Investigations on the spatial extent of the effect of wind turbines on radar data

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***Abstract*— In many European countries more and more wind power stations are installed. For weather radar service providers, however, this trend causes concern as wind power stations can affect the radar signals and thus impact the data quality of weather radar networks. EUMETNET OPERA [1] has initiated studies to reassess its current guidelines towards wind turbines in the vicinity of weather radar stations for ensuring wind-turbine-free areas around radar sites. In this context, the present study investigates the spatial extend of the effect of wind turbines on weather radar data. The areas around two wind farms in the Netherlands that are surveilled by the radar in Emden, Germany, were investigated. The general approach was to categorize the radar coordinates according to their relative location and distance to the coordinates of the wind farm. The coordinates in front, behind, and at the side (as seen from the radar) of the wind farms were analyzed separately. The distribution of the measurements was investigated. First results indicate that especially coordinates separated laterally only by 1° seem to be influenced by wind turbines.**

***Index Terms*—Weather radar, wind turbine coordinates, neighboring coordinates**

I. Introduction

As a motivation, the map of the mean reflectivity during high-pressure weather conditions around the weather radar in Emden is shown (Fig. 1). Ideally, no echoes are to be expected. However, the readings exhibit values greater than 40 dBZ. Echoes can be seen that coincide with the shipping route and the harbor facilities in Emden. In Fig. 2 another representation of the same data is depicted. However, the coordinates containing wind turbines appear in grey as they are masked out. It can be noted that some coordinates in the vicinity of these grey areas still exhibit increased values. The reasons can be manifold, and a detailed description is beyond the scope of this article. However, some aspects are mentioned here.

First, the huge rotor of a wind turbine can cover more than a 1°-radar-coordinate (especially in the vicinity of the radar). Second, the antenna emits and detects signals also beyond the main lobe, which can lead to incorrectly placed echoes. In addition, also multipath echoes cannot be ruled out.

This paper is organized as follows: In Section II the study area and the analyzed operational product are described. Section III gives the details of the applied methods. The results are given in Section IV in the form of mean reflectivity- and exceedance probability maps as well as statistical measures. A summary and outlook is given in Section V.

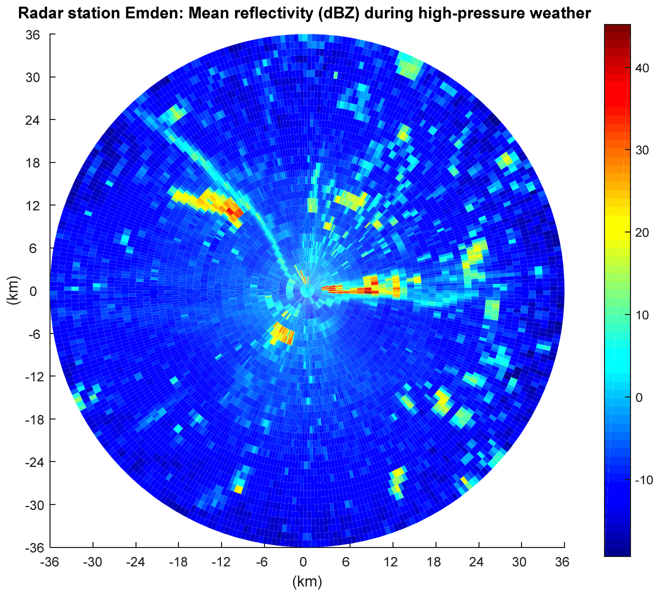


Fig. 1. Mean reflectivity map calculated over periods with high-pressure weather in the range up to 36 km around the weather radar in Emden, Germany.

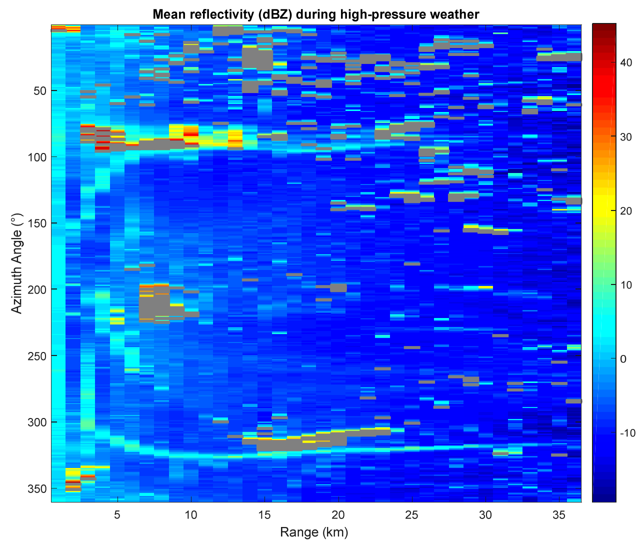


Fig. 2. Azimuth-range-representation of the data in Fig.1 in order to make also the measurements in the vicinity of the radar depictable and masking (in grey) the coordinates containing wind turbines.

II. Study area

Two wind farms in the Netherlands were chosen for this study. One wind farm is located near Delfzijl, the other at Eemshaven. Both areas are surveilled with good visibility by the German weather radar in Emden, since as of the period of investigation (from November 2010 to October 2012) no other wind turbines were located between these wind farms and the radar. Fig. 3 shows a map of the whole study area.

A. Analysed product

The analysis is based on the polar radar reflectivity product labelled DX. This product was chosen because it offers the best resolution of all operational radar products. DX has an operating range of 128 km with a range resolution of 1 km and an angular resolution of 1°. The product is updated every 5 minutes and the values range from -32 to 95 dBZ with a 0.5-dBZ-resolution. The DX-product features a terrain-based scan-elevation. Due to the flat terrain around the radar site Emden, the scan-elevation is constantly 0.8°.

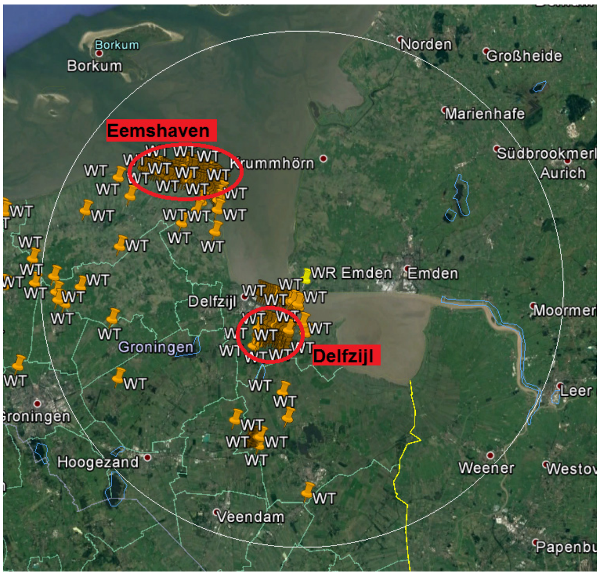


Fig. 3. The location of the two selected wind farms in the Netherlands with respect to the weather radar in Emden, Germany. The wind farm near Delfzijl is located to the south-west of Emden [Annotation: the wind turbines (WT) between this wind farm and the radar site did not exist during the two-year period of investigation]. The wind farm at Eemshaven is situated northwestern of Emden (Map: Google Earth).

III. Method

In order to depict the spatial extent of the influence of wind turbines, two forms of representations are chosen: reflectivity maps and exceedance probability maps.

Reflectivity maps show the mean reflectivity over the study area and thus allow a visual examination of the particular measures. Radar coordinates that comprise wind turbines extending into the radar beam, generally show persistent echoes. As a consequence the mean reflectivity (calculated over the whole period of investigation or over specific weather situations) is high.

Due to multiple scattering scenarios, radar coordinates in the vicinity of the wind turbine may show echoes only sporadically yet more often than at coordinates farther away from the wind turbine. Such patterns may not be visible in averaged reflectivity maps. Therefore, maps depicting the probability of exceedance of certain reflectivity thresholds are shown.

The statistical approach quantitatively summarizes the information in the maps. It is based on a frequency analysis of the measurements at wind turbine sites, compared to sites in their vicinity. The empirical cumulative distribution function (CDF) is applied to reveal the differences between the measurements at different sites.

The coordinates chosen for the statistical analysis are situated in front, behind, and to the side of the wind farm (as seen from the radar). Fig. 4 shows the coordinates of the two wind farms that were selected. It should be noted, that the selection is an initial attempt to classify the neighboring coordinates. Wind-turbine-free coordinates within the wind farm were not considered. The spatial extent of wind farms led to constellations where a coordinate in front of a wind turbine is at the same time to the side of another wind turbine. As the front coordinates are seen as a reference, only such coordinates are termed "in front" that are not to the side (up to 4°) of another coordinate comprising a wind turbine.

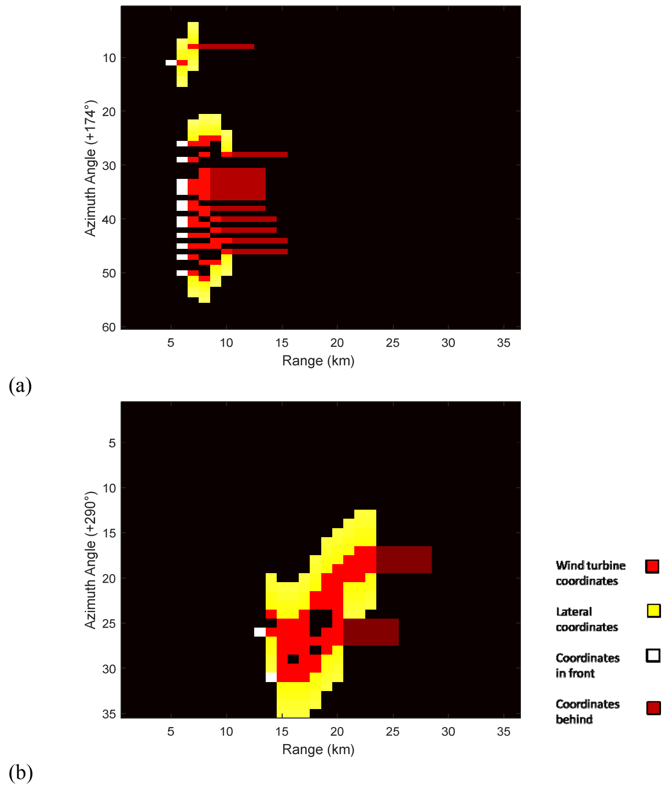
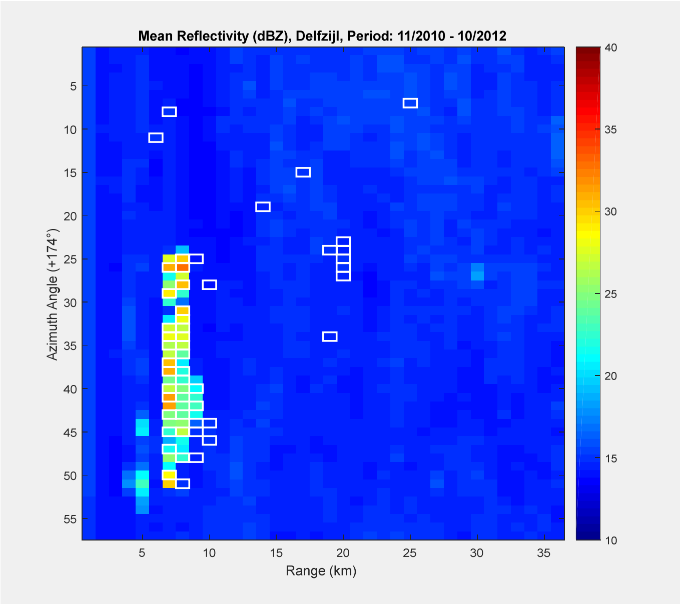
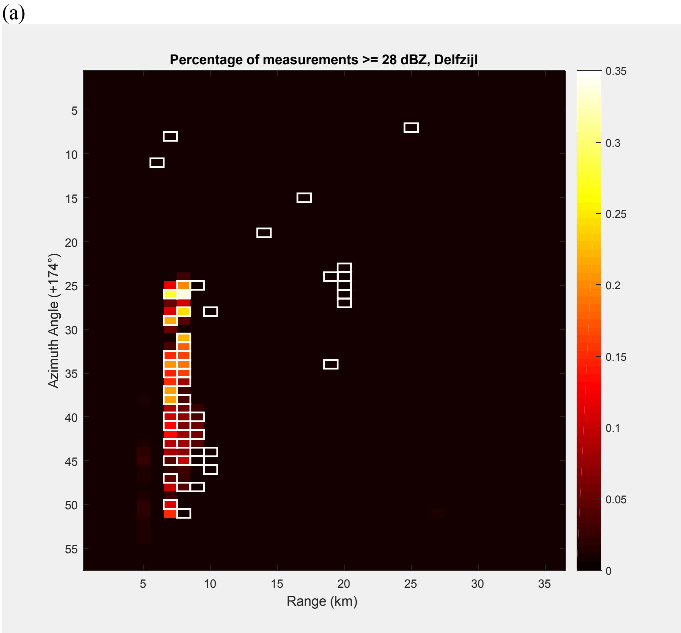


Fig. 4. Coordinate selection of the wind farms near Delfzijl (a) and Eemshaven (b).

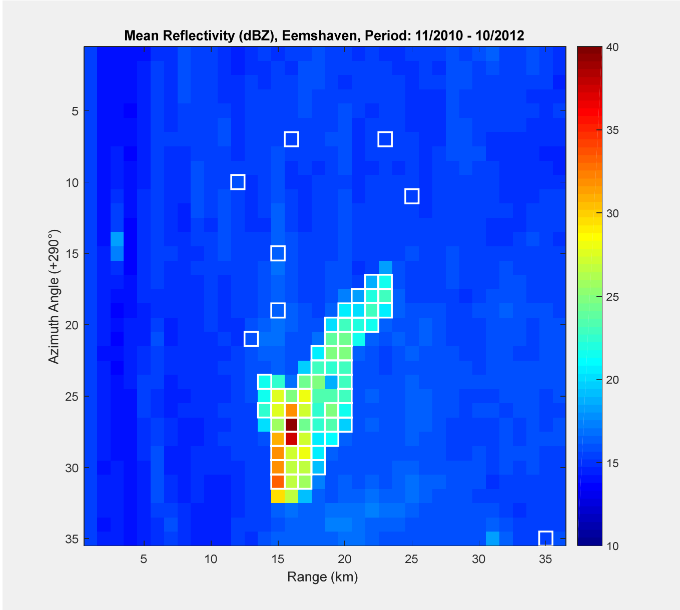


(a)

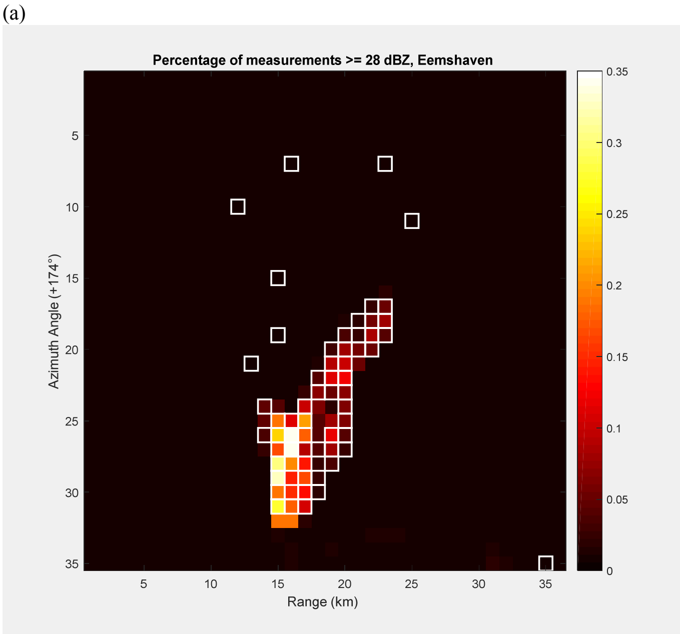


(b)

Fig. 5. Mean reflectivity map of the vicinity of the windfarm near Delfzijl (a) and percentage of the measurements passing the 28 dBZ threshold (b) [Annotation: Coordinates containing wind turbines are edged in white].



(a)

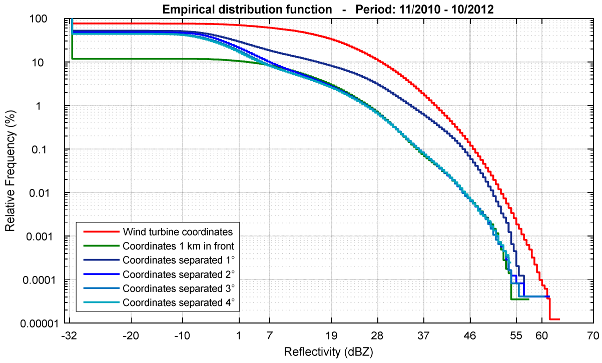


(b)

Fig. 6. Mean reflectivity map of the windfarm near Eemshaven (a) and Percentage of the measurements passing the 28 dBZ threshold (b).

IV. Results

In Fig. 5a the mean reflectivity in the vicinity of Delfzijl is depicted. The highest readings were detected at wind farm coordinates. The single wind turbines that are believed to be smaller in size, do not show readings other than those at wind-turbine-free coordinates. The same pattern can be recognized at the wind farm in Eemshaven (Fig 6a). In addition, it is apparent that high readings extend into neighboring coordinates. When regarding the exceedance-probability of the 28 dBZ threshold, it is noticeable that the percentage is near zero at wind-turbine-free coordinates and single wind turbines respectively. However, at both wind farms, values up to about 33 % are detected. Which means that during the whole period of investigation, one out of three measurements at these coordinates exceeds 28 dBZ. The mean value for both wind farms is around 10 %. This can be seen in the empirical CDFs in Fig. 7 and 8. For comparison, the respective values for the reference coordinates lie at 1 % or below. It is noted that in this regard,



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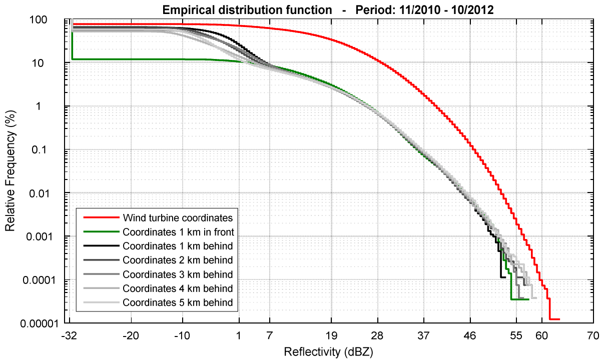
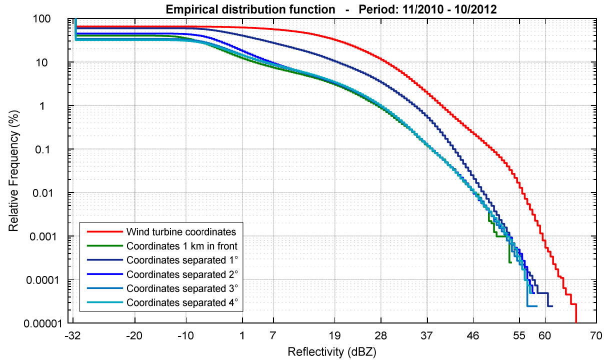
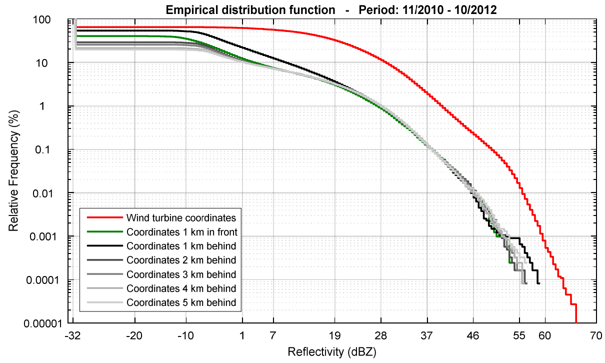


(b)

Fig. 7. Empirical CDFs of the measurements at the wind turbine coordinates of Delfzijl contrasted with the reference measurements in front and coordinates to the side (a) as well as coordinates behind (b).



(a)



(b)

Fig. 8. Empirical CDFs of the measurements at the wind turbine coordinates of Eemshaven contrasted with the reference measurements in front and coordinates to the side (a) as well as coordinates behind (b).

coordinates behind the wind farm and coordinates laterally separated 2° to 4° do not show distinct differences. Solely coordinates separated only 1° exhibit higher values. At the wind farm Delfzijl it is noteworthy that the coordinates in front exhibit -32 dBZ readings ~90 % of the time.

V. Summary & Future Work

The coordinates of the investigated wind farms exhibit on average a 10- to 20-fold exceedance of the reflectivity threshold levels than the reference coordinates in the front.

Coordinates laterally separated 2° to 4°, as well as the coordinates behind the wind farm, exhibit a similar distribution as the reference coordinates.

The higher values at coordinates separated only 1° is attributed to the presence of wind turbines.

In the future, it is envisaged to test other metrics such as the absolute temporal variation [2] and to apply the presented statistical techniques to validate the performance of advanced clutter mitigation approaches.

References

[1] http://www.eumetnet.eu/opera (accessed October 28, 2016)

[2] N. Donaldson, "Statistical Study of Echoes from Wind Farms and Other Moving Clutter Targets". 8th Europ. Conf. on Radar in Meteorology and Hydrology, Garmisch-Partenkirchen, September 2014.