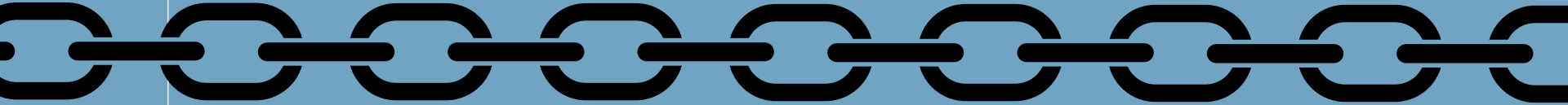


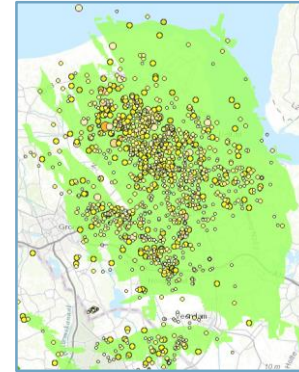
› MODEL CHAIN GRONINGEN



TNO innovation
for life

PROJECT CONTEXT

› Groningen induced seismicity

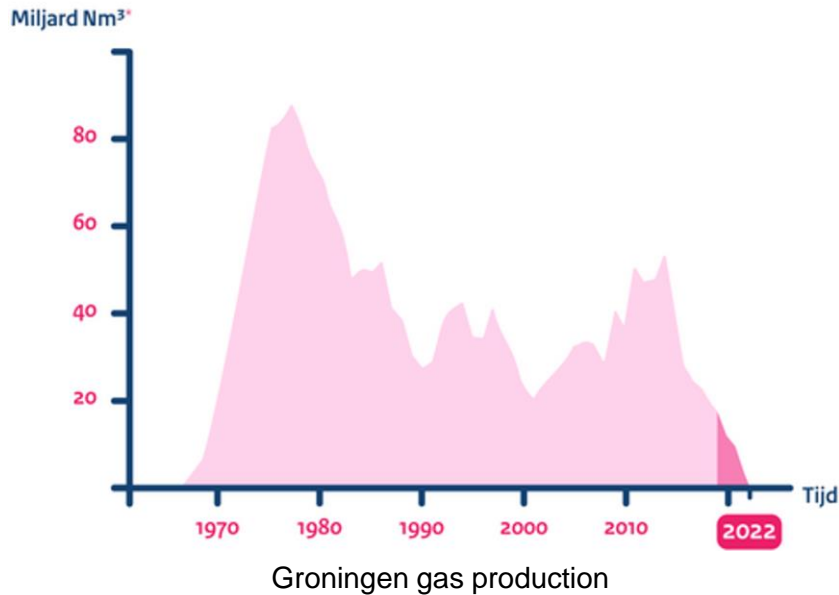


Groningen Field
+ earthquake catalogue



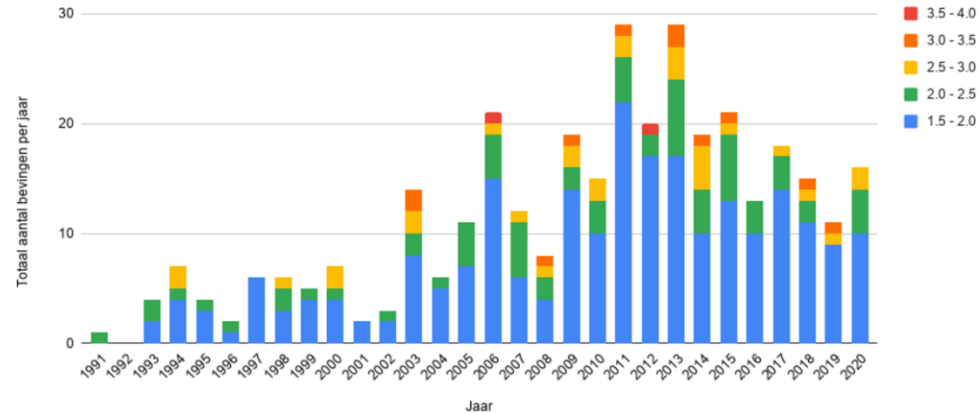
Stef Blok
Min. Economic Affairs

Gaswinning Groningenveld naar nul



Groningen gas production

Jaarlijks aantal aardbevingen boven magnitude 1,5 Groningenveld



Luister naar
02:23

Mogelijk toch meer gaswinning in Groningen dan afgesproken

Kamerbrief Door de vertraging van de bouw van een stikstoffabriek moet de komende maanden misschien toch meer gas worden gewonnen in Groningen dan afgesproken.

Mark Middeld 9 november 2021 Leestijd 1 minuut



Gaswinnings- en gasbehandelingslocatie van de NAM in het Groningse Scheemda.
Foto Vincent Jannink / ANP

Groningen vannacht opgeschrikt door een zware aardbeving van 3.2 bij Garrelsweer

Rob Zijlstra · 16 november 2021, 02:26 · Groningen Deel dit artikel    



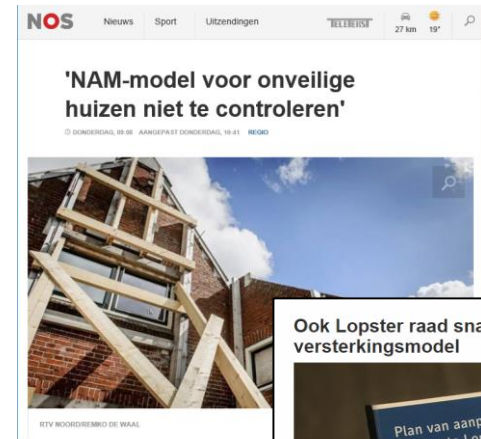
Johan Bakker uit Garrelsweer inspecteert zijn woning. Beeld: DVHN

MODEL CHAIN

- › *What:*
 - › A chain of physical-statistical models that translates the Groningen gas production in a forecast of earthquakes and associated effects.
- › *Why:*
 - › To assess the safety situation in the area and to steer mitigation policies (production plans, building strengthening program)
 - › To supply probabilistic ground motion forecasts for the building design codes, for construction and (dis)approval
- › *Isn't that the operators job, with their (in)famous HRA model?*
 - › The TNO model chain and the NAM HRA model answer the same question with (largely) the same models. Since 2021, TNO is responsible for performing the annual hazard and risk analysis.

PROJECT CONTEXT

- › NAM HRA tool used until 2020
- › Project assigned to TNO (2017)
- › pSDRA: public Seismic Hazard and Risk Assessment
 - › Advisory tool
 - › Research tool
 - › Public domain
- › Client: Ministry of Economic Affairs and Climate
- › Fully operational: pSDRA 2021



Ook Lopster raad snapt niets van versterkingsmodel



'Innavolgbaar, niet uitlegbaar.' Na veel kritiek van inwoners kraakt ook de gemeenteraad van Loppersum het risicomodel voor huizen in het aardbevingsgebied.

Wat is het 'HRA-model'?

Over het zogenaamde HRA-model bestaat veel onduidelijkheid. Wat houdt dit model eigenlijk in en waarom wordt er toch mee gewerkt?

HRA staat voor Hazard and Risk Assessment, een analyse van kans en risico's bij gebeurtenissen. De NAM moet onderzoeken waar de risico's vandaan komen. Het onderzoeksprogramma omvat onder meer de samenstelling van de ondergrond, het drukvermogen van de ondergrond, de aanwezigheid van ondergrondse openingen, etc. De risico's op ranssen wordt geïnterpreteerd, evenals de kans dat er schade valt bij een aardbeving. Dit hangt meer af van een aantal factoren, de manier van de bouw, de plek van de bouw, de sterkte van een gebouw etc. Dit is een ingewikkeld geheel, met veel aannames, onzekerheden, schattingen en kansberekening. De aannames worden door de NAM in het model gebruikt, met getallen, die van de NAM komen. Een deel van de aannames en de getallen (meer de getallen) zijn niet openbaar en dus niet te controleren, zelfs niet door het Soth. TNO is er niet nu toe in te slaagt een (overheid) nagelovend HRA te produceren, juist vanwege het gebrek aan kennis en de aannames. Omdat er kans op schade wordt bij ranssen, verschillen de Mijnsd en het Soth met het onderzoek. De Mijnsd vindt het voldoende om alle ranssen bij elkaar op te tellen. Soth wil de onderzoekers die bij elke ranssoort, graag meetellen om meer zekerheid te houden.

gelden moeten het gemakkelijk maken om ranssen in een bepaalde omgeving en op een bepaalde manier te versterken. Daarom kan het proces van versterkingsoverzicht worden versneld. Dit nog kan het gebouwen, zo schreef de NCC, dat van twee onderdelen is opgesplitst: de ene helft wil met een "verhogd risico" uit dit model komt en de andere helft niet. Daarom zijn inspectie of zelfs een legerevolutie (opname) en versterking zelf dus "maatwerk per woning". Voor de methode van versterking heeft Building (B) en Hance (H) een catalogus ontwikkeld die controleren van dit kan zijn bij het bouwen van meer gestandaardiseerde oplossingen.

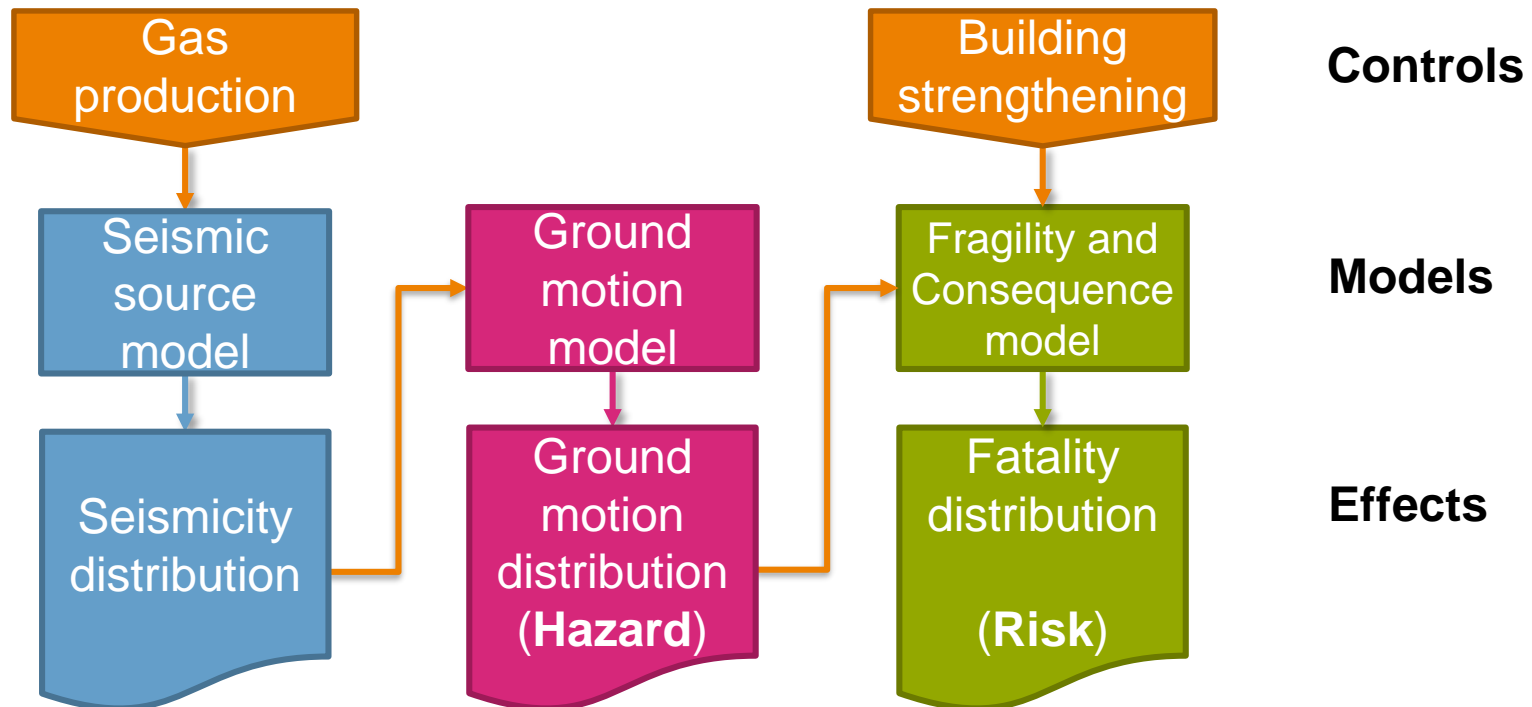


Wist je dat... Er gemiddeld 41 aardbevingen per jaar zijn in Groningen.

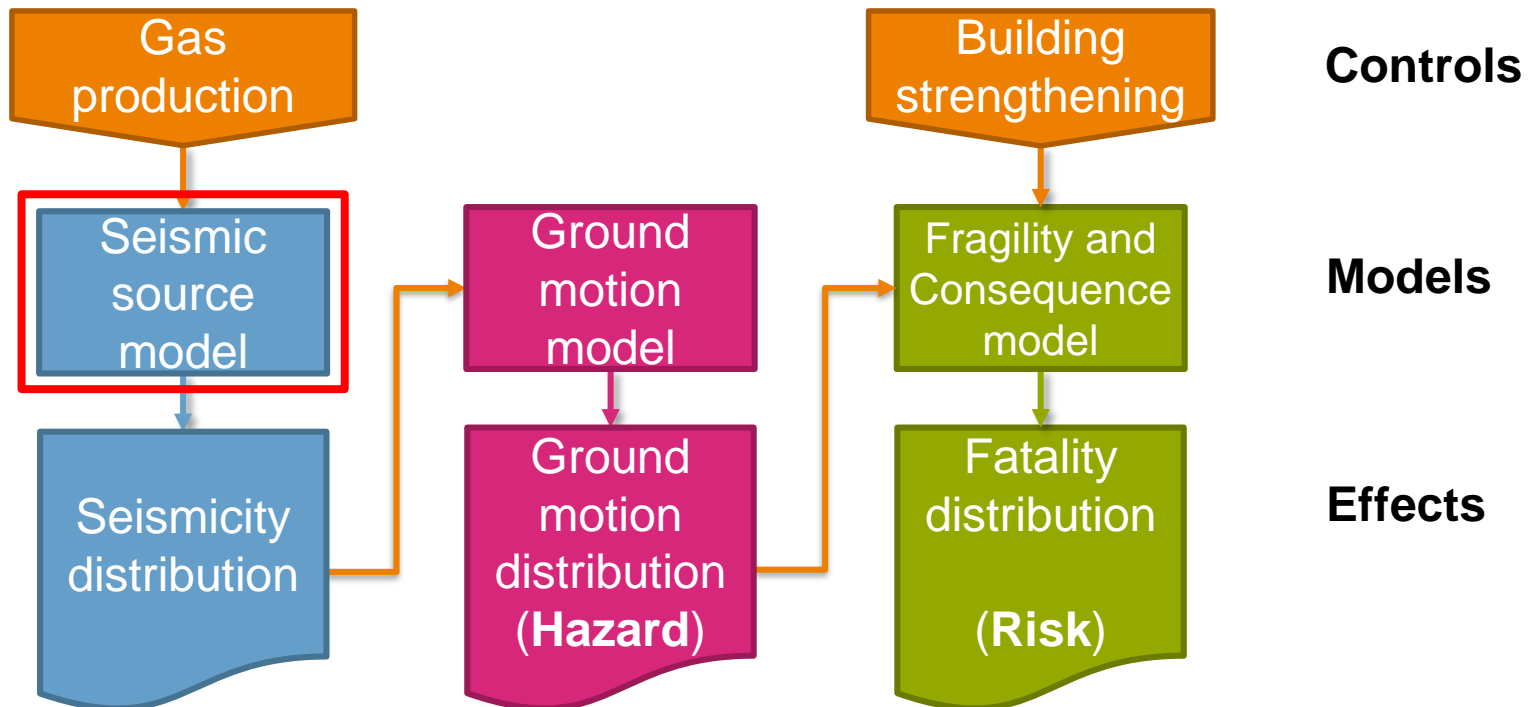
PSDRA CYCLE TIMELINE

- › Roles TNO: executive + research & development + advisory
- › October: Status report
 - › List available models
 - › Advice on pSDRA model selection
- › December: Model development plan (long term, short term)
- › February/March: Run pSDRA according to assignment, report
- › April: Advice on Groningen development plan (Vaststellingsbesluit)
- › All year: R&D model chain and components

MODEL CHAIN

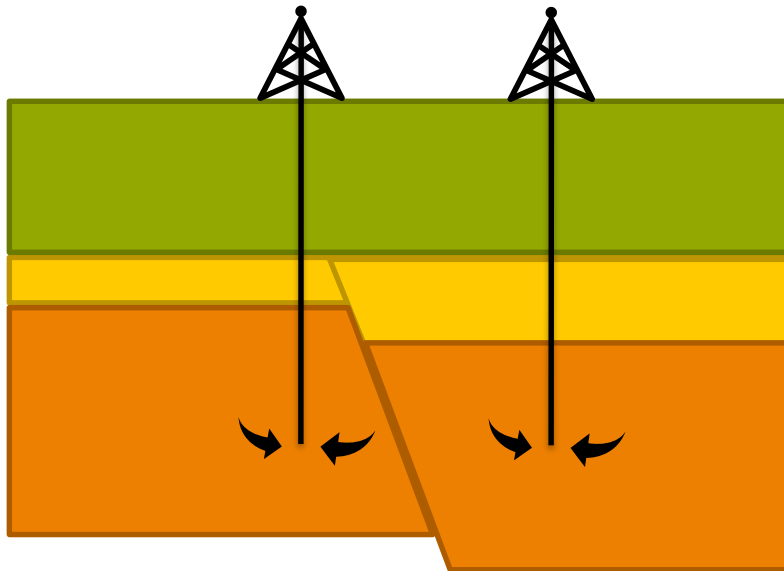


MODEL CHAIN



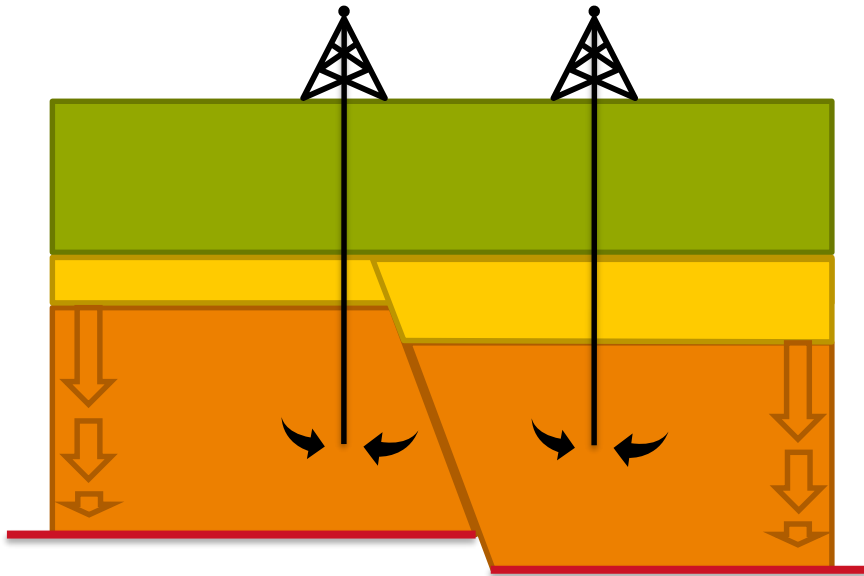
MODULE 1: SEISMIC SOURCE MODEL

GAS PRODUCTION → PRESSURE DROP



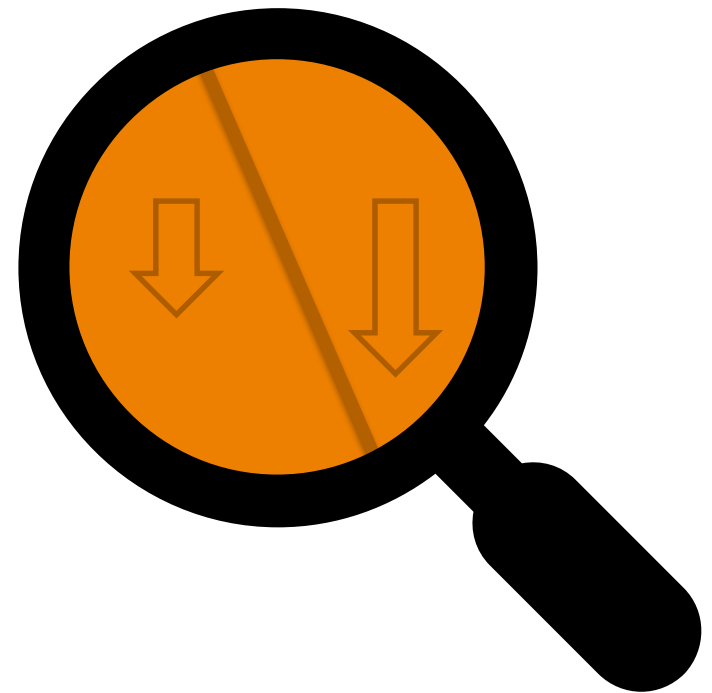
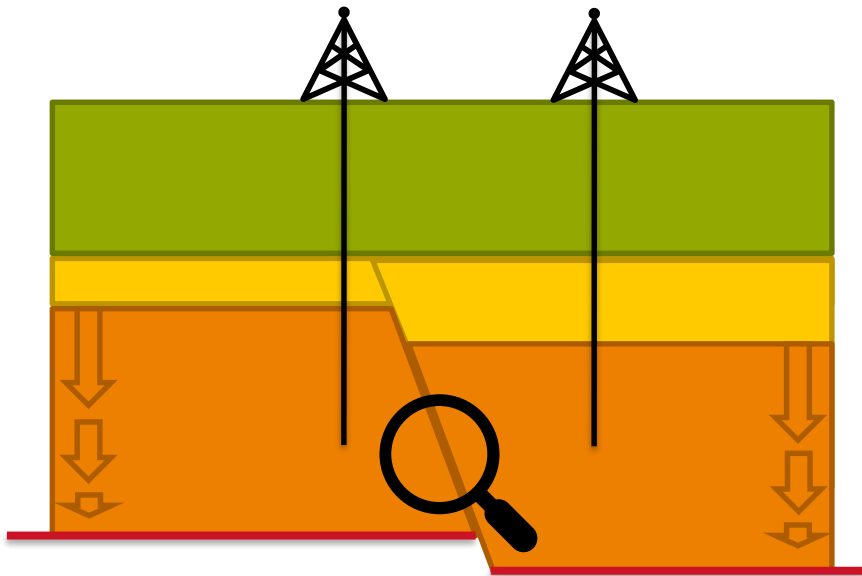
MODULE 1: SEISMIC SOURCE MODEL

PRESSURE DROP → COMPACTION



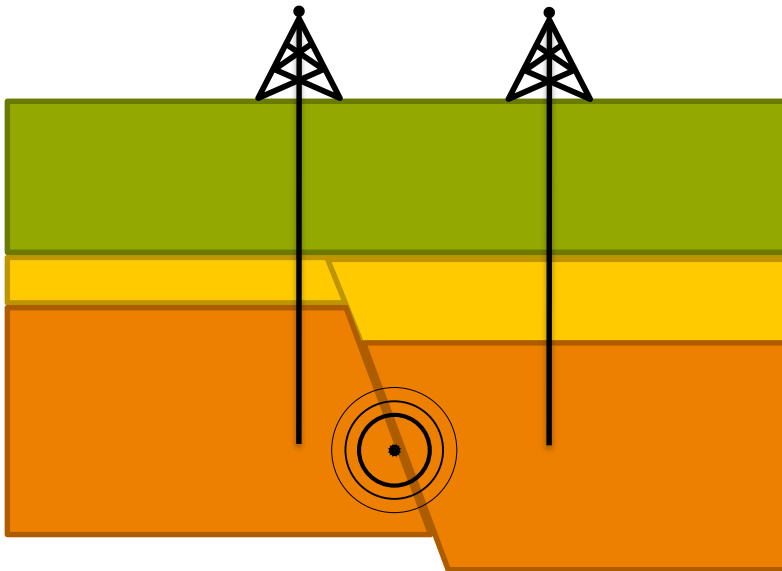
MODULE 1: SEISMIC SOURCE MODEL

PRESSURE DROP \rightarrow DIFFERENTIAL COMPACTION ON FAULTS

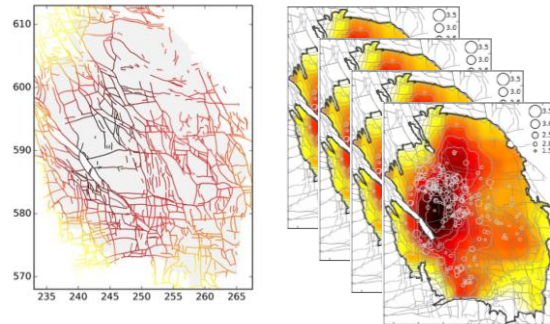


MODULE 1: SEISMIC SOURCE MODEL

PRESSURE DROP → DIFFERENTIAL COMPACTION ON FAULTS

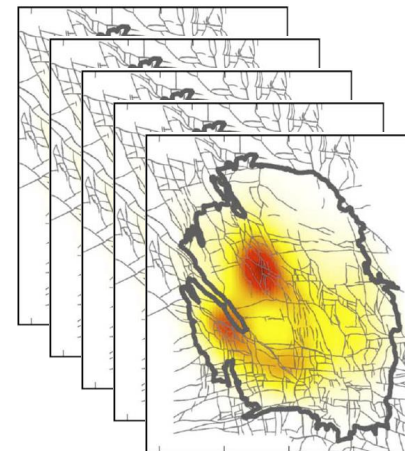
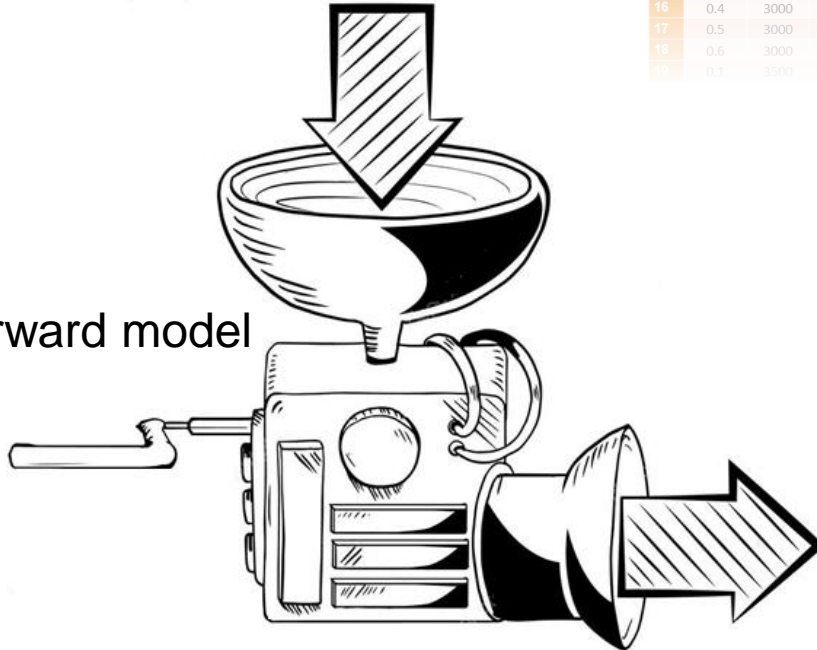


MODULE 1: SEISMIC SOURCE MODEL LEARNING PHASE

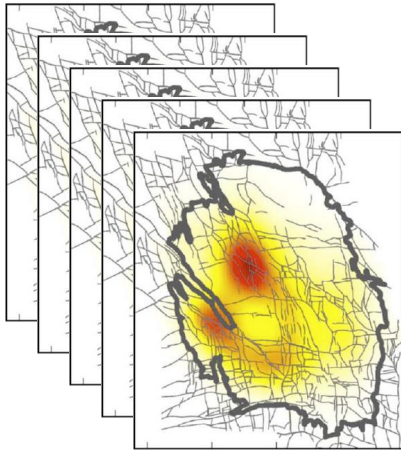


#	α	σ	θ	r_{max}	κ
1	0.1	2000	0.001	0.2	1.0
2	0.2	2000	0.001	0.2	1.0
3	0.3	2000	0.001	0.2	1.0
4	0.4	2000	0.001	0.2	1.0
5	0.5	2000	0.001	0.2	1.0
6	0.6	2000	0.001	0.2	1.0
7	0.1	2500	0.001	0.2	1.0
8	0.2	2500	0.001	0.2	1.0
9	0.3	2500	0.001	0.2	1.0
10	0.4	2500	0.001	0.2	1.0
11	0.5	2500	0.001	0.2	1.0
12	0.6	2500	0.001	0.2	1.0
13	0.1	3000	0.001	0.2	1.0
14	0.2	3000	0.001	0.2	1.0
15	0.3	3000	0.001	0.2	1.0
16	0.4	3000	0.001	0.2	1.0
17	0.5	3000	0.001	0.2	1.0
18	0.6	3000	0.001	0.2	1.0
19	0.1	3500	0.001	0.2	1.0

Forward model



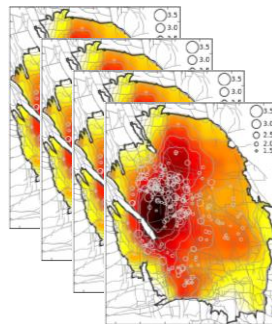
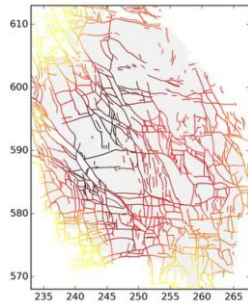
MODULE 1: SEISMIC SOURCE MODEL LEARNING PHASE



Bayesian inference

#	α	σ	θ	r_{max}	κ
1	0.1	2000	0.001	0.2	1.0
2	0.2	2000	0.001	0.2	1.0
3	0.3	2000	0.001	0.2	1.0
4	0.4	2000	0.001	0.2	1.0
5	0.5	2000	0.001	0.2	1.0
6	0.6	2000	0.001	0.2	1.0
7	0.1	2500	0.001	0.2	1.0
8	0.2	2500	0.001	0.2	1.0
9	0.3	2500	0.001	0.2	1.0
10	0.4	2500	0.001	0.2	1.0
11	0.5	2500	0.001	0.2	1.0
12	0.6	2500	0.001	0.2	1.0
13	0.1	3000	0.001	0.2	1.0
14	0.2	3000	0.001	0.2	1.0
15	0.3	3000	0.001	0.2	1.0
16	0.4	3000	0.001	0.2	1.0
17	0.5	3000	0.001	0.2	1.0
18	0.6	3000	0.001	0.2	1.0
19	0.1	3500	0.001	0.2	1.0

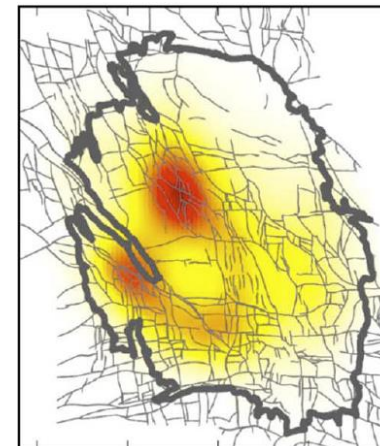
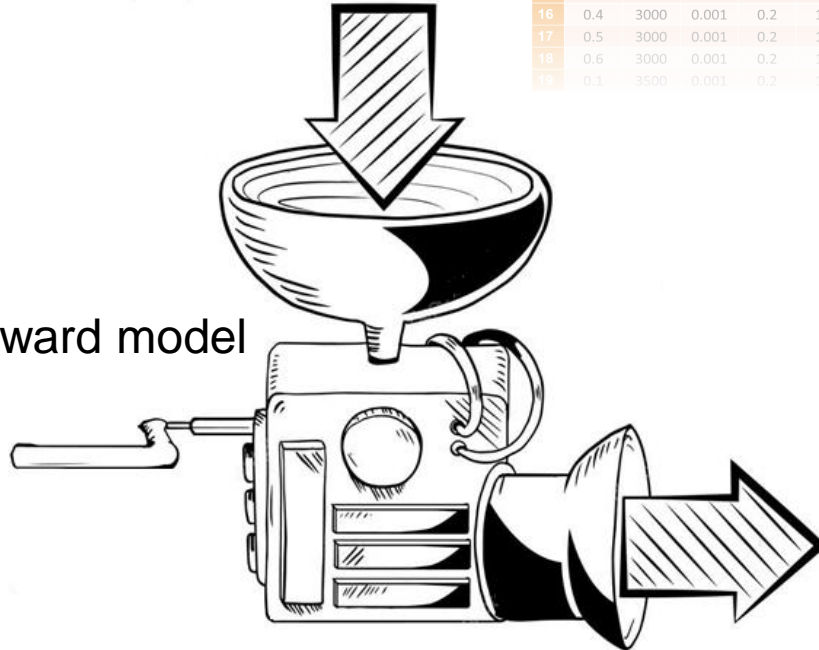
MODULE 1: SEISMIC SOURCE MODEL FORECAST PHASE



#	α	σ	θ	r_{max}	κ	SCORE
1	0.1	2000	0.001	0.2	1.0	0.01%
2	0.2	2000	0.001	0.2	1.0	0.02%
3	0.3	2000	0.001	0.2	1.0	0.06%
4	0.4	2000	0.001	0.2	1.0	0.05%
5	0.5	2000	0.001	0.2	1.0	0.04%
6	0.6	2000	0.001	0.2	1.0	0.02%
7	0.1	2500	0.001	0.2	1.0	2.0%
8	0.2	2500	0.001	0.2	1.0	2.1%
9	0.3	2500	0.001	0.2	1.0	1.9%
10	0.4	2500	0.001	0.2	1.0	1.8%
11	0.5	2500	0.001	0.2	1.0	1.3%
12	0.6	2500	0.001	0.2	1.0	1.0%
13	0.1	3000	0.001	0.2	1.0	3.2%
14	0.2	3000	0.001	0.2	1.0	3.6%
15	0.3	3000	0.001	0.2	1.0	3.9%
16	0.4	3000	0.001	0.2	1.0	3.9%
17	0.5	3000	0.001	0.2	1.0	3.7%
18	0.6	3000	0.001	0.2	1.0	3.4%
19	0.1	3500	0.001	0.2	1.0	1.5%

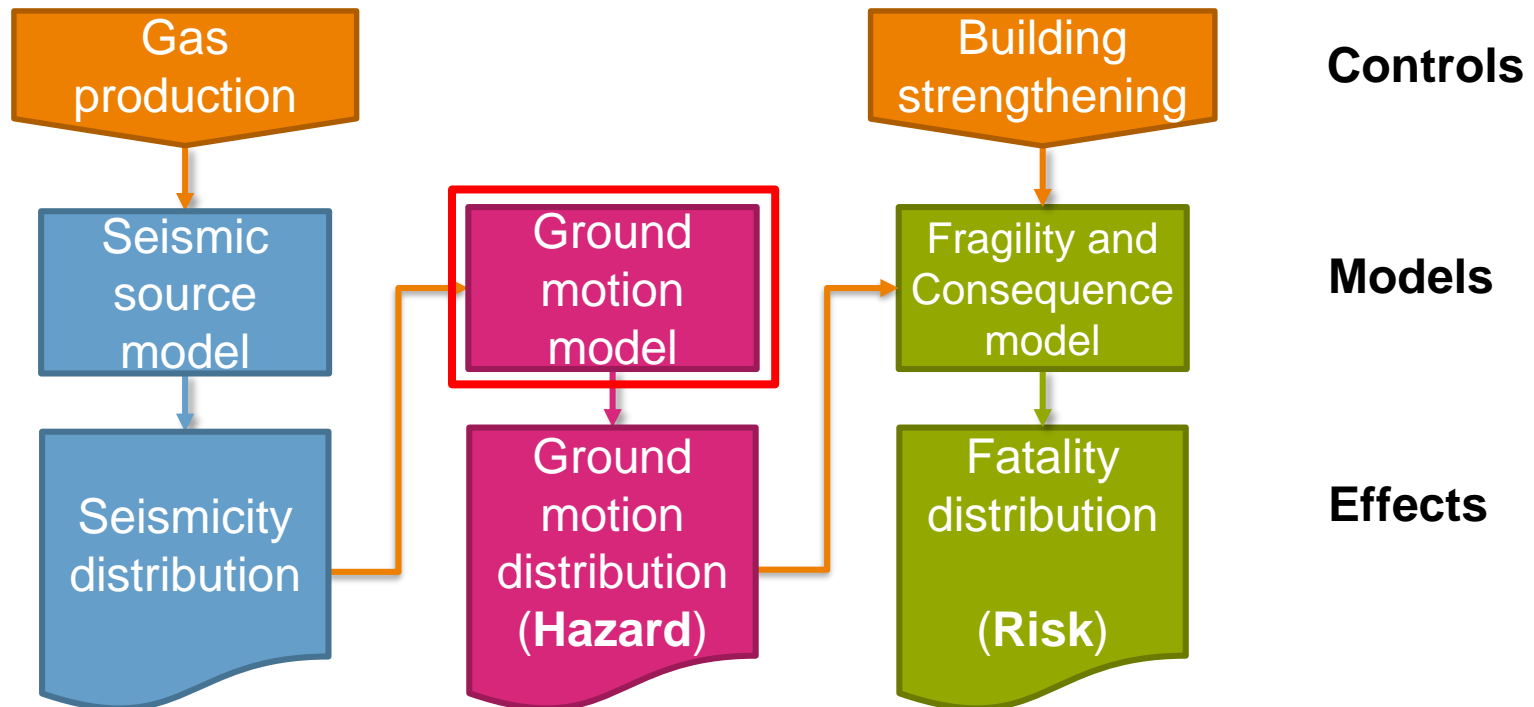
Posterior parameter distribution

Forward model

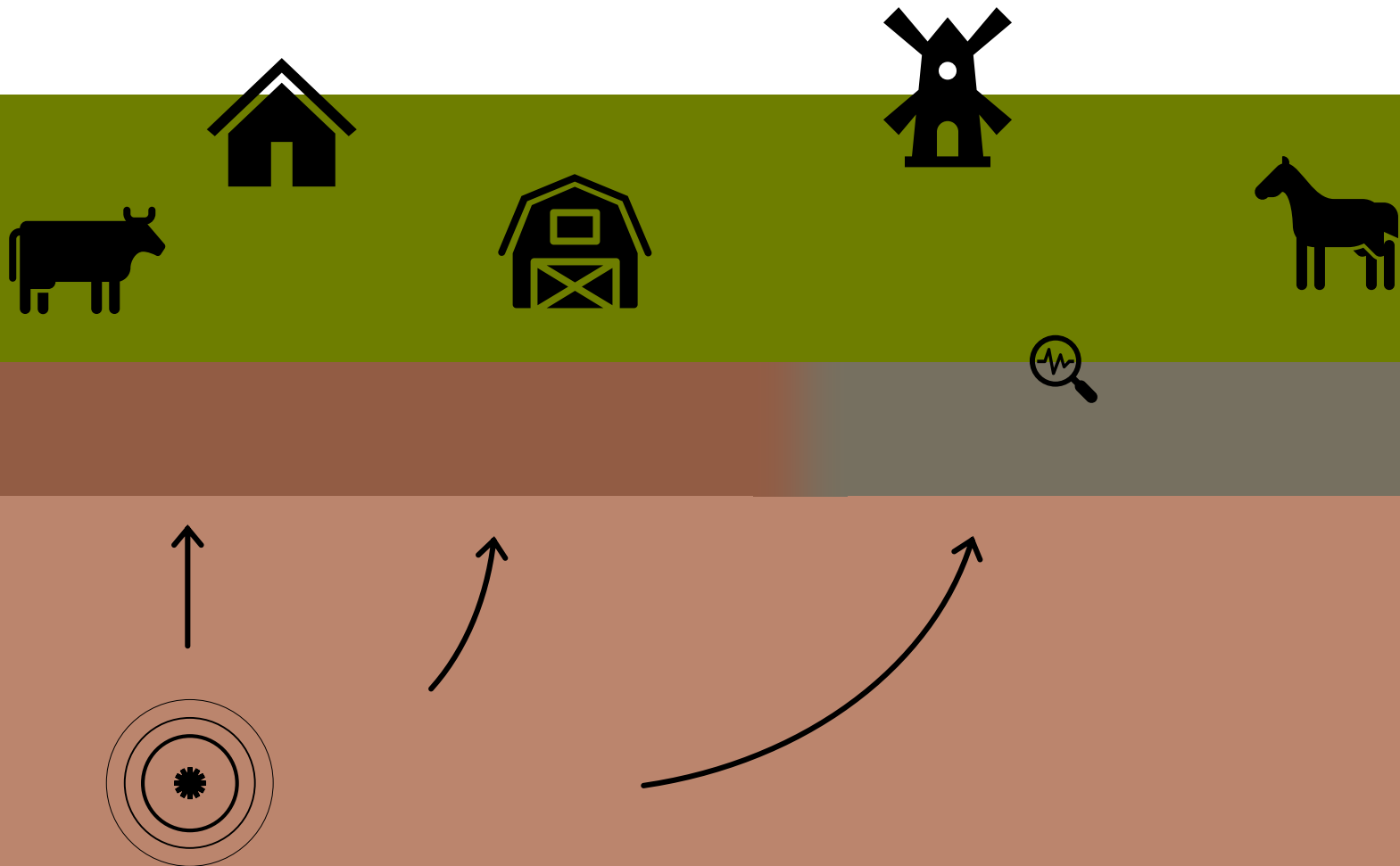


Posterior predictive seismicity distribution
 $\lambda(x, y, t, m)$

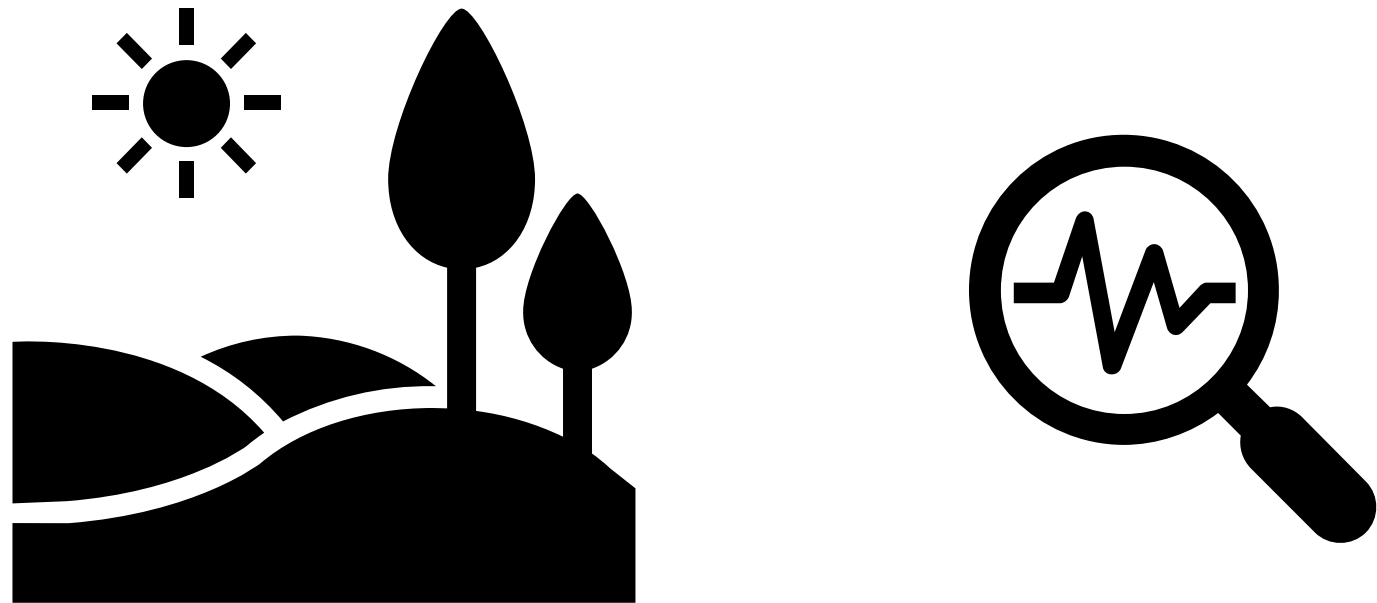
MODEL CHAIN



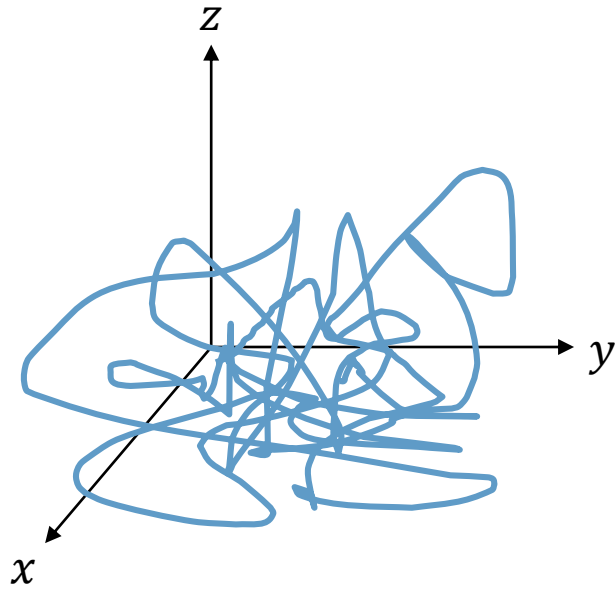
MODULE 2: GROUND MOTION MODEL



MODULE 2: GROUND MOTION MODEL



MODULE 2: GROUND MOTION MODEL



MODULE 2: GROUND MOTION MODEL

- › Use ground motion attributes that can be used for engineering purposes
 - PGA
 - PGV
 - Duration
 - ..

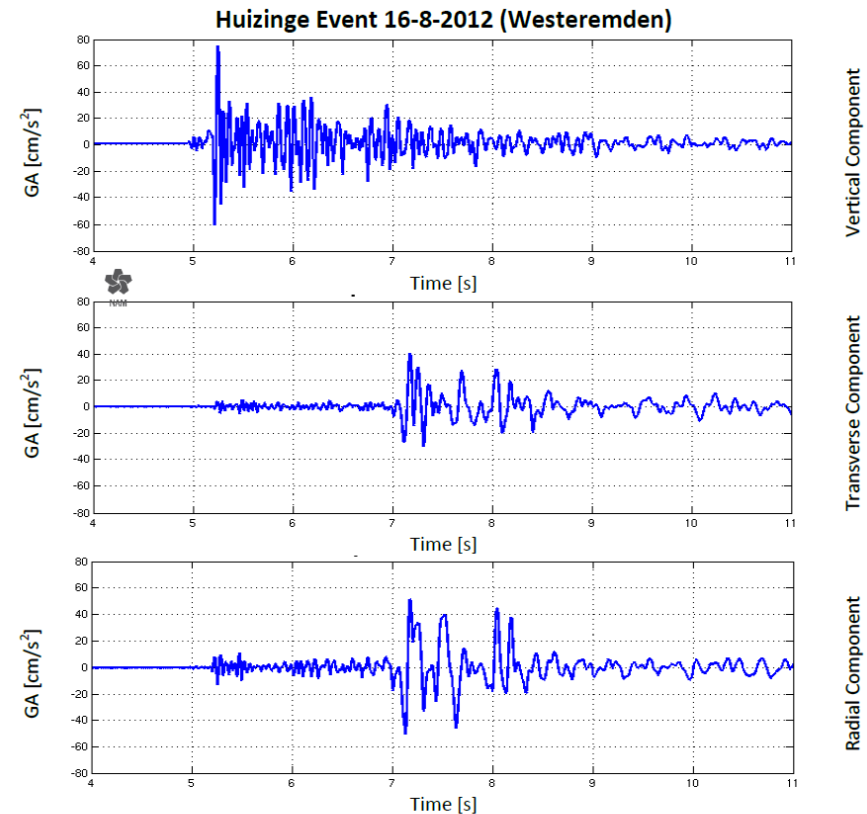
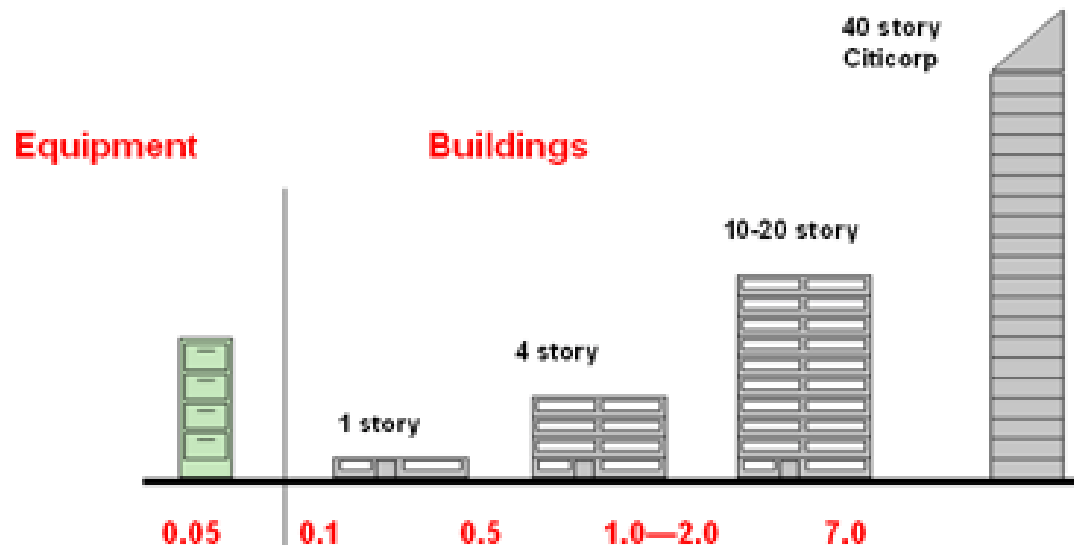


Figure 4.1 Accelerogram of the earthquake near Huizinge recorded at the 16th August 2012 by the accelerometer located near Westeremden.

MODULE 2: GROUND MOTION MODEL

› Ground motion attributes:

- Spectral Acceleration (S_a), $T=\{0.01s, \dots, 0.2s, \dots, 5.0s, \dots\}$
- Simulated single-d.o.f. building response



single d.o.f.
damped oscillators

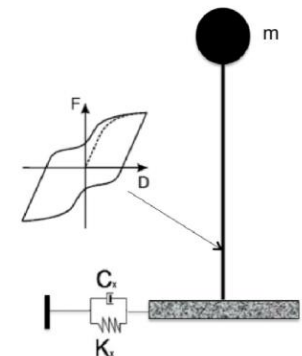
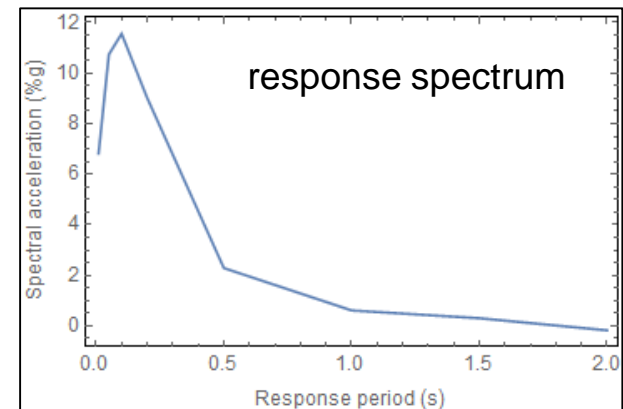
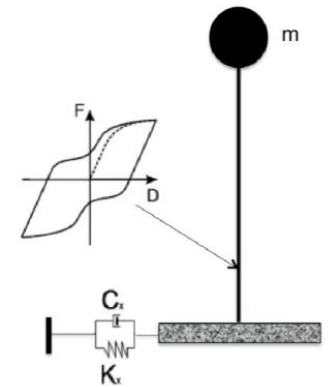
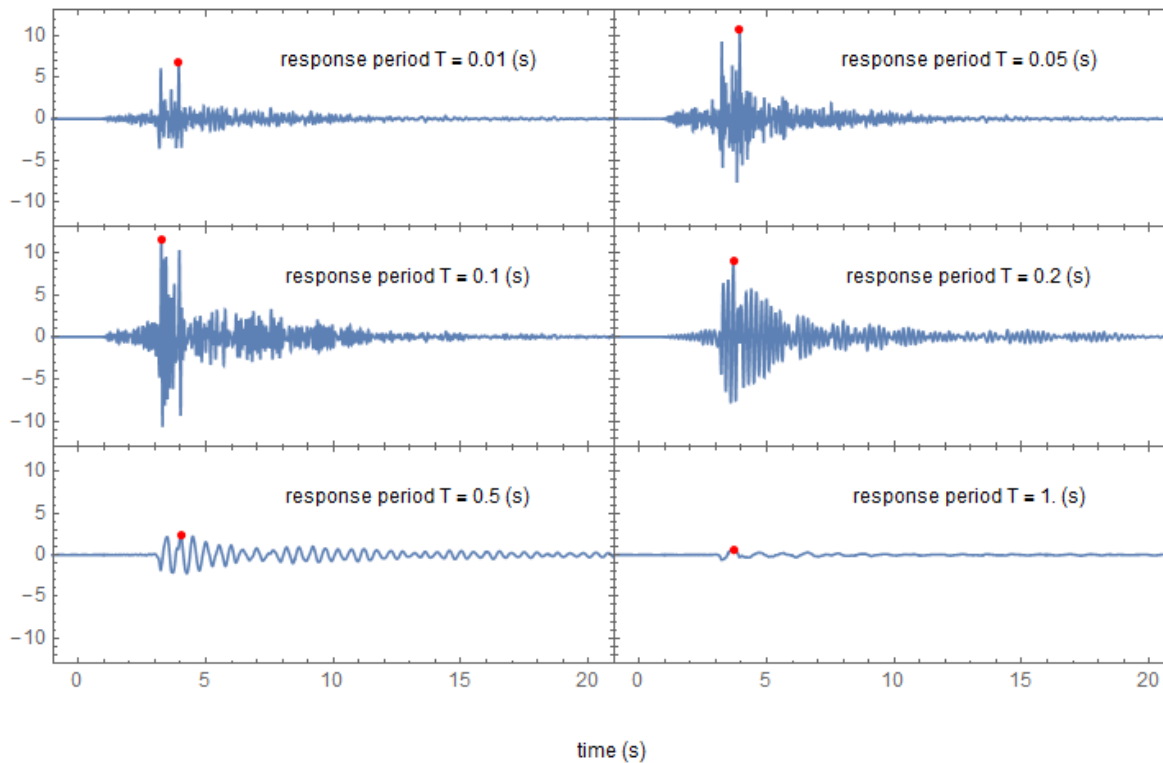


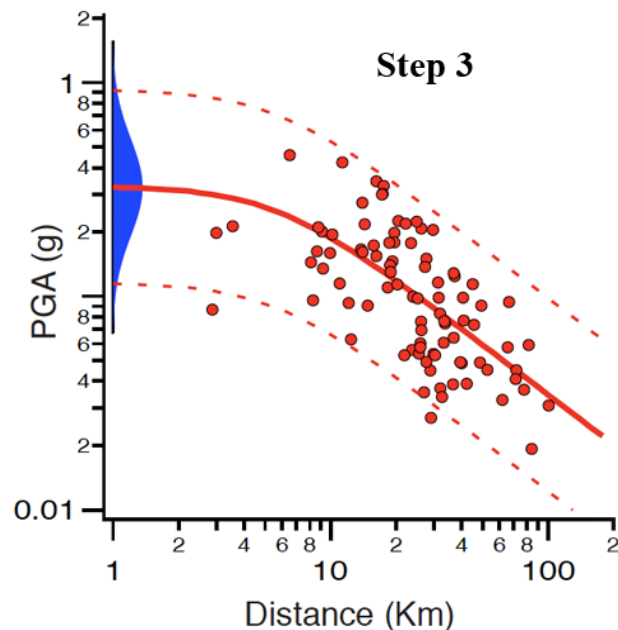
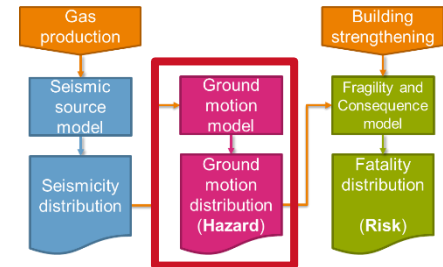
Figure: Crowley et al., V5 fragility

MODULE 2: GROUND MOTION MODEL

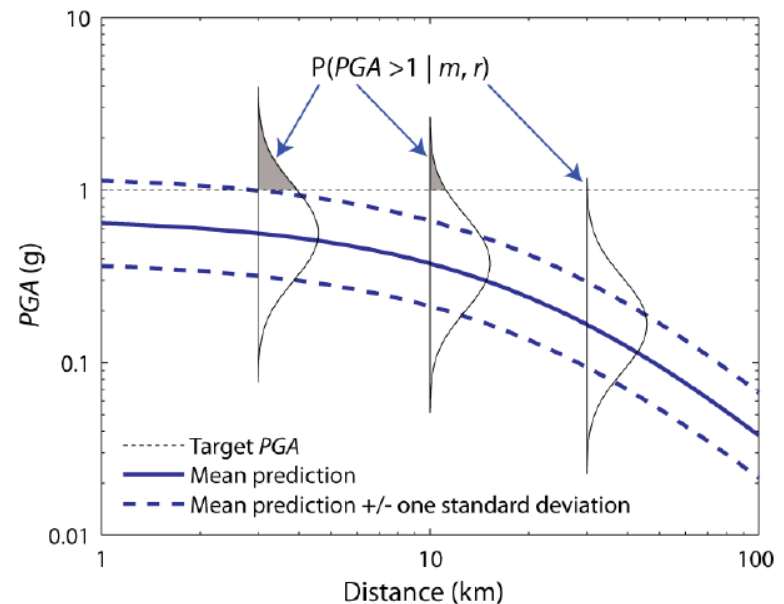


MODULE 2: GROUND MOTION MODEL

- › Provides probabilistic description of ground motion attributes conditioned on distance and magnitude (and...)



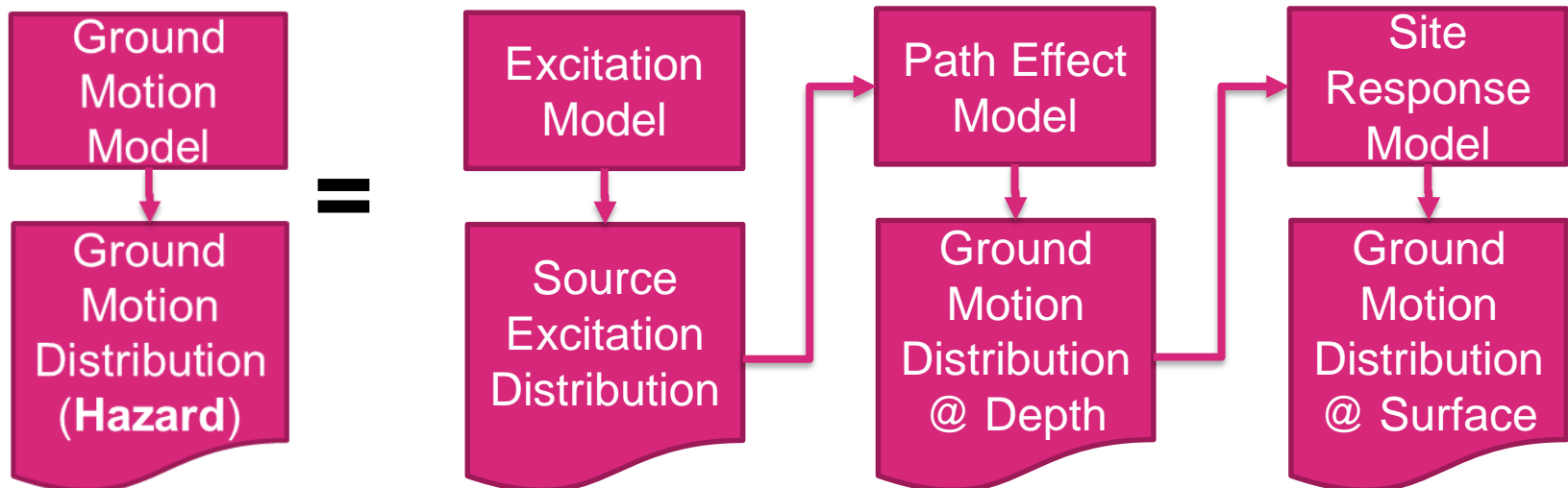
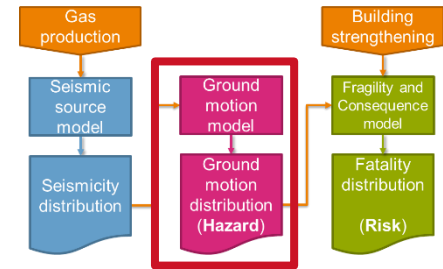
From: Kramer (1986)



From: Baker (2008)

MODULE 2: GROUND MOTION MODEL

- › Provides probabilistic description of ground motion attributes conditioned on distance and magnitude (and...)



MODULE 2: GROUND MOTION MODEL

- › Ground Motion Model by Bommer et al.
- › Includes site response model

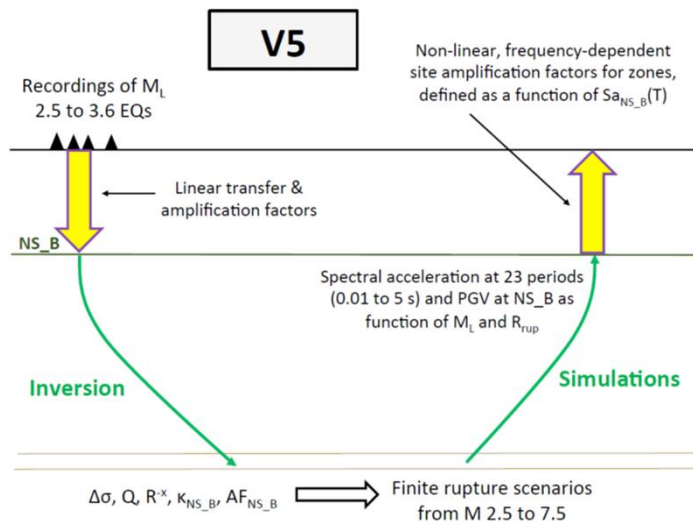
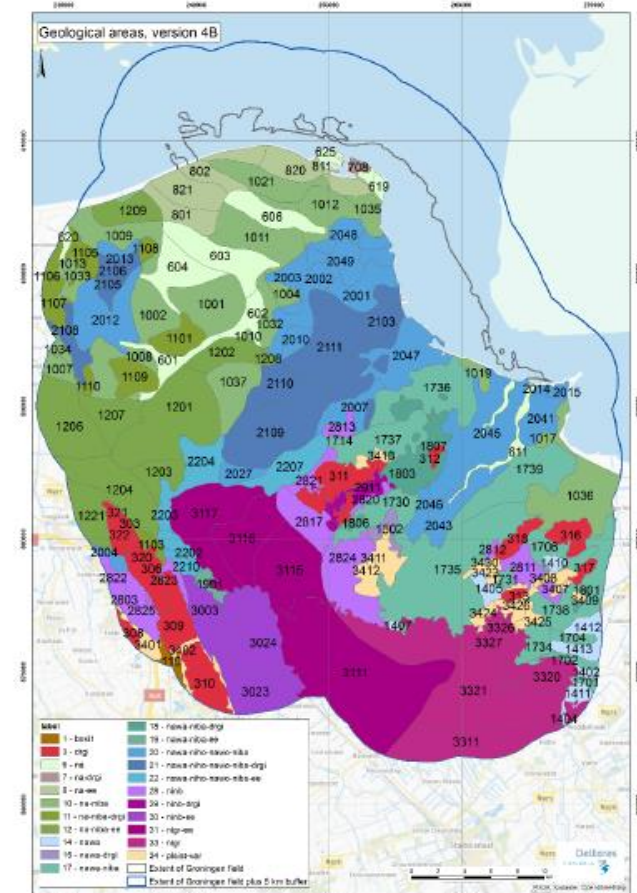
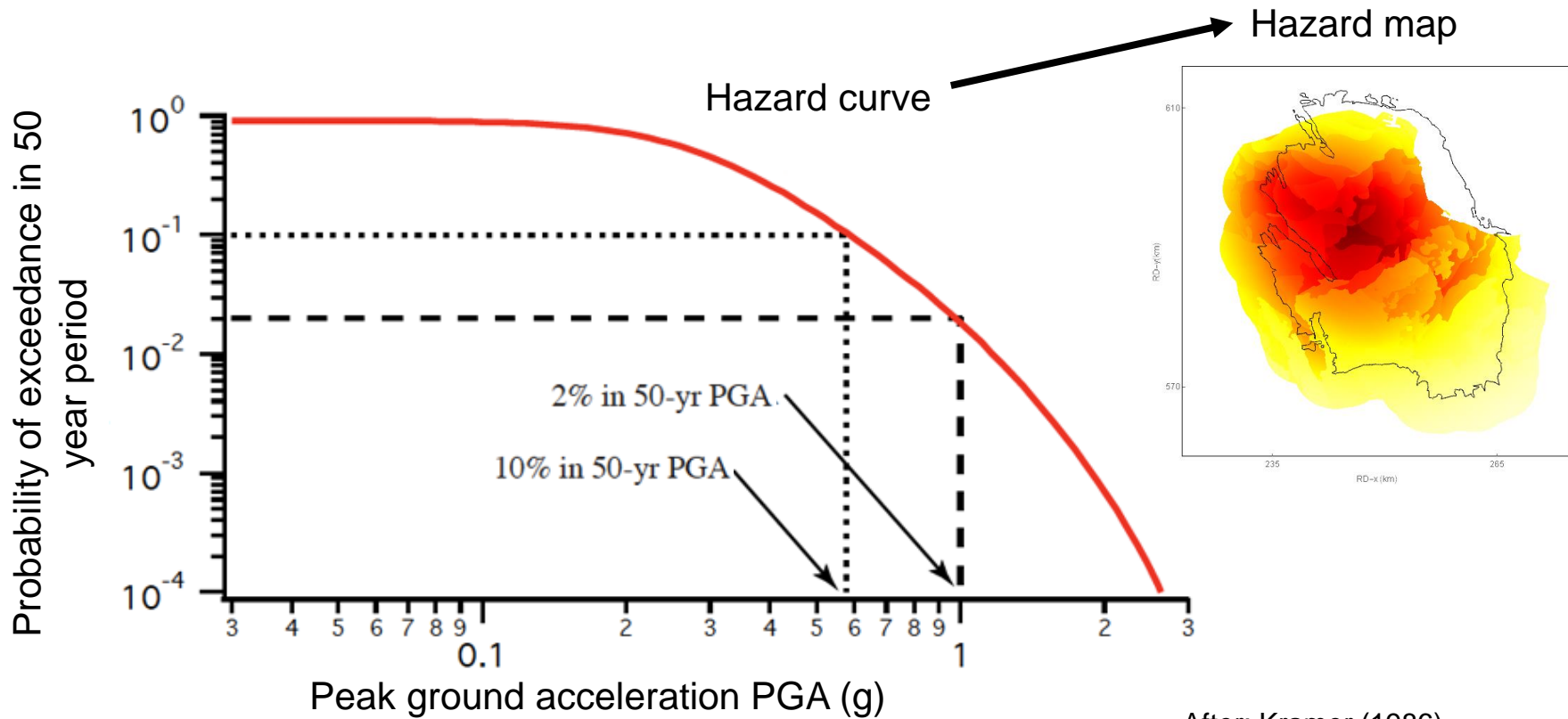


Figure: Bommer et al., 2017



Site response zonation map (Deltares)

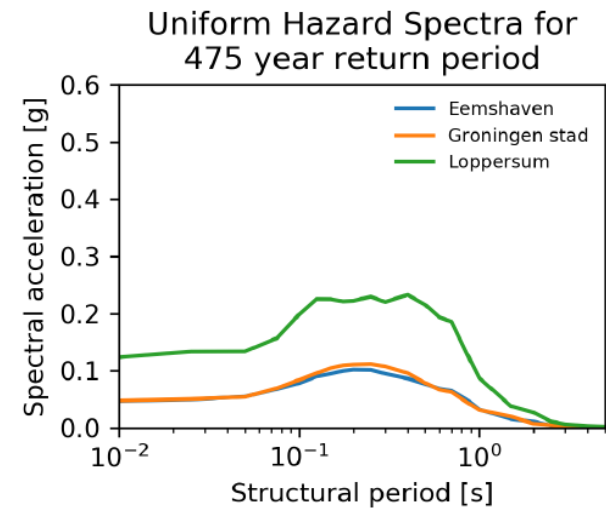
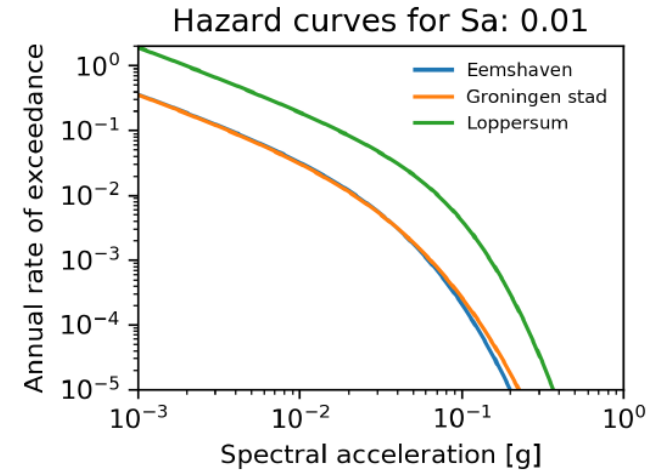
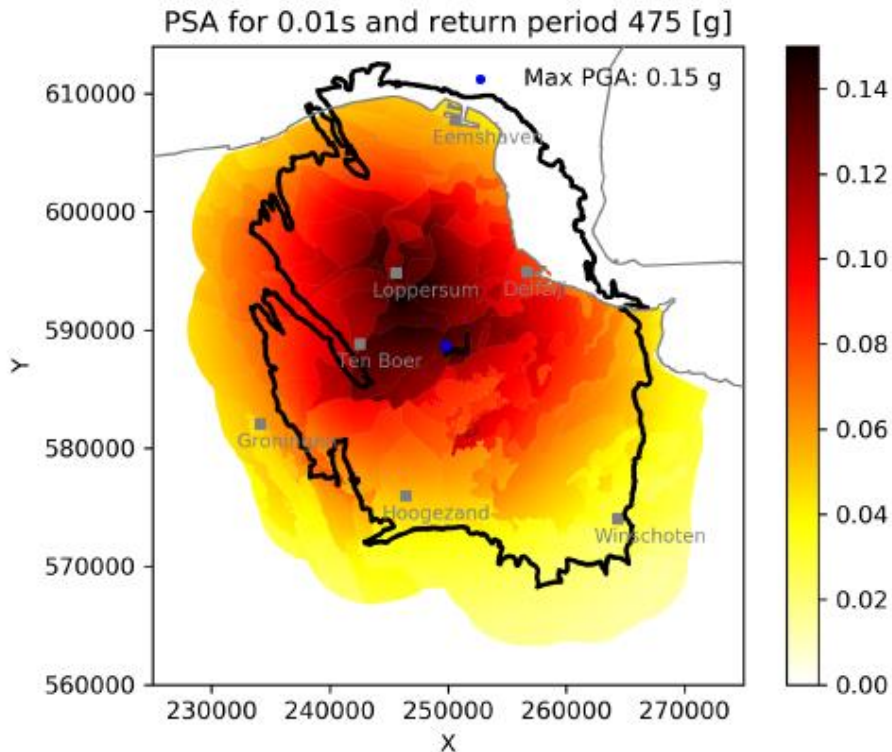
MODULE 2: GROUND MOTION MODEL



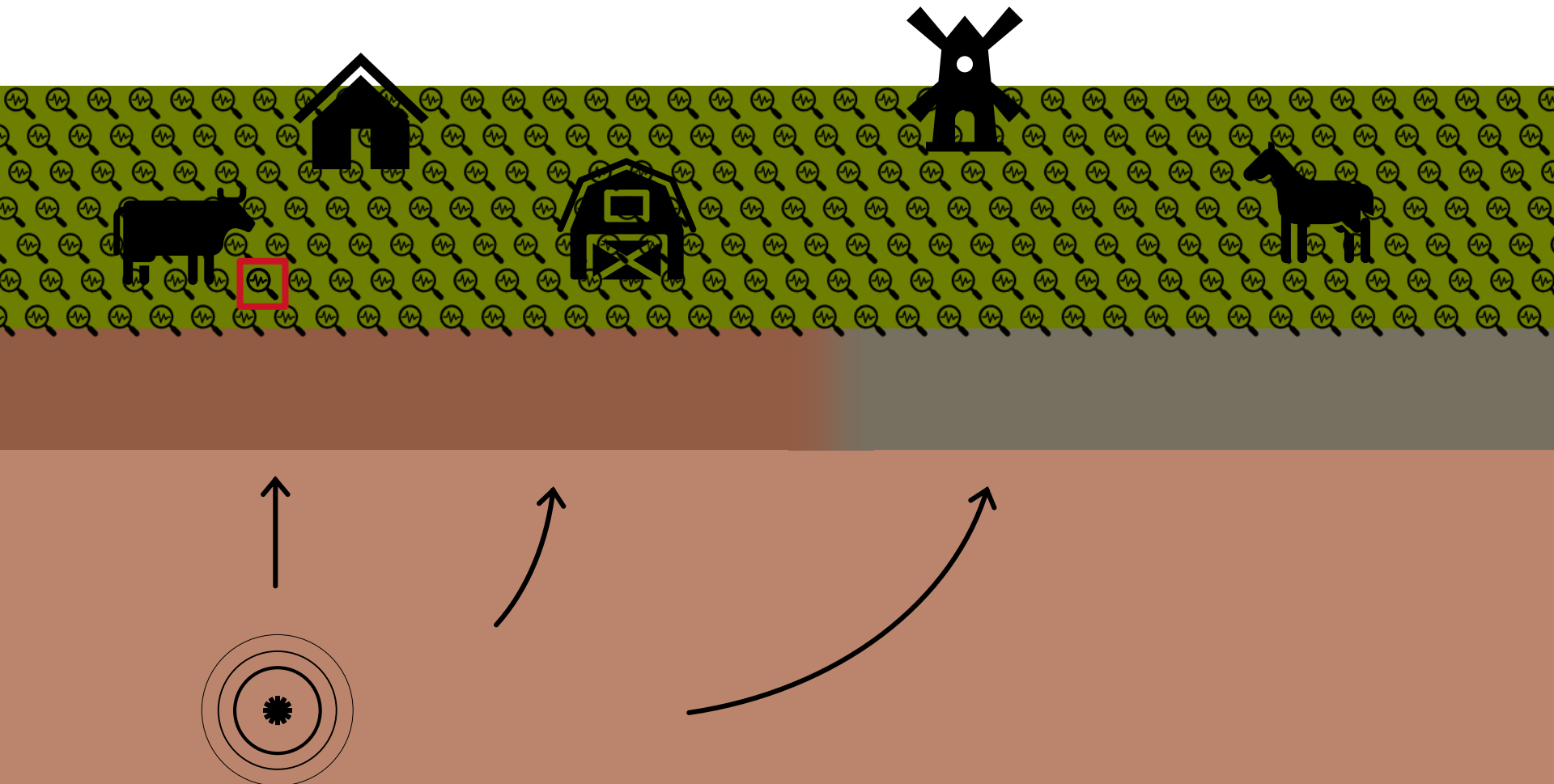
After: Kramer (1986)

MODULE 2: GROUND MOTION MODEL

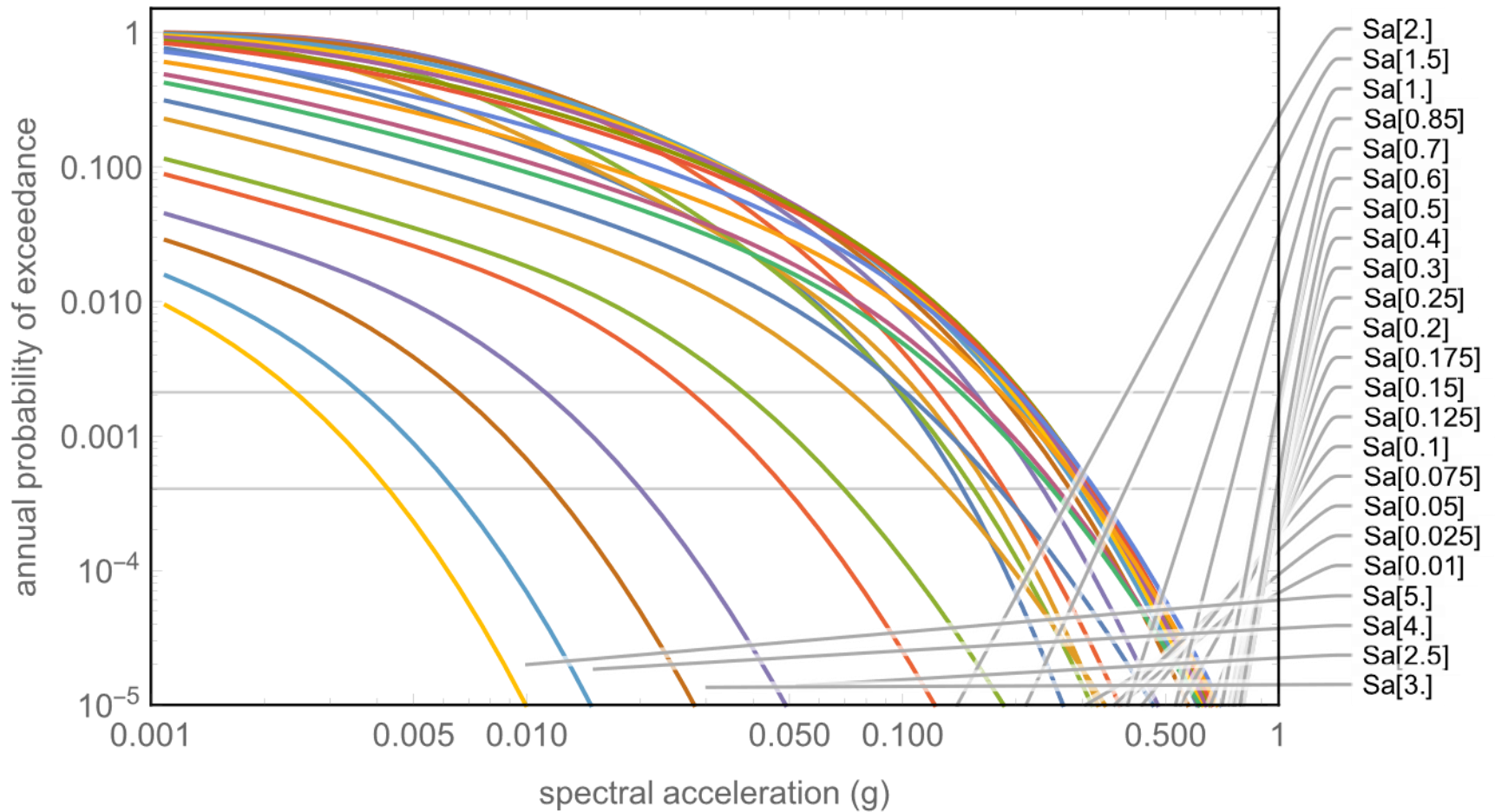
› examples hazard output



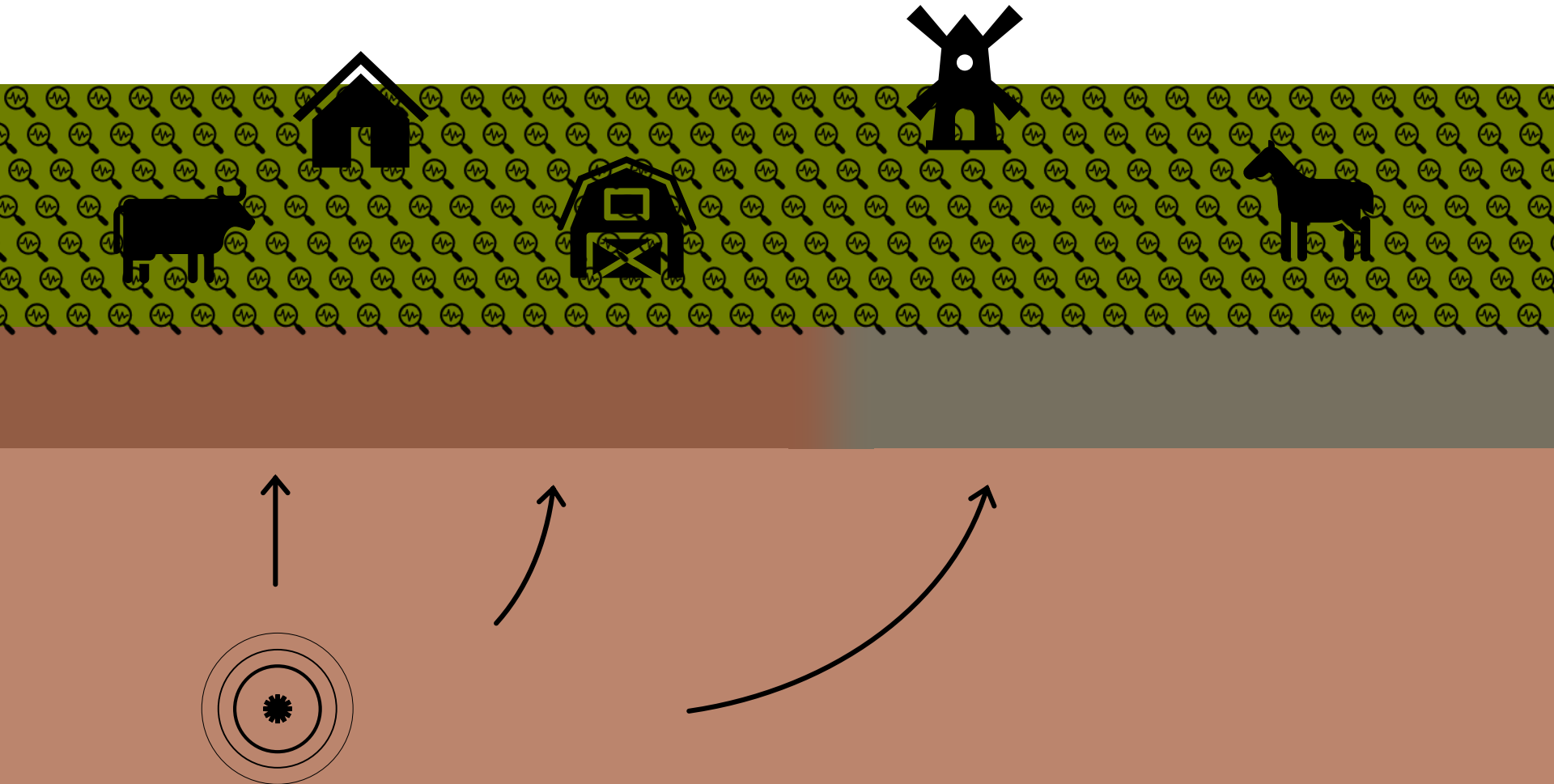
MODULE 2: GROUND MOTION MODEL



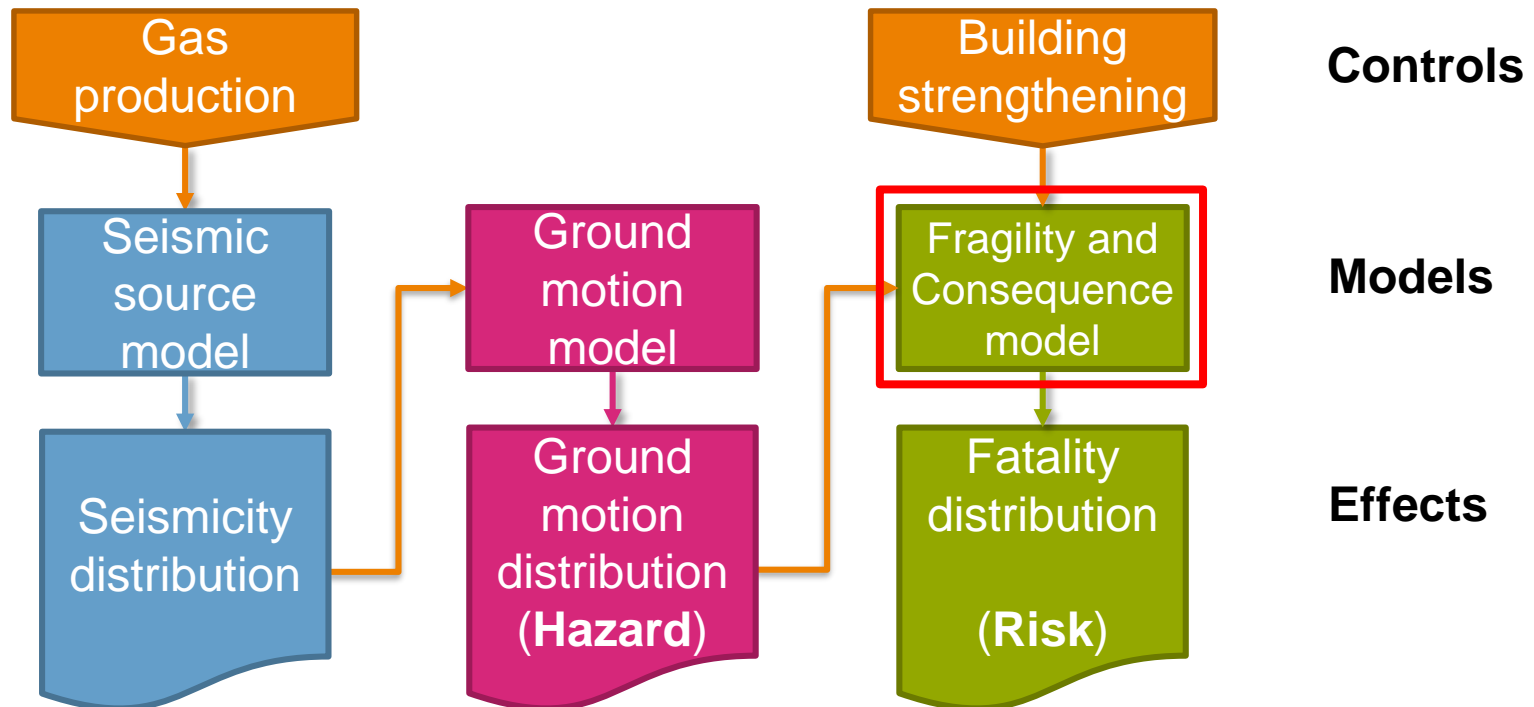
MODULE 2: GROUND MOTION MODEL



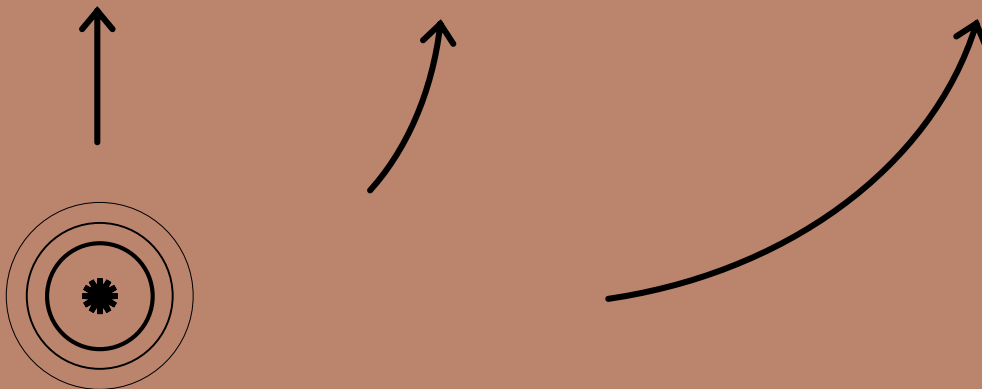
MODULE 2: GROUND MOTION MODEL



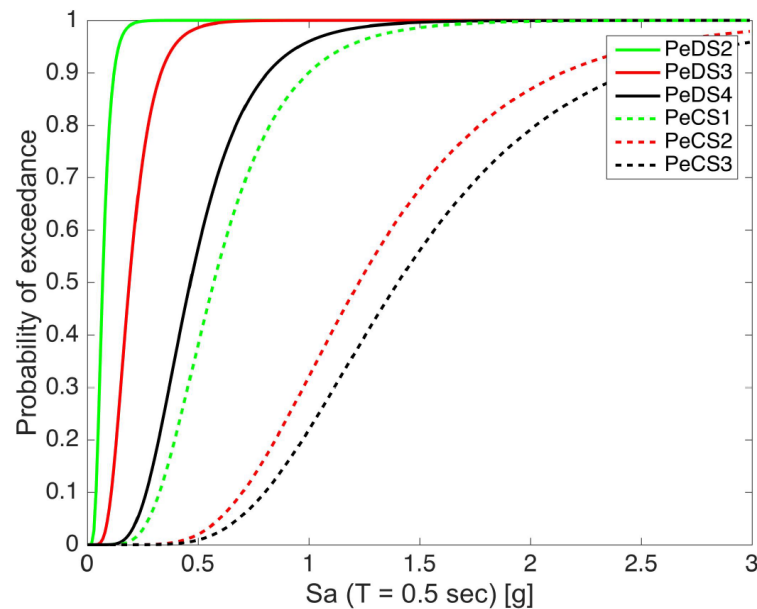
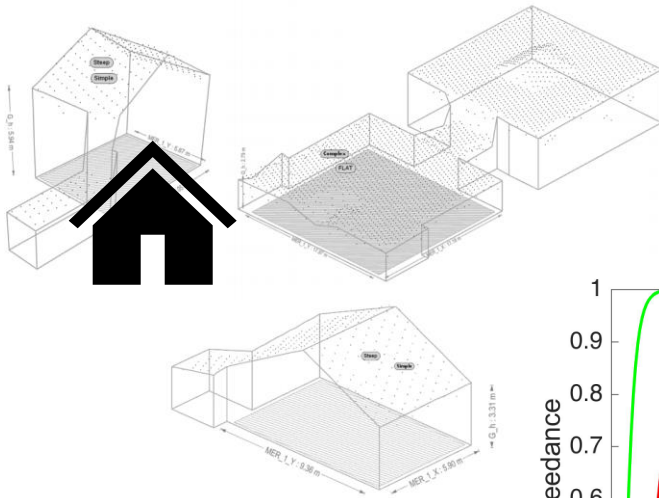
MODEL CHAIN



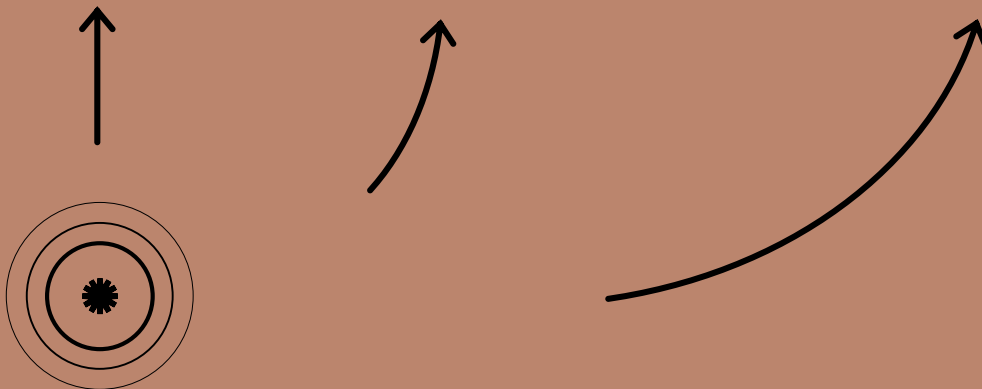
MODULE 3: FRAGILITY AND CONSEQUENCE



MODULE 3: FRAGILITY AND CONSEQUENCE



MODULE 3: FRAGILITY AND CONSEQUENCE MODEL



MODULE 3: FRAGILITY AND CONSEQUENCE

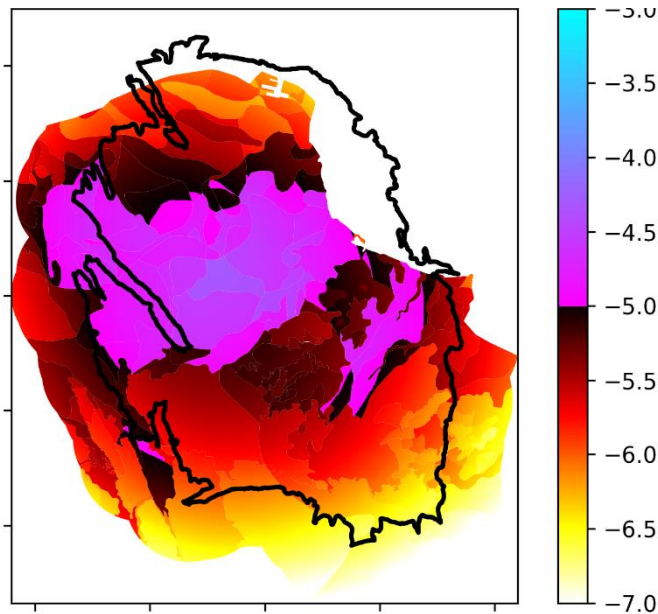


MODULE 3: FRAGILITY AND CONSEQUENCE

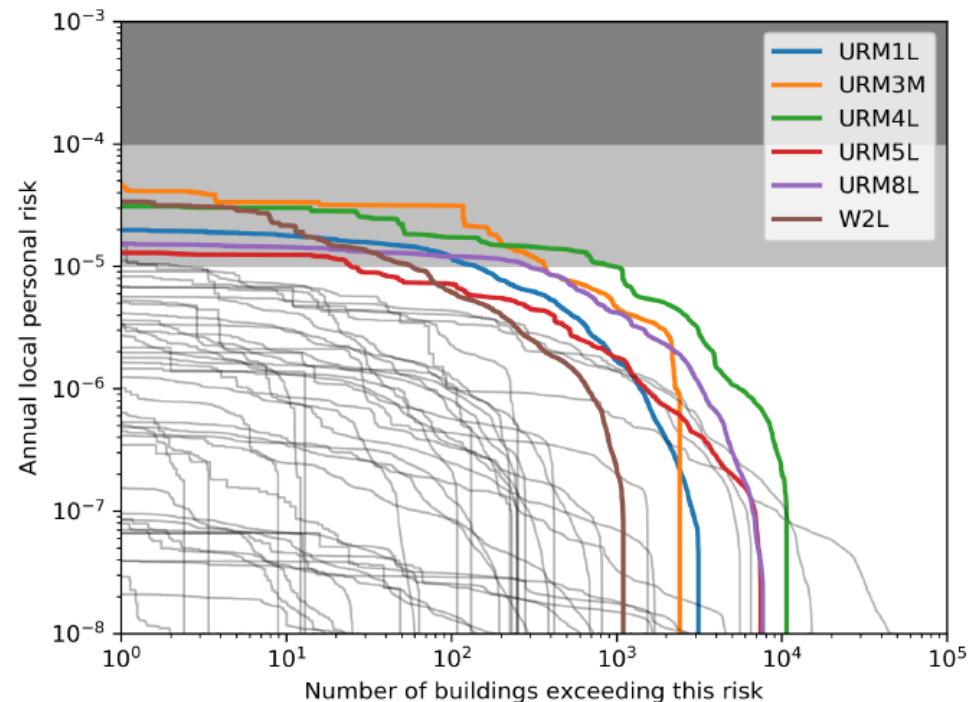


MODULE 3: FRAGILITY AND CONSEQUENCE

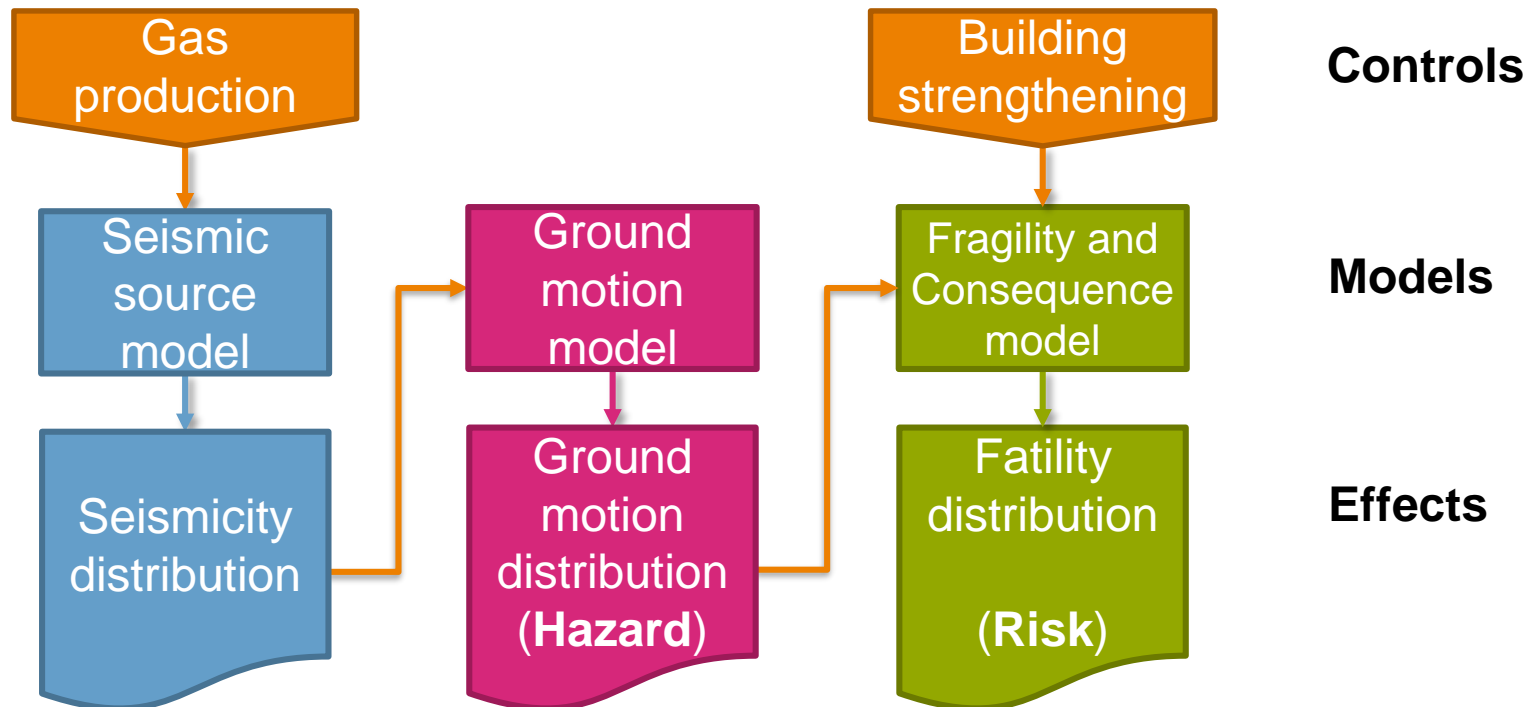
› Examples risk output (random scenarios)



personal risk associated to a certain building type



MODEL CHAIN

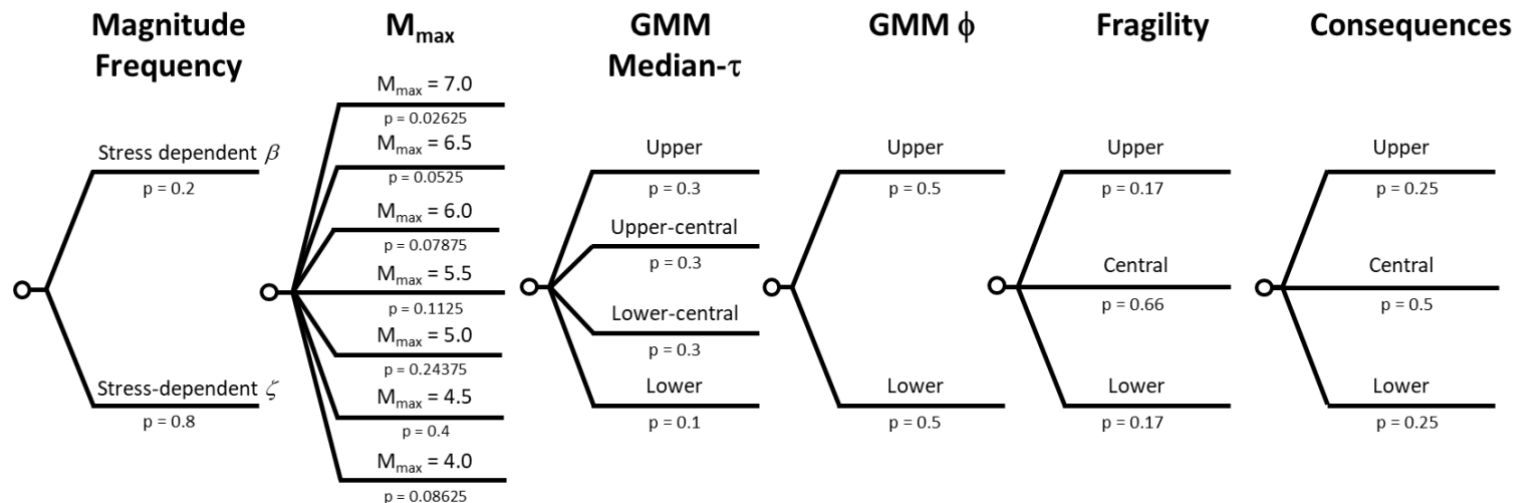
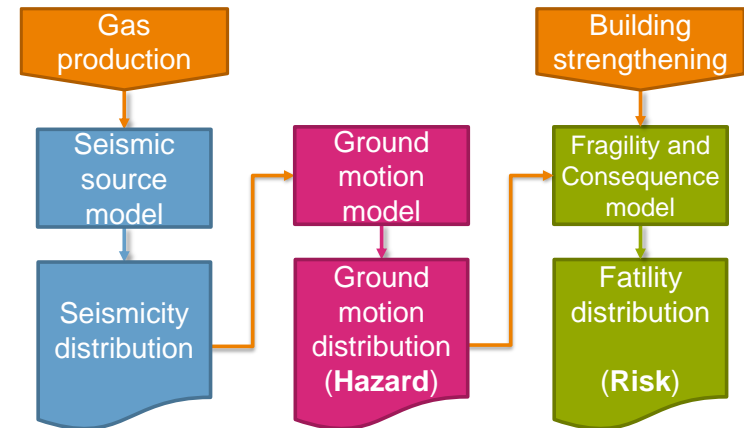


UNCERTAINTY AND VARIABILITY

- › The pSDRA model chain components are probabilistic models
- › We calculate the expected hazard and risk by taking into account as many uncertainties as we can
- › Two types: aleatory variability and epistemic uncertainty
- › Aleatory variability
 - › 'Unknowable'
 - › Integrated out : marginalized

UNCERTAINTY AND VARIABILITY

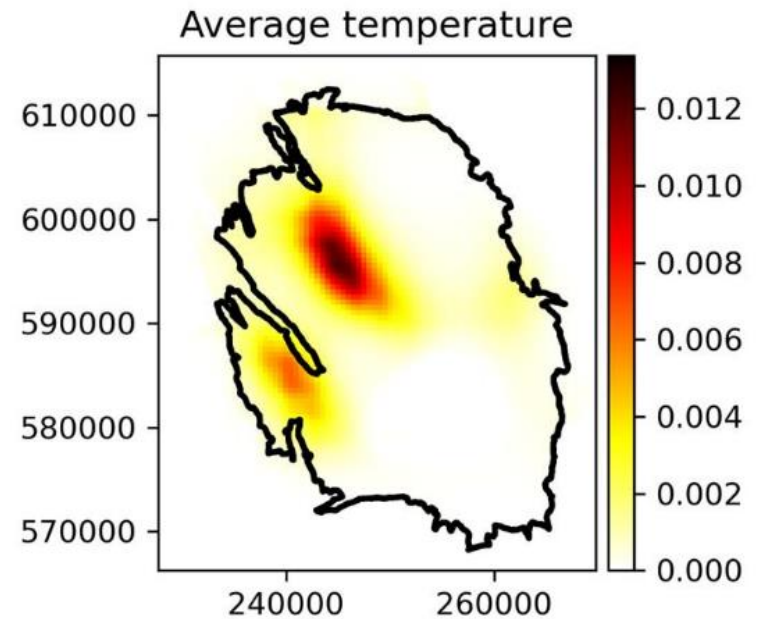
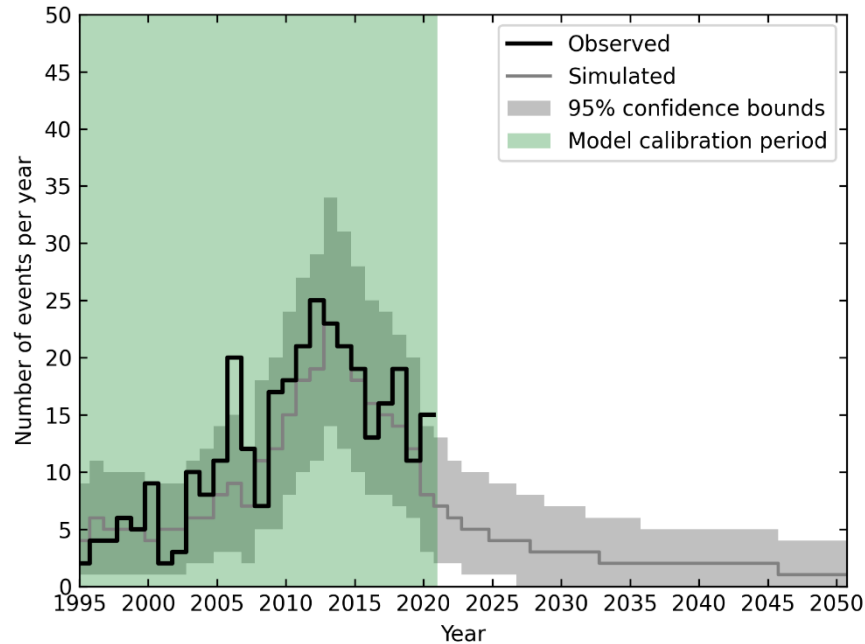
- › Epistemic uncertainty
 - › ‘Knowable’, but we don’t
 - › Represented in a so-called logic tree
 - › Kept available to calculate Pxx values of hazard and risk (e.g., P90)



PSDRA 2021

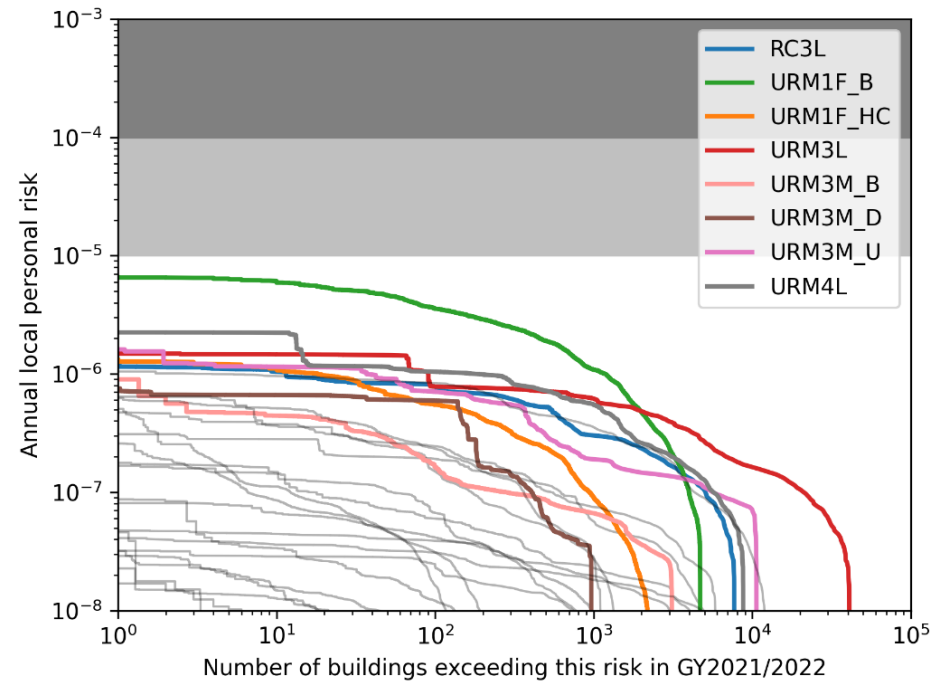
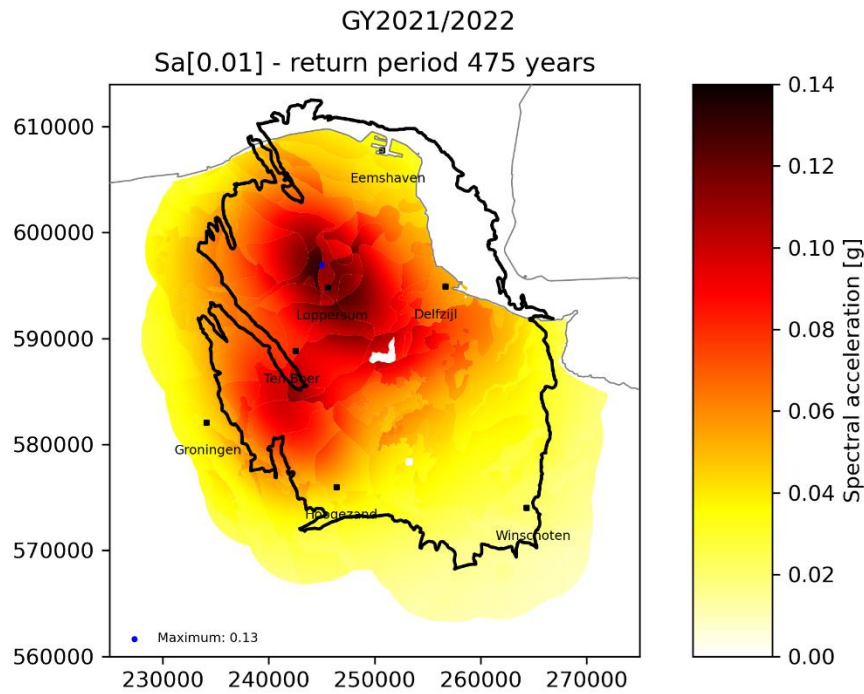


SEISMICITY FORECAST

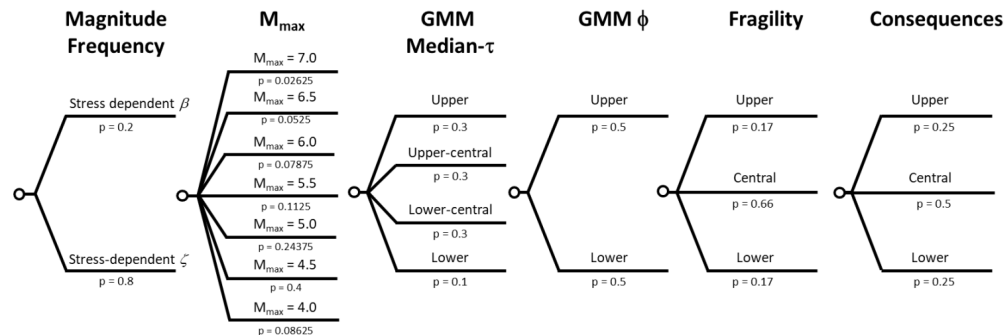
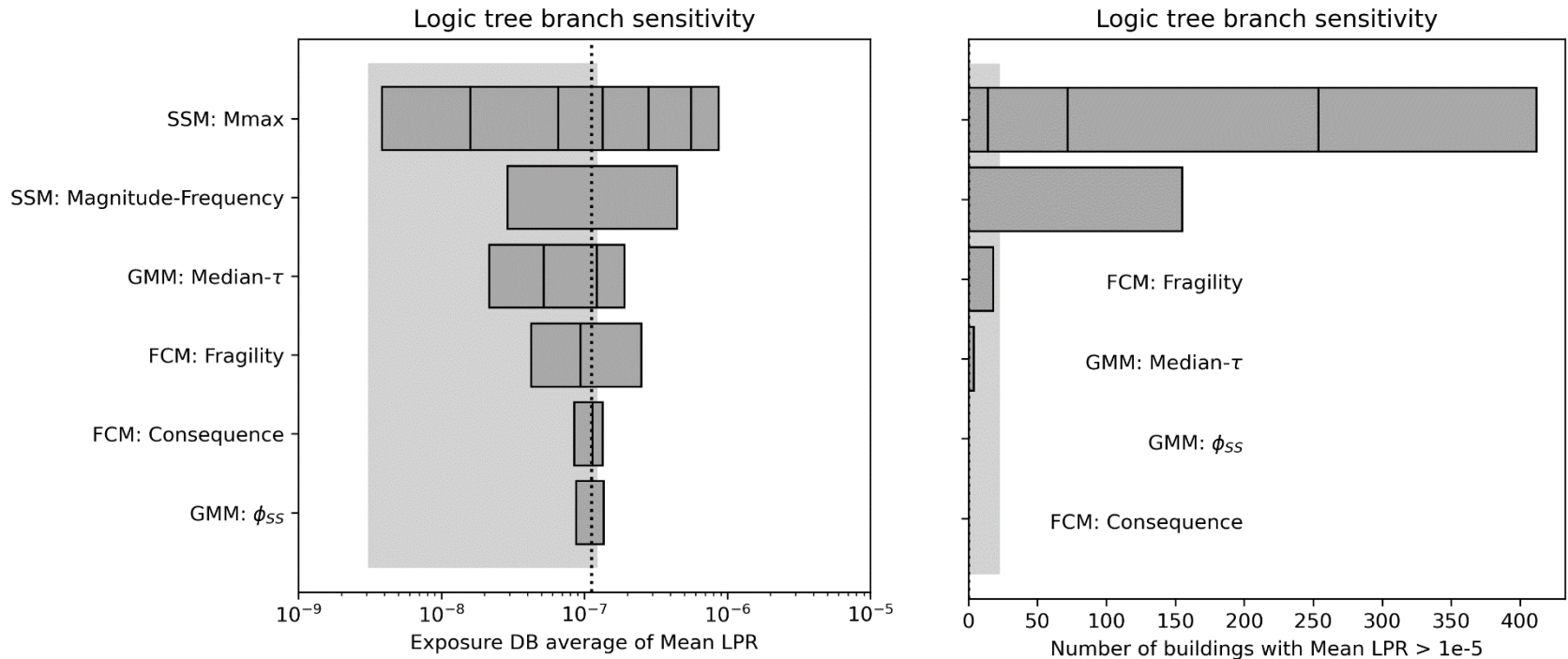


	Rate	M3.5	M3.6	M4.0	M4.5	M5.0
GY2021/2022	5.64	6.78%	5.15%	1.46%	0.20%	0.03%
GY2022/2023	4.98	6.02%	4.57%	1.30%	0.18%	0.03%
GY2023/2024	4.56	5.51%	4.18%	1.19%	0.16%	0.02%
GY2024/2025	4.18	5.06%	3.84%	1.09%	0.15%	0.02%
GY2025/2026	3.85	4.67%	3.54%	1.00%	0.14%	0.02%
GY2026/2027	3.53	4.28%	3.24%	0.91%	0.12%	0.02%
GY2027/2028	3.27	3.96%	2.99%	0.84%	0.11%	0.02%
GY2028/2029	3.03	3.66%	2.77%	0.78%	0.11%	0.02%
GY2029/2030	2.83	3.42%	2.58%	0.72%	0.10%	0.01%
GY2030/2031	2.66	3.21%	2.42%	0.68%	0.09%	0.01%

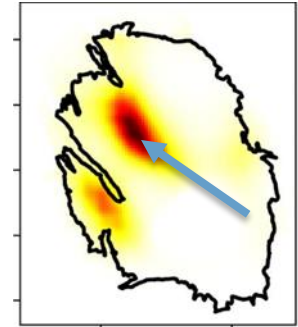
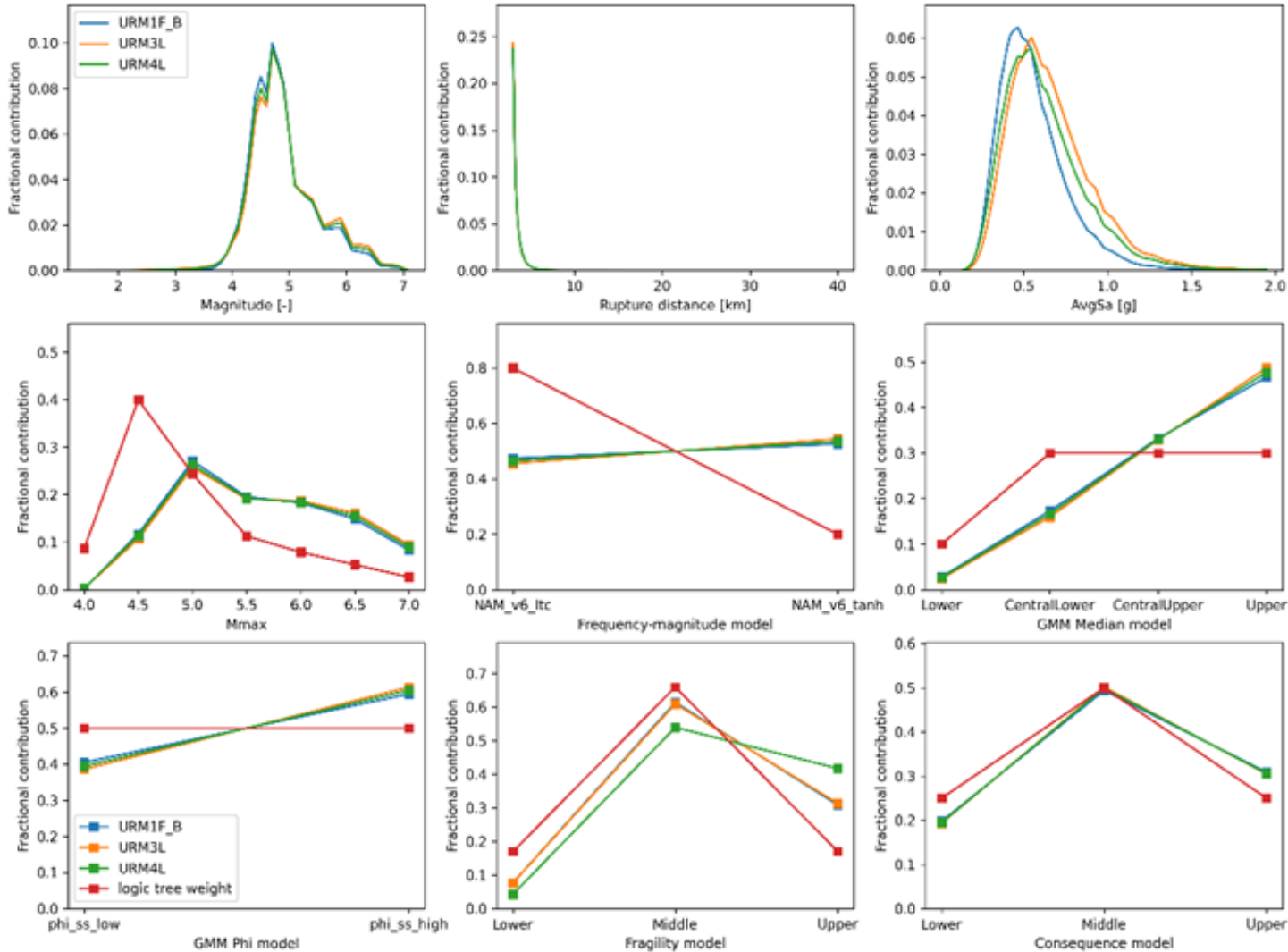
HAZARD AND RISK



LOGIC TREE SENSITIVITY

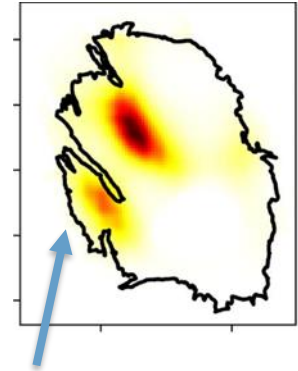
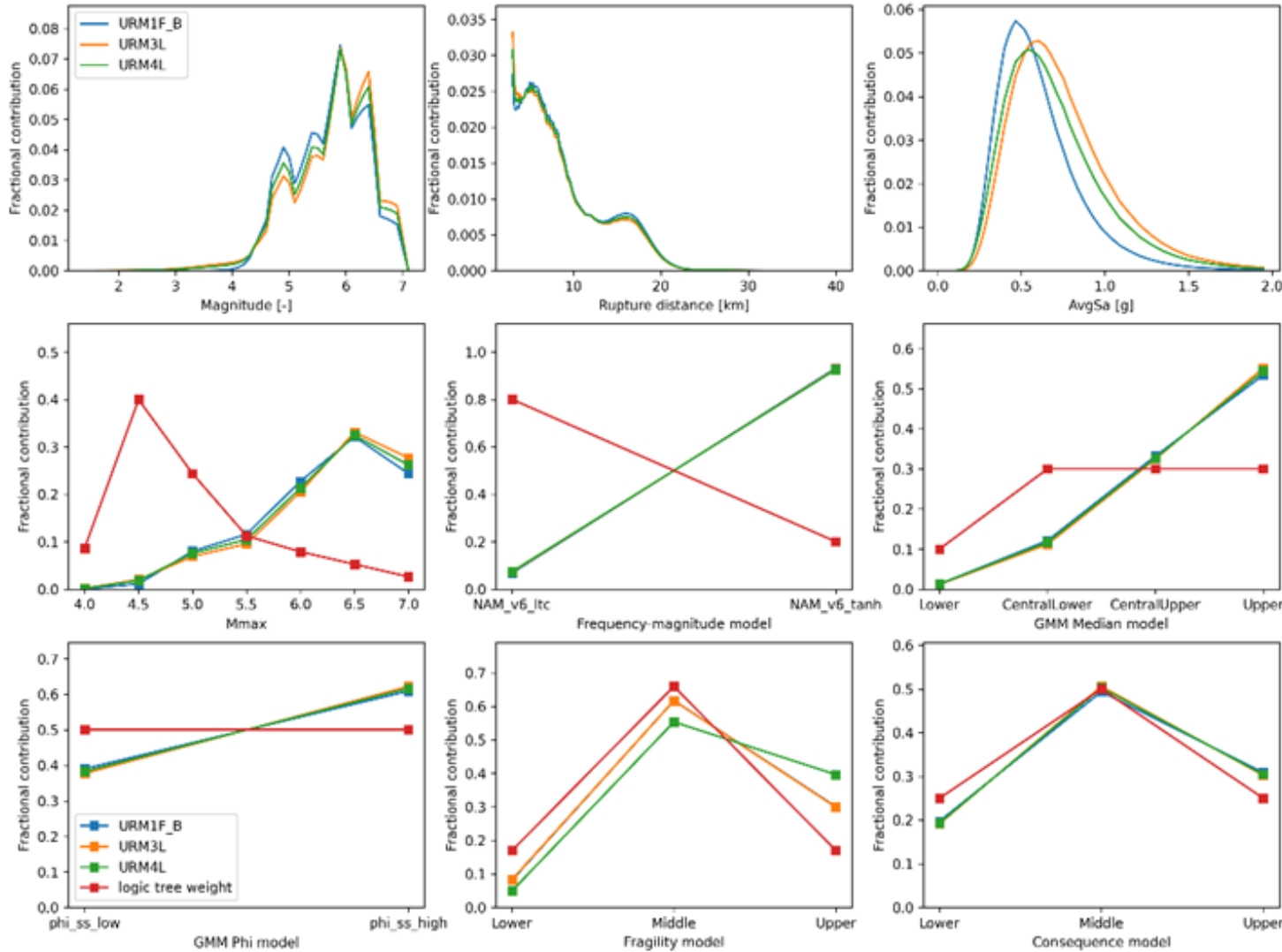


RISK DISAGGREGATION



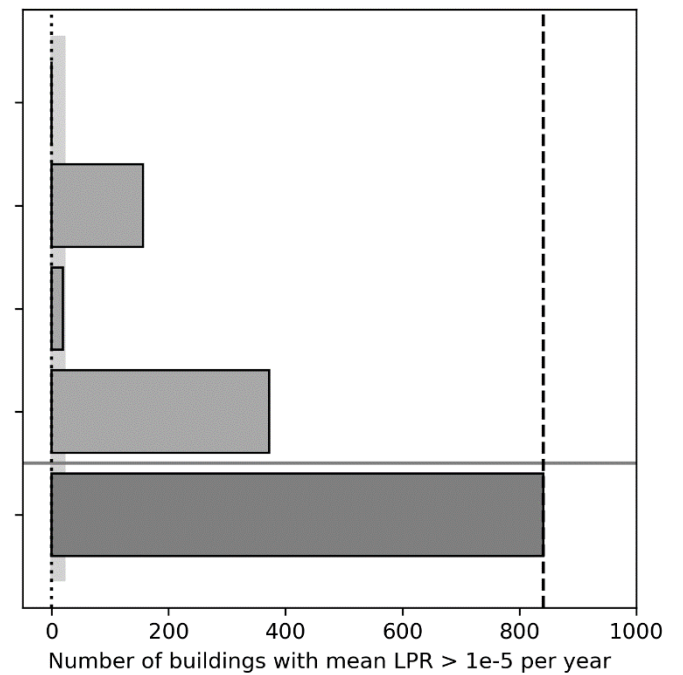
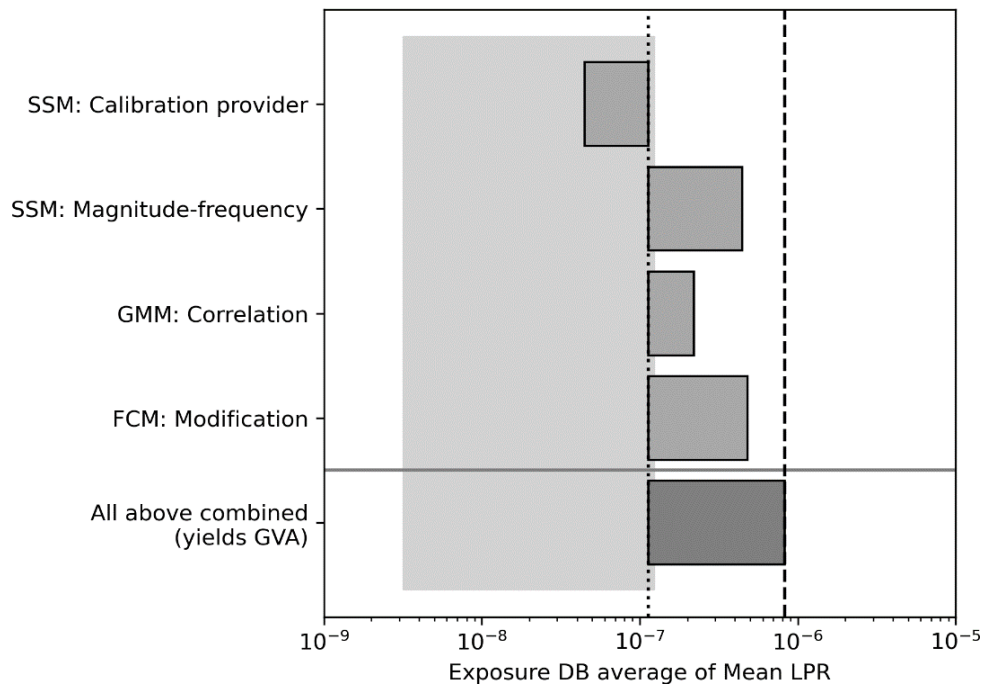
Loppersum

RISK DISAGGREGATION



Groningen (stad)

MODEL PREFERENCES TNO



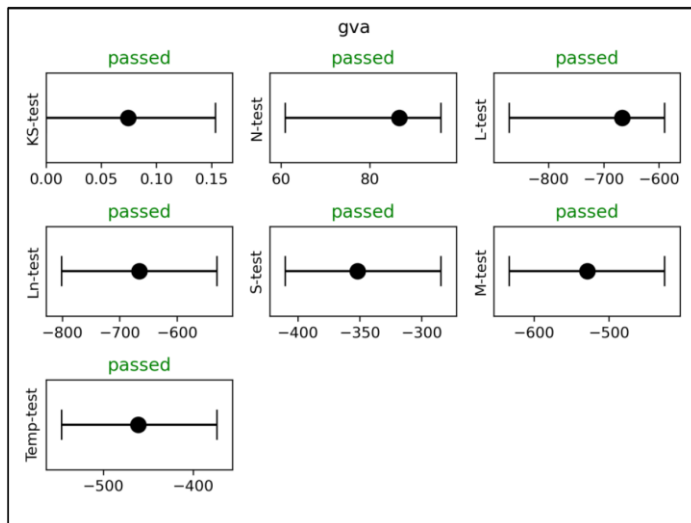
OUTLOOK

- › Model development
 - › Model chain facility
 - › Updates and improvements of existing models
 - › Open to new models from the community

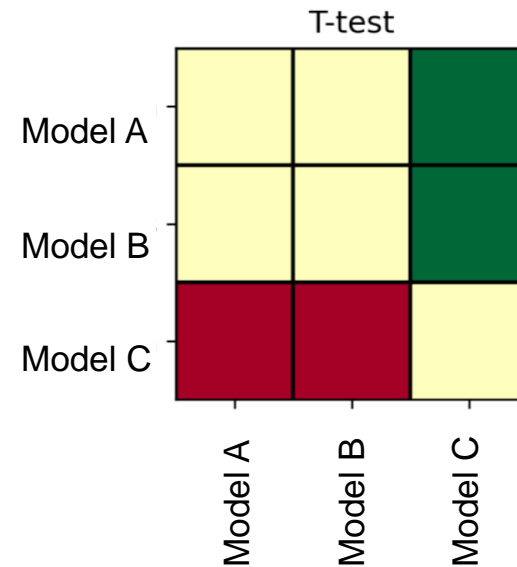
- › Inclusion in the pSDRA model chain
 - › Meet requirements
 - › Review status
 - › Impact
 - › Performance
 - › Efficiency

OUTLOOK

› Performance assessment tool



Green if row model outperforms column model
Red if column model outperforms row model



› Will be developed further in 2022

OUTLOOK

› Potential future contributions to the (Groningen) model chain

Pitches by the new projects from DeepNL Call 2a

1. Quantitative constraints on pre-production reservoir stresses in Groningen

Rob Govers (UU)

2. Deep, deeper, deepestNL; Imaging the Dutch crust and upper mantle using multi-geo-observables (DICTUM)

Islam Fadel (UT-ITC)

3. Impact of fluid extraction on the creep behaviour of clay-rich formations enveloping Rotliegend sandstone reservoirs

Suzanne Hangx (UU)

4. Geological analysis of multi-scale faults in reservoir systems and implications for fault mechanical behaviour in the Groningen field

Ernst Willingshofer & Job Arts (UU)

5. LabQuakeAI - AI-driven prediction and monitoring of laboratory earthquakes from passive and active acoustic data

Ivan Pires de Vasconcelos (UU)

6. PhysMmax: Constraining the maximum magnitude in Groningen through 3D multi-physics, data-driven modelling

Jan-Diederik van Wees (TNO/UU) on behalf of Ylona van Dinther (UU)

7. 3DSOIL: 3D soil variability in Groningen for accurate, local site response analysis

Ranajit Ghose (TUD)

CONCLUSION

- › TNO has developed a versatile and efficient probabilistic seismic hazard and risk assessment tool
- › The model chain has been applied successfully to the pSDRA 2021
- › We are open to new models to be tested and incorporated



THANKS FOR LISTENING

