Two methods to improve turbulence estimates above a forest in a CFD model

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Motivation

• WindSim users are satisfied with the wind speed and turbulence intensity (TI) calculations of the WindSim CFD software over forested areas (Envision/Siemens presentation today, EON presentation at WindEurope conference last year).

• The absolute cross-prediction error at 80-100 m above ground is below 5% for wind speed and around 10% for TI for most of the sites shown in these validations.

• WindSim simulates the relative change of TI above the forest very well.
Motivation

**But** there is always room for improvement:

- Wind Speed profiles inside the forest can be different from observations
- Absolute TI values inside and right above the forest can be too high

New forest data sets are available which give information about the vertical density distribution inside the forest => should we use them?

Seeking new parameterization to limit TI values and create a more realistic profile inside and right above the forest
Wind tunnel

- 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 set-up
- Wind speed and turbulence intensity data was collected at many locations downstream the forest edge
- Wind tunnel dimensions 2x2x26 m

CFD model
• Inlet wind conditions very similar between measurements and CFD model
New methods

We can try to produce a more reasonable wind profile and to reduce the TI inside and near the forest by two methods:

- Use a variable leaf area density instead of a constant one
- Closure coefficient modification

\[ S_k = C_2(\beta_p |U|^3 - \beta_d |U|k) \]

\[ S_\varepsilon = C_2 \left[ C_4 \beta_p \left( \frac{\varepsilon}{k} \right) |U|^3 - C_5 \beta_d |U|\varepsilon \right] \]
Method 1: Variable leaf area density

Generated LAD profile based on the tree geometry and varied it by ±20% to test sensitivity
Method 1: Variable leaf area density
Method 1: Variable leaf area density
Method 2: Closure coefficient modification

- Closure coefficients

\[ S_k = C_2 (\beta_p |U|^3 - \beta_d |U| k) \]

\[ S_\epsilon = C_2 [C_{\epsilon 4} \beta_p \left( \frac{\epsilon}{k} \right) |U|^3 - C_{\epsilon 5} \beta_d |U| \epsilon] \]

\[ \beta_p = \text{TKE production} \]
\[ \beta_d = \text{TKE destruction} \]
\[ C_{\epsilon 4} = \text{EP production} \]
\[ C_{\epsilon 5} = \text{EP destruction} \]

- Lopes hypothesis

Lopes (2011) used LES to show that forest only acted as sink \( \Rightarrow \beta_p \) was unnecessary (and thus also \( C_{\epsilon 4} \).)
Method 2: Closure coefficient modification

Coefficient combinations which have been tested:

<table>
<thead>
<tr>
<th>Source</th>
<th>$\beta_p$</th>
<th>$\beta_d$</th>
<th>$C_{\varepsilon 4}$</th>
<th>$C_{\varepsilon 5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>1.00</td>
<td>6.51</td>
<td>1.24</td>
<td>1.24</td>
</tr>
<tr>
<td>Dalpé &amp; Masson</td>
<td>1.00</td>
<td>5.03</td>
<td>0.79</td>
<td>0.79</td>
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<td>Lopes Long</td>
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<td>0</td>
<td>0.79</td>
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<tr>
<td>Lopes Edge</td>
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<td>0</td>
<td>0.68</td>
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<tr>
<td>Lopes Original</td>
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<td>0</td>
<td>0.90</td>
</tr>
<tr>
<td>Sanz calc’d</td>
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<td>3.00</td>
<td>0</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Method 2: Closure coefficient modification

![Diagram showing 2D Speed and Turbulence intensity at location 2 with different labels: Control, Dalpe & Masson, Lopes Long, Lopes Edge, Lopes original, Sanz calculated, Meroney Data.](image-url)
Method 2: Closure coefficient modification
Application to a real wind farm

TI cross-checking results

<table>
<thead>
<tr>
<th>Reference mast</th>
<th>Standard Forest</th>
<th>Lopes Forest</th>
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<tbody>
<tr>
<td>Mast 1</td>
<td>19.27%</td>
<td>9.67%</td>
</tr>
<tr>
<td>Mast 2</td>
<td>12.54%</td>
<td>4.78%</td>
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<tr>
<td>Mast 3</td>
<td>11.54%</td>
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<tr>
<td>Mast 4</td>
<td>23.25%</td>
<td>6.91%</td>
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<tr>
<td>Mast 5</td>
<td>12.51%</td>
<td>9.04%</td>
</tr>
</tbody>
</table>
Conclusion

• 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 it.

• Lopes modification for turbulence coefficients seems to improve the TI simulation.

• More wind tunnel validations and validations at real sites will follow.
Thank you

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