Detection of the deep cavern at the Felsőpetény, Hungary site using seismic ambient noise data

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Outline

description of a site

noise measurements

data processing

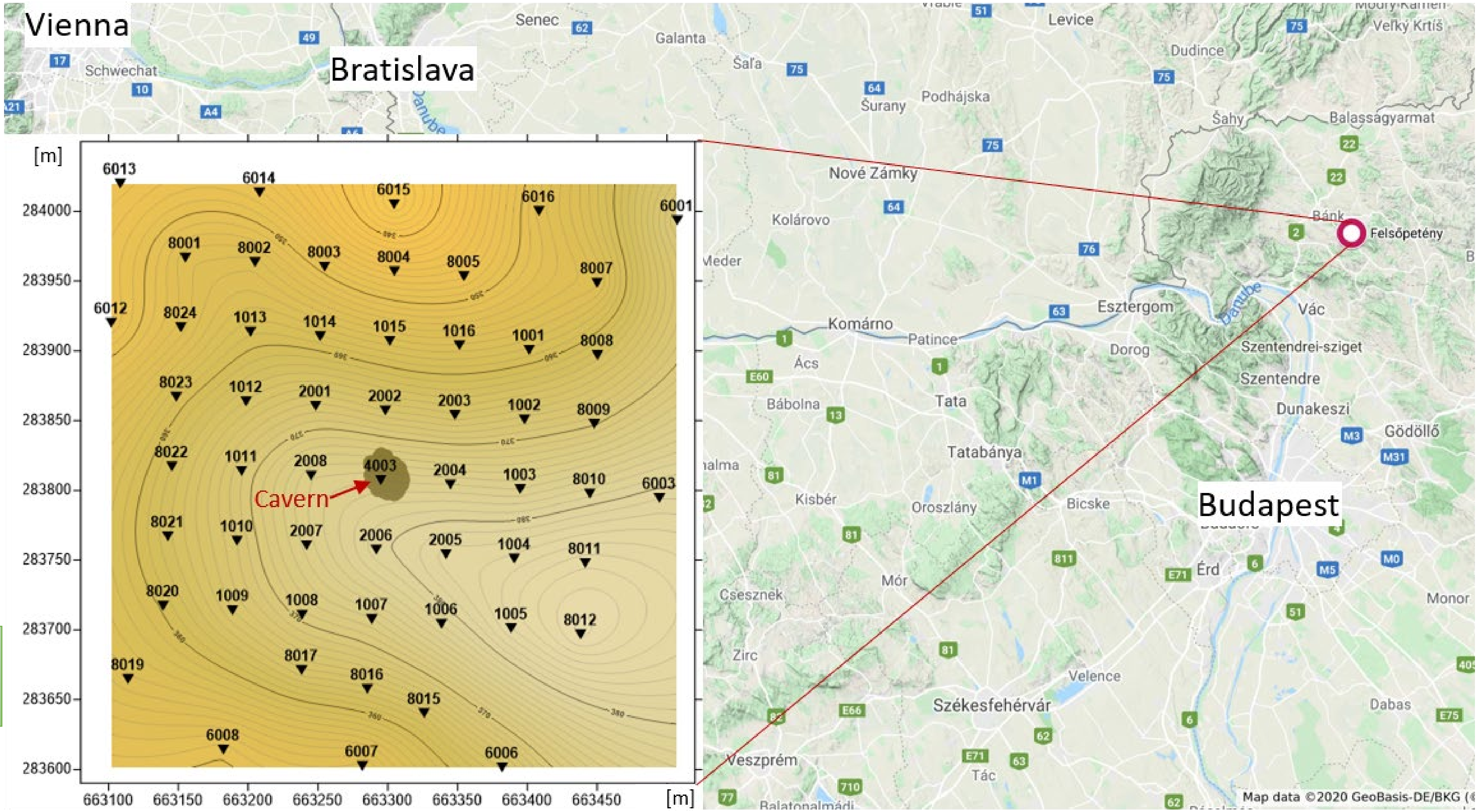
results

conclusions

Description of a Site

The team of experts
participating at the field test
performed
extensive geophysical measurements
in the area near the small village of
Felsőpetény, Hungary, in 2019

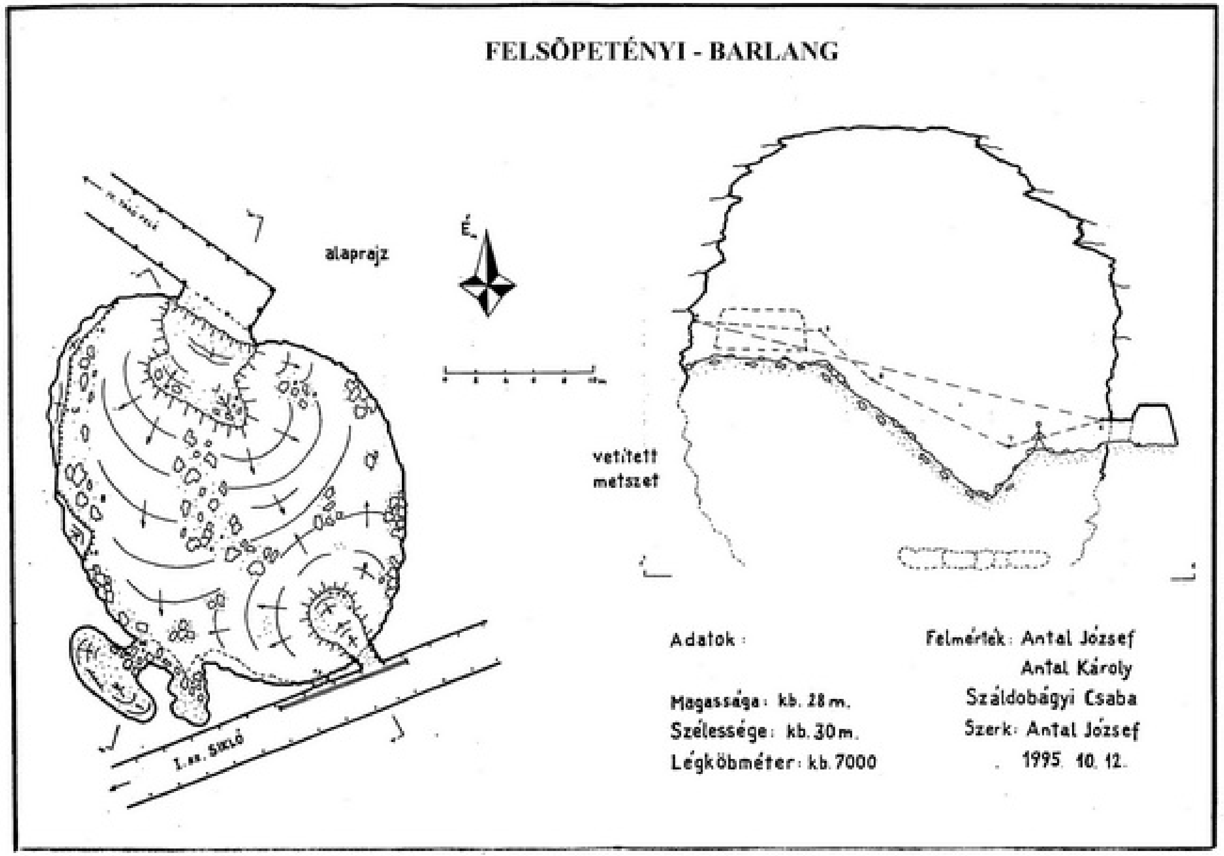
The goal
of the active and passive experiments
was to develop a geotechnical model
of the site
and
to investigate the effect of the cavern
on the measured geophysical fields.



Our goal was to identify horizontal cavity position based on seismic ambient noise wavefield recorded on ground surface

Description of a Site

The reason for selecting this site
was a known oval cavern
with a horizontal diameter of 28-30 m,
height of 25-28 m, and
ceiling located approximately 70 m
below the free surface.



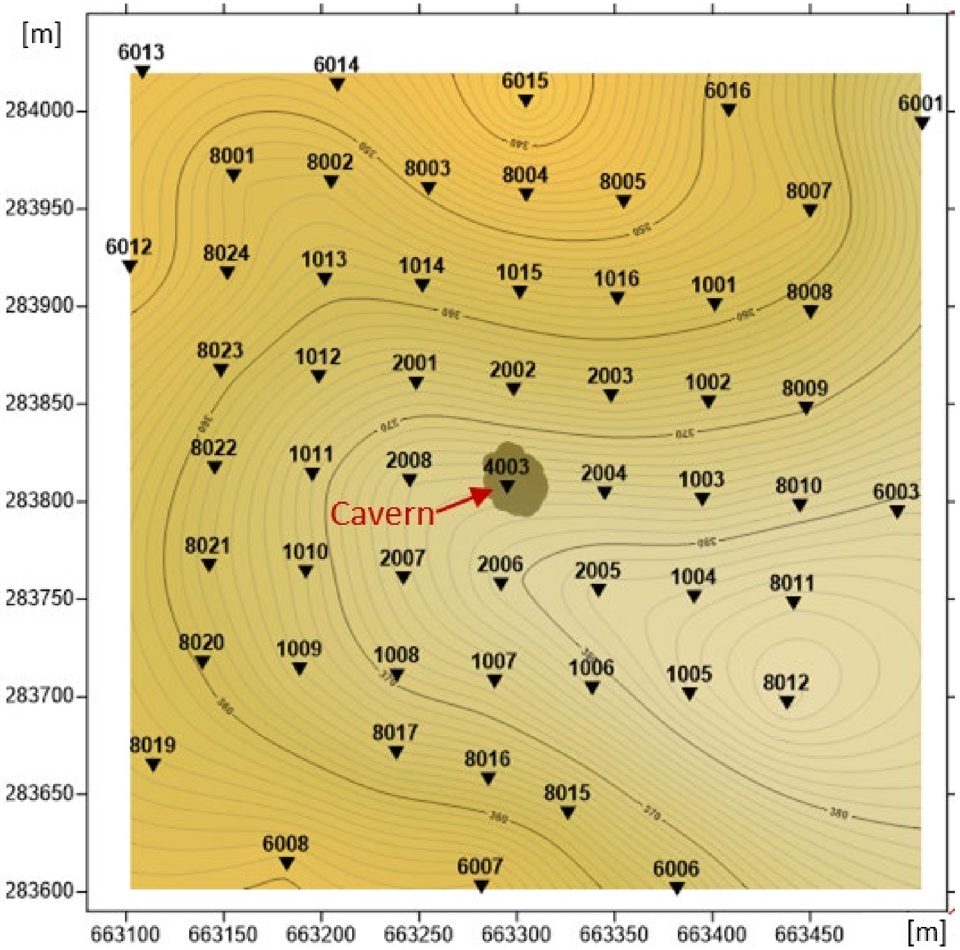
http://www.termeszetvedelem.hu/index.php?pg=cave_5222-3

Description of a Site

We were provided with continuous records of noise
at 55 measurement points in the area of interest.

The area (approximately 400 m x 450 m)
covered by the measurement points
is approximately centred at the horizontal position of the cavern.
The interstation distance is approximately 50 m.

We assume that the size of the area
is sufficient with respect to the size of the cavern.



Noise Measurements

Ambient noise was recorded continuously for almost 7 days, September 11-18, 2019.

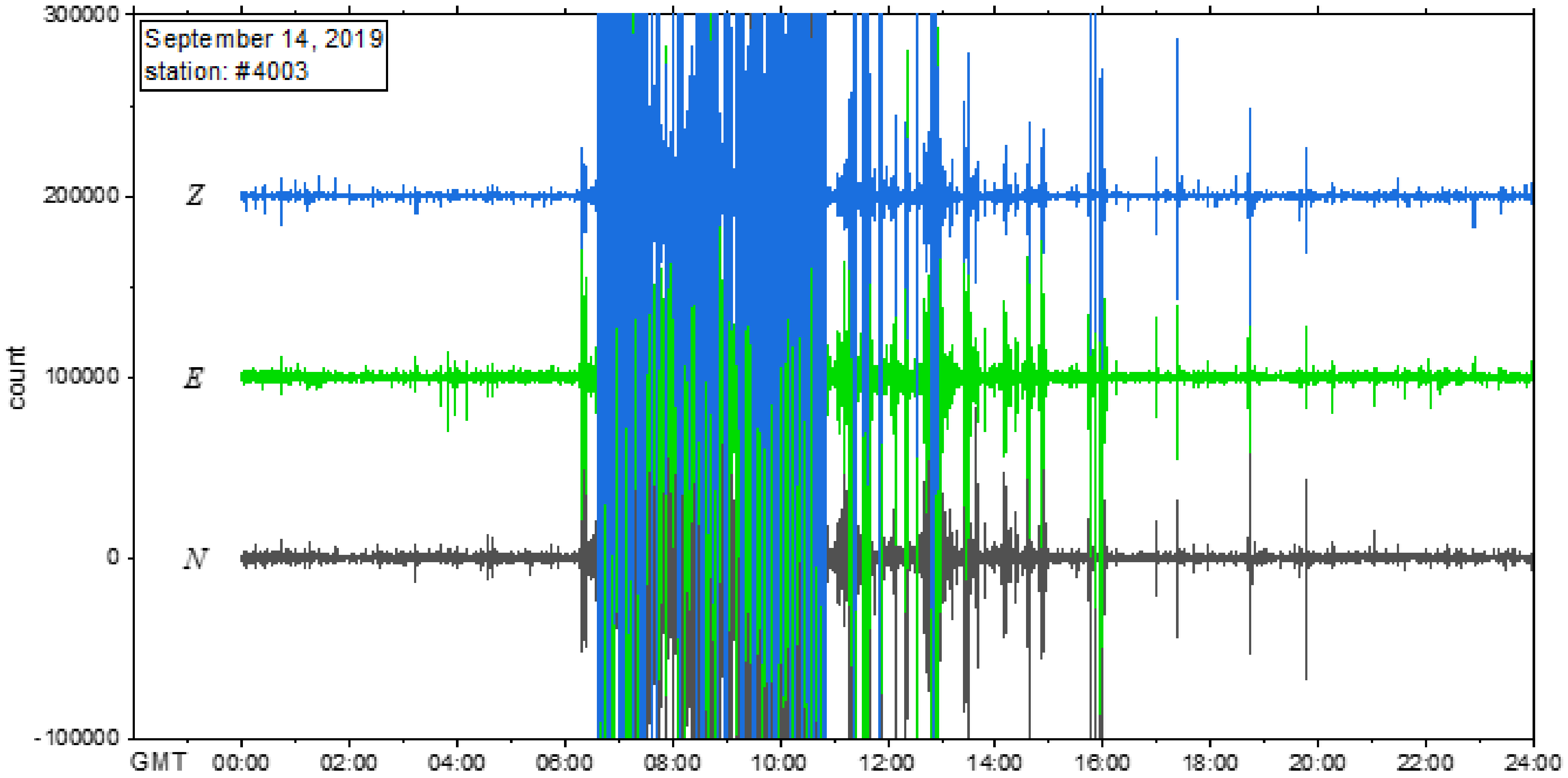
Thus, the records include noise during days and nights, workdays and holidays.

Lennartz LE3D light seismometers with sampling frequency 500 Hz were used.

The usable data are in the frequency range [0.5, 80] Hz.

The figure shows a continuous 24h record at the measurement point 4003. Transients and day-night variation of noise are clearly visible.

(large amplitudes are clipped)



Noise Measurements

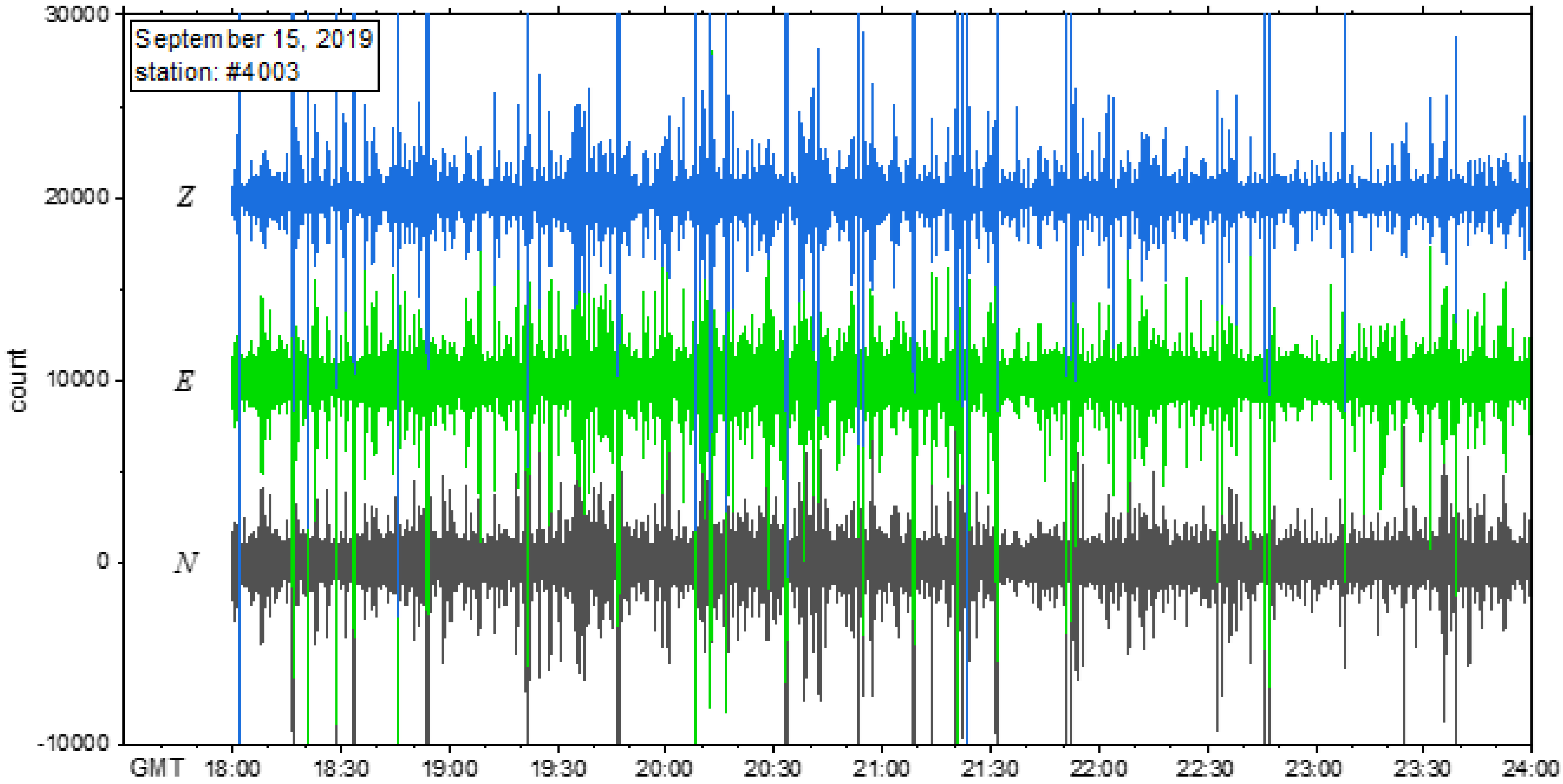
The record during the workday
is distorted by strong transients.

It is reasonable to use
a sufficiently long-time window
of quieter part of data,
i.e. of the night record.

We selected a 6h window
from 6h pm (Saturday) until midnight
as a suitable window
for all measurement points.

The selected time window
is shown in the figure.

(large amplitudes are clipped)



Data Processing

It was necessary to **carefully check quality of data**

and remove bad stations

(i.e., containing some parasitic signals of anthropogenic origin

or due to technical problems)

It was also necessary to check and **exclude**

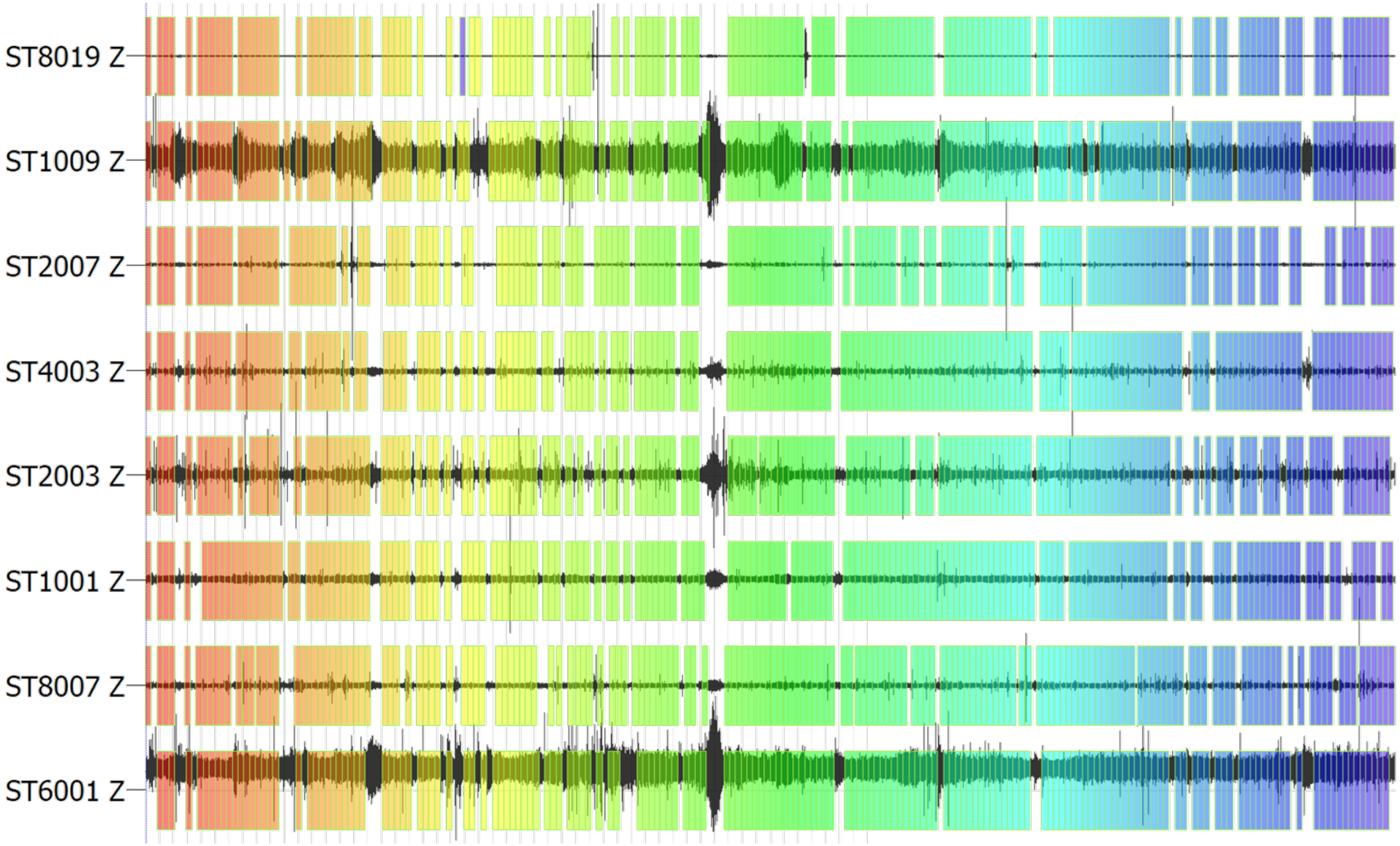
strong short-time anthropogenic noise (e.g. **transients**)

from the later processing

Data Processing

We divided the 6h window
into 863 50-second overlapping segments
and
removed those segments
containing
strong short-time anthropogenic noise
(e.g. transients)

Figure shows an example
of manually selected segments
using **`geopsy`** software



Data Processing

From selected time segments
we calculated power spectral density (PSD)
of each component
as a geometric mean of power spectra
of all selected time segments

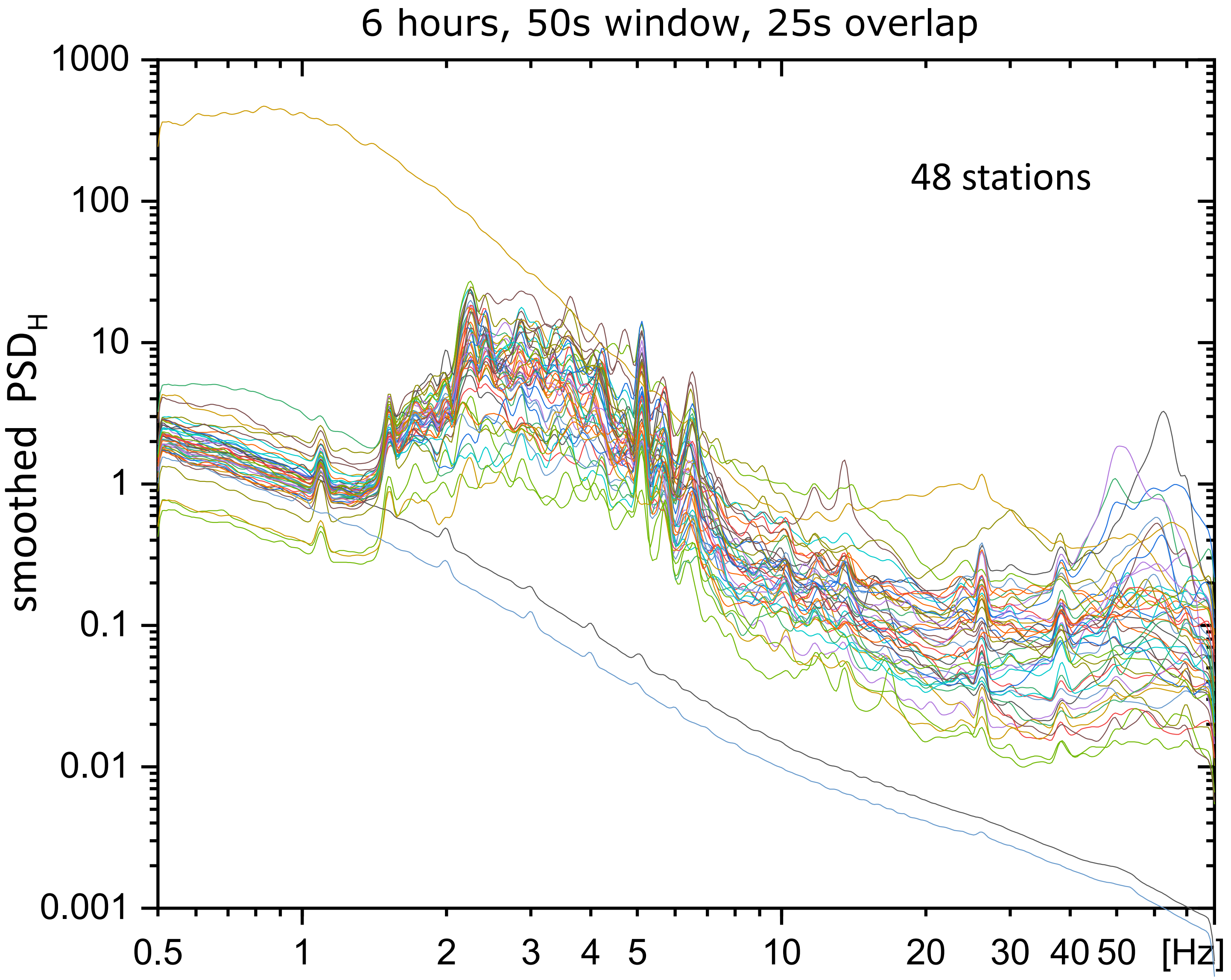
Further we used vertical component PSD_Z
and
a resultant horizontal component PSD_H
(instead of two individual horizontal components).

As in many other noise analyses,
it was necessary to smooth the obtained power-spectral densities,
e.g. using Konno-Ohmachi (1998) smoothing function

$$KO(f, f_c) = \left\{ \frac{\sin\left[b \log_{10}\left(f/f_c\right)\right]}{b \log_{10}\left(f/f_c\right)} \right\}^4$$

Data Processing

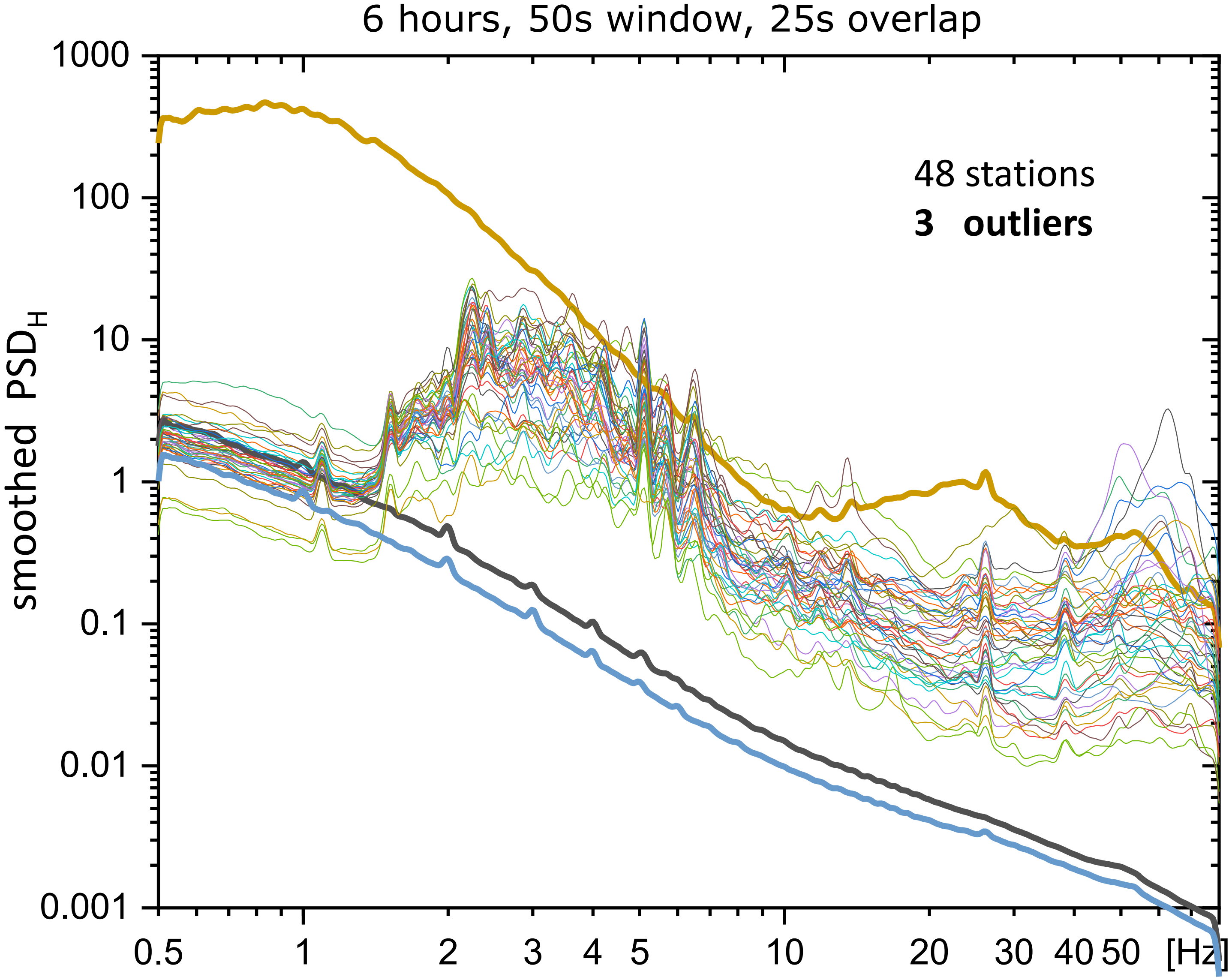
Figure shows smoothed PSD_H
for all stations as a function of frequency



Data Processing

Figure shows smoothed PSD_H
for all stations as a function of frequency

we identify evident outliers
among stations
(bold lines)
and
remove those stations
from the next processing

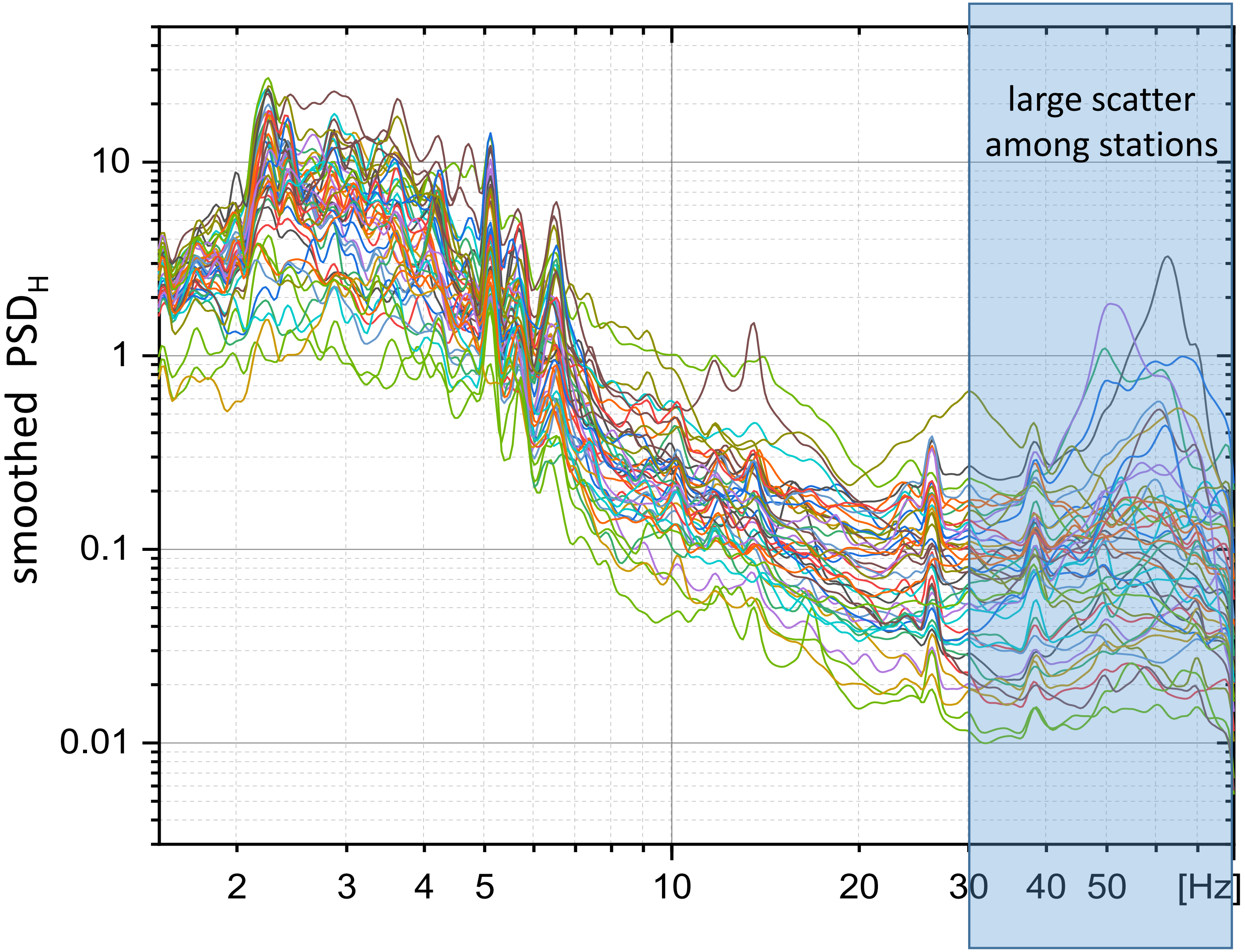


Data Processing

PSD_H above 30 Hz are more scattered than those inside the interval [1, 30] Hz.

PSD_H at higher frequencies are likely considerably affected by heterogeneities smaller than the cavity.

Looking at frequencies less than 30 Hz we can see that in the interval [approx. 5, 30] Hz there are several curves that differ from majority. This could be the potential effect of cavity.



Data Processing

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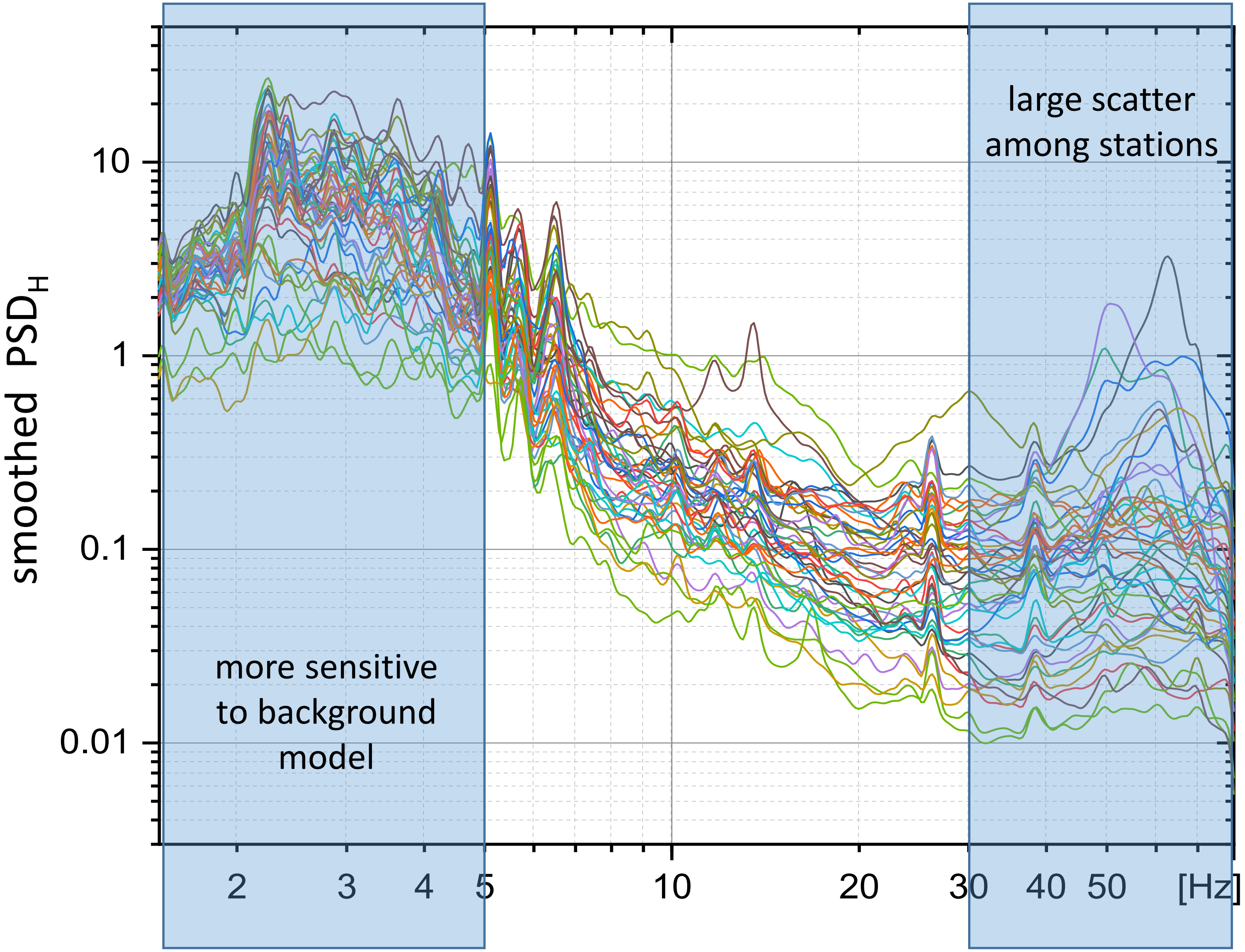
Looking at frequencies less than 30 Hz we can see that in the interval [approx. 5, 30] Hz there are several curves that differ from majority. This could be the potential effect of cavity.

PSD_H below 5 Hz could be more affected by medium much larger than the cavity and therefore the potential effects of cavity can be masked by the variability of surrounding medium.



Data Processing

Therefore, we selected
frequency interval [5, 30] Hz for calculating
finite-interval spectral power (FISP)
defined as

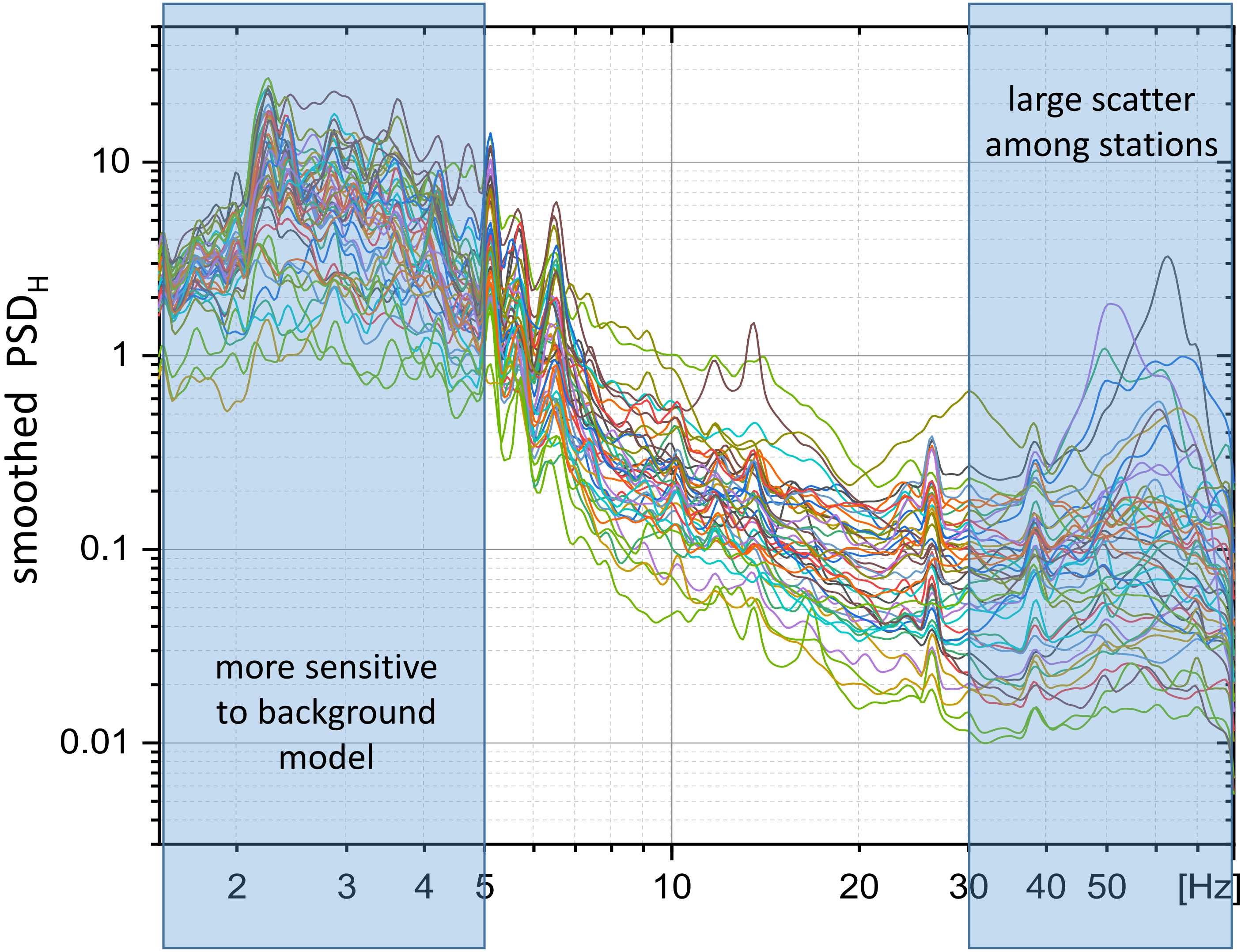
$$\mathrm{FISP}_H = \int_{F_{\min}}^{F_{\max}} \mathrm{PSD}_H(f)\,df$$

and

$$\mathrm{FISP}_Z = \int_{F_{\min}}^{F_{\max}} \mathrm{PSD}_Z(f)\,df$$

Obviously, the selection of the frequency interval
is approximate and based on visual evaluation of PSDs.

Therefore, FISPs should be always calculated and checked
also for other frequency interval(s).



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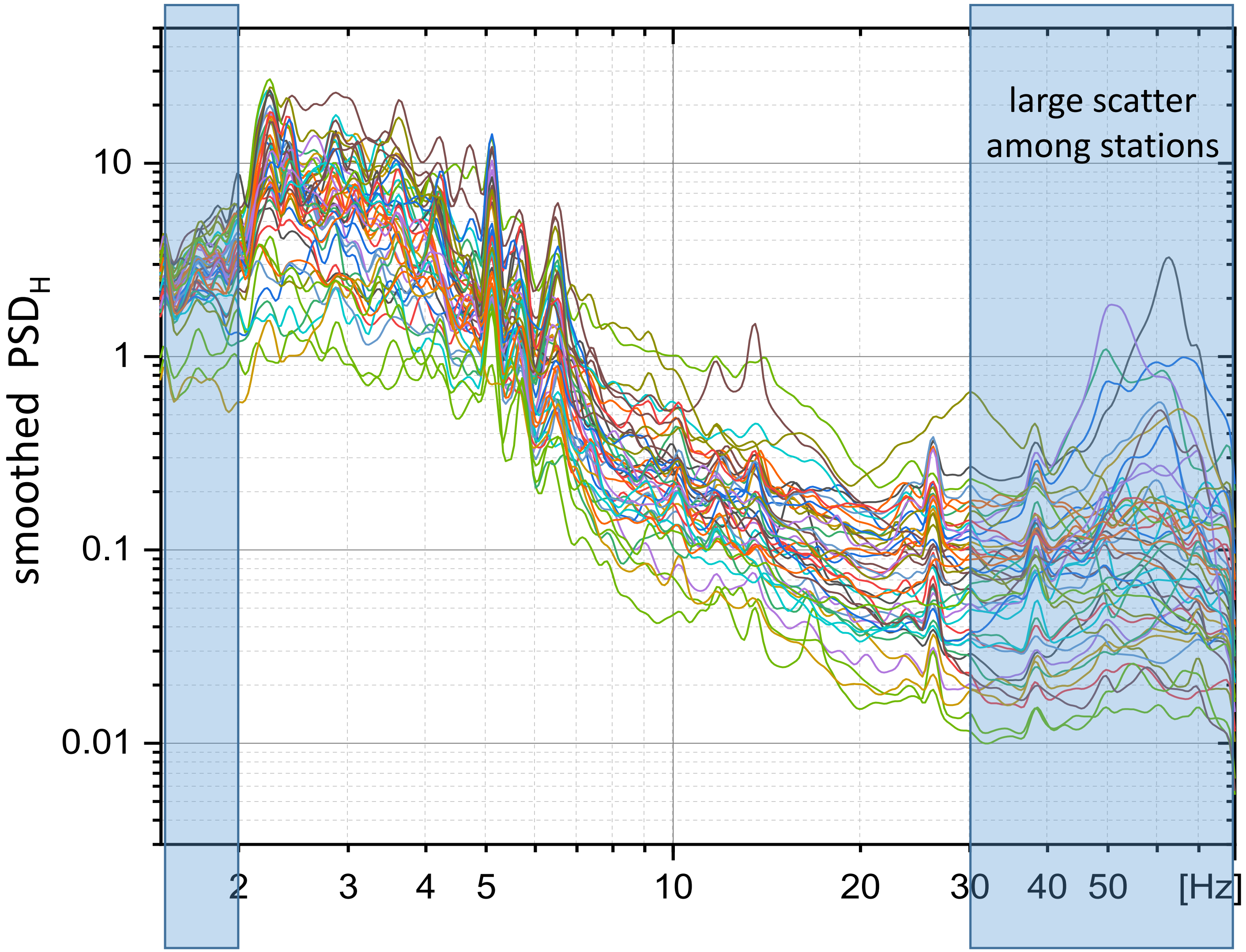
We calculated FISP also for a wider interval [2, 30] Hz.

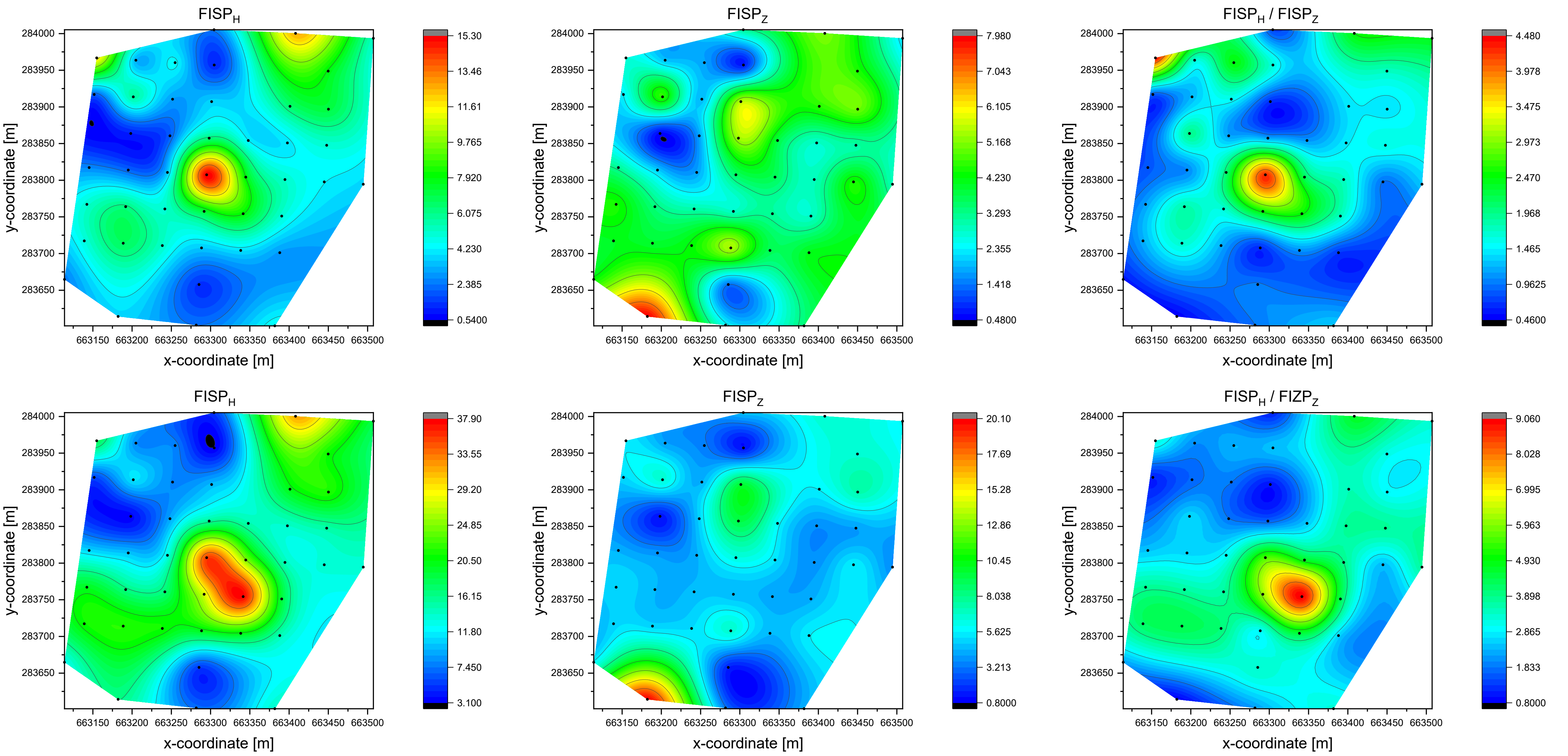


Results

maps showing $FISP_H$, $FISP_Z$, and $FISP_H/FISP_Z$ computed for two selected frequency intervals

5 - 30 Hz

2 - 30 Hz



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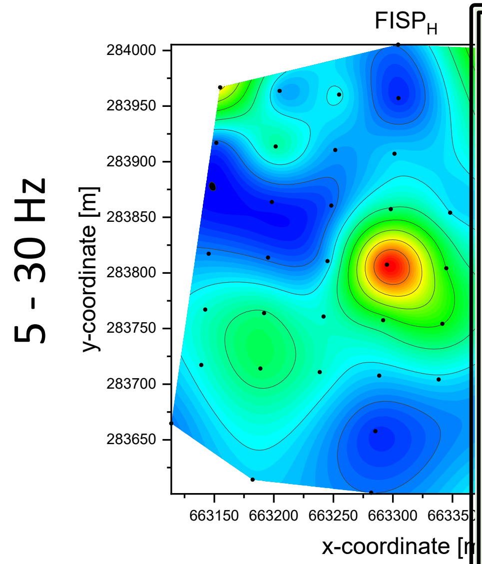
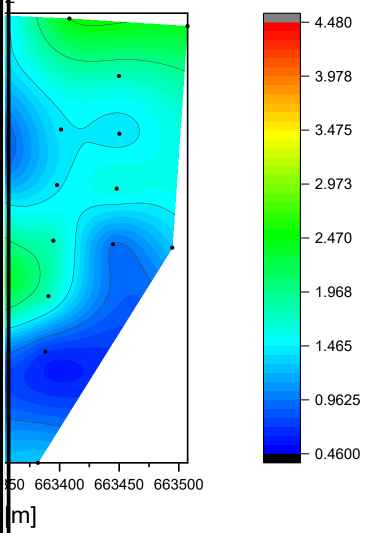




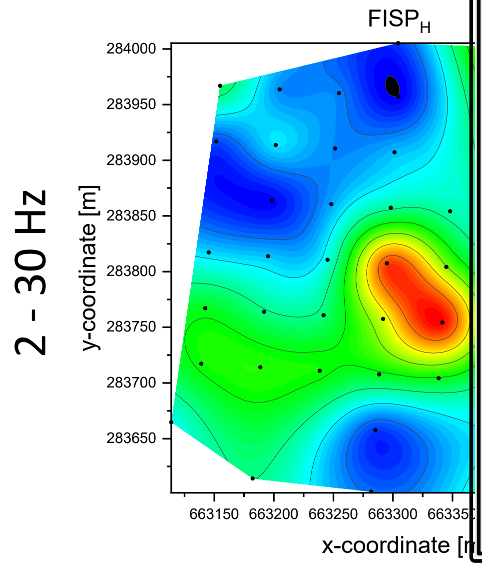
We clearly recognize localized anomalous pattern in maps of $FISP_H$ and $FISP_H$ /$FISP_Z$.

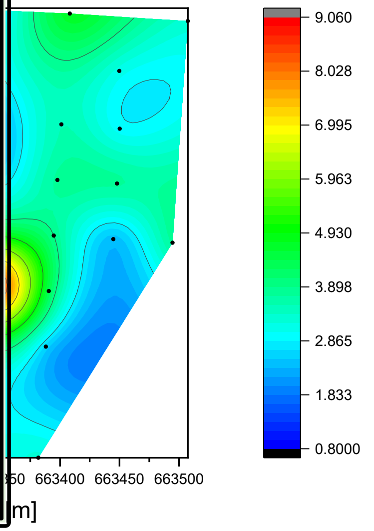
The centre of the anomalous pattern in the frequency interval [5, 30] Hz agrees with the horizontal position of centre of the cavern.

In case of the frequency interval [2, 30] Hz the centre is shifted approximately 60 m to SE.

The visual evaluation of PSDs for all stations led us to prefer frequency interval [5, 30] Hz because inclusion of lower frequencies considerably enhances effect of the medium much larger than the cavern and thus potentially decreases accuracy of location.

We cannot explain why the anomalous pattern is not visible in the maps of $FISP_Z$.
We do not see the possibility to explain this based on the available data.
We think that appearance of an anomalous patterns on the vertical and horizontal components may differ case to case depending on the geometry and depth of cavity, structural parameters and sources of noise.





Results

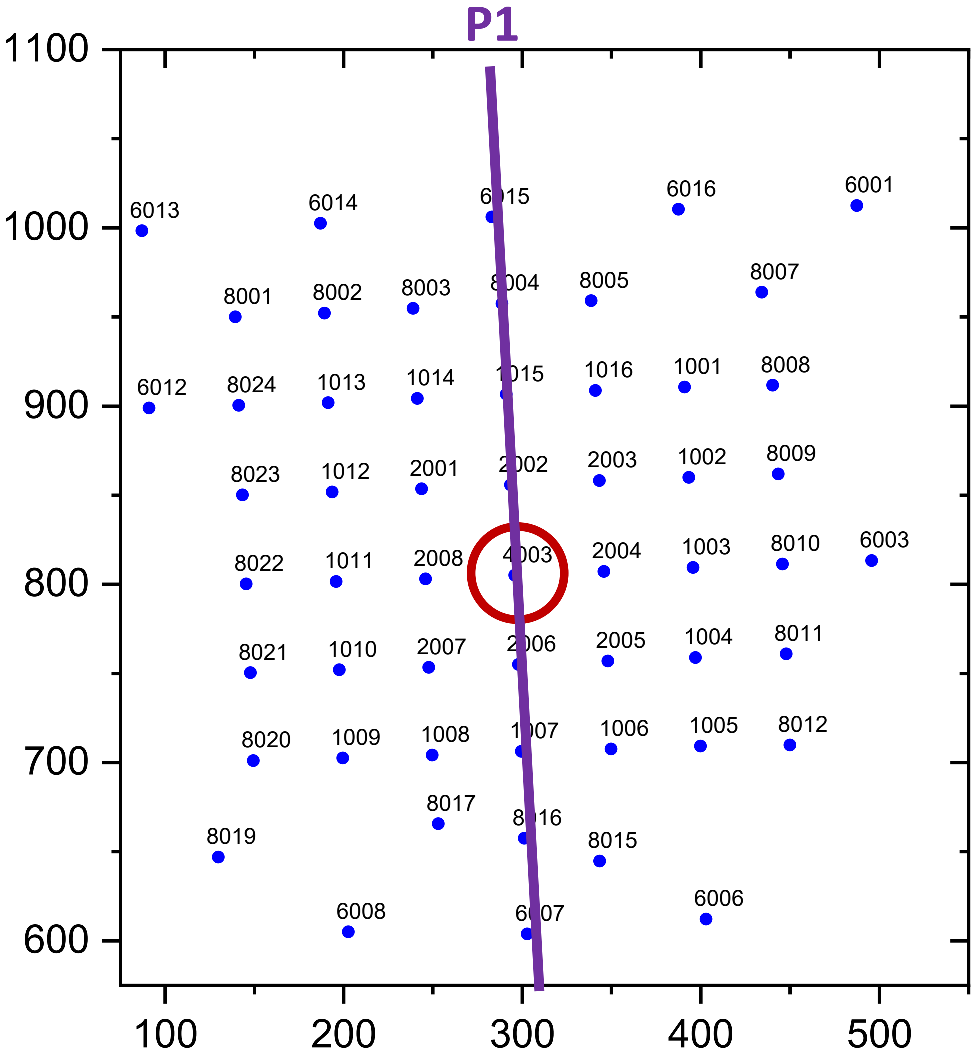
It is necessary to check
whether the anomalous values of FISPs
are not due to amplification at just one frequency
corresponding, e.g., to a monochromatic source
near or at a measurement point.

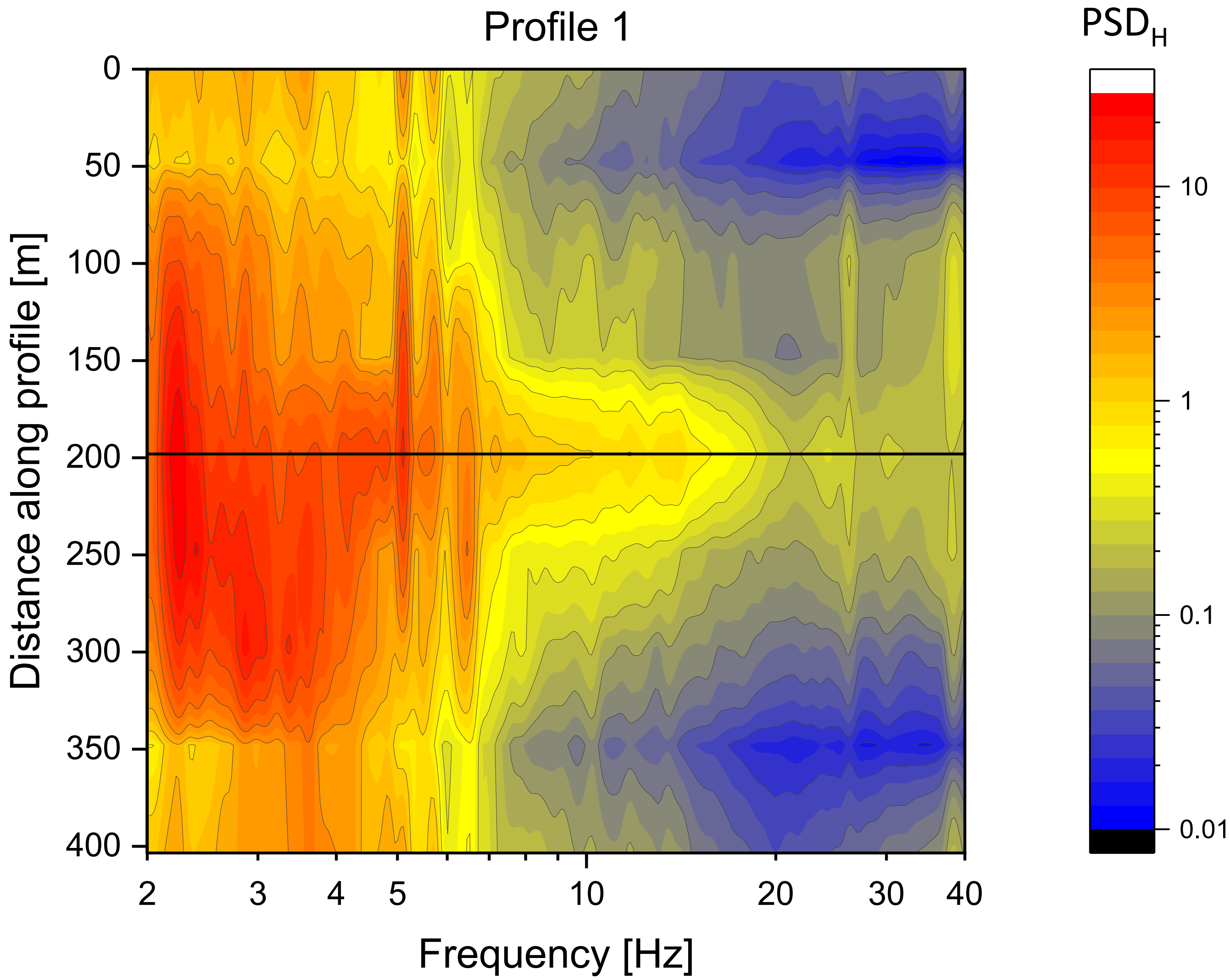
It is therefore important to see PSDs as a function of frequency.

This is possible along profiles of measurement points
crossing the position of the centre of the anomaly.

Results

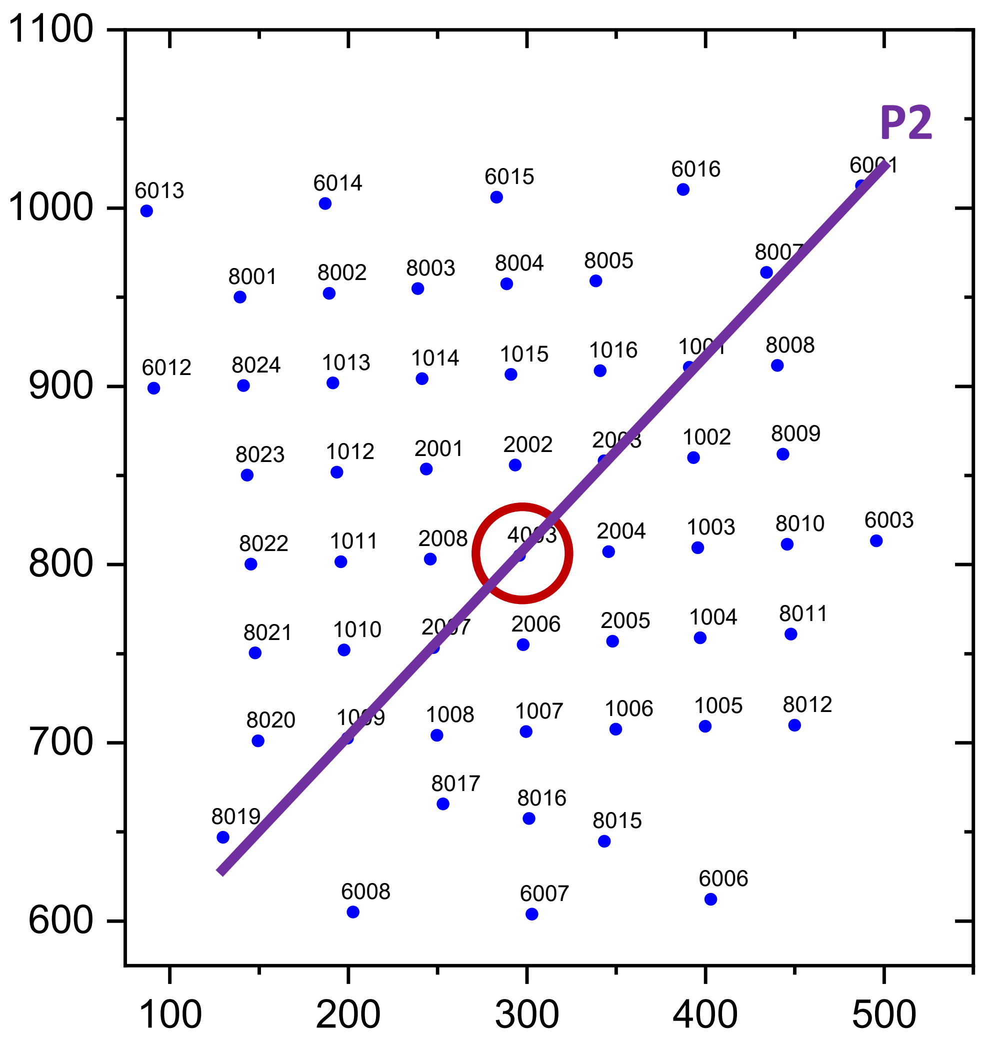
PSD$_H$ attains large values just at the horizontal position of the centre of the cavern in the frequency interval [5, 30] Hz

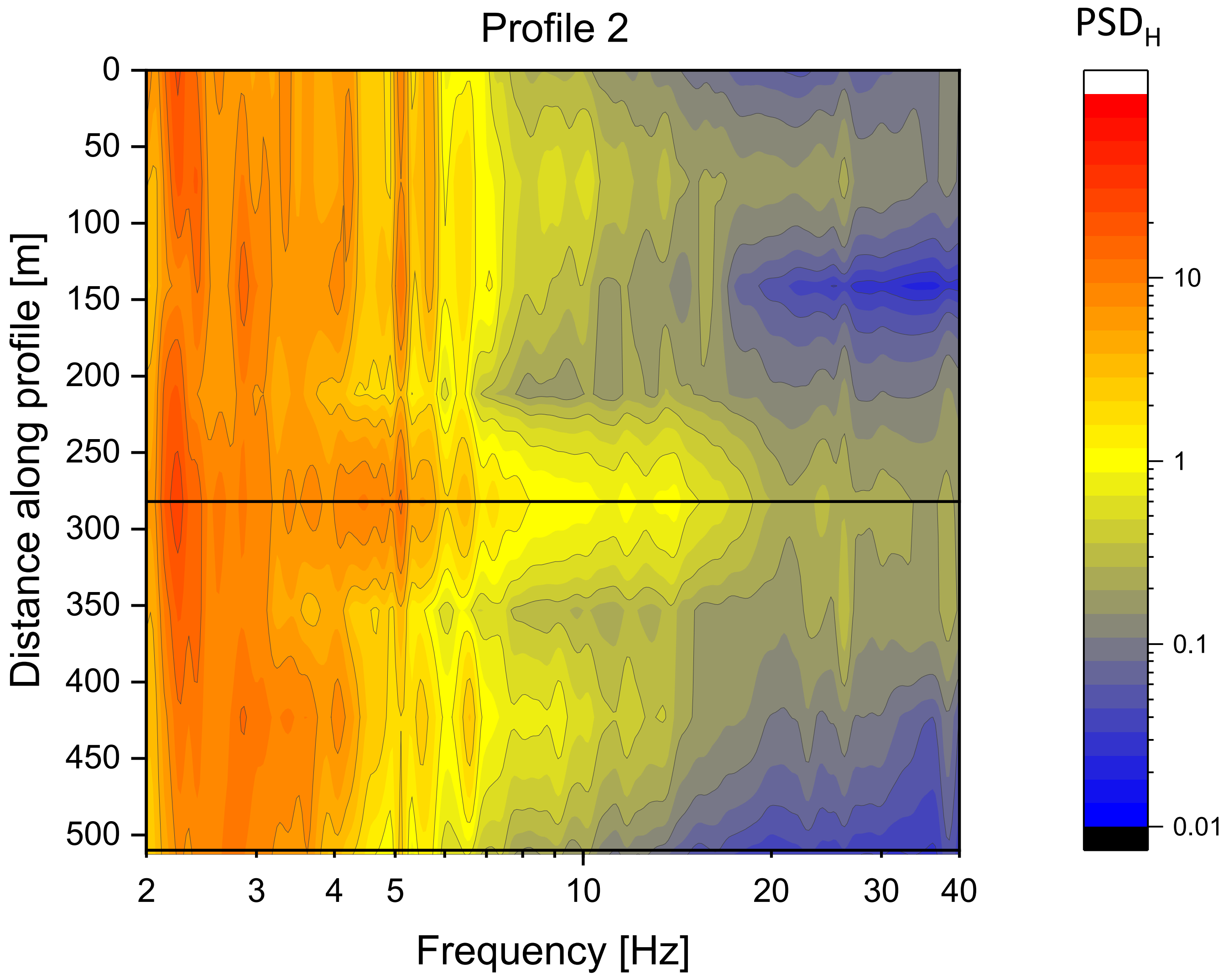




Results

PSD_H attains large values just at the horizontal position of the centre of the cavern in the frequency interval [5, 30] Hz





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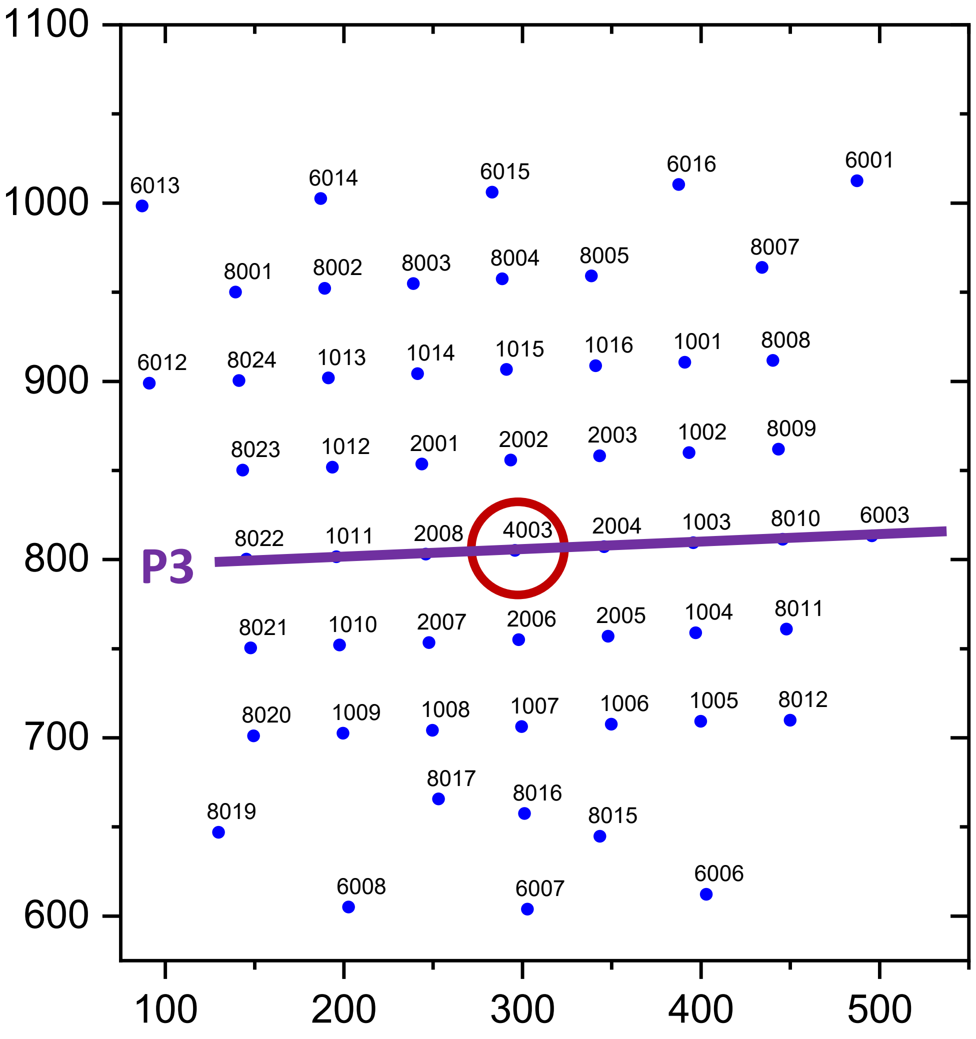

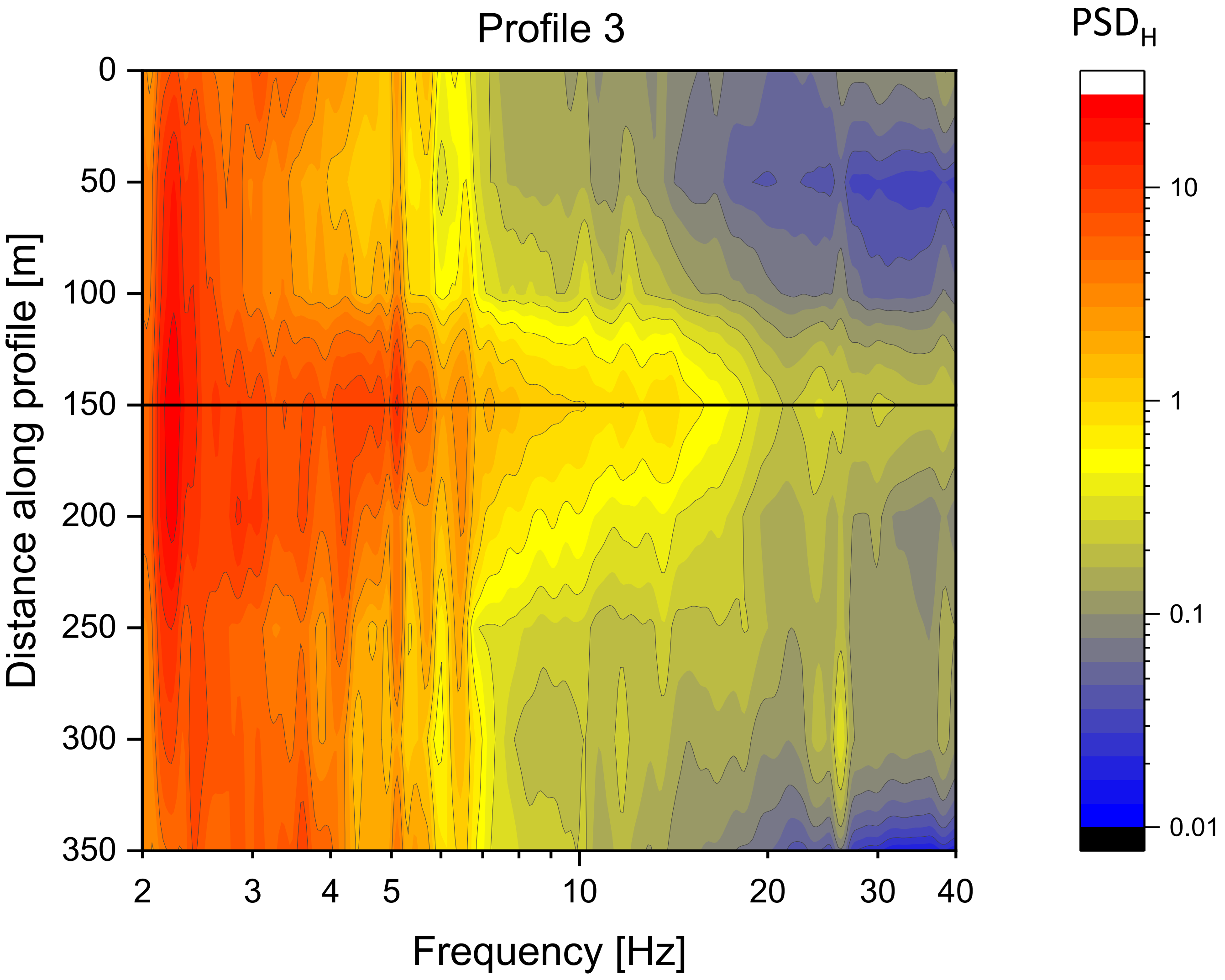

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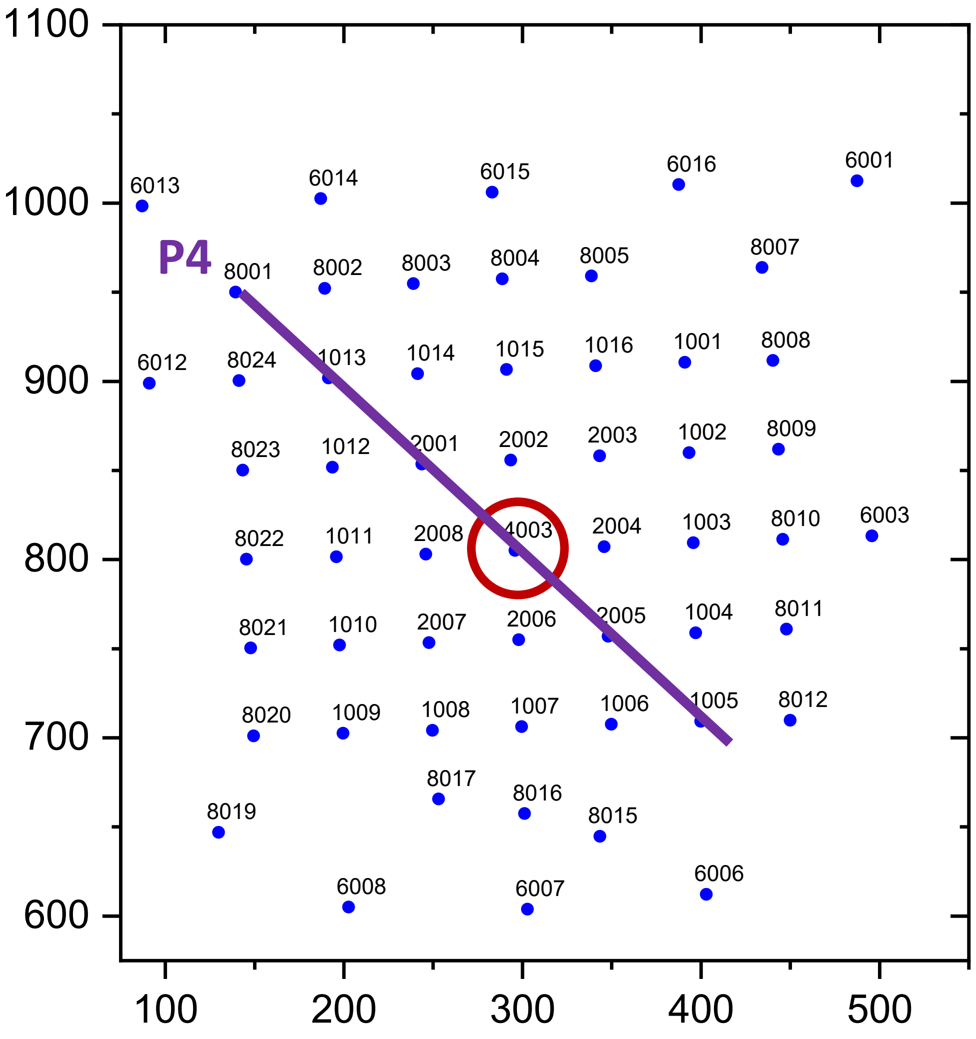
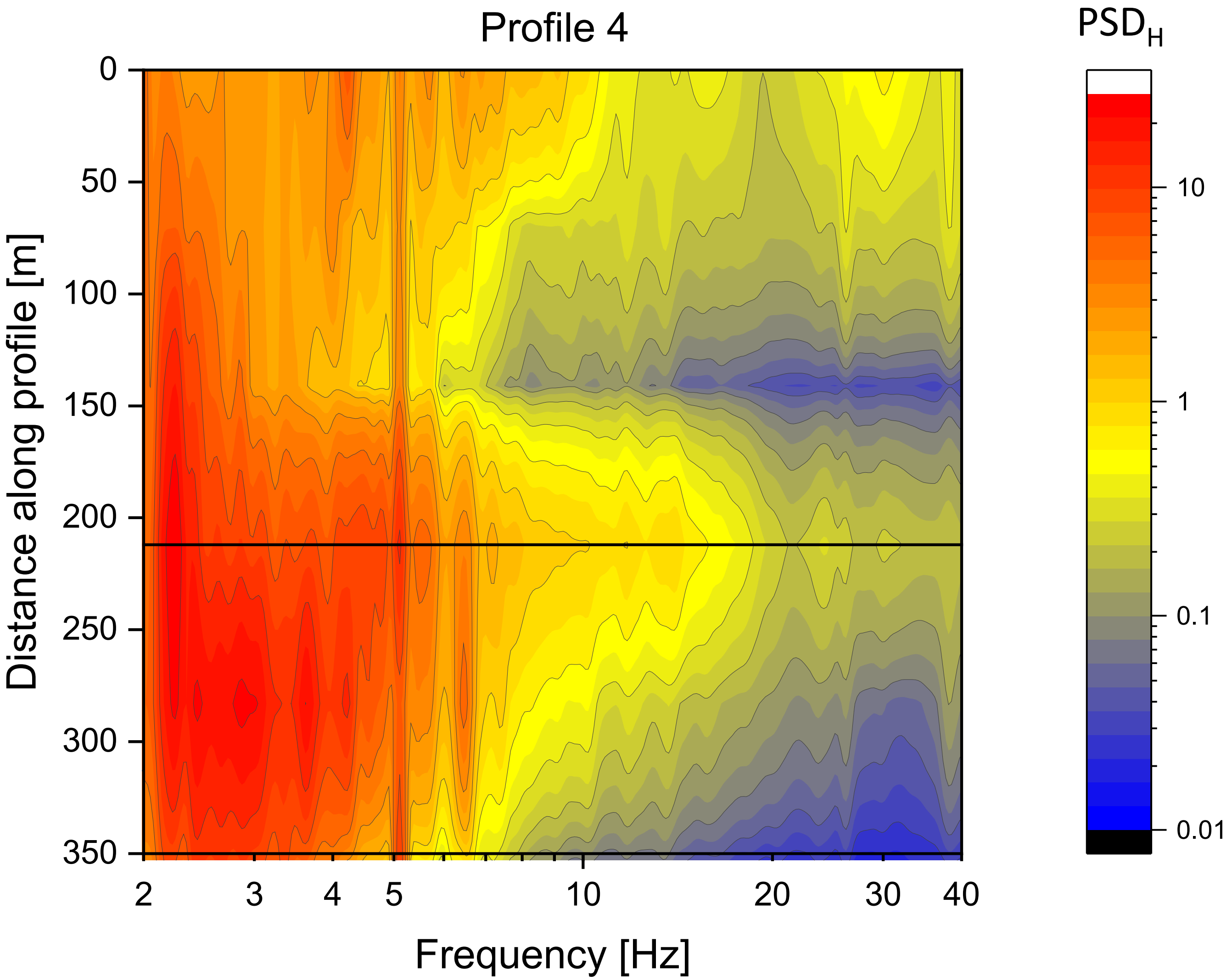




Results

Considering the size of the cavern

and

distribution of the measurement points,

we may intuitively guess

that the density of the measurement points is at the threshold level.

Therefore, it is interesting to check the aerial maps

of $FISP_H$, $FISP_Z$, and $FISP_H/FISP_Z$

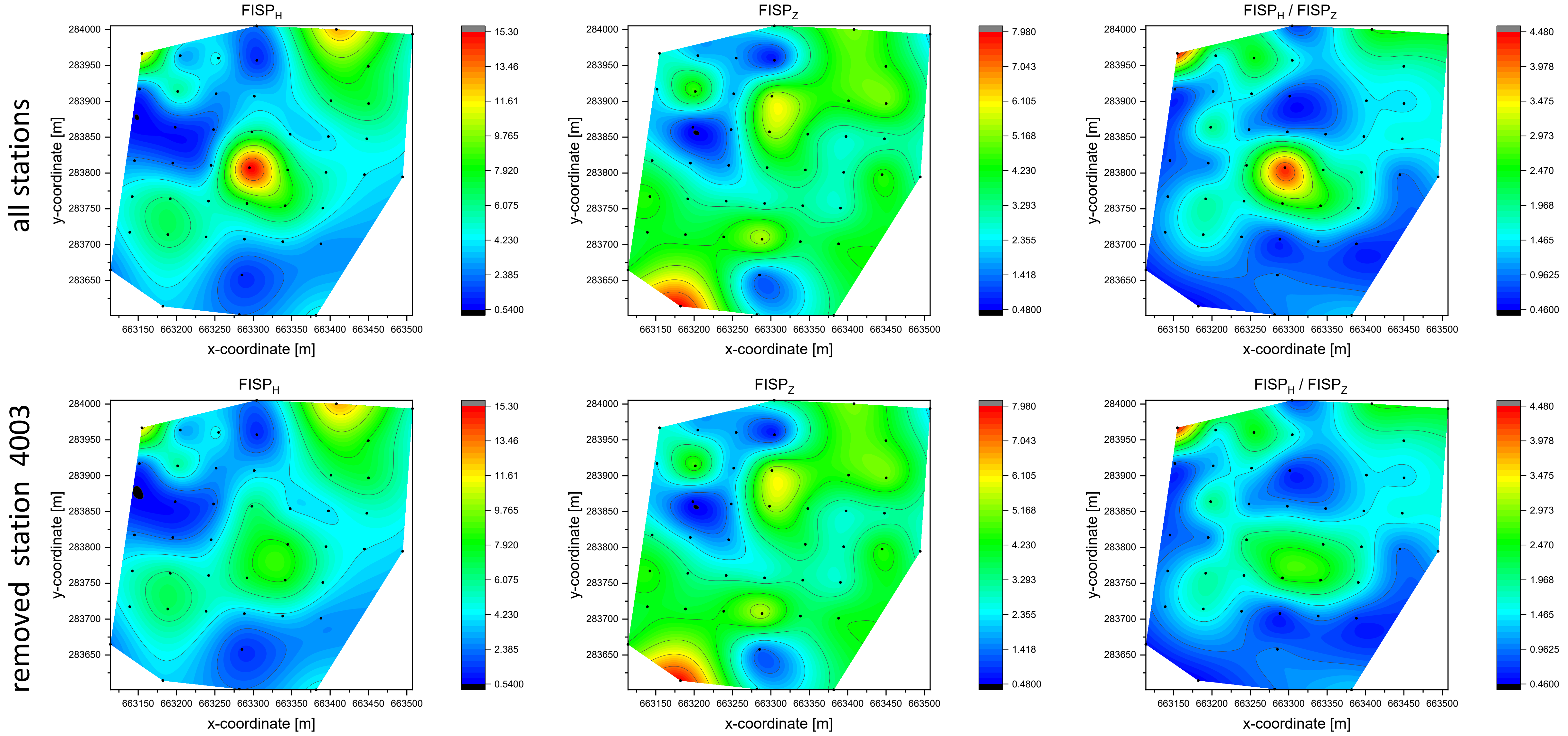
from which the contribution

of the measurement point 4003 (just above the cavern) is removed.

In other words, we want to check the robustness of the identified FISP anomaly.

Results

maps showing $FISP_H$, $FISP_Z$, and $FISP_H/FISP_Z$ computed for frequency interval [5, 30] Hz



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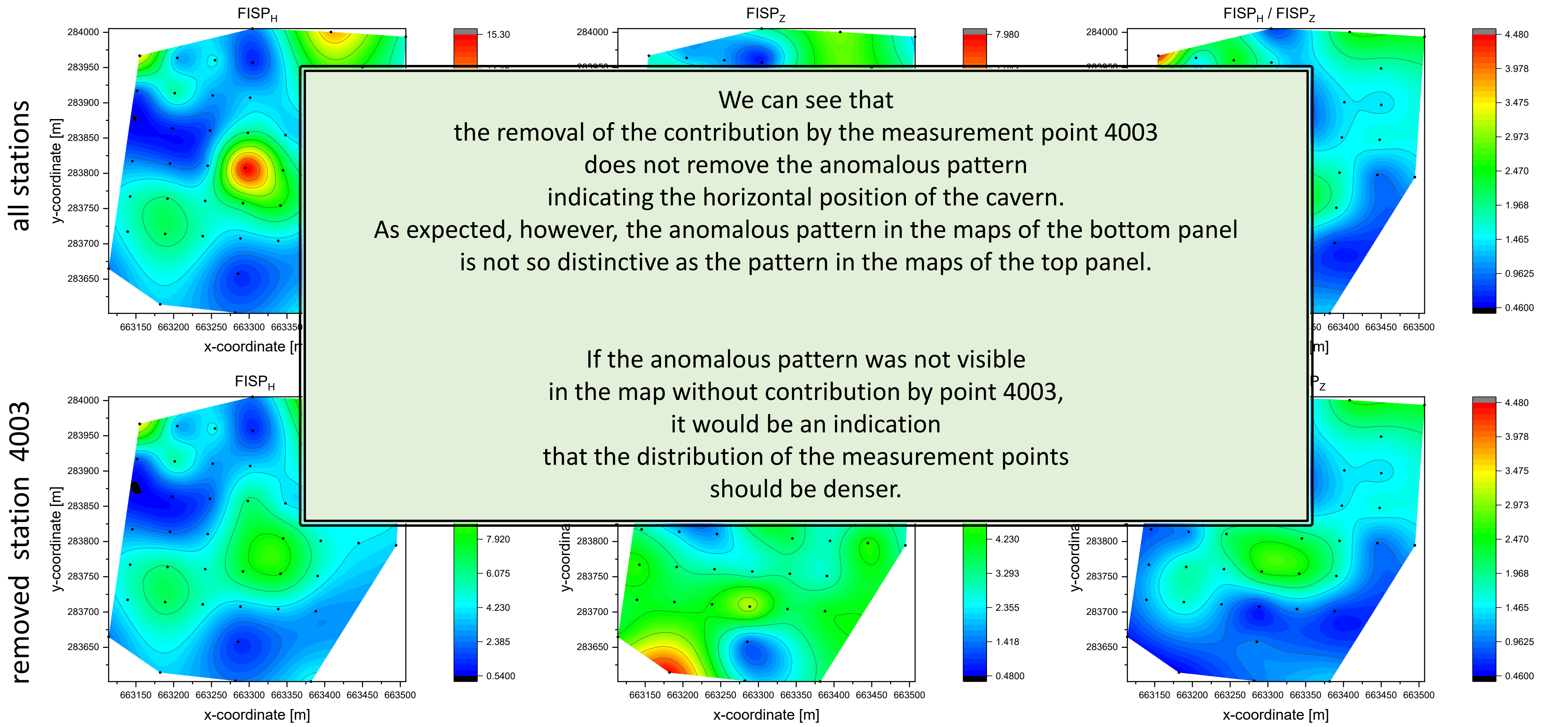

We can see that
the removal of the contribution by the measurement point 4003
does not remove the anomalous pattern
indicating the horizontal position of the cavern.
As expected, however, the anomalous pattern in the maps of the bottom panel
is not so distinctive as the pattern in the maps of the top panel.

If the anomalous pattern was not visible
in the map without contribution by point 4003,
it would be an indication
that the distribution of the measurement points
should be denser.

Conclusions

We present a new method
which uses the Finite-interval Spectral Power (FISP)
of seismic ambient noise
for detecting and locating a horizontal position
of underground cavity.

The application of the method in practice is simple because
it makes it possible to use
single-station measurements.

The method assumes
a set of potentially irregularly distributed
measurement points in the area
on the Earth's free surface
over a suspected cavity
and
sufficiently long 3-component records of noise
at all measurement points.

The records should be obtained in similar conditions but they can be
performed sequentially.

Conclusions

We tested applicability of the method
using records of seismic ambient noise
obtained from the Field Test in Felsőpetény (Hungary) in 2019,
the karst and clay-mining area.
The noise was recorded at 55 points distributed in the area
over a known cavity with the ceiling at 70 m depth.

Using our method we were able to locate the horizontal position of the cavity
in the aerial maps of the Finite-interval Spectral Power
of the recorded seismic ambient noise.

The method is ready for further tests
in different cavity conditions and applications.