Application of the deterministic scheme for estimating cloud inhomogeneity effects in a high-resolution numerical model

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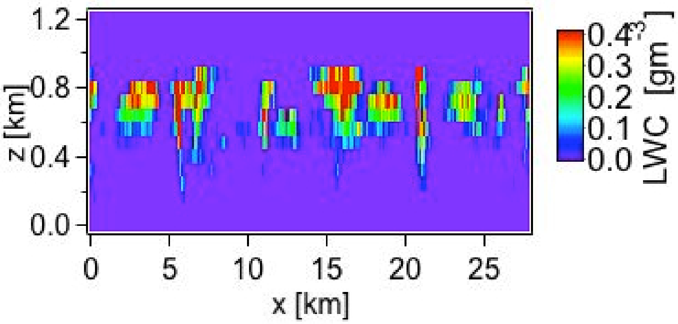
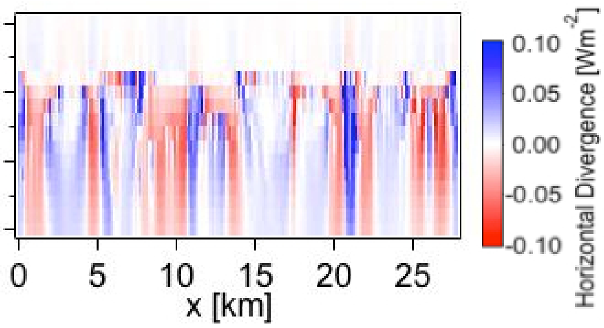
Three-dimensional (3D) radiative transfer effects of spatially inhomogeneous clouds in a very high-resolution numerical simulation are estimated by applying a 3D radiative transfer calculation method that incorporates the deterministic (explicit) scheme. The spatial inhomogeneity of clouds often complicates transport of radiation energy and heating/cooling in the atmosphere, influencing local and global radiation budgets. It is therefore significant to clarify the 3D radiative transfer effects not only for energy budget estimation but also for simulation of the cloud development process. However, there are some problems that hamper the investigation of the 3D radiative transfer effects. One is that the 3D radiative transfer calculation in spatially inhomogeneous clouds usually needs a large resource for computation compared to a plane-parallel approximation. Another is that it is difficult to obtain cloud fields appropriate to estimation of radiative transfer effects, especially in fine spatial scale. Recently, a Large Eddy Simulation (LES) model with a very high-resolution (with the order of 10 m in spatial grid) has been developed, making it possible to provide detailed cloud structure for investigation of cloud physics. In this study, results of the LES model, which deals with development and decay of shallow cumulus and stratocumulus, are used to estimation of the 3D radiative transfer effects. The 3D radiative transfer calculation method applied in this study explicitly solves the 3-D radiative transfer equation by iterative calculation. The 3-D radiative transfer equation is discretized by spherical harmonics expansion and the bidirectional upwind difference scheme for suppression of numerical oscillations. This method consistently satisfies the conservation of radiative energy within both every local grid and a whole domain, and thus is appropriate to calculation of radiation fluxes and their divergence/convergence. This method also has an advantage in calculation for a sequence of time evolution (i.e., the scene at a time is little different from that at the previous time step). Furthermore, this method can treat radiation with strong absorption, such as the infrared regions. For efficient computation, this method utilizes a correlated-k distribution method refined for efficient approximation of the wavelength integration. For a case study, infrared broadband radiation for a time variation of a broken cloud field is calculated, deriving the horizontal radiation transport, which is neglected in the plane-parallel approximation. The calculation result shows not only cloud top cooling but also an additional cooling at the boundaries of clouds and within optically thin clouds, which is caused by the horizontal divergences of infrared radiation. The radiative cooling at lateral boundaries of clouds may reduce infrared radiative heating in clouds as well as cooling at gaps of clouds (i.e., clear sky). The difference between the cooling/heating rates of 1D and 3D sometimes reaches the order of 10 K/day, which should not be ignored in the cloud development and dissipation process. It is suggested that incorporation of 3D radiative transfer into a high-resolution numerical model is helpful for the quantitative estimation of 3D effects.

Keywords: radiative transfer, cloud inhomogeneity effects, high-resolution numerical model, radiative energy flux


z [km]
x [km]
LWC [gm^-3]
0.4
0.3
0.2
0.1
0.0


x [km]
Horizontal Divergence [Wm^-2]
0.10
0.05
0.00
-0.05
-0.10