Meeting at KNMI, de Bilt, 28 February 2019

Impact on the NAM Seismic Hazard and Risk Models of the Calibration Error in the G-Network Surface Accelerographs

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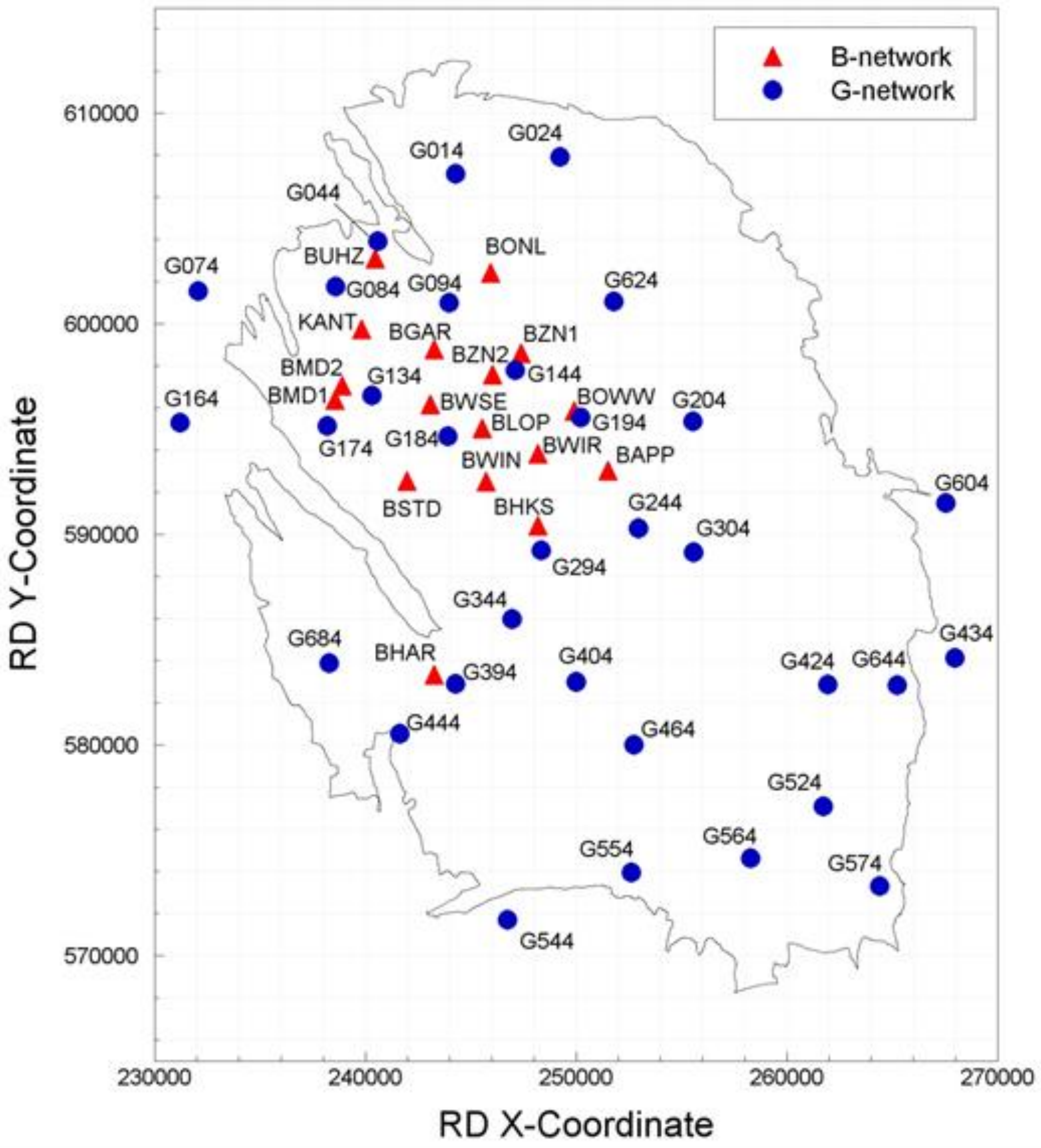
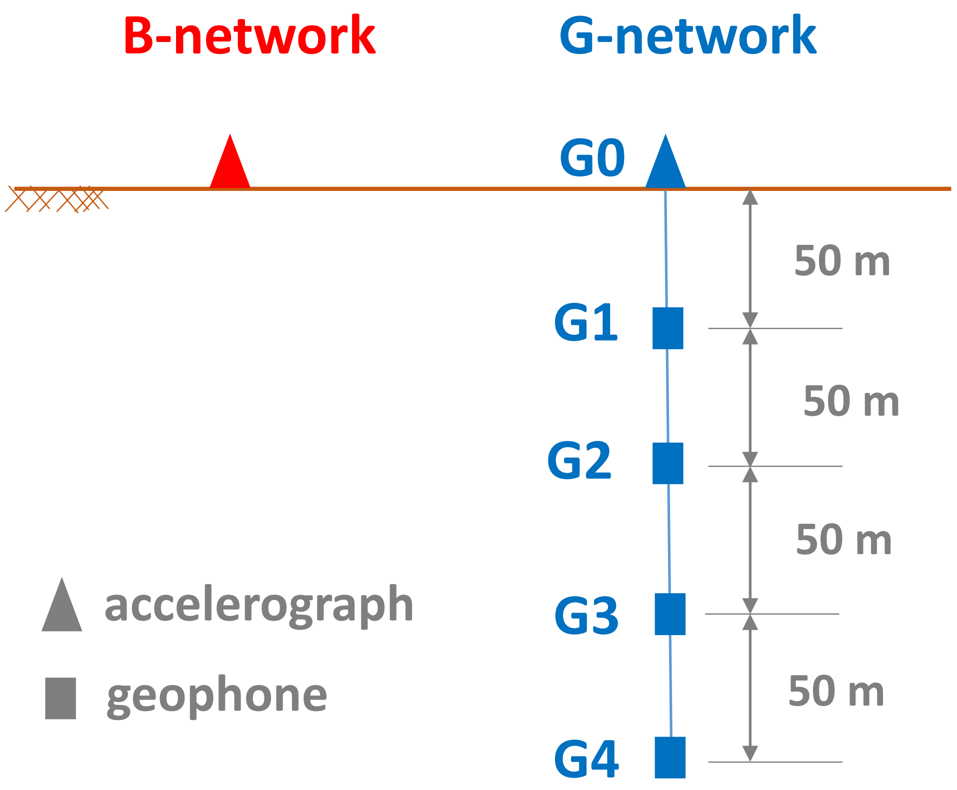
Background



In late 2018, it was identified that the G0 instruments (surface accelerographs of the G-network) had been installed with a calibration error that resulted in recorded motions having approximately ***one half*** of the correct amplitude



Overview of Presentation

This presentation discusses the impact of this calibration error (now corrected) on the NAM hazard and risk models for induced seismicity in Groningen, through the ground-motion model (GMM), and specifically addresses the following issues:

1. The empirical GMPE for PGV from small-magnitude earthquakes
2. Derivation of the Ground-Motion Prediction Model for Duration
3. Relationships between the magnitude scales M_L and M_w
4. Derivation of the Ground-Motion Model for Spectral Acceleration

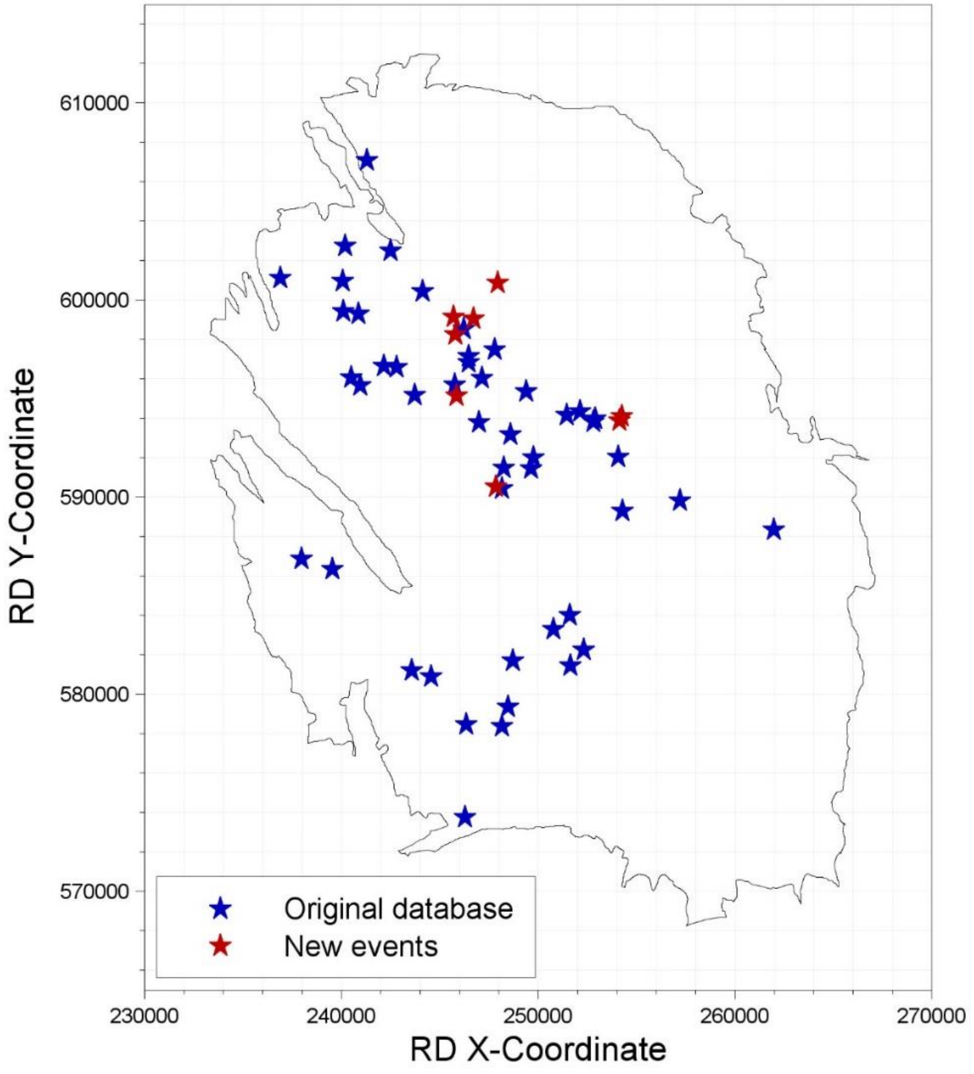
All make direct use of the G0 recordings (items 1–3)

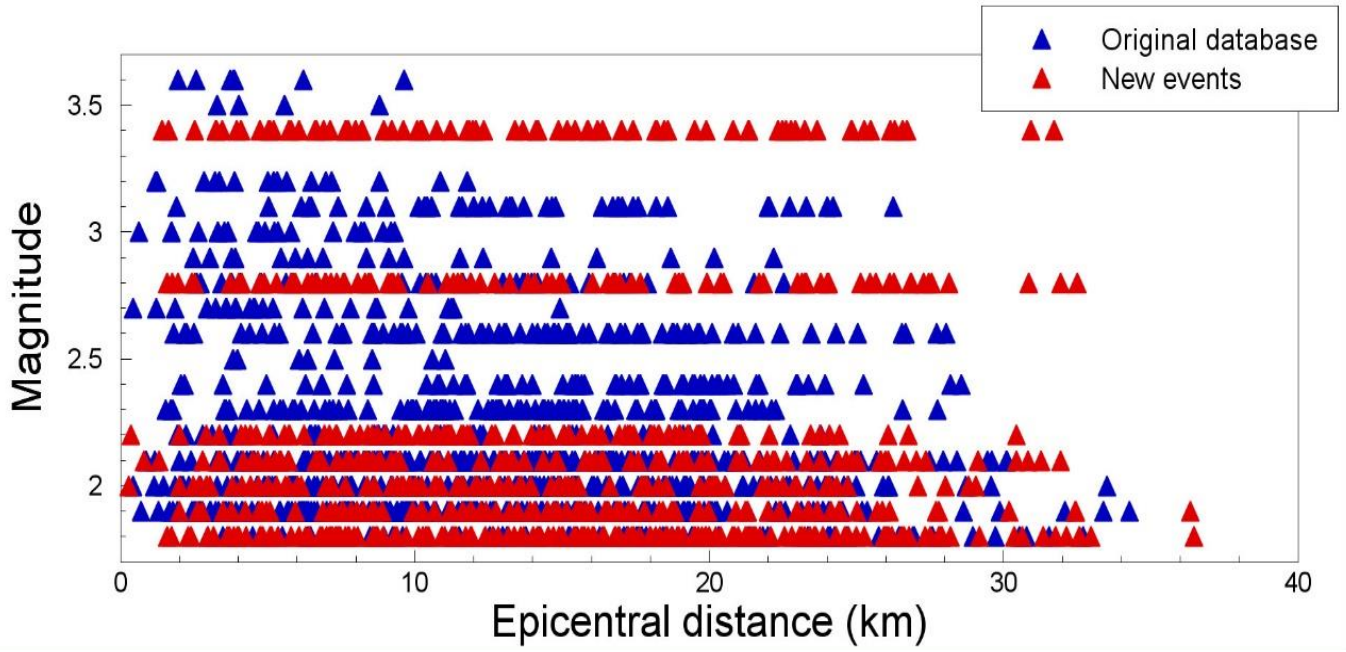
1. Empirical GMPE for PGV

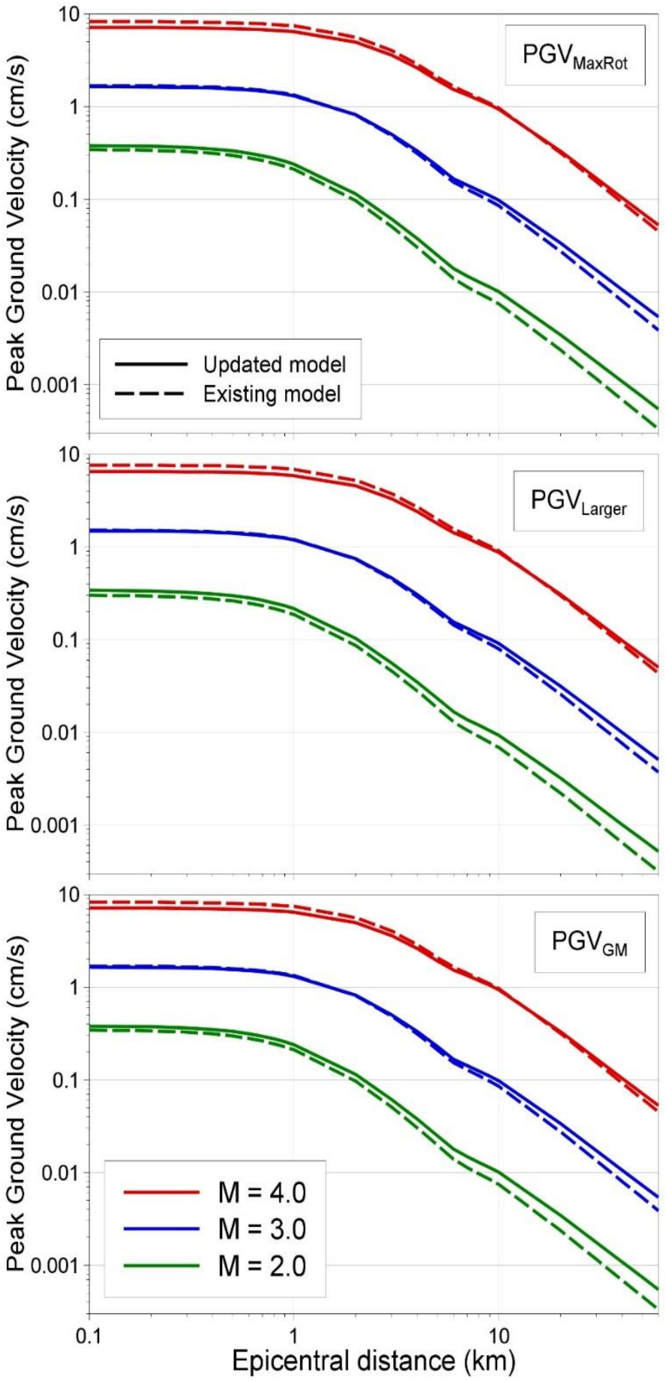
As well as the main GMM derived to be applicable to earthquakes of magnitudes from 2.5 to 7+ for implementation in the hazard and risk modelling undertaken by NAM, a model has also been derived for the prediction of PGV from events in the range of magnitudes of observed earthquakes (M_L 1.8 to 3.6) for use in damage assessments

The empirical GMPE for PGV is derived directly from regression on surface recordings of both the B-network and G-network, and consequently has required updating following the identification of the calibration issue

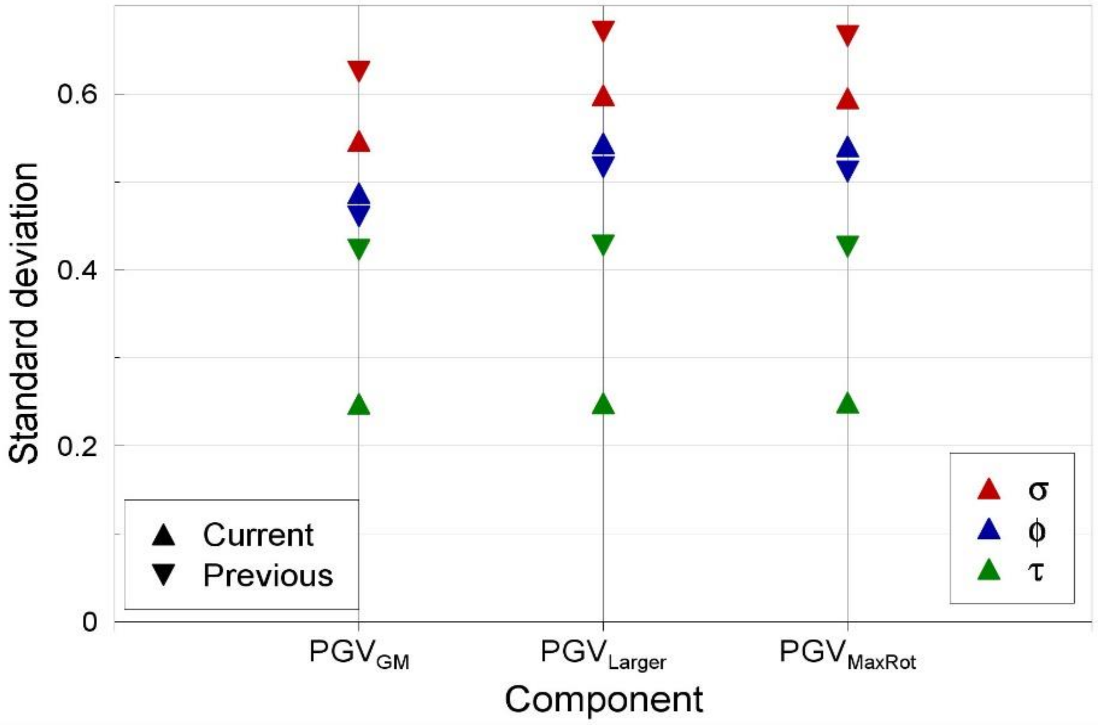
The opportunity was taken to also include additional recordings now available from 8 earthquakes that have occurred since the PGV model was first issued in November 2017


RD Y-Coordinate
RD X-Coordinate
610000
600000
590000
580000
570000
230000
240000
250000
260000
270000
Original database
New events

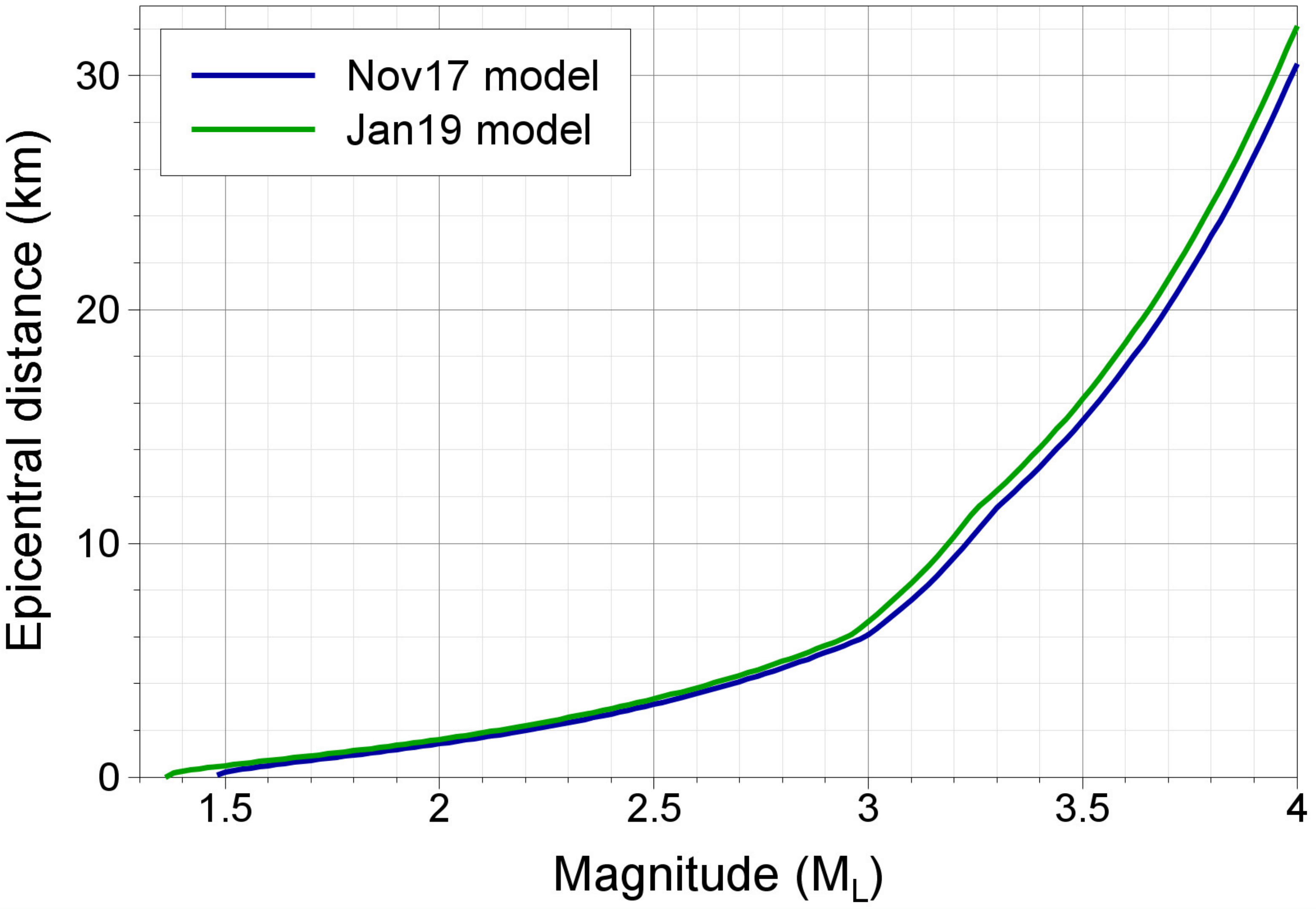

Magnitude
Epicentral distance (km)
3.5
3
2.5
2
0
10
20
30
40
Original database
New events



The resulting changes in the predictive model has been to increase the amplitudes at larger distances, particularly for smaller magnitudes, and a modest decrease at short distances for magnitude 4.0; the sigma values have been appreciably reduced, mainly due to a significant decrease in the value of the between-earthquake variability



The contour of magnitude-distance pairs that lead to median predicted PGV values of 1.5 mm/s has been changed very subtly by the model update, the main change being a small increase (~1 km) in the epicentral distance for $M_L \geq 3.0$

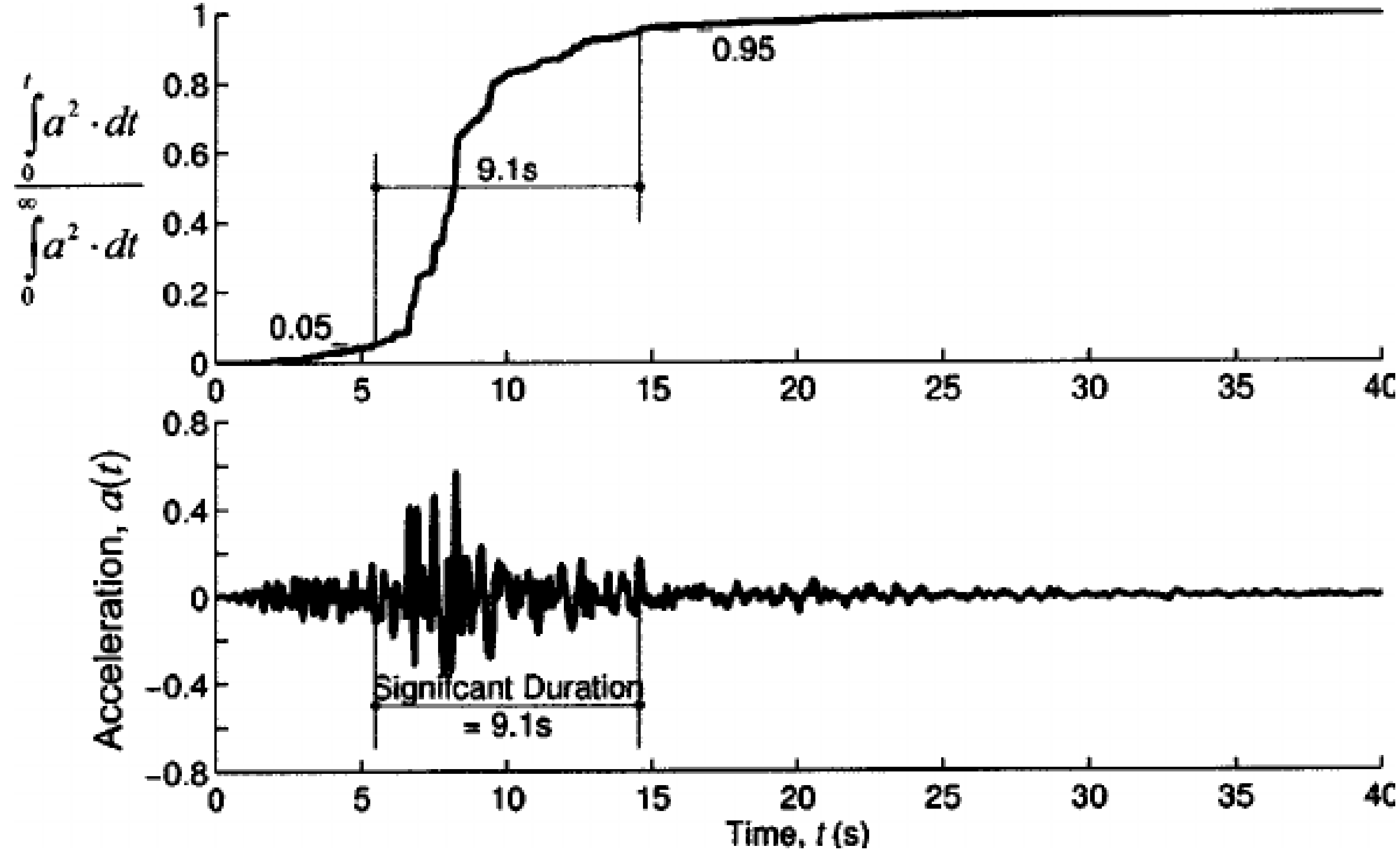


2. GMM for Durations

For some structural typologies, the fragility functions are defined in terms of spectral acceleration and duration, hence the risk model also requires the prediction of the duration of shaking

The duration model is based mainly on the NS_B motions obtained from the final-fault simulations adjusted to the surface through V_{S30}-based factors adopted from a GMPE for durations of motions from tectonic earthquakes, but also taking into account the measured durations from surface recordings in the field: therefore, the calibration error could potentially have an impact on this element of the GMM

However, the duration definition employed (the significant duration between the 5% and 75% limits of the total Arias intensity accumulated) is dependent on the shape of the waveforms and is invariant with scaling of the amplitudes



Consequently, the GMM for duration is insensitive to errors in the amplitude of the ground-motion recordings and it can be concluded that the calibration issue will have had no influence on the derivation of the model

3. Magnitude conversions from M_L to M_w

The magnitude of Groningen earthquakes is reported by KNMI as local magnitude, M_L, and the NAM hazard and risk model is essentially developed in this magnitude scale

However, the inversions of Fourier amplitude spectra that is an essential part of the GMM derivation, as well as the calibration of the upper branch of the GMM logic-tree to match motions from tectonic earthquakes, require a relationship between M_L and moment magnitude, M_w

On the basis of joint work by KNMI and NAM consultants, it was determined that for $M_L \geq 2.5$, local magnitudes and moment magnitudes for Groningen earthquakes are equivalent on average (i.e., $M_L = M_w$) and this was applied in the derivation of the current (V5) GMM

The Relationship between M *and* M_L*: A Review and Application to Induced Seismicity in the Groningen Gas Field, The Netherlands*

by Bernard Dost, Benjamin Edwards, and Julian J. Bommer

ABSTRACT

The use of local magnitude (M_L) in seismic hazard analyses is a topic of recent debate. In regions of weak or moderate seismicity, small earthquakes (characterized by M_L) are commonly used to determine frequency–magnitude distributions (FMDs) for probabilistic seismic hazard calculations. However, empirical and theoretical studies on the relation between moment magnitude (**M**) and M_L for small earthquakes show a systematic difference between the two below a region-dependent magnitude threshold. This difference may introduce bias in the estimation of the frequency of larger events with given **M**, and consequently seismic hazard. For induced seismicity related to the Groningen gas field, this magnitude threshold is determined to be **M** ~ 2, with equality between **M** and M_L at higher magnitudes. A quadratic relation between **M** and M_L is derived for $0.5 < M_L < 2$, in correspondence to recent theoretical studies. Although the seismic hazard analysis for Groningen is internally consistent when expressed in terms of M_L (with the implicit assumption of equivalence between the two scales), a more physical interpretation of the seismicity model requires transformation of the earthquake catalog from local to moment magnitude, especially because the dataset currently used in estimating time-dependent hazard consists mainly of $M_L < 2.5$ events. We show that measured station effects, derived from **M** calculations, correspond to predicted model calculations used to determine a ground-motion model for the region.

can be important both because their effects are viewed as an imposed risk and also because they may occur in regions where buildings are designed and constructed without provision for lateral resistance against seismic shaking. In such situations, both seismicity models and ground-motion predictions are calibrated on small-magnitude earthquake data, the characterization of which—including the quantification in terms of magnitude—then becomes important. A particular challenge is to homogenize catalogs of induced earthquakes in terms of moment magnitude (Edwards and Douglas, 2014).

Gas production in the Groningen field in the northernmost part of the Netherlands is inducing earthquakes that potentially pose a threat to the built environment and to local inhabitants. As part of their response to the induced seismicity, a probabilistic seismic hazard and risk model (forming part of the production license application, or Winningsplan) is being developed for the Groningen field by the operator Nederlandse Aardolie Maatschappij BV (NAM, 2016). In addition, and independently from the field operator, the Royal Netherlands Meteorological Institute (KNMI) has developed a probabilistic seismic hazard model, which is compared with the Winningsplan model (Dost *et al.*, 2017; Spetzler and Dost, 2017b). As part of the development of seismic hazard and risk models, a site-specific ground-motion model (GMM) has been developed

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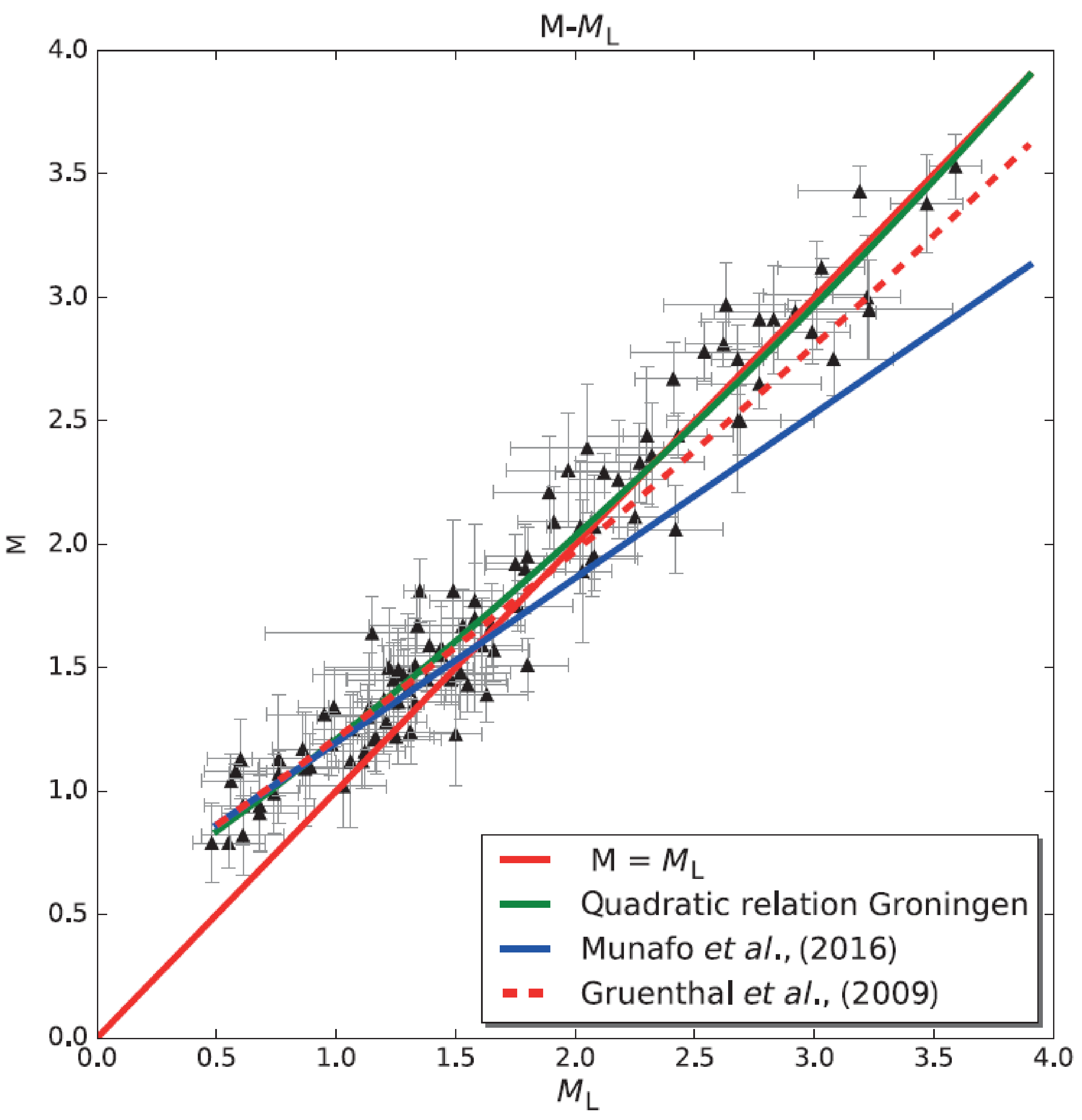
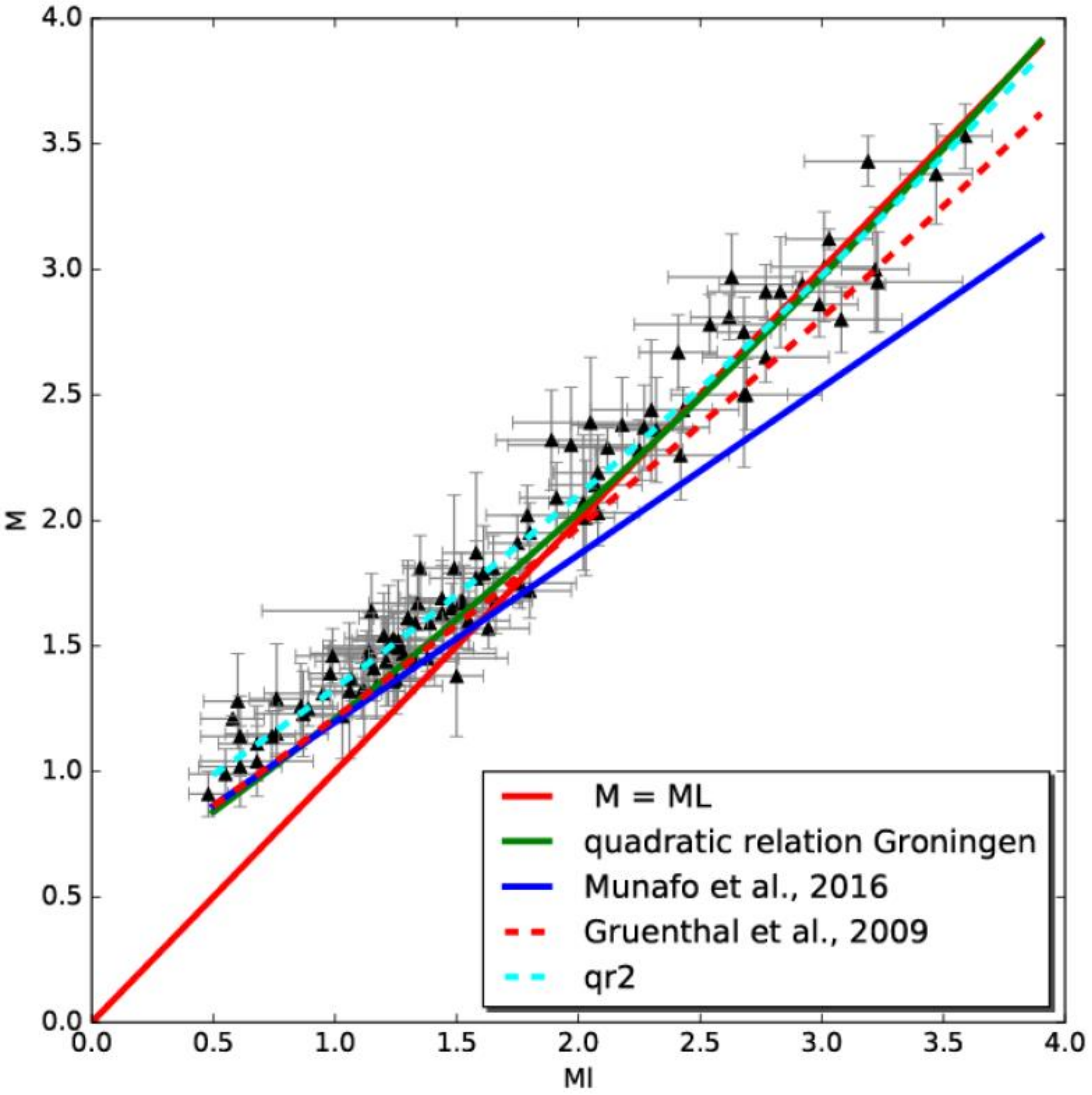


The moment magnitude values used in the derivation of the relationship were derived from accelerograph recordings, which for the period 2015-2017, included many G-network surface accelerograph records

If all the recordings used had come from G-network stations, the error would have been 0.2 magnitude units, but the majority of larger magnitude records were still those obtained from the B-network

Consequently, while the correction has led to an adjustment (larger M_w for a given M_L) at smaller magnitudes, in the magnitude range of relevance to the GMM development (≥ 2.5), the changes to the relationship between the magnitude scales was almost negligible (compare cyan and green curves in the plot, which shows the data after corrected of the M_w values)



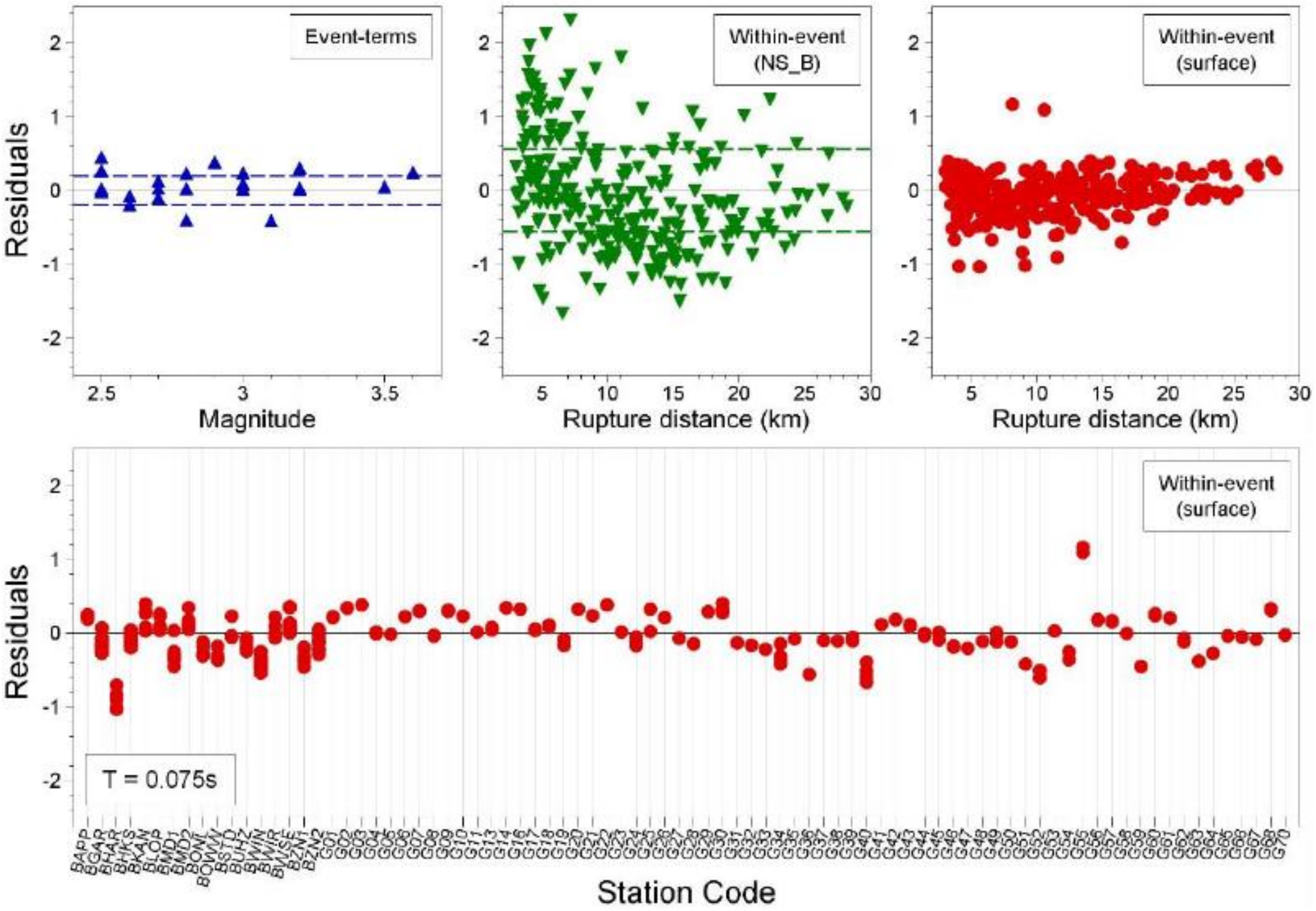
Courtesy of Bernard Dost, KNMI

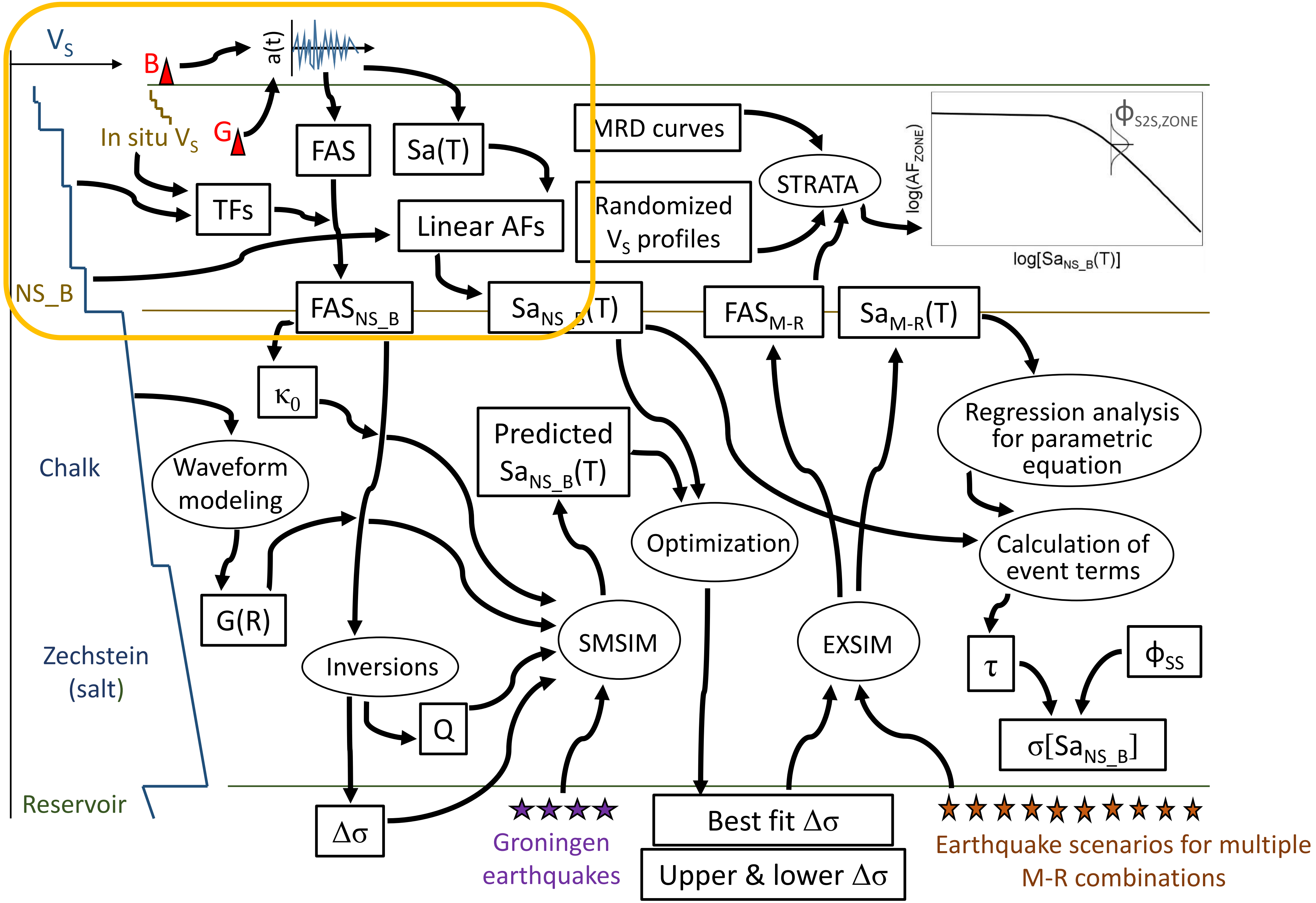
4. GMM for Spectral Accelerations

The most important ground-motion model is that for predicting spectral accelerations (which for an oscillator period of 0.01 seconds are equivalent to PGA), since these are used for hazard mapping by NAM (and KNMI), and are also the basic input to NAM risk calculations

The GMM for spectral accelerations, PGA and PGV should be entirely unaffected by the calibration error with the surface accelerographs of the G-network because the model is derived from analyses of the B-station accelerograph recordings and recordings from the 200-metre geophones of the G-network

The only use made of recordings from the surface accelerographs of the G-network in the GMM derivation has been in comparing these with predicted surface motions (see opposite) but these comparisons did not directly influence the model parameters





V_S
B
a(t)
G
In situ V_S
FAS
Sa(T)
MRD curves
STRATA
TFs
Linear AFs
Randomized V_S profiles
log(AF_ZONE)
ϕS2S,ZONE
log[Sa_NS_B(T)]
NS_B
FAS_NS_B
Sa_NS_B(T)
FAS_M-R
Sa_M-R(T)
κ0
Regression analysis for parametric equation
Waveform modeling
Predicted Sa_NS_B(T)
Chalk
Optimization
Calculation of event terms
G(R)
SMSIM
EXSIM
Inversions
τ
ϕSS
Zechstein (salt)
Q
σ[Sa_NS_B]
Reservoir
Δσ
Best fit Δσ
Upper & lower Δσ
Groningen earthquakes
Earthquake scenarios for multiple M-R combinations

CONCLUSIONS

1. Those elements of the GMM that make direct use of the G0 recordings have either been unaffected or else experienced only minor perturbation:
   a) The empirical GMPE for PGV from small-magnitude earthquakes has been effected but an update of the model—combining a correction of the amplitudes and incorporation of newly-available data—has led to very modest changes in the predicted values
   b) The GMM for durations does make use of the surface recordings from accelerographs of the B- and G-networks but the duration definition is insensitive to the amplitude of the motions
   c) The M_L-M_w relationship was affected by the G-station calibration error, but analyses have shown that in the magnitude range of relevance, the impact was almost negligible
2. The derivation of the GMM for spectral accelerations and PGA does not make use of the surface recordings from the G-network (using instead the recordings from the 200-m geophones at the same stations) and hence should be completely immune to the G0 calibration error that has been identified

Summary

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Impact of the G0 calibration issue on the derivation of the V5 GMM

Dear Gentlemen:

I am writing in response to the specific question of how the V5 GMMwould change if its derivation were ow repeated after application of the calibration correction to the surface accelerographs of the G-network (i.e., G0 station recordings). The short answer is that there would be absolutely no change in the model at all. There are three main reasons for this conclusion, each of which I will briefly explain in turn:

1. The model for PGA, PGV and spectral accelerations is derived from analyses of the surface recordings of the B-network and recordings on the 200-m borehole geophones of the G-network (G4 stations). This approach was adopted because of the lack of measured near-surface velocity profiles at the G-stations.
2. The derivation of the model for durations does make use of the G0 recordings but the duration definition used is based on the accumulation of Arias intensity in the time-series, which is entirely insensitive to the scaling of the record amplitude. Therefore, the duration model is entirely immune to the correction of the G0 instrument gain.
3. The GMM derivation makes use of the assumption of equivalence of local magnitude ML and moment magnitude Mw, which has been confirmed for the magnitude range of relevance to the GMM ($M \geq 2.5$) in a study published in Seismological Research Letters in 2018. Some of the seismic moment values used in that study were calculated using G0 recordings as well as B-station recordings; the re-calculation of the moment magnitudes after application of the calibration correction leads to a small change in the ML-Mw relationship at smaller magnitudes, but the change in the magnitude range for which the GMM is derived was found to be negligible.

Consequently, were there a request to repeat the derivation of the V5 GMM using the same data and modelling procedures with the only change being the calibration correction to the G0 accelerographs, there would be no change at all to the model.

I remain available to answer any further questions.

Kind regards,

Julian