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Nanometrics

# Magnetic field background variations can limit the sensitivity of seismic broad-band sensors

Universität Stuttgart
Germany

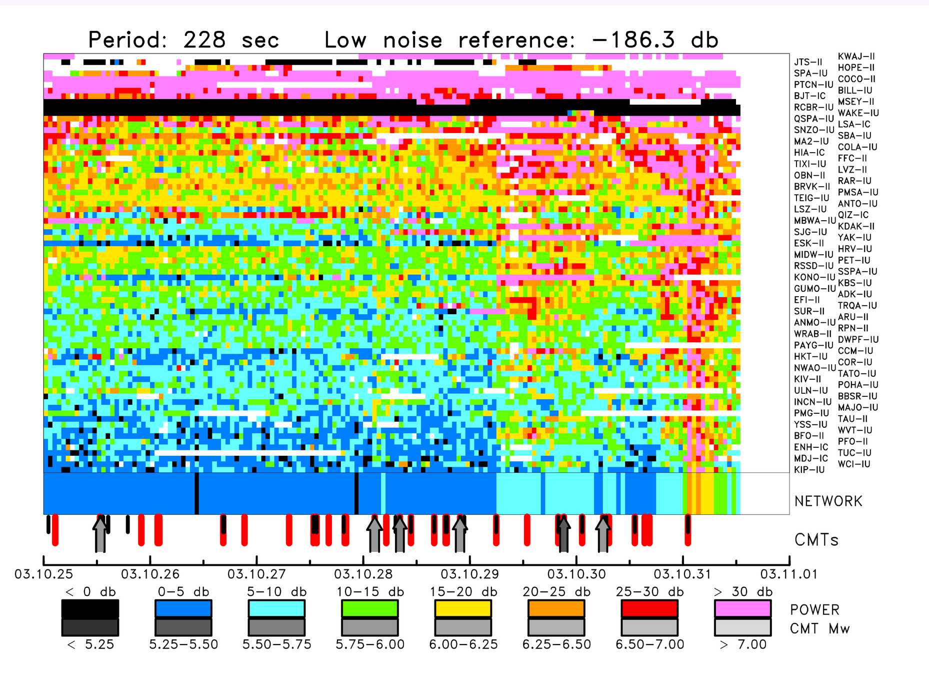
T. Forbriger[1,4], R. Widmer-Schnidrig[1,2], E. Wielandt[2], M. Hayman[3], and N. Ackerley[3]

[1] Black Forest Observatory (BFO) [2] Institute for Geophysics, Universität Stuttgart [3] Nanometrics Inc., Ontario, Canada [4] Thomas.Forbriger@gpi.uni-karlsruhe.de

## Sensitivity to the magnetic field

Most broad-band seismometers are sensitive to variations of the magnetic field (e.g. Wielandt 2002). This is due to the material of the suspension springs. The suspension springs are made of temperature compensated Elinvar alloys, which inherently are ferromagnetic and may respond to the magnetic field in various ways. Purely horizontal seismometers (such as the STS-1H) which require no suspension spring are not known to be sensitive to the magnetic field.
This effect is evident during magnetic storms (Fig. 1) and was believed to be limited to these rare events. Recently we observed a limitation of sensitivity due to this effect in a magnetically quiet period (Fig. 3).
Another surprising observation was reported by Joe Steim (Quanterra Inc., personal communication): Noise due to small magnetic fields induced by supply currents in batteries in close proximity to the seismic sensors became apparent in the USArray-TA.
We predict the magnetic field induced noise due to background variations in a particularly quiet period for seismometers of different sensitivity to the magnetic field. When comparing these preidctions to the New Low Noise Model, it becomes obvious that magnetic field background variations can limit the sensitivity of seismic broad-band sensors.

## Magnetic Storm



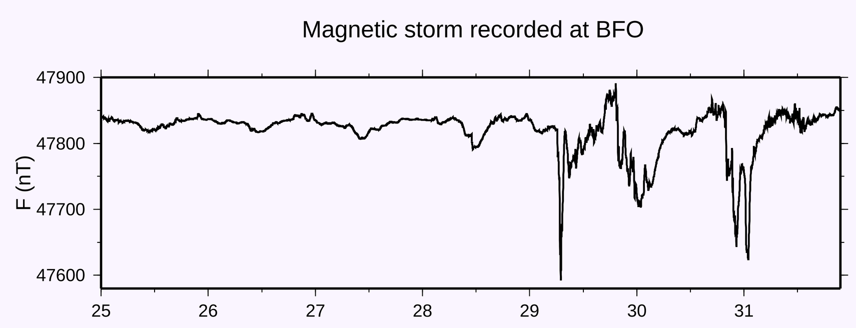




**Figure 1:** Top: Noise level at most quiet GSN stations at 228 s signal period relative to the NLNM 25.10.2003 and 1.11.2003 (Courtesy of Göran Ekström http://www.seismology.harvard.edu/~ekstrom/Research/Noise/RADB_hourly_rms.html). Bottom: Total magnetic field intensity at BFO. The noise level increases significantly at most stations in coincidence with the SSC (sudden storm commencement) of a magnetic storm at 29.10.2003 6:11:10 UT. The sensitivity to magnetic field can be observed at many stations of the global seismic network (GSN).

## Correction of long period seismograms

If the sensitivity of a seismometer to the vector components of magnetic field is known, this can be used to reduce the noise level in seismic recordings by subtracting the magnetic field induced noise (Forbriger 2007). An example for strong interference during a magnetic strom (Fig. 1) is shown in Fig. 2.

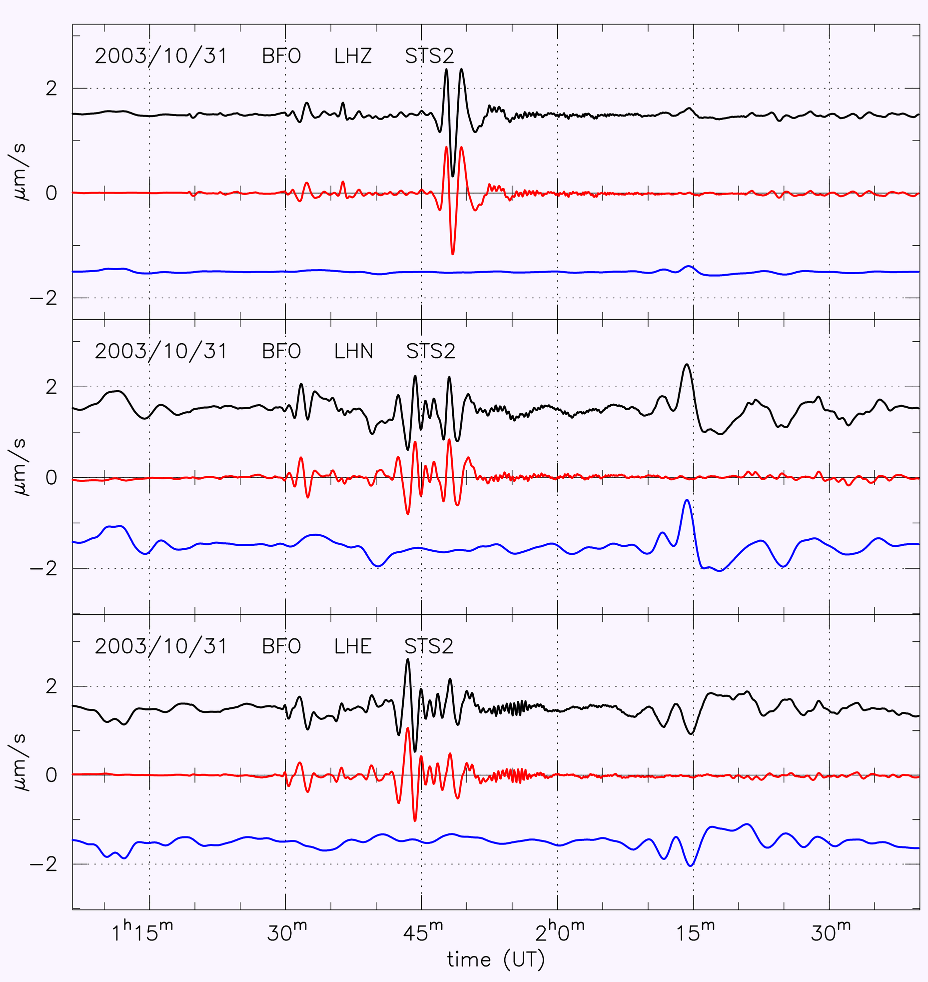



**Figure 2:** Black: Recordings for a long-period seismometer with 360 s free period simulated from the low-pass filtered output of the STS-2 at BFO. Blue: Magnetic field induced noise as predicted from independent recordings of the magnetic field and the known sensitivity of the seismometer to magnetic field variations. Red: Seismograms after correction. Each trace is vertically shifted by 1.5 $\mu\text{m}\,\text{s}^{-1}$ for better visibility.

## Magnetic field background variations

Effects like demonstrated in Fig. 2 can only be observed during strong magnetic storms or in environments that are contaminated by man-made magnetic fields. It was therefore believed that magnetic field induced noise imposes only minor limitations to long period seismology.
The signals in Fig. 3 were obtained during a huddle test of two Trillium 240 seismometers (produced by Nanometrics Inc.) and one STS-2 (produced by Streckeisen AG) at BFO in spring 2007. The displayed vertical component signals were recorded during a seismically quiet period and contain background noise only. The noise signal in the output of both Trillium seismometers is strikingly coherent, while it differs from the STS-2's signal. The coherent signals turned out to be due to the magnetic field background variations, which were not larger than usual during this period.
A linear regression with magnetic field recordings provides the sensitivity of the instrument to magnetic field (Tab. 1) and it can be used to reduce the magnetic field contribution to the seismic signal (Figs. 2 and 3). The sensitivity of a seismic component to the components $X$, $Y$, and $Z$ of the magnetic field are expressed by $s_X$, $s_Y$, and $s_Z$ and its magnitude $|\vec{S}| = \sqrt{s_X^2 + s_Y^2 + s_Z^2}$. The correction was only effective for the Trillium 240 seismometers. However, their sensitivity (Tab. 1) is not considerably larger than that of the most sensitive STS-2 in the GRSN (CLZ, Tab. 2).

## Time-domain observations

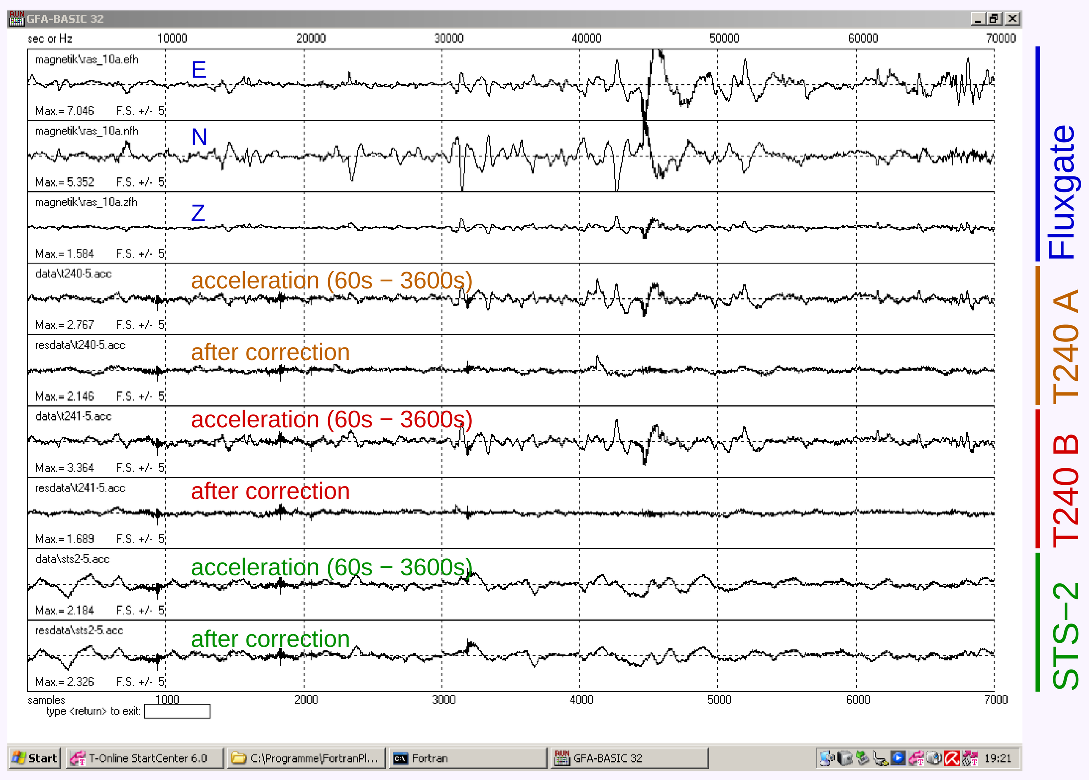



**Figure 3:** Magnetograms and seismograms as recorded at BFO during a huddle test of two Trillium 240 seismometers and an STS-2. Top three traces: Components of magnetic field variations. Bottom six traces: Vertical component output signals of the three seismometers. For each seismometer the raw signal as well as the signal obtained after correction is displayed. While the correction is quite effective for the Trillium 240s, no improvement is apparent for the STS-2. All signals are bandpass filtered to periods from 60 s to 3600 s. Seismic signals are converted to acceleration.

## Sensitivity

| Seismometer | $s_E\left(\frac{\text{m}}{\text{Ts}^2}\right)$ | $s_N\left(\frac{\text{m}}{\text{Ts}^2}\right)$ | $s_Z\left(\frac{\text{m}}{\text{Ts}^2}\right)$ | $\lvert\vec{S}\rvert\left(\frac{\text{m}}{\text{Ts}^2}\right)$ |
|---|---|---|---|---|
| T240 A | 0.0633 | 0.0186 | 1.4840 | 1.485 |
| T240 B | 0.0890 | -0.1409 | 1.3116 | 1.322 |

**Table 1:** Sensitivities for the vertical components of the two Trillium 240 in the huddle test as obtained by a linear regression.

| Station | $s_X\left(\frac{\text{m}}{\text{Ts}^2}\right)$ | $s_Y\left(\frac{\text{m}}{\text{Ts}^2}\right)$ | $s_Z\left(\frac{\text{m}}{\text{Ts}^2}\right)$ | $\lvert\vec{S}\rvert\left(\frac{\text{m}}{\text{Ts}^2}\right)$ |
|---|---|---|---|---|
| BFO (STS-1) | 0.0035 | 0.0008 | -0.0693 | 0.069 |
| BFO (STS-2) | 0.0242 | 0.0020 | -0.0697 | 0.074 |
| BRG (STS-2) | 0.0155 | 0.0563 | -0.0334 | 0.067 |
| BUG (STS-2) | -0.1036 | -0.0771 | 0.4533 | 0.49 |
| CLL (STS-2) | -0.0072 | -0.0283 | 0.0414 | 0.051 |
| CLZ (STS-2) | 0.0981 | -0.2172 | 1.2001 | 1.2 |
| FUR (STS-2) | 0.1652 | -0.0003 | 0.3676 | 0.40 |
| MOX (STS-2) | -0.0418 | -0.0695 | -0.0598 | 0.11 |
| TNS (STS-2) | 0.1712 | -0.1220 | -0.1083 | 0.31 |

**Table 2:** Sensitivities for vertical components of selected stations in the GRSN (German Regional Seismic Network) obtained by linear regression with magnetic field recordings at BFO (Forbriger 2007).

## Acknowledgements

Sven Stäbler (IGM, Überlingen) established the contact between BFO and Nanometrics and supported two huddle-test campaigns. We are grateful to Walter Zürn for his support and many fruitful discussions. Peter Duffner contributed to the huddle-tests at BFO.

## References

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Peterson, J., 1993. Observations and modelling of background seismic noise. Open-file report 93-322, U.S. Geological Survey, Albuquerque, New Mexico.

Wielandt, E., 2002. Seismometry. In *International Handbook of Earthquake and Engineering Seismology*, eds. W. H. K. Lee, H. Kanamori, P. C. Jennings & C. Kisslinger, vol. A, pp. 283–304. Academic Press, Amsterdam.

## Limitation of sensitivity

The experience made during the huddle test, gives rise to the question, whether magnetic field background variations can limit the sensitivity of long period recordings even in magnetically quiet periods. Fig. 4 displays magnetic field variation as recorded at BFO during a particularly quiet week in January 2007.
From the low-level magnetic field background variations in January 2007 (Fig. 4) we predict the resulting noise-level for seismometers of different sensitivity to magnetic field (Fig. 5). Comparing them to the New Low Noise Model (Peterson 1993, NLNM) provides evidence, that the magnetic field background variations can limit the sensitivity to seismic signals. Two out of eight instruments in the GRSN for which sensitivity to magnetic field could be derived (Tab. 2) reveal a sensitivity of 0.5 $\text{m}\,\text{T}^{-1}\,\text{s}^{-2}$ or more. However, it could not be shown that noise in their recordings could be reduced during magnetically quiet periods for these stations. Their usual noise-level in the normal-mode band is even larger than that predicted from the magnetic field. Apparently other noise sources are still dominant.
The STS-1 vertical component at BFO provides a noise level close to the NLNM that could not effectively be reduced by corrections for air-pressure correlated noise below 1 mHz (a measure that is very effective with the ET-19 gravimeter in the same period band). A possible contribution of magnetic field induced noise, preventing the air-pressure correction from being effective was discussed. But the sensitivity of 0.07 $\text{m}\,\text{T}^{-1}\,\text{s}^{-2}$ for this instrument (Tab. 2) is too small to produce significant noise from magnetic field background variations (Fig. 5, black).

## Magnetic field background variations

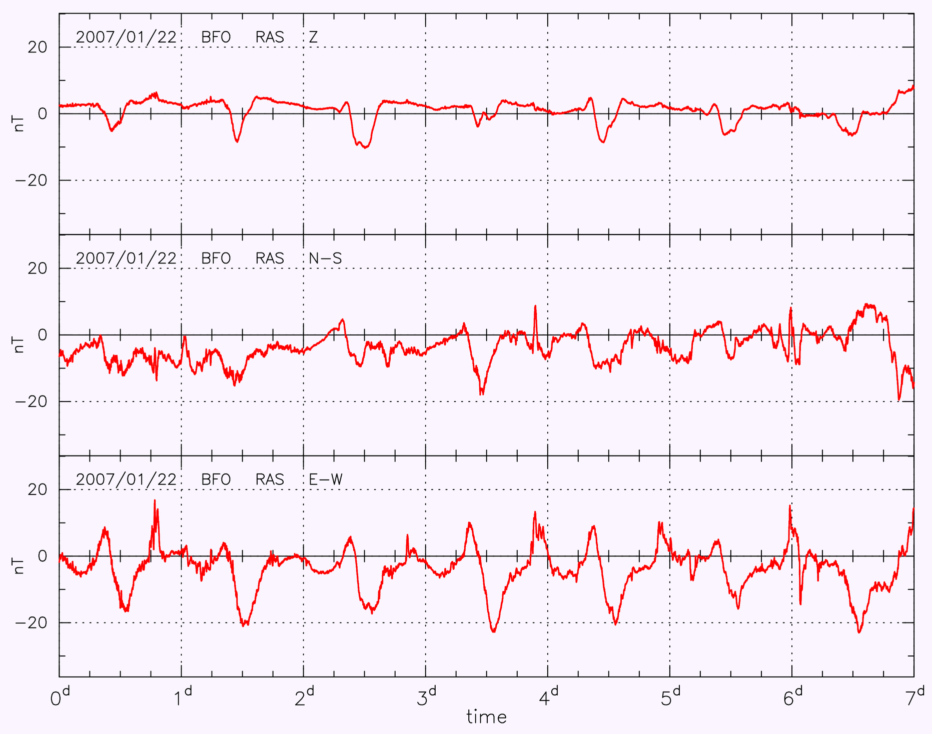


**Figure 4:** Magnetograms for variations of the three components of the magnetic field recorded at BFO with Rasmussen fluxgate sensors. The variations during the selected week in January 2007 were of particularily small amplitude.

## Limitations

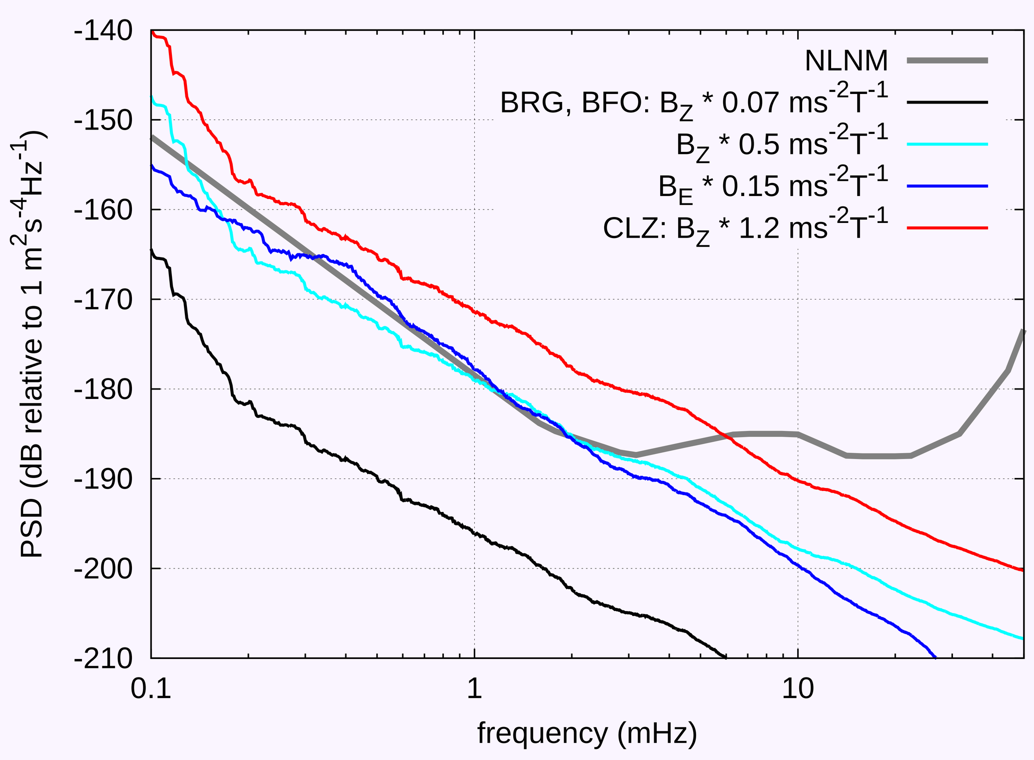


**Figure 5:** Predicted noise levels in broad-band seismometers due to background variations of the magnetic field during a particularly quiet week (Fig. 4) compared with the signal level defined by the New Low Noise Model (Peterson 1993, NLNM, gray). Examples for the most (red) and least (black) sensitive instruments in the GRSN are displayed (Tab. 2). Instruments with sensitivitiy of 0.5 $\text{m}\,\text{T}^{-1}\,\text{s}^{-2}$ to the vertical component of the magnetic field (cyan) or 0.15 $\text{m}\,\text{T}^{-1}\,\text{s}^{-2}$ to the east component (blue) would suffer from magnetic field induced noise just at the level of the NLNM in the normal mode band.

## Conclusions

- Noise induced by the magnetic field background variations can exceed the NLNM in the normal-mode band (between 0.3 mHz and 3 mHz) for instruments with sensitivity to the horizontal component of the magnetic field larger than 0.15 $\text{m}\,\text{T}^{-1}\,\text{s}^{-2}$.
- It is crucial to find appropriate means to ensure a low sensitivity to magnetic fields when designing and installing sensitive broad-band seismometers for the observation of normal modes.
- The ineffectiveness of air-pressure corrections below 1 mHz for the STS-1 vertical component at BFO cannot be explained by magnetic field induced noise.