Tobias Neuffer

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Characterization of the Seismic Wave Field Radiated by a Wind Turbine

Tobias Neuffer · Philipp Meckbach · Michael Mistler · Simon Kremers

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Abstract Due to the increased expansion of wind turbines (WTs) in the last two decades, seismologists have recently observed an impact of disturbing signals at seismic stations. Ground vibrations generated by WTs perturb the seismic background noise level at seismological monitoring sites causing that the performance and functional capability of a seismological network can be limited which leads a conflict between operators of WTs and seismological institutions. With regard to a conflict settlement, the research project MISS (Minderung der Störwirkung von Windenergieanlagen auf seismologische Stationen) was initiated to investigate in detail the seismic signals emitted by a WT in order to identify and discuss methods to reduce the disturbance impact on seismic stations. A part of this research project is presented in this study and deals with movement patterns of a WT tower, foundation and the immediate subsurface as well as the amplitude decay behavior of the seismic noise with increasing distances to the WT. For this purpose, short- and long-term measurements were conducted at a single WT of the "Bürgerwindpark A31 Hohe Mark" located in Heiden (North Rhine-Westphalia, Germany). First, the first four eigenfrequencies of the WT tower are identified at 0.3 Hz, 1.1 Hz, 3.25 Hz and 6.0 Hz using 1.5 hour recordings of sensors that were installed in different heights on the inner wall of the tower. Furthermore, linear, elliptical and circular motion patterns could be observed at the tower. The results of the long-term measurements using 15 mobile seismic stations installed over one month in two circular arrays with distances of 100 and 200 m around the WT and two additional stations, one deployed on the foundation and one directly beside in the field, also show linear, elliptical and circular particle movements of the foundation and shallow underground. By correlating power spectral density (PSD) spectra and vertical displacements with the prevailing wind direction, it can be shown that at the eigenfrequencies 0.3, 3.25 and 6.0 Hz Rayleigh waves are radiated in *crosswind* direction from the WT. In *downwind* direction the wave field is dominated by the Love wave type. In contrast, at 1.1 Hz the dominating wave type emitted by the WT in *crosswind* direction is Love wave and in *downwind* direction mainly of the Rayleigh wave type. In order to estimate an amplitude decay relationship of the WT-induced seismic waves, a 1.5 hour line-array measurement with 36 sensors installed 100 – 1000 m from the WT and a sensor spacing of 25 m could be used to determine attenuation curves of ground motion velocities proportional to r^{-b}, with r as the distance between sensor and WT and b as the decay parameter, for the four eigenfrequencies of the tower. The calculated b-values are increasing with frequency from 0.31 to 0.86.

Keywords Seismic Noise · Wind Turbine Noise · Eigenfrequencies of Wind Turbine Towers · Attenuation of Seismic Waves · Surface Waves · Seismic Wave Field

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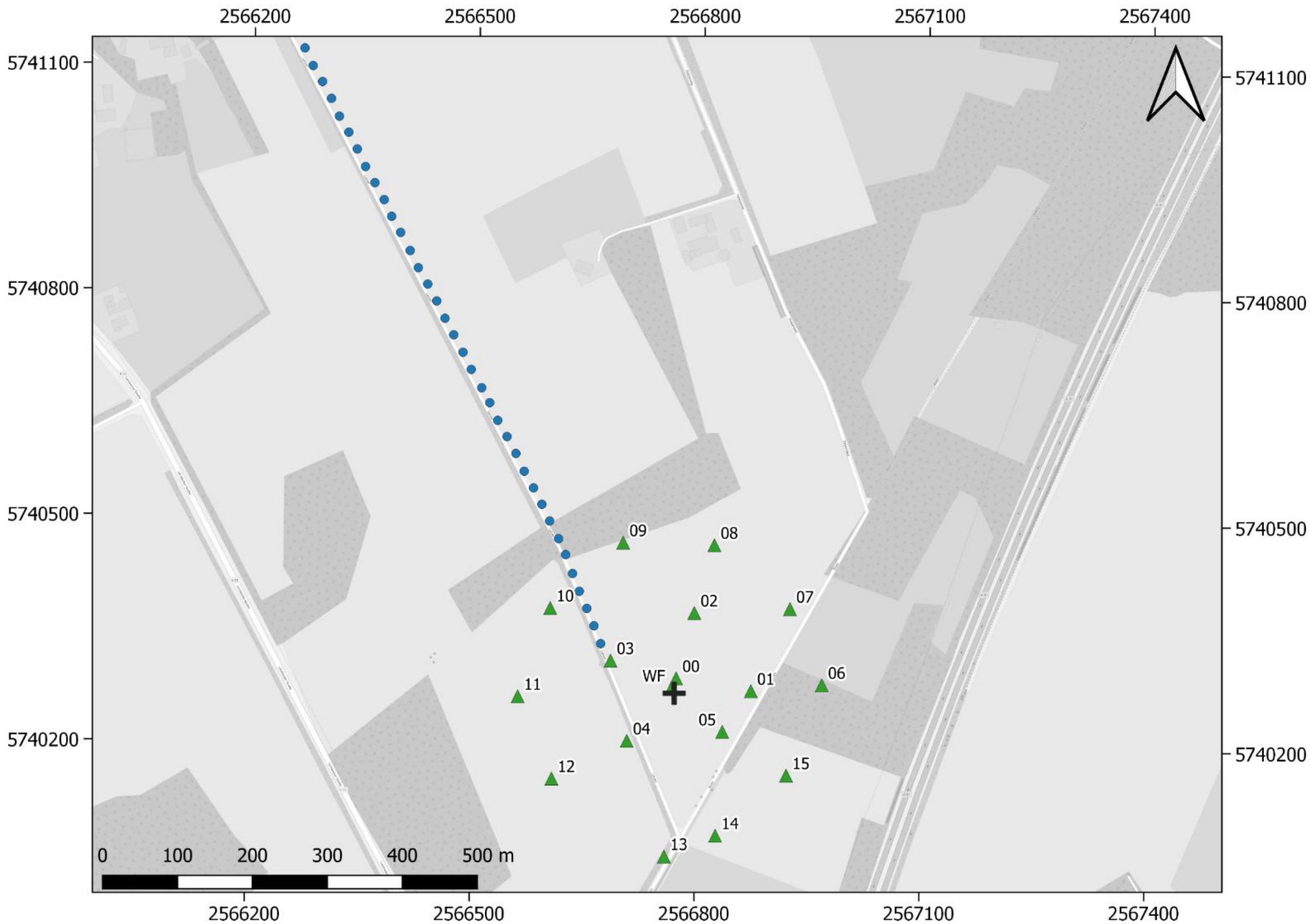
Sensor	Height [m]
T1	31,8
T2	68,2
T3	105,0
T4	124,1
T5	146,3

Inhalt Paper



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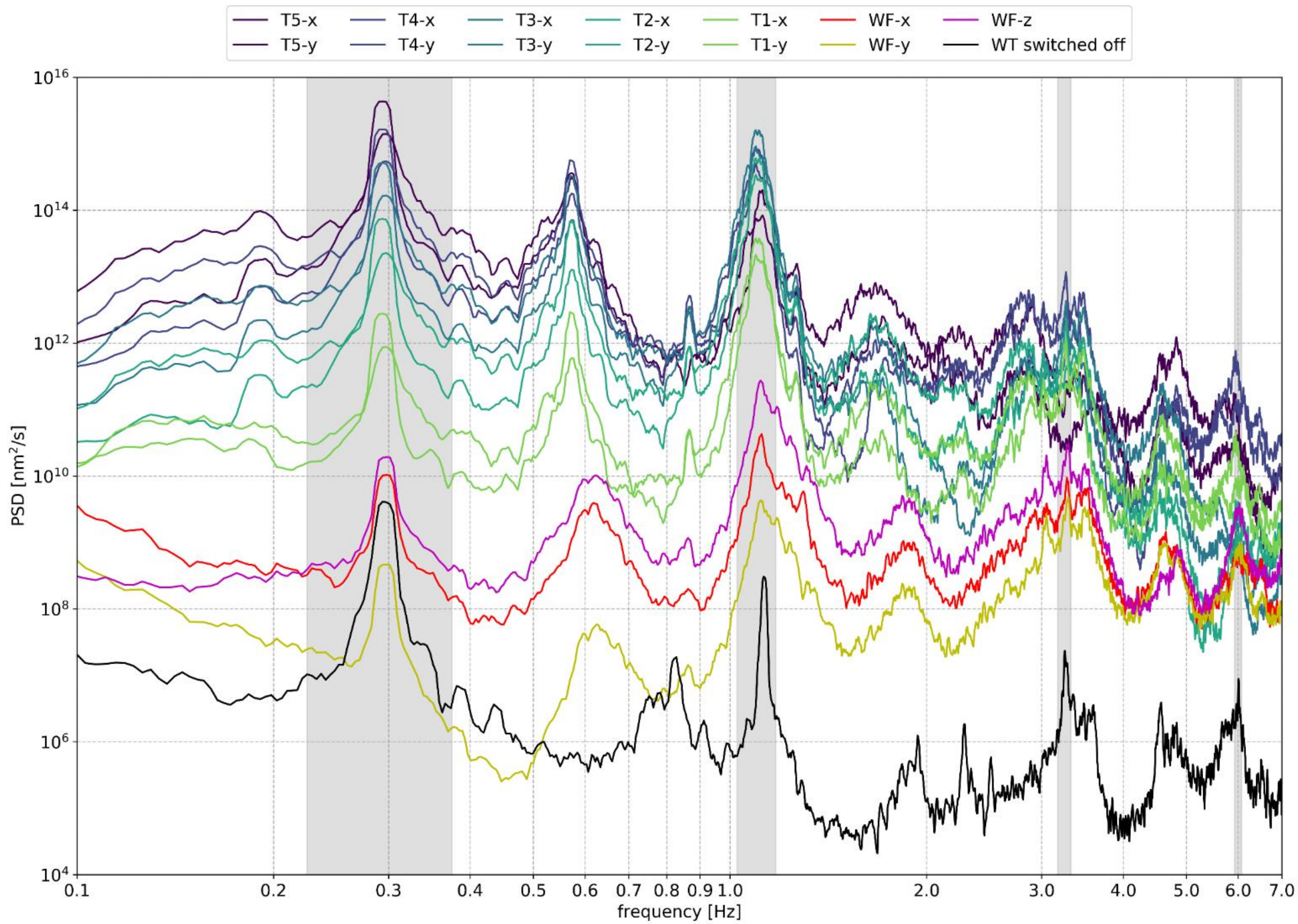

Sensor	Height [m]
T1	31,8
T2	68,2
T3	105,0
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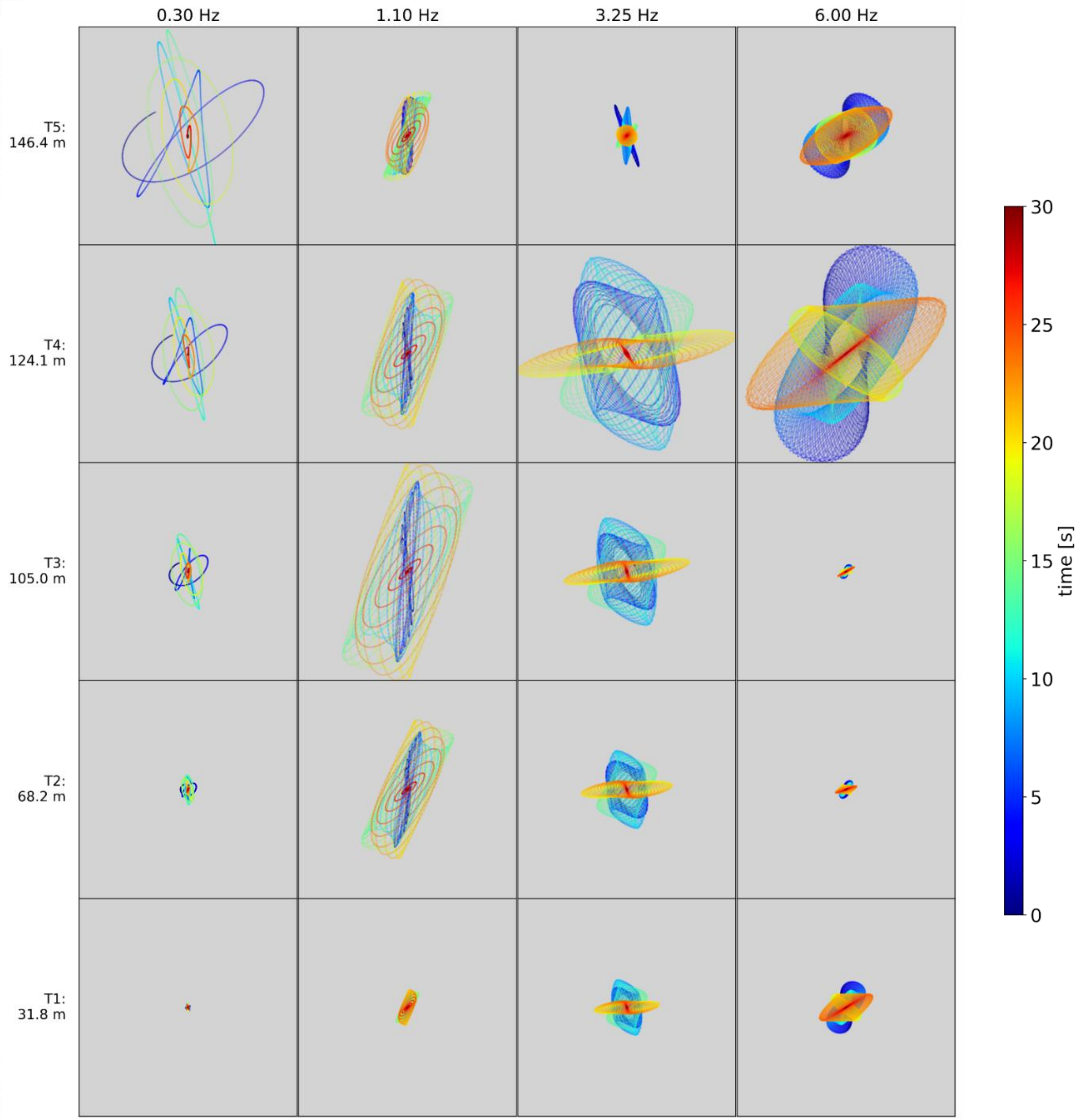
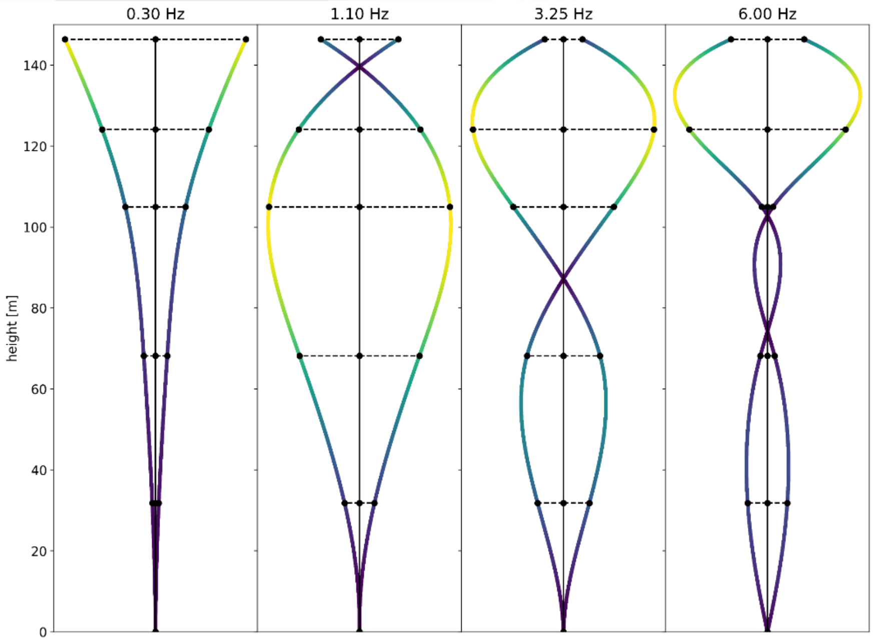
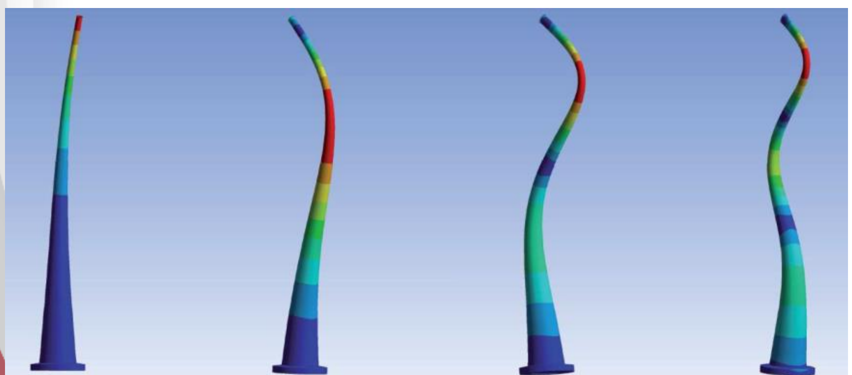
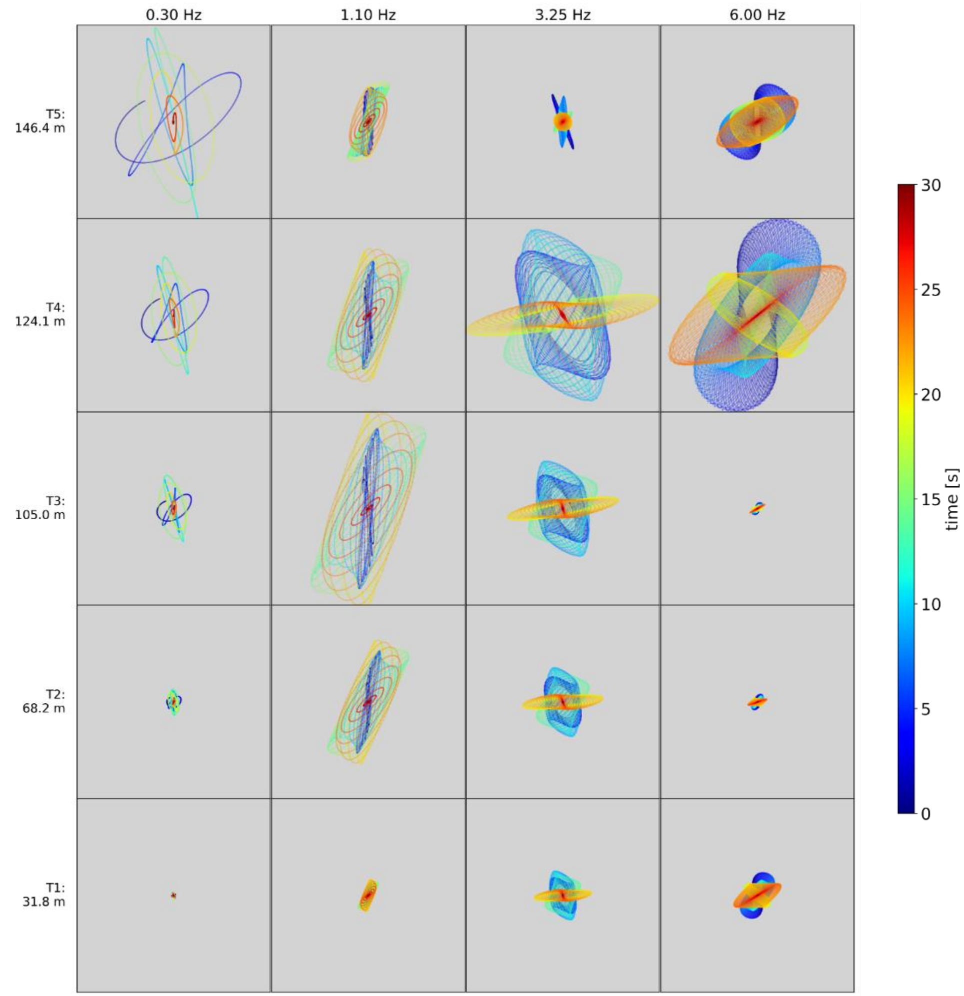
T5	146,3

- Horizontale Turmbewegung



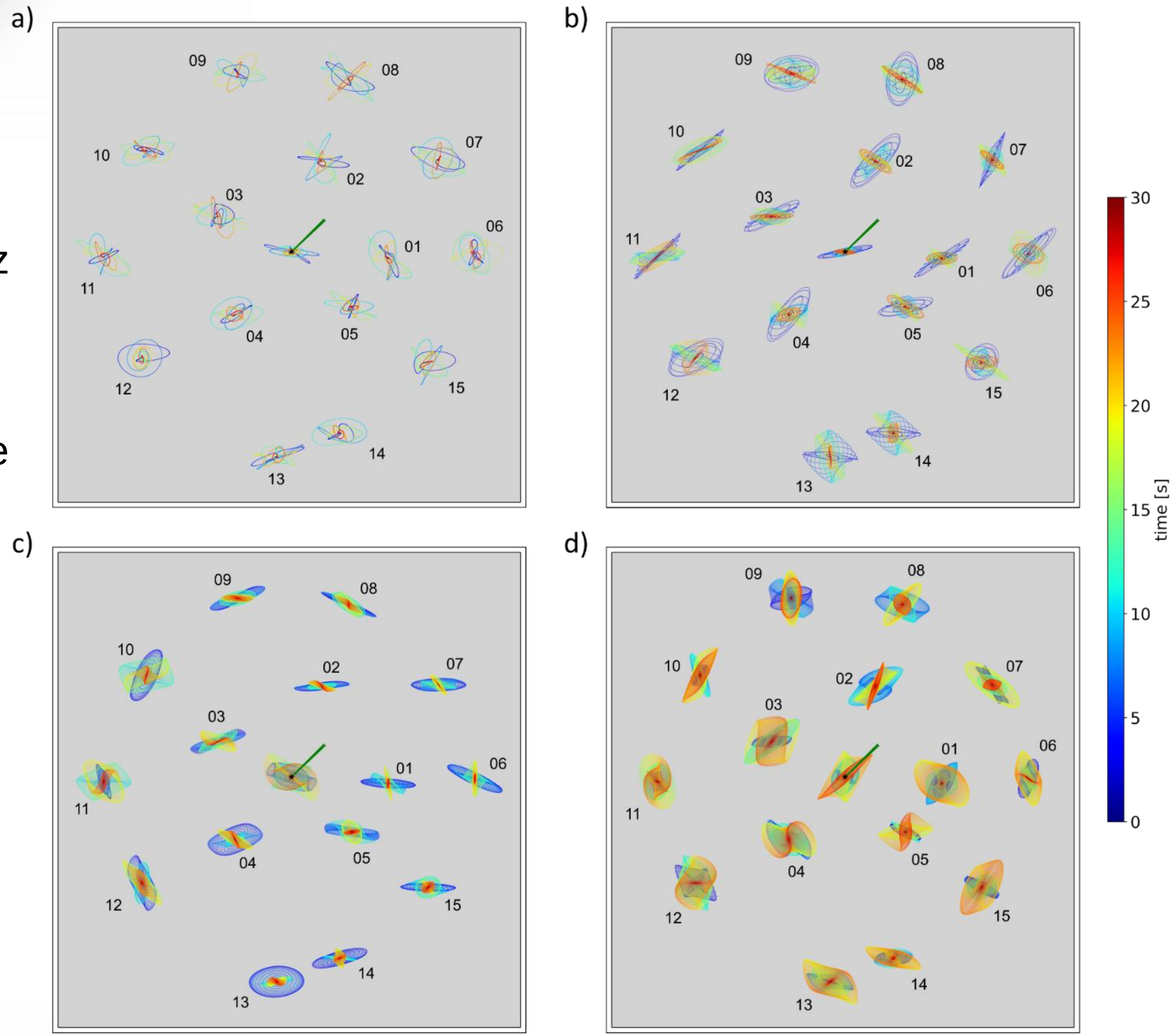

0.30 Hz
1.10 Hz
3.25 Hz
6.00 Hz
height [m]
0
20
40
60
80
100
120
140




0.30 Hz
1.10 Hz
3.25 Hz
6.00 Hz
T5: 146.4 m
T4: 124.1 m
T3: 105.0 m
T2: 68.2 m
T1: 31.8 m
time [s]
0
5
10
15
20
25
30

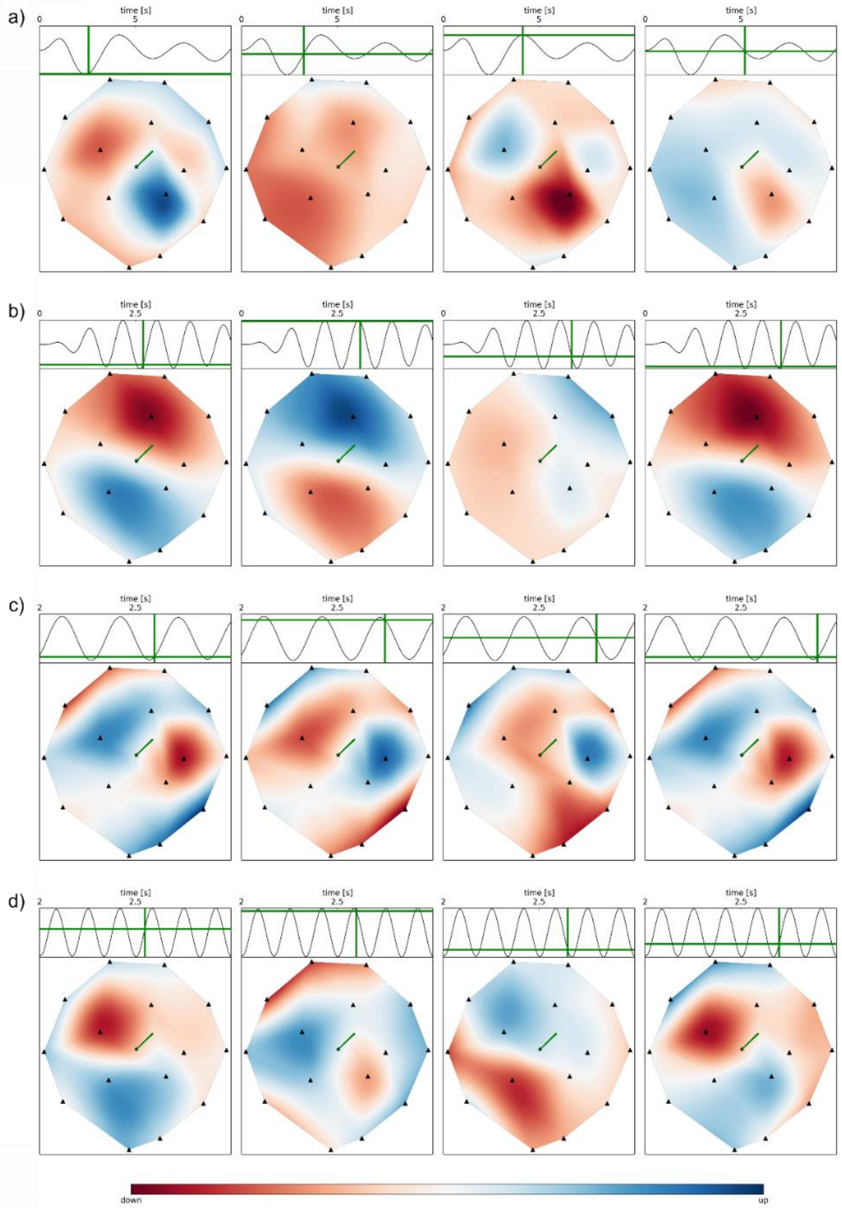
- A): 0.3 Hz
- B): 1.1 Hz
- C): 3.25 Hz
- D): 6.0 Hz

- Horizontale Bewegung

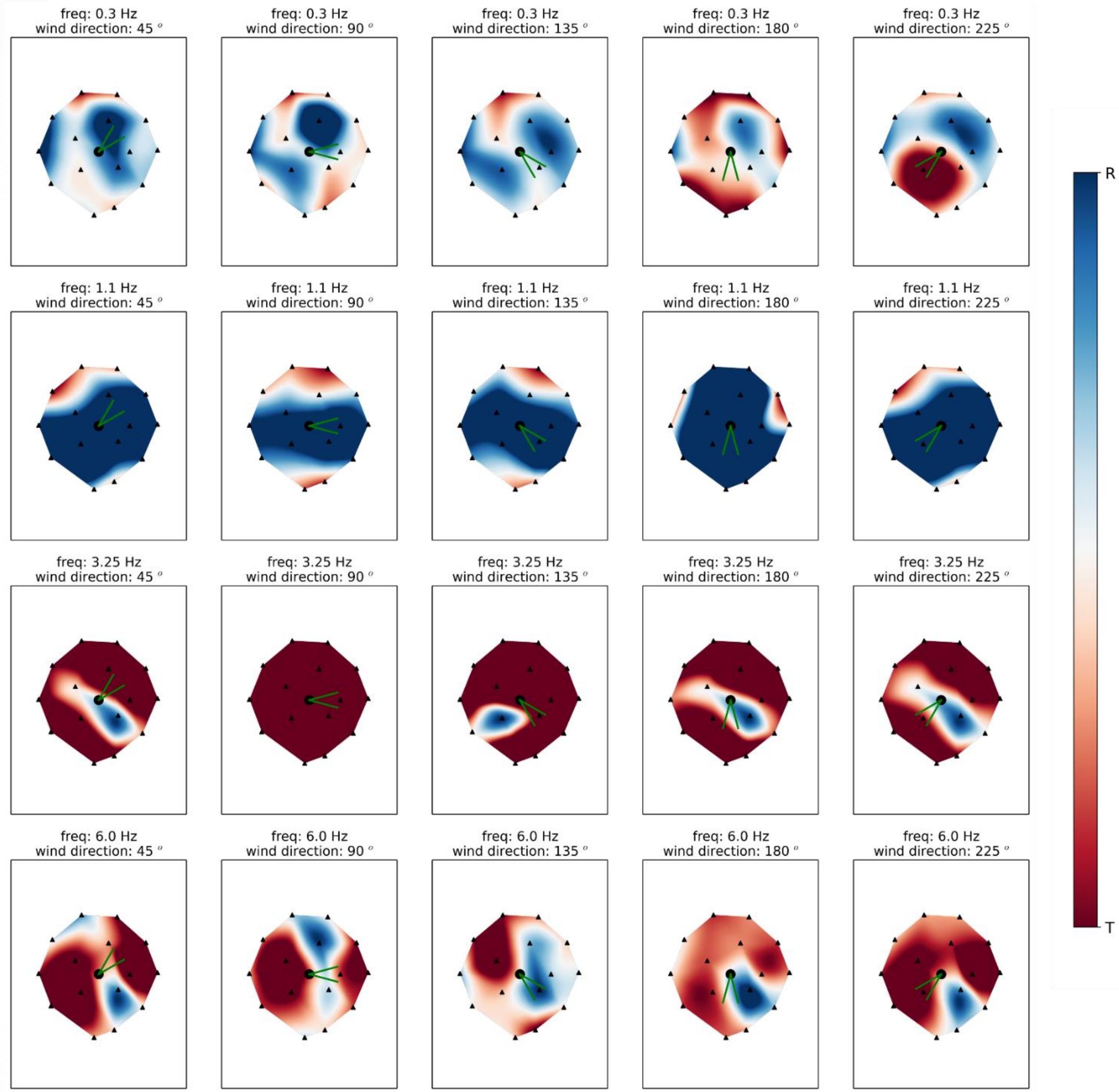


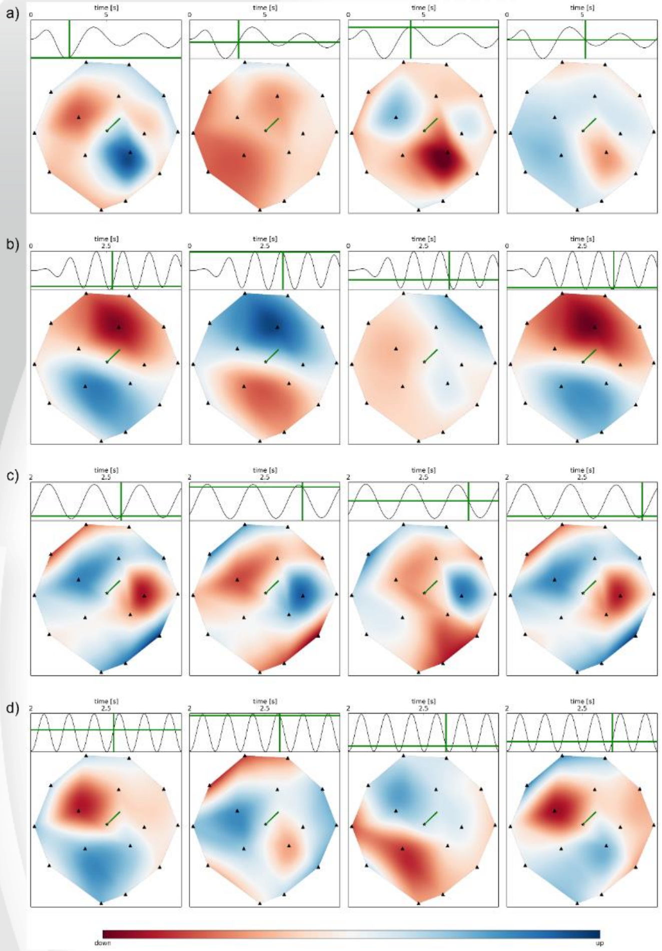
- A): 0.3 Hz
- B): 1.1 Hz
- C): 3.25 Hz
- D): 6.0 Hz

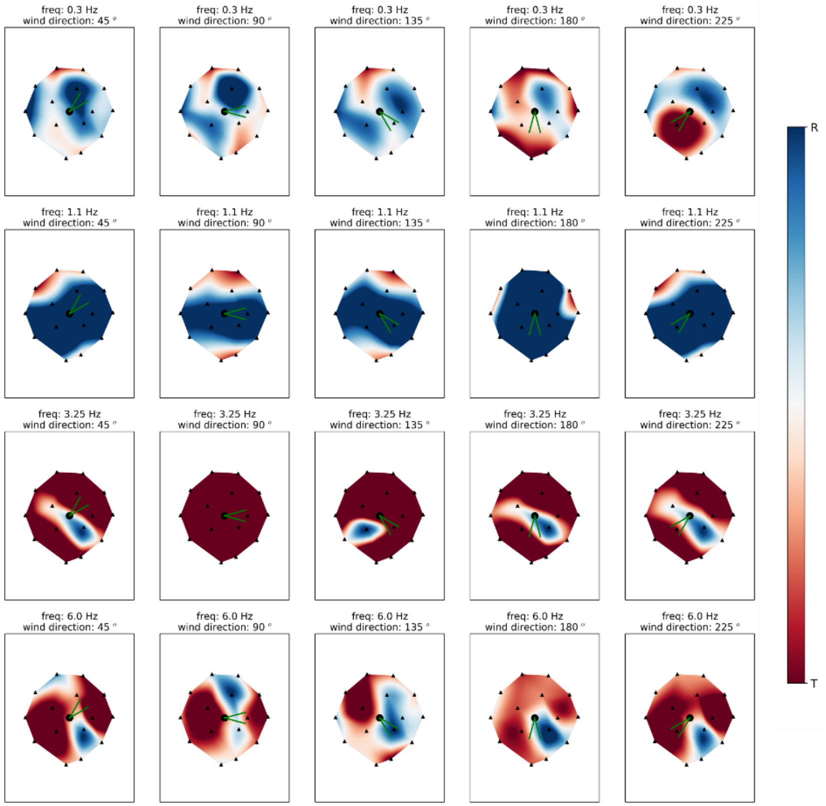
- Vertikale Bewegung



- Windrichtung bins (45°, 90°, 135°, 180°, 225°)
- Rotation der Komponente (N → WEA)
- 10-min PSDs
- Verhältnisse der Spektren
- $\text{Log}_{10}(\text{PSD}_{\text{radial}}\ /\ \text{PSD}_{\text{transversal}})$

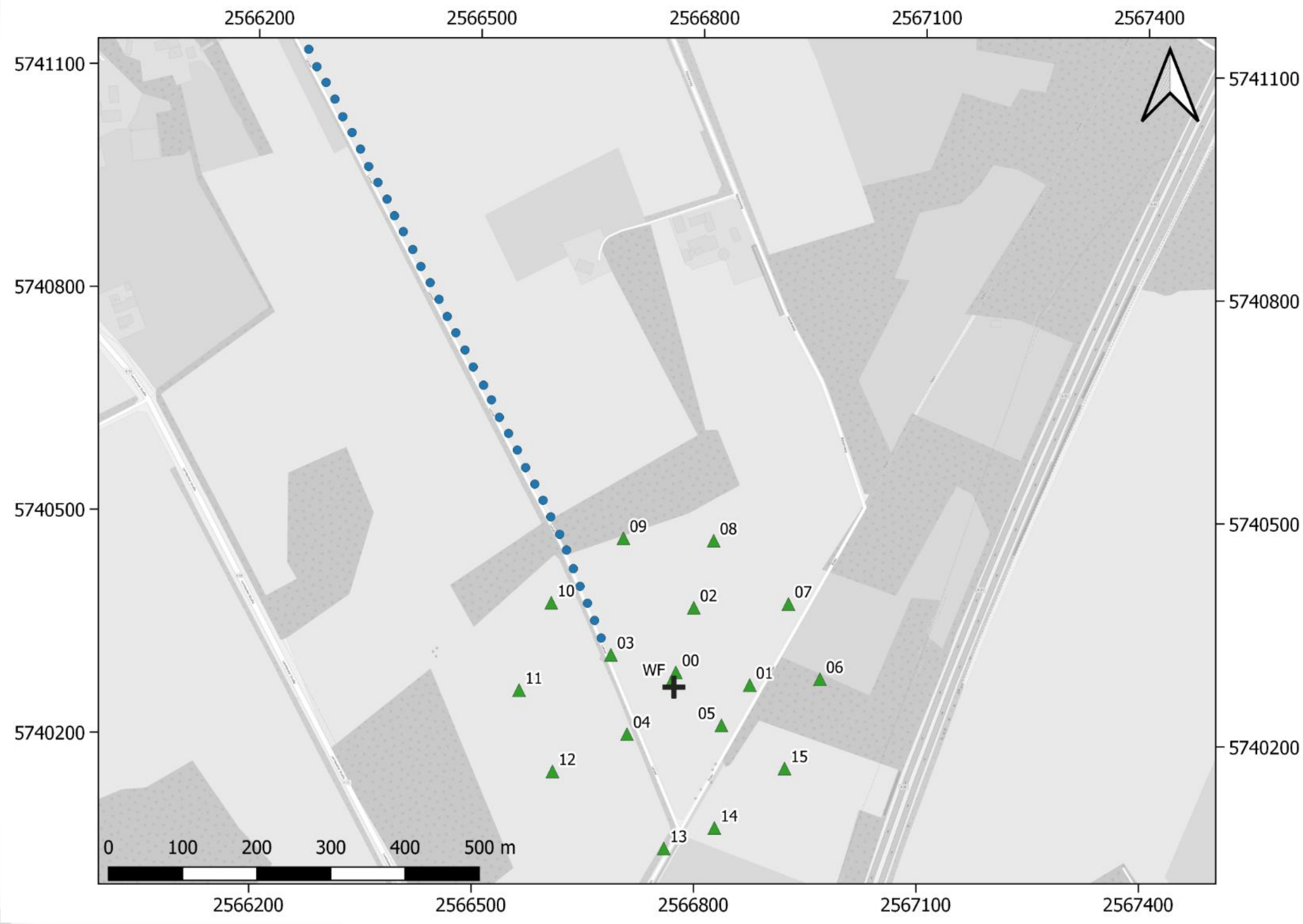






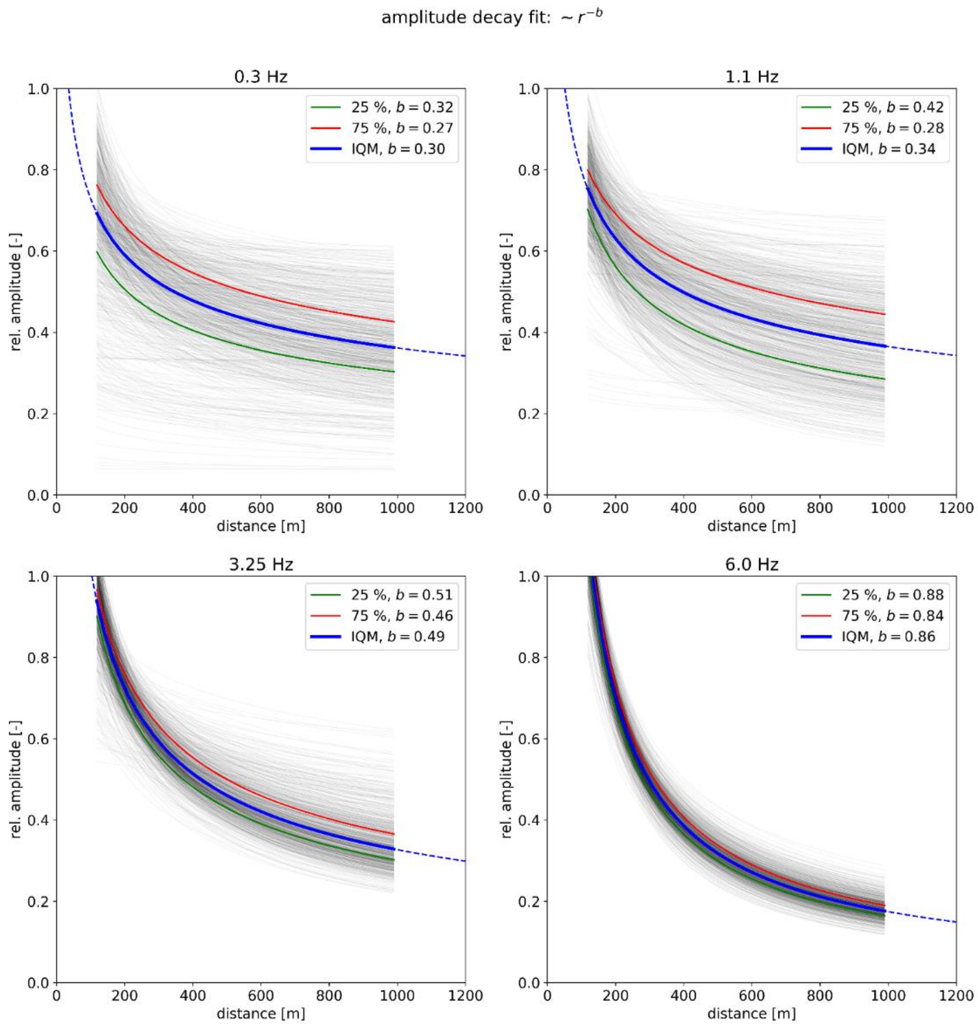
Frequenz	Parallel zur Windrichtung	Senkrecht zur Windrichtung
0.3 Hz	Love	Rayleigh
1.1 Hz	Rayleigh	Love
3.25 Hz	Love	Rayleigh
6.0 Hz	Love	Rayleigh

Inhalt Paper

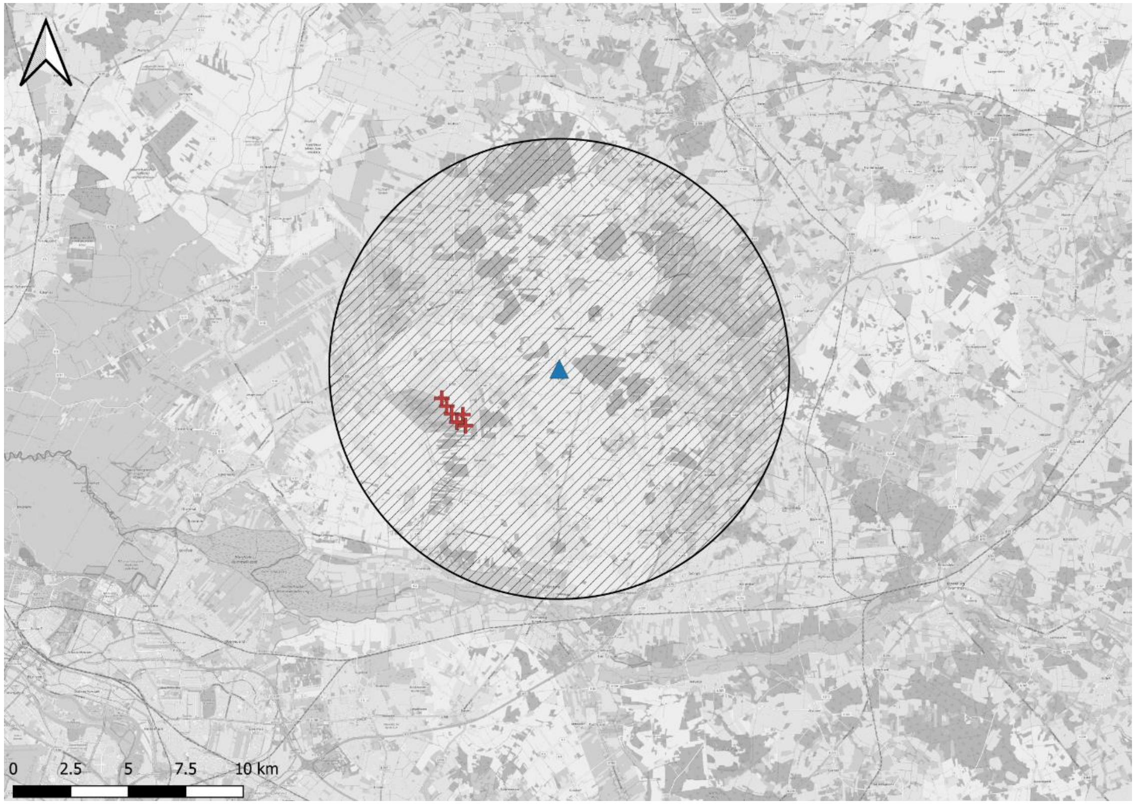


Inhalt Paper

- Amplitudenabnahme der Schwinggeschwindigkeiten im Zeitbereich
- Schmalbandig gefiltert
- I95 über 20 s
- Normierte Abnahmebeziehung der 20 s Fenster
- IQM zwischen 25 % und 75 %

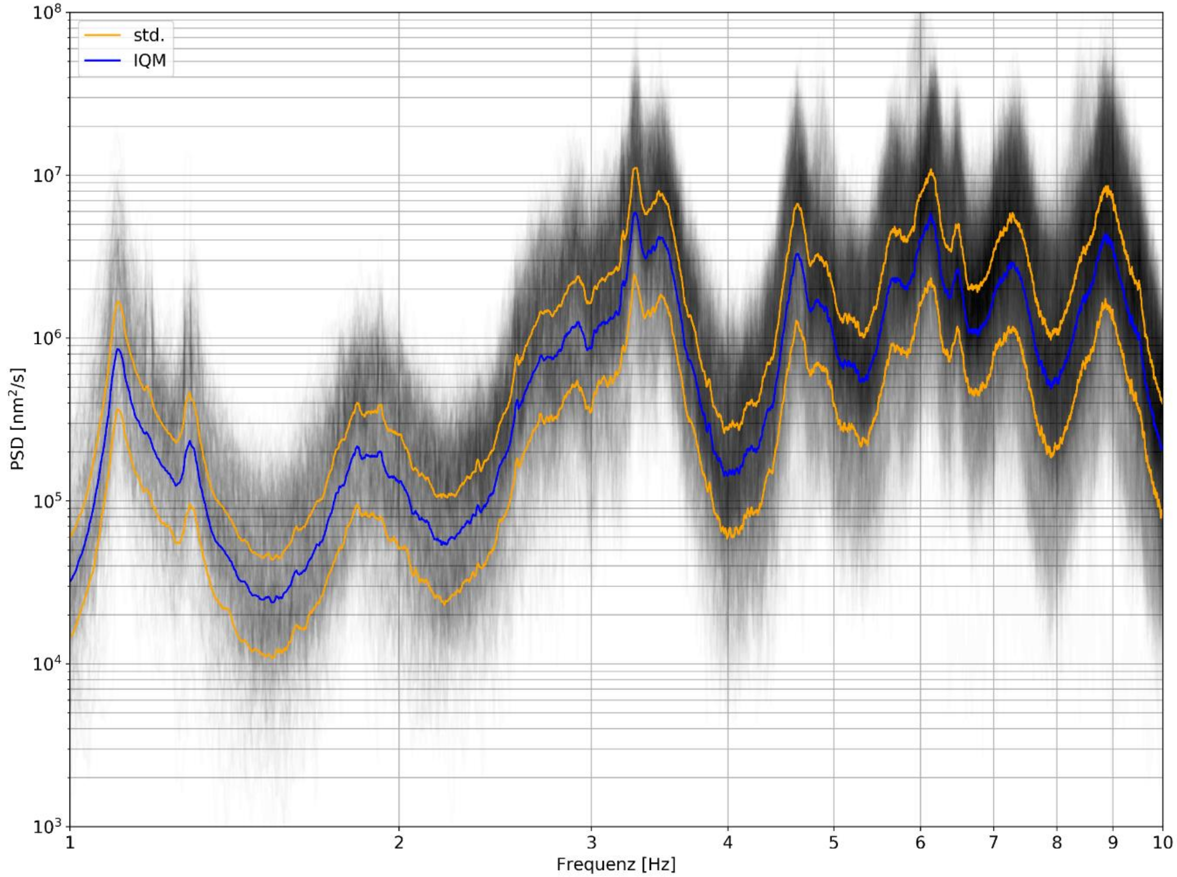


AP3 – Bewertung Störwirkung auf Messstation



- Fiktiver Fall: Zubau von n WEA gleichen Typs in einer Entfernung r
- Bestimmung des Quellsignals des entsprechenden WEA Typs (und Geologie)

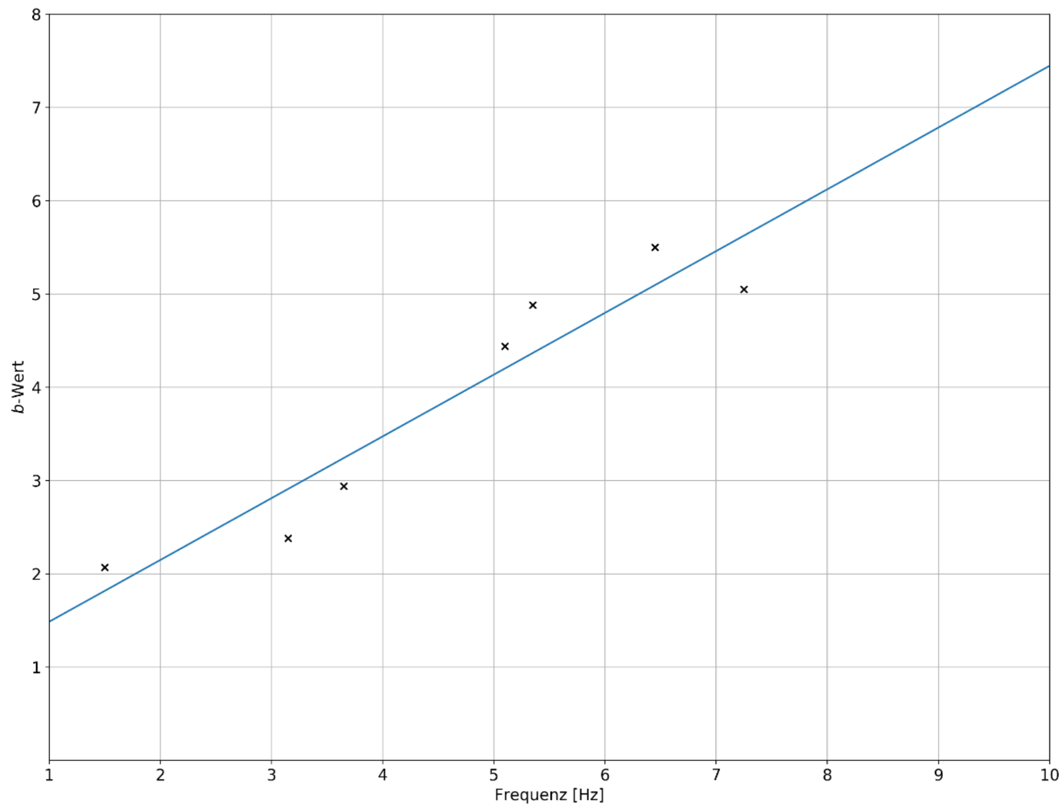
AP3 – Bewertung Störwirkung auf Messstation



- Quellsignalbestimmung durch Messungen in einer bestimmten Entfernung
- PSD-Spektrum als charakteristische Quelle

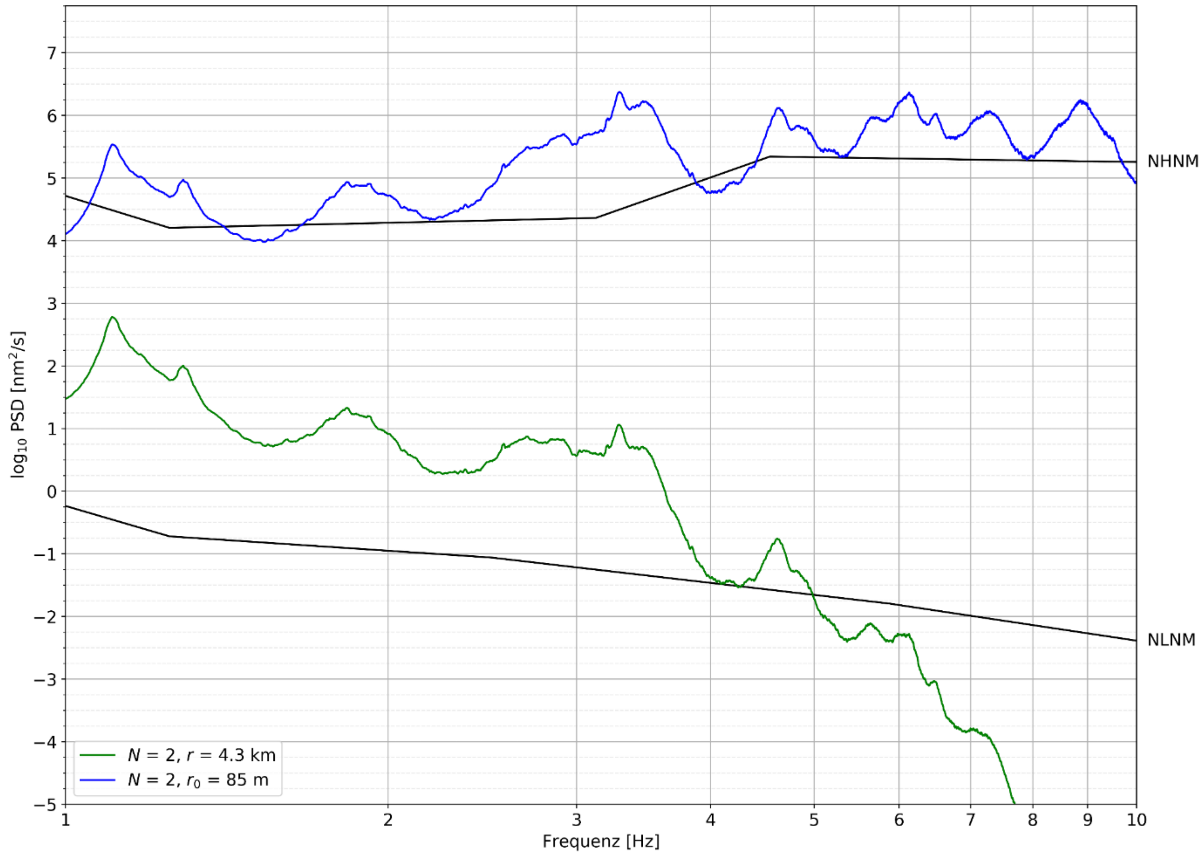
AP3 – Bewertung Störwirkung auf Messstation

Frequenz [Hz]	Stammler und Ceranna (2016)	Zieger (2019)	Neuffer et al. (2019)
1,2		0,57	
1,5		2,07	
3,0 - 3,3			2,38
3,3 - 4	2,7	3,12	2,94
5,0 - 5,2			4,44
5,2 - 5,5			4,88
6,3 - 6,6			5,50
7,1 - 7,4			5,05



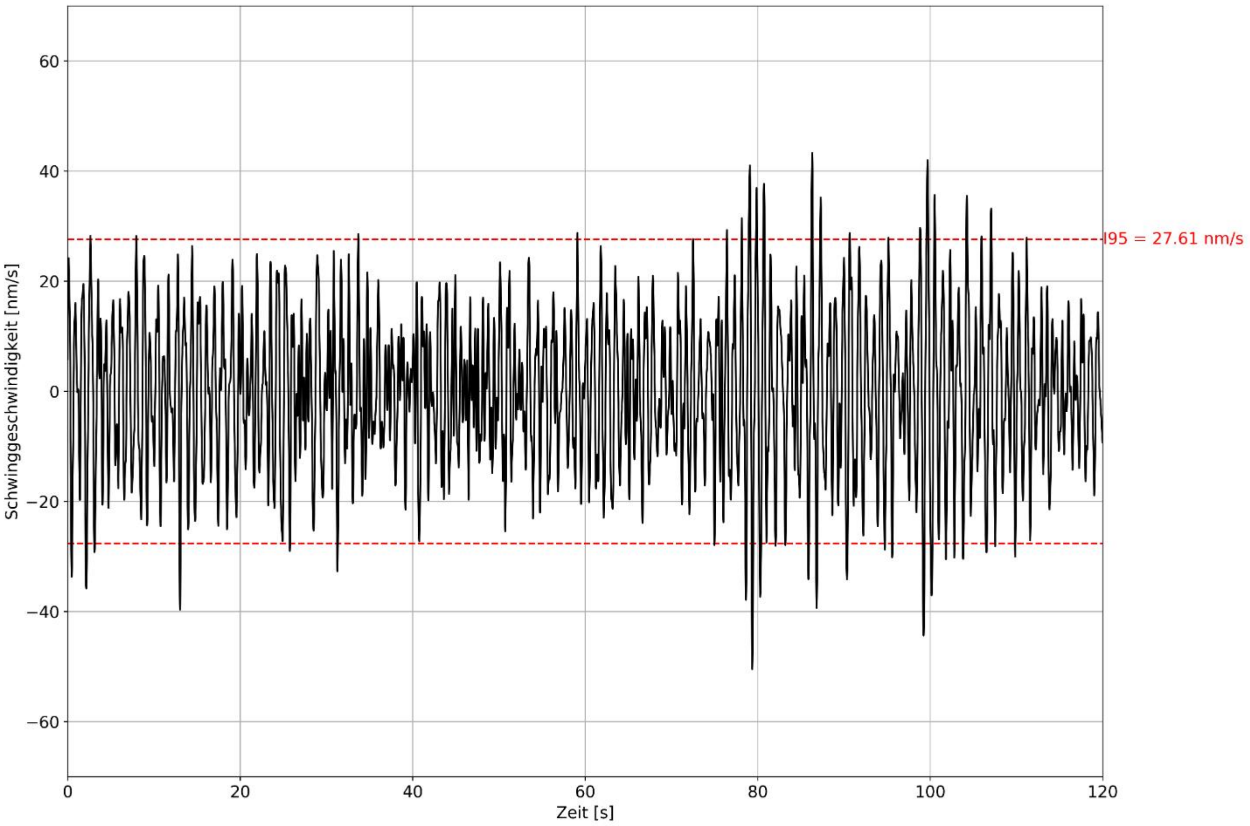
- Frequenzabhängige Abnahmekoeffizienten aus Literatur
- $\mathrm{PSD}(r, f) = A_0(f) r^{-b(f)}$

AP3 – Bewertung Störwirkung auf Messstation



- $\mathbf{PSD}(r,f) = A_0(f)r^{-b(f)}$
- Skalierung des Quellsignals

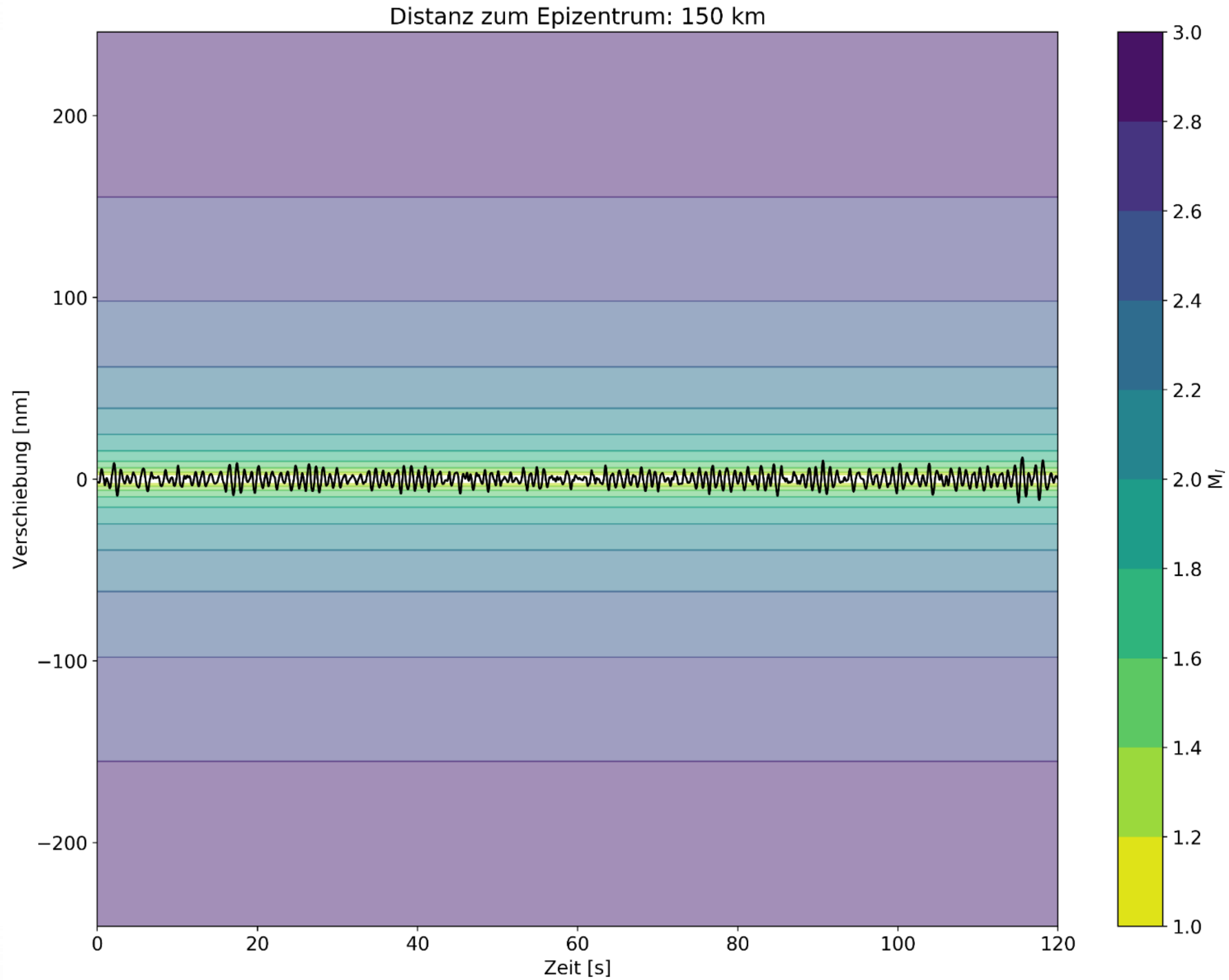
AP3 – Bewertung Störwirkung auf Messstation



- Rücktransformation in ein Zeitsignal
- Zufällige Phase

AP3 – Bewertung Störwirkung auf Messstation

- Berechnung der Amplituden eines Ereignisses in einer bestimmten Entfernung (Richter)
- $M_L = \log_{10}(A) + 1{,}11 \log_{10}(R) + 0{,}00189\, R - 2{,}09$



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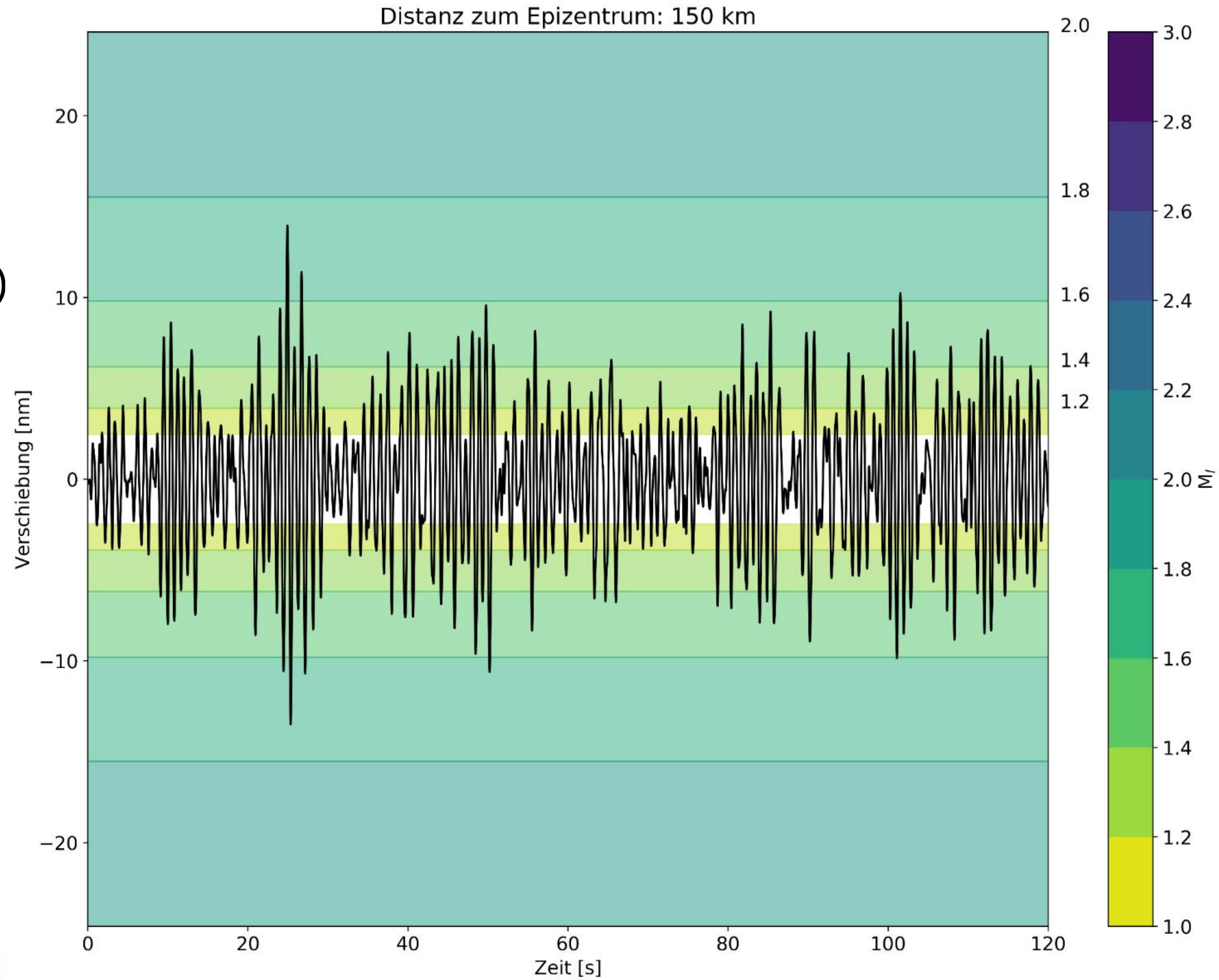
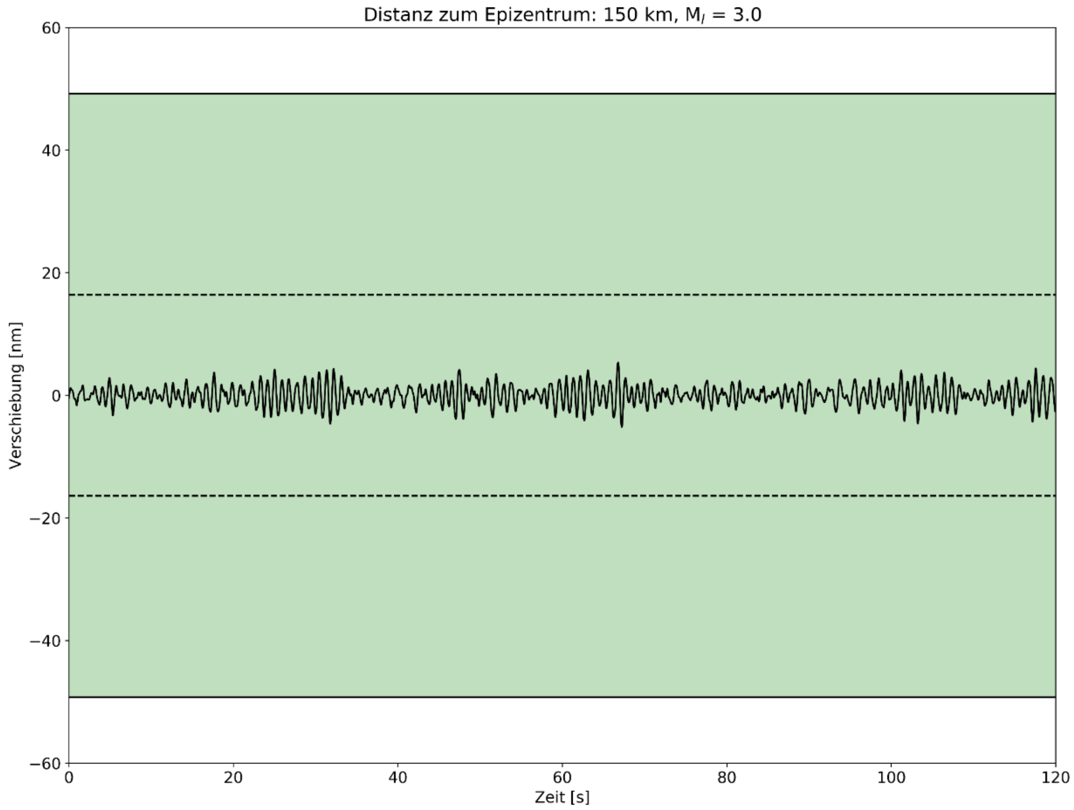


AP3 – Bewertung Störwirkung auf Messstation



- Signal-Rausch-Verhältnis: erwartete Amplitude bei gegebener Entfernung und Magnitude vs. Noise
- Bewertung, ob Messstation hinsichtlich der Gesamtaufgabenstellung gestört ist

EFRE.NRW Investitionen in Wachstum und Beschäftigung
EUROPÄISCHE UNION Investition in unsere Zukunft Europäischer Fonds für regionale Entwicklung

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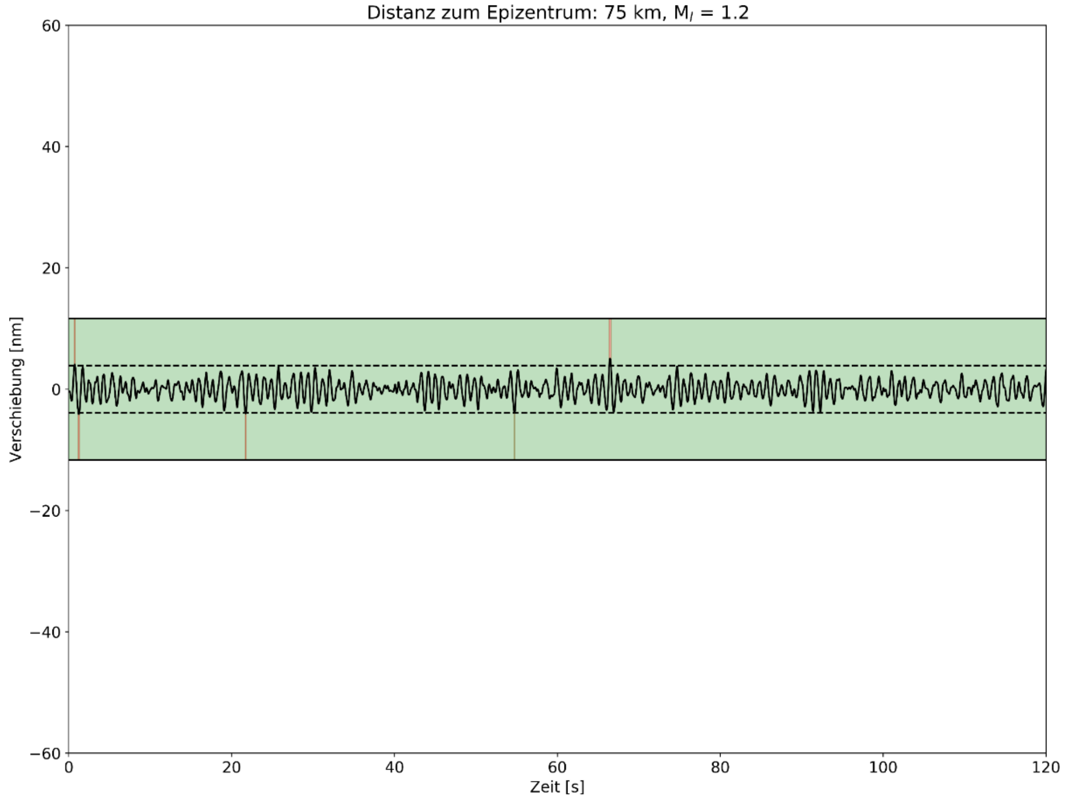

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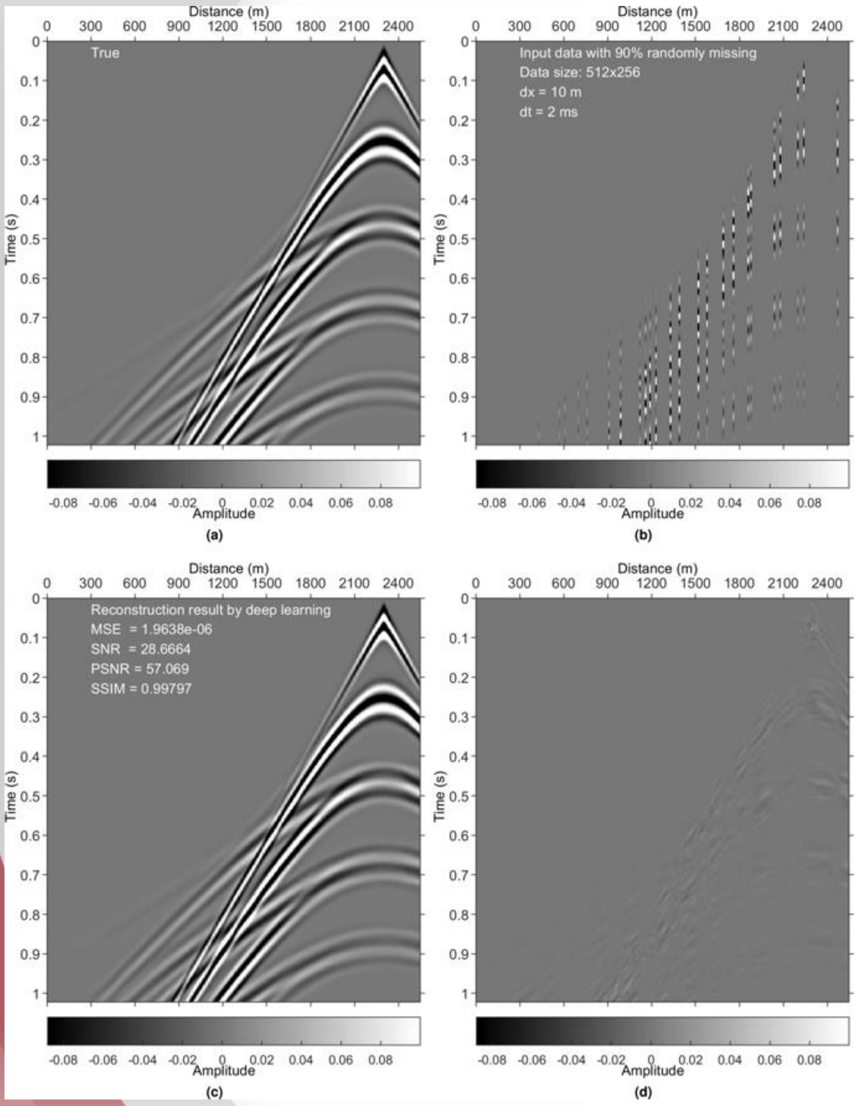
AP3 – Idee Filter



- Imputation of missing data
- Problem: 1D Zeitreihe – keine Kontrolle bei Interpolation
- Anwendung auf Spektrogramm