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How do changes in the stratospheric circulation impact ozone?

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The Brewer-Dobson circulation (BDC) and tropical upwelling in the lower stratosphere are predicted to increase with increasing greenhouse gas (GHG) concentrations by most climate models and chemistry-climate models (CCMs). This change in the meridional circulation is likely to alter the transport of trace gases, and in particular ozone. In addition, ozone is affected by other processes such as changes in stratospheric temperatures that act to change the reaction rates of ozone-relevant chemistry. These climate-change related modifications of the ozone amount and distribution are superimposed on the depletion and recovery of the ozone layer due to stratospheric halogen loading. To assess the recovery of ozone correctly, it is important to understand the processes that affect ozone in a changing climate. In this study, multiple transient numerical simulations and complementary sensitivity studies with the E39CA CCM are used to disentangle the direct effect of changes in GHG concentrations, the indirect effect of GHG-induced sea surface temperature (SST) changes, and changes in CFC concentrations. It is shown that the increase in tropical upwelling is driven by the changes in SSTs rather than by the direct radiative effect of increased GHG concentrations. Therefore, the sensitivity simulations that separate the direct effect of increased amounts of GHGs and the indirect effect via increased SSTs can be used to separate the impact of the increase in tropical upwelling and the impact of stratospheric cooling on ozone. It is shown that the changes in the meridional circulation cause weak negative trends in the tropical lower stratosphere and associated positive trends in the extra-tropical lower stratosphere. Stratospheric cooling, on the other hand, causes a broad increase in ozone in the stratosphere.

To study the processes that lead to changes in the ozone distribution in more detail, different diagnostics that can separate the changes in chemistry (production or destruction) and transport are used. A diagnostic that tags ozone according to its region of production provides a measure of the relative importance of ozone from different origins. Also, together with net production rates, it can be used to assess the month-to-month transport of ozone between the defined regions. The climatology and changes in transport of ozone are compared to transport of air masses obtained from a Lagrangian diagnostic. This allows differentiation between changes in transport of ozone due to higher concentrations in the source region or due to a change in the strength of transport of air. The results show an increase in transport of air masses from the troposphere into the lower stratosphere in the tropics and increases of transport of stratospheric air into the troposphere in mid-latitudes. This is reflected in ozone with, for example, higher contributions of stratospheric ozone in the mid-latitude troposphere.