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On the structure of greenhouse gas radiative forcing kernels

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A radiative forcing kernel (RFK) quantifies the change in top of atmosphere energy balance due to a small perturbation in atmospheric composition applied as a function of altitude and latitude. RFKs have been used to compute the radiative forcing from modeled or observed changes in atmospheric composition (Rap et al., 2015), and show the spatial characteristics of the effect of greenhouse gases on Earth's radiative balance. Previous RFK calculations have shown a change in composition in the UTLS induces a larger radiative forcing than the same change applied in the lower troposphere (e.g. Riese et al., 2012). This is commonly used to emphasise the importance of UTLS science. In this study, we investigate the factors that determine the spatial structure of RFKs for the major greenhouse gases (CO_2, CH4, N2O, O_3, CFC-11) using a radiative transfer model. We explore the dependence of the magnitude and spatial structure of RFKs on: the background concentration of the gas; the presence of cloud radiative effects; the presence of water vapour in the atmosphere; and the thermal structure of the atmosphere.

The range of magnitudes of the RFKs can be explained to zeroth order by differences in current day concentrations of each gas, which span parts per trillion to parts per million levels. When this effect is removed by applying consistent background concentrations for all gases, the magnitude of the RFK for CH4 is found to be substantially weaker than for the other greenhouse gases, owing to its weaker line strengths. There are also found to be differences in the altitude at which the RFKs for different gases peak, which cannot be explained by the radiative effects of clouds or water vapour. For an isothermal atmosphere, there is no greenhouse effect and the RFKs are near zero. The results provide physical context for why changes in UTLS composition are particularly important for climate.

References

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