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SPECIAL REPORT

New Techniques for Wind Measurement at Fraunhofer IWES

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Wind lidar measurements

The Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) runs a manifold measurement infrastructure for the investigation of wind characteristics at onshore and offshore sites in Germany. Lidar systems, as a remote sensing technique, become more important and are a main topic of the current research.

The pulse-doppler lidar systems used at the Fraunhofer IWES, are applied to measure the vertical wind profile in a contactless way (remote sensing) up to great heights and over the whole rotor diameter.

The measurement is based on the optical Doppler effect: The frequency of a radiation respectively its wave length is changed in as a function of the relative movement of source and receiver against each other. This principle is valid for acoustic as well as for electromagnetic waves.

The wind noticeable to us is based on the collective movements of molecules and aerosols in the atmosphere. The basic idea of a lidar wind measurement is to send out laser light waves to these components of the atmosphere. The reflected radiation can be detected and analyzed with respect to a frequency shift.

Ground based remote sensing using lidar technique is a new option to complement or eventually replace mast mounted measurements. Lidar measurements have shown a high accuracy in even, homogeneous terrain i.e. offshore or in flat lands. In contrast, applying these techniques in hilly or mountainous terrain, results in considerable bias. The reason for that is the assumption of homogeneous wind flow on distinct heights due to the principle of the 3D wind vector reconstruction, which is not sufficiently fulfilled in complex terrain.

In a lidar wind measurement the radial wind components in direction of the laser (line-of-sight) are being determined in at least three spatial directions. To calculate the wind vector from these radial components it is usually assumed that the wind field between the different measurement points is (horizontally) homogeneous. Measurements in flow fields that do not meet these assumptions are biased.

The determination of the wind speed with lidar measurement devices equals the calculation of a vectorial mean. Firstly the radial components are being determined at different location, which equals calculating the mean for each vector component. From these components the mean wind speed is being constructed as a vectorial mean.

The measurement of the radial vector components is carried out at different measurement points above the measurement device, depending on measurement height and cone angle. The measurement geometry usually follows the velocity azimuth display principle (VAD). Azimuth and measurement height

FIELDS OF APPLICATION

Onshore – Wind power onshore has still a huge potential for further growth. To assess this potential, especially in forested and complex terrain, a detailed knowledge about the wind conditions up to higher altitudes is important. With current tower technologies allowing the installation of turbines with hub heights up to 150 m, extrapolation methods for traditional mast based measurements at low heights are becoming increasingly unreliable – particularly under consideration of today's large rotor diameters. tobias.klaas@iwes.fraunhofer.de

Offshore – In the field of offshore wind energy the use of lidar systems on floating platforms under the influence of wave motion is studied. Different kinds of movements, like rotation, heave and surge distort the measurement procedure and influence the obtained wind speeds and directions. Methods for the correction of the falsified data are developed and verified using simulations as well as well defined experiments, where wave motion is simulated and the result compared with a met mast. gerrit.wolken-moehlmann@iwes.fraunhofer.de

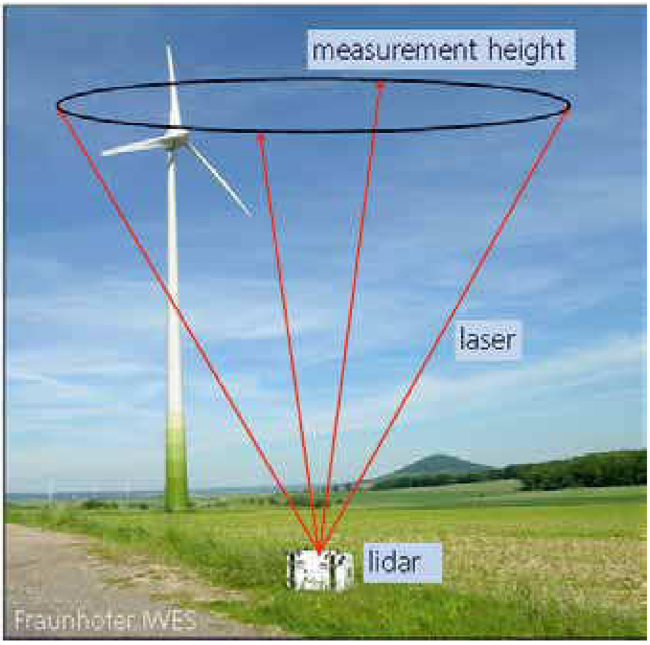

Figure 1: Lidar wind measurement system

can be varied, while the angle of inclination is fixed. With this determination it is not possible to accurately measure the wind speed in inhomogeneous wind fields.

As soon as the z-component of the wind speed is a function of the x- or y-coordinates, measurement bias occurs in comparison to a point measurement by cup anemometers. This bias can be corrected by different methods.

For the correction of lidar wind measurements in complex terrain flow models are more and more used. Depending on the complexity of the terrain a reliable correction is only possible with complex flow models. One main reason for this is that the classic boundary layer theory is no longer applicable in complex terrain. Failures in simple flow simulations (e. g. WAsP) are the consequence.

With a flow simulation of a complex site the lidar wind measurement as well as the common point measurement can be simulated. Both measurements can be compared to each other and methods for correction can be developed. As an example it is possible to characterize the change of the vertical wind speed between the different measurement points and to correct the lidar measurement in this manner.

Figure 5 illustrates the influence of the change of the vertical wind speed at the accuracy of a lidar wind measurement. The grey points equal the measurement points for the radial wind speed components at 100 m height with a laser inclination angle of 30°.

The wind field has been simulated for the site of the 200 m wind met mast, which is located near the top of a hill range. The hill flow at west wind conditions is clearly shown. The strong deviation in the z-component of wind speed between the southern and the northern measurement point results in a high measurement failure in wind speed.

200 m wind meteorological mast

The use of lidar as a novel and advanced measurement technique puts special emphasis on the new 200 m high quality reference mast that is used to validate and develop those measurements in detail.

Particularly with regard to system immanent failures of lidar measurements in complex and mountainous terrain, the 200 m met mast enables Fraunhofer IWES to develop and evaluate advanced correction algorithms for future onshore applications.

Figure 2 shows a schematic illustration of the wind met mast. The mast is designed as a steel framework with a cross-section area of only one square meter. Along its height of 200 m it is guyed with steel cables in four directions at a total of ten heights.

With this building the Fraunhofer IWES owns a worldwide unique measurement system for the exploration of wind characteristics in forested, complex inland terrain, especially qualified for research topics in the field of wind energy.

The measurement site is located at the ridge of a hill at a potential wind energy site in a low mountain range in northern Hesse. Within the current project research activities in wind characteristics, lidar measurements, load measurements and wind energy potential are planned.

The mast is equipped with cup and 3D ultra sonic anemometers as well as multiple wind vanes. Additionally pressure, temperature, temperature difference, humidity, rainfall and global radiation measurements give access to current weather and atmospheric conditions.

With a vertical distance at the utmost of 20 m wind speed sensors are installed all in all at 13 heights, resulting in a highly detailed wind profile measurement up to great heights. Measured wind profiles can therefore be evaluated and analyzed in a very detailed way. In addition to the 10 minute mean values and the measured 1 Hz data, the installed ultra sonic anemometers are recording 3D wind data at a high frequency of 50 Hz. Based on these data, detailed examinations of the 3D turbulence of the wind can be carried out.

Figure 4 shows first measurement results of a measurement campaign around Christmas 2011. For this campaign one lidar system was set up next to the measurement mast. During the time of the measurement no anemometers above 100 m apart from the top anemometer on 200 m were available. Lidar measurement data has been recorded for heights up to 220 m. The results show that the lidar measurement failure is relatively low for this site during the measurement time. The roughness parameter of the log law fit is slightly higher for the mast. At data points where lidar and mast can be directly compared, the mean values for the profile are slightly higher for the mast. This means the lidar tends to underestimate the wind speed.

For a detailed analysis of the measurement failures more data is needed. Wind speeds during the above shown measurement campaign were mostly quiet high with wind coming only from a narrow direction sector. After a longer measurement campaign more data will be available to compare lidar and mast measured

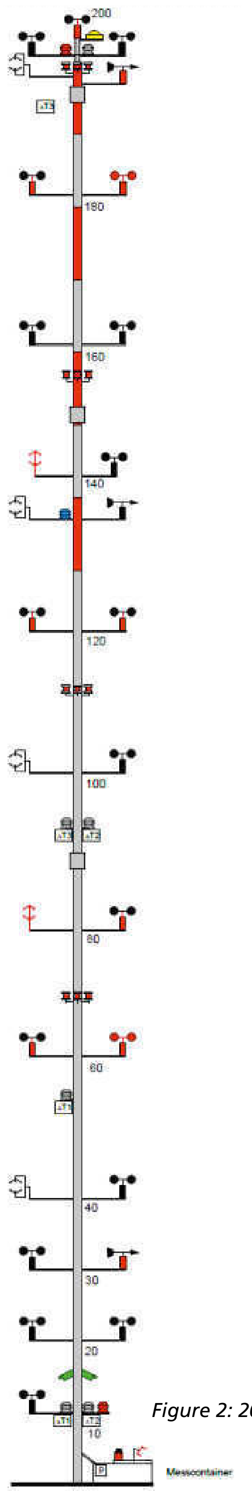

Figure 2: 200 m wind met mast

Figure 3: Construction of the 200 m wind met mast

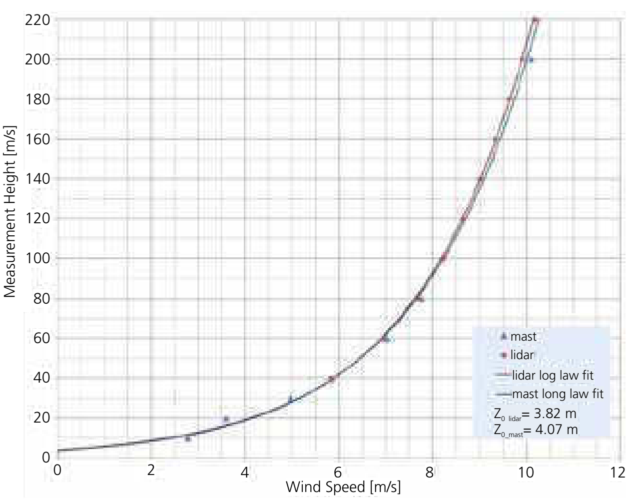

Figure 4: First measurement results lidar and mast. Short measurement campaign around Christmas 2011

wind speeds in dependence of direction, daytime and weather conditions more detailed.

Conclusion

The 200 m wind met mast is a valuable tool for both: The evaluation of flow models for complex and forested terrain as well as the testing and development of state-of-the-art correction algorithms for lidar wind measurements in inhomogeneous wind fields.

A comparison of the wind measurements with the data of the 200 m wind met mast forms a beneficial basis for increasing the accuracy of the measurements in complex terrain and the development of reliable correction algorithms for lidar wind measurements.

As a first approach the actual measurement failures of the lidar are being evaluated in a comparison to the mast based point measurements. The wind profile can be analyzed as a function of wind speed and wind direction. With the parallel measurement of the most important atmospheric parameters a classification of the wind profiles into different atmospheric stabilities is possible. With sufficient measurement time scientific findings can be made about the influence of measurement height, wind speed and atmospheric stability at the measurement. All the effects can therefore be considered during the development of accurate correction algorithms.

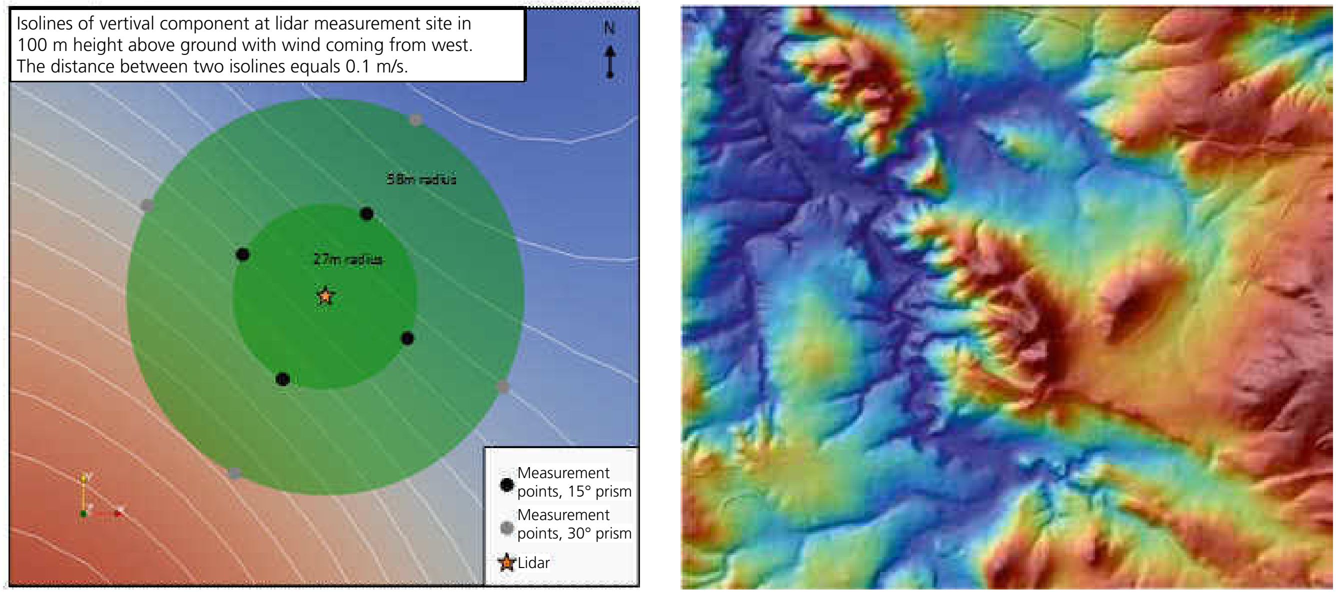

Figure 5: Left: Isolines at vertical wind component at a lidar measurement site (simulation), Right: Shaded relief of the measurement site with hill range in the middle

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