Influence of wind turbines on seismic noise at monitoring stations in Northern Germany

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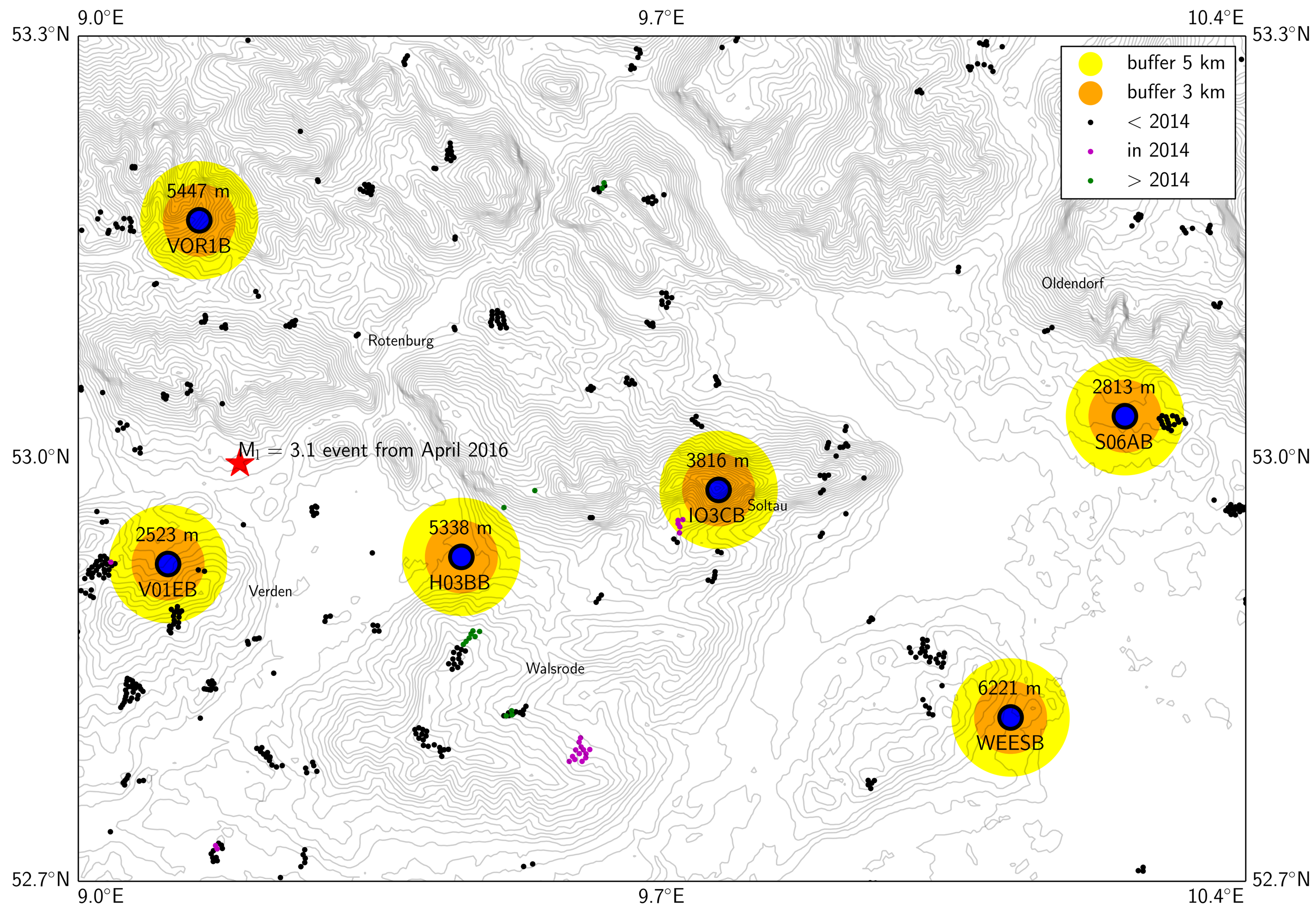

Fig. 1: Location of borehole stations of the seismic monitoring network in Northern Germany (blue spheres) overlaid with the regional wind turbine distribution (black, green and purple dots). The different color patches mark the start of operation times of the wind turbines. The yellow and orange circles around the station sites describe buffer radii of 3 and 5 km, respectively. The length indications represent the distance from station site to the closest wind turbine. The red star denotes the epicenter of the chosen seismic reference event from April 2016 in Langwedel. Map created on the SRTM 90 m database for the globe (see Jarvis et al, 2008). Data from: Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz.

Introduction

In recent years, the expansion of wind power systems in Germany has been intensified to realize the transition from fossil to renewable energies. It has been noted that at strong wind conditions local and regional noise levels at seismic monitoring sites are influenced by the operation of wind turbines [Stammler and Ceranna, 2016]. Since the recording quality of a seismic station depends on the noise level, station sites are chosen to be remotely located. Unfortunately, the same sites are often well suited for wind power systems (*fig 1*). The generated noise of these wind turbines is incidentally recorded by the seismic monitoring stations and thus seismic networks or stations are disturbed or decimated with regard to functionality and task fulfilment.

Methods

- PSDs and I95 of one year measuring period correlated with wind speed.
- Determination of Rayleigh wave proportion in the observed wave field → back-azimuth of noise sources.
- Magnitude of completeness depending on wind speed (induced seismic event as master event).

Surface Station

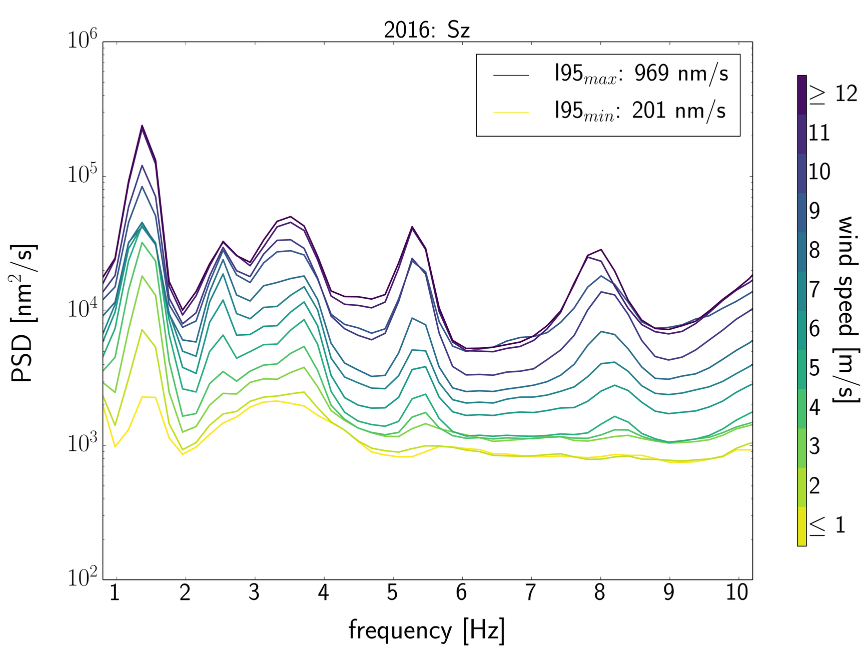

Fig. 2: Inter-quantile mean between 5 % and 95 % (IQM95) of all PSD functions seperated for channel Sz between January and October 2016 at surface station BROKB. Dark colors denote high, bright colors low measured wind speed.

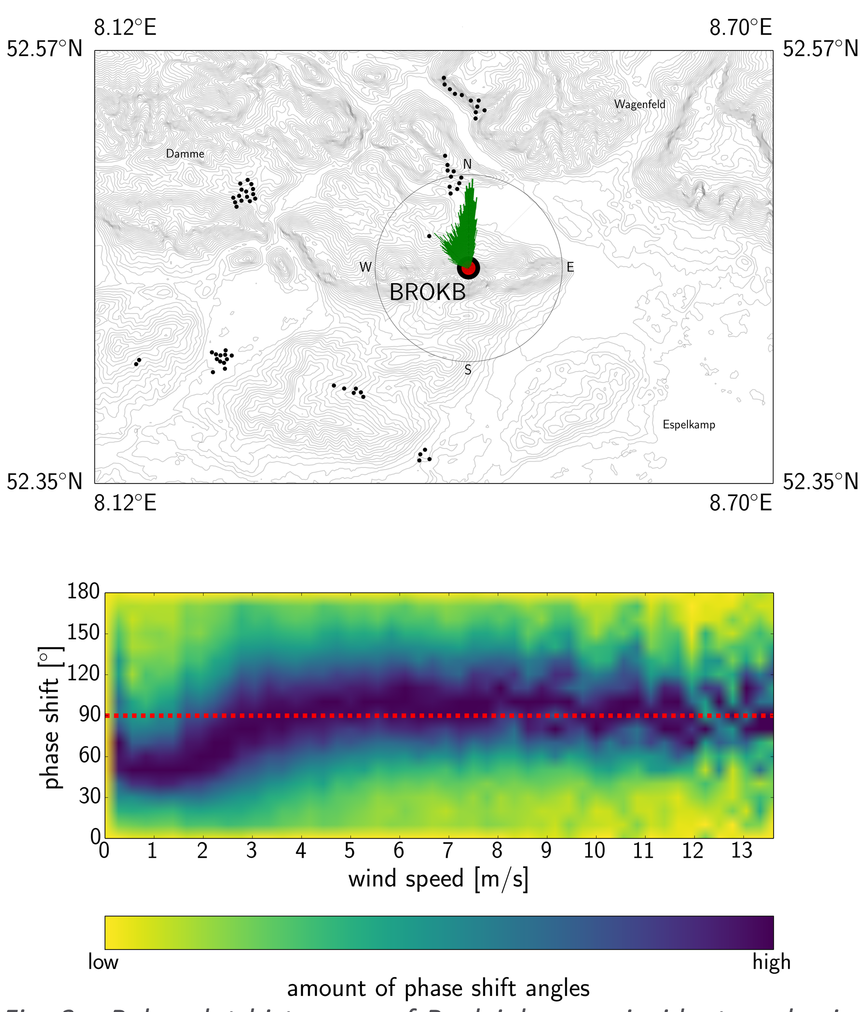

Fig. 3: Polar-plot histogram of Rayleigh wave incident angles in the frequency band between 3 – 4 Hz at surface station BROKB pointing to wind turbines as noise sources (top). Distribution of phase shift angles yielding the largest coherence between the vertical and horizontal component at station BROKB in a frequency band of 3 – 4 Hz correlated and normalized to wind speed (bottom).

- The noise level reflected by the PSD functions is visibly enhanced, showing a good correlation with wind speed at four distinct peaks between 1 – 2 Hz, 3 – 4 Hz, 5 – 6 Hz and 7 – 9 Hz (*fig 2*).
- In a small frequency band between 3 – 4 Hz the dominating portion of the noise wavefield is represented by Rayleigh waves. The Rayleigh waves are produced by the blade pass at wind turbines [Xi Engineering Consultants Ltd, 2014] with back-azimuths pointing to wind parks in the proximity to the monitoring site (*fig 3*).
- Rayleigh waves are increasingly observed with rising wind speeds starting from 4 m/s, which indicates a higher entry of wind turbine induced ground vibrations with higher wind speeds (maximum coherence between the horizontal and vertical component at a phase shift angle of 90°).

Borehole Stations

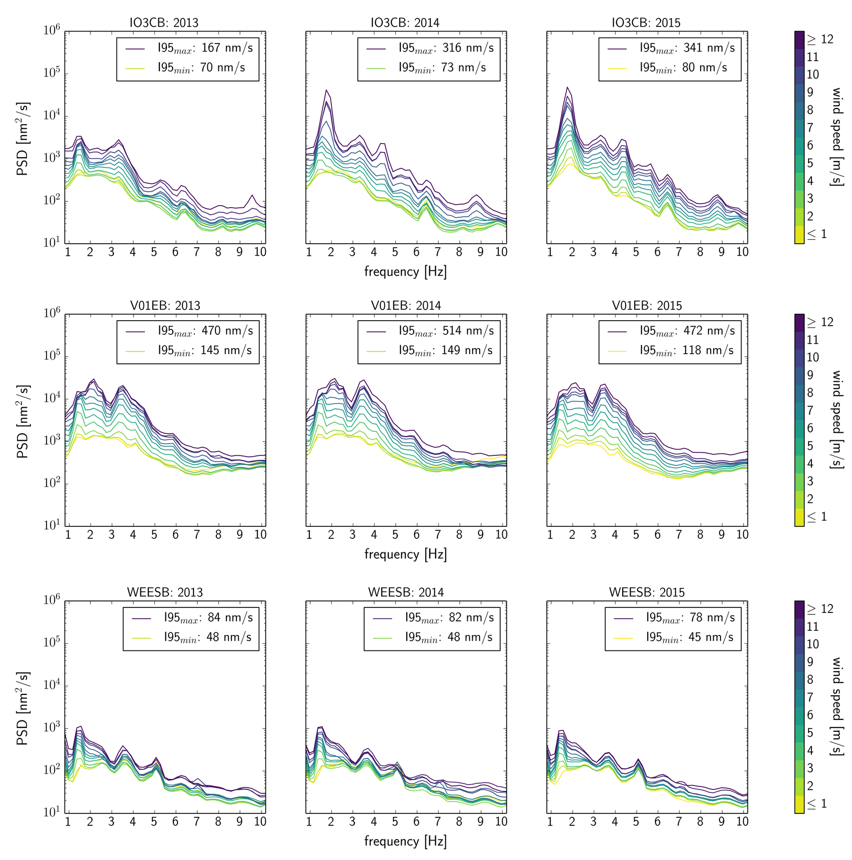

Fig. 4: One year averaged PSD functions separated for wind speed for horizontal component By of ground velocity between 2013 and 2015 at station IO3CB (top), V01EB (middle) and WEESB (bottom). Dark colors denote high, bright colors low measured wind speed.

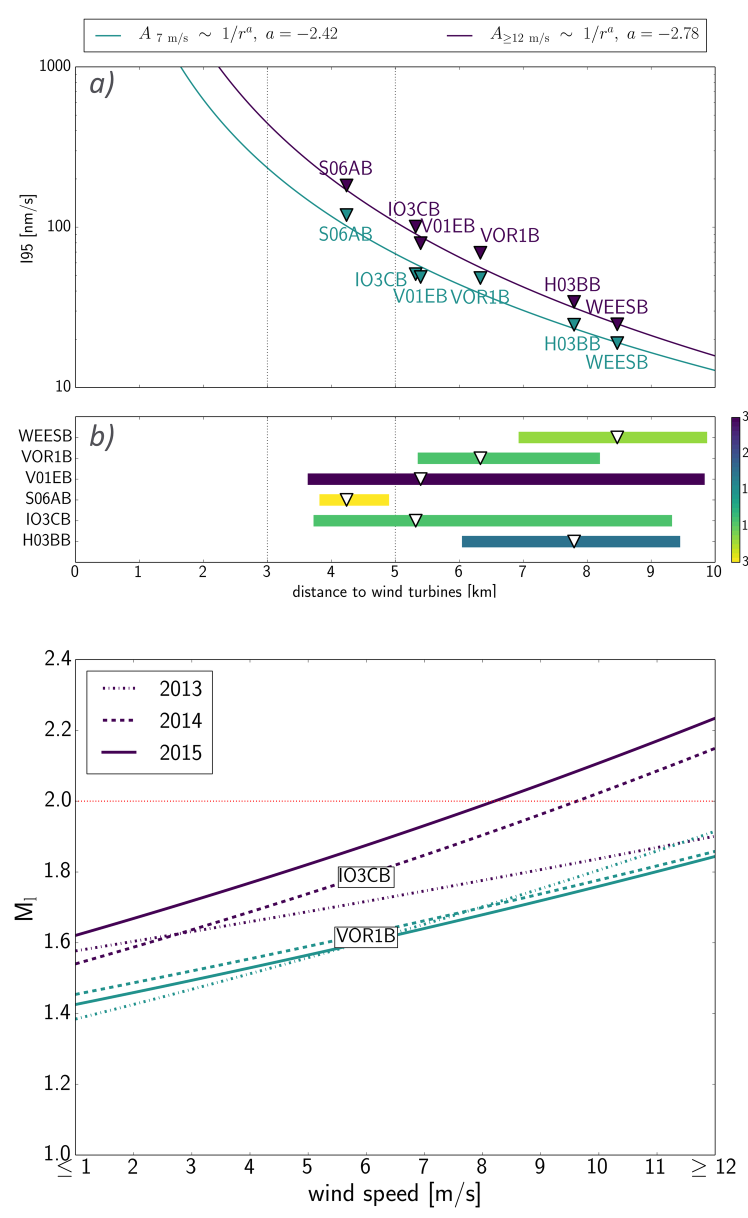

Fig. 5: Top: Amplitude decay in the frequency band 1 – 10 Hz of I95 values representing noise levels at the vertical component of all borehole stations, plotted against distance between station site and wind turbines in 2015. (a) Cyan color denotes calculated I95 values at medium wind speed (7 m/s), purple calculated I95 values at high wind speed (≥ 12 m/s). The absolute I95 values at the respective monitoring station are divided by Vn, with n as the number of ≥ 2 MW wind turbines in a radial distance up to 10 km. (b) Distance range of all ≥ 2 MW wind turbines in a radial distance up to 10 km around the six borehole stations. Dark colors denote a high number of nearby wind turbines, bright colors a low number. The white triangles represent the harmonic mean of the distances distributions. Bottom: Detection level of seismic events at stations IO3CB (purple lines) and V01EB (cyan lines) depending on wind speed correlated noise level and local magnitude M_l over a range of three years. The Langwedel M_l = 3.1 from 22 April 2016 that is assumed to be induced by gas production, serves as master event that is rescaled over a range of magnitudes. The stations have different hypocentral distances and different distances between monitoring site and wind turbines.

- PSD functions of borehole stations yielding a correlation of the noise level with increasing wind speeds and decreasing distances between monitoring sites and wind turbines (*fig 4*).
- The height of nearby wind turbines is affecting the frequency content of the noise wavefield (ground vibrations generated by taller turbine towers show lower frequencies, while smaller towers radiate higher frequencies) (*tab 1*).
- The operational performance of the seismic network deteriorates with increasing number of nearby wind turbines (*fig 5*).
- The minimum local magnitude that has to be reached to ensure a correct and successful automatic detection of seismic events is increasing with higher wind speeds and smaller distances between wind turbines and monitoring station.

Station	Wind turbine type	Number	Distance range [km]	Stated power [MW]	Start of operation	Hub height [m]
IO3CB	Enercon E-92	5	3.8 – 4.8	2.35	2014	108
	not specified	7	5.4 – 9.2	2	2001 – 2005	60
V01EB	Gamesa G 80	9	3.7 – 9.3	2	2005 – 2006	60
	AN-Bonus	3	5.4 – 5.6	2	*not specified*	60 / 80
	Enercon E-70 E4	9	4.6 – 6.3	2	*not specified*	85
	Enercon E-82	2	9.6 – 9.7	2	2010	108
	Enercon E-82 E2	12	4.4 – 6.0	2.3	2011 – 2014	85 / 108
WEESB	Vestas V-90	8	7.0 – 9.8	2	2006	105

Tab. 1: Wind turbines ≥ 2 MW in the proximity to the monitoring stations in radial distances up to 10 km. Data from: Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz.

References:

Jarvis A., Reuter H. I., Nelson A., Guevara E. (2008): Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database.

Stammler K., Ceranna L. (2016): Influence of Wind Turbines on Seismic Records of the Gräfenberg Array.

Xi Engineering Consultants Ltd (2014): Seismic vibration produced by wind turbines in the Eskdalemuir region (Tech. Report).

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