The inaudible noise of wind turbines

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Presented at the Infrasound Workshop
November 28 – December 02, 2005, Tahiti

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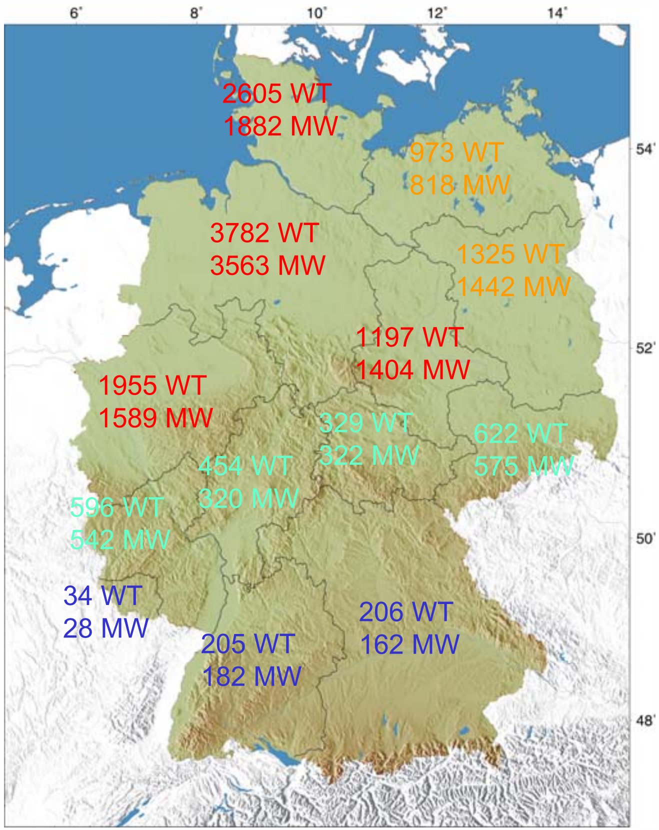
Regional distribution of wind turbines in Germany

source: Ender, 2003



Baden-Würtemberg	0.6
Bayern	0.3
Saarland	1.1
Hessen	2.1
Rheinland-Pfalz	3.0
Sachsen	3.4
Thürigen	2.2
Brandenburg	4.5
Mecklenburg-Vorpommern	4.1
Niedersachen	8.0
Nordrhein-Westfalen	5.9
Sachsen-Anhalt	5.8
Schleswig-Holstein	16.6

wind turbines / 100 km²

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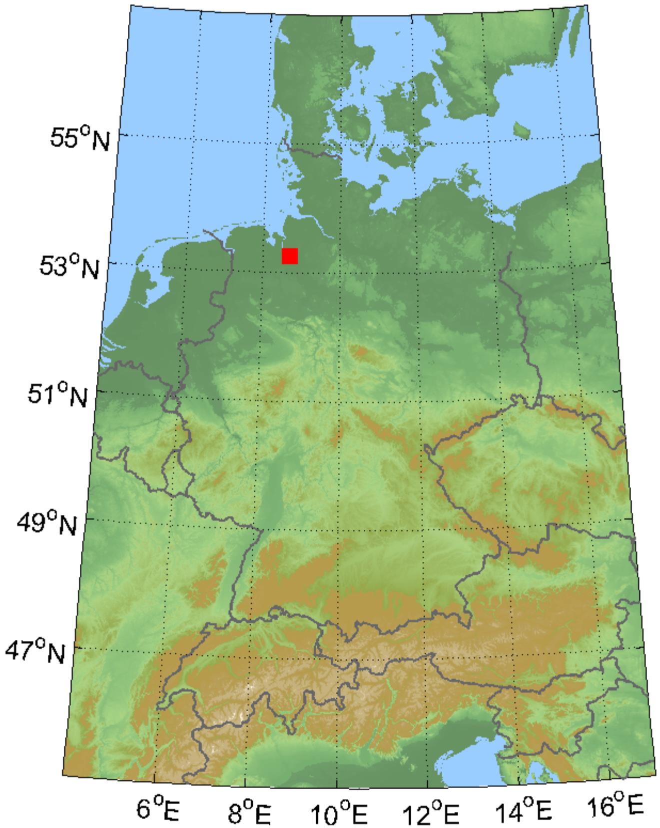
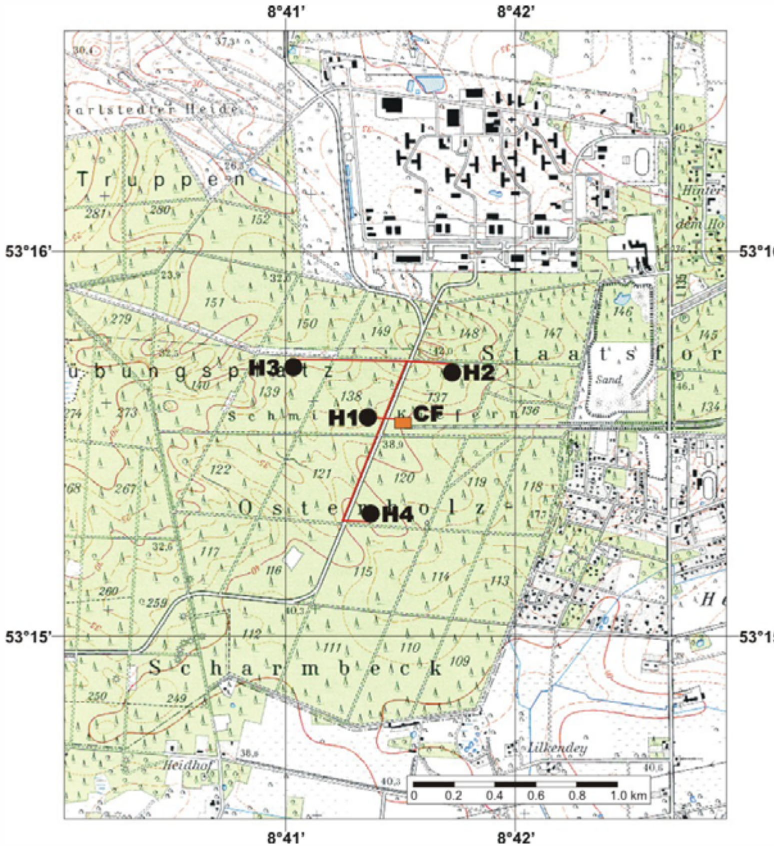
Content

- ➢ The Influence of Wind turbines on Infrasound recordings: IGADE
    - The German Infrasound Station IGADE
    - Data Examples, routine Analysis
- ➢ Noise Measurements at a single Wind Turbine
- ➢ Theoretical Estimation of the Sound Pressure Level
    - Comparison with Measurements
    - Scenarios, large Wind Farms, 5 MW Wind Turbines
- ➢ Conclusions

The German infrasound station IGADE





Milestones of the establishment of IGADE

Site Inspection

30 April 2003

Installation of IGAH1

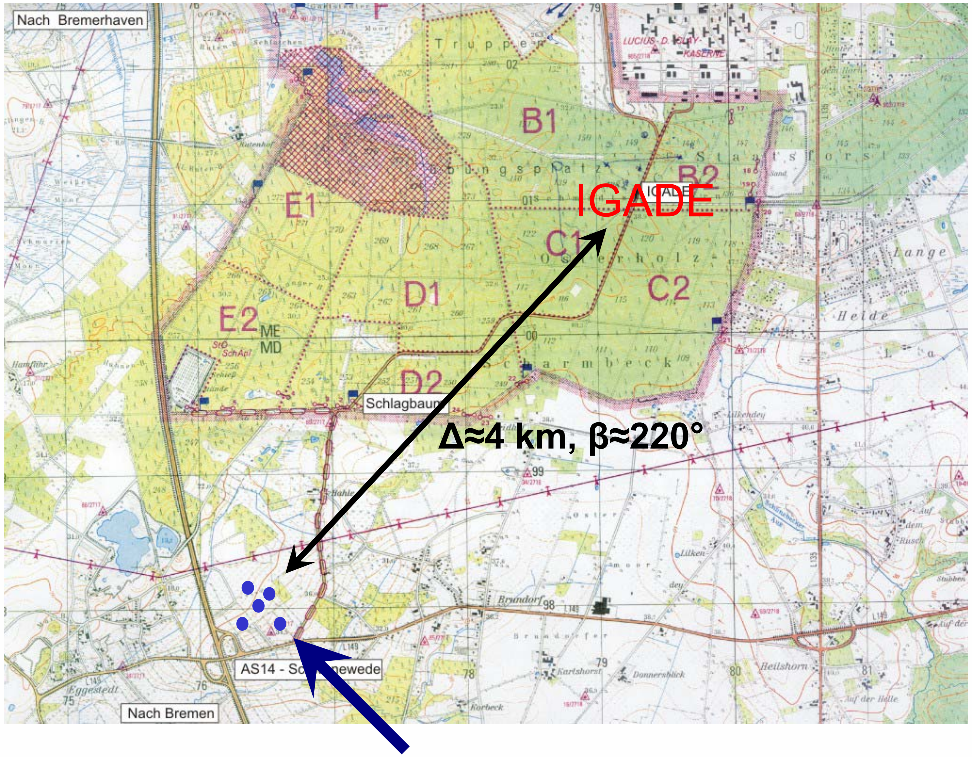
September / October 2003

Extension to
4 element array

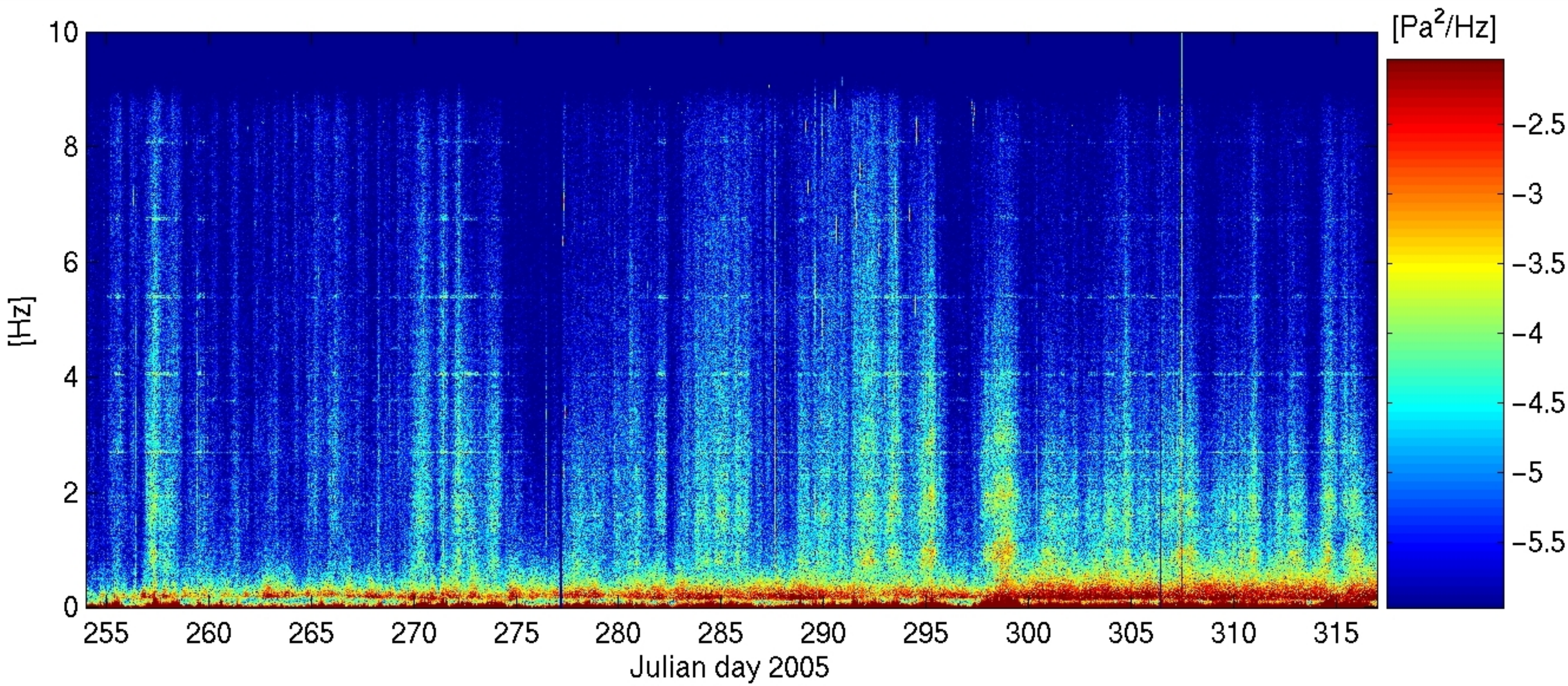
September 2004 - January 2005

Growing number of Wind
turbines close to the array

April / May 2005



The spectral fingerprint of wind turbines: IGAH1



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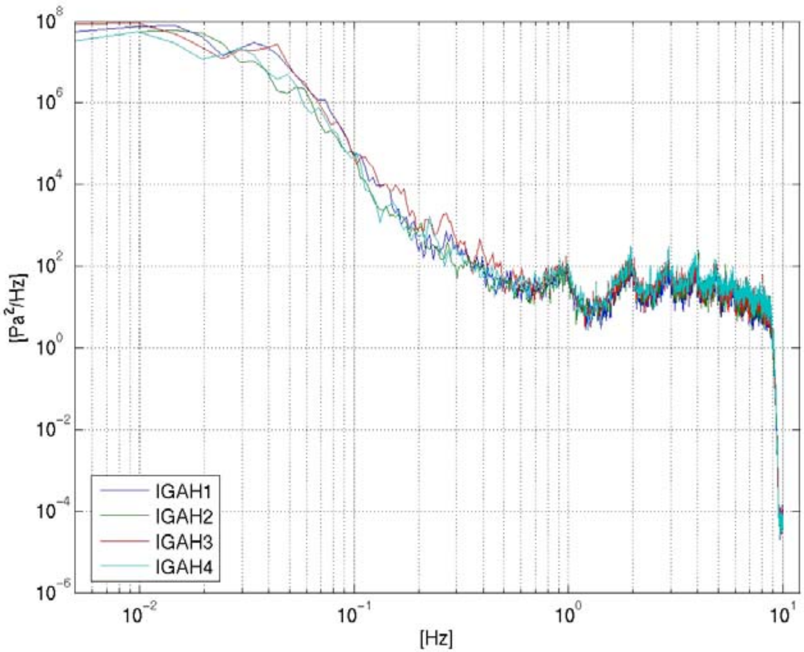
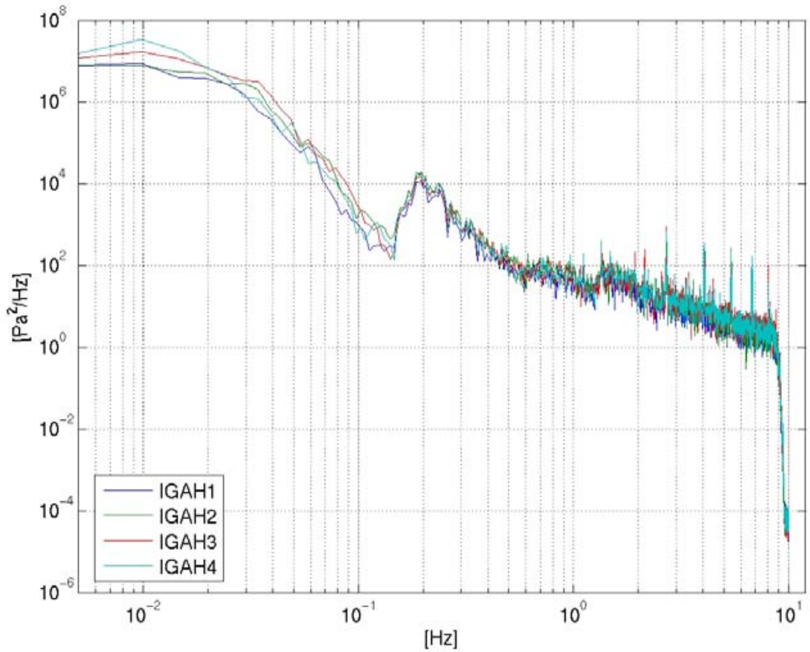
The spectral fingerprint of wind turbines: IGADE

07-May-2005 12:10 – 12:30 (UTC)



3 blades, Δf=1 Hz, 20 rpm

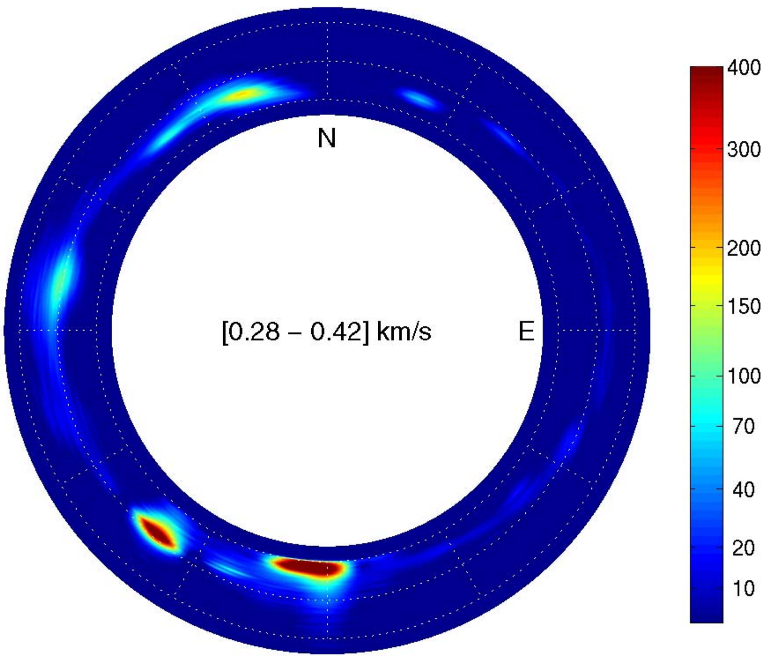
14-Sep-2005 19:40 – 20:00 (UTC)



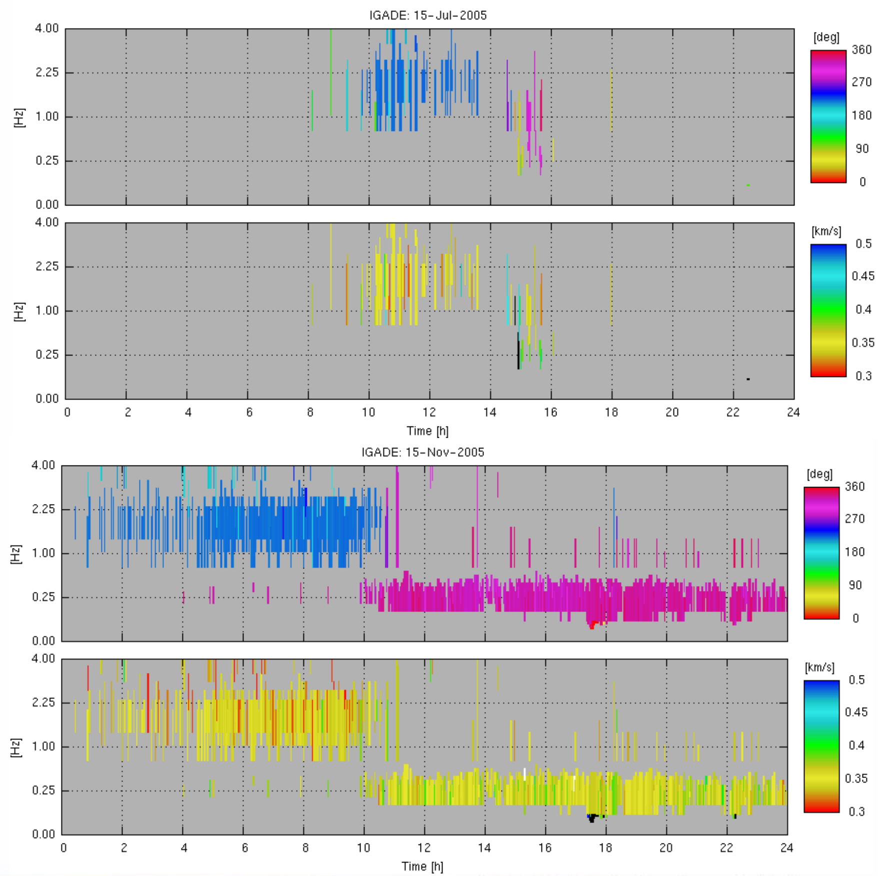
3 blades, Δf=1.35 Hz, 27 rpm

The fingerprint of wind turbines in the routine analysis

PMCC analysis



February – November 2005, [0.7 4.0] Hz



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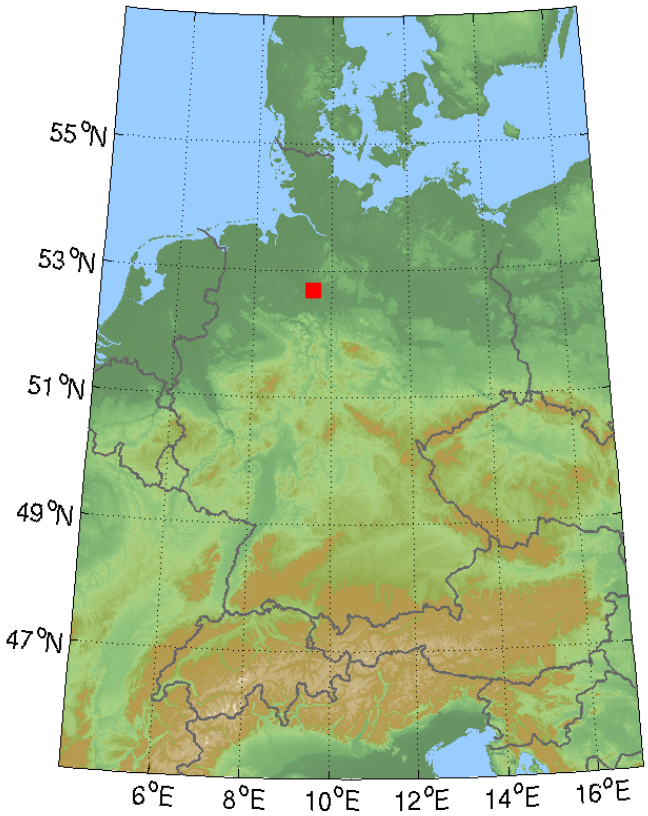
A single wind turbine in northern Germany

VESTAS V47
200 kW
h=65 m, r=24 m
rpm=[20 26]



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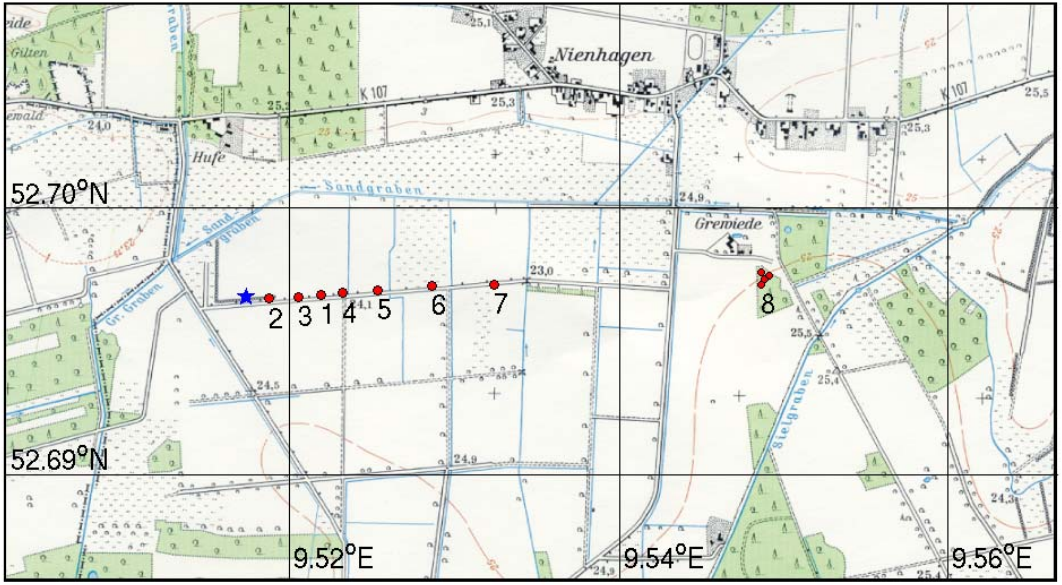
Configuration of the Hufe field experiment



1 2 3 4: 07-Jul-2004 - 19-Jul-2004, HUF01, HUF02, HUF03, HUF04
1 5 6 7: 19-Jul-2004 - 29-Jul-2004, HUF01, HUF05, HUF06, HUF07
8 : 29-Jul-2004 - 05-Aug-2004, HUF08, HUF09, HUF10, HUF11

Measuring along the track and in the wood

Huf07

Huf06

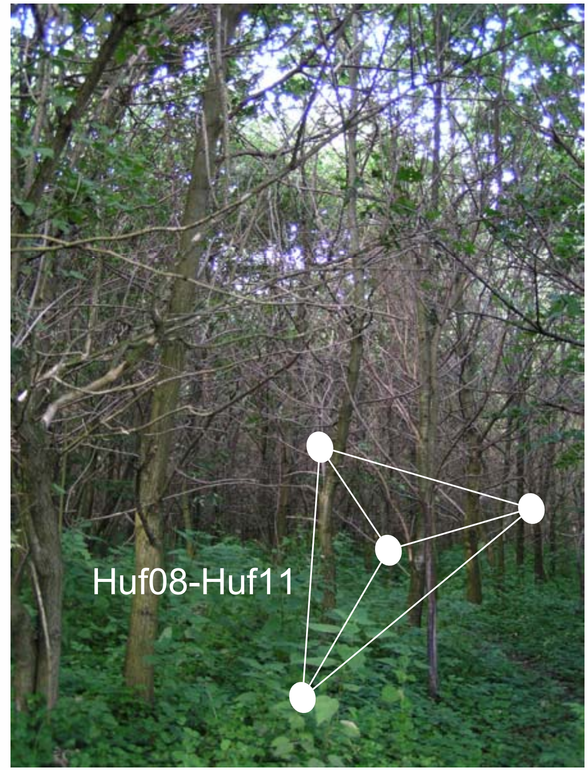
Huf05

Huf04

Huf03

Huf02

Huf01



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Station Huf01

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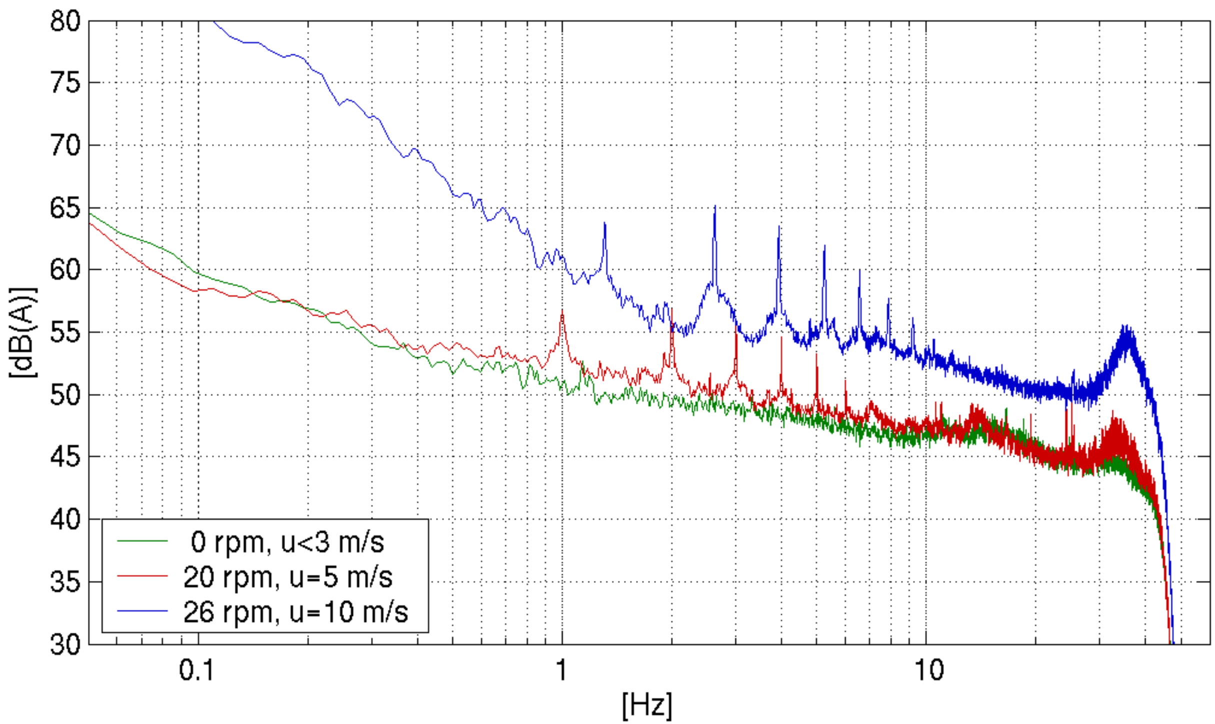
Measured signals, Huf03, d=200 m

frequency domain



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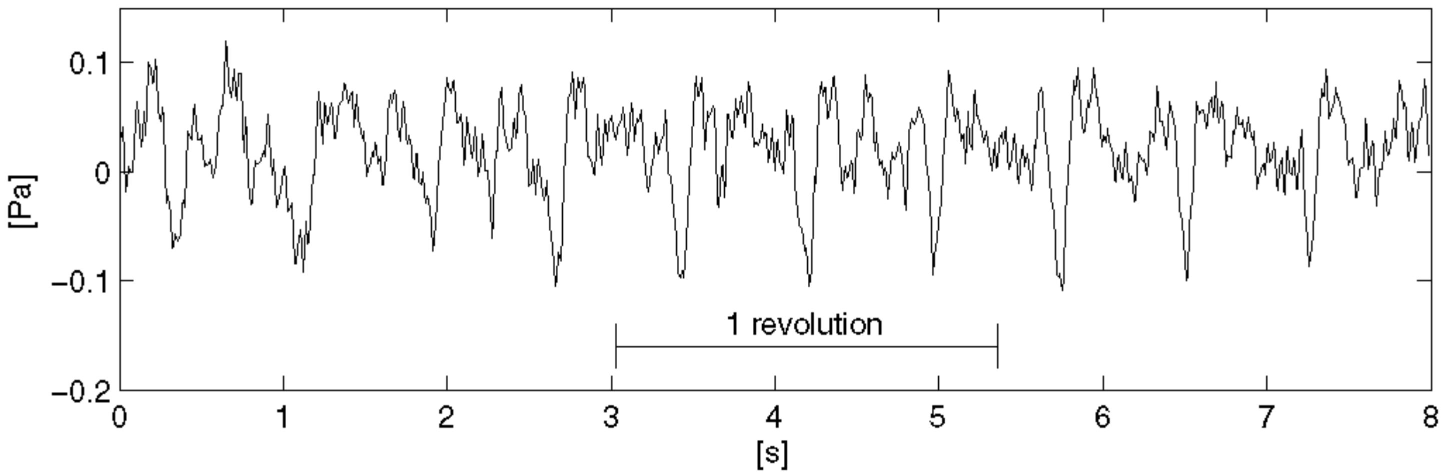
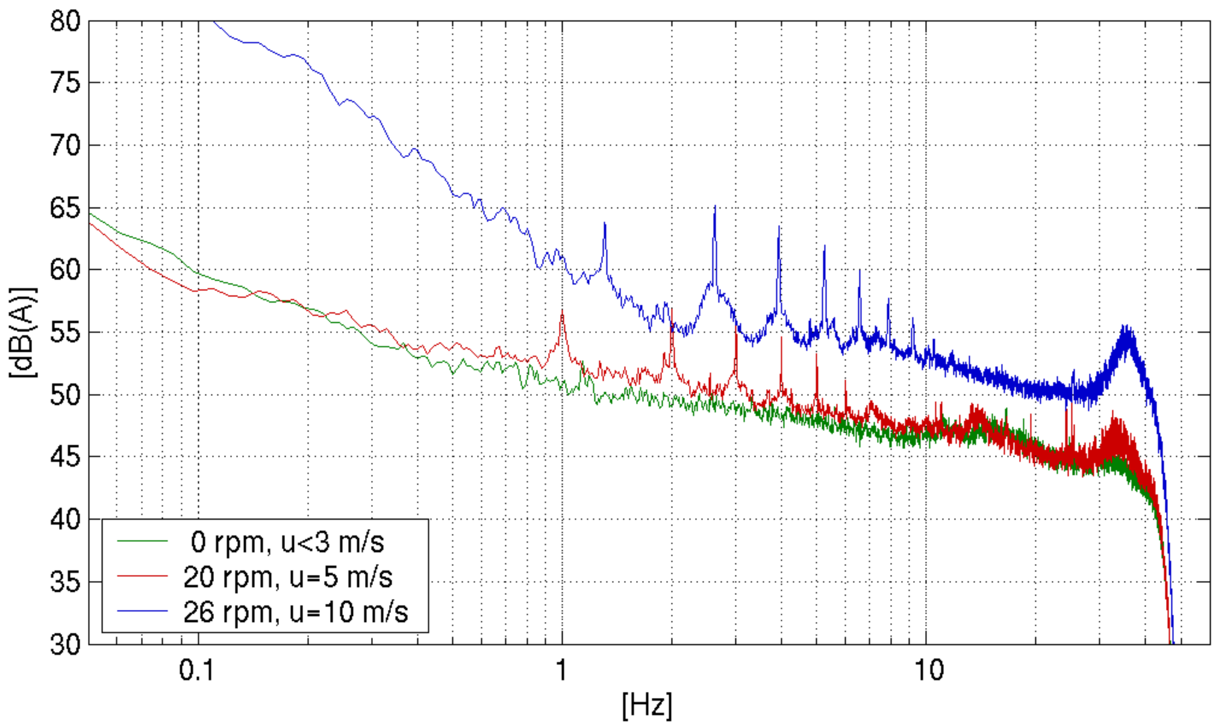
Measured signals, Huf03, d=200 m

time domain, 0.5 Hz high pass filtered



Measured signals, Huf03, d=200 m

frequency domain



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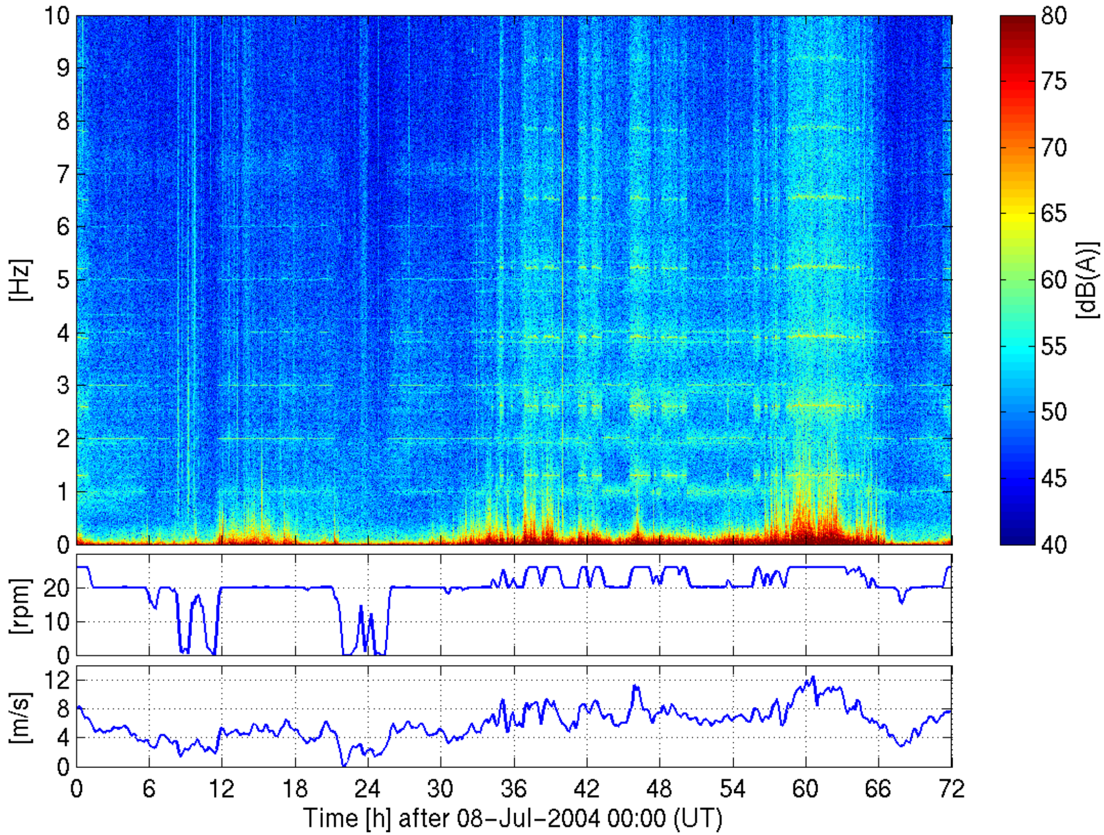
Time-frequency analysis, Huf03, d=200 m



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Theoretical SPL-estimation

Hubbard & Shepherd (1991, JASA)

$$P_n = \frac{k_n\sqrt{2}}{4\pi d}\sum_m \left(e^{im(\theta-\pi/2)} J_x(k_n R_e \sin\gamma)\right)\cdot\left(a_m^T \cos\gamma - \frac{nB-m}{k_n R_e} a_m^Q\right)$$

P_n – RMS sound pressure of the n-th harmonic
n – sound pressure harmonic number
k_n – nBω/c
B – number of blades
ω – rotor speed
c_0 – sound speed
R_e – effective blade radius

d – distance from the rotor
m – blade loading harmonic index (m=…,-1,0,1,..)
J_x – Bessel function of first kind and of order x=nB-m
γ – azimuth to listener
θ – altitude angle to listener
a_m^Q – complex Fourier coefficients of thrust forces
a_m^T – complex Fourier coefficients of torque forces

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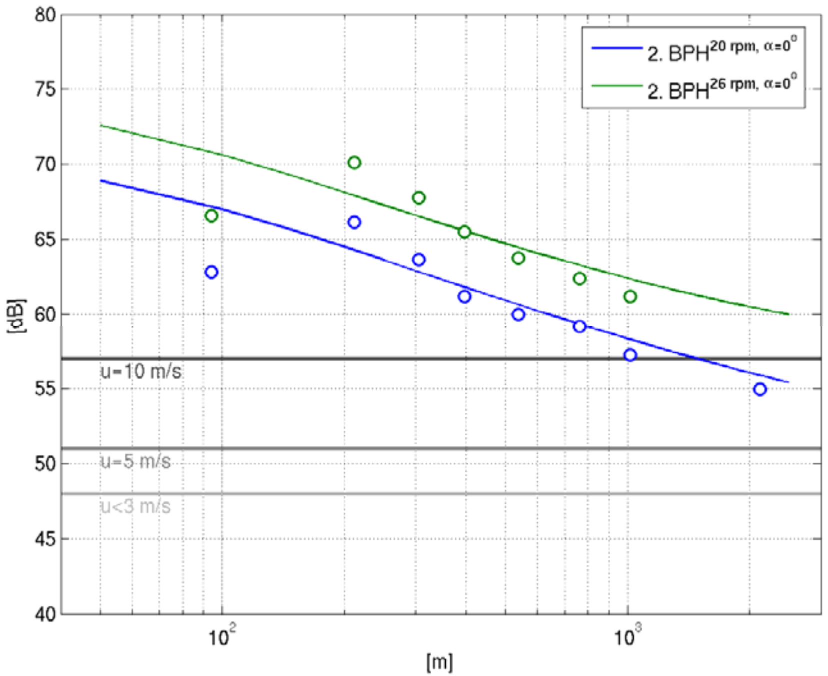
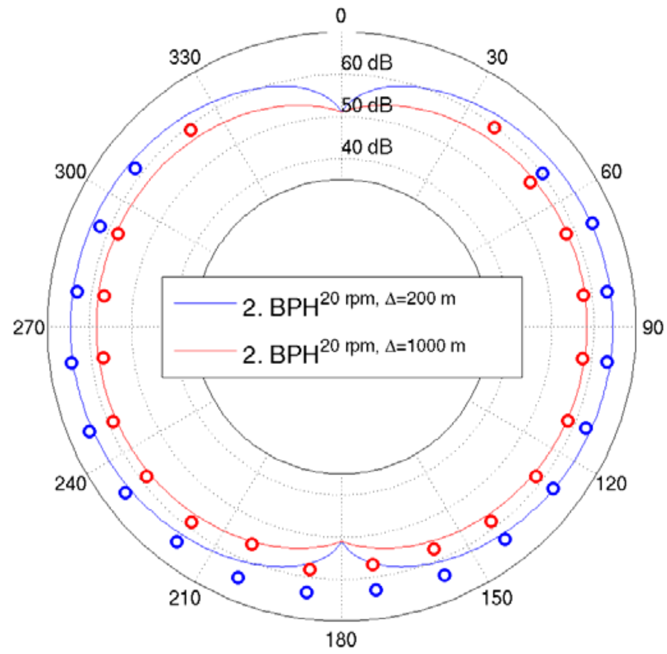
Comparison between measured and estimated SPL

SPL as a function of distance

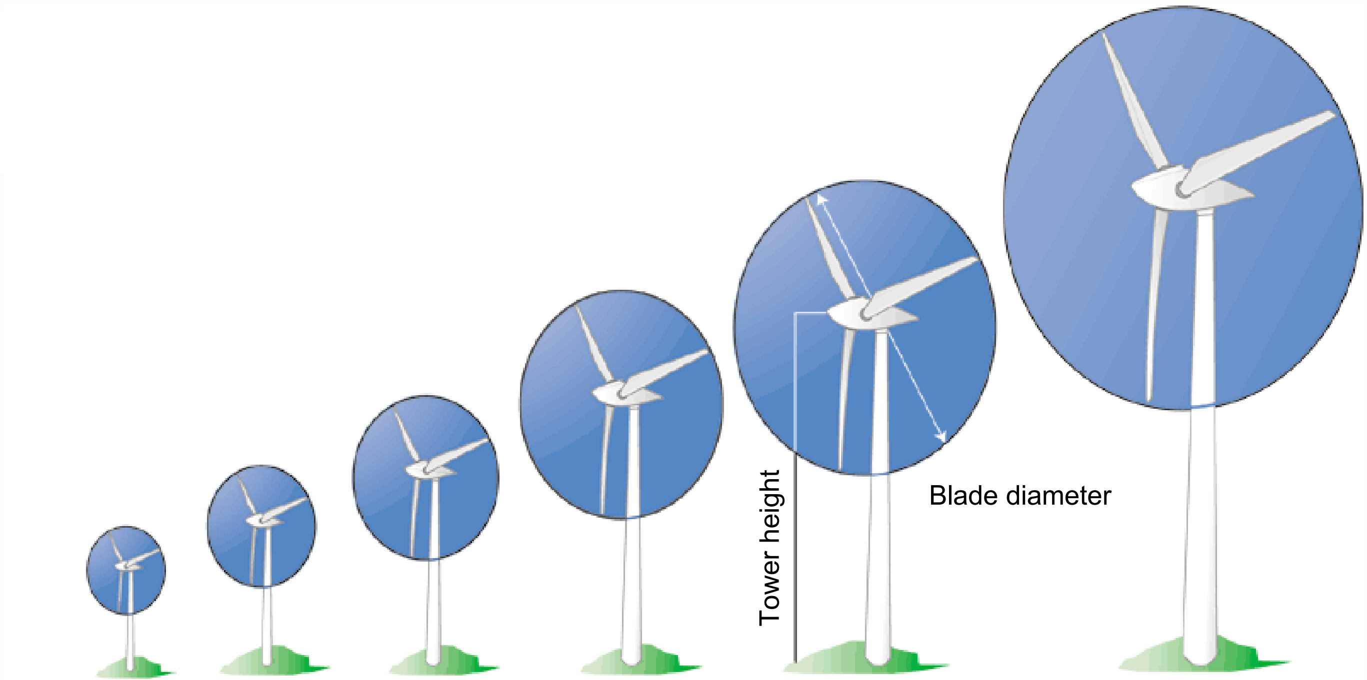


SPL as a function of azimuth



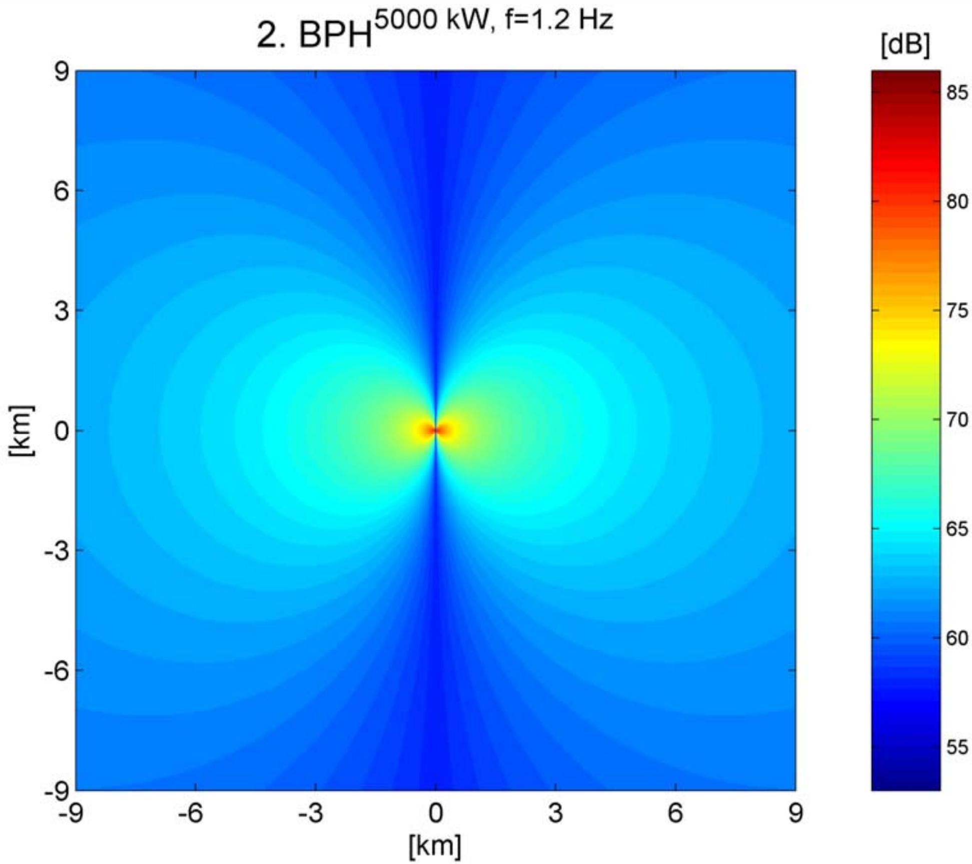
account for surface effects (e.g. reflections) by adding 3 dB to the estimated curves

Estimating the SPL generated by wind turbines



	1980	1985	1990	1995	2000	2005
Power	: 30 kW	80 kW	250 kW	600 kW	1.500 kW	5.000 kW
Blade diameter	: 15 m	20 m	30 m	46 m	70 m	115 m
Tower height	: 30 m	40 m	50 m	78 m	100 m	120 m
Energy production per year	: 35.000 kWh	95.000 kWh	400.000 kWh	1.250.000 kWh	3.500.000 kWh	ca. 17.000.000 kWh

Estimating the SPL generated by (a) large wind turbine(s)



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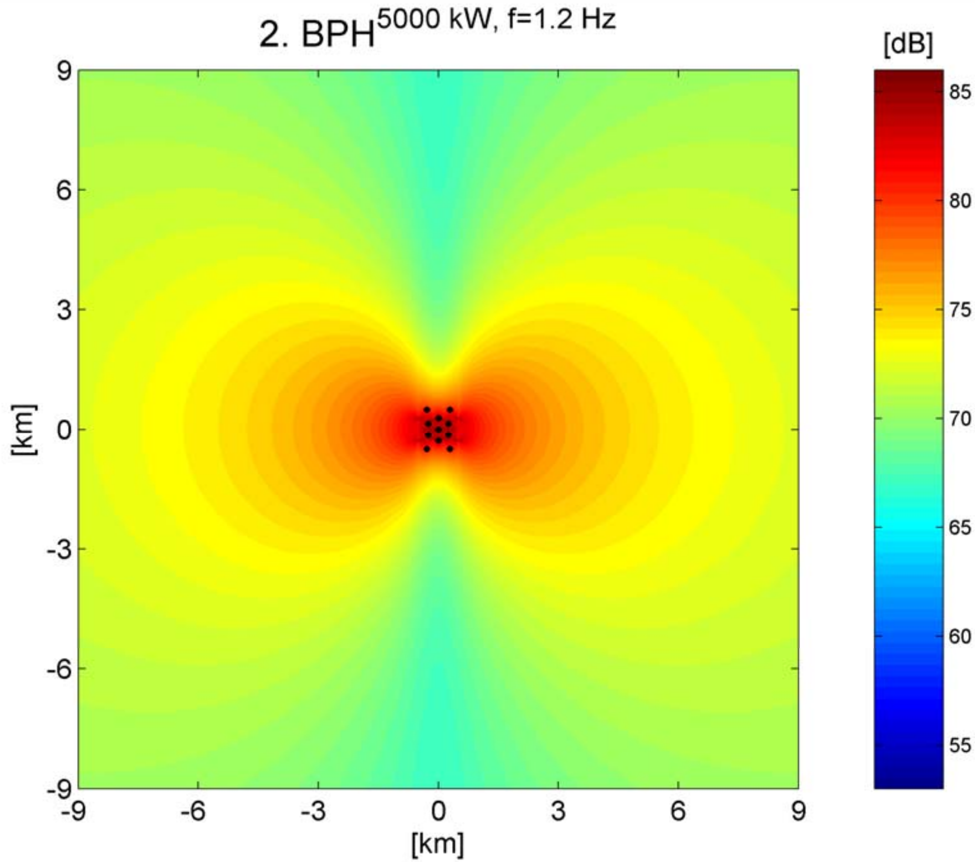
Estimating the SPL generated by (a) large wind turbine(s)



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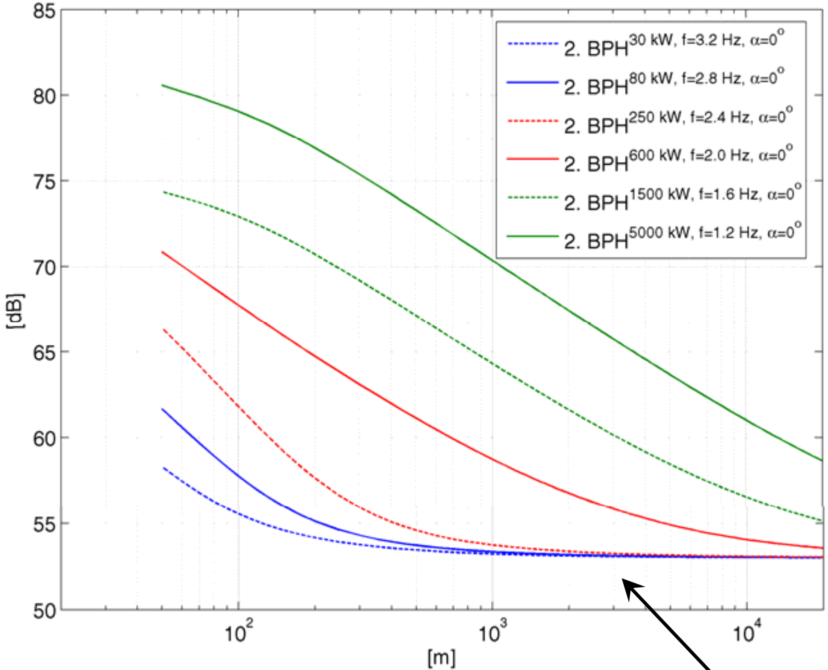
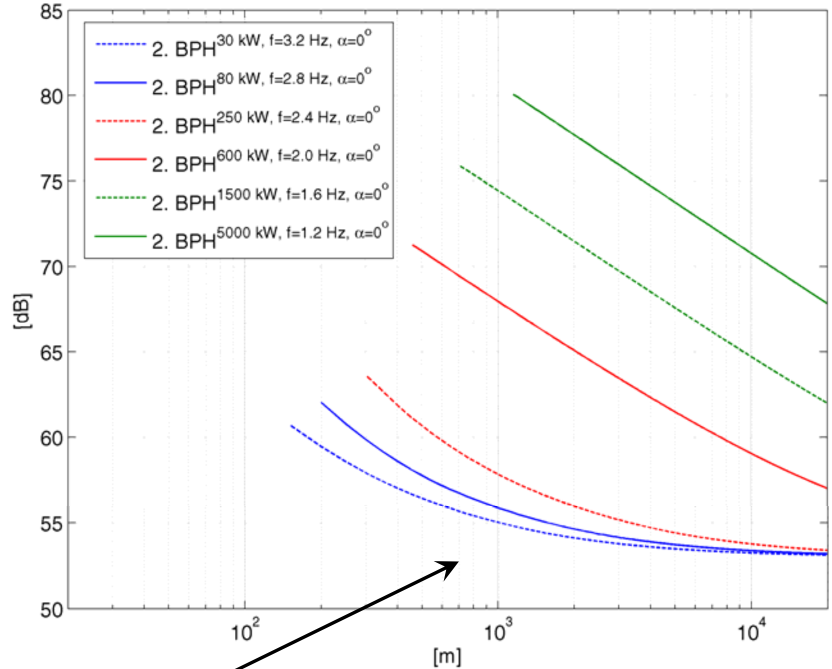
Estimating the SPL generated by Wind Turbines/Farms at ~2 Hz

single wind turbine



11-element wind farm



noise level

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Conclusions

- number of wind turbines and their size is constantly growing

- wind turbines and wind farms generate strong infrasonic noise which is characterized by their blade passing harmonics (monochromatic signals)

- generated noise of wind turbines can theoretically be estimated
  - geometrical spreading ~ R^{-1}
  - SPL ~ rpm^4

- recordings from field measurements near a single wind turbine show that the theoretical model is also valid for frequencies below a few Hz

- minimum distance between an infrasound array and a wind farm can be estimated to avoid reduction of the array's detection capability (e.g. 600MW wind turbine: d>15 km, 11-element wind farm: d>30 km)

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