05 February 2019

MEMO N° 18P17_05022019

To:

CC.:

From:

Subject: KEM04 Project: issues related to the records collected at the KNMI B-Stations

Dear ,

In anticipation of our next meeting, there is an important issue that we have to share with you and to discuss on Friday, as it has an important impact on the organization of the next steps.
In order to be sufficiently precise, we have prepared this memo that put the issue in perspective in the executive summary and that offers a more technical justification in the additional chapters.

Thanks and best regards,

EXECUTIVE SUMMARY

Within the framework of the KEM04 project "Data driven study on seismic structural features of Groningen ground motions", an important task is the collection and analysis of the recorded ground motions for the induced events in the field (at depth and at surface). The induced earthquakes are recorded at the KNMI stations consisting of two networks: the B and G networks. These data are publicly accessible from the KNMI portal (http://rdsa.knmi.nl/dataportal/) and have been downloaded and processed by the project team.

Several B and G stations are located very close to each other, having an interstation distance of few hundred meters. As a consistency analysis, we selected pairs of B and G stations located close to each other and compared the records from the same event. We expected to observe similar ground motions, especially in terms of velocity and displacement time histories, because of the similar wave propagation from the source to the two stations and relatively homogenous local site conditions. However, based on our analyses over several recorded events in the field, this is not the case. We observe:

1. Systematically larger ground motion (Fourier amplitude spectra) at the B stations compared to G stations in a broad frequency range for both horizontal and vertical components. For the horizontal component there is roughly a factor of 2 in the low and mid-frequency range decreasing and approaching 1 at high frequencies. For vertical component, we observe a factor of about 2 in the whole frequency band.

2. The vertical component of the Fourier amplitude spectra at the B stations shows a systematic peak in the range 10-15 Hz that is not present in the horizontal components. The peak is not visible on closely located G stations. Such systematic peak is difficult to explain as a source/path or site effect.

These observations point out a clear inconsistency between records obtained at B and G stations, that may be caused by instrumentation problems or settings and that need to be addressed.

We have repeated the same analysis for pairs of G stations being located at relatively short interstation distance, and the records are this time consistent with a ratio close to 1 in the whole frequency range.

We cannot stress enough the importance of having reliable earthquake records for the projects. Such inconsistencies, if confirmed, have clearly large implications for the project.

An immediate interaction with KNMI is necessary in order to assess the causes of the inconsistencies of B- and G-stations records. Potentially an interaction with the developers of the GMM V5 may also be valuable to better understand if this issue was observed and treated. If support from KNMI is granted, it will certainly provide insights on the raised issues and KNMI may possibly suggest solutions. Additionally, we propose to perform an independent check of the stations installation in order to discard the hypothesis of an installation problem and/or of structure-related interaction and contamination effects. The team at the Hanze University of Applied Sciences in Groningen, , has the capability to perform such a task without extra budget for the project. Support and permission of access from KNMI would thus be mandatory for such a mission to be conducted.

If the inconsistency between B and G records can't be properly understood quickly, it will be impossible to develop a suitable simulation model. To make the project viable we will have to discard the set of records from the B stations only keeping the records from G stations (at surface and at depth).

Data from TNO housing network (when made available, hopefully no later than February 11) may also be used as independent check of B stations records.

INTRODUCTION

Within the framework of the KEM04 project "Data driven study on seismic structural features of Groningen ground motions", an important task is the collection and analysis of the recorded ground motions for the induced events in the field. The induced earthquakes are recorded at the KNMI stations consisting of two networks: the B and G networks (Figure 1). These data are publicly accessible from the KNMI website and have been downloaded by the project team. The B network consists of accelerometers at the surface (EpiSensor starting from 2014) whereas the G stations consists of a vertical array of 1 accelerometer (EpiSensor) at the surface and 4 geophones at 50m, 100m, 150m and 200m depth. Only records at the surface are considered in this Memo. Records from these networks are used in the project to:

1. Investigate the features of the Groningen ground motion records (spatial variability, vertical motion, attenuation);
2. Calibrate and validate the 3D simulations of wave propagation performed using the SPEED code;
3. Test the current GMM V5 in order to assess its performance in reproducing the observed ground motion records.

The reliability of recorded motions at these stations is thus of paramount importance for the project.

The initial analyses conducted on the records from some earthquakes at these stations pointed out potential issues that will be detailed in this Memo. These issues were initially discussed in the project internal meeting in Milano (17 December 2018) and further discussed in a dedicated web-meeting between Seister/Polimi/Hanze UAS (10 January 2019).

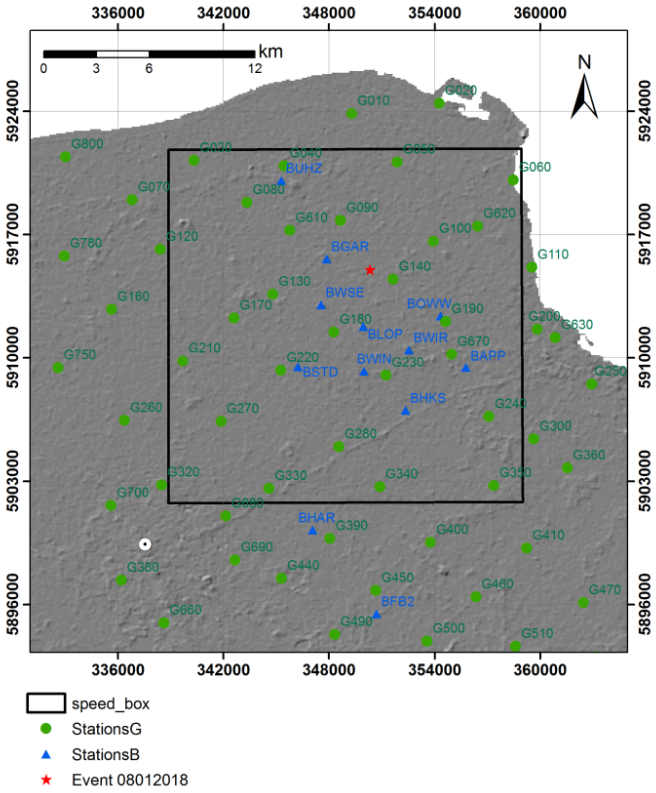

Figure 1. Location of B and G stations (at surface) recording the Zeerijp event (08.01.2018) in the Northern part of the Groningen field.

IDENTIFIED ISSUES AT THE B STATIONS

During the compilation of the project ground-motion database and the processing of earthquake records the following issues are identified.

- A first analysis is conducted considering records from the 8th January 2018 (M=3.4) Zeerijp event, showing significantly different records for close-by B and G stations. In particular, the B stations accelerations, velocity and displacement peaks are systematically larger than those at the G stations. This is very surprising because the velocity and displacement time histories are expected to be similar for very closely located station pairs due to the relatively homogeneous soil conditions. Such difference is also observed on the Fourier spectra that confirm the larger Fourier Amplitude Spectrum (FAS) values over a broad frequency range for the B stations. Examples are shown in Figure 2 for the pair BOWW and G190 (separated by 400 m), in Figure 3 for the pair BWIN-G230 (separated by 1.3 km) and in Figure 4 for the pair BSTD-G220 (separated by 1 km).

  We note that there are also polarity issues: for example at the BOWW stations where an inversion of the two horizontal components would improve the agreement with G190 at least in terms of polarity of P-waves displacement.

  It is interesting to observe that the comparison of records between pairs of G stations does not show such large differences even in case of stations separated by distances of several kilometers. An example is shown in Figure 5 where the records

at stations G210 and G270 (located southwest of the epicenter and with an interstation distance of about 5 km) are compared.

- The vertical component of the FAS at the B stations shows a systematic peak in the range 10-15 Hz (not present in the horizontal components), as shown in Figures 2b, 3b and 4b. The peak is not visible on closely located G stations. Such systematic peak is difficult to explain as a source/path or site effect. The peak is in the range of the building response and it could be related to installation issues or interaction with the building or with other elements of the installation set. It is difficult to verify the installation issues because there are no photos of other available information for a quick check. A similar comparison is performed for another recent event on the 13/04/2018 (M=2.8). This confirms the features observed for the previous event. In Figure 6 the FAS obtained at BOWW and G190 stations for both events (EQ1=08/01/2018; EQ2=13/04/2018) are shown. The peak between 10 and 15 Hz in the vertical component is visible in several stations and peak amplitudes at B stations tend to be larger than those recorded at adjacent G stations (not shown here for brevity).
- Following the findings from these events and stations, a more global analysis is conducted on a larger number of events and of pairs of stations with short interstation distance. Ratios between FAS recorded at adjacent B and G stations are calculated for several events located in different regions of the field. This is done for the horizontal (geometric mean of as-recorded horizontal components) and vertical components. The records are processed and filtered and only Fourier spectra within the usable frequency band are considered for calculating the spectral ratios. FAS are smoothed using the Konno-Ohmachi algorithm with the b-parameter set equal to 40.

  Figure 7 shows B to G stations FAS ratios for the considered pairs, color-coded according to the recorded earthquake. Figure 8 shows the ratios from all events and pairs of stations with the median ratio depicted by the thick blue curve. Similar plots are presented for the vertical component in Figure 9 and Figure 10.

  The figures clearly show systematically larger FAS at the B stations in a broad frequency range for both horizontal and vertical components. For the horizontal component there is roughly a factor of 2 in the low and mid-frequency range decreasing and approaching 1 at high frequencies. For vertical component, we observe a factor of about 2 in the whole frequency band. This further corroborates the findings discussed in the previous points.

  In order to further stress this unexpected amplitude differences between records at B and G stations, we performed the same comparison for pairs of G stations. Clearly, the interstation distance is this time larger and we can expect larger variations of the spectral ratios. The following pairs are selected

```
staG1={'G190';'G230';'G220';'G040';'G140';'G130';'G390';'G670';'G450'};
staG2={'G670';'G180';'G170';'G080';'G100';'G170';'G340';'G190';'G490'};
```

The ratios for all pairs of stations and all events are shown in Figure 11. Despite the larger interstation distance between pairs of G stations, we do not observe any

systematic effect and the median ratios are around 1 (slightly larger at high frequencies for the horizontal component probably related to local differences in the uppermost soil layers).

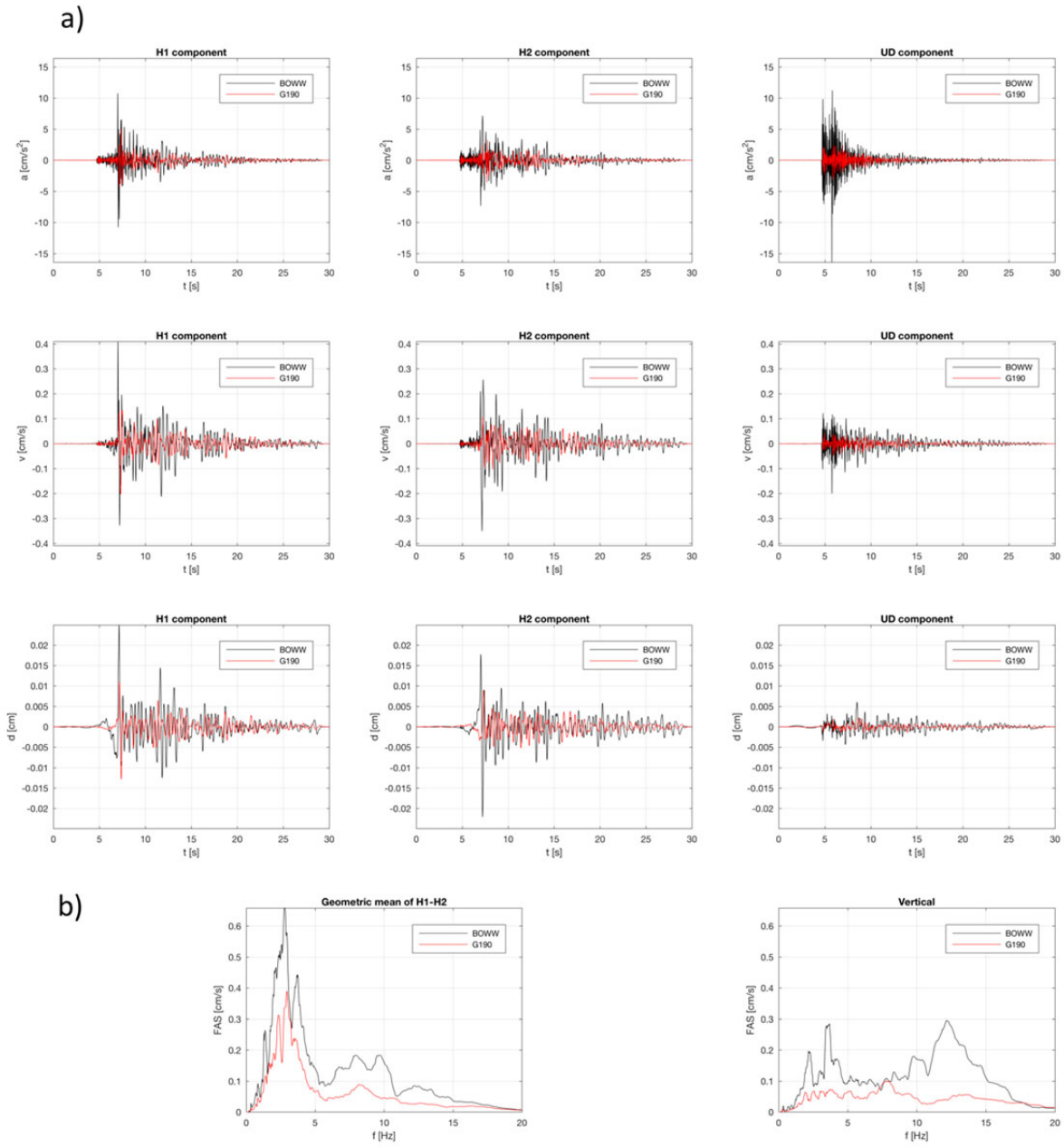

Figure 2. a) Comparison between acceleration (top) , velocity (middle) and displacement (bottom) time histories at BOWW (black) and G190 (red) stations for the 3 components. b) Comparison in terms of acceleration Fourier Amplitude Spectra – FAS (left: geometric mean of horizontal component; right: vertical component).

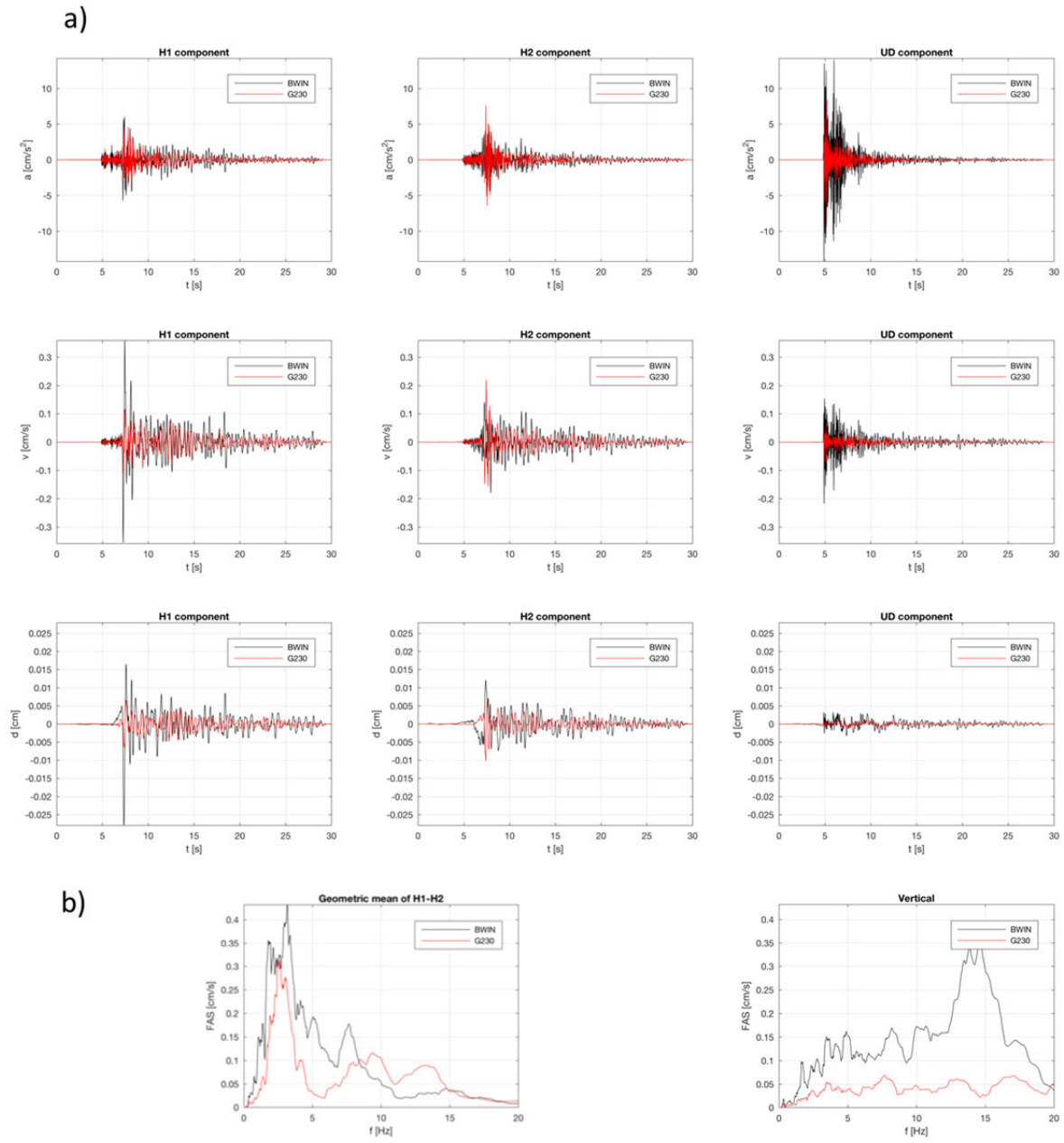

Figure 3. Same as in Figure 2 but for BWIN (black) and G230 (red) stations.

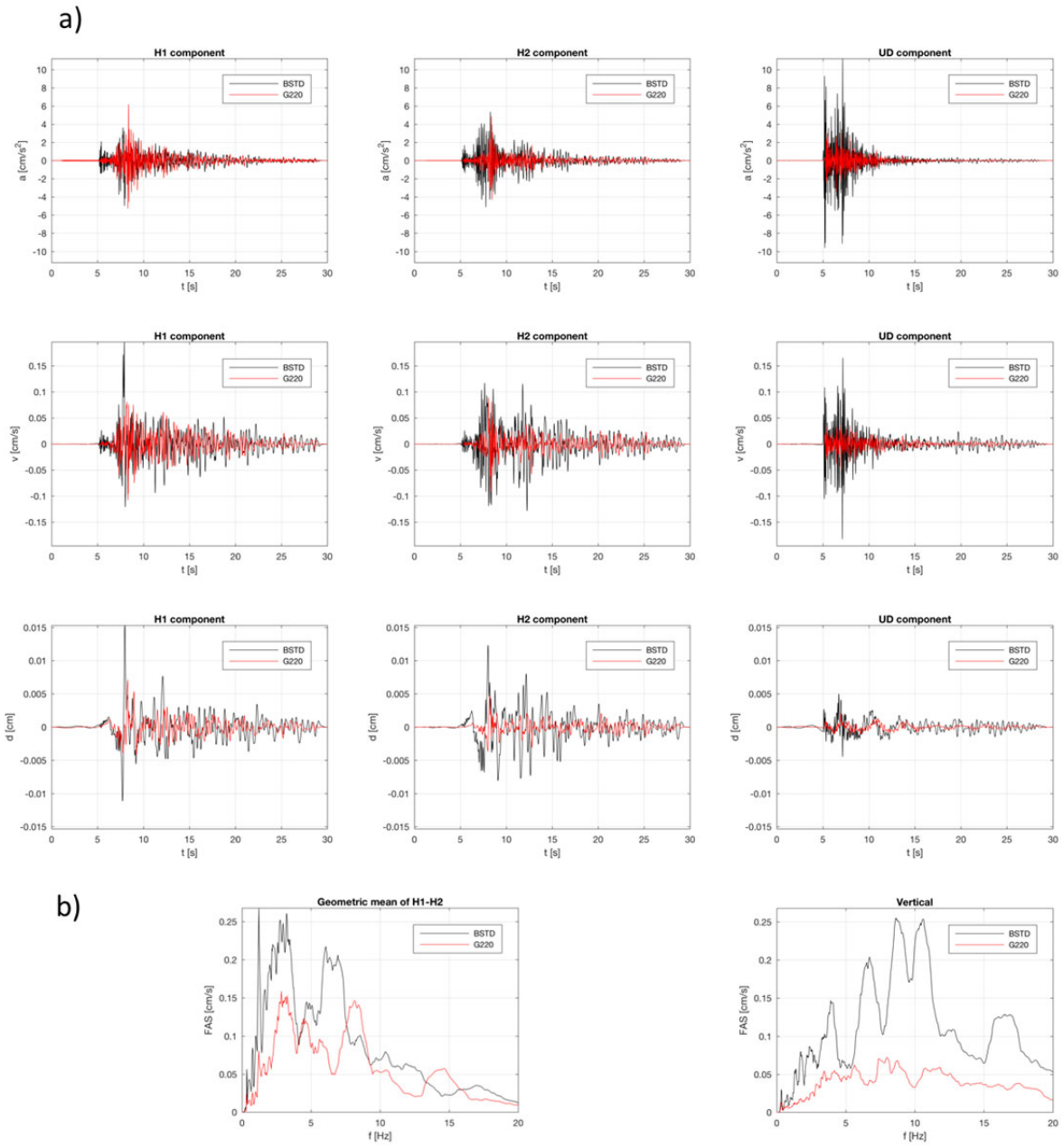

Figure 4. Same as in Figure 2 but for BSTD (black) and G220 (red) stations.

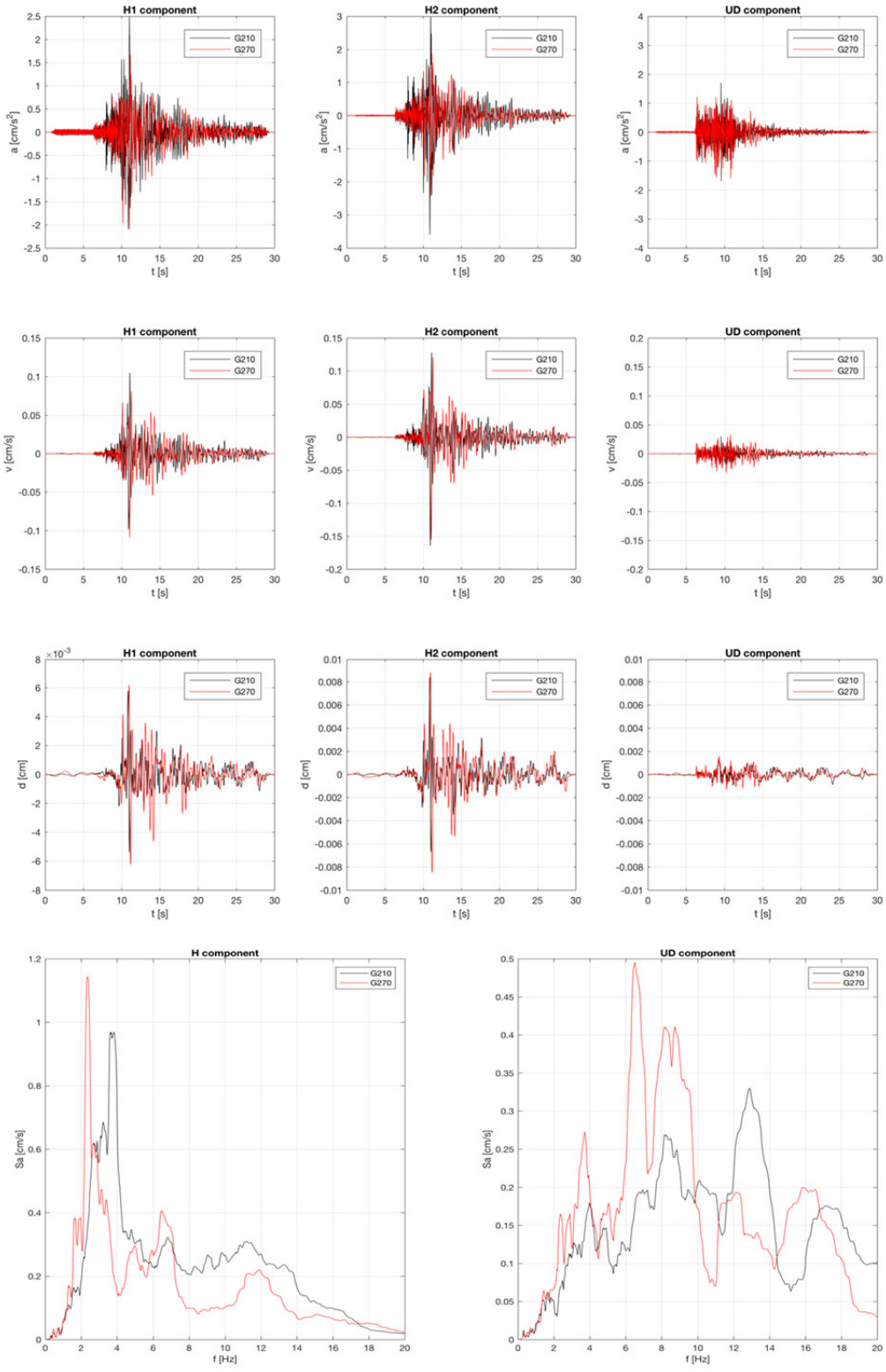

Figure 5. Same as in Figure 2 but for G210 (black) and G270 (red) stations.

o

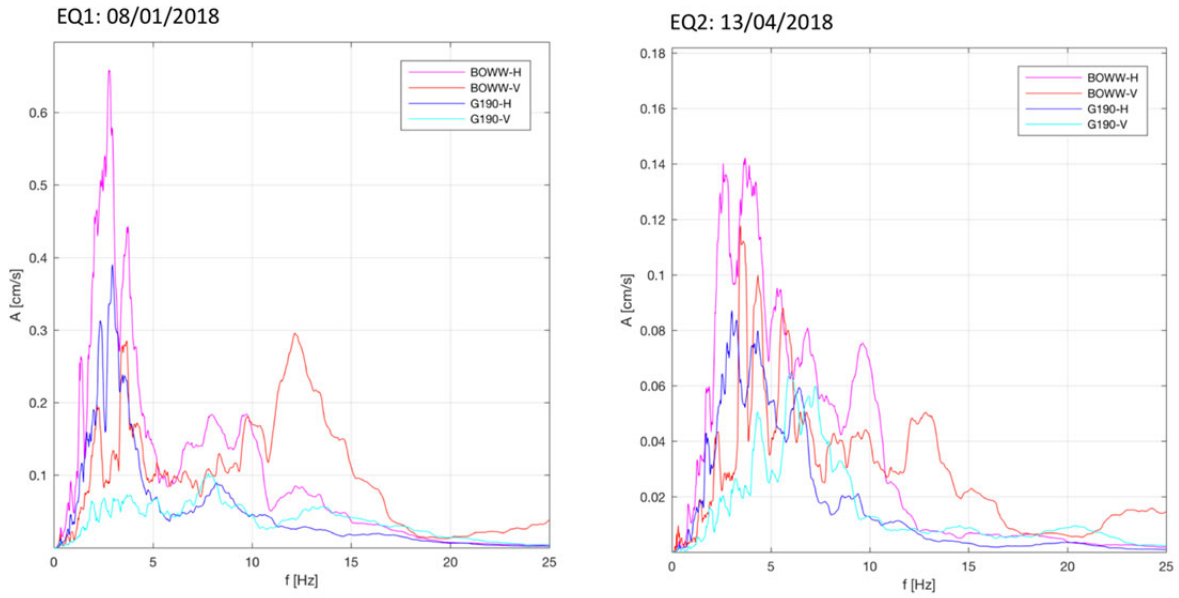

Figure 6. Comparison between FAS at BOWW and G190 stations, horizontal (geometric mean) and vertical components, for EQ1 - 08/01/2018 (left) and EQ2 - 13/04/2018 (right).

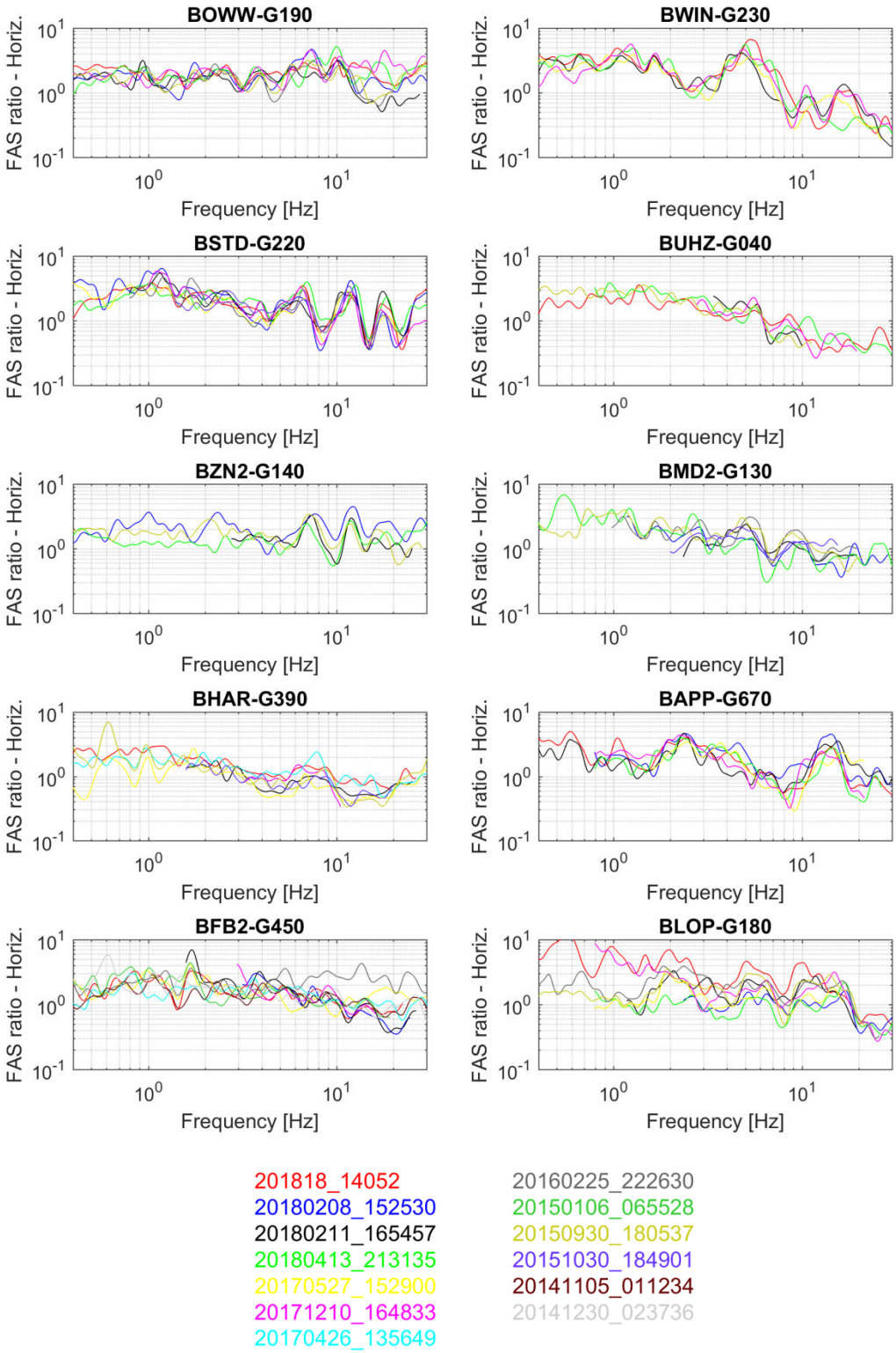

Figure 7. B-to-G Fourier Amplitude Spectra (FAS) ratio plotted for each pair of stations and for several recorded events. Horizontal component.

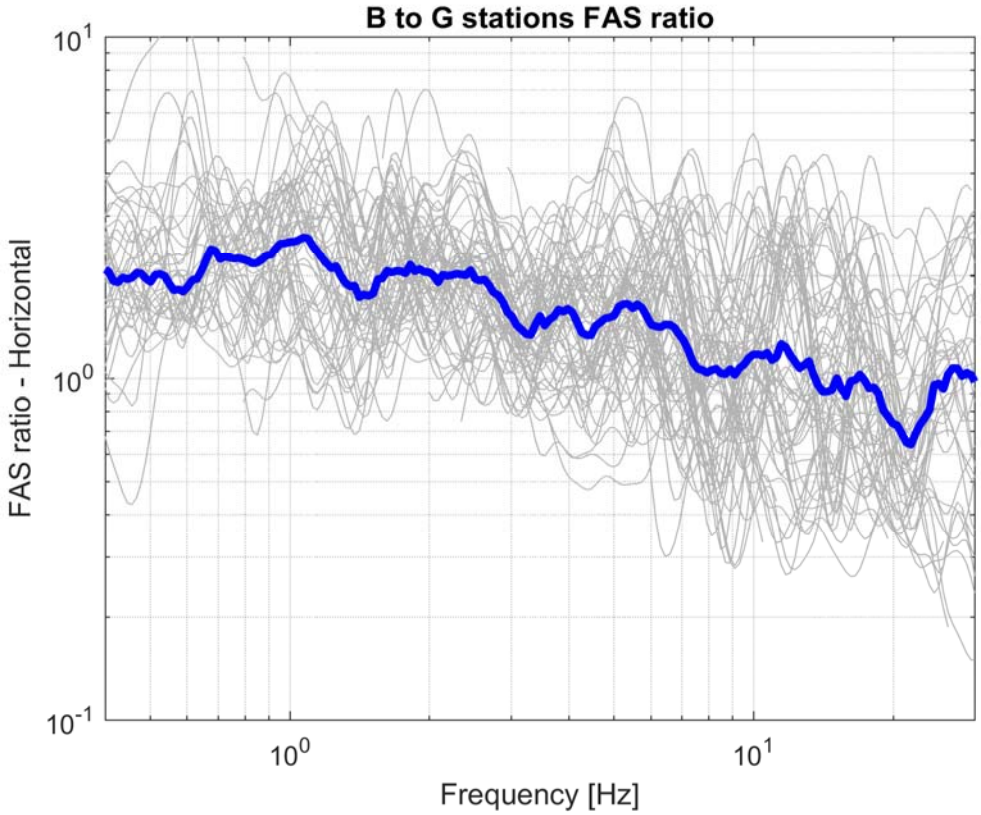

Figure 8. B-to-G Fourier Amplitude Spectra (FAS) ratio plotted for all considered pairs of stations and events. The median ratio is shown in blue. Horizontal component.

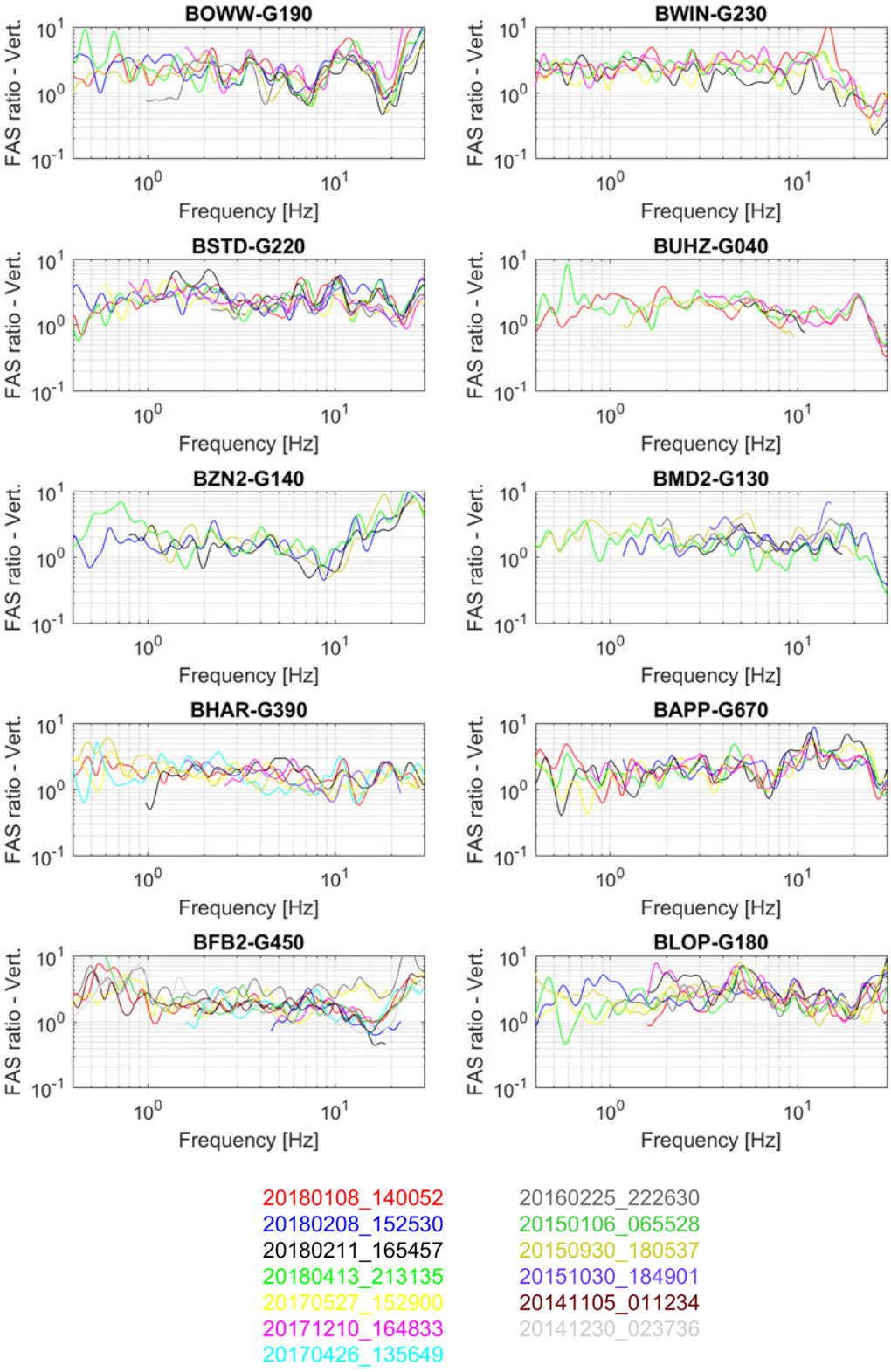

Figure 9. B-to-G Fourier Amplitude Spectra (FAS) ratio plotted for each pair of stations and for several recorded events. Vertical component.

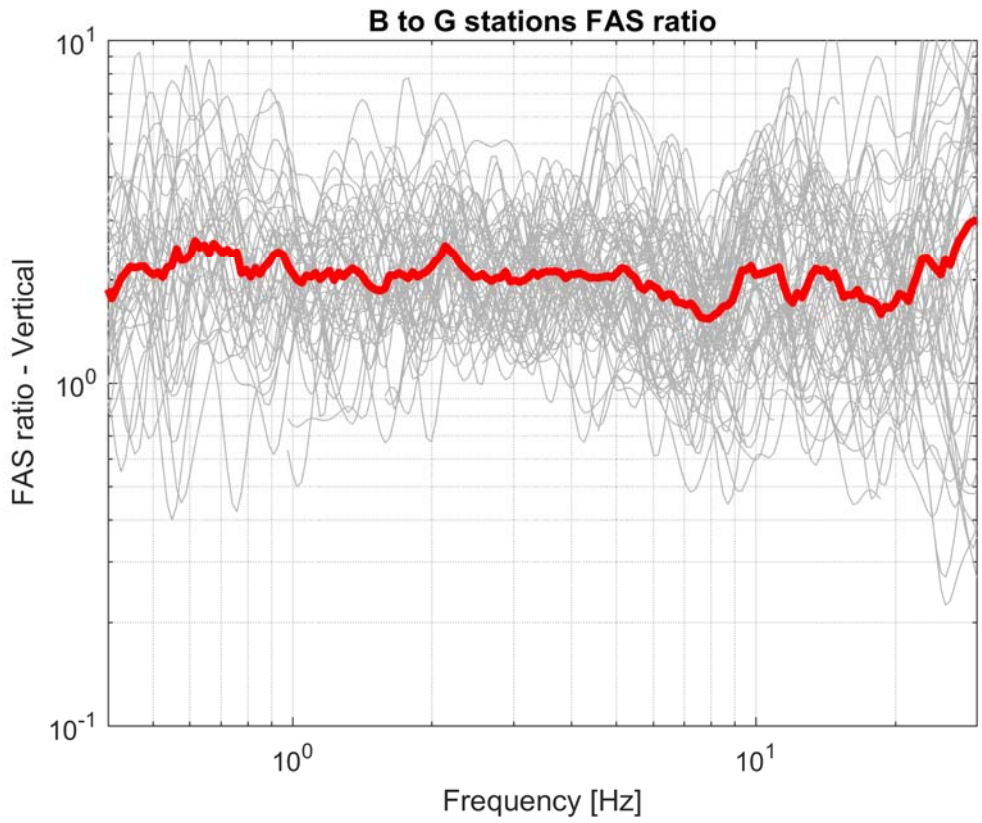

Figure 10. B-to-G Fourier Amplitude Spectra (FAS) ratio plotted for all considered pairs of stations and events. The median ratio is shown in red. Vertical component.

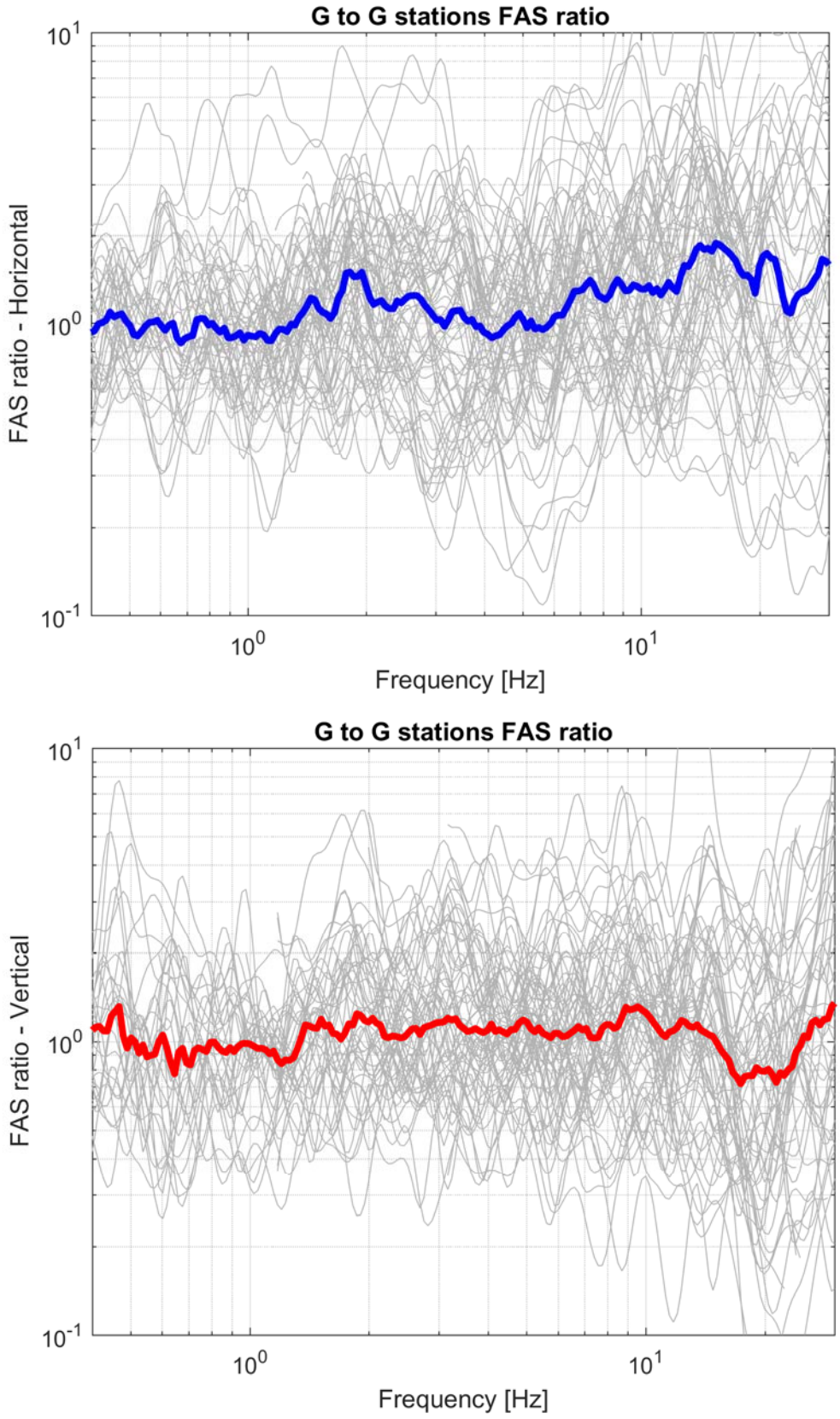

Figure 11. G-to-G Fourier Amplitude Spectra (FAS) ratio plotted for all considered pairs of stations and events. Top: horizontal component. Bottom: vertical component.

DISCUSSION AND PATH FORWARD

We cannot stress enough the importance of having reliable earthquake records for the projects. If doubts exist on the correct functioning or installation of a station, we need to address them or alternatively the station (and records) shall be discarded.

It appears that differences of B stations with respect to the G stations have already been discussed in the framework of the GMM development for Groningen during a project workshop on the GMM v5, in May 2018, where from Hanze UAS were also present. Similar issues were shortly pointed out during the workshop regarding systematic differences between G and B stations and orientation issues of B stations, although a clear conclusion on such issues was not drawn.

In the GMM V5 report it is stated [p. 85] "*Analyses are also being undertaken to assess the level of consistency of the surface recordings from the G-stations and the B-stations, and also of the NS_B motions that would result from deconvolution of the surface recordings and the 200-m deep geophone recordings of the G-network. All of these analyses will be documented to establish the database to be used in future refinements of the Groningen GMM.*" We wonder whether these analyses have been undertaken and have produced some conclusions on the consistency between B and G stations.

We suggest starting an immediate interaction with KNMI in order to assess the reliability of the B-stations records. Additionally, we propose to perform an independent check of the stations installation in order to discard the hypothesis of an installation problem and/or of structure-related interaction and contamination effects. The team at the Hanze University of Applied Sciences in Groningen, , has the capability to perform such a task without extra budget for the project. Support and permission of access from KNMI would thus be mandatory for such a mission to be conducted.

Based on the issues raised, we propose that, at the time being and for the continuation of the project and specifically for the 3D simulations, only the G stations will be considered for calibration and validation of the 3D model.

B stations will be reconsidered in the future if issues will be resolved.