Validation of CFD based forest modeling for large forested areas with many measurement masts

Gibson Kersting E.ON Climate & Renewables, United States ,
Catherine Meissner, Matteo Mana, WindSim AS, Norway

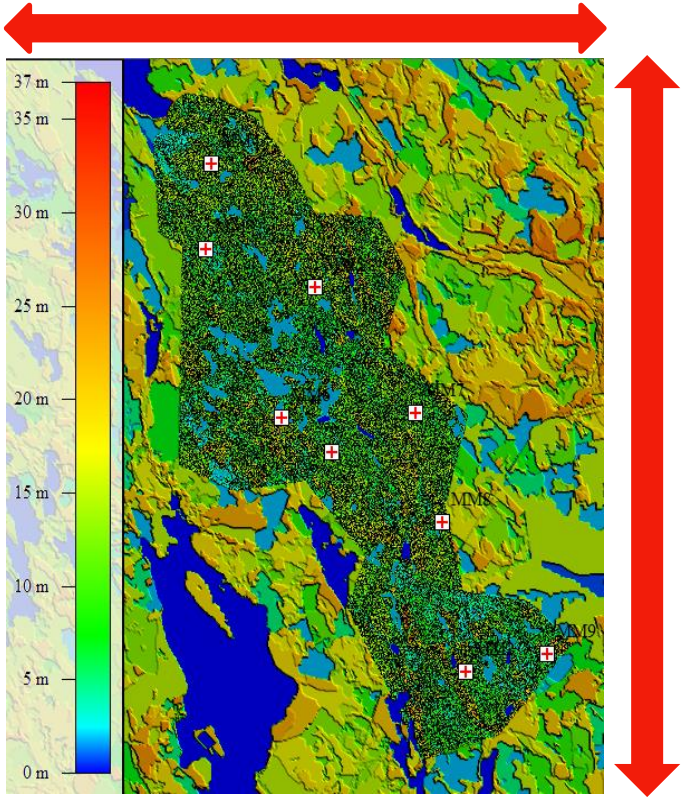
Outline

- Introduction
- Forest maps
- CFD forest models
- Validations
- Atmospheric stability
- Conclusion

Introduction

- Forested sites in complex terrain represent a great challenge for development of wind farms.
- Using multiple met masts to reduce wind flow model uncertainty.
- Using WindSim CFD code with forest model and high resolution GIS data is a great opportunity to test the impact of different forest parameters in complex terrain.

Example →



- 8.5 km wide
- 13 km long
- 9 met masts (all higher than 80m equipped with class I sensors)

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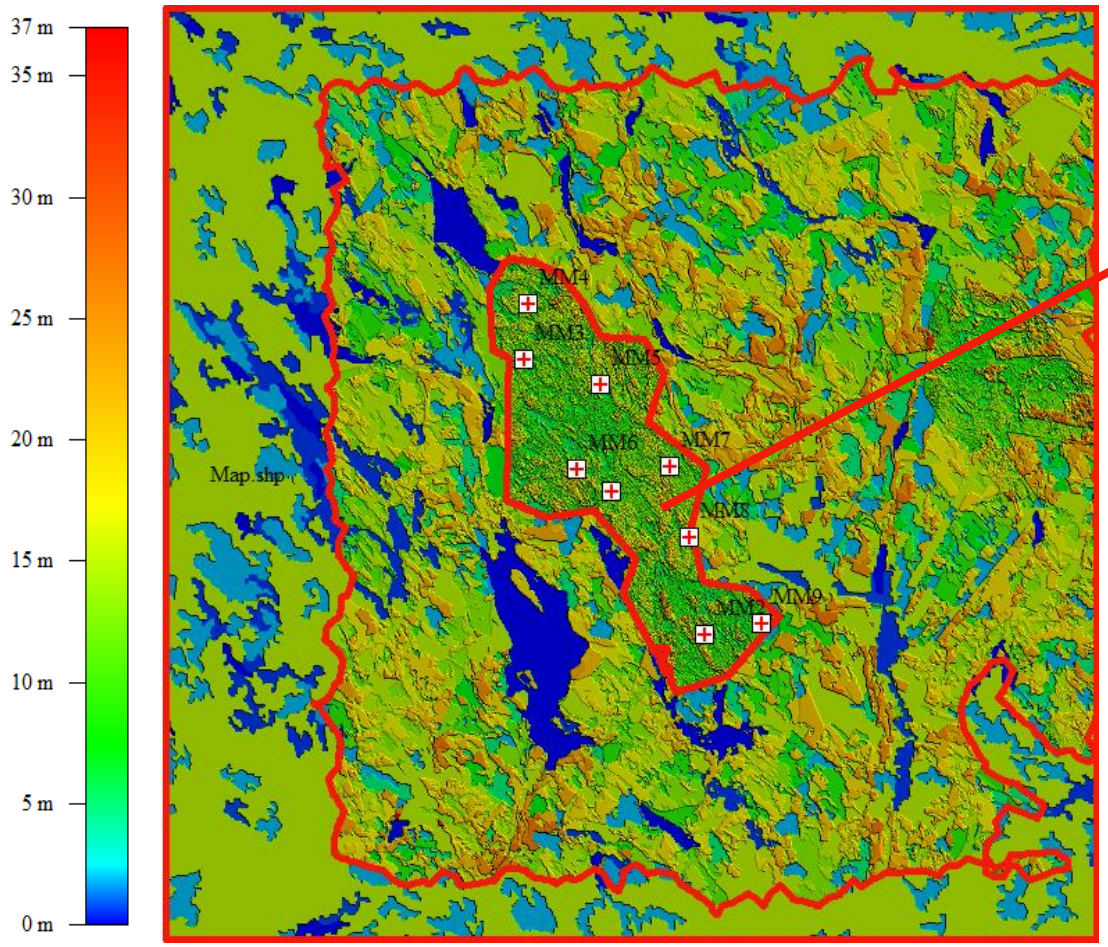
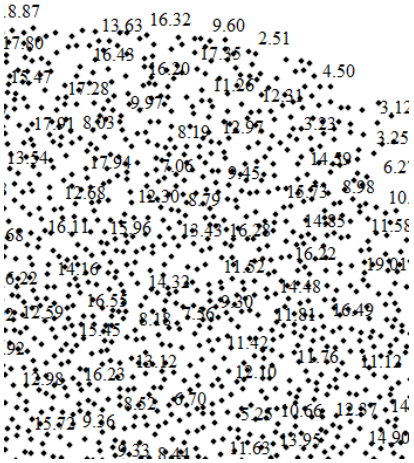
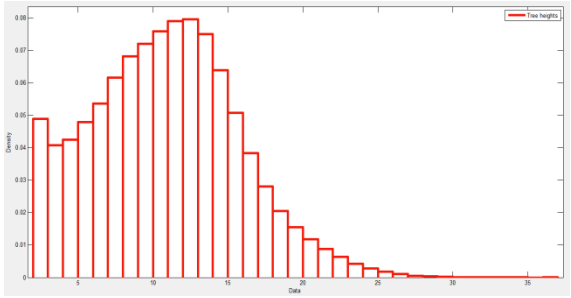
Forest maps



High Resolution Data





Example

- ~ 2.3 million trees above 2m
- ~ 52 square kilometers
- ~ 1 tree for every 22 square meters

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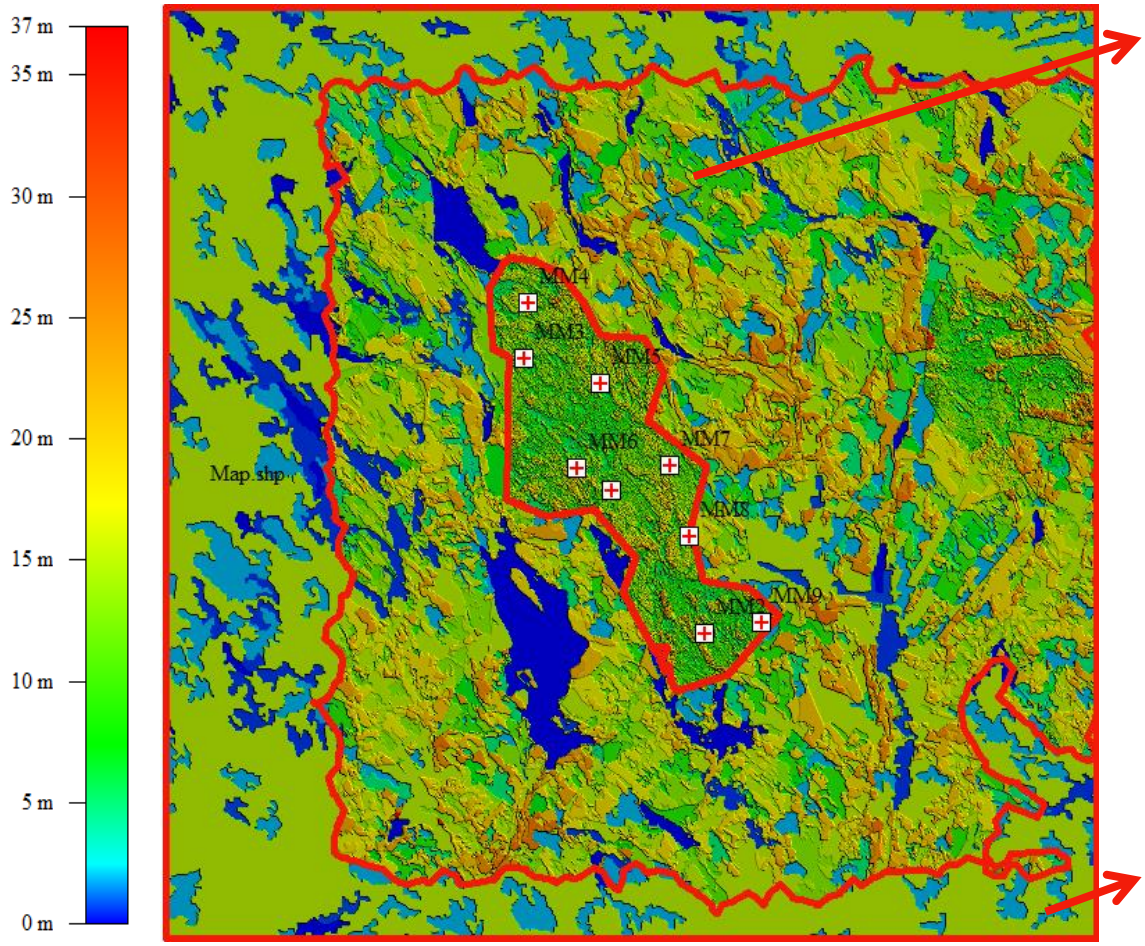
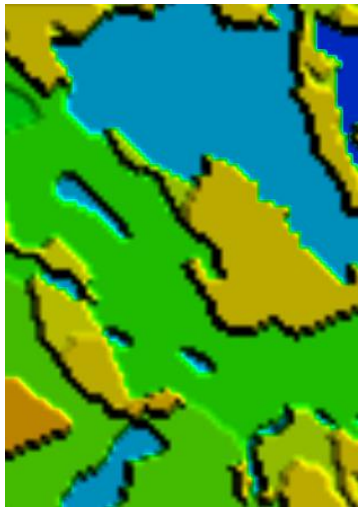
Forest maps



Mid resolution data



- Data surveyed by the forest manager.
- Average tree height and species in each polygon
- Tree type

Low resolution data

- CORINE Land Cover

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CFD forest models

- Influence of the forest on the turbulence equations and calculation of parameters

$$\rho u_i \frac{\partial u_j}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial p}{\partial x_j} + \rho f_i + S_j$$ → Momentum

$$S_j = -\alpha C_2 \sqrt{u_j u_j} u_j$$ → Momentum sink high Re

$$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k - \rho\varepsilon + S_k$$ → TKE

$$\frac{\partial}{\partial x_i}(\rho \epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}P_k - C_{2\epsilon}\rho\frac{\varepsilon^2}{k} + S_\epsilon$$ → Dissipation rate

$$S_k = C_2\left(\beta_p \sqrt{u_i u_i}^3 - \beta_d u_i k\right)$$ → Source and sink in TKE

$$S_\varepsilon = C_2\left(C_{\varepsilon 4}\beta_p \frac{\varepsilon}{k} u_i^3 - C_{\varepsilon 5}\beta_d u_i \varepsilon\right)$$ → Source and sink in ε

$$\beta_p = 1.0, \beta_d = 6.51, C_{\varepsilon 4} = C_{\varepsilon 5} = 1.24$$ → Parametrization

$$C_2 = \frac{LAI}{h} C_d$$ → Forest information

- Formally the model has been implemented as in Sanz (2003) and Katul (2004) with the model constants revised to be compatible with the default set of constants of the standard k-ε model.

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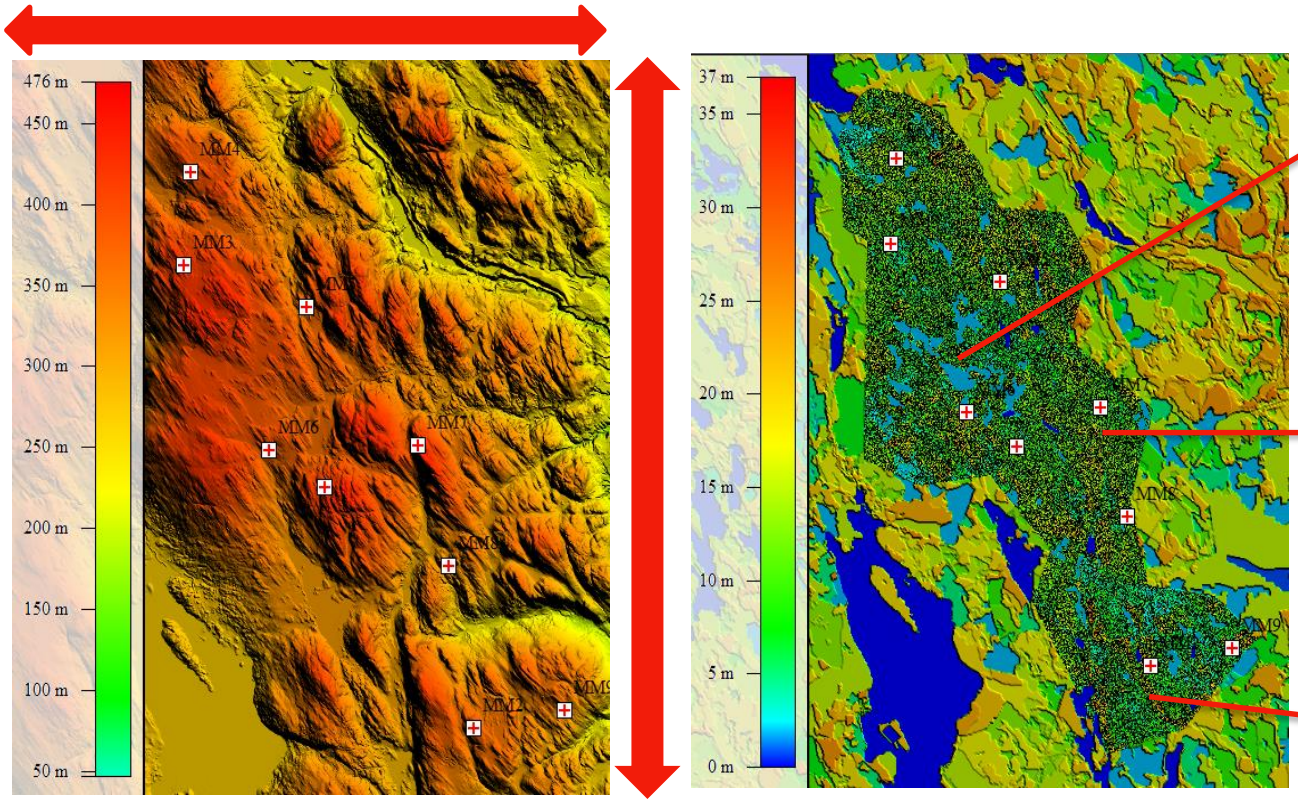
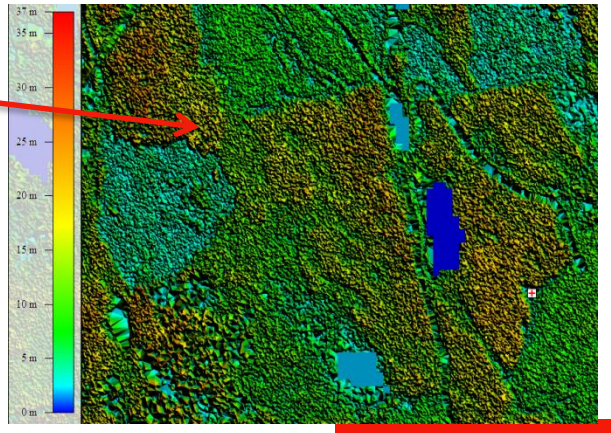
Validation Site I





- 8.5 km wide
- 13 km long
- 9 met masts (all at least 80m high equipped with class I sensors)

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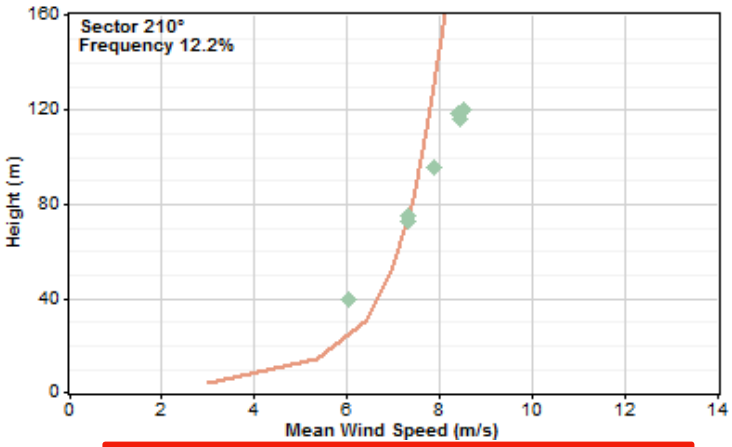
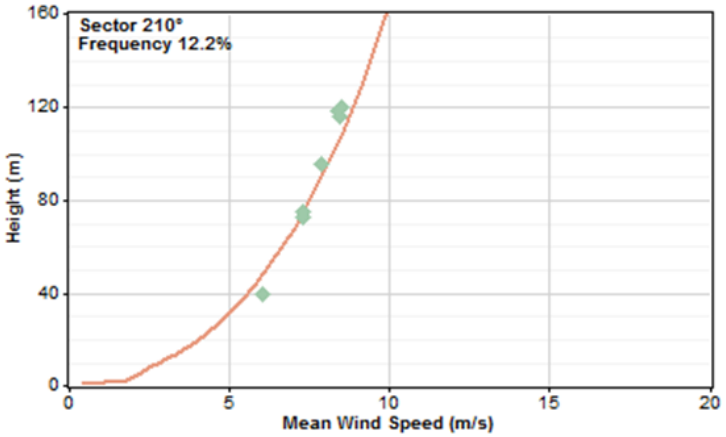
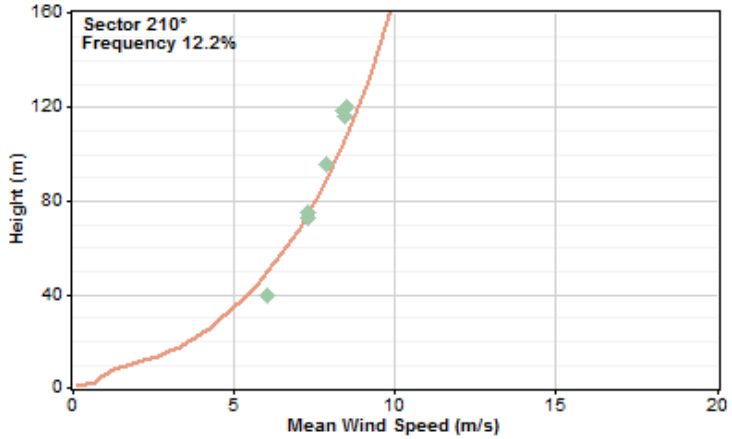
Validation Site I



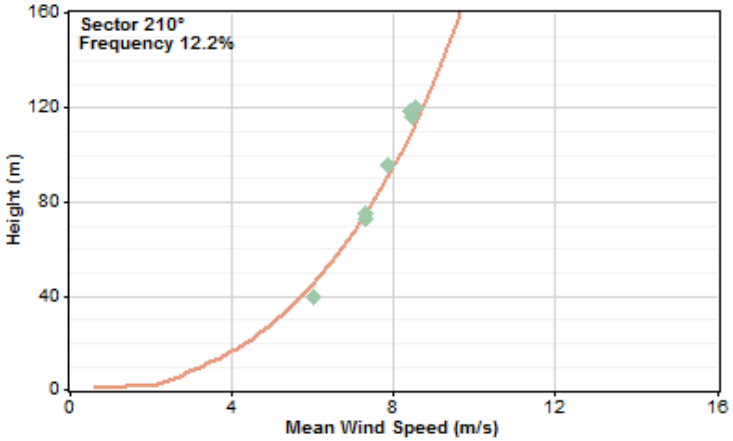
Displacement height only



Forest model C2 = 0.1



Forest model C2 = 0.5



Forest model C2 = 0.05

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Validation Site I

Forest parameter	Average absolute error [%]
C2 = 0.05	4.51
C2 = 0.1	5.56
C2 = 0.5	5.75
Displacement Height	5.51

Cross Prediction results neutral simulation C2= 0.05 for all forest types

	MM1	MM2	MM3	MM4	MM5	MM6	MM7	MM8	MM9
MM1	-	5.32	1.96	3.84	3.48	1.06	0.28	4.3	12.24
MM2	4.43	-	1.56	0.44	1.99	4.45	6.35	0.03	7.05
MM3	2.54	3.84	-	0.63	1.06	0.54	-	2.22	12.49
MM4	4.11	2.46	0.62	-	0.32	1.18	4.91	0.7	8.06
MM5	3.07	3.19	0.73	0.74	-	0.04	4.97	2.62	10.39
MM6	2.12	5.22	4.01	0.89	0.48	-	4.03	5.79	12.7
MM7	1.43	8.33	-	8.42	7.72	4.94	-	10.47	14.32
MM8	4.64	0.14	1.09	0.07	2.07	5.72	8.36	-	6.48
MM9	10.1	6.4	8.79	4.96	7.86	10.66	11.39	5.55	-

Met Mast 9 seems to be not well described by the CFD model

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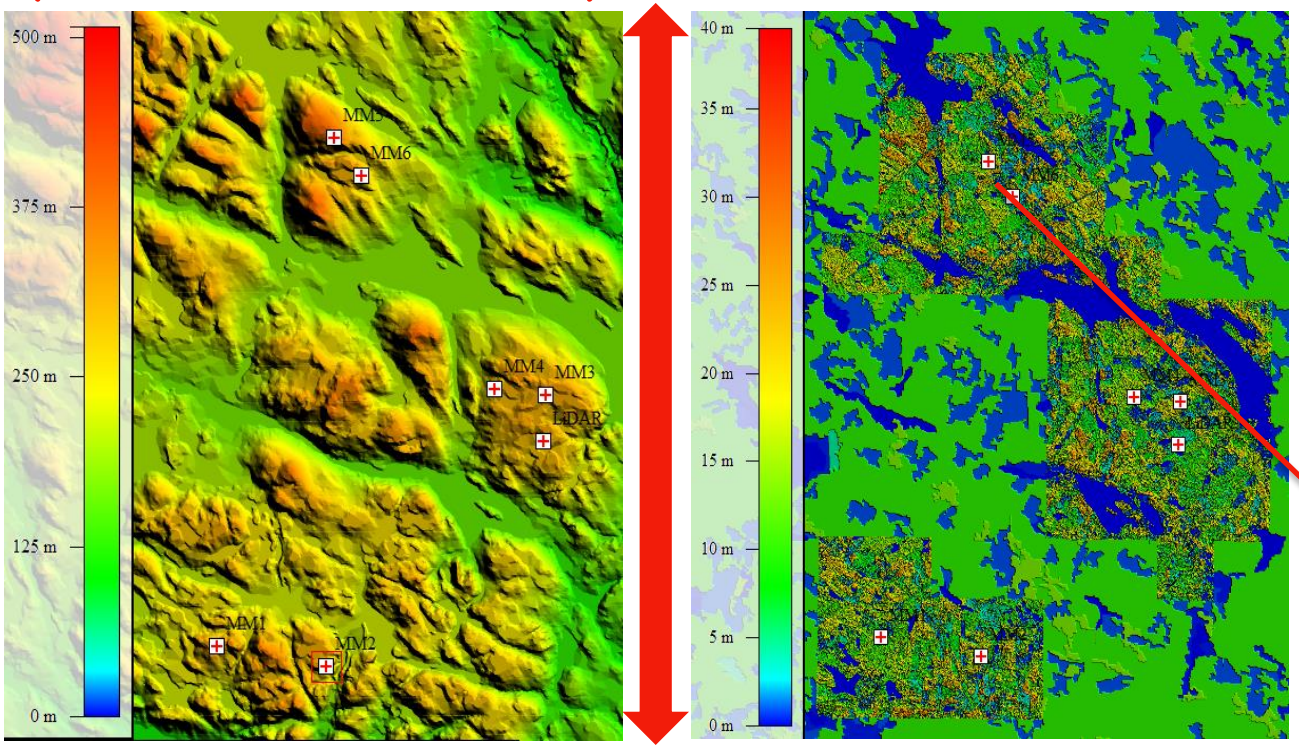
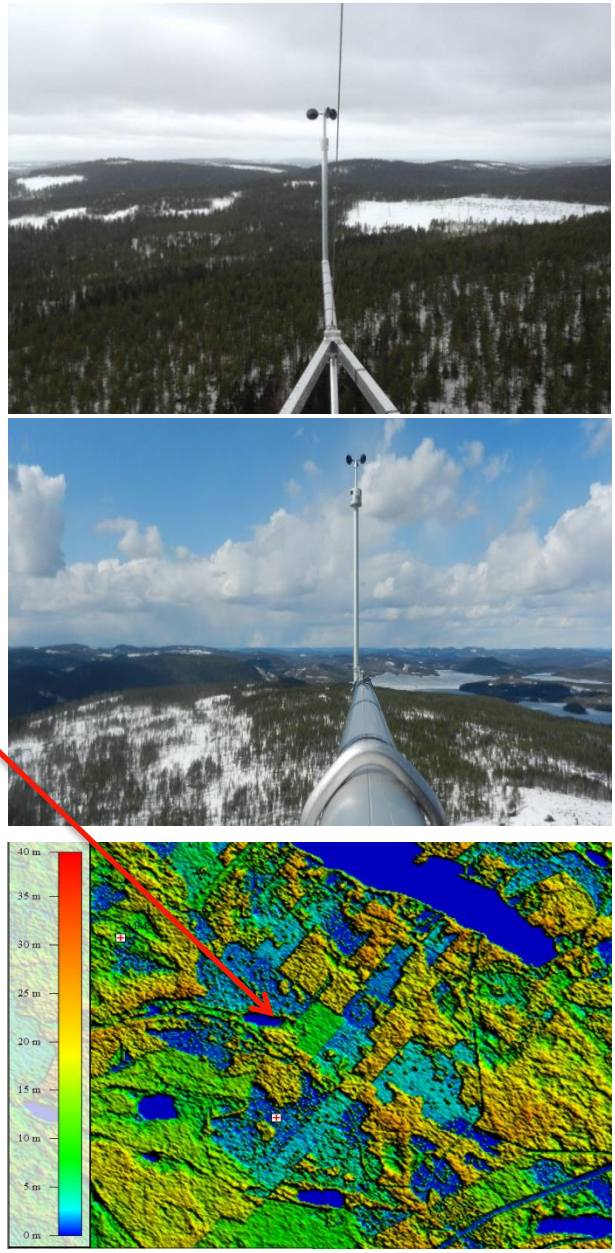
Validation Site II





- 13 km wide
- 21 km long
- 6 met masks (at least 100m high equipped with class I sensors) and 1 LiDAR

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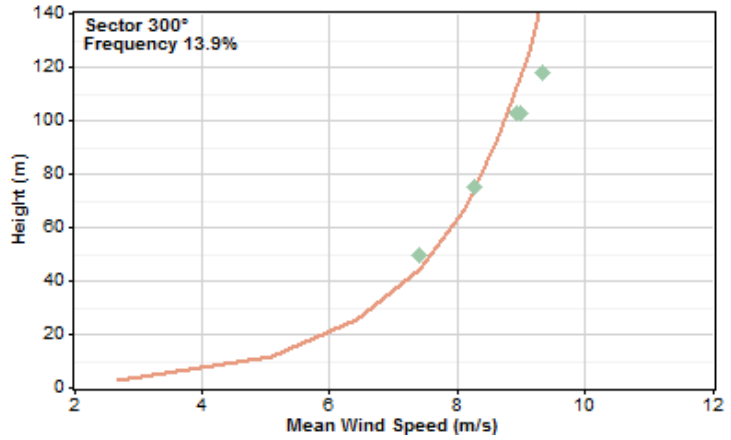
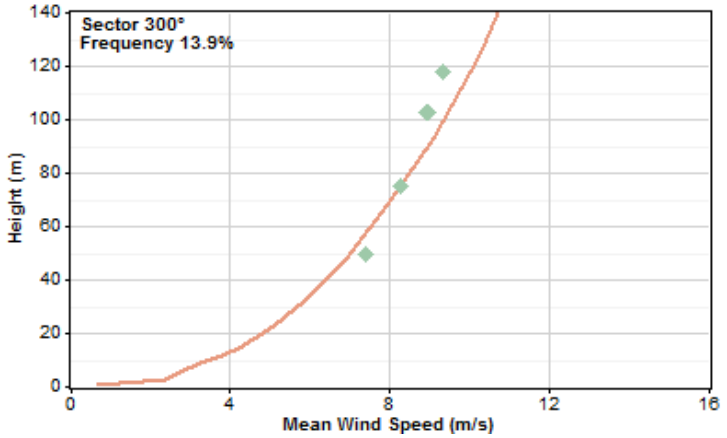
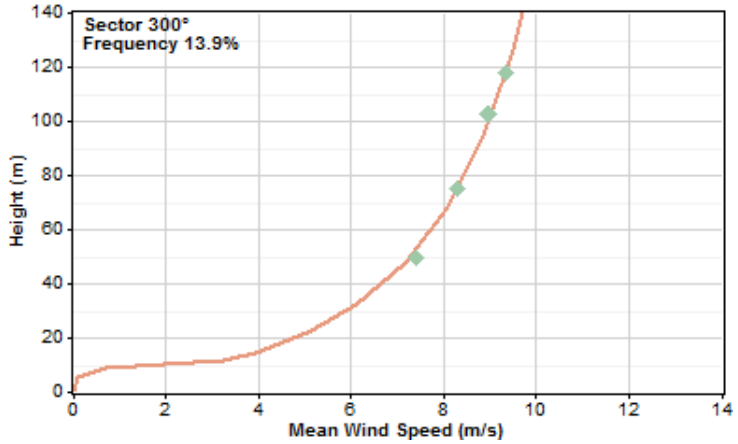
Validation Site II



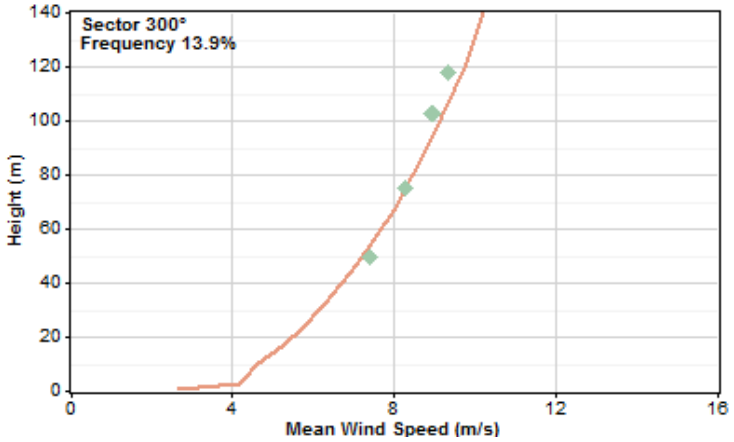
Displacement height only



Forest model C2 = 0.1



Forest model C2 = 0.5



Forest model C2 = 0.05

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Validation Site II

Forest parameter	Average absolute error [%]
C2 = 0.05	9.20
C2 = 0.1	9.46
C2 = 0.5	4.39
Displacement Height	4.93

Cross Prediction results neutral simulation C2= 0.5 for all forest types

	MM1	MM2	MM3	MM4	MM5	MM6
MM1	-	2.59	8.47	1.11	0.47	1.19
MM2	3.66	-	11.93	0.32	2.25	1.03
MM3	6.5	8.62	-	7.94	7.33	9.53
MM4	1.48	2.16	11.7	-	3.87	1.44
MM5	1.93	0.1	10.44	2.25	-	0.3
MM6	1.58	2.64	12.85	1.67	4.37	-

Met Mast 3 seems to be not well described by the CFD model

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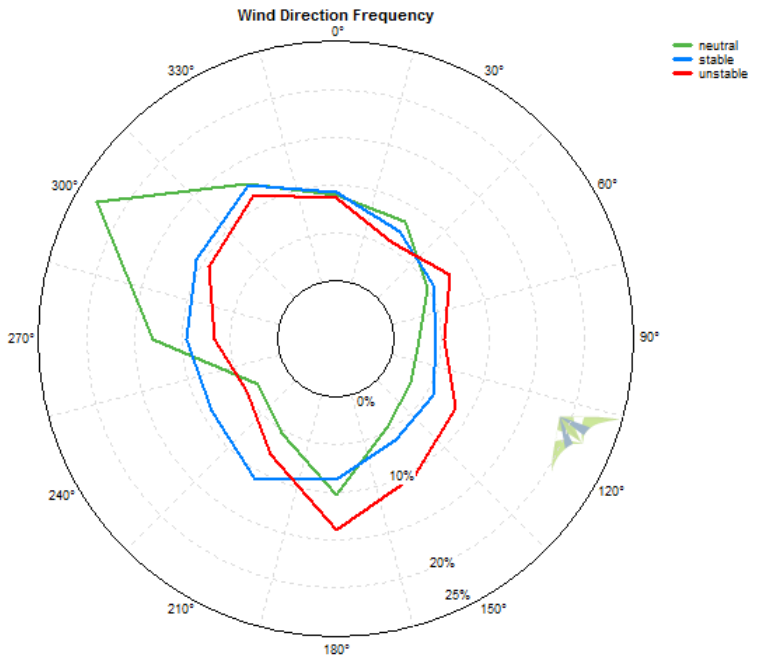
Atmospheric stability

- Why does it matter and how we obtain good information?



- Some sectors do not have in average neutral conditions
- In cold areas often the measurement devices have longer downtime and therefore the wind rose of the atmospheric stability conditions from measurements is misleading
- High resolution mesoscale modeling based on reanalysis data can overcome this problem

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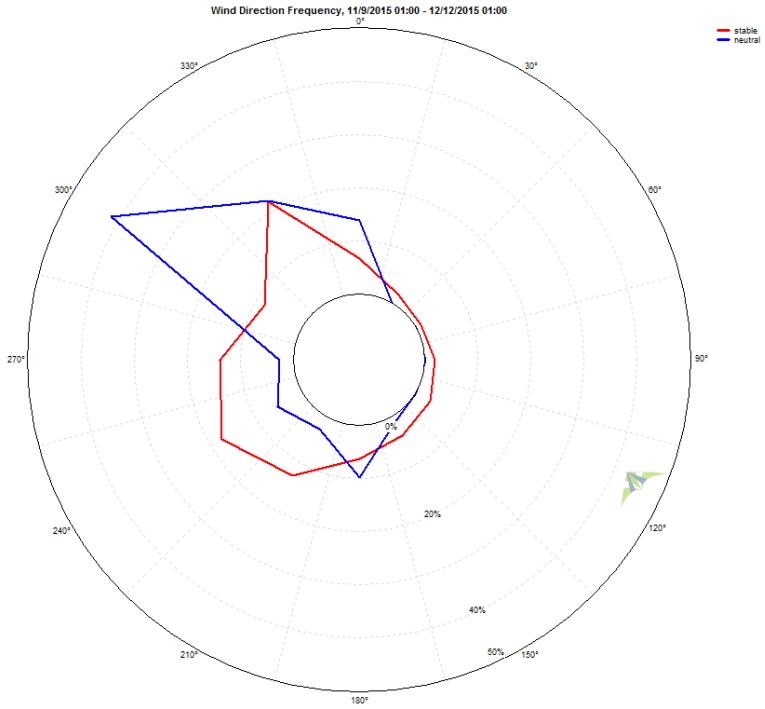
Validation Site II

- Validation with Lidar on November and December 2015
  - Stable simulations represent much better the shear and the profile is improved at hights higher than 160 meter.



Blue – Neutral Frequency

Red – Stable Frequency

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Validation Site II

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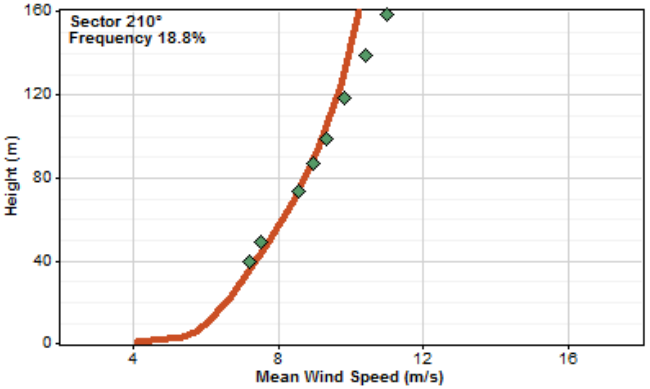
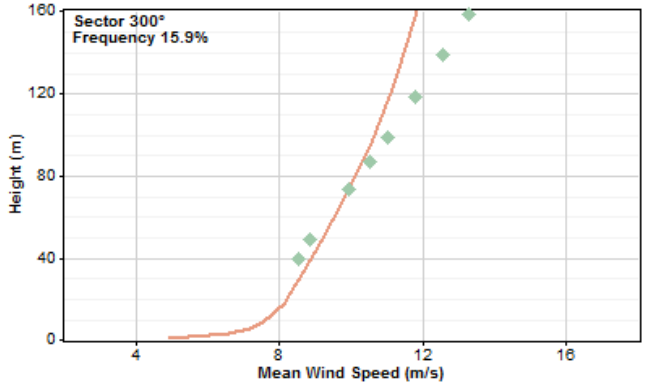
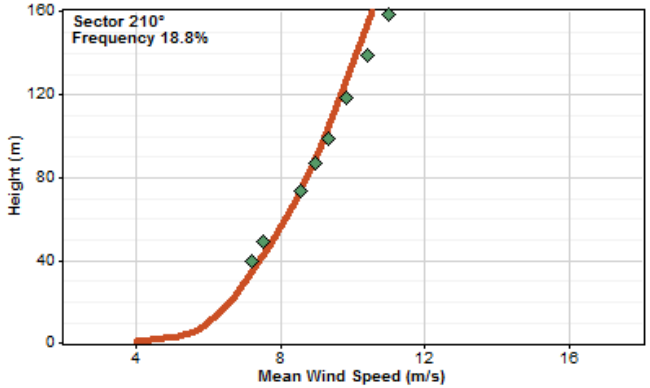
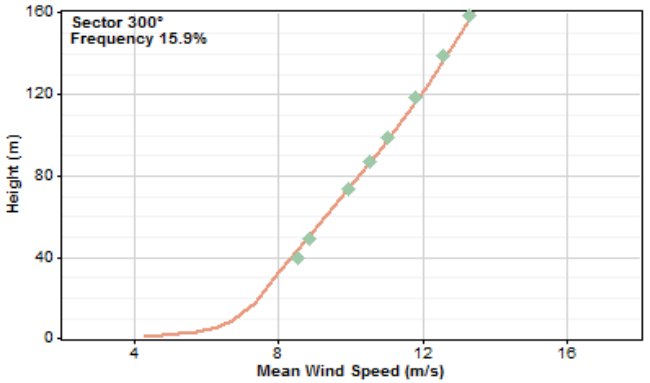
Neutral





Stable





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Conclusions

- Good vegetation data reduces errors both on the speed up factors and shear profile.
- Careful forest modelling around the met masts is key for a successful CFD run.
- Atmospheric stability information from mesoscale models improves shear profiles.