NAM

Harkstede 2A Microseismic Monitoring Summary

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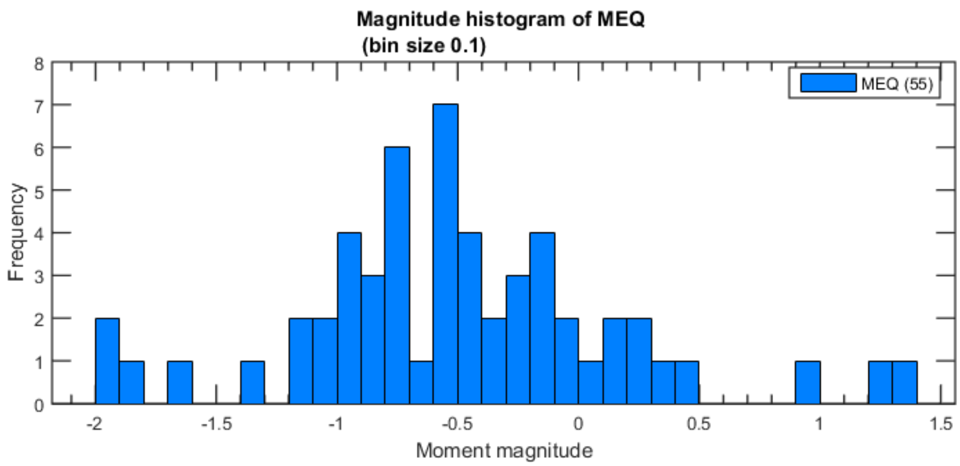
Samenvatting

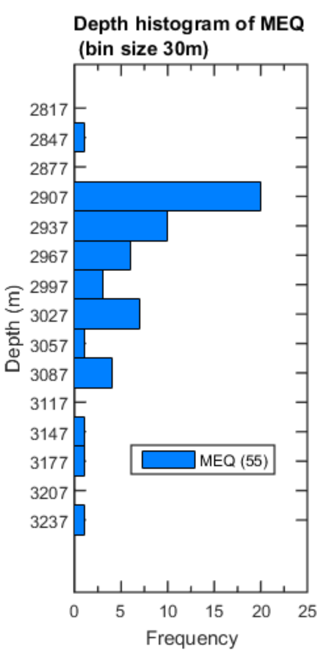
In de diepe Harkstede put (HRS-2A), gelegen bij de stad Groningen, zijn gedurende 3 maanden metingen met geofoons uitgevoerd. De meetcampagne begon op 6 oktober 2016 en werd beëindigd door een defect van de apparatuur op 6 januari 2017.

Het niveau van de geregistreerde seismiciteit in Harkstede was laag:

- 55 “interne” aardbevingen met magnitudes van -2 tot 1.4, waarvan de plaats goed bepaald kon worden.
- 56 “externe” aardbevingen die wel geregistreerd konden worden (verschil tussen de P- en S-aankomsttijd >1 s), maar die hun oorsprong buiten de straal van 10 km rond HRK-2A put hadden.
- 80 aardbevingen konden niet gelokaliseerd worden door de slechte kwaliteit van het signaal (dit betreft kleine aardbevingen)
- In totaal zijn er 191 aardbevingen geregistreerd.
- De diepte van het hypo-centrum van de aardbevingen is vastgesteld tussen 2847 en 3237 m TVD (verticale diepte). Dit plaatst alle bevingen binnen het Rotliegend reservoir.



Histogram van de frequentie van de aardbevingen tegen de grootte (magnitude) sinds het begin van de waarnemingen toont een pseudo-clustering rond magnitude -0.5.



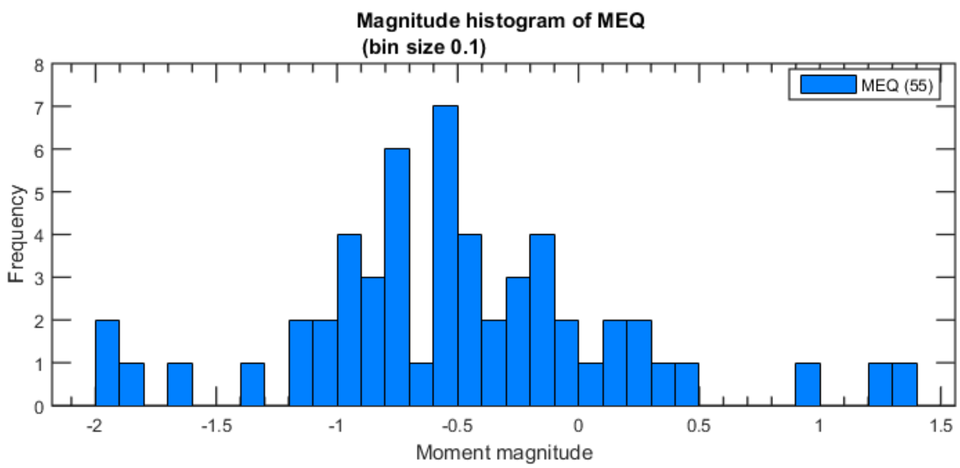
De externe aardbevingen zijn gecorreleerd met aardbevingscatalogi, zoals van KNMI en de Duitse CSEM. Ook werden er enkele aardbevingen op grote afstand gedetecteerd: in Italie M5.8, Polen M4.5 and the Zuidelijke Noordzee M3.8. Dit laat zien hoe gevoelig de geofoons in de diepe put waren en ondersteunt dat het gebied rond de monitoring put seismisch heel stil was.

Van de 55 interne aardbevingen zijn er 3 ook geregistreerd en gelokaliseerd door het oppervlakte netwerk van KNMI. Deze bevingen hadden magnitudes variërend van 0.2 tot 1.4.

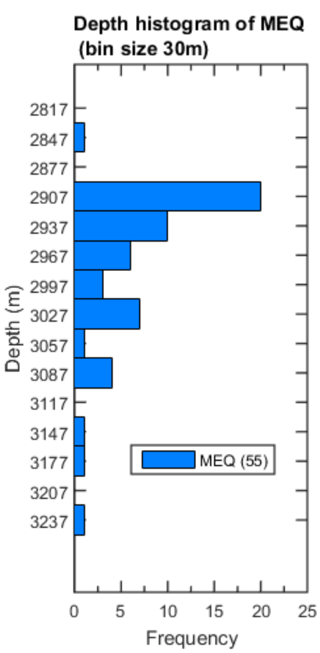
Summary

A downhole-array seismic monitoring campaign in the duration of 3 months, from Oct/06/2016 until Jan/06/2017 was completed at HRS-2A, close to the city of Groningen; campaign ended due to the tool string failure. The overall level of seismicity detected by the Harkstede downhole array was low:

- 55 locatable "internal" earthquakes ranging in magnitude from -2 to 1.4
- 56 detected "external" earthquakes (S-P time > 1 sec), i.e. originate outside of the 10 km box around the HRS-2A area.
- 80 earthquakes were non-locatable due to the poor quality signal (i.e. very small magnitude)
- Total number of 191 detected earthquakes
- Determined hypocentral depths range of 2847-3237 m TVD (true vertical depth) places all located events within the Rotliegend reservoir



Histogram of the event frequency versus magnitude since the beginning of recording on October 06. 2016 shows pseudo-clustering around magnitude -0.5.



The external events were correlated with other catalogues such as KNMI and Germany's CSEM. Events were detected as far as Italy M5.8, Poland M4.5 and the Southern North Sea M3.8, demonstrating the sensitivity of the downhole array, and thus validating the seismic quiescence of the local monitored area.

Of the 55 internal events, 3 events were also detected and located by the KNMI surface arrays. These had magnitudes ranging from 0.2 to 1.4.

Histogram of event frequency versus depth since the beginning of recording on

October 06. 2016 shows pseudo-clustering around 2907 m.

Overview

The first notable earthquake in the municipality of the city of Groningen (gemeente Groningen) occurred on April 8th 2000 and had a magnitude of M_L1.2. Due to the concerns of the possibility of increasing background seismicity in the proximity of the city of Groningen and the EKL (Eemskanaal) production cluster, the observation well Harkstede 2A (herein referred to as HRS-2A; red dot in Figure 1) has been selected as a monitoring well for the microseismic activity in the Eemskanaal area. A better understanding of the nature of seismicity in the vicinity of the city of Groningen has been the driving rationale behind initiating the installation of a microseismic monitoring system. In response to the onset of seismicity, the implementation of regional production caps resulted in the reduction of the production from the Eemskanaal region to a maximum of 2 BCM per year (Figure 2).

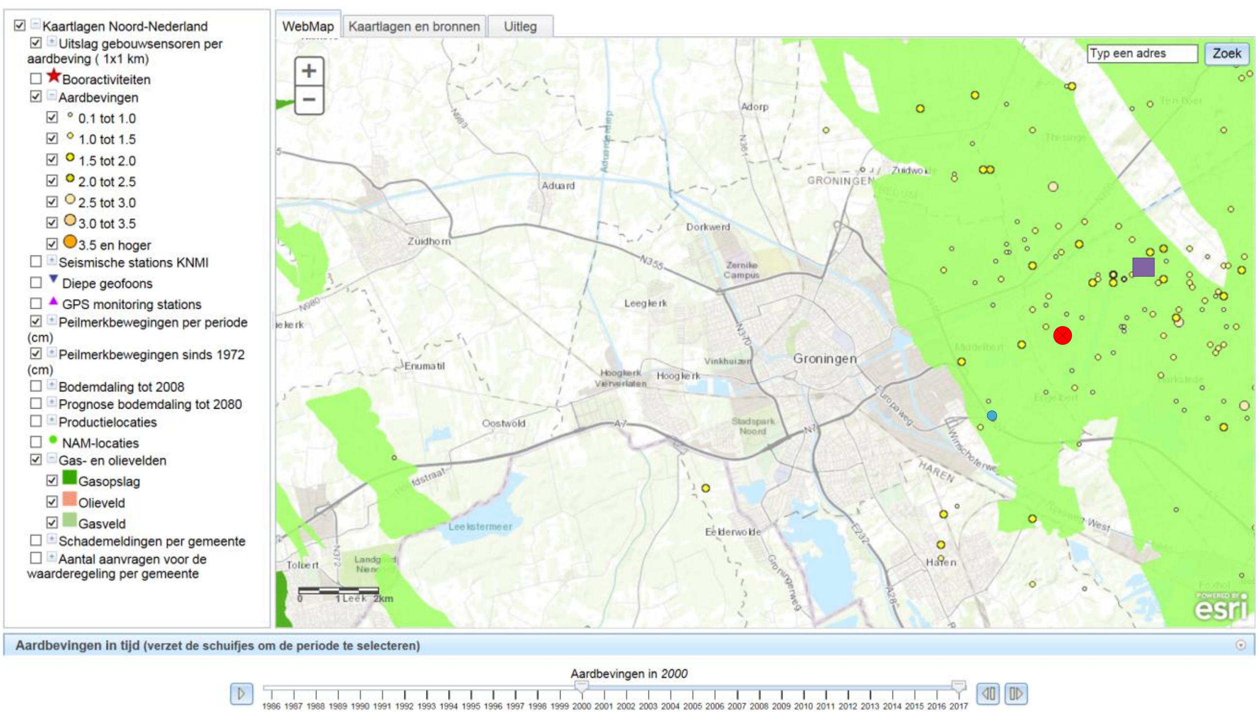


Figure 1. *Map of seismicity from 2000 to early 2017 close to the city of Groningen as detected and located by the KNMI network. The first Groningen event M_L1.2 in 2000 is shown in blue. Light green outlines gas fields, dark green shows the underground gas storage reservoirs. Seismic events from 2000 onward are denoted as yellow circles scaled by magnitude as per legend on the left. The Harkstede monitoring well is shown as a red dot; Eemskaanal production facility is marked as a purple square. (Link to the map and NAM platform tool)*

The HRS-2A well recorded microseismic events (largest magnitude M_L 1.4; figure 12) from October 06, 2016 to January 06, 2017. The recording period was notably quiescent, totalling in 191 detected earthquakes of which 80 were non-locatable due to a poor quality signal (i.e. very small magnitude events). Of the detected events, 55 were located "internally" i.e. had S-P time of less than 1 second. Another 56 are "external" events, occurring at distances with S-P times greater than 1 sec. The magnitude ranged from M_L -2 to M_L 1.4. For a detailed summary of events please refer to Table 1 and figure 10.

A total system failure occurred on January 06. 2017 at 08:00 UTC after which point in time no additional seismic data has been recorded at HRS-2A.

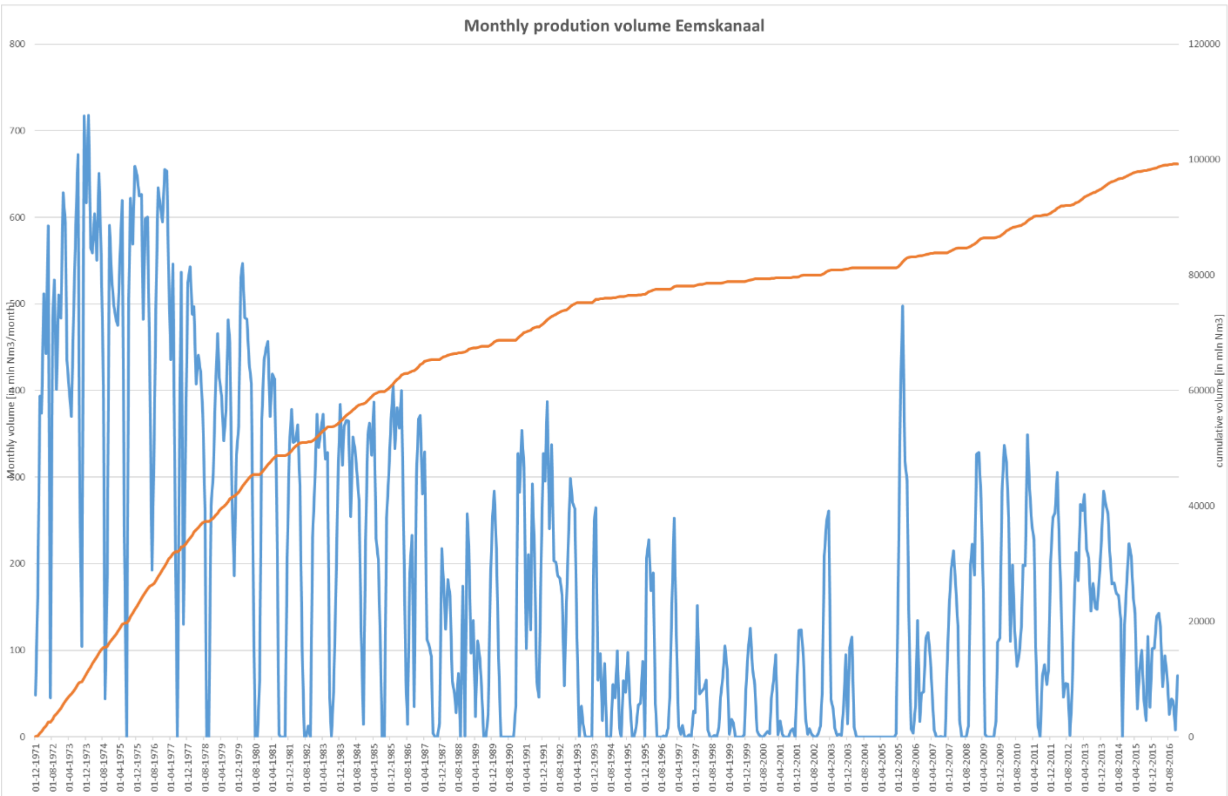


Figure 2. *Monthly production volume in million cubic meters per month for a period of 46 years starting in January 1971. The first notable earthquake within the Groningen city area occurred in 2000, years after production declined, as evidenced by the cumulative curve (right ordinate).*

HRS 2A monitoring and data management was provided by Baker Hughes Magnitude, and is one in a campaign of several deep downhole monitoring wells that have spanned a few years of microseismic monitoring. Similar downhole equipment had been installed in Stedum (SDM-1) and Zeerijp (ZRP) wells and was operational intermittently spanning a period of several years (appendix B). For more information please refer to the complete set of Magnitude reports on the internal SharePoint website.

Operating period	10/06/2016 to 01/06/2017	Magnitude Range
Total detected events	191	-2 < M < 1.4
Total internal (S-P < 1sec) events	135	
Class 1	4	
Class 2	17	
Class 3	24	
Class 4	10	
Class 5 (detected but not located)	80	

Table 1. *Summary of event history for the recording period.*

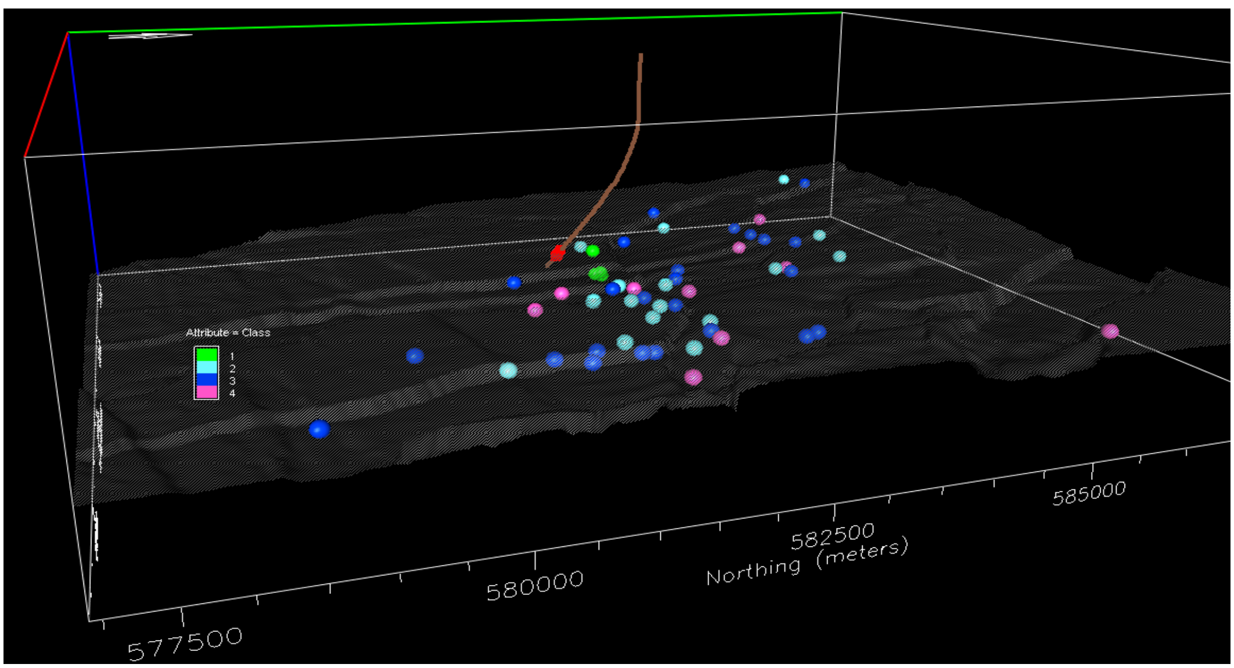


Figure 3. *Oblique view of all the located seismicity recorded by HRS2A, displayed with respect to the top of the Rotliegend reservoir. Red symbols along the wellbore are the geophones.*

Well location

The Harkstede (HRS) 2A observation well is located 7 km east of the citycentre of Groningen in the Eemskanaal area. This location has been selected as a strategic point to monitor any potential induced seismicity in the proximity of an EKL production cluster and the city of Groningen, an area with a high population density. Initially, the plan was to monitor seismicity for a 12-month period. However, an unexpected failure of the geophones occurred 4 months into the monitoring period (seismic array operational from Oct. 6. 2016 to Jan. 6. 2017).

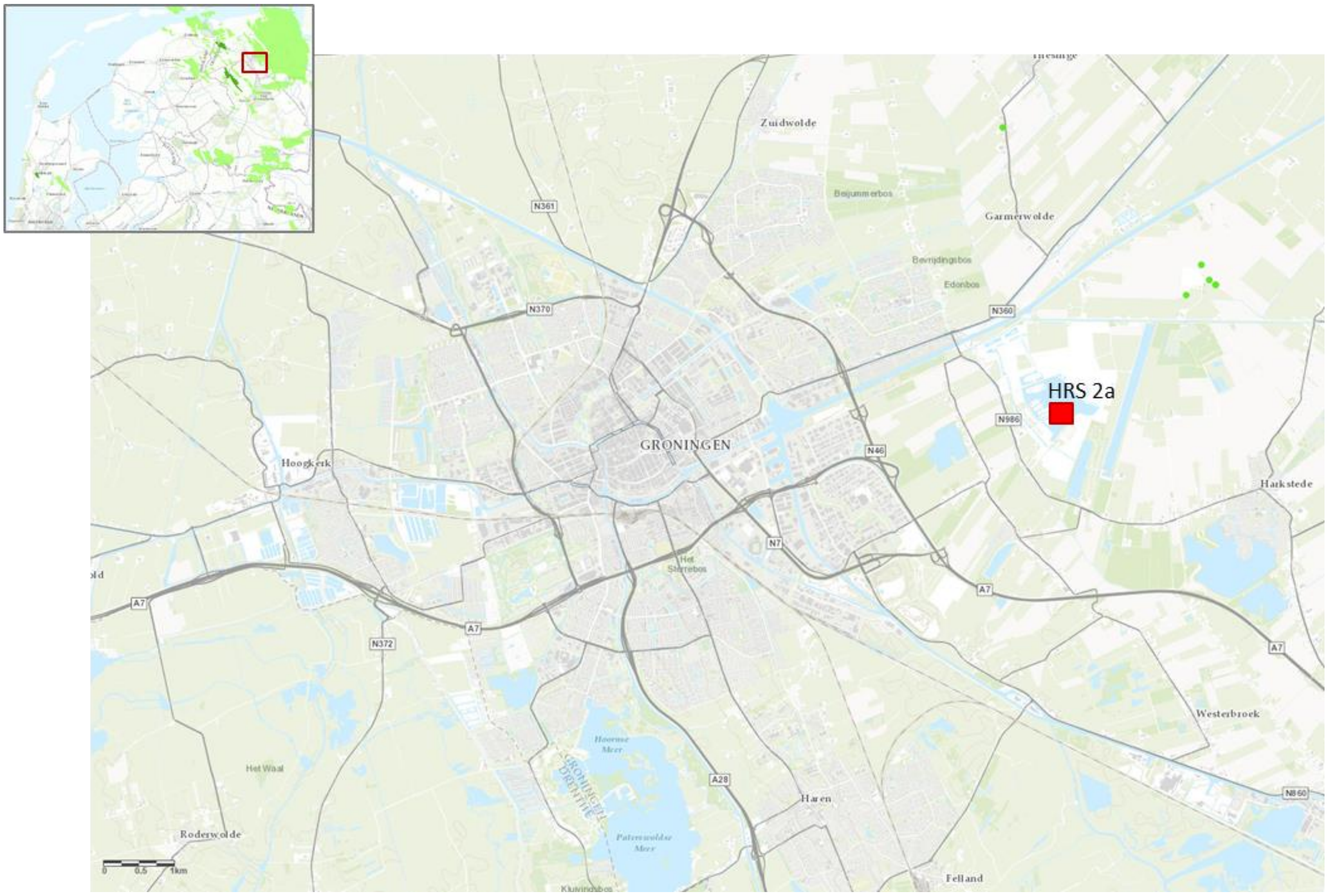


Figure 4. *Location of the Harkstede-2a well (HRS-2a), and the proximity to the city of Groningen.*

Well History

The HRS-2 was drilled and then side-tracked as HRS-2A in 1980 as a replacement well for HRS-1 which was lost due to a salt squeeze.

The well is perforated in the lower Slochteren and following a production test, completed as an observation well. The well is not hooked up to a production flowline. In December 2015 attempt to kill the well using “Groningen Kill Pill” was unsuccessful leading to a delay of geophone installation exercise which was supposed to follow the well kill. To isolate the perforations interval, top bridge plug was set at 3214 m MD, followed by cement dumping on top of it and bleeding off of gas. Upon geophones being lowered in, the well was topped off with KCl in a controlled way.

Figure 5. *HRS 2a well head ("xmas tree")*

Geophones & Installation

The monitoring array at Harkstede well consists of a 120 m long geophone tool string housing 9 Geospace Omni 2400, 15 Hz phones placed at approximately 10 to 60 m intervals. Geophone placement and well schematic are shown in figures 6 and 7 respectively.

Brief list of key geophone characteristics

- 3-component omni-directional response
- -40 to 200° C operational temperature range
- Natural frequency 15 Hz
- High output sensitivity (1.32 volt/in/sec)

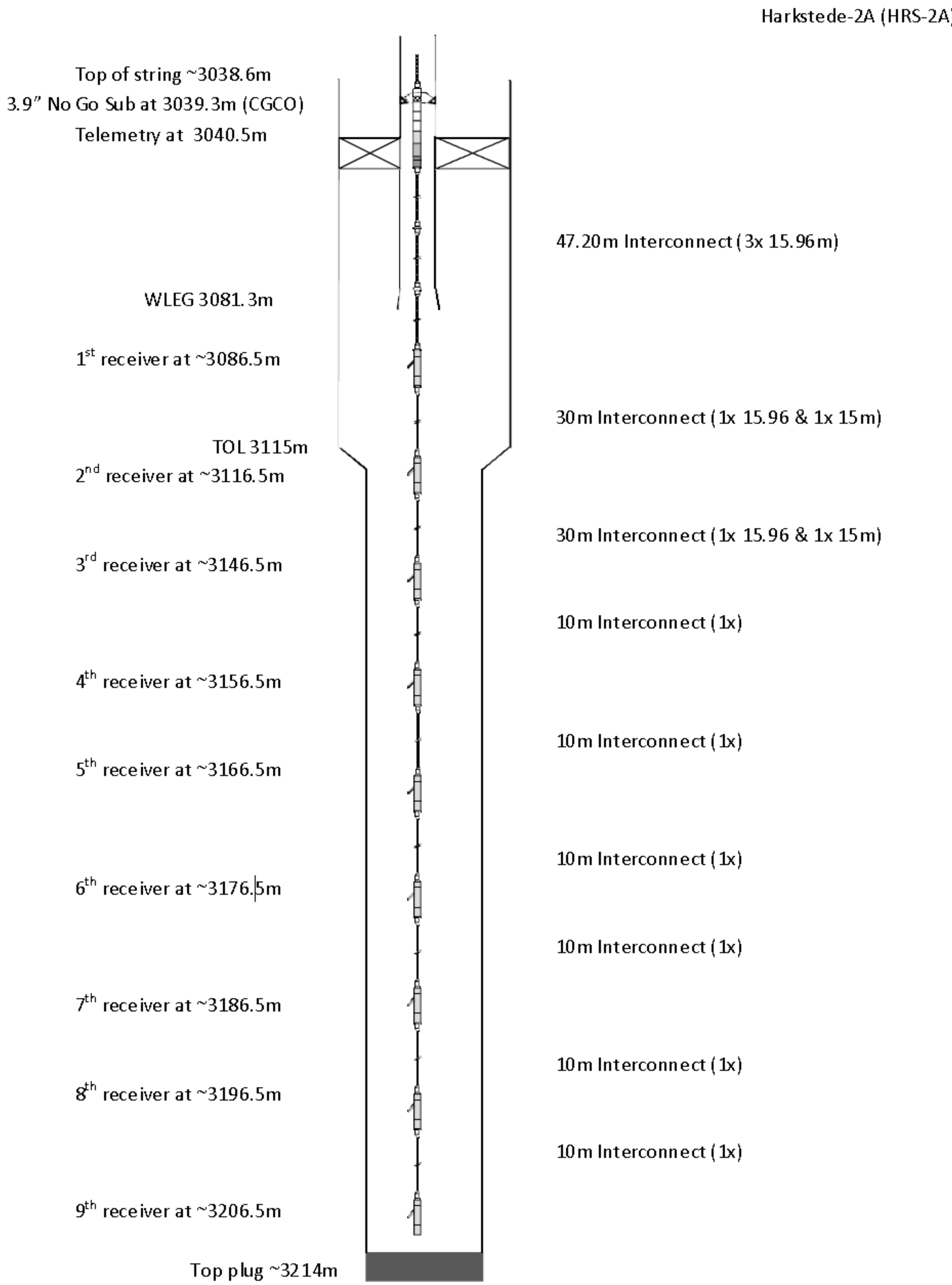


***Figure 6**. A well schematic Depths shown are measured using DFE (Drill Floor Elevation).*

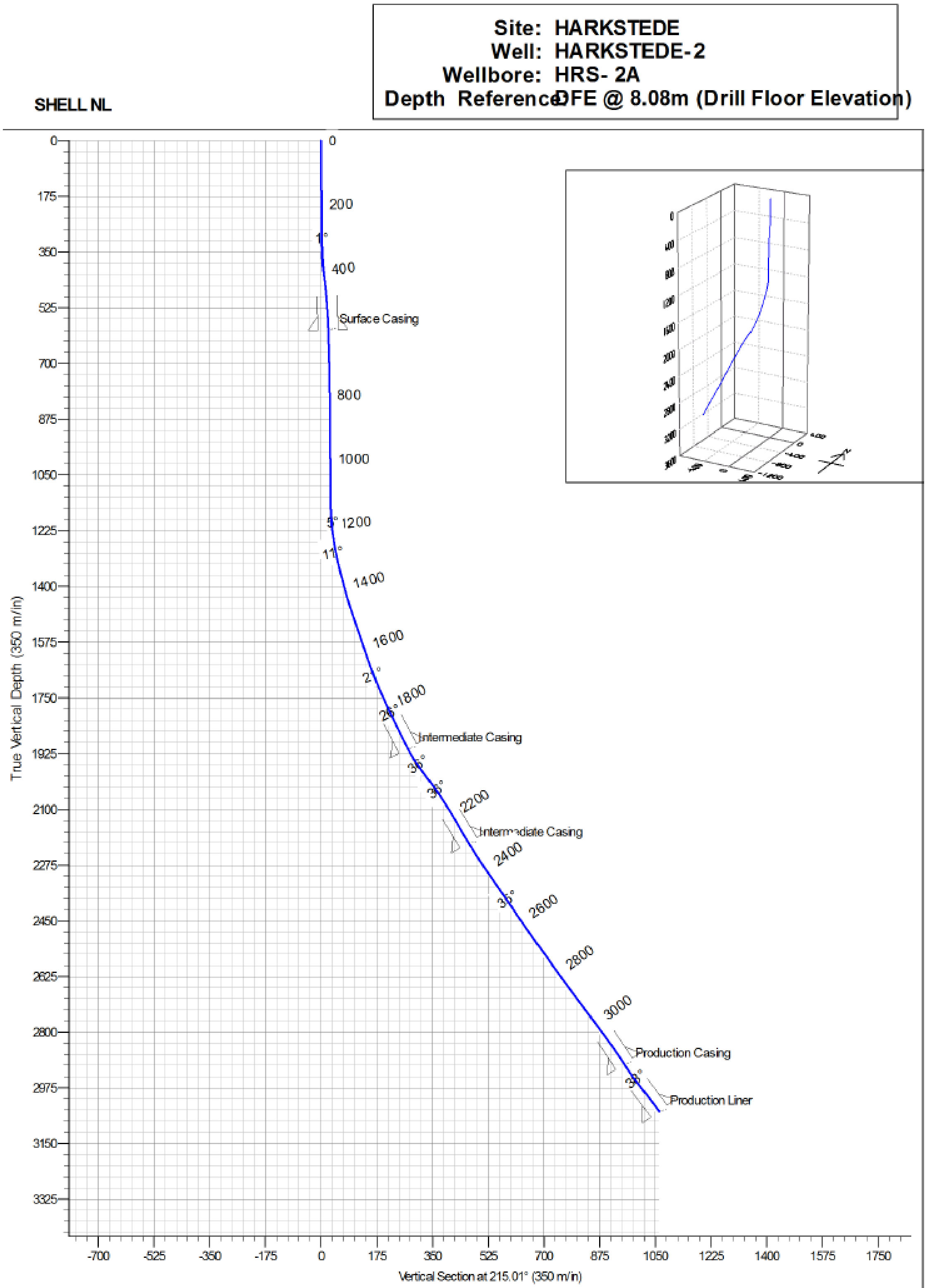


Figure 7. *Schematic of the deviated well trajectory. Depth reference is DFE (Drill Floor Elevation).*

Instrument orientation

Orientation of the HRS-2A sensors was completed on 11/21/2016 using seismic events recorded by HRS-2A array and located independently by KNMI. Nine events of sufficient SNR, detected by both HRS-2A and KNMI arrays where identified in the dataset during the time-period between 2016/10/06 and 2016/11/10. These events have magnitudes M≥0.5, are located at different azimuths, and exhibit good quality recordings (high SNR) on HRS-2A geophones.

An important prerequisite for a reliable orientation campaign using these reference events is to use events which cover a wide aperture in azimuth. The correlated events are mainly located in the NE direction with respect to the HRS2A sensors. That is why, in case of future event recording with more azimuthal aperture, the orientation could benefit from being updated.

Key points:

- Reference events coordinates have been converted from geographical coordinates in degrees (WGS 84) to Amersfoort RD-new coordinates (in meters).
- *Note that depths have been arbitrarily set within the Rotliegend reservoir (i.e. 3000 m depth), as the location from KNMI might not be well constrained in depth, due to the sub-surface configuration of KNMI monitoring network*.
- We have made the hypothesis that Z-components of geophones are aligned along HRS-2A well deviation. Doing that, only the orientation of X- and Y- components will be estimated from the direction of first-particle motion.

Levels 1, 4, 5 and 9- sensors Y were out of order within hours of the installation, thus the orientation was never computed / available for those sensors. Note that for the orientation purposes seismic rays are modelled in a homogeneous velocity model.

Coordinate of the events used for the orientation tools and location map

	KNMI WGS84 Coordinates				RD/NAP Amersfoort converted coordinates	
Date and Time (UTC)	Mag	Lat. (°)	Lon. (°)	Area	X (m)	Y (m)
2016/10/12 07:12:46	0.5	53.305	6.725	Ten Post	244178	591775
2016/10/29 14:36:14	0.6	53.288	6.846	Appingendam	252282	590040
2016/11/01 00:12:28	1.9	53.301	6.807	Wirdum (Gr.)	249653	591435
2016/11/01 00:57:46	2.2	53.306	6.809	Wirdum (Gr.)	249775	591994
2016/11/08 11:23:17	1.4	53.331	6.795	Wirdum (Gr.)	248788	594758
2016/11/08 11:25:33	0.9	53.329	6.794	Wirdum (Gr.)	248725	594534
2016/11/10 06:35:47	0.7	53.239	6.874	Siddeburen	254261	584626
2016/11/20 17:58:40	1.2	53.300	6.802	Garrelsweer	249296	591304
2016/11/20 18:57:56	1.6	53.336	6.838	Oosterwijtwerd	251615	595358

Depth of the events is constrained by KNMI to 3000m.

Location of the events used in tool orientation

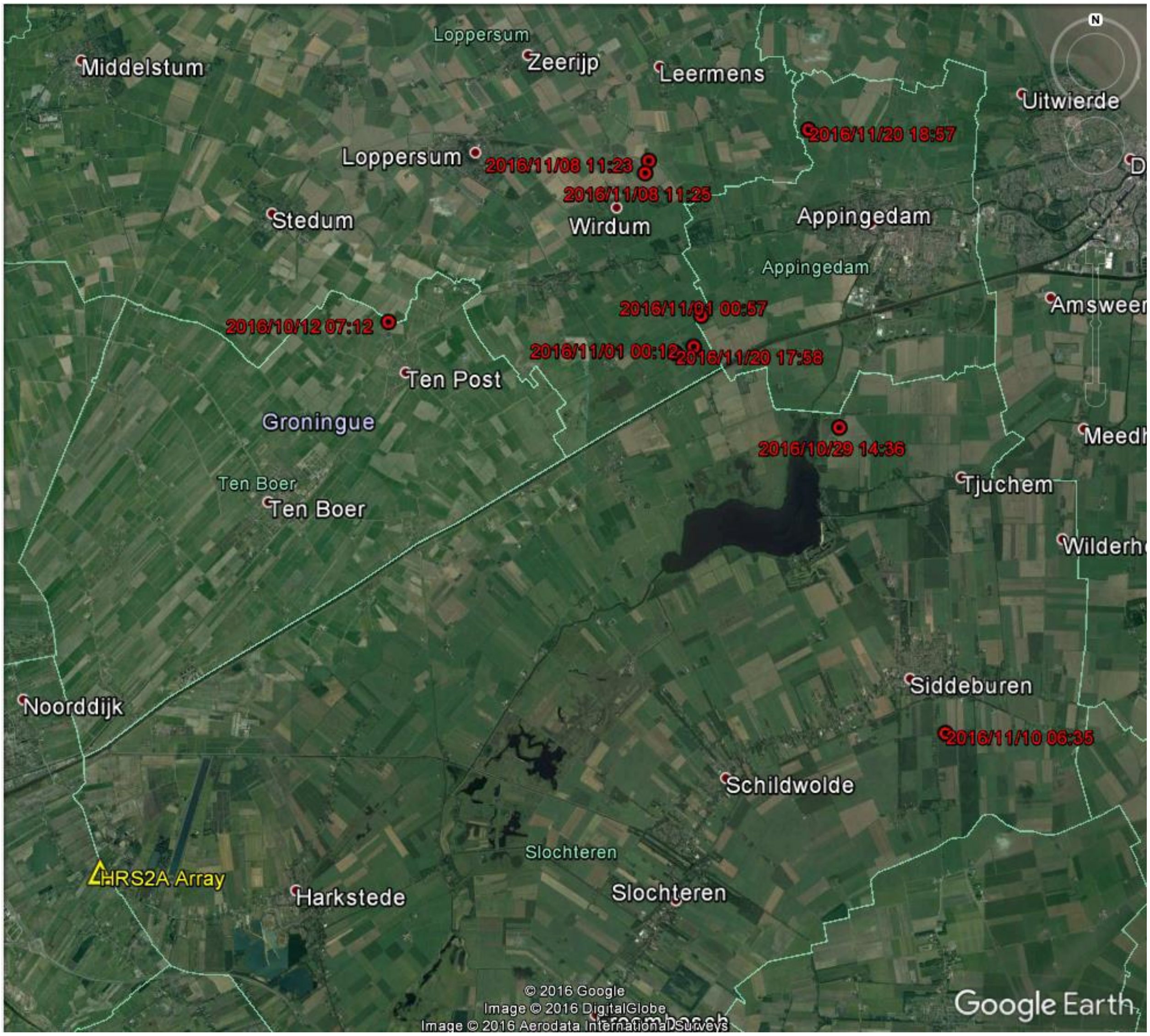


Figure 8. *Locations of all 9 events used in the data orientation are shown in map view (red lettering) as computed by KNMI. The HRS-2A well is in the lower left hand corner shown as a yellow triangle.*

Screen-shot of the seismic event used for the orientation

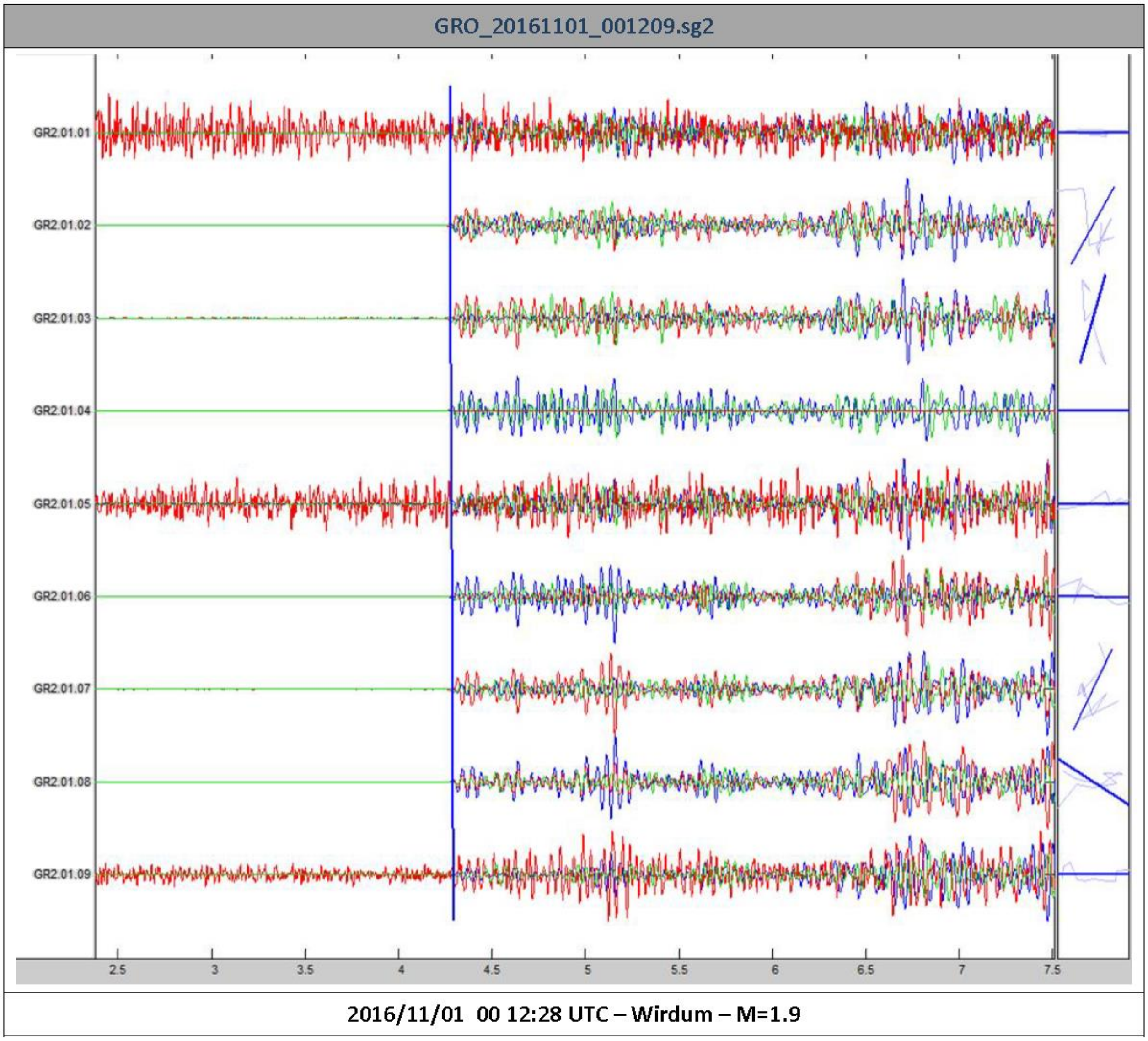


Figure 9. *A screenshot showing waveforms of the M1.9 Wirdum event, one the events used in tool calibration*.

Sensors Coordinates

Channel	East	North	Depth	INC_Z_(DU)	AZI_Z(NW)
GR2.01.01*	239242.2	581906.4	2830.12	36.12	-209.42
GR2.01.02	239233.6	581891.3	2854.54	35.42	-209.55
GR2.01.03	239225.4	581876.6	2879.39	33.91	-209.39
GR2.01.04*	239222.6	581871.8	2887.72	33.72	-209.39
GR2.01.05*	239219.9	581867	2896.05	33.61	-209.42
GR2.01.06	239217.2	581862.2	2904.39	33.58	-209.48
GR2.01.07	239214.4	581857.4	2912.71	33.64	-209.69
GR2.01.08	239211.7	581852.4	2920.99	34.22	-208.52
GR2.01.09*	239209.2	581847.2	2929.11	35.16	-206.75

*Y component of the sensors in red is out of order

Operations performed for the orientation of the tools down hole

- Selection of the seismic events recorded by HRS-2A array and located by KNMI
- Coordinates conversion of KNMI location from WGS84 (deg) to RN/NAP (meter) and use these coordinates as input parameter for orientation tools
- Computation of tools coordinates using sensors depths and well deviation
- P wave arrival picking from level 1 to 9
- Polarization analysis on P wave: azimuth & inclination computation - view from the sensors
- 90 Hz low-pass filtering for polarization analysis

Summary of the orientation of each component - Geographic frame

Station	Channel	Azimuth	Inclination
GR2.01.02	X	295.0 °NE +/- 2.8 °	86.7° UD
GR2.01.02	Y	202.6 °NE +/- 2.8 °	54.8° UD
GR2.01.02	Z	29.6 °NE +/- 2.8 °	35.4° UD
GR2.01.03	X	302.3 °NE +/- 10.9 °	91.9° UD
GR2.01.03	Y	213.6 °NE +/- 10.9 °	56.2° UD
GR2.01.03	Z	29.4 °NE +/- 10.9 °	33.9° UD
GR2.01.06	X	44.1 °NE +/- 6.0 °	122.7° UD
GR2.01.06	Y	309.8 °NE +/- 6.0 °	96.8° UD
GR2.01.06	Z	29.5 °NE +/- 6.0 °	33.6° UD
GR2.01.07	X	296.7 °NE +/- 3.6 °	88.0° UD
GR2.01.07	Y	205.3 °NE +/- 3.6 °	56.4° UD
GR2.01.07	Z	29.7 °NE +/- 3.6 °	33.6° UD
GR2.01.08	X	17.5 °NE +/- 2.7 °	123.7° UD
GR2.01.08	Y	291.0 °NE +/- 2.7 °	84.9° UD
GR2.01.08	Z	28.5 °NE +/- 2.7 °	34.2° UD

Earthquake data: event detection statistics

The total number of detected events for the entire period of the recording campaign is 191. This number includes events that were not located due to the poor signal to noise ratio. There are a total of 55 located events, that are divided into following categories: 4 class-1 events, 17 class-2 events, 24 class-3 events, and 10 class-4 events. There are 80 class-5 or non-locatable events, and another 56 events that were detected and classified as “external”, i.e. originate outside of the 10 km box around the HRS-2A area.

A separate section on event classification describes in detail how that is done. Events are classified into two major categories: internal events are the ones where S-P time is less than 1 second; and the external events, with S-P time greater than 1 second. Further, events are classified by the quality of the arrivals, as discussed in section Event Classification below.

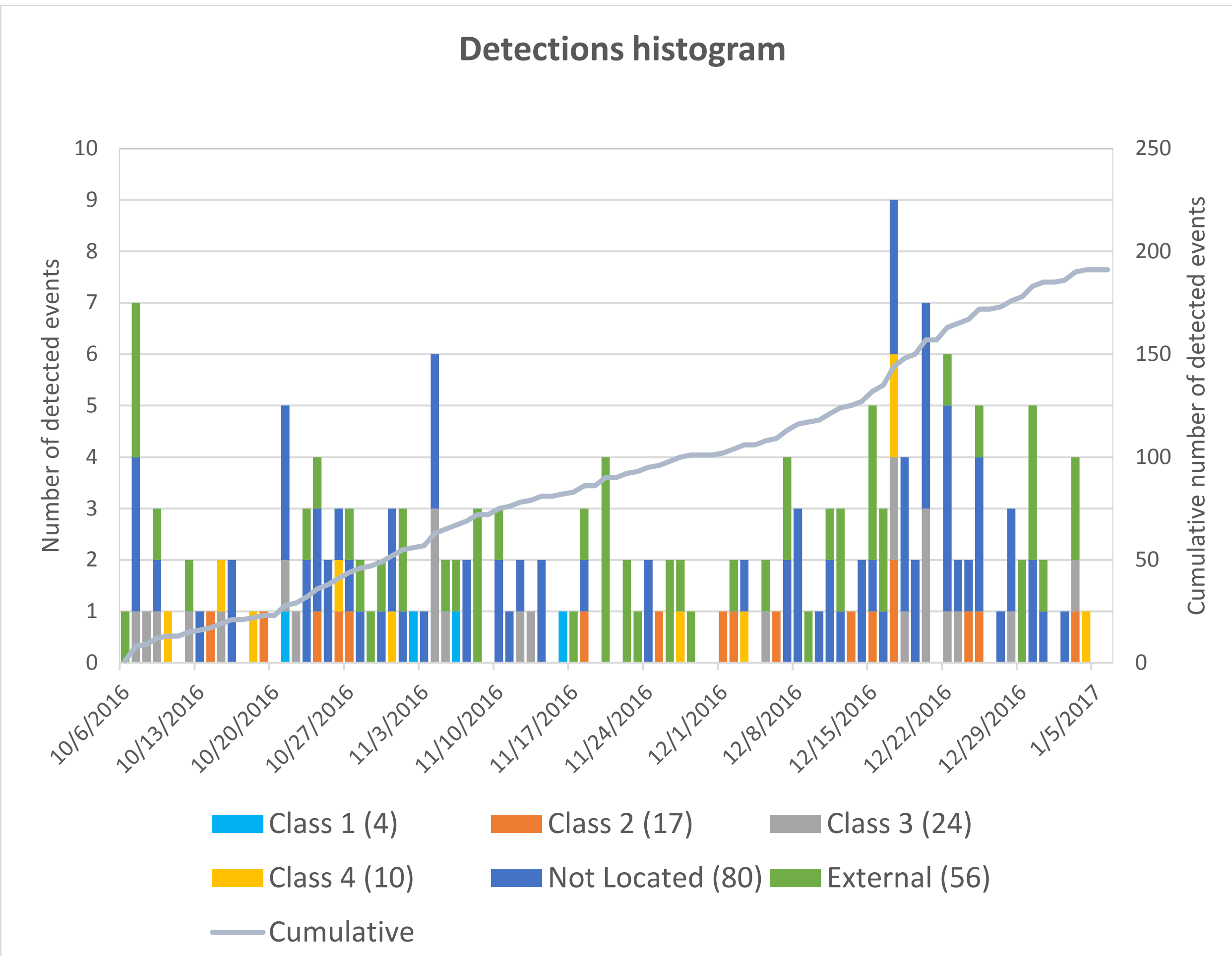


Figure 10. *Distribution of event classes per week of recording period. Bin size is 1 day. Total system failure occurred January 06, 2017 at 08:00 UTC. No seismic records available subsequently. Class 1 events have clear arrivals and high SNR, with progressive degradation of SNR toward class 4. For further explanation of event classes please refere to Table 3 and section therein.*

Events Correlated with KNMI Catalogue

Several internal and external events that have been recorded and located by the HRS-2A downhole array and correlated with the KNMI catalogue. Of the internal events, the following three earthquakes (listed in table 2) have been recorded and located by both HRS-2A downhole and the KNMI surface arrays (figure 11).

Date yyyy/mm/dd	Origin Time UTC	X (m) lat_{KNMI}	Y (m) lon_{KNMI}	Z (m)	M_W M_{Ln}	Category	Place
2016/11/25	02:11:17.007	23900 53.25	585280 6.64	3000	0.2 0.3	2	Garmerwolde
2016/12/20	16:15:39.656	242880 53.22	581020 6.70	3000	1.4 1.1	3	Harkstede
2016/12/17	11:56:47.455	241060 53.21	581740 6.65	3000	0.9 0.6	2	Groningen

Table 2. *Events recorded and located by both HRS2A downhole and KNMI surface arrays (KNMI solutions in blue text). Note differences in the determined magnitude due to a different type of magnitude computed: moment magnitude M_w and local magnitude M_L.*

There are some differences in the estimate of events' magnitudes as well as locations for all three. The KNMI publishes epicentral locations in latitude and longitude and rounds the precision off at two decimal places, indicating a location certainty for the given location method and density of the surface array. In contrast, Baker Hughes Magnitude locations from the downhole array offer a higher precision, listed here in the local Cartesian coordinate system.

The differences in the magnitude range from 0.1 to 0.3 in value, as would be expected between moment magnitude M_W and the local magnitude M_{Ln}. This difference in the estimated magnitude values emphasizes the important aspect of magnitude determination and the fact that the same event will appear to have a different magnitude depending on a variety of factors such as the type of magnitude calculation applied, the specific stations' signal to noise ratio, the choice of P or S phase used, weather the computation was performed in time or frequency domain, data windowing treatment, etc. For a thorough and interesting summary of the computational differences in magnitude estimation refer to Stork et al., 2014.

Figure 11. *Map view of the three earthquakes (yellow dots) recorded by both KNMI and the HRS-2Aarrays. The approximate location of the HRS2A array is marked in with a red star.*

There are approximately 40 or so of the external events that were detected by the array and were correlated with other catalogues such as KNMI and Germany's CSEM. These events occurred as far as Italy (M5.8 on 10/28/2016 north of Palermo), Poland (M4.5 on 12/16/2016 in Grebocice) and the Southern North Sea (M3.8 on 01/03/2017), demonstrating the high sensitivity of the downhole array, thus validating that the total number of events in the database is indeed low. In other words, the area around the Harkstede well was seismically quiescent for the duration period of this monitoring campaign.

Distribution of earthquake magnitude and depth

As mentioned earlier, the range of magnitudes of the events for which it was possible to determine this was from M_w-2 to M_w1.4 (figure 12). The determined hypocentral depth range 2847-3237 TVD places all located events within the Rotliegend reservoir.

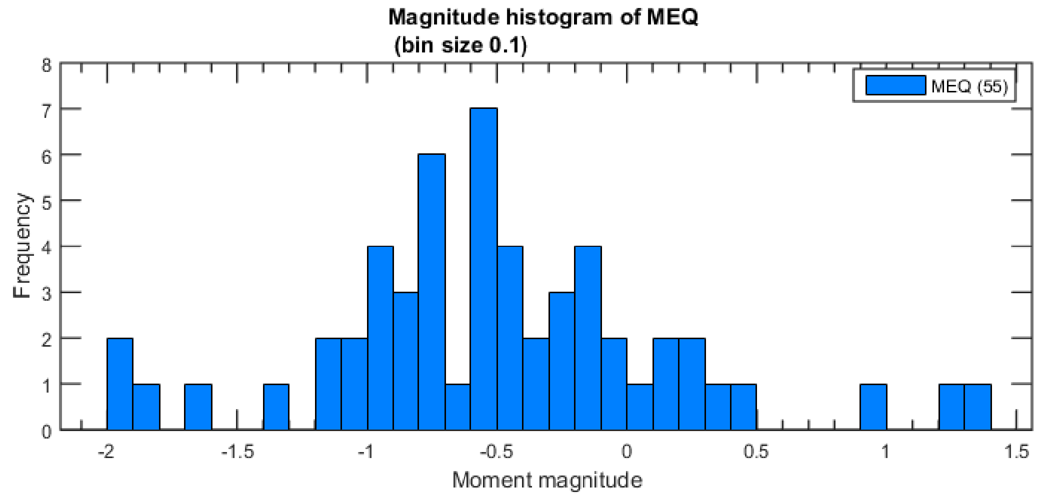


Figure 12. *Histogram of the event frequency versus magnitude since the beginning of recording on October 06. 2016 shows pseudo-clustering around -0.5.*

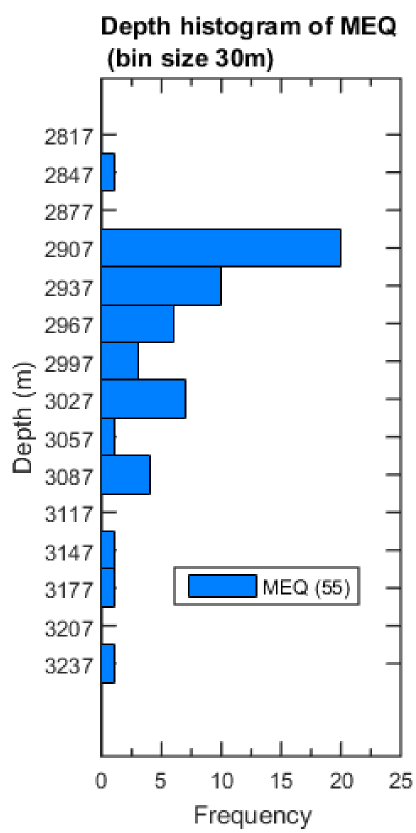


Figure 13. *Histogram of event frequency versus depth since the beginning of recording on October 06. 2016 shows pseudo-clustering around 2907 m.*

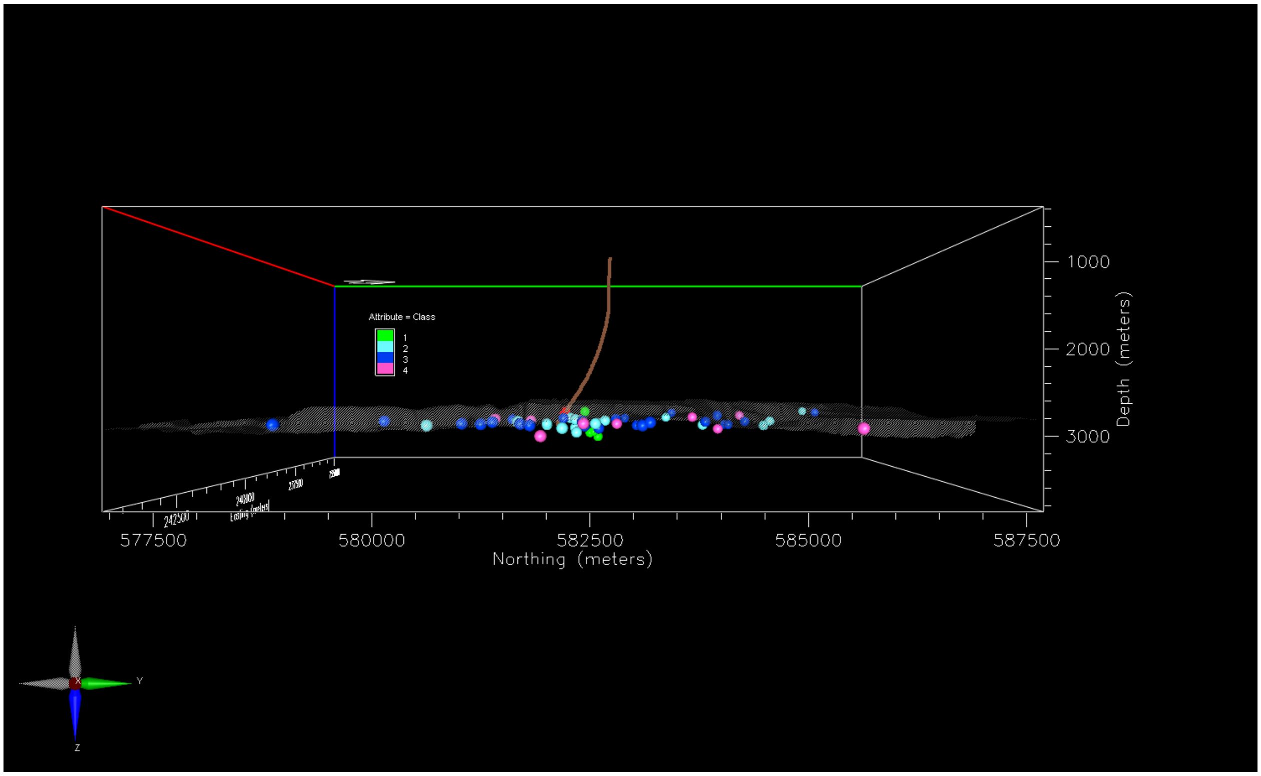


Figure 14. *Depth view of the entire data catalog. HRS2A well shown as brown-ish line. The grey draped surface indicates the top of the Rotliegend reservoir.*

Earthquake locations

The total number of located earthquakes (classes 1 through 4; see tables 1 and 3) for the duration of the operation of the downhole array is 55. No events could be located prior to the completion of the instrument orientation on 11/21/2016. The location method applied for this data set is Ray tracing in 1D velocity model using P&S direct arrivals or P&S refracted arrivals at the bottom of the reservoir (with polarization information). All 15 Hz sensors are used depending on Signal/Noise ratio. The velocity model was provided by NAM in October 2014.

Uncertainty assessment

Uncertainty assessment takes into account estimated P & S wave pick errors. For P-wave the estimate is 10ms, while for the S-wave it is take to be 15ms. Also accounted for is the polarization analysis: Azimuth = 20°, Inclination = 40°.

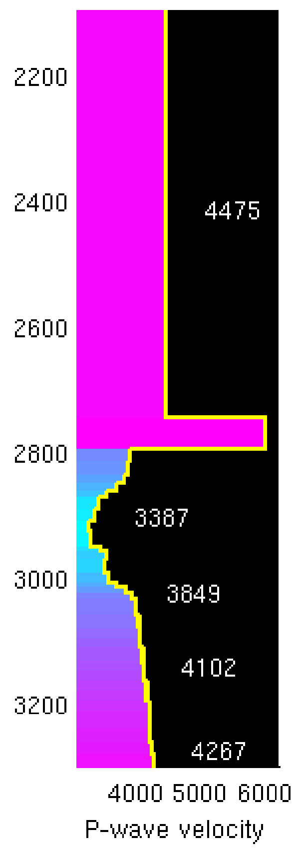


Figure 15. *Velocity model used in the location of events. Provided by NAM on 20/23/2014.*

Note:

- All coordinates are given in referential EPSG Projection 28992 - Amersfoort / RD New, Depth referential: MSL, meters
- S-wave velocity used = 1950 m/s

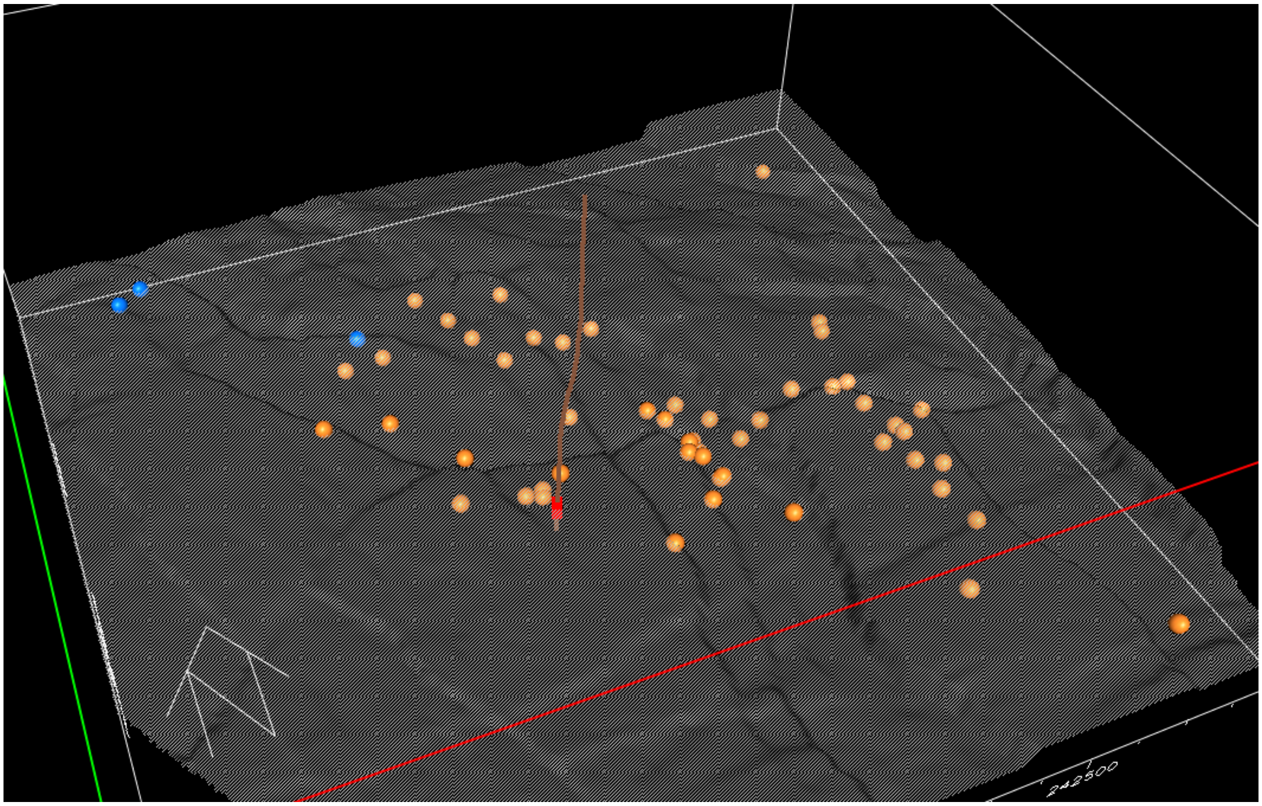


Figure 16. *All of the recorded events from October 06, 2016 to January 06, 2017. Magnitude ranged from -2 to 1.4. Magnitude distribution is shown in figure (8).*

Legend:

MEQ locations from 2016/10/06 to 2017/01/01

MEQ locations from 2017/01/02 to 2017/01/08

Event classification

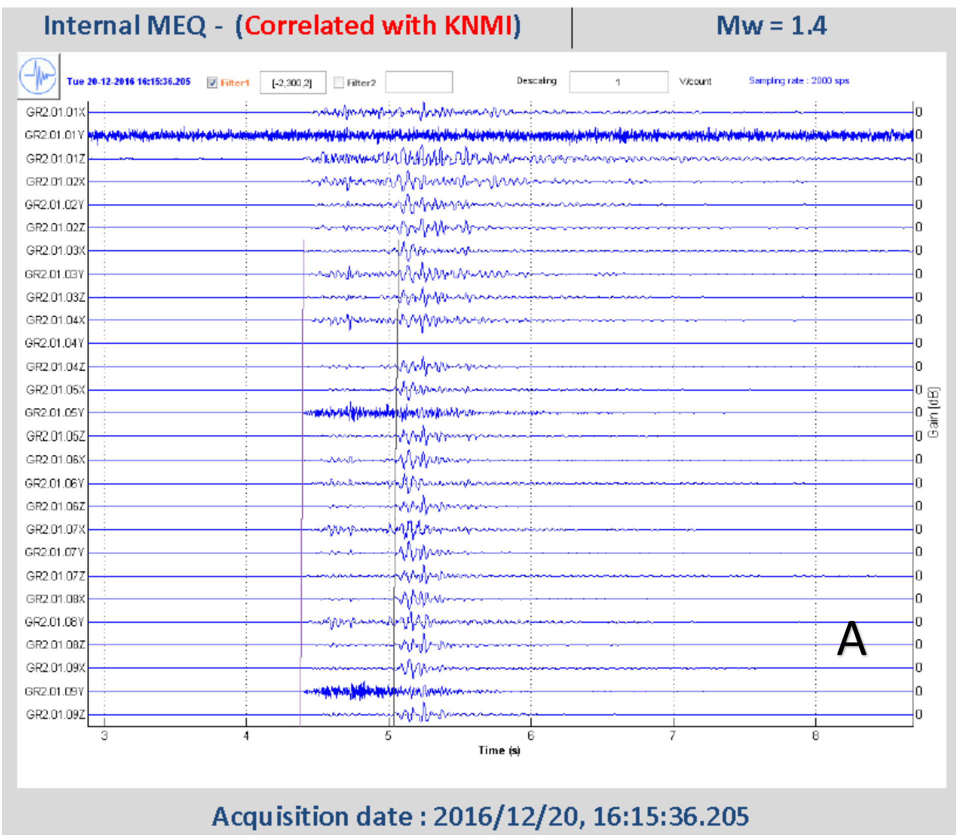
As described in table below, the events are classified according to several robust, comprehensive criteria: the signal-to-noise ratio (SNR), complexity of the waveform and clarity of the individual arrivals (P and S). Waveforms with high SNR, clear P and S arrivals and relatively simple signal (what could be thought of as a "text-book example" of an earthquake waveform) are deemed "high confidence level" events and have the highest location fidelity. In contrast to those are the more complex signals with multitude of arrivals besides the direct P and S. An example of a simple waveform event, and a complex waveform event are listed in figure 17 below.

Not listed in the table is an additional, class 5, encompassing all detected but not located events due to their large distance to the monitoring array, of which there are 80 for this monitoring campaign.

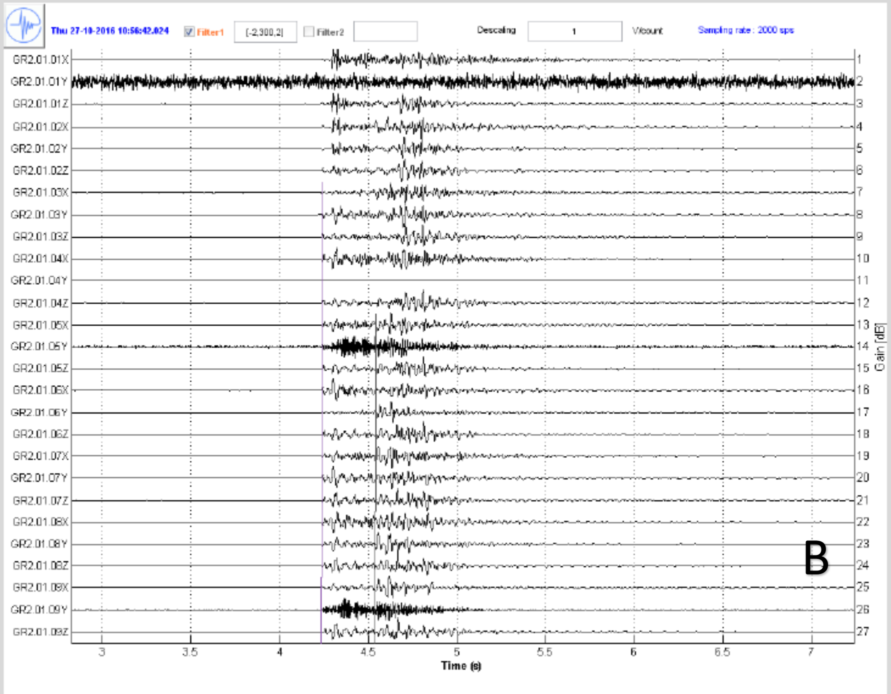
Index	Confidence level	Characteristics
1	High	Clear arrivals, Simple signals, High SNR
2	Good	Clear secondary arrivals, Medium-to-High SNR
3	Poor	Complex signals, Medium SNR
4	Very poor	Complex signals, Low SNR

Table 3. *Event classification scheme (as devised by Baker Hughes Magnitude).*

Event Class 1 through 4 Examples

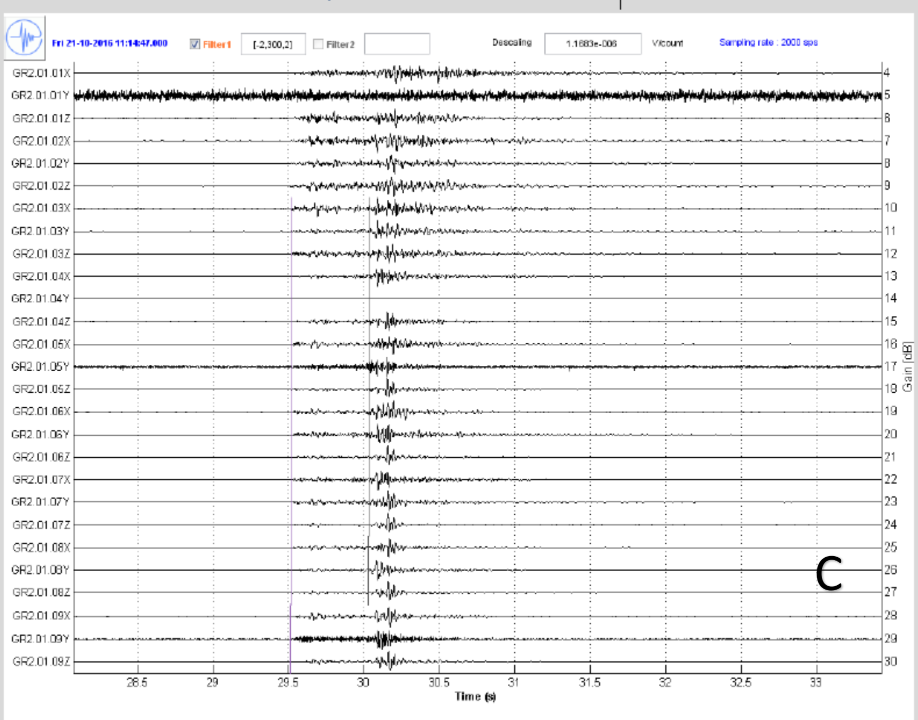


Internal MEQ – Class 2	Mw = 0.1



Acquisition date : 2016/10/27, 10:56:45.832

Internal MEQ – Class 3	Mw = 1.2



Acquisition date : 2016/10/21, 11:14:47.000

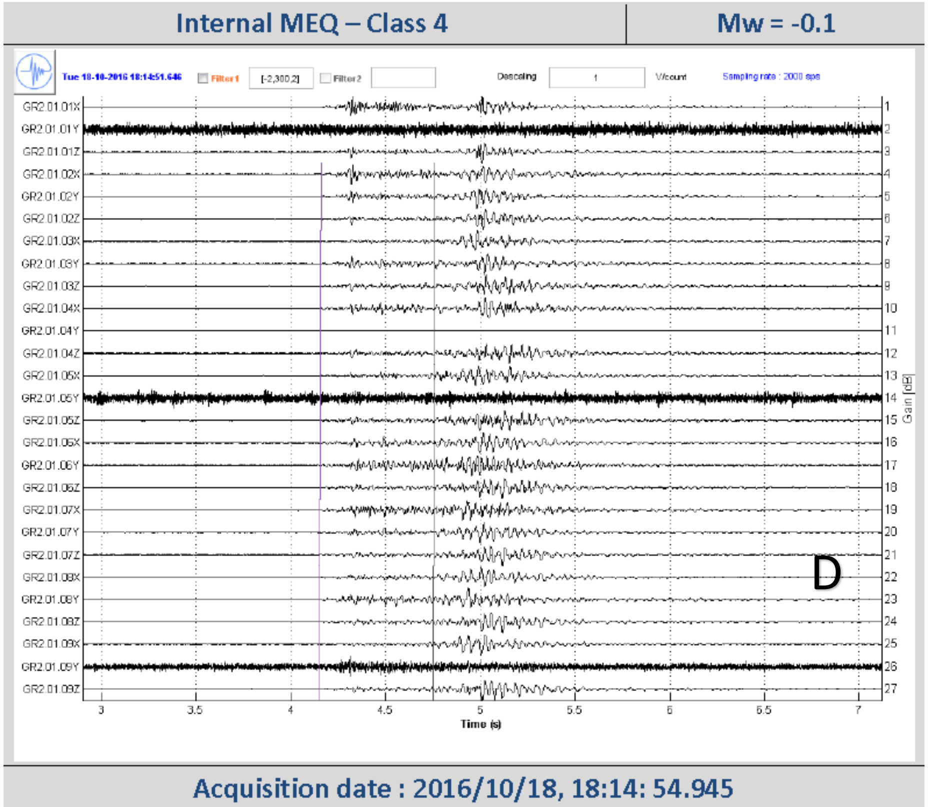


Figure 17 (A-D). *Examples of Class 1 through 4 events shown in figures A to D, also correlated with KNMI database. Figure A shows an event that has also been detected by the KNMI surface array. Note that KNMI determines the magnitude of this event at 1.1. See discussion in section Events Correlated with KNMI Catalogue for more detail.*

Waveform Complexity

As evidenced in figures 17 and 18, the waveforms of the local events are highly complex and present a unique challenge in understanding and differentiation of P from S arrivals, and other reflected, refracted or converted phases. This complexity in the energy packets that arrive at the geophone is due to the stark velocity contrasts between the reservoir and the layers above it and below it. Above is the sealing Zechstein salt bounded by a high velocity anhydrite layer of approximately 50 m thickness (figure 15), and below is the faster Carboniferous. Moreover, the velocity in the reservoir is not constant but rather first decreases with depth, then increases (figure 15). The result of this complex velocity pathway is that the propagating energy becomes trapped in the reservoir that acts as a wave-guide, and the head waves then become the first breaks (see Shell internal report SR.16.12678). In general, the internal events have considerably simpler arrivals due to the smaller source to receiver distances. In contrast, the external events are virtually impossible to interpret without a more sophisticated approach such as the full wave-field modelling.

Internal and External Event Examples

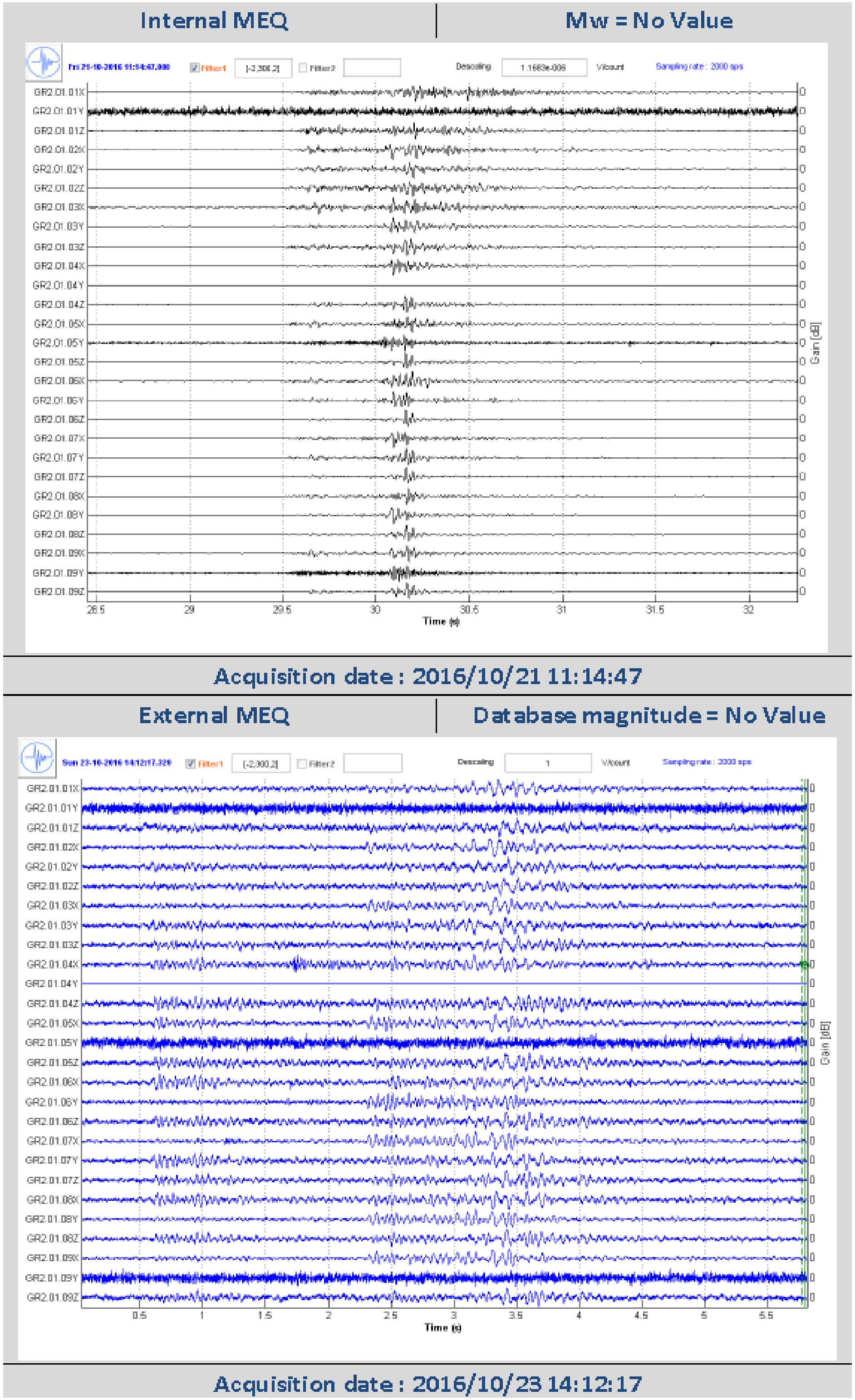


Figure 18*. Examples of an internal and external event waveforms. Upper figure shows a recording of a typical earthquake waveform for a near-by event (deemed "internal") where S-P time difference is less than 1 second. The lower graph shows an earthquake that occurred further away or "externally" with S-P time over 1 second.*

Concluding highlights

- A downhole-array seismic monitoring campaign in the duration of 4 months, from Oct/06/2016 until Jan/06/2017 was completed at HRS-2A, close to the city of Groningen; campaign ended due to the tool string failure
- Array consisted of 9-level 3C 15Hz geophones; the deepest level set at 3120m.
- The overall level of seismicity detected by the Harkstede downhole array was low:
    - 55 locatable “internal” earthquakes ranging in magnitude from -2 to 1.4
    - 56 detected “external” events (S-P time > 1 sec)
    - 80 were non-locatable due to a poor quality signal (i.e. very small magnitude events)
    - Total number of 191 detected earthquakes
- Events were detected as far as Italy M5.8, Poland M4.5 and the Southern North Sea M3.8, demonstrating the sensitivity of the downhole array, thus validating seismic quiescence of the local monitored area
- Of the 55 internal earthquakes, 3 events were also detected and located buy the KNMI surface arrays, magnitude ranging from 0.2 to 1.4.
- Waveform complexity due to the stark velocity contrasts between the reservoir and the layers above it and below it renders most events highly challenging to pick:
    - The reservoir acts as a wave-guide, and as a result
    - (in most cases) direct P and S waves are not the first breaks
    - instead, the head waves are the first arrivals
- Depth range:
    - all located events occurred within the Rotliegend reservoir, in broad agreement with the indications of the reservoir compaction.

Appendix A

Table below provides overview of some of the basic well data.

Basic well data

Well name	HRS-2A
Well type	Observation Well
Well depth	3337 m AHTBF
Elevation of reference (ORT):	8.08 m
Current well status:	Observation
eWIMS status:	Green. No WIT. SIT valid to 10/05/2017
Tree cap connection:	7 ½ 4G ACME

Reservoir data

Reservoir:	NLSPB_ROSL
Perforated Interval	3220-3270 m AHORT
Fracture gradient	2.26 bar/10m TVD (664 bar @ 2940mTVD)
BHP	160 barA
BHT	102.9 degC
CITHP	133 barA (max based on BHP in unloaded well)
FTHP	N/A
FTHT	N/A
Production Line Pressure	N/A
Last production rate	N/A
LSA	No
H2S	No
CO2 Concentration	0.862mol%
WGR	N/A
CGR	N/A
A	N/A
F	N/A
Sand Production	N/A
Hydrate Curve	Generic for Groningen

Completion data

Completion size:	5" x 4"
Completion material	C75
Xmas-tree	Cameron Solid Block 7 1/16" 10K Bottom x 4 1/16" 10K top & SOV UMGV currently closed
Xmas-tree cap size/dimensions	7 1/2" 4G ACME x 4-1*16"10K API Flange

Wire cutting UMGV	No
SC-SSSV Type/ Depth	N/A
CGCO (X-over from 5",15# to 4", 10.9# TBG) NO-GO Sub to be landed here	3039.30 mAHORT
3.313" SLSD (Shift up to open)	3044.03 m AHORT
SPM 1" Shear Disc 200 bar	3046.80 m AHORT
SPM 1" Dummy Valve installed	3060.74 m AHORT
3.313" X-LN	3067.17 m AHORT
Tripping Nipple	3071.97 m AHORT
Packer	3072.08 m AHORT
3.313" X-LN	3080.94 m AHORT (E-Plug – 350 bar)
Entry Guide	3081.30 m AHORT
Smallest ID completion	3.313"
Latest HUD	3340.7 m AHORT December 2015
Annulus Fluid	1.05 K2CO3/Brine

Depth references	**M**	**Comments**
ORT-TBF	**10.70m**	

Deviation data.

Max. Deviation @ what depth	38.95 deg @ 3241 m AHORT

Tubing / Casing data

Tubing / Casing	**Weight (lb/ft)**	**ID (inch)**	**Drift (inch)**	**Burst (Bar)**	**Collapse (Bar)**	**Capacity (L/m)**	**From and To (mAHORT)**
5" (C75)	15	4.408	4.283	528	474	9.85	0 to 3039.30
4" (C75)	10.9	3.476	3.351	585	572	6.1	3039.30 to 3081.3
7" (N80)	57	6.004	5.125	1432	1432	13.9	3072.08 - 3116.00
4.5"(N80) liner	13.5	3.920	3.795	588	621	7.7	3116.00 -3348.61

Perforation data.

Perforation Type	**Top Depth mAHTBF**	**Base Depth mAHTBF**	**Top Depth mAHORT**	**Base Depth mAHORT**	**Interval Length**
NA	3210.2	3253.3	3220	3264	43.1
NA	3255.3	3259.3	3266	3270	4

Table A1. *Basic well data*

Operation	Primary barrier	Secondary barrier	Tertiary barrier
Remove XMT cap	Upper Master Gate Valve	Swab valve	Lower Master Gate Valve
Retrieving E-plug and HUD Run (Slickline)	Stuffing box, Lubricators	Dual BOP	Upper Master Gate Valve
Set Bridge Plugs, Dump Cement (E-Line)	Grease Injector, Lubricators	Triple BOP	Shear Seal BOP
Deploy Geophones, Install Geophones (E-Line)	Bridge plug with cement, kill fluid, grease Injector, lubricators, Coiled Tubing BOP	Triple BOP	Shear Seal BOP
Pumping Operations	Backpressure valve in pumping line	Upper Master Gate Valve	Lower Master Gate Valve
Suspending well over night (if required)	Triple BOP	Shear Seal BOP	

Table A2. *Summary of Well Barriers*

Appendix B

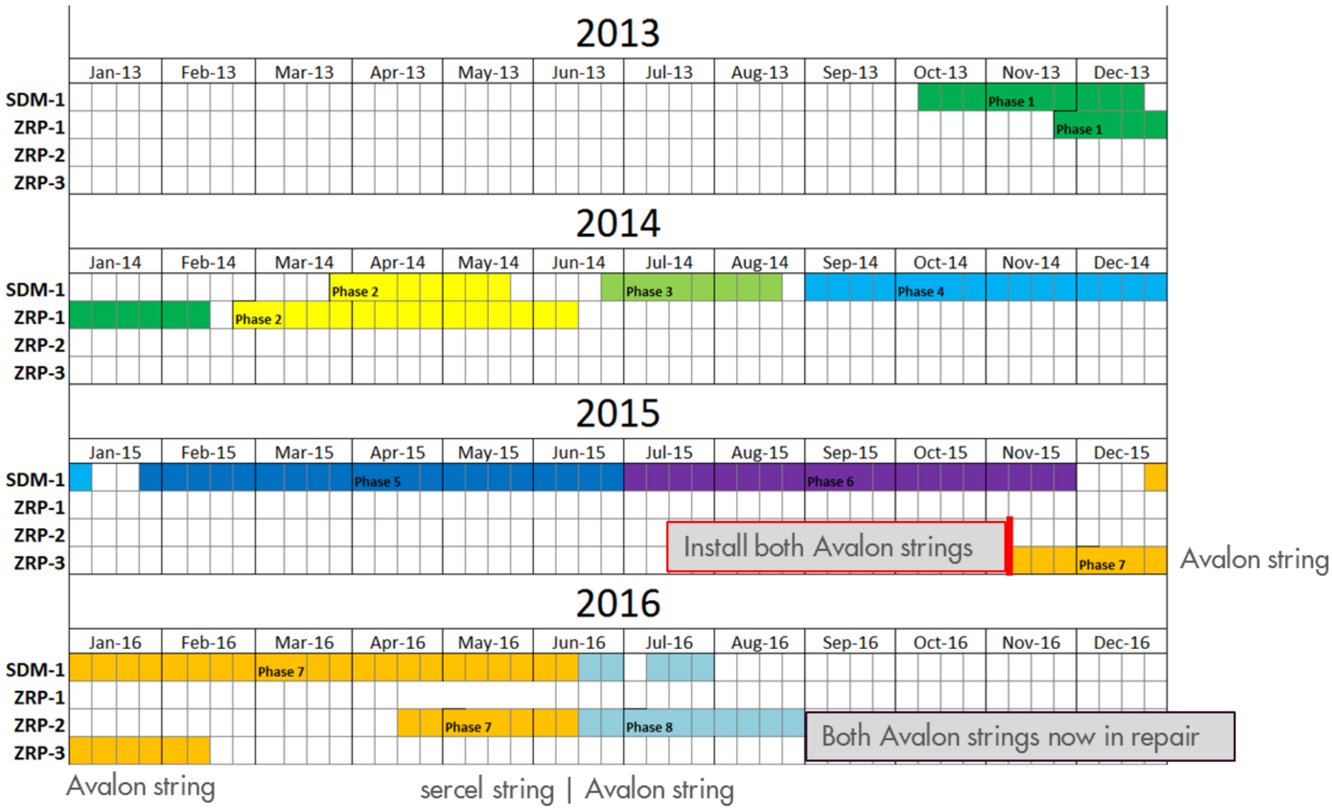


Figure B1. *Time span of microseismic monitoring campaigns for 3 dedicated wells.*