The Impact of an Isolated, Semi-Porous Object on Momentum Fluxes in the Atmospheric Boundary Layer

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Introduction:

In order to find the impact on momentum fluxes within the atmospheric boundary layer due to the presence of an isolated semi-porous object a study is to be conducted. Specifically we will examine the impact on momentum and mass transport due to the presence of the isolated object.. This will be done in order to gain a further understanding of the physics involved in these tranports. The physical setup of the study will consist of an isolated tree located within a large field. The study will utilize large eddy simulation (LES) computational fluid dynamics to numerically analyze the physical features of interest. All features investigated will be analyzed over a large range of scales to ascertain their importance with scale. Features will also be analyzed across several different atmospheric conditions such as within a neutral atmospheric boundary layer and within a stratified flow atmospheric boundary layer. Some of the features to be assessed are: the non-dimensional momentum flux, the non-dimensional stresses in the flow, and the 3D energy spectra of the flow.

Mathematical Setup:

LES utilizes a low pass filter on the Navier-Stokes equations in order to segregate the equations based on flow scales. The larger flow scales are directly resolved through solving the Navier-Stokes equations whereas the smaller scales are modeled. The equational form of the equations to be solved is:

$$\frac{\partial \tilde{u}_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\tilde{u}_i \tilde{u}_j\right) = -\frac{1}{\rho}\frac{\partial \tilde{p}}{\partial x_i} + 2\nu \frac{\partial \tilde{S}_{ij}}{\partial x_j} - \frac{\partial \tau_{ij}}{\partial x_j} + F_i$$

Where ~ indicates a filtered value, u is the velocity at each point, p is the pressure at each point S_{ij} is the rate of strain tensor, τ_{ij} is the stress term that must be modeled and F_i is the applied forces within the flow (Saugaut, 2006). The filtered velocity dependent drag force imposed by the tree will be wrapped into the F_i term. The equational form that will be used to represent the tree is:

$$F_i = -C_d a(z) \tilde{u}_i |\tilde{u}|$$

Where $a(z)$ is the leaf area density which will be selected based on reference data for trees, and C_d is the drag coefficient of our tree which will also be selected based on reference material (Shaw and Schumann, 1992). The model to be used in order to solve τ_{ij} is an eddy viscosity model. The equational form of such a model is:

$$\tau_{ij} = -2\nu_t \tilde{S}_{ij}$$

Where ν_t is the eddy viscosity (Pope, 2000). τ_{ij} in our case will be determined using a dynamic smagorinsky model. The equational form of this model including its definition of eddy viscosity is:

$$\tau_{ij} - \frac{1}{3}\tau_{kk}\delta_{ij} = -2(C_s\Delta)^2 |\tilde{S}| \tilde{S}_{ij}$$

Where Δ is the filter width, δ_{ij} is the kronecker delta tensor, and C_s is the smagorinsky coefficient that must be found dynamically within the flow using the dynamic procedure (Porte-Agel, 2000).

Numerical Implementation:

The LES code to be utilized utilizes spectral methods with a Adams-Bashforth time stepping scheme. The boundary conditions of the domain to be utilized are periodic in both spanwise and streamwise directions. In order to address problems associated with the wake region of the tree flowing through the periodic streamwise boundary conditions a dampening layer was added to the front of the domain. The dampening layer dampens the inlet velocity field to a resolved velocity slice that most be found a priori the simulation by using a precursor simulation. The equational form of the dampening operation is:

$$u_{i,inlet} = \frac{x}{L} u_{i,resolved}$$

Where L is the length of the dampening layer in the streamwise direction and x is the distance in the streamwise direction (Keating, 2003). In order to address the continuity problems from this artificial dampening many resolved velocity slices are switched through until there is no statistical correlation between the initial resolved slice and the current slice. After this has been attained the slices are recycled continuously throughout the simulation.

Past the inflow and outflow conditions a vertically stretched grid will be utilized. This will allow for greater refinement in the area around the tree with minimal increased cost. On top of the vertical grid stretching horizontal grid refinement will be utilized to get even better resolution of the tree.

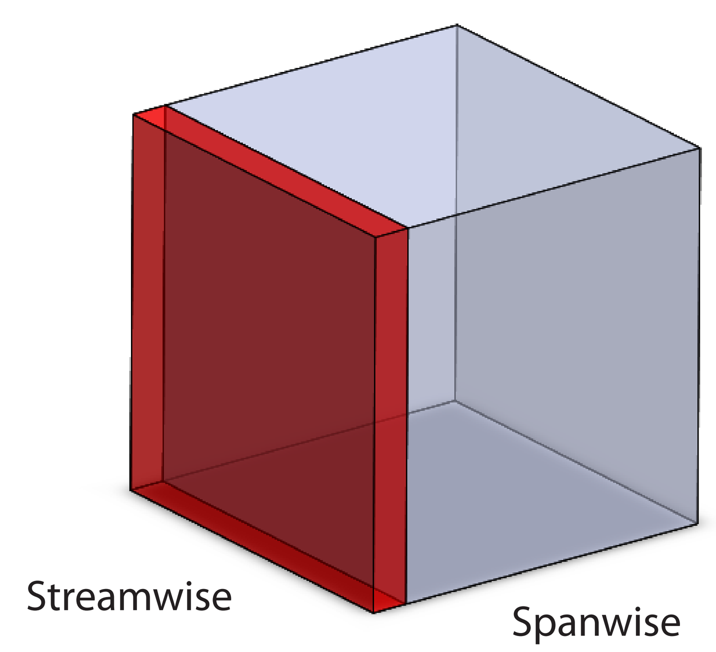

Fig. 1: Dampening layer within the domain

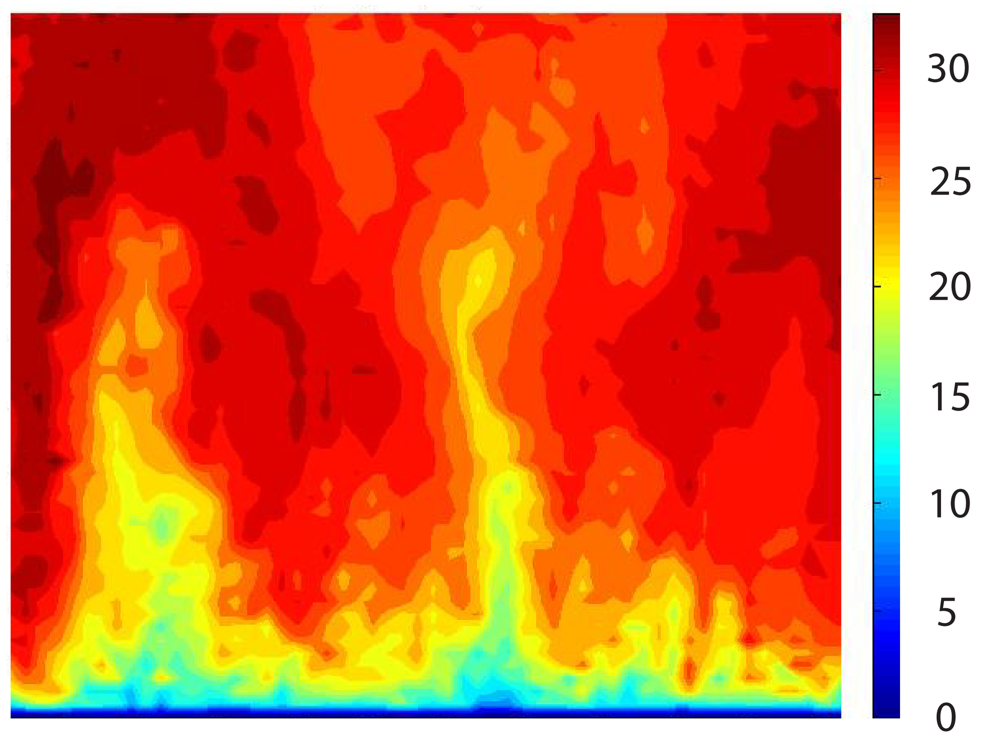

Fig. 2: Resolved Velocity Slice by Velocity Magnitude (m/s)

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