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Modelling Wind Conditions for Tall Hub Heights

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Abstract

Tall hub heights which reach 100 m and more pose a challenge for wind resource assessment: Conventional measurements seldom cover these heights and common industry flow models are technically not valid in those levels of the atmospheric boundary layer (ABL).

Theory and practical measurements show that flow features for tall hub heights differ from the well-known relations of the surface layer.

The demonstration of consequent modelling errors of common industry flow models and some immediate remedies conclude this analysis.

Theory

Tall hub heights reach into the so-called Ekman layer, where the common scaling assumptions of the surface layer are not valid anymore. With increasing height coriolis force, stability effects and mesoscale effects get more and more important, making a unified description of the wind profile in the ABL difficult. To this date no commercial microscale modelling software contains the full physical description of the entire ABL.

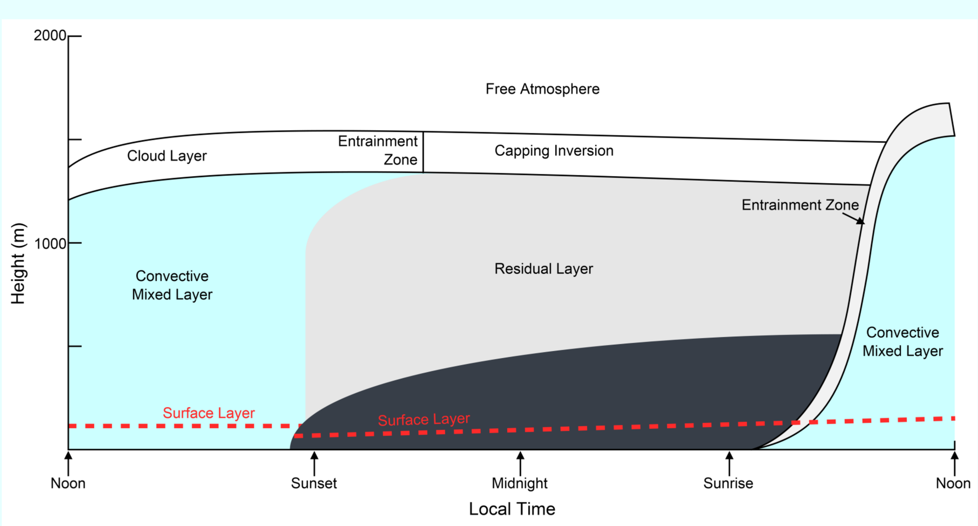

Fig. 1: ABL with its characteristic diurnal features [1].

Attempts to describe the wind profile above the surface layer require meteorological parameters which are not available from standard mast measurements ([2],[3],[4]). A flow model would furthermore need to maintain the capping inversion (Fig. 1) to describe the whole ABL successfully. This involves assumptions which are hard to verify for practical cases.

Therefore, it may also be reasonable to apply surface layer flow models and study their uncertainties. Depending on the site specific conditions, any of those attempts may lead to false estimates of the wind conditions at tall hub heights.

Measurements

Practical measurements of wind conditions at tall hub heights in different terrain:

Sites in simple terrain | Site in complex terrain

Wind speed

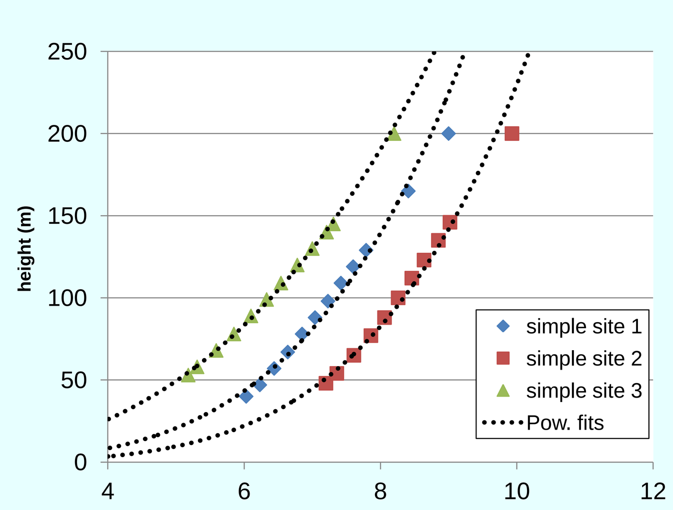

Fig. 2: Common power law fits tend to underestimate the wind speed at heights above 100 meter.

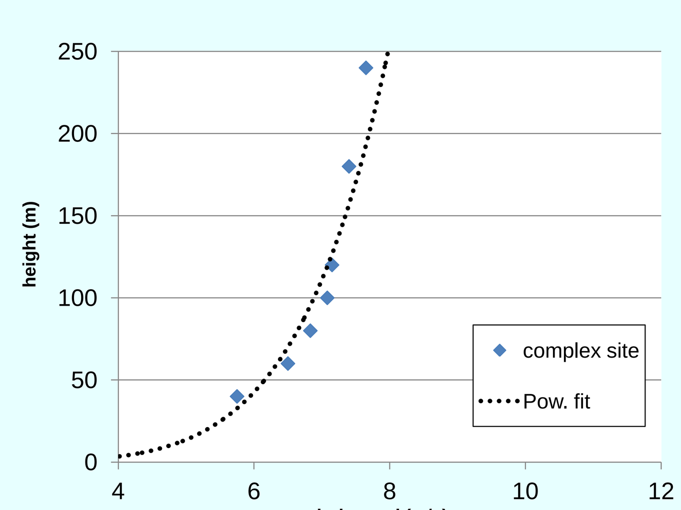

Fig. 3: Orography induces low shear, so wind speed at high heights is overestimated with power law fit.

Wind shear

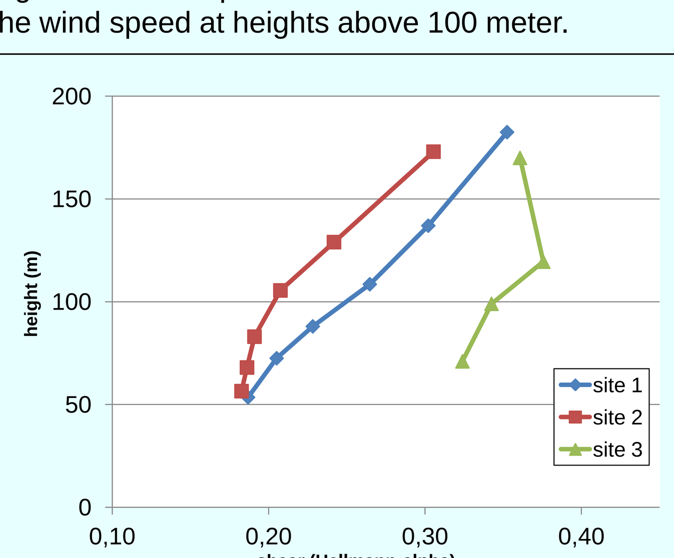

Fig. 4: Measurements show how the wind shear varies – and increases – over height.

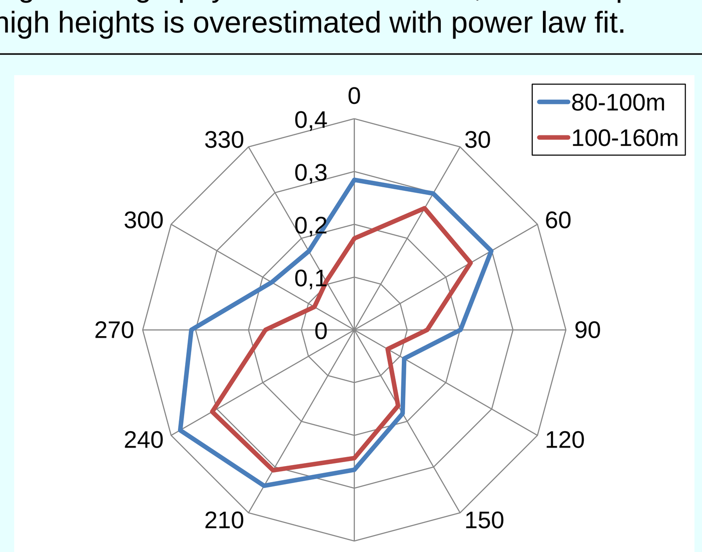

Fig. 5: The shear decreases with height at this site, and the extent depends strongly on the wind direction.

Wind veer

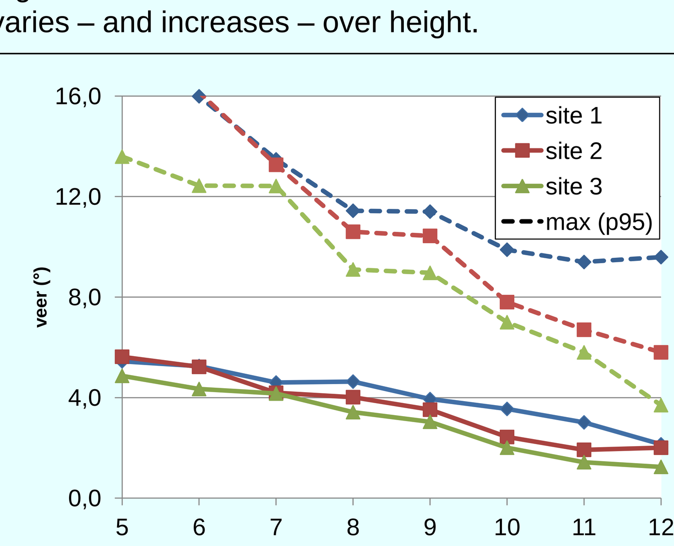

Fig. 6: Variation of wind veer between top and lowest measurement height (average and max values).

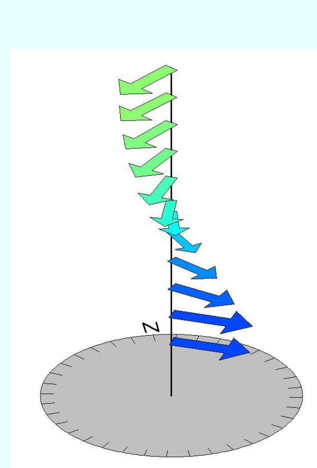

Fig. 7: Wind vector plotted over height reveals the typical Ekman spiral for this 10-min sample.

Modelling Errors

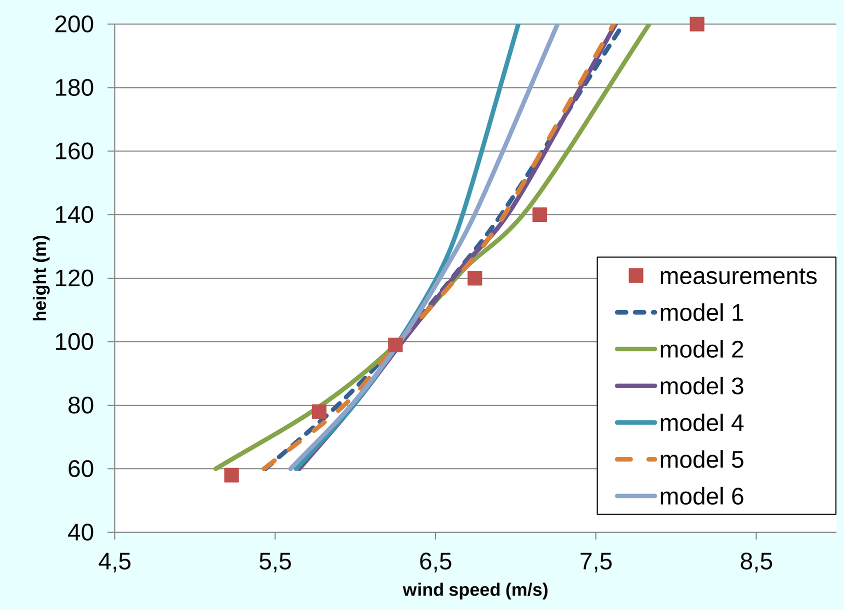

Fig. 8: Six different model results compared to remote sensing measurements. The measured data has been filtered for neutral atmospheric conditions.

Results from six different flow models compared to remote sensing measurements at a site in simple terrain demonstrate modelling errors (Fig. 8). In this example measured data from 100 m served as a reference. All models underestimate the wind resource above 100 m whilst most of them achieve good profile matches for lower heights.

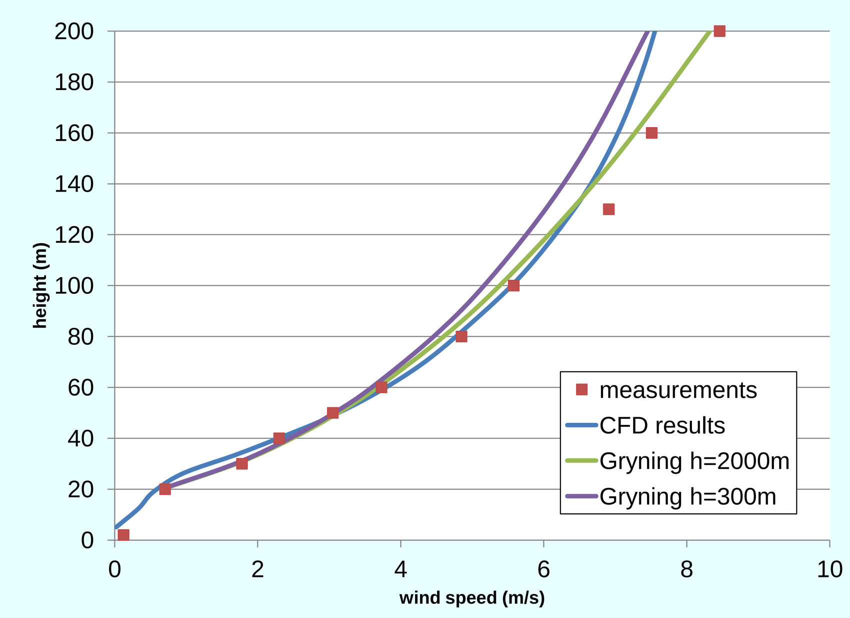

Fig. 9: CFD model results and analytical profiles according to [3] for two estimates of the ABL height (h). The measured data has been filtered for neutral atmospheric conditions.

CFD results and analytical profiles according to Gryning [3] using different assumptions for the ABL height are compared to measurements (Fig. 9). Again the CFD model has difficulties predicting the flow above 100 m. The analytical profiles depend on the ABL height, a parameter which is not available from standard mast measurements. Thus, the correct or incorrect assumption of the ABL height has a decisive influence on their performance.

Remedies

High measurements can serve as an immediate remedy:

In Fig. 10 it can be observed that measurements within the surface layer do not suffice for a reliable extrapolation to high hub heights. If conversely measurements up to or even above hub height are available, the uncertainty of model based vertical extrapolation for tall turbines can be reduced significantly.

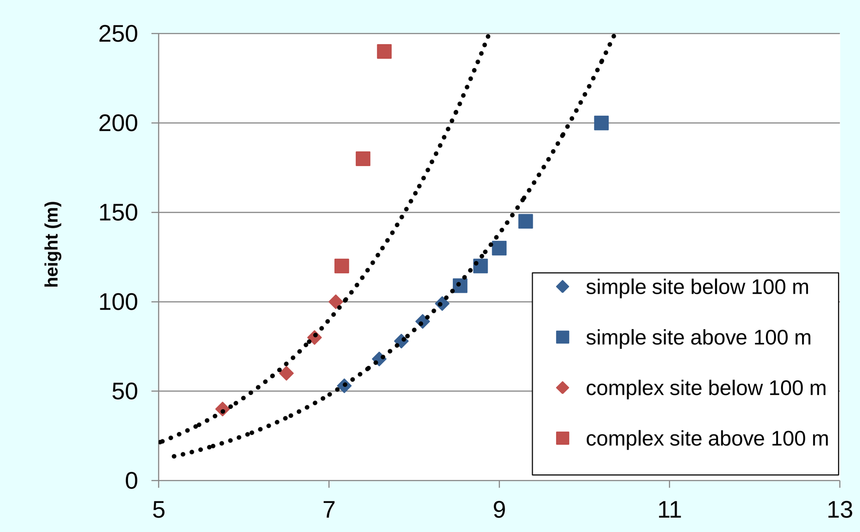

Fig. 10: Vertical extrapolations based on lower measurement heights compared to actual measurements.

Furthermore high measurements can help in a proper model setup. Fig. 11 shows a standard CFD model which roughly matches measurements below 80 m, but performs poorly above. Using available high measurements the model settings can be adjusted so to achieve satisfying results even above 100 m.

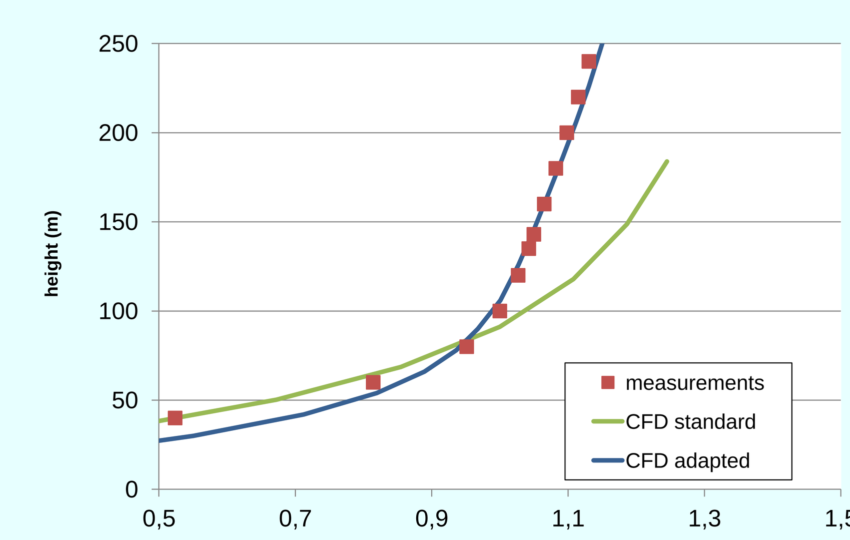

Fig. 11: Comparison of flow model setups (standard/ adapted for higher measurements)

Conclusion

Tall hub heights reach into the Ekman layer, where the common scaling assumptions of the surface layer are not valid anymore. Attempts to describe the wind profile above approx. 100 m require meteorological parameters which are not available from standard mast measurements. Thus, assumptions have to be made which are hard to verify for practical cases. Depending on the site specific conditions, these facts may lead to (severely) false estimates of the wind conditions at hub height.

When using flow models which have been validated well in the surface layer to estimate the wind conditions for tall hub heights, remote sensing measurements reaching heights above are essential in reducing extrapolation errors to acceptable levels. They can also aid in the model setup, thus achieving a better overall "model fit".

High measurements are finally a prerequisite for developing and validating new parameterizations for ABL flow, specifically for areas above the surface layer.

Acknowledgements

The authors hereby thank the Meteorological Institute at the Karlsruhe Institute of Technology for providing the measurement data for Fig. 9.

[1] Adapted from http://commons.wikimedia.org/wiki/File:Atmospheric_boundary_layer.svg
[2] Wilson, J.D., Flesch,T.K., 2004: An idealized mean wind profile for the atmospheric boundary layer. Bound.-Layer Meteorol. 110, 281-299.
[3] Gryning , S-E., Jørgensen, H., Larsen, S., Batchvarova, 2007: The wind profile up to 300 meters over flat terrain. J. Phys.: Conf. Ser. 75.
[4] Kelly, M.,Gryning, S-E., 2010: Long-Term Mean Wind Profiles Based on Similarity theory. Bound.-Layer Meteorol. 136, 377-390.