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Why are Black carbon aerosols less effective in causing climate warming than CO_2?

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Several past studies have shown that the Black carbon (BC) aerosols are less effective in warming the climate compared to CO_2, but a mechanistic explanation is lacking in the literature. In this study, using idealized step-forcing simulations, we provide a mechanistic explanation for the lower efficacy of BC aerosols. For the estimation of the radiative forcing of BC aerosols, we use Gregory's regression approach (REG) and the Hansen's prescribed-SST method (pSST). Radiative forcing estimated using these two methods is considered as the effective radiative forcing (ERF) by IPCC (2013).

A sixty-fold increase in the BC aerosol mixing ratio from the present day (2000 climatology) level in the NCAR CAM5 climate model leads to the same equilibrium global mean surface warming ($\sim$4.1 K) as a doubling of atmospheric CO_2 concentration. However, for this same equilibrium global mean surface warming, the ERF estimated from the pSST method is larger in the BC aerosol forcing case ($\sim$5.5 Wm-2) relative to doubled CO_2 case ($\sim$3.8 Wm-2) by 1.7 Wm-2 indicating that the efficacy of BC aerosol is 0.69 ± 0.03. When we use the REG approach, the efficacy is estimated as 0.53 ± 0.10. We show that the differences in the fast climate adjustments between the BC aerosol forcing and CO_2 forcing are associated with the differences in the ERF. The direct and the semi-direct effects of BC aerosols causes substantial upper atmospheric warming ($\sim$8.0 K) and consequently decreased high clouds ($\sim$-2.0 %) and increased low clouds ($\sim$1.0 %). In contrast, a CO_2 doubling causes longwave induced stratospheric cooling ($\sim$-3.0 K) and increased high clouds ($\sim$1.0 %) and decreased low clouds ($\sim$-1.0 %). These differences in the fast adjustments in the vertical profile of temperature and clouds lead to the difference in the ERF. Further, these differences in fast climate adjustments also produce differences in the climate states from which the slow response begins to evolve and hence they are likely associated with the differing feedbacks and a lower efficacy of BC aerosols. Our study indicates the importance of fast climate adjustments, primarily adjustment to the vertical profile of temperature and clouds due to BC aerosols to understand its efficacy and hence highlights the need for improved measurements and modeling of the vertical profiles of BC aerosols.