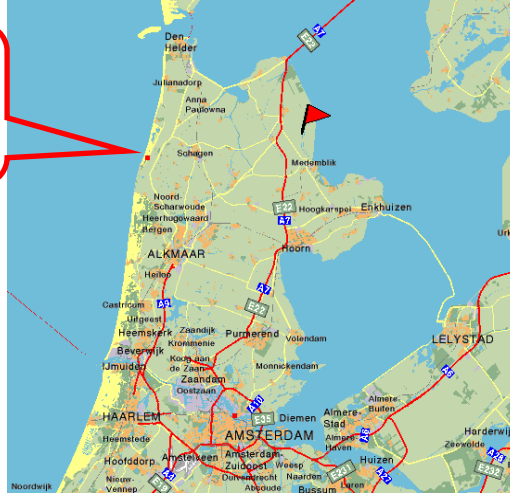


ECN-MW Testfield measurements in the ECN Wind Turbine Test Site Wieringermeer, EWTW

Gerard Schepers

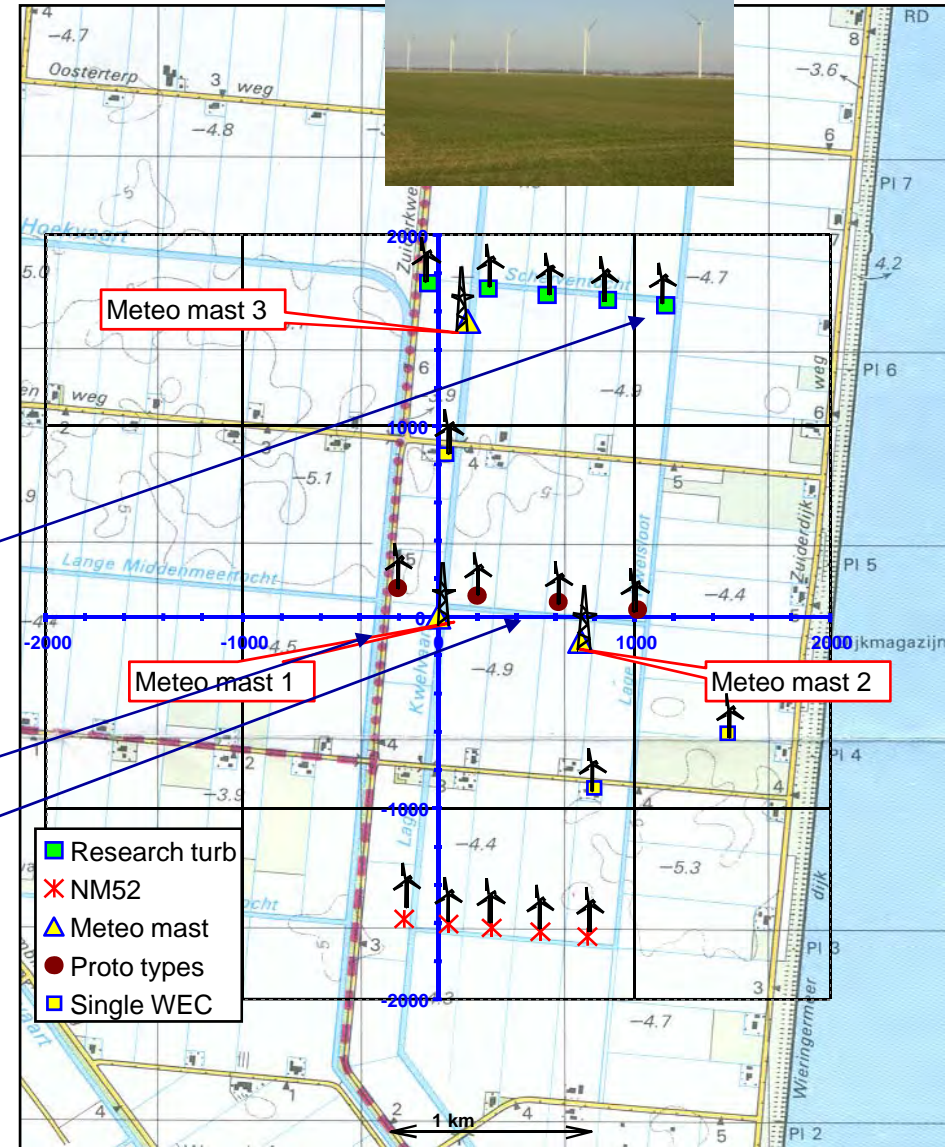


ECN



ECN Wind Turbine Test Farm Wieringermeer (EWTW)

- Two rows:
 - Five **research** turbines with one 108m high meteorological mast (mm3)
 - Four **prototype** turbines with two 108m high meteorological masts (mm1 and mm2)
 - Scaled farm
- Measurement Infrastructure
- Measurement Pavilion



Research Turbines at EWTW

- EWTW Research Turbines:
- Five turbines in a single line
- Mutual distance: $3.8 D$
- A 108m high mast is installed with equipment at 52m, 80m and 108m heights.

Hub height: 80m

Rotor diameter: 80m

Rated. Power: 2.5MW



ECN Wind Turbine Test site Wieringermeer, EWTW

- State of the art turbines
- Research farm
- Turbine data available



Meteorological Measurements MM3

- Top mounted at 108 m:
Gill 3D Sonic anemometer



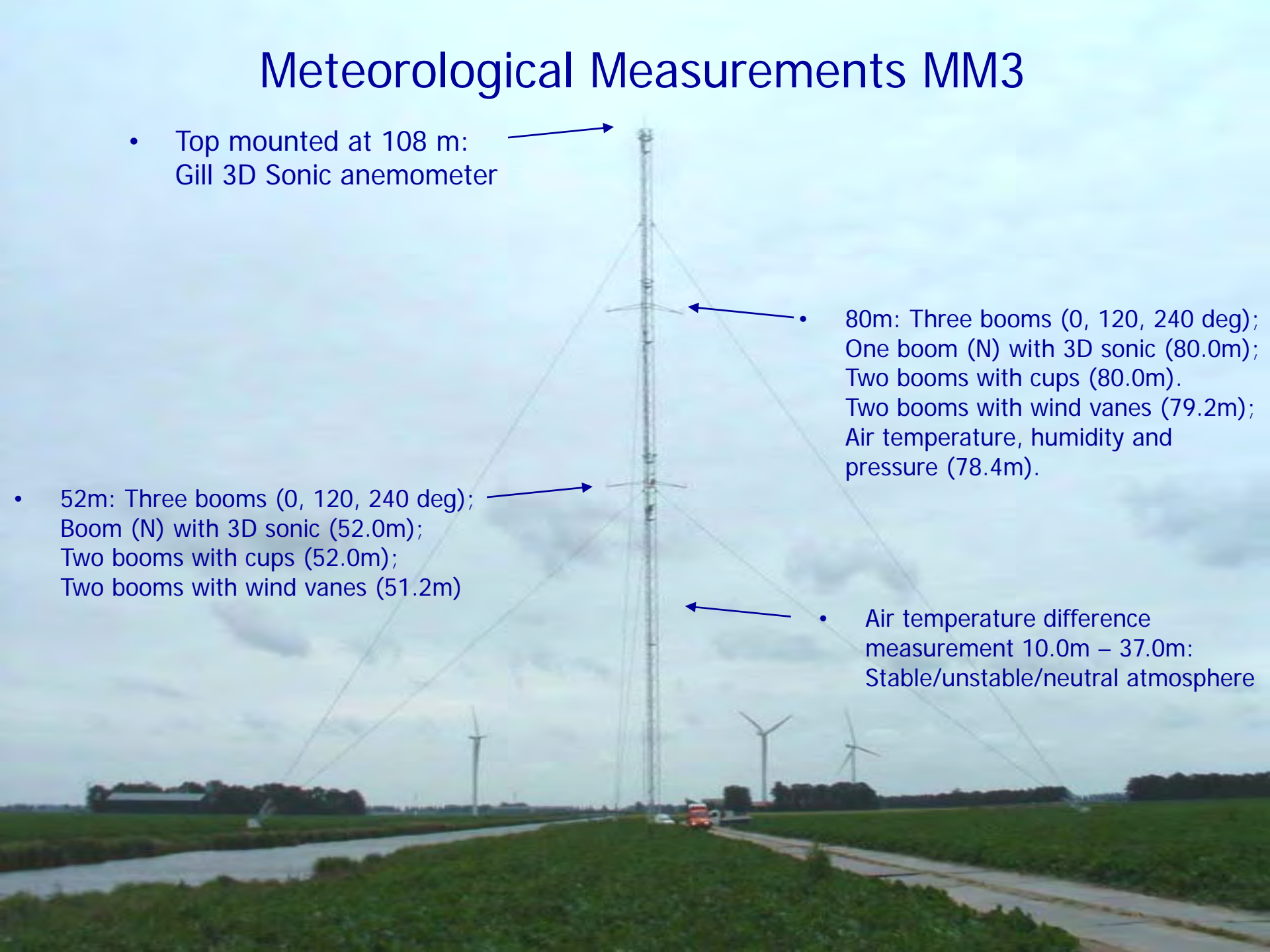
- 80m: Three booms (0, 120, 240 deg);
One boom (N) with 3D sonic (80.0m);
Two booms with cups (80.0m).
Two booms with wind vanes (79.2m);
Air temperature, humidity and
pressure (78.4m).



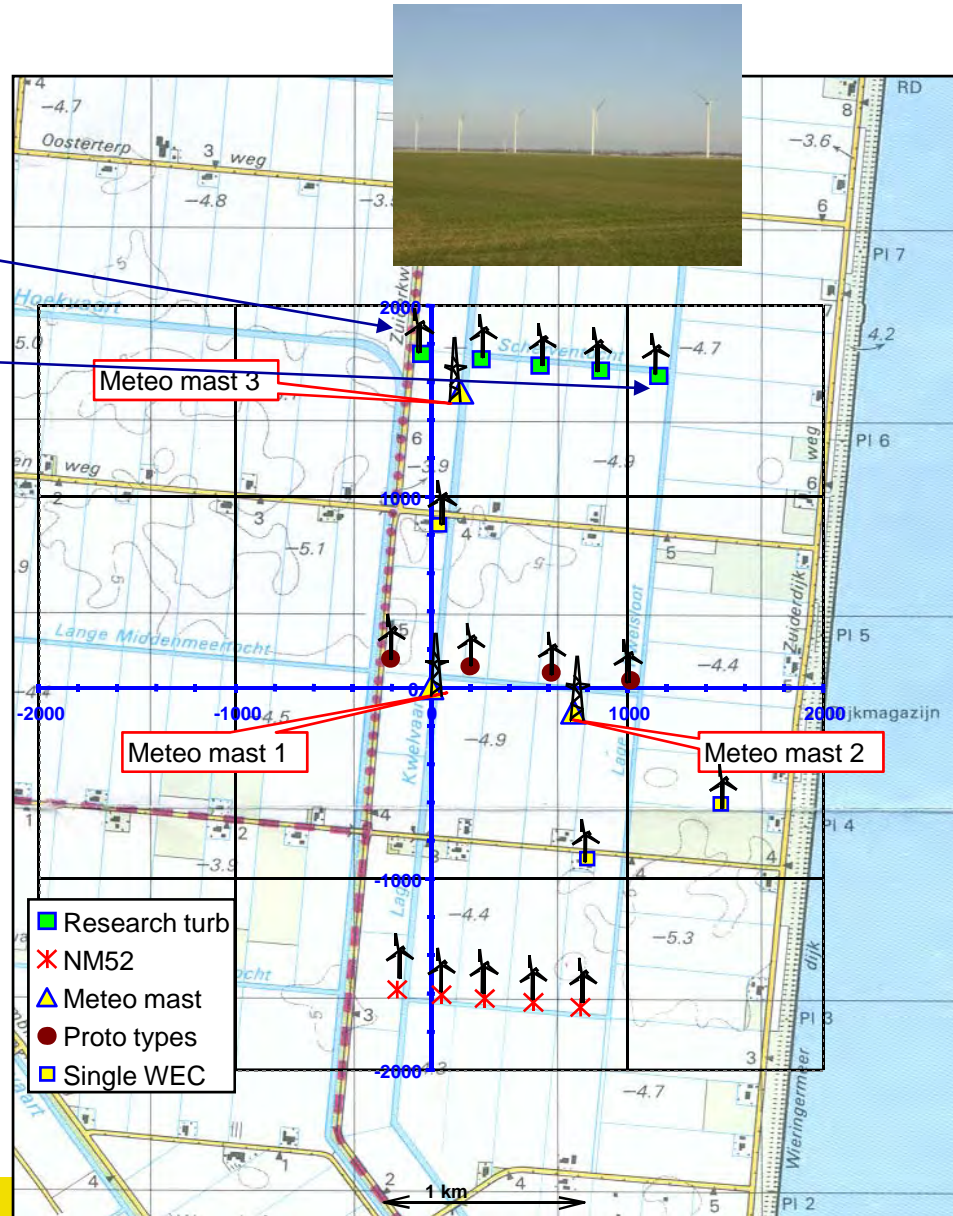
- 52m: Three booms (0, 120, 240 deg);
Boom (N) with 3D sonic (52.0m);
Two booms with cups (52.0m);
Two booms with wind vanes (51.2m)



- Air temperature difference
measurement 10.0m – 37.0m:
Stable/unstable/neutral atmosphere



- Research turbines numbered from 5 (most Westerly) to 9 (most Easterly)
- Wind farm line: 95-275 degrees
- MM3 at 3.5 D and 315 degrees from turbine 5
- MM3 at 2.5D and 31 degrees from turbine 6
- Sonic anemometers on boom in Northern direction, well suited for wake measurements



Measurements at research turbines

- Five turbines are equipped to measure a variety of signals
- From PLC (25Hz). All turbines:
 - Electric active power PLC
 - Generator speed PLC
 - Wind speed nacelle PLC
 - Wind direction nacelle PLC
 - Nacelle position PLC
 - Pitch angle axis 1 PLC
 - Pitch angle axis 2 PLC
 - Pitch angle axis 3 PLC
 - Operation mode (0-24) PLC
- On a daily basis, files are received with 10-minute averaged statistics (avg, min, max, std) of 132 signals measured with SCADA system



Measurements at research turbines

- Load measurements at turbine #6 with 32 Hz:
 - blade 1, Root, Flap moment
 - blade 1, Root, Edge moment
 - blade 2, Root, Flap moment
 - blade 2, Root, Edge moment
 - blade 3, Root, Flap moment
 - blade 3, Root, Edge moment
 - Tower bottom bending N-S
 - Tower bottom bending E-W
 - Tower bottom bending, +45 deg.
 - Tower bottom bending, -45 deg.
 - Rotor Azimuth
- Autumn 2007-Spring 2008: Load measurements are also performed on turbine #8 and torque on high speed shaft and main shaft strain measurements on both turbines



Database

- ECN has developed a database in SQL 4.5 years of data (Some data were added a later stage)
 - Meteorological data of masts
 - Turbine data from PLC's
 - Turbine data from SCADA
 - Load measurements
 - Pseudo signals (functions)

Standardised database structure

The data are synchronised and easily accessible/selectable on 10-minute statistics data.

The raw data are also easily accessible.

The screenshot shows the pgAdmin III interface. On the left, a tree view displays the database structure under 'Schema's (2)', with 'public' expanded to show various objects like Aggregaties, Conversies, Domeinen, Funties, Trigger Functies, Operators, Operator klassen, Opeenvolgingen, Tabellen, Typen, Views, denoord, sodar, and tulipo. The main window displays the 'Eigenschappen' (Properties) tab for the 'public' schema, showing a table of properties and values:

Eigenschap	Waarde
Naam	public
DID	2200
Eigenaar	postgres
ACL	{=UC}

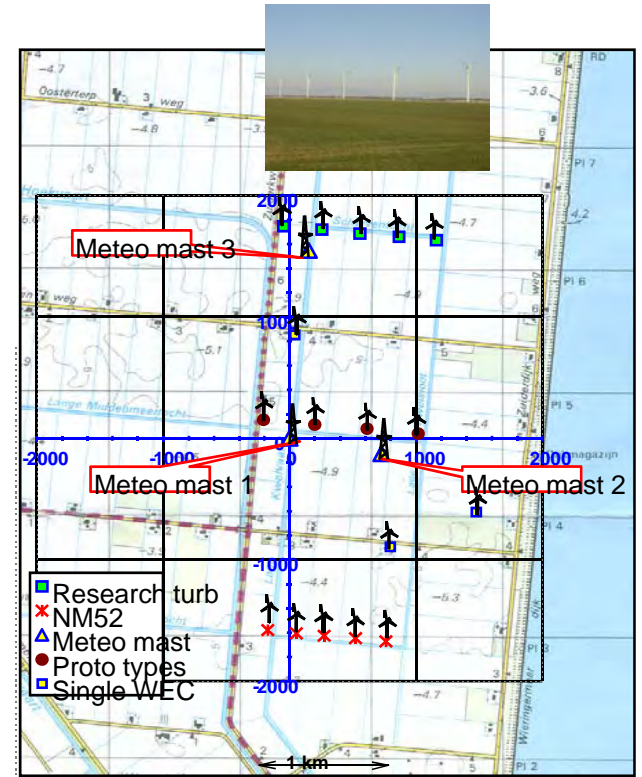
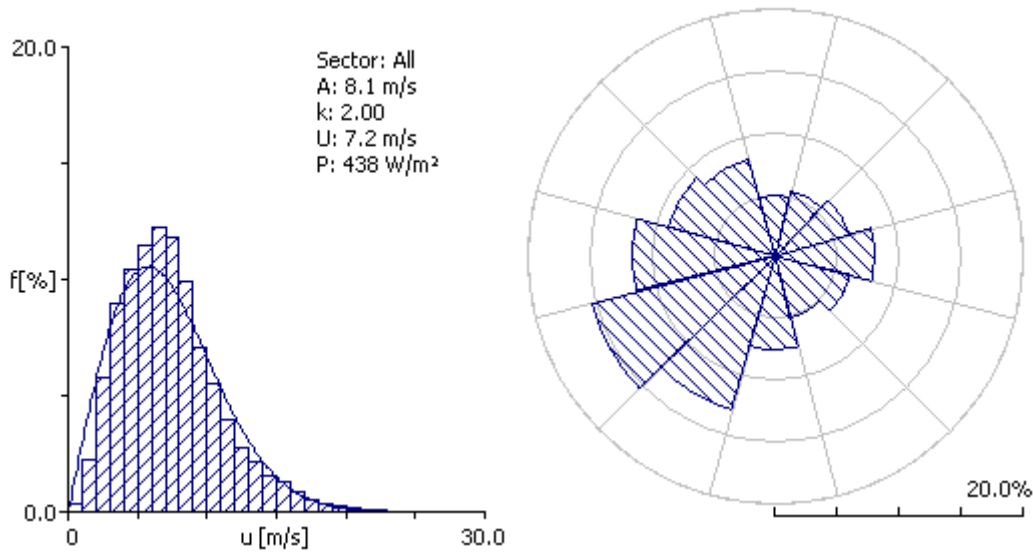
Below the table, the 'Statistieken' (Statistics) tab is active, showing the SQL command used to create the schema:

```
-- Schema: "public"  
-- DROP SCHEMA public;  
  
CREATE SCHEMA public  
  AUTHORIZATION postgres;  
GRANT ALL ON SCHEMA public TO public;
```

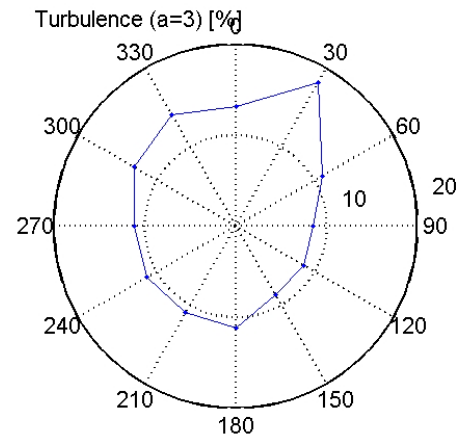
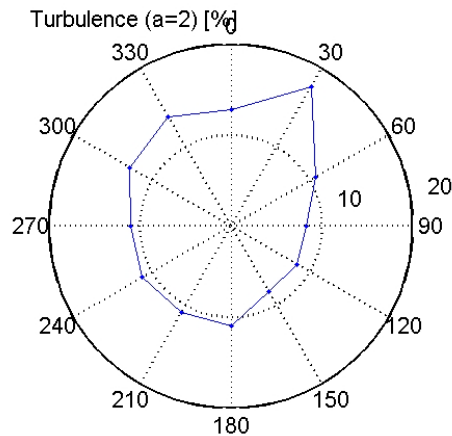
The status bar at the bottom indicates the operation was completed in 0.45 seconds.

Wind Climate

MM1: H=71.6 m, June 2003-May 2005



MM 3:H=80m, Turb. Int. according to IEC 61400-1



Turbine 1: 315 deg.;
 Turbine 2: 31 deg.;
 Turbine 3-5: 71-85 deg

Research projects at EWTW

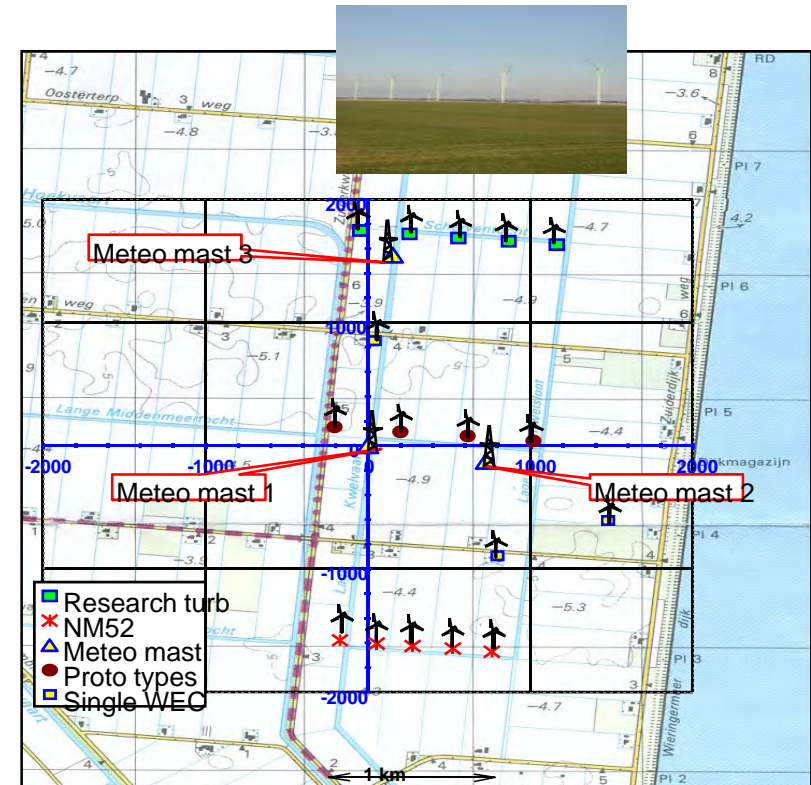
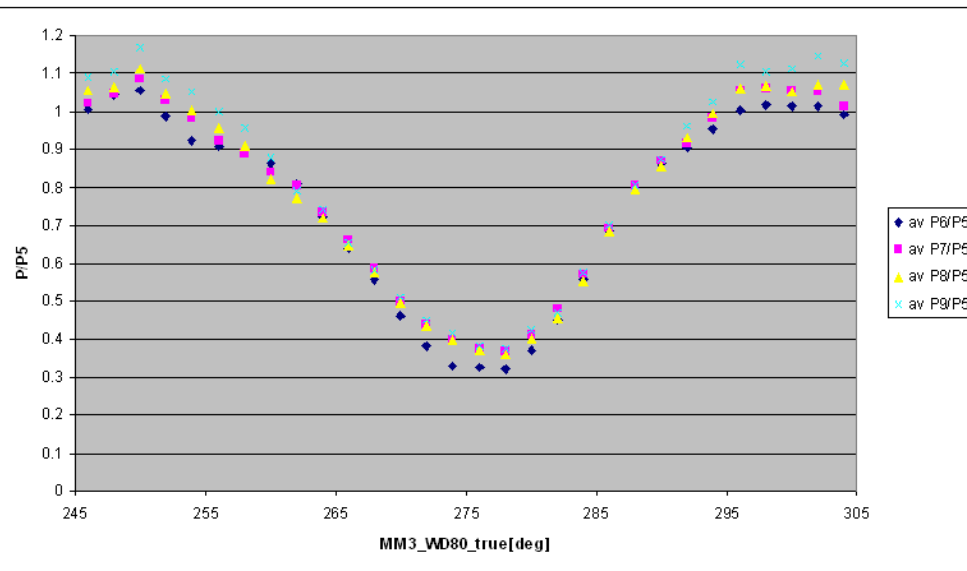
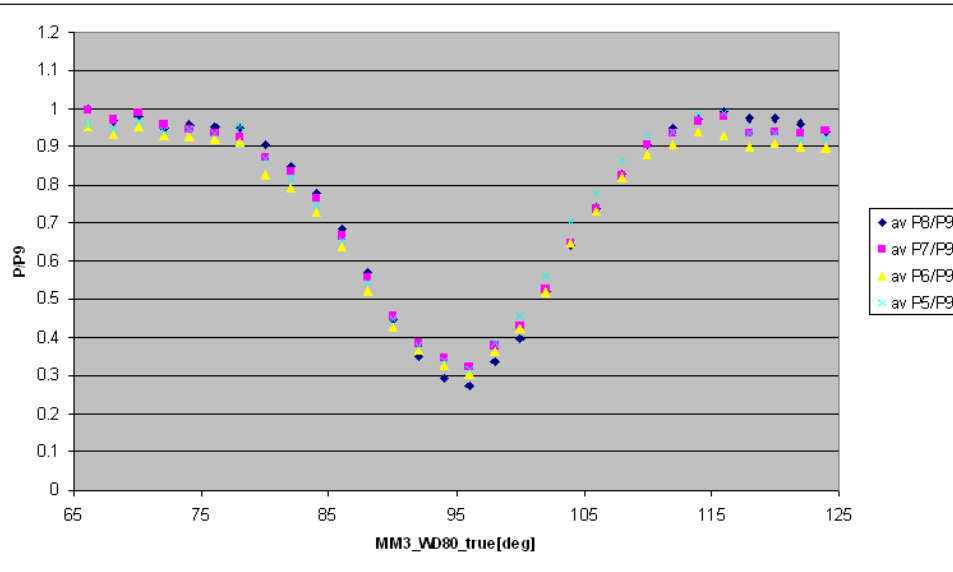
- WT-Bird: A method for registration of bird collisions using video cameras and microphones triggered by acoustic vibration measurement
- FOBM: Measurement methods to monitor wind turbine blades by means of fiber optic measuring systems
- O&M Cost Estimator: Methods to analyze SCADA data, loads data and O&M data for estimating future O&M costs
- Flight Leader: Methods to monitor and assess the equivalent loads on main components of any turbine in a wind farm. Such method can be used to determine the most heavily loaded turbines and components
- PROTEST: procedures for designing mechanical components (viz. gearbox, pitch system, and yaw system) and specifying the loads on these components.
- Sirocco: Silent Rotors by Acoustic Optimisation
- Extrapolation of extreme loads
- Crisp: An EU project to investigate, develop and test advanced intelligence by ICT technologies to reduce costs of integration and control of distributed generation and RES to the EU power grid. Includes a considerably wake investigation
- Aeolus: A project from the EU ICT program coordinated by University of Aalborg to develop models that allow real-time predictions of flows and incorporate data from a network of sensors, and control paradigms that acknowledges the uncertainty in the modelling and dynamically manages the flow resource in order to optimise specific control objectives. Includes a Wake work package!
- Project on (time dependant) meteorological characterisations
- Wake reducing concepts (Heat and Flux)
- Projects on wake characterisation(national project 'LTVM database' and supply of data to the partners in the EU project Upwind (WP8: flow))



Relative power production ($V_w < V_{rated}$)

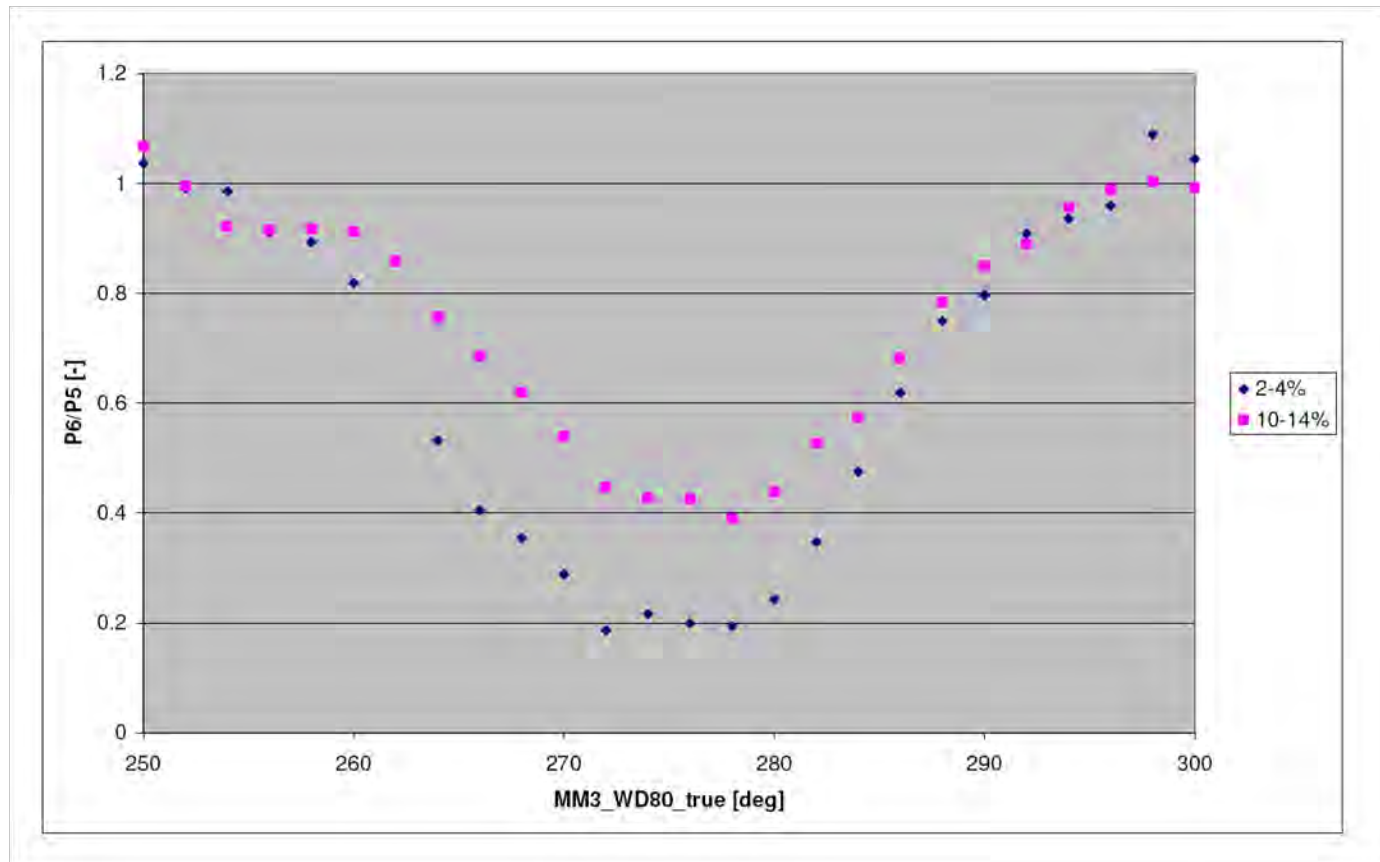
Single/double/triple/quadruple:
Single wake gives largest power deficits, other deficits are similar

Slightly larger deficit when wind blows from the East, i.e. at low turbulence level



Effect of ambient turbulence intensity on relative production of second turbine

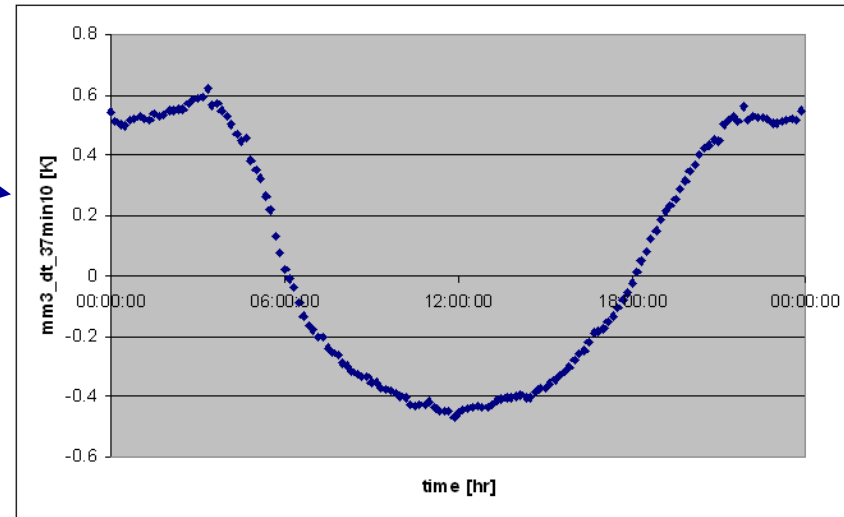
Low ambient turbulence intensity: P_6/P_5 much lower



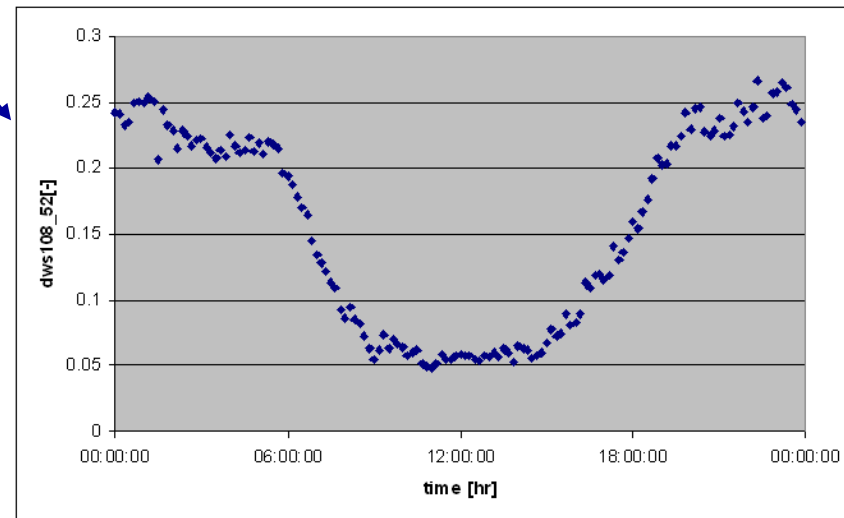
Summer: Diurnal cycle of temperature difference, wind shear and turbulence intensity (V108-V52/V80) and turbulence intensity (h=80m)

- 2005-2008
- Summer period ¹⁾
- $V(h=80m) < 12$ m/s
- Binning interval: 10 min.

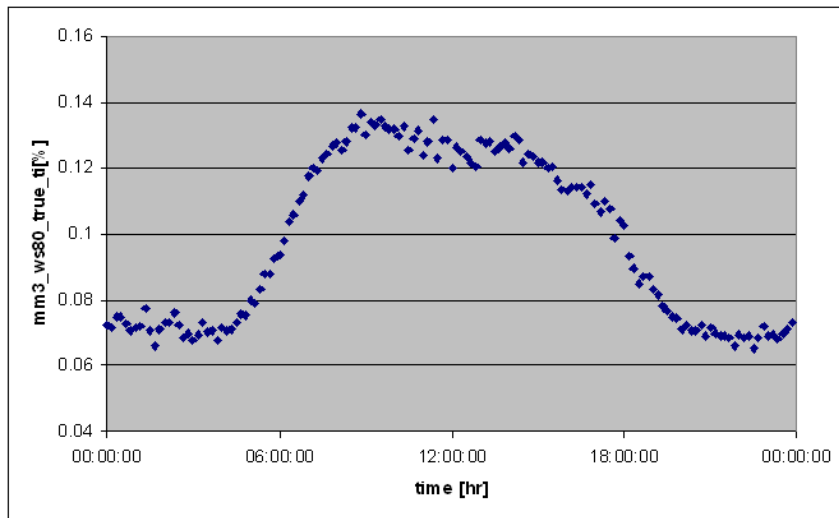
Temperature difference
 $T_{37m} - T_{10m}$



Wind shear



Turbulence intensity

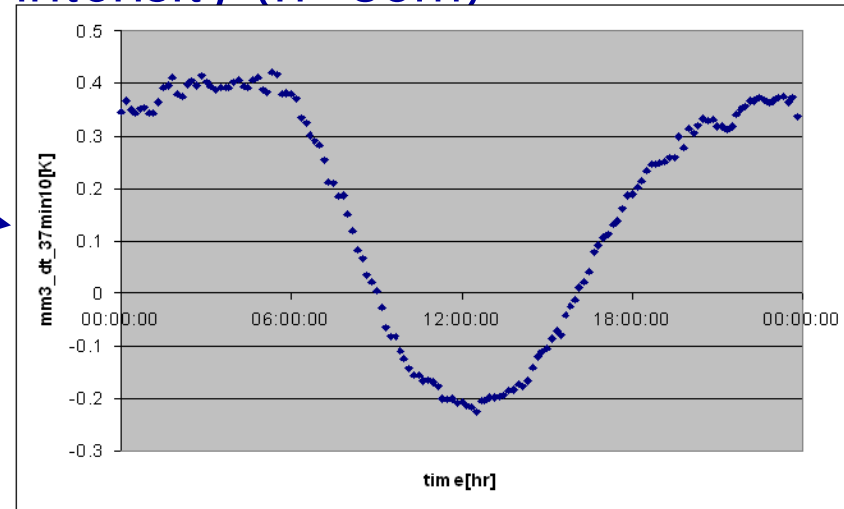


¹⁾ April 15 – October 15

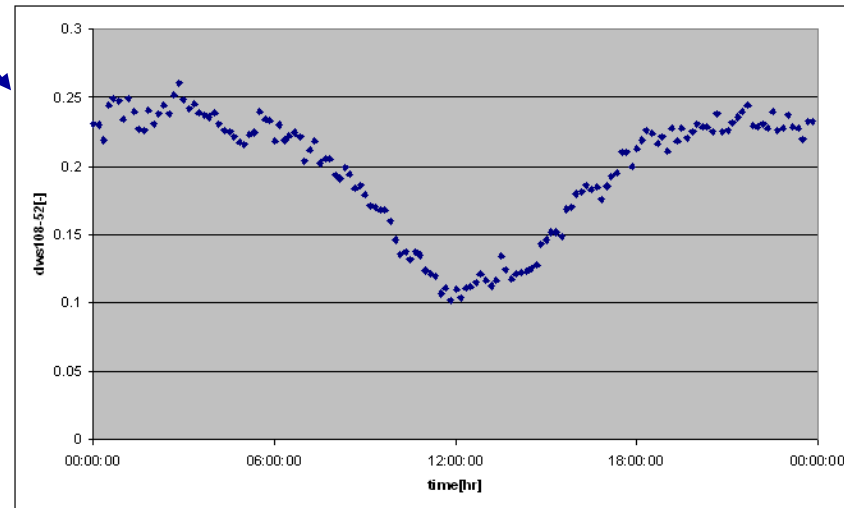
Winter: Diurnal cycle of temperature difference, wind shear and turbulence intensity (V108-V52/V80) and turbulence intensity (h=80m)

- 2005-2008
- Winter period ¹⁾
- $V(h=80m) < 12$ m/s
- Binning interval: 10 min.

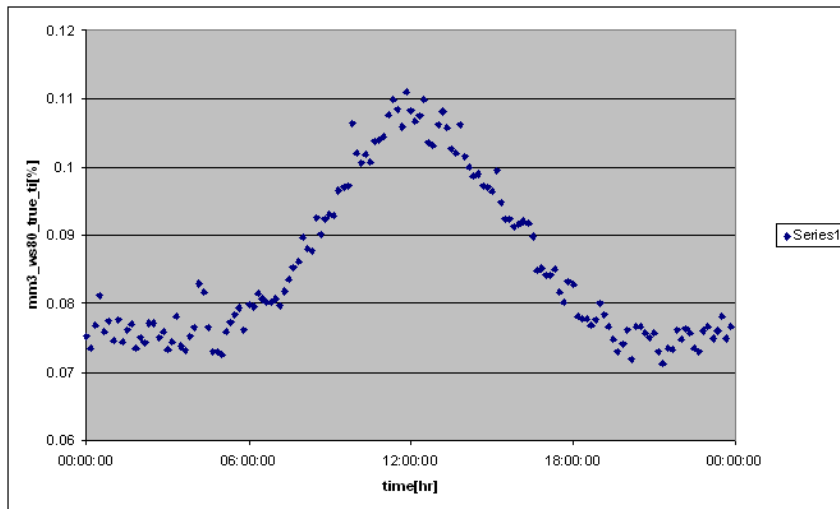
Temperature difference
 $T_{37m} - T_{10m}$



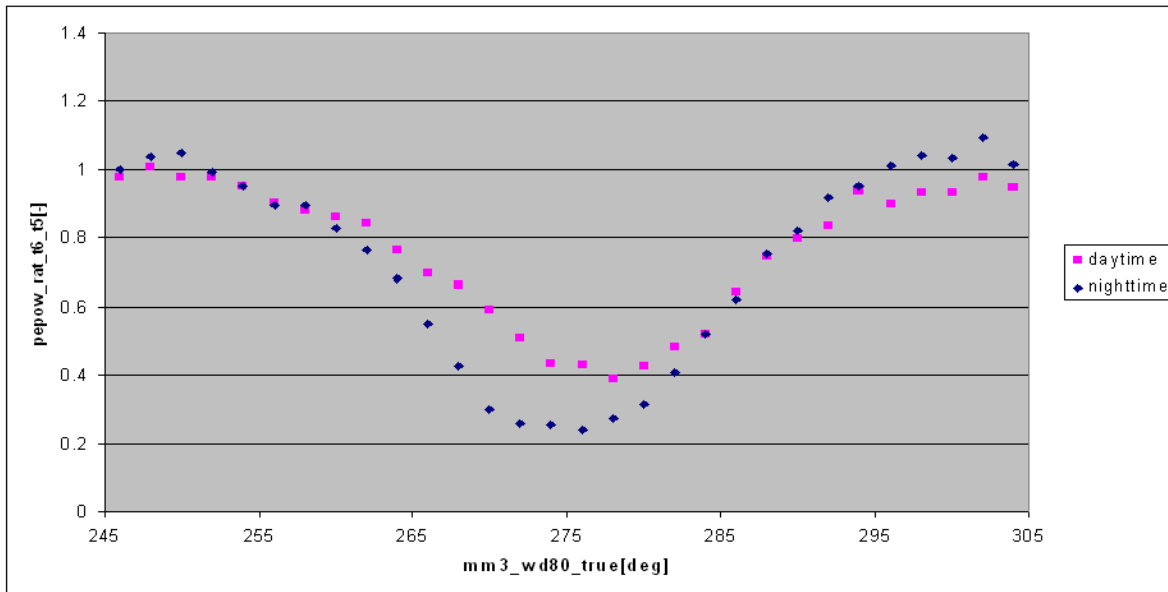
Wind shear



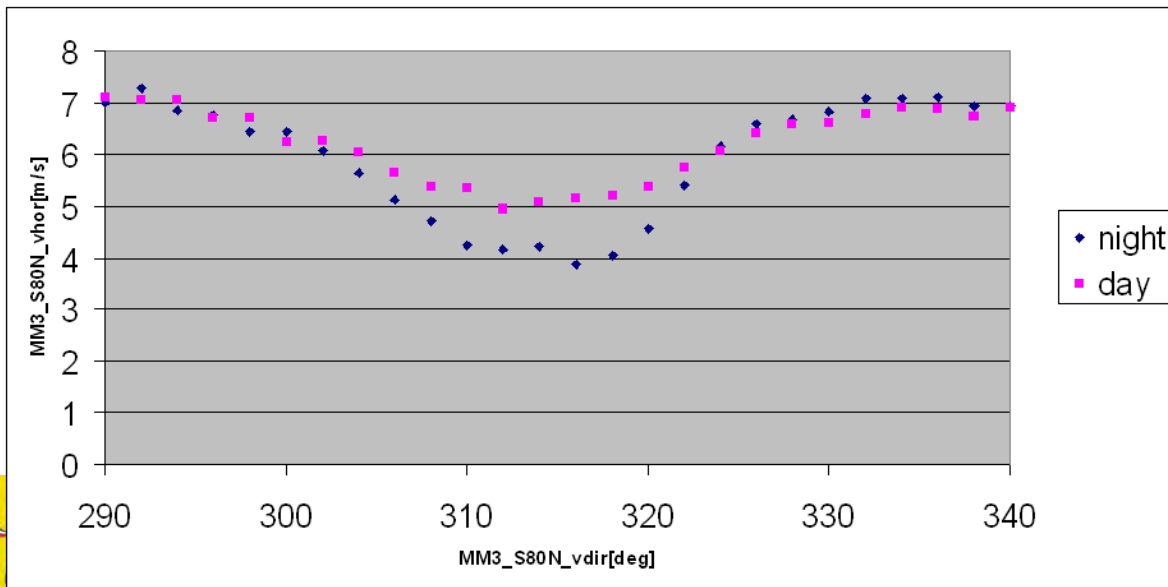
Turbulence intensity



Relative production of second turbine and velocity deficit at 3.5D (summer period) at day and night time



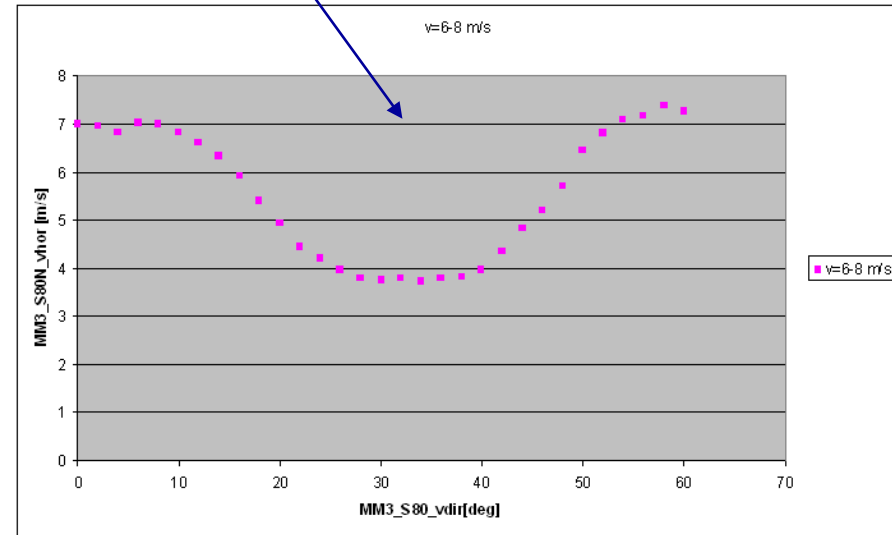
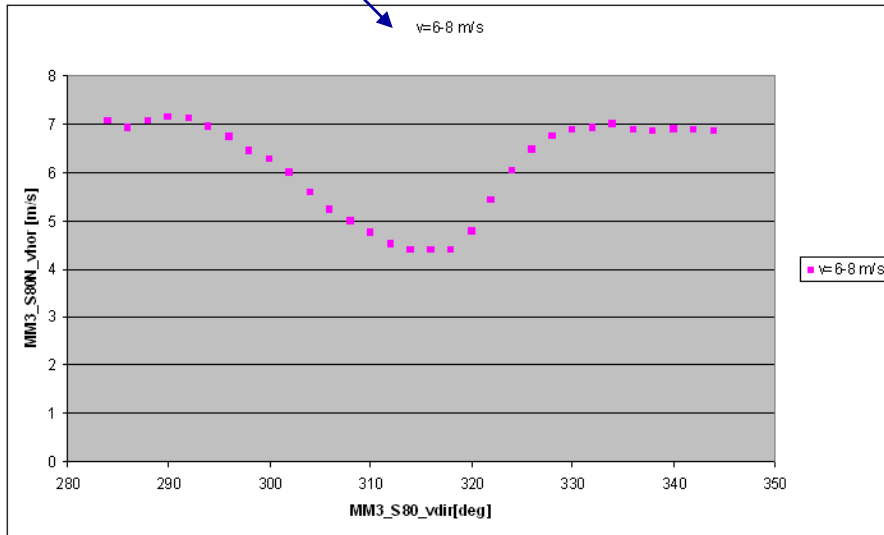
Night time: Much stronger wake effects



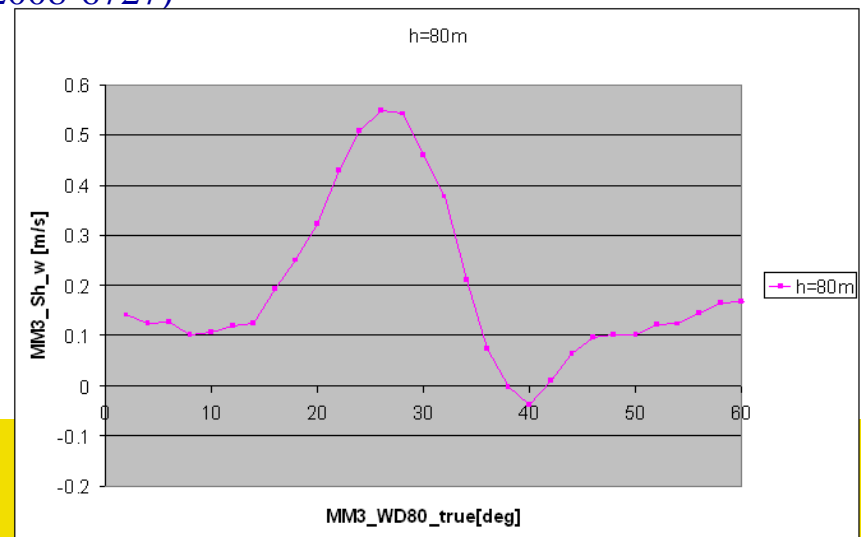
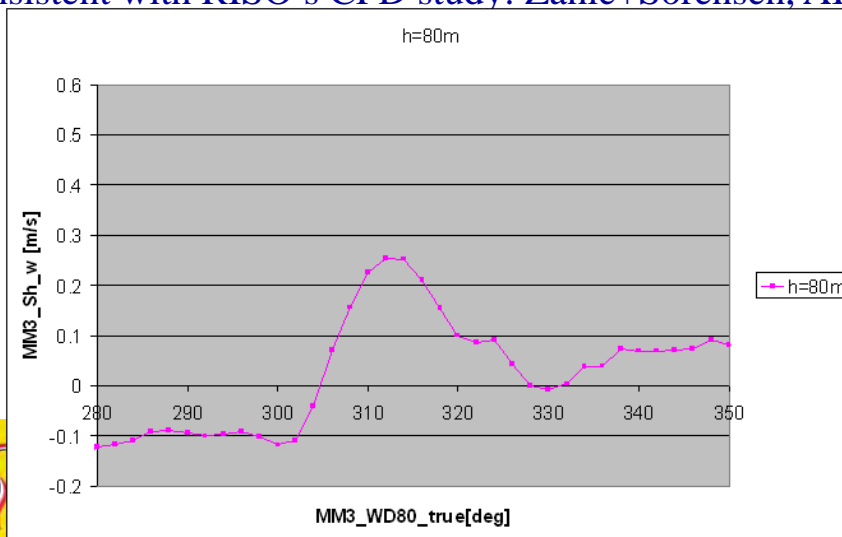
Meteorological wake measurements: Velocity deficit at hub height as function of wind direction

MM3 at 3.5D(315 degrees) from turbine 5 and 2.5D(31 degrees) from turbine 6

V_{free} between 6-8 m/s, derived from P(V) curve



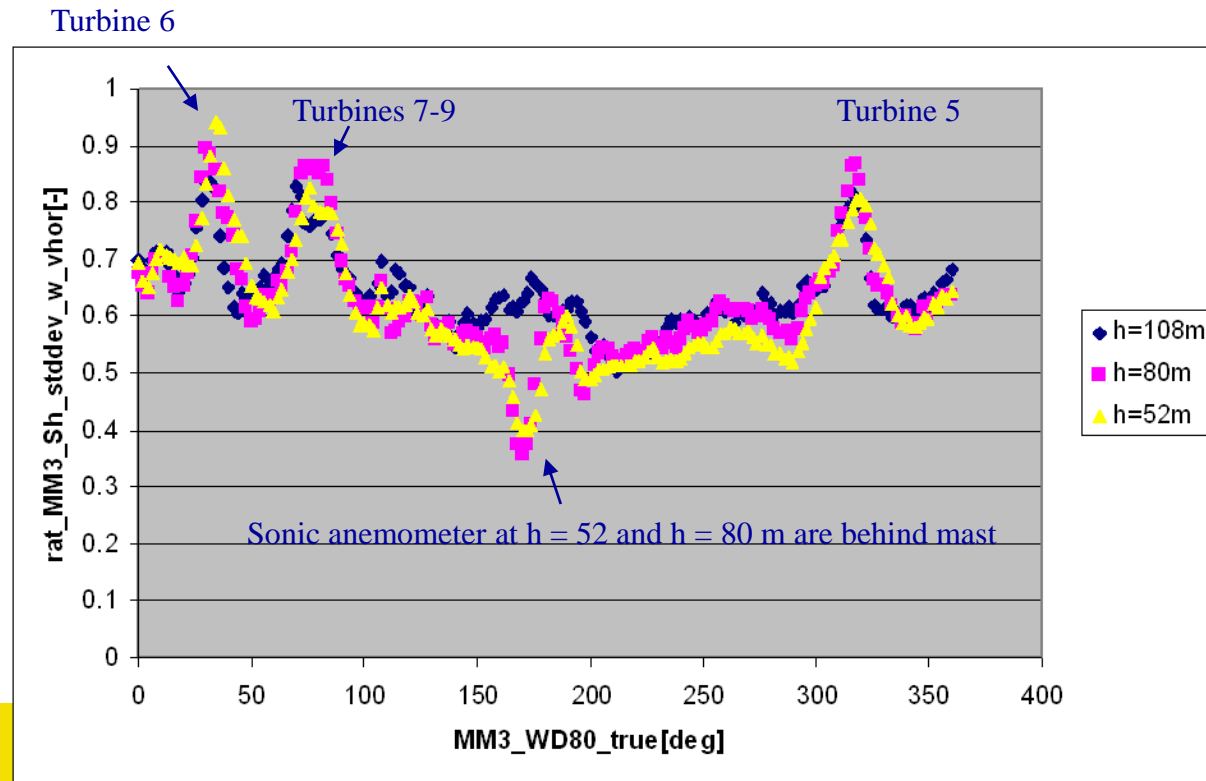
‘Asymmetry’ in wake profile, with lower velocities ‘left’ may be caused by wake rotation, see vertical velocity at hub height as function of wind direction: Larger vertical velocity at ‘left’ part of the rotorplane (looking from downwind) is consistent with counterclockwise wake rotation and leads to momentum transfer from low wind speed region (consistent with RISO’s CFD study: Zahle+Sorensen, AIAA-2008-6727)



Anisotropy in wake:

σ_w/σ_{hor} (sonic) at $h=52m$, $h=80m$ and $h =108 m$ as function of wind direction

- Free stream: $\sigma_w/\sigma_u \sim 0.6$ (Panofsky Dutton: 0.52)
- In wake: Turbulence more isotropic
- Mast disturbance visible at $h =52m$ and $h=80m$

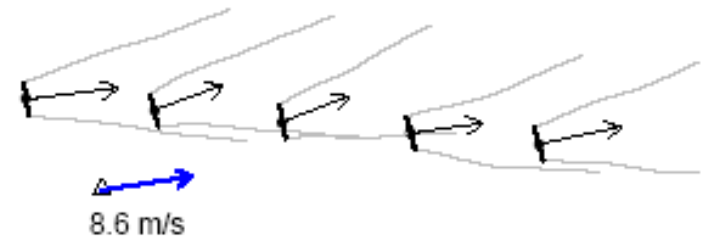


Animation showing wind direction variation (+wakes)

$$\bar{w}(T, \tau) = \int_T^{T+\tau} w(t) dt$$

Sampled with 2 Hz
Empirical wake expansion

440 min.



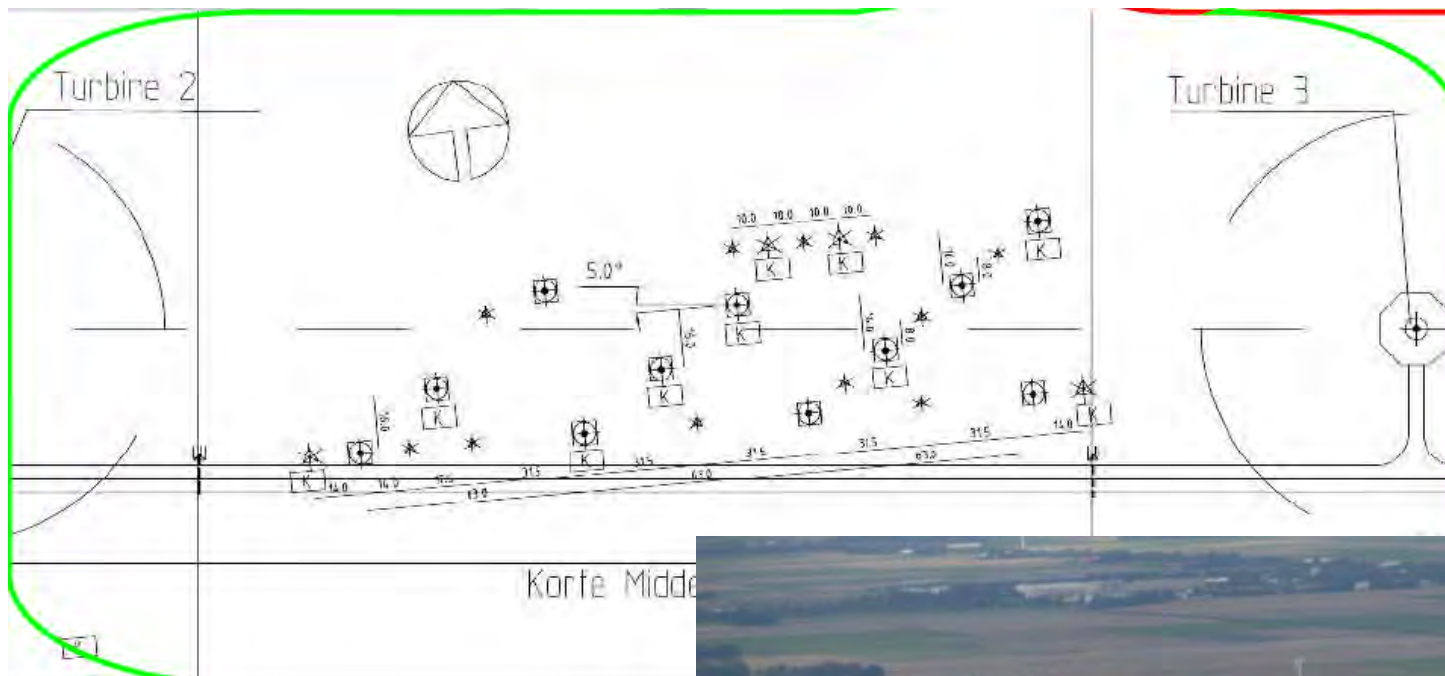
Energy Research Centre of the Netherlands (ECN)



Conclusions from EWTW wake measurements

- Largest power deficit is found at 2nd turbine. The power deficit from the 3rd to the 5th turbine is slightly lower
- At low ambient turbulence intensities:
Power deficit > 80%
- Turbulence becomes more isotropic in wake
- Effect of wake rotation visible in measurements of vertical velocity at hub height at 2.5 and 3.5D which results in asymmetric wake profile
- A clear diurnal cycle appears in temperature difference, wind shear, turbulence and resulting wake effects. Wake effects are much stronger at night time
- Data are used for validation of different types of (stationary, i.e. averaged) wake models in EU project Upwind.
- Wakes are very instationary





Scaled farm at EWTW prototype farm

- Farm with many small wind turbines and met-masts
- Research risks can be taken
- Along dominant wind direction
- Control of turbines in 'own hands'
- Side by side row comparison



Turbines

- 10 Aircon P10 turbines
- Rotor diameter: 7.6 m
- Hub height: 7.5 m
- Rated power: 10 kW
- Erected in March 2008
- 11th turbine 'at request'



Meteo masts

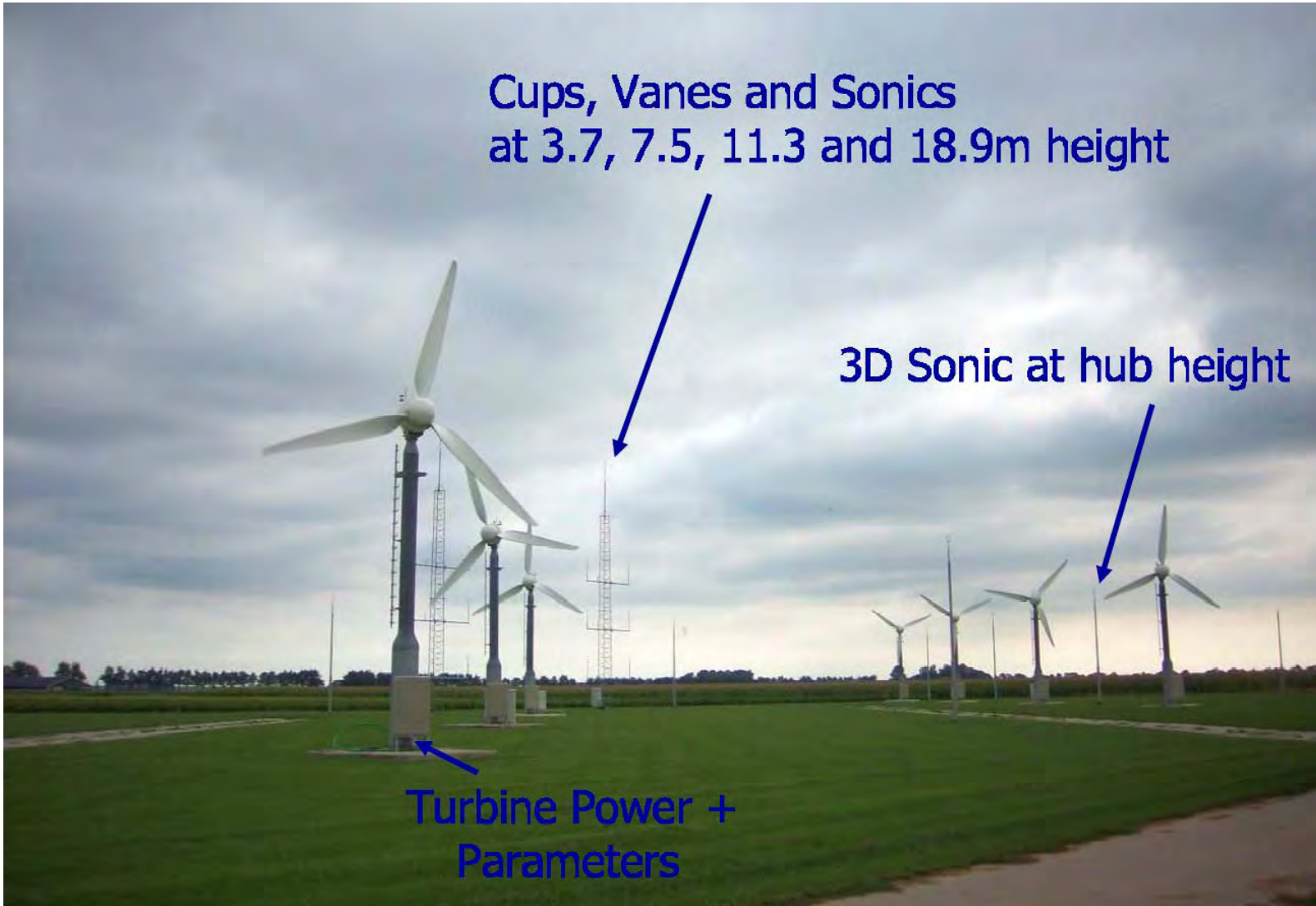
- 10 masts of 7.5 m
 - Measurement height: 7.5 m (hub height)
- 4 masts of 19 m
 - Measurement height: 3.7 m, 7.5m, 11.3m, 18.9 m



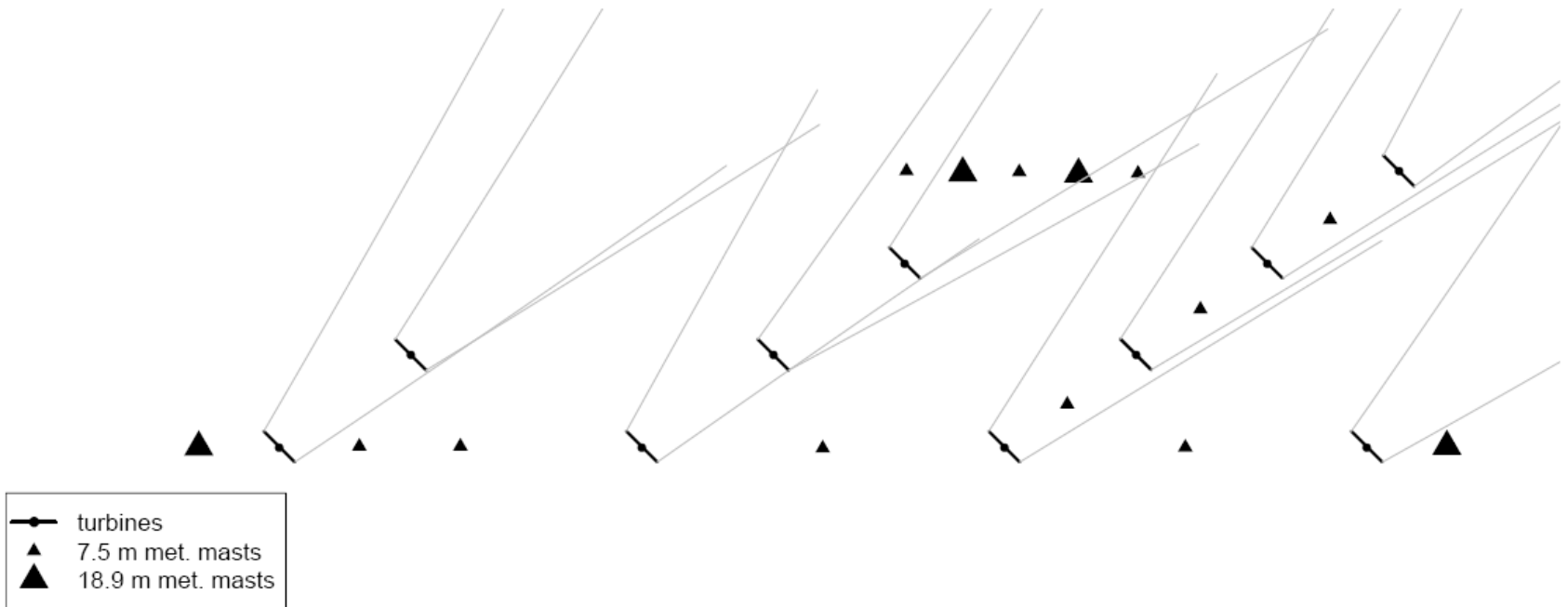
Cups, Vanes and Sonics
at 3.7, 7.5, 11.3 and 18.9m height

3D Sonic at hub height

Turbine Power +
Parameters



mean wind direction 225 °



Side by side row comparison

Wind farm control strategies

Side by side turbine comparison

Experiments to demonstrate turbine improvements

