E-TEST Einstein Telescope EMR Site & Technology

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and Water Management

Interreg Euregio Meuse-Rhine
European Regional Development Fund
EUROPEAN UNION

Nikhef

RWTH AACHEN UNIVERSITY

LIÈGE université

Wind Turbine Seismic Monitoring Campaign for ETEST

Preliminary results

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But first an update on the 3T network

https://www.fdsn.org/networks/detail/3T_2020/

International Federation of Digital Seismograph Networks

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3T (2020-2024): Einstein Telescope Seismic Campaigns

FDSN Network Information

Are you the operator of this network? Update this information.

FDSN code	3T (2020-2024)	Network name	Einstein Telescope Seismic Campaigns (ET)
Start year	2020	Operated by	Royal Netherlands Meteorological Institute (KNMI) ROR
End year	2024	Deployment region	-
Description	In the scope of E-TEST (*E*instein *T*elescope *E*uregio Meuse-Rhine *S*ite & *T*echnology), Multiple seismic campaigns are planned. In each campaign, hundreds of sensors are deployed. This includes geophones, seismometers, acoustic instruments, and others.		

Citation Information

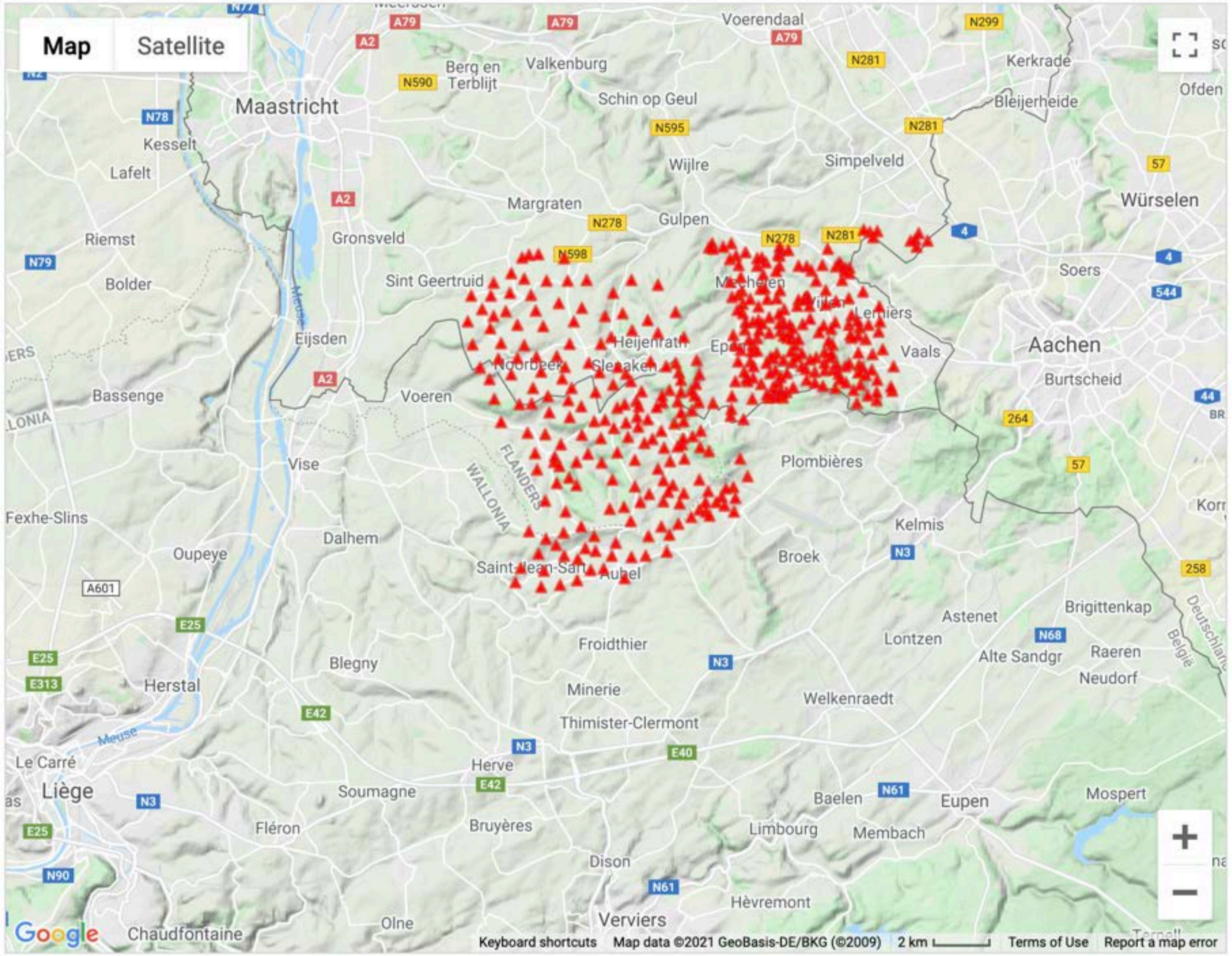
Digital Object Identifier (DOI)	https://doi.org/10.7914/SN/3T_2020
Citation	Shahar Shani-Kadmiel, Frank Linde, Läslo Evers, & Bjorn Vink. (2020). *Einstein Telescope Seismic Campaigns* [Data set]. Royal Netherlands Meteorological Institute (KNMI). https://doi.org/10.7914/SN/3T_2020 For more: DataCite (JSON | XML | BibTeX)

Data Access

Data Availability	Data available from: The ORFEUS Data Center (ORFEUS) : http://www.orfeus-eu.org/fdsnws/dataselect/1/ FDSN Web Services provide a common data access API for seismic data. Availability based on irisws-fedcatalog service. Full fedcatalog information for this network
Additional Notes	Through KNMI/ORFEUS/EIDA

- More than 400 stations deployed and retrieved
- Campaign Data available on ORFEUS FDSN

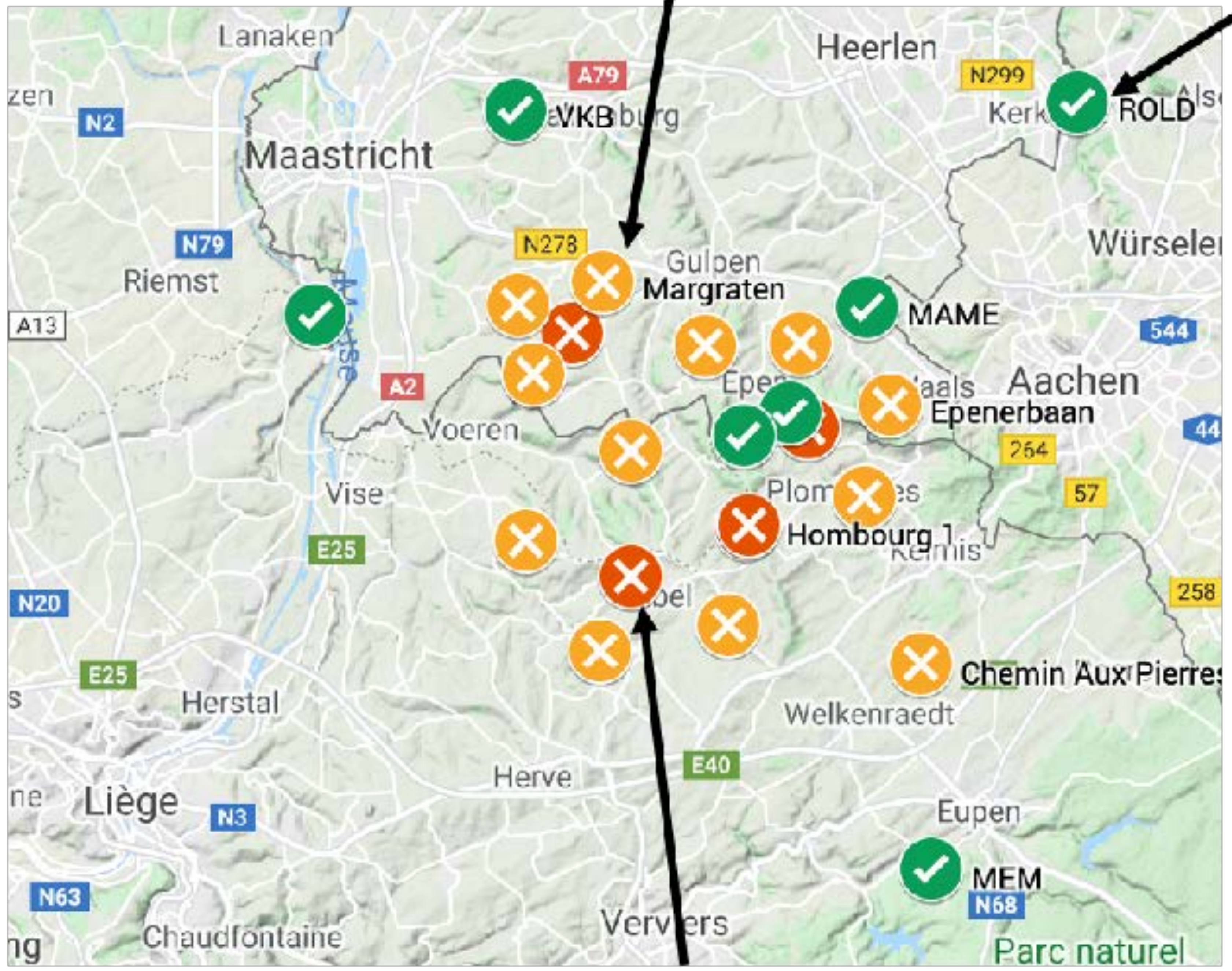
Stations in this Network



More broadband seismic stations in South-Limburg

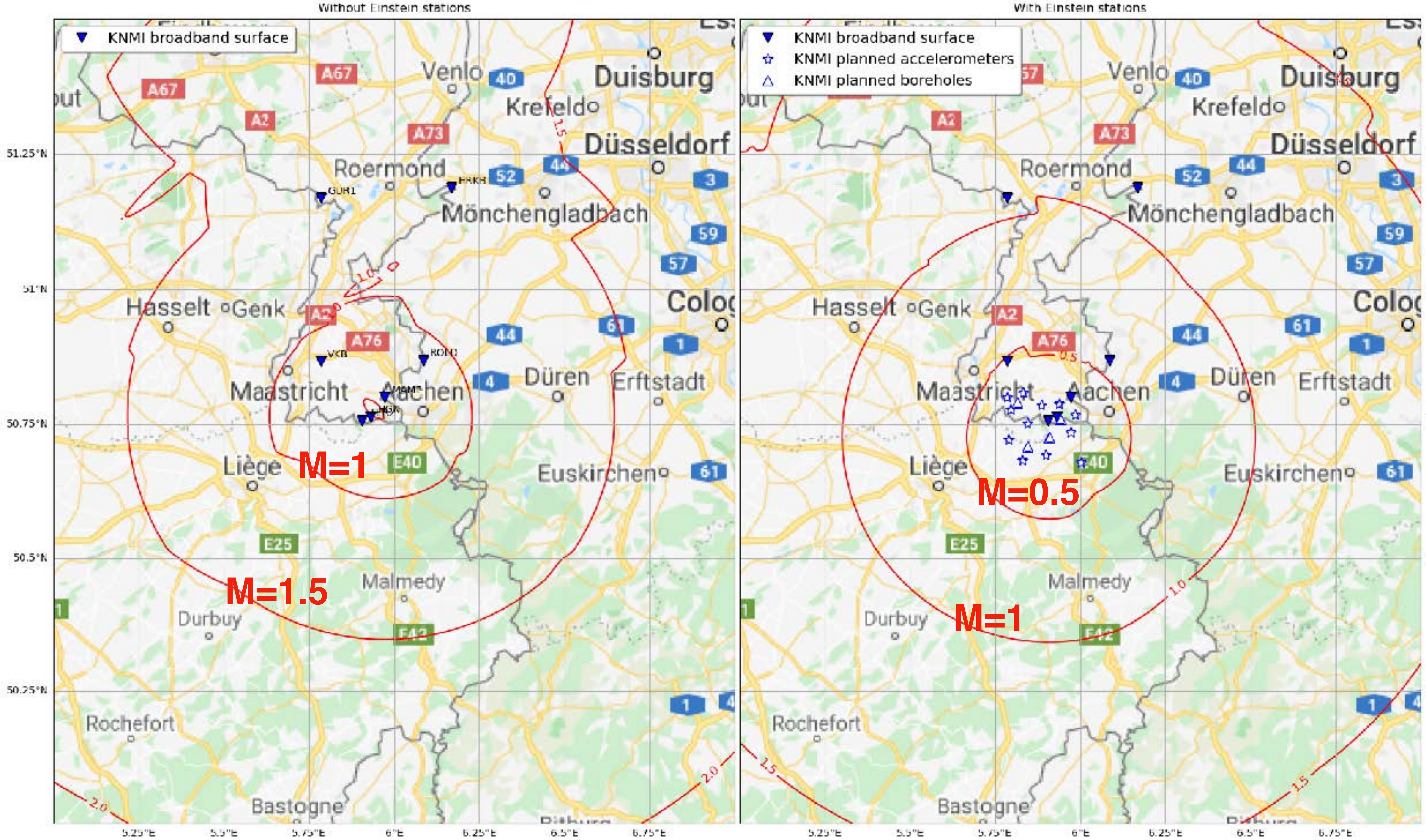
Surface stations

Existing stations



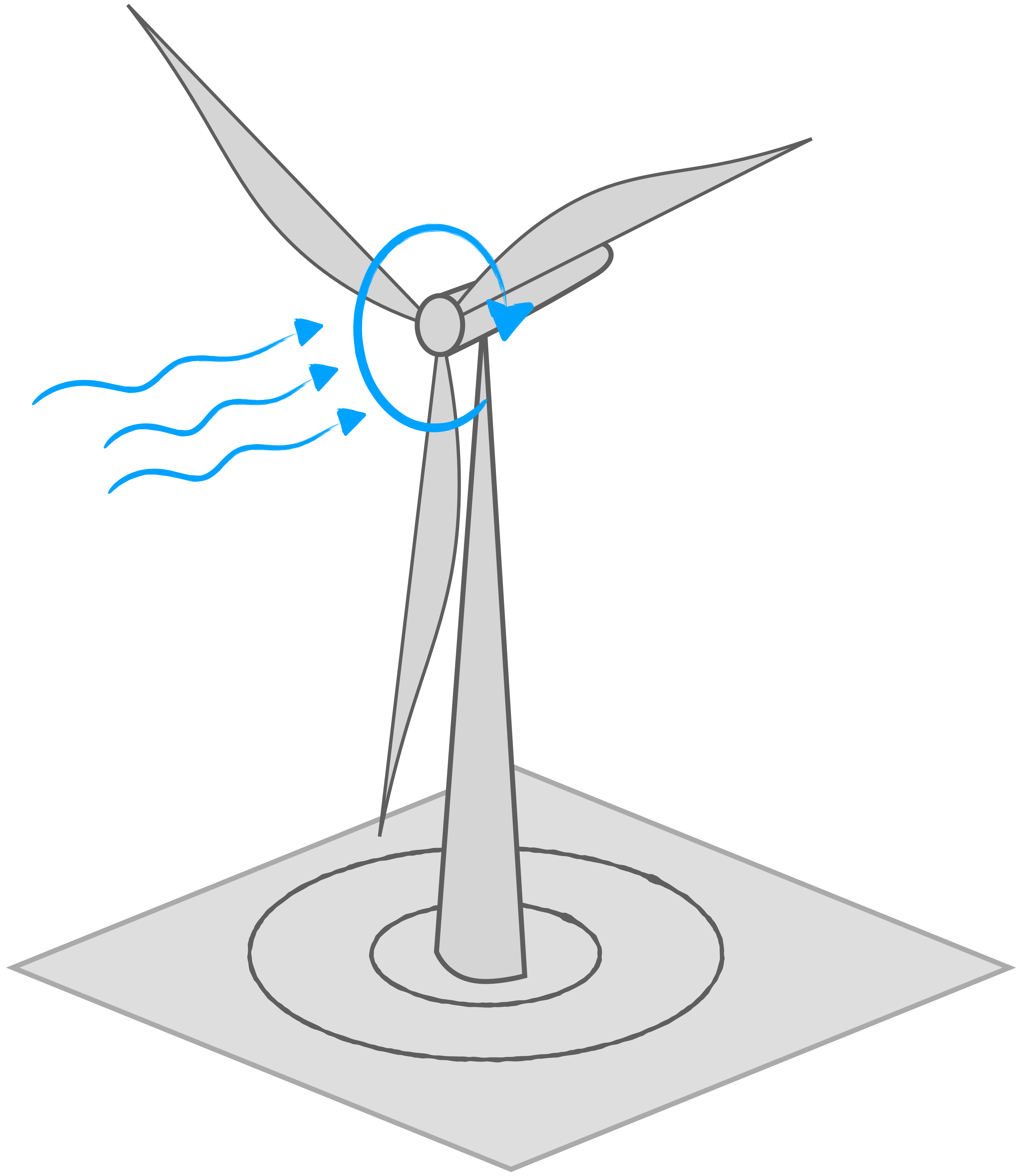
Borehole & Surface stations

Candidate sites for new BB stations

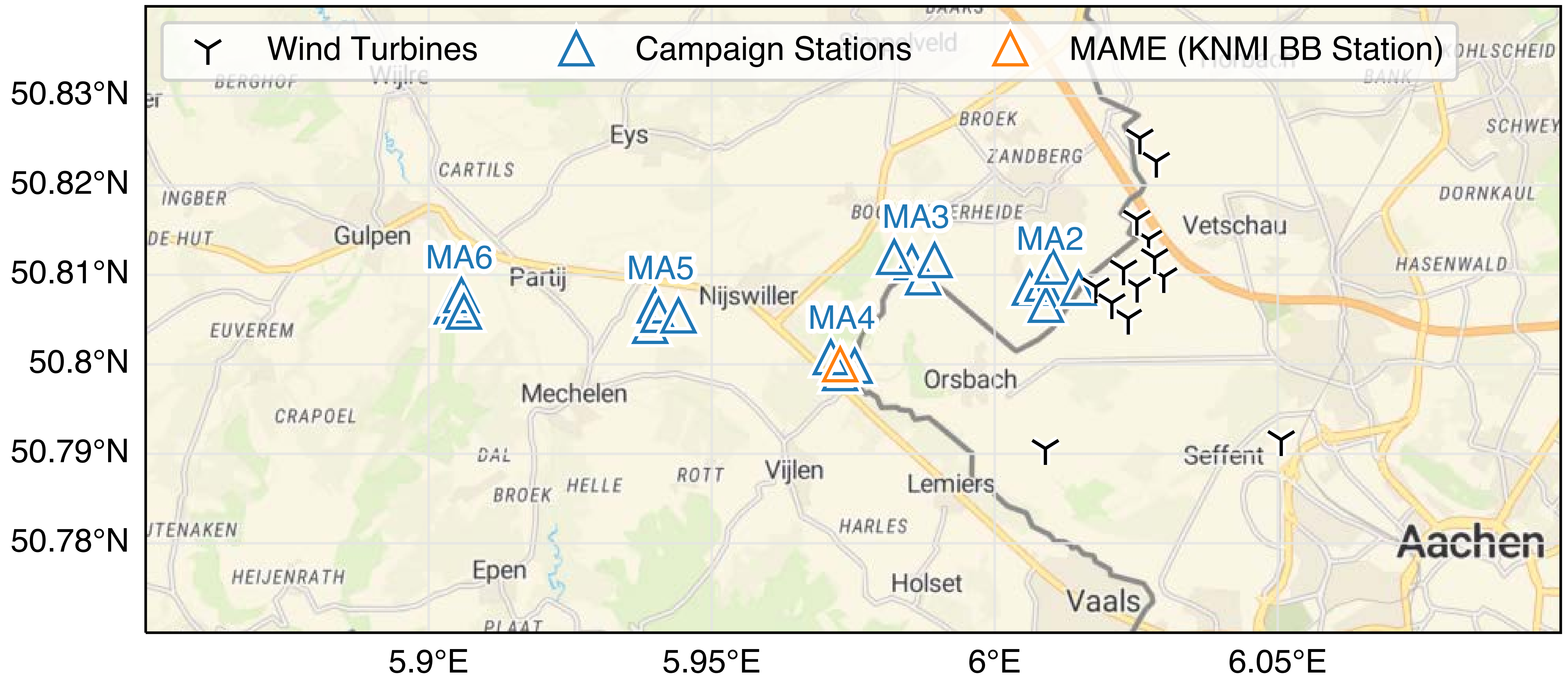


What does a wind turbine do?

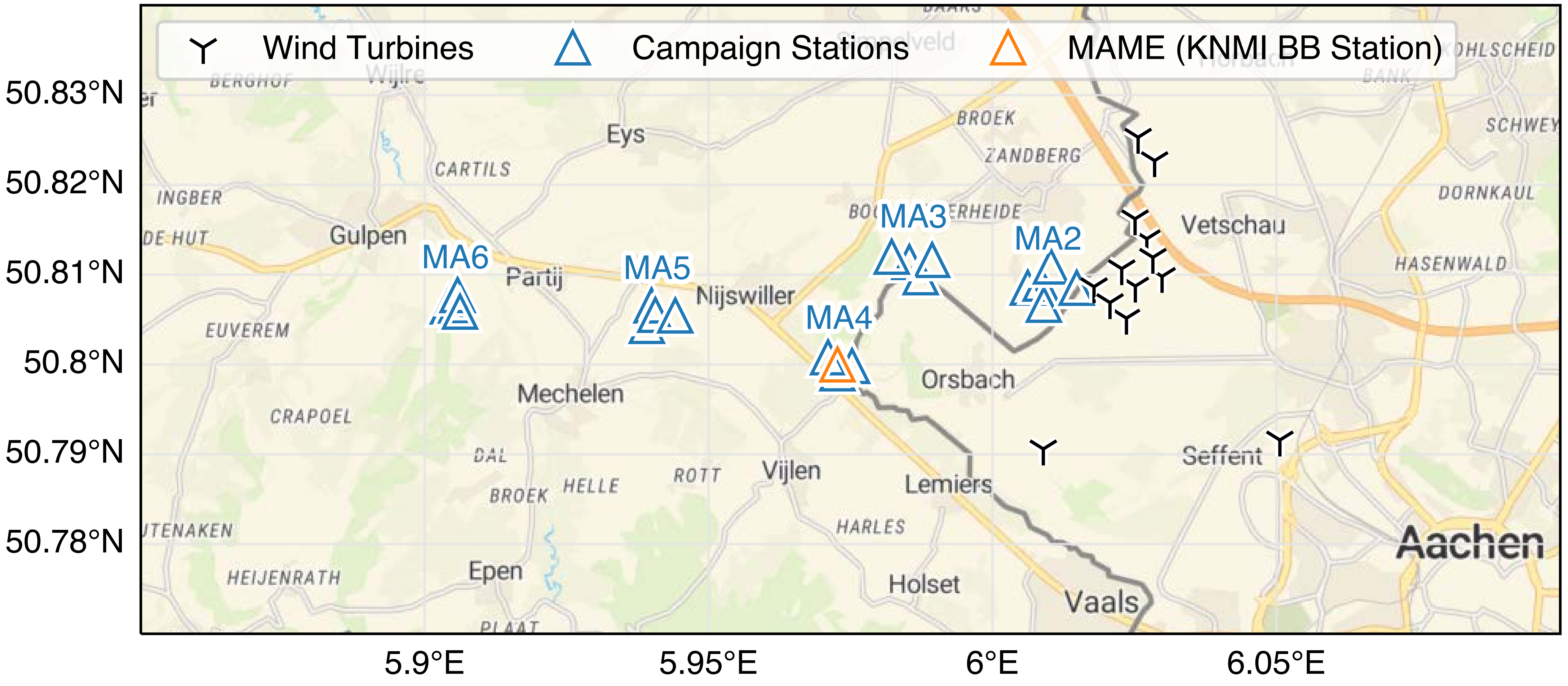
Objectives:

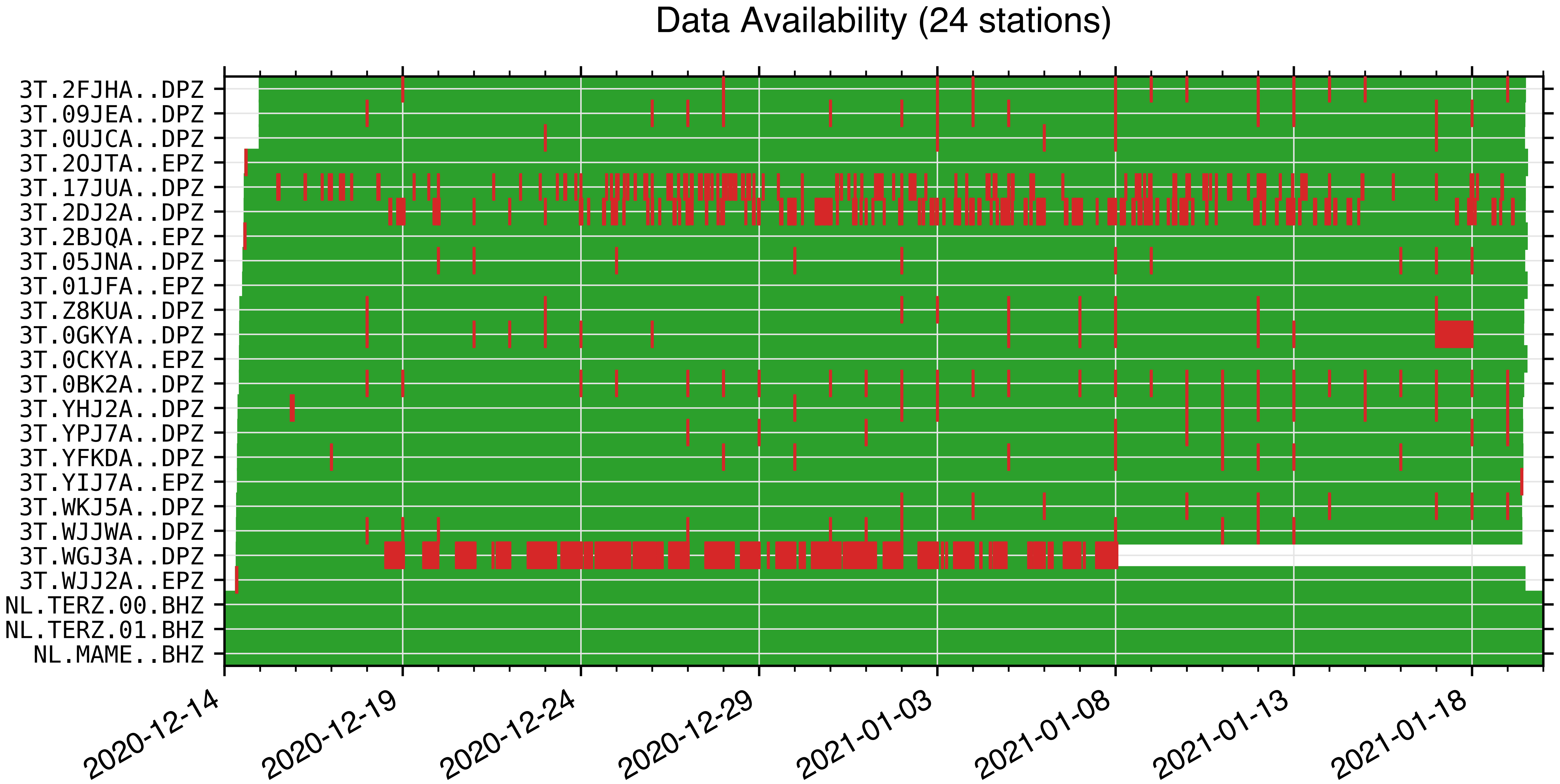


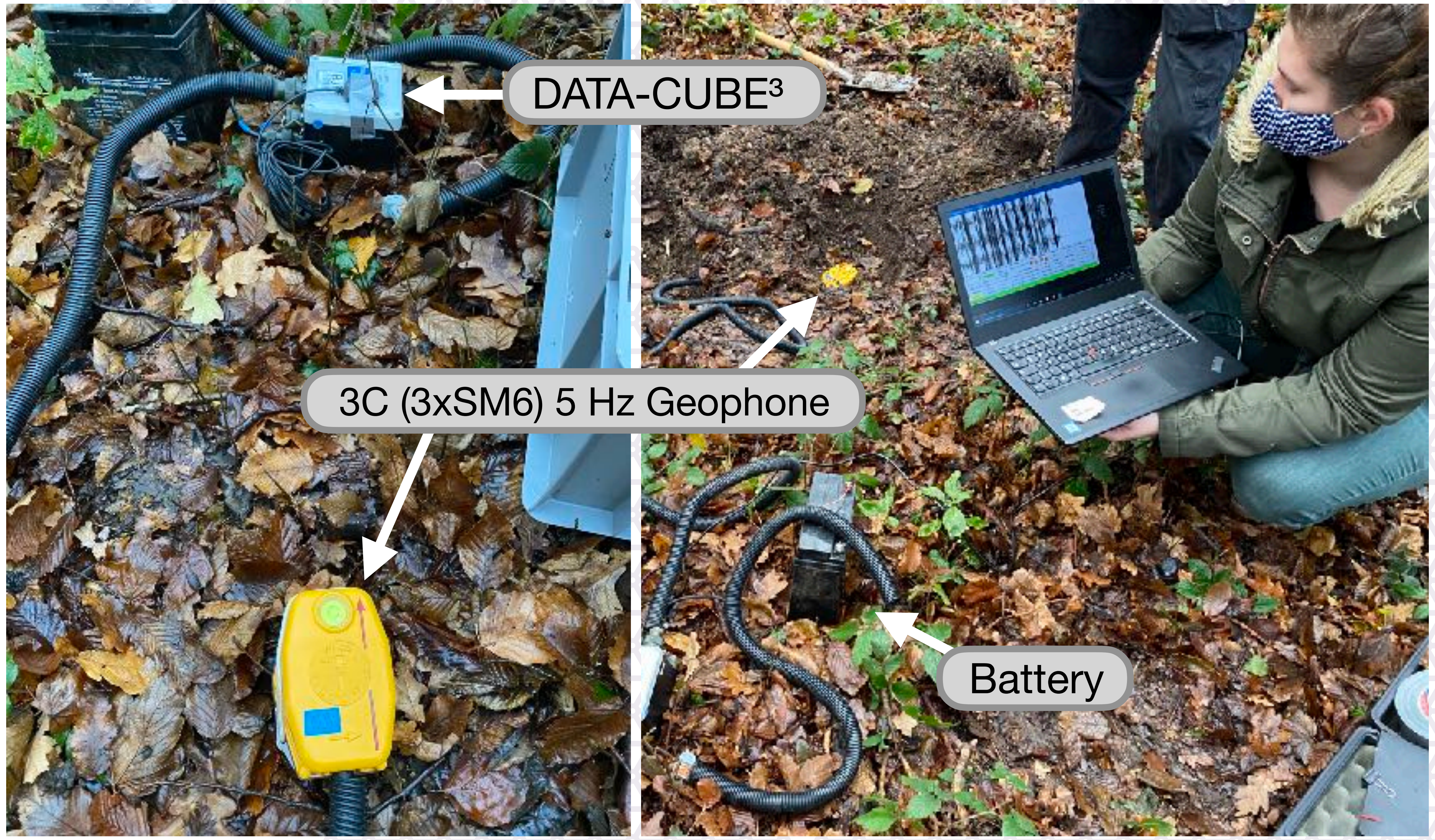
- To characterize the amplitude-frequency distribution of the seismic field radiated by wind turbines
- Identify spectral peaks related to single/combined wind turbines.
- Identify other sources of noise
- Provide insight to these effects at depth

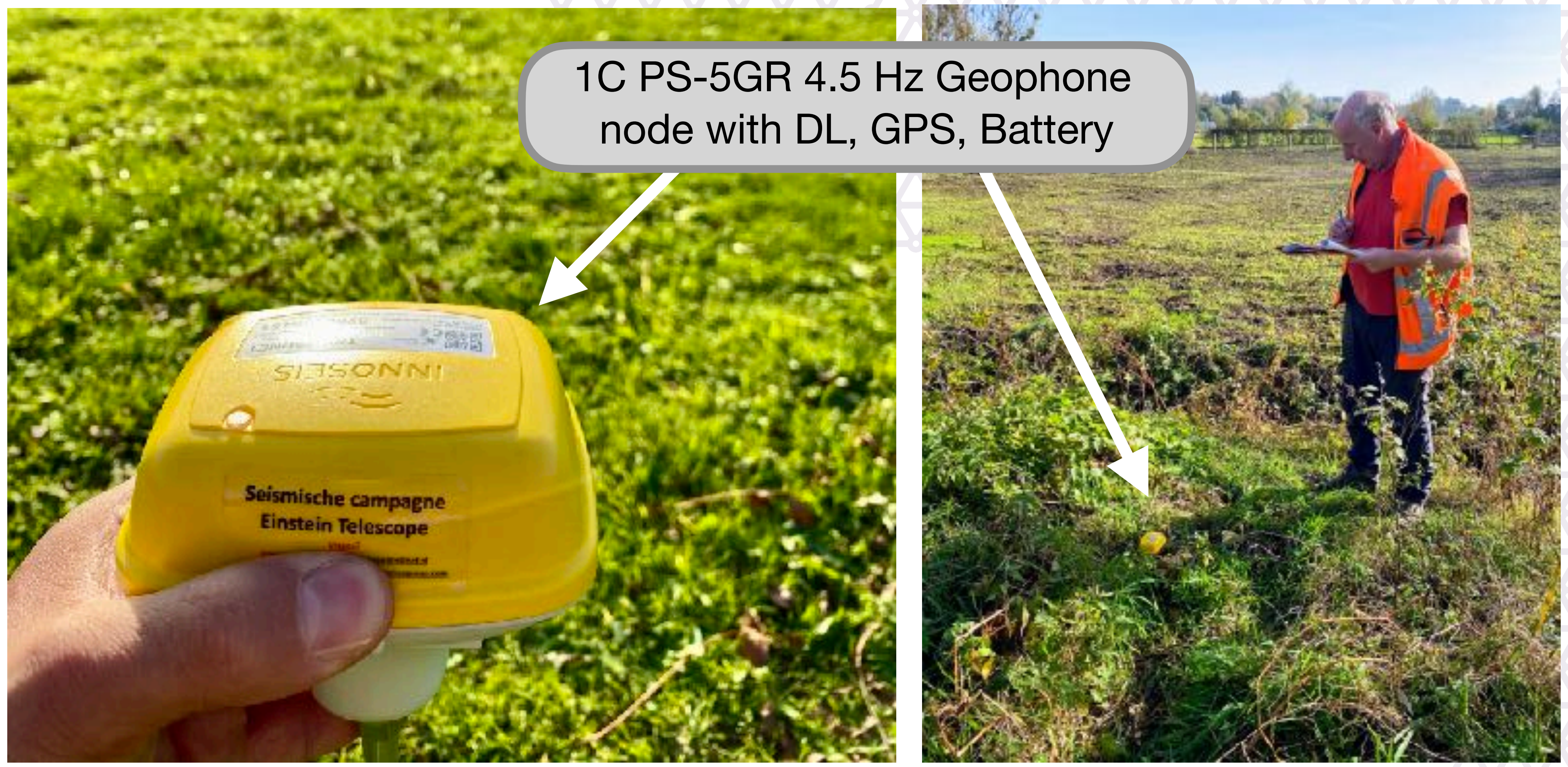


The Aachen Windpark seismic monitoring campaign









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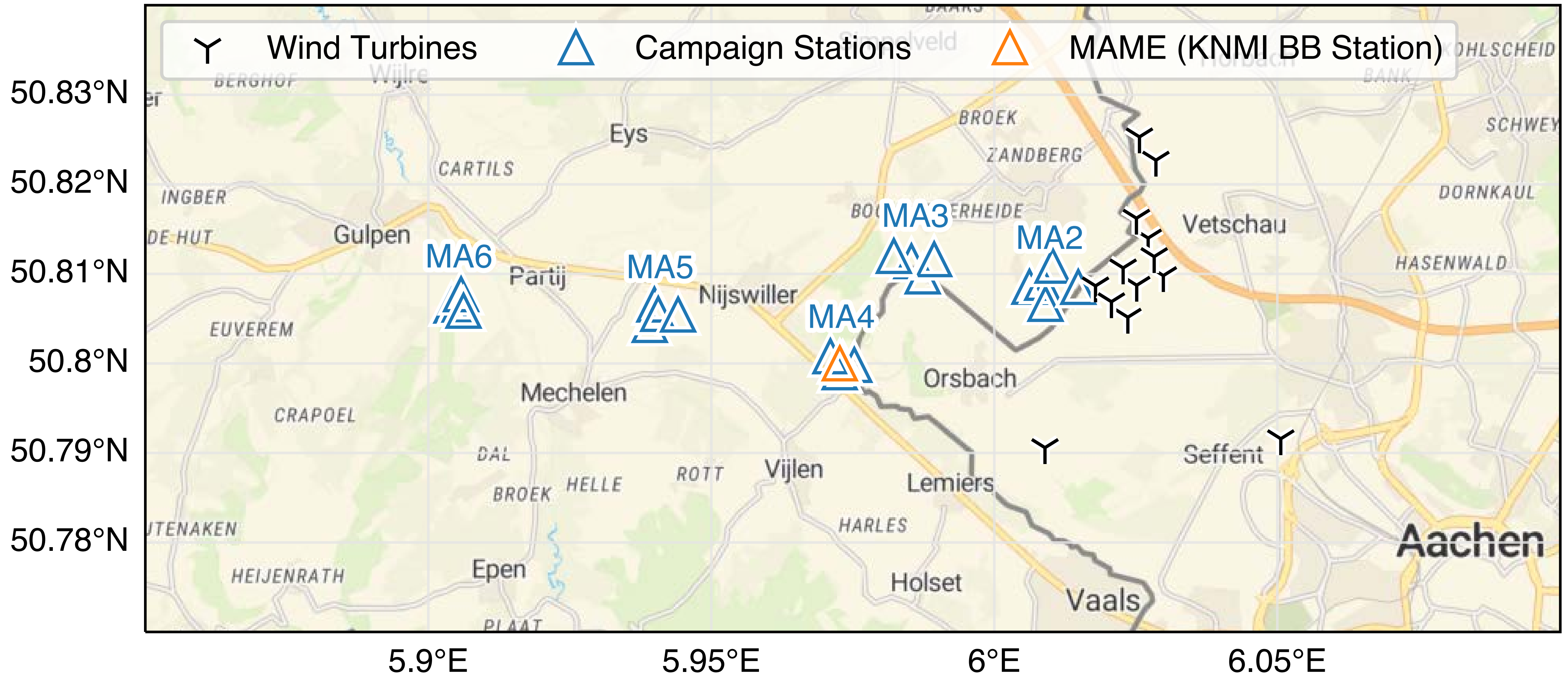
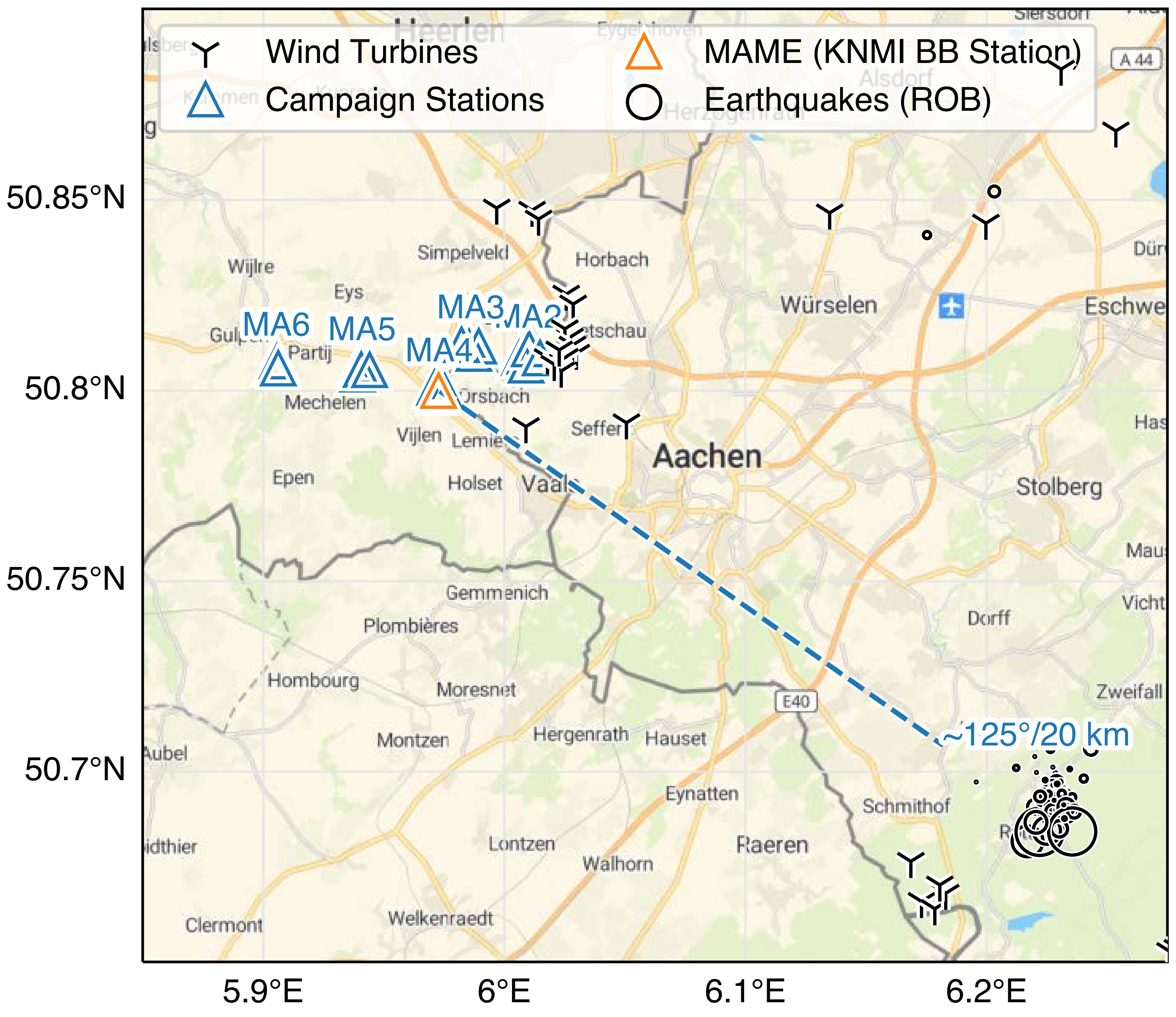
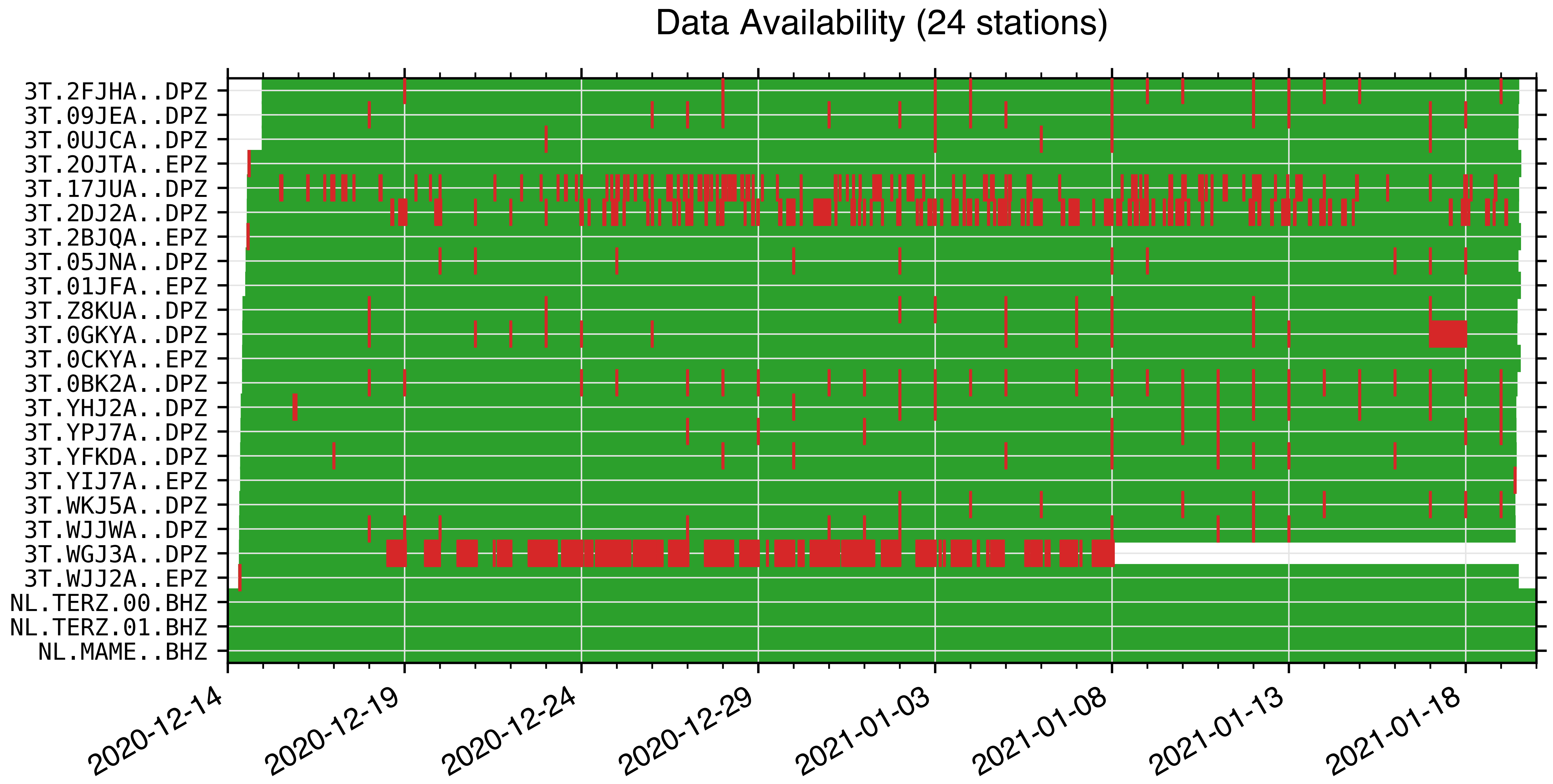
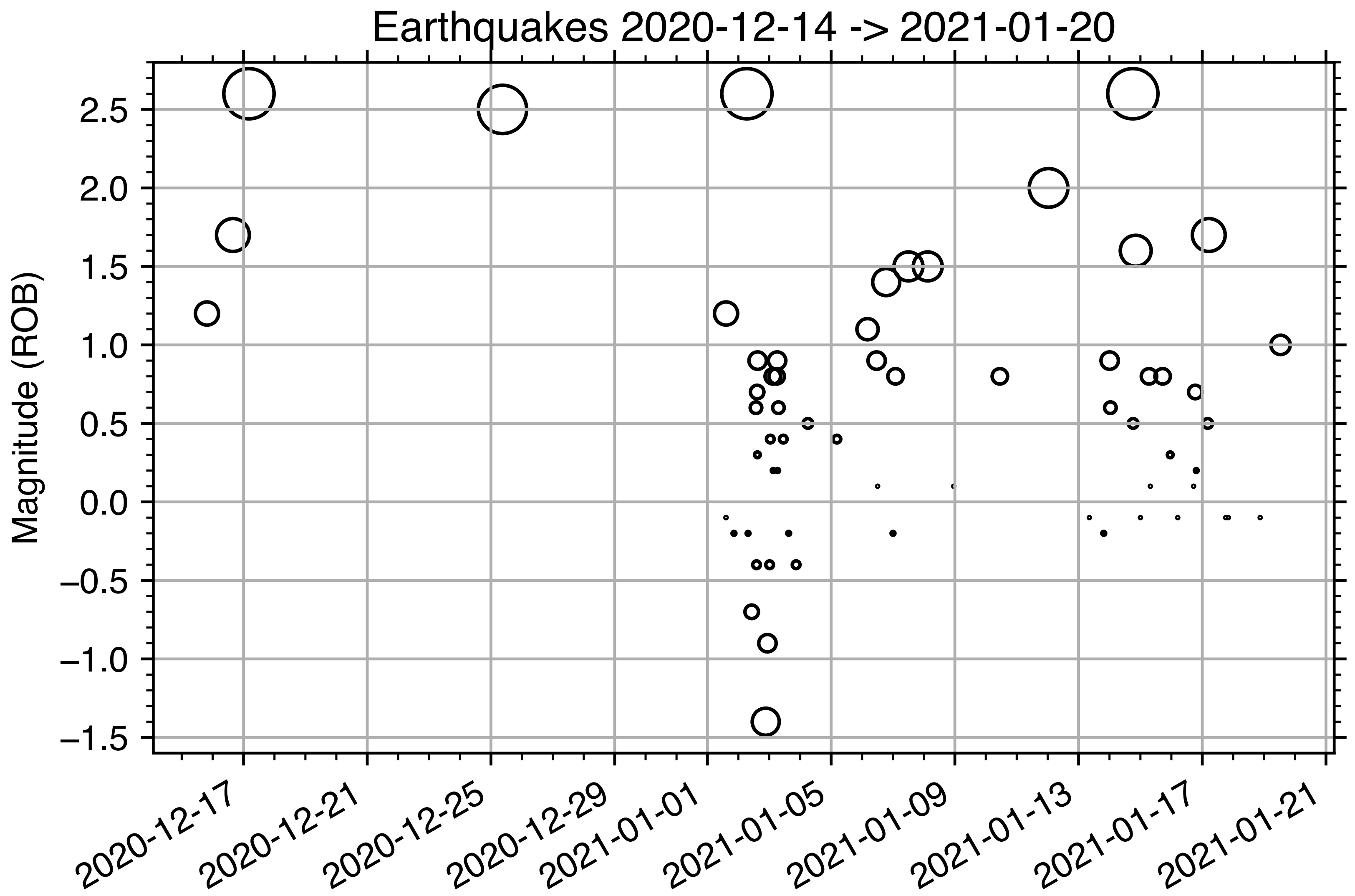




ROTT sequence





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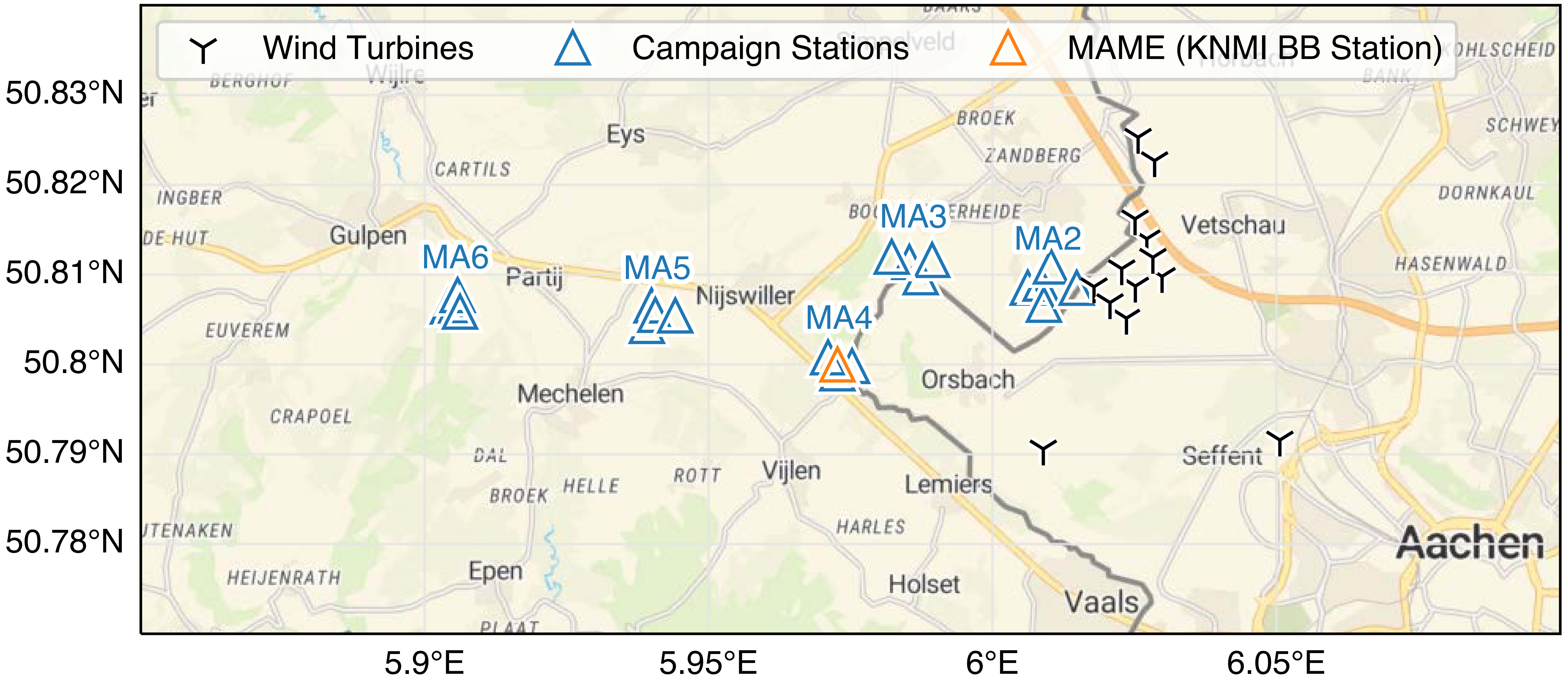
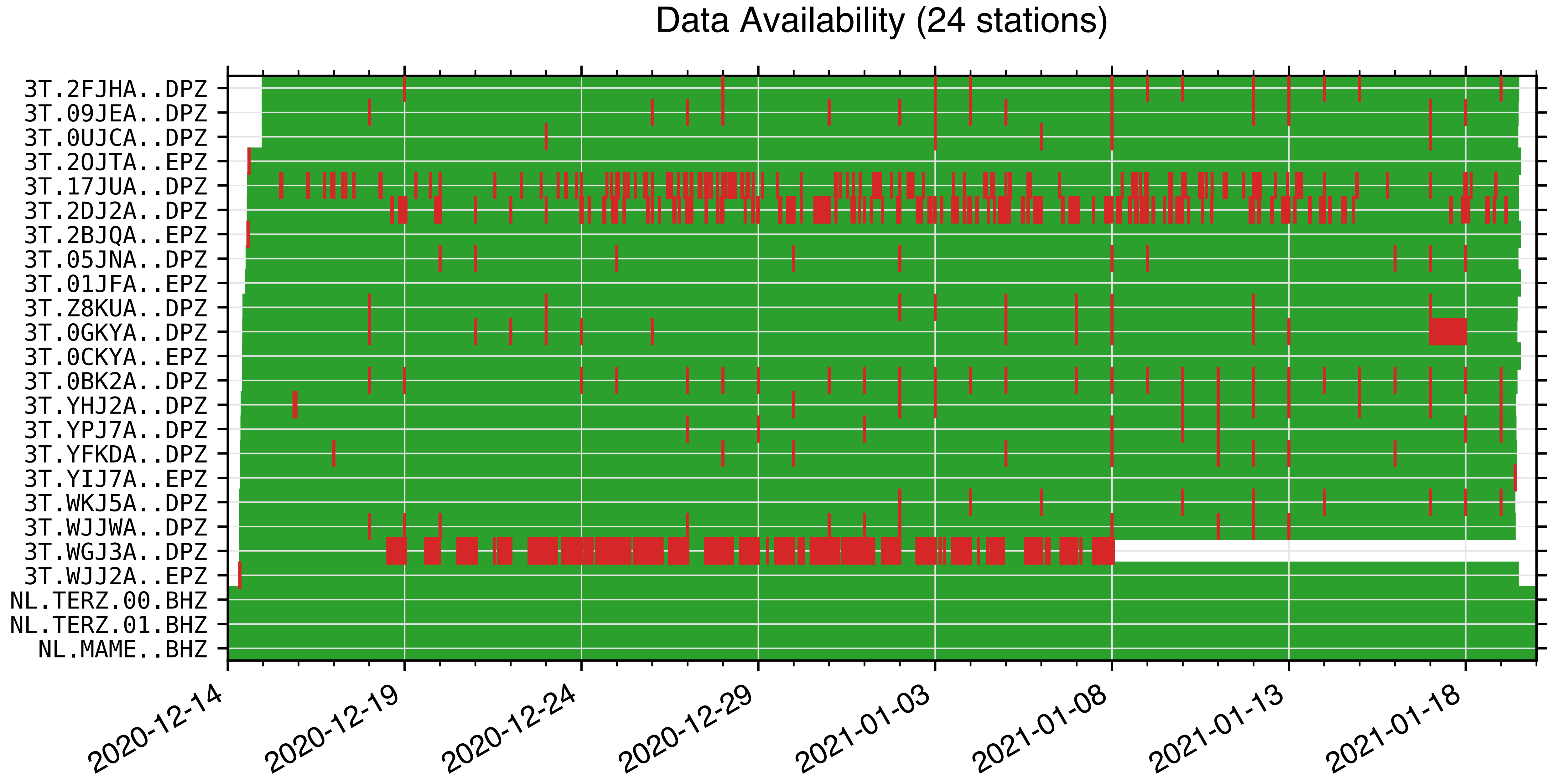
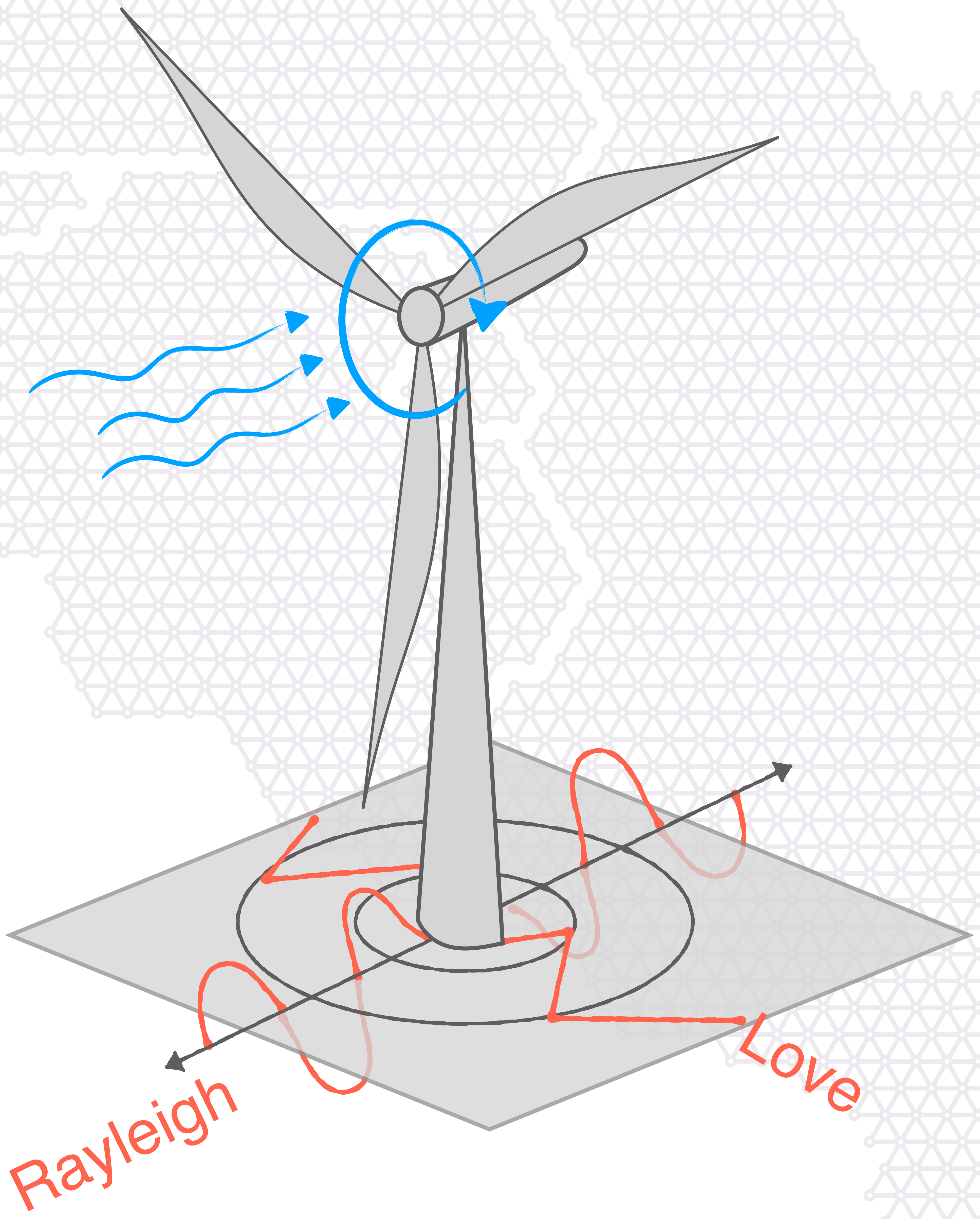
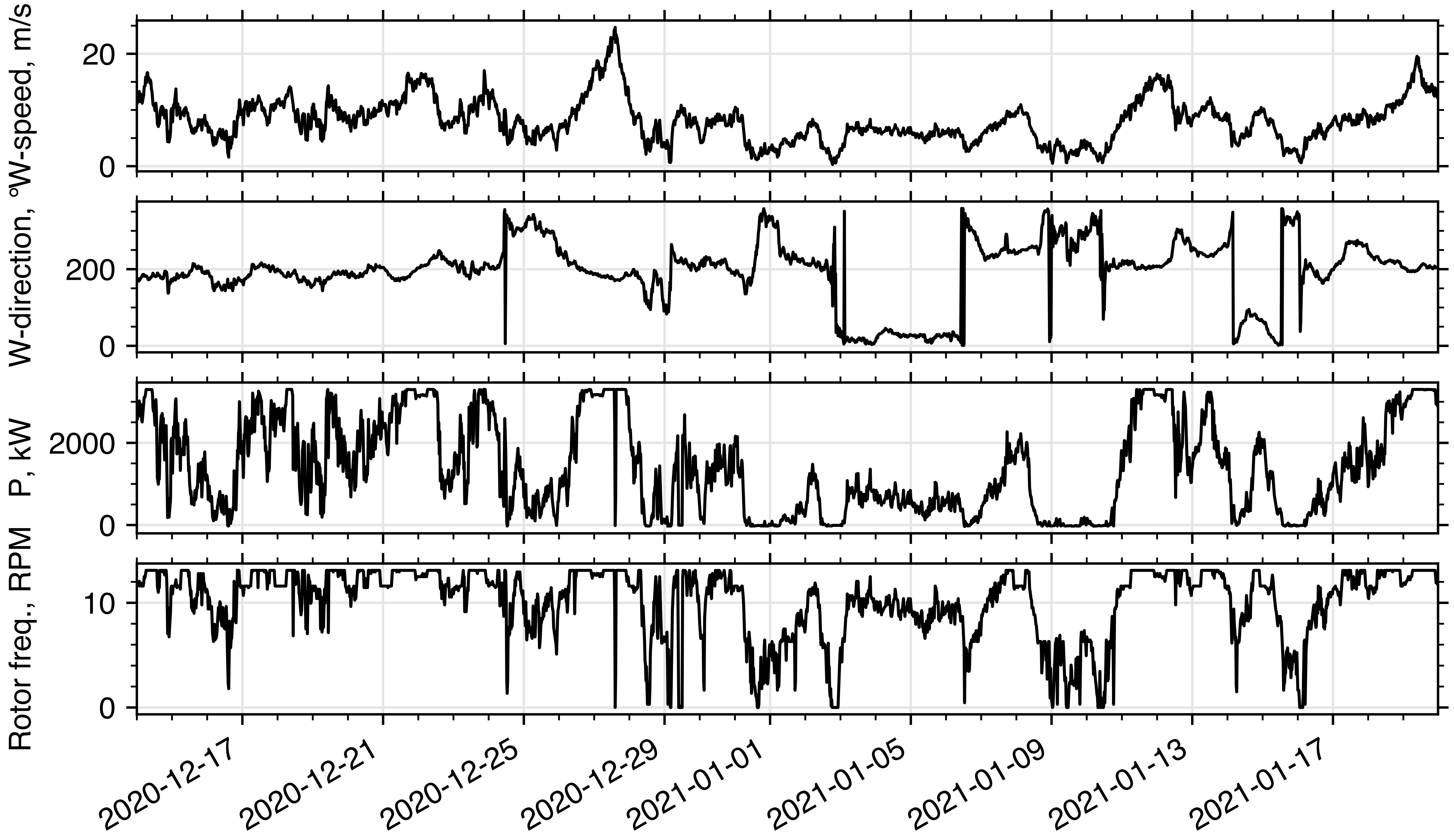




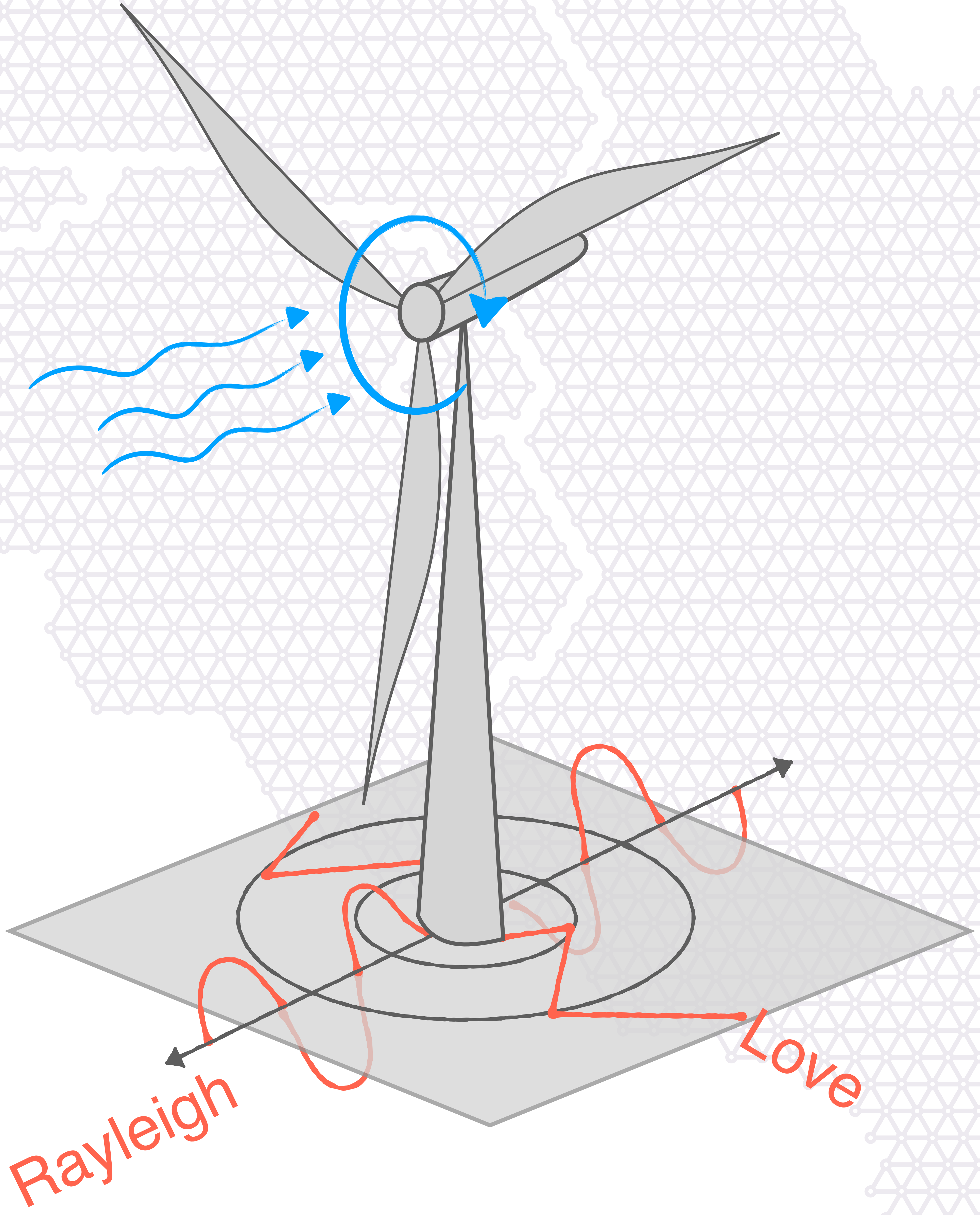


What does a wind turbine do?

And in what frequencies?



Data courtesy of STAWAG



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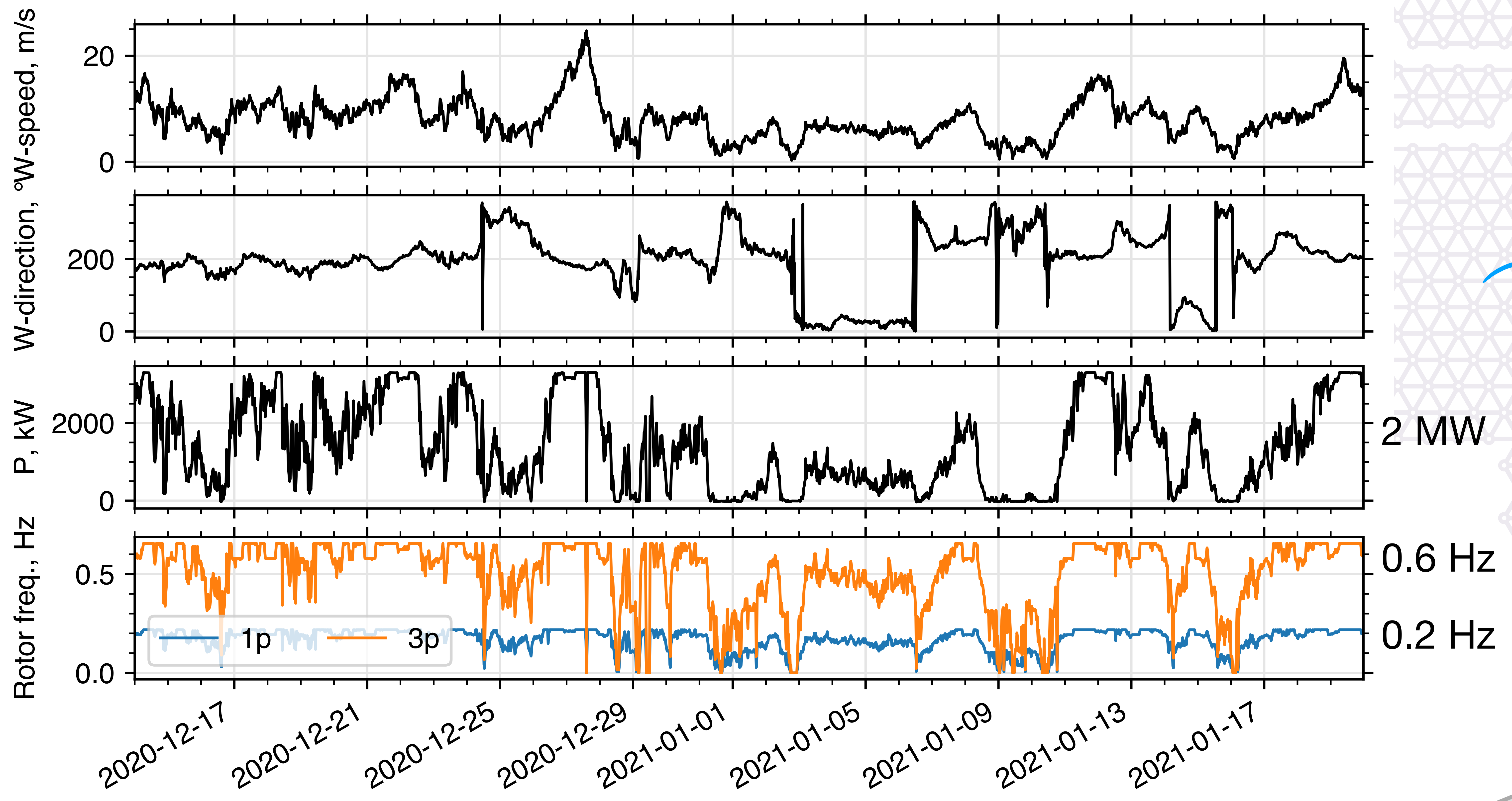

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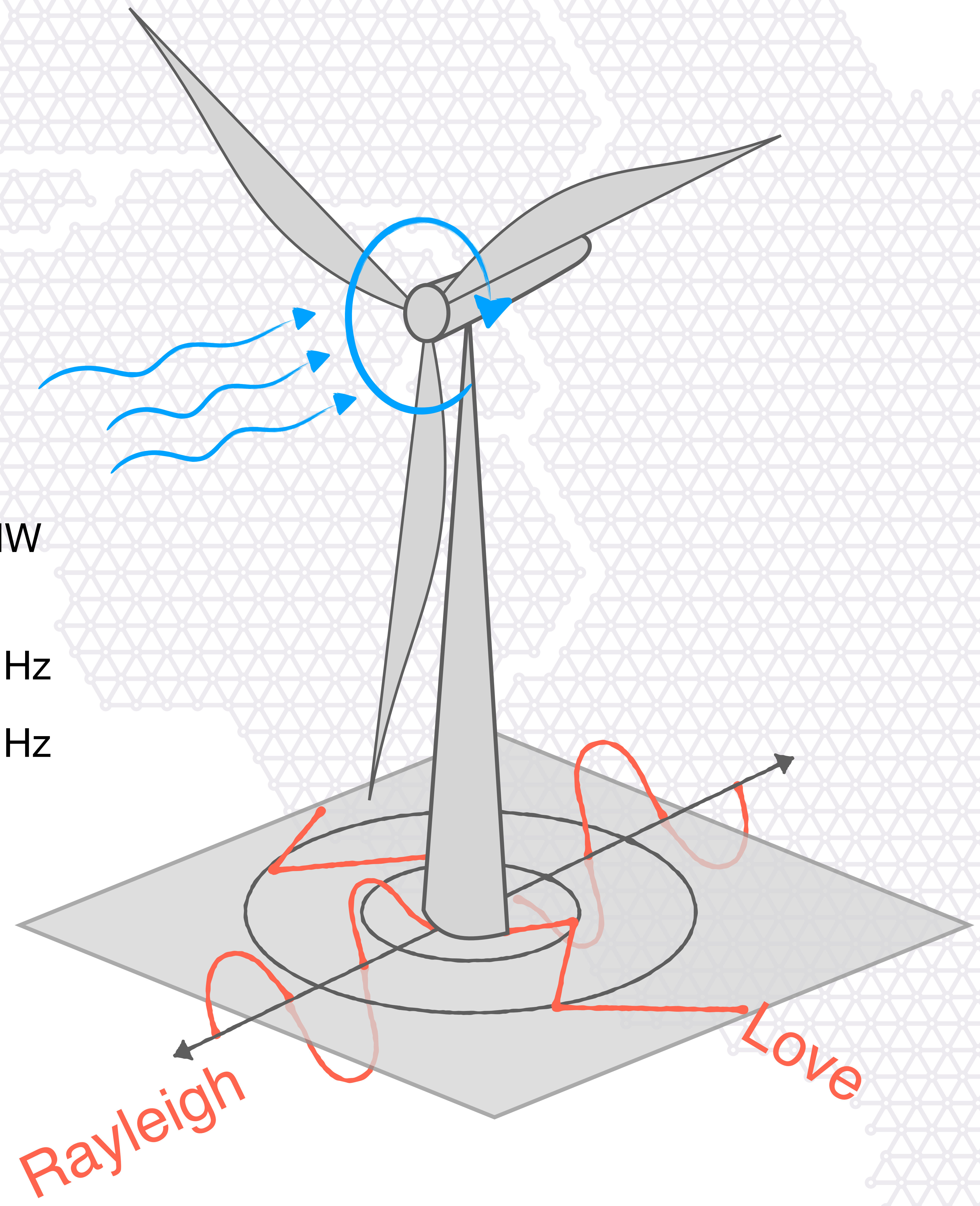

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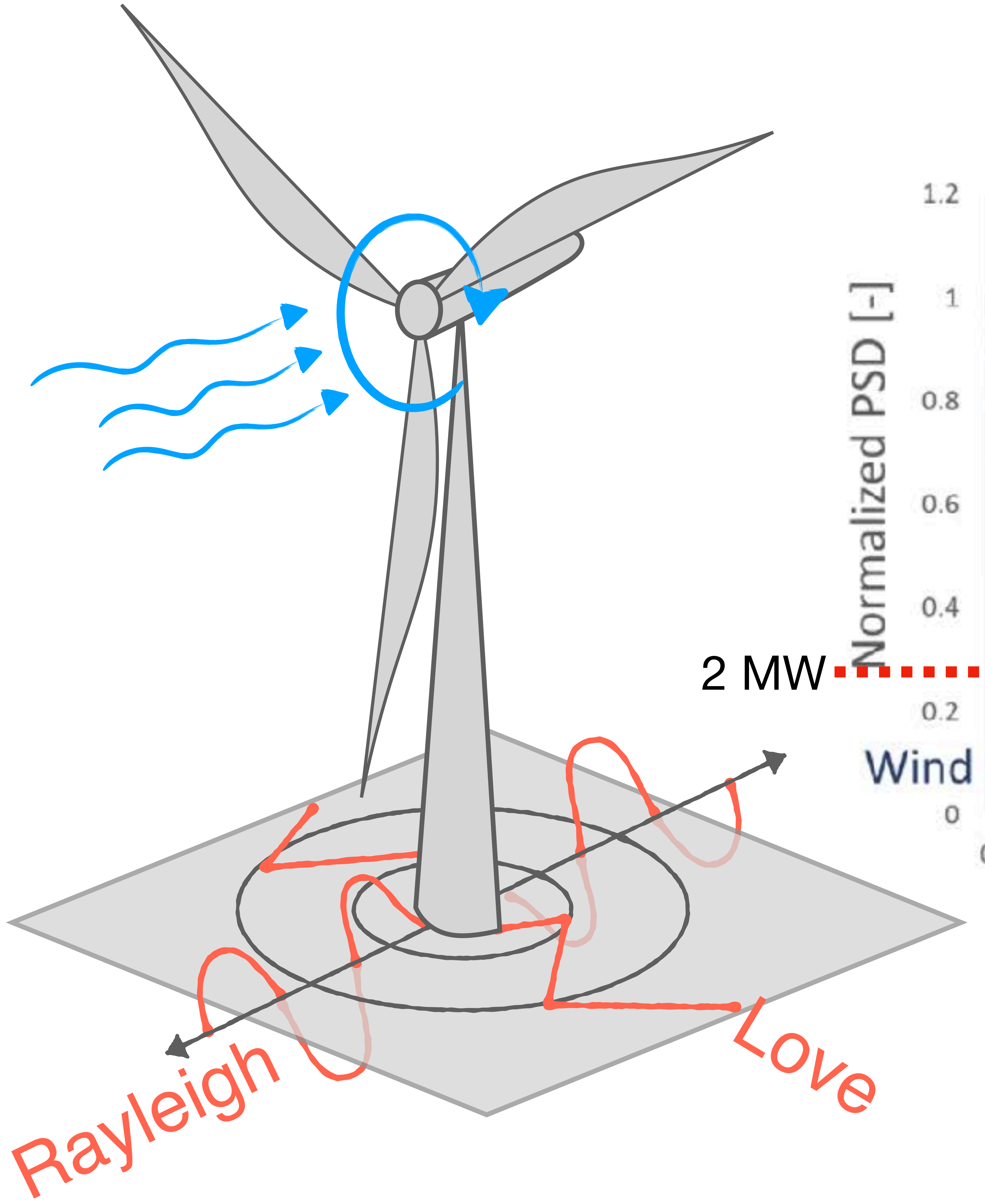
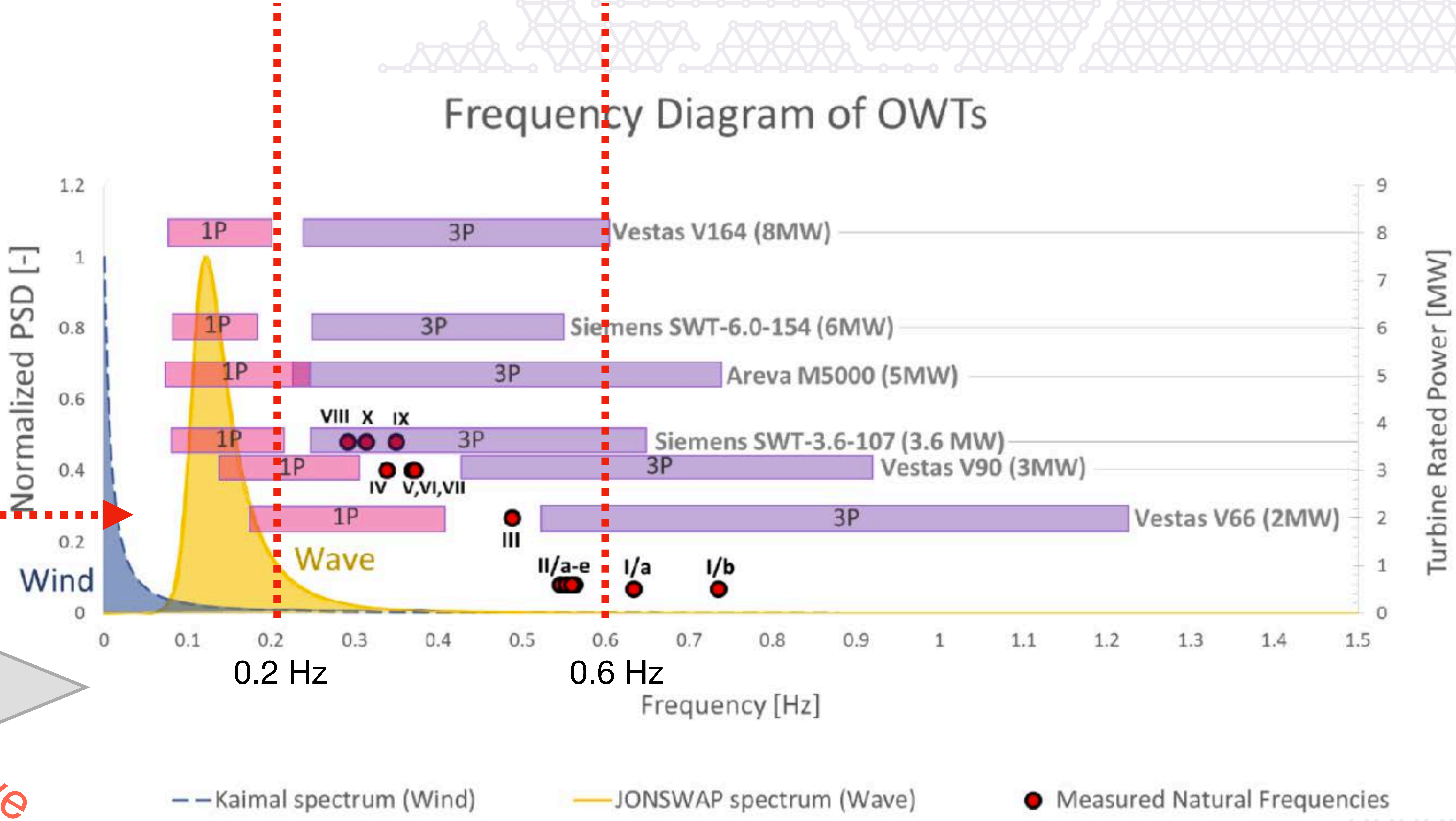
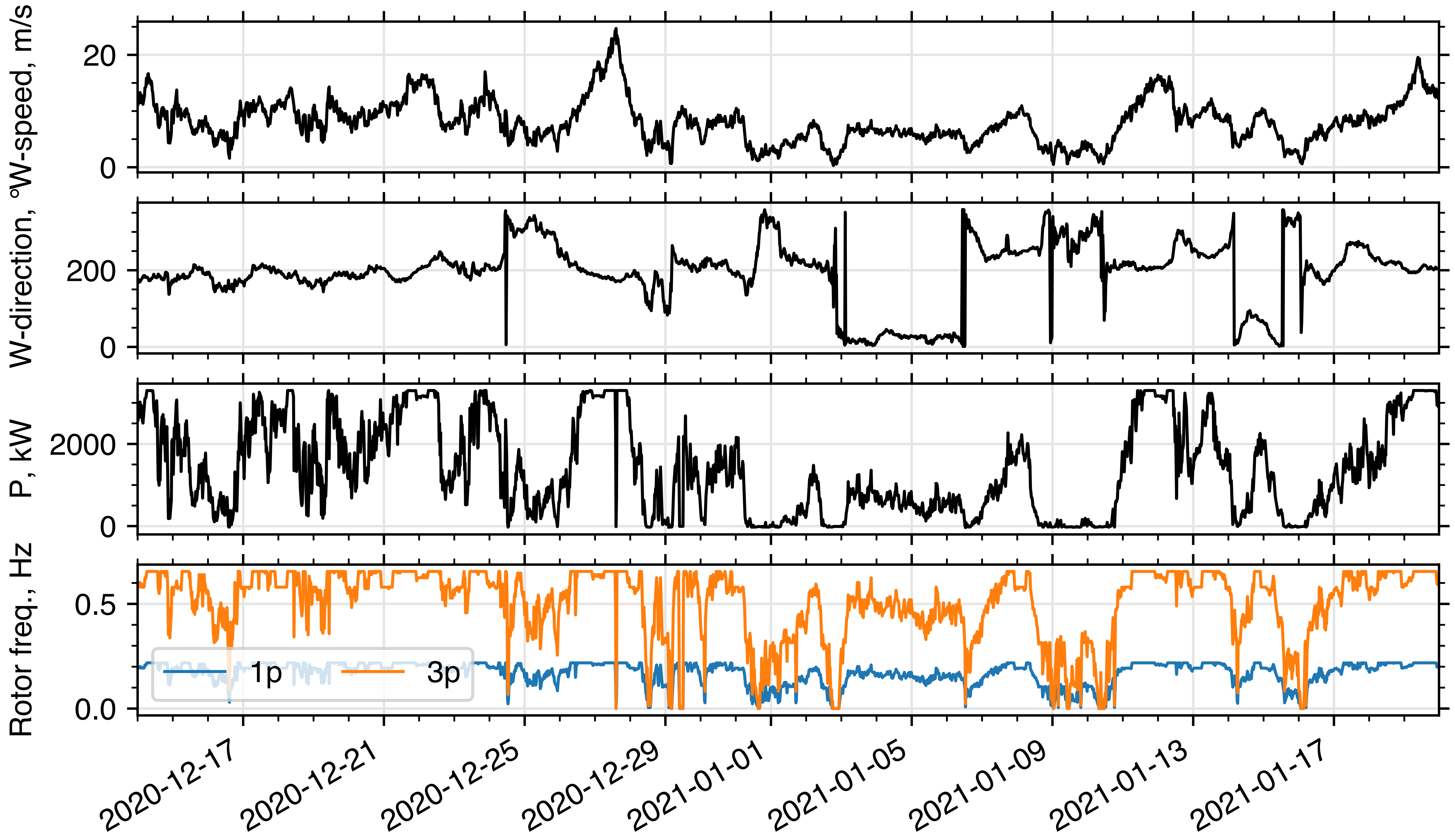
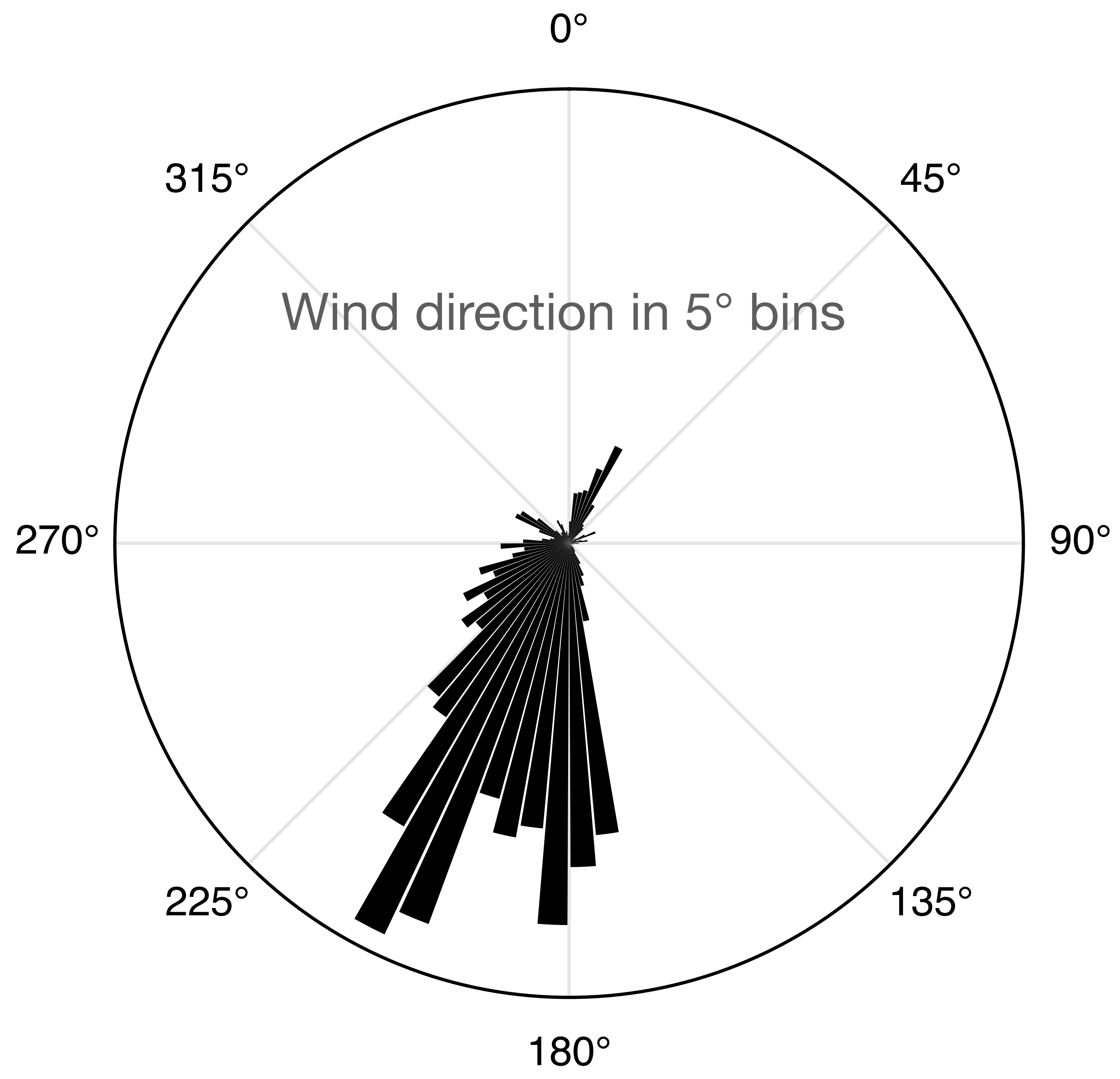




Arany et al. (2016) https://doi.org/10.1016/j.soildyn.2015.12.011

The Aachen Windpark seismic monitoring campaign





Data courtesy of STAWAG

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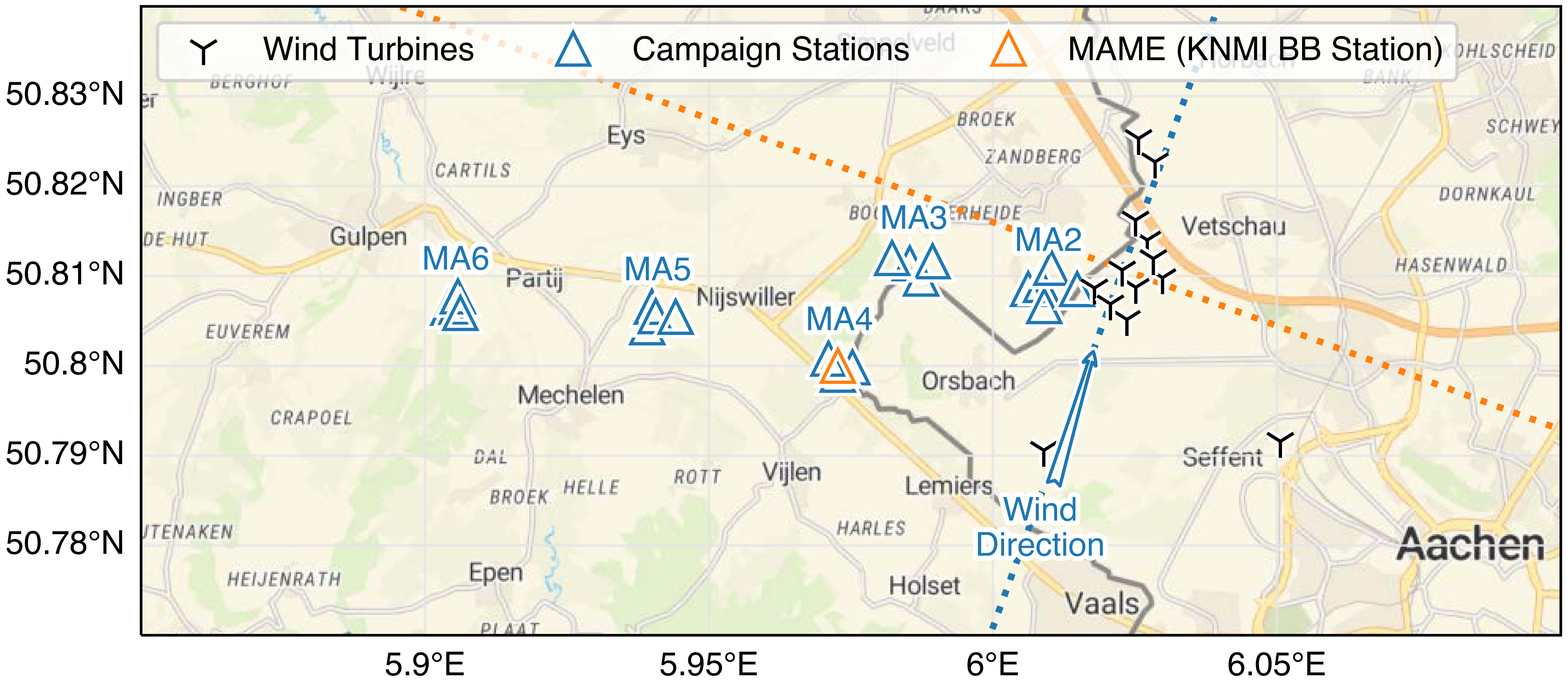
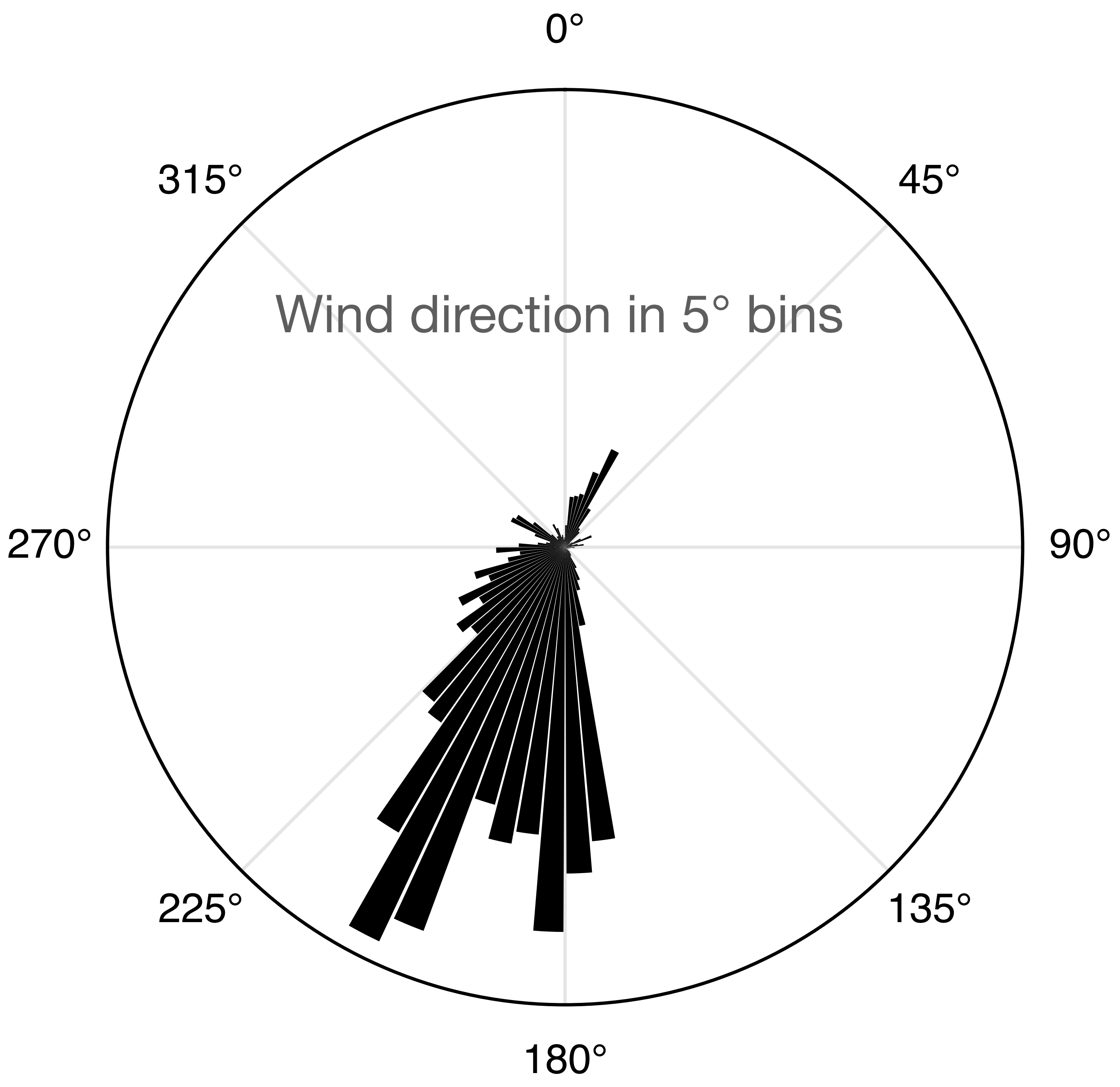
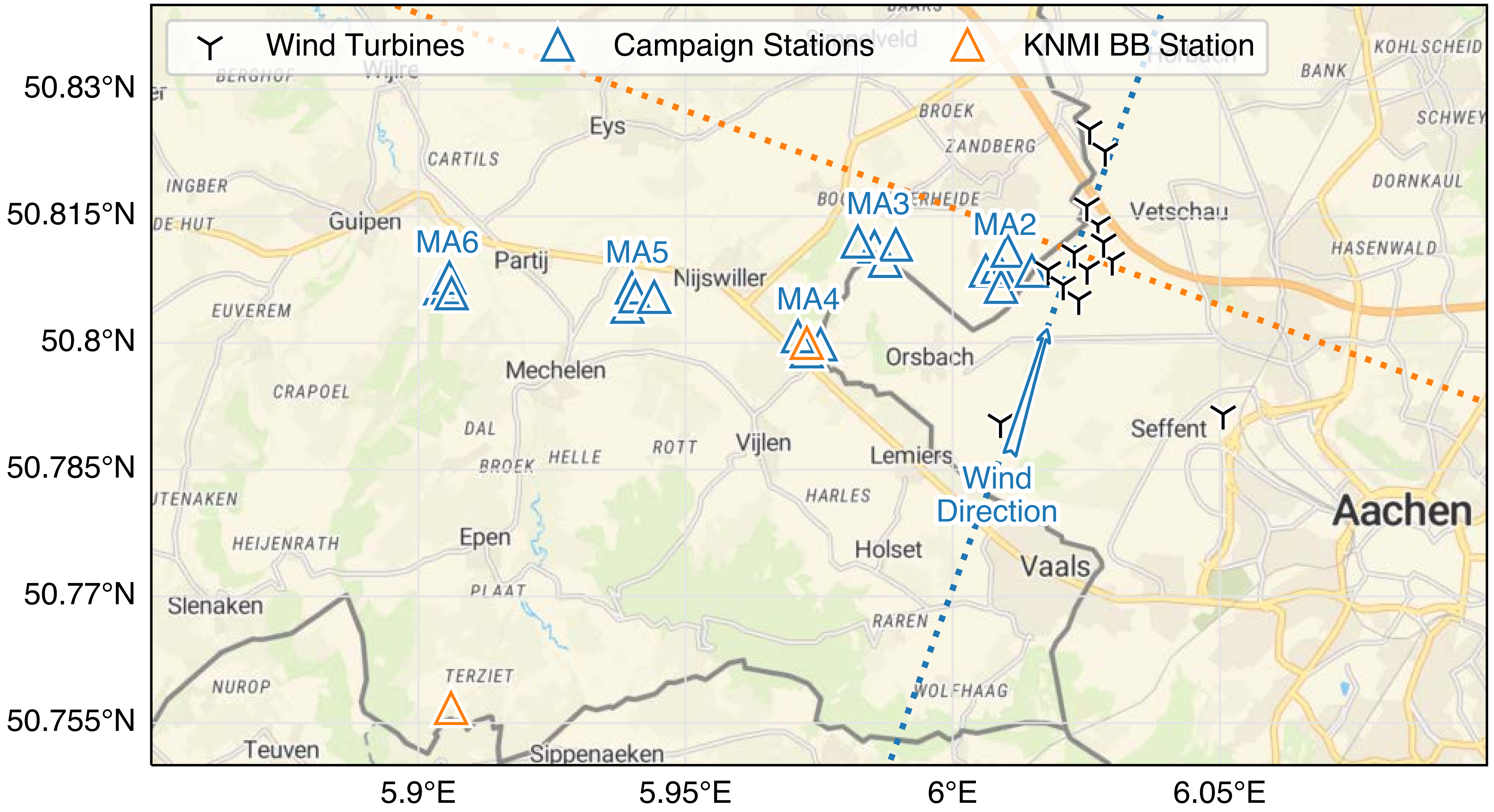


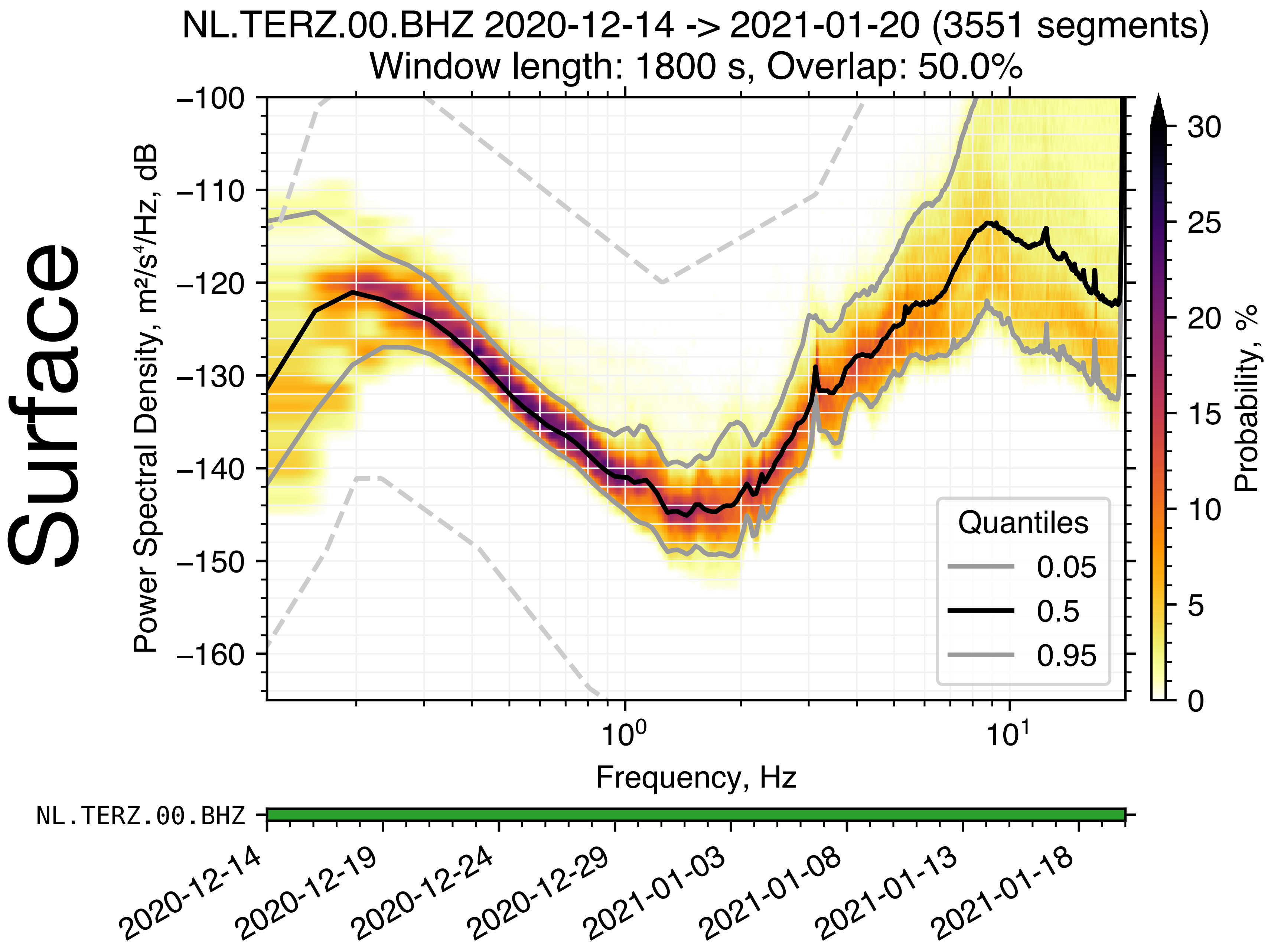


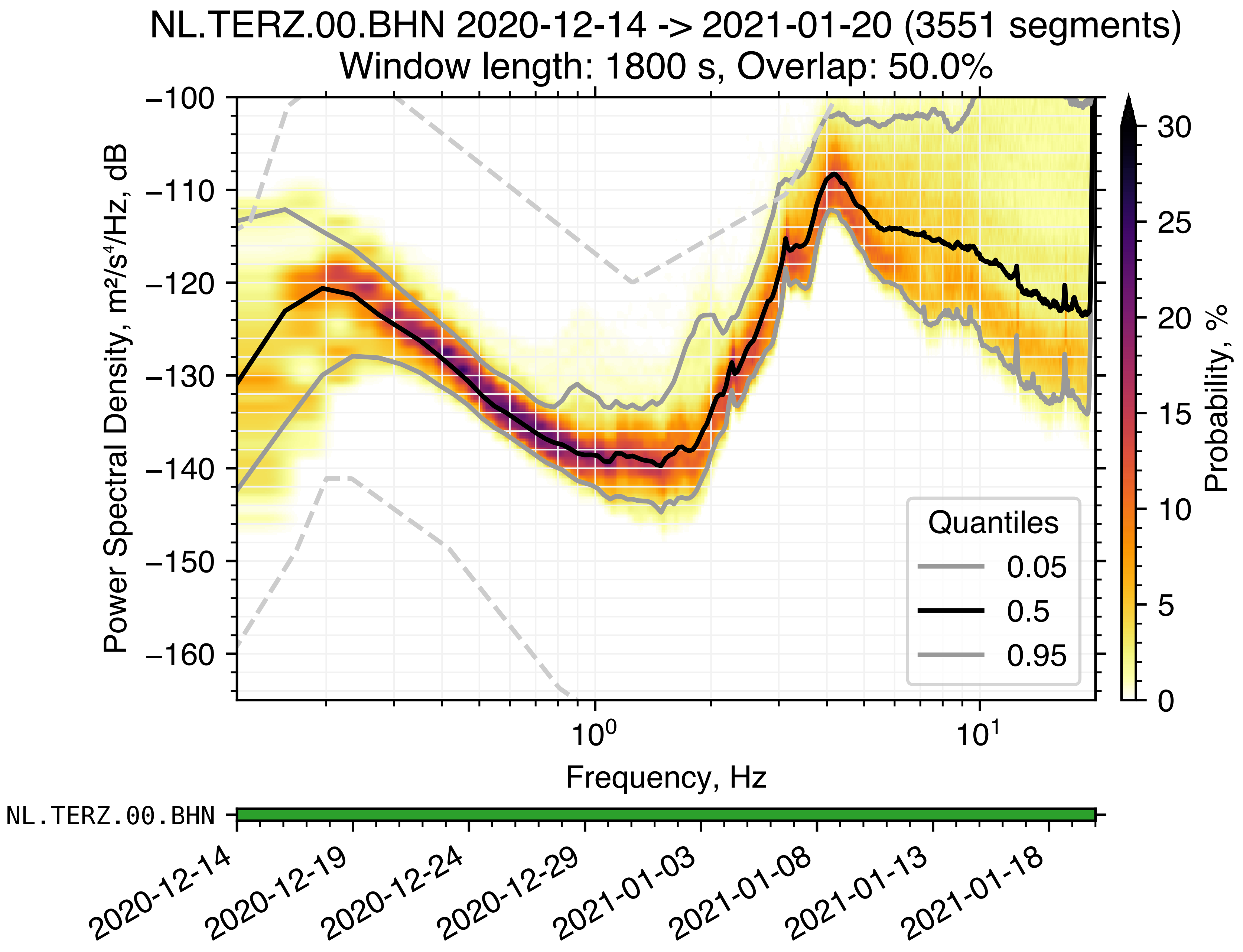
Results: PSDs

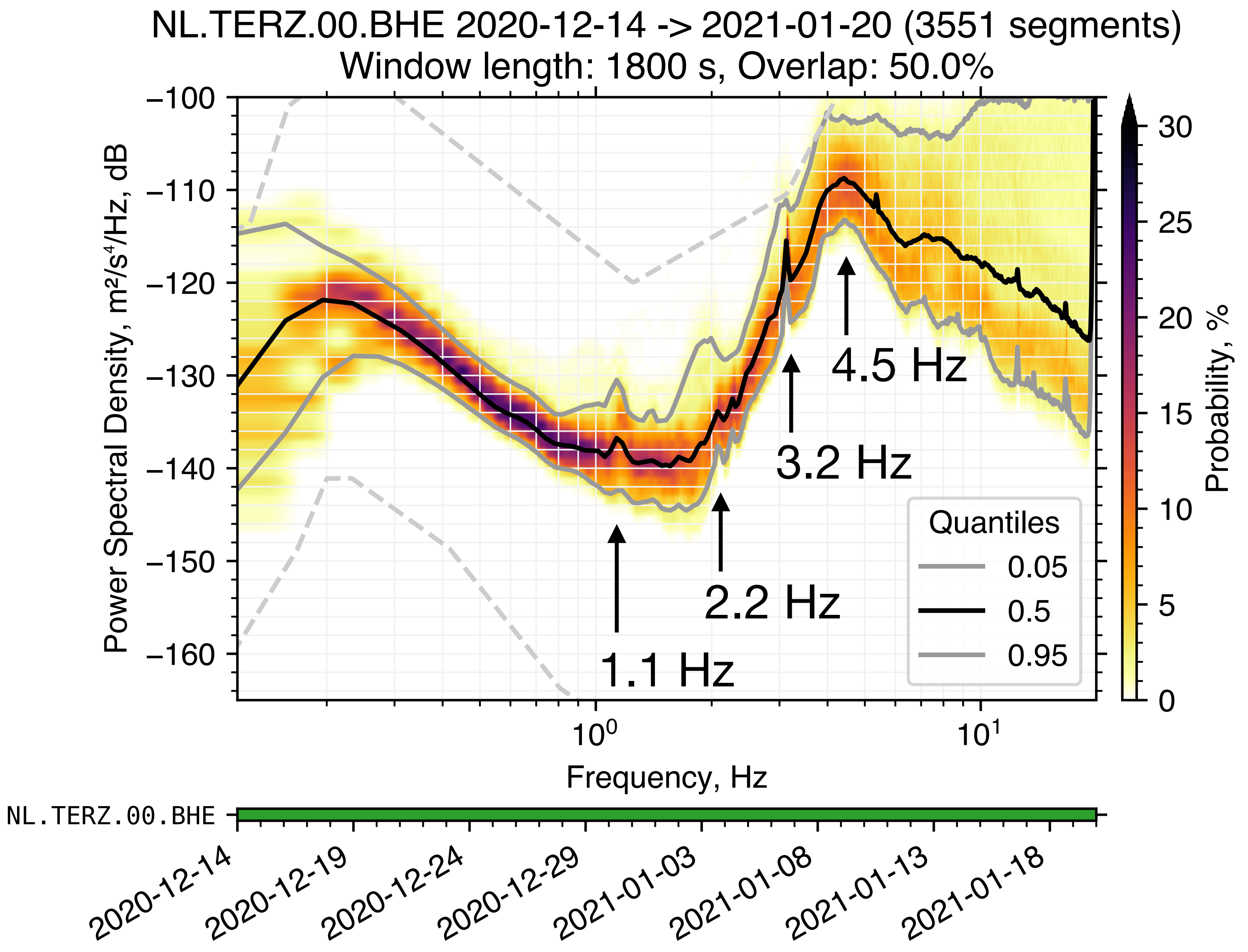
TERZ:
- Horizontal comp. show more noise
- Spectral spikes at ~1.1, 2.2, 3.2 Hz
- Broader peak at ~4.5 Hz



Surface



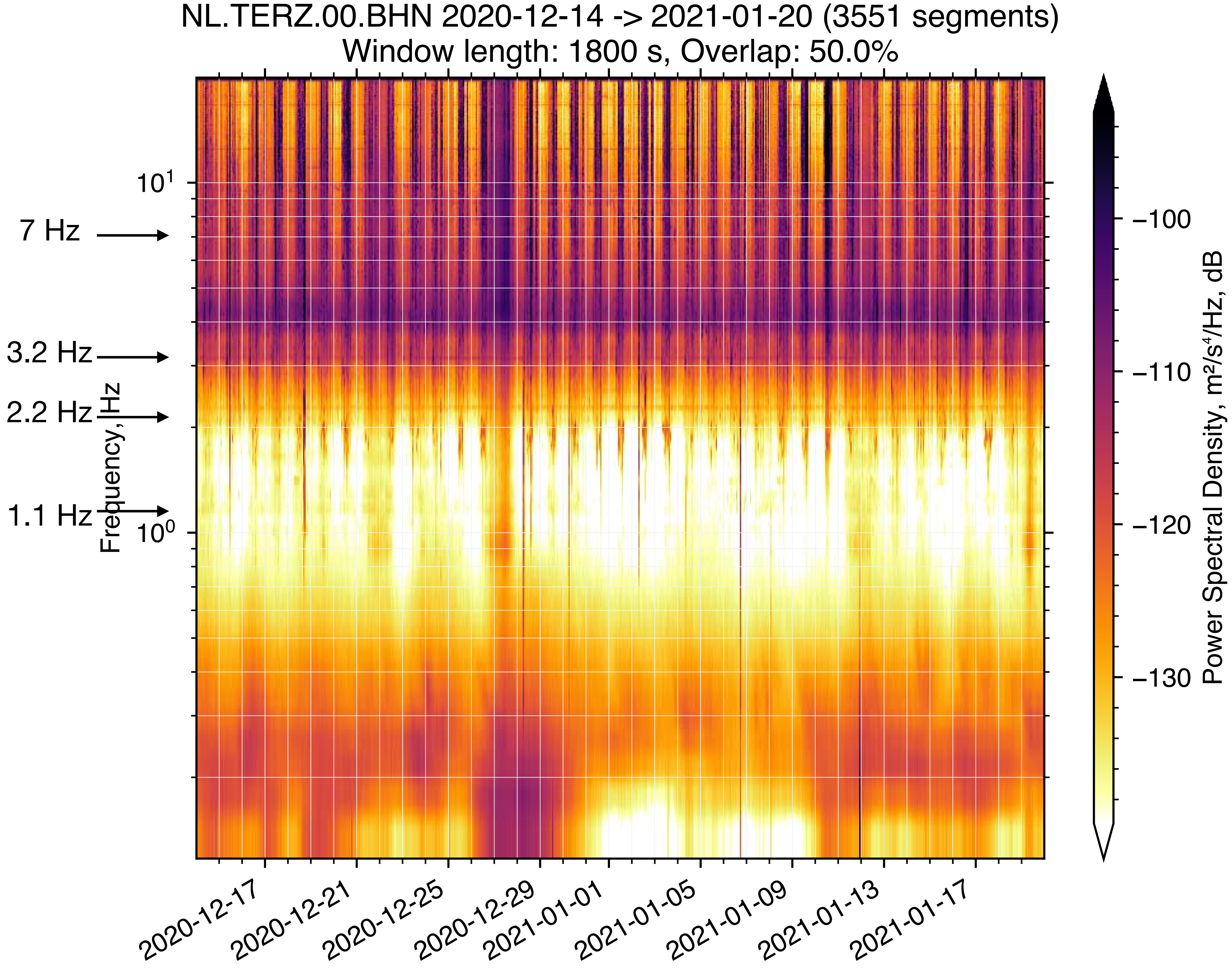


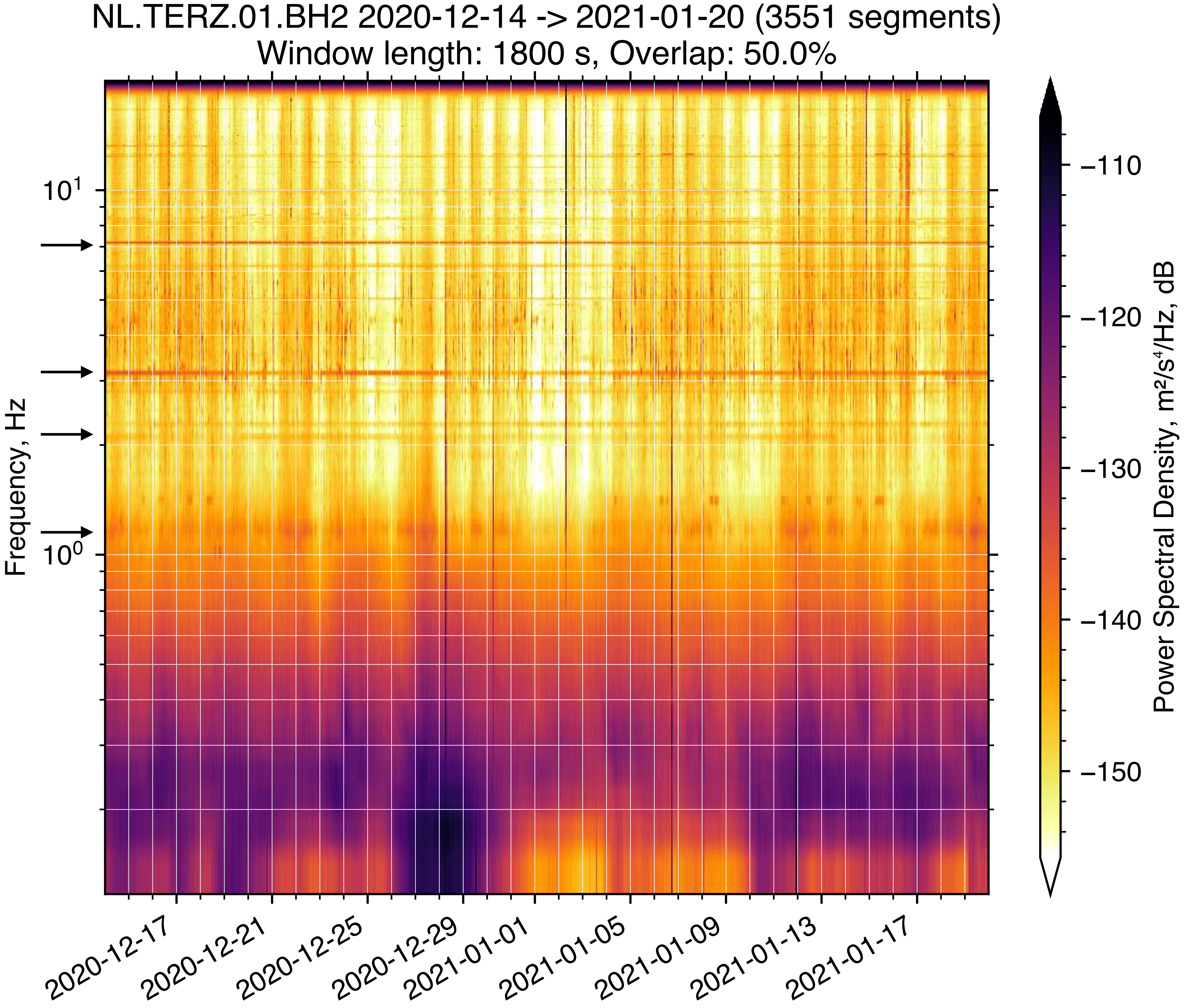


Results: PSDs

Results: Spectrograms

- Diurnal variations
- Surface: High freq.
- At depth: Low freq.





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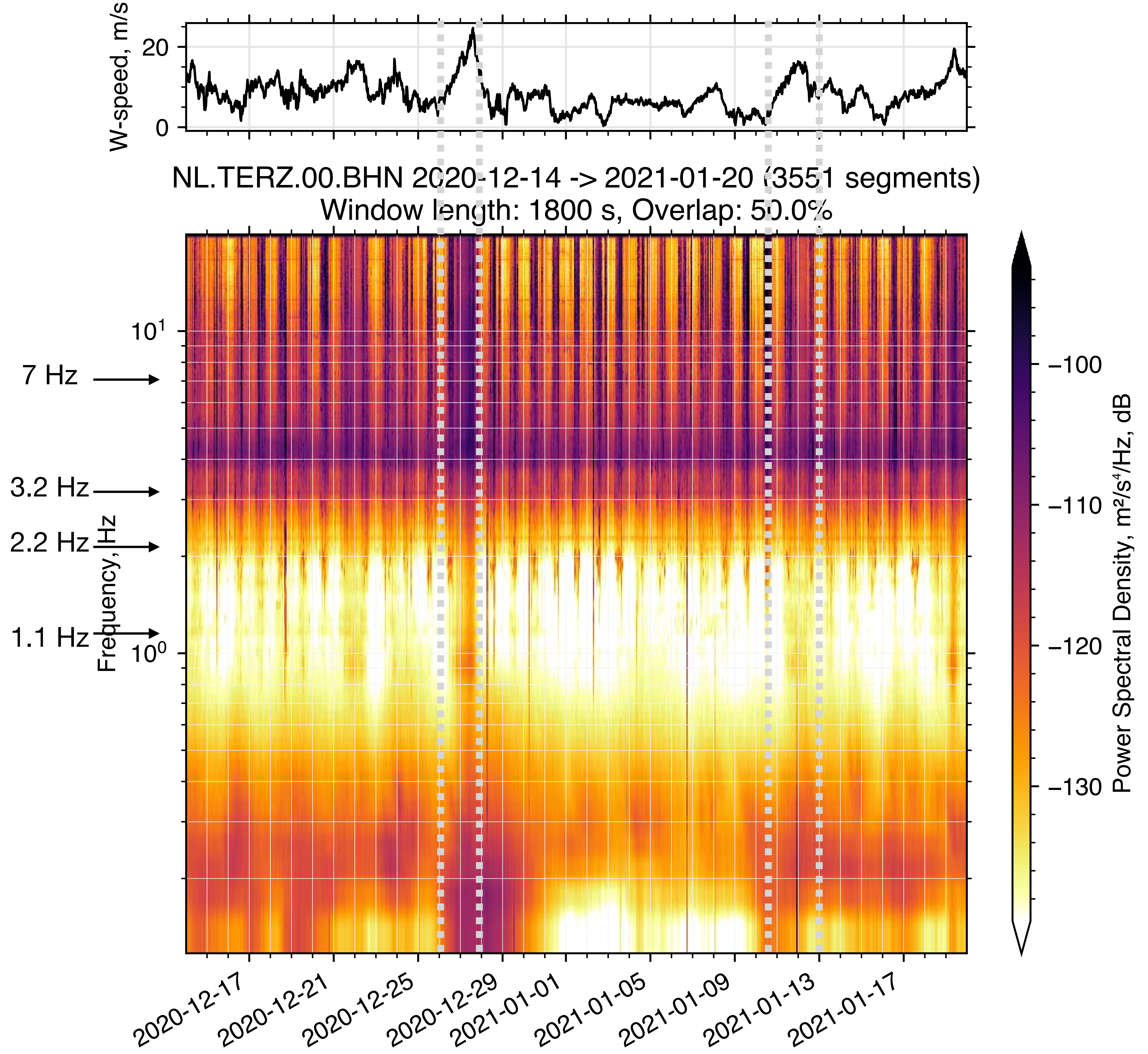
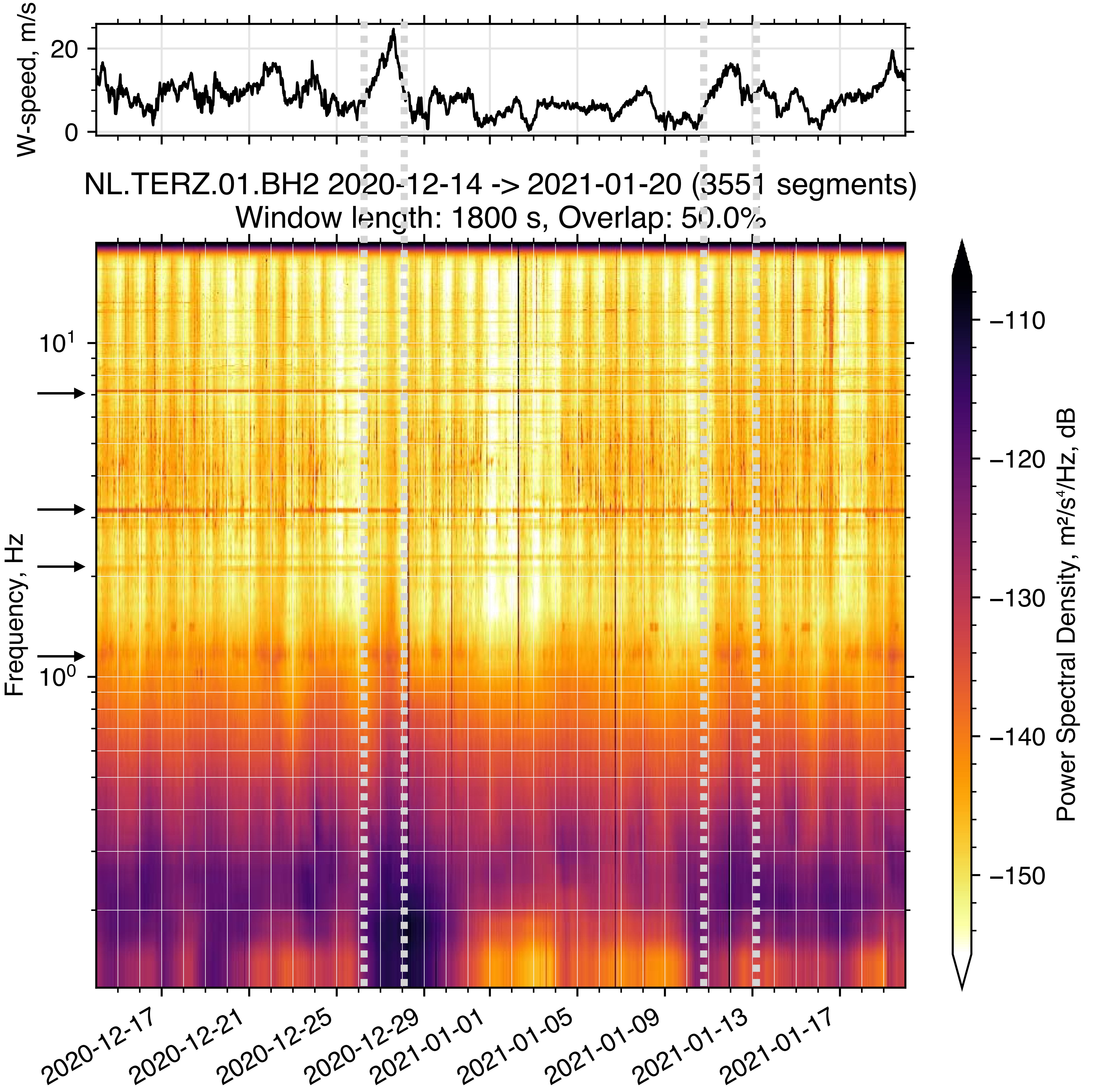
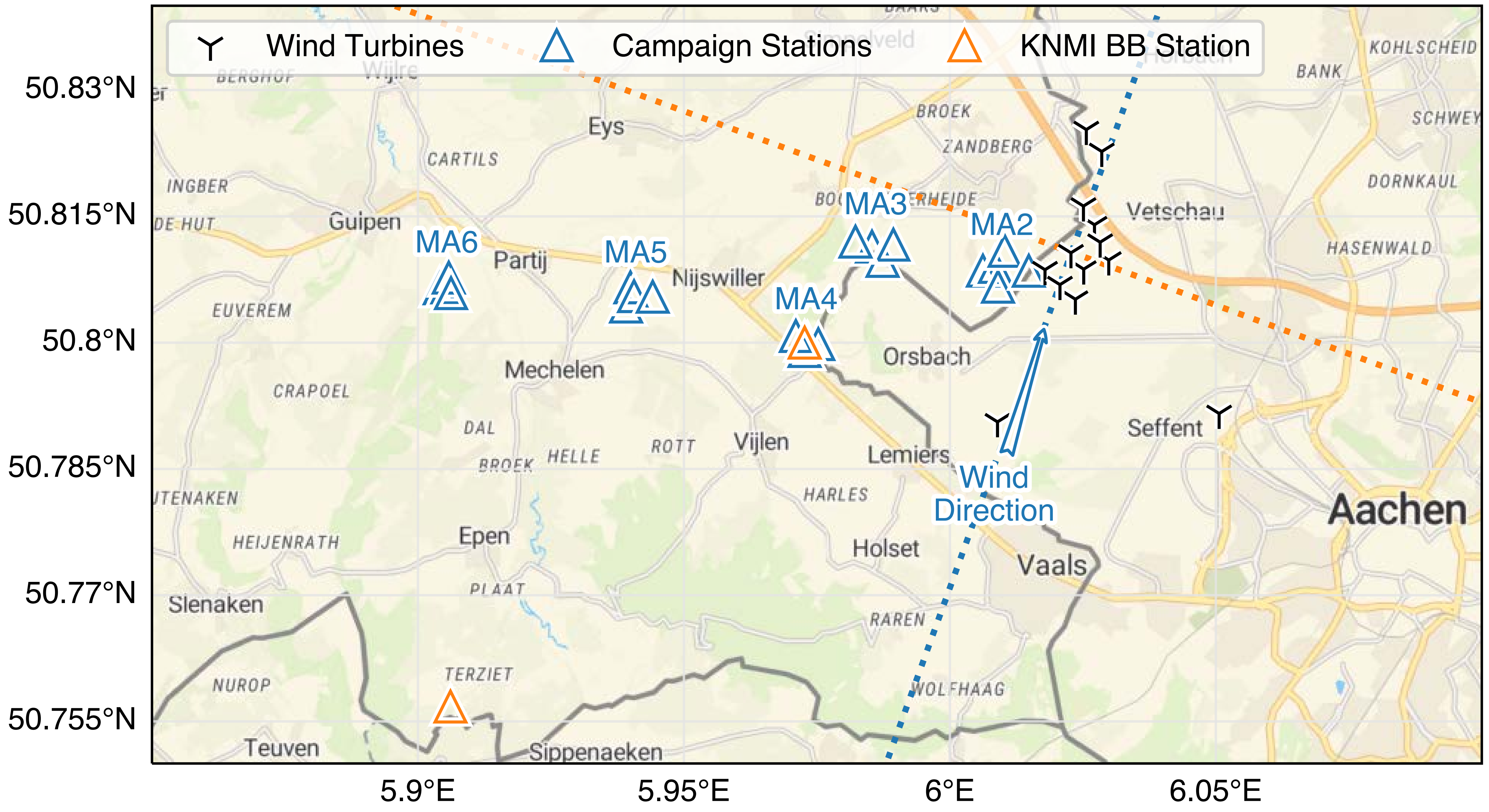
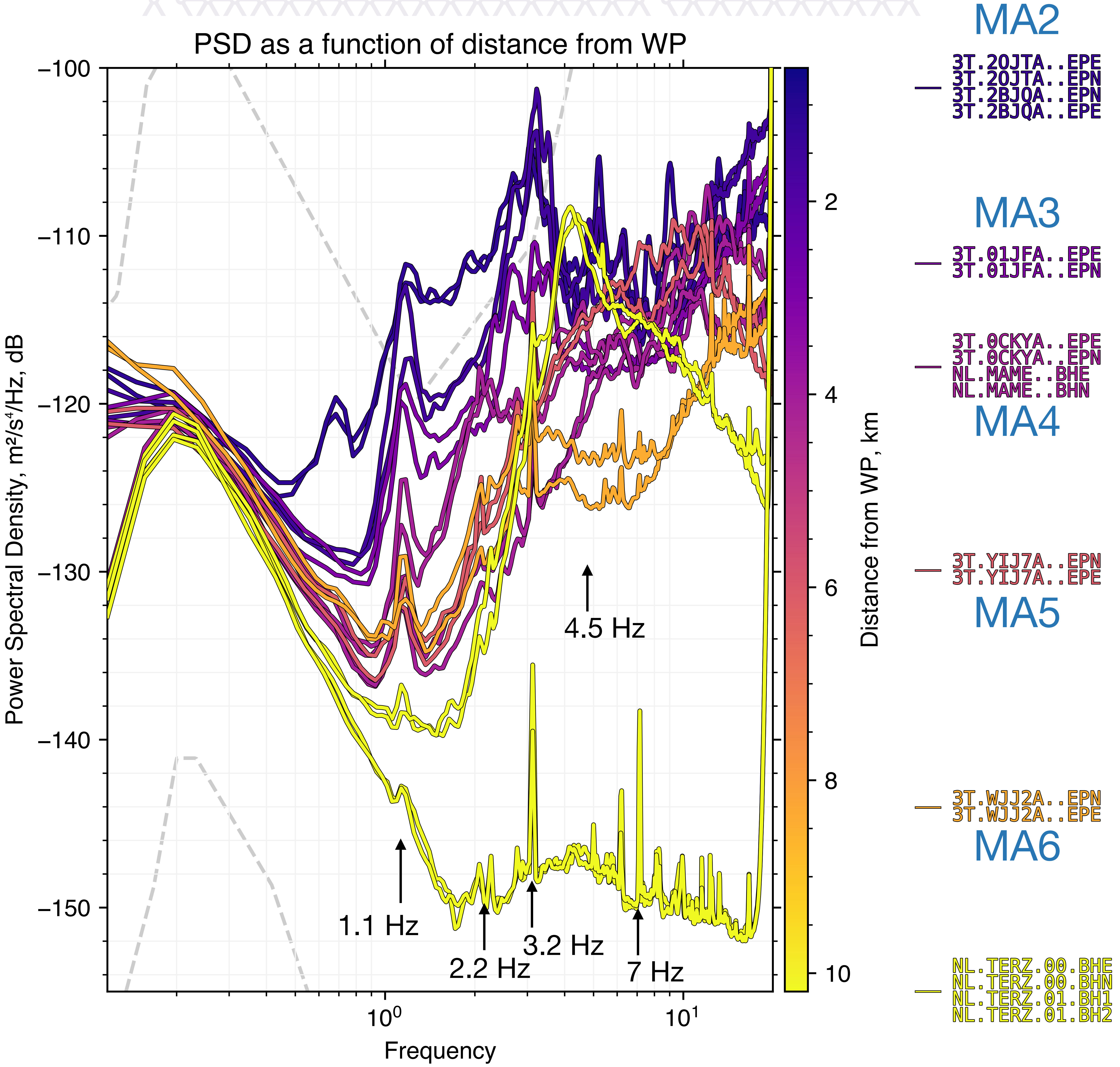




Results: Spectrograms

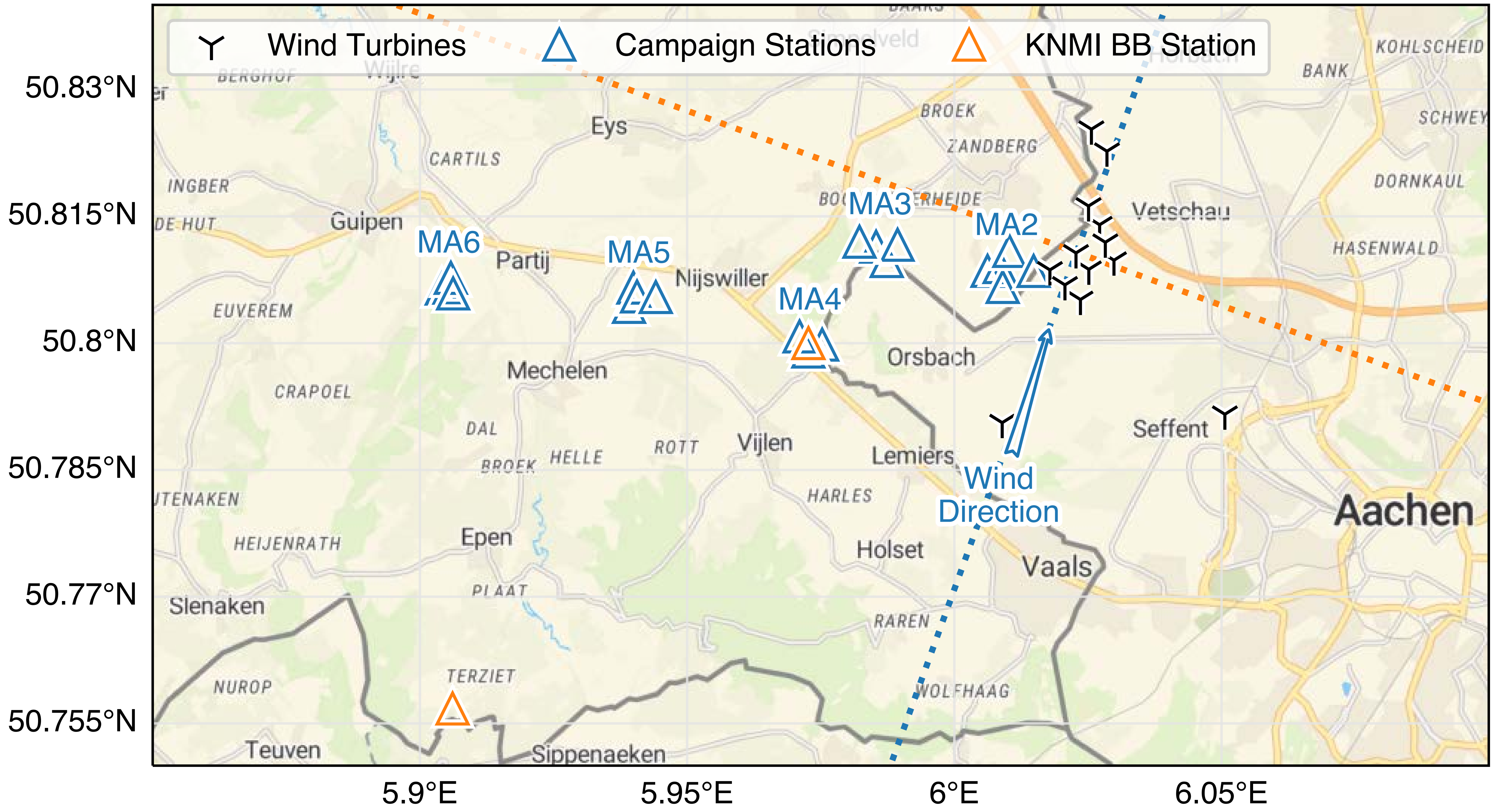
Results: PSD vs Distance





Horizontal comp.
- 1.1 spike consistent
- Decreases with distance

Results: PSD vs Distance



Vertical comp.

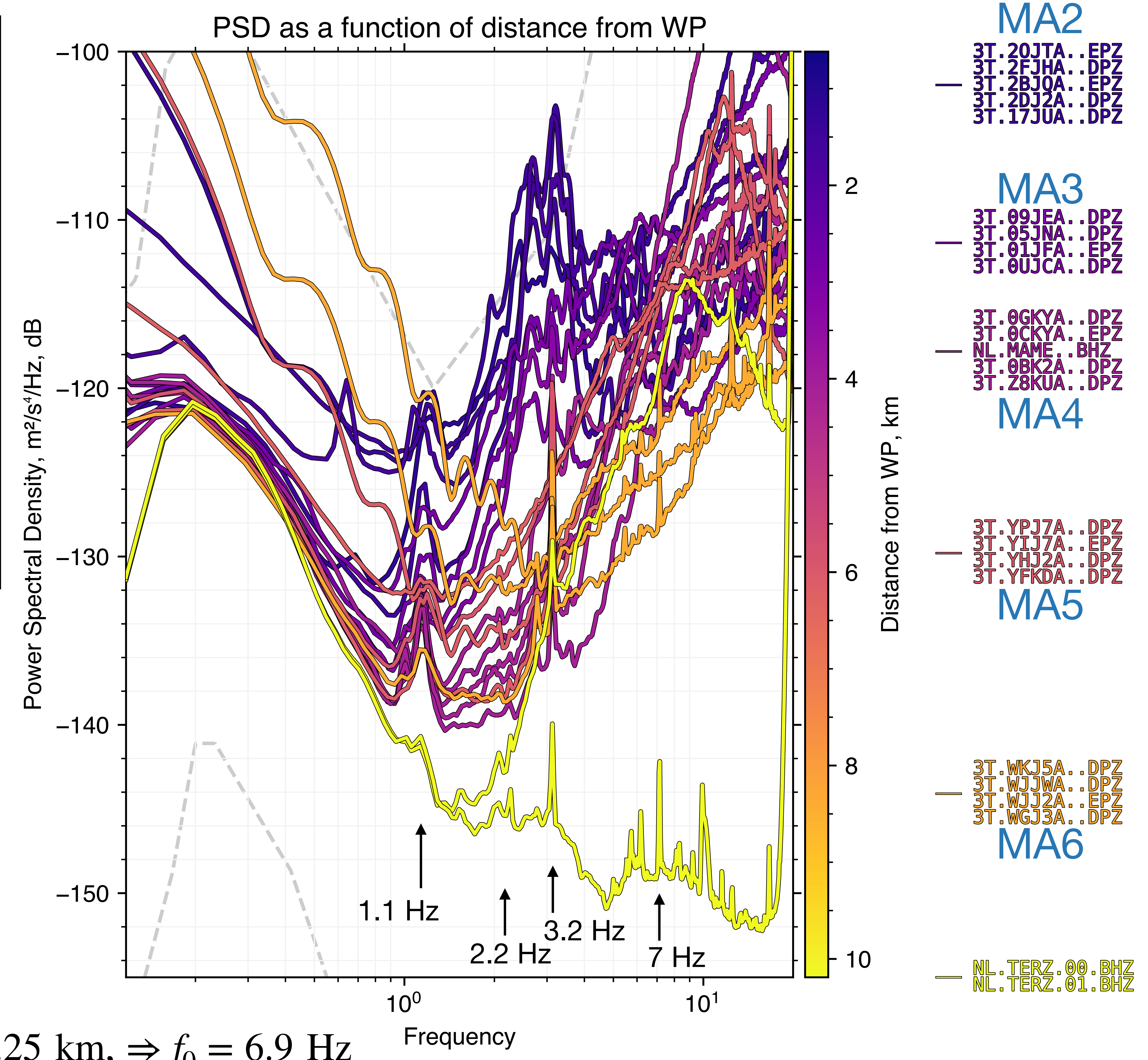
- 4.5 Hz peak gone

7 Hz peak is most likely related to the fundamental resonant mode in the steel casing:

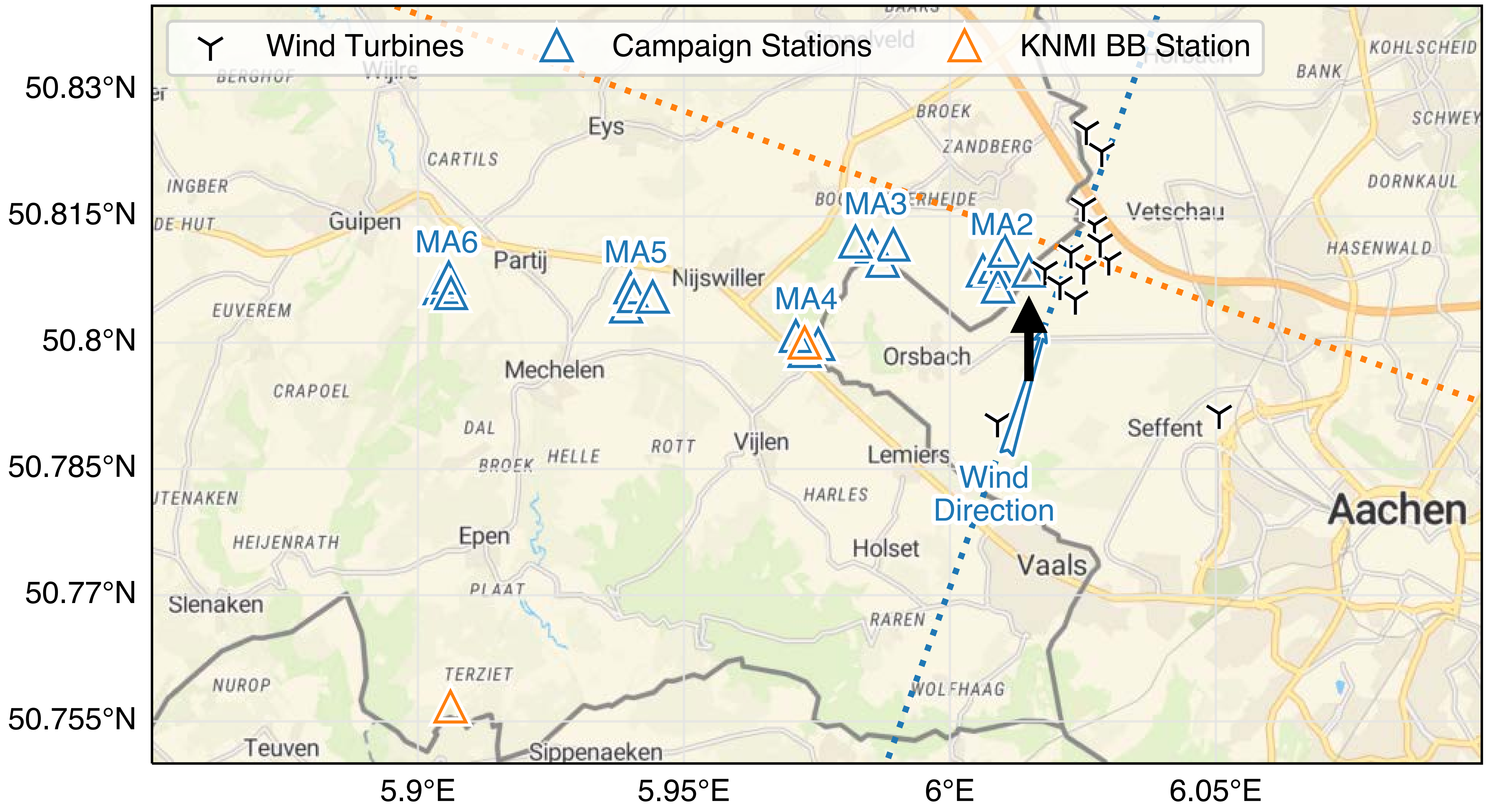
$f_0 = V/(4h)$ or $f_0 = V/(2h)$

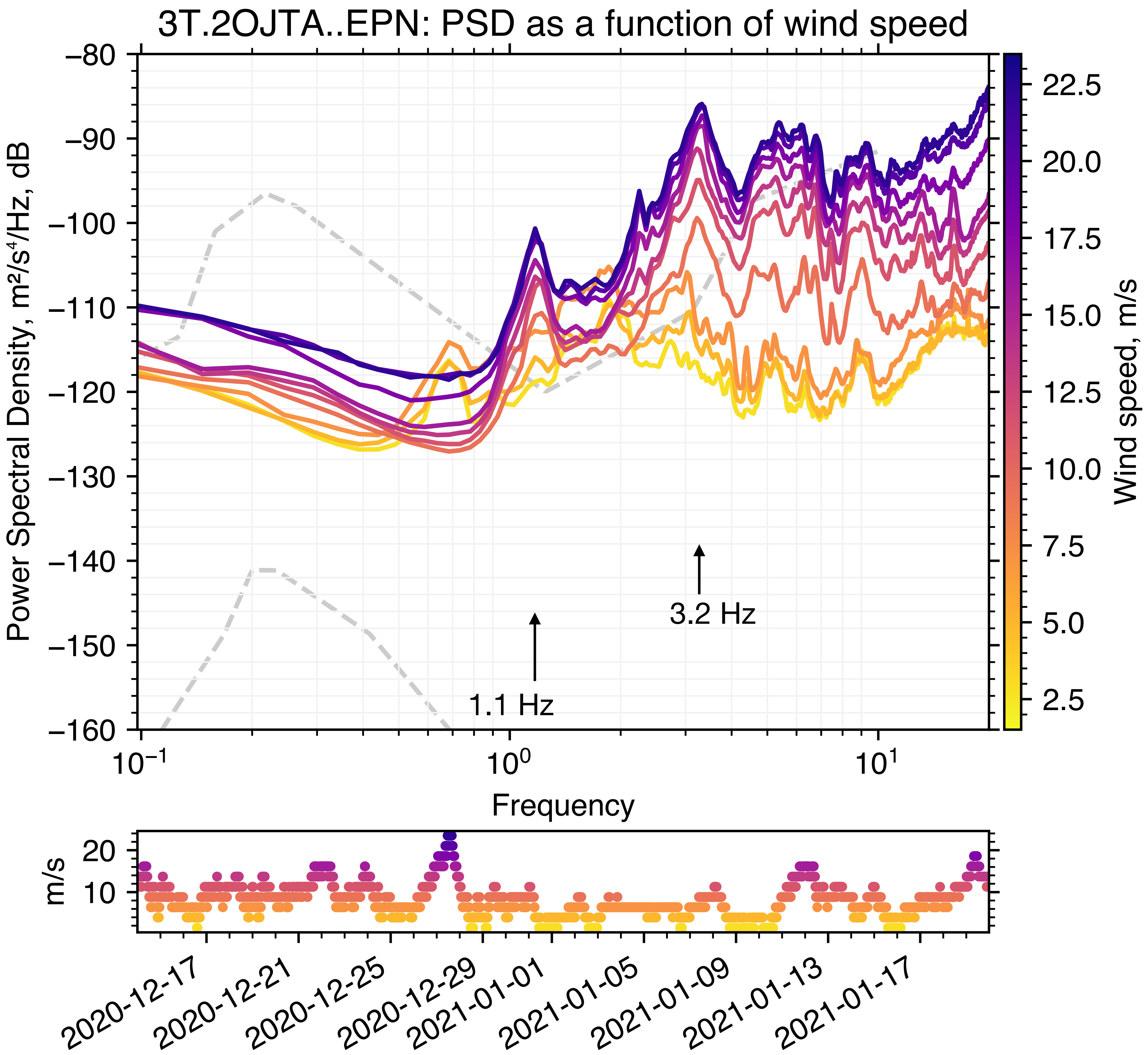
$V_P = 6\ \mathrm{km/s}, h = 0.25\ \mathrm{km}, \Rightarrow f_0 = 6\ \mathrm{Hz}$

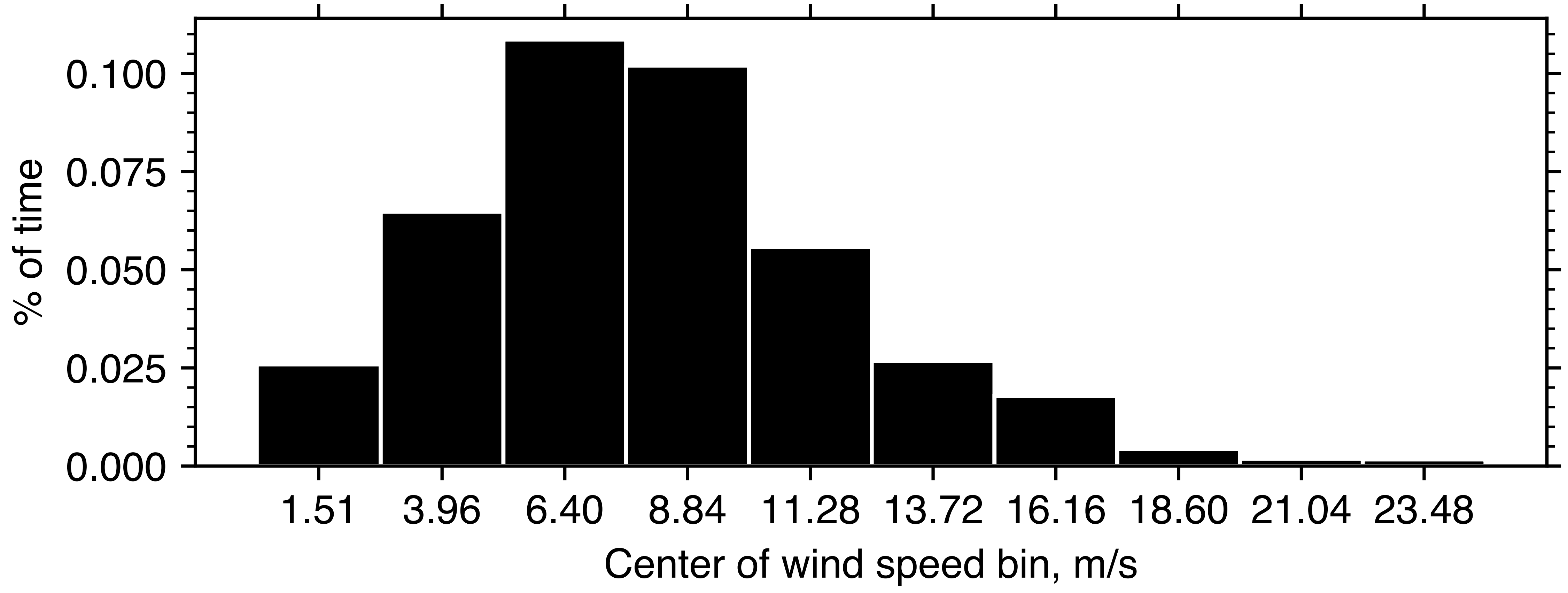
$V_S = 3.45\ \mathrm{km/s}, h = 0.25\ \mathrm{km}, \Rightarrow f_0 = 6.9\ \mathrm{Hz}$



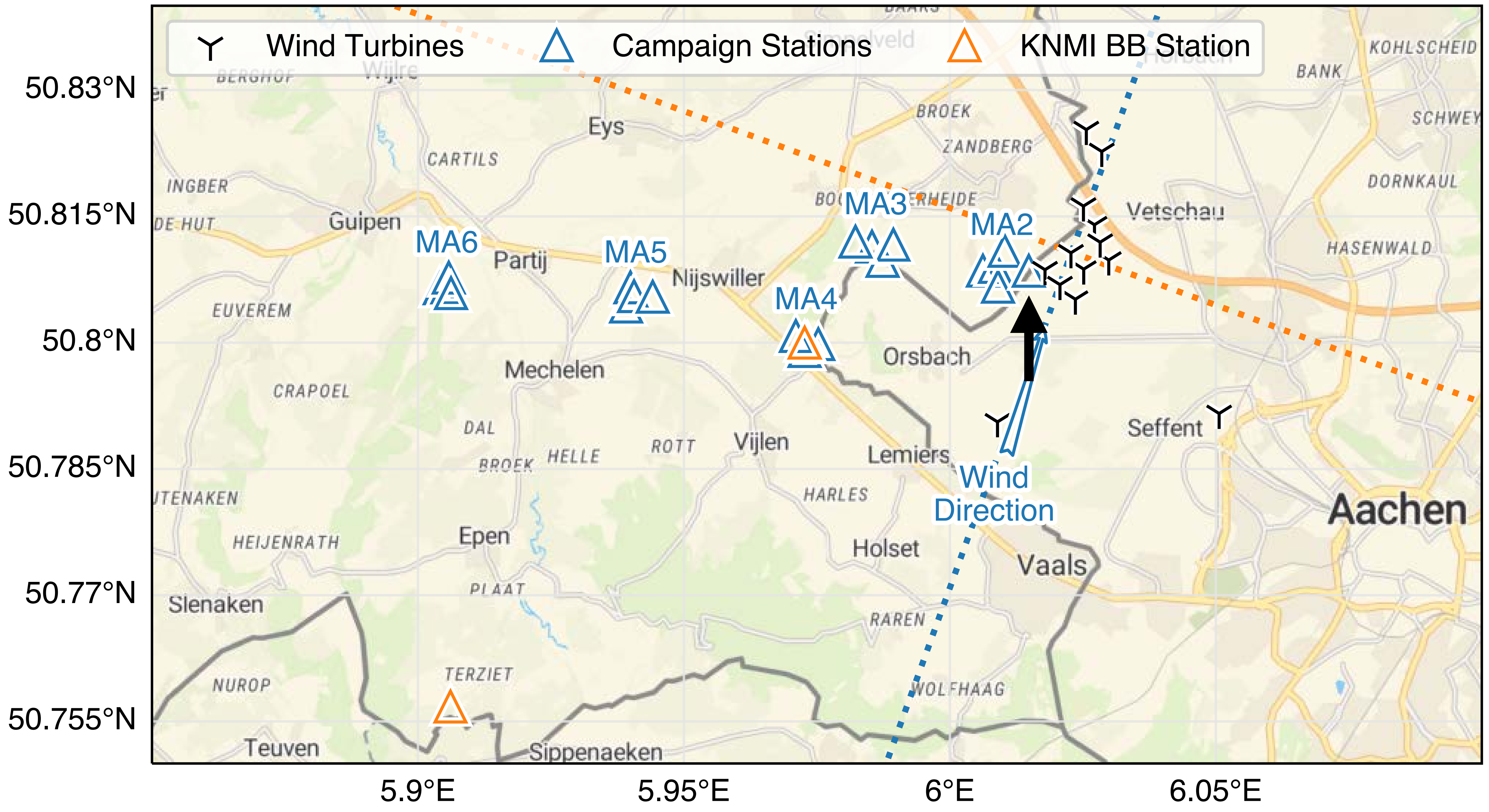
Results: PSD vs Wind Speed

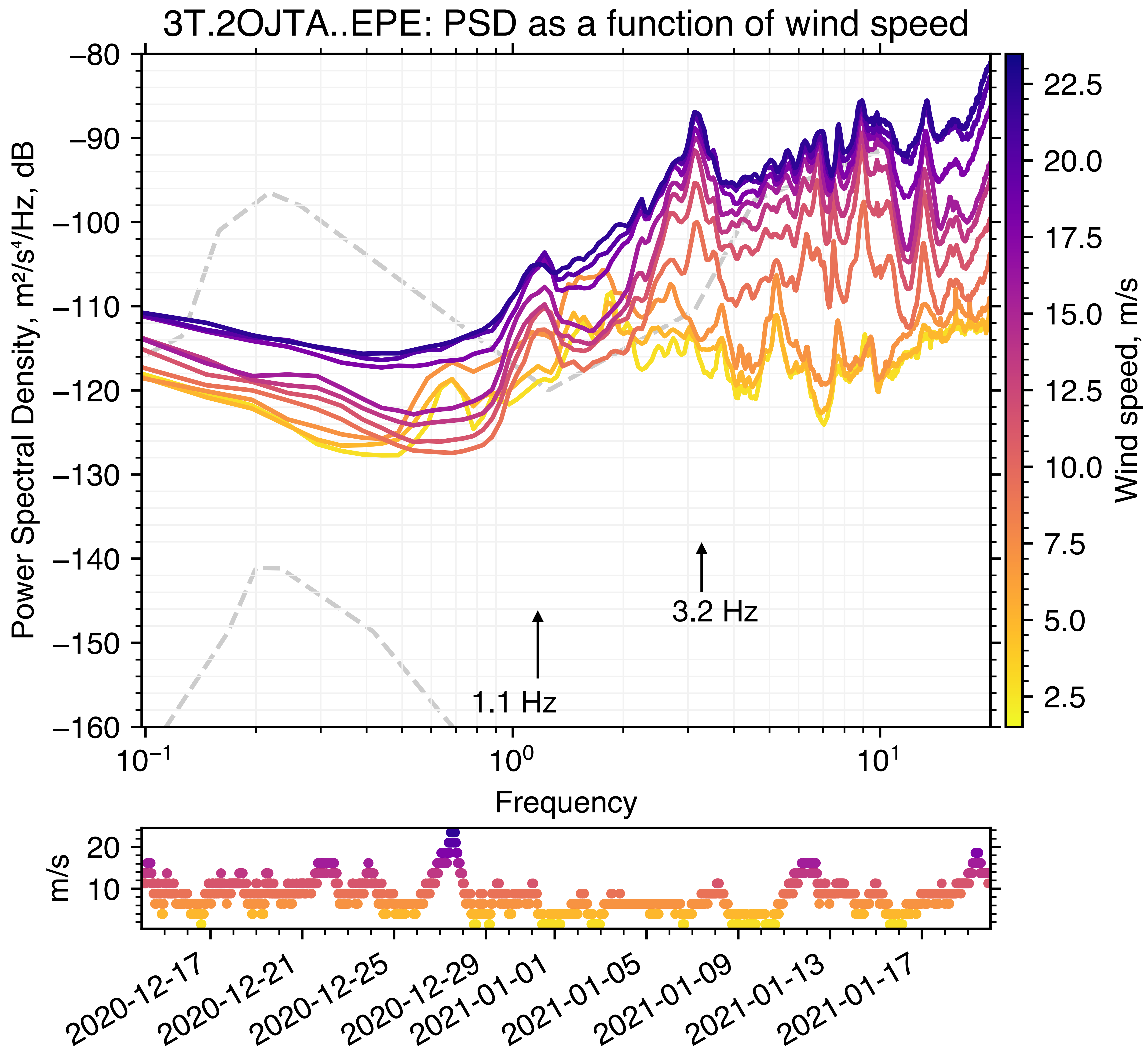






Results: PSD vs Wind Speed





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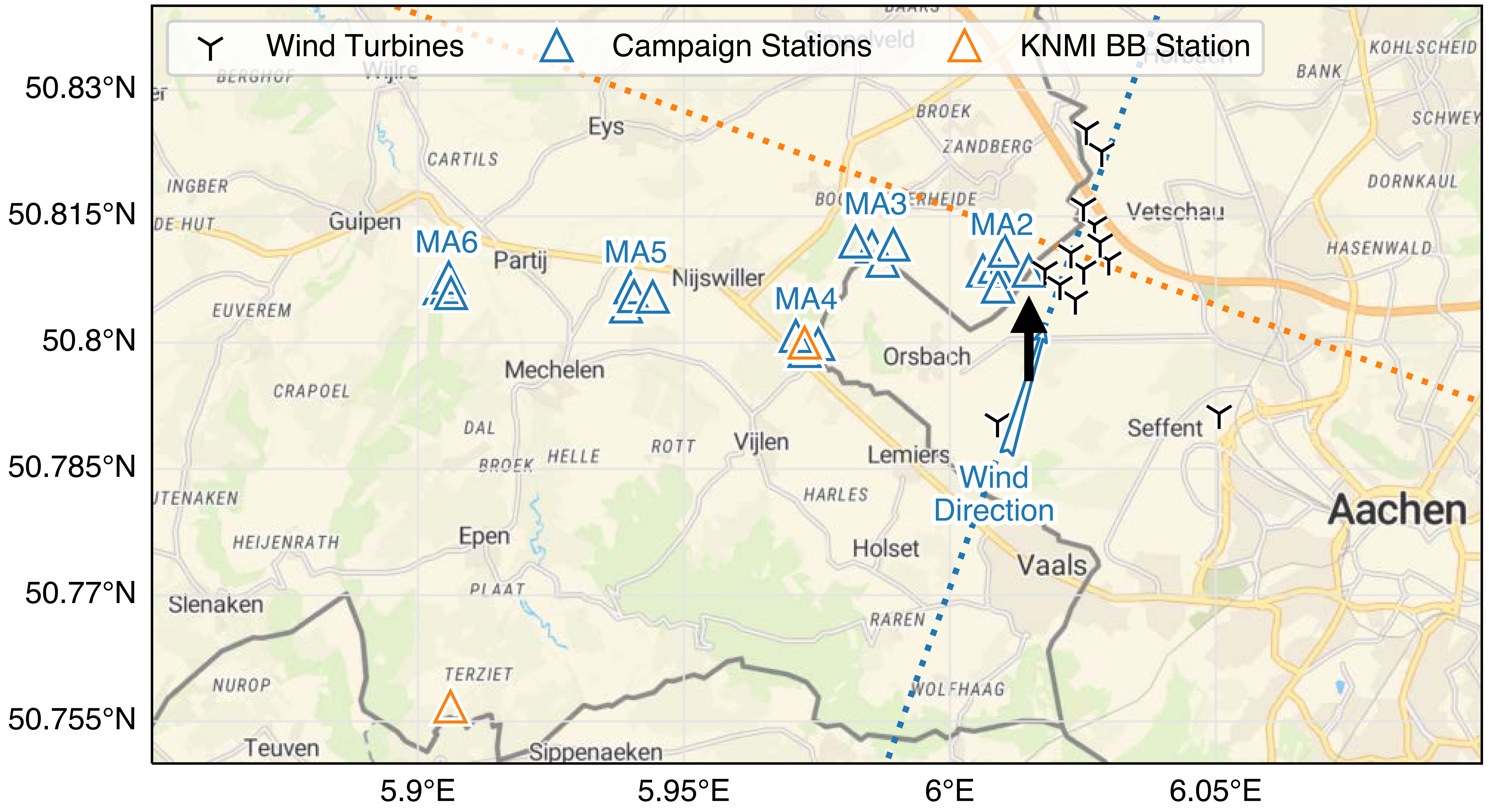

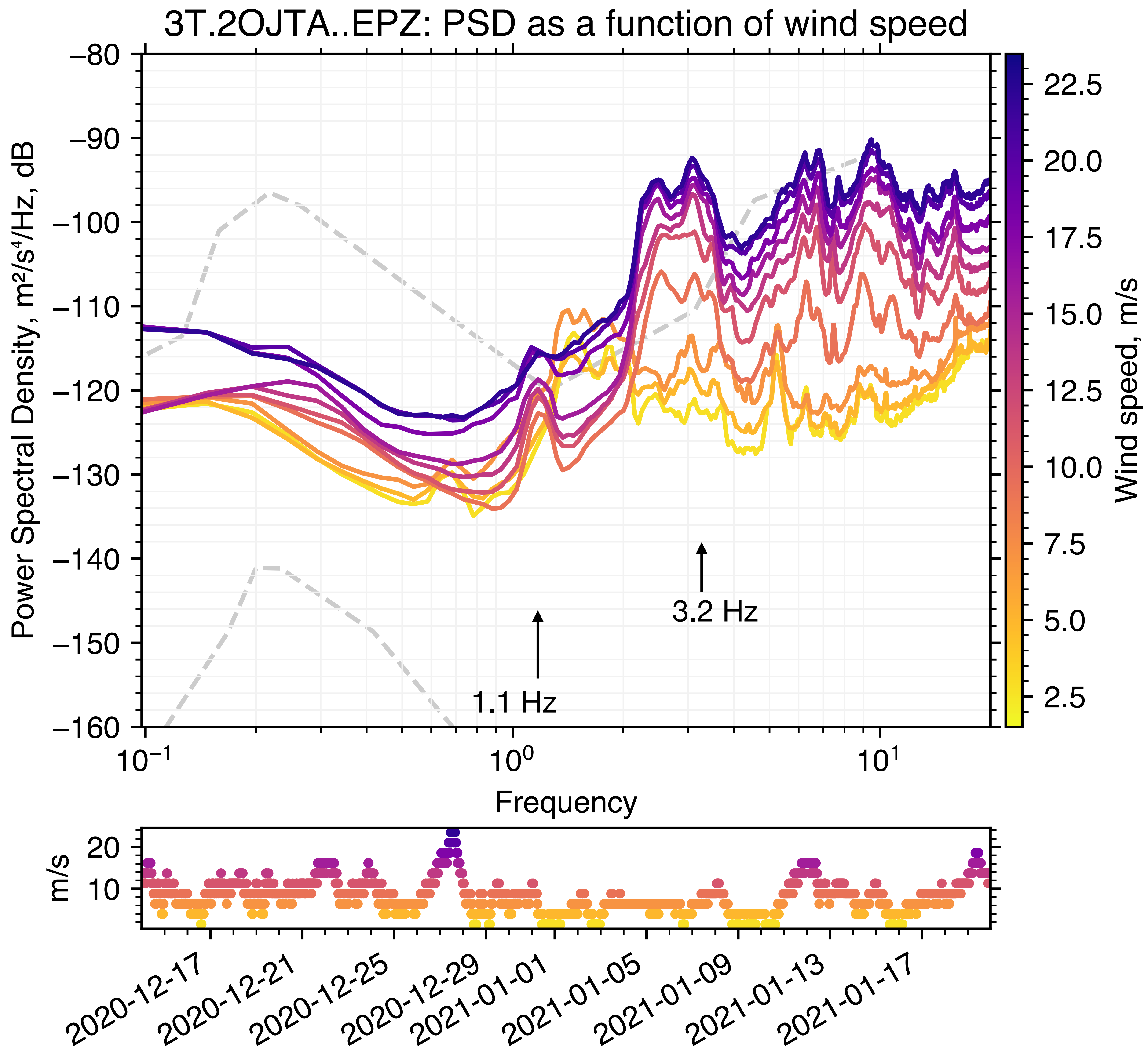

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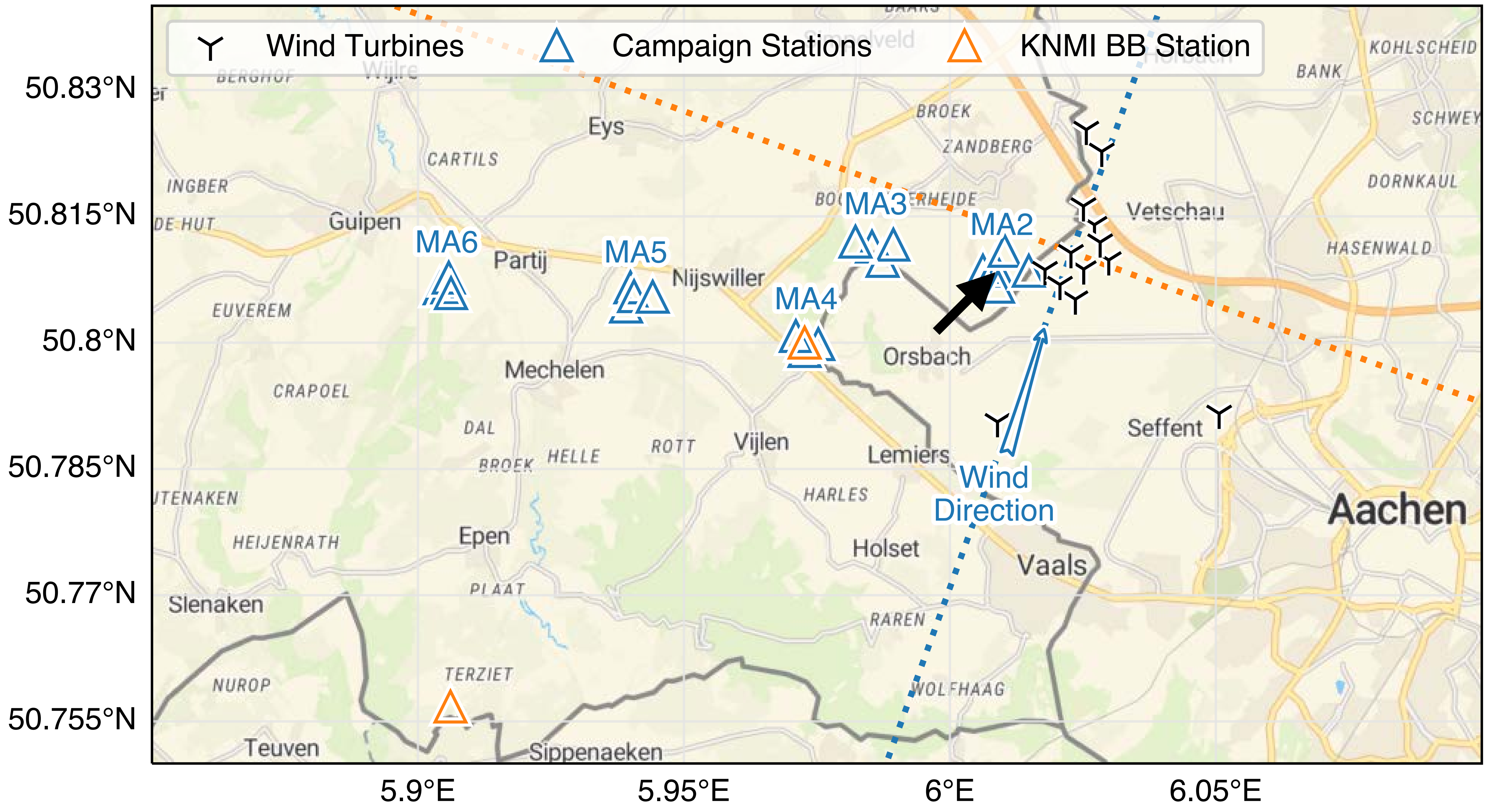

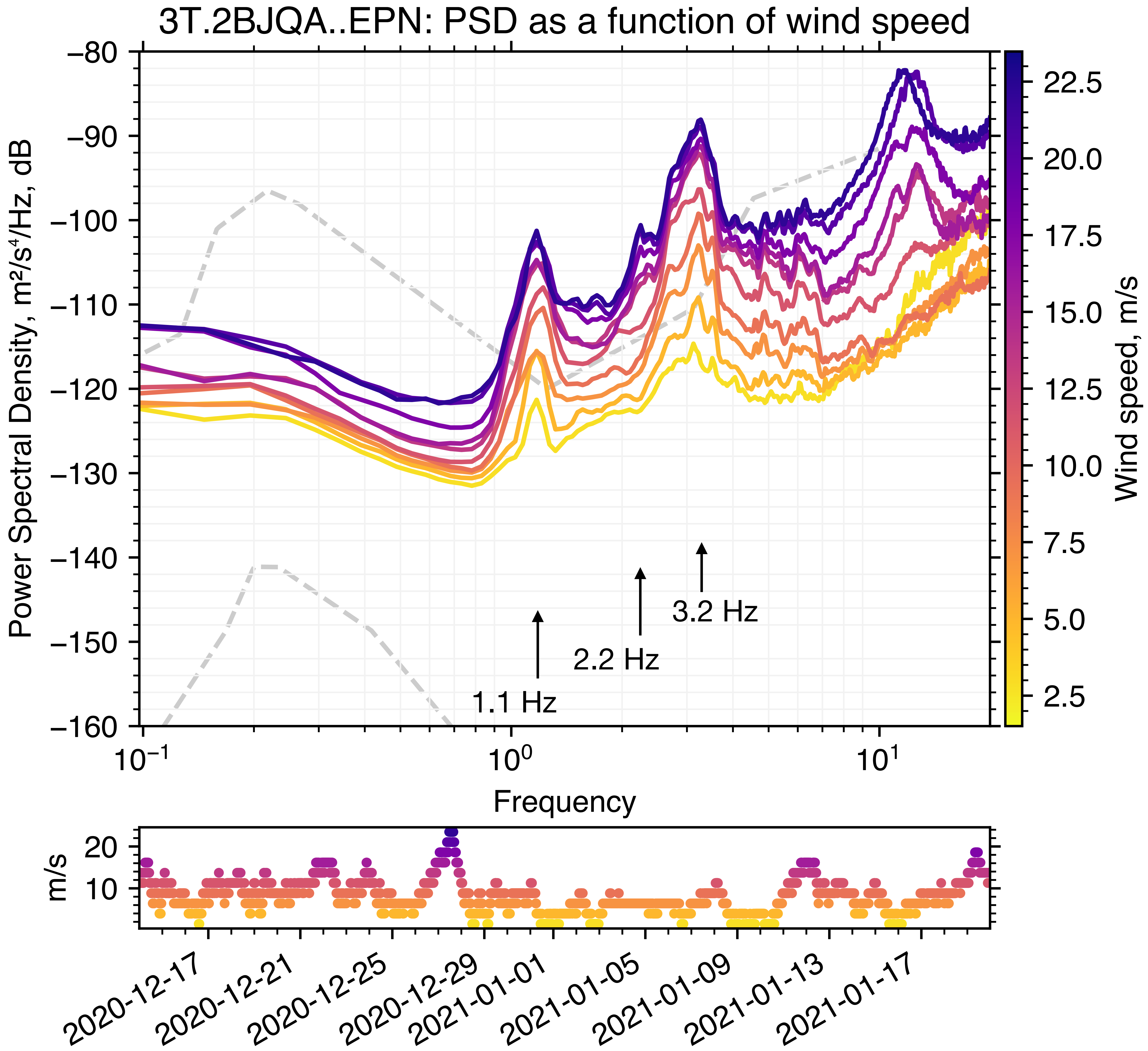

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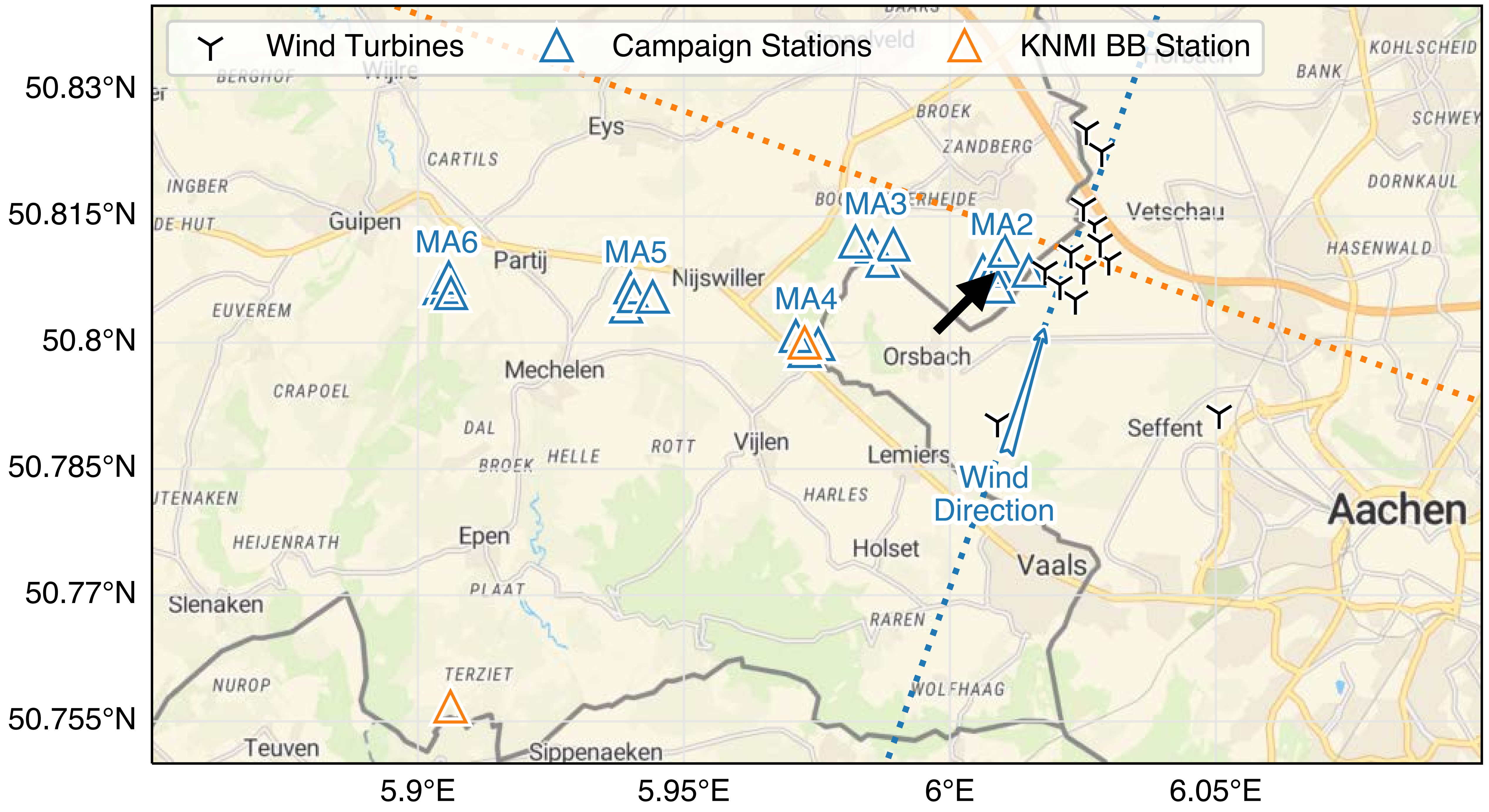

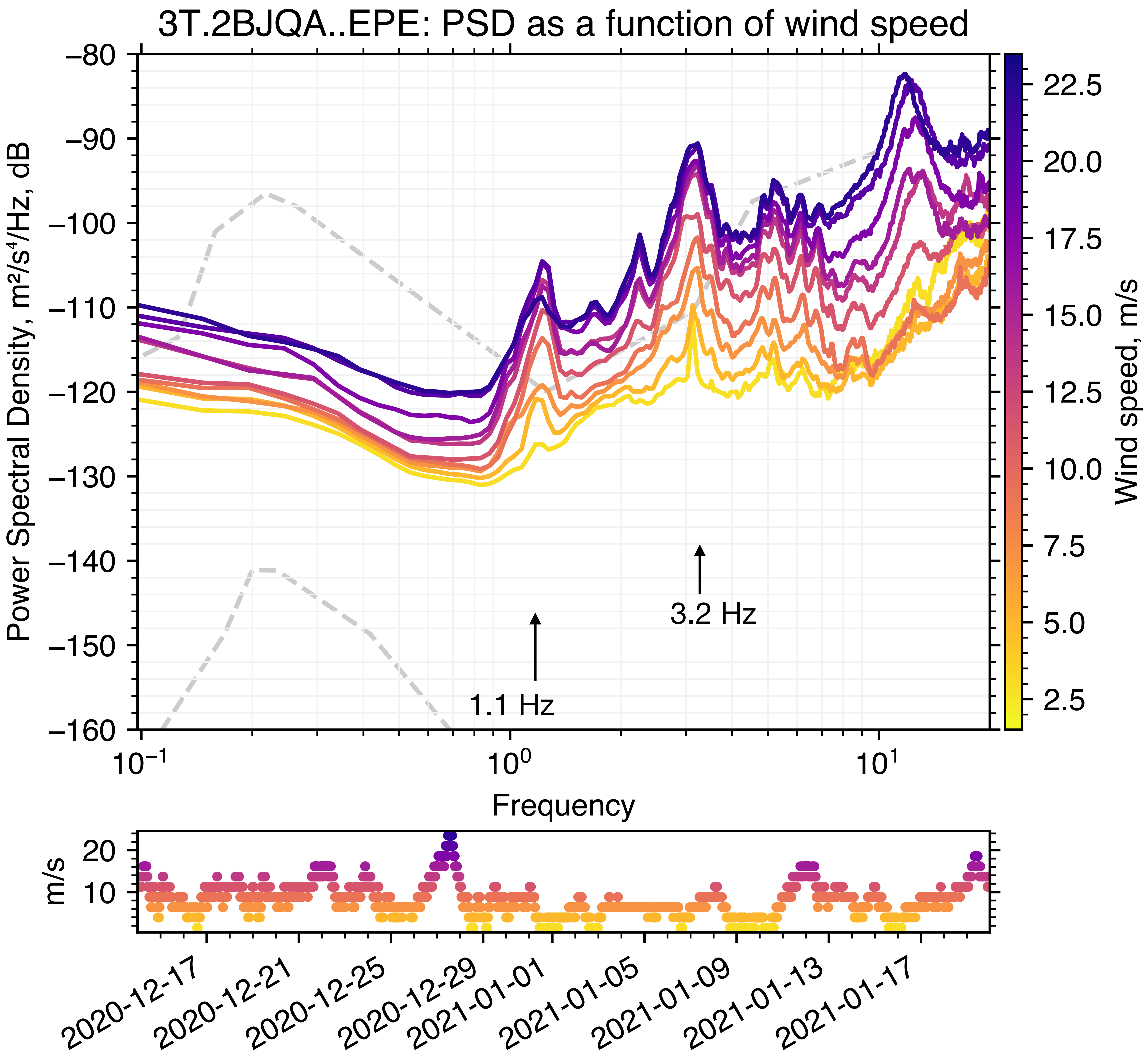

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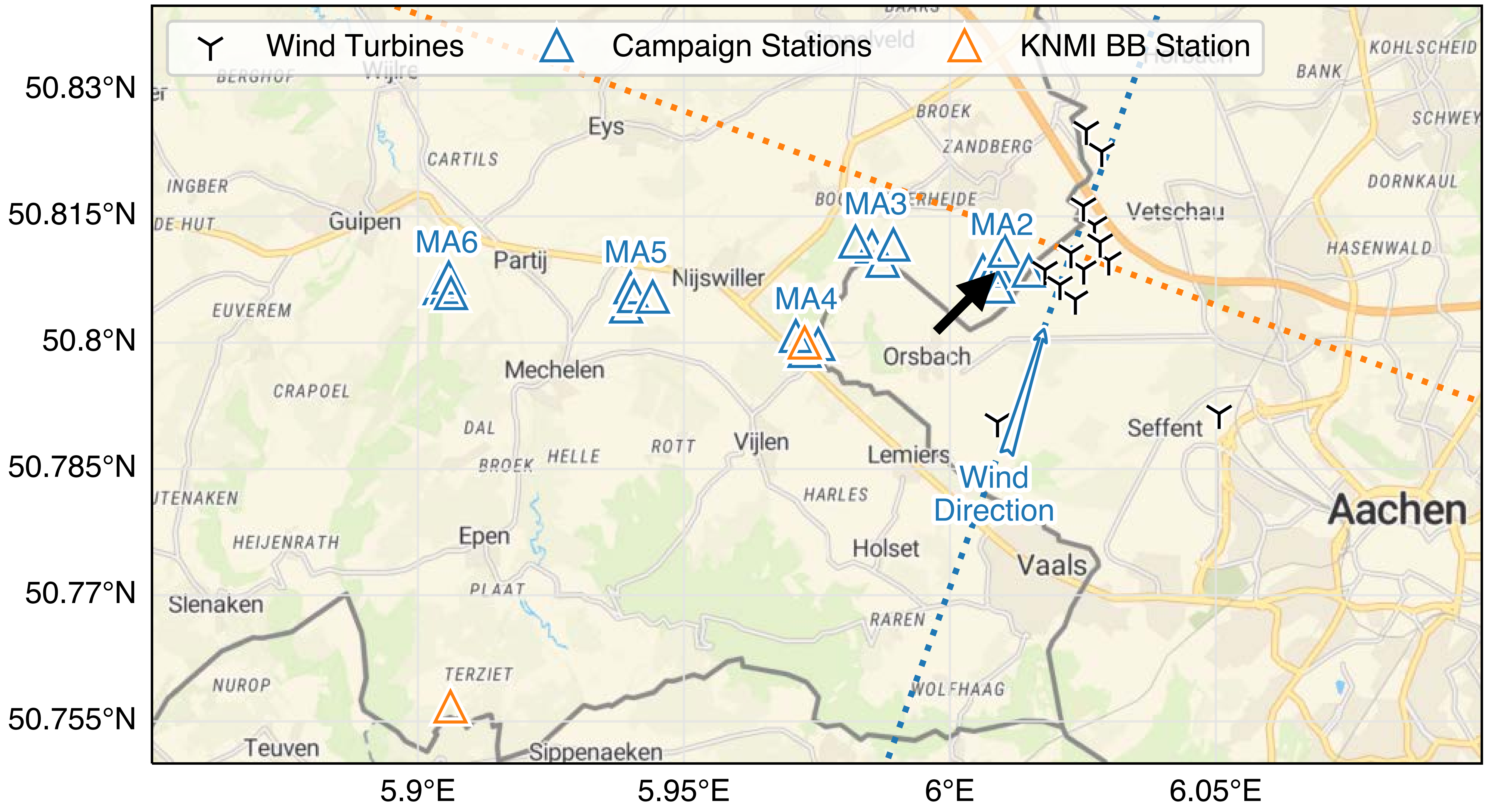

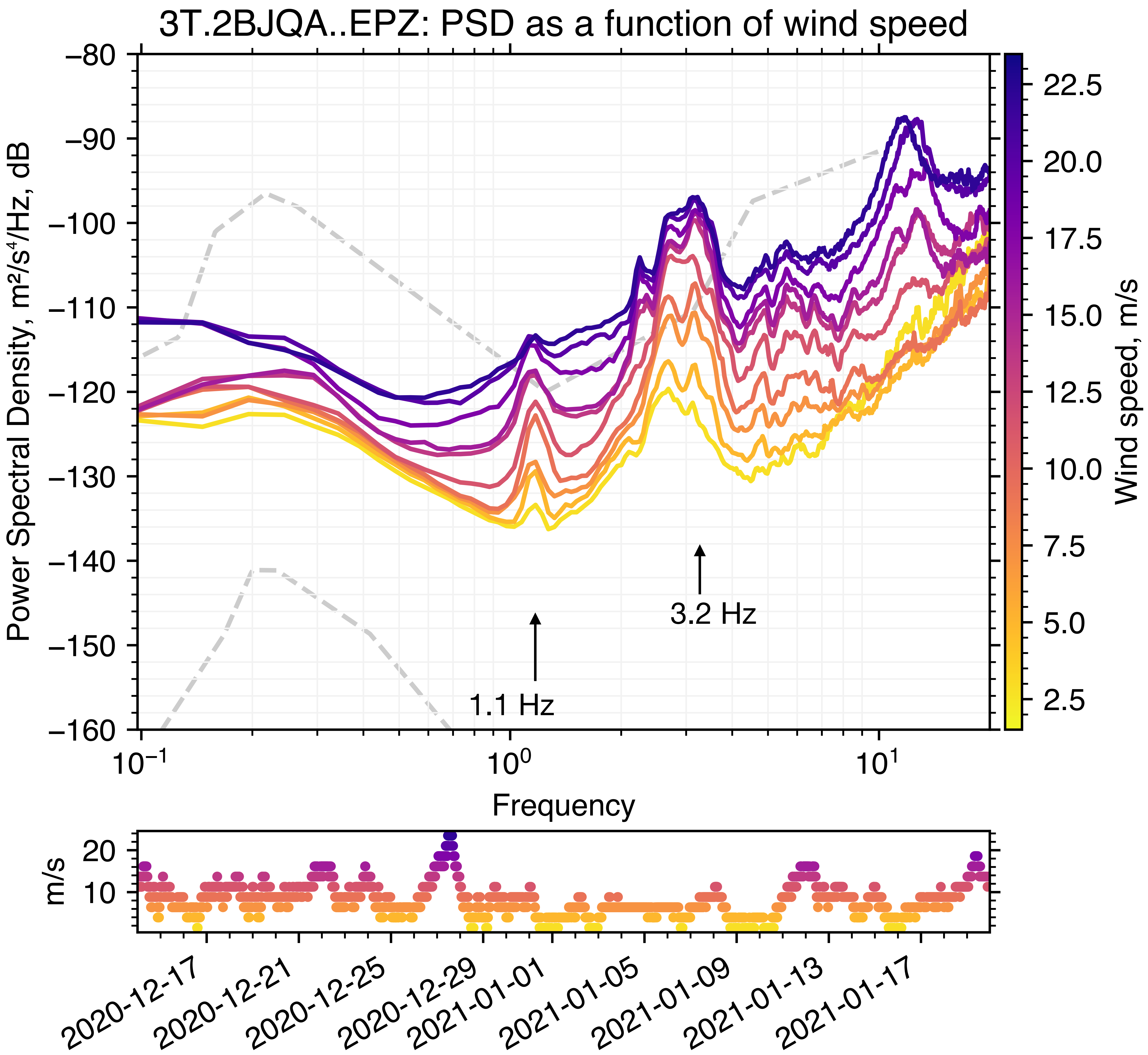

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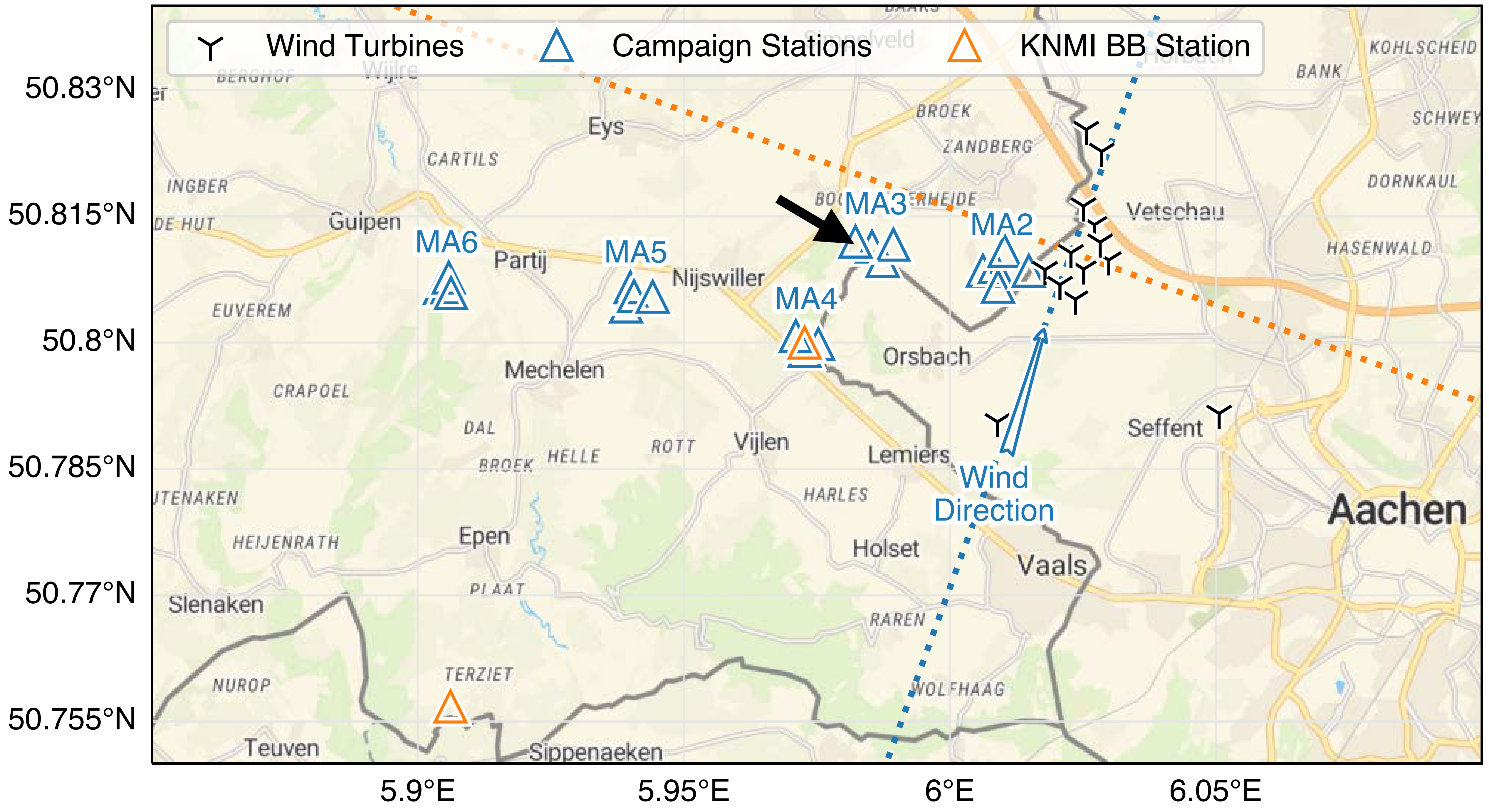

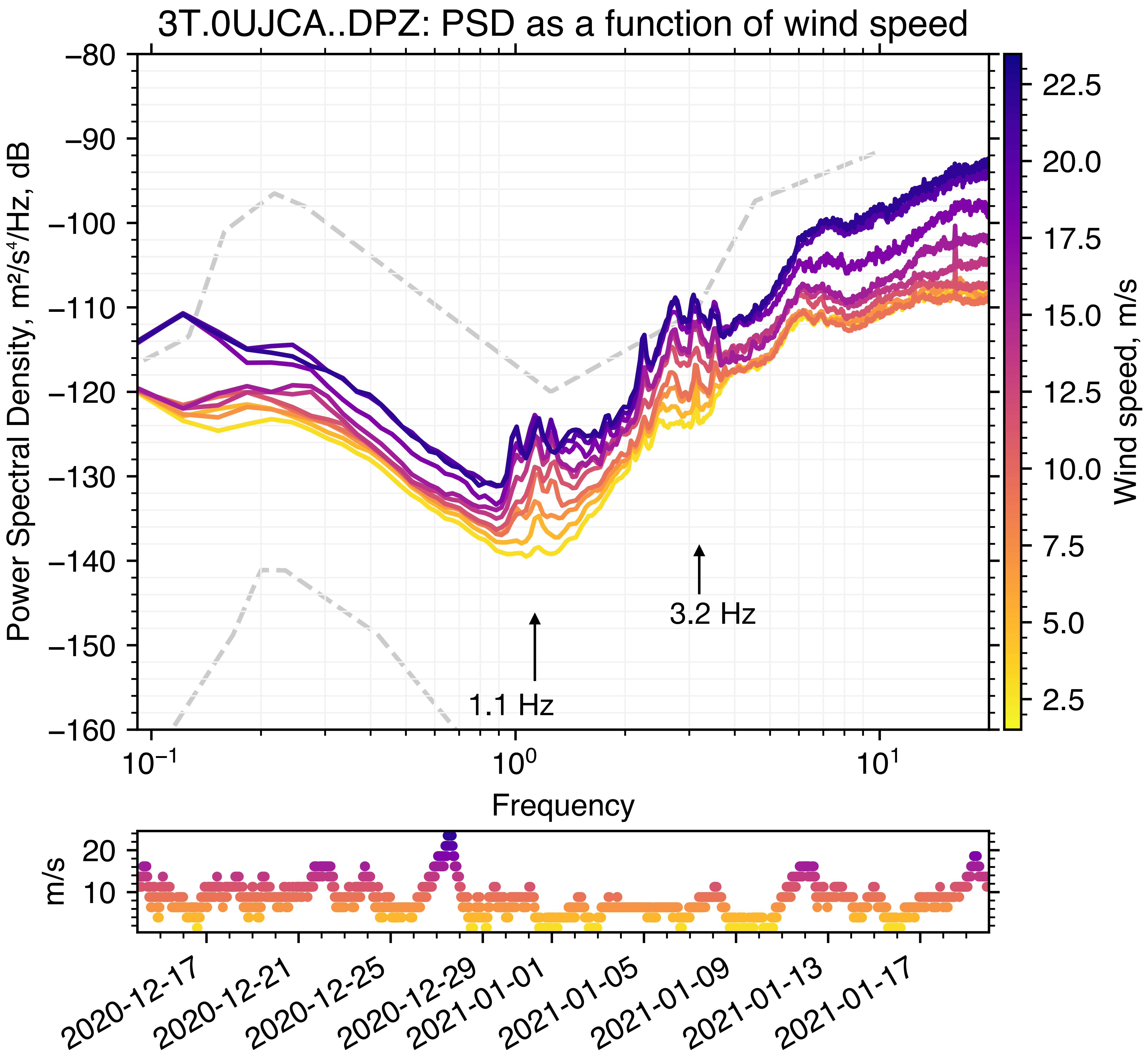

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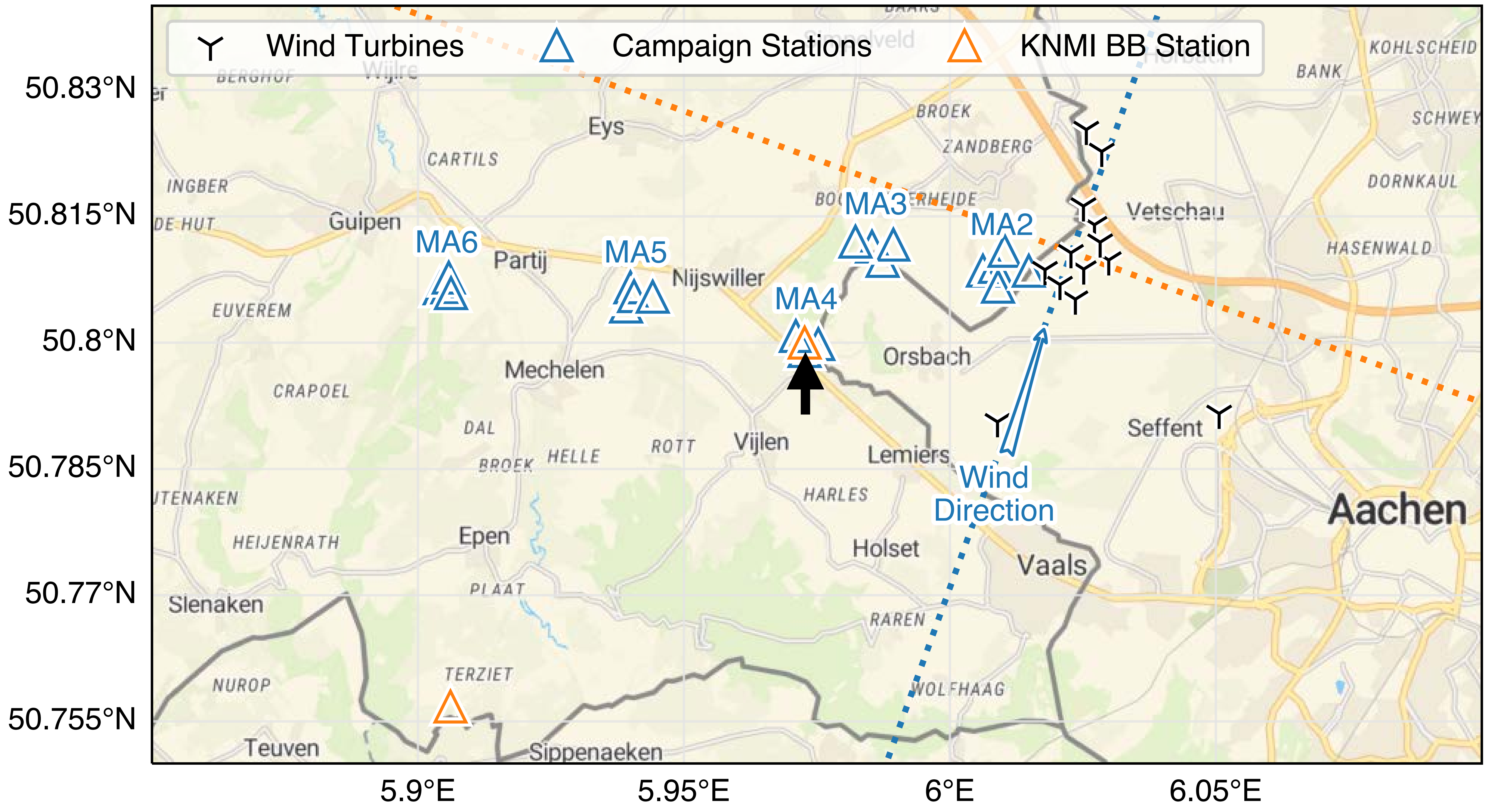

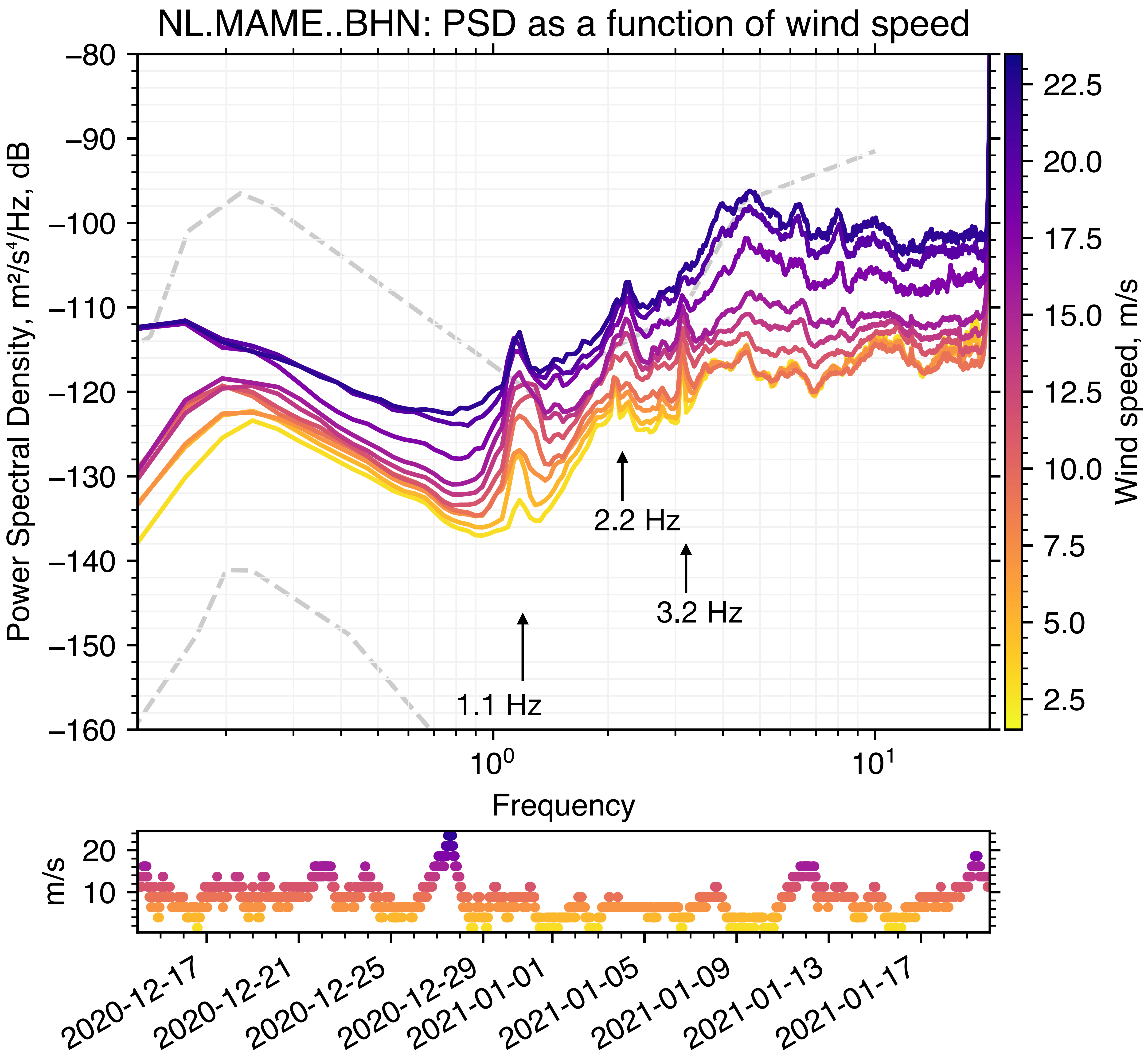

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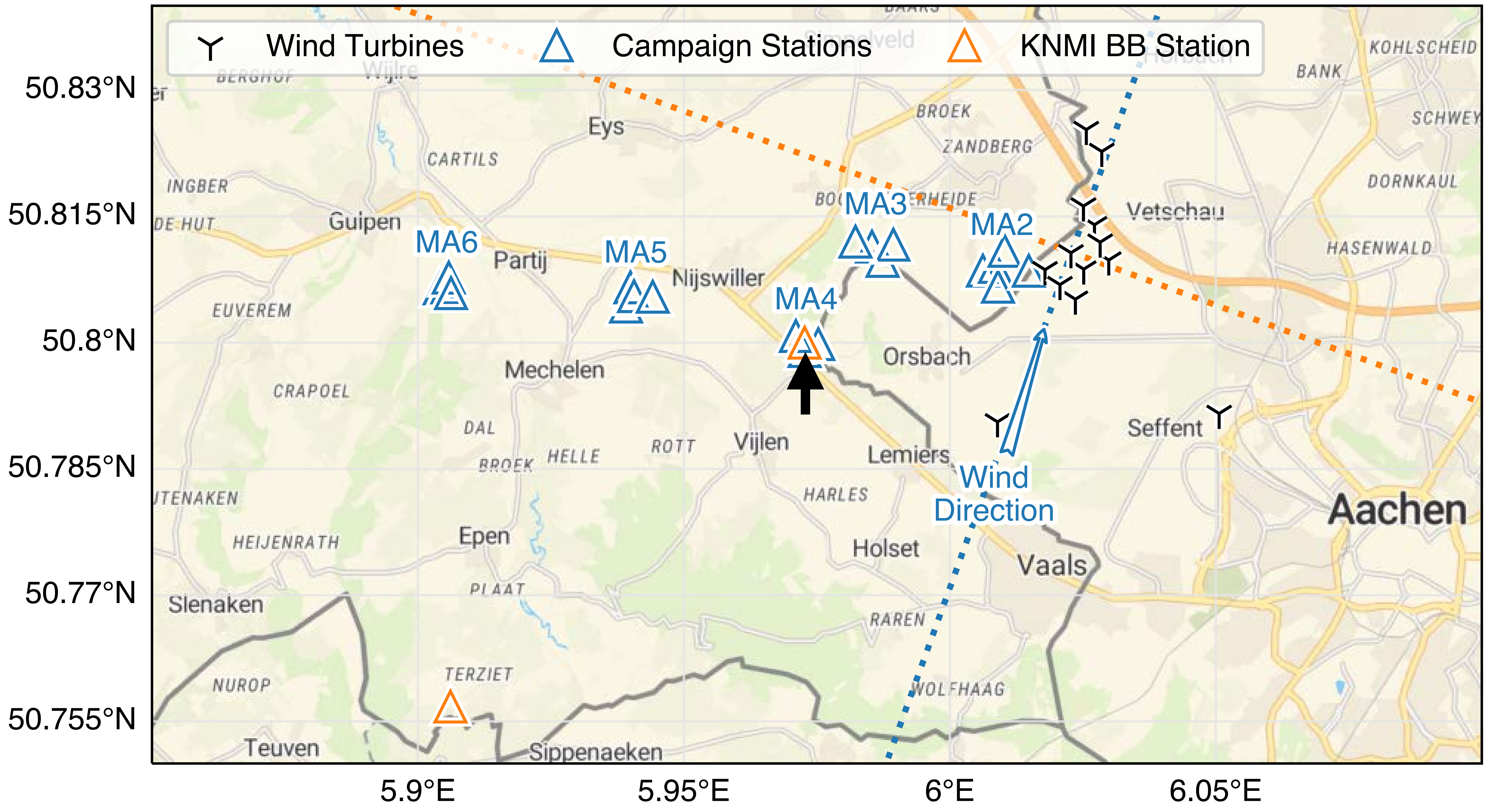

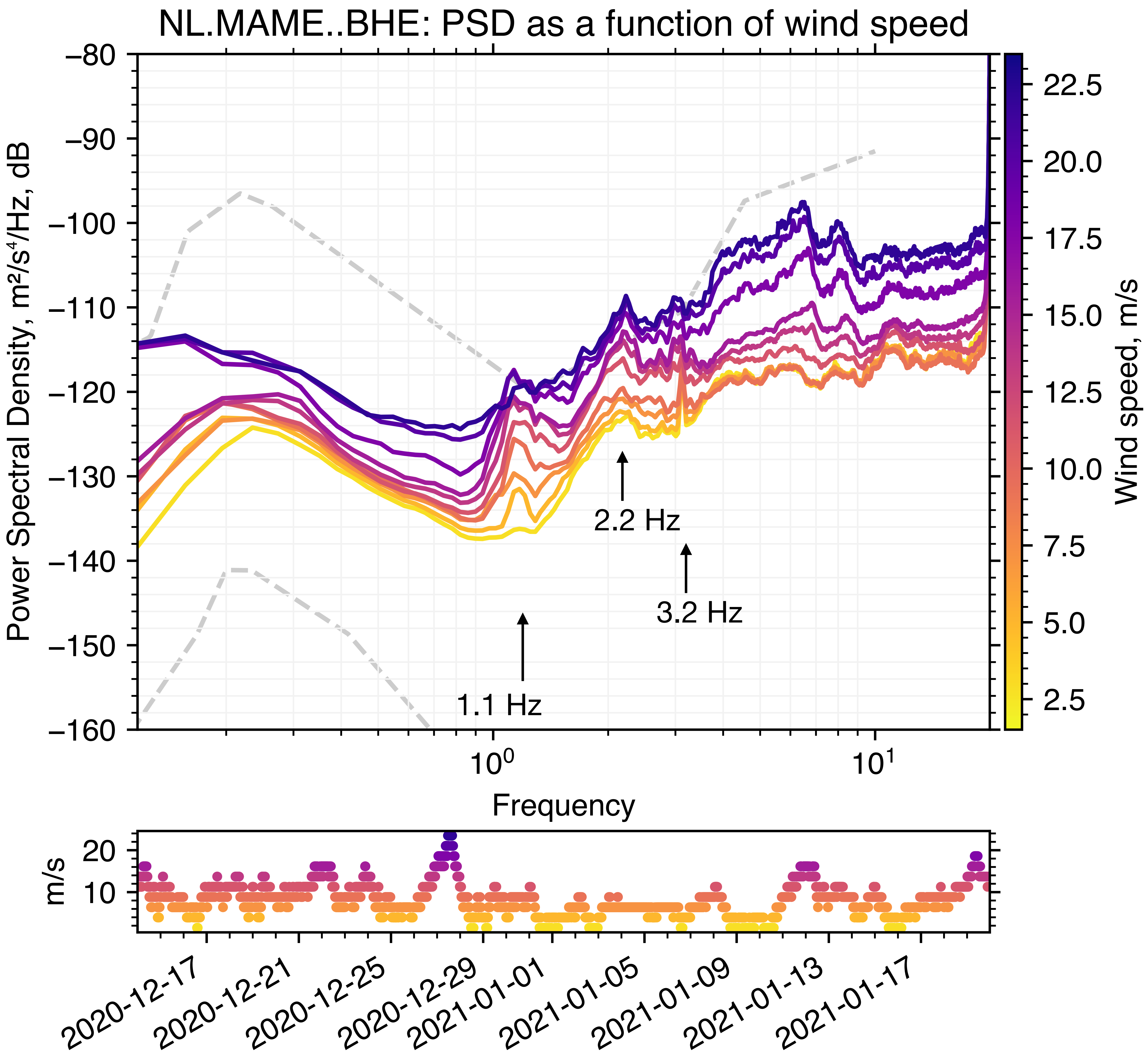

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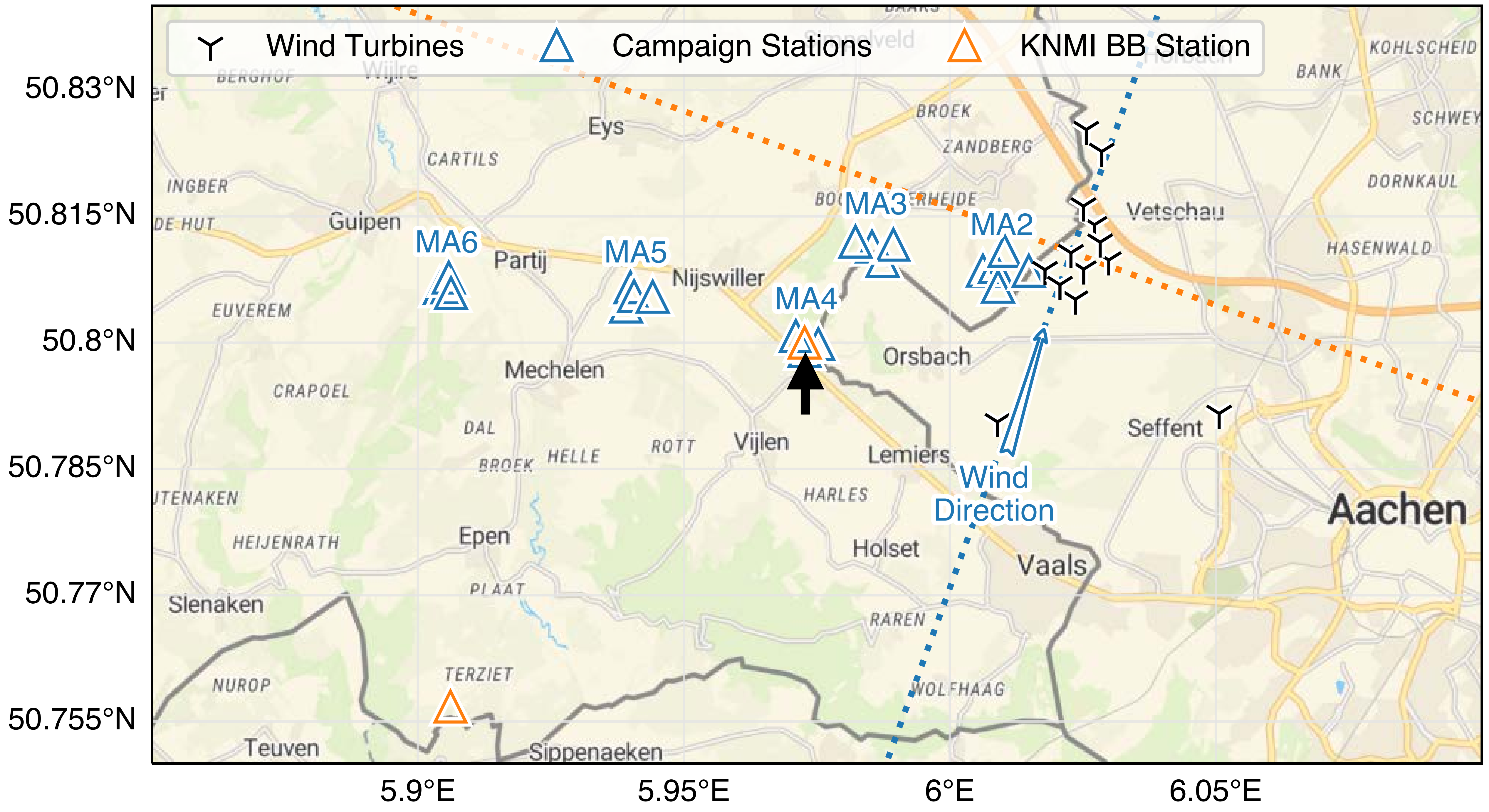

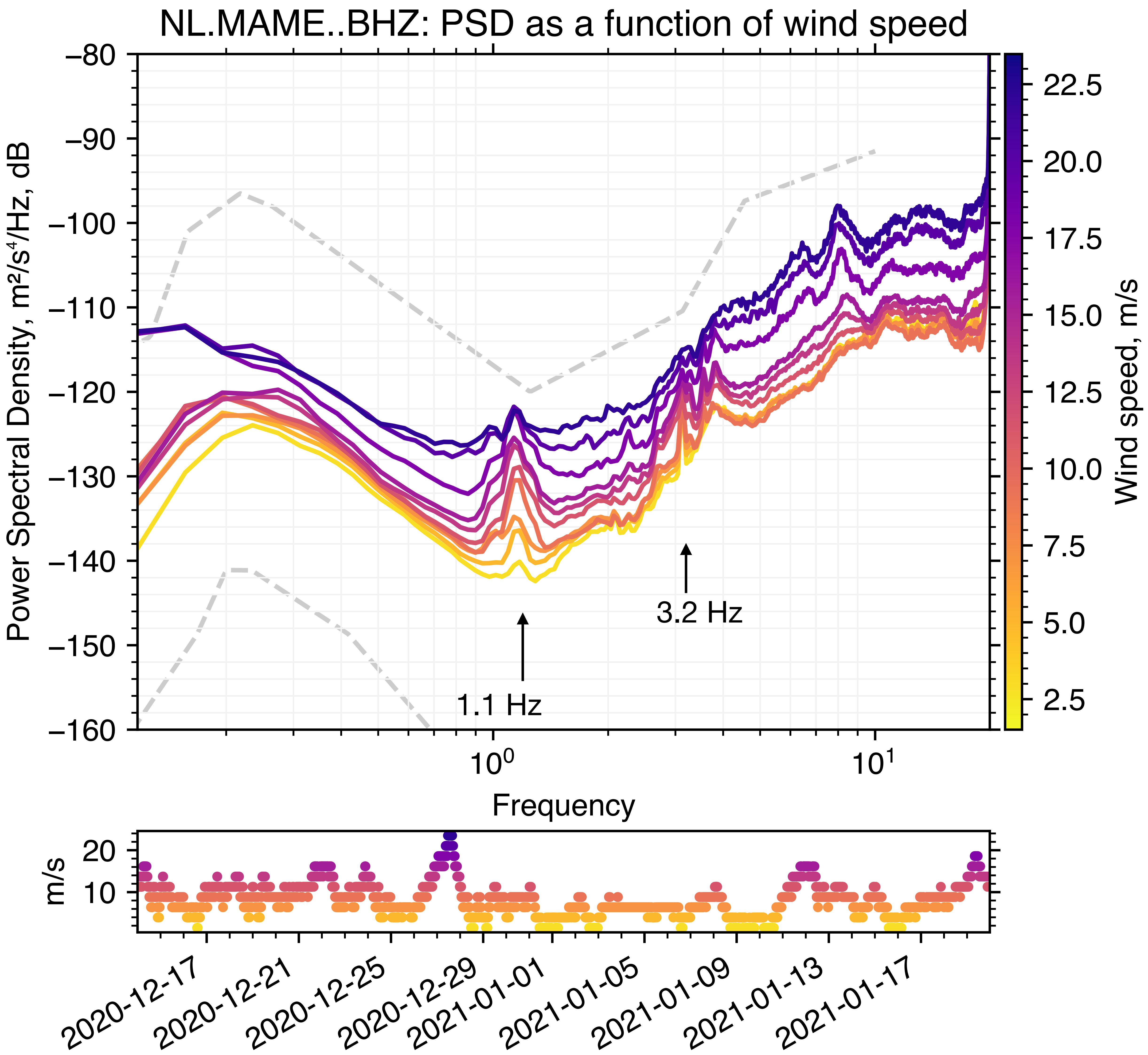

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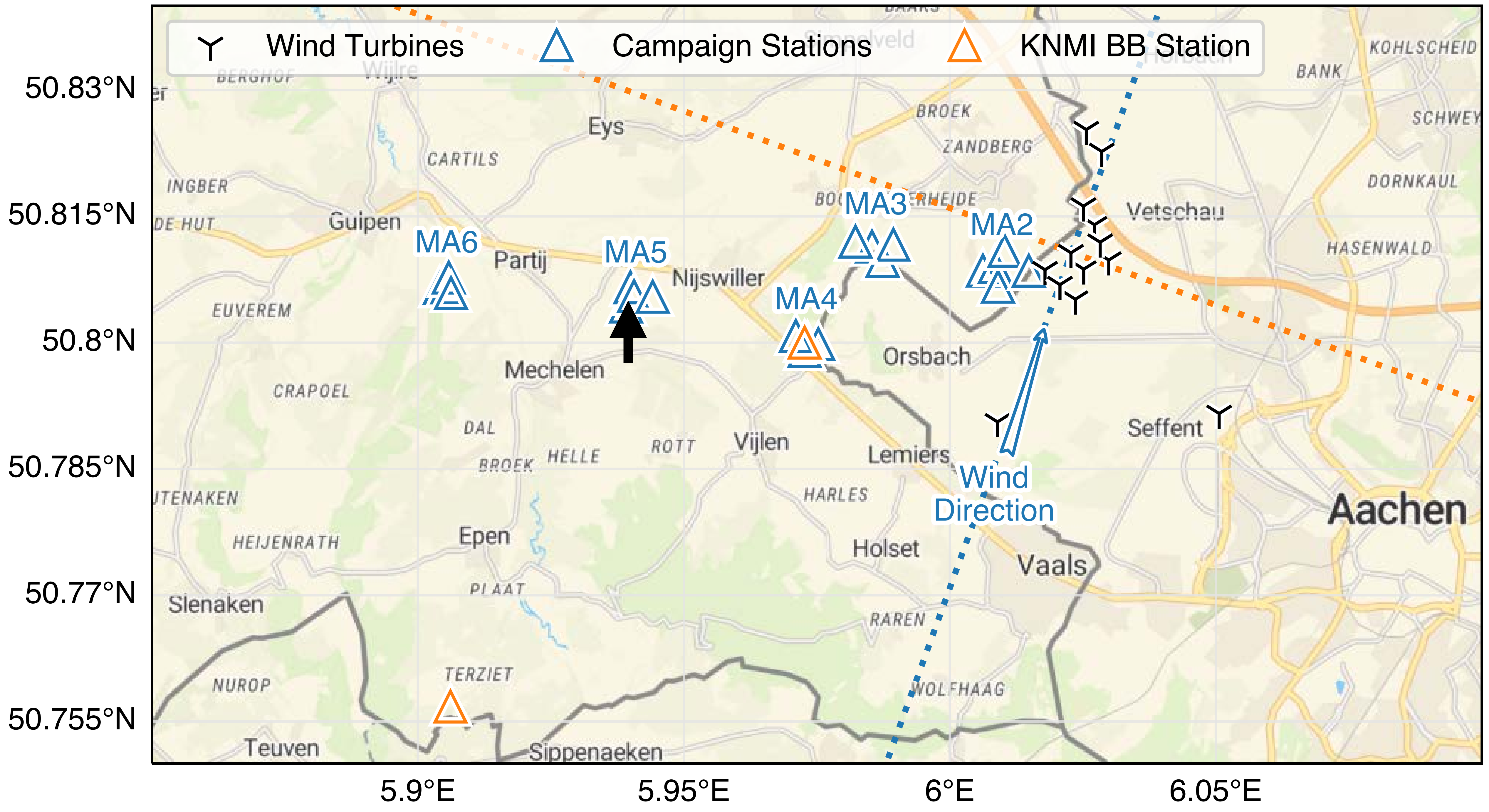

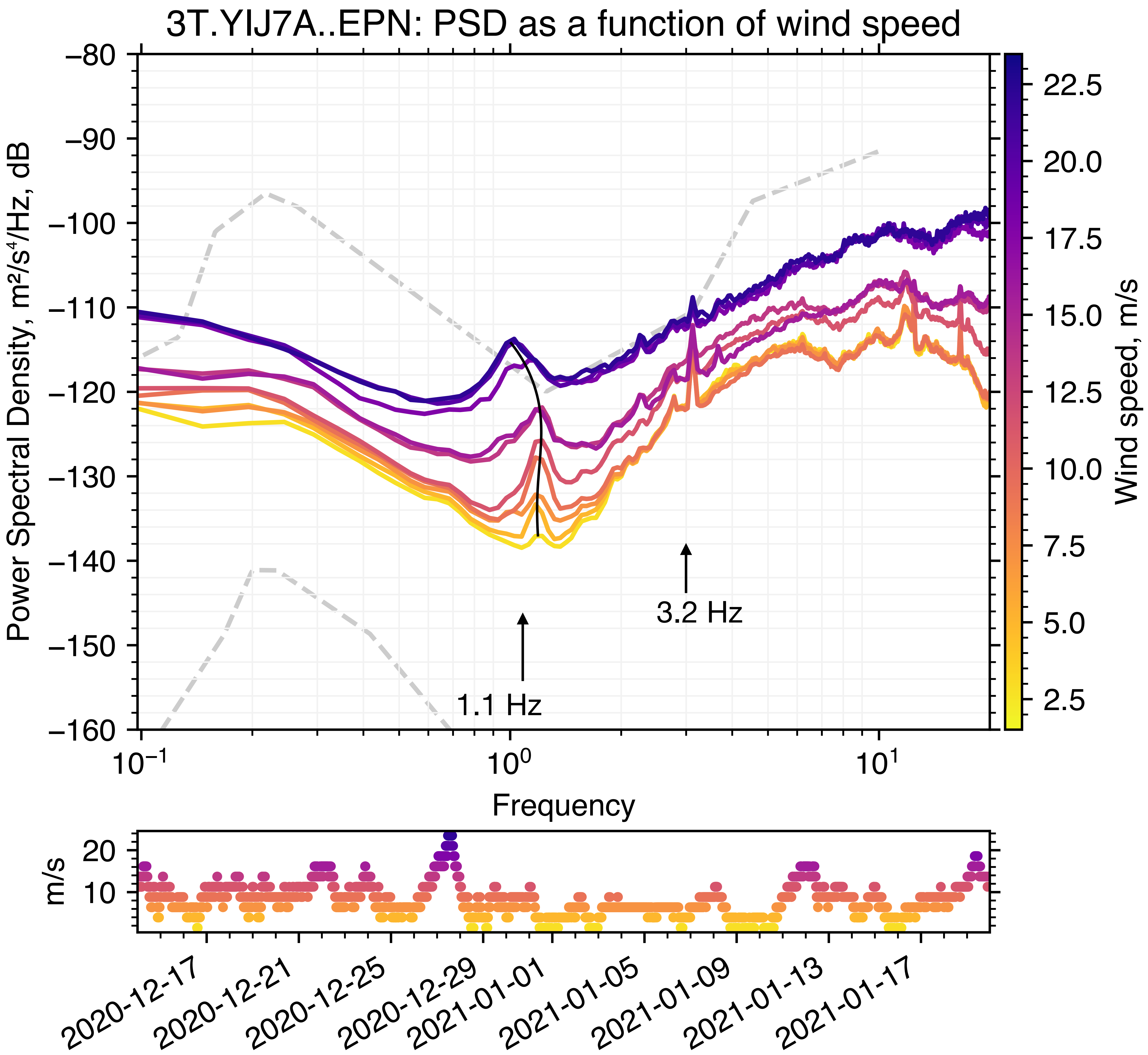

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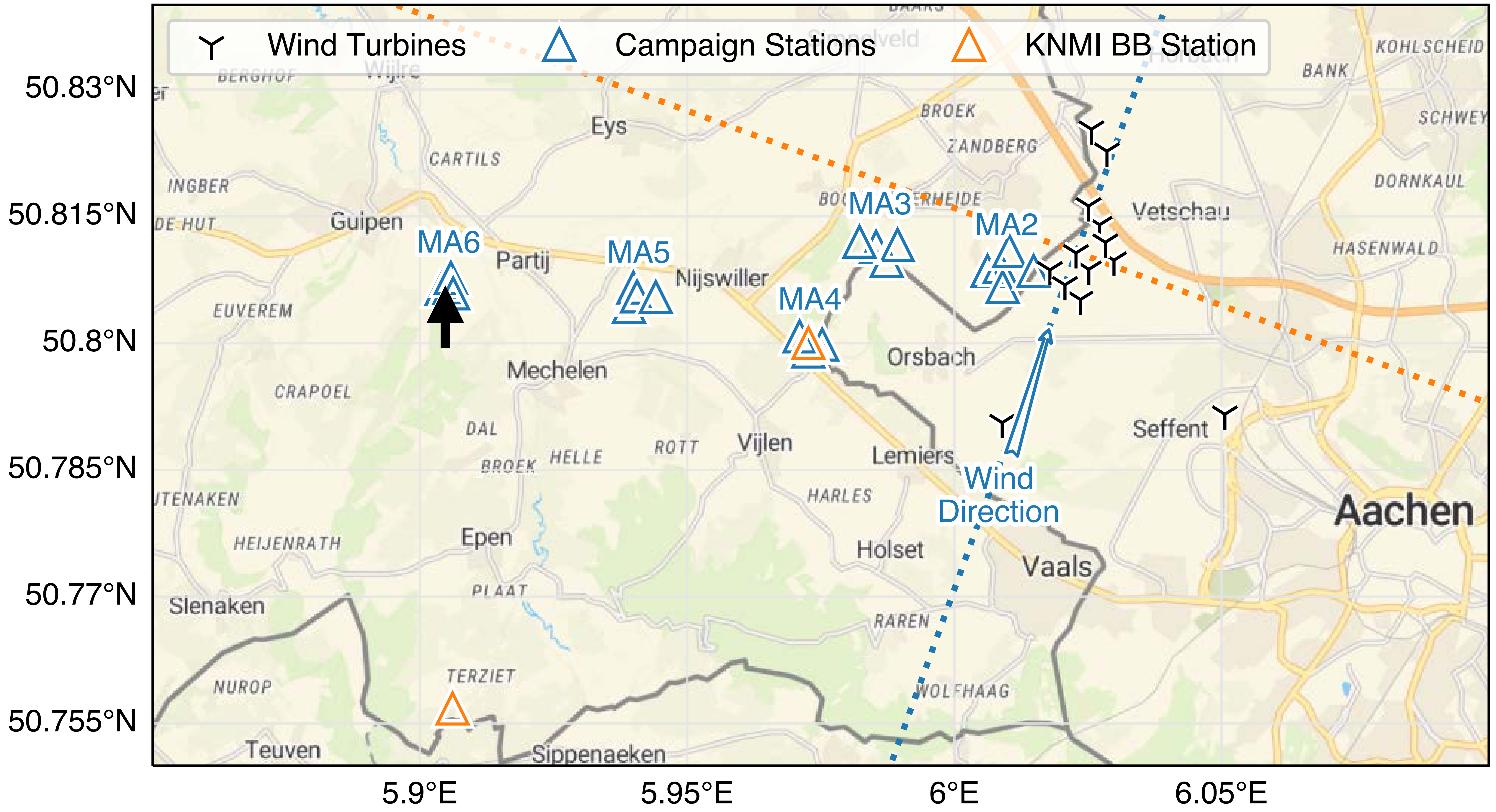

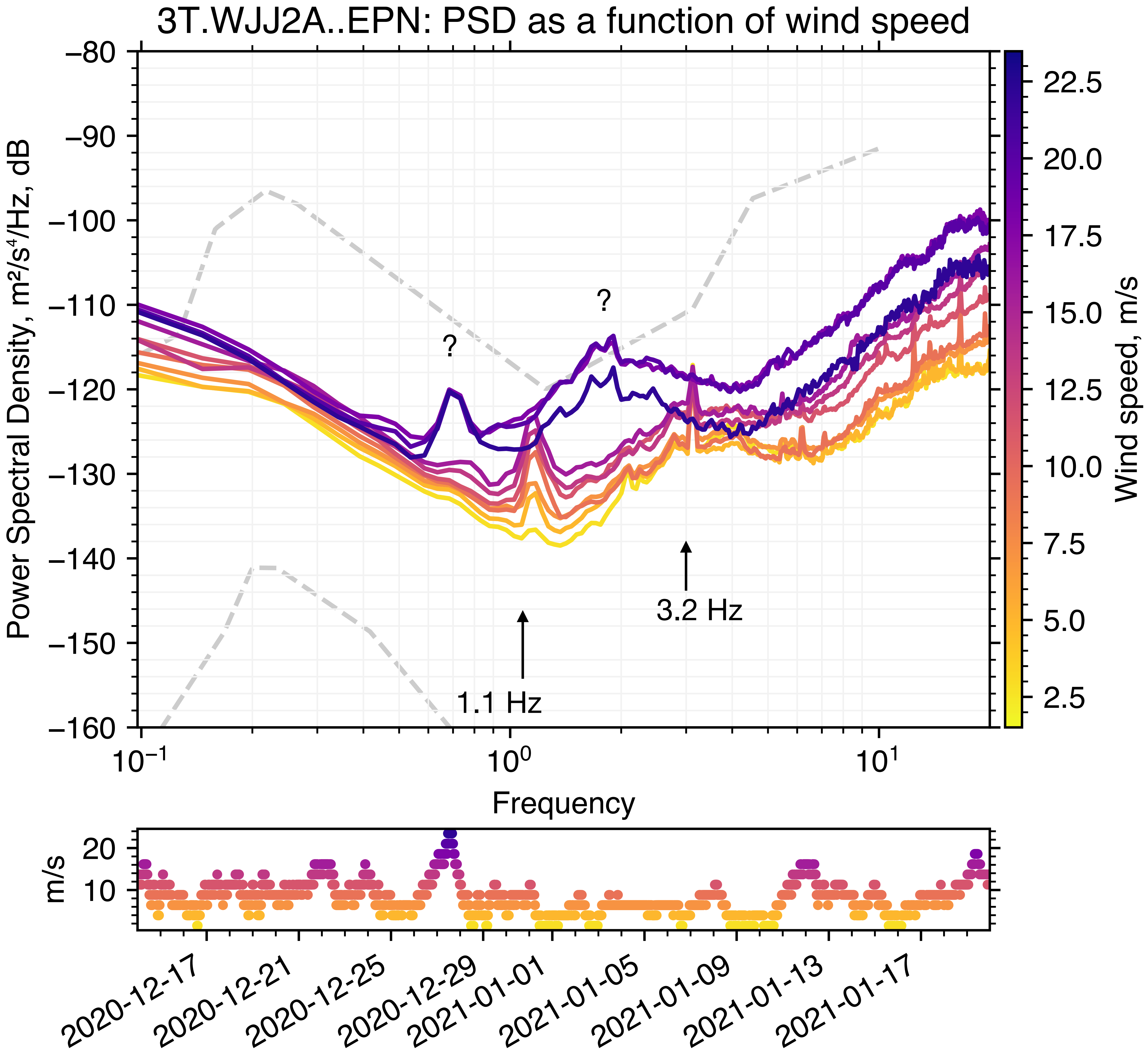

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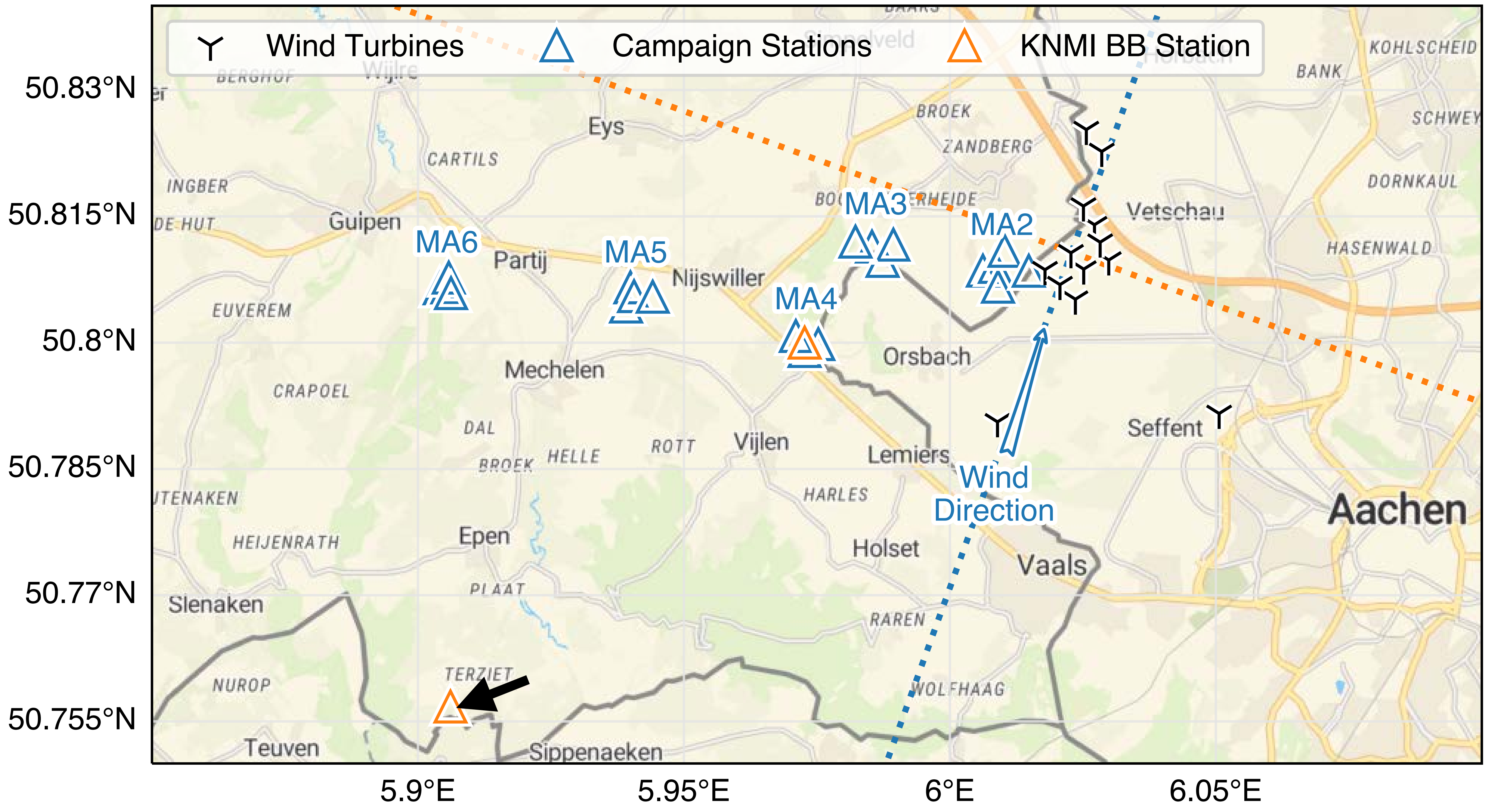
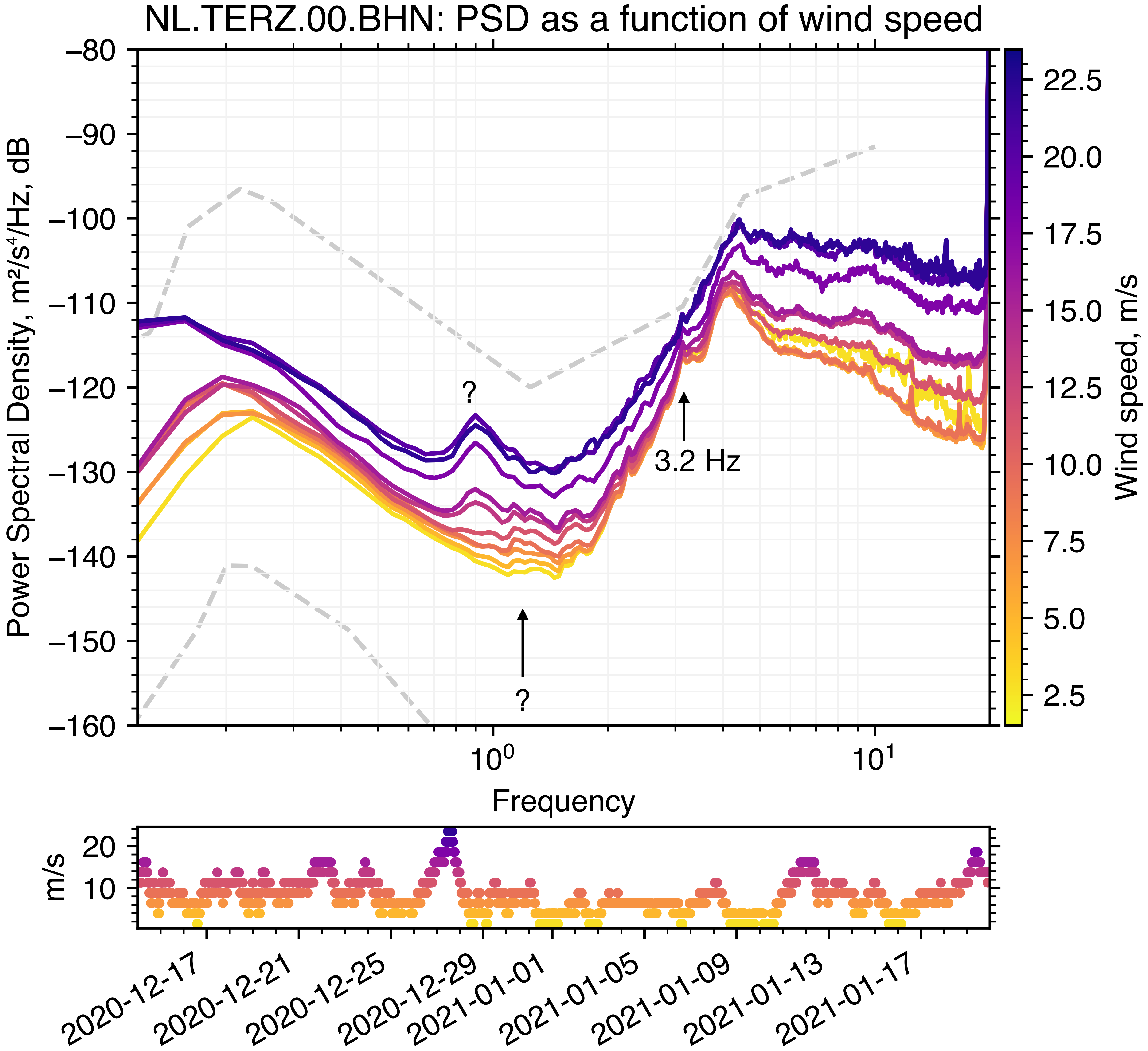
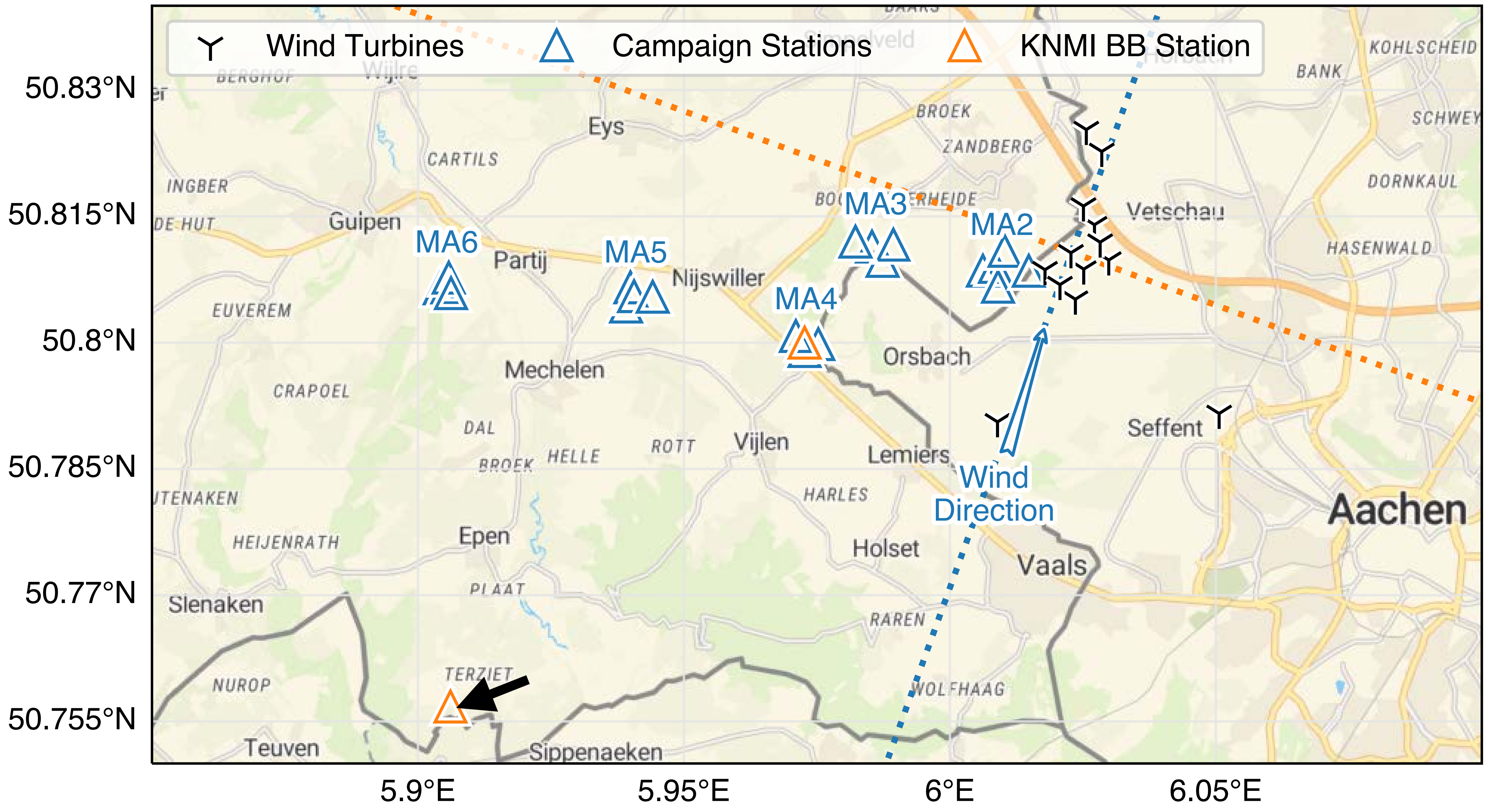
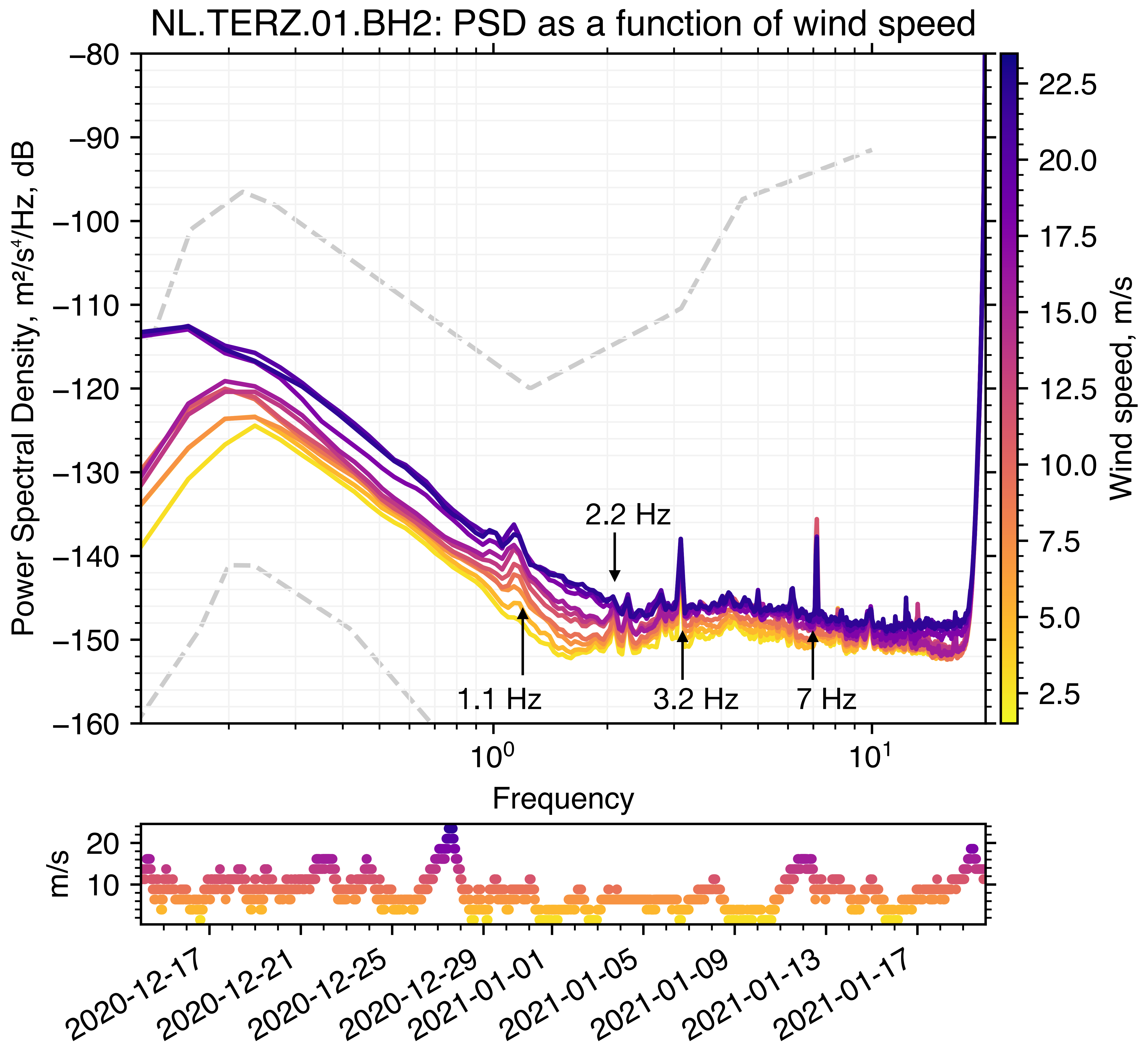


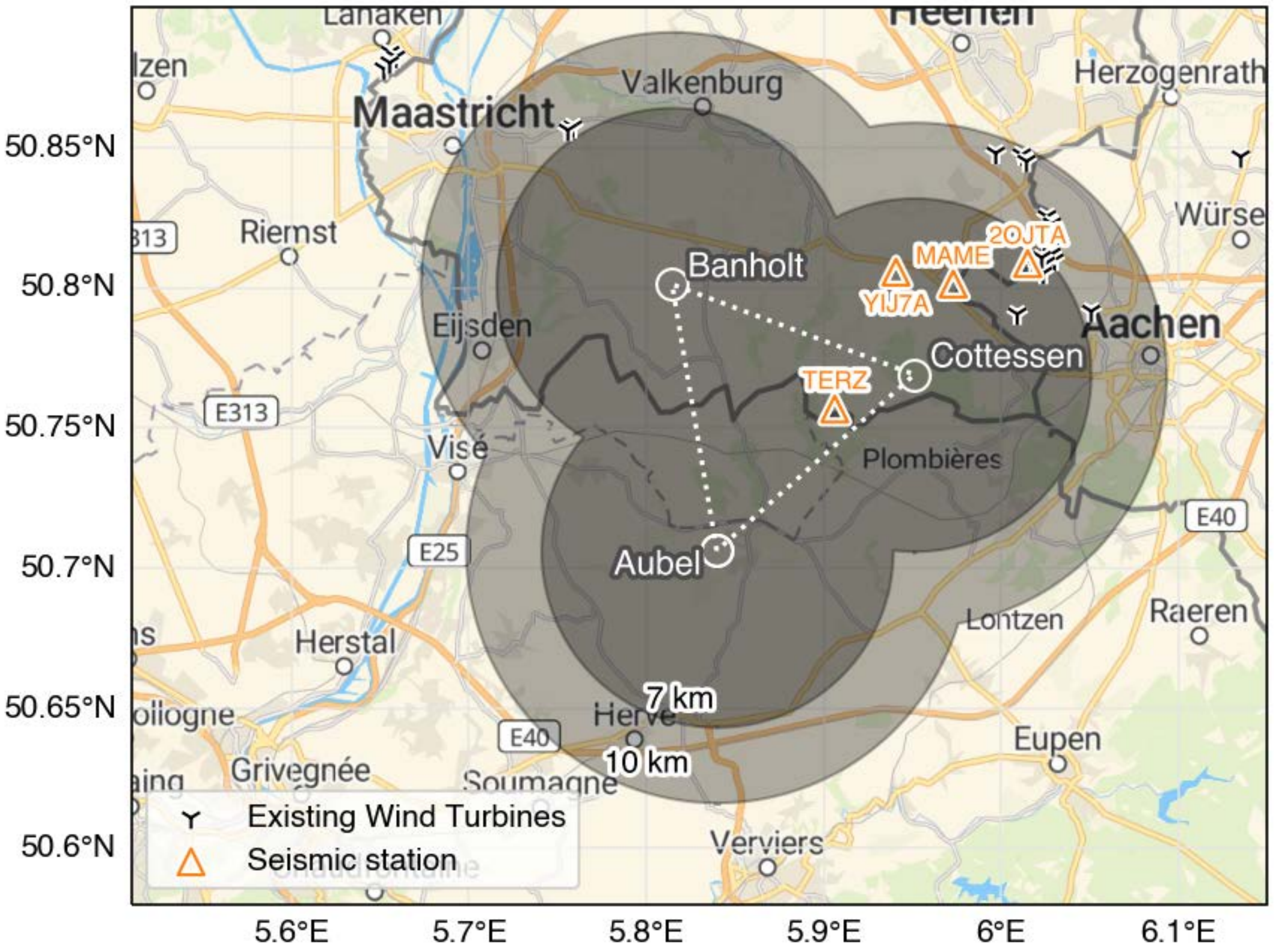


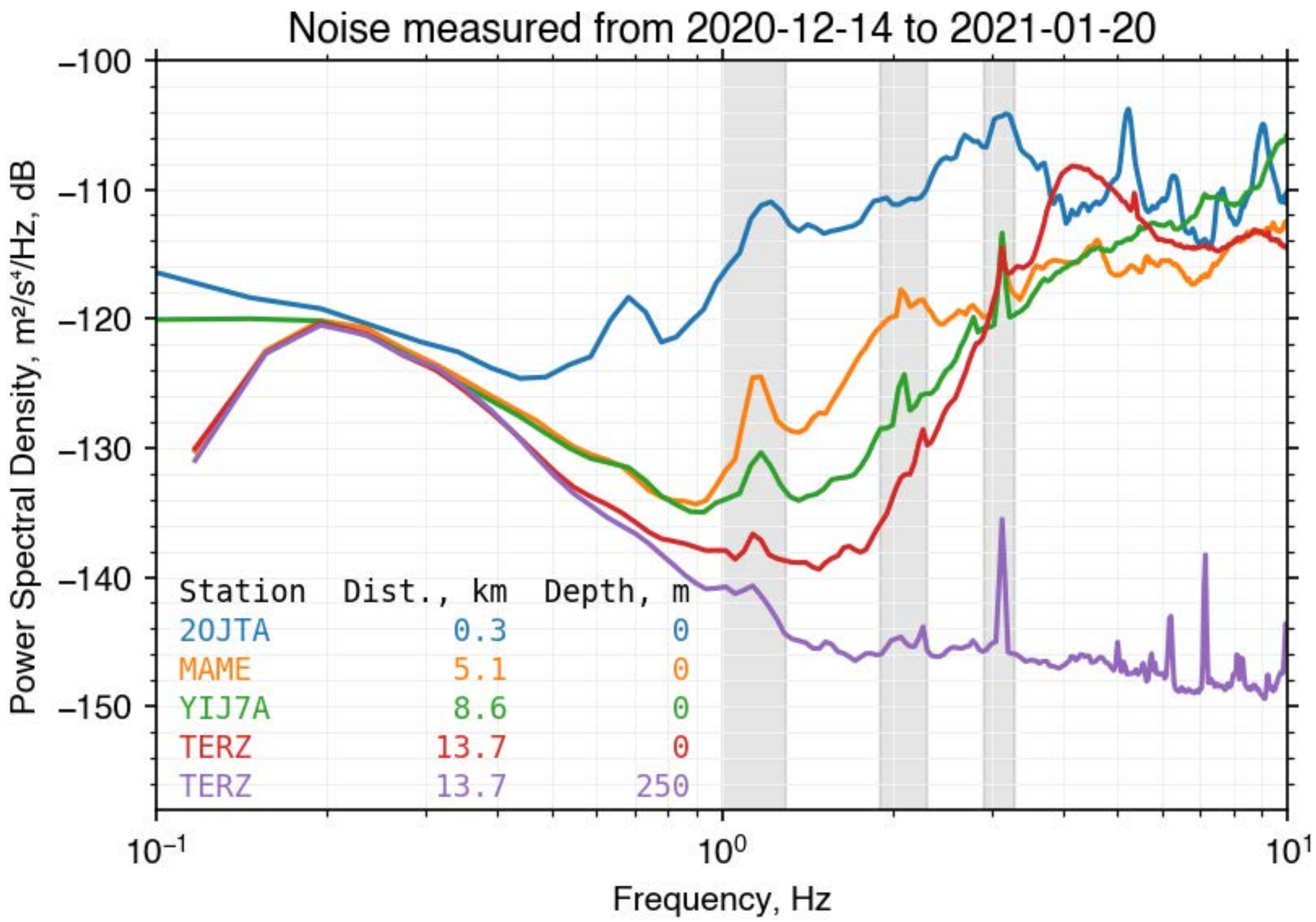
Results: PSD vs Wind Speed





Buffer zones around the potential corner points

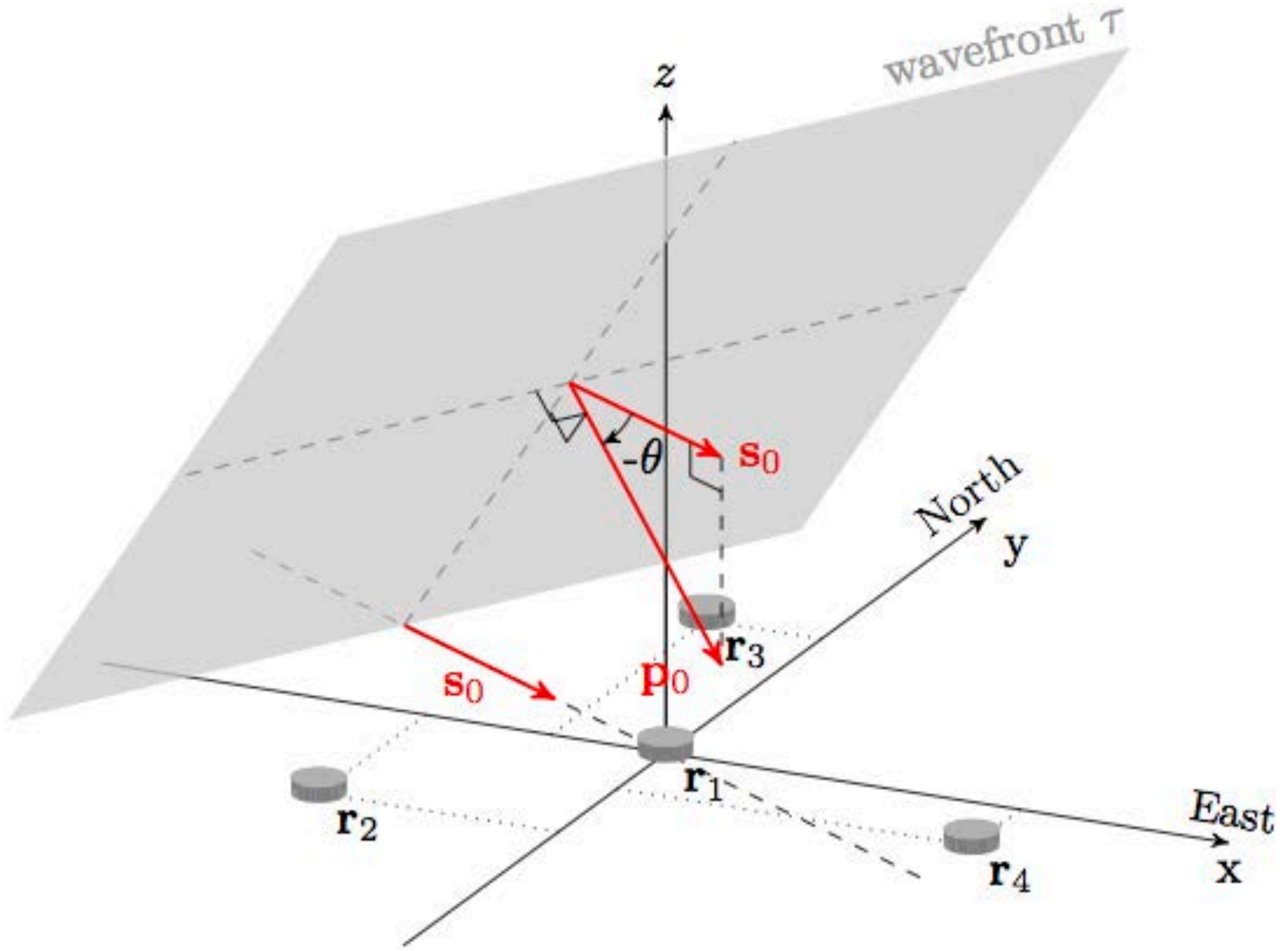


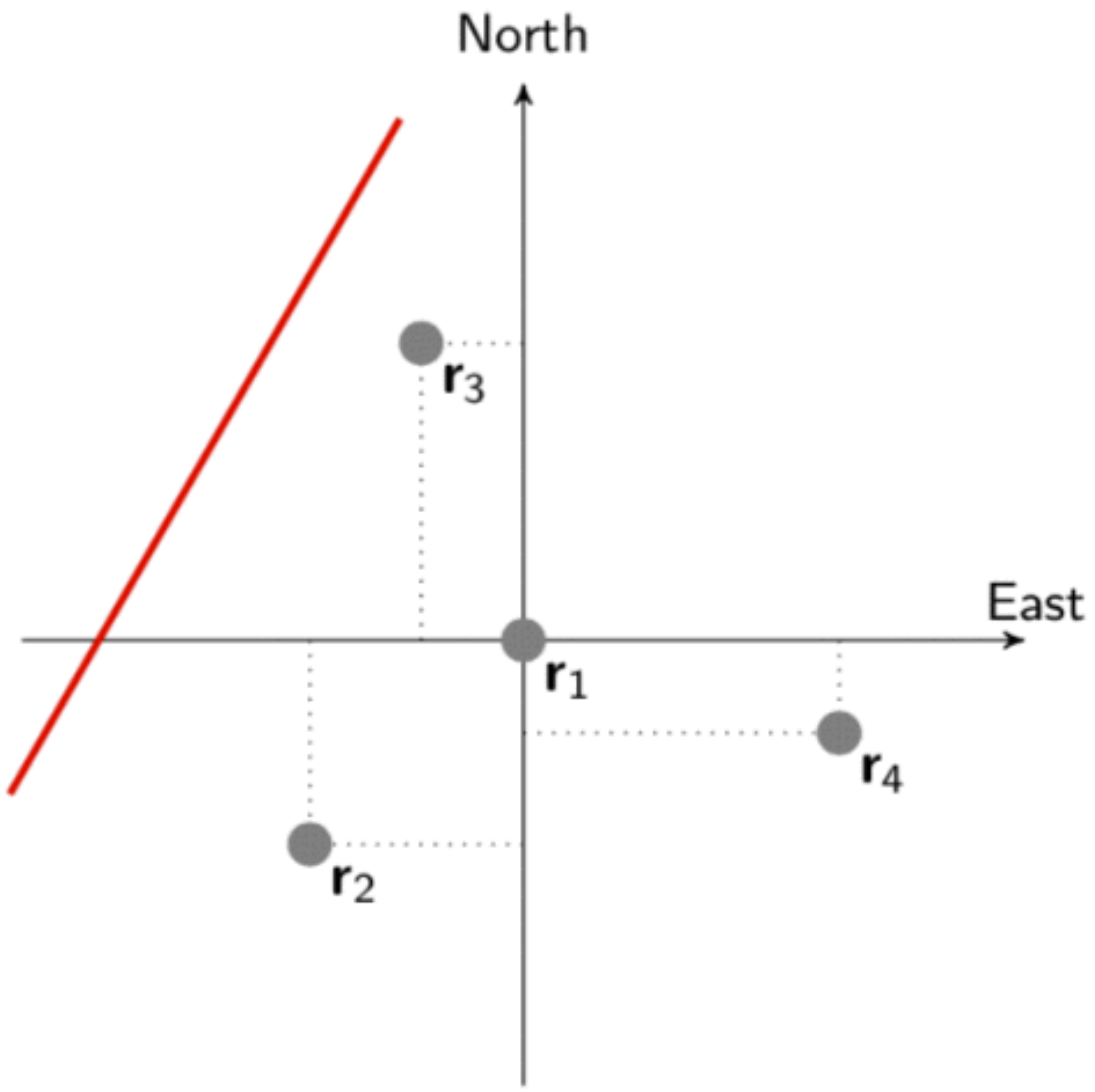


Results: Beamforming

Array processing:

- Improved signal-to-noise ratio (signal summation)
- Resolve wave vector of propagating coherent signal (beamforming)

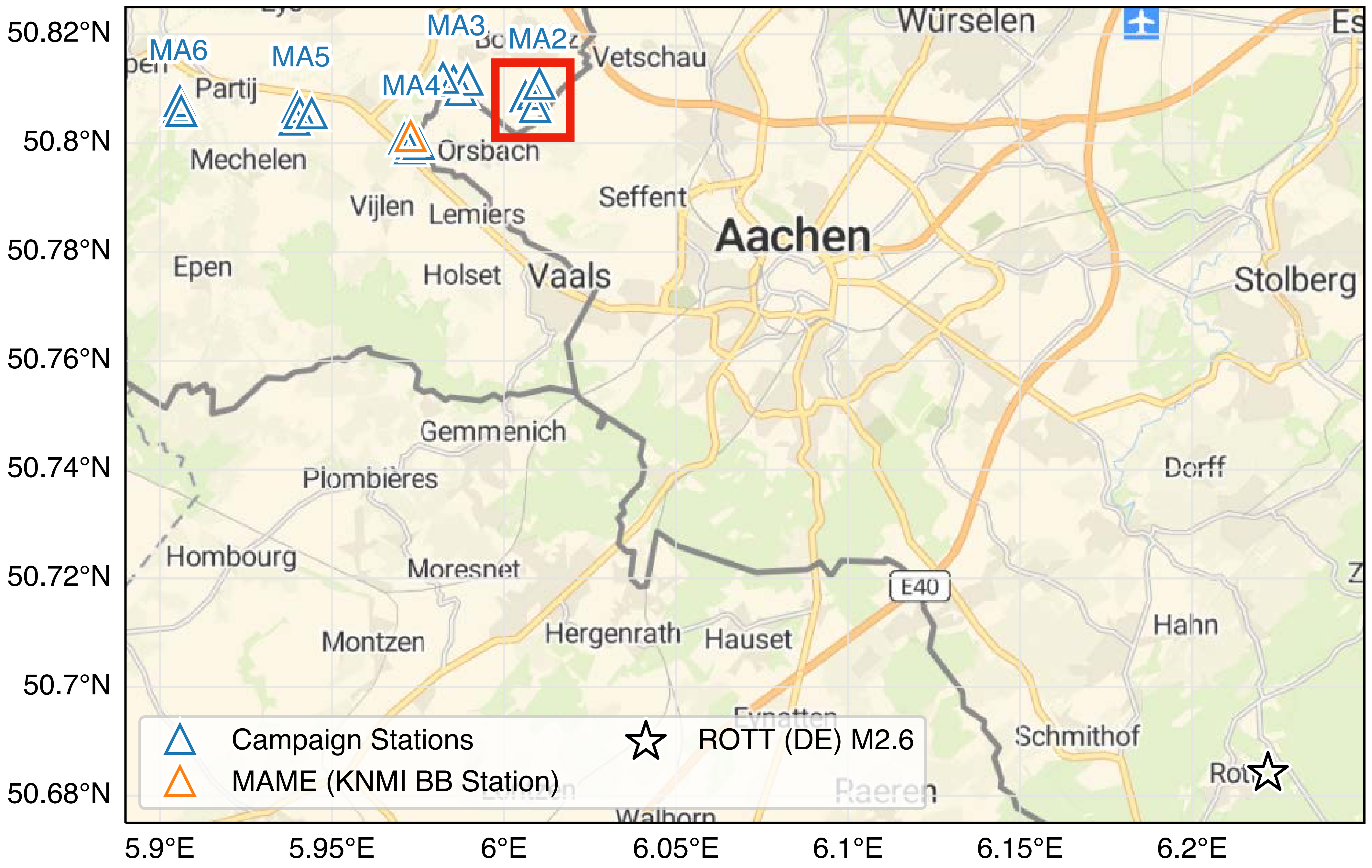


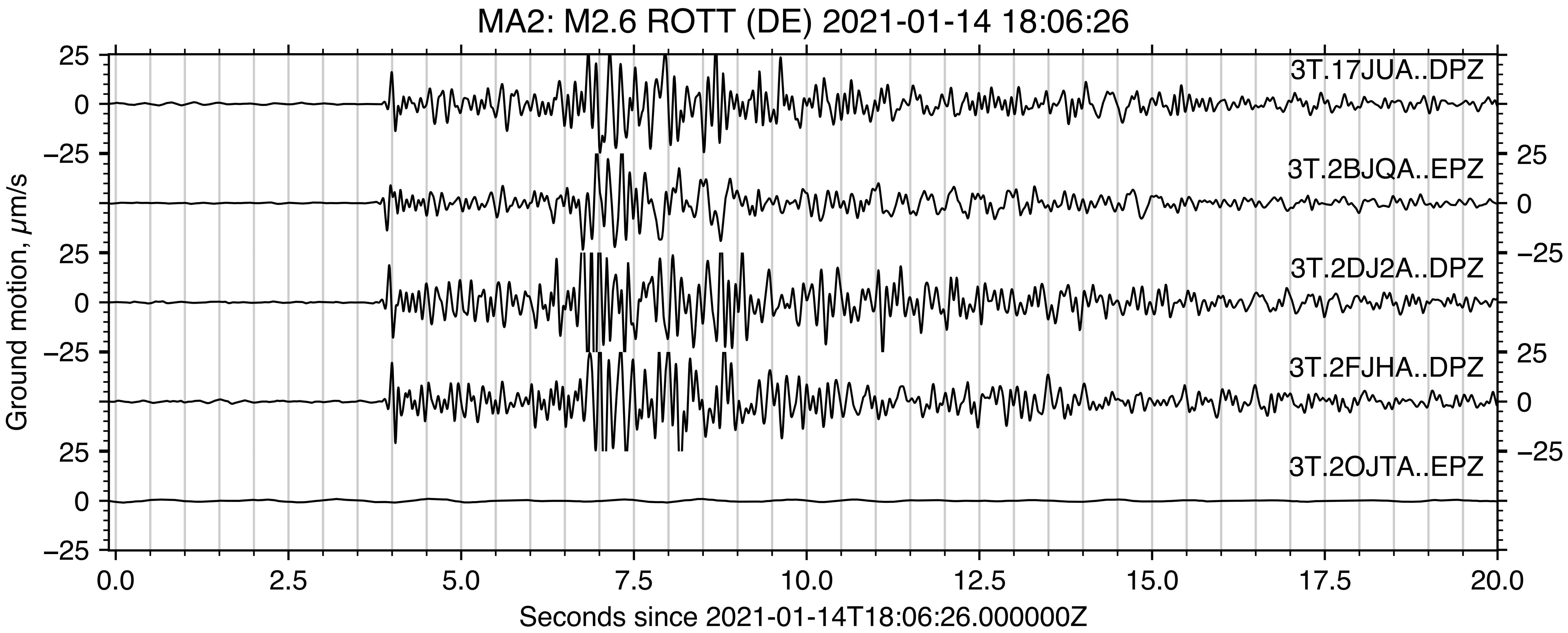


Inter-element distance >> array-event distance

Results: Beamforming

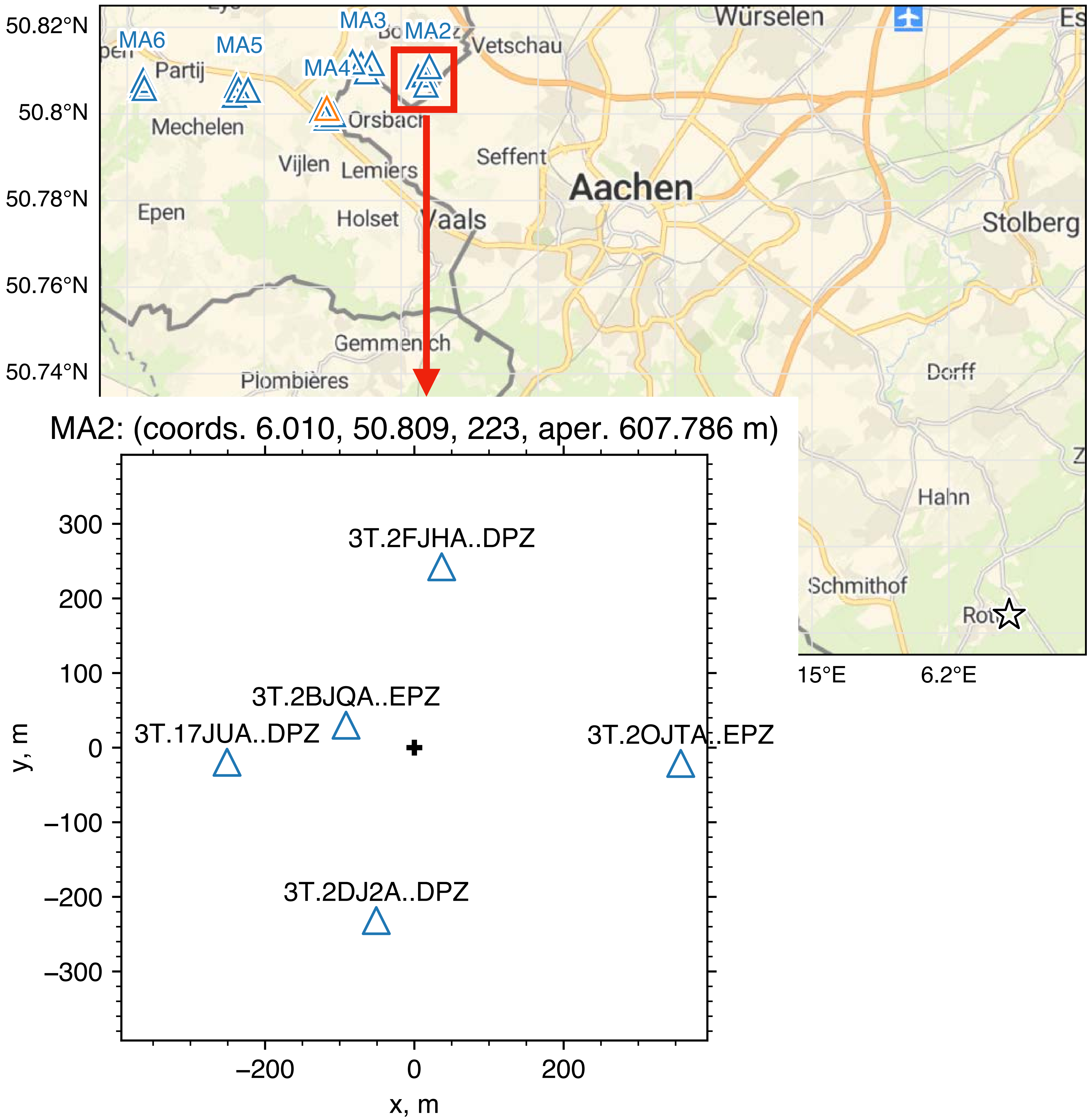
An example:

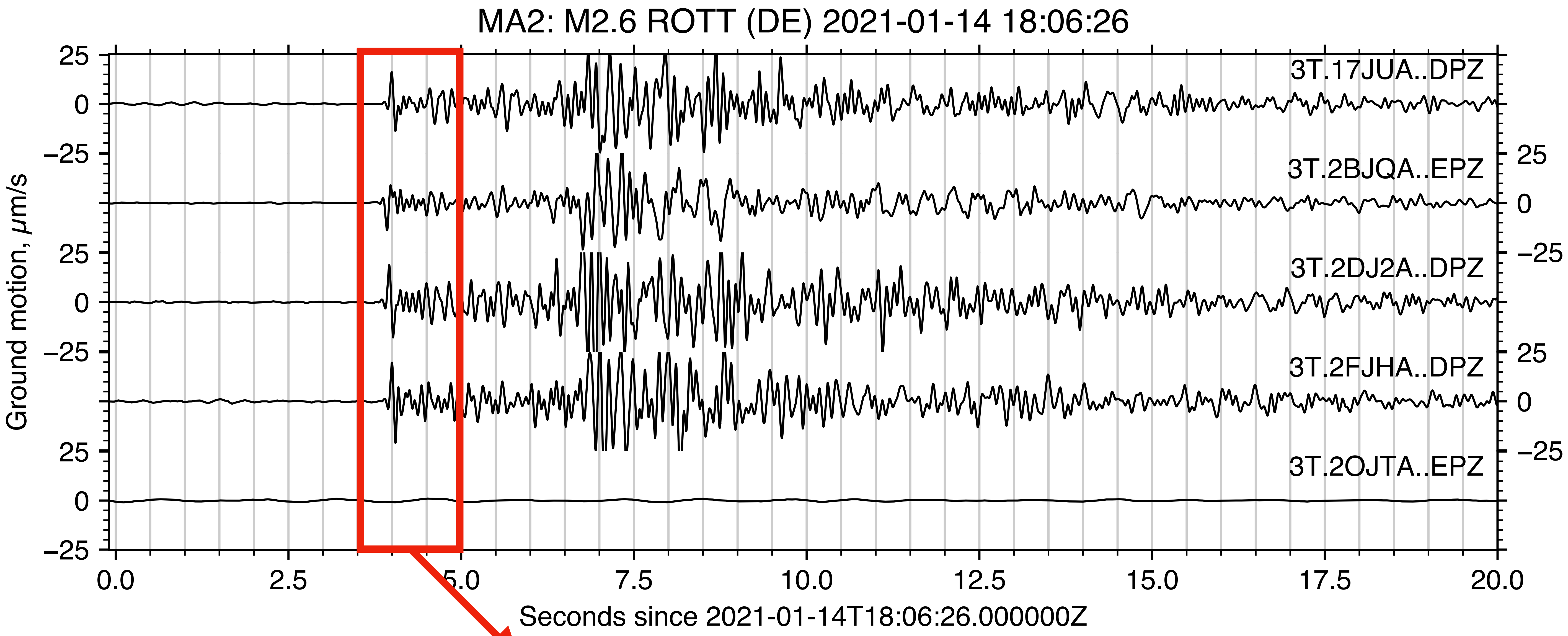


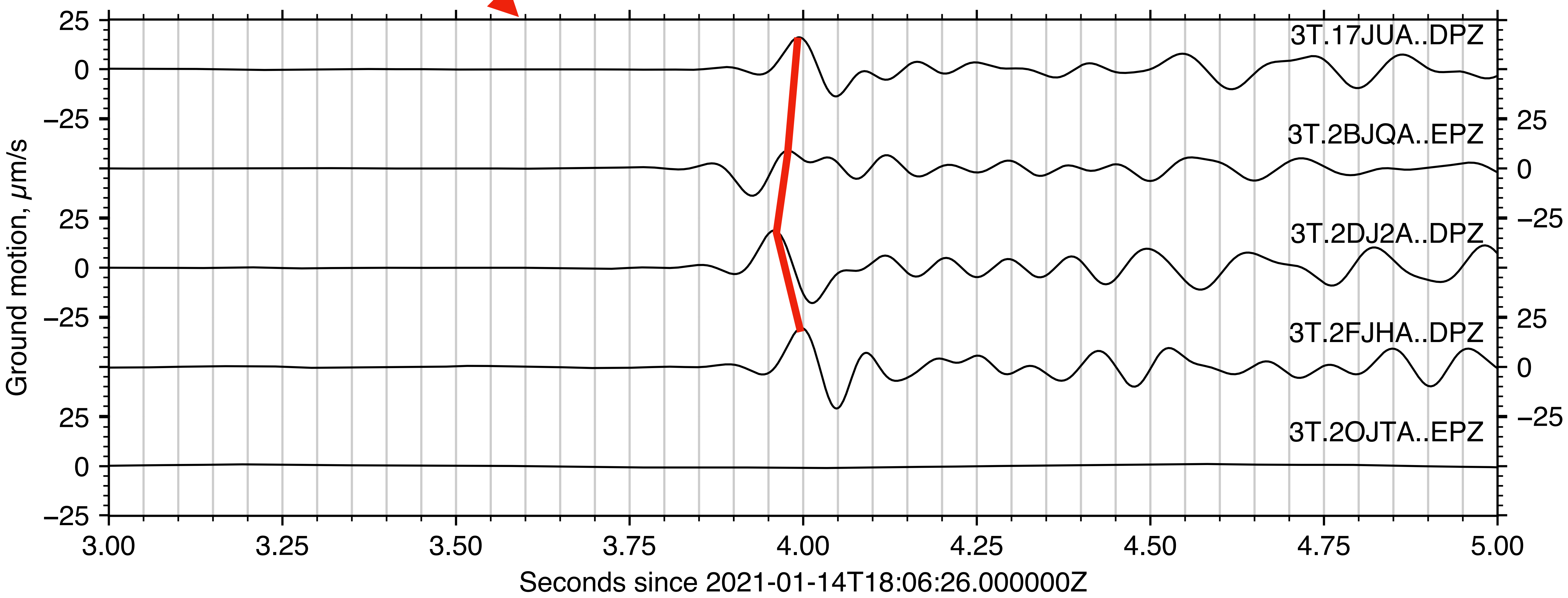


Results: Beamforming

An example:

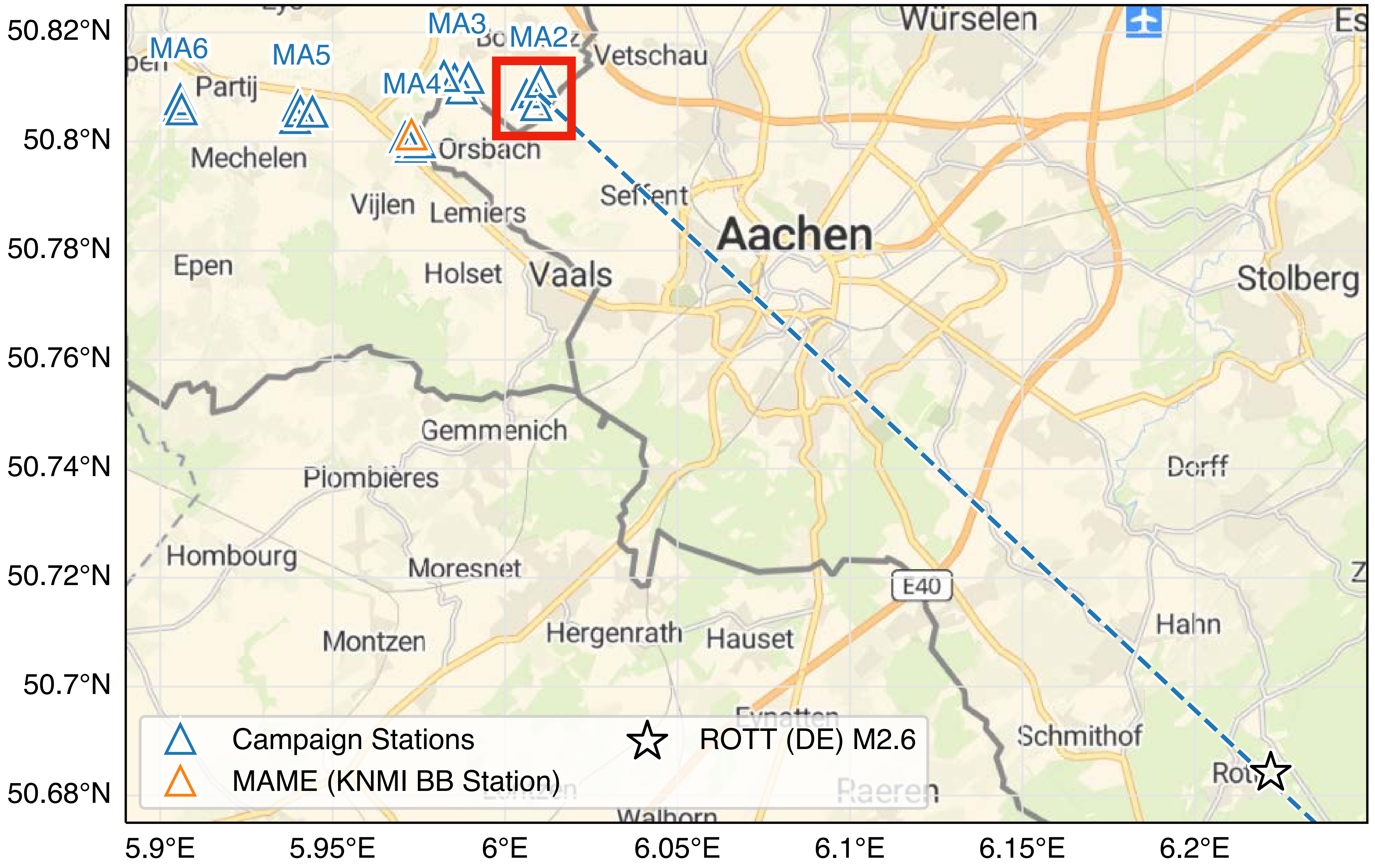


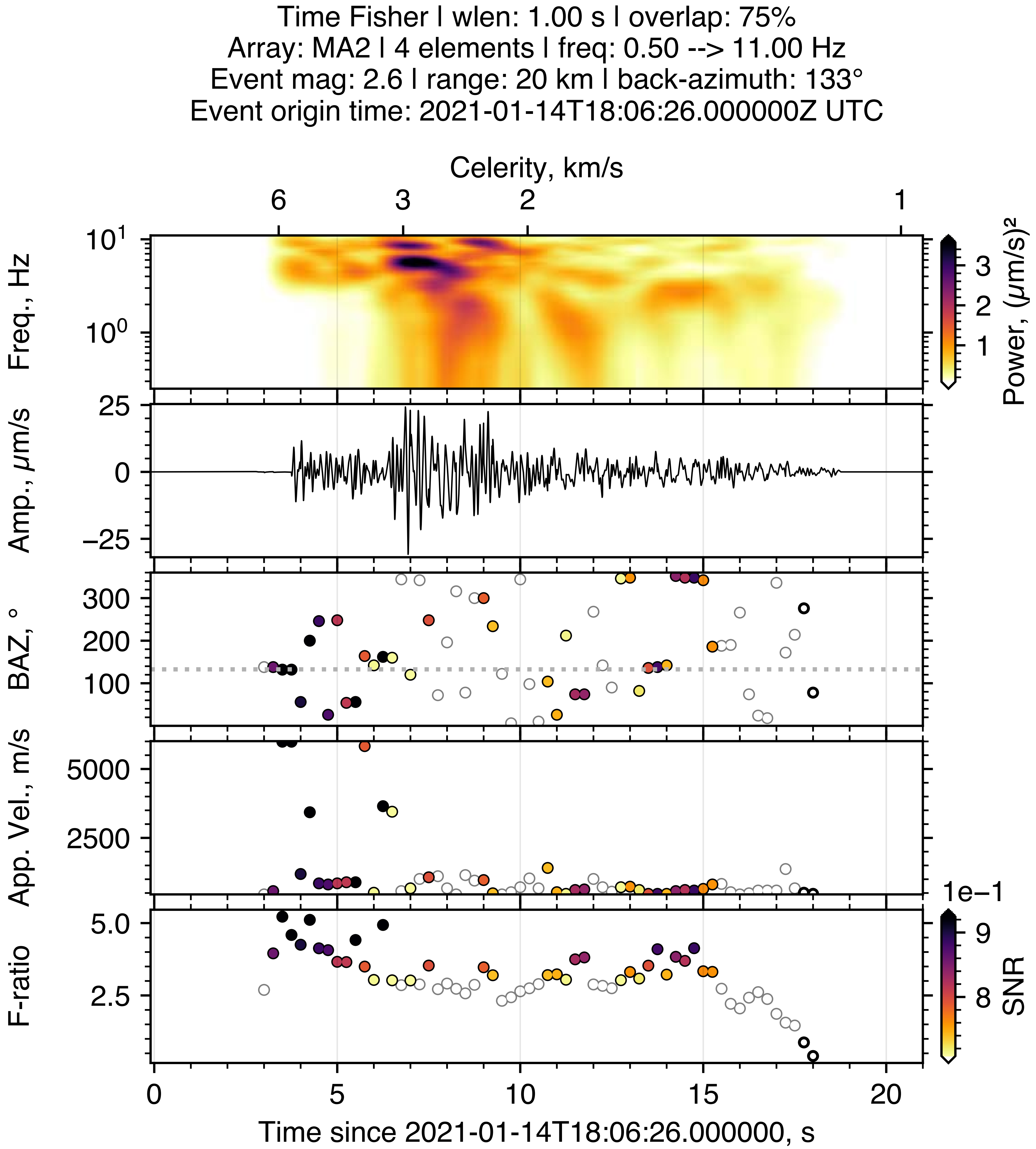




Results: Beamforming

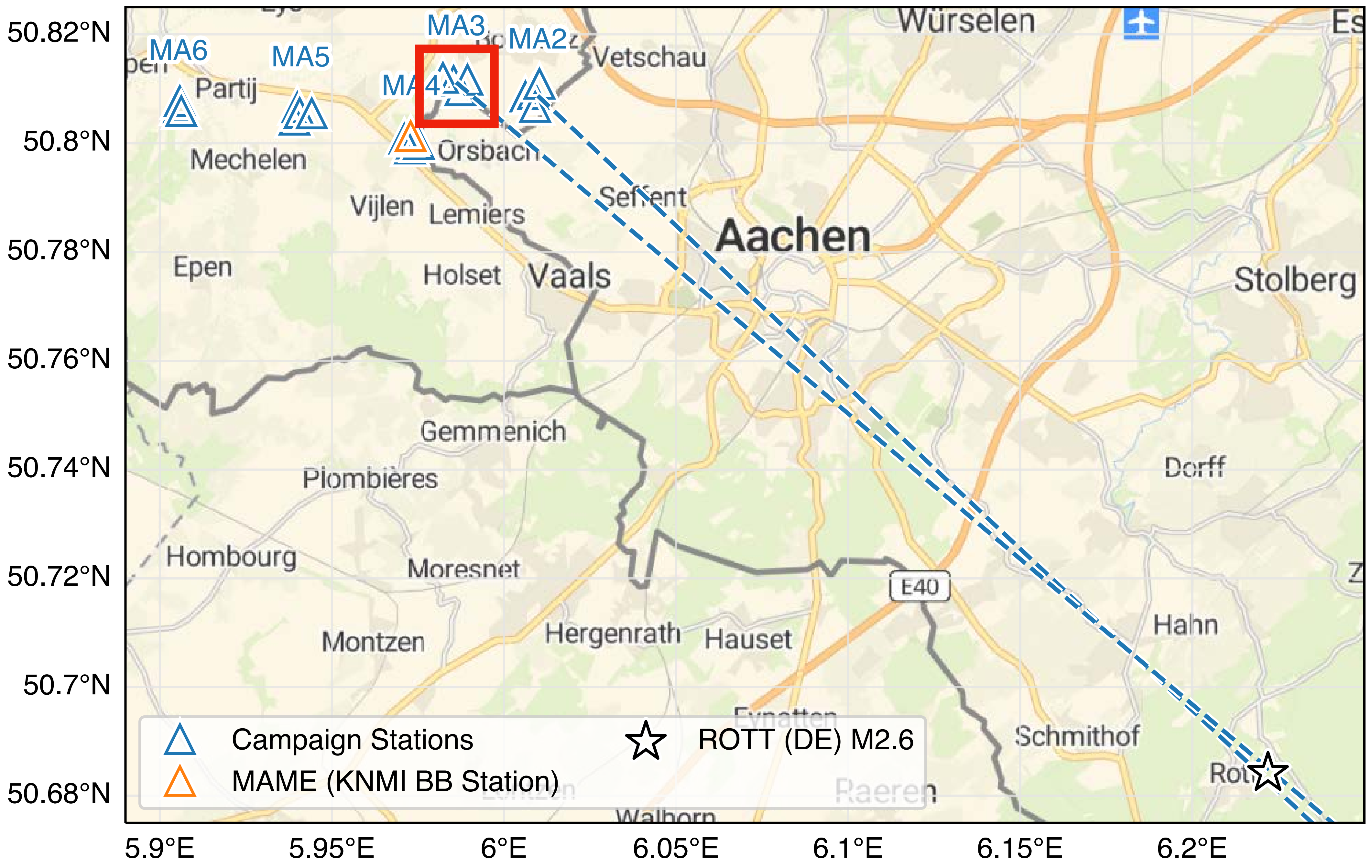
An example:

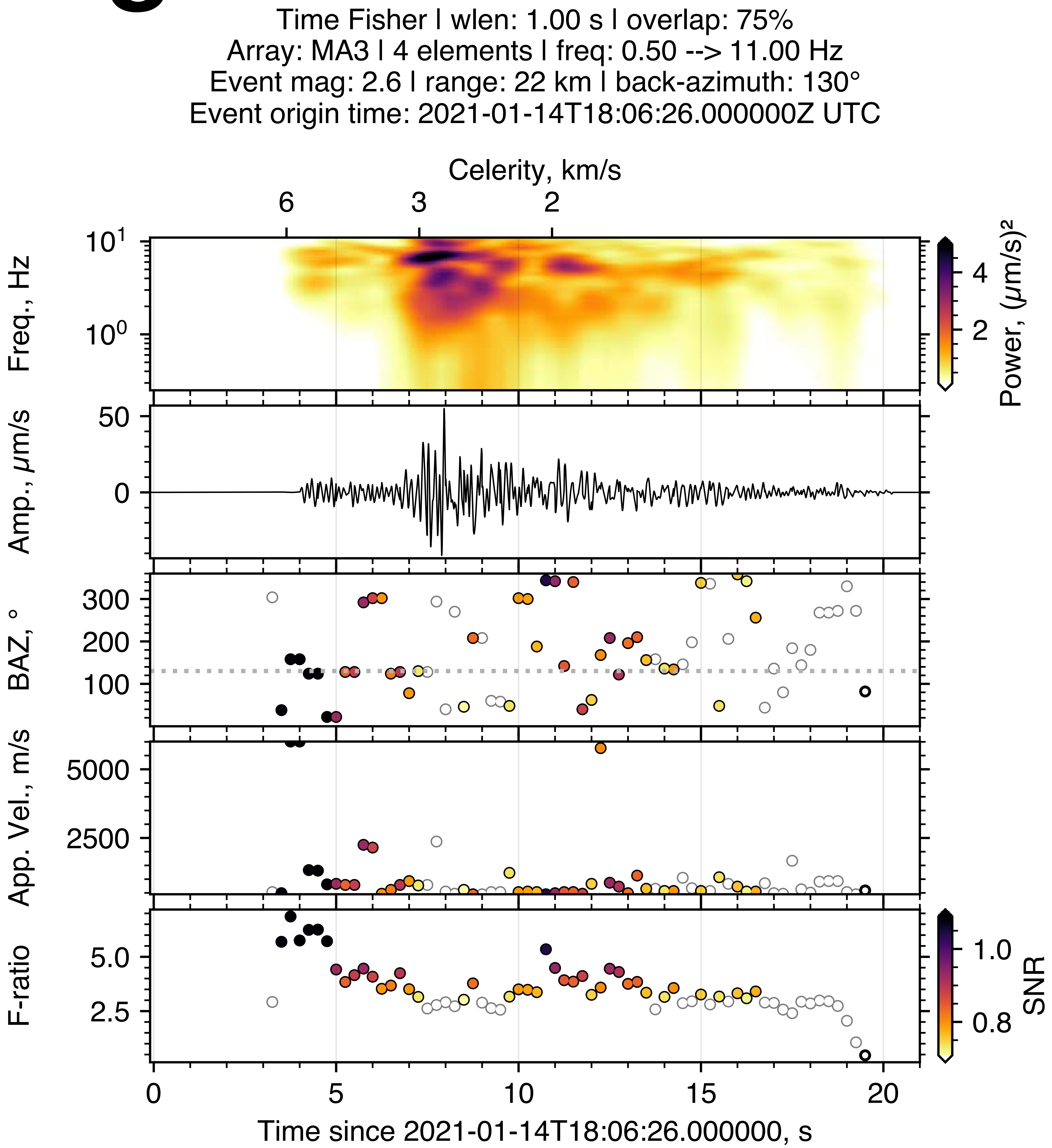




Results: Beamforming

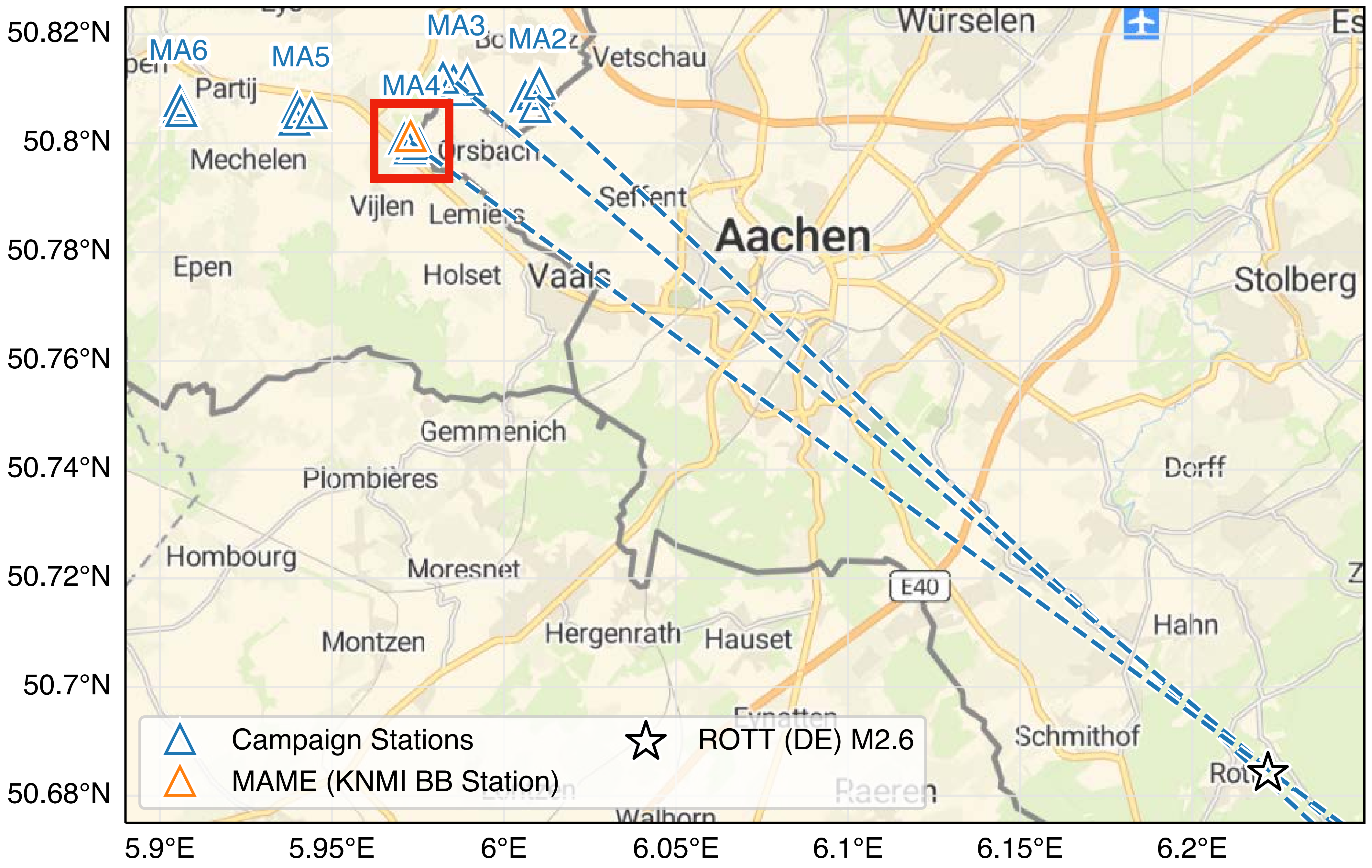
An example:

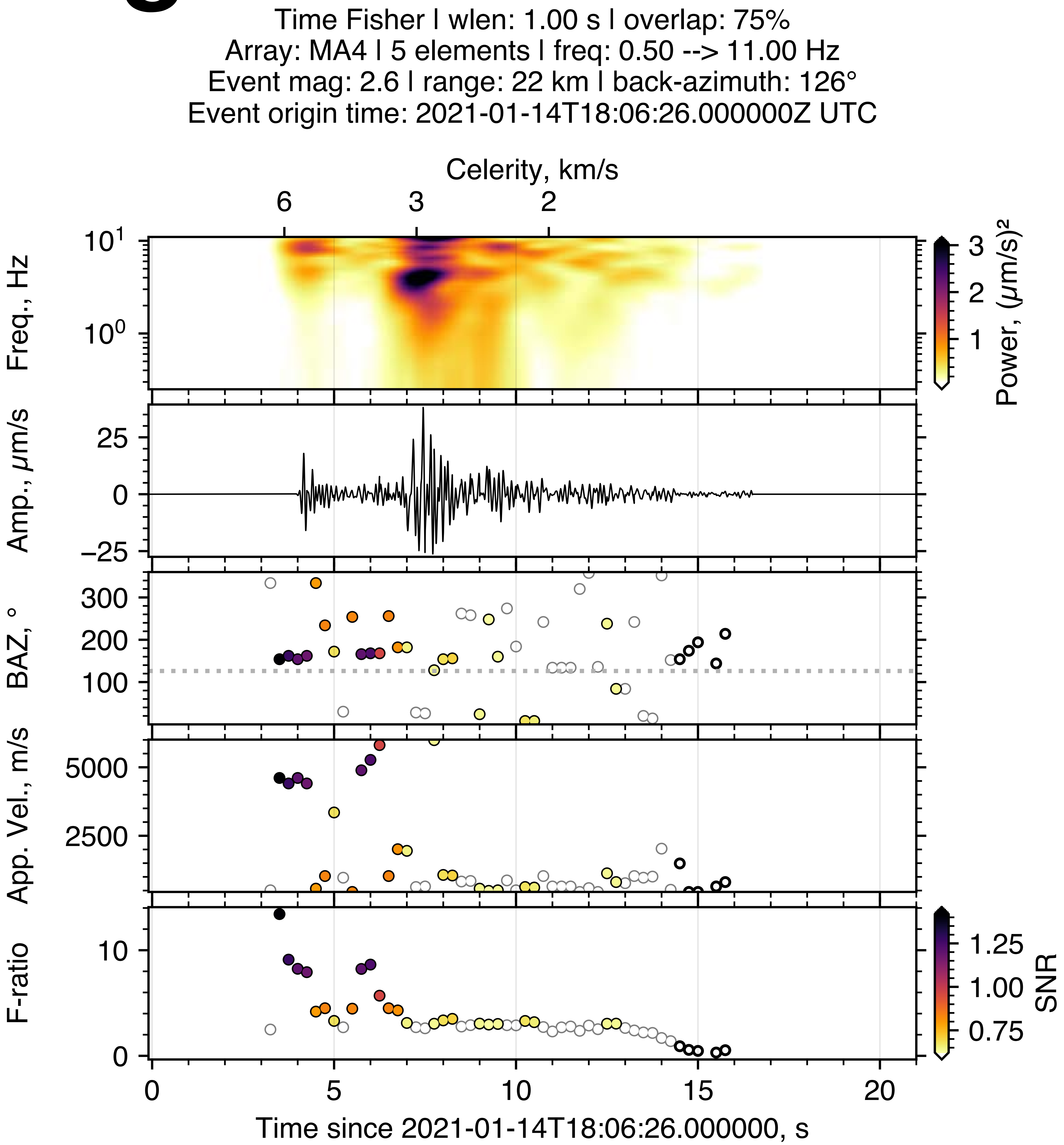




Results: Beamforming

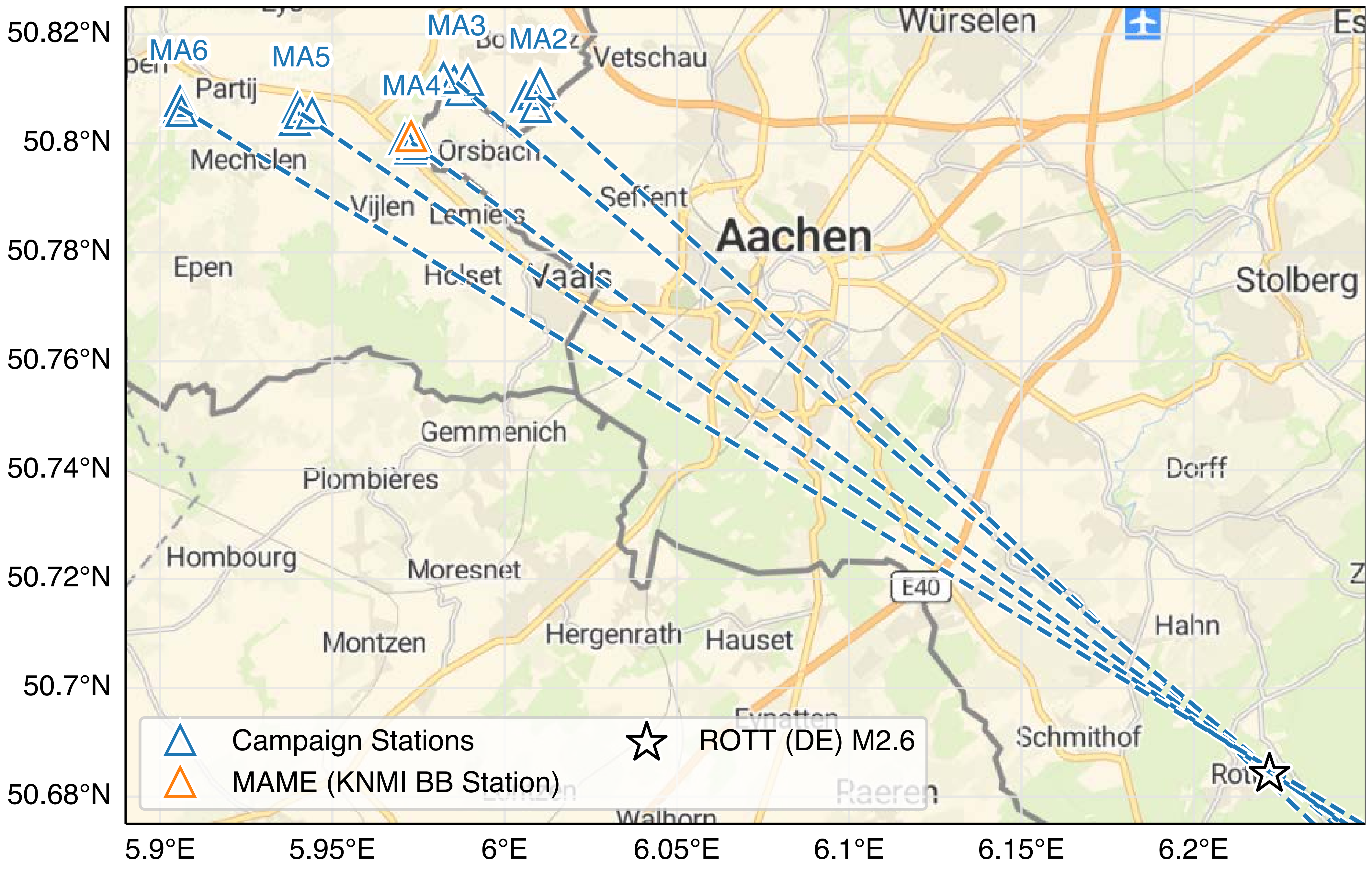
An example:

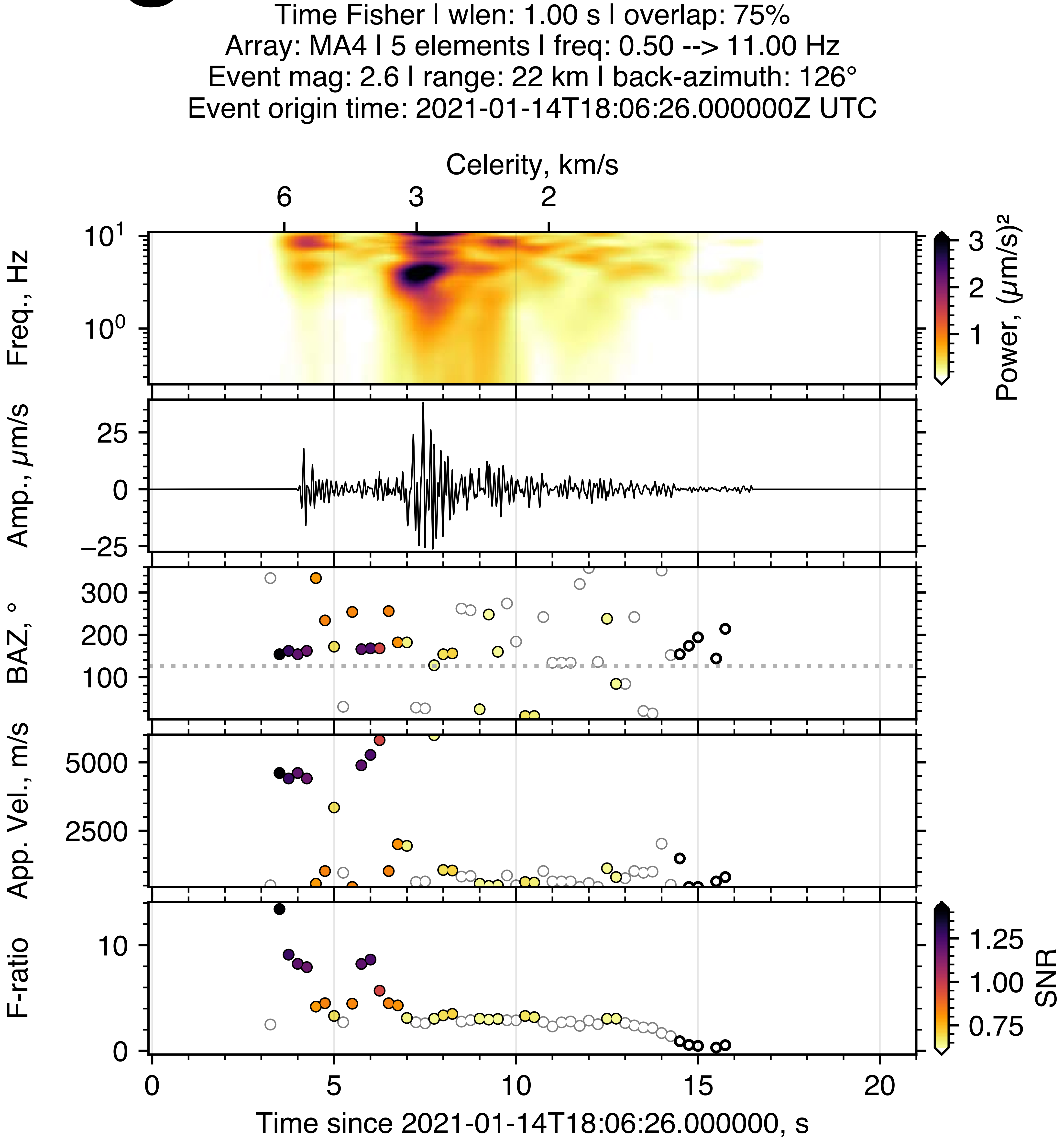




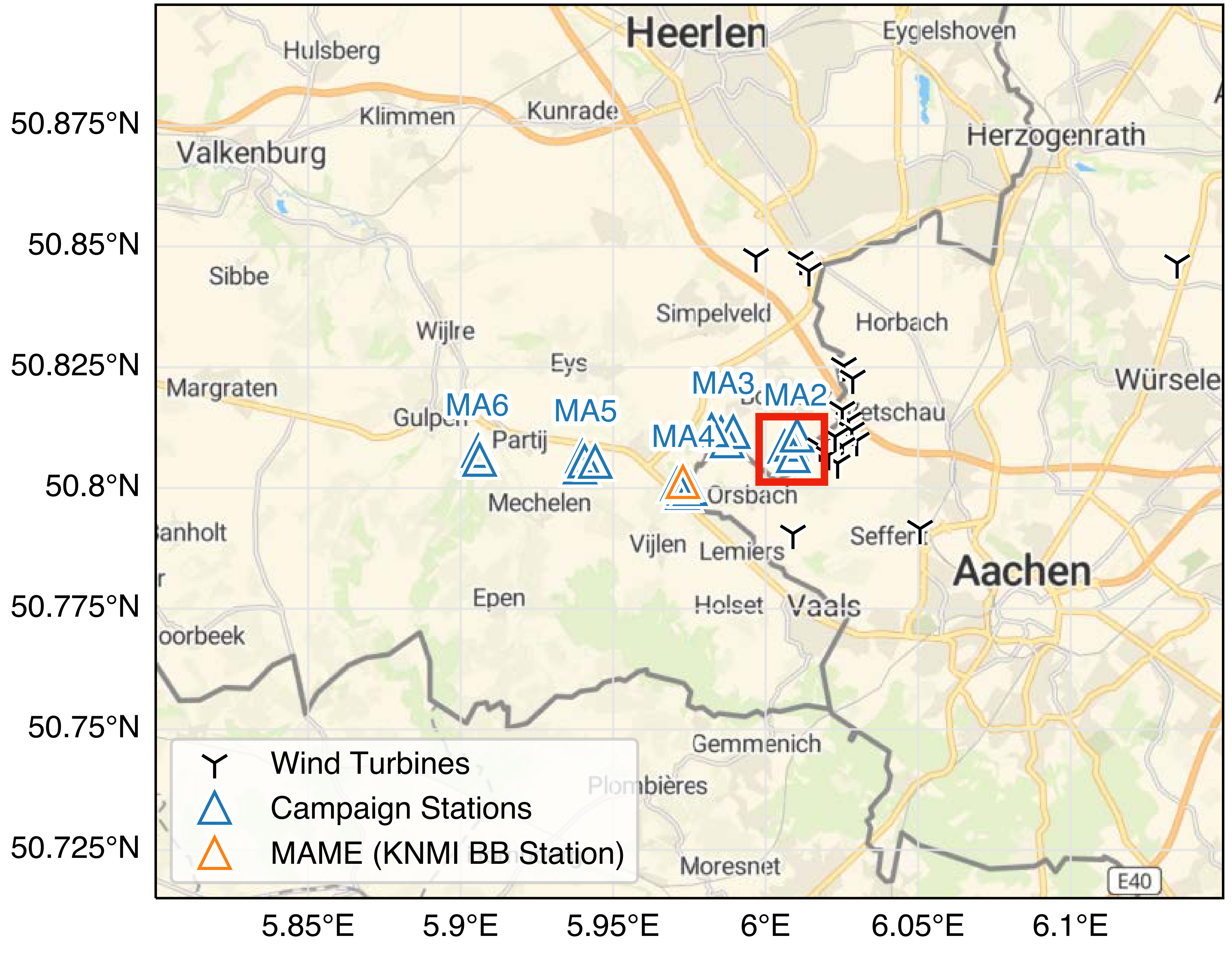
Results: Beamforming

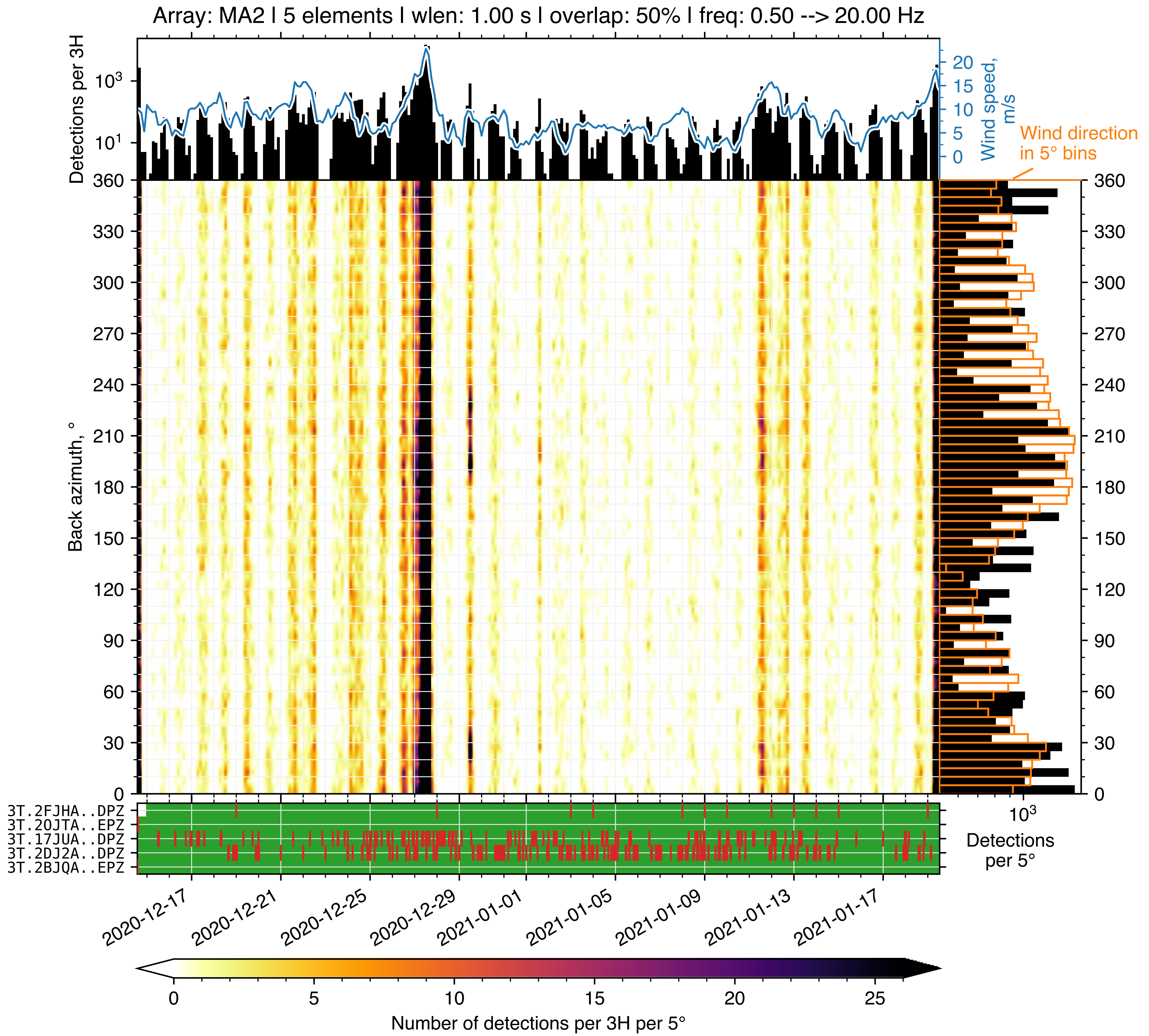
An example:



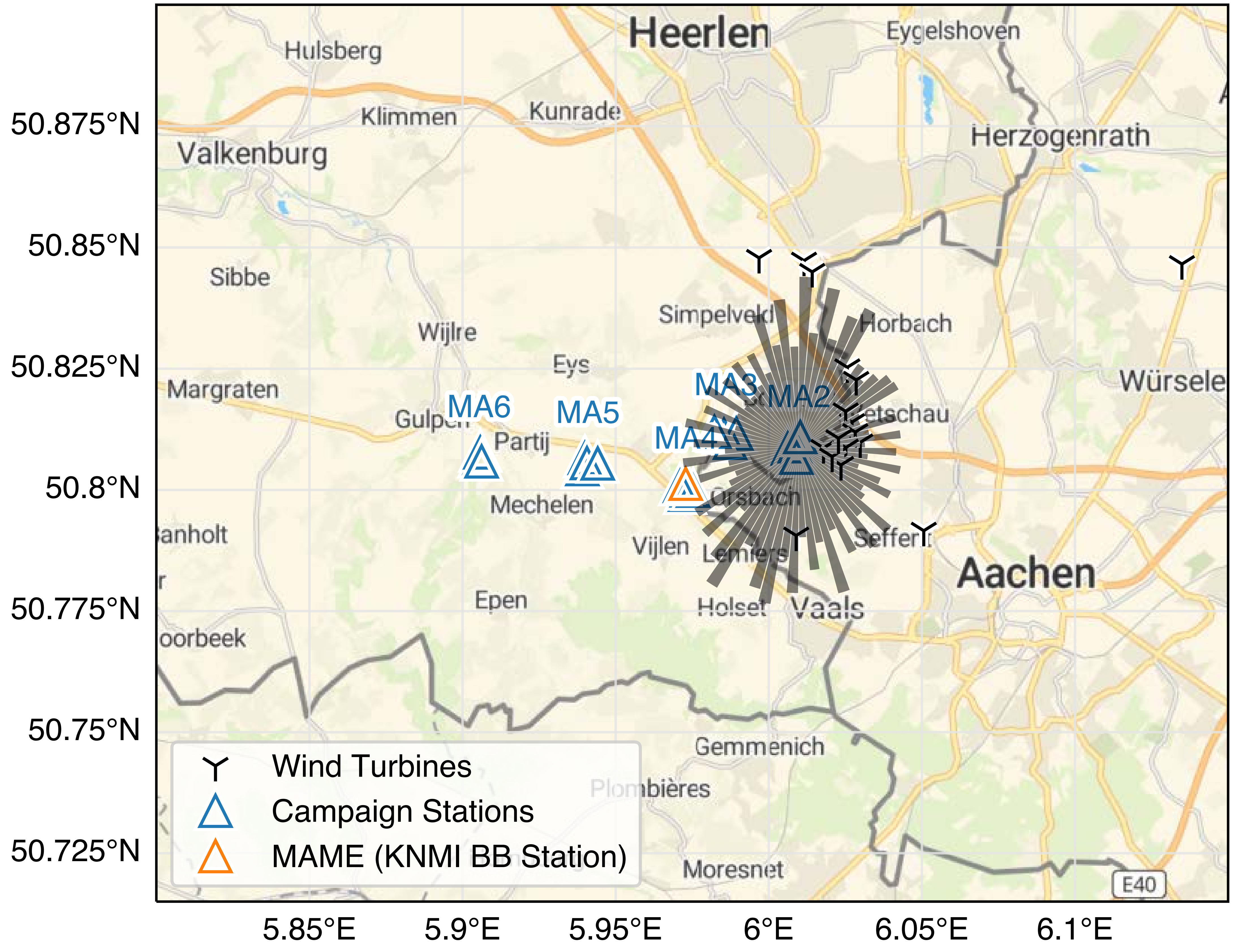


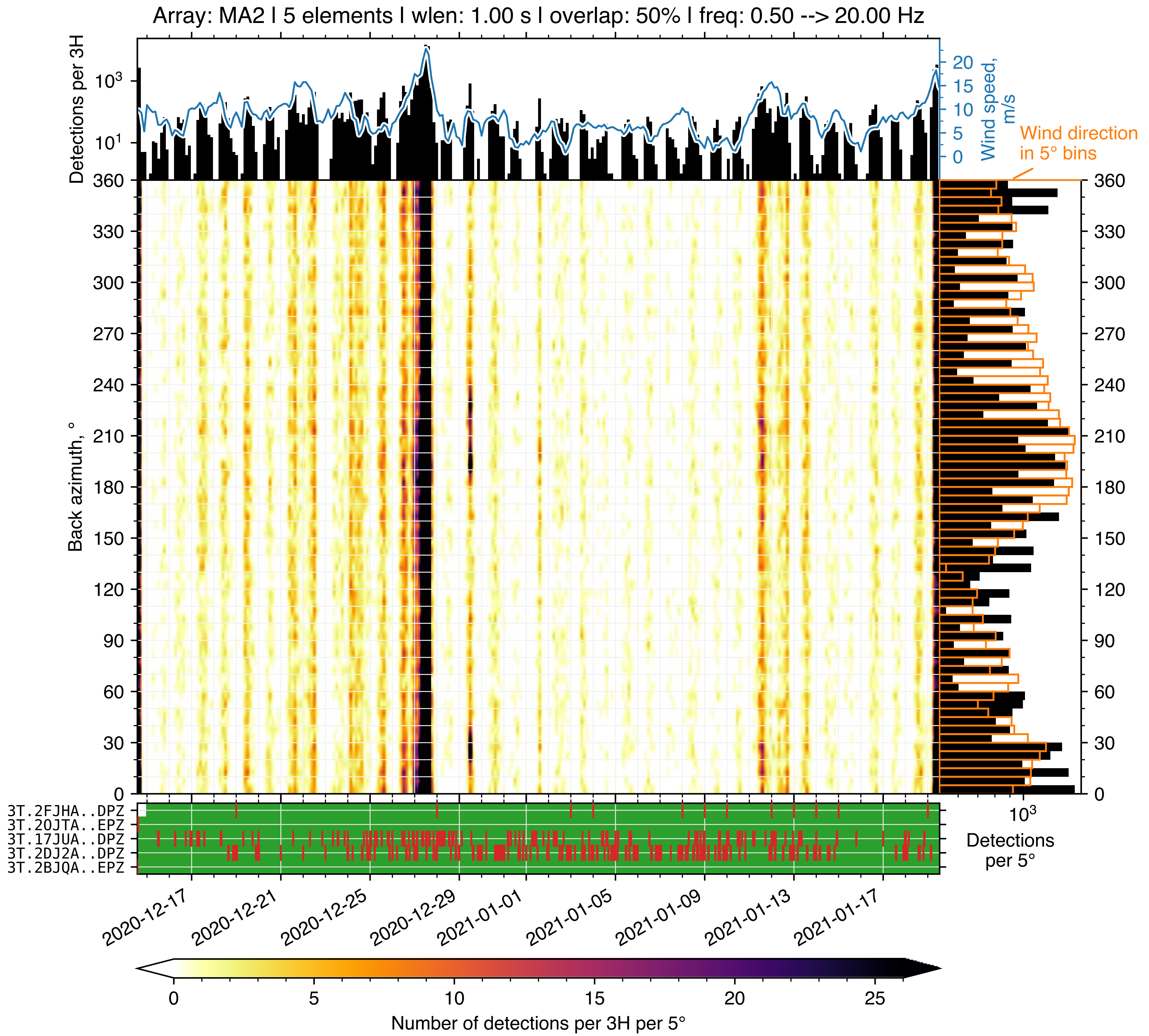
Results: Beamforming



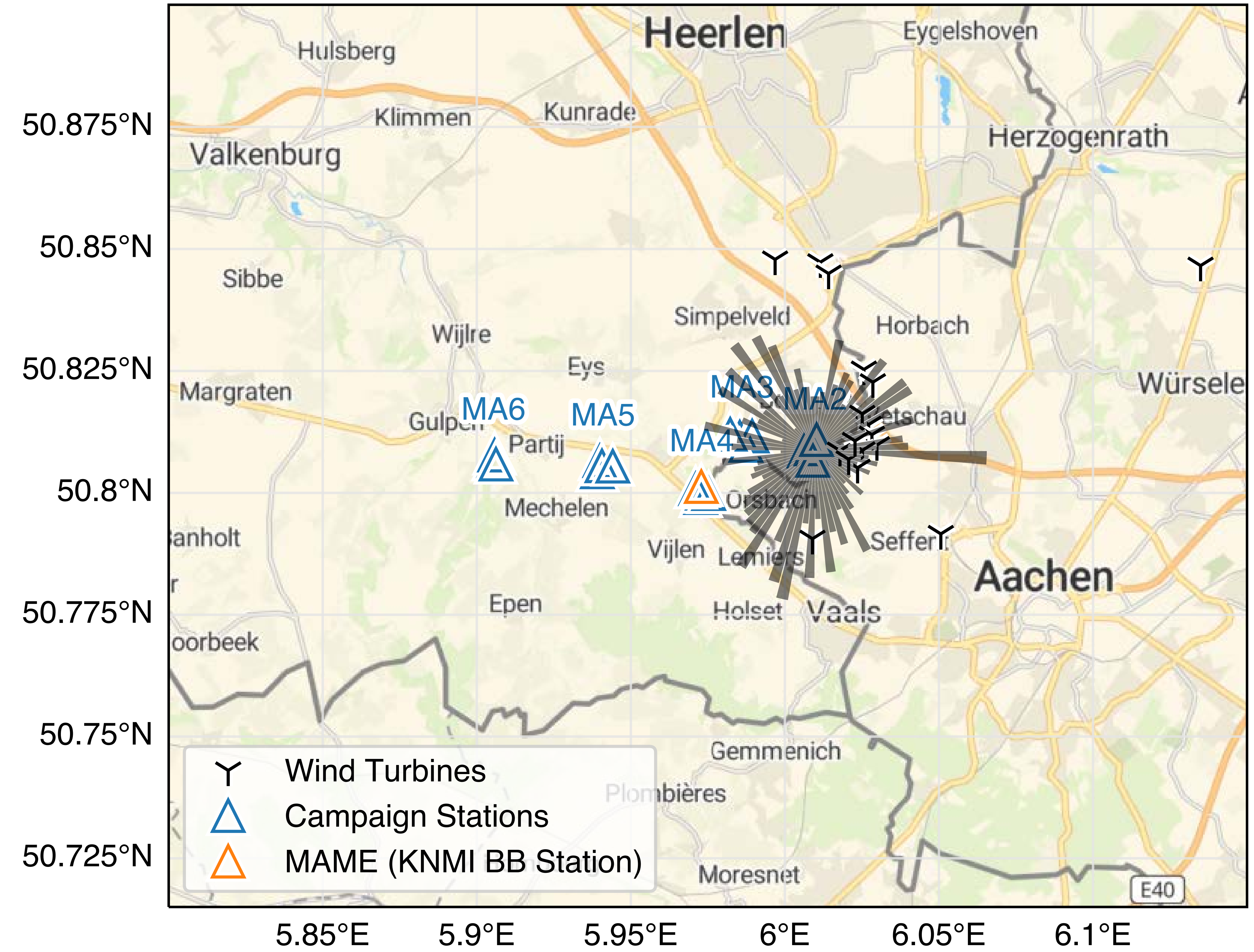


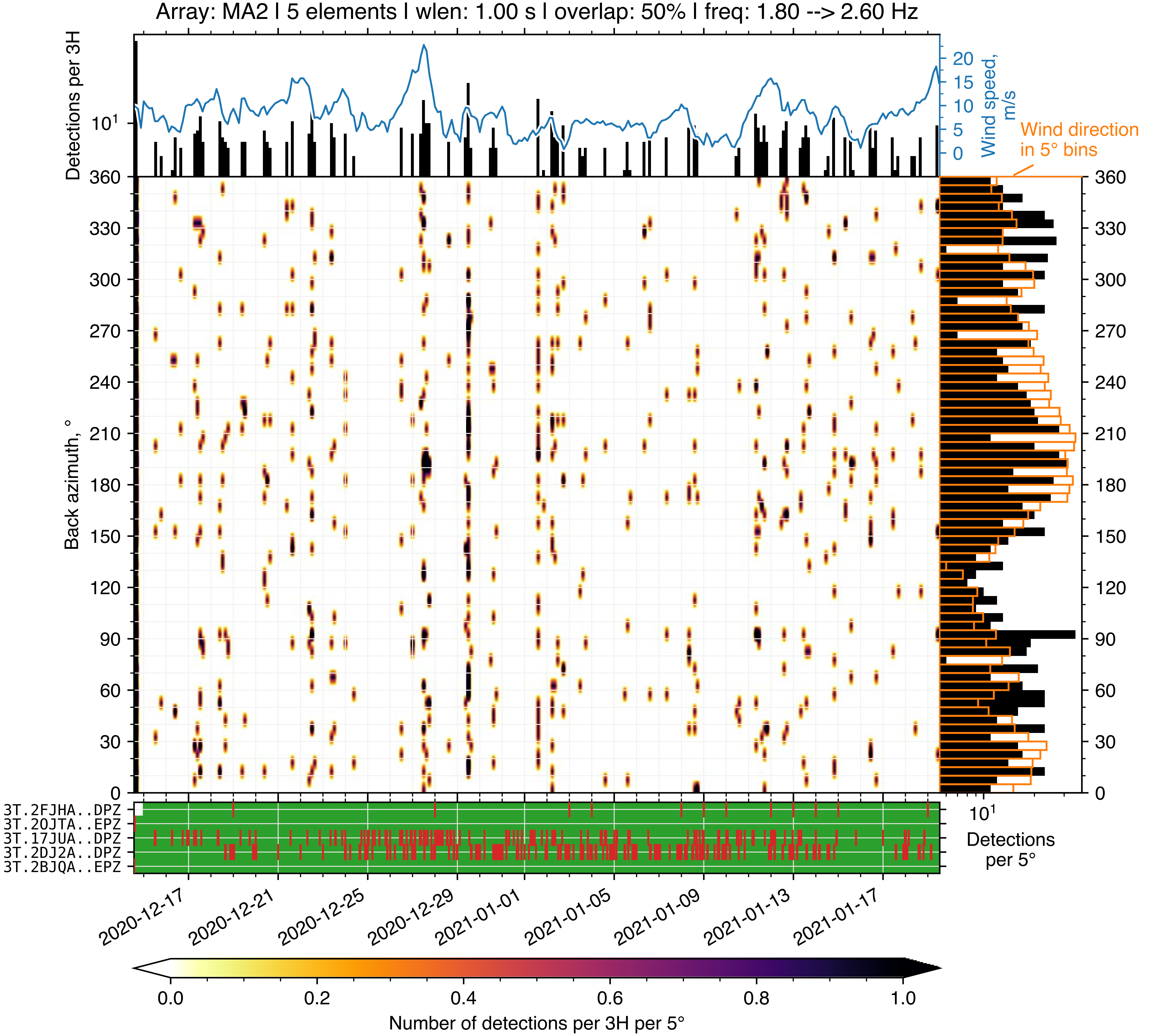
Results: Beamforming



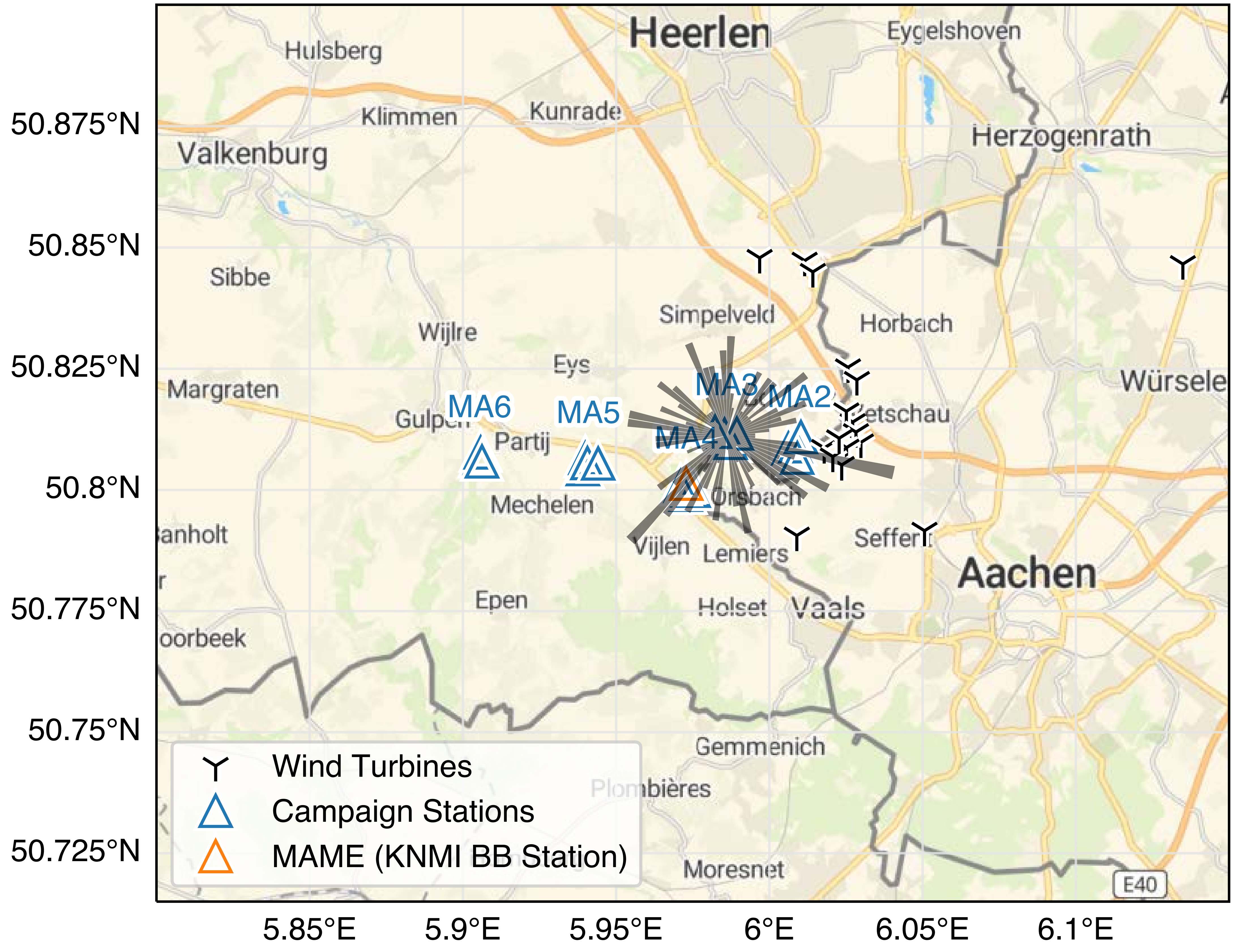


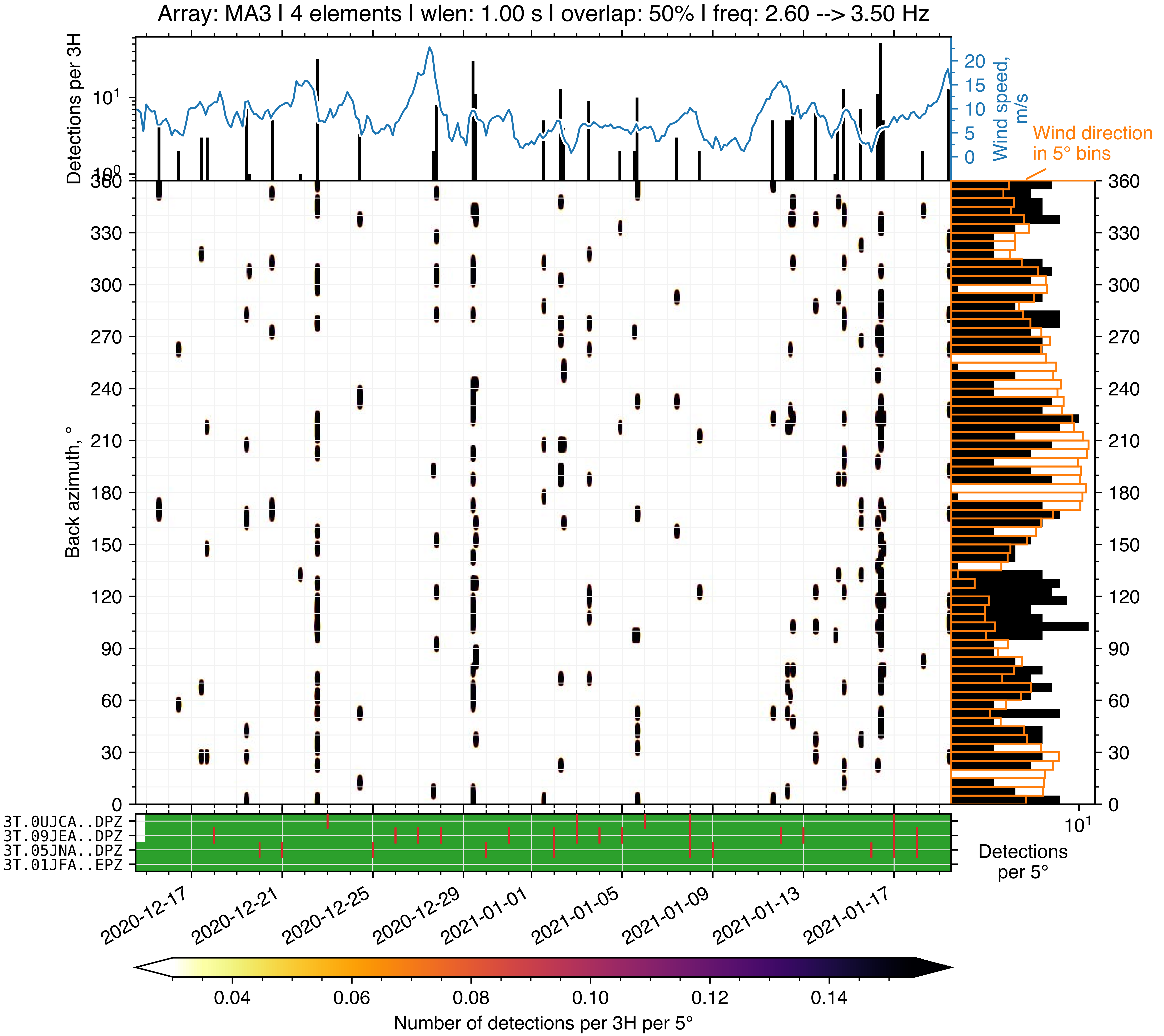
Results: Beamforming



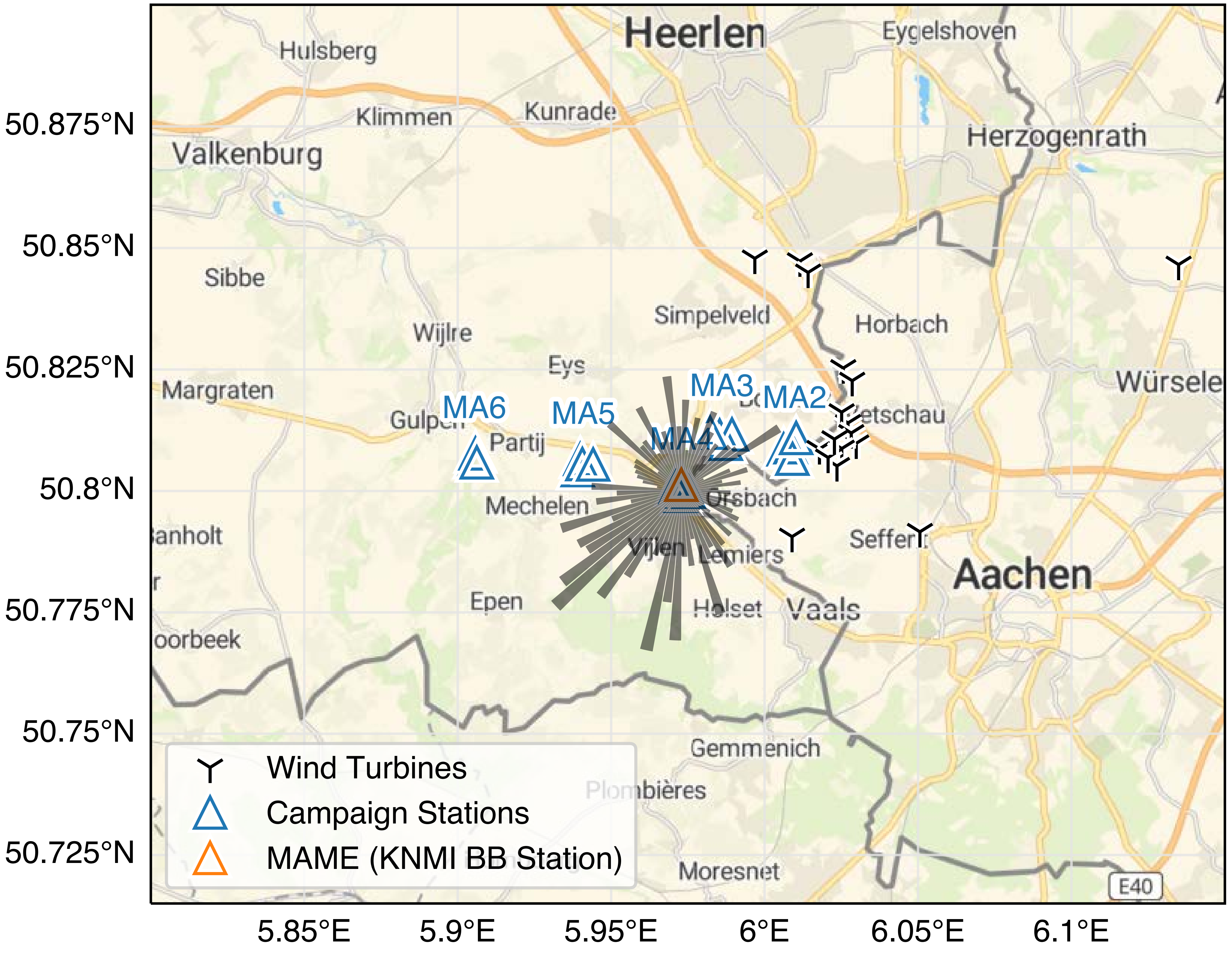


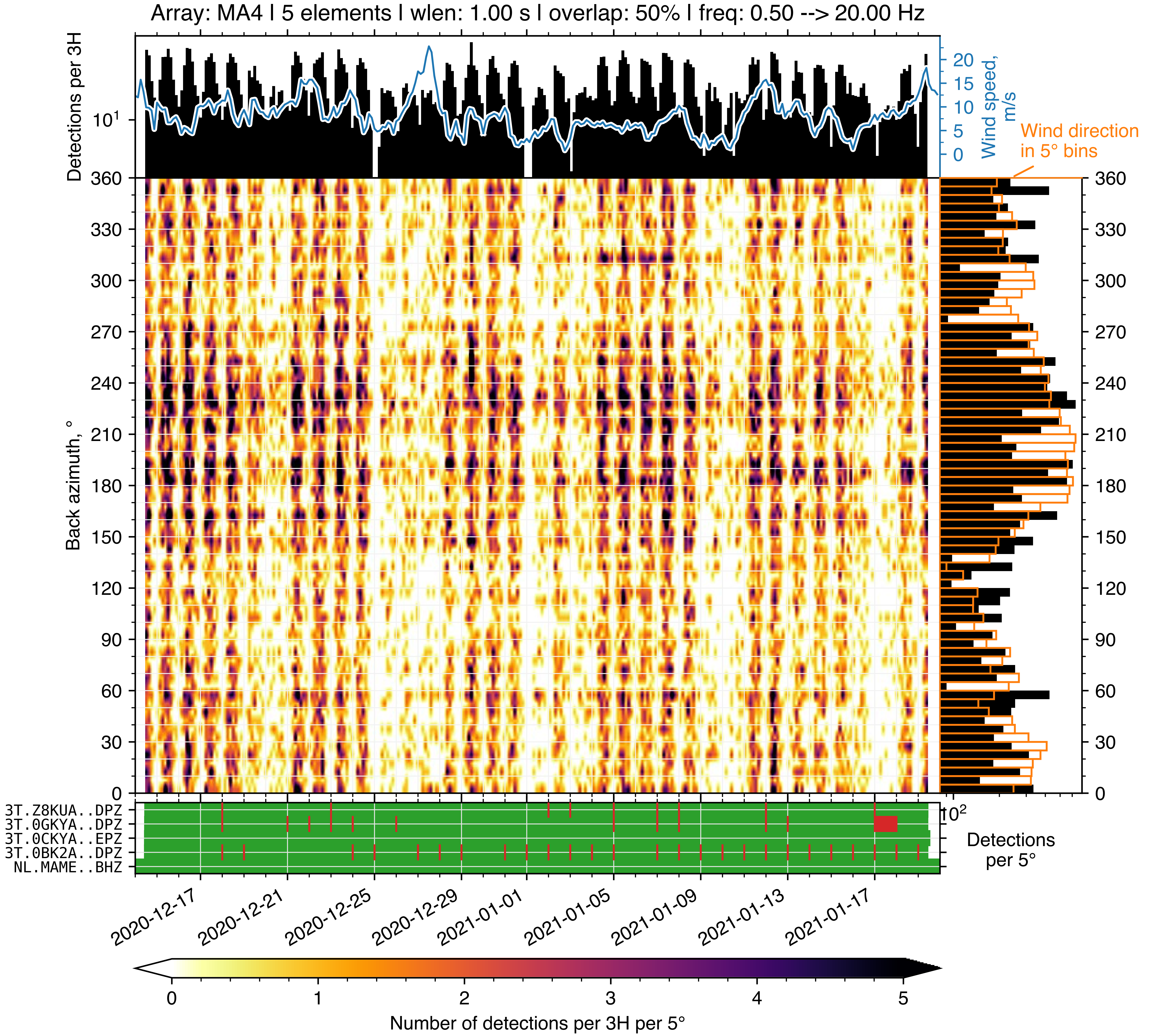
Results: Beamforming



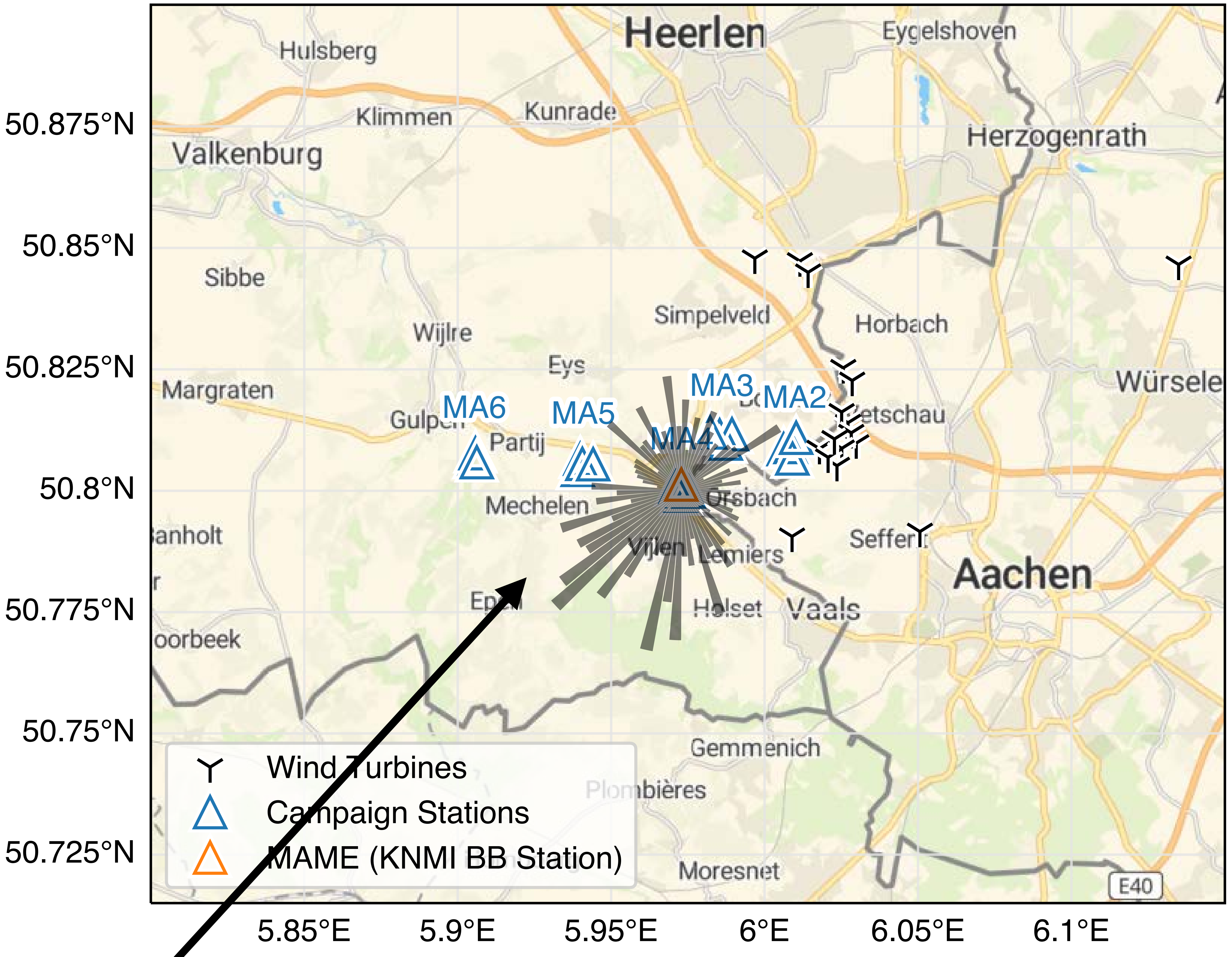


Results: Beamforming

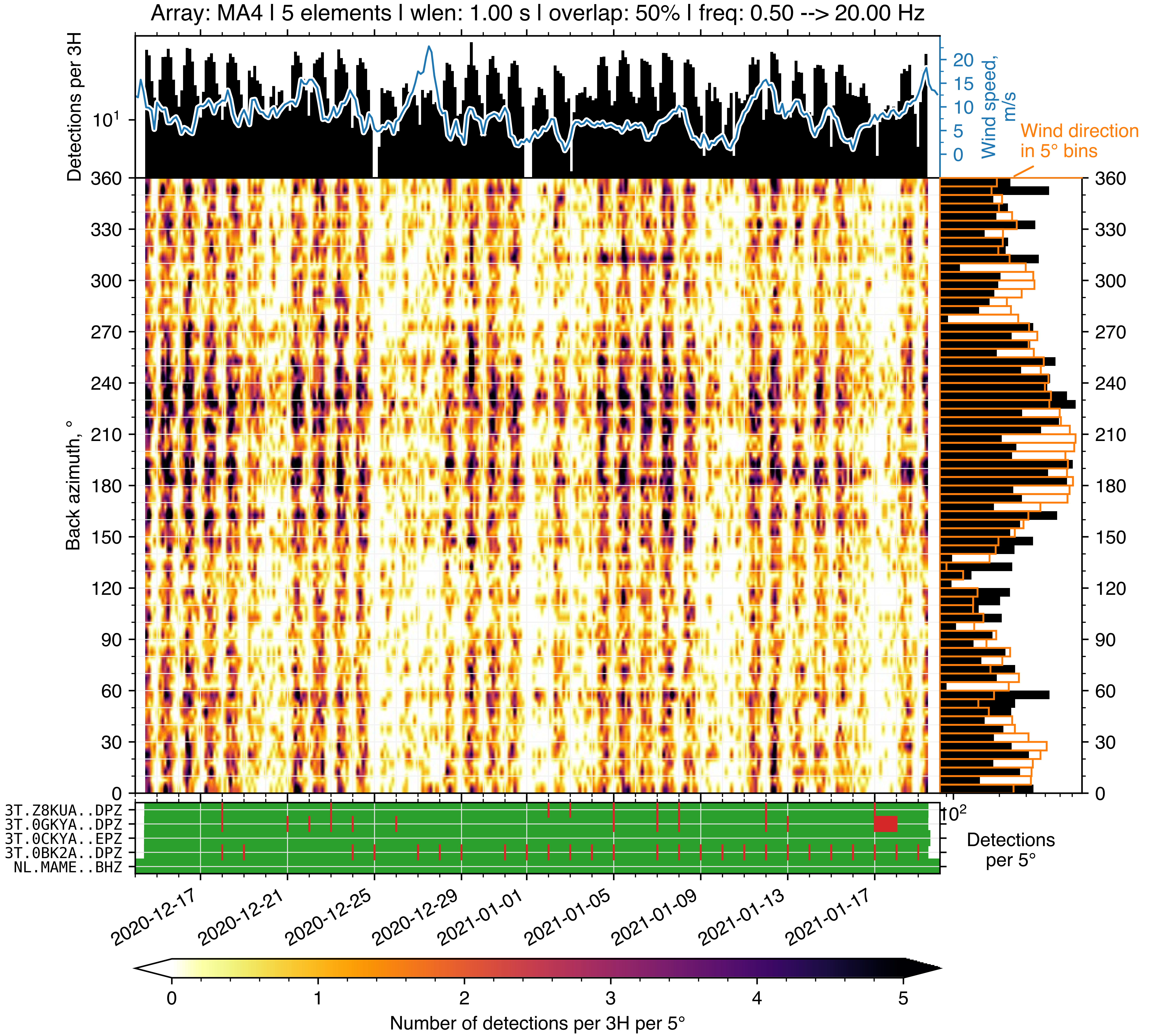




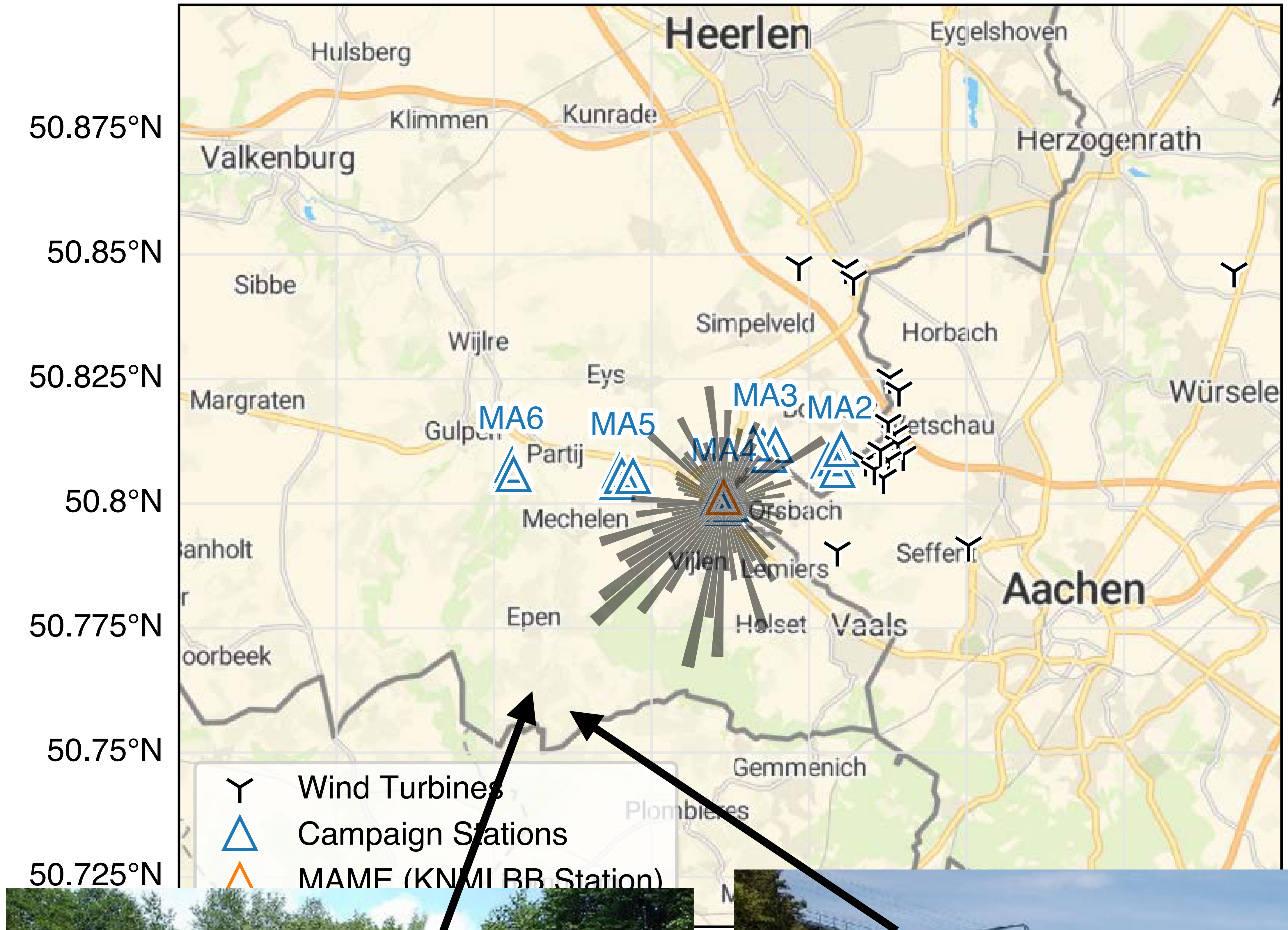
Results: Beamforming

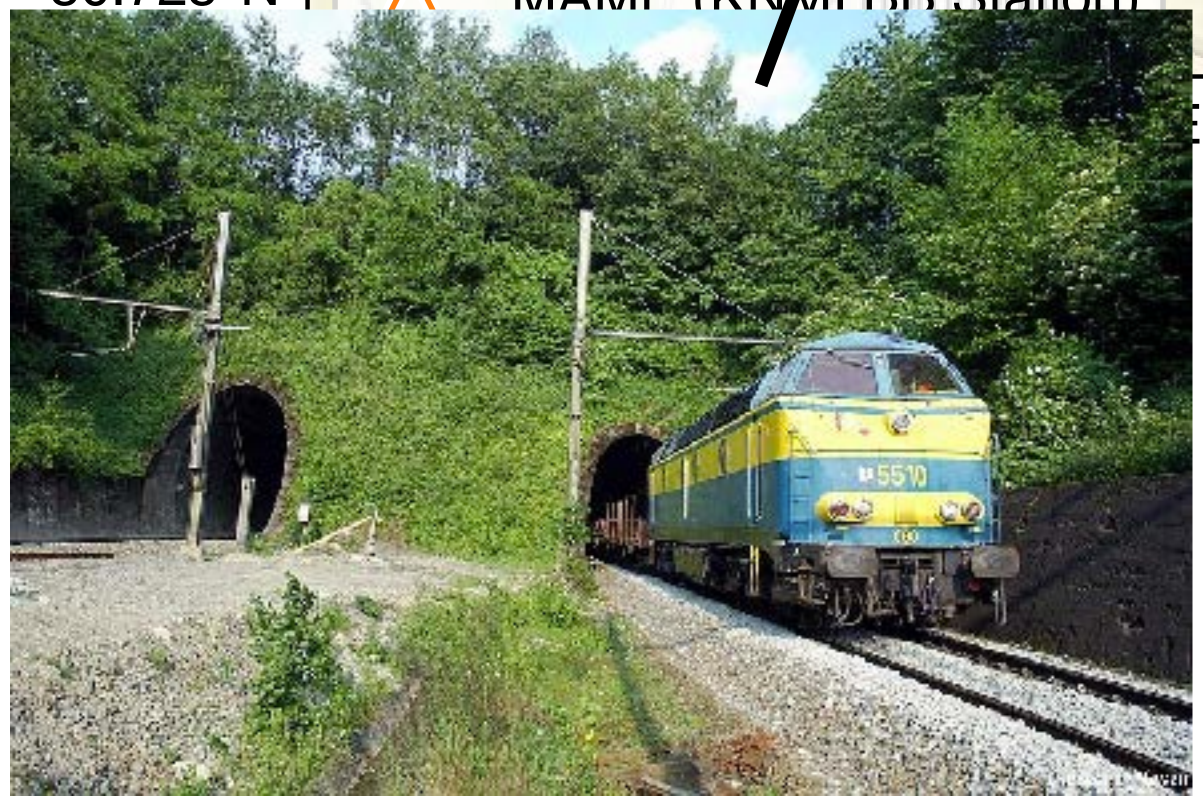


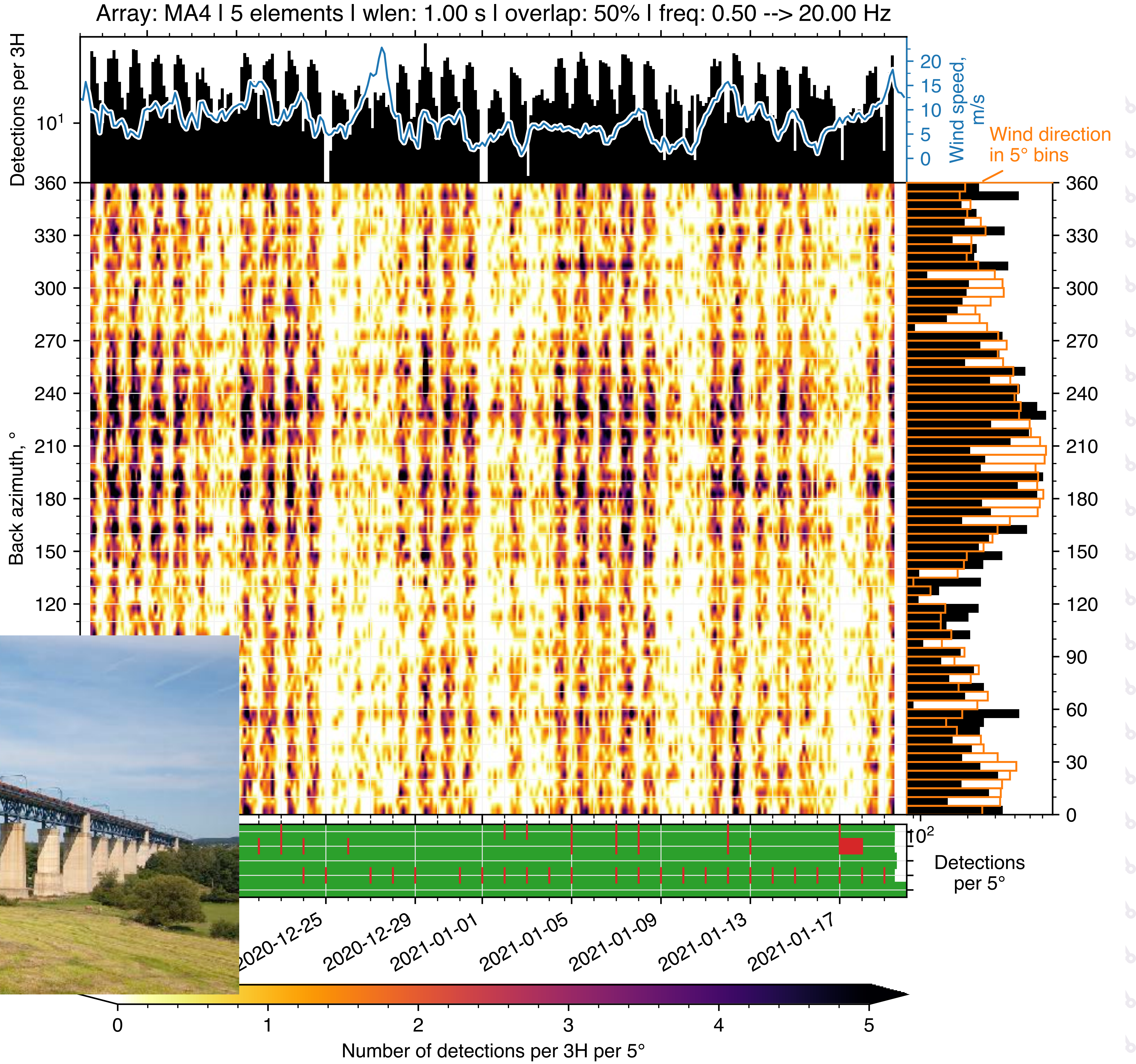
Water pump



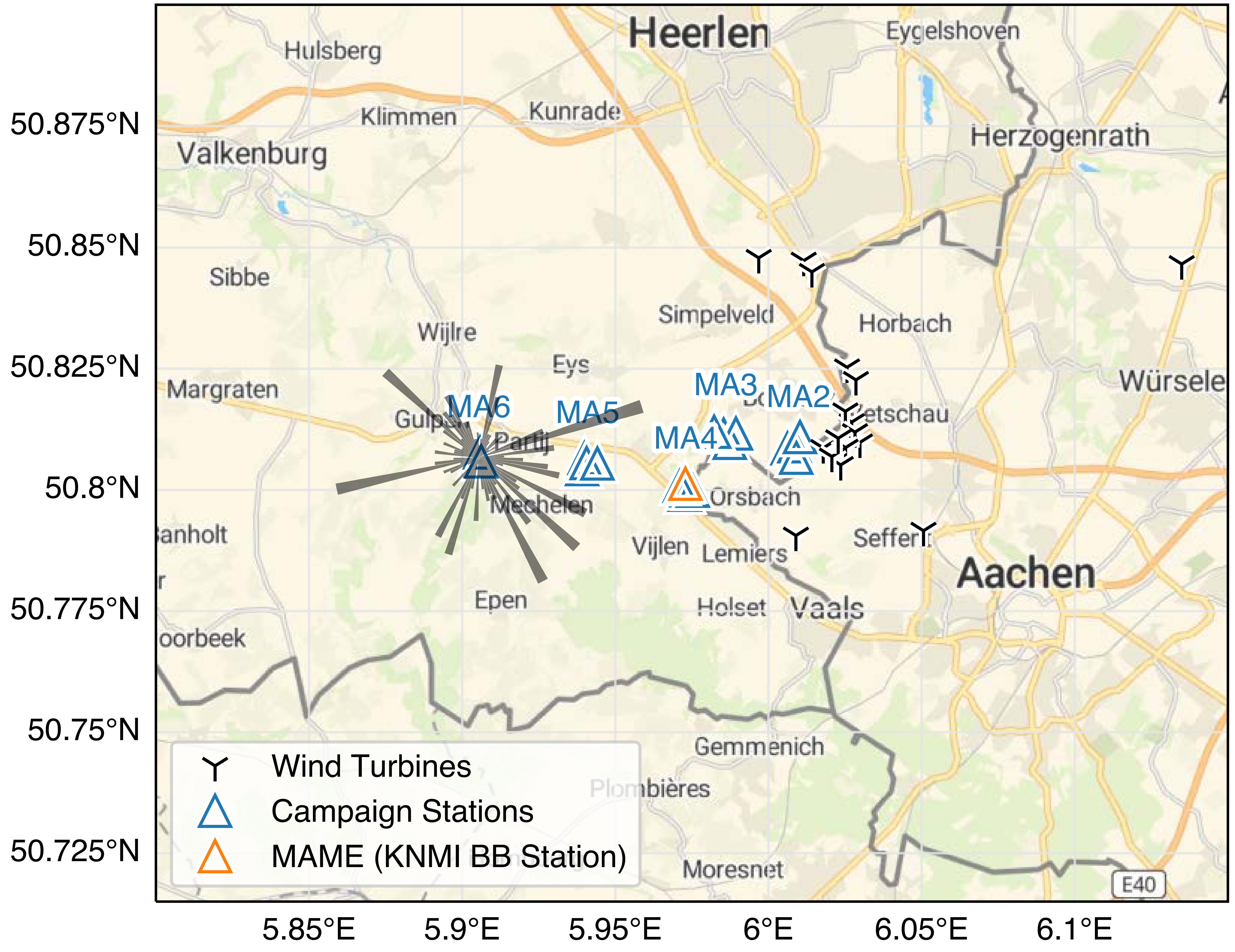
Results: Beamforming

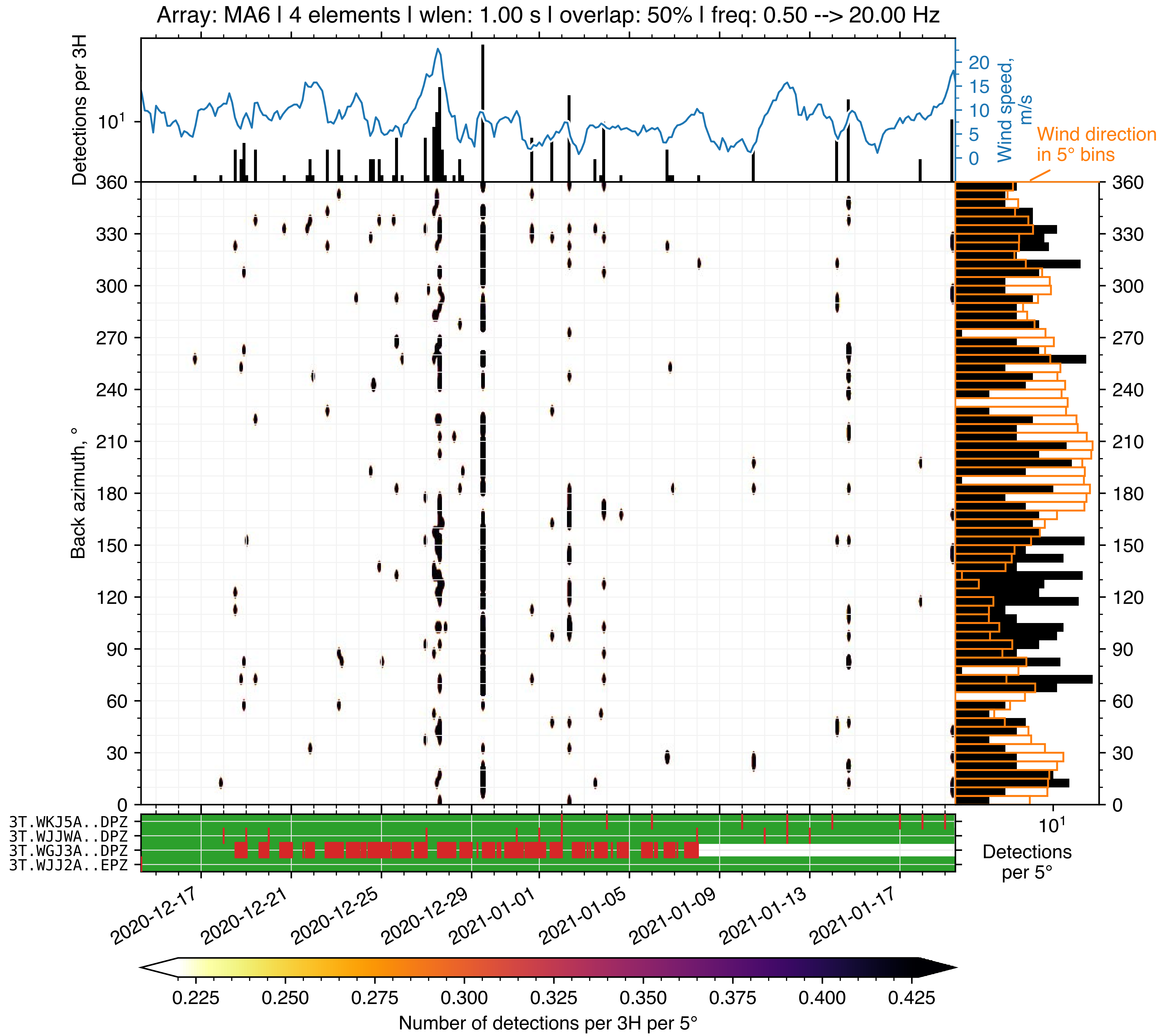




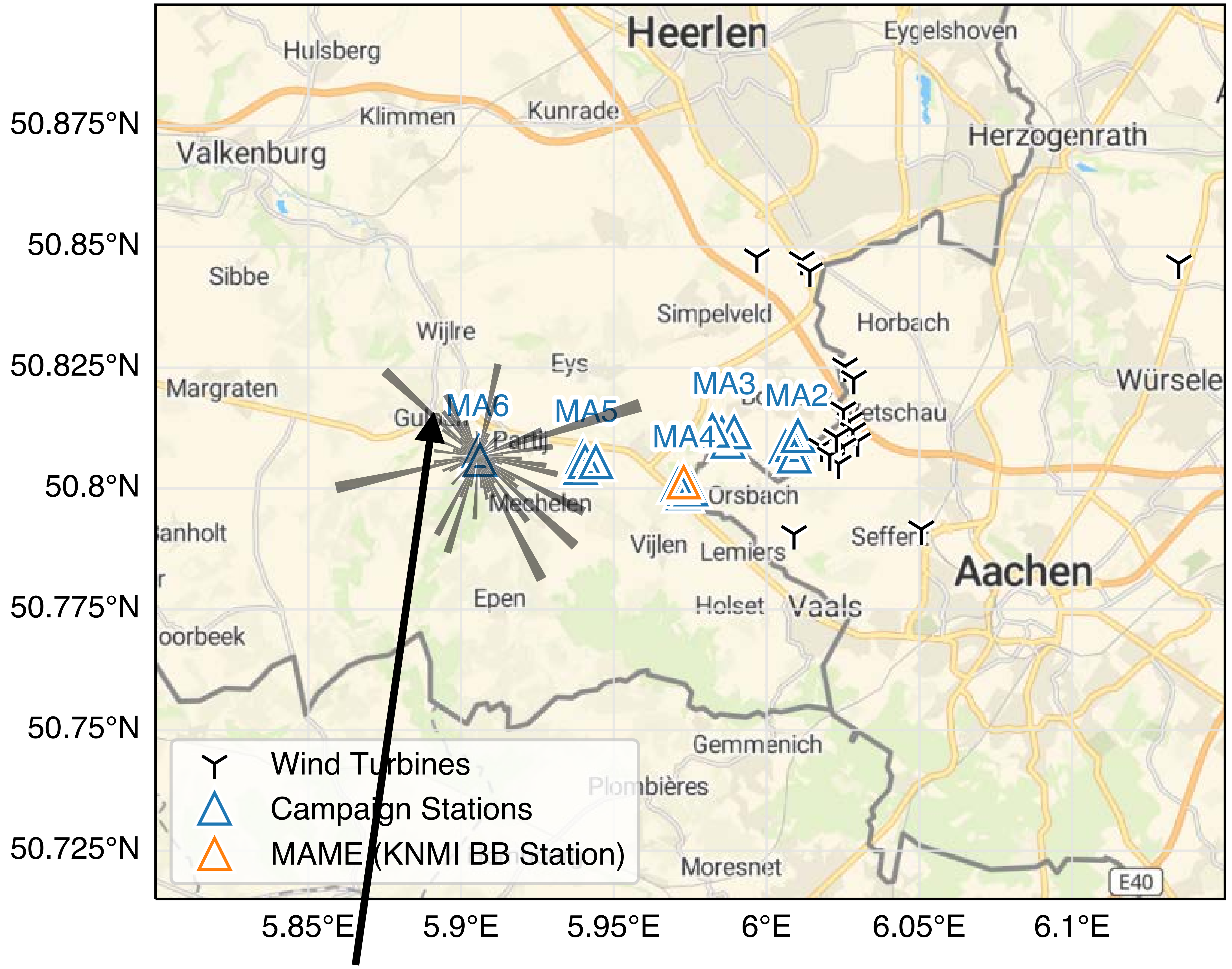


Results: Beamforming



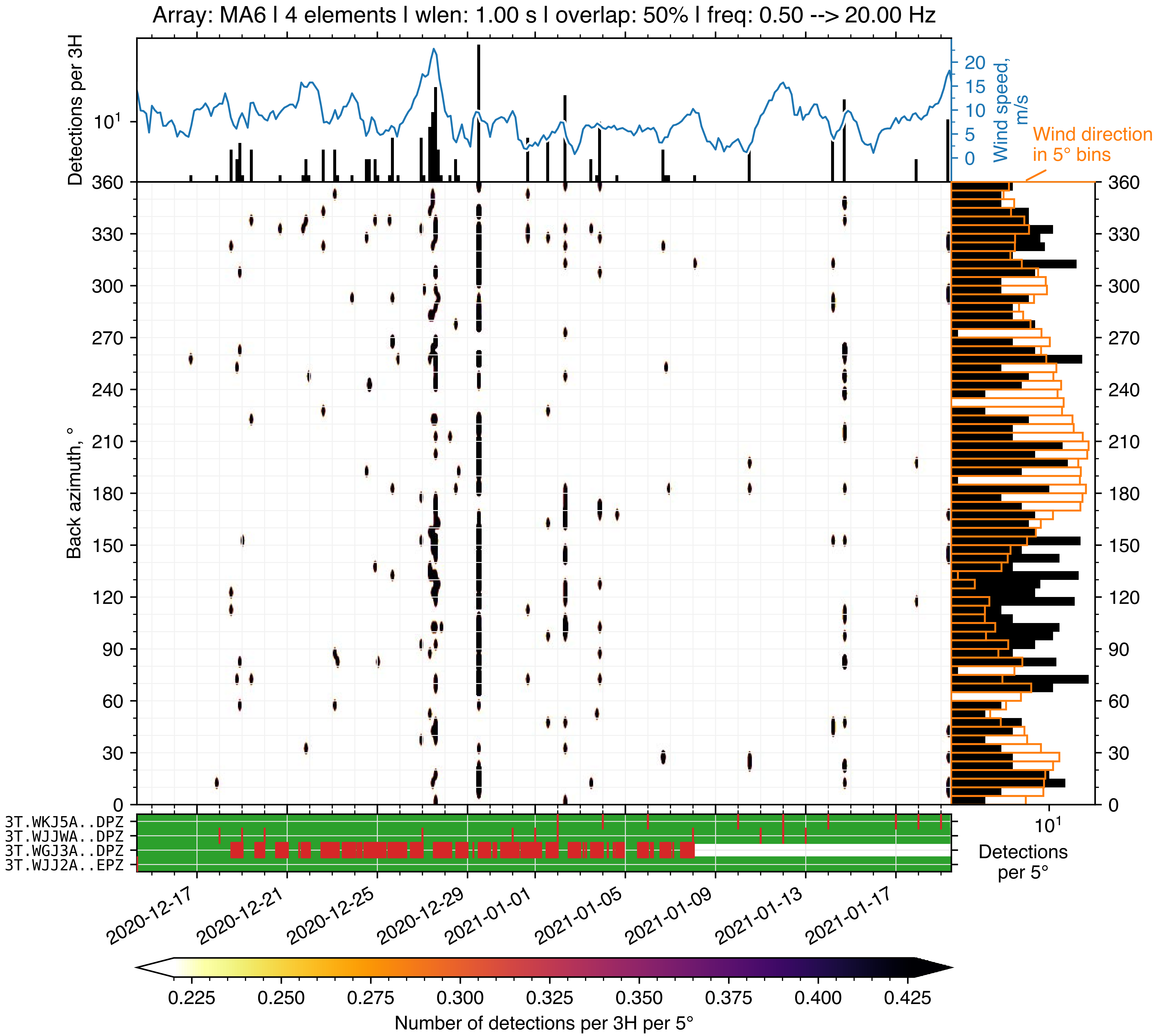


Results: Beamforming



Deep water well

Treatment facility



Final (but initial) remarks:

- Spectral peaks of ~1.1, 2.2, 3.1 have been clearly identified to be related to wind turbines.
- These change as a function of wind speed and as a function of distance from the wind park.
- The assumption that the upper soil layer is a vibration insulator is correct for anthropogenic activity on the surface but fails when structures are founded in the hard rock, or when the activity is ***in*** the hard rock itself.
  - In this case, the vibrations are directly coupled to the hard rock with little regard to the top soil layer.
  - Wind turbines, bridges, tall buildings, road & railway tunnels, water pumps, etc. will have this effect.
- Why is the entire spectrum is affected by wind?
  - At the surface: Probably due wind interaction with the surface itself, trees, vegetation, and other structures.
  - At depth: Probably due to structures founded in the hard rock.