Project: **850**

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

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Report period: **2016-01-01 to 2016-12-31**

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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 (provided by the MPI-Met, Hamburg), reanalysis data (ERA-Interim, MERRA) and 3D wind fields derived from Aura/MLS satellite data (balanced and non-balanced winds; temperature and H_2O profiles are provided by NASA), where 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 which combines the 3D Eulerian and eddy time-mean flow (e.g., Sato et al., *JAS*, 2013). The project is funded by the Deutsche Forschungsgemeinschaft (DFG) and will end during 2018.

During the report period the simulations for the years 1979-2100 have been analysed. The raw model output was kindly provided by Marco Giorgetta (MPI-Met, Hamburg). An advantage of the model is that it generates the Quasibiennal Oscillation (QBO) between easterly (QBO-E) and westerly (QBO-W) equatorial stratospheric winds internally, with a realistic period of ~28 months. We find that, in comparison to the used observational data, the effects of the QBO on northern mid-winter temperature, zonal wind and 3D residual circulation (stationary wave one during QBO-E and wave two during QBO-W) are very well captured by the model throughout the whole middle atmosphere. As an example, Figure 1 (upper panels) shows the vertical residual wind w_{res} at 60°N for the first 20 years of the simulation forced by the moderate scenario RCP4.5 (increase of CO_2 up to ~650 ppm during the 21st century, increase in global surface temperature by ~2°C).

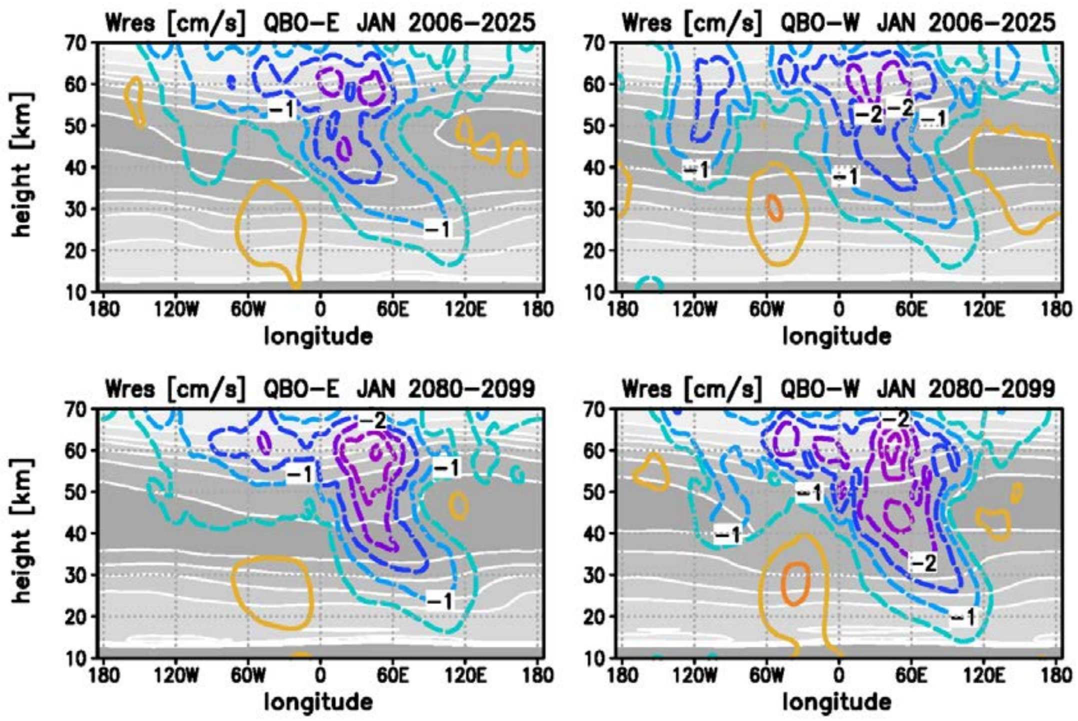

Figure 1: Long-term means of the vertical residual wind w_{res} (distance of colored lines: 0.5 cms^{-1}, zero-line is not shown) at 60°N, January, for (upper panels) the first 20 years and (lower panels) the last 20 years of the RCP45 simulation (shaded areas denote H_2O where non-labeled white isolines indicate 2, 3, 4, 4.5, 5, 5.5 and 5.9 ppm).

During QBO-E (Figure 1, top, left), both w_{res} and H_2O are characterized by a stationary planetary wave-1 pattern with downwelling from the mesosphere towards the center of the stratospheric polar low over Northern Europe/Siberia, but during QBO-W by a second branch of downwelling at 90°-150°W (i.e., by a stationary wave-2). This modulation is related to an increase of transient wave activity over North America when changing from QBO-E to QBO-W (indicated by the zonal wave flux component $\nabla \cdot F2$, Figure 2, upper panels), which diminishes the vertical propagation of planetary Rossby waves excited by the Rocky Mountains and its contribution to the stationary wave-2 pattern in the zonal wind. These changes agree well with those derived from observations and from the simulation forced by AMIP-SST 1979-2008 (here not shown).

A remarkable result of the project period is that the trends in temperature, zonal wind and 3D residual circulation are generally much stronger during QBO-W than QBO-E (by a factor of ~4). For example, comparing with the time-means of the last 20 years of the RCP4.5 simulation (Figures 1 and 2, lower panels), the increase of the downwelling over Europe/Siberia is much stronger during QBO-W than during QBO-E, and the increase in the transient wave fluxes over North America is clearly related to QBO-W and not to QBO-E. In a related publication (currently going to be submitted) we demonstrate that the increase in the local wave fluxes, either due to the transition from QBO-W to QBO-E or due to increasing greenhouse gas (GHG) emissions, enhances the stationary wave-1 by shifting the polar vortex towards Asia, and that an increase of the wave-1 leads to an eastward shift of both the polar low and the Aleutian high anomaly due to the induced change in the β-effect (i.e., the cross-polar transport of planetary vorticity). The latter controls the westerly or easterly flow over the Rocky Mountains and, thus, the excitation and propagation of the orographically excited planetary waves. Therefore, the trend behavior during QBO-W is much more sensitive to increasing GHG emissions than during QBO-E.

The results are quite encouraging for further work and open a new perspective for understanding local trends. For example, we found that the change in the downwelling significantly affects the winter surface high anomaly over Northern Europe/West-Siberia and, hence, climate conditions in this region. The in-depth-analysis of simulations with weaker and stronger scenarios (RCP2.6, RCP8.5) is currently under work, as well as the planned sensitivity simulations including specific forcing terms derived from the assimilations or satellite data (surface temperatures, corrections of tropospheric and/or stratospheric eddy fluxes). Therefore additional computer resources are applied for the next time period (2017) in order to finish the project successfully during 2018.

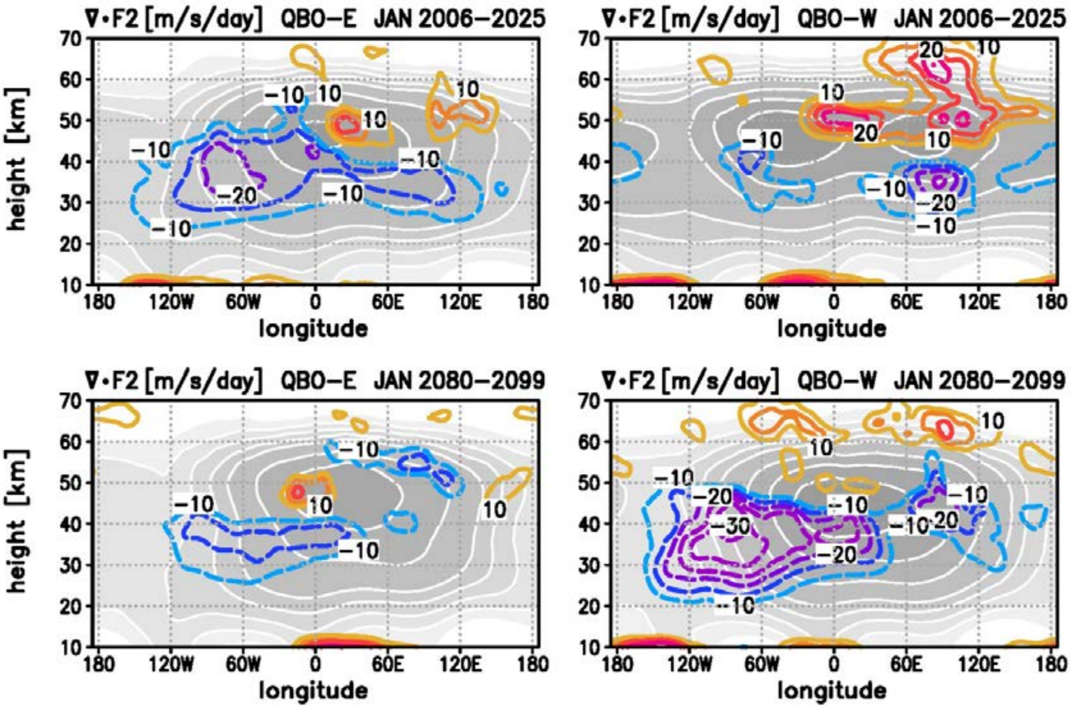

Figure 2: Similar to Figure 1, but for the zonal component of wave flux divergence $\nabla \cdot F2$ (distance of colored lines is 5 ms^{-1} day^{-1} where the zero-line is not shown; shaded areas denote zonal wind U where non-labeled white isolines indicate 10, 15, 20, 25, 30, 40, 50 and 60 ms^{-1}).