UPDATE ON MAGNETIC NOISE AT SOS ENATTOS

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with the contribution of many other people: A. Allocca, G. Ballardin, D. Barrale, A. Cardini, A. Contu, L. D'Onofrio, L. Errico, V. Fanti, I. Fiori, K. Janssens, C. Migoni, D. Mura, F. Paoletti, R. Romero, D. Rozza, M. C. Tringali, L. Trozzo, …

Summary

- Introduction
- EM noise
- Noise Variability
- Noise Coupling
- Surface and Underground Noise
- Conclusions

EM noise

Introduction

- Electromagnetic noise represents a widespread disturbance for any electronic equipment and magnetic (or charged) materials.

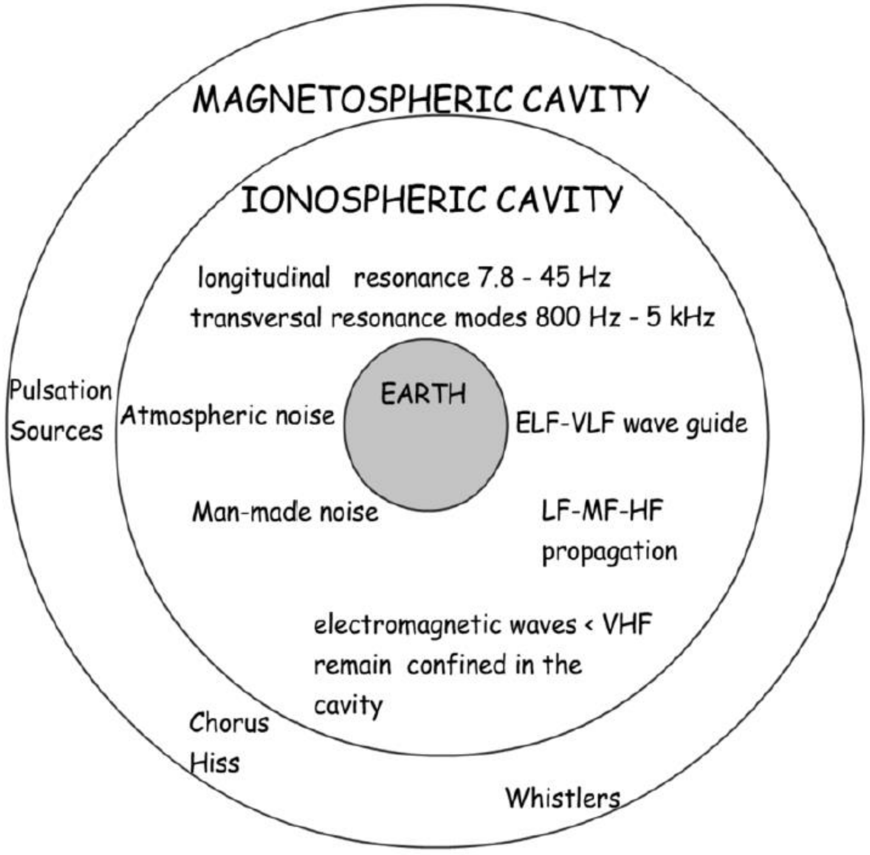
- In the frequency band of interest for ET, the main direct disturbance comes from the ULF (0.001-3 Hz), ELF (3-3000 Hz) up to VLF (3-30 kHz) radio bands, since they are overlapped with both ET-LF and ET-HF frequency bands;

- Other frequencies have also to be monitored, in the MHz range (HF: 3-30 MHz and VHF: 30-300 MHz), for possible disturbances on phase/amplitude modulation of the laser beams for locking/alignment purposes.

EM noise

Most relevant sources for LF-ET

- The main natural EM noise in the ULF/ELF bands is generated by resonance phenomena in magnetosphere and/or ionosphere cavities;
- The most important mechanisms, of interest for LF-ET, are:
  - Geomagnetic pulsations: mainly Pc1 (0.2 - 5 Hz):
    - Ion/proton-cyclotron waves in magnetospheric plasma;
  - Schumann resonances (5 - 100 Hz):
    - Combined effect of global lightning;
- There are also several artificial ELF sources. Most relevant for LF-ET:
  - Power lines (50 or 60 Hz);



C. Bianchi, A. Meloni,
Ann. of geophysics, 50, n. 3, June 2007

EM Noise

Sites Characterization

Magnetometers installed in the Sos Enattos area:

- 1 mag probe (N-S direction) in surface at Sos Enattos (SOE0)
- 2 mag probe (N-S and E-W directions) at -111 m underground at Sos Enattos (SOE2)
- 2 mag probe (N-S and E-W directions) in surface at Bitti (P2)

EM Noise

Site Comparison

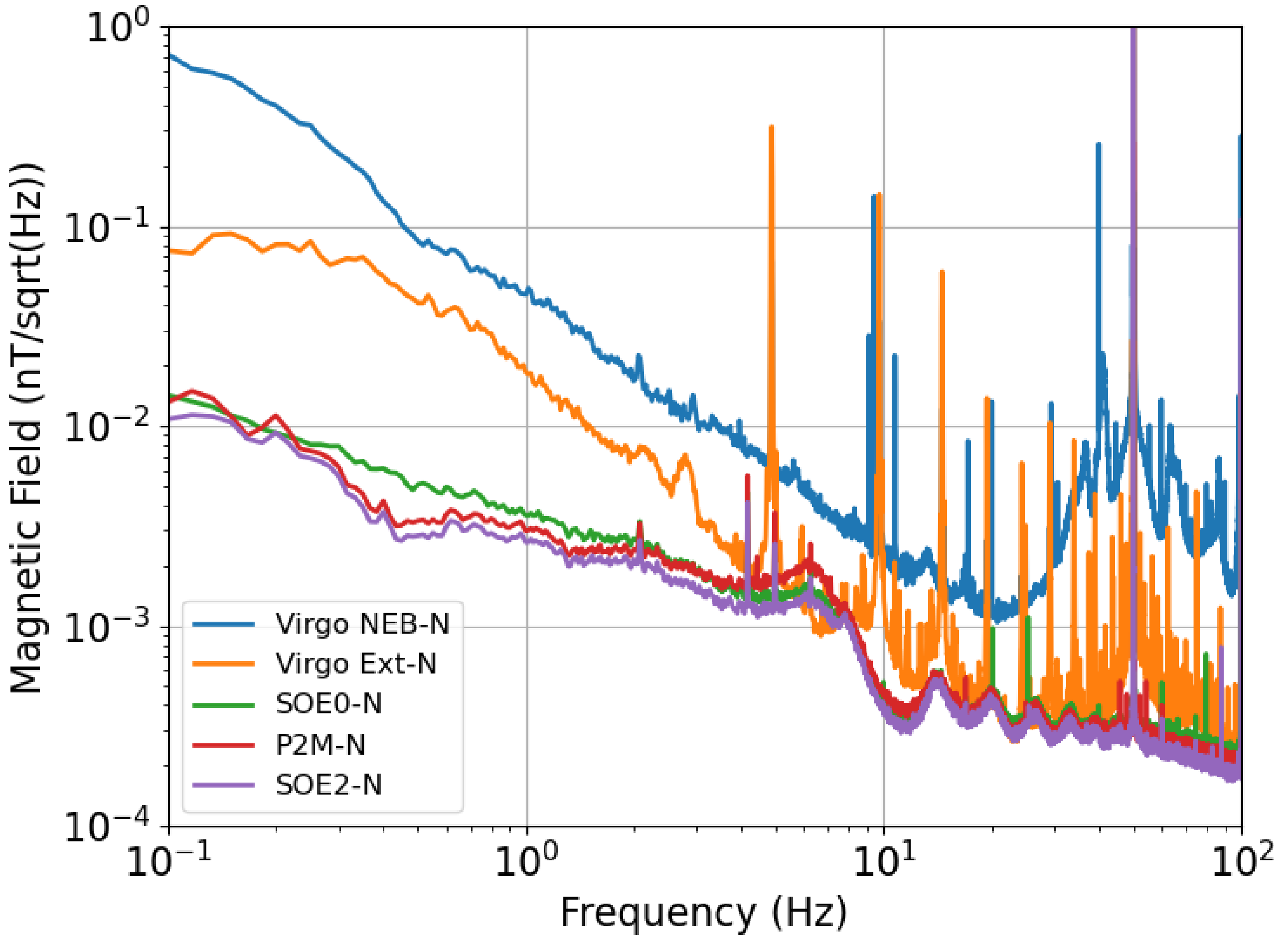
- The EM noise is strongly dependent on the location, mainly for the impact of the anthropogenic contribution;
- An example of magnetic noise spectrum for the same time, at different locations (Virgo, Sos Enattos, P2)

All data collected with same probe: MFS 06/MFS 06e

Different digitizer were used

Data starts at 2022-07-02_00:00:00

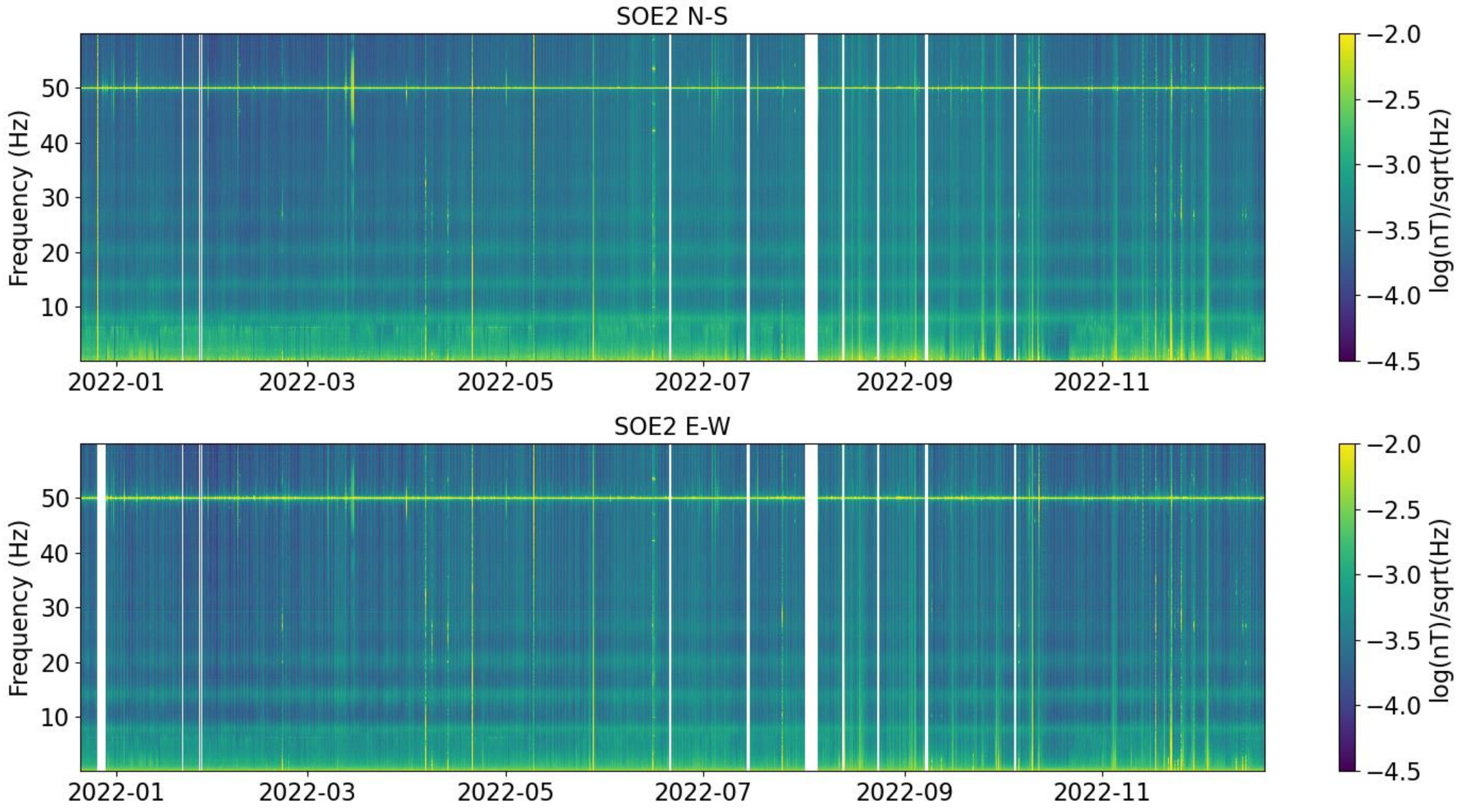
Duration: 7200 s



Noise Variability

Long Term Monitoring

- The long-term monitoring in a such quiet site, allows to clearly detect regular structure or periodic variability;



Probes installed at SOE2:
Sos Enattos level 2 (-111 m)

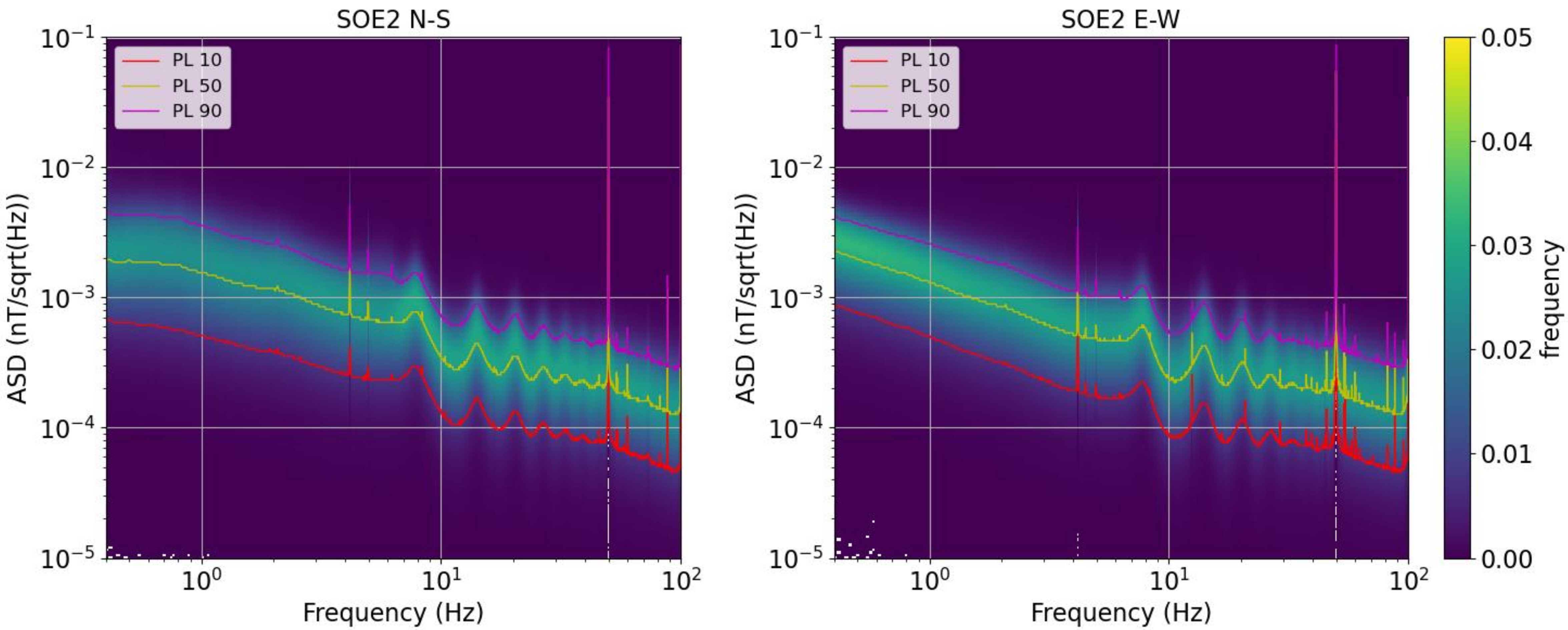
Data starts at
2021-12-21_00:00:00

Duration: one year

Noise Variability

Long Term Monitoring

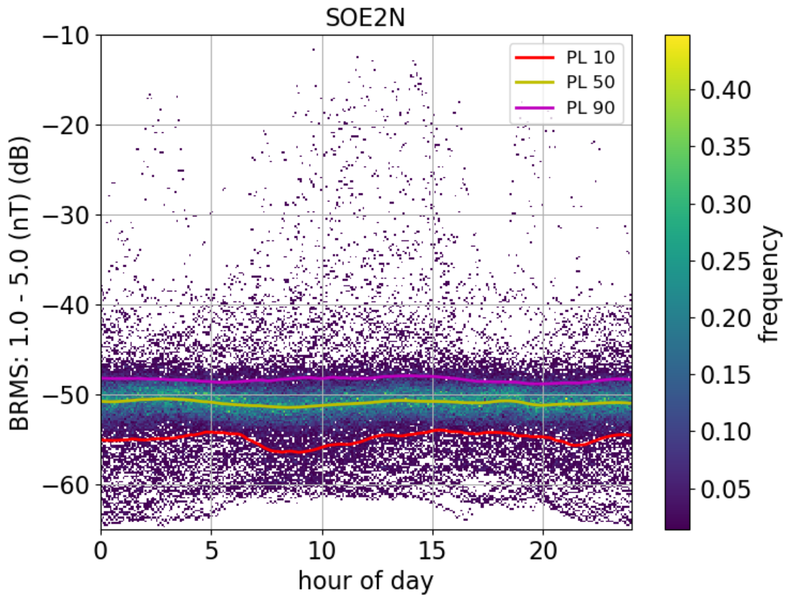
- SR well visible up to 6[th] order

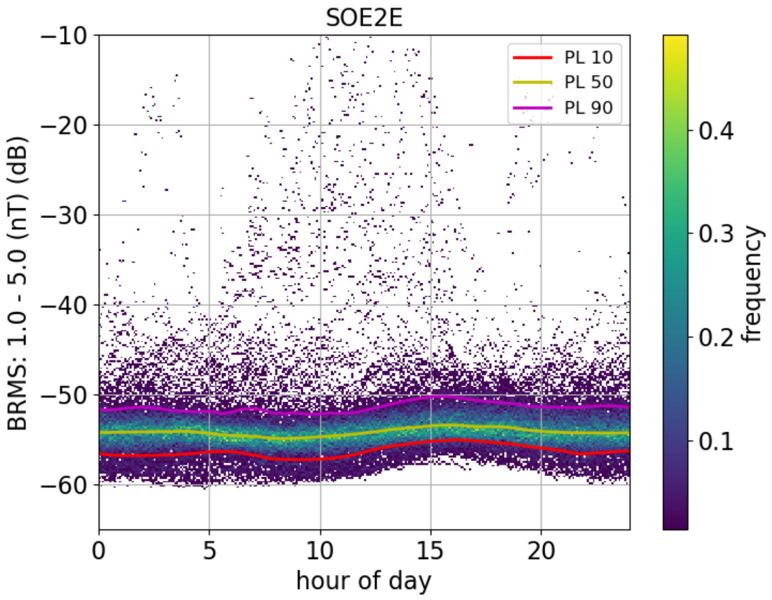


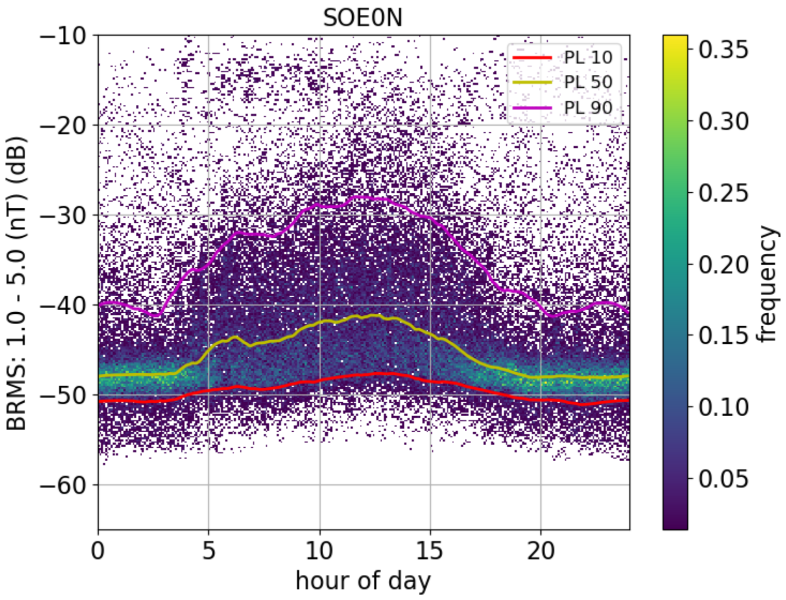
Noise Variability

BRMS

- Day-Night variation in the band 1-5 Hz;
- Noise increasing during daytime significant only in surface;



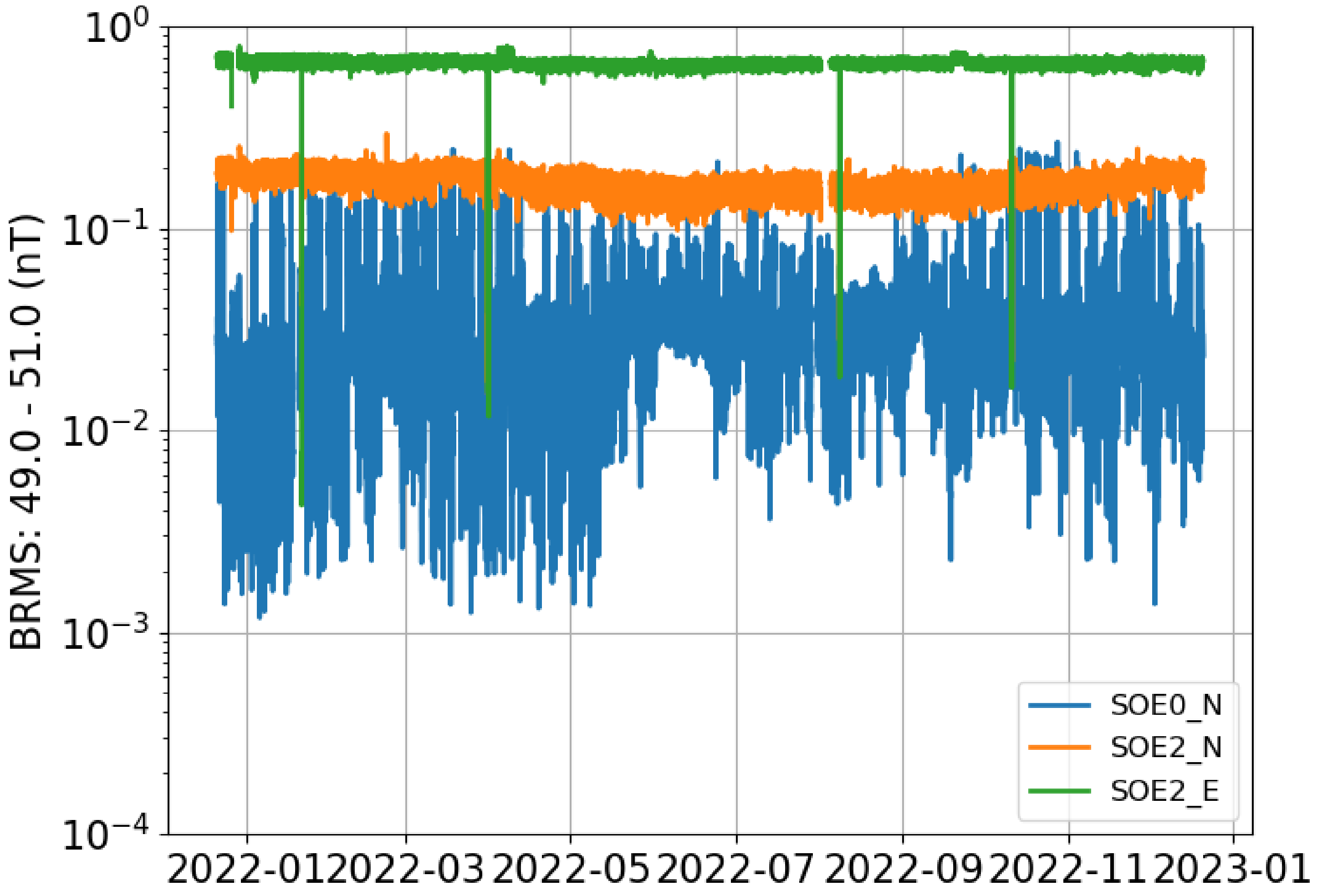




Noise Variability

BRMS

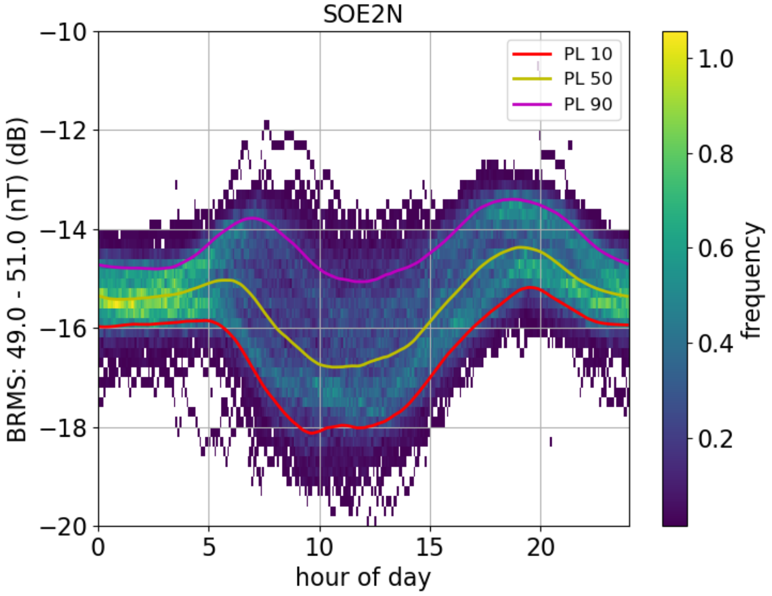
- Noise in the band 49-51 Hz
- Underground probes close to electronics device and mains
- Low contamination visible in the surface magnetometer;

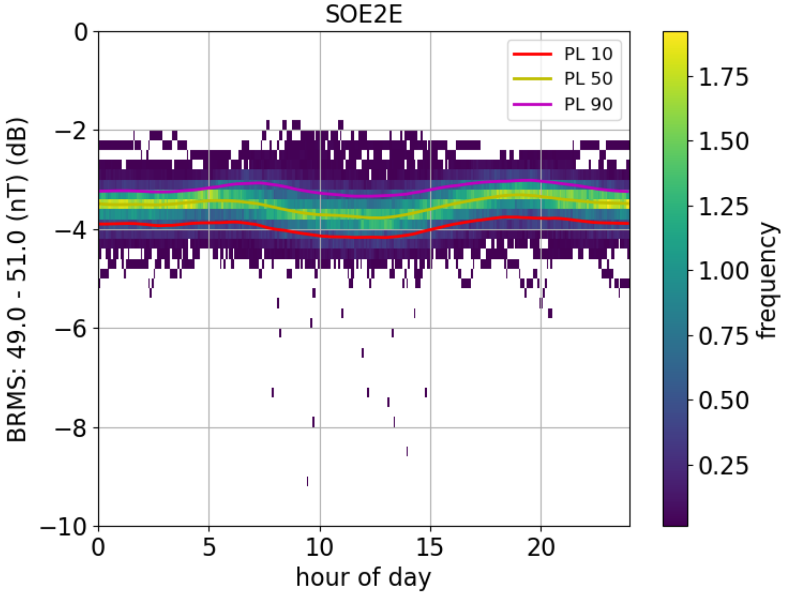


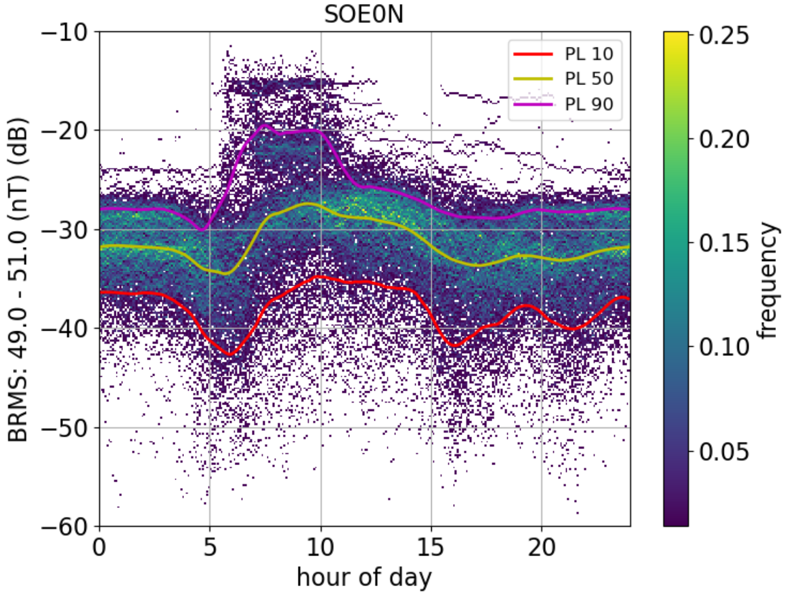
Noise Variability

BRMS

- Noise in the band 49-51 Hz
- No strong dependency from day/night time, especially for underground probes







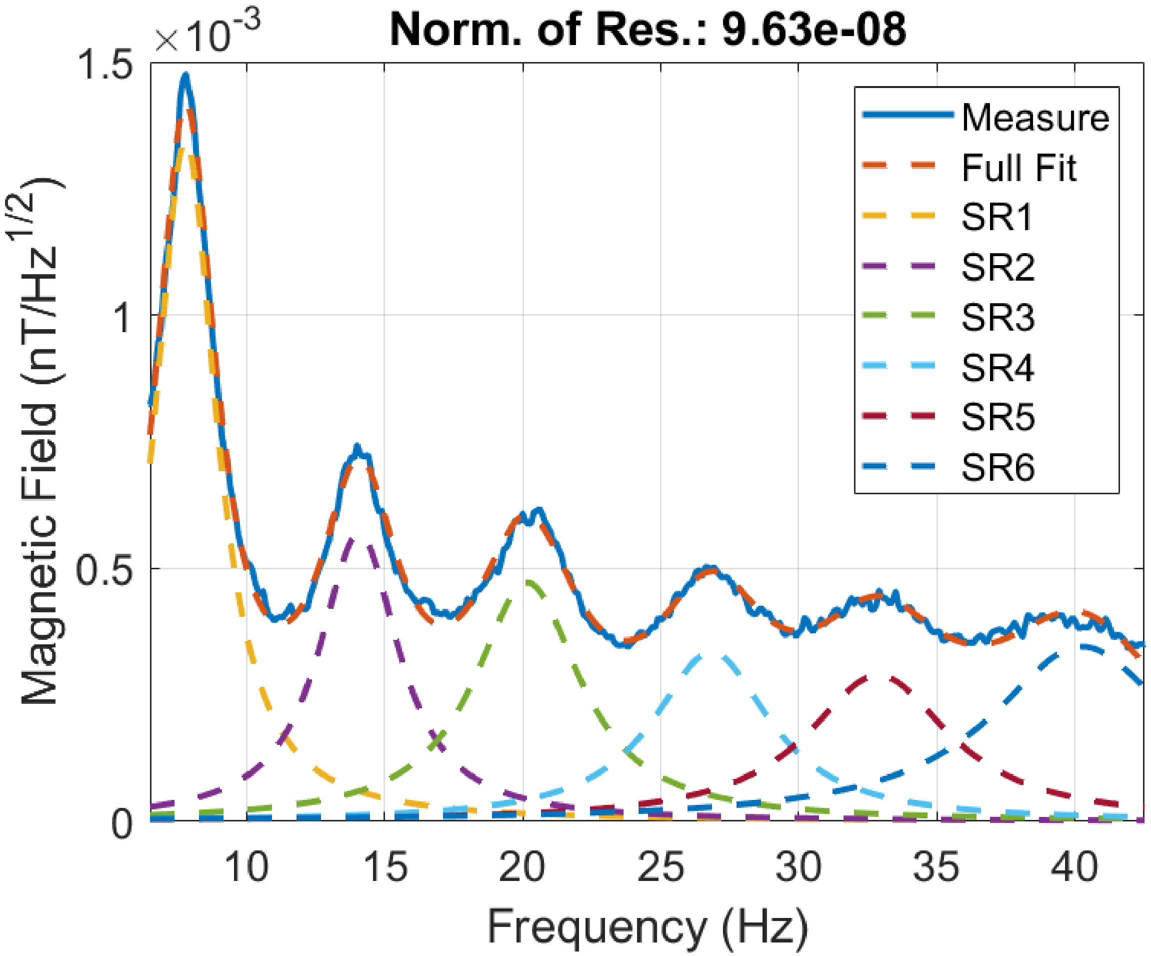
Noise Variability

Schumann Resonances Fit

- To effectively study the variability of the SR, a standard Lorentzian fit was used

- $\tilde{B}(f) = \sum_{i=1}^{N} \frac{A_i}{\frac{(f-f_i)^2}{B_i^2}+1}$

- Where A_i, f_i and B_i are the peak-amplitude, the center frequency and the bandwidth of the i-th resonance respectively.

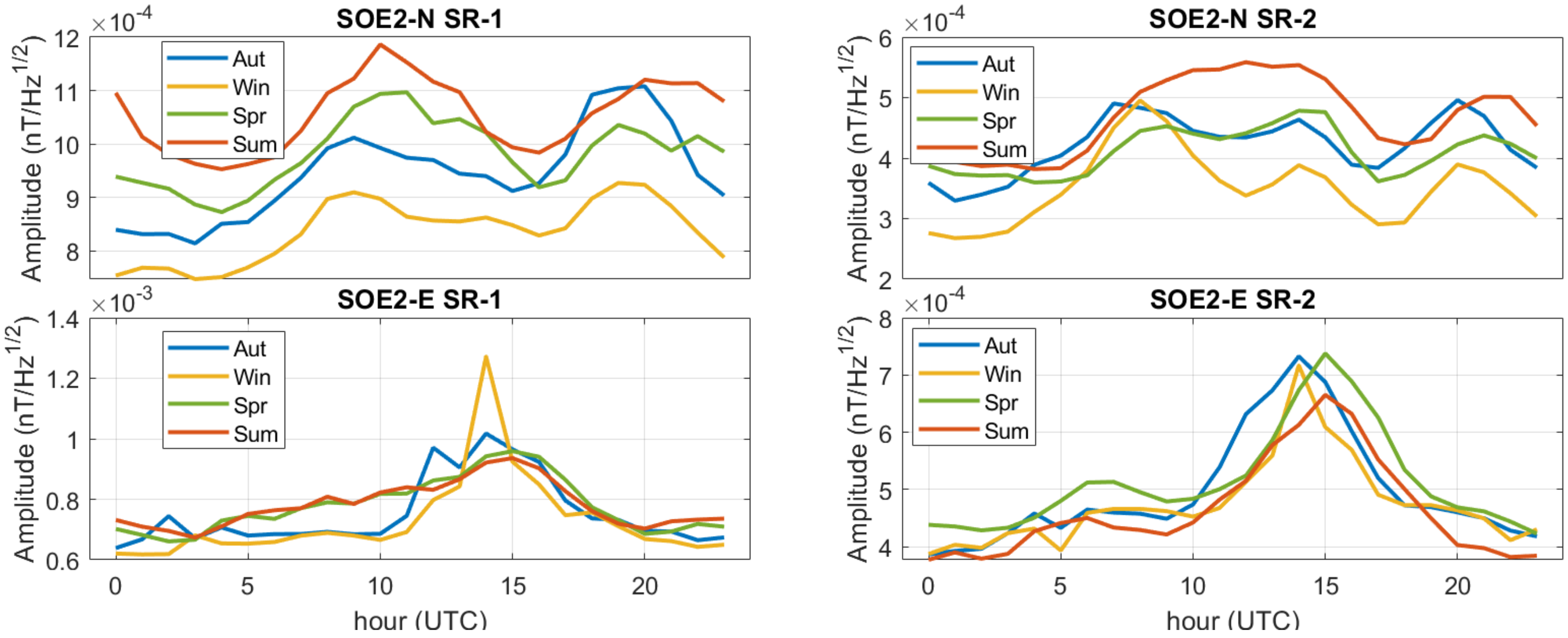


C. Price, A Melnikov, *Journal of Atmospheric and Solar-Terrestrial Physics* ***66*** *(2004) 1179– 1185*

Noise Variability

Daily and Seasonal variability

- SR show typical daily/seasonal variation in amplitude;
- The daily variation is due to the contribution of the three main lightning sources, located in tropical regions: South-East Asia (08:00 UTC), Africa (14:00 UTC) and South-America (20:00 UTC);



Waves from Africa are more clearly visible in E-W oriented probe, while the other are dominant in the N-S probe

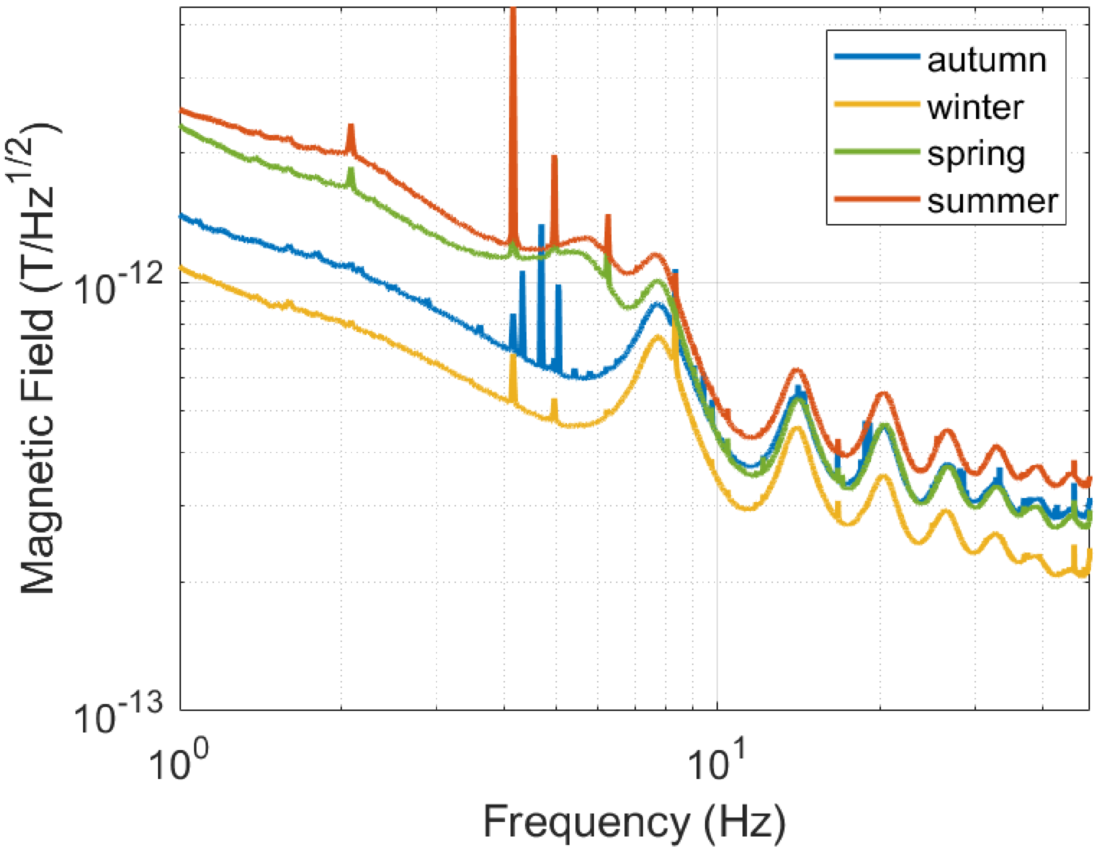
H Zhou, H Yu, B Cao, X Qiao, *Journal of Atmospheric and Solar-Terrestrial Physics* **98** (2013) 86–96;

G. Tatsis et al., *Science of the Total Environment* **715** (2020) 136926.

Noise Variability

Daily and Seasonal variability

- The seasonal variability is evident;
- It is driven by the intensity of lighting activity;

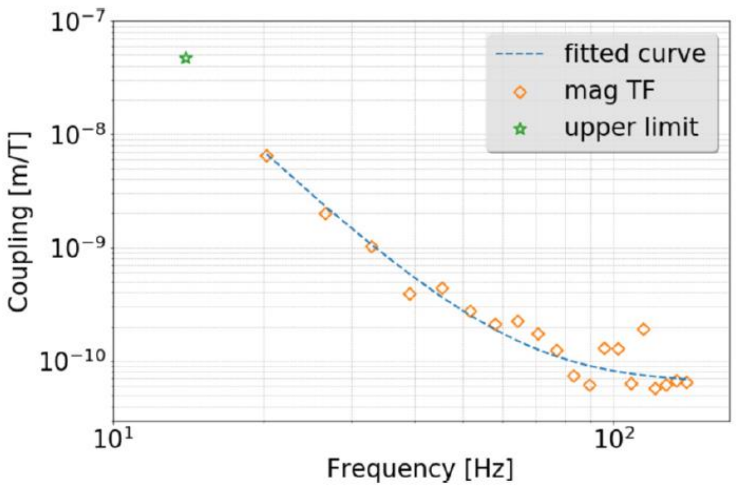


Data collected in SOE2 NS oriented MFS 06 magnetometer

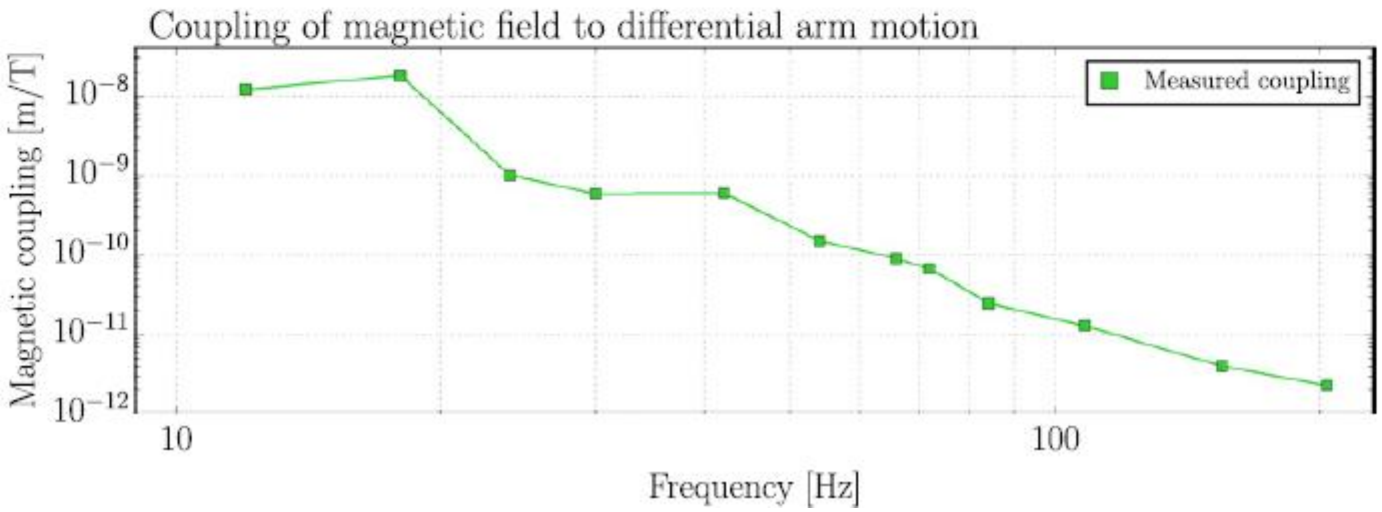
Noise Coupling

Old Studies

- EM Noise coupling is enough well understood at low frequency:
  - it couples directly with electromagnetic actuators of mirrors or other element of the suspension chain;
  - At higher frequency, still inside the detector band, the coupling is more difficult to model, since the noise is believed to couple with cabling going inside the chamber or with electronic devices managing critical signal of the ITF;
  - Several works published on this item…



A Cirone *et al* 2019 *Class. Quantum Grav.* **36** 225004

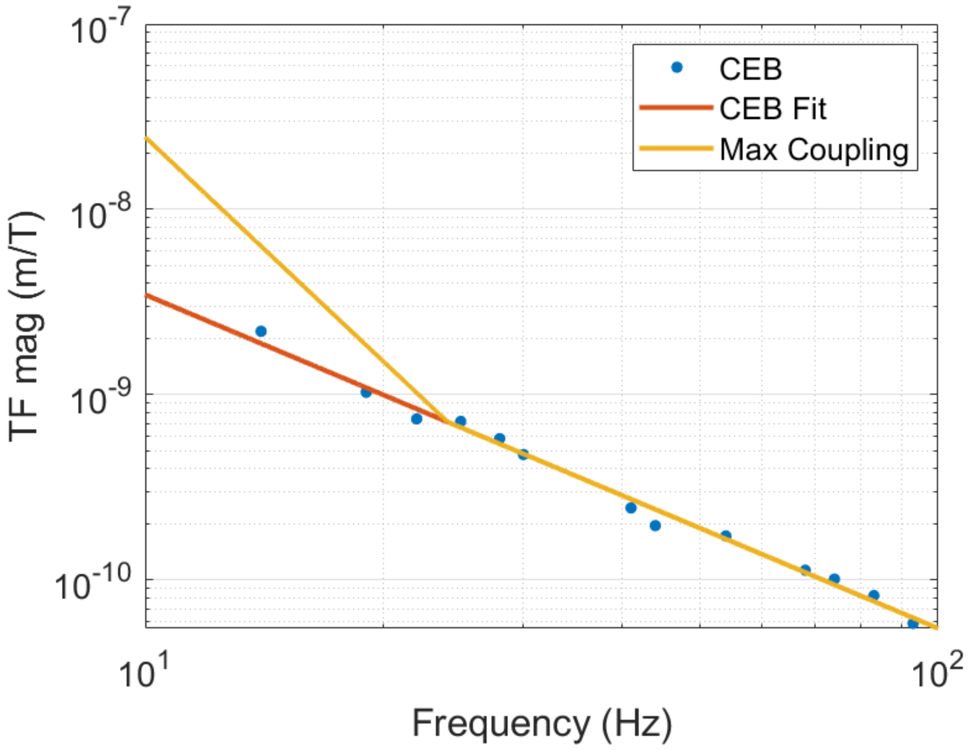


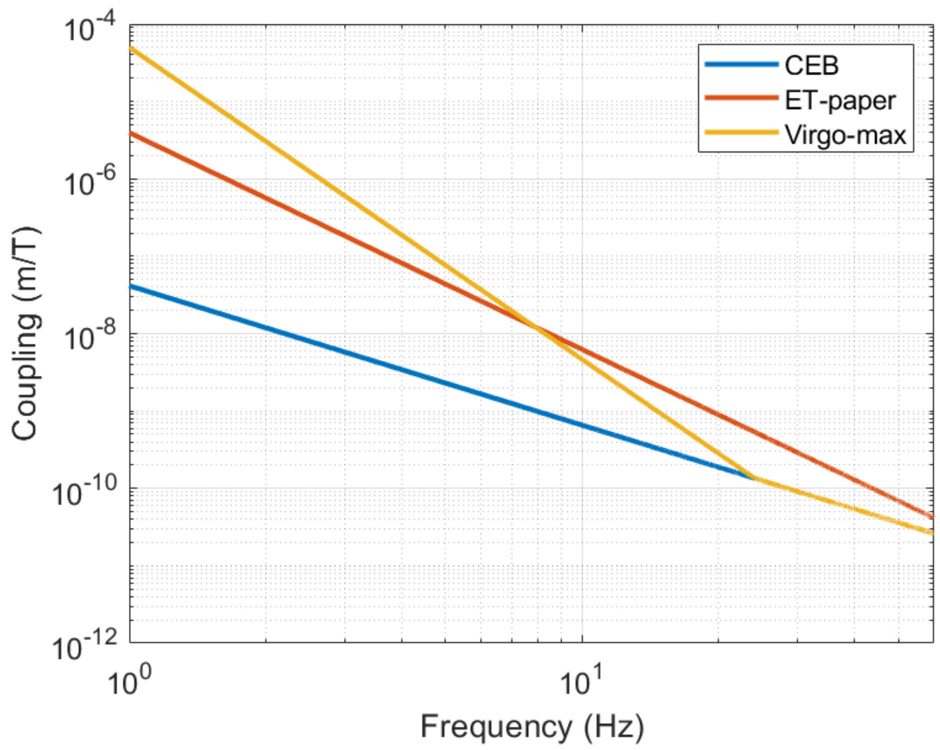
B.P. Abbot *et al.*, *2016 Class. Quantum Grav.* **33** 134001

Noise Coupling

Results from Virgo and Sos Enattos

- The noise coupling as measured at Virgo, including only the contribution measured at CEB, or the full contribution (CEB+NEB+WEB) is compared with the coupling used in the ET paper. The noise model is compared with the measurements performed in Sos Enattos

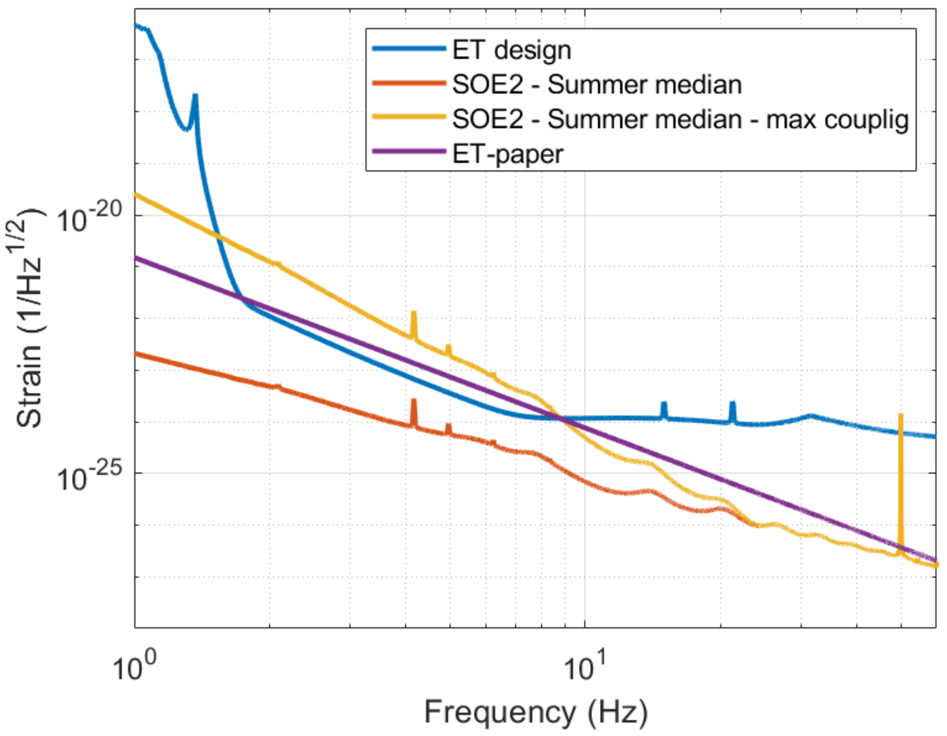


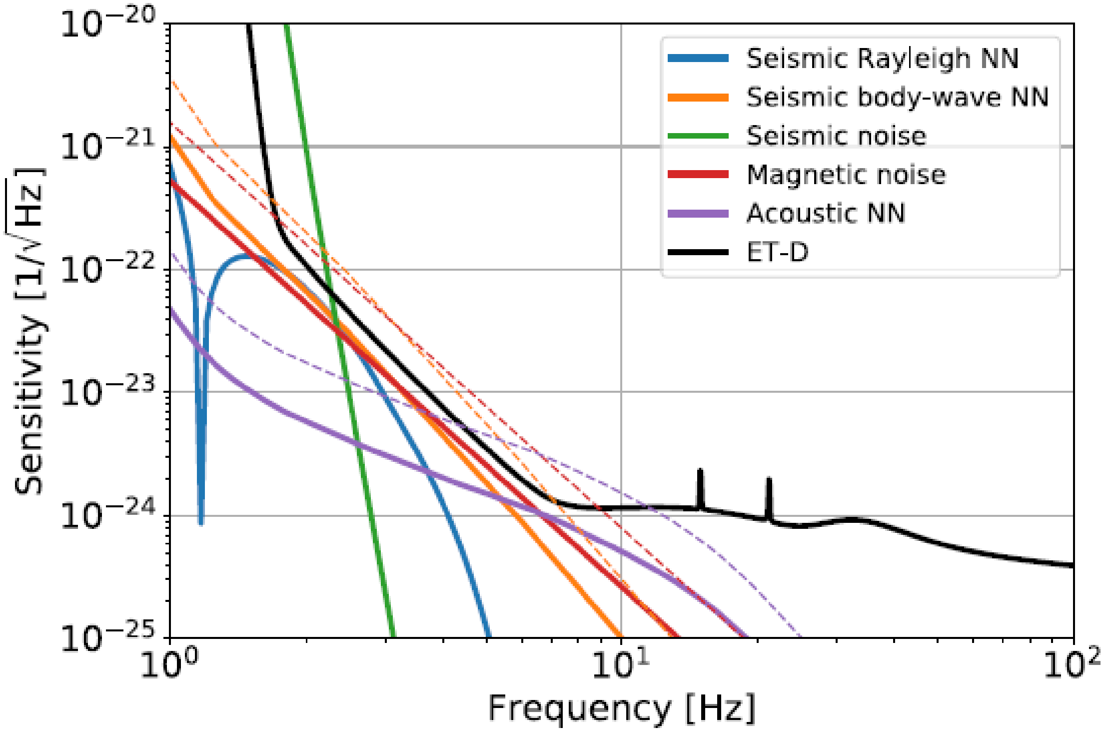


Noise Coupling

Noise Projections

- The magnetic noise projections with different assumption, compared to the published projection;
- Coupling measured from10 Hz, extrapolated for lower frequencies;



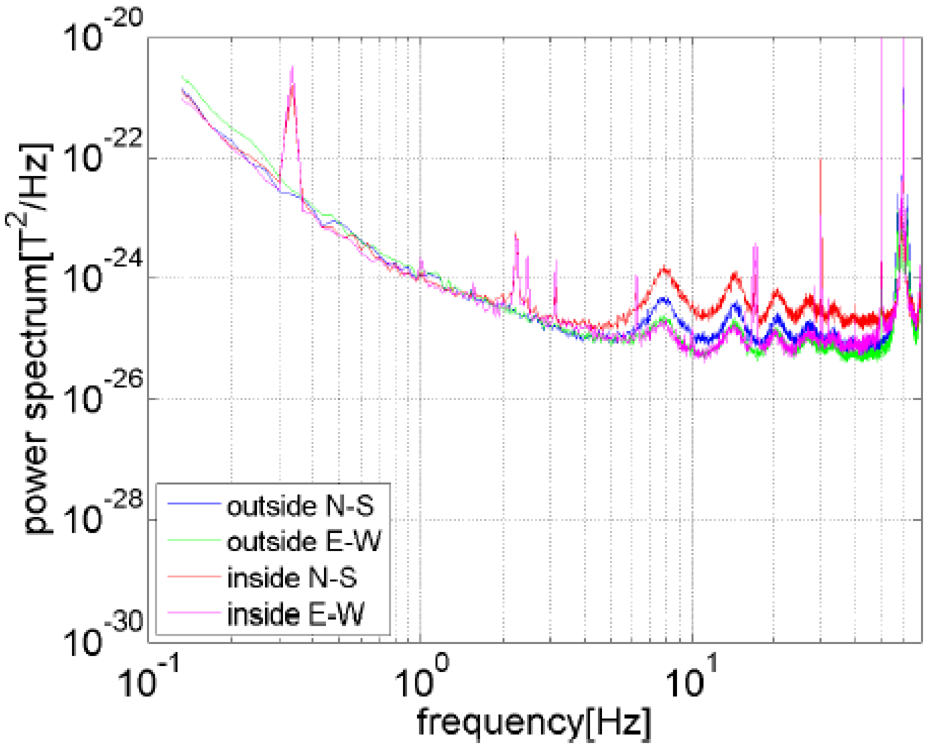


F. Amann *et al. 2020 Rev Sci Instrum.* **91** 094504

Surface and Underground Noise

Measurement Results

- Following the published paper, the magnetic noise should be subtracted to reach the ET sensitivity goal;
- Noise subtraction relies on magnetic field measurements performed in a quiet environment;
- Old measurements reported increased underground magnetic noise due to rock composition or alterations induced by close metallic;
- More recent studies suggested that the noise excess was due to the magnetic filed induced by vacuum pipes;



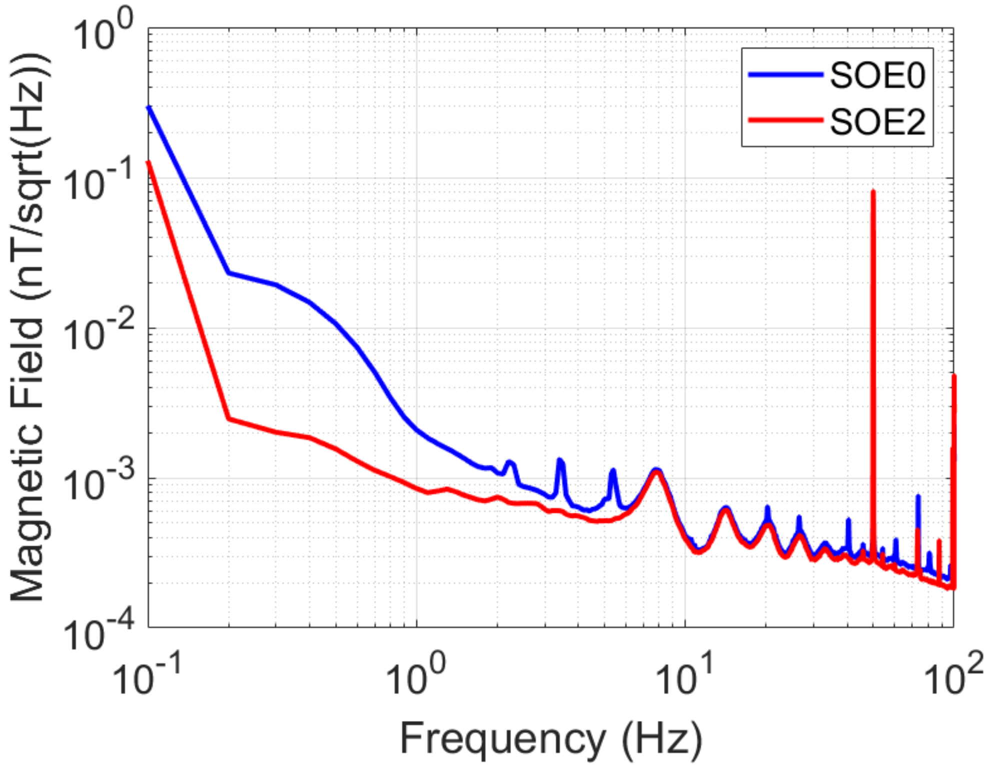
S. Atsuta *et al.* *2016 J. Phys. Conf. Ser.* **716** 012020

Surface and Underground Noise

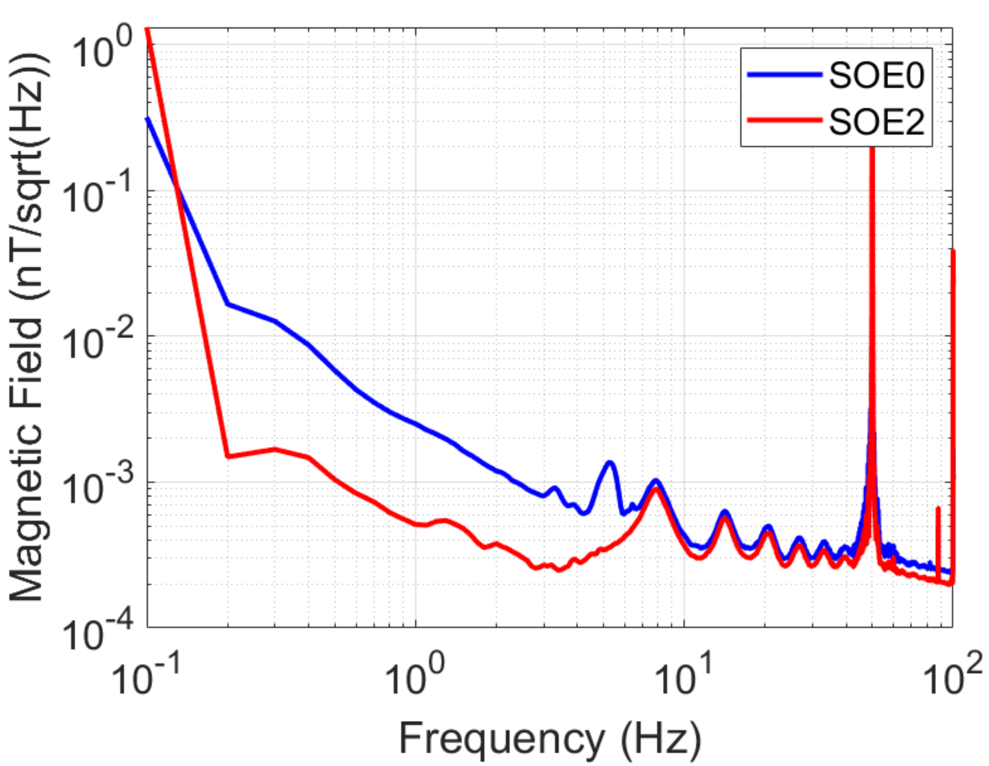
Measurement Results

- In Sos Enattos there are hints that the underground magnetic field is equal or even lower respect to the surface;

Data collected on 2021 October 17, 20:00:00



Data collected on 2022 October 17, 20:00:00



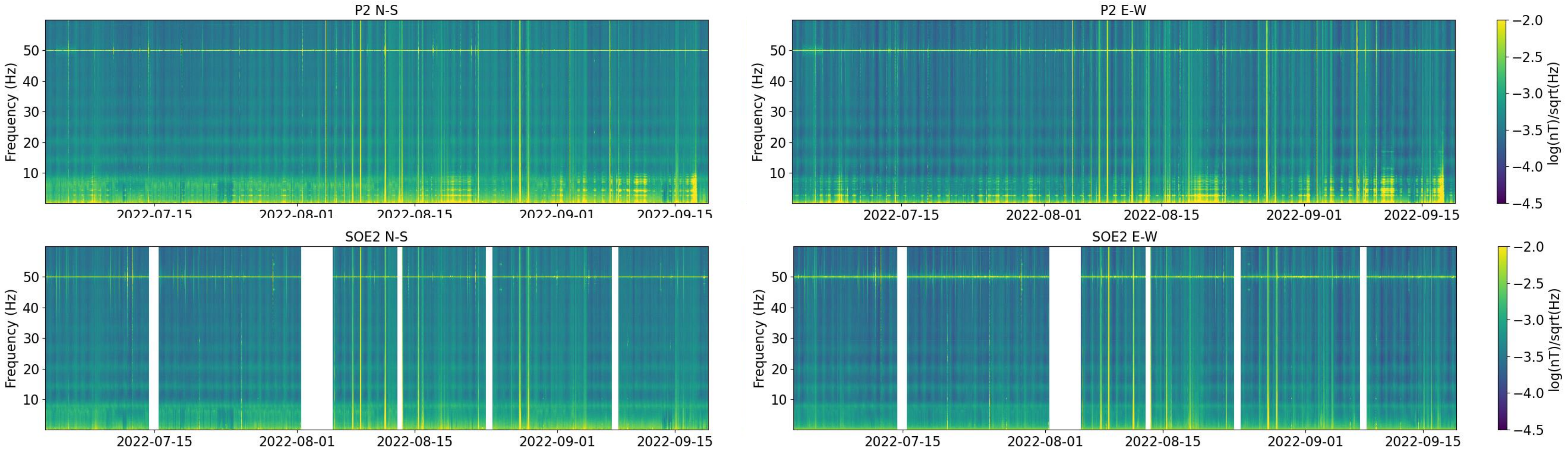
Surface and Underground Noise

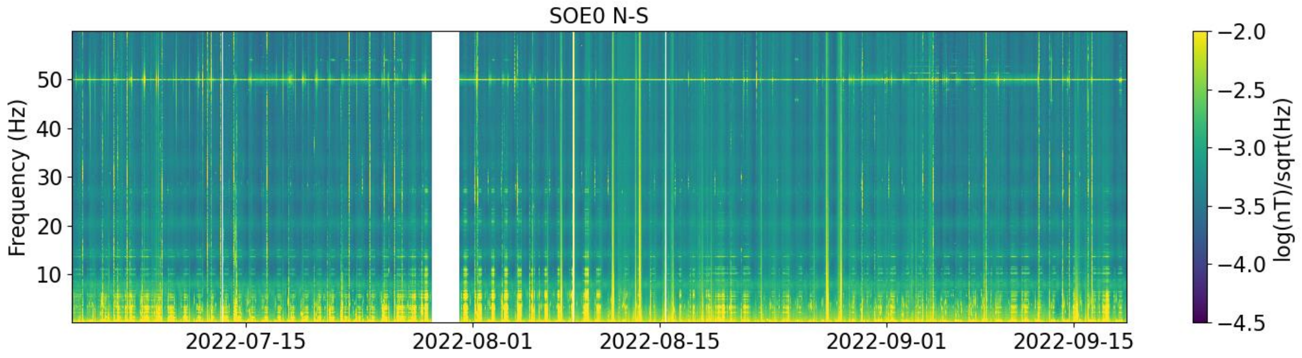
Measurement Results

- Thanks to the probes installed at P2 (Bitti) it is possible to compare far (about 10 km) magnetometers;
- The probes at P2 were first installed on 18 September 2021, and re-arranged in a better way (and orientation) on 2 July 2022;
- Probes were buried at few cm depth (surface probes);

Surface and Underground Noise

Measurement Results



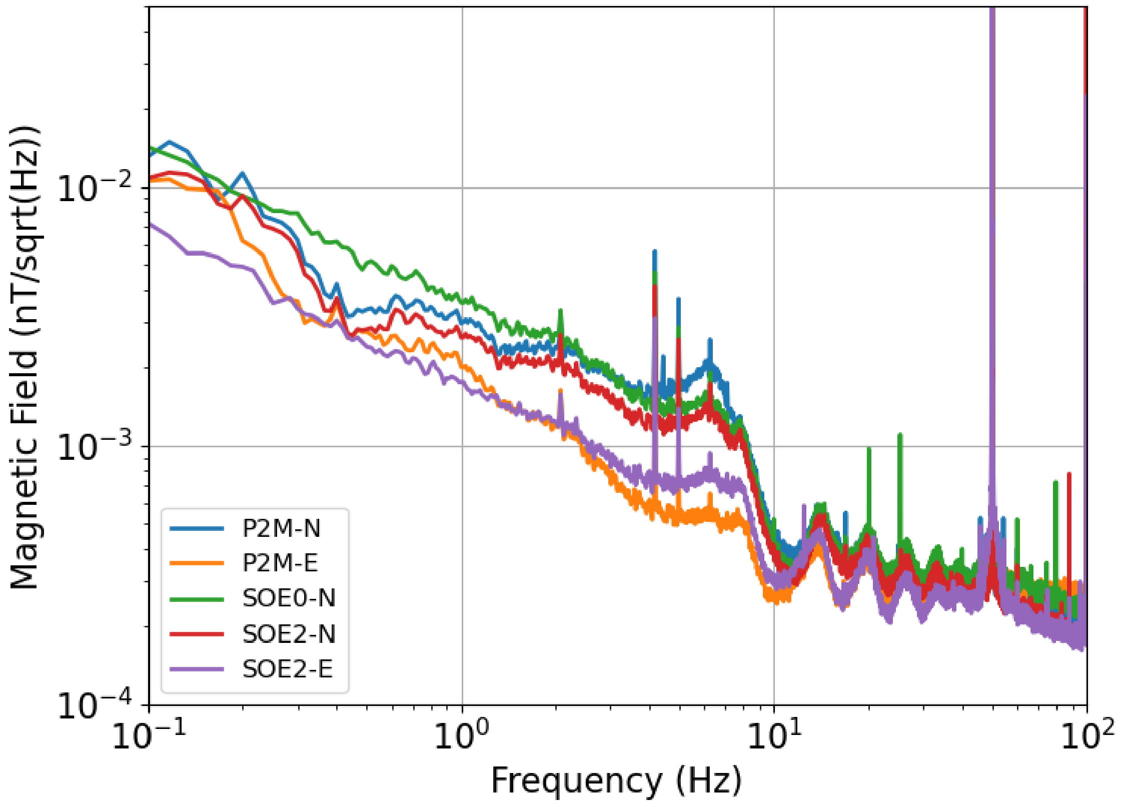


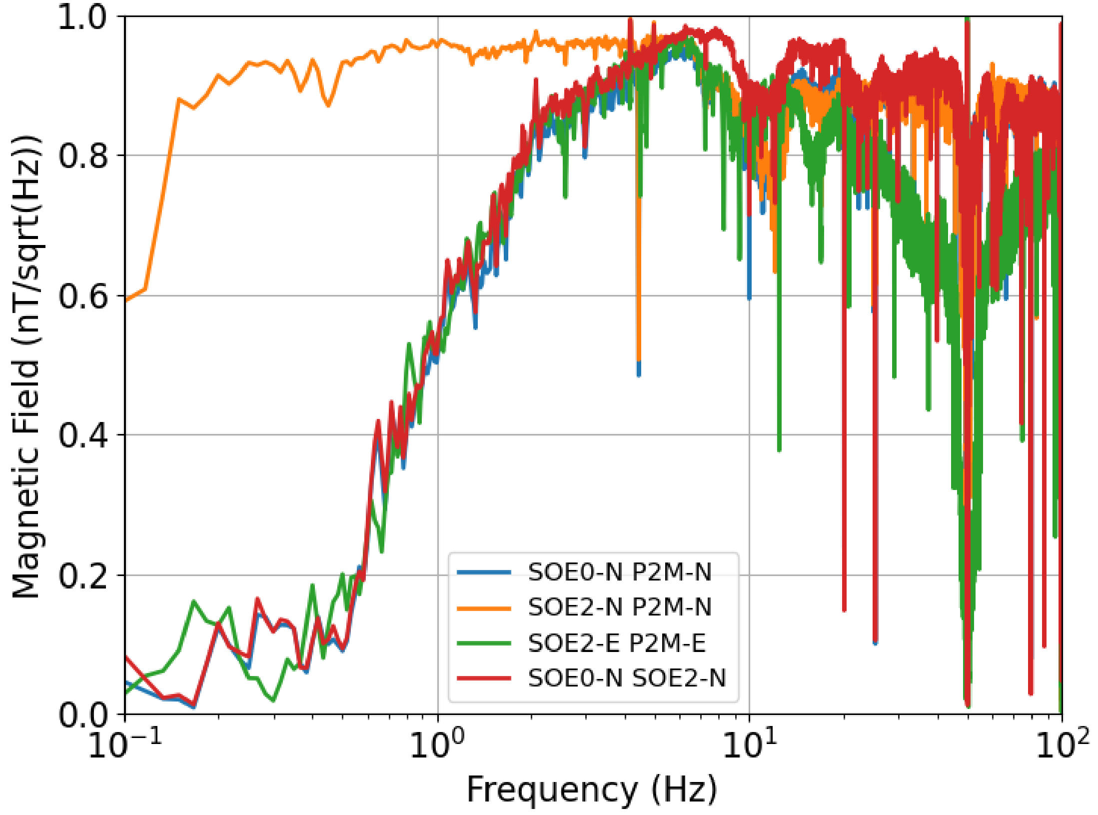
Data from 2022_07_02-00:00:00
Duration 79 days

Surface and Underground Noise

Measurement Results

- Good coherence for magnetometer with same orientation in the SR band;
- Unexpected large coherence at low frequency for SOE2-N and P2M-N





Next Steps

- Installation of vertical magnetometer at P2
- Installation of 3 magnetometers at P3
- Installation of a surface magnetometer at SOE0 (E-W direction)
- Centaur DAQ at P2 and P3 instead of ADU08 (more safe: require interface electronics already in production)

- Going on with long-term site characterization

Conclusions

- Data available from 3 probes at Sos Enattos from 2021 November 15;
- Some data chunk collected at P2 from horizontal magnetometer from 2021 September 18;
- Study of SR well established;
- Underground noise level limited by SR in the range 7-40 Hz;

- Preliminary noise projection strongly depend on the coupling mechanism
- Limited impact of antropogenic e.m. noise;