Sensitivity of 21st century stratospheric ozone to greenhouse gas scenarios

Veronika Eyring[1], Irene Cionni[1], Jean-Francois Lamarque[2], and CCMVal Team

[1]Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany; [2]National Center for Atmospheric Research, Boulder, USA

Abstract

To understand how greenhouse gas (GHG) emissions may affect future stratospheric ozone, 21st century projections from four chemistry-climate models are examined for their dependence on six different GHG scenarios. Compared to higher GHG emissions, lower emissions result in smaller increases in tropical upwelling with resultant smaller reductions in ozone in the tropical lower stratosphere and less severe stratospheric cooling with resultant smaller increases in upper stratospheric ozone globally. Increases in reactive nitrogen and hydrogen that lead to additional chemical ozone destruction mainly play a role in scenarios with higher GHG emissions. Differences among the six GHG scenarios are found to be largest over northern midlatitudes (~20 DU by 2100) and in the Arctic (~40 DU by 2100) with divergence mainly in the second half of the 21st century. The results suggest that effects of GHG emissions on future stratospheric ozone should be considered in climate change mitigation policy and ozone projections should be assessed under more than a single GHG scenario.

We also show results from the AC&C / SPARC ozone database that was used as forcing in a subset of CMIP5 models without interactive chemistry. We are planning to extend this study to include CMIP5 model simulations with interactive stratospheric chemistry and to compare them to the AC&C / SPARC ozone database and other results.

CCMVal-2 Simulations

Simulation name	Period	GHGs	ODSs	SSTs/SICs	Main Reference
REF-B1	Transient 1960-2006	Observations	Observations	Observations (HadISST1)	*SPARC CCMVal Report (2010)*
REF-B2	Transient 1960-2100	OBS + SRES A1B(medium)	OBS + adjusted A1 scenario	Modeled SSTs and SICs	*SPARC CCMVal Report (2010)*
fODS Fixed ODSs in 1960	1960-2100	Same as in REF-B2	ODSs fixed at 1960 levels	Same as in REF-B2	*Eyring et al., ACP (2010)* *Charlton-Perez et al., ACP (2010)*
fGHG Fixed GHGs in 1960	1960-2100	GHG fixed at 1960 levels	Same as in REF-B2	1955-1964 average of REF-B2, repeating each year	*Eyring et al., ACP (2010)* *Charlton-Perez et al., ACP (2010)*
GHG-x SRES A2, B1 RCP 2.6, 4.5, 8.5	2000-2100	GHG scenario different from A1B	Same as in REF-B2	Consistent with GHG scenario	*Eyring et al., GRL (2010)*

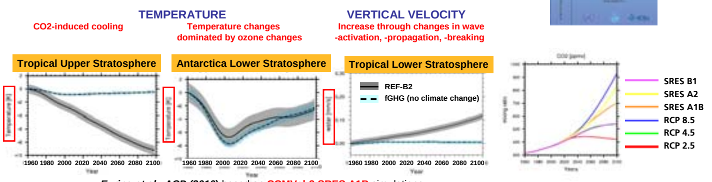
Scenarios for ozone depletion substances (ODSs) and greenhouse gases (GHGs)

IPCC SRES (2000) in IPCC AR4, new scenarios Reaction Concentration Pathways (RCPs) for IPCC AR5

Impact of climate change on the stratosphere:

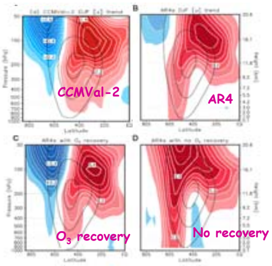
Cooling of the middle and upper stratosphere

Accelerated stratospheric circulation (leading e.g. to an increase in tropical upwelling).



Eyring et al., ACP (2010) based on **CCMVal-2 SRES A1B** simulations

AC&C/SPARC ozone database for CMIP5 models without interactive chemistry



Motivation: Effect of including a realistic stratosphere: Example Trop. Jet

Owing to the disappearance of the ozone hole in the 1st half of 21st century:

- **Deceleration poleward side of jet** in multi-CCM mean.
- Opposite response in mean of IPCC AR4 simulations.
- **Importance of ozone** can be seen by comparing AR4 models with & without ozone recovery.

Son et al., JGR (2010)

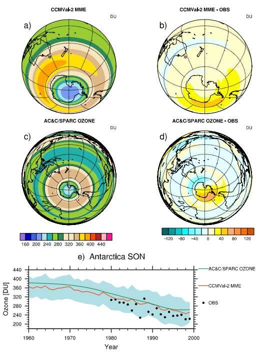
- **Other impacts of the ozone hole** on surface climate have been investigated but have yet to be fully quantified (e.g. observed increases in sea-ice area averaged around Antarctica; decreases of carbon uptake over the Southern Ocean.)

2010 WMO/UNEP Ozone Assessment

Stratosphere

Cionni et al., ACP (2011)

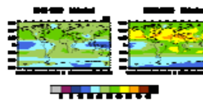
- A multiple linear regression analysis of SAGE I+II satellite observations and polar ozonesonde measurements is used for the stratospheric dataset during 1979 to 2005. The regression includes terms representing equivalent effective stratospheric chlorine (EESC) and the 11-year solar cycle variability. The EESC regression coefficients are used to extrapolate that data back in time, and form a stratospheric ozone time series backward to cover the entire historical time period 1850-2009.
- The stratospheric ozone projections are taken from the future reference simulations (REF-B2) of the 13 CCMs that performed a future simulation until 2100 under the SRES A1B GHG scenario and the A1 adjusted halogen scenario in CCMVal-2 (SPARC CCMVal, 2010). In the stratosphere, the multi-model mean of the REF-B2 simulations is used in all RCP scenarios.

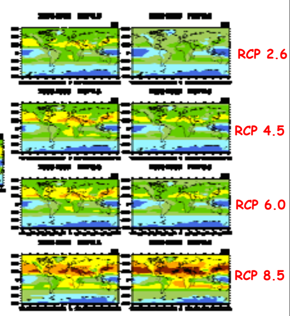


Troposphere

- Tropospheric data are derived from the chemistry-climate models Community Atmosphere Model (CAM) version 3.5 and the NASA-GISS PUCCINI model (past) and from CAM3.5 in the future.

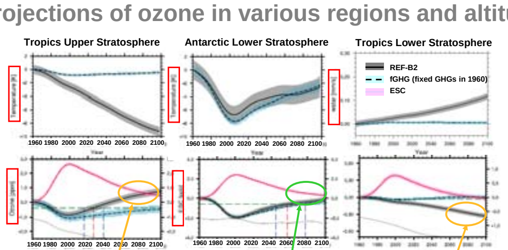
Figure 2. Decadal averages of tropospheric column ozone from the 1850s to the 2090s for the historical database and three future scenarios.





- Both models simulate tropospheric and stratospheric chemistry with feedback to the radiation and were driven by the recently available historical (1850-2000) emissions succinctly described in *Lamarque et al.* (ACP, 2010)..

Projections of ozone in various regions and altitudes



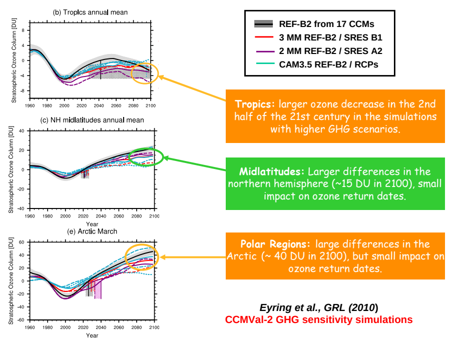
Ozone increases above 1980-values due to increasing GHGs and decreasing chlorine (ESC).

Ozone evolution dominated by ESC; greenhouse gases have only a small impact.

Ozone decrease to values lower than in 1980 due to climate change; nearly no impact of ESC.

Eyring et al., ACP (2010) based on **CCMVal-2 SRES A1B** simulations

Ozone evolution under different greenhouse gas scenarios



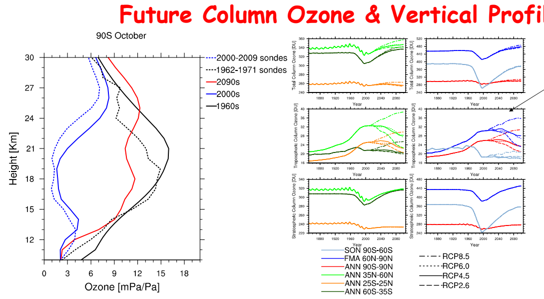
Tropics: larger ozone decrease in the 2nd half of the 21st century in the simulations with higher GHG scenarios.

Midlatitudes: Larger differences in the northern hemisphere (~15 DU in 2100), small impact on ozone return dates.

Polar Regions: large differences in the Arctic (~ 40 DU in 2100), but small impact on ozone return dates.

Eyring et al., GRL (2010)
CCMVal-2 GHG sensitivity simulations

Future Column Ozone & Vertical Profiles



Large differences in tropospheric column ozone among the four RCPs are likely **due the different CH_4 mixing ratios.**

ANN Midlat NH
ANN Midlat SH
ANN Tropics
FMA NH polar
ANN Global
SON SH polar

Stratosphere: SRES A1B

References and Acknowledgement

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Email: Veronika.Eyring@dlr.de