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Seasonality of the mean age in the UTLS region: Hemispheric differences and impact of the Asian monsoon

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The seasonality of the composition of air in the UTLS region is determined by the seasonality of different transport processes like convection, Brewer-Dobson circulation (BDC) and two-way irreversible isentropic transport across the tropopause. Whereas during winter (seasons are related to the northern hemisphere), the subtropical jets form a strong transport barrier between the tropics and extratropics, this barrier weakens significantly in the northern hemisphere during summer. This is a result of the hemispheric asymmetry of the land-sea distribution and of the orography, which leads to hemispheric differences in the distribution and intensity of the wave drag driving the BDC.

Based on a multi-annual CLaMS simulation covering the period from 2001 to 2012 with the model transport driven by the ECMWF ERA-Interim reanalysis, we discuss the seasonality of the mean age (measuring the mean transport time of an air parcel traveling from the boundary layer) in the tropical tropopause layer (TTL) and in the extratropical lowermost stratosphere (LMS). During the considered period, the simulated trace gases (like CH4, N2O, F11, CO_2, CO, H_2O and O_3) are in fairly good agreement with in-situ and satellite observations, especially in the lower stratosphere and around the tropopause.

In the TTL, the mean age shows a pronounced annual cycle that is driven by the seasonality in tropical upwelling and horizontal transport from the extratropics (inmixing) with youngest air during late boreal winter and oldest air during late boreal summer, respectively. On the other side, strong hemispheric differences can be diagnosed in the polar high latitude LMS. Here, air in the northern hemisphere is much younger during summer than during the same season on the southern hemisphere. A regionally resolved climatology of the mean age further shows youngest air in the TTL in winter above the West Pacific warm pool, whereas in summer the Asian summer monsoon forms the key pathway for transport into the LMS.

By quantifying the wave forcing in terms of the transformed Eulerian mean formalism (TEM), we derive respective climatologies of dynamical sources (EP-flux divergence) and explain transport and its seasonality within this framework. In this way, we trace back the seasonality and hemispheric differences of the mean age to the respective differences in the strength of the Arctic and Antarctic polar vortices, different climatological patterns of the upper tropospheric anticyclones and of the orographic Rossby waves in the troposphere. By analysing the TEM version of the transport equation we also quantify the impact of the residual circulation and of eddy mixing on causing the mean age seasonality. Regionally resolved analysis emphasizes the importance of the Asian continent and in particular of the Asian monsoon on the composition of air in the UTLS region over the northern hemisphere.