Re-Analysis of seismological data to characterize the decay of ground motions induced by wind turbines

by Dr. Fabian Limberger & Prof. Dr. Georg Rümpker

Motivation

An investigation of the decay of wind-turbine (WT) induced seismic signals can be done by analyzing noise levels recorded with seismometers as function of frequency, distance to the wind farm (WF), and wind speed. The computation of power spectral densities (PDSs) of continuous seismic recordings is highly suitable for this task.

Processing

The analysis of CWP and EKA seismic recordings involved cutting (up to) six months of Z-component ground motion data into 10-minute PSDs and binning the spectra to wind speed measured at the Haggis Side meteorological tower. The 25% highest noise amplitudes were considered as outliers and were excluded to avoid bias from short-term-signals not related to wind turbines. PSDs were then sorted by daytime and night time (6 pm – 6 am) and averaged per wind speed group to obtain statistically robust distance- and wind-dependent spectra.

WT-induced peaks are generally defined by four criteria

(1) Clear Peak detection close to the WF.

(2) Systematic decrease of signal energy with increasing distance to the WF.

(3) Increase of signal energy with increasing wind speed.

(4) No significant signal energy during low-wind conditions, except close to the WTs due to slight tower swaying at low wind speeds even without WT rotation.

CWP data

Recordings along the profile stations provided by CWP show near-field spectral peaks between 1 and 10 Hz fulfilling the mentioned criteria: 1.14 Hz, 1.63 Hz, 2.28 Hz, 2.72 Hz, 3.41 Hz, 3.89 Hz, 4.6 Hz, 6.4 Hz, and 7.7 Hz. Peaks between 2 and 4 Hz are insignificant at larger distances due to low initial emission amplitudes. Peaks above 4 Hz have high near-field amplitudes but damp quickly with distance along the profile. WT signals remain observable at station 6v71 (5.4 km) with very low amplitudes, but vanish at 6v70 (8.6 km). Stations 6o87 (300 m), 6w19 (6.7 km), and 6o89 (10 km) were

excluded due to high noise (likely by very local wind-dependent noise sources). Day/night comparisons systematically show no significant impact on the peaks, while the overall noise level is slightly reduced. This indicates WT-dominated noise fields in the near-field at both day **and** night.

EKA data

Recordings at EKB1, EKB2 and EKB3 reveal peaks ≥ 3 Hz, which are very sharp and are present at low and high wind speeds, which is untypical for WT-induced signals. Suspicious peaks at 2.10, 2.66, and 2.95 Hz share some WT-like characteristics but are not confirmed at near-field stations. The near-field peaks at 1.14 and 1.63 Hz are not detected at EKA stations. A minor peak at approx. 1.33 Hz is observed, however, this peak cannot be confirmed by near-field measurements. Day/night comparisons show significantly lower noise at night, indicating that the noise field at day is dominated by anthropogenic noise (unrelated to WTs).

Conclusions

(1) Peaks identified near WTs attenuate strongly, being undetectable at 8.6 km and only weakly visible at 5.4 km.

(2) Distinct peaks observed at the EKA stations do not meet WT-signal criteria and cannot be reliably related to the measurements in the near field of the WTs.

(3) Day/night analysis indicates WT-dominated noise fields up to ~5.4 km in the vicinity of the WF at day and night, while anthropogenic noise (not WT related) dominates at EKA during the day.

(4) Short-term analysis using spectrograms of signals measured during wind-turbine operational changes at high wind speeds does not show significant changes of the noise level at station EKB1. Monochromatic noise is visible at EKA stations, although wind turbines are not operating.

Note: All necessary figures are included in the attached presentation.

Report for CWP

Re-Analysis of seismological data to characterize the decay of ground motions induced by wind turbines

by Dr. Fabian Limberger & Prof. Dr. Georg Rümpker lr.geophysics@posteo.de

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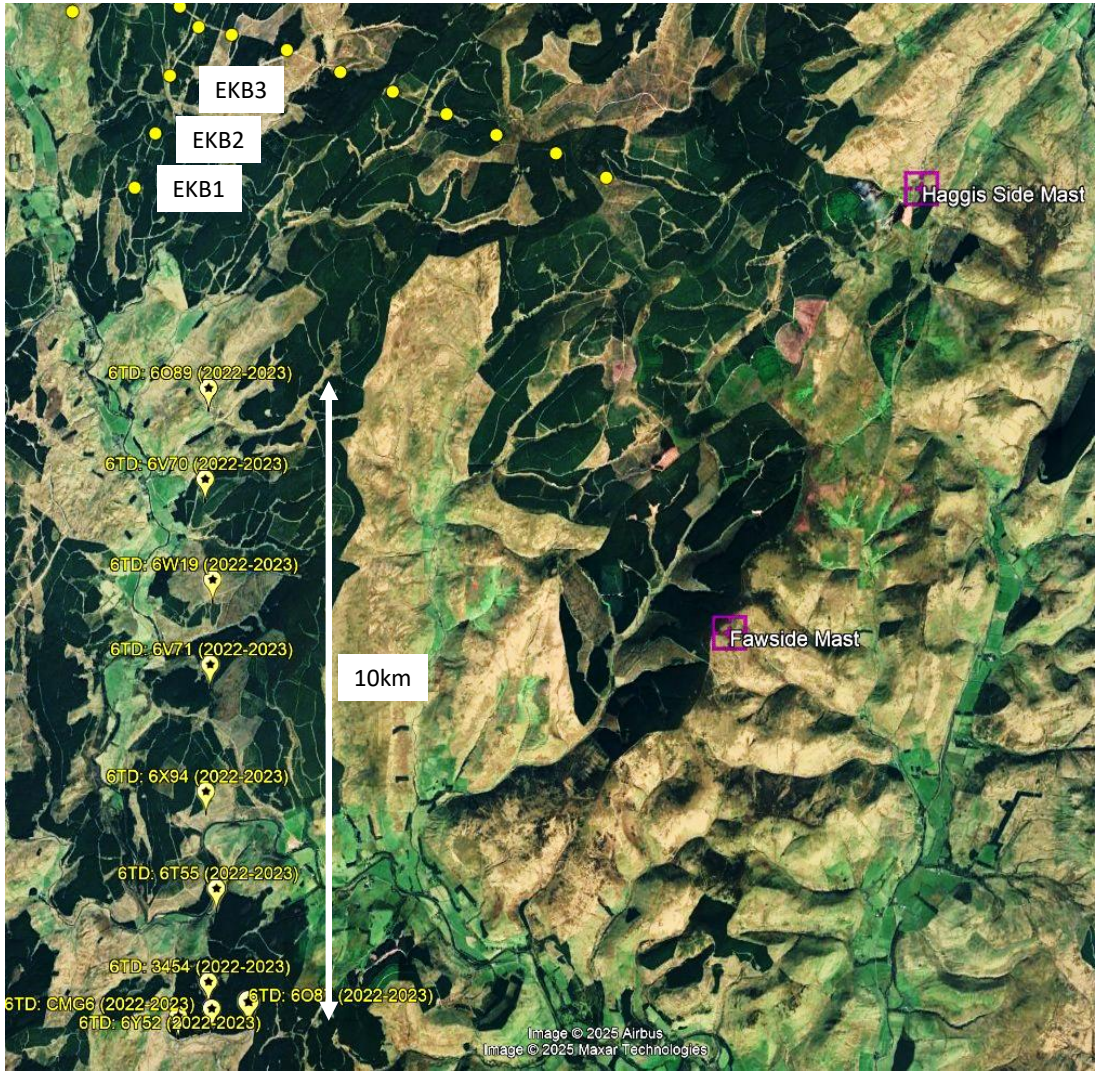


WT-induced peaks must fulfill the following criteria:

1. Detected close to the WT (300m).

2. Systematically decrease with increasing distance to WTs.

3. Increase with wind speed.

4. No signal energy when there is no wind (except close to WTs, due to slight tower swaying at low wind speeds, even given non-rotating WT)

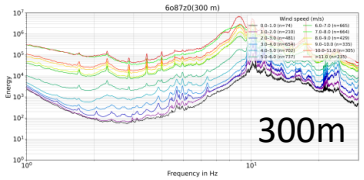
Data processing steps

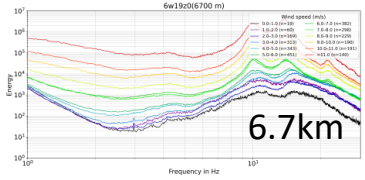
1. Cutting approx. 6 months of data (Z-comp) into 10min PSDs.
2. Bin PSDs to wind speed from Haggis Side met. tower.
3. Remove upper 25% of outliers to avoid bias by short-term non-WT related signals.
4. Sort by day and night (6 pm – 6 am).
5. Average all PSDs per wind speed group to obtain statistically robust spectra.

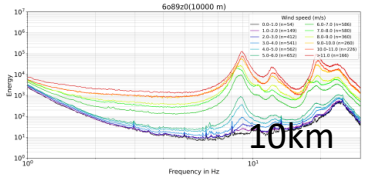
Profile Stations

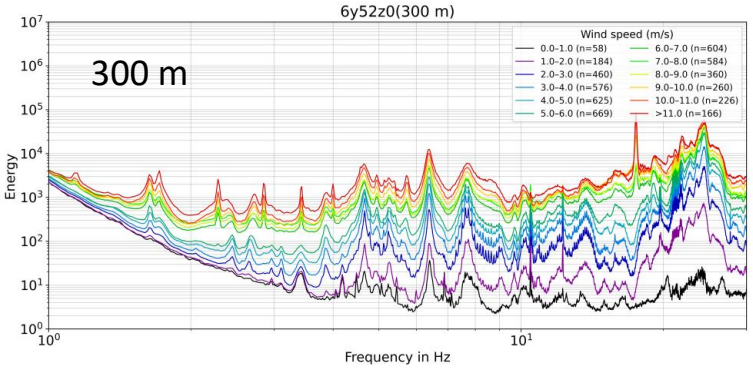
at night (6pm – 6am)

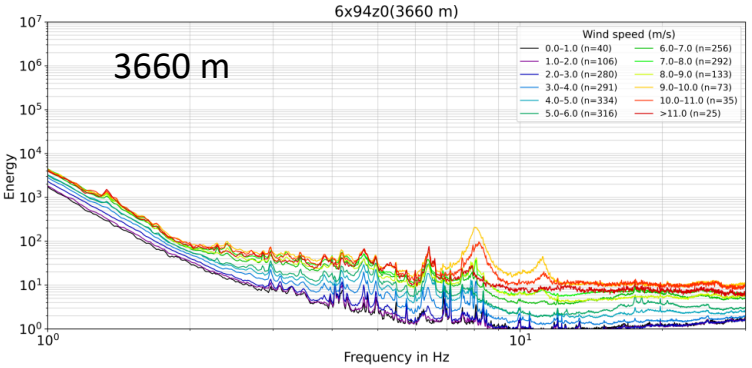
Stations excluded:

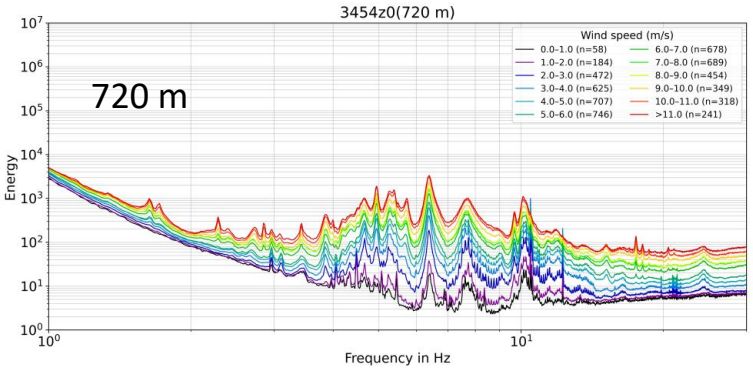


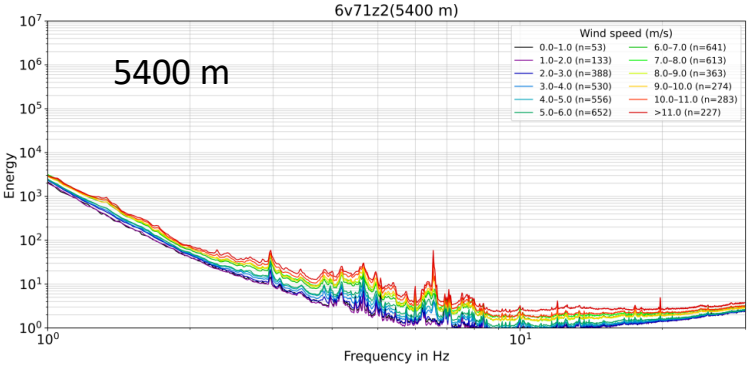


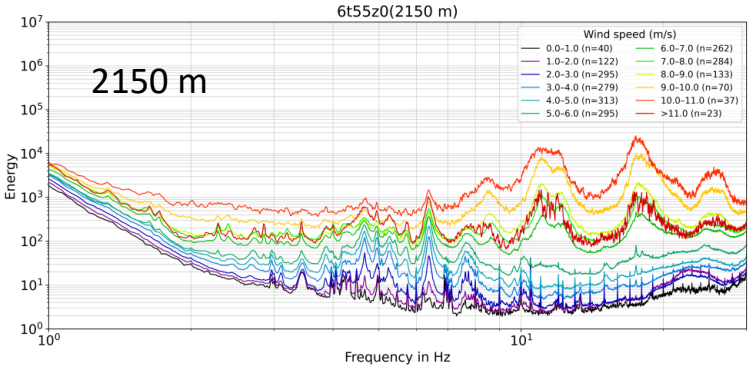


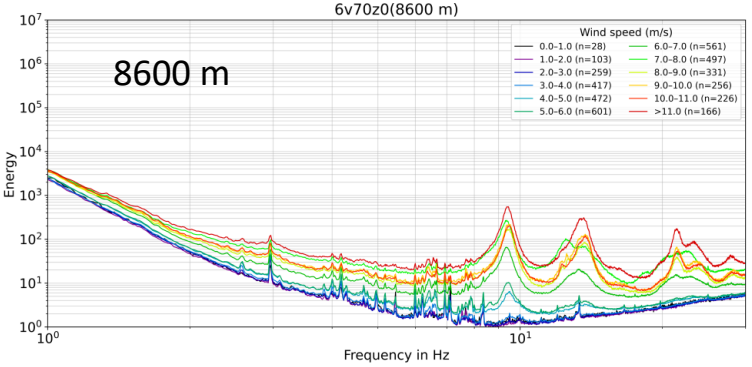






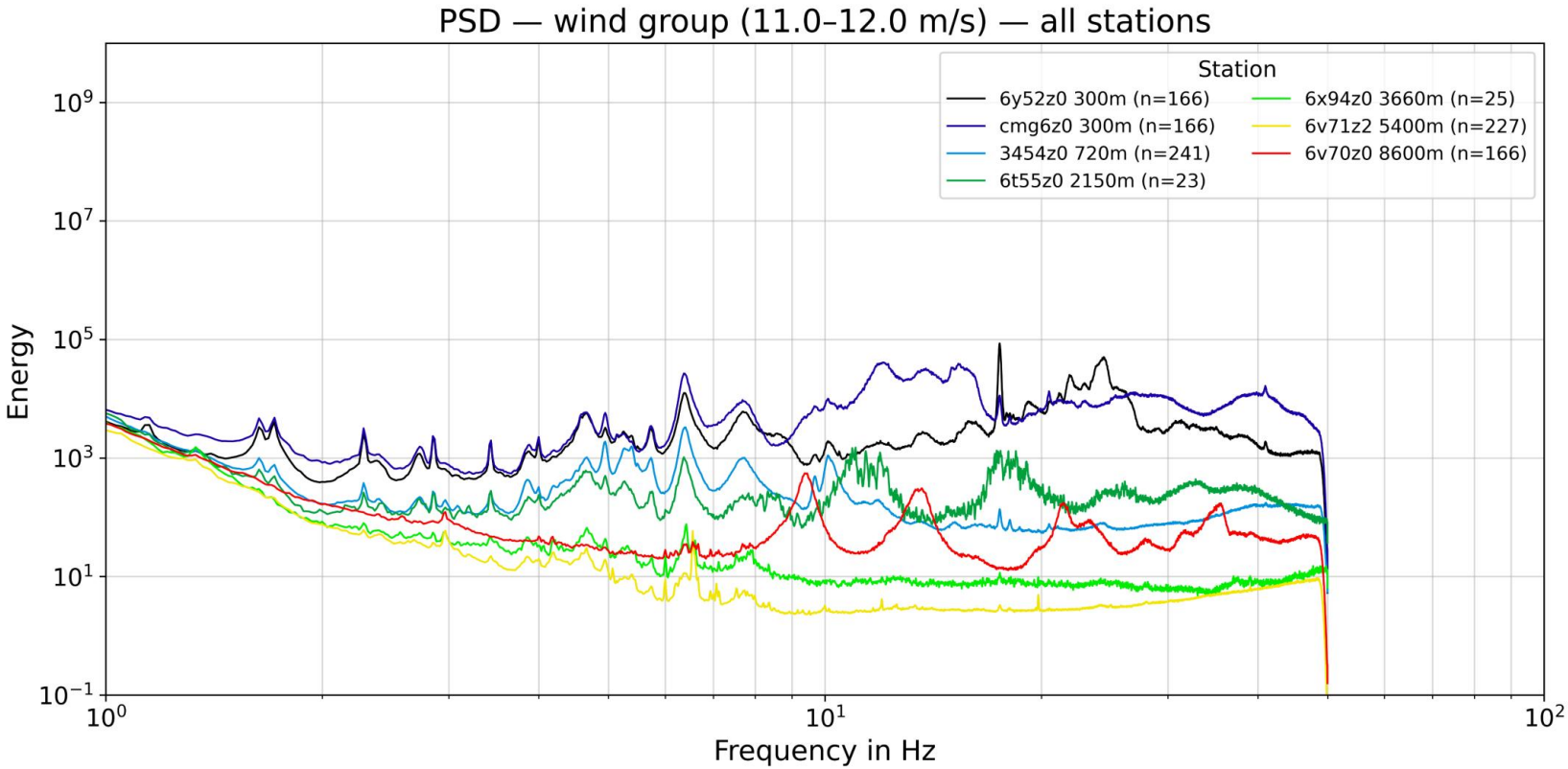




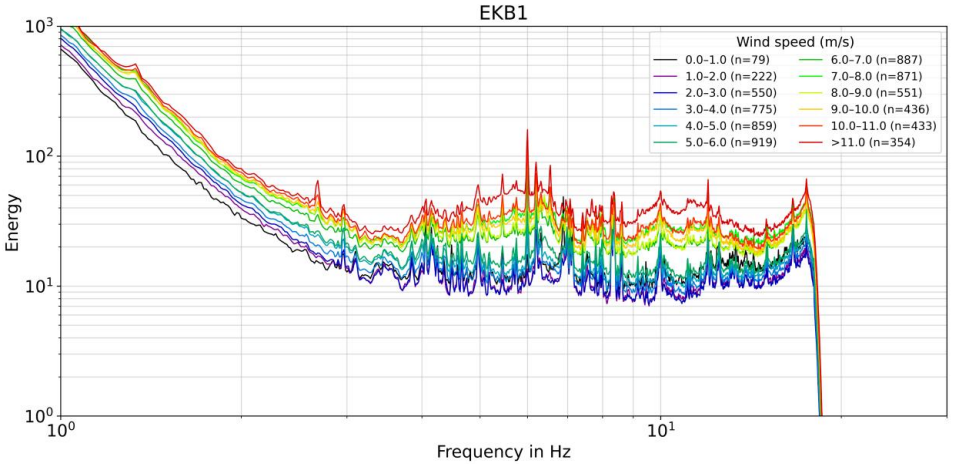


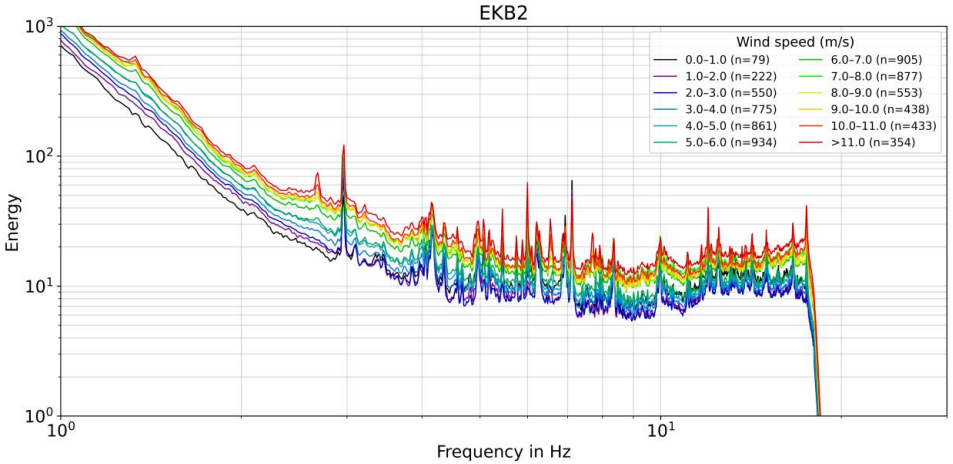
Profil stations sorted by distance

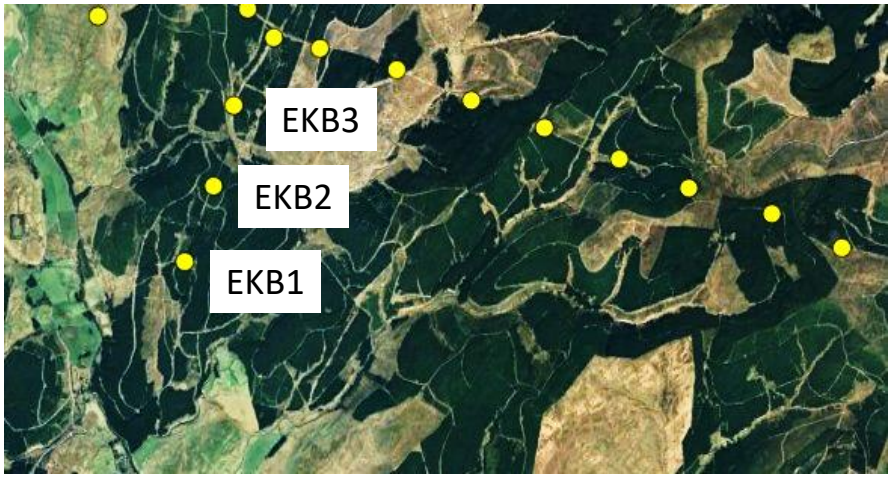
(wind speed = 11 - 12 m/s)

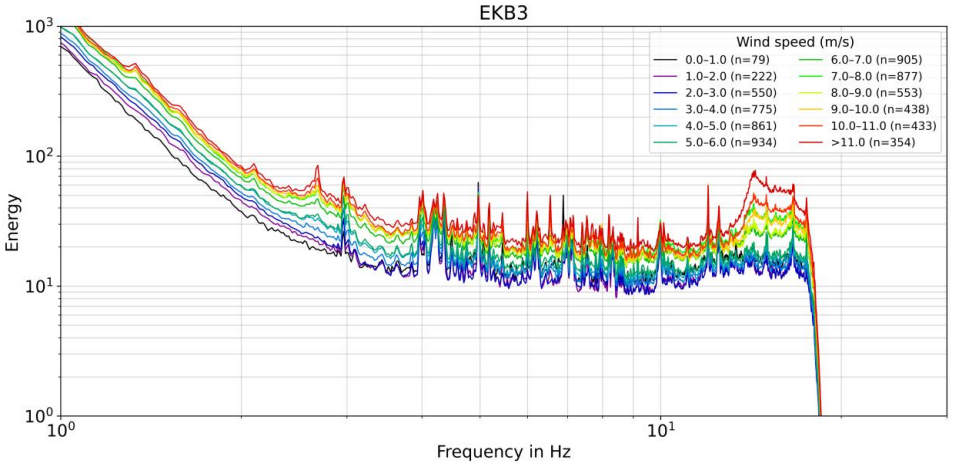


EKA Stations

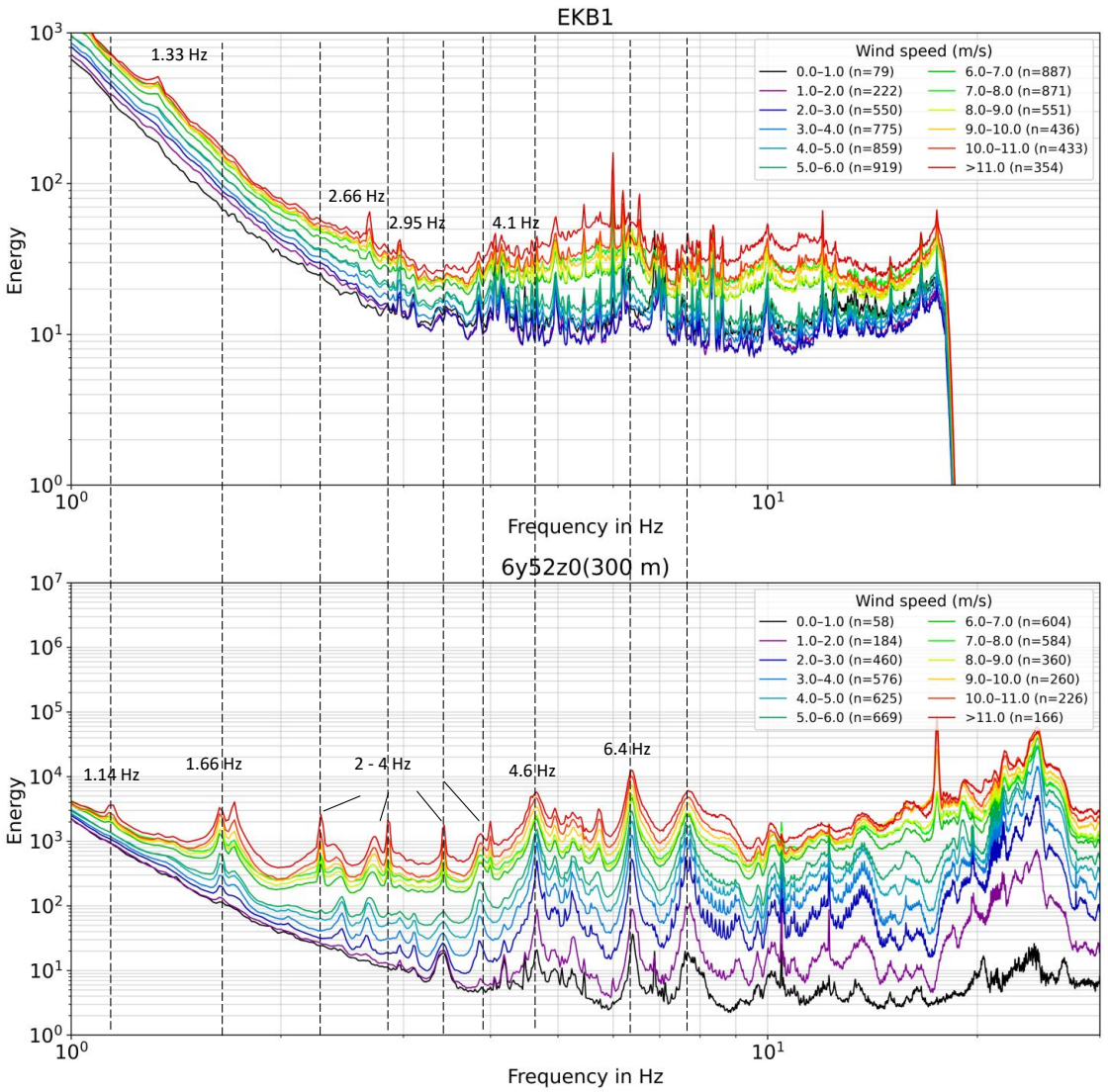






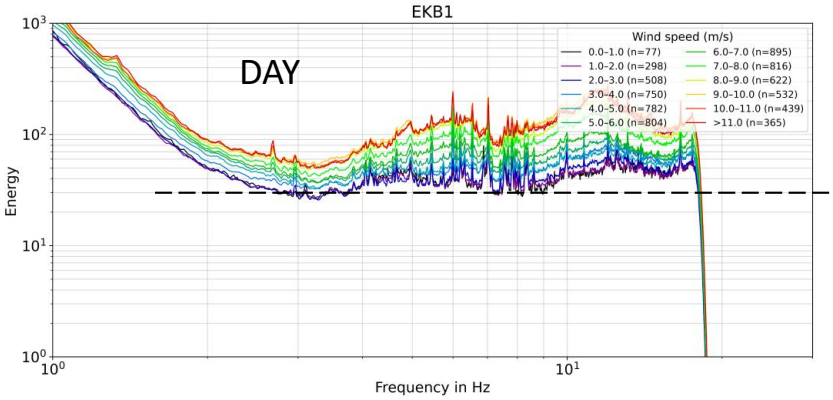


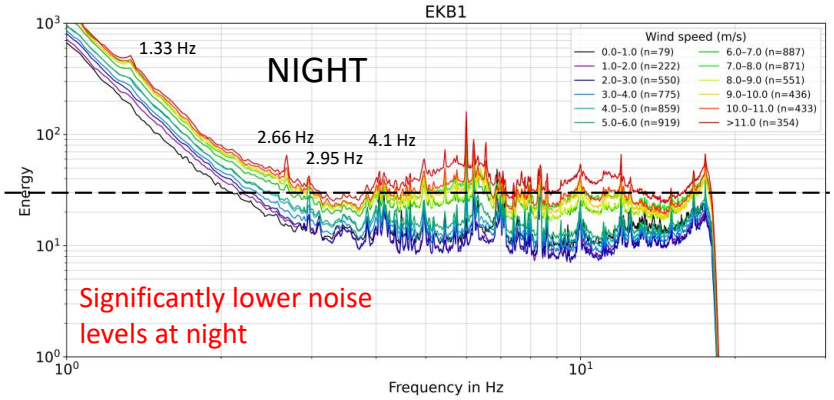
Peak comparison at EKA (far field) and 6y52 (near field)



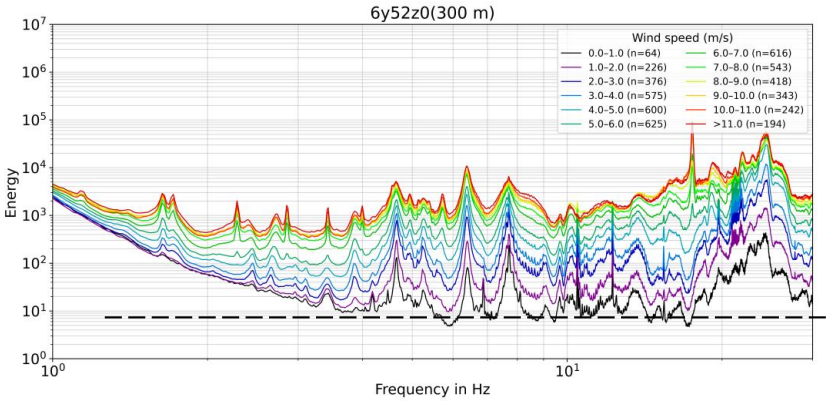
Day / Night effect

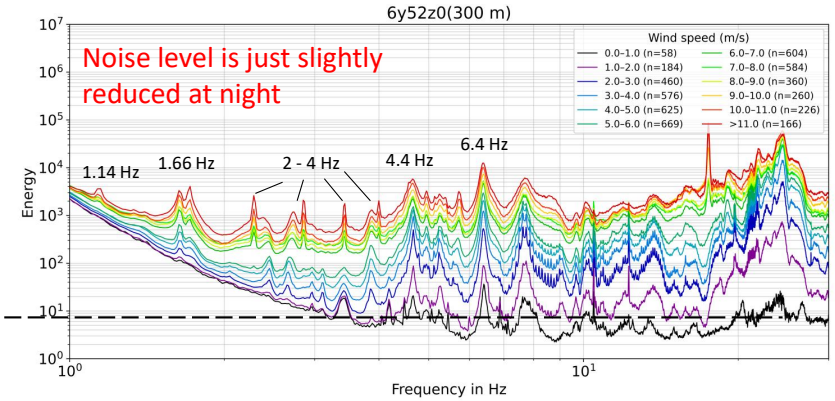
Station EKB 1 (closest EKA station)

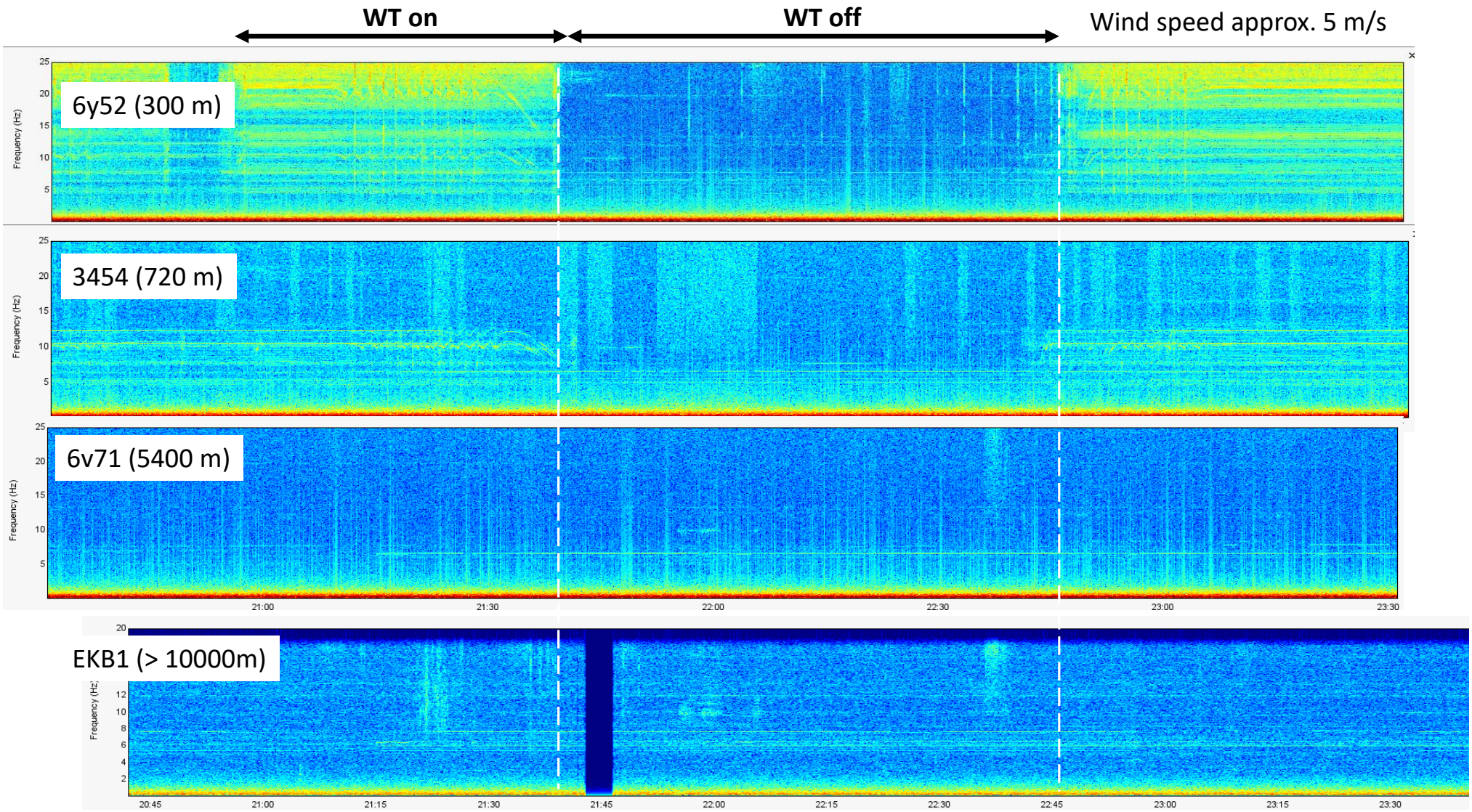


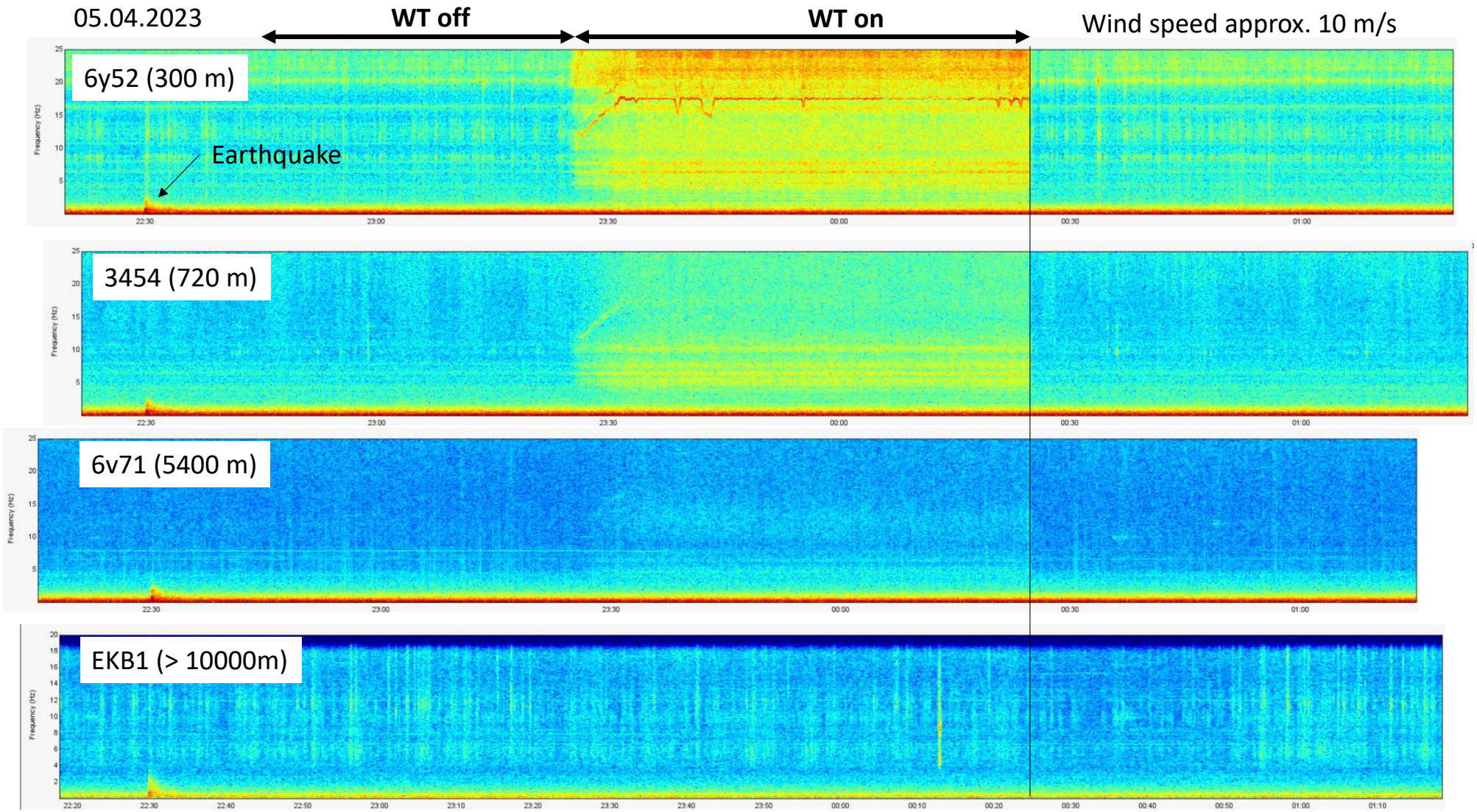


Station 6y52 in 300 m distance





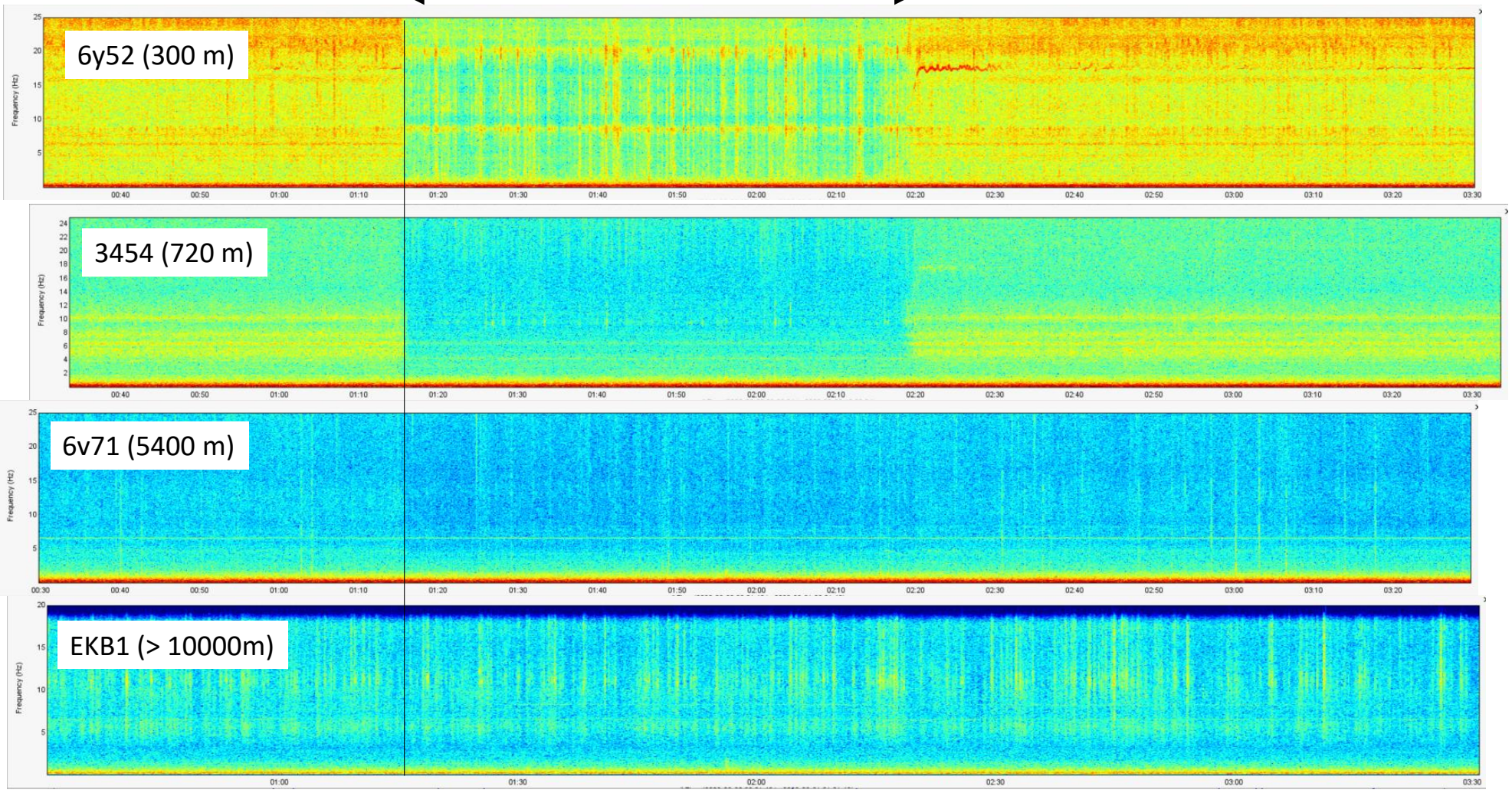

WT on
WT off
Wind speed approx. 5 m/s
6y52 (300 m)
3454 (720 m)
6v71 (5400 m)
EKB1 (> 10000m)
Frequency (Hz)
21:00
21:30
22:00
22:30
23:00
23:30
20:45
21:15
21:45
22:15
22:45
23:15


05.04.2023
WT off
WT on
Wind speed approx. 10 m/s
6y52 (300 m)
Earthquake
3454 (720 m)
6v71 (5400 m)
EKB1 (> 10000m)
Frequency (Hz)

21.03.2023 00:30 – 3:30

WTs (partly) off

Wind speed approx. 10 m/s



Main conclusions derived from the data

1. Peaks identified close to the WTs are significantly attenuated at distances of 5.4 km and are not reliably detectable at 8.6 km.

2. Distinct peaks at the three EKA stations EKB1, EKB2, and EKB3 do not fulfill WT-induced signal criteria. None of the peaks can be reliably related to the WT-induced signals measured in the near field.

3. Day/night comparison suggests WT-dominated noise field at day **and** night in the vicinity of the WF (approx. up to the distance of 5.4 km); however, anthropogenic noise dominates at EKA stations mainly during the day (unrelated to WTs).

4. Short-term analysis of wind-turbine operational changes at high wind speeds does not show significant changes of the noise level at station EKB1.