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The Use of Computational Fluid Dynamics to Post-Process ZephIR 300 Wind Speed Data in Complex Terrain

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Abstract

Data from remote sensing devices (RSD) are now widely considered as being bankable for use in wind resource assessment campaigns. Once installed, both the position and height of conventional anemometry such as cups are fixed, limiting their measurements to certain turbine locations and dimensions. These benefits, including the ability of RSD to measure at greater heights than current masts are generally capable of, can help to reduce project development risks and secure more favourable investment.

The current draft of the IEC 61400-12-1 ed.2 includes guidance on how to deploy a RSD for the purpose of turbine power performance testing. This version of the standards limits the use of RSD to flat terrain. Ground-based vertically-scanning RSD, whether based on sodar or lidar principles, calculate the mean wind speed based on measurements taken from the circumference of a scanned area. This process relies on the assumption that the line-of-sight velocities measured around the scan are representative of the wind speed at the centre of the scan. It is possible for this assumption to break down in strongly non-uniform flow, which can lead to possible differences in measured wind speeds between RSD and conventional anemometry.

By using a flow model, such as Computational Fluid Dynamics (CFD), it is possible to compute a set of factors that enable the conversion of RSD measurements to ones comparable with those from the point measurements sampled by conventional anemometry. This process is key to ensuring continued project financing based on data from RSD alone by reducing the uncertainty between a RSD and conventional anemometry in complex terrain.

In this work, CFD conversion of measurements taken by a Continuous Wave lidar, ZephIR 300, in varying terrain types and complexity is demonstrated, highlighting a transparent methodology that is capable of producing bankable measurements in terrain not considered to be simple.

What is Considered Complex Terrain and Why is CFD Conversion Needed?

Ground-based vertically-scanning RSD, whether based on sodar or lidar principles, calculate a mean wind speed vertically above the sensor location on the basis of measurements around a scanned area that typically encompasses a diameter comparable to the measurement height. This process relies on an assumption that the line-of-sight Doppler shifts measured around the circumference of the sampling disk are representative of the wind speed at the scan centre; however, this assumption breaks down in strongly non-uniform flow leading to possible differences in measured horizontal wind speed. By using a flow model, such as Computational Fluid Dynamics (CFD), it is possible to compute a set of factors that enable the conversion of RSD measurements to a comparable point measurement similar to that of conventional anemometry [1]. This process is key to ensuring continued project financing based on data from RSD alone by reducing the uncertainty between a RSD and traditional anemometry.

The current draft of the IEC standards [2] includes guidance on how to deploy a RSD for the purpose of turbine power performance measurement, but limits the use of RSD to simple terrain. This work aims to demonstrates that ZephIR 300 lidar can produce reliable measurements in terrain not considered to be simple.

The complexity of terrain can be described by the ruggedness index (RIX) [3], [4], which is defined as the fractional area of the terrain within the circular vicinity of a point of interest that exceeds a steepness threshold or critical slope. Mortensen *et al.* [5] investigates the relationship between WAsP prediction errors and site ruggedness. The main drawback in applying RIX is the necessity to choose the reference critical slope and the fact that forestry influences on the wind flow are ignored. Site specific ruggedness classes were suggested by Bingöl [6] to define the complexity of a site. Table 1 summarises how site complexity was interpreted for this study.

All remote sensors make the underlying assumption of homogenous wind flow throughout their scan volume. In complex terrain it is possible for this assumption to break down. Figure 2 depicts how the upwind and downwind components of the wind may not be aligned as a result of terrain induced flow distortion. Depending on the site terrain, these non-homogenous flow vectors can be a function of both direction and height above the sensor. The conversion method used here considers only the predominant wind direction i.e. along a line parallel to the wind at the centre of the scan disk. A conversion factor rose (Figure 3) is deduced from the directional analysis at a site automatically in the CFD model.

Figure 1. Example of ZephIR 300 deployment in complex terrain

	Class 0 Z_o < 0.01 m	Class 1 Z_o in [0.01, 0.05]	Class 2 Z_o [0.05, 0.4]	Class 3 Z_o > 0.4 m
Flat	Simple	Simple		
Hilly . hill height <100 m . slope in [5°, 10°]	Moderately complex	Moderately complex	Moderately complex	Complex
Vegetated flat sites canopy height in [5m, 10m]		Moderately complex	Moderately complex	
Mountains without forest with slope > 10°	Complex	Complex	Complex	
Flat with Forests canopy height >10m				Complex
Mountains with forests				Highly complex

Table 1: Complexity Classes used in study

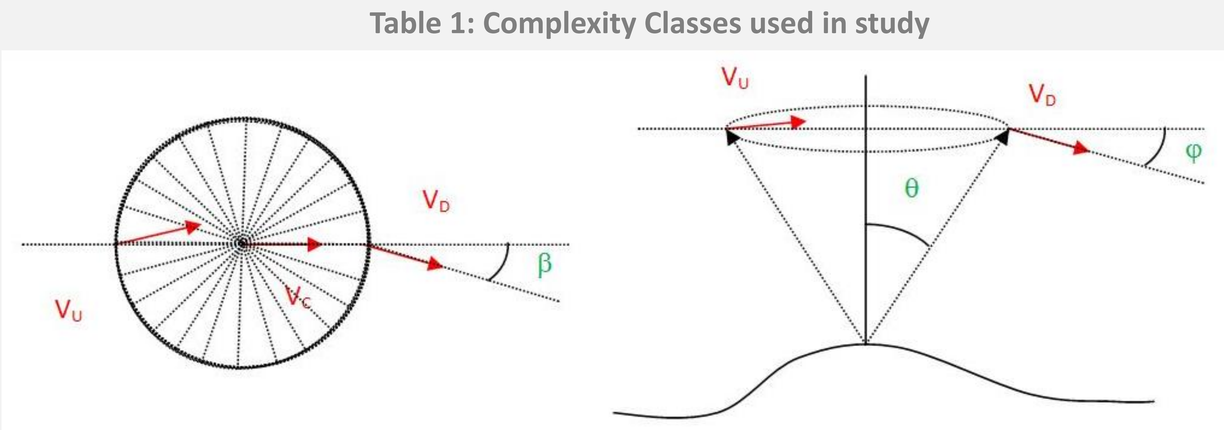


Figure 2: Plan and side view of the lidar scan geometry

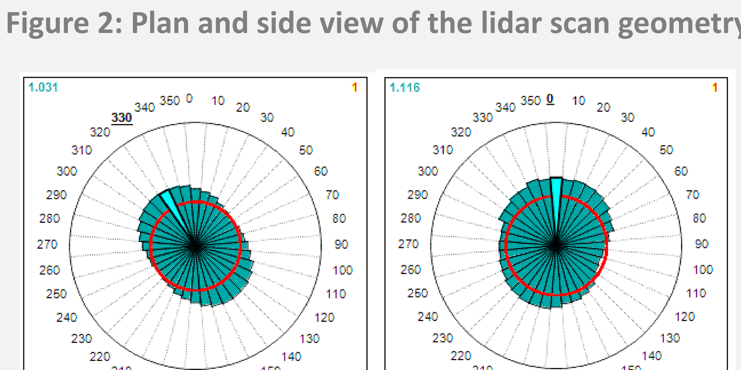


Figure 3: Example conversion factors as a function of direction for two test sites for a site

Results

Site Configuration	Forestry	Height (m)	Before Conversion R^2	Before Conversion Gradient	After Conversion R^2	After Conversion Gradient	Improvement in gradient (% within unity)
1 - Simple Site	No	20	0.996	1.000	0.996	1.001	Negligible
		45	0.995	1.001	0.995	1.002	Negligible
		70	0.997	1.002	0.997	1.003	Negligible
		90	0.994	1.000	0.994	1.001	Negligible
2 - Moderately Complex	No	30	0.992	0.988	0.992	0.994	0.60%
		60	0.994	0.985	0.994	0.994	0.90%
3 - Complex	Yes	20	0.992	0.999	0.991	1.007	-0.60%
		40	0.992	0.985	0.991	0.995	1.00%
		60	0.989	0.988	0.988	1.000	1.20%
		80	0.983	0.985	0.984	1.000	1.50%
4 - Highly Complex	No	20	0.993	0.934	0.993	1.008	5.80%
		40	0.994	0.918	0.996	0.995	7.70%
		45	0.994	0.908	0.995	0.983	7.50%
5 - Highly Complex	Yes	60	0.966	0.957	0.968	0.992	3.50%
		80	0.965	0.974	0.965	1.005	1.90%
6 - Complex	No	20	0.989	1.002	0.989	1.011	-0.90%
		50	0.993	0.992	0.993	1.017	-0.90%
		60	0.994	0.977	0.994	1.002	2.10%
		80	0.993	0.976	0.993	1.002	2.20%
7 - Complex	No	20	0.989	0.989	0.988	0.990	Negligible
		35	0.990	0.994	0.990	0.997	0.30%
		50	0.989	0.996	0.990	1.001	0.30%
8 - Complex	No	44	0.993	1.000	0.992	0.990	-1.00%
9 - Highly Complex	No	44	0.989	0.983	0.992	0.995	1.20%
11 - Highly Complex	No	44	0.997	0.987	0.997	1.019	-0.60%

Table 2. Results of pre- and post-CFD conversion for 11 sites that were tested with varying terrain complexity

The conversion factors in this study were deduced from the CFD code Meteodyn WT. Meteodyn WT solves the Reynolds Averaged Navier-Stokes (RANS) equations, using a refined mesh at the ZephIR 300 location and computing wind speed and inflow angle. Orographic and roughness data from SRTM and Corine Land coverage database were used as model inputs for defining the site in the CFD software.

Improved agreement between the ZephIR 300 and mast measurements was achieved by applying the conversion factors to the ZephIR 300 10-minute wind speed measurements. Figure 4 shows an example correlation between the mast and the ZephIR 300 10-minute measurements for Site 4 at 45 m above the ground.

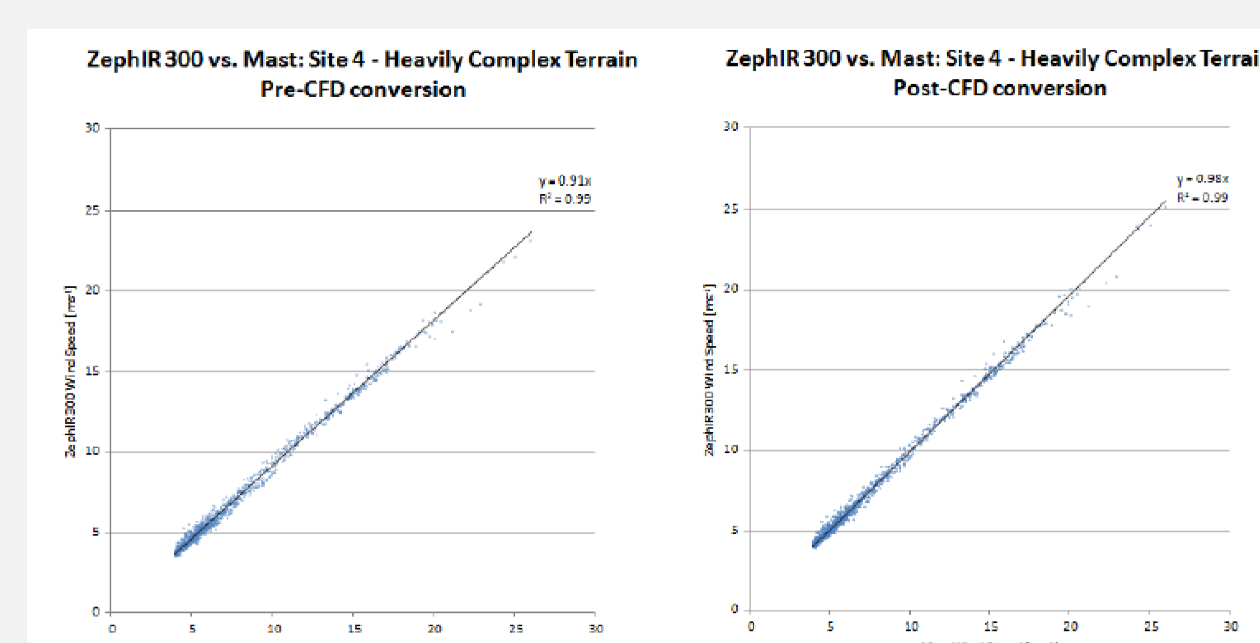
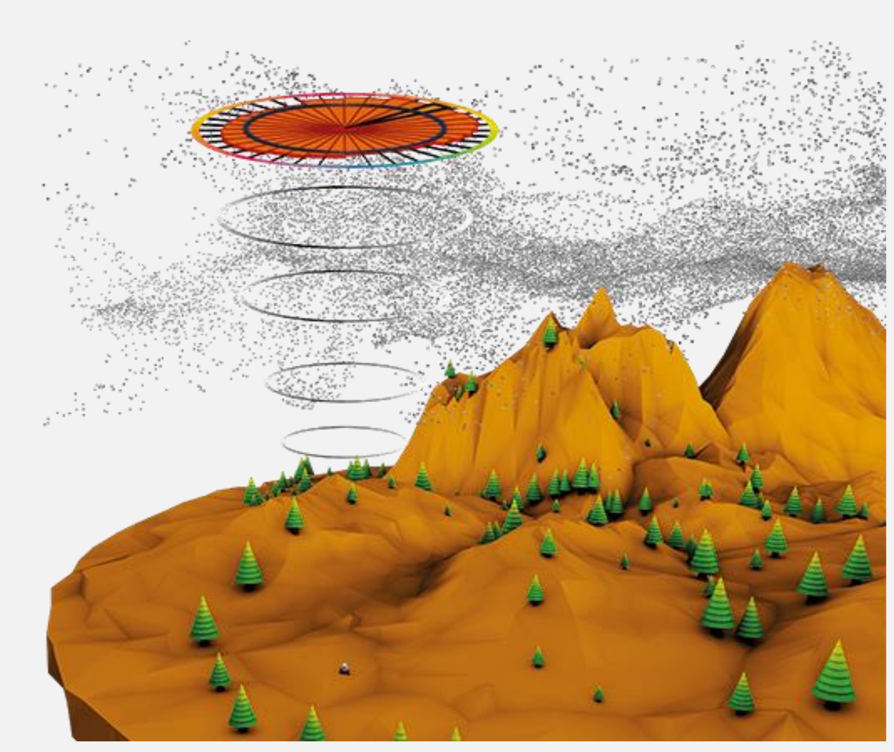


Figure 4: Regression plot showing the correlation between mast and ZephIR 300 at 45 m above ground level for site 4 (highly complex)

Figure 5: A computer visualisation of how complex terrain might influence the wind flow passing over it. These complex flow patterns can cause a breakdown in the underlying assumption that flow throughout the scan volume of a RSD is homogenous, which can lead to biases in horizontal wind speed when compared to measurements from conventional anemometry such as cups.

Using Meteodyn WT CFD solver, a set of conversion factors are generated for thirty-six ten degree wind sectors, as depicted in the upper most scan circle to the right, for each measurement height being interrogated at a specific deployment.

These factors are then used to convert the ZephIR ten minute horizontal wind speeds into a comparable point measurements that would be obtained from cups at the same location and measurement height.



Summary and Conclusions

Applying CFD conversion to data from RSD in complex terrain improves the agreement between wind speed measurements from RSD and masts – one example reduced the difference from approximately 9 % to less than 1 %. For moderately complex terrain and simple sites with forestry, CFD conversion of RSD measurements should be considered a standard process when the coefficient of determination is very close to unity (> 0.98). For extremely complex terrain, CFD conversion of RSD measurements showed good results also. The limit to the application of this methodology should only be governed by the ability of the numerical model to accurately predict the flow characteristics at the site in question.

ZephIR 300 data is considered by DNV GL to be at Stage 3 under "benign" conditions, meaning its data is accepted for use in bankable / finance-grade wind speed and energy assessments with either no or limited on-site met mast comparisons. With this approach it has been demonstrated that ZephIR 300 data, coupled with CFD based conversion, can be extended and treated as finance-grade in complex terrain also.

References

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