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6.5 Seismometer and digitizer tests at NOA subarray NC6

6.5.1 Introduction

CTBTO intended to perform an instrument test for several Guralp and Nanometrics broadband sensors and digitizers. NORSAR offered to provide the experimental setup and the data collection at the NOA subarray NC6. The site has all the necessary infrastructure and is connected via landline and broadband to NORSAR. The experiment started in the beginning of August 2008, and lasted until the beginning of December 2008. We forwarded all data to CTBTO for detailed analyses. In the following we give a brief overview on the setup and some data examples.

6.5.2 Instruments and experimental setup

From CTBTO we received five Guralp CMG-3T seismometers, two Nanometrics Trillium 240 seismometers, seven Nanometrics Europa T digitizers inclusive GPS antennae and one Linux PC for data acquisition. We expanded the instrument pool with one Guralp CMG-3ESPC seismometer, one Streckeissen STS2 seismometer, seven Guralp DM24 digitizers inclusive GPS antennae and one low-power industrial Windows PC (PIP10).

We installed the sensors and digitizers in the long-period vault of NC6. Figure 6.5.1. shows a pit with five CMG-3T, two Trillium 240 and the CMG-3ESPC; the STS2 is in another pit about 1.5 meter away. The pit was covered with a styrofoam lid for thermic insulation. The right hand side of Figure 6.5.1. shows the shelf with the Guralp and Nanometrics digitizers, the DC-power distribution box and the industrial PC. There are no active AC power supplies in the vault during normal operation. The power distribution box is connected to DC and only DC/DC-converters are in use. The DM24s are connected via serial cables to a serial-to-USB module, which in turn is plugged into the fan-less low-power industrial PC. The PC as well as the Europa T digitizers are connected directly via 3 hubs to a local network.

Figure 6.5.1. Left: One of the three pits in the Long-Period Vault (LPV) of the NOA subarray NC6. Right: Shelf with data acquisition equipment.

Data from Guralp digitizers were sent via a Scream server that runs on the PIP10 to a client computer at the NDC, where they are stored in Guralp GCF-format. Additionally we were running Scream2cd1 servers on the PIP10 to forward the data to a cd1.0-receiver at the NDC. CD1.1 data from Europa T digitizers were forwarded to the Linux computer outside of the LPV. On this machine we were running SSI-software to send the data in cd1.1-format to the NDC. At the NDC the cd1.x-data are subsequently converted and integrated into a CSS-database. Due to some performance issues with SSI, we changed the data forwarding to Nanometrics Naqstocd1.1 software after a while.

Figure 6.5.2. shows the transfer functions of the different sensors. The STS-2 is the sensor with the highest sensitivity (20000 V/(m/s)). The STS-2 and the Trillium 240 have a high-frequency amplification, whereas the Guralp sensors have a simpler flat transfer function. The transfer functions and the digitizer-specific sensitivities are used to compute instrument-corrected true ground velocities.

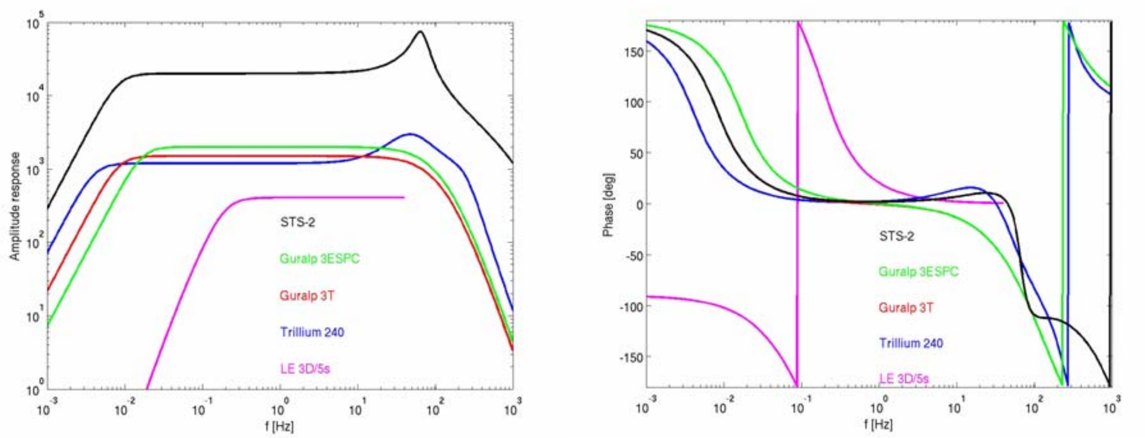

Figure 6.5.2. Transfer functions of the different sensors. Left: Nominal amplitude response in units of V/(m/s). Right: Nominal phase responses.

6.5.3 Determination of instrument noise

In order to determine the instrument noise we are following the approach of Szekely et al. (2007) originally developed by Holcomb (1989). In case of a side-by-side configuration seismic sensors are subjected to the same ground motion. In the frequency domain we have

$$P_{11} = |H_1|^2 [X+N_1] \quad (1)$$

$$P_{22}=|H_2|^2 [X+N_2] \quad (2)$$

$$P_{12}=H_1 H_2^* X \quad (3)$$

where P_{11}, P_{22} and P_{12} are the power spectral densities (PSD) for system 1 and 2 and cross-spectral density between the systems outputs, respectively. H_1 and H_2 are the transfer functions of the systems, X is the power spectral density of the common input to the sensors, and N_1 and N_2 are PSDs of the channel noise. If one assumes equal levels of noise power $N= N_1 = N_2$

(even though statistically independent for the two systems) and introduces the coherence function

$$C^2=|P_{12}|^2/(P_{11}P_{22}), \quad (4)$$

the channel noise can be computed using:

$$N=P_{12}/(H_1H_2)\ (1/C^2-1). \quad (5)$$

6.5.4 Application to selected data examples

Over the experimenting period various sensor/digitizer configurations have been used. Table 6.5.1. shows the configuration for the time period when the following data examples have been recorded.

Table 6.5.1. Station names and associated sensor/digitizer

Station name	Sensor (serial number)	Digitizer (serial number)
NRX6	CMG-3ESPC (T3T15)	Guralp DM24 (A208)
NRX8	Nanometrics Trillium 240 (0447)	Nanometrics Europa T (0748)
NRX9	Nanometrics Trillium 240 (0225)	Nanometrics Europa T (0757)
NRX10	Streckeisen STS2	Guralp DM24 (A091)
NRX11	Guralp CMG-3T (T35348)	Nanometrics Europa T (0727)
NRX12	Guralp CMG-3T (T35437)	Nanometrics Europa T (0762)
NRX13	Guralp CMG-3T (T35345)	Nanometrics Europa T (0708)
NRX14	Guralp CMG-3T (T35349)	Nanometrics Europa T (0764)
NRX15	Guralp CMG-3T (T35347)	Nanometrics Europa T (0699)

Figure 6.5.3. shows the vertical components of the stations for a 5-minute time window. The waveforms are corrected for instrument response and the digitizer scaling factor for a frequency band between 0.01 and 39 Hz (the data are originally sampled with 80 Hz). Figure 6.5.4. shows the traces overlayed for a 90-second time window. The waveforms are practically identical as expected for the colocated sensors.

Figure 6.5.5. and Figure 6.5.6. are power spectral density plots for all stations computed for a 3-hours time window (2008-289 21:00 - 24:00) with relatively low ambient noise level. To obtain these spectra we applied Welch’s method. That means:

- each time series is split up into overlapping segments
- the segments are windowed
- for each segment the periodogram is computed (FFT and squaring the magnitude of the result)
- the periodograms are time-averaged in order to reduce the variance of the individual power measurement

For our PSD results we subdivided the 3-hour time window into 200-s windows with an overlap of 100 s.

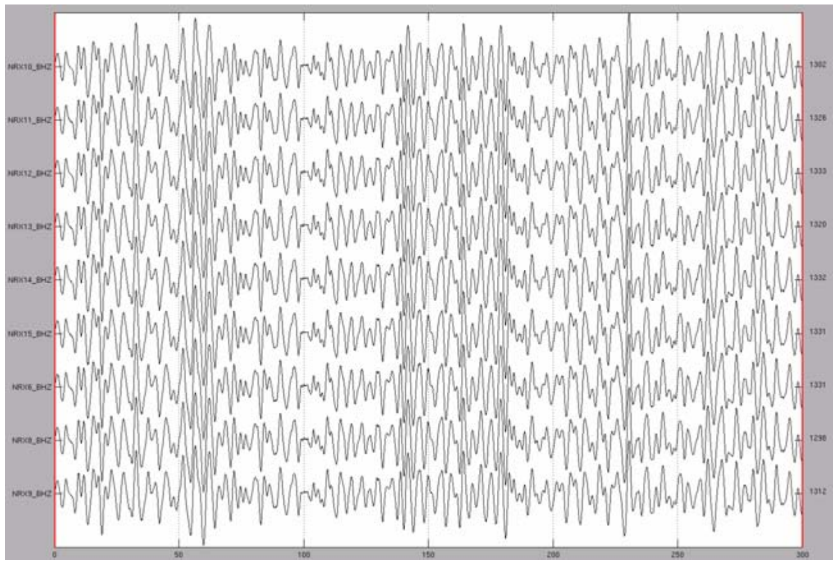

Figure 6.5.3. Instrument-corrected (0.01 - 39 Hz) vertical components (see Table 6.5.1. for station names) for a 5-minute time window.

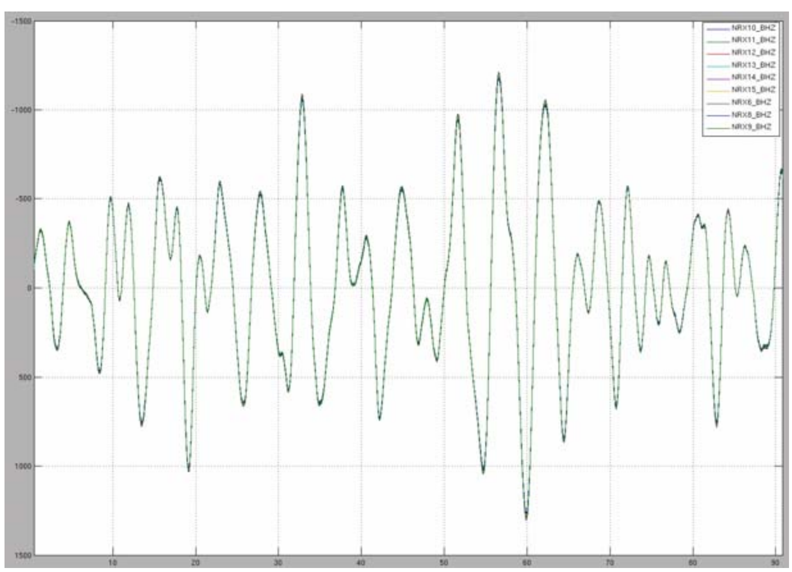

Figure 6.5.4. Overlaid instrument-corrected vertical components (in units of nm/s) for a 90s time window.

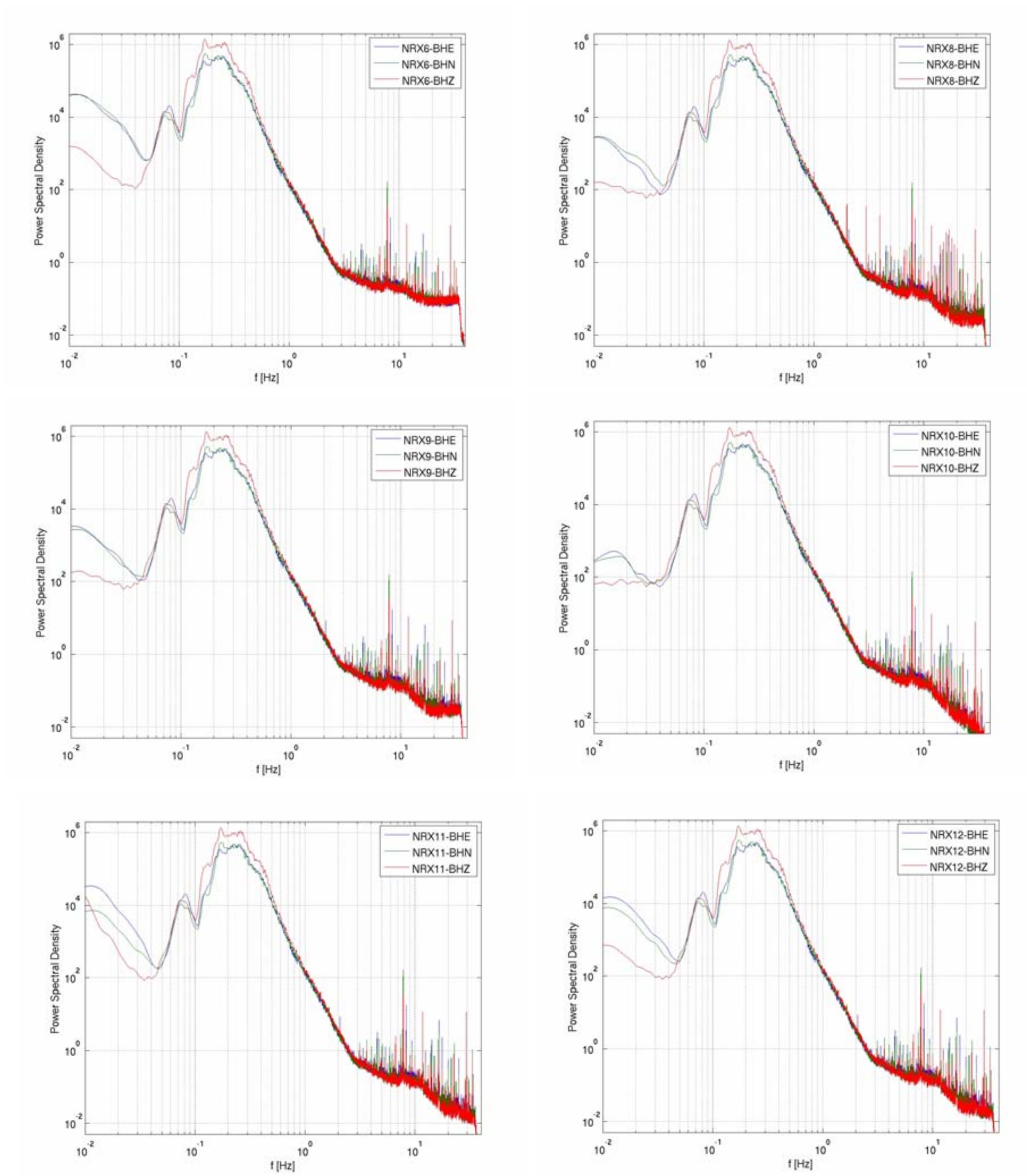

Figure 6.5.5. Power spectral density plots for the East (blue), North (green) and Z (red) components of stations NRX6, NRX8 - NRX12. The units of the PSD is in $(nm/s)^2/Hz$

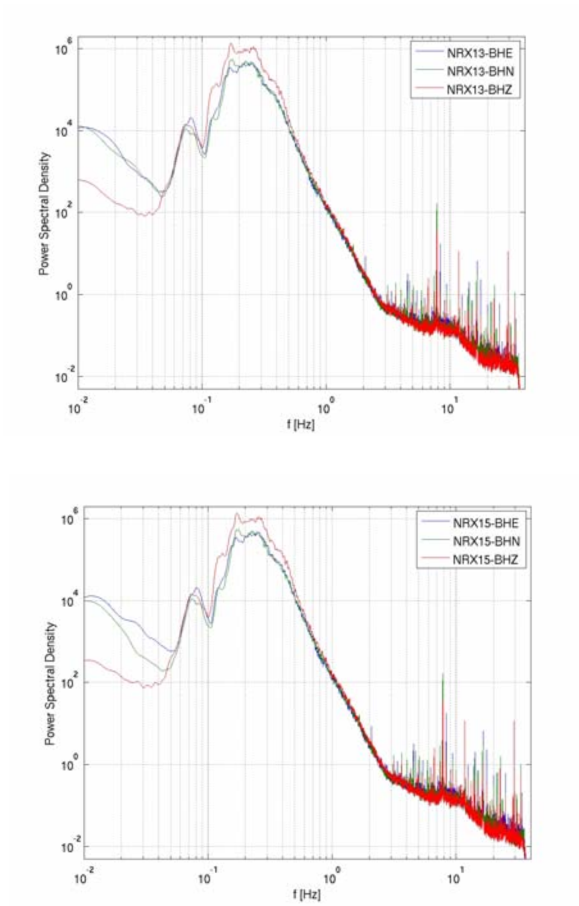

Figure 6.5.6. Power spectral density plots for the East (blue), North (green) and Z (red) components of stations NRX13 - NRX15. The units of the PSD is in (nm/s)^2/Hz

The PSD plots of all instruments and channels have distinct noise peaks above 2 Hz. Most of the noise is probably coupled into the systems over the ground motion, since the amplitudes of the peaks are almost identical for all systems. We would expect that electronic noise that is coupling into the cables, seismometers or digitizers has different peak amplitudes for the different systems. However, a clear electronic noise contamination is present in two stations NRX8 (Trillium 240/Europa T) and NRX10 (STS2/DM14). Both stations are picking up a 1 Hz (and higher harmonics) noise signal, which is most probably a leakage of the GPS signal into the digitizer. This was confirmed, when at a later time we rearranged the GPS cables and the 1 Hz signal dissapeared.

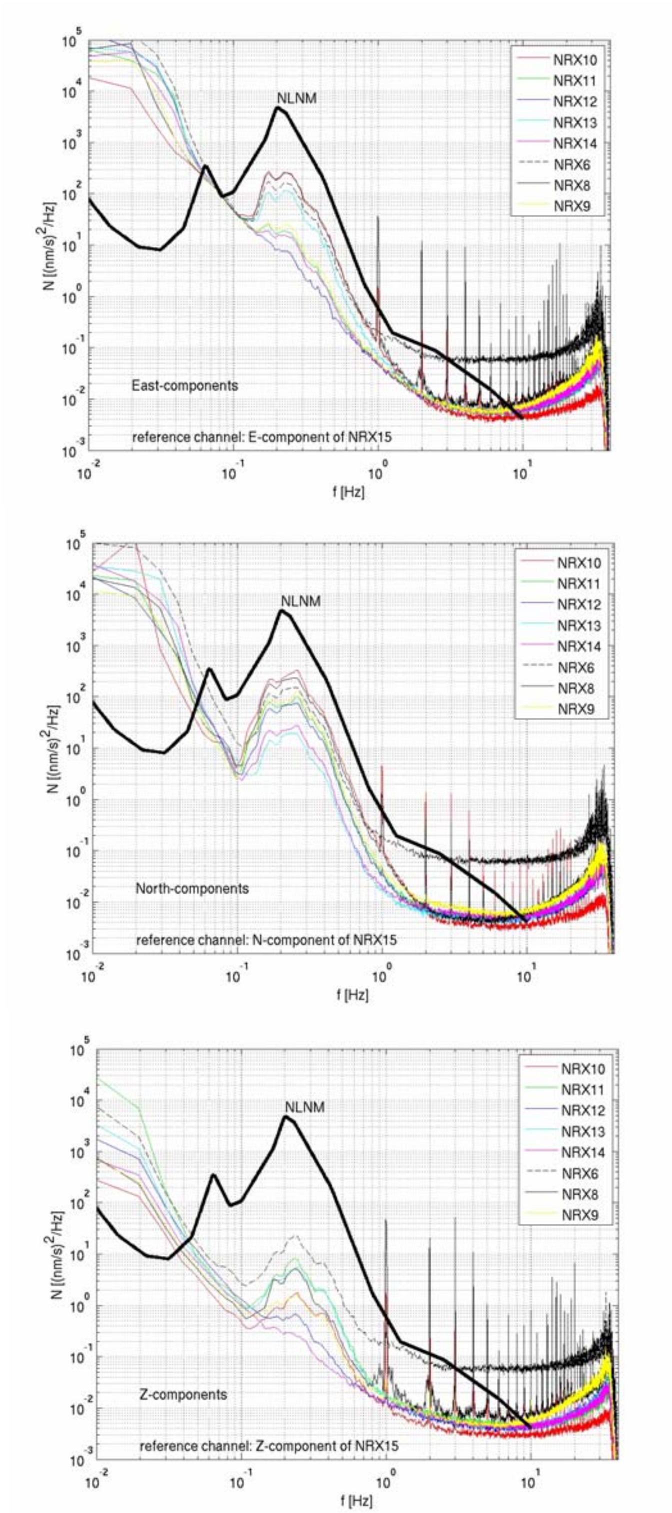

Figure 6.5.7. Instrument noise computed from PSD, cross spectral density and coherence of the instrument-corrected traces (eq.(5)). Top: east components, middle: north components, bottom: vertical components. The reference instrument was NRX15 (i.e. the Guralp GCM-3T (T35347) connected to the Europa T (0699)).

Figure 6.5.7.shows the channel noise of the stations computed with eq. (5) and with NRX15 as reference station. The contamination of stations NRX8 and NRX10 becomes very clear with amplitudes reaching over the New Low Noise Model (NLNM, Peterson, 1993). Generally for all stations the vertical components exhibit lower noise levels than the horizontal components. Station NRX6 (Guralp CMG-3ESPC/DM24) is below the NLNM for frequencies between ~0.6 Hz and 3 Hz, whereas the level for the other stations remains below the NLMN for frequencies up to 10 Hz. The observed high noies level of the CMG-3ESPC with regard to the other instruments is an expected result of the channel noise determination method, as the ESPC is a more narrowband and noisier sensor than the CMG-3T.

6.5.5 Conlusions

The NOA subarray NC6 has all necessary infrastructure to perform instrument tests in a controlled environment. The site is remote with low cultural noise and it is suitable for long-term instrument tests. All waveform data have been delivered to CTBTO, Guralp, and Nanometrics for further detailed analyses.

References

Holcomb, G. L. (1989). A direct method for calcultating instrument noise levels in side-by-side seismometer evaluations. USGS Open-File Report 89-214.

Peterson, J. (1993). Observations and modeling of seismic background noise. USGS Open-File Report 93-322.

Szekely, I., Y. Starovoit, E. Farkas, P. Martysevich, and P. Melichar (2007). Technical requirements to signal detection at seismic stations of the international monitoring system - test method. International Measurement Confederation Proceedings.

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