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Measurements of Sound from Wind Turbines

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Abstract

An extensive measurement program, with economical support from the Swedish Energy Agency, have been started up to measure the long-time meteorological effects on sound propagation from wind turbines at three sites in Sweden. The measurements will be performed continuously during 1-2 years. The sound propagation is studied in a 1) forest area, 2) over a water bay and 3) over heterogeneous terrain. The sites are representative for typical Swedish conditions, which are quite common on other geographical locations around the world. The first two of them are located in the southern part of Sweden and the third is located in the northern part of Sweden. The meteorological conditions change over the day and the year and vary a lot depending of the terrain conditions. Variations of the order of 20-25 dB at an immission point for different weather conditions have been found in earlier investigations [1]. Greatest variations of the immission levels have found between day and night for sources close to the ground. Variations of the same order are expected during different parts of the year for sound propagation over sea.

The aim of the project is to improve the knowledge about sound propagation from wind turbines and especially over varying terrain and different weather conditions. The hub height of the studied wind turbines varies from 80-138 m and the effect of the source heights on the sound propagation will be investigated. The result shall be improved sound propagation models, updated measuring requirements, validation of modelled sound levels and methods for deriving meteorological input data for a sound propagation model. These measurements will validate the sound propagation model, Nord2000, for varying terrain and weather. The sound propagation model will then be improved according to the long-term measurements. A numerical boundary layer model, MIUU-model, which has been used for mapping the wind energy resources over Sweden, will be used to produce meteorological input data to the sound propagation model. Statistical distribution of the sound level can be calculated for different terrain and weather conditions.

Introduction

In the light of global warming, the society needs to increase the usage of renewable power sources. One important renewable source is wind turbine power. Swedish energy agency have recommended a national goal, 30 TWh year 2020, where 20 TWh should be land based wind power and 10 TWh sea based [2]. The future goal would mean that the number of wind power turbines must increase from around 1000 today to between 3000-6000 depending of effect until 2020 [2].

The public opinion of wind turbines is generally positive, both in cities and on countryside. It is the energy source that we should commit most to according to opinion polls [3]. However, when wind turbines are planned close to people, many change their mind. This phenomenon is often related to as "not in my backyard". International research has found that the sound level is the greatest disturbance, when asking people living close to wind power plants. The sound level from a wind turbine varies a lot. The main factors causing this variation are of course the rotational speed of the turbine but also the meteorological situation. Meteorological effects have a great influence on sound propagation. The effect could be seen already at distances of 25 m from the source and is growing with distance [1]. Meteorological effects of sound propagation are, refraction, air absorption and scattering from turbulence. The scientific field of sound propagation in the atmosphere has been studied for many years. Studies of sound propagation from wind turbines are, however more rare. Wind turbine sound is a relatively new type of environmental noise. One could maybe expect the sound propagation from these elevated sound sources to be different from sources closer to the ground. Knowledge about sound propagation in the atmosphere and how often a certain extreme values of the sound pressure levels occur is crucial, when planning locations for new turbines. Regarding environmental planning, sound propagation models are used. These have until recently not included the meteorological effects, which have been a great disadvantage. Newly developed models do, but need more validation before we can trust their predictions.

The objective of this paper is to discuss the sound propagation in three different landscapes (in forest, over sea and in complex terrain). The meteorological conditions in these three landscape types could be very different from those over a plain ground. The knowledge of sound propagation over plain ground is today by many considered to be pretty good. However sound propagation in forest, over sea and in heterogeneous terrain are more complex.

The aims of the recently started measurement campaign will also be presented together with the distribution of sound levels at the Ryningsnäs site so far.

Meteorological effects on sound propagation

The knowledge on sound propagation outdoors has been improved a lot during the last decades [1,4,5,6]. The meteorological impact on sound propagation has been investigated since 1976 at Uppsala University at the Department of Meteorology, which 1998 merged into the Department of Earth Sciences. Wind turbines are high-

elevated sound sources and the sound propagation could be different from sources located closer to the ground. The three most important meteorological effects on sound propagation are: refraction, scattering by turbulence and air absorption.

Refraction of sound rays occurs if there is a change of temperature with height and/or a change of the wind speed with height, i.e., there are vertical gradients of temperature and wind. Two examples of wind and temperature profile measurements are given in Fig. 1. The refraction influences the sound level. The angle of sound incidence at the ground changes the ground attenuation. The sound rays are bent upwards in upwind conditions and/or temperature lapse. They are bent downwards in downwind conditions and/or temperature inversion. When the sound rays are bent upwards shadow zones are created, where no direct sound rays can reach. When the refractive conditions change, the path lengths of different frequency waves reaching the receiver also change. Thus, depending on the phase relations, a change in the refractive conditions could amplify some frequencies and damp others. Temperature gradients often show a diurnal variation over land surfaces as in Figure 1 and a seasonal variation over sea surfaces.

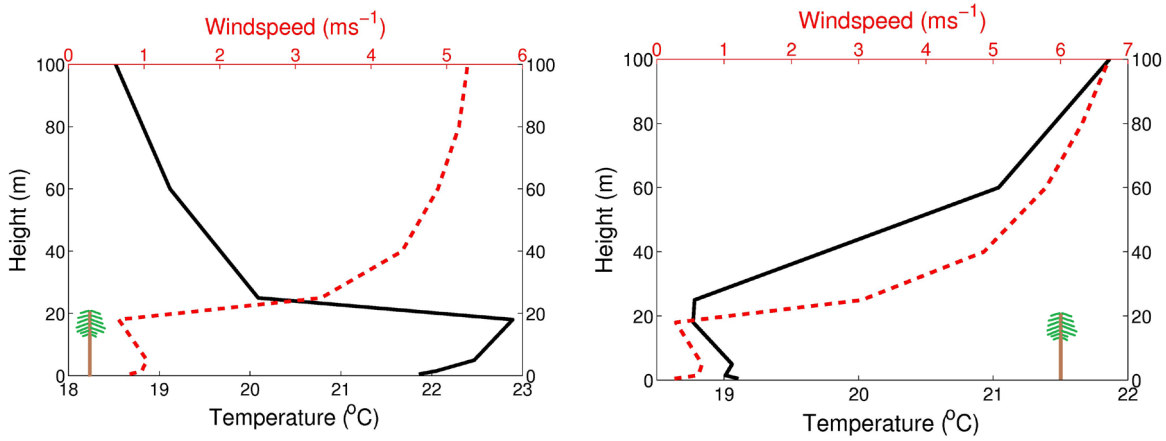

Figure 1. Examples of wind and temperature profiles in a forest during a) a summer day, 1 July 2010 12:40 and b) a summer night, 12 July 2010 03:10. The values are 10 minutes averages from the Ryningsnäs site. Black solid line gives the temperature and red dashed line gives the wind speed.

Turbulence in the boundary layer influences the sound propagation. Temperature and wind speed fluctuations produce random distortions of the sound wave front. These distortions scatter sound into sound shadow zones and cause fluctuations in phase and amplitude of the sound waves, thus destroying the interference between different rays reaching the receiver. This will mean higher sound levels than expected for frequencies were the ground attenuation has its maximum. The effect of turbulence is smaller for low frequency sound. If measurements are performed over many turbulence cycles the random fluctuations can be evened out. Mean sound levels for 10 minutes give more reproducible results than instantaneous measurements.

Atmospheric absorption depends on frequency, relative humidity, temperature and atmospheric pressure. The absorption increases linearly with distance and is a very important phenomenon when larger sound propagation distances are studied. Monthly and diurnal variations in relative humidity and temperature introduce great variations in atmospheric absorption. The values of atmospheric absorption need to be calculated using data from local meteorological stations instead of global mean values of relative humidity which are discussed in [4].

Measurement campaign

Simultaneous long-term measurements of wind turbine sound levels and meteorological variables will be carried out at three different locations in Sweden. The measurements will be continuous and last for around 1-2 years at the following three sites:

Figure 2. The sound station in the forrest in the autumn (left picture) and the meteorological mast at the edge of the forrest in the winter (right picture) at Dragaliden.

The Dragaliden station (65.45º N 20.54º E) 50 km west of Piteå in the north of Sweden. This is the planned area for one of the greatest wind parks in the world (1101 wind turbines). Today 12 wind turbines are located on a hill 1 km south of the microphone and the terrain in between is complex and covered by coniferous trees. The microphone is located 1.5 m above ground within the forest, see Figure 2. The surroundings are very less populated so apart from vegetation induced sound, small disturbances are expected. Meteorological parameters are given at 6 levels from a 120 m mast in the area. A separate 20 m high meteorological mast placed at the

edge of the forest measure temperature and wind at 4 different levels together with relative humidity and atmospheric pressure.

The Ryningsnäs station (57.28º N 16.00º E) 25 km south of Hultsfred represent sound propagation in a relatively flat terrain covered by coniferous trees. The acoustical measurement site is located at a distance of around 400 m from 2 wind turbines. A road is located 1.8 km south and a railway 4 km west of the measurement location but is not though to disturb the measurements. The microphone is located at 1.5 m above the ground inside the forest. A 140 m high meteorological mast gives the wind speed at 7 levels, temperature at 3 levels and wind direction at 5 levels. A separate 20 m high meteorological mast placed in the forest measure temperature and wind at 4 different levels together with relative humidity and atmospheric pressure.

The Burgsviken station (57.05º N 18.29º E) is located on the island of Gotland. The sound level is measured at 1.5 m close to the shore. At a distance of around 4 km across the bay around 100 wind turbines are located at Näsudden. At this site sound propagation over sea surface will be investigated. The microphone is mounted on a board according to [7] to reduce the effect of wind induced sound. A 145 m tall meteorological mast at Näsudden gives wind speed at 12 levels, wind direction at 5 levels and temperature at 7 levels. An additional 20 m mast gives temperature, wind speed (4 levels), humidity and air pressure close to the microphone.

The acoustical data at all three sites are measured at 1.5 m height by a Norsonic 140 sound level meter. The equivalent sound level L_{eq} and the sound spectrum in 1/3 octave band every second is measured. The values are averaged over 10 minutes. The higher resolution measurements will be needed to detect environmental disturbances from the surroundings.

First indications

When making long-term measurements of wind turbine sound it is of great importance to be sure that the actual sound pressure level measured actually originate from the wind turbines. The measurements will be disturbed by wind induced sound from the vegetation, sound from aeroplanes flying over the area and sound from biological activity. The measurements at our three sites will mostly be influenced by vegetation sound and at the Burgsviken site also waves. One idea to detect these sounds is to use Karl Bolin's model for vegetation sound [6]. The model will first be further validated against our measurements during periods where the wind turbines are standing still. Then the model will give 10 minutes averaged sound pressure levels for the vegetation sound. The main advantage using Karl Bolin's model would be that we still could use all our measurements. The other possibility is to set a criterion for when the wind turbine sound is dominant. In this way we reject a number of the measurements. Van den Berg [5] used L_5-L_{95}< 4.0 dB to distinguish when wind turbine sound was the dominant sound source. Van den Berg's measurement site was located in a relatively open landscape and a different criterion for dominant wind turbine sound could be expected at forest sites.

Figure 3 gives the sound spectrum at the site Ryningsnäs for three different times. During these measurements a person were detecting the different sound sources. Figure 3 shows that under very windy conditions where the wind at 100 m height (v_{100}) is 12.5 ms^{-1}, the sound from the vegetation is dominant. The typical frequency peak for wind turbines at around 200 Hz could also be seen. The difference between the background sound (black solid line) and wind turbine (WT) sound (red dashed line) is 6.2 dB.

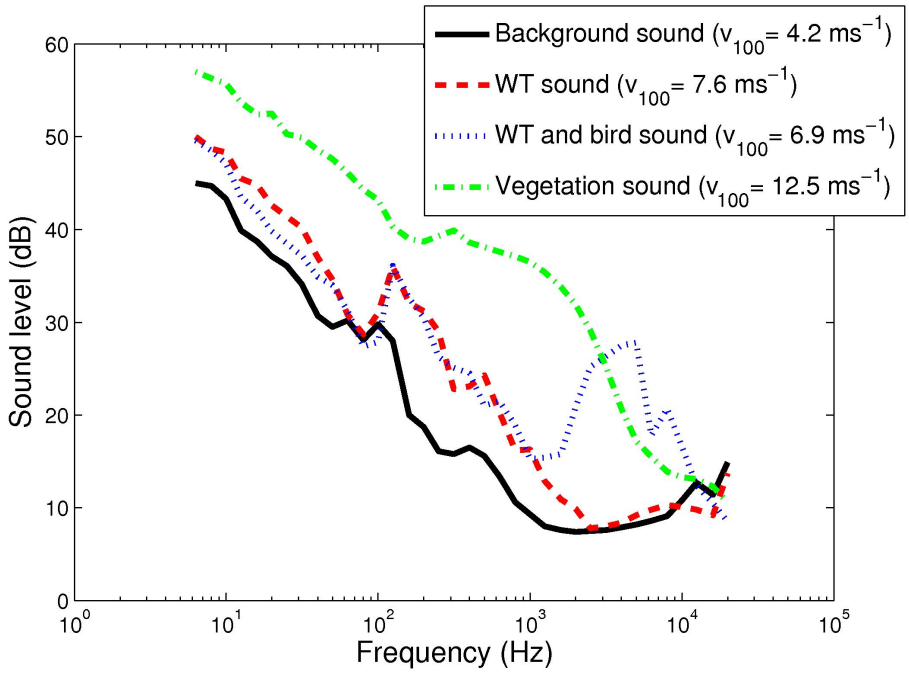

Figure 3. 1/3 octave band sound pressure spectrum from the Ryningsnäs site at three different times. WT stands for wind turbine. The wind speed at 100 m height is given for each measurement. All measurements are made under snow conditions.

The vegetation-induced sound is dependent of the wind speed at the tree tops. A criterion for when no sound come from the vegetation was set during an inspection at the Ryningsnäs site. This criterion imposes a ceiling on the wind speed at 25 m height (v_{25}), which is right above the tree tops. The requirement for the standard deviation of the wind speed (σ_{v25}) excludes measurements with a lot of turbulence. No vegetation sound is expected when v_{25}< 2.7 ms^{-1} and σ_{v25}< 1 ms^{-1}. An example of a measurement sequence from Ryningsnäs, fulfilling this criterion is shown in Figure 4. The figure shows that the sound level at the imission point is strongly correlated with the wind speed at hub height, which creates the wind turbine sound. All the measurements from the site Ryningsnäs fulfilling v_{25}<2.7 ms^{-1} and σ_{v25}< 1 ms^{-1} is shown in Figure 5.

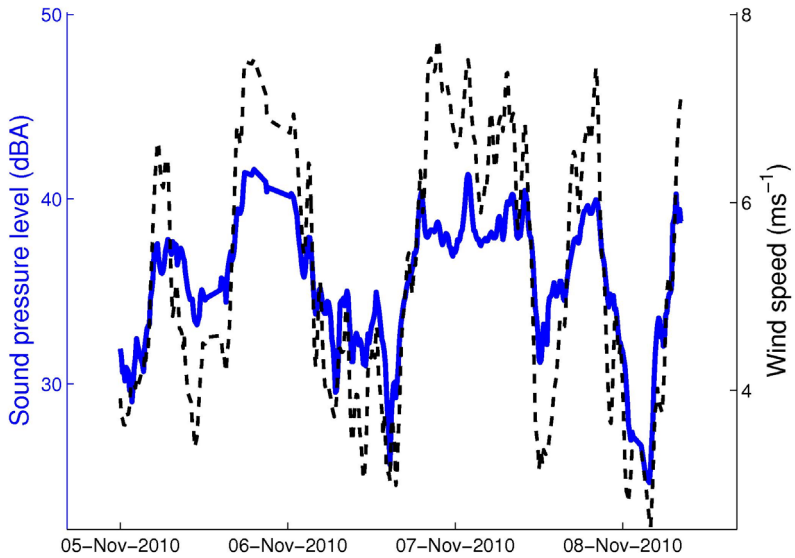

Figure 4. One hour running mean sound pressure level (solid line) plotted against one hour running mean wind speed at 100 m height (dashed line) for the Ryningsnäs site.

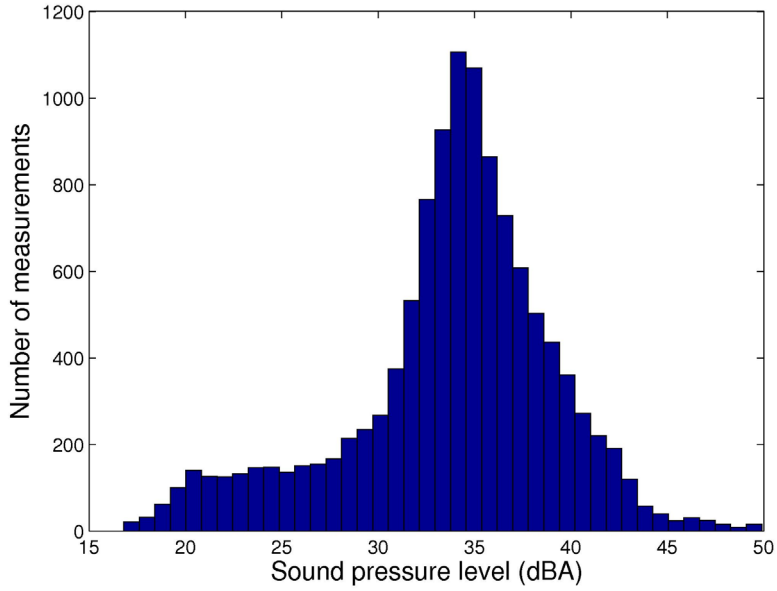

Figure 5. Histogram for all the measurements from Ryningsnäs fulfilling v_{25}<2.7 ms^{-1} and σ_{v25}< 1 ms^{-1}.

According the Swedish wind turbine noise recommendation [8], the highest recommended sound level is either 35 dBA (if the area is seen as an important area for recreation and wildlife) or 40 dBA otherwise. The measurement station at Ryningsnäs is clearly located at a very interesting distance according to these recommendations.

Conclusions

The meteorological effects of sound propagation are very important. The meteorological parameters as wind, humidity and temperature change during the day and year and influence the vertical sound speed profile. When using these parameters in sound propagation models it is necessary to use a cumulative distribution instead of mean values to get a more reliable picture of the sound environment. Wind turbines are high-elevated sound sources. Meteorological parameters in a deep layer may therefore be of interest, especially when studying larger propagation distances. Meteorological phenomena like low level jets are also very important. Wind turbines as sound sources are extended in space and the horizontal and vertical directivity pattern need to be further looked upon. Sound propagation within a forest canopy and hilly terrain is very complex and the meteorological parameters are not expected to behave as over plain open ground.

Performing long-term measurements is necessary to get a reliable distribution of how the sound level at a certain location varies with difference meteorological conditions during the year. However long-term measurements need to be carefully analysed to exclude disturbances from other sources such as vegetation sound and sound from breaking sea waves.

Sound propagation models like the Nord2000 model could be improved, for varying terrain and weather condition cases, using the result from long-term measurements. A meteorological boundary layer model, like the MIUU-model could produce meteorological input data to a sound propagation model for a specific geographical location. This would further improve the sound propagation model.

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