WINES

Wind turb**I**ne Noise ass**E**s**S**ment in the Italian site candidate for Einstein Telescope

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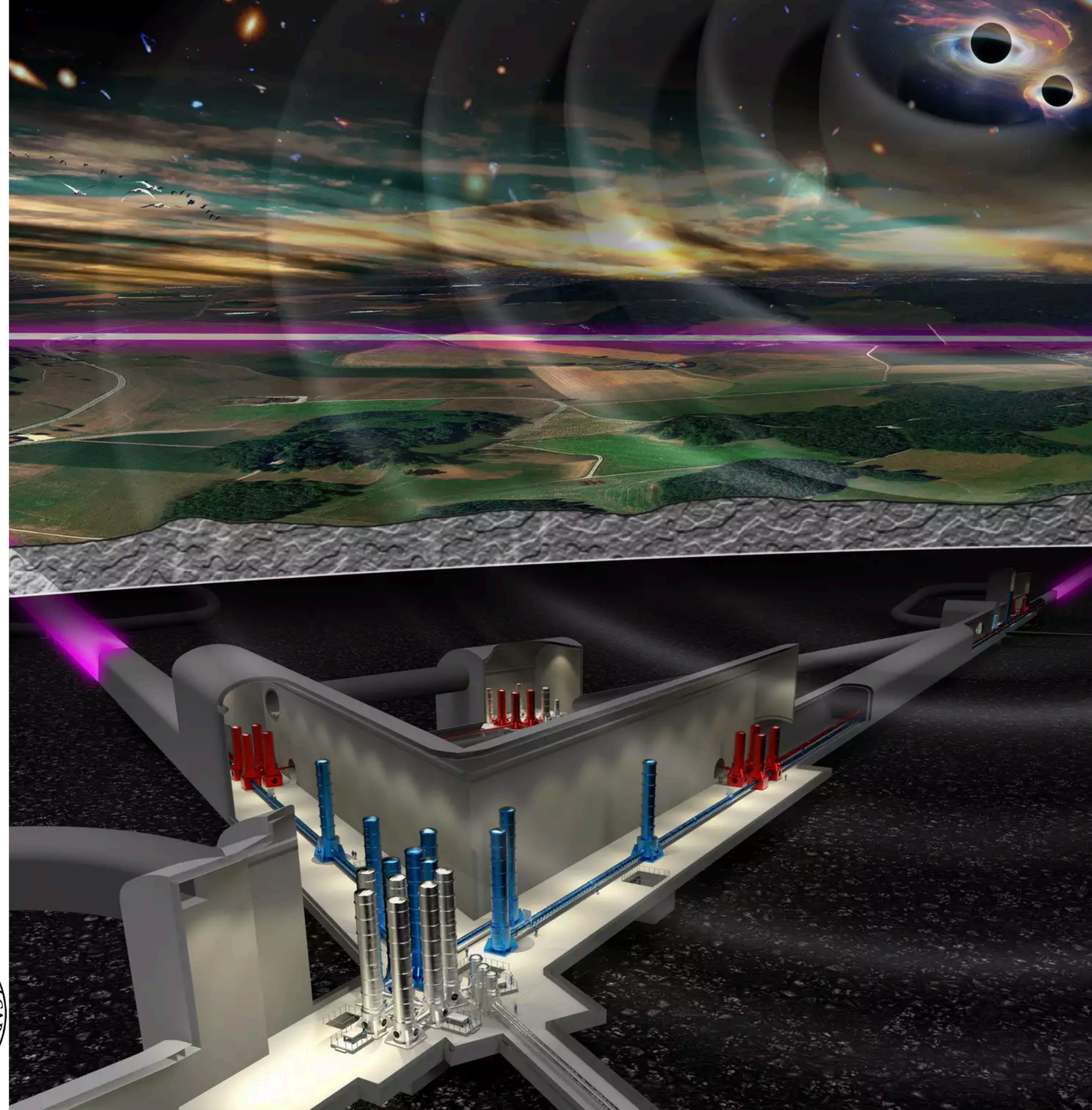

INFN Istituto Nazionale di Fisica Nucleare

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ET ITALY Einstein Telescope

INGV

SARDINIA FABER FAR FAULT OBSERVATORY

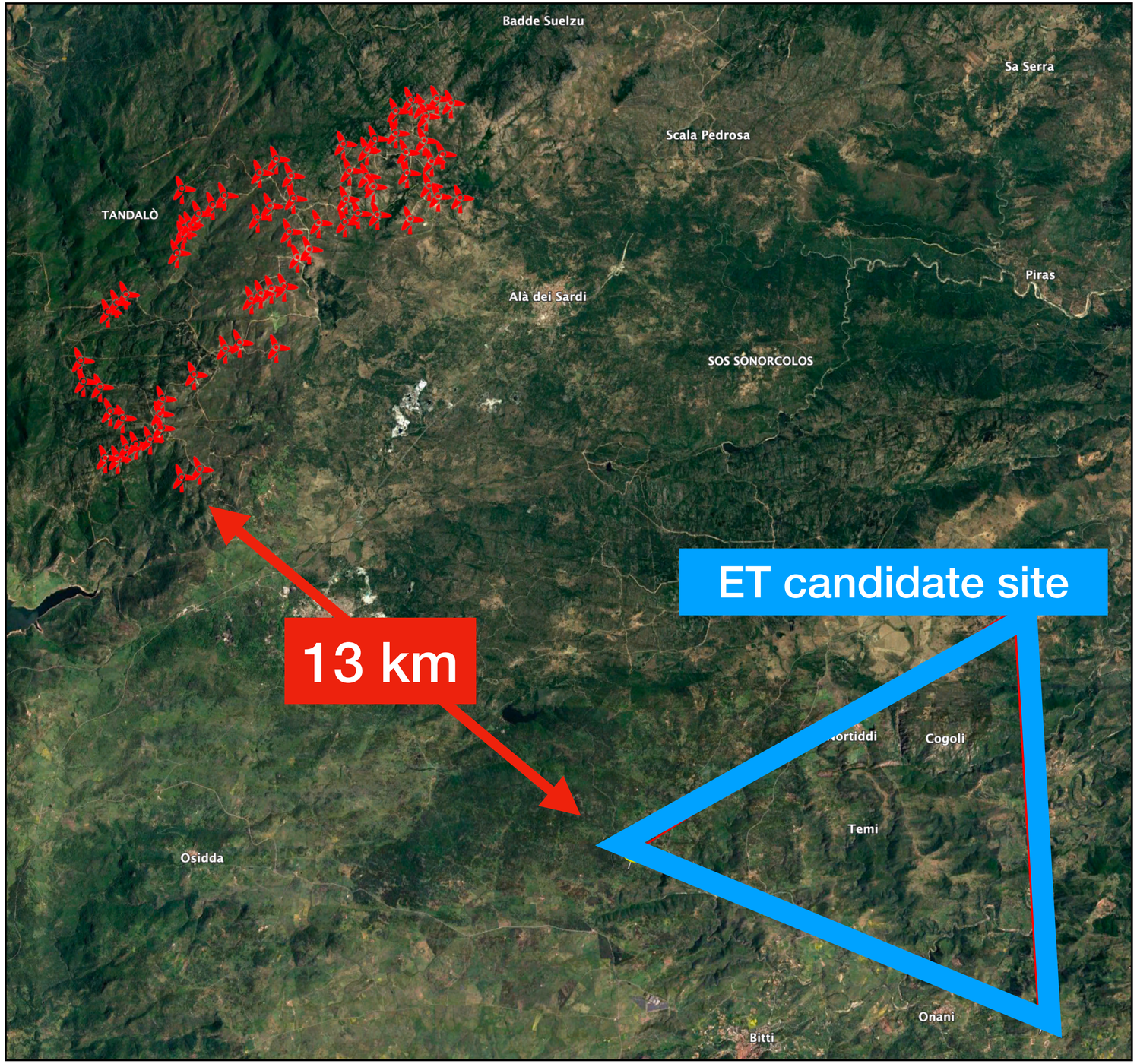
The Buddusò Wind Park

- one of the largest Wind park in Italy
- 69 turbines (~2MW each)
- 130 MW installed

For wind energy exploitation, the area is **exceptionally promising** due to the:

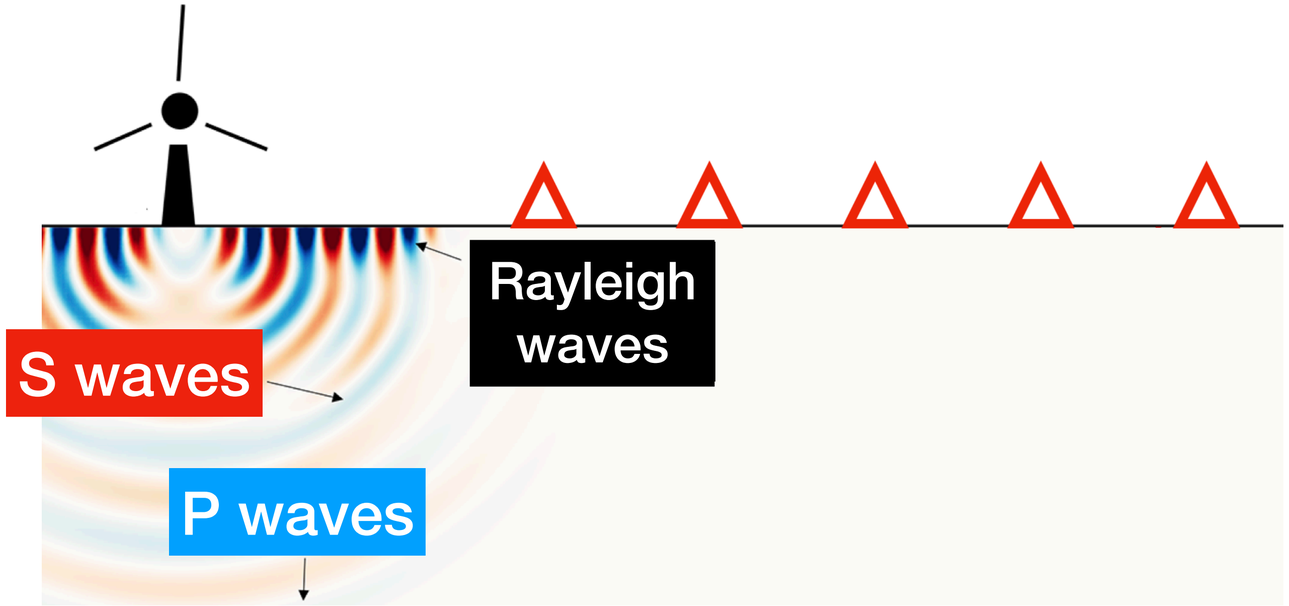
- rural environment

- strong and persistent winds in any season



Windpark and seismic noise…

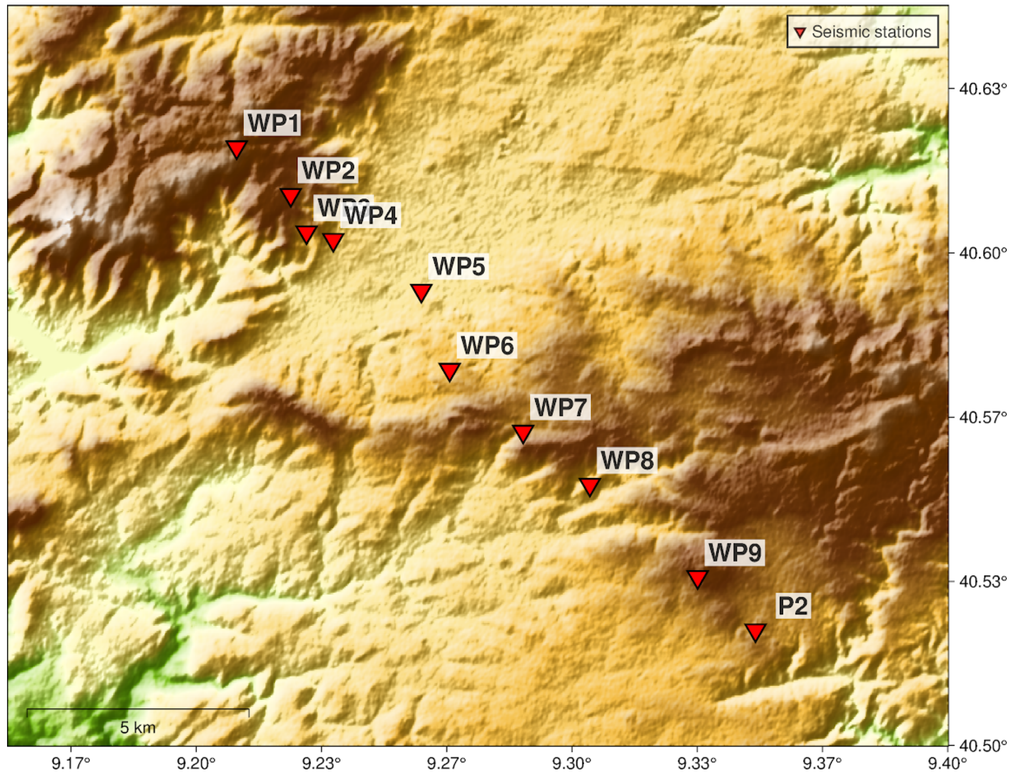
- **Blades motion** is transferred to tower, from tower **to the ground**
- Seismic noise propagates as **surface waves** (mainly Rayleigh waves)
- Generated noise is found in the **1-10 Hz frequency band**…

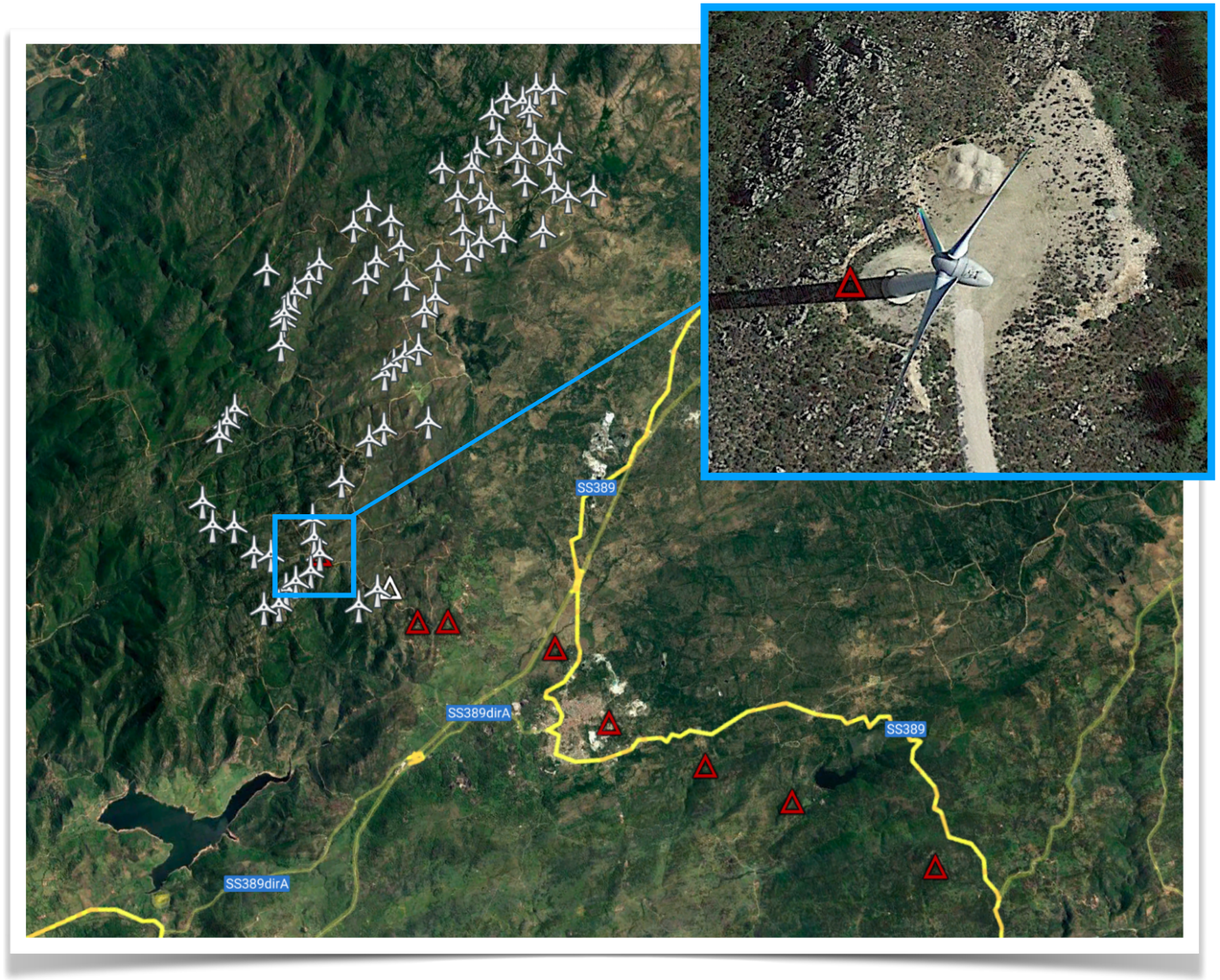


- what are **the characteristics** of the generated noise signal?
- **how far can we track it**?
- how does the seismic noise signal **decay with distance**?

The WINES experiment

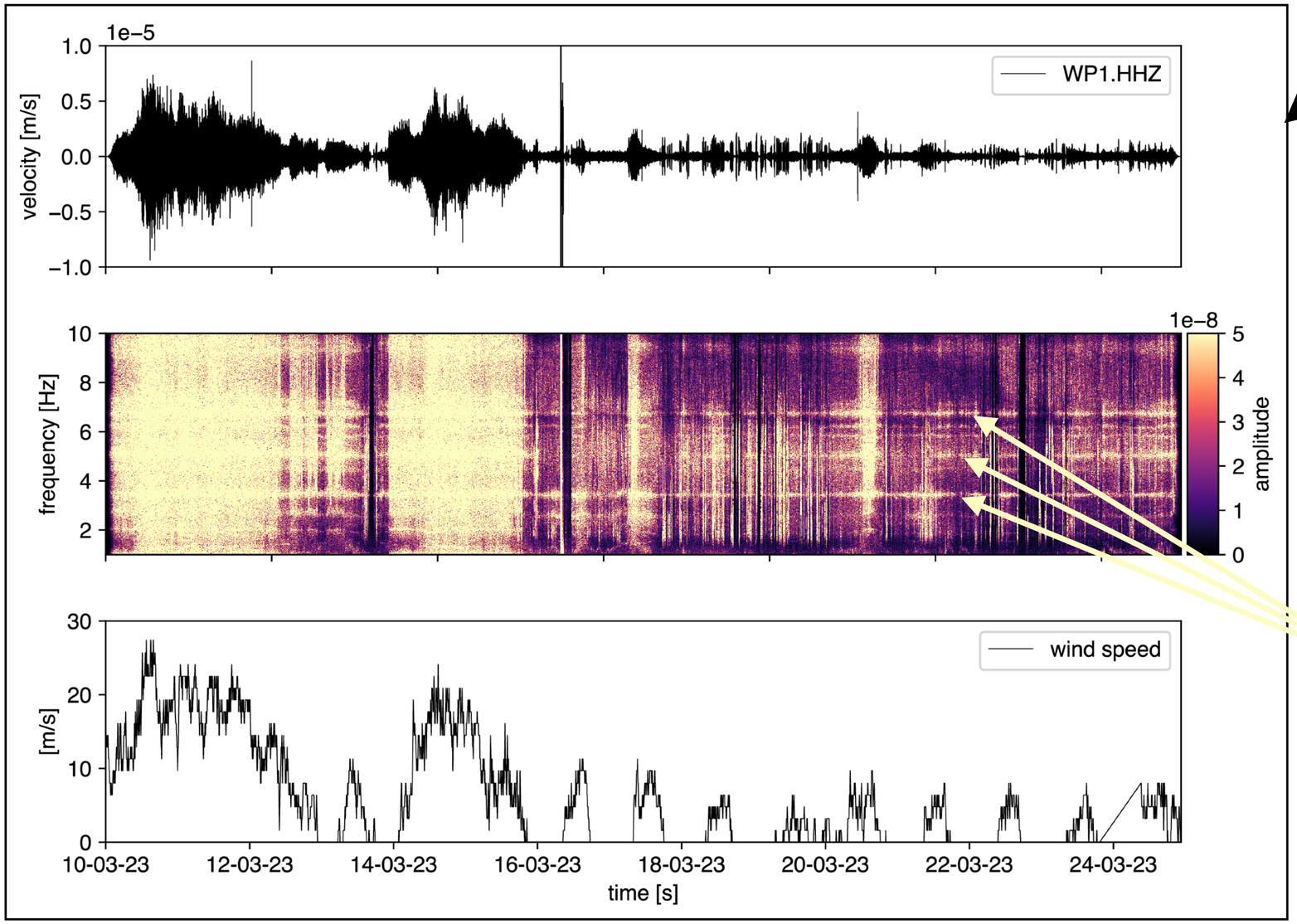
- **9 broad-band** seismic stations
- **~13 km** linear array
- **~2 months** of recording (8/04-30/05/2023)
- wind-speed data from a **nearby meteorological station**

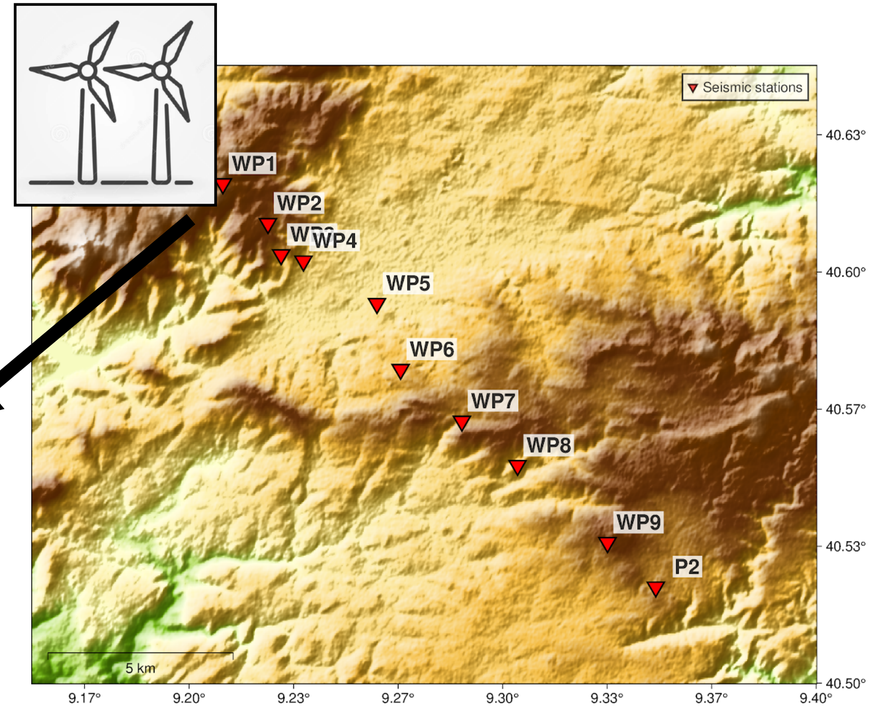




NB: in our analysis we also include the permanent stations **P2, P3**, located on the **two closest vertices of the ET candidate site**

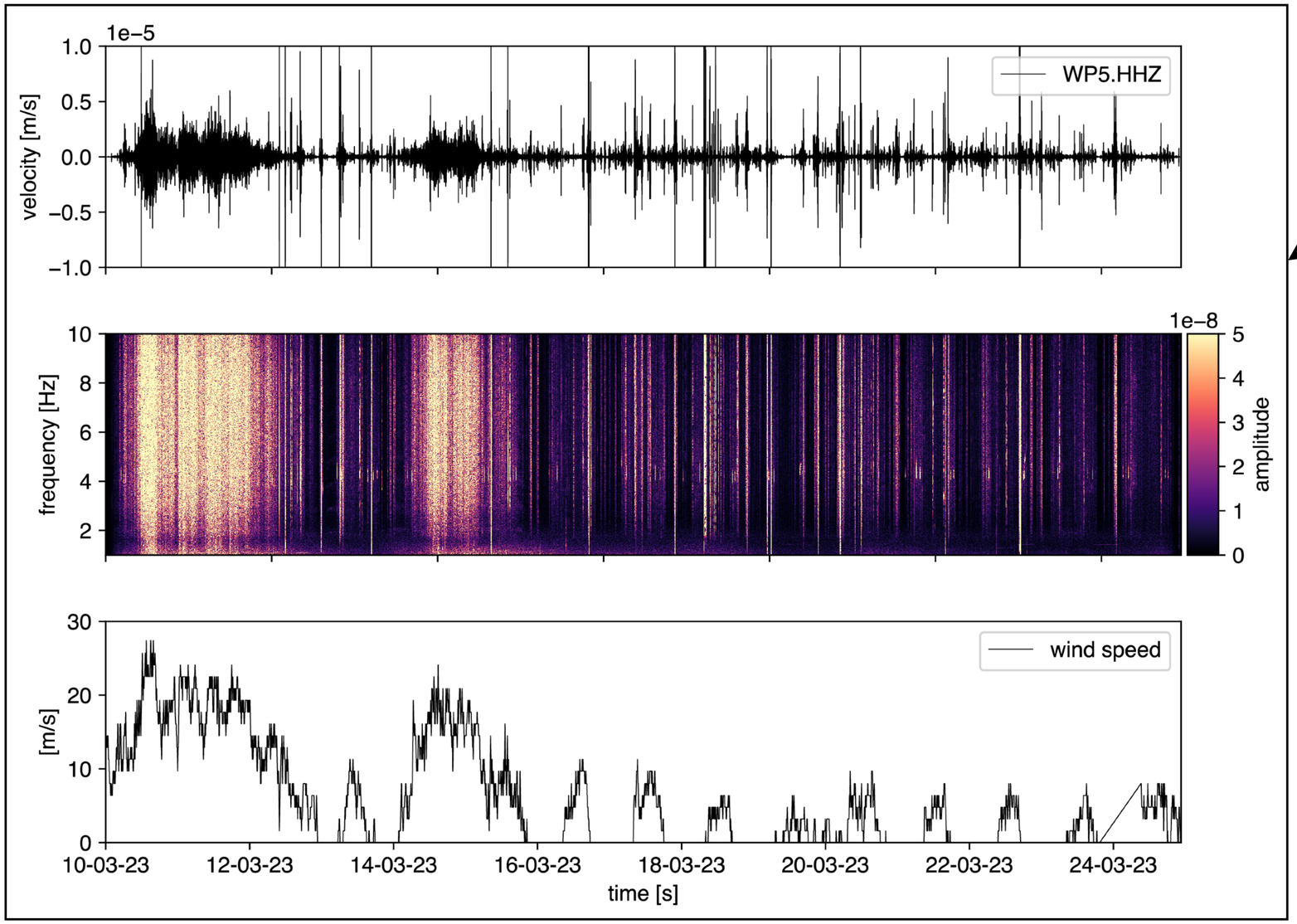
15 days-long spectrogram

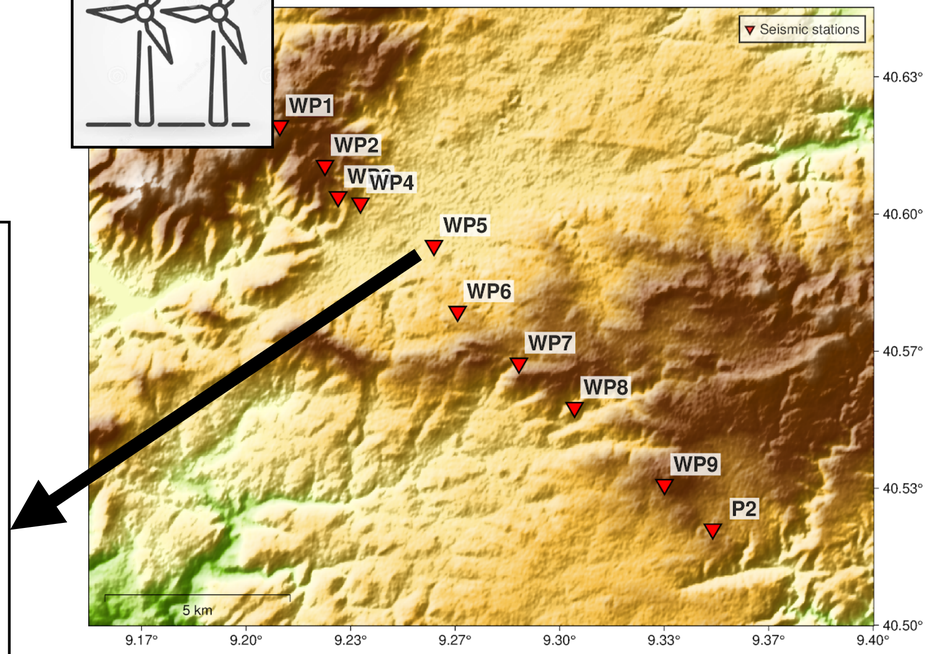




harmonics

15 days-long spectrogram





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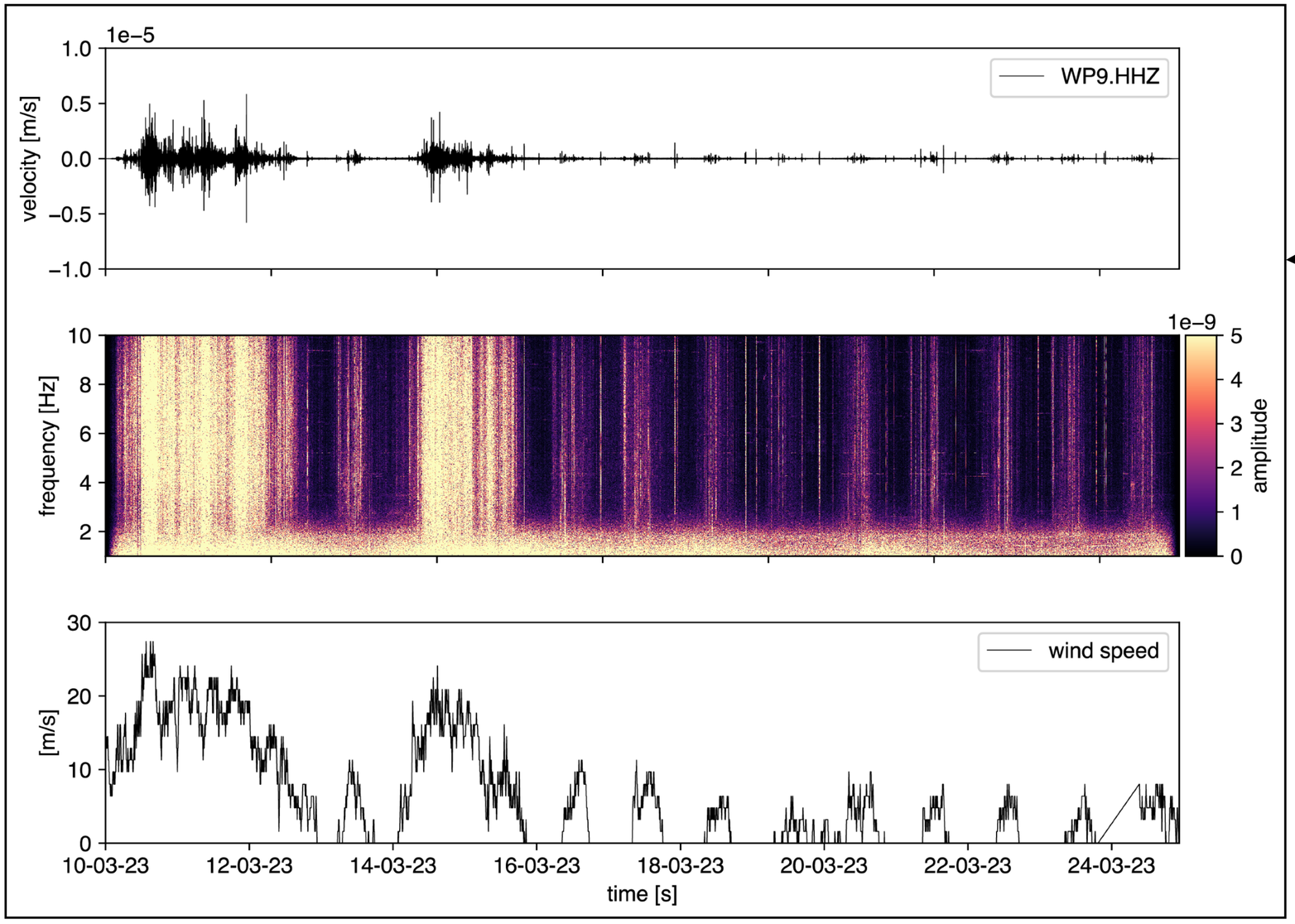

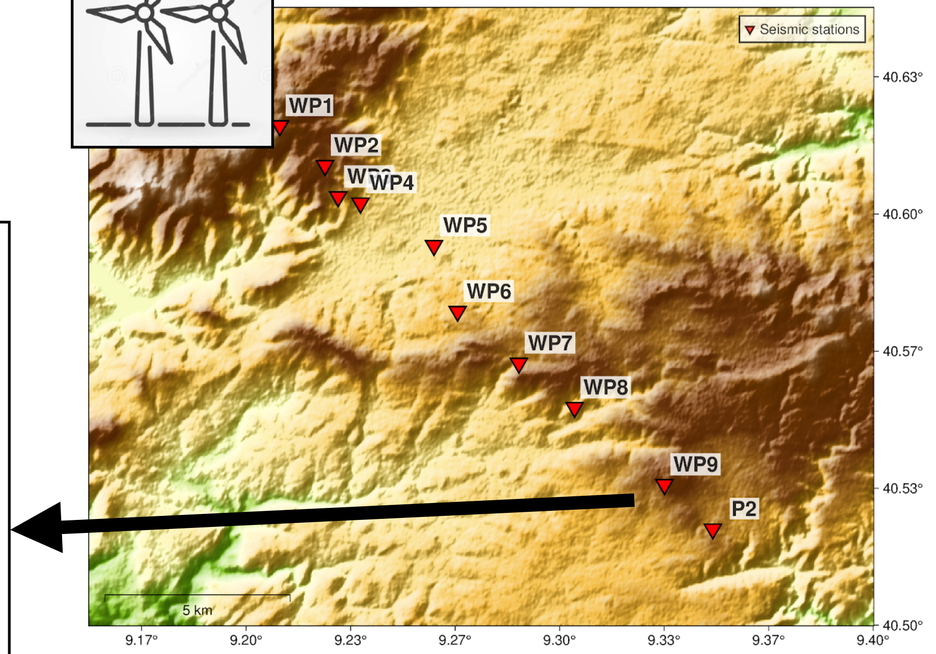

Power spectral densities (PSDs)

- **5 min-long window**
- **welch's method** for spectral estimation
- analysis of the **entire continuous recording**
- **median value** across time windows, **in the selected wind bands (i.e. 0-5, 10-20, 20-30 m/s)**

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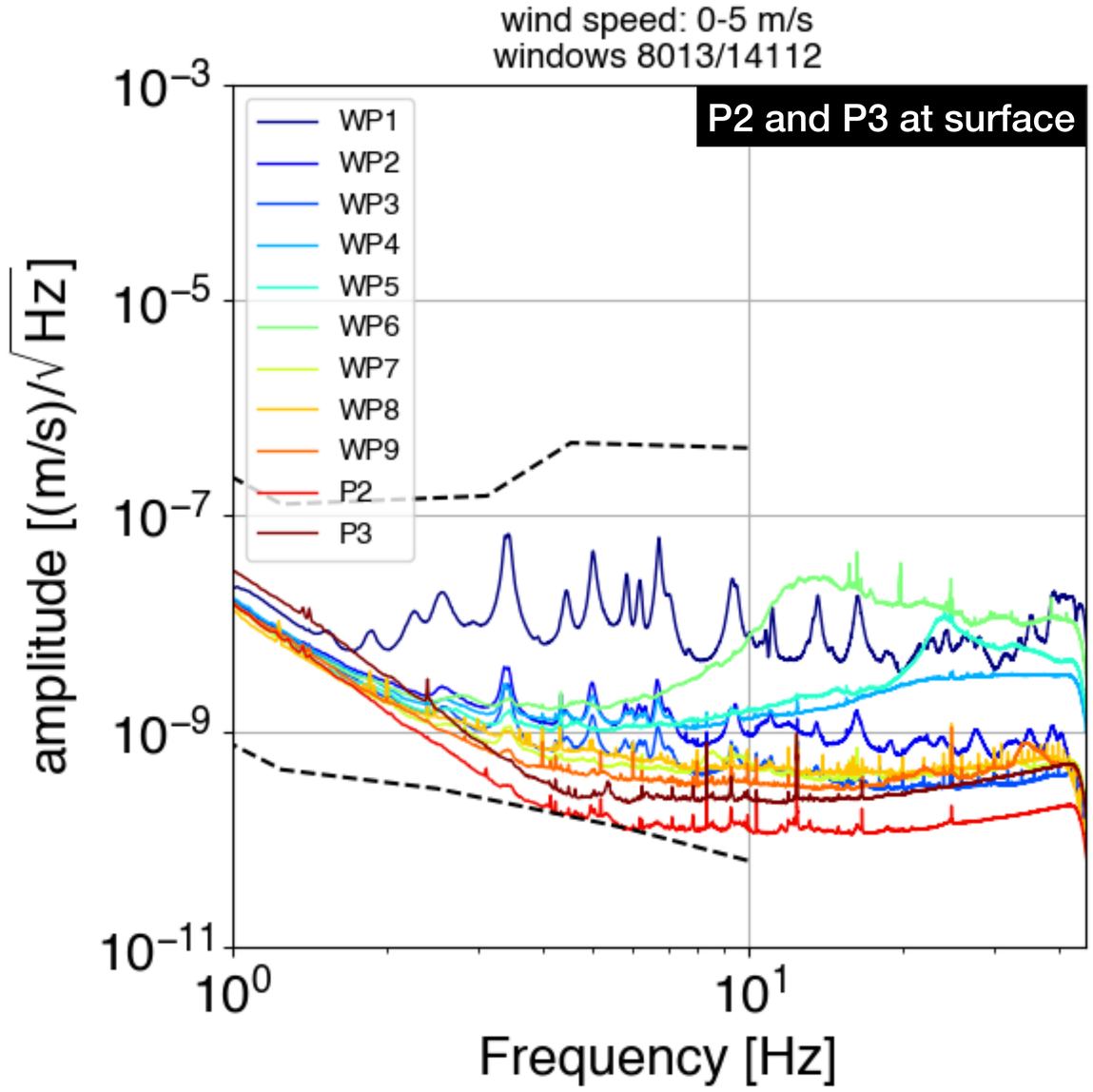

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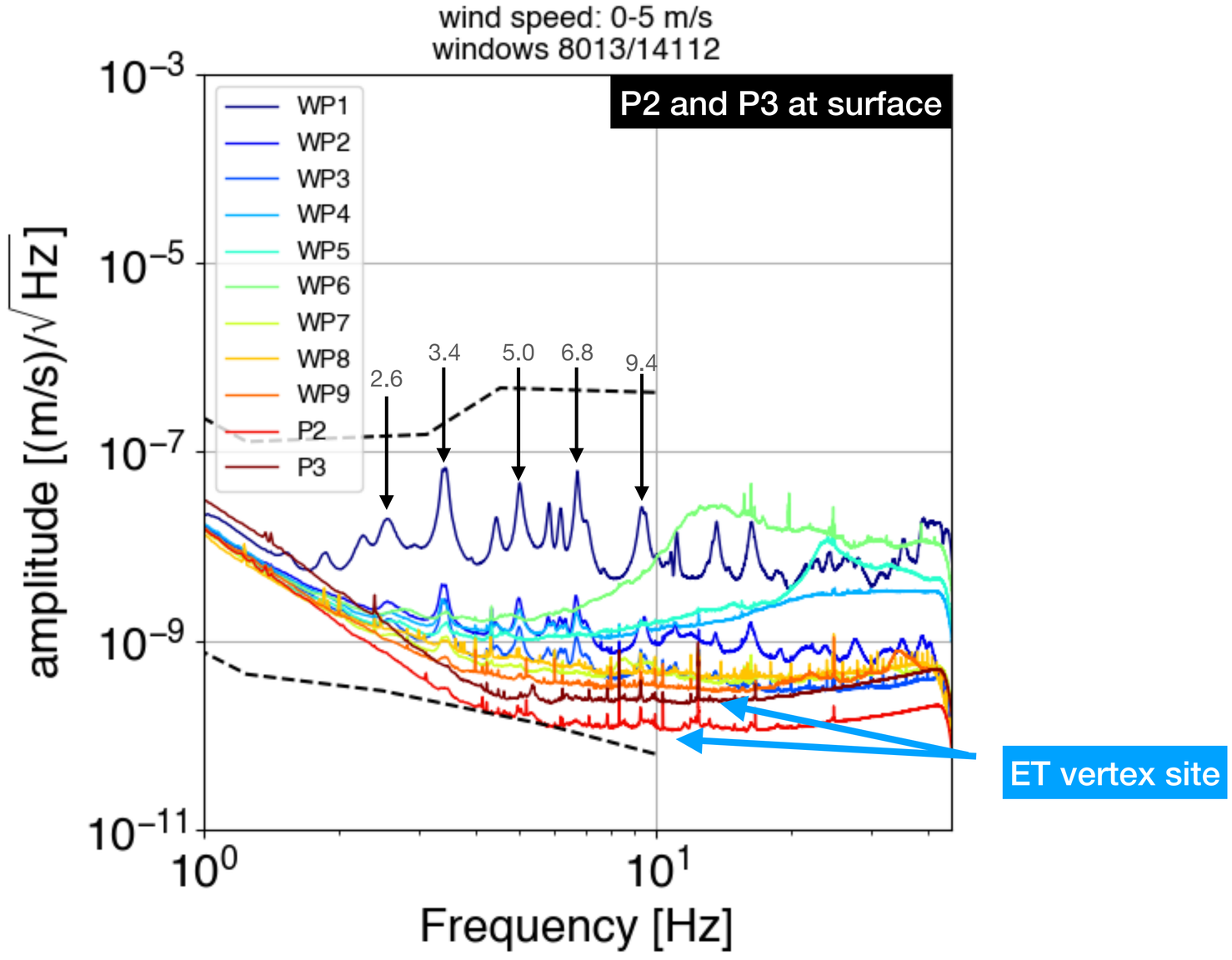

ET vertex site

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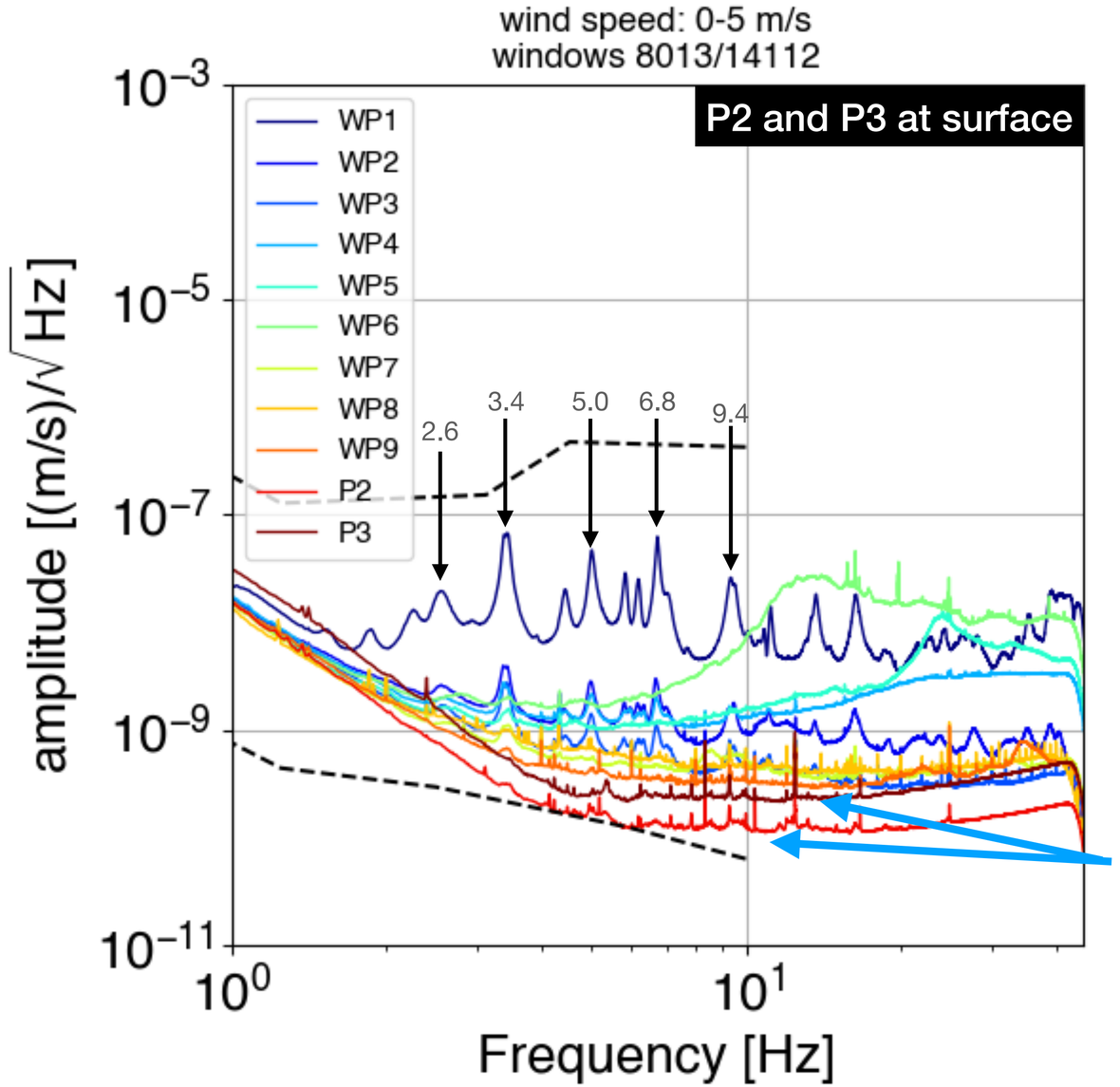

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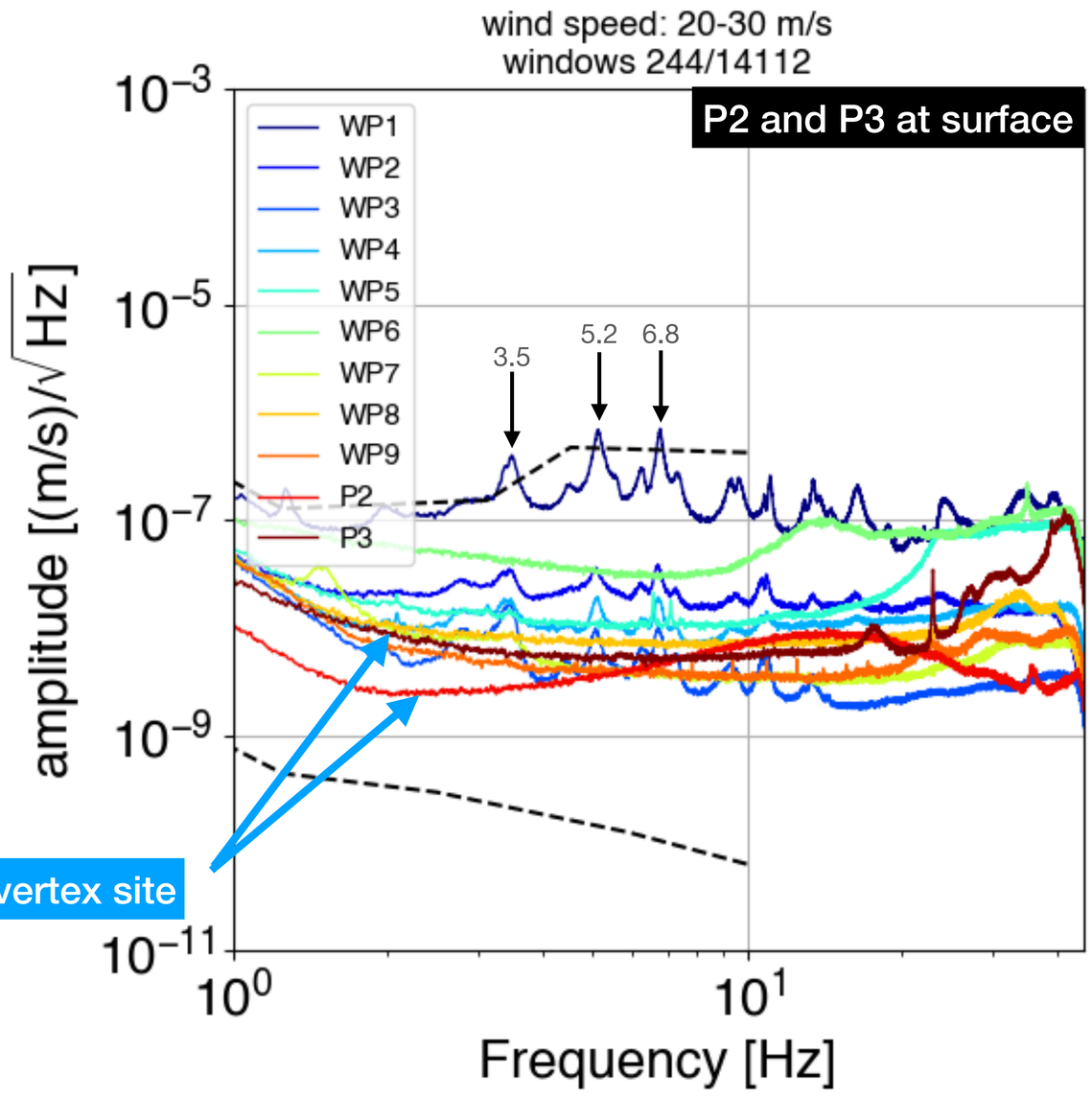

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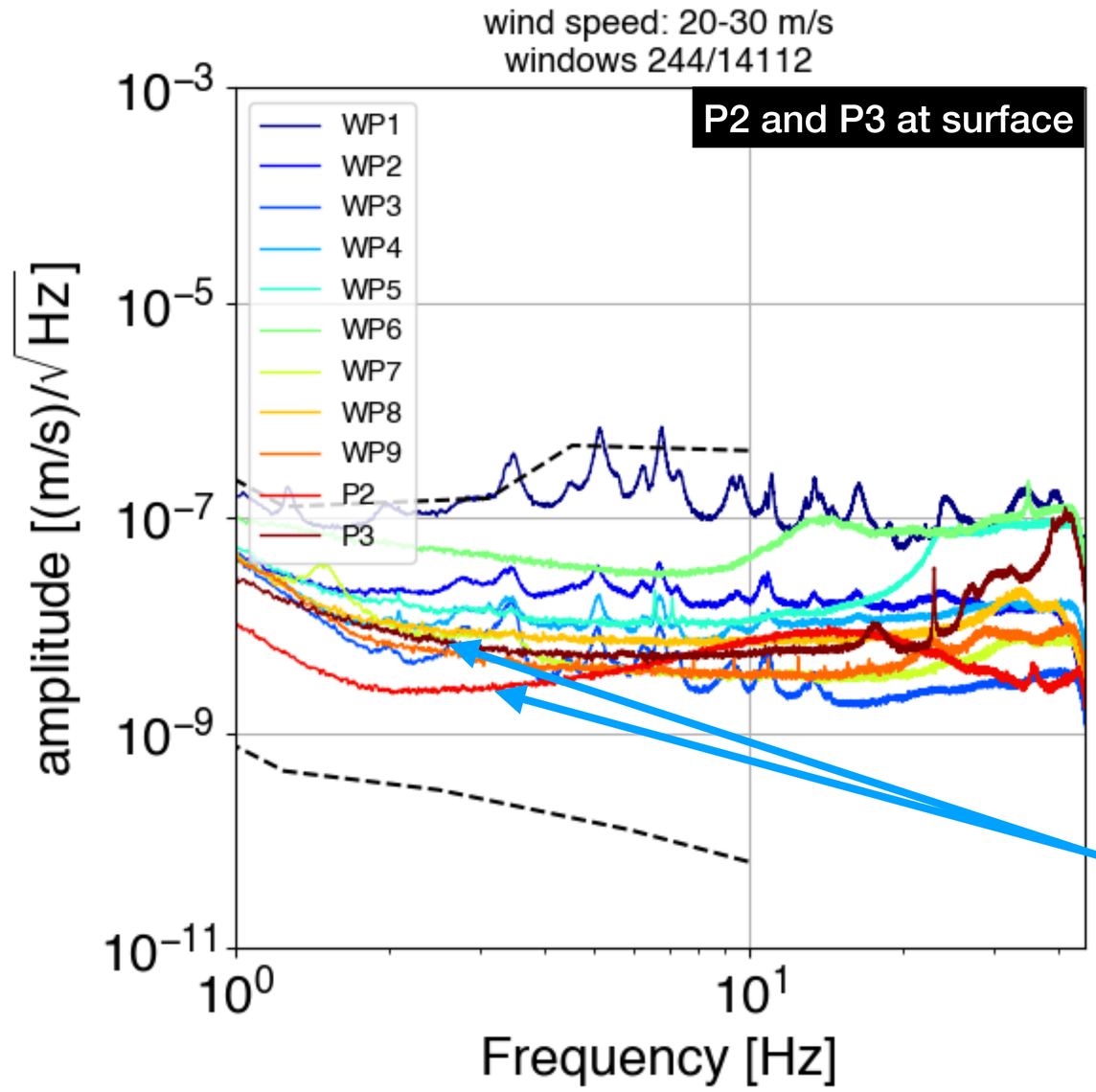
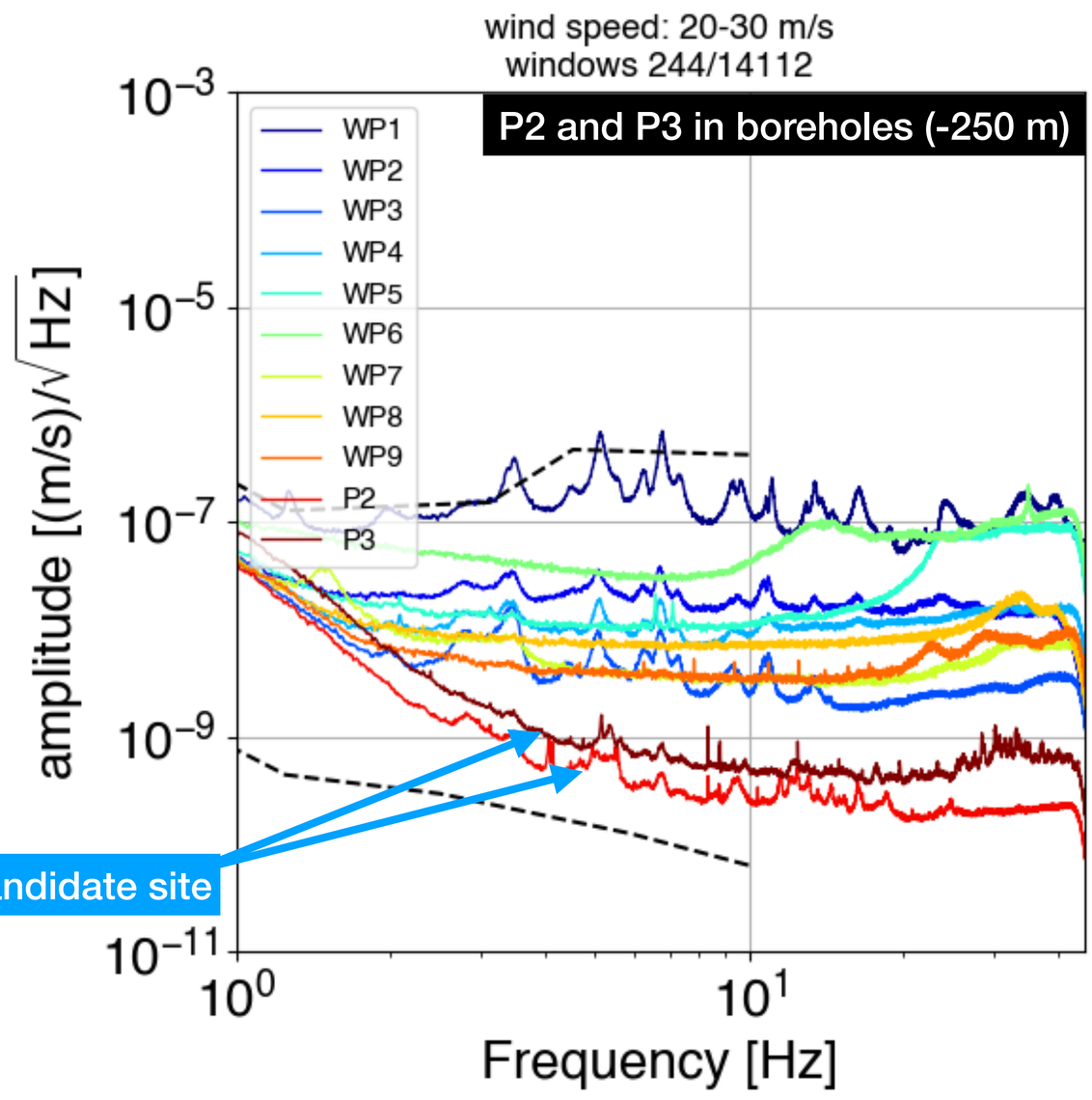
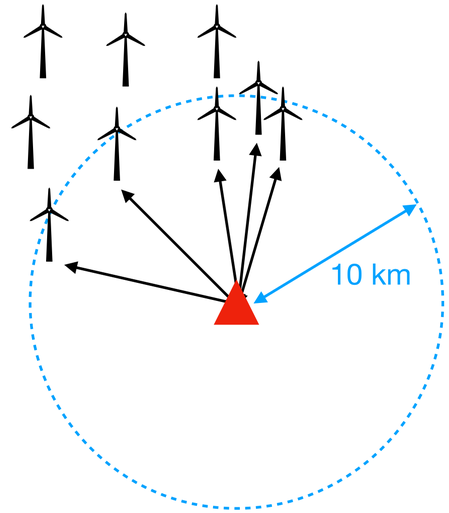




ET candidate site

Amplitude decays vs. distance

- for each station, we take the **number (N) of turbines within 10 km**
- calculate **harmonic mean distance** of all **N stations**
- **divide** spectral amplitude by $\mathbf{N^{1/2}}$



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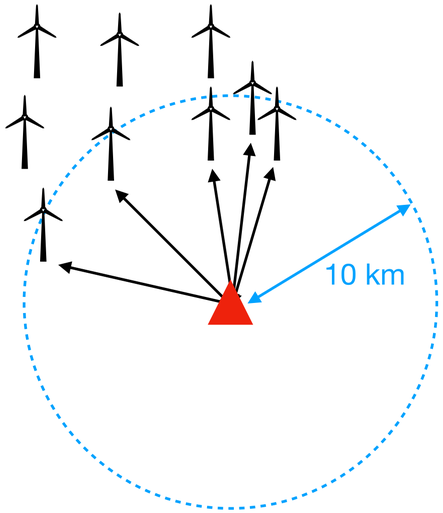
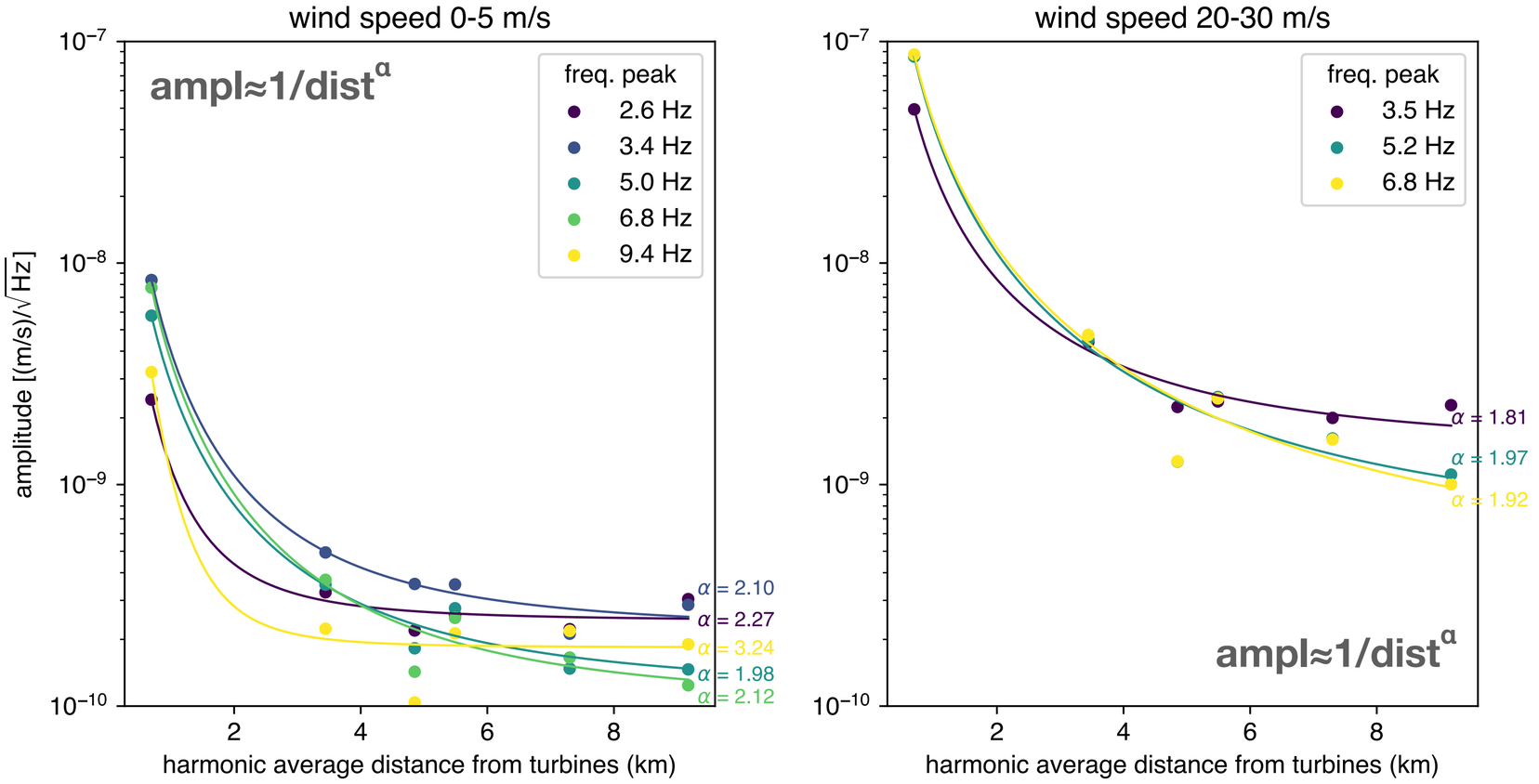




- clear **exponential decay**
- **stronger decay** for **higher frequencies**
- **~1 order of magnitude** decay in **10 km**
- **strong wind** condition increase noise **by ~1 order of magnitude**

Analysis of noise directionality

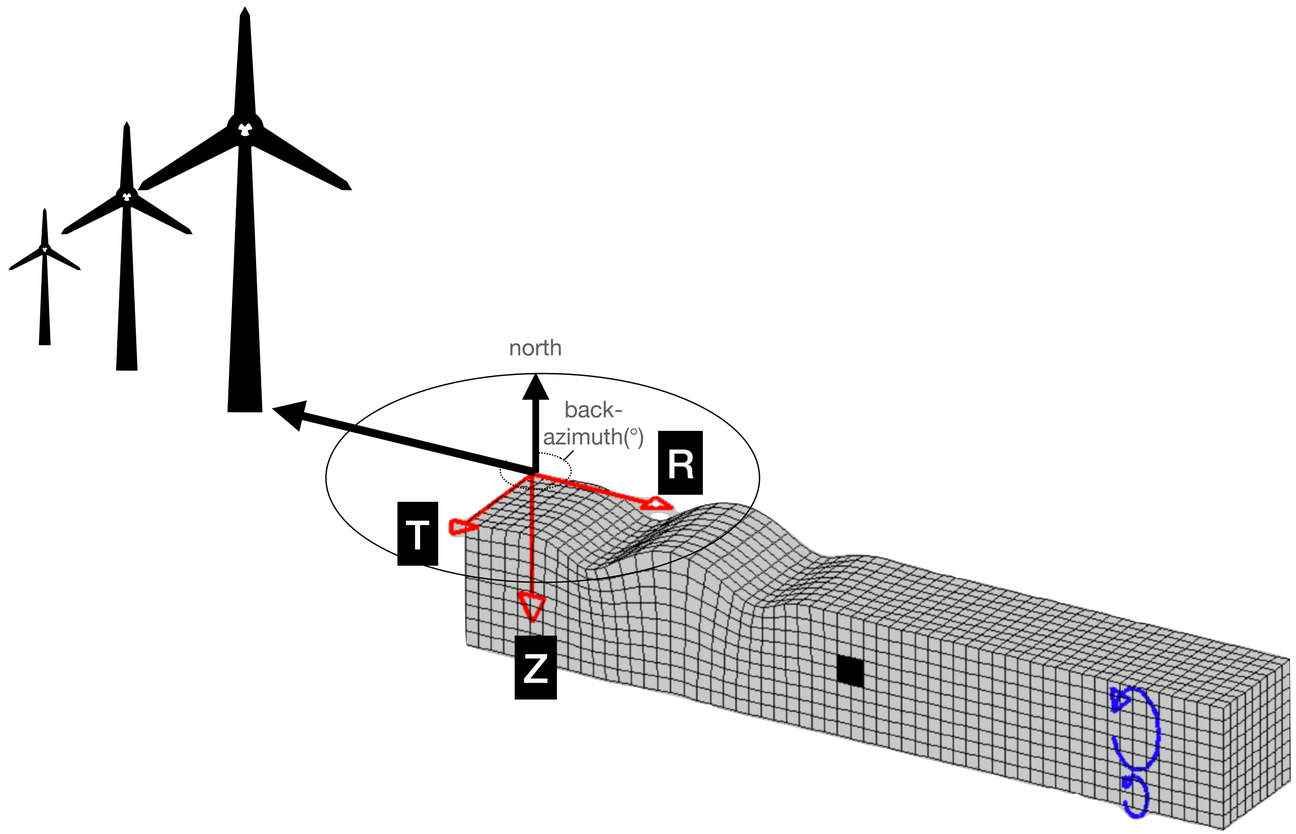
- For **Rayleigh waves**, **vertical** and **radial components** are (ideally) **90° phase shifted**

- The **back-azimuth** of a seismic source can be obtained by:

  - **rotating the N- and E-components to R- and T- components**, for various back-azimuth angle (0-360°).

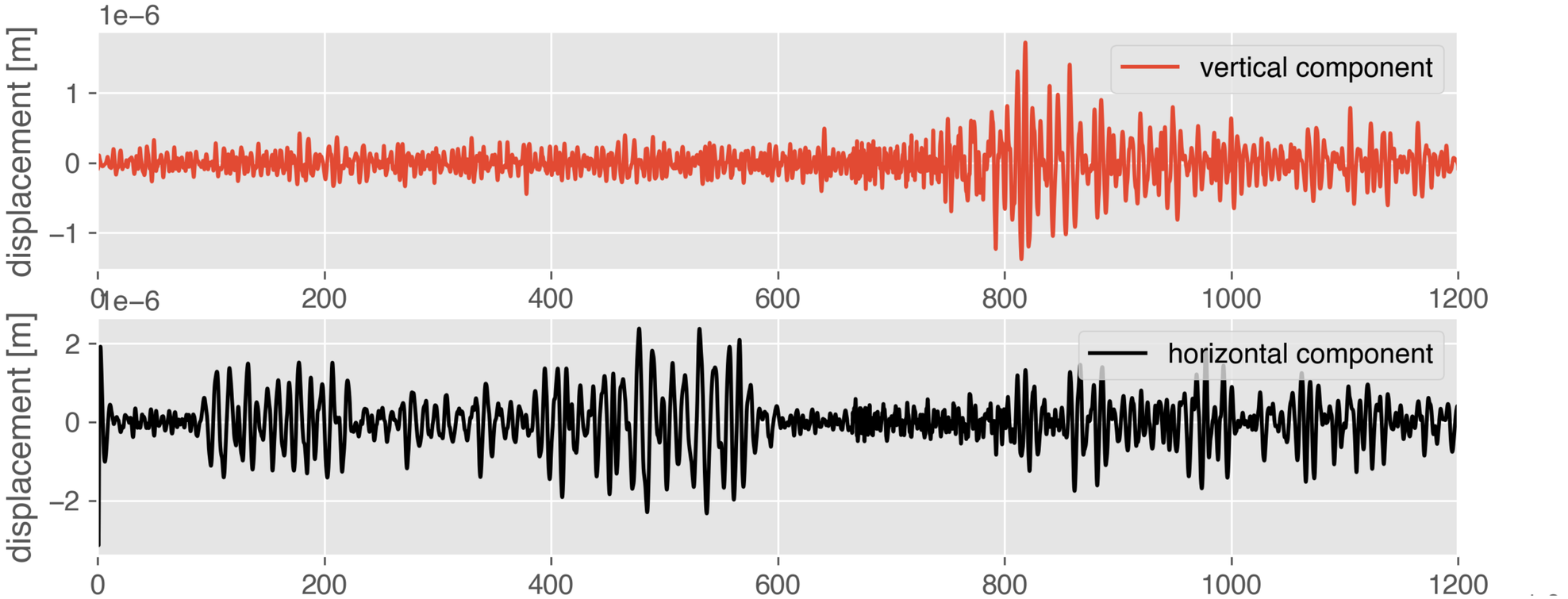
  - Find the angle that **maximize** the **cross-correlation between the Z-component** and the **Hilbert-transformed R-components** (to compensate for the 90° phase shift).

  - **Cross-correlation is maximum** when the **rotation angle** is **equal to the direction of the incoming Rayleigh wave**



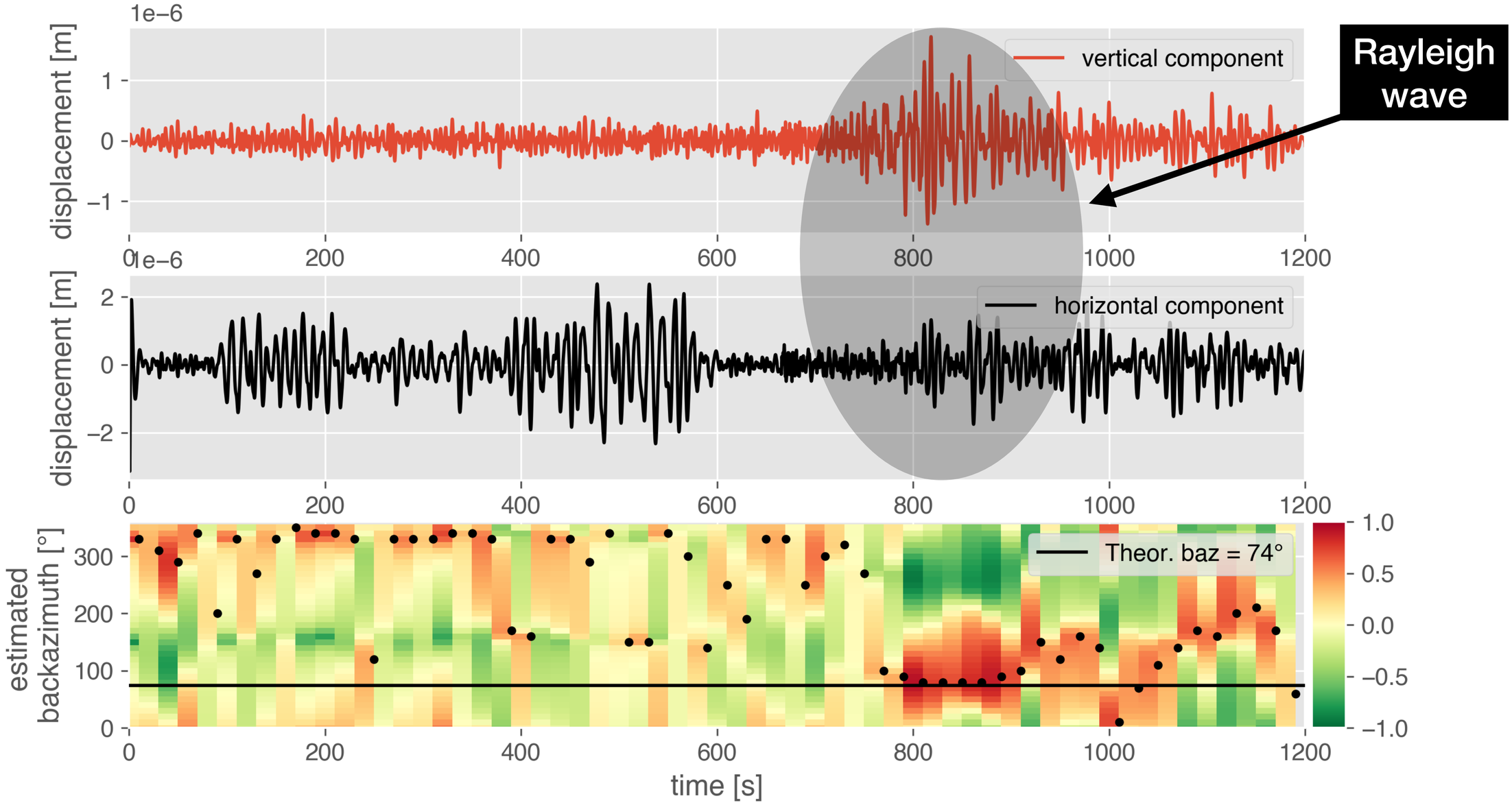
Analysis of noise directionality

Application with a known source:
M4.6 earthquake occurred on **28-03-2023**, with a **back-azimuth of 74°**



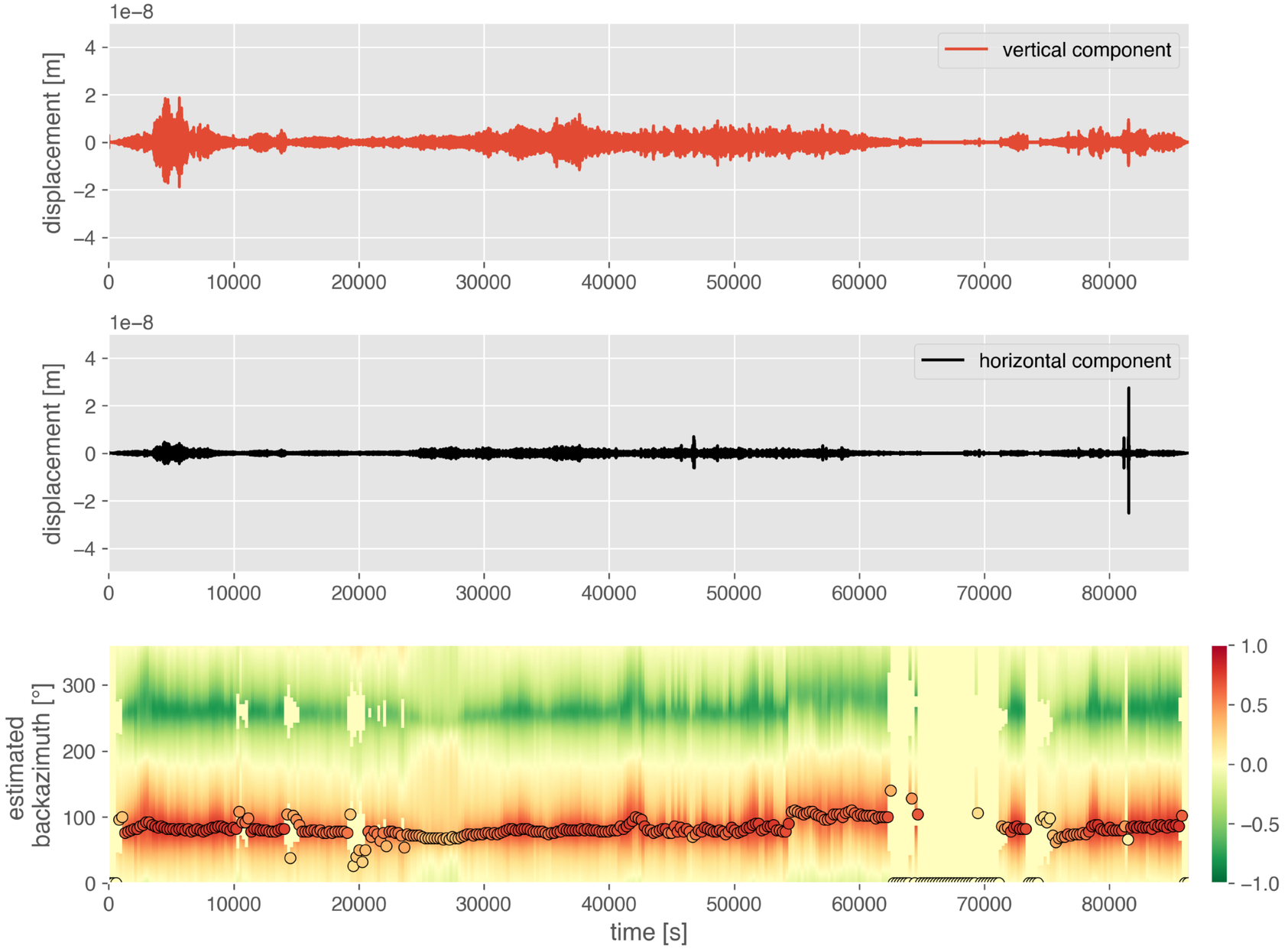
Analysis of noise directionality: a test

Application with a known source:
M4.6 earthquake occurred on **28-03-2023**, with a **back-azimuth of 74°**



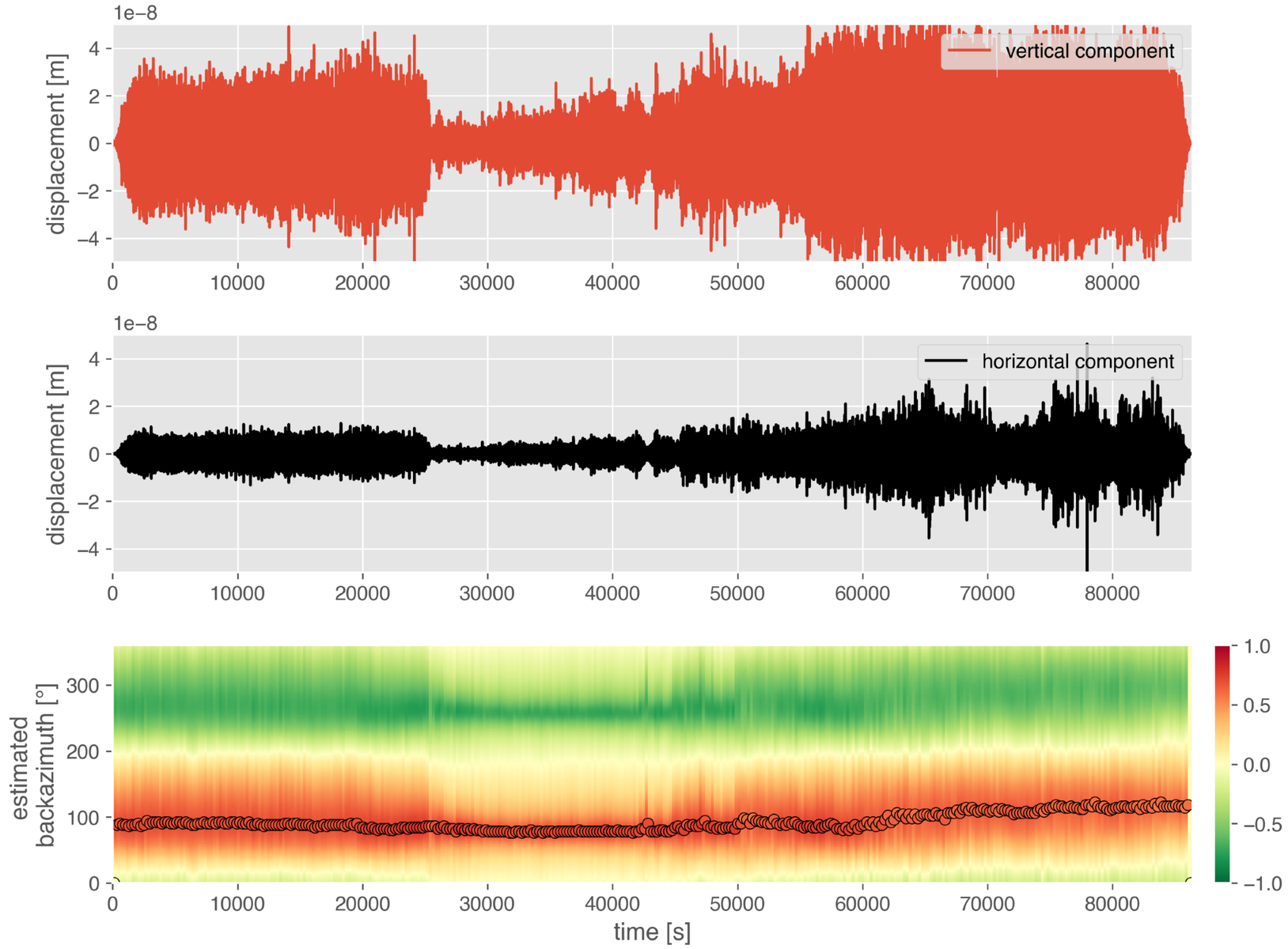
Analysis of noise directionality

station: **WP1**
duration: **24 hrs**
wind: **almost absent**



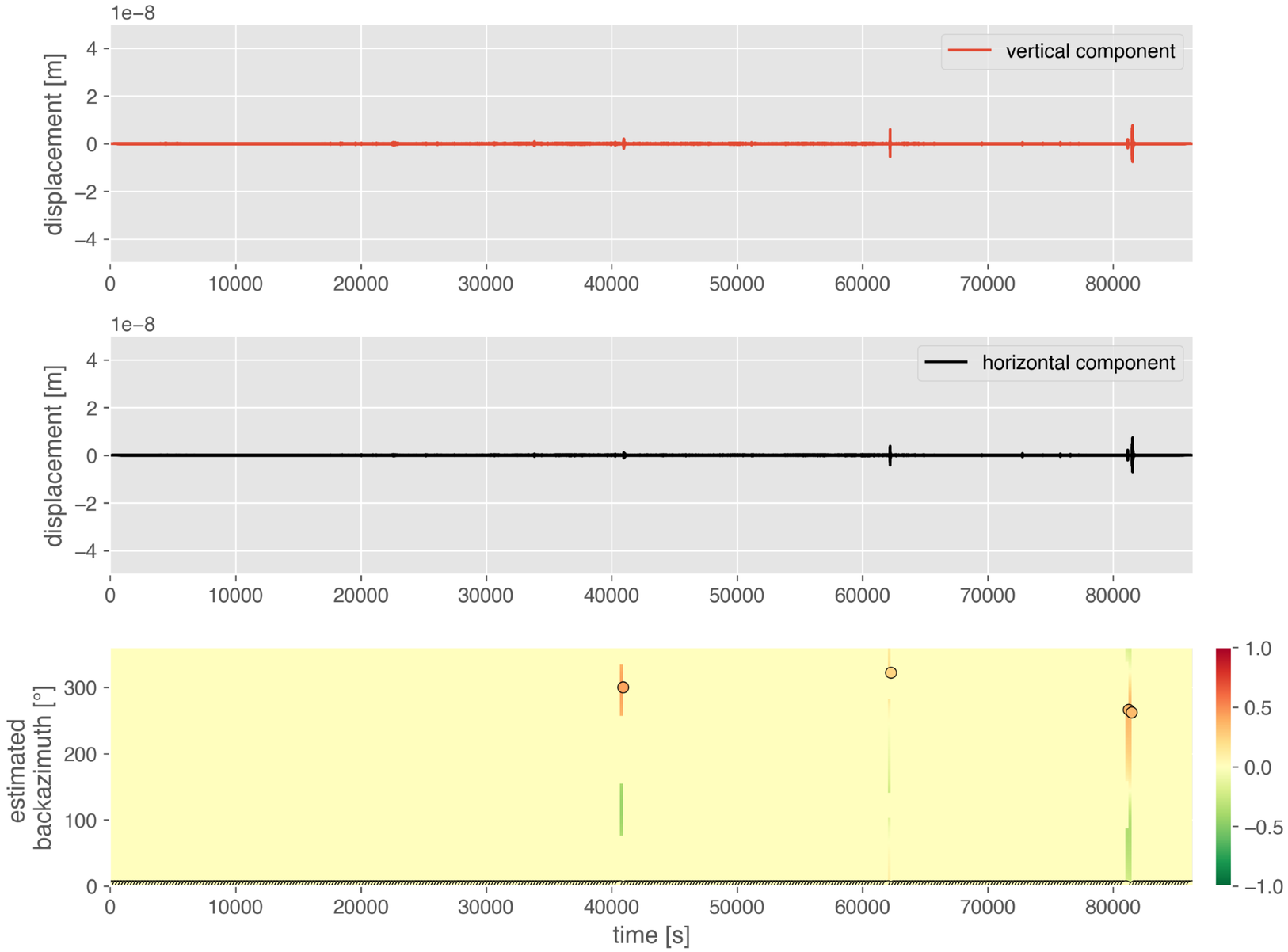
Analysis of noise directionality

station: **WP1**
duration: **24 hrs**
wind: **strong (>20 m/s)**



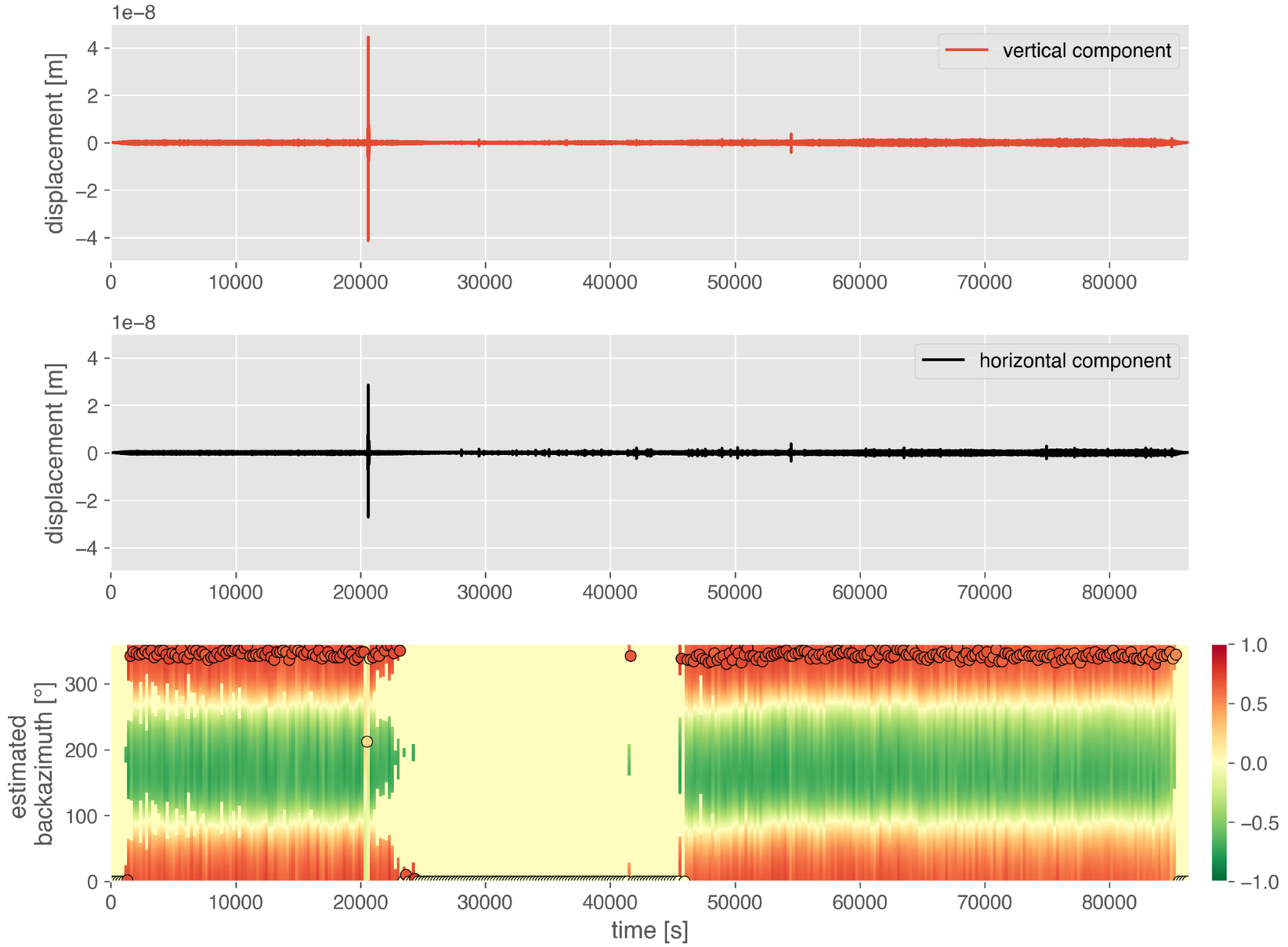
Analysis of noise directionality

station: **WP3**
duration: **24 hrs**
wind: **almost absent**



Analysis of noise directionality

station: **WP3**
duration: **24 hrs**
wind: **strong (>20 m/s)**



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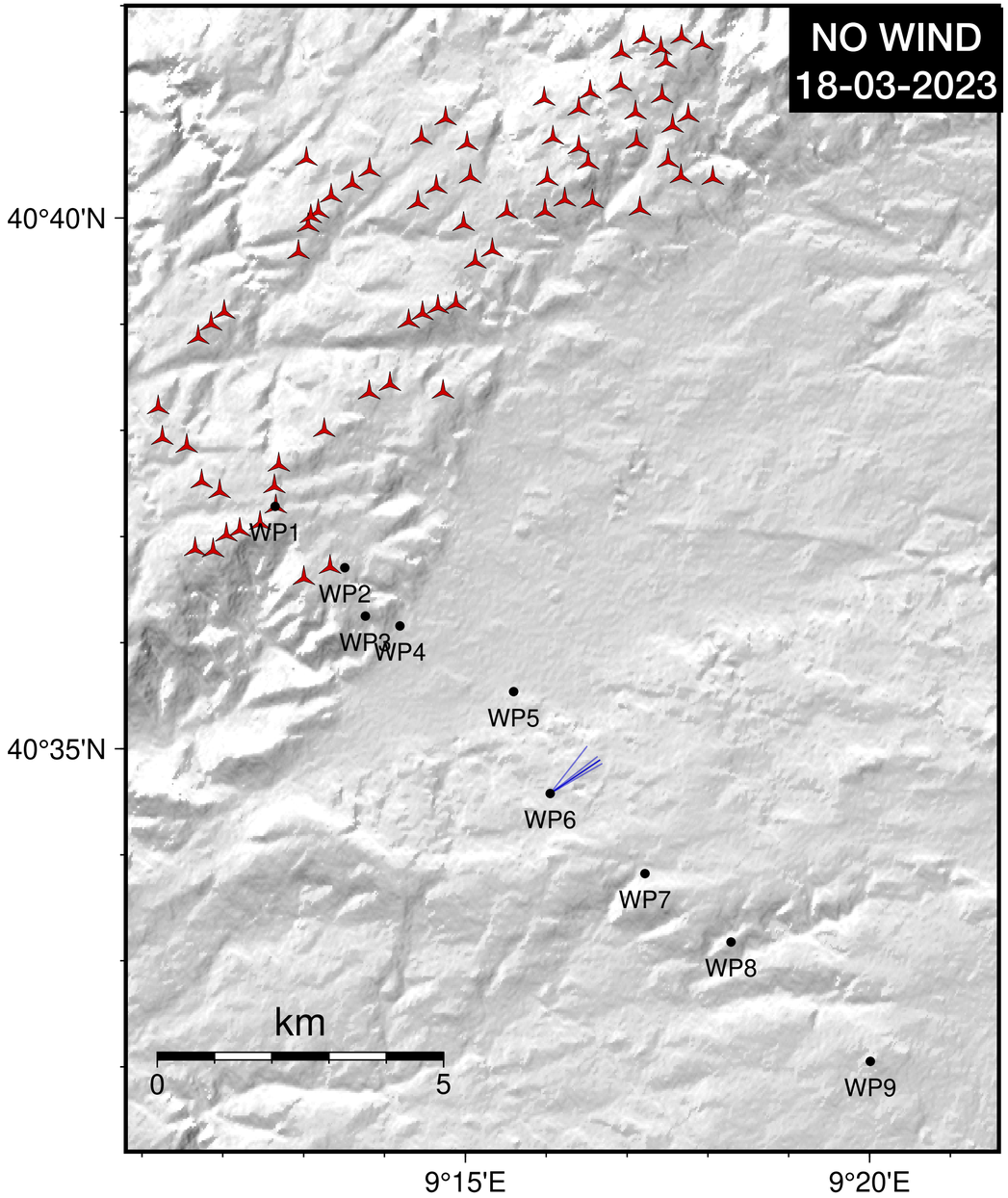

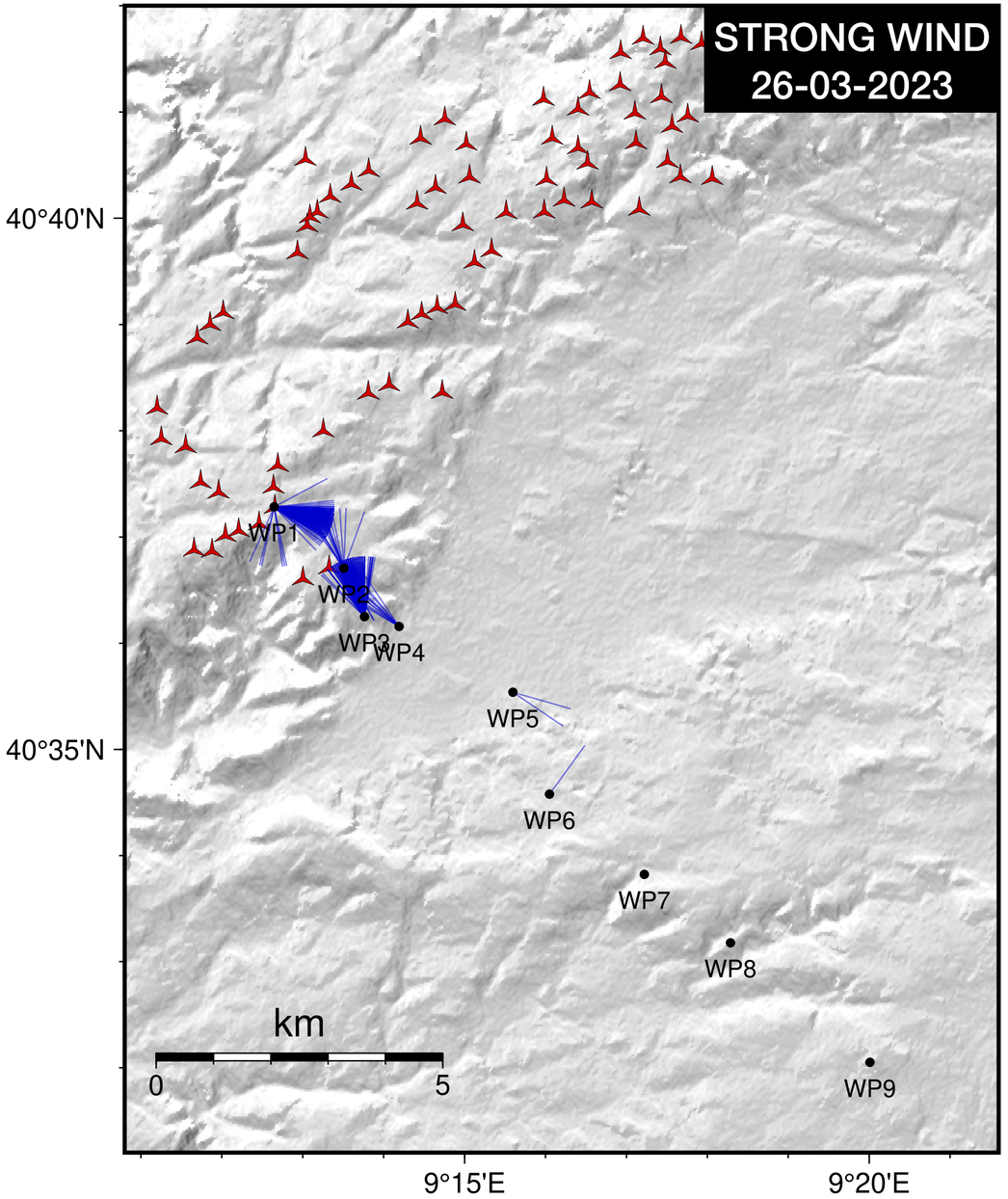

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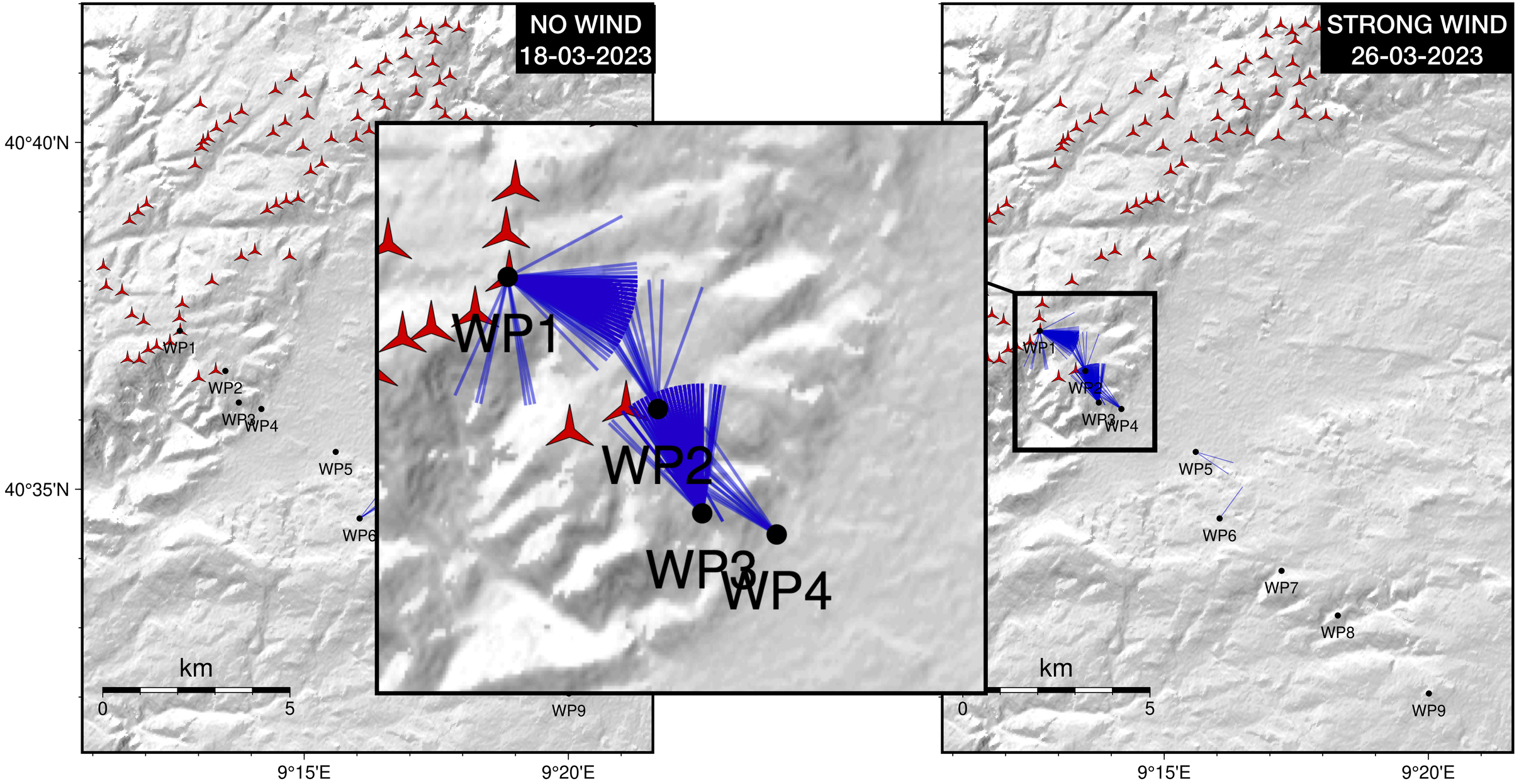

Conclusions and future directions

- As expected, **Buddusò wind park** generates **substantial seismic noise** with distinct frequency peaks (2.6, 3.4, 5.0, 6.8, 9.4 Hz)

- In case of **strong wind (>20 m/s)**, noise amplitude **increases** by roughly **one order of magnitude** w.r.t **weak or no wind (0-5 m/s)**

- Seismic amplitude is **exponentially damped** with distance, **decreasing by an order of magnitude in about 10 km**.

- **Boreholes stations** (**P2, P3** at **~250 m depth**): with strong wind **spectral peaks are visibile. Influence from wind park** or effect of wind **at local scale?**

- Analysis of **noise polarization** works up to **5 km from windpark**, showing a direction that is **fully compatible** with the position of the wind park w.r.t. the deployed array.

- The **analysis will be improved** by using the **full dataset** (RPM, power throughput, wind speed at each turbine) just released by the wind turbine operator.