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LARGE-EDDY SIMULATION ON THE EFFECTS OF DRAG FORCE OF TREES

A REAL CASE STUDY

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1. INTRODUCTION

As acoustic propagation, forest fire (Pimont et al., 2006), tree stability (Dupont and Brunet, 2008b) or pollen dispersion (Chamecki et al., 2009), a lot of applications needs an accurate representation of the boundary layer to observe its influence on these phenomena. Then, in order to better represent the dynamics into the surface layer, Large-Eddy Simulations (LES) are carried on using thinner and thinner vertical resolutions until the order of the meter (Bohrer et al., 2009, Dupont and Brunet, 2008b). In these cases, influence of some objects (*e.g.* trees, buildings, ...) on dynamics should not be taken into account only through surface schemes - as usually done in mesoscale meteorological model - but directly in the dynamic equations of the model. In this way, instead of using the current roughness approach, a drag force approach has been implanted in some meteorological mesoscale models: MM5 (Otte et al., 2004), ARPS (Dupont and Brunet, 2008a), RAMS (Bohrer et al., 2009). This study presents its implementation in Meso-NH.

Here, the objective is to compare LES results with a real case experiment over a large domain (until 10 km²). In this way, the originality of this study is to quantify the positive impact of drag force approach on LES boundary layer representation in real case situation.

After a discussion in the Section 2 about the formulation and implementation of the scheme into the research mesoscale model (Meso-NH), section 3 consists to validate it thanks to numerical predictions issued from (Dupont and Brunet, 2008c) and (Shaw and Schumann, 1992). Large Eddy Simulations at very fine scales (until 2m) over real case are presented in section 4. Simulation results are confronted, with and without the canopy scheme, to observations from Lannemezan-2005 experience (Junker et al., 2006). At last, Section 5 provides conclusions and implications for future work.

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2. CANOPY PARAMETERIZATION FORMULATION

Meso-NH (Lafore et al., 1998) is the non-hydrostatic mesoscale atmospheric model of the French research community. It intended to be applicable to all scales ranging from large (synoptic) scales to small scales (Large-Eddy Simulation). The main parameterizations used in this study, are :

- a 3D turbulence scheme of 1.5 order closure with two different mixing length parameterization (Deardorff, 1980, Cuxart et al., 2000 or Bougeault and Lacarrere, 1989).
- The soil scheme Interactions-Soil-Biosphere-Atmosphere (ISBA; Noilhan and Planton, 1989).

This allows us to investigate all types of boundary layers (stable, neutral, instable) over different types of surface cover and to use a resolution at the order of the meter. However, for those fine vertical resolutions (~1m), a description of canopy effects on flow by a roughness approach, as usually done in large scale atmospheric model, is not convenient. A solution is to use a drag force approach.

Thus, an additional term is added to the momentum equations as follows:

$$\frac{\partial V}{\partial t} = F_v - C_d A_f(z) V (U^2 + V^2)^{0,5} \quad \textbf{(1)}$$

$$\frac{\partial U}{\partial t} = F_u - C_d A_f(z) U (U^2 + V^2)^{0,5} \quad \textbf{(2)}$$

where U, V are the two horizontal wind components; F_u, F_v are the model's general forcing terms in each equation; C_d is the canopy drag coefficient and $A_f(z)$ is the canopy area density (function of the height above the surface z).

In addition, in order to traduce dissipation of turbulence by the trees, a term is added on the subgrid parameterization of turbulence as:

$$\frac{\partial e}{\partial t} = F_e - C_d A_f(z)e$$

where *e* is the turbulence kinetic energy, and F_e the general forcing terms.

The canopy area density $A_f(z)$ represents the surface area of the tree face to the wind per unit volume of canopy. This coefficient corresponds to the variation of drag on the wind and the TKE dissipation by the density of leaves in the trees. It is a combination between A_i, the product of the fraction of vegetation in the grid cell by the *LAI* (leaf area index), and a weighting function to represent the shape of trees.

Drag of the wind and dissipation of TKE are dependent on the drag coefficient C_d (Eq. 1, 2 and 3). C_d is considered constant for all vegetation canopies and is set to 0.2.

3. VALIDATION

In order to validate the model, the same simulation set-up as (Dupont and Brunet, 2008a), (Shaw and Schumann, 1992), (Su et al., 1998) has been chosen. It consists in carrying on three dimensional simulations over homogeneous continuous forest canopies in dry neutral atmosphere. The results are confronted with measurements from (Su et al., 1998) within and above a deciduous forest at Camp Borden in Ontario, Canada.

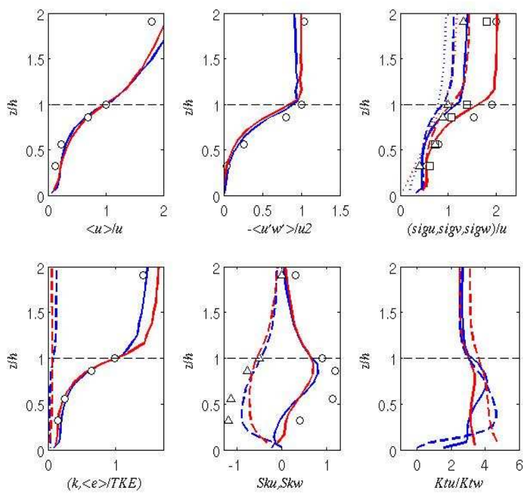

Figure 1 Validation of Meso-NH model (red) against ARPS (blue, Dupont and Brunet, 2008b) and measurements (dots, Su et al., 1998) in a homogeneous forest canopy. Vertical profiles of mean horizontal wind velocity (a); momentum flux (b); standard deviations of the three wind components (c), (σ_u : solid line, empty circle; σ_v : long dashed line, empty square; σ_w : small dashed line, empty triangle) ; total TKE (d); skewnesses of u and w (e)(Sk_u: solid line, empty circle; Sk_w: dashed line, empty triangle); kurtosis of u and w (f)

On *Figure 1*, the good agreement between Meso-NH model, ARPS model simulations (Dupont and Brunet, 2008a) and measurements (Su et al., 1998) is presented. It shows that Meso-NH is able to reproduce the well-known characteristics of turbulence under and above canopy.

The implementation of the drag force approach in Meso-NH allows the ability to reproduce a good behavior of the fluxes above and within a canopy layer.

4. REAL CASE

4.1. Lannemezan 2005

Lannemezan-2005 (Junker et al., 2006) is an experiment leaded by the Laboratoire Central des Ponts et Chaussees, Electricite De France, Ecole Central de Lyon and SNCF near the city of Lannemezan (France). It was designed to be a three months experiment (between June and August 2005) in order to study effects of meteorology on outdoor acoustic propagation. The topography of the Lannemezan-2005 site (

Figure 2) is flat covered with prairie grass and trees barriers each side of the studied domain. In addition to microphones, a large number of meteorological sensors have been deployed in this general area. The current study uses data collected from six 10 m and one 60 m meteorological towers, and two sonic anemometers. To validate our meteorological model, 2 clear sky typical conditions are chosen:

- the 17th of June during day-time corresponding to convective unstable conditions,
- the 03rd of July during night-time corresponding to stable conditions with a nearly laminar flow near the surface.

Simulations were conducted using three grid-nested 200 x 200 x 80 domains centered on the area of Lannemezan 2005. Large-eddy simulations are performed with grid-nested models and horizontal resolutions of 50m, 10m until 2m in order to resolve the smallest eddies. A vertical terrain-following stretched grid is used with 50 levels in the first 100m. In order to initialize the simulations, a vertical profile is built using measurements from the 60-m tower and ARPEGE analysis (Dequé et al., 1994) above 60m .

All the following vertical profiles result from a space averaging on the experimental area and a time averaging during 15min.

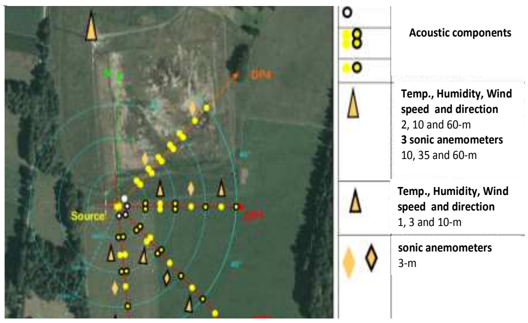

Figure 2 Experimental site of Lannemezan 2005

4.2. Results

4.2.1. *Qualitative*

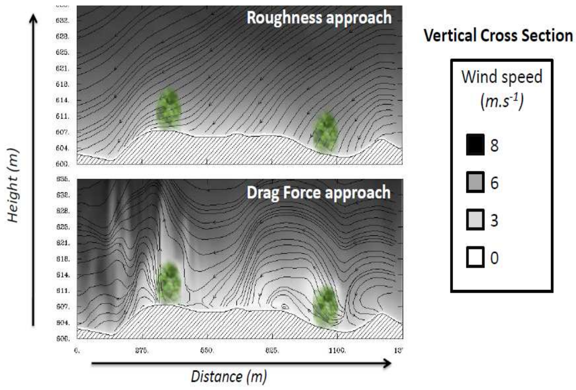

Figure 3 Vertical cross section of instantaneous wind fields simulated with roughness (a) and drag force approach (b).

Qualitative results underline the differences between the two approaches. The drag of the trees increases turbulence by shear force creation and the downstream wind speed is weaker.

4.2.2. *Unstable atmosphere*

Midday of 17th June 2005 has been chosen as representative of unstable boundary layer (BL) conditions. The results are presented in *Figure 4*. Simulations results are in good agreement with the observations. Moreover, implementation of the drag force approach induces a weak but positive impact on the mean wind speed. Effects on the other variables seem to be negligible.

Better agreement with measurement might be obtained by a better knowledge of trees height, location and shape.

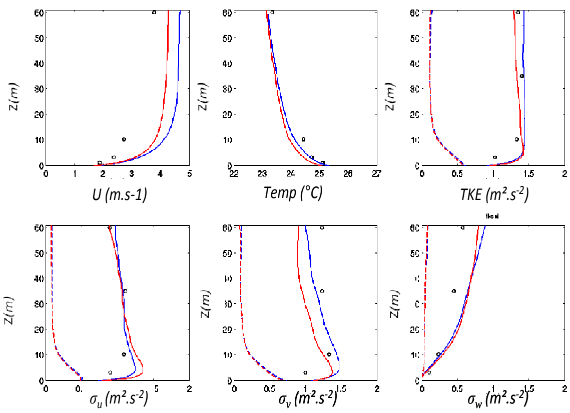

Figure 4 Comparison of Meso-NH model with (red) and without (blue) the drag force implementation over the Lannemezan 2005 experimental site. Mean vertical profiles of horizontal wind velocity (a); temperature (b); turbulence kinetic energy (c) (total : solid line, sub-grid : long dashed) ; and standard deviations of the three wind components (d,e,f) (total : solid line, sub-grid : long dashed).

4.2.3. Stable atmosphere

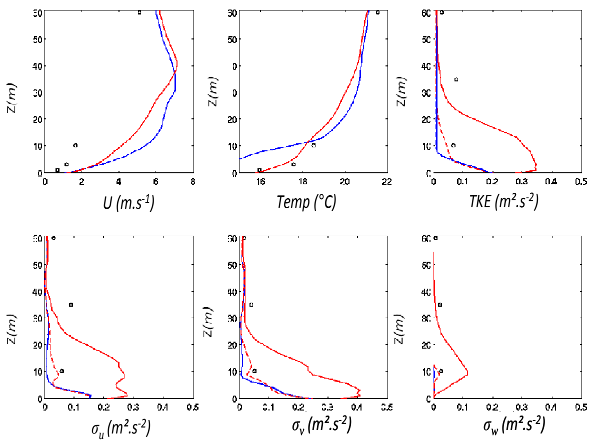

Figure 5 Comparison of Meso-NH model with (red) and without (blue) the drag force implementation over the Lannemezan 2005 experimental site. Mean vertical profiles of mean horizontal wind velocity (a); temperature (b); turbulence kinetic energy (c) (total : solid line, sub-grid : long dashed) ; and standard deviations of the three wind components (d,e,f) (total : solid line, sub-grid : long dashed).

Midnight of 03rd July 2005 is considered as representative of stable BL conditions. The results are presented in *Figure 5*. Thanks to the drag force approach, we can see a better agreement between simulations and observations for the wind speed and the temperature.

However, the creation of turbulence near the surface, too weak before the drag force implementation is now too important. It has to be noticed that we know the difficulty of the model to well-represent the turbulence near the surface in stable condition.

AS for unstable case, it can be expected that better agreement can be obtained by a better knowledge of trees height, location and shape.

5. CONCLUSION

In this paper, the implementation and the validation of the drag force approach of trees in the mesoscale model Meso-NH is presented. Above and within a homogeneous cover, Meso-NH results are in good agreement with the literature and a qualitative approach exhibits the good behavior of the model with this implementation. Then, real case simulation under stable and unstable conditions had been carried on. Results will be completed soon by simulations under neutral conditions.

Different ways could be investigated to increase the agreement between simulations and observations. The description of the trees field could be more precise and a different turbulence scheme is necessary to realize better simulations in stable condition. Moreover, taking accurately into account the trees into a mesoscale model can't only be done through a drag force scheme. The thermal fluxes (Denmead and Bradley, 1985) can play an important role on the flow too. In this way, numerous completion of this scheme could be realized.

However, it has to be noticed that due to the low computation time of this method and its positive impact, the drag force approach seems to be useful in real case simulations every time the vertical resolution is thinner than the vegetation height.

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