Project: **850**

Project title: **Past and future changes of the three-dimensional Brewer-Dobson circulation**

Principal investigator: **Axel Gabriel**

Report period: **2017-01-01 to 2017-12-31**

Report (27.10.2017)

The aim of the project is to investigate the past and future changes of the three-dimensional (3D) Brewer-Dobson circulation (BDC), i.e. the time-mean mass circulation and tracer transport of the middle atmosphere (10-100km), in order to better understand the local long-term changes in the middle atmosphere and the associated vertical coupling with the troposphere and surface climate. The examinations are primarily based on the CMIP5 simulations with the Earth System Model MPI-ESM-MR (data provided by the MPI-Met, Hamburg), reanalysis data (ERA-Interim) and daily-mean wind fields derived from Aura/MLS satellite data (balanced and non-balanced winds; temperature and H_2O profiles provided by NASA). The latter provide verification of the model dynamics for altitudes where local wind measurements are sparse (30-80km). For diagnosis, we use the concept of the 3D residual circulation that combines the 3D Eulerian and eddy time-mean flow (Sato et al., *JAS*, 2013). Additional sensitivity simulations with forcing terms derived from observations will help to understand the troposphere-stratosphere coupling via the 3D BDC. The project is funded by the Deutsche Forschungsgemeinschaft (DFG) and will end during 2018.

The previous project periods focused on the simulations including sea surface temperature (AMIP-SST 1979-2008) and the moderate scenario RCP4.5 (increase in CO_2 up to ~650 ppm during the 21st century, increase in global surface temperature by ~2°C). The current project period focuses on the weak and strong scenarios RCP2.6 and RCP8.5 (increase in CO_2 up to ~490 ppm and ~1370 ppm), and on the validation of the model data with reanalysis. One result is that the linear trend in the 3D BDC of the RCP2.6 simulation is not significant compared to the model variability; therefore, further analysis focusses on the RCP4.5 and RCP8.5 simulations. Unexpectedly, ongoing publishing of the results has led to strong critical comments concerning the general quality of the MPI-ESM-MR simulations, requiring more extended model validation against reanalysis beyond the original scope of the project. This has led to some delay in carrying out the planned additional model experiments. However, we expect that the project can be finished successfully during 2018. Some selected results are given in the following (more details soon available in Gabriel, 2017: Long-term changes in the northern mid-winter middle atmosphere in relation to the Quasibiennal Oscillation, *J. Geophys. Res.*, in revision).

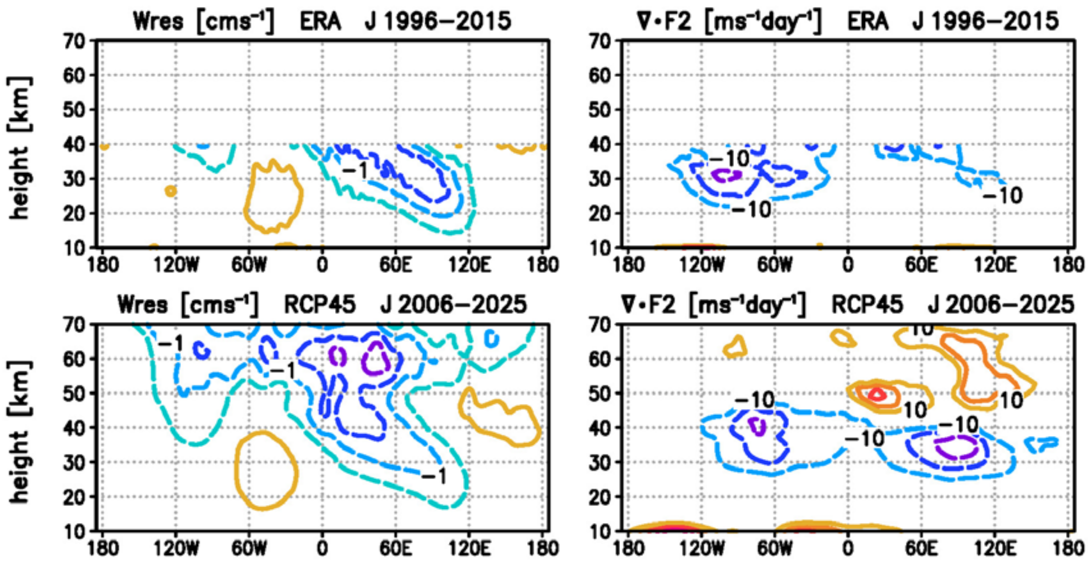

Figure 1: Time-mean vertical residual wind w_{res} (isolines in 0.5 cms^{-1}, zero-line not shown) and zonal component of wave flux divergence $\nabla \cdot F2$ (isolines: -20, -15, -10, 10, 15, 20 $ms^{-1}day^{-1}$) at 60°N, January, for ERA-Interim 1996-2015 and the first 20 years of the RCP45 simulation.

In the RCP4.5 simulation, the linear trends at high latitudes are strongly dependent on the phase of the tropical Quasibiennal Oscillation (QBO), which is produced internally in the MPI-ESM-MR simulations, i.e. they are much stronger during the westerly (QBO-W) than the easterly (QBO-E) phase of the QBO. The key process controlling this trend behavior is a change in the modulation of the extra-tropical stationary wave patterns due to the QBO: for current mid-winter conditions (January) we find a pronounced wave one during QBO-E and a wave two during QBO-W, and the latter will change towards wave one in case of increasing CO_2 emissions. This trend behavior includes a change of the westerly flow over the Rocky Mountains and an increase of the local downwelling of the 3D BDC over Northern Europe/West-Siberia. During the current project period, further analysis confirmed these results, including the required validation of the model simulations concerning the quality of the QBO, its effects on the extra-tropics, and the reliability of the linear change. We find that

• In the AMIP-SST simulation and the first 30 years of the RCP4.5 and RCP8.5 simulations, the tropical QBO and its effects on the northern winter extra-tropics are in good agreement with ERA-Interim. The month-to-month variations show that the characteristic differences (warming of the stratosphere and cooling of the mesosphere at high latitudes, accompanied by a weaker westerly jet; modulation between stationary wave one during QBO-E and wave two during QBO-W) are particularly strong and significant during January. The time-mean 3D residual circulation and wave flux divergences are also in good agreement with ERA-Interim (Figure 1).

• In the RCP4.5 and RCP8.5 simulations, the tropical QBO itself does not change significantly up to the end of the 21st century. Here it is to consider that the response of the QBO to increasing GHGs is constrained by the prescribed gravity wave source spectrum in the gravity wave parameterization; however, the MPI-ESM-MR simulations provide a suitable and unique tool to examine future long-term changes in the extra-tropics in case of a reliable QBO in the tropics.

• The linear trend in stratospheric temperature, zonal wind and residual circulation of the AMIP-SST simulation is in good agreement with ERA-Interim; only for the trend analysis of the residual circulation we have to exclude the years 1979-1984 because of spurious effects over the tropics in the ERA-Interim data. The spatial structures of the linear trends of the RCP4.5 and RCP8.5 simulations are very similar to those of ERA-Interim and the AMIP-SST simulation and very similar to the change in the extra-tropical circulation from QBO-W to QBO-E.

• The linear trends are stronger in the RCP8.5 than the RCP4.5 simulation but clearly confirm the discussed change of QBO-W towards QBO-E signature, which is faster in case of stronger radiative cooling; the linear trends are significant compared to decadal variations (Figure 2).

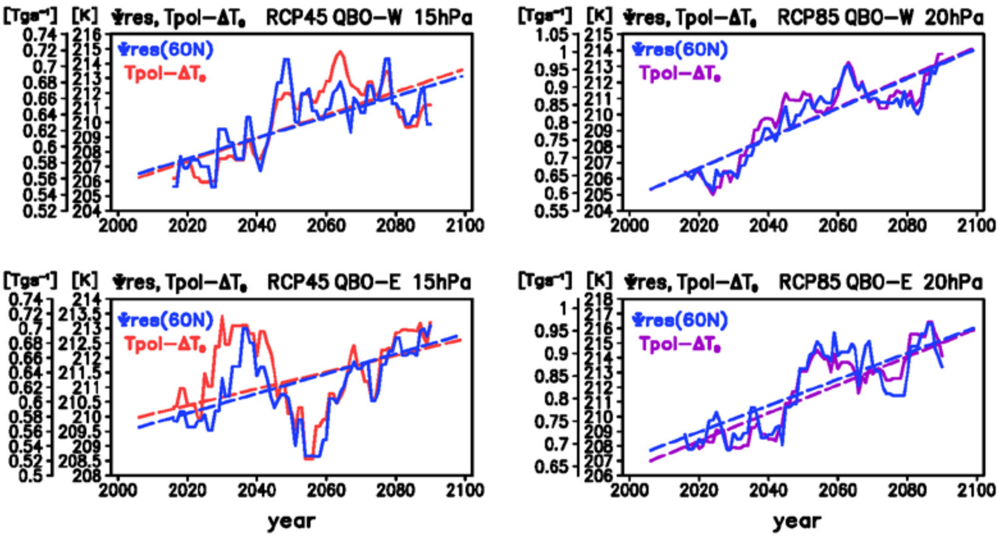

Figure 2: Time series of the difference between polar cap temperature T_{pol} (60-90°N) and global mean temperature decrease ΔT_0 (where $\Delta T_0=0$ for 2006) at stratospheric levels (15hPa, 20hPa), for the (red) RCP4.5 and (violet) RCP8.5 simulation (solid: 20-year running mean; dashed: linear trend), separated for QBO-W and QBO-E; ΔT_0 represents the radiative cooling due to increasing GHGs (up to -2K in the RCP4.5 and -5K in the RCP8.5 simulation), which is overcompensated by adiabatic warming due to increasing residual downwelling as indicated by the residual mass stream function Ψ_{res} at 60°N (blue).