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Black Sea CROSS BORDER COOPERATION

REDACt Rapid Earthquake Damage Assessment ConsorTium

Procedura de selecție a ecuațiilor de predicție a mișcării solului pentru zona proiectului

WP3: GMPEs Evaluations and Selection with emphasis in Cross-Border Areas

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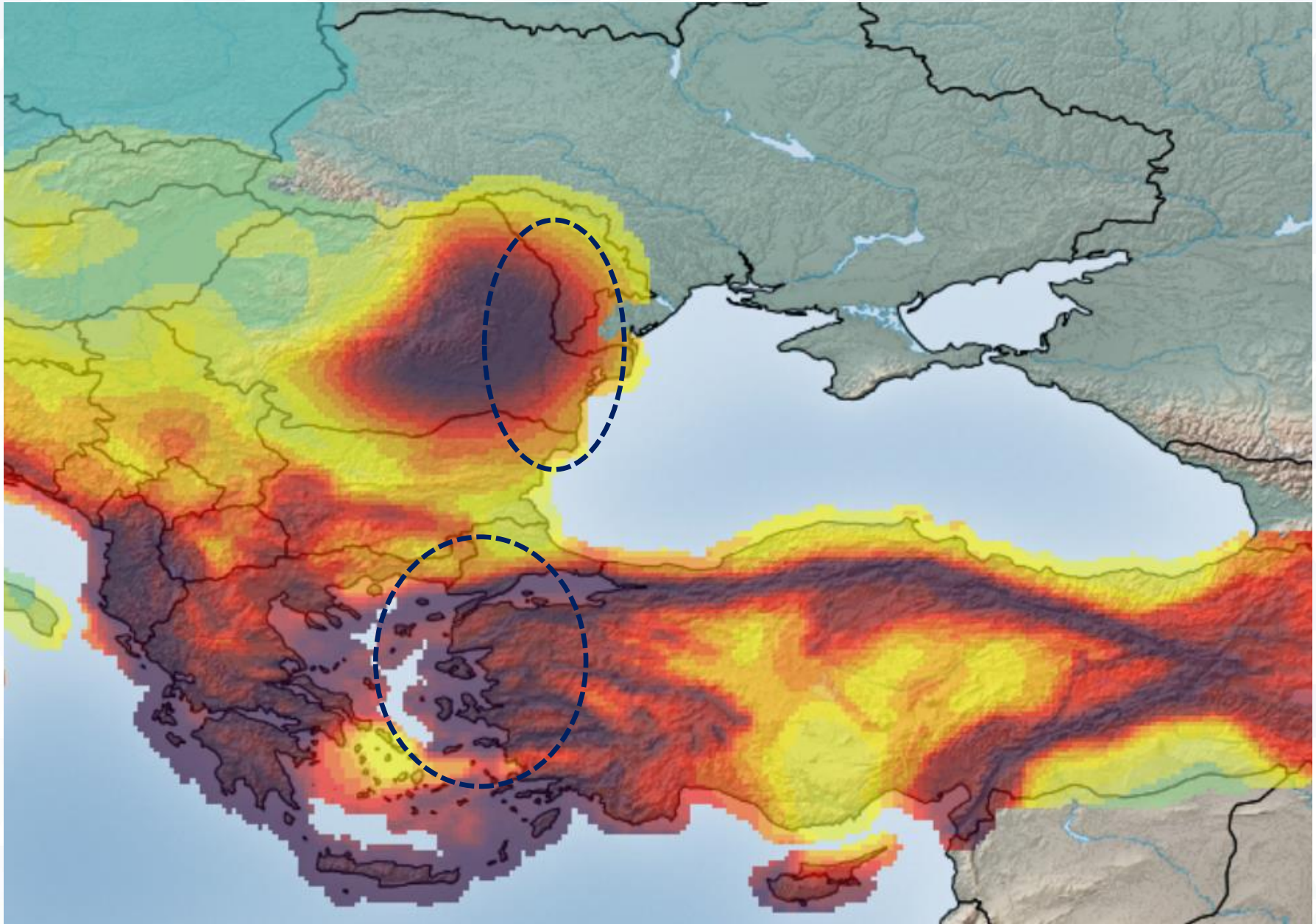
Cross-Border Areas and Need for Harmonization of GMPMs



Testing GMPMs for Project Cross-Border Areas

[Similar to SHARE 2013, strategy]

Pre-Selection of candidate GMPMs

- Selection of regional & worldwide GMPMs (see Douglas 2019)
- Application of exclusion criteria (see Cotton et al. 2006)
- Review of the GMPMs applicability range of their dependent variables
- Evaluation of the GMPMs using the criteria of Bommer et al. (2010)

↓

Testing Using data

- Ranking of GMPMs based on Scherbaum et al. (2009)

↓

Proposition of logic tree

- Selection of the final GMPMs
- Proposition of different sets of weights (if necessary)

↓

Final Logic Tree of GMPMs

(a) Normalized Residuals analysis

Modelling both epistemic and aleatory variability, each GMPE is considered in the form of a probability lognormal distribution, as determined by the equation

$$\log y_{ij} = \mu(m_i, r_{ij}, \boldsymbol{p_{ij}}) + z_{Tij}\,\sigma_T$$

where the yij represents the ground motion recorded at location j due to an event i, the term μ (mi, rij, pij) represents the expected ground motion from an earthquake of magnitude mi, recorded at distance rij and finally the term pij corresponds to other model parameters

Calculating the normalized residual the term y_{ij} is the recorded ground motion, $\mu\ (m_i, r_{ij}, p_{ij})$ is the mean estimate of the GMPE and σ_T is the total standard deviation of the GMPM. From the above, it follows that

$$z_{Tij} = \frac{\log y_{ij} - \mu(m_i, r_{ij}, \boldsymbol{p_{ij}})}{\sigma_T}$$

A GMPM is considered as a good fit to the recorded data if its normalized residuals follow closely a standard normal distribution, with a mean zero and standard deviation equal to 1.0

(b) LogLikeliHood (LLH) analysis based on information theory approach:

A model g, defined as the distribution used to approximate a reference model f.
The divergence between these 2 models represented by their PDFs is defined as:

$$D(f,g) = E_f\left[\log_2(f)\right] - E_f\left[\log_2(g)\right]$$: Kullback-Leibler Divergence

where E_f *is the statistical expectation with respect to f*

The goal of this strategy is to identify the smallest set of GMPEs to capture the epistemic uncertainty in ground-motion prediction in CBA

The term $-E_f[\log2(g)]$ can be approximated via the observations by the negative average sample log-likelihood (LLH):

$$\mathrm{LLH}(g,\mathbf{x}) := -\frac{1}{N}\sum_{i=1}^{N}\log_2\left(g(x_i)\right)$$

where $x = \{ x_i \}$, $i = 1, \ldots, N$ are the empirical data and $g(x_i)$ is the likelihood that model g has produced the observation x_i

In the case of GMPE selection, g is the PDF given by a GMPE to predict the observation produced by an earthquake M, at distance R, at site *i* …

Testing GMPMs for REDACt Cross-Border Areas

Final Selection of GMPMs using normalized residual & LLH analyses

The weighting factors of the final GMPMs computed separately for each evaluation method.

The equation applies for the LLH approach is:

$$w_l = \frac{2^{-LLH}}{\sum_{k=1}^{K} 2^{-LLH}}$$

For the residual-based approach the weighting factors are computed in a similar way, according to equation:

$$w_l = \frac{e^{Z*}}{\sum_{k=1}^{K} e^{Z*}}$$

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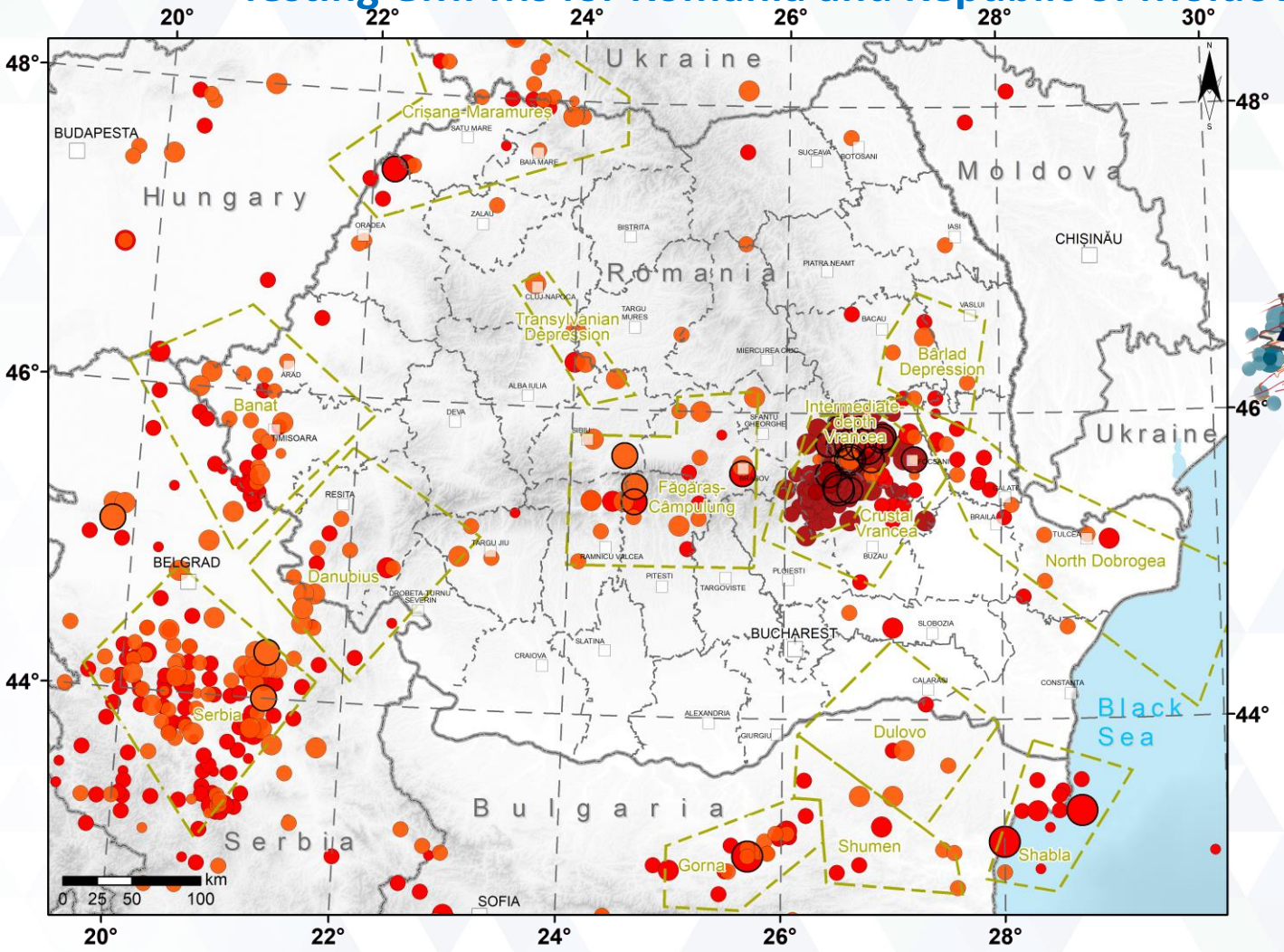
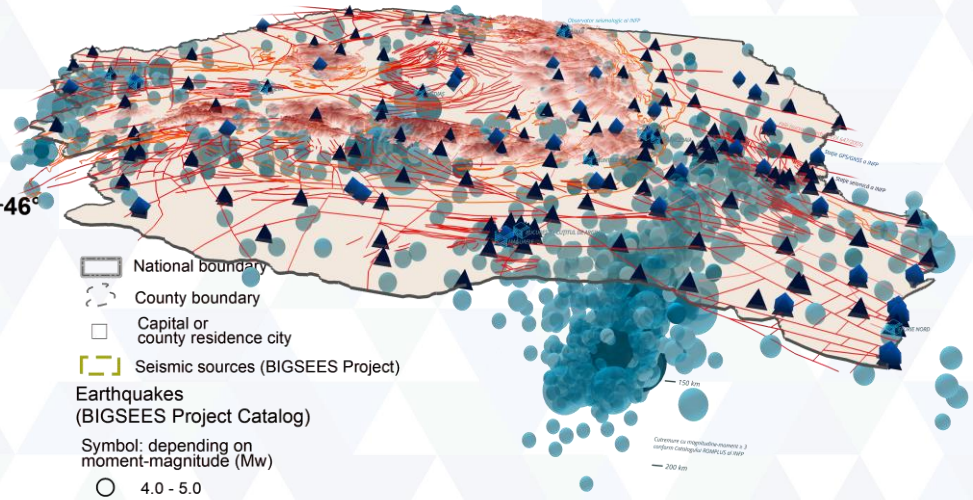
Testing GMPMs for Romania and Republic of Moldova





National boundary
County boundary
Capital or county residence city
Seismic sources (BIGSEES Project)

Earthquakes
(BIGSEES Project Catalog)

Symbol: depending on moment-magnitude (Mw)
- 4.0 - 5.0
- 5.1 - 6.0
- 6.1 - 7.0
- 7.1 - 7.9

Colour: depending on depth [km]
- 0 - 10 km
- 10.1 - 60 km
- 60.1 - 218 km

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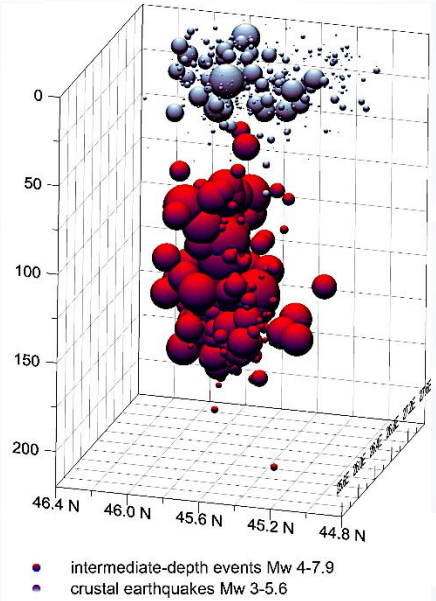
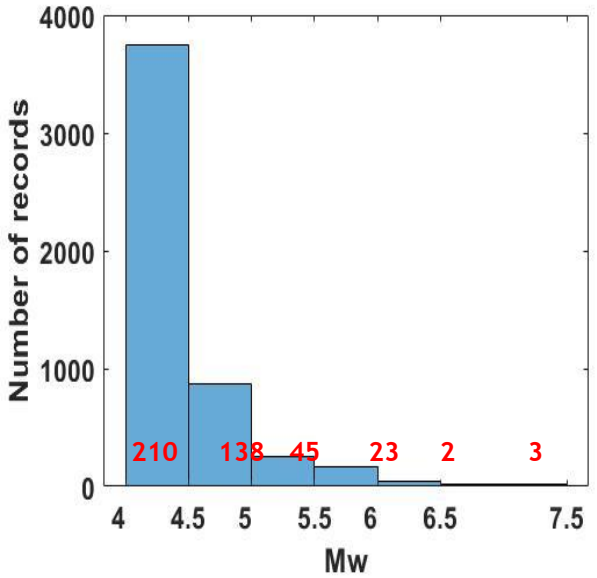
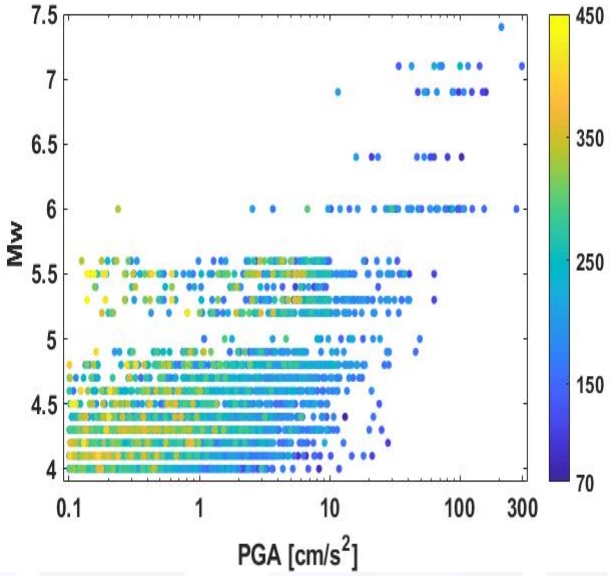
Testing GMPMs for Vrancea Intermediate-Depth earthquakes

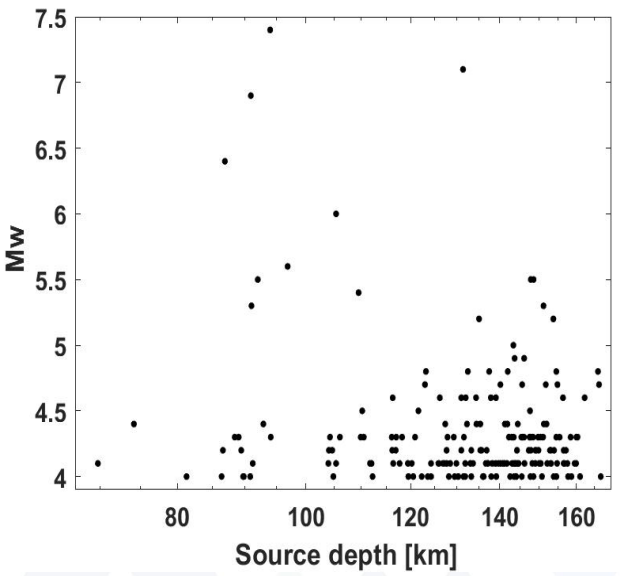
Evaluation of the up-to-date GMPMs for intermediate-depth events (Cioflan et al., 2020) is based on the selection of models from previous seismic hazard analyses, currently used in the Romanian ShakeMap and from recent works (e.g. Douglas 2021).

The database comprises 5200 records selected out of 22000, of 425 Vrancea events occurred between 1977 and 2020. Moment magnitudes Mw range from 4 to 7.4 and depths 60 - 170 km.









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Testing GMPMs for Vrancea Intermediate-Depth earthquakes

GMPMs for the Vrancea seismogenic area

Model	Parameter PGA, PGV, SA	Mw range	Dist_range [km]
Abrahamson et al 2016 **(Aetal16)**	SA(<10s)	5 - 7.9	< 300
Atkinson and Boore 2003 **(AB03)**	SA(<4s)	5 - 8.3	< 300
Garcia et al. 2005 **(Getal05)**	SA(<5s), PGV	5.2 - 7.4	< 400
Lin and Lee 2008 **(LL08)**	SA(<5s)	5.3 - 8.4	< 630
Sokolov et al. 2008 **(Setal08)**	SA(<3s), PGV	6.3 - 7.4	< 300
Vacareanu et al. 2015 **(Vetal15)**	SA(3.5s), PGV	5.1 - 7.4	< 400

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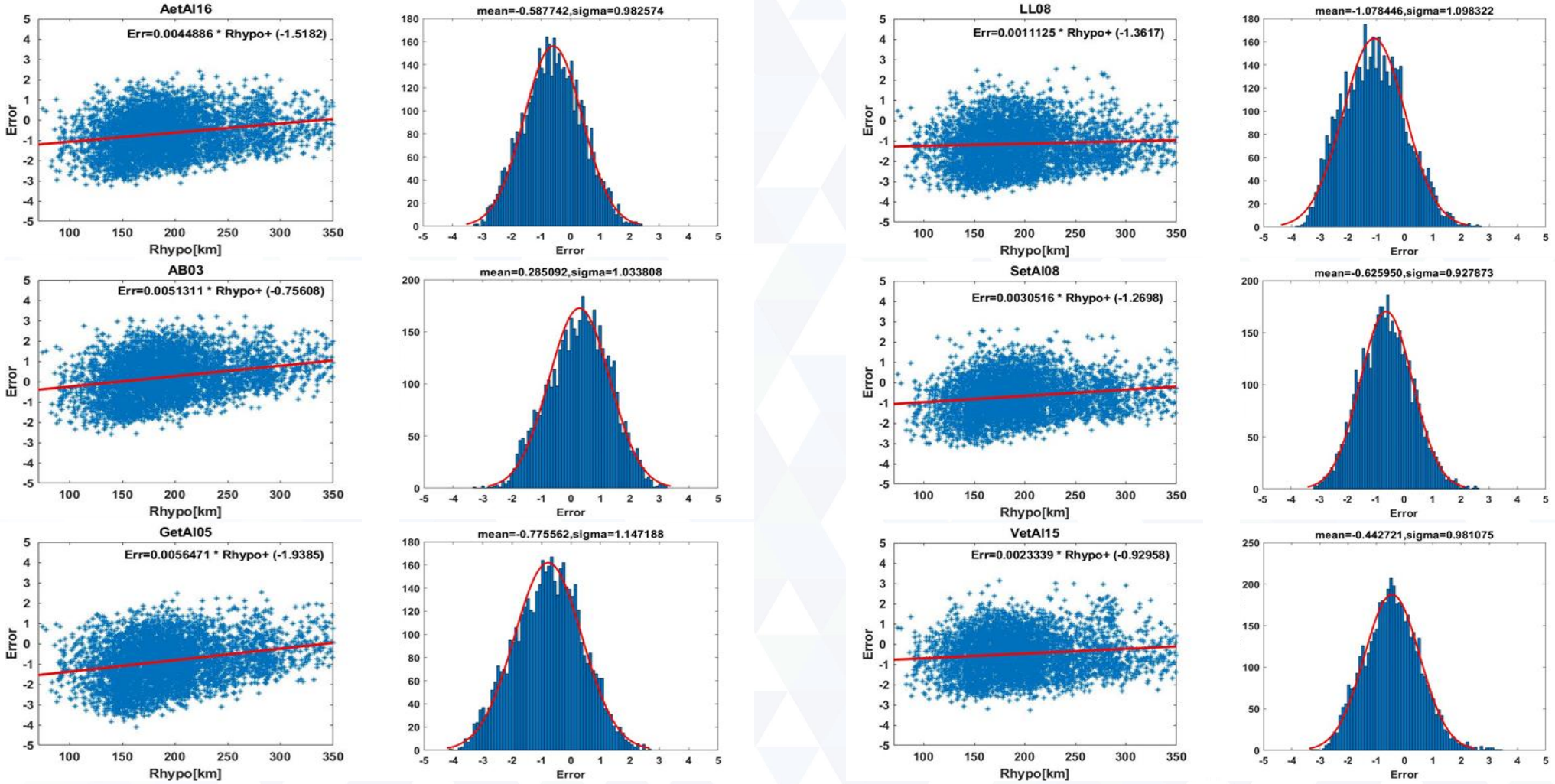
Testing GMPMs for Vrancea Intermediate-Depth earthquakes

Residuals as a function of hypocentral distance (left column) and their histograms (right column)



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Testing GMPMs for Vrancea Intermediate-Depth earthquakes

Ranking	GMPM	MeanNorm	std dev PGA	Z(PGA)
		ResPGA		
1	Atkinson and Boore 2003 (AB03)	0.285092	1.033808	-0.3189
1	Vacareanu et al. 2015 (Vetal15)	-0.442721	0.981075	0.461646
2	Abrahamson et al 2016 (Aetal16)	-0.587742	0.982574	0.605168
3	Garcia et al. 2005 (Getal05)	-0.775562	1.147188	0.628374
4	Sokolov et al. 2008 (Setal08)	-0.62595	0.927873	0.698077
5	Lin and Lee 2008 (LL08)	-1.078446	1.098322	0.980124

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Testing GMPMs for Vrancea Intermediate-Depth earthquakes

Results of LH and LLH tests

GMM abbrev	PGA			PGV			SA(0.3s)			SA(1s)			SA(3s)		
	Mean LH	Rank	LLH	Mean LH	Rank	LLH	Mean LH	Rank	LLH	Mean LH	Rank	LLH	Mean LH	Rank	LLH
Aetal16	0.38	B	0.71	-	-	-	0.16	D	1.42	0.18	D	1.17	0.255	C	-0.29
AB03	0.44	A	-0.25	-	-	-	-	-	-	0.2	C	-1.15	0.11	D	-1.79
Getal05	0.33	B	0.83	0.3	B	0.72	0.25	C	0.85	0.27	C	0.38	0.0056	D	-2.67
LL08	0.22	C	1.14	-	-	-	0.0	D	2.00	0.08	D	1.72	0.244	C	-1.04
Setal08	0.4	A	0.67	0.38	B	0.53	0.21	C	1.24	0.43	A	-0.63	0.1	D	-1.6
Vetal15	0.45	A	0.47	0.26	C	1.06	0.23	C	1.17	0.35	B	1.17	0.05	D	-1.9

The ground motion models are ranked using the statistical methods (LH, LLH) as follows: Setal08, AB03, Vetal15, Getal05. All the models with the exception of Aetal16 and LL08 should not be used to predict spectral accelerations at longer periods (after 3 seconds).

Recently, a new GMPM for PGA, PGV, and 5% damped PSA up to 10s became available (Manea et al., 2022). The model is region-specific (only Vrancea records have been used).

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Testing GMPMs for Vrancea Intermediate-Depth earthquakes

GMPM	residuals-based approach			LLH approach			Final weights	
	Wz	Wz1	Wz2	Wl	Wl1	Wl2	W1	W2
Atkinson and Boore 2003 (AB03)	0.184	0.536		0.285	0.622		0.579	
Vacareanu et al. 2015 (Vetal15)	0.159	0.464	0.379	0,173	0.378	0.377	0.421	0.378
Abrahamson et al 2016 (Aetal16)	0.138			0.147				
Sokolov et al. 2008 (Setal08)	0.135			0.151		0.329		0.314
Garcia et al. 2005 (Getal05)	0.126		0.321	0.135		0.294		0.3075
Lin and Lee 2008 (LL08)	0.095			0.109				

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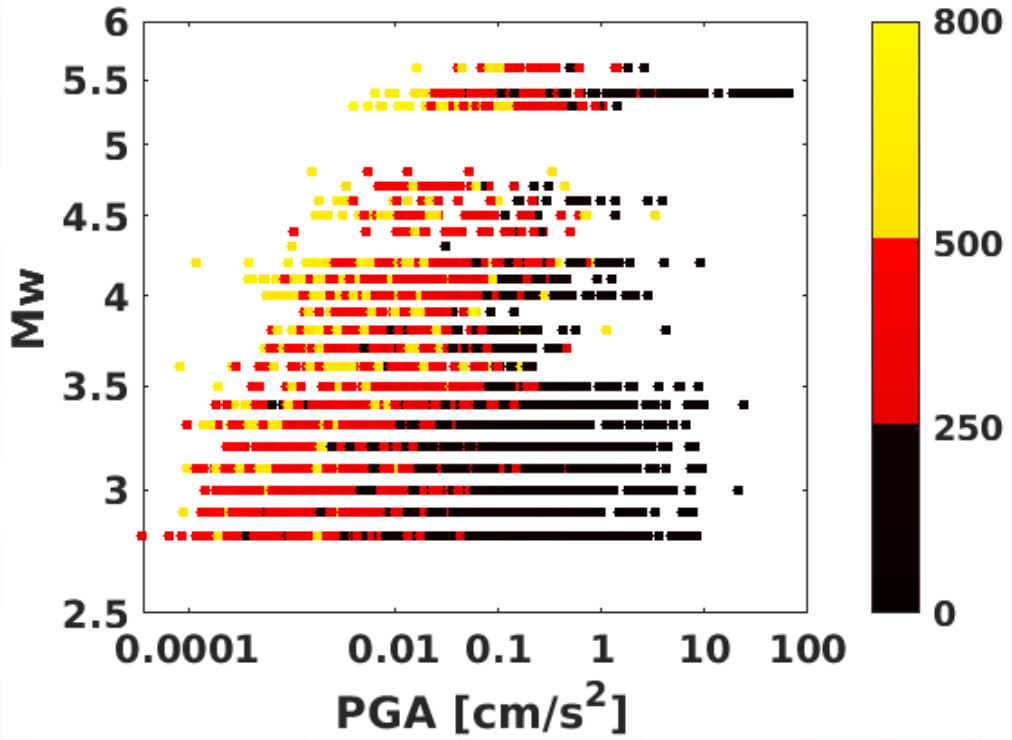
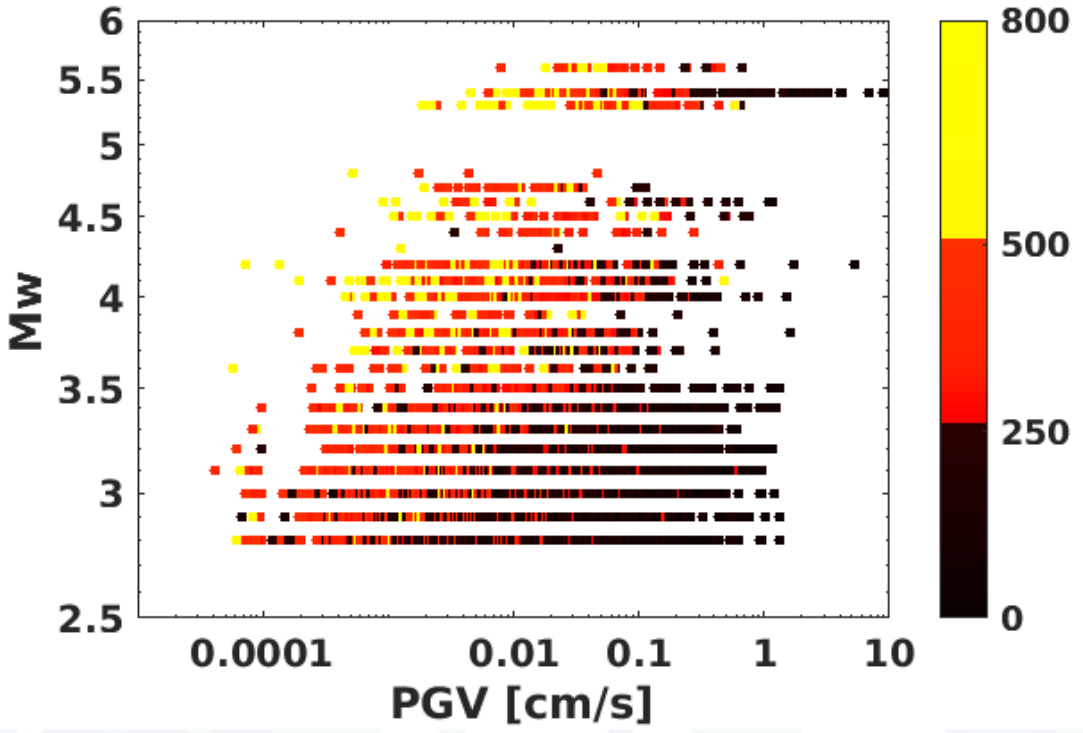
GMPMs for crustal earthquakes

Our data base regarding the crustal seismicity comprises almost 2000 records of 221 events with magnitude Mw = [2.8-5.6] and maximum depth of 60 km from the Romanian National Seismic Network or recorded within national/international projects since 1985.





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GMPMs for crustal earthquakes

GMM	Parameter PGA, PGV, SA	Mw range	Dist_range [km]
Akkar et al. 2014	SA(<4s)	4-7.6	0-200
Bindi et al. 2014	SA(<3s)	4-7.6	0-300
Boore et al. 2014	SA(<10s)	3-7.9	0-400
Cauzzi et al. 2014	SA(<10s)	4.5-7.9	0-150
Chiou and Youngs 2014	SA(<10s)	3.5-8.5	0-300
Kale et al. 2015	SA (≤4s)	4-8	0-200

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GMPMs for crustal earthquakes

GMM	PGA		PGV		SA (0.3s)		SA (1s)		SA (3s)			
		LLH		LLH		LLH		LLH		LLH	Average LLH	weight
Akkar et al. 2014	B	-0.39	A	0.13	B	-0.2	A	-0.2	D	-1.27		
Bindi et al. 2014	B	-0.85	A	-0.33	C	-0.47	C	-0.95	D	-1.46		
Boore et al. 2014	B	-0.86	A	-0.19	C	-0.82	B	-0.58	A	-0.52	-0.594	0.214174
Cauzzi et al 2014	A	-0.29	C	0.96	B	0.14	A	-0.18	C	-1.23	-0.12	0.297478
Chiou and Youngs 2014	B	-0.38	A	0.03	B	-0.58	B	-0.67	C	-1.12	-0.544	0.221727
Kale et al 2015	A	-0.47	A	0.22	B	-0.09	A	0.06	C	-1.11	-0.278	0.26662

From the above results it is visible the high performance of Kale et al. (2015) GMPM considering both PGA and PGV tests; in the long period part of the ground motion (>3s), the performance of all GMMs drops to class D

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- Selected GMPMs and weighting schemes are included in the REDACt Platform (completed 2023)

Rapid **E**arthquake **D**amage **A**ssessment platform + **Smartphone** app + **Edu**cational **Hub** = Improve **Emergency Response Efficiency in the Black Sea Area**

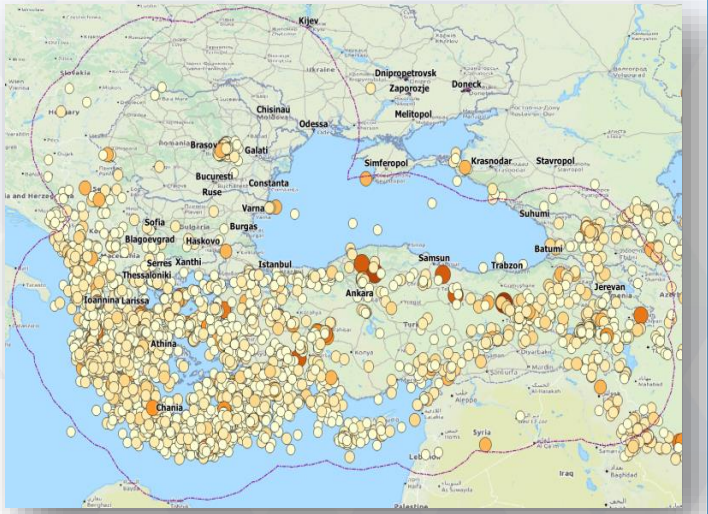
2020 - 2023

- **near Real-Time** and **scenario based damage estimation** supporting **Earthquake Disaster Prevention and Preparedness**
- **Cross Border Coverage**
- **harmonized approach**
- **loss estimates based on fragility functions**
- **analysis of geotechnical hazards**

- **Provide real-time info and communication**
- Improve Public Response in line with State Emergency plans
- **Receive feedback**

- Improve Public awareness;
- Help the public develop “own” emergency plans (personal, family, work etc) **in line with State Emergency Plans**

Proposed triggering area (initial)



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THANK YOU FOR YOUR KIND ATTENTION!

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