Ozone and UV projections from the Chemistry-Climate Model Initiative

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Abstract. The Chemistry-Climate Model Initiative is the most recent multi-model intercomparison activity targeting the simulation and projection of global ozone. It has produced ozone projections spanning 1960-2100, following the Representative Concentration Pathways. While the models in CCMI are considerably more advanced than those participating in earlier comparable activities, e.g. regarding the widespread usage of whole-atmosphere chemistry schemes and several of them now using an interactive ocean module, projections for total-column ozone are qualitatively similar to older projections. Here we summarize the salient results of CCMI regarding stratospheric ozone depletion and recovery.

Introduction

Ozone depletion due to man-made chlorinated and brominated compounds has been documented for several decades. Following the discovery of the ozone hole (Farman et al., 1985), legislation was enacted globally, and subsequently strengthened, to phase out the usage of ozone-depleting substances (ODSs). This legislation, known as the Montreal Protocol, has been hailed as the most successful environmental protection treaty in human history. It has resulted in a sustained reduction of stratospheric halogen, and first signs of ozone recovery are now evident in various atmospheric regions, including in Antarctica (WMO, 2014). However, due to their long lifetimes, man-made halogens remain elevated in the stratosphere, the ozone hole keeps occurring every spring and will continue to do so for the coming decades, and there remain threats to the ozone layer. Also the linkages between climate change and ozone depletion have received increasing attention. A full appreciation of these linkages, and in particular of the climate effects of ozone depletion, requires the usage of complex models that simulate both climate and atmospheric chemistry. A coordinated exploitation and evaluation of the current class of such models is the subject of the Chemistry-Climate Model Initiative (CCMI; Eyring et al., 2013; Morgenstern et al., 2017). CCMI will inform upcoming ozone, climate, and perhaps air quality assessments.

Here we review selected results from CCMI, focusing on total-column ozone in the Southern Hemisphere.

Ozone return dates

Ozone return dates are defined as the dates when total-column ozone (TCO) in a particular region returns, in the annual mean or for a particular month, to its state e.g. in 1980. Figure 1 shows October Antarctic TCO as simulated by the CCMI models. On average, in the scenario discussed here, ozone is projected to return to its 1980s value in about 2062. This is significantly later than the average return dates derived from the previous generation of models (2051 by Eyring et al., 2010, or 2035 by WMO, 2014). In southern midlatitudes, ozone recovers a little earlier; here the models indicate that ozone will return to 1980 levels in about 2046 (figure 2). This is also later than the return dates found earlier (2041 by Eyring et al., 2010, and 2035 by WMO, 2014) for the previous generation of models. In the tropics, in several models ozone never returns to 1980 values and towards the end of the century undergoes a renewed decline (figure 3). Here, ozone depletion due to halogenated substances was always smaller than in mid- and high latitudes, and the behaviour shows the impact of climate change and also of chemical effects of climate gases such as methane and nitrous oxide (see below).

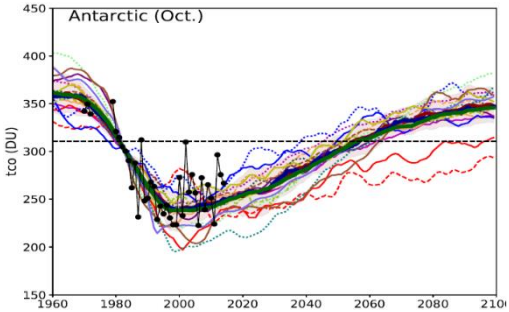

Figure 1. October Antarctic total-column ozone (TCO) in the CCMI models, after baseline adjustment. Green: multi-model mean. Black dots: observations. Colours: CCMI models. From Dhomse et al. (2018).

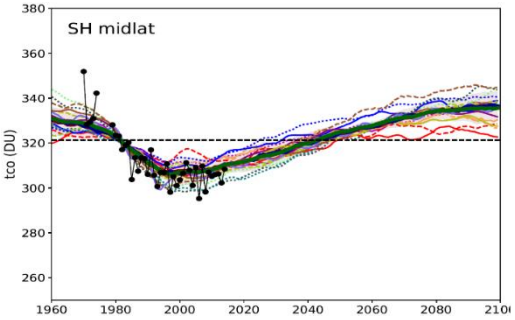

Figure 2. As figure 1 but for southern midlatitude annual-mean TCO.

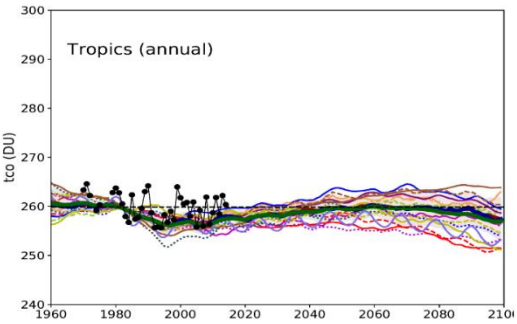

Figure 3. As figure 1 but for tropical annual-mean TCO.

Ozone depletion versus climate change

The CCMI ensemble of model simulations includes "sensitivity" simulations in which ODSs and non-ozone depleting greenhouse gases (GHGs), respectively, are held fixed at their 1960 values (Morgenstern et al., 2017). Similar experiments were also conducted in earlier intercomparisons (Eyring, 2010). Such studies are used to identify the individual impacts of reductions in halogenated ODSs versus continuing increases in climate gases. Important impacts of climate change relate to stratospheric cooling which in the extrapolar regions mostly increases stratospheric ozone but in the polar regions in winter enhances polar stratospheric cloud formation which promotes ozone depletion. Methane and nitrous oxide increases, in the global mean, lead to ozone increases and decreases, respectively, but regionally can also have opposite effects (Morgenstern et al., 2018). Climate change also causes changes in stratospheric circulation, which also affects ozone. Here we just assess the combined effects in the Representative Concentration Pathway (RCP) 6.0 (Meinshausen et al., 2011), which forms the basis of the CCMI reference simulations.

Continuing increases in GHGs, in the RCP 6.0 scenario, will substantially shorten the time to recovery in southern midlatitudes (figure 4), and in the northern extratropics (not shown), but will have a small impact on the Antarctic ozone hole. In the tropics, GHG increases will outweigh any gains from reductions in ODSs. This is similar to what has been seen before using the previous generation of models (Eyring et al., 2010), but there are differences in detail. The slower increase in methane assumed in the CCMI reference simulations (Meinshausen et al., 2011), versus the earlier assessments which follow the IPCC SRES A1b scenario (IPCC, 2000), is a major factor in the delays in ozone return dates found above.

Impacts on UV

At the time of writing, UV impacts of the ozone changes projected by CCMI have not yet been quantified, but conclusions reached from previous assessments (Bais et al., 2011) qualitatively still stand. Basically, a moderate reduction in UV reaching the surface in southern midlatitudes can be expected under ozone recovery; this trend is somewhat amplified by climate change. However, other aspects of climate change, in particular a possible change in cloudiness, could have significant impacts on the UV climate as well. While we have relatively high confidence in projected ozone changes, any change in cloud regimes would be subject to larger uncertainty, and chemistry-climate models characterized by low resolution are likely not the ideal tools to simulate this effect. Upcoming simulations under the 6th Coupled Model Intercomparison Project (CMIP6) may be of the quality needed to make more definitive statements about any trends in UV in the Southern Hemisphere.

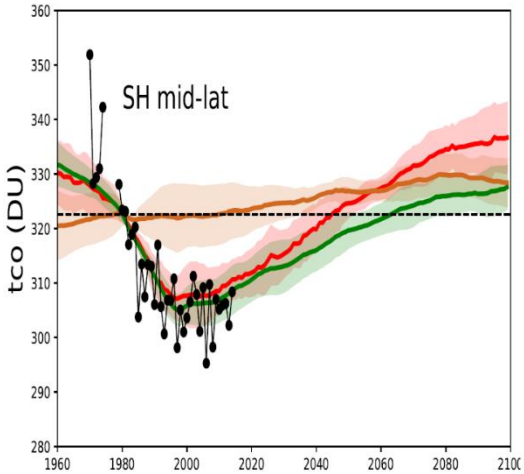

Figure 4. Southern mid-latitude annual-mean TCO in the reference (red), fixed-ozone depleting substances (brown) and fixed greenhouse gases (green) experiments. From Dhomse et al. (2018).

Acknowledgements. We acknowledge the modelling groups for making their simulations available for this analysis, the joint WCRP IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) for organizing and coordinating the model data analysis activity, and the British Atmospheric Data Centre (BADC) for collecting and archiving the CCMI model output.

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