IE-SAWM-EBBE-0021
BAF REF: 3D/XXXX

Simple Assessment Beauvechain wind-turbine mitigation

EDF Luminus - Herentals

Edition: 001
Date: 14-Nov-17
Status: Released Issue

Document Characteristics

General	
Simple Assessment Beauvechain wind-turbine mitigation EDF Luminus - Herentals	
Edition:	001
Edition Date:	14-Nov-17
Status:	Released Issue
Keywords:	Study on wind-turbine mitigration
Abstract:	This document is the study on possible mitigation of wind-turbines on radars.

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Document Control Information	
Document Name:	IE-SAWM-EBBE-0021_Herentals_Beauvechain_EDFLuminus.odt
Reference Number	IE-SAWM-EBBE-0021

Document Change Record

Revision	Date	Reasons for change	Pages Affected	Approved by
001	14-Nov-17	New document	All	WBR

Document Validation Record

Responsible		Date	Signature
Author	Wim Branders	14-Nov-17	

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Icon Conventions Used

Intersoft Electronics doesn't see any problem for the radar.

Intersoft Electronics expects that there will be no problem for the radar, but just needs to check this at the radar site after turbine installation. Radar parameter adaption could be required.

Intersoft Electronics expects that there will be interference for the radar. NGSP mitigation technology is necessary to solve this problem.

Intersoft Electronics expect serious problems for the quality of the radar data and radar performance.

This icon to indicate a very important remark.

Glossary of Terms

AMSL	Above Mean Sea Level
ACP	Azimuth Change Pulse
dB	Decibel
Downlink	The signal path from aircraft to ground
FL	Flight Level, unit of altitude (expressed in 100's of feet)
IE	Intersoft Electronics
MSSR	Monopulse Secondary Surveillance Radar
Multipath	Interference and distortion effects due to the presence of more than one path between transmitter and receiver
NM	Nautical Mile, unit of distance
Plot extractor	Signal-processing equipment which converts receiver video into digital target reports suitable for transmission by land lines
PSR	Primary Surveillance Radar
Radar	Radio Detection And Ranging
RASS-R	Radar Analysis Support Systems – Real-time measurements
RASS-S	Radar Analysis Support Systems – Site measurements
RCS	Radar Cross Section
RF	Radio Frequency
SLS	Side Lobe Suppression, a technique to avoid eliciting transponder replies in response to interrogations transmitted via antenna sidelobes
SLB	Side Lobe Blanking
SSR	Secondary Surveillance Radar
STC	Sensitivity Time Control

1. Introduction

1.1. Purpose

The performance of radar system can be negatively impacted by wind turbines. The EUROCONTROL GUIDELINES ("Guidelines on how to Assess the Potential Impact of Wind Turbines on Surveillance Sensors") explain how to assess the potential impact of wind turbines.

Instead of working with theoretical models and assumptions, Intersoft Electronics (IE) works with measured data. This is a huge advantage as IE can directly see the possible influence by just looking at the radar data.

This assessment is only applicable on the number of turbines, wind-farm location and radar as described in this document. Conclusions for other wind-farms, radar or different number of turbines based on this document are not included.

1.2. Site Under Test

This simple assessment report describes the study to investigate the possible mitigation of wind turbines on radars.

Simple Engineering Assessment	
On behalf of	EDF Luminus
Number of turbines	2
Location	Herentals
Affected radar	Beauvechain

Table 1: General information

Belgian Airbase Beauvechain Air Surveillance Radar (TA10)	
Coordinates	50:45:4.61N - 04:46:29.55E
Height ([m] corresponding MSL)	134
Height ([m] corresponding MSL)	60

Table 2: Radar information

Figure 1.1 shows the layout of the turbines, as provided by EDF Luminus plotted in Google Earth. They are indicated by yellow pins and are showing the turbine identification (ID) numbers. The red pins mark the location of operational turbines or turbines under construction[1]. This project will be located around 25 NM (+/- 45 km) from the radar. Table 3 displays the turbine parameters:

Turbine	Position [Lat/Lon]		Ground level AMSL [m]	Tower height AGL [m]	Tower height AMSL [m]	Blade Length [m]	Tip height AGL [m]	Tip height AMSL [m]
WT01	51:09:28.37	04:49:33.09	13	89	102	60	149	162
WT02	51:09:24.51	04:49:53.17	13	89	102	60	149	162

Table 3: Turbine Information

For the analysis Intersoft Electronics used the AMSL tower height and tip height of the turbine.

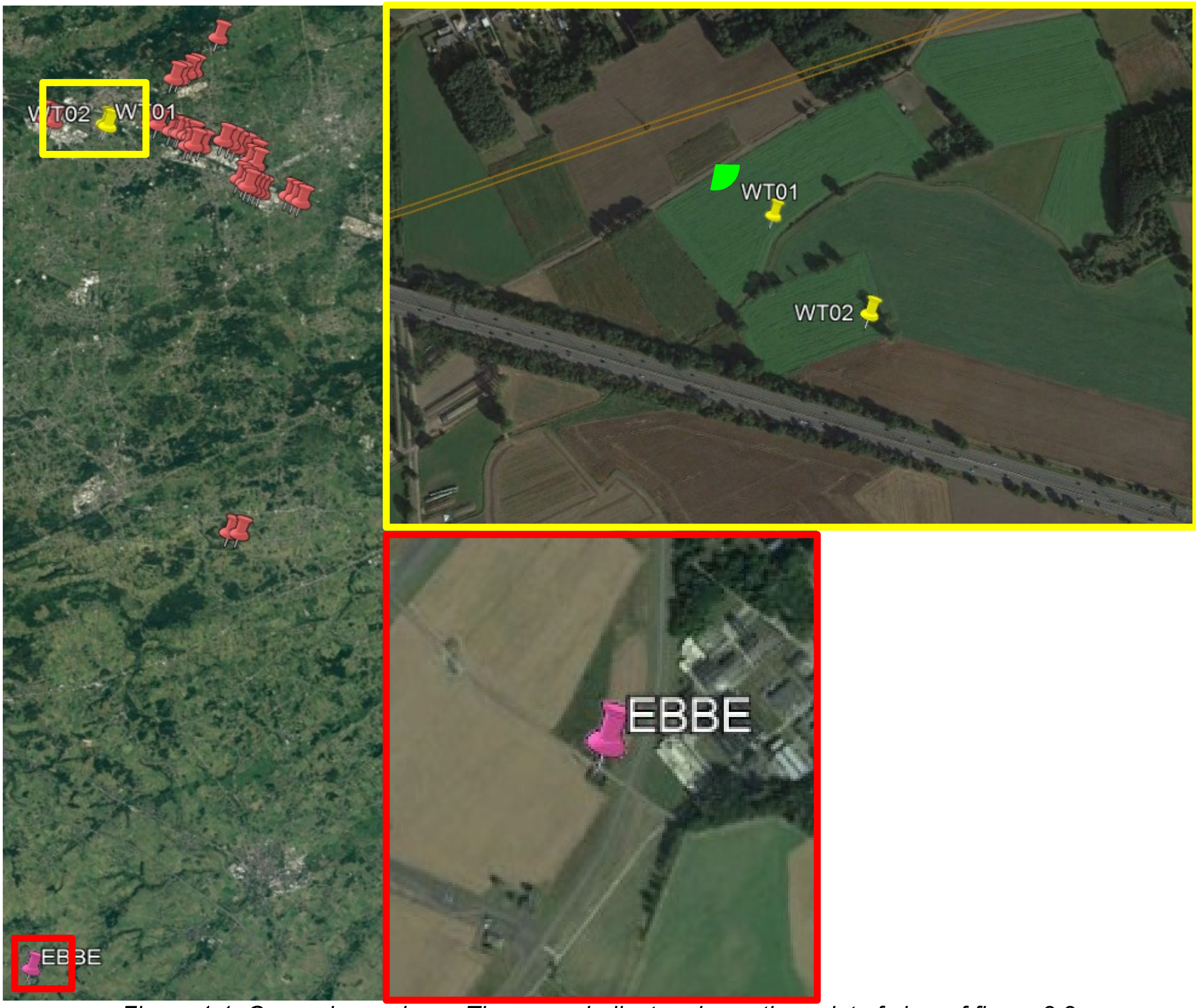

Figure 1.1: General overview – The green indicator shows the point of view of figure 2.2

1 http://data.gov.be/nl/dataset/eeb20d55-0742-4996-841c-3bb817626337

1.3. Turbine environment overview

Figures 1.1 and 1.2 show the wind farms environment. The turbines will be constructed in a meadow along the E313 highway in Herentals. The site location is near the towns of Herentals, Olen and Noorderwijk.

Along the E313 highway there are several operational wind farms or projects under construction. These have tip heights of 143m to 150m. North of the project site there is a high voltage power line, the height of these pylons is negligible.

Figure 1.2: Turbine Environment

2. EUROCONTROL GUIDELINES

According to the EUROCONTROL guidelines[2] a simple assessment is needed for Wind Turbines further than 15km (8.1Nm) from the radar and within line of sight. For such assessment following topics have to be addressed:

Assessment	Eurocontrol guidelines section number Simple assessment
PSR: Probability of Detection	Yes
PSR: False Target reports (due to echoes from wind turbines)	Yes
PSR: Processing Overload	Yes

Table 4: EUROCONTROL Simple Assessment

The EUROCONTROL guidelines describe methods for theoretical assessment based on mathematical models. Examples and conclusions of similar mathematical studies are widely available.

Intersoft Electronics gathered 24-hour data recordings from August 13th on to August 19th 2017. These recordings were analyzed to determine the visibility of the turbines on the radar.

The following paragraphs investigate the required PSR assessments like Line-of-Sight, probability of detection, false target reports and processing overload.

2How to Assess the Potential Impact of Wind Turbines on Surveillance Sensors

2.1. Turbines in Line-of-Sight (LoS)

For this purpose the first priority is to find out if Line-of-Sight (LoS) conditions are to be expected when the requested turbines are placed.

If all geometrical data about the radar and the target is known, it is theoretically possible to calculate whether LoS conditions are present or not. Such a theoretical calculation is often not very realistic however, as the objects in close vicinity to the radar can dramatically change the LoS conditions in a positive or negative way.

Indeed the presence of hills, trees, buildings or other elevated obstructions can limit the coverage of the radar to a specific elevation angle for different azimuth directions. On the other hand, objects that obstruct in one azimuth can reflect the radar pulses and actually provide a mirror view to low level objects normally not detectable. This indirect LoS can be extremely complex for land based radar. Considering the number of objects close to the radar, it is not realistic to rely on theoretical calculations to determine the possible impact of a wind turbine for a given range.

The purpose of this study is to find proof rather than an estimate for the LoS, based on identifying objects from the radar point of view. The following data is gathered by making recordings at the Beauvechain radar and identifying different objects in view. Table 5 shows the azimuth versus the vertical elevation angle of all turbines.

Turbine	Range [NM]	Azimuth [Deg]	*AMSL Terrain Height [m]*	AMSL Tower Height [ft]/[m]	Tower Elevation [Deg]	AMSL Tip Height [ft]/[m]	Tip Elevation [Deg]
WT01	24.50	4.51	13	335/102	-0.19	531/162	-0.12
WT02	24.45	5.01	13	335/102	-0.19	531/162	-0.12

Table 5: Turbines Position and Elevation Information

Figure 2.1 shows the location of the newly planned turbine. The distance to the TA10 radar at Beauvechain is around 25 NM(+/- 45 Km). The tower height is 335 feet Above MSL and the tip of the rotor blade will be at maximum 531 feet Above MSL.

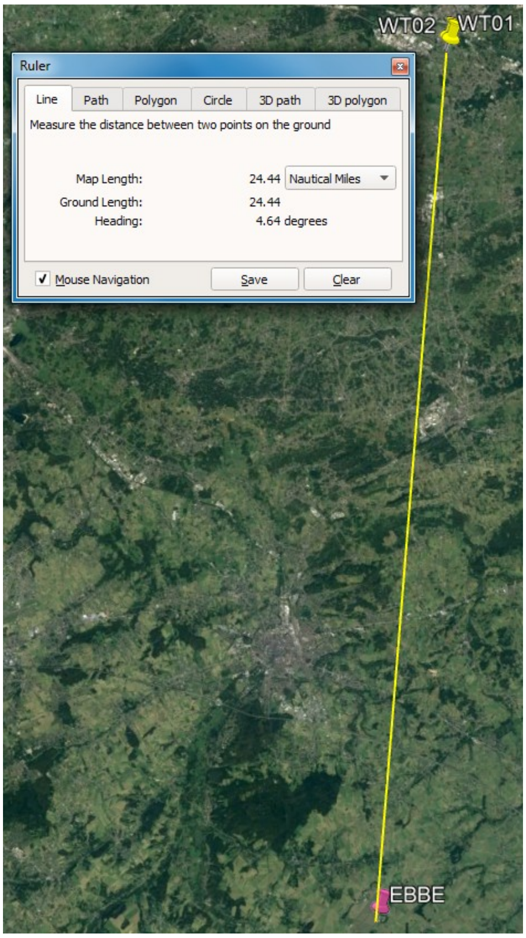

Figure 2.1: Wind-Farm Location

Figure 2.2 shows the theoretical radar LoS for various altitudes based on digital terrain data. The colored curves represent radar coverage for defined altitudes, calculated the RASS-R Coverage Map Calculator (CMC), part of the RASS-R toolbox. These calculations are based on commonly available digital elevation models that are obtained from satellite observations of the earth. The terrain data has a resolution of 3 arcsec, corresponding to ca. $90M^2$.

- **Yellow** **300ft**
- **Red** **400ft**
- **Green** **500ft**

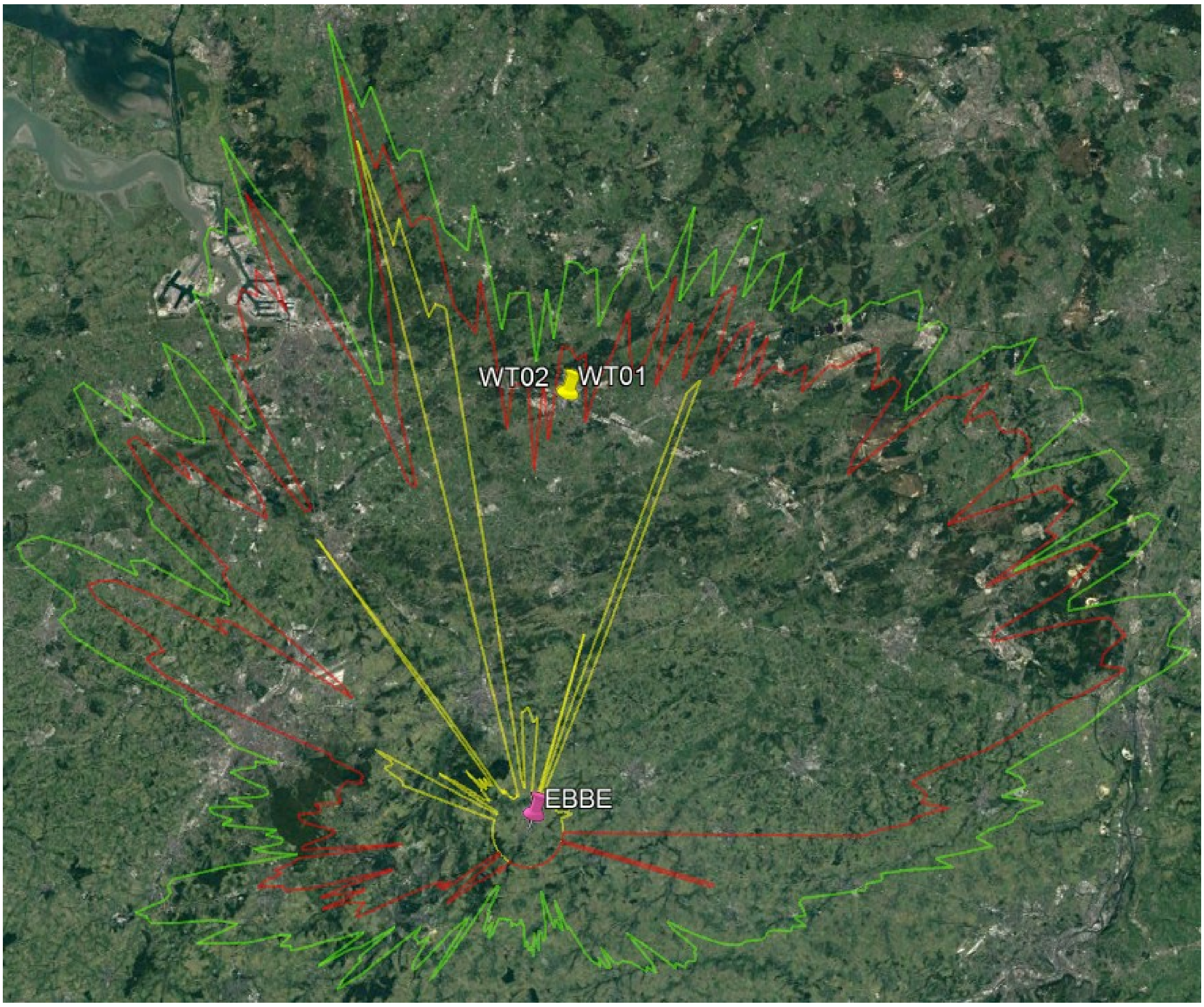

Figure 2.2: Theoretical Line of Sight

Figure 2.2 indicates that the turbines will be in LoS, the radar can see down to around 400ft at the projects location.

This theoretical model indicates that the turbines at 335ft will not be in LoS, however the tipheigths at 531ft will be in LoS.

The LoS assessment based on digital terrain data indicates that the turbine tips will be in LoS.

2.2. Clutter map TA-10 Beauvechain

Figure 2.3 show the complete clutter map (recorded in 2009 during tuning of the TA-10 extractor) 360 degrees out to 60NM range these will help us to estimate the Line-Of-Sight.

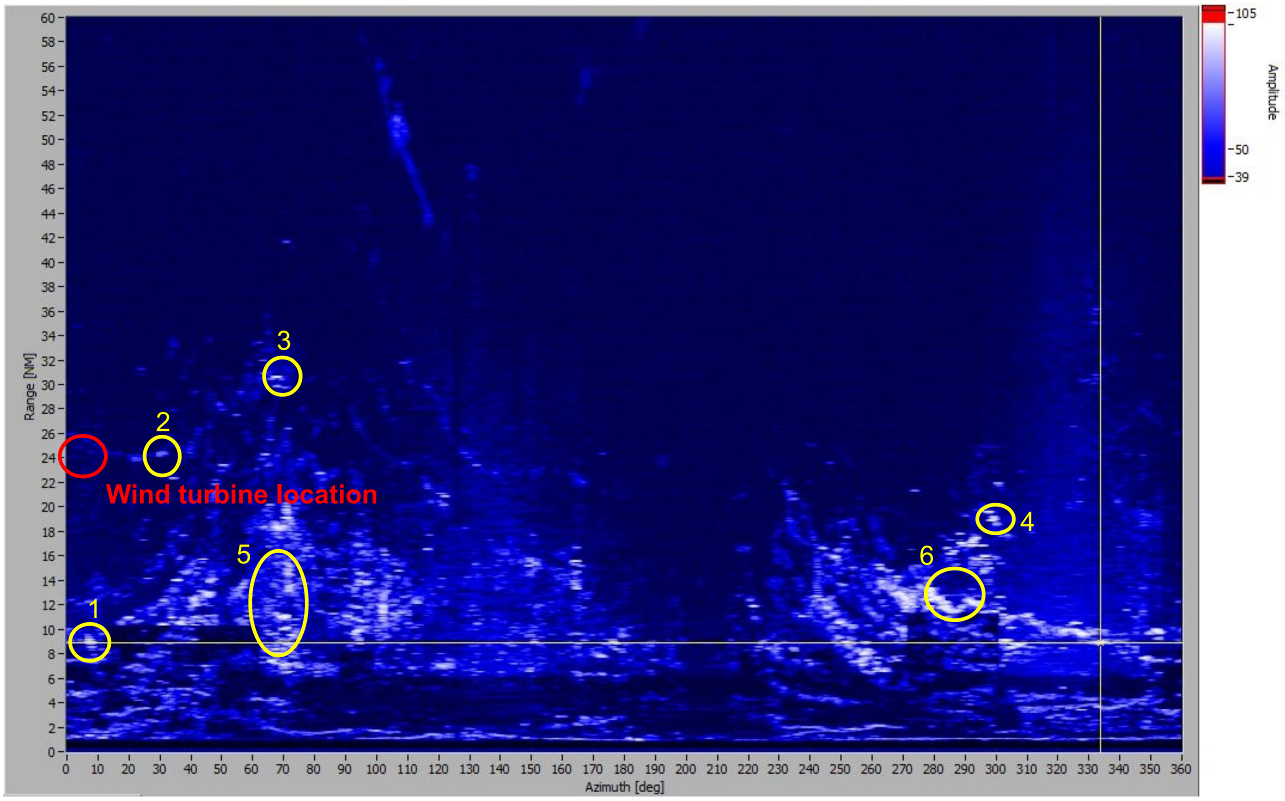

Figure 2.3: Clutter map

The reflections at approximately 9NM and 7.3 degrees (position 1 and figure 2.4) are high voltage towers with height of 197ft (60m) located near Lubbeek (Leuven). The second position at approximately 24NM and 30 degrees azimuth are the wind turbines from Nike in Ham (see figure 2.5). The clutter at the third location is from the radio tower in Langerlo (figure 2.6). Also the Atomium in Brussels with a height of 334.6ft is visible for the radar (see location 4 and figure 2.7). Positions 5 and 6 is clutter from trees and forests

Figure 2.3 also displays the location of the future turbines. The surrounding detected obstructions indicate that the turbines will be visible for the radar.

Figure 2.4: High voltage pilones Lubbeek

Figure 2.5: Wind Turbines Nike Ham

Figure 2.6: Radio tower Langerlo

Figure 2.7: Atomium Brussels

The LoS assessment based on digital terrain data and the clutter map recording indicate that the turbine will be in LoS.

2.3. PSR: Probability of detection

24 Hour data recordings from August 13th on to August 19th 2017 were analyzed for this purpose. Before loading the data in the RASS-S Inventory tool, IE performed a height correction with the Radar Comparator Mono tool applying barometric sounding data[3] and correction. This provides a better height indication of the targets and leads to a more accurate analysis.

The actual signal loss due to interference effect from the wind turbine is highly dependent on the proximity of the target behind the turbine and theoretically very difficult to assess. Especially as multipath propagation is not limited to just a single wind turbine. Ground reflections, atmospheric refraction, trees and other constructions add to the interference pattern.

The wind turbine towers are not blocking the signals as there is lots of space between them unless the target is very low and in close proximity to the obstruction. This is not the case and only possible with a helicopter. In reality the zone further behind the towers is affected by multipath and interference patterns. However this is similar to the effect of other obstructions like trees and buildings or high voltage lines. This disturbance manifests as Swerling, some locations receive less signal, other locations in the interference pattern receive more signal, the Pd averages out.

3 Refer to section 5.2.2: IE-UM-00029-008 (or later) RCM

Figure 2.8[4] shows the elevation of combined SSR/PSR targets with a range larger then 24.45NM in function of azimuth and this for 10 degrees around the turbine location.

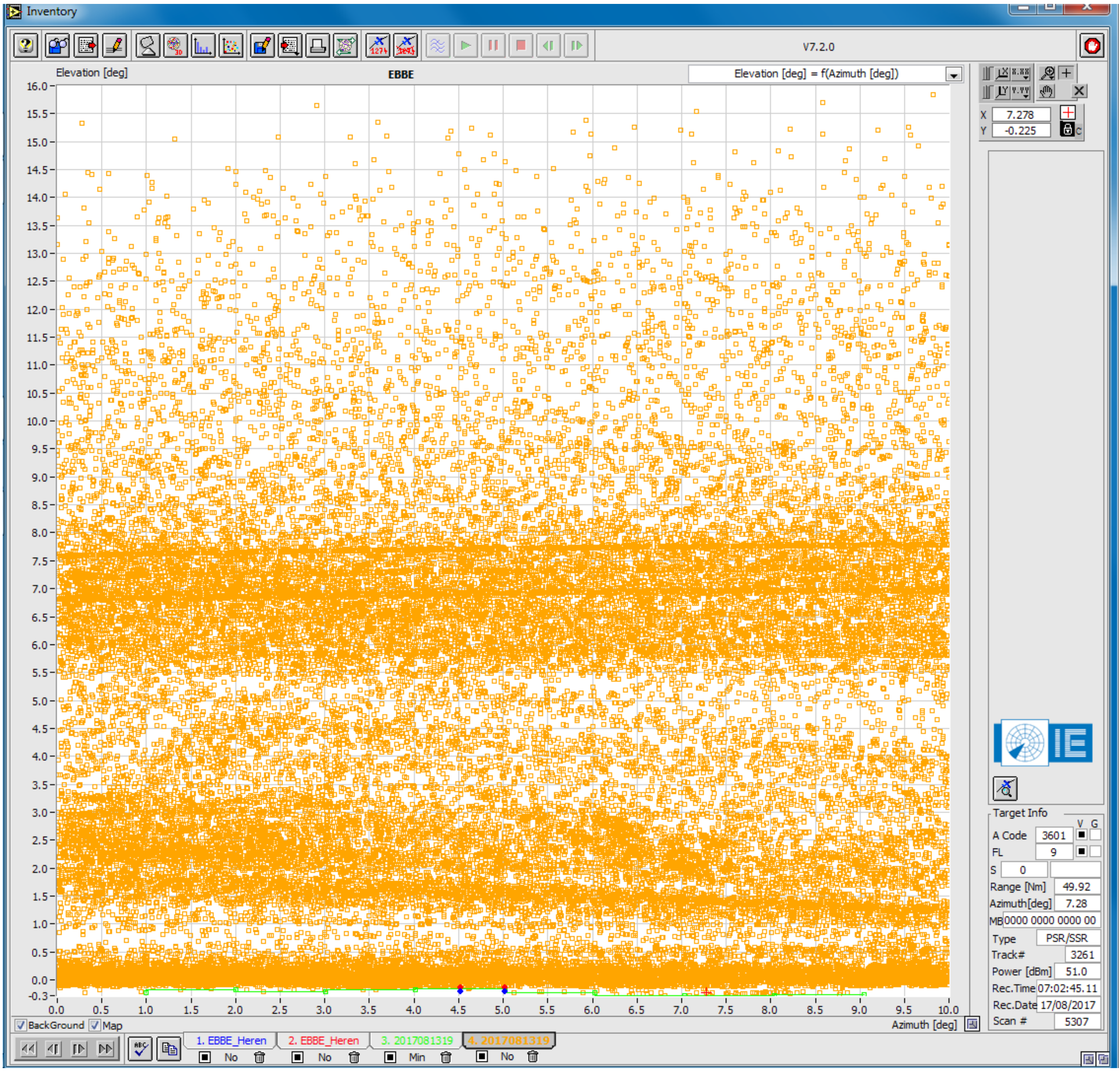

Figure 2.8: PSR target elevations in function of Azimuth

4 These graphs are made with Intersoft Electronics' RASS-S Inventory tool. The Inventory is developed to view the radar data in different forms and ways. It is an well known tool in the radar world and very useful for radar analysis assessments.

Figure 2.9 shows the accumulative distribution of targets in function of elevation. This distribution indicates that 99% of all detected traffic in 10 degrees azimuth around the turbines is located above -0.1 degrees in elevation.

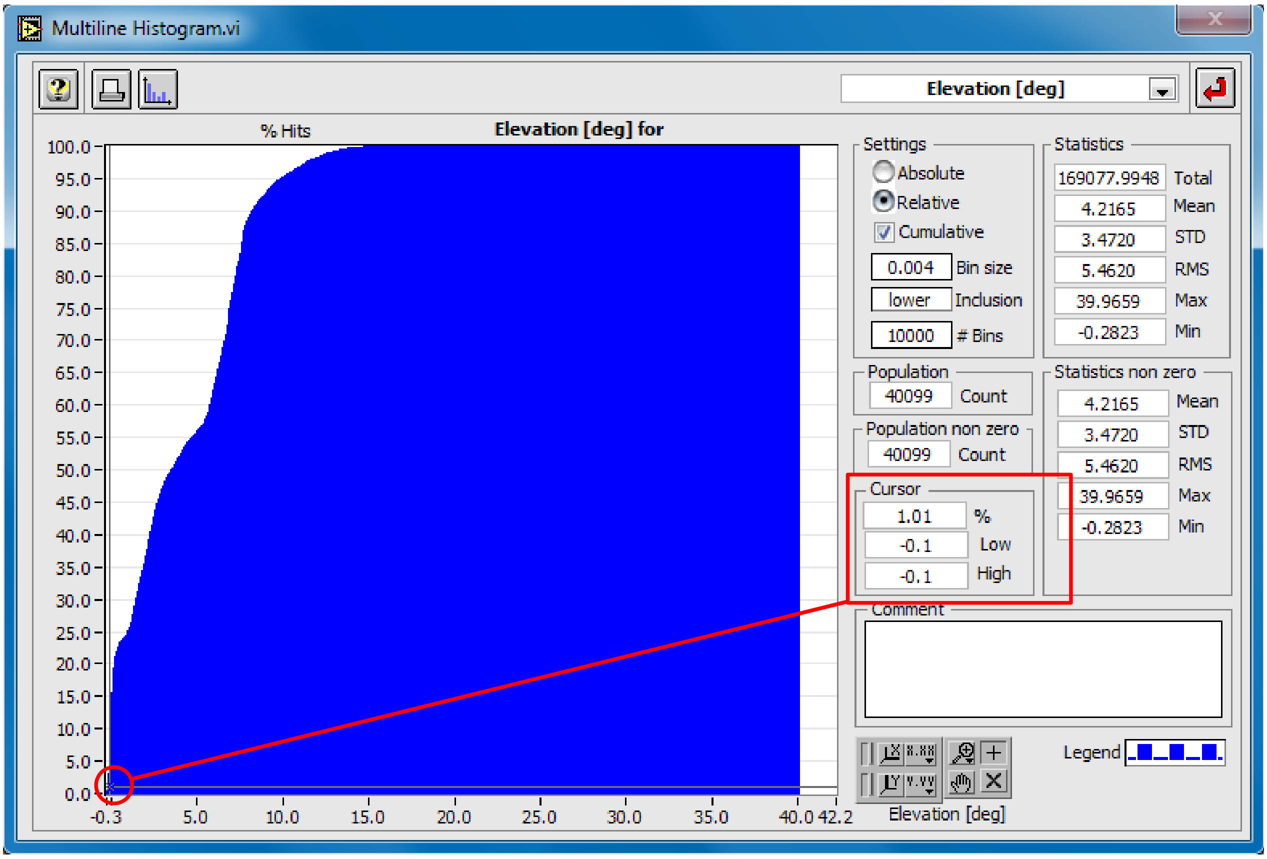

Figure 2.9: Accumulative distribution of targets in function of elevation

If we take the data of figure 2.8 and zoom in to 1 degree[5] in elevation and 10 degrees around the turbine location this gives figure 2.10, providing a view on the screening angles mostly created by objects close to the radar being trees and buildings. The red dots are the tips of turbines, the blue dots are the tower heights/elevations. The green line is the lowest detectable elevation angle for that azimuth and the orange dots are all the target reports for that area.

Figure2.10 confirms the theoretical model of figure 2.2. The turbine itself is below the detection of the radar. The tip height is in the line of sight. From 5 up to 10 degrees in azimuth there are plots detected in lower elevation, this also confirms the conclusion of the theoretical LoS model in chapter 2.2.

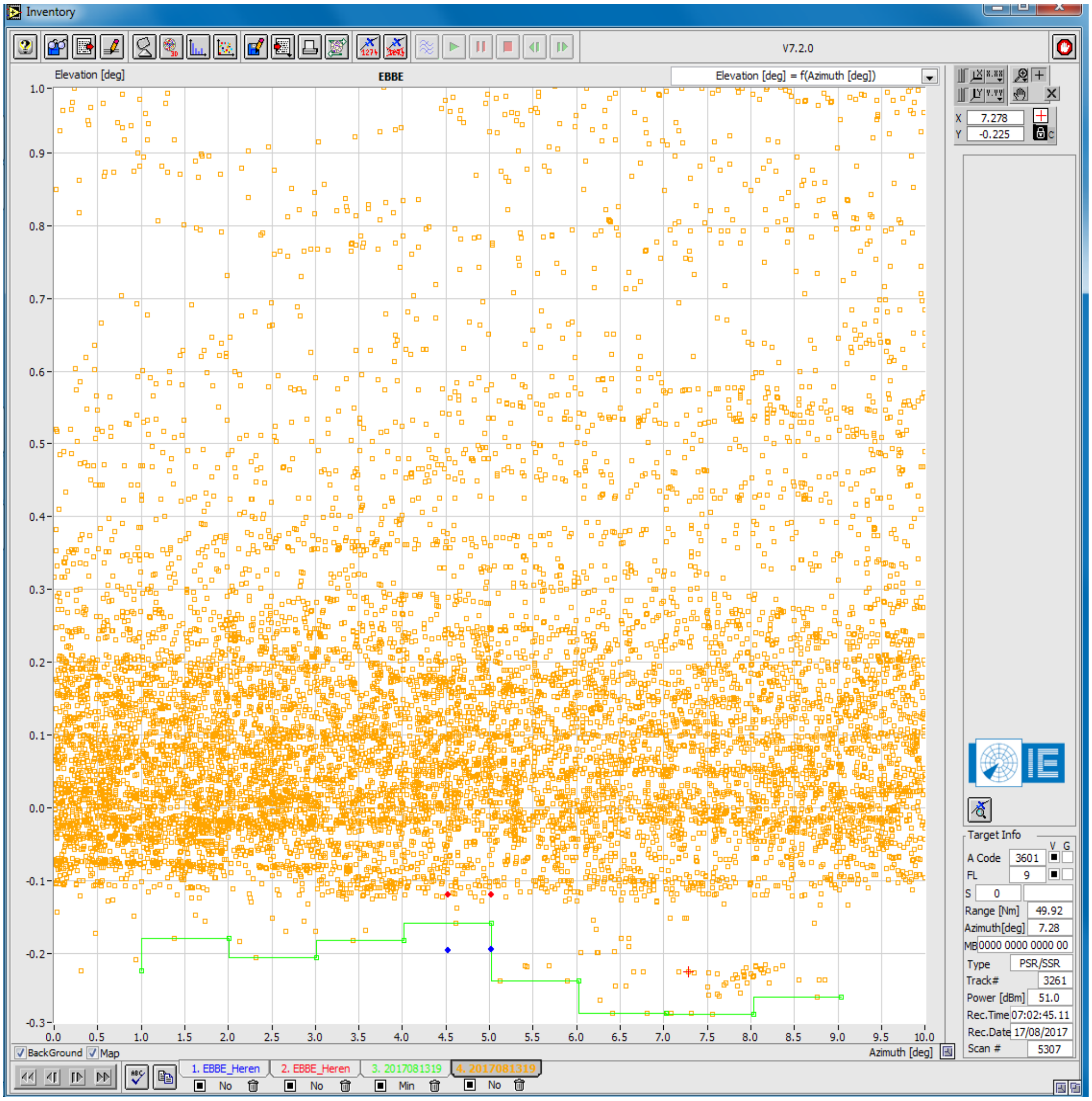

Figure 2.10: PSR lowest detection angles in function of Azimuth (zoomed at 1 degree elevation)

5 The Eurocontrol specifications for PSR evaluation actually exclude all targets below 1 degrees in elevation as it is normal to loose these due to local screening effects.

In figure 2.11 we select the tip elevation of -0.12 degrees in the same graph as figure 2.9. This shows us that 0.27% of the targets is located below this -0.12 degrees mark. This 0.27% of targets is the equivalent of 116 detected plots.

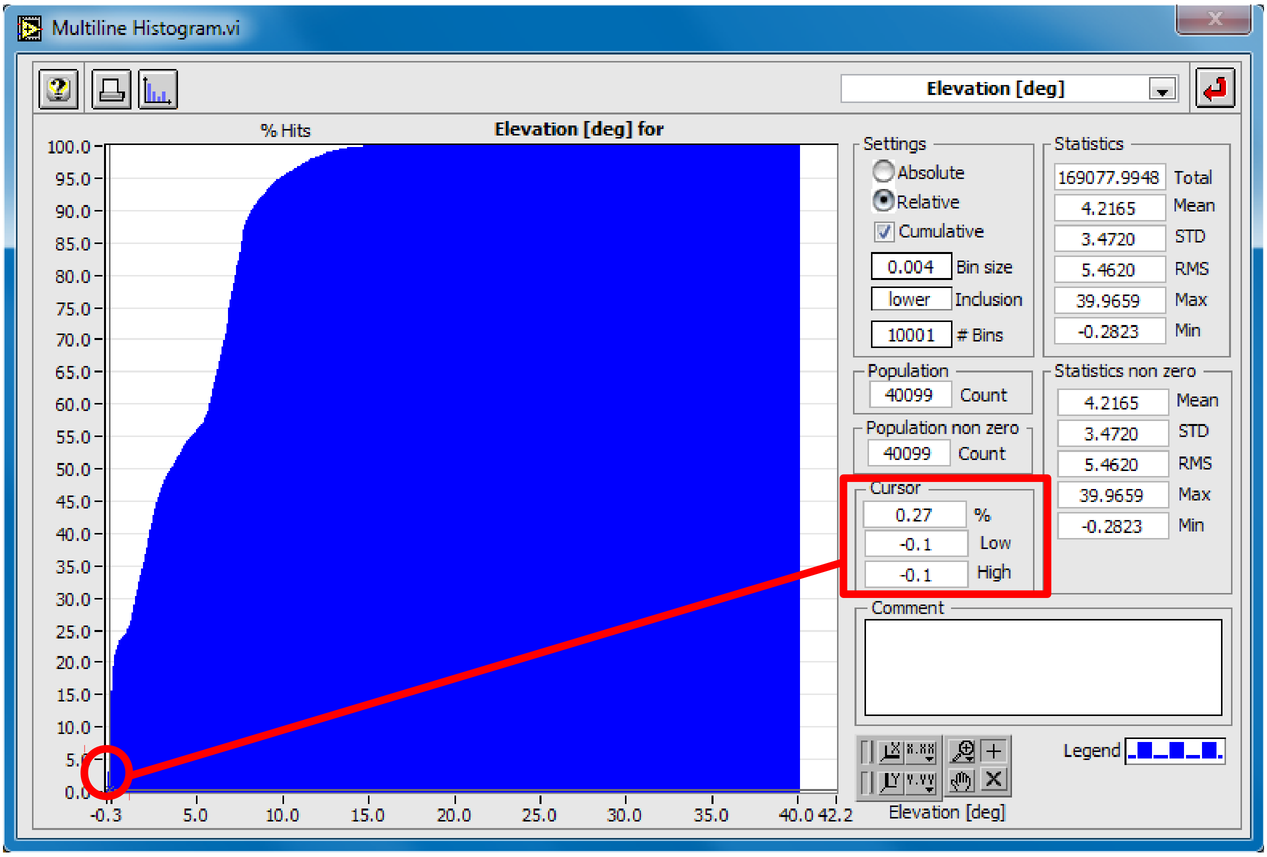

Figure 2.11: Accumulated distribution of targets in function of elevation at turbine height (zoomed)

The measured LoS assessment based on digital terrain data indicates that the turbine tip heights will be in the Line of Sight

2.4. PSR: turbine clutter ("false targets")

Recordings made on 16 October 2009 show that existing turbines create “false target reports”. Although the tracker will remove most of these plot reports, among others because of the speed filter, false targets remain present in the track output and thus displayed on the screen of the air traffic controller.

The Line-Of-Sight assessment indicates that the turbine will be visible for the radar, what will increase the clutter and the number of false targets. Intersoft Electronics NGPS mitigation technology can be a possible solution to mitigate and discard the introduced false targets.

The turbine will be in LoS and will create false targets from the turbine. The NGSP mitigation technology can be a solution to mitigate and discard the introduced false targets.

2.5. PSR: processing overload

The TA10M PSR plot processing overload mechanism will reduce receiver sensitivity when overload is detected:

Overload condition is generated when **one** of the following conditions is met:

- The number of plots per scan is higher than the threshold value of default 160 plots/scan. <u>**OR**</u>
- There are too many replies per read cycle of the extractor. (default value 100 000 replies/ read cycle.) <u>**OR**</u>
- DLL buffer overrun. This condition occurs when the number of new replies in the DLL buffer is larger than the buffer size. This condition is normally never triggered, the previous condition occurs earlier. <u>**OR**</u>
- The average loop time (average over last 3 value’s) is larger than the loop time limit (default 2 sec).

The study on the turbines of Lommel learned us that the effect on processing load is highest on plot processing. Overload mechanism on tracker is set to 500 active tracks. Previous measurements learned us that in the track output an average of 0.026 track reports/scan are present due to the existing wind turbines in Lommel.

The turbine will increase the processing load. The NGPS mitigation technology can be a possible solution to prevent processing overload.

2.6. PSR: range/azimuth errors

The measured position of a target can theoretical be affected by the multipath reflections of the turbine. Effects due to local screening like trees, high voltage power lines and high buildings are much larger. Previous RCM (Radar Comparator Mono) accuracy assessments (study on wind farm of Lommel) reveal no significant degradation in range nor azimuth accuracy.

The effect on the range and azimuth accuracy by the wind-turbine is negligible

2.7. PSR: receiver saturation

The turbines will not saturate the receiver. Existing wind turbines at approximately the same range do not saturate the receiver and it is not expected that the planned new turbines will do so.

Intersoft Electronics expects that the turbine will not saturate the receiver.

3. Conclusions and recommendations

The coverage measurements indicate that the turbines will be detectable for the radar of Beauvechain. The shadow effects will negligible. The raised CFAR threshold, processor overload and false targets can be mitigated by the RAG function of the NGSP mitigation solution.

After investigation of all the parameters, Intersoft Electronics makes the following recommendation if an installation permit is delivered by the responsible authorities:

- The TA-10 radar of Beauvechain needs to upgraded with the NGSP mitigation solution to mitigate the windfarm effects. This upgrade will not only discard the influence of the new turbines, but as well of the existing/operational ones and other unwanted clutter objects.
- A second recommendation is to perform a mitigation and tuning verification of the radar performance after turbine installation.

ANNEX 1: VCC Solution

As demonstration of its wind farm solution, Intersoft Electronics investigated the wind farm mitigation of the wind turbines in Lommel[6] and the improvements of using the VCC technology for wind turbine mitigation on the TA-10 radar at Kleine-Brogel in 2012.

For this purpose IE used a newly designed receiver to down convert the S-band signals, available directly after the LNA, and feed an IF signal of both high and low beam to the ISP894, used as a recording device.

The signals of both beams were tapped directly after the LNA and down-converted in two intermediate steps to an IF frequency of 13MHz, making them compatible to the ISP894.

The recordings contain the azimuth reference data and I/Q information at 6MHz rate of full scan and full range. Some of the following samples will not indicate the correct azimuth as North correction was not always applied.

The following pictures illustrate some of the findings. Each time, both the high and low beam are processed.

The dual receiver also uses a switch to sample the signal of the Tx and include this is in the recording. On processing this sample is used as “pulse compression” automatically providing a matched filter for the Rx and the “coherent-on-receive” function.

In figure 3.1 we can see a zoom of the area of the wind turbines and its surroundings. The left hand side B-scope is the signal strength on the low-beam. The middle window can be processed in different ways, in this case it shows the high beam in MTI mode. Notice most clutter is gone proving the proper working of coherency. The right hand side is the response out of a specifically selected Doppler filter.

6 Hub height is minimum 462 feet above MSL and tip of the rotor blade will be at maximum 610 feet above MSL. Ranged between 7.5Nm and 8.8Nm, Azimuth 286 and 288 degrees.

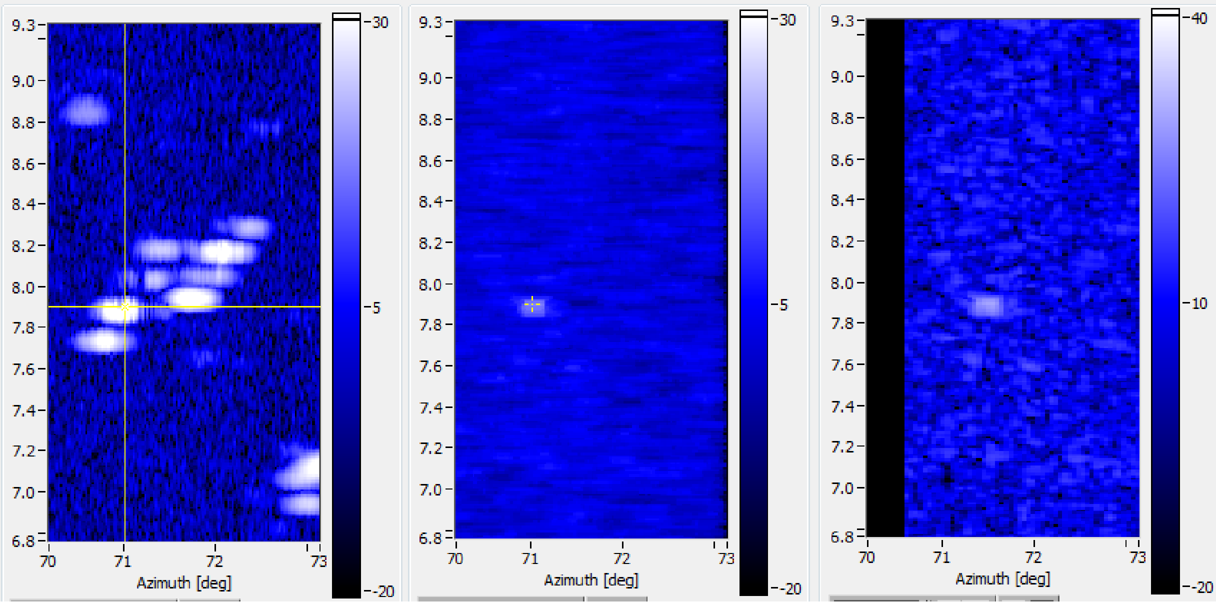

Figure 3.1: Recording Scan #4

Despite a reasonable amount of wind on the day of recording the stability of the clutter returns of the 8 wind turbines was better than expected. It is assumed this is depending on the wind direction and positioning of the rotating blades versus the radar. For this scan #4 the only turbine returning a doppler shifted signal was the second on the left, marked with the cursor. The MTI reveals a signal that can be detected in multiple Doppler filters but with the strongest return in filter #3.

The following graph (fig 2) shows that the signal strength on high beam (**Gray**) is not reduced by MTI processing (**Red**), a false plot would emerge and all the Doppler clutter maps would be elevated in this scan.

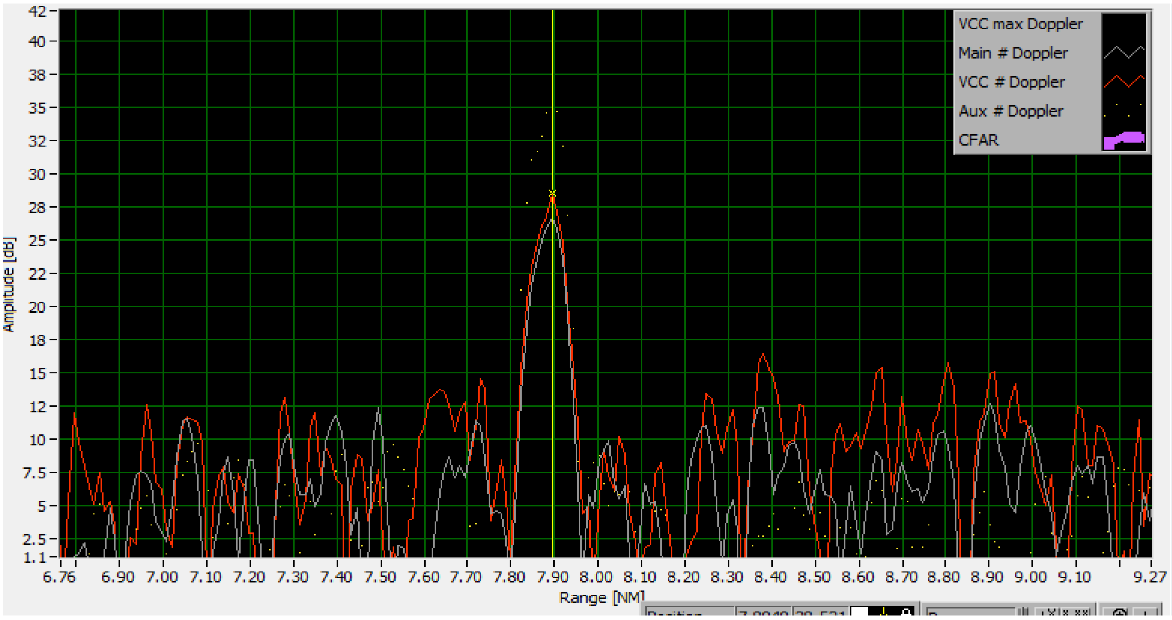

Figure 3.2: A-scope of the unstable response

If we then switch to VCC processing for the same scan # we can see an almost complete suppression of all the wind turbines. Furthermore also the filter bank where the stable clutter used to be is now in the clear.

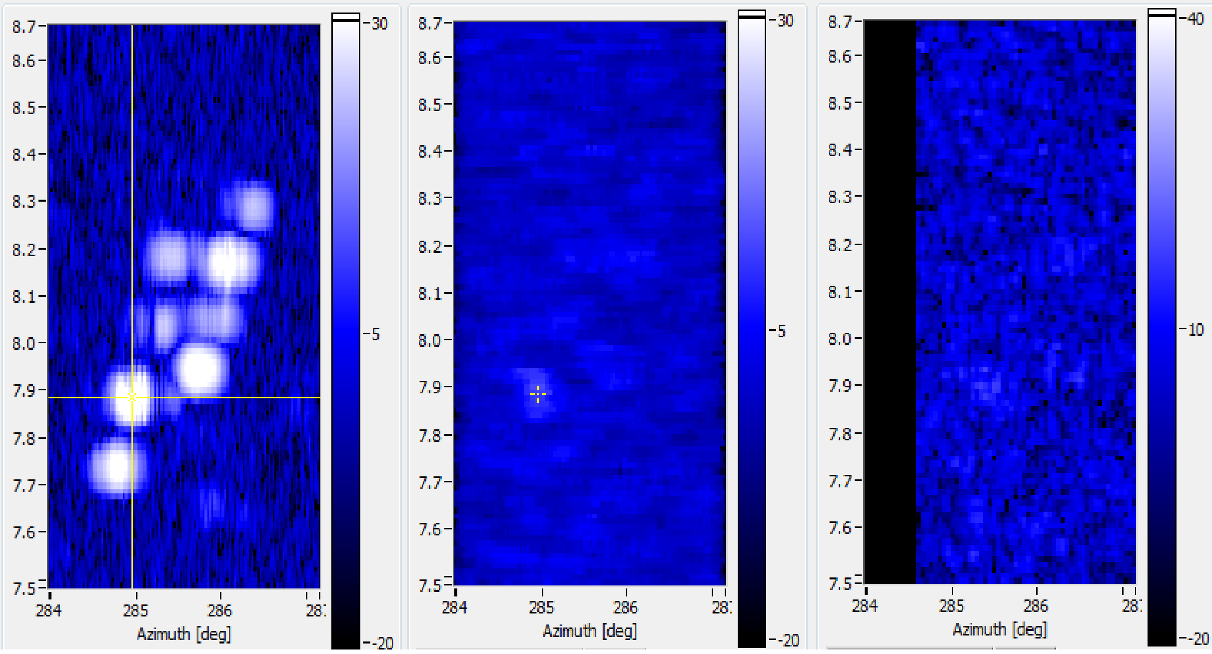

Figure 3.3: When processing with VCC all the clutter is suppressed

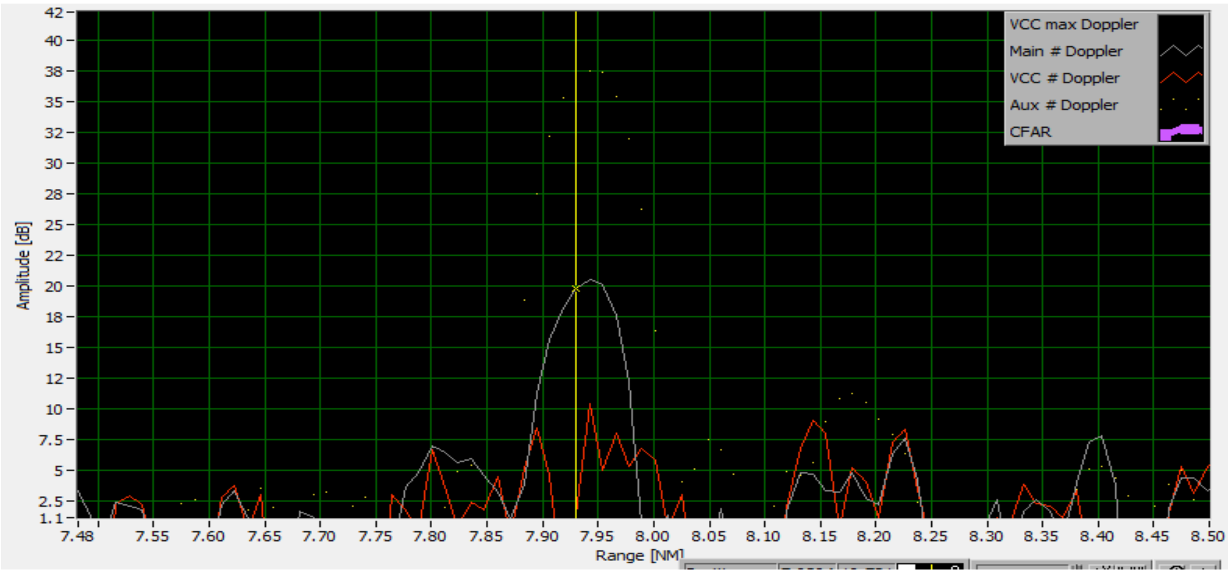

Figure 3.4: A-scope original clutter (Gray) after VCC (Red)

For several of the following scans the clutter returns were quite stable, the MTI and/or Doppler filters would suppress well. However before the clutter adaptive threshold is recovered more turbine returns kick in.

The next example taken is for scan #21 where the first turbine from right responds unstable.

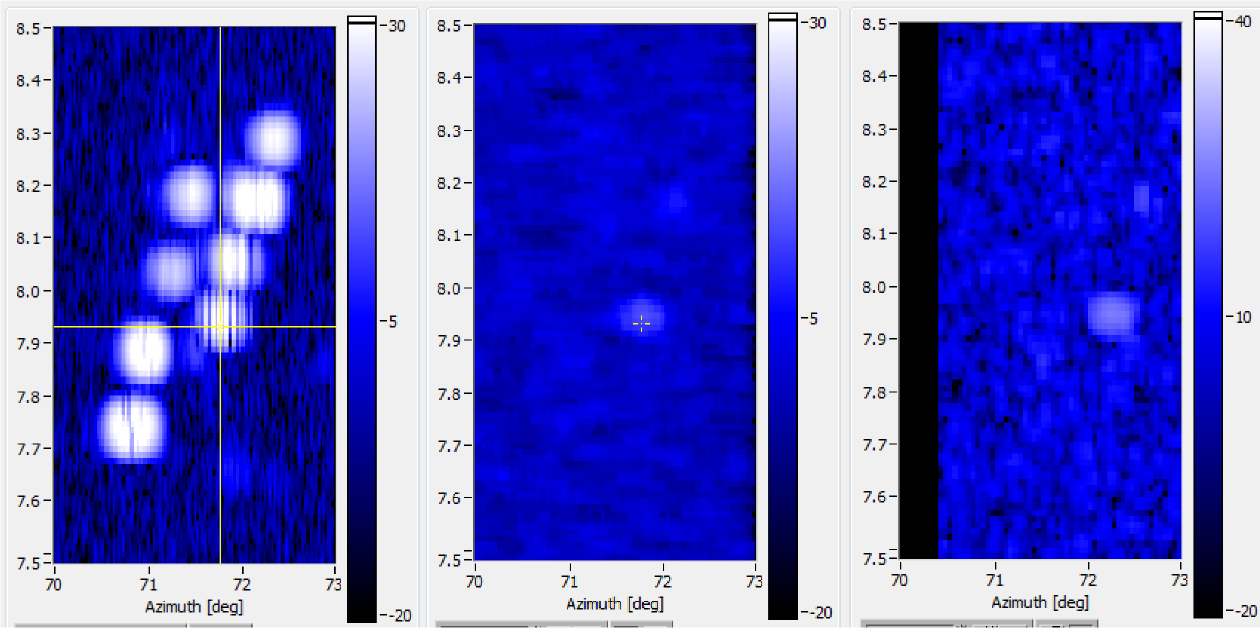

Figure 3.5: Scan #21

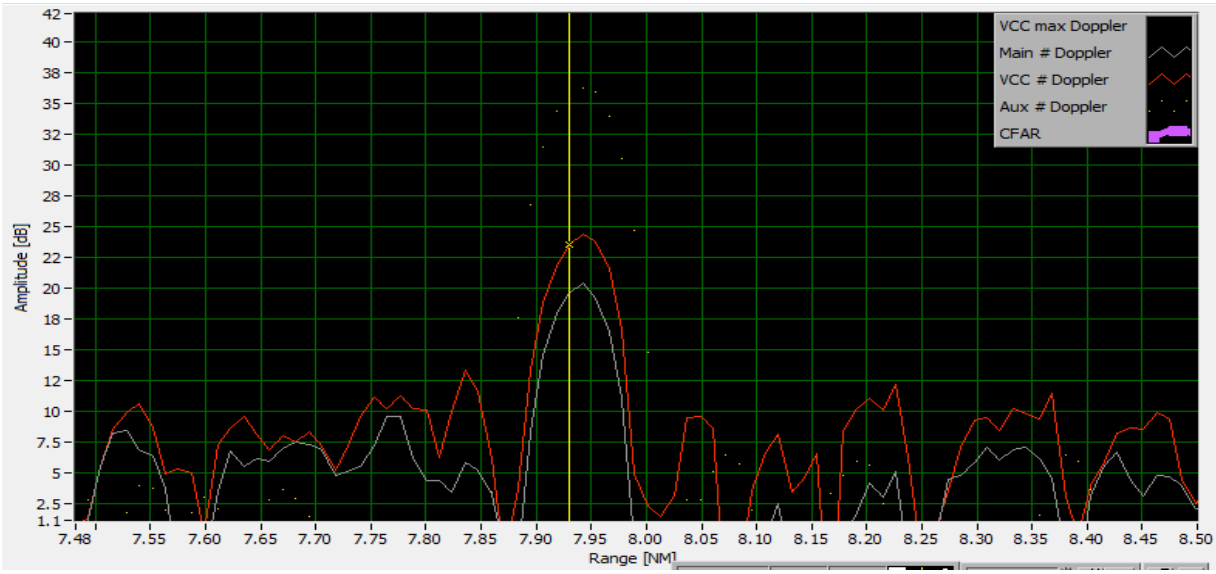

Figure 3.6: The High beam MTI (Red)

Again after processing with VCC all clutter returns are weakened to a very low level.

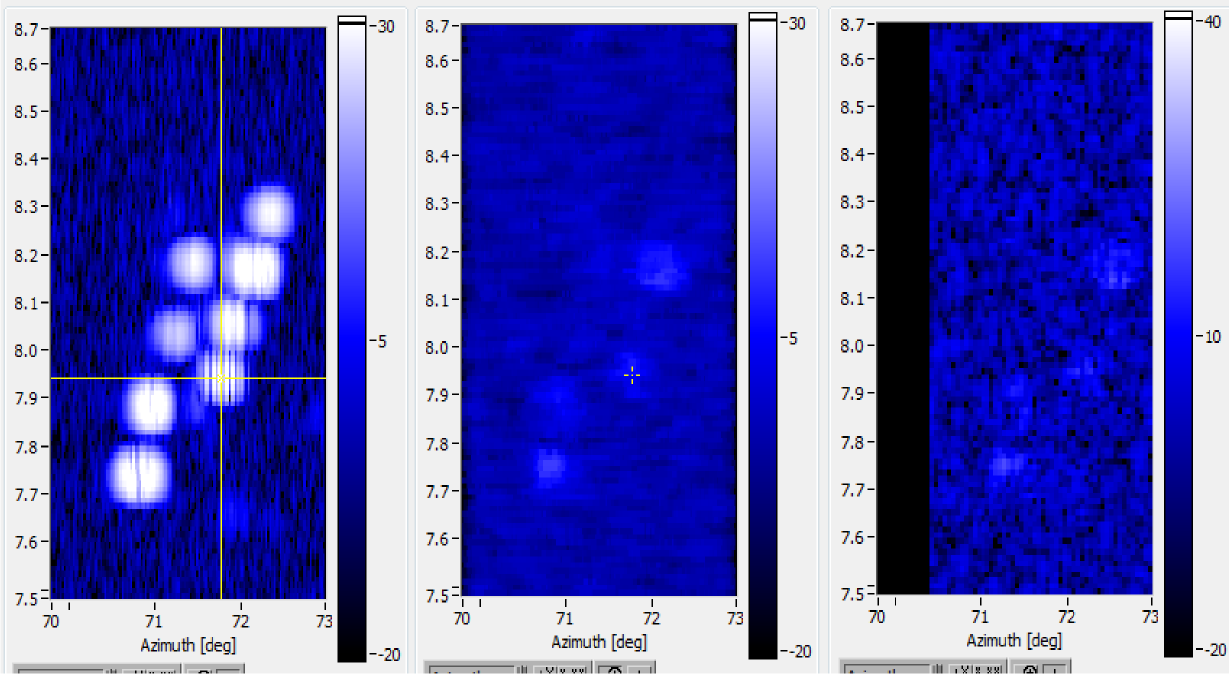

Figure 3.7: Scan #21 after VCC processing

Only a faint image of the clutter remains, no false detections would emerge.

ANNEX 2: Target detection when processing in VCC mode

The question can be raised whether VCC processing would affect aircraft detection in a negative way. For this purpose a test signal of low level is injected on top of the recorded High beam signal.

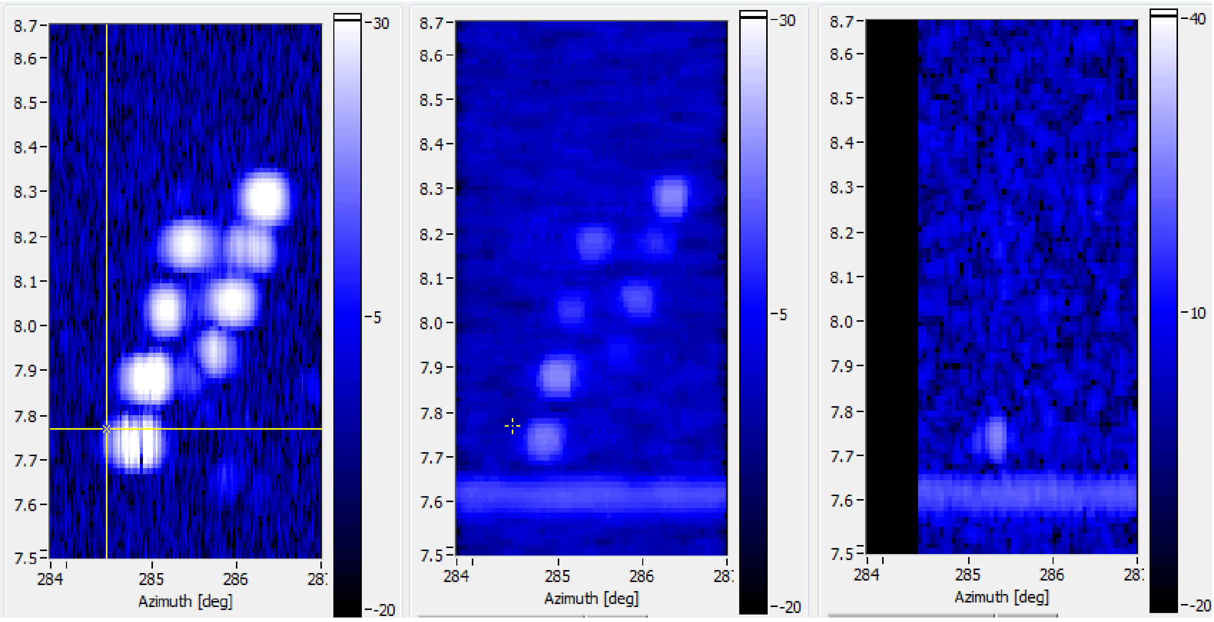

Figure 3.8: Test signal inserted

In the above scan the first turbine on the left pushed through all Doppler filters. On the left B-scope is the high beam signal, on the middle-one the low beam levels. The test signal presents a continuous azimuth response on 7.6 NM and is showing up on the right in the corresponding Doppler filter just in front of the disturbing turbine.

If we now process with VCC and move the target line to 7.75 NM we can see the interaction of a test pulse with the VCC processing.

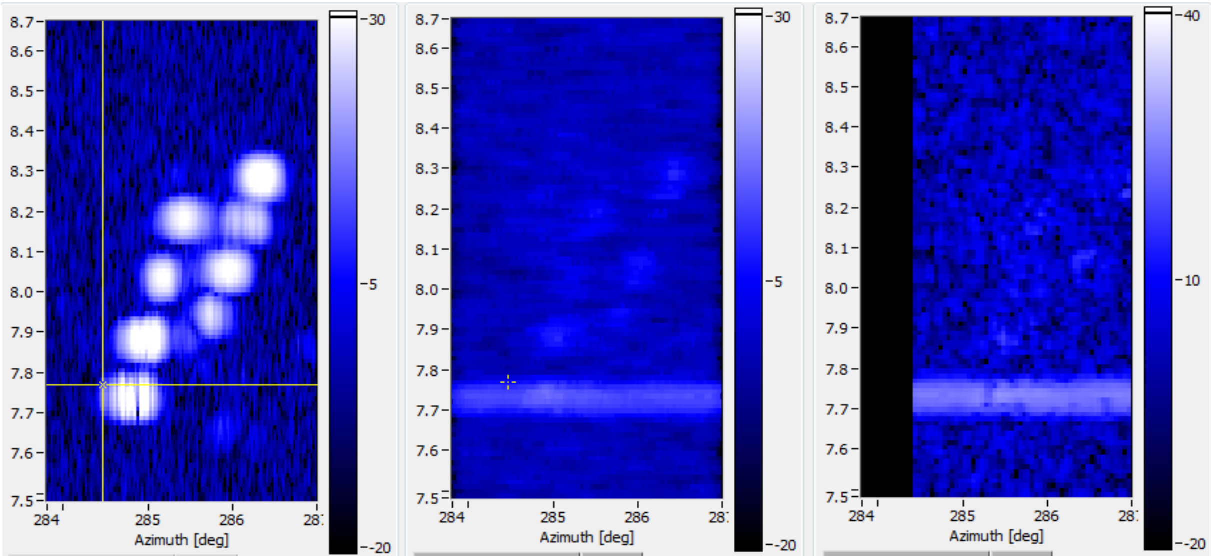

Figure 3.9: Test signal on top of turbine unstable response

The test pulse is slightly interacting with the VCC clutter suppression but a target at any of the azimuth positions would remain intact for detection. No loss of sensitivity on target detection can occur.

ANNEX 3: CFAR and pulse compression

CFAR (Constant False Alarm Rate) is the mechanism used to estimate the noise level before evaluating a signal for possible target detection. The noise averaging should be long enough for accurate noise estimation in order not to lose sensitivity but short enough not to include other unwanted signals like clutter.

The TA-10 settings were optimized before to 16 range samples or equivalent to a length of ¾ NM (one end).

This means that any unstable clutter like wind turbines will affect the sensitivity for target detection over a much larger area than the one occupied by the disturbing clutter only.

Turbines will create a degraded area due to CFAR and beam width. The ISP signal processor with its VCC algorithm driven by a high resolution map can suppress the clutter in any individual range/azimuth cell to avoid unwanted signals entering the MTD/CFAR processor. This mode can be used in the event that some unstable clutter is more resilient than these wind turbines.

If this mode is used, the degraded area would not be affected anymore.

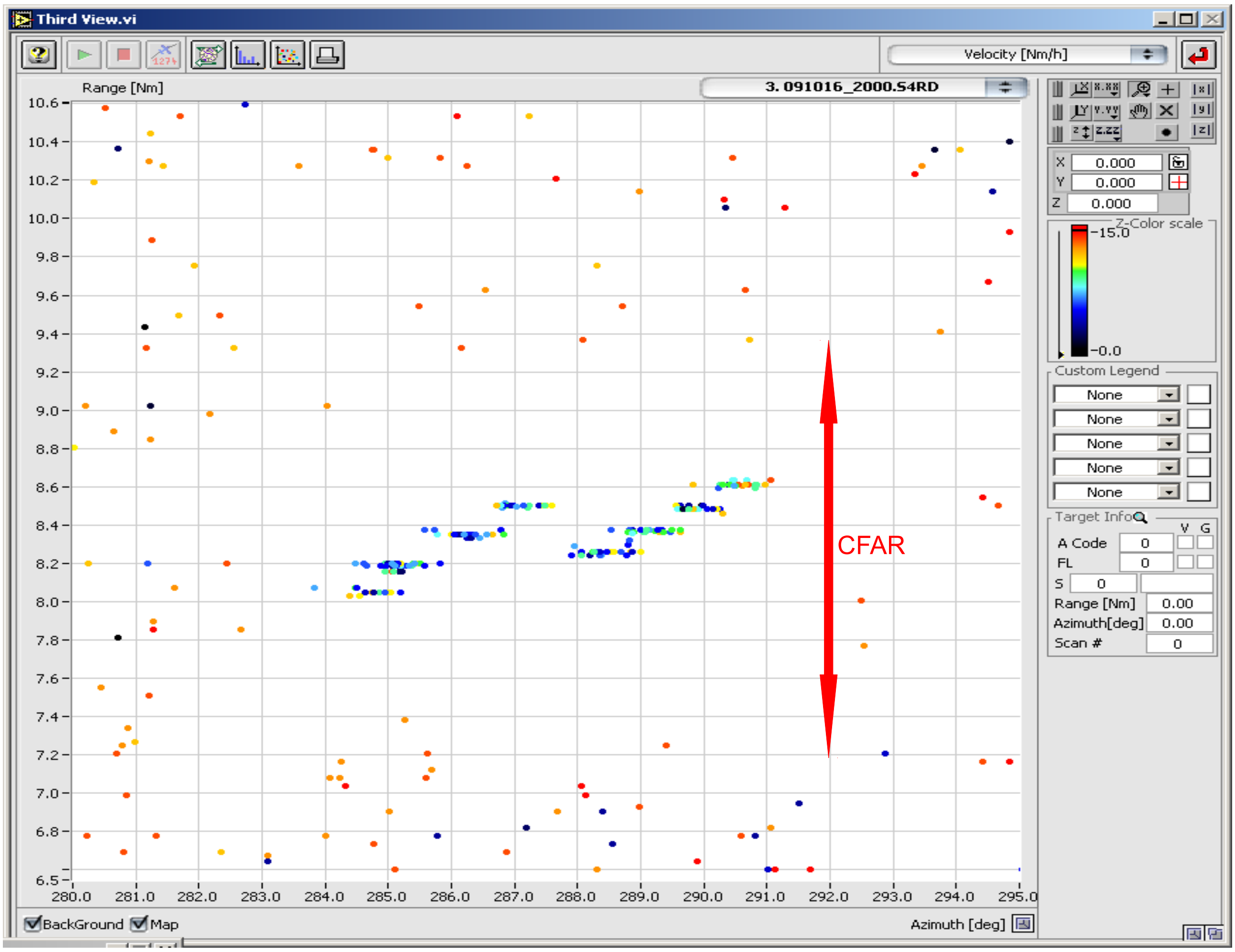

Figure 3.10: Example of raised CFAR due to turbines in Lommel (no VCC applied)

ANNEX 4: Reference list of previous assessments

[1] Wind turbine study HAM, September 2012

[2] Wind turbine study Kleine-Brogel, December 2012 (wind turbines Lommel)

[3] IE-SAWM-EBKB-00001, June 2013

[4] IE-SAWM-EBBE-00001, June 2013

[5] IE-SAWM-EBKB-00002, July 2013

[6] IE-SAWM-EBKB-00003, July 2013

[7] IE-SAWM-EBKB-00004, July 2013

[8] IE-SAWM-EBKB-00005, July 2013

[9] IE-SAWM-EBKB-00007, August 2013

[10] IE-SAWM-EBFS-00001, August 2013

[11] IE-SAWM-EBBE-00002, September 2013

[12] IE-SAWM-EBKB-00008, October 2013

[13] IE-SAWM-EBBE-00003, November 2013