Special Report on the earthquake near Zeerijp on 11th April 2024 with a magnitude M_L 2.1

Michail Ntinalexis

Datum April 2024

General Introduction

On 11 April 2024 an earthquake with magnitude M_L=2.1 was recorded with an epicentre near Zeerijp. In this report, the recordings of this earthquake are analysed in support of the half-yearly seismic monitoring report for Groningen (Ref. 1). This analysis was performed to establish peak ground velocity and peak ground acceleration for the earthquake with the largest magnitude during the reporting period of this monitoring report. The results show no surprises. Given the large number of earthquakes previously recorded with this or similar magnitude this was to be expected.

References:

1. Rapportage Seismiciteit Groningen – Mei 2024, Jan van Elk and Onno van der Wal, Mei 2024.

NAM

Title	**Special Report on the earthquake near Zeerijp on 11th April 2024 with a magnitude M_L 2.1**	**Date**	April 2024
		Initiator	NAM
Autor(s)	Michail Ntinalexis	**Editors**	Jan van Elk
Organisation	Independent expert	**Organisation**	NAM
Place in the Study and Data Acquisition Plan	Study Theme: Ground Motion Prediction Comment: On 11 April 2024 an earthquake with magnitude M_L=2.1 was recorded with an epicentre near Zeerijp. In this report, the recordings of this earthquake are analysed in support of the half-yearly seismic monitoring report for Groningen (Ref. 1). This analysis was performed to establish peak ground velocity and peak ground acceleration for the earthquake with the largest magnitude during the reporting period of this monitoring report. The results show no surprises. Given the large number of earthquakes previously recorded with this or similar magnitude this was to be expected.		
Directliy linked research	(1) Seismic Monitoring Groningen gas field. (2) Hazard Assessment.		
Used data	Accelerograms from the accelerometers placed in the Groningen area.		
Associated organisation			
Assurance			

An Analysis of the Surface Ground-Motions Recorded During the Zeerijp ML 2.1 Earthquakes of 11 April 2024

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28 April 2024

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Introduction

On Thursday 11 April 2024, at 09:10 UTC, an earthquake of local magnitude (M_L) of 2.1 occurred near the village of Zeerijp, in the northern part of the Groningen field (Figure 1). The WGS84 epicentral coordinates provided by the online platform of the KNMI (1993) are N53.36°, E6.74°, which corresponds to 245084, 596801 in the RD coordinate system (Figure 1). The focal depth assigned by the KNMI is 3 km, the average depth of the gas-bearing sandstone where the Groningen earthquakes occur. The last event with a magnitude equal or larger to M_L1.8–the lower end of the magnitude range of applicability of the current empirical ground-motion prediction equations (GMPEs) used to estimate values of peak ground velocity (PGV) occurring during earthquakes in the Groningen field (Bommer *et al*., 2021)-was the M_L1.9 Zandeweer earthquake of 15 September 2023.

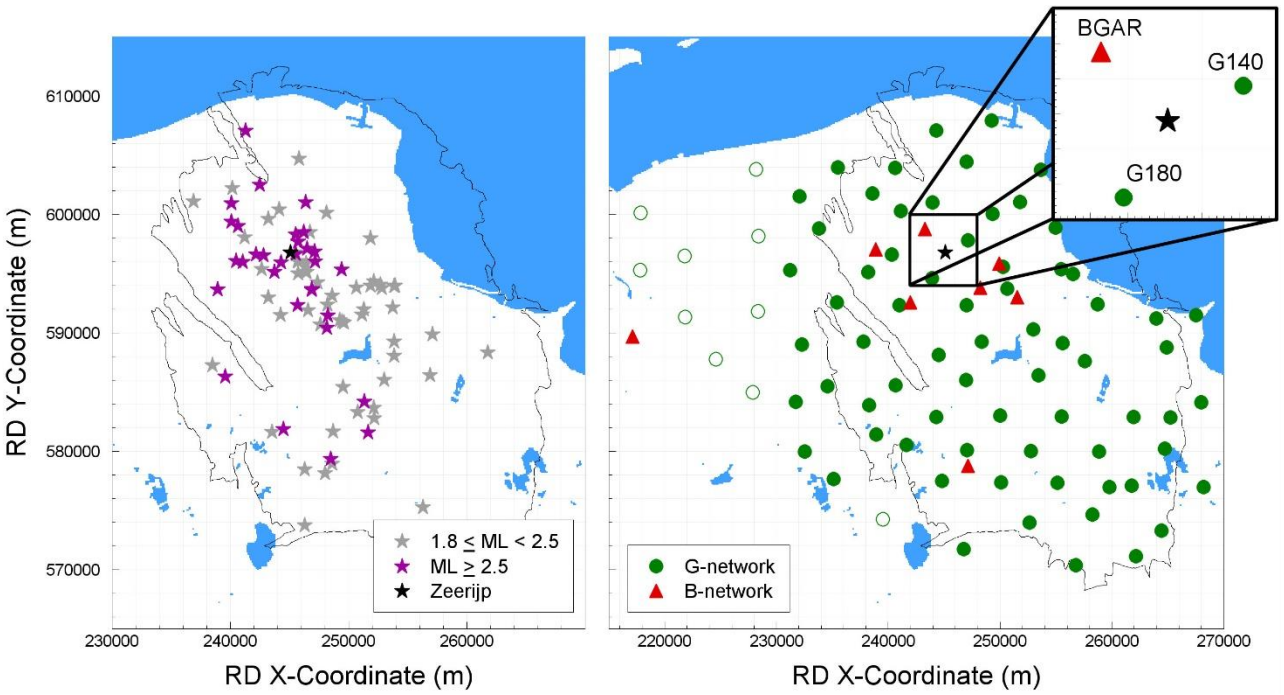

Figure 1. Epicentre of Zeerijp earthquake (*black star*) together with epicentres of previous earthquakes of $M_L \geq 2.5$ (*red stars*) and of M_L 1.8-2.4 (*blue stars*) from the database of Ntinalexis *et al*. (2023), and the locations of the KNMI stations in the Groningen region

A total of 79 three-component recordings from the surface stations of the KNMI B- and G-networks were downloaded for this preliminary assessment of the motions. The records were processed as described by Edwards & Ntinalexis (2021). Figure 2 shows the usable recordings in the magnitude-distance occupied by the database used to derive the empirical PGV GMPEs (Ntinalexis *et al*., 2023). This report presents an overview of the recorded motions from the Zeerijp events in terms of their amplitudes and discusses how the recorded amplitudes of motion compare with predictions from the empirical PGV GMPE. The discussions focus primarily on peak ground acceleration (PGA), which is assumed equal to the spectral acceleration at a period of 0.01 seconds, and PGV.

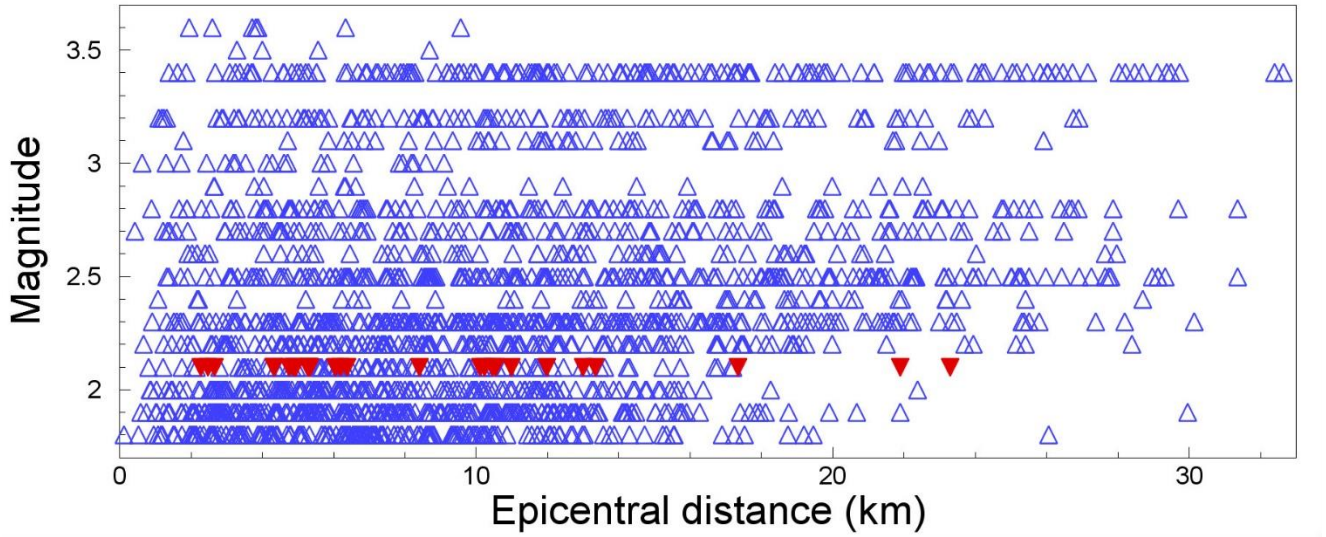

Figure 2. Magnitude-distance distribution of the Groningen strong-motion database including the recordings of the 11 April 2024 Zeerijp earthquake

Peak Ground Accelerations and Velocities

Figures 3 and 4 show the horizontal values of PGA and PGV of three component definitions from each recording obtained during the Zeerijp earthquake plotted against the distance of the recording site from the epicentre. The largest amplitudes of ground-motion were recorded by the H2 (EW) component of station G140, which is the closest station to the epicentre at a distance of 2.27 km; the largest value of PGA is 7.44 cm/s^2, while the largest PGV value is 0.176 cm/s. The second-largest horizontal PGA and PGV values were recorded at station BGAR, 2.65 km from the epicentre, and are 5.14 cm/s^2 and 0.124 cm/s, respectively.

From Figures 3 and 4 it is immediately apparent that the amplitudes of motion are consistent with previous earthquakes of comparable size. Figure 5 shows the horizontal components of PGA and PGV obtained within 5 km of the epicentres, from which it can be appreciated that the very strong polarisation often observed in Groningen recordings (*e.g.*, Bommer *et al.*, 2017a) is also apparent in records of this event. As already shown in Figures 3 and 4, the amplitudes decay rapidly with distance and it is clear that outside the epicentral area, the motions are of low amplitude: < 0.015*g* for PGA and < 0.1 cm/s for PGV.

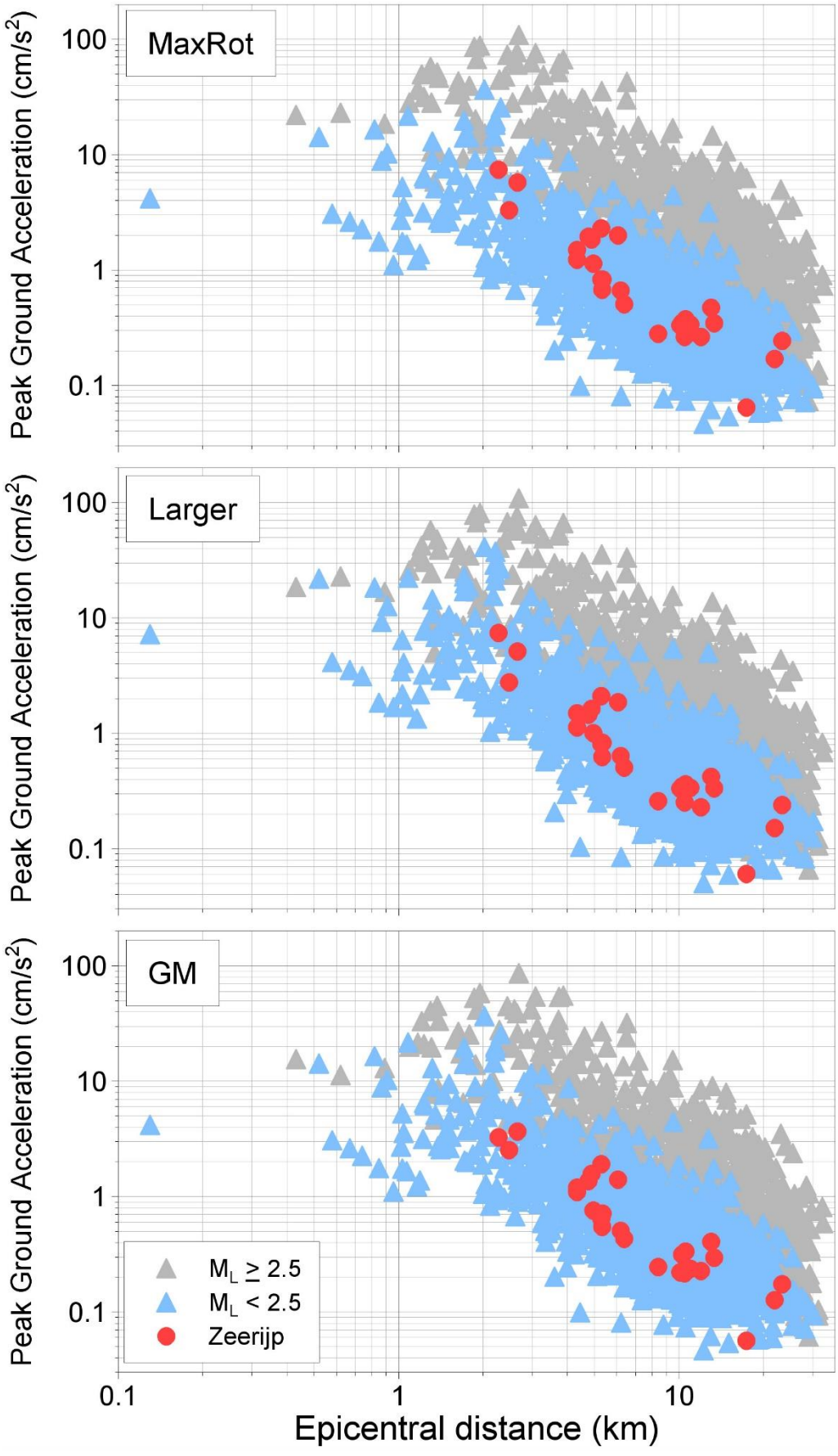

Figure 3. Horizontal components of PGA recorded during the Zeerijp earthquake and previous earthquakes plotted against epicentral distance

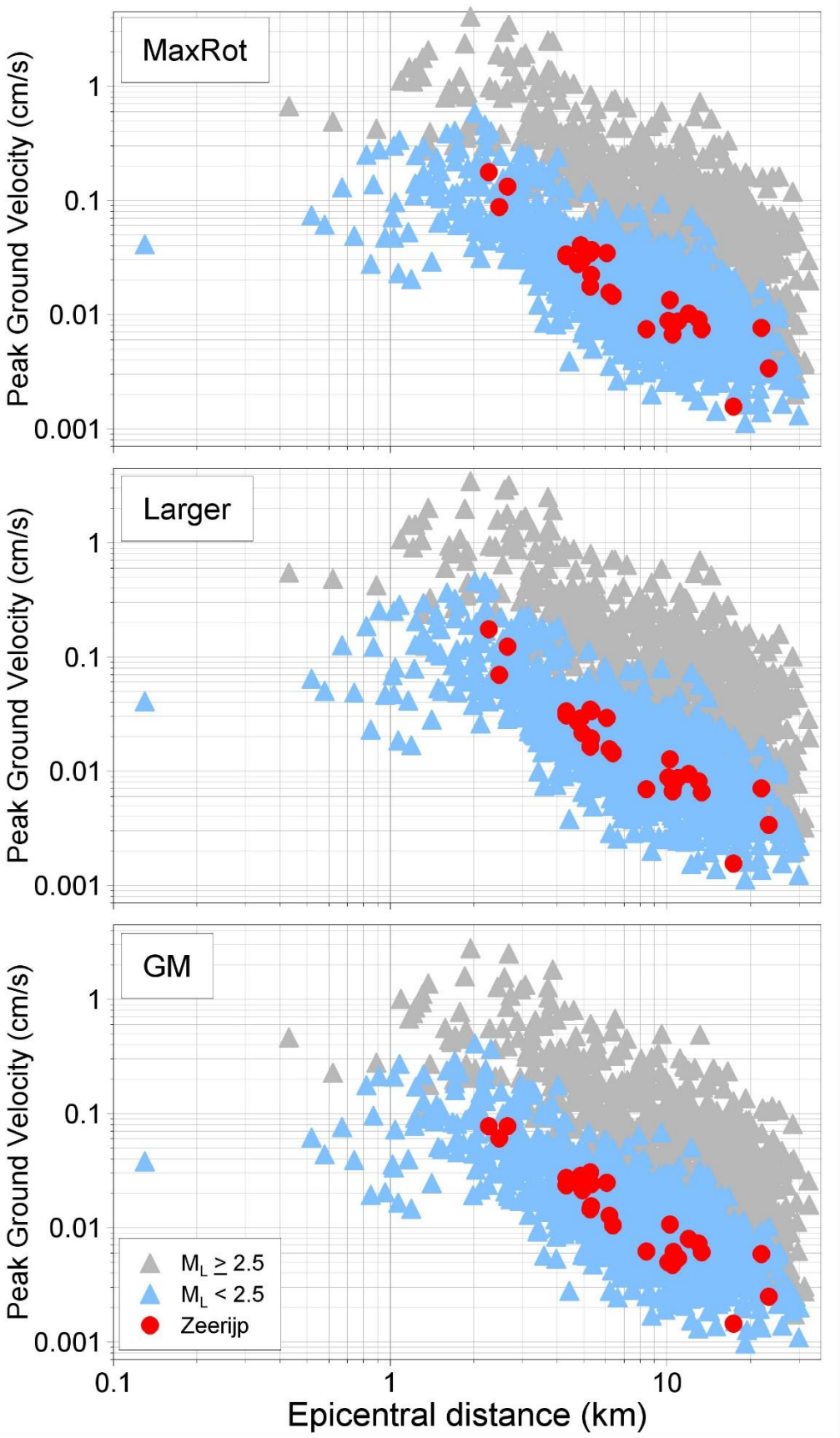

Figure 4. Horizontal components of PGV recorded during the Zeerijp earthquake and previous earthquakes plotted against epicentral distance

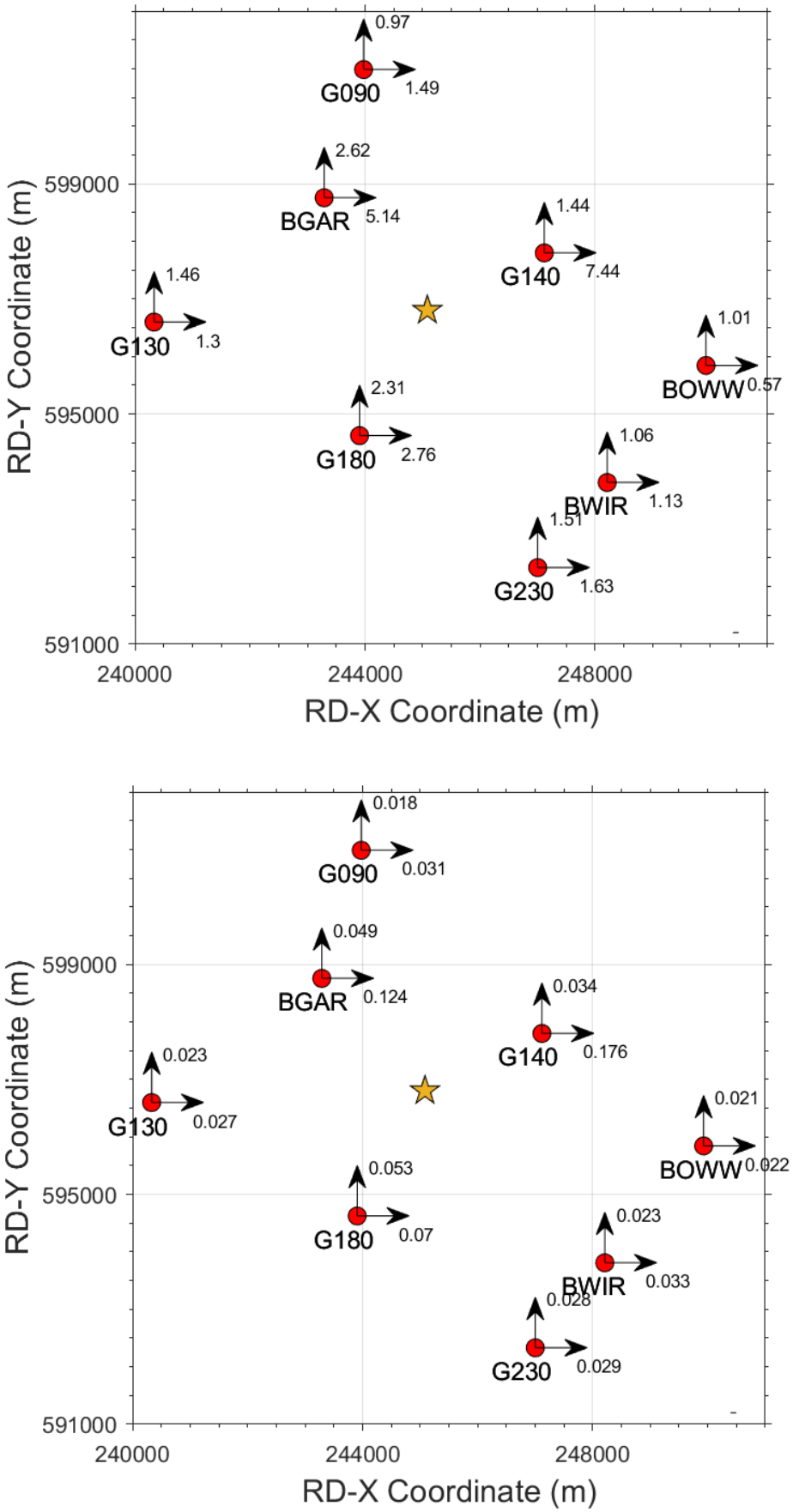

Figure 5. Horizontal components of PGA (*upper*) and PGV (*lower*) recorded during the M_L2.1 Zeerijp event earthquake at epicentral distances of less than 5 km; units are cm/s^2 and cm/s, respectively.

Overall, the motions appear similar to those observed in previous earthquakes. Figure 6 shows the geometric mean horizontal components of PGA and PGV plotted against magnitude together with the corresponding values from the complete database. The amplitudes recorded are well within the bounds of the amplitudes that have been previously observed during events of the same magnitude in Groningen, with the exception of one record that appears to have smaller amplitude. On average, the PGA and PGV values of the Zeerijp event appear to be centred marginally below the centre of the values recorded during previous events of the same magnitude. Figures 7 and 8 show the acceleration and velocity traces from the strongest two records, as well as the accumulation of Arias Intensity.

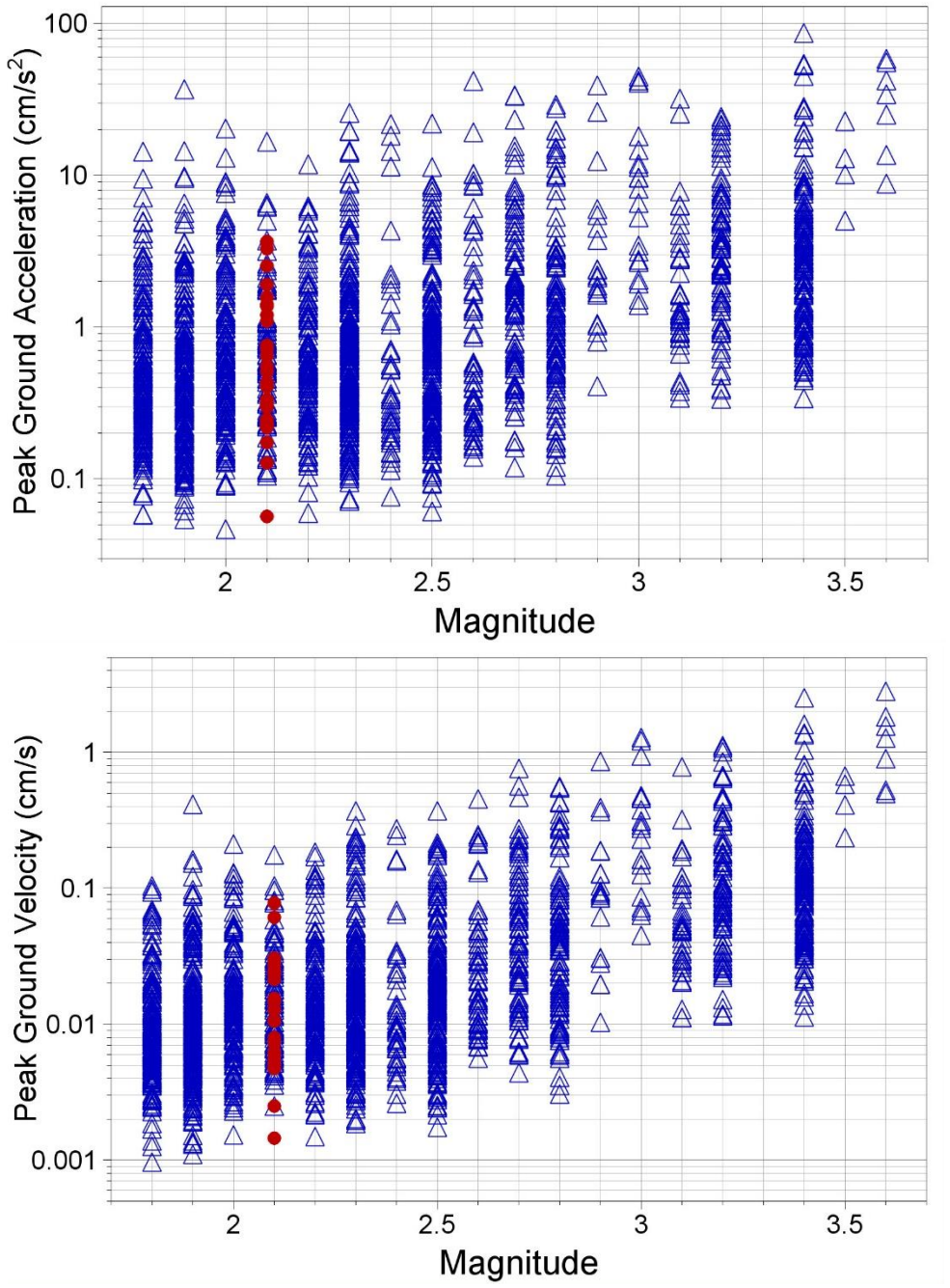

Figure 6. Geometric mean horizontal components of PGA (*upper*) and PGV (*lower*) recorded during the Zeerijp earthquake (*red*) and in previous earthquakes (*blue*) plotted against local magnitude (M_L)

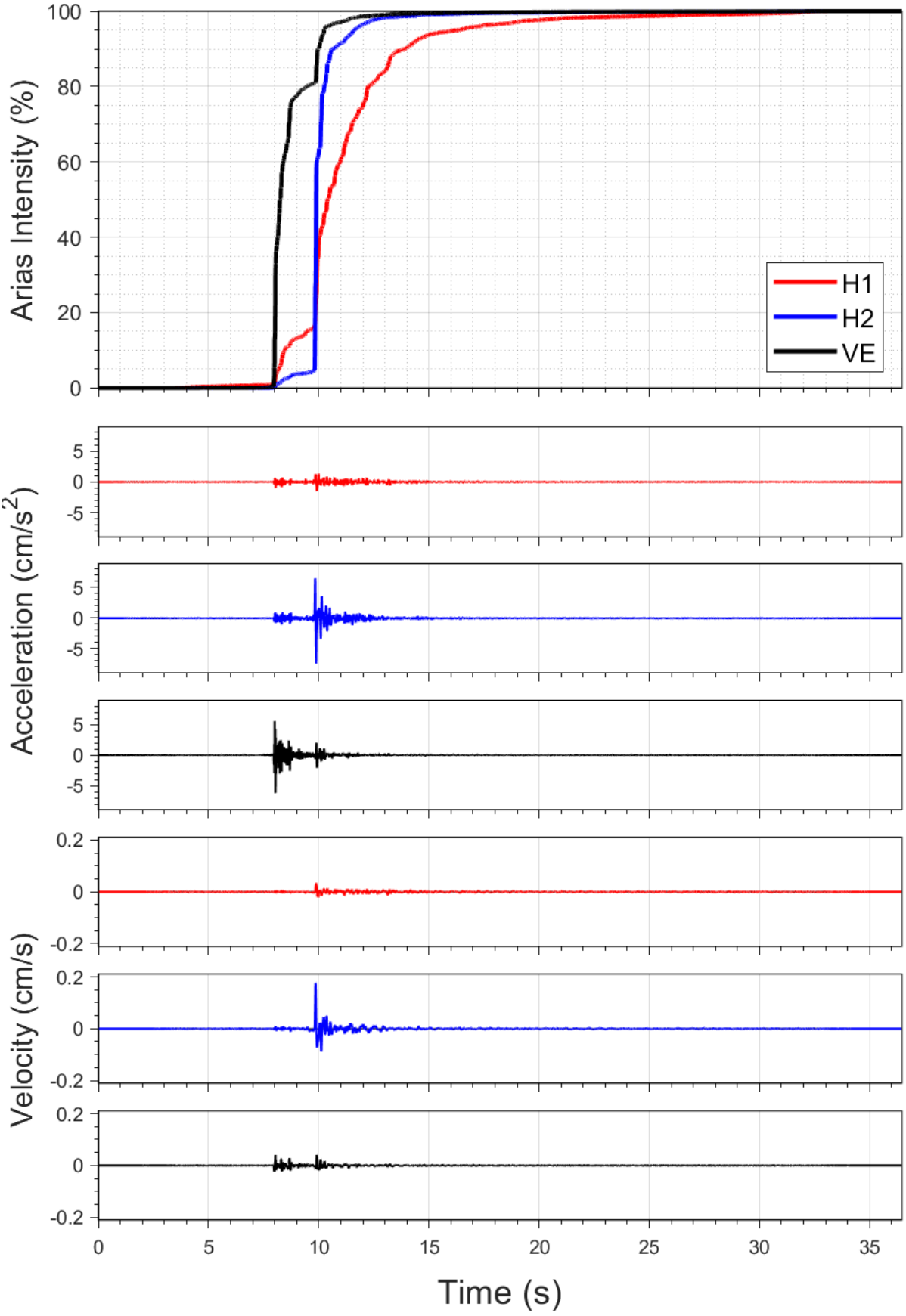

Figure 7. Horizontal components of acceleration and velocity recorded at the G140 station during the Zeerijp earthquake; the upper frame shows the accumulation of Arias intensity (energy) over time.

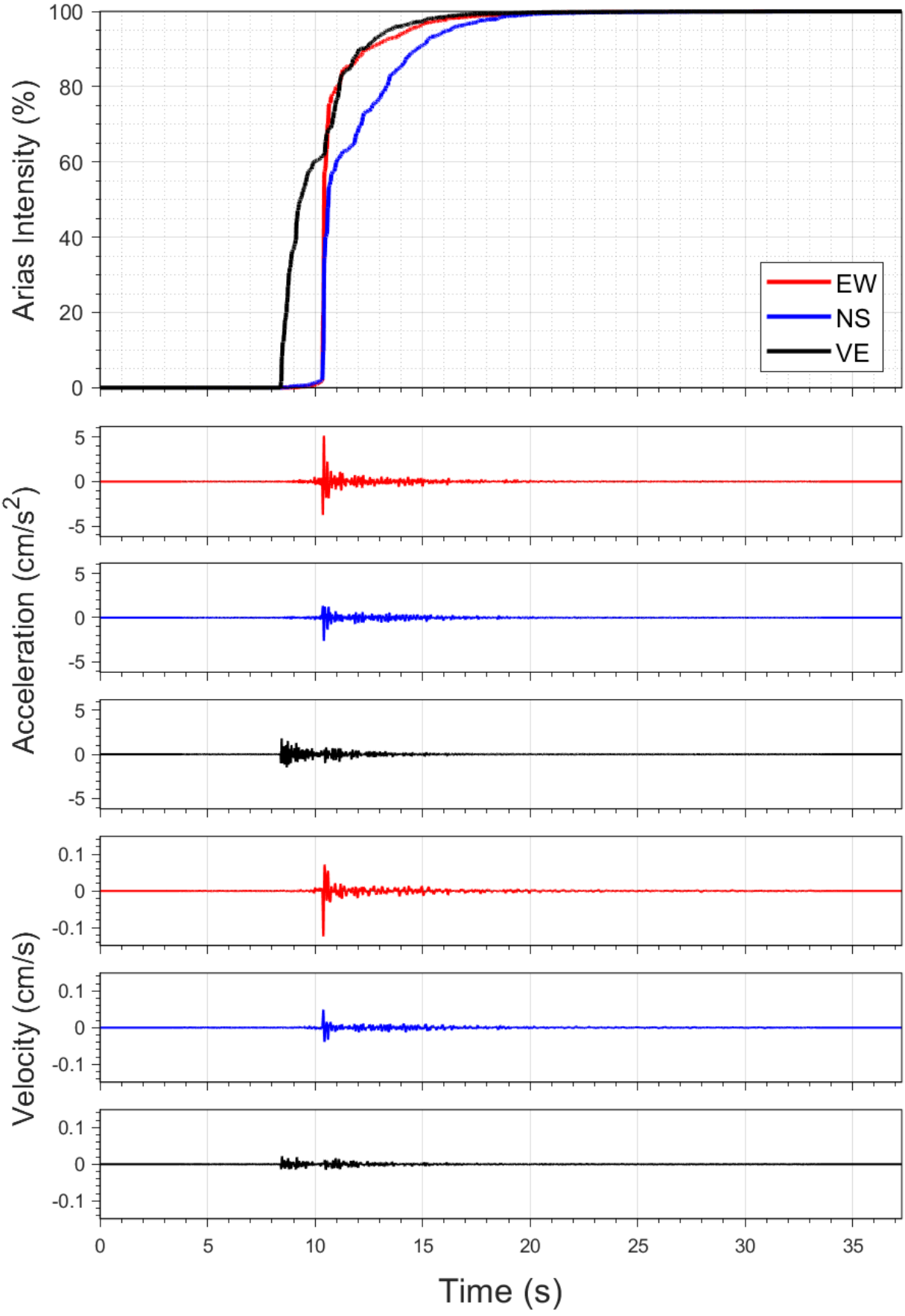

Figure 8. Horizontal components of acceleration and velocity recorded at the BGAR station during the Zeerijp earthquake; the upper frame shows the accumulation of Arias intensity (energy) over time.

Spectral Accelerations and Comparison with Ground-Motion Models

Additional insight into the nature of the ground motions can be obtained from the 5%-damped acceleration response spectra. The horizontal acceleration response spectra from the G140 of the Zandeweer earthquake are shown in Figure 9. The spectral shapes are consistent with previous observations in the field. The divergence between the red and blue curves in both frames shows that the horizontal polarisation of both recordings seen for PGA and PGV (Figures 7 & 8) persists across the entire range of usable response periods. Additionally, and consistently with observations during previous events (Bommer *et al*., 2017b), the vertical component of record G140 displays amplitudes which are large in comparison to the horizontal components at short oscillator periods.

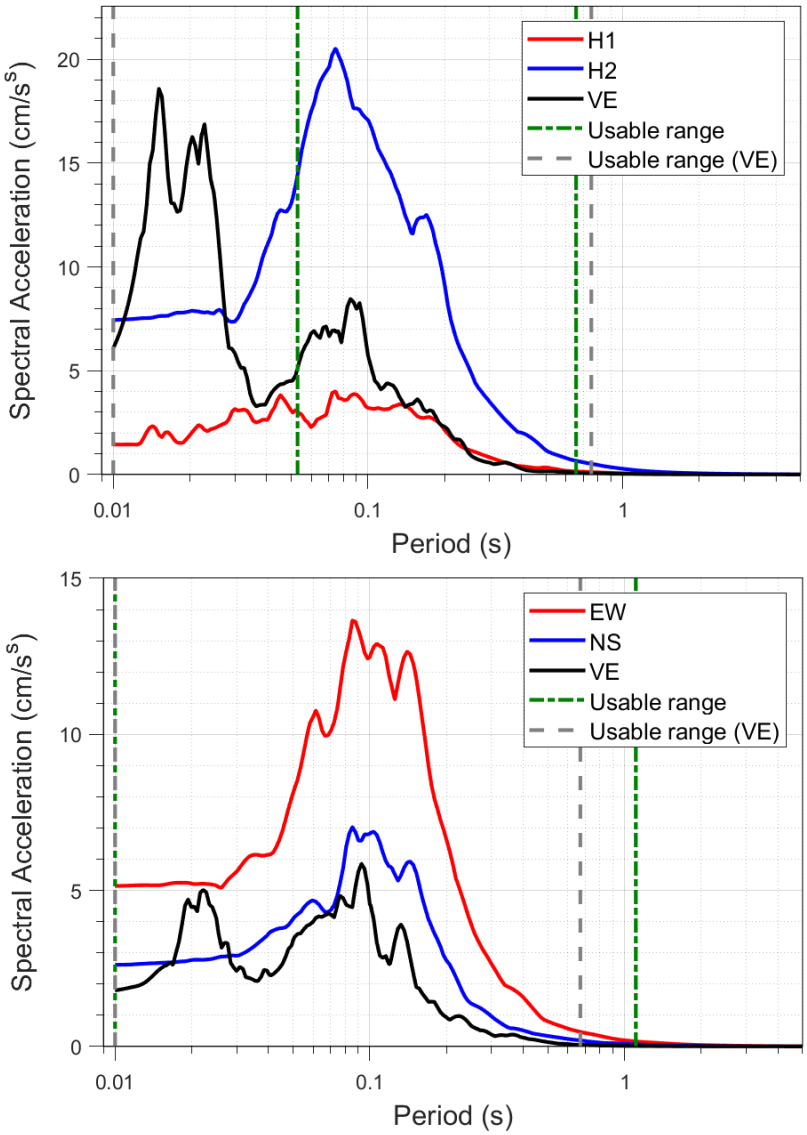

Figure 9. Horizontal response spectra from the records obtained at the G140 (upper) and BGAR (lower) stations events; vertical spectra plotted as dashed lines beyond maximum usable period.

For this preliminary analysis, the key question of interest is whether the motions recorded in this earthquake are consistent with the current GMM and empirical PGV GMPEs being used in the Groningen field. The current empirical PGV model was developed in 2021 (Bommer

et al., 2021) and we have calculated the total, inter- and intra- event residuals. In each case, the residual is the natural logarithm of the ratio of the observed (recorded) to the median predicted value, so a residual of 0.7 indicates that the recorded value was underestimated by a factor of 2 by the model and a residual of -0.7 would indicate over-prediction by a factor of 2. Figures 10 shows the intra-event residuals of three component definitions of PGV with respect to the empirical GMPE plotted against hypocentral distance. Nearly all within-event residuals of the Zeerijp earthquake recordings are within one standard deviation of the zero line, while all residuals are within two standard deviations, which suggests that the model captures well the variability of the data.

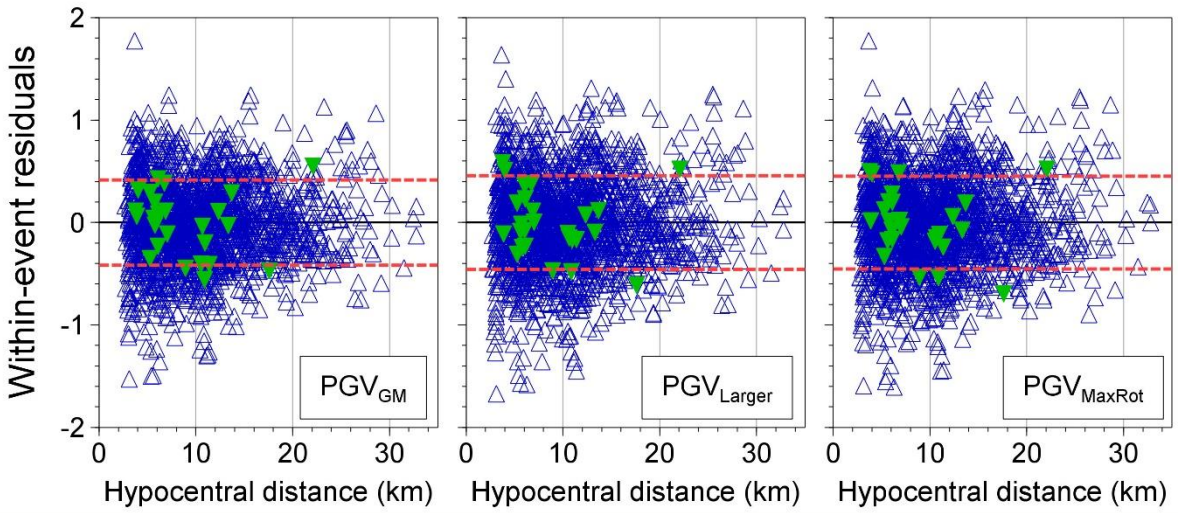

Figure 10. Event- and station-corrected within-event residuals of three component definitions of PGV with respect to the equations of the empirical PGV GMPE (Bommer *et al*., 2021b). Residuals of the M_L2.1 Zeerijp earthquake recordings are shown in *green* and of other events in *blue*. The within-event standard deviation (φ_{SS}) is shown in *red dashed* lines.

Figure 11 compares the inter-event residuals (event-terms) of the Zeerijp earthquake to those of the previous events of the database. The event terms effectively represent the average offset of the recorded motions of each event with respect to the median predictions of the model, with a positive event-term indicating a stronger-than-average earthquake and a negative event-term a weaker-than-average earthquake. The event-terms of the Zeerijp earthquake have a negative value, indicating that the PGV values recorded during this event are over-predicted by the medians of the GMPEs, and are smaller than what would be expected for an event of this magnitude. Nonetheless, the event-terms are very small and hence this over-prediction is limited. Moreover, they lie well within one standard-deviation of the inter-event variability of the GMPEs and therefore well within the range of event-terms expected to be observed. Therefore, it can be said that the PGV values observed during this event are well-predicted by the GMPE.

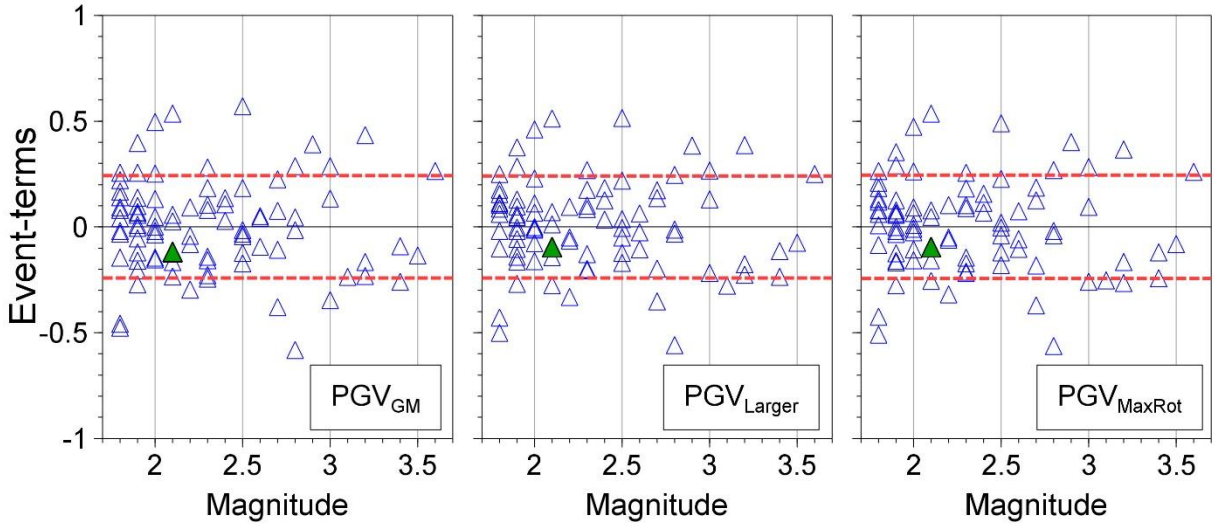

Figure 11. Inter-event residuals of three component definitions of PGV with respect to the equations of the empirical PGV GMPE (Bommer *et al*., 2021b). Residuals of the Garrelsweer earthquake recordings are shown in *green* and of older events in *blue*. The inter-event standard deviation is shown in *red dashed* lines.

Concluding Remarks

The M_L 2.1 Zeerijp earthquake of 11 April 2024 has generated a large number of ground-motion recordings. The largest value of PGA recorded in this earthquake is 0.008*g,* significantly smaller than the largest PGA values recorded in Groningen (0.11*g* in the 8 January 2018 M_L3.4 Zeerijp earthquake and 0.08*g* in the 16 August 2012 Huizinge earthquake). The largest value of PGV—which is generally considered a better indicator of the damage potential of the motion—recorded in this latest event is just 0.18 cm/s, which is only slightly larger than 5% of the largest value of the Groningen ground-motion database, a 3.46 cm/s recorded in the Huizinge earthquake.

An important observation is that the motions recorded in the Zeerijp earthquake are consistent with the predictions from the empirical PGV GMPEs that have been developed for the induced seismicity of the Groningen field and are used to assess damage claims.

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