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Quantitative assessment of the variability of the diabatic circulation of the stratosphere from age of air data

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We present a time-dependent theory to quantitatively determine the strength of the diabatic circulation of the stratosphere. The steady state theory predicts that the difference between the age of upwelling air and downwelling air on an isentrope is a measure of the diabatic circulation, neglecting only diabatic mixing. We explore a modified time-dependent theory and then verify this theory in an idealized atmospheric model with a seasonal cycle. We find that the transient terms are large instantaneously but small upon annual averaging, so this steady state theory holds approximately true at the yearly timescale in this idealized model. This demonstrates the need for annual and global data coverage in order to quantitatively assess the circulation changes. We then apply the theory to SF6-based age estimates from the MIPAS instrument over the years for which continuous measurements were available (2007-2011). We find that in the lowermost stratosphere, there was little change in the circulation. On the 600K isentrope and above, SF6-based age changes suggest that the diabatic circulation weakened significantly, from 12% at 600K up to a maximum of 20% at 1000K.