Session: C7 Poster: M20A

On the possible role of zonally asymmetric stratospheric ozone and water vapor on long-term changes in the atmospheric circulation

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Radiation perturbations due to zonal asymmetries in stratospheric ozone and other absorbers may be an important factor in the atmosphere circulation system. Therefore a detailed diagnosis of the origin and effects of zonal asymmetries in ozone, water vapor and other important absorbers may help to validate and to improve current general circulation and chemistry models used for future climate scenarios. In the presented project zonal asymmetries in stratospheric ozone and water vapor and their effects are investigated based on assimilated data (ERA-40, ERA-Interim), satellite data (SAGE, GOME, ODIN, AURA-MLS) and general circulation and chemistry models (MAECHAM5, HAMMONIA). The observations show that, in the Northern Hemisphere, the tracers are characterized by a spiral-shaped wave one pattern which intensifies during autumn, maintains its amplitude during winter and decays during spring, with maximum amplitudes of up to 20% of zonal mean values. During winter, the maximum and minimum of the wave one in ozone are related to the positive geopotential height anomaly over North Pacific / Aleutians and to the negative geopotential height anomaly over North Atlantic / Northern Europe, i.e. to the zonal asymmetry of the winter polar vortex. In the Southern Hemisphere, similar patterns occur during spring when the polar vortex breaks down. In the middle stratosphere, the wave one pattern of water vapor mixing ratio is nearly anti-correlated with that of ozone. Based on a three-dimensional transport approach we can explain these wave patterns in ozone and water vapor as a result of zonal asymmetries in the wave-driven Brewer-Dobson circulation. Additional influences due to zonal asymmetries in temperature-dependent chemistry are discussed. Based on radiation calculations and model simulations with the GCM MAECHAM5 we demonstrate that the radiation perturbation due to zonally asymmetric ozone forces a planetary Rossby wave pattern in geopotential height and, subsequently, an improvement in amplitude and phase of the stratospheric wave one pattern of the model when comparing with observations. We show that the induced changes are related to zonal asymmetries in vertically propagating planetary waves in both the troposphere and stratosphere, and to a change of the tropospheric circulation towards a negative phase of the North-Atlantic Oscillation (NAO). We show also that the long-term changes in zonally asymmetric ozone may have contributed substantially (in the order of 30%) to observed long-term trends in local temperature profiles. Based on two 30-year equilibrium simulations with the general circulation and chemistry model HAMMONIA for maximum and minimum of the 11-year solar cycle and two 16-year ensemble means for years during solar maximum and minimum derived from ERA-40 we found similar effects in the wave one patterns when changing from solar minimum to maximum, i.e. an increase in amplitude and a shift in phase of the wave one patterns in the zonal asymmetries of ozone, water vapor, geopotential height and wave-driven transport, as well as a response leading towards the negative phase of NAO. We conclude that the solar cycle may have a stronger impact on the troposphere-stratosphere circulation system than currently assumed if zonal asymmetries in ozone and other important absorbers are taken into account.