mHz

A comparison of the seismic noise levels at various GGP stations

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Mean PSD of the 5 quietest days

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Abstract

Since 1997 a network of superconducting gravimeters (SG) has been monitoring the variations of the Earth's gravity field. Data from the network, under the coordination of the Global Geodynamics Project (GGP), allow a comparison of the noise levels of the different contributing stations. We use a standardized processing procedure to evaluate the combined instrument plus site noise in the long-period seismic band (200s-600s). Most of the stations have Power Spectral Densities (PSD) contained in a 10 dB wide range, i.e. there is a factor 3 in amplitude between the least and the most noisy station. In the high frequency part of the PSD, the decrease induced by the decimation filter to one minute affects the computation of the Seismic Noise Magnitude (SNM) for many stations. The SNM is a summary statistics introduced by Banka in 1997 to enable a quick comparison of the quality of a site-sensor combination. From T=16 min to T=3.5 h, PSD are below the New Low Noise Model of Peterson (NLNM). SG's data are therefore appropriate for studying long-period seismic and subseismic modes. Knowledge of the noise levels of each station is important in a number of studies that combine the data to determine global Earth parameters. We cite for example the stacking of the data to determine the period of the free core nutation and the Chandler wobble, and the potential use of the data in the search for the gravity variations associated with the translational mode of the inner core.

Introduction

Since 1997 a network of superconducting gravimeters (SG) (Crossley et al., 1999) has been monitoring the variations of the Earth's gravity field. Data from the network, under the coordination of the Global Geodynamics Project (GGP) (Crossley and Hinderer, 1995), allow a comparison of the noise levels of the different contributing stations.

The analysis of the noise level at a gravimeter station is well realized by the use of a Power Spectral Density of the instrument series. The PSD has the advantage of being independent of the length and sampling rate of the signal. Moreover the integration over a frequency band leads to the estimate of the mean power within this band, and the PSD is always representative of a physical phenomenon, particularly if it is aperiodic or transient. In the present study, the New Low Noise Model (NLNM) of Peterson (1993), designed for seismometers, is used as a reference level to give an estimate of the quality of the site-sensor combination. With a single instrument at a site, it is not possible to separate site noise from instrument noise.

Banka (1997) introduced a summary statistics that can be derived from the PSD. It is called the Seismic Noise Magnitude (SNM), a quantity that is based on a narrow window in the normal mode band between 200s and 600s. We divide the paper into three sections, the first deals with the processing procedure, the second is for the study of the noise level at the Strasbourg station and the third one presents a comparison of the seismic noise levels at 19 GGP stations.

1. The processing procedure for the Seismic Band, 200s-600s

The processing procedure is fully described and evaluated in Banka and Crossley (1999); here it will be only briefly summarized.
Gravity and pressure data are analysed for each day of a given year at a superconducting gravimeter station. The following steps are applied:

- amplitude calibration of raw gravity and pressure data;
- subtraction of the tides computed using an elastic reference earth model:
  the difference between using an elastic model and calculating local tides is insignificant. Banka and Crossley (1999) found that the inclusion of ocean tides does not affect the noise levels in the seismic band nor in fact the use of a highly accurate tidal potential. Besides it does not make any difference whether the FCN correction is used or not. The Xi Qinwen (1989) tidal potential with a cut-off of 0.0001 for the Doodson amplitude yielding 383 waves was used.
- reduction of the influence of the air pressure with an admittance factor of -0.3 µgal/mbar: the pressure data must have been fixed for spikes, gaps and offsets so that problems in the pressure do not get transferred into the gravity data.
- subtraction of a best-fitting 9th degree polynomial to eliminate the instrument drift and any residual tidal signal;
- computation of the RMS deviation;
- selection of the 5 quietest days (based on those with the lowest RMS);
- Fast Fourier Transform and average of the 5 amplitude spectra;
- computation of the Power Spectral Density (PSD).

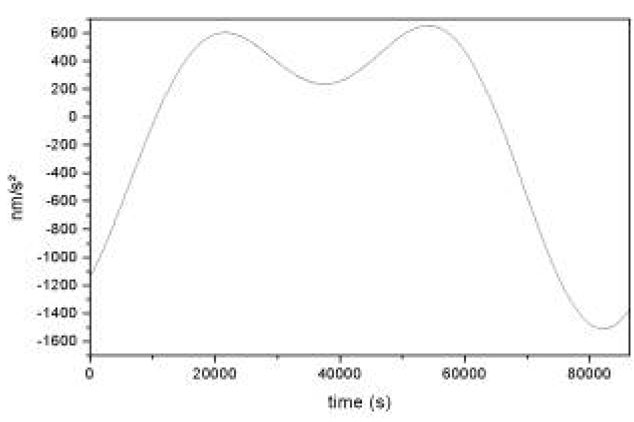
In the period range 200s-600s, the Seismic Noise Magnitude is defined through the relation:

$$SNM = \log10(\text{meanPSD}\ (\mu gal^2/Hz)) + 2.5$$

Thus the sphere resonance mode, which usually has a period shorter than 200s, is excluded from the computation for all the superconducting gravimeters (SGs).

By taking the log of the PSD and normalizing it so the NLNM is zero, we are able to use a single figure that acts as a quality factor for site-instrument noise. Such a figure clearly contains much less information than the PSD, but in some cases, it may be useful in quickly comparing the high-frequency performance of instruments.

(a)



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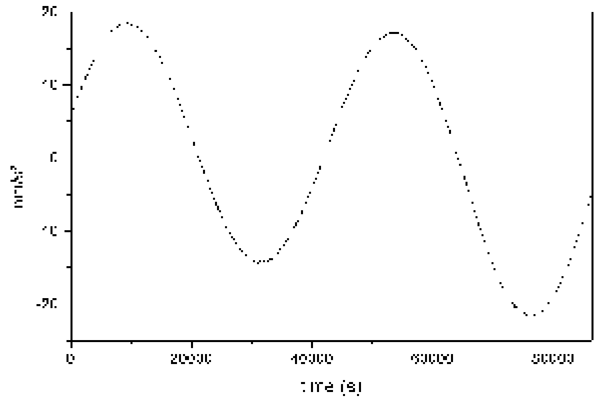

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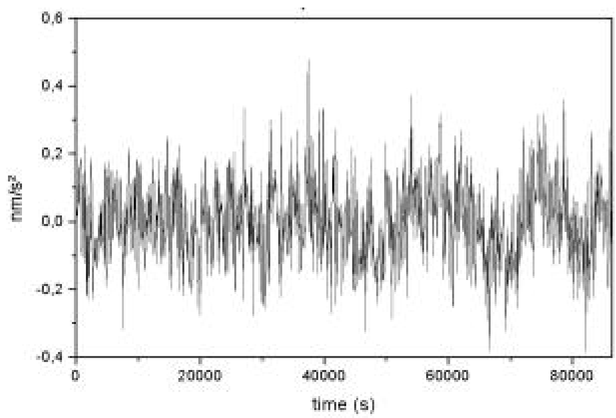


Figure 1: Example of procedure at Strasbourg for one day (98/01/26)
(a) Raw gravity (b) Tides and pressure subtracted (c) a 9th degree polynomial subtracted

For instance at Strasbourg station, the amplitude of the raw gravity signal is about 200µgal (Figure 1 (a)). After tide and pressure correction, it is about 4µgal (Figure 1 (b)) and after the subtraction of a ninth degree polynomial the amplitude is of the order of 0.01µgal (Figure 1 (c)).

2. The Power Spectral Density at Strasbourg

The procedure was first applied to the original 2 second sampling data of Strasbourg. The sphere resonance of this SG appears at 2 minutes (8 mHz), see Figure 2.
The high frequency decrease of the PSD is due to the GGP2 anti-aliasing filter, shown in Figure 3. The smooth diminution in the long period part of the PSD is caused by the subtraction of the 9th degree polynomial.

The procedure was then carried out on the 1 minute decimated data. The influence of the low pass filter has a small but noticeable effect in the seismic band 200s-600s used for our Seismic Noise Magnitude computation (Figure 3 (a)). For Strasbourg, the decrease in the SNM due to the attenuation of the decimation filter is only about 4%, Figure 3 (b).

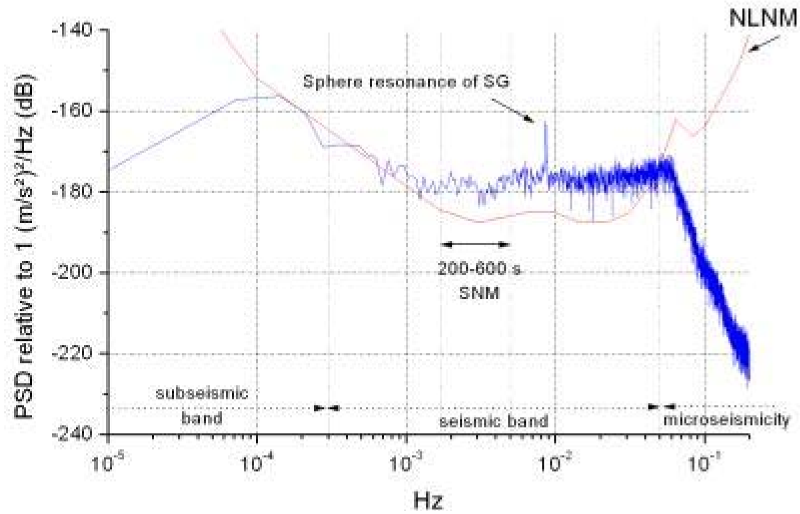


Figure 2: Power Spectral density of 5 quiet days at Strasbourg, 1998. The raw data are sampled at 2 seconds.

(a)

(b)

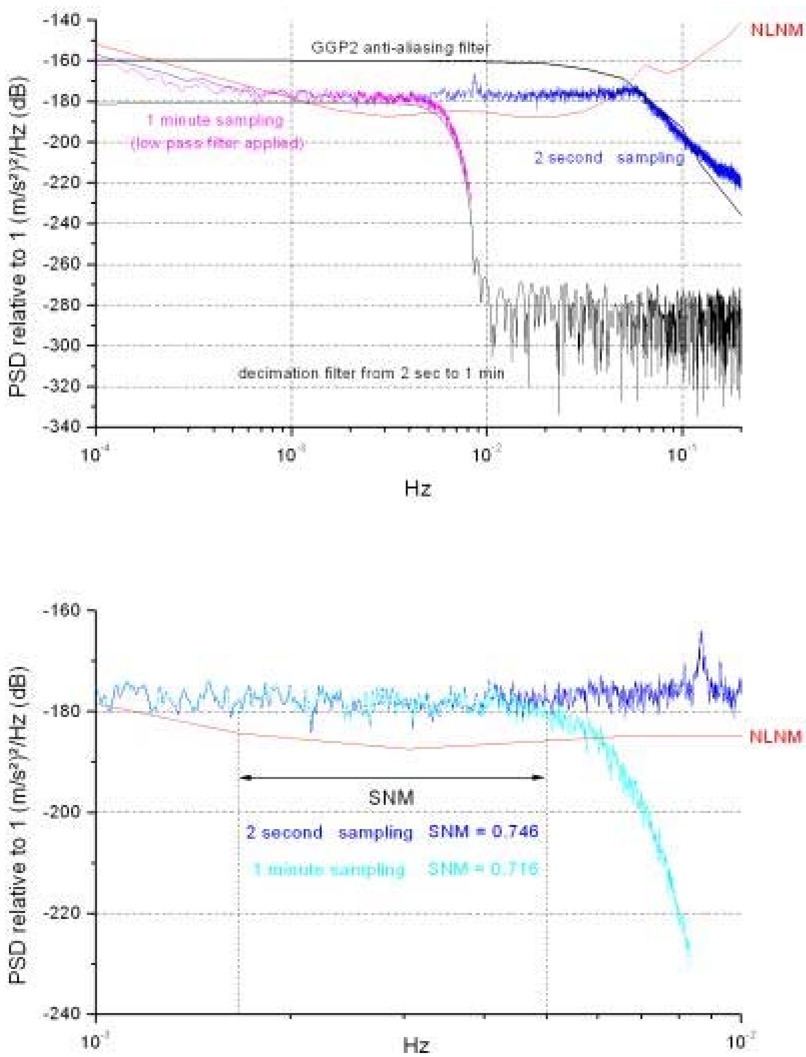


Figure 3: Power Spectral Density of 5 quiet days at Strasbourg. (a) shows the effect of the GGP2 and decimation filters, (b) shows the influence of the decimation filter from 2 seconds to 1 minute on the Seismic Noise Magnitude.

Table 1 points out the stability of the SNM in Strasbourg with time. The data are plotted in Figure 4 and show that from 1997 to 2001 the noise magnitude decreased by 4.8%.

Table 1. SNM for Strasbourg, various years.

Year	The 5 quietest days	Range of RMS for 5 days (nm/s^2)	SNM
1997	271, 192, 65, 257, 66	0.13-0.14	0.757
1998	26, 39, 129, 37, 277	0.12-0.13	0.737
1999	73, 72, 89, 326, 70	0.11-0.13	0.731
2000	73, 78, 91, 14, 1	0.13-0.14	0.723
2001	91, 213, 112, 244, 90	0.12-0.14	0.720
All years	99073, 98026, 99072, 01091, 01213	0.11-0.12	0.708

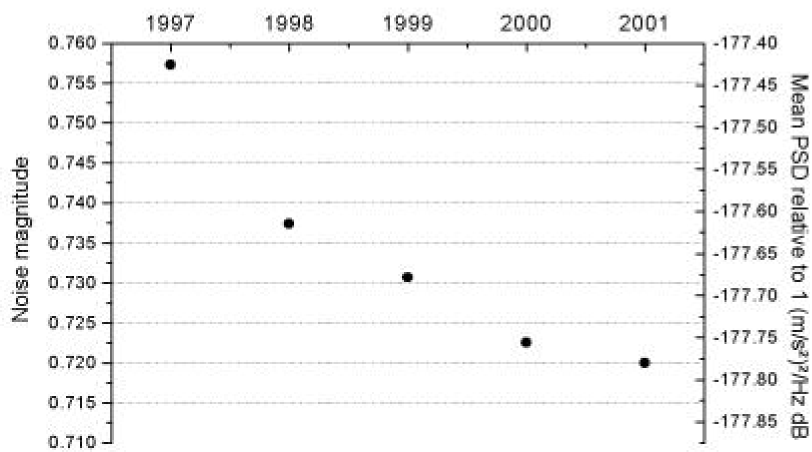


Figure 4: Evolution of the Seismic Noise Magnitude in Strasbourg from 1997 to 2001.

The distribution of RMS deviations for year 1998 is represented in Figure 5. It is a non-Gaussian distribution with a median value of 0.28 nm/s^2. Notice that the value corresponding to the 5 best days is of course smaller (0.12 nm/s^2).

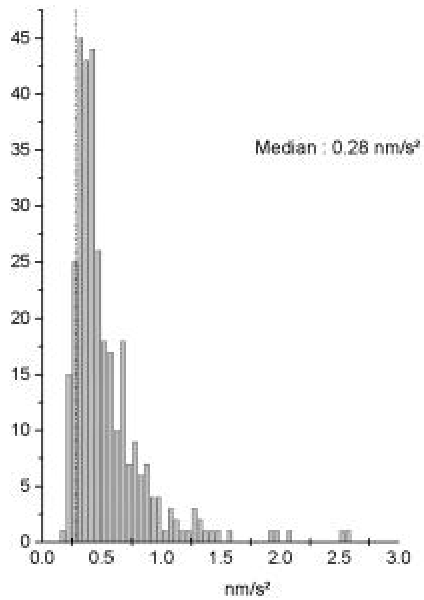


Figure 5: Histogram of RMS deviations in 1998 at Strasbourg

Figure 6 reveals the evidence of the good correlation between RMS deviation and mean PSD in our case. Indeed these selection criteria are only equivalent because the high-frequency micro-seismic noise is cut-off by the decimation filter and because the 9th degree polynomial has removed the long-period signals (Figure 7). For instance, if there was no high frequency filtering, the micro-seismic noise would be added to the seismic noise and would make the new selection of quiet days unsuitable to compute the seismic noise levels.

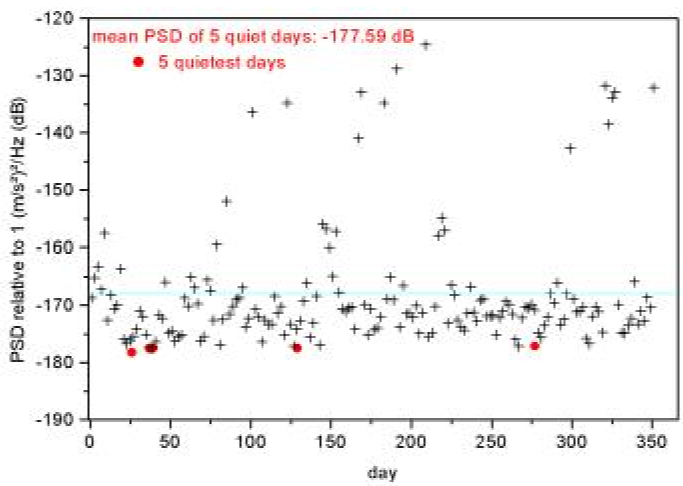


Figure 6: Mean Power Spectral Density values for each day of 1998 at Strasbourg. The mean PSD corresponding to the 5 quietest days (with lowest RMS deviations) are represented with circles.

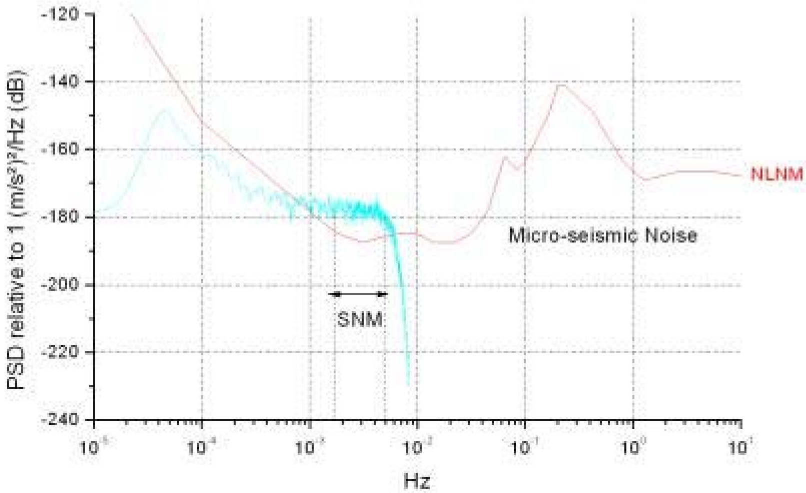
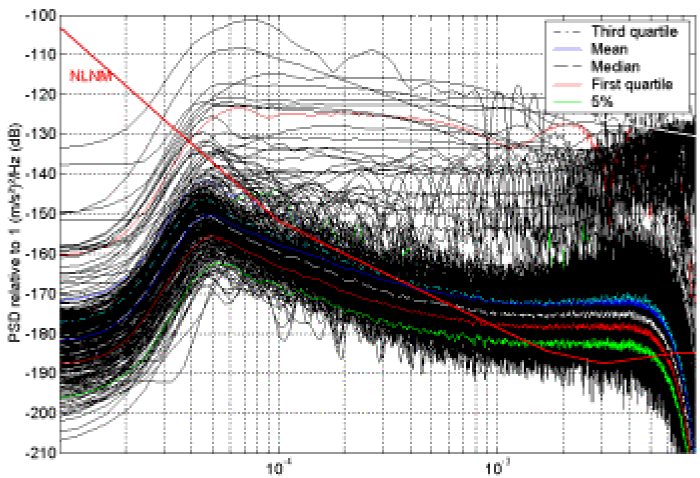


Figure 7: Power Spectral Density of 5 quietest days in 1998 at Strasbourg showing the attenuation in the long period band due to the 9th degree polynomial and the high frequency filtering due to the decimation to 1 minute.

(a)



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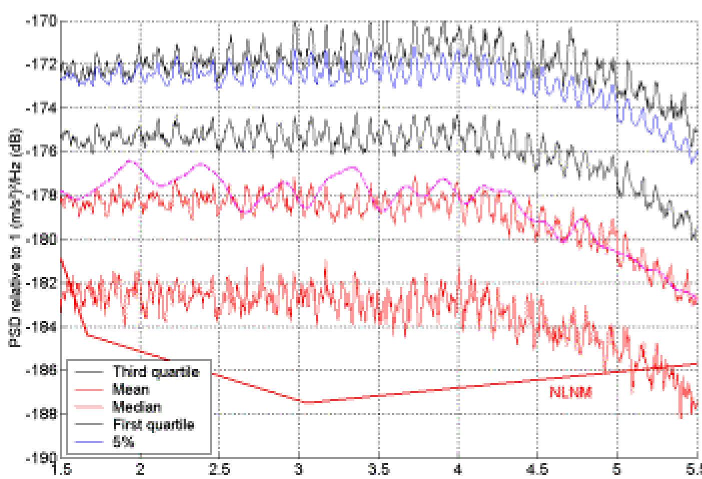
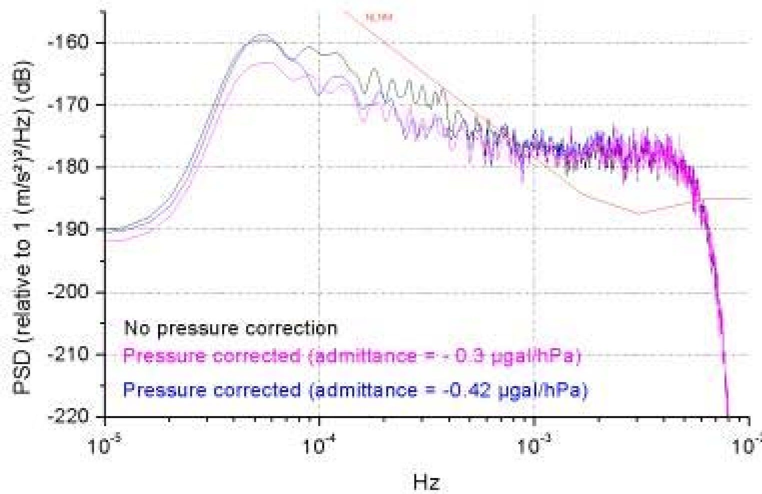


Figure 8: Statistics on all the daily PSD at Strasbourg for 1998. (a) shows all the individual spectra. The 5%, first quartile, median, mean and third quartile are plotted in (a) and (b).

Statistics on the PSD for each day of a year at Strasbourg are represented in Figure 8. The mean PSD of the 5 quietest days is at the same level as the first quartile. The mean and the third quartile levels are close and they are the highest levels. They seem to show some organized oscillations that are the background free oscillations or "hum" (Nawa et al., 2000). The mean and the median values are different which indicates a non-Gaussian distribution of the RMS deviations.

It was already noticed in previous studies (Freybourger et al., 1997 – Zürn and Widmer, 1995) that the pressure correction with an admittance is not efficient at high frequencies on seismic data. It can be seen in Figure 9 that the air pressure correction has however a substantial effect at frequencies less than 1 mHz.

(a)



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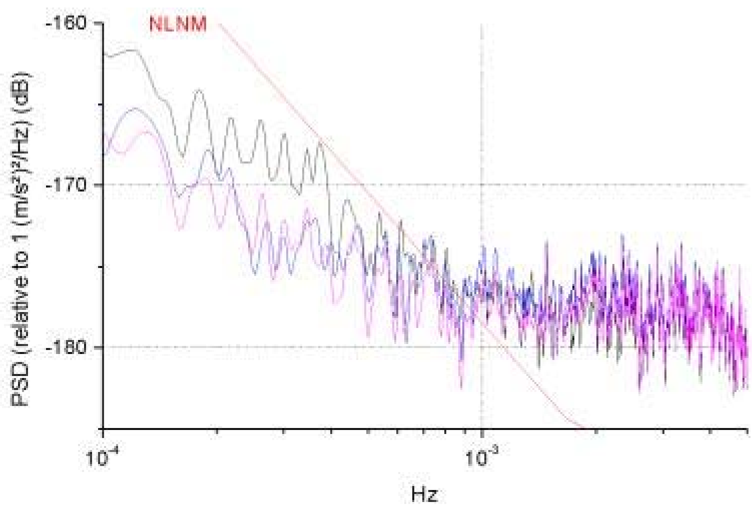
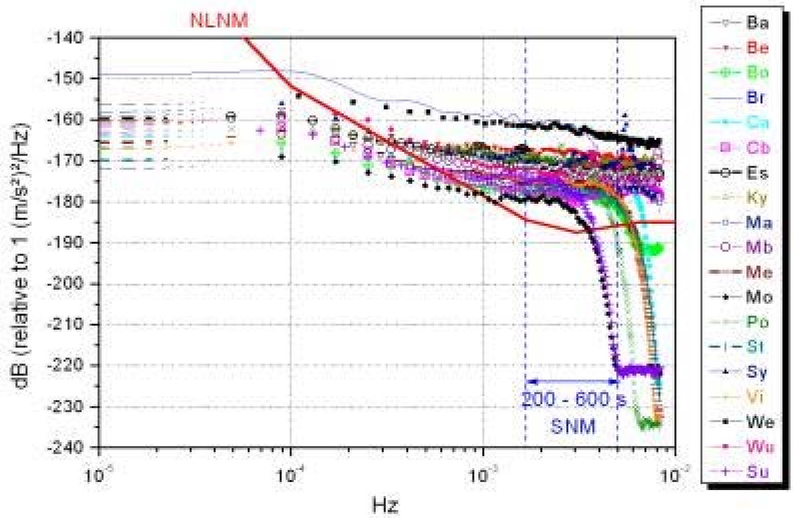


Figure 9: Influence of pressure reduction on the PSD levels, Strasbourg, 1998. (b) is an enlargement of (a) showing the pressure effect more clearly.

3. The Power Spectral Densities at GGP stations and the Seismic Noise Magnitudes

The processing procedure summarized in part 1 was applied to 19 GGP stations in order to make a comparison of the different noise levels. The stations considered were Bandung (BA), Brussels (BE), Brasimone (BR), Boulder (BO), Canberra (CB), Cantley (CA), Esashi (ES), Kyoto (KY), Matsushiro (MA), Membach (MB), Metsahovi (ME), Moxa (MO), Potsdam (PO), Strasbourg (ST), Sutherland (SU), Syowa (SY), Vienna (VI), Wetzell (WE) and Wuhan (WU). The PSD were smoothed in the frequency domain with a 501-point Parzen window in Figure 10 and with a 2001-point Parzen window in Figure 11.

(a)



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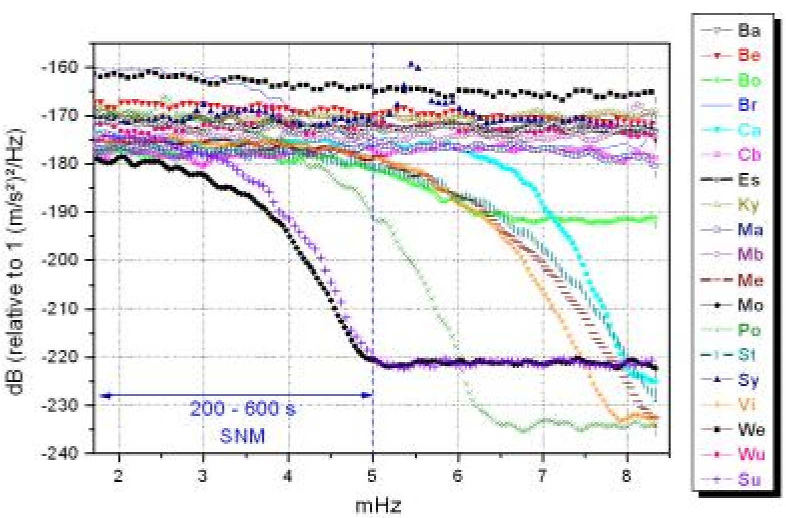

Figure 10: Power Spectral Densities of the 5 quietest days of a year at 19 GGP stations.
(b) is a zoom in the seismic band. The PSD are smoothed with a 501-point Parzen taper.

Figure 10 underlines the decimation filter used at each station. Moxa and Sutherland have low pass filters that attenuate the fastest and the steepest, so their SNM computed in the 200s-600s band will be altered towards lower values by the decimation. We must keep this in mind when comparing all the 19 SNM. It will be the case also for Potsdam. Concerning Strasbourg which has the next steepest decimation filter, the decrease introduced by the attenuation is of 4% (as seen in section 2). The sphere resonance is clearly visible at Syowa.

Most PSD are contained in a 10 dB range corresponding to a factor of 3 in amplitude between the least and the most noisy stations.

Figure 11 presents a comparison of the levels in the seismic band 200s-600s. Four stations have their noise levels considerably altered by their decimation filters in that band. They are Brasimone, Potsdam, Sutherland and Moxa. The levels at Boulder, Strasbourg, Metsahovi and Vienna are also slightly affected. The other stations have roughly constant levels over the whole band.

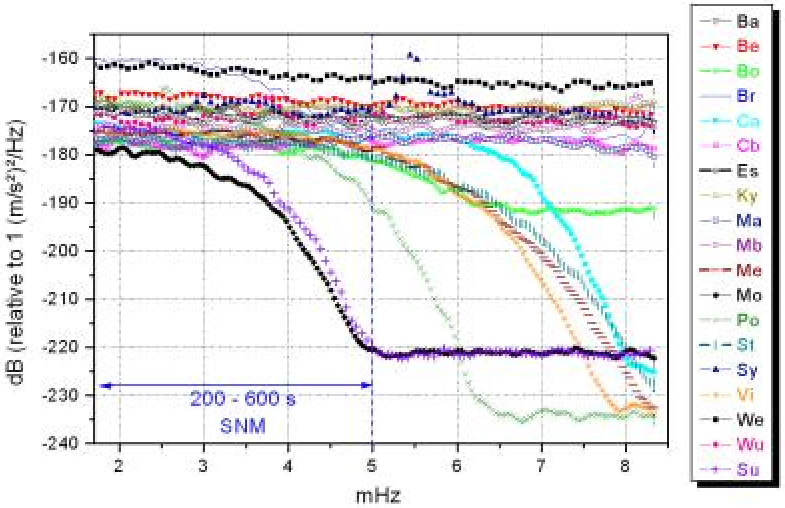

Figure 11: Power Spectral Densities of the 5 quietest days of a year at 19 GGP stations in the seismic band 200s-600s. The PSD are smoothed with a 2001-point Parzen window.

A quick comparison in the seismic band 200s-600s can be obtained by computing the Seismic Noise Magnitudes; these are plotted in Figure 12. The SNM computed by Banka (1997) for a STS-1 seismometer at the Black forest Observatory (BFO) is also indicated for comparison. The former SG at Strasbourg (TT070) is represented to show the important improvement realized with the new instrument C026 since 1996. The SNM decreased by 51% from the TT070 to the present SG at Strasbourg.

Moxa has the lowest SNM, however it must be underlined again that this value is lowered by 63% by the decimation filter.

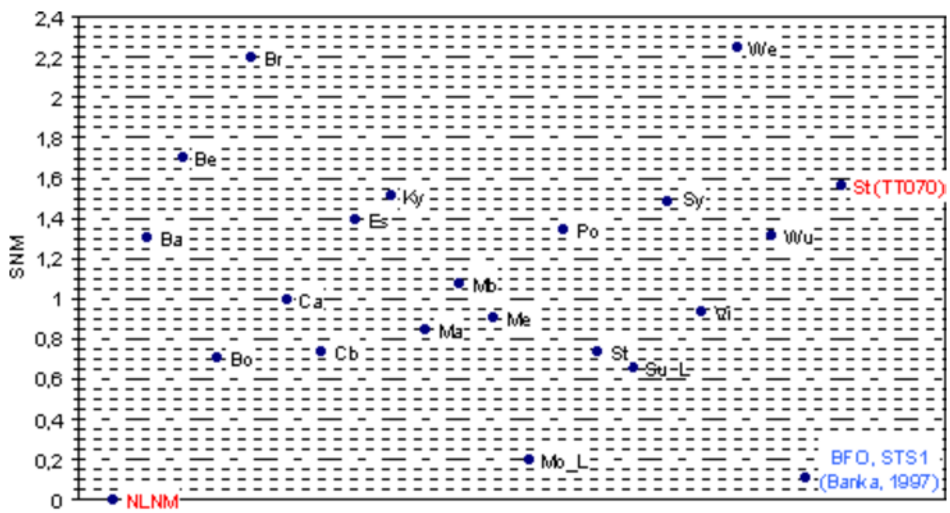

Figure 12: Noise Magnitudes in the frequency band 200s-600s for the 19 GGP stations.

Conclusions

In the high frequency band the decrease induced by the GGP2 anti-aliasing filter on raw gravity data was presented. In the seismic band, the decimation filter from raw sampling rate to one minute data alters the Seismic Noise Magnitude computation. A link between RMS and PSD was stressed; in particular, there is a strong correlation when the micro-seismic noise has been filtered out. The effect of pressure reduction is noticeable at frequencies less than 1 mHz. The PSD of 19 GGP stations were plotted and most of them are contained in a 10 dB range. The SNM was also computed for these stations.

In general, GGP stations have very low noise levels in the long period seismic band, except Brasimone and Wettzell (instrument SG103) that show large Seismic Noise Magnitude values.

The knowledge of all GGP decimation filters appears to be necessary to understand the high frequency trends of the Power Spectral Densities.

GGP station levels are crossing the New Low Noise Model from T=16min to T=3.5h. Superconducting gravimeters are therefore excellent instruments for studying long period signals. In that purpose, a pressure correction is necessary to further decrease the noise level.

A comparison of the noise levels in the subseismic band and in the tidal bands of GGP stations has to be carried out in the future, leading to a selection of the quietest stations for optimal stacking in the search for the Slichter mode (Slichter, 1961).

Acknowledgements

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