Comparison of noise levels of different magnetometer types and space environments

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1. Abstract

The plasma environment around Earth is divided into several distinct regions with vastly different characteristics of the magnetic field. For example, inside the magnetosphere the magnetic field can reach tens of thousands of nanotesla. In the magnetosheath between Earth's magnetosphere and the bow shock, the magnetic field is lower, but significantly more turbulent. In the solar wind outside Earth's magnetic influence, magnetic fields are low and less fluctuating. Magnetic fields in space have typically been measured with fluxgate magnetometers on spacecraft. In recent years, various magnetometer types have been discussed and/or flown, i.e. optically pumped magnetometers or anisotropic magnetoresistive (AMR) magnetometers. We discuss and compare noise level performances of diverse magnetometer types and contrast them with the requirements needed to accurately observe the magnetic field and distinct plasma phenomena therein in particular regions of space for scientific research.

2. Methods and Data

- Magnetosphere: ioncyclotron waves as found in [1] on 04-07-2007
- Magnetosheath: list provided with [2] of THEMIS data between 24-06-2008 to 28-09-2009
- Solar wind intervals: list by Thilo Glißmann (personal communication) of THEMIS B data between 12-06-2008 and 13-12-2009
- Magnetometer: standard fluxgate and the AMR magnetometer for the SOSMAG mission put in a magnetically shielded environment and measured over night

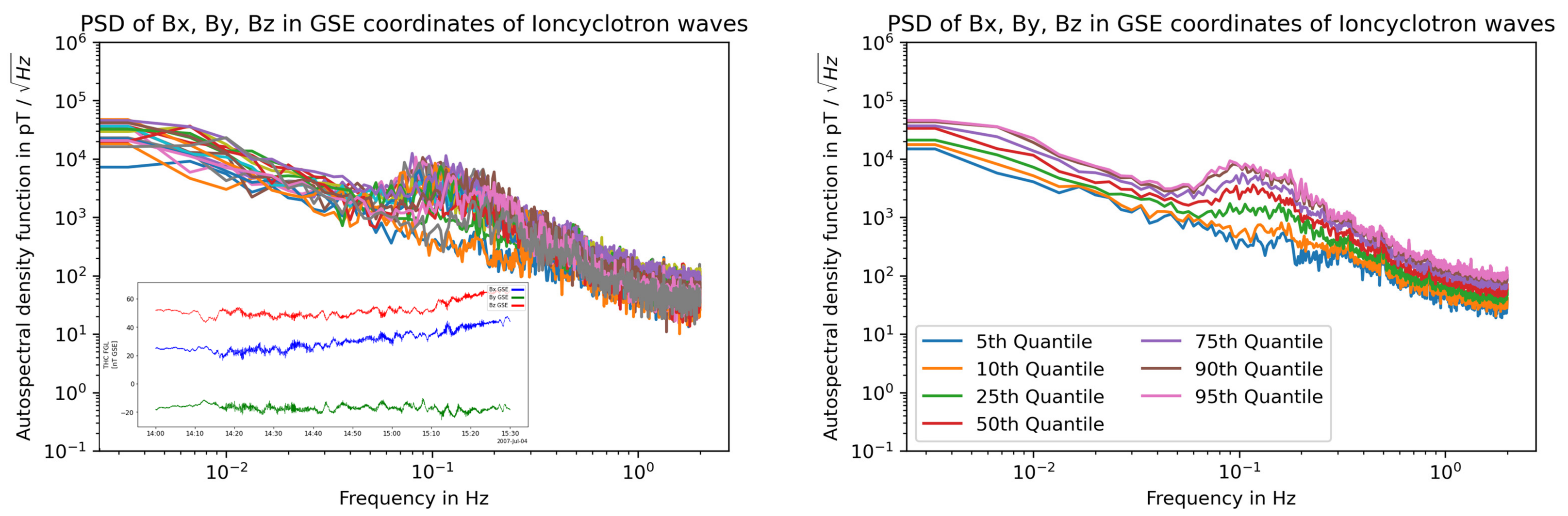
For all the data sets, the following approach was used:

- Read in raw data and split it in 5 min long intervals, discard any possible rest
- Calculate the power spectral density (PSD) with a discrete Fourier transform according to the following formula:

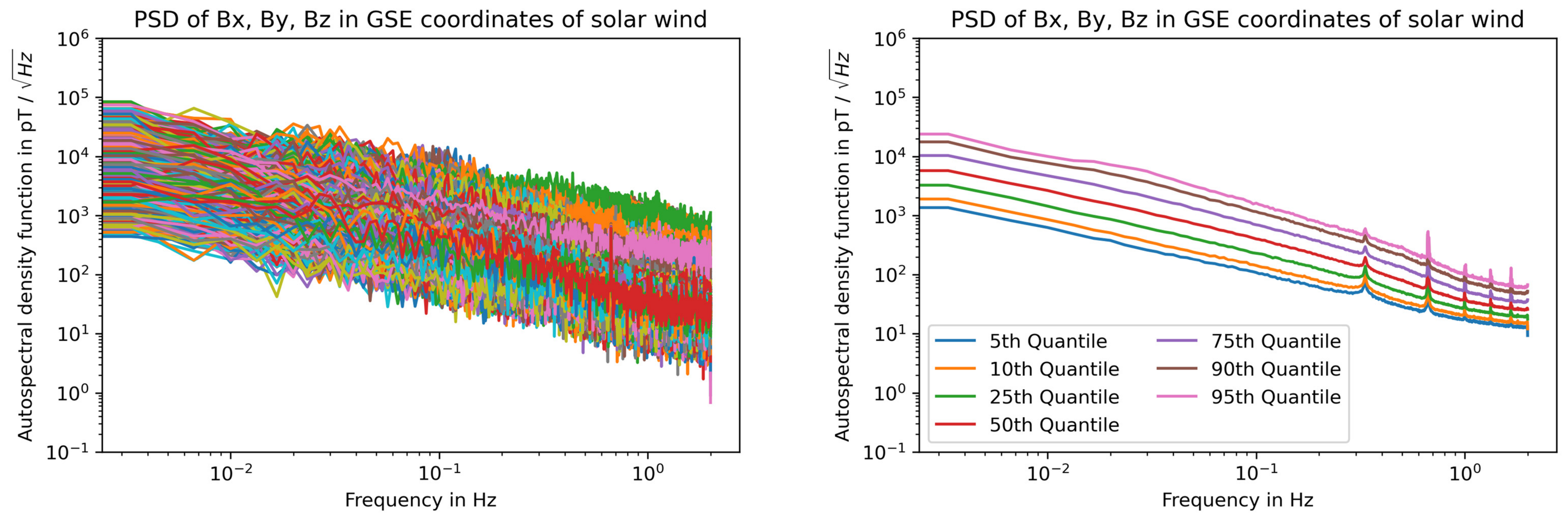
$$PSD = \frac{2\,dt}{N}\sum_{x,y,z}\left|\sum_{m=0}^{N-1} a_m \exp\left\{-2\pi i\,\frac{mk}{N}\right\}\right|^2$$ N: length of input k: 0,1,..., N-1

- Calculate the 5th, 10th, 25th, 50th, 75th, 90th, and 95th quantile
- Plot the PSD of each of the 5 min intervals all in one figure as well as the quantiles in another

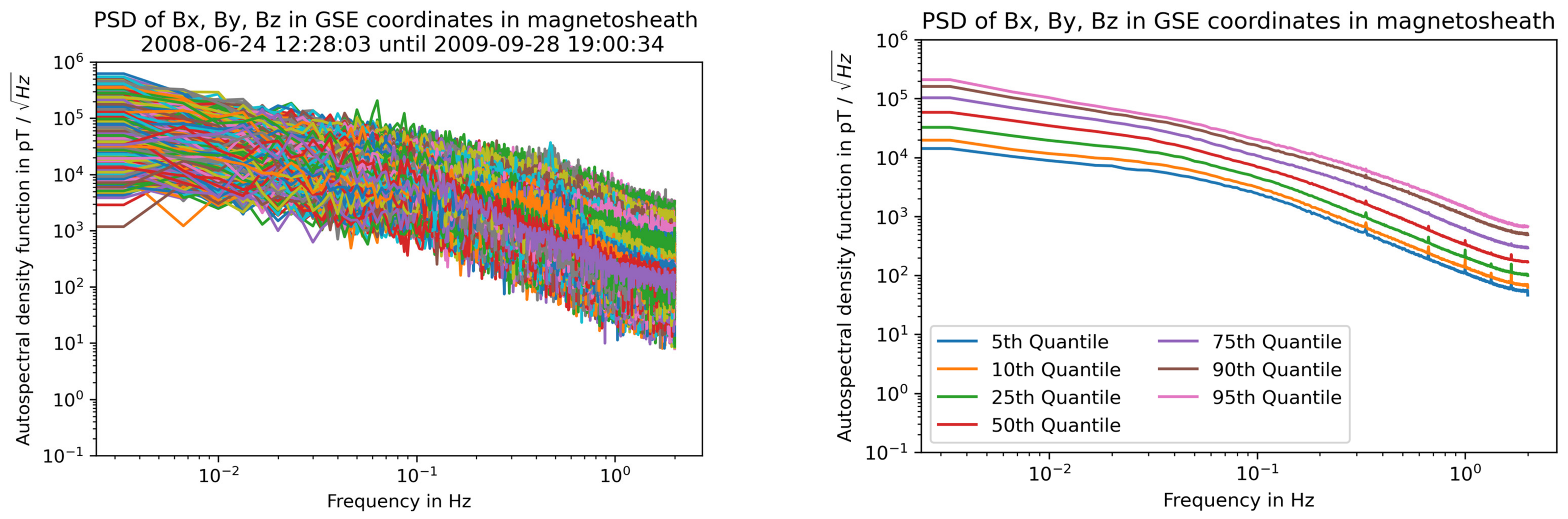
3a. Ioncyclotron waves in the magnetosphere



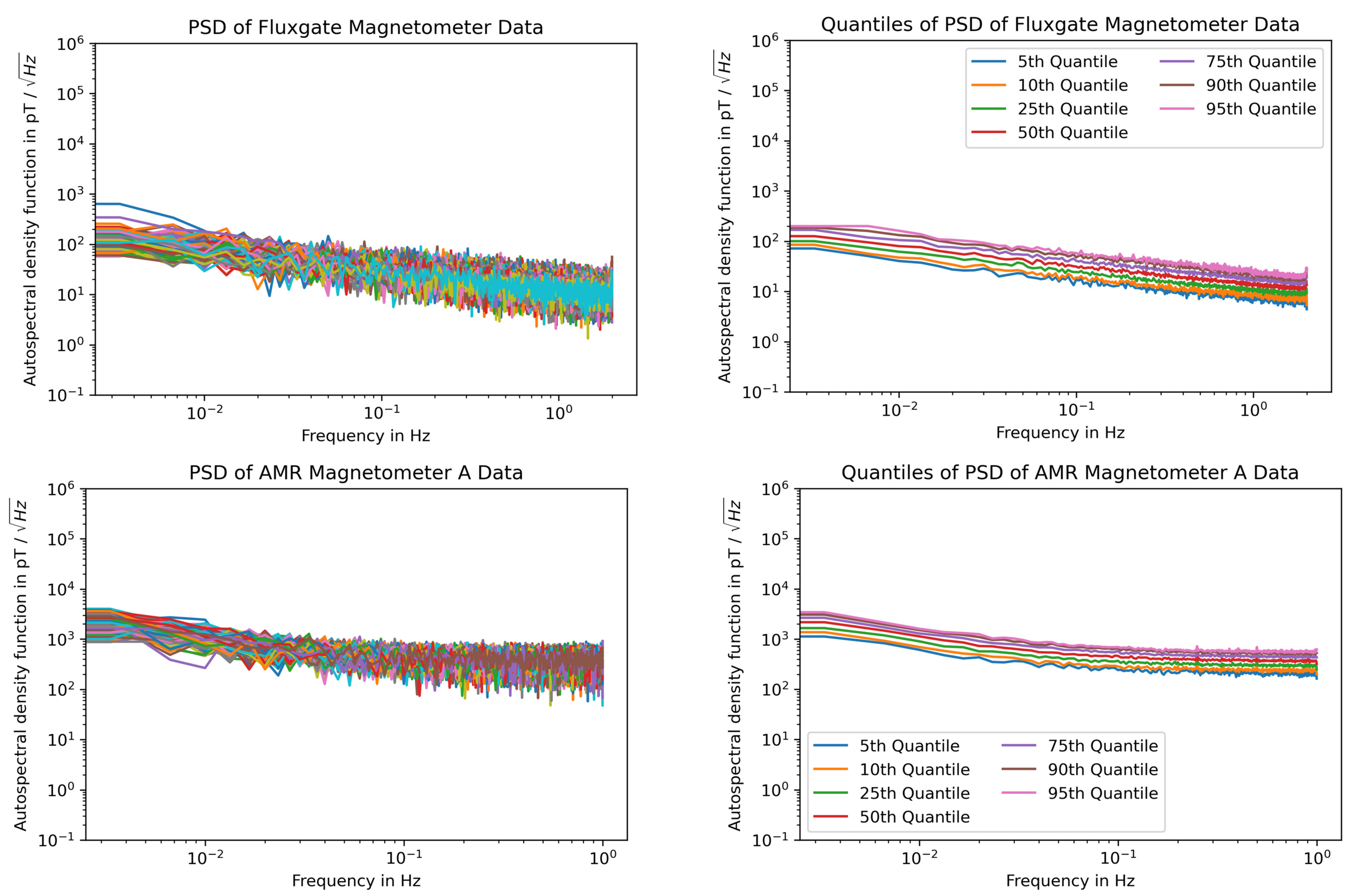
3b. Solar wind data



3c. Magnetosheath data



4. Magnetometer: Fluxgate and AMR



5. Discussion and Conclusion

- Ioncyclotron waves:
  - Waves are clearly visible in frequency band around $0.1\ Hz$
  - Whole spectrum between 10^1 and $10^5\ pT/\sqrt{Hz}$ with slight downward slope
- Solar wind:
  - Values between 10^0 and $10^5\ pT/\sqrt{Hz}$ descending with higher frequencies
  - Quantiles ranging between 10^1 and $10^4\ pT/\sqrt{Hz}$
  - Space craft's spin frequency of $0.3\ Hz$ and their harmonics clearly visible in quantiles
- Magnetosheath:
  - Values between 10^1 and $10^6\ pT/\sqrt{Hz}$, again descending with frequency
  - Space craft's spin frequency visible in quantiles
- Magnetometer:
  - Slight downward slope in whole frequency range of about 10^1 to $10^2\ pT/\sqrt{Hz}$
  - Fluxgate: lower noise, measures down to $10^1\ pT/\sqrt{Hz}$ at $1\ Hz$
  - AMR: only measures down to $2 \cdot 10^2\ pT/\sqrt{Hz}$ at $1\ Hz$
- Comparison:
  - AMR magnetometer can only measure in regions with higher values of the PSD contiunuously above $10^1\ pT/\sqrt{Hz}$ such as ioncyclotron waves in magnetosphere
  - For solar wind and magnetosheath, we need the higher capabilities of the fluxgate magnetometer in this frequency region
- Conclusion:
  - Think about expected phenomena when picking the magnetometer
  - Save money and complication by choosing a magnetometer just good enough to measure what is there, but not way too precise
- Future work:
  - Turbulent solar wind
  - Other regions around earth, e.g. low earth orbit or the magnetotail
  - Different phenomena within magnetosphere and magnetosheath
  - Other planets and their magnetospheres
  - Compare other kinds of magnetometers such as optically pumped magnetometers

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[2] F. Koller et al. (2023). Magnetosheath jet formation influenced by parameters in solar wind structures. *Journal of Geophysical Research: Space Physics*, 128, e2023JA031339. https://doi.org/10.1029/2023JA031339

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