EINSTEIN TELESCOPE

SEISMIC NEWTONIAN NOISE AND SEISMIC GLITCHNESS AT THE CANDIDATE SITES

R. De Rosa

with the contribution of many other people involved in these activities…

A. Allocca, E. Calloni, A. Cardini, M. Carpinelli, A. Contu, L. Di Fiore, M. Di Giovanni, L. D’Onofrio, D. D’Urso, L. Errico, I. Fiori, C. Giunchi, A. Grado, J. Harms, E. Majorana, M. Marsella, C. Migoni, L. Naticchioni, M. Olivieri, F. Paoletti, M. Punturo, P. Rapagnani, F. Ricci, D. Rozza, G. Saccorotti, M. C. Tringali, L. Trozzo.

Outline

- Introduction

- Newtonian Noise
- Newtonian Noise Glitchness
- Results of the analysis

- Conclusions

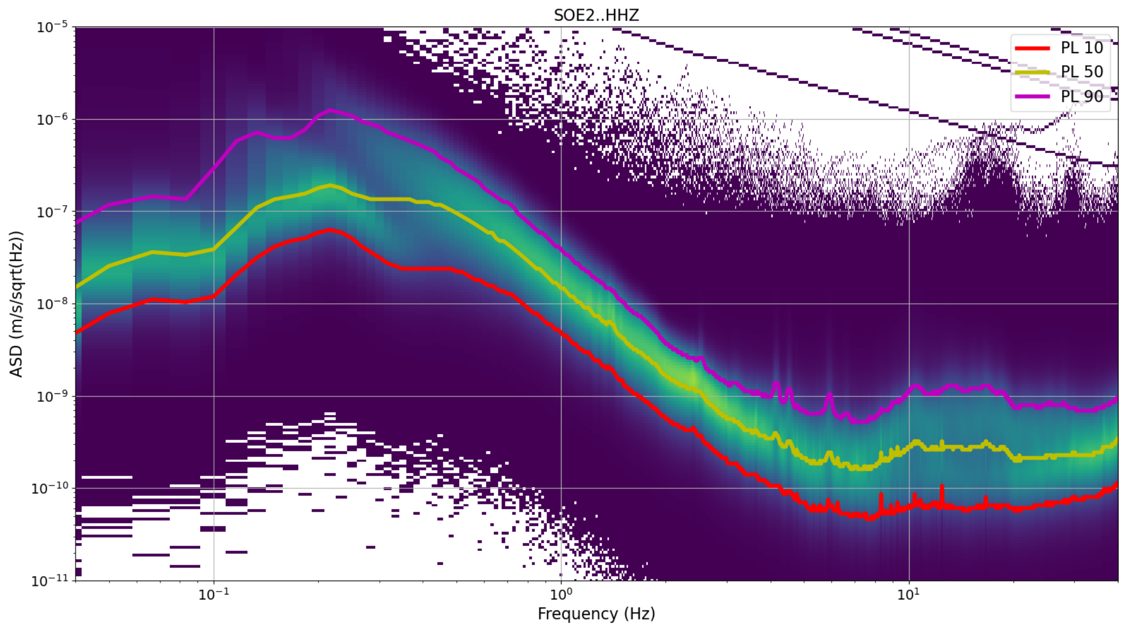
Introduction

- We focused on the effect of Newtonian Noise on the low frequency band (2-10 Hz) for the GW sources whose expected signal is limited in that band, for example coalescence of Intermediate Mass Black Holes;
- The Newtonian Noise is expected to be one of the dominant noise source in this frequency band;
- An excess of Newtonian Noise, even for a short time interval, could even completely hide such kind of signals;
- The aim of this work is to provide a lower limit for the detectability of short duration signals in the low frequency band, like IMBH;
- This work is an update of the results of measurements already presented in the ET Workshop 2020;

Newtonian Noise

Motivation

- Newtonian Noise have a large variability, depending on the site, season, weather and other local conditions;
- The variability can be easily recognized by directly analyzing the seismic noise



Seismometer at Sos Enattos
Placed in cavern at -111 m
Data from:
21/12/2021
To
20/12/2022

- Variability of about one order of magnitude in the 1-10 Hz band

Newtonian Noise

Model

- The NN can be estimated from the measured seismic noise using a simplified model:
- $\tilde{h}_{NN} = \frac{4\pi}{3} G \rho_0 \frac{2\sqrt{2}}{L} \frac{1}{(2\pi f)^2} \tilde{x}$

F. Badaracco, J. Harms,
Class.Quant.Grav. 36 (2019) 14, 145006

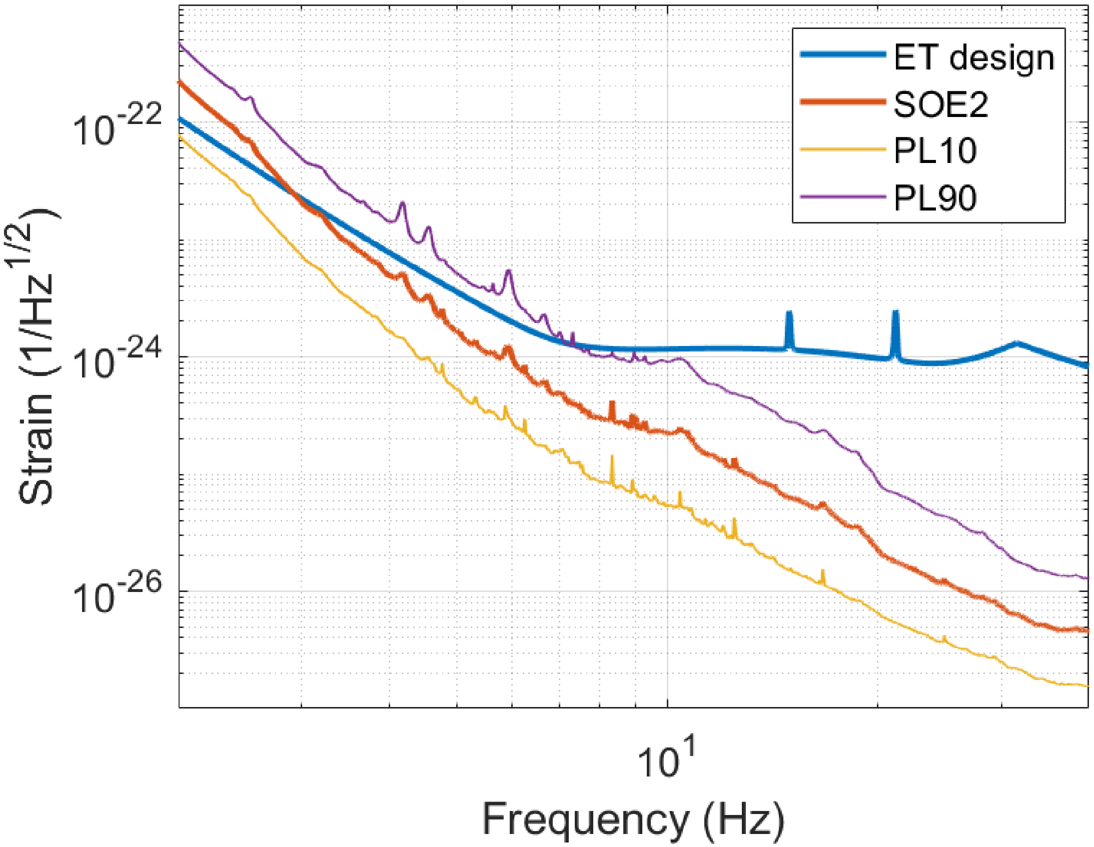
- Assuming:
  - Contribution only from body waves;
  - 1/3 of contribution to seismic noise coming from compressional waves;
  - Spherical or cubic cave;
  - Uncorrelated NN on the ITF Test Masses;
- Other mechanism can increase the NN level;
- Anyway, this expression provides for a credible lower limit;

J. Harms et al.,
Eur. Phys. J. Plus (2022) 137:687

Newtonian Noise

Model

- Example: Projection of the NN with the measurements collected at Sos Enattos, at level 2 (111 m underground)



Newtonian Noise Glitchness

Noise to Target Ratio

- Anyway, a simple projection does not provide the effect of non-stationarity of NN (Glitchness) on the detectability of short duration GW signals.
- To this aim a more effective indicator is the so-called Noise to Target Ratio (NTR):

- $NTR = \sqrt{\frac{1}{\Delta f} \int_{f_1}^{f_2} df \ \frac{\tilde{h}_{NN} \tilde{h}_{NN}}{S_n}}$

A. Allocca et al.,
Eur. Phys. J. Plus (2021) 136:511

- S_n is the PSD of the ET target sensitivity;
- $\Delta f = f_2 - f_1$ is the selected bandwidth;

Newtonian Noise Glitchness

Noise to Target Ratio

- A value of NTR larger than one implies that, in the selected dataset, the contribution of the NN is limiting the ET sensitivity;
- If the bandwidth of the GW signal is larger than f_2 one can recover the signal since the NN is not significant for high frequency (f_2=10 Hz);
- Otherwise, the GW signal is fully lost;
- In order to quantify the impact of the NN glitchness, it is necessary to fix a time scale for the typical signal duration;

Newtonian Noise Glitchness

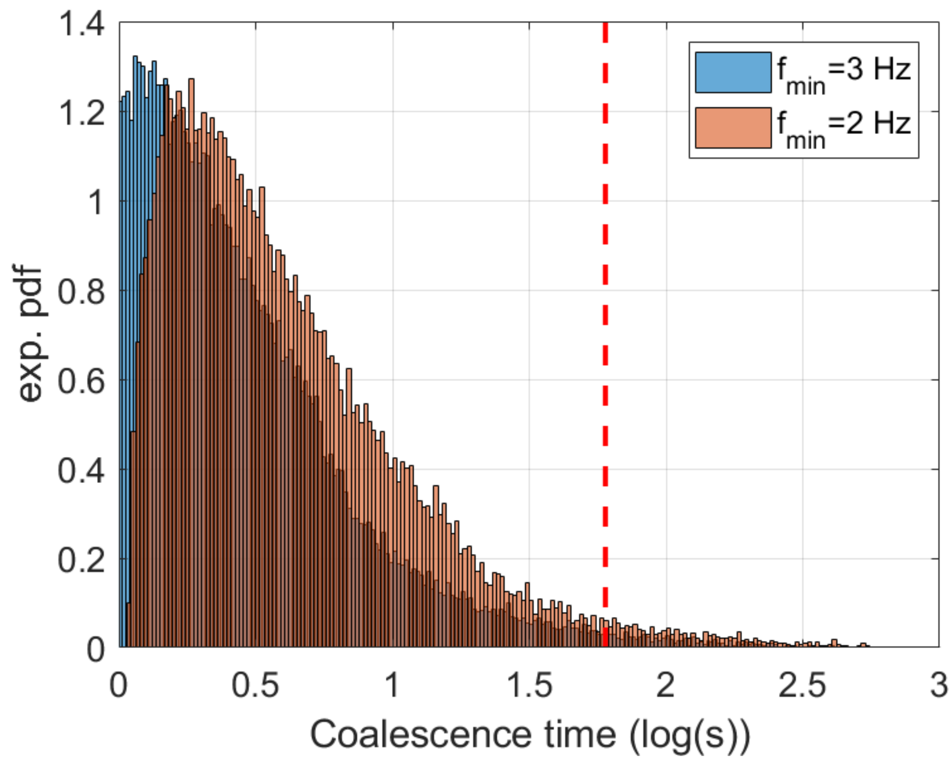
Time Window Definition

- To choose the time window for computing the NTR we set a reference mass *m* of the binary BH system from the relation:
- $\frac{m}{M_\odot} = 2.2\ kHz\ \frac{1}{f_{ISCO}}$
- with $f_{ISCO} = \frac{f_2}{2}$
- than, by randomly selecting the masses m_1 and m_2 according to the condition:
- $f_1 < 4.4\ kHz \frac{M_\odot}{m_1+m_2} < f_2$
- we obtain the coalescence time:
- $\tau = 2.2\ s \left(\frac{1.21\ M_\odot}{M_c}\right)^{\frac{5}{3}} \left(\frac{100\ Hz}{f_1}\right)^{\frac{8}{3}}$

Newtonian Noise Glitchness

Time Window Definition

- This procedure was applied in two different cases:
  - f_1=2 Hz, f_2=10 Hz
  - f_1=3 Hz, f_2=10 Hz



- In both cases, by setting **Δt=60 s** more than 97% of the resulting coalescing time is included

Results of the Analysis

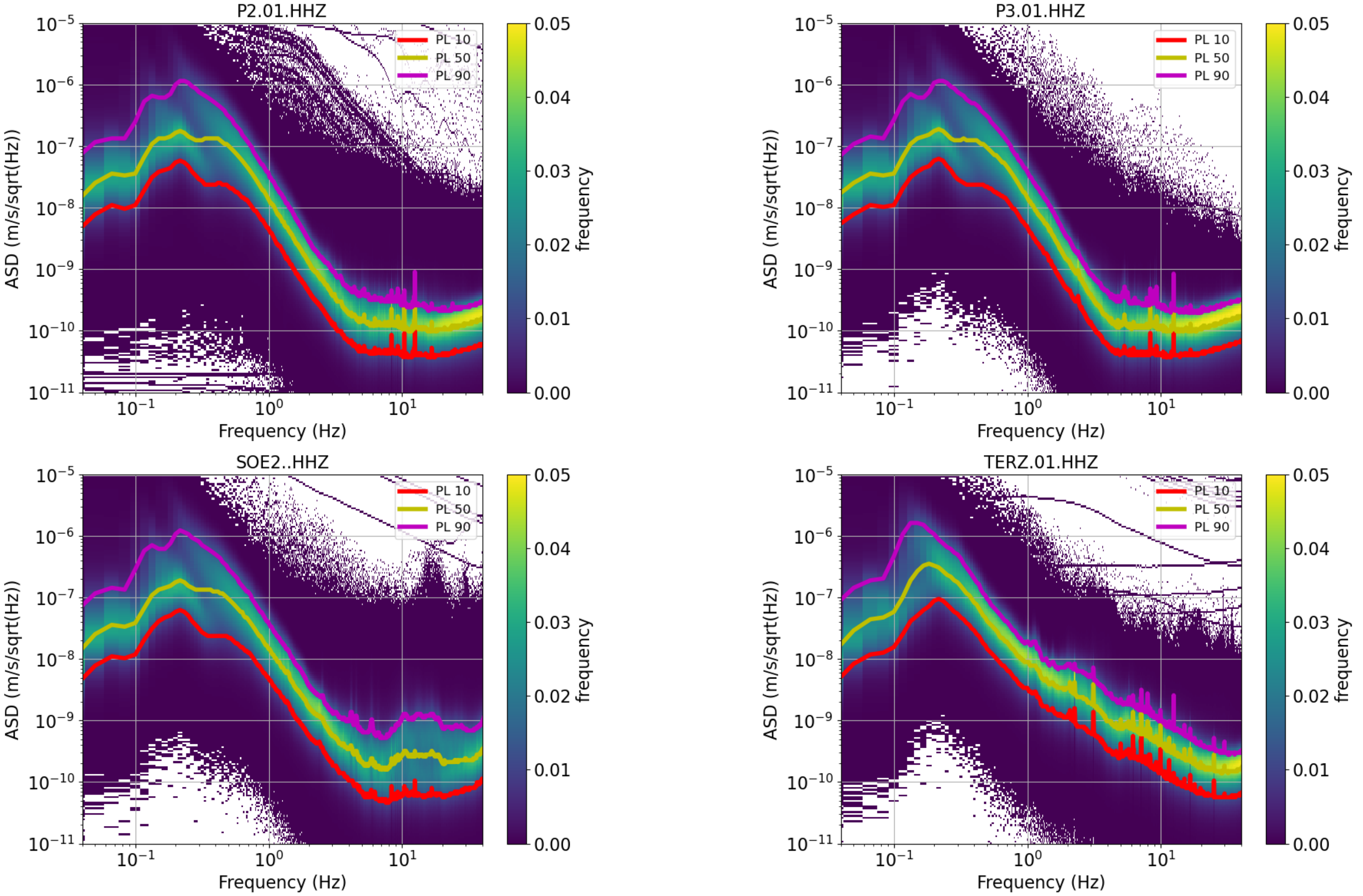
Location and time interval

- Once selected the time window, the NTR can be computed over a long-time interval by properly processing the seismic data collected in that interval;
- In particular we applied this procedure to seismic data collected in:
  - Terziet (Euregio Meuse-Rhine):
    - NL.TERZ.01.HHZ: seismometer at -250 m;
  - Sos Enattos (Sardinia):
    - ET.P2.01.HHZ seismometers at -250 m;
    - ET.P3.01.HHZ seismometers at -250 m;
    - ET.SOE2..HHZ: seismometer at -111 m;
- Time interval: 21/12/2021 – 20/12/2022

Results of the Analysis

Seismic Noise

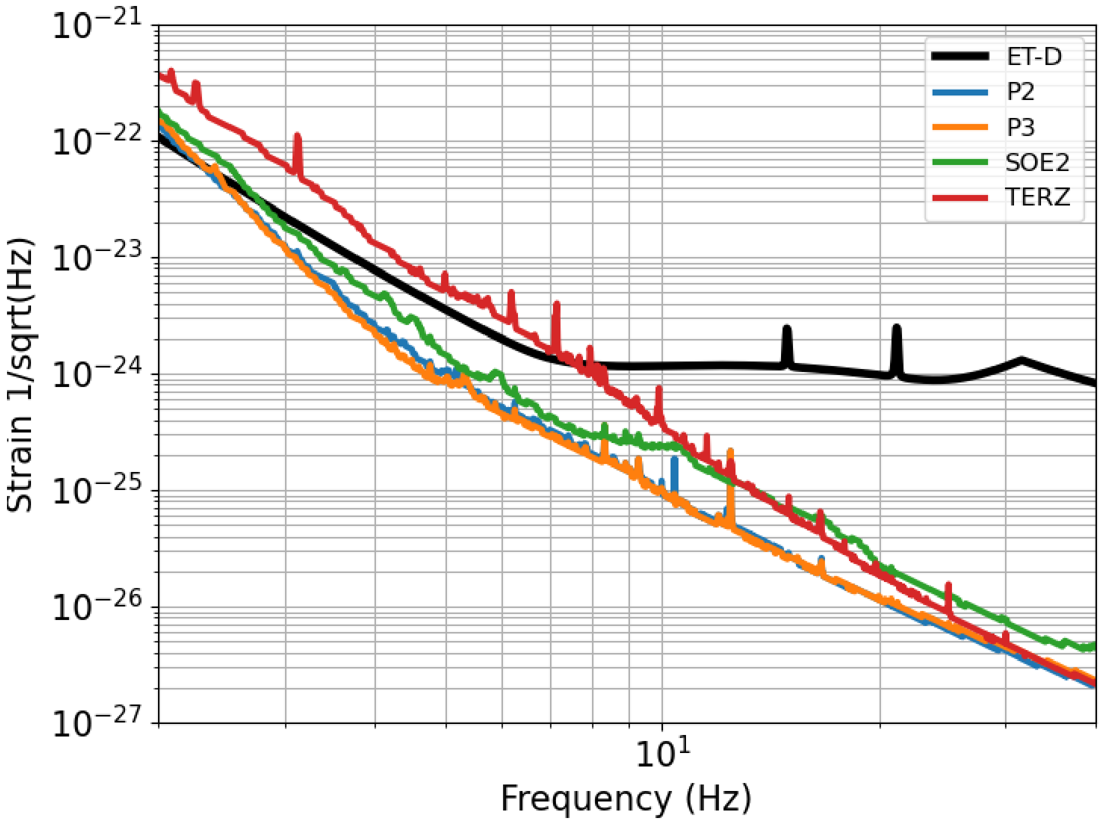
- Variability of seismic noise in the selected locations



Results of the Analysis

Newtonian Noise

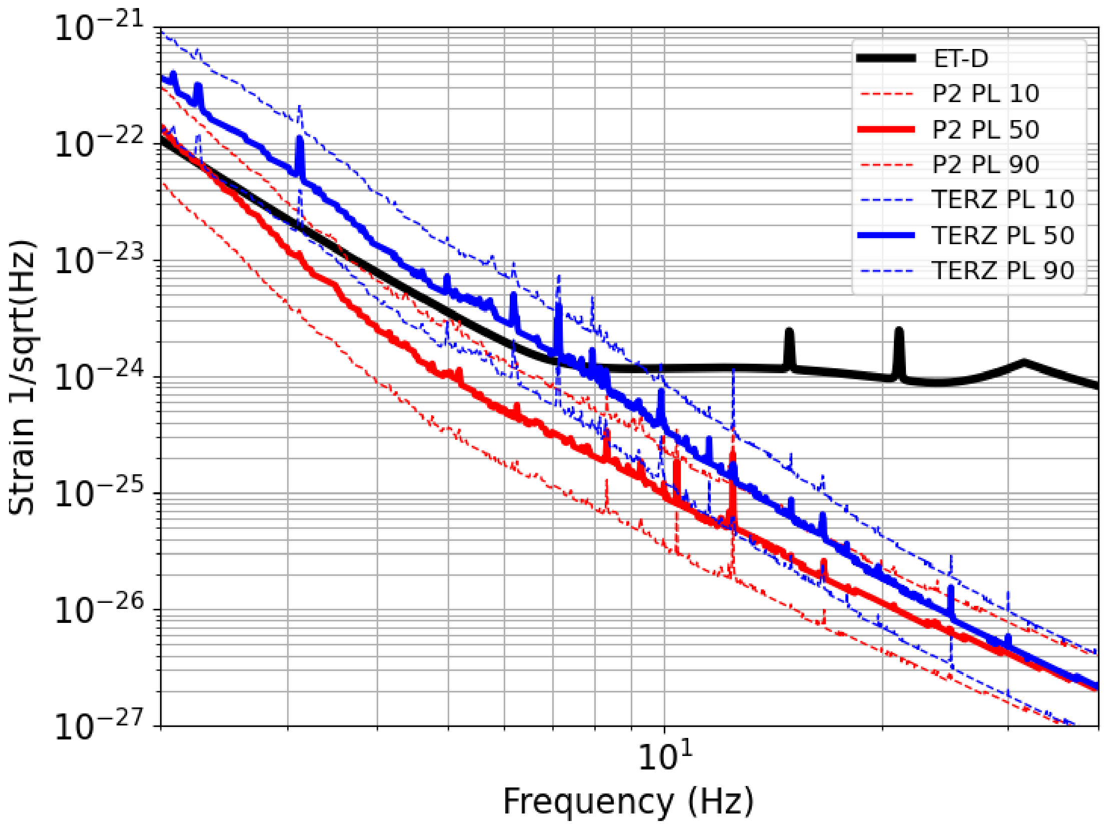
- A rough comparison can be done by directly estimating the NN from the median spectra



Results of the Analysis

Newtonian Noise

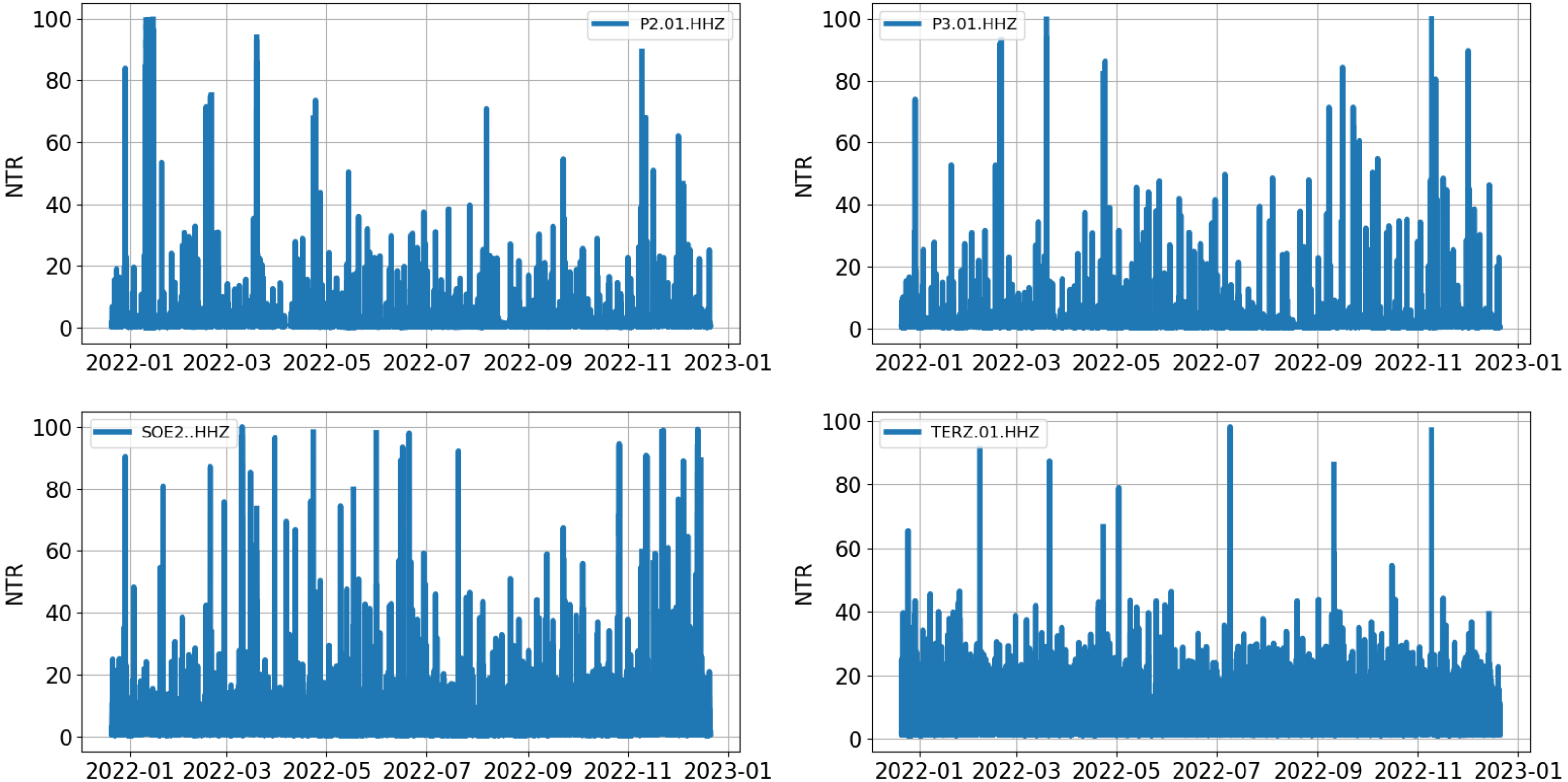
- Variability is also important: better information from the percentiles (only two sites for clarity)



Results of the Analysis

NTR 2-10 Hz

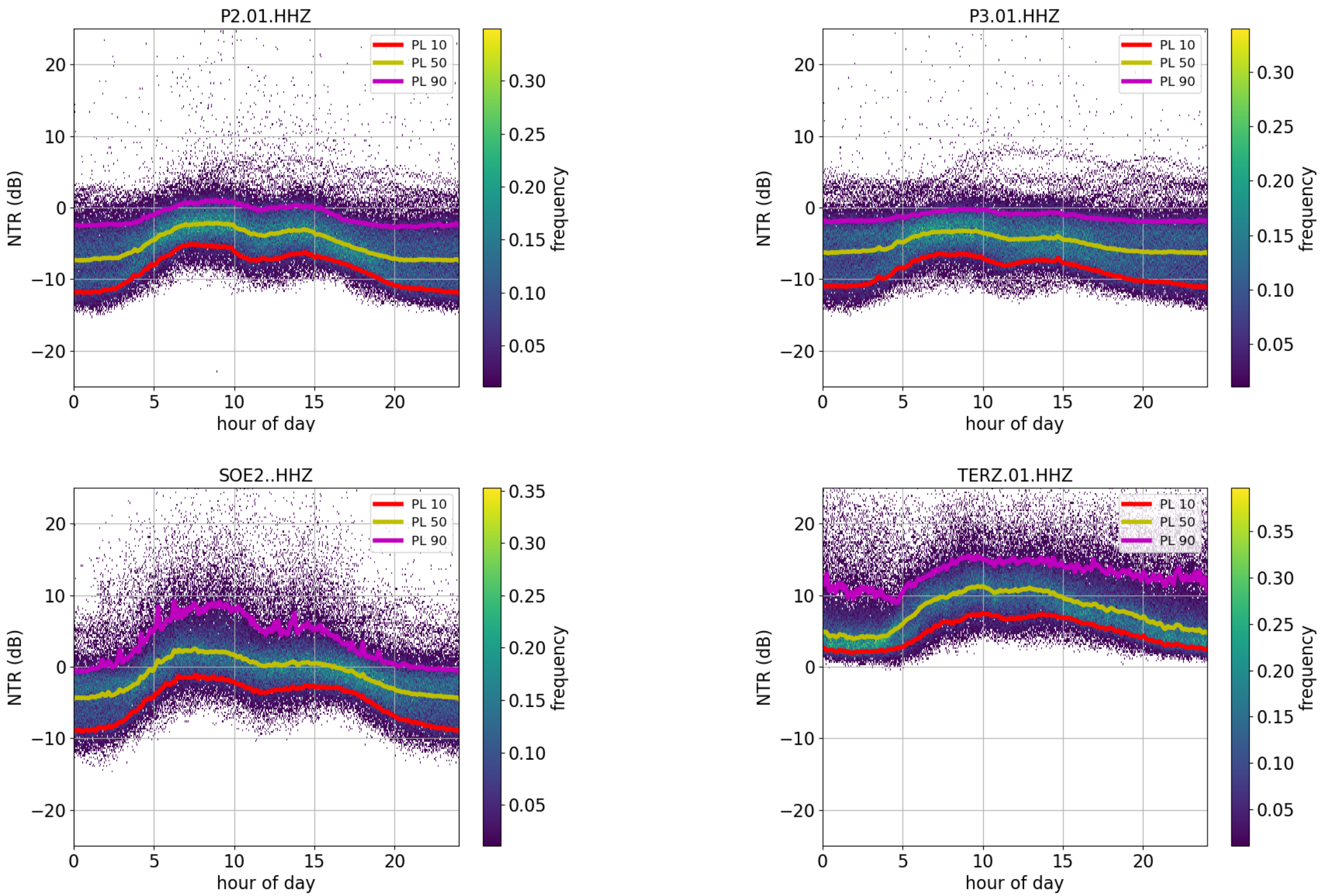
- For the details, the NTR can be analyzed.
- Values larger than 100 were excluded (less than 0.003% in all cases)



Results of the Analysis

NTR 2-10 Hz

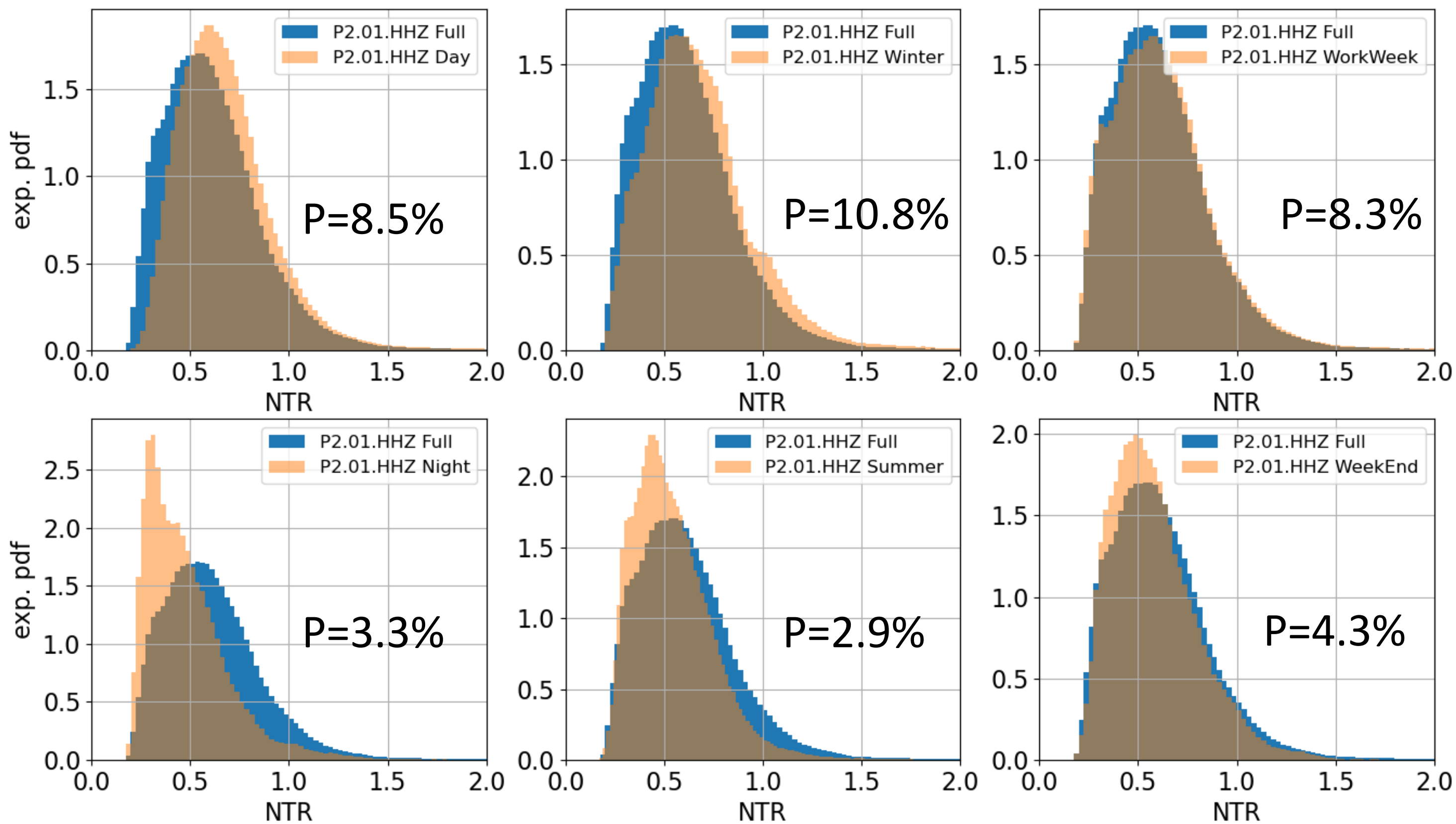
- Distributions along the day



Results of the Analysis

P2 - NTR 2-10 Hz

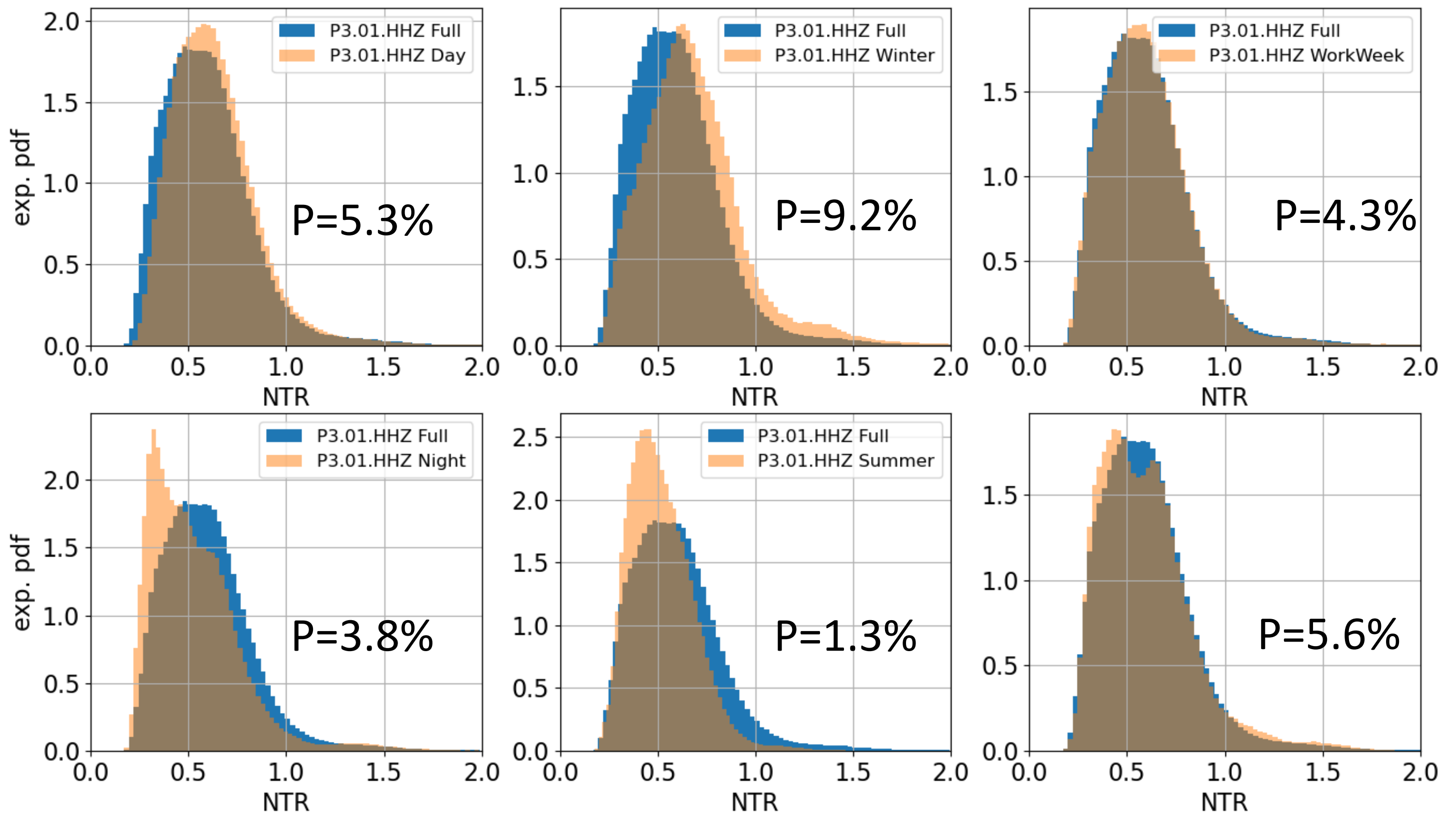
- Detailed distributions for each site:
  - P(NTR>1)=6.3%



Results of the Analysis

P3 - NTR 2-10 Hz

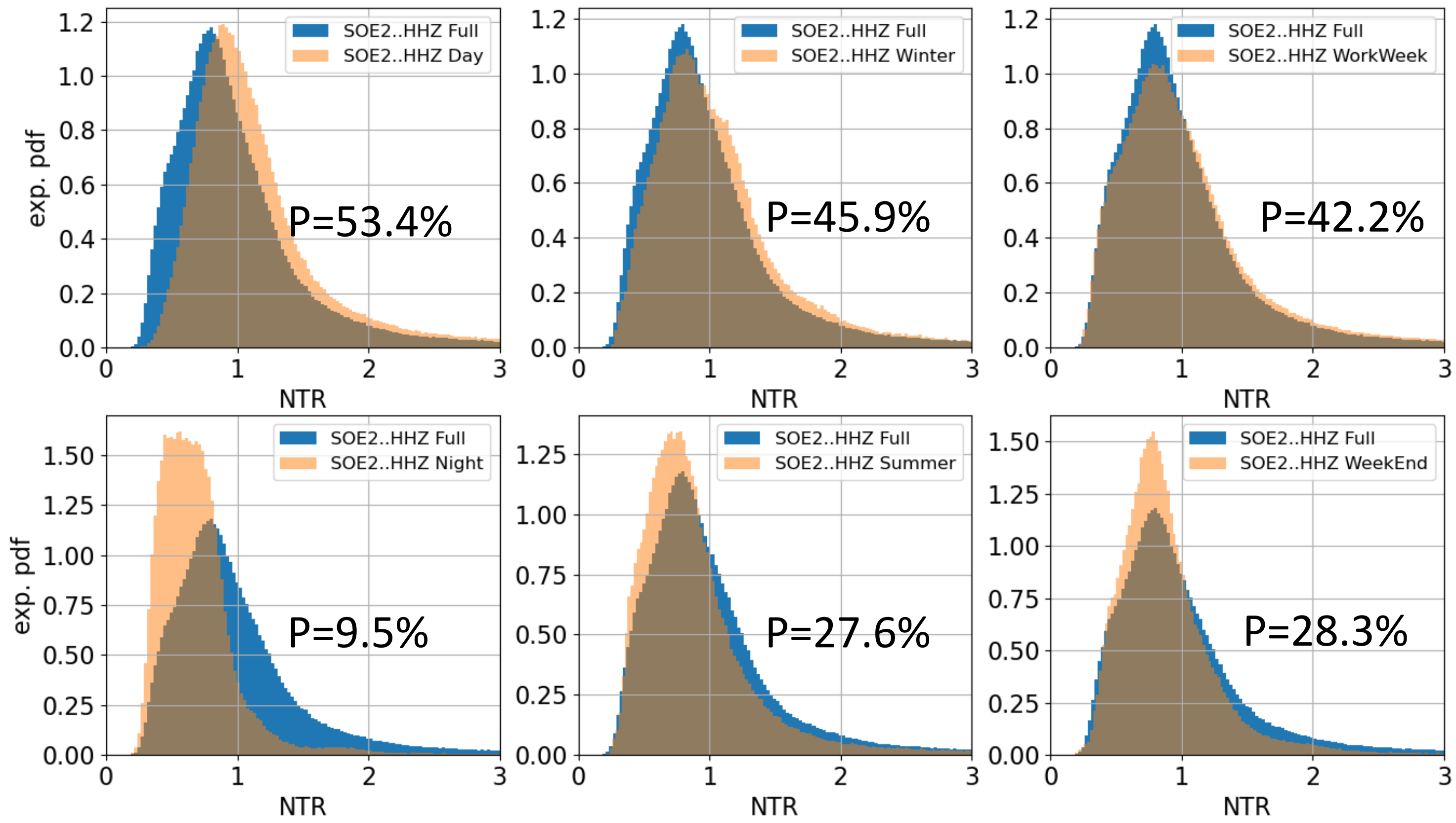
- Detailed distributions for each site:
  - P(NTR>1)=4.7%



Results of the Analysis

SOE2 - NTR 2-10 Hz

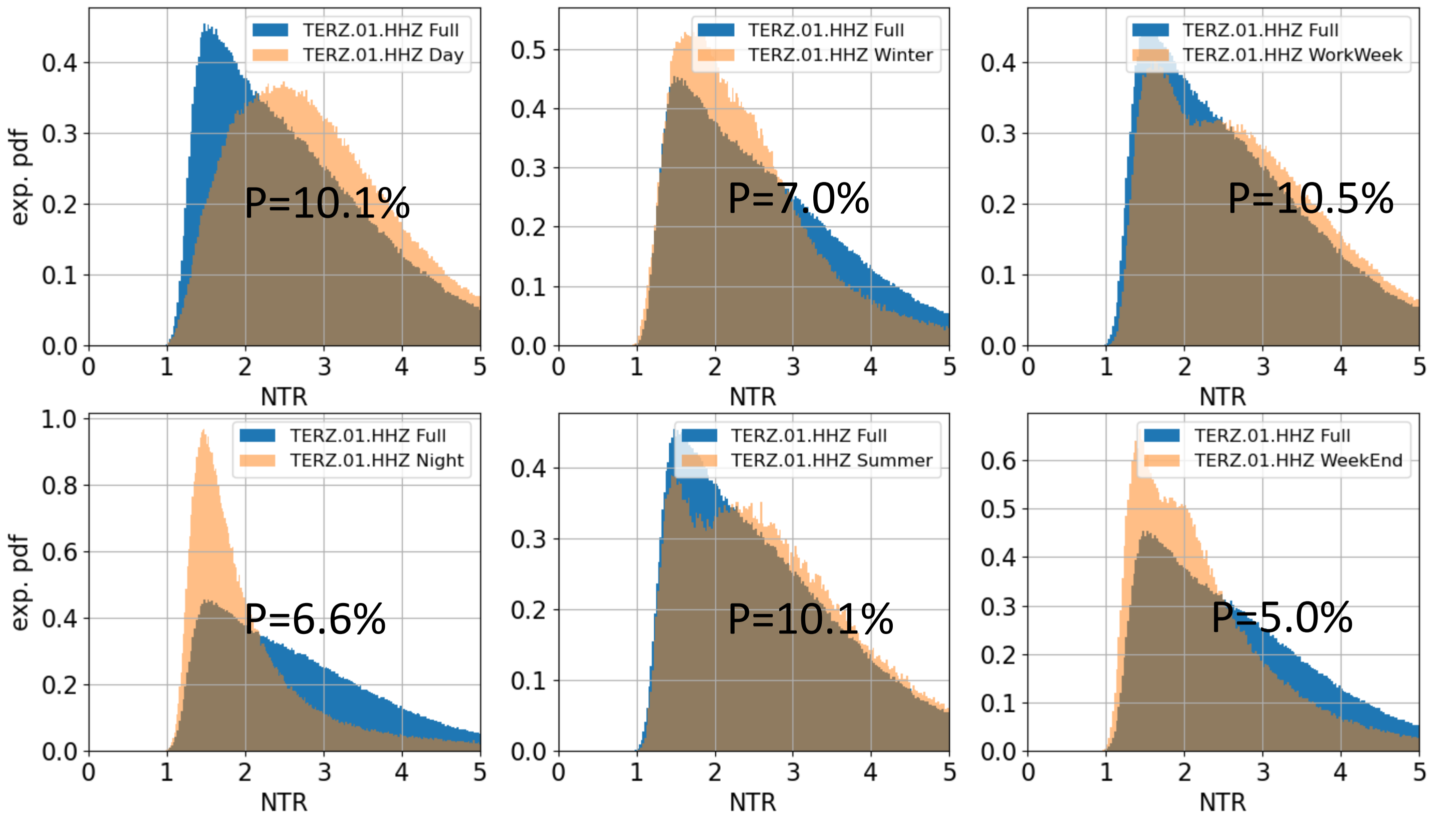
- Detailed distributions for each site:
  - P(NTR>1)=38.6%



Results of the Analysis

TERZ - NTR 2-10 Hz

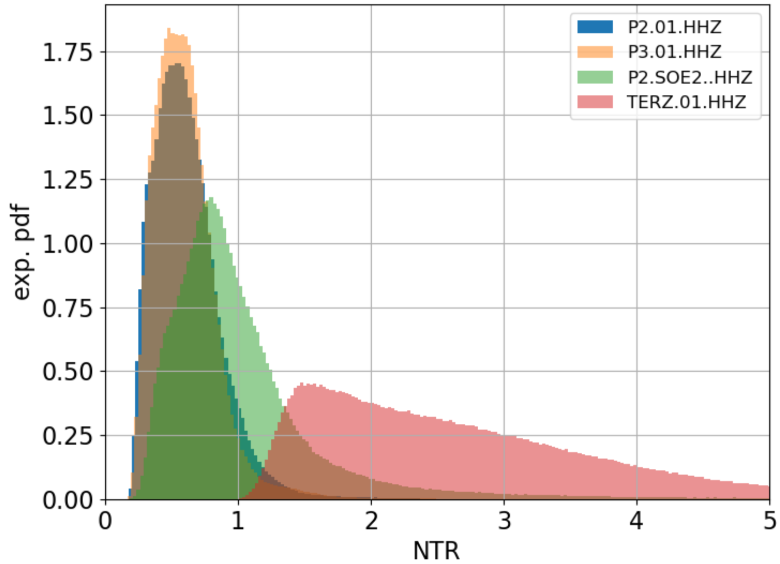
- Detailed distributions for each site:
  - P(NTR>5)=8.9%



Results of the Analysis

Full NTR Comparison

- Comparison of the full distributions for each site



- The NN estimations for P2 and P3 sensors (and hopefully for SOE2 also if provided with a sensor in a borehole…) indicate that NN could not limit the sensitivity for a large fraction of the time
- Anyway, they only provides for a lower limit…

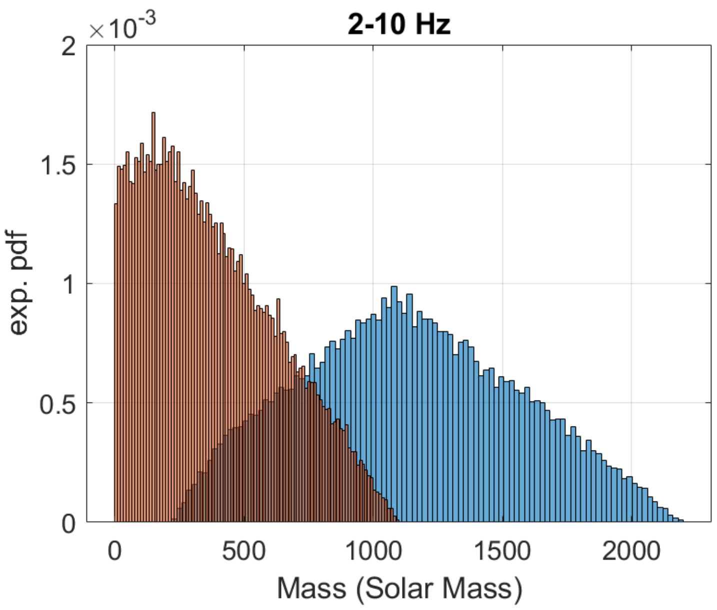
Conclusions

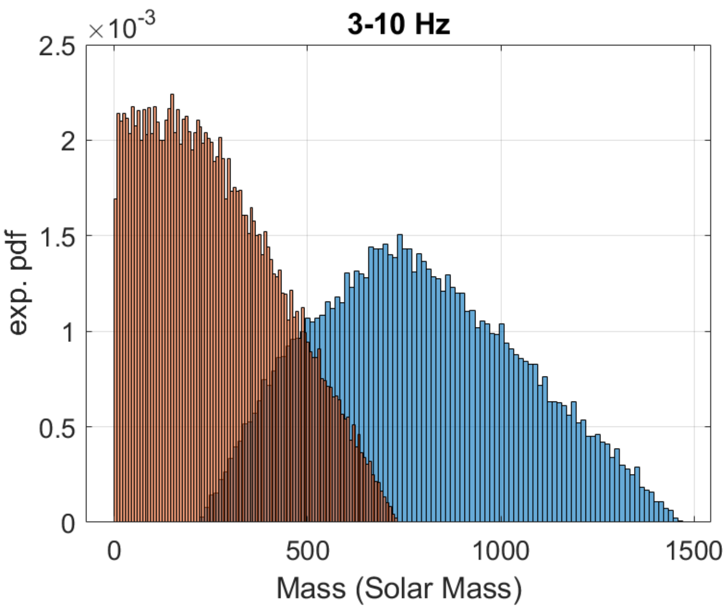
- Clear indication that, at least for Sardinia, NN could be a limited issue for sources whose spectrum is limited in the 2-10 Hz frequency band;
- Otherwise, a NN cancellation of a factor 5 is needed to recover to final ET sensitivity for more than 90% of time;
- A change in the detector geometry and length (L shape, 20 km long) should reduce the effect of NN.

Spare Slides

IMBH Mass Distribution

- Mass of the IMBH binary systems resulting from the simulation used to set the time window

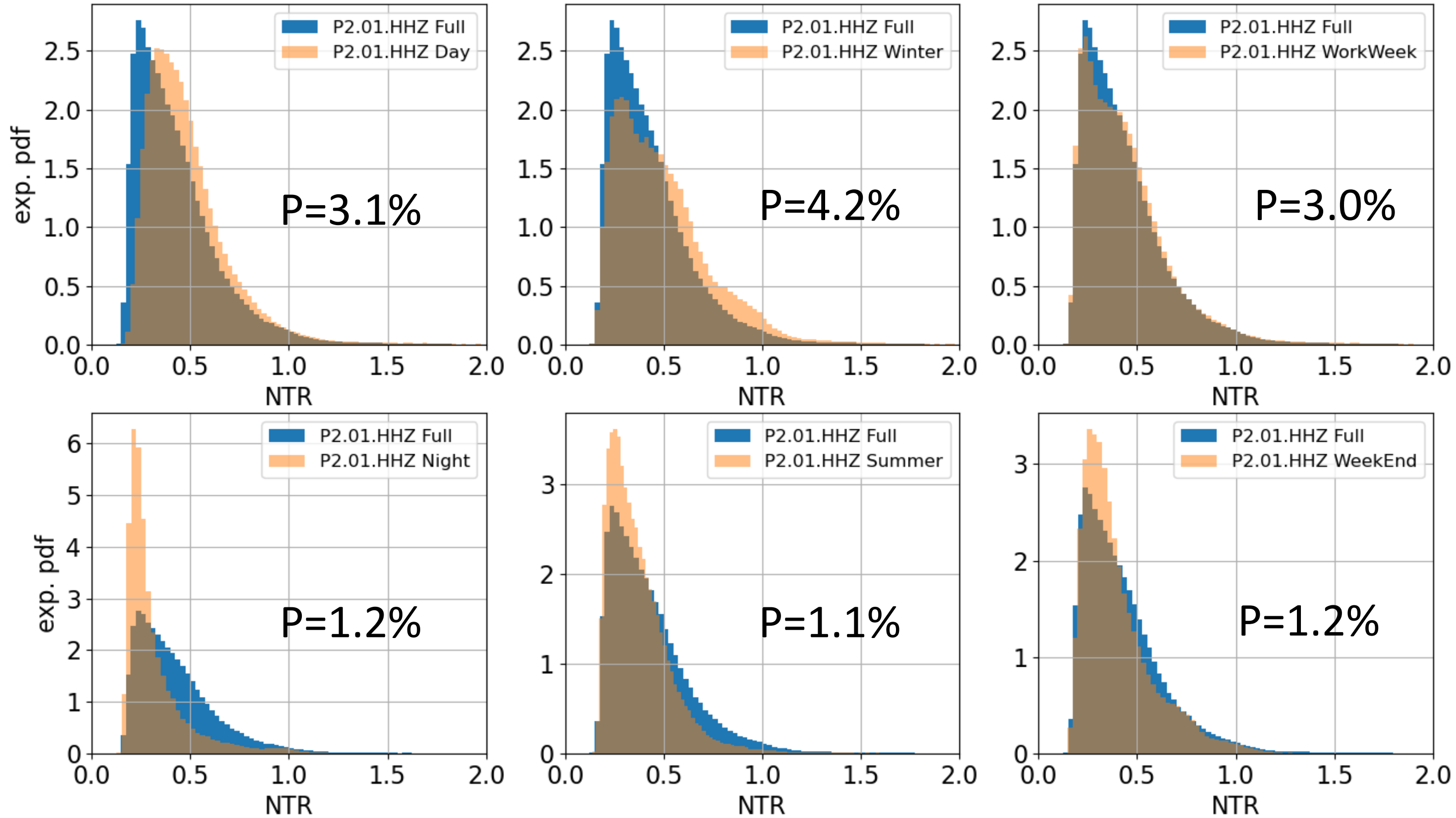




Spare Slides

P2 - NTR 3-10 Hz

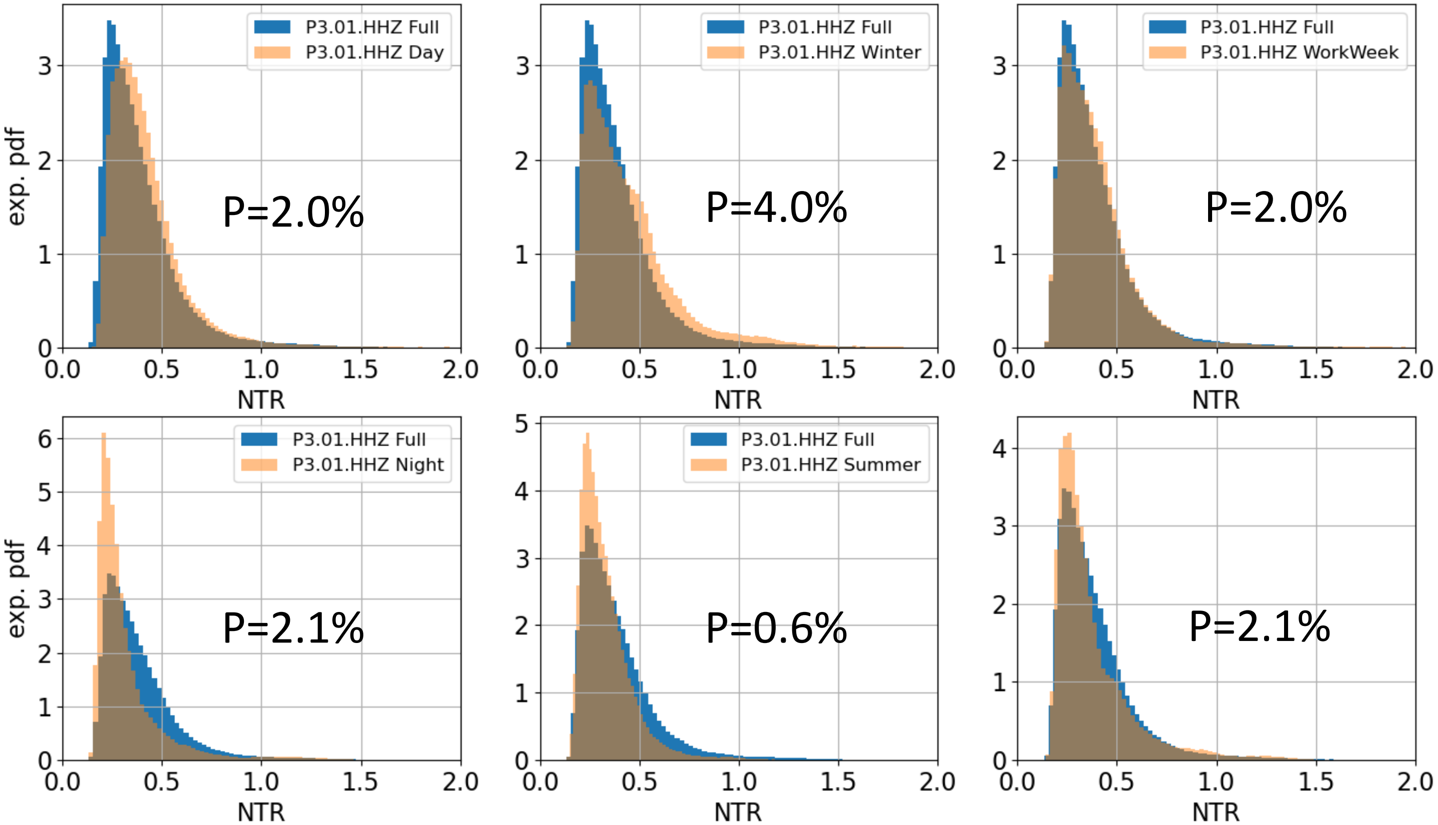
- Detailed distributions for each site:
  - P(NTR>1)=2.3%



Spare Slides

P3 - NTR 3-10 Hz

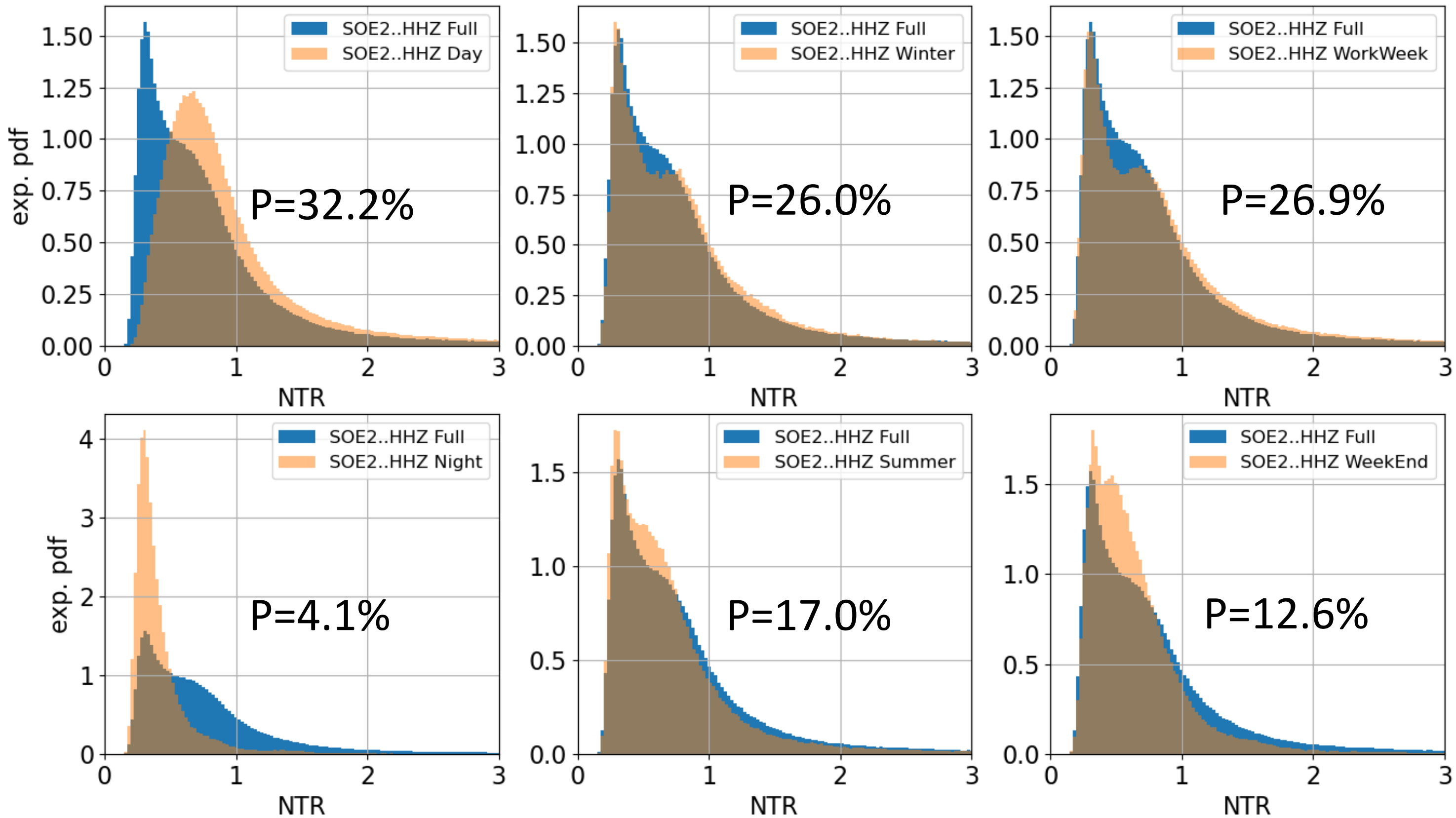
- Detailed distributions for each site:
  - P(NTR>1)=2.0%



Spare Slides

SOE2 - NTR 3-10 Hz

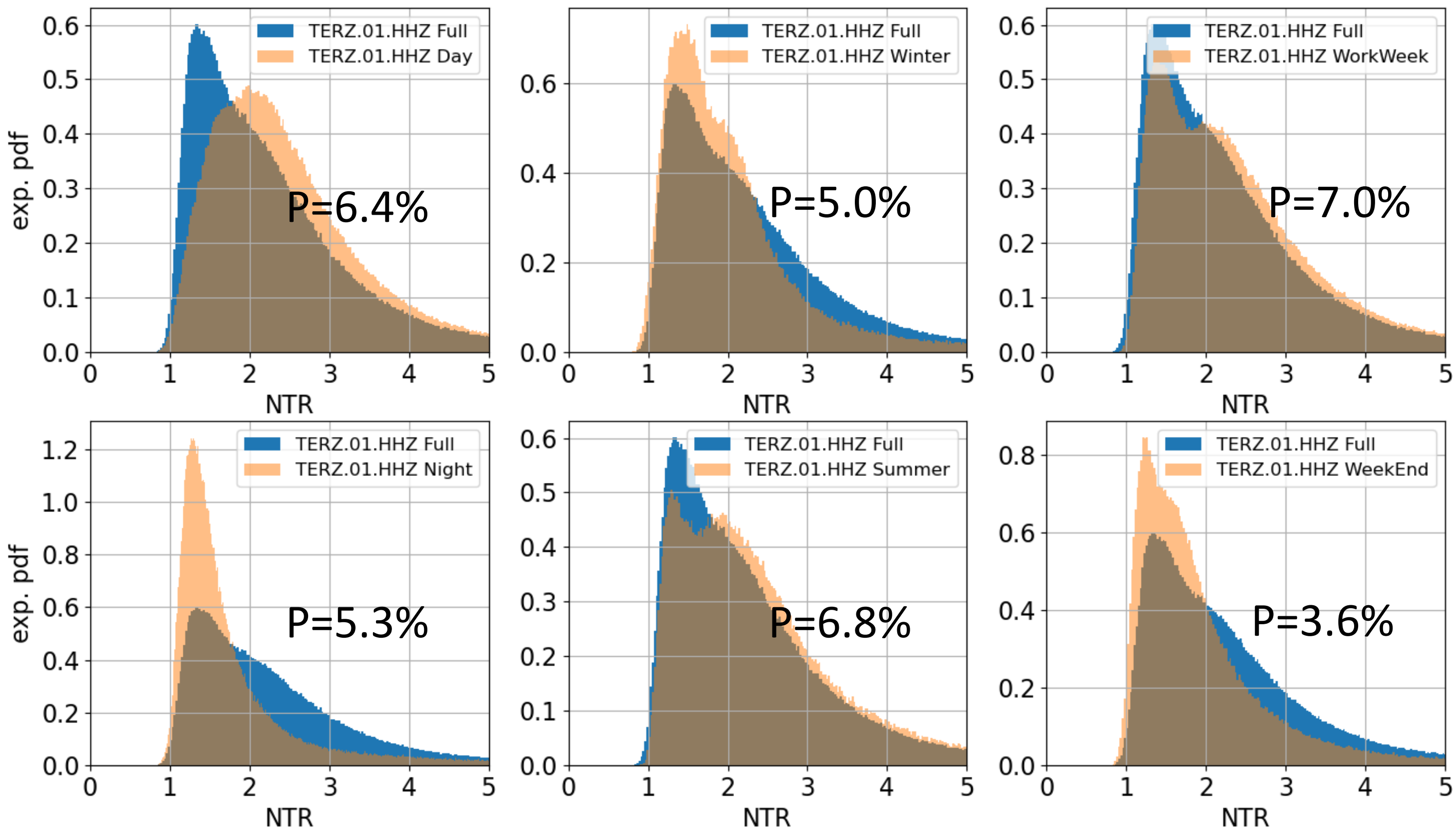
- Detailed distributions for each site:
  - P(NTR>1)=22.9%



Spare Slides

TERZ - NTR 3-10 Hz

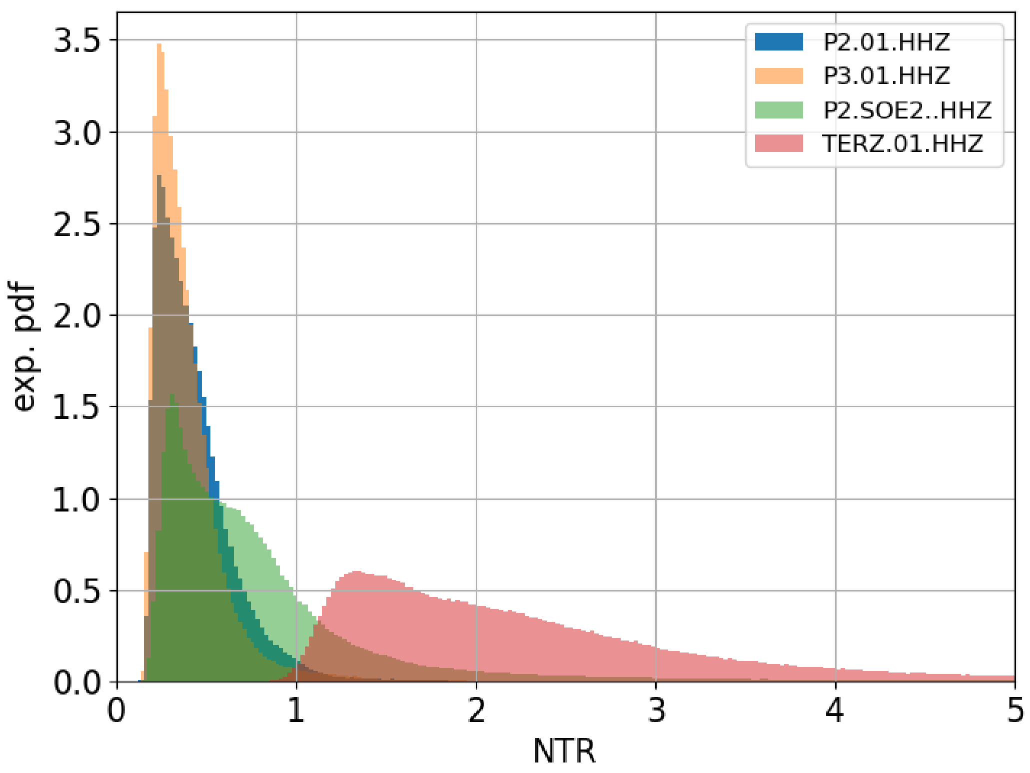
- Detailed distributions for each site:
  - P(NTR>5)=6.0%



Spare Slides

NTR Comparison (3-10 Hz)

- Comparison of the full distributions for each site



Spare Slides

V/H channels

- Comparison between NN estimation by vertical and horizontal channels