Effects of 3D Thermal Radiation on the Development of Shallow Cumulus Clouds: Parameterization and LES Application

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The development of clouds is highly influenced by radiative effects. In the first place, solar radiation heats the Earth’s surface, thus causing updrafts of warm and moist air, which, while rising cools again and eventually forms a cloud. From the moment on that a cloud exists, radiation interacts with clouds and clouds interact with radiation. Clouds cause shadows at the surface, which in turn affect cloud formation by reducing solar insolation and thus forming updrafts. At the same time, solar radiation is absorbed by the clouds, causing heating at the illuminated cloud sides. Emission and absorption of thermal radiation lead to cooling at the cloud top and clouds sides and to modest warming at the cloud bottom. While the average cooling rate under cloudless sky conditions is only -1 to -2 K/d, heating rates can become orders of magnitude larger at the interface between cloud and air. The calculation of these heating and cooling rates of up to a few 100 K/d is a three-dimensional problem.

Although these 3D radiative effects are known and can be calculated with accurate radiative transfer models, their representation in cloud resolving models remains poor. With increasing resolution of today’s cloud resolving models, these 3D effects become more and more important. Due to the high computational costs of accurate 3D radiative transfer models, 3D effects have been neglected in cloud model application. The so far used plane-parallel 1D approximations omit horizontal transport of radiation and thus neglect the cloud side heating and the shift of the cloud shadow (according to the solar zenith angle) in the solar spectral range, as well as cloud side cooling in the thermal spectral range. Recent development of fast 3D radiative transfer parameterizations allows now for the first time to account for the 3D effects and for systematical studies of the development of cloud fields under this more appropriate treatment of radiation.

In this talk, the focus will be on the effects of 3D thermal radiation on cloud development. The ’Neighboring Column Approximation’ (NCA), a fast approach to account for 3D thermal heating rates in cloud resolving simulations will be introduced. The NCA can be efficiently parallelized since it only considers exchange of radiation with the neighboring column which turns out to be a good approximation. Computational costs of the NCA are a factor 1.5 –2 compared to a 1D radiation approximation. Results of the application of the NCA in cloud resolving models will be shown. A comparison of the results of the application of 1D and 3D thermal radiative effects shallow cumulus cloud fields and possible differences in cloud development both in terms of cloud dynamics and cloud microphysics will be outlined.

Keywords: 3D Thermal Radiation, Cloud Development, LES

