheric chlorine
\( \text{ClO} \): active chlorine
\( \text{FAP} \): fractional area of PSCs
\( \text{FAS} \): fractional area of vortex exposed to sunlight

Fit parameter \( \alpha \) is determined by fitting the ClO model to observations (Figure 1) and to CCM output from the UMETRAC model (Figure 2).

This result indicates that for the same deactivation rate UMETRAC activates chlorine over all levels combined slower than the observations.

Summary The fit quality in the chlorine activation model for both observations and the CCM, varies with pressure level but captures the overall year-to-year variability and intra-seasonal evolution. The fit parameters indicate that for the same deactivation rate the UMETRAC model activates chlorine over all levels combined slower than what we see in the observations.

From the chlorine activation model, a total mass of activated chlorine can be estimated. This metric is used to describe ozone depletion in the Antarctic stratosphere. The ozone depletion model captures the year-to-year variability really well. Larger differences between model and observations can be seen in the earlier years.

Future Work Next steps in this study include a) fitting of the ozone depletion model to the UMETRAC ozone and b) fitting both semi-empirical equations to other CCM outputs (e.g., SOCOL and CMAM). Comparison of the resulting fit coefficients can be used for CCM validation and to better understand the differences between different CCMs or CCMs and observations.

Acknowledgements This work has been supported by the FRST contract C010709. We would like to thank Paul Newman for providing the ClO data, Michelle Santee for providing the UARS MLS ClO profiles, and NCEP/NCAR for providing the reanalysis data.