Empirical models developed for Swiss GM data

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Outline

- Motivation
- Available data
- Development of simple GMPEs for Switzerland
- Comparisons
- Issue of extrapolation to higher magnitudes
- „Conclusions“

Motivation

for the development of a simple empirical GMPE for Switzerland

- Enable the extension/adjusment of selected published GMPEs to the small magnitudes in Switzerland (in a practical way)
- Make use of available instrumental data
- But: Lack of data for instrumental recordings for strong earthquakes
  - Macroseismic observations available through the new Swiss earthquake catalgue
- Available data: 709 records from 34 earthquakes and 203 stations

Motivation

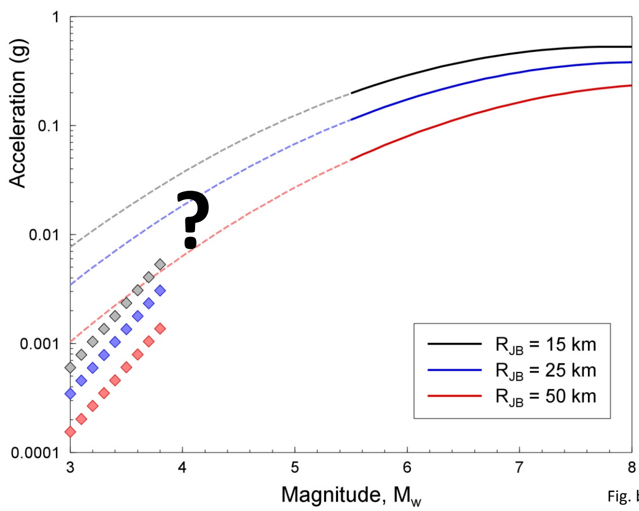

Fig. by courtesy of Prof. Dr. J. Bommer
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Example comparison of the Median predictions of SA(0.2) from the model of Akkar & Bommer (2010), shown as curves, dashed where extrapolated beyond the limit of applicability; and the median predictions from the Swiss empirical model shown as diamonds.

Magnitude-distance-mechanism distribution of selected data

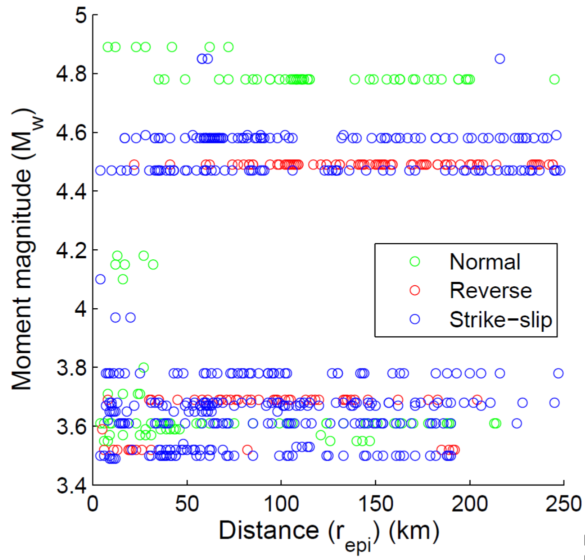

Fig. by courtesy of Dr. J. Douglas
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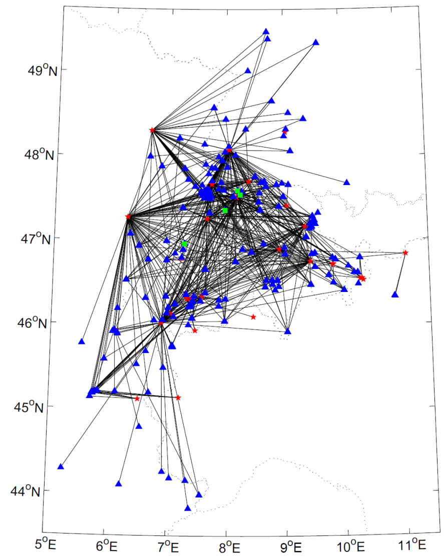
Earthquakes were classified using the same scheme as Boore and Atkinson (2008): plunge of T axis > 40° means reverse, plunge of P axis > 40° means normal and plunges of T and P axes < 40° means strike-slip.

Used earthquake data

Name	YYYY	MM	DD	HH	MM	M_w	Mech.	NR(A)	NR(B)	NR(C)	NR(D)	r_{epi} range
Albstadt	1978	01	16	14	31	4.10	S	0	1	0	0	4
Wildhorn/Anzere	1989	09	30	04	41	3.62	S	0	0	1	0	8
Wutoeschingen	1992	12	30	21	34	3.52	S	0	14	4	0	21–69
Valpelline	1996	03	31	06	08	4.15	N	0	3	0	0	12–32
Annecy/Epagny	1996	07	15	00	13	4.59	S	0	4	2	1	28–246
Kirchberg	1996	08	24	02	38	3.59	N	0	2	4	1	28–46
Fribourg	1999	02	14	05	57	3.97	S	0	0	2	0	12–20
Bormio	1999	12	29	20	42	4.89	N	0	4	3	0	8–72
Bormio (aftershock)	1999	12	31	04	55	4.18	N	0	1	1	0	13–27
Buchs	2000	03	04	15	43	3.59	R	0	0	0	1	5
Bormio	2000	04	06	17	40	4.10	N	0	1	0	0	16
Martigny	2001	02	23	22	19	3.55	N	0	3	1	2	6–147
Merano	2001	07	17	15	06	4.85	S	1	0	1	2	58–216
Bormio	2001	10	01	06	36	3.8	N	0	0	1	0	27
S. Maria Maggiore	2002	04	29	15	14	3.54	S	0	1	0	0	48
St Die	2003	02	22	20	41	4.78	N	0	15	24	9	38–245
Salgesch	2003	04	29	04	55	3.52	R	0	5	7	4	6–192
Urnerboden	2003	05	06	21	59	3.67	S	4	14	12	1	7–206
Modane	2003	05	25	23	03	3.65	S	0	1	1	3	54–63
Sertig	2003	07	17	02	27	3.57	N	0	2	0	0	16–25
Sertig	2003	07	18	11	01	3.57	N	0	2	1	1	9–121
Sertig	2003	08	01	03	20	3.71	N	0	3	1	0	8–25
Glarey	2003	08	22	09	21	3.65	S	0	4	6	2	9–98
Glarey	2003	08	22	09	30	3.49	S	0	1	4	0	9–12
Besancon	2004	02	23	17	31	4.49	R	4	24	37	13	22–244
Val Susa	2004	05	14	00	30	3.53	S	0	1	1	2	108–115
Brugg	2004	06	28	23	42	3.50	S	4	17	23	1	4–190
Waldkirch	2004	12	05	01	52	4.58	S	4	33	47	7	17–241
Rumisberg	2005	05	12	01	38	3.69	R	3	16	19	1	8–204
Vallorcine	2005	09	08	11	27	4.47	S	3	32	28	9	4–248
Moenthal	2005	11	12	19	31	3.61	N	4	15	24	0	4–214
Paspels/Thusis	2008	01	21	16	40	3.68	S	4	21	19	2	9–245
Wildhaus	2009	01	04	15	30	3.78	S	4	21	21	4	7–247
Steinen	2009	05	05	01	39	3.61	S	4	21	27	2	14–225
34 earthquakes						3.49–4.89	711	39	282	322	68	4–248
12 normal earthquakes						3.55–4.89	128	4	51	60	13	4–245
18 strike-slip earthquakes						3.49–4.85	449	28	186	199	36	4–248
4 reverse earthquakes						3.52–4.49	134	7	45	63	19	5–244

The 11 earthquakes with Mw>4 are highlighted in bold (119 records = 4% of data).

Map showing the epicentral locations (red stars), station locations (blue triangles) and travel paths (black lines) of the data selected



Earthquakes within 250km of sites

$M_w \geq 3.5$

$r_{epi} \leq 250$km

Blue: Stations

Red: Earthquakes

Green: Sites

Fig. by courtesy of Dr. J. Douglas
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Development of simple GMPEs

Functional form used to develop the GMPE for r_{epi}:

$$\log y = b1 + b2\, M + b3 \log(\sqrt{r_{epi}^2 + b4^2})$$

Functional form for r_{hypo}:

$$\log y = c1 + c2\, M + c3 \log(r_{hypo})$$

- A more complex functional form (e.g. magnitude-dependent decay or quadratic magnitude scaling) was not used because of the limited magnitude range (only 1.4 magnitude units) covered by the available data.
- The one-stage maximum-likelihood regression method of Joyner and Boore (1993) has been used to develop the equations since it accounts for the inter- and intra-event variabilities.
- Both a classical regression procedure using all the available 709 records and a ten-fold cross-validation regression procedure have been followed.

Development of simple GMPEs

- The standard deviations of the developed GMPEs were assumed to be homoscedastic (magnitude-independent) for simplicity and due to the limited magnitude range of available data.
- The inter- and intra-event standard deviations (and the total standard deviation) of the developed GMPEs are higher than the standard deviations of the selected published GMPEs, which are developed using data from much larger earthquakes. (In agreement with previous studies e.g. Bommer et al., 2007; Douglas, 2007)

Comparisons

Comparisons between predicted PSAs from the GMPEs using r_{epi} and those predicted by the four GMPEs selected for the PRP using r_{jb} for M_w4, strike-slip faulting and hard rock/rock sites.

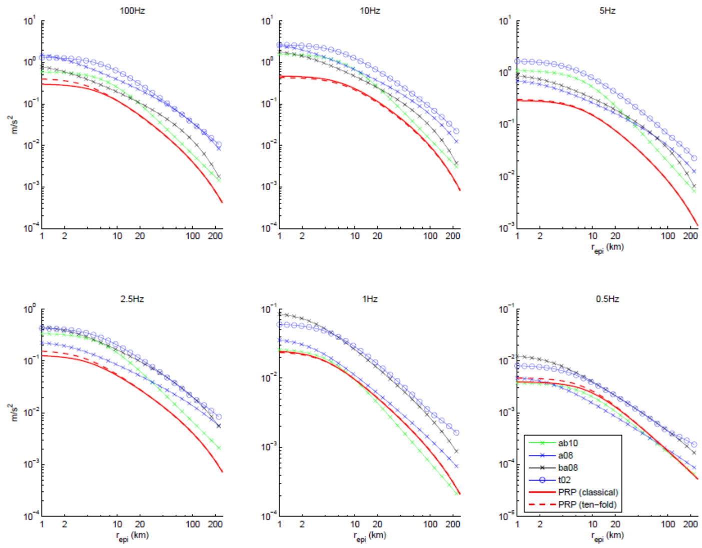

Fig. by courtesy of Dr. J. Douglas
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Comparisons between predicted PSAs from the GMPEs using r_{hypo} and those predicted by the five GMPEs selected for the PRP using r_{rup} for M_w4, strike-slip faulting and hard rock/rock sites.

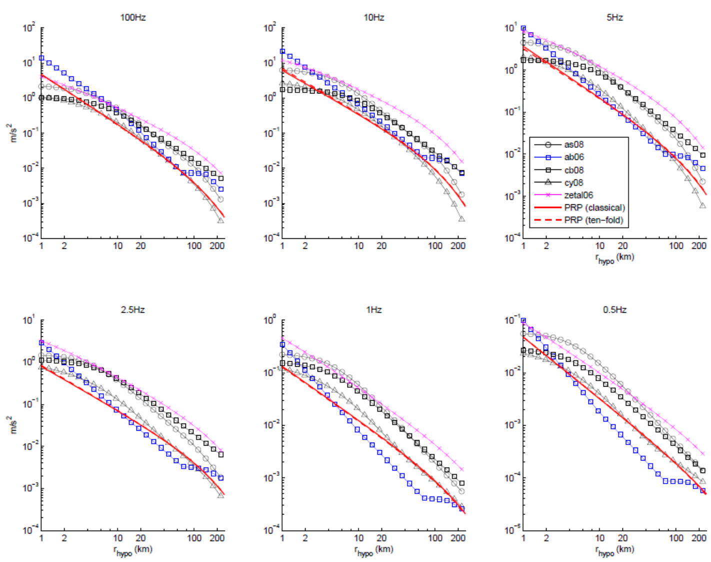

Fig. by courtesy of Dr. J. Douglas
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Comparisons - Observations

- For M_w4 the GMPEs developed using the PRP dataset predict lower ground motions at high frequencies, particularly in the near-source region, than the nine selected GMPEs (which is in agreement with the findings of e.g. Bommer et al., 2007), but that for lower frequencies the predictions from the developed GMPEs are within the large scatter of PSAs estimated by the selected GMPEs.
- For M_w5 the GMPEs developed predict similar PSAs as the selected GMPEs.
- The predictions using the classical and ten-fold cross-validation approaches are almost identical except in the near-source region suggesting that the regressions are stable.

Issue of extrapolation to higher magnitudes

- Swiss stochastic model is based on records between magnitude ≈2.0-5.0 and distances between ≈ 3-300 km
- Strong magnitude dependence of the stress-drop increasing from 2 bars for M2.5 to 30 bars for M4.5
- But: Relevant to the hazard is the scaling of the stress-drop above M4.5
- As there is no empirical constraint on the high magnitude stress-drop scaling, a suite of alternative stochastic models was developed.
- *Note: The <u>empirical</u> Swiss model was not extrapolated or used for higher magnitudes in the project!*

Alternative models of the magnitude dependence of the stress drop for extrapolation of the Swiss stochastic model to high magnitudes.

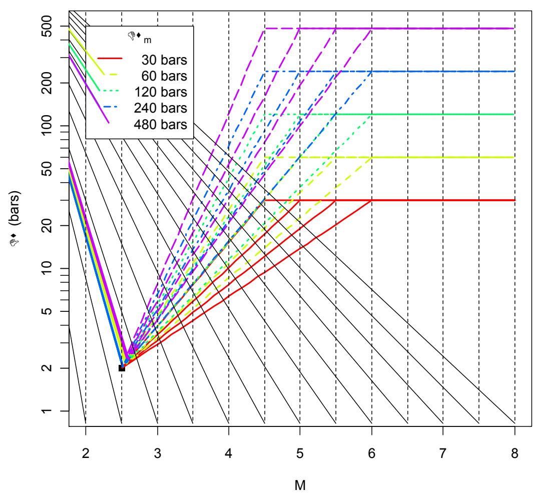

Fig. by courtesy of Dr. B. Edwards
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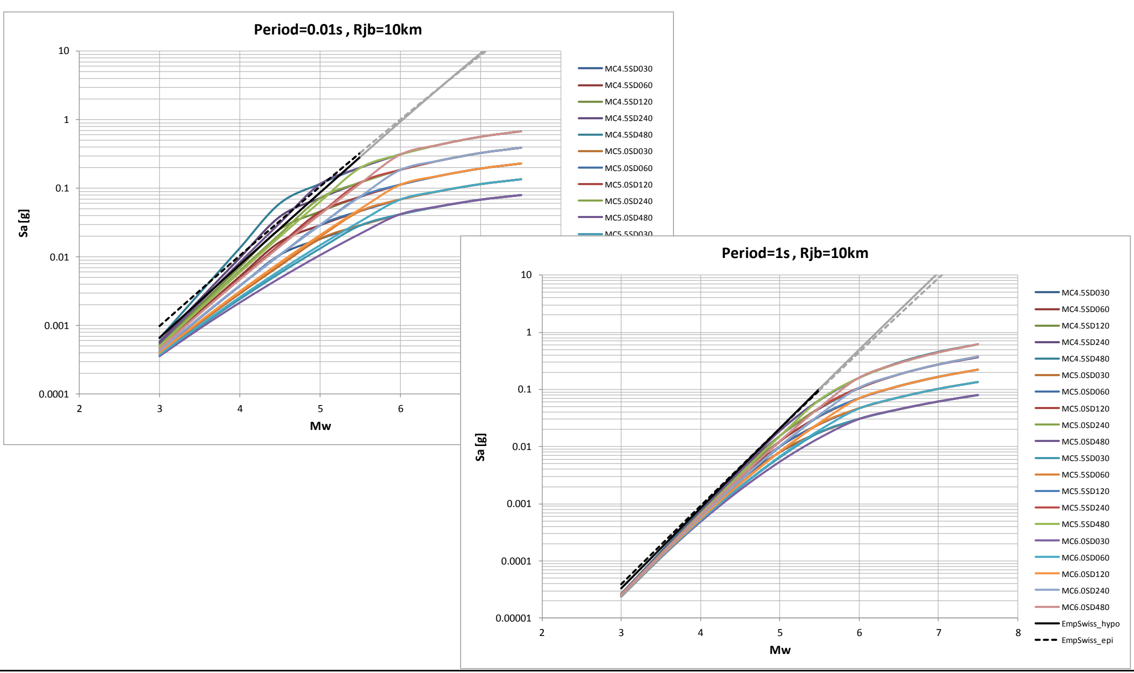
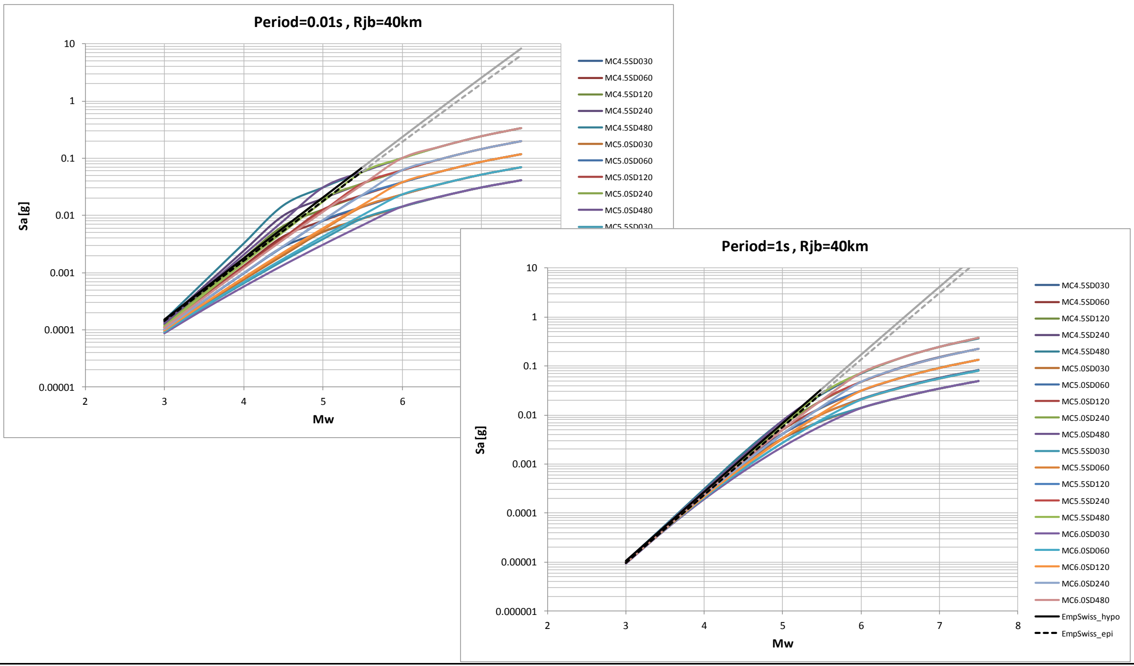
Two parameters:
- the maximum stress drop (30-480 bars) and
- the “cutoff” magnitude (4-6) at which the stress drop reaches this maximum level.

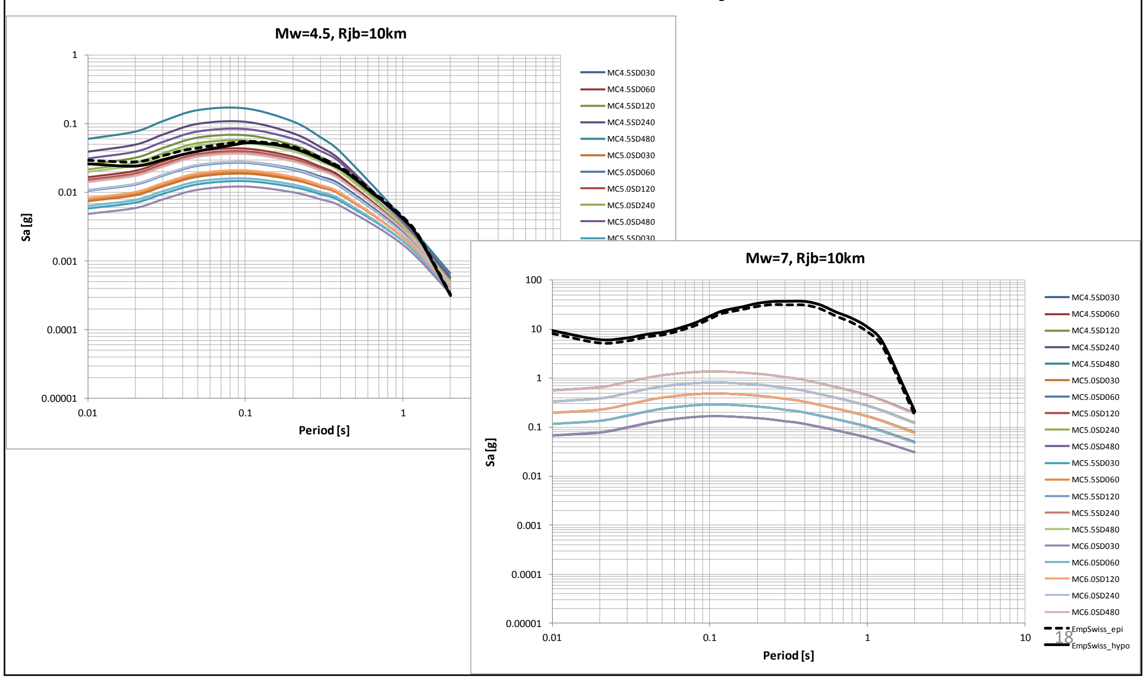
Example comparisons of parameterized Swiss stochastic and empirical model



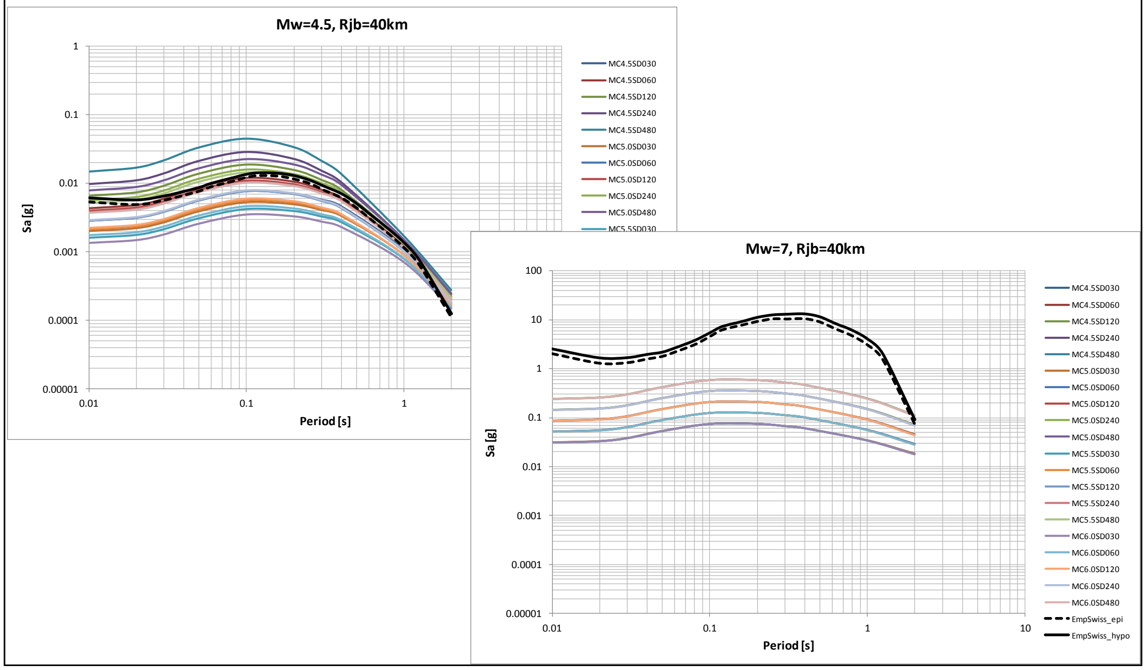
Example comparisons of parameterized Swiss stochastic and empirical model



Example comparisons of parameterized Swiss stochastic and empirical model



Example comparisons of parameterized Swiss stochastic and empirical model



„Conclusions“

- How much does the strong magnitude dependence of the stress-drop at lower magnitudes tell us about the behavior at larger magnitudes?
- The developed empirical model is limited in its applicability beyond the available data and its scope (for the presented case here).
- The parameterized version of the Swiss stochastic model covers a large range of possibilities for the Swiss GM and thus, seems reasonable to be used for hazard computation

References

- Douglas, J. (2009): Comparisons of observations and simulations to predictions from selected ground-motion models for the PEGASOS Refinement Project (PRP) and development of empirical ground-motion prediction equations based on available instrumental data from Switzerland and the surrounding region, Draft PRP report TP2-TB-1040, 27th Nov.
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