PERFORMANCE VERIFICATION

Functional tests & full performance verification:

Velocity testing, system integrity check, focus mechanism and performance verification:

Associated parties:

System supplied by:

ZephIR Lidar

Verification certificate:

System	ZephIR laser anemometer
Supplier	ZephIR Lidar, UK
Unit Number	ZP428
Variant	ZephIR 300
Order number	-
Date of tests and verification	22/07/2017 - 31/07/2017
Test Station	**A** (397557 E 249426 N BNG), Separation = 5m

If fully complete and compliant this certificate documents the traceability of systems to a full verification test against a tall mast with calibrated cups, and the subsequent functional tests at a UK Remote Sensing Test Site (Pershore, UK) operated by ZephIR Lidar. Users may request additional full verification tests at their expense.

Approved signatures:

	Test Engineer	Quality Manager	Date
PRINT:	M Mangat	M Harris	04/08/2017
SIGN:			

Functional tests:

Velocity testing and system integrity tests provide a check of several key components including wedge angle, wedge mounting, laser wavelength, and software configuration:

Test:	*Criteria:*	*Result:*
VELOCITY TEST*	**VELOCITY ERROR < 0.5%**	**PASS**
DIRECTION TEST*	**DIRECTION ERROR < 0.5°**	**PASS**
SENSITIVITY*	**SNR > 60**	**PASS**
FOCUS CALIBRATION**	**RANGE ERROR < 1m**	**PASS**

***Velocity, direction, and SNR checked against calibrated moving belt at speeds up to 5m/s**

****Focus calibrated at 68m focus range**

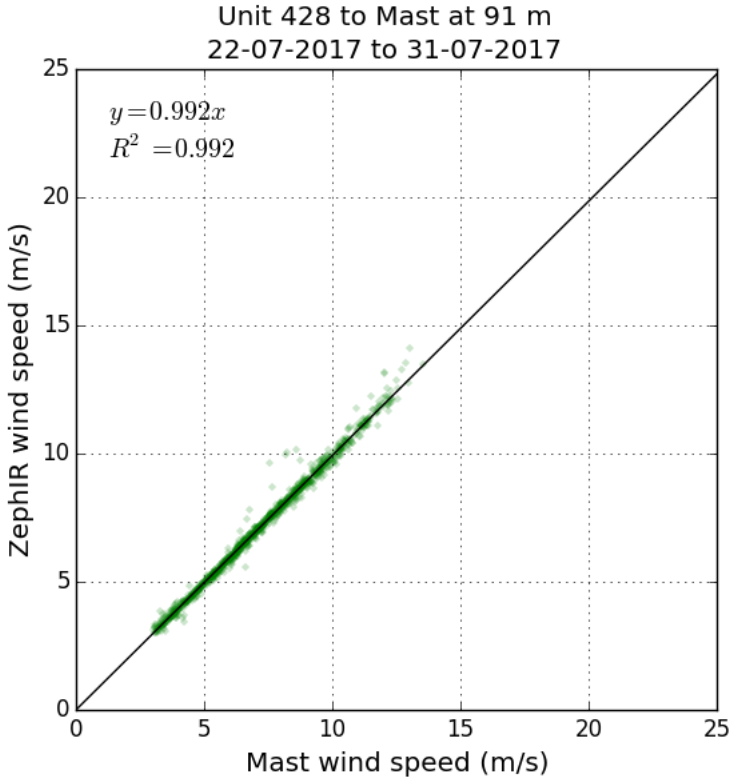
Full performance verification against a tall mast:

Verification of horizontal wind speed performance against the certified tall mast at the UK Remote Sensing Test Site operated by ZephIR Lidar. The comparison is based on the slope of the forced regression line for 10-minute average values obtained over consecutive days. The ZephIR data is processed using standard filters with an additional calm filter of 3m/s. Mast filters are also applied to eliminate invalid cup data. A minimum of 400 valid concurrent data points is required for the comparison.

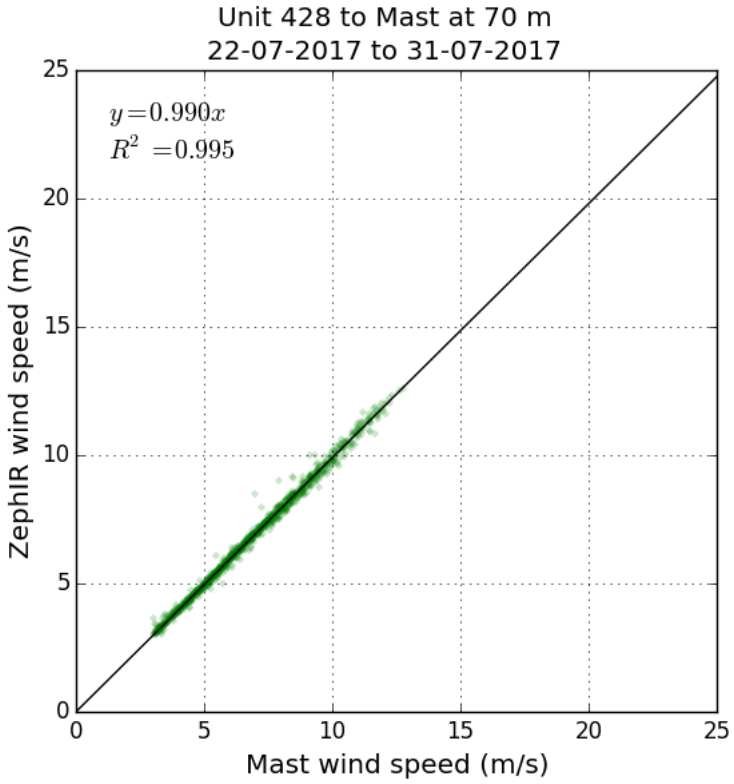
Test:	*Criteria:*	*Value:*	*Result:*
AVERAGE WIND SPEED	**Slope 1.00 +/-2.0%**	**-0.78%**	**PASS**
AT 91 METRES	**R^2 > 0.970**	**0.992**	**PASS**
AVERAGE WIND SPEED	**Slope 1.00 +/-2.0%**	**-1.02%**	**PASS**
AT 70 METRES	**R^2 > 0.970**	**0.995**	**PASS**
AVERAGE WIND SPEED	**Slope 1.00 +/-2.0%**	**-0.95%**	**PASS**
AT 45 METRES	**R^2 > 0.970**	**0.995**	**PASS**
AVERAGE WIND SPEED	**Slope 1.00 +/-2.0%**	**-0.67%**	**PASS**
AT 20 METRES	**R^2 > 0.970**	**0.995**	**PASS**

Additional comments:

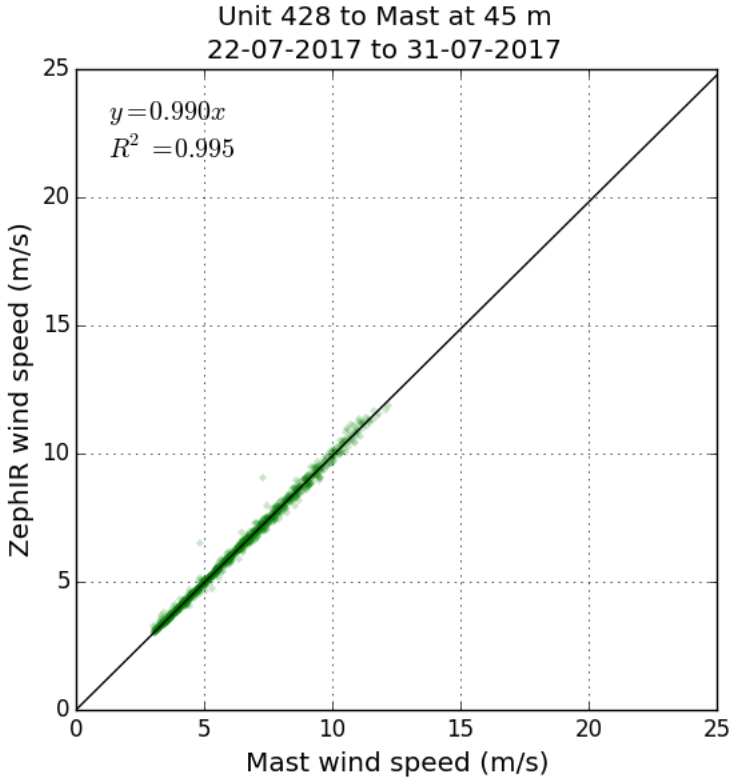
The tall mast at the UK Remote Sensing Test Site operated by ZephIR Lidar has been constructed to conform fully with the recommendations for mast anemometry in IEC 61400-12-1: *Power Performance Measurements of Electricity Producing Wind Turbines* and has been approved for the use by technical and engineering services provider *DNV-GL*. Technical details of the test mast are presented in the annex to this document.



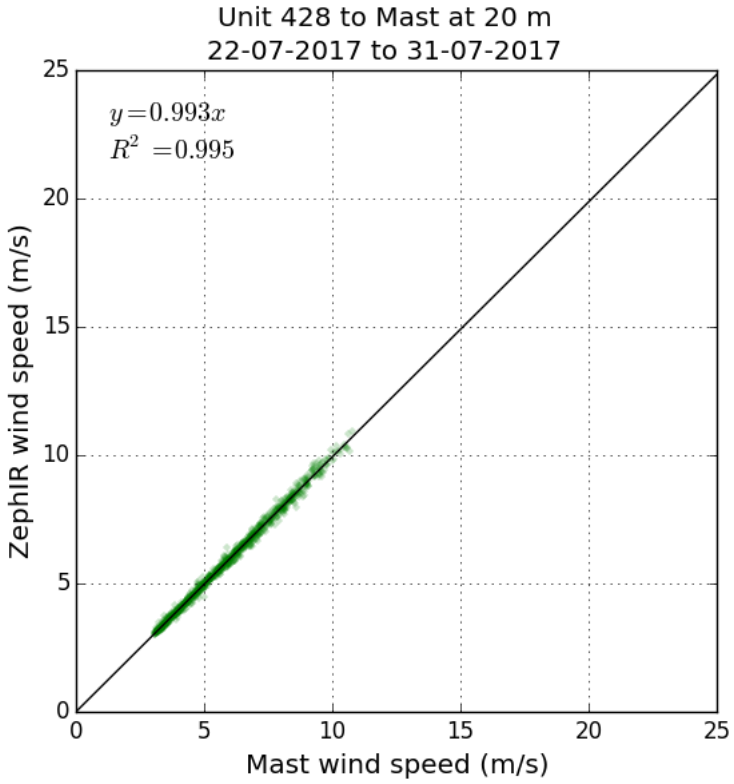
Correlation Plot of Unit 428 v Tall Mast at Height 91m
Date Range: 22/07/2017 - 31/07/2017



Correlation Plot of Unit 428 v Tall Mast at Height 70m
Date Range: 22/07/2017 - 31/07/2017

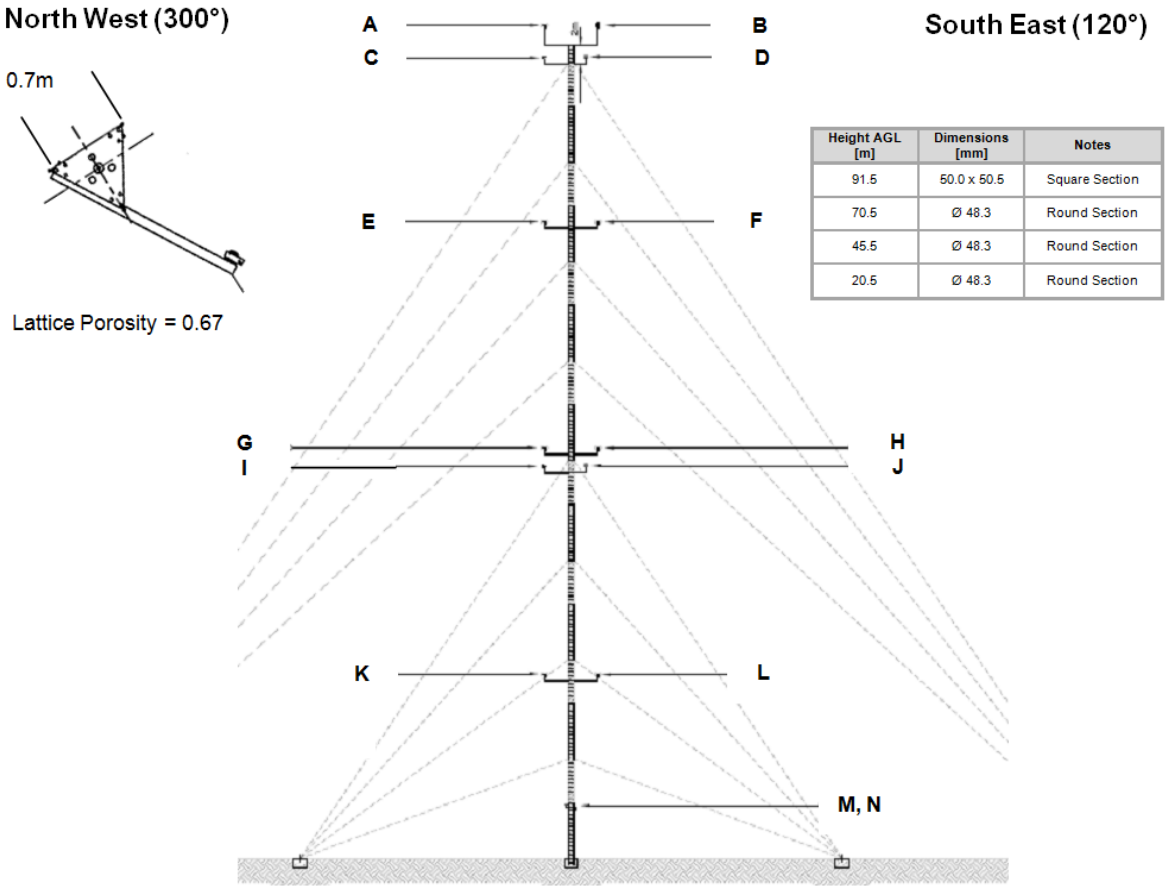


Correlation Plot of Unit 428 v Tall Mast at Height 45m
Date Range: 22/07/2017 - 31/07/2017



Correlation Plot of Unit 428 v Tall Mast at Height 20m
Date Range: 22/07/2017 - 31/07/2017

Annex A: Test Mast Technical Specification



Height AGL [m]	Dimensions [mm]	Notes
91.5	50.0 x 50.5	Square Section
70.5	Ø 48.3	Round Section
45.5	Ø 48.3	Round Section
20.5	Ø 48.3	Round Section

Label	Height (m)	Orientation (°) Mast to Instrument	Type	Manufacturer/Model	Calibration*	Calibration Date	Cup to boom centre height (mm)	Instrument to mast centre length (mm)
A	91.5	300	Cup Anemometer	Thies First Class Advanced	DWG	14-10-2016	1520	1025
B	91.5	120	3D Sonic Anemometer	Thies First Class Advanced	DWG	22-11-2016	1500	1025
C	88	300	Direction Vane	Vector W200P	-	-	920	3700
D	88	120	Temperature/Humidity	Campbell Scientific CS215	-	-	-	-
E	70.5	300	Cup Anemometer	Thies First Class Advanced	DWG	22-11-2016	960	3700
F	70.5	120	Cup Anemometer	Thies First Class Advanced	SOH / DWG	06-10-2015 / 17-08-2015	915	3700
G	45.5	300	Cup Anemometer	Thies First Class Advanced	SOH / DWG	06-10-2015 / 17-08-2015	955	3700
H	45.5	120	Cup Anemometer	Thies First Class Advanced	DWG	22-11-2016	1160	3700
I	43.5	300	Direction Vane	Vector W200P	-	-	920	3700
J	43.5	120	Temperature/Humidity	Campbell Scientific CS215	-	-	-	-
K	20.5	300	Cup Anemometer	Thies First Class Advanced	DWG	22-11-2016	960	3700
L	20.5	120	Cup Anemometer	Thies First Class Advanced	SOH / DWG	06-10-2015 / 17-08-2015	930	3700
M	6	-	Pressure	Campbell Scientific CS100	-	-	-	-
N	6	-	Data Logger	Campbell Scientific CR1000	-	-	-	-

*Cup anemometer calibration certificates are available on request.
Mast installed 13/08/2010.

Annex B: Location and Environment

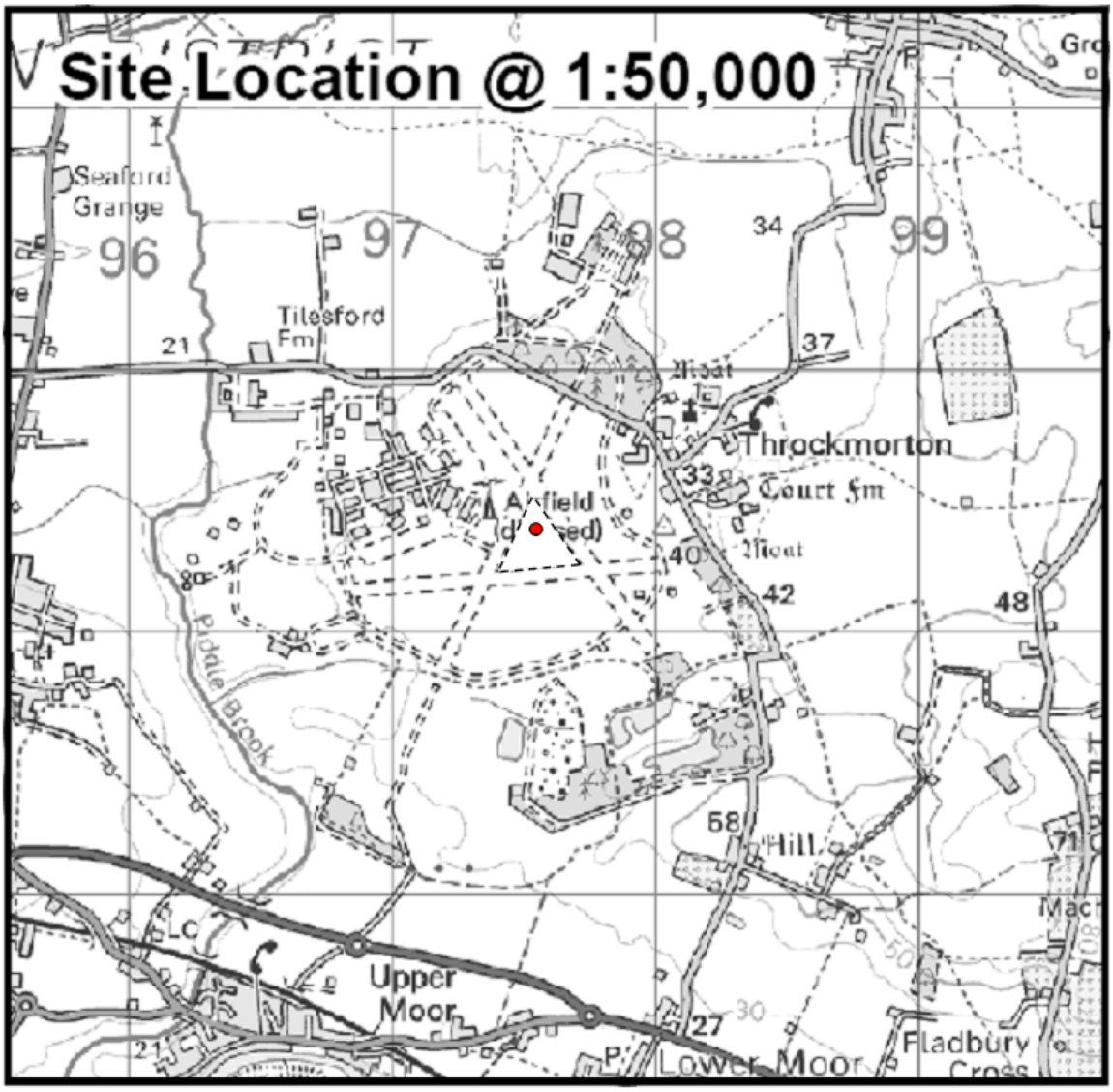


Figure B1: Test Mast Location and Environment

The terrain in the vicinity of the mast is flat and covered with sparse low growing vegetation. A free standing lattice tower of approximately 40m in height exists on a bearing of 270° at 230m from the mast. A number of hangars and outbuildings exists in sectors between 250° and 317° at distances between 300m and 700m from the mast. These buildings are estimated not to exceed 14m in height. Approximately 500m to the North-East lies the small village of Throckmorton which consists of a few scattered farms and houses. 700m to the South-West of the mast between 190° and 240° lies an area of spoil heaps and filtration pools associated with a mining operation. On a wider scale the site is surrounded by flat arable land that is devoid of any dense closed canopy forest. The larger conurbations of Pershore and Evesham lie at distances of 5km and 9km to the South-West and South-East respectively.

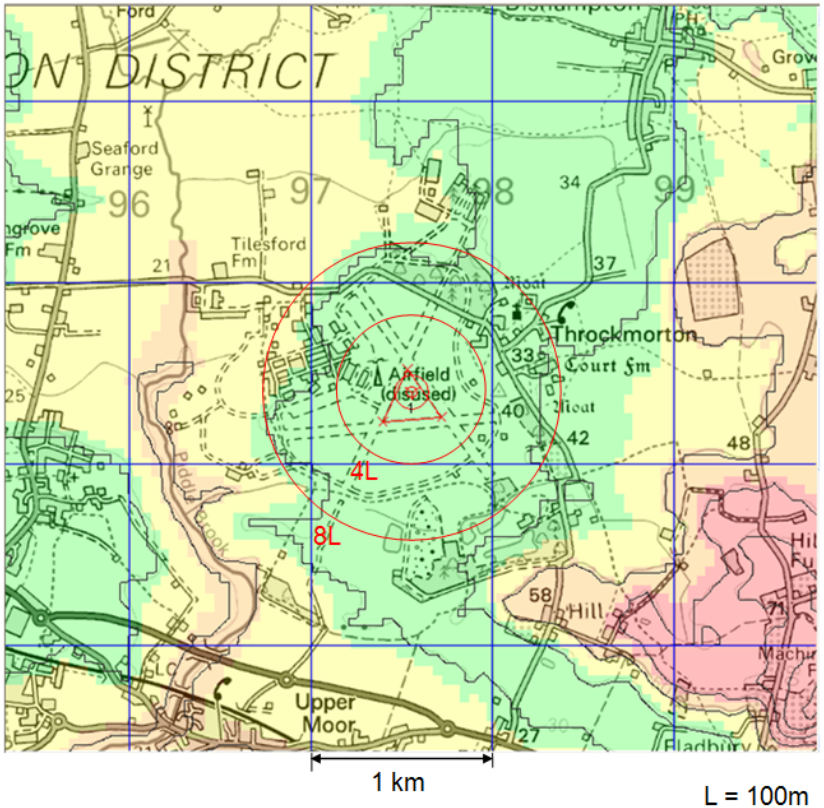


Figure B2: Local Deviation from Plane

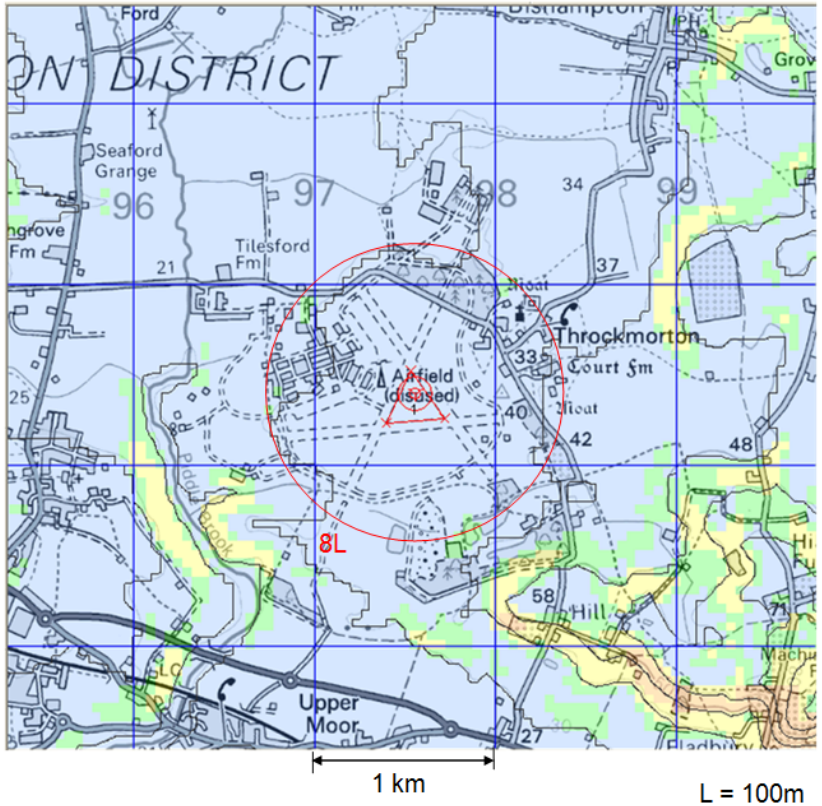


Figure B3: Local Slope

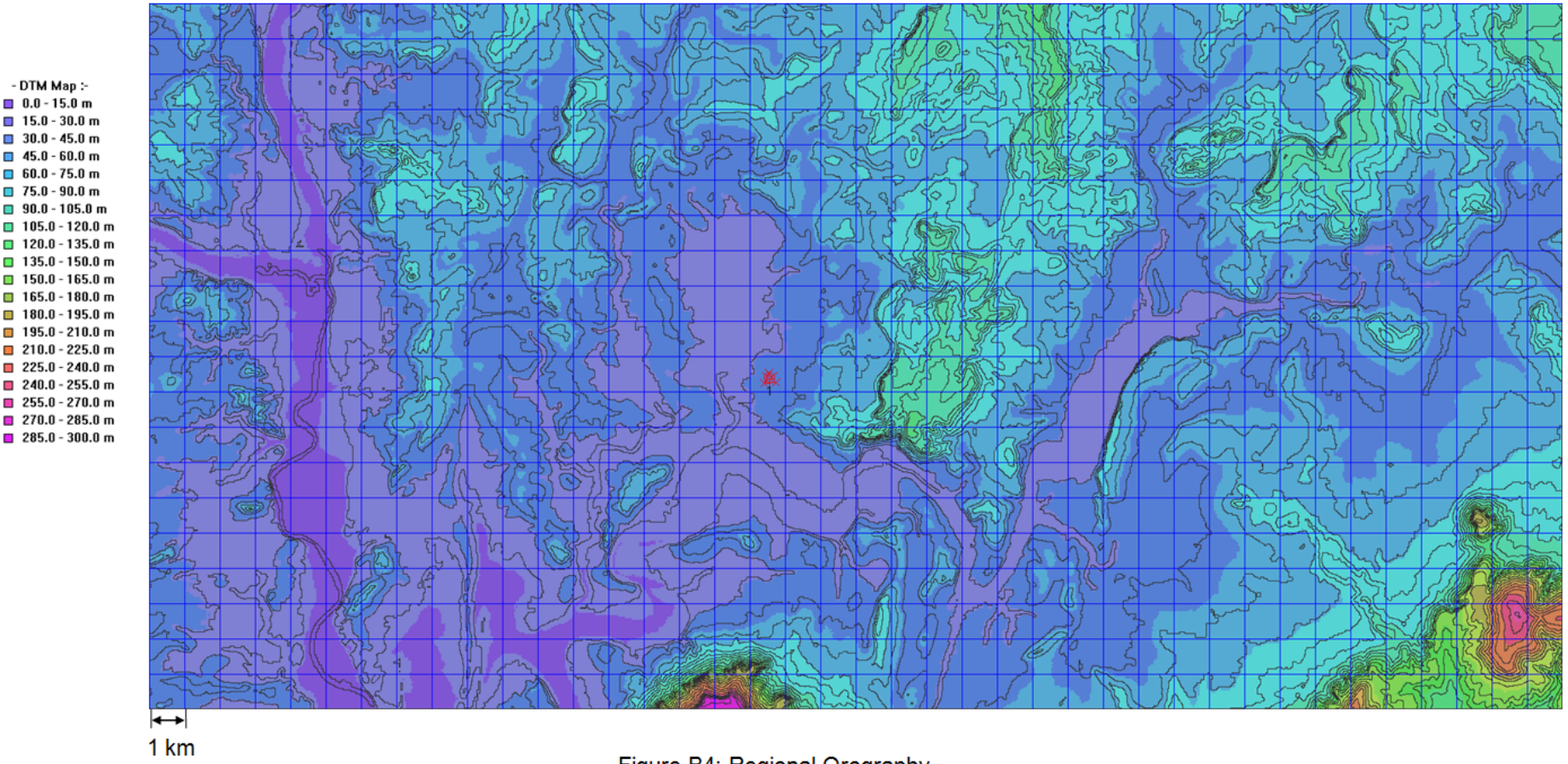


Figure B4: Regional Orography

The terrain surrounding the tall mast at Pershore has been assessed against IEC 61400-12-1 (*Power Performance Measurements of Electricity Producing Wind Turbines*)[1] in order to determine whether any sectors need to be screened from the mast data due to the orography of the site or local obstacles. Figure B2 shows the difference in height between points within the local area of the mast and that of the mast base. The colour bands in this plot have been set to match the criteria for maximum terrain variations from the plane assuming a level plane through the mast base. Green represents variations within 0.04 times the top instrument height (H). Yellow represents variations within 0.08 times H. The site meets the IEC requirements for maximum terrain variation in all sectors. Figure B3 shows the slope of the terrain with the local area of the mast. The colour bands in this plot have been set to match the criteria for maximum slope in [1]. The coloured bands from blue to red represent slopes of > 3%, 3% - 5%, 5% - 10%, 10% - 30%, and 30% + respectively. The site meets the IEC requirements for maximum slope in all sectors.

An obstacle assessment against [1] has been carried out for the lattice mast located to the South-West of the test mast. This analysis indicates that screening of data from direction ±14° about a bearing of 270° should be considered. Detailed analysis of lidar versus mast measurements from this sector has shown negligible impact on slopes, but potentially lower R^2 values at 20m and 45m.

Annex C: Instrument Selection and Data Filtering

Mast

Validation wind speed data is provided by class 1A instruments as defined in [1]. Comparison of paired cups is used to provide a robust method for identifying any problems with the mast instrumentation. Direction data is taken from the Vector W200P wind vanes at the 88.0m and 43.5m levels.

Data has been screened where it may be affected by instrument or tower shadow. Direction measurements at 88.0m were used to screen wind speed data at 91.5m and 70.5m. Direction measurements at 43.5m were used to screen wind speed data at 45.5m and 20.5m.

ZephIR

Wind measurements obtained with any method of anemometry are prone to increased levels of uncertainty in certain conditions. ZephIR's filtering software identifies rare conditions of reduced certainty and rejects the corresponding wind measurements from the output data file. The standard set of filters supplied to ZephIR customers was used to screen the wind speed data presented in this report.

Note that some outlier data can appear on the correlation plots. This is the result of atmospheric conditions at the edges of ZephIR's quality filters, and does not imply any malfunction of the lidar. Filter boundaries are chosen as a compromise between accuracy and availability; to eliminate the risk of any outlier data will bring about a reduction in valid measurements. ZephIR has acquired a large body of statistics showing that the filter boundaries have been correctly chosen to provide high availability and minimal error in AEP over a typical resource assessment period.

Annex D: References

[1]: IEC 61400-12-1 International Standard: *Part 12-1: Power performance measurements of electricity producing wind turbines*, Edition 1.0 2005-12, International Electrotechnical Commission.