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

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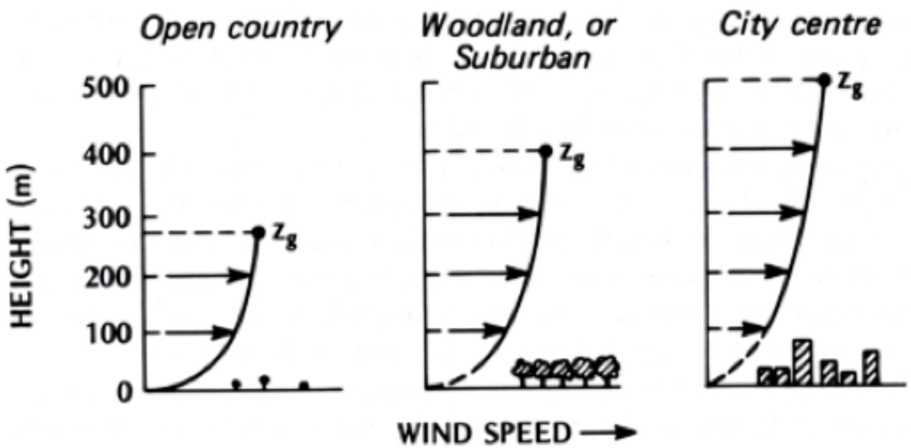
Geographical & Infrastructure Parameters used to drive the road weather prediction model

Geographical Parameters	**Infrastructure**
Sky View Factor (ψ_s)	Road Type
Altitude	Roughness Length (Z_0)
Slope	Traffic Density
Aspect	Emissivity
Latitude	Albedo
Longitude	

Roughness length (Z_0)

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



Source: Oke (1992)

• 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

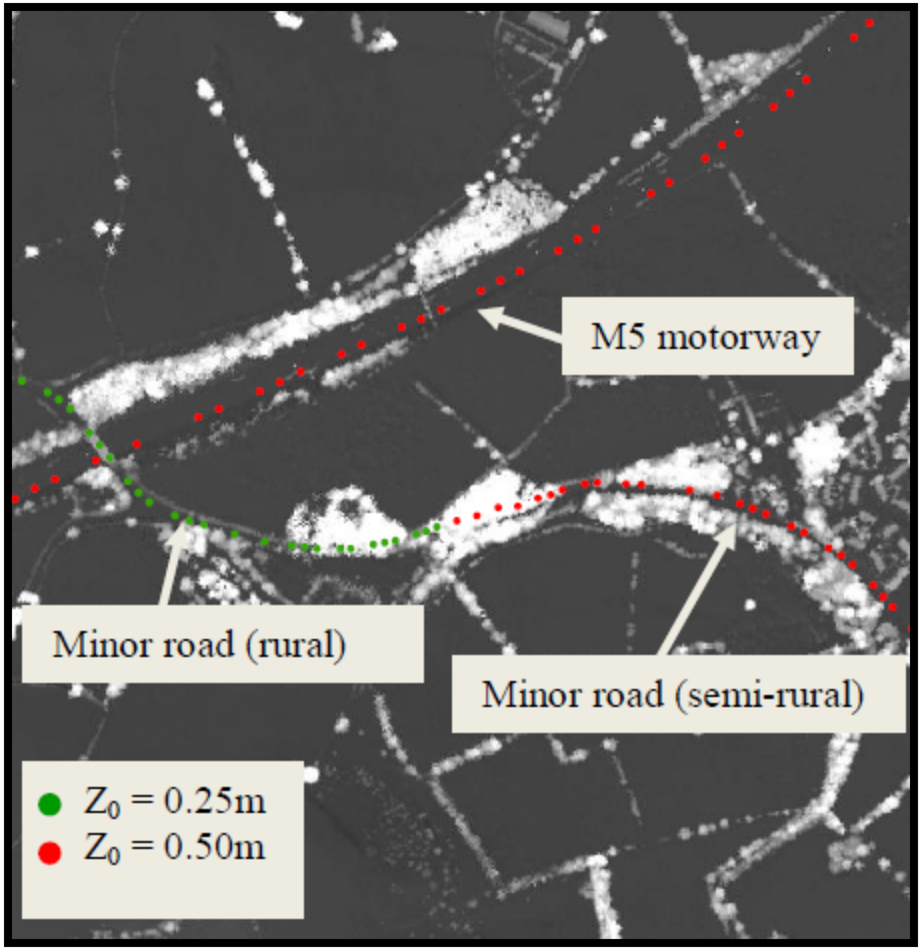
- Simple look-up table of Z_0 values assimilated from scientific literature

- Ordinal dataset of Z_0 – major oversimplification

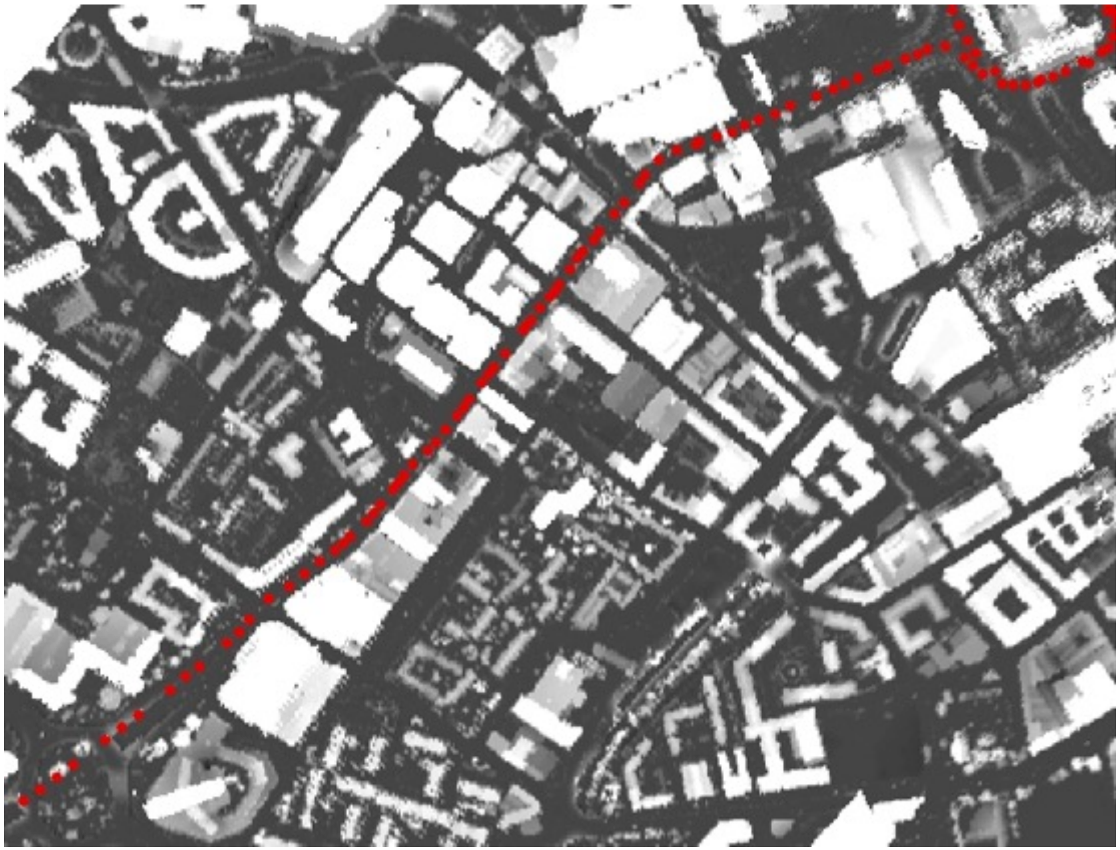
	Rural	Semi-rural	Suburban	Urban	City Centre
Motorway	0.50	0.50	0.75	1.00	2.00
A-road	0.25	0.50	0.75	1.00	2.00
B-road	0.25	0.50	0.75	1.00	2.00
C-road	0.25	0.50	0.75	1.00	2.00

Modified from Chapman (2002)

Example of Z_0 classification



Use LIDAR data to obtain surface elements heights



LIDAR data © 2009 Landmap

Simple rule of thumb:

$$Z_0 = f_0 \overline{Z_H}$$

(Oke, 1992; Grimmond & Oke, 1999)

$$f_0 \approx 0.1$$

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

Effective roughness length (Z^{eff}):

$$Z_0^{eff} = \left\langle \overline{Z_0} \right\rangle$$

(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^{eff} using areal area average of local Z_0 values

$$Z_0^{eff} = \langle \overline{Z_0} \rangle$$

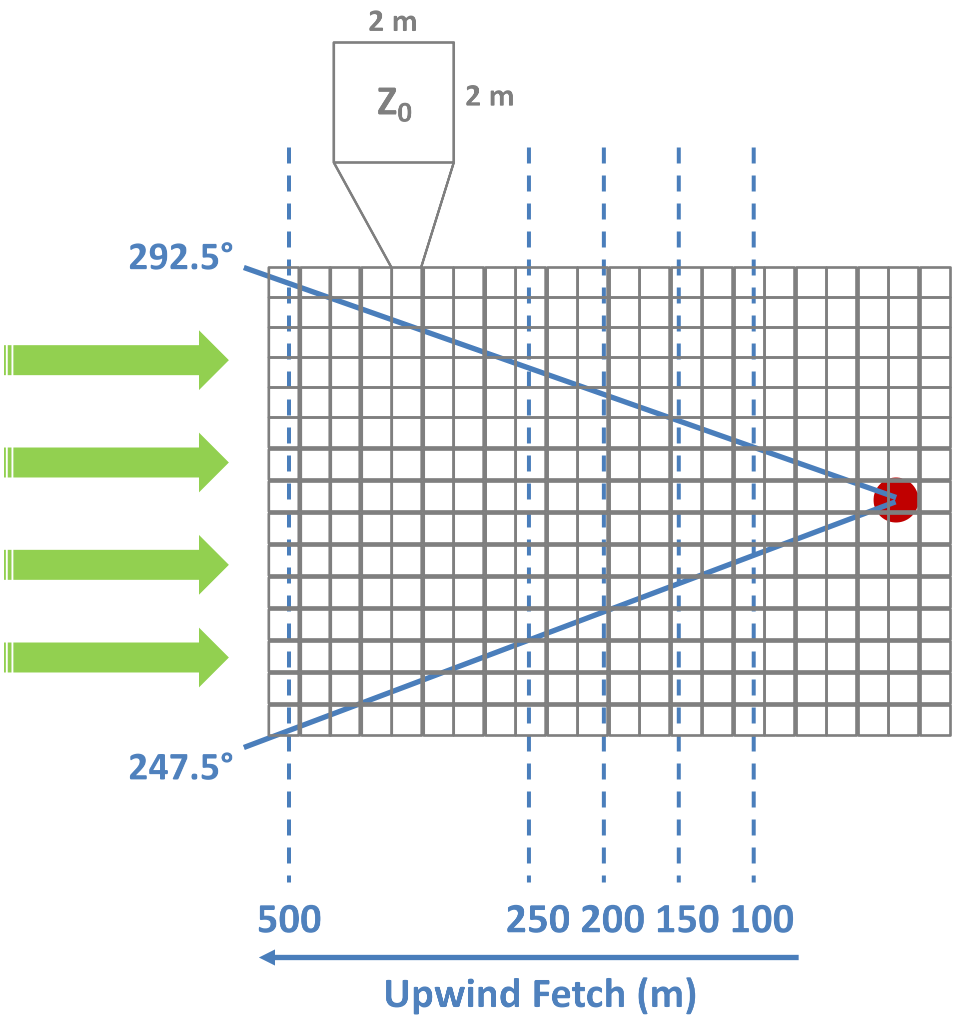
Methodology

ArcMap

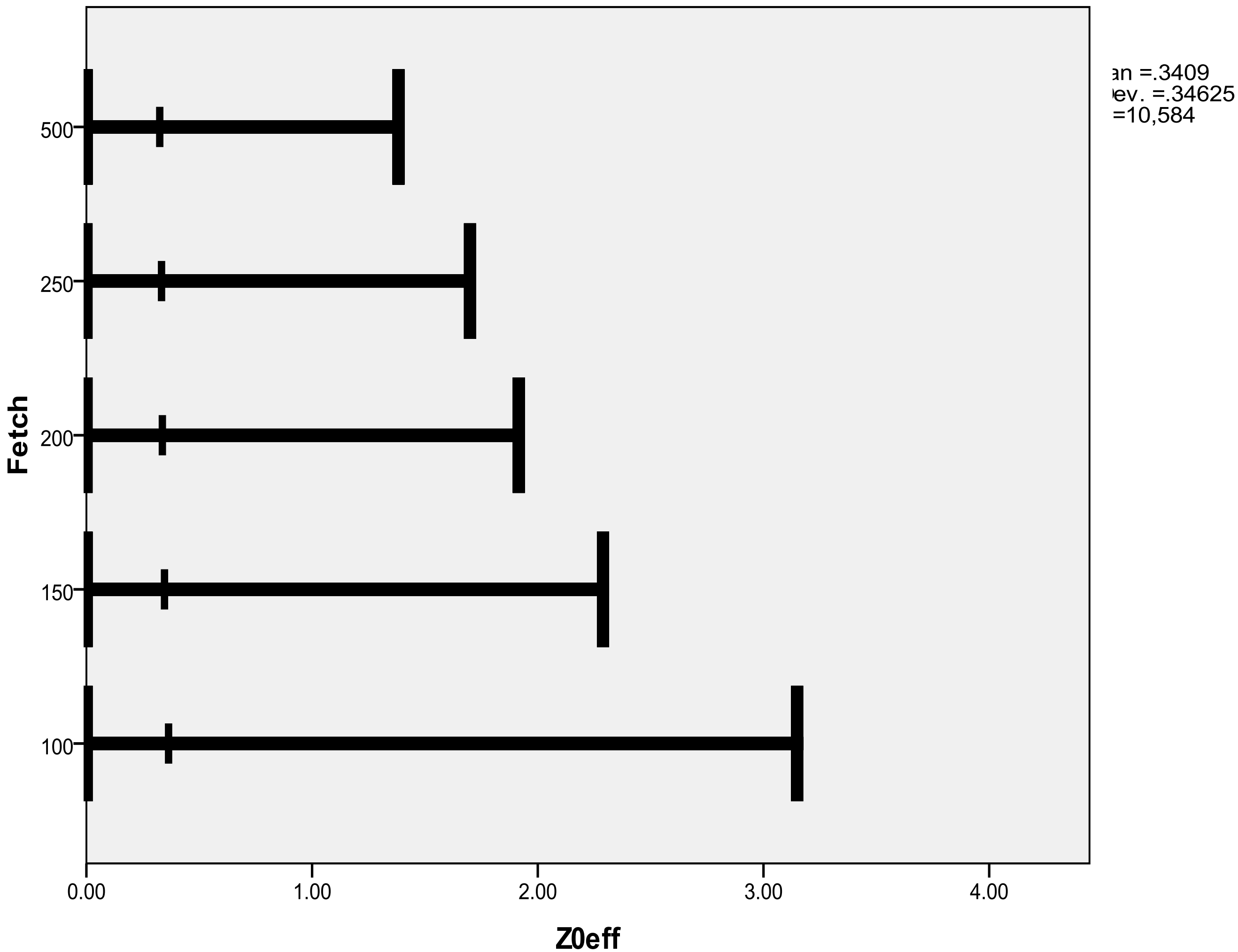
•Focal Mean neighbourhood function

•5 distances of upwind fetch = 5 Z_0^{eff} datasets

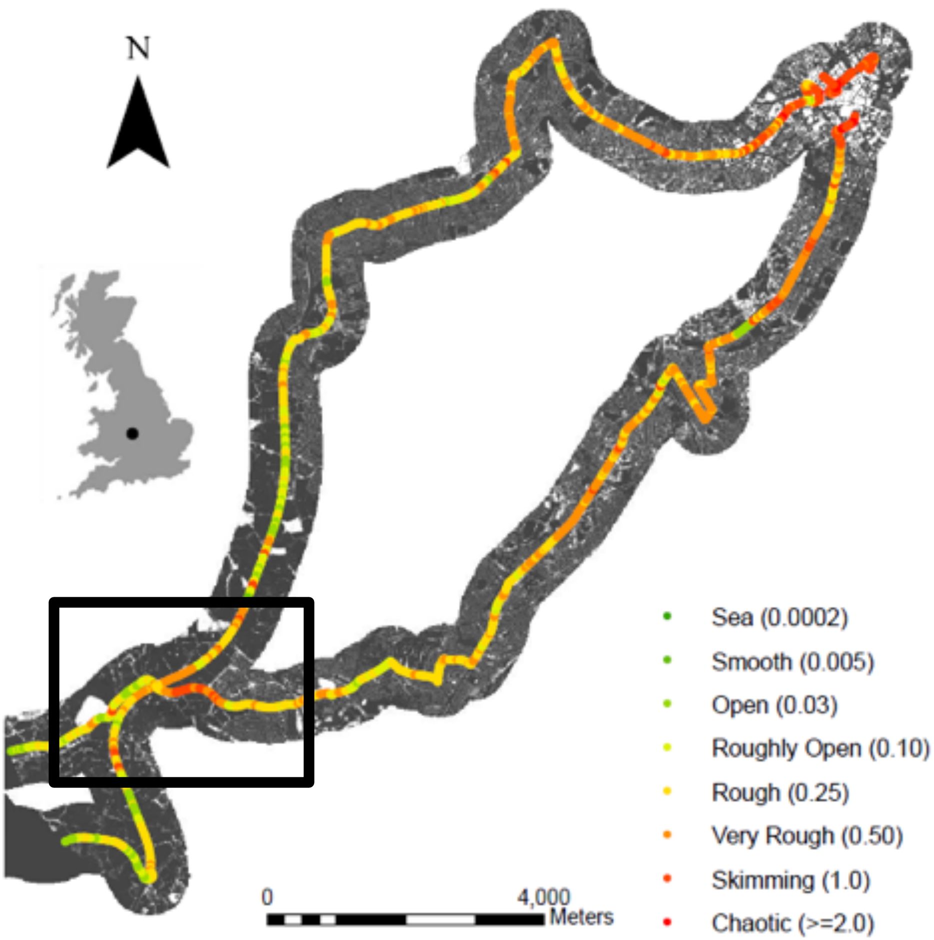
•Prevailing westerly wind



Distribution of Z_0^{eff} values



Distribution of Z_0^{eff} values

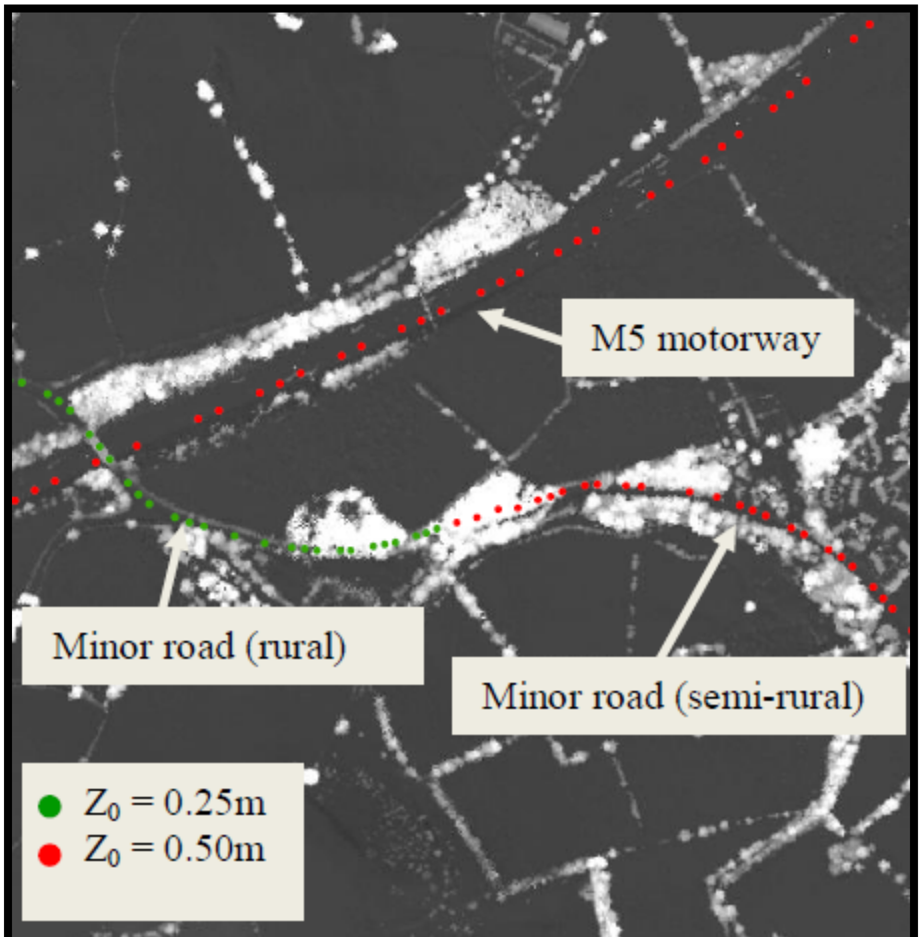


Davenport classification of effective terrain roughness

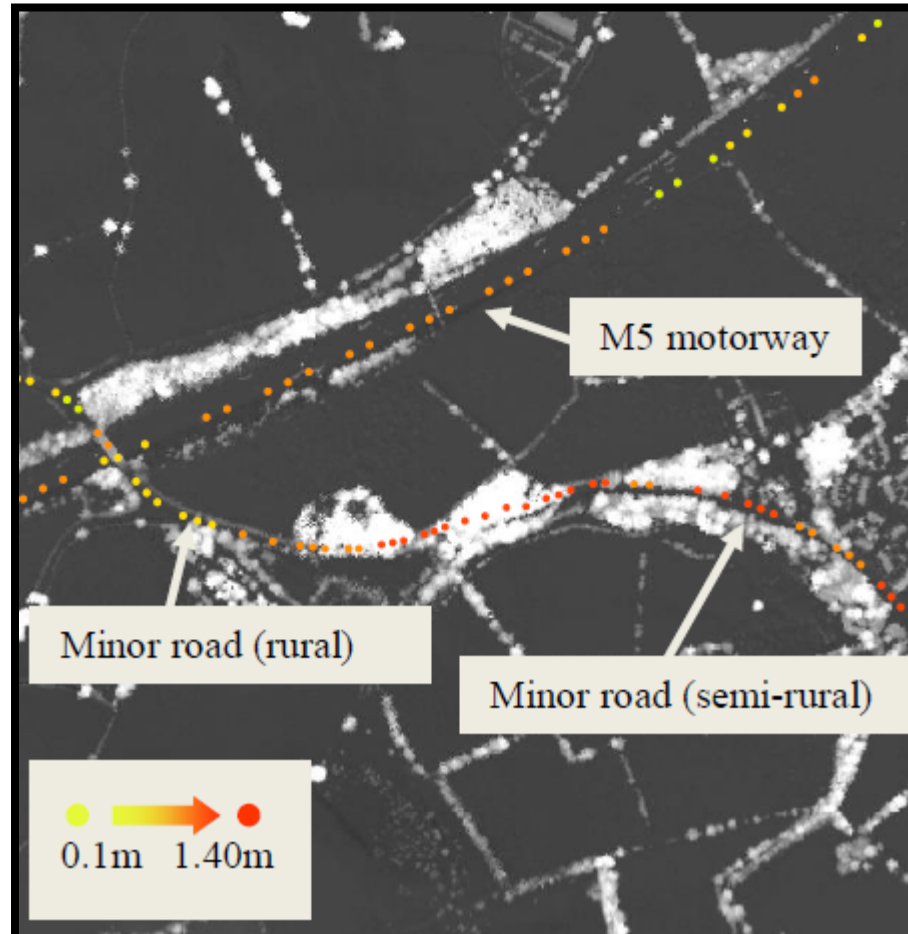
Z_0 (m)	Landscape Description
1. 0.0002 “*Sea*”	Open sea or lake (irrespective of wave size), tidal flat, snow-covered flat plain, featureless desert, tarmac and concrete, with a free fetch of several kilometres.
2. 0.005 “*Smooth*”	Featureless land surface without any noticeable obstacles and with negligible vegetation; e.g. beaches, pack ice without large ridges, marsh and snow-covered or fallow open country.
3. 0.03 “*Open*”	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.
4. 0.10 “*Roughly Open*”	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.
5. 0.25 “*Rough*”	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).
6. 0.5 “*Very Rough*”	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.
7. 1.0 “*Skimming*”	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.
8. ≥ 2.0 “*Chaotic*”	City centres with mixture of low-rise and high-rise buildings, or large forests of irregular height with many clearings.

Ordinal v Ratio Dataset

Existing Ordinal Z_0 Classification



New LIDAR based Z_0^{eff} Classification



Statistical Analysis

- Are there significant differences in Z_0^{eff} values between land use categories?
- 2 land use datasets used in the comparison
- Kruskal-Wallis rank-order statistical analysis

ENTICE **Land Use**	***OWEN*** **Land Use (Owen** ***et al*****, 2006)**	
1. Rural	1. Villages/farms	6. Urban
2. Semi-Rural	2. Suburban	7. Light urban/open water
3. Suburban	3. Light suburban	8. Woodland/open land
4. Urban	4. Dense suburban	
5. City Centre	5. Urban/transport	

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

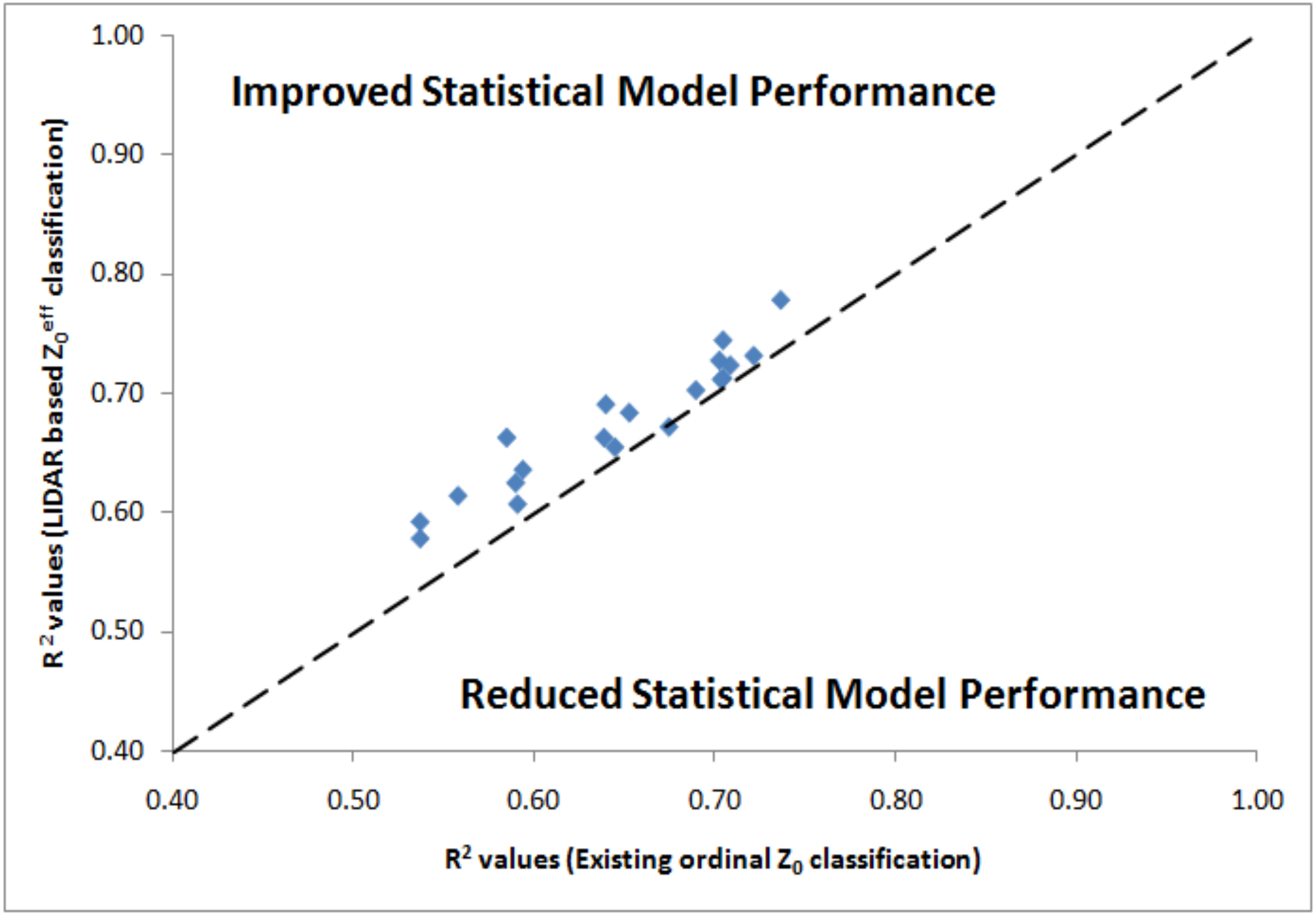
Slope

Aspect

Z_0^{eff}

- 1st run - Existing Z_0 classification
- 2nd run - New Z_0^{eff} dataset

Statistical Model Performance



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_0^{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

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