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The Global Patterns of Instantaneous CO_2 Forcing at the Top of the Atmosphere and the Surface

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Abstract

The radiative forcing of carbon dioxide (CO_2) at the top of the atmosphere (TOA) has a rich spatial structure and has implications for large-scale climate changes, such as poleward energy transport and tropical circulation change. Beyond the TOA, additional CO_2 increases downwelling longwave at the surface, and this change in flux is the surface CO_2 forcing. Here we thoroughly evaluate the spatiotemporal variation of the instantaneous, longwave CO_2 radiative forcing at both the TOA and surface. The instantaneous forcing is calculated with a radiative transfer model using ERA5 reanalysis fields. Multivariate regression models show that the broadband forcing at the TOA and surface are well predicted by local temperatures, humidity, and cloud radiative effects. The difference between the TOA and surface forcing, the atmospheric forcing, can be either positive or negative and is mostly controlled by the column water vapor, with little explicit dependence on the surface temperature. The role of local variables on the TOA forcing is also assessed by partitioning the change in radiative flux to the component emitted by the surface versus that emitted by the atmosphere. In cold, dry regions, the surface and atmospheric contribution partially cancel out, leading to locally weak or even negative TOA forcing. In contrast, in the warm, moist regions, the surface and atmospheric components strengthen each other, resulting in overall larger TOA forcing.

The relative contributions of surface and atmosphere to the TOA forcing depend on the optical thickness in the current climate, which in turn is controlled by the column water vapor.

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