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(Second Session)
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Sub-Agenda Item: 5.4. **Quality and interference issues**

Impact of wind turbines on radar wind profiler

(Submitted by Volker Lehmann)

SUMMARY AND PURPOSE OF DOCUMENT

The paper discusses the impact of wind turbine clutter on radar wind profilers.

Impact of wind turbines on radar wind profiler

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ABSTRACT

This document is intended as an input to the Joint Meeting of the CIMO Expert Team on Operational Remote-Sensing (First Session) and CBS Expert Team on Surface-based Remotely-Sensed Observations (Second Session), Geneva 5-9 December, 2011. The paper discusses the impact of wind turbine clutter on radar wind profilers.

1. The problem

Radar wind profiler (RWP) operation is mainly based on the backscattering of electromagnetic waves on atmospheric clear air turbulence. Due to the nature of this process, the backscattered signal is significantly weaker than echoes returned from hard targets. Therefore, there is a permanent threat of unwanted echos due by birds, airplanes and ground objects.

The increasing interest in renewable energy has led to a rather rapid development of large wind turbine parks in Germany and other industrial countries. The wind turbines used already exceed heights of 100 m for the nacelle and the propeller blades have diameters of more than 100 m, with a single blade weighting several 1000 kg. The actual power output of a single turbine is meanwhile 3 MW and more.

It is not surprising that solid structures of these dimensions are effective targets for many different radars, including air traffic control radars (Lemmon et al., 2008; Novak, 2009) and precipitation (weather) radars (Isom et al., 2009; Hood et al., 2010; Toth et al., 2011). RWP are also affected, if the wind turbines are located in the vicinity of a RWP. The specific problem for the latter radars is that the wind turbine (WT) clutter echoes are caused by the side-lobes of the antennas, because the beam directions are always near-zenith. While this is generally advantageous due to the lower gain in the side-lobes in comparison to the main lobe (differences are usually 20-40 dB), the lower antenna gain is at least partially offset by the higher sensitivity of RWP compared to most other radars. Also, it is more difficult to estimate potential impacts because of the difficulties to estimate the antenna radiation pattern at angles about 90 degrees off boresight. This latter problem is made even worse by the fact that the actual low elevation angle radiation pattern depends also on the properties of the surrounding landscape (orography, ground vegetation). This makes it virtually impossible to accurately predict the antenna gain of a RWP in the direction of a wind turbine.

The Meteorological Observatory Lindenberg of the Deutscher Wetterdienst (DWD) has been operating 482 MHz wind profiler radar/RASS since 1996 to measure wind and temperature profiles continuously up to heights of 16 and 4 km, respectively. The first radar of this kind (Steinhagen et al., 1998) was in use until 2009, before it was replaced by a modernized version (Lehmann et al., 2003), which started operating at the end of the same year. An aerial photograph shows both systems side by side in autumn of 2009, see Fig. 1.

In an attempt to minimize interferences with television transmitters operating in the same frequency band (UHF channel 22) the antenna of the first RWP installation was surrounded by a metallic clutter fence of 7 m height (Steinhagen et al., 1998). In terms of signal processing the simple ground clutter removal algorithm suggested by Riddle and Angevine (1991) was applied, which had proven to be sufficient over the years before the wind turbines were installed in the vicinity of the RWP site in 2002. Automatic (Weber and Wuertz, 1991) and manual quality control yielded an average suspect data rate in the low mode of less than 1% in the period 1996 - 2001.

During 2002 more than 40 wind turbines were installed to the East and South of Lindenberg in a distance between 2.5 and 8 km to the profiler site (Fig.3). Those wind turbines have a top height of up to 140 m above ground (100 m nacelle height, 80 m blade diameter) and were quickly identified as a new type of ground clutter for wind profiler radars (Görsdorf et al., 2003).

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2. Impact on wind measurements

The most detrimental influence on the wind measurements originated from the nearest wind farm to the East. As illustrated in Fig. 4 the rate of valid wind data in the low mode (pulse length = 1700 ns) is decreased by about 30% at heights between 2.5 and 3.5 km. This is associated with a high rate of suspect data and a reduction of accuracy. Furthermore, WT clutter effects can also be observed at levels between 5.5 and 6 km. In the high mode (pulse length = 3300 ns), the consequences are smaller than in the low mode but a greater suspect data rate can also be seen at about 3 km, 6 km and 7.5 km which correspond to the distances to the different wind farms. The reduced data quality is also visible in NWPM based data monitoring, see Fig. 5.

The occurrence of WT clutter shows strong temporal variations which are not completely understood. It is speculated that a variety of factors, like the orientation and the dielectric properties of the blades as well as the magnitude of the backscattered signal in the main lobe have an influence on the relative strength of the WT clutter echo in comparison to the atmospheric echo.

3. Signal characteristics of WT clutter

WT clutter contaminated spectra are often characterized by a significantly greater spectral width compared to a clear air signal as it is demonstrated in Fig. 6. This can be easily explained by the rotation of the propeller blades which leads to an unusual broad spectral peak. Currently existing signal processing algorithms are unable to deal with this clutter type. Attempts to use multi-peak processing methods like NIMA (Cornman et al., 1998; Morse et al., 2002) and CASPER (Law et al., 2002; Weber et al., 2004), which have been applied to selected cases, failed to discriminate the atmospheric (clear air) reliably from the WT clutter signal component.

Special RWP sampling settings were meanwhile employed to achieve a better understanding of the WT clutter signal characteristics. In particular it could be shown, that the WT clutter signal exhibits essential properties of a harmonic signal (Percival and Walden, 1993): At very high spectral resolution it is possible to demonstrate that the WT clutter spectrum consists of discrete lines which is typical for a harmonic process, see Fig.7. However, such a high spectral resolution can hardly be used in operational settings because this would require dwell times well in excess of 1 minute.

4. Conclusions

Wind turbines cause a new type of clutter in wind profiler Doppler spectra and have a significant potential to essentially disturb RWP wind measurements at height levels which correspond to the distance between the wind profiler radar and the wind turbines. Currently, no signal processing algorithm is able to suppress or filter out WT clutter. The only method that can be applied right now is the use of postprocessing data quality control.

Further investigations are required for an better characterization of wind turbine clutter in order to find suitable measures to solve or at least to reduce the problem in signal processing. A reduction of side-lobes in the antenna radiation pattern would also be helpful, wherever this is possible.

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Figure 1. Old and new 482 MHz RWP at Lindenberg. While the first installation was surrounded by a metallic clutter fence, the new radar is shielded by a berm.

Figure 2. Aerial view of the wind turbine parks in the vicinity of the Lindenberg 482 MHz RWPs (visible in the lower left corner).

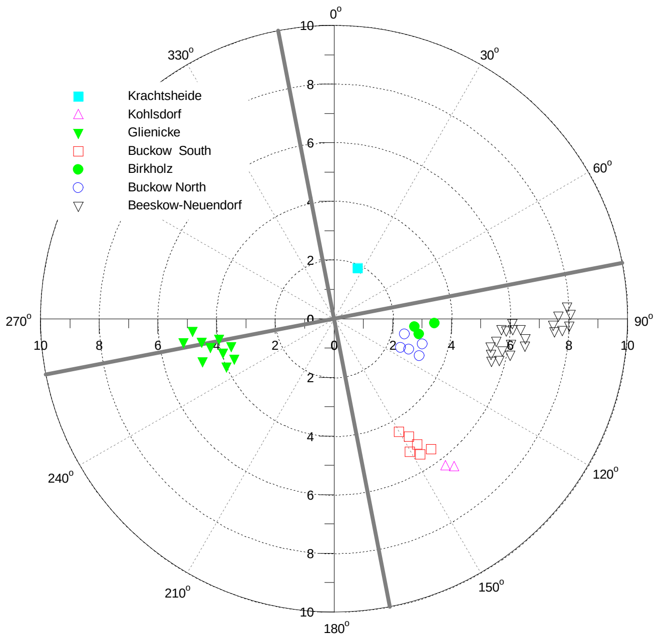

Figure 3. Locations of wind turbines, big cross indicates the orientation of tilted beams of the first 482 MHz RWP (1996-2009).

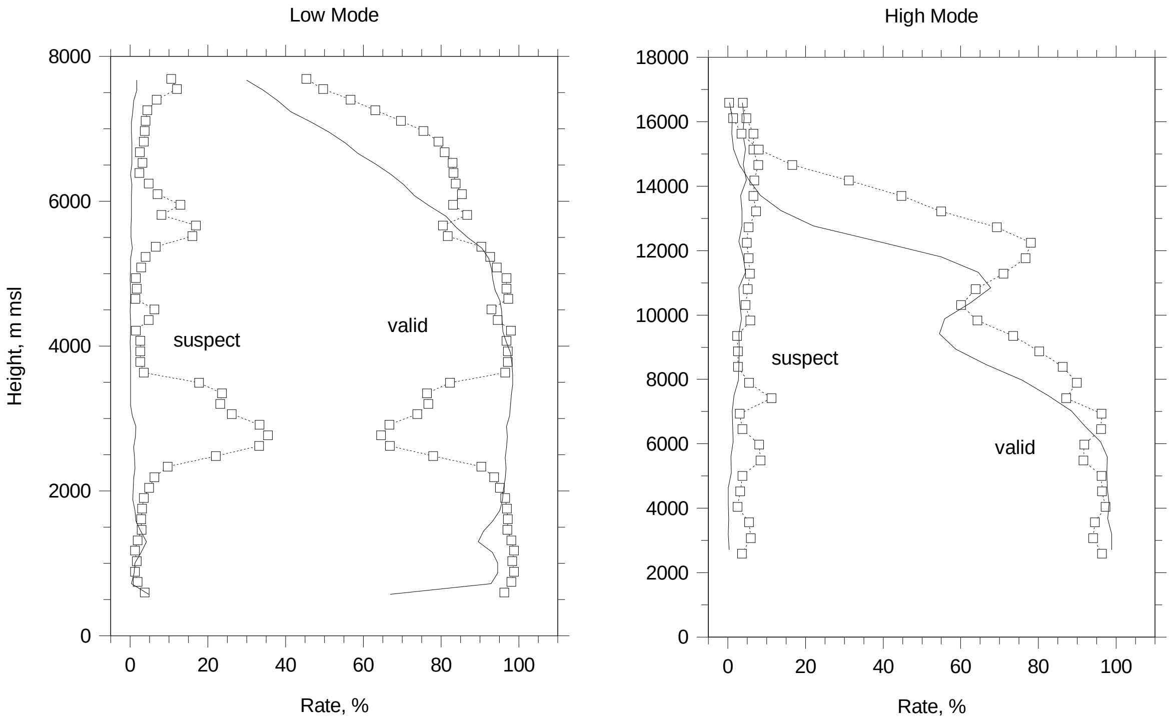

Figure 4. Rate of valid and suspect wind data measured with 482 MHz wind profiler as function of height in March 2002 (solid line, undisturbed situation) and in March 2003 (squares, disturbed situation)

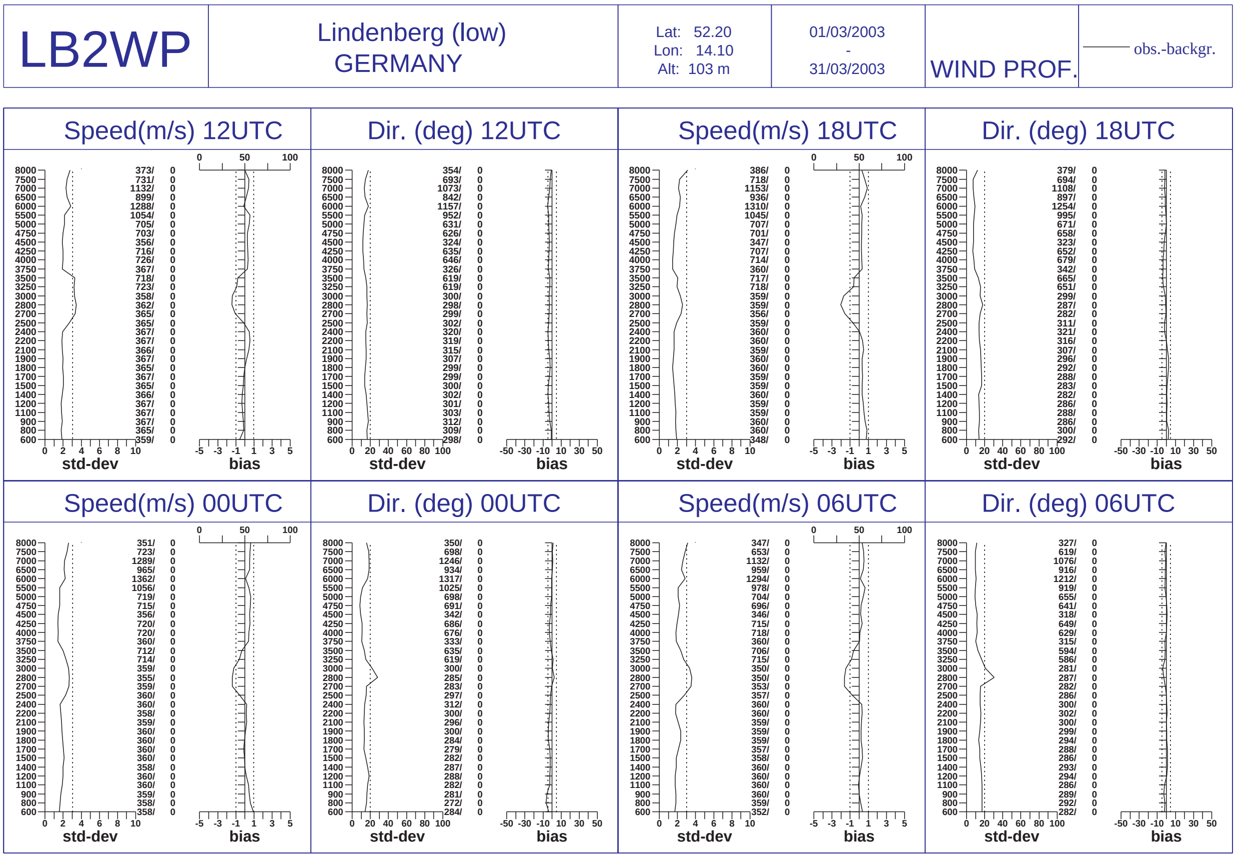

Figure 5. MeteoFrance monitoring results for the Lindenberg 482 MHz RWP for March 2003. The effects of WT clutter are clearly visible at heights between 2.5 and 3.5 km.

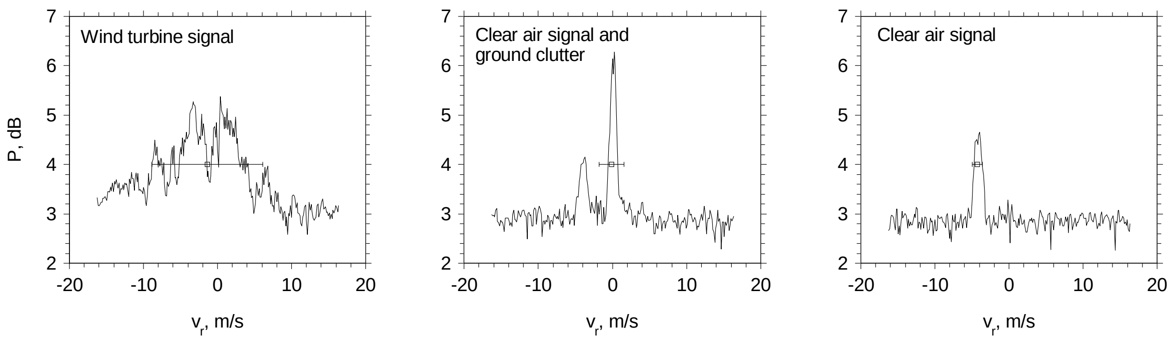

Figure 6. Power spectra illustrating a wind turbine, a ground clutter and a clear air signal

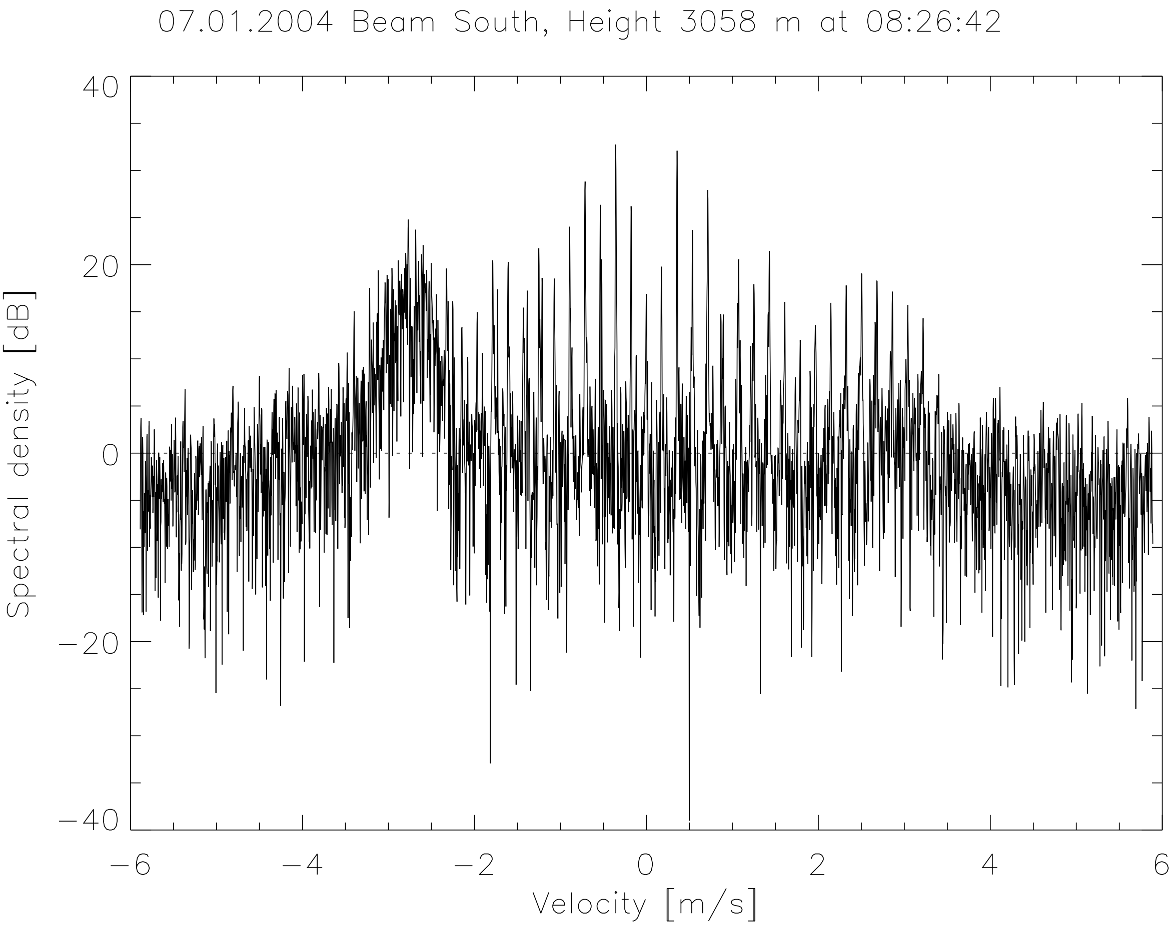

Figure 7. High resolution power spectrum of a wind turbine and a clear air signal.