The effect of stable stratification on boundary layer development and pollutant dispersion behind an obstacle

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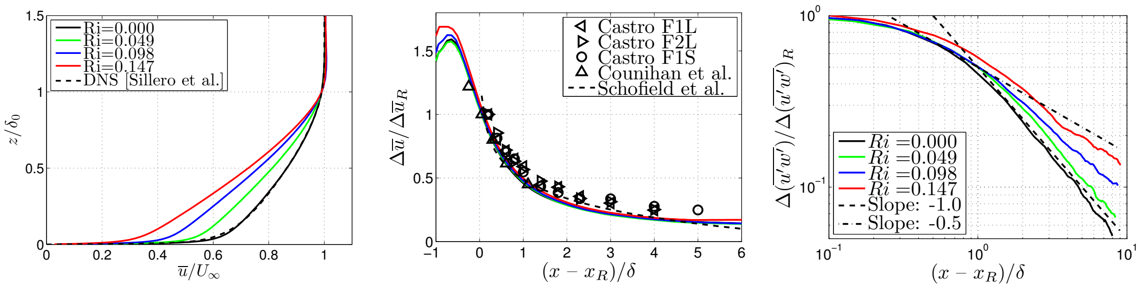
Introduction

Because of the global trend of urbanization there is an increasing demand for accurate predictions of urban air quality levels. Therefore, predicting the dispersion behaviour of pollutants within the urban canopy is of great interest. This requires knowledge about the urban boundary layer (UBL) in which the pollutants are released. Recently, several studies have been undertaken to investigate the UBL ([1]). Most of these studies focus on the fully developed regime in which the boundary layer has adapted to the underlying roughness. To understand how and how fast the transition in roughness takes place we investigate the streamwise development of the boundary layer behind a single roughness element over a long distance behind the obstacle. In addition, since it is often assumed that the urban canopy flow is neutrally buoyant, we take into account stable stratification effects. The effects on pollutant dispersion are studied by considering emissions of passive tracer gas.

Methods and results

Use is made of Large-Eddy Simulations (LES) to investigate the flow over both an infinite spanwise fence and a cube up to $100h$ behind the obstacle, where h is the obstacle height. The boundary layer height, δ, is ten times h to approximate atmospheric conditions. The inflow boundary layers are generated in separate driver simulations and have a friction Reynolds number, $Re_\tau = U_\tau \delta/\nu$, of 1950. The instantaneous velocity at the inlet plane of the driver simulations is generated using a recycling method similar to the method proposed by [2]. In addition, the inlet temperature field is generated in a similar vein as the velocity field by using the method developed by [3]. However, we take into account buoyancy effects to generate stably stratified flows up to a gradient Richardson number of 0.2 (Fig. 1a). To the best of our knowledge this has not been done before using a recycling method.
For validation purposes results for neutral flow over a fence of $h = 0.3\delta$ are compared with measurements from our water tunnel facility, showing good agreement. From the simulations with $h = 0.1\delta$ we conclude that the decay of maximum velocity and temperature deficit is independent of stability (Fig. 1b). However, the decay in added turbulence and concentration decreases with increasing stability (Fig. 1c). This means that for stable cases the presence of the fence is felt over a longer distance than for neutral cases. Results on the influence of a cube will be presented at the colloquium as well.



a b c

Fig. 1: a) $\overline{u}$ at domain inlet. b) Maximum $\Delta\overline{u}$ and c) maximum $\Delta\overline{u'w'}$ downstream of the fence.

References

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