The response of the middle atmosphere to anthropogenic and natural forcing in CMIP5 simulations with the MPI-ESM

H. Schmidt, S. Rast, F. Bunzel, M. Esch, M. Giorgetta, S. Kinne, T. Krismer, G. Stenchikov[1], C. Timmreck, L. Tomassini and M. Walz[2]

Max Planck Institute for Meteorology, Hamburg, Germany

contact: hauke.schmidt@zmaw.de, [1]: KAUST, Thuwal, Saudi Arabia, [2]: FU Berlin, Germany

Introduction

The middle atmosphere is strongly influenced by greenhouse gas changes, ozone depleting substances and natural forcings, such as solar variability and volcanic aerosols. However, the exact response of stratosphere and mesosphere to these different forcing types, the mechanisms creating these responses, and possible implications for tropospheric climate change are not fully understood. The extensive set of CMIP5 simulations with the MPI-ESM (that has its upper lid at an altitude of about 80 km) provides an opportunity to advance this understanding. The purpose of this work is to give a first overview on responses of middle atmosphere temperature and zonal wind to the different forcing types in the CMIP5 simulations and suggest areas of future, more detailed studies.

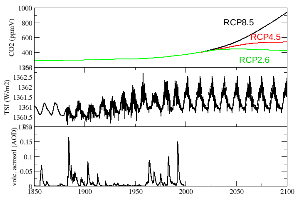

Fig. 1: Forcings used in the MPI-ESM for CO2 (top), total solar irradiance (middle) and volcanic aerosol (bottom).

The representation of solar and volcanic forcing in the CMIP5 simulations with the MPI-ESM

For solar irradiance data we follow the CMIP5 recommendations. We use spectrally resolved historic data for the period 1850 to 2008 that were reconstructed based on observations and proxy data by J. Lean (NRL, USA). For the future we repeat solar cycle 23, i.e. the period May 1996 to August 2008. To fully account for the change in stratospheric heating rates with solar activity we additionally prescribe a solar cycle dependence of stratospheric ozone.

The influence of stratospheric aerosol from volcanic eruptions on short and long-wave radiation is represented in terms of optical properties from sulfate aerosols based on a historic reconstruction published by Stenchikov et al. (JGR, 1998). No volcanic eruptions are assumed for the future.

The temperature response in the tropical stratosphere

The comparison with observation indicates a realistic simulation of the temperature trend in the tropical lower stratosphere for the period 1979 to 2005. In the historical simulations temperature signals from volcanoes are evident in the lower stratosphere while in the upper stratosphere a clear solar signal can be identified. The future evolution depends strongly on the chosen scenario. While the strong CO_2 increase of RCP8.5 leads to strong cooling everywhere, in RCPs 4.5 and 2.6, the trend may level off or even reverse late in the 21st century.

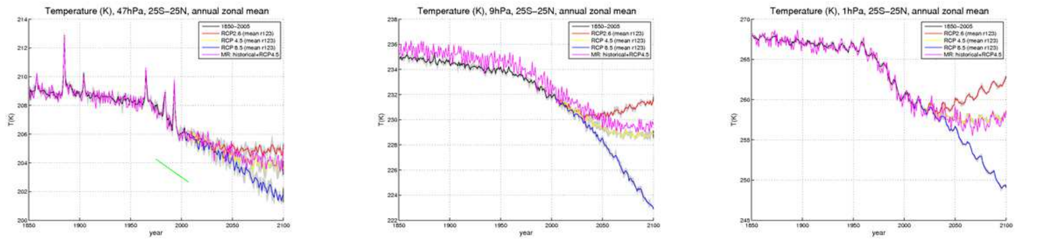

Fig. 2: Temperature (K) in the tropical (10S-10N) stratosphere for 47, 9, and 1 hPa. MPI-ESM-LR: Black: average historical ensemble; red, yellow, green: future scenarios RCP2.6, 4.5, AND 8.5, respectively; gray shading: range spanned by three ensemble members. MPI-ESM-HR: pink: historical and RCP4.5. Green: observed trend from Randel et al. (JGR, 2009).

The temperature response to natural forcing

The annually averaged stratospheric temperature responses as calculated by multi-linear regression from the historical simulations is similar as could be expected from observations and earlier simulations. The temperature response to solar forcing indicates a double peak structure with a secondary maximum in the lower tropical stratosphere. The CMIP5 simulations present an invaluable opportunity to analyze details of the temperature response like its seasonal dependence and possible changes with increasing green house gas concentration.

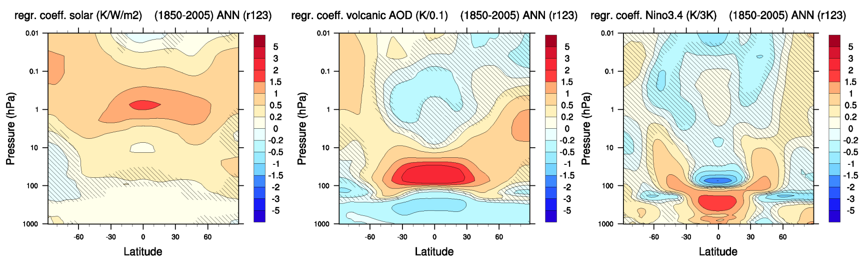

Fig. 3: Ensemble mean temperature response to solar, volcanic and ENSO forcing (in K/W/m2, K/0.1AOD, and K/3K(Nino3.4 index), respectively) calculated by multilinear regression from the historical simulations. Shading indicates regions where the significance of the signals is below 95%.

The future temperature trend

Temperature differences between the end of the 21st and the end of the 20th century depend strongly on the assumed future scenario. In the RCP2.6 scenario, the maximum of the temperature decrease occurs (depending on latitude in the middle to lower stratosphere while it shifts to the stratopause region for RCP8.5. The reason for this behavior is yet unexplained. The structure of the temperature response is modulated also by dynamical feedbacks (see below).

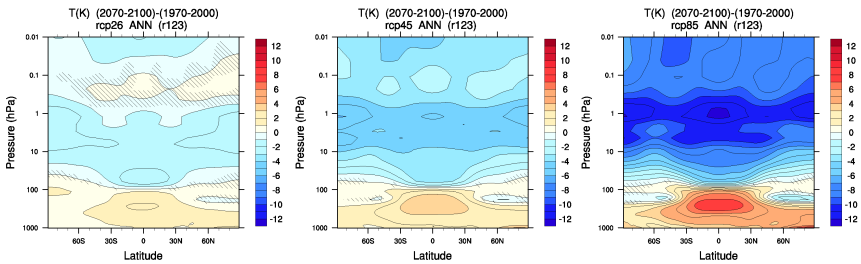

Fig. 4: Ensemble mean temperature difference (in K) between the periods 2070 to 2100 from the scenarios RCP2.6 (left), 4.5 (middle), and 8.5 (right) and the period 1970-2000 from the historical simulations. Shading indicates regions where the significance of the signals is below 95%.

Trends in the meridional circulation

The differences in the stream functions between the end of the 21st and the end of the 20th century for scenarios RCP8.5 and RCP4.5 indicate a clear structure with an increase in tropical upwelling and high latitude downwelling in both hemispheres throughout the stratosphere and lower mesosphere. In RCP2.6 the structure, however is more complicated with increased tropical upwelling near tropopause and stratopause and weakened upwelling in the middle stratosphere. The reason for this behavior might be related to the prescribed changes in stratospheric ozone dominating the relatively weak CO_2 increase in RCP2.6.

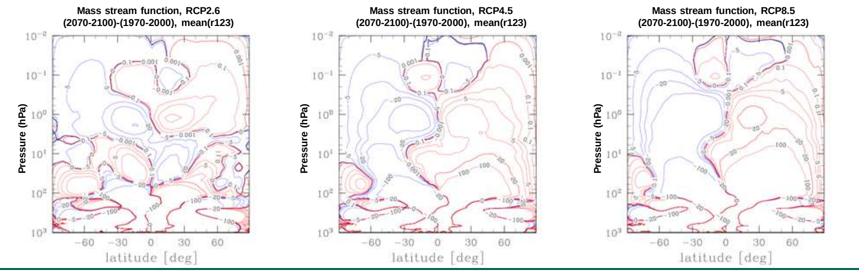

Fig. 5: Ensemble mean difference of the mass stream functions between the periods 2070 to 2100 from the scenarios RCP2.6 (left), 4.5 (middle), and 8.5 (right) and the period 1970-2000 from the historical simulations.

Trends in zonal winds

Differences in zonal mean zonal winds between the end of the 21st and the end of the 20th century are fairly similar in structure but different in magnitude in the different scenarios. Interestingly, the hemispheric trends differ strongly. While in the mid- to high-latitude northern hemisphere, a decrease of the average westerlies is simulated (a signal dominated by the winter response), the SH jets in general show anomalous westerlies throughout the seasons. The explanation of these signals and possible effects on the troposphere will be subject of upcoming studies.

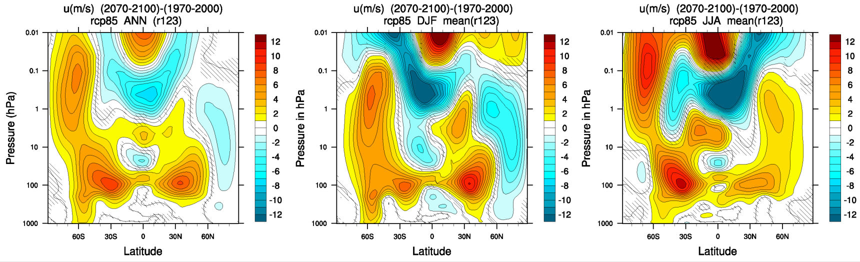

Fig. 6: Ensemble mean difference in zonal wind (m/s) between the periods 2070 to 2100 from the scenario RCP8.5 for the annual mean (left), DJF (middle), and JJA (right) and the period 1970-2000 from the historical simulations. Shading indicates regions where the significance of the signals is below 95%.

Max-Planck-Institut für Meteorologie

Reference: Schmidt, H., et al. (2013): The response of the middle atmosphere to anthropogenic and natural forcing in the CMIP5 simulations with the MPI-ESM." J. Adv. Mod. Earth Sys., DOI:10.1002/jame.20014.

MAX-PLANCK-GESELLSCHAFT