Stratospheric Ozone and Temperature Changes in the Past: The Impact of Increased Concentrations of CFCs in Simulations with a Chemistry-Climate Model

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Introduction

In the last decades of the 20th century a decrease in the stratospheric ozone abundance has been observed, especially in the southern polar region but also at tropical and mid-latitude stations (e.g. WMO, 2002). Furthermore, the increase of atmospheric greenhouse gases (GHGs) leads to a temperature increase in the troposphere but a cooling of the stratosphere (e.g. WMO, 2002). These changes in ozone and temperature between 1960 and the end of the 20th century are investigated by analysing simulations with the Chemistry-Climate Model (CCM) EMAC. In order to analyse the impact of increasing emissions of ozone depleting substances (ODSs) (e.g. chlorofluorocarbons, CFCs) from 1960 to 2000 different sensitivity studies have been performed: two reference simulations with boundary conditions for the year 1960 and 2000, respectively, and one simulation with CFC emissions fixed at 1960 but GHG concentrations for 2000. These simulations allow to isolate the ozone and temperature changes that are caused by the CFC increase only and separate the CFC effect from other processes affecting ozone, e.g. climate change.

Model Setup & Experimental Design

- Chemistry-Climate Model (CCM) ECHAM5/MESSy (EMAC) version 1.7 (Jöckel et al., 2006)
- Three-dimensional atmospheric circulation model (ECHAM5) with fully coupled interactive chemistry (MECCA) (Sander et al., 2005)
- EMAC-FUB Configuration:
  - FT/RT shortwave radiation scheme (Nosen et al., 2007)
  - Spectral T42 resolution (2.8°×2.8°) and 39 layers in the vertical with a model top at 0.01 hPa (~80 km)
  - Prescribed sea surface temperatures (SSTs) and sea ice concentrations (SICs)

Definition of sensitivity studies

- "Timeslice" experiments over 20 years (model run with fixed boundary conditions)
- Present day (2000) and past (1960) reference simulations
- Sensitivity study with greenhouse gas (GHG) concentrations for 2000 and CFCs fixed at 1960 level ("SEN")

Temperature

The impact of increasing chlorine concentrations on stratospheric ozone and temperatures between 1960 and 2000 is analysed in sensitivity studies with the Chemistry-Climate Model EMAC. The temperature decrease by up to 4 K in the upper stratosphere can be attributed by nearly 50% to the ozone loss caused by increased chlorine abundances. In the southern polar lower stratosphere, however, the temperature decrease is mainly caused by ozone loss, only slightly modified by GHG induced processes. The increasing CFC concentrations do not result in lower minimum temperatures in the polar regions, but lead to a delayed springtime temperature increase and delayed circulation transition in the southern hemisphere. While the maximum SPC area in the southern polar region is not affected by CFC-related cooling, the period when PSC formation is possible is significantly longer.

Ozone

The ozone loss in the stratosphere is directly related to the increase of chlorine in the atmosphere. However, the CFC increase alone leads to lower ozone mixing ratios than caused by both GHG and CFC increased by the controlling factors of chemistry and transport to the relative ozone change it can be shown that the effect of increasing CFCs depends on altitude and latitude and that a modification of the ozone transport plays also an important role.

The change in the O3 column due to the chlorine increase is dominant in the southern hemisphere throughout the year. In the northern hemisphere, however, only the springtime ozone loss can be attributed to CFC increase. The decrease in column ozone due to CFC in the other seasons is balanced by ozone changes related to climate change.

Summary

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References