SPARC Workshop SHARP2016

Characteristics of transport in the lower stratosphere inferred from the age of air spectrum

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We present seasonally and inter-annually varying age spectra in the lower stratosphere calculated with the Lagrangian transport model CLaMS driven by ERA-Interim winds. The approach is based on multiple boundary impulse responses, and addresses the following questions: (i) How variable are lower stratospheric age spectra on seasonal to inter-annual time scales, and how do multiple peaks in the spectrum develop? (ii) How do residual circulation and mixing affect the age spectrum?

Seasonal age spectra in the lower stratosphere show large deviations from an idealized stationary mono-modal shape. Multiple modes emerge in the spectrum throughout the stratosphere (strongest at high latitudes), caused by the interplay of seasonally varying tropical upwelling mass flux and stratospheric transport barriers. While the annual mean spectrum is well described by an idealized stationary spectrum, seasonal age spectra can only be well approximated by a superposition of such functions. In addition, inter-annual variations in transport (e.g., QBO, ENSO) cause significant modulation of the age spectrum shape. Indeed, one particular QBO phase may determine the spectrum mode during the following 2-3 years. Interpretation of the age spectrum in terms of residual circulation and mixing is not straightforward, in general. Advection by the residual circulation turns out to represent the dominant pathway in the deep tropics and in the winter hemisphere extratropics above about 500K, and controls the modal age in these regions. In the summer hemisphere, particularly in the lowermost stratosphere, on the contrary, eddy mixing controls the modal age, representing the most probable pathway. We show that consideration of the full age spectrum is highly beneficial compared to mean age for separating the effects of different transport processes and for understanding stratospheric chemistry and composition, and strongly recommend the age spectrum as a diagnostic for model inter-comparison.