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Influence Of Thermal Stratification on CFD Simulations

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Abstract

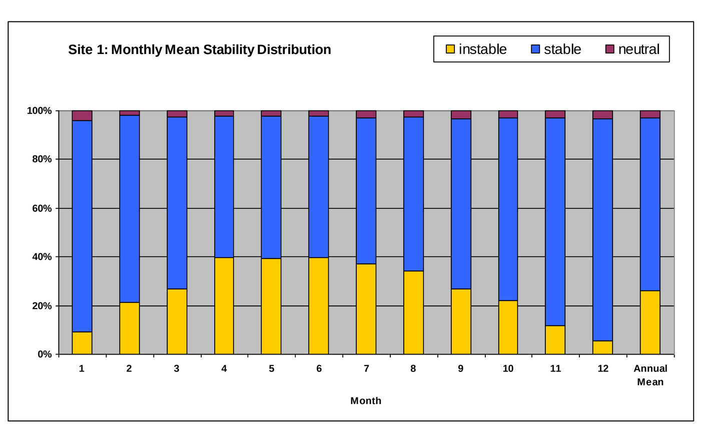
The neutral stratification assumption is commonly used when studying the wind conditions of a wind farm site with CFD. However, meteorological investigations have shown that often a more stable stratification prevails when looking at the long term means. Using the neutral stratification therefore leads to erroneous simulation of wind shear. Blocking effects over hilly terrain are not considered in the neutral simulation. These effects can significantly affect the wind farm energy output and its variations in time. Therefore, it is necessary to consider non-neutral stratifications also in the simulation of the wind flow.

Stratification of the atmosphere

Two sites will be presented here in more detail:

- **Site 1,** a moderately complex, but densely forested area in southern Germany
- **Site 2**, a very complex terrain in southern Spain

The stability investigations show that the majority of the measurements are taken under stable conditions and that the highest percentage of stable cases is found during winter time (Fig.1 and Fig. 2). Summer months have an of 55% stable cases, while winter differs considerably at both sites with maxima over 90% stable cases at Site 1 compared to 78% at Site 2.



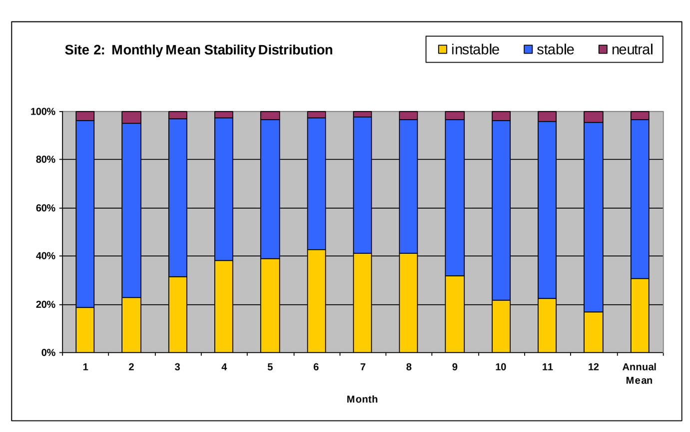
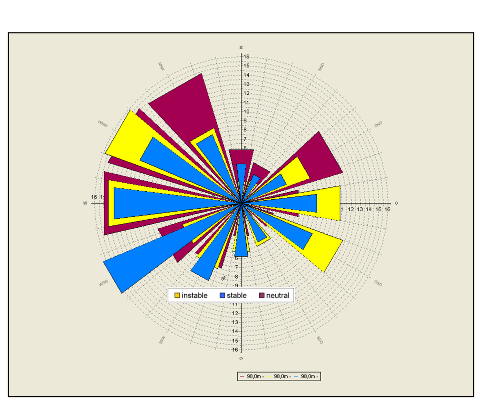


Fig. 1: Distribution of stability conditions over the year for Site 1 (left) and Site 2 (right).

In regions like Site 1 with no dominant seasonal wind systems, stable conditions have no prevailing wind directions, especially for forested areas. The mediterranean Site 2 clearly shows the influence of the land-sea breeze in summer, with stable conditions mainly coming along with northerly winds (Fig. 2).



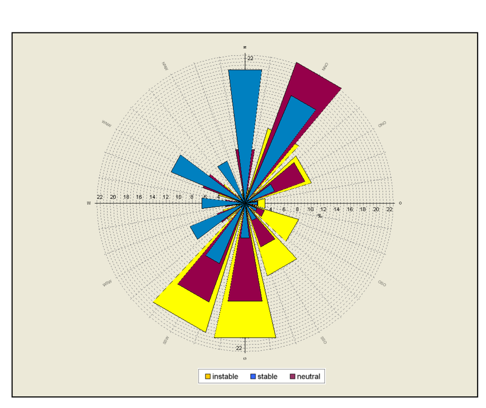
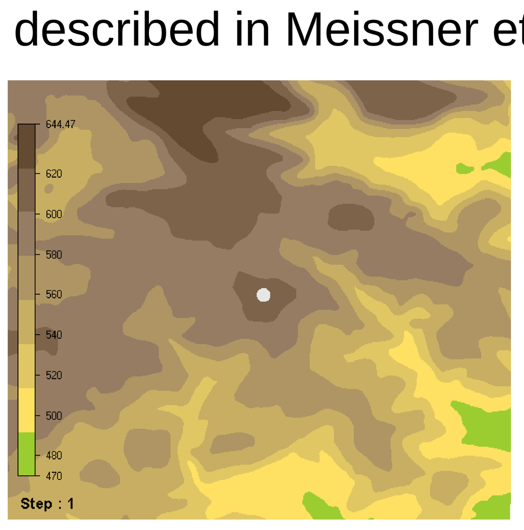
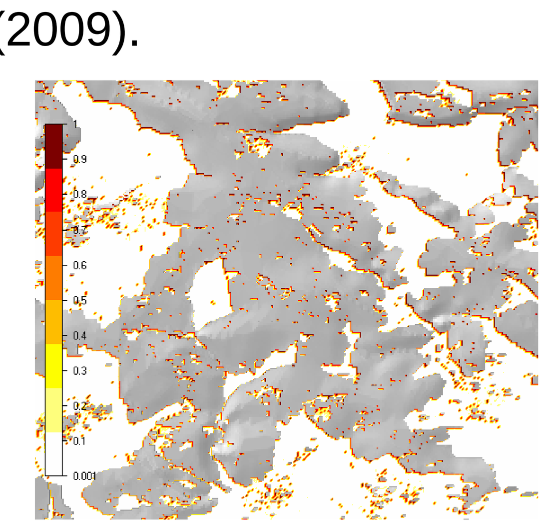


Fig. 2: Distribution of stability conditions over the year for Site 1 (left) and Site 2 (right).

CFD-Simulations for the sites

The CFD simulations for the site were run once with a default neutral atmosphere and then for different stability classes. The calculation of the wind field is done by using **CFD RANS simulations**, performed with the commercial software **WindSim**. The procedure to consider thermal effects in CFD wind field simulations and the improvements of simulations results due to the usage of this procedure are described in Meissner et al. (2009).





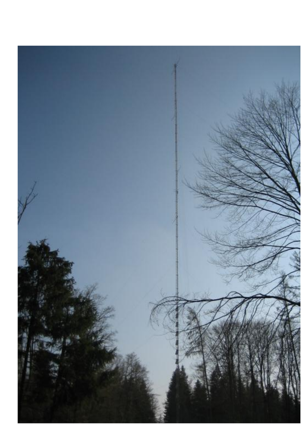
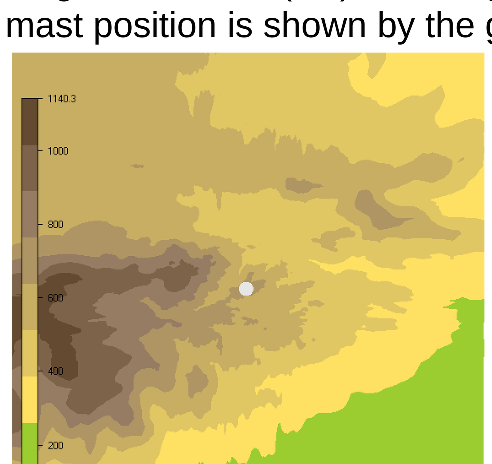


Fig. 3: Terrain height for Site 1 (left) and roughness height including forested areas shown in grey (right). The measurement mast position is shown by the grey point.



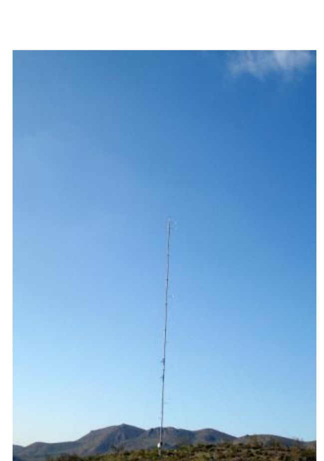
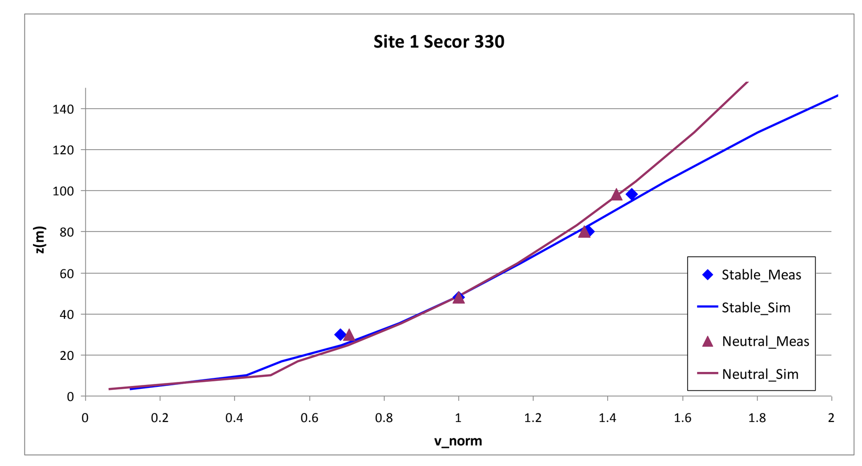


Fig. 4: Terrain height for Site 2. The measurement mast position is shown by the grey point.

In addition to the above climatic variations, both sites have strong orographic and roughness differences that can modify the wind flow, depending on stability.

Site 1

Due to the turbulence above the forest, differences in the measured neutral and stable wind profile occur mainly from 80 m and above. Here the wind speeds are higher in the stable conditions (Fig.5). The use of stable conditions in the simulation improves the results when comparing model results to the stable measurements.



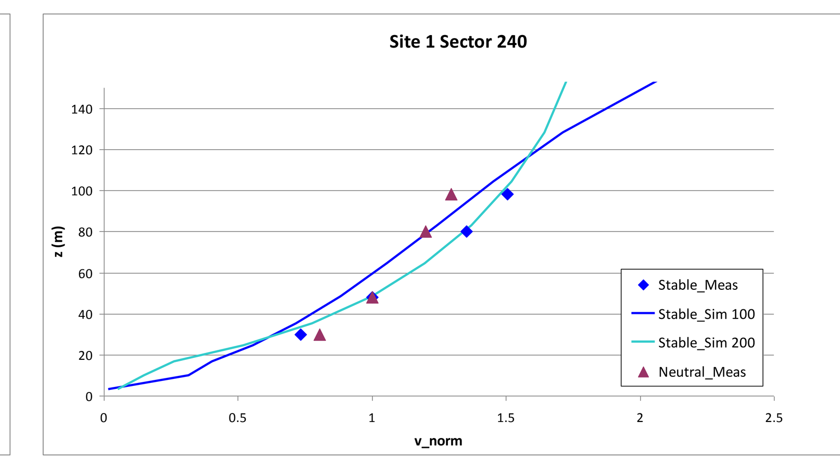


Fig. 5: Site1 comparison of normalized wind profiles for different sectors. Measurement values are plotted as single points, lines show model results. In the picture to the right simulations with Monin-Obukhov length 100 (stable_sim_100) and 200 (stable_sim_200) are compared.

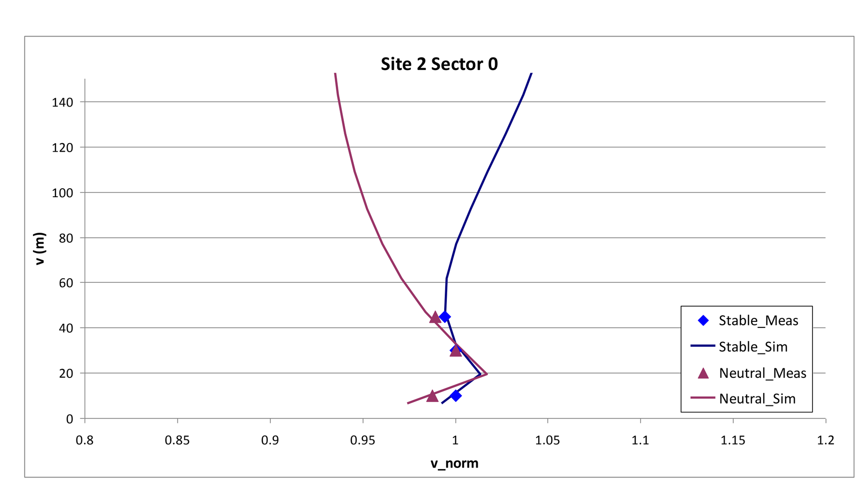
The choice of the right stability class is important to get a good fit with the measurements in the stable case (Fig. 5, right). Using a too moderate stability class (Monin-Obukhov length 200) leads to a less linear profile and therefore to an underestimation of the wind speed.

With correct introduction of stability classes, WindSim is able to fit the measured profiles and reproduce the stronger wind shear in the upper elevations coming along with stable conditions

Site 2

The site is influenced by two major meteorological phenomena, the land-sea breeze in the summer months and more stable conditions in the wintertime. Stable wind regimes occur most often for the northern sectors (Fig. 2).

Due to the position of the measurement mast on a hill, speed-up close to the ground and negative shear above can be seen in the measurements, especially for these northern sectors.



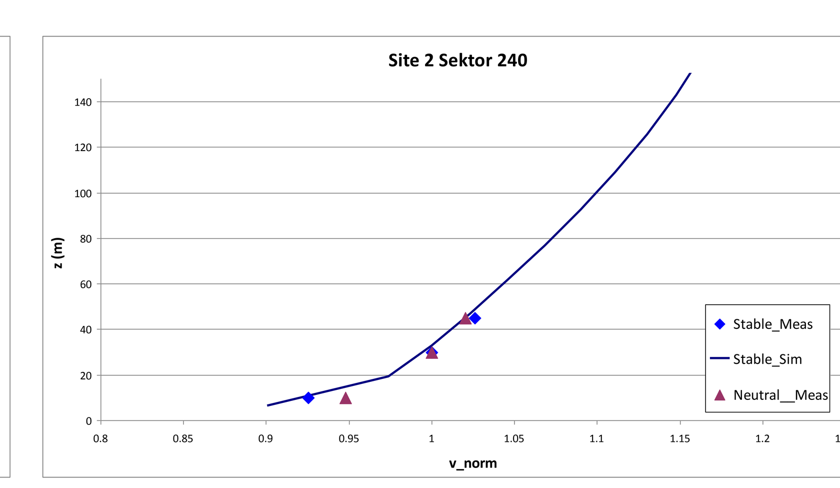


Fig. 6: Site2 comparison of normalized wind profiles for different sectors. Measurement values are plotted as single points, lines show model results

Comparison of two sectors – one with a strong hill speed-up effect and another with a normal wind gradient – shows that WindSim is able to simulate this behavior and that for this site the simulation with stable conditions improves the simulated profiles when compared to the measurements in stable conditions (Fig.6). Especially for the northern directions, neutral simulations can't capture the real shape of the profile and predict decreasing wind speed for all upper elevations, leading to underestimation of wind park energy yield.

Conclusions

Measurements show that the stability conditions can often be more stable than neutral at wind park sites and also offer a wide variety of individual conditions. With WindSim, we have been able to improve in wind shear estimate for an example of forested sites and sites with land-sea breeze. The inclusion of thermal stratification has proven to enhance CFD simulation results and lead to more precise calculations.

References

1. Meissner, et al. 2009: Including thermal effects in CFD simulations. *Journal of the Environmental Sciences,* 833-839,