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Two Methods to Improve Turbulence Estimates Above a Forest in a CFD Model

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windsim

Introduction

In this investigation, we make two modifications to the forest model of the WindSim CFD software, evaluate their impact on wind speed and turbulence intensity (TI) estimates by using wind tunnel data, and test the findings against data from a forested site. The first method is a variable profile of leaf area index (LAI) to represent the physical shape of the forest more accurately, and the second is modification to the closure coefficients in the turbulence transport equations. The modifications focus on the work of Lopes et al. (2011), who used a LES model to show that the turbulence production terms originally proposed by Green (1992), expanded upon by Sanz (2003), and widely used in the industry may be unnecessary.

Forest Modeling in WindSim

In WindSim' s CFD code the Reynolds Averaged Navier-Stokes equations are solved in steady and incompressible form (Gravdahl, 1998). The forest has influence on the momentum equation (1) and the equation for turbulent kinetic energy (2) and dissipation (3). The individual source and sink terms are given below the equations.
Formally the model has been implemented as in Sanz (2003) and Katul et al. (2004) with the model constants revised to be compatible with the default set of constants of the standard k-ε model (4). That model has been selected by WindSim based on work from Hilbert (2012) where several forest models were addressed and this one was the best fit for WindSim.
Beside the height of the trees the coefficient C2 needs to be specified for that model which is dependent upon the leaf area index, the height of the canopy and the drag coefficient of the trees (5). Look-up tables are available for leaf area index around the world and drag coefficients depending on the forest density.

(1) $$\rho u_i \frac{\partial u_j}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial p}{\partial x_j} + \rho f_i + S_j$$

$$S_j = -\alpha C_2 \sqrt{u_j u_j}\, u_i$$

(2) $$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_{\boldsymbol{k}} - \rho\varepsilon + S_k$$

$$S_k = C_2\left(\beta_p \sqrt{u_i u_i}^3 - \beta_d u_i k\right)$$

(3) $$\frac{\partial}{\partial x_i}(\rho \epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}P_k - C_{2\epsilon}\rho\frac{\varepsilon^2}{k} + S_\epsilon$$

$$S_\varepsilon = C_2\left(C_{\varepsilon 4}\beta_p \frac{\varepsilon}{k} u_i^3 - C_{\varepsilon 5}\beta_d u_i \varepsilon\right)$$

(4) $$\beta_p = 1.0, \beta_d = 6.51, C_{\varepsilon 4} = C_{\varepsilon 5} = 1.24$$

(5)

Wind Tunnel & Model Modifications

- Recreated wind tunnel from Meroney experiment (1968)
- Selected for its use of zero-pressure-gradient ceiling and the inlet wind speed and TI profile which is the same as the WindSim standard
- Wind speed and turbulence intensity data was collected at many locations downstream the forest edge
- Wind tunnel dimensions 2x2x26 m

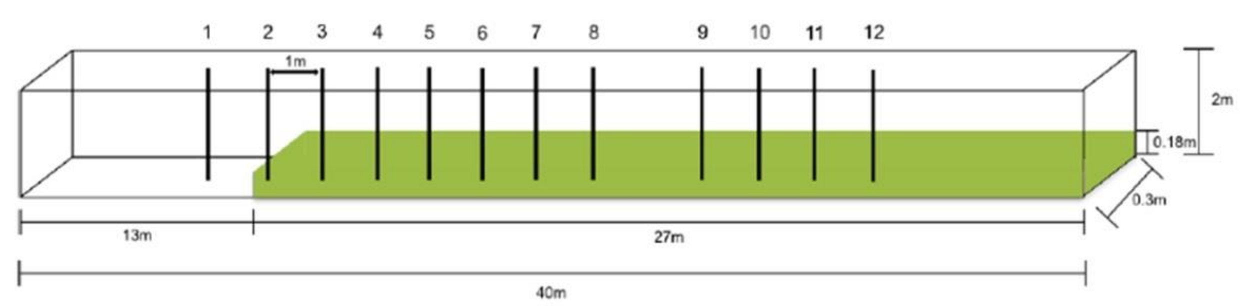

Figure 1 : CFD wind tunnel with measurement positions as black lines. Forested area is displayed in green.

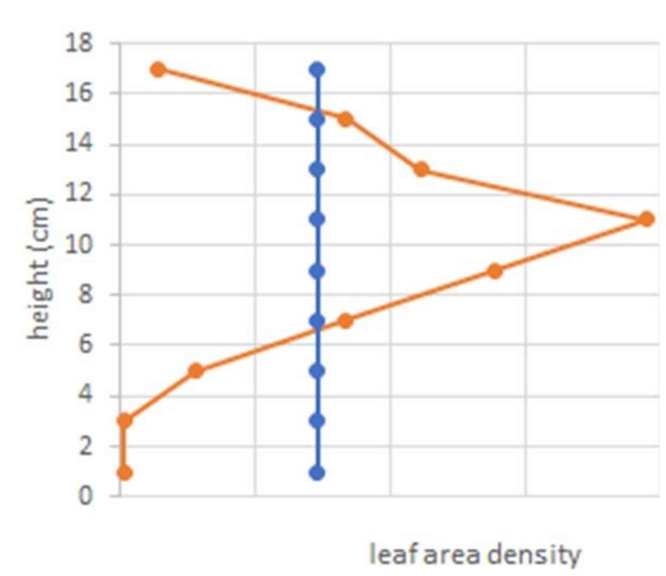

Figure 2 : Variable leaf area index (orange) compared to default fixed value (blue).

Source	β_p	β_d	$C_{\varepsilon 4}$	$C_{\varepsilon 5}$
Standard	1.00	6.51	1.24	1.24
Dalpé & Masson	1.00	5.03	0.79	0.79
Lopes Long	0	3.80	0	0.79
Lopes Edge	0	4.11	0	0.68
Lopes Original	0	4.00	0	0.90
Sanz calc'd	0	3.00	0	0.83

Table 1: Closure coefficient modifications.

Method I: Variable leaf area index

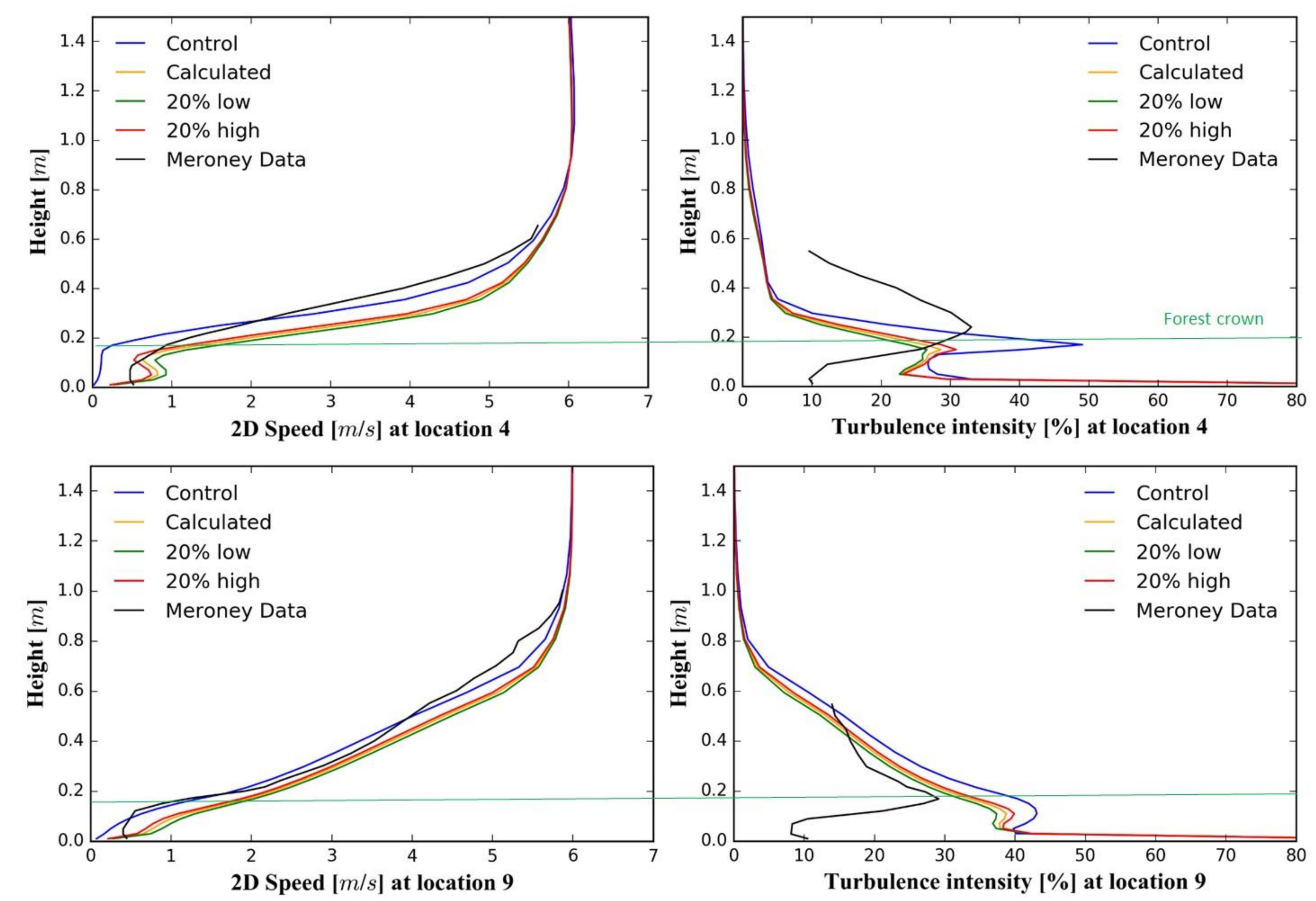

Figure 3 : Wind speed (left) and TI (right) for measurement position 4 (top) and 9 (bottom) for the measurements, the control run and the new LAI values.

Method II: Closure coefficient modification

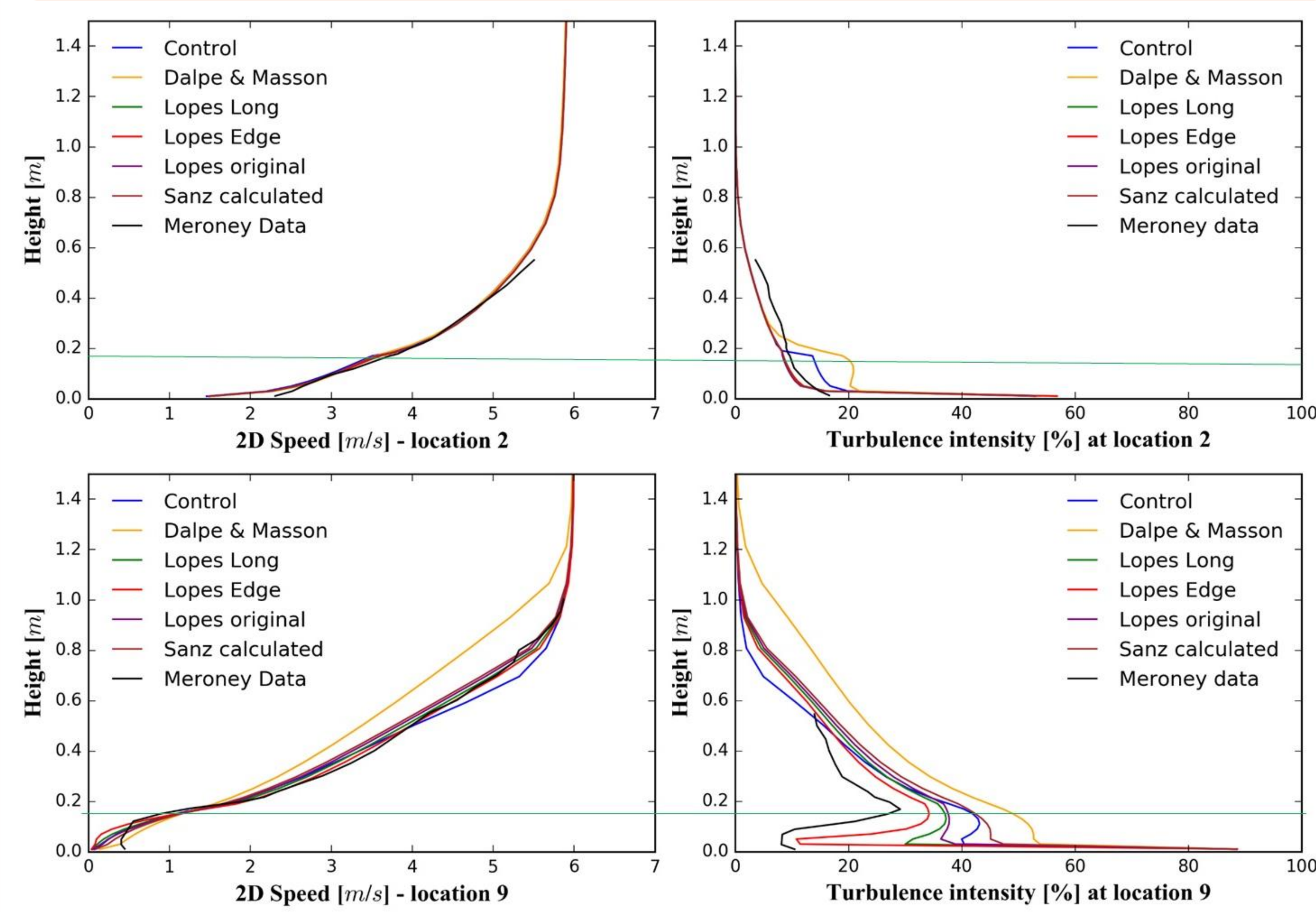

Figure 4 : Wind speed (left) and TI (right) for measurement position 2 (top) and 9 (bottom) for the measurements, the control run and the different closure coefficients.

Conclusions

- Using variable leaf area density instead of a constant value does improve the TI simulation results. If such data is available for a site, it might be worth using.
- Lopes modification for turbulence coefficients seems to improve the TI simulation for the wind tunnel experiment and also on real sites (not shown).
- More wind tunnel validations and validations at real sites will follow.

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