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PGV levels and location uncertainty for the Winde 27-09-2020 event

E. Ruigrok and B. Dost

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Introduction

The Winde event on 27-09-2020:01:39:45 UTC with a local magnitude of 1.83 was detected by the KNMI network (*KNMI*, 1993) and located near-real time with the Hypocenter method (*Lienert et al.*, 1986). In this report, an updated epicenter and its uncertainty are listed. Moreover, peak-ground velocity (PGV) contours are computed with the approach detailed in *Ruigrok and Dost* (2020) as a test of the proposed method.

Location

In the operational chain, the Hypocenter method (*Lienert et al.*, 1986) is used to provide a fast location. Location is done with an average 1D model for the north of the Netherlands (*Kraaijpoel and Dost*, 2013). Here the epicenter is improved by using a best-fitting traveltime versus distance model based on a database of local P-wave traveltime picks. This data-driven model naturally incorporates actual underburden velocities and only well pickable phase arrivals. An error estimate is derived from the spread in picking times from the best-fitting model. This error incorporates both the local variations of the velocity field as well as picking errors. These errors are propagated further into an epicentral probability density function (PDF). This results into an updated epicenter and its 95% confidence region.

Fig. 1 shows the seismic sensors where manual P-wave picks are available for this event. A grid search is done for a region around the Hypocenter solution, as indicated by the red box in Fig. 1. 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 is derived from the EDT residuals, using a L1 norm (*Tarantola*, 2005). Fig. 2 shows the 95% confidence area of the resulting PDF. The location with the maximum probability is assigned to be the new epicenter.

In the Groningen region, events are relocated using a detailed 3D P-wave velocity model (*Romijn*, 2017), together with raytracing and an EDT algorithm (*Spetzler et al.*, 2018). Within the region with good station coverage, also a depth estimate is found. The Winde event is within the bounds of this 3D model, as are a few surrounding stations. The epicentral location found with the 3D model is on the edge of the 95% confidence zone as found in the preceeding (Figure 3). The hypocenter depth is estimated to be 3.3 km.

In the following the relevant parameters are listed. The new 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]: 6.4941, 53.1224

Epicenter in RD [m]: 229100, 571200

PDF major axis [m]: 664

PDF minor axis [m]: 440

Orientation of the PDF ellipse [deg]: -42.3

95% confidence contour RDx [m]: 229083, 229100, 229150, 229200, 229250, 229300, 229335, 229350, 229376, 229391, 229394, 229389, 229375, 229350, 229347, 229319, 229300, 229277, 229250, 229219, 229200, 229150, 229132, 229100, 229050, 229000, 228950, 228906, 228900, 228860, 228850, 228844, 228840, 228850, 228850, 228860, 228883, 228900, 228913, 228950, 228956, 229000, 229008, 229050, 229083, 229083

95% confidence contour RDy [m]: 570950, 570938, 570917, 570909, 570910, 570924, 570950, 570965, 571000, 571050, 571100, 571150, 571200, 571243, 571250, 571300, 571322, 571350, 571376, 571400, 571416, 571444, 571450, 571468, 571481, 571484, 571476, 571450, 571446, 571400, 571366, 571350, 571300, 571250, 571250, 571200, 571150, 571126, 571100, 571057, 571050, 571006, 571000, 570965, 570950, 570950

The underlying waveform data used in the above analysis is publicly available and can be obtained through

a GUI: http://rdsa.knmi.nl/dataportal/

FDSN webservices: http://rdsa.knmi.nl/fdsnws/dataselect/1/

PGV levels

For induced events outside Groningen, the protocol as established in *Ruigrok and Dost* (2020) is used to compute PGV[1] contours. Contours are computed for the P50, P90 and P99 probabilities. The P50 is the average field, which thus has a 50% probability of exceedance. The P90 is the 90th percentile, which PGV field has a 10% probability of exceedance. The P99 has a 1% probability of exceedance.

The PGV field is a combination of a model and local recordings. As a model is used BMR2, which is a ground-motion prediction equation that has been calibrated with 3291 PGV recordings. The used events are induced earthquakes in the northern half of the Netherlands, that occured between 1997 and 2019 and have magnitudes in the range 1.5 to 3.6. This model gives the PGV level as function of magnitude, distance and depth of the event. The recordings are used to estimate and remove an event term from the model and to perturb the modeled PGV field in the direct vicinity of the recordings. From the combined PGV field, PGV contours are extracted with levels of 2, 3, 4, 5, 10 mm/s until the maximum level, with steps of 5 mm/s.

For the Winde event, all accelerometer recordings at distances smaller than $R_{max} = 6 + 40M =$ 79 km are evaluated, which yields 21 recordings with a signal-to-noise ratio larger or equal to 6 dB. The nearest and furthest accepted stations are at 1.46 and 24.21 km, respectively. Table 1 lists the PGV values. Fig. 4 shows these recorded PGV values as function of epicentral distance, together with the event-term shifted BMR2 model for M=1.83. The gas-water contact of the (former) Roden gasfield is at 3 km depth. As hypocenter depth, 3.3 km is taken, as was found with the 3D EDT method.

Using the 21 recordings, the event term is computed to be 0.0463. This is the average difference between modeled and recorded PGV levels (expressed in natural log). With the event term quantified, the remaining model variability is the within-event variability $\phi = 0.536$. This remaining variability is implemented to yield the confidence regions as plotted in Fig. 4. In this figure it can be seen that only the P99 field reaches PGV levels of 2 mm/s and higher.

After perturbing the modeled PGV levels (Fig. 4) with the recorded PGVs, the maximum PGV

[1] In this report, as PGV measure we use 'PGVrot', which is defined as $max(\sqrt{u_E^2(t) + u_N^2(t)})$, where $u_E(t)$ and $u_N(t)$ are the particle-velocity recording on the East and North component, respectively.

Station name	Epicentral distance [km]	PGV [mm/s]
N010	1.46	0.716
N020	6.25	0.210
G660	8.78	0.057
G380	9.39	0.093
G710	10.83	0.083
VRS	12.12	0.020
ASS2	13.07	0.026
G720	13.81	0.052
G690	14.17	0.059
G440	15.59	0.060
ASS1	16.64	0.039
G490	16.88	0.061
G540	17.61	0.014
GK040	17.75	0.022
G260	18.09	0.028
G390	19.13	0.045
ELE	19.27	0.012
BFB2	19.49	0.020
G280	22.86	0.034
G340	23.14	0.025
G220	24.21	0.025

Table 1: Recorded PGVs

level in the P99 field becomes 1.81 mm/s. Since the lowest PGV level of interest was defined to be at 2 mm/s, no contour is drawn for this earthquake.

References

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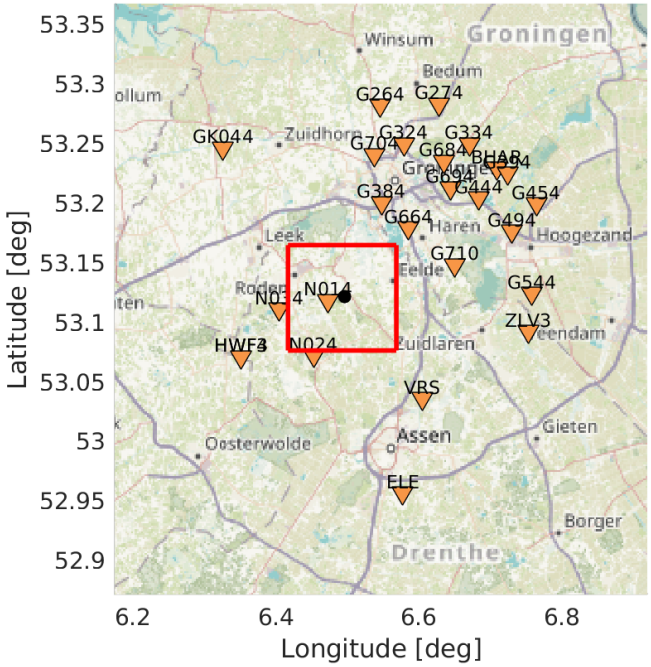

Figure 1: Overview map with locations of stations (orange triangles) where P-wave onsets were picked, the fast Hypocenter solution (black dot) and the boundary line of the area in which a grid search is done (red box). Background map is from www.openstreetmap.org.

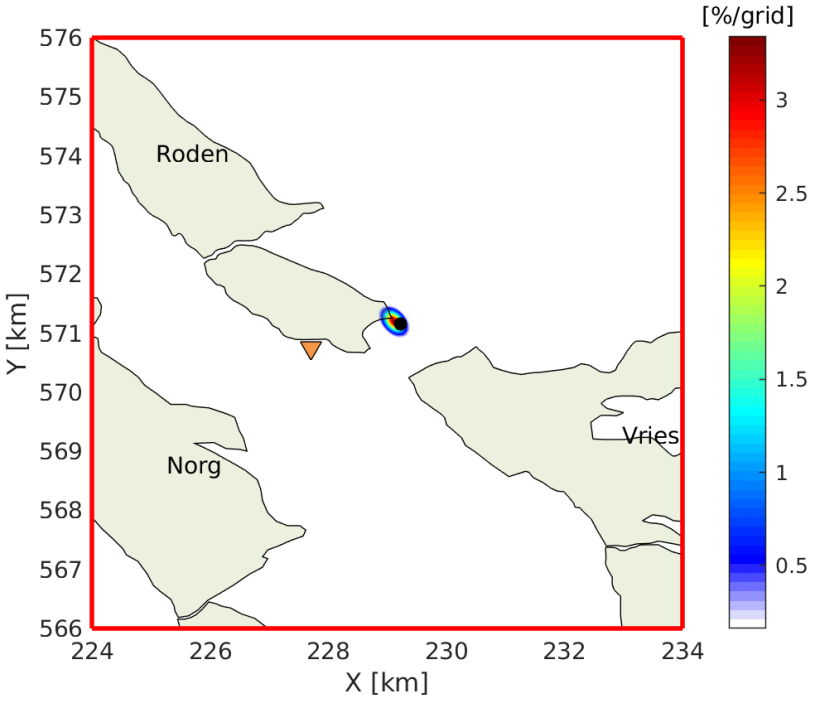

Figure 2: Map showing (former) hydrocarbon fields (green-filled polygons), the fast Hypocenter solution (black dot) and the epicentral probability density function (PDF) using time-differences and an optimized model. The 95% confidence area of the PDF is shown, with probabilities expressed in percentage per grid point. The field polygons are from www.nlog.nl, using the March 2020 update.

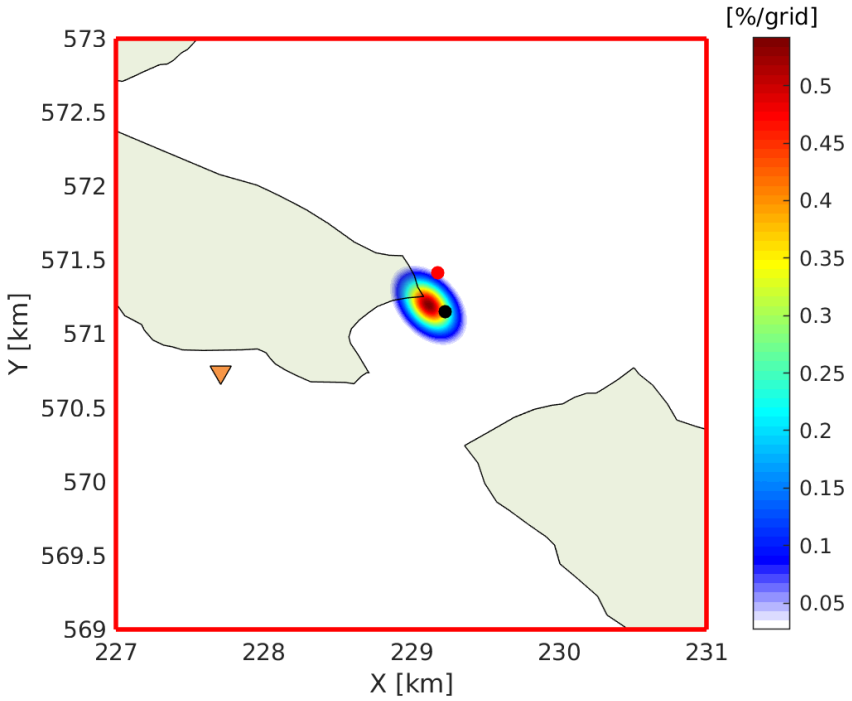

Figure 3: A detail of Figure 2 with the epicenter added as found with 3D EDT (red dot).

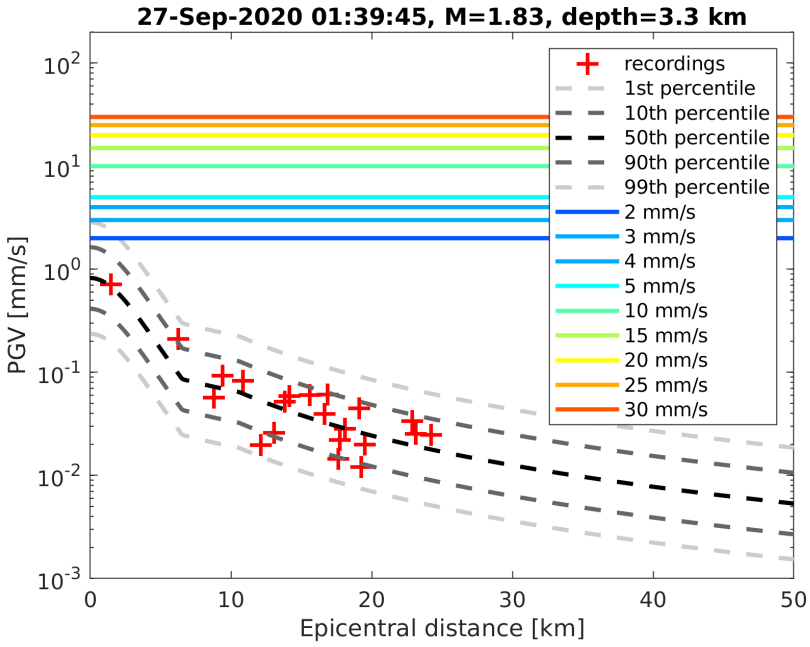

Figure 4: BMR2 model and confidence regions for this model (dashed lines), PGV thresholds (coloured lines) and measured PGV values for the Winde event (red crosses). Both the model and the recordings are expressed in PGVrot.

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PO Box 201 | NL-3730 AE De Bilt
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