Infrasound emission generated by wind turbines

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Abstract

Aerodynamic noise emissions from the continuously growing number of wind turbines in Germany are creating increasing problems for infrasound recording systems. Such systems are equipped with highly sensitive micro pressure sensors, which are accurately measuring acoustic signals in a frequency range inaudible to humans. At infrasound station IGADE, north of Bremen, a constantly increasing background noise has been observed throughout the years since its installation in 2005. The spectral peaks are reflecting well the blade passing harmonics, which vary with prevailing wind speeds. Overall, a decrease is noted for the infrasound array's detection capability. This aspect is particularly important for the other two sites of the German infrasound stations I26DE in the Bavarian Forest and I27DE in Antarctica, because plans for installing wind turbines near these locations are being under discussion. These stations are part of the International Monitoring System (IMS) verifying compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT), and have to meet stringent specifications with respect to infrasonic background noise.

Therefore data obtained during a field experiment with mobile micro-barometer stations for measuring the infrasonic pressure level of a single horizontal-axis wind turbine have been revisited. The results of this experiment successfully validate a theoretical model which estimates the generated sound pressure level of wind turbines and makes it possible to specify the minimum allowable distance between wind turbines and infrasound stations for undisturbed recording. Since the theoretical model also takes wind turbine design parameters into account, suitable locations for planned infrasound stations outside the determined disturbance range can be found, which will be presented; and vice versa, the model calculations' results for fixing the minimum distance for wind turbines planned for installation in the vicinity of an existing infrasound array.

Observations at IGADE

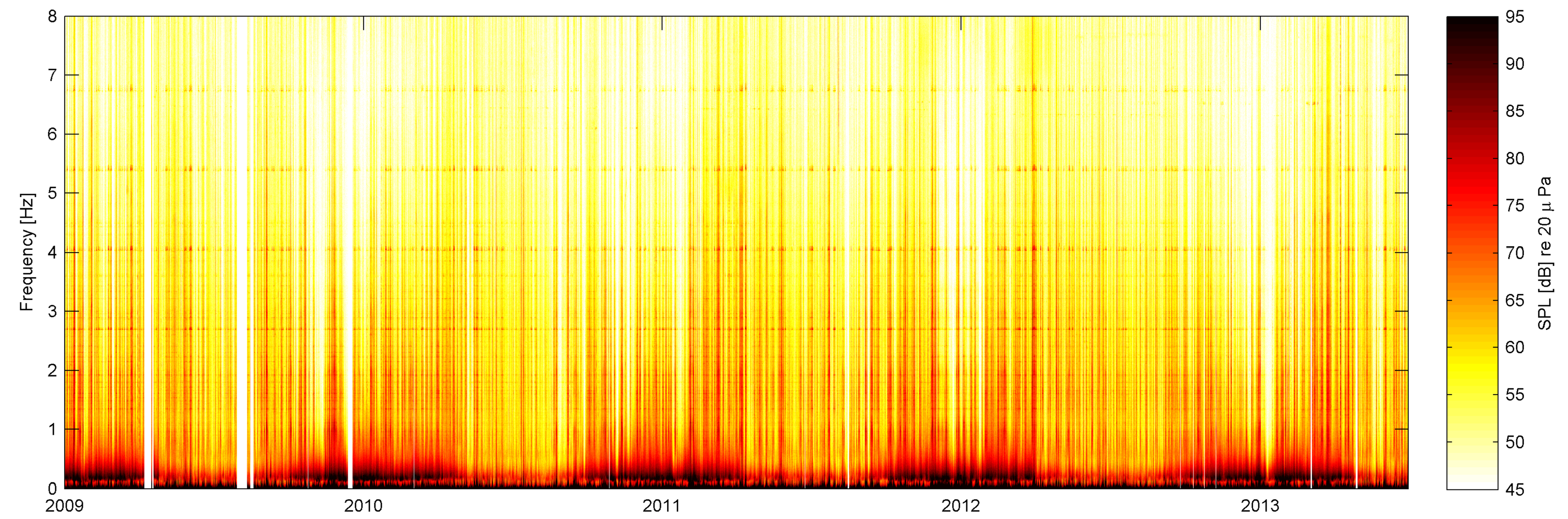

Fig. 1: *Sound pressure level (SPL) measured at stations site IGAH2, which is one of the four array elements of IGADE, over the time period from January 2009 to June 2013. Spectral peaks at 1.35, 2.70, 4.05, and 5.40 Hz are clearly visible throughout the years during those periods which are characterized by strong winds going along with an increased background noise level. Those spectral lines are generated by four 1.5 MW wind turbines being approximately 4.1 km away from the sensor; whereas 1.35 Hz is the blade passing harmonic (BPH) of these three-blade horizontal axis wind turbines, rotating with 27 revolutions per minute at moderate to high wind speeds.*

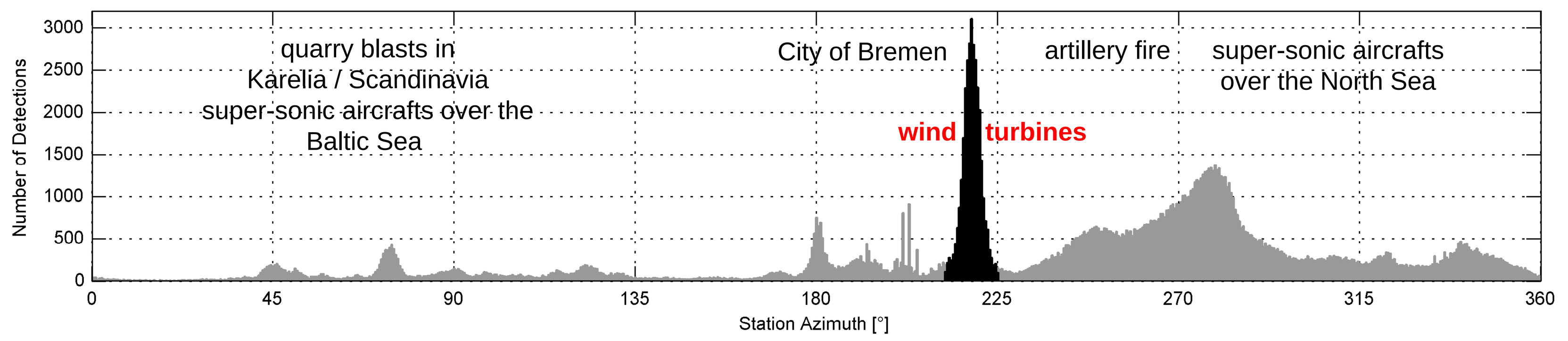

Fig. 2: *Distribution of station azimuths of coherent signal detections - generated by anthropogenic sources - obtained at IGADE in the frequency range from 0.7 to 4.0 Hz over 4.5 years; most prominent is the direction of 219°±6° which coincides with the near by wind park, overall ~16.5 % of all detections. Therefore infrasound emissions generated by large wind turbines have a strong impact on the detection capability of infrasound arrays, leading to partial blinding in the direction of those turbines.*

Field campaign – infrasound measurements at a single wind turbine

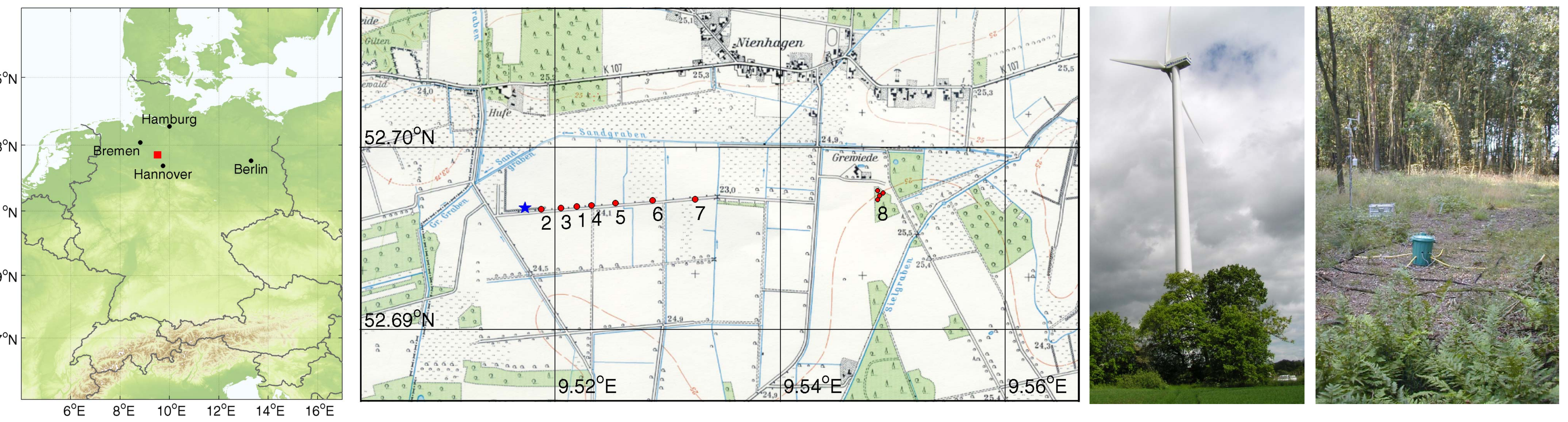

Fig. 3: *In summer 2004, BGR carried out four weeks fieldwork 20 km to the north of Hannover, near Schwarmstedt, using four mobile infrasound recording systems, each equipped with a MB2000 micro-barometer. Measurements were carried out at a single wind turbine (Vestas V47 200 kW) to clearly define the correlation between source and recorded signals, which was challenging because the average wind turbine density in Lower Saxony is about 1 per km². A total of eight sites were selected along an ~2 km long east-west line and the survey was divided into three consecutive periods: 1-4 from 7 to 19 July, 5 to 7 from 19 to 29 July, and 8 from 29 July to 5 August. In order to obtain optimum recording conditions for infrasound signals at low ambient noise, the vegetation along the survey line at sites 1 to 7 was used to reduce wind effects. The small array around measuring point 8 was located in a small grove. Furthermore, spatial filters consisting of four 3 m long porous hoses were laid out on the ground.*

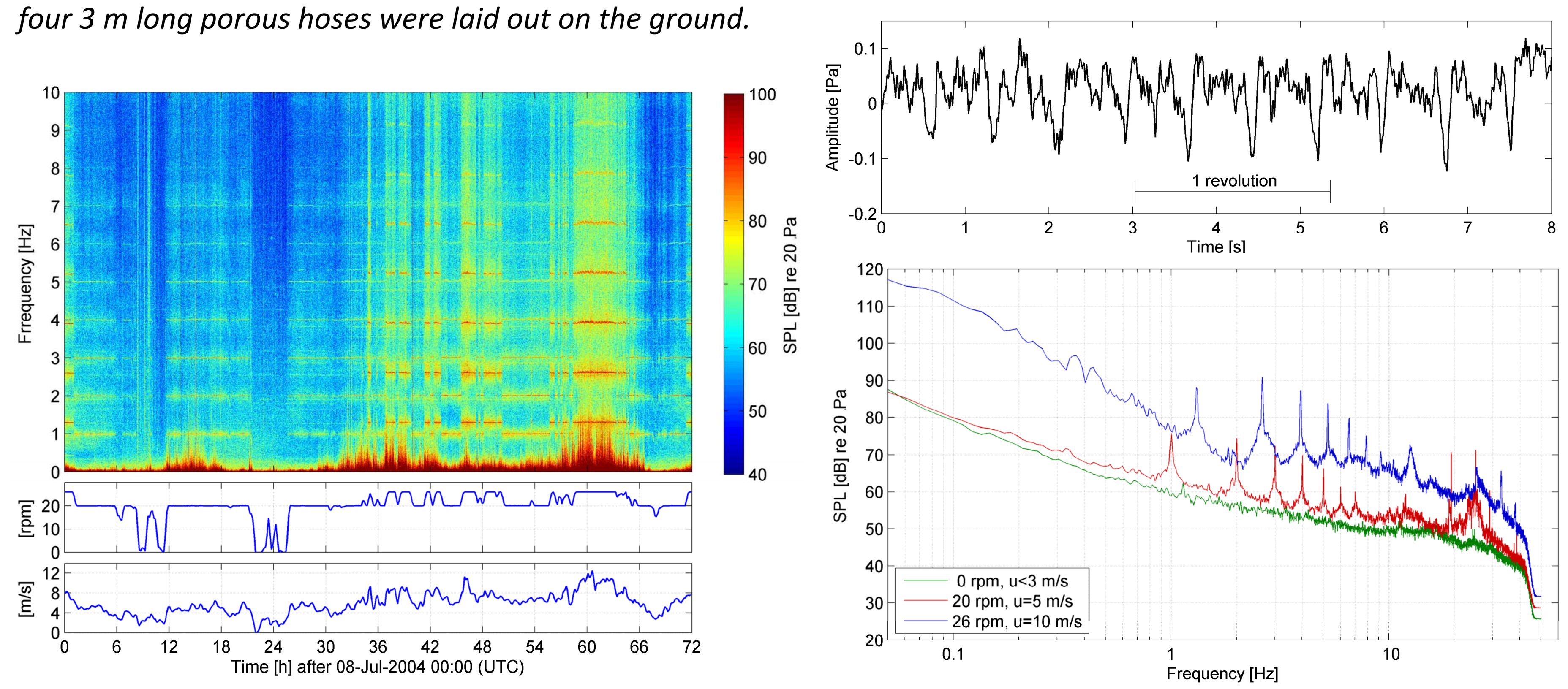

Fig. 4: *The time-frequency analysis clearly demonstrates the correlation between the emitted sound pressure level and the rotational speeds and wind speeds. For a period of 72 hours, the average SPL, calculated every five minutes, is plotted against the rotational speed, as well as the wind speed measured at the hub. The strong impact of the aerodynamic noise generated by wind turbines on infrasound recording systems becomes dominant at the time interval from 36 to 66 hours in particular. At site 3, about 200 m from the wind turbine, the signal amplitudes (blade passing harmonics –BPH) exceed the background noise by up to 20 dB and 10 dB at high and moderate wind speeds, respectively.*
Acoustic impulses arise from rapid changes in the aerodynamic load on the blades caused by the blades passing turbulent or discontinuous air flow. The time series shows that the aerodynamic wake of the horizontal-axis wind turbine's tower causes the strongest load variations by passing blades and therefore generates the strongest acoustic impulsive signals.

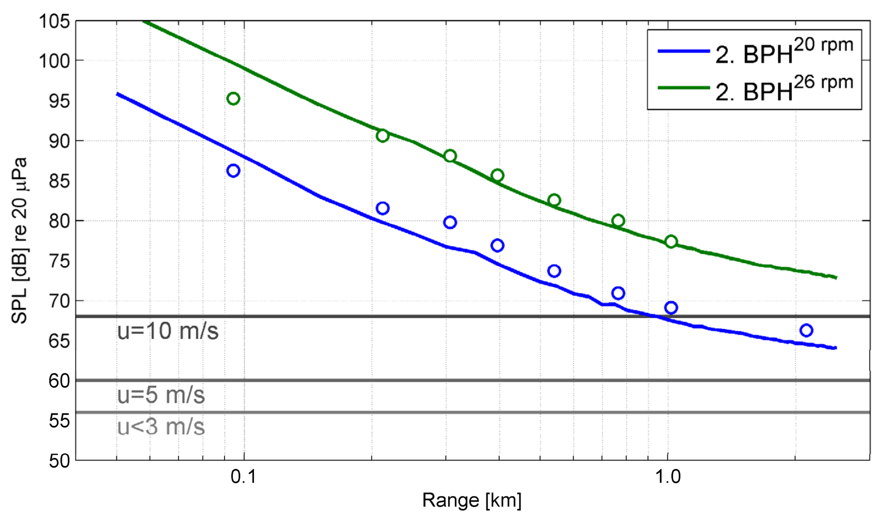

Fig. 5: *Comparison between the measured and theoretical SPL [Viterna, 1981, NASA CP 2815] is made for the whole range of 2 km considering rotational speeds of 20 and 26 rpm during westerly winds. The 2nd BPH is considered because it has the strongest spectral amplitude and therefore is most likely of being observed at all sites. In general, good agreement is observed, except at location 1 due to the fact that the signals were recorded in the proximal field at distances of a single wavelength. However, our theoretical model describes the SPL in the distal field of a wind turbine, hence overestimate the measured values of infrasonic.*

Estimating noise amplitudes

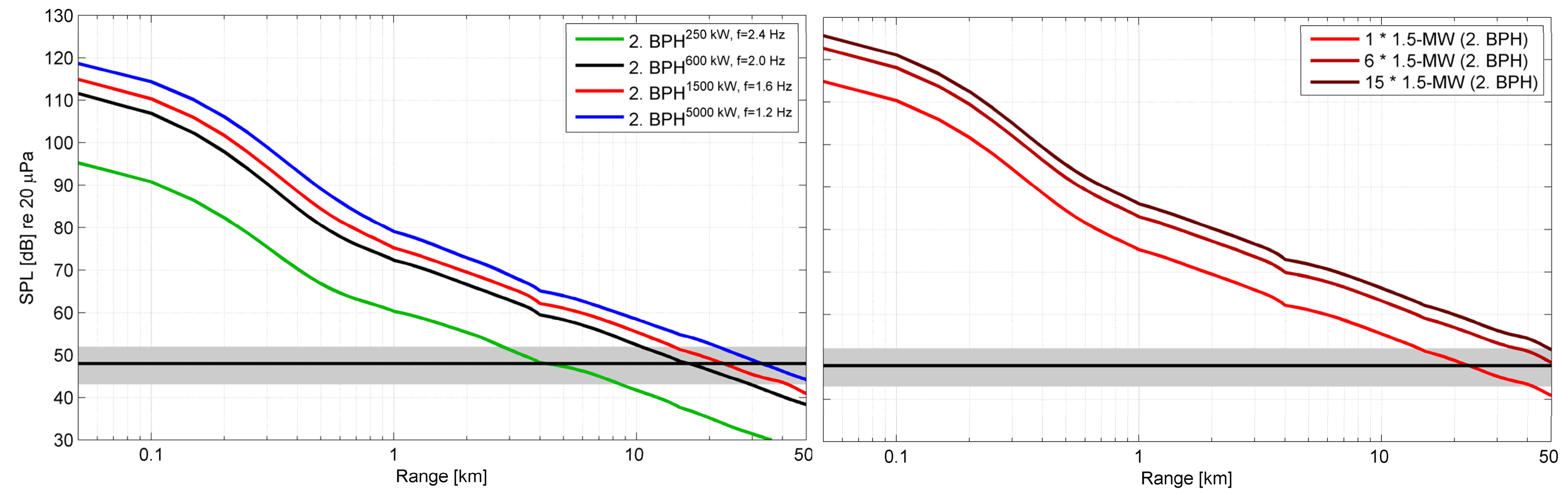

Fig. 6: *Based on the theoretical model sound pressure levels (SPL) are computed for the second blade-passing harmonic (BPH) as a function of distance and the wind turbine design parameters. Obviously, modern wind turbines with hub heights of about 80 m and larger as well as minimum 600 kW power output can emit aerodynamic noise signals in the 1 to 2 Hz frequency range which can be recorded at distances of more than 10 km. At such large distances, the SPL still exceeds the background noise level between 1 and 3 Hz at the German IMS station I26DE, which is marked by horizontal black line; the grey bar shows its variation. Considering wind farms of 1.5-MW turbines the computed SPL of the second BPH the signal amplitudes exceed background noise level even at distances larger than 30 km.*

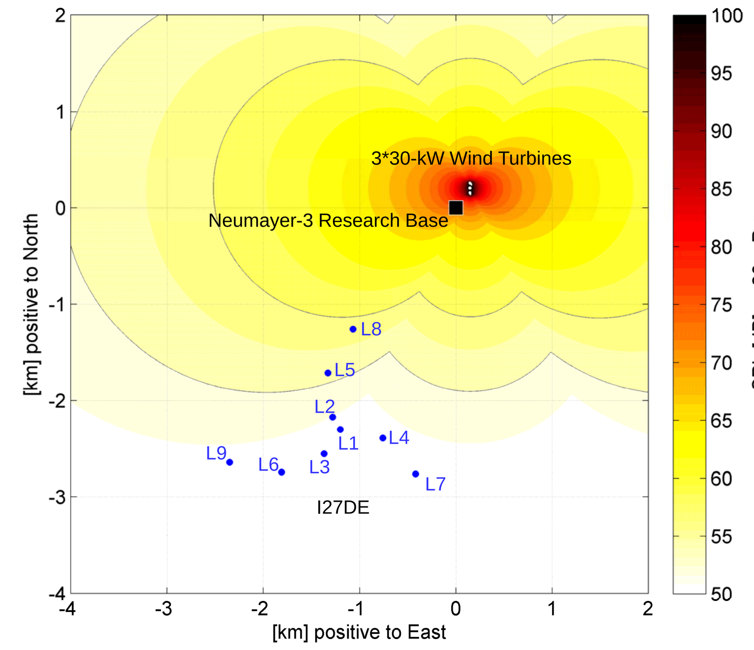

Fig. 7: *For the independent power supply of the German Antarctic research base Neumayer-3 a park of three 30-kW horizontal axis wind turbines has been planned. To estimate in advance the impact on the near-by infrasound array I27DE, our theoretical model has been applied: The most prominent wind directions are from south and east directions. The super-position of both radiated SPL shows that only two of nine array elements (L5 and L8) are slightly affected with signal amplitudes above 60 dB. Moreover, the research base itself provides acoustic shadow for the single sensors, which might explain why since its installation no spectral peak have been observed so far.*

Findings & Conclusions

The effects of a wind farm on the detection capability of a nearby infrasound array become apparent at station IGADE. The 4-element array with an aperture of about 800 m is only 4 km away from a small wind farm. This causes a partial blinding of a 10° segment; whereas the detection capability of an infrasound array with respect to transient signals is only reduced by noise disturbances if their bearings and apparent velocities are identical or very close to each other. Anyway, these observations underscore that it is essential to define minimum distances between infrasound stations and wind turbines which take into account their design parameters and number, especially for IMS stations.

Therefore all the necessary procedures have been collected for estimating the minimum allowable distance between wind turbines and infrasound stations to guarantee undisturbed recordings. Vital data was provided by the measurements at a single wind turbine north of Hannover, and the experience gained from other infrasound stations. The theoretical model for computing the SPL of the aerodynamic noise generated by wind turbines as a function of their design parameters, as well as the verification of this model for the infrasound frequency range, also made a valuable contribution.

As a rule, a distance of 15 to 20 km should be kept between an infrasound station and wind turbines to guarantee unhindered recording and detection conditions. The distance might need to be larger in the case of a wind farm comparable to the considered 15 turbine facility with 1.5-MW turbines. However, geometrical spreading, turbulences, and terrain effects might yield that a distance of 20 km also appears to be adequate for every kind of wind farm.

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