

Noise & HVSR

and interferometry

Thomas Lecocq & Koen Van Noten



24 February 2025



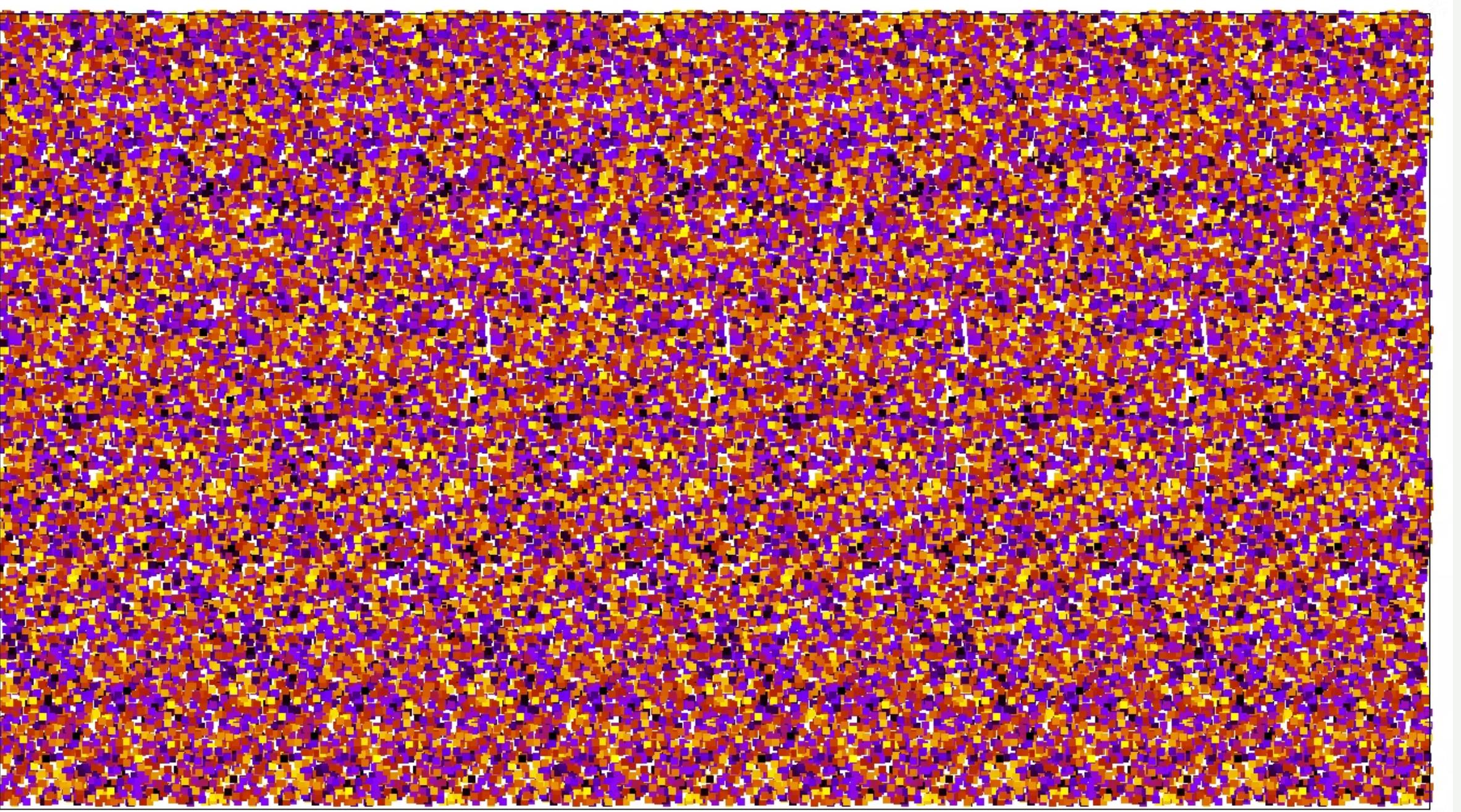
Overview —

01 Know Your Noise

02 Continuous HVSR of a
building site

03 MSNoise power

Noise or Data?

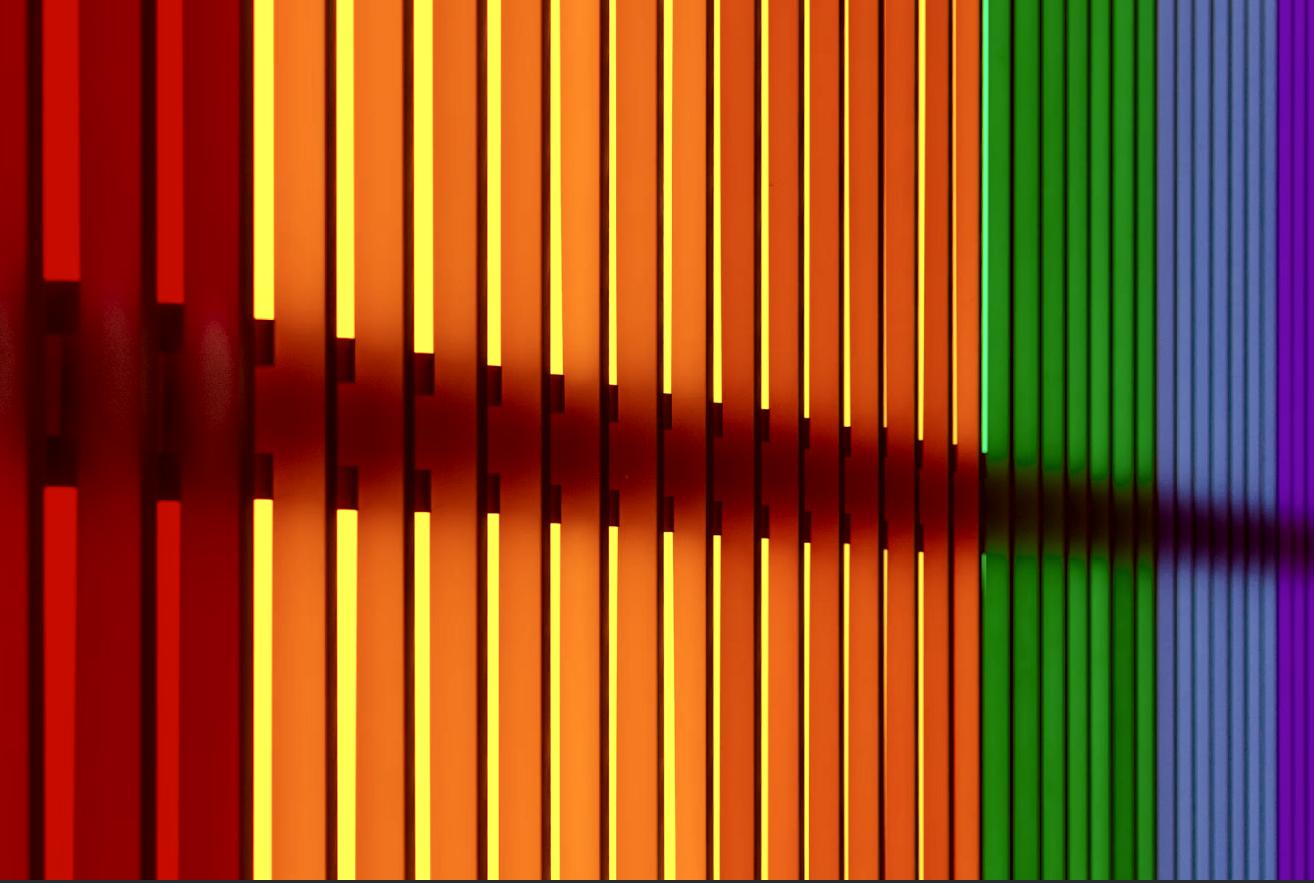




PART 1

Know your Noise

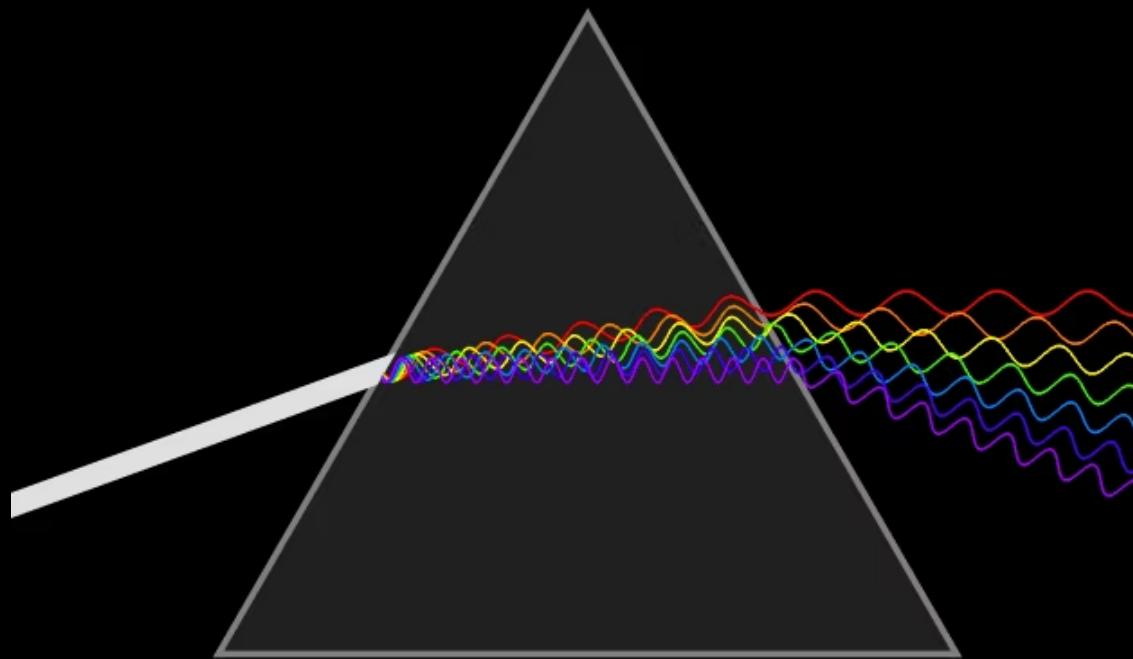
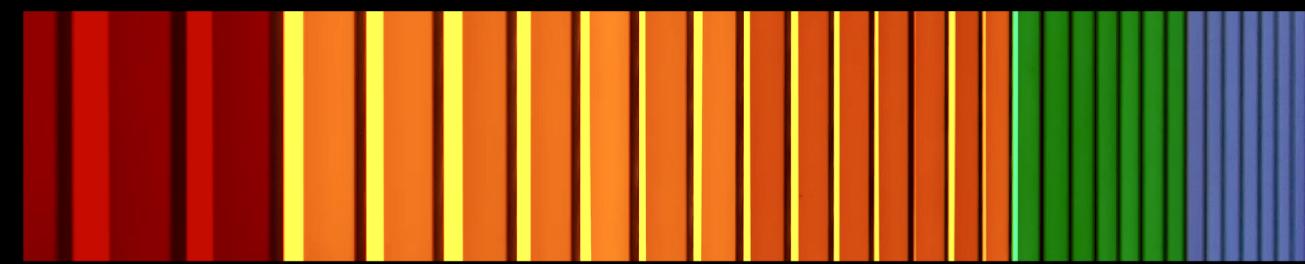
*Time domain
Daily-Weekly variations
Spectrograms
Noise statistics*



The Noise Spectrum

(on Earth)

THE NOISE ? SPECTRUM

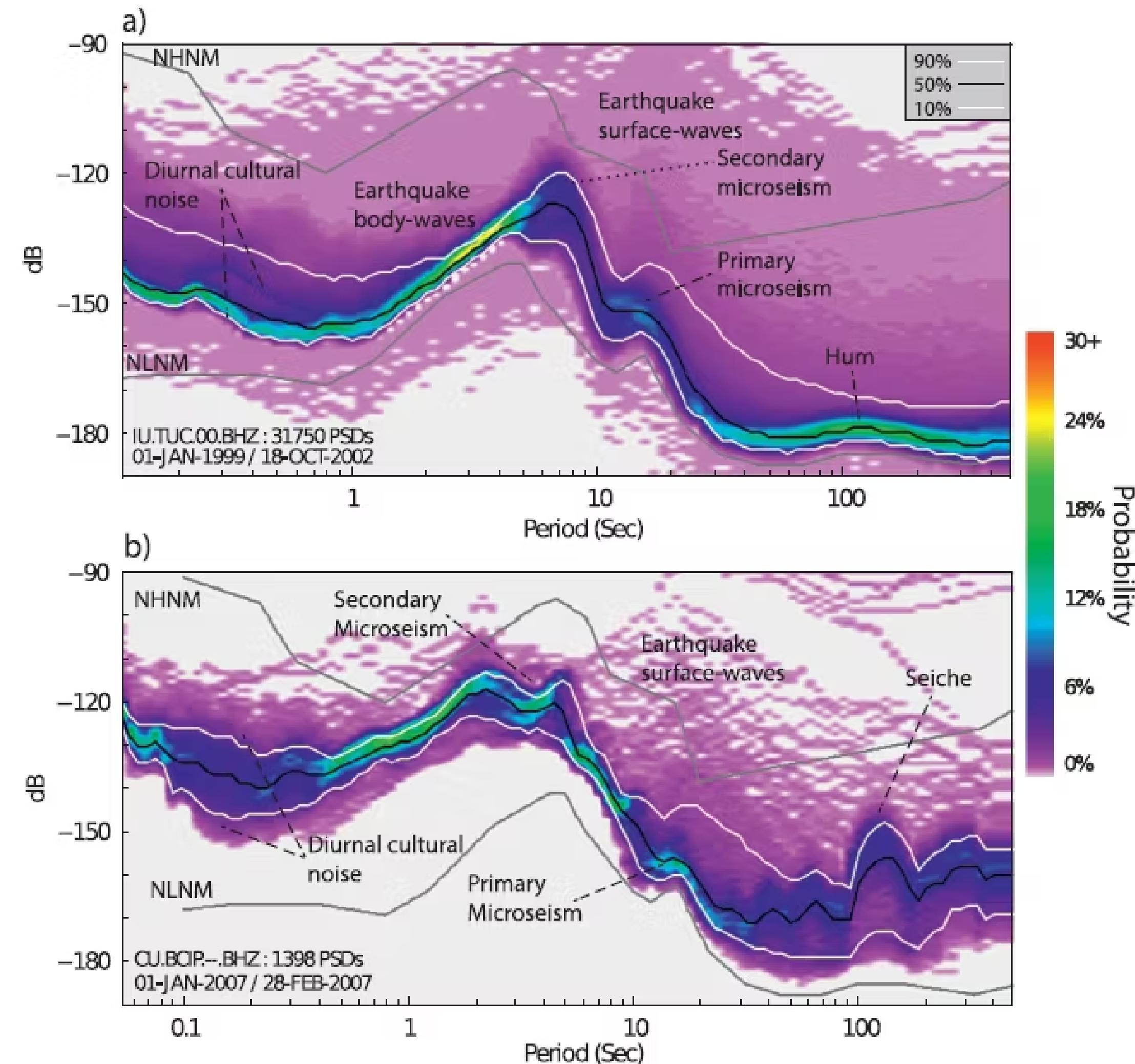


Sources:

https://en.wikipedia.org/wiki/Dispersive_prism

Try Pitch

Nakata, Gaultier & Fichtner 2019



</>

LOW FREQUENCY NOISE

weather related?

Noisy, and we "know" it since forever (...)

Bulletin Mensuel

DE LA

STATION GÉOPHYSIQUE D'UCCLE

(STATION ERNEST SOLVAY)

LATITUDE : 50° 47' 53" N.

LONGITUDE : E. DE GREENWICH 4° 21' 44"

JANVIER A MARS 1903

BRUXELLES
Imprimerie Veuve FERDINAND LAROCHE
25, RUE DES MINIMES
1903



Observations générales. — Le temps employé est celui de Greenwich, compté de minuit à minuit. Les pendules sont orientés : Le pendule M (éridien) dans le méridien; le pendule E (st), à 120° vers l'est; le pendule W (west), à 120° degrés vers l'ouest. T = tremors ou première onde sismique; P, onde principale ou seconde; F = fin (toujours approchée); ca = circa; da = de... à; A. S. = agitation microsismique; Tr. = macrosismes non sensibles; Tr_f = macrosismes sensibles; M. S. = mouvements sismiques; C. = constante; Cf. = constante et forte; C^t = commencement. Les lectures sont faites à ± 8 secondes près.

N ^o s	DATES.	M. S.	T			P			F			A. S.	
			W h. m. s.	M h. m. s.	E h. m. s.	W h. m. s.	M h. m. s.	E h. m. s.	W h. m. s.	M h. m. s.	E h. m. s.	C ^t h. m. s.	F h. m. s.
1	1	A. S.	"	"	"	"	"	"	"	"	"	C	"
2	2	Tr.	?	?	?	?	12,56, 1	12,56, 1	?	?	?	C	"
3	3	A. S.	"	"	"	"	"	"	"	"	"	C	"
4	4	Tr.	?	5,17,34	5,17,34	5,25,32	5,25,32	5,25,32	?	?	?	Cf	"
5	5	Tr.	?	1, 0,35	, 0,35	?	1,11,34	1,11,34	?	?	?	C	"
6	5	Tr.	22,22,22	22,22,22	22,22,22	22,39,50	22,39,50	22,39,50	?	?	?	C	"
7	6	Tr.	?	?	?	?	?	17, 8,58	?	?	?	C	"
8	7	A. S.	"	"	"	"	"	"	"	"	"	C	"
9	8	A. S.	"	"	"	"	"	"	"	"	"	Cf	"
10	9	A. S.	"	"	"	"	"	"	"	"	"	Cf	"
11	10	T	?	?	?	?	?	?	?	?	?	Cf	"

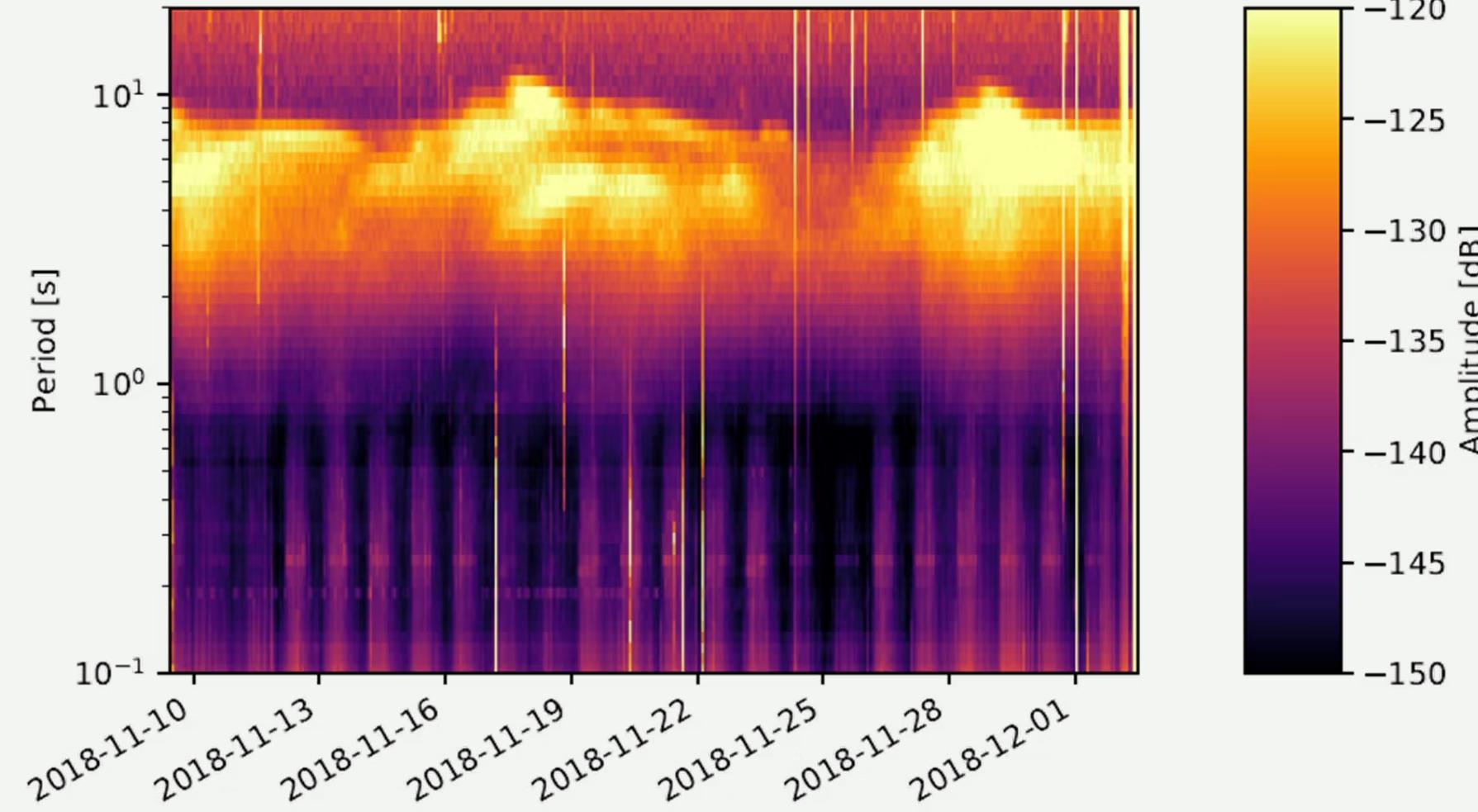
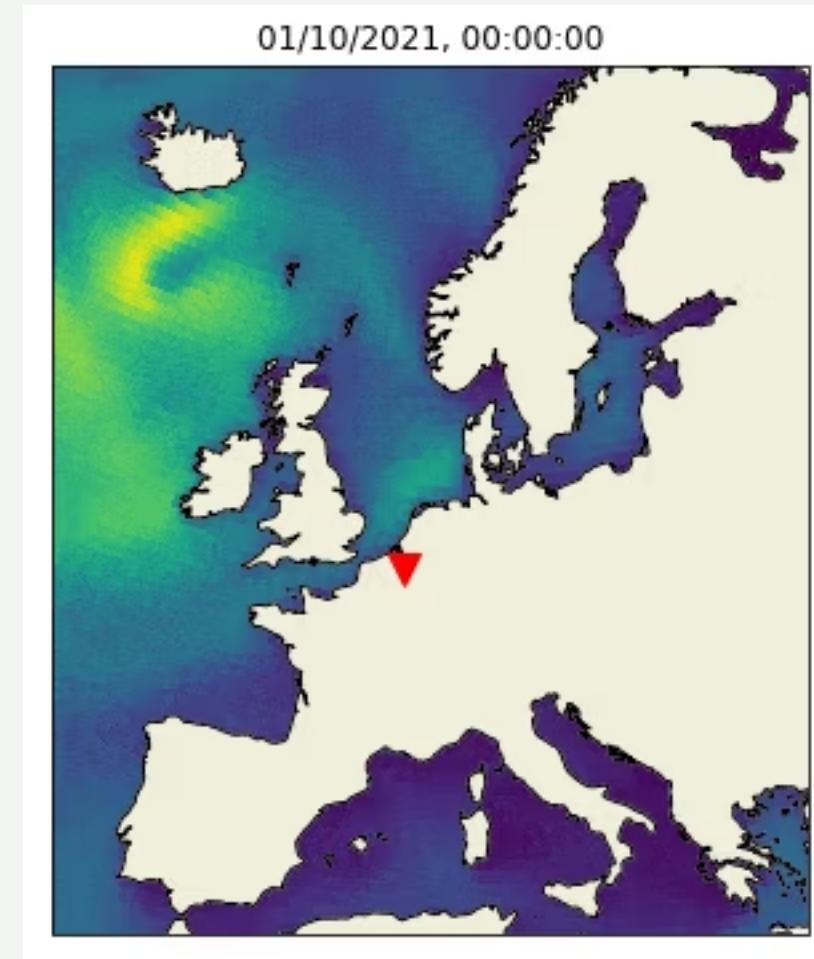
JANVIER 1903

L'agitation sismique, constante pour ainsi dire et souvent très forte que les dépressions barométriques amènent à Uccle pendant les mois d'hiver, rend la constatation générale des phénomènes dus aux tremblements de terre lointains, assez difficile. C'est une remarque qui nous paraît de plus en plus établie et dont il y aura lieu de tenir compte peut-être dans l'établissement d'une station future.

The seismic agitation, constant so to speak and often very strong that barometric depressions bring to Uccle during the winter months, makes the general observation of phenomena due to distant earthquakes quite difficult. This is a remark which seems more and more established to us and which it will perhaps be necessary to take into account in the establishment of a future station.

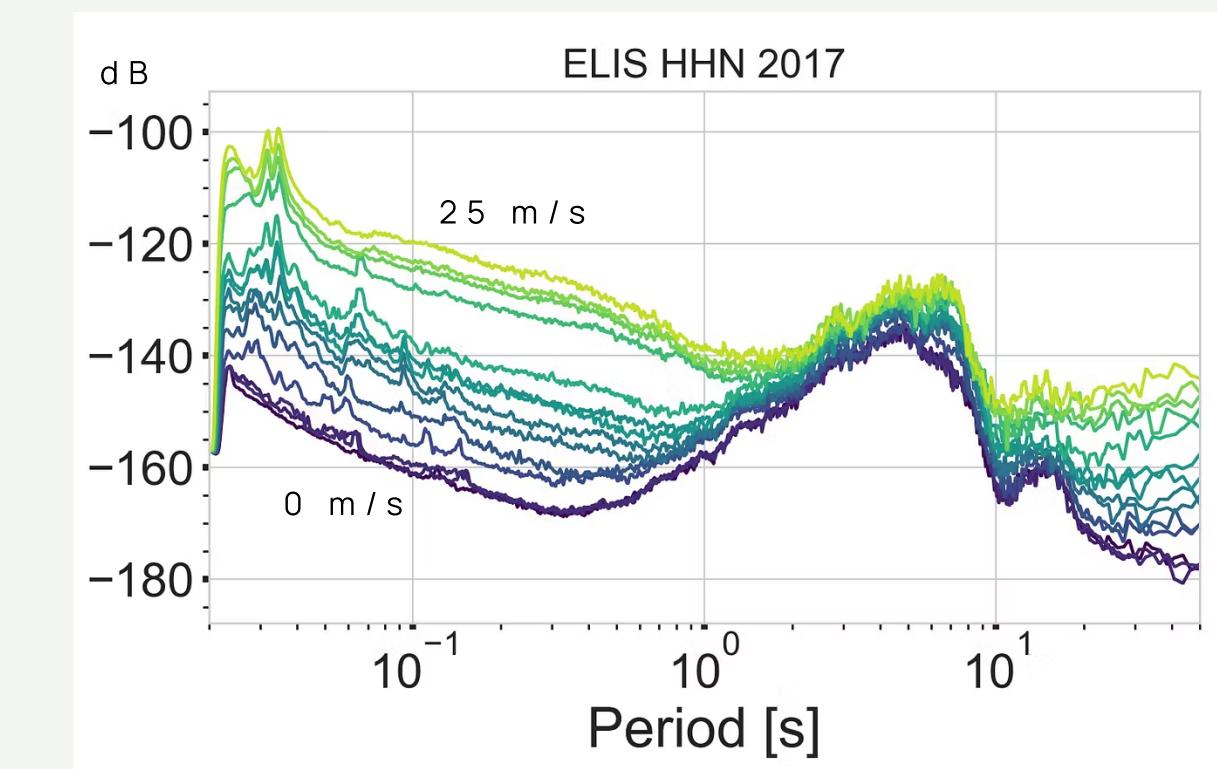
E. LAGRANGE, D. S.

Professeur à l'École militaire.

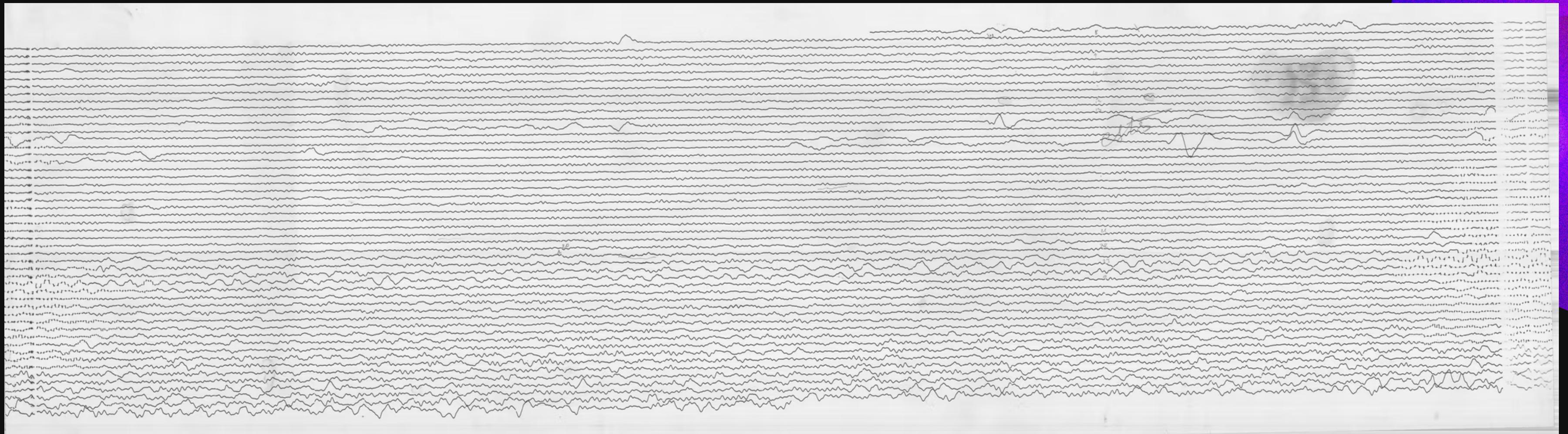


oceans?

winds?



Noisy, and we "know" it since forever (...)



ENR
7-28
30-1-53



</>

HIGH FREQUENCY NOISE

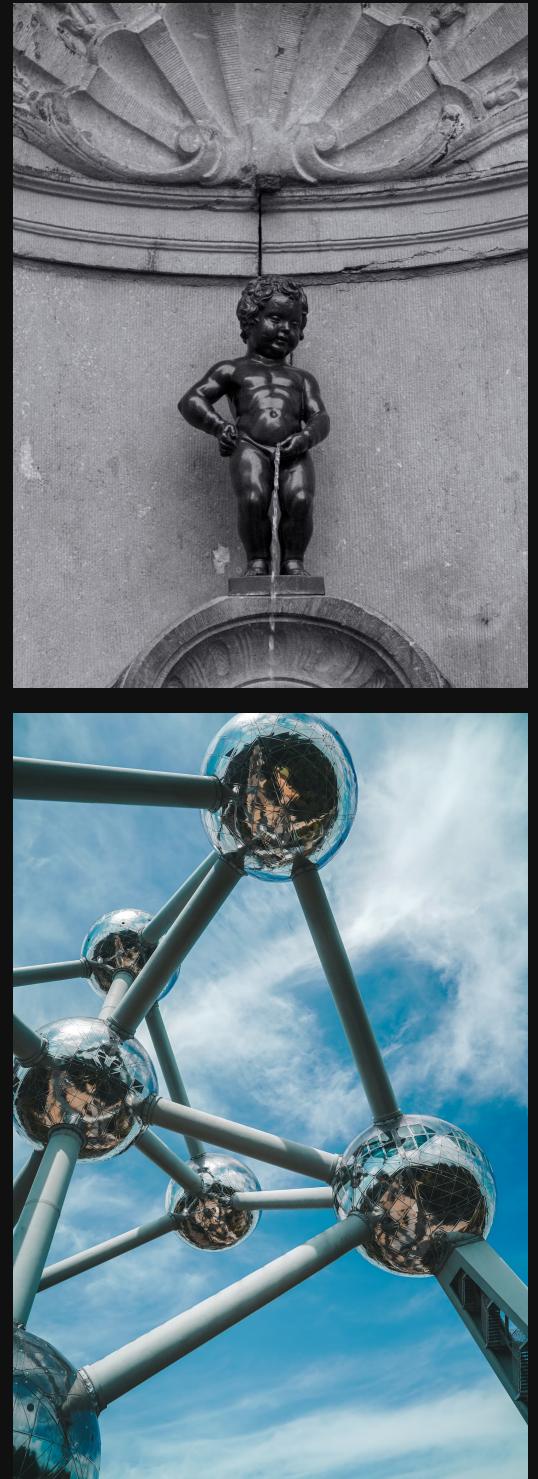
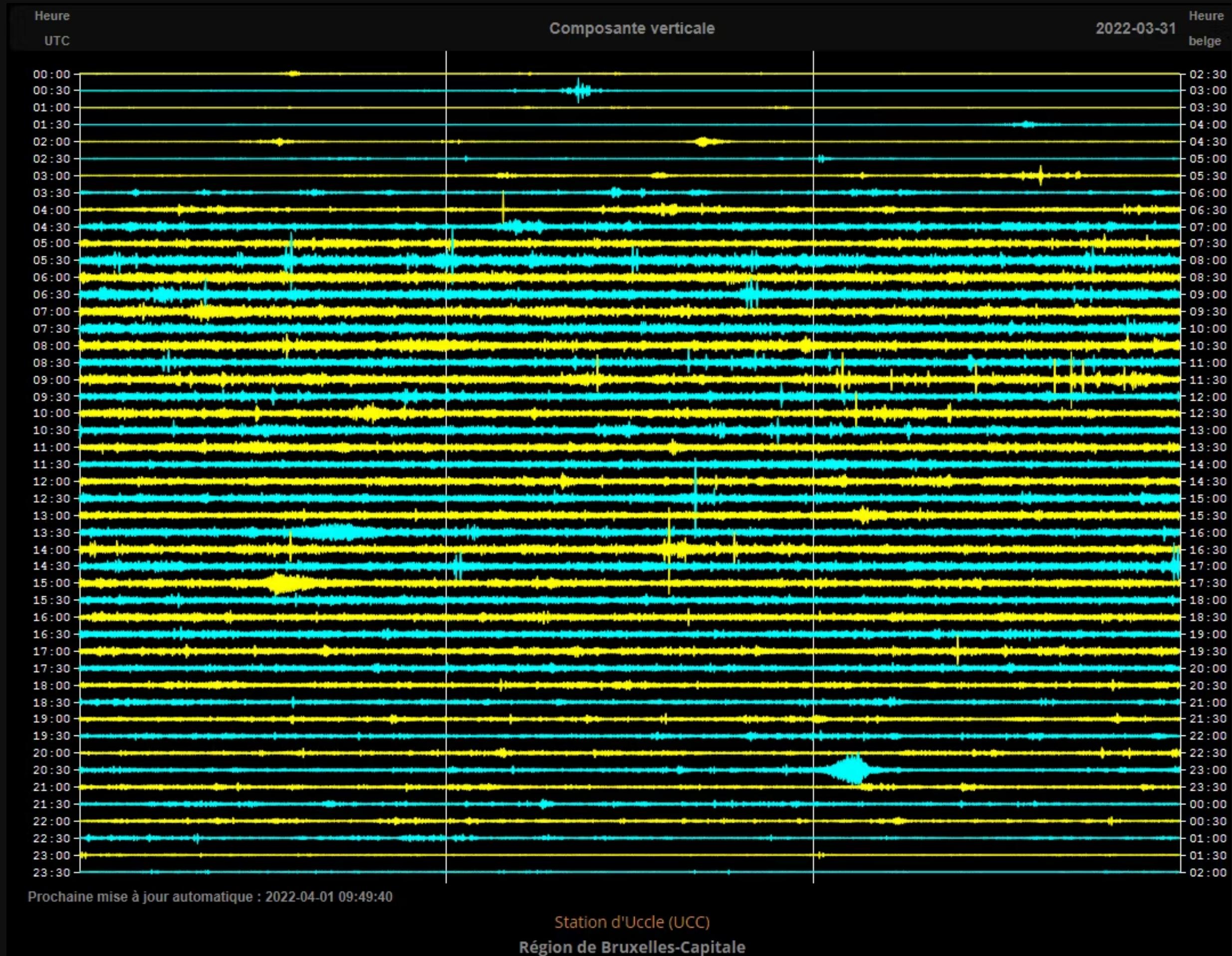
human related?

</>

HOW DO WE KNOW?

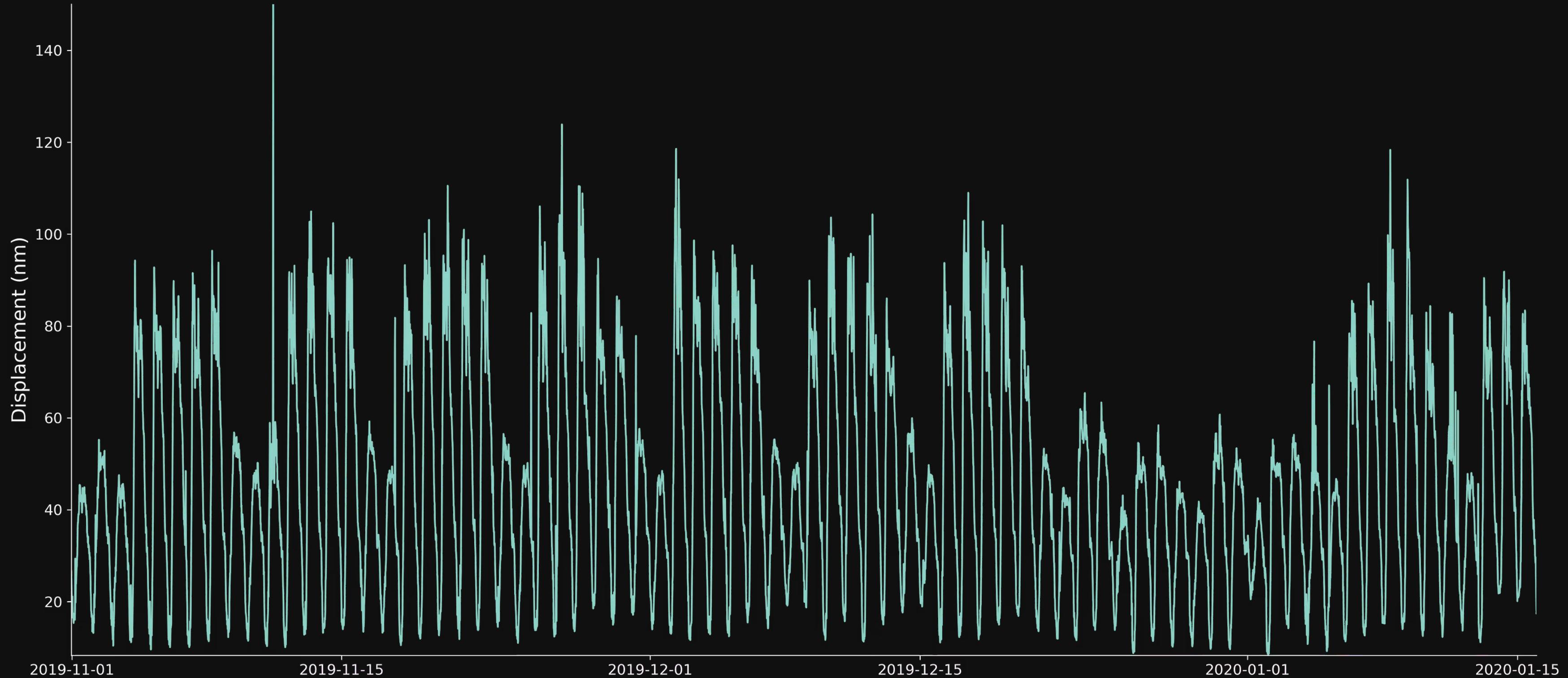
we are responsible for high-frequency seismic noise
in the city...

A typical day at the office



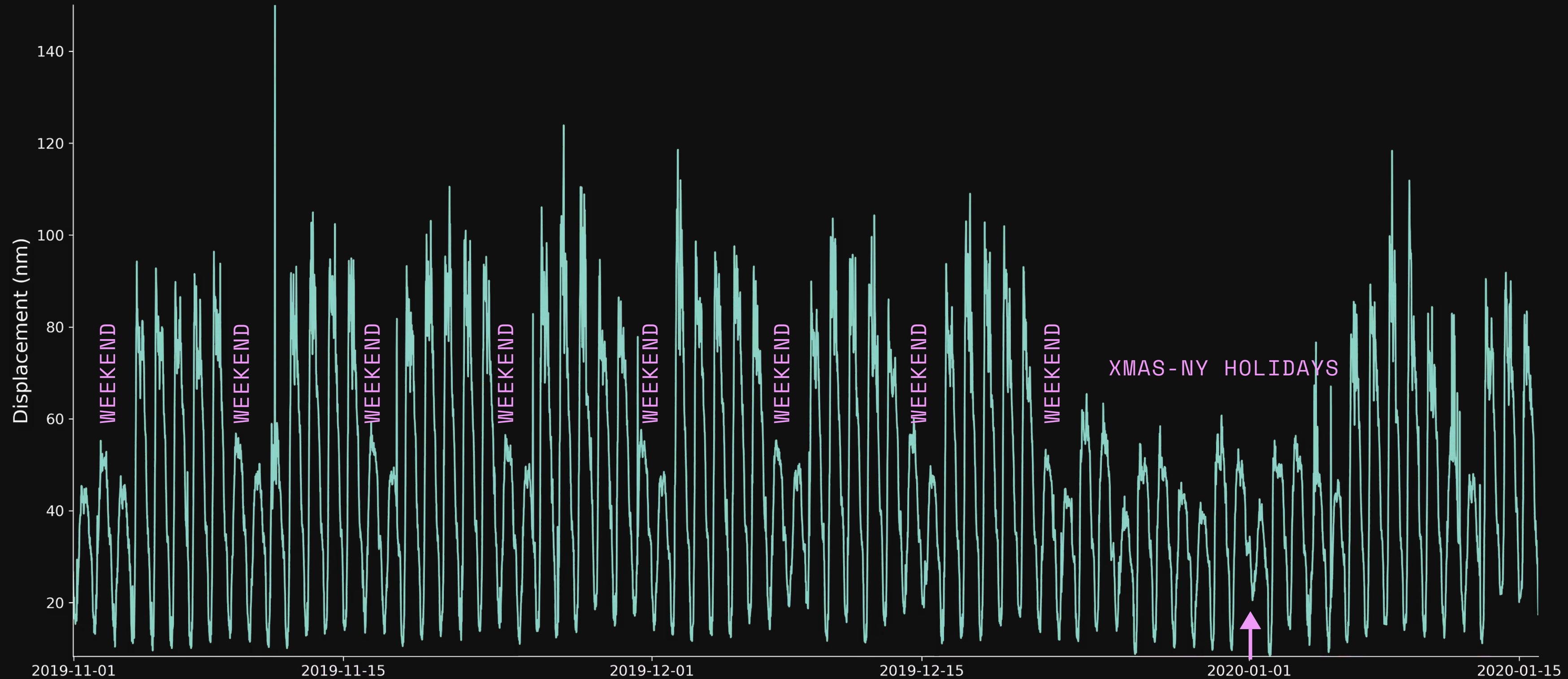
HIGH FREQUENCY NOISE & HUMANS

How do we know we are guilty?



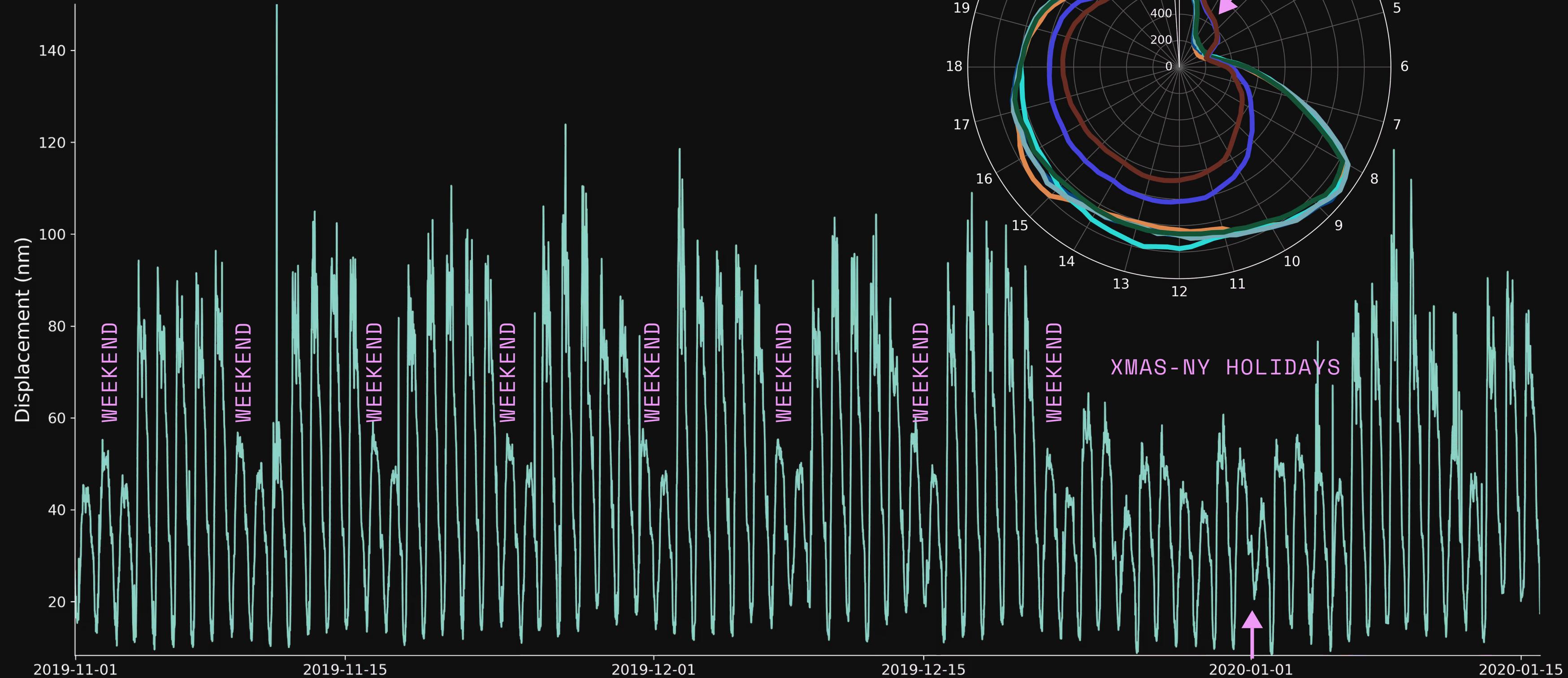
HIGH FREQUENCY NOISE & HUMANS

How do we know we are guilty?



HIGH FREQUENCY NOISE

How do we know we are guilty?



Who cares about city noise?



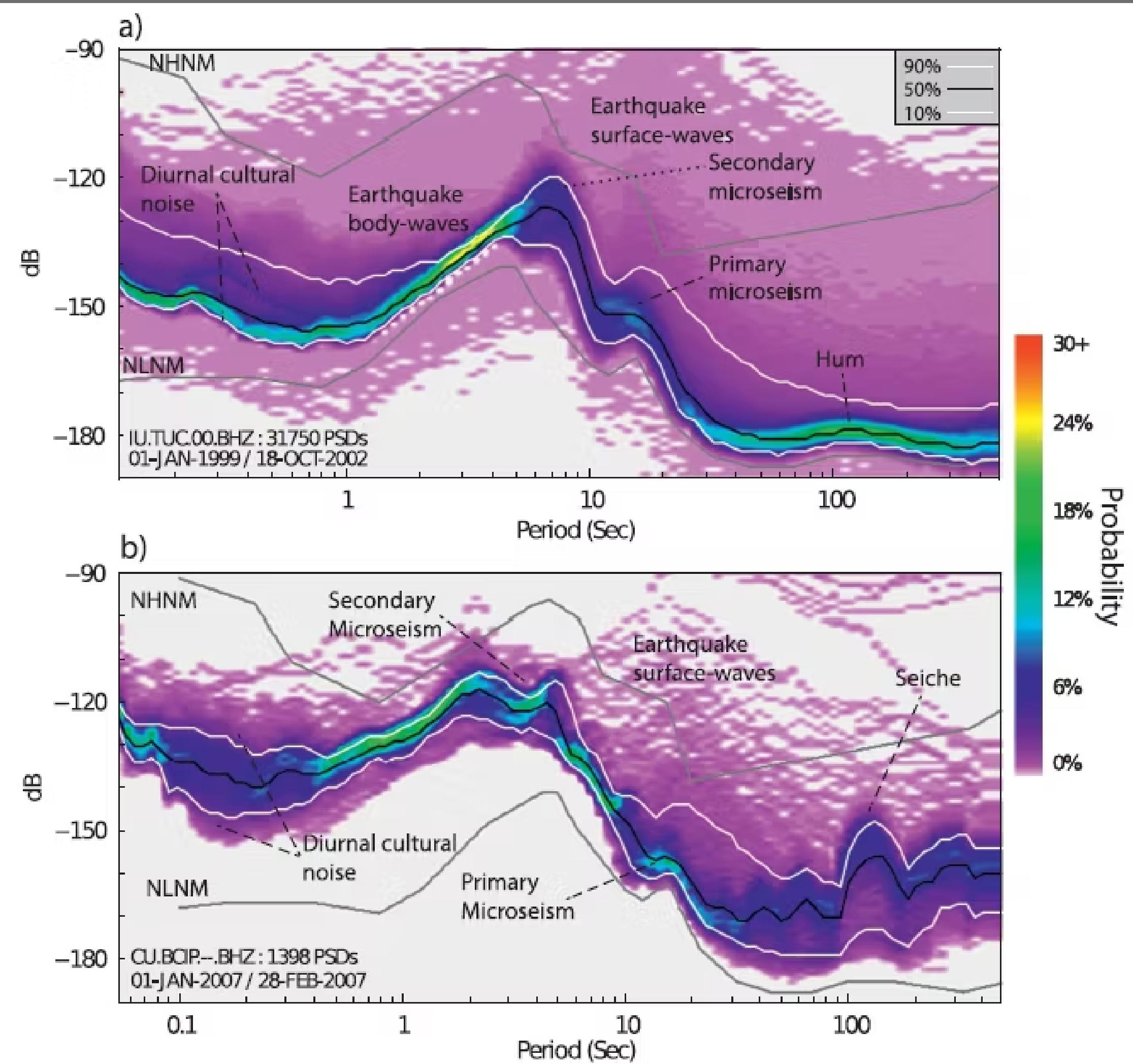
[Home / Inicio](#) [Information / Información](#) [Program / Programa](#) [Registration / Inscripción](#) [Sponsors / Patrocinadores](#) [Field Trips / Excursiones](#) [Workshops / Talleres](#)



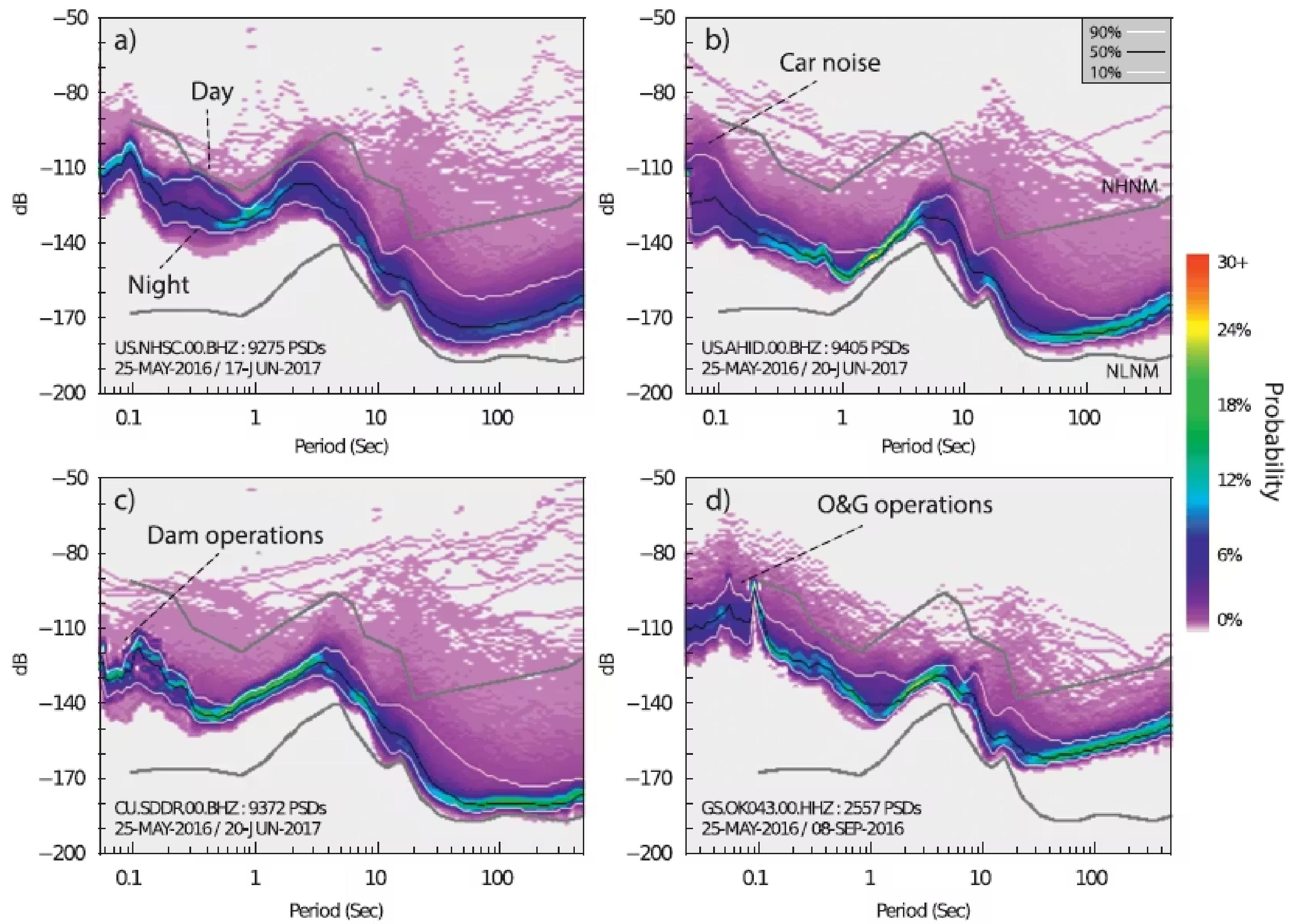
COV12 in La Antigua Guatemala

Get to know the Land
of volcanoes

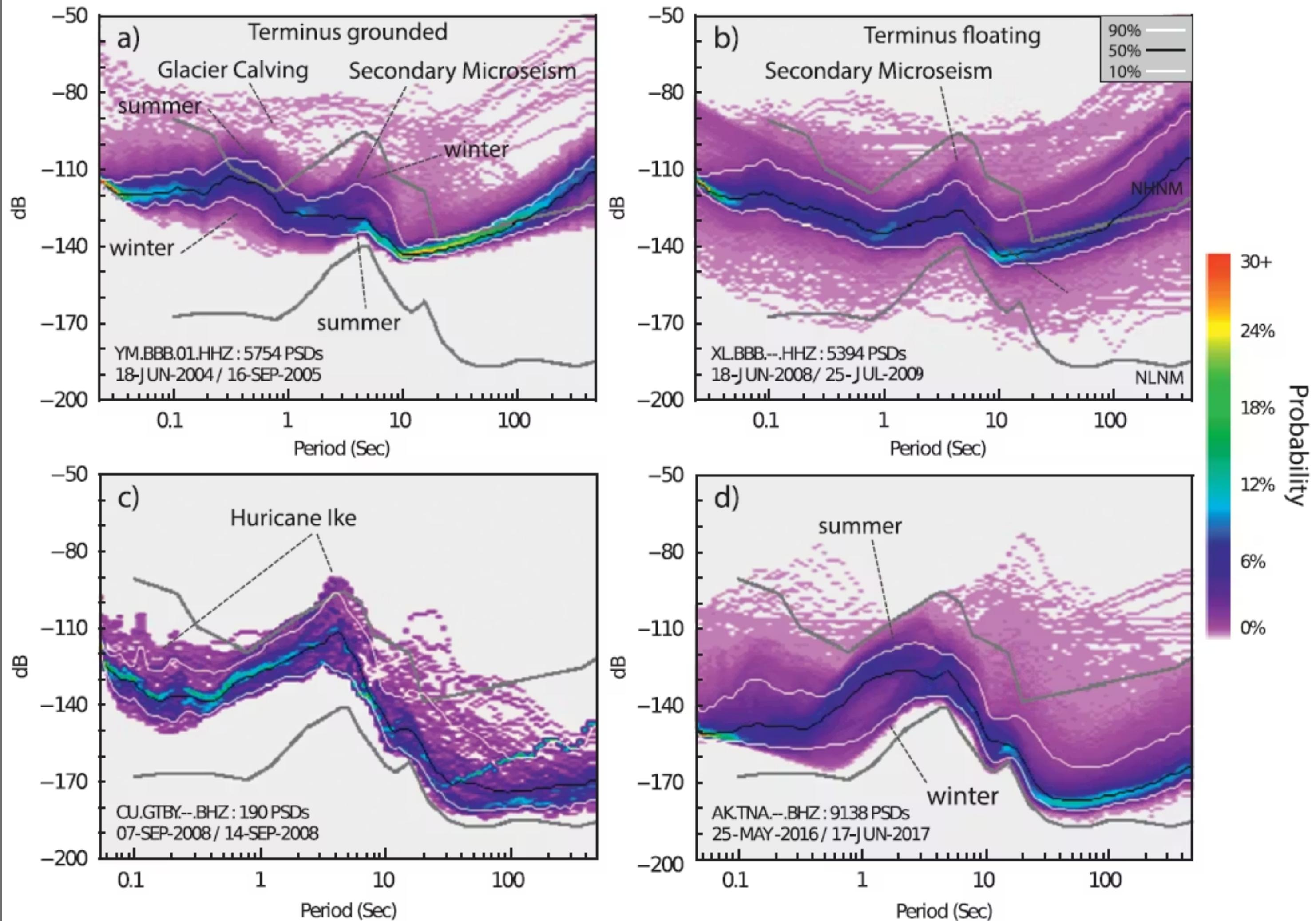
Noise ?



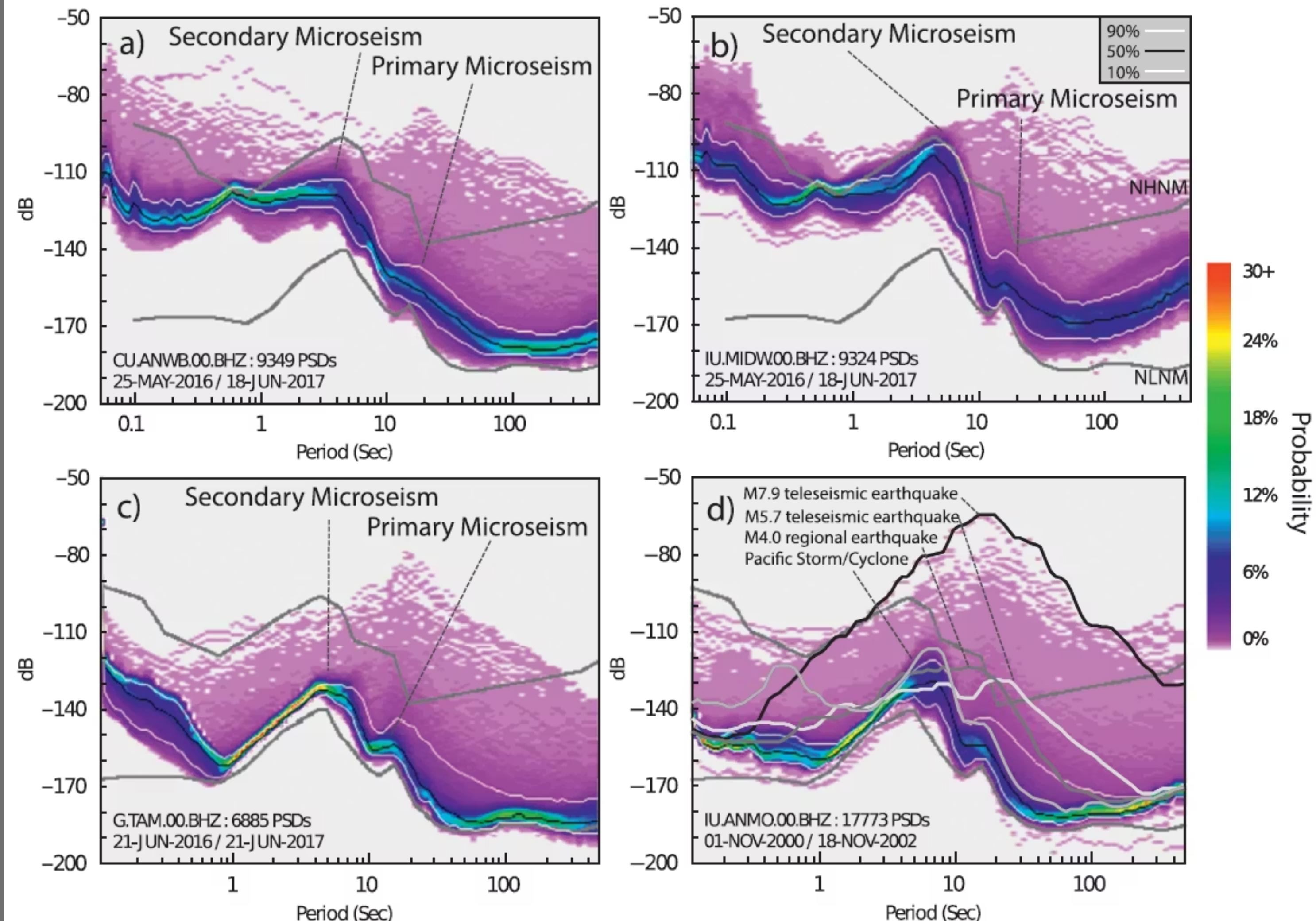
Noise ?



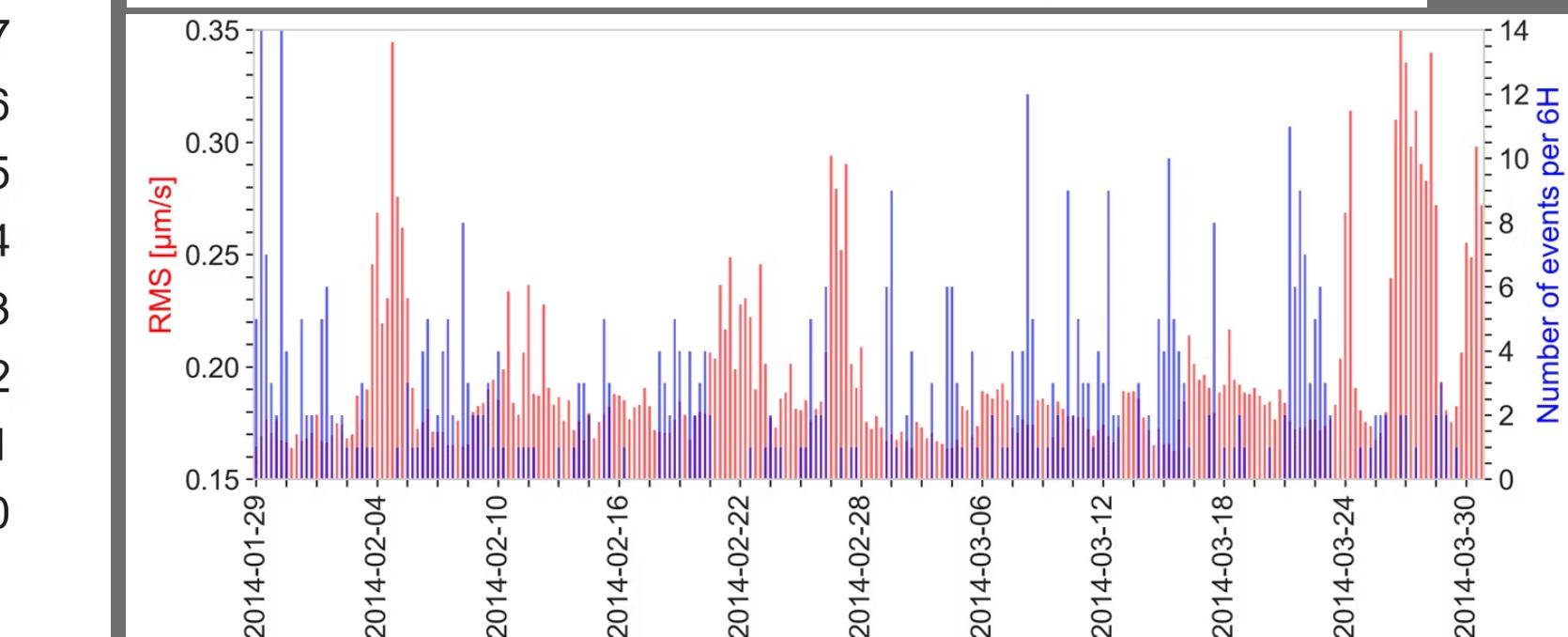
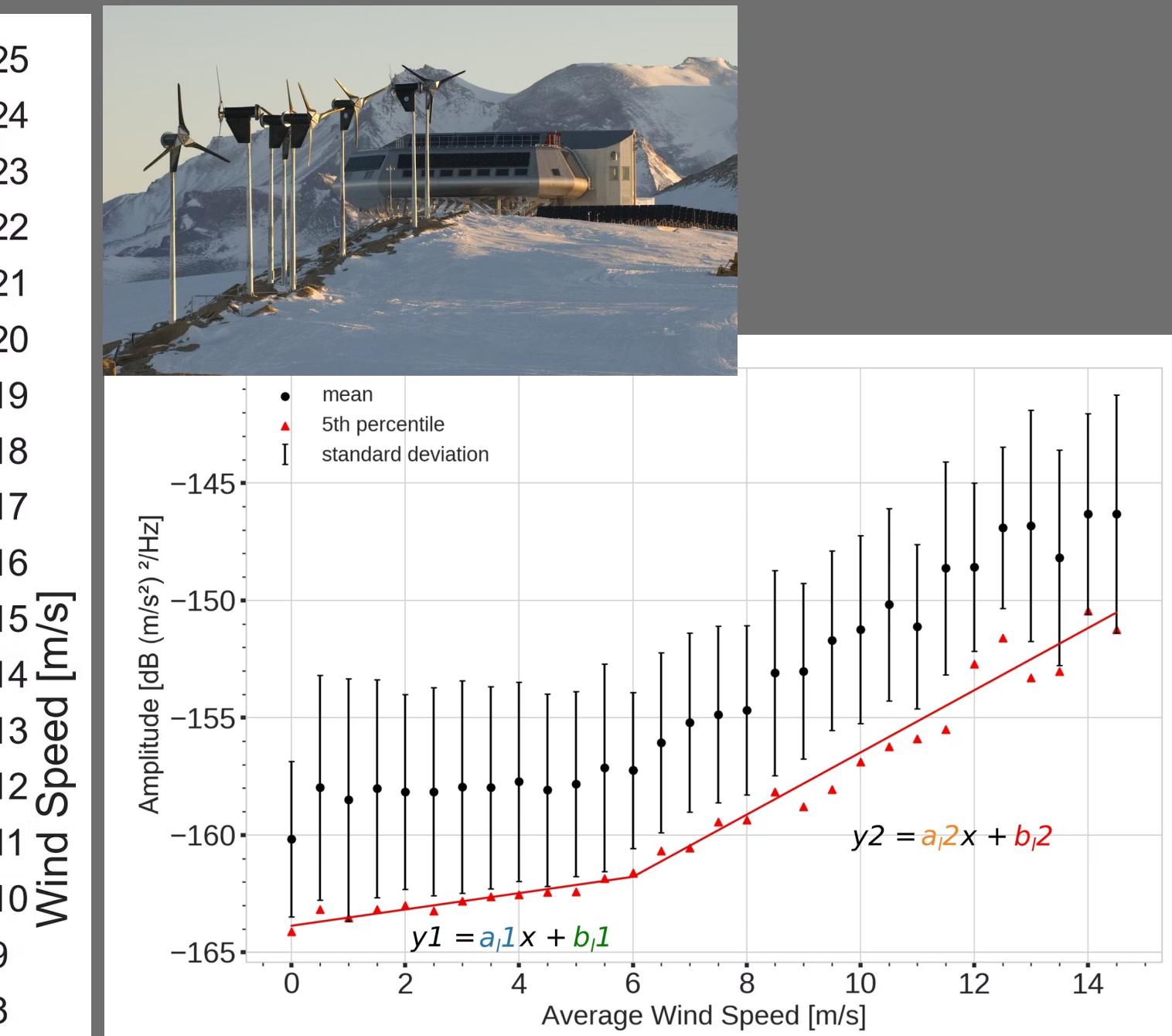
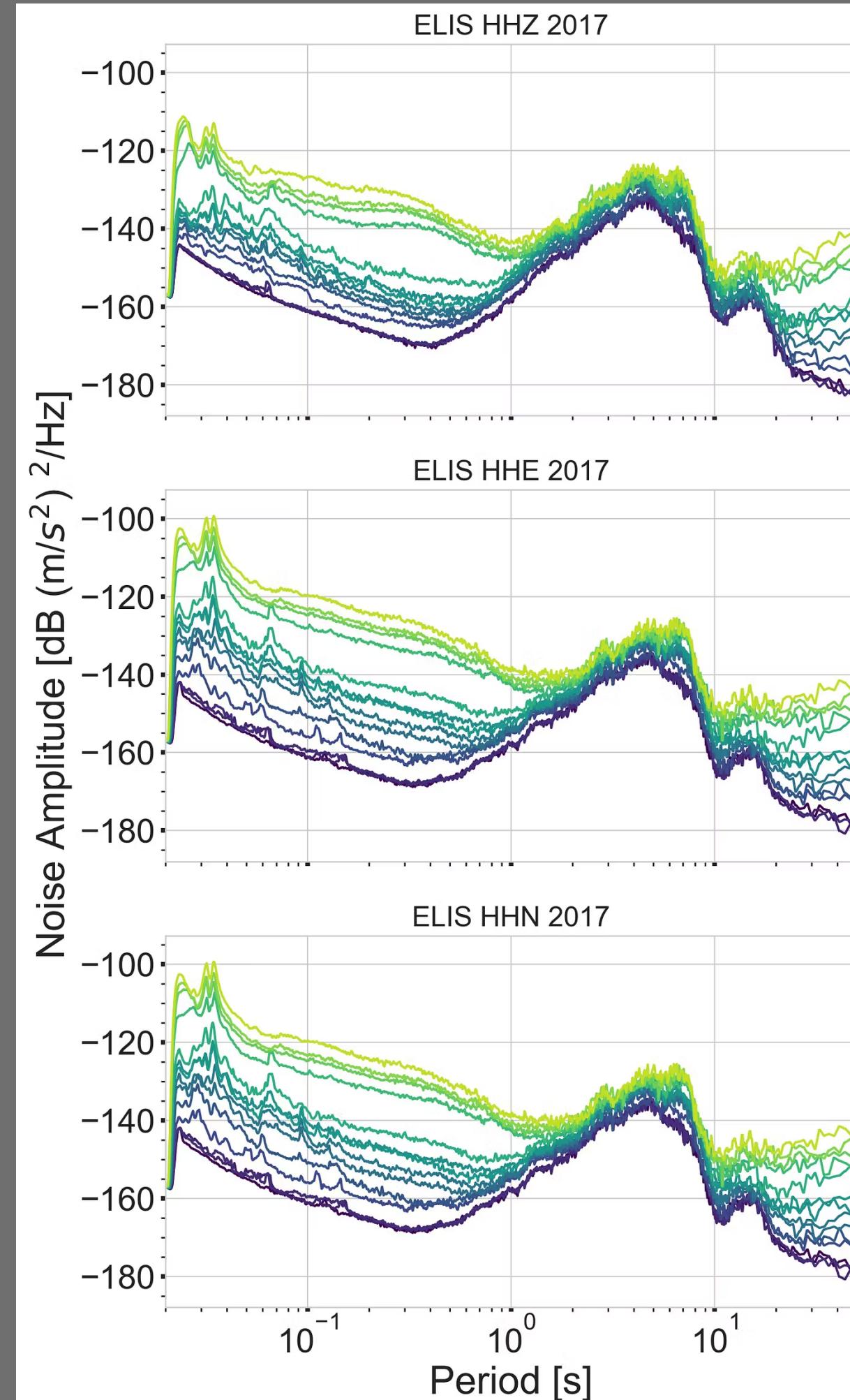
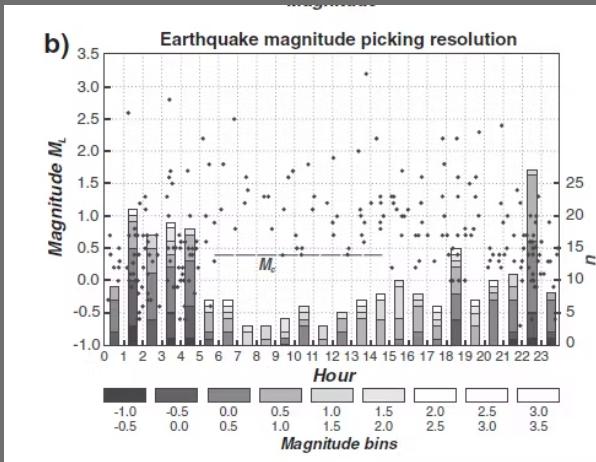
Noise ?



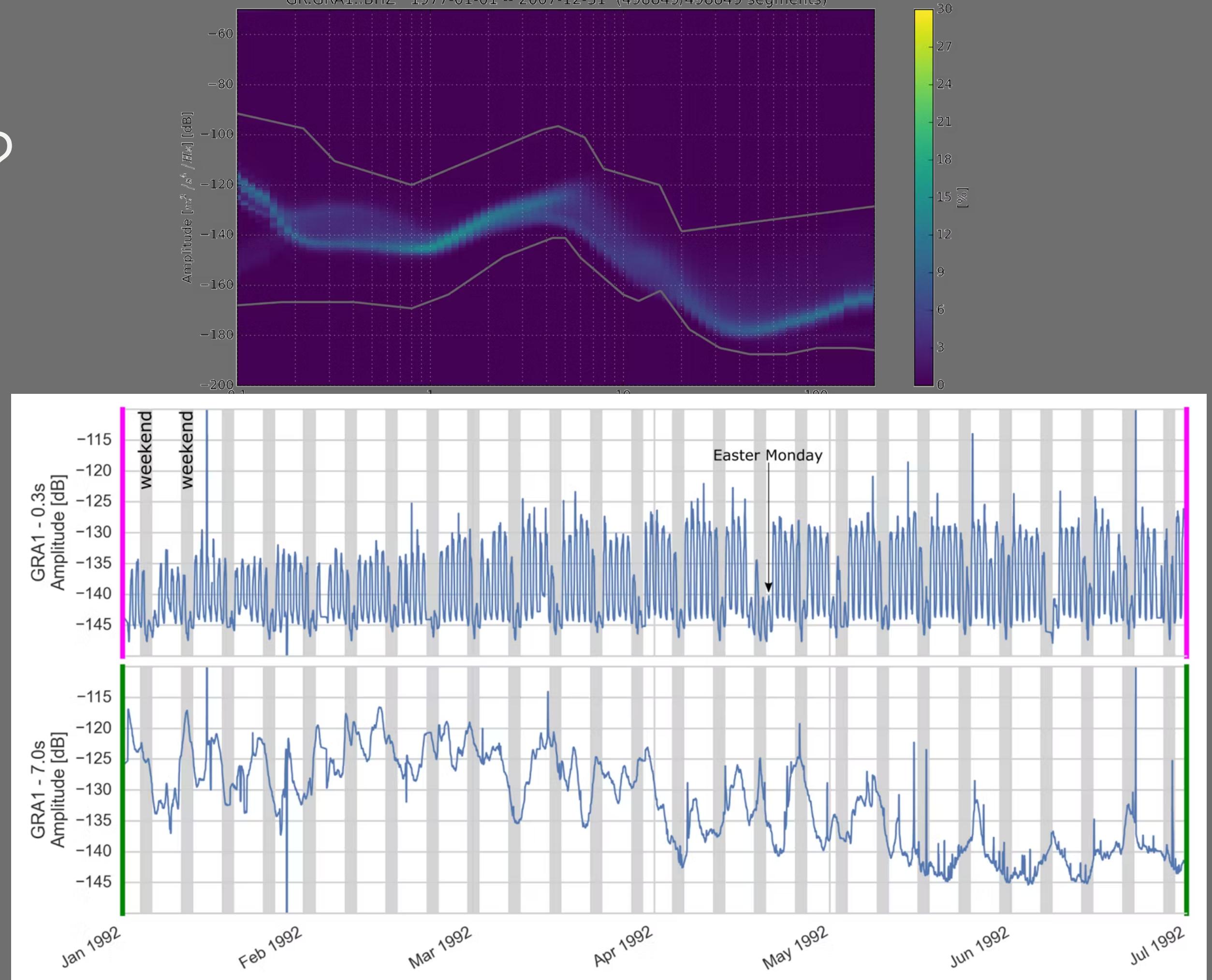
Noise ?



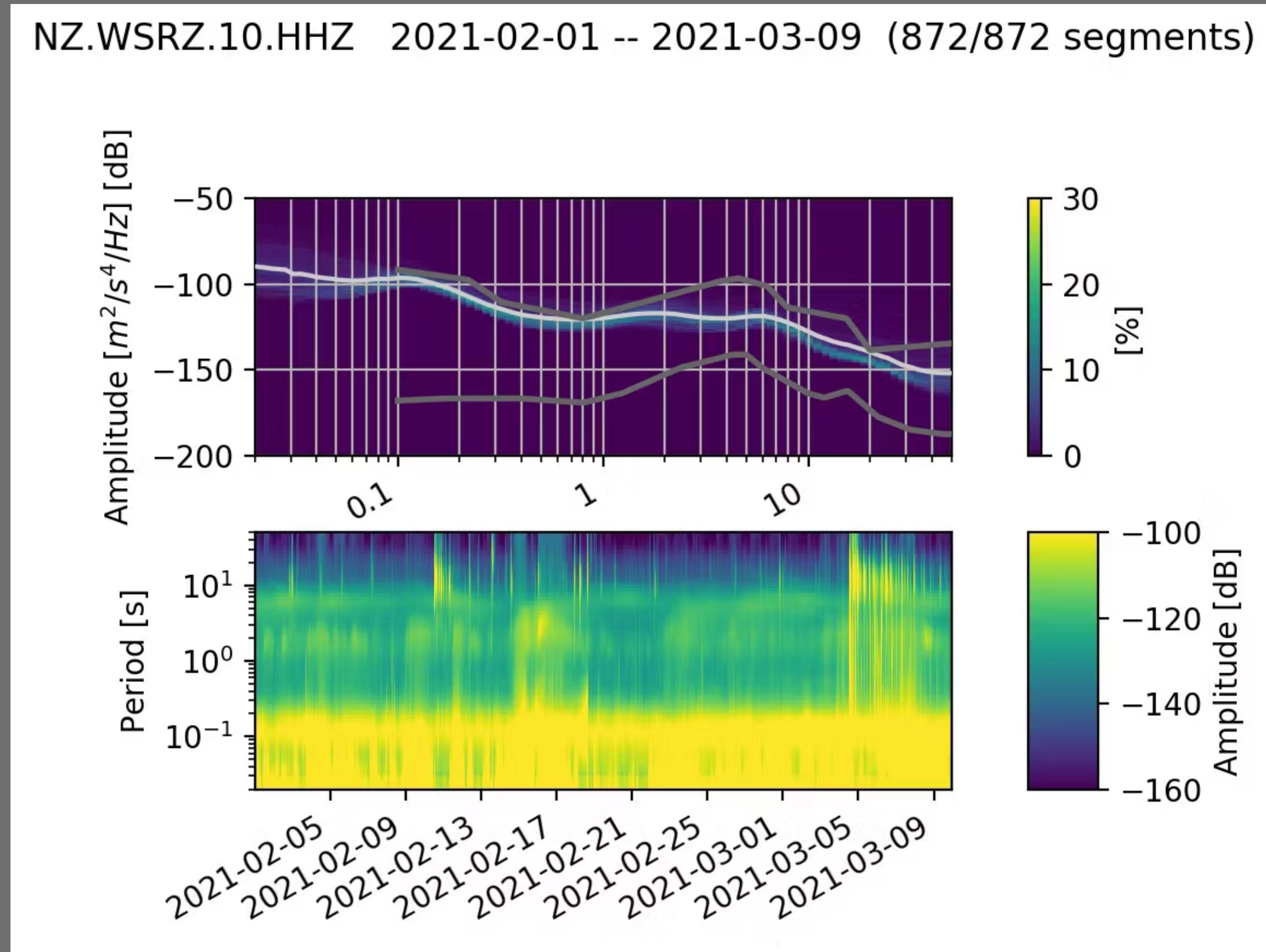
Noise ?
so what?



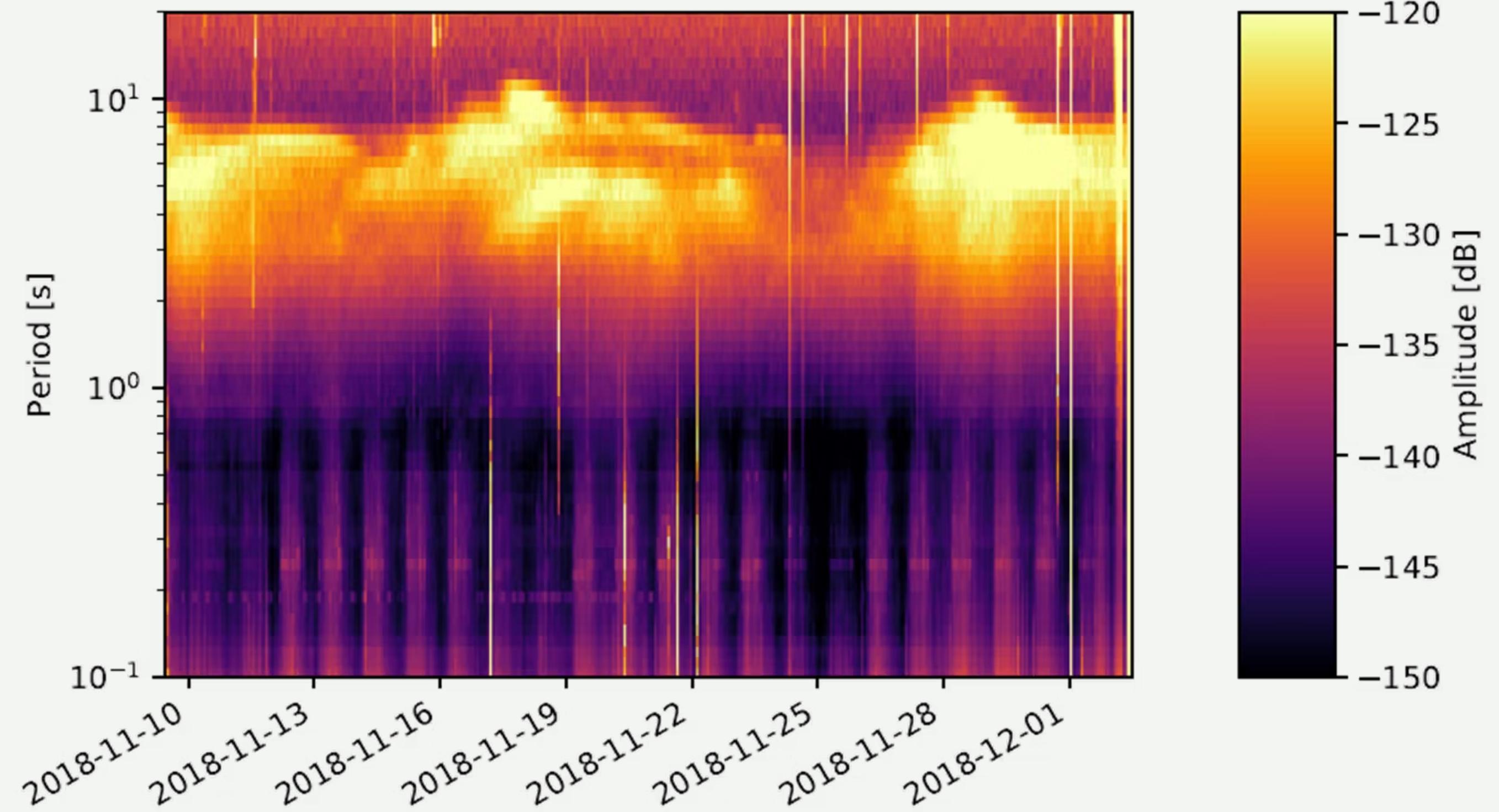
vs Time?



vs Time?



vs Time?





PRACTICALS

Case Study



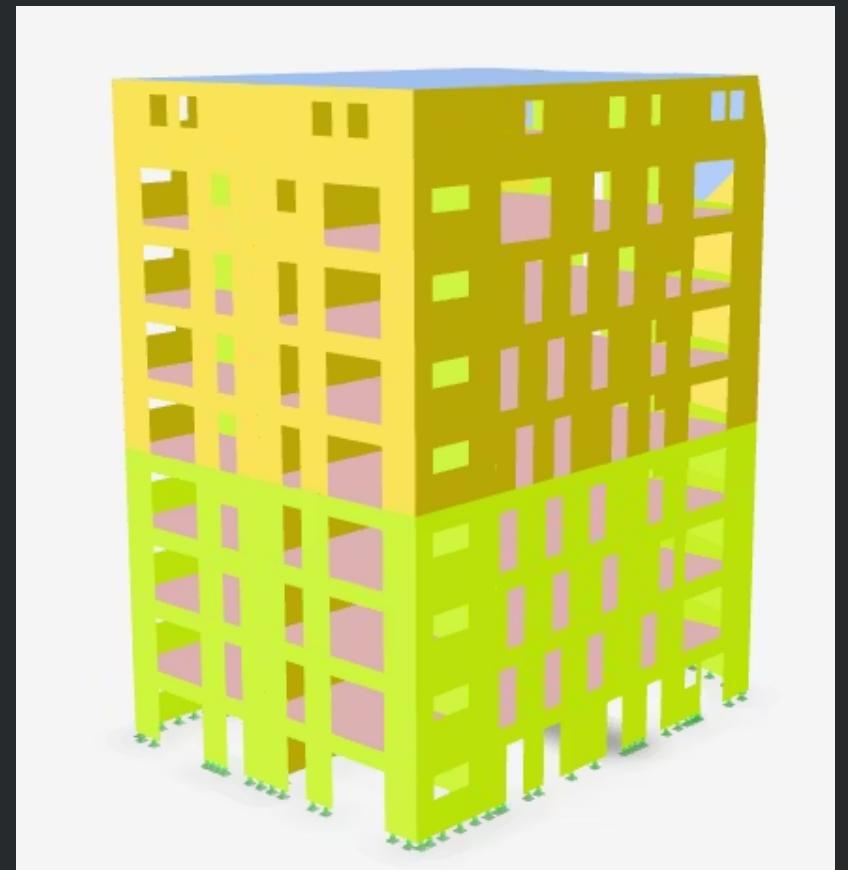
Temporary instrumentation of the Hautbois Wooden High-Rise building in Grenoble (France) for Structural Health Monitoring and earthquake engineering

Two 9- and 6-story residential buildings

- 56 units in total
- 52,972 ft³ of zinc-coated wood,
- architectural masterpiece
- innovative achievement
- 99 ft high - 30.1752 meters



Try Pitch



[https://www.dlubal.com/en/downloads-and-information/references/customer-projects/001161?
srsltid=AfmBOoomdamUo2jT6ovM9USthYaP8uOe6Dw0c4dZGu0hIEZiBXppInEJ](https://www.dlubal.com/en/downloads-and-information/references/customer-projects/001161?srsltid=AfmBOoomdamUo2jT6ovM9USthYaP8uOe6Dw0c4dZGu0hIEZiBXppInEJ)



Monitoring:

- 52,972 ft³ of zinc-coated wood,
- architectural masterpiece
- innovative achievement

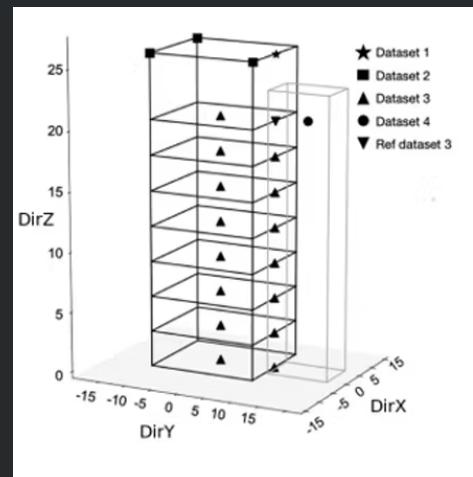
24-bit Nanometrics dataloggers,
coupled with high-sensitivity 3-
component Lennartz 3D-5s
velocimeters, 200Hz

https://www.fdsn.org/networks/detail/8N_2021/

HB01	Grenoble, 38185, Isere, Auvergne-Rhone-Alpes, France	45.1725	5.73044	2021-12-20	2025-12-31	RESIF
HB02	Grenoble, 38185, Isere, Auvergne-Rhone-Alpes, France	45.1725	5.73044	2021-12-20	2025-12-31	RESIF
HB03	Grenoble, 38185, Isere, Auvergne-Rhone-Alpes, France	45.1725	5.73044	2021-12-20	2025-12-31	RESIF
HB04	Grenoble, 38185, Isere, Auvergne-Rhone-Alpes, France	45.1725	5.73044	2022-06-22	2025-12-31	RESIF



Gueguen, P., & Vieux Champagne, F. (2023). *Monitoring of the Hautbois Wooden High-Rise building in Grenoble, France (RESIF-SISMOB)* [Data set]. RESIF - Réseau Sismologique et géodésique Français. <https://doi.org/10.15778/RESIF.8N2021>



Background – Janot, Guegein et al.

The emergence in the last 5 years of Tall Wood Buildings is part of the development of the wood industry and represents one of the relevant responses to current environmental and urban densification constraints. Among the technical challenges posed by such buildings, **horizontal oscillations are a key issue**. Indeed, the strength / lightness ratio of wood gives buildings interesting properties regarding earthquake but also more difficult to manage regarding wind loads, with induced vibrations that can be detrimental to the comfort of the occupants. Operational Modal analysis on wooden structures showed significant variations in the dynamic properties of wooden high-rise buildings (frequencies, damping...) and many questions are related to the evolution over time (at during its use) of the dynamic properties of wood high-rise buildings. The scientific objectives of this experiment are therefore: the modal analysis of the wooden structure under ambient vibrations; the evaluation of modal fluctuations over time and their impact in terms of building performance (comfort and earthquake); the interpretation of the physical processes at the origin of these fluctuations. The selected building is a wooden high-rise (9 stories) building under construction (2020-2021) as part of the "Le Haut-Bois" project.

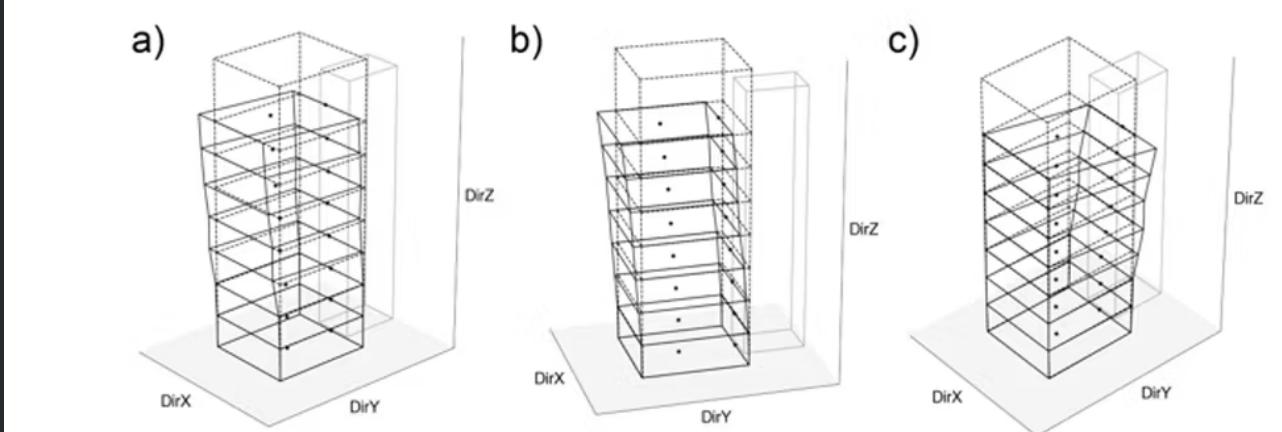


Figure 4

Mode shapes of HBB8: DirX mode (a), DirY mode (b) and DirZ mode (c). Gray lines correspond to the concrete stairwell shape for referencing, black dotted lines represent the building shape at rest and black straight lines correspond to the modal shapes. Stars indicate the positions of the sensors. Linear extrapolation is performed to match the shape of HBB8 walls.



PRACTICALS

Part 1: Noisy Noisy

Tutorials 01 to 03
Time series & temporal variations
Power Spectral Densities
Noise statistics



PRACTICALS

Open a console

CD to the folder where the notebooks are downloaded

start "jupyter notebook"

Set computer to "maximum performance" ("battery saving")



Tutorial 01-03 results



PART 2

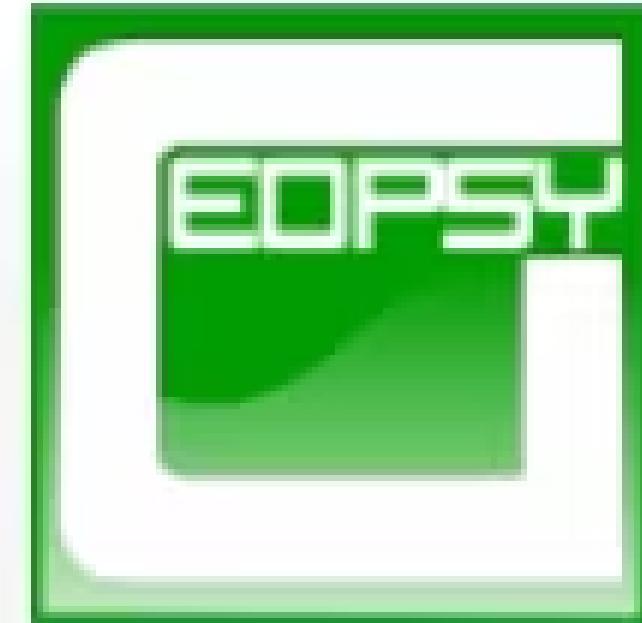
Resonance? What?

*Horizontal to Vertical Spectral Ratio
Continuous HVSR*

Open the 10. Continuous HVSR Geopsy notebook



Geopsy.exe Instruction



For Windows:

```
geopsy_exe = 'YOUR_PATH/geopsypack-win64-3.4.2/bin/geopsy-hv.exe'
```

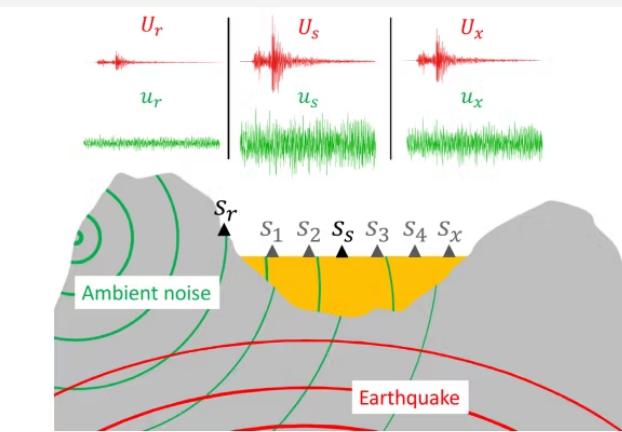
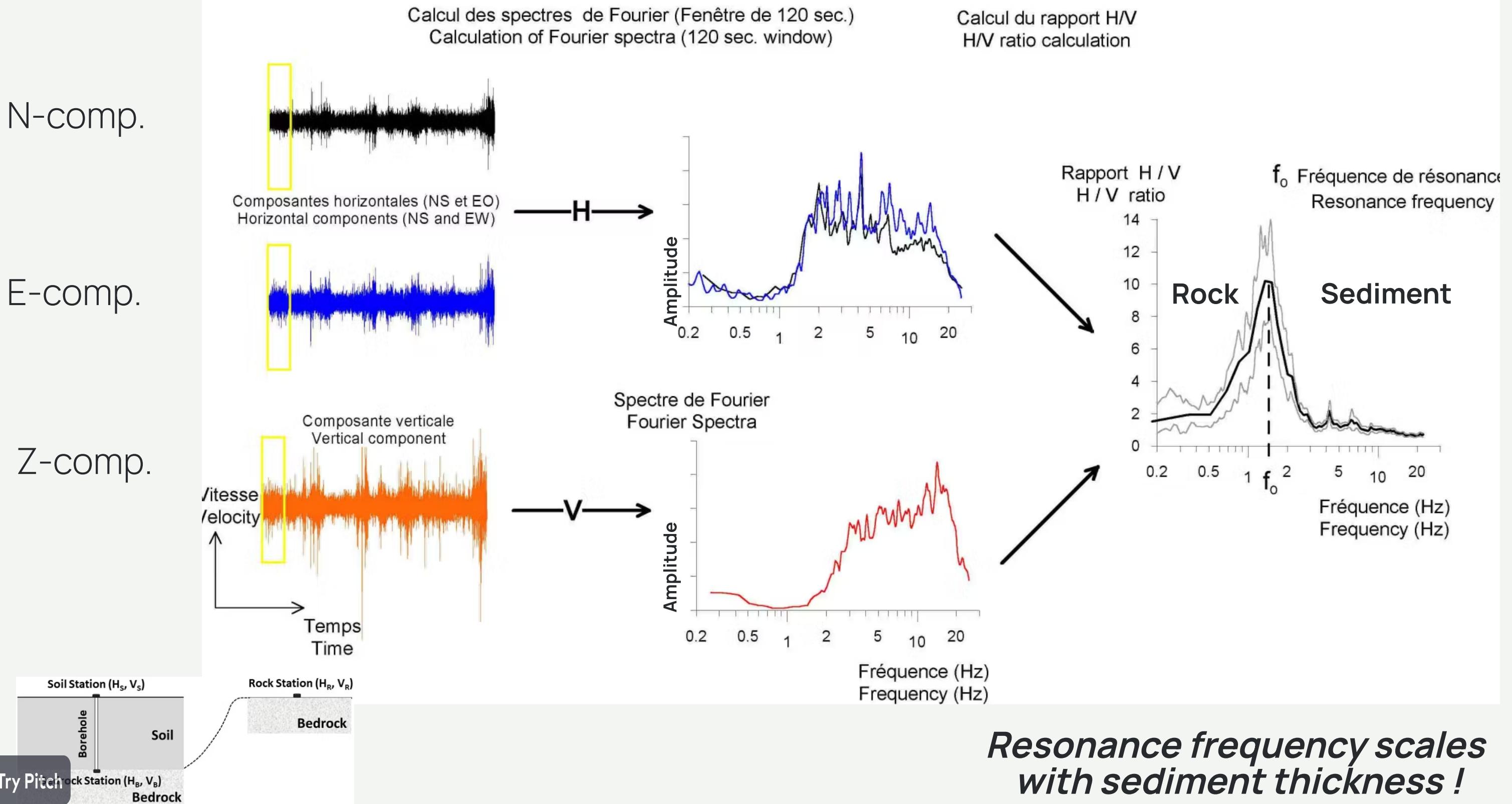
For Linux:

```
geopsy_exe = "geopsy-hv"
```

Marc Wathelet, Jean-Luc Chatelain, Cécile Cornou, Giuseppe Di Giulio, Bertrand Guillier, Matthias Ohrnberger, Alexandros Savaidis;
Geopsy: A User-Friendly Open-Source Tool Set for Ambient Vibration Processing. *Seismological Research Letters* 2020;; 91 (3): 1878–1889.
doi: <https://doi.org/10.1785/0220190360>

H/V spectral ratio analysis

Noise field: surface waves



Theoretical background = DEBATED

J Seismol (2022) 26:653–685
<https://doi.org/10.1007/s10950-021-10062-9>
 ORIGINAL ARTICLE
 Check for updates

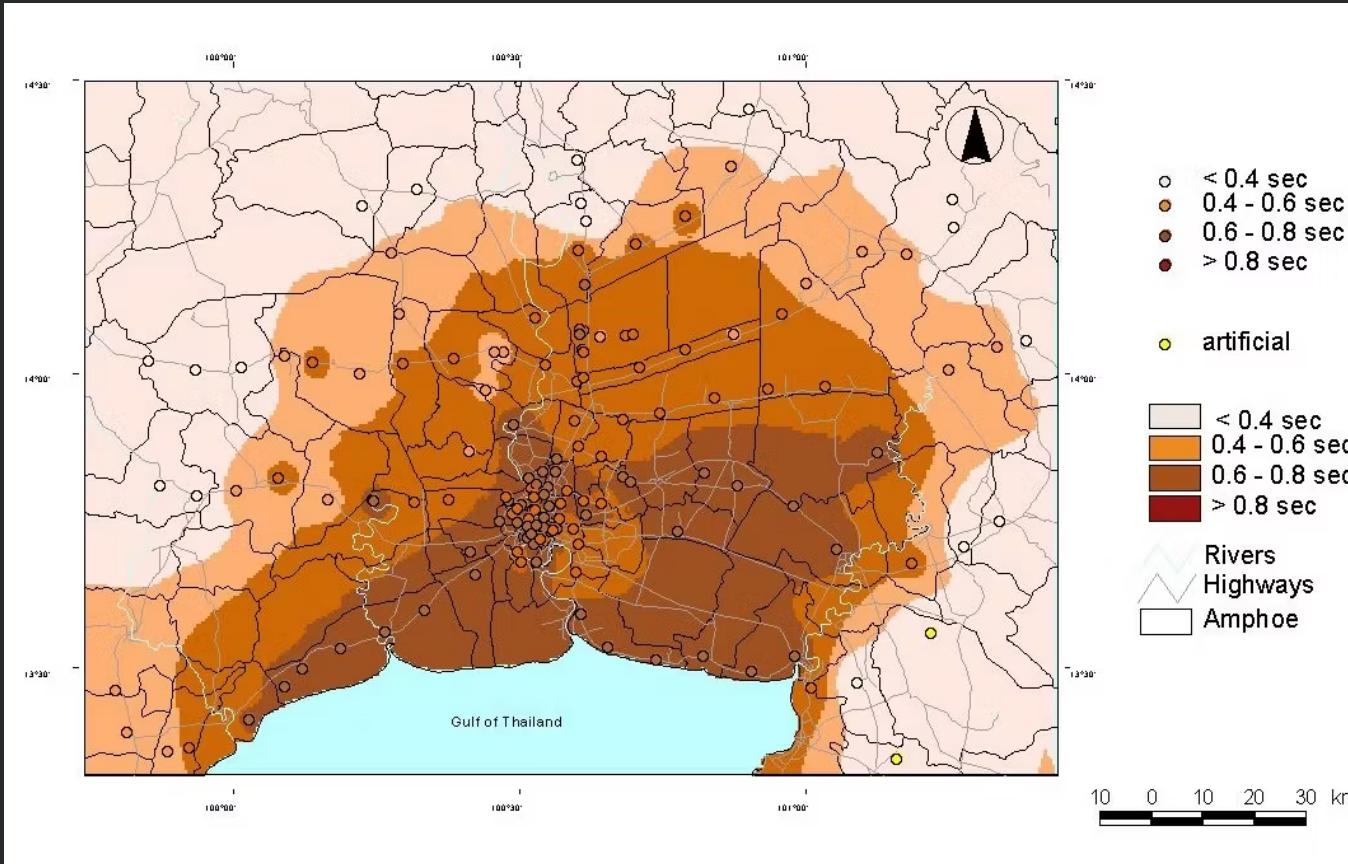
A review of the microtremor horizontal-to-vertical spectral ratio (MHVSR) method
 S. Molnar · A. Sirohey · J. Assaf · P.-Y. Bard · S. Castellaro · C. Cornou ·
 B. Cox · B. Guillier · B. Hassani · H. Kawase · S. Matsushima ·
 F. J. Sánchez-Sesma · A. Yong

Resonance frequency scales
with sediment thickness !



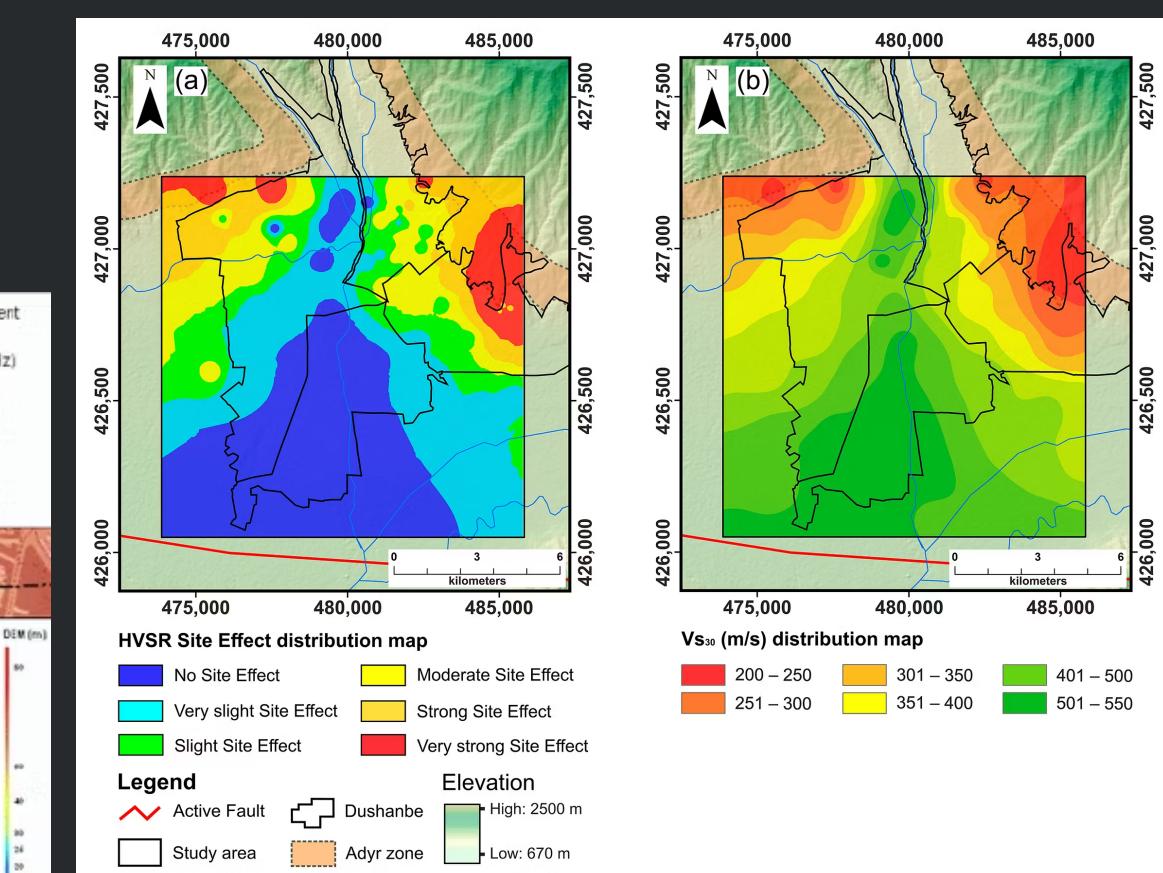
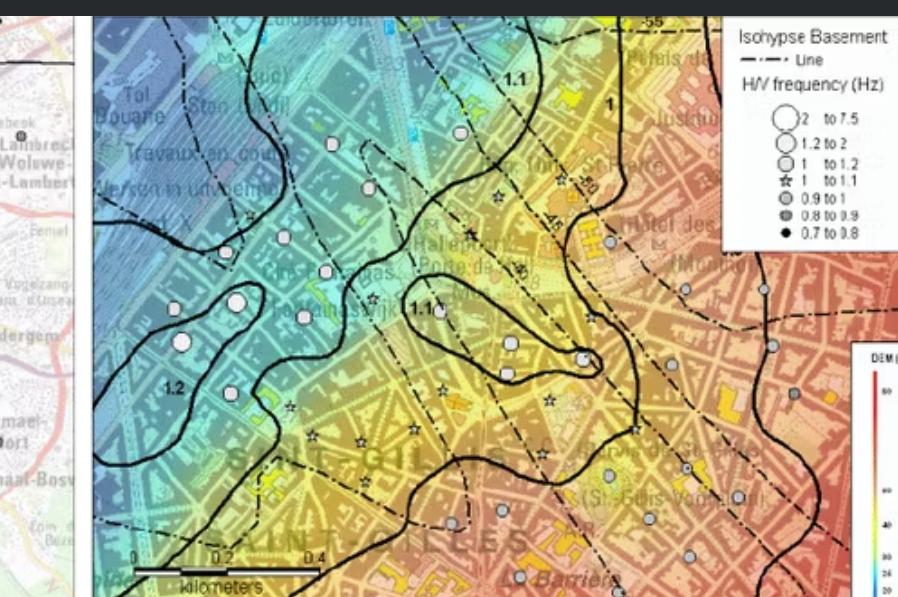
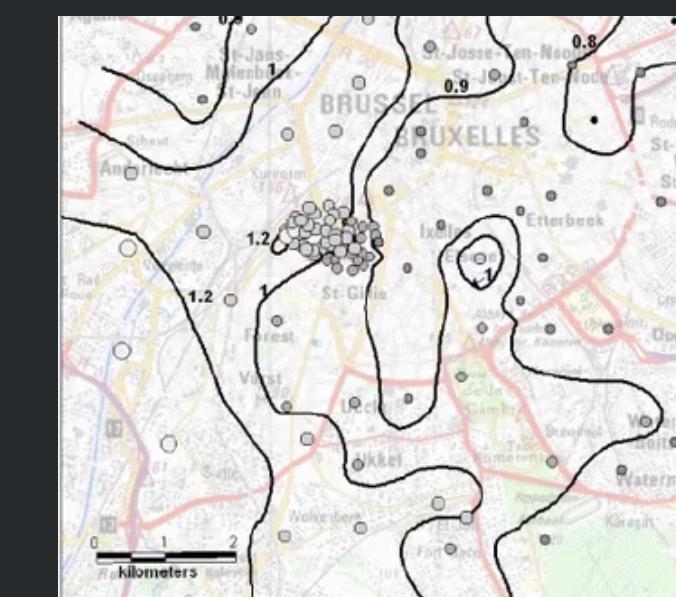
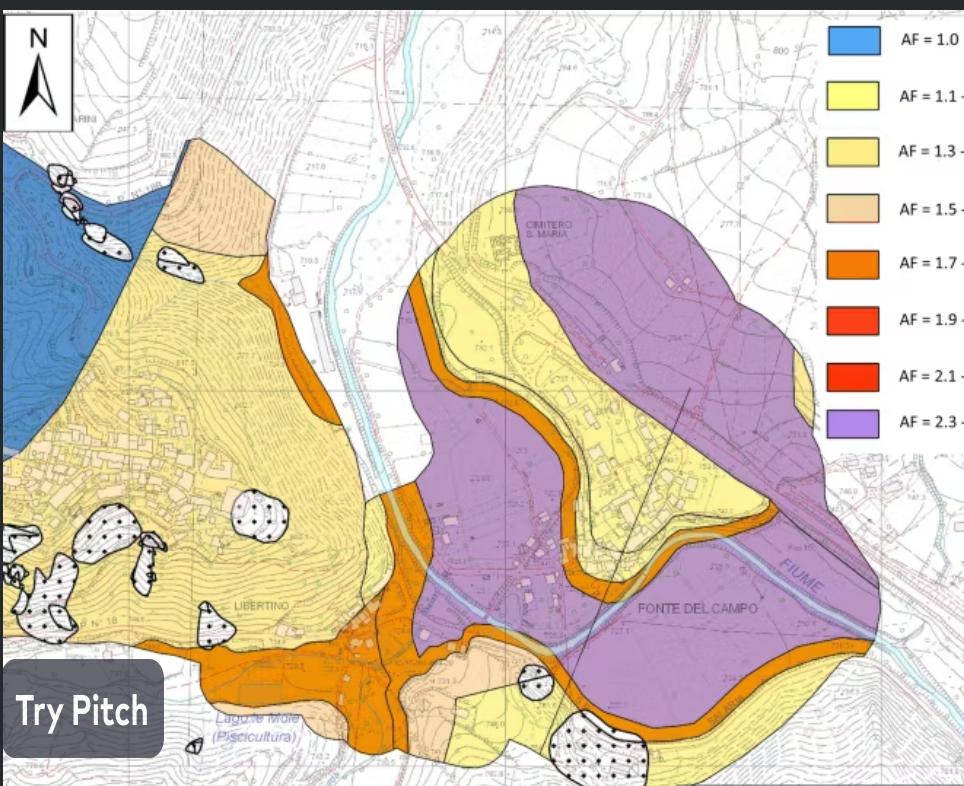
Microzonation

Microzonation provides the basis for site-specific risk analysis
 'Micro' → distinguish from zonation of regional earthquake hazard



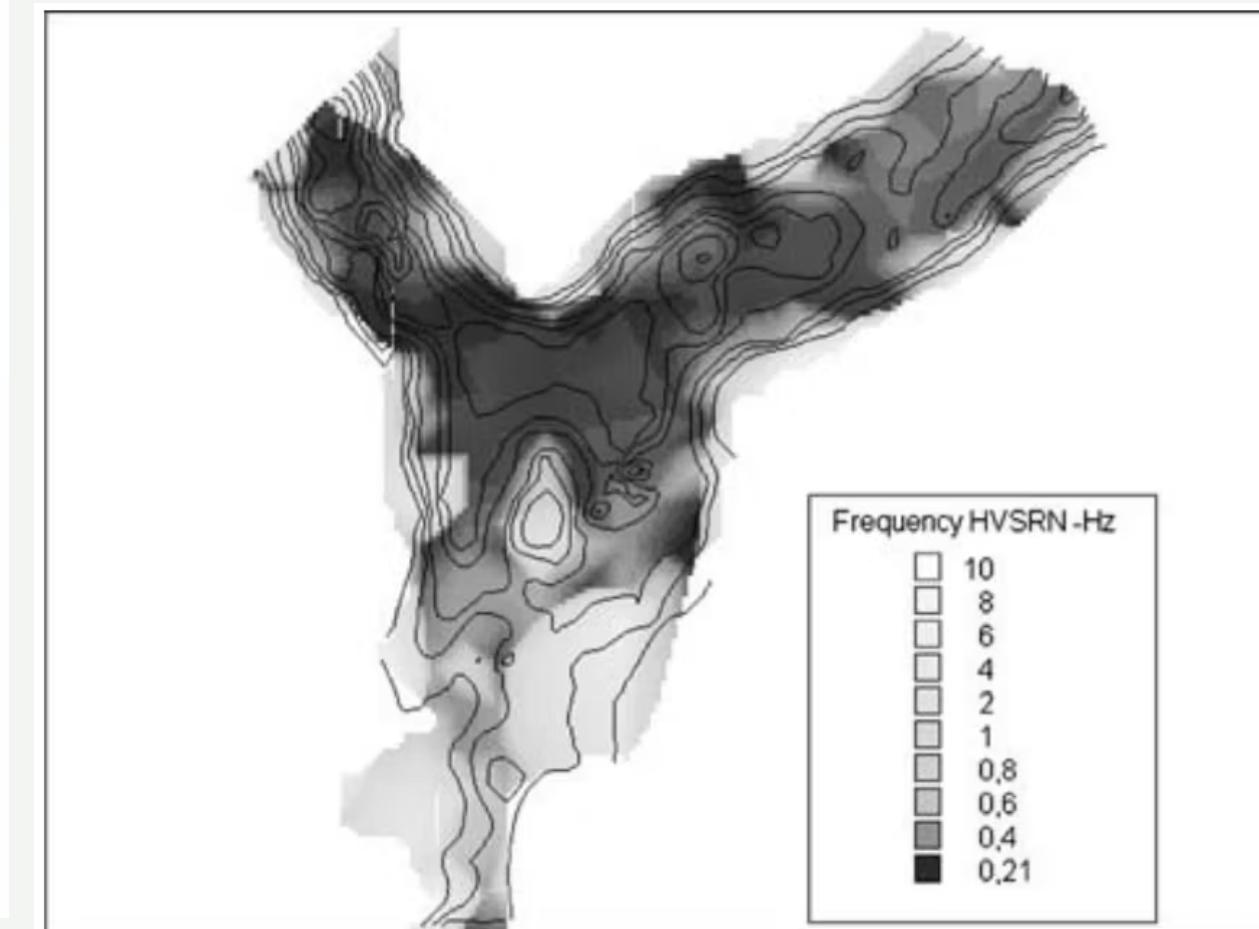
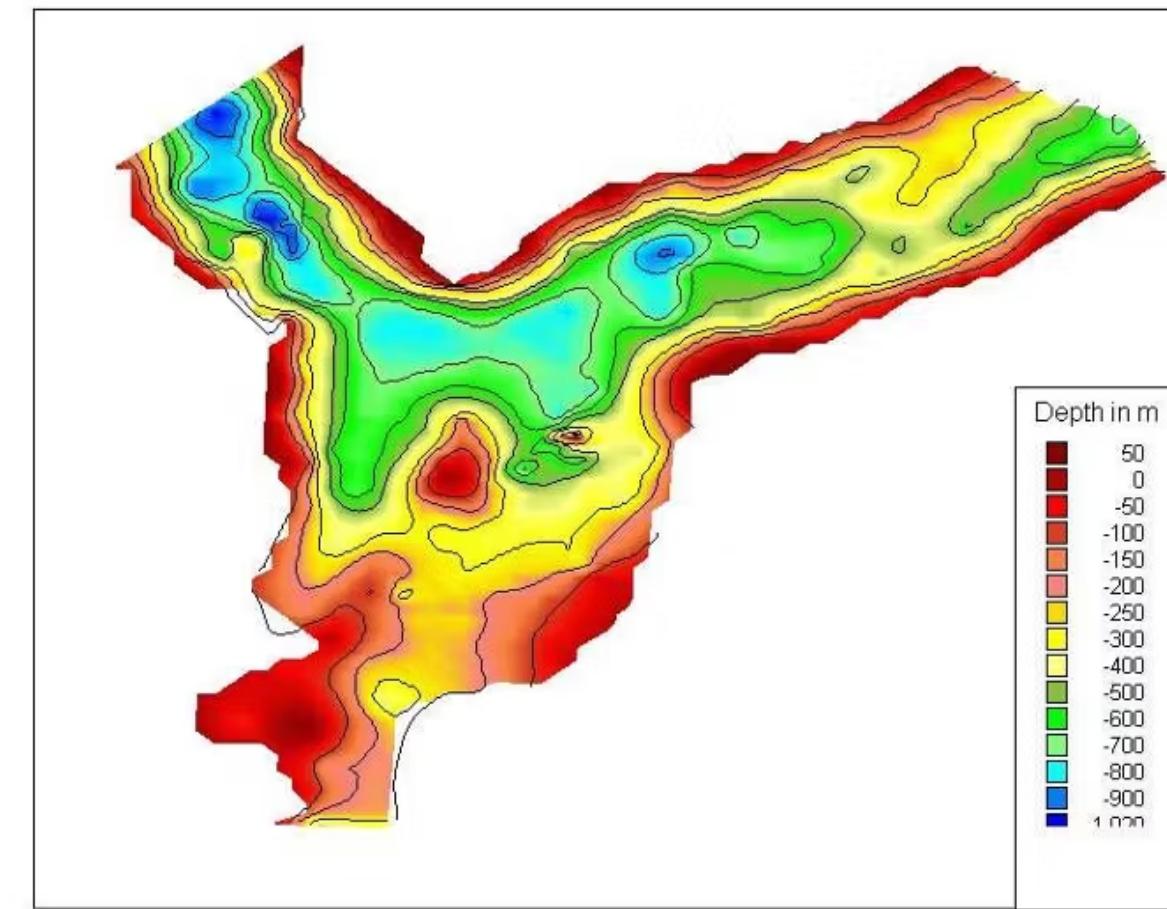
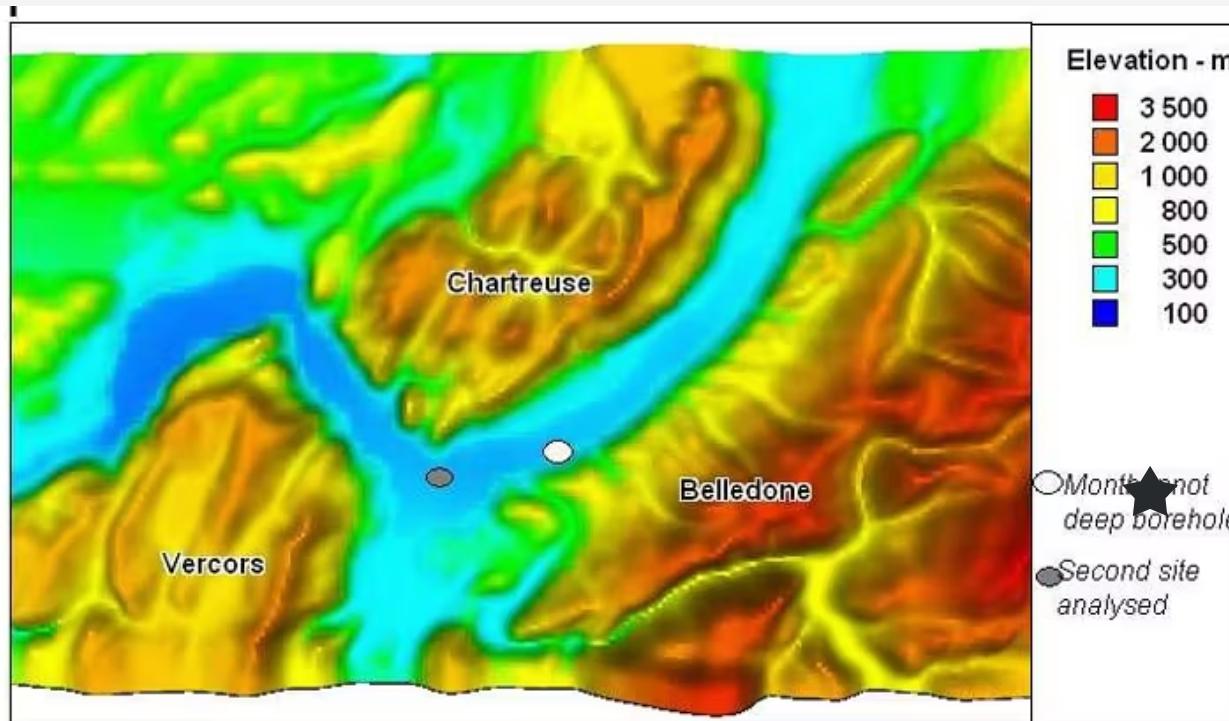
Hazard subdivided into

- seismic amplification - impedance contrasts of soft sediments on hard rock
- liquefaction
- terrain instability landslid -rockfall





Grenoble basin - resonance



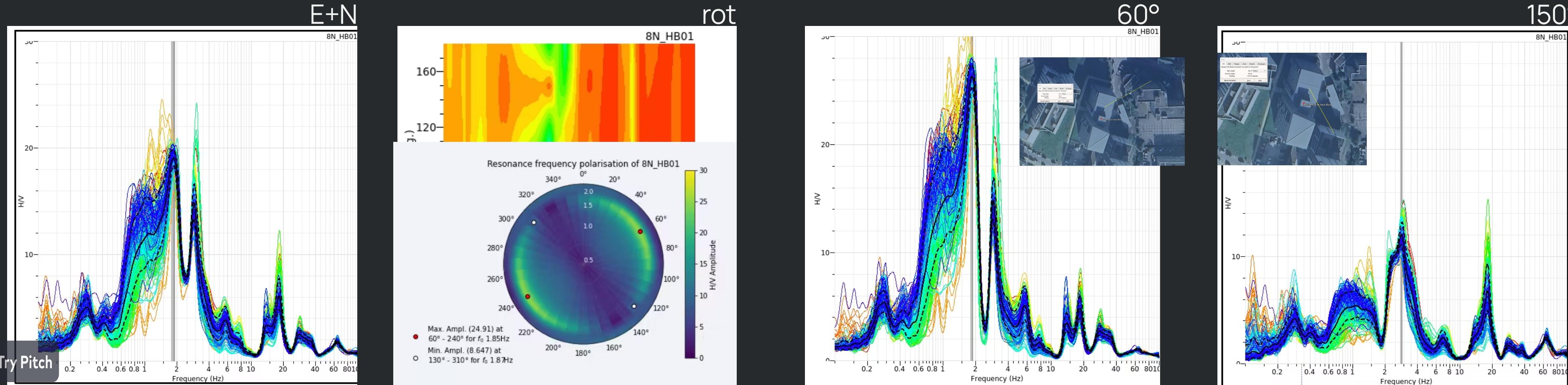
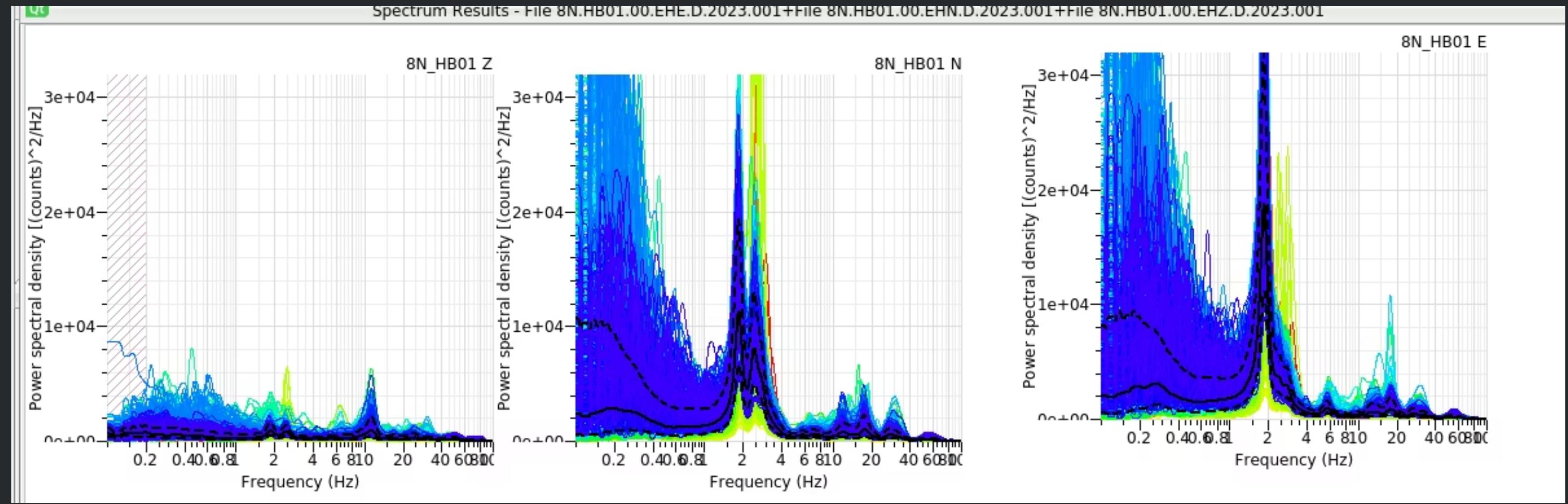
10.1617/s11527-024-02540-6

As mentioned and validated previously by Lebrun et al. (2001), the lower frequency is linked to the S-wave resonance frequency of the entire column of sediments.



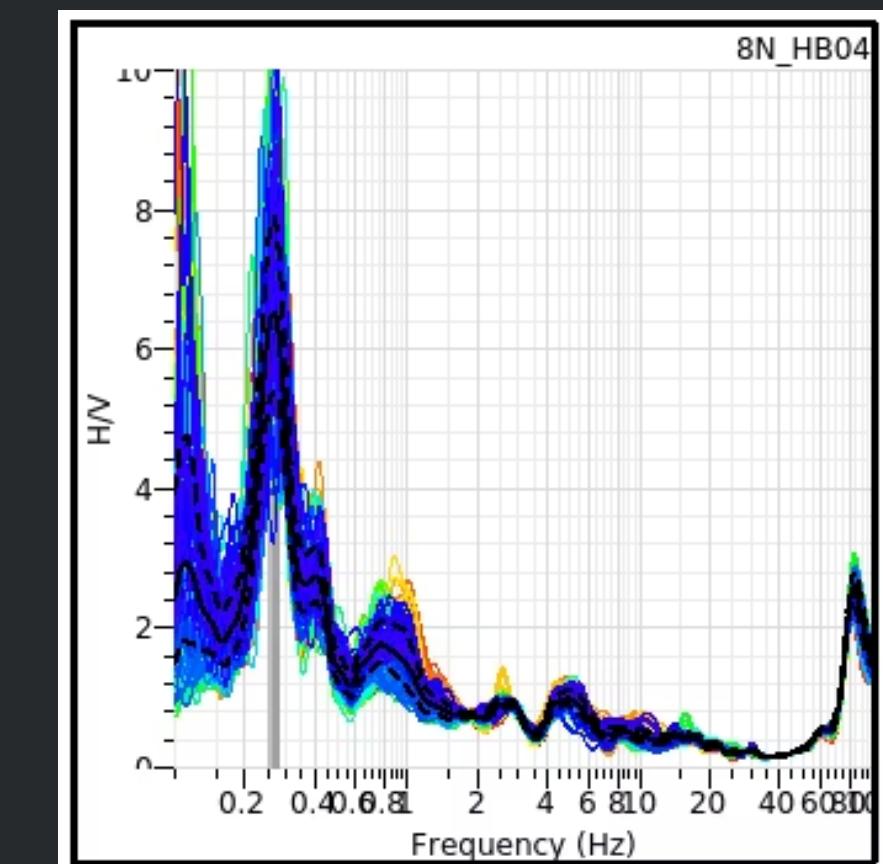
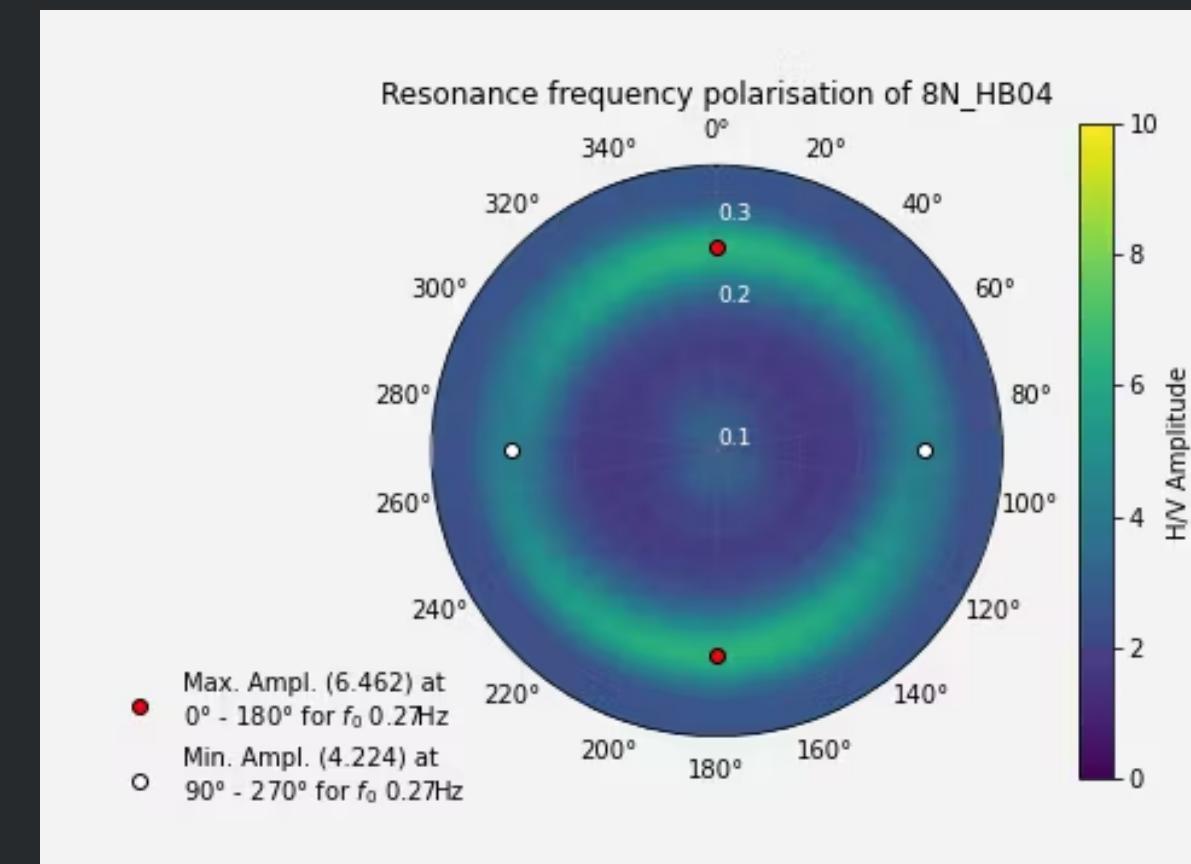
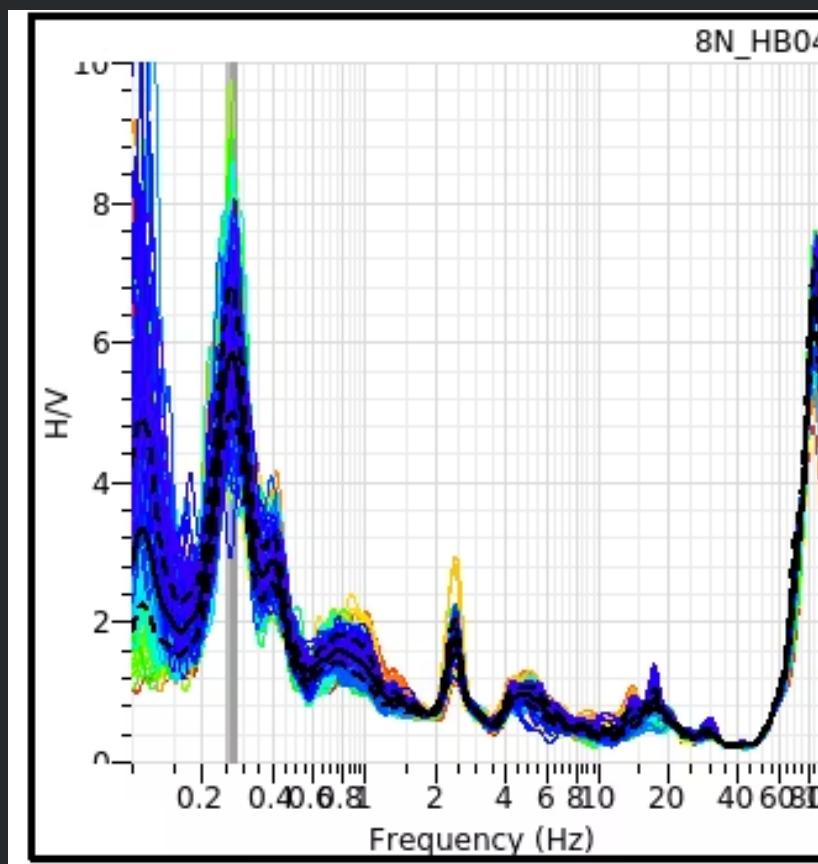
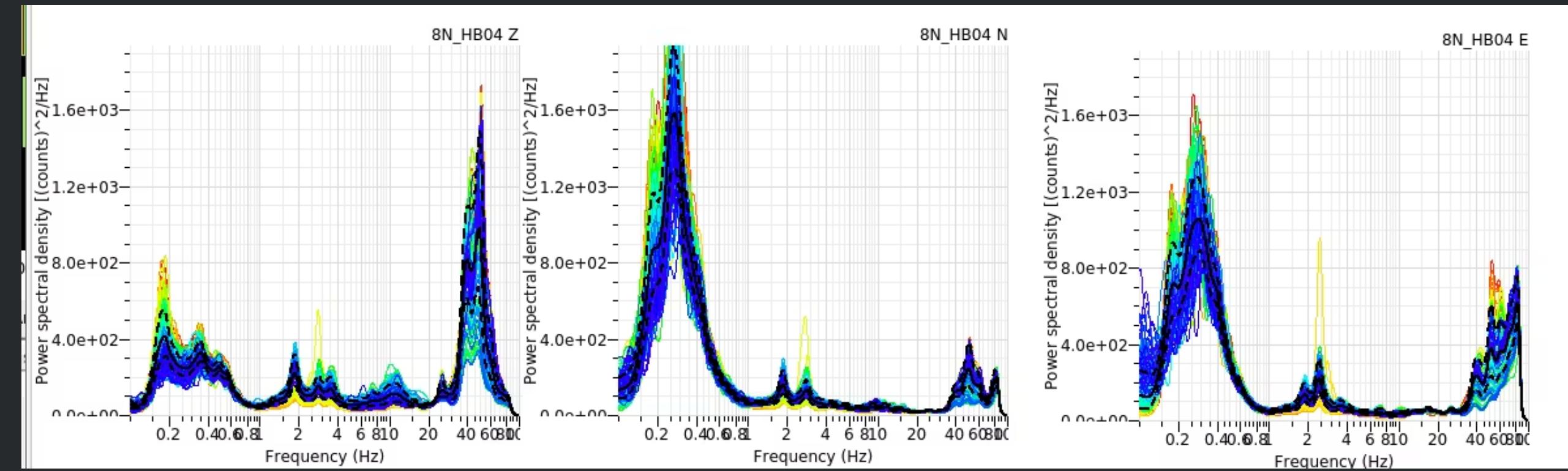
Tutorial 10 results

Continuous HVSR



15 th MESS

HB04 – Base



0°



PRACTICALS

Part 2: Resonance is fun

Tutorial 10:

Automatic Processing for 1 day: 30 January 2024

Explore January 2024 continuous HVSR (precomputed)

Explore time & frequency

24 February 2025



Questions

* **Question 1: how much data is needed to know the resonance of a building: minutes? hours? days? months?**

* **Question 2: how much data is needed to know the resonance frequency of the soil: hours? days? months?**

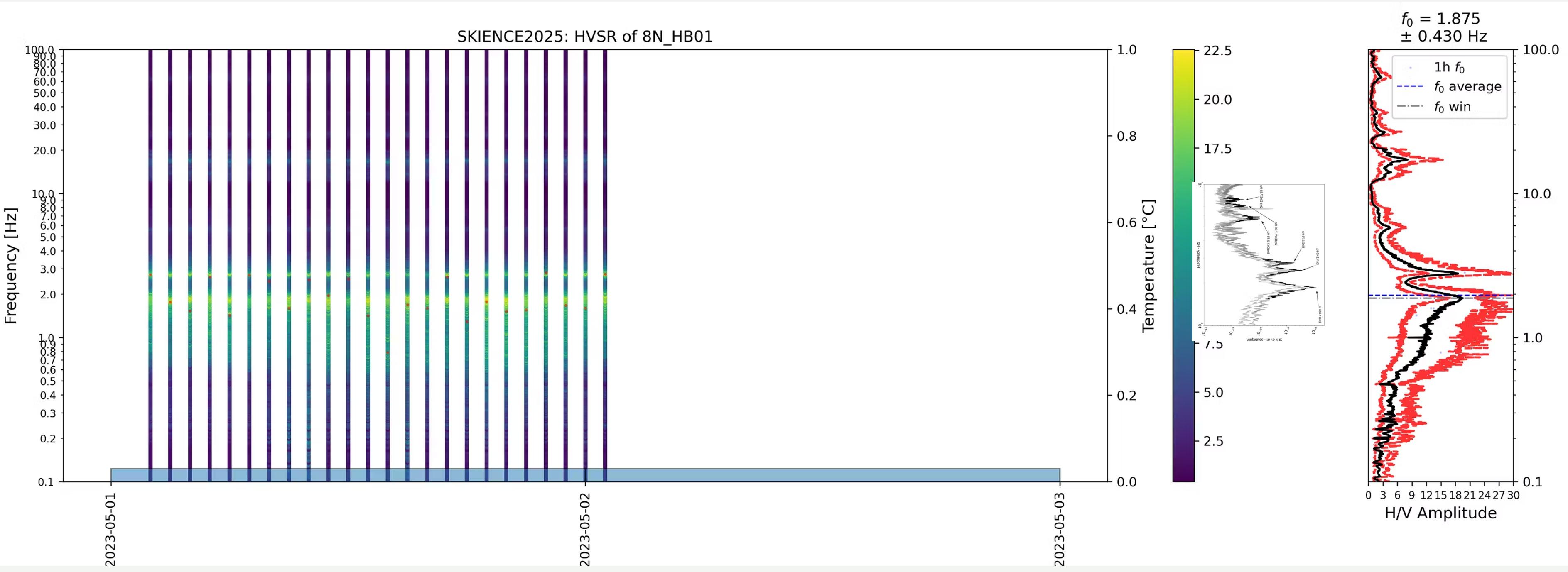
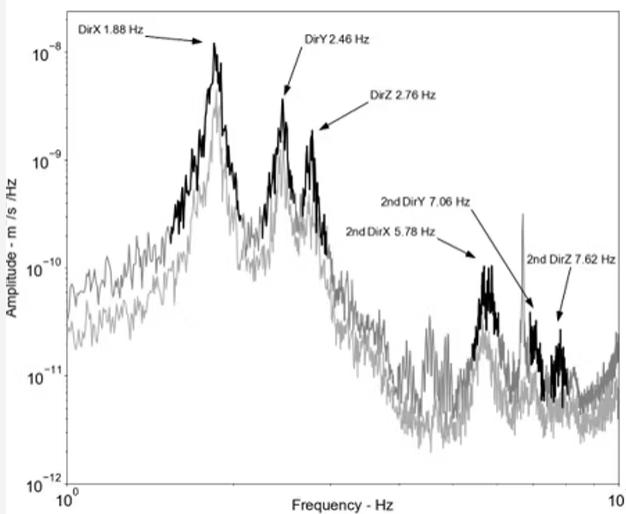
* **Question 3: Can you see the resonance frequency of the soil at the rooftop in HB01, HB02, HB03 ?**

* **Question 4: Can you see the resonance of the building at the base of the building in HB04 ?**

24 February 2025



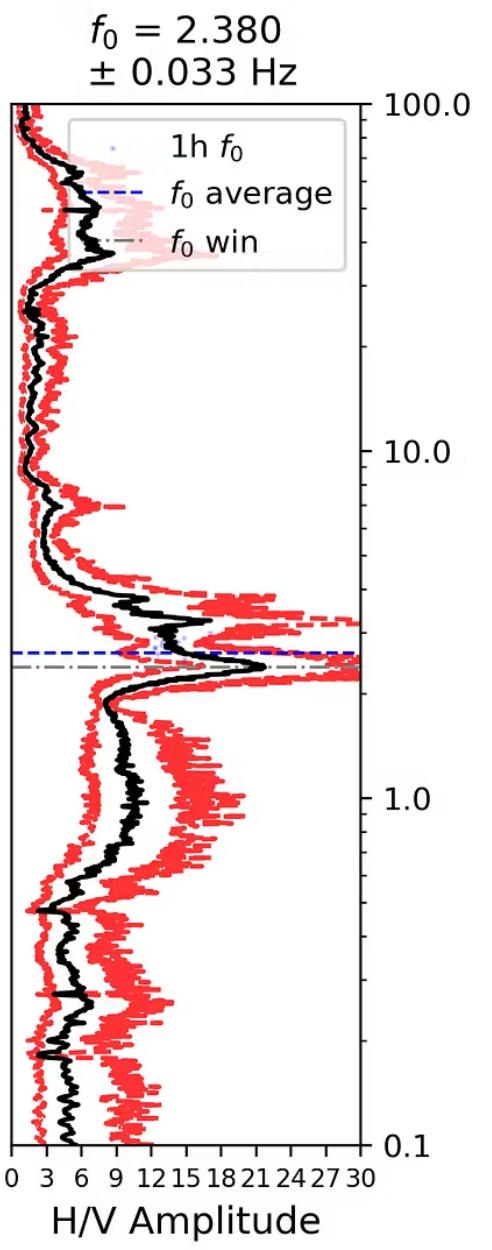
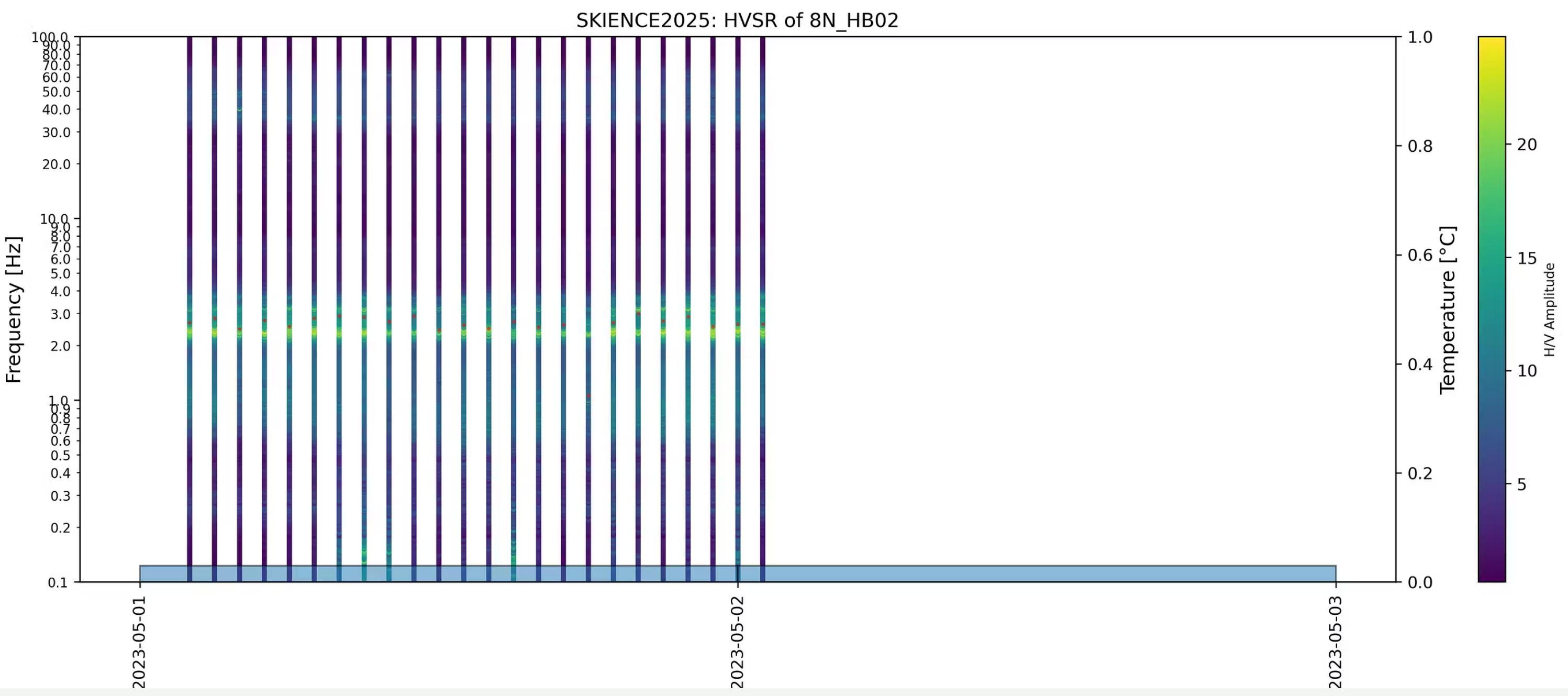
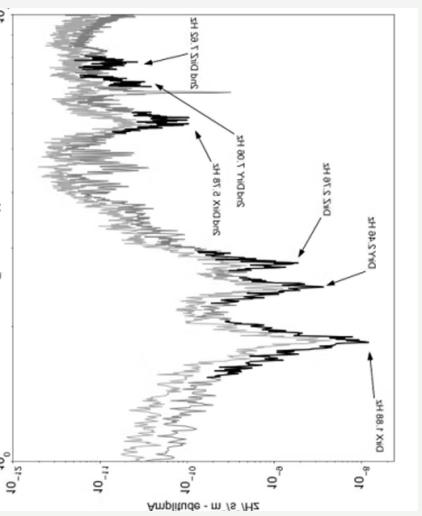
HB01 – Rooftop - 1 Day analysis



24 February 2025



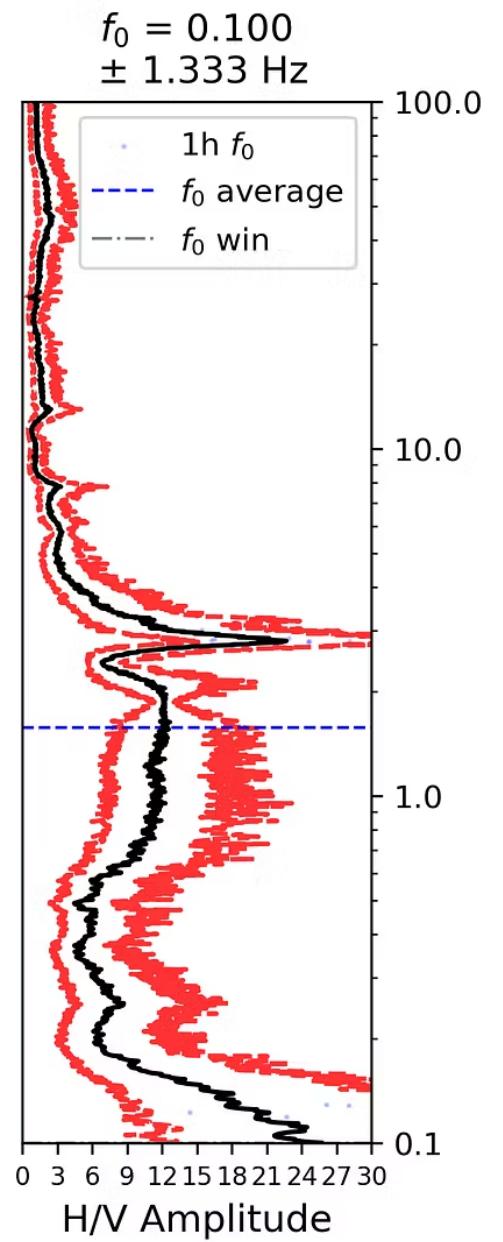
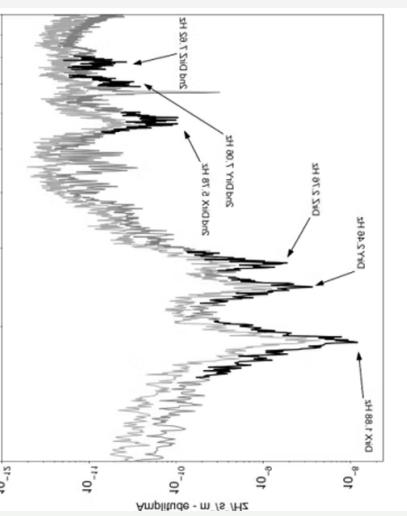
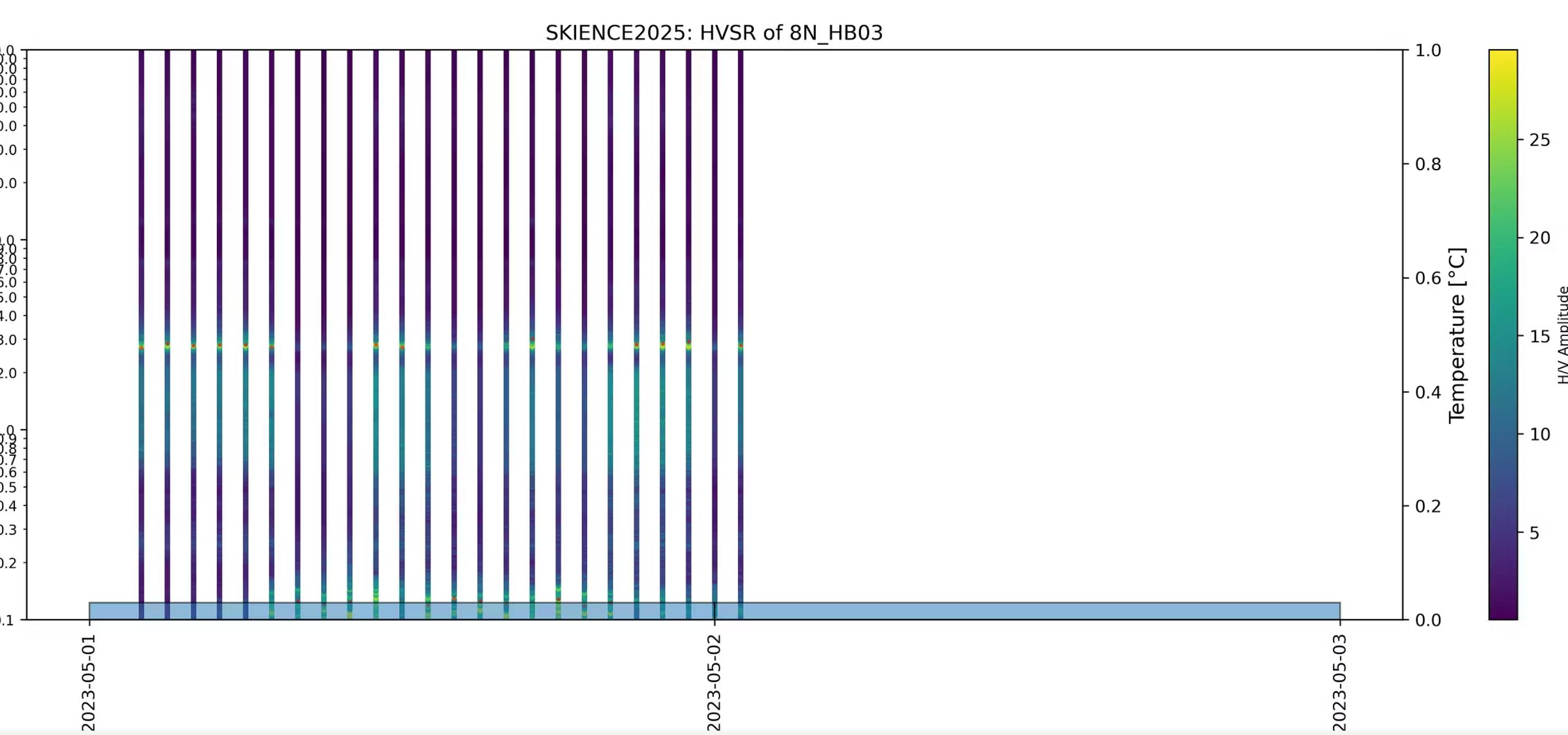
HB02 – Rooftop - 1 Day analysis



24 February 2025



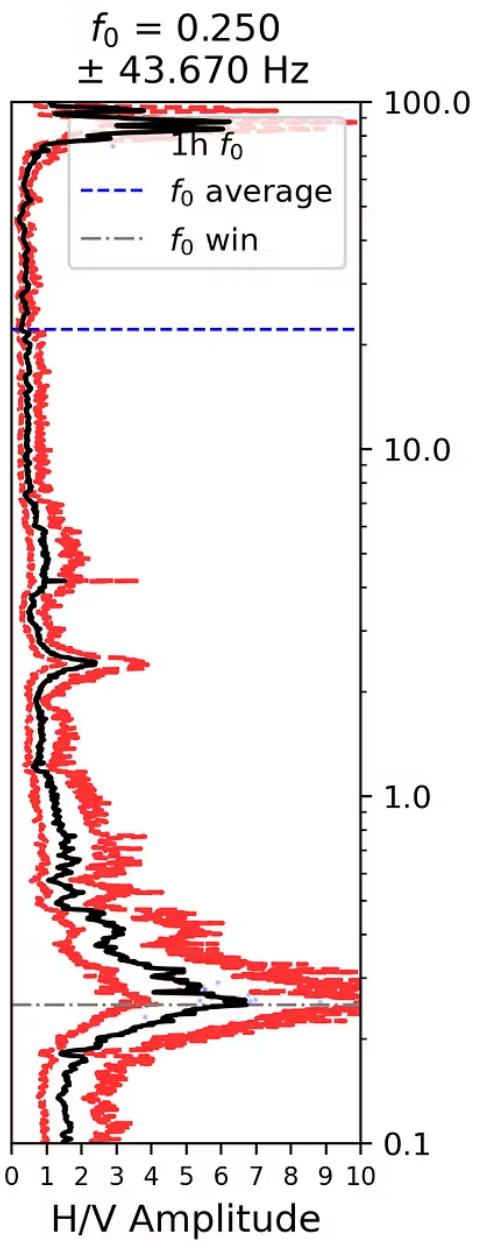
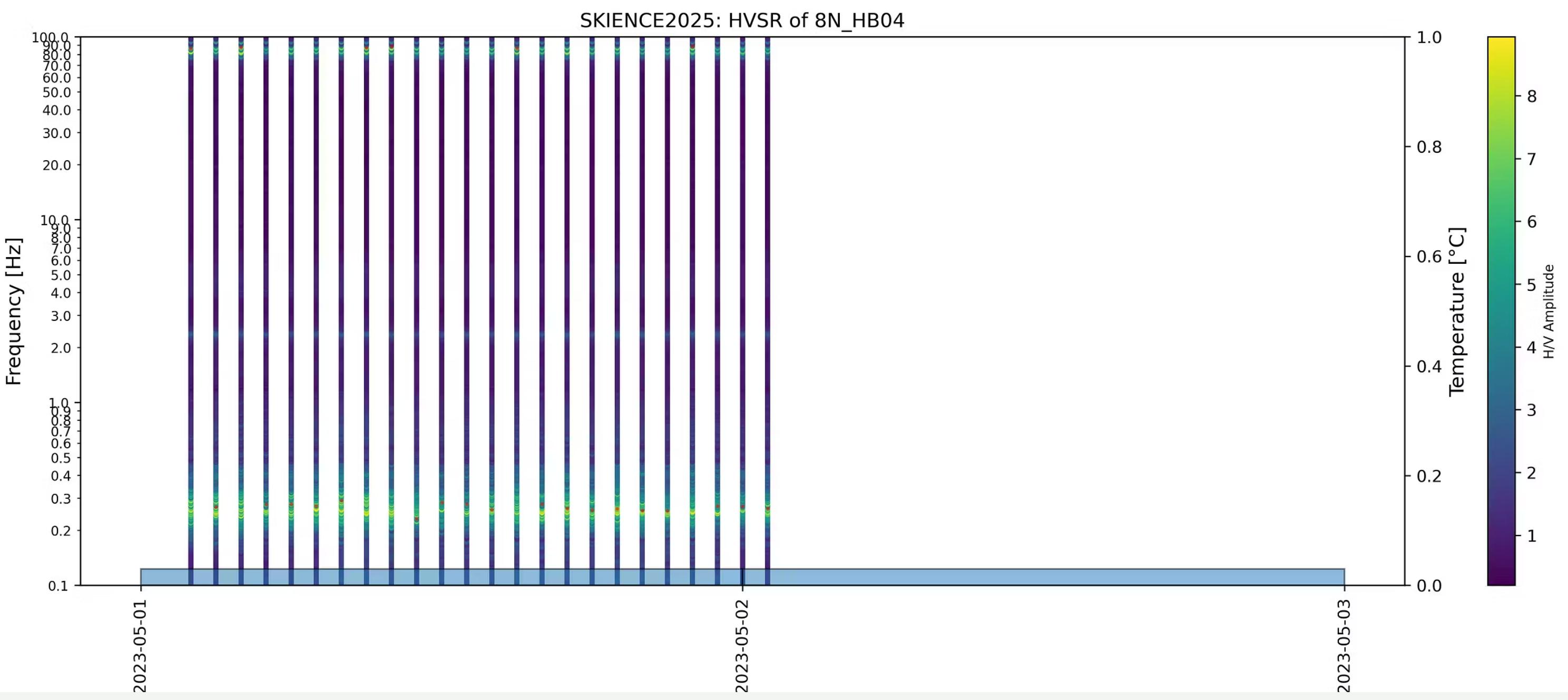
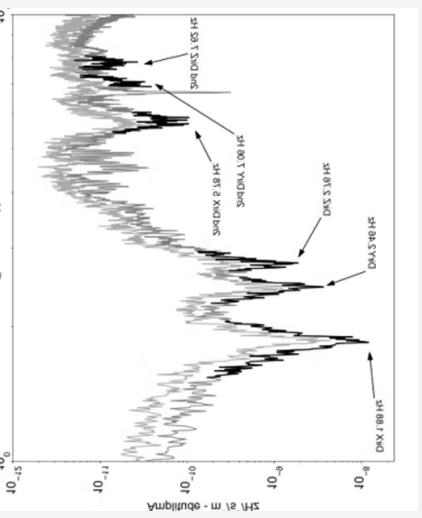
HB03 – Rooftop - 1 Day analysis



24 February 2025



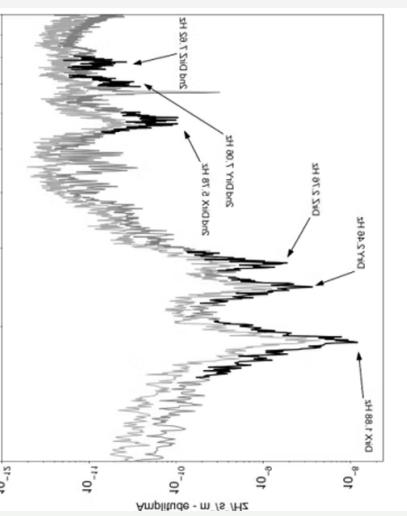
HB04 – Base - 1 Day Analysis



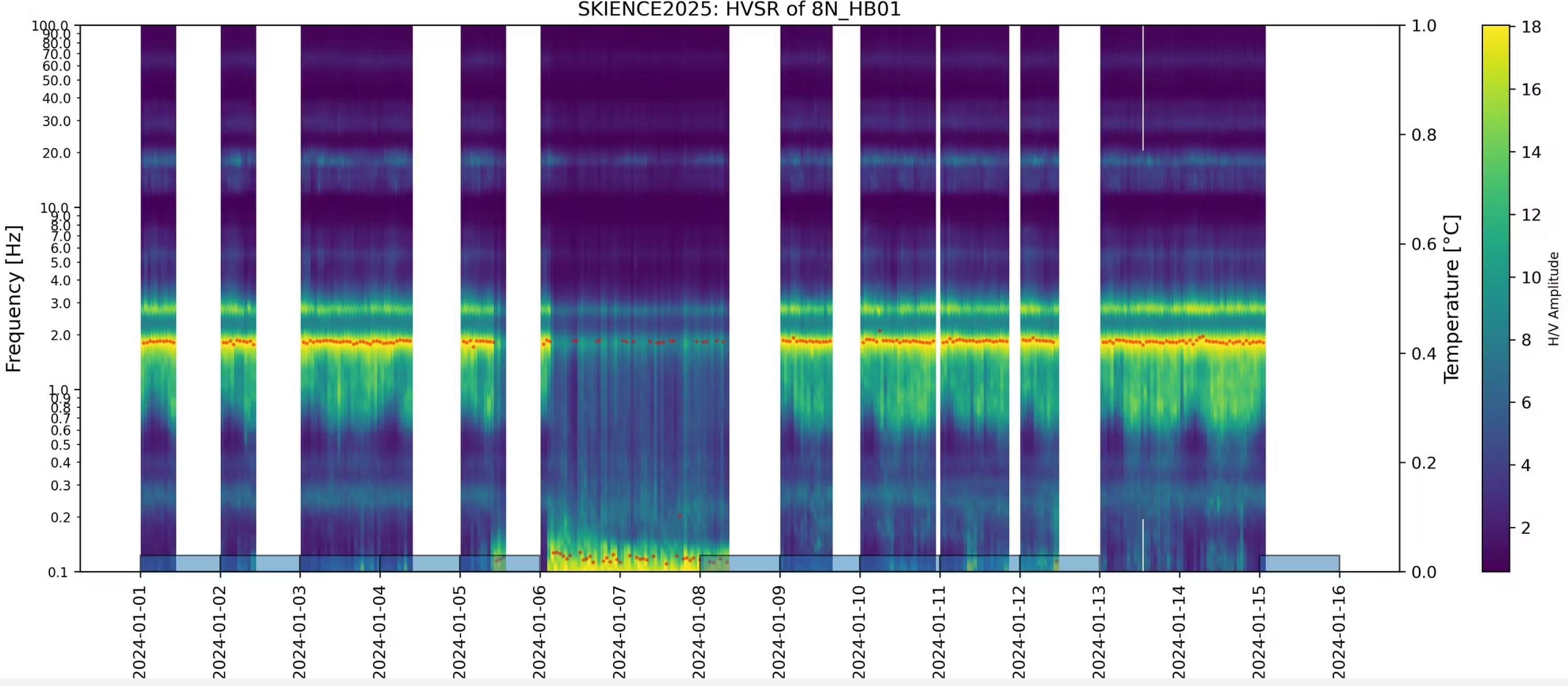
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HB01 – Rooftop - 1 month



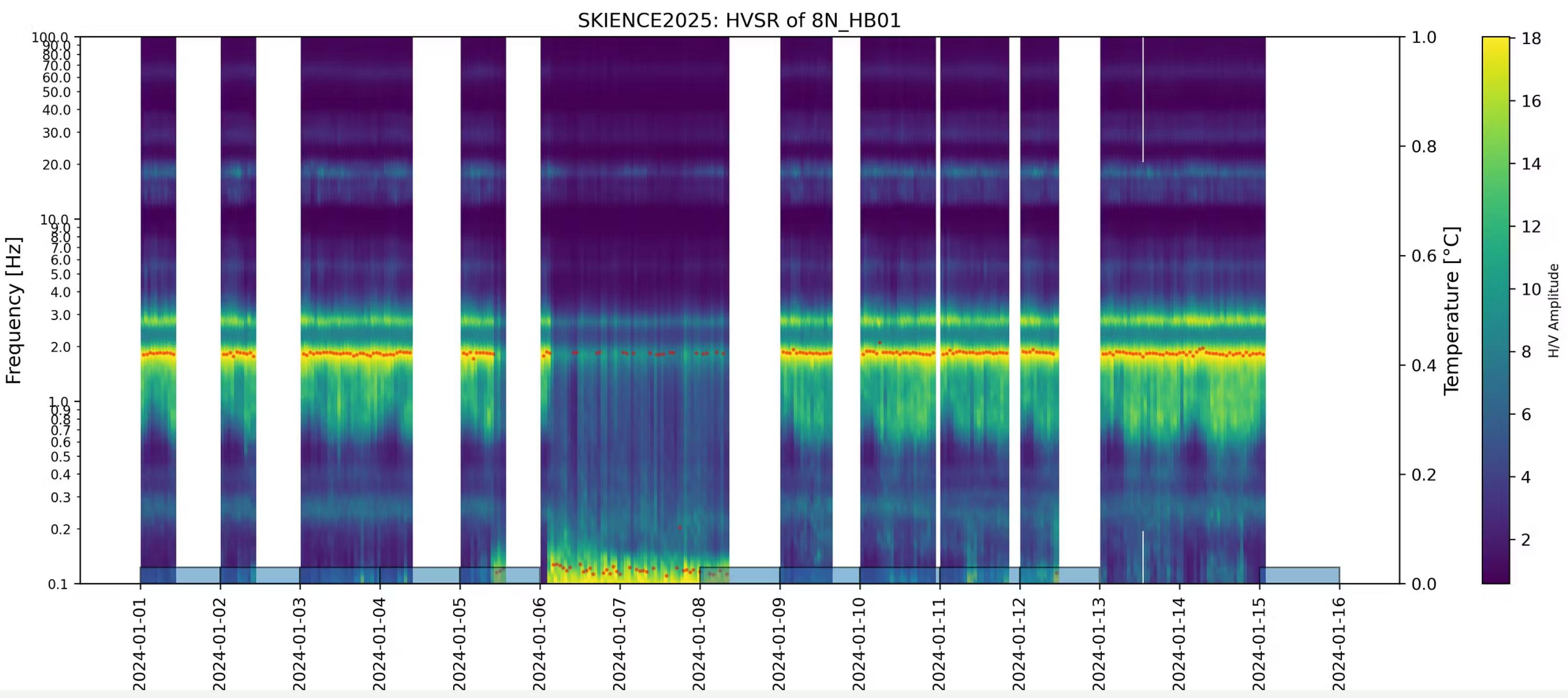
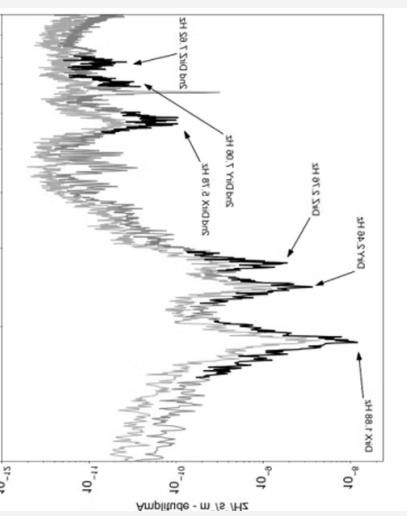
SKIENCE2025: HVSR of 8N_HB01



24 February 2025



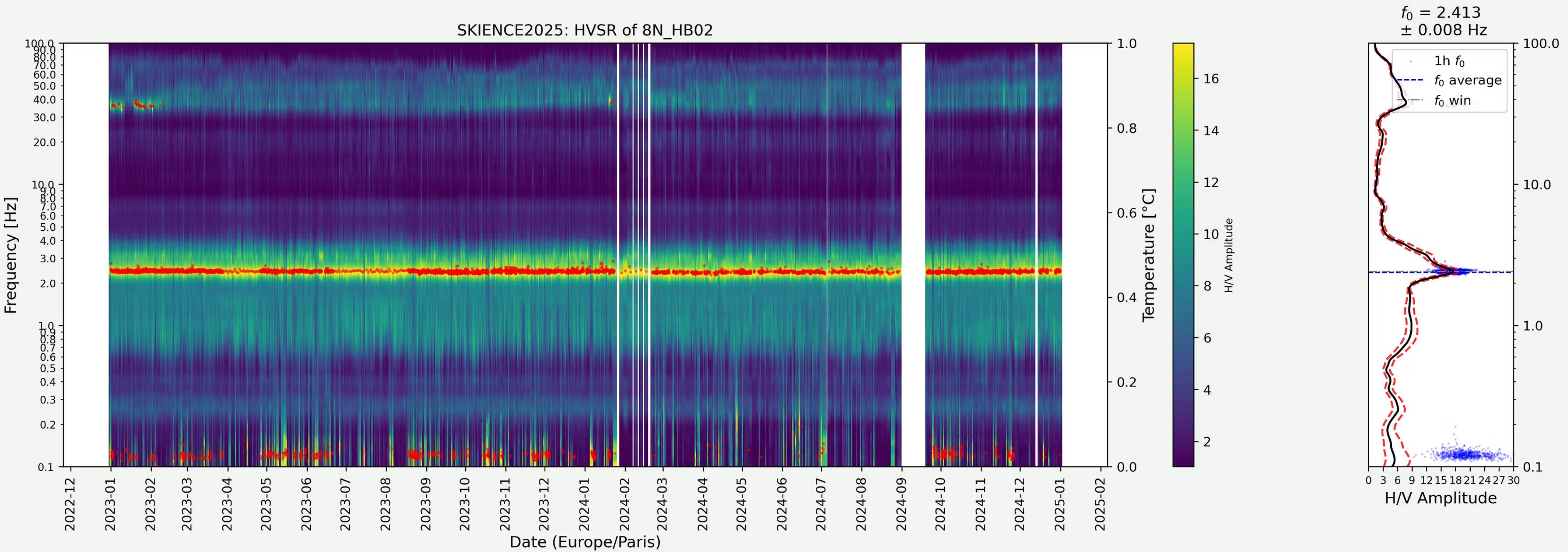
HB02 – Rooftop - 1 month



24 February 2025



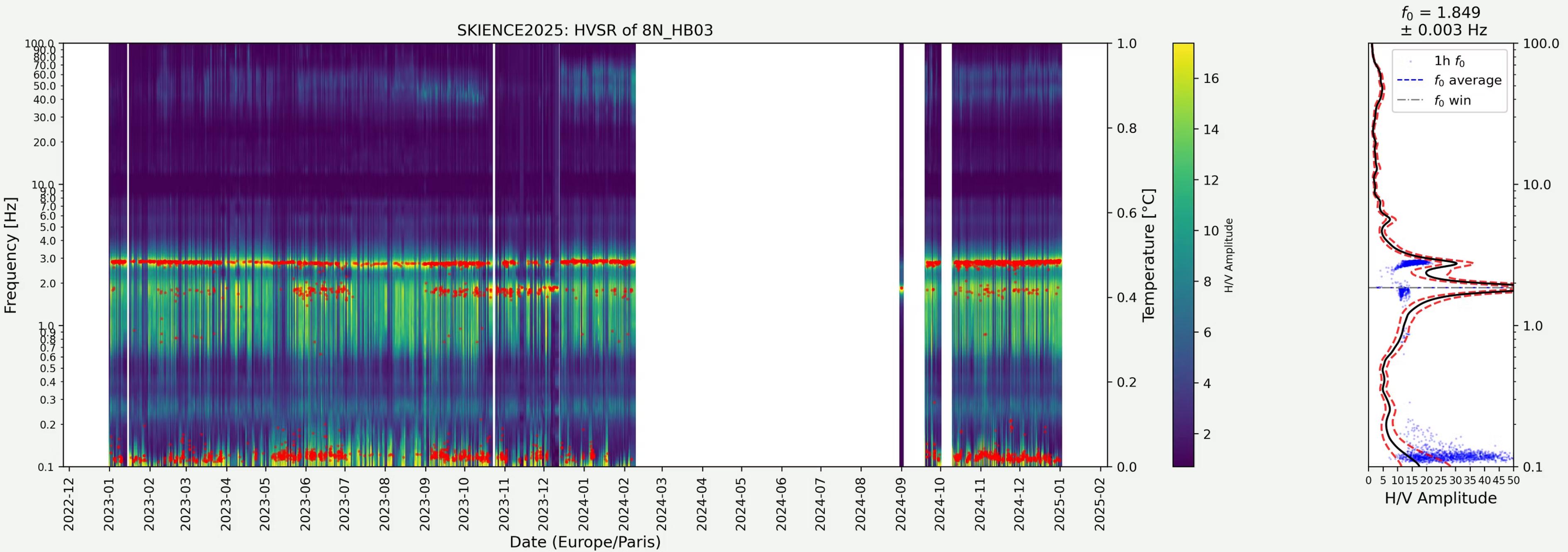
HB02 – Rooftop - 2 yr



24 February 2025



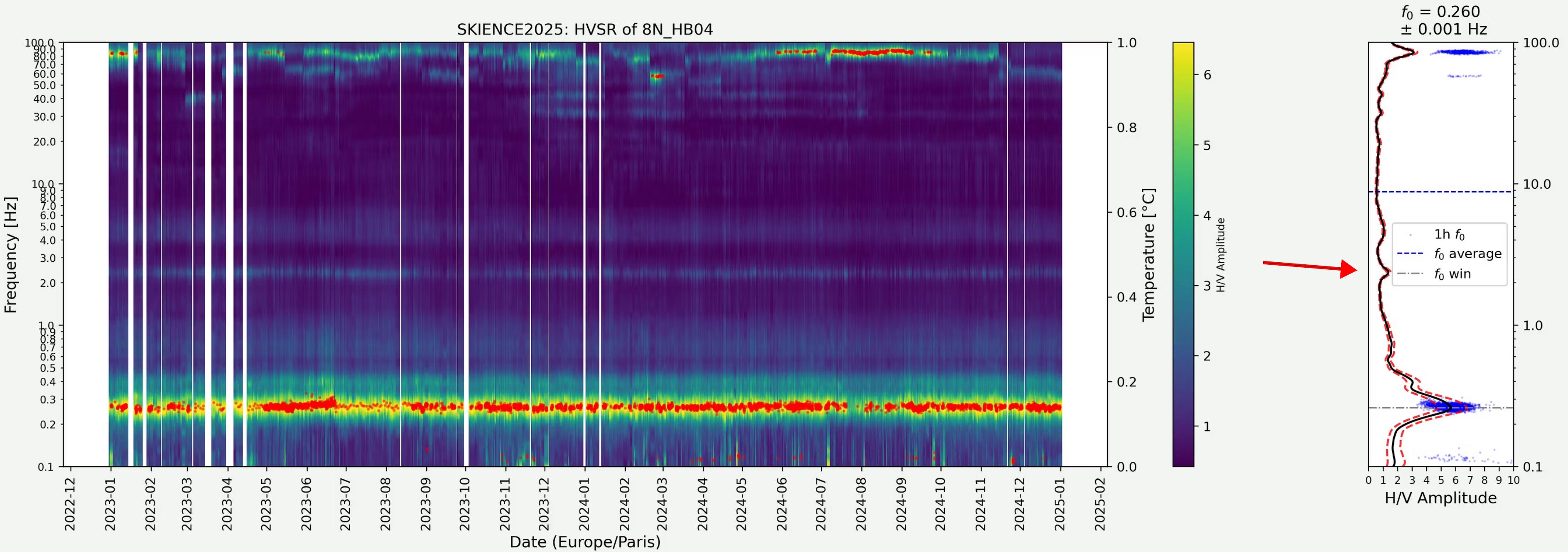
HB03 – Rooftop - 2 yr



24 February 2025



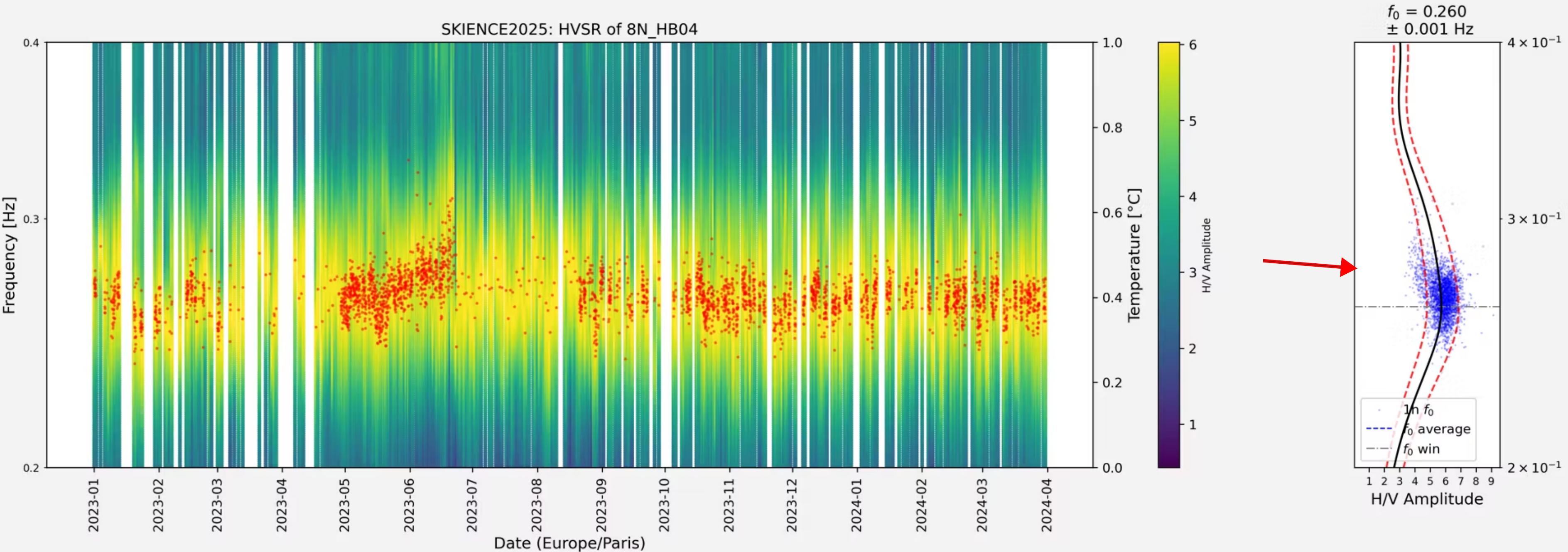
HB04 – Base - 2 yr



24 February 2025

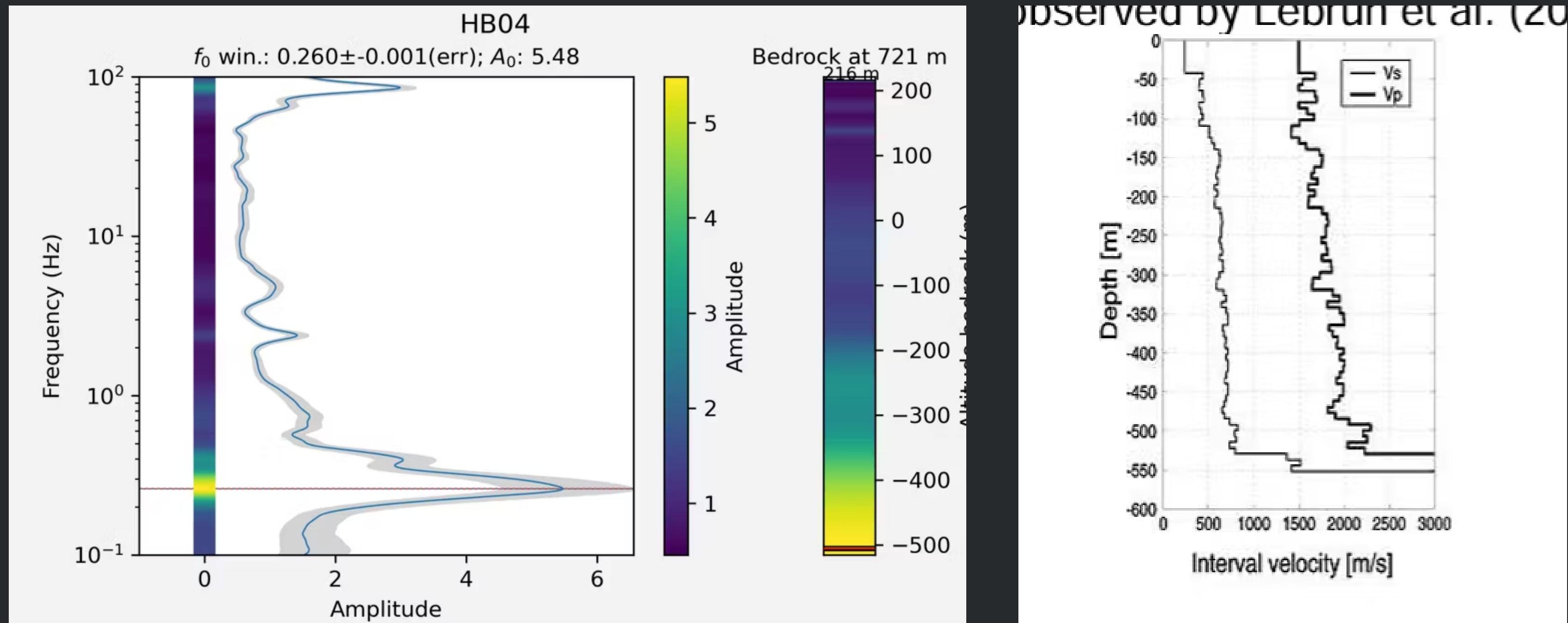


HB04 – Base - 2 yr



Virtual borehole – Fixed Vs 600 m/s

Lebrun et al. 2001





PRACTICALS

Part 2: Resonance is fun

Tutorial 11:
HVSR from PSDs
Spectral Ratios (~SSR)



Tutorial 11 results



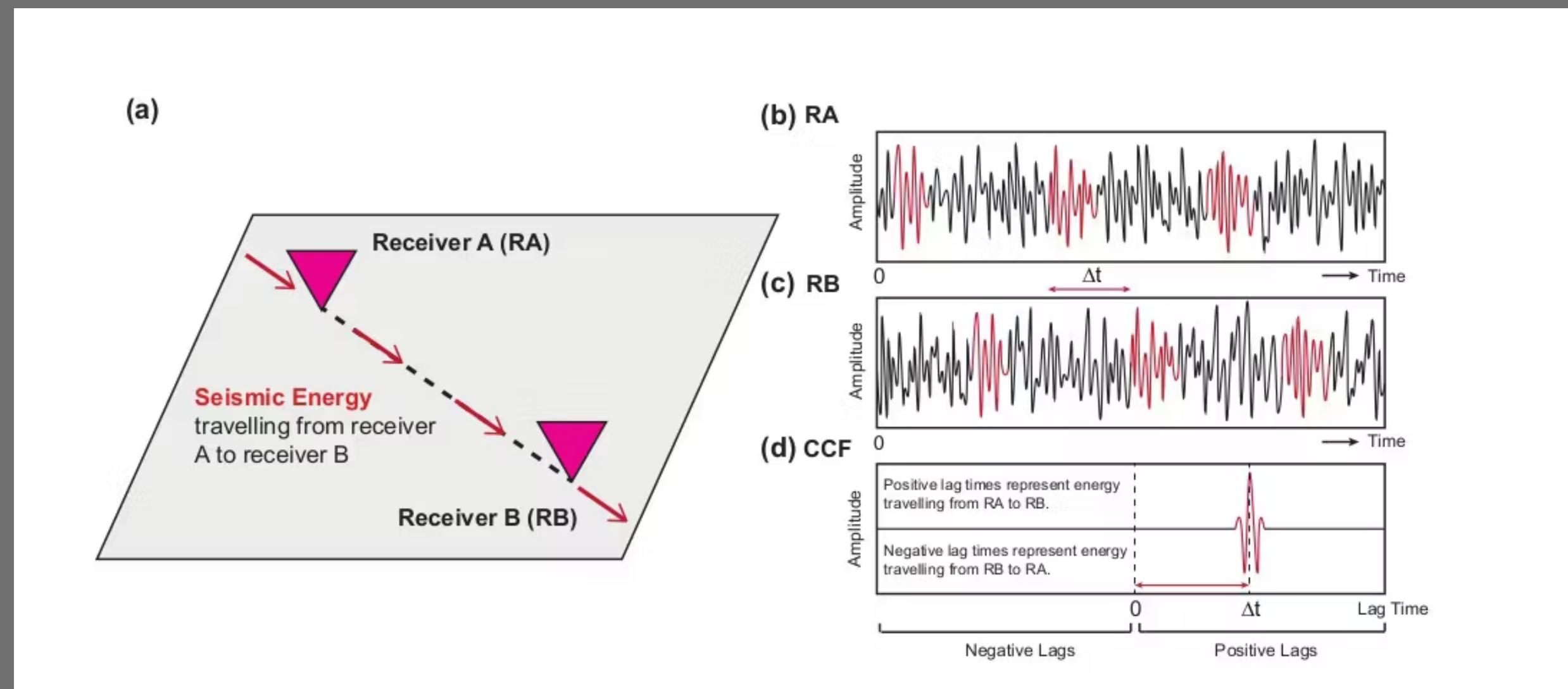
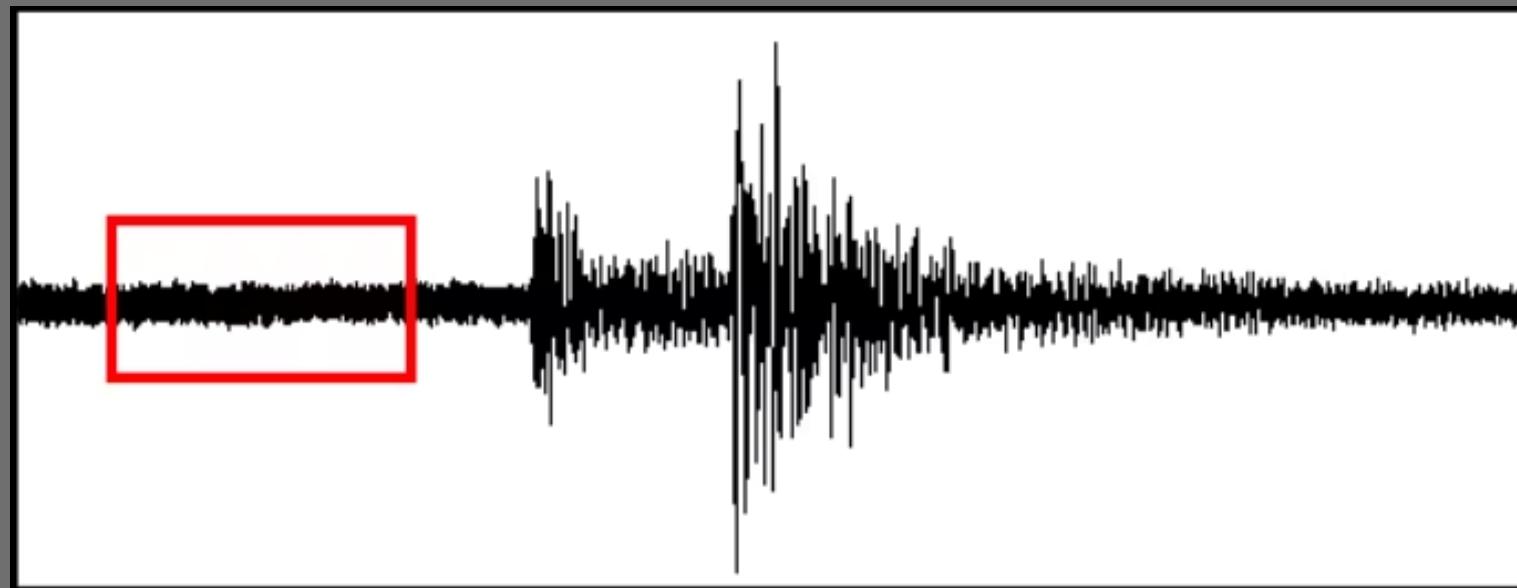
PART 3

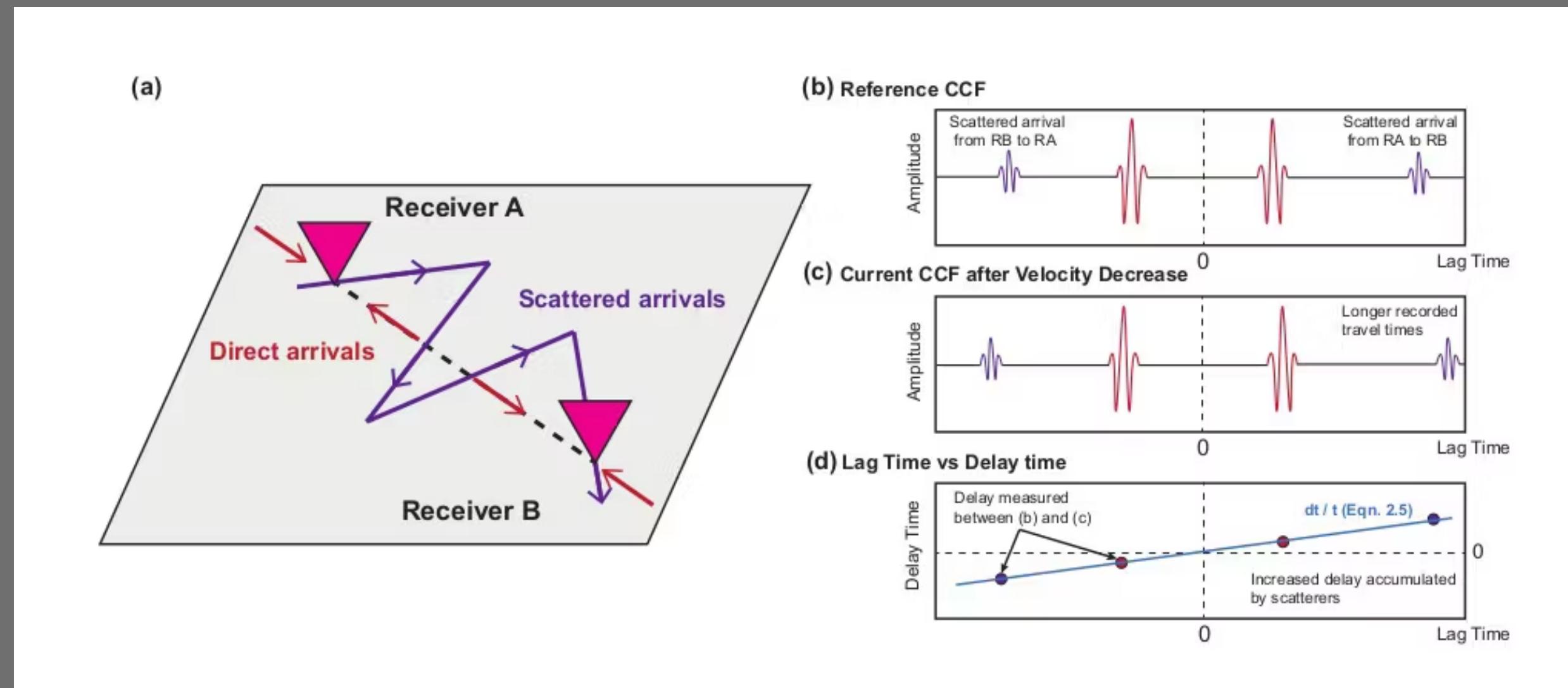
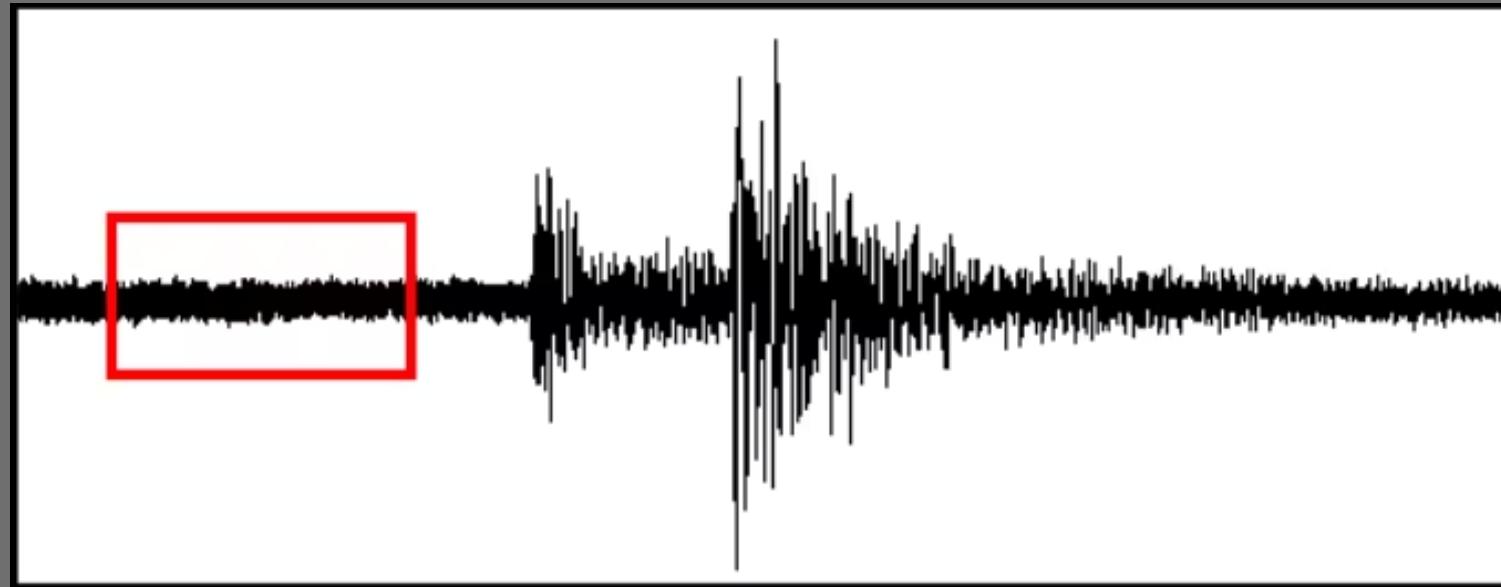
Interferometry

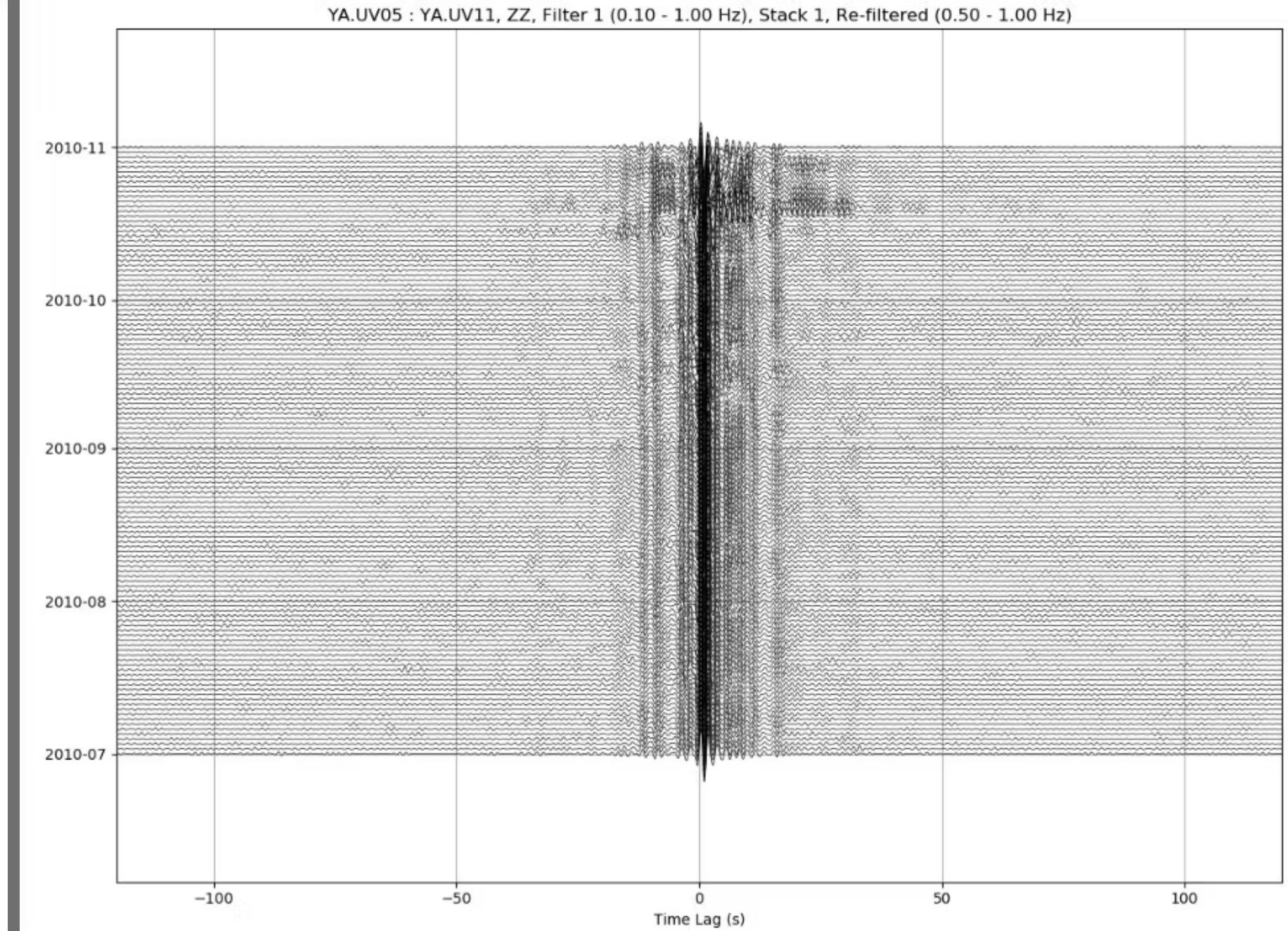
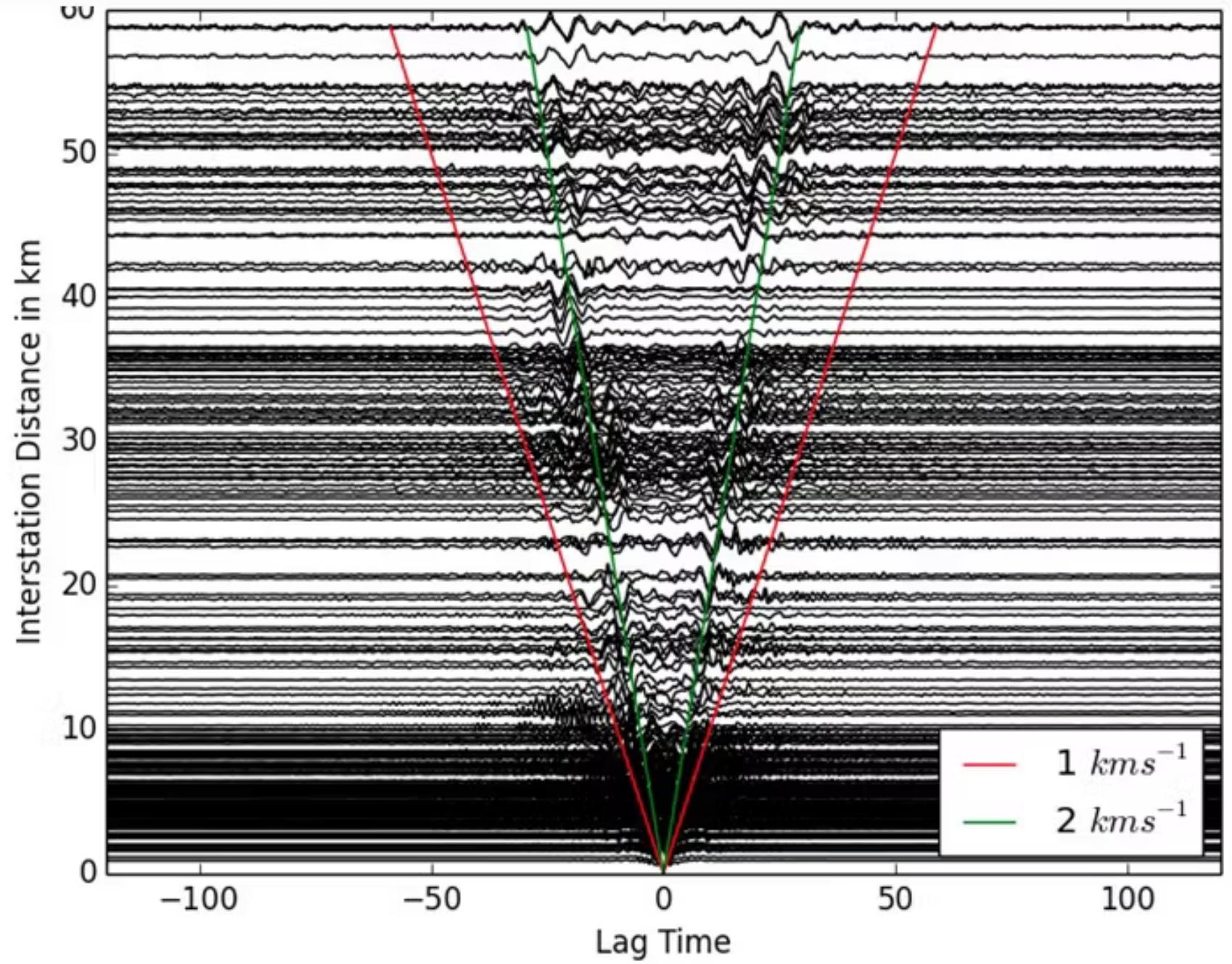
*Cross-correlation of seismic "noise"
"velocity" variations*

Interferometry Cross-Correlations





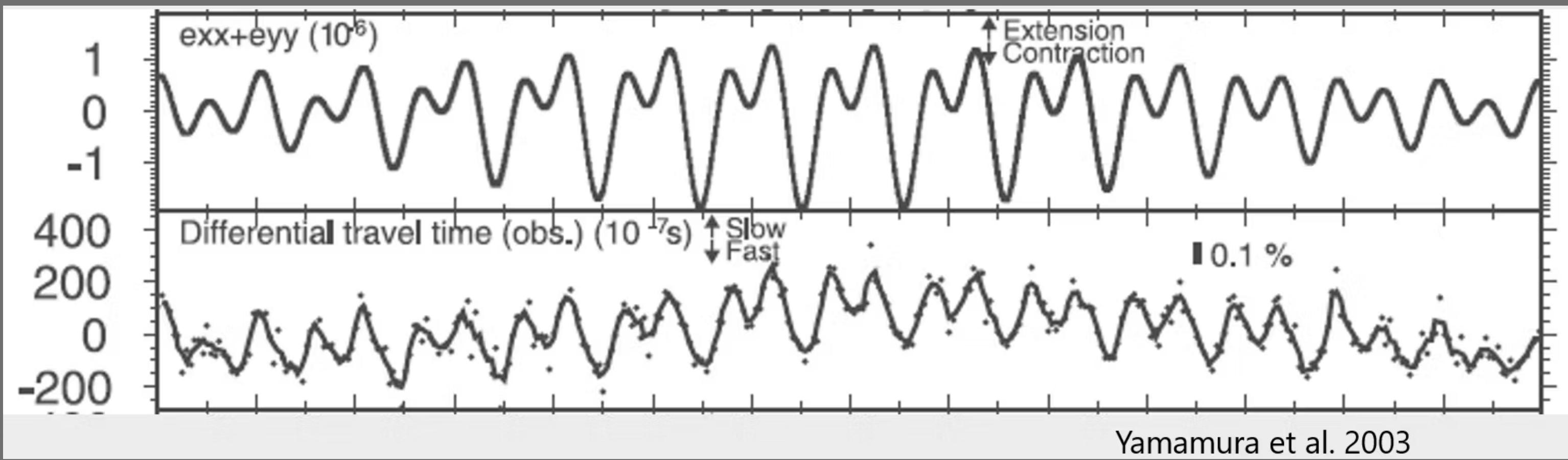




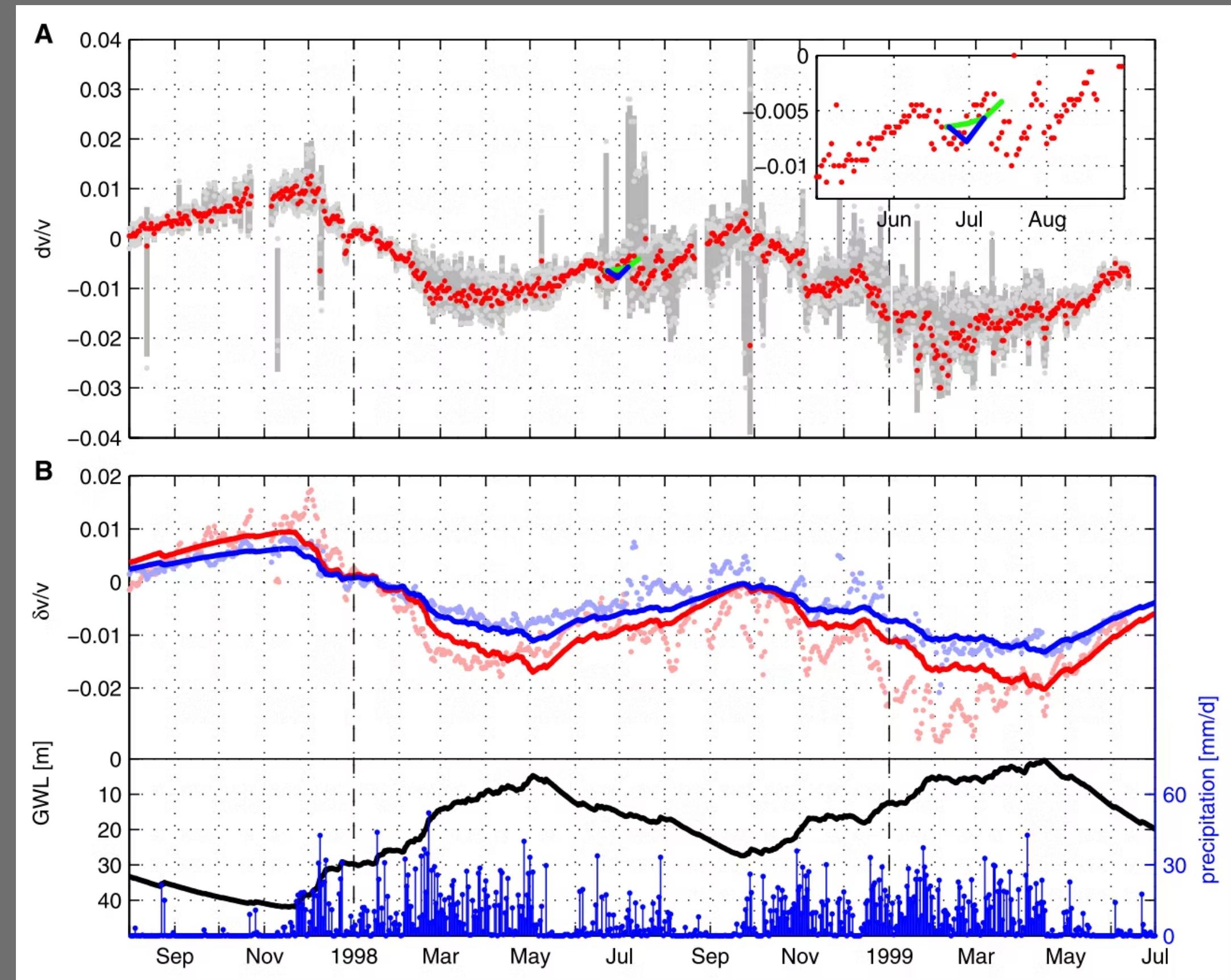
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CAN WE USE SEISMIC NOISE?

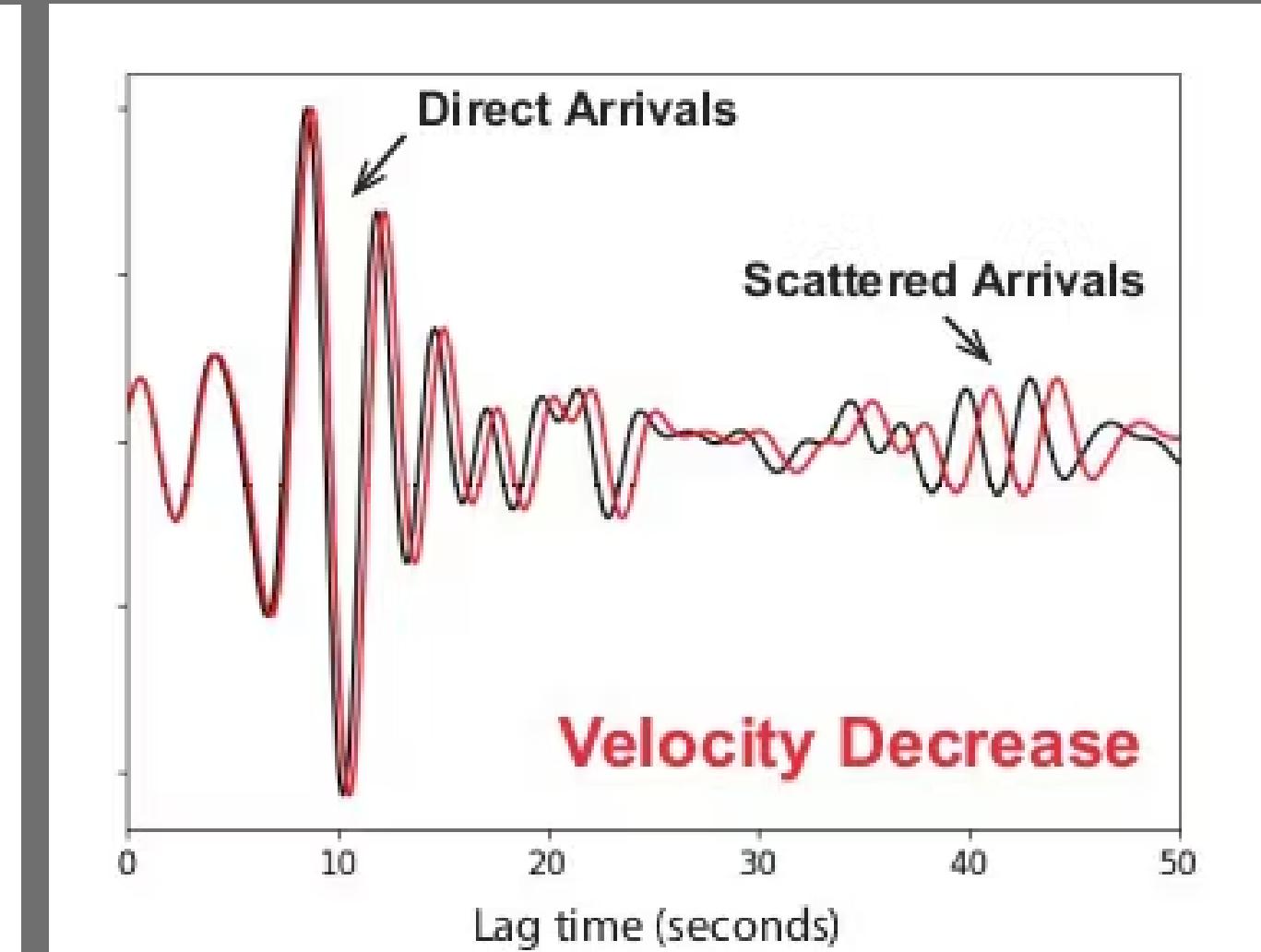
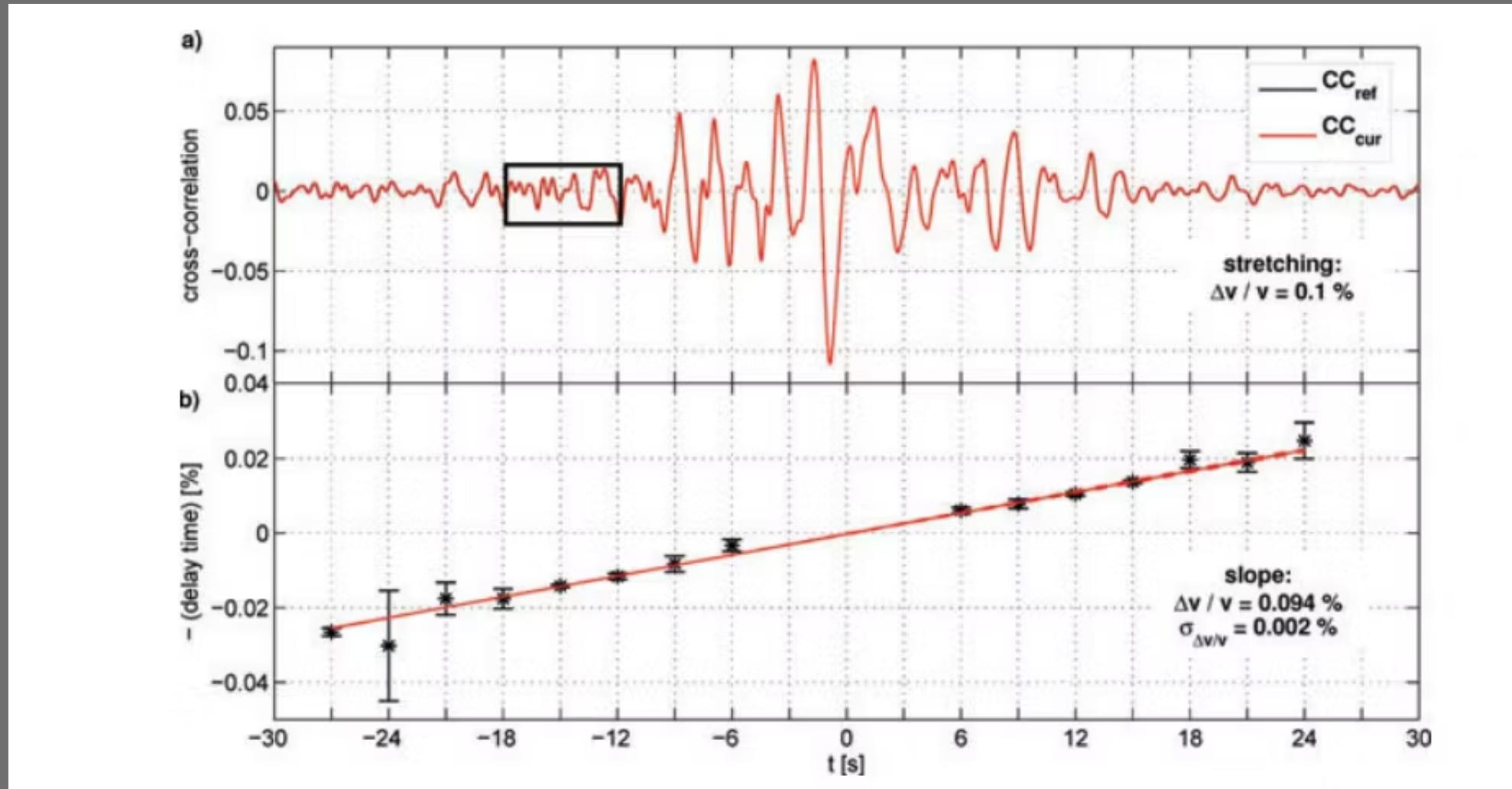
for monitoring or imaging the Earth

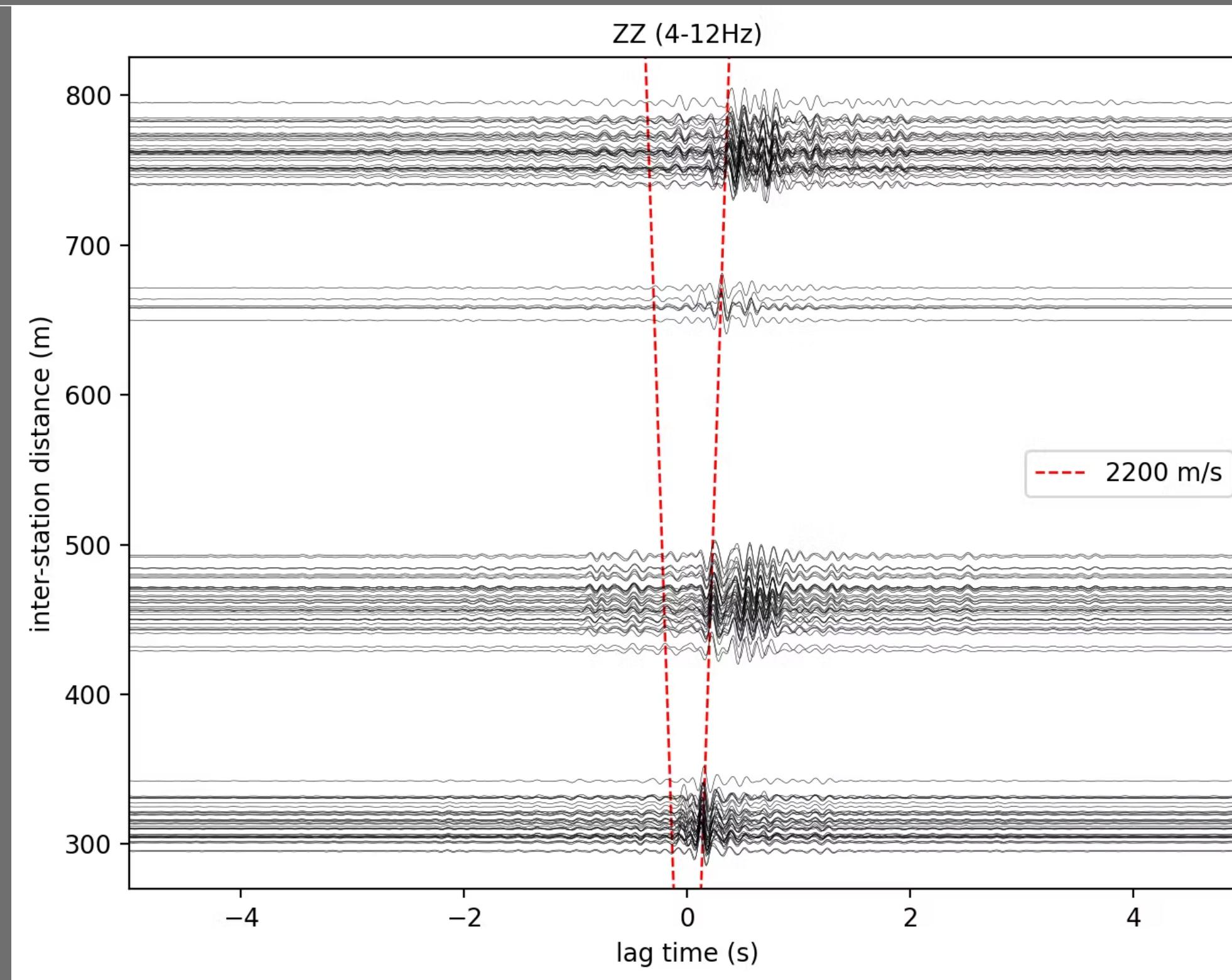


World's first



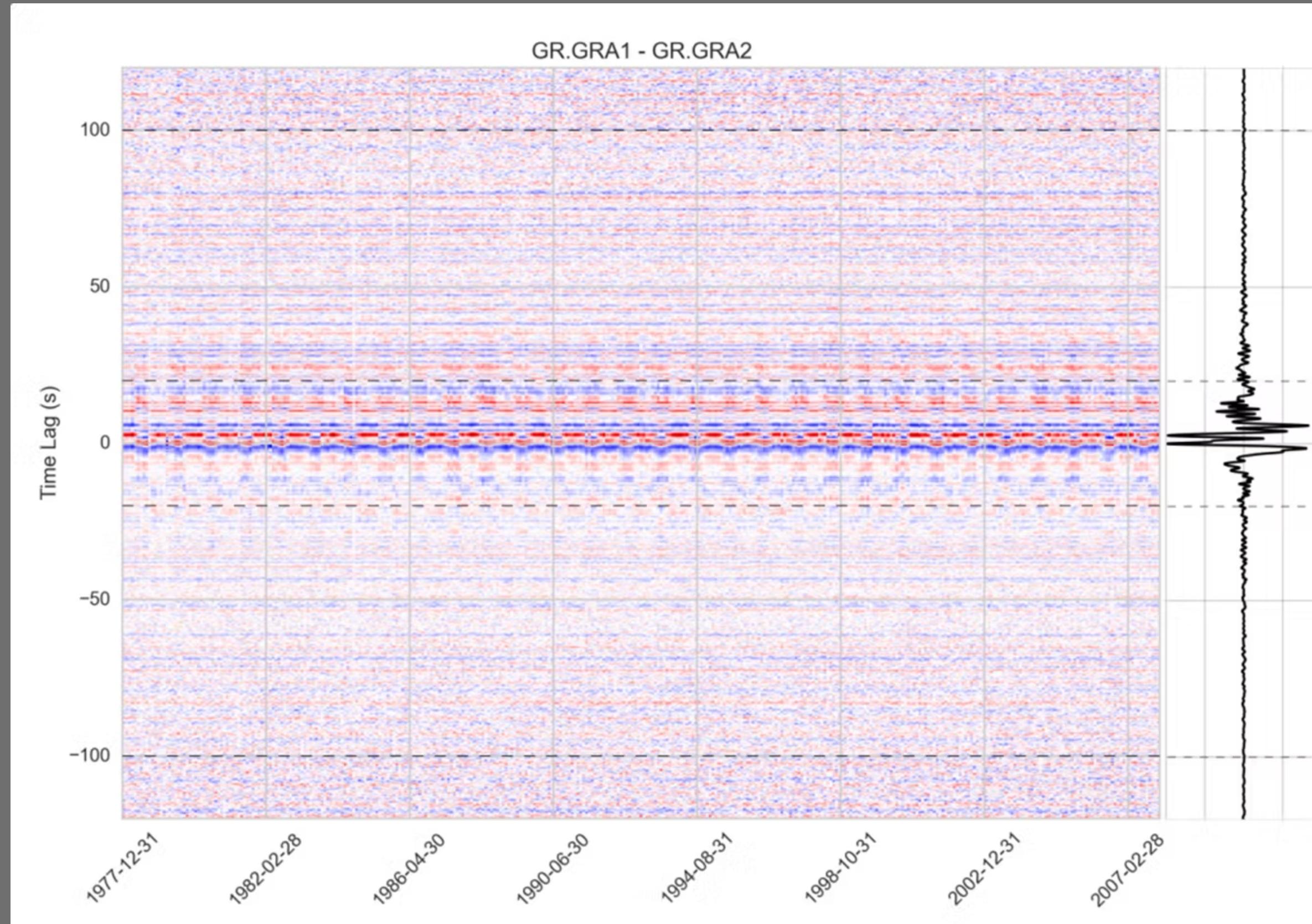
Comparing daily CCF to "a" reference



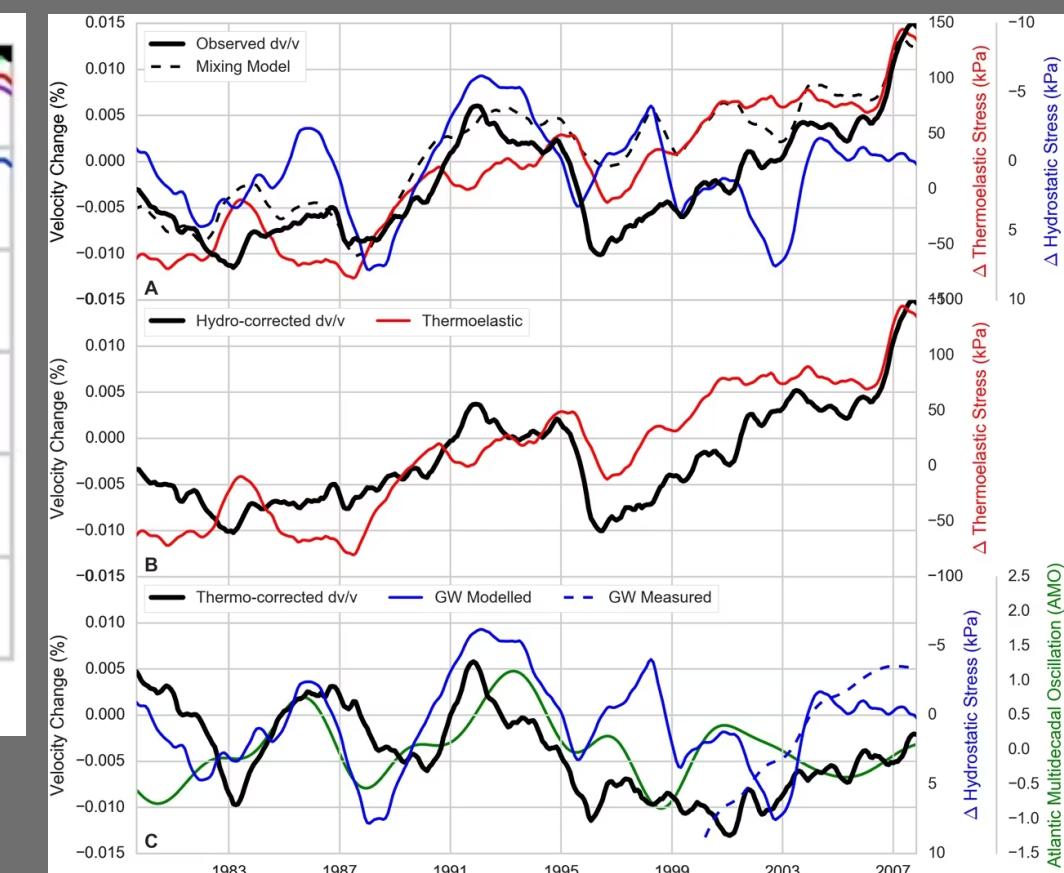
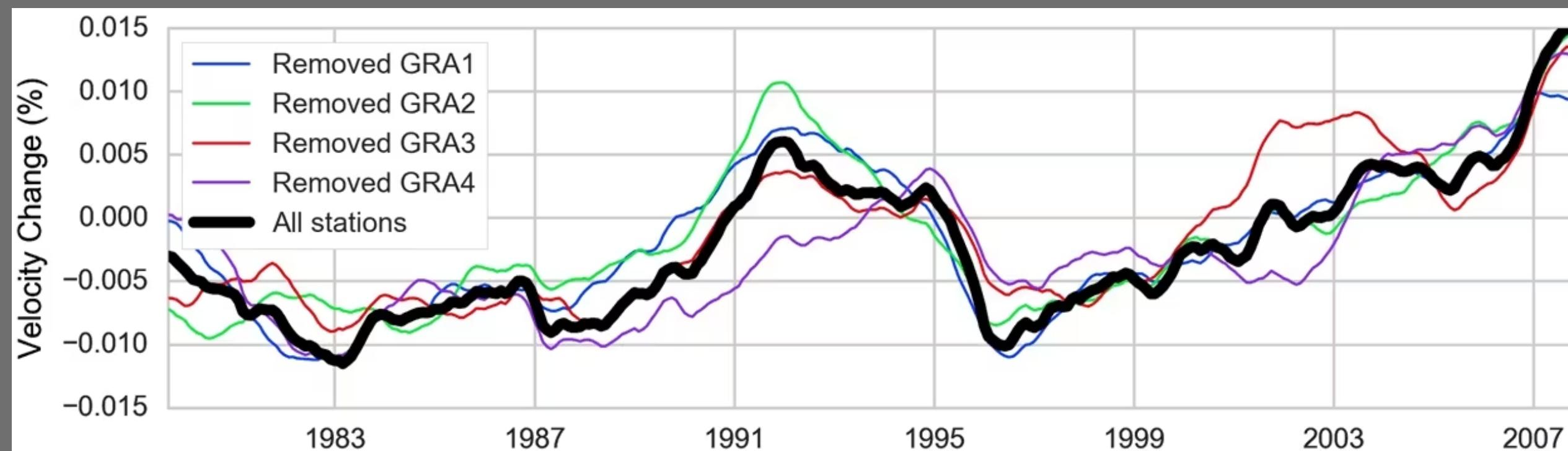
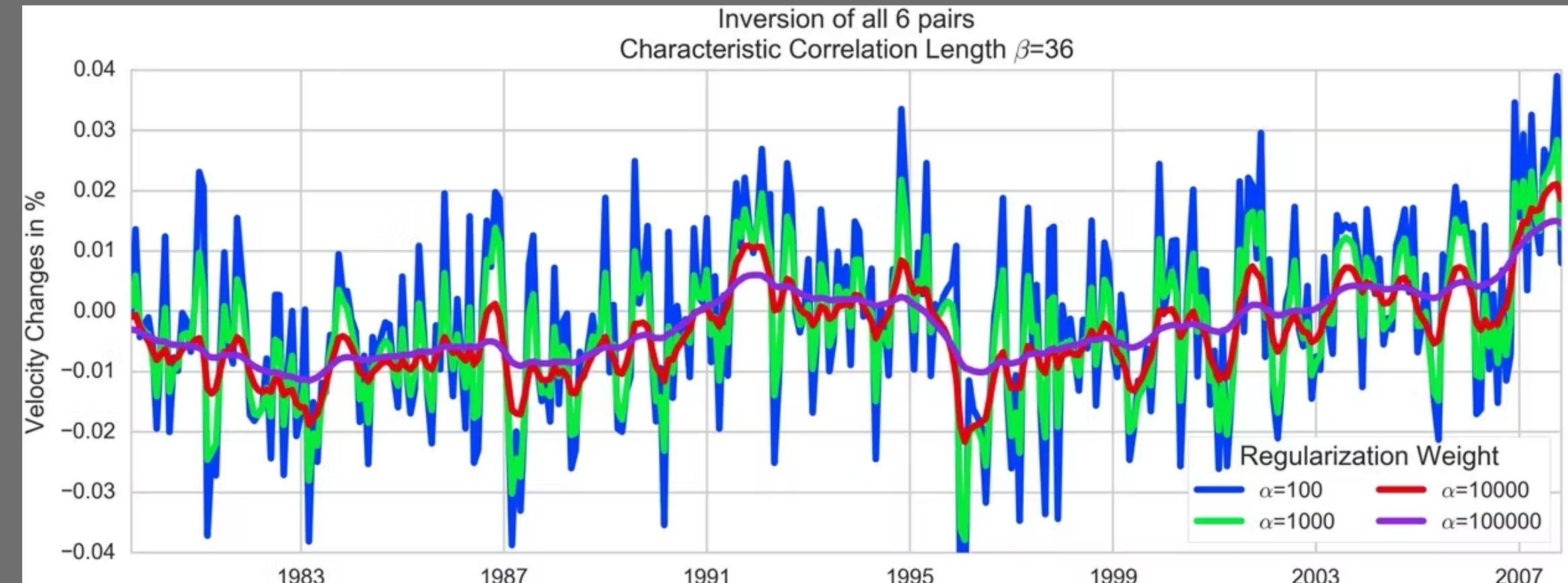
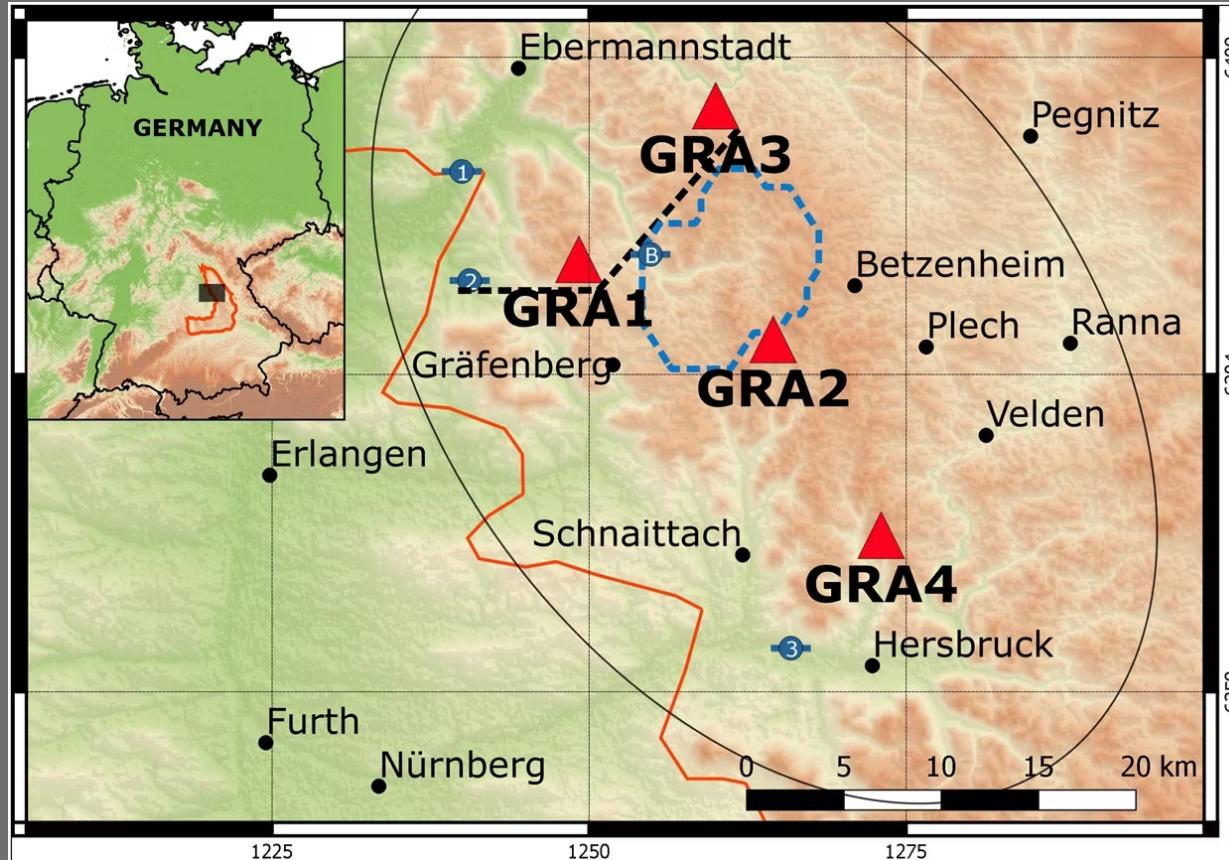


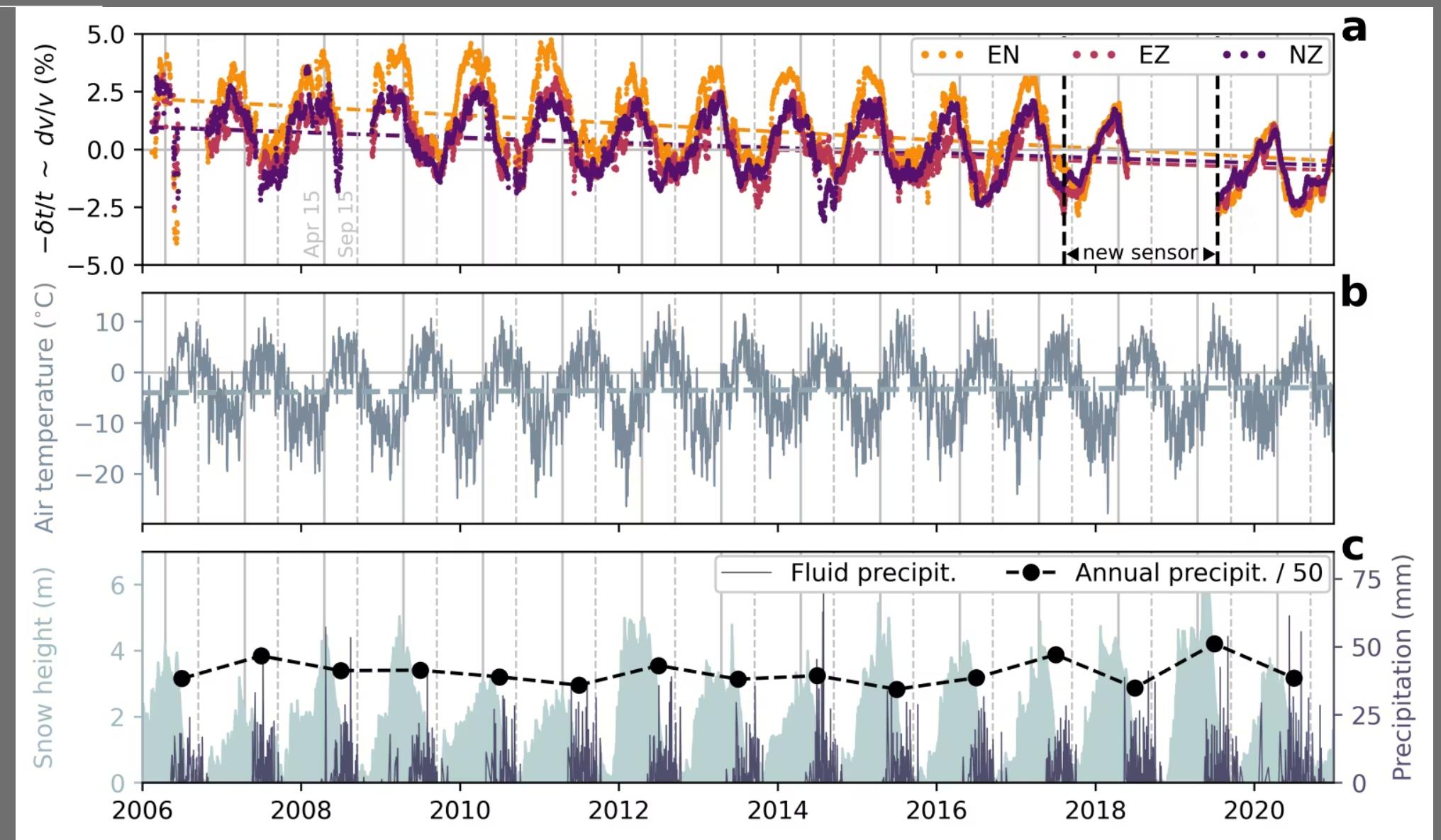
One-sided cross-correlations:
stationary anthropogenic
noise source

Stable in time

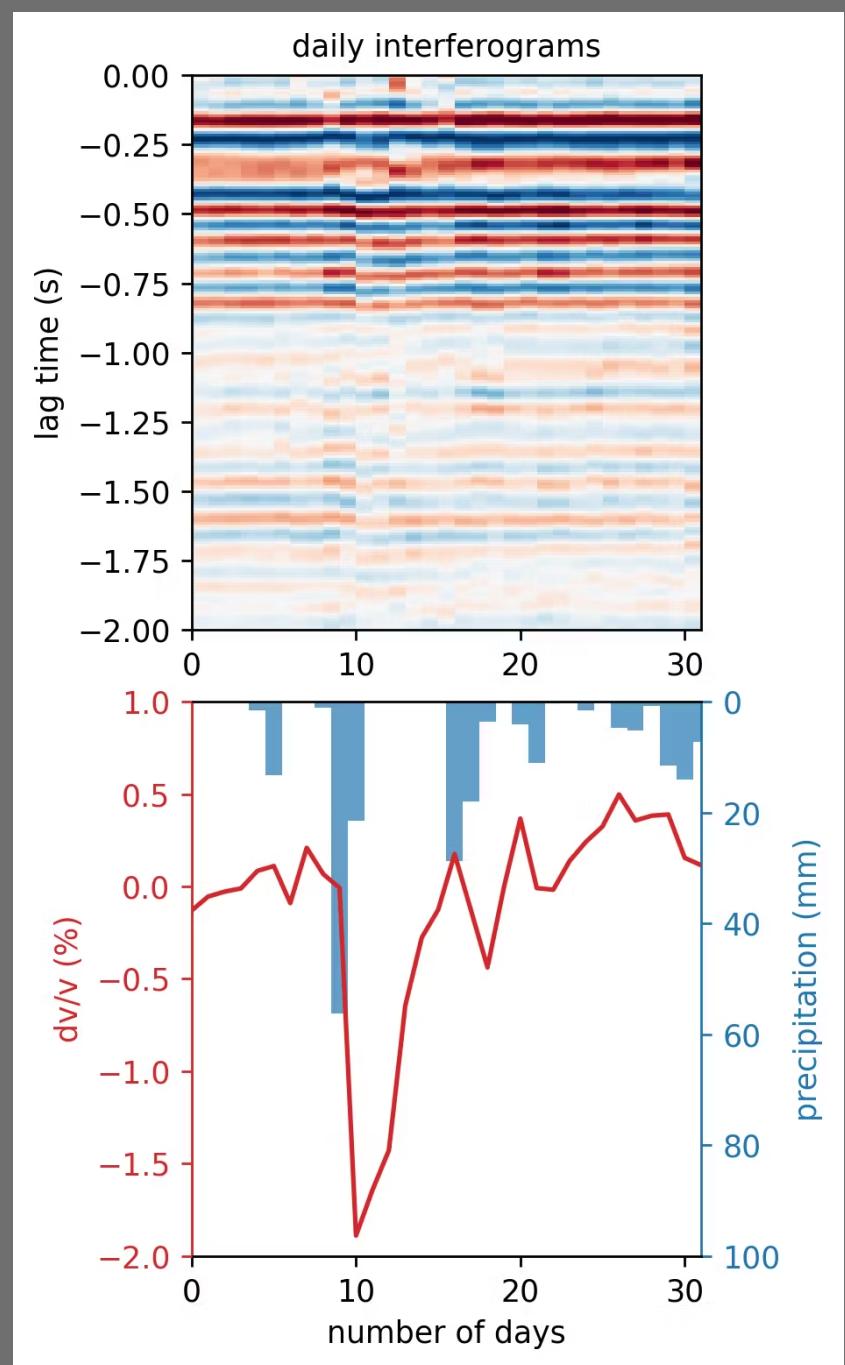


dv/v over 30 years



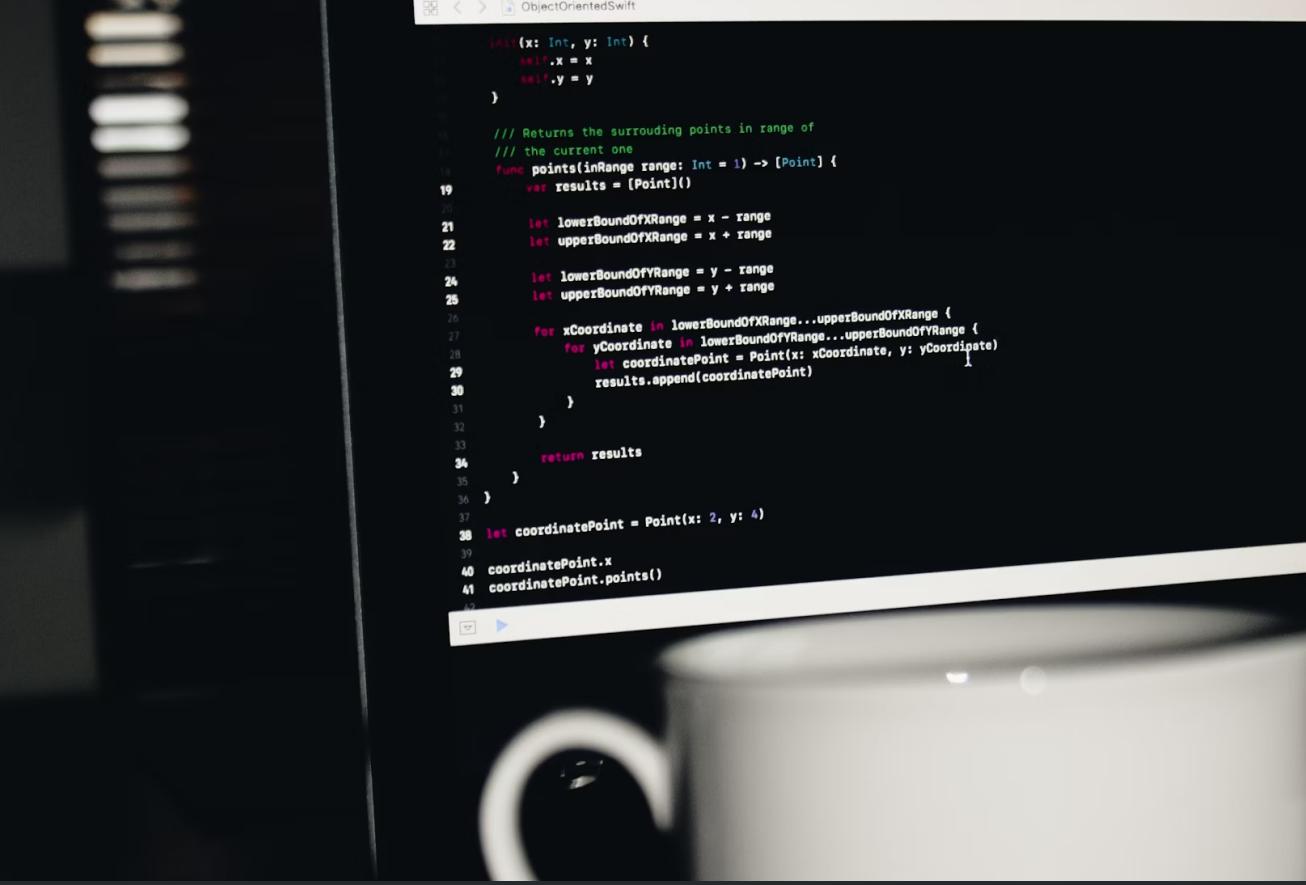


seasonal and long-term changes due to
freeze-thaw and permafrost degradation:
relevant for glacierized volcanoes



velocity change due to precipitation
(Lindner et al, in preparation)

MSNoise



Try Pitch

What is MSNoise

2010 - Today



Try Pitch

Pre 2010: Brenguier's work



After 2010: python :-)



MSNoise 2.0 Workflow

Initializing and Configuring a Project

Commands in this workflow have the `msnoise <command>` form.

- Project Initialization
 - Initialize Project
 - MSNoise Admin (Web Interface)
 - Populate Station Table
 - → Plot Station Map
 - Scan Archive
 - → Plot Data Availability
 - New Jobs

Cross-Correlation Functions

Commands in this workflow have the `msnoise cc <command>` form.

- Workflow: Cross-Correlation Functions
 - Compute Cross-Correlations
 - → Plot CCF vs Time
 - → Plot Interferograms
 - → Plot CCF's spectrum vs Time
 - Stack
 - → Plot REF stacks vs Distance

Computing Relative Velocity Variations

Commands in this workflow have the `msnoise cc dvv <command>` form.

- Workflow: Relative Velocity Variations
 - Compute MWCS
 - → Plot MWCS results
 - Compute dt/t
 - → Plot dv/v

Computing Power Spectral Densities (Quality Control)

Commands in this workflow have the `msnoise qc <command>` form.

- Workflow: Power Spectral Densities
 - Compute Power Spectral Densities
 - → Plot Power Spectral Densities

Cross-Correlation Workflow

Cross-Correlation Jobs

[Reset CC jobs "in progress"](#) [Reset all CC jobs](#) [Delete all CC jobs](#)

0 CC jobs in the database: 0 todo, 0 in progress and 0 done

Nan%

Stack Jobs

[Reset STACK jobs "in progress"](#) [Reset all STACK jobs](#) [Delete all STACK jobs](#)

0 STACK jobs in the database: 0 todo, 0 in progress and 0 done

Nan%

MWCS Jobs

[Reset MWCS jobs "in progress"](#) [Reset all MWCS jobs](#) [Delete all MWCS jobs](#)

0 MWCS jobs in the database: 0 todo, 0 in progress and 0 done

Nan%

Relative Travel Time Jobs

[Reset DTT jobs "in progress"](#) [Reset all DTT jobs](#) [Delete all DTT jobs](#)

0 DTT jobs in the database: 0 todo, 0 in progress and 0 done

Nan%

DV/V jobs

[Reset DVV jobs "in progress"](#) [Reset all DVV jobs](#) [Delete all DVV jobs](#)

0 DVV jobs in the database: 0 todo, 0 in progress and 0 done

Nan%

QC Workflow

Power Spectral Density Jobs

[Reset PSD jobs "in progress"](#) [Reset all PSD jobs](#) [Delete all PSD jobs](#)

0 PSD jobs in the database: 0 todo, 0 in progress and 0 done

Nan%

PSD to HDF

[Reset PSD2HDF jobs "in progress"](#) [Reset all PSD2HDF jobs](#) [Delete all PSD2HDF jobs](#)

0 PSD2HDF jobs in the database: 0 todo, 0 in progress and 0 done

Nan%

HDF to RMS

[Reset HDF2RMS jobs "in progress"](#) [Reset all HDF2RMS jobs](#) [Delete all HDF2RMS jobs](#)

0 HDF2RMS jobs in the database: 0 todo, 0 in progress and 0 done

Nan%



PRACTICALS

Part 3: Noise is Data

Tutorials 91 & 92



PART 4

Bonus

Comparing HVSR from geopsy, PSDs & CCFs



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