Integrated use of two dimensional airflow model Aquilon and mechanistic model HWIND for risk assessment of tree stands to wind damage
Heli Peltola, Sylvain Dupont, Veli-Pekka Ikonen, Hannu Väisänen, Ari Venäläinen, Seppo Kellomäki

To cite this version:
Heli Peltola, Sylvain Dupont, Veli-Pekka Ikonen, Hannu Väisänen, Ari Venäläinen, et al.. Integrated use of two dimensional airflow model Aquilon and mechanistic model HWIND for risk assessment of tree stands to wind damage. 2.International Conference on Wind Effects on Trees, Oct 2009, Freiburg, Germany. hal-02753729

HAL Id: hal-02753729
https://hal.inrae.fr/hal-02753729
Submitted on 3 Jun 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Integrated use of two dimensional airflow model Aquilon and mechanistic model HWIND for risk assessment of tree stands to wind damage

Heli Peltola¹, Sylvain Dupont², Veli-Pekka Ikonen¹, Hannu Väisänen¹, Ari Venäläinen³, Seppo Kellomäki¹

¹University of Joensuu, Faculty of Forest Sciences, Finland
²INRA, France
³Finnish Meteorological Institute, Finland

Abstract

In this work, we will apply a two dimensional airflow model Aquilon together with a mechanistic model HWIND for risk assessment of wind damage in Scots pine (Pinus sylvestris) and Norway spruce (Picea abies) stands under a range of forest configurations in Finnish conditions. In the above context, Aquilon will provide for HWIND vertical wind profiles for different forest configurations, including either a clear-cut area or another shorter stand upwind the stand edge considered to have a risk. HWIND will then predict the critical wind speeds needed for wind damage. Based on these simulations, we will demonstrate how the critical wind speeds are affected by different tree and stand characteristics at the downwind stand edges of clear-cut areas and by shelter provided by another shorter stand upwind the stand edge considered to have a risk for Scots pine and Norway spruce stands.

1. Introduction

Forest damage caused by high wind speeds and storms has during the past decades caused significant economic losses in forestry both in central and northern Europe. For example, in January 1990 and December 1999 about 100 and 175 million m³ of timber was damaged in these regions by storms. Again, in January 2005 a storm damaged about 70 million m³ of timber in southern Sweden, but spared Finland. So far, the most destructive storm damages observed in Finland have occurred in December 2001, when two separate storms (named as Pyry and Janika) blew down about 7 million m³ of timber in southern Finland. The economic impacts of damage are particularly severe in managed forests because of the reduction in the yield of recoverable timber, increased costs of harvesting in damaged forests, and timber price reductions due to the quality decrease of damaged timber and additional unscheduled cutting operations.

In Finland, even relatively low wind speeds have caused significant damage (e.g. Janika: 10-min mean wind of 15-19 m/s; Pyry: 8-13 m/s, coupled with wet and heavy snow load of 30 kg/m² crown area). In addition to the properties of wind, also individual tree and stand characteristics and site conditions affect the susceptibility of tree stands to damage. Determining appropriate management practices for reducing the risk of damage is a complicated task because the probability of damage changes as a consequence of tree growth, interactions between neighbouring stands, and management actions (see e.g. Zeng et al. 2006). When risk assessment is concerned in Finnish conditions, the most crucial question is how the new clear-cuts will affect the local wind speeds and the wind loading on trees adjacent to the clear-cut areas.
For the assessment of risk of wind-induced damage, we should understand the mechanisms of tree stability and the resistance of trees against strong winds (Gardiner et al., 2000; 2008). Mechanistic models such as HWIND (Peltola et al., 1999), GALES/ForestGales (Gardiner et al., 2000; 2008) and FOREOLE (Ancelin et al., 2004) were developed for this purpose, i.e. predicting the critical wind speeds needed for uprooting or breaking trees at stand edges or within stands (even-aged stands) under a range of silvicultural conditions, based on the properties of the trees and stands.

In this work, we will apply a two dimensional airflow model Aquilon together with a mechanistic model HWIND for risk assessment of wind damage in Scots pine (Pinus sylvestris) and Norway spruce (Picea abies) stands under a range of forest configurations in Finnish conditions. Based on these simulations, we will demonstrate how the critical wind speeds are affected by different tree and stand characteristics at the downwind stand edges of clear-cut areas and by shelter provided by another shorter stand upwind the stand edge considered to have a risk for Scots pine and Norway spruce. As a comparison, we will use corresponding predictions done by HWIND, applying a logarithmic wind profile at the upwind stand edge (see Zeng et al. 2009).

2. Outlines for the component models and simulations

2.1 Outlines for the Aquilon model simulations

The Aquilon model is a CFD type model that has been adapted to canopy flow (Foudhil et al., 2005). Turbulence is modelled statistically with a k-ε closure scheme. The flow equations in the canopy are modified to account for the drag forces and the production of turbulent kinetic energy by the vegetation. The dynamic part of the model has been previously validated in 2D cases (continuous and discontinuous vegetation canopies), against wind-tunnel and in-situ measurements (Foudhil et al., 2005), and in a 3D heterogeneous urban park (Dupont and Brunet, 2006).

Fig. 1: Layout for the Aquilon simulations and examples of simulated wind profiles for Scots pine and Norway spruce at -0.5 tree heights before the downwind edge considered to have a risk; figure legends: L = clear-cut area, H1 = height of upwind tree stand (Tree1) with leaf area index (LAI) of 1 and H2 = height of downwind stand at risk (Tree2) with LAI of 2.
In this work, Aquilon will provide vertical wind profiles for HWIN at upwind stand edge with different forest configurations, including either a clear-cut area (L) or another shorter stand (H1) upwind the stand edge (H2) considered to have a risk (see Fig. 1, Table 1). The simulated relative wind profiles at -0.5 tree heights before the edge are then used as input for further HWIN computations on critical wind speeds.

Table 1: Simulated cases by Aquilon for Norway spruce (NS) and Scots pine (SP)

<table>
<thead>
<tr>
<th>Cases</th>
<th>L (m)</th>
<th>H1 (m)</th>
<th>H2 (m)</th>
<th>LAI1</th>
<th>LAI2</th>
<th>Tree1</th>
<th>Tree2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 4</td>
<td>Infinity</td>
<td>-</td>
<td>20.0</td>
<td>-</td>
<td>1</td>
<td>NS, SP</td>
<td></td>
</tr>
<tr>
<td>2, 5</td>
<td>Infinity</td>
<td>-</td>
<td>20.0</td>
<td>-</td>
<td>2</td>
<td>NS, SP</td>
<td></td>
</tr>
<tr>
<td>3, 6</td>
<td>Infinity</td>
<td>-</td>
<td>20.0</td>
<td>-</td>
<td>3</td>
<td>NS, SP</td>
<td></td>
</tr>
<tr>
<td>7, 8</td>
<td>200.0 (10 h)</td>
<td>20.0</td>
<td>20.0</td>
<td>2</td>
<td>2</td>
<td>NS, SP</td>
<td></td>
</tr>
<tr>
<td>9, 10</td>
<td>100.0 (5 h)</td>
<td>20.0</td>
<td>20.0</td>
<td>2</td>
<td>2</td>
<td>NS, SP</td>
<td></td>
</tr>
<tr>
<td>11, 15</td>
<td>0.0</td>
<td>5.0</td>
<td>20.0</td>
<td>2</td>
<td>2</td>
<td>constant</td>
<td></td>
</tr>
<tr>
<td>12, 16</td>
<td>0.0</td>
<td>10.0</td>
<td>20.0</td>
<td>2</td>
<td>2</td>
<td>constant</td>
<td></td>
</tr>
<tr>
<td>13, 17</td>
<td>0.0</td>
<td>5.0</td>
<td>20.0</td>
<td>2</td>
<td>1</td>
<td>constant</td>
<td></td>
</tr>
<tr>
<td>14, 18</td>
<td>0.0</td>
<td>10.0</td>
<td>20.0</td>
<td>2</td>
<td>1</td>
<td>constant</td>
<td></td>
</tr>
<tr>
<td>19, 21</td>
<td>0.0</td>
<td>15.0</td>
<td>20.0</td>
<td>2</td>
<td>2</td>
<td>constant</td>
<td></td>
</tr>
<tr>
<td>20, 22</td>
<td>0.0</td>
<td>15.0</td>
<td>20.0</td>
<td>2</td>
<td>1</td>
<td>constant</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>400 (20 h)</td>
<td>20.0</td>
<td>20.0</td>
<td>2</td>
<td>2</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>800 (40 h)</td>
<td>20.0</td>
<td>20.0</td>
<td>2</td>
<td>2</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

We simulated by Aquilon the two dimensional airflow: i) over forest clearing (gap perimeter corresponding 5 and 10 tree heights of downwind stand height) and consequently for downwind stand edge of clearing, but also ii) in the conditions when there existed upwind stand instead of open area, with relative height of 25, 50 and 75 % of that of downwind stand height for Scots pine and Norway spruce (with average tree height of 20 m and diameter at breast height of 20 cm, and crown ratios of 40 and 70% for Scots pine and Norway spruce, with leaf area index (LAI) of 2, corresponding 700 stems/ha). We also used LAI of 1 and 3 in some cases to study the sensitivity of results on upwind edge stand density. Similarly, we simulated cases with large perimeters (from 20 h to infinity) as a comparison to above described cases.

2.2 Outlines for the HWIN model simulations

The HWIN model was originally developed to calculate the mean critical wind speeds of one hour average needed to uproot or break Scots pine, Norway spruce and birch (Betula spp.) trees at different distances from the downwind edge of a newly created clear-cut area (see Peltola et al., 1999). In the model, a tree is assumed to be uprooted if the maximum bending moment exceeds the resistance of the root-soil plate. Respectively, the stem is assumed to be broken if the breaking stress exceeds the critical value of modulus of rupture.

A good agreement has been demonstrated between HWIN, GALES and FOREOLE models at newly created stand edge conditions (see Ancelin et al., 2004), despite of the
fact that HWIND was originally designed to calculate the critical wind speeds at upwind stand edges in Finnish conditions, whereas GALES and FOREOLE were designed to calculate them within forest stands for British and French conditions. HWIND has also predicted critical wind speeds in line with those speeds actually caused damage in Finnish and Swedish conditions (see e.g. Talkkari et al., 2000; Blennow and Sallnäs, 2004). The properties of the HWIND model, its parameters, inputs and the validity of its outputs have been discussed previously by Peltola et al. (1999), Gardiner et al. (2000, 2008), Blennow and Sallnäs (2004) and Zeng et al. (2006, 2009).

Zeng et al. (2009) recently modified slightly the parametrization of logarithmic wind profile in HWIND in order to consider also a shelter effect by another shorter stand upwind the stand edge considered to have a risk (i.e. resulting lower wind loading). However, this theoretical approach has not yet been validated based on experimental data or airflow simulations. In this sense, Aquilon simulations offer now possibility to validate HWIND model’s assumption for logarithmic profile at upwind stand edge considered to have a risk. Therefore, we will make corresponding simulations by HWIND for upwind stand edges, by applying a logarithmic wind profile (see in details, Peltola et al. 1999, Zeng et al. 2009).

Based on HWIND simulations, we will analyze how the critical wind speeds are affected by: i) tree and stand characteristics (e.g. tree height, diameter and breast height, stand density) at the downwind stand edges of clear-cut areas (with different sizes) and ii) shelter provided by another shorter stand (i.e. height varies from 0, 25, 50 and 75 % of that of downwind stand edge at risk) upwind the stand edge considered to have a risk in Scots pine and Norway spruce. We consider here only uprooting as wind damage type regardless of tree species because it is in Finnish conditions the most typical type of wind damage under unfrozen soil conditions. The range used for different tree and stand characteristics in simulations correspond well the range observed in sample trees of forest inventory data representing permanent inventory plots in southern Finland.

3. Example results of simulations

The model simulations showed in general, that increase in tree height of the downwind stand or perimeter of the upwind stand decreased the critical wind speeds needed to uproot trees regardless of tree species. Increasing dbh/height-ratio of the downwind stand or shelter (relative tree height) offered by the upwind stand increased the critical wind speeds (Figs. 2 and 3). In Norway spruce with longer crown (crown ratio of 70% in simulations), the shelter effect of upwind stand height was stronger than in Scots pine (crown ratio of 40%). Norway spruce needed also on average lower wind speeds for damage than Scots pine. The simulated results by the Aquilon and HWIND differed also in some cases significantly from those by HWIND (see Fig. 2). For Fig. 3, the critical wind speeds at canopy top were transformed by the logarithmic wind profile into corresponding wind speeds at 10 m above ground at the stand edge of clear cut area (following original HWIND approach).

In general, the probability for strong wind speeds and, thus, risk of damage, differ also spatially much in Finland. Thus, the risk considerations are especially important on areas having high probabilities of damage (e.g. in Helsinki (south coast) probabilities for winds < 17 m/s are highest), when decisions for management of forests are made.
Fig. 2: Examples of predicted critical wind speeds: i) a clear-cut area (with perimeters of 5 and 10 tree heights (h) of downwind stand edge), and ii) another shorter stand (with relative height of 25, 50 and 75% of downwind stand edge) upwind the stand edge, considered to have a risk; the tree height = 20 m, stem taper = 1:100 for bars and 1:75 and 1:125 for error bars.

Fig. 3: Predictions for critical wind speeds (by Aquilon and HWIND) for trees of varying sizes with different forest configurations (see legends in Fig. 2); perimeter of clear-cut area is 10x downwind stand edge height.

4. Conclusions

Compared to the integrated use of Aquilon and HWIND models, HWIND predicted alone larger critical wind speeds for Scots pine especially when the relative height of upwind stand, providing shelter for downwind stand edge at risk, increased significantly.
or when perimeter of clear-cut area decreased. In Norway spruce, corresponding shelter effect differences were even more evident. This results from the fact that the modified logarithmic profile parametrization used in HWIND (see Zeng et al. 2009) seemed to output too low wind speeds in lower tree canopy compared to the Aquilon, resulting underestimation of the wind loading on trees and thus, overestimation of the shelter effect. Anyway, modelling tools like demonstrated in this work could support the decision making of forest managers when considering the silvicultural risks by wind.

References


Blennow, K., Sallnäs, O., 2004: WINDA - a system of models for assessing the probability of wind damage to forest stands within a landscape. Ecological Modelling 175, 87-99.


Authors’ addresses:

Dr. Heli Peltola (Heli.Peltola@joensuu.fi),
Dr. Veli-Pekka Ikonen (Veli-peka.Ikonen@joensuu.fi),
Mr. Hannu Väisänen (Hannu.Vaisanen@joensuu.fi)
Prof. Dr. Seppo Kellomäki (Seppo.Kellomaki@joensuu.fi)
Faculty of Forest Sciences, University of Joensuu
Yliopistokatu 7, FI-80101 Joensuu, Finland

Dr. Sylvain Dupont (sdupont@bordeaux.inra.fr)
INRA, UR1263 Ephyse
71 Avenue Edouard Bourlaux, F-33140 Villenave d’Ornon, Cedex, France

Dr. Ari Venäläinen (Ari.venalainen@fmi.fi)
Finnish Meteorological Institute
Erik Palmen place 1, FI-00101 Helsinki, Finland