REMOTE SENSING DEVICES IN COLD CLIMATES

IAIN CAMPBELL, MInstP
WIND RESOURCE AND REMOTE SENSING ANALYST
RES GROUP

WINTERWIND, 13 FEBRUARY 2013

ACKNOWLEDGEMENTS

Malcolm MacDonald

Gail Hutton

Marine Lannic

Euan George

Alan Derrick

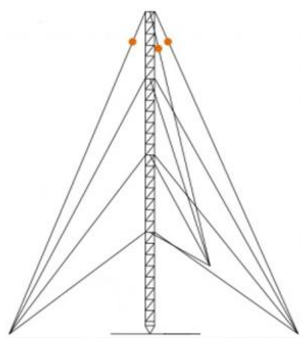
This work was funded by the Swedish Energy Agency (Energimyndigheten)

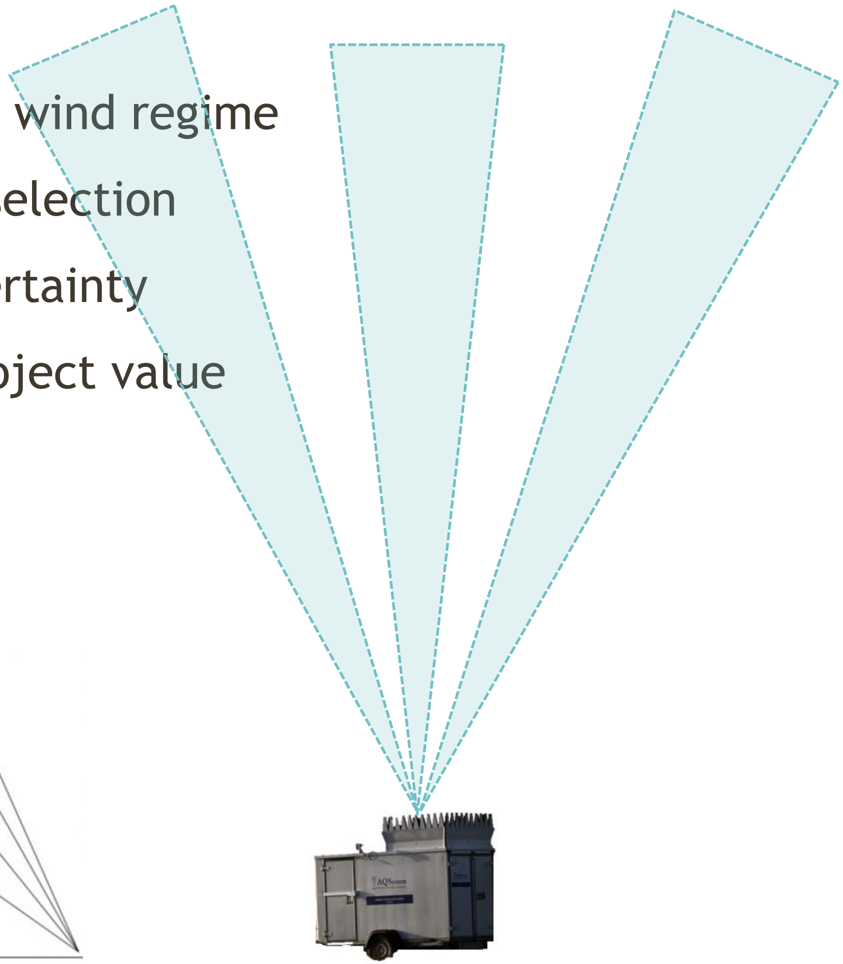
MET MASTS AND REMOTE SENSING DEVICES: WHY

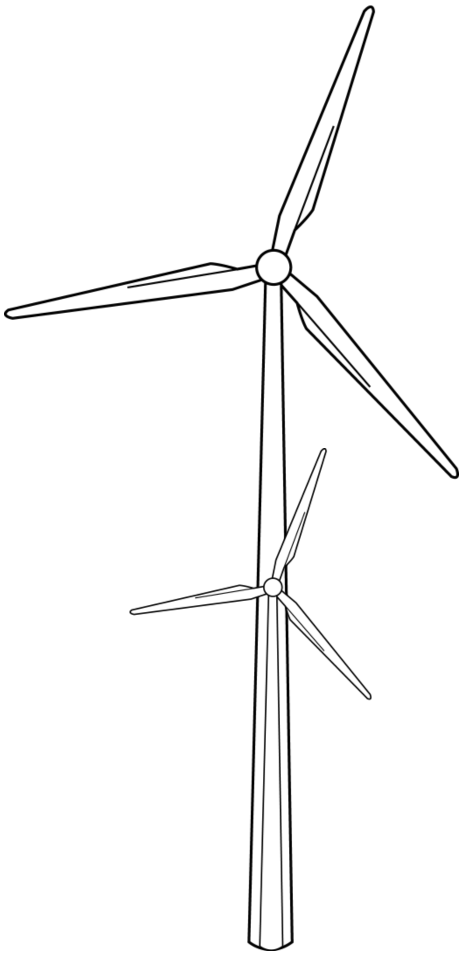
Met masts can:

- Characterise wind regime
- Aid turbine selection
- Reduce uncertainty
- Maximise project value

But…

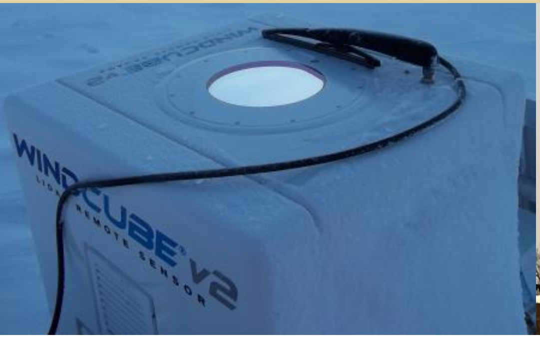






With increasing hub heights RSD have much to offer:

- Validate mast measurements at hub height and across the rotor diameter
- Provide hub height measured turbulence and extreme wind speed data
- Offer insight into the effects of low turbulence intensity and high shear on turbine energy yield



REMOTE SENSING DEVICES IN COLD CLIMATES

This presentation will consider:

- The validation of mast measured shear
- The reliability of turbulence and extreme wind speed data from RSD
- The impact of low turbulence intensity and stable atmospheric conditions on energy content

Remote Sensing Instrumentation Setup

- 1 power performance mast
  - Multiple heated & unheated instruments
- 1 WINDCUBE V1 LiDAR
  - 10 measurement heights
  - 50 m separation distance

Three shear methodologies are used:

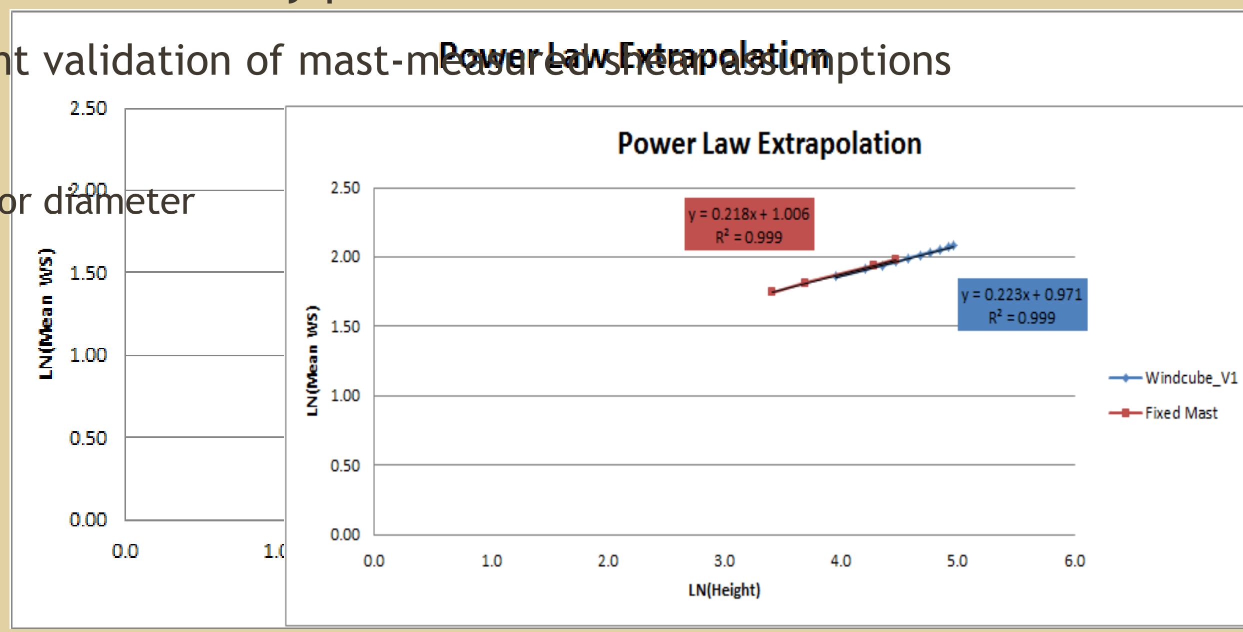
- One-point theoretical log law
  - Roughness length & displacement height
  - 1 wind speed measurement
  - Assume logarithmic profile
- Two-point power law
  - 2 wind speed measurements
  - Power law used for extrapolation
- Multi-point fitted log law
  - 3 or more wind speed measurements
  - Fitted logarithmic profile

SHEAR AT HAVSNÄS

LiDAR–Mast Multi-Point Shear Comparison

- There is excellent agreement between fixed mast and WINDCUBE
  - Benefits from small separation distance for LiDAR devices
  - Different measurement techniques yet remarkable agreement

❖ The WINDCUBE-measured velocity profile
  - provides excellent validation of mast-measured shear assumptions
    - To hub height
    - Across full rotor diameter

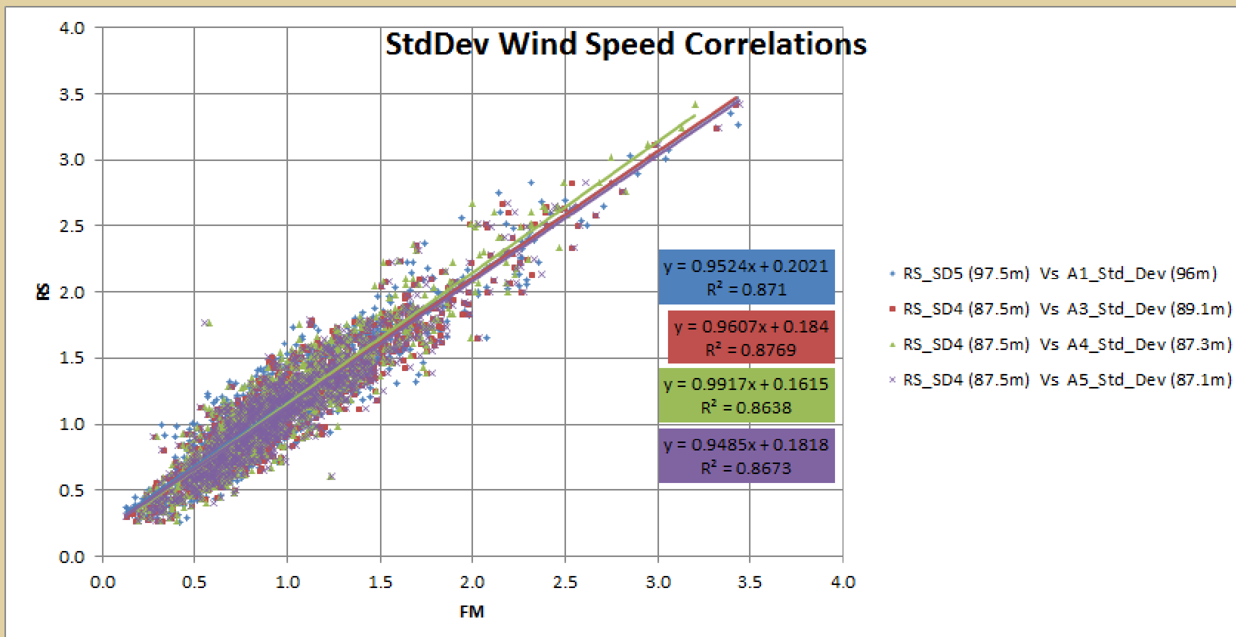


Extrapolating measurements to hub height

- All three methods perform acceptably well, where
  - Forestry is well parameterised
  - Measurements are IEC-compliant
  - Class 1 anemometry is used
- On more complex sites
  - Theoretical log law is not recommended
- The multi-point method performs best overall
  - Leading to the lowest extrapolated wind speed error
  - Least sensitive to canopy height errors

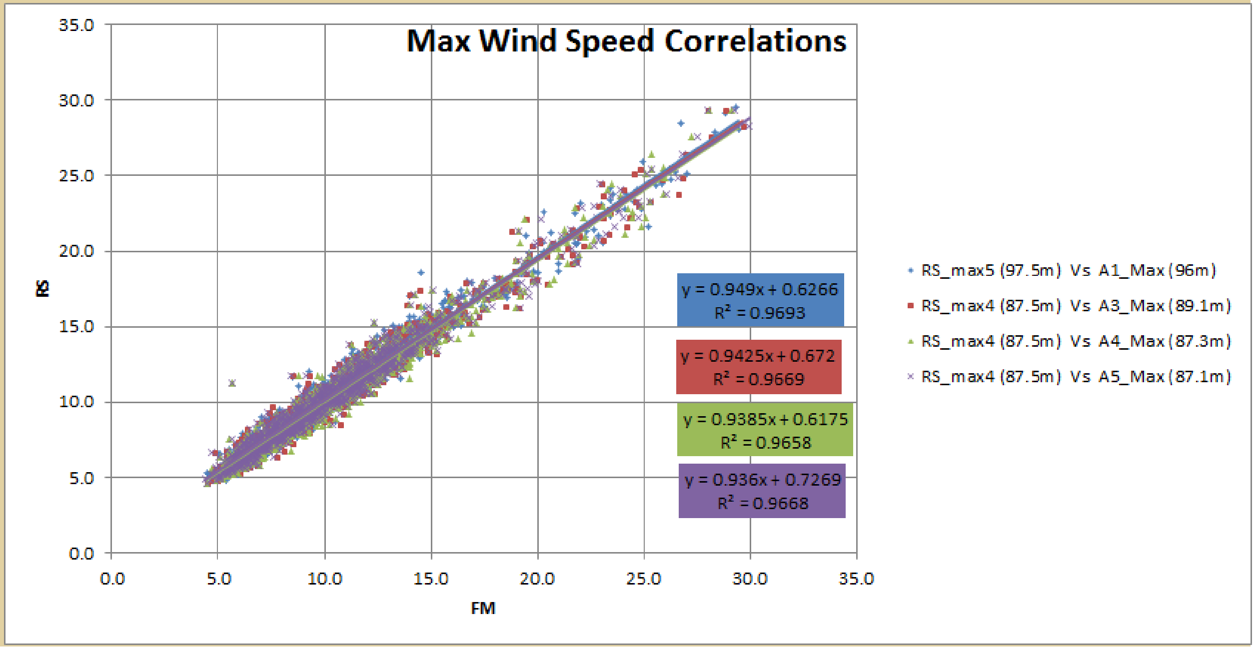
❖ For extrapolating wind speed to hub height
  - The multi-point method is recommended

- At Havsnäs, there is a well-defined relationship between the WINDCUBE and fixed mast standard deviation of mean wind speed data
- Slope variation
  - For very similar anemometer heights
  - Flow distortion experienced by anemometers is responsible for variation



RELIABILITY OF EXTREME WIND SPEED DATA FROM WINDCUBE

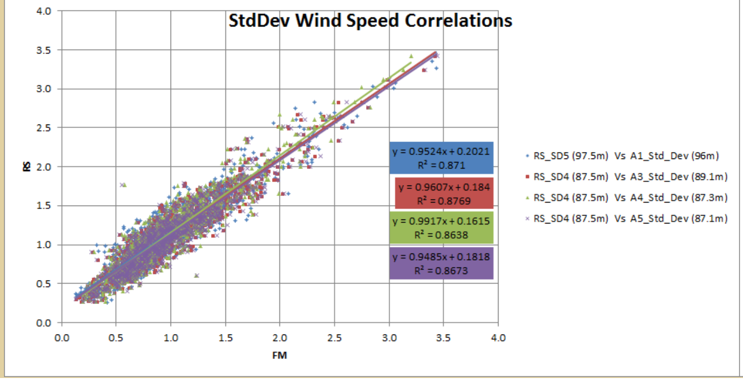
- At Havsnäs, there is a well-defined relationship between the WINDCUBE and fixed mast maximum wind speed data
- ≈ 6% underestimation of maximum wind speed
  - Result of volume averaging
  - Gust underestimation

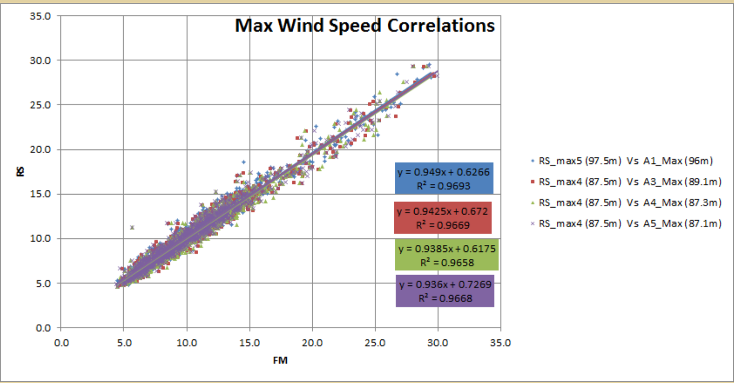


RELIABILITY OF TURBULENCE AND EXTREME WIND SPEED DATA: FINDINGS

- At Havsnäs, there is a well-defined relationship for
  - Standard deviation of mean wind speed
  - Maximum wind speed
- Agrees with RES' prior experience
  - Variety of sites
  - Differing levels of terrain complexity

❖ WINDCUBE provides reliable turbulence and extreme wind speed data
  - Data should be examined on a deployment-by-deployment basis



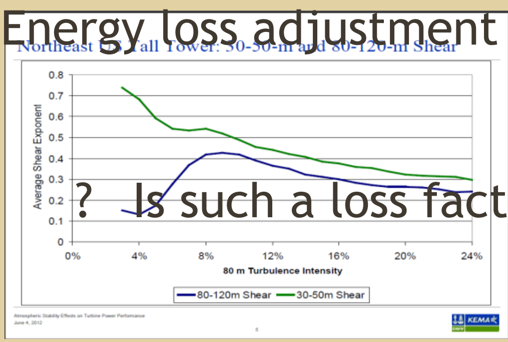


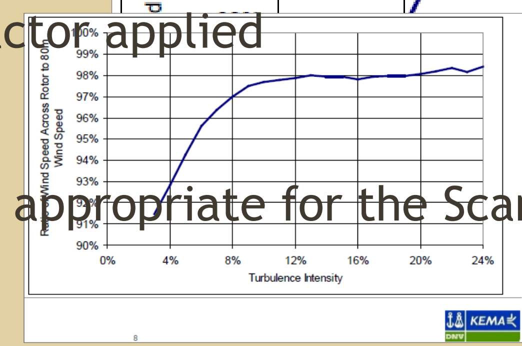
DNV KEMA findings from northeast USA

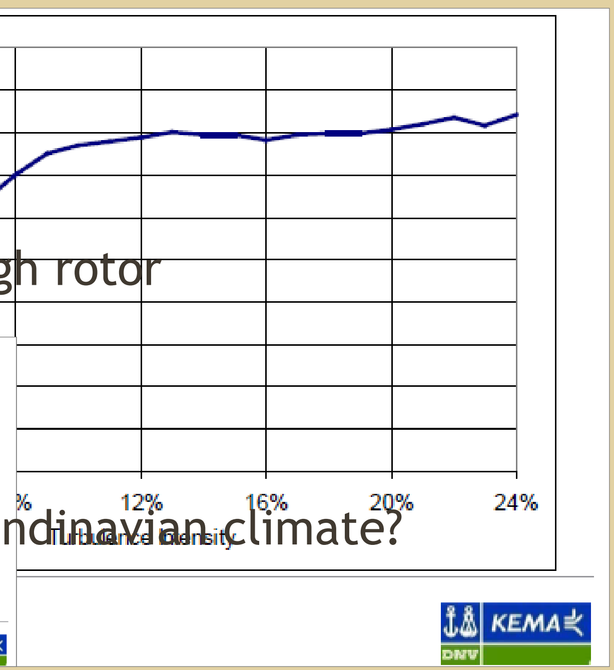
- At turbulence intensities below ≈ 9%
  - Shear not consistent across rotor
  - Hub height wind speed significantly overestimates energy through rotor
- For sites with stable atmospheric conditions
  - High shear
  - Low TI

❖ Mast likely to overestimate energy content through rotor

❖ Energy loss adjustment factor applied

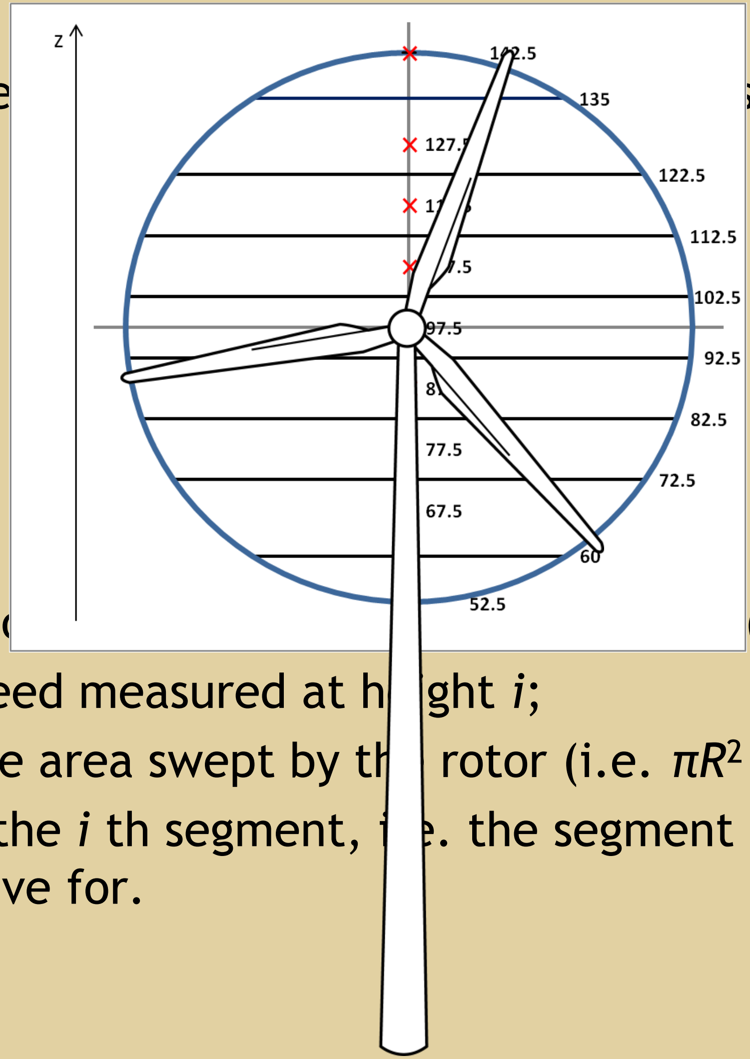






? Is such a loss factor appropriate for the Scandinavian climate?

The rotor-averaged or e



where

- n is the number (… ($n \geq 3$);
- v_i is the wind speed measured at h ight i;
- A is the complete area swept by th rotor (i.e. πR^2 with Radius R);
- A_i is the area of the i th segment, i e. the segment the wind speed v_i is representative for.

A shear correction factor is defined as a ratio of the equivalent wind speed relative to the wind speed measured at hub height according to

$$f_{r,X} = v_{eq,X} / v_{h,X}$$

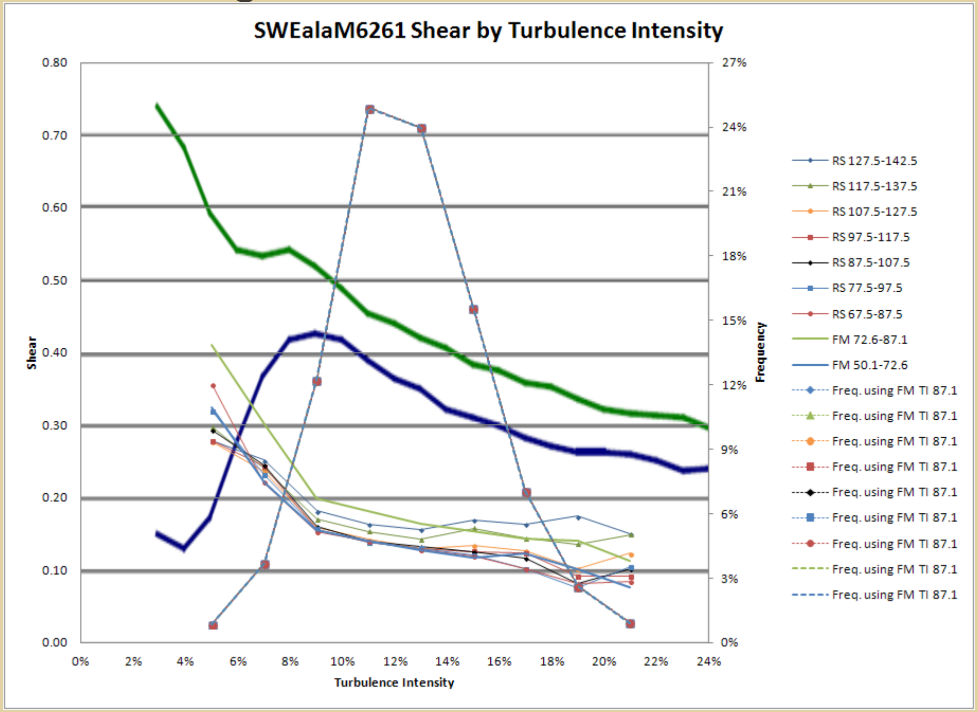
where

- $v_{eq,X}$ is the equivalent wind speed (as defined in previous slide);
- $v_{h,X}$ is the wind speed measured at hub height;
- and the index X specifies the instrument or instrument setup both, $v_{eq,X}$ and $v_{h,X}$, are measured with.

It is also possible to calculate a shear correction factor for wind speed extrapolated to hub height, something that is done in this analysis.

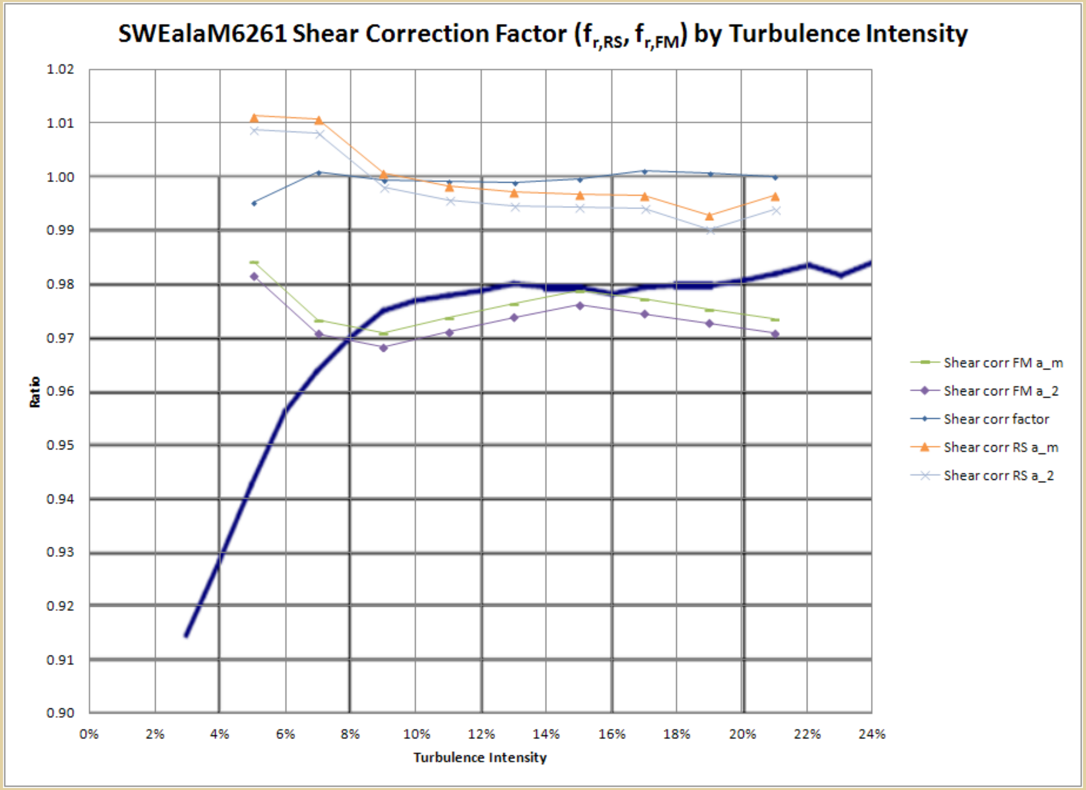
LOW TURBULENCE STABLE ATMOSPHERIC CONDITIONS: FINDINGS

- Shear is consistent across full rotor
- At low TI
  - Turning point exists
  - But shear remains consistent across full range
  - No divergence at ≈ 9%



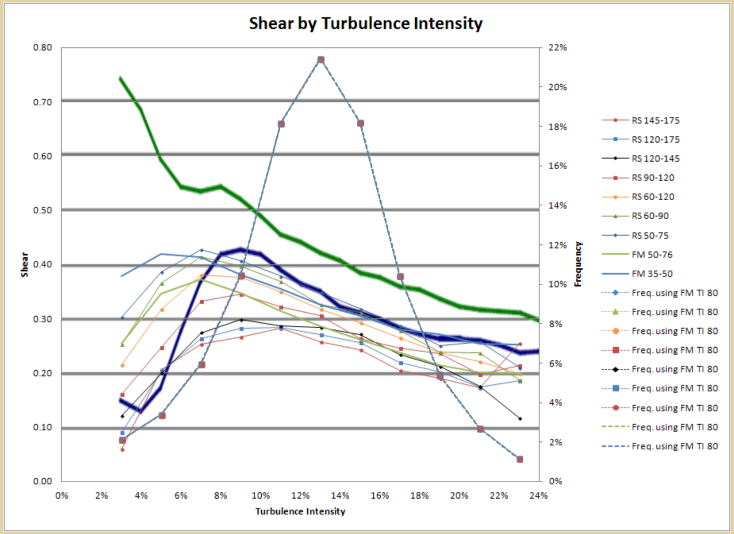
LOW TURBULENCE STABLE ATMOSPHERIC CONDITIONS: FINDINGS

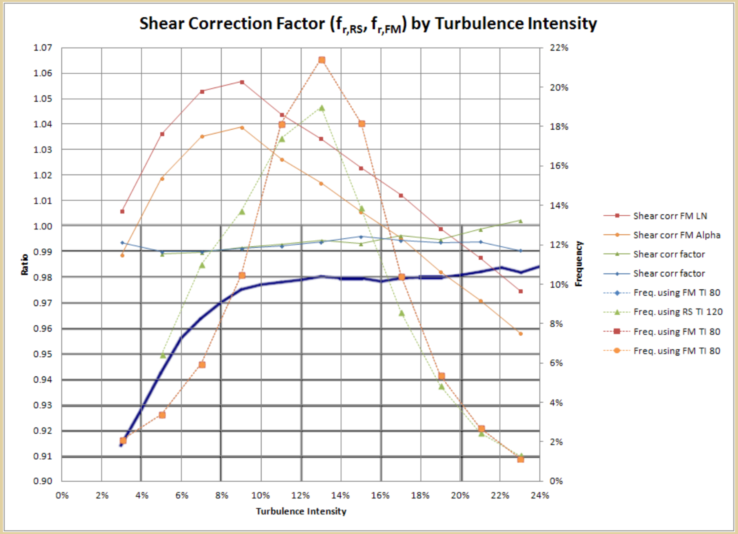
- Shear correction factors do not vary strongly with turbulence intensity
- At low TI
  - Turning point exists at ≈ 9%
  - Small variation
  - No dramatic plunge



LOW TURBULENCE STABLE ATMOSPHERIC CONDITIONS: FINDINGS

- ❖ The presence of low TI
  - – Does not lead to an overestimation of hub height wind speed
  - – Shear profile is not significantly over estimated by only using below hub height measurements
- ❖ Fixed mast measurements are likely to underestimate energy content
- • Findings are consistent with another Swedish site



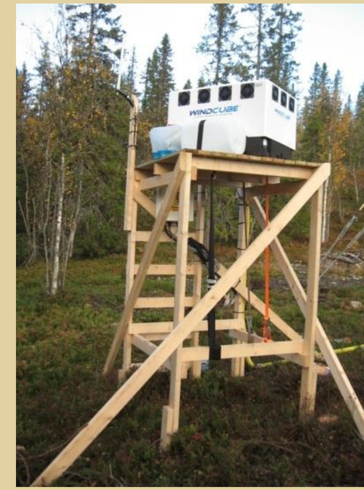


LOW TURBULENCE STABLE ATMOSPHERIC CONDITIONS: CONCLUSIONS

- Justification for a universal energy loss adjustment factor is not evident
- What has been observed in the USA cannot simply be applied in other regions where stable atmospheric conditions prevail
  - Not all stable atmospheric conditions result in an overestimation of energy through the rotor diameter
- Each region should be treated separately
- Each individual site should be considered on its own merits
- RSD and long-term reference mast will indicate appropriateness of an energy loss adjustment factor

Following best practice is very important! (For all RSD types)

- Device Siting
- Snow Platform
- IEC Measurement Height Recommendations
- Correctly Configured Measurement Heights
- Low Aerosol Configuration
- Cold Weather Insulation
- Device Monitoring
- Deploy Webcam



SUMMARY: KEY POINTS

- Following best practice is very important
  - Maximise project value
- Multi-point shear most appropriate for extrapolation to hub height
  - Minimises error
- WINDCUBE gives excellent validation of mast-measured shear assumptions
  - Across full rotor
- WINDCUBE provides reliable turbulence and extreme wind speed data
  - Should be judged on a site-by-site basis
- RSD should be deployed to investigate impact of stability on rotor energy content
  - No negative impacts at Havsnäs or ‘Other Swedish Site’

FINAL CONCLUSION

- The deployment of an appropriate RSD in conjunction with a long-term reference mast at each wind farm site
  - Is highly recommended
  - Will enable informed judgements to be taken
  - Minimise uncertainty
  - Maximise project value
- Full details of analysis in ‘Havsnäs Pilot Project Report’
  - With Swedish Energy Agency for publication

res

power for good

REMOTE SENSING DEVICES IN COLD CLIMATES

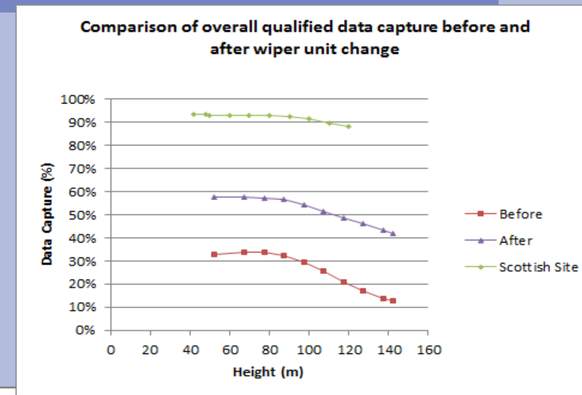
ADDITIONAL CONTENT

WINDCUBE & FIXED MAST MEASUREMENT HEIGHTS

Mast	Sweden, RT90, National Map on 2.5 gon W		Mast Altitude (m ASL)	Anemometer Heights (m)	Vane Heights (m)	Data Currently Available
	X (m)	Y (m)				Dates
SWEalaM6261	1495312	7111825	521	30.1, 30.1, 50.1, 50.3, 70.8, 72.6, 72.8, 87.1, 87.3, 89.1, 96.0, 96.0	48.1, 48.3, 70.6, 85.1, 85.3	16/09/2011-25/07/2012

Mast	Sweden, RT90, National Map on 2.5 gon W		Mast Altitude (m ASL)	Measurement Heights (m)	Data Currently Available
	X (m)	Y (m)			Dates
SWEalaM814	1495302	7111875	520	52.5, 67.5, 77.5, 87.5, 97.5, 107.5, 117.5, 127.5, 137.5, 142.5	16/09/2011- 24/07/2012

OPERATIONAL CONSIDERATIONS: DATA CAPTURE

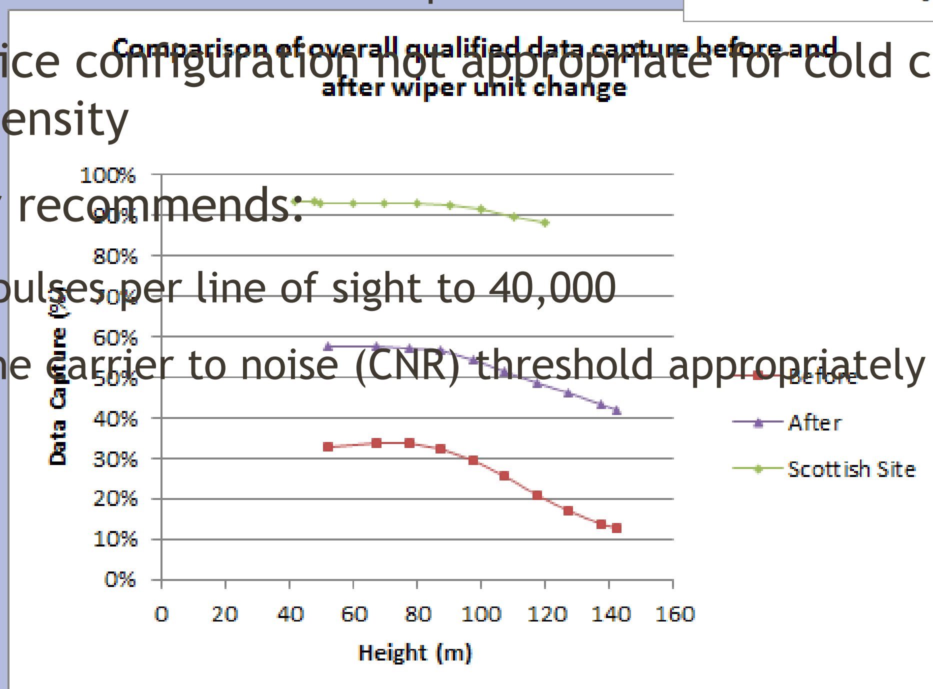


Cold Climate: Clean air & low aerosol density

- Initial low data capture due to wiper failure
- Following wiper replacement:
  - Data capture still lower than expected

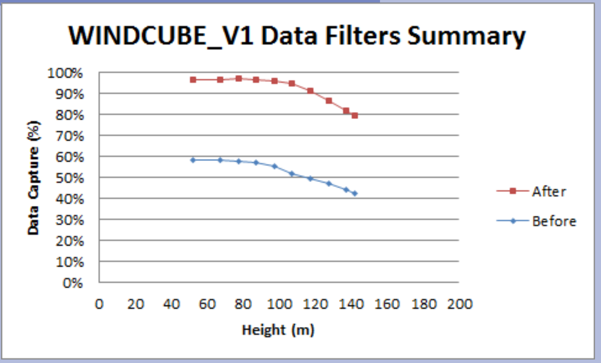
❖ Standard device configuration not appropriate for cold climate sites with low aerosol density

- Manufacturer recommends:
  - Increase pulses per line of sight to 40,000
  - Reduce the carrier to noise (CNR) threshold appropriately (2dB).



OPERATIONAL CONSIDERATIONS: DEVICE RECONFIGURATION

- Reconfiguration results in increased data capture
  - Absolute increase around 37%
- Other aspects of device performance unaffected

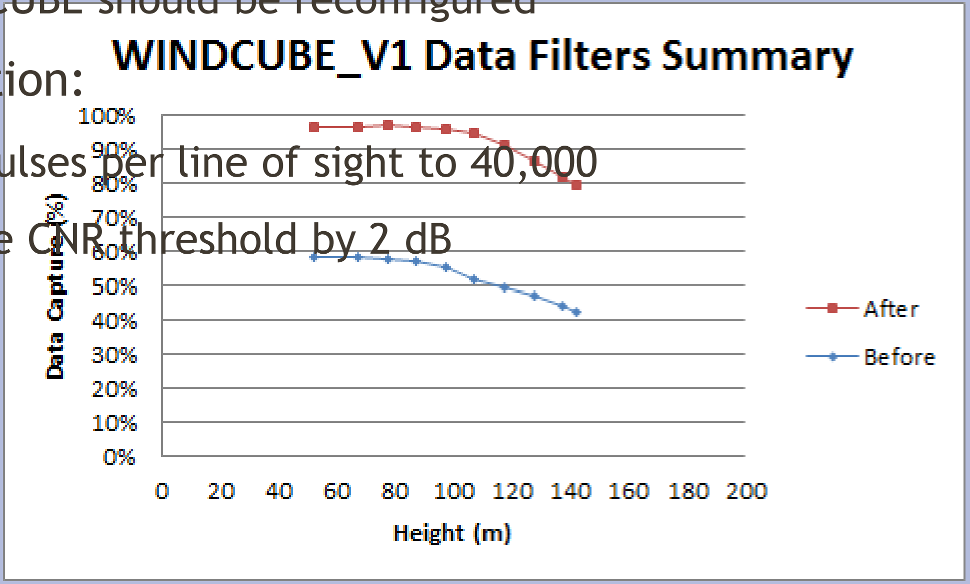


❖ At sites with low aerosol densities

- The WINDCUBE should be reconfigured

❖ Recommendation:

- Increase pulses per line of sight to 40,000
- Reduce the CNR threshold by 2 dB



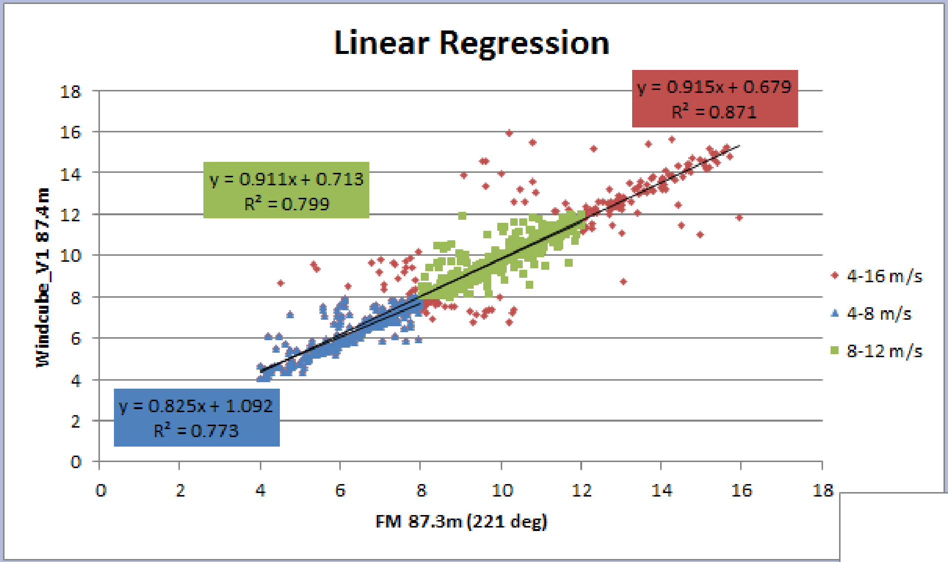
WINDCUBE V1 FILTERING REGIME

WINDCUBE V1 Filters	
Vertical wind speed censor ($m.s^{-1}$)	1.5
Availability (%)	90

MAST SEPARATION DISTANCES

	M626	M628	M630
M628	7653		
M630	7131	5025	
M814 (LiDAR)	51	7699	7181

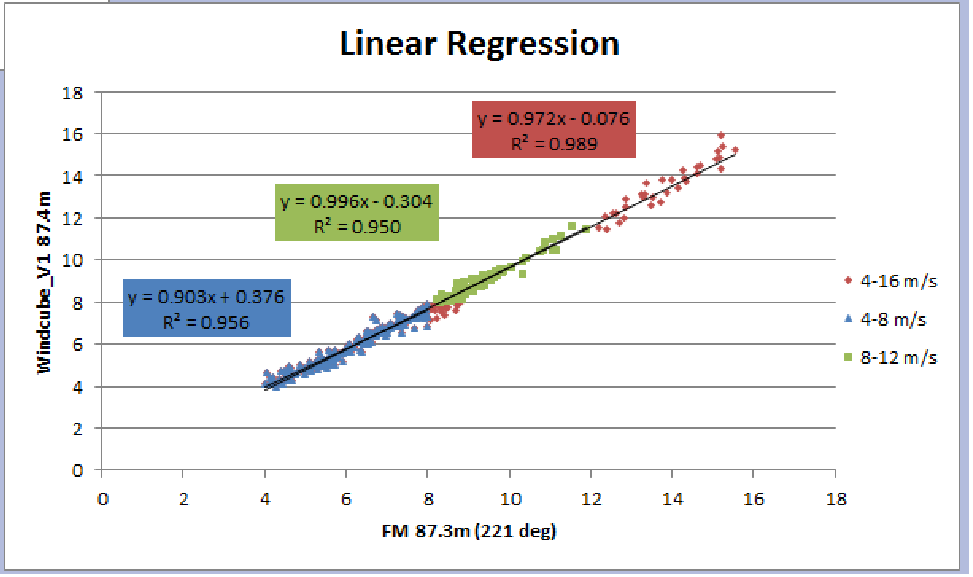
EFFECT OF WIPER REPLACEMENT: CORRELATIONS



Data from

16/09/2011 until 17/11/2011

with the original wiper unit

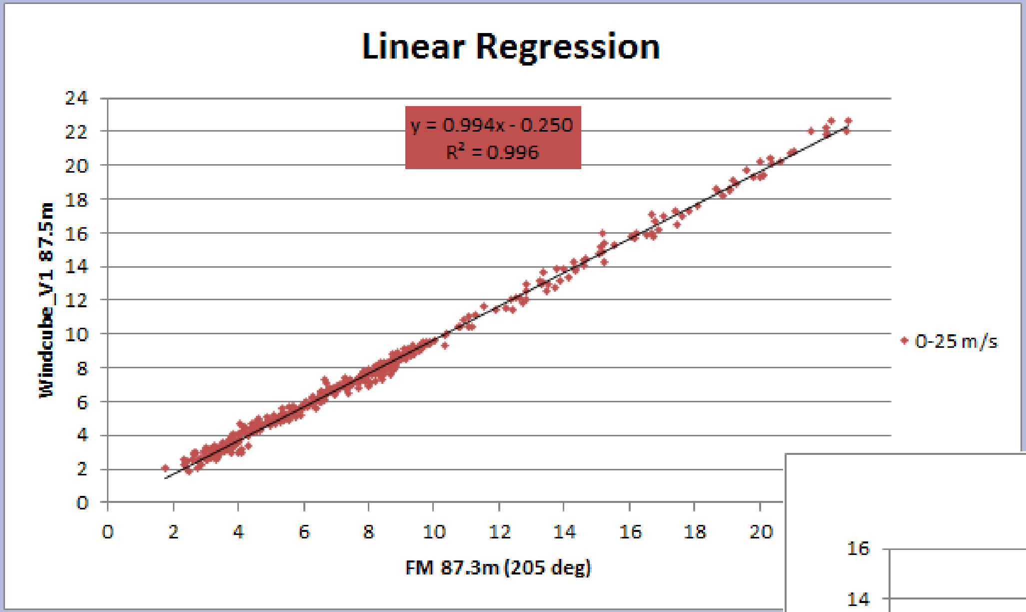


Data from

21/11/2011 until 06/01/2012

with the replacement unit

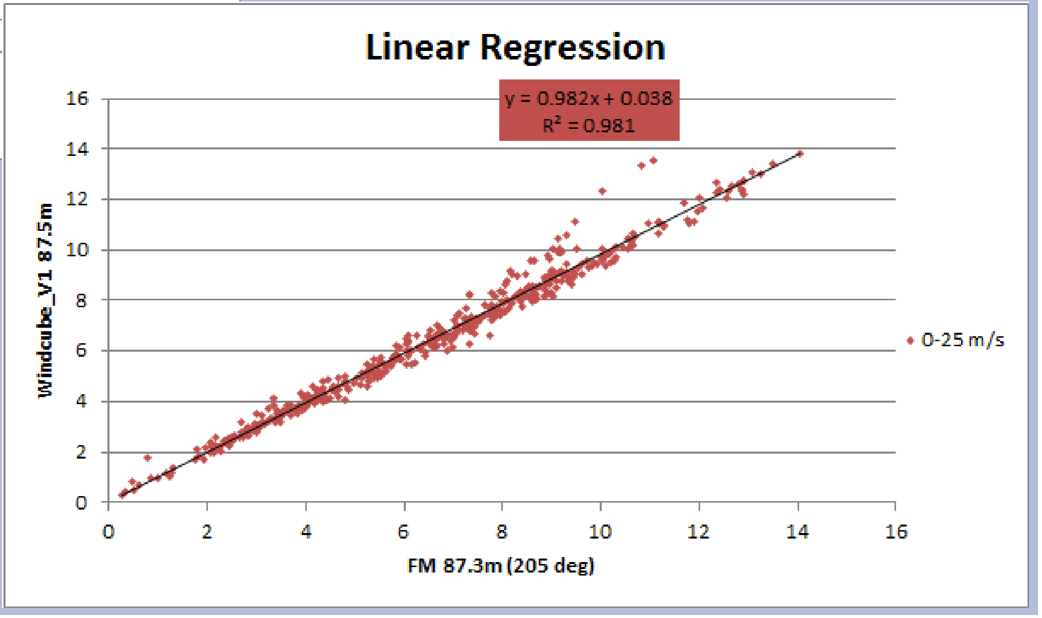
EFFECT OF RECONFIGURATION: MEAN WIND SPEED CORRELATIONS



Data from

21/11/2011 until 06/01/2012

with the original configuration

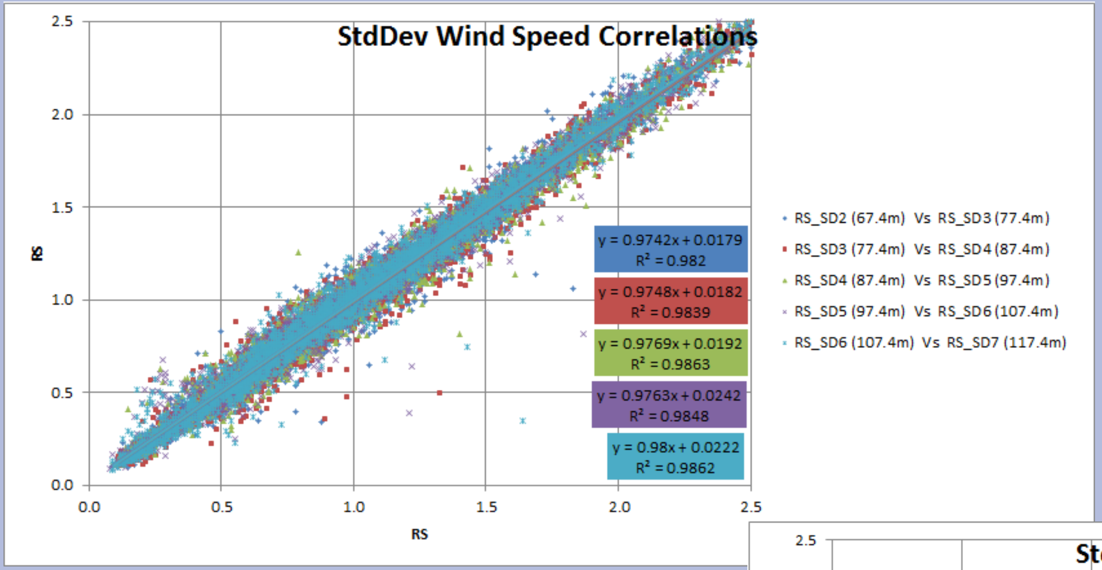


Data from

01/02/2012 until 16/02/2012

With new configuration

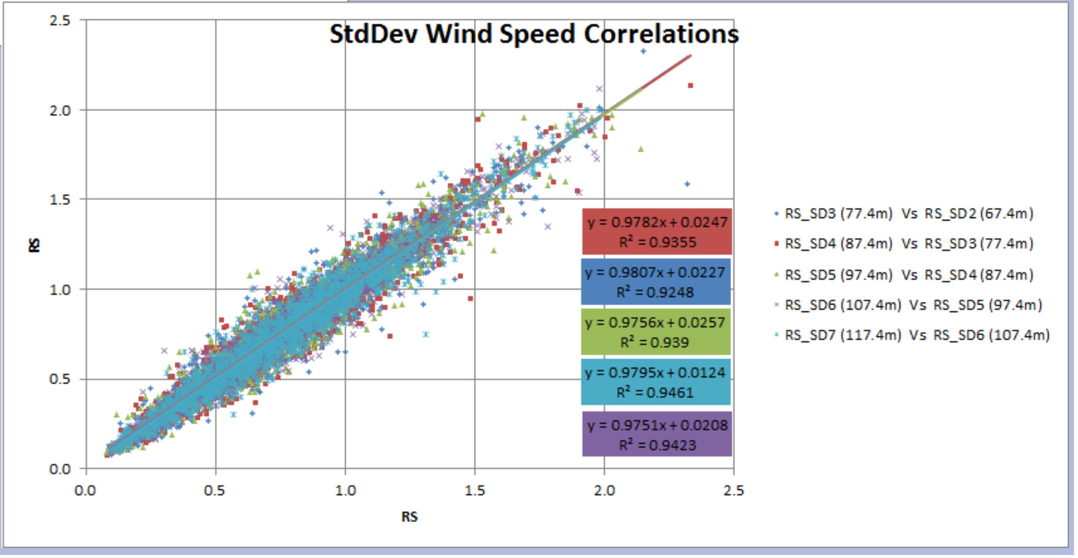
EFFECT OF RECONFIGURATION: STANDARD DEVIATION CORRELATIONS



Data from

21/11/2011 until 06/01/2012

with the original configuration



Data from

01/02/2012 until 16/02/2012

With new configuration

ACCEPTANCE TEST CRITERIA

Parameter	Criteria	Ranges (height & speed)
Absolute error	<0.5m/s for WS range 2-16m/s Within 5% above 16 m/s Not more than 10% of data to exceed those values	All valid data
Data Availability	Assessed case by case – Environmental conditions dependent	All valid data
Linear Regression - Slope	Between 0.98 and 1.01 <0.015 variation in slope etween WG-ranges (b) and (c)	Heights all 60 to 116m WS-ranges: (a) 4-16m/s, (b) 4-8m/s & (c) 8-12 m/s
Linear Regression – R^2	>0.98	Heights: all 60 to 116m WS-ranges: 4-16m/s, 4-8m/s & 8-12 m/s

Acceptance criteria

sgurrENERGY sustainable energy solutions

The following criteria for acceptance tests have been adopted and easily satisfied in the past by lidar operators under contract

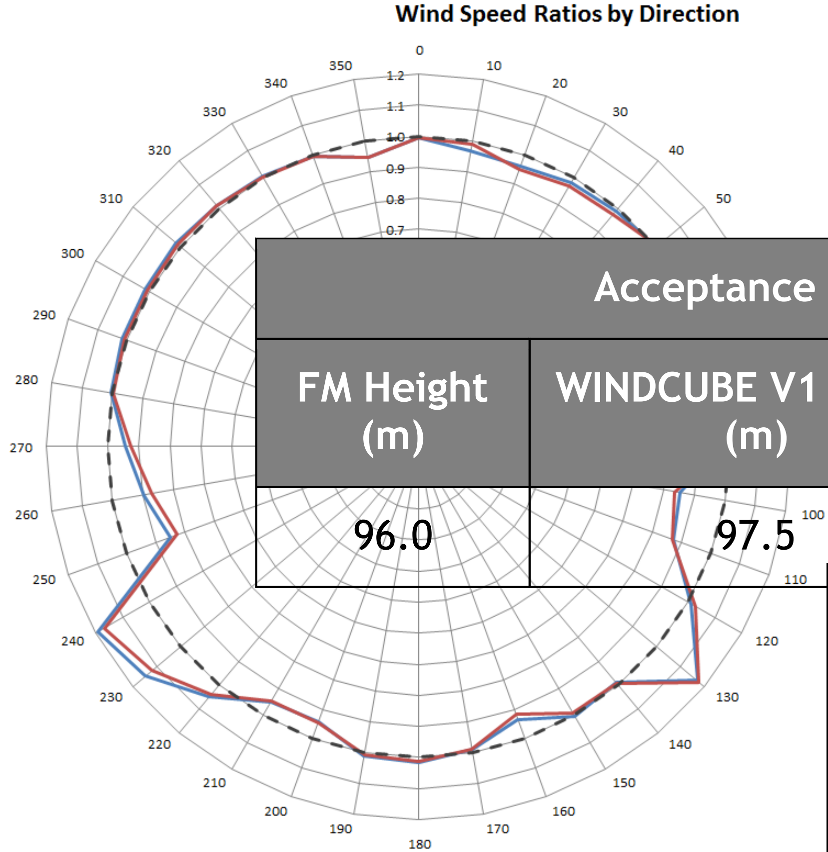
1) 2 week data period
2) R^2 value on wind speed correlations >0.96
3) Slope of wind speed correlation: 0.97<x<1.03
4) RMS on wind direction difference <5°
5) Units located adjacent to a tall mast (>40m):
   - Calibrated instruments
   - Mounting in accordance with IEC Pt .11
   - Sited to minimise differences in wind between locations

In addition data availability >95% is typical. The IEA expert committee, on which SgurrEnergy is represented, will publish guidelines by the end of the summer.

© SgurrEnergy Ltd

Quoted from "Practical Experience with Remote Sensing - A Consultancy Perspective", Neil Douglas, IEA Remote Sensing Experts Meeting, Risø, January 2007

www.sgurrenergy.com

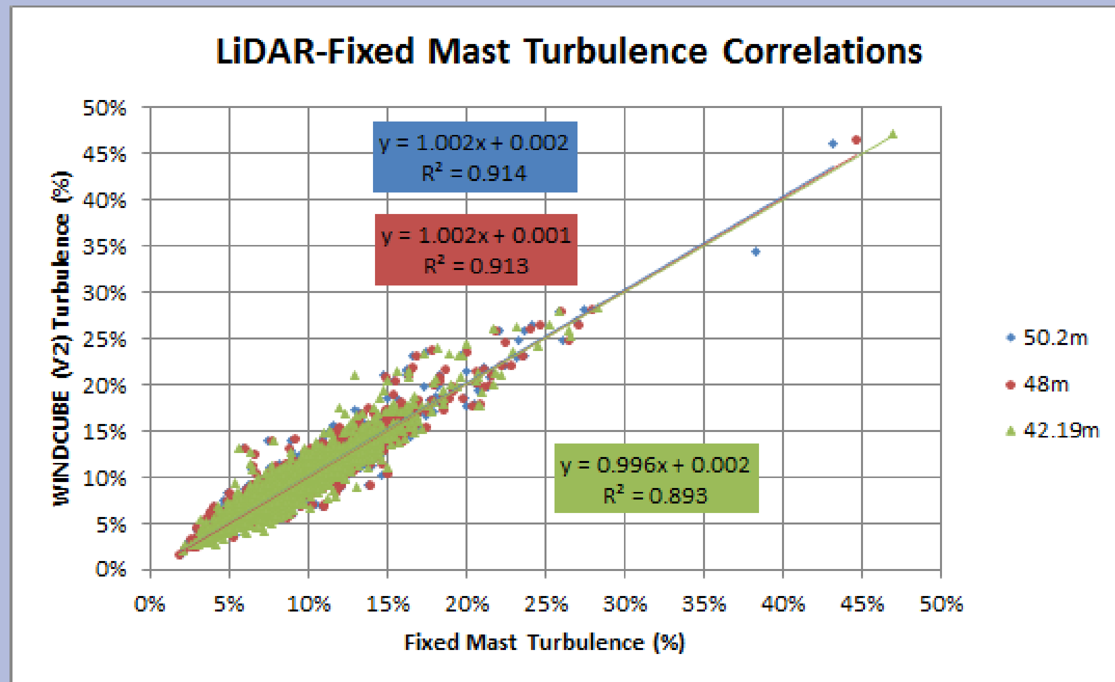


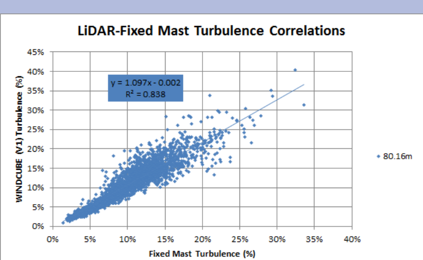
Acceptance Test Results				
FM Height (m)	WINDCUBE V1 Height (m)	Slope	R^2	Pass/Fail
96.0	97.5	0.975	0.995	PASS

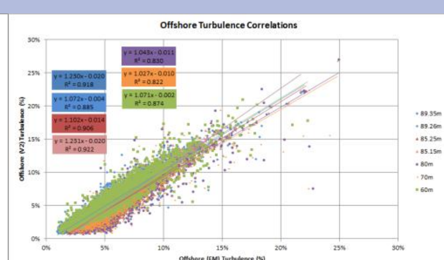
Mast	Wake Free Sector Start (°)	Wake Free Sector End (°)
M626	297	75
M814 (LiDAR)		

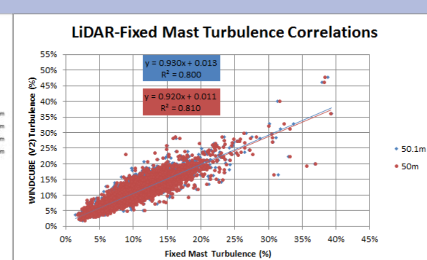
TURBULENCE: VARIOUS SITES

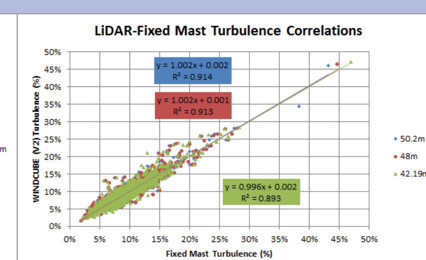
- Simple
- Offshore
- Moderately complex site1
- Moderately complex site2





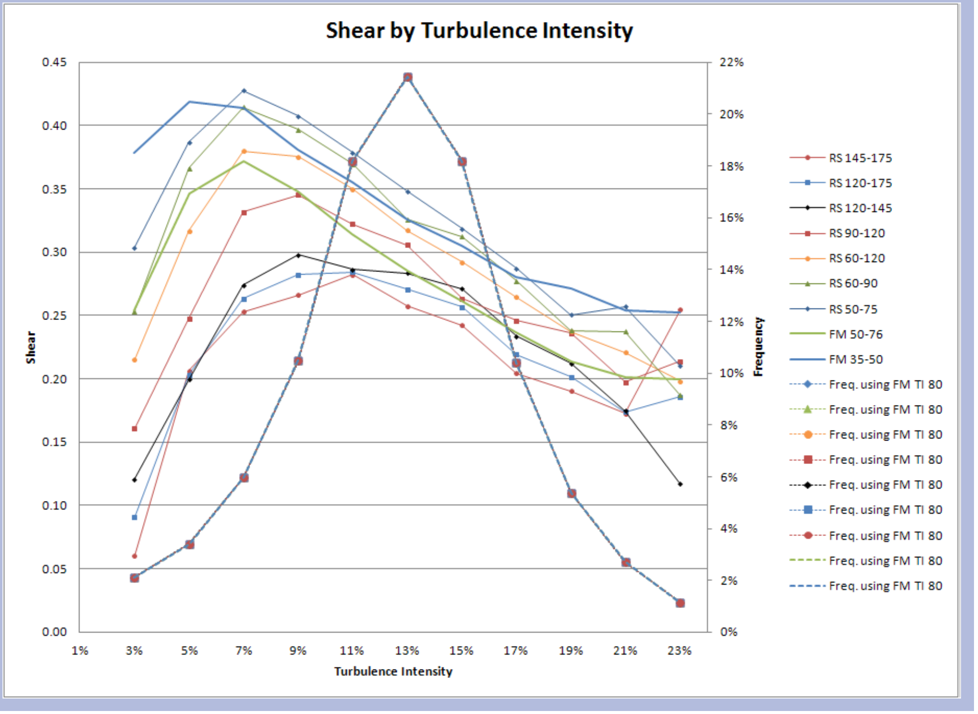




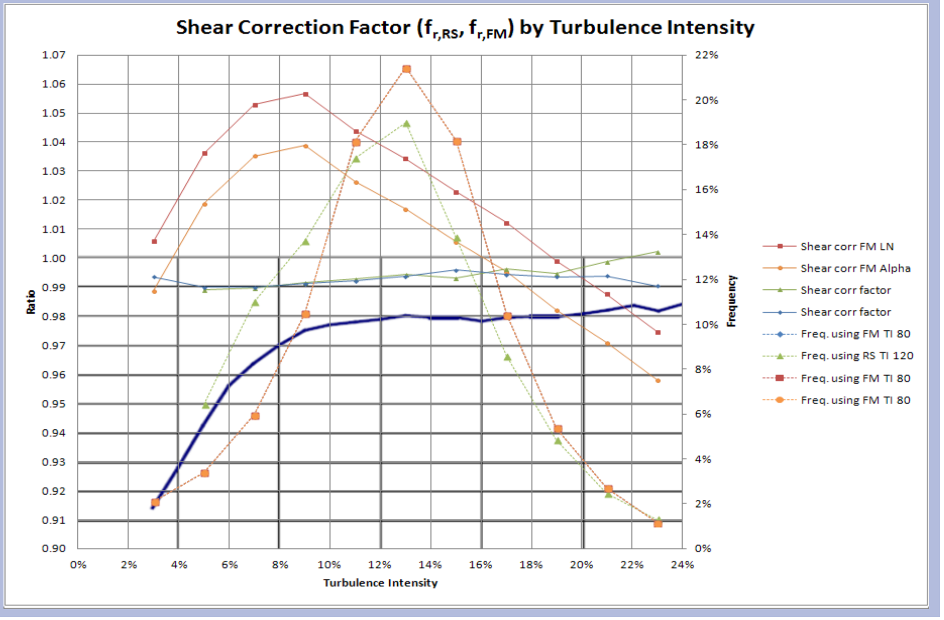


LOW TURBULENCE STABLE ATMOSPHERIC CONDITIONS: OTHER SWEDISH SITE

- Shear is consistent across full rotor
- At low TI
  - Turning point exists
  - But shear remains consistent across full range
  - No divergence at ≈ 9%



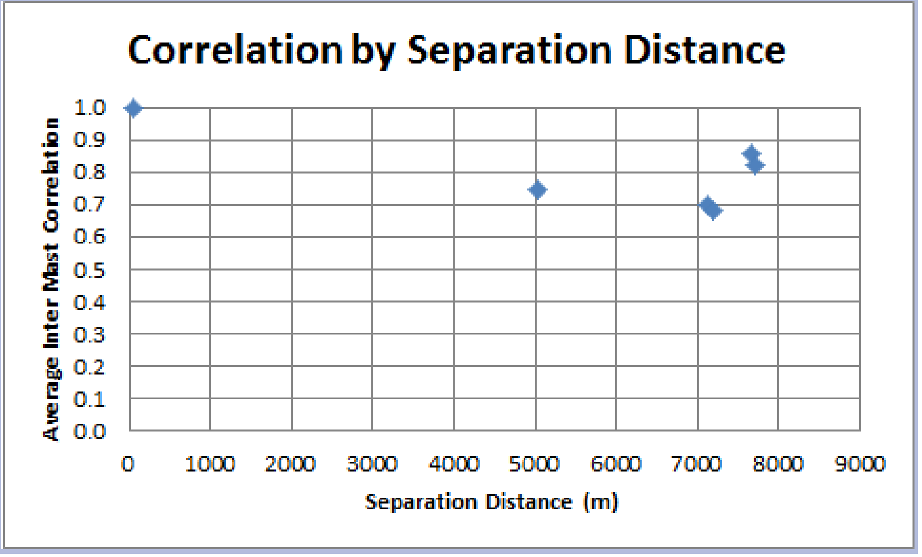
- RS shear correction factors do not vary strongly with turbulence intensity
- At low TI
  - Small variation
  - No dramatic plunge
- FM hub height wind speed tends to underestimate rotor wind speed
- At low TI underestimation decreases
  - Due to the fixed shear exponent not capturing the turbulence dependency of shear
- However, the result does not suggest that an energy loss factor is appropriate



INTER MAST WIND SPEED CORRELATIONS

The relationship between correlation and separation distance:

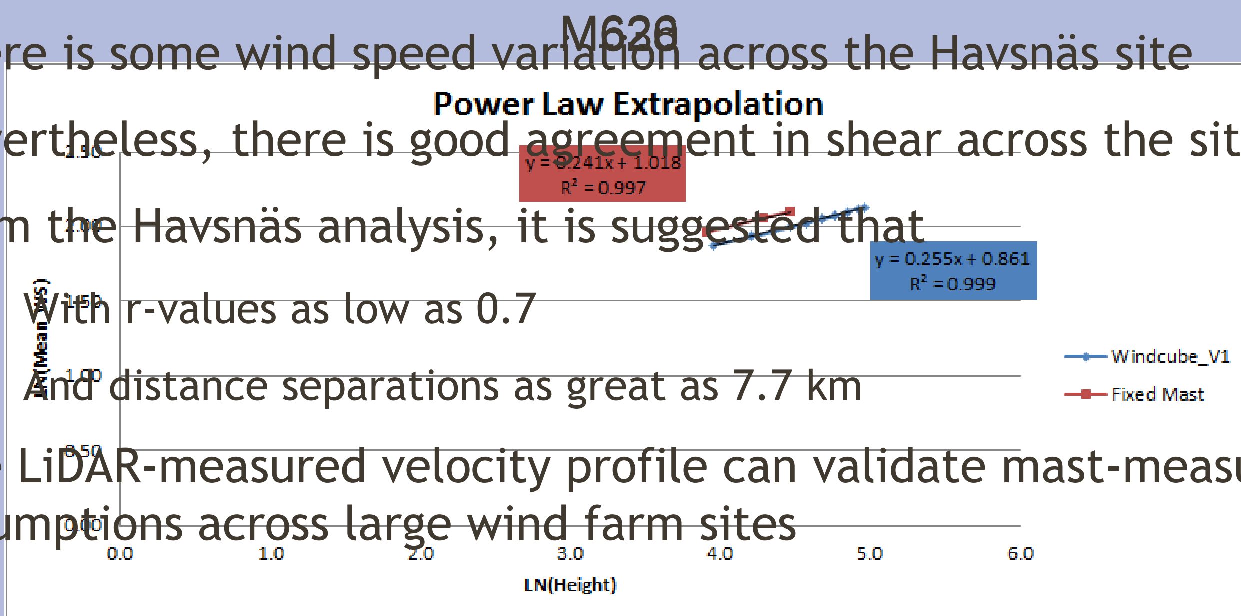
- The nature of the relationship is likely to be site dependent
- At Havsnäs
  - For every 1 km increase in separation distance,
  - The r-value decreases by approximately 0.03
- Generally, measurement height is not a factor

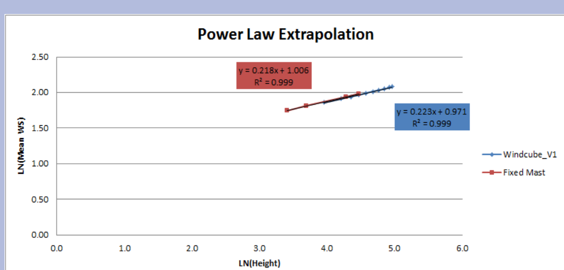


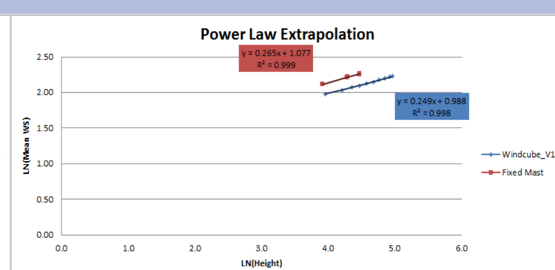
LiDAR-Mast Multi-Point Shear Comparisons

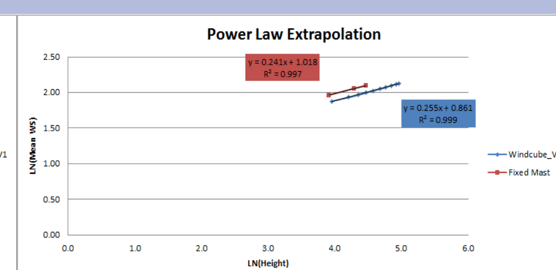
- There is some wind speed variation across the Havsnäs site
- Nevertheless, there is good agreement in shear across the site
- From the Havsnäs analysis, it is suggested that
  - With r-values as low as 0.7
  - And distance separations as great as 7.7 km

❖ The LiDAR-measured velocity profile can validate mast-measured shear assumptions across large wind farm sites









power for good