



Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

ETH zürich

The Earthquake Risk Model of Switzerland

ERM-CH23

the ERM-CH23 team:

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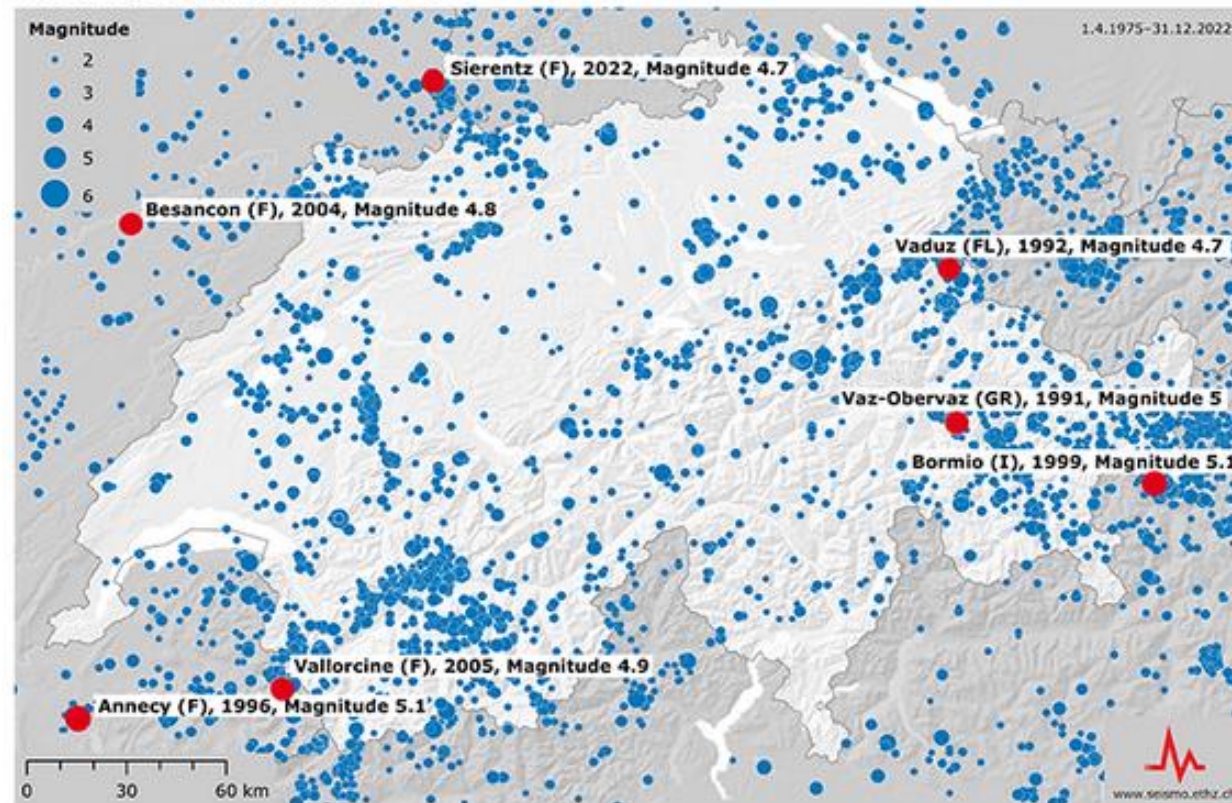
³ EPFL Lausanne

⁴ RED Risk Engineering and Development

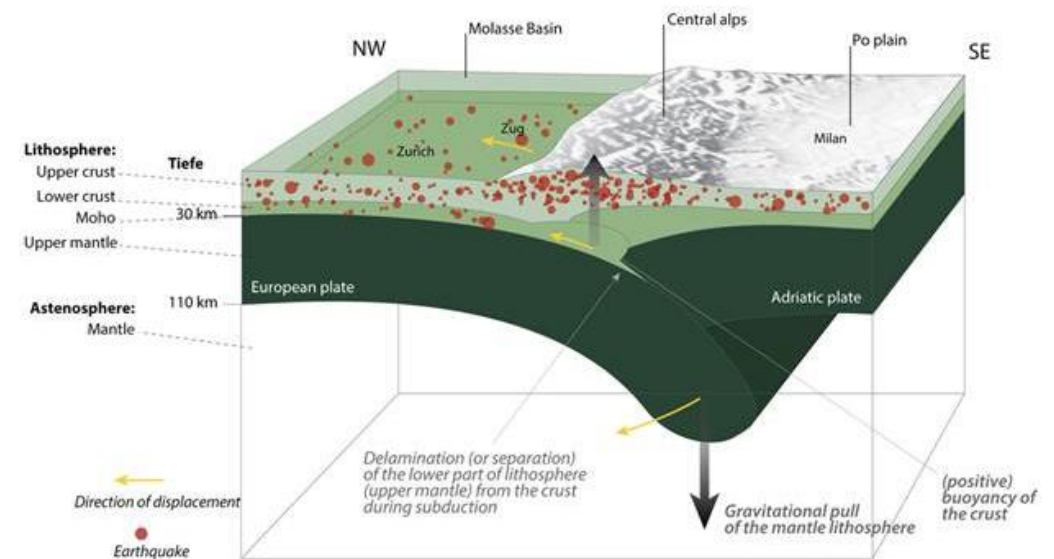
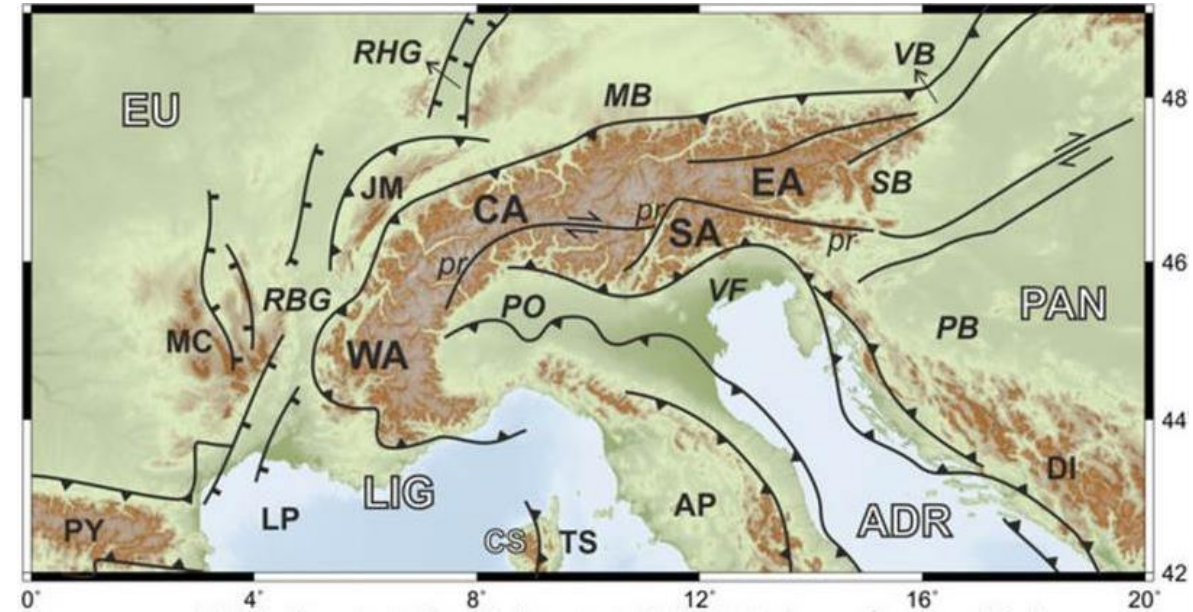
...seismicity in Switzerland

Sanchez et al. (2018)

The strongest earthquakes since 1975

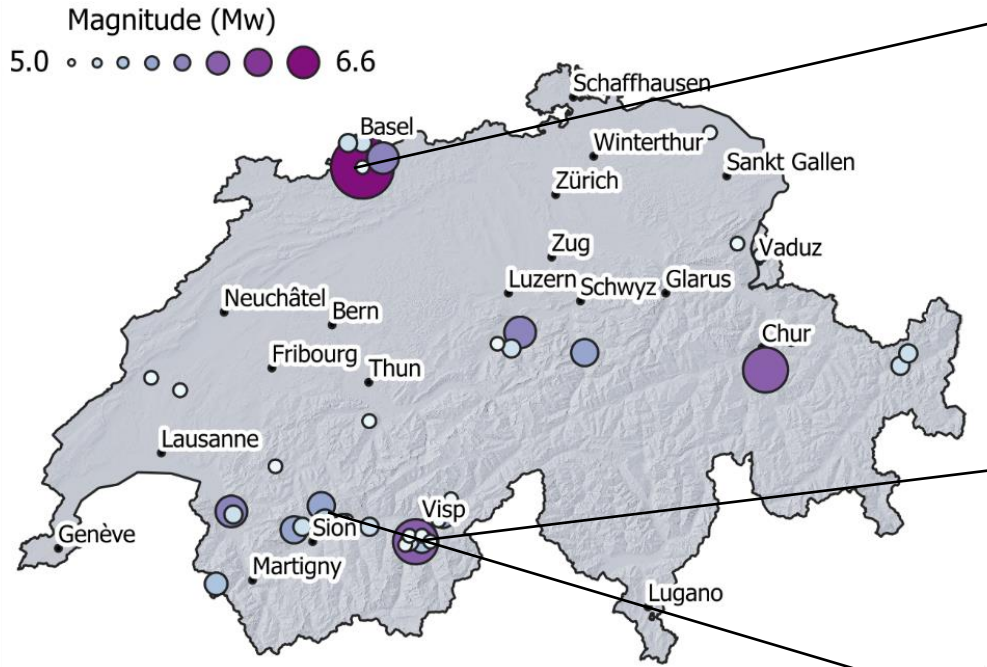


Map of the instrumental recorded earthquakes between 1975 and 2022 with a minimum magnitude of 2. (<http://seismo.ethz.ch>)



Singer et al. 2014

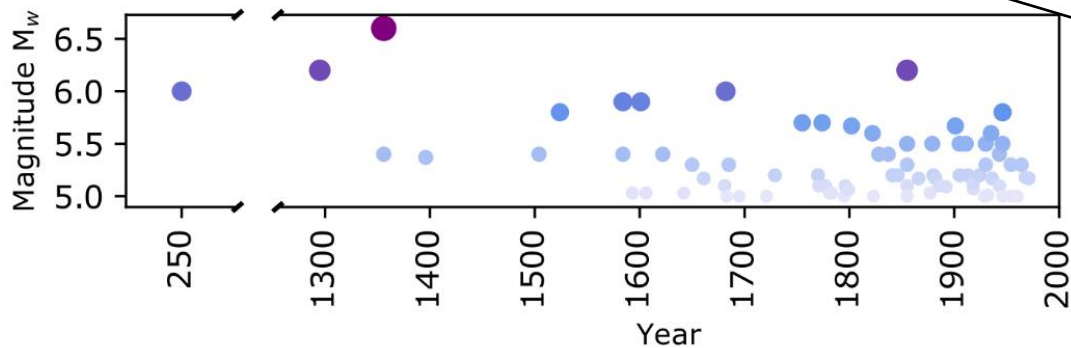
...historical earthquakes



Basel 1356 Mw 6.6



Visp 1855 Mw 6.2



Sierre 1946 Mw 5.8
~3500 damaged buildings
4 fatalities

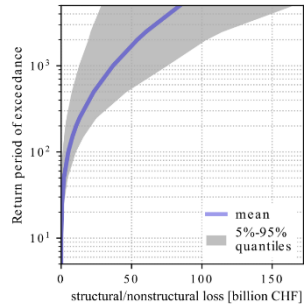
...road to ERM-CH23

The Federal Council mandates BAFU, together with SED and BABS, to develop a model to quantify seismic risk in Switzerland



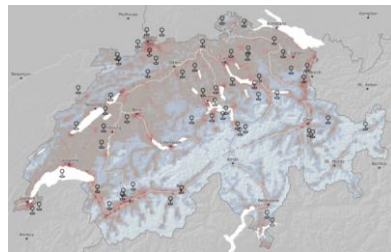
...what does ERM-CH23 provide?

PRODUCTS:



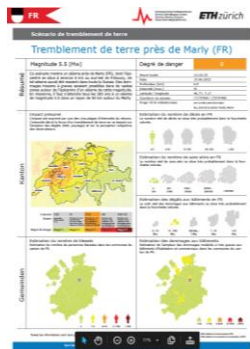
Probabilistic risk estimates

AAL
Loss exceedance curves



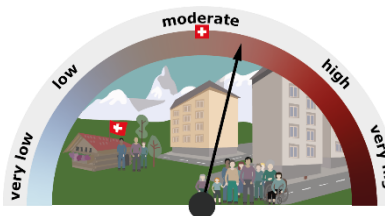
Earthquake scenarios

59 historical and fictitious earthquake scenarios



Rapid impact assessment (RIA)

Near-real-time Shakemap-informed impact estimates after earthquakes
 $M_w > 3$



Interactive risk tool

Approximation of personal earthquake risk

LOSS TYPES

Structural/
Nonstructural loss
[CHF]



Injuries



Fatalities



Contents
loss [CHF]

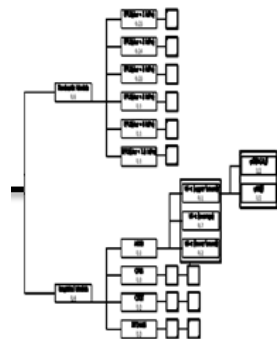


Displaced population

...the anatomy of ERM-CH23

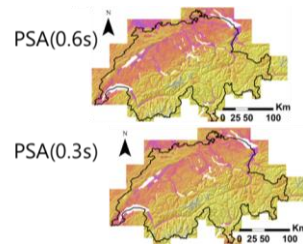


Seismic Hazard Model
2015 for Switzerland
SUIhaz2015
(Wiemer et al., 2016)

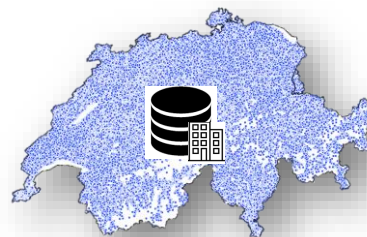


Logic tree of
stochastic and
empirical GMPEs
and IPES

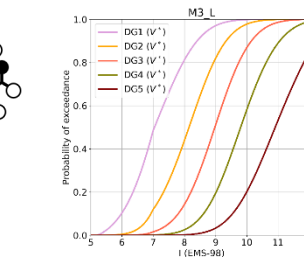
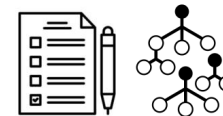
High-resolution site
amplification model +
associated uncertainty
(φ_{s2s} and φ_{ss})



Geo-localized database
of >3 million building
objects

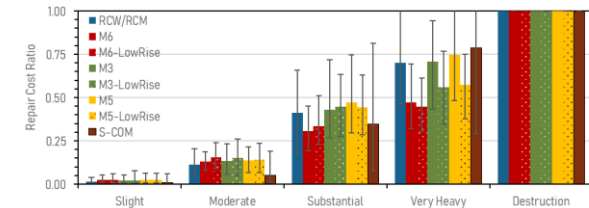


Structural typology to
building schemes
informed from field
surveys



Two sets of fragility
models:

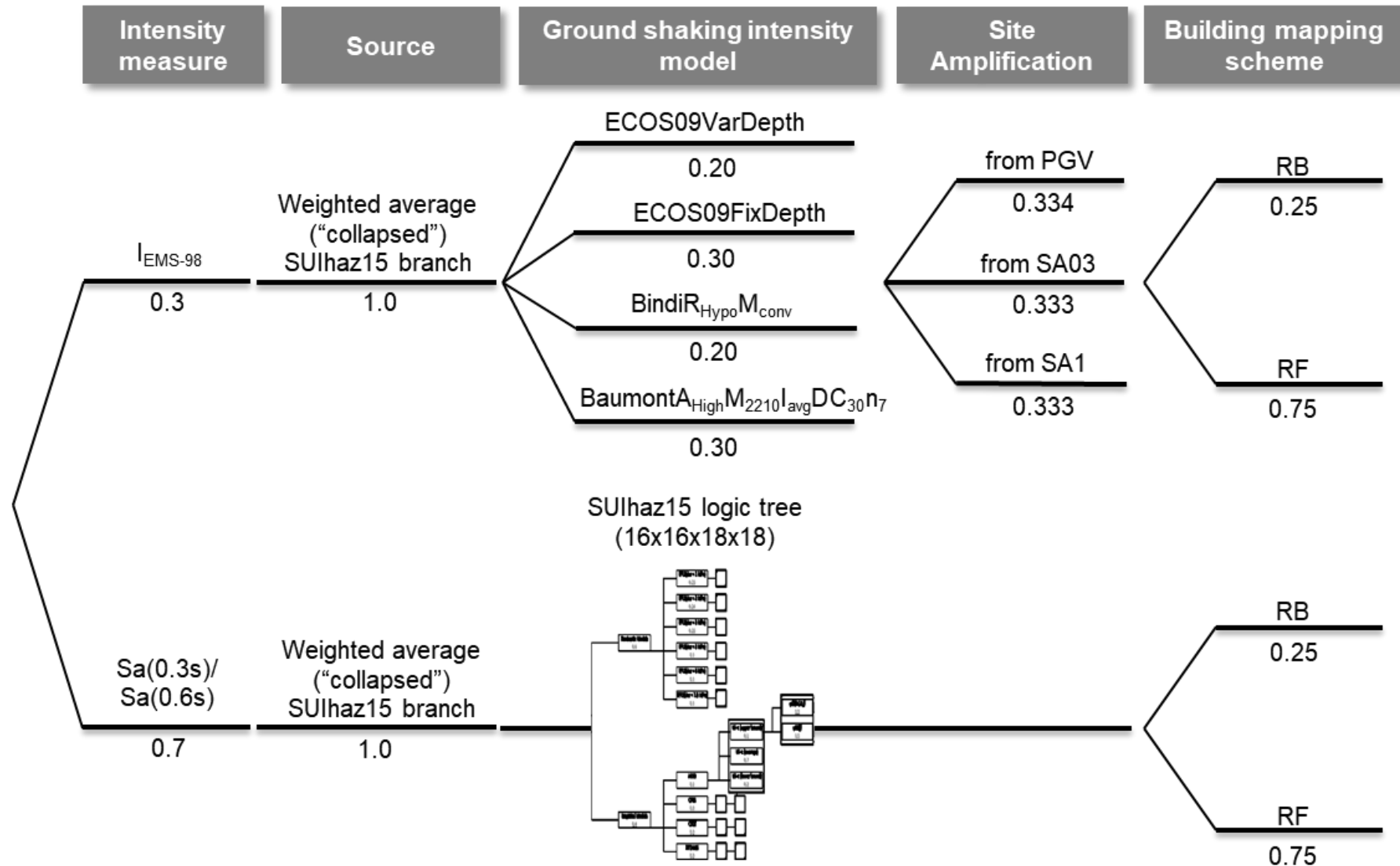
- SA-based,
- I_{EMS98} -based



CH-specific simulation-
based consequence
model for structural/
nonstructural loss

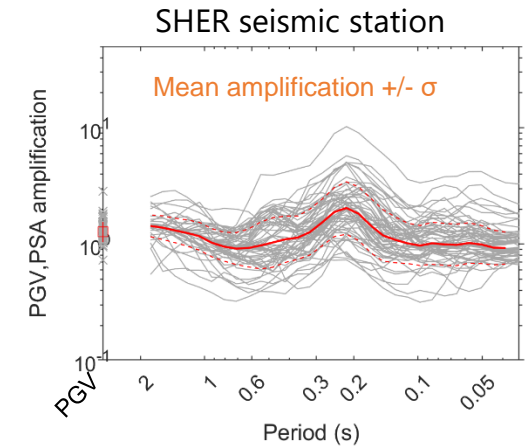
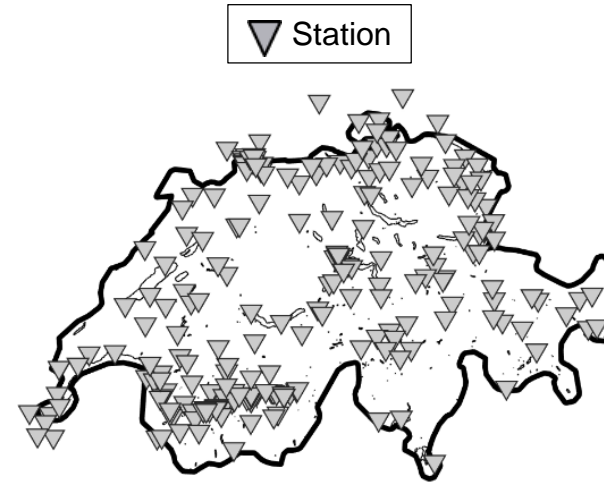
+
literature-informed
models for other loss
types

...epistemic uncertainty in ERM-CH23

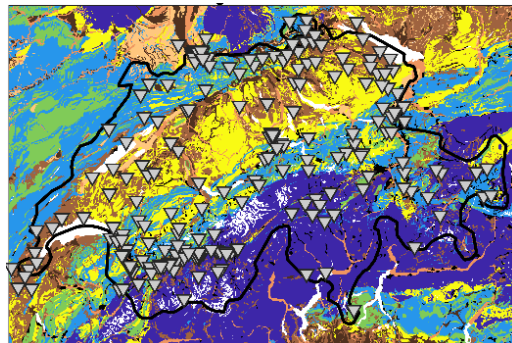


...site amplification model for Switzerland

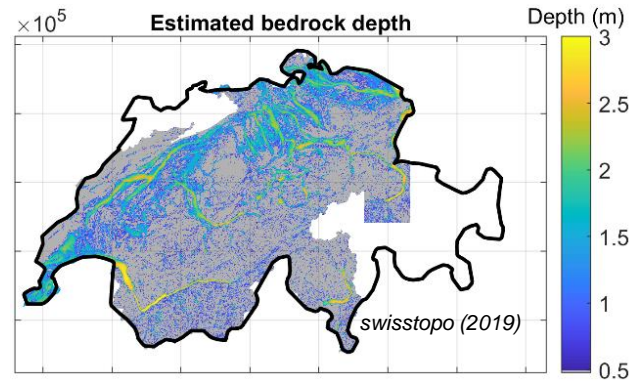
- Measured amplifications at 245 seismic stations in Switzerland relative to the reference rock for earthquakes in 2000-2022
- Measurements of shear wave profiles and natural frequencies at many sites to interpret the observed amplifications
- Amplifications are correlated with site characteristics such as geology (lithology), characterisation of topography, and thickness of sedimentary deposits



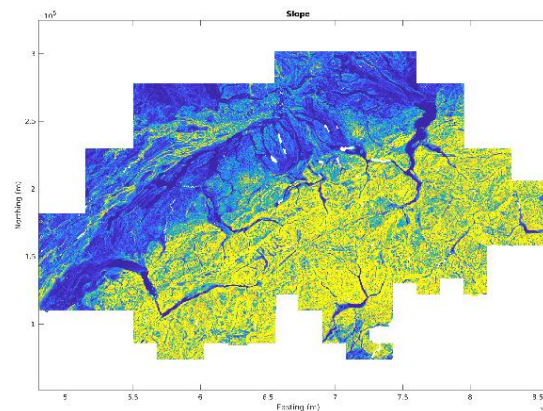
Lithology



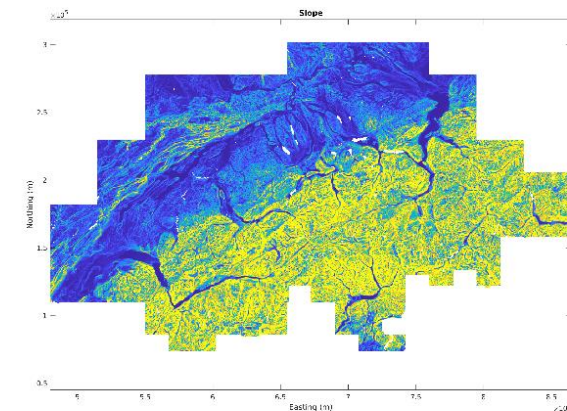
Sediment thickness



Topographic index 275m scale

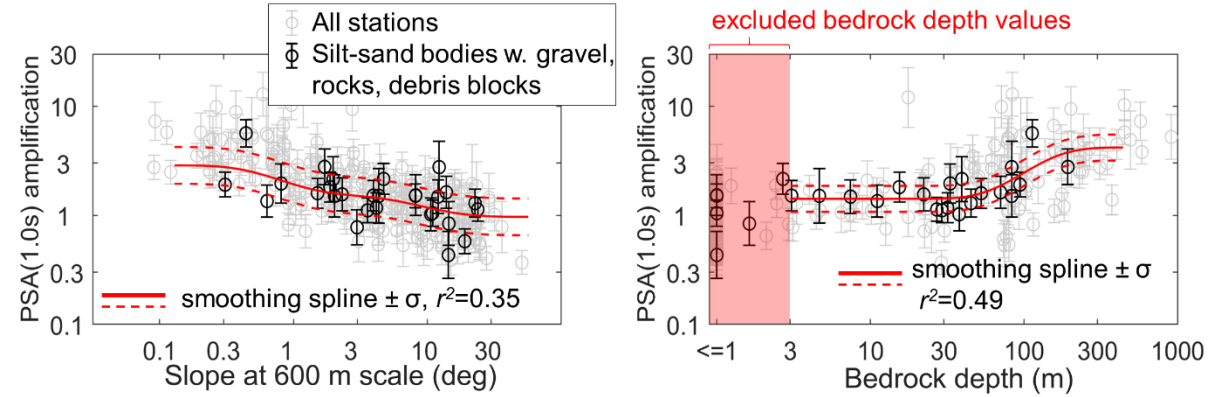


Topographic index 600m scale

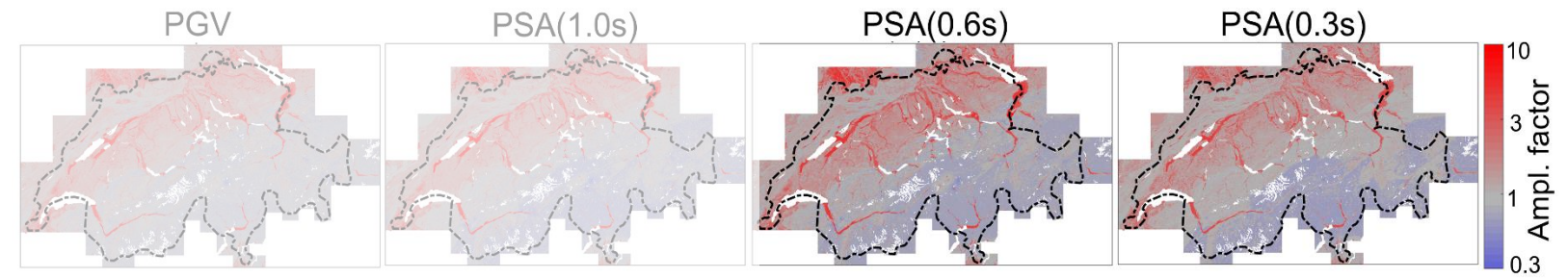


...site amplification model for Switzerland

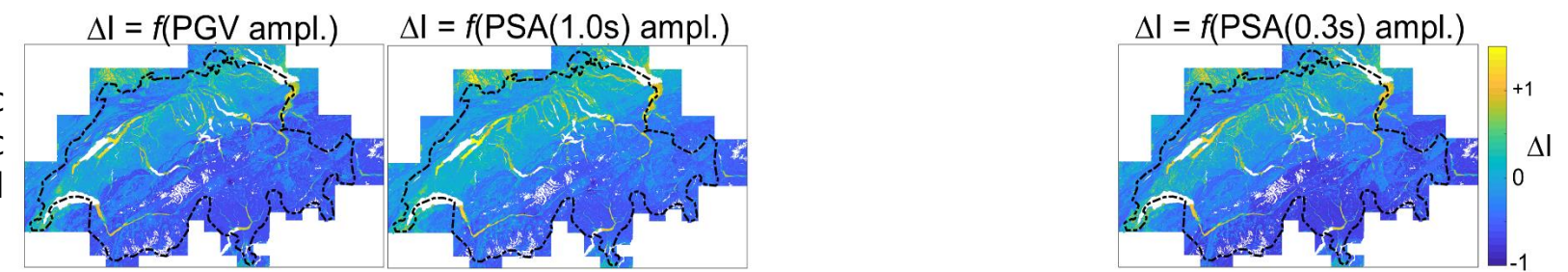
- Application of multivariate statistics and regression-kriging



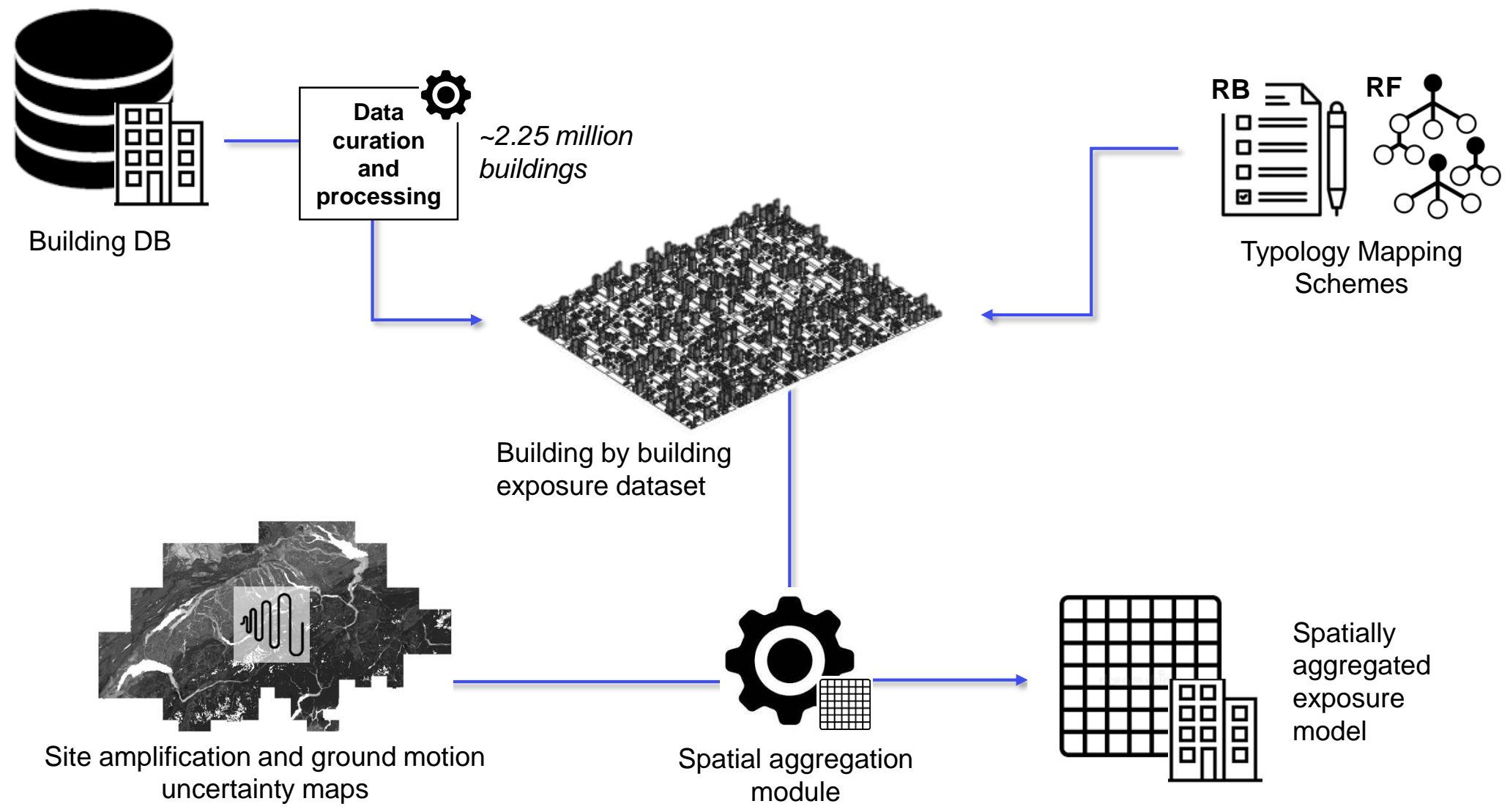
Maps showing amplification relative to the reference rock



Amplification in macroseismic intensity relative to the macroseismic reference ground



...assembling the exposure model



...assembling the exposure model

~ **2.25 million buildings** in exposure model

+

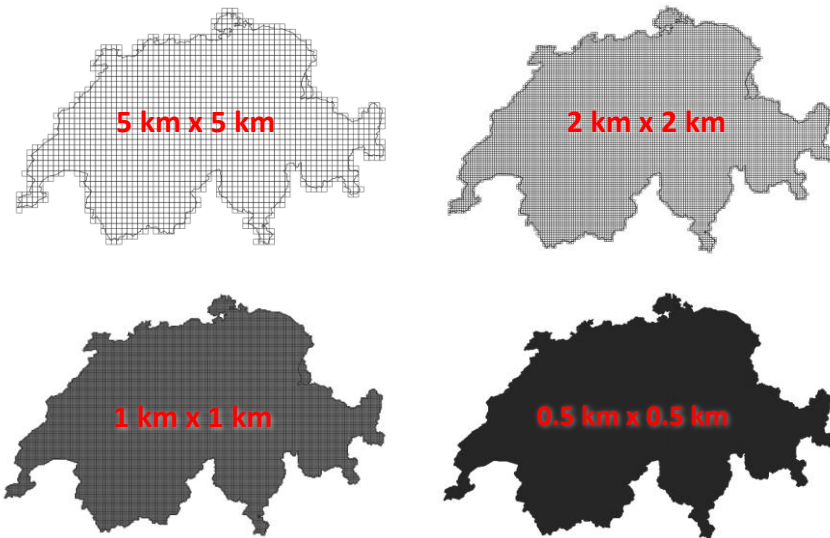
hundreds of **logic tree** branches

+

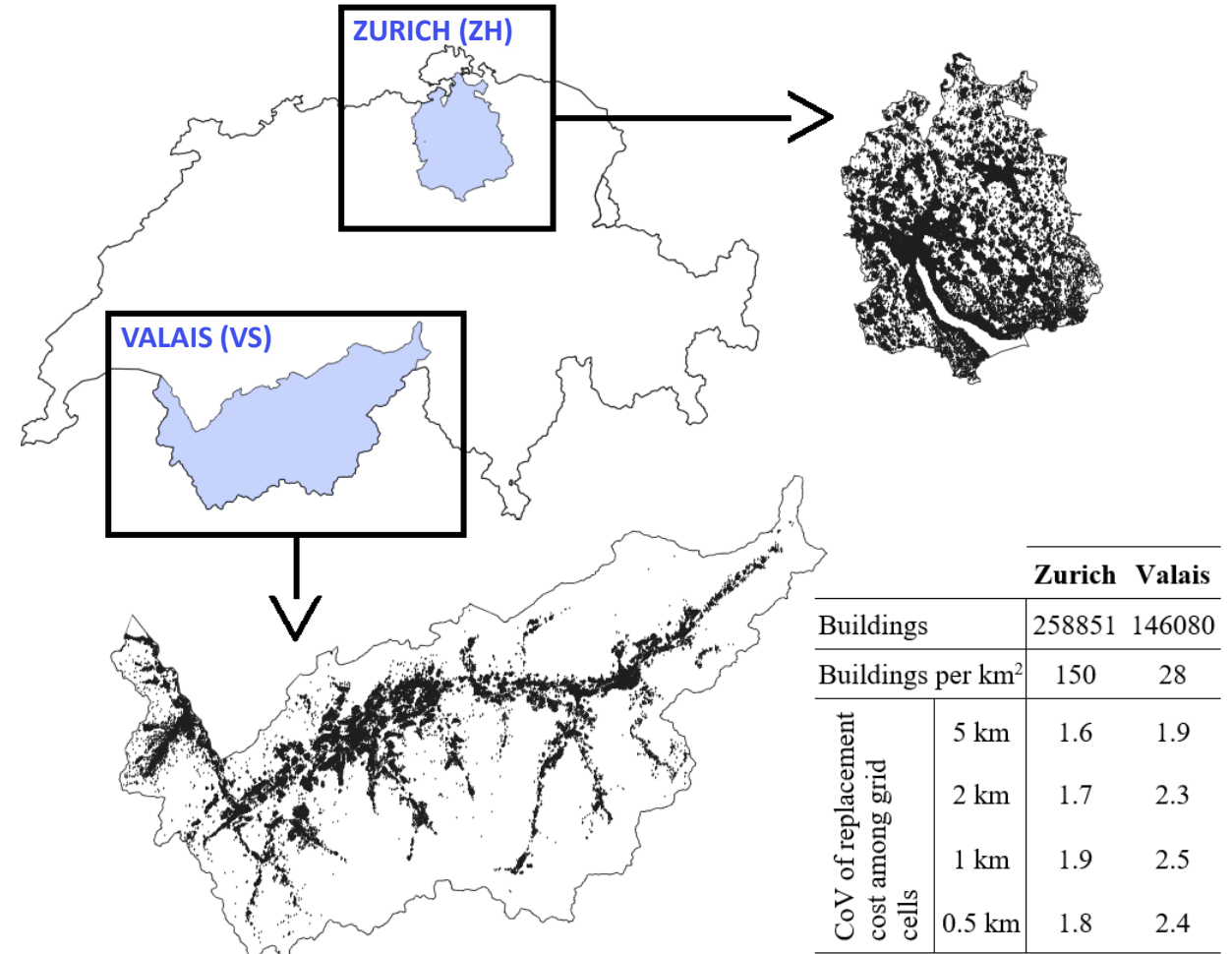
results required at **multiple spatial scales** with **uncertainty**

→ → **Challenging** even for our 256 CPU threads - 2TB SDRAM machine

→ **Exposure aggregation needed!**

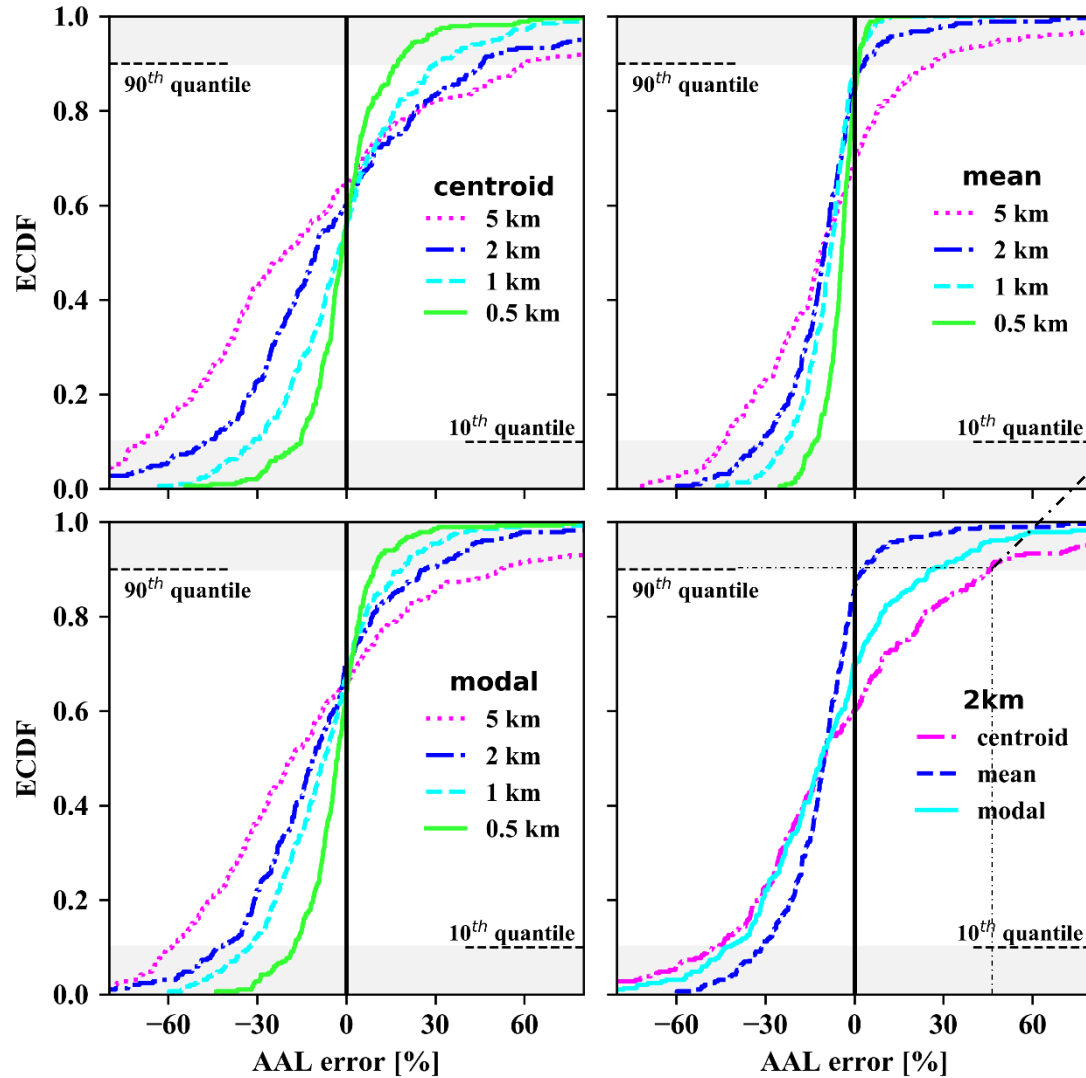


Sensitivity testbeds



...assembling the exposure model

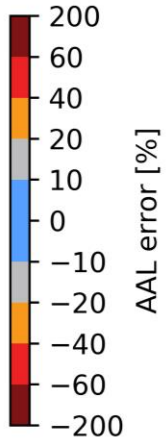
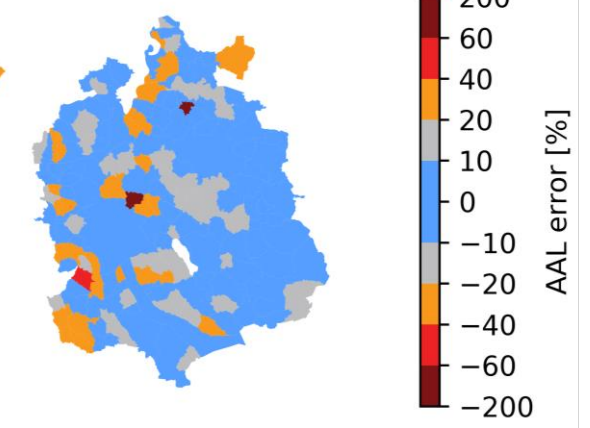
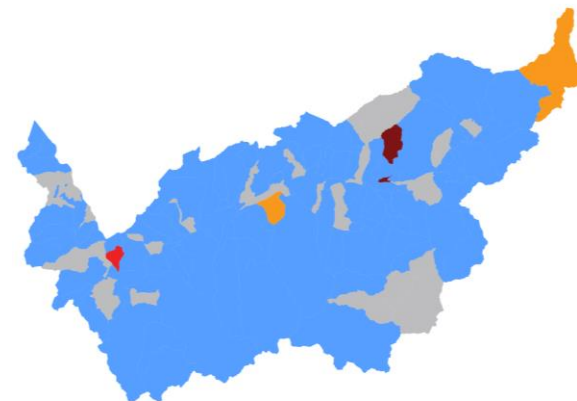
→ aggregation effect on AAL



Empirical CDFs of municipality AAL errors (comparison to benchmark building-by-building analysis)

For instance, 10% of the (ZH and VS) municipalities present AAL errors of > ~45% if a 2 km x 2 km aggregation is used with site conditions assumed at the grid cell centroid

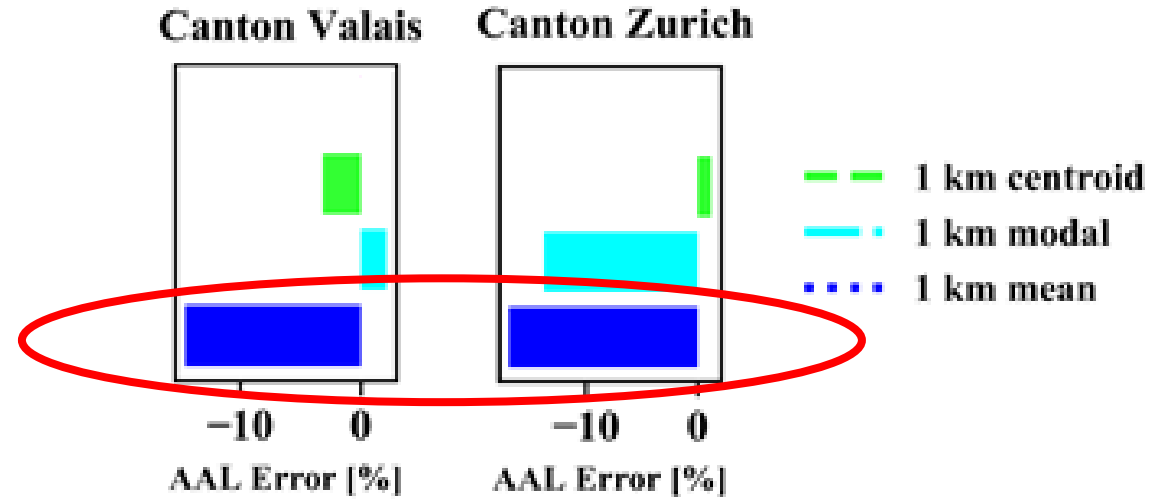
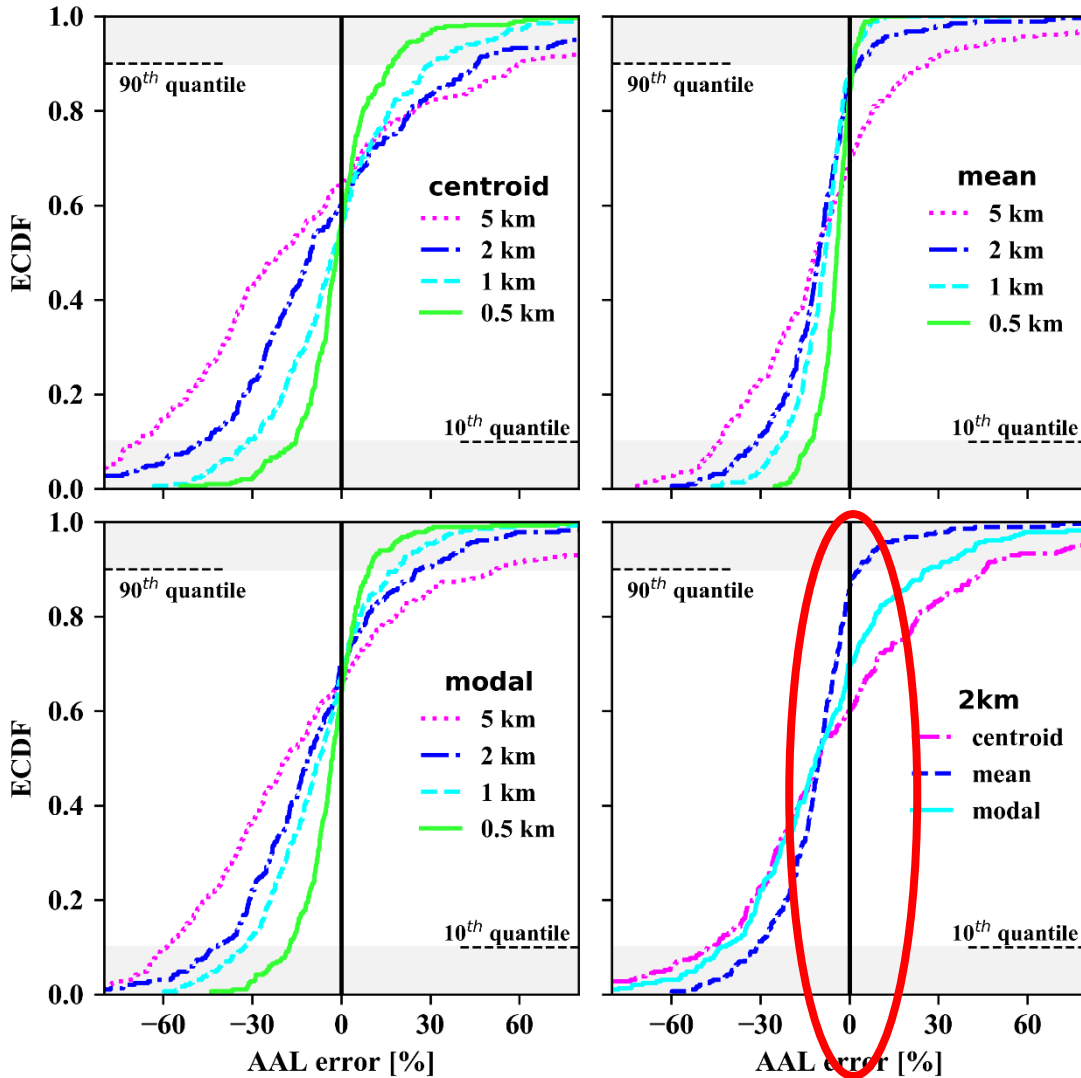
0.5 km modal



...assembling the exposure model

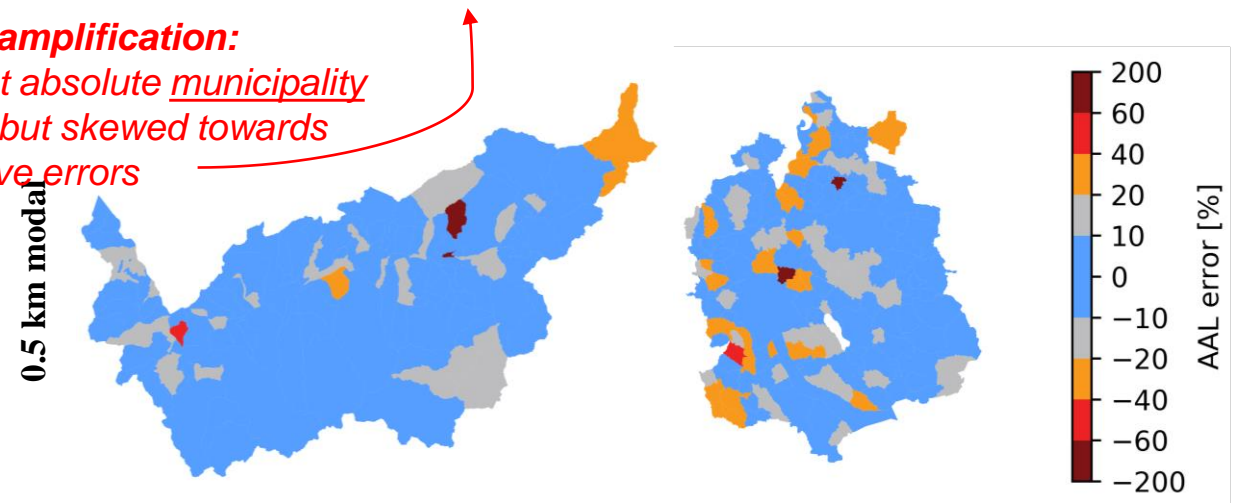
→ aggregation effect on AAL

Results at Canton-level

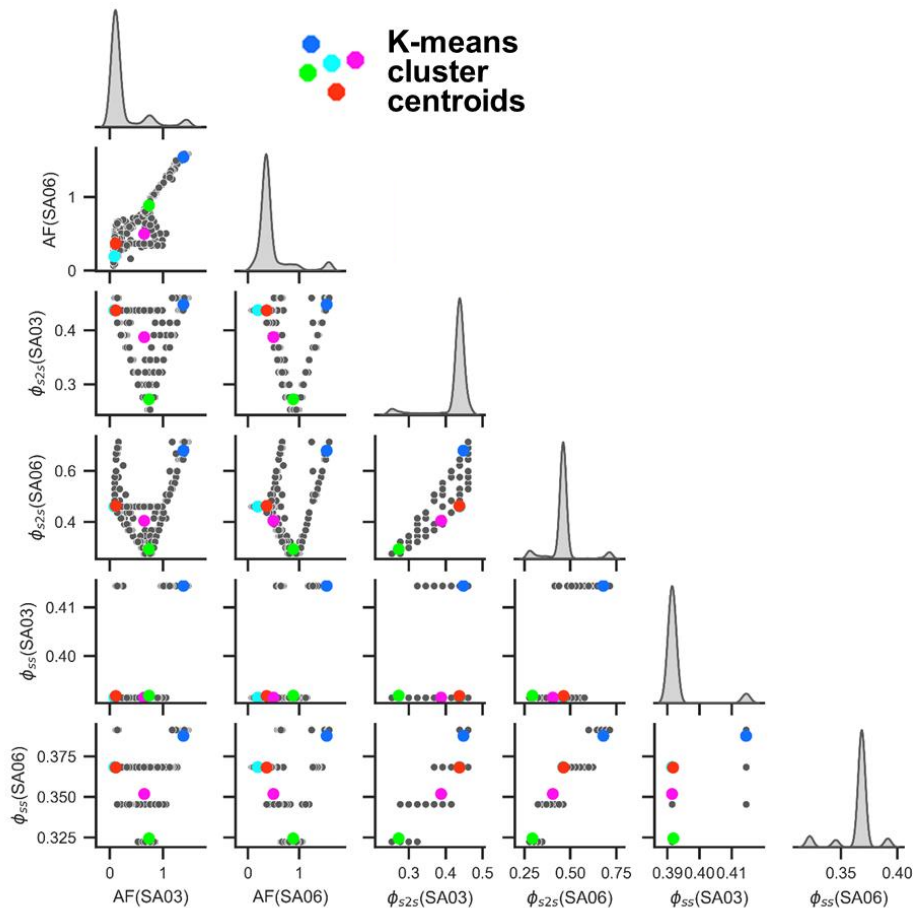
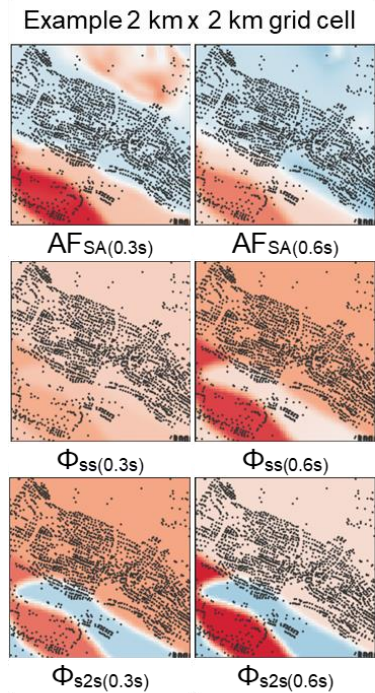


Leads to larger error at the canton level

Mean amplification:
Lowest absolute municipality
errors but skewed towards
negative errors

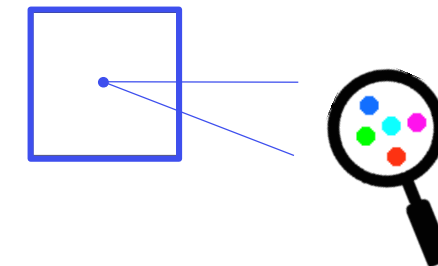


...assembling the exposure model

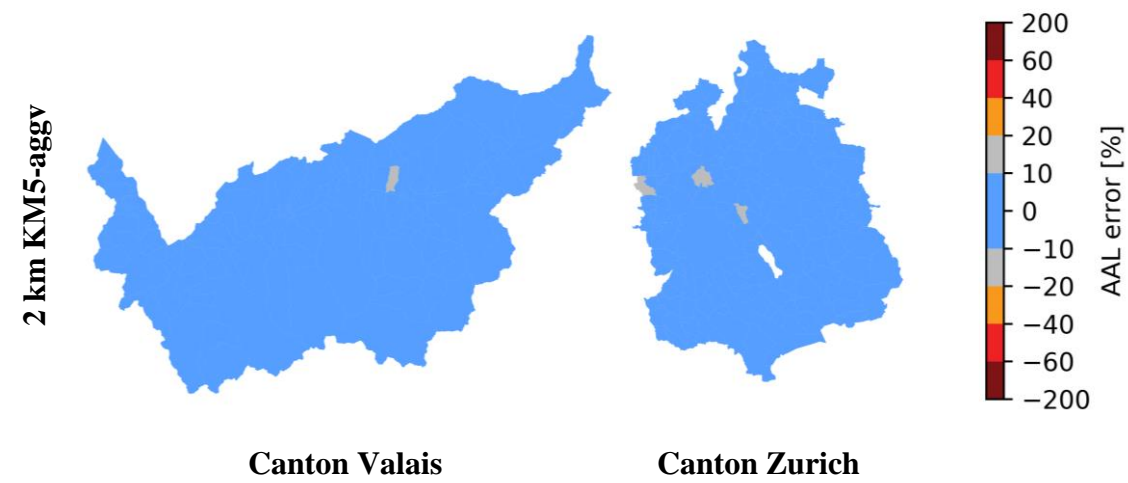
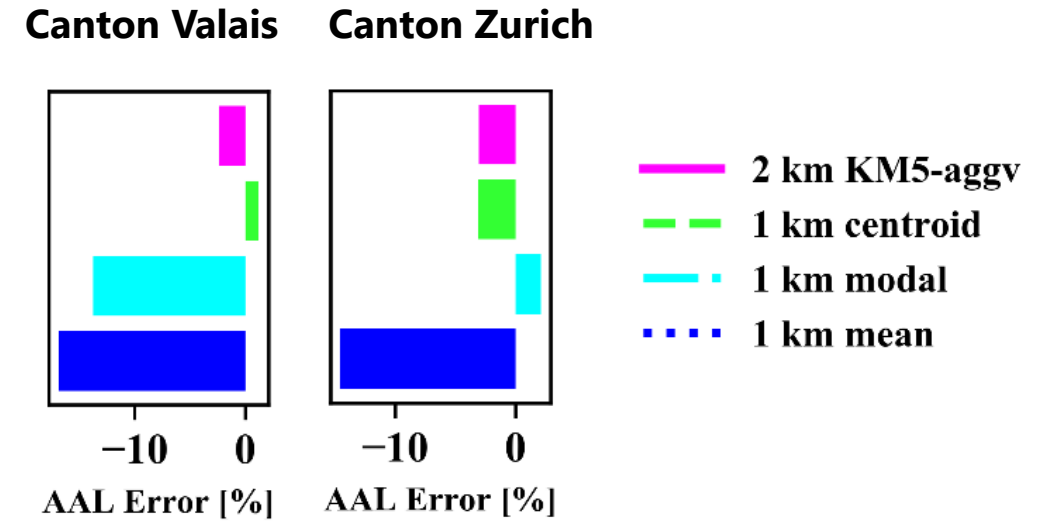
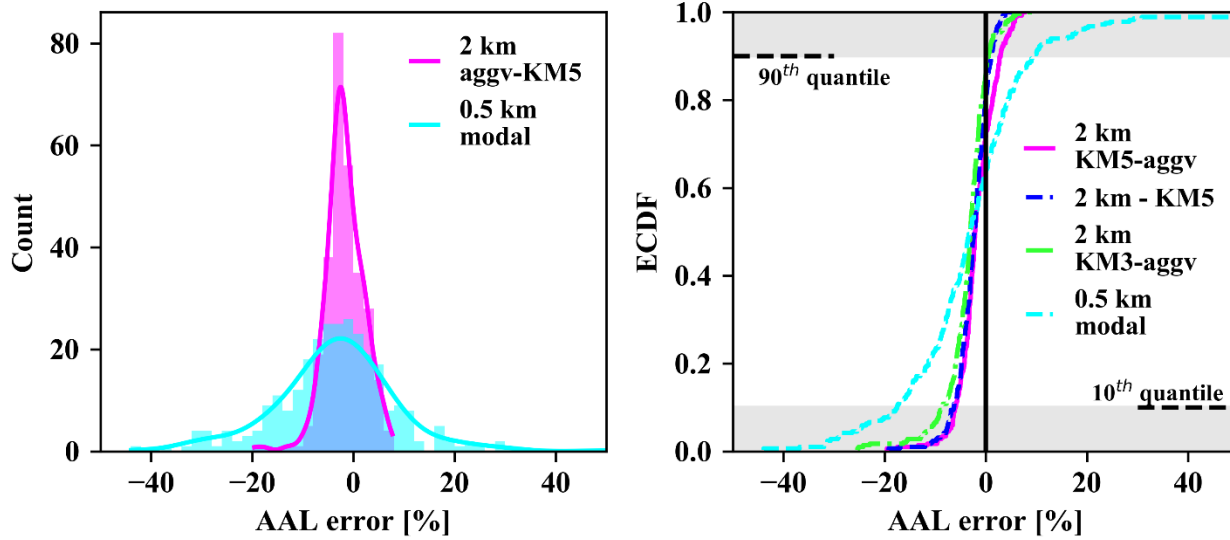


K-Means clustering for aggregation

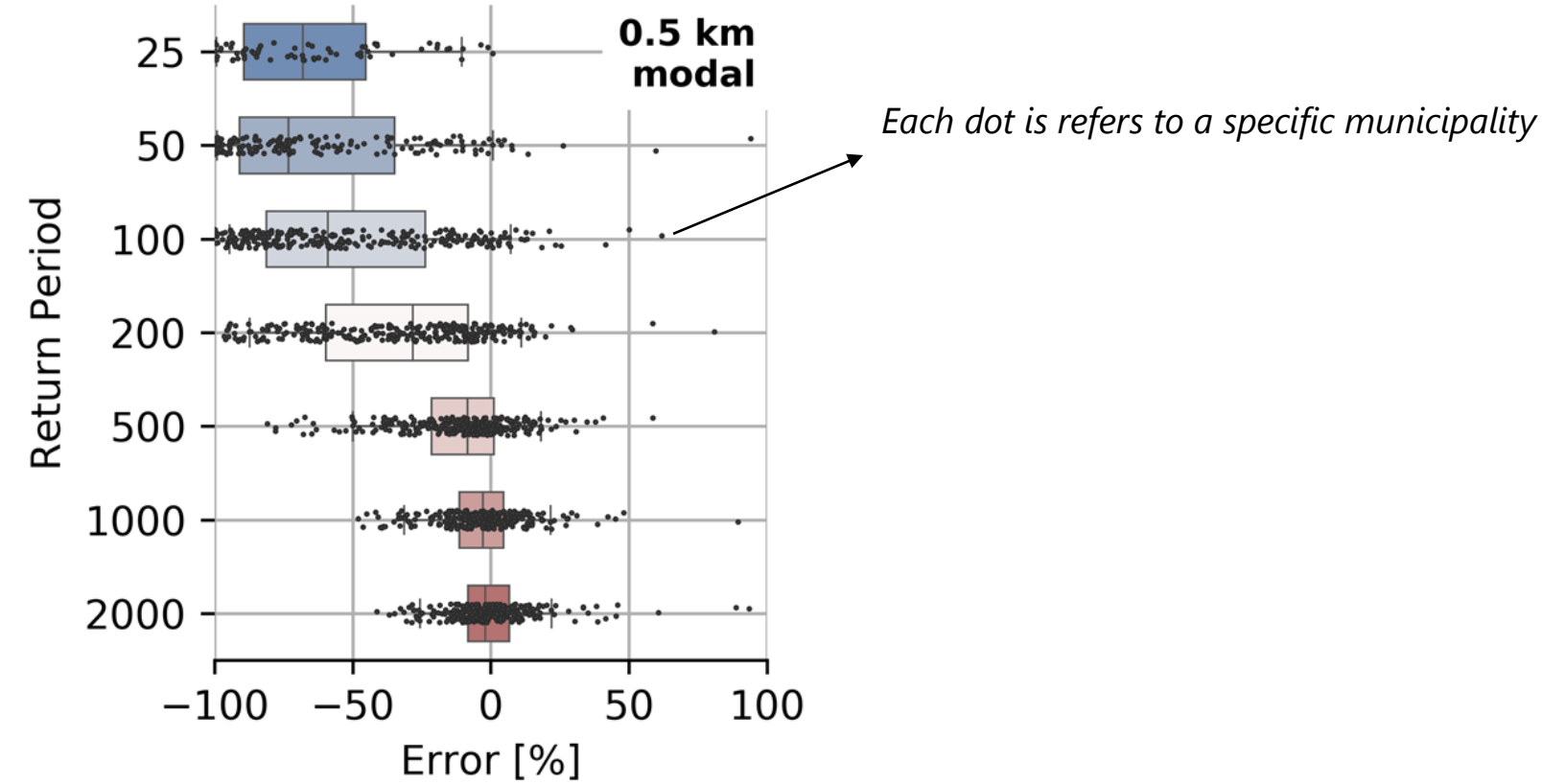
- The site parameters are extracted at the locations of all buildings in the grid cell
- **K-means clustering** is to identify **n site parameter clusters**
- The buildings within the cell are **split to n clusters** and aggregated at n adjacent locations near the cell centroid (a few meters apart).
- The associated K-means **cluster centroid site parameter values** are assigned to the n aggregation locations



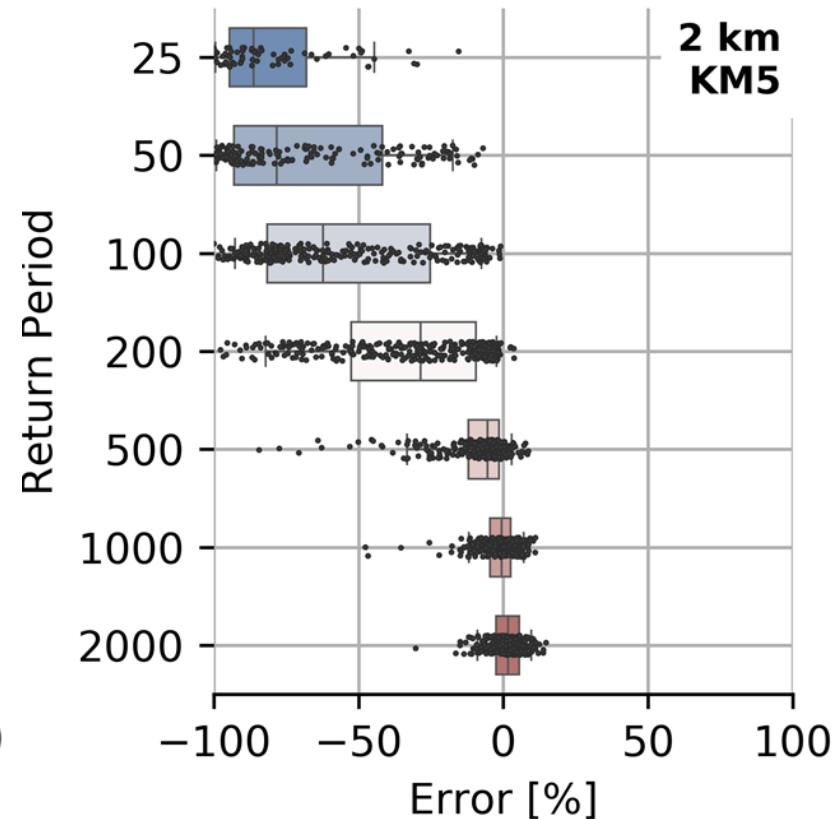
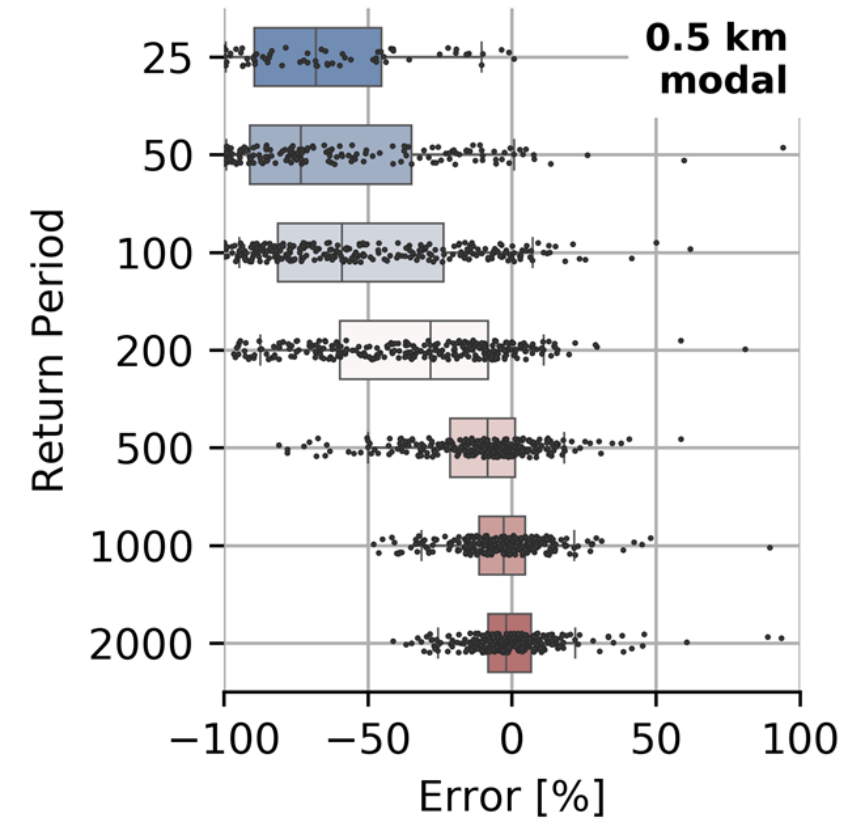
...assembling the exposure model



...assembling the exposure model



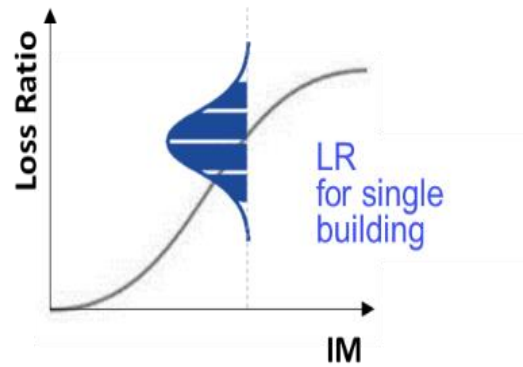
...assembling the exposure model



...assembling the exposure model

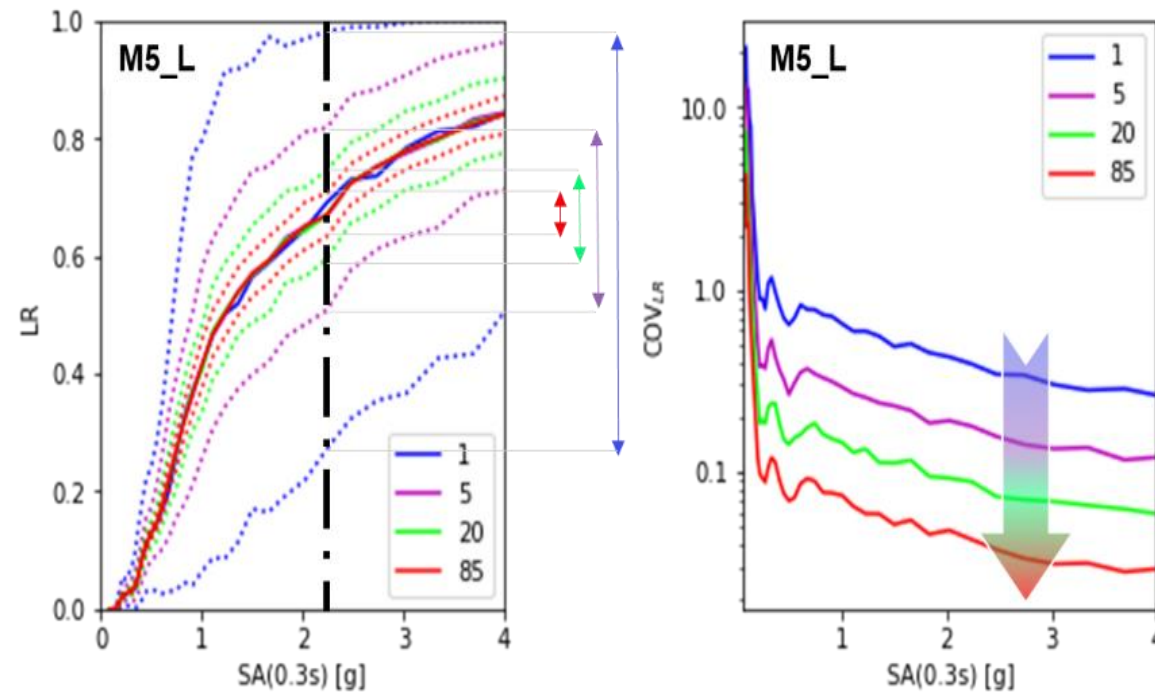
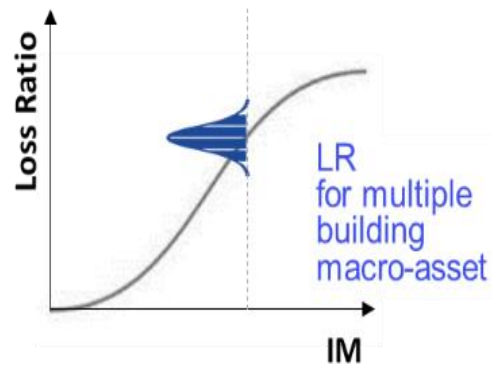
Derived functions for:

- 1 building (assigned to macro-assets of 1 building)
- 5 buildings (assigned to macro-assets of 2-9 buildings)
- 20 buildings (assigned to macro-assets of 10-39 buildings)
- 85 buildings (assigned to macro-assets of ≥ 40 buildings)



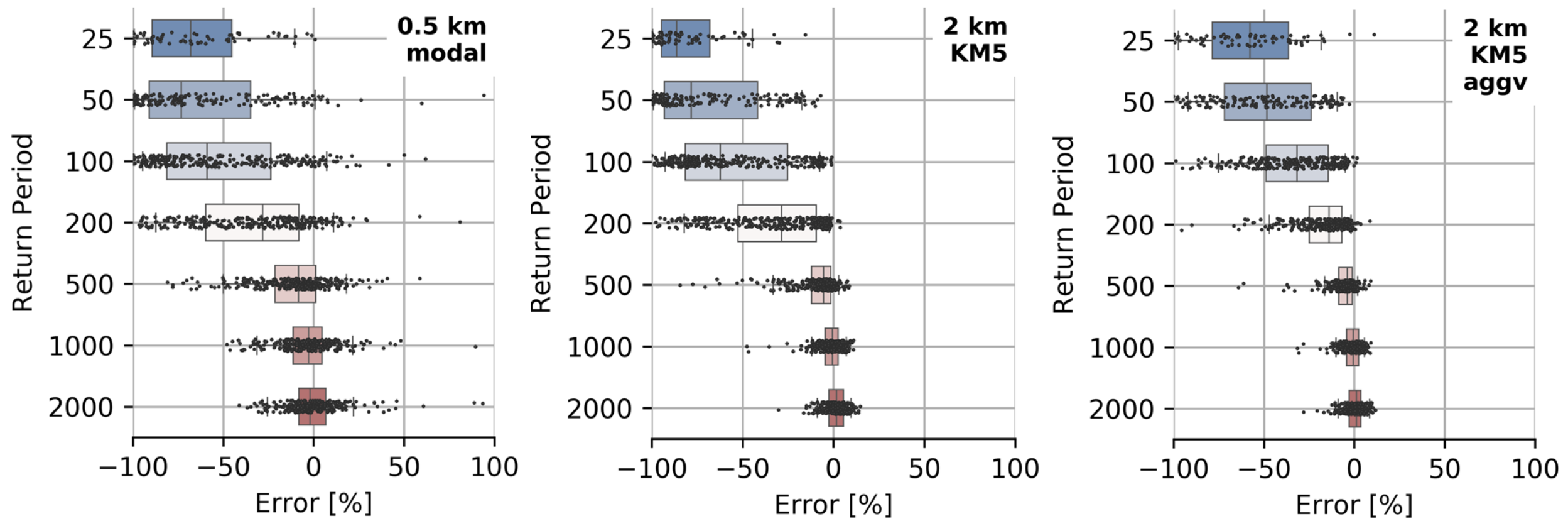
$$E[X + Y] = E[X] + E[Y]$$

$$\text{Var}[X + Y] = \text{Var}[X] + 2\text{Cov}[X, Y] + \text{Var}[Y]$$



Dotted curves:
10%/90% LR quantiles

...assembling the exposure model



...risk estimates

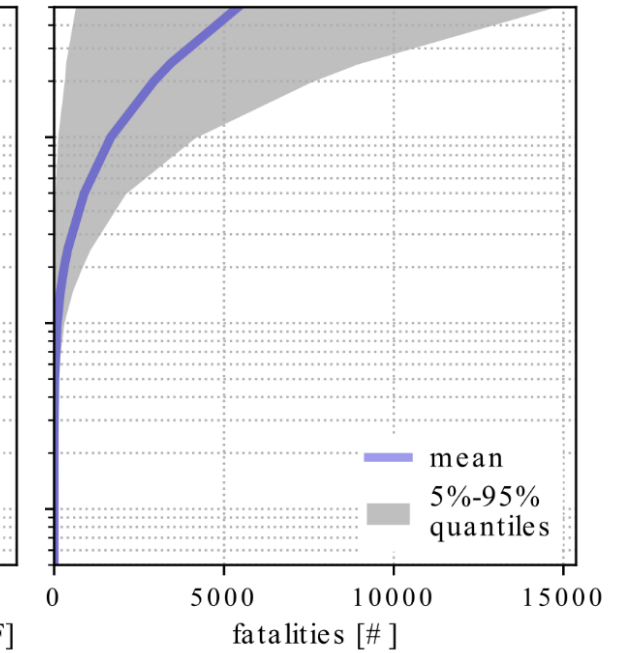
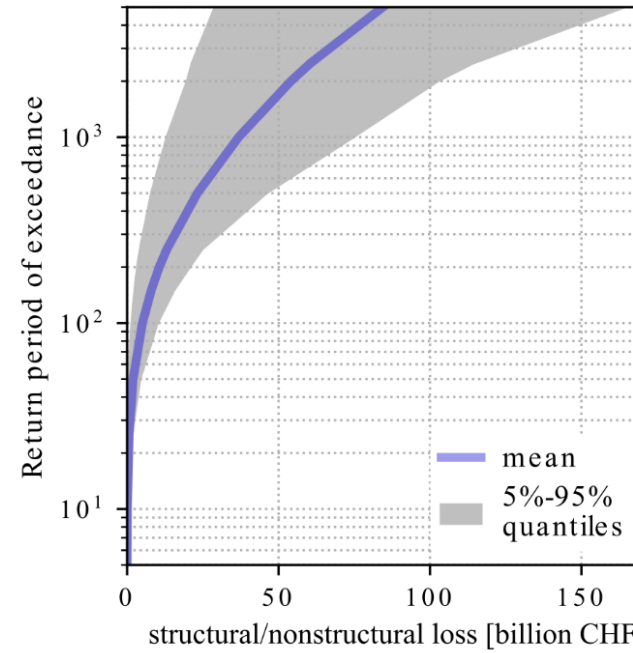
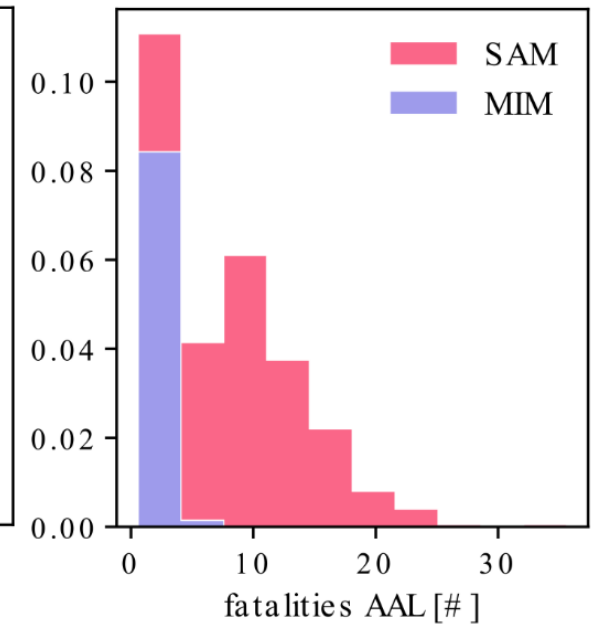
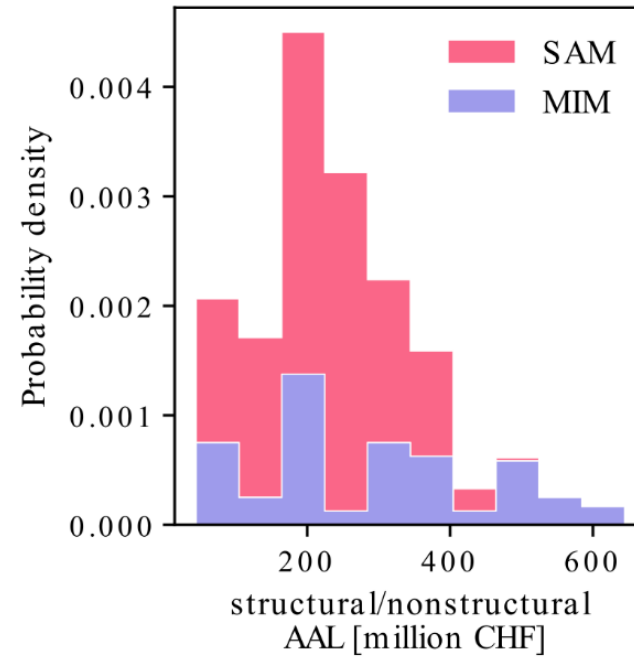
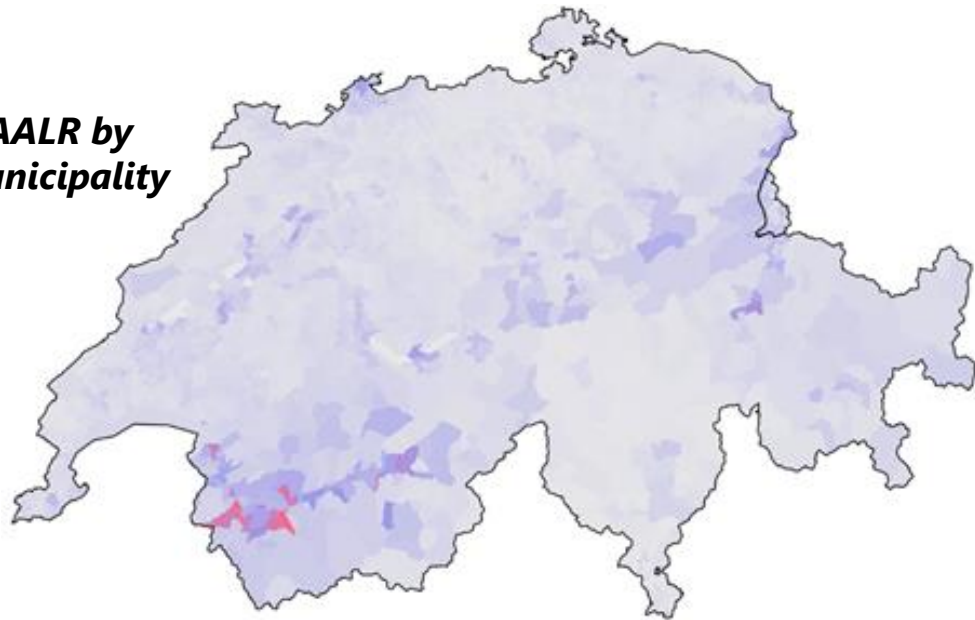


Seismic Hazard on rock



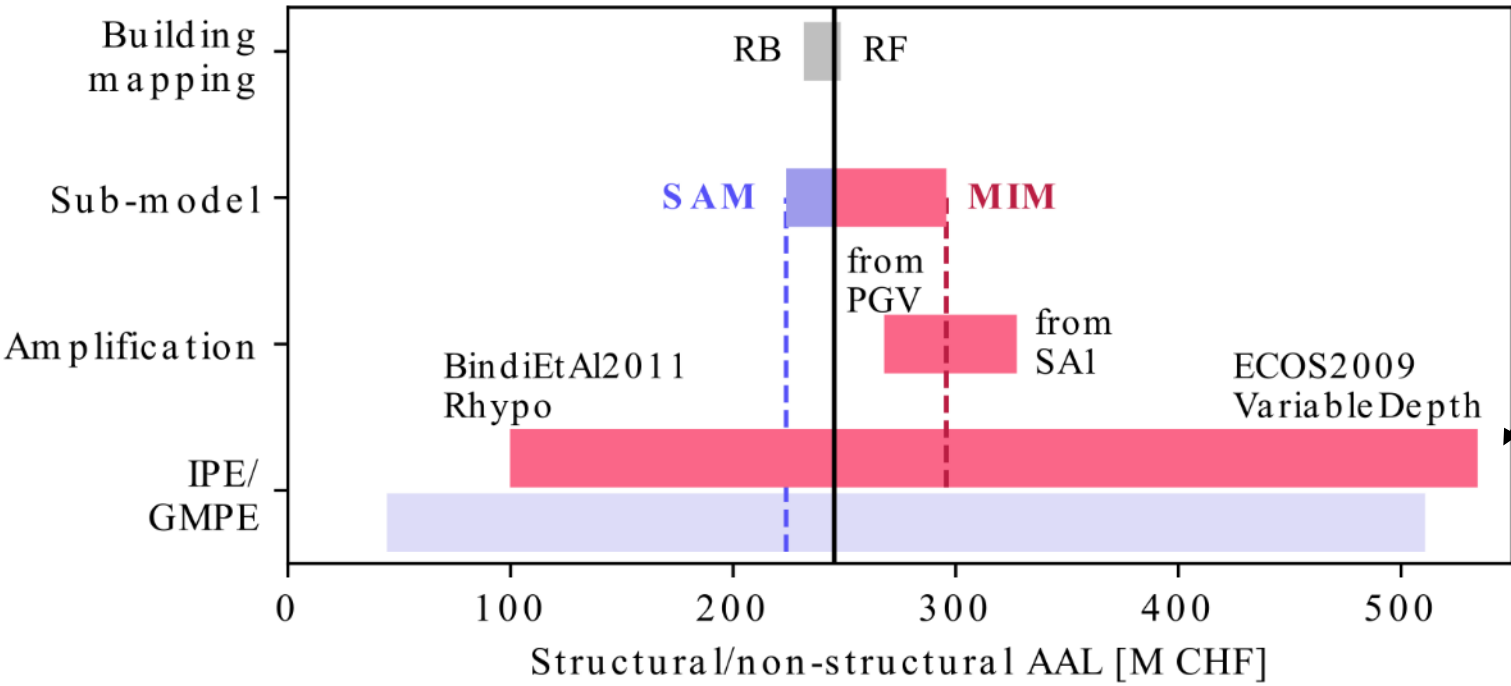
Site amplification

AALR by municipality



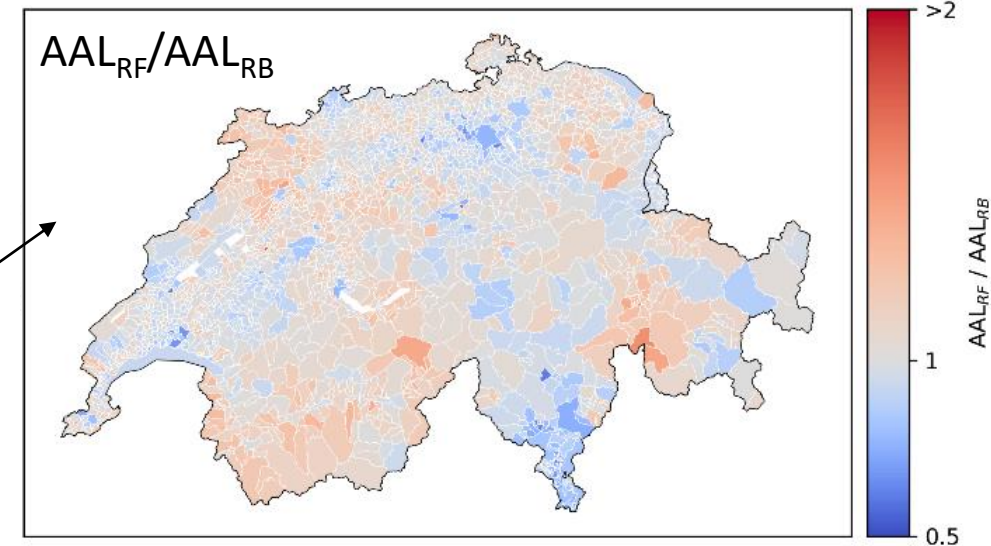
...model exploration

Epistemic uncertainty tornado plot

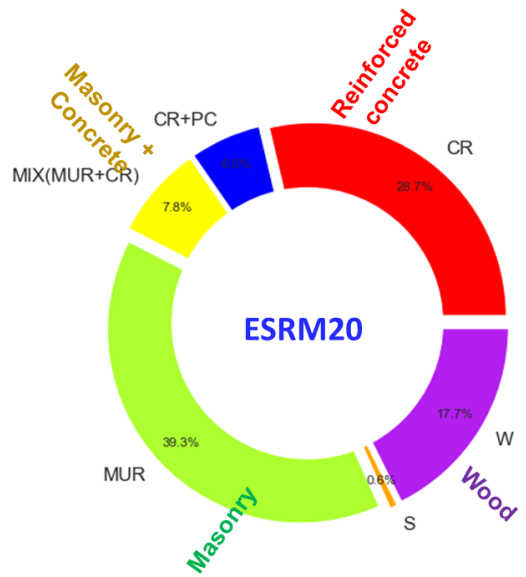
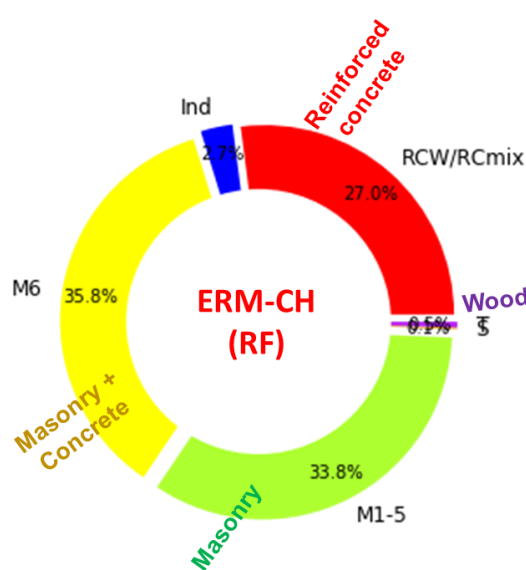
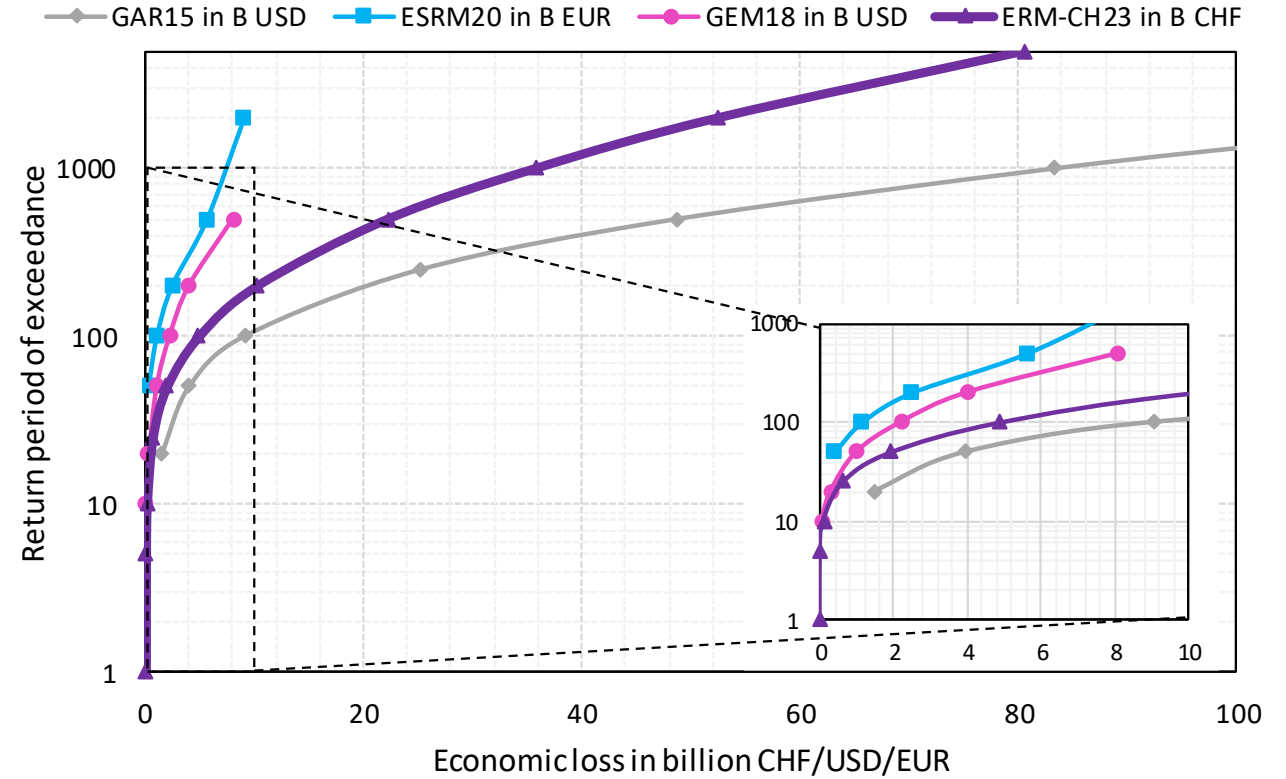
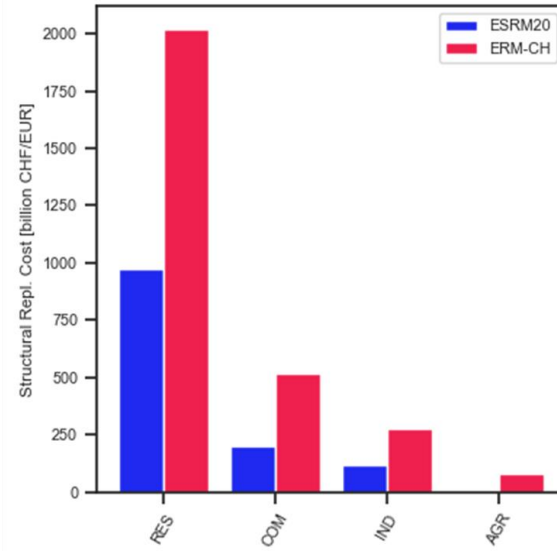
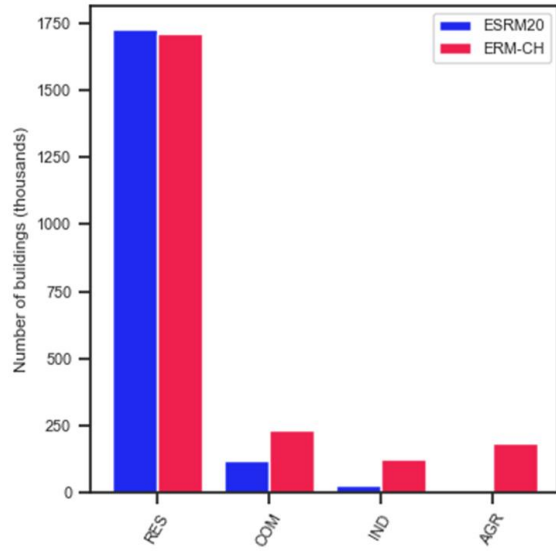


IPEs/GMPEs are the main contributors to the epistemic variance

Other epistemic variables might have small effect on countrywide results, but are relevant at local level (e.g. building mapping scheme)



...comparisons with other models



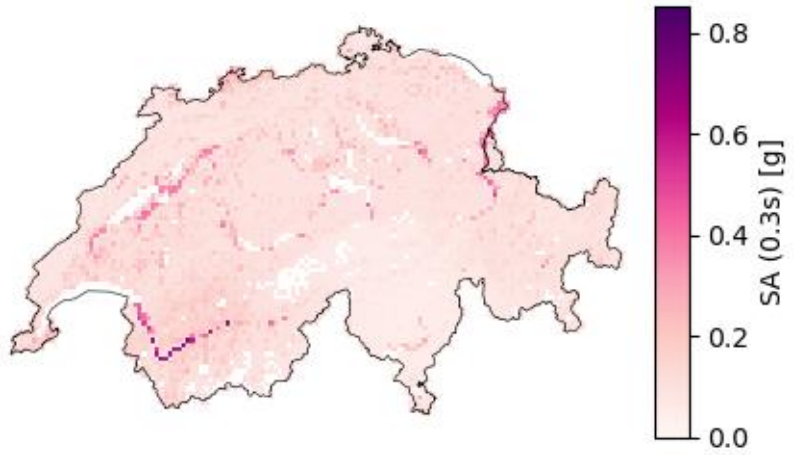
		ERM-CH23	ESRM20	GEM18	GAR15
Structural/Non-structural loss	AAL	245 M CHF	55 M EUR	100 M USD	785 M USD
	AALR [‰]	0.084	0.043	0.07	
Fatalities	AAL	7.6	2		
	AALR [‰]	0.00099	0.0002		

...comparisons with other models

HAZARD MAPS

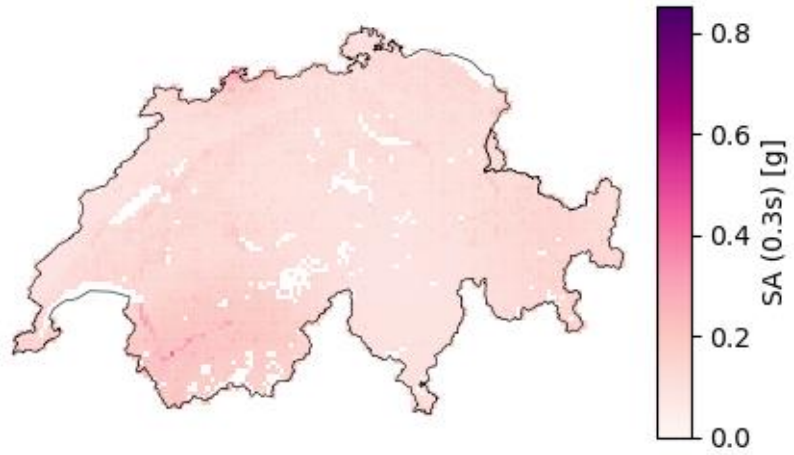
ERMCH23 - SAM

475 years



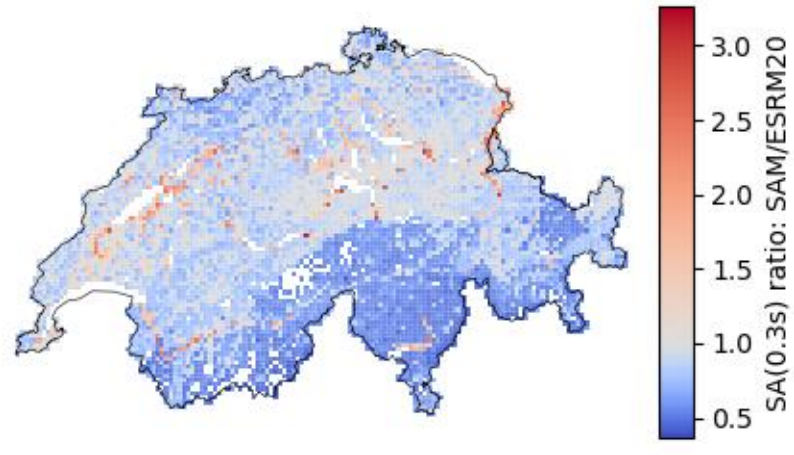
ESRM20

475 years

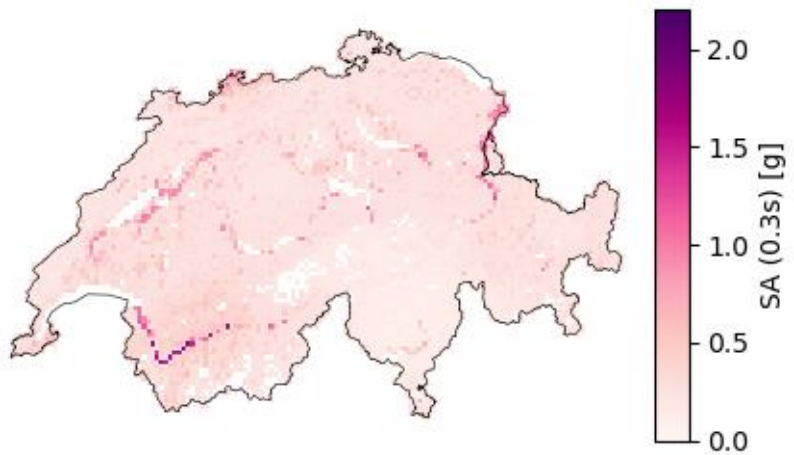


RATIO

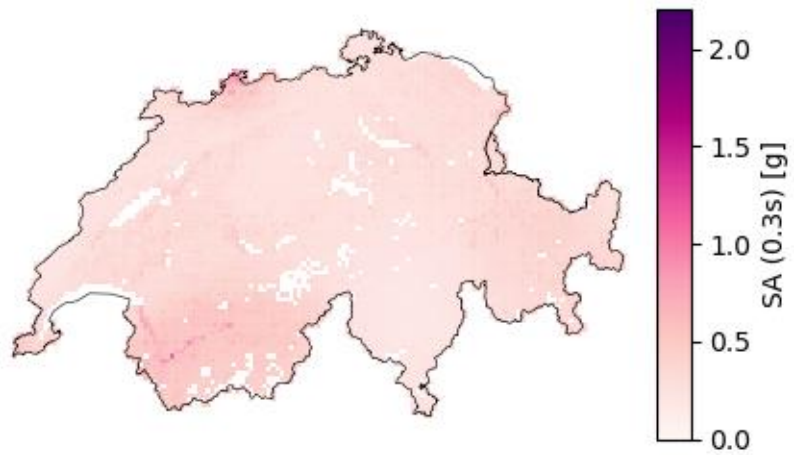
475 years



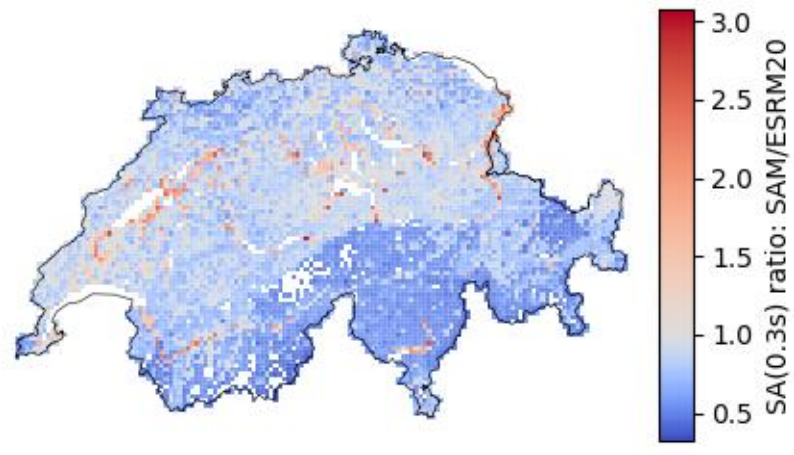
2500 years



2500 years



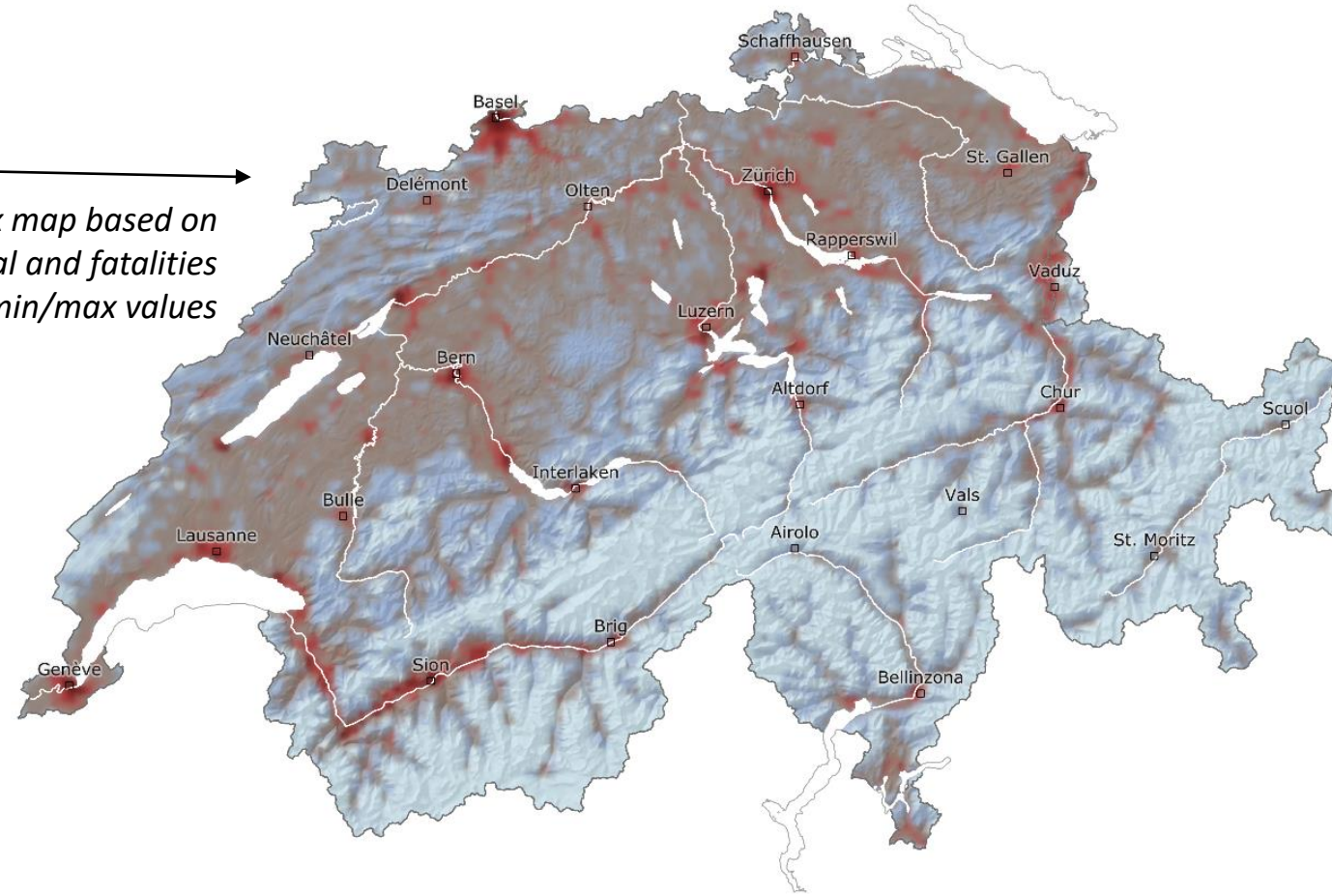
2500 years



...communication products

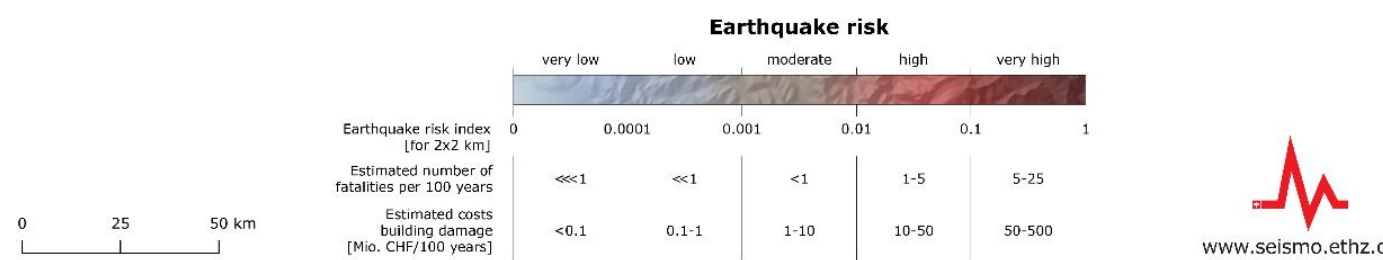
Visuals (e.g. RIA sheets, risk map) and key messages for public outreach

Risk index map based on structural/nonstructural and fatalities AAL – normalized on min/max values

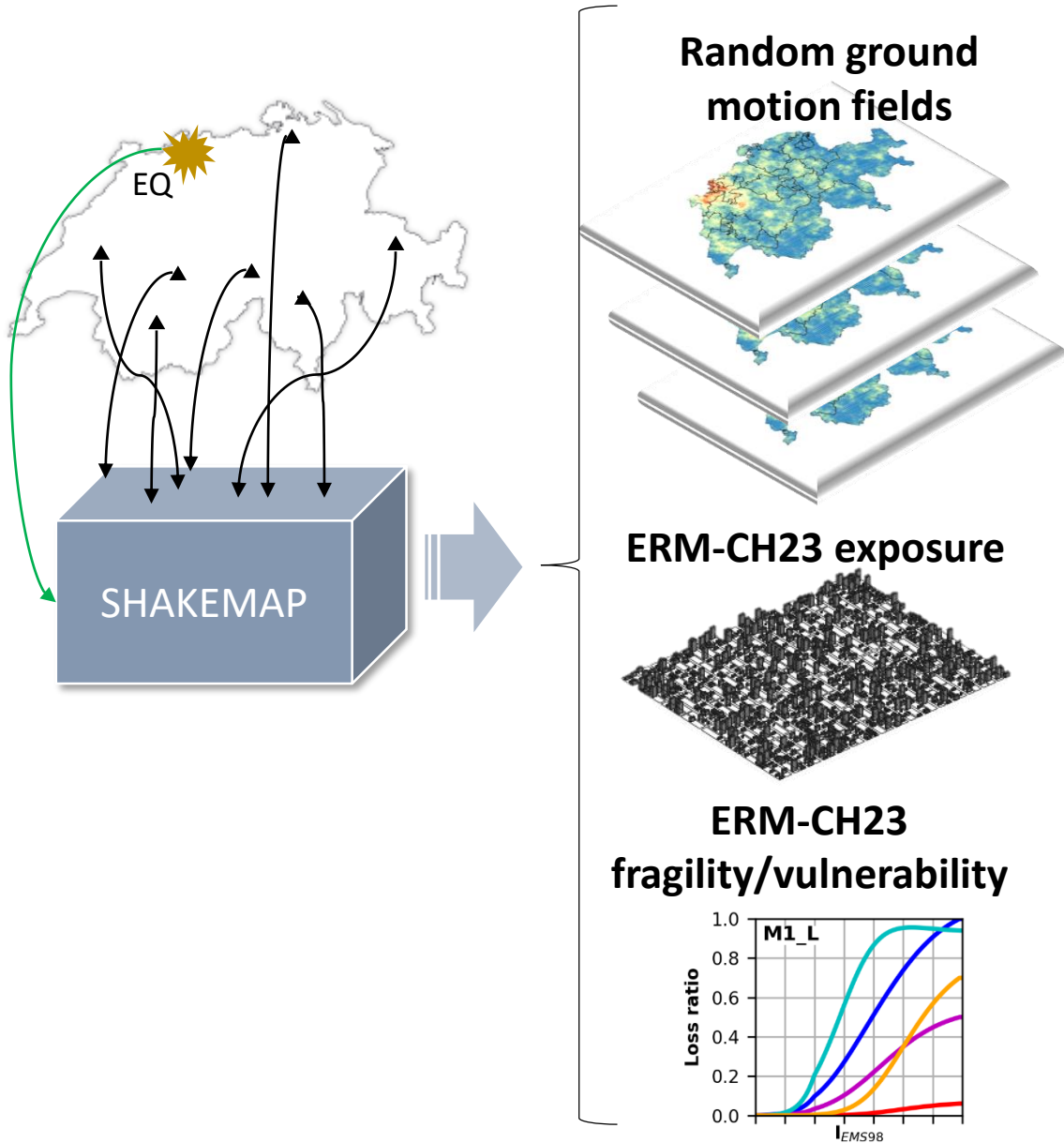


Collage of news articles and reports related to earthquake risk in Switzerland:

- Les séismes pourraient faire jusqu'à 1600 morts en 100 ans en Suisse**
- ETH-Modell zeigt erstmals, was schwere Erdbeben anrichten können**
- In diesen Regionen die Schäden am größten**
- Über 1000 Tote und massive Zerstörung: Ein neues Modell zeigt, was Erdbeben in der Schweiz anrichten können – und wie stark Ihre Region gefährdet ist**
- Bis zu 1.600 Erdbebenopfer Schweiz möglich in 100 Jahren**
- «Nur weil die Gebäude in der Schweiz viel teurer sind, heisst nicht, dass sie erdbebengerechter gebaut sind»**
- Neues ETH-Modell quantifiziert das Erdbebenrisiko**
- Was ein Erdbeben anrichten würde**
- ETH-Experte Stefan Wiemer: «Wir müssen uns auf ein schweres Erdbeben vorbereiten»**
- Starkes Erdbeben in der Schweiz ist gar nicht so unwahrscheinlich**
- So kann man sich in der Schweiz gegen Erdbeben versichern**
- Neues Modell zeigt, was passiert, wenn bei dir die Erde bebt**
- Was ein Erdbeben anrichten würde**



...downstream applications – 1) rapid impact assessment (RIA)



Scénario de tremblement de terre

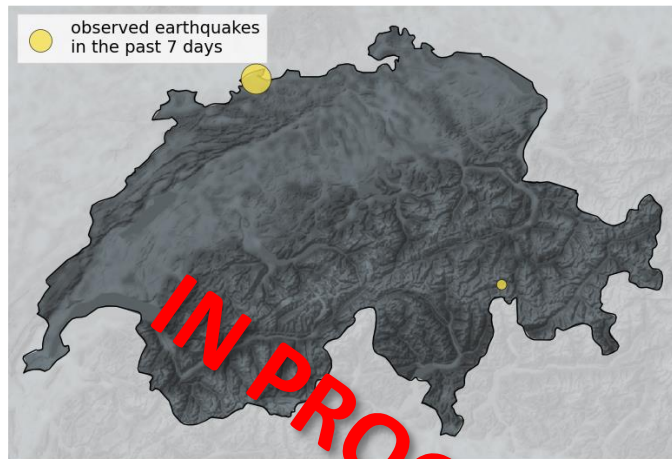
Séisme près d'Haute Sorne (JU)

Magnitude 6.5 [Mw]		Degré de danger	5
Aperçu	<p>Ce scénario concerne un tremblement de terre dont l'épicentre se situerait sur le site de géothermie profonde de Haute-Sorne (JU). Sa profondeur a été fixée à 4.5 km. Les effets modélisés sont ceux, moyens, auquel il faudrait s'attendre indépendamment de l'heure à laquelle le séisme se produit.</p>	Heure locale	-
		Date	-
		Profondeur du foyer [km]	4.5
		Magnitude [Mw]	6.5
		Évaluation	automatique
	Coordonnées suisses	7°58'475 / 1°24'2483	
	Autres données de l'événement	Lien	
National	<p>Estimation des impacts</p> <p>Les impacts estimés sont décrits sous forme d'intensités. L'intensité décrit la force d'un tremblement de terre en se basant sur l'étendue des effets et la perception subjective des personnes.</p>	<p>Nombre de victimes en Suisse</p> <p>Le nombre de décès se situe très probablement dans la zone colorée.</p> <p>aucun 5 50 500 5'000</p>	
		<p>Nombre de personnes recherchant un abri en Suisse</p> <p>Le nombre de personnes en quête d'un abri se situe très probablement dans la zone colorée.</p> <p>aucun 50 500 5'000 50'000</p>	
		<p>Coûts des dégâts aux bâtiments en Suisse</p> <p>Les coûts des dégâts aux bâtiments se situent très probablement dans la zone colorée.</p> <p>aucun 10 Mia. 100 Mia. 1 Mia. 10 Mia.</p>	
Cantonal	<p>Nombre de blessés</p> <p>Le nombre de personnes par canton et dans le Principauté de Liechtenstein se situe très probablement dans la zone colorée.</p>	<p>Étendue des dégâts aux bâtiments</p> <p>L'étendue des dégâts modérés à très importants aux bâtiments par canton et dans le Principauté de Liechtenstein se situe très probablement dans la zone colorée.</p> <p>Le pourcentage correspond à la part moyenne de bâtiments endommagés par canton.</p>	

Toutes les informations sont fournies sans garantie et sous réserve de modifications. Avec le soutien de: Schweizerische Eidgenossenschaft, Confédération suisse, Confederaziun Svizra, Confederaziun Svizra, Confederaziun Svizra. Office National de l'Environnement (ONE), Office National de la protection de la population (ONP).

...downstream applications – 2) OELF

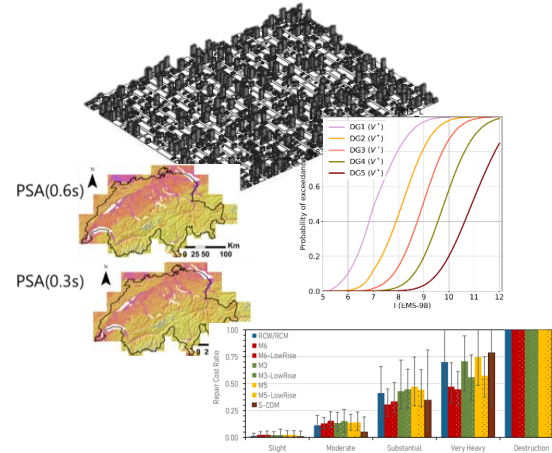
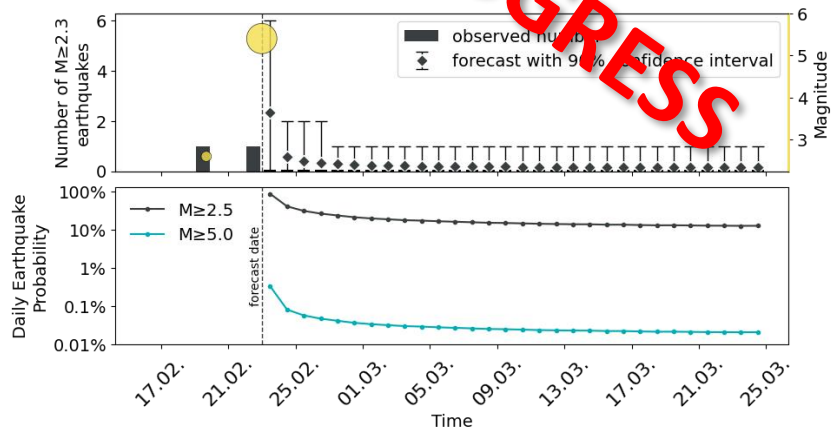
OEF → time-dependent daily earthquake probabilities



ERM-CH23

OELF → time-dependent daily loss/damage probabilities

IN PROGRESS



IN PROGRESS

...downstream applications – 3) Evaluation of mitigation actions

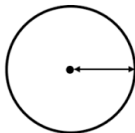
Feasibility of EEW



Warning times



Alert accuracy



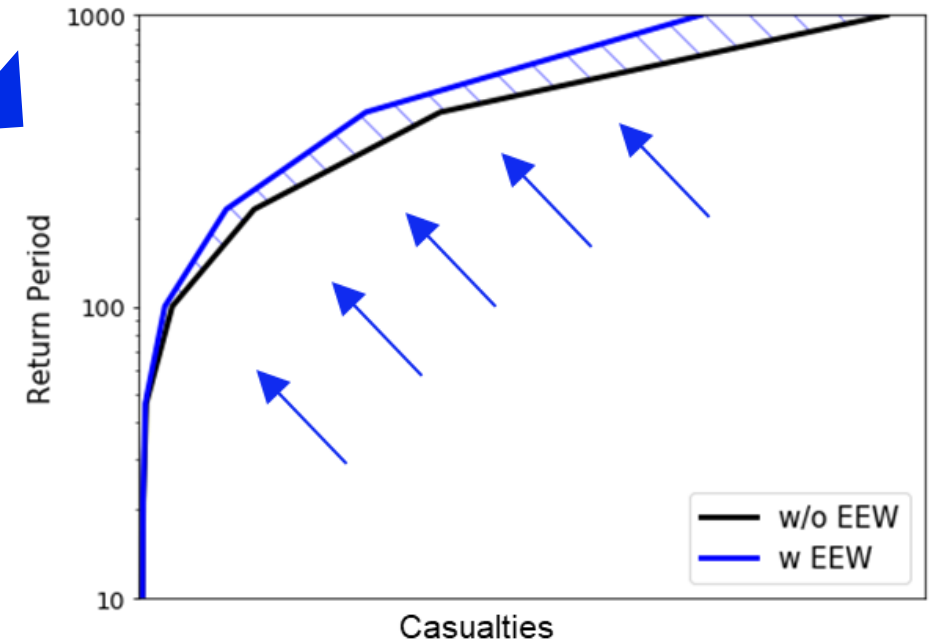
Size of no-alert zones



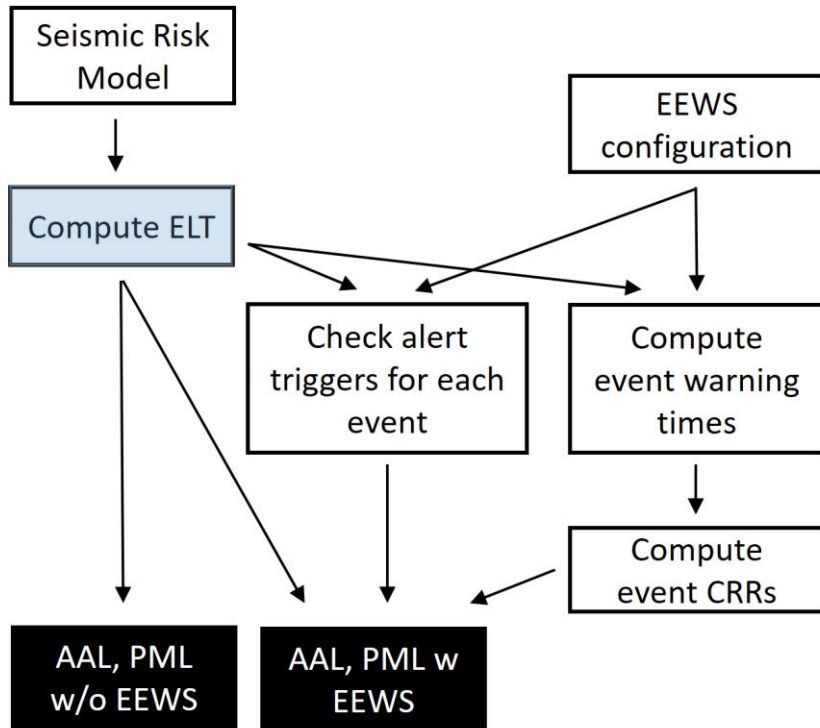
Composite indices

Useful but not necessarily actionable

Better Question:
How much can EEW reduce current risk?



...downstream applications – 3) Evaluation of mitigation actions

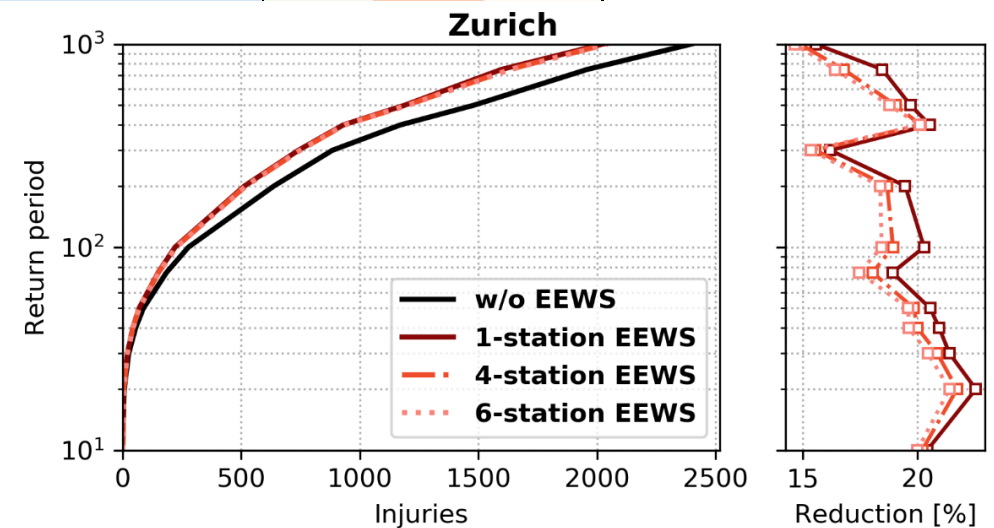


Original event loss table (ELT)				EEW-related extension			
Event ID (<i>i</i>)	Magnitude	Longitude Latitude Depth	Event Fatalities w/o EEWS	F_{alert}^i / F_{day}^i	$t_{w_i}^w$ (s)	CRR_i	Event Fatalities with EEW
1	5.35	6.975 47.425 22.500	10	1.0/0.0	10	0.13	10
2	6.45	7.625 46.525 13.5	2178	1.0/1.0	0	0	2178
3	6.55	8.377 46.924 8.9	217	1.0/1.0	0	0.25	163
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
<i>k</i>	5.05	11 47					

Is an alert issued?
Is it during the day?

Warning time

Casualty reduction ratio





Thank you!

*Karl Jauslin (1842-1904)
The Basel Earthquake, October 10, 1356*

...references and acknowledgements

ERM-CH23 Technical report

Wiemer, S., Papadopoulos, A., Roth, P., Danciu, L., Bergamo, P., Fäh, D., Duvernay, B., Khodaverdian, A., Lestuzzi, P., Odabaşı, O., Fagà, E., Bazzurro, P., Cauzzi, C., Hammer, C., Panzera, F., Perron, V., Marti, M., Valenzuela, N., Dallo, I., Zaugg, S., Fulda, D., Kästli, P., Schmid, N., and Haslinger, F. *Earthquake Risk Model of Switzerland ERM-CH23*, Swiss Seismological Service (SED), <https://doi.org/10.12686/a20>, 2023.

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