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Application of Lattice Boltzmann Method to Simulate Forest Edge

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Abstract. This study is focused on the forest edge flow by using numerical method. To model the effects of a forest canopy on airflow, source terms are introduced into the governing equations. The lattice Boltzmann method in conjunction with the standard $k-\varepsilon$ model is applied to solve the turbulent wind field. In order to perform the simulation on non-uniform grids, the Taylor series expansion and least square based lattice Boltzmann method (TLLBM) is adopted to improve the accuracy and computational efficiency. The present method and code are verified with an earlier forest edge simulation. A series of forest canopies are established to explore the impacts of canopy morphology on wind field. These canopies cover 3 canopy architectures and the Leaf Area Index (LAI) ranges from 2.0 to 4.0. The further study is carried out by adjusting the canopy foliage amount and the canopy architecture. The present study demonstrates the potential of lattice Boltzmann method to simulate the high Re number forest edge flow. The impacts of canopy morphology on zero plane displacement, aerodynamic roughness length, friction wind velocity, permeability coefficient, wall-shear stress are illustrated in detail. The results show that the canopy sub-layer wind field, especially the wind velocity profiles within and above the forest canopy, are mainly determined by canopy morphology.

AMS subject classifications: 76F05, 76G25, 76M28, 76S99

Key words: Forest edge, lattice Boltzmann method, non-uniform grids, canopy morphology.

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1 Introduction

As the most complex and multifunctional terrestrial ecosystem, forests have the functions of conserving water sources, regulating microclimate, and maintaining ecological balance. They are of great value in both ecology and economy. In particular, forest canopies play active roles in the prevention of wind erosion by reducing wind speed and shear stress of the ground surface [1, 2]. Numerous studies have shown that the turbulent transport processes of mass, momentum and energy between a forest canopy and the atmosphere are characterized by the features of both multi-physics coupling and multi-scale [3]. Parameters associated with a forest canopy including leaf area density, leaf area index as well as the canopy height directly affect momentum fluxes near the ground surface, and further influence some important scalar transport processes within and above the canopies [4,5]. For all these reasons, understanding the wind flow characteristics of a forest edge is crucial to the wind energy industry, such as the prevention of wind erosion and desertification as well as the microclimate improvement.

In recent decades, many literatures have been published to reveal the transport mechanism between the forest canopies and their atmosphere [6–8]. Among those works, the earlier studies were mainly performed by field experimental measurement. The experimental data were recorded, such as the wind velocity, temperature and humidness [9–12]. From the data, turbulence intensity, aerodynamic roughness, zero plane displacement as well as the wind shear could be further calculated. In addition, statistical approaches have been applied to analyse the measurement data and infer the large-scale coherent structures in canopy sub-layer, which are perceived as a dominant role to most of the momentum transport [8, 13]. Results derived from the field measurements helped to reveal the basic turbulent characteristics of the forest edge. However, few measure points were set in these experiments and thus limited information were collected. Nonetheless, the experiment revealed the fact that the canopy elements dissipate momentum of wind by aerodynamic drag and results in a reduction in mean velocity and momentum flux. As a consequence, a vegetation canopy could be simplified as porous media in the framework of numerical simulation. After the spatial averaging treatment, source terms associated with canopy resistance were incorporated into the governing equations [14]. Based on the theories, Large-eddy simulation (LES) was first performed to simulate the forest edge flow by Shaw and Schumann [15]. The vertical profiles of wind velocity and Reynolds stress showed coincided with the earlier observations. With the help of LES, the spatial-temporal evolution of three-dimensional coherent structures could be solved and visualized [4, 16–19]. However, researchers had to adopt limited domain (usually about 10-20 times of forest hight (h) in streamwise) due to the enormous expense in computation caused by LES approach. It seems impossible to capture enough large-scale eddies, whose size are comparable with h. The large-scale structures, which resulst from Kelvin-Helmholtz instability, locate above the canopies and are believed to dominate most of the momentum exchange [4, 13, 16]. In parallel, as the success in other engineering application, Reynolds-averaged Navier–Stokes (RANS) models also received attentions by au-