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Development of computational method for micrometeorological field using SGS model based on turbulence structures

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The diffusion phenomena of heat and pollutants caused by heat convection and turbulent flows in the non-isothermal field is one of the important phenomena concerned with local heavy rain or high levels of air pollution. For example, it can be considered that the heat or the vapor exchange perform actively around the rapidly developed cumulonimbus clouds, or it is said that the circulating flow over an urban area under the heat island phenomenon leads to high concentration of the air pollution. Therefore, it is considered that understanding of those behavior and turbulence structures contributes to a short time prediction of the local heavy rain or a relaxation of the air pollution. And recently, the local heavy rain showing the tendencies to increase occur in the region with horizontal dimensions of a few kilometers and within about 1 hour, they are small scale phenomena both spatially and temporally compared with the heavy rain caused by the typhoon or the movement of the front. The large eddy simulation (LES) which can analyze the turbulence structures in the non-isothermal field is considered as one of the effective means for investigating those phenomena.

The purpose of this study is to develop a computational method for the LES of the turbulent transport of heat and vapor in the micrometeorological field. The governing equations are the continuity equation, Navier-Stokes equations, heat, vapor and liquid water transfer equations, and the condensation process is applied for considering the phase change of water. The governing equations are discretized by the finite volume method in a generalized curvilinear coordinate system so that it can be also applicable to a complex terrain. The coherent-structure Smagorinsky model (CSM) based on the turbulence structures suggested by Kobayashi (2005) is applied as a subgrid-scale (SGS) turbulence model. This turbulence model enables to calculate a suitable model coefficient automatically depending on the turbulent flow field, and is also superior in a numerical stability.

The numerical experiments of turbulent channel flow and back-step flow in the isothermal field were carried out to demonstrate the validity of this turbulence model. The present method was also applied to the LES of the Reyleigh-Bénard convection and the shallow cumulus convection which was similar to the intercomparison study carried out by Siebesma et al. (2003). The computed results showed the good agreements compared with the physical or the other numerical experimental results, so the results suggested the possibility of this method for the analysis of the turbulent transport of heat and vapor.

Keywords: micrometeorology, LES, SGS model, turbulent transport of heat, local heavy rain, air pollution