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Subgrid scale energy fluxes and effective length scale in the wake of a fractal tree

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The vegetation canopy has a significant impact on various physical and biological processes such as microclimate, rainfall evaporation distribution and climate change. Most scaled laboratory experimental studies have used canopy element models that consist of rigid vertical strips or cylindrical rods that can be typically represented through only one or a few characteristic length scales, for example the diameter and height for cylindrical rods. However, most natural canopies and vegetation are highly multi-scale with branches and sub-branches, covering a wide range of length scales. Fractals provide a convenient idealization of multi-scale objects, since their multi-scale properties can be described in simple ways (Mandelbrot 1982). We present analysis of data that were obtained using Particle-Image-Velocimetry (PIV) in the near-wake flow of a fractal-like tree. The tree is a pre-fractal with five generations, with three branches and a scale reduction factor 1/2 at each generation. Its similarity fractal dimension is $D \sim 1.58$. We review our findings related to the mixing length-scale that is identified from the data by comparing momentum fluxes to mean velocity gradient. We also summarize how the mixing length-scale can be related to the geometric length-scales in the pre-fractal object, in particular their fractal length-scale distribution. The data are spatially filtered to address questions related to subgrid-scale kinetic energy fluxes, of relevance to Large Eddy Simulations. For canonical flows, in which typically kinetic energy is injected into the turbulence at a well-defined large scale, the subgrid-scale flux is typically independent of scale within the inertial range of the flow. In the wake of the fractal tree, on the other hand, the data exhibit strong scale-dependence. Using the data, we measure the scale-dependent injection of kinetic energy and examine various approaches to collapse the data using dimensionless quantities. We find that the length-scale associated with momentum transport identified before successfully collapses the measured trends of kinetic energy injection. The results confirm that information about multi-scale clustering of branches as it occurs in fractals has to be incorporated into subgrid-scale models of flows through canopies with multiple scales.

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