# MEMORANDUM

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|---|---|
| **Subject** | Investigation of malfunctioning earthquake recording stations for Groningen earthquake events over period 2014 - 2018 |
| **Project** | Verification of the quality and correctness of KNMI seismic recordings Groningen field |
| **Client** | Staatstoezicht op de Mijnen |
| **Project code** | 113982 |
| **Status** | Final version |
| **Date** | 13 May 2019 |
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| **Author(s)** | KEM02 team: |
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| **Initials** | |
| **Appendices** | - |
| **To** | SODM dr. |
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# 1 INTRODUCTION

## 1.1 Background

Staatstoezicht op de Mijnen (SODM) requested the KEM02-team (consisting of Witteveen+Bos, TU Delft and TNO) to perform additional verifications on the correctness and quality of KNMI earthquake recordings for events of the Groningen field. The objective of these verifications is to determine which recordings cannot be used for future Ground Motion Model verification analyses.

## 1.2 Scope and limitations

Records by stations far from the earthquake epicenter are considered less relevant because the recorded signal will be dominated by noise. For this reason, the evaluation has been limited to stations within the area North-East of RD-coordinates 226100;567100 as illustrated in figure 1.1.

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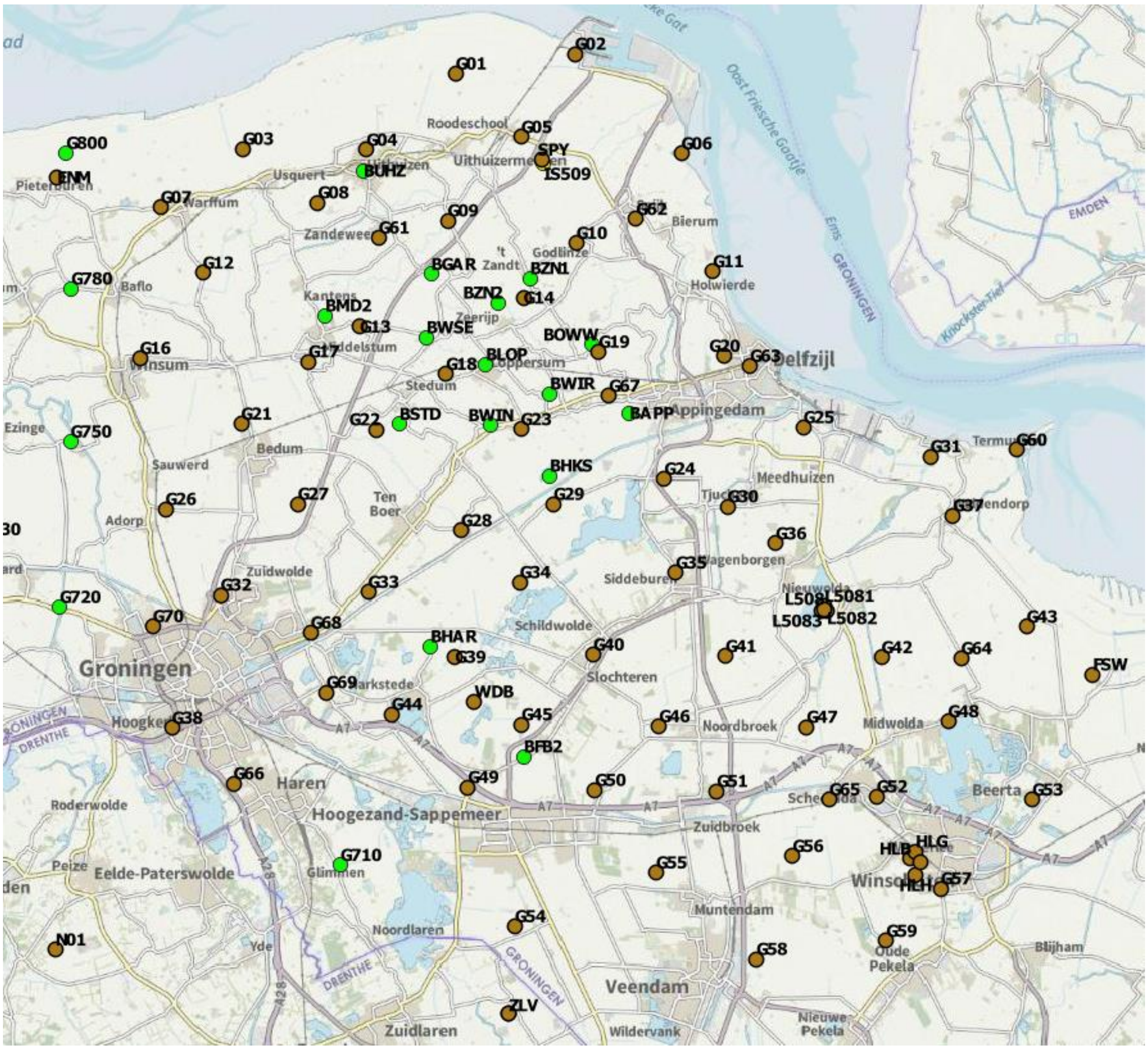
Figure 1.1 Overview of stations for which records are verified. Brown coloured stations are G-stations downhole arrays with an accelerometer at ground surface and geophones at 50, 100, 150 and 200 m depth. Green coloured stations are the B-stations positioned in buildings at foundation level




Very low magnitude earthquakes are considered less relevant because their impact on hazard and risk calculations is limited and their potential to damage buildings is low. Therefore the evaluation has been limited to events with $M_L > 2.0$. The events for which the recordings have been evaluated are listed in table 1.1. 29 events are taken into account.

Table 1.1 List of events for which records are verified

| EventID | Event Location Name | Time | Latitude | Longitude | Depth [km] | Mag Type | Magni-tude |
|---|---|---|---|---|---|---|---|
| knmi2014data | 't Zandt | 2014-02-13 02:13:14 | 53.35683 | 6.781667 | 3 | MLnq | 3.01 |
| knmi2014ewtu | Schildwolde | 2014-03-11 09:08:23 | 53.22783 | 6.821667 | 3 | MLnq | 2.29 |
| knmi2014fkmh | Rottum | 2014-03-18 21:15:18 | 53.39 | 6.618333 | 3 | MLnq | 2.05 |
| knmi2014mvwi | Slochteren | 2014-07-02 17:34:17 | 53.21367 | 6.79 | 3 | MLnq | 2.11 |
| knmi2014pnef | Appingedam | 2014-08-09 15:55:33 | 53.32516 | 6.835 | 3 | MLnq | 1.97 |

| EventID | Event Location Name | Time | Latitude | Longitude | Depth [km] | Mag Type | Magni-tude |
|---|---|---|---|---|---|---|---|
| knmi2014rcnr | Froombosch | 2014-09-01 07:17:43 | 53.19383 | 6.786667 | 3 | MLnq | 2.63 |
| knmi2014tdvz | Garmerwolde | 2014-09-30 11:42:03 | 53.258 | 6.655 | 3 | MLnq | 2.82 |
| knmi2014vqvi | Zandeweer | 2014-11-05 01:12:34 | 53.37433 | 6.678333 | 3 | MLnq | 2.92 |
| knmi2014znkv | Scharmer | 2014-12-30 02:37:37 | 53.20833 | 6.728333 | 3 | MLnq | 2.77 |
| knmi2015ajrf | Wirdum | 2015-01-06 06:55:28 | 53.32383 | 6.768333 | 3 | MLnq | 2.69 |
| knmi2015dxgo | Appingedam | 2015-02-25 10:02:57 | 53.32317 | 6.856667 | 3 | MLnq | 2.29 |
| knmi2015fuvx | Appingedam | 2015-03-24 13:27:57 | 53.32167 | 6.855 | 3 | MLnq | 2.27 |
| knmi2015khoy | Uithuizen | 2015-05-27 10:52:10 | 53.40417 | 6.668334 | 3 | MLnq | 2.01 |
| knmi2015ndxi | Zuidwolde | 2015-07-07 03:09:01 | 53.262 | 6.631 | 3 | MLn | 2.08 |
| knmi2015qcyg | Kolham | 2015-08-18 07:06:13 | 53.185 | 6.754 | 3 | MLn | 2.03 |
| knmi2015teiq | Hellum | 2015-09-30 18:05:37 | 53.234 | 6.834 | 3 | MLn | 3.08 |
| knmi2015vhfe | Meedhuizen | 2015-10-30 18:49:01 | 53.285 | 6.92 | 3 | MLn | 2.25 |
| knmi2016dyfc | Froombosch | 2016-02-25 22:26:31 | 53.184 | 6.781 | 3 | MLn | 2.42 |
| knmi2016rgqn | Schildwolde | 2016-09-02 13:16:01 | 53.218 | 6.844 | 3 | MLn | 2.07 |
| knmi2016vlii | Wirdum | 2016-11-01 00:57:46 | 53.306 | 6.809 | 3 | MLn | 2.18 |
| knmi2016zdjh | Zuidlaren | 2016-12-23 14:29:49 | 53.083 | 6.712 | 3 | MLn | 2.43 |
| knmi2017exbf | Zeerijp | 2017-03-11 12:52:48 | 53.35 | 6.761 | 3 | MLn | 2.08 |
| knmi2017idel | Scharmer | 2017-04-26 13:56:49 | 53.21 | 6.713 | 3 | MLn | 2.01 |
| knmi2017khyc | Slochteren | 2017-05-27 15:29:01 | 53.211 | 6.834 | 3 | MLn | 2.59 |
| knmi2017ydyv | 't Zandt | 2017-12-10 16:48:33 | 53.37 | 6.765 | 3 | MLn | 2.07 |
| knmi2018anwg | Zeerijp | 2018-01-08 14:00:52 | 53.363 | 6.751 | 3 | MLn | 3.43 |
| knmi2018cspq | Loppersum | 2018-02-08 15:25:31 | 53.335 | 6.751 | 3 | MLn | 2.04 |
| knmi2018cyfc | Garrelsweer | 2018-02-11 16:54:57 | 53.293 | 6.78 | 3 | MLn | 2.16 |
| knmi2018hfzx | Garsthuizen | 2018-04-13 21:31:35 | 53.371 | 6.75 | 3 | MLn | 2.81 |

# 2 RECORDS PROCESSING

## 2.1 Collection

The record data has been downloaded from the KNMI data portal (API: http://rdsa.knmi.nl/fdsnws/) on 20 March 2019. The length of the signals for download has been set to 30 seconds before the recorded event to 120 seconds after the recorded event.

## 2.2 Pre processing

Pre-processing of the downloaded signals comprises the following steps:

1 Stations with a number of channels different from 3 are not further considered in the analyses.
2 Signal trimming to achieve signals with the same duration for all 3 channels (*method in ObsPy:* `Stream.trim(starttime, endtime)`).

3 Signal detrending with lineair detrend in order to overcome offset and linear drift (*method in ObsPy:* `Stream.detrend(type='linear'))`.
4 Notch filtering for power-hum. A bandstop filter over range 49 to 51 Hz. Non causal Butterworth filter of 4th order (*method in ObsPy:* `Stream.filter('bandstop', freqmin=49, freqmax=51, corners=4, zerophase=True)`)

## 2.3 Trigger signal

A copy of the original signal has been created in order to identify the earthquake trigger point of arrival of primary waves. This trigger point is required in order to set the windows for signal, noise and signal-to-noise ratio calculations. The method followed to calculate the trigger signal comprises the following steps:

1 Apply high-pass and low-pass filtering to the signal. The low-pass filter threshold has been set to 30 Hz. The high-pass filter threshold has been set to 0.7 Hz and 1.4 Hz for 200 Hz and 100 Hz sampling frequency respectively. This has been done because low frequency noise of records from the (newer) stations with 200 Hz sampling frequency is constrained to lower frequency bands compared to noise in records from the (older) 100 Hz sampled stations. This seems to be related to the station quality rather then there is an analytical/mathematical relation. Example records are illustrated by figure 2.1 and figure 2.2.
(*method in ObsPy:*

```
cutoff_low = 140 * (1/['fs'])
Stream.filter('highpass', freq=cutoff_low, corners=4, zerophase=True)
Stream.filter('lowpass', freq=30, corners=4, zerophase=True)).
```

2 Trigger detection on the vertical signal using a trigger detection threshold at 1.5 using ObsPy toolbox ([ref. 1], [ref. 2]). *(method in ObsPy:* `trigger.classic_sta_lta(vertTr.data, nsta=5*['fs'], nlta=10*['fs']))`
When this threshold is not met the threshold has been lowered with 0.3 and the test has been repeated. The trigger time is constrained to be after the event time reported by KNMI.
3 The trigger time determines the start of the earthquake ground motion at the specific station. The end of the earthquake ground motion window has been set to be 20 seconds after the trigger time. Automatic methods for the end of the window in literature, such as [ref. 3], are created for tectonic earthquakes and contain parameters not in the range of Groningen induced earthquakes. An automatic calculation of the end of earthquake ground motion based on 75 % Arias intensity has been attempted but turned out to be not successful for our purpose. Using these methods results very short event windows of about 1 second resulting the tail of the ground motion to be not part of the event window and a poor low frequency resolution. For the purpose of signal-to-noise ratio analysis therefore the previously described approach turned out to be preferable.

Figure 2.1 Signal with low-frequent noise, sample frequency 200 Hz, cut-off frequency 0.7 Hz (green line), event: knmi2016rgqn - Schildwolde, 2016-09-02, mag: 2.07, station: G311, distance 14.71 km

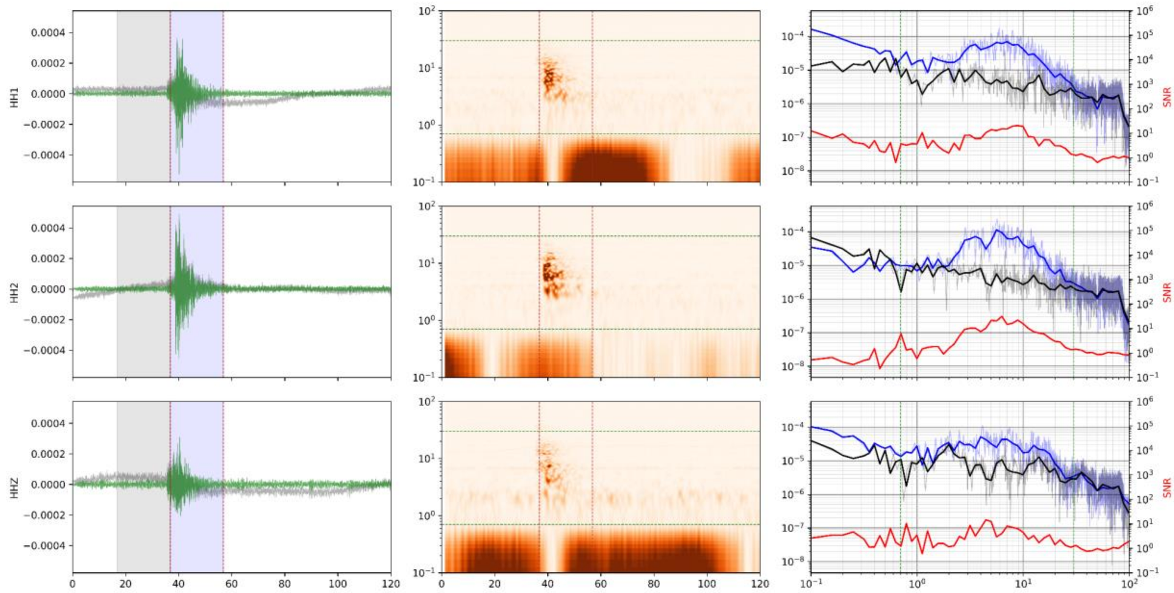
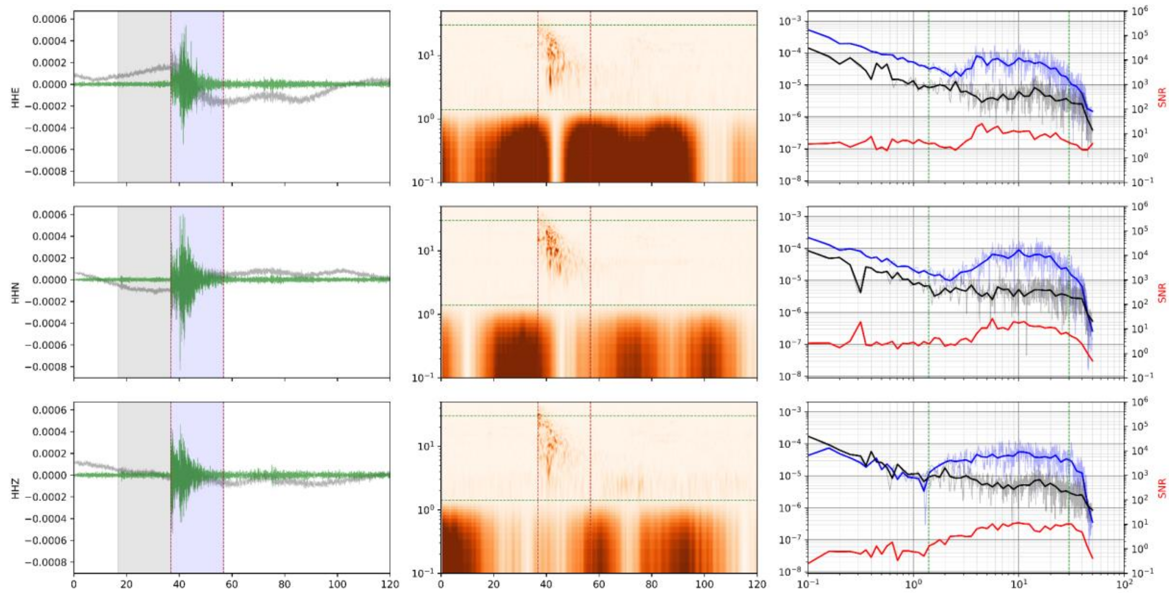


Figure 2.2 Signal with low-frequent noise, sample frequency 100 Hz, cut-off frequency 1.4 Hz (green line), event: knmi2017idel - Scharmer, 2017-04-26,, mag: 2.01, station: ZL21, distance 13.40 km



## 2.4 SNR plot

The frequency diagrams are calculated for the signal windows assigned to the earthquake ground motion and the pre earthquake noise. Smoothening is applied over the frequency spectrum where an average has been taken over multiple frequency bins [ref. 3]. Subsequently the signal-to-noise ratio (SNR) is calculated dividing the smoothened event window FAS by the smoothened noise window FAS.

# 3 RECORD QUALITY VERIFICATION

## 3.1 Methodology and processing results

The quality/correctness of records has been evaluated based on visual inspection of the:
- Original and processed acceleration - time signal representation.
- Frequency - time spectrogram representation.
- FAS and SNR plot representation.

A high level verification for a sampled sub set of records has been made for the processed results (both raw data and filtered data) by comparing to the strong motion data from KNMI (http://rdsa.knmi.nl/opencms/nl-rrsm/). The check confirmed that deviations (if any) are typically small and are explained by the processing pipeline. The verification confirmed the validity of the data used in the present study to perform the signal quality and station malfunctioning screening.

An example of the record visualization used for the evaluation has been illustrated in the previous chapter by figure 2.1 and figure 2.2. In the SNR plots the FAS of the noise window is represented by the black line, the FAS of the event window by the blue line and the SNR by the red line.

A complete set will be, for readability purposes, provided as a .zip file submitted together with this document.

## 3.2 Verification results

Table 3.1 gives an exclusive list of the stations/channels that were malfunctioning with the time frame indicated over which malfunctioning has been identified.

Malfunctioning has been defined as something being wrong with the sensor itself or its connecting components, such as broken connections with practically zero registration, extreme noise levels in certain channels compared to the others, extreme noise levels at frequencies that cannot be explained from common external sources.

Not all remaining records that have been analysed are usable in the analysis because of signal to noise ratio, which is often too low at large epicentral distances, or interference from other vibration sources. These records however are not listed herein and not assigned to sensor malfunctioning. Depending on the application more or less of these records need to be discarded for further use.

Table 3.1 List of stations/channels that malfunction with indicated the period of malfunctioning

| Station | Channel(s) | Start | End | Comments |
|---|---|---|---|---|
| G050 | all | 10-12-2017 | 13-4-2018 | |
| G061 | HHZ | 26-4-2017 | 13-4-2018 | |
| G062 | HH1 | 30-10-2015 | 13-4-2018 | |
| G071 | HH1 | 30-10-2015 | 13-4-2018 | |
| G084 | HH2 | 11-3-2017 | 11-2-2018 | events 't Zandt (2017) and Zeerijp (2018) are correct |
| G320 | HGZ | 10-12-2017 | 8-2-2018 | |
| G330 | HGZ | 27-5-2017 | 13-4-2018 | Z-channel, gain factor 10 to 100 too high |
| G383 | HH2 | 2-9-2016 | 13-4-2018 | |

| Station | Channel(s) | Start | End | Comments |
|---|---|---|---|---|
| G441 | HH1, HH2 | 25-2-2015 | 13-4-2018 | |
| G450 | HG1 | 13-4-2018 | 13-4-2018 | for last recorded event the noise level is factor 100 to 1000 higher |
| G454 | HH2 | 6-1-2015 | 13-4-2018 | |
| G494 | HH2 | 6-1-2015 | 13-4-2018 | |
| G520 | all | 7-7-2015 | 8-2-2018 | unclear if malfunctioning. There is a strong 25 Hz signal overshadowing the earthquakes |
| G530 | HG2 | 25-2-2016 | 13-4-2018 | channel HG2 seems not to operate well for some events. High noise level, possibly a too low gain setting |
| G634 | HH1 | 30-9-2015 | 13-4-2018 | |
| G653 | HH2 | 25-2-2016 | 13-4-2018 | |
| G680 | HG2 | 2-9-2016 | 13-4-2018 | HG2 shows much higher noise level than other channels 100-1000 times higher. Possibly a wrong gain setting. |
| WDB1 | HHZ | 2-9-2016 | 27-5-2017 | |
| WDB3 | all | 13-2-2014 | 27-5-2017 | |
| ZLV4 | HHN | 10-12-2017 | 13-4-2018 | |
| ZLV5 | HHE, HHN | 27-5-2015 | 25-2-2016 | channel HNN does not operate well for some events. HHE does not operate well for all events in this period |
| BAPP | HGN | 23-12-2016 | 26-4-2017 | channel HGN shows much higher noise level than other channels in low frequency |
| BLOP | all | 2-7-2014 | 2-7-2014 | invisible earthquake signal while comparable distance/magnitude with earlier/later events that showed clear signal |
| BZN1 | all | 7-7-2015 | 11-2-2018 | very strange spikes with only positive amplitude |
| BZN2 | all | 18-8-2015 | 18-8-2015 | |
| ENM1 | HHE | 11-3-2014 | 13-4-2018 | HHE malfunctioning. For Slochteren (2014) event malfunctioning of all channels |
| ENM2 | HHN | 2-9-2016 | 13-4-2018 | for Garsthuizen (2018) also malfunctioning of HHE |
| ENM3 | HHE | 27-5-2015 | 13-4-2018 | |
| FSW1 | all | 23-12-2016 | 11-3-2017 | strange pattern of noise, not clear if due to large distance or malfuntion |
| FSW2 | all | 23-12-2016 | 11-3-2017 | strange pattern of noise, not clear if due to large distance or malfuntion |
| FSW3 | all | 23-12-2016 | 11-3-2017 | strange pattern of noise, not clear if due to large distance or malfuntion |
| FSW4 | HHN | 27-5-2015 | 18-8-2015 | strange pattern of noise, not clear if due to large distance or malfuntion |
| FSW5 | all | 1-11-2016 | 13-4-2018 | strange pattern of noise, not clear if due to large distance or malfuntion |

Table 3.2 summarizes the percentages of malfunctioning stations out of the total number of stations

Table 3.2 Summary of analysed records and quality

| Description | Value |
|---|---|
| Total number of stations | B-stations locations: 16<br>G-stations array locations 65<br>Older array locations: 5 |
| Total number of event - station requests | 5395 |
| Number and % of successfully downloaded records | 5395 (100 %) |
| Number and % of successfully processed records | 5395 (100 %) |
| Number and % of records that imply malfunctioning station | 328 (6 %) |

## 4 CONCLUSIONS

This document summarizes the investigation of KNMI earthquake recording stations in the Groningen field region, aiming for identification of malfunctioning stations of which records could not be use in subsequent evaluation of Ground Motion Model performance.

Table 3.1 lists the malfunctioning stations/channels with an indication of the period over which these stations/channels did not operate well.

The records from stations that were concluded to not function well, will not be further used in the evaluation and validation study of the site amplification component of the Groningen GMM (KEM-02).

## 5 REFERENCES


1 Withers, M., Aster, R., Young, C., Beiriger, J., Harris, M., Moore, S., and Trujillo, J. (1998), A comparison of select trigger algorithms for automated global seismic phase and event detection, Bulletin of the Seismological Society of America, 88 (1), 95-106.
2 Trnkoczy, A. (2012), Understanding and parameter setting of STA/LTA trigger algorithm, in New Manual of Seismological Observatory Practice 2 (NMSOP-2), IS 8.1, 20 pp.
3 Kishida, T., Kayen, R.E., Ktenidou, O., Darragh, R., PEER Arizona Strong-Motion Database and GMPEs Evaluation, PEER 2014/09, June 2014.