Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2020-384-RC1, 2020

Atmospheric Measurement Techniques Discussions
Open Access

Interactive comment on "Insights into wind turbine reflectivity and RCS and their variability using X-band weather radar observations" *by* Martin Lainer et al.

Anonymous Referee #1

Received and published: 7 December 2020

Review on

Insights into wind turbine reflectivity and RCS and their variability using X-Band weather radar observations by Martin Leiner et al.

Overview:

For a long time I did not review a manuscript that was as interesting and gave me as much pleasure as this one. The paper discusses a relevant topic, it is clearly structured and comprehensive, most of it could be published as it is. Thank you to the authors and congratulations.

Printer-friendly version

Discussion paper

Disturbing backscatter from wind turbines (WT) is discussed fiercely in the radar meteorology community. Getting insights into the properties of wind turbine echoes is the needed basis to develop methods to alleviate or overcome the problems. The authors discuss widely the echo intensity of WT echoes based on target-oriented (in double sense) scanning strategies.

As I said, this contribution is helpful and interesting as it is. Nevertheless, the measurements as they are described provide further information about the echoes from locations nearby around the WT and on the properties of other variables (spectral width, polarimetric variables) at the WT location and around. This information is urgently needed to comprehend the WT problem and I want to encourage the authors to add further publications based on the data of this experiment.

Major remarks:

As I did not find differing information I assume (I have to assume) the given data are measured without a Doppler Filter and any other quality filter applied. It might be I forgot that this information is given somewhere. If not, it has to be clearly stated how the data are processed (by the radar).

Furthermore, for practical application of the results the differences between uncorrected reflectivity (uZh) and Dopper corrected reflectivity (Zh) need to be shown and discussed. The guessing about the importance of the (mainly static) nacelle of the WT for the echoes is not necessary as a Doppler filter will separate echoes from the static parts of the WT from rotor echoes.

The first part of chapter 3 introduces some theoretical terms, especially radar cross section (RCS). It starts from the standard discussion of an single, isolated target. Equation (1) is valid for an particle on the radar axis. If its position deviates from the main axis, the directivity pattern of the radar antenna has to be taken into account.

A WT is not small compared to the 3dB beamwidth. Here the limitations start. The RCS as it is derived here _is_ sensitive to the directivity patten of the antenna. A different pattern would produce a different weighting of individual parts of the WT, resulting in a different RCS. Additionally, the WT is not small compared to the radial resolution of the measurements (75 m). Already a flagpole (i.e. a point in a PPI) contributes to two consecutive range gates if it is not perfectly positioned at the center of one range gate. As the diameter of the antenna is nearly twice the length of a range gate, the echo from the WT is distributed in three or four range gates if the relative yaw angle is 90 degrees or close to it. One range gate never contains all the echo from the WT. This needs to be explained and taken into account when deriving RCS from reflectivity.

In the following text and the figures the authors provide sometimes reflectivities, sometimes RCS values. As stated above, I do not trust the RCS and I do not want to calculate back an forth to compare RCS and Z values. My recommendation is: (i) improve the derivation of RCS by discussing the effect of the spatial extend of the WT, (ii) determine the offset between RCS and Z for each of the WTs, and then (iii) stay to the measured reflectivities without introducing additional uncertainties from the conversion to RCS.

I do not follow the argument of the orientation of the nacelle to be important for the backscatter (line 288 and later). (i) The (scattering) area of the nacelle is small compared to the area of the rotor. (ii) The nacelle often has more or less straight "walls", leading to a stealth behaviour: as long as the radar is not perpendicular to the nacelle surface, the (strong) echo is not scattered back to the radar. (iii) The scatter properties of a nacelle might be severely dependent on corners on the surface of the nacelle, which can have the effect of a corner reflector. Thus the properties of this individual nacelle are not representative for other type of WTs.

In order to prove the theory of strong nacelle echoes, the authors should discuss the effect of a Doppler filter. Such a filter should be able to suppress the nacelle echo, as the nacelle is (nearly) not moving.

The last concern is about the linear correlation coefficients used in Fig. 11 and the text on it. In case there is a relation between WT physics and radar echoes it is not necessarily linear but probably strong. Assuming a linear relation between pitch angle and echo strength means - just to clarify my argument - a significant stronger echo at 390 degrees pitch angle than at 30 degrees. The surfaces on the rotor blade are in no way changing in a linear way.

With this argument, taking |sin| of the yaw angle is useful step. The images in Fig 12 bring some evidence that linear relations are not totally misleading. Nevertheless for |sin(yaw angle)| there is a significant shift to stronger echoes, not described by the linear relation.

Fig 11 shows 28 correlation coefficients for three different samples of the measurements. Only 16 of them relate a WT related value (psi, theta, rs, and u) with a radar variable (Zmax, Zmin, delta Z, Zmedium). Wouldn't it be possible to show more of these scatter plots but only the four relations for two different samples?

In Figs 12 and 13 there are 95 % confidence intervals marked by shaded areas. But in no case 95 % of the measurements fall into these intervals. What is the meaning of these 95 % confidence intervals?

Lately, the values for Zhmax are limited by saturation of the receiver as the authors mention. What does this mean for correlation coefficients of Zhmax to some other value?

Minor remarks:

L 23: 205 GW is the _installed_ capacity of WTs. As the wind is unsteadily blowing, the amount of yearly produced energy is significantly less than 205 GW times 8760 hours (=1.8 PWh). The real production was "only" 417 TWh. These 417 TWh correspond to 15 % of the electricity consumption of Europe. Do not mix up these terms. BTW: There is no proof that the number of wind turbines needs to increase. It might be the size of the turbines instead.

L 93: The directions towards the WT from the radar are 337.8°, 343.3°, and 340.2°. The RHI scans (according to Tab. 3) are only performed until 342.9° in fine resolution. Why does the range not cover the turbine at 343.3°? In Fig. 4d the positions of the most intense echoes are at roughly 338.5°, 341.5° and 343.3° which does not fit to the (first two) given WT locations. Same discrepancy for Fig. 5 and Tab. 4 also gives a different location of WT 1.

L 149: Sorry, I do not "clearly" see low ZDR and high RhoHV values at the wind turbine positions. Could you add an isoline of reflectivity at 35 dBZ to make it easier to see the effect? ZDR and RhoHV show an intense variation (noise) making it hard to assign individual pixels to a WT effect.

L 177: The inline equation contains two different Pr. One has the unit mW, one the non-unit dBm. The equation enables us to determine Pr. I know the problem to introduce dB and values on a logarithmic scale, but this way is wrong.

L 179: sigma is not described as a scalar but deeply discussed as a function of the two angles occurring. What is a scalar is sigma(pi), the _back_scatter cross section.

L 180: I added a linefeed before "Precipitation".

L 192: In equation 4 the gain G0 looses its 0 without further notice. Why?

L 198: if you change equation 5 to sigma_i = piˆ5 |K|ˆ2 D_iˆ6/lambdaˆ4, there is no need to change from sigma_d to sigma_i.

L 201: You did not introduce Z, so you cannot convert from Z to RCS.

L 204: You should give all three conversion factors for the three WT.

L 248: "Averaged value"? How did you average? In dB or in mˆ2?

L 248: The difference between two logarithmic values is always dB, not dBsm.

L 280: Yes. The yaw angle of the WT is independent of reflectivity values. It is even independent of the presence of the radar. The message should be, the maximum reflectivities are insensitive to the yaw angle. - BTW: 10 dB difference is not really insensitive. It might be less intense than expected, but 10 dB is a factor 10.

L 285: The variation of the maxima (in a) is in the order of 10 dB. The variation of the P99 values is also 10 dB. Why do you say, a directivity is more visible in b than in a? Same question occurs for the median values. - Plot (just for you) the figures into a Cartesian coordinate system and see if the messages is stable.

L 417: See remark on line 248.

Figures:

The figures are a main drawback of this paper. It is the duty of the authors to provide figures the show - not hide - the information. Along all the figures only a few axis descriptions, titles and so on are readable. I do not want to use a magnifying glass to read the figures! Hardly any of these figures can be accepted as it is.

Additionally, figure 12 makes use of bright and dark green and blue. It might be that the printer of the authors (or their screen) shows these differences. Mine not. There are colors which are better distinguishable than bright and dark blue. There are different marks but + signs.

Fig 1. The black + for the radar position is totally invisible in my printout in subfigure a. Same for the border lines in both figures. Axis labels and tic labels are fine for a and b, tic marks for c are at the limit.

Fig 2. Absolutely unreadable in printout. On the screen at 400 % size acceptable but the velocities at the color codes.

Fig 3: Axes labels and tic labels at the limit. Sketch of wind turbines is a good try to explain nacelle orientations. I think, a view from the top is easier to see.

There is no additional information but only more confusion in showing absolute and relative orientations of the WT. Simply give the offset angle and show one of them.

What is the source of the echoes left of WT 1 in d and e?

Fig 4: Can you provide a PPI of spectral width as well? Labels in a through c at the limit, in d through f totally ridiculous.

Fig 5 and 6: If you assess the patterns around the wind turbine to the directivity pattern of the radar antenna, we need that directivity pattern to be shown in the same form. Is there any difference between the top rows and the bottom rows but an offset? If not, bottom rows are not needed.

Axis and tip labels are below the limit.

Fig 7: In a, c and f the local maximum at the position of the WT is a bit larger then the overall maximum around the WT. This is not possible by definition.

Axis, tip and legend labels are totally unreadable. Digitally they appear to be readable at roughly 250 %.

Fig 7/8: One figure shows RCS in dBsm, one figure shows reflectivity in dBZ. This is not helpful. Please show always Z in dBZ.

Fig 8: Axis and tip labels at the very limit.

Moving average in dB, not in mmˆ6/mˆ3?!

Fig 9: Labels and so on much too small.

The figures are strongly missleading! Whereas the reflectivity scales show a range of 60 dB, the cross section scales only show 40 dB. This changes the shape massively!. Max reflectivity at 110° is roughly 80 dBZ, at 140° it is 70 dBZ, 10 dB less. Max RCS at 110° is fairly 45 dBsm, at 140° it is 35 dBsm, also 10 dB less but the "bulge" looks much stronger - it is not.

The median reflectivity has a difference of 68 dBZ (170°) down to 56 dBZ (310°), i.e. roughly 12 dB. The median RCS varies between 32 dBsm (170°) and 20 dBsm (310°), also 12 dB. All the difference that are visible between a/b and c/d are caused by the way of presentation.

I recommend to combine a and b into one figure (having three dot circles instead of two, showing only values between 80 dBZ (max value of all) and 50 dBZ (min value of median values).

Bin width are differences and thus always given in dB, not in dBZ or dBsm (see comment on line 240).

Fig 10: "WT1 blade angles" means pitch angles?

Fig 11: Do we need more than the lower 4x4 CC values? Probably instead of simple linear correlation coefficients scatter plots could tell more.

Fig 12: Especially the legend is unreadable. Bright and dark green, bright and dark green are indistinguishable in my printout. Choose other colors.

Fig 14: Legend unreadable.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2020-384, 2020.