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Global impact of 3D cloud-radiation interactions

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Clouds have a decisive impact on the Earth's radiation budget and on the temperature of the atmosphere and surface. However, in global weather and climate models, cloud-radiation interaction is treated in only the vertical dimension using several non-realistic assumptions, which contributes to the large uncertainty on the climatic role of clouds. We provide a first systematic investigation into the impact of horizontal radiative transport for both shortwave and longwave radiation on a global, long-term scale.

For this purpose, we have developed and validated the SPARTACUS radiation scheme, a method for including three-dimensional radiative transfer effects approximately in a one-dimensional radiation calculation that is numerically efficient enough for global calculations, allowing us to conduct 1D and quasi-3D radiation calculations for a year of global of ERA-Interim re-analysis atmospheric data and compare the results of various radiation treatments. SPARTACUS includes the effects of cloud internal inhomogeneity, horizontal in-region transport and the spatial distribution of in-cloud radiative fluxes.The impact of varying three-dimensional cloud geometry can be described by one parameter, the effective cloud scale, which has a characteristic value for each cloud type.

We find that both the 3D effects of cloud-side transport and of horizontal in-cloud radiative transport in the shortwave are significant. Overall, 3D cloud effects warm the Earth by about 4 W m-2, with warming effects in both the shortwave and the longwave. The dominant 3D cloud effect is the previously rarely investigated in-region horizontal transfer effect in the shortwave, which significantly decreases cloud reflectance and warms the Earth system by 5 W m-2, partly counteracted by the cooling effect of shortwave 3D cloud-side transport. Longwave heating and cooling at various heights is strengthened by up to 0.2 K d^{-1} and-0.3$Kd\ ^{-1}\ respectively.$

These 3D effects, neglected by current models, are noticeably stronger than the effect of anthropogenic greenhouse gases and therefore worth considering in climate simulations. Our method is able to achieve this in an efficient way on a global scale.