Royal Netherlands
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Detection and location thresholds for scenario events at existing and planned Nedmag salt caverns

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Introduction

Nedmag is planning to mine two new salt caverns: VE-5/6 and VE-7/8. Also, Nedmag is commissioning the installation of a new seismic station, which we christen for the moment as GNM. In this short note, the impact of the new borehole station on the location threshold for induced seismicity in the Veendam region is assessed. Furthermore, the location uncertainty is assessed in case local magnitudes M_L 1.0 earthquakes would occur at the new mining sites, or at the existing mining site TR-1.

Location threshold

The new borehole station GNM is planned at the following location: [RDx RDy]=[252.210 570.780] km, as indicated with the red dot on Fig. 1. The 200 m depth geophone is used for detection and location. The noise level at 200m depth is assumed to be comparable to the level at the other borehole stations in the region. In addition to the main existing production location, as indicated with a pink dot in Fig. 1, two new production clusters are planned: VE5/6 and VE7/8. The former approximately 2.8 km west from the current production cluster, the latter app. 2.4 km to the southwest. The three production clusters are indicated in green in Figs. 2 and 3.

Fig. 2 shows the current situation without the planned station. The production clusters fall within the $0.2 < M_L < 0.4$ range. This means that with the current network all events of minimum magnitude between 0.2 and 0.4 (dependent on production site) can be detected and located. In the new situation (Fig. 3) all production sites fall within the $M_L = 0.2$ range.

Addition of one station south of the existing borehole network would have an impact on the location uncertainty, especially for VE7/8 (see next sections), but will improve the location threshold only marginally.

Epicentral uncertainty

We assume that the earthquakes would be detected and located with P waves. From a database of Groningen seismicity, we determine untill which distances P-waves can be detected and picked. For $M_L = 1.0$ events we find a maximum distance of 19.7 ± 7.6 km, where 7.6 is the standard

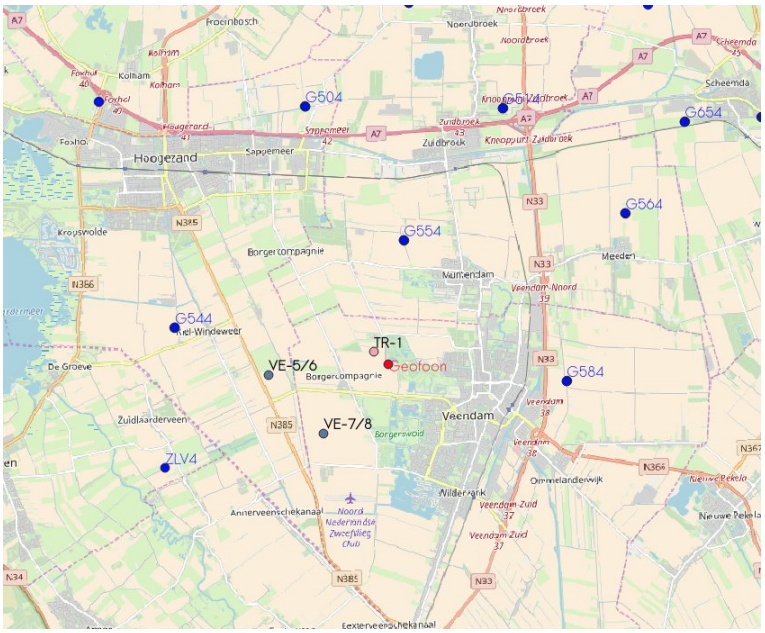

Figure 1: Overview of the Veendam area with a current Nedmag mining site (TR-1), exisiting KNMI borehole stations (blue dots), two planned Nedmag mining sites (grey dots) and a planned Nedmag borehole station (red dot). Background map is from www.openstreetmap.org.

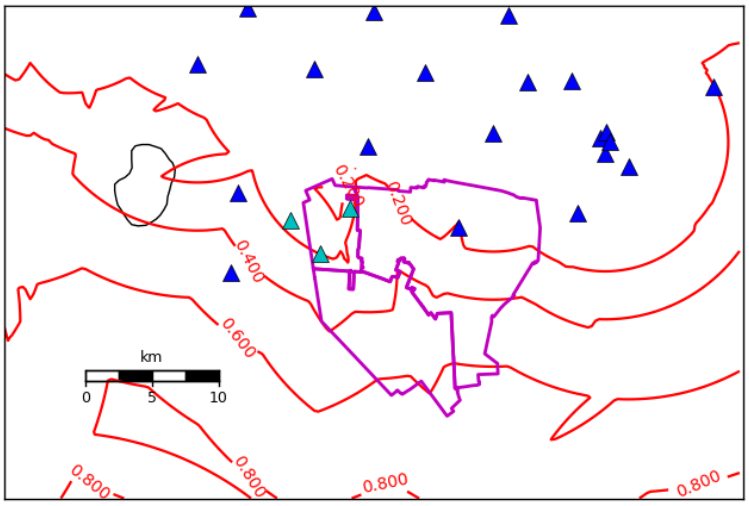

Figure 2: Location threshold contours expressed in M_L (red) based on existing borehole stations (blue) in the Veendam region. Salt caverns are shown in green and the Veendam community borders in purple.

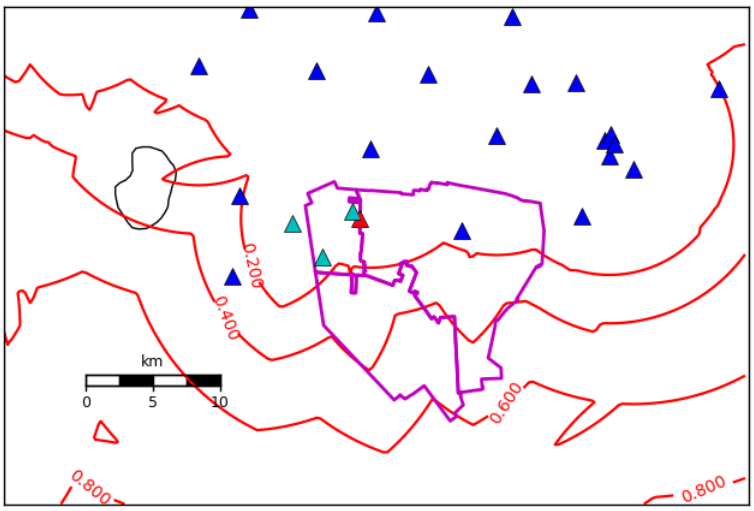

Figure 3: Location threshold contours expressed in M_L (red) based on existing (blue) and a planned (red) borehole stations. For further description, see Fig. 2.

deviation over events that occured between January 2015 and December 2018. To have a conservative assessment of the location uncertainty, we include all KNMI stations that are within 19.7-7.6=12.1 km radius. Moreover, we assume that the planned seismic station GNM has already been installed. Furthermore, we assume the same velocity model and traveltime error as determined from a recent event near Veendam ($M_L = 1.3$, 07-01-2019:11:12:49.2). This error incorporates both the local variations of the velocity field as well as picking errors. The traveltime error is propagaged further into epicentral probability density functions (PDFs), from which the 95% confidence regions are shown.

Scenario TR-1

In this section we assess the epicentral uncertainty for a scenario event at the existing mining site TR-1 (Fig. 1). Fig. 4 shows the seismic sensors where manual P-wave picks would be available for this event. A grid search is done for a region around the Hypocenter solution, as indicated by the red box in Fig. 4. In the first step, equal differential time (EDT, *Zhou*, 1994) residuals are computed. That is, for each grid point and for each station combination, the traveltime differences are forward modelled and tabulated. From these values, the observed traveltime differences are subtracted to obtain the EDT residuals. In the second step, the PDF (*Tarantola*, 2005) is derived from the EDT residuals, using a L1 norm. Fig. 5 shows the 95% confidence area of the resulting PDF.

In the following, the relevant input and output is listed. The scenario epicenter is listed both in wgs84 and in the Dutch national triangulation system (RD). Also a gridded version of the 95% confidence contour of the PDF, and its major and minor axes, can be found.

Epicenter in wgs84 [deg]: 6.834, 53.118

Epicenter in RD [m]: 251850, 571100

PDF major axis [m]: 919

PDF minor axis [m]: 694

Orientation of the PDF ellipse [deg]: -3.3

95% confidence contour RDx [m]: 251816, 251850, 251900, 251920, 251950, 252000, 252015, 252050, 252061, 252093, 252100, 252122, 252145, 252150, 252170, 252187, 252196, 252200, 252200, 252196, 252187, 252171, 252150, 252146, 252117, 252100, 252076, 252050, 252018, 252000, 251950, 251914, 251900, 251850, 251800, 251750, 251745, 251700, 251650, 251650, 251600, 251599, 251562, 251550, 251537, 251518, 251508, 251503, 251501, 251503, 251508, 251517, 251532, 251550, 251554, 251577, 251600, 251611, 251650, 251653, 251700, 251709, 251750, 251800, 251816

95% confidence contour RDy [m]: 570600, 570592, 570594, 570600, 570608, 570636, 570650, 570686, 570700, 570750, 570763, 570800, 570850, 570863, 570900, 570950, 571000, 571050, 571100, 571150, 571200, 571250, 571289, 571300, 571350, 571371, 571400, 571426, 571450, 571464, 571490, 571500, 571506, 571515, 571514, 571502, 571500, 571485, 571450, 571450, 571401, 571400, 571350, 571324, 571300, 571250, 571200, 571150, 571100, 571050, 571000, 570950, 570900, 570862, 570850, 570800, 570766, 570750, 570703, 570700, 570656, 570650, 570621, 570603, 570600

Scenario VE-5/6

In this section we assess the epicentral uncertainty for a scenario event at the planned mining site VE-5/6. Fig. 6 shows the seismic sensors where manual P-wave picks would be available for this event. A grid search is done for a region around the Hypocenter solution, as indicated by the red box in Fig. 6. Fig. 7 shows the 95% confidence area of the resulting PDF.

In the following, the relevant input and output is listed. The scenario epicenter is listed both in wgs84 and in the Dutch national triangulation system (RD). Also a gridded version of the 95% confidence contour of the PDF, and its major and minor axes, can be found.

Epicenter in wgs84 [deg]: 6.793, 53.113

Epicenter in RD [m]: 249150, 570500

PDF major axis [m]: 1049

PDF minor axis [m]: 803

Orientation of the PDF ellipse [deg]: -22.4

95% confidence contour RDx [m]: 249132, 249150, 249200, 249250, 249300, 249350, 249354, 249400, 249435, 249450, 249482, 249500, 249514, 249537, 249550, 249551, 249564, 249571, 249573, 249571, 249565, 249553, 249550, 249541, 249525, 249500, 249500, 249476, 249450, 249441, 249400, 249398, 249350, 249344, 249300, 249268, 249250, 249200, 249150, 249100, 249050, 249000, 248950, 248918, 248900, 248852, 248850, 248808, 248800, 248776, 248756, 248750, 248740, 248730, 248726, 248727, 248733, 248745, 248750, 248759, 248776, 248800, 248803, 248830, 248850, 248865, 248900, 248909, 248950, 248961, 249000, 249028, 249050, 249100, 249132

95% confidence contour RDy [m]: 570000, 569993, 569980, 569977, 569982, 569998, 570000, 570022, 570050, 570063, 570100, 570127, 570150, 570200, 570248, 570250, 570300, 570350, 570400, 570450, 570500, 570550, 570559, 570600, 570650, 570700, 570700, 570750, 570787, 570800, 570848, 570850, 570896, 570900, 570934, 570950, 570961, 570981, 570992, 570996, 570995, 570987, 570969, 570950, 570940, 570900, 570898, 570850, 570838, 570800, 570750, 570728, 570700, 570650, 570600, 570550, 570500, 570450, 570437, 570400, 570350, 570307, 570300, 570250, 570222, 570200, 570159, 570150, 570109, 570100, 570067, 570050, 570035, 570010, 570000

Scenario VE-7/8

In this section we assess the epicentral uncertainty for a scenario event at the planned mining site VE-7/8. Fig. 8 shows the seismic sensors where manual P-wave picks would be available for this event. A grid search is done for a region around the Hypocenter solution, as indicated by the red box in Fig. 8. Fig. 9 shows the 95% confidence area of the resulting PDF.

In the following, the relevant input and output is listed. The scenario epicenter is listed both in wgs84 and in the Dutch national triangulation system (RD). Also a gridded version of the 95% confidence contour of the PDF, and its major and minor axes, can be found.

Epicenter in wgs84 [deg]: 6.814, 53.099

Epicenter in RD [m]: 250550, 569000

PDF major axis [m]: 1414

PDF minor axis [m]: 795

Orientation of the PDF ellipse [deg]: -12.8

95% confidence contour RDx [m]: 250565, 250600, 250650, 250700, 250750, 250767, 250800, 250834, 250850, 250876, 250900, 250905, 250928, 250944, 250950, 250958, 250969, 250977, 250981, 250983, 250983, 250981, 250976, 250969, 250958, 250950, 250946, 250935, 250919, 250900, 250898, 250880, 250852, 250850, 250827, 250800, 250792, 250753, 250750, 250706, 250700, 250650, 250645, 250600, 250550, 250546, 250500, 250450, 250400, 250381, 250350, 250300, 250295, 250250, 250249, 250216, 250200, 250193, 250174, 250162, 250154, 250150, 250150, 250146, 250146, 250149, 250150, 250153, 250158, 250166, 250176, 250191, 250200, 250206, 250221, 250243, 250250, 250264, 250289, 250300, 250316, 250350, 250350, 250385, 250400, 250429, 250450, 250484, 250500, 250550, 250565

95% confidence contour RDy [m]: 568300, 568284, 568274, 568275, 568290, 568300, 568318, 568350, 568366, 568400, 568442, 568450, 568500, 568550, 568573, 568600, 568650, 568700, 568750, 568800, 568850, 568900, 568950, 569000, 569050, 569079, 569100, 569150, 569200, 569244, 569250, 569300, 569350, 569354, 569400, 569438, 569450, 569500, 569504, 569550, 569556, 569597, 569600, 569630, 569649, 569650, 569663, 569666, 569658, 569650, 569639, 569605, 569600, 569551, 569550, 569500, 569464, 569450, 569400, 569350, 569300, 569250, 569250, 569200, 569150, 569100, 569094, 569050, 569000, 568950, 568900, 568850, 568825, 568800, 568750, 568700, 568685, 568650, 568600, 568581, 568550, 568500, 568500, 568450, 568432, 568400, 568378, 568350, 568336, 568306, 568300

Depth uncertainty

A well callibrated 3D P-wave velocity model is available for the region (*Romijn*, 2017). For scenario TR-1 and VE5/6, the 5 and 4 stations within the 5.5 km range (Figs. 5 & 7) would allow for a similar depth-estimate precision as can be obtained for most of the events within the Groningen network (*Spetzler et al.*, 2018). For scenario VE7/8, also 5 stations are available within a 5.5 km radius (Fig. 9). However, there is a large azimuthal monitoring gap at the south-southeastern side of this potential mining site. This will result in a somewhat larger depth uncertainty than for sites TR-1 and VE5/6.

References

Romijn, R. (2017), Groningen velocity model 2017, *Tech. rep.*, NAM (Nederlands Aardolie Maatschappij).

Spetzler, J., E. Ruigrok, and B. Dost (2018), Improved 3D hypocenter method for induced earthquakes in Groningen, Nederlands Aardwetenschappelijk Congres, March 15-16. Veldhoven, the Netherlands.

Tarantola, A. (2005), *Inverse Problem Theory and Methods for Model Parameter Estimation*, SIAM, Philadelphia.

Zhou, H.-w. (1994), Rapid three-dimensional hypocentral determination using a master station method, *Journal of Geophysical Research: Solid Earth*, *99*(B8), 15,439–15,455.

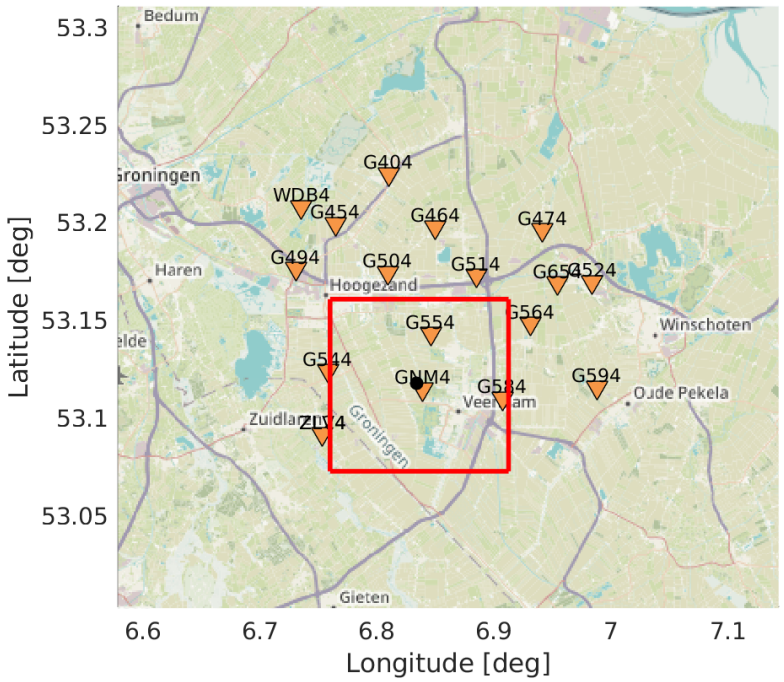

Figure 4: Overview map with locations of stations (yellow triangles) where P-wave onsets are picked, the scenario epicenter (black dot) at existing salt cavern TR-1 and the boundary line of the area in which a grid search is done (red box). Background map is from www.openstreetmap.org.

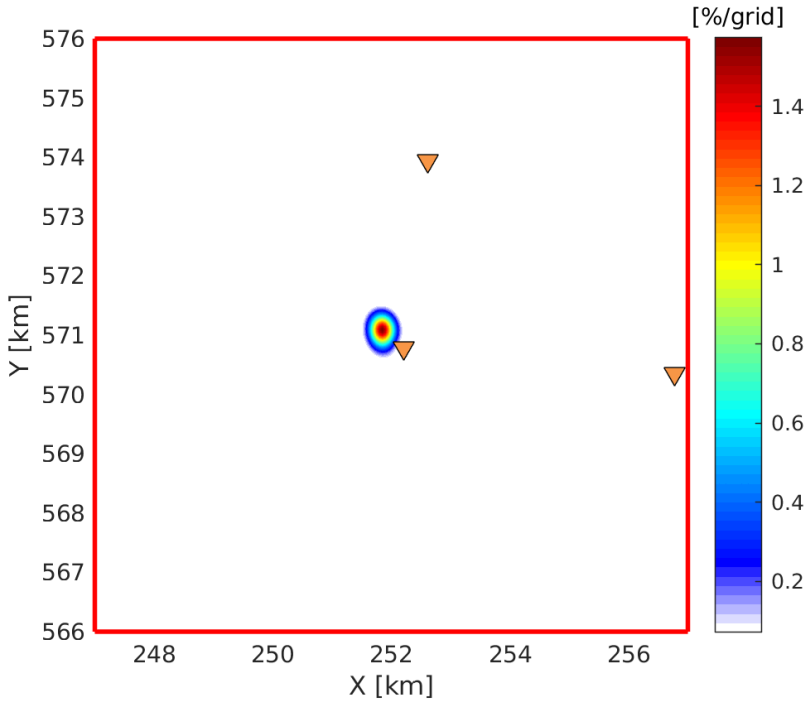

Figure 5: Map showing the epicentral probability density function (PDF) for a scenario event at existing salt cavern TR-1. The 95% confidence area of the PDF is shown, with probabilities expressed in percentage per grid point.

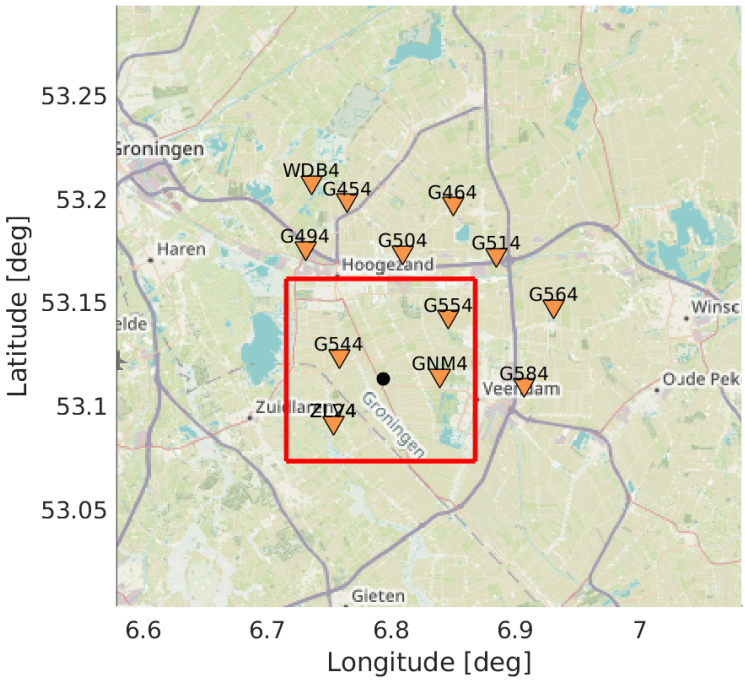

Figure 6: Overview map with locations of stations (yellow triangles) where P-wave onsets are picked, the scenario epicenter (black dot) at planned salt cavern VE-5/6 and the boundary line of the area in which a grid search is done (red box). Background map is from www.openstreetmap.org.

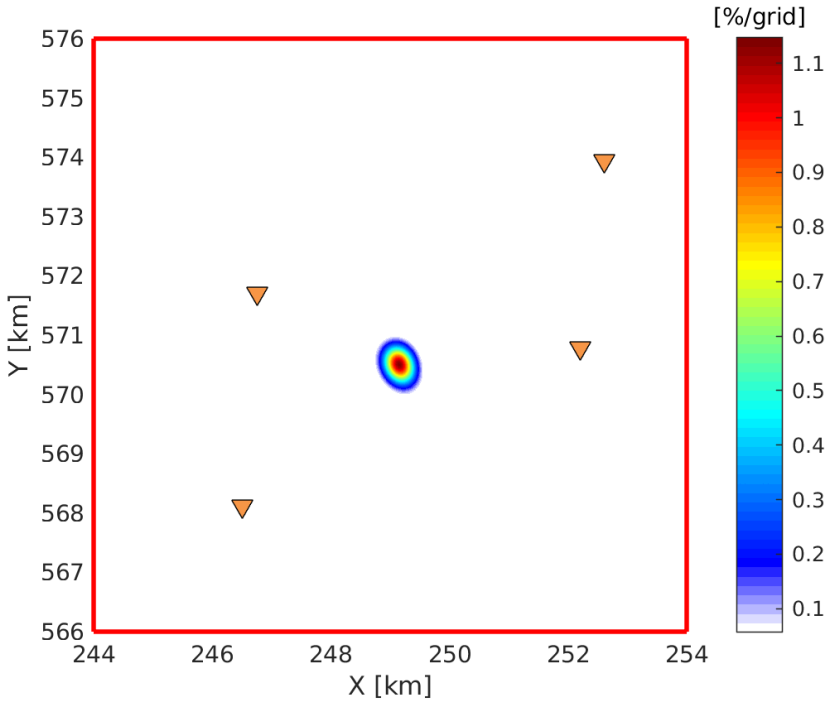

Figure 7: Map showing the epicentral probability density function (PDF) for a scenario event at planned salt cavern VE-5/6. The 95% confidence area of the PDF is shown, with probabilities expressed in percentage per grid point.

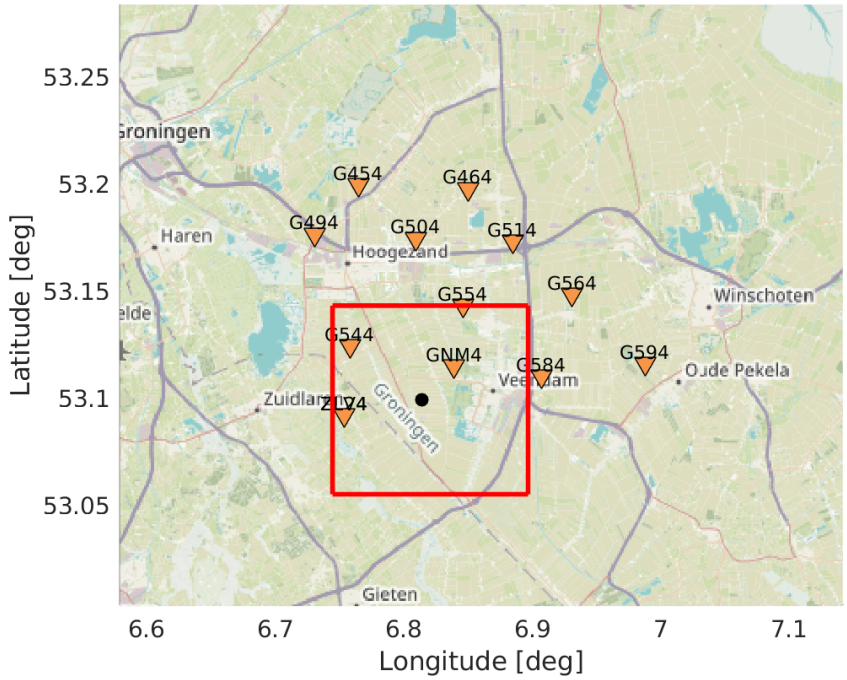

Figure 8: Overview map with locations of stations (yellow triangles) where P-wave onsets are picked, the scenario epicenter (black dot) at planned salt cavern VE-7/8 and the boundary line of the area in which a grid search is done (red box). Background map is from www.openstreetmap.org.

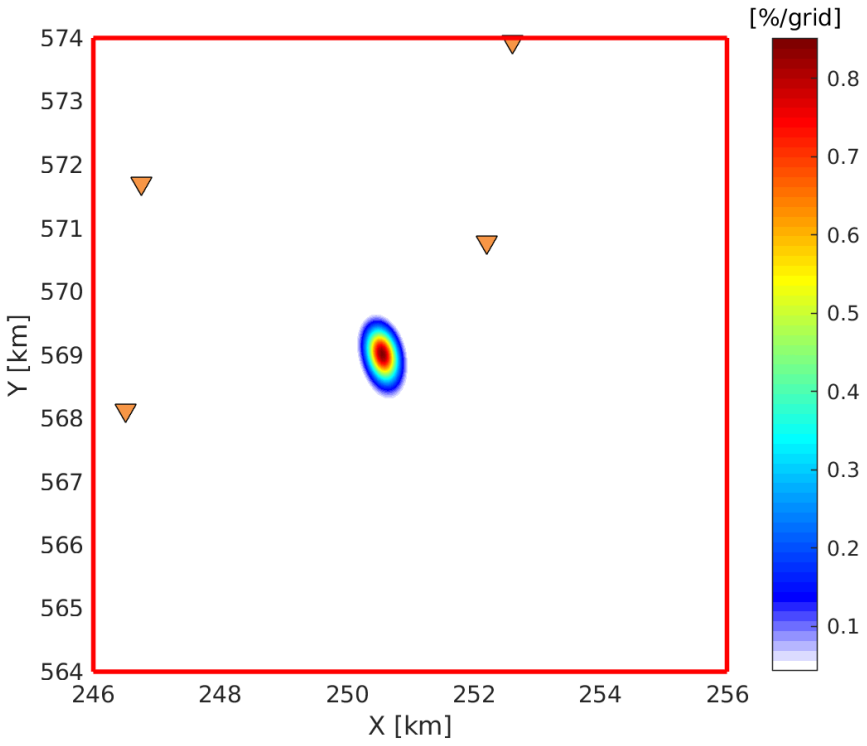

Figure 9: Map showing the epicentral probability density function (PDF) for a scenario event at planned salt cavern VE-7/8. The 95% confidence area of the PDF is shown, with probabilities expressed in percentage per grid point.