6th International Meeting
on
Wind Turbine Noise
Glasgow 20-13 April 2015

Background noise map creation through a CFD wind model

Andrea Bartolazzi Studio Rinnovabili srl, Corso Vittorio Emanuele II 282-284, 00186 Rome. E-mail: a.bartolazzi@studiorinnovabili.it

Simone Marletti Studio Rinnovabili srl, Corso Vittorio Emanuele II 282-284, 00186 Rome. E-mail: s.marletti@studiorinnovabili.it

Beatrice Pistoni Studio Rinnovabili srl, Corso Vittorio Emanuele II 282-284, 00186 Rome. E-mail: b.pistoni@studiorinnovabili.it

Summary

Many countries such as France, New Zealand, UK, Italy use background noise to limit the noise of a wind farm. For this reason background noise assessment is a key process in the planning of a wind farm. Usually therefore every possible receiver must be measured to determine which is its level of background noise. This measurement should last at least a week to be able to intercept enough range of wind speed and direction. Wind during the measurement is necessary to determine the variation of noise with wind and model a situation in which turbines would be in operation. This process is costly and for this reason developers of wind farms tend to delay it to a later moment during the planning of the wind farm. So it happens that when planners arrive to the measurement of receivers many important decisions on the layout have already been taken and noise constraints have been underestimated.

For this reason it would be useful to have a background noise map already at the beginning of the planning process, in such a way to check as early as possible what is the situation of impact. Creating a reliable background noise map is pretty complicated since you should be able to evaluate all sources of noise on a very large area. What is less complicated is to evaluate only that part of noise that depends on wind, since the relation between local wind and noise is already well known. Estimating winds at receivers height on a large area can be done with a computational fluid dynamics (CFD) model of the wind in the area.

The first purpose of this paper is to report the experience done with the study of a large wind farm in which this method has been used. It reports what kind of CFD model has been implemented to study the wind. Then it reports what kind of calculation has been done to convert the wind map at low height into a noise map. Afterwards it reports which receivers were measured and what is the difference between the noise map calculated and the measurements at the receivers.

Finally we analyze what differences arise, what is the possible reason for these differences and which are possible further developments of the method.

1. Introduction

In the early stages of a wind project we study all the elements that help move the project forward smoothly. The four most important elements that need to be analyzed preliminarily are

the wind resource map, the constraints map including noise, the connection to the network, and the possibility of transporting and mounting. In this analysis one of the most important constraint is certainly noise. It would be convenient to have already at an early stage a noise constraints map in order to avoid planning the turbines in disturbing areas.

The problem encountered in the execution of a constraint map of noise usually depends on the limited information on background noise of the area. This is hard to describe because the background noise depends on parameters that are very specific to the spatial position of receiver, and sometimes vary greatly also within its property. Given the number of possible receivers that is too complex and expensive to study at an early stage, because there are too many different possible sources of noise. We classify the sources of noise into two main categories: noise sources independent from the wind and sources whose intensity depends on the wind [1]. A formula to describe it is the following

$$L = 10 \cdot log_{10}\left(10^{\frac{L_{WR10} \cdot log_{10}(V_w)}{10}} + 10^{\frac{L_{NWR}}{10}}\right) \tag{1}$$

L_{WR10} = Noise parameter for wind related noise. The meaning of this parameter, as expressed here, is the noise that we would have at 10 m/s in absence of not wind related noise [dB]

L_{NWR} =Noise parameter for not wind related noise [dB]

in which the second term under brackets refers to the noise independent from the wind. This represents all the sounds of the territory that are statistically significant, such as roads, watercourses the presence of animals, the presence of human activity, and more.

The first term under brackets is the wind dependent noise. It is typically given by the flapping of the vegetation and on the effect of wind on houses and on all objects in the territory.

While the second term is difficult to map because of its dependence from specific characteristics of the territory, the first term is strongly dependent from the wind and therefore it is easier to map.

The result can be seen in Figure 1. Clearly the logarithmic curve parameter L_{WR10} depends largely on vegetation and exposition to the wind of the structures and objects surrounding the sound level meter.

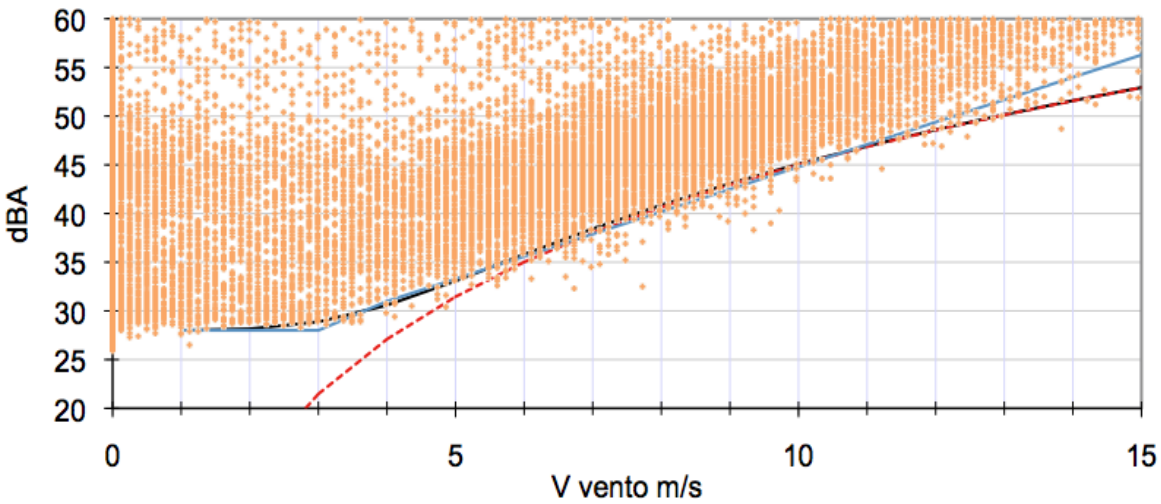

Figure 1 - Measurement of noise and wind at a 7 meters distance. The L_{WR10} parameter is 45

The experience of identification of noise in many installations showed that L_{WR10} is typically in the range 40-60 decibels. As said, the meaning of this value is simple: in the absence of wind independent noise this value identifies the noise levels that we would have at 10 m/s.

In this case wind is measured very close to the receiver. Clearly one of the major uncertainties of this logical process is the need to establish a correlation between the wind at the receiver and the wind at turbines height. For this reason the correlation between noise and wind refers usually to the wind at the mast, either at 10m height or at turbine height.

Among wind modeling softwares there are two main groups:

- Mass conservation softwares such as Wasp, Windfarm, Windfarmer and WindPro.
- CFD softwares that use computational fluid dynamics such as WindSim.

The CFD softwares give a more accurate modeling of the correlation between the high winds and the wind on the ground because they consider the second order and some following terms of the Navier-Stokes equations. This allows identifying in particular the areas of macro turbulence.

This aspect is very important also in our case. If the receiver is covered from the wind by a hill, the wind at the receiver could easily be a secondary wind coming from turbulence, as shown in the figure 2.

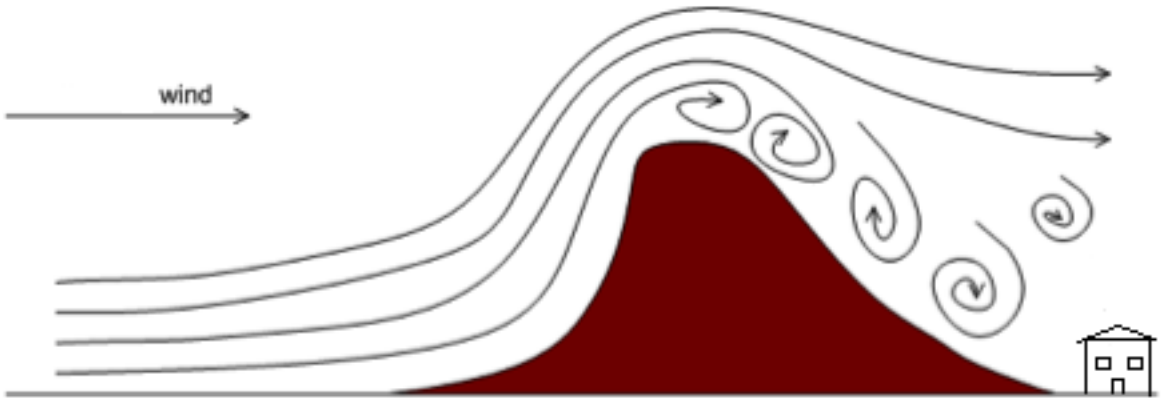

Figure 2 - A typical case of turbulence on a ground discontinuity

Turbulent areas are not modeled by the mass conservation software. At the same time these are the very sensible points that can more easily be disturbed by the presence of a wind farm. In these points the perceived noise of the wind park is related to the distance while the background noise is related to local winds and therefore it is presumably low due to the effect of shelter. The effect of disturb of the turbine is increased, so these are precisely the most delicate points.

Our work aims at identifying these particular points as soon as possible in the planning process. as the positioning of turbines must respect greater distances from this type of receivers. For this reason we are interested in analyzing the possibility of creating a map of the background noise even if only for the first term of the equation (1), or to calculate a map where the first term in more accurately calculated while the second term is a constant coming from typical values. Especially for high winds the first term appears predominant and finally as more relevant compared with the second.

Experimental design

The first term under brackets of the equation (1) depends on wind. Therefore we need to calculate wind on the whole area of the project. We therefore try to perform a wind mapping with Windsim in the whole area with the aim to identify winds at receiver level. Then we will calculate noise level with the formula (1) and create a noise map. After this calculation we will be able to compare the result with some measured point where we have collected the data.

During this process it is important to analyze all parameters involved in the dependence of the noise from wind:

- wind direction
- wind frequency distribution
- set of structures present at the receiver that may change the parameter L_{WR10}
- stability of the air

The **wind direction** would completely change the speed ups in all the area. An area that is protected from north wind and therefore have a very low speed up, is maybe open to south wind. To simplify this identification process we use a model with a wind coming from the main direction, in our case the north (-15° |15°). Also measurements will refer only to north winds.

The second parameter that identifies the wind is the **frequency distribution**. In a generic site the frequency distribution follows the so-called Weibull distribution. The typical yearly parameters of this distribution (amplitude A in the range 5-8, shape k in the range 1.7-2.5) are unfit to identify the wind at the receiver over short periods. If we used a typical k=2, A=7 distribution this would mean that for some seconds over the 10 minutes we have a very high winds. This corresponds to an increased noise level. Fortunately we have the standard deviation measurement. To represent the wind in the 10 minutes we convert the normal distribution measured and the measurement in the Weibull distribution (Figure 3). In the modeling software we use the following conversion function:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1,086} \qquad (2)$$

Where k is the shape factor, σ is the standard deviation and and *v* is the mean speed velocity

site name			
filename			
measurement period			# records = 188543
position	x =	y =	z (agl) = 70.0
Weibull param., average speed	k = 7.26	A = 11.76	average = 11.00

Table 1. Climatology characteristics, including Weibull (k,A) and average wind speed (m/s) of all sectors.

Frequency distribution

◄ ► **Sector: all Sectors**

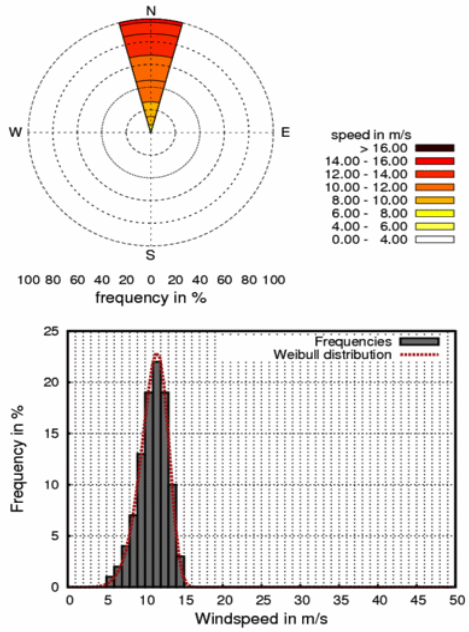

Fig 1. Above: Climatology -
Below: Frequency distribution -

Figure 3 – Frequency distribution of north wind avg.10 m/s

Another parameter that influences the conversion of wind in noise is the presence of **structures** like vegetation and houses and it is peculiar to each point the territory. Since this aspect is too peculiar for every receiver we disregard it. As further evolution we could consider a mapping of the vegetation done from the roughness map.

The procedure in the norm we follow for the measurement at the site, 5 meters distance from the local vegetation to minimize the impact of noise from the flapping of the trees and bushes.

The fourth parameter that influences this conversion is the **air stability**. The measurements on the site are shown in the following figure 4. As known air is more stable during night and therefore wind ratio between hub and receiver is higher. As the most interesting period for the noise map is night, the stability class used during CFD calculation is set to neutral (Pasquill = D) [3].

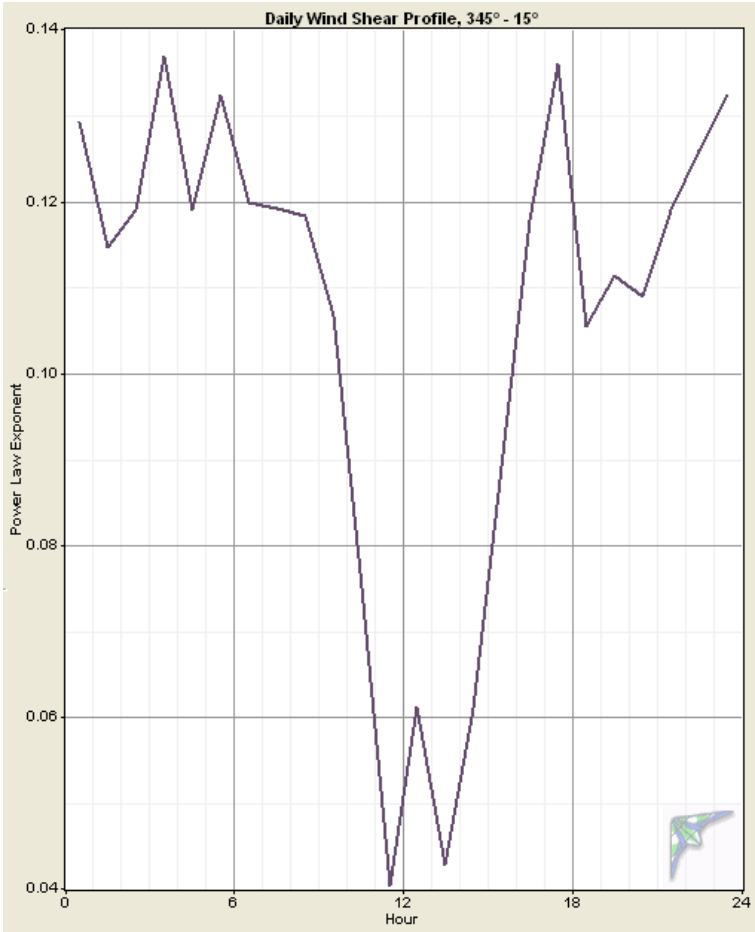

Figure 4 - The power law exponent change between night and day

Another difficulty that we found is transferring the wind rose from the position of the anemometer to the position of the receivers. The wind rose at the receiver can be qualitatively different from the one at the anemometer. In our case the north direction at the anemometer is represented by a wind distributed on 30 degrees. As an example at one receiver this generates a wind rose with winds coming from both the north and from the west. This is because the wind flow changes path even for small inflow deviations. We considered this aspect that represents a reduction of the wind at the receiver and that therefore constitutes also a decrease of noise.

Generation of the background noise map

The CFD software creates a map of wind at 2 meters height. This considers the terrain and the roughness of the site. The conversion of wind in noise is done with the formula (1) with the coefficients L_{WR10} = 45, and L_{NWR} = 25.

The result is showed in the figure 5. The receivers of the site are also shown.

This map allows us to indicate which zones have lower noise in comparison to others. It also gives a numerical measure of noise. This map is done for 10 m/s @ 70m height, and we can obtain maps for every wind speed. This will be rather easy. As a matter of facts the behavior of the software is linear. We only need to scale up or down the wind map, and then to convert it into a noise map with the given (1) equation.

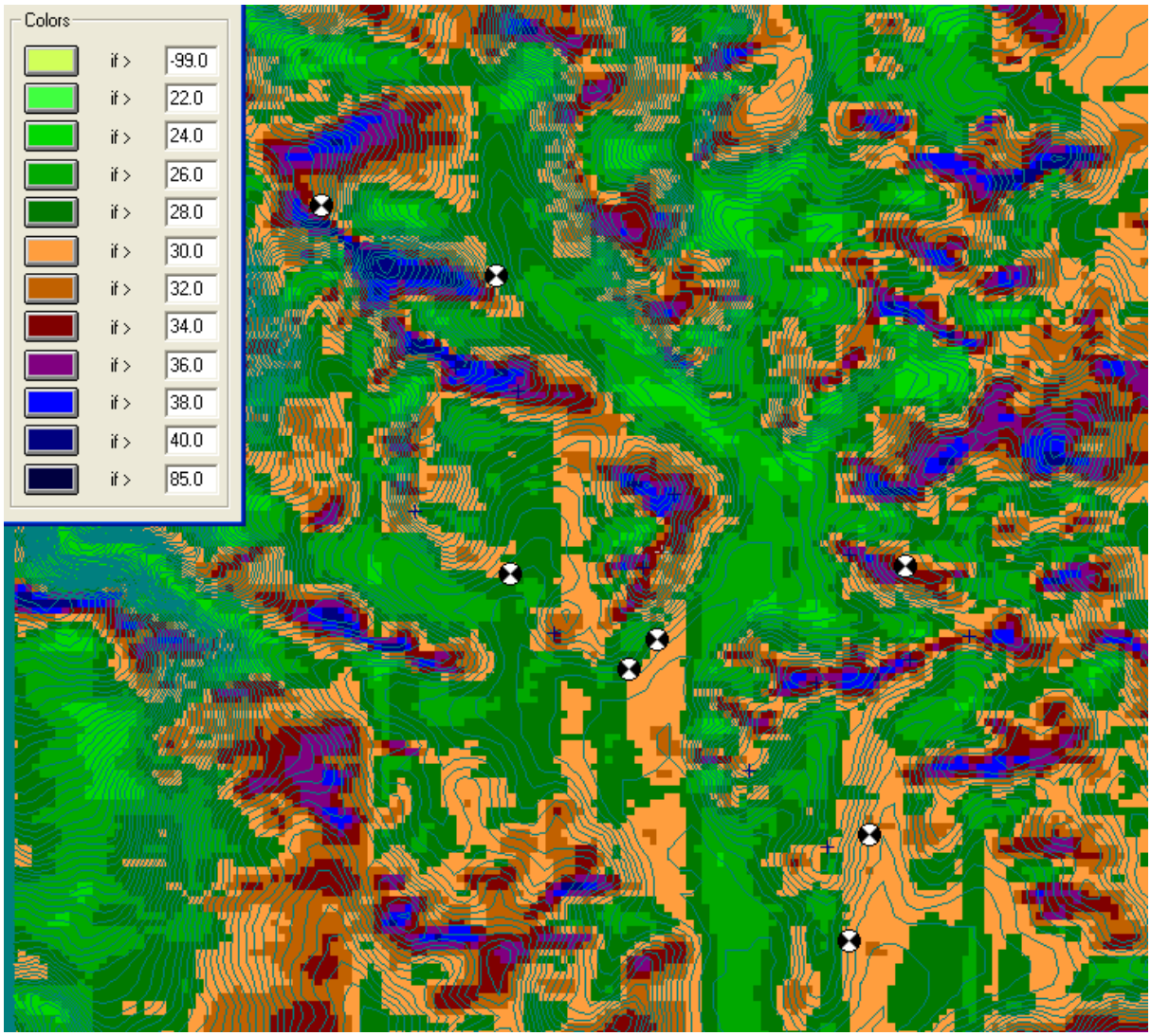

Figure 5 - Background noise map for 10 m/s, North wind, night

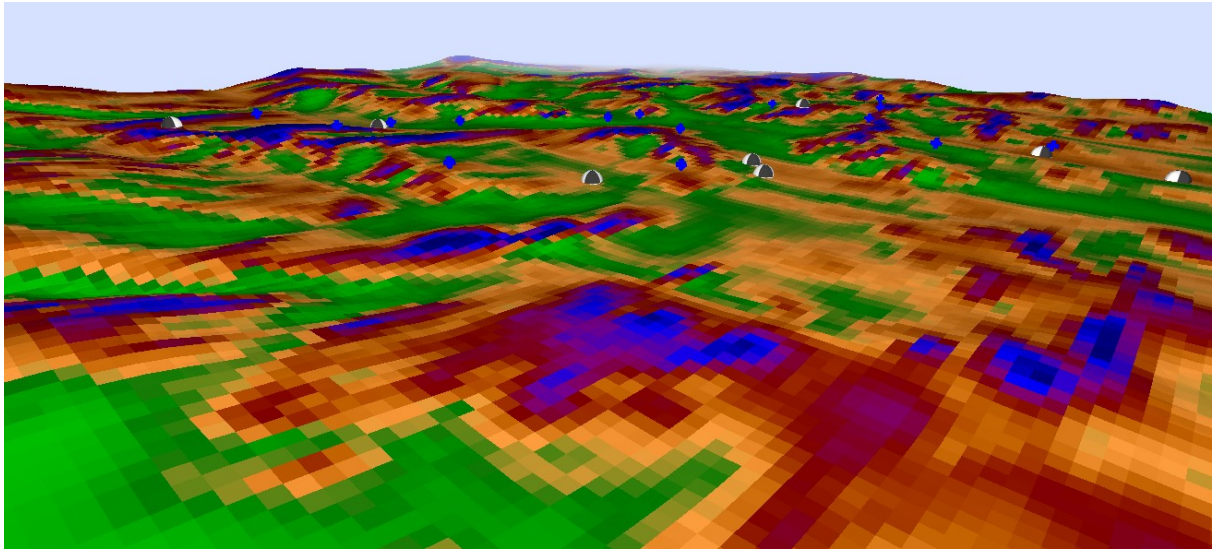

Figure 6 - Background noise 3D map for 10 m/s, North wind, night

Noise measurements

This is the description of the process that we have used to identify L_{WR10} parameter from the measured data. We measured the noise data with meteo stations that were installed on site for one month. The noise's sensors were at 1.5 meters height and they were protected from rain

and from wind with a windshield. At the meteo station there's a rain sensor. The Measures during periods of rain were cancelled from the data.

The noise point are LA_{eq} sampled on 1 minute while the wind is sampled on 10 minutes. For this reason the wind data are then extended on the one minute sampling simply putting 10 times the same value. We consider this procedure more reliable than the other procedure which would be to average the noise on the 10 minutes. The correlation is done between the noise and the wind at the anemometer measured at 70 meters. The wind is measured at the central anemometer of the park and it is measured in two positions every position has height of 70 meters and direction sensors.

We filtered those data considering the influence of other events like, for example, human interactions, cars and other types of noise not depending on wind. After this process we choose the parameter L_{WR10} either graphically or mathematically. The mathematical process would be to use a minimization with least-square distance from a log curve

Comparison between noise model and site measurements

As a following step we are interested in knowing if the numbers given by the noise map are reliable or not. To understand this we have measured the background noise of 8 points. During these measurements we have also recorded the wind velocity at the anemometer. Some points have a clear model. For example the point in the figure 7 has a very clear logarithmic curve model for strong winds.

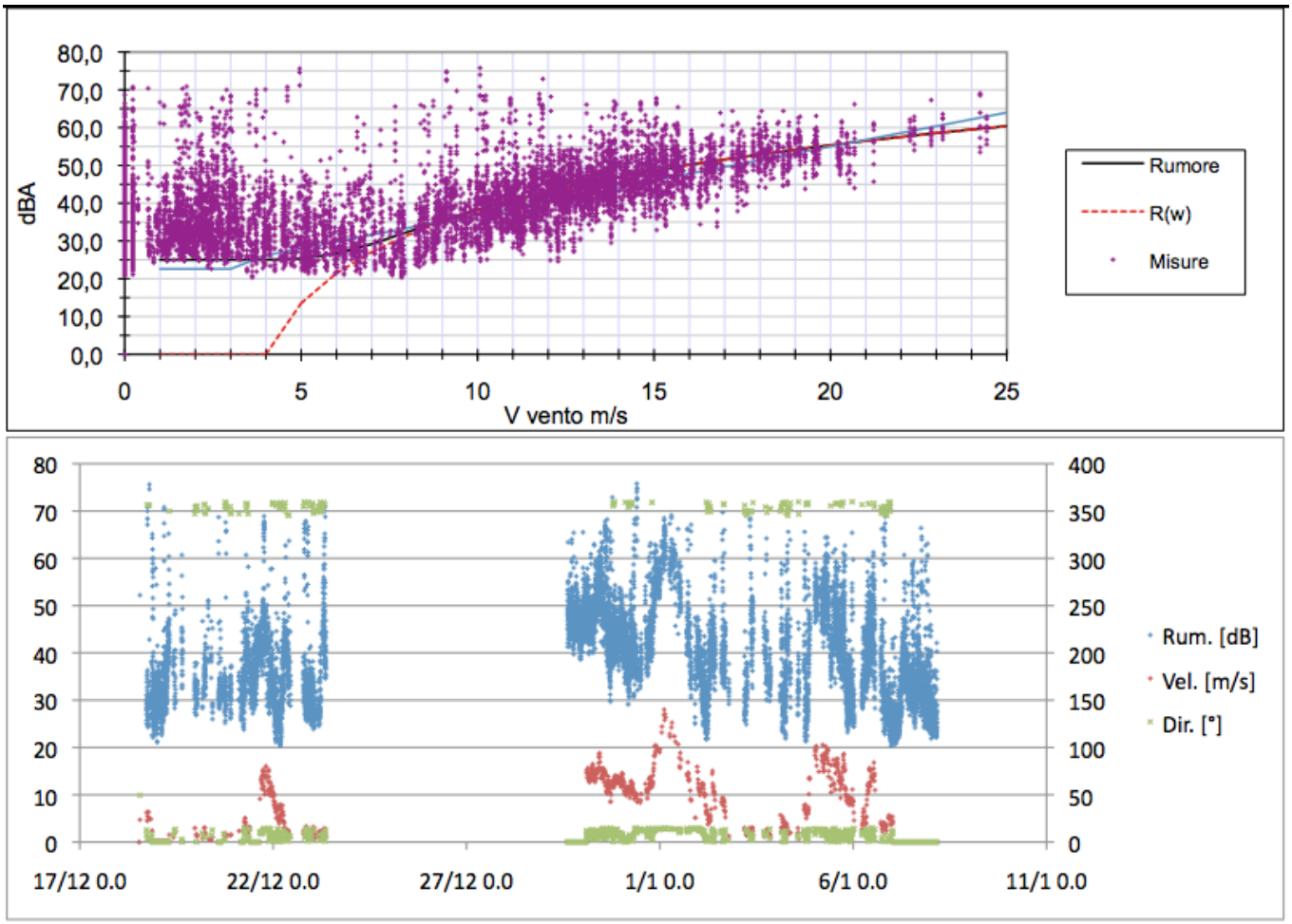

Figure 7 - Model and time series of the measurements of one receiver. In addition to the not wind related noise there is a clear noise at around 55 dB given by road traffic

We have done a model of background noise of every point. If we compare the coefficient L_{WR10}, which should be the noise at 10m/s in absence of NWR noise, withthe noise obtained from the calculation we find a very poor correlation.

Attempting another way, if we instead chart the noise from the map, vs. the lowest level of measured noise around 15 m/s (Figure 8) a correlation emerges (Figure 9).

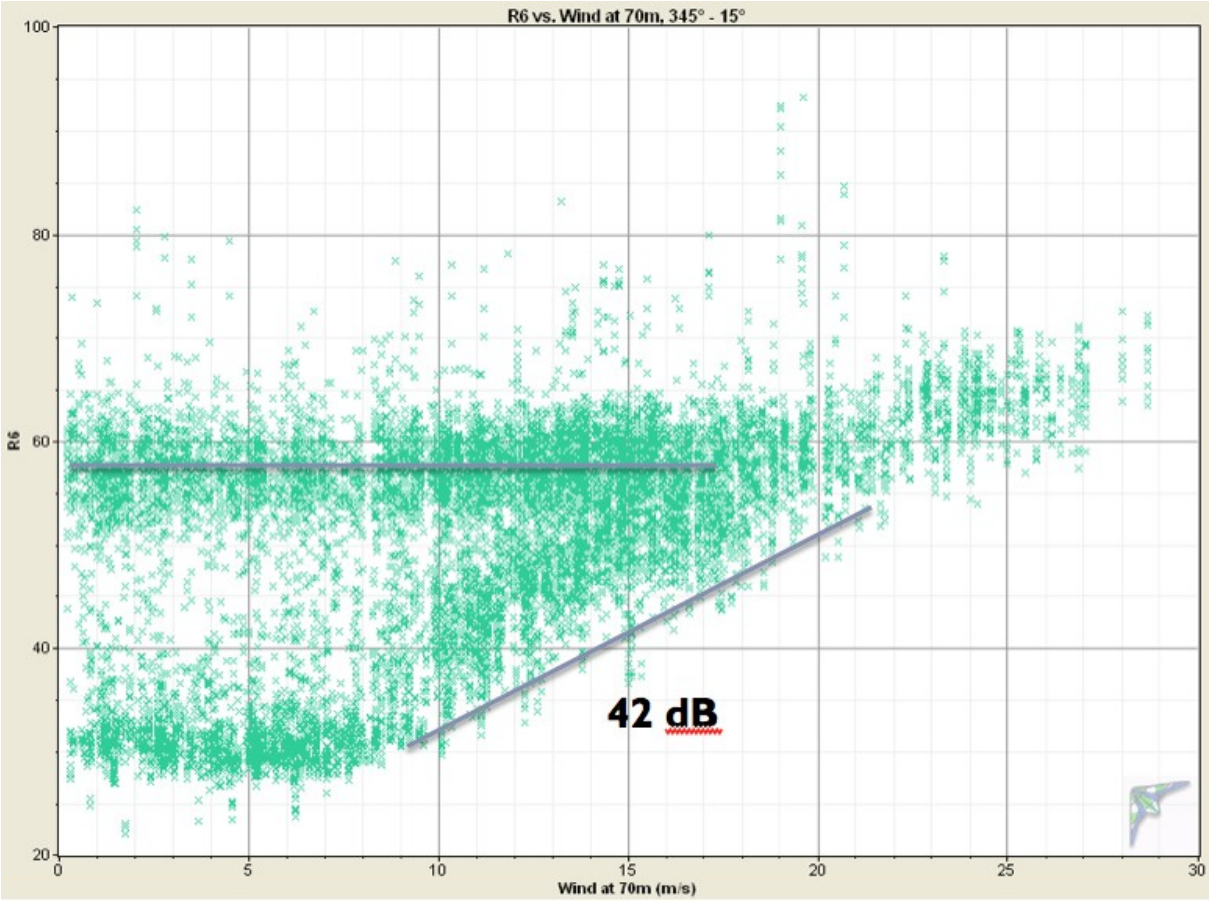

Figure 8 - Model of the measurements of one receiver. In addition to the not wind related noise there is a clear noise at around 55 dB given by road traffic

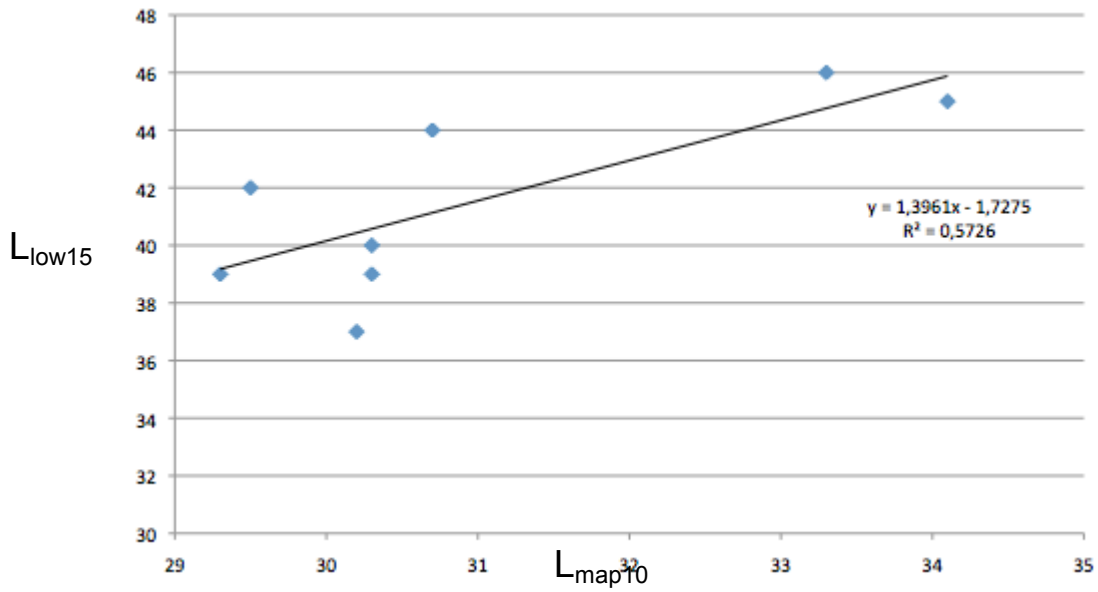

Figure 9 - Correlation factor between the lowest level of noise at 15 m/s factors and measure on the background map (@ 10 m/s)

The reason of the correlation only for stronger winds seems to be that at 15 m/s the component of wind related noise is more visible and important compared to NRW noise. Moreover the identification of the level at 15 m/s has been done using the lowest possible measures of wind. So the effect of casual NWR noise is diminished.

Conclusions

This result suggests that this method produces background noise maps not usable to predict correctly the background noise in every point because the differences between receivers in local vegetation and structures are too high. This has an influence on the parameter L_{WR10} that need eventually to be mapped or corrected point by point.

On the other hand this approach can be useful in a preliminary stage as qualitative maps, and used to identify which receivers should be kept at higher distances.

A second possible use of this kind of analysis is acquiring information in order to extend the background noise campaign to sites that were not measured.

Suggestions for a new background noise studies

Some key points could be taken into consideration in order to deepen this approach:

- Identify if roughness map, which usually describe vegetation and use of soils, influences the noise map and allows the indentification of L_{WR10}.
- The flow of wind at mast height is less affected by obstacles in the area. To better the receiver noise model we can simply create a relationship between wind at mast and wind at the receiver with a wind modeling software.
- Execute a map of total and differential noise once a turbine layout has been decided

References

1. Dick Bowdler, What is the Real Background Noise?, Proceedings of WTN Conference, Lyon (F), 2007
2. Kathryn M. B. Haugen, International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns, Minnesota Department of Commerce: Energy Facility Permitting, October 19, 2011
3. Bill Dawson, Neil Mackenzie, Meteorological stability impacts on wind turbine noise assessments, Proceedings of Acoustics 2013 – Victor Harbor
4. O. Fegeant. Wind-induced vegetation noise. part 1: A prediction model. Acta Acustica, 85:228–240, 1999;
5. O. Fegeant. Wind-induced vegetation noise. part 2: Field measurements. Acta Acustica, 85:241–249, 1999;

6. A. Bartolazzi, M. Mariani, Optimization of energy production of a large windfarm with noise constraints: a numerical toolkit, Proceedings of WTN Conference, Aalborg (DK), 2009.

7. Sathyajith Mathew, Wind Energy – Fundamentals, Resource Analysis and Economics. Springer 2006