NIWA
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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 O_3 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.

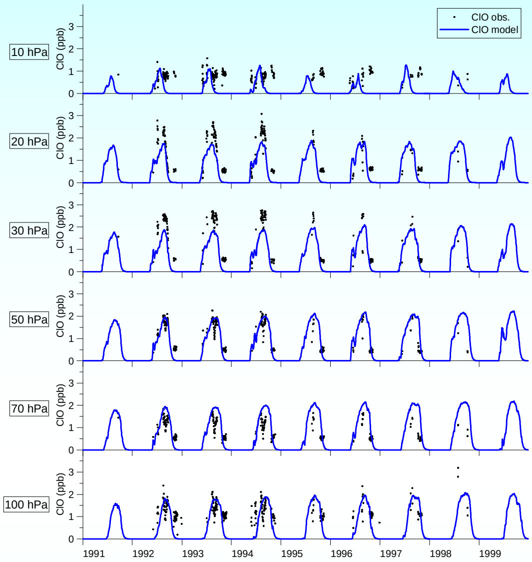

Figure 1: Model fit (blue) to MLS ClO data (black) on different pressure levels.

Chlorine Activation Model

$$\frac{dClO}{dt} = \alpha \cdot (Cl_y - ClO) \cdot FAP \cdot FAS - \frac{1}{\tau} \cdot ClO$$

α: fit parameter
τ: chlorine deactivation half life (10 days)
Cl_y: total stratospheric chlorine
ClO: active chlorine
FAP: fractional area of PSCs
FAS: fractional area of vortex exposed to sunlight

Fit parameter α is determined by fitting the ClO model to observations (Figure 1) and to CCM output from the UMETRAC model (Figure 2).
$\Rightarrow \alpha_{obs}=0.316418$
$\Rightarrow \alpha_{umetrac}=0.093785$
This result indicates that for the same deactivation rate UMETRAC activates chlorine over all levels combined slower than the observations.

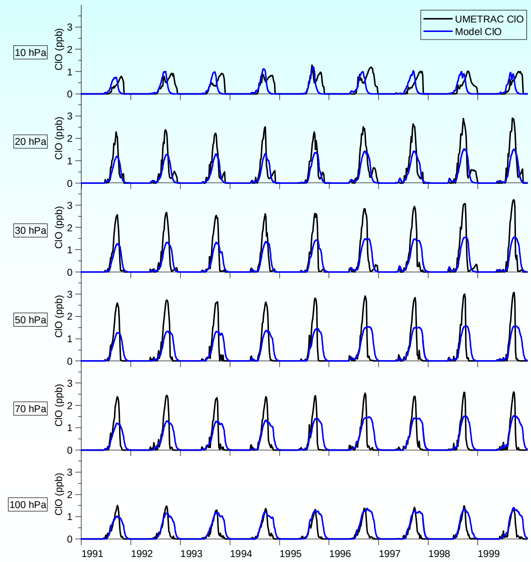

Figure 2: Model fit (blue) to UMETRAC ClO data (black) on different pressure levels.

Ozone Depletion Model

Mass of Activated Chlorine

$$MAC = \sum_p \frac{M_{Cl} \cdot p \cdot (ClO - ClO_{pre-1980}) \cdot 10^{-12} \cdot A \cdot z}{8.314 \cdot T}$$

M_{Cl}: atomic mass of chlorine
p: pressure; T: temperature
ClO: daily ClO from chlorine activation model
$ClO_{pre-1980}$: daily ClO averaged from 1979-1981
A: area within polar vortex; z: thickness of layer

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

A, B, C, D: fit coefficients
OMD: ozone mass deficit; MAC: mass of activated chlorine
OMD_{150}: the value OMD would have if ozone everywhere inside the vortex was 150 DU
F_{act}: measure of the actinic flux available to form O_3
WP: total wave power at 60°S
$\kappa(\kappa_{max})$: maximum of the meridional impermeability on this day (for all equivalent latitudes and days in a given year)

Ozone Mass Deficit

$$OMD = (bg - x) \times 2.11 \times 10^{-5} \times A$$

bg: background (pre-1980) value in DU
x: total column ozone in DU
A: area in km^2

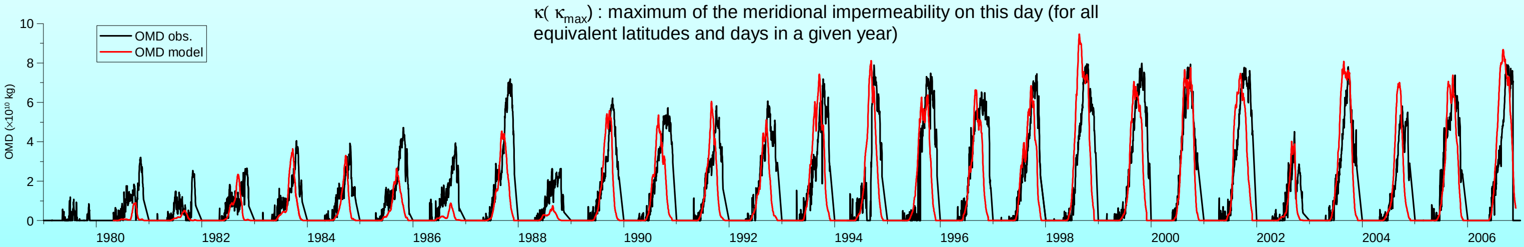

Figure 3: Model fit (red) to OMD data (black) derived from NIWA combined total column ozone data base.

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

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