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Two and a half reasons why CO_2 cools the stratosphere

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Complex models of the atmosphere show that increased CO_2-concentrations, while acting to warm the surface, lead to lower temperatures in the stratosphere and above. Stratospheric cooling, which is evident also in observations, is considered to be one of the fingerprints of anthropogenic global warming, yet explanations for the phenomenon in the literature are to some extent ambiguous. Using a simple window-grey radiation model of the atmosphere, we illustrate the physical essence of three mechanisms by which CO_2 cools the stratosphere. These are (I) a transient (hence "half") cooling effect that is due to decreased upward thermal radiation after CO_2-concentrations are increased (when the surface temperature is still below its new equilibrium value), (II) a permanent cooling effect in places where additional (e.g. solar) heating terms raise the local temperature above the "grey" solution (which is particularly the case in the upper parts of the ozone layer), and (III) a permanent cooling effect intensifying with height that is due to non-uniform opacity of the atmosphere for thermal radiation. Using a complex climate model we provide some evidence on the (vertically varying) relative importance of the mechanisms. While often only the effect associated with solar heating due to ozone is addressed in textbooks, our results suggest that the non-uniform opacity for thermal radiation contributes most to CO_2-induced stratospheric cooling.