Project: **850**

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

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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), based on climate model simulations, reanalysis data and 3D wind fields derived from satellite data. For diagnosis we use the concept of the 3D residual circulation which combines the 3D Eulerian and eddy time-mean flow (e.g., Kinoshita et al., *JMSJ*, 2010; Sato et al., *JAS*, 2013). Both the long-term trend and the interannual variability are examined. The project is funded by the Deutsche Forschungsgemeinschaft (DFG).

During the report period the tool of algorithms necessary for an in-depth analysis of the 3D BDC and the 3D wave forcing has been optimized. For the time period where validation with satellite data is possible, the effects of the Quasibiennal Oscillation (QBO) of equatorial stratospheric winds on the variability of the 3D BDC at mid- and high latitudes and associated vertical coupling processes were examined, based on simulations with the general circulation and chemistry model HAMMONIA (data provided by H. Schmidt, MPI-Met, Hamburg), ERA-Interim (provided by ECMWF, Reading), and daily-mean 3D wind fields for the whole middle atmosphere which we derived from temperature and H_2O profiles of the Aura/MLS satellite data (profiles provided by NASA), including altitudes where only sparse local wind observations are available (≈30-80km). Figures 1 and 2 give some few examples (publications are in preparation).

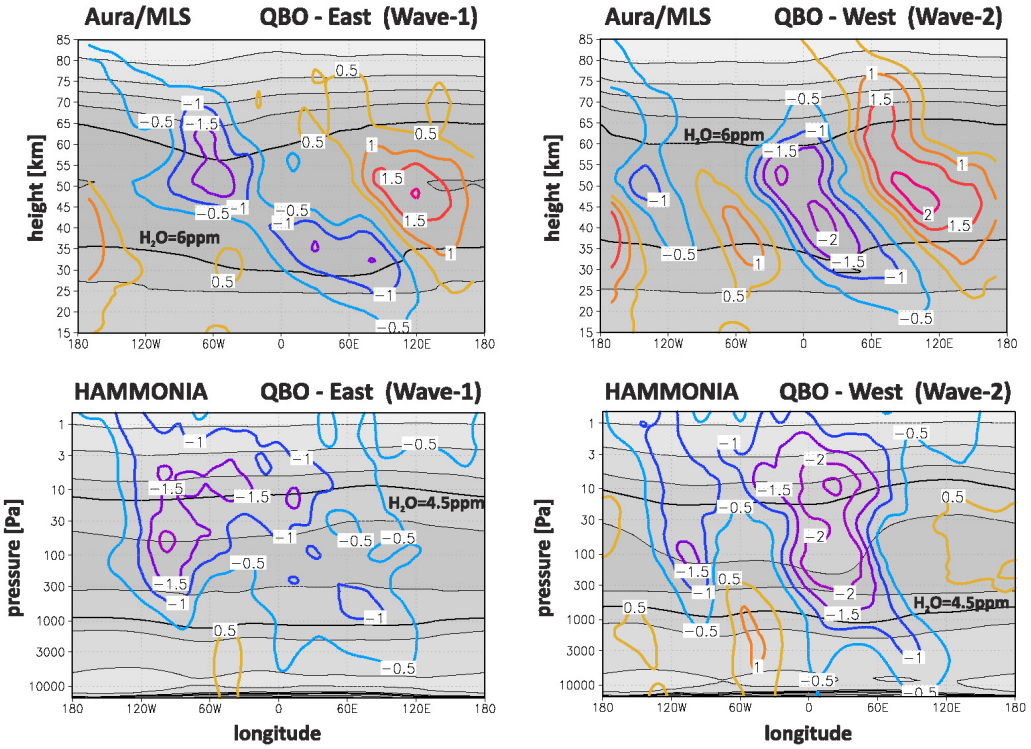

Figure 1: Vertical residual wind w_{res} [coloured, in cms^{-1}] and H_2O [shaded, in ppm, only thick line is labelled), (top) Aura/MLS, (bottom) HAMMONIA; ensemble means of 3 Januaries at 60°N show (left) a wave-1 pattern during QBO-East and (right) a wave-2 pattern during QBO-West (note that the time period is relatively short but representative for the associated QBO-signal in zonal wind and temperature); in HAMMONIA the picture is more disturbed because of too strong transient waves at the cost of stationary waves (as usual for state-of-the-art circulation models).

For northern winter, the results reveal deficiencies in capturing the QBO-induced year-to-year variations in the stratospheric and lower mesospheric planetary wave patterns for HAMMONIA

(Figure 1) but also for ERA-Interim (here not shown). We found that the QBO modulates these wave patterns in the 3D BDC and, hence, in the westerlies by inducing strong transient wave activity over North America during QBO-East and subsequent modulation in the vertical propagation of planetary Rossby waves that are excited by the Rocky Mountains. We also identified an important top-down effect of the QBO on the northern winter surface high anomaly over Northern Europe/West-Siberia (Figure 2) due to the variations in the downwelling branch of the 3D BDC shown in Figure 1.

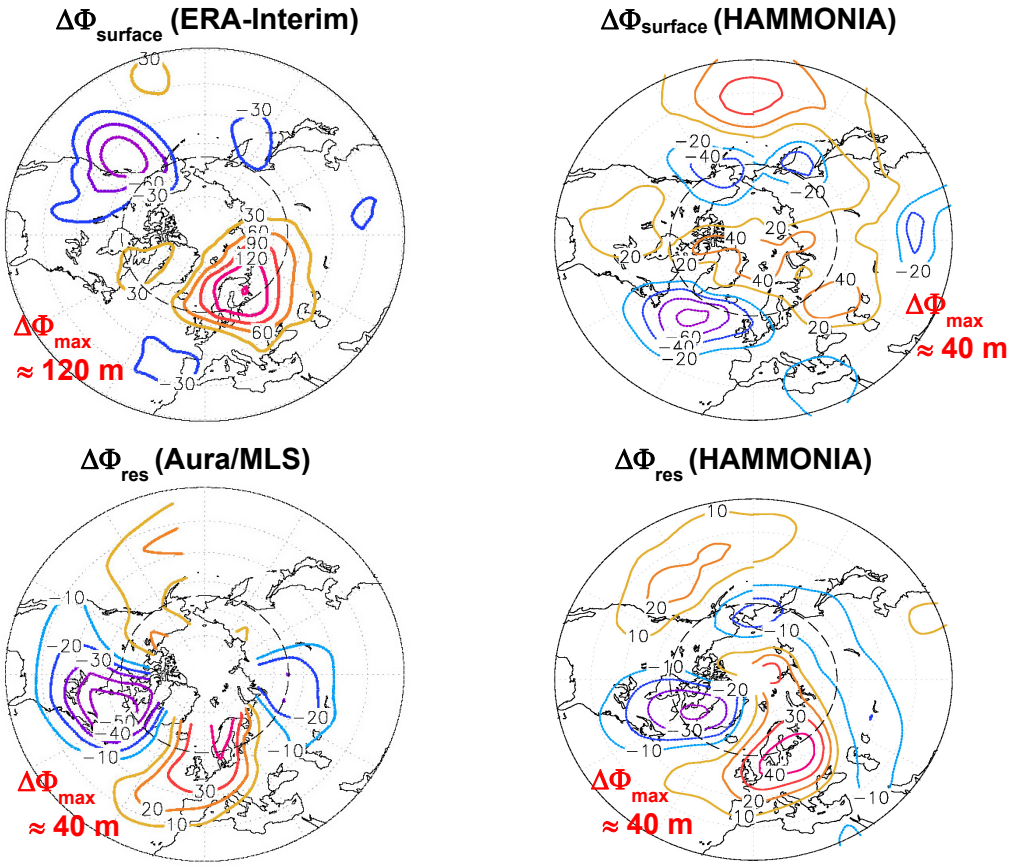

Figure 2: (Upper left) Differences $\Delta\Phi_{surface}$ in geopotential height at 1000 hPa between ensembles of 3 Januaries for QBO-East and QBO-West derived from ERA-Interim (the high anomaly over Northern Europe is representative for longer time periods and consistent with colder surface temperature shown by Thompson et al., J. Climate, 2002); (lower left) the linear change $\Delta\Phi_{res}$ due to the linear change Δw_{res} derived from Aura/MLS suggests a contribution of Δw_{res} to the surface anomaly of ≈30% (here we assume $d\theta/dt \approx \Delta w_{res} \cdot \partial\theta_0/\partial z \approx -\alpha\,\Delta\theta_{res}$ and $\Delta\Phi_{res} = g^{-1} \int RH^{-1}\Delta T_{res}\,\partial z$, where $\alpha = 1/15$ days, $\Delta T_{res} = \Delta\theta_{res}\,(p/p_0)^{R/cp}$, $g = 9.81\ ms^{-2}$, $R = 287.05\ Jkg^{-1}K^{-1}$, $cp = 1005.46\ Jkg^{-1}K^{-1}$, $H = 7$ km); in HAMMONIA (lower right) the linear effect of Δw_{res} is principally captured, but (upper right) the total high anomaly is strongly perturbed because of too strong transient waves.

The results provide a solid basis for analysing the long-term trends in the consortia simulations with the Earth-System Model MPI-ESM (CMIP5 simulations RCP2.6, RCP4.5, RCP8.5). First examinations have shown that the vertical resolution provided by the World Data Centre or the CERA archive is not sufficient enough for an in-depth analysis; therefore we use the original output of the MPI-ESM simulations stored at the HPSS archive of the DKRZ (kindly provided by M. Giorgetta, MPI-Met Hamburg). This work is currently going on and we expect significant results suitable for publication soon. The additional sensitivity simulations with the MPI-ESM including specific forcing terms derived from the assimilations or the satellite data (surface temperatures, corrections of tropospheric and/or stratospheric eddy fluxes) are prepared but not carried out up to now because of the rapid change from HLRE-2 to HLRE-3 – experiences during the previous change of the supercomputer suggest that accurate reproducibility and comparability of the model results are not guaranteed if the model simulations are not carried out with exactly the same hardware and machine-dependent software; therefore it is planned to carry out these sensitivity simulations on the HLRE-3 during the time period November 2015 to February 2018.