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Atmospheric Measurement Techniques Discussions

Interactive comment on "Estimating reflectivity values from wind turbines for analyzing the potential impact on weather radar services" *by* I. Angulo et al.

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General Comments

The author explores a simplified technique to estimate the potential impact of wind turbines on weather radar returns, namely reflectivity. More sophisticated optical models are used to validate some of the proposed simplifications. Outputs from the more sophisticated model are presented as evidence of some assumptions made in the overall simplification. The reflectivity estimates are presented as a measure to estimate the impact of wind farms on weather radars, until such time as signal processing mitigation

techniques are available. Much of the paper focuses on the simplification of the wind turbine/radar interaction. In doing so, the author does make assumptions about wind farm locations and impacts. It is often unclear what reference frame the parameters refer to. Some of the conclusions are based on validation that is difficult to corroborate as little information is provided regarding the optical model simulations, and no real wind turbine data is provided. However, the exercise is useful in the effort better estimate wind turbine impact for a variety of weather radars, and can likely be extended to other frequencies.

The authors would like to thank the referee for his/her constructive comments to improve the manuscript. We have carefully considered all the comments and revised the manuscript accordingly.

Specific Comments

Abstract 1. Page 1478, Line 4 Replace 'Since nowadays' with 'Current'

The text of the paper has been changed according to the reviewer's comment: "Current signal processing techniques to mitigate Wind Turbine Clutter (WTC) are scarce, so the most practical approach to this issue is the assessment of the potential interference from a wind farm before it is installed."

Section 2 1. Page 1480, First Paragraph Avoid enclosing statements in parenthesis in the manner used in this paper. Commas should be used instead. The use of parenthesis is colloquial and should be reworded to be more formal.

The text of the paper has been changed according to the reviewer's comment: "These errors may be due to: clutter caused by signal echoes from the wind turbines; signal blockage, as the physical size of the wind turbine creates a shadow zone behind them of diminished detection capacity; and interference to the Doppler mode of the radar, on account of frequency shifted echoes from the rotating blades (Angulo, 2014)"

2. Page 1480, Line 6 Signal blockage is mentioned, but is not discussed in the paper

other than the paragraph beginning in Line 20. Mention that this paper does not focus on addressing the signal blockage estimates.

A sentence has been added at the end of the paragraph that begins in Line 20 in order to make clear that this paper does not address the signal blockage estimates: "Consequently, this paper does not focus on addressing the signal blockage estimates."

3. Page 1480, Line 14 Add a sentence or two discussing how the stationary clutter increases the noise floor.

"Detection of precipitation requires a signal that exceeds the noise floor by at least the signal to noise ratio. Energy scattered from wind turbines results in the occurrence of increased noise that might cause desired targets to be undetected. Although the signal processing techniques may mitigate the display of false targets generated by the stationary clutter from a wind farm, it will not eliminate effects that raise the noise floor of the radar."

4. Page 1481, Line 19 Replace 'neither' with 'nor'

The text of the paper has been changed according to the reviewer's comment: "The presented method requires neither complex calculations nor the use of a simulation tool, whereas (. . .)"

Section 3 1. Page 1481, Section 3 Consider moving this section to be the opening statements of Section 4, Methodology, prior to subsection 4.1.

As suggested by the referee, the content of former Section 3 has been included to become the opening statements of the new Section 3, Methodology.

2. Page 1481, Line 26 Remove the statement in the parenthesis.

The statement has been removed from the text.

Section 4.1 1. Page 1482, Line 22 Remove the parenthesis and include the 300 km limit as a normal part of the sentence.

The mentioned parenthesis has been removed: "S-Band is well suited for detecting heavy rain at very long ranges, up to 300 km;".

2. Page 1483, Line 1 The 'less usual' statement seems out of place.

The referred statement has been removed from the text.

3. Page 1483, Line 1 X-band radars, and shorter wavelength radars, are not more sensitive in general. The sensitivity depends on power, directivity, etc. Remove the comment about the sensitivity, as it is unnecessary for the discussion.

The text of the paper has been changed according to the reviewer's comment: "(. . .) and X-Band weather radars are used only for short range weather observations up to a range of 50 km (ITU-R and WMO, 2008)."

4. Page 1483, -Relative location of weather radar and wind turbine: : : In some cases, wind farms are located in flat areas, but it is not true for all scenarios. Further, depending on the distance from the radar, contamination from the wind farm can be significant in the antenna sidelobe region, and extend well beyond the lowest elevation angles. Reword this section to indicate that the study is simplifying the scenario, and does not represent every case, but will serve as a proof-of-concept for the model.

The text of the paper has been changed to clarify that the proposed model is based on a representative scenario: "As a proof-of-concept for the proposed model, a representative scenario has been chosen. This scenario considers that weather radars are usually located in open places that allow unobstructed scanning of a wide area, up to 300 km. Wind farms are also placed on clear areas, where potential wind energy is higher. As weather radar beams use quite directive lobes (usually 1° beam width), wind turbines are illuminated only when radar transmission is pointing to the wind farm. Therefore, the scenario to be analyzed is the potential incidence of the lowest elevation angles of the radar beam on the wind turbines. Lowest elevation angles of the scanning routine are usually transmitted just above horizon, for radar located in flat areas, or slightly below the horizon, for radars located on top of the hills. Accordingly, a reasonable range of the lowest elevation angles where the radar beam can illuminate a wind turbine is -2° to +4° with respect to the horizon (WMO, 2014) (Grande, 2015). The previous assumption leads to incidence angles on the wind turbine nearly perpendicular to the vertical axis of the mast, in particular, within the range 88° < θ < 94°."

Section 4.2.2 2. Page 1484 Consider combining this subsection with the previous, it is very short to be given its own section.

Former Section 4.2.2. has been included as the last paragraph of the previous section, forming a new Section 3.1.1, "Simulation tool and wind turbine models". The change in the order of the subsections is explained later.

3. Page 1484 Add more information about the models. This would be a good place to mention that the model is a tapered cylinder, or a truncated cone. Anything to describe the 'uppermost radius' to the reader would be helpful. Further, it would be useful to know perhaps the kW rating of the turbine for reference.

According to the referee's comments, more information about the wind turbine models and a note about the actual geometry of the mast have been included in the text. Moreover, the rated power of the wind turbine models to be analyzed has been included in Table 1. The first three paragraphs of the resulting new Section 3.1.1, "Simulation tool and wind turbine models", are as follows: "The present study is based on the accurate assessment of RCS values of wind turbines by applying the Physical Optics (PO) theory. More precisely, the software tool POfacets (Jenn, 2005) has been used to calculate RCS patterns of three different wind turbine models. To do so, detailed facets-based representations of these wind turbine models have been prepared for the application of numerical solutions of the PO method for RCS estimations. More in depth descriptions of the Physical Optics Method and the simulation tool can be found in (Jenn, 2005), (Grande, 2014), (Grande, 2015). It should be noted that this tool provides accurate

RCS values for a specific rotor orientation and blade position, but at the expense of having to design rigorous representations of the wind turbine models. Hence, estimations of RCS values for each specific position of the blades must be conducted, and therefore, hundreds of RCS simulations are required in order to obtain a detailed characterization of the RCS patterns for different working conditions. The analysis of this huge set of RCS values is the basis of the proposed simplified model to be integrated in the prediction tools for potential interference from a wind farm. In fact, the main motivation of the proposed simplified model is precisely avoiding the need of such a simulation effort in future cases under study. As previously mentioned, three commercial wind turbine models were chosen for the analysis, which constitutes a representative selection of the wind turbines that are currently installed. Typical horizontal-axis wind turbines are composed of a mast or supporting tower, commonly made from tubular steel; a nacelle that holds all the turbine machinery and rotates to follow the wind direction; and a rotor with three blades of complex aerodynamic surface, being the rotor shaft tilted above the horizontal to enable greater clearance between the blades and the mast. Characteristics of the selected models are summarized in Table 1. It should be noted that upper and lower radii of the masts are different because the geometry of the supporting tower of the wind turbines is not a perfect right circular cylinder but a tapered cylinder."

Section 4.2.3 1. Page 1484 Accuracy is not the correct term to use. Use 'Precision' or 'Quantization' in the subsection title. Accuracy would refer to actual wind turbine RCS measurements to corroborate the model.

As suggested by the reviewer, the term accuracy has been replaced by precision in the subsection title.

2. Page 1484, Line 23-24 It is not apparent to the reader what the theta and phi parameters represent exactly. It should be clear in Figure 1 what phi represents, and that it is referenced to the normal of the blade face and toward the radar along the radar line of sight (I think?). It would also be useful to define a parameter for the blade

rotation plane, again with explicit descriptions so the reader can visualize easily.

In order to make the coordinate system clearer, Fig. 1 has been simplified. Moreover, theta and phi parameters have been explained in Section 3.1.1, “Simulation tool and wind turbine models”, which was Section 3.2.1 before but has been moved to the beginning of Section 3 in order to clarify the coordinate system before explaining the considerations of the analysis (now in Section 3.2). The last paragraph of Section 3.1.1 is now as follows: “Fig. 1 shows the reference coordinate system for the analysis. The wind turbine rotor is supposed to be oriented towards the x-axis and R refers to the radar position. As shown in the figure, θ is the angle from the zenith that defines the radar position in the vertical plane, and Ðď specifies the horizontal position of the radar with respect to the rotor orientation, i.e., with respect to the rotor shaft axis ”

Section 5 1. Page 1485, Line 19 This is the first mention of the slant surface. A drawing or more discussion about the model (Section 3) should be included.

As explained in Comment 3 referring to former Section 4.2.2, a note about the actual geometry of the mast has been including in the text, in the new Section 3.1.1.

2. Page 1486, Line 5 When the blades are in a vertical position, shouldn’t the maximal return be at 90 degrees? Or is there a slant angle to the blades as well? This should be discussed more in the description of the wind turbine model (Section 3).

As suggested by the reviewer and detailed in the response to Comment 3 referring to former Section 4.2.2., a more detailed description of the wind turbine models has been included in Section 3.1.1. This description includes a comment about the aerodynamic design of the blades, which scatters incident energy in multiple directions, and the fact that the rotor shaft is tilted above the horizontal, which further complicates the a priori estimation of the direction of the maximum scattering from the blades.

Section 6.1 1. Page 1487, Line 8 Remove the term ‘really’.

The term “really” has been removed from the text: “(. . .) the half cone angle α that

defines the slant surface of the mast is small (see Figure 7),”

Section 6.3 1. Whole section Some effort is spent in validating the simplified model against the optical model, but no effort is spent in validating the reflectivity calculation. It would greatly strengthen the work if the estimates for wind turbine reflectivity could be corroborated with real data, particularly the Doppler or blade reflectivity estimate.

The authors fully agree with the referee on the value of comparing the results of the model with real data. Unfortunately, such data are not available for the authors. Even though the proposed model cannot be validated against real reflectivity values, the authors think that the model provides a practical and easy-to-apply estimation of reflectivity values from wind turbines that may be of interest in order to avoid interference effects of wind farms on weather radars.

Section 7 1. Page 1494 It is not clear how the reflectivity values will be used. Please be explicit to the reader in how this model will aid in the planning for wind turbine clutter impact. Specifically, address the two issues mentioned at the beginning of the paper, clutter and Doppler, and how this technique can help plan for impact assessments.

According to the referee’s comments, additional discussion has been included in Section 6 (former Section 7): “The proposed RCS model can be used to estimate the maximum clutter due to the presence of a wind turbine, estimating the scattered power from the mast. On the other hand, even if the Doppler radar under study uses a clutter filter that suppresses stationary objects, the rotating blades of a wind turbine might still be detected. As proved in (Norin, 2015), weather information from radar cells affected by a wind turbine is not always lost. In fact, when precipitation gives rise to reflectivity values stronger than those due to wind turbines, radar data could still be used. Therefore, the reflectivity model proposed in this paper is of interest not only to assess a potential detrimental impact on the performance of a weather radar, but also to evaluate to which extent this degradation might exist, if reflectivity values from precipitation and wind turbine blades are compared.”

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/8/C431/2015/amtd-8-C431-2015-supplement.pdf

Interactive comment on Atmos. Meas. Tech. Discuss., 8, 1477, 2015.

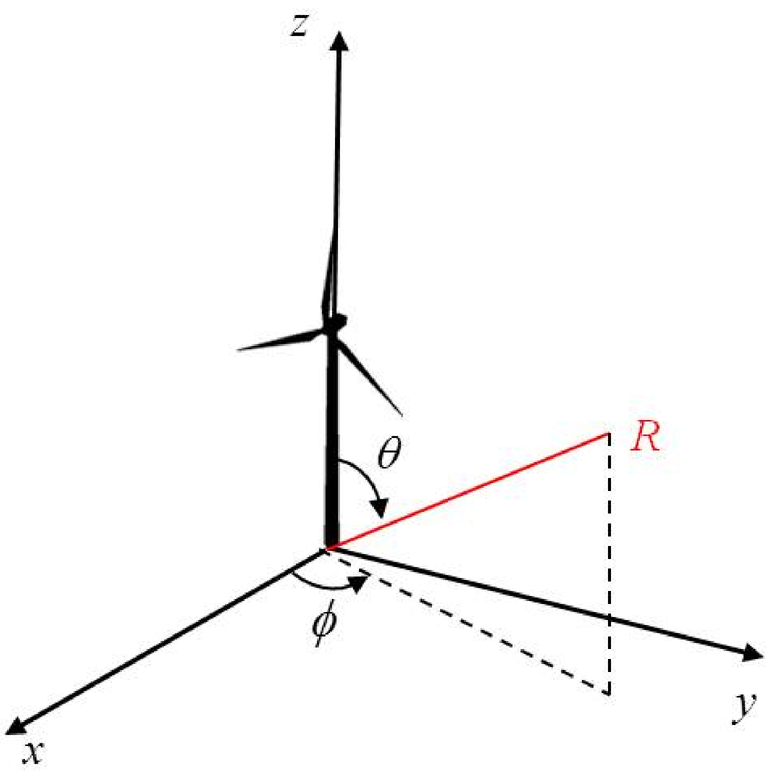

Fig. 1.