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Meteorological effects on wind turbine sound propagation

Olof Öhlund *, Conny Larsson

Department of Earth Sciences, Uppsala University, Villavägen 16, SE-752 36 Uppsala, Sweden

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ABSTRACT

Immission sound measurements were performed near two wind turbines sites in Sweden. Data were collected continuously for two years to cover the seasonal and daily variation in the weather. Vertical profiles of meteorological parameters like wind speed, wind direction, temperature, and relative humidity were measured in parallel with the acoustic measurements. Large variations in the transmission of wind turbine sound were found under various refractive atmospheric conditions. The meteorological effects on wind turbine sound increase with distance and start to be important at distances somewhere between 400 and 1000 m from turbines. A comparison of commonly used wind turbine sound propagation models in Sweden such as ISO 9613-2 and Swedish Environmental Agency model is presented. It is shown that usage of a harder ground factor in ISO 9613-2, even though the actual ground is porous, improves the result.

1. Introduction

Many countries are trying to decrease their carbon dioxide emissions to avoid an increased greenhouse effect in the future. One way to do this is by using wind power, which is an environmentally friendly energy source. At the end of 2012 Sweden had 2385 turbines, and the number is increasing every year [1]. In the past wind turbines (WTs) were placed mostly in open fields but with the increasing hub heights of the turbines, they are now also being placed in forested areas to reach the high winds above the forest. Given that a large part of Sweden is covered by forest, the opportunity to place WTs there increases the potential for renewable energy in Sweden. In Sweden people generally have a positive attitude to wind power. Some people living in the vicinity of turbines are annoyed by them. One common concern is the sound from the turbines [2]. It has been shown that wind turbine (WT) sound is perceived as annoying at lower sound levels than sound from other sources such as aviation, road traffic and rail traffic [3,4]. One reason for this may be the fact that WT sound is amplitude modulated with time, producing what is often referred to as a rhythmic "swish" [5]. Regulations regarding WT sound vary from country to country. Some countries stipulate a fixed sound level where others take into account the level of background noise and the wind speed. The current Swedish regulation regarding WT sound do not recommend it to exceed 40 dBA outside dwellings during conditions with 8 ms^{-1} wind speed at 10 m height above ground. In areas with very low background sound or used for recreational activities, the recommended level is 35 dBA. There are plans for many new WTs, and to ensure future public support it is important that the WT sound level at dwellings can be predicted correctly. Previous studies on sound sources close to the ground have shown that meteorological conditions effect sound propagation [6,7]. Vertical differences in wind and temperature force sound waves to bend either up or down, resulting in lower or higher sound levels respectively. Sound levels are also affected by turbulent scattering and atmospheric absorption. This article investigates the influence of meteorological parameters on sound propagation from high elevated sound sources like WTs. Variation in meteorological parameters with height over different land surfaces are also investigated. Long time measurements of WT sound and meteorological parameters have been performed during two years at two different sites to capture a wide range of different weather conditions. The measurements began December 2010 at one site and August 2010 at the second site and run continuously during two years. The accuracy of two sound propagation models is examined by comparing the measurements with model predictions.

2. Description of sites

2.1. The Dragaliden site

The Dragaliden site is located in northern Sweden (65.44°N 20.52°E). The landscape is heterogeneous and covered by forest

* Corresponding author.
E-mail address: olof.ohlund@geo.uu.se (O. Öhlund).

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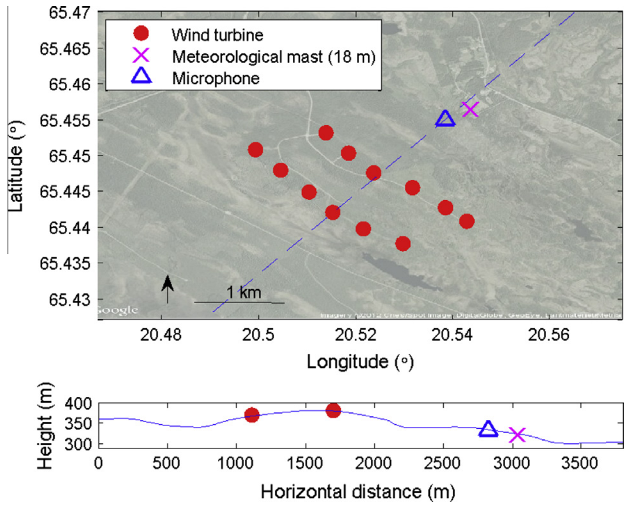

Fig. 1. Map of the Dragaliden site. The sound propagation direction of interest for the Dragaliden site (indicated by the dashed line) is 37° used in Eq. (3) to be able to calculate the sound speed in Eq. (2) (courtesy of Google Earth).

and swamp. Hills are between 400 and 500 m above sea level in the surrounding area. The tree height around the acoustic measurement site is approximately 15 m. The village of Strömnäs is located around 1 km north of the acoustic measurement station and has a population of 6 people. The road through the village carries very little traffic. There are twelve WTs on the Dragaliden hill. The twelve Enercon E82 (2 MW) WTs have hub heights of 108 m and 138 m. The high turbines are numbers 3 and 6 in the front row as seen from the west in Fig. 1. These WTs are the first built as part of a much larger project that aims to be one of Europe's largest WT parks.

2.2. The Ryningsnäs site

The Ryningsnäs site is located in southern Sweden (57.28°N 15.99°E). The surroundings are very quiet with the closest permanent living neighbor 1.5 km to the north. A road between Målilla and Kalmar is located around 1.7 km south and carries some traffic. There are two WTs in the flat landscape, which is covered by forest. The forest is approximately 20–25 m high with some clearings in the area, as can be seen in Fig. 2. The microphone is placed inside

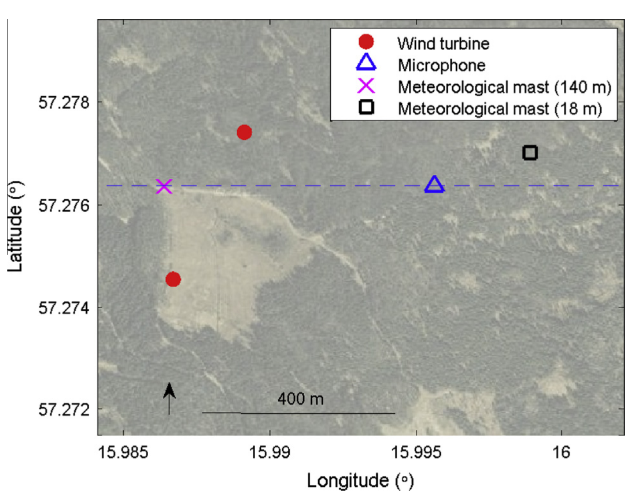

Fig. 2. Map of the Ryningsnäs site. The sound propagation direction of interest for the Ryningsnäs site (indicated by the dashed line) is 90° used in Eq. (3) to be able to calculate the sound speed in Eq. (2) (courtesy of Google Earth).

the forest. The WTs are two Nordex 2500 LS machines (2.5 MW) with 80- and 100 m hub heights. The higher WT is the one closest to the microphone in Fig. 2.

3. Measurements

3.1. Acoustic measurements

As immission measurements according to IEC 61400-11 at ground level were not possible due to snow coverage during the winter, acoustic measurements were carried out 1.5 m above the ground inside the forest with a Norsonic Nor140 sound level meter. The microphone at the Dragaliden site can be seen in Fig. 3. A Nor1214 outdoor 1/2″ microphone with rain hood and dust mesh was used. The sound level meter is a class 1 instrument and measures the sound spectrum in 1/3 octave band levels with midband frequencies from 6.3 Hz to 20 kHz. For the analysis 10 min values of the equivalent sound pressure level (SPL), the percentiles L_5 and L_{95} (i.e., sound levels exceeded 5% and 95% of the time) and the average sound spectrum were used. The sound level meter was connected to a modem, so that data could be downloaded to a computer. The systems are connected to the grid by long cables through the forest. The instrument was calibrated regularly on visits to the sites.

3.2. Meteorological measurements

Meteorological parameters were measured simultaneously with the acoustic measurements. 10 min average values were collected for the entire measurement period and vertical profiles were obtained. Every 10 min period of meteorological parameters had a matching acoustical 10 min period. All gradients were calculated as linear differences between two heights. Throughout this paper wind directions follow the meteorological convention (i.e., they are given in terms of the direction from which the wind is blowing) and all meteorological values are given as 10 min averages if nothing else is stated. The setup was similar for the two measurement

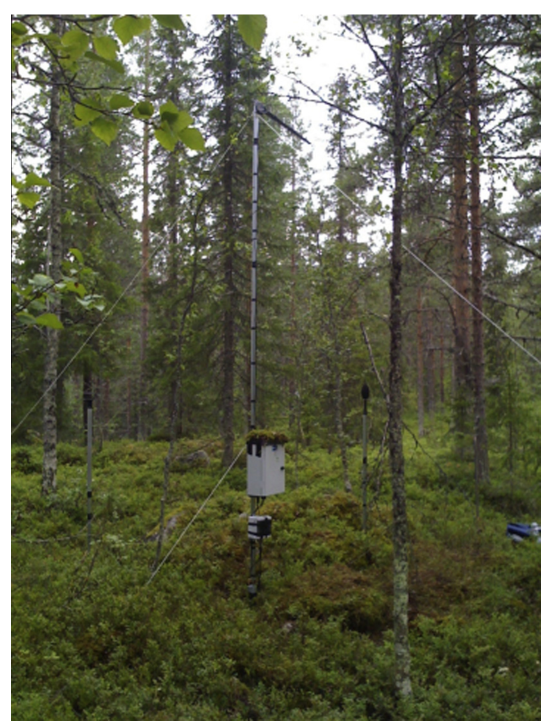

Fig. 3. The acoustic measurement station at the Dragaliden site.