# Wind Flow over Mountains and Forested Regions

## CFD activities at Centre for Wind Energy and Atmospheric Flows. An opportunity for collaboration within the UT Austin - Portugal Program (CoLab)

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**Abstract**

The current trend of increasing the electricity production from wind energy has led to the installation of wind farms in areas of greater orographic complexity with and without forest, raising doubts on the use of simple, linear, mathematical models of the fluid flow equations, so common in the wind energy engineering.

The presentation shows how the CFD techniques can be used under conditions of incomplete knowledge of domain size and boundary conditions, and still be useful in all stages of wind farm design. Progress in both methodologies to overcome these shortcomings and turbulence modelling over forested regions will be shown.

A feature that distinguishes canopy flows from more familiar boundary layer flows is the removal of momentum from the air stream as aerodynamic drag on the foliage over an extended vertical region, rather than just at the surface plane. This is combined with a high rate of dissipation of turbulent kinetic energy (TKE) by the intense very fine scale shear layers, due to the vegetation. Vegetation enhances turbulence production as well as dissipation.

The state of the art of canopy flows was set by [1] and more recently by [2]. These two review papers, 20 years apart, evidence two alternative, and in our view also complementary, approaches to the modelling of flow over vegetation, respectively the Reynolds-averaged-Navier-Stokes (RaNS) and the Large-Eddy Simulation (LES). The physics of the flow over trees, as interpreted by [2], because of its eddy and time-dependent structure can be modelled by LES only. The work by [3] is one of such studies, showing good agreement with measured field data, to which others followed, [e.g., 4; 5; 6; 7; 8; 9], all taking

advantage of LES as a tool for studying the turbulent field, spectra and its mechanisms, within and above a forest canopy.

In spite of all of its advantages, because LES requires high computational resources, it is not a tool for engineering daily routines. Computer simulations of atmospheric flows tend to rely on RANS turbulence models. According with [10], gradient diffusion models are good enough if there is no need to know the individual terms of the Reynolds stress tensor, and in practical applications, the greatest uncertainty is still associated with the canopy drag coefficients and not with the turbulence model [11]. Ref. [12], in an overview of canopy models available on literature, argues that even simple one-equation turbulence model are good enough. However, being a widespread turbulence model found in many commercial CFD codes, canopy models are usually extensions of the two-equation $k$-$\varepsilon$ model [13]. Contrary to standard applications of the $k$-$\varepsilon$ model, the literature survey shows a still ongoing development of canopy models extensions to this model [cf., 12; 14]. Agreement cannot be found in simple matters such as the mathematical form of the terms in the transport equation for $k$ and $\varepsilon$, or the most appropriate set of constants [15; 16; 17]. Nevertheless, a good use has been made of these models for solving practical and engineering problems, eg. [18; 19].

The work by [20] was our starting points, and the canopy models were implemented into VENTOS® computer code [20] and are currently being used in the design methodology of modern wind farms.

For the appraisal of existing RaNS canopy models, good data is required, based on very simple conditions, such as a stationary flow over a flat and continuous (infinite) forest. Experimental data of atmospheric flows in those conditions are almost impossible to obtain. On the other hand, the complexity and scales of the flow make DNS (Direct Navier-Stokes) calculations not practical to implement.

As a result, LES over a flat and continuous ideal forest was used to provide a basis for comparison with different RaNS canopy models on the same conditions. The comparison will be made on its velocity, TKE and turbulent viscosity results. These parameters are the more representative of the characteristics of the atmospheric flow when one is studying a wind farm. Other important issue are the turbulent mechanisms among a forest and its correct reproduction by the RaNS models. To validate the model behaviour, we will compare the vertical profiles of the $k$ equation terms with LES equivalents.

**Keywords:** wind flows, LES, canopy flows

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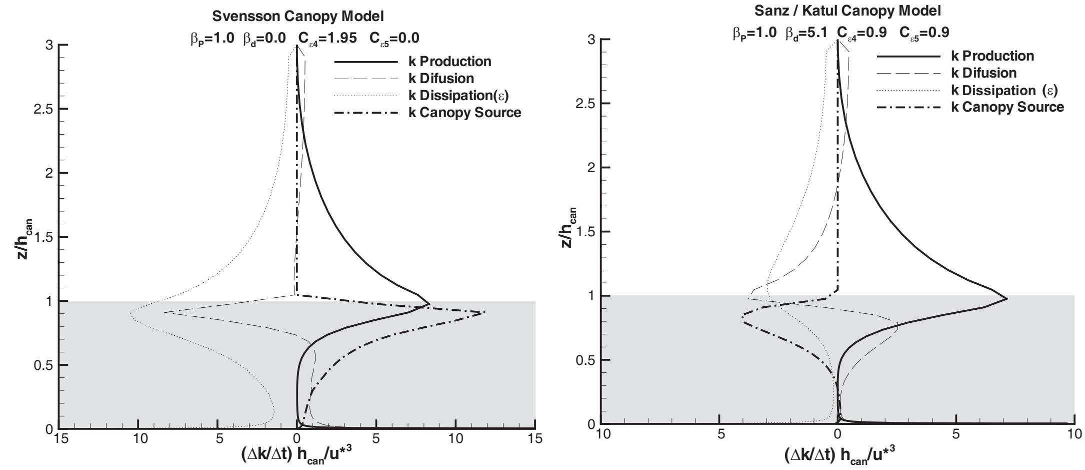


Figure 1: RaNS calculations TKE budget terms for the "Svensson CM" and "Sanz CM". Note that the horizontal scale range is different.

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