PO. 79

Direct Lidar Measurement in Complex Terrain

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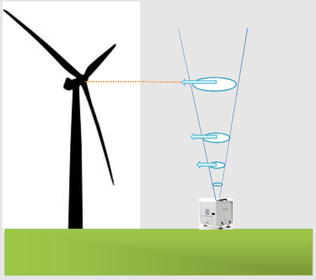
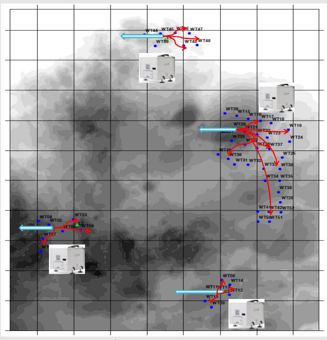
Abstract

In the context of constant aim to reduce wind farm projects uncertainties, remote sensors are gaining attraction, because they have the ability to measure up and even above the turbines hub height and can easily be moved to measure at several locations of the project site.



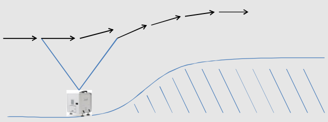


Indeed remote sensors allow a more secure assessment of the wind resource…

… If only the technology used provide accurate wind data with a high confidence level!

Complex Flow Challenge

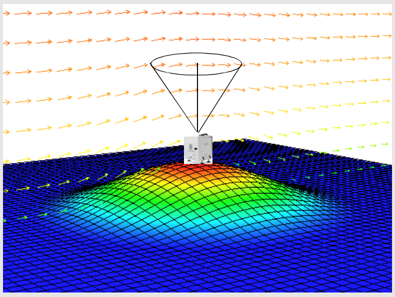
All remote sensors (RS) probe a volume of atmosphere, differentiating them from cups measurement. At a given height, they measure several Line of Sight (LoS) wind speeds and convert them into horizontal wind speed and wind direction using the assumption that the flow is homogeneous through the LoS beams.



In complex terrain, the variation of flow inclination cross the beams is the main source of bias because the flow homogeneity assumption is not always sufficiently true.

Flow Inclination difference (°)	-5°	-2.5°	0°	2.5°	5°
Bias (%) Semi-cone angle=30°	7.5%	3.8%	0%	-3.8%	-7.5%
Flow Inclination difference (°)	**-2.5°**	**-1.25°**	**0°**	**1.25°**	**2.5°**
Bias (%) Semi-cone angle=15°	8.1%	4.1%	0%	-4.1%	-8.1%

The use of CFD models



CFD models can be used to estimate the flow inclinations over a site. The remote sensor LoS measurements and the conversion process are simulated to estimate the order of magnitude of the bias. **Various topographies** (here a sinusoidal hill), **various model configurations** (various wind speed and shear values, turbulence levels and atmospheric stabilities), as well as **various RS locations** can be tested in order to inform on the **bias sensitivity**.

Configuration	RS Error alt. 80m	RS Error alt. 100m	RS Error alt. 120m
Lidar placed at top, Mean WS at 10m = 5m/s, Shear value = 0.15, Atmo. Stability = Neutre, Turbulence = Low	-3.45%	-3.63%	-3.71%
Lidar placed at top, Mean WS at 10m = 2m/s, Shear value = 0.55, Atmo. Stability = Stable, Turbulence = Low	-2.58%	-2.66%	-2.74%
Lidar placed in slope, Mean WS at 10m = 5m/s, Shear value = 0.15, Atmo. Stability = Neutre, Turbulence = Low	-1.46%	-1.63%	-1.78%

CFD models can help define the most suitable RS locations on a wind farm project site, or to **correct the bias** induced by the conversion of LoS measurements into horizontal wind speed under the flow homogeneity assumption. This methodology has been applied successfully several times for different RS types and on a variety of sites.

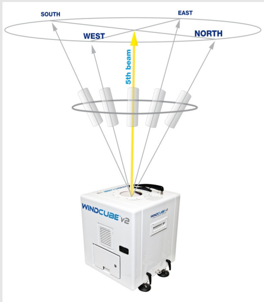
However, CFD calculations are done for a finite number of flow situations and are **partly representative of the real life conditions**.

Taking this concern into account, **Leosphere has developed a direct measurement of the wind speed** without using the flow homogeneity assumption.

FCR™ *Flow Complexity Recognition* for WINDCUBE™ v2

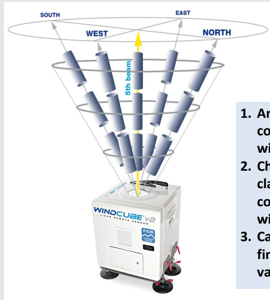
Based on unbiased LoS measurements and direct measurement of vertical wind speed through a 5th vertical beam provided by the WINDCUBE™ v2, a patent pending smart flow analysis has been developed for complex terrain situations.

Normal mode



Independent Heights Measurement
Assumption : homogenous wind flow

FCR™ mode

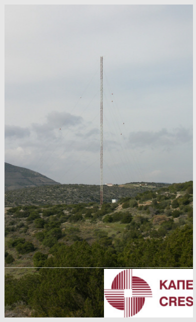


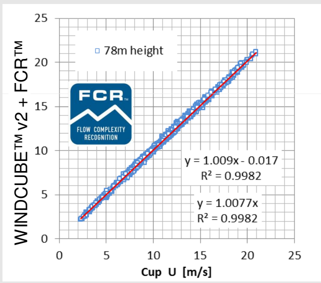
Entire Profile Direct Measurement
No Assumption on flow homogeneity

1. **Analysis and comparison of radial wind of all LOS gates**
2. **Characterization & classification of the complexity of the wind**
3. **Calculation of the final wind speed value**

On site validation

One of the three on site validations was conducted on the CRES test facility in Greece. Three months of measurements were continuously collected in the summer 2010, covering a wide range of wind speeds, shear values and atmospheric conditions. A WINDCUBE™ v1, operated by CRES, and a WINDCUBE™ v2 with FCR™ were located close to a 100m met mast equipped with MEASNET calibrated cups.





Dimitri Foussekis (CRES): "***At 78m height, wind speed deviations are kept below 0.1%, with a coefficient of determination R^2>0.998. This is an outstanding value approaching results obtained before only in flat terrains.***"

Wind Speed Correlation vs. mast	WINDCUBE® v1			WINDCUBE® v2 + FCR™		
	Slope	Offset (m/s)	R^2	slope	Offset (m/s)	R^2
54m	0.938	0.044	0.996	1.006	0.076	0.998
78m	0.942	-0.079	0.996	1.009	-0.017	0.998
100m (vs. Sonic)	0.954	-0.289	0.988	1.012	-0.152	0.988

Full report available under http://www.lidarwindtechnologies.com/

Theoretical validation

The FCR™ measurement process can be simulated and applied on the flow calculations realized over the sinusoidal hill. The comparison with the normal mode helps to validate the new concept.

Configuration	FCR™ Error alt. 80m	FCR™ Error alt. 100m	FCR™ Error alt. 120m
Lidar placed at top, Mean WS at 10m = 5m/s, Shear value = 0.15, Atmo. Stability = Neutre, Turbulence = Low	0.79%	0.84%	0.78%
Lidar placed at top, Mean WS at 10m = 2m/s, Shear value = 0.55, Atmo. Stability = Stable, Turbulence = Low	0.66%	-0.78%	-0.81%
Lidar placed in slope, Mean WS at 10m = 5m/s, Shear value = 0.15, Atmo. Stability = Neutre, Turbulence = Low	0.44%	0.33%	0.30%

Conclusion

Remote sensors are very attractive to reduce project uncertainties, especially in complex sites where uncertainty on the wind speed resource may be high. However, complex flow challenges the remote sensors accuracy. **To overcome the flow homogeneity assumption used by remote sensors, Leosphere innovates by introducing the FCR™ *Flow Complexity Recognition* add-on for WINDCUBE™ v2, increasing its return on investment of several hundreds of k€.**

EWEA 2012, Copenhagen, Denmark: Europe's Premier Wind Energy Event