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Wind Resource Assessment in Forests

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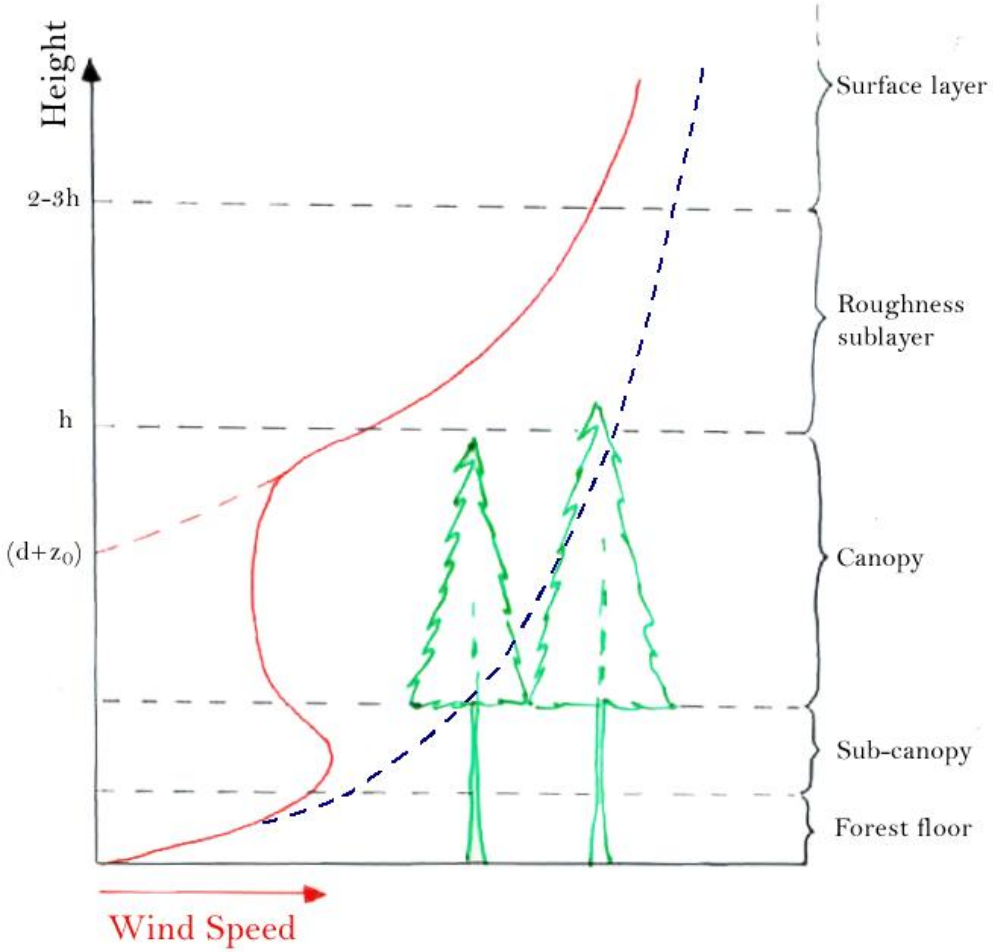
Introduction

- Benefits
  - Increased land area
  - Easier permitting
- Problems
  - Reduced wind speed
  - Increased turbulence intensity and wind shear
  - Uncertainty in wind resource assessment

Wind Profile in the Forest



Presentation Outline

- Forest Models
- Analysis
- Results
  - Inside forests
  - Near forests
- Recommendations

Scope of the Project

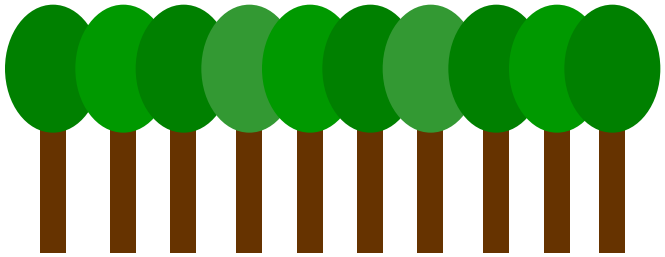
- Evaluating and optimizing wind resource assessments, using:
  - WAsP: wind speed and AEP
  - WEng: turbulence intensity and shear
  - WindSim: all of the above
- Modifying only user-defined parameters:
  - Roughness length
  - Displacement height

Forest Parameters

- Depends on:
  - Mean height of the trees
  - Density of the forest

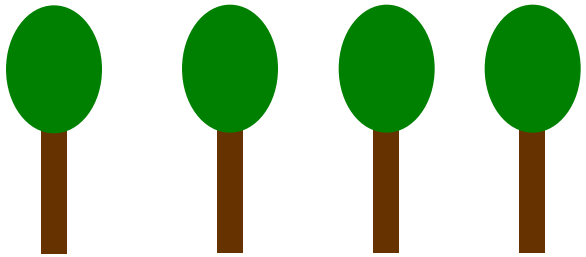
Dense Forest

- low roughness
- high displacement height



Sparse Forest

- high roughness
- low displacement height



Forestry Models

- A literature review found over 50 possible combinations of displacement height and roughness length
- Mostly based only on tree height
- More complex models also include forest density

Forestry Models

- Examples:

$$d = 0.64h$$

$$z_0 = 0.1h$$

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

$$d = h\left(1 - \frac{1 - \exp\left(-\sqrt{2c_{d1}\lambda}\right)}{\sqrt{2c_{d1}\lambda}}\right)$$

$$z_0 = (h-d)\exp\left(-\kappa\left(\frac{U_h}{u_*}\right)_{Rau} + \Psi_h\right)$$

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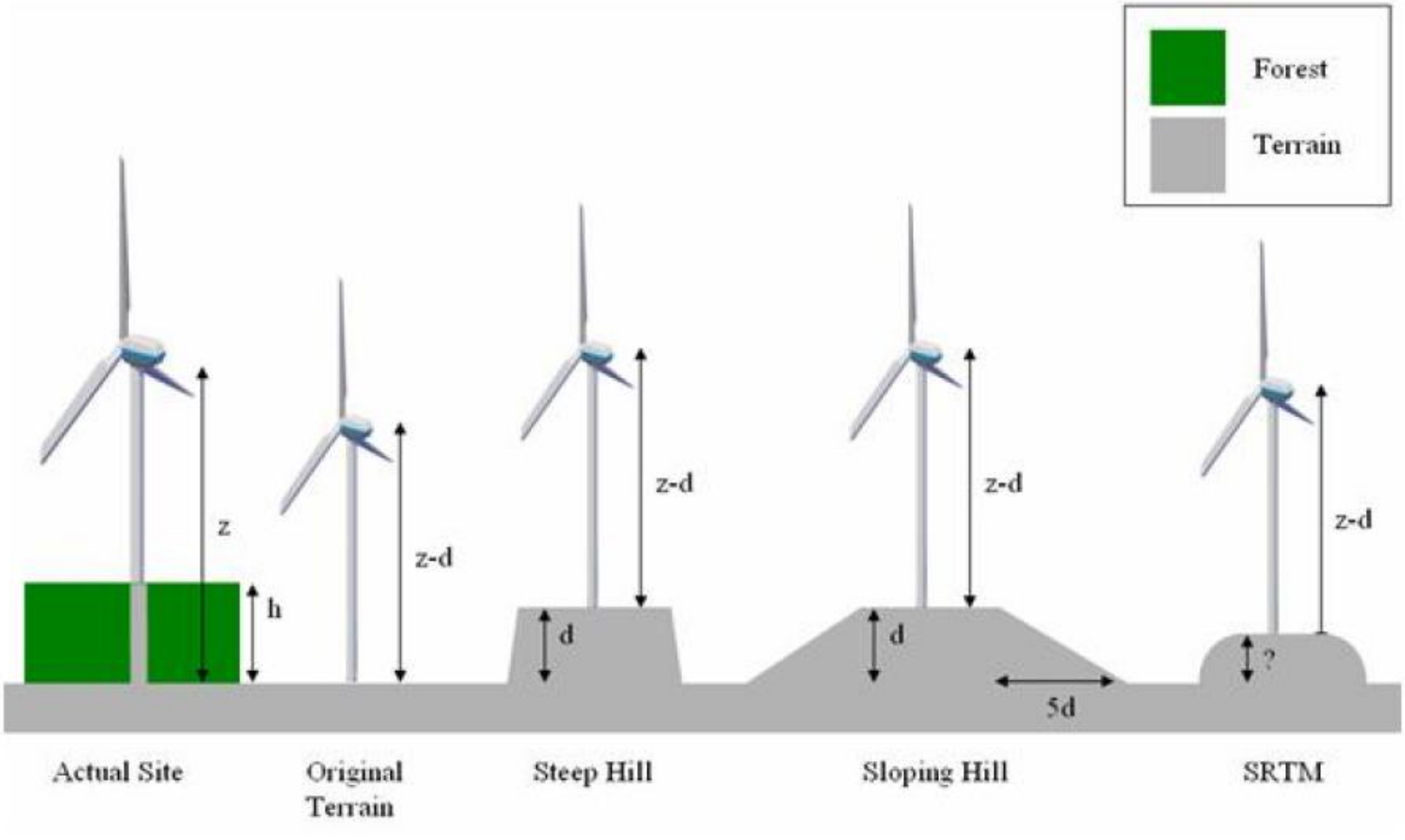
Applying Displacement Height



Data

- Wind speed, turbulence intensity and wind shear data from Risø measurement campaigns at three forests in Denmark
- Wind speed and energy production data from two wind farms in forested areas (courtesy of Siemens Wind Power)

Method

1. Evaluated all of the possible combinations of roughness length and displacement height
   - Using WAsP to predict wind speeds at a few sites
   - Comparing estimates to measurements
2. Selected best forestry models

Method

3. Predicted wind speed, turbulence intensity, wind shear and AEP using the best models
   - Using WAsP, WEng and WindSim
   - At sites inside and near forests
4. Validated the estimates
5. Evaluated the forestry models and wind resource assessment software

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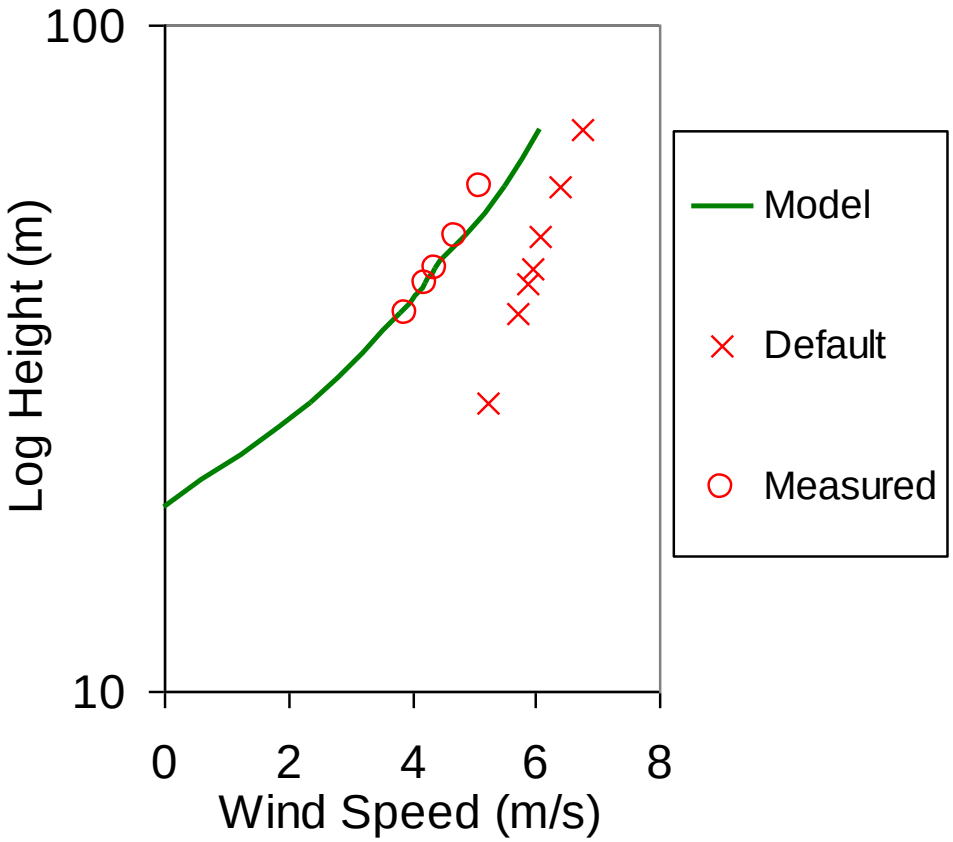
Results – inside forest

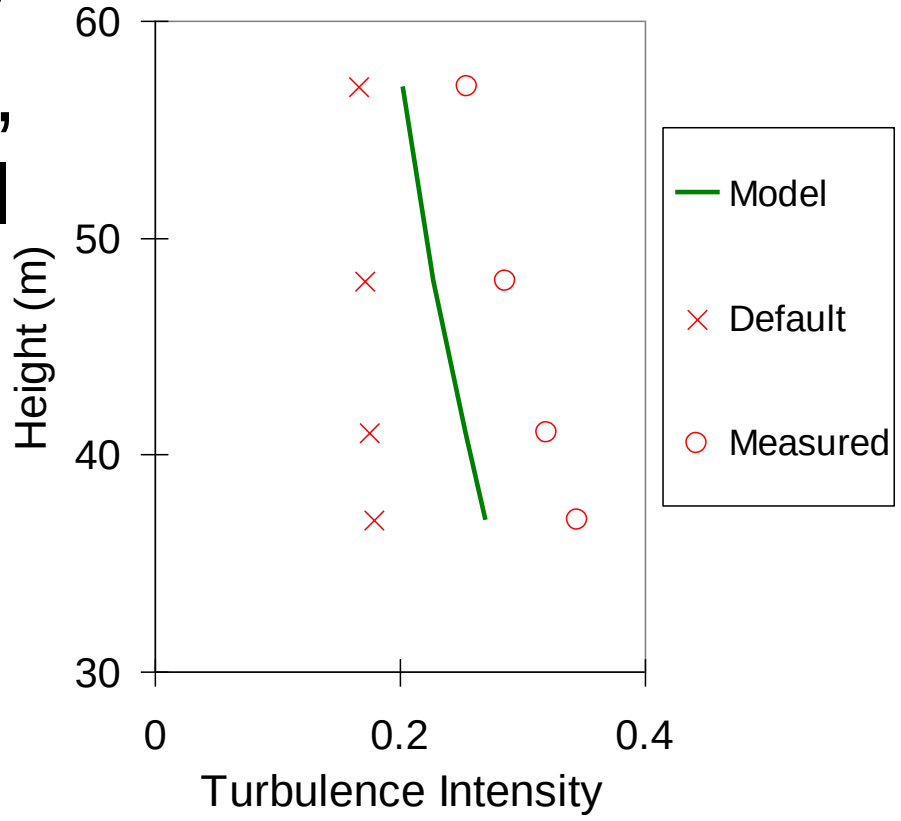
WAsP Results – inside forest

- Significant improvements in wind speed prediction
- Different ‘terrains’ yield no further improvements



WEng Results – inside forest

- Turbulence intensity prediction improved, but still below actual levels
- Wind shear prediction also improved, but not consistently



WindSim Results – inside forest

- Wind speed and energy production predictions are significantly improved (slightly better than WAsP)
- Models had negligible effects on turbulence intensity predictions
- (Inconsistent) improvements in shear prediction: still under- and over-predict
- WindSIM Forest Module produced poor results

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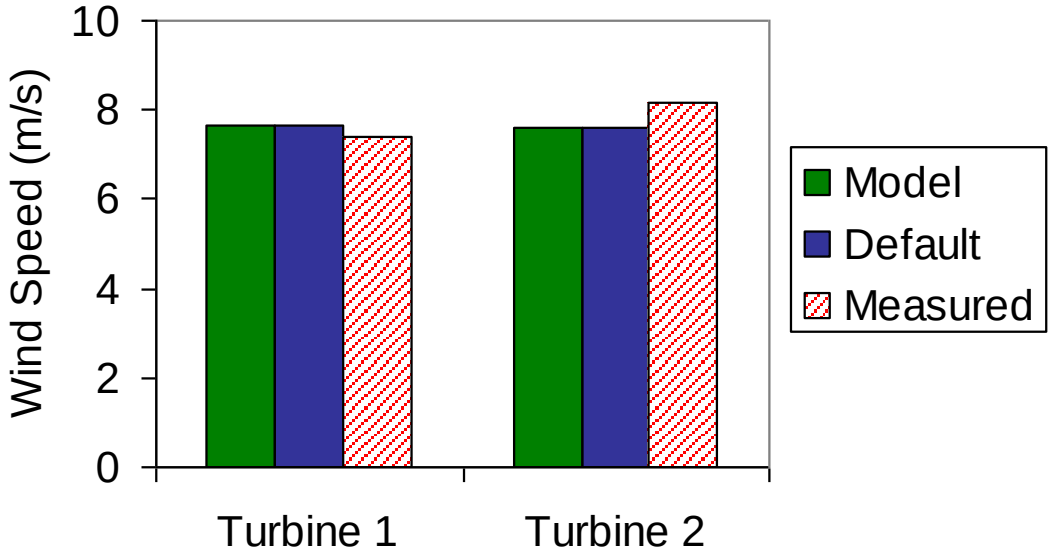
Results – near forest

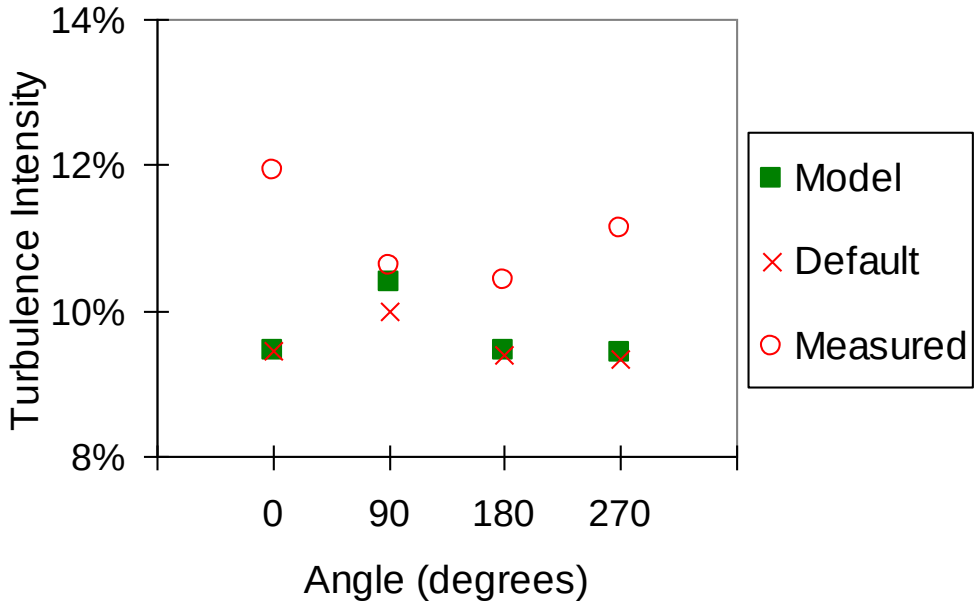
WAsP Results – near forest

- Models have negligible effects on wind speed or AEP prediction



WEng Results – near forest

- Models have negligible effects on turbulence intensity or wind shear prediction



WindSim Results – near forest

- Models have negligible effects on any predictions
- WindSIM Forest Module produced very poor results

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Recommendations

- The four best forestry models were:

	Model	Displacement Height	Roughness Length
1	Garratt-Dolman	$d = 0.75h$	$z_0 = 0.1h$
2	Jarvis-Hicks	$d = 0.8h$	$z_0 = 0.075h$
3	Choudhury & Monteith	$d = 1.1h\ln\left(1+(0.2LAI)^{1/4}\right)$	$z_0 = z_{0s} + 0.3h(0.2LAI)^{1/2}$ $\quad 0 \le 0.2LAI \le 0.2$ $z_0 = 0.3h\left(1-\frac{d}{h}\right)$ $\quad 0.2 < 0.2LAI \le 1.5$
4	Raupach	$d = h\left(1-\frac{1-\exp\left(-\sqrt{15\lambda}\right)}{\sqrt{15\lambda}}\right)$	$z_0 = (h-d)\exp\left(\frac{-0.4}{\min\left[(0.003+0.3\lambda)^{1/2},0.3\right]}+0.193\right)$

Recommendations

- Inside forests, wind resource assessments can be significantly improved with the correct selection of forestry model
- Near forests, forestry models do not improve predictions
- WAsP and WindSim produce similar results
- WEng is more accurate than WindSim

Questions?