Improving estimates of roughness length ($Z_0$) in a road weather prediction model using airborne LIDAR data

D.S. Hammond, L. Chapman & J.E. Thornes

School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK

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Geographical & Infrastructure Parameters used to drive the road weather prediction model

<table>
<thead>
<tr>
<th>Geographical Parameters</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sky View Factor ($\psi_s$)</td>
<td>Road Type</td>
</tr>
<tr>
<td>Altitude</td>
<td>Roughness Length ($Z_0$)</td>
</tr>
<tr>
<td>Slope</td>
<td>Traffic Density</td>
</tr>
<tr>
<td>Aspect</td>
<td>Emissivity</td>
</tr>
<tr>
<td>Latitude</td>
<td>Albedo</td>
</tr>
<tr>
<td>Longitude</td>
<td></td>
</tr>
</tbody>
</table>
Roughness length \((Z_0)\)

- Air flow in boundary layer largely controlled by frictional drag imposed on flow by the underlying surface

- \(Z_0\) - measure of the aerodynamic roughness of a surface

- “Height at which the neutral wind profile extrapolates to a zero wind speed.” (Oke, 1992)
How is $Z_0$ currently parameterised in the road weather prediction model

- Simple look-up table of $Z_0$ values assimilated from scientific literature

- Ordinal dataset of $Z_0$ – major oversimplification

<table>
<thead>
<tr>
<th></th>
<th>Rural</th>
<th>Semi-rural</th>
<th>Suburban</th>
<th>Urban</th>
<th>City Centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorway</td>
<td>0.50</td>
<td>0.50</td>
<td>0.75</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>A-road</td>
<td>0.25</td>
<td>0.50</td>
<td>0.75</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>B-road</td>
<td>0.25</td>
<td>0.50</td>
<td>0.75</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>C-road</td>
<td>0.25</td>
<td>0.50</td>
<td>0.75</td>
<td>1.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Modified from Chapman (2002)
Example of $Z_0$ classification
Use LIDAR data to obtain surface elements heights

Simple rule of thumb:

\[ Z_0 = f_0 Z_H \]

(Oke, 1992; Grimmond & Oke, 1999)

\[ f_0 \approx 0.1 \]

(Garratt, 1992; Hanna & Chang, 1992; Grimmond & Oke, 1999)

Effective roughness length \( (Z_{\text{eff}}) \):

\[ Z_{0\text{eff}} = \langle Z_0 \rangle \]

(Vihma & Savijärvi, 1999)
Methodology

Process LIDAR data

DSM – DTM = $Z_H$

Apply $f_0 = 0.1$ rule of thumb

$Z_0 = 0.1 \times (Z_H)$

Calculate $Z_0^{\text{eff}}$ using areal area average of local $Z_0$ values

$Z_0^{\text{eff}} = \langle Z_0 \rangle$
Methodology

**ArcMap**
- Focal Mean neighbourhood function

- 5 distances of upwind fetch = 5 $Z_0^{\text{eff}}$ datasets

- Prevailing westerly wind
Distribution of $Z_0^{\text{eff}}$ values

$an = 0.3409$
$ev = 0.34625$
$= 10.584$
### Distribution of $Z_0^{\text{eff}}$ values

**Davenport classification of effective terrain roughness**

<table>
<thead>
<tr>
<th>$Z_0$ (m)</th>
<th>Landscape Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 0.0002 “Sea”</td>
<td>Open sea or lake (irrespective of wave size), tidal flat, snow-covered flat plain, featureless desert, tarmac and concrete, with a free fetch of several kilometres.</td>
</tr>
<tr>
<td>2. 0.005 “Smooth”</td>
<td>Featureless land surface without any noticeable obstacles and with negligible vegetation; e.g. beaches, pack ice without large ridges, marsh and snow-covered or fallow open country.</td>
</tr>
<tr>
<td>3. 0.03 “Open”</td>
<td>Level country with low vegetation (e.g. grass) and isolated obstacles with separations of at least 50 obstacle heights; e.g. grazing land without wind breaks, heather, moor and tundra, runway area of airports. Ice with ridges across-wind.</td>
</tr>
<tr>
<td>4. 0.10 “Roughly Open”</td>
<td>Cultivated or natural area with low crops or plant covers, or moderately open country with occasional obstacles (e.g. low hedges, isolated low buildings or trees) at relative horizontal distances of at least 20 obstacle heights.</td>
</tr>
<tr>
<td>5. 0.25 “Rough”</td>
<td>Cultivated or natural area with high crops or crops of varying height, and scattered obstacles at relative distances of 12 to 15 obstacle heights for porous objects (e.g. shelterbelts) or 8 to 12 obstacle heights for low solid objects (e.g. buildings).</td>
</tr>
<tr>
<td>6. 0.5 “Very Rough”</td>
<td>Intensively cultivated landscape with many rather large obstacle groups (large farms, clumps of forest) separated by open spaces of about 8 obstacle heights. Low densely-planted major vegetation like bush land, orchards, young forest. Also, area moderately covered by low buildings with interspaces of 3 to 7 building heights and no high trees.</td>
</tr>
<tr>
<td>7. 1.0 “Skimming”</td>
<td>Landscape regularly covered with similar-size large obstacles, with open spaces of the same order of magnitude as obstacle heights; e.g. mature regular forests, densely built-up area without much building height variation.</td>
</tr>
<tr>
<td>8. ≥ 2.0 “Chaotic”</td>
<td>City centres with mixture of low-rise and high-rise buildings, or large forests of irregular height with many clearings.</td>
</tr>
</tbody>
</table>

LIDAR data © 2009 Landmap
Ordinal v Ratio Dataset

Existing Ordinal $Z_0$ Classification

New LIDAR based $Z_0^{\text{eff}}$ Classification

LIDAR data © 2009 Landmap
Statistical Analysis

• Are there significant differences in $Z_0^{\text{eff}}$ values between land use categories?

• 2 land use datasets used in the comparison

• Kruskal-Wallis rank-order statistical analysis

<table>
<thead>
<tr>
<th>ENTICE Land Use</th>
<th>OWEN Land Use (Owen et al, 2006)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Rural</td>
<td>1. Villages/farms</td>
</tr>
<tr>
<td>2. Semi-Rural</td>
<td>2. Suburban</td>
</tr>
<tr>
<td>3. Suburban</td>
<td>3. Light suburban</td>
</tr>
<tr>
<td>4. Urban</td>
<td>4. Dense suburban</td>
</tr>
<tr>
<td>5. City Centre</td>
<td>5. Urban/transport</td>
</tr>
<tr>
<td></td>
<td>6. Urban</td>
</tr>
<tr>
<td></td>
<td>7. Light urban/open water</td>
</tr>
<tr>
<td></td>
<td>8. Woodland/open land</td>
</tr>
</tbody>
</table>
Kruskal-Wallis Analysis

• Results of Kruskal-Wallis analyses were highly significant \((p < 0.001)\) over all 5 distances of upwind fetch for both land use datasets

• Significant differences do exist in the Z0eff values between at least two land use classes in each dataset, but it doesn’t reveal where these differences exist

Wilcoxon rank-sum Tests

• Analysis performed on the Z0eff values within each independent land use class

• Overall the vast majority of the land use comparisons are statistically significant for both land use datasets

• New method of roughness parameterisation does distinguish well between different land use categories around the route
Multiple Regression on Thermal Mapping data

• 20 nights Thermal Mapping data (dependent variable)

• ENTICE GPD parameters (independent variables)

Thermal Mapping Data

Sky View  Road Type  Altitude

Slope  Aspect  $Z_0^{\text{eff}}$

• 1st run - Existing $Z_0$ classification

• 2nd run - New $Z_0^{\text{eff}}$ dataset
Statistical Model Performance

Improved Statistical Model Performance

Reduced Statistical Model Performance

R² values (LIDAR based \( Z_e \) classification)

R² values (Existing ordinal \( Z_0 \) classification)
Potential Future Improvements

• Distance of upwind fetch calculated for each individual forecast point as a function of obstacle height

• Same technique could be used to assimilate a look-up table of $Z_{0e}^{\text{eff}}$ values for various directions of upwind fetch

Limitations

• Technique assumes constant direction of upwind flow, with each portion of the upstream surface considered to be an equal contributor to the aerodynamic character at a given forecast point

• Technique fails to account for moving surface elements, such as vehicle traffic
References


