



Can you see the wind for all the trees?

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Overview

- Introducing Garrad Hassan
- Introduction to flow in forests
- Roughness and displacement height
- The frontal area index for beginners
- Practical advice

Garrad Hassan and Partners Ltd (GH)

Independent expert advice on wind energy **since 1984**

Over **220 staff** in **16 countries**

Recognised as the leading **independent authority**.

Client list includes all the major wind turbine manufacturers, developers, banks, lenders

Advised on over **17,000 MW** of onshore and offshore wind farms around the world, providing due diligence work, contract review and monitoring for banks and lenders.

Energy resource assessment and wind farm design has been carried out for over **50,000 MW** to date.

For manufacturers our services include design and analysis of wind turbines, components, and control systems, as well as certification support and on site measurements.



More on GH....

We provide leading products for the design and operation of wind turbines and wind farms:

GH Bladed, wind turbine performance and loading design software.

GH WindFarmer, design and analysis of wind farms.

GH SCADA, wind farm management, information and reporting tool.

GH Forecaster, short term forecasts of wind farm energy production.

Training and open courses

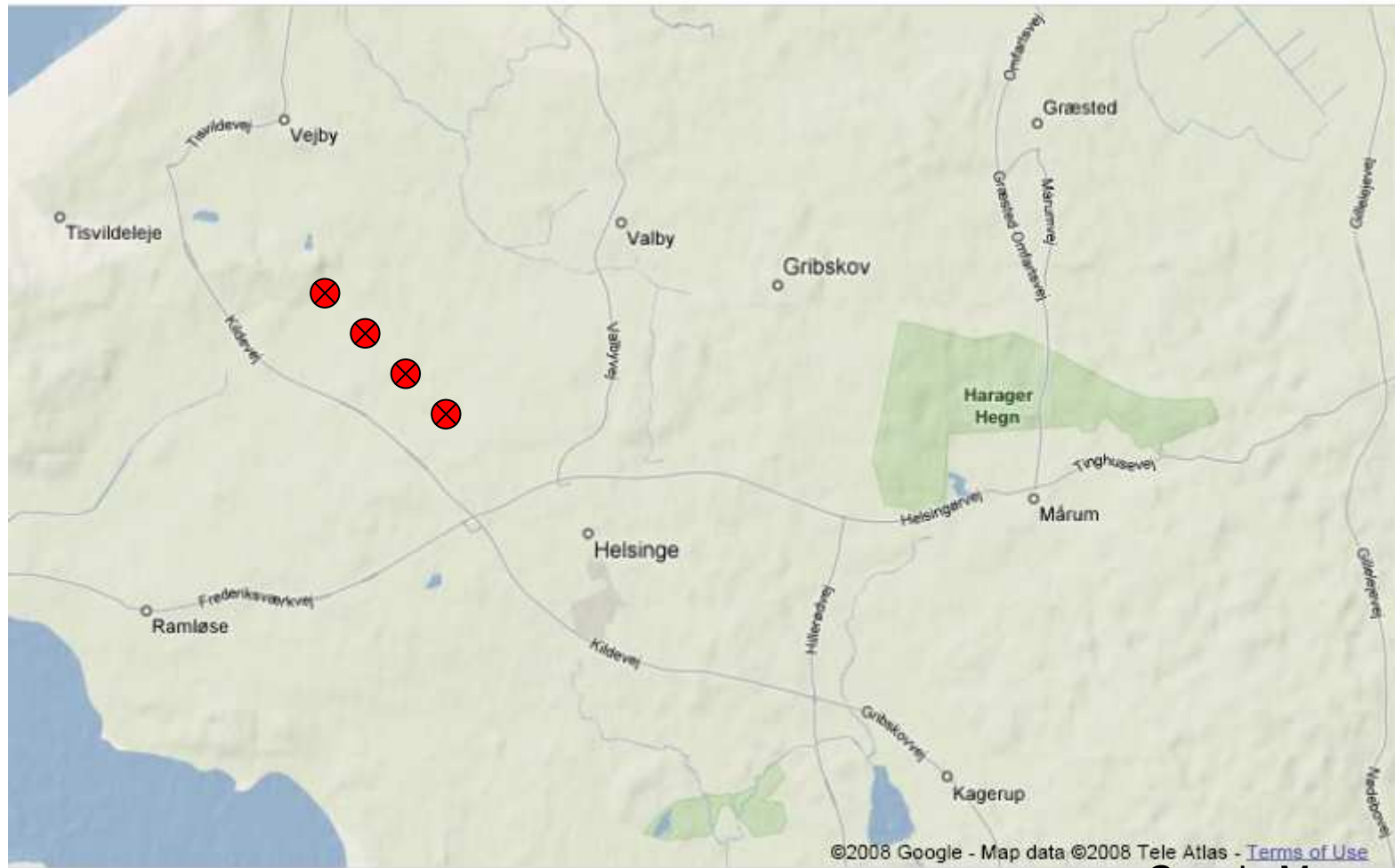
QMS accredited to ISO 9001:2000.

Quite a bit of experience working with wind energy and forests!



Introduction

In the old days...



Google Maps

Forests: just far-away roughness



Now!



Forestry is the dominant roughness!

Google Maps





Roughness and Displacement height

Roughness and displacement height

What is it?? It is the effect of the forestry in two ways:

Aerodynamic Roughness Length: how much is the wind slowed down?

Zero-plane Displacement height: how much to "chop off" the masts and turbines

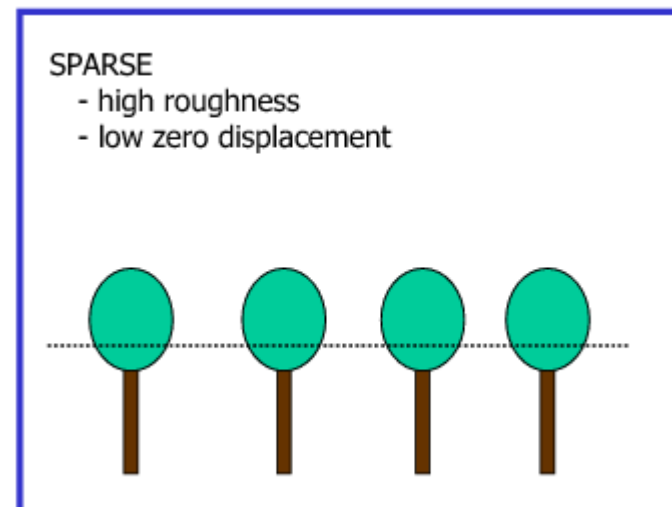
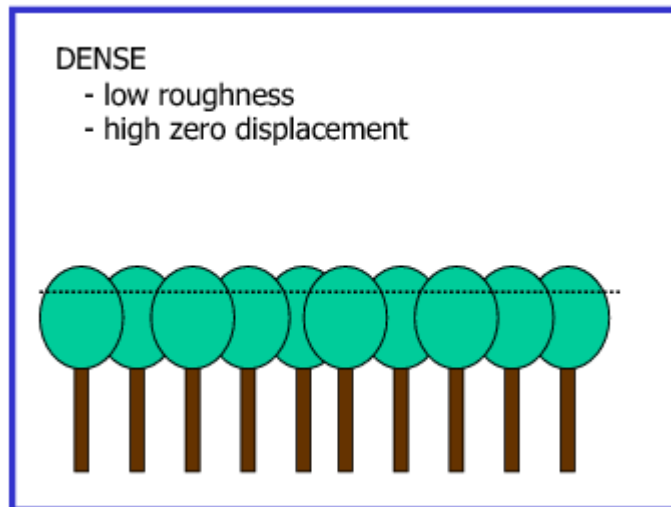
$$u(z) = \frac{u_*}{\kappa} \ln \left(\frac{z-d}{z_0} \right)$$

Displacement height

Roughness

Roughness and displacement height

$$u(z) = \frac{u_*}{\kappa} \ln \left(\frac{z-d}{z_0} \right)$$



Dellwik, Jensen & Landberg, BWEA Tree Workshop, 2004

The frontal area index, λ

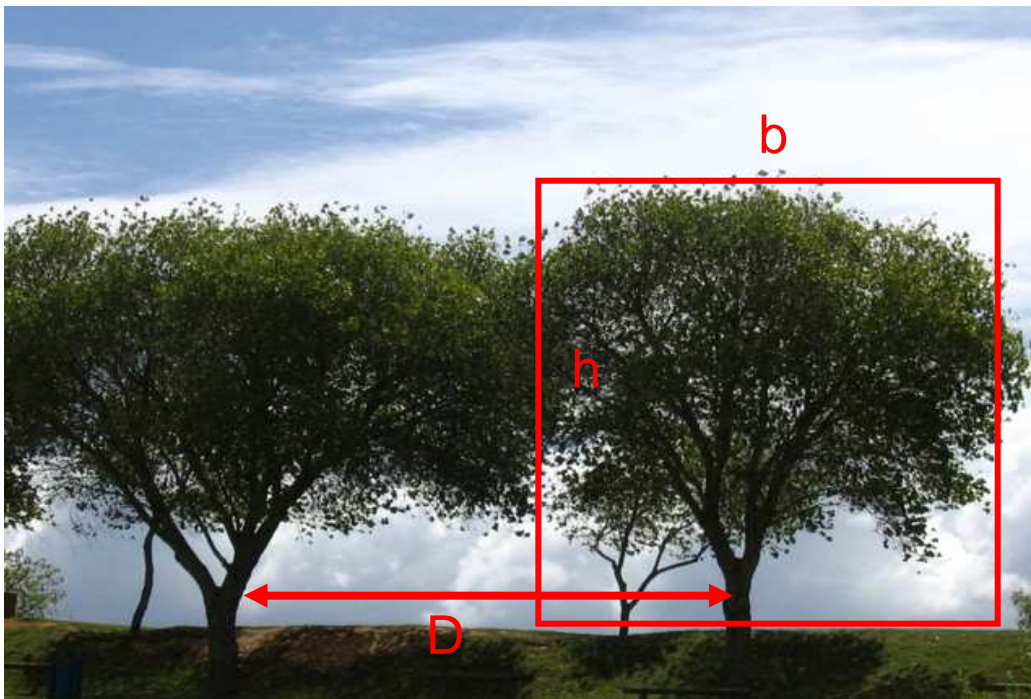
$$\lambda = \frac{bh}{D^2}$$

Where:

b is the tree breadth

h the canopy height

D typical distance between trees



*Physically "easily"
estimated parameters*

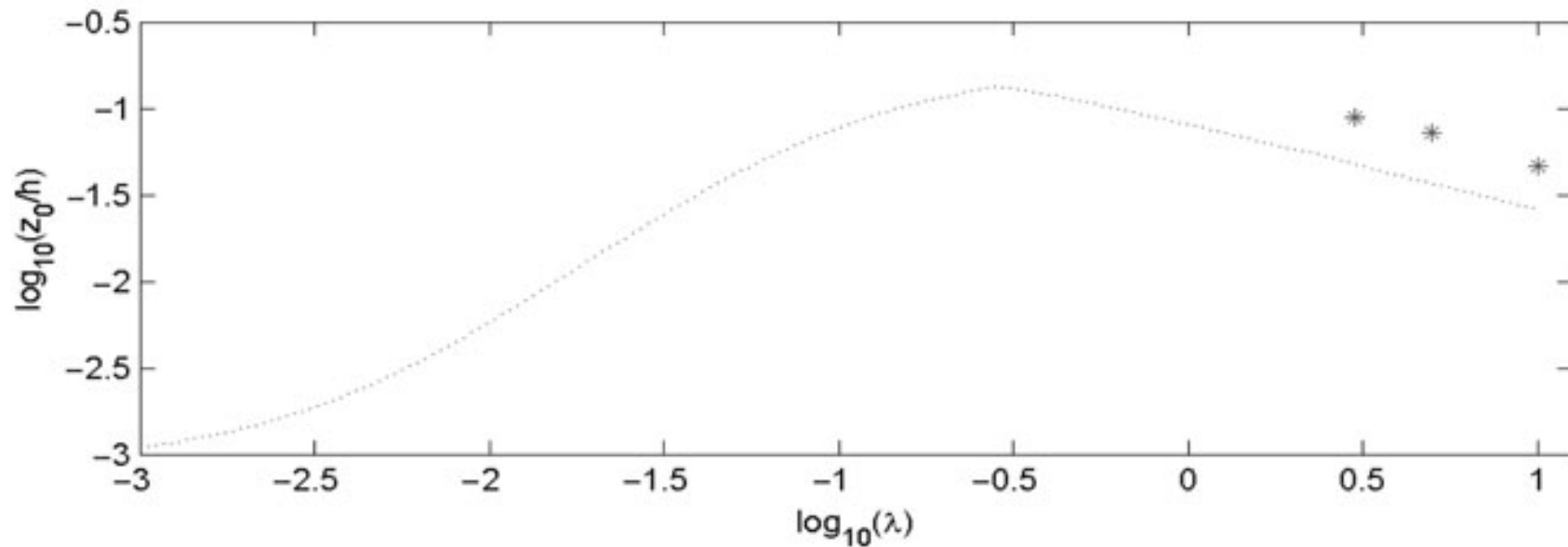
Equations! Roughness

Raupach, BLM, 1994:

$$z_0 = (h-d) \exp(-\kappa\gamma + \Psi_h)$$

constant

Function (λ)



Dellwik, Landberg & Jensen, *Wind Energy*, 2006

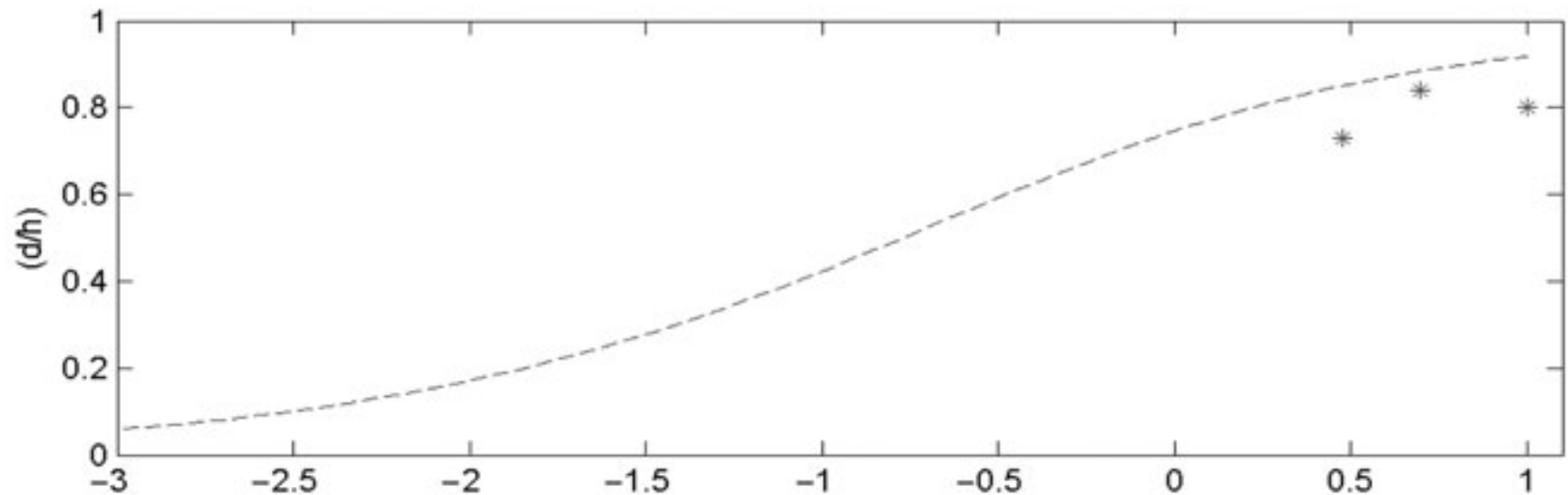


Equations! Displacement height

Raupach, BLM, 1994:

$$d = h \left(1 - \frac{1 - \exp(-\sqrt{2c_{dl}\lambda})}{\sqrt{2c_{dl}\lambda}} \right)$$

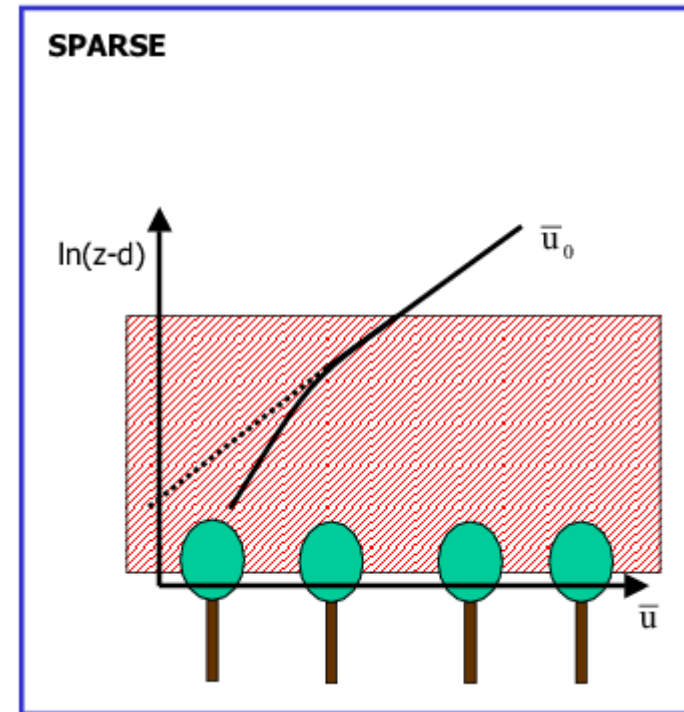
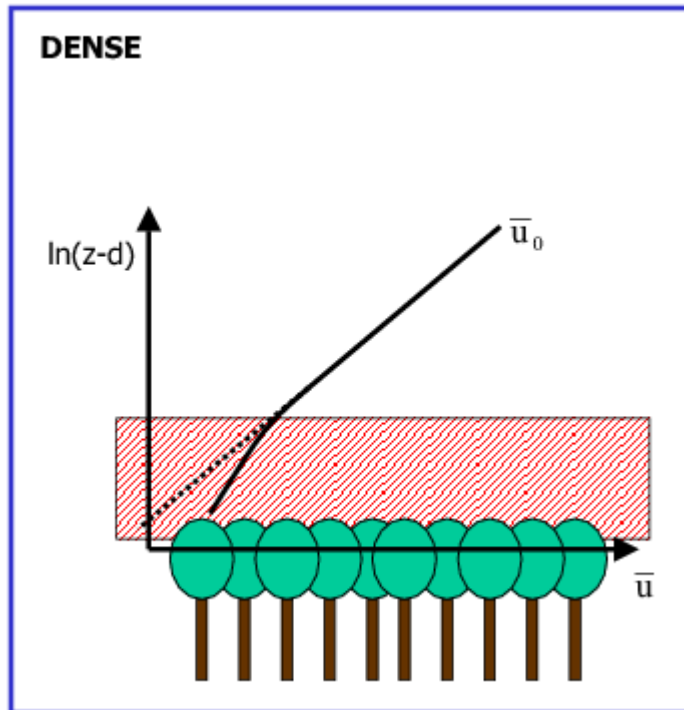
constant



Dellwik, Landberg & Jensen, Wind Energy, 2006

Profiles

Profiles, idealised



Dellwik, Jensen & Landberg, BWEA Tree Workshop, 2004

Note, sublayer thicker over the sparse forest

Practical advice

Practical advice

- Don't do it! Not an option in large parts of the Nordic and Baltic region....
- Seek help 😊
- Measure: use more masts than usual, think hard where to put them (including forestry characteristics), measure at several heights (profile important)
- Do not try to clear/fell your way out of the problem: most likely things are made worse, unless you go really far away
- Use taller hub heights and bigger spacing than you would normally do

More practical advice

Some rules of thumb:

- $d=2/3$ to 1 x tree height
- z_0 : 0.4 – 0.8 m
- (not long ago many people used: $d=0$, $z_0=0.4$)

Split wind farm up in three areas and treat them differently:

1. Far away from the forest → roughness
2. Near forest edge → tapering off of z_d , roughness, orography?
3. Within forest → roughness and z_d

Summary

Forests give us new challenges!

Important parameters: roughness and displacement height, can be calculated from physical characteristics of forestry

Treat in three different parts

What I did not talk about:

- Turbulence (higher)
- Forests on hills (\neq forest + hill!)



Thank you!

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