# EBN Internship report: SCAN seismic data analysis

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*Internship duration: January-July 2020*

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*UU supervisor: Dr. Ivan Pires de Vasconcelos*

**Abstract**

The SCAN programme maps the geothermal potential of the Netherlands. For this programme, new 2D seismic acquisition takes place in the Netherlands. This study analyses the newly acquired seismic data for lines 2-11. Acquisition parameters are mainly constant for all lines. Parameters that vary are charge size, shot depth and external circumstances such as noise. For the analysis signal amplitudes, noise amplitudes and the Signal-to-Noise ratio (SNR) are quantified and investigated per shot and line. The most important driver of variation in the data quality is the near surface geology. Signal amplitudes are higher with increasing shot depth and charge size. Therefore an increased shot depth and larger charge size is recommended to increase the data quality and to image deeper targets successfully. The most significant noise source across all lines is traffic, therefore noise levels can be reduced by avoiding main roads and/or shooting at times with less traffic.

# Contents

# Introduction

This research project is part of the SCAN programme.

The SCAN programme ‘Netherlands Seismic Campaign for Geothermal Energy’ (Seismische Campagne Aardwarmte Nederland) has been initiated by the Dutch government with the goal to map and explore the geothermal potential of the Dutch subsurface. Because of previous oil and gas exploration, large parts of the subsurface are already mapped in detail. There are however areas which are not mapped in this level of detail, the goal of the SCAN programme is to fil in these blanks and map these in detail.

The image below shows in what level of detail the Base Rotliegend – Base North Sea Group geology is mapped throughout the Netherlands.

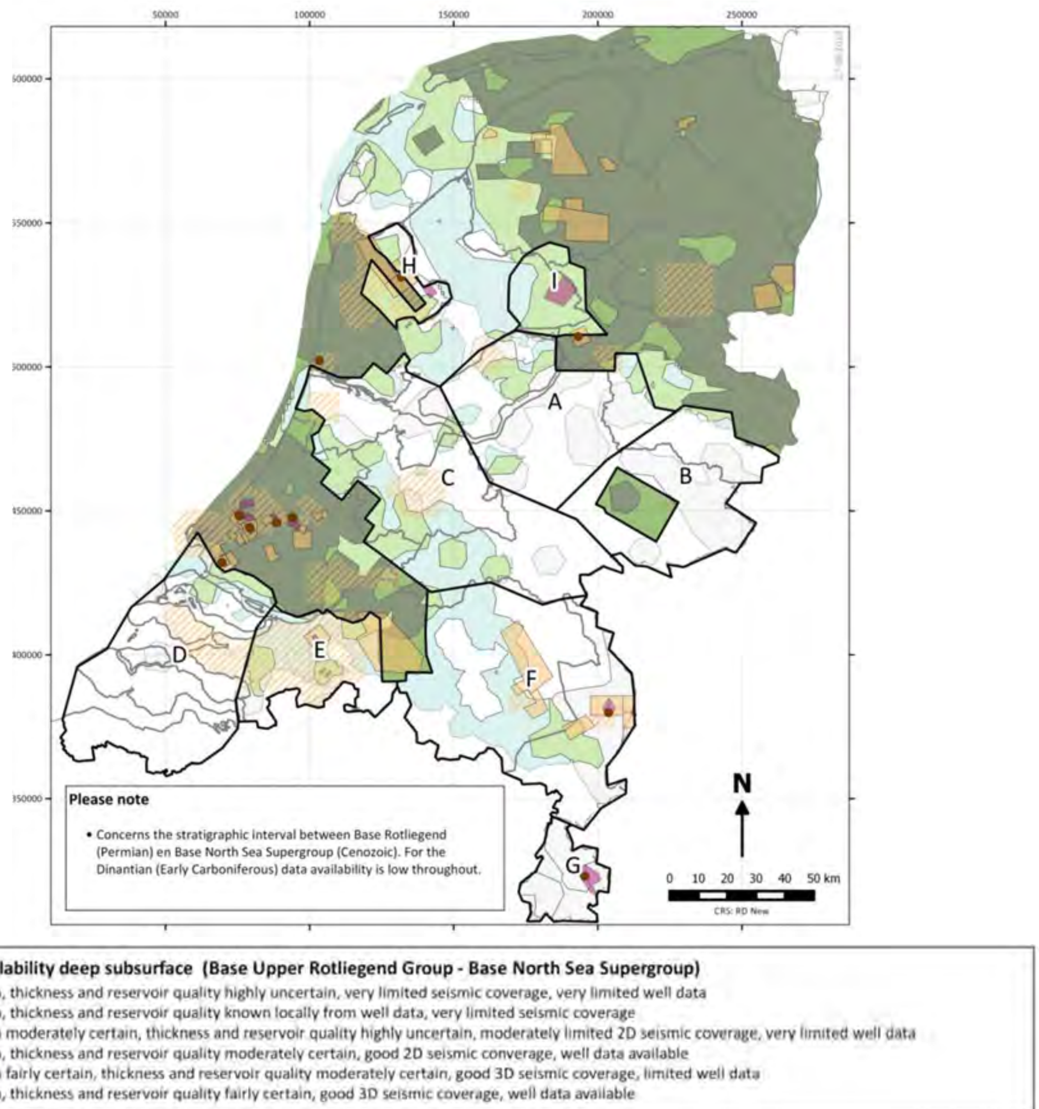



*Figure 1: Data availability for the Base Rotliegend – Base North Sea Group. The SCAN programme divides areas by letters A-H, these are shown in the map. (Ter Borgh & Mijnlieff, 2019)*

As part of the SCAN programme these areas will be investigated by

1) New 2D acquisition
2) Reprocessing of pre-existing seismic data
3) Scientific drilling

This research will focus on data analysis of the newly acquired 2D seismic data.

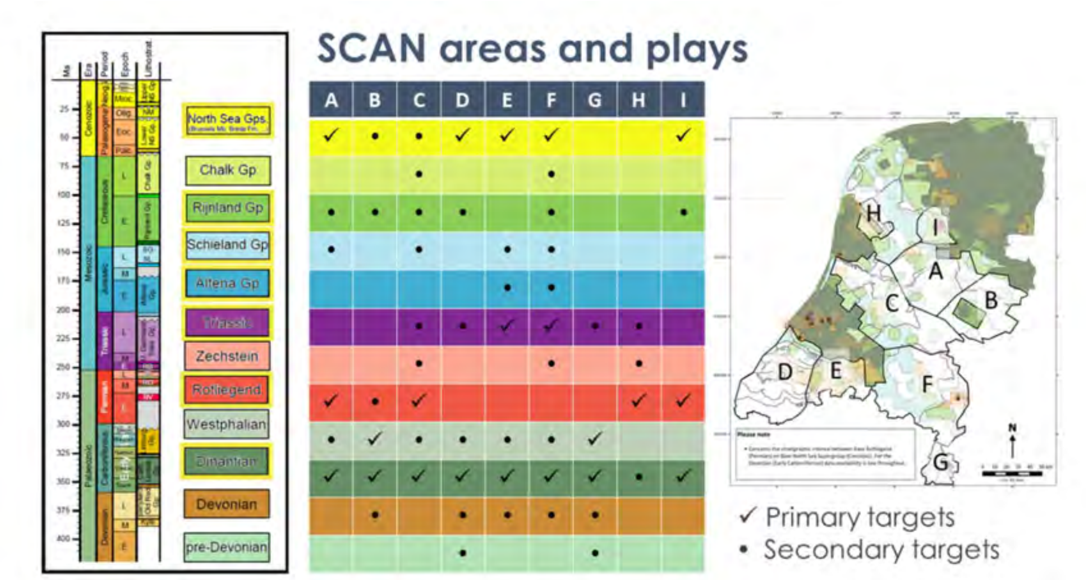



*Figure 2: SCAN targets by area. (Ter Borgh & Mijnlieff, 2019)*

Figure 2 shows the targets of the SCAN programme. As the DInantian is a primary target for all SCAN areas, it is important the seismic data is of sufficient quality even at larger depths.

As part of the SCAN programme a test line (2019 EBN test line) was carried out to determine the most efficient parameters to be used for the 2D acquisition throughout the Netherlands. Based on this line the following parameters have been chosen for the 2D acquisition:

| | |
|---|---|
| Seismic design | Split spread |
| Maximum offset | 6997.5 m |
| Receiver station interval | 5 m |
| Receiver station type | 5 Hz geophone |
| Source type | Explosive source |
| Source interval | 60 m |
| Source depth | 4 - 26 m |
| Charge size | 220 g – 1560 g |
| Sample rate | 2 ms |
| Record length | 10 s |

# Research questions

The goal of this internship is to assess the data quality of the newly acquired 2D data. Previously another student mainly studied the SCAN 2019 EBN test line (Janssen, 2020) in detail. This study will assess the data quality of newly acquired seismic data before the end of the internship, this includes the lines 2 to 11 (Figure 1).

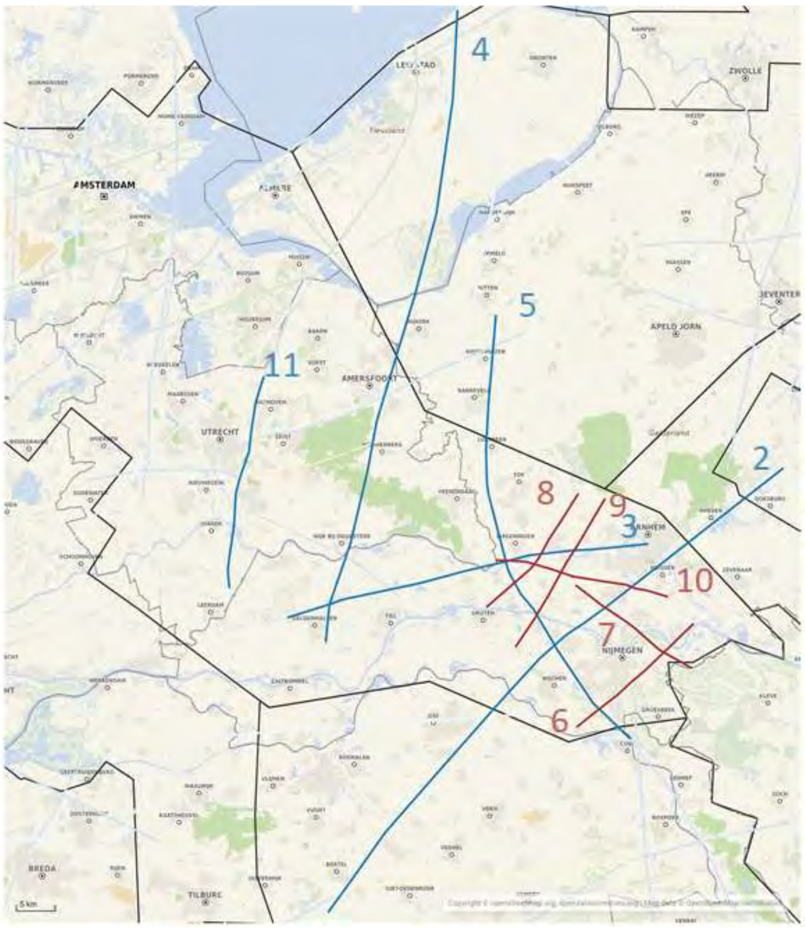



*Figure 3: An overview of the seismic lines 2-11 analyzed in this study.*

In particular, the goal is to answer the following research questions:

- Is there a relationship between shot data quality* and weather (particularly wind noise)?
- Is there a relationship between shot data quality* and traffic, industrial or residential noises?
- Is there a relationship between shot data quality* and day time of shooting?
- Is there a relationship between shot data quality* and shot depth?
- Is there a relationship between shot data quality* and charge size?
- Is there a relationship between shot data quality* and near surface geology (based on available geological data from DINOloket)?
- Is there a relationship between shot data quality* and measured uphole times?
- Is there a relationship between the measured uphole time and the near surface geology?
- Can we make recommendations on shot design based on near surface geology?
- Is there a relationship between ground roll variation (e.g. dominant frequency, ground roll velocity) and near surface geology?

*Shot quality evaluated based on signal amplitude, amplitude spectrum, dominant frequency, strength of ground roll, analysed in time, FK or other domains

Because of the large amount of data analyzed, this study mainly focusses on assessing data quality by analyzing the signal amplitudes, noise amplitudes and signal-to-noise ratio (SNR) of the data. As this a good and quick indication of the data quality of a shot.

# Method

The acquired 2D seismic data to be assessed is delivered in SEGY format as raw data. Software used for the data analysis is GLOBE Claritas. The data quality will be assessed in the shot domain. For each shot the average RMS amplitude is quantified for both a signal and a noise window. Together, this gives a signal-to-noise ratio (SNR):

$$SNR = \frac{Average\ RMS\ signal\ amplitude\ of\ a\ sho}{Average\ RMS\ noise\ amplitude\ of\ a\ shot}$$

This is used as a measure of the data quality of a shot.

## Noise amplitude analysis

For the noise analysis, the RMS amplitudes are quantified per individual trace of a shot in a particular time and offset window. Subsequently these RMS amplitudes are summed and divided by the number of nonzero traces. In the previous study on the SCAN 2019 EBN test line, ambient noise amplitudes were calculated in the last second of each shot gather, specifically in the 19-20 s window (Janssen, 2020). For the newly acquired data of lines 2-11 however, the record window is only 10 s. The goal of the ambient noise analysis is to find the average noise amplitude of a shot without any shot energy. As is visible in Figure 4 below, the 8998-9998 ms window still contains shot energy.

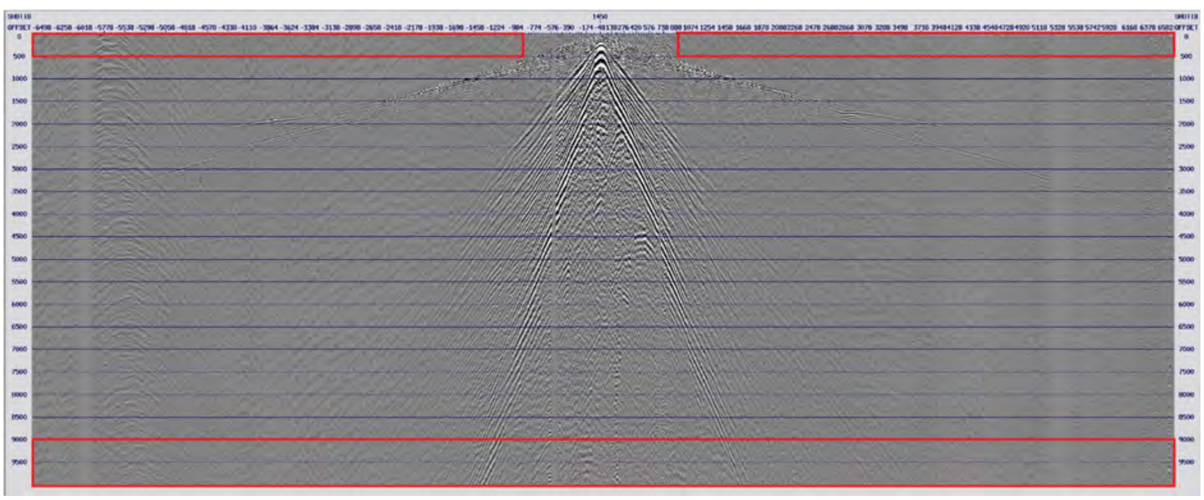


*Figure 4: Ambient noise definition. This shows two windows: a) 0-500 ms excluding -900 m to + 900 m offsets and b) 8998-9998 ms for all offsets*

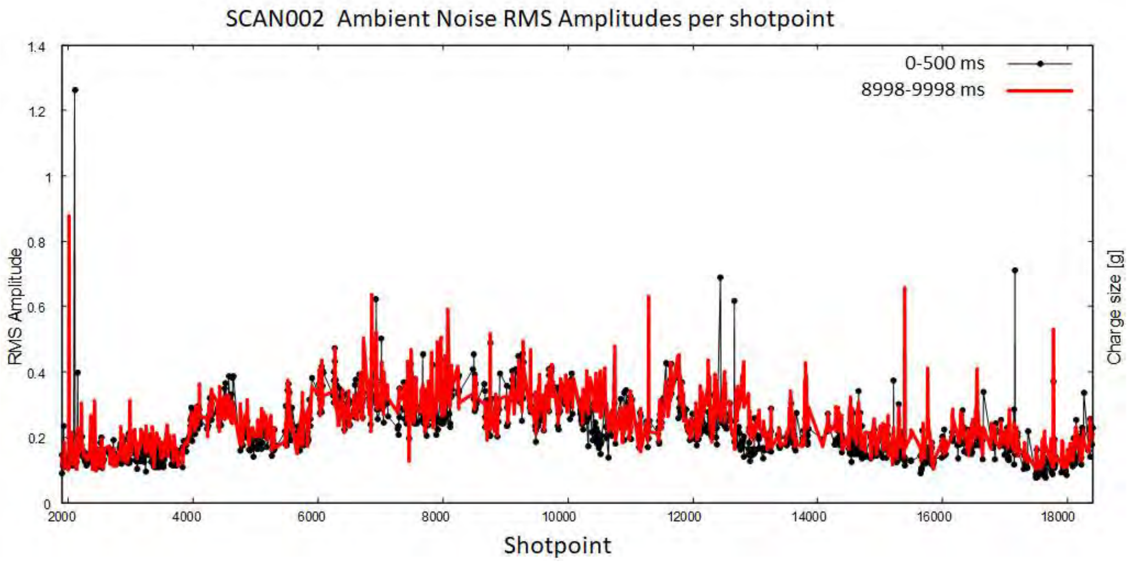



*Figure 5: SCAN002 Ambient noise RMS amplitudes per shot point for two windows a) 0-500 ms excluding -900 m to + 900 m offsets and b) 8998-9998 ms for all offsets*

Figure 5, above shows the SCAN002 Ambient noise RMS amplitudes per shot point for the 0-500 ms and the 8998-9998 ms window. The last second window (red) shows a similar trend as the 0-500 ms window (black) but has slightly higher amplitudes, likely because some shot energy is still present in the window. Therefore instead of quantifying the ambient noise in the last second, this study will take the RMS amplitudes in the 0-500 ms window, excluding the -900 m to +900 m offsets that contain shot energy (Figure 4).

## Signal amplitude analysis

Quantification of signal amplitudes is done in a similar way as the ambient noise, however in this case the analysis window is taken over a window with shot energy to determine average signal amplitude of a shot. In the previous study (Janssen, 2020) a window was selected between 0-1 s over offsets -1750 to -350 m and +350 to +1750 m (Figure 6)

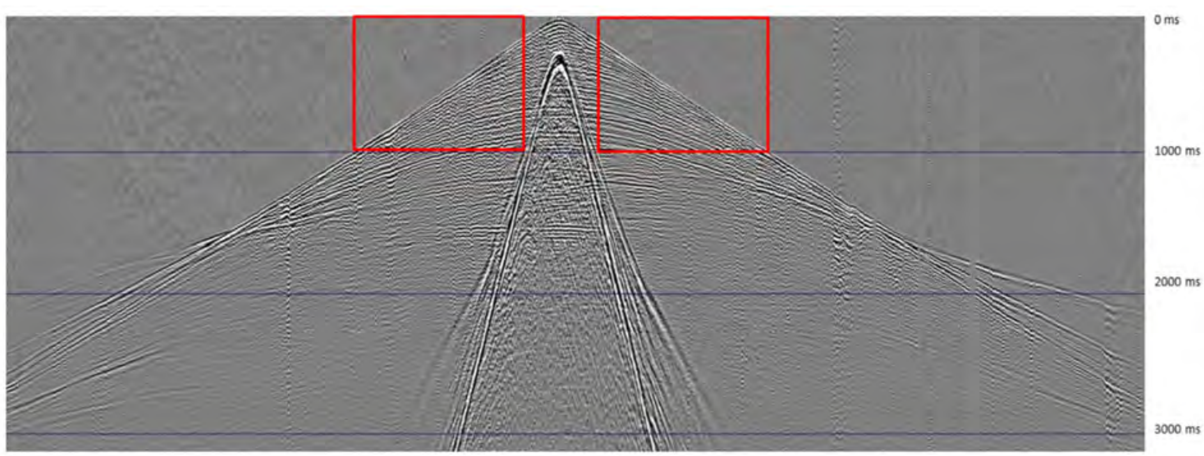



*Figure 6: Window used to quantify the RMS signal amplitudes in the previous study of the 2019 EBN test line (Janssen, 2020).*

Similar to the previous study (Janssen, 2020), I have attempted to filter the ground roll. These attempts were not successful as higher amplitudes remained present in the window where ground roll is present (Figure 8). More aggressive filtering would have affected signal data too much.

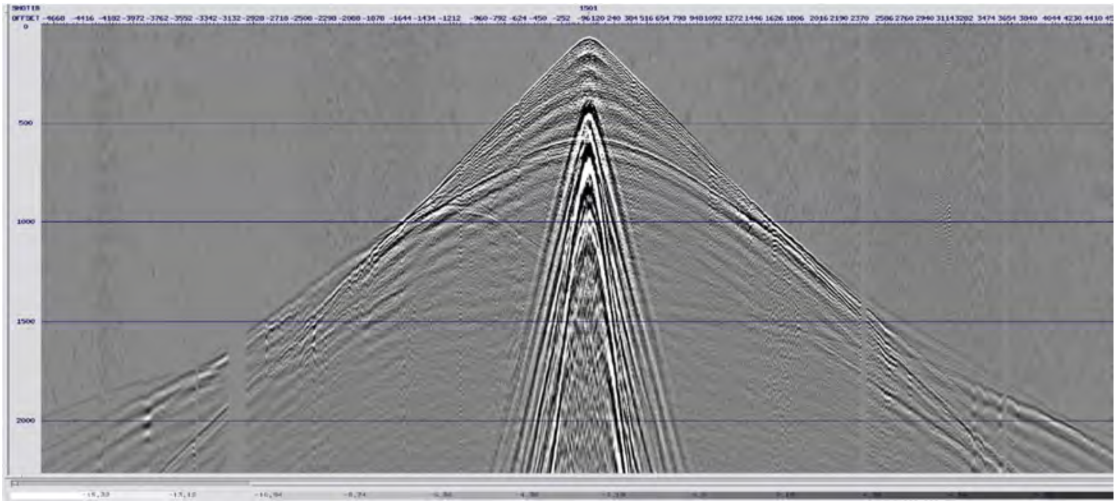


*Figure 7: SCAN002 Shot 1501 raw data.*

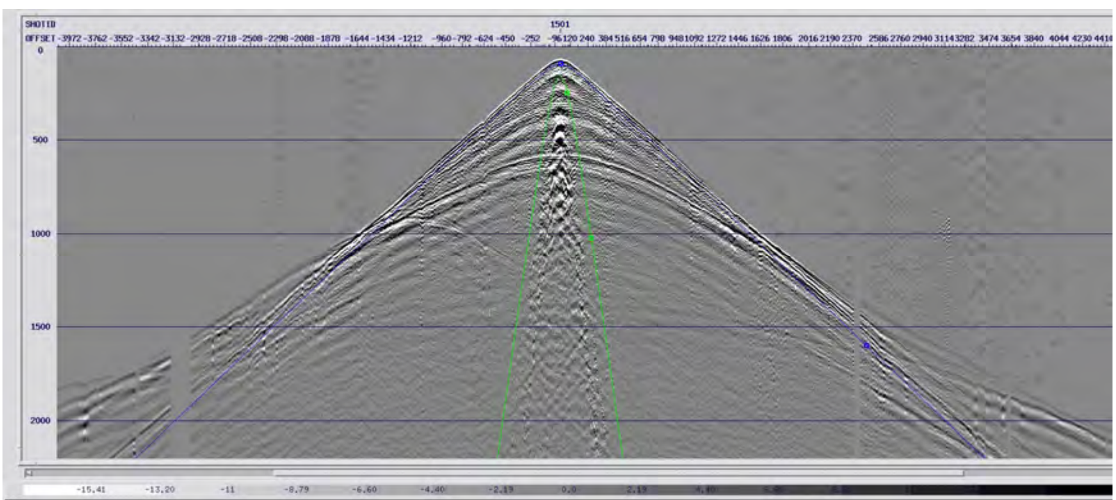


*Figure 8: SCAN002 Shot 1501 after an FK-filter was applied. Higher amplitudes remain in the ground roll window. The green and blue lines indicate the areas muted to remove high amplitude data.*

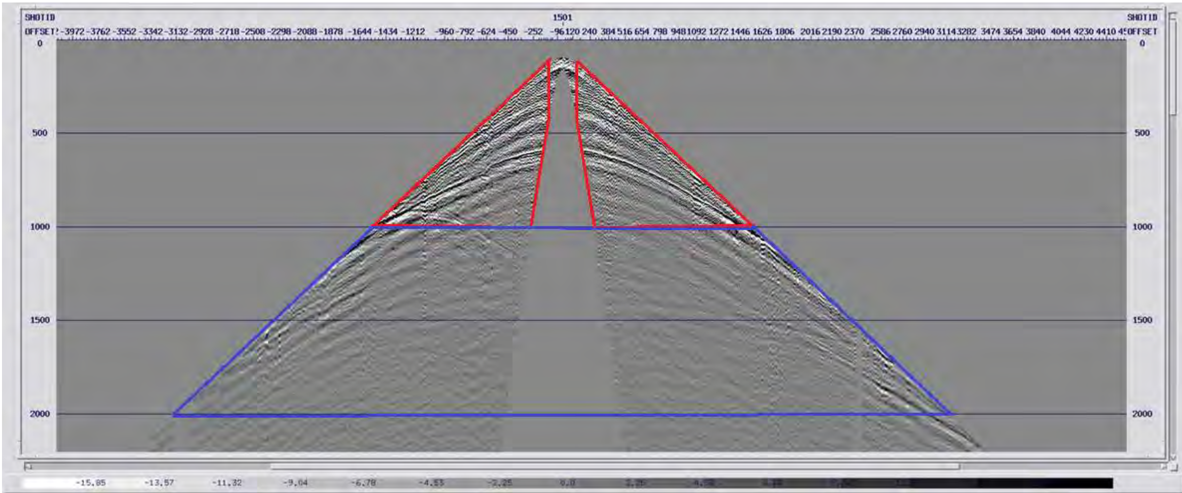



*Figure 9: SCAN002 Shot 1501 after an FK-filter was applied and first break and ground roll were removed. The red window shows the used signal window between 0-1 s, offsets -150 to +150 m are excluded because of high amplitude data. The blue window shows the used signal window to analyse the results at larger depths: 1-2 s.*

In this study I have taken a slightly different approach to quantify the signal amplitudes of the shots in order to use more data. As shown in figure 6 above, I have muted the ground roll to enable the use of signal data in the offsets between -350 to -150 m and 150 to 350 m, offsets between -150 and 150 m were excluded because these traces record very high amplitudes that would substantially increase the average signal amplitude whereas it is not the part of the signal that is most interesting. I have continued using the FK-filtered data, because although the FK-filter doesn't remove the gound roll completely it does successfully removed the fastest portion of the ground roll, thereby requiring a smaller part of the data to be muted. In addition, the first break energy was removed, as the first break also records high amplitudes and is also of less interest. Two windows were selected to be analysed, one between 0-1 s and one between 1-2 s, to also quantify the signal amplitudes at larger depths.

Once the average RMS signal amplitudes are quantified per shot between 0-1 s and 1-2 s, the SNR is calculated for both the 0-1 s and 1-2 s windows. The noise amplitudes, signal amplitudes and SNR are then compared to acquisition variables, such as shooting time, shot depth, charge size and near surface geology. All of this data is loaded into QGIS to allow for a detailed map view analysis and visualization.

The near surface geology data used for this study is taken from the 3D DINOloket REGIS II model, which is based on an extrapolation of a selection of well (Vernes et al., 2006). This model can be viewed in SubsurfaceViewer. The locations of the shotpoints of each seismic line can be loaded into SubsurfaceViewer to give a cross section of the near surface geology of the line. This is then compared to the signal amplitudes, SNR, uphole velocities and frequency data. The results are also compared to the lines after DUG fast track processing. This is only based on about 2 weeks of processing and the final results may differ significantly.

# Results

The results are given below for each line, first in the shot domain and then the receiver domain. The results are given and discussed on a line-by-line basis.

## SCAN002

The acquisition of SCAN002 was done in September-October 2019. The line is 82.64 km in length and runs from the NE towards the SW (Figure 10).

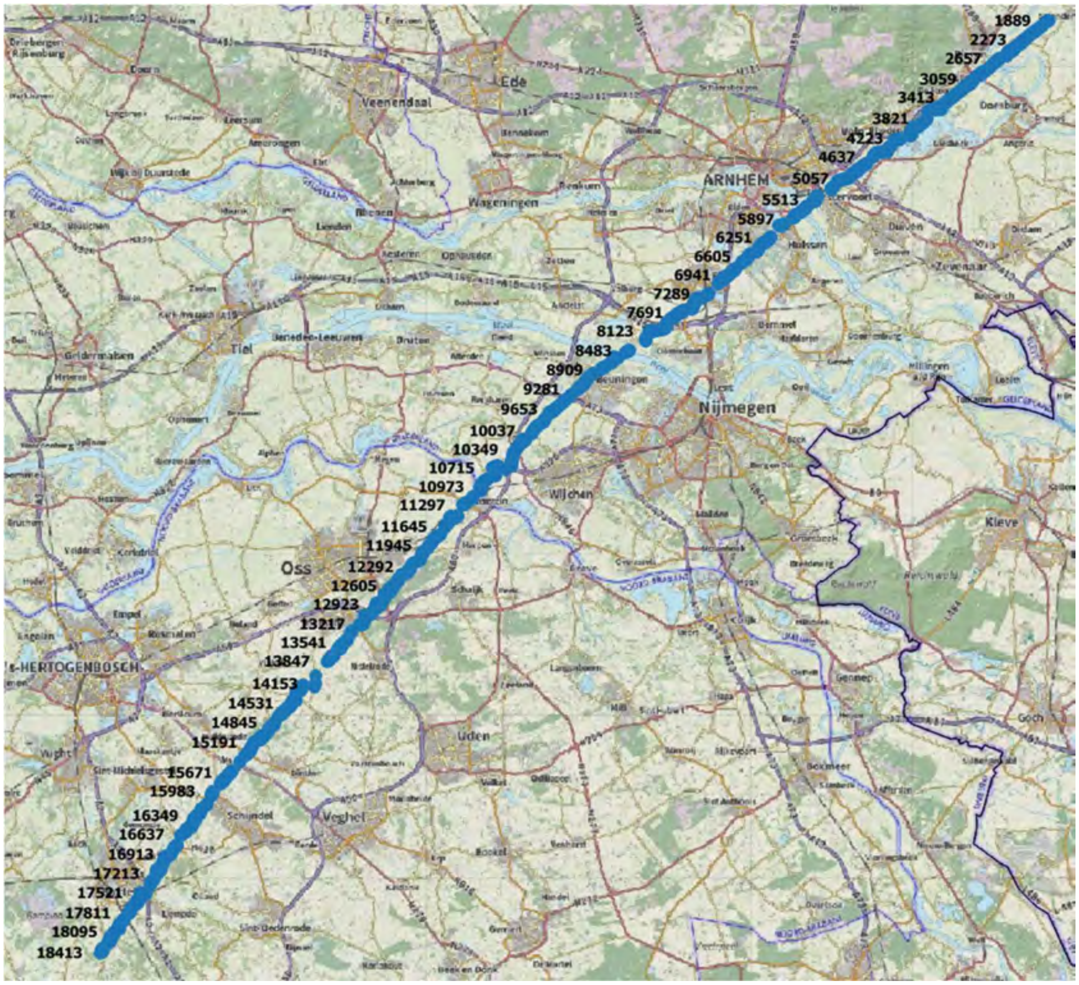



*Figure 10: SCAN002 location and numbering*

**Shot domain: Noise**

Noise is mostly related to background activity that is present during the time of the shot, examples of causes of noise are traffic, industrial activity, wind (near trees/windmills). Below, the average noise amplitudes are visualized for each shotpoint of line 2.

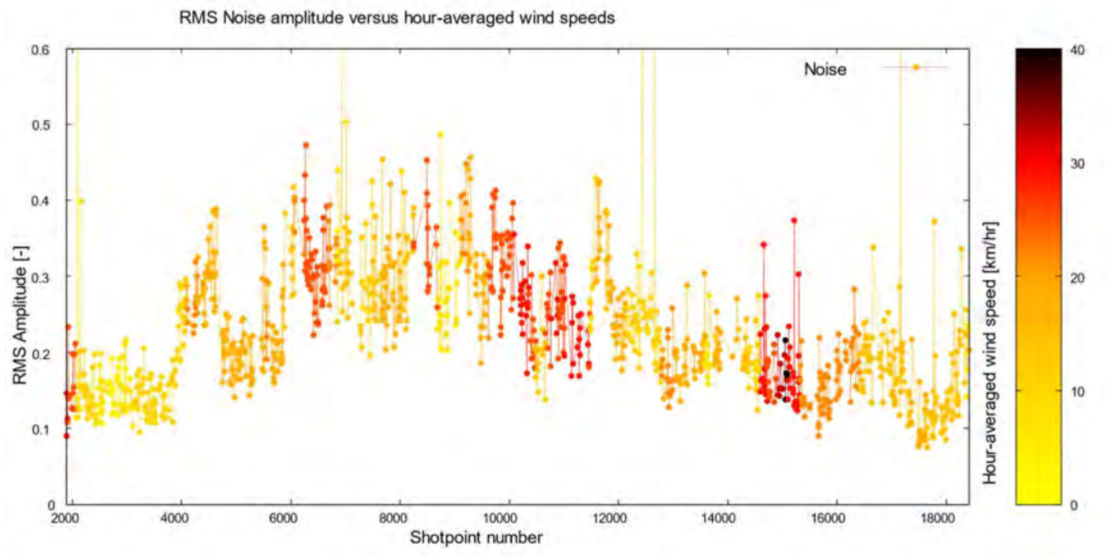



*Figure 11: SCAN002 Noise amplitudes (0-500 ms) per shotpoint – color indicates average hourly windspeed at the Volkel weatherstation. Left=NE, Right=SW.*

In addition Figure 12, shows the noise amplitudes versus the time of shooting

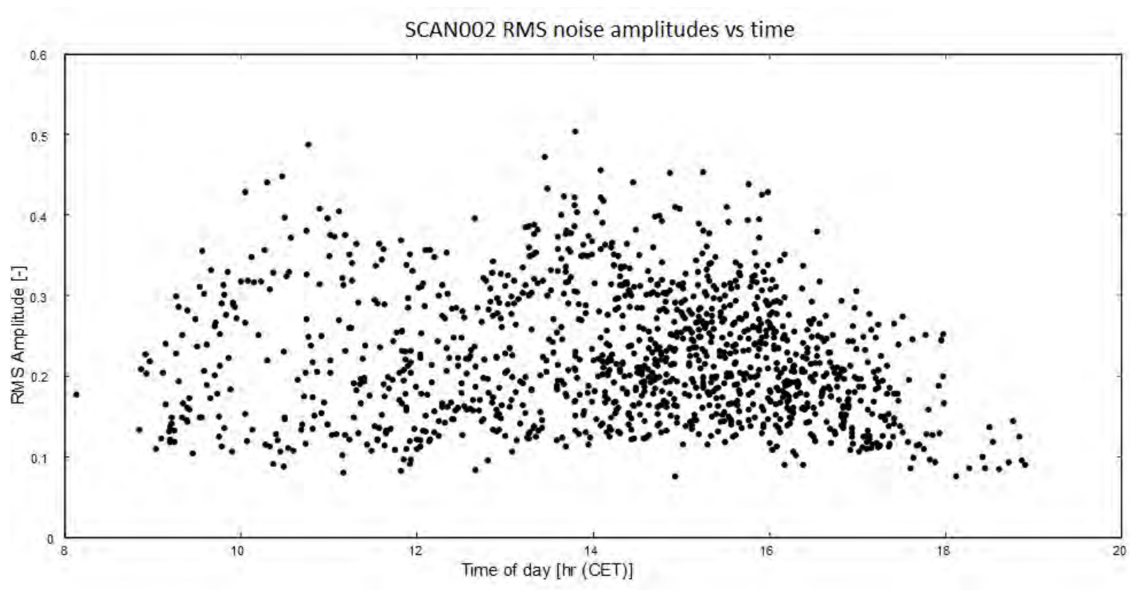
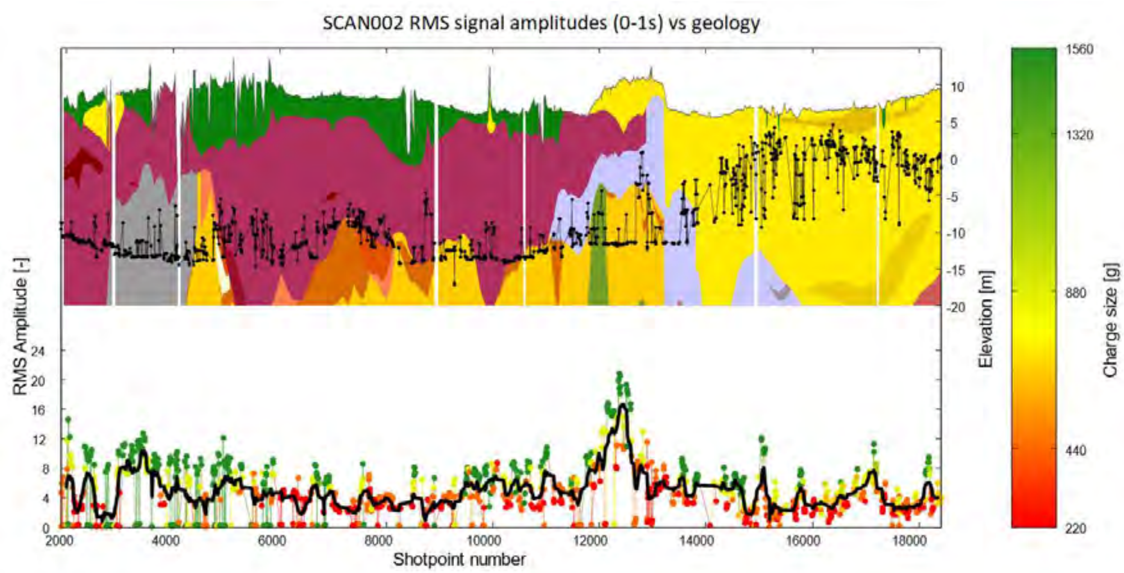



*Figure 12: SCAN002 Noise amplitudes by time of day.*

**Shot domain: Signal**

a)





b)

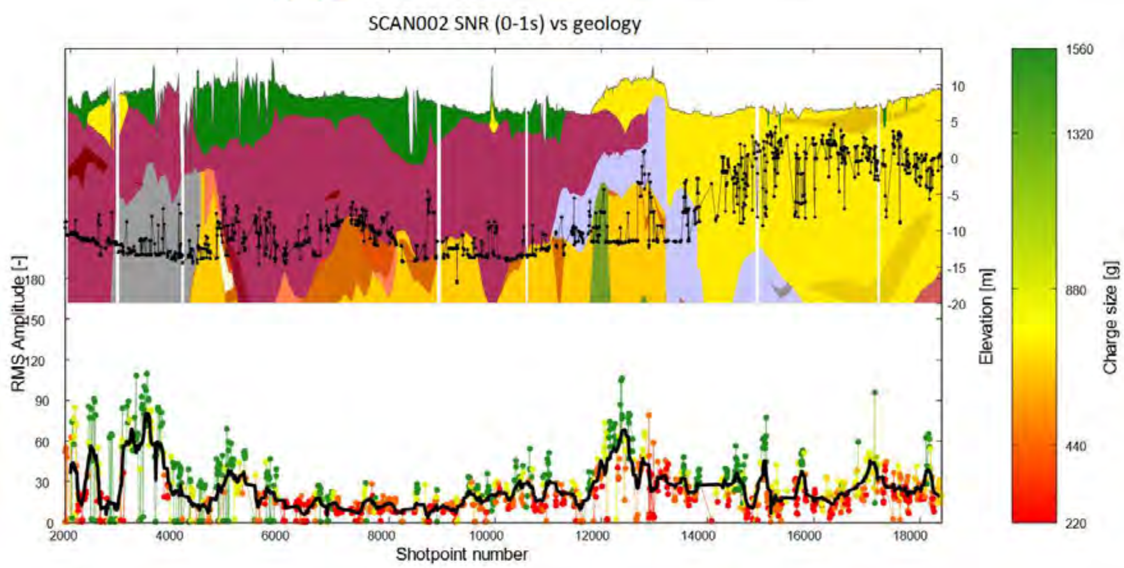



*Figure 13: SCAN002 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in. Left=NE, Right=SW.*

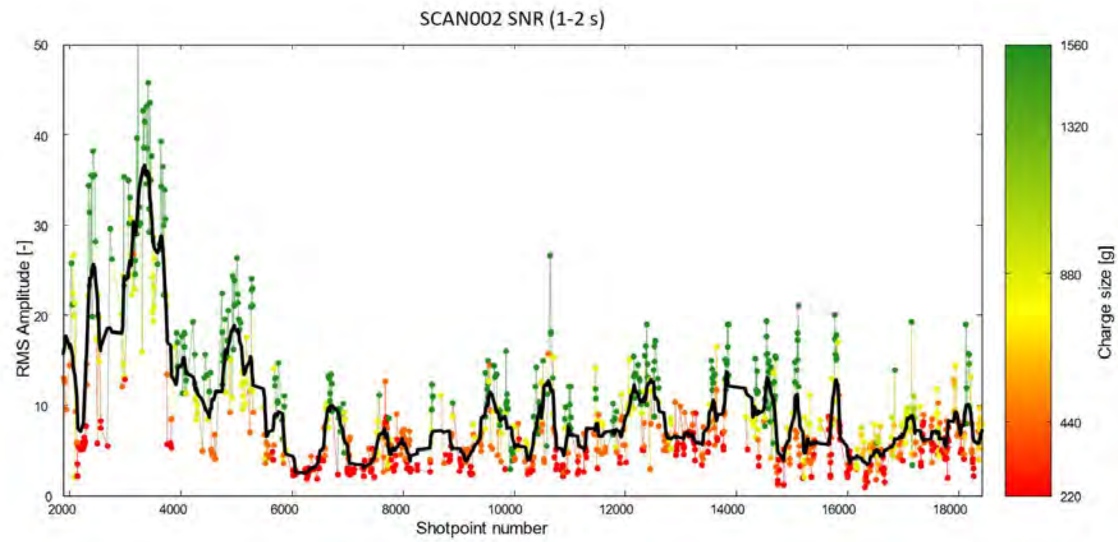



*Figure 14: SCAN002 SNR (1-2 s). Color indicates charge size. For this graph shots identified as weak have been removed. Left=NE, Right=SW.*

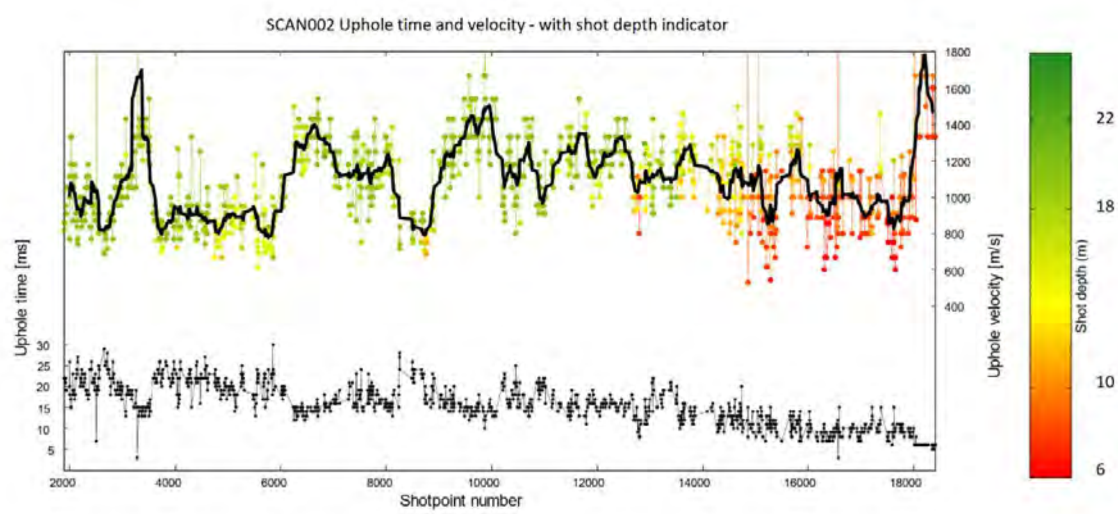



*Figure 15: SCAN002 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=NE, Right=SW.*

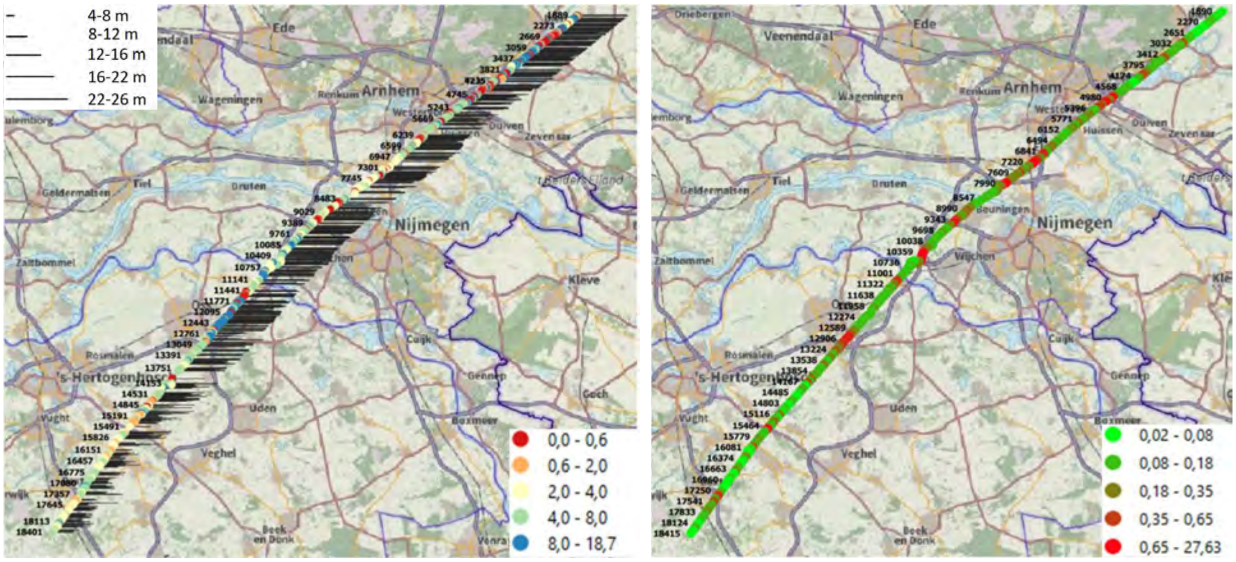



*Figure 16: Map view of SCAN002 signal amplitudes (left) (0-1 s) with black lines indicating the shot depth, and average noise amplitudes per receiver (right).*

**Receiver domain: Noise**

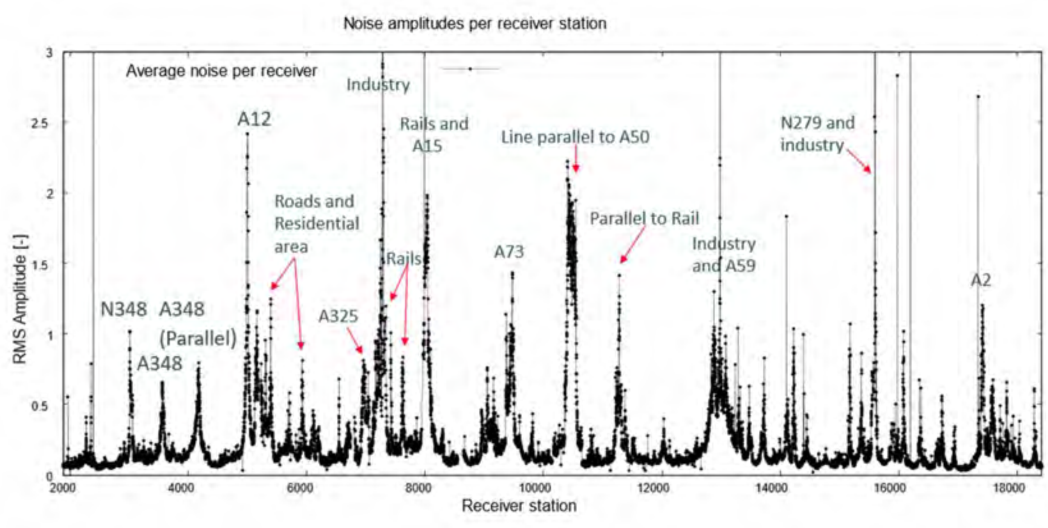



*Figure 17: SCAN002 Noise amplitudes per receiver station. Likely noise sources are indicated. Left=NE, Right=SW.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.226 | 4.97 | 25.08 | 1.615 | 8.16 | 176 (14.1 %) |

**Discussion and comparison to DUG Fast Track**

Noise amplitudes per shot vary between about 0.1 and 0.5, for this line the noise amplitudes were compared to the hourly average windspeed of the nearest KNMI weather station. There does not appear to be a significant correlation between windspeed and the average noise amplitude of a shot.

The data quality for line 2 generally is quite good, the average SNR is above 8 even for data at larger depths (1-2 s two way travel time). However, a problem is the relatively large amount of shots that register low signal amplitudes. For this analysis I have defined shots as 'weak' when the average RMS signal amplitude is lower than 0.6. Using this definition, SCAN002 has 176 weak shots, or 14.1 % of the data. Especially shots in the Northeast of the line are affected and even some high charge size shots can be classified as weak.

The signal amplitudes vary quite a bit over the course of the line, and are generally quite dependent on the used charge size. Although shots in the Southwestern part of the line were taken a lot shallower, the signal amplitudes and SNR remain at relatively high levels. Uphole velocities vary between 800 m/s up to 1600 m/s over the length over the line. Areas with a thicker package of Holocene generally have lower uphole velocities (for example shotpoints 4000-6000 and 8000-8500).

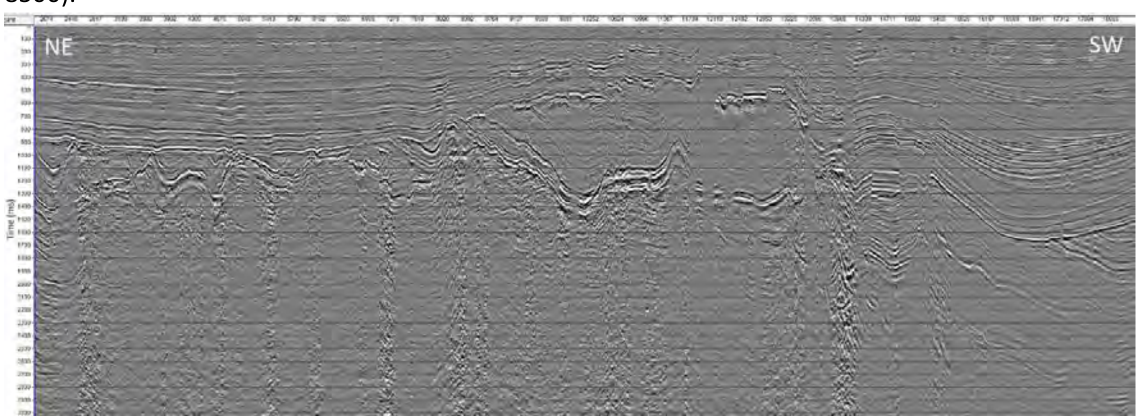



*Figure 18: SCAN002 DUG true amplitude fast track.*

The fast track processing by DUG is generally of good quality up to 2 s. Several areas of lower quality appear to be mainly caused by gaps in the line: e.g. around shotpoint 8400 (because of the Waal river) and 13900 (permitting issues)

As for the noise analysis in the receiver domain: Most noise sources can clearly be correlated to traffic. The most likely noise sources have been indicated on Figure 17. Noise is especially elevated around receiver stations 10400-10500, where the line was parallel to the A50 highway. This area is also noisy in the fast track, but it remains unclear if this is directly related to the highway noise.

SCAN003

The acquisition of SCAN003 was done in October-November 2019. The line runs from W-E and is 46.705 km in length.


*Figure 19: SCAN003 location and numbering.*

**Shot domain: Noise**

The results of the noise analysis for SCAN003 are given below.

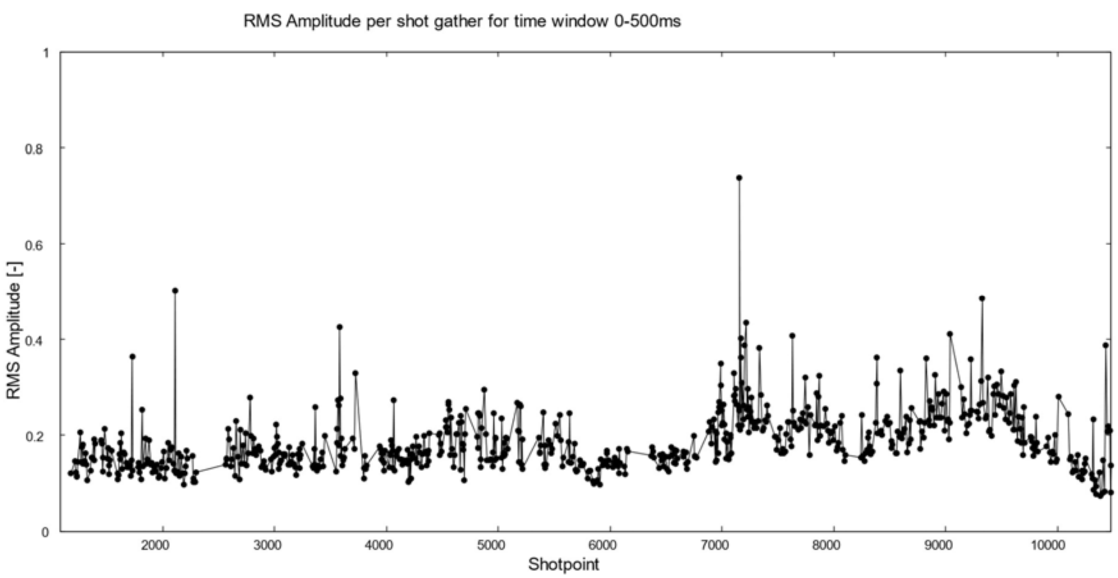



*Figure 20: SCAN003 Noise amplitudes per shotpoint. Left=W, Right=E.*

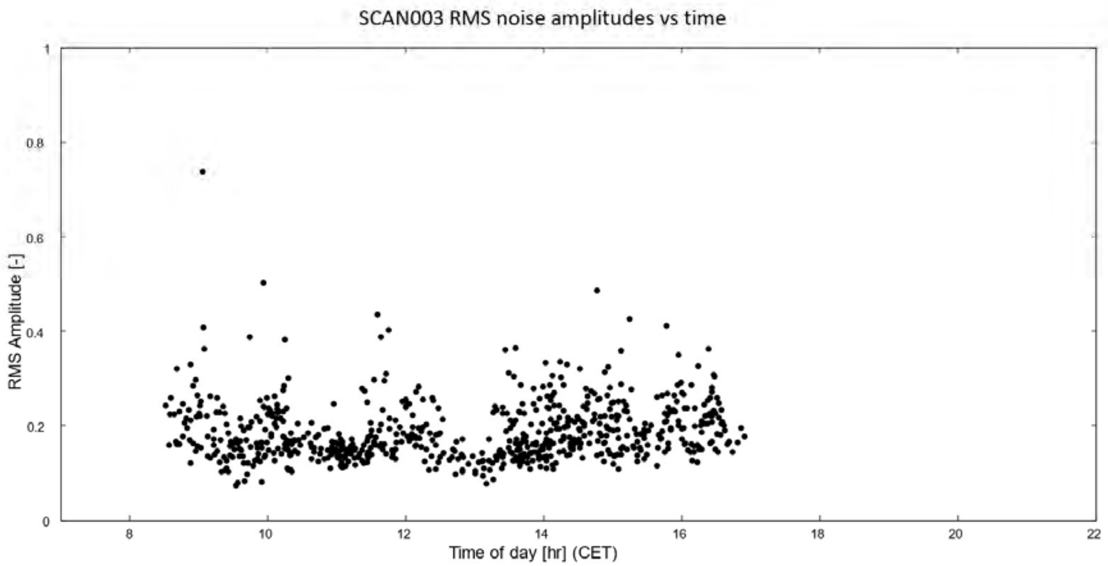



*Figure 21: SCAN003 Noise amplitudes by time of day.*

**Shot domain: Signal**

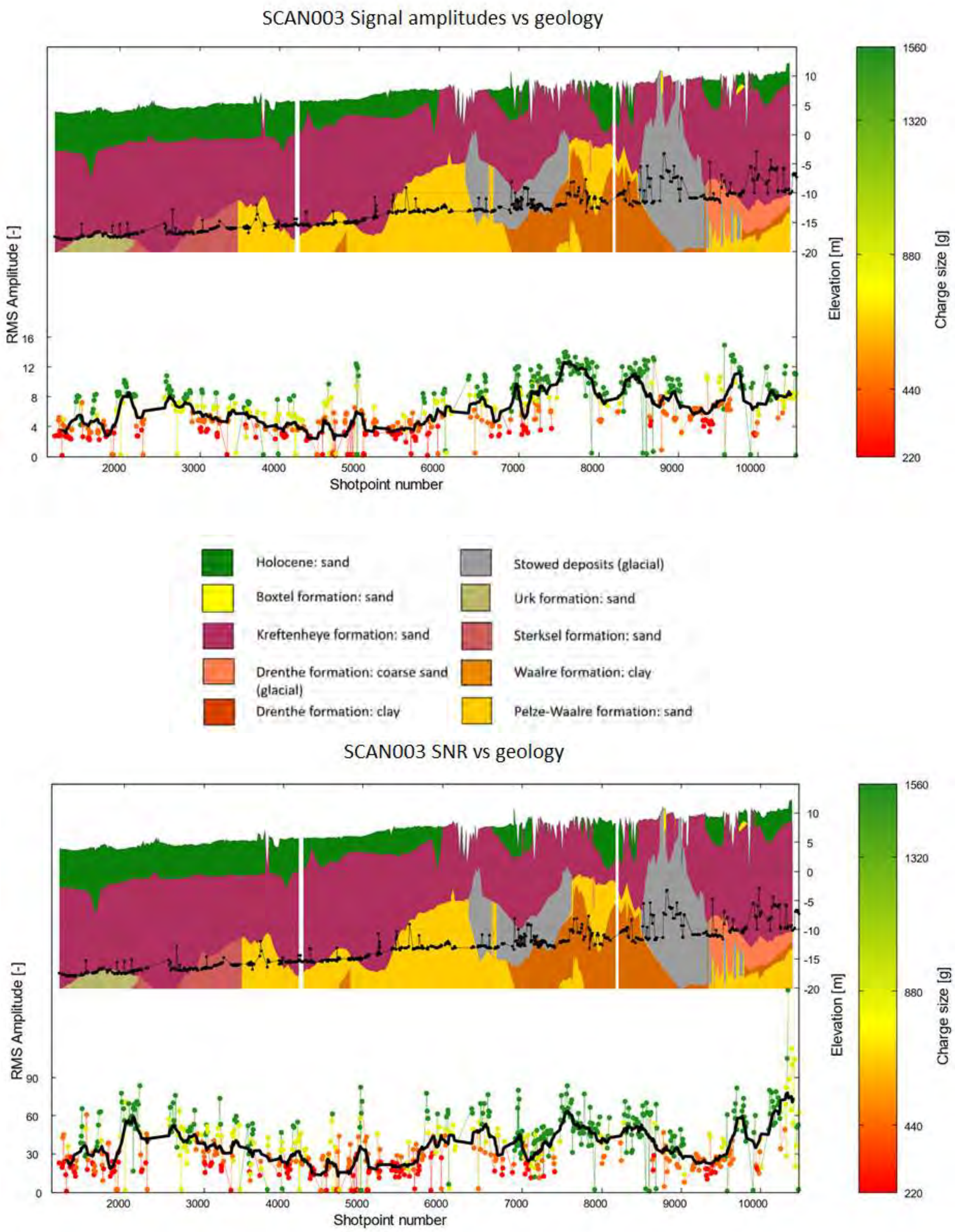



*Figure 22: SCAN003 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was theoretically fired in. Left=W, Right=E.*

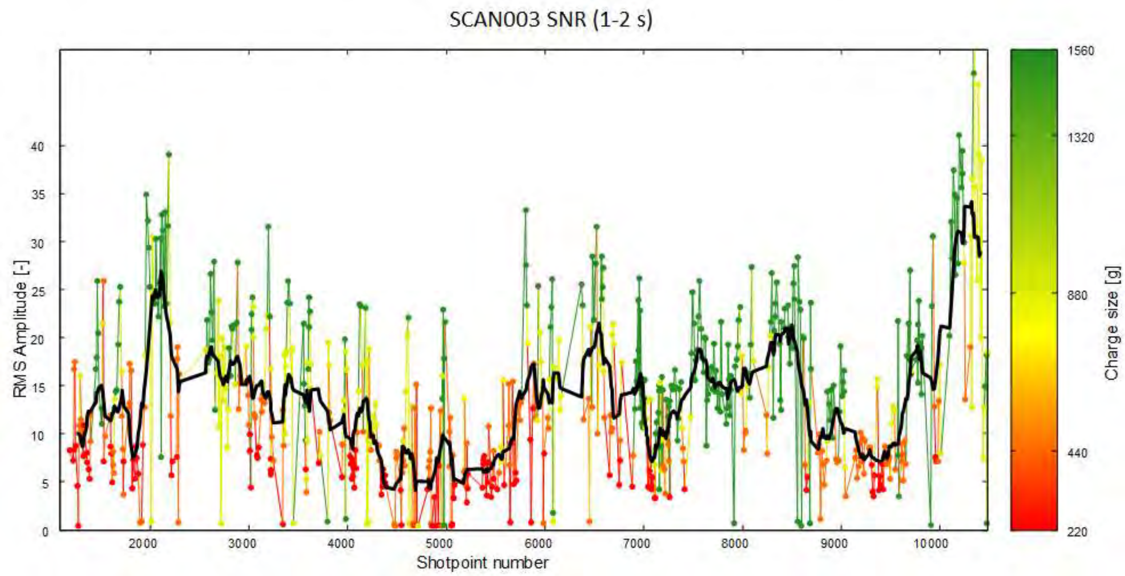



*Figure 23: SCAN003 SNR (1-2 s) per shotpoint. Color indicates charge size. Left=W, Right=E.*

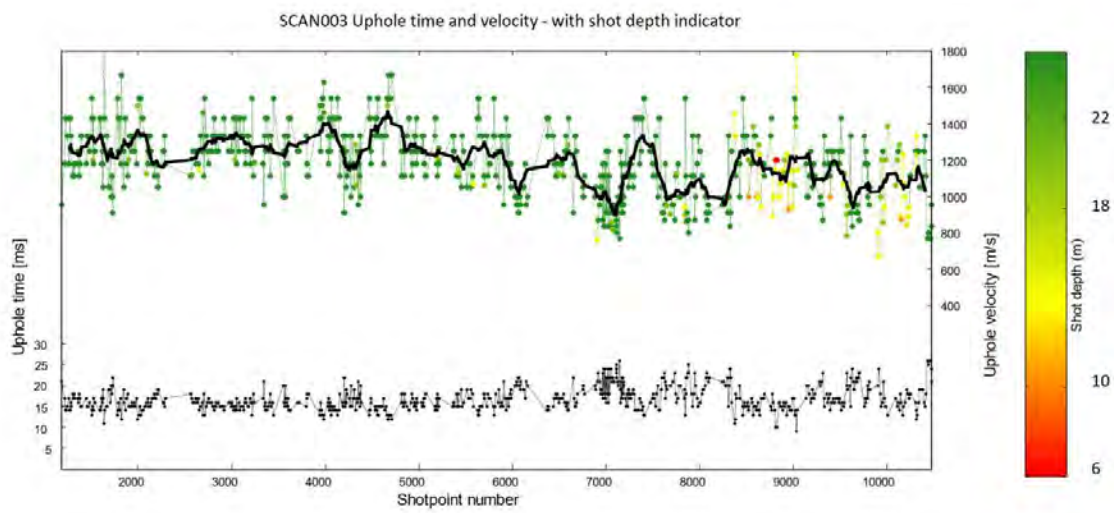



*Figure 24: SCAN003 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=W, Right=E.*


*Figure 25: Map view of SCAN003 Signal amplitudes (0-1s) with shot depth indicators.*

**Receiver domain: Noise**

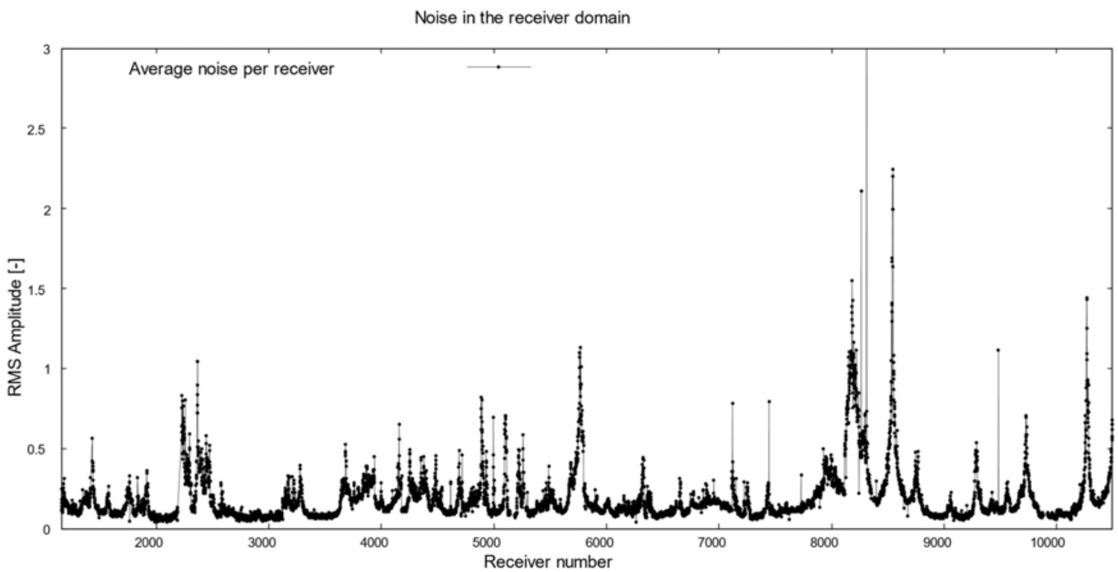



*Figure 26: average RMS noise amplitudes per receiver station for SCAN003*


*Figure 27: Map view of the average RMS noise amplitudes per receiver station for SCAN003. Numbers indicate receiver stations.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.188 | 6.43 | 35.28 | 2.341 | 13.54 | 45 (6.4 %) |

**Discussion and comparison to DUG Fast Track**

The results for the SCAN003 line are good, with the SNR generally above 15 in the 0-1 s window and above 5 in the 1-2 s window for most shots. There is still a decent amount of weak shots scattered across the line, here – similar to SCAN002 - some high charge size shots are also classified as weak.

For this line the shot depth was largely constant throughout the line. The uphole velocity fluctuates between 1000 m/s and 1400 m/s throughout the line.

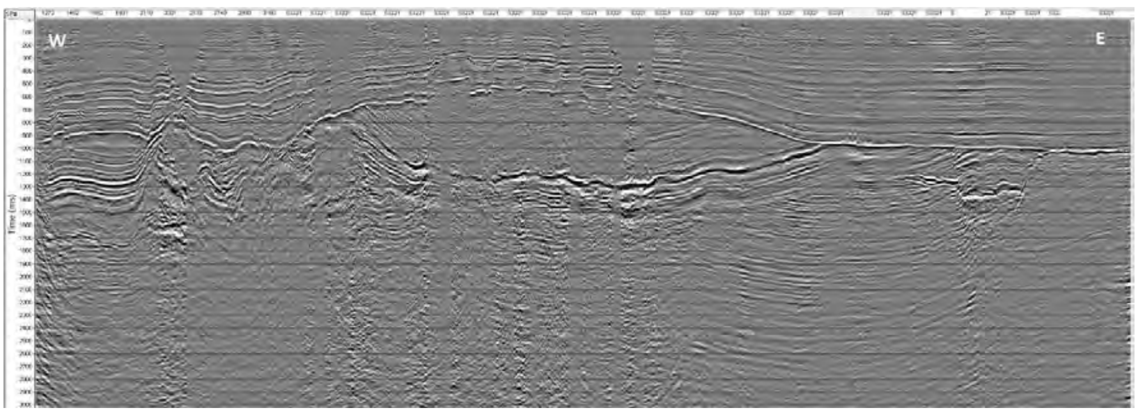



*Figure 28: SCAN003 DUG true amplitude fast track.*

There are two large gaps in the line, one around shotpoint 2400 (~1350 m or about 21 shots missing) and the second around shotpoint 6250 (~1300 m or about 20 shots missing). These again reduce the data quality significantly.

High noise amplitudes are generally located around main roads, with receivers near highways and train tracks registering the highest amplitudes.

## SCAN004

The acquisition of SCAN004 was done in November-December 2019. The line runs from North to South and is 82.9 km in length. This line runs east from the test line through the Southern Polder, here *Janssen, 2020* noticed a region of low signal amplitudes and high frequency attenuation.

*Figure 29: SCAN004 location and numbering*

**Shot domain: Noise**

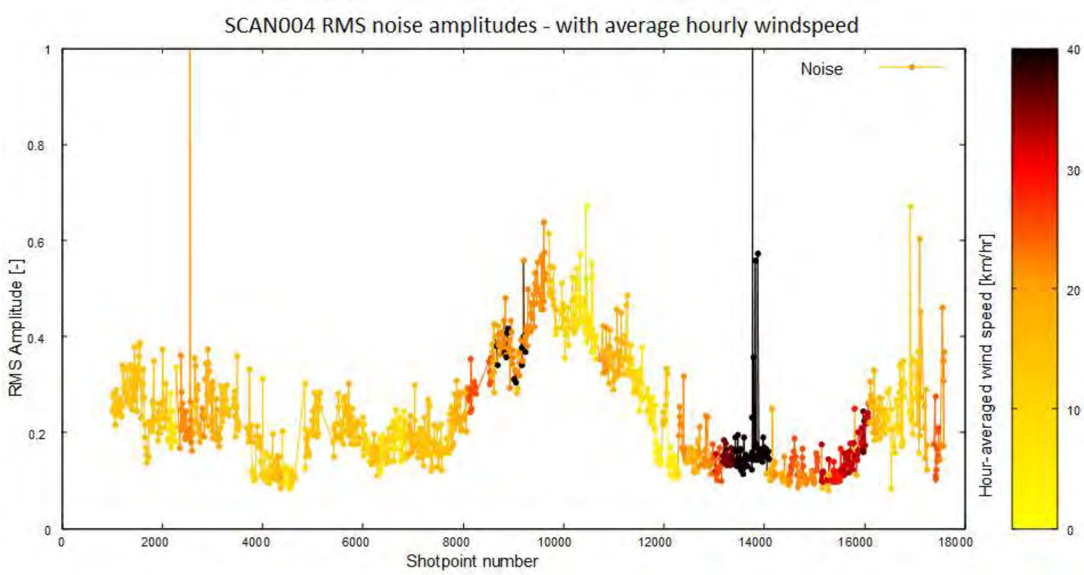



*Figure 30: SCAN004 Noise amplitudes per shotpoint – color indicates average hourly windspeed at the Lelystad weatherstation. Left=N, Right=S.*

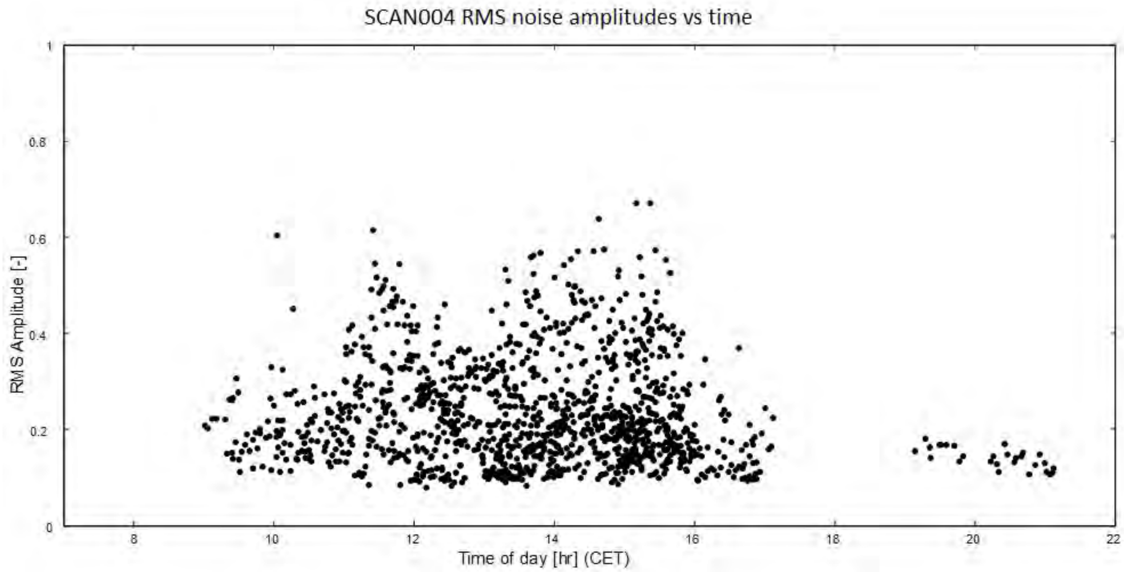



*Figure 31: SCAN004 Noise amplitudes by time of day.*

**Shot domain: Signal**

a)

b)

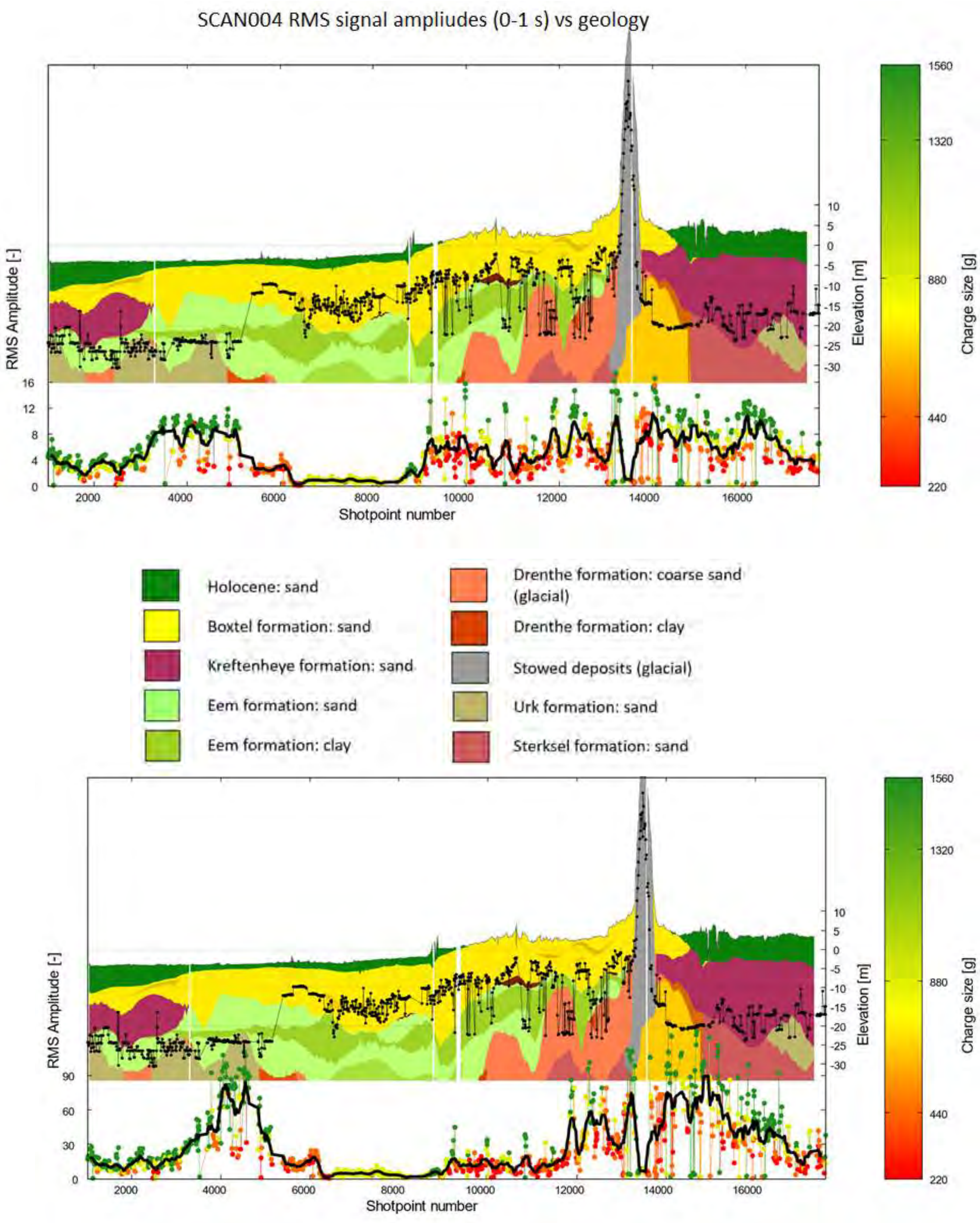



*Figure 32: SCAN004 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in. Left=N, Right=S.*

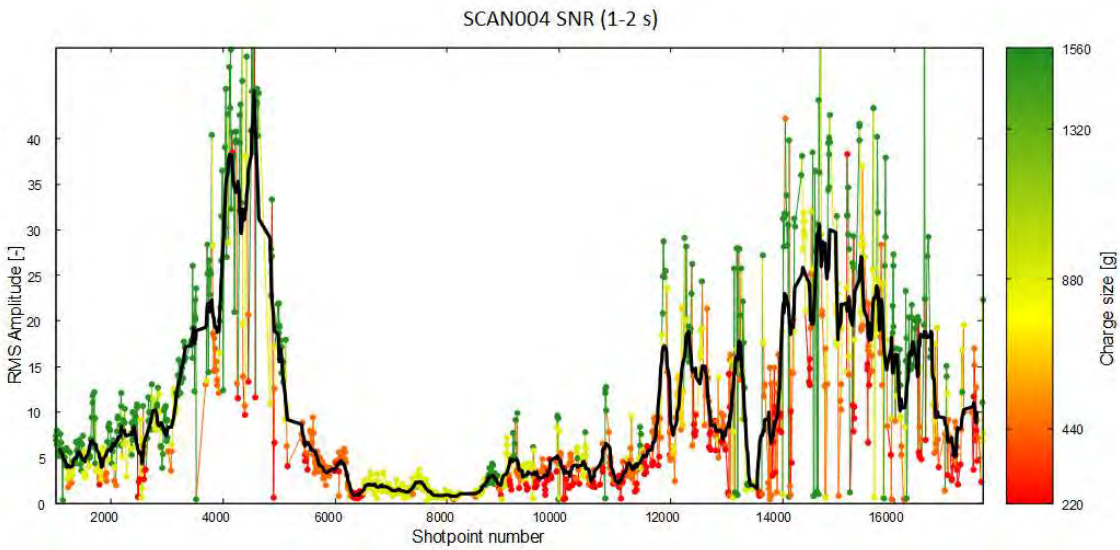



*Figure 33: SNR (1-2 s) per shotpoint. Color indicates charge size. Left=N, Right=S.*

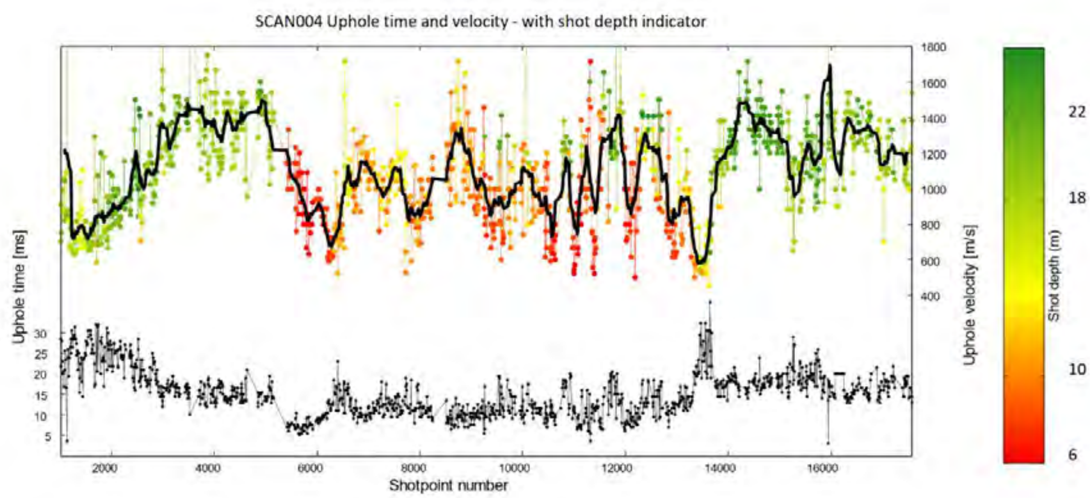



*Figure 34: SCAN004 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=N, Right=S.*

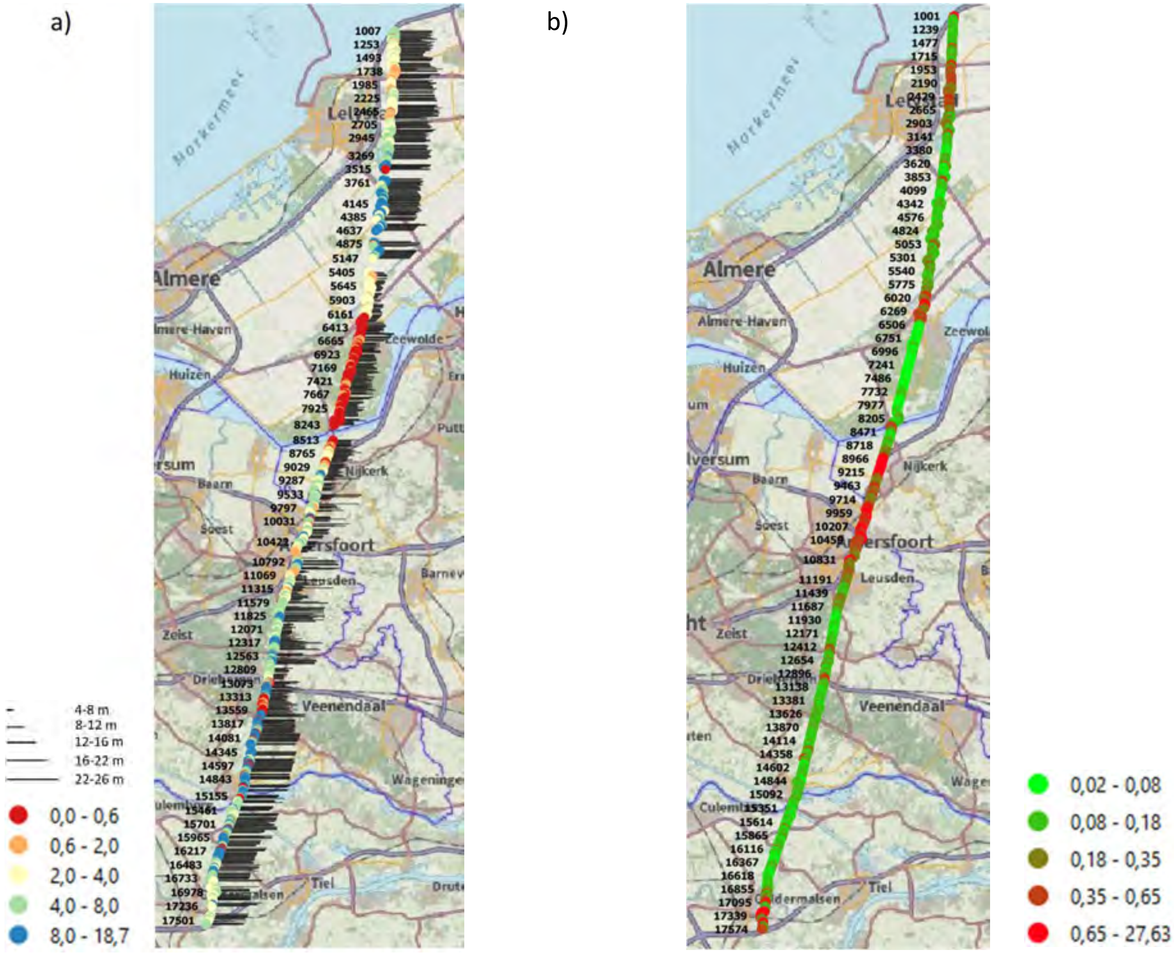



*Figure 35: Map view of SCAN004 a) Signal amplitudes (0-1s) with shot depth indicators and shotpoint numbering and b) average RMS noise amplitudes per receiver station*

**Receiver domain: Noise**

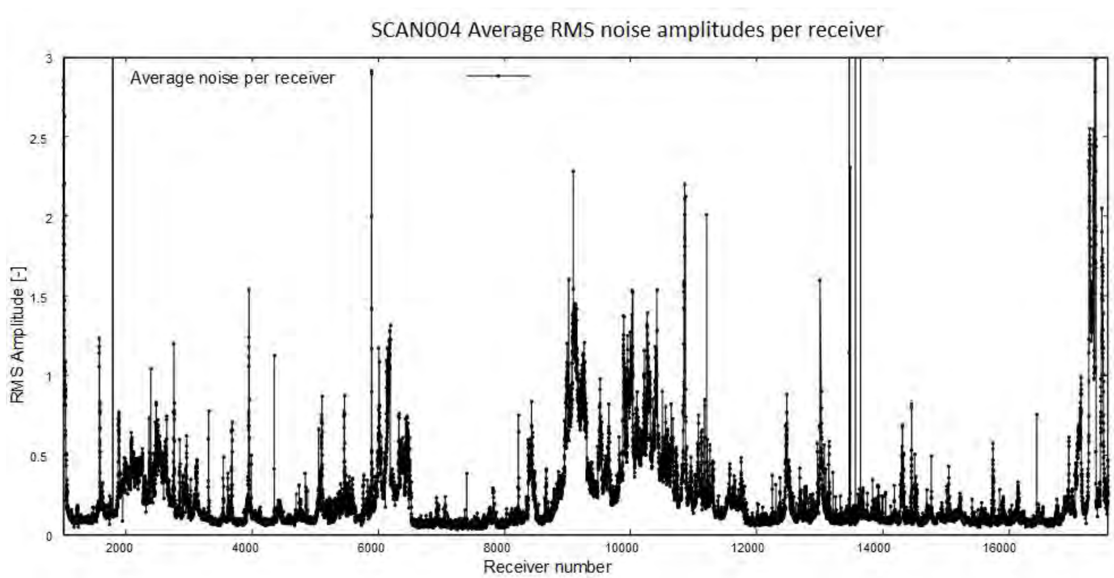



*Figure 36: average RMS noise amplitudes per receiver station for SCAN004. Left=N, Right=S.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.235 | 4.81 | 26.77 | 1.83 | 10.31 | 92 (7.4 %) |

**Discussion and comparison to DUG Fast Track**

Noise amplitudes by shot increase significantly for shots located around the center of the line (shotpoint 10000), this is likely caused by the fact that here the line is located closely to Amersfoort and significant highway traffic. The correlation to windspeed again seems absent if averaged over the whole shot. Noise vs time data shows a large cloud of data during the daytime, shots at night have a lower average noise amplitude.

Overall, the data quality of SCAN004 is quite good. However, there are several areas of interest for the line. Similar to the SCAN Testline, the Southern Polder (shotpoint 6100-8500) again has a zone of low signal amplitudes and SNR with high frequency attenuation. This is also visible in the fast track (Figure 34) although quite a lot can be improved through processing. In addition, the area around shotpoint 13500 has significantly lower signal amplitudes and SNR, the is likely caused by the glacial stowed deposits which cause a significant increase in elevation (up to 50 m). The data quality of the fast track is significantly impacted in this area

Uphole velocities vary between 600 m/s and 1600 m/s over the line. The lowest velocities correspond to the shots fired in the glacial stowed deposits around shotpoint 13500.  Shallow shots near the center of the line also record low uphole velocities.

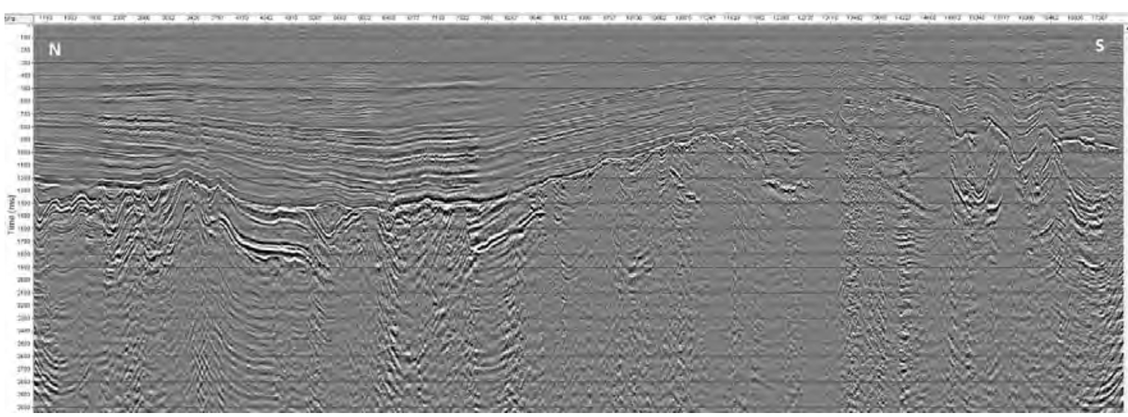



*Figure  37: SCAN004 DUG true amplitude fast track.*

Receivers with the highest recorded noise amplitudes are again located near highways, these also affect a wide area around it – noise amplitudes for receivers near the A28 are heightened up to over 300 m away. Usually this is around 200 m, in this case it is likely higher because the average amount of traffic on the A28 is relatively large. Although the effect can be seen up to 300 m away, the most significant increase is present for receivers within 100 m of the highway. Some other significant noise sources include windmills – e.g. around receiver station 5100, 5450 and 5900 – industry, and train tracks. These sources however don't affect a very wide area.

## SCAN005

SCAN005 was acquired in December 2019 and January 2020. The line runs from near Putten to the South of Nijmegen (North to South) and is 60.01 km in length.

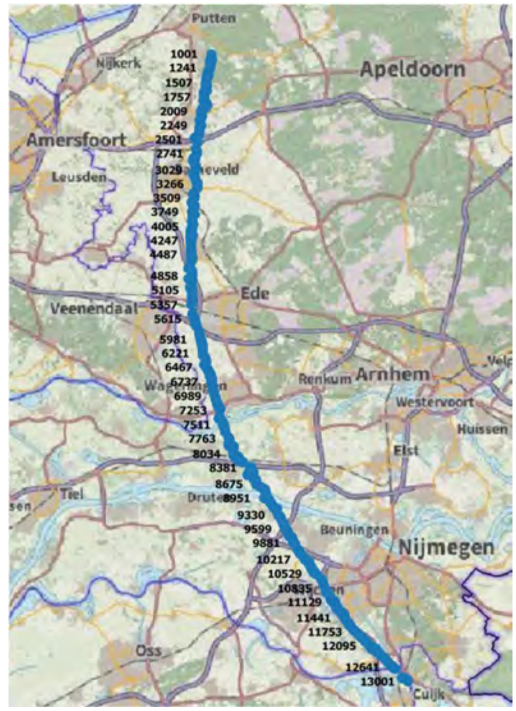



*Figure 38: SCAN005 location and numbering*

**Shot domain: Noise**

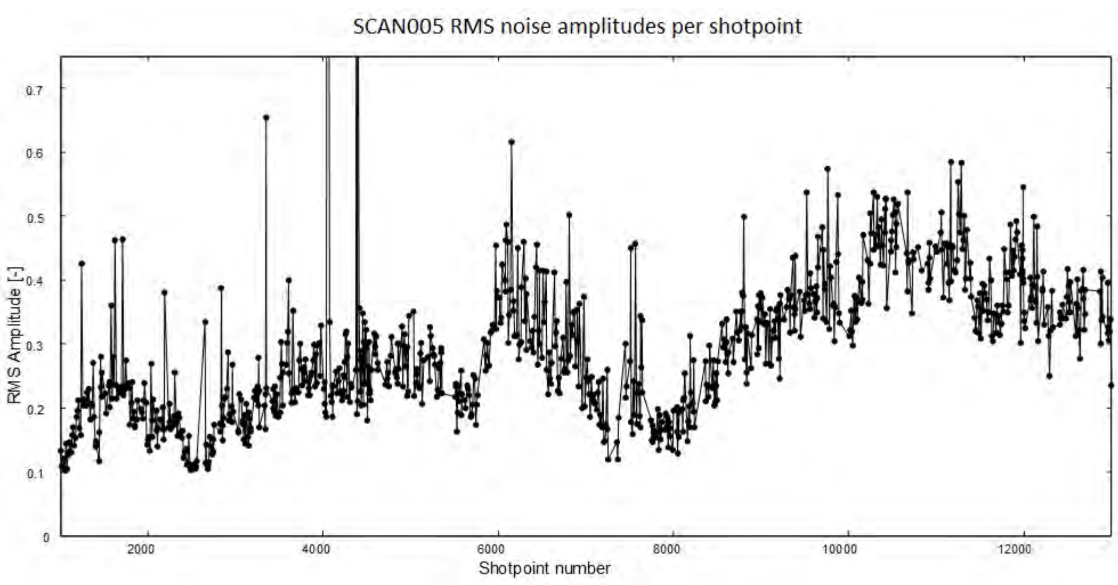



*Figure 39: SCAN005 Noise amplitudes per shotpoint. Left=North, Right=South.*

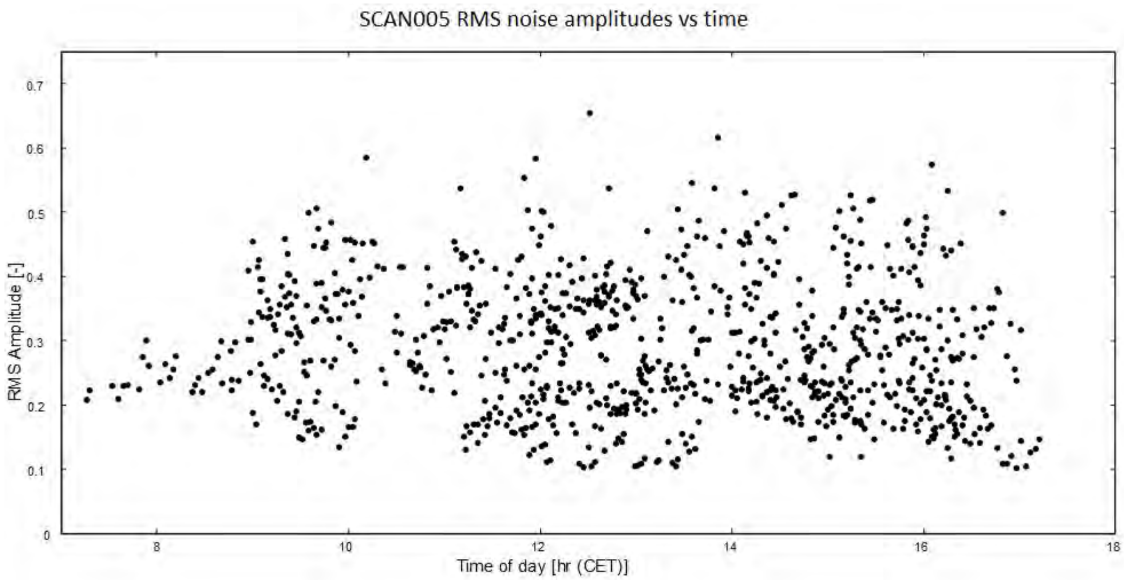
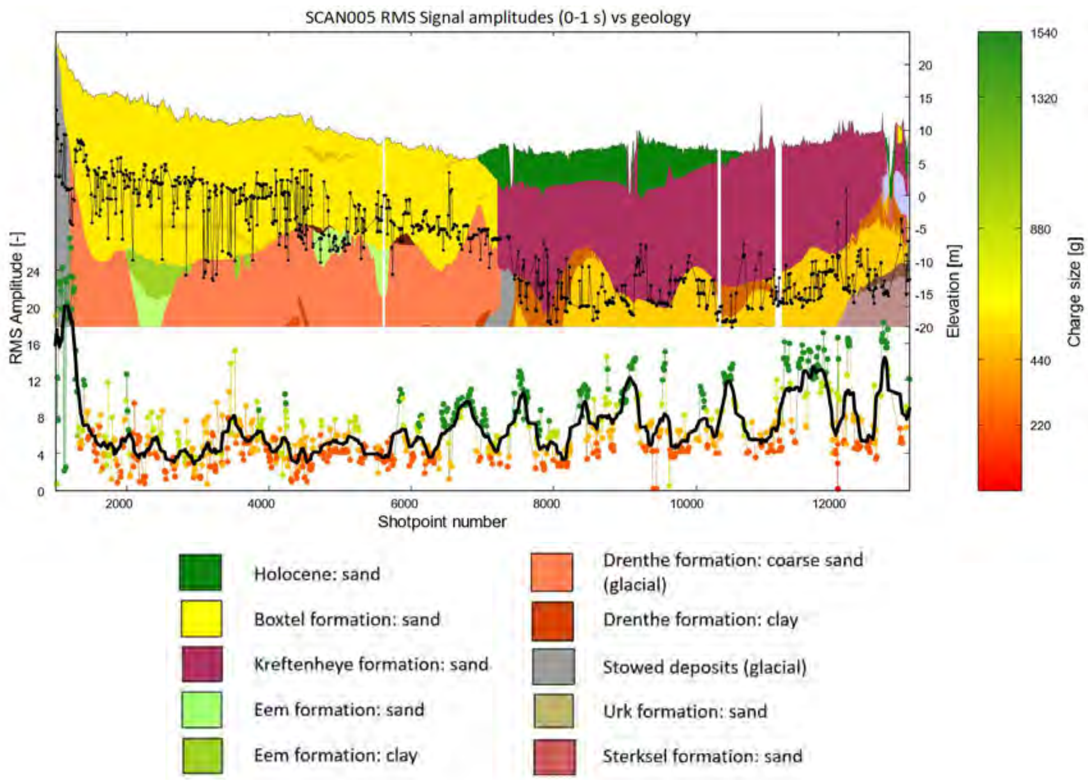



*Figure 40: SCAN005 Noise amplitudes by time of day.*

**Shot domain: Signal**

a)




b)

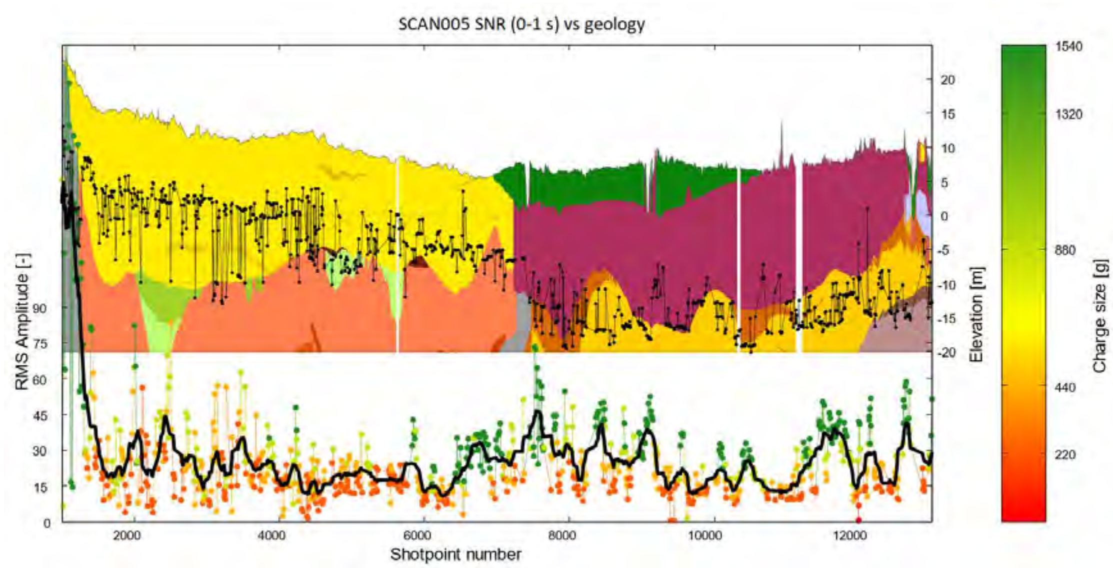



*Figure 41: SCAN005 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in.*

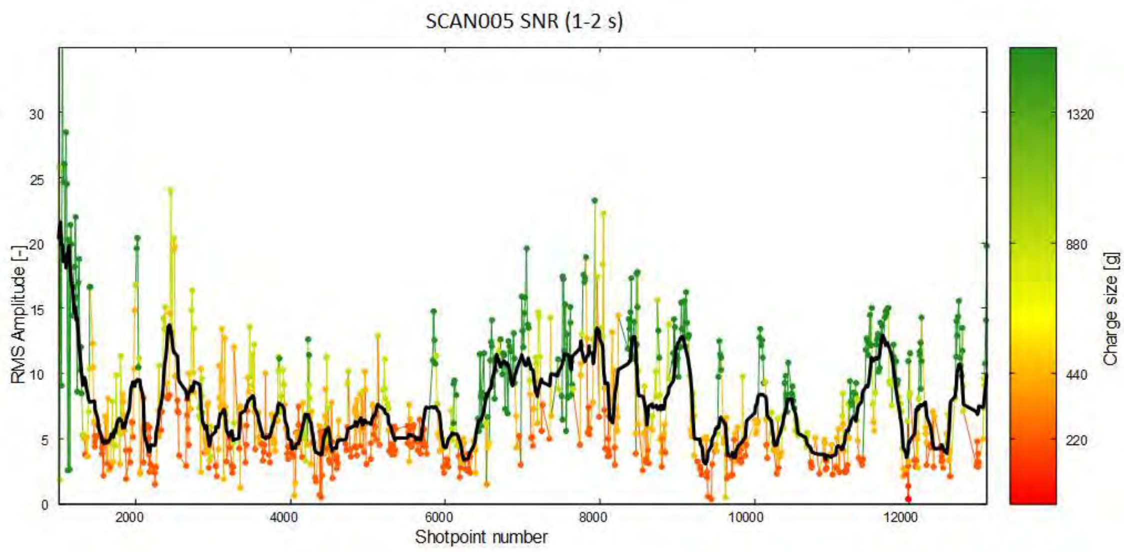



*Figure 42: SCAN005 SNR (1-2 s) per shotpoint. Color indicates charge size. Left=N, Right=S.*

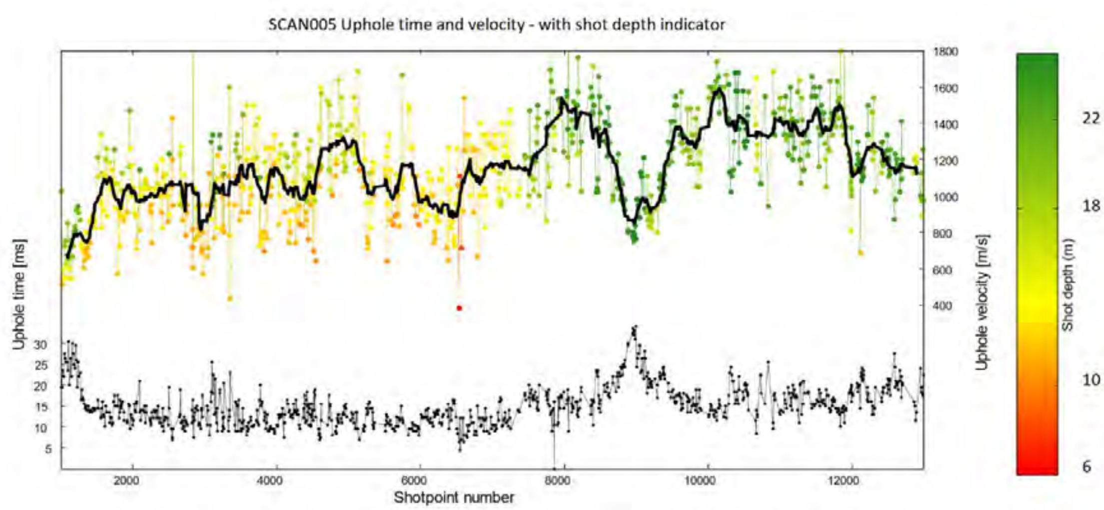



*Figure 43: SCAN005 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=N, Right=S.*

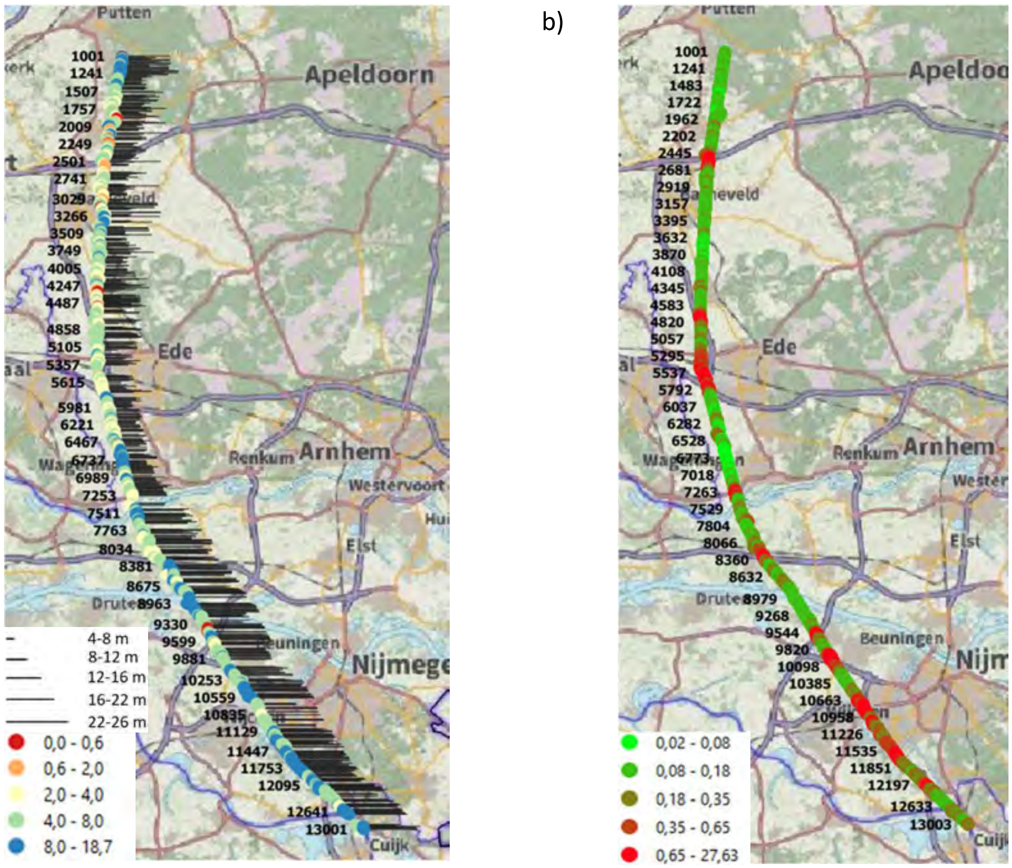



*Figure 44: Map view of SCAN005 a) Signal amplitudes (0-1s) with shot depth indicators and shotpoint numbering and b) average RMS noise amplitudes per receiver station*

**Receiver domain: Noise**

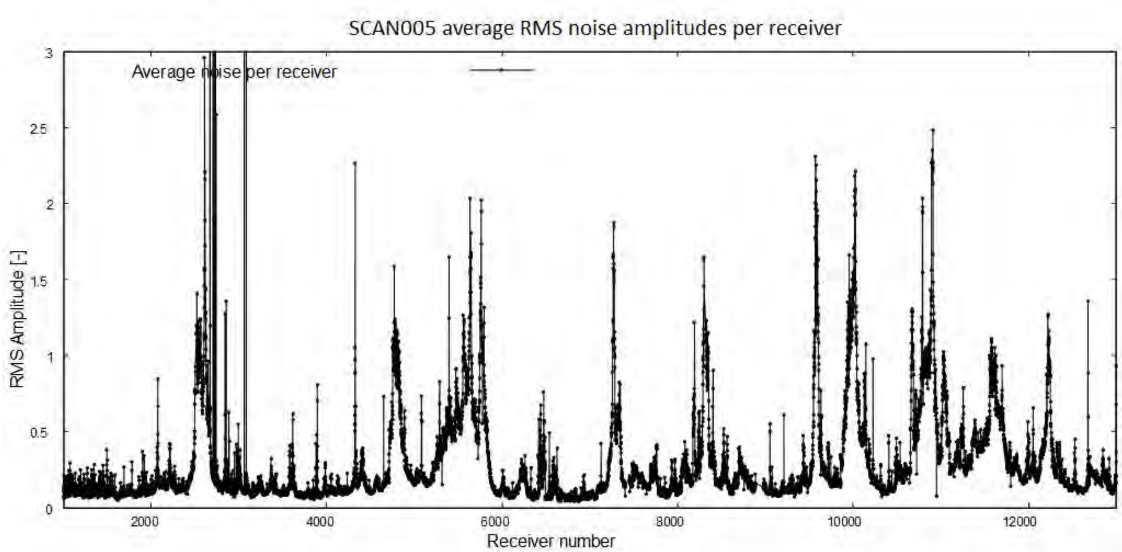



*Figure 45: average RMS noise amplitudes per receiver station for SCAN005. Left=N, Right=S.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.295 | 6.95 | 26.46 | 2.03 | 7.51 | 5 (0.6 %) |

**Discussion and comparison to DUG Fast Track**

The average noise amplitude for line 5 is slightly higher when compared to the earlier lines.

Line 5 has significantly fewer weak shots compared to the other lines. Shots on the Northern side of the line were taken at shallower depth and with lower charge sizes as shots on the Southern side of the line.

The uphole velocity varies between 800 m/s and 1600 m/s over the line, with lower velocities generally on the Northern side of the line. Striking is the presence of a dip in the uphole velocities around shotpoint 9000. It is hard to correlate this to the near surface geology data from REGIS II.

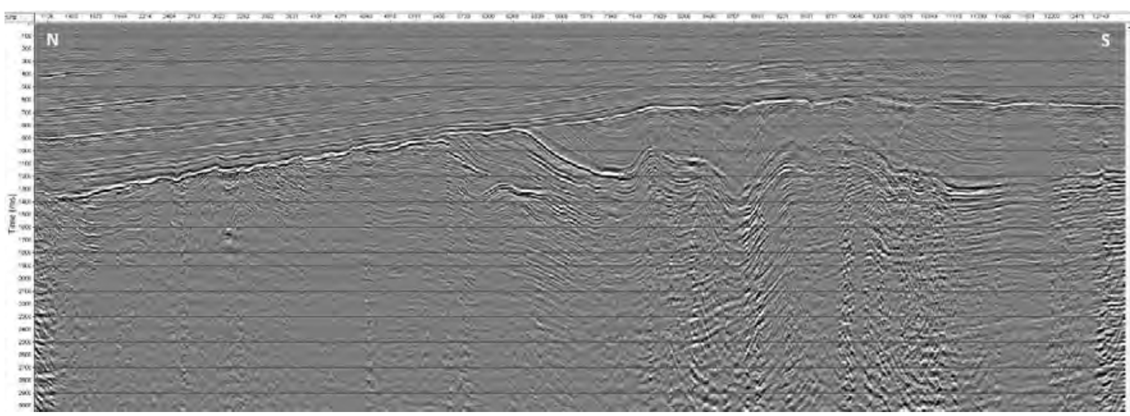



*Figure 46: SCAN005 DUG true amplitude fast track*

The highest average noise amplitudes are again measured by receivers near highways, other main roads and train tracks.

## URKM006

Line 6 is a shorter line, it is 20 km in length and was acquired in January 2020. It runs from the Southwest towards the Northeast along the Eastern side of Nijmegen.

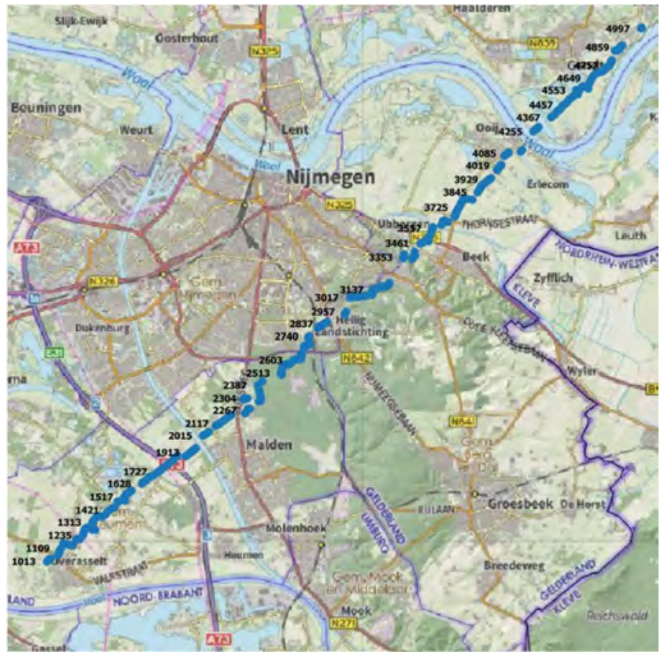



*Figure 47: Line 6 location and numbering*

**Shot domain: Noise**

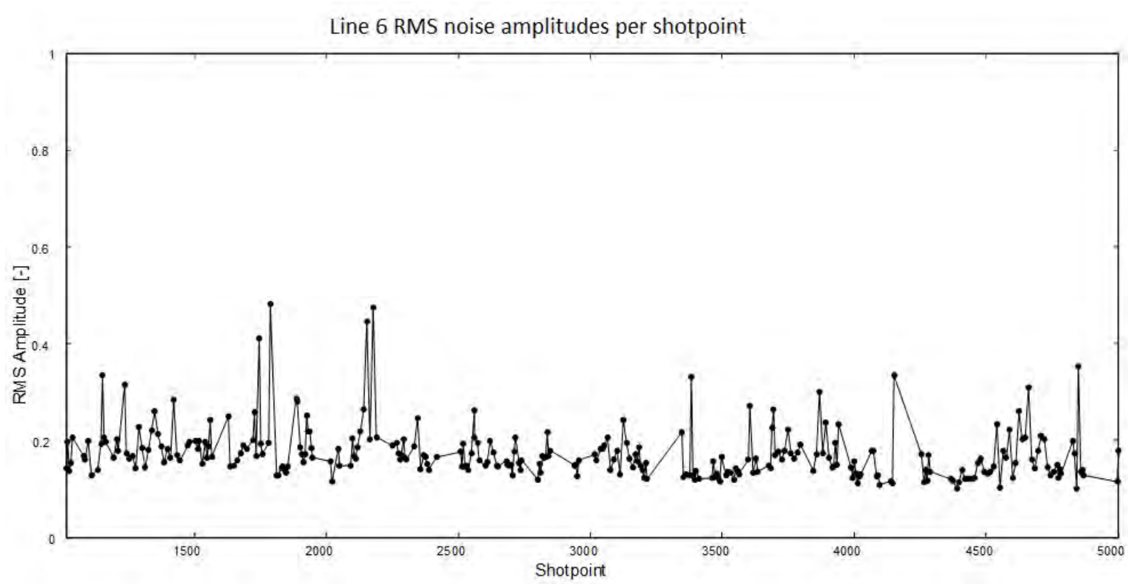



*Figure 48: Line 6 Noise amplitudes per shotpoint. Left=Southwest, Right=Northeast.*

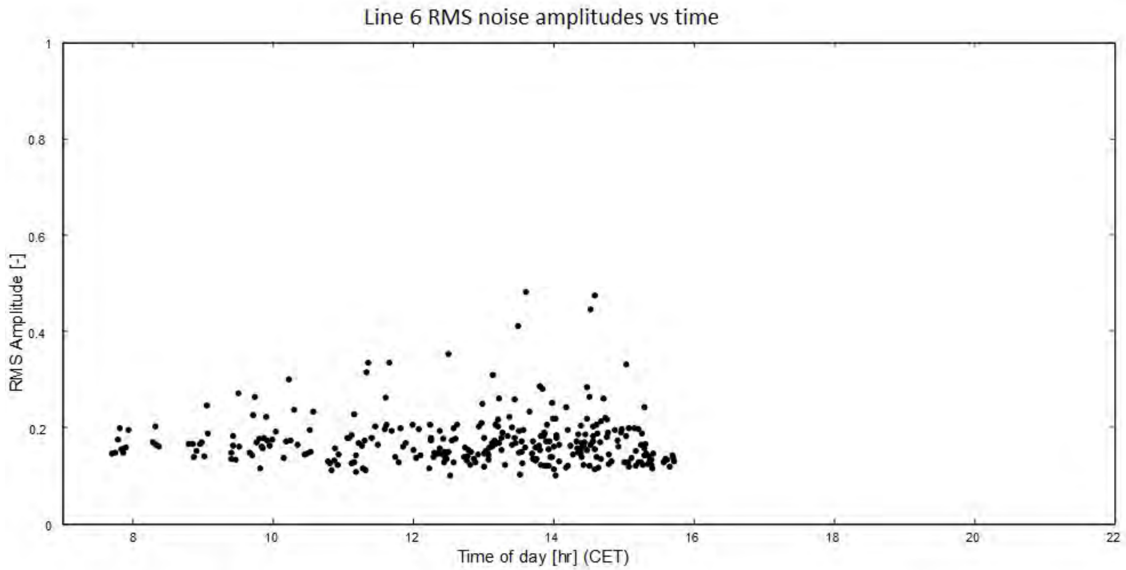
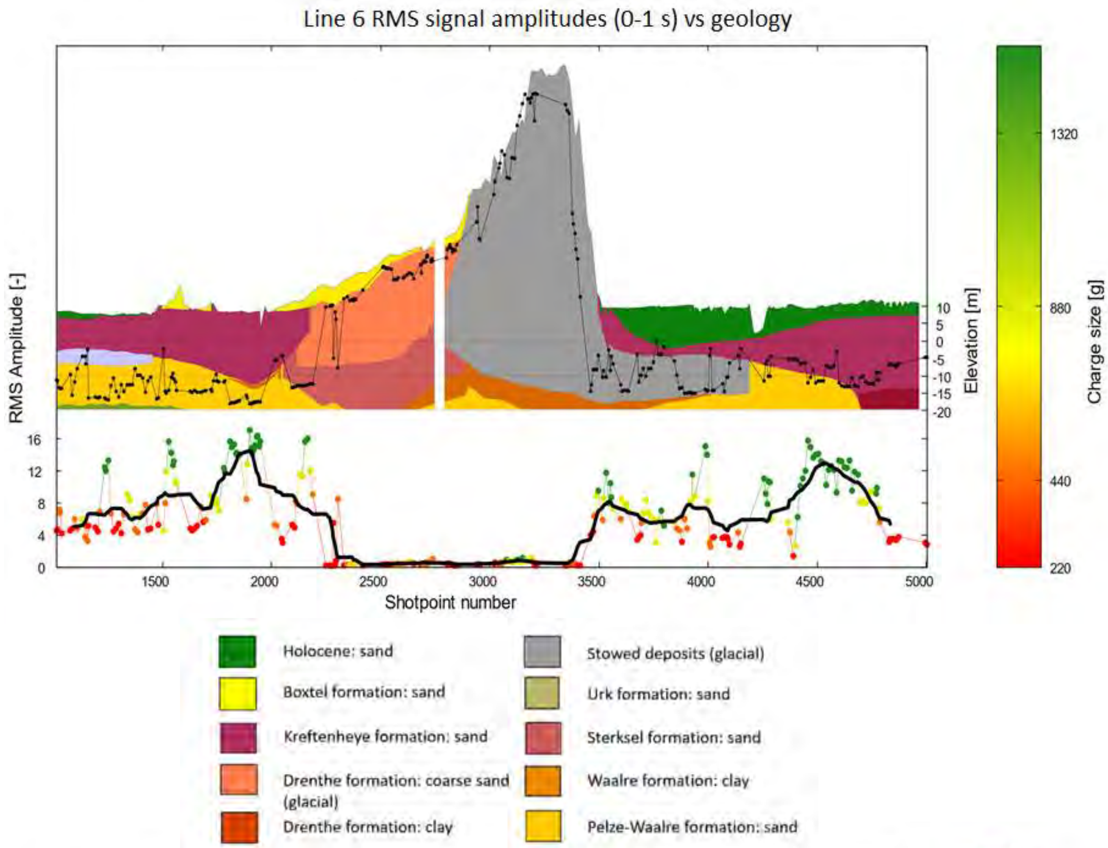



*Figure 49: Line 6 RMS noise amplitudes vs time. Left=Southwest, Right=Northeast.*

**Shot domain: Signal**

a)




b)

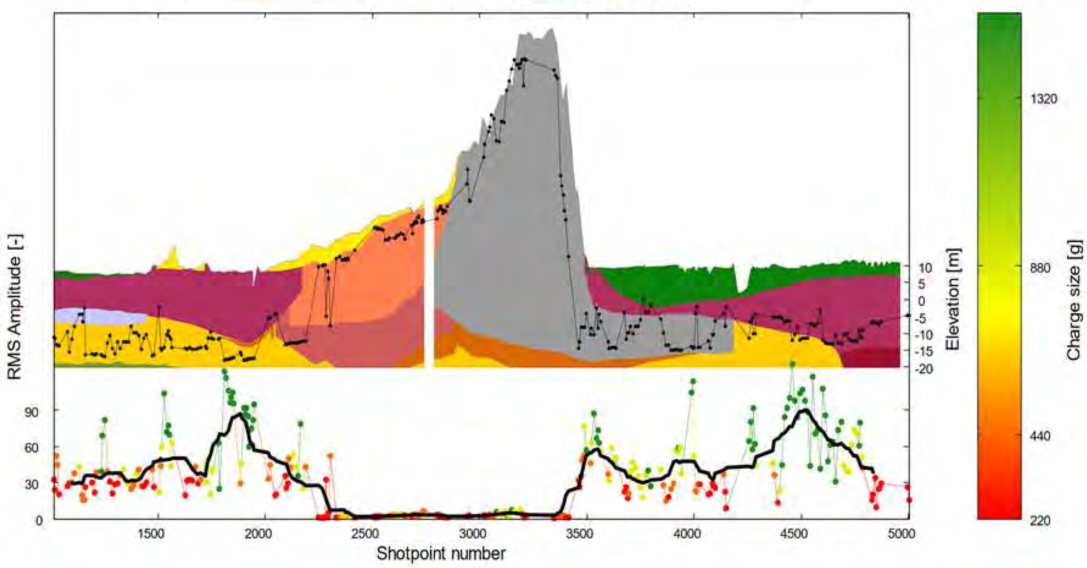



*Figure 50: Line 6 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in. Left=Southwest, Right=Northeast.*

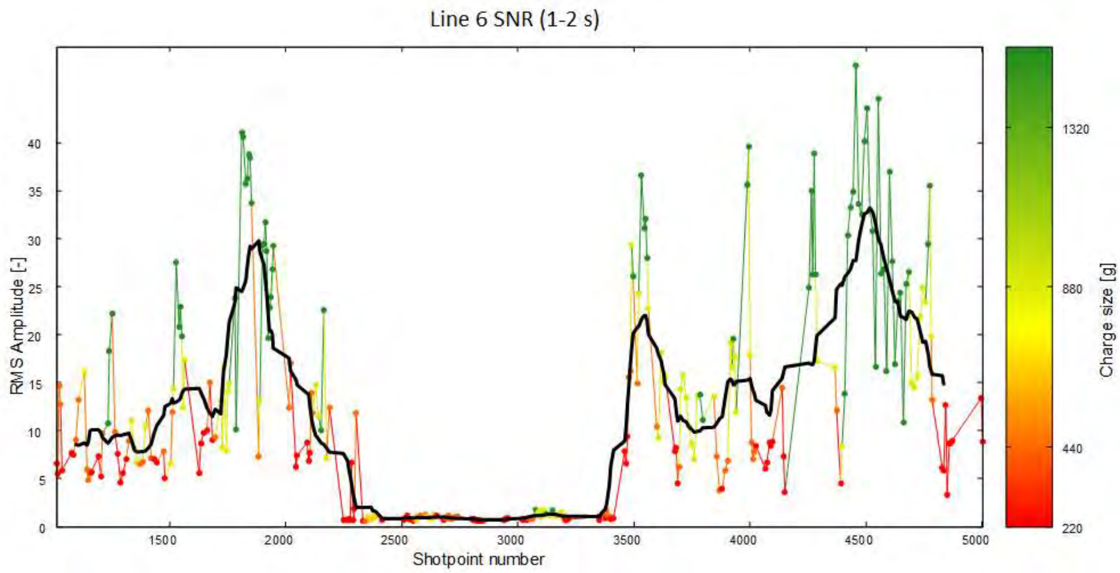



*Figure 51: Line 6 SNR (1-2 s) per shotpont. Color indicates charge size. Left=Southwest, Right=Northeast.*

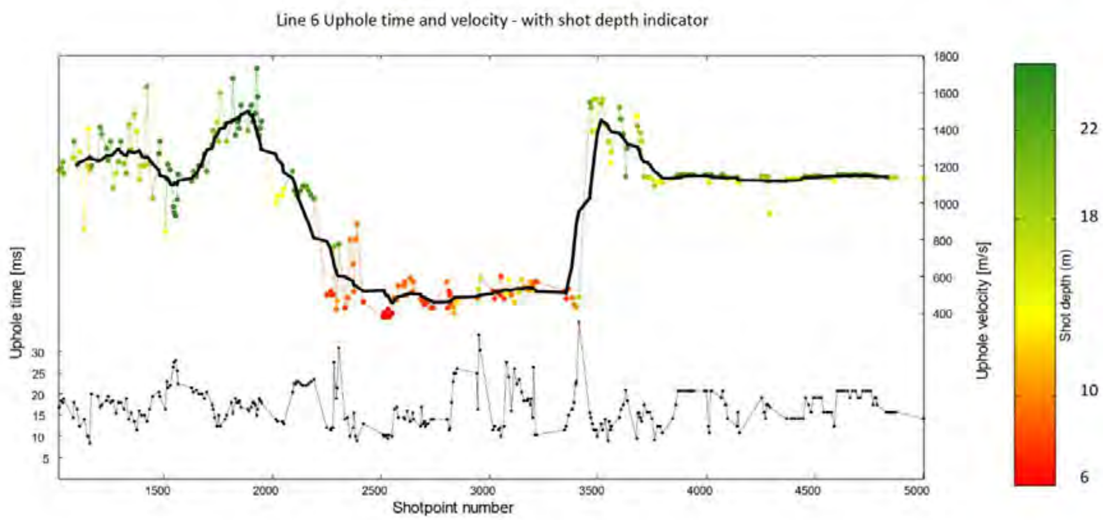
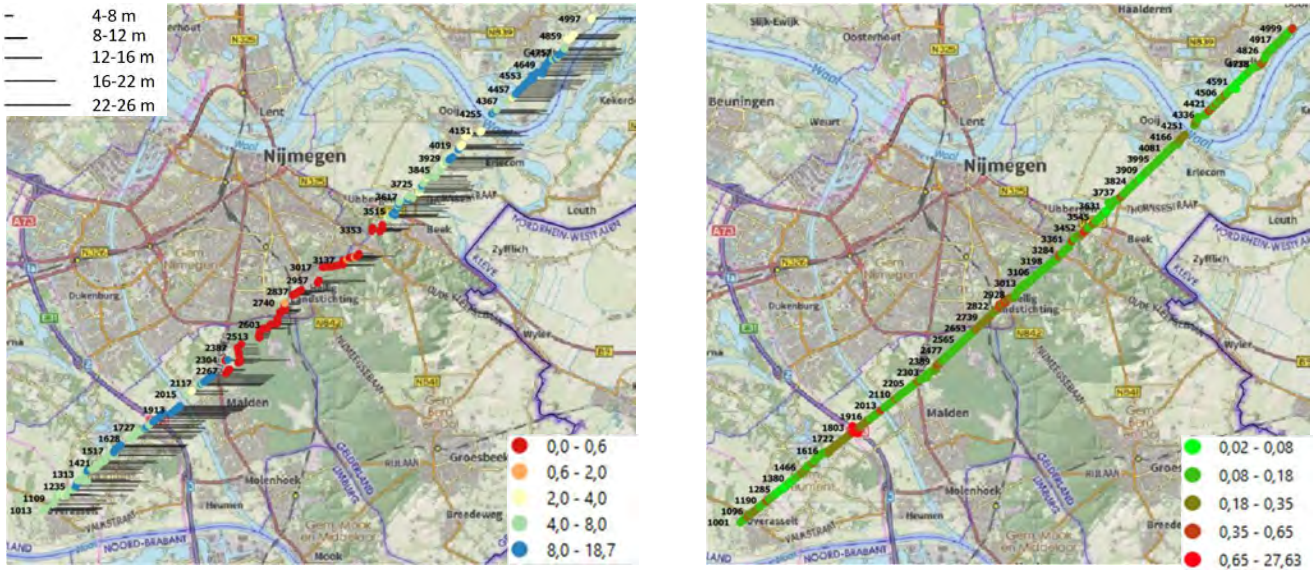



*Figure 52: Line 6 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=Southwest, Right=Northeast.*




*a)* *b)*

*Figure 53: Map view of Line 6 a) Signal amplitudes (0-1s) with shot depth indicators and shotpoint numbering and b) average RMS noise amplitudes per receiver station*

**Receiver domain: Noise**

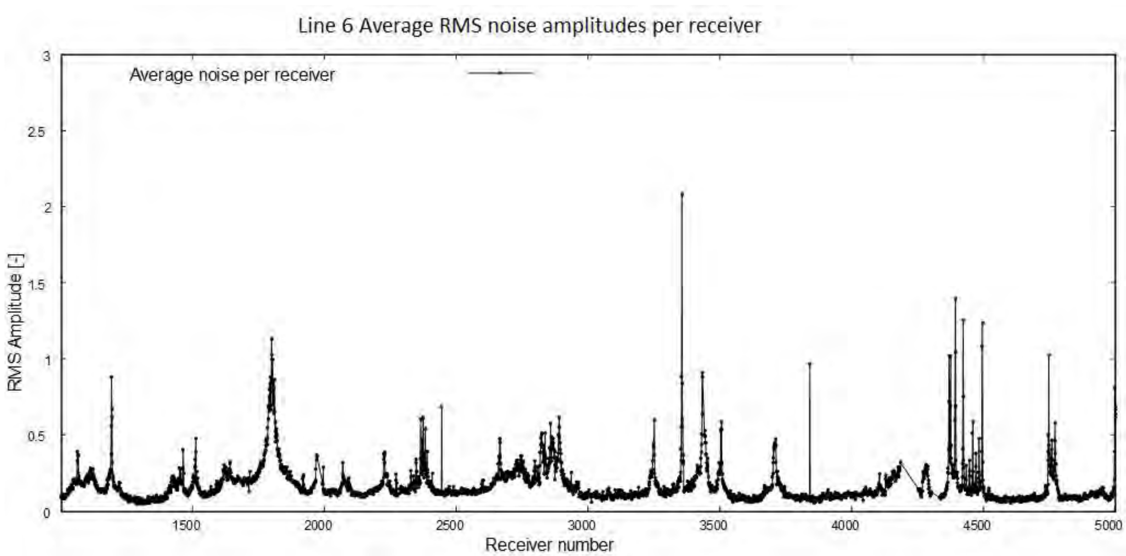



*Figure 54: average RMS noise amplitudes per receiver station for Line 6. Left=Southwest, Right=Northeast.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.174 | 5.87 | 35.57 | 2.08 | 11.87 | 69 (23. 6%) |

**Discussion and comparison to DUG Fast Track**

Line 6 is in general less noisy, with an average noise amplitude of 0.174.

For line 6 the effect of the near surface geology on the data quality is obvious, signal amplitudes drop off completely near the center of the line. Here the geology changes to the Drenthe formation/stowed glacial deposits, this is combined with an increase in elevation. This effect is also clearly visible in the fast track where the quality of the data is reduced between shotpoints 2200-3400. The uphole velocity is around 1100 m/s to 1400 m/s for most of the line, for shots in the center of the line this is reduced to about 500 m/s.

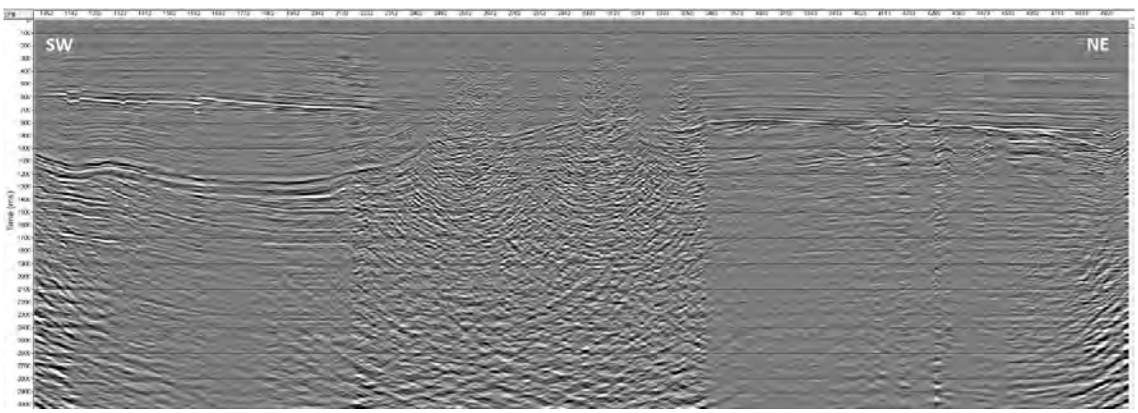



*Figure 55: Line 6 DUG true amplitude fast track*

The highest recorded noise amplitudes per receiver for the line are again clustered around roads and a train track.

## URKM007

Line 7 is another short line, it is 18 km in length and was acquired in January 2020. The line runs from the Southeast towards the Northwest and is located on the Northern side of Nijmegen.


*Figure 56: Line 7 location and numbering*

**Shot domain: Noise**

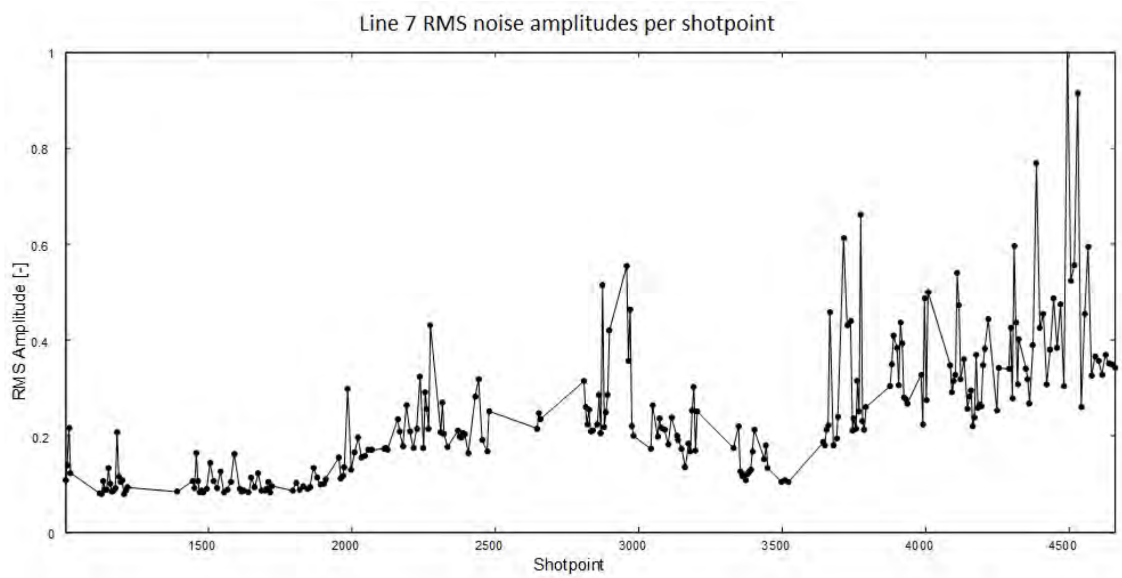



*Figure 57: Line 7 Noise amplitudes per shotpoint. Left=Southeast, Right=Northwest.*

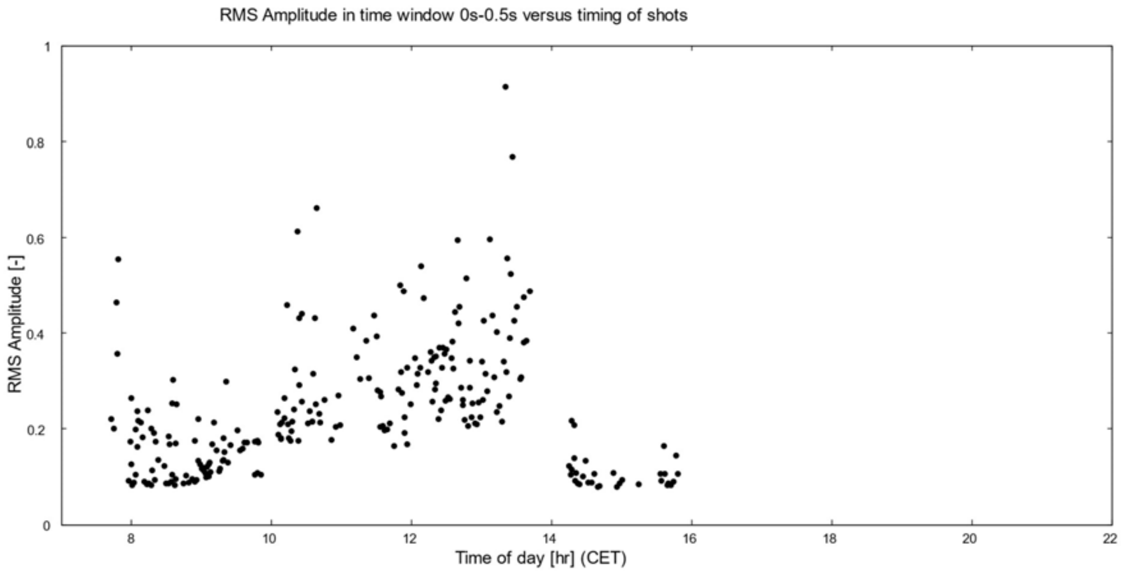



*Figure 58: Line 7 RMS noise amplitudes vs time*

**Shot domain: Signal**

a)

b)

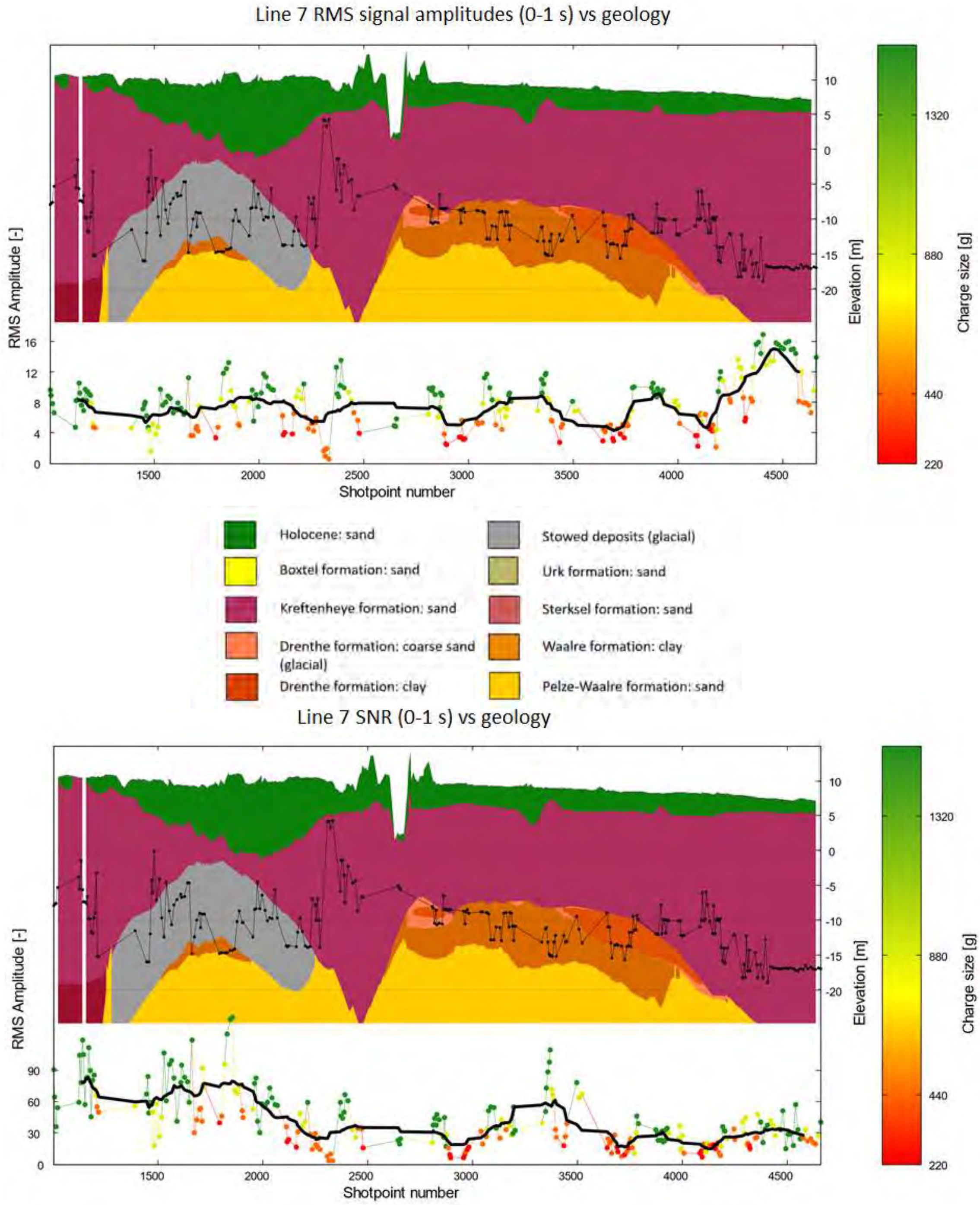



*Figure 59: Line 7 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in.*

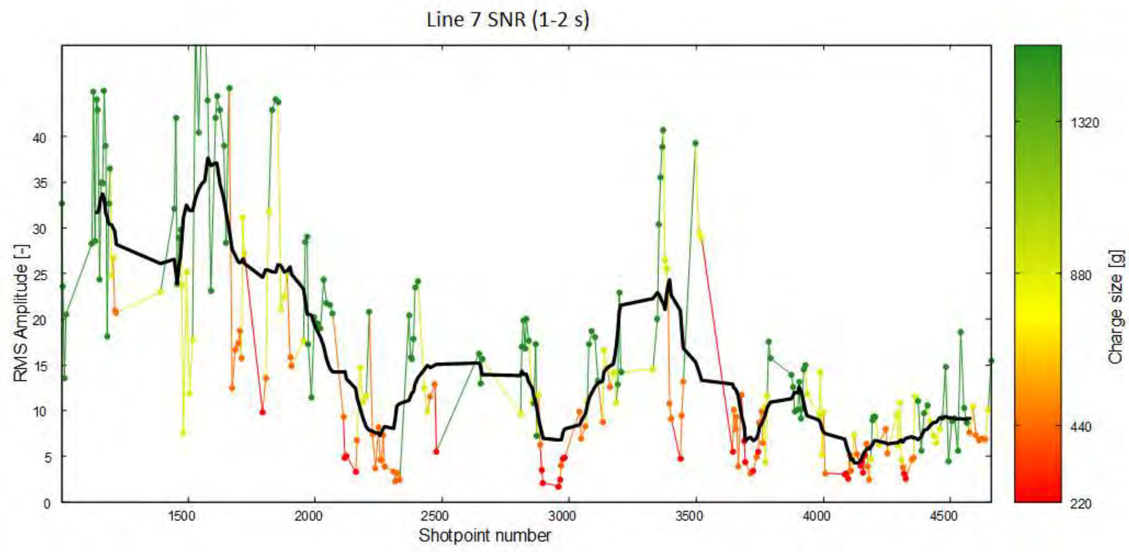



*Figure 60: Line 7 SNR (1-2 s) per shotpoint. Color indicates charge size Left=Southeast, Right=Northwest.*

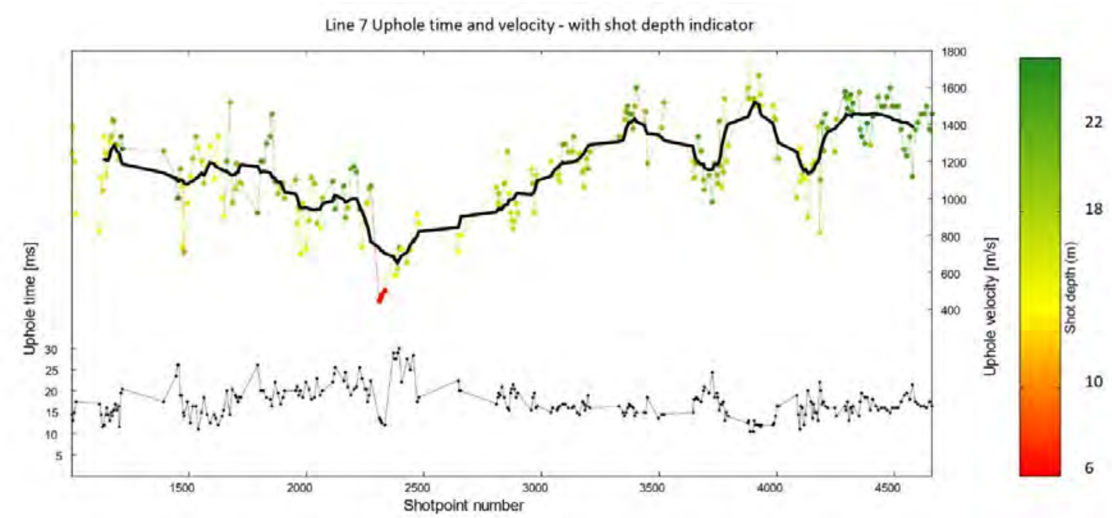



*Figure 61: Line 7 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth.*

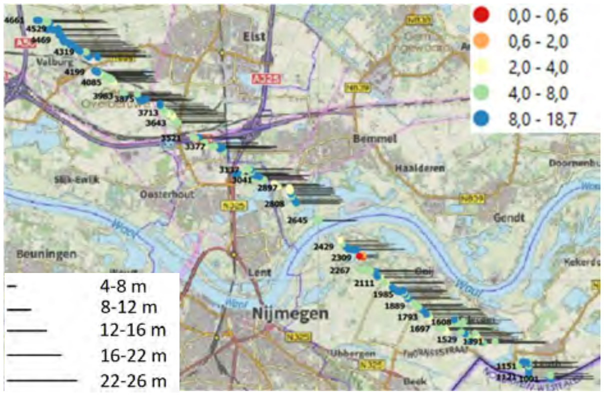




*Figure 62: Map view of Line 7 a) Signal amplitudes (0-1s) with shot depth indicators and shotpoint numbering and b) average RMS noise amplitudes per receiver station*

**Receiver domain: Noise**

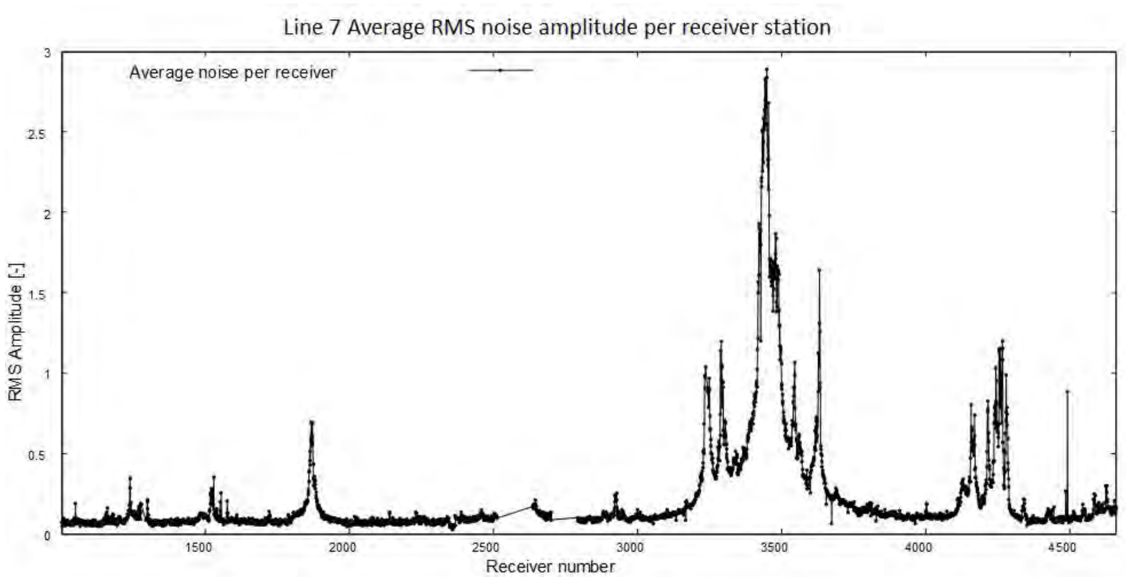



*Figure 63: average RMS noise amplitudes per receiver station for Line 7. Left=Southeast, Right=Northwest.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.242 | 7.70 | 41.64 | 2.754 | 15.76 | 1 (0.4 %) |

**Discussion and comparison to DUG Fast Track**

Line 7 has almost no weak shots and very high signal amplitudes. With 15.76 it has the highest SNR for data between 1-2 s.

The uphole velocity mostly varies between 1000 m/s and 1500 m/s. It is lowest for the shallowest shots – around shotpoint 2400.

There were two gaps in the line near shotpoint 2600 due to the river the Waal, the effect of this can clearly be seen on the fast track (in total ~1480 m or about 24 shots are missing here).

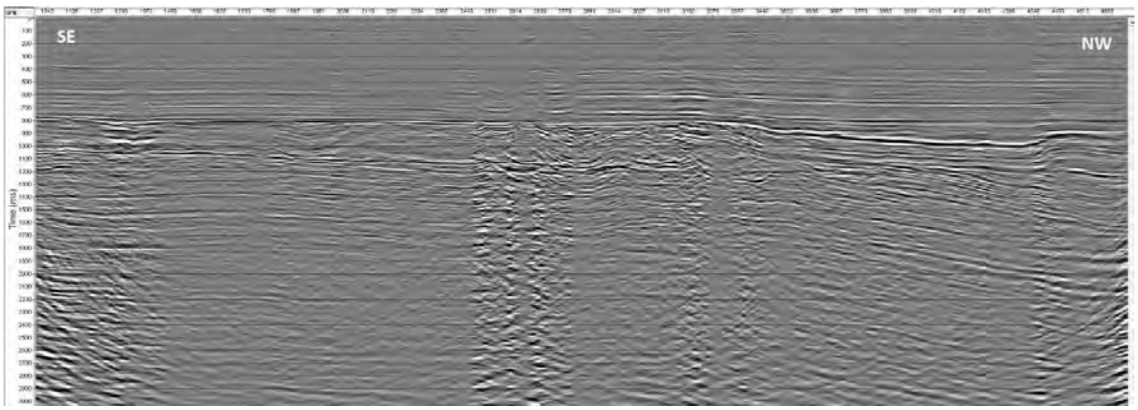



*Figure 64: Line 7 DUG true amplitude fast track*

The highest noise levels per receiver are recorded around shotpoint 3500, where the line passes a highway, another main road, two train tracks and a windmill.

## URKM008

Line 8 is another short line. It is 19 km in length and was acquired in February 2020. The line runs South to North along the Eastern side of Wageningen


*Figure 65: Line 8 location and numbering*

**Shot domain: Noise**

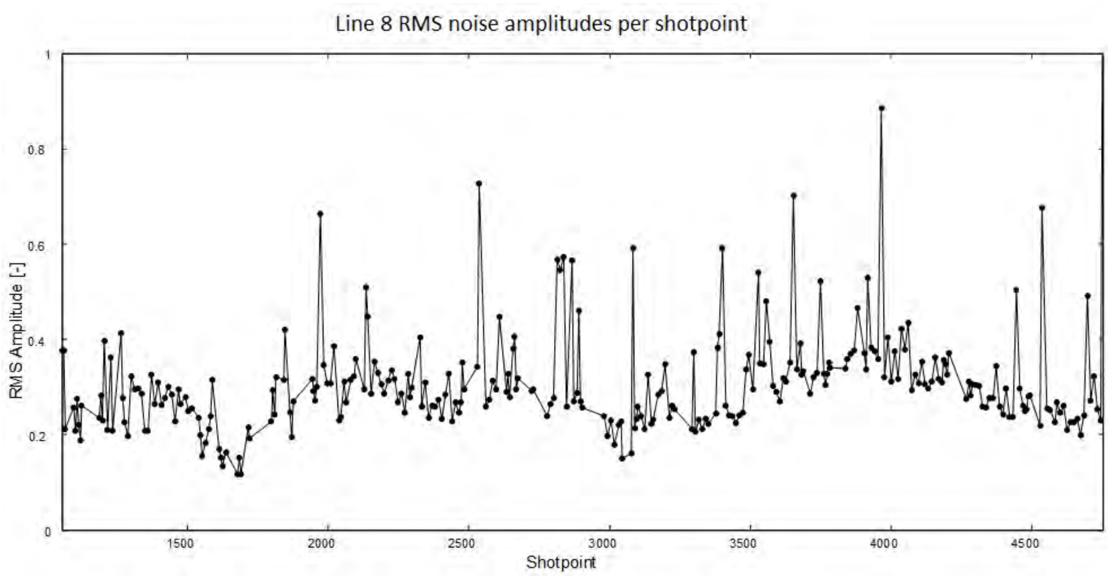



*Figure 66: Line 8 Noise amplitudes per shotpoint. Left=Southwest, Right=Northeast.*

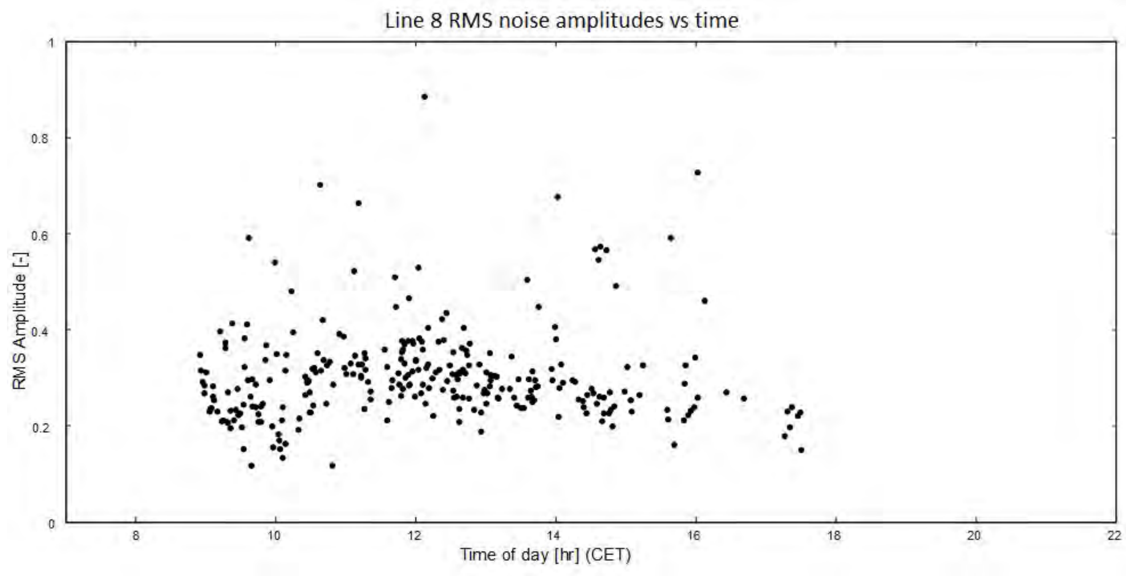
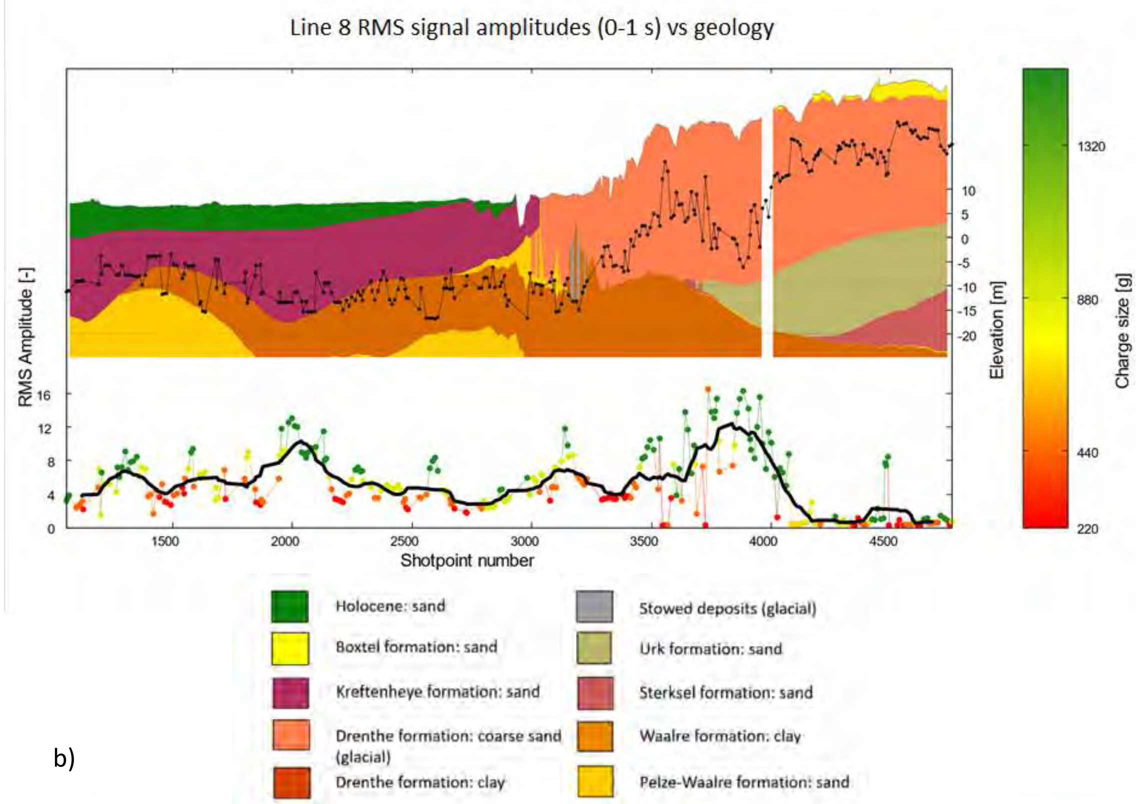



*Figure 67: Line 8 RMS noise amplitudes vs time*

**Shot domain: Signal**

a)




b)

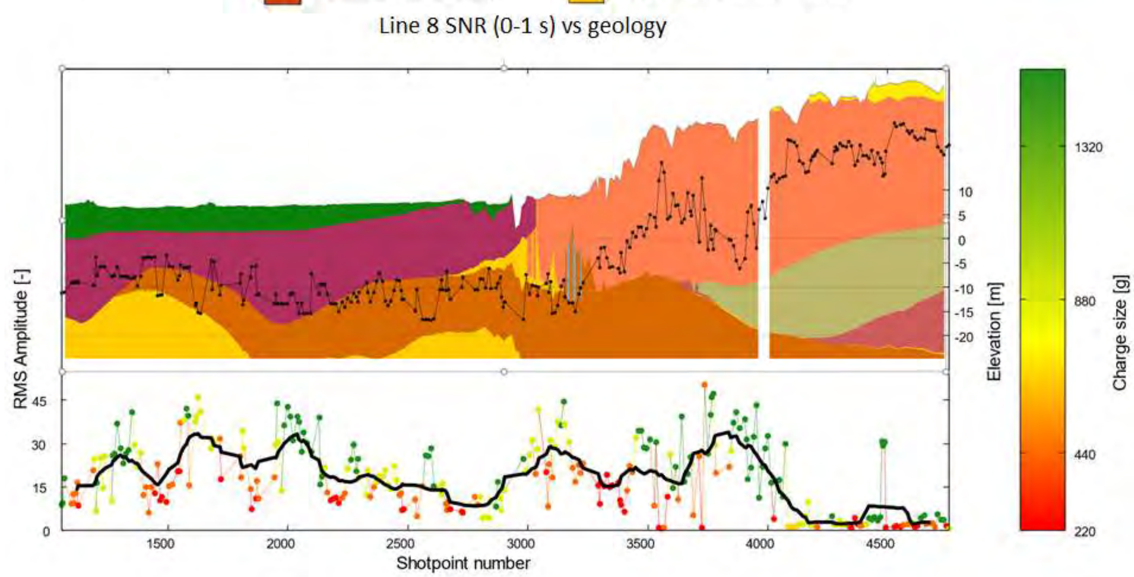



*Figure 68: Line 8 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in. Left=Southwest, Right=Northeast.*

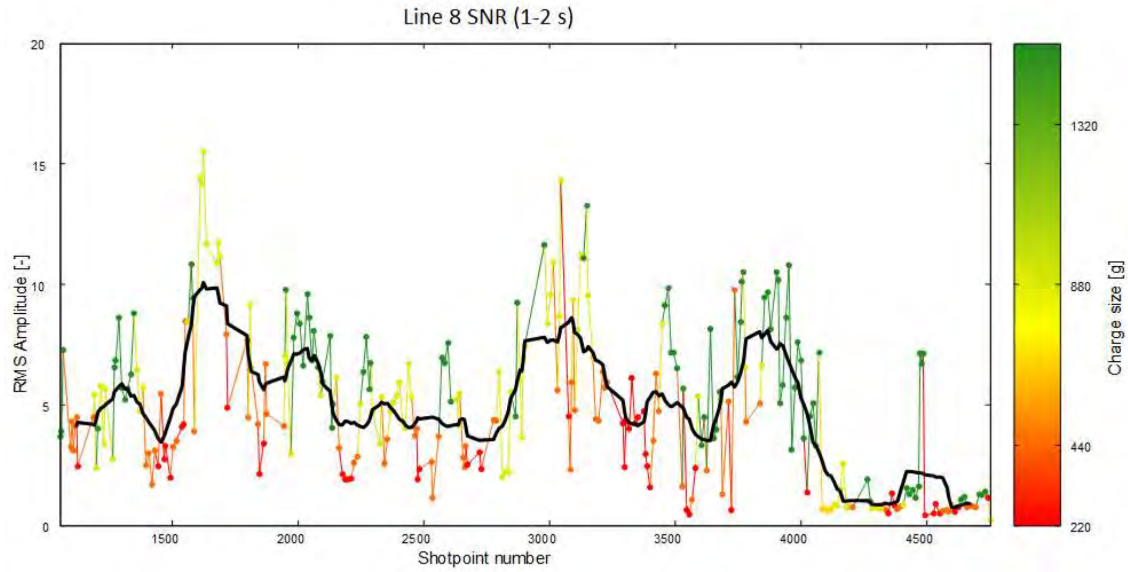



*Figure 69: Line 8 SNR (1-2 s) per shotpoint. Color indicates charge size. Left=Southwest, Right=Northeast.*

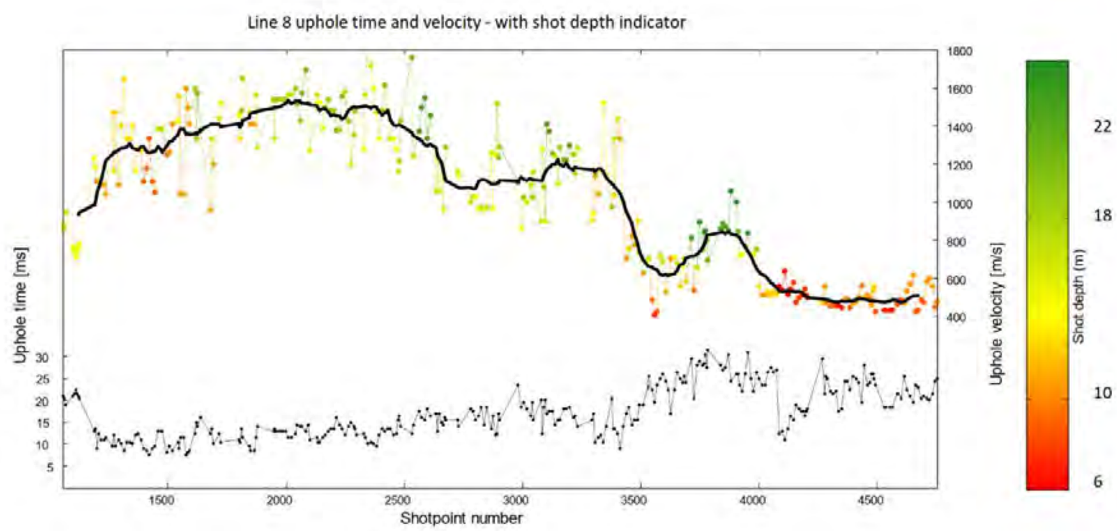



*Figure 70: Line 8 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=Southwest, Right=Northeast.*

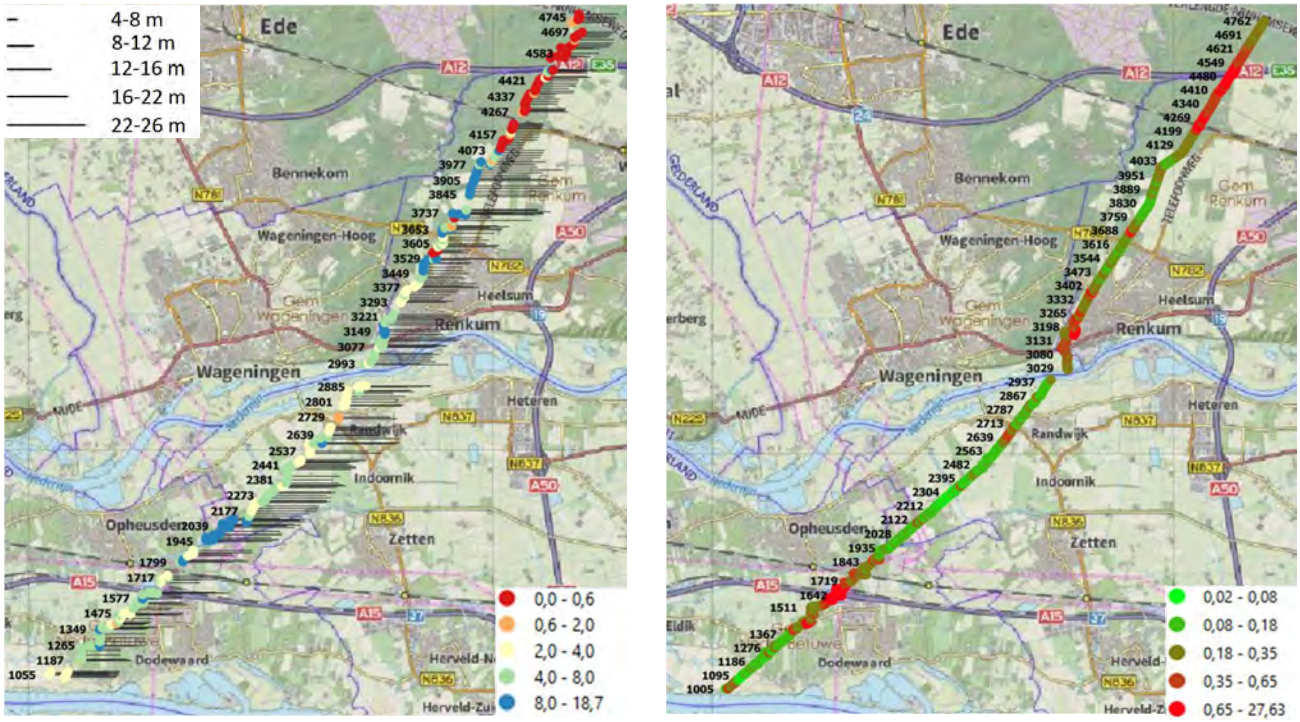



*Figure 71: Map view of Line 8 a) Signal amplitudes (0-1s) with shot depth indicators and shotpoint numbering and b) average RMS noise amplitudes per receiver station*

**Receiver domain: Noise**

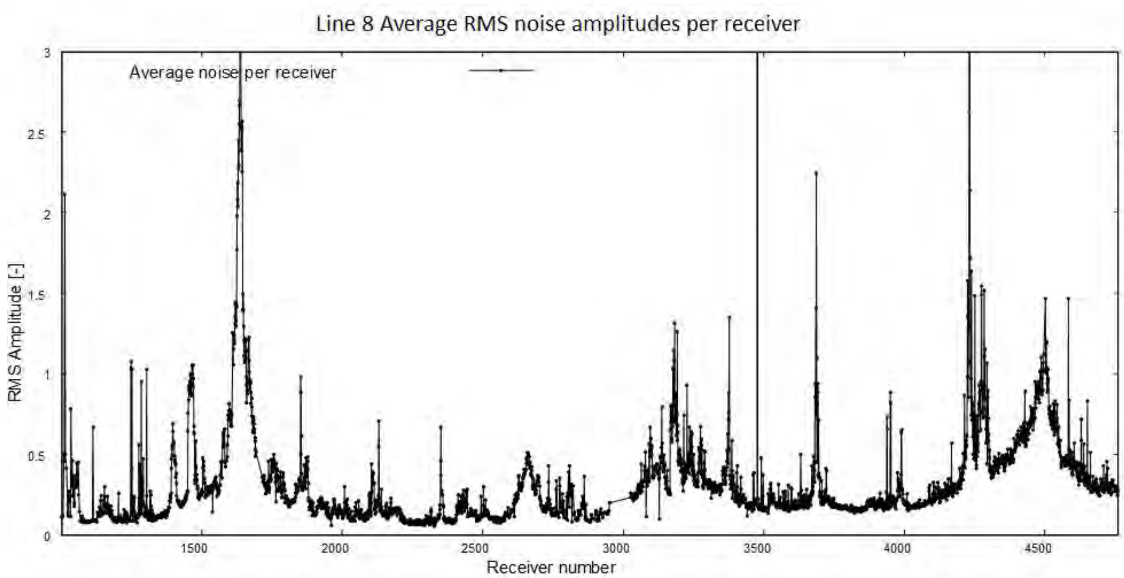



*Figure 72: average RMS noise amplitudes per receiver station for Line 8. Left=Southwest, Right=Northeast.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.309 | 5.11 | 17.73 | 1.36 | 4.79 | 33 (11.5 %) |

**Discussion and comparison to DUG Fast Track**

The average noise amplitude of line 8 is a bit higher than most other lines, with 0.309.

Signal amplitudes drop off on the Northeastern end of the line, here glacial deposits of the Drenthe formation occur and elevation increases. All of the weak shots are clustered around this area. The effect of the lower signal amplitudes and SNR is visible in the DUG fast track.

Uphole velocities are generally 1000 m/s - 1600 m/s for the Southwestern portion of the line. In the Northeastern are the uphole velocity drops off to about 500 m/s. Deeper shots in the Drenthe formation have an uphole velocity around 850 m/s.

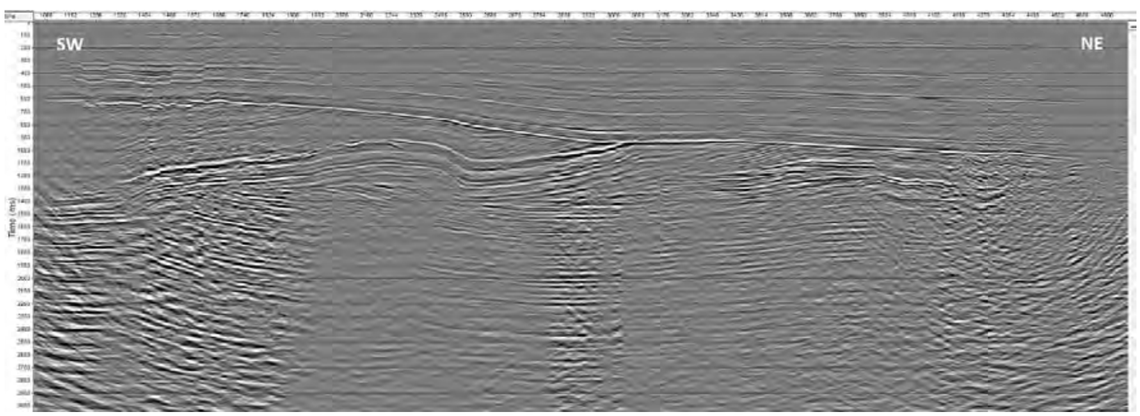



*Figure 73: Line 8 DUG true amplitude fast track*

Highest noise amplitudes are again recorded by receivers near highways: e.g. around receiver station 1650 and 4500. The effect of train tracks around receiver station 4270 is also visible.

## URKM009

Line 9 is 22 km in length and it runs just East of line 8.
The line runs from the Southwest towards the Northeast.

*Figure 74: Line 9 location and numbering*

**Shot domain: Noise**

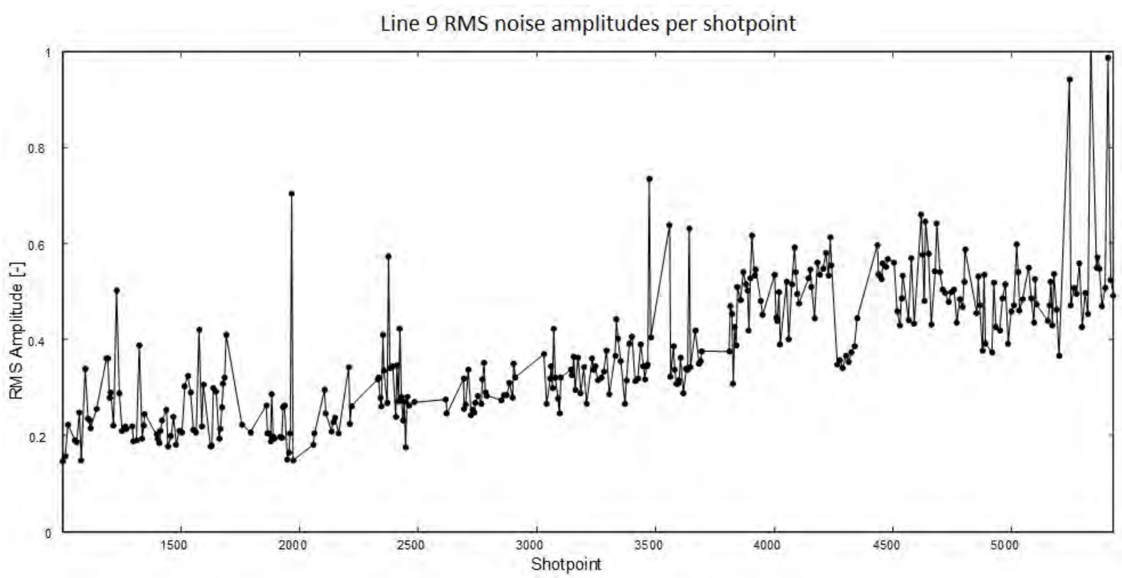
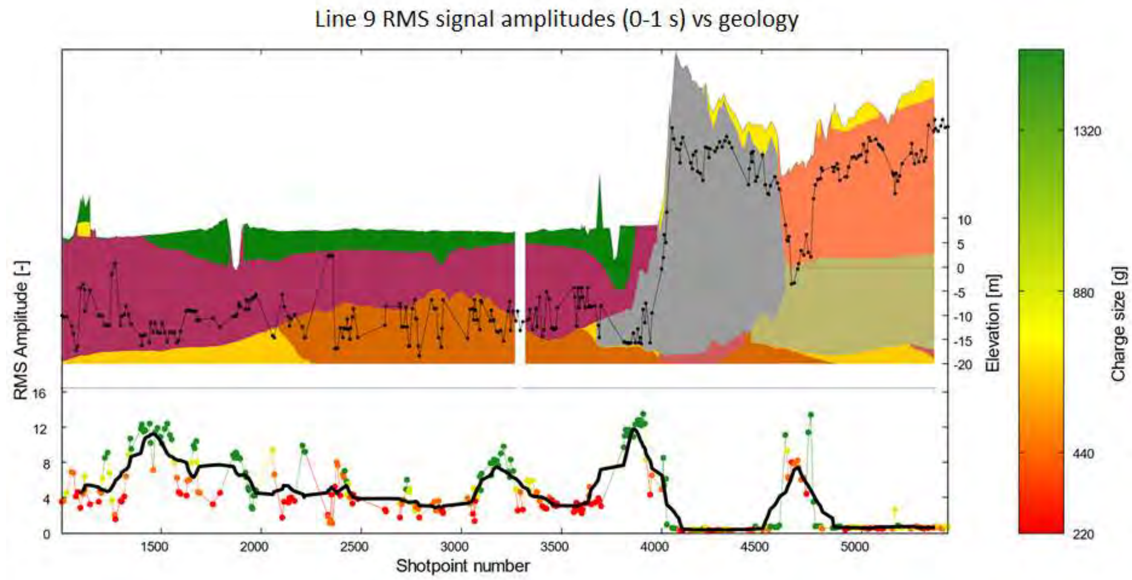



*Figure 75: Line 9 Noise amplitudes per shotpoint. Left=Southwest, Right=Northeast.*

**Shot domain: Signal**

a)





b)

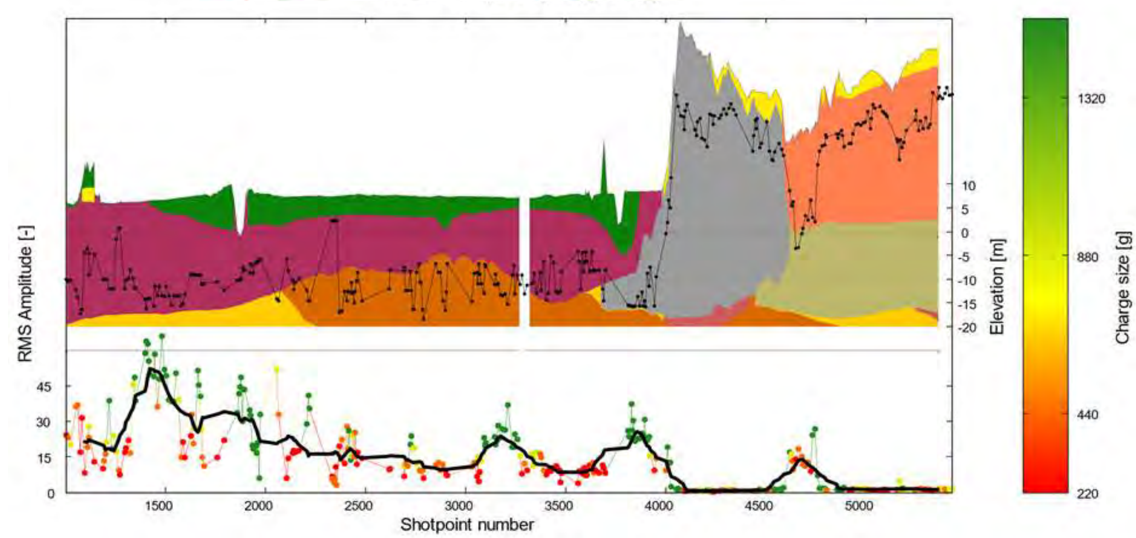



*Figure 76: Line 9 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in. Left=Southwest, Right=Northeast.*

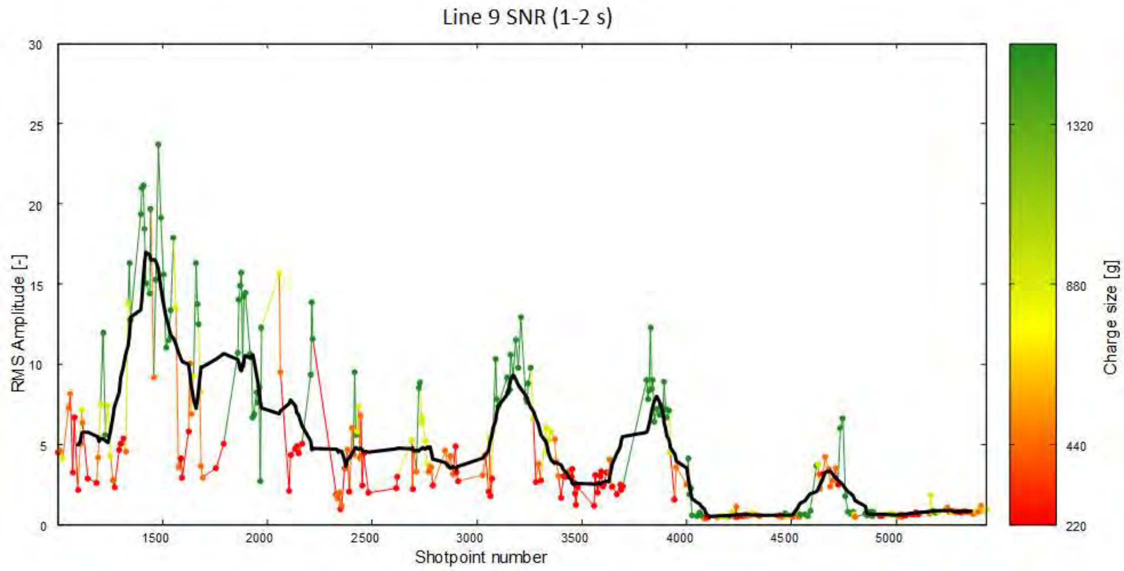



*Figure 77: Line 9 SNR (1-2 s) per shotpoint. Color indicates charge size. Left=Southwest, Right=Northeast.*

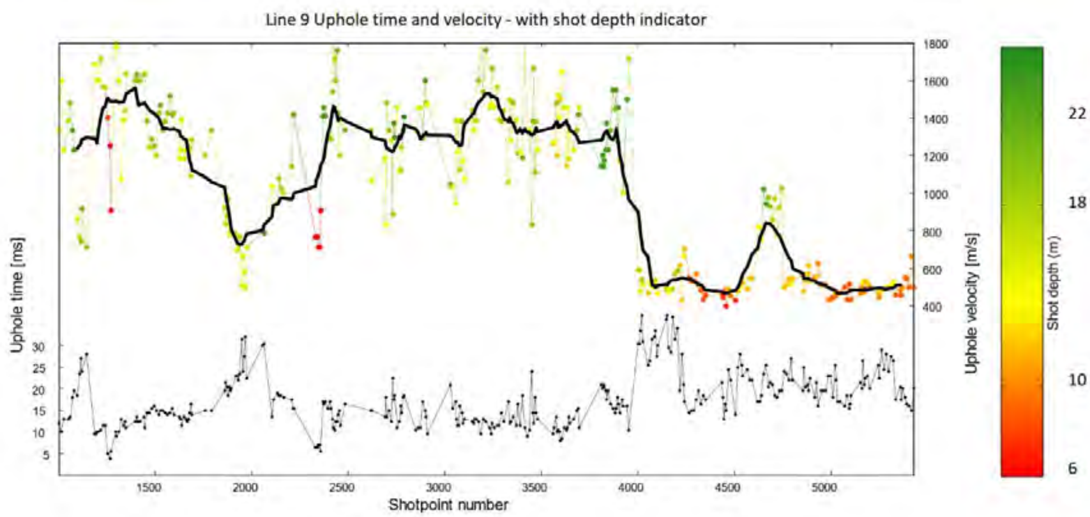



*Figure 78: Line 9 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=Southwest, Right=Northeast.*

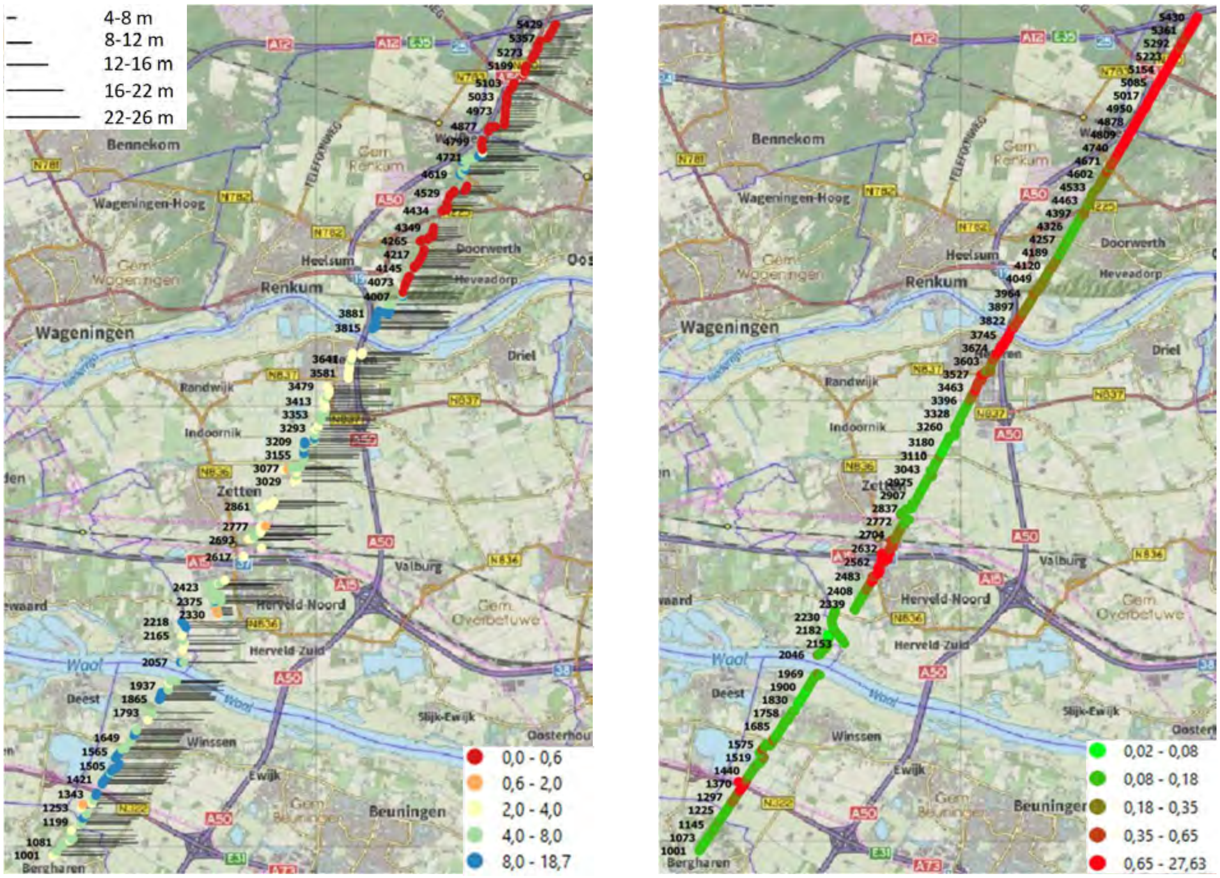


*Figure 79: Map view of Line 9 a) Signal amplitudes (0-1s) with shot depth indicators and shotpoint numbering and b) average RMS noise amplitudes per receiver station*

**Receiver domain: Noise**

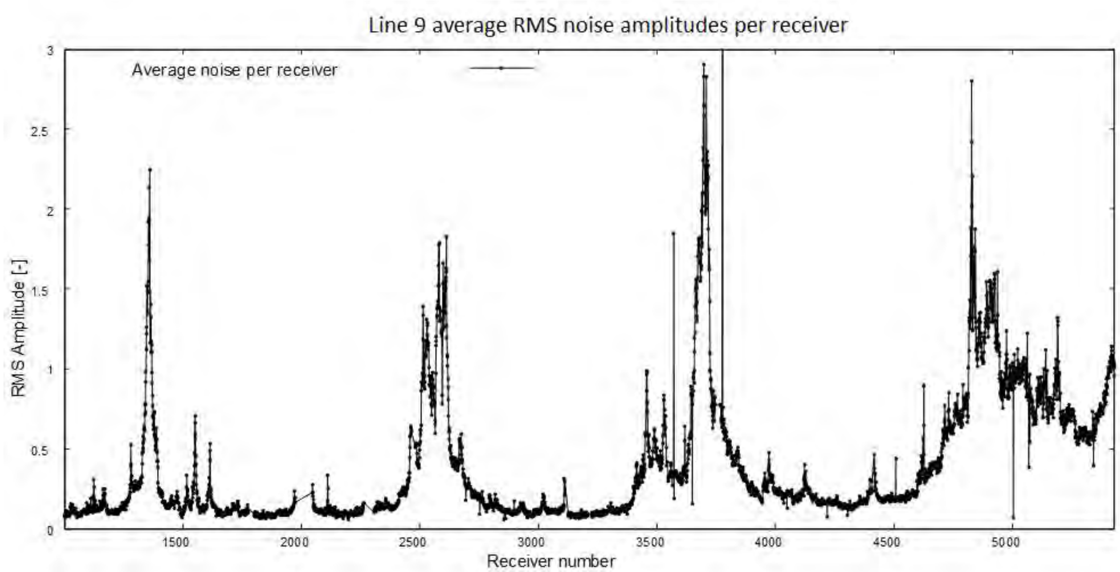



*Figure 80: average RMS noise amplitudes per receiver station for Line 9. Left=Southwest, Right=Northeast.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.377 | 4.44 | 15.02 | 1.415 | 4.77 | 66 (20.5 %) |

**Discussion and comparison to DUG Fast Track**

Line 9 has the highest average noise amplitudes of all lines, with 0.377.

Line 9 has the lowest signal amplitudes (0-1s) and SNR of the lines analyzed. On the Northeastern side of the line - from shotpoint 4000 and upwards - the near surface geology changes to stowed glacial deposits, with an elevation increase. The signal amplitudes drop off here and the effect of this is clearly visible in the fast track. Around shotpoint 4700 there is a small cluster of shots that had a deeper shot depth, these shots had a much higher signal amplitude and uphole velocity.

The uphole velocity is around 1300 m/s for most of the southwestern portion of the line. This decreases to 500 m/s for the weak shots. The cluster of deeper shots around shotpoint 4700 have an uphole velocity around 950 m/s.

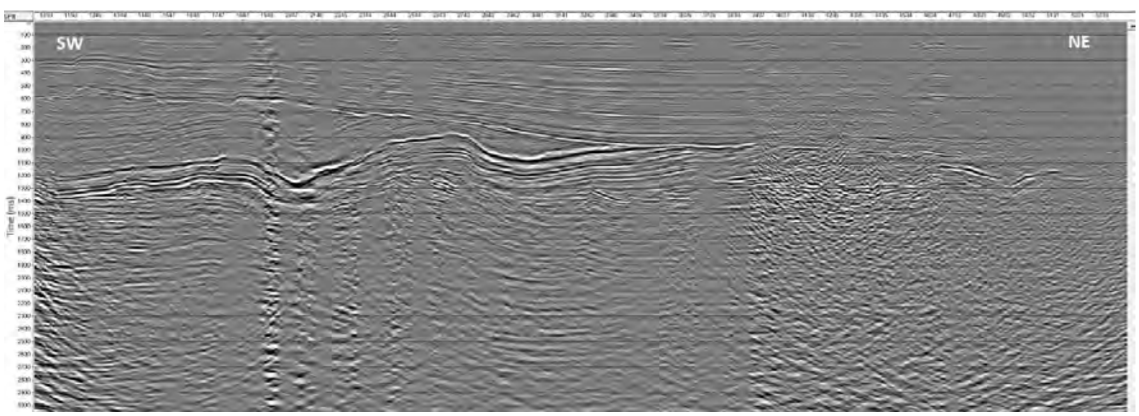



*Figure 81: Line 9 DUG true amplitude fast track*

Once again, receiver stations located near highways record the highest noise amplitudes. The Northern part of the line is parallel to the A50, this causes very high noise amplitudes for this line.

URKM010

Line 10 is another short line. It is 23 km in length and runs from East to West on the Southern side of Arnhem.

Figure 82: Line 10 location and numbering

**Shot domain: Noise**

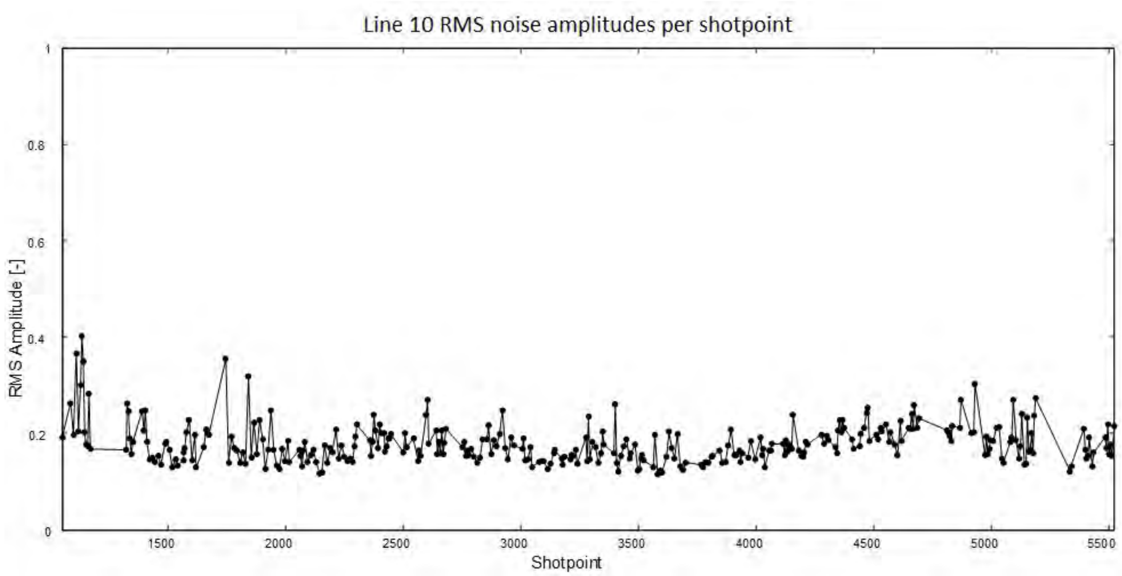



*Figure 83: Line 10 Noise amplitudes per shotpoint. Left=East, Right=West.*

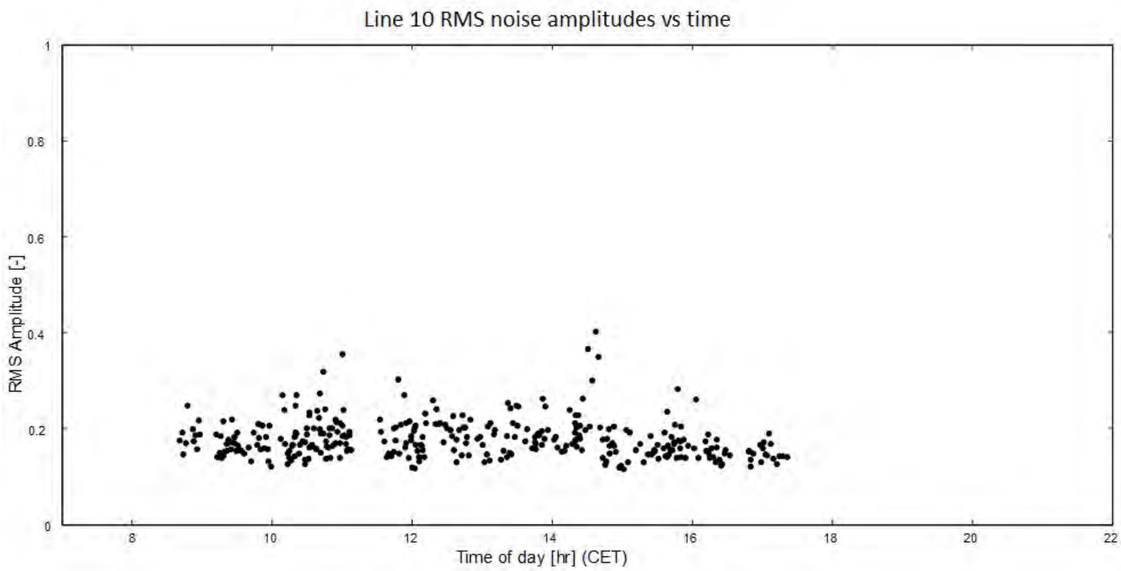
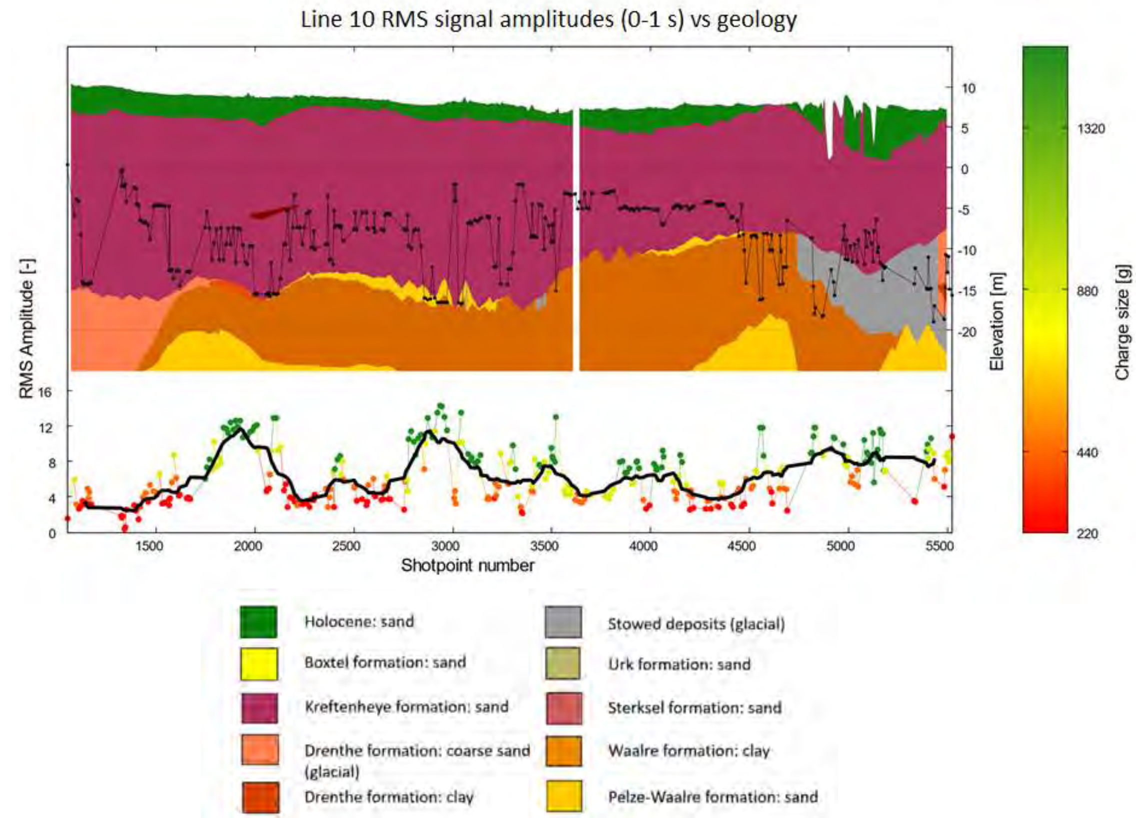



*Figure 84: Line 10 RMS noise amplitudes vs time.*

**Shot domain: Signal**

a)




b)

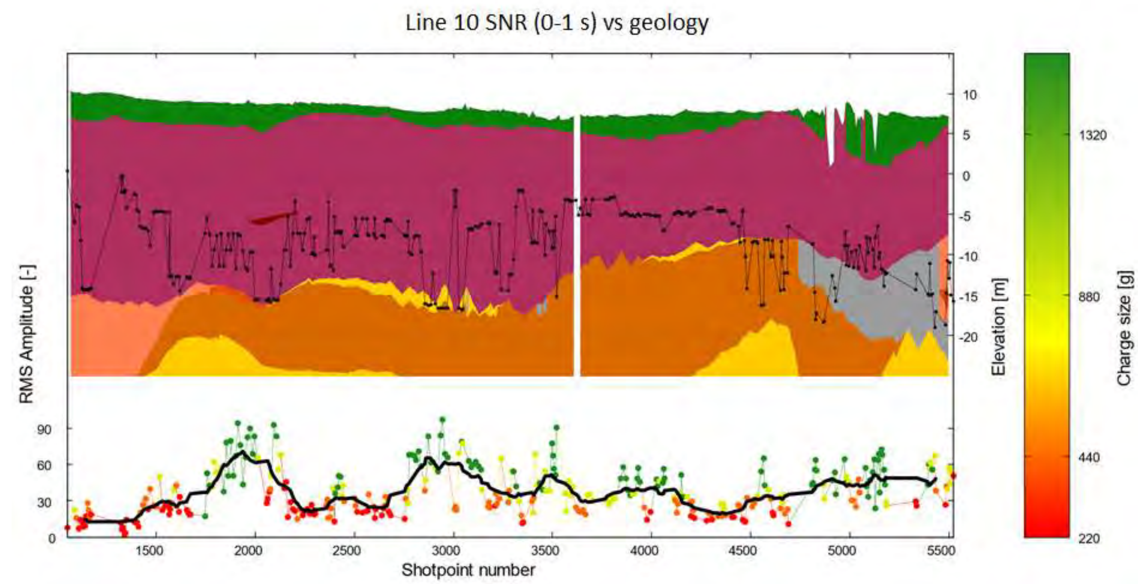



*Figure 85: Line 10 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in. Left=East, Right=West.*

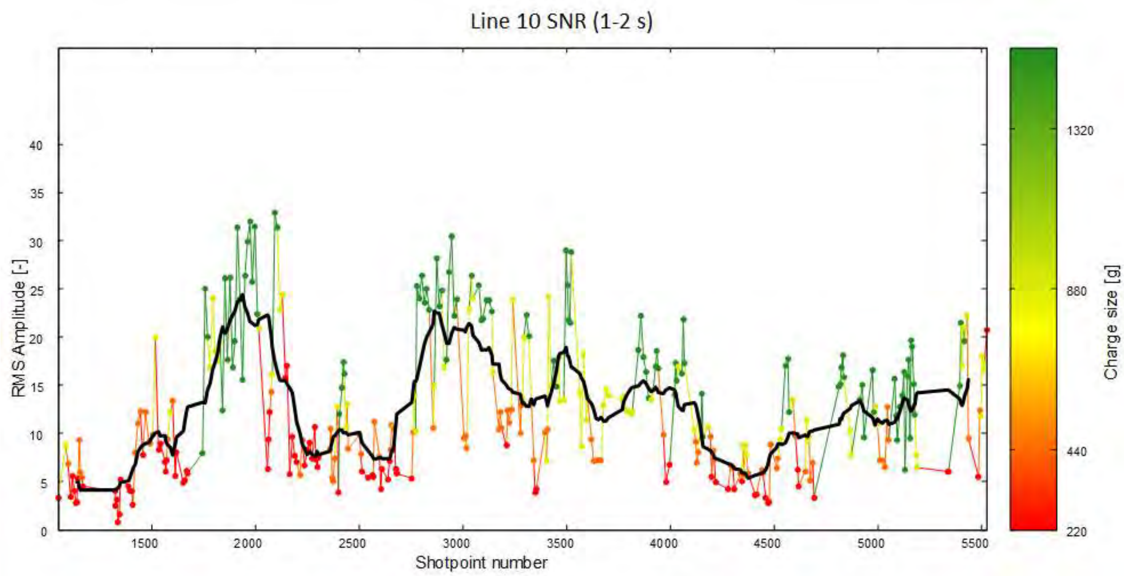



*Figure 86: Line 10 SNR (1-2 s) per shotpoint. Color indicates charge size. Left=East, Right=West.*

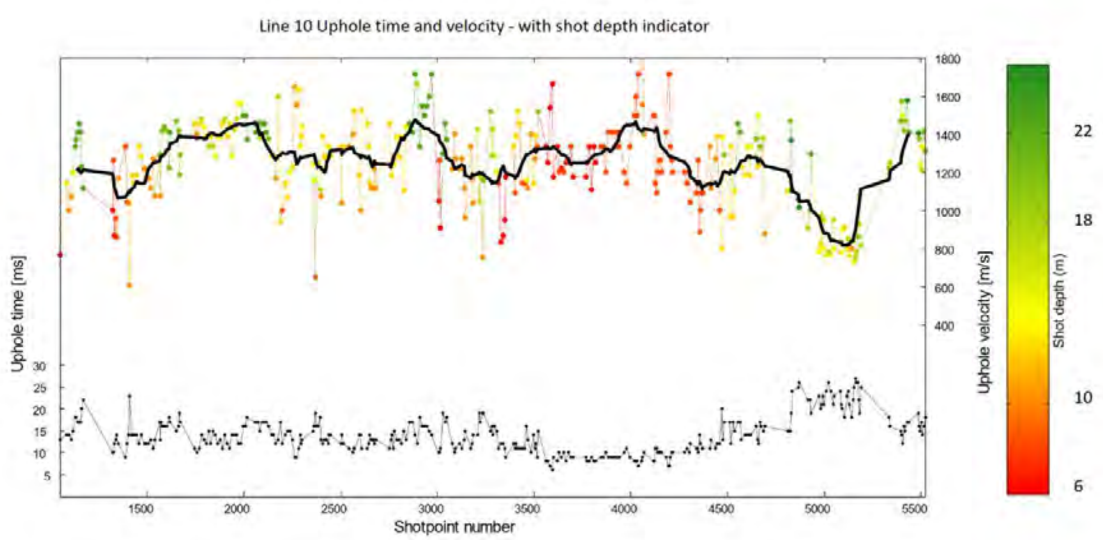



*Figure 87: Line 10 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=East, Right=West.*

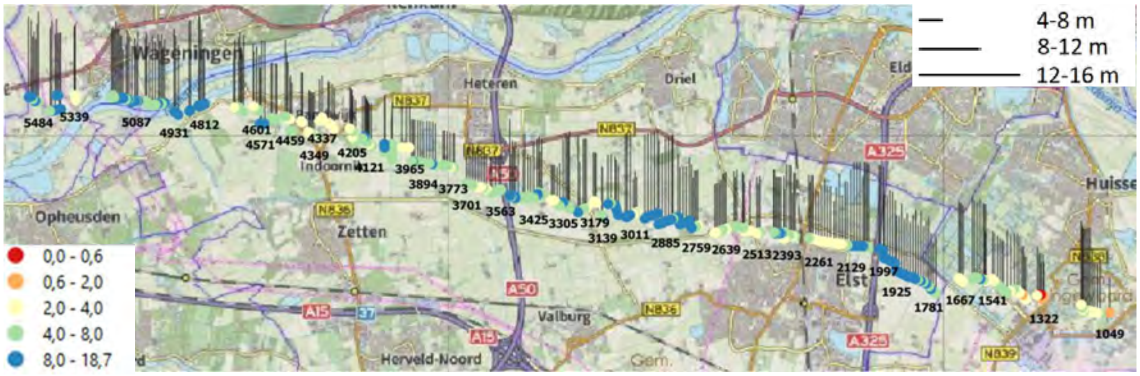


*Figure 88: Map view of Line 10 Signal amplitudes (0-1s) with shot depth indicators and shotpoint numbering.*

**Receiver domain: Noise**

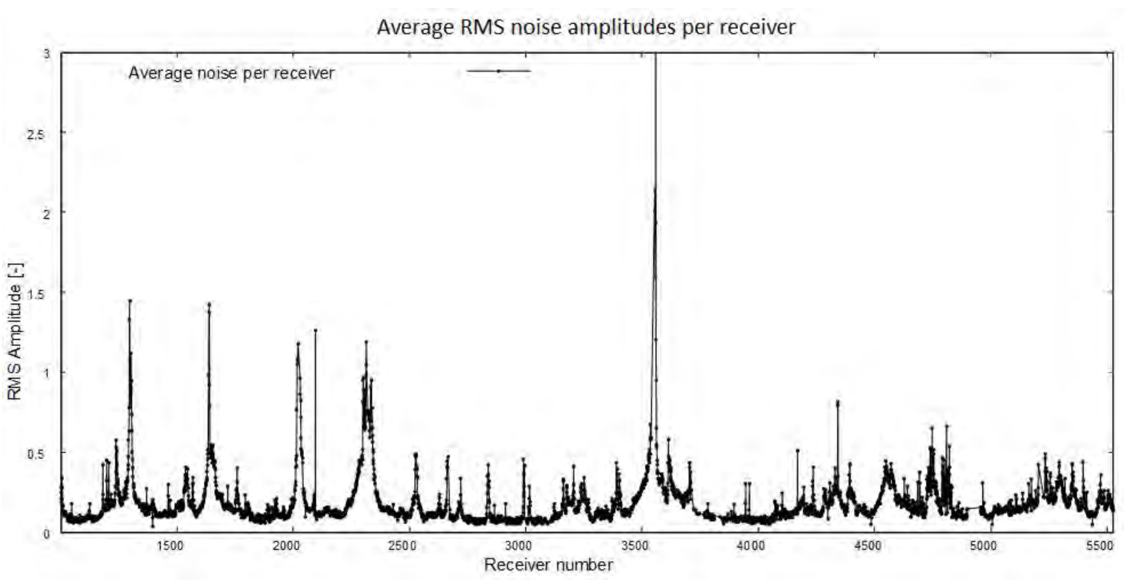


*Figure 89: average RMS noise amplitudes per receiver station for Line 10. Left=East, Right=West.*

*Figure 90: Map view of Line 10 Noise amplitudes per receiver station.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.179 | 6.39 | 37.39 | 2.14 | 12.60 | 2 (0.6 %) |

**Discussion and comparison to DUG Fast Track**

The average noise amplitude of line 10 is low, at 0.179.

Line 10 has high signal amplitudes and a high SNR. It also has very few weak shots (<1 %), thus generally the data for this line is very good.

The uphole velocities mostly fluctuate between 1100 m/s - 1500 m/s, although shots near shotpoint 5100 have an uphole velocity around 800 m/s. The REGIS II model shows a thicker layer of Holocene in this vicinity, which could explain the lower uphole velocity.

There is a gap in the line around shotpoint 1200 (~700 m or about 11 shots are missing), the effect of this can be seen in the fast track.

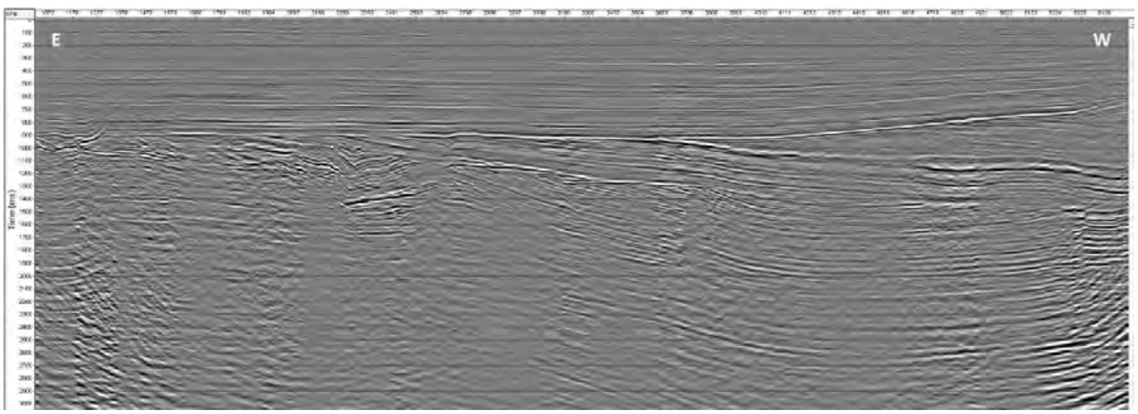



*Figure 91: Line 10 DUG true amplitude fast track*

The highest noise amplitudes for this line are recorded by receiver stations near highways and train tracks.

## SCAN011

Line 11 has only been partially acquired in February and March of 2020, before persistent rain and subsequently the coronavirus forced acquisition to a halt. 23.5 km has been acquired. The line runs along the Eastern side of Utrecht from the South towards the North.


*Figure 92: SCAN011 location and numbering*

**Shot domain: Noise**

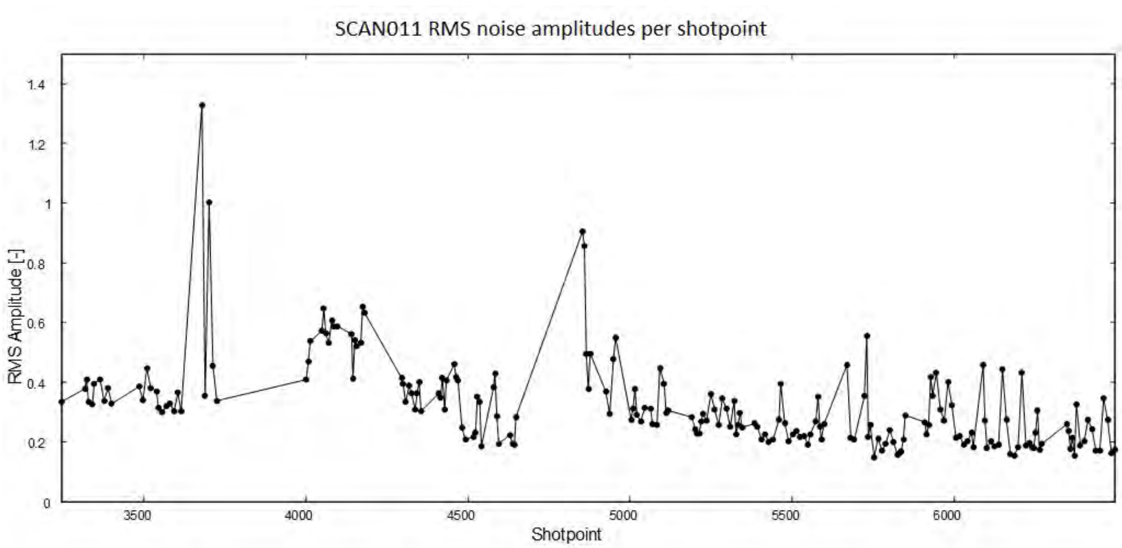



*Figure 93: SCAN011 Noise amplitudes per shotpoint. Left=South, Right=North.*

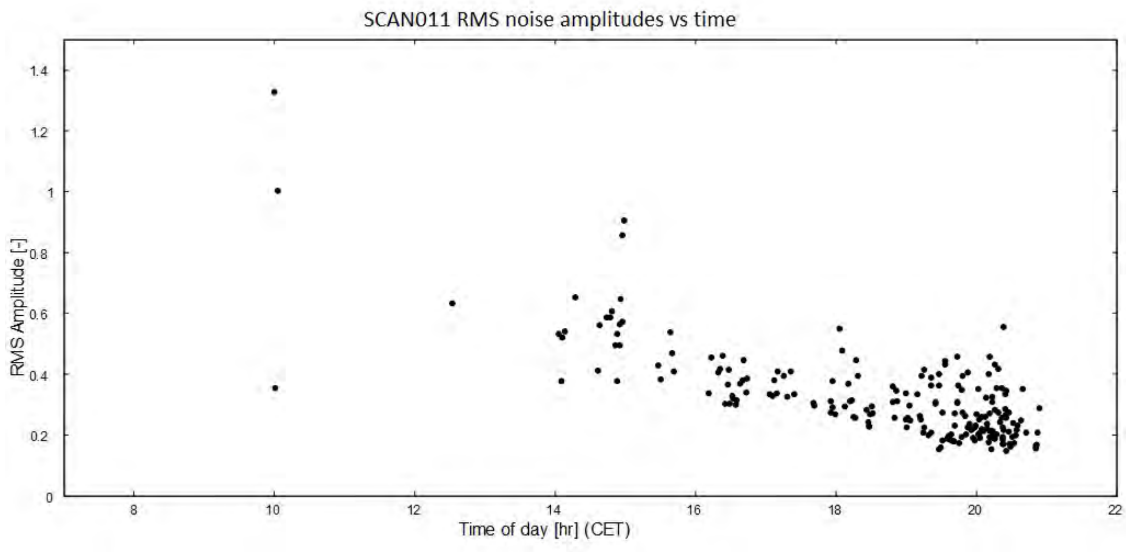
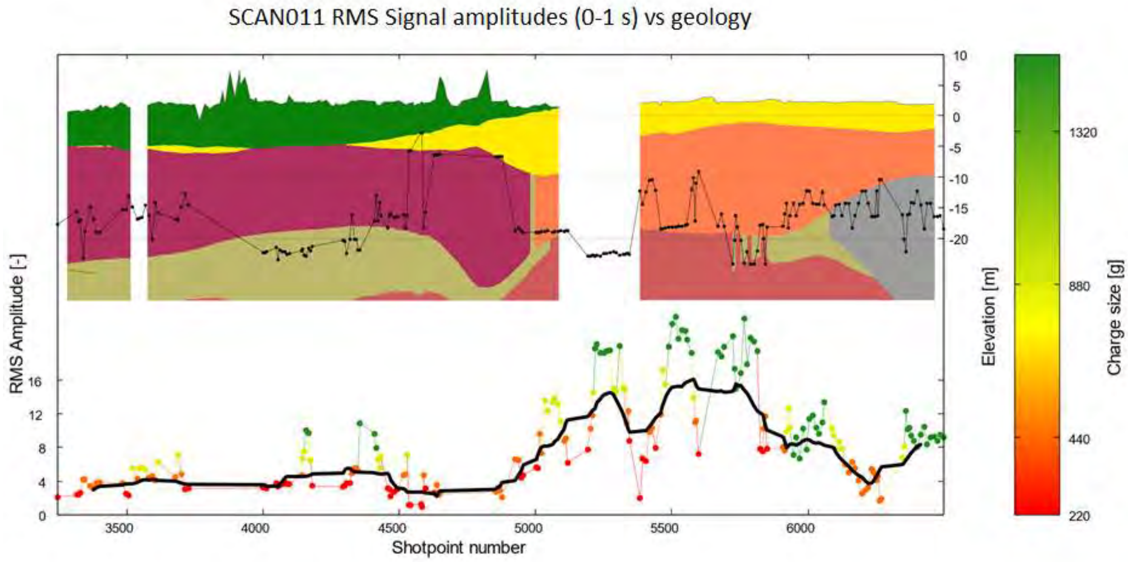



*Figure 94: SCAN011 RMS noise amplitudes vs time.*

**Shot domain: Signal**

a)




b)

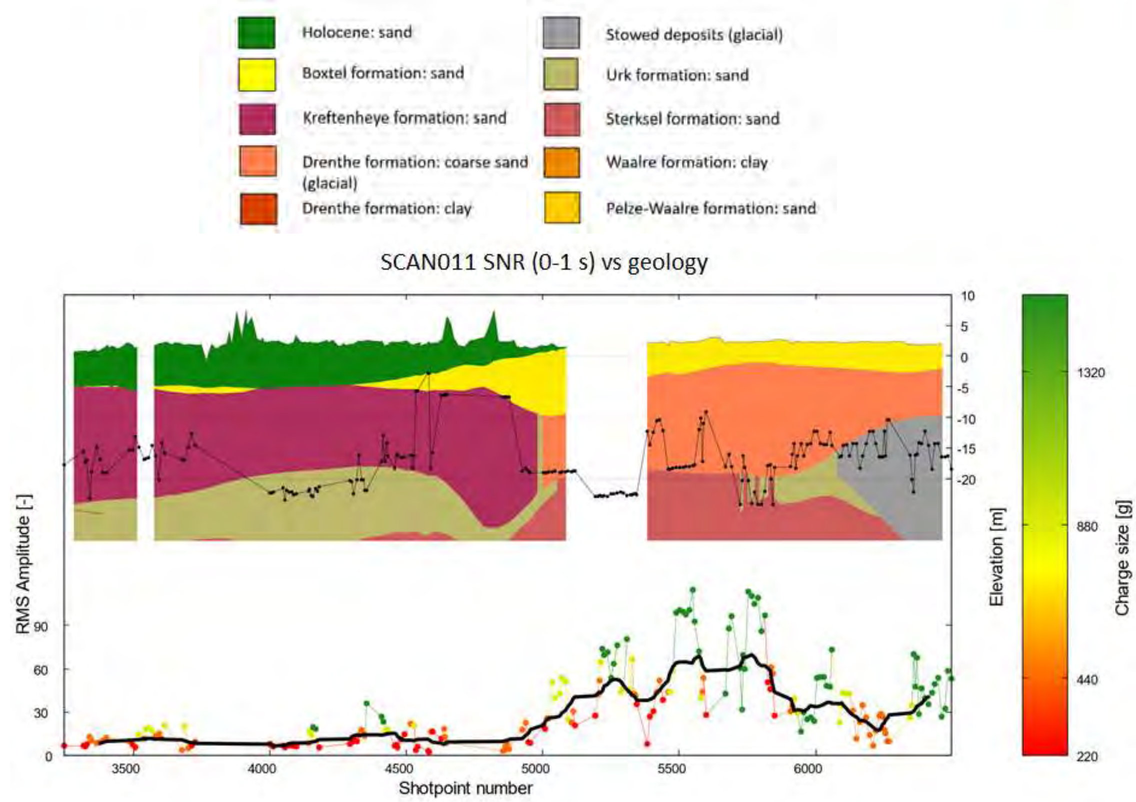



*Figure 95: SCAN011 a) RMS Signal amplitudes (0-1 s) per shotpoint vs geology (from REGIS II – DINOloket), and b) SNR (0-1 s) per shotpoint vs geology. Color indicates charge size, the black line indicates a 15-pt moving average of the RMS signal amplitudes/SNR. Black dots in the top of the graph indicate the elevation adjusted shot depth and the geological formation the shot was fired in. Left=South, Right=North.*

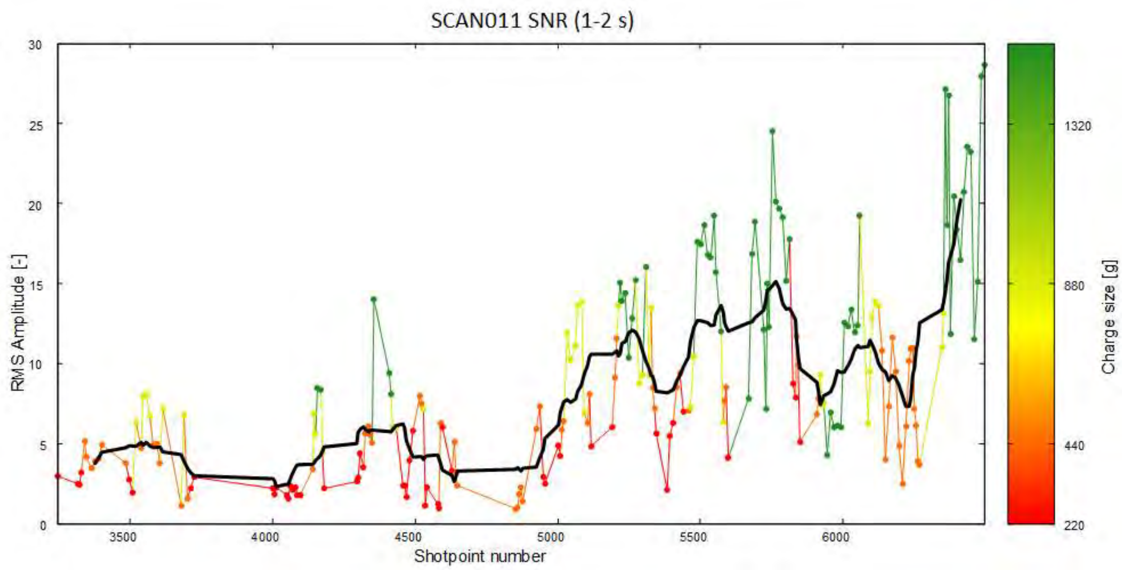



*Figure 96: SCAN011 SNR (1-2 s) per shotpoint. Color indicates charge size. Left=South, Right=North.*

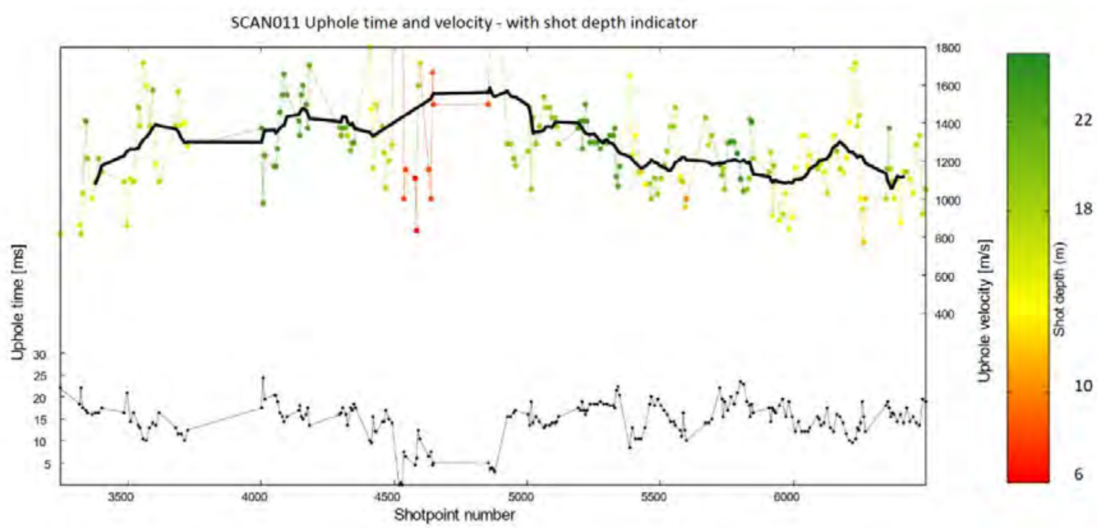
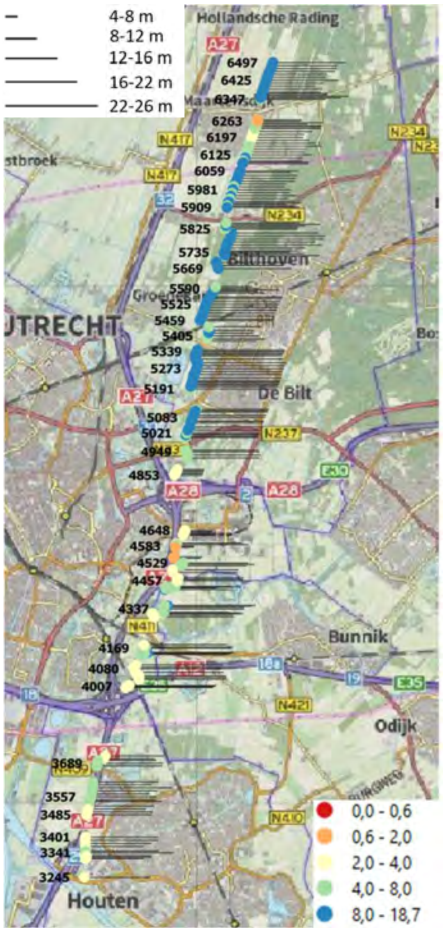



*Figure 97: SCAN011 Uphole time and velocity. The black line at the top of the graph indicates the 15-pt moving average. Color indicates shot depth. Left=South, Right=North.*



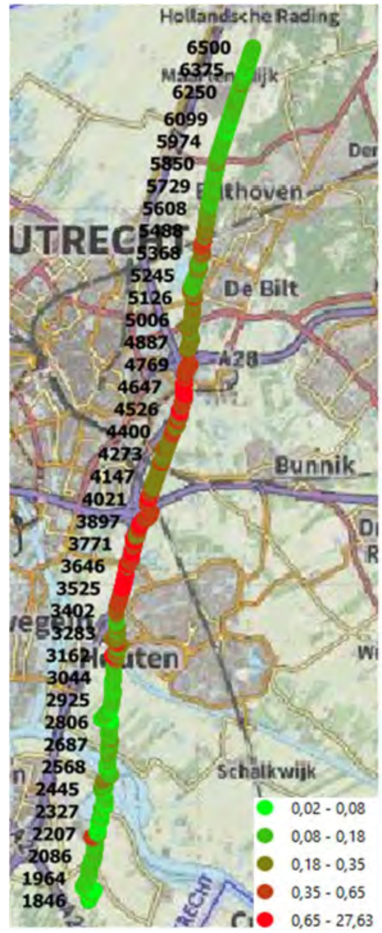


*Figure 98: Map view of SCAN011 a) Signal amplitudes (0-1s) with shot depth indicators and shotpoint numbering and b) average RMS noise amplitudes per receiver station*

**Receiver domain: Noise**

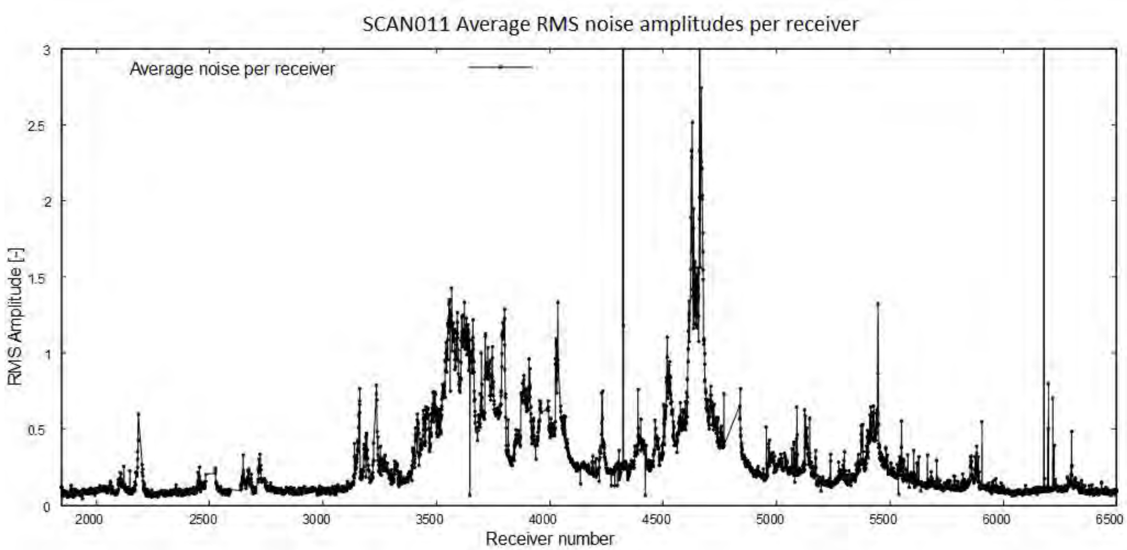



*Figure 99: average RMS noise amplitudes per receiver station for SCAN011. Left=South, Right=North.*

**Averages for the line**

| Noise amplitudes (0-500 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (signal amplitude (0-1 s) < 0.6) |
|---|---|---|---|---|---|
| 0.325 | 8.58 | 32.83 | 2.275 | 8.55 | 0 (0 %) |

**Discussion**

Noise amplitudes are quite high for this line, the can be explained because the line is located near Utrecht and crosses several highways.

The signal amplitudes for this line are quite good, mainly for the Northern end of the line. The SNR and signal amplitudes are a bit lower for the Southern end of the line (shotpoints 3200-4800), with an average SNR (1-2 s) around 4.

The uphole velocity mainly fluctuates between 1100 m/s - 1500 m/s over the length of the line.

**Amsterdam – Test Line**

In Amsterdam a short test line was acquired to investigate the data quality in the Amsterdam area. This line consists of 19 shots from 4 different shotpoints. Shots at a similar shotpoint were conducted with a different charge size/shot depth.

*Figure 100: Amsterdam testline location. – Industrial area*

Averages for the line:

| Noise amplitudes (8998-9998 ms) | Signal amplitudes (0-1 s) | SNR (0-1 s) | Signal amplitudes (1-2 s) | SNR (1-2 s) | Weak shots: (SNR (0-1 s) < 2.5) |
|---|---|---|---|---|---|
| 1.95 | 1.89 | 1.06 | 0.96 | 0.51 | 18 (94.6 %) |

**Discussion**

The average noise amplitude for this short testline is on average 7.6x larger than the average noise amplitude of the other lines. This is caused by the fact that the line was shot in a very busy industrial area in Amsterdam.

Because of the large amount of noise, the SNR's are low. Note that for the data between 1-2s the signal amplitude < the noise amplitude. This is largely because the application of the FK filter also reduces the noise amplitudes in the signal window. The average amplitude in the signal window between 1-2s is thus weaker than average noise amplitude

In addition a short frequency analysis was carried out for this line. The results for this line show that deeper shots tend to give higher frequencies. Higher charge size shots give lower frequencies.

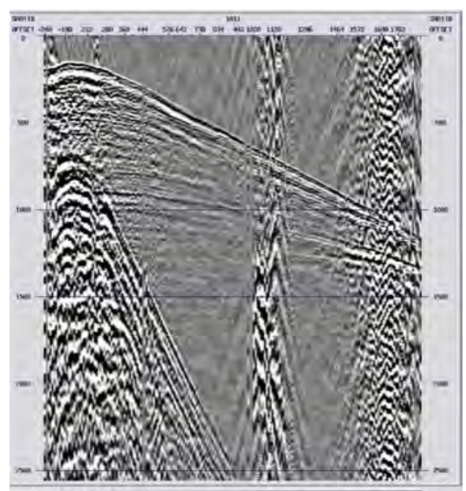


*Figure 101: Example of a shot taken on the Amsterdam testline. This was shotid 1011, with a charge size of 880 g and a shot depth of 32 m*

**Overview – All lines**

The table below shows an overview of the noise and signal amplitudes and SNR for all lines.

| Line | Avg. (2-11) | 002 | 003 | 004 | 005 | 006 | 007 | 008 | 009 | 010 | 011 | AMS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Noise (0-500 ms) | 0.255 | 0.226 | 0.188 | 0.235 | 0.295 | 0.174 | 0.242 | 0.309 | 0.377 | 0.179 | 0.325 | 1.946 |
| Signal (0-1 s) | 6.12 | 4.97 | 6.428 | 4.81 | 6.952 | 5.873 | 7.704 | 5.105 | 4.435 | 6.386 | 8.575 | 1.888 |
| SNR (0-1 s) | 29.4 | 25.08 | 35.28 | 26.77 | 26.46 | 35.57 | 41.64 | 17.73 | 15.02 | 37.39 | 32.83 | 1.062 |
| Signal (1-2 s) | 1.98 | 1.615 | 2.341 | 1.833 | 2.026 | 2.084 | 2.754 | 1.362 | 1.415 | 2.135 | 2.275 | 0.961 |
| SNR (1-2s) | 9.78 | 8.16 | 13.54 | 10.31 | 7.51 | 11.87 | 15.76 | 4.79 | 4.77 | 12.60 | 8.55 | 0.51* |

*Table 1: An overview for all lines. Marked in green are the two best lines, marked in red are the two worst lines.*

In addition table 2 below shows the number of weak shots I have identified per line, my numbers are compared to analysis by DUG and Rossingh Geophysics.

| Line | 002 | 003 | 004 | 005 | 006 | 007 | 008 | 009 | 010 | 011 | AMS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total shots | 1250 | 709 | 1247 | 912 | 293 | 254 | 287 | 322 | 336 | 207 | 19 |
| Weak shots (signal amp. (0-1s) < 0.6 | 176 (14.1%) | 45 (6.4%) | 92 (7.4%) | 5 (0.6%) | 69 (23.6%) | 1 (0.4%) | 33 (11.5%) | 66 (20.5%) | 2 (0.6%) | 0 (0%) | 0 (0%) |
| Weak shots (SNR (0-1s) < 2.5 | 172 (13.8%) | 40 (5.6%) | 87 (7.0%) | 6 (0.7%) | 46 (15.7%) | 0 (0%) | 41 (14.3%) | 94 (29.1%) | 1 (0.3%) | 1 (0.5%) | 18 (94.7%) |
| Weak shots (SNR (1-2s) < 1.5 | 186 (14.9%) | 47 (6.6%) | 178 (14.3%) | 11 (1.2%) | 78 (26.6%) | 0 (0%) | 56 (19.5%) | 98 (30.3%) | 1 (0.3%) | 7 (3.4%) | 19 (100%) |
| DUG weak and killed shots | 182 | 50 | 78 | 12 | 35 | 8 | 40 | 57 | 0 | - | - |
| Rossingh QC failed and weak shots (from line completion report) | 181 | 50 | 72 | 1 | 83 | 0 | 25 | 109 | 53 | 0 | - |

*Table 2: Weak shots per line. I have defined the number of weak shots by three different definitions and compared the results with analysis by Rossingh and DUG*

Furthermore I have combined the data of all lines and sorted it by charge size and shot depth to investigate the effect of increasing charge size and shot depth on the signal amplitudes. These results are visible in table 3 and 4.

| Charge size (g) | Avg. signal amplitude (0-1s) | Number of shots |
|---|---|---|
| 220 | 3.16 | 1255 |
| 440 | 4.40 | 1459 |
| 880 | 5.58 | 1167 |
| 1540 | 9.13 | 1542 |

*Table 3: Average signal amplitude (0-1 s) by charge size.*

| Shot depth (m) | Avg. signal amplitude (0-1s) | Number of shots | Avg. charge size (g) |
|---|---|---|---|
| 6m | 1.66 | 103 | 386 |
| 8m | 2.95 | 301 | 483 |
| 10m | 3.32 | 374 | 645 |
| 14m | 4.96 | 325 | 824 |
| 20m | 6.48 | 1818 | 885 |
| 24m | 8.40 | 561 | 869 |
| 26m | 10.59 | 132 | 1163 |

*Table 4: average signal amplitude (0-1 s by shot depth)*

## Discussion

**Noise amplitudes**

Based on the results of all lines the most dominant noise source is highway traffic. Highways affect a relatively large surrounding area, up to about 200-300 m depending on the highway and traffic, the most significant rise in noise amplitudes occurs within about 100 m of a highway. Other important sources of noise are: other roads, trains, industrial areas, residential areas, windmills. Shots fired early in the morning or late in the evening generally have lower noise levels, this is likely mainly related to the lower amount of traffic and/or industrial activity.

This study investigated the effect of windspeed on noise levels for lines 2 and 5. On a full receiver spread no major correlation can be found between windspeed and the average noise amplitude of a shot. A high windspeed likely mainly causes high noise amplitudes for receivers near windmills/single trees - the previous study (Janssen, 2020) showed single trees are more affected by windspeed than forests.

An open question remains: How much does noise affect the final product? How much of the noise can be removed by processing? This is a topic of interest for further research.

**Signal amplitudes**

There is significant variation in signal amplitudes over the length of a line, even when other parameters do not change. A major parameter that does change throughout a line is the near surface geology. Therefore this is the most likely cause of major change in signal propagation.

As shown in table 3 signal amplitudes (0-1 s) increase from an average of 3.16 for 220 g charge size shots to 9.13 for 1540 g charge size shots. An increase in charge size clearly benefits the amplitude of a shot significantly – however it should be noted that this is not a linear correlation, a doubling of charge size does not double the average signal amplitude. Table 4 shows signal amplitudes (0-1 s) increase with increasing shot depth. This is partly caused by an increase in charge size (deeper shots are allowed to use higher charge sizes), but not fully. An increased shot depth also clearly benefits the average signal amplitude.

**Uphole velocity**

The uphole velocity is mainly influenced by the near surface geology. A change in the near surface geology causes a change in uphole velocities in most cases. An example are the glacial stowed deposits that occur near the surface. These areas have a much lower uphole velocity: between 400 m/s - 600 m/s. A major factor in this is that the seismic velocity through air is 343 m/s whereas in water it is ~1500 m/s. Therefore the level of the groundwater table is a very important factor in the average uphole velocity of a shot. This shows that almost all shots in the areas with the stowed deposits at the surface are fired above the water table. Shallower shots also generally have a lower uphole velocity, this can be explained by the fact that the shallowest geology is generally less compacted and has a lower seismic velocity (the shot energy travels more through air filled pore space).

**Weak shots**

Over the course of all lines there are several areas with a clustering of shots with significantly lower signal amplitudes. These occur mainly in areas where the near surface geology consist of glacial deposits - but only when combined with an increase in elevation. A cause for this could be that the material is more unconsolidated, this would increase absorption of shot energy. Another possibility is that these shots are fired above the groundwater table and that this causes the reduction in signal amplitudes (or a combination of both) – this is a topic of interest for further study.

An example of a weak shot is shotid 1122 from URKM006 in figure 102 below. This shot was fired at shotpoint 2687.5 (see figure 50) in the glacial deposits. In the shot you can clearly see the effect of seismic scattering caused by large rocks/boulders present in the glacial deposits.

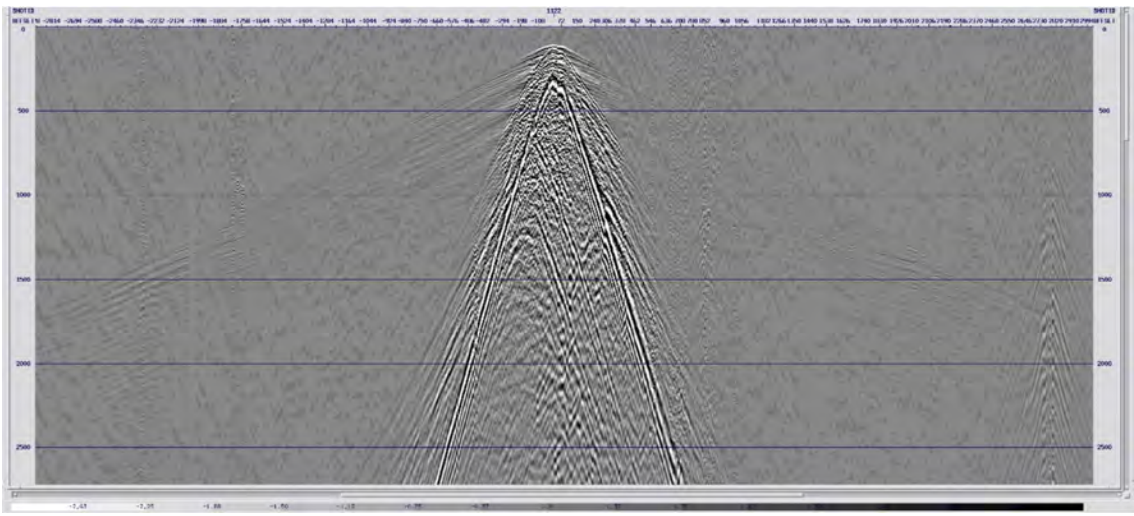


*Figure 102: Shotid 1122 from URKM006. Example of a seismic scattering.*

As visible in line 9 (Figure 76), near shotpoint 4750 there are several shots that were drilled in the same geological formation as neighbouring shots, these were however drilled deeper. These shots have significantly higher signal amplitudes and are not classified as weak.

Another area with weak shots is the Southern Polder of line 4. Shots between shotpoint 6000 and 8500 are a lot weaker. In figure 103 on the next page, the geology of the top 150 m is compared to the DUG fast track for this area. The previous study (Janssen, 2020) identified several possible causes for this on the 2019 EBN test line (which runs about 10 km west of line 4). Among others he listed the Woudenberg peat formation, Eem formation clay, the Drenthe formation clay and a large seismic velocity contrast as potential causes in this region.  This large seismic velocity contrast was determined based on analysis by Geofizyka Torún and it is found below the Eem formation, here the seismic velocities transition to much faster levels (Janssen, 2020).

A more detailed look at the geology of this region for this line also finds a thickened layer of the Eem formation clay and Drenthe formation clay for the impacted area (figure 103). So these remain candidates for a reduction in the signal amplitudes in the region. An interesting observation is that a very shallow reflector ~50 ms is no longer visible in the affected area. This suggests that even very shallow data is affected and the cause is thus shallower. A possible cause could then be the Woudenberg peat formation. It is represented as a very thin layer in the Dinoloket REGIS II model, but as this is an extrapolation of well data it is possible that this formation is thicker in this area. The reduction in data quality in the regions could be due to a combination of these causes, this is in line with what was previously found by *Janssen, 2020.*

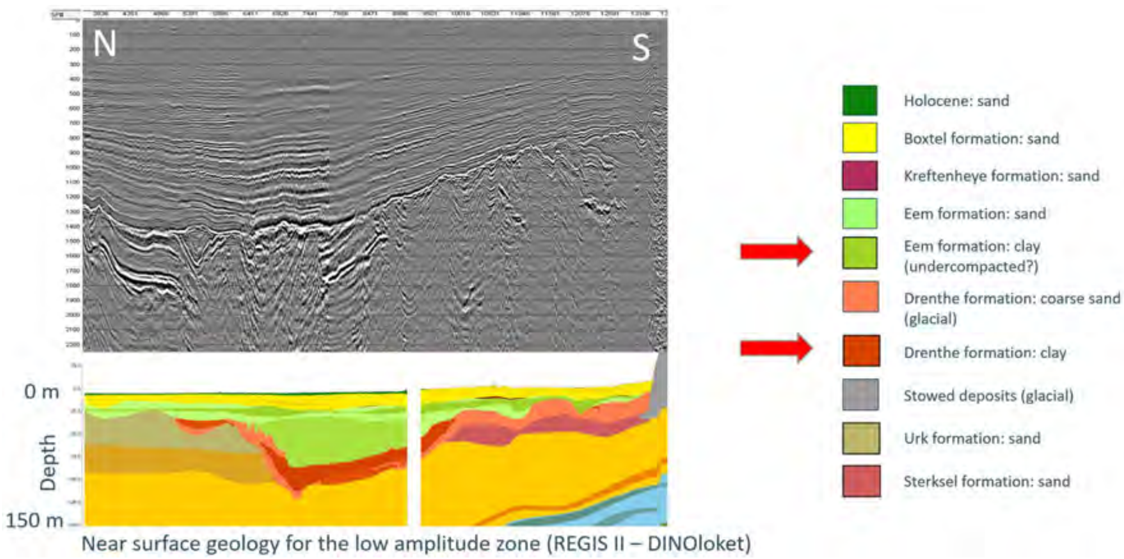



*Figure 103: SCAN004 deeper geology (from REGIS II) compared to the DUG fast track for the area where weak shots were acquired*

This study mainly focused on quantifying the signal amplitudes/noise amplitudes and SNR of all lines. Less emphasis has been placed on analysing the frequency content. That is because of the amount of data that was to be analysed the amplitude analysis was prioritized. A more detailed frequency analysis remains of interest for further study.

**Recommendations on shot design**

Larger shot depths and charge size clearly benefit signal amplitudes. In order to guarantee a better image quality and successfully map the deeper targets as well it is recommended to use deep and high charge size shots as much as possible. Furthermore, stowed glacial deposits that are combined with an increase in elevation should be avoided – as these reduce the data quality significantly.

In addition, noise sources should be avoided if possible. It is especially important to stay away from highways, as these are the most dominant sources of noise and they affect a wide area.

An analysis of the DUG fast track data quality shows the effect of gaps in a seismic line. These gaps reduce the imaging quality significantly and should also be avoided if possible.

# Conclusions

Signal amplitudes, noise amplitudes, the SNR and the number of weak shots have been quantified for lines 2-11. This allows for a comparison of the data quality of the lines. These parameters can be viewed in QGIS for a detailed analysis. (Signal amplitudes (0-1 s) per shot, SNR (0-1 s) per shot and noise amplitudes (0-500 ms) per shot and receiver have been loaded into QGIS)

The most important driver of variation in the signal amplitudes over the course of a line is the near surface geology. Other important parameters are the shot depth and charge size. Deeper and higher charge size shot generally cause an increase in signal amplitudes and thus allow for a better imaging quality at larger depths. Glacial stowed deposits that are combined with an increase in elevation cause a very significant reduction of the data quality, these areas should be avoided for acquisition as much as possible. The most likely cause for this reduction in data quality is that the material is unconsolidated and absorbs/scatters shot energy and/or that shots in these areas are fired above the groundwater table.

The most important source of noise is traffic and the highest noise amplitudes are recorded around highways. Therefore shooting at times with low traffic (e.g. in the morning or late in the evening) reduces noise amplitudes. As noise can be removed through processing, the full extent of the effect of high noise amplitudes on the data quality remains unclear and is a topic of interest for further research.

References:


1) Ter Borgh, M., Mijnlieff, H. (2019). Geological evaluation for the seismic acquisition programme for SCAN area C (Nijmegen – Haarlem). SCAN report.
2) Janssen, W. (2020) Seismic campaign for geothermal energy in the Netherlands (SCAN): an analysis of test line data quality. EBN internship report.
3) Vernes, R. W., Van Doorn, T. H., Bierkens, M. F. P., Van Gessel, S. F., & De Heer, E. (2005). Van gidslaag naar hydrogeologische eenheid: toelichting op de totstandkoming van de dataset REGIS II. TNO.