ZephIR Lidar

The use of CFD to post-process wind speed data from remote sensing devices in complex terrain

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Presentation Summary

- The use and benefits of lidar within the wind industry
- Challenges in extreme environments (masts vs. lidar)
- Use of lidar in complex terrain
- Case study of lidar use in complex terrain
- Lidar Practicalities and Recommendation in extreme climates
- Summary and Conclusions

The Use and Benefits of Lidar to the Wind Industry

- The industry has historically used fixed meteorological masts for measurement needs.

- Data from lidar are now considered bankable for use in many aspect of wind resource assessment campaigns.

- They offer considerable opportunities in producing high quality, cost reduced wind measurements especially where the use of conventional meteorological masts are technically or financially challenging.

- Other benefits include:
  - Measurements up to and exceeding standard hub heights;
  - Wind climate characterisation across the full rotor diameter (REWS);
  - Easy installation in difficult to access sites and climatic conditions; and
  - Lower risk operation in climates subject to structural icing.

Wind Resource Assessment Challenges – Masts and Lidar

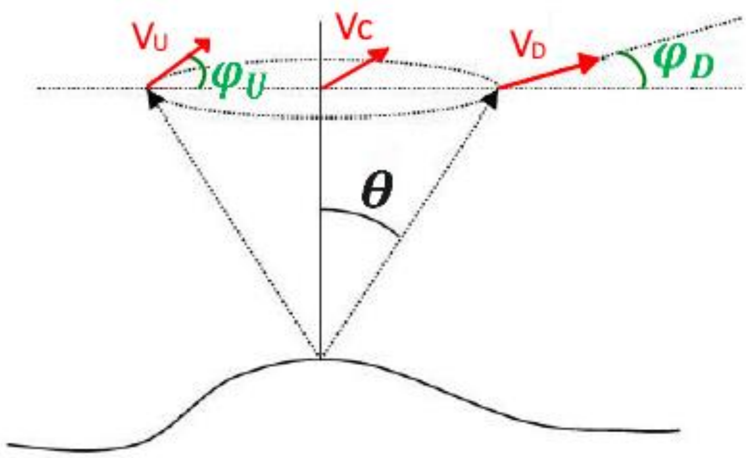
- At extreme sites a certain amount of problems are to be expected when compared to simple / benign sites.

- Mast vs. Lidar complexities to consider here:
  - The terrain is complex (point to volume conversion applied);
  - They are remote and hard to access (reliability important);
  - The winds can be extreme;
  - Icing can be severe (not just the instruments, the mast itself can ice and cause higher flow distortion); and
  - Temperatures can be very low (ZephIR can operate down to -40ºC)

- It's important to maintaining power, keeping device communication running and also understanding how the conditions influence measurements from both mast and lidar

Complex Flow and Lidar

- When using a lidar, the assumption is made that the flow over the entire scan is homogeneous (in fact this assumption is made for all remote sensors)



Homogeneous flow → $\varphi_U = \varphi_D$

$$V_C = \frac{(V_U + V_D)}{2}$$

θ scanning angle

β horizontal deviation

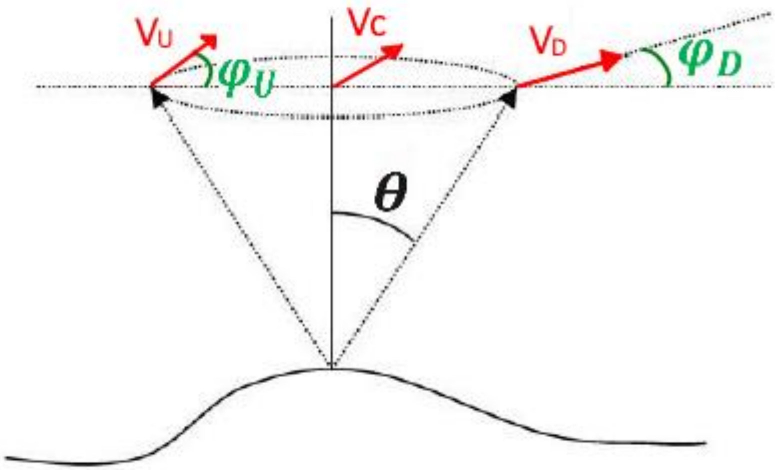
φ inflow angle

- In complex terrain this assumption can break down and cause a bias in the lidar measurement compared to that of standard anemometry (point measurement).

- As a result, CFD can be used to compensate for this bias and produce a point equivalent measure of the wind more in line with what standard anemometry would report.

CFD Conversion Factor

- Any CFD model can be used, example below assumes we're only looking at the upwind and downwind direction:

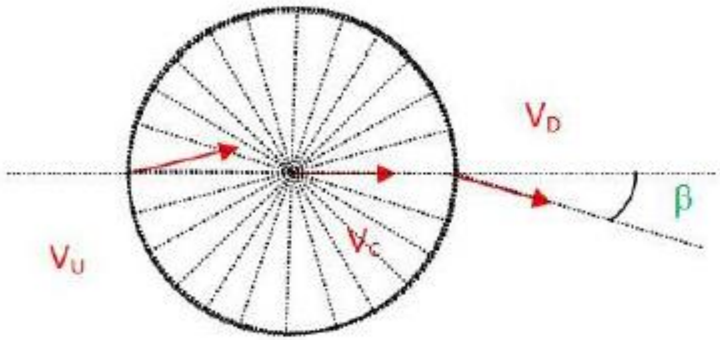


$\mathbf{V_C}$ wind speed at the scan centre

$\mathbf{V_U}$ upstream wind speed

$\mathbf{V_D}$ downstream wind speed

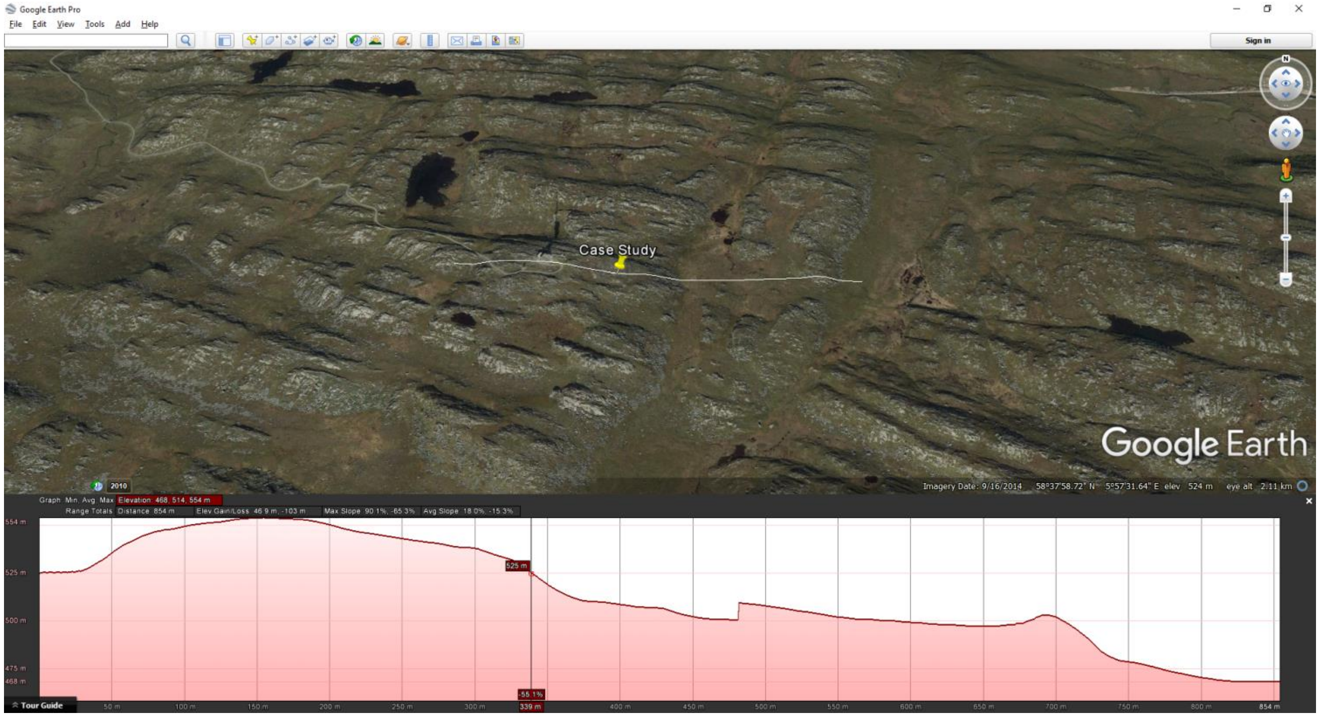
$\mathbf{V_L}$ Lidar wind speed calulated using the inflow angle from the CFD model



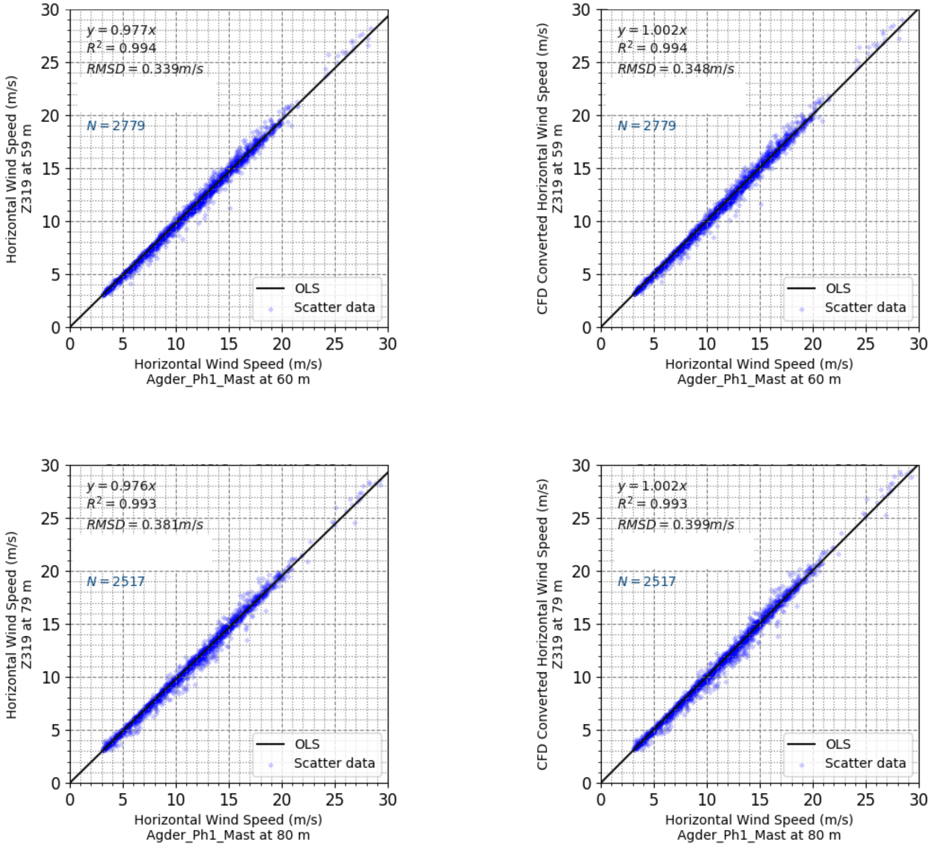
$$\alpha = \frac{V_C}{V_L} \text{ CFD conversion factor}$$

Case Study – Norwegian Deployment

- Complex terrain deployment in Norway
- 80 m mast installed close to the location of the ZephIR
- CFD conversion of ZephIR wind speed data applied at two heights – 60 m and 80 m.



Case Study – Norwegian Deployment



- 60m and 80m measurement had a 2.3% and 2.4% bias respectively (left hand plots).
- CFD conversion of ZephIR wind speed data reduced this bias to < 0.5% at both heights (right hand plots).
- R^2 unaffected at a value of 0.99.
- Deployments such as this would have difficulty installing a mast any taller than 80m.
- Confidence gained in ZephIR measurements to extend analysis to higher heights.

Complex Terrain analysis over 11 sites

Site Configuration	Forestry	Height (m)	Before Conversion		After Conversion		% bias from unity	% bias from unit	Improvment in gradient
			R^2	Gradient	R^2	Gradient	(pre-CFD)	(post-CFD)	(% within unity)
1 - Simple Site	No	20	0.996	1.000	0.996	0.998	0.00%	-0.20%	Negligible
		45	0.995	1.001	0.995	1.000	0.10%	0.00%	Negligible
		70	0.997	1.002	0.997	1.001	0.20%	0.10%	Negligible
		90	0.994	1.000	0.995	1.000	0.00%	0.00%	Negligible
2 - Modertaely Complex	No	30	0.995	0.982	0.994	0.994	-1.80%	-0.60%	1.20%
		60	0.995	0.984	0.995	0.995	-1.60%	-0.50%	1.10%
3 - Complex	Yes	20	0.991	0.995	0.990	1.001	-0.50%	0.10%	0.40%
		40	0.991	0.982	0.991	0.991	-1.80%	-0.90%	0.90%
		60	0.992	0.984	0.992	0.996	-1.60%	-0.40%	1.20%
		80	0.987	0.982	0.988	0.997	-1.80%	-0.30%	1.50%
4 - Highly Complex	No	20	0.992	0.932	0.992	0.974	-6.80%	-2.60%	4.20%
		40	0.994	0.917	0.993	0.978	-8.30%	-2.20%	6.10%
		45	0.993	0.908	0.992	0.971	-9.20%	-2.90%	6.30%
5 - Highly Complex	Yes	60	0.966	0.957	0.969	1.000	-4.30%	0.00%	4.30%
		80	0.965	0.974	0.965	1.020	-2.60%	2.00%	0.60%
		100	0.952	0.987	0.948	1.034	-1.30%	3.40%	-2.10%
6 - Complex	No	20	0.989	1.002	0.989	1.015	0.20%	1.50%	-1.30%
		50	0.992	0.992	0.993	1.017	-0.80%	1.70%	-0.90%
		60	0.994	0.977	0.994	1.004	-2.30%	0.40%	1.90%
		80	0.993	0.976	0.993	1.007	-2.40%	0.70%	1.70%
7 - Complex	No	20	0.989	0.989	0.990	1.005	-1.10%	0.50%	0.60%
		35	0.990	0.994	0.991	1.014	-0.60%	1.40%	-0.80%
		50	0.989	0.996	0.990	1.016	-0.40%	1.60%	-1.20%
8 - Complex	No	44	0.993	1.004	0.991	1.017	0.40%	1.70%	-1.30%
9 - Highly Complex	No	44	0.980	0.986	0.991	1.006	-1.40%	0.60%	0.80%
10 - Highly Complex	No	44	0.997	1.009	0.994	0.987	0.90%	-1.30%	-0.40%
11 - Highly Complex	No	44	0.997	0.987	0.997	0.999	-1.30%	-0.10%	1.20%

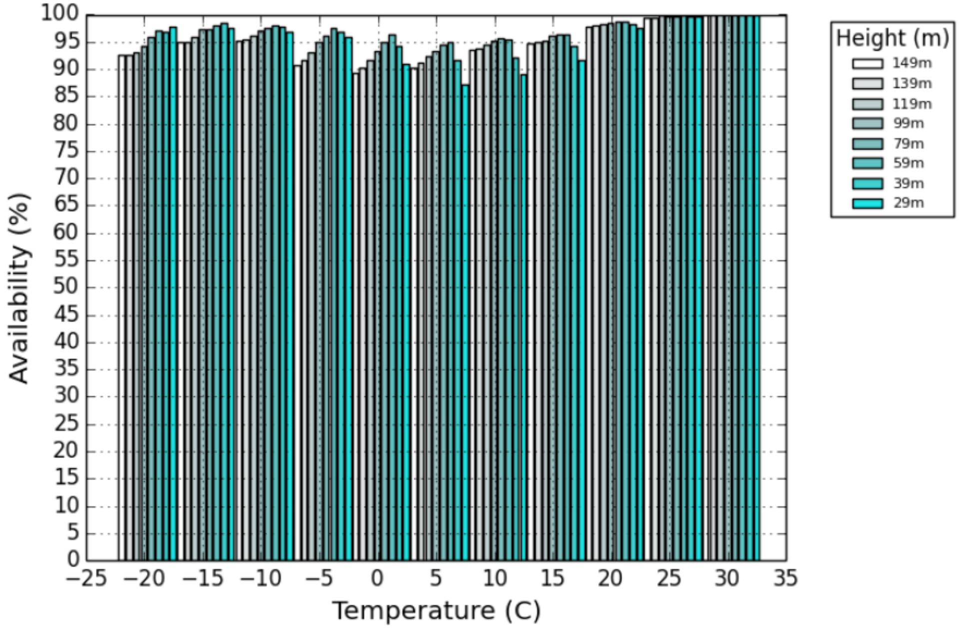
Quality of mast instrumentation, mounting error, etc was not looked into here. It is possible that some of the bias seen after conversion is related to cup response

Case Study: Icing (Extreme Norwegian Deployment)

- Standard anemometry is prone to icing in low temperature environments
- Fully Heated and shaft only heated cup pairs allow for iced periods to be identified in the wind data
- Periods of time when the fully heated cup was showing signs of icing also, which could have gone unnoticed without lidar
- Icing of the mast can also increase distortion beyond IEC levels even if cup heating is keeping the cup turning

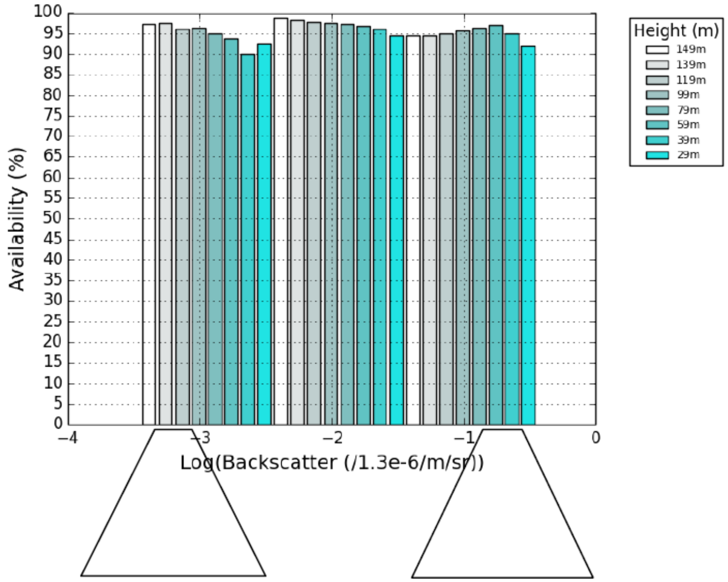
Data Availability vs. Temperature (High Latitude Deployment)

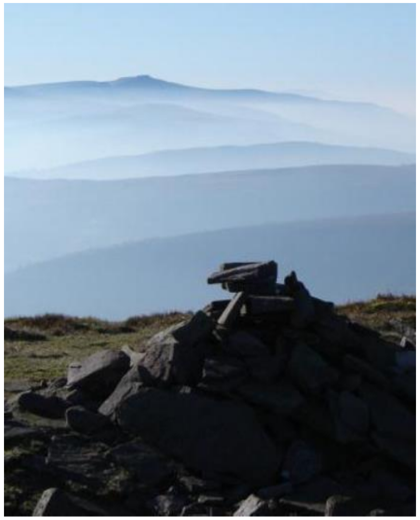
- ZephIR rated down to -40 ºC with internal temperature management ensuring that essential components are fully functional and operating correctly
- Extremely high (> 90%) availabilities achieved across a broad temperature range
- No height dependence on availability as a function of temperature was seen



Case Study: “Clean Air” (High Latitude Deployment)

- Very cold atmosphere … osol concentration because airborne wat … sols responsible for backscattering the Ze … out of the air
- ZephIR data can prov … ation via a backscatter parameter
- Data availability was … n for the lowest recordable levels of b … bility (shown next) are caused by other quali … ly to the data.





Lidar Practicalities and Considerations

- Considerations in extreme environments can be vastly different to those in benign conditions:
  - Measurement instrument(s) and data quality
  - Power supply solution – heated instruments need power too if deploying in cold climates
  - Are conventional masts appropriate due to environmental conditions or site terrain and access
- Planning is key
  - Good local knowledge of both terrain and conditions will allow the lidar to be best utilised, deployed and ran most efficiently
- ZephIR can measure down to 10 m AGL:
  - It can be paired with short mast (cheaper, less prone to structural failure as with taller masts, provides measurement traceability, etc)
  - ZephIR can be mounted on platform to avoid being effected by heavy snowfall

Summary and Conclusions

- Remote Sensing offer the opportunity to conduct measurement campaigns in harsh or extreme conditions

- Confidence can be had in ZephIR measurements in complex terrain through the addition of CFD conversion of the wind speed data.
  - Transparent method, providing the confidence and traceability needed for financing
  - CFD results validated across 11 sites with 3 different CFD codes

- Lidar wind speeds compare extremely well with in-situ masts using conventional anemometry
  - CFD conversion shows ability of lidar to produce mast equivalent measurements in complex terrain.

- Examples here have show that lidar can also operate successfully in extreme conditions:
  - Cold (extremely) climates
  - High latitudes / clean air deployments
  - Lidar can be used for secondary icing detection - even heated instruments are pushed to their limits in certain cases

- Reported data availabilities are high regardless of deployment type, terrain and environmental conditions
  - These trends were shown up to and including 150 m above ground level

Thank you!

Any Questions?

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