Revisit of Horizontal Homogeneity of Atmospheric Boundary Layer Flows

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Abstract

Fully developed atmospheric boundary layer flows are usually assumed to obey the log-law velocity profiles varying along the vertical direction only. However, the log-law atmospheric boundary layer inflow profiles are inconsistent with turbulence models and wall functions that are usually adopted in CFD simulations. Such inconsistency can lead to the dramatic variation in vertical velocity profiles even within the fetching distance, usually named “horizontal inhomogeneity”. This in turn is deemed to increase the numerical inaccuracy in CFD simulations of urban environmental models. Thus, special treatments have been proposed to ensure the horizontal homogeneity of the incoming atmospheric boundary layer flows.

The objectives in this study are in two-folds: Firstly, we will revisit the consistency requirements for ensuring the horizontal homogeneity of fully-developed atmospheric boundary layer flows, taking account of two types of log-law inflow profiles; Secondly, the practical process, when the horizontal homogeneity conditions are applied for urban environmental modelings, is demonstrated together with the highlight of some conflicting issues arising from the enforced horizontal homogeneity. The consistency conditions have been derived subject to the following assumptions: 1) Neutral-state atmospheric boundary layer flows with constant shear stress; 2) standard k-ε two-equation turbulence model and 3) standard wall functions.

The effectiveness of horizontal homogeneity of ABL flows is first demonstrated in a test case without any building obstructions, and followed by the modeling of airflow and tracer gas dispersion in the Mock Urban Setup Test (MUST) field tracer experiment - which was configured in real-life outdoor environment in the desert area of Utah State to emulate urban-like area. All the simulations have been carried out using OpenFOAM – an open source CFD code. Results indicate that the enforced consistency conditions can lead to the well-preserved horizontal homogeneity of the atmospheric boundary layer profiles, as anticipated. However, when the buildings are explicitly modeled in the urban environment, it is found that the improvement in numerical accuracy due to the enforced consistency conditions is not significant. This may be related to the conflicting issues including the inconsistency in surface roughness settings, values of empirical parameters adopted in turbulence model and wall functions, and the grid resolution near the ground for various areas. Thus, continuous efforts are deserved well to be spent to resolve the inconsistency between the atmospheric boundary layer flow and the local flow within the urban environment of concern.

Keywords: **CFD, atmospheric boundary layer, horizontal homogeneity, OpenFOAM, urban environment modeling**