Havsnäs Research

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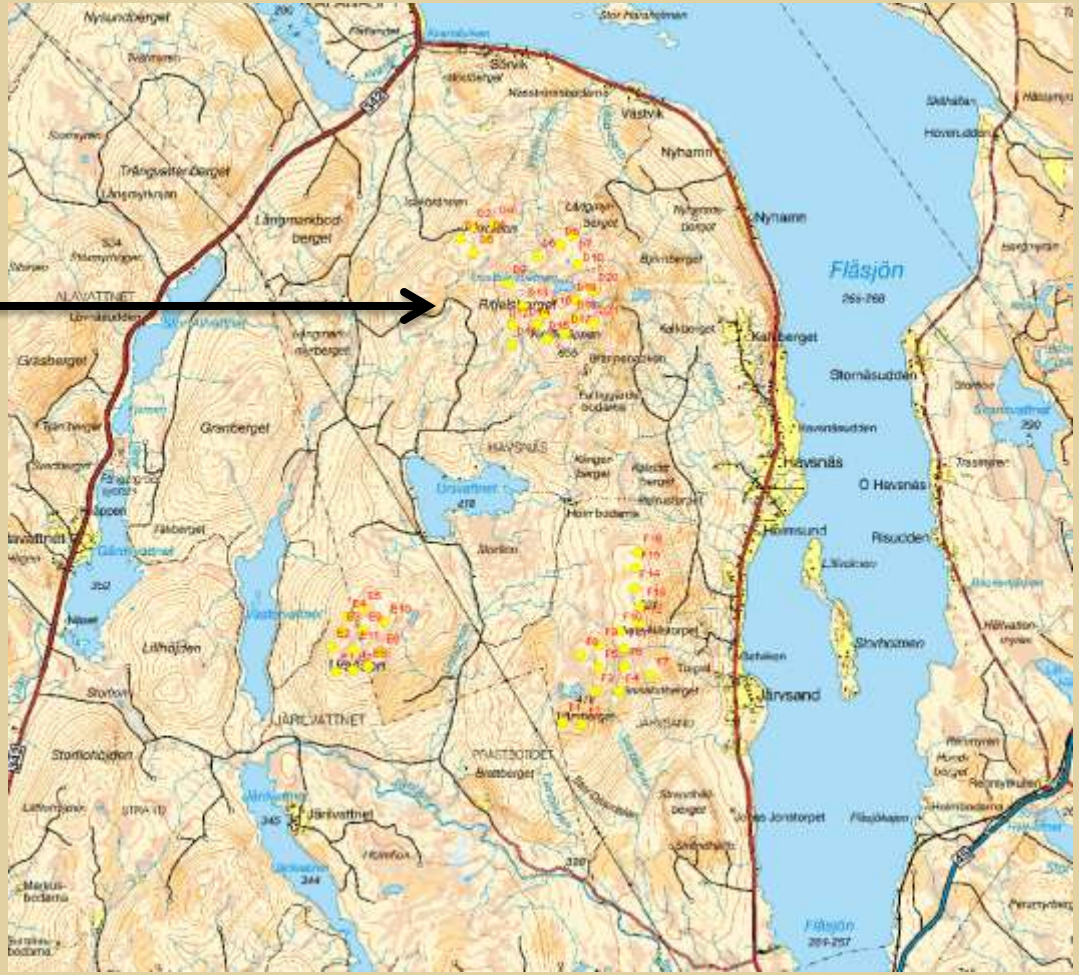
Swedish Energy Agency Pilot Grant
Winterwind, Umeå February 2011

The Havsnäs Project

- 110 km North of Östersund, Jämtland (240km West of Umeå)
- Area of national interest for wind power.
- Spread over 3 hills.
- 510 to 650m asl
- Surroundings are lakes, marsh and forest.
- 48 x Vestas V90 on 95m towers
  - 45 x 2.0 MW + 3 x 1.8 MW
- Commissioned Summer 2010.

Awarded a Pilot Project grant by Swedish Energy Agency in 2009.

Havsnäs Site Location



Summary of R&D Sub-Projects In Progress at Havsnäs .....

- Impact of shear extrapolation to hub height
  - Agreement between short (50m) and hub-height (95m) mast predictions
  - Impact of measurement heights on accuracy of derived shear profile
- Forest Canopy and Displacement Height
  - Use of Aerial Lidar Surveys to map tree heights/improve shear modelling.
- Shear Profiles Above Hub Height
  - Comparison of extrapolated and measured profiles; seasonal impact
  - Relating shear uncertainty to atmospheric stability indicators
- Wind Flow Model Validation and Tuning
  - linear models
  - CFD
  - Mesoscale
  - Tuning models to stability conditions

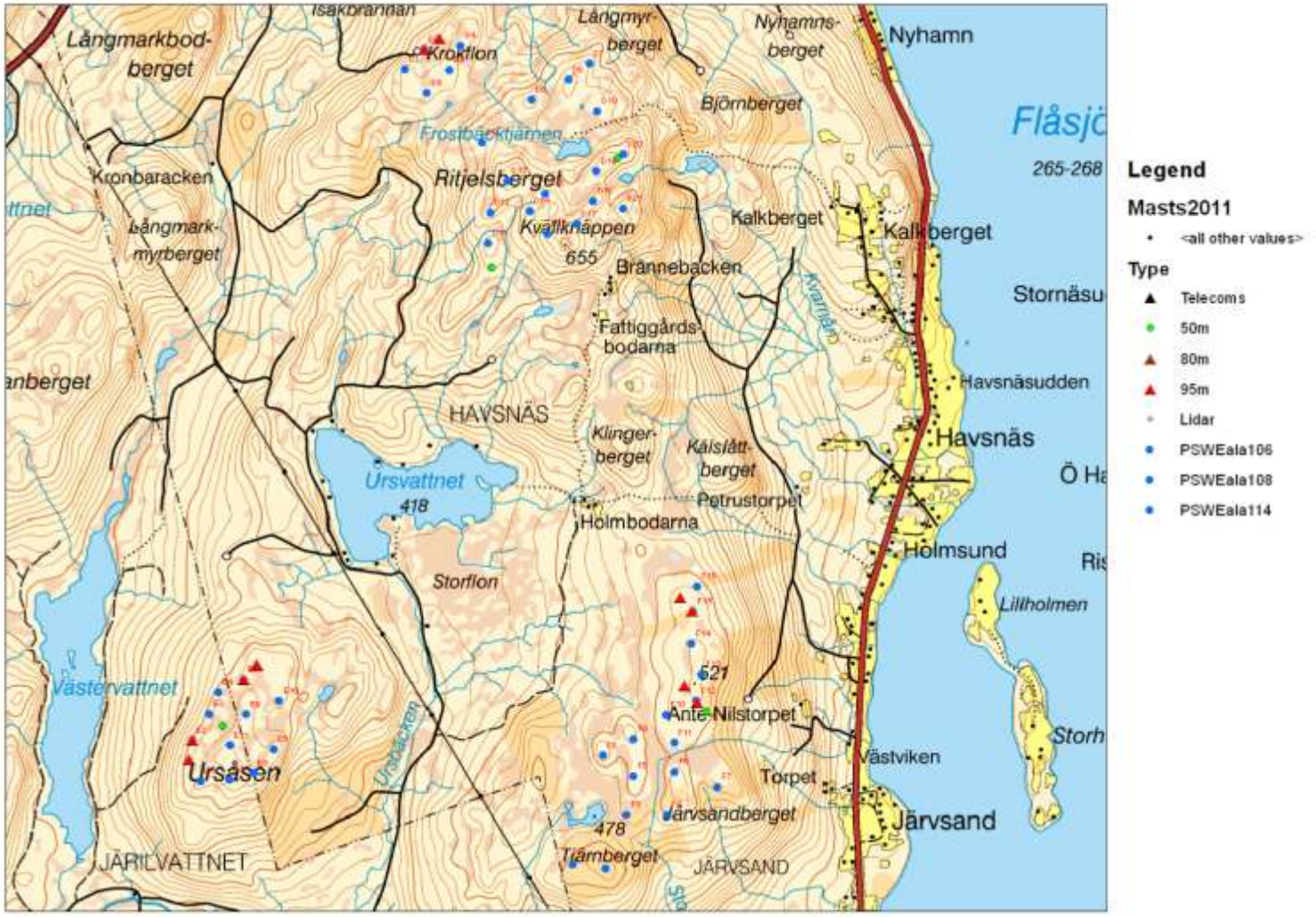
Summary of R&D Sub-Projects In Progress at Havsnäs (contd)

- Power Curves in Cold Climates
  - Power Curve Measurement using Rotor Averaged Wind Speed (Lidar)
  - Trialling of draft IEC 61400 12-1 rotor averaging procedures
  - Effect of ice on turbine and wind farm performance
- Remote Sensing
  - Testing of fuel cell lidar power supply in cold climate conditions
  - Practical implications of lidar measurements in cold climates
    - High shear/volumetric measurement error
    - Low temperature effects
    - Snow/rain/ice sensitivity
    - Lidar data availability

Wind Measurements at Havsnäs

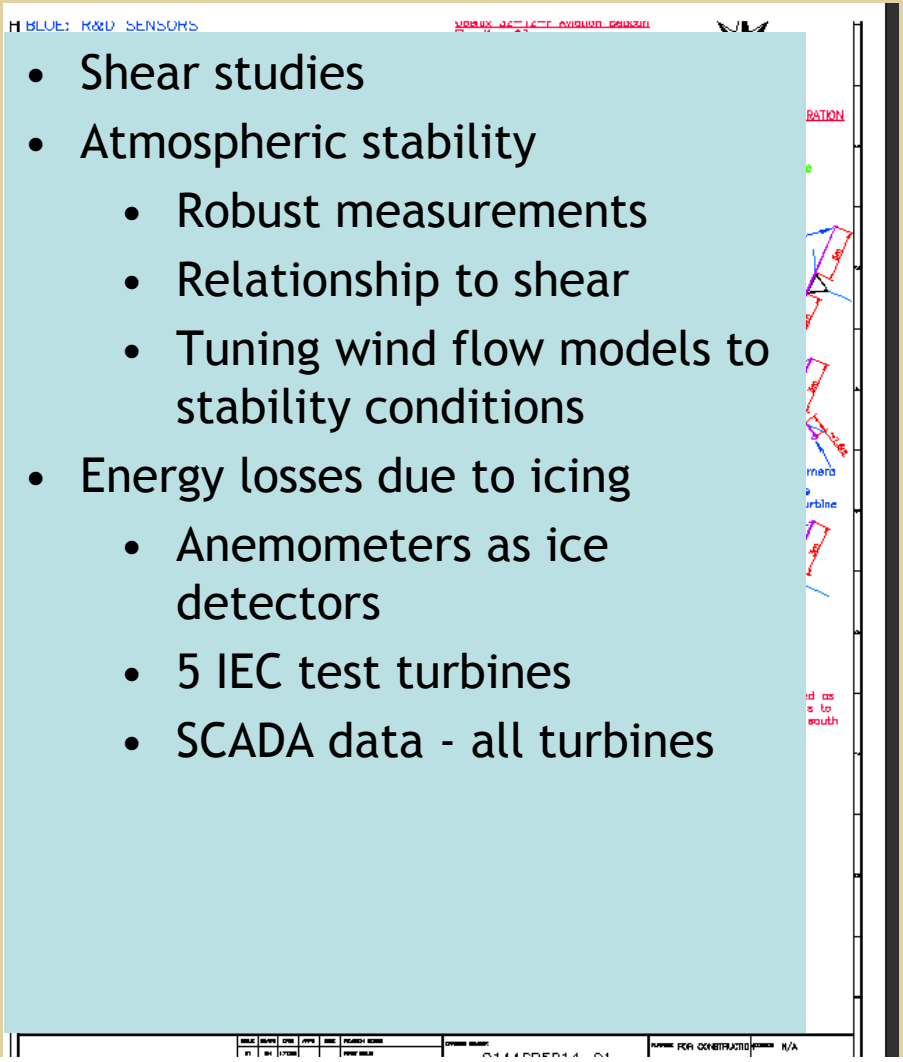
- Wind measurements started November 2003
  - 4 x 50m masts, 1 x 80m mast
  - 1 x off-site telecoms mast with heated reference instruments from 2003 to present day.
- 10 x 95m masts installed Summer 2008 for site calibration
  - 5 removed pre-construction
  - 5 remain for power performance and R & D
  - 3 of 5 masts fully instrumented for research purposes Summer 2010.
- Leosphere Windcube Mark 1 lidar deployed for R & D.

Measurement Locations



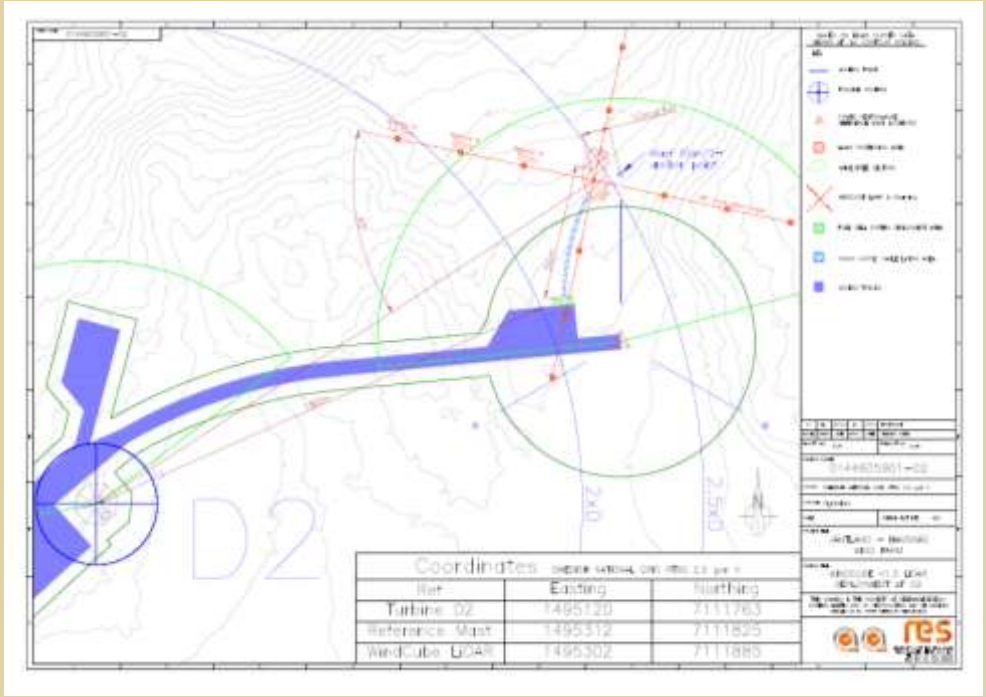
95m R & D Measurement Mast (3 – off)

- Pairs of heated (WAA252) and un-heated (A100) Ano's at 3 elevations (with heated booms)
- Pairs of heated (WAV252) and un-heated (W200P) wind vanes at 3 elevations
- Ultrasonic aneometers at 2 elevations.
- Mast blockage anemometer pairs at one elevation.
- Temperature, pressure, humidity, solar radiation and rain sensors
- Web cam
- Permanent Mains Power!



Remote Sensing

- Leosphere Windcube V1
- Long-term shear measurements at power performance test turbine
- Ultimately to be mains powered from turbine
- Initially to be powered using novel Fuel Cell technology (hired)



Shear Assumption Investigations: Results so far.

- Investigation of the impact of original 50m met mast based shear assumptions on energy yield prediction by implementing:
  - Wind resource predictions derived from 95m unheated power performance anemometers (missing winter data)
  - Wind resource predictions derived from new 95m heated anemometers (all year round data).
  - Lidar and 95m mast shear measurements to validate original 50m mast based wind shear assumptions.
  - Use of Lidar to measure the shear profile over the turbine rotor disk and to investigate the validity of the assumption of a power law profile over the entire rotor disk.

Vertical Wind Shear Profiles - How well d

- Extrapolating wind spee
  - Original site assessme
  - New site calibration m

95m Wind Speed Normalised wrt Nearest 50m Mast (sheared up to 95m)

95m Wind Speed Normalised wrt Nearest 50m Mast (sheared up to 95m)

95m

Järvsandberget

	M279	M629	M630
Wind Flow Model Predicted Wind Speed:	1.00	1.08	1.08
MCP Derived Wind Speed (original tree h estimate):	1.00	1.01	1.01
MCP Derived Wind Speed (Aerial Lidar tree h meas.):	1.00	1.02	1.03
MCP Prediction Uncertainty:	5.3%	5.1%	5.1%
MCP Prediction Uncertainty:	5.4%	4.9%	4.9%

	Ritjelsberget	Ursåsen	Järvsandberget
Relative Nett EnergyYield Difference E95m - E50m)/E50m:	-0.9%	1.4%	-0.1%

Vertical Wind Speed Extrapolation Conclusions

- Predicted wind speeds at 50m site assessment and 95m power performance masts
  - 50m and 95m masts not on same locations (separated by km's in some cases)
  - High uncertainty in wind speed model for point to point extrapolation
  - Direct comparison of wind speeds at masts not meaningful
- Energy Yield Analyses based on either 50m or 95m Masts
  - Uncertainties in wind flow model partially correlated across wind farm
  - Lower overall errors in wind farm energy yield
  - Good agreement (circa ±1%) between 50m and 95m mast based wind farm energy predictions
- Good spatial coverage of masts to counteract wind flow model uncertainties more important than hub height measurements
  - Assuming best practice applied in measurement and analysis.
  - Outcome of research will be to document best practice and improve understanding of failings of wind flow modelling in cold climate locations.

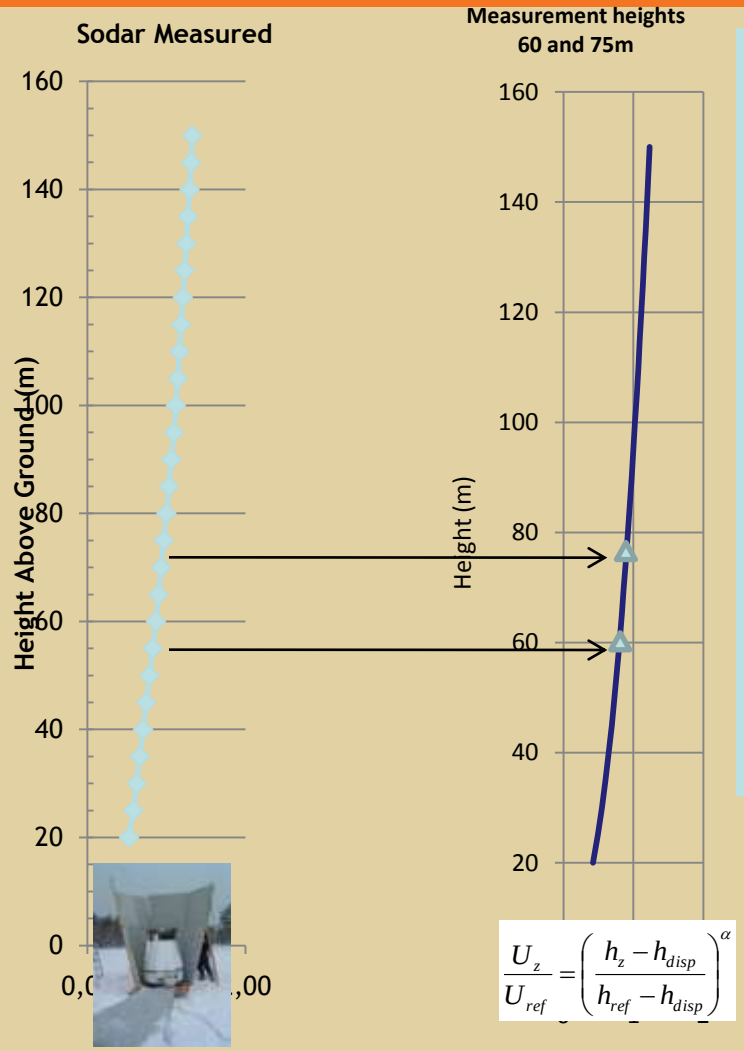
What impact does shear measurement height have?

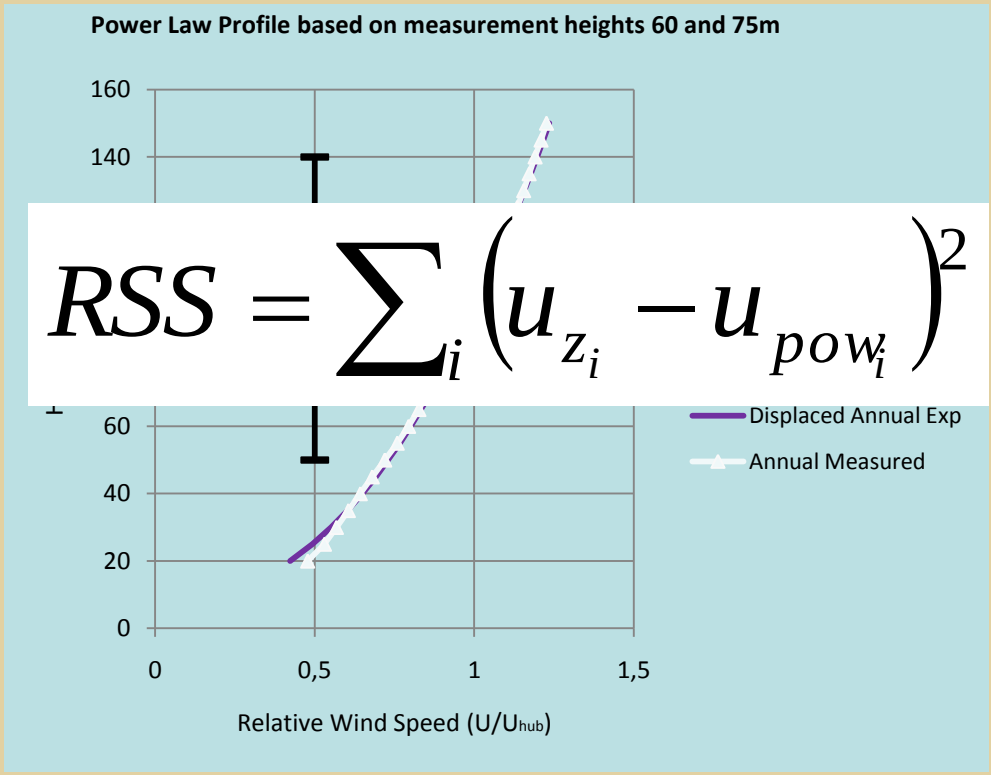
On 50m met mast we derive shear from 35m and 50m wind measurements, on 80m masts we derive shear from 50m and 75m measurements.

Based on data from another site in Sweden where we have used remote sensing (Sodar) for more than a year:

- **Sodar measurements at 27 heights between 20 and 150m**
- **Compare power law shear profile derived from pairs of measurements at 15m intervals (20-35m, 25-40m, ……. 135-150m) with measured profile.**

Comparison of Power Law and Measured Profile



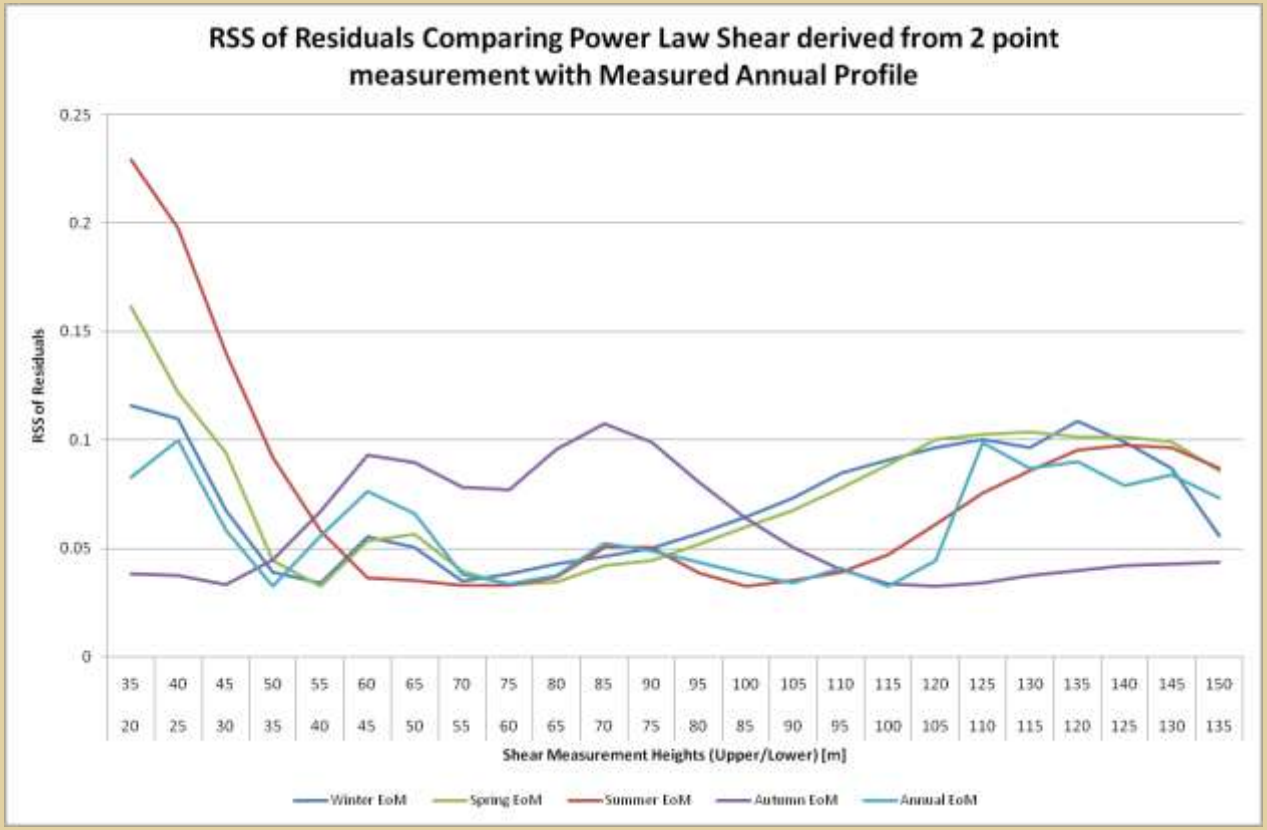


$$RSS = \sum_i \left(u_{z_i} - u_{pow_i}\right)^2$$

- determine profile residual error across rotor disk height.
- repeat for each height pair.
- repeat for measurements
- during each season compared to annual profile

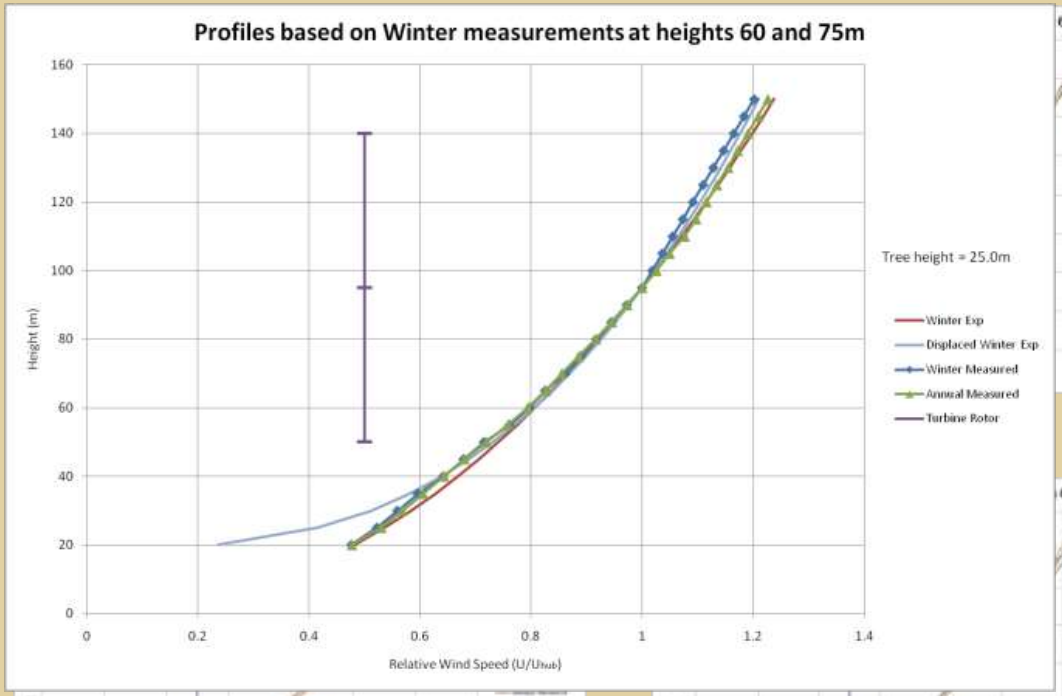
Virtual Mast
2 Meas Heights

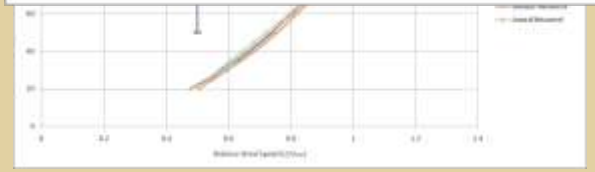
Power Law Profile Residual Errors

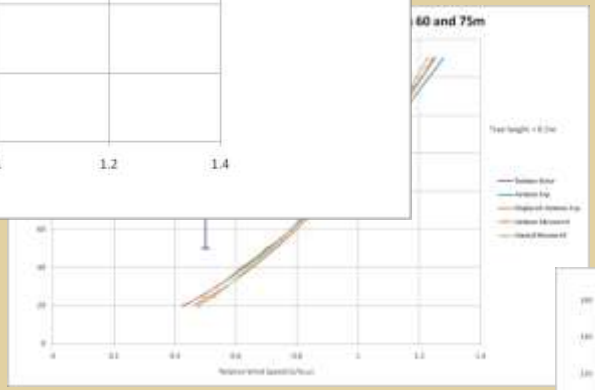


- Power law profile less accurate if measurement heights too low or high.
- Seasonal effects can bias power law profile wrt annual profile.
- Can only confirm this with hind sight!

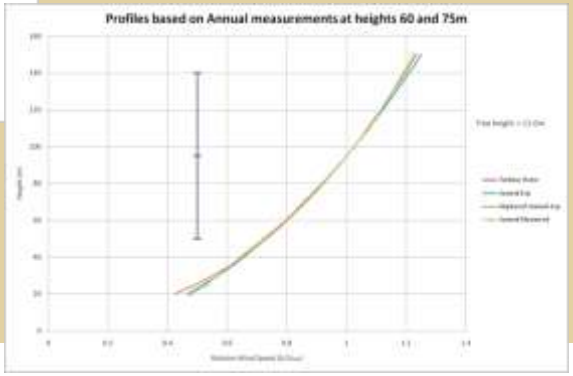
Power Law Profiles based on 2-Height Seasonal Measurements



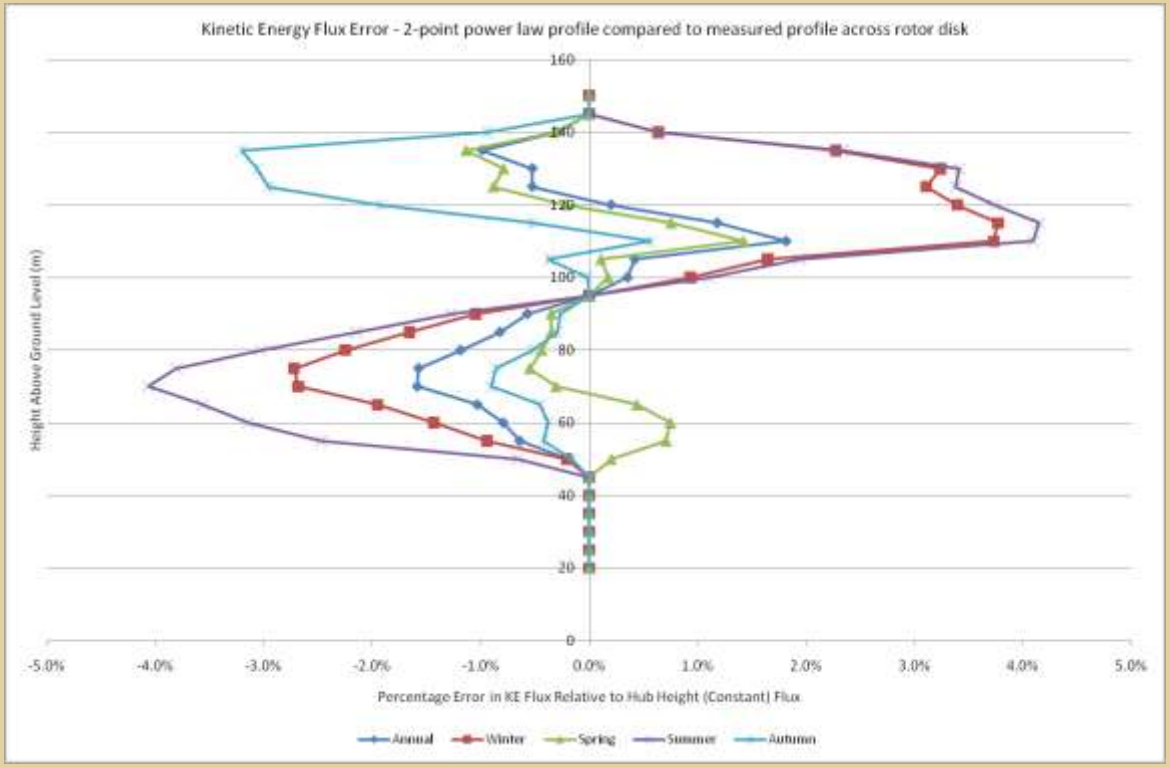




- Best-fit displaced power law profile does not necessarily match with physical forest height (11m).
- Profile error introduced by short-term measurements can be high.



Energy Flux through Rotor – Seasonal Profiles Compared to Annual



- Consider kinetic energy profile (U^3) rather than wind speed profile
- Often, what we lose below hub height, we get back above hub height
- But not always – uncertainty remains.

Shear Validation – Preliminary Conclusions

Mast measured shear based on up to hub height measurements:

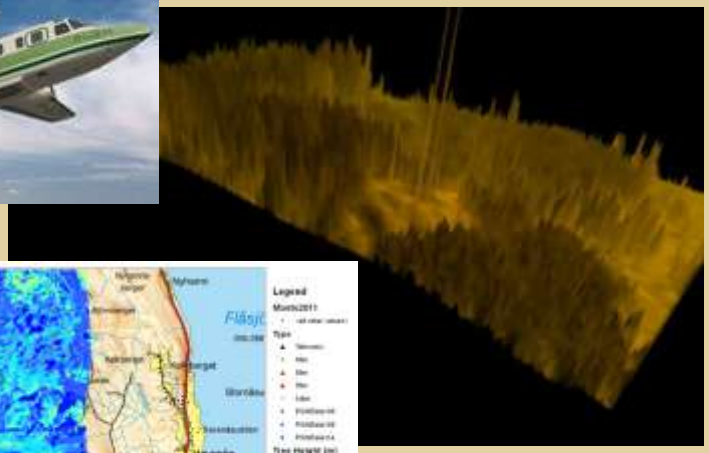
- Profile may deviate from power law above hub height > energy flux error
- Profile may not be a good fit to the power law > energy flux error
- Generally don't know if this is true for a specific site until you have a year of measurements
- Recommendation is to get at least a year of profile measurements.

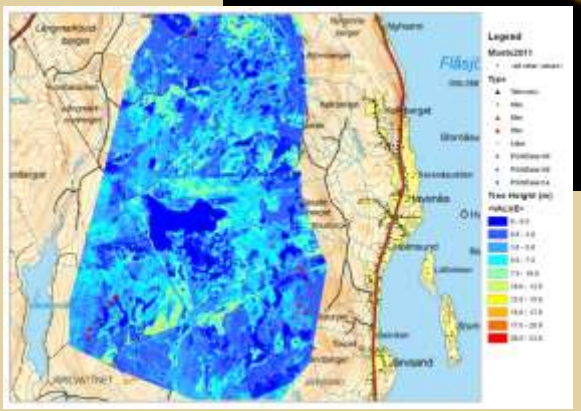
Shear Validation – Havsnäs provides:

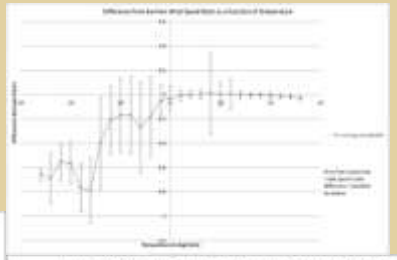
- a more comprehensive set of met mast instruments to investigate and classify the atmospheric conditions dictating good/poor agreement between power law and actual shear profile
- Mast measurements at three separate locations providing more generic results.
- Profile measurements implemented using Lidar rather than Sodar to obtain measurements very close to a tall met mast.

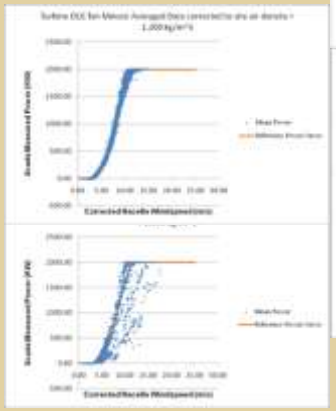
Other Interesting things underway at Havsnäs

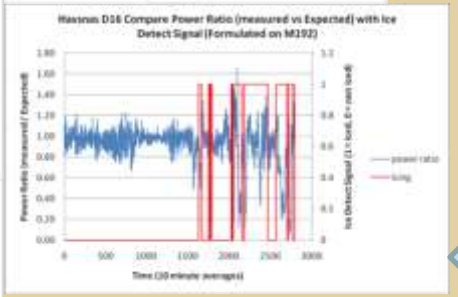
- Use of 3-D aerial lidar scan of forest height to optimise displaced shear profile model.











Ice detection and ice impact on power curve.


power for good