First results from a borehole network for the seismic characterization of the Einstein Telescope Euregio Meuse-Rhine candidate site

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Narrative and scope

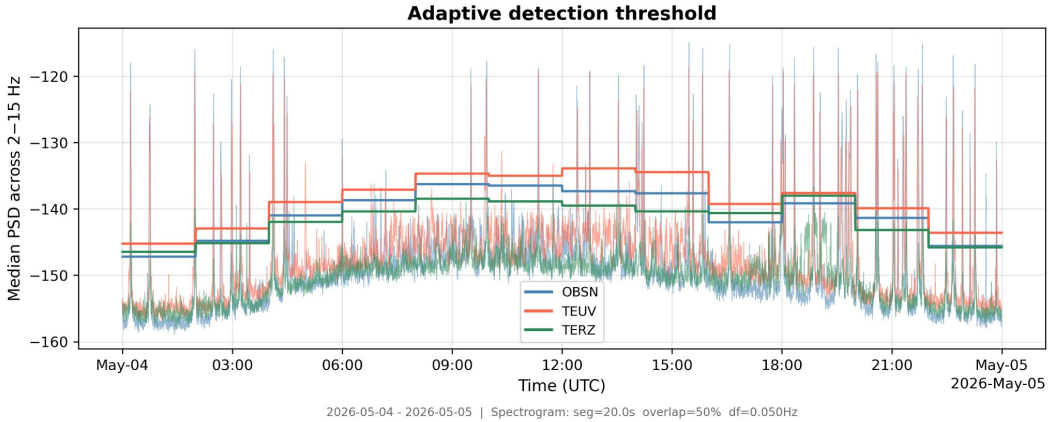
- First results from the borehole network in the Terziet area: OBSN, TEUV, TERZ, BSDL **(Jan–Aug 2026)**
- Boreholes sited next to the railway **on purpose** → we measure how anthropogenic noise is generated and attenuated in this geology, not corner-point levels
- A step in the EMR effort towards an integrated noise model: 3D geology + measured field + propagation → NN → mitigation

What's new in the paper

- **SiteChar**: a general-purpose Python framework for site characterization, agnostic to sensor and scale; on git.et together with the catalogue (private for now, just ask me)
- Explicit separation of stationary background vs transients, with a simple detection algorithm (z-score by Soumen)
- Characterization of the transient catalogue and a tentative classification
- Tentative modelling with TRAFFIC

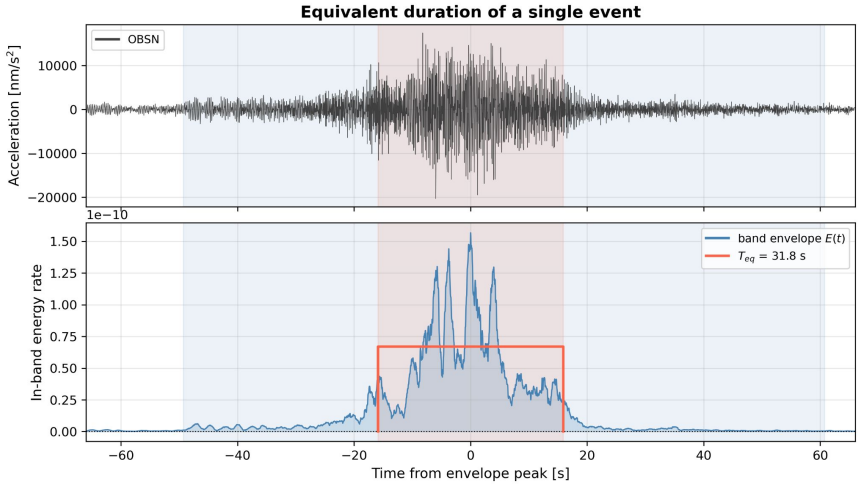
Z-score

$$z(t) = \underset{f_1 \le f \le f_2}{\text{med}} \frac{\log_{10} S(f,t) - m(f)}{\text{MAD}(f)}$$



Equivalent duration

the duration of a rectangular pulse with the same (90%) energy and effective power as the observed transient



SiteChar

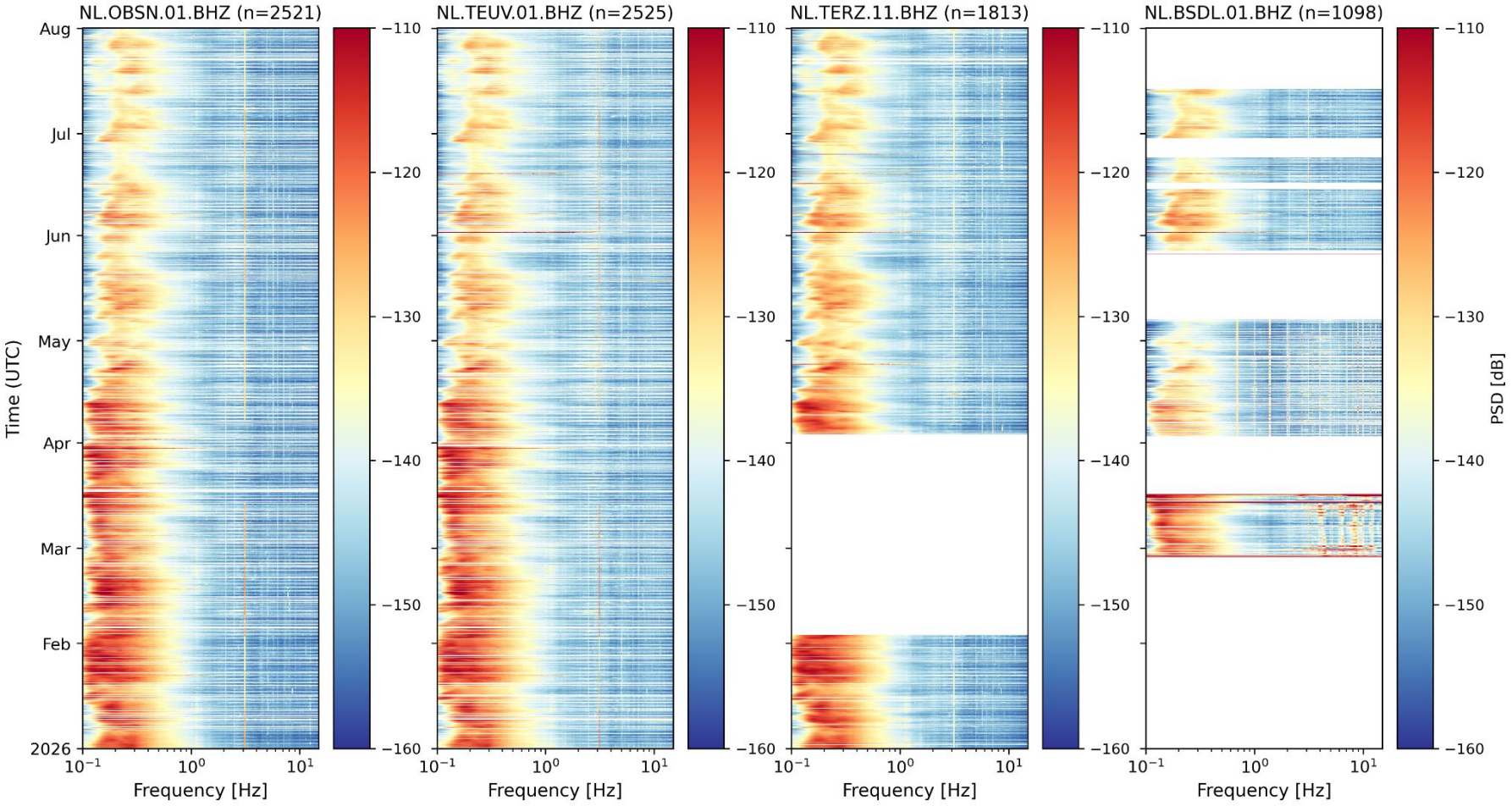
https://gitlab.et-gw.eu/donofrio/SiteChar/-/blob/main/start_here.ipynb

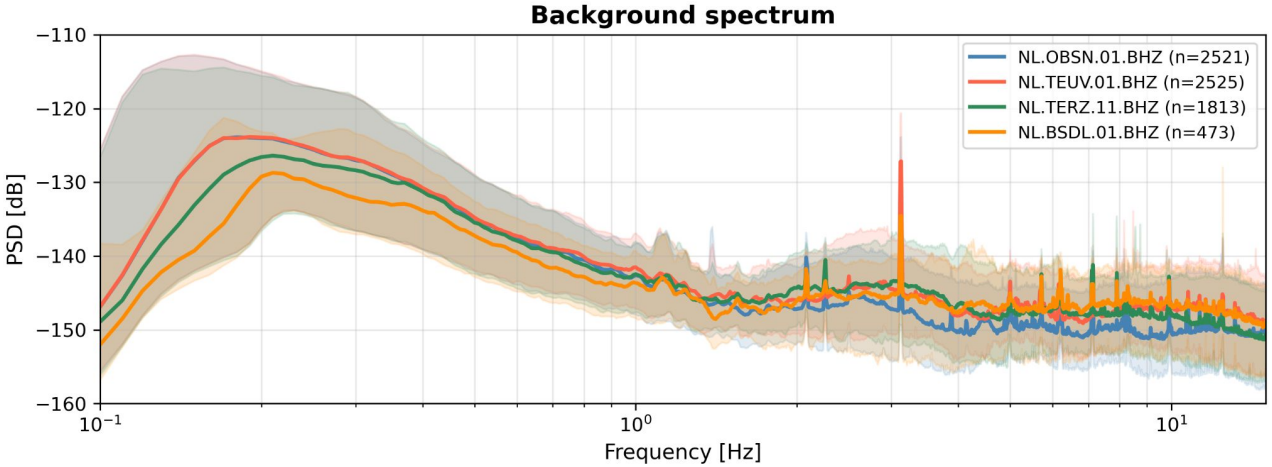
Dataset → 2-hours chunk → triggers → background

- **The chunk spectrum** “what does the ambient seismic field look like overall, transients included, averaged over this period?”
- **The background spectrum** “what is the seismic field like in the absence of the fast disturbances that were detected?”
- **The event spectrum** “how much a given transient elevates the noise level above the ambient background?”

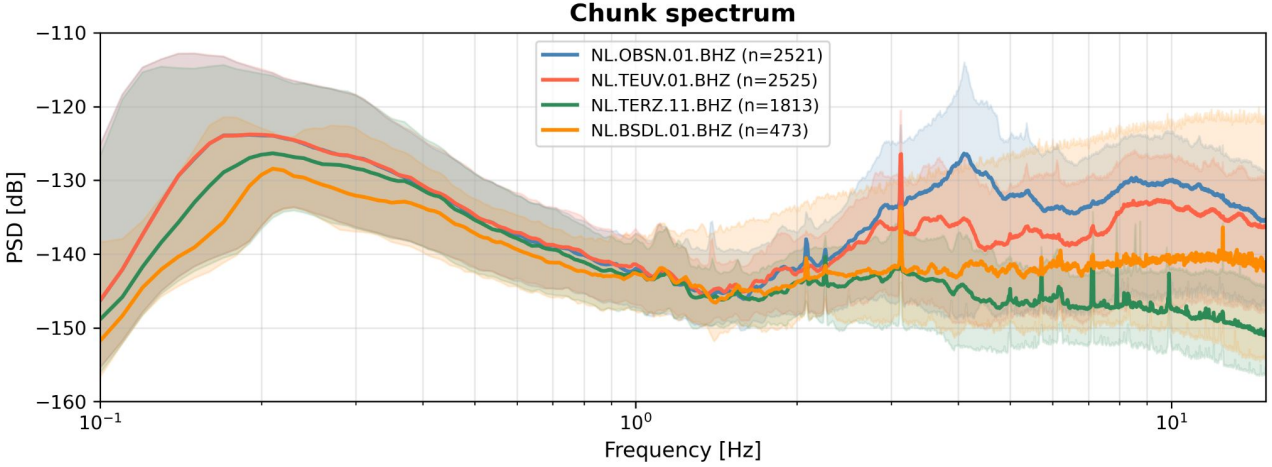
triggers → catalog → analysis single-event → population analysis

Background PSD over time





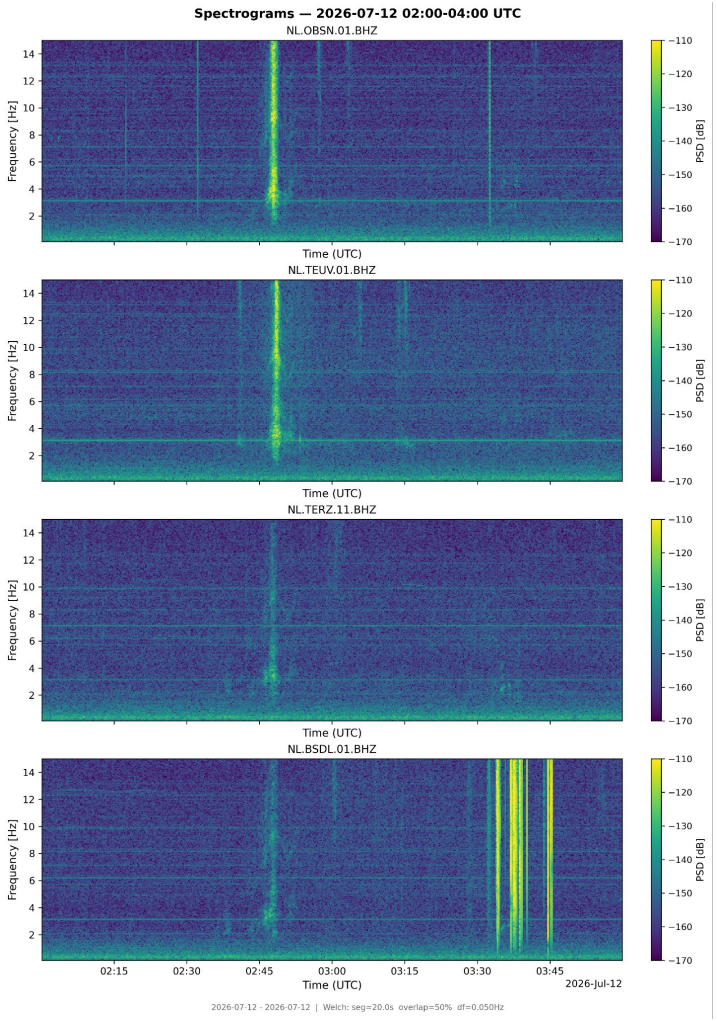
2026-01-01 - 2026-08-01 | BSDL 2026-05-15 - 2026-08-01 | Welch: seg=100.0s overlap=50% df=0.010Hz

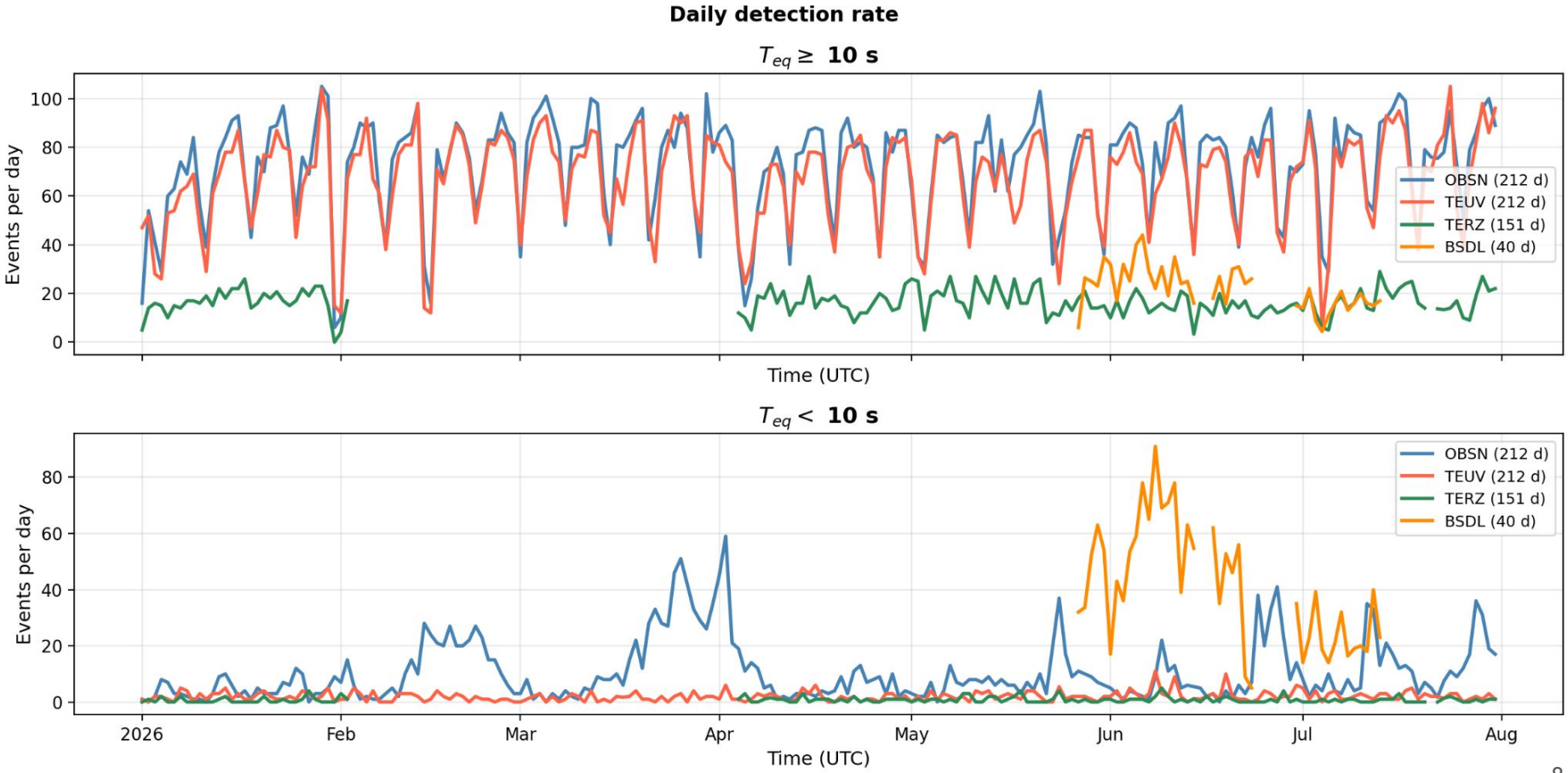


2026-01-01 - 2026-08-01 | BSDL 2026-05-15 - 2026-08-01 | Welch: seg=100.0s overlap=50% df=0.010Hz

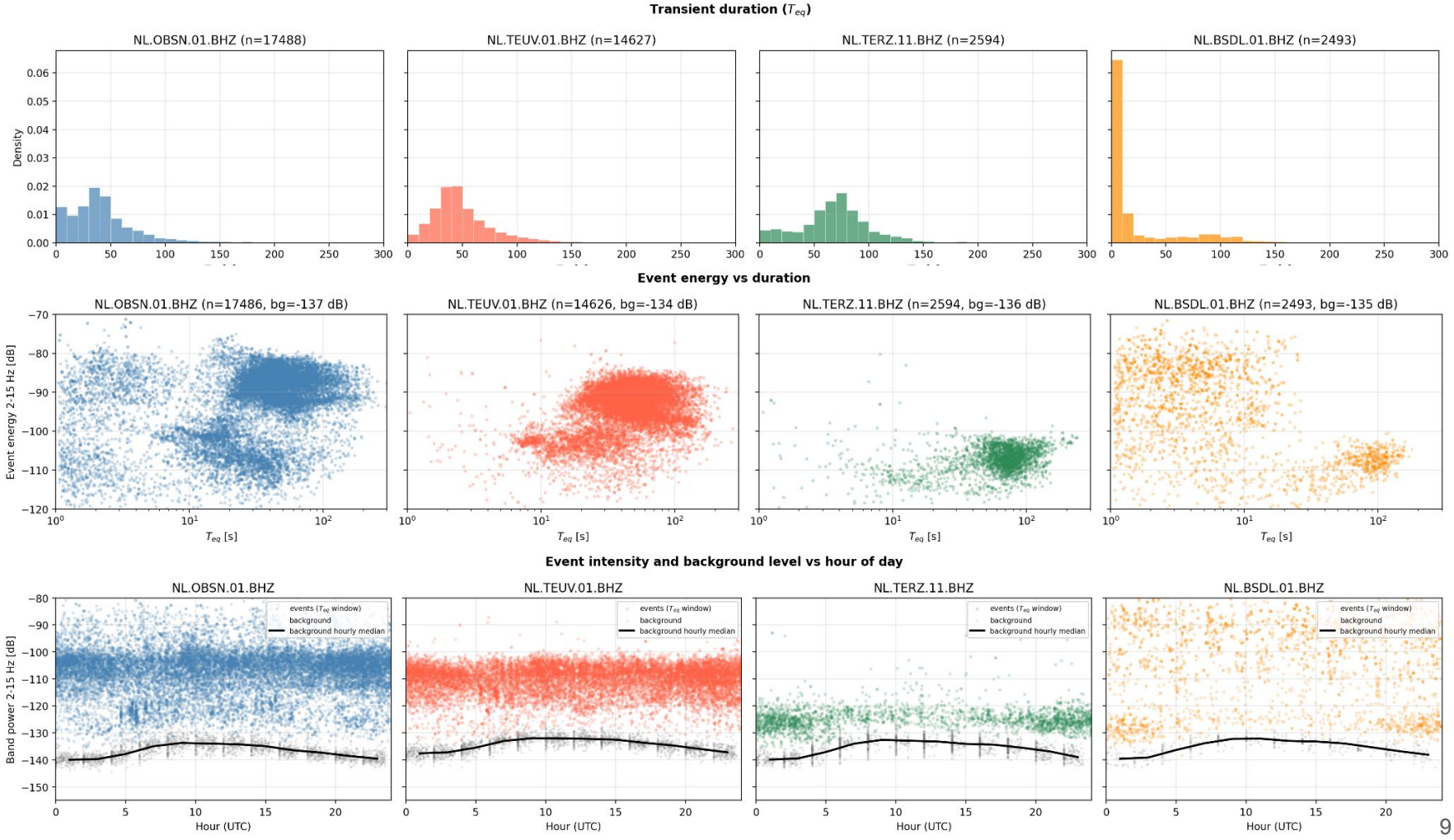
Single-event analysis

- Timeseries, narrowband spectrum, event/background ratio
- Including corresponding surface sensor for each station: coherence, attenuation, detection statistic
- Details of this and other 4-sensors coincident events at the public link: https://www.nikhef.nl/~ldonofri/single_events/index.html
- For most of the events, TERZ and BSDL are not triggered on surface…

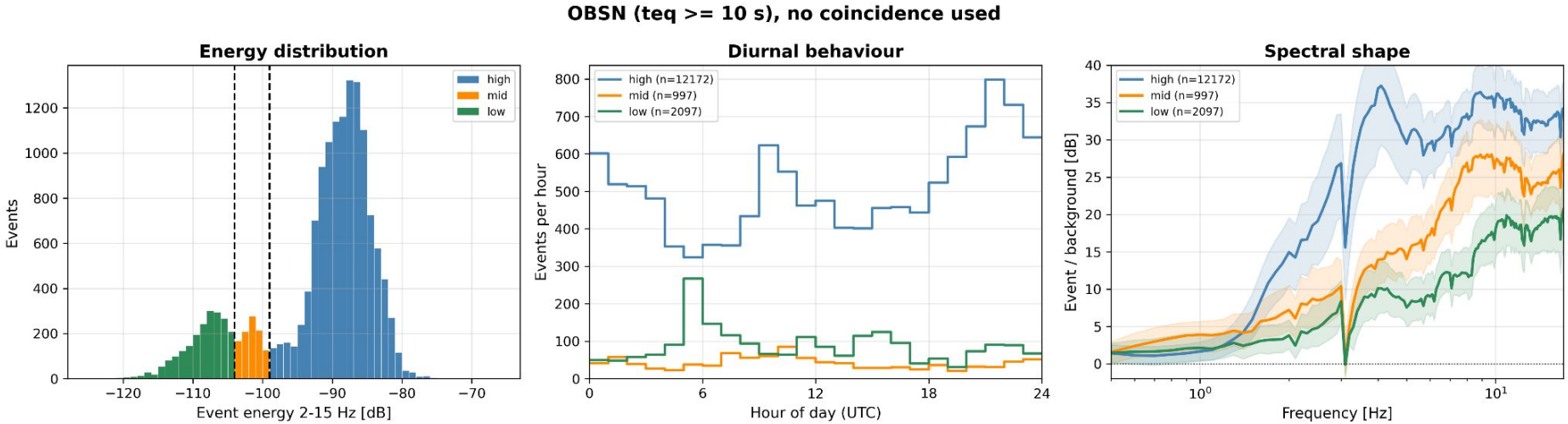



Daily detection rate
$T_{eq} \geq$ 10 s
Events per day
Time (UTC)
OBSN (212 d)
TEUV (212 d)
TERZ (151 d)
BSDL (40 d)
$T_{eq} <$ 10 s
Events per day
2026
Feb
Mar
Apr
May
Jun
Jul
Aug
Time (UTC)
OBSN (212 d)
TEUV (212 d)
TERZ (151 d)
BSDL (40 d)

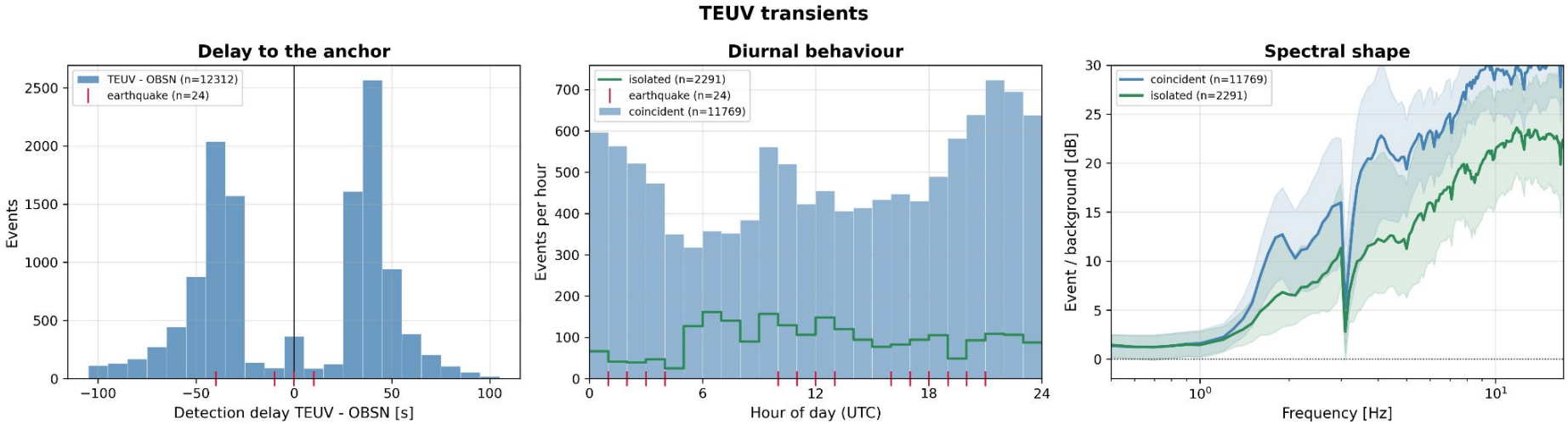
Catalog analysis



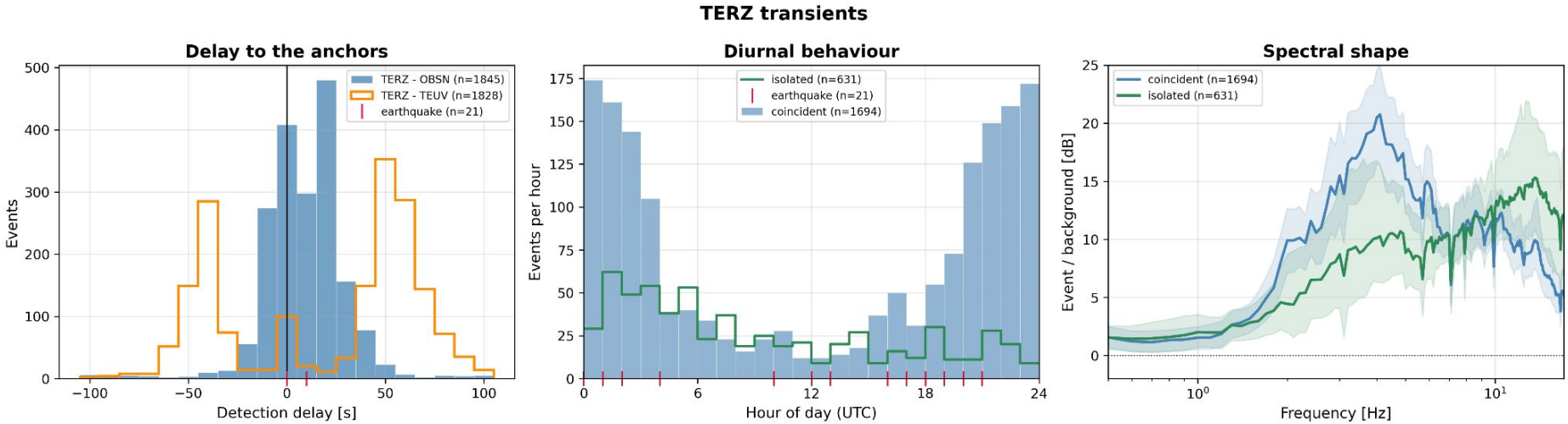
Classification - OBSN



Classification - TEUV



Classification - TERZ



Conclusion

- **First analysis of a borehole network:** 4 boreholes, first 7 months of 2026
  - **SiteChar**: common analysis framwork for site characterization
  - Catalog of detected triggers (added to the publication?)
- Once fast non-stationarities are removed, the four boreholes describe essentially the same stationary field. **The background is itself non-stationary**: 5–8 dB diurnal cycle above 1 Hz, seasonal microseism tracking North Atlantic swell
- **Trains dominate the transient catalog** and are seen at all stations, including TERZ (2.5 km away, 250 m deep). Coincidence resolves the transit along the line and splits the catalog into classes, but single events cannot be labelled without traffic data
- **Transients exceed the local background by tens of dB, a few times per hour** → NN mitigation schemes designed against a stationary field need also this population as input (for seismic we should be safe but experts opinion is needed)

What's next

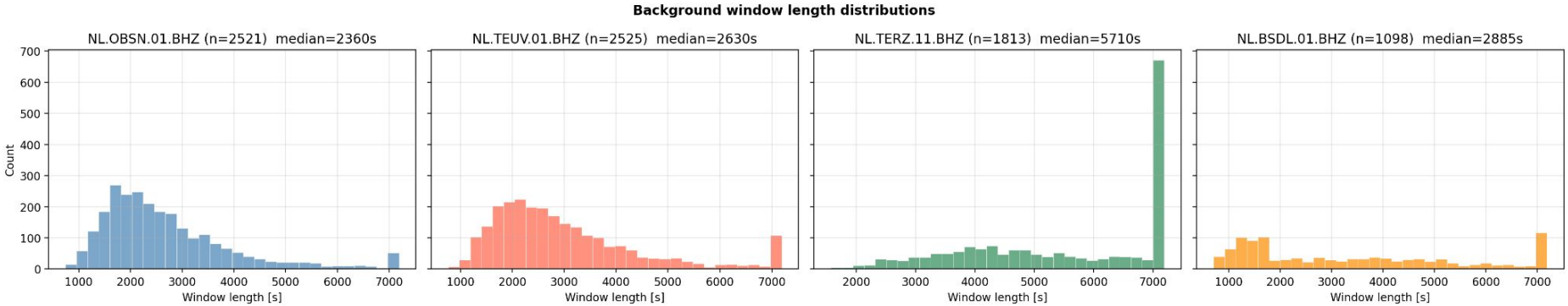
- understand the short glitches/transients
- change the detection parameters, for example f_band=[2,5] to focus only on the trains, [3,3.5], [10,12] → confirm the classification
- horizontal components
- HOOF and HRBS
  - short glitches, highway traffic…
- define as a sensor MEM of the ROB and identify local sismicity, cave blusts, helicopters (?)
- run SiteChar on the Lusatia site with the 4 boreholes
- full site comparisons in SiteChar
  - how many/which sensors? when? collaborative work within SCB?
- define Sensor as magnetometer and do the same analysis of transients but in different frequency bands (geomagnetic activity)

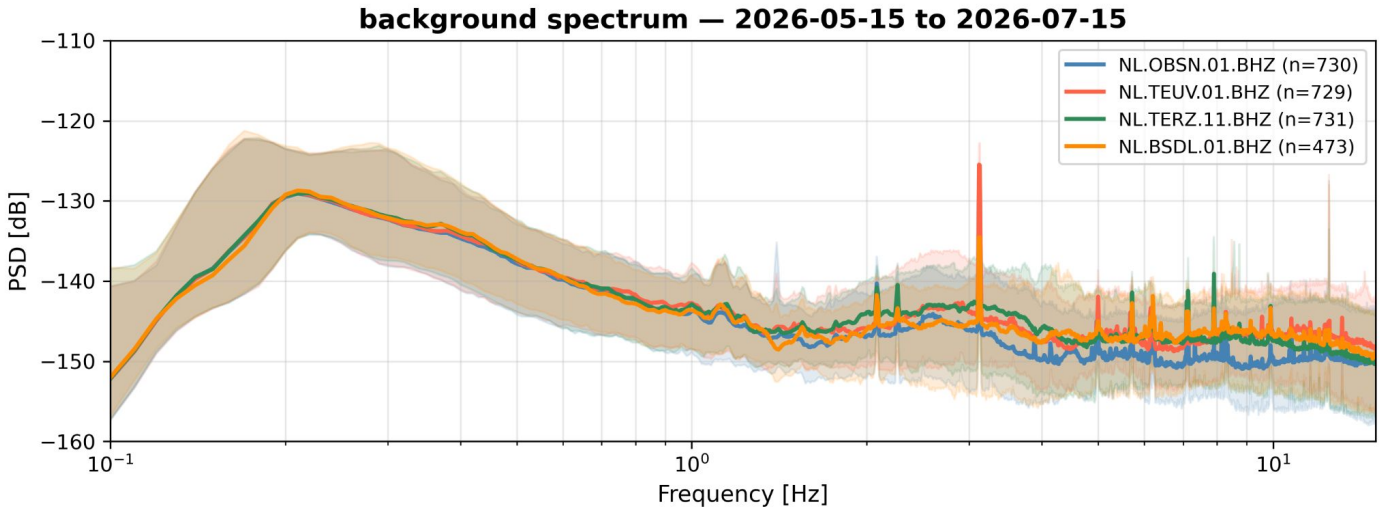
Thanks!

public page to single event analysis:
https://www.nikhef.nl/~ldonofri/single_events/index.html

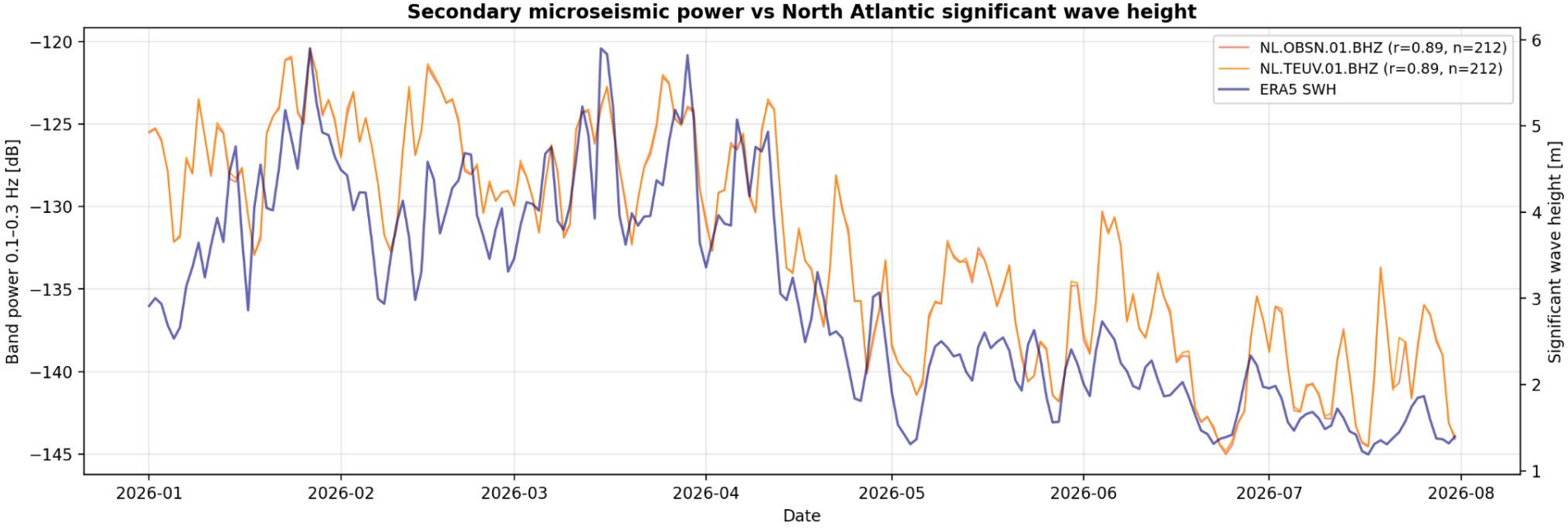
git SiteChar: https://gitlab.et-gw.eu/donofrio/SiteChar
(for now private, ask me to have access)

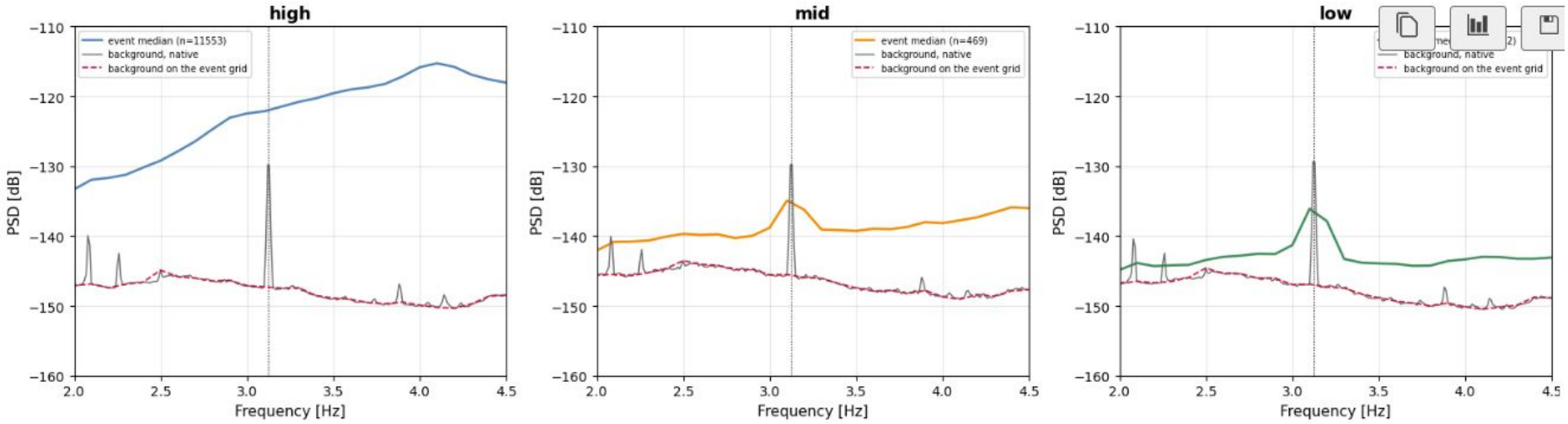
Paper opt-in: please contact me l.donofrio@nikhef.nl

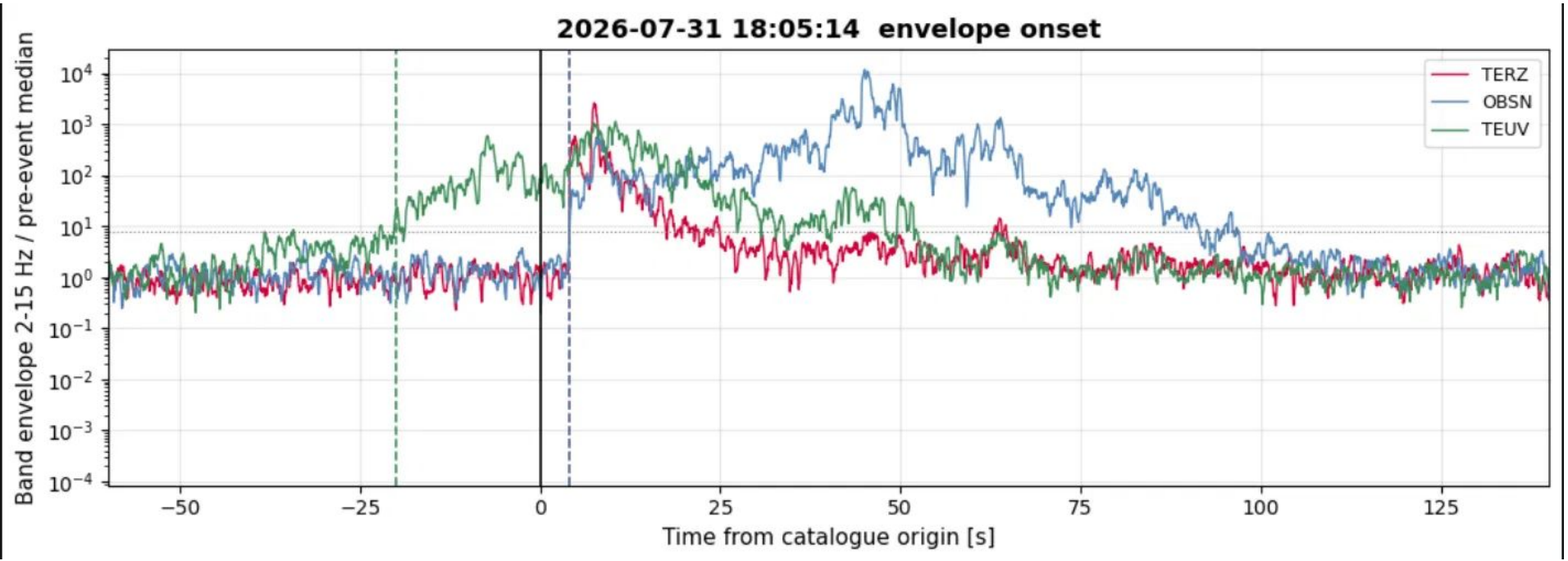


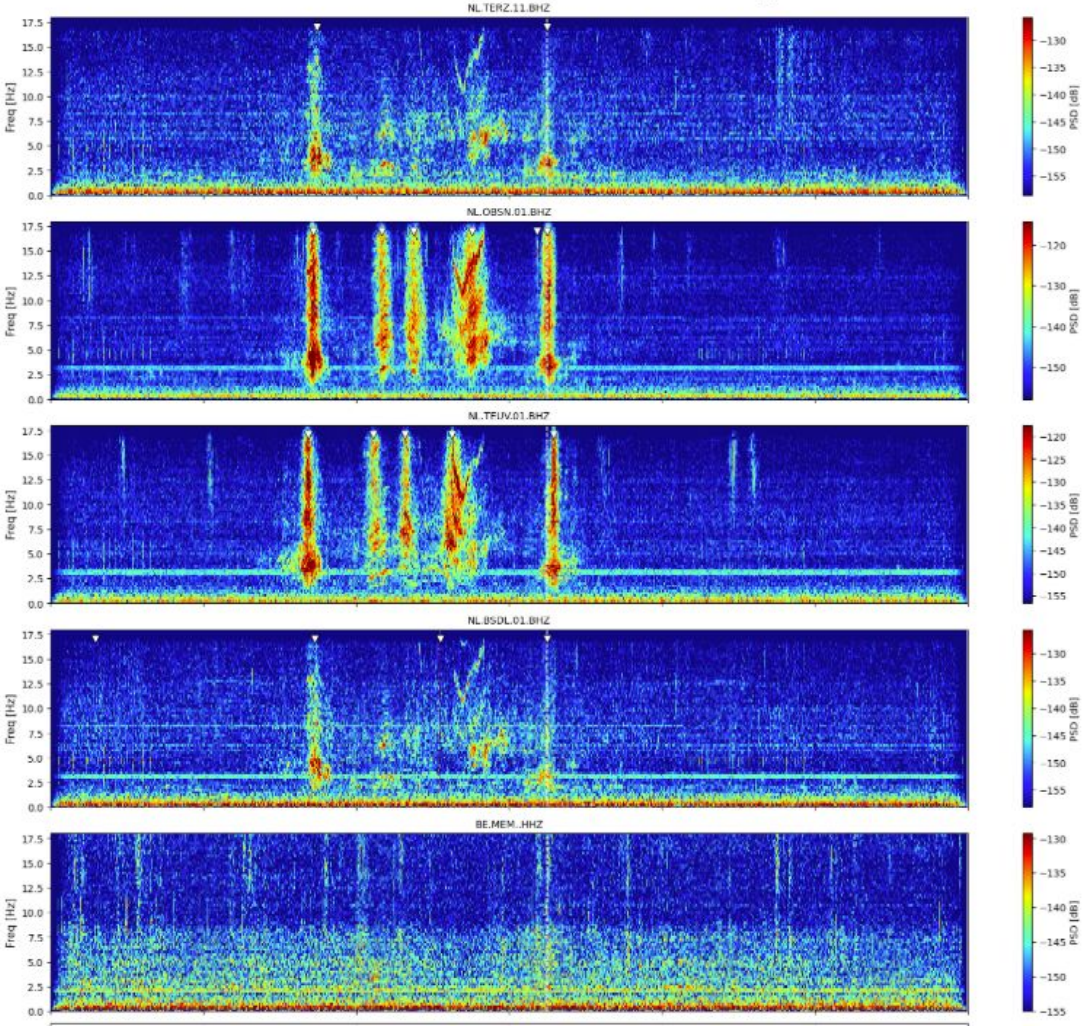


2026-01-01 - 2026-08-01 | Welch: seg=100.0s overlap=50% df=0.010Hz


Secondary microseismic power vs North Atlantic significant wave height
NL.OBSN.01.BHZ (r=0.89, n=212)
NL.TEUV.01.BHZ (r=0.89, n=212)
ERA5 SWH
Band power 0.1–0.3 Hz [dB]
Significant wave height [m]
Date
−120
−125
−130
−135
−140
−145
6
5
4
3
2
1
2026-01
2026-02
2026-03
2026-04
2026-05
2026-06
2026-07
2026-08


high
event median (n=11553)
background, native
background on the event grid
PSD [dB]
Frequency [Hz]
mid
event median (n=469)
background, native
background on the event grid
PSD [dB]
Frequency [Hz]
low
background, native
background on the event grid
PSD [dB]
Frequency [Hz]


2026-07-31 18:05:14 envelope onset
Band envelope 2-15 Hz / pre-event median
Time from catalogue origin [s]
TERZ
OBSN
TEUV
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
−50
−25
0
25
50
75
100
125


2026-06-13T23:00:00.000000Z to 2026-06-14T01:00:00.000000Z — array plus BE.MEM
NL.TERZ.11.BHZ
NL.OBSN.01.BHZ
NL.TFUV.01.BHZ
NL.BSDL.01.BHZ
BE.MEM..HHZ
Freq [Hz]
PSD [dB]